
# Laboratório de Instrumentação e Física Experimental de Partículas

## Activity Report

## 2011

# Contents

# Chapter 1

# Overview

## 1.1 Resumo

O LIP é uma associação científica e técnica de utilidade pública sem fins lucrativos, para a pesquisa em Física Experimental de Partículas e Instrumentação Associada, criado há 25 anos como o laboratório de referência nacional para a colaboração com o CERN.
Os domínios de investigação têm crescido e agora abrangem:
- Física Experimental de Altas Energias,
- Física Experimental de Astropartículas,
- Instrumentação de Deteção de Radiação, Aquisição de Dados e Processamento de Dados,
- Computação Avançada,
- Física Médica e outras aplicações
e são complementadas por compromissos fortes em Outreach, Educação e Formação, e de contacto com a indústria, sendo o LIP responsável pela transferência de tecnologia e serviço de ligação industrial para o CERN e outros laboratórios internacionais.
As atividades de investigação principais do LIP são desenvolvidas no âmbito de grandes colaborações no CERN e outras organizações internacionais e grandes instalações na Europa e em outros lugares, como o GSI, ESA, NASA, SNOLAB e o Observatório Pierre Auger, em memorandos de entendimento ou contratos-programa específicos.
O LIP partilha recursos físicos (equipamentos) e humanos com um grande número de grupos de investigação e instituições, nacionais e internacionais, contribuindo com seus próprios recursos técnicos e científicos para benefício de programas científicos comuns. As infraestruturas de computação são as maiores da comunidade académica Portuguesa e são usadas atualmente por mais de 150 instituições de investigação; as oficinas de mecânica de precisão também se encontram abertas às necessidades da comunidade científica nacional e internacional; o LIP trabalha numa instalação conjunta, nomeadamente o Laboratório do Tagus LIP para Física Médica, em conjunto com centros de pesquisa, hospitais e com o setor privado.
O LIP é um "Laboratório Associado"desde 2001, avaliado como "Excelente"em quatro avaliações sucessivas por painéis internacionais; é composto de três unidades, em Coimbra, Lisboa e Minho, com acordos específicos com cada universidade para a partilha de recursos. O LIP tem cerca de 170 pessoas, mais de 80 com um grau de doutor, muitos sendo professores contratados nas universidades locais, onde também outros pesquisadores ensinam alguns cursos, e recebe por ano muitos estudantes de mestrado e doutoramento para preparação das suas teses.
O LIP coordena a rede de Doutoramento Internacional em Física de Partículas, Astrofísica e Cosmologia e o programa de doutoramento FCT / IDPASC.

## 1.2 Abstract

LIP is a non-profit scientific and technical association of public utility, for research in Experimental Particle Physics and Associated Instrumentation, created 25 years ago as the reference national laboratory for collaboration with CERN.
The research domains have grown and now encompass:
Experimental High Energy Physics,
Experimental Astroparticle Physics,
Radiation Detection Instrumentation, Data Acquisition and Data Processing,

Advanced Computing,
Medical Physics and other applications
and are complemented by strong compromises in Outreach, Education and Training, and contact with industry, LIP being responsible for Technology Transfer and the industrial liaison office for CERN and other international laboratories.
The main research activities of LIP are developed in the framework of large collaborations at CERN and other international organizations and large facilities in Europe and elsewhere, such as GSI, ESA, NASA, SNOLAB and the Pierre Auger Observatory, under specific memorandum of understandings or project contracts.
LIP shares equipment and resources with a large number of research groups and institutions, both national and internationally, contributing with its own technical and scientific resources for the purpose of common scientific programs. The computing facilities are the largest in the Portuguese academic community and are currently used by more than 150 research institutions; the precision mechanics workshops are also open to the needs of the Portuguese and international scientific community; and, LIP works together with research centres, hospitals and the private sector, namely in a shared dedicated facility, the Tagus LIP Laboratory for Medical Physics.
LIP is an "Associated Laboratory"since 2001, assessed as "Excellent"in four successive evaluations by international panels, it is composed of three units, in Coimbra, Lisboa and Minho, with specific agreements with each University for the sharing of resources. LIP has around 170 people, more than 70 with a PhD degree, many being hired professors at the local universities, where also other researchers teach some courses, and it receives per year many students completing master or PhD works. LIP coordinates the International Doctorate network in Particle Physics, Astrophysics and Cosmology and the FCT/IDPASC PhD grant program.

## 1.3 Objectives

LIP is committed to the consolidation and growth of the six main areas named above. These areas are both diverse and complementary, in which they allow us to follow most of the important fundamental particle physics questions, in accelerator physics and with natural sources, which are important also for astrophysics and cosmology. The research and development of instrumentation to be used in detectors and the study of their adaptation for future experiments and other applications, namely in the field of Medical Physics, is an important part of this work. Also the development of data acquisition and processing tools and advanced computing is necessary for our experiments but also more generally useful for other scientific domains. LIP´s projects cover all these areas, creating a coherent framework to follow and participate in the international developments, and integrating with national researchers in the adjacent areas.
One of the main objectives of the overall LIP activity is the continuous training of scientists in these several areas and the integration of promising young scientists in our supported research program. In all areas, but primarily the basic research ones, the maintenance of strong links to higher education is a clear priority. With the establishment of the IDPASC network, the Education Area is a strategical line of activity to be followed in the years to come. The outreach of fundamental science to the general public, and mostly high-school students and their teachers is a well established secondary objective of LIP, together with the training of engineers and the technology transfer between the international research facilities we work with and the national industry. These points are discussed in the last chapter of this report.
In the following pages, there are the individual reports for each project, here we will concentrate only on the main scientific highlights.

## 1.4 Achievements

LIP keeps a diversified program in Experimental High Energy Physics, with important technical and analysis responsibilities in COMPASS, for which a new upgrade is being prepared, and HADES, whose analysis team was extended in 2011. The main focus for more than 15 years is, however, in the LHC accelerator at CERN. After the design, construction and commissioning of specific sub-detectors, we now participate in many physics analysis, in both the ATLAS and CMS experiments, for which important results have already been obtained. In 2011, a LIP member was elected as vice-spokesman of the international CMS collaboration.
LIP participates also in several Astroparticle Physics projects. The results from the Pierre Auger Observatory have increased the interest in exploring particle physics in high energy cosmic rays, the LIP group is involved in the analysis and in R&D for the next generation experiments. Lower energy cosmic ray research is done with the AMS detector, installed in the International Space Station in 2011, and is followed in space radiation projects under contracts with ESA. LIP has a long record of R&D and data analysis for dark matter with liquid Xenon detectors, the ZEPLIN-III experiment has finalized data-taking in 2011 and the group is now focused

on the commissioning of the LUX project. The final results of the SNO neutrino experiment were published in 2011, and installation of new systems for SNO+ started.
LIP has an internationally recognized leading role in the development of gaseous detectors, namely Resistive Plate Chambers. R&D in RPCs for several purposes continues in the framework of international collaborations, RD51 and NeuLand-R3B; they´re used by HADES, and under study for Auger and CMS; while medical applications prototypes are in tests. Gaseous/liquid Xenon detectors are used in the search of dark matter and a new group exploring this technique for rare neutrino processes joined LIP in 2011. Studies of basic properties with interest for detector development and long-term R&D programs on micro-structure detectors are under way. Both in Coimbra and Lisbon, silicon photo-detectors are being studied and tested for different applications. In 2011, a group studying gamma-ray polarimetry for Space missions joined LIP.
The most interdisciplinary research activity of LIP is Medical Physics. Two projects have developed and are testing Positron Emission Tomography scanner prototypes based on the use of technologies from Particle Physics experiments, scintillating crystals procured for CMS and RPCs. These should allow better imaging precision with lower radiation doses for patients, other projects deal with different aspects of this question, as well as radiation monitoring and protection.
The Advanced Computing area started from the need to meet the LHC computation requirements, but the Grid is now used actively by many research communities. The main focus is now on the development of tools for general use in the framework of the National, Iberian and European Grid Initiatives, in addition to the Worldwide LHC Computing Grid.

## 1.5 Sources of Funding for LIP Lisboa

| Project | Code | Funding | Entity | Start | End |
|---|---|---|---|---|---|
| AMS | PTDC/FIS/122567/2010 | 40.000 € | FCT | 2011-12-07 | 2013-12-06 |
| ATLAS | CERN/FP/116346/2010 | 267.000 € | FCT | 2011-01-01 | 2012-03-31 |
| CMS | CERN/FP/116367/2010 | 277.000 € | FCT | 2011-01-01 | 2012-03-31 |
| COMPASS | CERN/FP/116376/2010 | 137.000 € | FCT | 2011-01-01 | 2011-12-31 |
| GRID | G-CAST | 1.000 € | FCT | 2008-01-01 | 2011-09-30 |
| | EGI InSPIRE | 485.000 € | EU | 2010-05-01 | 2014-04-30 |
| | IBERGRID FCT-CSIC 20 10/11 | 4.250 € | LIP | 2007-01-01 | 2012-06-30 |
| | TIMBUS | 112.268 € | EU | 2011-03-01 | 2014-02-28 |
| HECR | CERN/FP/116330/2010 | 127.000 € | FCT | 2011-01-01 | 2012-01-31 |
| OUTREACH | MC2011_RadAmb2010-11 | 15.000 € | Ciência Viva | 2010-10-01 | 2011-06-30 |
| | MC2012_RadAmb2011-12 | 15.000 € | Ciência Viva | 2011-10-01 | 2012-06-30 |
| | OCJF2011 | 1.200 € | Ciência Viva | 2011-06-15 | 2011-09-15 |
| | CERN TPP 2011 | 37.860 € | Ciência Viva | 2011-04-01 | 2011-12-31 |
| PET - Mammography | Endo TOFPET-US256984 | 509.400 € | EU | 2011-01-01 | 2014-12-31 |
| | PIC/IC/83228/2007 | 67.550 € | FCT | 2009-03-26 | 2012-03-31 |
| SNO+ | PTDC/FIS/115281/2009 | 108.971 € | FCT | 2011-01-01 | 2013-12-31 |
| Space | 6403/10/NL/SFe | 50.000 € | ESA | 2011-01-17 | 2012-06-18 |
| | ESA:223981/09/NL/PA | 150.000 € | ESA | 2009-05-01 | 2012-03-31 |
| Laboratório Associado | PEst-C/FIS/LA0007/2011 | 1.797.273 € | FCT | 2011-01-01 | 2012-12-31 |
| Quotas | 2011 | 157.120 € | FCT | 2011-01-01 | 2011-12-31 |

## 1.6 Sources of Funding for LIP Coimbra

| Project | Code | Funding | Entity | Start | End |
|---|---|---|---|---|---|
| ATLAS GRID | GRID/GRI/81727/2006 | 140.000 € | FCT | 2007-04-12 | 2011-04-11 |
| Compton in PET | PTDC/FIS/67002/2006 | 72.000 € | FCT | 2009-01-01 | 2011-12-31 |
| Dark Matter Search | CERN/FP/116374/2010 | 45.000 € | FCT | 2011-01-01 | 2012-03-15 |
| GEMs | FP7-GA226507 | 80.640 € | EU | 2009-02-01 | 2012-01-31 |
| | CERN/FP/116389/2010 | 9.000 € | FCT | 2011-01-01 | 2011-12-31 |
| HADES | EU Contract 515876 D IRAC-Phase-1 | 52.000 € | EU | 2005-10-01 | 2011-03-31 |
| | PTDC/FIS/113339/2009 | 91.742 € | FCT | 2011-04-01 | 2014-01-31 |
| | LIP-GSI contract | 414.000 € | GSI | 2005-10-01 | 2011-03-31 |
| Human PET | PTDC/SAU-BEB/104630/ 2008 | 120.856 € | FCT | 2010-04-01 | 2013-03-31 |
| NeuLand - R3B | PTDC/FIS/114876/2009 | 99.589 € | FCT | 2011-01-01 | 2013-12-31 |
| OrthoImaging | OrthoImaging 1 | 5.000 € | | 2010-12-15 | 2011-02-28 |
| | OrthoImaging 2 | 6.000 € | | 2011-05-15 | 2011-09-30 |
| Phenomenological Studies at the LHC | CERN/FP/116397/2010 | 32.000 € | FCT | 2011-01-01 | 2012-02-15 |
| RD51 | CERN/FP/116392/2010 | 27.000 € | FCT | 2011-04-01 | 2012-06-30 |
| | CERN/FP/109355/2009 | 30.000 € | FCT | 2010-04-01 | 2011-03-31 |
| Laboratório Associado | PEst-C/FIS/LA0007/2011 | 1.149.076 € | FCT | 2011-01-01 | 2012-12-31 |
| Quotas | 2011 | 87.280 € | FCT | 2011-01-01 | 2011-12-31 |
| Oficinas | 2011 | 24.380 € | | 2011-01-01 | 2011-12-31 |

## 1.7 Scientific Statistical data

| Project | Publications | | | Conferences | | | Semi- | Outr. | Theses | | | Evts. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jrn-I | Jrn-II | other | int.o | int.p | nat. | nars | Sem. | G | M | D | |
| ATLAS | 53 | 7 | 18 | 5 | 4 | | 5 | 1 | | 2 | 2 | |
| CMS | 78 | 7 | 31 | 10 | | 1 | 10 | 2 | | | | |
| COMPASS | 1 | | 7 | 8 | | | 1 | 2 | | 1 | 2 | |
| HADES | 4 | | | | | | | | | | | |
| Phenomenological Studies at the LHC | 2 | 2 | | | | | | | | | | |
| GRID | 1 | 1 | 7 | 4 | | | | 1 | | 1 | | 1 |
| AMS | | | 2 | | | 1 | | 3 | | | | |
| SNO+ | 1 | | 1 | 1 | | | 1 | 1 | | | | |
| Dark Matter Search | 5 | 5 | | 3 | 2 | 2 | 3 | 1 | | | | 1 |
| HECR | 12 | 3 | 8 | 16 | 3 | | 6 | | | 1 | 1 | 2 |
| Space | 2 | 2 | 1 | 3 | 1 | 1 | | | | | | |
| PET - Mammography | 1 | 1 | 2 | | 1 | | 3 | | | 1 | | |
| Human PET | | | 1 | | 1 | | | | | | | |
| Compton in PET | | | | | | | | | | 1 | | |
| MC in Medical Physics | 3 | 3 | 2 | 2 | 2 | 3 | | | 1 | 2 | | 1 |
| OrthoImaging | | | 3 | 3 | 2 | 2 | 1 | | | | | |
| RD51 | | | 1 | | | | 1 | | | | | |
| NeuLand - R3B | | | | | | | | | | | | |
| GEMs | 3 | 3 | 1 | 1 | 1 | | | | | | | |
| DUAL | 2 | 2 | 4 | | | 4 | 2 | | | | | 1 |
| NEXT | 2 | 2 | | | | | | | | | | |
| ICNAS | | | 1 | | 1 | | | | | | | |
| OUTREACH | 2 | 2 | | | | | | 23 | | | | |
| TTN-ILO | | | | | | | | | | | | |
| Education | | | | | | | | | | | | |
| Scientific Conferences and Seminars | | | | | | | | | | | | 9 |
| Totals: | 172 | 40 | 90 | 56 | 18 | 14 | 33 | 33 | 1 | 9 | 5 | 15 |

**Legend:**

**Publications:**

**Jrn-I:** Publications in international journals with scientific peer review co-authored by LIP members

**Jrn-II:** Subset of publications Jrn-I in which LIP members had a major responsibility

**Other:** Internal notes, conference proceedings, etc. with direct involvement of LIP members

**Conferences:**

**Int.o:** Oral presentations by LIP members in international conferences

**Int.p:** Poster presentations by LIP members in international conferences

**Nat.:** Presentations by LIP members in national conferences

**Seminars:** Invited seminars in Institutes or Universities

**Outr. Sem.:** Seminars for students or general public

**Theses:** Theses concluded during this year (G - Graduation, M - Master, D - PhD)

**Evts:** Organisation of events (conferences, workshops, collaboration meetings, etc.)

## 1.8 Human resources (people)

| Project | Researchers | Technicians | Post-Docs | Students | | | |
|---|---|---|---|---|---|---|---|
| | | | | D | M | G | O |
| ATLAS | 11 | 1 | 4 | 7 | 5 | | 2 |
| CMS | 5 | 1 | 5 | 1 | 1 | | 1 |
| COMPASS | 3 | 1 | 3 | 2 | 1 | | |
| HADES | 6 | 3 | | | | | |
| Phenomenological Studies at the LHC | 8 | | 2 | 2 | 1 | 2 | |
| GRID | 7 | 4 | 1 | | 1 | | |
| AMS | 3 | | 2 | | 3 | | |
| SNO+ | 4 | 5 | | 1 | | | 1 |
| Dark Matter Search | 5 | 2 | 4 | 1 | | | |
| HECR | 13 | 3 | 4 | 3 | 1 | | 1 |
| Space | 5 | 1 | 3 | 1 | 1 | | 1 |
| PET - Mammography | 1 | 2 | 1 | 3 | 2 | | |
| Human PET | 4 | 8 | | | | | |
| Compton in PET | 7 | 5 | 3 | | | | |
| MC in Medical Physics | 5 | | | 3 | 4 | 1 | 3 |
| OrthoImaging | 1 | | | | | | |
| RD51 | 4 | 10 | | 1 | | | |
| NeuLand - R3B | 2 | 9 | | | | | |
| GEMs | 5 | 2 | 1 | 1 | | | |
| DUAL | 7 | | | 2 | | | |
| NEXT | 6 | | | 1 | | | |
| ICNAS | 3 | | | 1 | | | |
| OUTREACH | 9 | 2 | 1 | 2 | 1 | | |
| TTN-ILO | | 1 | | | | | |
| Education | | | | | | | |
| Scientific Conferences and Seminars | | | | | | | |
| Totals: | 76 | 21 | 27 | 30 | 19 | 3 | 8 |

**Legend:**

**Students:** D - PhD, M - Master, G - Graduation, O - Other

**FTE:** Full Time Equivalent

## 1.9 Human resources (FTE)

| Project | Researchers | Technicians | Post-Docs | Students | | | | total |
|---|---|---|---|---|---|---|---|---|
| | | | | D | M | G | O | |
| ATLAS | 6.25 | 0.50 | 3.20 | 5.89 | 4.00 | | 1.60 | 22.63 |
| CMS | 4.35 | 0.85 | 4.83 | 1.00 | 0.46 | | 1.00 | 14.35 |
| COMPASS | 3.00 | 1.00 | 3.00 | 2.00 | 1.00 | | | 11.25 |
| HADES | 0.74 | 0.65 | | | | | | 1.39 |
| Phenomenological Studies at the LHC | 2.20 | | 1.60 | 1.50 | 0.20 | 2.00 | | 8.10 |
| GRID | 6.43 | 3.15 | 1.00 | | 0.50 | | | 11.08 |
| AMS | 0.76 | | 1.24 | | 0.90 | | | 2.90 |
| SNO+ | 0.85 | 0.75 | | 1.00 | | | 0.25 | 2.85 |
| Dark Matter Search | 2.10 | 0.60 | 3.55 | 0.50 | | | | 6.75 |
| HECR | 6.83 | 1.15 | 2.11 | 2.15 | 0.29 | | 0.50 | 13.91 |
| Space | 0.91 | 0.29 | 2.40 | 1.00 | 0.33 | | 0.33 | 5.76 |
| PET - Mammography | 0.10 | 1.05 | 1.00 | 3.00 | 0.52 | | | 6.67 |
| Human PET | 0.75 | 0.90 | | | | | | 1.65 |
| Compton in PET | 1.55 | 0.40 | 0.45 | | | | | 2.40 |
| MC in Medical Physics | 3.10 | | | 2.40 | 1.35 | 0.30 | 1.30 | 8.95 |
| OrthoImaging | 0.50 | | | | | | | 2.92 |
| RD51 | 0.74 | 1.39 | | 0.53 | | | | 2.66 |
| NeuLand - R3B | 0.40 | 1.75 | | | | | | 2.15 |
| GEMs | 2.50 | 0.30 | 0.15 | 1.00 | | | | 3.95 |
| DUAL | 2.20 | | | 1.60 | | | | 4.30 |
| NEXT | 1.55 | | | 0.60 | | | | 2.35 |
| ICNAS | 0.50 | | | 1.00 | | | | 1.69 |
| OUTREACH | 1.60 | 0.32 | 0.05 | 0.40 | 0.20 | | | 3.97 |
| TTN-ILO | | 1.00 | | | | | | 1.00 |
| Education | | | | | | | | |
| Scientific Conferences and Seminars | | | | | | | | |
| Totals: | 49.91 | 16.05 | 24.58 | 25.57 | 9.75 | 2.30 | 4.98 | |

**Legend:**

**Students:** D - PhD, M - Master, G - Graduation, O - Other

**FTE:** Full Time Equivalent

## 1.10 Organisational Structure

### Directors

José Mariano Gago, Gaspar Barreira, Mário Pimenta, Paulo Fonte, Rui Marques

### Secretaries of the Scientific Council

Sofia Andringa, Helmut Wolters

### Administrative Staff

Cláudia Delgado, Elisabete Neves, Isabel Melo, João Pedro Santos, Lina Barata, Natália Antunes, Ricardo Caeiro, Sandra Dias, Teresa Marques

### Technical Staff

Alberto Blanco, Alexandre Moita, Américo Pereira, Carlos Manuel, Carlos Silva, Christophe Pires, Emir Sirage, Henrique Matos, Hugo Gomes, João Silva, Joaquim Oliveira, José Aparício, José Carlos Nogueira, José Carlos Silva, Luís Gurriana, Luís Lopes, Luís Mendes, Miguel Ferreira, Nuno Carolino, Nuno Filipe Silva Dias, Orlando Cunha, Pedro Parracho, Rui Alves, Rui Pereira da Silva

# Chapter 2

# Particle Physics with Accelerators

## 2.1 Collaboration in the ATLAS experiment at CERN

### 2.1.1 Resumo

ATLAS é uma das experiências que operam no Grande Colisionador de Hadrões (LHC) no CERN, onde se dão colisões protão-protão e entre iões pesados a altas energias e luminosidades, abrindo uma nova fronteira na Física de Partículas. O objectivo é o estudo das propriedades fundamentais da matéria, principalmente a natureza da quebra da simetria electro-fraca e a origem da massa, através da procura da peça que falta no Modelo Padrão, o bosão de Higgs. A estrutura genérica do detector vai também permitir a sensibilidade a sinais de nova Física que se poderão manifestar a altas energias, como o modelo da Supersimetria, que pode explicar a abundância de Matéria Escura no Universo.
O grupo português de ATLAS contribui para os estudos de Física e para as actividades de manutenção e funcionamento do detector. Em termos de estudos de Física, procuramos o bosão de Higgs, estudamos o quark top, os bosões W e dibosões WW, e também o comportamento de jactos de partículas em ambiente de colisão

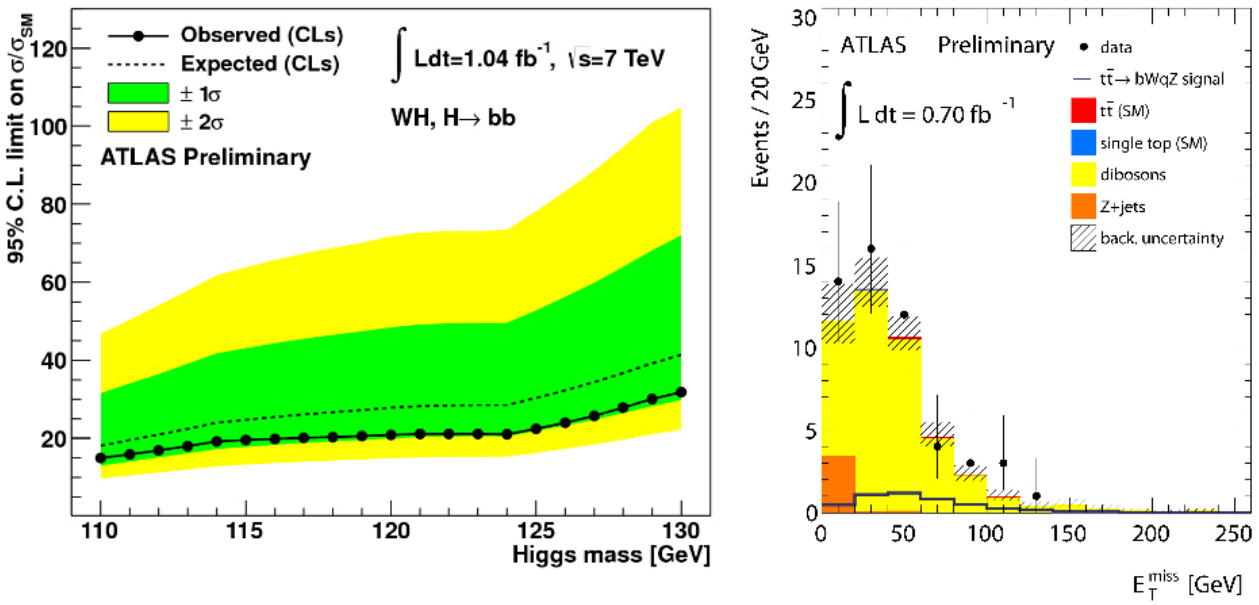



Figure 2.1: Left: Exclusion limits for the Higgs boson in channel $WH \to l\nu b\bar{b}$ expressed as the ratio to the Standard Model cross-section. Right: Distribution of missing transverse energy for the FCNC top decay $t \to qZ$.

de iões pesados de chumbo. Estamos activos na certificação, operação e estudos de desempenho do calorímetro hadrónico TileCal e do segundo nível do sistema de trigger, bem como na certificação do monitor de luminosidade absoluta ALFA.
Participámos na primeira nota pública de ATLAS relativa à pesquisa do bosão de Higgs do Modelo Padrão, produzido em associação com um bosão W e decaindo num par de quarks b, sendo uma investigadora da nossa equipa co-editora da nota. O trabalho efectuado para estudos de dibosões foi adaptado à pesquisa do bosão de Higgs decaindo em WW, onde contribuimos para o cálculo dos fundos de Z+jactos e Drell-Yan utilizando um método alternativo baseado em dados ("data-driven"). A medição da secção eficaz de produção inclusiva de W no canal em que o W decai em muão+neutrino foi actualizado, tal como o respectivo software de análise "WZbenchmark". Nesta fase, o decaimento do quark top também é importante, pois pode ser usado como teste para identificação do quark b e calibração da escala de energia. Foram estudados o vértice Wtb utilizando a helicidade do W e simetrias angulares. A observação da supressão de jactos no plasma de quarks e gluões resultante da colisão de iões pesados foi um dos resultados publicados por ATLAS em tempo recorde, e para isso contribuiu fortemente uma colaboradora da nossa equipa que foi responsável pela configuração da infraestrutura da qualidade dos dados de jactos no ambiente de iões pesados.
O estudo do desempenho para jactos do segundo nível de trigger (LVL2) prosseguiu, tendo em conta o significativo empilhamento de sinais que passou a existir ao longo de 2011 derivado das múltiplas colisões por evento proporcionadas pelo LHC. Trabalhou-se também no desenvolvimento de um trigger que permita melhorar a calibração hadrónica e avaliar a incerteza na escala de energía dos jactos utilizando hadrões isolados.
Foi analisado o efeito do empilhamento de sinais e energia transversa em falta (ETmiss) devida a problemas de funcionamento dos calorímetros TileCal e LAr, no desempenho da reconstrução de jactos e ETmiss. Continuou também o estudo do ruído do calorímetro TileCal.
Continuamos com o envolvimento no Sistema de Controlo do TileCal (DCS). O sistema está operacional, e foram feitos desenvolvimentos para optimizar o reconhecimento dos estados do hardware e os tempos de ligação das fontes de baixa tensão de cada vez que estas se desligam automaticamente. Conseguiu-se baixar o tempo de ligação para cerca de metade ($\approx$1 minuto) o que é significativo face ao número de ocorrências. Além disso participámos nos testes das novas fontes de alimentação e no processo de substituição de cerca de 40 fontes no detector.
Contribuímos também para o controlo operacional da qualidade dos dados do TileCal, tendo um membro da equipa assegurado a função de "Data Quality Leader"no CERN pelo período normal (um mês).
No que diz respeito às componentes ópticas do TileCal mantiveram-se algumas actividades, tal como o melhoramento da funcionalidade do sistema de monitorização com laser. Foi ainda mantida a participação na certificação do detector de fibras cintilantes (detector ALFA) para medição da luminosidade de ATLAS e também estudos de avaliação do envelhecimento da óptica do TileCal com vista ao Super-LHC.
As actividades de bases de dados do Trigger/DAQ para controlo, configuração e monitorização de dados continuaram, centradas na ferramenta de apresentação de histogramas de controlo de qualidade Node2 e infraestrutura associada.
O projecto inclui também uma componente de divulgação, que foi intensa ao longo de 2011, com vários dos membros deste projecto a participarem nas MasterClasses em várias universidades, na escola para professores de língua portuguesa no CERN, em actividades do programa Ciência Viva para jovens estudantes do Verão e em exposições destinadas ao público em geral.

### 2.1.2 Abstract

ATLAS is one of the experiments that operates at the CERN Large Hadron Collider (LHC) where proton-proton and heavy ion collisions take place at unprecedented high energies and luminosities, opening a new frontier in particle physics. The goal is to study the fundamental properties of matter, mainly the nature of the electroweak symmetry breaking and the origin of mass, through the search for the missing cornerstone of the Standard Model, the Higgs boson. The general purpose detector structure will also allow the sensitivity to new Physics, such as Supersymmetry, that could explain the abundance of Dark Matter in the Universe.
The portuguese group contributions to ATLAS concern both Physics studies and detector performance and operation. In terms of Physics studies, we focus on searches for the Higgs boson, studies with the top quark, the W boson and WW dibosons, and heavy ion Pb collisions. We are active in the operation and performance studies of the TileCal hadronic calorimeter and High-Level Trigger and in the commissioning of the ALFA absolute luminosity monitor.
The ATLAS detector maintenance, commissioning and Physics studies have been continued. Measurement of the W boson cross section, top quark properties and jet suppression in heavy ion Pb collisions were carried out. The jet performance in the second level of the trigger system was studied in the strong pile-up conditions delivered by the LHC this year. The TileCal DCS was operational and significative improvements were done at

the level of hardware state identification and automatic switch on procedure of low voltage power supplies that became faster and more efficient, a very welcome improvement taking into account that ≈5000 trips occurred in 2011 and many more are expected for 2012.
We have also contributed to the TileCal data quality control: one of the members of our team took the operational role of "Data Quality Leader"at CERN for the normal period (one month).
The involvement in the Tilecal optics continued, with the improvement of the functionality of the laser monitoring system.
The LHC operation in 2011 was a success, allowing to record an integrated luminosity of ≈5fb-1 that is being analysed.

### 2.1.3 Objectives

Exploitation of the full physics potential of the ATLAS/LHC experiment at CERN is our final goal.
The ATLAS detector is expected to take good quality data the full year LHC and data analysis will continue. The W benchmark tool for W related analysis, in particular for W->mu nu channel will be set operational and the measurement of the production cross section of the W boson and dibosons will be updated. W+bjets and Z+bjets production cross sections will also be measured. The study of the top quark physics with emphasis in the anomalous couplings and measurement of the forward-backward asymmetry in top decays will continue, as well as the heavy ion activities with jets and maintenance of the jet calibration at the level 2 trigger system and respective performance study.
Higgs boson searches in the channel H->b bbar at low mass range and high pT is a very important goal, but following our preliminary studies, the standard non boosted method deserves also a trial since it seems to have advantages at the lower energy that LHC is running.
Operation and maintenance activities in TileCal including reconstruction software, second laser setup and laser monitoring, correlated noise studies and DCS system activities, and in Trigger-DAQ tasks, including mainly the development and support of NODE2 histograms browser and associated infrastructure, are part of our long term responsibilities.
It is planned to improve the lifetime estimate of the optical components of TileCal, using natural and/or accelerated ageing, to participate in the commissioning of the ALFA luminosity detector, and also in several outreach activities, such as Masterclasses and the School for portuguese language teachers at CERN.

### 2.1.4 Achievements

The ATLAS detector took collisions data smoothly and eficiently along 2011. The main tasks carried out have been Physics and Performance studies and operation and maintenance of the detector. A summary of the main achievements follows.
Analysis of Higgs boson search in channel H-> bb, in associated production with a W boson, in the non-boosted regime.
Calculation of the Z+jets and Drell-Yan backgrounds and associated systematic uncertainty with an alternative data-driven method for the case of Higgs boson decaying in WW.
Determination of the W production cross section, update of the WZBenchmark. Validation of the code for the analysis of WW events.
Measurement of the W polarisation in top decays using single lepton and dilepton events.
Constraints of the Wtb vertex structure using W polarization observables (angular asymmetries and W helicity fractions).
Search for rare decays of the top quark through the Flavour Changing Neutral Current t->qZ, allowing to obtain 95% confidence level limits on the branching fraction for this decay.
Search for same-sign top quark pair production using dileptonic events.
Calculation of jet energy scale, resolution and reconstruction efficiencies in the heavy ion collisions environment. The jet calibration at the Second Level Trigger (LVL2) was shown to work well in the increasing pile-up environment. Optimized triggers for E/p studies using isolated single hadrons were proposed and implemented for the 2012 data taking.
Small non linearity effects in TileCal studied/corrected using the laser
"Figures of merit"to parametrize noise correlations in TileCal were obtained.
TileCal DCS improvements allowing to save half of the time in the switch on of each power supply, very useful in the recovery of the frequent trips.
In what concerns TDAQ, several new functionalities have been added to Node2Gui to increase its usage efficiency. Tool to convert the ALFA detector raw data to a format suitable for analysis, and software for quality control distributions.

### 2.1.5 Sources of Funding

| Code | Funding | Start | End |
|---|---|---|---|
| CERN/FP/116346/2010 | 267.000 € | 2011-01-01 | 2012-03-31 |

### 2.1.6 Team

**Project coordinator: Amélia Maio**

| Name | Status | %of time in project |
|---|---|---|
| Ademar Delgado | Master student (LIP) | 100 |
| Agostinho Gomes | Researcher (LIP) | 85 |
| Alberto Palma | PhD student (LIP/FCT) | 100 |
| Alexandre Lopes | Master student (LIP) | 75 |
| Amélia Maio | Researcher (LIP/FCUL) | 55 |
| António Amorim | Researcher (FCUL) | 15 |
| António Onofre | Researcher (LIP/UMinho) | 35 |
| Belmiro Pinto | Researcher (LIP) | 100 |
| Bruno Galhardo | PhD student (LIP) | 100 |
| Emanuel Gouveia | Student (LIP) | 80 |
| Emiliano Pinto | Master student (LIP) | 25 |
| Filipe Veloso | Post-Doc (LIP/FCT) | 90 |
| Helena Santos | Researcher (LIP) | 100 |
| Helmut Wolters | Researcher (LIP/FCTUC) | 40 |
| Joana Miguéns | PhD student (LIP/FCT) | 100 |
| João Carvalho | Researcher (LIP/FCTUC) | 30 |
| João Gentil | Post-Doc (LIP/FCT) * | 100 |
| João Rodolfo Alves | Student (LIP) | 80 |
| José Maneira | Researcher (LIP) | 70 |
| José Silva | PhD student (LIP) | 50 |
| Juan Espinosa | Master (LIP) | 19 |
| Lourenço Lopes | Master (LIP/FCUL) | 100 |
| Luís Gurriana | Technician (LIP) | 50 |
| Luís Seabra | Master student (LIP) | 100 |
| Manuel Maneira | Researcher (LIP/FCTUNL) | 15 |
| Mário Sargedas Sousa | PhD student (LIP) | 100 |
| Nuno Anjos | Post-Doc (LIP/FCT) | 100 |
| Nuno Castro | Post-Doc (LIP/FCT) | 30 |
| Oleksii Galan | PhD student (LIP/FCT) | 59 |
| Patricia Conde | Researcher (LIP) | 80 |
| Pedro Jorge | PhD student (LIP/FCT) | 80 |
| Susana Santos | Master student (LIP) | 100 |

### 2.1.7 Publications

**Articles in international journals (with direct contribution from LIP members)**

- *Studies of the performance of the ATLAS detector using cosmic-ray muons*
  The ATLAS Collaboration
  arXiv:1011.6665v1, Eur.Phys.J. C71 (2011) 1593

- *Measurement of the top quark pair production cross-section with ATLAS in pp collisions at sqrt(s) = 7 TeV*
  The ATLAS Collaboration
  arXiv:1012.1792v2, Eur.Phys.J.C71:1577,2011

- *Measurement of the WW cross section in sqrt(s) = 7 TeV pp collisions with ATLAS*
  The ATLAS Collaboration

Phys. Rev. Lett. 107, 041802 (2011)

- *Measurement of the centrality dependence of J/Ψ yields and observation of Z production in lead-lead collisions with the ATLAS detector at the LHC*
  The ATLAS Collaboration
  arXiv:1012.5419v1, Phys.Lett.B697:294-312,2011

- *Limits on the production of the Standard Model Higgs Boson in pp collisions at sqrt(s) =7 TeV with the ATLAS detector*
  The ATLAS Collaboration
  EPJC 71 (2011) 1728

- *Search for dilepton resonances in pp collisions at sqrt(s) = 7 TeV with the ATLAS detector*
  The ATLAS Collaboration
  Phys.Rev.Lett. 107 (2011) 272002

- *Search for massive colored scalars in four-jet final states in sqrts=7 TeV proton-proton collisions with the ATLAS detector*
  The ATLAS Collaboration
  Eur.Phys.J.C 71 (2011) 1828

**Articles in international journals (with indirect contribution from LIP members)**

- *Search for Quark Contact Interactions in Dijet Angular Distributions in pp Collisions at sqrt(s) = 7 TeV Measured with the ATLAS Detector*
  Atlas Collaboration
  Phys. Lett. B 694 (2011) 327-345

- *Search for Quark Contact Interactions in Dijet Angular Distributions in pp Collisions at sqrt(s) = 7 TeV Measured with the ATLAS Detector*
  The ATLAS Collaboration
  arXiv:1009.5069v1, Phys.Lett.B694:327-345,2011

- *Measurement of inclusive jet and dijet cross sections in proton-proton collisions at 7 TeV centre-of-mass energy with the ATLAS detector*
  The ATLAS Collaboration
  arXiv:1009.5908v2, Eur.Phys.J.C71:1512,2011

- *Measurement of underlying event characteristics using charged particles in pp collisions at sqrt(s) = 900 GeV and 7 TeV with the ATLAS Detector*
  The ATLAS Collaboration
  arXiv:1012.0791v2, Phys. Rev. D 83 (2011) 112001

- *Charged particle multiplicities in pp interactions measured with the ATLAS detector at the LHC*
  The ATLAS Collaboration
  arXiv:1012.5104v2, New J.Phys.13:053033,2011

- *Search for squarks and gluinos using final states with jets and missing transverse momentum with the ATLAS detector in sqrt(s) = 7 TeV proton-proton collisions*
  The ATLAS Collaboration
  Phys. Lett. B 701 (2011) 186-203

- *Measurement of Dijet Azimuthal Decorrelations in pp Collisions at sqrt(s)=7 TeV*
  The ATLAS Collaboration
  Phys. Rev. Lett. 106 (2011) 172002

- *Search for supersymmetry using final states with one lepton, jets, and missing transverse momentum with the ATLAS detector in sqrts = 7 TeV pp*
  The ATLAS Collaboration
  Phys.Rev.Lett.106:131802,2011

- *Luminosity Determination in pp Collisions at sqrt(s)=7 TeV Using the ATLAS Detector at the LHC*
  The ATLAS Collaboration
  Eur.Phys.J.C71:1630, 2011

- *Measurements of underlying-event properties using neutral and charged particles in pp collisions at 900 GeV and 7 TeV with the ATLAS detector at the LHC*
  The ATLAS Collaboration
  Eur.Phys.J. C71 (2011) 1636

- *Search for Contact Interactions in Dimuon Events from pp Collisions at sqrt(s) = 7 TeV with the ATLAS Detector*
  The ATLAS Collaboration
  Phys. Rev. D 84, 011101(R) (2011)

- *Measurement of the Inelastic Proton-Proton Cross-Section at sqrts=7 TeV with the ATLAS Detector*
  The ATLAS Collaboration
  Nature Comm. 2 (2011) 463

- *Search for high mass dilepton resonances in pp collisions at sqrts=7 TeV with the ATLAS experiment*
  The ATLAS Collaboration
  Phys Lett B700 (2011) 163-180

- *Search for an excess of events with an identical flavour lepton pair and significant missing transverse momentum in sqrts = 7 TeV proton-proton collisions with the ATLAS detector*
  The ATLAS Collaboration
  EPJC 71 (2011) 1647

- *Search for supersymmetric particles in events with lepton pairs and large missing transverse momentum in sqrts = 7 TeV proton-proton collisions with the ATLAS experiment*
  The ATLAS Collaboration
  EPJC 71 (2011) 1682

- *Search for a heavy particle decaying into an electron and a muon with the ATLAS detector in sqrt(s) = 7 TeV pp collisions at the LHC*
  The ATLAS Collaboration
  Phys. Rev. Lett. 106, 251801 (2011)

- *Search for supersymmetry in pp collisions at sqrts = 7TeV in final states with missing transverse momentum and b-jets*
  The ATLAS Collaboration
  Phys. Lett. B701 (2011), 398-416

- *Search for New Physics in Dijet Mass and Angular Distributions in pp Collisions at sqrt(s) = 7 TeV Measured with the ATLAS Detector*
  The ATLAS Collaboration
  New J. Phys. 13 (2011) 053044

- *Measurement of the Muon Charge Asymmetry from W Bosons Produced in pp Collisions at sqrt(s) = 7 TeV with the ATLAS detector*
  The ATLAS Collaboration
  Phys. Lett. B 701 (2011) 31-49

- *Search for stable hadronising squarks and gluinos with the ATLAS experiment at the LHC*
  The ATLAS Collaboration
  Phys. Lett. B 701 (2011) 1-19

- *Search for high-mass states with one lepton plus missing transverse momentum in proton-proton collisions at sqrt(s) = 7 TeV with the ATLAS detector*
  The ATLAS Collaboration
  Phys.Lett.B701:50-69,2011

- *Search for Massive Long-lived Highly Ionising Particles with the ATLAS Detector at the LHC*
  The ATLAS Collaboration
  Phys.Lett.B698:353-370,2011

- *Study of Jet Shapes in Inclusive Jet Production in pp Collisions at sqrt(s) = 7 TeV using the ATLAS Detector*
  The ATLAS Collaboration
  arXiv:1101.0070v1, Phys.Rev.D83:052003,2011

- *Measurement of the production cross section for W-bosons in association with jets in pp collisions at sqrt(s) = 7 TeV with the ATLAS detector*
  The ATLAS Collaboration
  arXiv:1012.5382v2, Phys.Lett.B698:325-345,2011

- *Search for pair production of first or second generation leptoquarks in proton-proton collisions at sqrt(s)=7 TeV using the ATLAS detector at the LHC*
  The ATLAS Collaboration
  Phys. Rev. D 83, 112006 (2011)

- *Measurement of the differential cross-sections of inclusive, prompt and non-prompt J/psi production in proton-proton collisions at sqrt(s) = 7 TeV*
  The ATLAS Collaboration
  Nucl. Phys. B 850 (2011) 387-444

- *Measurement of dijet production with a veto on additional central jet activity in pp collisions at sqrt(s)=7 TeV using the ATLAS detector*
  The ATLAS Collaboration
  JHEP 09 (2011) 053

- *Measurement of Wgamma and Zgamma production in proton-proton collisions at sqrt(s)=7 TeV with the ATLAS Detector*
  The ATLAS Collaboration
  JHEP 09 (2011) 072

- *Search for new phenomena with the monojet and missing transverse momentum signature using the ATLAS detector in sqrt(s) = 7 TeV proton-proton collisions*
  The ATLAS Collaboration
  Phys.Lett.B 705 (2011) 294-312

- *Measurement of the Upsilon(1S) Production Cross-Section in pp Collisions at sqrt(s) = 7 TeV in ATLAS*
  The ATLAS Collaboration
  Phys.Lett.B 705 (2011) 9-27

- *Search for Heavy Long-Lived Charged Particles with the ATLAS detector in pp collisions at sqrt(s) = 7 TeV*
  The ATLAS Collaboration
  Phys. Lett. B 703 (2011) 428-446

- *Measurement of the W to tau nu Cross Section in pp Collisions at sqrt(s) = 7 TeV with the ATLAS experiment*
  The ATLAS Collaboration
  Phys.Lett.B 706 (2012) 276-294

- *Search for a heavy gauge boson decaying to a charged lepton and a neutrino in 1 fb-1 of pp collisions at sqrt(s) = 7 TeV using the ATLAS detector*
  The ATLAS Collaboration
  Phys.Lett.B 705 (2011) 28-46

- *Inclusive search for same-sign dilepton signatures in pp collisions at sqrt(s) = 7 TeV with the ATLAS detector,*
  The ATLAS Collaboration
  JHEP 10 (2011) 107

- *Measurement of the inclusive isolated prompt photon cross-section in pp collisions at sqrt(s)= 7 TeV using 35 pb-1 of ATLAS data*
  The ATLAS Collaboration
  Phys.Lett.B 706 (2011) 150-167

- *Search for neutral MSSM Higgs bosons decaying to tauˆ+ tauˆ- pairs in proton-proton collisions at sqrt(s) = 7 TeV with the ATLAS detector*
  The ATLAS Collaboration
  Phys.Lett.B 705 (2011) 174-192

- *Measurement of the transverse momentum distribution of Z/gamma* bosons in proton-proton collisions at sqrt(s)=7 TeV with the ATLAS detector*
  The ATLAS Collaboration
  Phys.Lett.B 705 (2011) 415-434

- *Measurement of multi-jet cross sections in proton-proton collisions at a 7 TeV center-of-mass energy*
  The ATLAS Collaboration
  Eur.Phys.J.C 71 (2011) 1763

- *Search for Diphoton Events with Large Missing Transverse Energy with 36 pbˆ-1 of 7 TeV Proton-Proton Collision Data with the ATLAS Detector*
  The ATLAS Collaboration
  Eur.Phys.J.C 71 (2011) 1744

- *Properties of jets measured from tracks in proton-proton collisions at center-of-mass energy sqrt(s) = 7 TeV with the ATLAS detector*
  The ATLAS Collaboration
  Phys. Rev. D 84, 054001 (2011)

- *Search for a Standard Model Higgs boson in the H->ZZ->llnunu decay channel with the ATLAS detector*
  The ATLAS Collaboration
  Phys.Rev.Lett. 107 (2011) 221802

- *Search for the Standard Model Higgs boson in the two photon decay channel with the ATLAS detector at the LHC*
  The ATLAS Collaboration
  Phys.Lett.B 705 (2011) 452-470

- *Search for the Higgs boson in the H->WW->lvjj decay channel in pp collisions at sqrts = 7 TeV with the ATLAS detector*
  The ATLAS Collaboration
  Phys.Rev.Lett. 107 (2011) 231801

- *Search for the Standard Model Higgs boson in the decay channel H->ZZ(*)->4l with the ATLAS detector*
  The ATLAS Collaboration
  Phys.Lett.B 705 (2011) 435-451

- *Measurement of the inclusive and dijet cross-sections of b-jets in pp collisions at sqrt(s) = 7 TeV with the ATLAS detector*
  The ATLAS Collaboration
  Eur.Phys.J.C 71 (2011) 1846

- *Measurement of the Z to tau tau cross section with the ATLAS detector*
  The ATLAS Collaboration
  Phys.Rev.D 84 (2011) 112006

**International Conference Proceedings**

- *Iberian ATLAS Cloud response during the first LHC collisions*
  M Villaplana Perez, G Borges, J Carvalho, M David, J Gomes, M Oliveira, H Wolters et al.
  J. Phys.: Conf. Ser. 331 072068 doi:10.1088/1742-6596/331/7/072068

**Collaboration notes with internal referee**

- *Performance of the ATLAS Trigger in 2010 running at the LHC*
  The ATLAS Collaboration
  ATL-COM-DAQ-2011-009

- *Measurement of the W-boson polarization in top quark decays in pp collision data at $\sqrt{s}$=7 TeV using the ATLAS detector*
  The ATLAS Collaboration
  ATLAS-CONF-2011-037

- *Centrality dependence of Jet Yields and Jet Fragmentation in Lead-Lead 2 Collisions*
  H. Santos et al.

- *Centrality dependence of Jet Yields and Jet Fragmentation in Lead-Lead 2 Collisions*
  H. Santos et al.
  ATL-COM-PHYS-2011-463

- *Inclusive Jet Trigger Efficiencies for the Early 2011 Data*
  The ATLAS Collaboration
  ATLAS-COM-DAQ-2011-031.

- *Search for FCNC top quark processes at sqrt(s)=7 TeV with the ATLAS detector*
  The ATLAS Collaboration
  ATLAS-COM-CONF-2011-025, ATL-COM-PHYS-2011-152, ATL-PHYS-INT-2011-036

- *Search for the Standard Model Higgs boson produced in association with a vector boson and decaying to a b-quark pair with the ATLAS detector at the LHC*
  The ATLAS Collaboration
  ATLAS-CONF-2011-103

- *Jet Trigger Performance with 2011 Data*
  The ATLAS Collaboration
  ATLAS-COM-DAQ-2011-063

- *Energy response uniformity to cosmic muons of the ATLAS Hadronic Tile Calorimeter, with calorimeter-based reconstruction*
  M.J. Sousa et al
  ATL-TILECAL-INT-2011-007

- *Search for FCNC in Top Quark Decays at sqrt(s) = 7 TeV in 0.70 fb-1 of pp collision data collected with the ATLAS Detector*
  J. Carvalho et al.,
  ATLAS-COM-CONF-2011-111, ATL-COM-PHYS-2011-690

**Internal Notes**

- *Calorimeter energy fluctuations in Pb+Pb collisions*
  Helena Santos et al.
  ATL-COM-PHYS-2011-299

- *Centrality Dependence of Jet Yields and Jet Fragmentation in Lead-Lead Collisions*
  H. Santos et al
  ATL-COM-PHYS-2011-463

- *Measurement of the W-boson polarization in top quark decays in pp collision data at sqrt(s) = 7 TeV using the ATLAS detecto*
  J.A. Aguilar-Saavedra et al
  ATL-PHYS-INT-2011-044

- *Commissioning of the ATLAS tile calorimeter LASER calibration system*
  D. Calvet et al.
  ATL-TILECAL-INT-2011-004

- *The TileCal/ATLAS subdetector calibration systems*
  J. Carvalho
  ATL-COM-TILECAL-2011-030, ATL-COM-TILECAL-2011-029

- *Background estimates in the H->WW->lnln analysis with 4.7 fb-1 of data collected with the ATLAS detector at sqrt(s)=7TeV*
  J. Machado Miguéns, P. Conde Muíño, et al
  ATL-COM-PHYS-2011-1728

- *Search for the Standard Model Higgs boson in the $H \rightarrow WW^{(*)} \rightarrow \ell\nu\ell\nu$ decay mode with 4.7 $fb^{-1}$ of ATLAS data at $\sqrt{s}$ = 7 TeV*
  J. Machado Miguéns, P. Conde Muíño et al.
  ATL-COM-PHYS-2011-1729.

### 2.1.8 Presentations

**Oral presentations in international conferences**

- *ATLAS Results on Pb+Pb Collisions*
  presented by Helena Santos
  HEP EPS 2011 — Grenoble, France.

- *H -> bb searches at ATLAS*
  presented by Patricia Conde
  SUSY11, 19th International Conference on Supersymmetry and Unification of Fundamental Interactions — Fermilab, Batavia, Illinois USA.

- *New Physics Searches Involving Top Quarks with the ATLAS Detector*
  presented by Nuno Castro
  Beyond the Standard Model: Results with the 7 TeV LHC Collision Data — ICTP, Trieste, Italy.

- *W polarization and constraints on Wtb vertex*
  presented by Nuno Castro
  TOP 2011, 4th International Workshop on Top Quark Physics — Sant Feliu de Guixols, Spain.

**Poster presentations in international conferences**

- *Search for the Standard Model Higgs boson produced in association with a vector boson and decaying to a b-qark pair with the ATLAS detector at the LHC*
  presented by Patricia Conde
  HEP EPS 2011 — Grenoble, France.

- *Performance and Calibration of the ATLAS Jet Trigger*
  presented by Joana Miguéns
  EPS-HEP 2011 — Grenoble, France.

- *Study of the correlated noise in TILECAL*
  presented by Susana Santos
  2011 European School of High Energy Physics — .

- *Search for the SM Higgs decaying to a b-quark pair with ATLAS*
  presented by Alberto Palma
  Hadron Collider Physics Symposium 2011 (HCP201) — Paris, France.

**Oral presentations in international meetings**

- *HadCalib triggers*
  presented by Mário Sargedas Sousa
  Jet Trigger Meeting — CERN.

**Oral presentations in collaboration meetings**

- *W+b-jets plans*
  presented by Nuno Anjos
  WZ+b-jets meeting — CERN.
- *Underlying Event in Pb+Pb Collisions*
  presented by Helena Santos
  — CERN.
- *Update on Winter 2010/11 analysis: FCNC*
  presented by Filipe Veloso
  — CERN.
- *Multiplicities and layer efficiencies*
  presented by Luís Seabra
  LFA TB10 analysis — CERN.
- *LASER intervention*
  presented by Bruno Galhardo
  — CERN.
- *Multiplicities and layer efficiencies*
  presented by Luís Seabra
  — CERN.
- *Single top fast simulation and POWHEG validation for the Wt-channel*
  presented by Inês Ochoa
  Single top meeting — CERN.
- *Status of Lisbon WH analysis*
  presented by Patricia Conde
  — CERN.
- *Status of Lisbon WH analysis*
  presented by Patricia Conde
  — CERN.
- *Update: Search for FCNC*
  presented by Filipe Veloso
  — CERN.
- *TileCal DCS conditions in the HI run*
  presented by Helena Santos
  — CERN.
- *HadCalib triggers for E/p*
  presented by Mário Sargedas Sousa
  E/p meeting — CERN.
- *WH cut-flow comparison in rel.16*
  presented by Patricia Conde
  — CERN.
- *Laser Hardware status*
  presented by Bruno Galhardo
  — CERN.
- *L2 Calibration*
  presented by Joana Miguéns
  — CERN.
- *Studies of the E/P Triggers*
  presented by Mário Sargedas Sousa
  Jet Trigger Meeting — CERN.

- *Laser status*
  presented by Bruno Galhardo
  — CERN.
- *DCS in Athena status*
  presented by Helena Santos
  — CERN.
- *Dijet asymmetries with full statistics*
  presented by Helena Santos
  — CERN.
- *L2 JES Update*
  presented by Joana Miguéns
  — CERN.
- *Noise Correlation study in new generation of LVPS*
  presented by Susana Santos
  Tilecal Calibration, Data Quality, Performance and Processing — CERN.
- *Effect of pileup on L2*
  presented by Lourenço Lopes
  Jet Trigger Meeting — CERN.
- *H->WW->lnulnu (0 jet) Release 16 Cut Flow*
  presented by Joana Miguéns
  — CERN.
- *L2 Jet Trigger Validation with 2011 Data*
  presented by Joana Miguéns
  — CERN.
- *L2 Validation*
  presented by Nuno Anjos
  Jet Trigger Meeting — CERN.
- *Asymmetries with 2 and 3 jet topologies*
  presented by Helena Santos
  — CERN.
- *Physics Analysis Tools for Heavy Ions*
  presented by Helena Santos
  — CERN.
- *ALFA layer efficiencies and noise contributions*
  presented by Luís Seabra
  ALFA TB10 analysis meeting — CERN.
- *Layer efficiencies and noise contributions*
  presented by Luís Seabra
  — CERN.
- *LVL2 Trigger Pileup studies*
  presented by Lourenço Lopes
  Jet Trigger Meeting — CERN.
- *Jet reconstruction performance*
  presented by Helena Santos
  — CERN.
- *Jet reconstruction performance*
  presented by Helena Santos
  — CERN.

- *Status of Lisbon WH analysis*
  presented by José Maneira
  — CERN.
- *L2 Performance with 2011 Data*
  presented by Joana Miguéns
  — CERN.
- *L1/L2 Jet Trigger Performance with 2011 Data*
  presented by Joana Miguéns
  — CERN.
- *Laser Linearity*
  presented by Bruno Galhardo
  — CERN.
- *Status of the Lisbon WH* $\rightarrow \mu\nu bb$ *analysis*
  presented by Patricia Conde
  — Dubna.
- *Relevant material from the live-page for Lar hole*
  presented by João Gentil
  Jet/Etmiss Phone Conference — CERN.
- *Update on the FCNC analysis*
  presented by Filipe Veloso
  — CERN.
- *Laser linearity*
  presented by Bruno Galhardo
  — CERN.
- *CaloBackgrounds and dijets studies with reprocessed data*
  presented by Helena Santos
  — CERN.
- *HadCalib trigger status*
  presented by Mário Sargedas Sousa
  E/p meeting — CERN.
- *DCS on call report*
  presented by Agostinho Gomes
  TileCal Week Operations/Maintenance — CERN.
- *Jet energy scale as a function of* $pT$ *and* $\nu$
  presented by Helena Santos
  — CERN.
- *Properties - FCNC in decay*
  presented by Filipe Veloso
  — CERN.
- *Update on LAr hole with track jets*
  presented by João Gentil
  Jet/Etmiss Phone Conference — CERN.
- *Laser status*
  presented by Bruno Galhardo
  — CERN.
- *Summary of noise and pileup studies*
  presented by Susana Santos
  — CERN.

- *Hit multiplicity, layer efficiency and noise contribution*
  presented by Luís Seabra
  ALFA General Meeting — Prague.
- *Hit multiplicity, layer efficiency and noise contribution*
  presented by Luís Seabra
  — Prague.
- *L2 Noise Suppression and Performance*
  presented by Lourenço Lopes
  Jet Trigger Meeting — CERN.
- *L2 Jet Trigger Performance with Pile-Up Suppression*
  presented by Joana Miguéns
  — CERN.
- *Performance and Outlook for Jets and Missing ET Triggers*
  presented by Joana Miguéns
  — CERN.
- *DCS report*
  presented by Agostinho Gomes
  TileCal Operation Weekly Meeting — CERN.
- *Laser system plans during the Technical Stop*
  presented by Bruno Galhardo
  — CERN.
- *Analysis performance studies*
  presented by Helena Santos
  — CERN.
- *Update on Pile-Up Suppression at L2*
  presented by Lourenço Lopes
  — CERN.
- *hadCalib Trigger Optimization*
  presented by Mário Sargedas Sousa
  Jet Trigger Meeting — CERN.
- *Jet update*
  presented by Helena Santos
  — CERN.
- *Properties – FCNC in top decay*
  presented by João Carvalho
  — CERN.
- *Plots*
  presented by Lourenço Lopes
  Jet Trigger Meeting — CERN.
- *Properties – Search for FCNC in decay*
  presented by Filipe Veloso
  — CERN.
- *Photons in top FCNC decays*
  presented by João Carvalho
  — CERN.
- *Plots for LP2011*
  presented by Joana Miguéns
  — CERN.

- *Plots for LP2011*
  presented by Joana Miguéns
  — CERN.
- *validation of HIJetRec in v17*
  presented by Helena Santos
  — CERN.
- *Analysis Update - validation of HIJetRec in v17*
  presented by Helena Santos
  — CERN.
- *Analysis Update*
  presented by Helena Santos
  — CERN.
- *Analysis Update - validation of HIJetRec in v17*
  presented by Helena Santos
  — CERN.
- *FCNC update*
  presented by Filipe Veloso
  — CERN.
- *Search for FCNC in top decay*
  presented by Filipe Veloso
  — CERN.
- *Analysis Update - Jet Monitoring for the next run*
  presented by Helena Santos
  — CERN.
- *Jet Monitoring for the next run*
  presented by Helena Santos
  — CERN.
- *Met dependence with n, mu and distance from front in rel 16*
  presented by João Gentil
  Jet/Etmiss hadronic calibration workshop at SLAC — SLAC.
- *Update FCNC*
  presented by Filipe Veloso
  — CERN.
- *Report from Heavy Ions*
  presented by Helena Santos
  — CERN.
- *Full disclosure: FCNC (3 leptons)*
  presented by Filipe Veloso
  — CERN.
- *DAQ Report*
  presented by João Gentil
  TileCal Operation Weekly Meeting — CERN.
- *Comparisons between atlfastII and full Geant4*
  presented by Helena Santos
  — CERN.
- *Jet performance with new MC*
  presented by Helena Santos
  — CERN.

- *DCS report*
  presented by Agostinho Gomes
  TileCal Operation Weekly Meeting — CERN.
- *Etmiss with rel17*
  presented by João Gentil
  Etmiss Subgroup meeting — CERN.
- *DCS report*
  presented by Agostinho Gomes
  TileCal Operation Weekly Meeting — CERN.
- *HadCalib trigger optimization*
  presented by Mário Sargedas Sousa
  E/p meeting — CERN.
- *Performance of track jets and dependence on vertex z*
  presented by Helena Santos
  — CERN.
- *First look at jet reco performance with overlay*
  presented by Helena Santos
  — CERN.
- *hadCalib Trigger*
  presented by Mário Sargedas Sousa
  Jet Trigger Meeting — CERN.
- *First look at asymmetries*
  presented by Helena Santos
  — CERN.
- *HadCalib trigger status*
  presented by Patricia Conde
  E/p meeting — CERN.
- *Data quality plots*
  presented by Luís Seabra
  ALFA General Meeting — CERN.
- *Overlay*
  presented by Helena Santos
  — CERN.
- *Trigger performance in the central-forward transition region*
  presented by Nuno Anjos
  — CERN.
- *Overlay vs HIJING*
  presented by Helena Santos
  — CERN.

**Seminars**

- *Little Bangs at ATLAS/LHC*
  presented by Helena Santos
  LIP seminar — LIP.
- *Triggering on Higgs*
  presented by Patricia Conde
  IDPASC Higgs School — Foz do Arelho.
- *O LHC à descoberta do Higgs*
  presented by Agostinho Gomes
  Public session of IDPASC Higgs School — Caldas da Raínha.

- *Higgs Searches in the H->bb channel in ATLAS.*
  presented by Patricia Conde
  CFTP Seminar — Centro de Física Teórica de Partículas, Instituto Superior Técnico.

- *Latest results on the Standard Model Higgs searches in ATLAS and CMS at LHC*
  presented by João Carvalho
  palestra "Café com Física"palestra Café com Física — Departamento de Física da Universidade de Coimbra.

**Outreach seminars**

- *O LHC, as suas redescobertas e descobertas*
  presented by Nuno Anjos
  Actividades de Ocupação Científica — Lisboa.

### 2.1.9 Academic Training

**PhD Theses**

- *The Control System of the ATLAS/Tilecal*
  João Pina, 2011-01-21

- *Measurement of the W -> mu nu production cross section with the ATLAS detector*
  Pedro Jorge, (on-going)

- *Calibration and Performance of the Tile Calorimeter of ATLAS with cosmic ray muons*
  João Gentil, 2011-01-27

- *Medição da secção eficaz de produção do bosão W em ATLAS/LHC/CERN*
  Alberto Palma, (on-going)

- *Medida da taxa de decaimentos raros do quark top, na experiência ATLAS no LHC*
  Bruno Galhardo, (on-going)

**Master Theses**

- *Contribution to Construction and Performance Tests of the ALFA/ATLAS/LHC*
  Luís Seabra, 2011-12-09

- *Estudo de novas formas de visualização e análise da evolução temporal das estatísticas de controlo e qualidade: Aplicação ao detector ATLAS*
  Ademar Delgado, 2011-12-15

### 2.1.10 Project Summary

| | number |
|---|---|
| Articles in international journals (with direct contribution from LIP members) | 7 |
| Articles in international journals (with indirect contribution from LIP members) | 46 |
| International Conference Proceedings | 1 |
| Collaboration notes with internal referee | 10 |
| Internal Notes | 7 |
| Oral presentations in international conferences | 4 |
| Poster presentations in international conferences | 4 |
| Oral presentations in international meetings | 1 |
| Oral presentations in collaboration meetings | 93 |
| Seminars | 5 |
| Outreach seminars | 1 |
| PhD Theses | 2 |
| Master Theses | 2 |

## 2.2 Collaboration in the CMS experiment at CERN

### 2.2.1 Resumo

O LIP é membro da experiência Compact Muon Solenoid (CMS) no acelerador Large Hadron Collider (LHC) no CERN. O objectivo da experiência é o estudo de colisões de protões e núcleos pesados a muito alta energia. Pretende-se investigar as propriedades fundamentais da matéria, em particular estudar a natureza da quebra de simetria na interacção electrofraca e a origem da massa das partículas. A actividade do LIP tem as seguintes componentes principais:
1) A operação e manutenção do trigger e do sistema de leitura de dados do calorímetro electromagnético de CMS;
2) Análises da física das colisões protão-protão, explorando as possibilidades de descoberta proporcionadas pela energia do LHC;
3) Análises de física de iões pesados, em particular o estudo do plasma de quarks e gluões através da análise da produção de quarkonia;
4) Investigação e desenvolvimento do trigger de calorimetria de CMS no LHC a alta luminosidade (SLHC).
O LHC realiza colisões de feixes de protões a 7 TeV desde Março 2010. Depois da pausa de inverno, colisões a 7 TeV foram retomadas em Março de 2011. Em geral o desempenho do colisionador LHC e dos detectores das experiências foi notável. A luminosidade do LHC em 2010 aumentou de várias ordens de grandeza desde 10^27cm-2s-1 na fase inicial até 2x10^32 no fim do ano. Em 2011 a luminosidade atingiu 3.5^33. Em 2011 o LHC forneceu uma luminosidade integrada de 5 /fb. Um período de operação com iões de chumbo de cerca de um mês teve lugar no fim de 2011. Os dados adquiridos permitiram excluir a existência do bosão de Higgs previsto pelo Modelo Standard num extensa gama de valores de massa, restando aberta uma janela em torno de 125 GeV.
O detector CMS funcionou com grande eficiência (acima de 90%) fornecendo dados de grande qualidade para análise de física. A computação GRID funcionou de forma excelente e a qualidade do software offline permitiu realizar a reconstrução de eventos, análise de dados e obtenção de resultados num intervalo de tempo extraordinariamente curto. O espectro completo de processos conhecidos em colisões de protões foi estudado e medido, incluindo a produção de jactos, produção do quark-b, produção dos bosões W e Z, e a produção do quark top. Até ao momento todos os resultados são compatíveis com as previsões do Modelo Standard. Muitas pesquisas de Nova Física foram realizadas com os dados de 2010-11. Estas pesquisas permitiram estabelecer

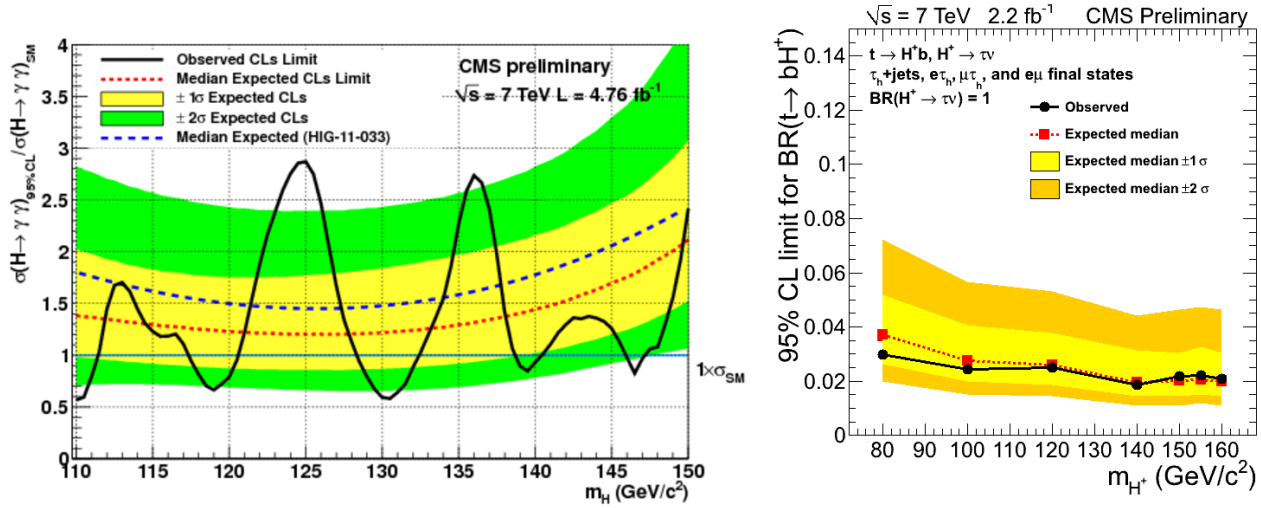



Figure 2.2: Left: Exclusion limit on the cross section of a SM Higgs boson decaying into two photons as a function of the boson mass relative to the SM cross section, where the theoretical uncertainties on the cross section have been included in the limit setting. The limit is calculated using the frequentist CLs method. The expected limit obtained in the earlier analysis of the same dataset is shown for comparison. — Right: Upper exclusion limit on charged Higgs ($H^+$) production on BR($t \to H^+b$) assuming BR($H^+ \to \tau\nu$)=1 as a function of $m_{H^+}$. The yellow bands show the one and two sigma bands around the expected limit.

limites mais apertados dos que foram estabelecidos no Tevatron, em particular relativamente aos modelos de supersimetria. Resultados muito interessantes foram igualmente observados nas colisões de iões pesados, em particular a supressão relativa da produção dos estados Upsilon 2S e 3S.
Em 2013 está planeada uma longa pausa do LHC por forma a realizar as alterações necessárias à sua operação à energia de 14 TeV e luminosidade 10^34. Estas condições de operação permitirão novas oportunidades de descobertas em física, mas implicam igualmente novos desafios na operação dos detectores. Durante este intervalo, CMS planeia instalar um novo trigger de calorimetria que lhe permitirá funcionar a alta luminosidade.
O grupo do LIP teve uma participação muito activa em várias áreas da experiência CMS. O grupo teve uma forte participação na operação do detector, em particular no ECAL e no Trigger. O grupo liderou ou teve um forte envolvimento em várias análises de física, em particular 1) a primeira medida da secção eficaz e da massa do quark top a 7 TeV no canal dileptónico; 2) a primeira medida da secção eficaz de produção de fotões isolados; 3) na pesquisa do Higgs carregado no decaimento do quark top; 4) na pesquisa do Higgs no decaimento em dois fotões; 5) na medida da polarização dos estados quarkonia nas colisões de protões e de iões pesados. O grupo iniciou este ano a participação na pesquisa o parceiro supersimétrico do quark top. O grupo participa activamente no projecto de Upgrade do Trigger de Calorimetria desenvolvendo protótipos de novas ligações ópticas de alta velocidade destinadas a transmitir os dados de trigger do ECAL.

### 2.2.2 Abstract

LIP is a member of the CMS experiment at the Large Hadron Collider at CERN. The experiment will study very high energy collisions of proton and nuclear beams. The experiment´s scope is the investigation of the most fundamental properties of matter, in particular the study of the nature of the electroweak symmetry breaking and the origin of mass. The LIP activity has the following main components:
1) The operation and maintenance of the trigger and the readout system of the CMS electromagnetic calorimeter;
2) Proton-proton physics analyses, exploiting the discovery opportunities offered by the new LHC energy;
3) Heavy-ion physics analyses, in particular the study of the QGP through measurements of quarkonia production;
4) Research and development in view of the upgrade of the CMS trigger system at high luminosity (SLHC).
The LHC is colliding proton beams at 7 TeV since March 2010. In general the performance of the LHC machine and of the experiments detectors has been outstanding. The LHC luminosity in 2010 increased by several orders of magnitude, from 10^27cm-2s-1 in the first runs up to 2x10^32 at the end of the year. In 2011 the luminosity increased steadily up to 3.5x10^33 and the machine delivered an integrated luminosity of 5 /fb. One month of running with lead ions took place in 2011. The acquired data allowed already to exclude the existance on the Standard Model Higgs boson in an extensive range of masses, remaining open a small window around 125 GeV. The CMS detector is operating with very high efficiency (above 90%) and is providing data of very high quality for physics. The GRID computing has operated flawlessly and the offline-software quality allowed event reconstruction, data analysis and physics results in an unprecedented short time scale. The full spectrum of known processes in proton collisions were already measured, including jet production, b-quark production, W and Z vector boson production, and top quark production. Up to now, all the results appear to be compatible with the predictions of the Standard Model. Many different searches of New Physics processes were performed with 2010-11 data, having already established limits more stringent than those obtained at the Tevatron, in particular regarding super-symmetry. Very interesting new results were also obtained in heavy ion collisions, in particular in the relative suppression of the production of Upsilon 2S and 3S states.
In 2013 it is planned a long LHC shutdown aiming at the upgrade of the collider to a center-of-mass energy of 14 TeV and instantaneous luminosity of 10^34 and above. These operating conditions will bring new opportunities for physics discoveries but also additional challenges for the CMS detector operation. During this shutdown CMS has plans to install a new calorimeter trigger which would allow to trigger at high luminosity.
The LIP group has been very active in many areas of the CMS experiment. The group has a strong participation in the operation of the detector, in particular the ECAL and the Trigger system. The group had a leading role or strong involvement in several physics analysis, in particular 1) in the first measurement of the top quark mass and cross-section at 7 TeV in the dilepton channel; 2) in the first measurement of the isolated photon production cross-section; 3) in the search for the charged Higgs produced in top decays and decaying in tau leptons; 4) the search for the Higgs boson in diphoton decays; 5) in the measurement of quarkonia polarization in proton and lead collisions. The group initiated this year the participation in the search of the supersymetric partner of the top quarks. The group is participating actively in the Calorimeter Trigger Upgrade project in particular developing prototypes of new high-speed optical links to transmit the trigger data from ECAL.

### 2.2.3 Objectives

**Summary of Activities**

The LIP group has important responsibilities in the maintenance and operation of the CMS detector, namely the ECAL trigger and data acquisition system, including hardware and software, following its strong participation in the CMS construction. It includes the SLB boards which are used to synchronize and transmit the ECAL and HCAL trigger data, the DCC boards used for the data acquisition of the ECAL detector and the ECAL online software.
The LIP group has a team of four people in permanence at CERN dedicated to the operation of the ECAL data acquisition and online monitoring, in particular during the LHC Collision Periods. In the last year the following tasks were undertaken:
a) maintenance of the ECAL Off-Detector Crates in the experiment;
b) upgrades of the DCC firmware to correct several problems identified during data taking;
c) maintenance and updates of the online software;
d) integration tests with CMS central DAQ and central Trigger.
The group was directly involved in the ECAL and Trigger operation during the LHC runs in 2010-11. Several members of the group are "experts on-call"available during LHC runs to intervene in case of system faults. The group assured a number of data taking Shifts both in ECAL and in the central Trigger, as required by the Collaboration. Members of the group also served as Run Field Manager, Shift Leader and Trigger Field Manager at several occasions during the data taking periods.
The LIP group is also responsible for the operation of the ECAL data acquisition hardware and software in the CMS Electronics Integration Center (904) and at the H2/H4 test-beam lines, where the spare ECAL Supermodule (SM37) is installed.
The LIP/CMS GRID activities were focused in the exploitation of the Portuguese LHC Tier-2 Federation for CMS physics analysis. The LIP center is supporting the activities of CMS central operations, while NCG site supports the central Monte Carlo production and the activities of physics groups. Both sites serve as well the computing needs of the local physics community. The Tier-2 has been continuously monitored and proven to operate with high computing efficiencies and data transfer throughputs and quality on both download and upload streams.
The participation in the detector operation and physics analysis of the first LHC data was a major goal of the LIP/CMS group in 2010-11, which was fully achieved. The group was actively involved and/or had a leading role in various physics analysis. This includes: 1) the measurement performed by the LIP group of the top quark mass in the dilepton channel, which was the first top quark measurement at LHC; 2) the participation in the measurement of top-quark pair production cross section in the dilepton channel, contributing with the independent cross-section measurement in events with one jet; 3) the measurement led by the LIP group of the isolated prompt photon cross section based on the cluster shape analysis method developed in the group; 4) the measurement performed by the LIP group of the limits in the branching ratio of top decay in charged Higgs, using events with one lepton (electron or muon) and one hadronic decaying tau; 4) the search for the Higgs boson decay in two photons, having developed the algorithms used for primary vertex identification.
The Heavy Ion group was very active in the measurement of the J/Psi prompt and non-prompt cross sections in pp collisions and in the measurement of the J/Psi polarization.
In 2011, the members of the group presented results in international conferences (6 talks), seminars (12 talks) and in meetings of the CMS collaboration (33 talks). Group members were authors in 78 publications (70 papers in international scientific journals and 8 papers in conference proceedings), in 9 CMS public notes with internal referee, and in 14 CMS internal analysis notes.
The LIP/CMS group members have the following CMS management positions:
- CMS Deputy Spokesperson (J. Varela)
- ECAL Run Coordinator (A. David,)
- ECAL Electronics Coordinator (J. C. Silva).

Member of the LIP group have been selected to participate in many Analysis Review Committees (ARC) which review and finally approve the physics results obtained in the Collaboration.
The series of seminars on LHC Physics ("Physics on the road to discovery") was pursued in 2011 in collaboration with CFTP/IST.

**Project Coordination**
Group coordinator: João Varela

- Detector and computing coordinator: João Varela
  - DAQ/trigger coordinator: André David

  - Electronics coordinator: José Carlos Silva
  - Computing coordinator: Nuno Almeida
- Proton-proton physics coordinator: Michele Gallinaro
- Heavy-ion physics coordinator: João Seixas

### 2.2.4 Achievements

**Physics studies**

A more detailed description of the physics studies performed in 2011 are included here. The CMS references PAS (Physics Analysis Summary) are public. The references AN (Analysis Note) are detailed analysis documents internal to the Collaboration.
1.Top Quark Physics
1.1 Top quark mass:
Measurement of the Top quark mass in the dilepton channel in pp collisions at sqrt(s)=7 TeV (CMS AN-2012/009, CMS PAS TOP-11-016, CMS AN-2010/374, CMS AN-2010/311, CMS PAS TOP-10-006):

- top quark mass measurement by the LIP group using the KINb method in the dilepton channel. This is the single most precise measurement in the dilepton channel to date.

1.2 Top pair production cross section:
Measurement of the Top quark pair production cross section in the e-tau and mu-tau dilepton channels in pp collisions at sqrt(s)=7 TeV (CMS AN-2011/245, CMS AN-2011/421, CMS PAS TOP-11-006):

- measurement performed by the LIP group of the t-tbar cross section with tau leptons in the final state. This is the first t-tbar cross section measurement explicitly including tau leptons at the LHC, and the most accurate in this final state to date.

1.3 Top branching fractions
Probing the heavy flavor content of the ttbar dilepton channel in proton-proton collisions at sqrt(s)=7 TeV (CMS-AN-11-394):

- measurement by the LIP group with data of the methods of measurement of the top quark branching ratio.

2. Higgs Physics
2.1 Charged Higgs boson in the top lepton-tau channel
Search for the charged Higgs boson in the decays of top quark pairs in pp collisions at sqrt(s)=7 TeV (CMS AN-2011/175, CMS PAS HIG-11-008, CMS AN-2011/422, CMS PAS HIG-11-019, CMS AN-2011/015, CMS PAS HIG-11-002):

- measurement performed by the LIP group on the limits in the search for the charged Higgs boson, using events with one lepton (electron or muon) and one hadronically decaying tau lepton, and events with two leptons (electron and muon). These are currently the world´s best limits to date.

2.2 Search for Higgs in two photon decays
In 2011, the LIP group participated in the search for the Higgs boson in the diphoton channel. The group led the development of the vertex identification algorithms in the multi pile-up environment, an important ingredient to achieve the best two-photon mass resolution. Members of the LIP group were in charge of editing the analysis documentation and managing the common analysis code. The experimental search for the Standard Model Higgs boson has been updated several times during 2011 (CMS-PAS-HIG-11-010, CMS-PAS-HIG-11-021, CMS-PAS-HIG-11-030) and submitted for publication in January 2012 (CMS-PAS-HIG-11-033, CERN-PH-EP-2012-024, arXiv:1202.1487, submitted to Physics Letters B).
3. SuperSymmetry Physics
3.1 Search for the scalar top quark
The LIP group has activities in the area of SUSY performing a search for the stop s-quark. The topology of these events is top-like and therefore the top mass reconstruction methods already developed find here a good application since top production is the main background in stop searches.
4. Heavy-ion physics
In 2010-11 the group was actively involved in the quarkonia and b-physics analysis group and contributed significantly to the following studies:

- Towards the experimental clarification of quarkonium polarization, Eur. Phys. J. C (to appear)
- Determination of chi-c and chi-b polarizations from dileptonangular distributions in radiative decays. Published in Phys.Rev. D83 (2011) 096001
- Quarkonium polarization in p p and p-nucleus collisions. Published in Nucl.Phys. A855 (2011) 116-124
- Model-independent constraints on the shape parameters of dilepton angular distributions. Published in Phys.Rev. D83 (2011) 056008
- Rotation-invariant observables in parity-violating decays of vector particles to fermion pairs. Published in Phys.Rev. D82 (2010) 096002
- Spin alignment of prompt and non-prompt J/Psi mesons in pp collisions at sqrt(s) = 7 TeV (AN-2011/091)
- Studies of the J/psi polarization fit with a toy Monte Carlo program (AN-2011/087)
- A Fitting Routine for Extracting the Spin Alignment of J/$\Psi$ mesons (AN-2011/092)
- A new procedure for the extraction of angular distribution parameters in dilepton vector meson decays"(AN-11-535)

==Publications== Publications by the CMS Collaboration are available at:
http://cdsweb.cern.ch/collection/CMS%20Papers?ln=en

### 2.2.5 Sources of Funding

| Code | Funding | Start | End |
|---|---|---|---|
| CERN/FP/116367/2010 | 277.000 € | 2011-01-01 | 2012-03-31 |

### 2.2.6 Team

**Project coordinator: João Varela**

| Name | Status | %of time in project |
|---|---|---|
| André Alves | Master (LIP) | 86 |
| André Tinoco Mendes | Researcher (LIP) | 100 |
| Aruna Nayak | Post-Doc (LIP/FCT) | 83 |
| David Christian Soares | Student (LIP) | 100 |
| João Pela | PhD student (LIP/Imperial) | 100 |
| João Seixas | Researcher (LIP/IST) | 50 |
| João Varela | Researcher (LIP/IST) | 85 |
| José Carlos Silva | Technician (LIP) | 85 |
| Michele Gallinaro | Researcher (LIP) | 100 |
| Nuno Almeida | Post-Doc (LIP/FCT) | 100 |
| Pasquale Musella | Post-Doc (LIP) | 100 |
| Pedrame Bargassa | Researcher (LIP) | 100 |
| Pedro Manuel Silva | Post-Doc (LIP/FCT) | 100 |
| Pedro Parracho | Collaborator (LIP/AdI) | 100 |
| Pietro Faccioli | Post-Doc (LIP/FCT) | 100 |
| Sérgio Sampaio | Master student (LIP/IST) | 46 |

### 2.2.7 Publications

**Articles in international journals (with direct contribution from LIP members)**

- *Measurement of the t t-bar production cross section and the top quark mass in the dilepton channel in pp collisions at sqrt(s) =7 TeV*
  CMS collaboration
  JHEP 1107 (2011) 049

- *Performance of tau-lepton reconstruction and identification in CMS*
  CMS
  J. Instrum. 7 (2012) P01001

- *Measurement of the ttbar production cross section and the top quark mass in the dilepton channel in pp collisions at 7 TeV*
  CMS collaboration
  JHEP 1107:049,2011 ;CMS PAS TOP-11-002

- *Performance of tau-lepton reconstruction and identification in CMS*
  CMS collaboration
  JINST 7 (2012) P01001; CMS PAS TAU-11-001

- *Determination of chi_c and chi_b polarizations from dilepton angular distributions in radiative decays*
  P. Faccioli, C. Lourenço, J. Seixas and H. K. Wöhri
  Phys. Rev. D 83, 096001 (2011)

- *Model-independent constraints on the shape parameters of dilepton angular distributions*
  P. Faccioli, C. Lourenço, J. Seixas and H. K. Wöhri
  Phys. Rev. D 83, 056008 (2011)

- *Heavy quarkonium: progress, puzzles, and opportunities*
  N. Brambilla et al.
  Eur. Phys. J. C 71, 1534 (2011)

**Articles in international journals (with indirect contribution from LIP members)**

- *Forward Energy Flow, Central Charged-Particle Multiplicities, and Pseudorapidity Gaps in W and Z Boson Events from pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  CMS-FWD-10-008 ; CERN-PH-EP-2011-141 (accepted)

- *Jet Production Rates in Association with W and Z Bosons in pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  CMS-EWK-10-012 ; CERN-PH-EP-2011-125 (accepted)

- *Measurement of the Rapidity and Transverse Momentum Distributions of Z Bosons in pp Collisions at sqrts=7 TeV*
  CMS collaboration
  CMS-EWK-10-010 ; CERN-PH-EP-2011-169 (accepted)

- *J/psi and psi(2S) production in pp collisions at sqrts = 7 TeV*
  CMS collaboration
  CMS-BPH-10-014 ; CERN-PH-EP-2011-177 (accepted)

- *Exclusive photon-photon production of muon pairs in proton-proton collisions at sqrts = 7 TeV*
  CMS collaboration
  CMS-FWD-10-005 ; CERN-PH-EP-2011-187 (accepted)

- *Search for signatures of extra dimensions in the diphoton mass spectrum at the Large Hadron Collider*
  CMS collaboration
  CMS-EXO-11-038 ; CERN-PH-EP-2011-173 (accepted)

- *Measurement of the $B^+$ Production Cross Section in pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Rev. Lett. 106 (2011) 112001

- *Search for Heavy Stable Charged Particles in pp collisions at sqrts = 7 TeV*
  CMS collaboration
  J. High Energy Phys. 03 (2011) 024

- *Search for Supersymmetry in pp Collisions at 7 TeV in Events with Jets and Missing Transverse Energy*
  CMS collaboration
  Phys. Lett. B 698 (2011) 196-218

- *Measurement of Bose-Einstein Correlations in pp Collisions at sqrts = 0.9 and 7 TeV*
  CMS collaboration
  J. High Energy Phys. 05 (2011) 029

- *Inclusive b-hadron production cross section with muons in pp collisions at sqrts = 7 TeV*
  CMS collaboration
  J. High Energy Phys. 03 (2011) 090

- *Dijet Azimuthal Decorrelations in pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Rev. Lett. 106 (2011) 122003

- *First Measurement of Hadronic Event Shapes in pp Collisions at sqrts=7 TeV*
  CMS collaboration
  Phys. Lett. B 699 (2011) 48-67

- *Measurement of Dijet Angular Distributions and Search for Quark Compositeness in pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Rev. Lett. 106 (2011) 201804

- *Observation and studies of jet quenching in PbPb collisions at sqrts$_{NN}$ = 2.76 TeV*
  CMS collaboration
  Phys. Rev. C 84 (2011) 024906

- *Measurement of BoverlineB angular correlations based on secondary vertex reconstruction at sqrts=7 TeV*
  CMS collaboration
  J. High Energy Phys. 03 (2011) 136

- *Strange Particle Production in pp collisions at sqrts = 0.9 and 7 TeV*
  CMS collaboration
  J. High Energy Phys. 05 (2011) 064

- *Search for a Heavy Bottom-like Quark in pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Lett. B 701 (2011) 204-223

- *Study of Z boson production in PbPb collisions at sqrts$_{NN}$ = 2.76 TeV*
  CMS collaboration
  Phys. Rev. Lett. 106 (2011) 212301

- *Measurement of $W^+W^-$ Production and Search for the Higgs Boson in pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Lett. B 699 (2011) 25-47

- *Search for a W´ boson decaying to a muon and a neutrino in pp collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Lett. B 701 (2011) 160-179

- *Search for Resonances in the Dilepton Mass Distribution in pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  J. High Energy Phys. 05 (2011) 093

- *Search for Supersymmetry in pp Collisions at sqrts = 7 TeV in Events with Two Photons and Missing Transverse Energy*
  CMS collaboration
  Phys. Rev. Lett. 106 (2011) 211802

- *Search for Physics Beyond the Standard Model in Opposite-sign Dilepton Events in pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  J. High Energy Phys. 06 (2011) 026

- *Measurement of the lepton charge asymmetry in inclusive W production in pp collisions at sqrts = 7 TeV*
  CMS collaboration
  J. High Energy Phys. 04 (2011) 050

- *Search for Large Extra Dimensions in the Diphoton Final State at the Large Hadron Collider*
  CMS collaboration
  J. High Energy Phys. 05 (2011) 085

- *Search for Neutral Minimal Supersymmetric Standard Model Higgs Bosons Decaying to Tau Pairs in pp Collisions at sqrts=7 TeV*
  CMS collaboration
  Phys. Rev. Lett. 106 (2011 ) 231801

- *Measurement of the Inclusive Z Cross Section via Decays to Tau Pairs in pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  J. High Energy Phys. 08 (2011) 117

- *Measurement of the differential dijet production cross section in proton-proton collisions at sqrts=7 TeV*
  CMS collaboration
  Phys. Lett. B 700 (2011) 187-206

- *Measurement of the $B^0$ Production Cross Section in pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Rev. Lett. 106 (2011) 252001

- *Charged particle transverse momentum spectra in pp collisions at sqrts = 0.9 and 7 TeV*
  CMS collaboration
  J. High Energy Phys. 08 (2011) 086

- *Search for new physics with same-sign isolated dilepton events with jets and missing transverse energy at the LHC*
  CMS collaboration
  J. High Energy Phys. 06 (2011) 077

- *Measurement of the Polarization of W Bosons with Large Transverse Momenta in W+Jets Events at the LHC*
  CMS collaboration
  Phys. Rev. Lett. 107 (2011) 021802

- *Long-range and short-range dihadron angular correlations in central PbPb collisions at sqrts$_{NN}$ = 2.76 TeV*
  CMS collaboration
  J. High Energy Phys. 07 (2011) 076

- *Measurement of Wgamma and Zgamma production in pp collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Lett. B 701 (2011) 535-555

- *Search for supersymmetry in events with a lepton, a photon, and large missing transverse energy in pp collisions at sqrts = 7 TeV*
  CMS collaboration
  J. High Energy Phys. 06 (2011) 093

- *Indications of Suppression of Excited Upsilon States in Pb-Pb Collisions at sqrts$_{NN}$ = 2.76 TeV*
  CMS collaboration
  Phys. Rev. Lett. 107 (2011) 052302

- *Search for First Generation Scalar Leptoquarks in the eujj Channel in pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Lett. B 703 (2011) 246-266

- *Measurement of the $t\bar{t}$ production cross section and the top quark mass in the dilepton channel in pp collisions at $\sqrt{s}$ =7 TeV*
  CMS collaboration
  J. High Energy Phys. 07 (2011) 049

- *Measurement of the Inclusive Jet Cross Section in pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Rev. Lett. 107 (2011) 132001

- *Measurement of the Ratio of the 3-jet to 2-jet Cross Sections in pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Lett. B 702 (2011) 336-354

- *Search for Physics Beyond the Standard Model Using Multilepton Signatures in pp Collisions at sqrts =7 TeV*
  CMS collaboration

Phys. Lett. B 704 (2011) 411-433

- *Measurement of the toverlinet Production Cross Section in pp Collisions at sqrts=7 TeV using the Kinematic Properties of Events with Leptons and Jets*
  CMS collaboration
  Eur. Phys. J. C 71 (2011) 1721

- *Search for Same-Sign Top-Quark Pair Production at sqrts = 7 TeV and Limits on Flavour Changing Neutral Currents in the Top Sector*
  CMS collaboration
  J. High Energy Phys.08 (2011) 005

- *Search for Light Resonances Decaying into Pairs of Muons as a Signal of New Physics*
  CMS collaboration
  J. High Energy Phys.07 (2011) 098

- *Measurement of the t-channel single top quark production cross section in pp collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Rev. Lett.107 (2011) 091802

- *Search for Supersymmetry in Events with b Jets and Missing Transverse Momentum at the LHC*
  CMS collaboration
  J. High Energy Phys.07 (2011) 113

- *Measurement of the $B_s^0$ Production Cross Section with $B_s^0$oJ/psiphi Decays in pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Rev. D84 (2011) 052008

- *Search for New Physics with Jets and Missing Transverse Momentum in pp collisions at sqrts = 7 TeV*
  CMS collaboration
  J. High Energy Phys.08 (2011) 155

- *Search for New Physics with a Monojet and Missing Transverse Energy in pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Rev. Lett.107 (2011) 201804

- *Missing transverse energy performance of the CMS detector*
  CMS collaboration
  J. Instrum.6 (2011) P09001

- *Measurement of the Underlying Event Activity at the LHC with sqrts = 7 TeV and Comparison with sqrts = 0.9 TeV*
  CMS collaboration
  J. High Energy Phys.09 (2011) 109

- *Inclusive search for squarks and gluinos in pp collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Rev. D85 (2012) 012004

- *Search for supersymmetry in pp collisions at sqrts=7 TeV in events with a single lepton, jets, and missing transverse momentum*
  CMS collaboration
  J. High Energy Phys.08 (2011) 156

- *A search for excited leptons in pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Lett. B704 (2011) 143-162

- *Search for Three-Jet Resonances in pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Rev. Lett.107 (2011) 101801

- *Determination of Jet Energy Calibration and Transverse Momentum Resolution in CMS*
  CMS collaboration
  J. Instrum.6 (2011) P11002

- *Dependence on pseudorapidity and on centrality of charged hadron production in PbPb collisions at $sqrts_{NN}$ = 2.76 TeV*
  CMS collaboration
  J. High Energy Phys.08 (2011) 141

- *Search for Resonances in the Dijet Mass Spectrum from 7 TeV pp Collisions at CMS*
  CMS collaboration
  Phys. Lett. B704 (2011) 123-142

- *Measurement of the Inclusive W and Z Production Cross Sections in pp Collisions at sqrts = 7 TeV with the CMS experiment*
  CMS collaboration
  J. High Energy Phys.10 (2011) 132

- *Search for $B_s^0 omu^+ mu^-$ and $B^0 omu^+ mu^-$ decays in pp collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Rev. Lett.107 (2011) 191802

- *Measurement of the Drell-Yan Cross Section in pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  J. High Energy Phys.10 (2011) 007

- *Measurement of the Differential Cross Section for Isolated Prompt Photon Production in pp Collisions at 7 TeV*
  CMS collaboration
  Phys. Rev. D84 (2011) 052011

- *Measurement of the $t\bar{t}$ Production Cross Section in pp Collisions at 7 TeV in Lepton + Jets Events Using b-quark Jet Identification*
  CMS collaboration
  Phys. Rev. D84 (2011) 092004

- *Search for Supersymmetry at the LHC in Events with Jets and Missing Transverse Energy*
  CMS collaboration
  Phys. Rev. Lett.107 (2011) 221804

- *Search for a Vectorlike Quark with Charge 2/3 in t + Z Events from pp Collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Rev. Lett.107 (2011) 271802

- *Performance of au-lepton reconstruction and identification in CMS*
  CMS collaboration
  J. Instrum.7 (2012) P01001

- *Measurement of energy flow at large pseudorapidities in pp collisions at sqrts = 0.9 and 7 TeV*
  CMS collaboration
  J. High Energy Phys.11 (2011) 148

- *Measurement of the weak mixing angle with the Drell-Yan process in proton-proton collisions at the LHC*
  CMS collaboration
  Phys. Rev. D84 (2011) 112002

- *Measurement of the Production Cross Section for Pairs of Isolated Photons in pp collisions at sqrts = 7 TeV*
  CMS collaboration
  J. High Energy Phys.01 (2012) 133

- *Measurement of the charge asymmetry in top-quark pair production in proton-proton collisions at sqrts = 7 TeV*
  CMS collaboration
  Phys. Lett. B709 (2012) 28-49

**International Conference Proceedings**

- *Top mass measurement at the LHC*
  M.Gallinaro
  CMS CR-2012/008 (accepted)

- *Measurement of the Isolated Prompt Photon Production Cross Section in pp Collisions at sqrts = 7≈TeV*
  CMS

- *Search strategies for charged Higgs bosons in CMS*
  M.Gallinaro
  PoS, Charged2010:011,2010; CMS CR-2011/027

- *Quarkonium polarization in p-p and p-nucleus collisions*
  P. Faccioli, C. Lourenço, J. Seixas and H. K. Wöhri
  Nucl. Phys. A 855, 116 (2011)

- *CMS status and spin physics at the LHC*
  P. Faccioli
  Journal of Physics: Conference Series 295, 012013 (2011)

- *Quarkonium polarization measurements*
  P. Faccioli, C. Lourenço, J. Seixas and H. K. Wöhri
  Nucl. Phys. B (Proc. Suppl.) 214, 97 (2011)

- *simple and robust method to measure chi_c and chi_b polarizations*
  P. Faccioli, C. Lourenço, J. Seixas and H. K. Wöhri
  Nucl. Phys. B (Proc. Suppl.) 214, 107 (2011)

- *Initial-state quark energy loss from Drell-Yan production in proton-proton and proton-nucleus collisions*
  H. K. Wöhri, P. Faccioli, C. Lourenço and R. Vogt
  Nucl. Phys. B (Proc. Suppl.) 214, 88 (2011)

**Collaboration notes with internal referee**

- *Combination of results and summary of measurement of the top pair production cross section at 7 TeV in 2010 data*
  CMS collaboration
  CMS-AN-2011-005

- *Search for Higgs in diphoton channel*
  CMS
  HIG-11-010

- *Search for Higgs in diphoton channel*
  CMS
  HIG-11-021

- *Search for Higgs in diphoton channel*
  CMS
  HIG-11-030

- *Measurement of the ttbar production cross section in the etau and mutau dilepton channels in pp collisions at 7 TeV*
  CMS collaboration
  CMS PAS TOP-11-006

- *Search for the charged Higgs boson in the e? and ?? dilepton channels of top quark pair decays in pp collisions at 7 TeV*
  CMS collaboration
  CMS PAS HIG-11-002

- *Search for the charged Higgs boson with H+ -> Tau decay mode in top quark decays*
  CMS collaboration
  CMS PAS HIG-11-008

- *Measurement of the b-tagging efficiency using tt events*
  CMS collaboration
  CMS PAS BTV-11-003

- *Measurement of the $t^{-}t$ production cross section in the dilepton channel at s=7 TeV*
  P.Bargassa+A.Nayak+P.Ribeiro
  CMS-AN-2010-414

**Internal Notes**

- *Search for Higgs in diphoton channel*
  CMS
  AN-11-129

- *Search for Higgs in diphoton channel*
  CMS
  AN-11-426

- *Performance of tau reconstruction algorithms with 2010 data in CMS*
  M. Bachtis et-al
  CMS AN-2011/045

- *TauID commissioning 2011*
  M. Bachtis et-al
  CMS AN-2011/239

- *Measurement of the Top quark mass in the dilepton channel using the 2011 proton-proton collisions dataset*
  P. Silva , A. Alves , P. Vischia , M. Gallinaro , J. Varela
  CMS AN-2012/009

- *Contribution to the measurement of the b tagging efficiency using the ttbar dilepton channel in pp collisions at 7 TeV*
  P. Silva , A. Alves , P. Vischia , M. Gallinaro , J. Varela
  CMS AN-2011/450

- *Search for the charged Higgs boson in the decays of top quark pairs in pp collisions at 7 TeV*
  N. Almeida , M. Gallinaro , A. Nayak , A. Nikitenko , P. Silva , J. Varela
  CMS AN-2011/422

- *Measurement of the ttbar production cross section in the etau and mutau dilepton channels in pp collisions at 7 TeV*
  N. Almeida , M. Gallinaro , A. Nayak , A. Nikitenko , P. Silva , J. Varela
  CMS AN-2011/421

- *Probing the heavy flavor content of the ttbar dilepton channel in pp collisions at 7 TeV*
  P. Silva , A. Alves , P. Vischia , M. Gallinaro , J. Varela
  CMS AN-2011/394

- *Measurement of the ttbar production cross section in the etau and mutau dilepton channels in pp collisions at 7 TeV*
  N. Almeida , M. Gallinaro , A. Nayak , A. Nikitenko , P. Silva , J. Varela
  CMS AN-2011/245

- *Search for a Higgs boson decaying into two photons in proton-proton collisions recorded by the CMS detector at the LHC*
  A. David, P. Musella, M. Gallinaro, J. Varela, et al
  CMS AN-2011/206

- *Search for the charged Higgs boson in the decays of top quark pairs in pp collisions at 7 TeV*
  N. Almeida , M. Gallinaro , A. Nayak , A. Nikitenko , P. Silva , J. Varela
  CMS AN-2011/175

- *Probing the heavy flavor content of Top quark events in the dilepton channel with 7 TeV*
  P. Silva , M. Gallinaro , J. Varela
  CMS AN-2011/152

- *Search for the charged Higgs boson in the etau and mutau dilepton channels of Top quark pair decays in pp collisions at 7 TeV*
  N. Almeida, M. Gallinaro, A. Nayak, A. Nikitenko, L. Pedro, P. Silva, J. Varela
  CMS AN-2011/015

### 2.2.8 Presentations

**Oral presentations in international conferences**

- *Isolated Photon measurements with the CMS Detector at sqrt(s)=7 TeV*
  presented by André Tinoco Mendes
  DIS 2011 — Virginia, USA.

- *Feed-down decays and quarkonium polarization*
  presented by Pietro Faccioli
  Quarkonium Production - Probing QCD at the LHC — Vienna.

- *Polarization measurements at the LHC*
  presented by João Seixas
  Quarkonium Production - Probing QCD at the LHC — Vienna.

- *Production of quarkonia at the LHC - experimental overview*
  presented by Pietro Faccioli
  Standard Model Benchmarks at High-Energy Hadron Colliders — DESY, Zeuthen (Germany).

- *Quarkonium polarization and a few related topics*
  presented by Pietro Faccioli
  Characterization of the Quark-Gluon Plasma with Heavy Quarks — Physikzentrum Bad Honnef (Germany).

- *New perspectives in polarization measurement*
  presented by João Seixas
  Quarkonia in deconfined matter — Acitrezza (Italy).

**Presentations in national conferences**

- *Polarization measurements at the LHC*
  presented by João Seixas
  The multidisciplinary universe — Lisbon.

**Oral presentations in international meetings**

- *A Search for H+ and H++ Higgs Bosons with the CMS detector*
  presented by Nuno Almeida
  SUSY 2011 — FNAL.

- *A search for H+ and H++ Higgs bosons with the CMS detector*
  presented by Aruna Nayak
  EPS-HEP — Grenoble.

- *Higgs and New Physics - experiment*
  presented by André Tinoco Mendes
  Implications of LHC Results for TeV-Scale Physics Workshop — CERN.

- *Top quark mass measurement at the LHC*
  presented by Michele Gallinaro
  — Sant Feliu de Guixols, Spain .

**Oral presentations in collaboration meetings**

- *Stop searches across production & decay modes*
  presented by Pedrame Bargassa
  SUSY-leptonic meeting — CERN.
- *Preview - Charged Higgs Search*
  presented by Nuno Almeida
  — CERN.
- *Measurement of the ttbar cross sections with the dilepton channel with taus*
  presented by Michele Gallinaro
  — CERN.
- *H+ ->tau nu analysis with W->lnu, tau->hadr.*
  presented by Michele Gallinaro
  — CERN.
- *Top dilepton cross-section with FOM. Njet=1*
  presented by Pedrame Bargassa
  TOP-dilepton meeting — CERN.
- *Measurement of the top pair-production cross section in dilepton channels at s = 7 TeV*
  presented by Pedrame Bargassa
  TOP-PAG meeting — CERN.
- *Status of H+ analysis with leptons*
  presented by Michele Gallinaro
  — CERN.
- *Stop searches across production & decay modes*
  presented by Pedrame Bargassa
  SUSY-leptonic meeting — CERN.
- *Search for the charged Higgs boson*
  presented by Michele Gallinaro
  — CERN.
- *Update on charged Higgs search*
  presented by Nuno Almeida
  — CERN.
- *LIP contribution in 2011*
  presented by Michele Gallinaro
  — CERN.
- *Charged Higgs: Lisbon report*
  presented by Nuno Almeida
  — CERN.
- *Update on the charged Higgs search*
  presented by Michele Gallinaro
  — CERN.
- *Update on xsec using the dilepton with taus channel*
  presented by Nuno Almeida
  — CERN.
- *Status of top pair cross section in tau dileptons (TOP-11-006)*
  presented by Michele Gallinaro
  — CERN.

- *Status of charged Higgs analysis*
  presented by Michele Gallinaro
  — CERN.

- *Measurement of the top-quark pair-production cross-section in the tau-dilepton channel with 2010 data*
  presented by Nuno Almeida
  — CERN.

- *Update on leptonic charged Higgs*
  presented by Nuno Almeida
  — CERN.

- *TOP-11-006 - Top pair cross section in tau dileptons (e+tau, mu+tau)*
  presented by Michele Gallinaro
  — CERN.

- *HIG-11-008 - H+ -> Tau in Top quark decays*
  presented by Nuno Almeida
  — CERN.

- *Search for H -> gamma gamma*
  presented by André Tinoco Mendes
  Lepton-photon approvals — CERN.

- *3rd generation effort: Phenomenology & MC needs*
  presented by Pedrame Bargassa
  SUSY workshop — CERN.

- *Report on the H+ analysis with lepton+Tau final state*
  presented by Nuno Almeida
  — CERN.

- *Top dilepton triggers with taus*
  presented by Aruna Nayak
  TOP trigger meeting — CERN.

- *Approval Talk HIG-11-002 Charged Higgs (35´+25´)*
  presented by Nuno Almeida
  — CERN.

- *Report on H+ analysis*
  presented by Nuno Almeida
  — CERN.

- *Summary of P5 status and prospects for 2012*
  presented by André Tinoco Mendes
  ECAL General Meeting — CERN.

- *Trigger Studies for stop searches in single lepton channel*
  presented by Alberto Ocampo
  SUSY-trigger meeting — CERN.

- *TT xsec with the dilepton channel with taus*
  presented by Nuno Almeida
  — CERN.

- *Charged Higgs Update in Leptonic Channel*
  presented by Michele Gallinaro
  — CERN.

- *Search for ≈t1 pair production in single lepton signature*
  presented by Pedrame Bargassa
  SUSY-leptonic meeting — CERN.

- *The case for stop: Proposal for searches*
  presented by Pedrame Bargassa
  SUSY-PAG meeting — CERN.

- *Trigger Studies for stop searches in single lepton channel*
  presented by Alberto Ocampo
  SUSY-trigger meeting — CERN.

**Seminars**

- *SUperSYmmetry search at LHC: The case for stop*
  presented by Pedrame Bargassa
  LIP 50 — LIP.

- *Measurement of the ttbar production cross section in pp collisions at s=7 TeV with the CMS detector*
  presented by Pedrame Bargassa
  LIP 50 — LIP.

- *Search for charged Higgs boson with CMS detector*
  presented by Aruna Nayak
  DHEP-50 — TIFR, Mumbai.

- *Search for a resonant SM Higgs boson in CMS using diphoton decays*
  presented by André Tinoco Mendes
  50io LIP — Lisboa, Portugal.

- *SUperSYmmetry search at LHC: The case for stop*
  presented by Pedrame Bargassa
  — Strasbourg.

- *Search for charged Higgs boson with CMS detector*
  presented by Aruna Nayak
  LIP-50 — LIP, Lisbon.

- *SUperSYmmetry search at LHC: The case for stop*
  presented by Pedrame Bargassa
  — Mons.

- *SUperSYmmetry search at LHC: The case for stop*
  presented by Pedrame Bargassa
  — DESY.

- *SUperSYmmetry search at LHC: The case for stop*
  presented by Pedrame Bargassa
  — Lyon.

- *Physics at the LHC*
  presented by Michele Gallinaro
  — Lisbon/IST.

**Outreach seminars**

- *LHC - The Lord of the (Collider) Rings*
  presented by André Tinoco Mendes
  Science Society and Technology class — Manila, Philippines.

- *CMS Experiment*
  presented by André Tinoco Mendes
  Escola de professores no CERN — CERN.

### 2.2.9 Project Summary

| | number |
|---|---|
| Articles in international journals (with direct contribution from LIP members) | 7 |
| Articles in international journals (with indirect contribution from LIP members) | 71 |
| International Conference Proceedings | 8 |
| Collaboration notes with internal referee | 9 |
| Internal Notes | 14 |
| Oral presentations in international conferences | 6 |
| Presentations in national conferences | 1 |
| Oral presentations in international meetings | 4 |
| Oral presentations in collaboration meetings | 33 |
| Seminars | 10 |
| Outreach seminars | 2 |

## 2.3 Collaboration in the COMPASS experiment at CERN

### 2.3.1 Resumo

A experiência COMPASS dedica-se ao estudo da estrutura do nucleão através da difusão inelástica profunda de muões na matéria, nomeadamente à medição da polarização do gluão $\Delta G/G$ (usando a produção de charme e a física de elevado pT), às funções de estrutura relativas às componentes transversas e longitudinais do spin, e às funções de fragmentação.
Com um feixe de hadrões COMPASS tem por objectivo o estudo de algumas questões espectroscópicas de actualidade, como a produção de novos mesões, nomeadamente exóticos ou híbridos.
COMPASS usa feixes de alta intensidade, de muões polarizados (ou de hadrões) interagindo com um alvo polarizado longitudinalmente ou transversalmente (ou um alvo de hidrogénio líquido) ao qual se segue um espectrómetro duplo: a primeira parte tem uma grande aceitância angular, e é seguida a jusante por outra de aceitância reduzida, concebida para a detecção de partículas ultrapassando os 100 GeV/c. Cada espectrómetro é formado por um magnete rodeado por detectores de posição, um conjunto de calorímetros electromagnético e hadrónico, filtros de muões e um detector de Cherenkov do tipo RICH para identificação de partículas.
O sistema de aquisição de dados baseia-se na leitura em paralelo da electrónica de frontend e num sistema distribuído de event-builders, especialmente concebidos para tratar grandes volumes de dados. De facto, todo o programa de muões que decorreu de 2002 a 2007 perfez um total de 1700 TB. O programa de 2008 e 2009 foi dedicado ao programa de hadrões. Em 2010 e 2011 decorreram as últimas tomadas de dados com alvo de amónia (respectivamente polarizado transversalmente e longitudinalmente), o que permitiu concluir o programa de Difusão Inelástica Profunda Semi-Inclusiva (SIDIS).
A farm de processamento de dados de COMPASS tem um desempenho do nível requerido em LHC, pelo que a experiência foi usada pelos grupos técnicos de apoio do CERN em vários domínios relativos à aquisição e ao controlo dos dados como um ambiente de teste em grande escala.
Neste contexto, a aposta do grupo do LIP-Lisboa de, ao ingressar em COMPASS em finais de 2002, tomar a total responsabilidade do Sistema de Controlo de Detectores (DCS), revelou-se muito importante para a estratégia de evolução do grupo no plano tecnológico. Daí o notável esforço de recursos humanos que foi necessário.
O objectivo principal do grupo do LIP, atingido em anos anteriores, era o desenvolvimento de uma nova arquitectura para o DCS de COMPASS. Mas continuadas evoluçõoes e adaptações têm sido necessárias.
Na verdade, o DCS não pode ser um sistema estático ou um produto finalizado pois é constituído por várias camadas de packages cujas versões têm de ser compatíveis entre si, pelo que a alteração de um deles, muitas vezes com aspectos incompatíveis em relação à sua versão precedente, implica em geral a adaptação de todos os outros, o que é uma tarefa muito pesada.
Por outro lado, devido à contínua instalação de novos detectores específicos dos diferentes programas com feixes de muões e hadrões, o software do DCS (bem como o seu hardware de interface) tem vindo a aumentar constantemente o seu grau de complexidade (interfaces de novo tipo, novos drivers), devido à não uniformidade dos detectores e do seu hardware.
Paralelamente, o grupo tem também levado a cabo um conjunto de tarefas, de grande importância para a Colaboração COMPASS e para o grupo do LIP. Estas tarefas, tanto relativas ao offline, como o estudo de geradores físicos e da sua simulação no detector e sua concordância com os dados, como em relação à análise de dados propriamente dita, no que diz respeito aos canais mais importantes estudados em COMPASS no programa de DIS. Nomeadamente, os estudos da polarização do gluão através do processo de charme aberto ("Golden Channel") ou de eventos de grande pT, e ainda sobre as assimetrias de sabor do mar do nucleão.
Nos primeiros meses de 2010, o grupo do LIP-Lisboa assumiu um papel de destaque na preparação da Proposta de COMPASS para o futuro Programa experimental (COMPASSII), entretanto aceite pela Direcção Científica do CERN, na secçãoo relativa a estudos de transversidade através do processo de Drell-Yan polarizado.
Neste contexto, tem vindo a participar activamente nos estudos de adaptação e optimização do espectrómetro.

### 2.3.2 Abstract

The COMPASS experiment is dedicated to the study of the structure of the nucleon through the deep inelastic scattering of muons, namely the gluon polarization $\Delta G/G$ (from open charm photoproduction and high pT physics), the longitudinal and the transverse spin structure and the fragmentation functions.
With a hadron beam, COMPASS aims to study some spectroscopy issues, as the production of new mesons, namely exotics or hybrids.
COMPASS uses high intensity beams, that is, a polarized muon (or hadron) beam impinging on a longitudinally or transversely polarized target (or liquid hydrogen target) followed by a two stage spectrometer: a first one with a large angular acceptance, followed downstream by a second one with a reduced acceptance, designed to detect particles up to more than 100 GeV/c. Each spectrometer is equipped with a magnet sorrounded by

trackers, a set of electromagnetic and hadronic calorimeters, muon filters and a Cerenkov detector (RICH) for particle identification. The data acquisition system is based in a parallel read-out of the front-end electronics plus a distributed set of event-builders, specially designed to cope with huge data volumes. In fact, during the whole muon program, from 2002 till 2007, COMPASS collected a total of 1700 TeraByte of data. The years 2008 and 2009 were dedicated to the hadron program. In 2010 and in 2011, took place the two last data takings with an ammonia target, respectively polarised transversely and longitudinaly, allowing to finalise the program concerning Semi-Inclusive Deep Inelastic Scattering (SIDIS) with muon beams.
COMPASS data processing farm also requires a LHC-like performance. That is why the experiment was used as large scale test environment by some CERN support technical groups in several data acquisition and data control domains.
In this context, the fact that when the LIP-Lisbon group ingressed in COMPASS in the late 2002, we took the full responsibility of the Detector Control System (DCS), was very important to the evolving strategy of the group on a technological ground. In that view, a big effort in human resources was undertaken.
The main purpose of our group was the development a new DCS architecture, which has been previously achieved. But a constant evolution of the system is needed.
In fact, DCS can not be a static system or a finalised product, because it is formed by a set of several packages, disposed in layers but strongly interacting. This means that the packages versions must be compatible among them. Thus, changing one package version, which may even be not backward compatible with its previous one, may imply the change of all other packages versions. This is usually a heavy task.
On the other hand, COMPASS continues its hardware upgrade, namely in what concerns new detectors specific to muon or hadron programs. In view of this, the DCS is always increasing in complexity (new types and number of hardware interfaces with the detectors, new drivers), namely due to the non uniformity of the COMPASS detectors hardware.
In parallel, a great effort concerning the offline and data analysis tasks is being performed
with a major contribution of LIP Group in the COMPASS Collaboration. This includes the development of new physics generators, their simulation through the detector and its compatibility with data; as well as the analysis of the most important physics channels in DIS COMPASS program, namely studies on the gluon polarisation from the open charm process ("Golden Channel") or high pT events, and the flavour asymmetries of the nucleon sea.
In the first 2010 months, our group has taken an important role in the preparation of the COMPASS Proposal concerning the future Physics experimental program (COMPASSII), in the meanwhile approved by the CERBN Research Board, in the section concerning transversity studies through the polarised Drell-Yan process.
From then on, it has actively participated in the spectrometer upgrade and optimisation studies in that view.

### 2.3.3 Objectives

LIP has the full responsibility of the Detector Control System (DCS) of the experiment, since it has been accepted as a member of the COMPASS Collaboration, in September 2002.
Another major activity of LIP is data analysis and studies for the COMPASS-II physics program. Indeed, the subjects carried on by LIP members are the most important analysis channels of the experiment, concerning the muon program, that is, deep inelastic muon scattering. Also the future approved polarised Drell-Yan program is being developed together with the Torino group, these two groups being the key ones concerning this subject.
The COMPASS experiment LIP group carried on the matters related with the working activities, namely: full responsibility of the Detector Control System (DCS); data analysis and offline studies; and general activities.

### 2.3.4 Achievements

**Detector Control System**
During the preparation of the 2011 muon run with longitudinal target polarisation, the DCS proceeded with some internal development tasks, as the installation of new patches to speed up the DataBase query facilities.
Several major interface tasks to include some new or refurbished very important spectrometer components were also performed, namely the monitoring of the relevant criogenic polarized target parameters, the cryogenic system of the silicon detectors, which was upgraded and extented, as well as the monitoring extension of the beam line control to include the collimator positions.
These were very important upgrades and much appreciated by the Collaboration. In fact, they allowed an economy of 30% concerning the manpower related to data taking (shifts) as the criogenic polarized target control parameters were previously done by hand (1 "shifter") and now is automaticaly done.
One should stress that the DCS has to deal with a vast variety of COMPASS equipments that are being or will be controlled or monitored. While for some devices commercial supervision solutions exist (like OPC servers),

for many others these solutions do not.
That is why case-by-case solutions must be applied, namely by writing the drivers to control/monitor such devices, and integrate them in PVSS, whenever necessary.
It is worth noting that the DCS system works practically 12 months per year. In fact, during the no-beam part of the year, several DCS sub-systems run, in order to control some devices, as it is the case of detectors gas systems. This requires the permanent presence of DCS experts.

**Data Analysis and Offline Studies**
The offline and analysis task has been a major concern of our group. The analysis subjects carried on by LIP members are among the most important analysis channels of the experiment. As a consequence, our members have presented their results in several International Conferences, on the behalf of COMPASS, and 2 papers which are the outcome of the 2 PhD LIP Theses concluded in December are being sent to publication.
In 2011 the following subjects were addressed:

- The analysis of high pT events, which purpose is the derivation of the gluon polarisation, with an extensive study of the systemaatics errors.
- The open charm studies, in view of the $\Delta G/G$ extraction, including an extensive study of the systematics errors.
- Quasi-online quality data check studies, in view of the 2011 run spectrometer stability.
- Asymmetries study concerning the low xBj and low Q2 new analysis channel.
- Studies on the setup optimization for the future polarised Drell-Yan process experiment, namely background studies w.r.t. different absorber configurations, and the dimuon trigger design;
- Development of a new method of asymmetries evaluation in view of the gluon polarisation extraction.

**General Activities**
COMPASS LIP-Lisbon members participated in the following general activities:

- Participation in the Collaboration meetings
- Participation in the Steering Committee meetings (the Project Leader)
- Participation in the monthly offline and analysis meetings
- Participation in the technical friday meetings
- Participation in the data taking periods
- Week coordinations of the data taking (Marcin Stolarski and Sofia Nunes)
- Stays at CERN for the run preparation.

### 2.3.5 Sources of Funding

| Code | Funding | Start | End |
|---|---|---|---|
| CERN/FP/116376/2010 | 137.000 € | 2011-01-01 | 2011-12-31 |

### 2.3.6 Team

**Project coordinator: Paula Bordalo**

| Name | Status | %of time in project |
|---|---|---|
| António Pacheco | Master (LIP) * | 100 |
| Catarina Quintans | Researcher (LIP) | 100 |
| Celso Franco | Post-Doc (LIP/FCT) * | 100 |
| Christophe Pires | Technician (LIP) | 100 |
| Gonçalo Terça | Master (LIP) | 25 |
| Hugo Fonseca | Master student (LIP) | 100 |
| Luis Silva | Post-Doc (LIP/FCT) * | 100 |
| Márcia Quaresma | PhD student (LIP/FCT) * | 100 |
| Marcin Stolarski | Post-Doc (LIP/FCT) | 100 |
| Paula Bordalo | Researcher (LIP/IST) | 100 |
| Sérgio Ramos | Researcher (LIP/IST) | 100 |
| Sofia Nunes | PhD student (LIP) | 100 |

### 2.3.7 Publications

**Articles in international journals (with indirect contribution from LIP members)**

- *First Measurement of Chiral Dynamics in* $\pi\gamma \to \pi^-\pi^-\pi^+$
  COMPASS Collaboration, M.G. Alekseev et al.
  CERN-PH-EP-2011-176, Phys. Rev. Lett. (accepted)

**International Conference Proceedings**

- *Exploring QCD with COMPASS-II*
  C. Quintans et al., for COMPASS Collaboration
  XIX International Workshop on Deep-Inelastic Scattering and Related Subjects, DIS2011

- *COMPASS results on gluon polarization*
  L. Silva et al., for COMPASS Collaboration
  Procs. of XXI International Europhysics Conference on High-Energy Physics, HEP2011

- *New COMPASS Results on Longitudinal Spin Effects*
  M. Stolarski et al., for COMPASS Collaboration
  Procs. of 19th Particles & Nuclei International Conference, PANIC11

- *Gluon polarization measurements at COMPASS*
  L. Silva et al., for COMPASS Collaboration
  Procs. of Nordic Conference on Nuclear Physics 2011, NCNP2011

- *Drell-Yan measurements in COMPASS*
  C. Quintans et al., for COMPASS Collaboration
  XIX International Workshop on Deep-Inelastic Scattering and Related Subjects, DIS2011

- *COMPASS results on the gluon polarisation from the Open-Charm analysis*
  C. Franco et al., for COMPASS Collaboration
  Proc. of XIV Workshop on High Energy Spin Physics, DSPIN11

**Collaboration notes with internal referee**

- *All-pT method of the $\Delta G/G$ extraction*
  M. Solarski
  COMPASS Note 2011-4

### 2.3.8 Presentations

**Oral presentations in international conferences**

- *COMPASS results on longitudinal spin physics*
  presented by Celso Franco
  XI International Workshop on Hadron Structure and Spectroscopy - IWHSS11 — Paris, France.
- *Exploring QCD with COMPASS-II*
  presented by Catarina Quintans
  XIX International Workshop on Deep-Inelastic Scattering and Related Subjects - DIS 2011 — Newport News, USA.
- *Drell-Yan measurements in COMPASS*
  presented by Catarina Quintans
  XIX International Workshop on Deep-Inelastic Scattering and Related Subjects - DIS 2011 — Newport News, USA.
- *Gluon polarisation measurements @ COMPASS*
  presented by Luis Silva
  Nordic Conference on Nuclear Physics 2011 - NCNP2011 — Stockholm, Sweden.
- *Longitudinal spin results from COMPASS*
  presented by Celso Franco
  8th Circum-Pan-Pacific Symposium on High Energy Spin Physics: PacSPIN2011 — Cairns, Australia.
- *COMPASS results on gluon polarisation*
  presented by Luis Silva
  Europhysics Conference on High-Energy Physics 2011 — Grenoble, France.
- *New COMPASS Results on Longitudinal Spin Effects*
  presented by Marcin Stolarski
  19th Particles & Nuclei International Conference - PANIC11 — Cambridge, USA.
- *COMPASS results on the gluon polarisation from the Open-Charm analysis*
  presented by Celso Franco
  XIV WORKSHOP ON HIGH ENERGY SPIN PHYSICS — Dubna, Russia.

**Oral presentations in collaboration meetings**

- *DY event rates expected in COMPASS and comparison to past experiments*
  presented by Catarina Quintans
  COMPASS Meeting — CERN.
- *Studies on Drell-Yan (MC) data reconstruction*
  presented by Catarina Quintans
  COMPASS Meeting — CERN.
- *Preliminary Checks on 2011 data*
  presented by Sofia Nunes
  COMPASS Meeting — CERN.
- *Monte-Carlo studies for Drell-Yan @ COMPASS*
  presented by Márcia Quaresma
  COMPASS Meeting — CERN.

- *News about monitoring of SM1 in the DCS*
  presented by Sofia Nunes
  COMPASS Meeting — CERN.
- *Impact of COMPASS Magnets on ECAL1*
  presented by Sofia Nunes
  COMPASS Meeting — CERN.
- *Preliminary Checks on 2011 data (II): Stability from COOOL Plots and First Set of Test Productions*
  presented by Sofia Nunes
  COMPASS Meeting — CERN.
- *SAS single muon trigge*
  presented by Catarina Quintans
  COMPASS Meeting — CERN.
- *Monte-Carlo studies for Drell-Yan at COMPASS - Update*
  presented by Márcia Quaresma
  COMPASS Meeting — CERN.
- *COMPASS 2011 Run - Wekly Report September 9th-16th*
  presented by Sofia Nunes
  COMPASS Meeting — CERN.
- *Weekly Report September 23th-30th*
  presented by Marcin Stolarski
  COMPASS Meeting — CERN.
- *All-pT method of the $\Delta G/G$ extraction*
  presented by Marcin Stolarski
  COMPASS Meeting — CERN.
- *New Monte-Carlo Studies for COMPASS Drell-Yan*
  presented by Márcia Quaresma
  COMPASS Meeting — CERN.
- *Open Charm asymmetries and Delta G/G (NLO)*
  presented by Celso Franco
  COMPASS Meeting — CERN.
- *Studies on pion beam energy for Drell-Yan*
  presented by António Pacheco
  COMPASS Meeting — CERN.
- *Status report on Monte-Carlos for Drell-Yan*
  presented by Catarina Quintans
  COMPASS Meeting — CERN.
- *Delta_M and x2 distributions for Drell-Yan at COMPASS*
  presented by Márcia Quaresma
  COMPASS Meeting — CERN.

**Seminars**

- *The COMPASS DCS UI*
  presented by Sofia Nunes
  NA62 — CERN.

**Outreach seminars**

- *...do muito grande ao muito pequeno*
  presented by Luis Silva
  — Esc. Sec. Henriques Nogueira, Torres Vedras.

- *COMPASS visit guide for 80 portuguese language teachers*
  presented by Sofia Nunes
  COMPASS Meeting — CERN.

### 2.3.9 Academic Training

**PhD Theses**

- *Measurement of the gluon polarisation from open charm production in COMPASS*
  Celso Franco, 2011-12-20
- *Measurement of the Gluon Polarisation through high pT hadron production in COMPASS*
  Luis Silva, 2011-12-19
- *Study of asymmetries with polarised proton target at low Q2*
  Sofia Nunes, (on-going)
- *Drell-Yan polarised studies in COMPASS-II*
  Márcia Quaresma, (on-going)

**Master Theses**

- *Simulation of the Drell-Yan process in hadronic interactions in the COMPASS experiment*
  António Pacheco, 2011-10-24
- *Study of spin dependent deep inelastic processes in the COMPASS experiment*
  Hugo Fonseca, (on-going)

### 2.3.10 Project Summary

| | number |
|---|---|
| Articles in international journals (with indirect contribution from LIP members) | 1 |
| International Conference Proceedings | 6 |
| Collaboration notes with internal referee | 1 |
| Oral presentations in international conferences | 8 |
| Oral presentations in collaboration meetings | 17 |
| Seminars | 1 |
| Outreach seminars | 2 |
| PhD Theses | 2 |
| Master Theses | 1 |

## 2.4 Collaboration in the HADES experiment at GSI

### 2.4.1 Resumo

A colaboração HADES (www-hades.gsi.de), acrónimo de "High Acceptance Di-Electron Spectrometer", é uma experiência internacional de Física das Partículas, onde participam 17 instituições de 9 países europeus entre os quais Portugal, através do Laboratório Associado LIP (www.lip.pt). Esta experiência está instalada no laboratório GSI (www.gsi.de), situado em Darmstadt, na Alemanha.
Fazendo colidir núcleos atómicos pesados acelerados no acelerador SIS18 do GSI, a experiência pretende criar um estado nuclear muito mais denso que o habitual. Essa densidade acrescida, ao provocar alterações mensuráveis nas propriedades das forças nucleares, permitirá estudar algumas propriedades destas forças que são responsáveis pela maior parte da massa da matéria comum.
A participação portuguesa nesta experiência, assegurada por equipas do LIP, consiste no projecto, construção e operação de um detector de partículas de concepção original que ajudará a identificar com mais rigor o tipo de partículas que emergem das referidas colisões nucleares. Este novo detector será capaz de medir o tempo de voo das partículas (desde o ponto da colisão até ao detector) com uma precisão equivalente ao tempo que demora a luz a percorrer uma distância de 3 cm (100 picosegundos, isto é 0,0000000001 s). Esta informação permite por sua vez determinar a velocidade das partículas, o que é um passo importante para identificar o tipo de partícula de que se trata.
Uma vez em funcionamento, o que deverá acontecer em 2012, pretendemos também participar no programa de física, acima delineado.

### 2.4.2 Abstract

The HADES collaboration (www-hades.gsi.de), "High Acceptance Di-Electron Spectrometer", is an international Particle Physics experiment in which participate 17 institutions from 9 European countries, including Portugal via the "Associated Laboratory"LIP (www.lip.pt). The experiment is installed in the laboratory GSI (www.gsi.de), located in Darmstadt, Germany.
By colliding heavy atomic nucleus accelerated by GSI´s SIS18 accelerator the experiment aims at creating a nuclear state much denser than usually. This increased density, causing changes in the measurable properties of the nuclear forces, will allow the study of some properties of these forces that are responsible for most of the mass of ordinary matter.
The Portuguese participation in the experiment, assured by LIP teams, includes the design, construction and operation of an original particle detector that will help to identify more accurately the kind of particles that emerge from the nuclear collisions. This new detector will be able to measure the time of flight of the particles (from the collision point to the detector) with a precision equivalent to the time that it takes the light to cross a

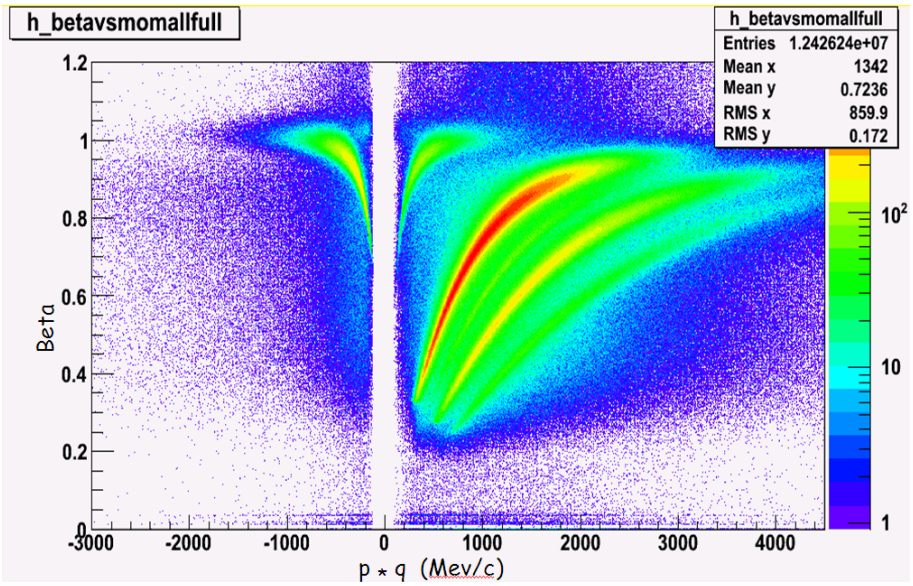



Figure 2.3: Particle identification plot obtained with the RPC TOF Wall.

distance of 3cm (100 picoseconds, or 0.0000000001 s). This information allows the determination of the velocity of the particles, which is an important step to identify the particle.
Once in operation, which should happen in 2012, we intend to participate in the above mentioned physics program.

### 2.4.3 Objectives

The HADES detector is dedicated to the study of heavy ion collisions at energies below 2 AGeV and elementary reactions below 4 GeV.
In recent years HADES has produced a series of relevant physics results, mostly with elementary particles or light ions owing to granularity limitations in the forward time-of-flight (TOF) detector. From 2010 onwards the work will be continued with heavy ions. Furthermore, the experimental program is expected to be continued at the higher beam energies (8-10 AGeV) available at the future FAIR facility.
Since several years LIP is contributing to the upgrade of HADES. The involvement of LIP has been mostly technical with the design, construction and commissioning of a large RPC wall (8 square meters), which will cover the most forward region of the spectrometer and provide time of flight information with a resolution of $\approx$70 ps.
Our group is now responsible for all detector hardware, auxiliary systems and software of the RPC TOF Wall, while the detector electronics, both front-end and digital acquisition, are the responsibility of GSI and of groups from the Universities of Santiago de Compostela and Valencia, Spain. LIP assures also the general coordination of the HADES RPC group and of the RPC slow control tasks. The RPC-specific software is a responsibility of the University of Santiago de Compostela.
LIP is expected to take a major role in the exploration of the new system (2012 onwards), joining other international institutions in sharing the load of running the experimental setup, by taking part into beamtimes and by participating in the physics program.

### 2.4.4 Achievements

#### HADES RPC TOF WALL

The RPC TOF Wall has been operating since January 2010 with all major hardware components active.
The operation has been smooth, except for the apearance of some gas leaks that have been remediated as possible. A full solution would imply the removal of the RPC detectors from the spectrometer and the replacement of the O-ring seals. We will try to postpone this operation for when HADES will be moved to the new GSI accelerator, SIS100. Other minor problems concerning the FEE (broken channels) and low voltage power supplies have been also solved.
A major shift happened in what regards the detector-related software (calibration, low-level data-processing, simulation) as the group previouslly responsible for this task cannot anymore carry it forward. The direct responsibility now lies with the LIP staff member Alberto Blanco, who is now formally in charge of the RPC TOF system and a member of the HADES Technical Board. Indeed, full responsibility for the operation of the detector systems and software now lies with LIP.
In 2011 we participated in a decisive commissioning beam time, with an Au-Au beam at 2 AGeV, aimed at verifying the performance of the spectrometer under high multiplicty conditions. The RPC system has shown excellent performance, yielding at the design multiplicity an intrinsic time resolution of around 80 ps for all particles; well below of the requirement of 100 ps. The degradation in time resolution due to this high multiplicity environment is only a few ps with respect to the low multiplicity situation, thanks to the innovative design adopted (individually shielded RPCs). Additionally, the RPC system also shows a spatial resolution of around 10 mm sigma and moderate timing tails at a level of 3%.
A new method for the calibration of the RPC TOF system based on the use of protons allows to obtain the calibration parameters faster and accurately than previous method based on fast pions. This is possible since protons are the most abundant particle covering almost all the active surface of the detector at high statistic. Additionally, fine tuning of the existing software (e.g. new slewing correction, improvement of the calculation of the position inside the cell or introduction of new parameter container for the validation of RPC cells) has been performed in order to optimize and improve the corrections needed to achieve the 80 ps.
The current calibration of the spectrometer shows a system time resolution for the RPC at a level of 150 ps, in which contributions from other systems as the start detector and the tracking system are included in this figure. Nevertheless, the current particle identification plot fig. below, clearly resolve the different types of particles (electrons, pions, protons, ...) with superior performance when compared with the old TOF system based on scintillators.

Work was finished on small auxiliary systems, including: a spare electronics box for the gas system, connection of the gas system to the slow control via CANBUS, readout of the small reference chambers installed within the gas boxes for gas monitorization purposes, remote readout of the multiplicity trigger signals for debugging purposes. Together with this hardware, new software, which uses the reference chambers and the multiplicity trigger signals, will allow a more precise diagnosis of the status of the detector in the future.

**PARTICIPATION IN THE PHYSICS PROGRAM**

There was a major and very interesting shift of focus in the perspectives for the participation in the physics program: the senior LIP researchers Paula Bordalo and Sergio Ramos have agreed to participate in the experiment, supervising the work of a new project fellow, Luís Silva, who has been previouslly a PhD student in the COMPASS experiment at CERN. Another LIP post-doc, Celso Franco, will share its time between the HADES and COMPASS experiments. This development opens excelent perspectives for a strong LIP-HADES physics program.

**FUNDING**

The participation in HADES is now formalized via a Memorandum of Understanding (MOU) celebrated between the Collaboration, GSI and FCT. Within this MOU, FCT has committed to support the maintenance of the system and the common fund until 2012.
Funding of 91.742€ for these activities was granted by the project PTDC/FIS/113339/2009 over three years.

### 2.4.5 Sources of Funding

| Code | Funding | Start | End |
|---|---|---|---|
| EU Contract 515876 DIRAC-Phase-1 | 52.000 € | 2005-10-01 | 2011-03-31 |
| LIP-GSI contract | 414.000 € | 2005-10-01 | 2011-03-31 |
| PTDC/FIS/113339/2009 | 91.742 € | 2011-04-01 | 2014-01-31 |

### 2.4.6 Team

**Project coordinator: Paulo Fonte**

| Name | Status | %of time in project |
|---|---|---|
| Alberto Blanco | Technician (LIP) | 14 |
| Alessio Mangiarotti | Researcher (LIP) | 40 |
| Carlos Capela | Researcher (ESTGL) | 1 |
| Carlos Neves | Researcher (ESTGL) | 0 |
| Carlos Sousa | Researcher (ESTGL) | 2 |
| Luís Lopes | Technician (LIP) | 40 |
| Milena Vieira | Researcher (ESTGL) | 2 |
| Paulo Fonte | Researcher (LIP/ISEC) | 29 |
| Ricardo Caeiro | Technician (LIP) | 11 |

### 2.4.7 Publications

**Articles in international journals (with indirect contribution from LIP members)**

- *Hyperon production in Ar plus KCl collisions at 1.76A GeV*
  The HADES collaboration
  Eur. Phys. J. A 47 (2011) 21

- *Dilepton production studied with the HADES spectrometer*
  The HADES collaboration
  International Journal of Modern Physics 26 (2011) 384

- *pp and pi pi intensity interferometry in collisions of Ar+KCl at 1.76A GeV*
  The HADES collaboration

Eur.Phys.J.A 47 (2011) 63

- *Dielectron production in Ar plus KCl collisions at 1.76A GeV*
  The HADES collaboration
  Physical Review C 84 (2011) 014902

### 2.4.8 Presentations

**Oral presentations in collaboration meetings**

- *RPC - status/results*
  presented by Alberto Blanco
  HADES collaboration meeting XXIII, 14-18 Nov. 2011 — GSI, Darmstadt, Germany.

### 2.4.9 Academic Training

**PhD Theses**

- *Construccion y evaluacion de un prototipo de tomografo de emision de positrones basado en la tecnologia de camaras de placas resistivas*
  Alberto Blanco, 2012-01-09

### 2.4.10 Project Summary

| | number |
|---|---|
| Articles in international journals (with indirect contribution from LIP members) | 4 |
| Oral presentations in collaboration meetings | 1 |

## 2.5 Phenomenological Studies at the LHC

### 2.5.1 Resumo

Um importante esforço conjunto de preparação da comunidade experimental e teórica de Física de Partículas Elementares é necessário por forma a responder ao desafio do LHC. Este esforço deve ser concentrado não apenas no estudo dos melhores observáveis em LHC que permitam realizar testes de precisão do Modelo Padrão (SM) da Física Elementar de Partículas, mas também no desenvolvimento de novas ideias de Física para além do SM. Com o objectivo de concretizar uma estreita colaboração entre a comunidade de Físicos Experimentais e Teóricos de Partículas, foram propostas várias tarefas no âmbito do presente projecto, e cujo estado actual se passa a descrever.
A primeira tarefa envolveu o estudo de processos associados a correntes neutras com troca de sabor (FCNC) na produção simples de quarks top em LHC. Para o efeito foi desenvolvido um modelo teórico efectivo e desenvolvido um novo gerador (MeTop) que inclui processos FCNC para além do nível árvore (NLO). Quer o Pythia quer o Herwig podem ser usados na hadronização dos acontecimentos produzidos a nível partonico. Uma segunda tarefa envolveu o estudo da produção de bosões de Higgs através do processo gg(qq)->h+jatos->tau+tau-+jatos. Foi realizado um estudo detalhado a nível partónico e os resultados foram aplicados a alguns modelos de física para além do Modelo Padrão que prevêm um aumento significativo da largura de decaimento do Higgs para dois taus. Os resultados levam à conclusão que várias regiões do espaço de fase dos parâmetros podem ser excluídas com uma luminosidade de apenas alguns fb-1 em LHC. Outra tarefa desenvolvida no âmbito deste projecto, envolveu o estudo de assimetrias angulares em decaimentos do quark top produzidos aos pares e de forma simples em LHC. No SM o vértice Wtb é considerado puramente esquerdo com uma intensidade proporcional ao elemento Vtb da matriz de Cabibbo-Kobayashi-Maskawa (CKM). Apesar da secção eficaz de produção dupla de quarks top em LHC não ser sensível ao valor de Vtb, as correlações angulares dos produtos de decaimento destes quarks podem dar informação valiosa sobre a estrutura do vértice Wtb. Novas assimetrias foram introduzidas (A+ e A-) bem como novas razões entre as polarizações dos bosões W ($\rho$R e $\rho$L). Foi possível verificar que os novos observáveis introduzidos são mais sensíveis aos acoplamentos anómalos vectoriais e tensoriais do que os previamente utilizados em LHC. Foram estudadas as correlações entre os vários observáveis e desenvolveu-se o programa (designado por TopFit) que permite fazer o ajuste global de todos os observáveis (quer associados à produção simples quer dupla de quarks top em LHC) em função dos novos acoplamentos anómalos. Foram obtidos limites preliminares nos acoplamentos anómalos em experiencias do LHC. No âmbito do presente projecto foram ainda estudados sinais de nova Física que produzem, em LHC, eventos com estados finais com 3 leptões (que permitem estudar o mecanismo que possibilita aos neutrinos adquirirem massa) e produção de novas ressonâncias vectoriais. Foram ainda desenvolvidos novos Modelos Teóricos implementados em geradores de sinal.

### 2.5.2 Abstract

In order to address the physics potential of the LHC program, a significant joint effort of the experimental and theoretical particle physics community is required. This effort must consider not only the study of the best physical observables to perform a precise test of the Standard Model (SM) of Elementary Particle Physics at LHC, but also to develop new ideas for physics beyond the SM. Several tasks were proposed in the present project to implement a strong collaboration between experimental and theoretical particle physicists. The status of such tasks is summarized in what follows.
Top Quark FCNC Processes: The main goal of this task is to study signals of physics beyond the SM in single top quark Flavour Changing Neutral Currents (FCNC) processes at LHC. Following the development of a model independent analysis for single top production via FCNC (where dimension 5 and 6 effective flavour changing and flavour conserving quark-gluon vertices were considered), the impact of these new couplings on the physical observables at LHC were studied. Current status of the present task: the theoretical model is well developed (with publications in international scientific journals and presentations in conferences) and a new generator (MeTop), that includes NLO corrections to FCNC processes, was developed (it can be interfaced with Pythia or Herwig for hadronization).
Non-Standard Higgs Production: Until a thorough experimental Higgs analysis is performed it will be very hard to distinguish between the different models proposed associated to the Higgs physics (2HDM,Fermiophobic Higgs,etc.). The main goal of this task was to test, for a chosen set of luminosities (from the first year of data taken at the LHC to the full Super-LHC sample), which models could be tested and for which regions of the parameter space.
Current status of the present task: A detailed study at parton level was performed for the production of Higgs bosons through the processes gg(qq)->h+jets->tau+tau-+jets. The obtained results were interpreted in terms of parameter phase space exclusion regions for few models of Physics Beyond the Standard Model. It was shown

that even with few fb-1 of luminosity at the LHC, significant portions of the phase space can be excluded. First studies on a general purpose experiment at LHC were performed which constituted the core study of one Master student seminar.
Top Quark Couplings :The LHC will is a top quark factory. This fact allows to measure with high precision the Wtb vertex and the couplings of the top quark. Although the double top production is insensitive to the Vtb CKM matrix element, the angular asymmetries between the top quark decay products can nevertheless give valuable information on the structure of the Wtb vertex. New right-handed couplings can be introduced within an effective lagrangian approach which can be probed at the LHC.
Current status of the present task: New asymmetries (A+ and A-) and new W polarization states ratios ($\rho$R and $\rho$L) were introduced and tested at the LHC. The program, TopFit was used to perform a global fit of all relevant observables (taking into account the correlations between them) in order to set the most stringent limits to the anomalous couplings. The ttbar and single top physics were combined to get a global fit from both channels at the LHC.
Tri-leptons and the seesaw mechanism, New physics in models of strong EWSB and, Theoretical Models and Monte Carlo Generators: One of the fundamental tasks of this project is the development of theoretical models which allow a better comprehension of the SM and physics beyond the SM. The search for new physics in tri-lepton final state topologies were studied at the LHC to probe the seesaw mechanism and neutrino mass generation mechanism as well as the production of new vector resonances in models of strong EWSB.
Current status of the present tasks: although several models have already been developed (see tasks 1 and 2 of the project) associated either to the single top quark production via FCNC or with the top quark decays (and the study of the Wtb vertex), these tasks are still in development.

### 2.5.3 Objectives

The main objective of the project is to continue and strengthen the collaboration between experimental and theoretical physicists for phenomenological studies with a special impact on the LHC physics. The discussion is intended to be concentrated in: (1) the top quark physics and Flavour Changing Neutral Current processes associated with single top quark production at colliders (Tevatron and LHC); (2) the Wtb vertex structure and asymmetries in top quark decays which are related to possible anomalous couplings beyond the SM; (3) non standard Higgs boson production within several extensions of the Standard Model; (4) the seesaw mechanism and neutrino mass; (5) new vector like resonances related to fermions by custodial symmetry and (6) theoretical improvements related to models under development.

### 2.5.4 Achievements

- A better knowledge of the top quark physics was observed at the end of this project. The SM and FCNC couplings of the top quark were better understood as well as the general structure of the Wtb vertex including possible extensions to the SM. New upgrades of already developed software tools (like TopFit) were made available to the community. These tools allow a global fit to several observables in order, for example, to extract the sensitivity of the LHC to new top quark anomalous couplings.
- Dedicated Monte Carlo generators (like PROTOS and MeTop with FCNC couplings at NLO) were developed and made available to the scientific community.
- The training of undergraduate and graduate students was also an important priority and achievement of the project. The non standard Higgs boson production within several extensions of the Standard Model were explored at the LHC, as well as the seesaw mechanism and the models associated to strong eletroweak symmetry breaking.
- This activity was extended to the University of Minho, in the Northern part of Portugal, where several members of the team are already working since February 2010. A team of 2 senior PhD researchers, 1 PhD student, 2 undergraduate students and 3 Master students is already established at the newly created branch of LIP in the University of Minho (LIP-Minho).
- Several papers were published by the team who also presented the work done at Conferences and Workshops

### 2.5.5 Sources of Funding

| Code | Funding | Start | End |
|---|---|---|---|
| CERN/FP/116397/2010 | 32.000 € | 2011-01-01 | 2012-02-15 |

### 2.5.6 Team

**Project coordinator: António Onofre**

| Name | Status | %of time in project |
|---|---|---|
| António Onofre | Researcher (LIP/UMinho) | 50 |
| Augusto Barroso | Researcher (FCUL) | 20 |
| Francisco del Aguila Giménez | Researcher (UGR) | 20 |
| João Carvalho | Researcher (LIP/FCTUC) | 35 |
| José Santiago Perez | | 20 |
| Juan Aguilar-Saavedra | Researcher (LIP) | 40 |
| Juan Espinosa | Master (LIP) | 25 |
| Marco Oliveira Pena Sampaio | | 15 |
| Miguel Fiolhais | PhD student (LIP/FCT) | 100 |
| Miguel Won | PhD student (LIP/FCT) | 50 |
| Mikael Chala | Master student | 20 |
| Nuno Castro | Post-Doc (LIP/FCT) | 60 |
| Nuno Rodrigues | Graduate student (LIP/UMinho) | 100 |
| Paulo Gonçalves | Graduate student (LIP/UMinho) | 100 |
| Pedro Martins Ferreira | Researcher (LIP/FCUL) | 15 |
| Rita Monteiro | Post-Doc (LIP) | 100 |
| Roberto Pittau | Researcher (UGR) | 20 |
| Rui Santos | Researcher (LIP/FCUL) | 20 |

### 2.5.7 Publications

**Articles in international journals (with direct contribution from LIP members)**

- *Using single top rapidity to measure V_td, V_ts, V_tb at hadron colliders*
  J. A. Aguilar-Saavedra, A. Onofre
  Phys.Rev.D83:073003,2011

- *Constraints on the Wtb vertex from early LHC data*
  J. A. Aguilar-Saavedra, N. F. Castro, A. Onofre
  Phys.Rev.D83:117301,2011, Phys.Rev.D84:019901,2011

### 2.5.8 Academic Training

**PhD Theses**

- *Non-standard Higgs and top-quark production and decay at the Large Hadron Collider: a collaboration between theory and experiment*
  Miguel Won, (on-going)

- *Study of the Wtb vertex structure in top quark decays*
  Miguel Fiolhais, (on-going)

### 2.5.9 Project Summary

| | number |
|---|---|
| Articles in international journals (with direct contribution from LIP members) | 2 |

# Chapter 3

# Computing

## 3.1 Grid Computing

### 3.1.1 Resumo

As atividades do grupo de computação centram-se na investigação e desenvolvimento de sistemas distribuídos para ciência computacionalmente intensiva (e-Science). Estas atividades tiveram origem no *Large Hadron Collider* (LHC), cujas experiências requerem capacidades de processamento e armazenamento massivas apenas obtidas através da junção dos recursos dos institutos participantes.
Desde 2001 o grupo de computação do LIP tem participado em importantes projetos e iniciativas no âmbito da computação grid. Estes projetos culminaram na criação da Iniciativa Europeia Grid (EGI), cujo objetivo é a disponibilização de uma infraestrutura pan-Europeia de computação para e-Science.
No âmbito da Iniciativa Nacional Grid (NGI) o LIP coordena uma infraestrutura de computação grid de âmbito nacional. A infraestrutura nacional encontra-se integrada na Iniciativa Ibérica de computação Grid (IBERGRID) e no EGI. O LIP opera o centro de recursos (Tier-2) Português para o *Worldwide LHC Computing Grid* (WLCG) e suporta as experiências ATLAS e CMS.

#### Atividades em 2011

**Worldwide LHC Computing Grid (WLCG)**
A capacidade de processamento fornecida pelo Tier-2 cumpriu e excedeu os parâmetros previstos no âmbito do memorando de entendimento para o WLCG. Os três centros do Tier-2 exibiram boa fiabilidade e disponibilidade. Recentemente todos os centros atingiram 100% no relatório mensal de fiabilidade. O grupo de computação operou o Tier-2 em estreita colaboração com os grupos de ATLAS e CMS locais e equipas de operações das experiências. O Tier-2 Português foi o décimo maior Tier-2 Europeu.

**Iniciativa Nacional grid**
O Tier-2 depende dos serviços da infraestrutura nacional para operar de forma integrada na grid internacional, por isso a infraestrutura grid nacional é de importância vital para o LIP. Neste sentido o LIP efetua a gestão

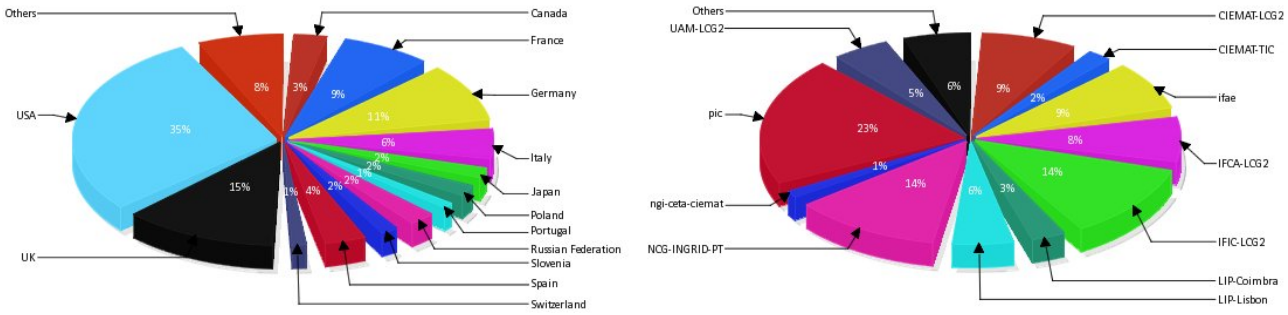



Figure 3.1: Portuguese Tier-2 in percentage of delivered processing time and jobs

tanto dos serviços grid centrais assim como da infraestrutura no seu todo incluindo a coordenação dos diversos centros. O LIP efetua também a gestão do nó central grid (NCG).O NCG é um centro de computação que disponibiliza recursos à comunidade científica nacional.
A infraestrutura nacional suporta atividades de investigação tais como o Tier-2, simulações de plasma em lasers, reconstrução de sequencias genomicas, imagiologia cerebral, imagiologia para endoscopia, dobramento de proteínas, modelação de ondas para simulação de derrames de petróleo, astro-partículas, simulação de turbulência em jatos, e simulações morfo-dinamicas costeiras, entre outros.

**Iniciativa Grid Iberica**
As infraestruturas Portuguesa e Espanhola estão integradas de forma completa e transparente numa única infraestrutura Ibérica. A iniciativa IBERGRID tem sido muito bem sucedida tanto ao nível técnico como estratégico. Tanto os recursos computacionais como o esforço necessário para operar a infraestrutura são partilhados por ambos os países, o que permite otimizar a utilização dos recursos instalados, reduzir significativamente o esforço de operação e melhorar a qualidade e robustez do serviço. Através da iniciativa IBERGRID Portugal e Espanha participam conjuntamente no EGI.
O conjunto de serviços disponibilizados inclui:

- operação de serviços grid críticos, incluindo serviços tolerantes a falhas e/ou redundantes
- primeiro nível de suporte aos utilizadores e gestores de sistemas
- turnos regionais de operação para monitorização/atuação sobre problemas na infraestrutura
- operação do portal de operações e *wiki* do IBERGRID
- coordenação dos centros que compõem a infraestrutura, reuniões semanais de coordenação e relatórios semanais

O LIP organizou em Dezembro de 2011 o 1º encontro IBERGRID de "cloud computing". Em resultado deste encontro um serviço piloto de cloud computing Ibérico está a ser implementado. Este serviço tem por objetivo facilitar o acesso aos recursos já existentes para utilizadores que não necessitem da sofisticação da computação grid.

**Iniciativa Europeia Grid**
As atividades do EGI têm lugar no âmbito do projeto EGI-Inspire e são realizadas em colaboração com Espanha no contexto do IBERGRID. As tarefas do LIP no EGI possuem duas vertentes: coordenação e interface da infraestrutura nacional/regional com o EGI, e a realização de tarefas de coordenação a nível Europeu.

- serviços técnicos para organizações virtuais incluindo ferramentas, documentação e apoio
- coordenação do teste e entrada em produção de novas versões de *middleware*
- definição de critérios de validação e aceitação do *middleware*
- concepção de um sistema de gestão de relações e contactos para o EGI
- gestão de incidentes de segurança e vulnerabilidades

Finalmente o LIP opera uma autoridade de certificação (CA) que emite credenciais de autenticação para utilizadores grid. A LIP CA está acreditada pelo IGTF e EUgridPMA e encontra-se registada na Terena.
O LIP participou ativamente no conselho do EGI e representou os interesses de Portugal e Espanha no painel de gestão do projeto.

**Serviços de computação do LIP**
Para além da gestão regular dos serviços de computação e redes do LIP, foram desenvolvidas atividades com vista ao melhoramento dos serviços. Melhorou-se significativamente a imagem web do LIP através de novas páginas para o público, e implementaram-se novas aplicações web para os utilizadores e serviços administrativos. Otimizou-se o funcionamento do CPD de Lisboa obtendo-se reduções significativas de consumo. Continuou-se a introdução das boas praticas ITIL no âmbito de uma tese de mestrado.
O LIP iniciou um novo projeto denominado TIMBUS com vista ao estudo da preservação de dados e processos aplicada à analise de dados em Física de Partículas. Neste projeto o LIP apresenta-se com um caso de uso para a preservação e recuperação de antigas analises de dados.

### 3.1.2 Abstract

The LIP computing group activities are centred in the research and development of highly distributed network environments for computationally intensive science, commonly known as e-Science. These activities were born out of the Large Hadron Collider (LHC) whose experiments constitute huge computing challenges. To process and analyze the experiments data massive computing and storage capacity is needed. This can only be attained by joining the capacity of all collaborating institutes.
Since 2001 the group has been participating in major grid computing projects and initiatives. These culminated in the creation of the European Grid Initiative (EGI), a pan-European effort to provide an e-Science infrastructure for European researchers from all domains.
In the framework of the National Grid Initiative (NGI), LIP coordinates a national grid infrastructure. The NGI infrastructure is seamlessly integrated in the Iberian grid initiative (IBERGRID) and in the European Grid Initiative (EGI). LIP operates the Portuguese Tier-2 centre for the Worldwide LHC Computing Grid (WLCG) supporting the ATLAS and CMS experiments.

**2011 Activities**

**Worldwide LHC Computing Grid (WLCG)**
The Portuguese Tier-2 delivered capacity exceeded the WLCG pledges and the Portuguese centres exhibited good reliability and availability metrics. Recently all three centres achieved 100% in the WLCG monthly reliability reports. The LIP computing team operated the Tier-2 in close collaboration with the local ATLAS and CMS groups and with the experiments computing operations teams. The Portuguese Tier-2 was the 10th largest European provider in WLCG.

**Portuguese Grid Initiative**
The Tier-2 depends on the NGI infrastructure to operate as part of the international grid. Therefore the NGI infrastructure is of strategic importance to LIP. As such LIP is both managing the infrastructure core services and coordinating the infrastructure sites. In addition LIP is managing the Portuguese main centre for grid computing (NCG), a shared computing facility that provides resources to Portuguese researchers. The infrastructure is currently supporting research activities such as the WLCG Tier-2, laser beam plasma simulations, genomic sequence assembly, brain imaging, endoscopy imaging, protein folding, wave modelling for oil spills simulation, astroparticles, turbulent plain jets, and morphodynamics of coastal systems, among others.

**Iberian Grid Initiative**
The Portuguese and Spanish grid infrastructures are seamlessly integrated into a single Iberian grid. The IBERGRID initiative has been very successful both at the technical and strategic levels. Both the computing capacity and the effort required to operate the infrastructures are shared across borders. IBERGRID maximizes the return of the installed capacity and reduces significantly the operations burden allowing for better service quality and resilience. IBERGRID is also providing the collaborative framework under which Portugal and Spain participate in EGI as a unified regional infrastructure.
The set of services provided include:

- Operation of critical middleware services, and deployment/operation of resilient systems;
- First level support for users and site managers;
- Regional operations shifts performing monitoring and acting on infrastructure issues;
- Operation of the IBERGRID wiki and operations portal;
- Coordination of the sites including weekly meetings and reporting to EGI, etc;

LIP has organized the 1st Ibergrid cloud meeting which took place in December of 2011. As a result of this meeting a cloud pilot is now being deployed. The aim of this service is to provide simplified access to the existing resources for individual users and small groups that don´t require the sophistication of the grid.

**European Grid Initiative**
The EGI activities take place within the context of the EGI-Inspire project and are performed in collaboration with Spain in the IBERGRID context. The LIP tasks within EGI are twofold; they include the coordination interface between the national/regional infrastructure and EGI, and the provisioning of services which are performed on behalf of the whole EGI collaboration. These included:

- technical services for virtual organizations including tools, documentation and support;
- middleware testing and deployment coordination;
- definition and validation of middleware acceptance requirements;
- design of a relations and contacts management system for EGI dissemination activities;
- European wide security incident and vulnerabilities coordination (weekly shifts);

Finally LIP operates a Certification Authority (CA), an IGTF and EUgridPMA accredited CA that issues authentication credentials for grid users and services.
LIP participated actively in the EGI council and represented the interest of both Portugal and Spain in the EGI project management board.

**LIP Computing Services**
Besides the regular management of the LIP computing services several enhancements took place. New web pages for the public improved significantly the LIP Internet presence. New web applications for both the users and administrative services were developed. The Lisbon datacenter optimization produced significant improvements in power consumption. The introduction of ITIL best practices continued in the context of a master thesis.
Finally LIP started a new project named TIMBUS, aimed at study data and processes preservation applied to the data analysis in Particle Physics. In this project LIP is a use-case for the preservation and recovery of past data analysis activities.

### 3.1.3 Objectives

The major objectives established for 2011 were:

- Operation of the Portuguese Tier-2 working closely with the ATLAS and CMS experiments, keeping the provided capacity at the same level of the previous years while improving reliability and availability.
- Improve the LIP computing infrastructure in the domains of energy efficiency, integration between centres and best practices.
- Coordinate the Portuguese NGI grid infrastructure and leverage the cooperation with the Spanish NGI in the context of IBERGRID establishing the Iberian grid as a major regional infrastructure in EGI.
- Assume European wide responsibilities in relevant EGI activities in the areas of middleware lifecycle and virtual organizations services.
- Act as Portuguese NGI infrastructure point-of-contact in the context of the IBERGRID and EGI initiatives.
- Expand the NGI computing service to new users and applications
- Develop skills in the domain of data preservation aiming at potential applications in High Energy Physics and e-Science in general.

### 3.1.4 Achievements

- The Portuguese Tier-2 attained and exceeded the WLCG requirements and service level agreements.
- The Portuguese Tier-2 provided capacity well above the MoU pledges.
- The computing team performed relevant technical services and coordination tasks in the areas of virtual organizations and middleware rollout.
- Consolidation of IBERGRID as major infrastructure in EGI.

- LIP represented both Portugal and Spain at the EGI management board.
- LIP worked with the Portuguese Civil Engineering Laboratory to successfully integrated its parallel computing cluster in the Portuguese grid.
- Major improvements in datacenter energy efficiency were attained.
- First steps towards the implementation of the ITIL practices were performed and a master thesis in this domain was finalized.
- A new project in the domain of data preservation was started, LIP developed skills in the domain of data and processes preservation.

### 3.1.5 Sources of Funding

| Code | Funding | Start | End |
|---|---|---|---|
| IBERGRID FCT-CSIC 2010/11 | 4.250 € | 2007-01-01 | 2012-06-30 |
| G-CAST | 1.000 € | 2008-01-01 | 2011-09-30 |
| EGI InSPIRE | 485.000 € | 2010-05-01 | 2014-04-30 |
| TIMBUS | 112.268 € | 2011-03-01 | 2014-02-28 |

### 3.1.6 Team

**Project coordinator: Jorge Gomes**

| Name | Status | %of time in project |
|---|---|---|
| Carlos Manuel | Technician (LIP) | 100 |
| Gaspar Barreira | Researcher (LIP) | 50 |
| Gonçalo Borges | Researcher (LIP) | 100 |
| Henrique Matos | Technician (LIP) | 15 |
| Hugo Gomes | Technician (LIP) | 100 |
| João Martins | Researcher (LIP) | 100 |
| João Pina | Post-Doc (LIP/FCT) * | 100 |
| Jorge Gomes | Researcher (LIP) | 100 |
| José Aparício | Technician (LIP) | 100 |
| Mário David | Researcher (LIP) | 100 |
| Miguel Oliveira | Researcher (LIP) | 93 |
| Nuno Ribeiro Dias | Researcher (LIP) | 100 |
| Sara Valente | Master student (LIP) | 50 |

### 3.1.7 Publications

**Articles in international journals (with direct contribution from LIP members)**

- *Software Provision Process for EGI*
  M. David, G. Borges, J. Gomes, J. Pina, et al
  Software Provision Process for EGI, M. David, G. Borges, J. Gomes, J. Pina, et al, Computing and Informatics, Vol. 31 number 1, 2012, pp 61-72, ISSN 1335-9150

**International Conference Proceedings**

- *Experience on running the Ibergrid infrastructure within EGI*
  I. Campos, E. Fernandez, A.Lopez, J. Marco, P.Orviz, G.Borges, J. Gomes, H. Gomes, M. David, J. Pina, J. Martins et al
  IBERGRID, 5th Iberian Grid Infrastructure Conference Proceedings ISBN 978-84-9745-884-9, pag 3-16

- *Fostering multi-scientific usage in the Iberian production infrastructure*
  G. Borges, M. David, H. Gomes, J. Gomes, J. Martins, J. Pina et al
  IBERGRID, 5th Iberian Grid Infrastructure Conference Proceedings ISBN 978-84-9745-884-9, pag 17-27

- *Software Provision Process for EGI*
  M. david, G. Borges, J. Gomes, J. Pina, et al
  IBERGRID, 5th Iberian Grid Infrastructure Conference Proceedings ISBN 978-84-9745-884-9, pag 235-246

- *Software Provision Process for EGI*
  M. David, G. Borges, J. Gomes, J. Pina, et al
  IBERGRID, 5th Iberian Grid Infrastructure Conference Proceedings ISBN 978-84-9745-884-9, pag 235-246

- *Iberian ATLAS Cloud response during the first LHC collisions*
  M Villaplana Perez, G Amorós, G Borges, C Borrego, J Carvalho, M David, X Espinal, A Fernández, J Gomes, S González de la Hoz, M Kaci, A Lamas, J Nadal, M Oliveira, E Oliver, C Osuna, A Pacheco, J J Pardo, J del Peso, J Sa
  Iberian ATLAS Cloud response during the first LHC collisions; M. Villaplana Perez et al 2011 J. Phys.: Conf. Ser. 331 072068

**Collaboration notes with internal referee**

- *Deploying Software Into the EGI Production Infrastructure (EGI Inspire milestone: MS409)*
  M.David
  Deploying Software into the EGI Production Infrastructure, EGI Inspire: MS409, M.David

- *IBERGRID: 2011 Year Report*
  I. Campos, J. Gomes
  (accepted)

### 3.1.8 Presentations

**Oral presentations in international conferences**

- *NGI_IBERGRID experiences with regional tool*
  presented by Gonçalo Borges
  EGI User Forum 2011 — Vilnius, Lithuania.

- *Fostering multi-scientific usage in the Iberian production infrastructure*
  presented by Gonçalo Borges
  IBERGRID 2011 — Santander, Spain.

- *Software Provision Process for EGI*
  presented by Mário David
  IBERGRID 2011 — Santander, Spain.

**Oral presentations in international meetings**

- *EGI VO Services Activity*
  presented by Gonçalo Borges
  EGI User Forum 2011 — Vilnius, Lithuania.

**Oral presentations in collaboration meetings**

- *SW Provisioning: StagedRollout*
  presented by Mário David
  SA2 F2F — EGI, Amsterdam, Netherlands.

- *From gLite to EMI: Staged Rollout and production infrastructure*
  presented by Mário David
  Operations Management Board — Vilnius, Lithuania.

- *High Energy Physics and Data Preservation*
  presented by Gonçalo Borges
  TIMBUS Kick of Meeting — Zurich, Switzerland.

- *UMD 1.0: status and release schedule*
  presented by Mário David
  EGI OMB meeting — EGI, Amsterdam, Netherlands.

- *Top-BDII HA configuration*
  presented by Gonçalo Borges
  EGI OMB meeting — EGI, Amsterdam, Netherlands.

- *UMD Release Calendar*
  presented by Mário David
  EGI OMB meeting — EGI, Amsterdam, Netherlands.

- *HEP Use Case*
  presented by Gonçalo Borges
  TIMBUS F2F meeting — Lisbon, Portugal.

- *Staged Rollout*
  presented by Mário David
  WLCG Grid Deployment Board — CERN, Switzerland.

- *Supporting Tools: CRM introduction*
  presented by Gonçalo Borges
  EGI NIL KoM — EGI, Amsterdam, Netherlands.

- *UMD release 1.4.0*
  presented by Mário David
  EGI OMB meeting — EGI, Amsterdam, Netherlands.

- *Middleware components : What is expected from UMD, EA and the staged rollout process*
  presented by Mário David
  Rencontre LCG-France — CC-IN2P3 Lyon, France.

**Outreach seminars**

- *About LIP*
  presented by Gonçalo Borges
  TIMBUS Kick of Meeting — Zurich, Switzerland.

### 3.1.9 Academic Training

**Master Theses**

- *Concepção de uma Plataforma de Gestão Integrada para Sistemas de Suporte à Computação Distribuída*
  Sara Valente, 2011-11-01

### 3.1.10 Events

- *1st IBERGRID cloud meeting*
  Collaboration Meeting, Lisbon, Portugal, 2011-12-13

### 3.1.11 Project Summary

| | number |
|---|---|
| Articles in international journals (with direct contribution from LIP members) | 1 |
| International Conference Proceedings | 5 |
| Collaboration notes with internal referee | 2 |
| Oral presentations in international conferences | 3 |
| Oral presentations in international meetings | 1 |
| Oral presentations in collaboration meetings | 11 |
| Outreach seminars | 1 |
| Master Theses | 1 |
| Collaboration Meetings | 1 |

# Chapter 4

# Astroparticle Physics

## 4.1 Collaboration in AMS - Alpha Magnetic Spectrometer

### 4.1.1 Resumo

O modelo standard da cosmologia (modelo do Big Bang) baseia-se na expansão do Universo a partir de um estado inicial muito quente e denso e tem como suporte experimental as descobertas do movimento de recessão das galáxias por Hubble em 1929 bem como a descoberta da radiação cósmica de fundo por Penzias e Wilson em 1964. No estado inicial do Universo, iguais quantidades de matéria e antimatéria terão sido produzidas, no entanto, o que se observa actualmente nos raios cósmicos que são detectados na Terra é uma clara assimetria na sua composição no que respeita a matéria e antimatéria. A procura de eventuais aglomerados de antimatéria no Universo e o entendimento do mecanismo que produziu esta assimetria são questões essenciais na astrofísica actual. Outra questão fundamental é a compreensão da natureza da matéria que compõe o Universo. Mais de 90% da matéria existente é não-luminosa, isto é, matéria escura, mas a sua composição permanece um mistério. Os raios cósmicos são compostos de partículas neutras e carregadas que atravessam a galáxia em todas as direcções. Um melhor entendimento dos mecanismos de aceleração e propagação requer uma medida dos fluxos de raios cósmicos tão precisa quanto possível e abrangendo o maior intervalo de energias. O detector AMS instalado na Estação Espacial Internacional desde 19 de Maio de 2011 permitirá inspecionar a existência de antimatéria e matéria escura com uma precisão nunca antes alcançada dada a elevada estatística recolhida e a exactidão das medidas que o instrumento está apto a fazer.
O grupo LIP participa desde 1997 de forma activa e continuada na experiência AMS e em particular nas actividades do RICH. Durante este tempo, o grupo participou em actividades de construção do detector, da sua simulação, de desenvolvimento de métodos de reconstrução dos anéis de Cherenkov e de análise de dados de teste recolhidos num protótipo. Em particular, o grupo desenvolveu algoritmos de reconstrução de carga

Figure 4.1: AMS on S3 Truss of the International Space Station

eléctrica e velocidade e assegura o seu bom funcionamento. Em Maio de 2011, o detector AMS foi instalado finalmente na Estação Espacial e prevê-se que tome dados até pelo menos 2020. Desde a instalação do detector o grupo está envolvido em actividades de monitorização do desempenho do mesmo, em especial do RICH, e também em actividades de análise de dados. Além disso, os membros do grupo têm participado nos turnos de monitorização contínua da experiência no Payload Operation Control Center, localizado inicialmente em Houston e agora no CERN.

### 4.1.2 Abstract

The standard model of cosmology (Big Bang model) is based on the Universe expansion from an extremely hot and dense initial state and has as experimental support the discoveries of the recession movement of the galaxies by Hubble in 1929 and of the cosmic microwave background radiation by Penzias and Wilson in 1964. In the initial state of the Universe, equal amounts of matter and antimatter would have been produced. However, what is now observed in the cosmic rays detected at Earth is a clear asymmetry in their composition in what concerns matter and antimatter. The search for possible clusters of antimatter in the Universe and the understanding of the mechanism that produced such asymmetry are essential issues for present astrophysics. Another fundamental question is the understanding of the origin of the matter of which the Universe is composed. More than 90% of the existing matter is non-luminous, i.e, dark matter, but its composition remains a mystery. Cosmic rays are composed of neutral and charged particles that cross the galaxy along all directions. A better understanding of the acceleration mechanisms and propagation requires a measure of the cosmic-ray fluxes as accurate as possible and over a wider range of energies. The AMS detector, installed on the International Space Station on 19th May 2011, will allow to search for the existence of antimatter and dark matter with an unprecedented accuracy. The LIP group has been actively taking part in the AMS experiment, and in particular in the RICH activities, since 1997. During this time, the group took part in the detector´s construction and simulation as well as in the development of reconstruction methods for the Cherenkov rings and data analysis with data collected with a prototype. In particular, the group is responsible for the development of algorithms for charge and velocity reconstruction and ensures their maintenance. On May 2011, the AMS detector was finally installed on the International Space Station and data taking is foreseen at least up to 2020. Since the detector´s installation on the ISS the group has been involved in activities of detector performance monitoring, in particular with the RICH, as well as in data analysis activities. In addition, group members have been taking part in the shifts for continuous monitoring of the experiment at the Payload Operations and Control Center located initially in Houston and now at CERN.

### 4.1.3 Objectives

AMS (Alpha Magnetic Spectrometer) is a particle physics experiment installed on the International Space Station facility (ISS), since May 2011. The main physics objectives will be the search for antimatter and dark matter and the study of the cosmic ray spectrum composition with an unprecedented statistics. Such measurements will contribute to a better understanding of the propagation and confinement of cosmic rays in the Galaxy.
The capabilities of the AMS spectrometer, compared to the one which flew in the space shuttle Discovery on June 1998, were largely improved and extended through the inclusion of new detectors, a Ring Imaging Cherenkov Detector (RICH), an Electromagnetic Calorimeter (ECAL) and a Transition Radiation Detector (TRD). The electromagnetic calorimeter will provide AMS with the capability of identifying electrons/positrons and photons up to 1 TeV. The inclusion of a TRD will allow AMS to distinguish antiprotons from electrons with a rejection power of 10ˆ5. The RICH detector will provide an independent measurement of the particle velocity and of the electric charge. A resolution goal on velocity for singly charged particles of the order of 10ˆ-3 and on charge of around 0.2 units of charge is aimed. Such a precision will allow to distinguish nuclei up to iron.
In three years of data taking AMS will gather about 10 million positrons and 1 million antiprotons up to an energy of 400 GeV.

### 4.1.4 Achievements

The AMS detector assembly was finished during 2010 at CERN´s building 867 clean room. The detector was subsequently transported to NASA´s Kennedy Space Center (KSC) where it underwent the final testing procedures before its launch aboard Space Shuttle Endeavour in mission STS-134, on 16th May. The minimum expected data acquisition time is three years, but the detector´s robustness may allow it to operate for a significantly longer period which might exceed a decade.
Following a successful launch, a large amount of data have been collected (approximately 40 million events per day).

This data was extensively used to perform detector alignment and comissioning. The detector launch and the temperature variations require a continuous alignment of the tracker planes made with cosmic protons. In addition other detectors like RICH have temperature dependent sensors and therefore require a continuous monitoring of their gain.
Following the detector´s installation aboard the International Space Station, the mission´s POCC (Payload Operations and Control Center) operations were headquartered at NASA´s Johnson Space Center (JSC) in Houston for several months before moving to CERN in the end of June. The team members participated regularly either at Houston or CERN in the AMS monitoring activities.
The main tasks where the group was involved in 2011 were the following:

- Evaluation and monitoring of the RICH detector performance on flight. The aimed accuracy on the velocity and charge reconstruction implies the control of several parameters such as: - mirror reflectivity - refractive index uniformity - calibration of the detection cells (slow control) The group was involved on these studies and on the preparation of analysis tools for monitoring the performance of the detector.

- Geant4 description of the RICH detector: the AMS detector is simulated according to the Geant3 and Geant4 package whilst the Geant3 is the default version used, there was an effort on the collaboration toward the full Geant4 description. The group took part in the implementation of the forward scattering effect in the Geant4 simulation.

- AMS software: the AMS software includes the reconstruction algorithms. The Portuguese group developed reconstruction algorithms for the RICH detector. The collected data was used to evaluate and fine tune the reconstruction algorithms developed by the group for velocity and charge. All the LIP developed algorithms were updated to run in multithread context according to the collaboration directives. In addition, the code was optimized to reduce the computing time.

- RICH reconstruction performance: the velocity and charge reconstruction of the cosmic events with the LIP algorithms was used to monitor their accuracy and also to monitor the RICH detector, namely on the light yield, reflectivity of the mirror and refractive index of the aerogel.

- Data analysis: the first months of the data taking have been devoted to the commissioning of the different detectors. Nevertheless, and taking profit of the accumulated experience of the group on the velocity and charge measurements with the RICH, the physics channels where the group started to focus are charge identification and cosmic ray fluxes measurements together with solar modulation effects. The study of the detection rate was also undertaken. Concerning the light isotopic separation: the degradation of the tracker resolution from 2 to around 8% imposes strong limitations on the classical mass separation method that uses both the velocity and rigidity measurements. For instance, the beryllium mass separation requires around 3% of mass resolution which seems impossible with the current permanent magnet. The study and implementation of a new mass separation method relying both on the geomagnetic cutoff and the very accurate measurement of the velocity made by the RICH was done. The first results indicated that the beryllium mass separation is feasible up to around 15 GeV/n.

- RICH event display: a RICH event display was developed in order to have a detailed view of the different kind of reconstructed rings; this tool was widely used to monitor the RICH event reconstruction and help tagging background events.

- AMS event rate: the launch of AMS occurred during a solar minimum (beginning of the 24th cycle) and therefore the impact of the low solar modulation factor and Earth geomagnetic field in the cosmic ray rates detected by AMS was studied.

The outcome of the Lisbon group has been regularly presented in the collaboration meetings, conferences and in several outreach activities.

### 4.1.5 Sources of Funding

| Code | Funding | Start | End |
|---|---|---|---|
| PTDC/FIS/122567/2010 | 40.000 € | 2011-12-07 | 2013-12-06 |

### 4.1.6 Team

**Project coordinator: Fernando Barão**

| Name | Status | %of time in project |
|---|---|---|
| Bruno Santos | Master student (LIP) | 30 |
| Fernando Barão | Researcher (LIP/IST) | 66 |
| Gaspar Barreira | Researcher (LIP) | 5 |
| Luís Batalha | Master student (LIP) | 30 |
| Luisa Arruda | Post-Doc (LIP/FCT) | 24 |
| Patrícia Gonçalves | Researcher (LIP) | 5 |
| Pedro Nunes | Master student (LIP) | 30 |
| Rui Faísca Pereira | Post-Doc (LIP/FCT) | 100 |

### 4.1.7 Publications

**International Conference Proceedings**

- *The AMS-02 RICH detector: performance during ground-based data taking at CERN*
  R. Pereira, on behalf of the AMS RICH collaboration
  NIM A 639 (2011) 37-41 (accepted)

**Collaboration notes with internal referee**

- *Beryllium Isotopic Separation with AMS-02 using the Geomagnetic Field*
  L. Derome, F. Barao, W. Gillard
  (accepted)

### 4.1.8 Presentations

**Presentations in national conferences**

- *AMS: Detection of cosmic rays on the International Space Station*
  presented by Rui Faísca Pereira
  XXIENAA — Coimbra, Portugal.

**Oral presentations in collaboration meetings**

- *AMS RICH velocity and charge reconstruction: the LIP algorithms*
  presented by Rui Faísca Pereira
  — Kennedy Space Center, Cape Canaveral, USA.
- *Evaluation of the AMS trigger rate*
  presented by Fernando Barão
  TIM AMS — Kennedy Space Center, Cape Canaveral, USA.
- *Status of AMS RICH software development and analysis at LIP*
  presented by Rui Faísca Pereira
  — CIEMAT, Madrid, Spain.
- *Forward Scattering in Geant4*
  presented by Luisa Arruda
  — CIEMAT, Madrid, Spain.
- *AMS rate evaluation from new physical triggers: acceptances, rates and livetime results*
  presented by Fernando Barão
  — Johnson Space Center, Houston, USA.
- *LIP results on first flight data analysis –RICH measurements*
  presented by Fernando Barão
  — CERN, Genebra, Suiça.

**Outreach seminars**

- *Raios Cósmicos: mensageiros do nosso Universo*
  presented by Luisa Arruda
  Masterclasses FCUL — Faculdade de Ciências da Universidade de Lisboa, Lisboa, Portugal.

- *AMS: à procura de matéria escura e antimatéria Participação do IST/LIP no projecto*
  presented by Luisa Arruda
  Yuri´s Night — Instituto Superior Técnico, Lisboa, Portugal.

- *Raios Cósmicos: mensageiros do nosso Universo*
  presented by Luisa Arruda
  — EB23S Dr. João Brito Camacho, Almodôvar, Portugal.

### 4.1.9 Project Summary

| | number |
|---|---|
| International Conference Proceedings | 1 |
| Collaboration notes with internal referee | 1 |
| Presentations in national conferences | 1 |
| Oral presentations in collaboration meetings | 6 |
| Outreach seminars | 3 |

## 4.2 Collaboration in the SNO+ experiment

### 4.2.1 Resumo

O grupo de Física de Neutrinos do LIP foi formado em 2005 para participar na experiência de Neutrinos Solares, SNO (Sudbury Neutrino Observatory), e integrou desde 2006, a proposta da experiência sucessora, SNO+. Os resultados de SNO comprovaram o fluxo total previsto de neutrinos solares de $^8B$, medido por interacção de corrente neutra (sensível a todos os sabores de neutrinos), e simultaneamente a diminuição da taxa de neutrinos do electrão, medida por correntes carregadas - confirmando a oscilação de neutrinos e resolvendo o chamado Problema dos Neutrinos Solares.
A inovação da experiência SNO consistia na utilização de 1000 ton de água pesada como alvo e meio activo, numa esfera central de 6m de diâmetro, tornando possível a interacção de neutrinos de baixa energia por correntes carregadas e por correntes neutras. Estas interacções resultam na produção de radiação de Cherenkov, detectada por cerca de 9500 PMTs colocados numa estrutura geodésica com 8m de diâmetro. A medição das correntes neutras implica a detecção de neutrões, feita de três formas distintas em diferentes fases da experiência (I - por captura na água pesada; II - por captura em $^{35}Cl$ com maior secção eficaz e maior sinal; III - com contadores proporcionais, permitindo uma separação evento-a-evento e não só estatística como anteriormente). Durante a tomada de dados e parte inicial da sua análise, o grupo do LIP desenvolveu vários métodos e melhorias na calibração óptica do detector. Nos últimos anos, o grupo teve a responsabilidade da análise final de oscilações de neutrinos que, tendo melhorado substancialmente a precisão nos parâmetros, constituiu uma parte fundamental dos resultados incluídos na última publicação de SNO, submetida em 2011.
Reutilizando o detector SNO, substituindo o alvo e meio activo de água pesada por cerca de 800 ton de cintilador líquido, SNO+ está em fase avançada de preparação no SNOLAB, entretanto expandido. Em Junho de 2009, o financiamento da experiência foi aprovado pelas agências científicas canadianas. Em Dezembro de 2009, a Fundação para a Ciência e a Tecnologia (FCT), o LIP, a colaboração SNO+ e o SNOLAB celebraram um acordo de cooperação científica, sob a forma de um Memorandum of Understanding. A participação do LIP é financiada pela FCT através de um projecto do concurso "Todos os domínios científicos", por três anos a partir de 2011.
Os objectivos científicos de SNO+ são múltiplos, sendo o principal a pesquisa com elevada sensibilidade do sinal de duplo declíneo beta sem neutrinos (Neutrinoless Double Beta Decay - 0NDBD), a assinatura mais promissora do eventual carácter de Majorana dos neutrinos massivos. A utilização de cintilador líquido permitirá baixar significativamente o limiar de energia, de modo a medir neutrinos solares pep e CNO, geo-neutrinos e anti-neutrinos produzidos em reactores nucleares, aumentar a sensibilidade a neutrinos de supernovas, e procurar o sinal de 0NDBD do isótopo $^{150}Nd$, dissolvido em grande quantidade no cintilador.
Em SNO+ o grupo efectuou já vários estudos para a optimização do detector e de sensibilidade a análises de

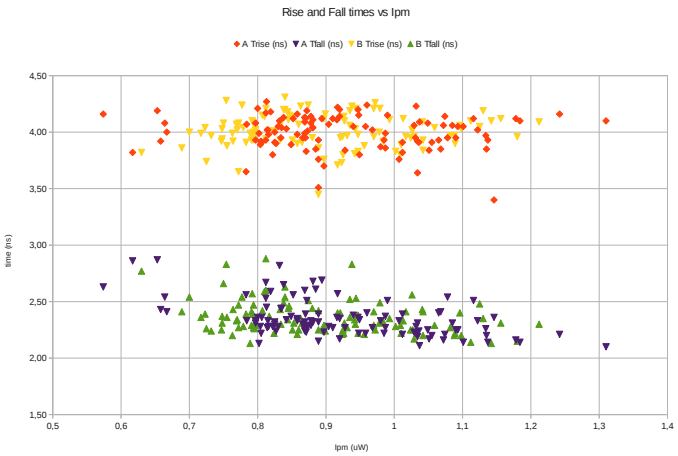



Figure 4.2: The full set of 110 double optical fibres were tested in Lisbon for light output intensity, timing characteristics and opening angle. In the figure the timing response is shown as a function of the measured optical power.

Física, assim como planos para a futura calibração e reconstrução de dados.
Implementámos a geometria de SNO+ nos dois códigos de simulação utilizados (um deles adaptado do código original de SNO, extensivamente testado, o outro baseado em GEANT4 que o deverá substituir a curto prazo) e estudámos em detalhe os fundos externos, com um impacto directo no desenho final do detector, estabelecendo requisitos de radiopureza dos novos materiais a utilizar.
Desenvolvemos, construímos, e estamos a instalar um novo sistema de calibração em tempo dos fotomultiplicadores (PMTs), fundamental para uma eficiente reconstrução dos eventos e redução do ruído de fundo. Este sistema é não-invasivo, baseado em vários cabos longos de fibra óptica, com ligação sequencial a um conjunto de LEDs. As fibras serão instaladas em posições fixas no detector, reduzindo a necessidade de introdução de fontes dentro do volume interno de cintilador. Para o desenvolvimento e testes do novo sistema foram utilizadas as instalações do grupo ATLAS no Centro de Física Nuclear da Universidade de Lisboa. O sistema final foi construído pelo LIP, nas oficinas de Coimbra, e está a ser instalado em SNO+ em 2012. Neste projecto colaboramos com as Universidades de Sussex e Leeds (UK), que são responsáveis pela iluminação das fibras com LEDs.
Devido à experiência adquirida em SNO, a calibração óptica de SNO+ irá ser uma das nossas responsabilidades principais no futuro. O nosso grupo é desde já responsável por este subgrupo de trabalho, em que estamos a desenvolver o plano de análise.
Propomo-nos também desenvolver um conjunto de ferramentas de reconstrução de dados bem adaptado às características ópticas e temporais do detector, que será utilizado nos vários estudos de física, para a reconstrução de energia, que é fundamental para a identificação dos sinais de 0NDBD ou dos neutrinos solares pep, e a reconstrução de eventos não pontuais, fundamental para a identificação e redução de fundos. Estes algoritmos serão inicialmente testados em simulações Monte Carlo e posteriormente adaptados de acordo com as medições mais precisas das propriedades do cintilador líquido e do dopante $^{150}Nd$.
Focando os aspectos organizativos, membros do grupo do LIP asseguram a coordenação dos subgrupos de Calibração Óptica e de Física de Antineutrinos, e estão representados no "Analysis Coordination Committee". Entre Setembro de 2010 e Agosto de 2011, o responsável pelo grupo do LIP assegurou (por eleição) a vice-presidência da "Collaboration Board", e ocupa a presidência desde Setembro de 2011.

### 4.2.2 Abstract

The LIP group on Neutrino Physics was created in 2005 to participate in the solar neutrino experiment SNO (Sudbury Neutrino Observatory), SNO, and integrated since 2006 the proposal for its successor experiment SNO+.
The SNO results confirmed the predicted total $^{8}B$ solar neutrino flux by measuring neutral current interactions, sensitive to all neutrino flavors, and simultaneously proved the disappearance of electron neutrinos measured by charged current interaction - proving neutrino oscillations and solving the so-called Solar Neutrino Problem. The innovation in SNO consisted in the use of 1000 tons of heavy water as target and active medium, in a 6m diameter central sphere, allowing for the neutral and charged current interaction of low energy neutrinos, and the production of Cherenkov radiation, detected by around 9000 PMTs mounted on a 8m diameter geodesic structure. The measurement of neutral current implies the detection of the neutron, made differently in different phases of the experiment (I - by capture in heavy water; II - by capture in $^{35}Cl$, with higher cross-section and light output; III - in proportional counters, allowing for an event-by-event, and not only statistical, identification). During the data-taking, and in the initial part of data analysis, the LIP group carried out several analyses and improvements in the optical calibration of the detector. In the last few years, the group had the responsibility for the final analysis of neutrino oscillations that, having substantially improved the parameter precision, is a fundamental part of the results included in the last SNO publication, submitted in 2011.
Re-using the SNO detector, replacing the target and active medium of heavy water by about 800 tons of liquid scintillator, SNO+ is in an advanced stage of preparation at the extended SNOLAB. In June 2009, the experiment funding was approved by the Canadian scientific agencies and, in December 2009, a Memorandum of Understanding for scientific cooperation was signed between FCT, LIP, the SNO+ Collaboration and SNOLAB. The LIP participation is funded bY FCT through a project in the "All Scientific Domains"call, for three years, starting in 2011.
SNO+ has multiple scientific goals, the main one being the high sensitivity search for Neutrinoless Double Beta Decay (0NDBD), the most promising signature for the possible Majorana character of massive neutrinos. The liquid scintillator will allow for a significantly lower energy threshold, so that SNO+ can measure pep and SNO solar neutrinos, geo-neutrinos, and nuclear reactor anti-neutrinos, increase the sensitivity to supernova neutrinos, and search for the 0NDBD signal from the $^{150}Nd$ isotope dissolved in high quantities in the scintillator.
The LIP group has already developed several studies for the detector optimization and sensitivity to physics channels, and plans for future calibration and data reconstruction in SNO+.

We´ve implemented the SNO+ geometry in the two simulation codes used (one adapted from the original SNO code, extensively tested, and another based on Geant4 which should replace it soon) and studied the external backgrounds, with a direct impact in the final detector design, by establishing the radiopurity requirements for the new materials.
We have developed, built, and are installing a new method for PMT timing calibration, fundamental for the efficient event reconstruction and background reduction. The system is non-invasive, based on several long cables of optical fibers, with a sequential connection to LEDs. The fibers are placed in fixed positions in the detector, reducing the need to introduce sources inside the scintillator internal volume. The ATLAS group lab at Centro de Física Nuclear da Universidade de Lisboa was used for the development and test of this system. The final system was built by LIP, in the Coimbra workshops, and is being installed in SNO+ in 2012. We collaborate with the Sussex and Leeds Universities (UK), which are responsible for the LED illumination.
Building on the experience acquired in SNO, in the future we will take the SNO+ optical calibration as one of our main tasks. Our group is already responsible for this analysis subgroup, for which we are developing the analysis plans.
We also propose to develop a set of data reconstruction tools well adapted to the optical and timing characteristics of the detector, to be used in the several physics studies for energy reconstruction, fundamental for the ONDBD and pep-neutrino signals identification, and for reconstruction of non point-like events, fundamental for background identification and reduction. These algorithms will first be tested with Monte Carlo simulations, and progressively adapted with more precise measurements of the liquid scintillator and $^{150}Nd$ loading.
Focusing on the organizational aspects, members of the LIP group organized are coordinators of the Optical Calibration and Antineutrino Physics subgroups, and belong to the "Analysis Coordination Committee". Between September 2010 and August 2011, the head of the LIP group held the elected position of chair-elect for the Collaboration Board, and of chair since September 2011.

### 4.2.3 Objectives

**SNO+**

The main goals for for 2011 were to provide a final design and prototype for the external fiber PMT time calibration system, submit this design to the approval of the SNO+ collaboration and initiate the production of the final system.
We intended to adapt the SNO optical calibration analysis to SNO+, to increase the sensitivity to the PMT angular response, previously shown to have a degradation with time.
Additionally, for reactor anti-neutrino oscillations, the goal was to test the feasibility of this measurement during the $^{150}Nd$ loading phase, in which pile-up can mimic the time coincidence characteristic of the anti-neutrino signal.

**SNO**

Having carried out the main developments and verification tasks of the neutrino oscillation three-phase analysis in previous years, the goal for 2011 was to apply them to the real data for the production of the final results and prepare the final publication of the SNO solar neutrino results.

### 4.2.4 Achievements

**SNO**

The neutrino oscillation analysis of the combined 3-phase SNO data set, was completed in 2011. After a few years of analysis preparation, its verification and documentation, the full data set was finally analyzed by our group. The results were impressive, with a very significant improvement in the precision of the neutrino oscillation $\theta_{12}$ and $\theta_{13}$ mixing angles. These final solar neutrino results from SNO were submitted for publication in September 2011.

**SNO+**

The main activity for SNO+ was the preparation of the PMT calibration system with optical fibers.

**Fiber-based Calibration system**

- Finalization of the detailed system design:

* Choice of the type of fiber (1 mm PMMA with polyethylene coating) based on its robustness, good light transmission, low radioactivity (tested by SNOLAB), and low impurity diffusion in water (tested by BNL).
* Choice of the material for the fiber support plates (white PET) based on low impurity diffusion in water
* Drawing of the fiber feed-through plate.

- Finalization of the installation plan. The installation will be quite complex and needs to be done in several steps, because of the limitations in detector access – part will be installed from the experimental cavity floor, part from a boat during water filling. In 2011 we finalized the installation plan, that was approved by the collaboration.
- Production of the support plates

The production of 120 fiber support plates was carried out at the workshop of LIP-Coimbra in the Autumn of 2011

- Fiber Quality Control

After approval by the collaboration, we purchased 110 optical fiber cables with 45 m length. The quality control of these fibers was carried out in December, in the ATLAS group labs at CFNUL, Lisbon, where the characterization tests had been made in previous years. A colleague from the University of Sussex joined us for these tests. We used several parts of equipment already available at the lab (including the "fibrometer"), as well a digital oscilloscope from the Auger LIP group. The preliminary results from these measurements show that almost all fibers are suitable for installation.

**Optical Calibration**
We started the adaptation of the SNO code for optical calibration to SNO+.

**Antineutrino Physics**
In 2011, the studies on the sensitivity of SNO+ to reactor antineutrinos were carried on, and the effect of pile-up background in the Neodymium phase was studied. A member of our group was appointed coordinator of the Antineutrino Physics group.

**Organizational**
Roles held by LIP group members in the SNO+ collaboration structure:

- National spokesperson for Portugal;
- Chair of the Collaboration Board;
- Convenor of the Optical Calibration subgroup;
- Convenor of the Antineutrino Physics subgroup;

### 4.2.5 Sources of Funding

| Code | Funding | Start | End |
|---|---|---|---|
| PTDC/FIS/115281/2009 | 108.971 € | 2011-01-01 | 2013-12-31 |

### 4.2.6 Team

**Project coordinator: José Maneira**

| Name | Status | %of time in project |
|---|---|---|
| Amélia Maio | Researcher (LIP/FCUL) | 15 |
| Carlos Silva | Technician (LIP) | 15 |
| João Carvalho | Researcher (LIP/FCTUC) | 15 |
| Joaquim Oliveira | Technician (LIP) | 15 |
| José Maneira | Researcher (LIP) | 30 |
| Luís Gurriana | Technician (LIP) | 15 |
| Nuno Barros | PhD student (LIP/FCT) | 100 |
| Orlando Cunha | Technician (LIP) | 15 |
| Rui Alves | Technician (LIP) | 15 |
| Sofia Andringa | Researcher (LIP) | 25 |
| Sofia Leitão | Student (LIP) | 25 |

### 4.2.7 Publications

**Articles in international journals (with indirect contribution from LIP members)**

- *Low Multiplicity Burst Search at the Sudbury Neutrino Observatory*
  SNO Collaboration (incl. José Maneira and Nuno Barros)
  Astrophys.J.728:83,2011

**International Conference Proceedings**

- *Status and prospects of SNO+*
  J. Maneira (on behalf of the SNO+ Collaboration)
  Nucl. Physics B - Proc. Suppl., Vol. 217, 1, pp50-52 (NOW2010 Conference)

### 4.2.8 Presentations

**Oral presentations in international conferences**

- *Combined Analysis of the full 3-phase data set of the Sudbury Neutrino Observatory.*
  presented by José Maneira
  ICATPP Villa Olmo 2011 — Villa Olmo, Como, Italy 3-7 October 2011.

**Oral presentations in collaboration meetings**

- *Reactor Anti-Neutrinos in the Nd Phase*
  presented by José Maneira
  SNO+ Collaboration meeting — Seattle, USA.
- *In-situ Optics & Laserball*
  presented by José Maneira
  SNO+ Collaboration meeting — Seattle, USA.
- *ELLIE HW & Installation*
  presented by José Maneira
  SNO+ Collaboration meeting — Seattle, USA.
- *In-Situ Optical Calibrations, Summary*
  presented by José Maneira
  SNO+ Collaboration Meeting — SNOLAB, Sudbury, Canada.
- *TELLIE Hardware and Installation*
  presented by José Maneira
  SNO+ Collaboration Meeting — SNOLAB, Sudbury, Canada.
- *Reactor Antineutrino analysis in SNO+*
  presented by Sofia Andringa
  SNO+ Collaboration Meeting — SNOLAB, Sudbury, Canada.
- *TELLIE fibers QA at Lisbon*
  presented by Sofia Andringa
  SNO+ EU Meeting — Dresden, Germany.

**Seminars**

- *SNOLAB: à caça de neutrinos numa mina do Canadá*
  presented by José Maneira
  Seminários do Dep. de Física — FCUL, Campo Grande, Lisboa.

**Outreach seminars**

- *Neutrinos em OPERA*
  presented by Sofia Andringa
  — IST - XV Semana da Física.

### 4.2.9 Academic Training

**PhD Theses**

- *Optical calibration and neutrino oscillation measurements at the Sudbury Neutrino Observatory (SNO)* Nuno Barros, 2012-05-03

### 4.2.10 Project Summary

| | number |
|---|---|
| Articles in international journals (with indirect contribution from LIP members) | 1 |
| International Conference Proceedings | 1 |
| Oral presentations in international conferences | 1 |
| Oral presentations in collaboration meetings | 7 |
| Seminars | 1 |
| Outreach seminars | 1 |

## 4.3 Participation in Dark Matter experiments and R&D on Liquid Xenon Detectors for Dark Matter Search

### 4.3.1 Resumo

A natureza da matéria escura é uma das questões fundamentais mais intrigantes da física atual. A evidência observacional para a existência de uma componente não-bariónica, não luminosa e não-relativista, responsável por cerca de 85% da massa total do universo, tem vindo a crescer sucessivamente nos últimos anos. Estas evidências têm origem muito diversa e são hoje múltiplas. Todavia, quer a natureza quer a origem dessa matéria escura são por enquanto totalmente desconhecidas.
A existência de partículas de um novo tipo ainda desconhecido, ditas fracamente interativas, as chamadas Weakly Interacting Massive Particles (WIMPs), são normalmente tidas como uma hipótese possível para explicar a matéria escura. Partículas com semelhantes características são previstas em várias extensões do Modelo Padrão da física de partículas e suportadas por modelos de produção térmica de matéria escura no universo primitivo. Uma dessas partículas é o neutralino, previsto por teorias de supersimetria (SUSY). A existirem num halo centrado na nossa galáxia, essas partículas WIMP devem poder ser detectadas diretamente, ao observarmos recuos nucleares resultantes de colisão elástica com núcleos da matéria ordinária, em detectores com ruído de fundo ultra-baixo, em instalações subterrâneas de muito reduzida radioatividade natural. O grande desafio experimental consiste em realizar uma pesquisa de eventos muito raros (<1 evt / kg / ano), com assinaturas de muito baixa energia (alguns keV), em condições estáveis, durante muito tempo. Várias experiências têm vindo a procurar sinais dessas interações, usando diferentes técnicas de detecção, sobretudo em anos mais recentes.
O xénon líquefeito (LXe) pode funcionar como um excelente alvo para colisões de partículas WIMPs de massa

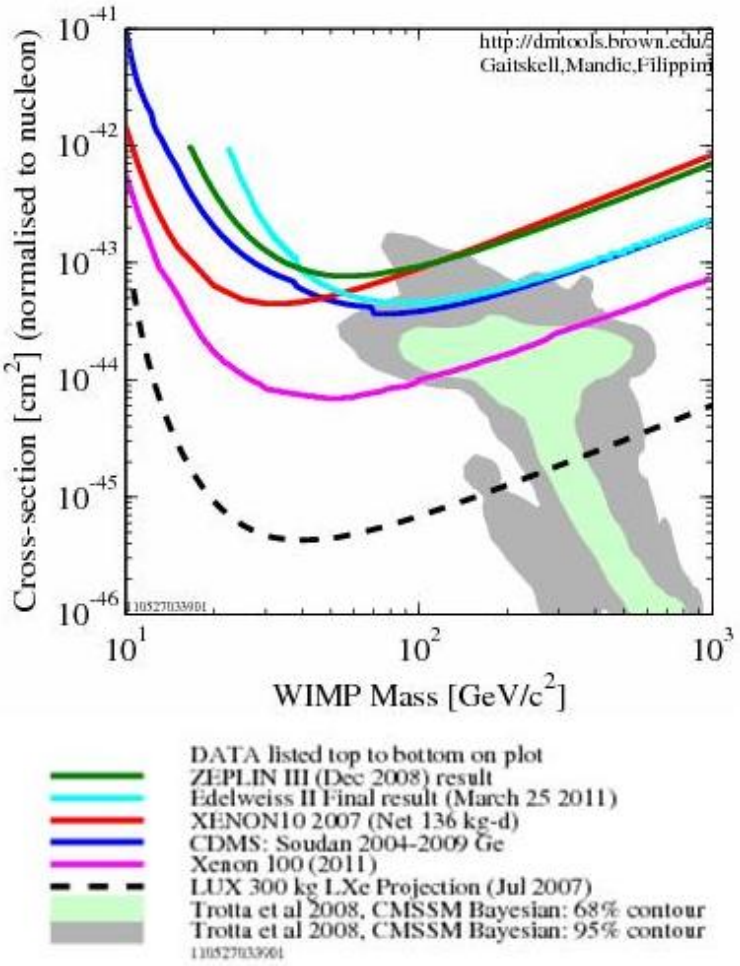



Figure 4.3: Limits (90% CL) on the WIMP-nucleon spin-independent cross-section for the current leading dark matter experiments.

intermédia (dezenas de GeV/$c^2$), devido à sua elevada massa atómica e à sensibilidade que permite em dois canais de resposta (de cintilação e ionização). Acima de tudo, a combinação das duas respostas permite fazer uma discriminação entre sinais devidos a electrões resultantes do fundo radioativo e os recuos nucleares genuinos, como os esperados devido a colisões de WIMPs. Esta técnica tem sido explorada com sucesso sob a forma de detectores de fase dupla de xenon.
Num detector de duas fases de xénon medem-se a emissão de cintilação rápida e a ionização resultantes de interações de partículas no meio de xénon líquido. As cargas libertadas na ionização são extraidas por um campo elétrico desde o local da interacção até uma região de vapor de xénon (de poucos milímetros) acima da superfície do líquido, onde são aceleradas e produzem cintilação secundária. Para o conseguir usam-se campos eléctricos altos, de vários kV/cm. Um ou dois conjuntos de fotomultiplicadores (PMTs) localizados no interior do meio detector convertem, quer a luz de cintilação primária quer a luz de cintilação secundária produzida instantes depois, em sinais elétricos facilmente detectáveis (denominados S1 e S2, respectivamente).
A colaboração ZEPLIN foi pioneira na implantação de um detector de fase dual de Xe para a procura de matéria escura, tendo o detector ZEPLIN-II dado origem ao limite de exclusão mais baixo à data da publicação (2007). Em seguida o detector ZEPLIN-III, um detector de dupla fase de Xe com uma massa fiducial de 6.5 kg, foi operado numa instalação subterrânea. Em 2010, uma análise de 847 kg * dias de dados excluiu colisões de WIMPs com a matéria com sigma_SI acima $7.7 \times 10^{-8}$ pb a 55 GeV/$c^2$ com um CL 90%, sendo um dos melhores resultados a nível mundial. Esta experiência demonstrou também que a técnica de duas fases de Xe é capaz de uma discriminação entre recuos de electrões e de nucleos até energias muito mais baixas do que se havia conseguido em experiências anteriores. O detetor ZEPLIN-III foi posteriormente melhorado quer com a substituição dos fotomultiplicadores por outros de fundo muito baixo quer com a instalação de um veto cintilador ativo. A segunda tomada de dados em busca de interações de WIMPs correu ao longo de 319 dias, entre 24 de junho de 2010 e 07 de maio de 2011. Os limites superiores das secções eficazes elásticas de colisões WIMP-nucleo estão representadas na Fig. 1, para interações independentes do spin.
A experiência LUX - the Large Underground Xenon experiment - surge como o passo seguinte na pesquisa de matéria escura utilizando detetores de fase dupla de xénon. Para além de ter uma massa muito mais elevada que as experiências precedentes (350 kg), o detector de LUX inclui avanços muito importantes, nomeadamente na redução do fundo, que é uma questão fundamental para melhorar a sensibilidade de deteção: a) através da imersão do detector dentro de um tanque com 8 m de diâmetro, cheio com água altamente pura para proteger o alvo detetor de raios gama e neutrões, ao invés de colocar chumbo e polietileno à sua volta; e b) tendo o cuidado de construir o criostato e a câmara do detector interior em titânio de baixa radioatividade. O detector de LUX tem um nível de sensibilidade previsto que é mais de 10 vezes melhor do que os limites existentes (Fig.1). LUX também introduz várias inovações tecnológicas que serão necessárias na próxima geração de detetores de fase dupla para matéria escura, na escala da tonelada, tal como o detetor LZS de 1,5 toneladas, que é uma proposta conjunta das colaborações LUX e ZEPLIN.
A integração do detector LUX com os demais sub-sistemas ficou concluída em março de 2011 nas instalações de superfície do complexo de Stanford - o chamado Sanford Research Facility (SURF), em Homestake, SD, EUA. Iniciou-se de seguida a fase de teste/calibração do detector, fase que decorre ainda à superfície. A instalação da experiência no laboratório Davis de SURF está programada para se iniciar na Primavera de 2012, à qual se deverá seguir uma nova fase de teste e calibração in situ, nas condições e ambiente em que será depois operado. A estratégia da aquisição de dados compreende: 1) uma primeira tomada de dados durante 60 dias para avaliar o desempenho do detetor a baixa energia in situ; 2) uma segunda tomada de dados de 300 dias para pesquisa de matéria escura em modo cego, numa região fiducial alvo com cerca de 100 kg, numa janela de energia esperada entre 5 e 25 kVnr, a qual deverá permitir atingir uma sensibilidade de $7 \times 10^{-10}$ pb a 100 GeV/$c^2$ (ver fig .1). O LIP aderiu formalmente à colaboração LUX em dezembro de 2010.

### 4.3.2 Abstract

The nature of dark matter is one of the most intriguing open questions in fundamental physics today. The observational evidence for the existence of a non-baryonic, non-luminous and non-relativistic component of the universe, accounting for ≈85% of its total mass, has been strengthen in recent years. That evidence arises from a large variety of sources. However, the nature and the origin of dark matter are unknown.
Weakly Interacting Massive Particles (WIMPs) are a class of candidates for this dark matter supported by many extensions to the Standard Model of particle physics and by thermal production models for dark matter in the early universe. One of the strongest candidates is the neutralino predicted by supersymmetric (SUSY) theories. WIMPs in a halo surrounding our galaxy would be directly detected by looking at nuclear recoils resulting from elastic scattering with nuclei in an ultra-low background target detectors deployed underground. The experimental challenge lies in conducting a rare event search (<1 evt/kg/yr) whilst maintaining efficient detection of very low energy signatures (few keV). Various experiments have searched for these interactions

using different detection techniques.
Liquid xenon (LXe) is an excellent target material for intermediate mass (tens of GeV/$c^2$) WIMPs due to its high atomic mass and sensitivity in two response channels (scintillation and ionization). Significantly, these allow discrimination between electron recoils resulting from radioactivity backgrounds and the nuclear recoils expected from WIMP elastic scattering. This has been successfully exploited in the form of dual-phase xenon detectors.
A two-phase xenon emission detector measures both prompt scintillation and ionisation responses from particle interactions in the liquid xenon. The ionization released at an interaction site is drifted upward and emitted into a thin (few mm) vapour phase above the liquid, where it is converted into an optical signal via electroluminescence. This is achieved with a strong electric field of several kV/cm . One or two arrays of photomultiplier tubes (PMTs) located inside the detector respond to the prompt scintillation and the delayed electroluminescence signals (termed S1 and S2, respectively).
The ZEPLIN collaboration was pioneer in deploying a dual-phase Xe detector for dark matter search, ZEPLIN-II, which produced a world-competitive result at the time of publishing (2007). Next, ZEPLIN-III, a dual-phase Xe detector with a fiducial mass of 6.5 kg, was deployed. In 2010, an analysis of 847 kg*days of data has excluded sigma_SI above $7.7 \times 10^{-8}$ pb at 55 GeV/$c^2$ with a 90% CL, being one of the world-leading results. It also demonstrated that the two-phase Xe technique was capable of discrimination between electron and nuclear recoils at low-energy significantly better than previous experiments. ZEPLIN-III was then upgraded with the replacement of the photomultipliers by very low background ones and the installation of an active scintillator veto. The second science run WIMP-search data were then acquired over 319 days between 24th Jun 2010 and 7th May 2011. The upper limits on WIMP-nucleon elastic scattering cross sections are plotted in Fig.1 for spin-independent interaction.
The Large Underground Xenon (LUX) experiment is the next step in Dark Matter experiments based on two-phase xenon detectors. Besides using a unprecedented large mass (350 kg), LUX includes very important advances, in particular for reducing the background which is a key issue to improve sensitivity: a) immersion of the detector inside an 8-m-diameter high purity water tank to shield out gammas and neutrons, instead of surrounding it by lead and polyethylene; b) cryostat and inner detector vessel made out of low-radioactive titanium. LUX has a projected sensitivity more than 10 times better than the existing limits (Fig.1). LUX also introduces technological innovations required for such a large dual-phase xenon TPC and ton-scale detectors foreseen for the next generation of dark matter experiments such as LZS, a 1.5 ton WIMP detector jointly proposed by the LUX and ZEPLIN Collaborations.
The integration of LUX detector with its auxiliary systems at the surface facility of Sanford Underground Research Facility (SURF), Homestake, SD, US, was completed in March 2011. The surface commissioning of the LUX detector was then started. The underground deployment in the Davis Lab at SURF is scheduled to initiate by Spring 2012, followed by the underground commissioning of the experiment. The science run strategy will be: 1) a 60 live-day run will allow an assessment of low energy performance and backgrounds in LUX at the underground site. 2) A 300 live-day blind dark matter run, with a 100 kg fiducial region and an expected energy window between 5 and 25 kVnr, will allow to achieve the sensitivity of $7 \times 10^{-10}$ pb at 100 GeV/$c^2$ (see fig.1).
LIP formally joined LUX in December 2010.

### 4.3.3 Objectives

**Participation in ZEPLIN-III experiment**

- To assure the maintenance of DAQ and slow control systems until the end of the second science run.
- To keep upgrading the ZEPLIN-III Data Reduction and Analysis (ZE3RA) tool according to the requirements of data analysis.
- To participate in the shifts until the end of the second science run.
- To participate in data analysis, namely, including:
  - To improve the vertex reconstruction algorithm previously used in the first science run to estimate both the energy and position of the interaction.
  - Optimization of several corrections to be applied to data
  - To assess the leakage of electron recoils into the nuclear recoil band in particular into the dark matter searching box

  - To characterize the single electron events in ZEPLIN-III.

- To write and submit for publication 3 papers which were of our leading responsibility: one on ZE3RA, the other on the position reconstruction algorithm and the other on the characterization of the single electron events in ZEPLIN-III.

**Participation in LUX experiment**

- Integration in LUX experiment
- Involvement in the detector surface commissioning taking place at Sanford Laboratory, Lead, SD USA.
- To carry out a design study of the driver for the LED array employed by LUX detector for the calibration and monitoring of the photomultipliers.
- To design and construct a prototype for the radioactive source automatic delivery system. This system must comply with following requirements: *i)High precision. It is necessary to achieve 1 cm precision in positioning at the bottom of 6-meter shaft; ii) High reliability. iii) Protection against jams. iv) Intelligent speed control. v) Remotely started automatic operation.
- Measurement of the reflectivity of the PTFE panels employed by LUX detector.
- Participation in the development of data analysis tools and in the analysis of calibration data taken during surface commissioning of the detector.

**R&D program on alternative readouts for two-phase xenon detectors**

- To test new models of SiPM (Silicon Photomultipliers) from Hamamtsu (under developed and not yet commercialized) at low temperatures and for the xenon scintillation light (lamda=175 nm).

### 4.3.4 Achievements

**Regarding our participation in ZEPLIN-III experiment**

- We were fully responsible for the DAQ and slow control systems and the ZEPLIN Data Reduction and Analysis Software (Z3BRA) until the end of the second science run (7th May 2011). A paper dedicated to Z3BRA software package was already published in JINST 6, P11004 (2011).
- We were also responsible for updating and maintaining the official Monte-Carlo simulation of the experiment.
- We were responsible for optimizing and performing all the corrections to be applied to the data to take into account slight variations of the detector tilt (to compensate for local geological movement), pressure and purity variations.
- The assessment of the leakage of gamma-ray signals into the nuclear recoil band, in particular the region in the parameter space where the signals for WIMPS were looked for (refereed to as the "box"), was performed.
- A vertex reconstruction algorithm for estimating the energy and position of the interaction, with a maximum likelihood method operating on the S1 response and a least squares fit on the S2 channel, was developed, implemented and validated with calibration data. The reconstruction capability made available by this algorithm was crucial for getting the upper limits on WIMP-nucleon elastic scattering cross sections from the data collected by ZEPLIN-III in the second science run. A paper dedicated to this algorithm was accepted for publication in Phys. Lett. B.

**Regarding the participation in LUX experiment**

- We contributed to the LUX detector surface commissioning, having contributed with 178 days*person on site in total. During those stays onsite, we participated in different tasks and got acquainted with different subsystems.
- The design and construction of a prototype of the radioactive source delivery system were completed (see Fig. 2). It is presently being tested.
- The measurements of the reflectance of samples of the PTFE tiles used in the LUX detector were performed in the interface argon-PTFE at room temperature (about 20°C). An internal note was produced with the results and their interpretation.
- The design of a pulsed current drive for the LED calibration system was completed. It was concluded that, due to the transmission lines (cables) connecting the drive to the LEDs a current source is not viable to operate the LEDs. Instead, a solution involving a voltage pulsed drive was considered taking the present installation of the LED array inside the detector. An internal note was written with the conclusions.
- The dependence of the LUX photomultipliers response with the angle of incidence of light was measured. The results were fed into the full simulation of the detector. An internal note was written with the results of these measurements.
- We joined the LUX Analysis Working Group (AWG). In this framework, the group has carried out several tasks related with the data analysis tools and the analysis of calibration data. All together, we wrote or we were co-authors of eight internal notes on data analysis issues.
- One of our members, Luiz de Viveiros, has chaired 2 committees charged with the internal review of papers submitted publication: the first paper reported the results of the screening of titanium used in the construction of the LUX cryostat, and the second detailed a GEANT4-based software package called LUXSim, developed to simulate LUX and other Dark Matter direct detection experiments.

### 4.3.5 Sources of Funding

| Code | Funding | Start | End |
|---|---|---|---|
| CERN/FP/116374/2010 | 45.000 € | 2011-01-01 | 2012-03-15 |

### 4.3.6 Team

**Project coordinator: Isabel Lopes**

| Name | Status | %of time in project |
|---|---|---|
| Alessio Mangiarotti | Researcher (LIP) | 15 |
| Alexandre Lindote | Post-Doc (LIP) | 85 |
| Américo Pereira | Technician (LIP) | 35 |
| Cláudio Silva | Post-Doc (LIP/FCT) | 80 |
| Filipa Balau | PhD student (LIP) | 50 |
| Francisco Neves | Post-Doc (LIP) | 90 |
| Isabel Lopes | Researcher (LIP/FCTUC) | 55 |
| José Pinto Da Cunha | Researcher (LIP/FCTUC) | 30 |
| Luiz de Viveiros | Post-Doc (LIP) | 100 |
| Nuno Carolino | Technician (LIP) | 25 |
| Vitaly Chepel | Researcher (LIP/FCTUC) | 30 |
| Vladimir Solovov | Researcher (LIP) | 80 |

### 4.3.7 Publications

**Articles in international journals (with direct contribution from LIP members)**

- *Radioactivity Backgrounds in ZEPLIN-III*
  H.M.Araújo et al.,
  Astropart. Phys. (2011) (accepted)

- *Performance of the veto detector incorporated into the ZEPLIN-III experiment*
  C. Ghag et al
  Astroparticle Physics 35(2): 76 (2011)

- *Nuclear recoil scintillation and ionisation yields in liquid xenon from ZEPLIN-III data*
  M.Horn et al
  Phys. Lett. B 705:471 (2011)

- *ZE3RA: the ZEPLIN-III reduction and analysis package*
  F. Neves et al.
  JINST 6, P11004 (2011)

- *Single electron emission in two-phase xenon with application to the detection of coherent neutrino-nucleus scattering*
  E. Santos et al.
  JHEP 1112 (2011) 115 (accepted)

### 4.3.8 Presentations

**Oral presentations in international conferences**

- *PTFE reflectance measurements, modeling and simulation for Xenon detectors*
  presented by Cláudio Silva
  Technology and Instrumentation in Particle Physics 2011 (TIPP 2011) — Chicago, IL, USA.

**Poster presentations in international conferences**

- *LUX - Large Underground Xenon - Next Generation Dark Matter Experiment*
  presented by Luiz de Viveiros
  COSMO 11 - 15th International Conference on Particle Physics and Cosmology — Porto, Portugal.

- *Position Reconstruction in ZEPLIN III Dark Matter Detector*
  presented by Vladimir Solovov
  2011 IEEE Nuclear Science Symposium and Medical Imaging Conference — Valencia, Spain.

**Presentations in national conferences**

- *Results from the ZEPLIN-III dark matter search experiment*
  presented by Francisco Neves
  XXI Encontro Nacional de Astronomia e Astrofísica — Coimbra, Portugal.

- *Searching for Dark Matter: The LUX Experiment*
  presented by Vladimir Solovov
  XXI Encontro Nacional de Astronomia e Astrofísica — Coimbra, Portugal.

**Oral presentations in international meetings**

- *Results from the ZEPLIN-III dark matter search experiment*
  presented by Francisco Neves
  IDPASC Dark Matter Workshop — Évora, Portugal.

- *The LUX dark matter search experiment*
  presented by Cláudio Silva
  IDPASC Dark Matter Workshop — Évora, Portugal.

**Oral presentations in collaboration meetings**

- *First Science Run Re-analysis*
  presented by Alexandre Lindote
  ZEPLIN-III Collaboration Meeting — Coimbra, Portugal.
- *Mercury 2.3: chi2 maps, FSR/SSR arrays*
  presented by Vladimir Solovov
  ZEPLIN-III Collaboration Meeting — Coimbra, Portugal.
- *Analysis support structures: the LUX analysis chain comparison and off site shifts*
  presented by Luiz de Viveiros
  — Lead, SD, USA.

**Seminars**

- *Dark Matter Direct Detection: An Overview*
  presented by Luiz de Viveiros
  — Universidade de Coimbra, Portugal.
- *Dark Matter Direct Detection: The ZEPLIN-III Experiment*
  presented by Alexandre Lindote
  — Departamento de Física, Universidade de Coimbra.
- *ZEPLIN-III and LUX: searching for dark matter with dual-phase xenon detectors*
  presented by Isabel Lopes
  — Czech Technical University in Prague, Czech Republique.

**Outreach seminars**

- *Detecção Direta de Matéria Escura*
  presented by Luiz de Viveiros
  Escola de Física para Jovens — Coimbra, Portugal.

### 4.3.9 Events

- *ZEPLIN-III Collaboration Meeting*
  Collaboration Meeting, Coimbra, 2011-02-04

### 4.3.10 Project Summary

| | number |
|---|---|
| Articles in international journals (with direct contribution from LIP members) | 5 |
| Oral presentations in international conferences | 1 |
| Poster presentations in international conferences | 2 |
| Presentations in national conferences | 2 |
| Oral presentations in international meetings | 2 |
| Oral presentations in collaboration meetings | 3 |
| Seminars | 3 |
| Outreach seminars | 1 |
| Collaboration Meetings | 1 |

## 4.4 High Energy Cosmic Rays

### 4.4.1 Resumo

O Observatório Pierre Auger é uma colaboração internacional de 17 países que estuda os raios cósmicos de energia extrema, e procura dar resposta a algumas das questões mais fascinantes da ciência actual. O observatório é o maior detector de raios cósmicos do mundo e está situado em Malargüe, na província de Mendoza na Argentina. Cobre uma área de 3000 $km^2$ e está em operação desde 2003. Combina as técnicas de amostragem dos chuveiros de raios cósmicos que chegam à superfície da Terra e de observação, em noites sem lua, da luz ultra-violeta emitida na interacção destes chuveiros com a atmosfera. Os resultados obtidos no fluxo de partículas para energias superiores a 6x10ˆ19 eV estão em concordância com a designada supressão GZK, devida à interacção a Radiação Cósmica de Fundo. As direcções de chegada dos raios cósmicos de maior energia indicam uma correlação marginal com Galáxias com núcleos activos (AGNs). Este resultado, que necessita um escrutínio aprofundado, pode ser a solução para o problema da origem dos raios cósmicos extra-galácticos.
Os resultados de Auger dão novas contribuições e levantam novas perplexidades no campo da física de partículas. A secção eficaz protão–ar foi medida para energias de cerca de 10ˆ18 eV (sqrt(s) = 57 TeV) e apresenta um acordo notável com a extrapolação dos resultados recentes do LHC para protão–protão a energias do centro de massa de 7 TeV. Contudo, os resultados da evolução com a energia da profundidade do ponto em que o chuveiro atinge o máximo número de partículas (Xmax) não estão de acordo com as expectativas. O mesmo acontece com o número de muões medido à superfície da Terra que está em claro desacordo com as previsões dos modelos de interacção hadrónica. Um debate intenso na interpretação destes resultados está em curso, nomeadamente para saber se estamos em presença de uma modificação da composição dos raios cósmicos primários ou de uma mudança na natureza das interacções hadrónicas, em particular um aumento rápido da secção eficaz. Não existe actualmente uma explicação simples!
Portugal tornou-se membro do Observatório Pierre Auger em Março de 2006. Auger mostrou ser o ambiente ideal para o enquadramento de estudantes aos vários níveis (primeiro, segundo e terceiro ciclo) e com vários perfis de formação. É também um ambiente favorável à colaboração próxima entre físicos teóricos e experimentais. A participação Portuguesa no Observatório Pierre Auger está centrada na exploração da componente de física de partículas que estes acontecimentos de energia extrema nos podem revelar. É um objectivo muito exigente que passa pela compreensão detalhada do detector, pela introdução de novas variáveis de análise que permitam uma melhor caracterização do desenvolvimento dos chuveiros, pelo estudo e desenvolvimento de modelos teóricos que integrem todos os dados existentes e, em particular, os resultados que já começaram a ser revelados no LHC.

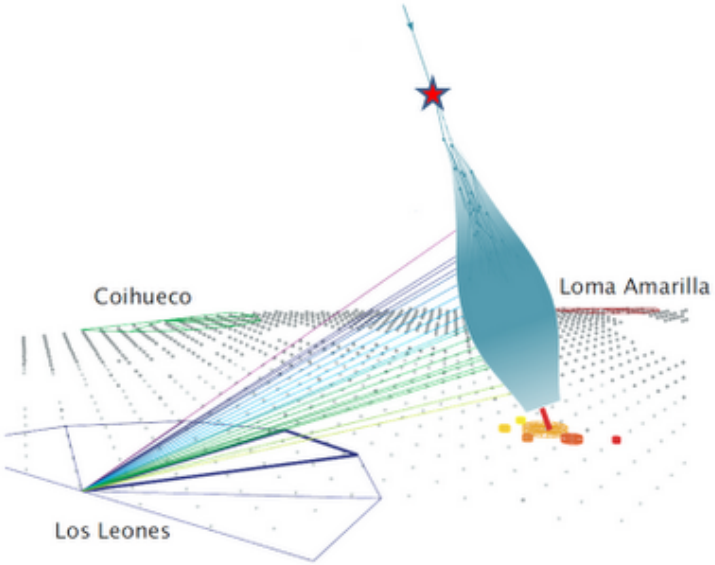



Figure 4.4: Auger: LIP works on several aspects of Auger, from the phenomenology of the first interaction on the top of the atmosphere, to R&D for new muon detectors and optical detectors. The analysis are centred in shower development and hadronic interaction studies and the search for exotic physis.

Os primeiros resultados obtidos pelo Observatório Pierre Auger acentuaram o interesse da comunidade de raios cósmicos na exploração da física de partículas nesta escala de energias. Um esforço de R&D está neste momento em desenvolvimento, em conjugação com os outros grandes projectos internacionais na área das Astropartículas. O LIP está envolvido na exploração de novos photo-sensores, nomeadamente os detectores SiPM, e na possibilidade de utilizar detectores RPCs em experiências de raios cósmicos a céu aberto.

### 4.4.2 Abstract

The Pierre Auger Observatory is a worldwide collaboration of 17 countries which studies the cosmic rays of extreme energy and seeks to answer some of the most fascinating questions of today´s science. The Observatory, the world´s largest cosmic ray detector, covering an area of 3000 km2 in Malargüe, province of Medonza, Argentina is in operation since 2003. It combines the sampling of air showers arriving at the Earth surface with the observation, in moonless nights, of the UV light emitted in the interaction of cosmic ray showers with the atmosphere. Its results for the particle flux above 6x10ˆ19 eV are in agreement with the so-called GZK cut-off, a suppression in the yield of protons above this threshold due to interaction with the photons from the cosmic microwave background. The arrival direction measurements by the Auger collaboration give a marginal indication that the direction of extremely high-energy cosmic rays might be correlated with the active galatic nuclei (AGNs); this result, which needs deeper scrutiny, might be the solution to the problem of the generation of extragalactic cosmic rays.
The Auger data also gave new insights and raised new puzzles in the field of particle physics. Proton-air cross sections were measured at energies as large as 10ˆ18 eV (sqrt(s) $\approx$ 57 TeV) showing a remarkable agreement with the extrapolation of recent LHC measurements for proton-proton (sqrt(s) $\approx$ 7 TeV). However, the results on the evolution with energy of the depth in the atmosphere at which the number of particles in the shower reaches its maximum (Xmax) are not in line with what was expected. Furthermore, the number of muons in air showers measured at ground is in clear disagreement with model predictions. An intense debate on whether these measurements indicate a change in composition, i.e., in the nature of primary cosmic ray particles, or a deep change in the nature of hadronic interactions, namely a rapid increase in the proton-proton cross-section with energy, is currently taking place. No simple explanation works.
Portugal has joined the Pierre Auger Observatory in March 2006. Auger has demonstrated to be an ideal environment for students at several levels (first, second and third cycle) and with different formation profiles. It´s also a favourable environment to the close collaboration between theoretical and experimental physicists. The Portuguese participation in the Pierre Auger Observatory is centred in the exploitation of the particle physics component that these extreme energy events can reveal. It´s a very demanding goal which involves the detailed understanding of the detector, the introduction of new analysis variables that allow a better characterization of the development of the air showers, the study and development of theoretical models that integrate all the existing data and, in particular, the results that have already started to be revealed in the LHC.
The first results obtained by the Pierre Auger Observatory have increased the interest in the community of cosmic rays in the exploitation of particle physics in this scale of energies. An effort of R&D is presently being developed along with other major international projects in the astroparticle field. LIP is involved in the development of new photo-sensors, namely, the SiPM detectors, and in the possibility of using RPCs detectors in outdoor cosmic rays experiments.

### 4.4.3 Objectives

Auger is working smoothly and high quality data is being acquired. The results published by Auger gave already new insights in the fields of astronomy and particle physics but further progress will be reached with an even better understanding of the detector and of the data, as well as an important increase of the statistics. The control of the systematic uncertainties, the design of new analysis , the development of phenomenological models dealing with both the UHECR and the recent LHC data as well as the development of an ambitious R&D program towards the construction of a new generation of High Energy Cosmic ray detectors have now a clear priority.
In 2011 the main topics of our work were centred in:
1) Determination of the systematic uncertainties on light propagation and collection;
2) Measurement of electromagnetic and muonic shower profiles;
3) Search for exotic and rare events;
4) Theory and Models for High Energy Interactions;
5) R&D for the next generation of high energy cosmic ray experiments.

### 4.4.4 Achievements

1) Characterization of the Multiple Scattering of the light produced by air showers, and its dependence on atmospheric conditions, using a method developed at LIP: the analysis of laser track images observed by the FD at various distances, with systematic comparison to dedicated simulation of the laser light propagation based on Geant4.
2)A dedicated framework to keep spatial information on the air shower development in particle generator codes, to use it directly in the production of Fluorescence and Cherenkov light. The fluorescence light was implemented and validated with real data events.
3)A systematic study of the shower longitudinal profile in terms of the new shape variables (R,L) introduced previously by the LIP group. The discriminant power of these new variables to disentangle the primary particle type from the properties of its hadronic interactions was accessed.
4)The study of the longitudinal profile of muon production along the shower axis, for different primary masses and energies, angles and high energy hadronic models. It is found that the shape of the profile displays universal features, similarly to what is known for the electromagnetic one and the relation between both was established.
5)The development of a model for the transport of muons in extensive air showers: the identification of the key elements, allow for the few relevant distributions at production and simple assumptions to be used. The obtained results compared well to the ground distributions given by a full Monte Carlo.
6)A joint interpretation of the Auger results on the maximum of the electromagnetic shower profile and the observed number of muons at ground, as a function of energy, showing that the current data cannot be fully explained by a simple change on composition or in the interaction cross-section. A change of the hadronic interaction models is needed.
7)The development and maintenance of specific tools for the search for rare and/or exotic events. A follow up of the data was done, both model-independently and in specific channels, feeding a "Zoo"of interesting events.
8)The development of a simple model to describe proton-proton cross-sections, reproducing all available data in pp from ISR to LHC. To achieve a fast growth in the very high energy cosmic rays, a fast black disk saturation followed by the dominance of geometric scaling was proposed.
9)A R&D program for SiPM cameras for Fluorescence and Cherenkov Telescopes, involving SiPMs characterization using a reference testbench; development of low cost and low noise readout electronics for many channels; a simple and efficient way of cooling without condensation and high temperature stability; efficient optical guides to maximize light collection.
10) A R&D program for autonomous RPC stations for air shower detector arrays, to know whether RPCs can operate under harsh field conditions i.e. low energy budget, low cost per unit area, and mechanical toughness. The first prototypes were built and the results are encouraging.

### 4.4.5 Sources of Funding

| Code | Funding | Start | End |
|---|---|---|---|
| CERN/FP/116330/2010 | 127.000 € | 2011-01-01 | 2012-01-31 |

### 4.4.6 Team

**Project coordinator: Mário Pimenta**

| Name | Status | %of time in project |
|---|---|---|
| Alessandro de Angelis | Researcher | 20 |
| Andreia Trindade | Post-Doc (LIP/FCT) | 8 |
| Bernardo Tomé | Researcher (LIP) | 85 |
| Catarina Espírito Santo | Researcher (LIP) | 95 |
| Eva Santos | PhD student (LIP/FCT) | 100 |
| Francisco Diogo | Master (LIP) * | 88 |
| Gonçalo Guiomar | Student (LIP) | 50 |
| João Espadanal | PhD student (LIP/FCT) * | 100 |
| Jorge Dias de Deus | Researcher (LIP/IST) | 15 |
| Jorge Romão | Researcher (LIP/IST) | 15 |
| José Micael Oliveira | Master student (LIP) | 29 |
| José Milhano | Researcher (LIP/IST) | 15 |
| Liliana Apolinário | PhD student (LIP) | 15 |
| Lorenzo Cazon | Researcher (LIP) | 100 |
| Luís Mendes | Technician (LIP) | 50 |
| Mário Pimenta | Researcher (LIP/IST) | 75 |
| Miguel Ferreira | Technician (LIP) | 50 |
| Nuno Filipe Silva Dias | Technician (LIP) | 15 |
| Patrícia Gonçalves | Researcher (LIP) | 50 |
| Pedro Abreu | Researcher (LIP/IST) | 65 |
| Pedro Assis | Post-Doc (LIP/FCT/IST) | 95 |
| Pedro Brogueira | Researcher (LIP/IST) | 15 |
| Pedro Rodrigues | Post-Doc (LIP/FCT) | 8 |
| Ruben Conceição | Post-Doc (LIP/FCT) * | 100 |
| Sofia Andringa | Researcher (LIP) | 75 |
| Thomas Schweizer | Researcher (LIP) | 58 |

### 4.4.7 Publications

**Articles in international journals (with direct contribution from LIP members)**

- *Mass composition and cross-section from the shape of cosmic ray shower longitudinal profiles*
  S. Andringa, R. Conceição, M. Pimenta
  Astroparticle Physics 34 (2011) 360

- *Multiple scattering measurement with laser events*
  P. Assis, R. Conceição, P. Gonçalves, M. Pimenta, B. Tomé and the Pierre Auger Collaboration
  Astrophys. Space Sci. Trans., 7, 383–386, 2011

- *GETFOCOS for Imaging Atmospheric Cherenkov Telescopes - A GEant4 Tool For Optimization and Characterization of an Optical System*
  L. Arruda, P. Assis, F. Barão, R. Pereira, M. Pimenta, B. Tomé
  Nuclear Inst. and Methods in Physics Research, A 659 (2011) pp. 282-288

**Articles in international journals (with indirect contribution from LIP members)**

- *Description of Atmospheric Conditions at the Pierre Auger Observatory using the Global Data Assimilation System (GDAS)*
  The Pierre Auger Collaboration
  Astroparticle Physics, in press (2012) (accepted)

- *The Pierre Auger Observatory Scaler Mode for the Study of Solar Activity Modulation of Galactic Cosmic Rays*

The Pierre Auger Collaboration
JINST 6, P01003 (2011)

- *Search for First Harmonic Modulation in the Right Ascension Distribution of Cosmic Rays Detected at the Pierre Auger Observatory*
  The Pierre Auger Collaboration
  Astropart. Phys. 34 (2011), 627-639

- *Advanced functionality for radio analysis in the Offline software framework of the Pierre Auger Observatory*
  The Pierre Auger Collaboration
  Nucl. Instr.and Meth. A 635 (2011) 92

- *Anisotropy and chemical composition of ultra-high energy cosmic rays using arrival directions measured by the Pierre Auger Observatory*
  The Pierre Auger Collaboration
  JCAP06 (2011) 022

- *The Lateral Trigger Probability function for UHE Cosmic Rays Showers detected by the Pierre Auger Observatory*
  The Pierre Auger Collaboration
  Astroparticle Physics 35 (2011) 266–276

- *Search for signatures of magnetically-induced alignment in the arrival directions measured by the Pierre Auger Observatory*
  The Pierre Auger Collaboration
  Astroparticle Physics 35 (2012) 354

- *The effect of the geomagnetic field on cosmic ray energy estimates and large scale anisotropy searches on data from the Pierre Auger Observatory*
  The Pierre Auger Collaboration
  JCAP 11 (2011) 022

- *Search for ultrahigh energy neutrinos in highly inclined events at the Pierre Auger Observatory*
  The Pierre Auger Collaboration
  Physical Review D 84, 122005 (2011)

**International Conference Proceedings**

- *Cosmic Ray Cherenkov and Fluorescence Imaging: Photosensors and data acquisition systems for a new generation of focal planes*
  P. Assis, P. Brogueira, O. Catalano, M. Ferreira, L. Mendes, M. Pimenta, P. Rodrigues, T. Schweizer, A. Trindade
  Nuovo Cimento C Volume 034 Issue 03 pp 141-146

- *R&D for future SiPM cameras for Fluorescence and Cherenkov Telescopes*
  P. Assis, P. Brogueira, O. Catalano, M. Ferreira, T. Hebbeker, M. Lauscher, E. Lorenz, L. Mendes, C. Meurer, R. Mirzoyan, T. Niggemann, M. Pimenta, P. Rodrigues, T. Schweizer, M. Stephan, M. Teshima
  Proceedings of the 32nd International Cosmic Ray Conference

- *Multiple Scattering measurement with laser events*
  P. Assis, for the Pierre Auger Collaboration
  Proceedings of the 32nd International Cosmic Ray Conference

- *R&D for an autonomous RPC station in air shower detector arrays.*
  P. Assis, A. Blanco, P. Brogueira, L. Cazon, P. Fonte, L. Lopes, A. Pereira, M. Pimenta, E. dos Santos, T. Schweizer
  Proceedings of the 32nd International Cosmic Ray Conference

- *R&D in Photosensors and Data Acquisition Systems for a New Generation of Cosmic Ray Cherenkov and Fluorescence Imaging Focal Planes*
  Pedro Assis, Pedro Brogueira, Osvaldo Catalano, Miguel Ferreira, Luís Mendes, Mário Pimenta, Pedro Rodrigues, Thomas Schweizer
  Nuclear Inst. and Methods in Physics Research, A (in press)

- *R&D for future SiPM cameras for Fluorescence and Cherenkov Telescopes*
  P. Assis, P. Brogueira, O. Catalano, M. Ferreira, T. Hebbeker, M. Lauscher, E. Lorenz, L. Mendes, C. Meurer, R. Mirzoyan, T. Niggemann, M. Pimenta, P. Rodrigues, T. Schweizer, M. Stephan, M. Teshima
  Proceedings of the ICRC2011, 32nd International Cosmic Ray Conference, Beijing, China

**Collaboration notes with internal referee**

- *Sensitivity to cosmic ray and hadronic models from the Fluorescence Detector Data of the Pierre Auger Observatory (PhD Thesis)*
  R. Conceicao
  GAP-2011-004

- *Measurement of Fluorescence Detector Photomultipliers (XP3062) non-uniformities*
  P. Assis, R. Conceição, F. Fraga, M.M. Fraga, A. Morozov, L. Pereira, M. Pimenta, J. Rodrigues
  GAP-2011-012

### 4.4.8 Presentations

**Oral presentations in international conferences**

- *The nuclear mass composition of UHECR with the Pierre Auger Observatory*
  presented by Lorenzo Cazon
  XII TAUP Conference — Munich.

**Poster presentations in international conferences**

- *R&D for future SiPM cameras for Fluorescence and Cherenkov Telescopes*
  presented by Pedro Assis
  32nd International Cosmic Ray Conference — Beijing, China.

- *Multiple Scattering measurement with laser events*
  presented by Pedro Assis
  32nd International Cosmic Ray Conference — Beijing, China.

- *R&D for an autonomous RPC station in air shower detector arrays.*
  presented by Mário Pimenta
  32nd International Cosmic Ray Conference — Beijing, China.

**Oral presentations in international meetings**

- *Projects at the Cosmic Rays Lab @ LIP*
  presented by Pedro Assis
  SiPM Lisbon Meeting — LIP, Lisboa.

- *Baseline Design of the SiPM Focal Plane*
  presented by Pedro Rodrigues
  SiPM Lisbon Meeting — LIP, Lisboa.

- *Development of the SiPM Focal Plane Prototype Elementary Readout Board*
  presented by Miguel Ferreira
  SiPM Lisbon Meeting — LIP, Lisboa.

- *Measurements on different SiPM, continuous calibration of gain and PDE in a future SiPM camera and some ideas for light concentration*
  presented by Thomas Schweizer
  SiPM Lisbon Meeting — LIP, Lisboa.

- *MPD General Status*
  presented by Lorenzo Cazon
  MPD Workshop — Granada, Spain.

- *A fit to the MPD in the time domain*
  presented by Eva Santos
  MPD Workshop — Granada, Spain.

- *Relation between the different muon distributions*
  presented by Lorenzo Cazon
  MPD Workshop — Granada, Spain.

- *Universal Shower Profiles. What we have learned from the EM component.*
  presented by Sofia Andringa
  MPD Workshop — Granada, Spain.

- *Characterisation of the muon longitudinal profile at production*
  presented by Ruben Conceição
  MPD Workshop — Granada, Spain.

- *Pierre Auger Observatory Results*
  presented by Ruben Conceição
  Low x workshop — Santiago de Compostela.

- *Proton-proton cross sections: the interplay between density and radius*
  presented by Mário Pimenta
  Low x workshop — Santiago de Compostela.

- *Inside the proton : From ISR to Auger*
  presented by Mário Pimenta
  The Multidisciplinary Universe - A conference in honor of Jorge Dias de Deus — IST, Lisboa, Portugal.

- *SiPM activities at LIP*
  presented by Pedro Assis
  SiPM Fluorescence Telescope Meeting — Aachen, Germany.

- *Improved UV transmission by Plasma Oxygen Etching*
  presented by Pedro Brogueira
  SiPM Fluorescence Telescope Meeting — Aachen, Germany.

- *Proton-proton cross-sections: the interplay between density and radius*
  presented by Ruben Conceição
  IDPASC Dark Matter Workshop — Évora, Portugal.

**Oral presentations in collaboration meetings**

- *Update on searches with CUSCA*
  presented by Catarina Espírito Santo
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.

- *Profile Shape Analysis*
  presented by Sofia Andringa
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.

- *MPD fit on the time domain*
  presented by Lorenzo Cazon
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.
- *Analysis of roving lasers data*
  presented by Bernardo Tomé
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.
- *Cross check on the MPD elongation rate*
  presented by Eva Santos
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.
- *Research with SiPMs at LIP*
  presented by Pedro Assis
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.
- *Report on searches with CUSCA*
  presented by Catarina Espírito Santo
  Pierre Auger Collaboration Meeting — Santiago de Compostela, Spain.
- *Multiple Scattering measurement with laser events ICRC MISC1 (Poster)*
  presented by Pedro Assis
  Pierre Auger Collaboration Meeting — Santiago de Compostela, Spain.
- *Analysis of roving lasers data*
  presented by Bernardo Tomé
  Pierre Auger Collaboration Meeting — Santiago de Compostela, Spain.
- *Understanding FD data, KG and 3D simulation event by event*
  presented by João Espadanal
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.
- *Reconstruction of the MPD profile from the time domain*
  presented by Eva Santos
  Pierre Auger Collaboration Meeting — Santiago de Compostela, Spain.
- *Determination of the first interaction point using USPV*
  presented by Francisco Diogo
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.
- *The muon production longitudinal profile and its relation with the electromagnetic component*
  presented by Ruben Conceição
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.
- *Transport model for muons in air showers: from production to ground*
  presented by Lorenzo Cazon
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.
- *Auger outreach at LIP, Portugal*
  presented by Pedro Abreu
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.
- *Studying the light transverse profile with roving lasers*
  presented by Bernardo Tomé
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.
- *3D simulation of EAS for the FD: validation with a fluorescence rich data sample*
  presented by João Espadanal
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.
- *Profile fit with USPv*
  presented by Sofia Andringa
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.

- *Autonomous RPC stations for air shower detection*
  presented by Lorenzo Cazon
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.

- *SiPM R&D@LIP*
  presented by Pedro Assis
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.

- *Particle Physics @ Auger South*
  presented by Mário Pimenta
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.

- *A model for the transport of muons in Extensive Air Showers*
  presented by Lorenzo Cazon
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.

- *Prospects of the Universal Shower Profile Variables for the electromagnetic profile analysis in the FD*
  presented by Sofia Andringa
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.

- *Status of the time domain fit of the MPD*
  presented by Lorenzo Cazon
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.

- *The muonic longitudinal profile at production*
  presented by Ruben Conceição
  Pierre Auger Collaboration Meeting — Malargüe, Argentina.

**Seminars**

- *Particle Physics With High Energy Cosmic Rays*
  presented by Mário Pimenta
  LIP-MINHO Seminars — Dept. Física da Univ. Minho, Braga, Portugal.

- *Mass composition and cross-section from the shape of the shower longitudinal profile*
  presented by Ruben Conceição
  Seminar for the Astroparticle group of USC — Santiago de Compostela, Spain.

- *O mistério dos raios cósmicos de energia extrema*
  presented by Mário Pimenta
  Colóquio do CFUM - a Ciência para tod@s na Universidade do Minho — Univ. Minho, Braga, Portugal.

- *Particle Physics @ Auger : Present and Future*
  presented by Mário Pimenta
  Seminar Physics Department INFN - Catânia — Catânia, Italy.

- *Particle Physics @ 100 TeV scale*
  presented by Mário Pimenta
  Colóquios do Departamento de Física — IST, Lisboa, Portugal.

- *Particle Physics With High Energy Cosmic Rays*
  presented by Mário Pimenta
  Colóquios IFIC — Valência, Spain.

### 4.4.9 Academic Training

**PhD Theses**

- *Sensitivity to Cosmic Ray Composition and Hadronic Models from the Fluorescence Detector Data of the Pierre Auger Observatory*
  Ruben Conceição, 2011-01-11

- *Cosmic Rays at the Ankle: Auger South Enhancements*
  Eva Santos, (on-going)

- *Study of hadronic interactions with the hybrid detector of the Pierre Auger Observatory*
  João Espadanal, (on-going)

**Master Theses**

- *Evolution of the longitudinal profiles of high energy cosmic rays in the Pierre Auger Observatory*
  Francisco Diogo, 2011-10-24
- *Muon production in Extensive Air Showers*
  José Micael Oliveira, (on-going)

### 4.4.10 Events

- *SiPM Lisbon Meeting*
  Workshop, LIP, Lisboa, 2011-02-21
- *Pierre Auger Observatory 2011 Finance Board*
  Collaboration Meeting, Lisboa, Portugal, 2011-09-26

### 4.4.11 Project Summary

| | number |
|---|---|
| Articles in international journals (with direct contribution from LIP members) | 3 |
| Articles in international journals (with indirect contribution from LIP members) | 9 |
| International Conference Proceedings | 6 |
| Collaboration notes with internal referee | 2 |
| Oral presentations in international conferences | 1 |
| Poster presentations in international conferences | 3 |
| Oral presentations in international meetings | 15 |
| Oral presentations in collaboration meetings | 25 |
| Seminars | 6 |
| PhD Theses | 1 |
| Master Theses | 1 |
| Workshops | 1 |
| Collaboration Meetings | 1 |

## 4.5 Radiation interaction simulations for space missions

### 4.5.1 Resumo

No espaço interplanetário do sistema solar, as fontes de radiação consistem em raios-X solares, protões e electrões em acontecimentos Solares de Partículas Energéticas (SEP) e partículas alfa, electrões Jovianos, raios cósmicos galácticos (GCR) e raiox-X e raios-gama galácticos. Nas órbitas terrestres os electrões e protões das cinturas de radiação são a fonte principal de radiação. O ambiente de radiação afecta os satelites e naves espaciais, sendo responsável por danos nos seus sub-sistemas e nos componentes electrónicos que os compõem e impõe também limites severos à exploração espacial com seres humanos.

As actividades desenvolvidas no âmbito do projecto *Space/ESA: Radiation interaction simulations for space missions* começaram por se centrar na aplicação da ferramenta de simulação Geant4 a experiências de astropartículas no espaço e têm vindo a alargar-se, abrangendo estudos do ambiente de radiação no espaço e planetários, modelização da degradação de componentes electrónicos e dos efeitos da radiação espacial em seres humanos. Estas actividades são complementadas pela participação em testes de radiação de componentes electrónicos a serem utilizados em ambiente espacial.

Estes testes são importantes para o desenvolvimento dos modelos de efeitos de eventos isolados (SEE do inglês – single event effects) na actividade CODES: a ferramenta de software CODES basea-se em Geant4 e destina-se à análise e à previsão dos efeitos da radiação, principalmente SEE, em componentes EEE a serem utilizados em ambiente espacial. Esta ferramenta tem vindo a ser desenvolvida no LIP e está em fase de implementação num ambiente integrado e de fácil utilização, e será disponibilizada pela ESA após o final do contrato.

A proposta "Alphasat radiation Environment and Effects Facility (AEEF) Component Technology Test-Bed (CTTB), Preparation of In-Flight Data Analysis"foi elaborada pelo LIP, em conjunto com a EFACEC S.A. e com a EVOLEO Technologies, Lda., e aceite pela ESA em Dezembro de 2010. O contrato teve início em Janeiro de 2010 e terminará em Junho de 2012. A EFACEC, S.A. é o principal responsável pelo contrato no qual o LIP assegura os seguintes work packages: *RADFET Calibration Test Plan Definition* (WP1100); *RADFET Calibration Test* (WP1200) e *Analysis of Radiation Ground Test Data* (WP2000). Neste contrato o LIP foi responsável por testes de radiação de componentes - RADFETs –evidenciando-se o aumento da importância dos testes de radiação de componentes nas actividades desenvolvidas.

O conhecimento adquirido no LIP sobre a descrição do ambiente de radiação no espaço, nomeadamente no desenvolvimento dos modelos do ambiente de radiação Marciano – MarsREC e dMEREM - começou a ser aplicado ao problema do ambiente de radiação para tripulações humanas em missões espaciais. Trabalho desenvolvido no LIP sobre o ambiente de radiação afectando missões a Marte e as suas implicações para tripulações humanas foi publicado em 2011 (nas versões online) das revistas internacionais Icarus e Planetary Space Science. A publicação definitiva destes artigos terá lugar em 2012.

Dados sobre a exposição dos astronautas à radiação no espaço são ainda escassos, em particular no que diz respeito às doses absorvidas ao nível da pele e dos órgãos internos, são critícas do ponto de vista dos riscos carcinogénicos e não carcinogénicos. Por esta razão, e tendo em conta as durações esperadas para futures missões e a possibilidade de futuras missões espaciais interplanetárias, fora da protecção da magnetoefera terrestre, como no caso de missões tripuladas a Marte, os estudos do ambiente de radiação espacial e dos seus efeitos em seres humanos são promissores como futura linha de trabalho. Uma actividade exploratória foi iniciada com base nos dados públicos obtidos pela unidade experimental Matroska da ESA, instalada na estação espacial internacional.

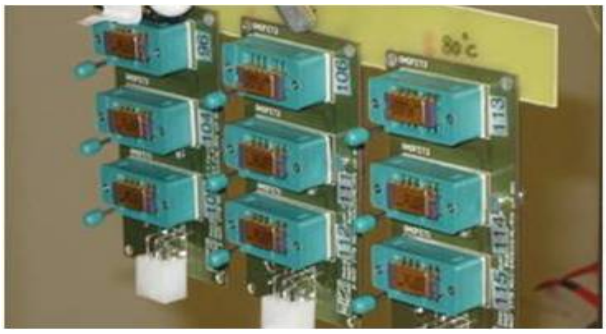



Figure 4.5: RADFET test board developed at LIP for the contract *Alphasat radiation Environment and Effects Facility (AEEF) Component Technology Test-Bed (CTTB), Preparation of In-Flight Data Analysis.*

Estes dados estão disponíveis na página do consórcio internacional HAMLET (http://www.fp7-hamlet.eu/).
A comparação entre modelos de propagação de acontecimentos solares (SEP) e dados recolhidos por um instrumento que fez parte da missão Ulysses (e também da missão ACE) é uma actividade que se actividade iniciou com a participação no projecto *Participação Portuguesa na Rede Heliosférica*. O LIP foi responsável pela simulação do instrumento HISCALE utilizando Geant4. A simulação completa do instrumento é fundamental para a compreensão dos dados recolhidos e para a sua interpretação à luz dos modelos de propagação de SEP. Encontra-se em preparação uma dissertação de doutoramento, a finalizar em 2012.
O trabalho desenvolvido tem vindo a tornar-se mais abrangente, cobrindo vários aspectos do problema do ambiente de radiação no espaço e dos seus efeitos. Este projecto tem permitido a iniciação e a integração de estudantes em ambiente de investigação e é um assunto atractivo e multidisciplinar que têm sido uma fonte de colaboração entre o LIP e outros institutos, empresas e com a industria, mas também com cientistas externos ao LIP.

### 4.5.2 Abstract

In interplanetary space in the Solar System the radiation population consists of: solar X-rays, Solar Event Protons (SEP) and alpha particles, solar event electrons, Jovian electrons, Galactic Cosmic Rays (GCR) and galactic X-rays and gamma-rays. In Earth orbits the radiation belts containing trapped electrons and protons constitute the major radiation source. Space radiation environment is responsible for the spacecraft system, sub-system and component hazard and damage and it is also responsible by strict constrains on human space exploration.
The activities developed within the project *Space Radiation Environment and Effect* started to be centred in the application of the Geant4 simulation toolkit to astroparticle experiments, and have been extended to encompass studies of the space and planetary radiation environment and studies and modelling of radiation effects in electronic components and for human spaceflight. These activities have been complemented by radiation testing activities of EEE components to be used in space.
Radiation ground tests became important for the development of the SEE models developed under CODES: the CODES software framework is a tool based on Geant4 for analysis and prediction of radiation effects (SEE in particular) in EEE components. The CODES tool has been developed at LIP and it is currently being implemented in a user friendly integrated framework enabling prediction of radiation induced degradation under different space environment scenarios.
The *Alphasat radiation Environment and Effects Facility (AEEF) Component Technology Test-Bed (CTTB), Preparation of In-Flight Data Analysis* proposal was elaborated in collaboration with EFACEC S.A. and EVO-LEO Technologies, Lda and accepted by ESA in December 2010. The corresponding contract, in which EFACEC S.A. was the prime contractor, started in January 2011 and has a duration of 18 months. LIP is responsible for the following work packages: RADFET Calibration Test Plan Definition (WP1100); RADFET Calibration Test (WP1200) and Analysis of Radiation Ground Test Data (WP2000). In this contract radiation tests with components – RADFETs – were performed by LIP, putting in evidence the increasing contribution of the testing activity for the project.
The knowhow acquired at LIP on the description of the radiation environment in space, namely in the development of the radiation environment models for Mars - MarsREC and dMEREM - has started to used in studies of the radiation environment for human space flight. Work previously developed at LIP on the radiation environment affecting eventual manned missions to Mars and its implications for crews, was published in 2011 in the online versions of the international magazines Icarus and Planetary Space Science. Final publication will take place in 2012.
Data concerning the exposure of astronauts to radiation in space are still scarce, in particular in what concerns the skin and internal organ absorbed doses, for which the exposure to radiation is critical from the point of view of future carcinogenic and non-carcinogenic health risks. For this reason, and taking into account the expected increase in mission duration and the possibility of interplanetary missions, outside the protecting earth magnetosphere, as in the case of Missions to Mars, the subject of radiation effects in human space flight is a promising line of work. An exploratory activity concerning radiation effects in human spaceflight was started. The experimental basis for this exploratory work on Human Space Flight was the public data set obtained with the European Space Agency Matroska experimental unit aboard the International Space Station. The data are available in the web page of the HAMLET consortium (http://www.fp7-hamlet.eu/).
Other ongoing activity concerns the application of SEP propagation models and their comparison with existing data collected with an instrument flown in the Ulysses mission (and in the ACE mission). This activity started with the participation in the project *Portuguese Participation in the Heliospheric Network* in which LIP was responsible for using the Geant4 simulation toolkit to simulate the performance of the instrument – HISCALE-flown aboard the Ulysses for more than a decade and for which a full simulation was required in order to fully

understand the collected data. A PhD thesis is being prepared in this subject, which will be finalized in 2012. The activities developed have been covering a wider range of aspects of the radiation environment in space and of its effects. These activities have enabled the initiation and integration of students in LIP, and are an interesting and multidisciplinary subject that has been a source of collaboration between LIP, other academic institutions and the industry, and also with scientists external to LIP.

### 4.5.3 Objectives

The objectives of the activity were the continuation of the ongoing activities; the CODES-III contract with ESA and the *Alphasat radiation Environment and Effects Facility (AEEF) Component Technology Test-Bed (CTTB), Preparation of In-Flight Data Analysis*; the development of the new lines of activity, as the case of radiation environment and effects studies and modelling for human spaceflight; and the search for partners, industrial and academic, to complement the activities of the project.
The objectives of CODES-III contract with ESA during 2011 were: the successful integration of the developed modules into a top-level interface to be available via web to the EEE community; the verification and release of CODES-III alpha version. LIP´s involvement in the *CTTB AEEF* contract had the objective of engaging in a line of activity involving radiation tests of EEE components and of participating in the preparation of the radiation analysis of the data of the AEEF. This contract concerns the development and preparation of data handling and analysis tools for a radiation monitoring facility in space which will fly on Alphasat satellite and whose launch was foreseen for 2012.
Preliminary studies of the problem of the radiation environment and of its effects for human spaceflight were initiated by exploratory work using the public data of the Matroska phantom, aboard the international space station. Also in the field of radiation effects for human spaceflight, a proposal is being prepared by LIP in collaboration with the French company TRAD (http://www.trad.fr/), in response to the ESA invitation to tender *Interplanetary and Planetary Radiation Model for Human Spaceflight*.
LIP prepared a proposal in a consortium with a EFACEC S.A. and other entities in response to the ESA ITT *Next Generation Radiation Monitor (Phase B/C/D) development*, where LIP would be responsible for the simulation, calibration and data analysis of the instrument. The proposal elaborated by the consortium in which LIP participated was not selected by ESA in the open competition.

### 4.5.4 Achievements

#### CODES III

In 2011 the final CODES architecture, already frozen in 2010, was implemented in a user friendly integrated framework enabling prediction of radiation induced degradation under different space environment scenarios. The application of the tool in the study of the reference SEU Monitor, and experimental data analysis was of great importance and contribute to the understanding of the limitation of current methodologies. The work developed in 2011 was published in IEEE RADECS 2011 proceedings and accepted by the Radiation and Environmental Biophysics Journal. TDM SEL Monitor devices were tested in irradiation facilities, and the data will be analysed to predict in-orbit SEU and SEL rates and compare against real in-flight data.

#### CTTB In-Flight Component Irradiation Test Data Analysis

In the *CTTB AEEF* contract LIP is responsible for: RADFET Calibration Test Plan Definition (WP1100); RADFET Calibration Test (WP1200) and Analysis of Radiation Ground Test Data (WP2000). WP1100 and WP1200 concerned the preparation and supervision of the RADFET calibration campaign at ESA/ESTEC Cobalt-60 facility. WP1100 was finalized with the delivery of the irradiation test plan (TN1),in February 2011. For WP1200 a readout RADFET PCB carrier board for irradiation was produced at LIP(see figure). The irradiation phase ended in October 2011 and the annealing phase will be finalized in beginning of 2012. In WP2000 a radiation analysis based on the CTTB topology, using radiation ground test data to predict component degradation rates in the Alphasat environment was performed. LIP participation in the project will finish with the delivery of the RADFET calibration results (TN2) and of the Data Analysis Report (TN3), to be presented in a progress meeting in March 2012.

#### Human Spaceflight

The Geant4 simulation toolkit was used to simulate parts of the Matroska phantom, aiming at a first comparison with the MATROSKA data, in order to gain insight of the problem of studying radiation effects using an anthropomorphic phantom. The work developed in this phase will be object of a publication, which is currently being prepared.

### 4.5.5 Sources of Funding

| Code | Funding | Start | End |
|---|---|---|---|
| ESA:223981/09/NL/PA | 150.000 € | 2009-05-01 | 2012-03-31 |
| 6403/10/NL/SFe | 50.000 € | 2011-01-17 | 2012-06-18 |

### 4.5.6 Team

**Project coordinator: Patrícia Gonçalves**

| Name | Status | %of time in project |
|---|---|---|
| Alessandro de Angelis | Researcher | 10 |
| Ana Keating | Post-Doc (LIP/FCT) | 100 |
| Andreia Trindade | Post-Doc (LIP/FCT) | 70 |
| Bernardo Tomé | Researcher (LIP) | 10 |
| Bruno Morgado | PhD student (LIP) | 100 |
| Gonçalo Guiomar | Student (LIP) | 33 |
| Mário Pimenta | Researcher (LIP/IST) | 20 |
| Micaela Cunha | Master (LIP) | 50 |
| Miguel Ferreira | Technician (LIP) | 29 |
| Patrícia Gonçalves | Researcher (LIP) | 46 |
| Pedro Brogueira | Researcher (LIP/IST) | 5 |
| Pedro Rodrigues | Post-Doc (LIP/FCT) | 70 |
| Sara Valente | Master student (LIP) | 33 |

### 4.5.7 Publications

**Articles in international journals (with direct contribution from LIP members)**

- *Characterization of the particle radiation environment at three potential landing sites on Mars using ESA´s MEREM models*
  McKenna-Lawlor, S., Gonçalves, P., Keating, A., Morgado, B. , Heynderickx, D., Nieminen, P., Santin,G., Truscott, P., Lei, F., Foing, B. and Balaz,J.
  Icarus Magazine

- *Overview of energetic particle hazards during prospective manned missions to Mars*
  McKenna-Lawlor, S., Gonçalves, P., Keating, A., Reitz, G., Matthiä, D.
  Planetary Space Science

**International Conference Proceedings**

- *Validation of the component degradation simulation tool (CODES)*
  A. Keating, P. Gonçalves, A.Zadeh, M.Pimenta, S. Coutinho, P.Brogueira, E.Daly
  RADECS 2011 (accepted)

### 4.5.8 Presentations

**Oral presentations in international conferences**

- *Geant4 simulation of SEE in EEE components*
  presented by Patrícia Gonçalves
  IV Scuola Nazionale Rivelatori ed Elettronica per Fisica delle Alte Energie, Astrofisica, Applicazioni Spaziali e Fisica Medica. Laboratorio Nazionali de Legnaro — Laboratorio Nazionali de Legnaro, Padova, Italia.

- *Radiation in Space*
  presented by Patrícia Gonçalves
  IV Scuola Nazionale Rivelatori ed Elettronica per Fisica delle Alte Energie, Astrofisica, Applicazioni Spaziali e Fisica Medica — Laboratorio Nazionali de Legnaro, Padova, Italia.

**Poster presentations in international conferences**

- *Validation of the component degradation simulation tool (CODES)*
  presented by Patrícia Gonçalves
  IEEE RADECS 2011 — Sevilla, Espana.

**Presentations in national conferences**

- *Desenvolvimento de Monitores de Radiação para Missões Espaciais*
  presented by Patrícia Gonçalves
  XXI Encontro Nacional de Astronomia e Astrofísica — Coimbra, Portugal.

**Oral presentations in international meetings**

- *Integrated Radiation Environment, Effects and Component Degradation Simulation Tool*
  presented by Ana Keating
  CNES & TEC-QEC final presentation Days — ESTEC, Noordwijk.

### 4.5.9 Project Summary

| | number |
|---|---|
| Articles in international journals (with direct contribution from LIP members) | 2 |
| International Conference Proceedings | 1 |
| Oral presentations in international conferences | 2 |
| Poster presentations in international conferences | 1 |
| Presentations in national conferences | 1 |
| Oral presentations in international meetings | 1 |

# Chapter 5

# Medical Physics

## 5.1 Development of Positron Emission Mammography

### 5.1.1 Resumo

O projecto de investigação científica e tecnológica "Development of PET Technologies"é realizado pelo LIP em colaboração com outras instituições nacionais e internacionais. Os novos equipamentos de imagem médica exploram tecnologias desenvolvidas para experiências de física de altas energias.

### 5.1.2 Abstract

The research and development project "Development of PET Technologies"is carried by LIP in collaboration with other national and international institutions. The medical imaging equipment under development exploit technologies developed for accelerator experiments.

### 5.1.3 Objectives

LIP pursued the program of development of PET technologies.
1) Clinical evaluation of the ClearPEM and ClearPEM-Sonic scanners
2) The investigation of new nuclear imaging technologies

### 5.1.4 Achievements

1) Clinical evaluation of the ClearPEM and ClearPEM-Sonic scanners
The LIP group is participating in the clinical studies and is providing support and maintenance of the ClearPEM machines installed at ICNAS, Coimbra, and in Hopital Nord, Université de la Méditerrané, Marseille, in the frame of the evaluation conducted by our research and clinical partners. Studies to improve the energy, time and spatial resolutions, as well as the scanner sensitivity were pursued. Several studies with small animals have been performed in collaboration with different groups in bio-medical research, demonstrating the high performance of the ClearPEM scanner for this application. A plan to adapt and use the available scanner as a national infrastructure for small animal PET imaging is under discussion. Exams with patients affected by beast cancer have been performed at ICNAS and at Marseille, demonstrating the ability of the machine to detect cancer tumors. The clinical investigation will be pursued.
2) The investigation of new nuclear imaging technologies was pursued in two complementary lines:
- Development of electronics and data acquisition in the frame of the EndoTOFPET-US project funded by FP7. This project aim at a new PET technology for endoscopic detection of pancreatic and prostate cancer. The excellent time resolution (≈200 ps FWHM) required is achieved using Silicon Photomultipliers associated to high-precision integrated TDCs. In 2011 the LIP group developed the design of a 64-channel ASIC in IBM 0.25 micron technology integrating low-power TDCs with 50 ps time binning. The chip will be fabricated in 2012.
- Evaluation of the ClearPEM detector modules in the 7 Tesla MR scanner at EPFL, Lausanne. Various tests and measurements were conducted in order to assess the electromagnetic interference between the PET electronics and materials and the MR imaging.

### 5.1.5 Sources of Funding

| Code | Funding | Start | End |
|---|---|---|---|
| PIC/IC/83228/2007 | 67.550 € | 2009-03-26 | 2012-03-31 |
| Endo TOFPET-US256984 | 509.400 € | 2011-01-01 | 2014-12-31 |

### 5.1.6 Team

**Project coordinator: João Varela**

| Name | Status | %of time in project |
|---|---|---|
| Ana Rodrigues | Master student (LIP) * | 50 |
| Catarina Ortigão | Post-Doc (LIP/FCT) | 100 |
| Cláudia Sofia Ferreira | PhD student (LIP/FCT) | 100 |
| Gonçalo Silva | Master student (LIP) | 2 |
| João Varela | Researcher (LIP/IST) | 10 |
| Jorge Neves | PhD student (FCT) | 100 |
| José Carlos Silva | Technician (LIP) | 5 |
| Manuel Rolo | PhD student (LIP) | 100 |
| Ricardo Bugalho | | 100 |
| Rui Pereira da Silva | Technician (LIP) | 100 |

### 5.1.7 Publications

**Articles in international journals (with direct contribution from LIP members)**

- *A low-noise CMOS front-end for TOF-PET*
  M D Rolo, L N Alves, E V Martins, A Rivetti, M B Santos, J Varela
  doi:10.1088/1748-0221/6/09/P09003

**International Conference Proceedings**

- *The ClearPEM breast imaging scanner*
  Jorge A. Neves, on behalf of the ClearPEM Collaboration
  Nucl. Instr. and Meth. A 628 (2011) 444–447

- *ClearPEM scanners: performance results and studies in preclinical environment*
  M. Abrantes, P. Almeida, F. Botelho, R. Bugalho, S. Carvalho, C. S. Ferreira,N. C. Ferreira, M. V. Martins, N. Matela, J. A. Neves, C. Ortigão, A. Rodrigues,A.S. Rodrigues, M. Rolo, J. C. Silva, R. Silva, J. Varela
  MIC Conference Record, 2011

### 5.1.8 Presentations

**Poster presentations in international conferences**

- *ClearPEM scanners: performance results and studies in preclinical environment*
  presented by Catarina Ortigão
  IEEE/NSS/MIC — Valencia, Spain.

**Oral presentations in collaboration meetings**

- *TOF-PET ASIC for the external plate – analogue*
  presented by Manuel Rolo
  EndoTOFPET-US collaboration meeting — Munich, Germany.

**Seminars**

- *Development and Evaluation of Combined PET-MR Imaging*
  presented by Jorge Neves
  Internal EPFL Seminar — EPFL, Lausanne, Switzerland.
- *ClearPEM scanners: performance results and studies in preclinical environment*
  presented by Jorge Neves
  3rd Workshop of the Department of Physics and Mathematics - ISEC — Coimbra.
- *Development and Evaluation of Combined PET-MR Imaging*
  presented by Jorge Neves
  Workshop Doctoral Program in Biomedical Engineering — IST, Lisboa.

### 5.1.9 Academic Training

**PhD Theses**

- *Estudo do tomógrafo Clear-PEM no diagnóstico do cancro da mama*
  Cláudia Sofia Ferreira, (on-going)
- *Development and evaluation of combined PET-MRI imaging*
  Jorge Neves, (on-going)
- *Development of advanced data acquisition technologies for PET applications*
  Ricardo Bugalho, (on-going)
- *Integrated Circuit Design for Picosecond Timing measurements on Radiation Detectors*
  Manuel Rolo, (on-going)

**Master Theses**

- *Study of detectability of breast cancer with the ClearPEM scanner using gelatin phantoms*
  Ana Rodrigues, 2011-10-01

### 5.1.10 Project Summary

| | number |
|---|---|
| Articles in international journals (with direct contribution from LIP members) | 1 |
| International Conference Proceedings | 2 |
| Poster presentations in international conferences | 1 |
| Oral presentations in collaboration meetings | 1 |
| Seminars | 3 |
| Master Theses | 1 |

## 5.2 PET with Resistive Plate Chambers (RPC-PET)

### 5.2.1 Resumo

**Objectivo**
A Tomografia de Emissão de Positrões (PET) é uma técnica poderosa de imagiologia molecular funcional. O nosso objectivo é o desenvolvimento um tomógrafo baseado numa tecnologia radicalmente nova de TOF-PET, que envolve todo o corpo do paciente, com resolução espacial a atingir os limites físico da técnica PET e sensibilidade uma ordem de grandeza superior à dos sistemas comerciais correntes, sem aumento de custo. Uma tal inovação fornecerá aos clínicos capacidades superiores de diagnosticar e detectar doenças oncológicas e de outros tipos, bem como de estudar mecanismos de doença, constituindo uma mudança de paradigma no uso clínico de PET. Realizados já os estudos básicos de viabilidade, neste projecto pretende especificamente desenhar, construir, testar e desenvolver um primeiro protótipo de dimensão real de um tomógrafo para corpo inteiro, com um campo de visão axial (AFOV) de 2m e uma abertura de 90 cm.
A demonstração desta tecnologia, radicalmente diferente da dos cristais tradicionalmente usados na detecção de raios gama, pode, aliás, abrir perspectivas totalmente novas na detecção de raios gama em áreas extensas, para lá das aplicações médicas.

**Ideia fundamental**
A sensibilidade é um parâmetro fundamental dos sistemas PET, determinando a quantidade de traçador radioactivo a administrar ao paciente, o tempo de observação e o nível de ruído para uma dada granularidade da imagem. Qualquer melhoria na sensibilidade permite o correspondente melhoramento num destes parâmetros ou numa combinação deles. Deve contudo garantir-se que qualquer nova tecnologia forneça os melhoramentos esperados sem contudo conduzir a um aumento significativo de custos relativamente aos sistemas disponíveis no mercado. Ora tal não é o que se passa com muitas das soluções que estão actualmente em estudo, podendo ser necessários compromissos [ERI06].
A nossa proposta para PET de alta sensibilidade a custo moderado envolve a técnica TOF-PET e o aumento dramático do AFOV [BLA03, ERI08] até uma dimensão de corpo inteiro (2 m) graças a um detector de radiação com custo por unidade de área moderado, capaz de fornecer excelente resolução espacial, uniforme ao longo do FOV, sensível à profundidade de interacção e com uma resolução de 300 ps para tempo de vôo.
Um campo de visão muito extenso, capaz de abranger todo o corpo dum paciente ("single bed"), tem ainda outras vantagens sobre os sistemas com AFOV reduzido. Entre elas, está a possibilidade de, obtendo imagens simultâneas de todo o corpo, permitir o estudo completo de processos dinâmicos graças a uma segmentação

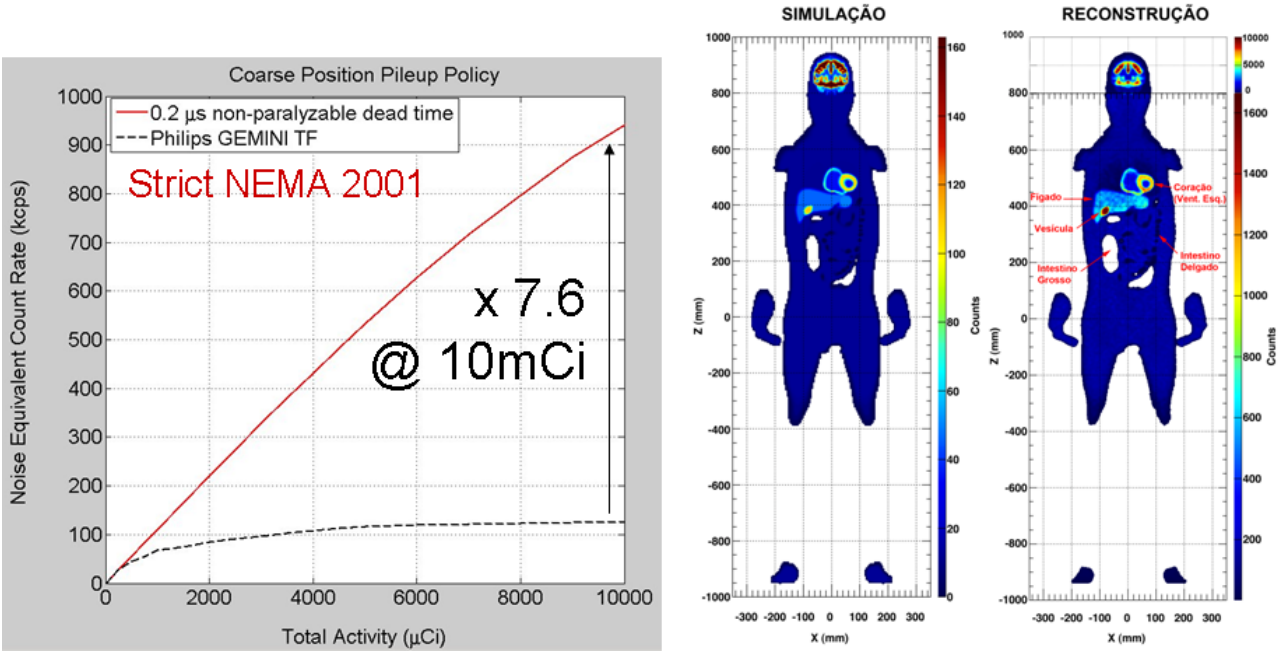



Figure 5.1: Results from simulations. Left: noise equivalent count rate (NEC) compared with published data. Right: whole body 3D TOF reconstruction algorithm.

temporal melhorada. Outra vantagem está na possibilidade de obter uma melhor quantificação da actividade através duma melhor correcção de difusão ("scatter"), dado não haver actividade fora do FOV.

**Aproximação inovadora**
A nossa aproximação baseia-se numa tecnologia de detecção já em uso na Física de Partículas para a medida de tempo de vôo de partículas elementares carregadas: as "timing Resistive Plate Chambers"(tRPCs). Esses detectores gasosos foram desenvolvidos para cobrir áreas de mais de uma centena de metros quadrados a preços moderados, fornecendo ao mesmo tempo excelente resolução temporal, abaixo dos 100 ps rms.
Há alguns anos este grupo propôs a aplicação destes detectores à tecnologia TOF-PET, tanto para tomógrafos de corpo inteiro para humanos, como para pequenos animais [BLA03]. Tal aplicação baseia-se no princípio das "placas conversoras"e tira partido da estrutura natural "em camadas"das tRPCs e de a sua construção em áreas grandes ser económica. A baixa eficiência naturalmente esperada para os fotões de 511 keV é mais que compensada [COU07a, ERI08, CRE09] pela possibilidade de alcançar campos de visão extensos, que poderão ir até 2 m.
O conceito foi também revisto independentemente [ERI08], embora assumindo condições diferentes, confirmando-se que poderá para corpo inteiro substituir com vantagem os tomógrafos de cristais que constituem o "state-of-the-art".

### 5.2.2 Abstract

**Aim of the project**

Positron Emission Tomography (PET) is a powerful diagnostic technique employed in functional medical imaging (molecular imaging). Our overall objective is to develop a radically new technology for TOF PET systems targeted at human whole-body scanning, with resolution down to the physical limit of the PET technique and with a sensitivity improved by over one order of magnitude with respect to current commercial systems, without increase in cost. Such breakthrough would provide physicians with superior capabilities for diagnosing and detecting oncological and other diseases and investigating disease mechanisms, potentially allowing a paradigm shift in PET clinical use.
As the basic feasibility studies have been already carried out, this project specifically aims at designing building, testing and developing a first prototype of a full-size human whole body TOF-PET scanner with a field-of-view of 2 m and a borehole of 90 cm (Fig. 1).
The demonstration of this technology, offering a radically different alternative to crystal-based gamma detection systems, may open totally new avenues for future research in large-area gamma detection, even beyond medical applications.

**Fundamental idea**

Sensitivity is a fundamental parameter of PET systems. It determines the amount of radioactive tracer to be administered to the patient, the observation time and the noise level in the image for a given image granularity. Any improvement in system sensitivity will allow a corresponding improvement in one of these parameters or in a combination of them.
However, a practical view should be kept in that a successful new technology should provide the expected benefits without any significant increase in cost over the presently available commercial systems. This is by far not evident with many of the currently researched approaches and some compromise may be necessary [ERI06].
Our proposal for high-sensitivity PET at reasonable cost involves the TOF-PET technique along with a dramatic extension of the FOV [BLA03, ERI08], up to whole-body size (2 m), using a low-cost per unit area particle detector, with excellent spatial resolution, uniform in the Field-of-View owing to its Depth-of-Interaction capability and time-of-flight resolution of 300 ps.
Furthermore, a very large field-of-view, taking the whole image simultaneously (single-bed), has supplementary potential advantages over narrow-FOV PET. These include the possibility of imaging simultaneously the whole body, allowing a more complete study of dynamic processes, covering the whole subject at any given instant with a better temporal segmentation. Other advantages include the possibility of achieving better quantitation through improved scatter correction, since there is no activity outside the FOV.

**Innovative approach**

Our approach is based on a detector technology already used in High Energy Physics Experiments for time-of-flight measurements on charged elementary particles: timing Resistive Plate Chambers (tRPCs). Such gaseous

detectors have been deployed in areas over one hundred square meters at reasonable cost, while generally providing an excellent time resolution below 100 ps rms.
Several years ago our group proposed that such detectors might find useful application in TOF-PET technology, both for whole-body human scanning and small animal imaging [BLA03]. The application is based on the "converter plate"principle and takes decisive advantage of the naturally layered structure of tRPCs and of its economic construction in large areas. The expectable low efficiency for 511 keV photons is more than offset [COU07a, ERI08, CRE09] by the possibility to afford a very large field of view (FOV), on the order of 2 m.
The concept has also been independently reviewed [ERI08], although on a different set of assumptions, confirming that it may replace with advantage the present state-of-the-art crystal-based scanners for whole-body scanning.
[BLA03] Perspectives for positron emission tomography with RPCs, Blanco, A; Chepel, V; Ferreira-Marques, R; Fonte, P; Lopes, M.I; Peskov, V; Policarpo, A., Nucl. Instrum. and Meth. A 508 (2003) 88-93.
[COU07a] RPC-PET status and perspectives, M.Couceiro, A.Blanco, Nuno C.Ferreira, R.Ferreira Marques, P.Fonte, L.Lopes., Nucl. Instrum. and Meth. A 580 (2007) 915-918.
[CRE09] Whole-body single-bed time-of-flight RPC-PET: simulation of axial and planar sensitivities with NEMA and anthropomorphic phantoms, P. Crespo et al., 2009 IEEE Nuclear Science Symposium Conference Record (NSS/MIC), Jan 2010, Page(s): 3420 - 3425
[ERI06] Future instrumentation in positron emission tomography, L. Eriksson et al., 2006 IEEE Nuclear Science Symposium Conference Record, Volume 4, Oct. 29 2006-Nov. 1 2006 Page(s): 2542 - 2545.
[ERI08] Potentials for large axial field of view positron camera systems, L. Eriksson et al., 2008 IEEE MIC Conference, published in the Conference Record.

### 5.2.3 Objectives

To develop a full-size prototype that will demonstrate scientifically the RPC-PET concept. Translate this result into a useful clinical tool.

### 5.2.4 Achievements

A national project (PTDC/SAU-BEB/104630/2008 – "RPC-PET - A novel technology for single-bed whole-body human molecular imaging with higher sensitivity and resolution") continued its execution with a global budget of 190k€ over 3 years. LIP´s budget amounts to 120k€, intended for the development of a single-layer, full-size, scanner.
A large area RPC detector with 0.8 x 0.4 m^2 made with six 0.18 mm glass plates defining five 0.35 mm gas gaps was developed. This is supposed to be the basic RPC module for the scanner. The first prototype has shown initially a healthy behaviour but subsequently suffered some current leakage problems over the chamber edges and a new iteration is required. There are also dificulties with the external manufacturing of the enclosing (large area) acrilic box, featuring very thin walls to minimize photon absorption. It is hoped that a newly aquired (in the framework of another project) large area milling machine will allow us to produce ourselves this component.
The DAQ system, a "slice"of the very modern HADES DAQ (recently upgraded) including 192 ADC channels, 256 TDC channels, trigger processor and data hub was fully integrated with the custom front-end electronics and the system debugged. It is now fully operational.
Some progress was made concerning the determination of the performance of the RPC readout system using the above-mentioned detector.
Strong progress was achieved in the simulation and reconstruction tasks.
A simultaneous full-body 3D reconstruction algorithm integrating the TOF information was developed and presented in a major conference (IEEE NSS-MIC) and will be submitted to IEEE TNS.
A full simulation of the scanner including all scatter was developed. With basis on this simulation the assesment of the scanner following the NEMA 2001 standard was performed. As the standard was developed for smaller field-of-view scanners some carefull interpretation of the results must be made, mostly in favour of RPC-PET. However the strict NEMA 2010 NEC (noise-equivalente count rate) performance of RPC-PET, excluding any possible advantage from TOF information, was shown to exceed the best current comercial tomograph (PHILIPS GEMINI TF) by a factor 7.6.

### 5.2.5 Sources of Funding

| Code | Funding | Start | End |
|---|---|---|---|
| PTDC/SAU-BEB/104630/2008 | 120.856 € | 2010-04-01 | 2013-03-31 |

### 5.2.6 Team

**Project coordinator: João Lima**

| Name | Status | %of time in project |
|---|---|---|
| Alberto Blanco | Technician (LIP) | 20 |
| Américo Pereira | Technician (LIP) | 10 |
| Carlos Silva | Technician (LIP) | 10 |
| Joaquim Oliveira | Technician (LIP) | 10 |
| Miguel Couceiro | Researcher (LIP/ISEC) | 20 |
| Nuno Carolino | Technician (LIP) | 10 |
| Orlando Cunha | Technician (LIP) | 10 |
| Paulo Crespo | Researcher (LIP/ISEC) | 20 |
| Paulo Fonte | Researcher (LIP/ISEC) | 25 |
| Ricardo Caeiro | Technician (LIP) | 10 |
| Rui Alves | Technician (LIP) | 10 |
| Rui Marques | Researcher (LIP/FCTUC) | 10 |

### 5.2.7 Publications

**International Conference Proceedings**

- *A Direct Time-of-Flight Reconstruction for Whole-Body Single-Bed RPC-PET: Results from Lesion and Anthropomorphic Simulated Data*
  P. Martins, A. Blanco, F. Caramelo, M. Couceiro, N. C. Ferreira, R. Ferreira Marques, P. Fonte, L. Mendes, P. Crespo
  2011 IEEE Nuclear Science Symposium Conference Record MIC9.S-217

### 5.2.8 Presentations

**Poster presentations in international conferences**

- *A Direct Time-of-Flight Reconstruction for Whole-Body Single-Bed RPC-PET: Results from Lesion and Anthropomorphic Simulated Data*
  presented by
  2011 Nuclear Science Symposium and Medical Imaging Conference — Valencia, Spain.

### 5.2.9 Academic Training

**PhD Theses**

- *Study of PET systems of very wide field of view*
  Miguel Couceiro, (on-going)

### 5.2.10 Project Summary

| | number |
|---|---|
| International Conference Proceedings | 1 |
| Poster presentations in international conferences | 1 |

## 5.3 Feasibility study of using Compton scattering for medical imaging with positrons

### 5.3.1 Resumo

O projecto visa estudar o efeito da dispersão Compton em imagiologia médica com positrões. Em particular, pretende-se avaliar, por meios computacionais, o impacto dos acontecimentos, que envolvem a dispersão Compton no detector na imagem reconstruida e a possibilidade de incluir esses acontecimentos nos dados usados na reconstrução reduzindo assim o tempo de aquisição e a dose ao paciente. É também um dos objectivos a avaliação do efeito da polarização dos fotões gama, provenientes da aniquilação, na distribuição espacial da dispersão no meio detector com o objectivo de avaliar a importância desta informação para a reconstrução da imagem. Os meios computacionais usados no projecto incluem simulação Monte Carlo da propagação de raios gama no objecto e nos detectores. Assim, torna-se importante a validação dos métodos usados pelo GEANT para simulação dos processos electromagnéticos à baixas energias e, em particular, o efeito da ligação dos electrões em átomos. Além disso, está planeado um esforço experimental para tentar medir a orientação dos traços dos electrões de recuo. Se for bem sucedido, esta informação poderá impor constrangimentos adicionais para a reconstrução dos acontecimentos que envolvem a dispersão Compton e deste modo possibilitar a sua utilização para a reconstrução da imagem.

### 5.3.2 Abstract

This project aims at studying the feasibility of using Compton scattering of gamma-rays in medical imaging with positrons. In particular, our intent is to evaluate, by computational means, the impact on the PET image of inclusion of the events, involving Compton scattering in the detectors, into the input data for the image reconstruction thus reducing the acquisition time and the dose administrated to the patient. We also plan to evaluate the effect of the polarization of the annihilation photons on the spatial distribution of the scattered gamma-rays in the detection medium in order to assess to what extend this information can be useful for the image reconstruction. The computational means used in the project include Monte Carlo simulation on gamm photon propagation in the object and detectors. This makes important to evaluate the reliability of the methods used by GEANT to describe electromagnetic processes at low energy, the effect of bound electrons on the Compton scattering cross section, in particular. Finally, an experimental effort has been undertaken to measure the orientation of the recoil electron track in the gamma-ray detector with the purpose of obtaining information on the scattering plane and the polarization of the incoming photon. This can allow setting additional constraints on the reconstruction of the Compton sequences thus making feasible the use of scattered events for the image reconstruction.

### 5.3.3 Objectives

Assess the feasibility of using Compton scattered events in PET imaging as well as the possibility of using polarization entanglement of the annihilation photons and recoil electron tracking for that purpose.

### 5.3.4 Achievements

1. A computational tool including the Monte Carlo simulation of photon propagation, identification of lines of response from multiple interactions, Compton tracing and image reconstruction has been developed. Using this tool, it has been shown that a large part of the acquired events involving scattering in the detector can be used for reconstruction of the image in PET with the benefit of a significant increase of the image statistics or, for the same statistics, decrease of the dose administrated to the patient, without significant degradation of the image quality.
2. Feasibility of using polarization entanglement of the annihilation photons to extract useful information for identification of the scattered events has been assessed. The effect was found to be small.
3. The scattering cross section used by different physics models of GEANT4 (version 4.9.4.p02) have been compared with the experimental data bases and with those provided by the GLECS package developed for GEANT3. Significant deviations have been found in the keV energy region affected by the electron binding to atom. It was concluded that the best description of Compton scattering at low energies is provided by the GLECS package which is not included into GEANT4.
4. An experiment has been set to assess the possibility of measuring the Compton electron orientation to provide additional information for the reconstruction of scattering sequences. In this project, we have attempted to obtain this information by measuring the signal rise time is double phase liquid xenon chamber equipped with

a gaseous electron multiplier (GEM) in the gas phase. Given the experimental results it has been concluded that this method is not feasible due to significant electron scattering in the liquid and field non-uniformities at the GEM entrance.

### 5.3.5 Sources of Funding

| Code | Funding | Start | End |
|---|---|---|---|
| PTDC/FIS/67002/2006 | 72.000 € | 2009-01-01 | 2011-12-31 |

### 5.3.6 Team

**Project coordinator: Vitaly Chepel**

| Name | Status | %of time in project |
|---|---|---|
| Alessio Mangiarotti | Researcher (LIP) | 15 |
| Alexandre Lindote | Post-Doc (LIP) | 15 |
| Américo Pereira | Technician (LIP) | 15 |
| Armando Policarpo | Researcher (LIP/FCTUC) | 20 |
| Carlos Silva | Technician (LIP) | 5 |
| Cláudio Silva | Post-Doc (LIP/FCT) | 20 |
| Francisco Neves | Post-Doc (LIP) | 10 |
| Isabel Lopes | Researcher (LIP/FCTUC) | 25 |
| Joaquim Oliveira | Technician (LIP) | 5 |
| José Pinto Da Cunha | Researcher (LIP/FCTUC) | 20 |
| Nuno Carolino | Technician (LIP) | 10 |
| Orlando Cunha | Technician (LIP) | 5 |
| Rui Marques | Researcher (LIP/FCTUC) | 10 |
| Vitaly Chepel | Researcher (LIP/FCTUC) | 45 |
| Vladimir Solovov | Researcher (LIP) | 20 |

### 5.3.7 Academic Training

**Master Theses**

- *Study of Compton scattering in PET*
  Susana Vieira da Silva, 2011-09-18

### 5.3.8 Project Summary

| | number |
|---|---|
| Master Theses | 1 |

## 5.4 Monte Carlo methods applied to dosimetry in medical radiologic exposures

### 5.4.1 Resumo

As actividades do projecto desenvolveram-se em três componentes distintas
1) Desenvolvimento de dosimetros de cintiladores para radiologia e protecção radiológica em salas de exame.
2) Microdosimetria com feixes de partículas alfa emitidas pelo gás radão e seus descendentes
3) Avaliação das protecções estruturais em instalações de radiodiagnóstico e medicina nuclear.
Na primeira componente desenvolveram-se dosimetros de plástico lidos por fibras ópticas e fotodiodos. Um prototipo foi testado em ambiente clínico tendo-se mostrado capaz de medir a dose fornecida por uma fonte clínica de Ir-192 com rigor equivalente a uma câmara de ionização. Um prototipo desenvolvido para aplicações em radiologia foi testado em laboratório.
Na componente de Exposição ao Radão foi construido um pacote de simulação Monte Carlo de transporte de partículas alfa na matéria (AlphaMC). Este pacote integra o código Ulysses de codificação de geometrias e histogramação, já desenvolvido pelo grupo. O código AlphaMC permite uma simulação rápida da interacção das partículas alfa com estruturas, cujas dimensões podem ser da ordem do micrometro. No âmbito deste trabalho desenvolveu-se um modelo microdosimetrico da extremidade da árvore pulmonar (bronquíolo e alvéolo). Este modelo permite obter a energia efectiva depositada nas estruturas celulares por partículas alfa.
Na componente de radioprotecção realizou-se o estudo de radiação dispersa em instalações de radiologia e mamografia. As actuais metodologias para o cálculo das barreiras de protecção conduzem a uma sobreestimação das mesmas, com custo financeiros significativos. Neste trabalho complementou-se as medições feitas com o equipamento GE SENOGRAPHE DMR+ , no Hospital de Faro, com simulações de Monte Carlo. Usou-se o código PENELOPE para simular a radiação dispersa num exame de mamografia. A comparação com os dados experimentais revelou uma acordo razoável. Esta validação é importante pois permite usar as simulações de Monte Carlo para estimar o efeito do paciente em posições em que os dados experimentais são logisticamente difíceis de obter. Estas simulações são morosas e, por isso, utilizou-se os recursos computacionais do LIP, nomeadamente a LIP FARM. Os dados experimentais foram obtidos com o detector UNIFORS Xi Survey , na situação de irradiação com a paciente, simulada pelo fantôma antropomórfico AR10A acoplado a uma mama comprimida de material PMMA. Os resultados obtidos implicam a revisão das recomendações internacionais (NCRP 147, 2004) e, consequentemente, da legislação nacional (DL 180/2002). Este trabalho foi apresentado em conferências internacionais e foi recentemente submetido numa revista internacional com arbitragem cientifica.

### 5.4.2 Abstract

The project activities developed into three distinct components
1) Development of scintillator dosimeters for radiation protection in radiology and exam rooms.
2) Microdosimetry with alpha particles emitted by radon and its progeny
3) Evaluation of structural protection in diagnostic radiology facilities and nuclear medicine.
In the first component plastic dosimeters read by optical fibers and photodiodes were developed. A prototype was tested in a clinical environment and has been shown to be capable of measuring the dose delivered by a source of Ir-192 clinical with accuracy equivalent to an ionization chamber. A prototype developed for applications in radiology has been tested in the laboratory.
In the the radon exposure framework a Monte Carlo simulation of transport of alpha particles in matter (AlphaMC) was developed. This package includes the code Ulysses for geometry coding and histogramming, already developed by our group. The AlphaMC code allows a fast simulation of the interaction of alpha

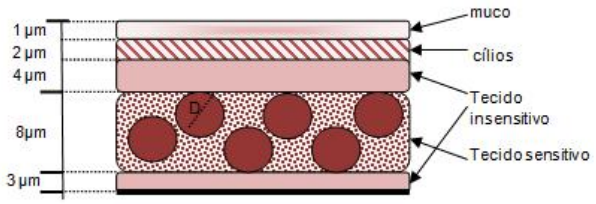



Figure 5.2: Model of the respiratory bronchioles generation 19 used in the microdosimetry studies.

particles with structures whose dimensions can be of the order of micrometer. In this work we developed a microdosimetrical model of the end of the pulmonary tree (bronchioles and alveoli). This model allows the computation of the effective energy deposited in the cell structures by alpha particles.
The component in radiation protection we studied the scattering of radiation in radiology and mammography. Current shielding methodologies can lead to an over-shielding of low energy X-ray facilities with significant financial costs. In this work we complemented measurements done with the GE SENOGRAPHE DMR+ equipment, at the Faro Hospital, with Monte Carlo simulations. The PENELOPE code was used to simulate the scattered radiation in mammography exams, including the effect of the patient. Comparison with experimental data shows a general good agreement between them. This validation is important since Monte Carlo simulations can be used to estimate the patient absorption effect in positions where experimental data is logistically hard to get. These time-consuming simulations were performed at LIP´s computing facilities, namely, the LIP FARM. The experimental data was obtained with the UNIFORS Xi Survey detector in the situation of a simulated patient exposure, using the anthropomorphic phantom AR10 coupled to a compressed breast made of PMMA. These results imply a revision of international recommendations (NCRP 147,2004) and , consequently of the national legislation (DL180/2002). This work as been presented at international conferences and was recently submitted for publication in a peer review journal.

### 5.4.3 Objectives

1) To build a plastic based dosimeter suitable for High Dose Rate Brachytherapy with 192Ir source
For more than a decade that plastic optical fiber based dosimeters have been developed for medical applications. In the energy range up to a few hundred keV, where the production of Cherenkov light by secondary electrons is negligible, the largest source of background are the fluorescence mechanisms. In recent years we have developed an optical fiber dosimeter, with photodiode readout, named DosFib, which has a small energy dependence in the range below 100 keV relevant for radiology.
2) To build a plastic based dosimeter suitable for radiology applications
Some of the existing active dosimeters are based on silicon devices, which are not water equivalent. Plastic scintillators on the other hand have better water equivalence, but suffer in the past from a lack of portability due to the use of PMT´s as the light readout device. High-sensitivity PIN-photodiodes or new high-gain Si-PMT´s can solve the portability issue, allowing the construction of a device that operates at low voltage. Furthermore, light can be collected and carried out to the photodetector with optical fibers.
3) Development of a fast Monte Carlo code for alpha particle transport.
The code must be able to handle complex geometries and transport alpha particles in the most common available materials.
4) Development of a model of the cell structure at the bronchioles and alveoli level for microdosimetrical studies.
In this project is our goal to analyze the interaction of radon and its direct descendants with the human respiratory tract cells. The model is based on the peripheral segments of the lung, commonly referred to as lobes, which includes the respiratory bronchioles, alveoli and pulmonary lymphatic region , where gas exchange takes place between the blood circulating in the capillaries lining the alveoli and alveolar air itself. The area under study has been constantly overlooked in radiological studies by assigning it a small percentage of lung tumors. However, the region is an area of considerable interest since the effects of tobacco are minimum in that region due to the small size of the structures studied, highlighting the importance of the effect of radon and its progeny in the development of radiation-induced cancers.
5) Radiation attenuation studies in heterogeneous materials used in shielding barriers for nuclear medicine.

### 5.4.4 Achievements

Main Achievements
1) Small dimension plastic dosimeter in High Dose Rate Brachytherapy with 192Ir source
The sensitive volume of the dosimeter consists of a plastic optical fiber BCF-10 from Saint-Gobain, 2 mm in diameter and 5-mm long, coupled to a clear optical fiber 1-m long. The scintillation light is read by an Hamamatsu S9195 photodiode which in turn is read by an electrometer. Our aim was to extend the device to brachytherapy applications, namely the ones using High Dose Rate 192Ir sources. The question was to know if the DosFib dosimeter could perform equally well with this type of source, in particular if the dose curve at clinical distances obtained in water was comparable to results of well established dosimeters, namely ionization chamber, frequently used for calibrations, and the MOSFET dosimeter used for in-vivo dosimetry. A phantom consisting of an acrylic box filled with water was custom made for the tests. The obtained DosFIB dose curve agrees well with the ones obtained using an ionization chamber and MOSFET, showing that the DosFib can be used to measure dose at clinical distances.

2) Plastic scintillator dosimetry in radiology applications
One one the build prototypes was constituted by a 2 cm x 2 cm and 3 mm thick slab of polystyrene doped with 1.5% of PTB and 0.044% POPOP. Glued to one side a red polystyrene WLS fiber 2 mm in diameter (810093 Industrial Fiber Optics) collects the blue light produce in the scintillator and re-emits it red-shifted. The WLS fiber is coupled to a Hamamatsu S9195 pin-photodiode which produces an electrical signal read by a Standard Imaging Max 4000 electrometer. Experimental tests were made using an X-ray tube (Philips PW2184/00) with a tungsten anode and voltages ranging from 20 to 100 kV. The device sensitivity define has the ratio between the measured signal in the photodiode and the dose in water was obtained. Our results suggest a sensitivity dependence both in the beam mean energy and used addition beam filtration (Al filtration). This dependence is in part due to the polystyrene-water ratio of the average mass energy absorption coefficients dependence on the beam energy. The observed sensitivity low energy dependence can also be due to ionization quenching as referenced by other authors.
3) Development of a fast Monte Carlo code for alpha particle transport.
The AlphaMC code for fast alpha particle transport has been developed. The code is capable of following alpha particles through complex geometries due to the use of the Ulysses code, developed within our group. The AlphaMC simulation results have been successfully compared with experimental data obtained with surface barrier detectors.
4) Microdosimetry
The model we present is a mixed model including respiratory bronchioles and regions consist of a series of concentric spheres which illustrate the variety of tissue constituents of the air sacs and lining capillary. The area can thus be divided into three regions: bb (bronchiolar), AI (alveolar) and L (lymphatic) following the recommendations of publication ICRP66. Our model considers the lung morphology of a Caucasian man with typical mass and height (50% percentile). It was assumed a characteristic house ventilation rate and a respiratory rate considered normal in a situation of little physical exercise.
The computation of the deposited dose in the radio-sensitive cells assumes a scenario of exposure to radon and its progeny corresponding to an housing occupancy of 80%, which corresponds to 7000 h per year. The annual effective dose is determined taking into account the sensitivity of cells studied.
Results are obtained for a number of microdosimetry variables in the nuclei of basal cells of the respiratory bronchioles generation 19 (G19), basal cells (PNI) and secretory (PnII) of the pulmonary alveoli, the basal cells lining the alveolar capillary blood and red blood cells .
The heterogeneity of the values found for the different microdosimetry variables may provide a clue on the incidence of radiation-induced tumors in the region of the human lung acinus.
5) Protective barriers
The mass attenuation coefficient was successfully measured for the material barite (concrete rich in barium sulfate) at the gamma energy of 662 keV. The present samples of barite are produced by the Portuguese company TABAL SEPOR Lda. This work was done in the framework of a protocol made with this company. A good accuracy in determining the mass attenuation coefficient at these energies is particularly relevant for radiation protection of Nuclear Medicine installations. This work will be published as part of a master degree thesis and the experimental results will be integrated in the material specifications brochure of the company.

### 5.4.5 Team

**Project coordinator: Luis Peralta**

| Name | Status | %of time in project |
|---|---|---|
| Alina Louro | PhD student (LIP) | 80 |
| Carmen Oliveira | PhD student (LIP) | 80 |
| Conceição Abreu | Researcher (LIP) | 50 |
| Florbela Rego | Researcher (LIP) | 80 |
| Jorge Sampaio | Researcher (CFA/FCUL) | 20 |
| Luis Filipe Silva | Student (LIP) | 80 |
| Luis Peralta | Researcher (LIP/FCUL) | 80 |
| Margarida Isabel Inácio | Master student (LIP) | 25 |
| Maria do Anjo Albuquerque | PhD student (LIP) | 80 |
| Marta Dias | Master student (FCUL) | 5 |
| Patricia Lima | Student (ESSUAlg) | 25 |
| Paulo Jorge Soares | Student (UBI) | 25 |
| Rui Carvalhal | Graduate student (LIP) | 30 |
| Sandra Soares | Researcher (LIP/UBI) | 80 |
| Sónia Dias | Master student (FCUL) | 5 |
| Tiago Ribeiro | Master (HSM) | 50 |
| Yoenls Bahu | Master student (LIP/FCUL) | 100 |

### 5.4.6 Publications

**Articles in international journals (with direct contribution from LIP members)**

- *Development of a scintillating optical fiber dosimeter with silicon photomultipliers*
  Luis Miguel Moutinho, M. Ismael, F Castro, Luís Peralta, Maria C Abreu e João F Veloso
  Nuclear Instruments and Methods A (accepted)

- *Can the HVL help the X-ray tube mechanical characterization?*
  Florbela Rêgo, Luis Peralta, Mafalda Gomes
  X-Ray Spectrometry 40 (2011) 235-239

- *Um exemplo de exposição ao rádon ambiental em Portugal*
  Luis Peralta e Alina Louro
  Revista Iberoamericana de Física, Vol. 7 Outubro 2011, 63-66

**International Conference Proceedings**

- *Plastic scintillator dosimetry for radiology aplications*
  C.H. Oliveira , F. Rego, L. Peralta and M.C. Abreu
  Proceedings of IEEE Nuclear Science Symposium and Medical Imaging Conference, Valencia, Spain, 23-29 Outubro 2011

- *Small dimension plastic dosimeter in High Dose Rate Brachytherapy with 192Ir*
  F. Rego, T. Ramos Ribeiro, L. Peralta and C. Jesus
  Proceedings of IEEE Nuclear Science Symposium and Medical Imaging Conference, Valencia, Spain, 23-29 Outubro 2011

### 5.4.7 Presentations

**Oral presentations in international conferences**

- *Should we reassess structural shielding design of mammographic installations?*
  presented by Jorge Sampaio
  EMPEC 2011, European Medical Physics and Engineering Conference 2011 — Dublin, Irelanda.

- *Monte Carlo simulation for elemental determination of uranium in contaminated areas*
  presented by Luis Peralta
  Workshop Heavy Metals, from the environment to man, 12 Dezembro 2011, Lisboa. — Lisboa.

**Poster presentations in international conferences**

- *Plastic scintillator dosimetry for radiology apllications*
  presented by Luis Peralta
  IEEE Nuclear Science Symposium and Medical Imaging Conference — Valencia, Spain, 23-29 Outubro 2011.
- *Small dimension plastic dosimeter in High Dose Rate Brachytherapy with 192Ir*
  presented by Florbela Rego
  IEEE Nuclear Science Symposium and Medical Imaging Conference — Valencia, Spain, 23-29 Outubro 2011.

**Presentations in national conferences**

- *Estudo da Distribuição da Radiação Dispersa numa Unidade de Mamografia*
  presented by Patrick Sousa
  I Jornadas de Radiologia da ESSUAlg,Faro, 29 e 30 de Abril, 2011 — Faro.
- *A Importância do Efeito Anódico na Qualidade da Imagem*
  presented by Patrick Sousa
  I Jornadas Técnicas de Radiologia da Escola Superior de Saúde Dr. Lopes Dias (ESALD), do Instituto Politécnico de Castelo Branco — Castelo Branco.
- *Estaremos a sobrestimar o dimensionamento das barreiras de protecção radiológica?*
  presented by Jorge Sampaio
  — Departamento de Fisica da FCUL, Novembro de 2011.

**(unspecified Communications)**

- *Should we reassess structural shielding design of mammographyc installations?*
  presented by Jorge Sampaio
  European Medical Physics and Engineering Conference, IPEM — Dublin, Irlanda.

### 5.4.8 Academic Training

**PhD Theses**

- *Environmental Radon Exposure and Human Health Risk*
  Alina Louro, (on-going)

**Master Theses**

- *Determinação da Concentração de Radão num Estabelecimento de Ensino Público*
  Paulo Jorge Soares, 2011-11-17
- *Novas técnicas de cálculo de barreiras de protecção para mamografia e radiografia toráxica*
  Luis Filipe Silva, (on-going)
- *A Física das Radiações no 3º Ciclo do Ensino Básico*
  Margarida Isabel Inácio, 2011-11-15
- *Study of scintillating plastic based dosimeters*
  Yoenls Bahu , (on-going)
- *Scan path optimization for active beam delivery in charged particle therapy*
  Marta Dias, (on-going)
- *Estudo da atenuação da radiação ionizante em materiais heterogéneos usados na construção de barreiras de proteção radiológica*
  Sónia Dias, (on-going)

**Graduation Theses**

- *Estudo da Distribuição da Radiação Dispersa numa Unidade de Mamografia*
  Patricia Lima, 2011-12-31

### 5.4.9 Events

- *Onde podemos encontrar o Radão?*
  Outreach Event, UBI, Covilhã, 2011-06-15

### 5.4.10 Project Summary

| | number |
|---|---|
| Articles in international journals (with direct contribution from LIP members) | 3 |
| International Conference Proceedings | 2 |
| Oral presentations in international conferences | 2 |
| Poster presentations in international conferences | 2 |
| Presentations in national conferences | 3 |
| *(unspecified Communications)* | 1 |
| Master Theses | 2 |
| Graduation Theses | 1 |
| Outreach Events | 1 |

## 5.5 Orthogonal Imaging for Radiology and Radiotherapy

### 5.5.1 Resumo

O LIP submeteu um registo provisório de patente ao INPI (Instituto Nacional da Propriedade Industrial) que aborda o conceito de tomografia computorizada baseada na detecção de radiação electromagnética emitida ortogonalmente em relação ao feixe incidente. O conceito foi denominado de OrthoCT e potencia obter informação morfológica do alvo (e.g. paciente) em 3D. Para tal, são utilizados um ou vários detectores de radiação e uma ou mais fontes de raios-X de megavoltagem. O feixe ou feixes incide(m) no alvo a partir de direcções opostas, com os eixos dos detectores posicionados a aproximadamente 90 graus relativamente ao eixo do feixe incidente. Resultados de simulação e experimentais (cf. Fig.) mostram que a OrthoCT providencia de facto informação morfológica do alvo em 3D, com rácios de densidades idênticos ou potencialmente melhorados relativamente à imagiologia tomográfica convencional (TAC). As simulações mostram ainda que é possível obter os resultados mencionados mesmo com uma redução da dose no alvo/paciente relativamente à TAC. Um exame OrthoCT a

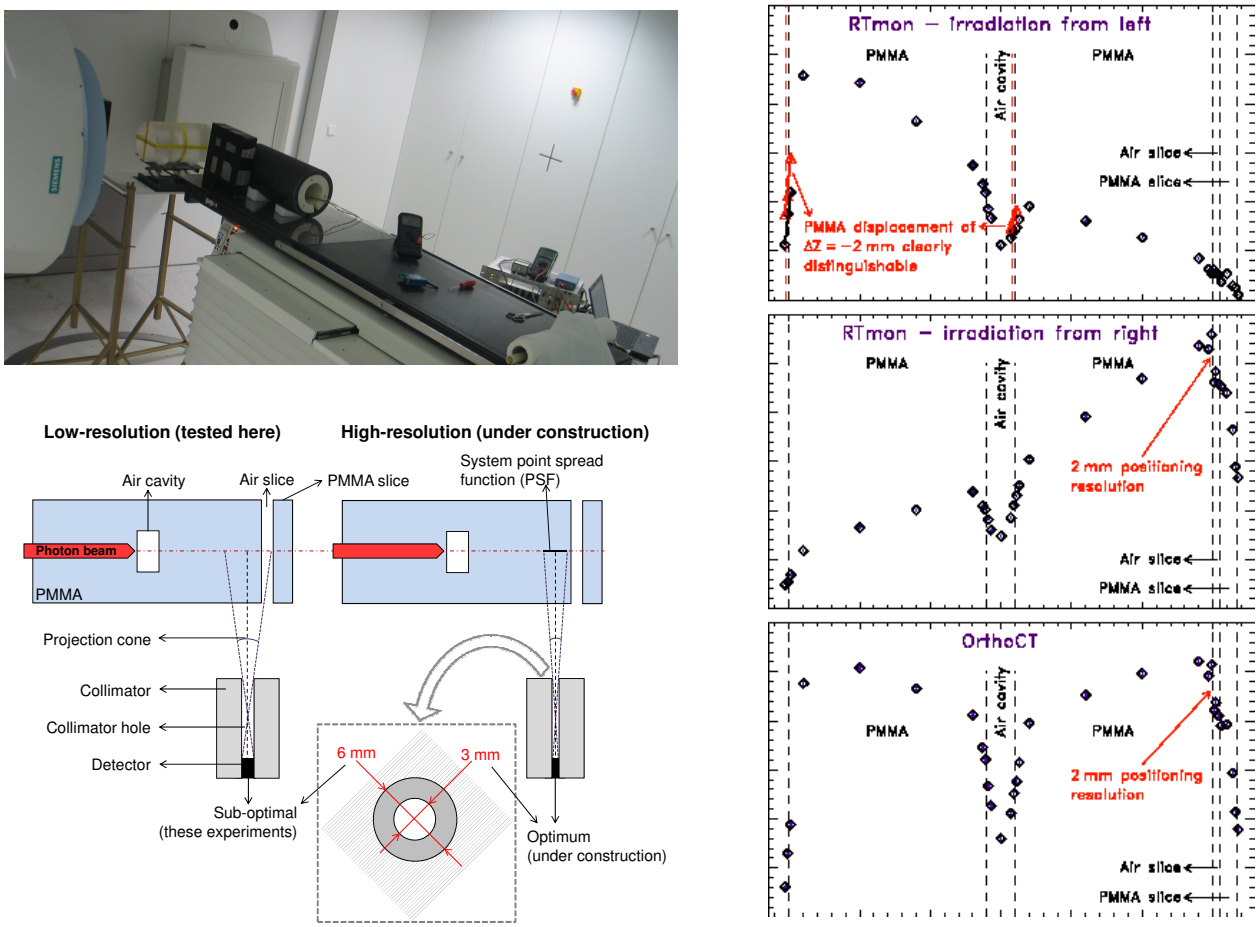



Figure 5.3: Experimental results obtained with a sub-optimal OrthoImaging setup mounted at the Oncology Center of Coimbra (IPOCFG, EPE) for proof-of-principle demonstration. A megavoltage X-ray beam was utilized, representing at this stage an isocenter dose of approximately 1 Gy. Left: Photograph (top) and scheme (bottom) showing the sub-optimal experimental setup utilized, together with the setup being constructed at LIP. Right top and middle: Experimental RTmon results show both unprecedented correlation with target dose (not shown) and also the capability of the technique to resolve target deviations of at least 2 mm. Right bottom: Experimental OrthoCT results showing a correlation of the detected counts profile with target density. The statistical error bars in all images are contained within each data point shown.

um cérebro de um adulto, por exemplo, sujeitá-lo-ia a uma dose pelo menos 40 vezes inferior relativamente à dose mínima tipica num exame TAC idêntico (sem prejuízo para a qualidade da imagem).
Anteriormente ao conceito de OrthoCT, foi proposto também no âmbito da nossa equipa um conceito igualmente inovador para monitorização in-vivo de dose em radioterapia com raios-X, que foi denominado de RTmon (real-time radiotherapy monitoring). Resultados de simulação e experimentais mostram que tal como na OrthoCT, a imagiologia RTmon providencia informação espacial 3D, desta vez correlacionada em tempo real com a dose in-vivo, enquanto esta está a ser aplicada. O mesmo conceito de detecção pode ser aplicado na monitorização de dose em hadroterapia, como o comprovam esforços a nível mundial nesse sentido. No entanto, na hadroterapia as exigências a nível do desempenho dos detectores são acrescidas devido a uma forte componente neutrónica gerada no alvo/paciente que perturba em grande medida a qualidade das imagens adquiridas em tempo real durante a irradiação. Estão a ser desenvolvidos esforços a nível das resoluções temporal e energética dos detectores que, resultados de simulação assim o indicam, mitigam em boa medida a degradação das imagens devido a esta forte presença de neutrões rápidos.
Tanto a OrthoCT como a RTmon são técnicas pertencentes ao conceito mais abrangente denominado de OrthoImaging que, nas suas vertentes em imagiologia com raios-X e em hadroterapia, está ser desenvolvido no âmbito de colaborações existentes entre o LIP e: a Universidade de Coimbra, o IPO de Coimbra (IPOCFG, EPE), a Faculdade de Medicina da Universidade de Sevilha em Espanha, a Universidade Técnica de Delft na Holanda (TU Delft), e o HIT (Centro de Radioterapia com Partículas de Heidelberg) na Alemanha. Muito recentemente, a Universidade da Catânia em Itália juntou-se também a estes esforços colaborativos.

### 5.5.2 Abstract

A provisional patent application has been submitted to INPI (Instituto Nacional da Propriedade Industrial) by LIP addressing the concept of orthogonal computed tomography (OrthoCT) for 3D imaging of target (e.g. patient) morphological information. The system is termed OrthoCT and comprises one or more photon detectors and one or more photon sources. Incoming photon fluxes impinge on the target from opposite directions, with one or several detectors positioned with their axes at approximately 90 degrees in respect to the beam axes. We have shown by simulation, confirmed by experiments, that OrthoCT is capable of providing 3D target density information (cf. Fig.). Density ratios equivalent or better than those attainable by state-of-the-art tomographic imaging have also been shown. The simulations also show that these results are obtained with a reduced dose in respect to that delivered by state-of-the-art clinical computed tomography (CT). For example, OrthoCT potentially reduces dose by a factor of at least 40 – without jeopardizing image quality – in respect to the minimum dose typically utilized in a brain CT scan of an adult. Finally, simulations also provide evidence that OrthoCT image contrast even at such low dosage is maintained or even enhanced in respect to that provided by modern CT technology.
Prior to engaging into OrthoCT, our team has also proposed and equally verified experimentally that such orthogonal imaging provides optimal information to be collected during X-ray-based radiotherapy treatments. Simulations and experimental results show that collecting data with the axes of the detector positioned at 90 degrees with respect to the beam axes profits from azimuthal particle emission which is well correlated with dose delivery not only for X-ray, but also for particle-based radiotherapy. Preliminary results indicate that the method is able to provide such dose correlation with one single portal, avoiding the typical need for several portals to be imaged before 3D in-vivo dose information may be reconstructed. For hadrontherapy dose monitoring, an added challenge arises due to the presence of fast neutrons that are generated in the target/patient, reaching the detectors. Collaborative efforts are being put forward at the level of improving detector time and energy resolutions which, simulations show, strongly mitigate the image deterioration that such a neutron component could represent.
The topic of OrthoImaging, comprising OrthoCT and RTmon, is being driven in its electromagnetic and hadron components within collaborative work between LIP and: the University of Coimbra, Coimbra Oncology Center (IPOCFG, EPE), the Medical Faculty of the University of Seville in Spain, Delft University of Technology (TU Delft) in The Netherlands, and the Heidelberger Ionenstrahl-Therapiezentrum (HIT) in Germany. Recently, we have further united efforts with the University of Catania in Italy.

### 5.5.3 Sources of Funding


| Code | Funding | Start | End |
|---|---|---|---|
| OrthoImaging 1 | 5.000 € | 2010-12-15 | 2011-02-28 |
| OrthoImaging 2 | 6.000 € | 2011-05-15 | 2011-09-30 |

### 5.5.4 Team

**Project coordinator: Paulo Crespo**

| Name | Status | %of time in project |
|---|---|---|
| Hugo Simões | | 37 |
| Marco Pinto | | 85 |
| Micaela Cunha | Master (LIP) | 28 |
| Patrícia Cambraia Lopes | | 92 |
| Paulo Crespo | Researcher (LIP/ISEC) | 50 |

### 5.5.5 Publications

**International Conference Proceedings**

- *Dose-free monitoring of radiotherapy treatments with scattered photons: concept and simulation study*
  M. Cunha, M. Pinto, B. Ferreira, M.C. Lopes, P. Fonte, P. Crespo
  2011 IEEE Nucl. Sci. Symp. & Med. Imag. Conf, Valencia, MIC11–5

- *Dose-free monitoring of radiotherapy treatments with scattered photons: first experimental results at a 6-MV linac*
  H. Simões, M. Pinto, M. Cunha, J. Gonçalves, L. Sampaio, R.J. Ferreira, H.M. Saraiva, A.R. Barbeiro, M. Capela, B. Ferreira, P. Fonte, S. Ghithan, A. Leal Plaza, M.C. Lopes, P. Martins, P. Crespo
  2011 IEEE Nucl. Sci. Symp. & Med. Imag. Conf, Valencia, MIC21.S–258

- *Range and density variations monitoring during proton therapy based on time-of-flight detection of prompt gamma radiation*
  A.K. Biegun, E. Seravalli, P. Cambraia Lopes, I. Rinaldi, M. Pinto, D.C. Oxley, P. Dendooven, F. Verhaegen, K. Parodi, D.R. Schaart, P. Crespo
  2011 IEEE Nucl. Sci. Symp. & Med. Imag. Conf, Valencia, MIC15.S–290

### 5.5.6 Presentations

**Oral presentations in international conferences**

- *Dose-free monitoring of radiotherapy treatments with scattered photons: concept and simulation study*
  presented by Marco Pinto
  2011 IEEE Nucl. Sci. Symp. & Med. Imag. Conf — Valencia.

**Poster presentations in international conferences**

- *Prompt gammas – physics capabilities for monitoring range and density variations during proton therapy*
  presented by A.K. Biegun
  PTCOG 50 — Philadelphia, PA, USA, 8-14 May 2011.

- *Dose-free monitoring of radiotherapy treatments with scattered photons: first experimental results at a 6-MV linac*
  presented by Hugo Simões
  2011 IEEE Nucl. Sci. Symp. & Med. Imag. Conf — Valencia.

**Presentations in national conferences**

- *Optimization of a detector for monitoring photon radiotherapy*
  presented by Paulo Crespo
  III Jornadas do Departamento de Física e Matemática do ISEC — ISEC, Coimbra.

- *Diagnóstico e Terapia: da radioterpia com raios X e gama aos iões de hidrogénio e carbono*
  presented by Paulo Crespo
  IV Encontro Radiação e Ambiente — Penacova.

**Oral presentations in international meetings**

- *Advantages and disadvantages of prompt versus delayed events for monitoring particle therapy*
  presented by Patrícia Cambraia Lopes
  Workshop — INP Lyon, France.

- *Advantages and disadvantages of prompt versus delayed events for monitoring particle therapy*
  presented by Patrícia Cambraia Lopes
  Invited seminar — Clermont Ferrand, France.

**Seminars**

- *RTmon: a device for real-time (dose) monitoring of radiotherapeutic treatments*
  presented by Marco Pinto
  Café com Física — Coimbra.

### 5.5.7 Academic Training

**PhD Theses**

- *Demonstration of a time-of-flight device for particle therapy monitoring*
  Patrícia Cambraia Lopes, (on-going)

### 5.5.8 Project Summary

| | number |
|---|---|
| International Conference Proceedings | 3 |
| Oral presentations in international conferences | 1 |
| Poster presentations in international conferences | 2 |
| Presentations in national conferences | 2 |
| Oral presentations in international meetings | 2 |
| Seminars | 1 |

# Chapter 6

# Detectors

## 6.1 Participation in the RD51 Collaboration

### 6.1.1 Resumo

A colaboração RD51 [RD51] tem como objectivo facilitar o desenvolvimento de tecnologias avançadas de detectores gasosos de partículas e dos sistemas de leitura associados para aplicação na investigação básica e aplicada. O principal objectivo do programa de I&D é o avanço da tecnologia de Detectores Gasosos de Microestruturas. A invenção de Detectores Gasosos de Microestruturas (MPGD), em particular o Multiplicador Gasoso de Electrões (GEM), da Estrutura Gasosa de Micro-grelhas (MICROMEGAS), e mais recentemente outros esquemas de microestruturas, oferece o potencial para desenvolver novos detectores gasosos com resolução espacial sem precedentes, elevada taxa de contagem, grande área sensível, estabilidade operacional e resistência à radiação. Nalgumas aplicações, requerendo a cobertura de áreas muito elevadas com resolução espacial moderada, detectores macroestruturados, por exemplo o GEM espesso (THGEM) ou câmaras de placas resistivas estruturadas poderão oferecer uma solução interessante e económica.
A constituição dos novos detectores microestruturados parece adequada à sua produção industrial. Adicionalmente, a disponibilidade de sistemas electrónicos altamente integrados de amplificação e leitura permite o desenvolvimento de sistemas de detectores gasosos com densidade de canais comparável à dos detectores de silício modernos. O pós-processamento moderno de bolachas de silício permite a integração de estruturas de amplificação gasosa directamente em cima de uma pastilha de silício pixelizada. Graças a estes desenvolvimentos recentes, a detecção de partículas através da ionização do gás tem largos campos de aplicação em futuras

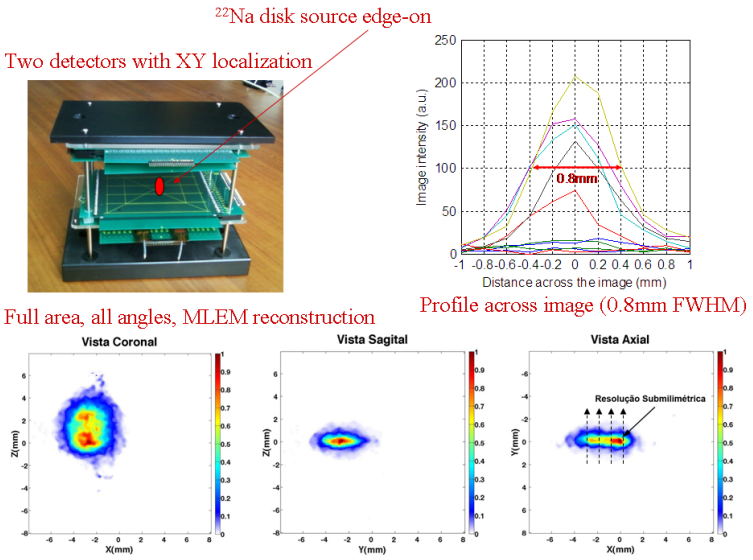



Figure 6.1: Experimental setup and results of a single-layer prototype of the animal RPC-PET scanner, showing a world-class position resolution of 0.8mm FWHM.

experiências de física das partículas, nuclear a de astro-partículas, com e sem aceleradores.
A colaboração RD51 envolve ≈350 autores, 59 Universidades e Laboratórios de 20 países na Europa, América, Ásia e África. Todos os parceiros perseguem activamente quer investigação básica, quer aplicada envolvendo uma variedade de conceitos de MPGD. A colaboração estabeleceu objectivos comuns, tais como ferramentas experimentais e de simulação comuns, métodos e conceitos de caracterização, infra-estruturas comuns em feixes de teste e instalações de irradiação, e métodos e infraestruturas para a produção de MPGD.
[RD51] RD51 proposal (http://rd51-public.web.cern.ch/RD51-Public/Documents/RD51Proposal_21082008.pdf)

### 6.1.2 Abstract

he RD51 collaboration [RD51] aims at facilitating the development of advanced gas-avalanche detector technologies and associated electronic-readout systems, for applications in basic and applied research. The main objective of the R&D programme is to advance technological development and application of Micropattern Gas Detectors.
The invention of Micro-Pattern Gas Detectors (MPGD), in particular the Gas Electron Multiplier (GEM), the Micro-Mesh Gaseous Structure (MICROMEGAS), and more recently other micro pattern detector schemes, offers the potential to develop new gaseous detectors with unprecedented spatial resolution, high rate capability, large sensitive area, operational stability and radiation hardness. In some applications, requiring very large-area coverage with moderate spatial resolutions, more coarse Macro-patterned detectors, e.g. Thick-GEMs (THGEM) or patterned resistive-plate devices could offer an interesting and economic solution.
The design of the new micro-pattern devices appears suitable for industrial production. In addition, the availability of highly integrated amplification and readout electronics allows for the design of gas-detector systems with channel densities comparable to that of modern silicon detectors. Modern wafer post-processing allows for the integration of gas-amplification structures directly on top of a pixelized readout chip. Thanks to these recent developments, particle detection through the ionization of gas has large fields of application in future particle, nuclear and astro-particle physics experiments with and without accelerators.
The RD51 collaboration involves ≈ 350 authors, 59 Universities and Research Laboratories from 20 countries in Europe, America, Asia and Africa. All partners are already actively pursuing either basic- or application-oriented R&D involving a variety of MPGD concepts. The collaboration established common goals, like experimental and simulation tools, characterization concepts and methods, common infrastructures at test beams and irradiation facilities, and methods and infrastructures for MPGD production.
[RD51] RD51 proposal (http://rd51-public.web.cern.ch/RD51-Public/Documents/RD51Proposal_21082008.pdf)

### 6.1.3 Objectives

The responsibilities of LIP are in the following workgroups (WG) and tasks (T):

- Common Characterization and Physics Issues (WG2):
  - (T2) Discharge studies and spark-protection developments for MPGDs;
  - (T3) Generic aging and material radiation-hardness studies;
- Applications (WG3):
  - (T1) MPGD based detectors for tracking and triggering;
  - (T7) Medical imaging and diagnostics applications.

For WG2-T2 we will collaborate in the elaboration of a bibliographic review of the breakdown features of gaseous detectors, aiming at the publication of a CERN yellow report.
For WG2-T3, we will study the chemical properties of the polymerized material that is produced by the operation of detectors in fluorinated gases and will address the possibility of adding polymerization inhibitors to the gas mixture.
For WG3 we will develop patterned RPCs for two applications: TOFtracker (T1) and small-animal PET (T7). These detectors will be capable simultaneously of sub-millimetric localization accuracy and timing resolution below 100ps.
The TOFtracker device will be aimed at high-multiplicity tracking because it provides a 4th coordinate, time, which can be used to match the hits corresponding to the same track and its correlation with the beam hodoscope readings. This may be of use, for instance, for NA60-like experiments where the exquisite time resolution would help matching the pre-absorber to the post-absorber tracks, while reducing the combinatorial background.

The small animal RPC-PET will feature a world-leading image resolution of close to 0.5 mm FWHM (already demonstrated at small scale [BLA06]), largely dominated by physical limitations and not by instrumental effects. This will be achieved in a compact, low cost, instrument, benefitting from the simplicity of construction of RPCs.
[BLA06] A.Blanco, et al., "RPC-PET: A new very high resolution PET technology", IEEE Trans. Nucl. Sci.53 (2006) 2489-2494

### 6.1.4 Achievements

For WG2-T2 we developed a new modelling strategy for avalanches and streamers on a hydrodynamic approach solved by finite elements. This was the subject of a half-day session at the "RD51 simulation school, CERN, Switzerland, 19-21 Jan. 2011". Detailed lecture notes were published internally as RD51-note 2011-005.
For the same workgroup we initiated the elaboration of a bibliographic review of the breakdown features of gaseous detectors, aiming at the publication of a CERN yellow report. This will be also published as a review in JINST, for which a contract has been signed.
For WG3-T3, progress was made in the implementation of the animal RPC-PET scanner. Tests of a prototype comprising two detectors with X,Y information imaging a disc-like 22Na source yielded reconstructed position resolution of 0.8mm FWHM. This is a world-class figure, unsurpassed by any known comercial scanner.The construction of a full scanner is in an advanced stage and it is expected for 2012.
Also for WG3-T7, progress was made on the implementation of a TOFtracker device that will deliver simultaneous time and position information on the order of 100ps and 0.1mm, respectivelly.
Two year funding of 50k€ was recommended for aproval by the "CERN program".

### 6.1.5 Sources of Funding

| Code | Funding | Start | End |
|---|---|---|---|
| CERN/FP/109355/2009 | 30.000 € | 2010-04-01 | 2011-03-31 |
| CERN/FP/116392/2010 | 27.000 € | 2011-04-01 | 2012-06-30 |

### 6.1.6 Team

**Project coordinator: Rui Marques**

| Name | Status | %of time in project |
|---|---|---|
| Alberto Blanco | Technician (LIP) | 16 |
| Américo Pereira | Technician (LIP) | 14 |
| Carlos Silva | Technician (LIP) | 14 |
| Joaquim Oliveira | Technician (LIP) | 14 |
| Luís Lopes | Technician (LIP) | 15 |
| Miguel Couceiro | Researcher (LIP/ISEC) | 12 |
| Nuno Carolino | Technician (LIP) | 14 |
| Nuno Filipe Silva Dias | Technician (LIP) | 11 |
| Orlando Cunha | Technician (LIP) | 14 |
| Paulo Crespo | Researcher (LIP/ISEC) | 12 |
| Paulo Fonte | Researcher (LIP/ISEC) | 21 |
| Paulo Martins | PhD student (LIP/FCT) | 53 |
| Ricardo Caeiro | Technician (LIP) | 13 |
| Rui Alves | Technician (LIP) | 14 |
| Rui Marques | Researcher (LIP/FCTUC) | 29 |

### 6.1.7 Publications

**Collaboration notes with internal referee**

- *Modelling of avalanches and streamers by finite elements*
  P.Fonte
  RD51 Note 2011-005

### 6.1.8 Presentations

**Seminars**

- *Modelling of avalanches and streamers by finite elements with COMSOL*
  presented by Paulo Fonte
  RD51 simulation school, 19-21 Jan. 2011 — CERN, Switzerland.

### 6.1.9 Academic Training

**PhD Theses**

- *Demonstration of a Positron Emission Tomography small-animal scanner based on Resistive Plate Chambers*
  Paulo Martins, (on-going)

### 6.1.10 Project Summary

| | number |
|---|---|
| Collaboration notes with internal referee | 1 |
| Seminars | 1 |

## 6.2 NeuLAND - An innovative high-energy neutron time-of-flight detector for experiments at GSI and FAIR

### 6.2.1 Resumo

De entre as experiências planeadas para FAIR (Facility for Antiprotons and Ion Research), no GSI (Gesellschaft fuer Schwerionenforschung), Darmstadt, Alemanha, a colaboração R3B (Reactions with Relativistic Radioactive Beams) procura esclarecer as propriedades nucleares de núcleos instáveis situados nos limites da matéria nuclear, as chamadas "drip-lines". As experiências terão lugar num sistema experimental complexo, constituído por detectores que medem e caracterizam todas as partículas envolvidas nos processos de reacção.
A detecção de neutrões de alta energia é essencial para a medida de muitas das reacções a observar no sistema R3B. Em particular, todos os processos que dependem da reconstrução da energia de excitação através da análise de massa invariante requerem a medição precisa do momento linear dos neutrões provenientes do projéctil. Prevê-se, por isso, instalar um novo detector de tempo de voo, o detector NeuLAND, para medir neutrões com energias entre 200 e 1000 MeV. Dependendo das exigências na aceitância e na resolução, esse detector poderá ser instalado a distâncias que vão dos 12 aos 30 m a 0°, para lá do alvo. Nas condições do sistema, uma resolução de tempo de voo abaixo dos 100 ps e uma resolução em posição de cerca de 1 cm, permitirá obter uma resolução 20 keV na massa invariante perto do limiar. Tal resultado abrirá uma nova era nas medidas de precisão dos estados fundamentais e das propriedades das ressonâncias de núcleos exóticos. Para além disso, uma alta resolução a baixas energias fornecerá informação exacta sobre reacções (gamma,n) em núcleos exóticos, uma informação relevante para o esclarecimento do processo r e do processo p da astrofísica nuclear.
O conceito do detector NeuLAND que nos propomos estudar e testar baseia-se na detecção em RPCs (Resistive Plate Chambers) de partículas secundárias induzidas pela interacção dos neutrões com material conversor de ferro. A detecção de partículas ionizantes com eficiência elevada (próxima dos 100%) e muito boa resolução temporal (abaixo dos 100 ps) foi já demonstrada experimentalmente com tRPCs (timing RPCs) de grande superfície. Aliás, o conceito está a ser usado, com sucesso, pela colaboração HADES, no GSI, para detectar produtos de reacção de colisões de iões pesados a energias de 1-2 AGeV.
O objectivo do presente projecto é contribuir para o desenvolvimento (e o melhoramento) do desenho do futuro detector NeuLAND, em dois aspectos centrais na presente fase: testes de protótipos e simulação do desempenho do detector. Esta equipa juntou-se há pouco ao NeuLAND Working Group da colaboração R3B. Inicialmente era esperado que todo este trabalho fosse contributo para o Technical Design Report (TDR) do detector NeuLAND, previsto para finais de 2010. Porém a colaboração R3B acabou por decidir incluir no TDR, em 2011, a versão do NeuLAND alternativa, baseada em cintiladores plásticos, com base em argumentos de que tais detectores teriam melhor resposta a eventos com emissão de mais de um neutrão; contudo ficou definido que a colaboração tem o maior empenho em clarificar a possível utilização dos detectores de neutrões rápidos baseados em RPCs, o que mantém todo o interesse científico neste projecto.
Trata-se de uma nova aplicação de "timing RPCs", tecnlogia em que este grupo vem tendo papel pioneiro ao longo da última década, a partir do envolvimento, em 1998/99, na fase de I&D do detector de tempo de voo, TOF, da Experiência ALICE do LHC. Depois de, com sucesso, ter produzido em Coimbra o detector de TOF com RPCs da experiência HADES, cabendo-lhe a coordenação do respectivo projecto, o detector de neutrões de R3B constituirá a continuação de um desafio na actividade de concepção, desenho e construção de detectores.
Compreende-se que, dada a dimensão do presente projecto, este será forçosamente levada a cabo em colaboração com outras equipas da colaboração R3B. O projecto será levado a cabo em colaboração com equipa da Univer-

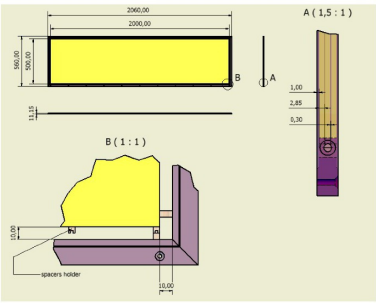


Figure 1. Schematic drawing of a detection module with 2 gas gaps.

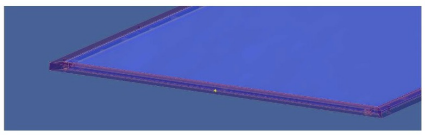


Figure 2. 3D representation of the two 0.3 mm gas gaps detection module.

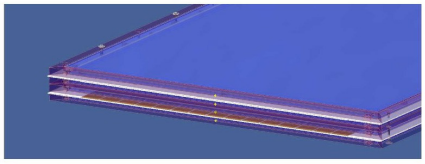


Figure 3. 3D representation of the stack of two 0.3 mm gas gaps detection uni

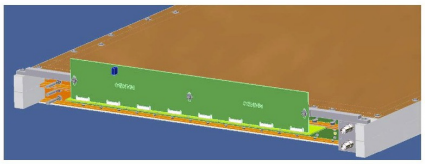


Figure 4. 3D representation of the two 0.3 mm gas gaps detection unit (detail).

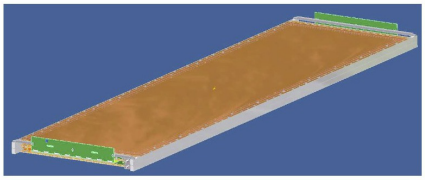


Figure 5. 3D representation of the two 0.3 mm gas gaps detection unit (overall view).

sidade de Lisboa liderada pelo investigador Daniel Galaviz Redondo, que se encarregará de todo o trabalho de simulação, competindo ao LIP o desenho, construção e teste dos protótipos.

### 6.2.2 Abstract

Among the different experiments planned at FAIR, "Facility for Antiprotons and Ion Research", at the "Gesellschaft fuer Schwerionenforschung"(GSI), in Darmstadt, Germany, the R3B (Reactions with Relativistic Radioactive Beams) collaboration aims to elucidate the nuclear properties of unstable nuclei located at the limits of existence of nuclear matter, the so-called drip-lines. Experiments will be performed in a complex experimental setup with detectors measuring and characterizing all particles involved in the reaction process.
For most of the reactions to be measured at the R3B experimental setup, the detection of high energy neutrons is essential. Especially all measurements relying on a reconstruction of the excitation energy by the invariant-mass analysis demand a precise measurement of the momentum vector of the neutrons emitted by the projectile. Therefore, a new time-of-flight detection system, the NeuLAND detector, is foreseen for the measurement of neutrons with energies between 200 and 1000 MeV. Depending on the demands on acceptance and resolution, the detector can be located at different distances from the reaction target between 12 and 30 meters downstream at $0^o$. Given the performance of the detector, a time-of-flight resolution of better than 100 ps and a position resolution of about 1 cm, it is possible to reach an invariant-mass resolution of 20 keV close to the threshold. This will open a new precision era in the measurement of the ground states and resonance properties of exotic nuclei. Additionally, the high resolution at low energies will provide exact information on ($\gamma$,n) reactions involving exotic nuclei, this being relevant for nuclear astrophysics processes like the r- and the p-process.
The concept of the NeuLAND detector that we intend to study and test is based on the detection of secondary particles, induced by the neutrons in iron converter material, in Resistive Plate Chambers (RPCs). The detection of minimum ionizing particles with high efficiency (close to 100%) and very good timing resolution (less than 100 ps) has already been shown for a large area timing RPC. Also, this concept has been also successfully used by the HADES collaboration at GSI in the detection of the reaction products from heavy ion collisions at energies of 1-2 AGeV.
The goal of the present project is to contribute to the development and improvement of the design concept of the future NeuLAND detector by considering the two key issues in the design phase: the prototype testing and simulation of the detector performance. Our teams have recently joined the NeuLAND Working Group within the R3B collaboration. The initial goal of the projectwas to contribute for the Technical Design Report of NeuLAND, foreseen for the end of 2010. However, due to arguments of a better response of the NeuLAND version based on plastic scintillators to events with several neutrons, the Collaboration decided to include this solution in the TDR issued in 2011. However, in view of its future applicability in other experiments, the Collaboration decided to carry on with the study of the RPC-based fast neutron detector, which means that the scientifica goals of the project are maintained.
This is a novel application of timing Resistive Plate Chambers, a technology our group pioneered in the Framework of the ALICE experiment at CERN and developed over the last decade. After the successful production of the HADES RPC TOF Wall and coordination of the project, the R3B neutron TOF detector constitute a challenging follow-up detector design and construction activity.
In view of the size of the project, it will be carried on in collaboration with other groups within the R3B collaboration, in particular the team of the University of Lisbon headed by Daniel Galaviz Redondo. This team will be in charge of all the simulation work, while LIP will carry out the design, construction and testing of the prototype.

### 6.2.3 Objectives

Once the design concept of the RPC module was established, following a lengthy and detailed simulation study carried out by our Lisbon collaborators, the work towards the construction of prototype modules immediately started.
These prototypes will be built in Coimbra during the first half of 2012 and made available for the beam period of the GSI experiment S406 "Characterization of NeuLAND prototypes and the LAND detector using fast monoenergetic neutrons", in which the performance of the constructed modules is to be tested.

### 6.2.4 Achievements

The design of the prototype detector will follow an approach in which the sensitive volume is physically separated from the signal pickup electrodes. The main idea behind this approach is to solve at the same time the high voltage insulation and gas tightness issues. Besides, this will considerably reduce the amount of feed-throughs,

thus easing the achievement of a gas thigh volume, and also decouples the high voltage from the front end electronics.
As shown in the attached "Figures.pdf"file, the detection module (see fig. 1) consists of two (or five) 0.3 mm gas gaps defined by 2000x500x3 mm3 glass electrodes. Each module is then closed inside an acrylic box (fig. 2). The high voltage is applied to a resistive acrylic layer painted on the outer glass electrodes. Just four feed-throughs are needed per module, two for high voltage and two for gas input and output.
It is foreseen to construct two detection units, one with detection modules of two gas gaps and the other with modules of five gas gaps. The signals, collected in two planes of strips, will be read out at both ends of the strips and fed to fast charge amplifiers. One pair of strip plans reads out the detection unit which consists of two detection modules stacked (figs. 3). Each detection unity will then consist in two strip planes and four detection modules closed inside an aluminum shielding box (fig. 3-5).
Following the decision of the NeuLAND Working Group to include in the TDR the option for the plastic scintillators - which does not affect the scientific goals of our project ! - a memorandum has been prepared to submit to FCT, in which we clearly explain the situation. Indeed, the scientific merit of our development has been recognized by the collaboration itself, which maintains its commitment to the GSI experiment S406 "Characterization of NeuLAND prototypes and the LAND detector using fast monoenergetic neutrons", in which the performance of our RPC-based modules is to be tested.
Aplicações computacionais - 1

### 6.2.5 Sources of Funding

| Code | Funding | Start | End |
|---|---|---|---|
| PTDC/FIS/114876/2009 | 99.589 € | 2011-01-01 | 2013-12-31 |

### 6.2.6 Team

**Project coordinator: Rui Marques**

| Name | Status | %of time in project |
|---|---|---|
| Alberto Blanco | Technician (LIP) | 30 |
| Carlos Silva | Technician (LIP) | 15 |
| Joaquim Oliveira | Technician (LIP) | 20 |
| Luís Lopes | Technician (LIP) | 30 |
| Nuno Carolino | Technician (LIP) | 15 |
| Nuno Filipe Silva Dias | Technician (LIP) | 20 |
| Orlando Cunha | Technician (LIP) | 15 |
| Paulo Fonte | Researcher (LIP/ISEC) | 15 |
| Ricardo Caeiro | Technician (LIP) | 15 |
| Rui Alves | Technician (LIP) | 15 |
| Rui Marques | Researcher (LIP/FCTUC) | 25 |

## 6.3 Microstructure Gas Detectors

### 6.3.1 Resumo

O projecto em curso envolve o desenvolvimento de detectores de radiação gasosos com sistemas de leitura ópticos, neste caso fotomultiplicadores. A cintilação é emitida pelas avalanches produzidas em microestruturas e permite a localização das interacções. Foram considerados especialmente estudos conducentes ao desenvolvimento de uma câmara Anger gasosa para imagiologia com neutrões térmicos.
Conforme se verificou ao longo do projecto o actual desempenho em localização deste tipo de detector é limitado pelo número de fotões recolhidos no sistema de leitura e pelas características físicas do sistema de leitura e janelas dos detectores . Assim o programa de trabalhos pode ser desenvolvido ao longo de duas linhas complementares, mas interligadas – características do sistema de leitura do detector e estudo dos processos de emissão de luz relacionados com a interacção em 3He-CF4, mistura gasosa utilizada nestes detectores.
Várias experiências em Física das Altas Energias têm considerado a utilização do tetrafluoreto de carbono ou CF4, quer como cintilador primário quer como gás de enchimento em contadores proporcionais de fio ou microestruturas, sozinho ou como aditivo. É sabido que o número de fotões emitidos pelo CF4 é menor que o emitido pelos gases raros puros, mas as suas características tais como a velocidade de deriva, coeficente de

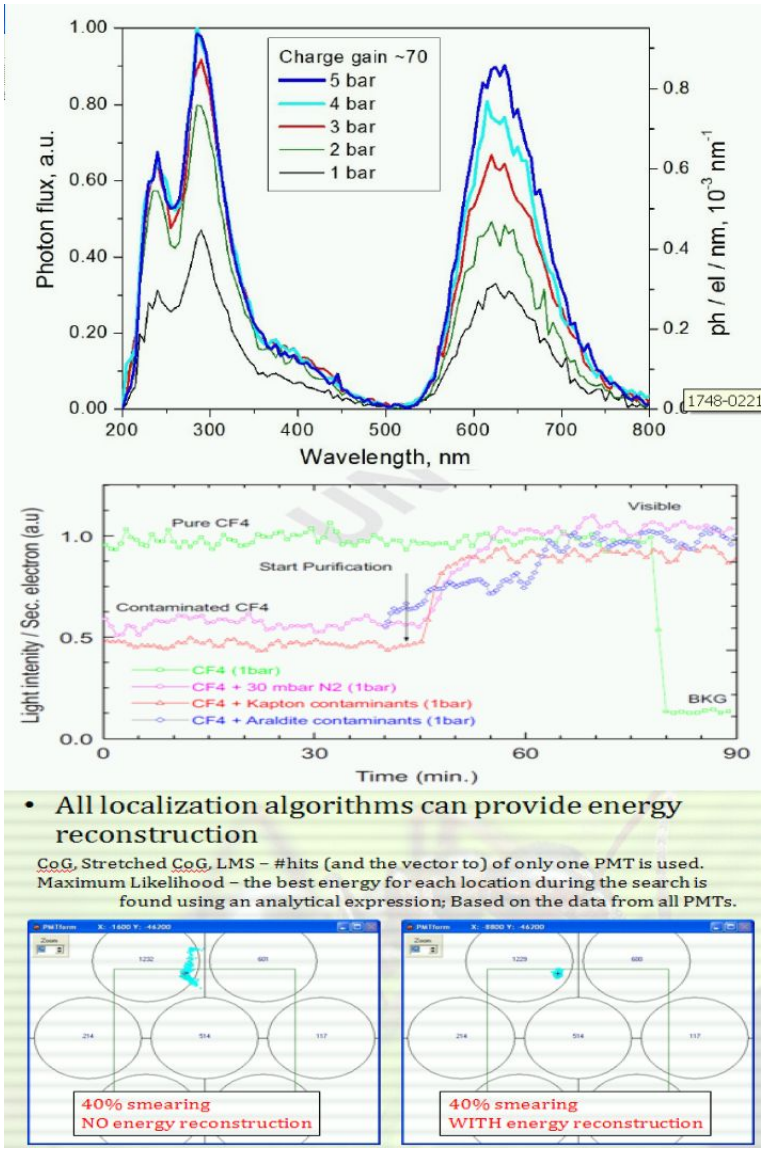



Figure 6.2: Spectra and photon yields of CF4 ; Effect of purifiers in CF4 scintillation; Localization in an Anger Camera - recent enhancements in ANTS

difusão, espectro de emissão e o custo inferior fazem dele um gás popular. Algumas das características da cintilação do CF4 foram estudadas para aplicações a detectores, mas não existe publicado nenhum trabalho sistemático sobre a sua cintilação. As publicações existentes estão focadas nas necessidades imediatas dos autores e cobrem regiões espectrais limitadas, uma só pressão e fontes de excitação únicas. Por causa das diferentes condições experimentais e dos modelos simplistas assumidos para aspectos básicos estes estudos não permitem comparação mútua e são de pouca utilidade geral. Este trabalho pretende complementar o actual conhecimento sobre a cintilação do CF4, considerando aplicações e fundamentos. O objectivo principal é o estudo detalhado das cintilações primária e secundária do CF4 entre os 200 e os 800 nm para pressões entre os 100 mBar e os 5 Bar e uma clarificação dos mecanismos envolvidos e o desenvolvimento, em colaboração com uma equipa internacional de um protótipo de um detector gasoso de posição para neutrões térmicos com leitura de tipo Anger. Os estudos experimentais foram efectuados com sistemas de detecção calibrados (calibração absoluta) e incluíram medidas de espectroscopia resolvida no tempo para correlacionar os espectros com aspectos fenomenológicos de cintilação.
Estes trabalhos foram desenvolvidos numa actividade financiada pelo 7º Quadro Comunitário de Apoio - Integrated Infrastructure Initiative for Neutron Scattering and Muon Spectroscopy (FP7), Project nº 226507 - NMI3. A nossa equipa está integradada na JRA WP22 Detetcors – tarefa 22.2 e no projecto CERN/FP/116389/2010 "Estudo da cintilação VUV/UV do CF4 para aplicações na área do desenvolvimento de detectores"

### 6.3.2 Abstract

In recent years, CF4 has been considered for several experiments in high energy physics, used either as a primary scintillator or as a proportional counter gas using wires or microstructures. The scintillation yields of CF4 are lower than those of pure rare gases, but its conditions of operation and characteristics such as drift velocity, diffusion coefficient, emission spectra and low cost make it a very popular gas. A few aspects of CF4 scintillation have been studied by the groups considering this gas for detector applications, but no systematic studies of its scintillation properties have been reported. These past valuable works focused mainly in their immediate requirements and were carried on in a limited spectral zone, fixed pressure and single excitation sources. As a consequence of these different experimental conditions and the oversimplified models assumed for the fundamental mechanisms and properties, these results have limited application outside their local community and cannot be mutually compared. This project pretends to complement the actual knowledge about CF4 scintillation, considering both the application in practical developments and the phenomenological aspects.
The experimental spectral studies were done using systems calibrated in absolute number of photons and included time resolved spectral studies as an attempt to infer a kinetic scheme that will explain the scintillation properties of CF4.
The main goal of this project is the accurate study of the primary and secondary scintillation of CF4 between 200 and 800 nm, for pressures between 100mBar and 6 Bar and the development of a prototype of a thermal neutron Anger Camera type position detector.
These studies were developed in an activity funded by the 7th Framework Programme - Integrated Infrastructure Initiative for Neutron Scattering and Muon Spectroscopy (FP7), Project nº 226507-NMI3. Our team is integrated in the JRA WP22 Detectors – task 22.2 and project CERN/FP/116389/2010 "Estudo da cintilação VUV/UV do CF4 para aplicações na área do desenvolvimento de detectores"(Study of CF4 VUV/UV scintillation for detector development).

### 6.3.3 Objectives

The aim of this JRA is the development of new detector technologies based on Gaseous Scintillation Proportional Counters (GSPC). These devices have the potential of improving the performance of high position resolution detectors used in reflectometry and time resolved SANS. Present state of the art detectors, such as 3He-based Multi Wire Proportion Chambers already limit the performance of existing reflectometers due to their moderate count rate capability. They only provide limited spatial resolution of x ≈1-2 mm and a time resolution in the microsecond range. More advanced devices based on solid 6Li-doped glass scintillators with Anger camera readout, e.g. as recently developed at the SNS, can partially improve the performance achieving high position resolution (≈1mm) and providing good timing resolution due to the fast scintillation light pulse with a duration of about 200 ns. The low light output of 6Li glass however, diminishes the count rate capability due to the signal integration time required. A major drawback of 6Li based glass scintillation detectors is a non negligible sensitivity to a high gamma background environment.
Micro pattern charge amplifying structures like MSGCs have been shown to be very efficient in the production of fast scintillation light in the visible region when operated in the proportional mode in gas mixtures of 3He-CF4.

Photon yields per detected neutron can be ≈100 times larger than that of 6Li-glass and light signal durations of less than 60 ns have been observed. In the proposed JRA particular emphasis is therefore placed on the development and study of new technologies based on these Gaseous Scintillation Proportional Counters with light readout.
The LIP team has now responsibilities in three areas – study and optimization of the conditions for high gas scintillation, spatial and angular characterization of the photomultipliers, both for development studies and prototype assembly, and simulation of the detector.

### 6.3.4 Achievements

During 2011 the studies of the secondary light emitted by the CF4 avalanches as studied at 1,2,3 and 5 bar using microstrip devices were completed and the program was extended to include measurements made with GEMs. The results were submitted and accepted for publication in the Journal of Instrumentation. These results not only extend the knowledge on the CF4 light emission but also give quantitative information useful for development of new schemes of optical read-out in modern state-of-the art detectors operating with CF4.
The extension of the CF4 scintillation studies to the VUV region demanded some changes in the experimental set-up. The gas chamber had to be modified to allow the coupling of a MgF2 window. The optical detection system, covering the wavelength region from 120 to 350 nm, is completely new. Many of its components were designed and made at the LIP Workshop. The optical detection system is already assembled and tested. The overlap between this and the previous set-up allows a cross check of our results. Dedicated set-ups for the radiometric calibration of the detection system were also designed. A new deuterium lamp with a MgF2 window was bought and sent to PTB (Germany) for the radiometric calibration. The first tests are underway with time resolved measurements for the UV light (above 200 nm) showing good agreement with previous results.
The complete and comprehensive interactive simulation package of the gaseous Anger Camera that was developed at LIP Coimbra, incorporating all the factors that can affect localization, such as detector geometry, primary interaction, avalanche properties, spectral emissions of the photons produced, several types of readout configurations, spectral sensitivity of PMTs and PMTs uniformity and angular dependence, became the simulation tool of the collaboration and is now being used by all collaboration teams. Many improvements were incorporated in the latest versions, only a few indicative ones are reported here: new mode has been added for Area simulations when distortion corrections are activated; reconstruction can be corrected for the distortion and displacement caused by the reconstruction method (Single and Mask modes); smearing in the number of photons generated per neutron is implemented; two new localization algorithms ( Stretched Center of Gravity and Least Mean Square (LMS) with gradient descent minimization); changes in the angular sensitivity data input (any data normalization is allowed now); new read-out pattern in Large Scale PMT mode is implemented and, for Large Scale PMT mode, users can disable any PMT. ANTS is now available online to collaboration members and a discussion list was created. ANTS was presented at IEEE2011 and will be object of a publication in 2012.
The effect of gas purity on CF4 primary scintillation was studied by recording time-resolved spectra and measuring the relative emission intensity for pure and contaminated CF4. The results show that the visible emission is much more sensitive to the gas contamination than the UV emission. The influence of purity of CF4 on the relative intensity of the secondary scintillation was also studied and it was found that both the UV and visible emission can be strongly affected. Two gas purifiers available from SAES, St 707 and MC1-905, were tested and it was shown that circulating the contaminated gas through these purifiers lead to the recovery of the scintillation intensity (primary and secondary scintillation) and effective decay time (primary scintillation) to the values shown by pure CF4. These results were presented at a conference and published in Nuclear Instruments and Methods.

### 6.3.5 Sources of Funding

| Code | Funding | Start | End |
|---|---|---|---|
| FP7-GA226507 | 80.640 € | 2009-02-01 | 2012-01-31 |
| CERN/FP/116389/2010 | 9.000 € | 2011-01-01 | 2011-12-31 |

### 6.3.6 Team

**Project coordinator: Francisco Fraga**

| Name | Status | %of time in project |
|---|---|---|
| Américo Pereira | Technician (LIP) | 15 |
| Andrey Morozov | Researcher (LIP) | 70 |
| Francisco Fraga | Researcher (LIP/FCTUC) | 80 |
| Luís Margato | Post-Doc (LIP) | 15 |
| Luís Pereira | PhD student (LIP) | 100 |
| Margarida Fraga | Researcher (LIP/FCTUC) | 70 |
| Nuno Carolino | Technician (LIP) | 15 |
| Paulo Mendes | Researcher (LIP/FCTUC) | 20 |
| Rui Marques | Researcher (LIP/FCTUC) | 10 |

### 6.3.7 Publications

**Articles in international journals (with direct contribution from LIP members)**

- *Effect of electric field on the primary scintillation from CF4*
  A. Morozov, M.M.F.R. Fraga, L. Pereira, L.M.S. Margato, S.T.G. Fetal, B. Guerard, G. Manzin, F.A.F. Fraga
  Nuclear Instruments and Methods in Physics Research Section A 628 (2011) 360-363

- *Effect of the gas contamination on CF4 primary and secondary scintillation*
  L.M.S. Margato, A.Morozov, L.Pereira, M.M.F.R. Fraga, F.A.F. Fraga
  Nuclear Instruments and Methods

- *Secondary scintillation in CF4: emission spectra and photon yields for MSGC and GEM*
  A Morozov, L M S Margato, M M F R Fraga, L Pereira and F A F Fraga
  Journal of Instrumentation

**International Conference Proceedings**

- *ANTS: a simulation package for gas scintillation Anger camera in thermal neutron imaging*
  A. Morozsov, I Defendi, R Eongen, F.A.F. Fraga, M.M.F.R. Fraga, B. Guerard, M. Jurkovic, G. Kemmerling, G. Manzin, L.M.S. Margato, H. Niko, L. Pereira, C. Petrillo, F. Piscitelli, D. Raspino, N.J. Rhodes, F. Sacchetti, E.
  IEEE2011 Conference Record

### 6.3.8 Presentations

**Oral presentations in international conferences**

- *Temperature Dependence of the UV Fluorescence Yield in Nitrogen and in Air*
  presented by Margarida Fraga
  8th AFWS — Karlsruhe, Germany .

**Poster presentations in international conferences**

- *Effect of the gas contamination on CF4 primary and secondary scintillation*
  presented by Luís Margato
  The 6th International Conference on New Developments in Photodetection — Lyon, França.

**Oral presentations in collaboration meetings**

- *Effect of purifiers on the CF4 primary and secondary scintillation*
  presented by Luís Margato
  FP7- WP22 Collaboration meeting — ILL, Grenoble.

- *Final results on the CF4 seconday scintillation*
  presented by Andrey Morozov
  FP7- WP22 Collaboration meeting — ILL, Grenoble.
- *Angular and area dependence of PMT experimental sensitivity: experimental data and effect on resolution*
  presented by Luís Pereira
  FP7- WP22 Collaboration meeting — ILL, Grenoble.
- *LIP task overview*
  presented by Francisco Fraga
  FP7- WP22 Collaboration meeting — ILL, Grenoble.
- *New features in ANTS*
  presented by Andrey Morozov
  FP7- WP22 Collaboration meeting — ILL, Grenoble.
- *The angular and area dependence of the 25mm PMTs - overview and effects on the position resolution*
  presented by Luís Pereira
  NMi3 3rd General Assembly, November 89th 2011 — Rome.

### 6.3.9 Project Summary

| | number |
|---|---|
| Articles in international journals (with direct contribution from LIP members) | 3 |
| International Conference Proceedings | 1 |
| Oral presentations in international conferences | 1 |
| Poster presentations in international conferences | 1 |
| Oral presentations in collaboration meetings | 6 |

## 6.4 Gamma-Ray Polarimetry with Fermi and DUAL Space Missions

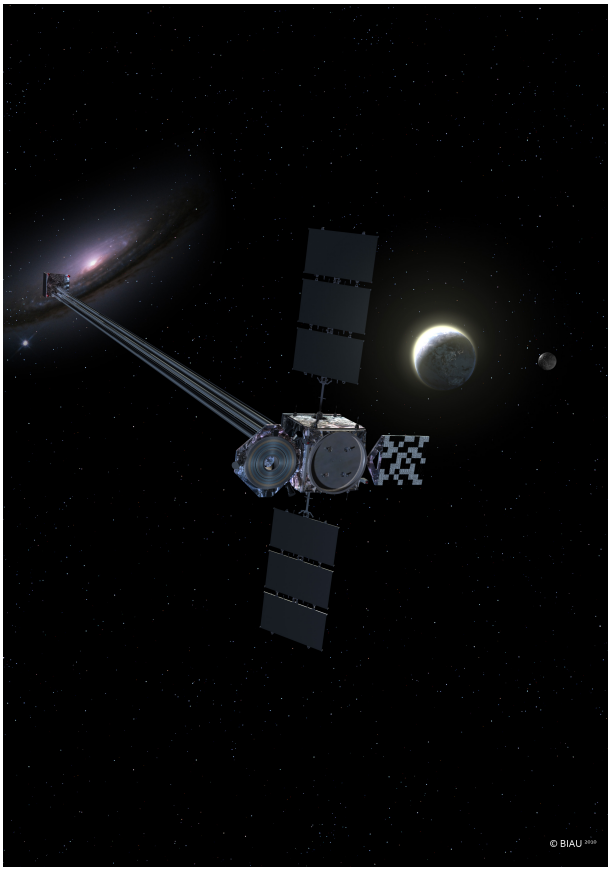
### 6.4.1 Resumo


**Desenvolvimento de um polarímetro para a Missão Espacial Dual**

Em 2011 o nosso grupo prosseguiu o desenvolvimento de um plano focal de CdZnTe (CZT) optimizado para a observar emissões polarizadas de raios gama no espaço no âmbito da proposta DUAL (http://dual.cesr.fr), que devera ser submetida à próxima chamada do programa Cosmic Vision da ESQA. Paralelamente, os parceiros japoneses e americanos do consórcio DUAL submeterão a esta missão aos concursos do programa CAST da JAXA e MIDEX da NASA. Está a ser desenvolvido e testado um novo conceito de detectores de CZT com informação tridimensional. O protótipo a desenvolver funcionará no modo Campo Plano Transverso com a recolha de sinal a ser efectuada por um sistema de micro-fitas, permitindo a leitura tridimensional da trajectória das partículas. De forma a tornar possível a absorção de fotões em cristais de CZT até 20 mm sem aumentar a distância de recolha de carga, aplica-se um campo perpendicular ao eixo óptico do cristal.
Está ser também preparado um teste preliminar num balão de alta altitude, a missão CIPHER (Coded Imager and Polarimeter for High Energy Radiation), em colaboração com o Istituto di Astrofisica Spaziale e Fisica Cósmica, Bolonha, Itália.
Os resultados experimentais e resultantes de simulações indicam que as prestações deste instrumento são compatíveis com os requerimentos estabelecidos pelo consórcio: sensibilidade de $10^{-6}$ fotões/(cm$^2$.s.keV) entre 100 keV e 1 MeV, resolução de 1% e polarização mínima detectável $< 1\%$ para uma fonte equivalente à Nebulosa do Caranguejo durante $10^{-6}$ s.

**Polarimetria de raios gama na missão Fermi**

Até hoje nunca foram observadas emissões polarizadas de raios gama acima de 1 MeV, logo a análise dos dados da missão Fermi da NASA constituirá uma importante contribuição para o conhecimento do universo na banda de raios gama. Apesar de os instrumentos da missão Fermi da NASA não terem sido concebidos para realizar polarimetria, as características e a geometria dos seus detectores teoricamente permitem a realização deste tipo de medidas. Os dados do instrumento LAT (Large Area Telescope) resultantes da observação de fontes de emissões polarizadas serão comparados com os dados gerados pela simulação do seu modelo de massa utilizando

o programa GEANT4. Deste cruzamento de dados poderemos inferir o ângulo e o grau de polarização do objecto celeste. Apesar de os dados do LAT terem sido tornados públicos pela NASA, o LIP acederá e analisará esses dados sob a supervisão do consultor de projecto Neil Gehrels do Goddard Space Flight Center da NASA.

### 6.4.2 Abstract

**Polarimeter development for DUAL Space Mission**

Our group pursues the development of a Laue lens focal plane instrument based on CdZnTe for DUAL consortium (http://dual.cesr.fr) to be submitted to the next ESA Cosmic Vision call. Furthermore, the participation of Japanese and USA partners in this consortium will allow DUAL to be soon presented to JAXA CAST program and to MIDEX-level NASA calls. A novel 3D position sensitive CdZnTe prototype is under development, that will operate in PTF (Planar Transverse Field) configuration with drift microstrip readout of each sensitive units and the three dimensional spatial resolution. In order to increase the photon absorption thickness up to 20 mm without increasing the charge collection distance, the charge collecting field is perpendicular with respect to the optical axis of the crystal.
A preliminary balloon borne version is being developed, entitled CIPHER (Coded Imager and Polarimeter for High Energy Radiation), in collaboration with the Istituto di Astrofisica Spaziale e Fisica Cósmica, Bologna, Italy.
So far, prototype experimental and simulation results are compatible with the performances required for DUAL main instrument established by the consortium: $10^{-6}$ photons/(cm$^2$.s.keV) detection sensitivity between 100 keV and 1 MeV, energy resolution of ≈1% and minimum detectable polarization $< 1\%$ for a Crab source equivalent and for $10^{-6}$s.

**Gamma-Ray Polarimetry analysis with Fermi mission**

Polarized gamma-ray emissions over 1 MeV was never observed, therefore NASA Fermi mission polarimetric data analysis should provide an important contribution for gamma-ray astrophysics knowledge. Although Fermi instruments were not specifically designed to perform polarization measurements, their characteristics and their configuration allow perform polarization measurements. LAT (Large Area Telescope) Fermi instrument permit e+-e- pair production based polarimetry up to GeV region. The data generated by this instrument when pointing to polarized radiation emission sources will be compared with the output obtained by its mass model based on GEANT4, allowing to determine the polarization angle and the degree of polarization of the emission source. LAT data is public. LIP Coimbra will access and analyse this data under the supervision of NASA Goddard Space Flight Center project consultant, Neil Gehrels.

### 6.4.3 Objectives

The driving idea of developing a 3D position prototype is the use of CZT crystals in PTF (Planar Transverse Field) configuration to increase the photon absorption thickness up to 20 mm without increasing the charge collection distance. In the PTF configuration the charge collecting field is perpendicular to the optical axis of the crystal, improving the spectroscopic performance of CZT. In its final configuration it will be composed of 64x64 cubic voxel. A miniaturised ASIC electronics integrating a pre-amplifying stage, an amplifying and signal shaping stage will be developed in order to fit to the pixelisation level of each detection plane, as well as a coincidence electronic subsystem suitable to detect double events produced by polarized Compton photons inside the semiconductor material. The 3D CZT prototype will be tested at the European Synchrotron Radiation Facillity, Grenoble, France under a ≈100% polarized beam, monitored by a Monte Carlo simulations to better understand the results of each test. Complementary and longer experimental tests will be performed on CZT prototypes with LIP laboratorial polarization precision table. A balloon borne version (CIPHER) will developed and tested.
Polarized gamma-ray emissions over 1 MeV was never observed, therefore NASA Fermi mission polarimetric data analysis should provide an important contribution for gamma-ray astrophysics knowledge. LAT (Large Area Telescope) Fermi instrument permit $e^+$-$e^-$ pair production based polarimetry up to GeV region. The data generated by this instrument when pointing to polarized radiation emission sources will be compared with the output obtained by its mass model based on GEANT4 (GEometry ANd Tracking), allowing to determine the polarization angle and the degree of polarization of the emission source.

### 6.4.4 Team

**Project coordinator: Rui Curado Silva**

| Name | Status | %of time in project |
|---|---|---|
| Alexandre Fonseca Trindade | Master (LIP) | 30 |
| Carlos Conde | Researcher (LIP) | 20 |
| Carlos Patacas | Master (LIP) | 20 |
| Collin Gloucester | PhD student (LIP) | 100 |
| Filipa Borges | Researcher (LIP) | 15 |
| Filomena Santos | Researcher (LIP) | 20 |
| João Barata | Researcher (LIP/UBI) | 20 |
| Jorge Maia | Researcher (LIP/UBI) | 45 |
| José Marques | PhD student (LIP) | 60 |
| Rui Curado Silva | Researcher (LIP) | 85 |
| Teresa Dias | Researcher (LIP) | 15 |

### 6.4.5 Publications

**Articles in international journals (with direct contribution from LIP members)**

- *Polarization degree and vector angle effects on a CdZnTe focal plane performance*
  R. M. Curado da Silva, E. Caroli, J. Stephen, N. Auricchio, J.M. Maia, S. del Sordo, N. Donati, F. Schiavone, J. B. Campos, C. P. Gloster, A. Trindade, V. Honkomäki
  IEEE Trans. Nucl. Sci. (2011) (accepted)

- *Polarimetry Study with a CdZnTe Focal Plane Detector*
  R. M. Curado da Silva, N. Auricchio, E. Caroli, A. Donati, S. Del Sordo, V. Honkimäki, J. M. Maia, F. Schiavone, J. B. Stephen, A. Trindade
  IEEE Trans. Nucl. Sci. 58(4) (2011) 2118

**International Conference Proceedings**

- *CdZnTe Focal Plane Polarimetric Performances for a Laue Lens Point Spread Function*
  J. B. de Campos, R. M. Curado da Silva, C. P. Gloster, Alessandro Pisa, E. Caroli, J. B. Stephen, Filippo Frontera
  IEEE Nuclear Science Symposium and Medical Imaging Conference, Oct. 23-29, Valencia, Spain, 2011.

- *A balloon-borne 3D CZT scattering polarimeter for hard X-ray astrophysics*
  E. Caroli, J. M. Alvarez, N. Auricchio, C. Budtz-Jørgensen, R. M. Curado da Silva, S. Del Sordo, P. Ferrando, P. Laurent, O. Limousin, J. L. Galvèz, C. P. Gloster, M. Hernanz, J. Isern, I. Kuvvetli, J. M. Maia, J. B. Steph
  Nuclear Science Symposium Conference Record, 2011, IEEE Nuclear Science Symposium and Medical Imaging Conference, Oct. 23-29, Valencia, Spain, 2011.

- *LaPolCaliste - Polarisation Performance of the CdTe/CZT Caliste Detector Modules*
  P. Ferrando, O. Limousin, E. Caroli, R. Silva, V. Honkimaki, C. Blondel, R. Chipaux, S. Del Sordo, B. Horeau, P. Laurent, J.M. Maia, A. Meuris, J.B. Stephen
  IEEE Nuclear Science Symposium and Medical Imaging Conference, Oct. 23-29, Valencia, Spain, 2011

- *CdTe/CZT Pixel Detector for Gamma-Ray Spectrometry with Imaging and Polarimetry Capability in Astrophysics*
  José-Manuel Álvarez, José -Luis Gálvez, Margarita Hernanz, Jordi Isern, Manuel Lozano, Giulio Pellegrini, Mokhtar Chmeissani, Ezio Caroli and Rui M. Curado da Silva.
  IEEE Nuclear Science Symposium and Medical Imaging Conference, Oct. 23-29, Valencia, Spain, 2011

### 6.4.6 Presentations

**Presentations in national conferences**

- *A missão espacial DUAL*
  presented by Rui Curado Silva
  XXI Encontro Nacional de Astronomia e Astrofísica — Coimbra, Portugal.
- *The Development of CdZnTe Detector for the DUAL Telescope Focal Plane*
  presented by Rui Curado Silva
  XXI Encontro Nacional de Astronomia e Astrofísica — Coimbra, Portugal.
- *A missão DUAL no contexto da astronomia de raios X e raios gama*
  presented by Carlos Patacas
  XXI Encontro Nacional de Astronomia e Astrofísica — Coimbra, Portugal.
- *Simulations of Mass Models of Gamma-Ray Detectors*
  presented by Colin Paul Gloster
  XXI Encontro Nacional de Astronomia e Astrofísica — Coimbra, Portugal.

**Seminars**

- *A missão espacial DUAL*
  presented by Rui Curado Silva
  Café com Física — Coimbra.
- *Astronomia & Tecnologia Espacial no Quotidiano*
  presented by Rui Curado Silva
  — Escola Secundária Alice Gouveia, Coimbra, Portugal.

### 6.4.7 Academic Training

**PhD Theses**

- *Simulations of Mass Models of Gamma-Ray Detectors*
  Colin Paul Gloster, (on-going)

### 6.4.8 Events

- *XXI Encontro Nacional de Astronomia e Astrofísica*
  Conference, Observatório Astronómico da Universidade de Coimbra, Portugal, 2011-09-07

### 6.4.9 Project Summary

| | number |
|---|---|
| Articles in international journals (with direct contribution from LIP members) | 2 |
| International Conference Proceedings | 4 |
| Presentations in national conferences | 4 |
| Seminars | 2 |
| Conferences | 1 |

## 6.5 High Pressure Xenon Doped Mixtures for the NEXT Collaboration

### 6.5.1 Resumo

Na colaboração internacional NEXT (Neutrino Experiment with a gas Xe Time Projection Chamber) estão envolvidos mais de 50 investigadores (onde se incluem 6 dos investigadores que subscrevem a presente proposta) de 9 instituições diferentes (Gómez- Cadenas2008 and Díaz2009). O objectivo da experiência NEXT é a detecção do decaimento beta duplo sem emissão de neutrinos do Xe-136 que permitirá aferir se o neutrino é ou não uma partícula Majorana. Este fenómeno far-se-á assinalar através de um pico no final do espectro do decaimento beta duplo, cujo período de decaimento também se pretende medir.
O sistema experimental a projectar envolverá uma TPC (Time Projection Chamber) (Nygren2009) de grandes dimensões, cheia com Xe a 10 atm. Em Fevereiro de 2009, o Comité Directivo do NEXT decidiu que o método a utilizar na medida da energia do par de electrões (com uma energia partilhada de 2.547 MeV) do decaimento do Xe-136, deverá ser baseado na medida da electroluminescência (também designada por cintilação proporcional ou cintilação secundária) (Conde 2004) dado ter o potencial para resoluções em energia da ordem de 1 % . A TPC deverá também permitir determinar o traço de ionização de toda a radiação detectada, definir um volume fiducial, rejeitar a radiação de fundo e identificar inequivocamente as duas "gotas"de ionização que se formam no final das trajectórias do par de electrões beta. Existem questões em aberto que requerem algum estudo antes de se tomarem decisões. Entre elas está a escolha entre Xe puro e Xe dopado com gases moleculares como o TEA (Tri-Etil-Amina), CH4, CF4, N2 e outros gases. O gás molecular que se adiciona pode permitir aumentar a velocidade de deriva dos electrões primários, minimizar a sua difusão e eventualmente actuar como conversor de comprimentos de onda (Charpak1988). O trabalho que se descreve nesta proposta tem como objectivo principal procurar a mistura gasosa que melhor permite registar o traço de ionização, a que apresenta melhores propriedades de cintilação e medir a energia do par de electrões com melhor precisão. A mistura gasosa escolhida deve ter uma grande percentagem de Xe, ou seja grandes quantidades do isótopo a estudar: Xe-136. Coeficientes de difusão mais baixos e velocidades de deriva mais elevadas podem ser relevantes porque os electrões primários do traço de ionização vão percorrer grandes distâncias (cerca de 1m) até chegarem à região de electroluminescência (EL) da TPC. Dadas essas grandes distâncias, é importante garantir que os electrões não são consumidos por anexação às moléculas dopantes. Este processo pode reduzir a intensidade da cintilação secundária e aumentar as suas flutuações, deteriorando a resolução em energia, para a mistura gasosa. Além do rendimento de cintilação secundária, o rendimento de cintilação primária da mistura também deve ser medido; esta cintilação deverá permitir determinar com rigor a coordenada Z (axial) dos electrões primários. Por outro lado, a cintilação secundária deve ter um comprimento de onda que seja bem reflectido pelo isolante (Teflon) que reveste as paredes interiores da TPC.
O objectivo da presente proposta é responder a estas questões em tempo útil para a colaboração NEXT, usando para isso, a nossa longa experiência em detectores gasosos de cintilação proporcional. O estudo de detectores gasosos de Xe dopados com TEA (Tri-Etil- Amina) ou outros gases moleculares, bem como o desenvolvimento de técnicas (baseadas na detecção de cintilação secundária com microestruturas onde se deposita CsI ) que permitam registar os traços de ionização dos electrões, são alguns dos assuntos que por nós serão desenvolvidos no âmbito da nossa participação na colaboração NEXT.
O trabalho a desenvolver consiste em:

1. Projectar, construir e testar um sistema, baseado num fotomultiplicador, para estudar as propriedades do Xenon a altas pressões dopado com gases moleculares; medida dos rendimentos de cintilação; interpretação dos resultados.

2. Projectar, construir e testar um sistema experimental para registar as trajectórias dos electrões, baseado na detecção da cintilação secundária com microestruturas com depósitos de CsI ; estudo do seu desempenho.

### 6.5.2 Abstract

The NEXT (Neutrino Experiment with a gas Xe Time Projection Chamber) International Collaboration (Gómez-Cadenas2008 and Díaz2009) involves more than 50 researchers from 9 different institutions, including 6 researchers in the present proposal. The goal of the NEXT experiment is the detection of the neutrinoless double beta decay of Xe-136 (to find out whether the neutrino is a Majorana particle) by searching for a peak at the end of the double beta decay spectrum, and measure at the same time the half-life of the decay. The NEXT Steering Committee has decided in February 2009 that the experimental method should be based on the measurement of the electroluminescence (also called proportional or secondary scintillation) yield (Conde2004), in order to achieve the best energy resolution ($< 1\%$) for the detection of the 2.547 MeV sum pair of electrons,

in a large size Time Projection Chamber (TPC) filled with Xe at 10 atm. This TPC (Nygren2009) must have good tracking properties in order to define the fiducial volume, reject background and unambiguously identify the two blobs at the end of the electrons tracks that characterize the double beta decay. However, there are a number of issues that are still open to discussion, which require further study before decisions are made.
Amongst them is the question of choosing between pure Xe, where tracking of the electrons is limited by low drift velocities and large diffusion coefficients, and Xe doped with molecular gases like TEA (Tri Ethyl Amine), CH4, CF4, N2 or other gases, where the addition of the molecular gas may improve electron drift velocity and minimize electron diffusion, and eventually act as a wavelength shifter (Charpak1988). The work in this proposal will search for gas compositions that offer good compromises between energy resolution, tracking and scintillation properties. Such mixtures should have, for working pressures of about 10 atmospheres, a high Xe content, which means large amounts of the Xe-136 isotope. Electroluminescence (EL) yields and their fluctuations should not be jeopardized as compared to pure Xe. Low electron diffusion coefficients and high electron drift velocities are required, because electrons will travel long drift distances (about 1m) until reaching the EL region of the TPC. Low electron attachment by the admixture is an important additional requisite, because attachment will cause electron loss in the long drift to the EL region, and also because the EL yield will be lowered and its fluctuations increased if attachment occurs. The mixture´s primary scintillation yield should also be high, for timing and Z coordinate determination, and the secondary scintillation (EL) should be in a wavelength that is well reflected by the insulator (Teflon) which covers the inner surface of the TPC.
The purpose of the present proposal is to answer these questions within a time useful for the NEXT collaboration, based on our long standing expertise with gas proportional-scintillation detectors. A study of gaseous Xe doped with TEA and a study of the potential of tracking techniques based on the detection of the secondary scintillation with microstructures covered with CsI are specific topics we will be addressing, as part of our contribution to the Collaboration.
The work to be carried out will consist of two main parts, namely:

1. Project, construction and test of a photomultiplier based system to study the properties of high pressure Xe doped with molecular gases; measurement of the scintillation yields; Interpretation of the results.

2. Project, construction and test of an experimental system for electron tracking based on the detection of the secondary scintillation with microstructures covered with CsI; study of its performance.

### 6.5.3 Objectives

This project has as objective to answer some still unanswered questions within the scope of NEXT international collaboration. Among these questions is the the choice between pure Xe, where tracking of the electrons is limited by low drift velocities and large diffusion coefficients, and Xe doped with molecular gases like TEA (Tri Ethyl Amine), CH4, CF4, N2 or other gases, where the addition of the molecular gas may improve electron drift velocity and minimize electron diffusion, and eventually act as a wavelength shifter (Charpak1988). The work in this proposal will search for gas compositions that offer good compromises between energy resolution, tracking and scintillation properties. Such mixtures should have, for working pressures of about 10 atmospheres, a high Xe content, which means large amounts of the Xe-136 isotope. Electroluminescence (EL) yields and their fluctuations should not be jeopardized as compared to pure Xe. Low electron diffusion coefficients and high electron drift velocities are required, because electrons will travel long drift distances (about 1m) until reaching the EL region of the TPC. Low electron attachment by the admixture is an important additional requisite, because attachment will cause electron loss in the long drift to the EL region, and also because the EL yield will be lowered and its fluctuations increased if attachment occurs. The mixture´s primary scintillation yield should also be high, for timing and Z coordinate determination, and the secondary scintillation (EL) should be in a wavelength that is well reflected by the insulator (Teflon) which covers the inner surface of the TPC. The purpose of the present proposal is to answer these questions within a time useful for the NEXT collaboration, based on our long standing expertise with gas proportional-scintillation detectors. A study of gaseous Xe doped with TEA and a study of the potential of tracking techniques based on the detection of the secondary scintillation with microstructures covered with CsI are specific topics we will be addressing, as part of our contribution to the Collaboration. The work to be carried out will consist of two main parts, namely: i) Project, construction and test of a photomultiplier based system to study the properties of high pressure Xe doped with molecular gases; measurement of the scintillation yields; Interpretation of the results. ii) Project, construction and test of an experimental system for electron tracking based on the detection of the secondary scintillation with microstructures covered with CsI; study of its performance.

### 6.5.4 Achievements

Experimental work:

- Project and design of the detector (gás proportional scintillation counter) e associated vacuum system with purification. We also design a proportional counter in order to eventually do charge measurements with the mixtures under study. These measurements may help to a better understanding the role of the additive in the energy resolution.
- Choice and order of the raw material to use in the prototypes to be built, namely, stainless steel, "macor", radiation windows, glues, vacuum parts.
- Order of gases to be used in the experiments and adequate gas purifiers.
- Assembly of both detectors and associated vacuum system with purification.

At this point we are testing the detectors and associated system. Within one or two weeks we expect to begin the experiments. The gas proportional scintillation counter will be used to measure the electroluminescence produced in the gas mixtures and compare it to the electroluminescence produced in pure xenon as well as assess the effect of the additive gas in the energy resolution, allowing us to choose the more convenient additive. Eventual measures with the proportional counter may clarify the role of both the drift region or scintillation region is responsible for the eventual energy resolution degradation.
Measurements of ion drift velocities with the existing system have been progressed, mainly with gases that may be of interest for gas mixtures to be used in NEXT, namely N2, one of xenon potential partners. This study resulted in a paper published in JNIST.
Monte Carlo simulation studies were also carried out for the fluctuations in the electroluminescence yield of Xe and CF4 and CH4 mixtures (also potential partners in the detection mixtures for NEXT) and compared with calculations made in pure xenon. It also compares electroluminescence performances in cylindrical and planar geometries. This study produced a publication in JINST.
The master degree thesis is progressing as scheduled.

### 6.5.5 Team

**Project coordinator: Filomena Santos**

| Name | Status | %of time in project |
|---|---|---|
| Carlos Conde | Researcher (LIP) | 30 |
| Filipa Borges | Researcher (LIP) | 30 |
| Filomena Santos | Researcher (LIP) | 50 |
| João Barata | Researcher (LIP/UBI) | 15 |
| Jorge Maia | Researcher (LIP/UBI) | 15 |
| José Escada | PhD student (LIP) | 60 |
| Paulo Rachinhas | Master (LIP) | 10 |
| Sérgio Carmo | Master (LIP/ITN) | 10 |
| Teresa Dias | Researcher (LIP) | 15 |

### 6.5.6 Publications

**Articles in international journals (with direct contribution from LIP members)**

- *Drift field limitations to the energy resolution in Time Projection Chambers for 136Xe neutrino-less double beta decay search*
  P.N.B. Neves, C.A.N. Conde and L.M.N. Távora
  Nucl. Instrum. Meth. Phys Res. A , vol. 641, p. 87-91, 2011

- *A Monte Carlo study of the fluctuations in Xe electroluminescence yield: pure Xe vs Xe doped with CH4 or CF4 and planar vs cylindrical geometries*
  J Escada, T H V T Dias, F P Santos, P J B M Rachinhas, C A N Conde and A D Stauffer
  JINST 6 P08006, 2011

### 6.5.7 Project Summary

| | number |
|---|---|
| Articles in international journals (with direct contribution from LIP members) | 2 |

## 6.6 Beam Monitoring System for Cyclotron Proton Beams at ICNAS

### 6.6.1 Resumo

O principal objectivo do projecto consiste em desenvolver um instrumento que possibilite monitorizar o feixe de protões do ciclotrão do ICNAS (Universidade de Coimbra). Variáveis fundamentais a ser monitorizadas incluem a distribuição espacial (2D) e energética do feixe, bem como a corrente instantânea e total (integrada no espaço e no tempo). Uma mais-valia não negligenciável seria a capacidade de providenciar estas variáveis em tempo real, possibilitando assim a implementação de um sistema de controlo da dose no alvo. Num primeiro passo foi efectuado o estudo de sistemas de monitorização de feixe existentes. Os passos seguintes consistem no desenho de um sistema com as características mencionadas, fazendo para tal uso de técnicas de simulação e de experimentação (cf. Fig.) baseadas na utilização do feixe de protões do ciclotrão do ICNAS (IBA Cyclone 18/9), com até 150 microampere de corrente e 18 MeV de energia que, até ao momento, é utilizado para fins de produção de radiosótopos para medicina nuclear. Outras potenciais aplicações foram já identificadas, com estudos de viabilidade igualmente já efectuados e/ou em vias de execução. Resultados promissores têm sido obtidos em vários campos científicos, como sejam a radiobiologia e radiodosimetria com protões, ou aplicações tanto em ciência fundamental como no âmbito da engenharia que envolvam irradiação com neutrões, produzidos com o feixe do ICNAS através do uso de alvos apropriados.
No que concerne o conhecimento especializado de detectores 2D de radiação, o LIP tem experiência e conhecimento acumulados tanto do ponto de vista teórico como experimental, tendo já implementado no passado sistemas de dosimetria 2D com feixes de protões, baseados tanto na leitura em carga como luminosa de detectores gasosos.
Um objectivo complementar do projecto passa pelo estabelecimento de parcerias com produtores de ciclotrões no sentido de explorar possíveis mais-valias no campo da propriedade intelectual. Neste contexto, variáveis como capacidade de prototipagem para produção em média/grande escala, ou uma relação custo/benefício equilibrada, constituem factores a ser igualmente explorados uma vez que existem à escala mundial centenas de centros possuidores de um ciclotrão para fins idênticos (produção de radioisótopos).

### 6.6.2 Abstract

The project aims at developing an instrument for both qualitative and quantitative characterization of cyclotron particle beams. Main monitoring variables include spatial and energy distributions, together with beam current.

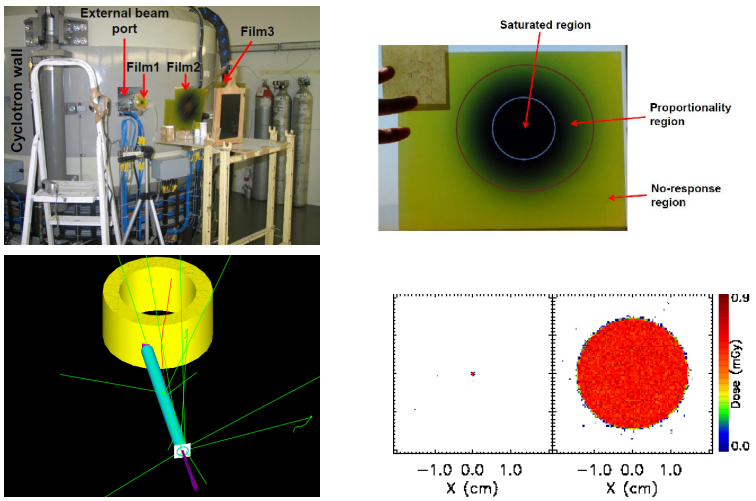



Figure 6.3: Experimental (top) and simulated (bottom) results obtained with the proton beam from the cyclotron at ICNAS. The experimental results were obtained in-air, with Geant4 simulations (not shown) reproducing and providing an explanation for the observed beam divergence. The simulations regard a possible proton irradiation setup to be installed at ICNAS, with a vacuum-filled aluminum pipe delivering a configurable beam width to a target (bottom right).

It is highly desirable that this beam monitor is able to readout and deliver these variables in real-time, therefore allowing the implementation of a system capable of controlling the dose and integrated current delivered at a given instant to any experimental setup. The evaluation of existing beam monitors has been addressed in a first stage. In the following steps, system design by advanced simulation tools and in-house experimental developments and testing (cf. Fig.) have been involving the use of the cyclotron (IBA Cyclone 18/9) in operation at ICNAS, University of Coimbra. This cyclotron, which delivers proton beams of up to 150 microampere at 18 MeV, is used at this stage solely for clinical radioisotope production. Other irradiation applications have nevertheless been identified and scientific viability studies are currently being carried out, with promising results expected in various scientific fields. These include proton radiobiology, neutron production and consequent radiobiological studies, together with applications involving neutron-based fundamental science and neutron-based applied engineering.
In what expertise on R&D of 2D radiation detectors is concerned, LIP has accumulated a large theoretica and experimental know-how, both with charge and light readout, having participated in the development of a position sensitive dosimeter for a radiotherapy proton beam.
A complementary project goal is the partnership with cyclotron manufacturers which may result in valuable intellectual property assets associated with the developed prototypes. Thus, issues like the ability for medium/large scale production and cost-effectiveness, which may render the device commercially attractive to hundreds of clinical cyclotron centers worldwide, are also being addressed. Application of the techniques developed to other types of radiation beams are also under consideration.

### 6.6.3 Team

**Project coordinator: Paulo Crespo**

| Name | Status | %of time in project |
|---|---|---|
| Francisco Fraga | Researcher (LIP/FCTUC) | 10 |
| Hugo Simões | | 19 |
| Paulo Crespo | Researcher (LIP/ISEC) | 30 |
| Rui Marques | Researcher (LIP/FCTUC) | 10 |
| Sharif Ghithan | PhD student (LIP/FCT) | 100 |

### 6.6.4 Publications

**International Conference Proceedings**

- *Radiobiology with cyclotron proton beams: A viability study*
  M. Cunha, M. Pinto, F. Alves, P. Crespo, R. Ferreira Marques

### 6.6.5 Presentations

**Poster presentations in international conferences**

- *Radiobiology with cyclotron proton beams: a viability study*
  presented by Micaela Cunha
  PTCOG 50 — Philadelphia, PA, USA, 8-14 May 2011.

### 6.6.6 Academic Training

**PhD Theses**

- *Research and development of a beam monitor for high-current particle accelerators*
  Sharif Ghithan, (on-going)

### 6.6.7 Project Summary

| | number |
|---|---|
| International Conference Proceedings | 1 |
| Poster presentations in international conferences | 1 |

## 6.7 Oficina-Coimbra

### 6.7.1 Resumo

A oficina mecânica (OM) do LIP foi criada em 1986 para apoiar as actividades experimentais a realizar em colaboração com o CERN. Foi na altura equipada com equipamento moderno de maquinação CNC e pessoal qualificado.
O equipamento da OM foi recentemente renovado com a entrada ao serviço, em 2008, de duas máquinas-ferramentas (torno e freza) CNC de alto desempenho adquiridas no âmbito do Programa Nacional de Reequipamento Científico.
O equipamento disponível e o pessoal técnico altamente qualificado, permitem actualmente assegurar uma larga gama de serviços mecânicos, desde a concepção e desenho, à maquinação, montagem e testes.
A experiência de mais de duas décadas, garante-nos que na ausência da OM não teria sido possível realizar com a elevada qualidade exigida e atingida, nem o trabalho de I&D em detectores gasosos centrado em projectos autónomos ou em pequenas colaborações, nem os compromissos assumidos no âmbito de médias e grandes colaborações internacionais (nomeadamente CP-LEAR, DELPHI, HERA-B, ATLAS, HADES).
São igualmente incontestáveis os benefícios para a comunidade nacional de I&D que a intervenção da OM do LIP trouxe aos seus projectos, tanto no plano local e nacional, como em colaborações internacionais, com destaque para o projecto CAMCAO-ESO.

### 6.7.2 Abstract

The Mechanical Workshop (MW) of LIP was established in 1986 to support experimental activities in the framework of CERN Colaborations. At that time it was equipped with modern CNC equipment and qualified personnel.
The equipment of the MW was recently renewed with the commissioning, in 2008, of two high-performance CNC machine tools (a mill and a lathe) acquired in the framework of the National Program of Scientific Reequipment. Nowadays, the equipment available and the highly qualified staff allow the MW to perform a large spectrum of mechanical services, from the design project to the production and testing of parts and systems.
An experience of over two-decades assures us that, in the absence of the LIP MW, it wouldn´t have been possible to perform with the same required high level of quality the R&D in gaseous detectors performed in the framework of autonomous projects or small collaborations, nor the construction responsibilities undertaken within medium and large international collaborations (CP-LEAR, DELPHI, HERA-B, ATLAS, HADES).
Equally evident are the benefits to the national R&D community of the intervention of the MW in its projects, at local and national level, with emphasis in CAMCAO/ESO.

### 6.7.3 Objectives

The LIP MW aims at providing high quality mechanical design and production services to the scientific community, namely:
- Supporting the participation in High Energy Physics or other international collaborations that imply the production of mechanical parts and systems
- Supporting the research on radiation detectors at LIP
- Providing mechanical engineering and production services to other research institutions
- Providing technology transfer services to other entities.

### 6.7.4 Achievements

During this year, along with current mechanical support given by the Mechanical Workshop (MW) on a daily bases to the ongoing LIP R&D projects and to the Physics Department of the University of Coimbra, progress has been made in the full exploitation of the modern machine tools, with a continuous effort put in the use of the TOPSOLID software. However, some difficulties remain in interfacing this software package with the milling machine, a problem to which the supplier company has been paying some attention, but still waits for a complete solution.
The work carried on for the LIP-Lisboa branch has clearly increased during this year.
Besides of design engineering and parts built for several projects on detector R&D (particularly the RPC-PET prototypes) and prototyping of some educational systems (e.g., the MiniPET and RPCs for a cosmic ray station), work has been carried on for several of the major current LIP projects, with emphasis on the maintenance for ATLAS, HADES along with construction of parts and R&D for LUX, RT-Mon, SNO and AUGER.

As for other institutions, besides of tasks performed for research groups of the Physics Department and for the Department itself, in fulfillment of the agreement with the University of Coimbra, the other main "clients"of the LIP MW were research teams from Coimbra and in one case the local Caner Hospital (IPO), except for one order from the University of Lisboa and another one from University Fernando Pessoa, Porto. The total of invoices issued to all the above institutions during this year was slightly above 24 k€, a value which we foresee to increase somewhat in the near future.
For simplicity, the next table summarizes the number of orders from each customer were accomplished by the workshop or were being executed by the end of the year, also giving the subtotal of orders from external entities, from the Physics Department of Coimbra and from the IP branches of Coimbra and Lisboa..

**Mechanical Workshop activity in 2011**

| Institution | Branch/Project | # Orders | Sub-totals |
|---|---|---|---|
| FCUL-Lisboa | Center for Atomic Physics | 1 | |
| UFP-Porto | Universuty Fernando Pessoa, Porto | 1 | |
| CNC-Coimbra | Molecular Biology | 6 | |
| CNC-Coimbra | Neurosciences | 3 | |
| IMAR-Coimbra | IMAR-Coimbra | 2 | |
| IPO-FG-Coimbra | IPO-Coimbra (Cancer Hospital) | 1 | |
| DEC-FCTUC | Civil Engineering Dep | 1 | |
| DEQ-FCTUC | PRODEQ | 2 | |
| DEM-FCTUC | CEMUC | 1 | |
| DEEC-FCTUC | ISR-Coimbra | 6 | 24 |
| Physics Dep. UC | General | 7 | |
| Physics Dep. UC | CEMDRX | 18 | |
| Physics Dep. UC | TNAM | 3 | |
| Physics Dep. UC | GEI | 1 | |
| Physics Dep. UC | SPF - Olimpíadas da Física | 1 | 30 |
| LIP-Coimbra | ATLAS | 6 | |
| LIP-Coimbra | LUX | 15 | |
| LIP-Coimbra | Scintillation | 4 | |
| LIP-Coimbra | Outreach | 7 | |
| LIP-Coimbra | FP7-NMI3 | 5 | |
| LIP-Coimbra | HADES | 7 | |
| LIP-Coimbra | Gaseous Detectors | 5 | |
| LIP-Coimbra | Human RPC-PET | 4 | |
| LIP-Coimbra | Animal RPC-PET | 2 | |
| LIP-Coimbra | RT-MON | 8 | |
| LIP-Coimbra | varia | 3 | 66 |
| LIP-Lisboa | AUGER | 11 | |
| LIP-Lisboa | SNO | 10 | |
| LIP-Lisboa | CLEAR PEM | 2 | |
| LIP-Lisboa | Medical Physics | 2 | |
| LIP-Lisboa | Education (Mini-PET) | 4 | |
| LIP-Lisboa | varia | 2 | 31 |

## 6.8 Instrumentation Laboratory

### 6.8.1 Resumo

**Resumo**

O laboratório de detectores foi criado logo na fundação do LIP para apoiar as actividades experimentais da delegação de Coimbra. Ao longo do tempo tem vindo a ser equipado para atender quer as necessidades gerais, quer às exigências específicas dos diferentes grupos de investigação.

**Objectivos**

O equipamento disponível e a especialização do pessoal técnico permitem actualmente prestar una larga gama de serviços, nomeadamente:

- Concepção, desenho, construção e reparação de equipamentos electrónicos,
- Construção e teste de detectores,
- Concepção, desenho, construção e reparação de sistemas de gases e de vácuo.

### 6.8.2 Abstract

**Abstract**

The detector laboratory was created at the very beginning of LIP, with the main aim of supporting the experimental activities of the Coimbra team. The laboratory has been continuously updated according to both general demands and specific needs of the research groups.

**Goals**

The available equipment and the technical staff expertise allow a variety of services to the research teams, covering:

- Design, construction and repair/maintenance of electronic equipment,
- Construction and test of detectors,
- Design, construction and maintenance of gas and vacuum systems.

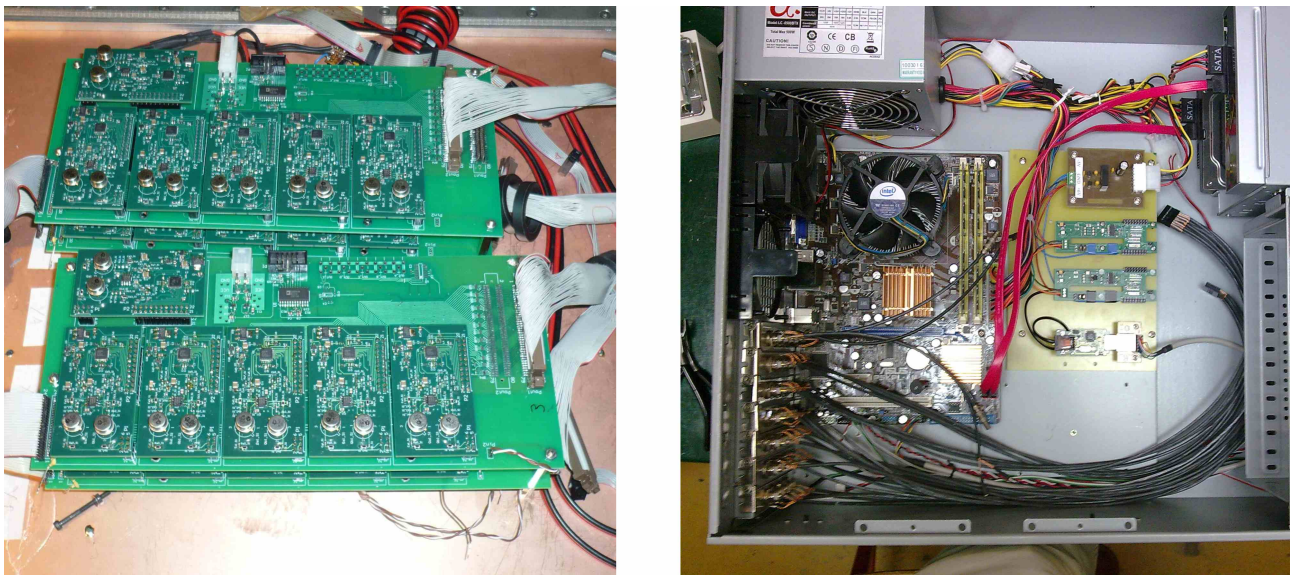


Figure 6.4: a) Front end electronics and mother boards for the RPC-PET project. b) Readout system for the monitoring of the RPC reference chambers of the RPC-TOF at the HADES experiment.

### 6.8.3 Achievements

The activity of the laboratory staff frequently overlaps with the experimental activities of the research groups and is therefore difficult to disentangle. During 2011, the main tasks developed in parallel with the daily support to the research groups were the following:

- Development of a system for autonomous RPC station monitoring (slow control). This system, based on the I2C protocol, easy to scale and able to implement for a variety of devices, currently comprehends temperature, humidity, pressure and voltage sensors.
- Development of a monitoring system with 8 + 8 Input / Output analog channels controlled by a micro-controller.
- Development of a system for the readout of the RPC reference chambers (48 chambers) and the readout of the multiplicity trigger signals (96 lines) of the RPC-TOF of the HADES experiment – see figure, part b). This system is based on the analog multiplexing of the different channels (with 1-wire® device), readout by two oscilloscope channels and later processed by a custom made C++ program.
- Update of the gas system control unit of the RPC-TOF for the HADES experiment to admit connection via CAN protocol.
- Development of a graphical user´s interface based on C++ for different laboratory devices (multimeter, oscilloscope, ...).
- Support to the development and assembly of the Front End Electronics (192 channels) and mother boards for the RPC-PET project – see figure, part a).
- Test and repair of the spare Front End Electronics (800 channels) for the RPC-TOF of the HADES experiment.
- Low cost HV power supply (6kV, 200uA) for the RPC detectors, based on commercial DC-DC converters.
- Design and construction of photomultipliers bases.
- Construction of one spark chamber for the outreach project.
- Different laboratory presentations to students in the framework of the Physics Department outreach program.
- Development of a low pressure open loop gas system for the RPC chambers.
- Participation in the design and construction of a purification gas system based on molecular Sieves.
- Participation in the design and construction of a electron gun of 15 keV.

# Chapter 7

# Outreach

## 7.1 Particle physics education and public outreach

### 7.1.1 Resumo

O Grupo de Outreach do LIP manteve em 2011 uma actividade significativa em várias linhas de acção. Destacam-se as apostas na divulgação para o público escolar, através das acções para alunos e professores, e para os media através dos comunicados de imprensa a propósito de acções específicas ou da adaptação para português dos comunicados de imprensa do grupo InterActions (incluindo o CERN) com relevância para Portugal. Não esquecemos contudo o público em geral, tendo participado em exibições públicas mostrando a Câmara de Faíscas e o que se faz no LIP (em particular na celebração dos 25 anos do LIP em Coimbra, e na XVI$^{a}$ Semana da Física no IST).
Mantendo a aposta iniciada em 2009 na internacionalização das acções para professores, 2011 foi o ano da concretização de um dos seus objectivos principais, que foi conseguir a participação de professores de todos os países membros da CPLP (Comunidade de Países de Língua Portuguesa). O financiamento das participações africanas foi partilhado entre o CERN e o LIP, através da Agência Ciência Viva, excepto o caso de Angola que patrocinou a participação dos seus professores.
Infelizmente, o plano inicial de trazer para Portugal a Exposição Itinerante do CERN "Accelerating Science"não pode ser concretizado, devido à incerteza no apoio logístico e financeiro. Por outro lado, também lamentamos o encerramento ao público do Centro de Ciência Viva da Amadora, com o qual tínhamos uma colaboração intensa.
As actividades realizadas em 2011 são apresentadas de seguida de forma aproximadamente cronológica.

- Em Março, foram realizadas as Masterclasses 2011, a 7$^{a}$ edição de uma actividade já regular no âmbito do grupo IPPOG - International Particle Physics Outreach Group, com a participação recorde de 1800 participantes em 10 institutos portugueses, mais um do que em 2009. Para permitir um número tão elevado de participantes, contámos com as instituições envolvidas e com o apoio voluntário e entusiástico de 25 cientistas nas palestras e aproximadamente 50 cientistas a apoiar as actividades de análise de dados. O número de participantes em Portugal continuou a ser bastante superior - em número absoluto e sobretudo em número relativo - ao dos outros países participantes no programa internacional.

- Na sequência da reunião da Colaboração Pierre Auger de 2010, onde foi feita uma apresentação sobre a utilização da câmara de faíscas como instrumento de divulgação, que suscitou bastante interesse, foi redesenhada a câmara de faíscas para funcionamento mais autónomo, especialmente no que respeita ao fluxo de gás, para responder a encomendas feitas por vários institutos. Na sequência disto já foram feitas desde 2010 um total de 7 câmaras de faíscas, das quais 6 foram entregues e estão em funcionamento no final de 2011, em locais tão diversos como Argentina, Áustria, Espanha e Portugal. Proximamente será entregue na Áustria a 7$^{a}$ câmara de faíscas feita no LIP Coimbra, e recentemente recebemos a encomenda de uma para Itália. Outros locais manifestaram o interesse em adquirir estes aparelhos (num total de 5), mas ainda não confirmaram a encomenda. Embora os objectivos do LIP não sejam o fabrico e venda de câmaras de faíscas, é um facto muito interessante que o modelo desenvolvido em Coimbra (a partir de um desenho inicial obtido no âmbito do IPPOG), tenha tido uma aceitação tão grande, e tenha ajudado a promover a Física de Partículas e Astropartículas.

- As actividades de Outreach do LIP foram apresentadas na 24$^{a}$ e 25$^{a}$ Reuniões do grupo EPPOG, que tiveram lugar em Kosice, Eslováquia, em Abril de 2011 e no CERN em Outubro de 2011, respectivamente.

Em Abril foi decidido mudar o logotipo e nome do grupo para IPPOG - International Particle Physics Outreach Group, para reflectir também a internacionalização das actividades do grupo e a crescente globalização do CERN e da Física de Partículas. O LIP interviu também nas 2 reuniões anuais do fórum EPPCN - European Particle Physics Communication Network, a rede criada pelo Conselho do CERN para promover a comunicação da Física de Partículas na Europa, que definiu como objectivo prioritário a preparação da comunicação associada à sessão de apresentação em Bruxelas da Estratégia Europeia de Física de Partículas, a ser preparada pelo CERN e que seria em 2012, mas que foi adiada para 2013.

- O LIP celebrou 25 anos no dia 9 de Maio de 2011. Foi realizada uma sessão comemorativa em Coimbra, na Biblioteca Joanina da Universidade de Coimbra, com a presença do Senhor Presidente da Assembleia da República, que assinou o acordo de adesão de Portugal ao CERN em 1985, na altura Ministro dos Negócios Estrangeiros, do Senhor Ministro da Ciência, Tecnologia e Ensino Superior, do Senhor Presidente da FCT, e de alguns reitores de Universidades portuguesas. A propósito desta comemoração foram preparados 13 posters de divulgação que mostraram ao público as várias actividades e história do LIP.

- Foram realizados 5 estágios para 15 alunos do ensino secundário, no âmbito do programa ´Ocupação Científica de Jovens em Férias´ da Agência Ciência Viva, em parceria com a FCUL e com a FCTUC. Os estágios tiveram duração variável, de 5 a 15 dias, e versaram temas como os detectores em Física de Partículas, Acontecimentos em ATLAS no LHC e dados públicos da Colaboração Pierre Auger.

- Foi co-organizada com o CERN a 5ª Escola de Física do CERN para Professores Portugueses, naquela que é reconhecidamente já uma actividade regular e estabelecida de grande sucesso, e aguardada com entusiasmo pelos organizadores e participantes. A internacionalização desta Escola, no âmbito da língua portuguesa, já justificou a alteração do seu nome para ´CERN Portuguese Language Teachers Program´. Em 2011 conseguiu-se pela primeira vez receber professores de todos os países de língua oficial portuguesa.

Foram assim levados ao CERN 41 professores de escolas portuguesas (de 193 candidatos), 20 professores brasileiros (de 250 candidatos), 4 professores moçambicanos, 4 professores angolanos, 1 professora cabo-verdiana, 1 professor santomense, 1 professor guineense e 1 professor timorense, num total de 73 participantes. Durante uma semana tiveram aulas, sessões experimentais e 6 visitas acompanhadas por investigadores portugueses e brasileiros. Esta escola teve um grande sucesso junto dos participantes, e potenciou o estabelecimento de novos contactos muito próximos com Professores de escolas remotas em Portugal, Brasil, Moçambique, Angola, Cabo-Verde, São Tomé e Príncipe, Guiné-Bissau, e Timor-Leste. Esta acção foi ainda acreditada no âmbito do Conselho Científico-Pedagógico para a Formação Contínua (de Professores do Ministério da Educação de Portugal), tendo sido atribuídos 1,4 créditos aos professores portugueses que participaram na avaliação obrigatória.

- Na Semana de Ciência e Tecnologia, o LIP participou na tarde da Física na Escola Secundária de Moimenta da Beira, com duas palestras e mostrando a Câmara de Faíscas.

- O LIP organizou a sessão pública "The Dark Universe"em Évora, no âmbito da "School on Dark Matter and Dark Energy"da rede IDPASC, com o Prof. Michael S. Turner e a participação de 200 alunos e professores de escolas secundárias da região de Beja, Évora, Lisboa, Portalegre, Santarém e Setúbal.

- Em 2007, foi lançado o projecto radão: ´Radiação Ambiente´, com 10 escolas, que aumentou para 55 em 2009 e foi limitado a 50 escolas em 2010 e 2011. É um projecto muito activo com escolas secundárias de todo o país (Norte, Centro, Sul e Ilhas), envolvendo quase 90 professores e perto de 300 alunos. Foram realizados 2 encontros nacionais em 2011, em Maio para avaliar os resultados do ano lectivo 2010/2011 e atribuir os prémios para os melhores trabalhos (com 250 participantes), e em Outubro para preparar o ano lectivo 2011/2012 (http://www.lip.pt/outreach/radao/public/index.php?cmd=smarty&id=4_len). Mais informação sobre este importante projecto pode ser consultada em http://www.lip.pt/oureach/radao.

- O LIP recebeu a visita de dois grupos de alunos de escolas básicas e secundárias ao longo do ano de 2011. O LIP tem mostrado o nó GRID do LIP no seu centro de cálculo, o laboratório de electrónica, e é feita uma palestra sobre a Física de Partículas aos visitantes. Tem-se mostrado e explicado também a Câmara de Faíscas e os Raios Cósmicos por ela detectados.

- Finalmente foram realizadas várias palestras de divulgação em Escolas e outros locais, num total de 35. Em particular palestras de preparação e acompanhamento de visitas de escolas ao CERN, Genebra, Suíça, que aumentaram significativamente nos últimos anos devido às Escolas de Professores no CERN em Língua Portuguesa.

### 7.1.2 Abstract

The LIP Outreach Group (LIP-OR) has the tasks of motivating the public and the young to be interested in science, of promoting the field of Experimental Particle and Astroparticle Physics, in particular the activities carried at LIP, and of conveying the importance and excitement of taking part in the development of science at large international research facilities and in international collaborations.
The group has kept its main focus in the scholar public, through actions directed at students and teachers, and in the media through press releases on specific events or the adaptation into portuguese of the press releases from InterActions (including CERN) relevant to Portugal. The general public is however not forgotten, with LIP participating in public exhibitions showing the Spark Chamber and the LIP activities.
In 2011 we have co-organized with CERN the fifth teachers program in portuguese, and for the first time we succeeded in receiving participants from all the portuguese speaking countries, causing a name change of the program to CERN Portuguese Language Teachers Program. In this 5th edition we received teachers from Brazil (20), Mozambique (4), Angola (4), Cape Verde (1), São Tomé and Príncipe (1), Guiné-Bissau (1), and East Timor (1). Thus 2011 marks the year of the full regularization of this program, that has set the standard for international editions in other languages, specially those that can congregate countries with different social conditions. The participation of the African countries was financed by CERN and by LIP, through Agency Ciência Viva (portuguese National Agency for the Scientific and Technological Culture), except for Angolan teachers that were supported by the Angolan Government.
In the following, a brief summary of the activities done in 2011 is provided in an approximately chronological order.

- In March we have organized the 2011 International Masterclasses Hands on Particle Physics, the 7th edition of a regular activity in the scope of IPPOG - International Particle Physics Outreach Group,

with a record participation of 1800 participants in 10 portuguese institutes, one more than 2009. To allow for such a large number of participants, we rely on the associated institutions (Universities and Higher Education Institutes), and on the voluntary and enthusiastic support of 25 scientists in the morning talks, and about 50 scientists as monitors for the classrooms analyzing the real data. The number of participants in Portugal has continued to grow, reaching a number far bigger than the numbers in other countries - absolute number and notoriously as relative numbers - participating in the international program.

- The Spark Chamber built at Coimbra (based on initial designs obtained in an IPPOG meeting), continues to raise the interest around the world in this fantastic and portable device. Since the first chamber

redesigned and built at LIP Coimbra, there were built already 7 Spark Chambers, of which 6 were delivered and are working properly in such diverse places as Argentina, Austria, Portugal and Spain.
Soon the 7th Spark Chamber will be delivered to Austria, and a new order for Italy was received in 2012. Other places have manifested interest in such device, for a total of 5 new Spark Chambers,
but the order was not yet placed. Although the LIP objectives do not include the manufacture and commercialization of Spark Chambers, it is still a very interesting fact that the model developed
at Coimbra had such a large acceptance and had helped to raise the awareness and interest of the Public and the youth in Particle and Astroparticle Physics.

- LIP Outreach activities were presented in the 24th and 25th IPPOG meetings, which took place respectively on April 2011 in Kosice, Slovak Republic, and on October 2011 at CERN. LIP has also

participated in the 2 annual meetings of the forum EPPCN - European Particle Physics Communication Network, the network of communicators and scientists created by the CERN Council to promote the
communication of Particle Physics in Europe, who defined as main aim the communication associated to the presentation by CERN in Brussels of the European Strategy on Particle Physics, that will take place in 2013.

- LIP has celebrated its 25th anniversary on May 9th, 2011. A commemorative public session took place in Coimbra, in the Baroque Library of the University of Coimbra, with the formal presence of the Chairman of the Parliament, who signed the adhesion agreement of Portugal to CERN in 1985 as he was then Minister of Foreign Affairs, the Minister for Science, Technology and Higher Education, the President of FCT (Portuguese Funding Agency), some rectors of portuguese universities, and the LIP Management. As a support for this celebration, 13 outreach posters were prepared to show the public the various LIP activities and LIP History.

- Summer internships, in the scope of the Agência Ciência Viva´s program "Summer in the Science-Ocupação Científica de Jovens em Férias, are always a high point in the LIP activities with students. Although the number of students that we can receive is not large, they stay between 5 and 15 days fully immersed in science, with the supervision of a scientist at all times. We have received 15 students from high-schools in 5 internships, that have worked the themes of detectors in particle physics, events in ATLAS at the LHC, and public data from the Pierre Auger Observatory.

- In September we have co-organized with CERN the 5th CERN Portuguese Language Teachers Program, a recognized and very successful established school, that serves as a reference for other CERN Member States. The internationalization of the school, in the scope of the portuguese language, has caused the name change to CERN Portuguese Language Teachers Program (it was CERN Portuguese

Teachers Program). In 2011 we succeeded in receiving, for the first time, teachers from all the portuguese speaking countries, one of the main objectives set in 2009 when the school opened to such
participation. There were at CERN 41 portuguese teachers (from 193 applications), 20 brazilian teachers (from around 250 applications), 4 mozambican teachers, 4 angolan teachers, and 1 teacher from
the countries Cape Verde, São Tomé and Príncipe, Guiné-Bissau, and East Timor, for a total of 73 participants. During one week they had theory classes, experimental sessions, and 6 visits guided by portuguese or brazilian scientists. This school had a great success within the participants, as new close contacts were established between teachers from remote schools of Portugal and the other countries.
This school was an action credited with 1,4 credits, in the scope of the relevant portuguese authorities for the progression of the portuguese teachers that have completed the mandatory test assessments.

- LIP participated in the Science Weeks of the Escola Secundária de São Pedro do Sul, in the Aveiro district, and of the Escola Secundária de Moimenta da Beira, giving talks and showing

the Spark Chamber.

- LIP organized the public session "The Dark Universe", in the scope of the IDPASC´s "School on Dark Matter and Dark Energy", with Prof. Michael S. Turner and the participation of 200 high school students and teachers from Beja, Évora, Lisboa, Portalegre, Santarém and Setúbal.

- The Environmental Radiation project ("Projecto Radão-- www.lip.pt/outreach/radao) was launched with 10 schools in 2007, but soon grew to 55 in 2009 and limited to 50 schools since 2010. It is a very active project with schools from all over the country (including Azores Islands!), envolving almost 90 teachers and 300 students. National events were organized in May and October. In May, closing the work of the year 2010/2011, students present the results of their activities within this project, and the best posters and discussions receive a diploma and symbolic prizes. In October, the year 2011/2012 is prepared and launched, circulating and/or updating the detectors and proposed experiments.

- Although LIP is not well suited for school visits, as the experiments with our participation are located at CERN, Argentina, Canada, Germany, etc., we still have received students from two schools in 2011. We have shown them the GRID cluster at LIP, the Instrumentation and Electronics Laboratory, and the Spark Chamber, explaining how it works. A talk about what is Particle Physics and what we do is also given.

- Finally we have made a total of 35 outreach talks in Schools and other places, in particular talks preparing the visits of portuguese schools to CERN, that have increased dramatically (from nearly zero

before 2006 to about 10 per year in 2011), despite the high costs that the students have to pay to cover the travel and lodgment expenses. We attribute this increased interest due to the CERN Portuguese Language Teachers Programs, as the teachers participants in the program want to go back to CERN with their students.

### 7.1.3 Objectives

The main objectives of LIP Outreach group are the following:

- motivate the public to be interested in science, and in particular Particle and Astroparticle Physics;

- engage the schools - teachers and students - to promote Particle and Astroparticle Physics in their environments (school, family, friends), through their enthusiasm in participating in activities (co-)organized by LIP;

- engage the scientists to promote Particle and Astroparticle Physics, through their enthusiasm in LIP activities, including public seminars at schools and other places, public exhibitions, etc;

- help the portuguese media when it comes to prepare articles and communication pieces about science, physics, particle and astroparticle physics, CERN, LHC, etc. In particular, LIP is adapting contents relevant to Portugal prepared elsewhere (for ex., CERN brochures, CERN´s Press Releases, etc), that are afterwards distributed to the media.

### 7.1.4 Achievements

The LIP Outreach group (LIP-OR) has achieved its objectives and in some cases surpassed them by large factors.
In particular, a few over-successful examples, namely those cases in which the results were greater than reasonable expectations, are detailed in the following, in approximate chronological order. LIP-OR consider its other successful activities as important achievements, and these are detailed in the section "Overview and Summary"in this report.

- IPPOG International Masterclasses in Particle Physics

In this activity in 2011, there was still one more location engaged into the activity, bringing the total number of sessions to 11 in 10 places. We increased the expectations in the number of participants to about 1400, but there were 1700 participants instead. In some places, the capacities of the institute were stretched to its maximum (for ex., the number of seats in the auditorium available for the talks and for the video-conference), and again two days at over-maximum capacity were organized at Lisboa-IST (with more than 300 participants in each day). That so many (more) students exchange their bed and cinema (on a Saturday) for "Be a Scientist for a day with Hands-on CERN"at the university, specially in Portugal, is a signal of the increased motivation of the Portuguese students and of the Portuguese teachers behind them, also due to the CERN´s Portuguese Language Teachers Programs.

- Environmental Radiation project

This subproject of the LIP Outreach had a lot of activities in 2011. In particular there were two meetings (in May and October). The increase of activity and participation in this project is also reflected in the number of 50 schools now participating in the project (that started in 2007 with 10 schools).

- CERN Portuguese Language Teachers Programs – Teachers Programs in Portuguese

The 5th edition of this program featured a new adventure: to receive more participants (73) that pushed CERN resources far beyond its limits, so that 41 teachers from Portugal, 20 teachers from Brazil, 4 from Mozambic, 4 from Angola, 1 from Cape Verde, 1 from São Tomé and Príncipe, 1 from Guiné-Bissau and 1 from East Timor could take part. For the first time we completed our initial very ambitious goal of having teachers from all the portuguese speaking countries.
The contacts established between the teachers and scientists (and between Portuguese, Brazilian, Mozambican, Angolan, Cape Verdian, São Tomé and Príncipe, Guiné-Bissau, and East Timor teachers) were very important for the cooperation in education between these countries, as well as for outreaching CERN to places far away from the laboratory - far way geographically as well as socio-economically. The edition – and the fact that happened for the third time with great success, has set the standard and pushed for other editions in different languages, which CERN recognizes and promotes as one of the
best teachers programs at CERN.

- Spark Chamber and other detectors

LIP has developed, in its workshop at Coimbra, 6 Spark Chambers since 2007. One was sold to Agency Ciência Viva, the other two are touring the country (one based at Coimbra, the other based at Lisboa), following seminars at schools and public exhibitions, ant the others are installed in such places as Argentina, Spain, and Austria. Following a continuous increase in its interest, due to its beauty, effectiveness and portability, the demand of production continued and 1 more chamber was built, soon to be delivered. More orders are expected in the near future.

- Seminars at schools and other places (and Visits to CERN)

The interest of Society in Particle and Astroparticle Physics has increased in recent years, mostly by the startup of LHC-Physics and related events (in 2010 and 2011), which in Portugal were also coordinated by LIP (as part of the EPPCN forum). The result of engaging the teachers and students in the LIP Outreach activities (most notable the CERN´s Portuguese Language Teachers Program and the IPPOG International Masterclasses in Particle Physics), was also reflected in the boost of requests to make a seminar (outreach talk) in the school or other places. In 2011, LIP-OR members made 35 such outreach seminars, and some were just before a school went with its students to visit CERN, which also puts pressure on the portuguese scientists at CERN, as they are requested to serve as guides for the visits in portuguese.

### 7.1.5 Sources of Funding

| Code | Funding | Start | End |
|---|---|---|---|
| MC2011_RadAmb2010-11 | 15.000 € | 2010-10-01 | 2011-06-30 |
| CERN TPP 2011 | 37.860 € | 2011-04-01 | 2011-12-31 |
| OCJF2011 | 1.200 € | 2011-06-15 | 2011-09-15 |
| MC2012_RadAmb2011-12 | 15.000 € | 2011-10-01 | 2012-06-30 |

### 7.1.6 Team

**Project coordinator: Pedro Abreu**

| Name | Status | %of time in project |
|---|---|---|
| Agostinho Gomes | Researcher (LIP) | 5 |
| Amélia Maio | Researcher (LIP/FCUL) | 15 |
| Américo Pereira | Technician (LIP) | 11 |
| Ana Rodrigues | Master student (LIP) * | 20 |
| Ana Fernandes | Collaborator | 20 |
| Ana Pinto | Collaborator | 20 |
| António Onofre | Researcher (LIP/UMinho) | 10 |
| Carlos Bernardino | Collaborator | 20 |
| Carmen Oliveira | PhD student (LIP) | 20 |
| Conceição Abreu | Researcher (LIP) | 40 |
| Cristina Melo | Collaborator (LIP) | 20 |
| Fernando Barão | Researcher (LIP/IST) | 5 |
| Florbela Rego | Researcher (LIP) | 10 |
| José Rogério Nogueira | Collaborator | 20 |
| Luis Peralta | Researcher (LIP/FCUL) | 20 |
| Maria António | Collaborator | 20 |
| Maria do Anjo Albuquerque | PhD student (LIP) | 20 |
| Miguel Ferreira | Technician (LIP) | 21 |
| Paula Pinho | Collaborator | 20 |
| Pedro Abreu | Researcher (LIP/IST) | 35 |
| Pedro Assis | Post-Doc (LIP/FCT/IST) | 5 |
| Sandra Soares | Researcher (LIP/UBI) | 20 |

### 7.1.7 Publications

**Articles in international journals (with direct contribution from LIP members)**

- *Cosmic ray detection made easy*
  Luis Peralta e Florbela Rego
  Physics Education (accepted)

- *Cosmic Rays Made Easy*
  Luis Peralta e Florbela Rego
  Physics Education (accepted)

### 7.1.8 Presentations

**Outreach seminars**

- *Física das Partículas Elementares e Interacções Fundamentais*
  presented by João Carvalho
  — Escola Secundária Rodrigues Lobo, Leiria.

- *O que fazem os Físicos no CERN?*
  presented by Pedro Abreu
  — Escola Secundária D. Pedro V, Lisboa.

- *A estrutura da matéria e a tabela periódica*
  presented by Pedro Abreu
  — Escola Secundária de Gama Barros, Cacém, Sintra.

- *O que fazem os Físicos no CERN?*
  presented by Pedro Abreu
  — Escola Secundária de Gama Barros, Cacém, Sintra.

- *Ao encontro do infinito*
  presented by Pedro Abreu
  — (Visita de Escolas ao LIP) - LIP, Lisboa.

- *O que fazem os Físicos no CERN?*
  presented by Pedro Abreu
  — Escola Secundária António Gedeão, Laranjeiro, Almada.

- *...do muito grande ao muito pequeno*
  presented by Luis Silva
  — Esc. Sec. Henriques Nogueira, Torres Vedras.

- *Ser Cientista e brincadeiras com a Luz*
  presented by Pedro Abreu
  — 3ªClasse da Escola piloto no Pavilhão do Conhecimento, Lisboa.

- *Anjos, Demónios, Matéria e Antimatéria*
  presented by Pedro Abreu
  — Oficinas de São José (Escola Salesiana de Lisboa), Lisboa.

- *O que fazem os Físicos no CERN?*
  presented by Pedro Abreu
  — Academia de Música de Santa Cecília, Lisboa.

- *Ao encontro do infinito*
  presented by Pedro Abreu
  — Escola Secundária de São Pedro do Sul, São Pedro do Sul.

- *Anjos, Demónios, Matéria e Antimatéria*
  presented by Pedro Abreu
  — Escola Secundária Camilo Castelo Branco, Vila Nova de Famalicão.

- *O que fazem os Físicos no CERN?*
  presented by Pedro Abreu
  — Escola Secundária Acácio Calazans Duarte, Marinha Grande.

- *Física das Partículas Elementares e Interacções Fundamentais*
  presented by João Carvalho
  — Escola Secundária Alves Martins, Viseu.

- *Física das Partículas Elementares e Interacções Fundamentais*
  presented by João Carvalho
  — Instituto Pedro Hispano, Granja do Ulmeiro.

- *Riscos para a Saúde Humana da Exposição Ambiental ao Radão*
  presented by Luis Peralta
  — Escola EB23 Vasco Santana, Odivelas, 4 de Maio, 2011.

- *Energia Nuclear*
  presented by João Carvalho
  — Escola Secundária de Carregal do Sal.

- *O que fazem os Físicos no CERN?*
  presented by Pedro Abreu
  — Escola Secundária Severim de Faria, Évora.

- *O que fazem os Físicos no CERN?*
  presented by Pedro Abreu
  — Oficinas de São José (Escola Salesiana de Lisboa), Lisboa.

- *Ao encontro do infinito*
  presented by Pedro Abreu
  — Escola Secundária Mouzinho da Silveira, Portalegre.

- *O que fazem os Físicos no CERN?*
  presented by Pedro Abreu
  — Escola Secundária de Moimenta da Beira, Moimenta da Beira.

- *Ao encontro do infinito*
  presented by Pedro Abreu
  — Escola Básica Integrada de Miraflores, no Auditório Municipal Ruy de Carvalho, Carnaxide, Oeiras.

- *Patentes: Problemática e Pesquisa*
  presented by Carlos Conde
  Seminário de Engenharia Física — Departamento de Física da Universidade de Coimbra.

### 7.1.9 Project Summary

| | number |
|---|---|
| Articles in international journals (with direct contribution from LIP members) | 2 |
| Outreach seminars | 23 |

## 7.2 Technology Transfer Network and Industrial Liaison Office

### 7.2.1 Resumo

Projeto Rede de Transferência de Tecnologia (TTN)
A contribuição do LIP para o WP4 (no âmbito da colaboração RD-51 em detectores gasosos - MPGDs) e a adoção do guia de Propriedade Intelectual (PI) foram os resultados positivos que mostram que o LIP é membro (Nó) ativo no projeto TTN. A estrutura do TTN está a alargar as suas fronteiras e, actualmente é composto pela maioria dos gabinetes de Transferência de Tecnologia nos principais organismos públicos de investigação nos Estados-Membros (tais como: CEA / DSM, CEPAN, CERN, Chalmers, Universidade de Copenhaga, CNRS/IN2P3, DESY, EPFL , GSI, INFN, ILL, JSI, PSI, UT Nacional de Atenas, STFC e Universidade de Sofia) e continua a captar a atenção de outras instituições (ex: IFIN-HH da Roménia). As atividades previstas em 2011 foram enquadradas em três níveis e tiveram os seguintes resultados: 1) O site do projeto TTN está totalmente operacional sob o título: "HEPTech: HEP tecnologias líderes para a indústria, oportunidades de Transferência de Tecnologia - TT"e é acessível em: http://www.heptech.org com 68 tecnologias e ofertas de serviços, assim como 12 histórias de sucesso. Este site é um canal de divulgação adequado para o LIP, quando se considerar, promover know-how e/ou uma tecnologia específica, 2) promoção dos principais indicadores sobre o impacto tecnológico da Física de Partículas na Europa, isto é: número de "disclosures"de invenções, transferência de PI e/ou acordos de exploração tecnológica, acordos de colaboração de I&D, spin-offs e número de FTEs (investigadores) relacionados com a Transferência de Tecnologia e Conhecimento (KTT), destacando que o indicador relativo ao número de acordos de colaboração de I&D mostram que os esforços de desenvolvimento entre a academia e a indústria resultam na transferência do conhecimento e know-how e só posteriormente no registo de patentes. Para o LIP é uma boa indicação de uma estratégia a considerar na divulgação dos resultados científicos que pode ser aproveitada por acordos de colaboração de I&D com a academia e/ou indústria que beneficiam a longo prazo o LIP na disseminação dos resultados de investigação em aplicações comerciais; 3) por último, melhorar a capacidade dos membros do TTN em matérias de TT resultou em: a) realização de evento de ligação entre empresas-academia b), projetos UE-FP7 (ex: AIDA infra-estruturas de I&D para desenvolvimento de detectores para a área de Fisica de Partículas, e c) sugestão do Conselho do CERN que os membros do TTN deviam estudar as lições aprendidas durante a construção do LHC nas áreas de "procurement"e Transferência de Tecnologia. Para, a) realizou-se o evento sobre Fotomultiplicadores (SiPM) e tecnologias relacionadas com cerca de 135 participantes, sendo 21 da indústria, para b) o projeto AIDA - FP7 adotou o modelo de workshops para a ligação entre empresas-academia nos seus eventos futuros e para c) na sessão de Junho de 2011 do Conselho do CERN sobre a Estratégia Europeia da Física, as lições aprendidas durante a construção do LHC nas áreas de "procurement"e Transferência de Tecnologia foram apresentados, e os destaques são: a grande escala de um programa científico na área da Física de Partículas estimula a inovação, o LHC promoveu a multiplicidade de tecnologias e know-how, uma grande fração do know-how e tecnologias originárias do CERN não é patenteável mas podem ser usadas em vários domínios aplicacionais e as tecnologias da área de Física das Partículas demoram entre 5 a 10 anos para entrarem no mercado como produtos e serviços. Para o LIP os outputs previamente mencionados, são de extrema importância e podem ser utilizados de forma orientada e nos meios adequados para promover ao público em geral e também outras partes interessadas de diferentes áreas científicas que a Física de Partículas tem impactos significativos na sociedade em geral.
Atividades do ILO
Em 2011, o ILO adotou a mesma estratégia em apoiar e promover ativamente a indústria nacional e/ou instituições de I&D, para o CERN, ESO, ESRF e contribuir para seu sucesso no processo de aquisições, e divulgação de oportunidades de projetos e tecnologias disponíveis*, por forma a garantir a sustentabilidade de um retorno positivo do coeficiente industrial para Portugal nestas organizações. O ILO prosseguiu a estreita colaboração com o Gabinete do Espaço da FCT na representação da delegação Portuguesa na Agência Espacial Europeia (ESA) para os assuntos industriais.
(oportunidades de projetos e tecnologias disponíveis* significa: documentos técnicos sobre oportunidades de concursos para fornecimento de bens e/ou serviços, tecnologias (incluíndo patentes, know-how e software) projetos de I&D ou colaborações).

### 7.2.2 Abstract

Technology Transfer Network (TTN)
LIP contribution to WP4 (in the context of the RD-51 Collaboration on Micro Pattern Gaseous Detectors – MPGDs) and the adoption of the Intellectual Property (IP) charter were positive outcomes that account LIP as an active Node member of the TTN project. The TTN structure is enlarging its boundaries and presently composed of most of the major Technology Transfer Offices from public research organizations in the Member States (such as: CEA/DSM, CEPAN, CERN, Chalmers, Copenhagen University, CNRS/IN2P3, DESY, EPFL,

GSI, INFN, ILL, JSI, PSI, National TU Athens, STFC and University of Sofia) and continuing to capture the attention of other Institutions (ex: IFIN-HH from Romania). The activities foreseen in 2011 were pursued at three levels with the following outputs: 1) The TTN website is fully operational under the heading: "HEPTech: Leading HEP technologies for industry, Technology Transfer Opportunities"and is accessible at: http://www.heptech.org featuring 68 technologies and service offerings as well as 12 success stories. This website is a suitable dissemination channel for LIP, when considering, promoting its know-how and/or a specific technology; 2) Raising awareness of key indicators on the impact of Technology Transfer in the area of Particle Physics in Europe: number of invention disclosures, IP transfer and/or exploitation agreements, R&D cooperation agreements, spin-offs and number of FTE researchers related to Knowledge and Technology Transfer (KTT), highlighting that the indicator related to the number of R&D cooperation agreements shows that the development efforts with academia and industry with a goal to building demonstrators are more likely to yield to a more effective technology and know-how transfer in which patenting comes as a result and is better focused on exploitation. To LIP this is a good indication that a optimal path of disseminating scientific results can be leveraged by R&D cooperation agreements with other academia and/or industry benefiting in the long-run from the exploitation of the R&D results in applications with commercial utilization; 3) lastly, improving the Nodes capability in dealing with TT matters resulted in a) the realization of industry-academia matching events b) EU-FP7 projects (ex: AIDA an integrating activity addressing infrastructures for detector R&D), and c) CERN Council suggestion that TTN members study the lessons learned from procurement and TT during LHC construction. For a) there was the realization of the industry-academia matching event at CERN on Silicon Photomultipliers (SiPM) and related technologies with 135 participants being 21 from industry, for b) The AIDA FP7 project has adopted the industry-academia model for future workshops in the framework of their responsibility towards the relation with industry and c) in June 2011 at the European Strategy Session of Council the lessons learned from procurement and TT during LHC construction were presented, and the highlights are: large scale physics research programme boosts innovation, the LHC programme has fostered a rich variety of technologies and know-how, a large fraction of the CERN know-how and technologies is not patentable, CERN technologies can be used in various domains but a large fraction lacks readiness level, CERN technologies require further applied R&D to increase their market readiness, typical time to market for Particle Physics technologies ranges between 5 to 10 years and pooling Particle Physics technologies can enhance dissemination prospects. For LIP the abovementioned outputs, are paramount and can be used in a targeted manner and in the right mediums to promote to the general public and also other stakeholders from distinct scientific areas that Particle Physics has significant impacts in society at large.
ILO activities
In 2011, the ILO followed the same strategy in actively supporting and promoting industry and R&D institutions towards CERN, ESO, ESRF and contribute to their success in the procurement process, seek project opportunities and available technologies*, further to ensure the positive sustainability of the industrial return coefficient for Portugal in these organizations. The ILO continued the close collaboration with the FCT Space Office in representing the Portuguese delegation at the European Space Agency (ESA) for industrial matters.
(project opportunities and available technologies* means: announcement of tender opportunities to supply goods and/or services, technologies (including patents, know-how, software), R&D projects or collaborations.)

### 7.2.3 Objectives

Technology Transfer Network (TTN)
- Consolidation of a web-page at LIP Outreach website that describes: About Technology Transfer (ex: Patenting process) and its importance for LIP, Description of the TTN project and elements of the IP charter, Interesting Links.
- Follow, as LIP TTN member, the developments of the socio-economic impact studies, related with the application areas of: PET imaging, hadron therapy, simulation software. Also follow the WP4: Implementation of MPGDs pilot. And, ensure the participation of a Portuguese company and/or national research center at the Industry-academia matching event on SiPM and related technologies organized at CERN.
- Organization of dedicated bilateral meetings with LIP researchers about the topic Intellectual Property issues: 1) The Patenting process and 2) Commercialization aspects of early stage technologies: Road-map from the lab to market, at LIP Lisbon and/or Coimbra.
ILO activities
- Populate with up to date content the passive web-page, located at the FCT official website, which describes CERN, ESO, ESRF and ESA (under the responsibility of the FCT Space Office) of the Portuguese participation at least in three levels (scientific, technical training and industry participation).
- Get underway the activation of the database to insert selected data of national companies (and research centers, such as LIP) to work as an information management system related to project opportunities and

available technologies* at CERN, ESO, ESRF and ESA (under the responsibility of the FCT Space Office).
- Establishment as much as possible, company presentations to technical departments and/or groups at CERN, ESO, ESRF.
- Continuation with the national road-show initiative to present CERN, ESO, ESRF to Portuguese companies. And, consolidation of the collaboration with the FCT Space Office to have an integrated approach towards the companies operating in the space sector.
- Organization of an industrial event to promote companies at CERN, ESO and/or ESRF, such as: Visit of firms @ CERN, industry day @ ESO and/or ESRF.
(project opportunities and available technologies* means: announcement of technical documents about tender opportunities to supply goods and/or services, technologies (including patents, know-how, software), R&D projects and/or collaborations).

### 7.2.4 Achievements

TTN
- Information related to Technology Transfer (TT) matters is available at https://web.lip.pt/seminarios.php. An effort to have an autonomous and dedicated web-page about TT at the LIP Outreach main page will continue in 2012.
- In tight collaboration with RD-51 (http://rd51-public.web.cern.ch/rd51-public/) researchers, the TT Network (TTN) has conducted a complete inventory of the technologies, expertise, processing facilities and software developed for Micro Pattern Gaseous Detectors (MPGD´s). LIP contributed to the inventory during 2011. Further, from a TT perspective, the identification of markets, stakeholders and key success factors has been conducted in collaboration with the Institute of Entrepreneurship and Innovation of the Vienna University of Economics and Business. It was also assessed a route to market of a combined MPGD-based neutron-gamma scanner for fast air cargo screening (study is available via LIP ILO contact)
- The industry-academia matching event was realized during the 1st trimester of 2011 at CERN on Silicon Photomultipliers (SiPM) and related technologies. Over 135 participants being 21 from industry were present. This event was advertised within the LIP community and other R&D Institutions in Portugal. National participation was represented by INOV INESC Inovação from Lisbon.
- It was organized during the 3rd trimester of 2011, a 2nd LIP Seminar on Technology Transfer with the title: "Patenting in the field of High Energy Physics: why, when and how". This seminar was held at LIP main locations (Coimbra and Lisbon). The invited speaker was CERN Patent Portfolio Manager. A total of 14 Physicists participated, and the seminar material was distributed to the LIP community (including the document – CERN IP management policy) via lip-users mailing-list.
ILO activities
- A fully populated web-page about CERN, ESO, ESRF and ESA is established and publicly promoted at the Fundação para a Ciência e Tecnologia (FCT) official website, and available at: http://www.fct.pt/apoios/cooptrans/cern/. The content in the pages is the following, as CERN example: About CERN, Portuguese Participation, Advanced training of Human Resources, Industrial Participation, Contacts about the Portuguese Delegation and relevant links from CERN.
- A beta version of a database that contains information of companies (and R&D Institutions, such as LIP) is operational and for internal use for the ILO to support him as an information management system related to project opportunities and available technologies * at CERN, ESO, ESRF and ESA (under the responsibility of the FCT Space Office).
- During 2011, the ILO continued in supporting company presentations to technical departments from CERN, ESO and ESRF by establishing different formats of discussion forum (ex: dedicated meetings or industry day). It is reported the company name and to whom it was presented, as follows:
CERN
Company: Inov-Inesc Inovação (Electronics Development); To Whom: Senior Head of GBT project - Physics Department/Microelectronics section and Senior Electronics Engineer – Beams Department/Controls
Company: Exatronic (Electronics); To Whom: Senior Staff for Electronics Production and Modules
Company: Nanium (Micro-chip large scale production and R&D); To Whom: Senior Staff for Electronics Production and Modules
Company: Solidal Condutores SA (Energy Transport and distribution and Power cables); To Whom: Head of Group Engineering Department/Electrical Engineering Group
Company: YDreams (Software and Augmented reality technologies); To Whom: Contracts and Procurement Group
Company EFACEC (Electronics Production business unit); To Whom: Section leader – Senior Electronics Engineer Technology Department/Interlocks, Controls & Monitoring

ESO
Company: Novabase (IT Services/Software Development); To Whom: Head of Software Division and acting Director of Engineering
ESRF
Company: Grupo Casais (Civil Engineering); To Whom: Director Contracts and Procurement
Company: PLC – Técnicas de Automação e Control (Automation technologies and services); To Whom: Director Contracts and Procurement
- The collaboration between the ILO and the FCT Space Office for the national road-show activities aimed at visiting several companies from different niche sectors that could be potential suppliers or project partners for CERN, ESO, ESA and ESRF, and also, national or R&D Institutions or labs such as LIP. In the framework of the road-show the companies visited were: A.Silva Matos, EFACEC, FeedZai, IPN, HPS Portugal, INEGI, Novabase, Schneider Electric Portugal, Thales Portugal.
- The ILO organized jointly with CERN IT Department, a 1st Computing Seminar in February 2011 with a Portuguese company called FeedZai. The event was called: "The power of event-driven analytics in Large Scale Data Processing"with the main objective to present the open-source product "FeedZai Pulse"and explore the topic of large-scale data processing using Complex Event Processing in the scope of CERN data processing needs. The event is accessible at this link: http://indico.cern.ch/conferenceDisplay.py?confId=123802. There were 25 to 30 participants from CERN.
- In February 2011, the ILO organized a dedicated meeting with ESO Head of Software Division and acting Director of Engineering and the Procurement Officer of ESO Administration Division at the FCT premises. The sector of IT/Software Development applicable to big science organizations was addressed and representatives from key Portuguese companies were present: Critical Software, Deimos Engenharia, GMV Solutions, Novabase and Edisoft. The objective of the meeting was to explore the procurement and project opportunities at ESO and in particular for the European Extremely Large Telescope (E-ELT).
- The organization of the 1st ESO Industry Day in Portugal took place in October 2011 at the Pavilhão do Conhecimento in Lisbon. With the support of the ILO a total of 41 participants (Industry and R&D Institutions) had the opportunity to be aware and discuss with ESO experts about the potential industrial opportunities in the framework of the future construction of the European Extremely Large Telescope (E-ELT) and other ESO projects (ex: ALMA). The event details can be consulted at: http://esoiday.fct.pt/en/

### 7.2.5 Team

**Project coordinator: Emir Sirage**

| Name | Status | %of time in project |
|---|---|---|
| Emir Sirage | Technician (LIP) | 100 |

## 7.3 Education and Advanced Training

### 7.3.1 Resumo

Um dos objetivos principais da atividade do LIP em geral é o treino continuo de cientistas e a integração de jovens cientistas nos nossos programas de investigação. O contacto próximo com o ensino superior, em todos os domínios mas principalmente nos de investigação fundamental, é assim uma prioridade clara. Esta linha estratégica foi reforçada com a recente criação da rede internacional de doutoramentos IDPASC e será seguida nos próximos anos.
A equipe de investigação do LIP envolve estudantes em diferentes níveis. Muitas teses de mestrado ou doutoramento são desenvolvidas nos projetos do LIP, os estudantes de pós-graduação trabalham em contacto próximo e sob orientação dos investigadores do LIP, em muitos casos beneficiando também da discussão alargada no âmbito das grandes colaborações internacionais em que os projetos se inserem. Em alguns casos é também possível integrar estudantes do 1º ciclo, proporcionando-lhes trabalhos de investigação interessantes mas que podem ser desenvolvidos em menos tempo.
Muitos dos investigadores do LIP são professores do quadro das várias Universidades, onde lecionam cadeiras nos vários ciclos de estudos; ao mesmo tempo, alguns dos investigadores contratados pelo LIP, são também professores convidados, lecionando cursos avançados ou contribuindo mais pontualmente com aulas no quadro das suas especialidades. O LIP tem acordos com as várias Universidades, em Coimbra, Lisboa e Minho, para partilha de recursos, e contribui com a criação de equipamentos específico para o ensino.
O Laboratório como um todo participa ativamente na Rede Internacional de Doutoramentos em Física de Partículas, Astrofísica e Cosmologia, e o LIP coordena de facto o sistema de gestão de cursos da rede assim como o programa de bolsas IDPASC/FCT. A rede IDPASC foi criada em 2010 para fortalecer a comunidade de investigação em física fundamental. Embora ainda esteja em crescimento, engloba já várias organizações internacionais de investigação – o CERN, o EGO (Observatório Europeu de Gravitação) e o CBPF (Centro Brasileiro de Pesquisas Físicas) – e muitas Universidades, incluindo todas as Universidades portuguesas com programas na área de Física de Partículas, Astrofísica e Cosmologia, e outras em Espanha, Itália e França.
As atividades da ISPASC incluem: um escola anual em que estudantes de doutoramento das várias áreas e instituições se juntam para uma ou duas semanas dos cursos interdisciplinares básicos; Escolas e cursos em temas específicos, em geral complementadas com workshops sobre os desenvolvimentos mais recentes e abertos aos outros investigadores da área; Conferências públicas dedicadas principalmente aos estudantes dos primeiros anos da Universidade e aos estudantes e professores dos últimos anos do ensino secundário. Os cursos organizados localmente são sempre anunciados para toda a rede de forma a promover a mobilidade entre as várias instituições que a compõem. As escolas anuais seguem o sistema europeu de créditos e têm uma avaliação individual final, para que eles possam ser reconhecidos pelas Universidades. No fim do doutoramento, os estudantes recebem um certificado IDPASC.
Além dos programas de ensino nas áreas de investigação fundamental, o LIP participa também na organização de programas de treino avançado para jovens licenciados portugueses nas grandes organizações científicas internacionais, CERN, ESA e ESO, em áreas tecnológicas de importância estratégica para aumentar a competitividade da indústria portuguesa. O programa de divulgação do LIP é especialmente dedicado aos estudantes do ensino secundário e aos seus professores e inclui um curso anual em física de partículas e áreas relacionadas, co-organizado com CERN, para os professores de todos os países de língua portuguesa. Estas atividades serão descritas nas secções seguintes.

### 7.3.2 Abstract

One of the main objectives of the overall LIP activity is the continuous training of scientists and the integration of young scientists in our research programs. In all areas, but primarily the basic research ones, the maintenance of strong links to higher education is a clear priority. This strategic line was reinforced recently with the establishment of the IDPASC network and will be pursued in the years to come.
The LIP teams involve students at different levels. Many post-graduate students develop their master and PhD thesis in the framework of the LIP projects under the close supervision of local researchers and benefiting from the inputs and discussion within large international collaborations. Specific subjects also provide interesting less-time demanding work examples for undergraduate students.
Many LIP researchers are hired professors at local Universities, where they teach courses at all levels; and many of the researches hired by LIP also do teach some full courses or invited lectures, primarily at advanced levels in areas closely connected to our activities. In its several units, in Coimbra, Lisboa and Minho, specific agreements exist with each University for the sharing of resources, and LIP has created specific laboratory equipment for educational purposes.

The Laboratory as a whole participates actively in the International Doctorate network in Particle Physics, Astrophysics and Cosmology and LIP coordinates the web-based course management system of the network and the FCT/IDPASC PhD grant program. IDPASC was created in 2010 to strengthen a community in fundamental physics research. While it is still growing, it now involves international research institutions - CERN, EGO (the European Gravitational Observatory), CBPF (in Brasil) – and many Universities – including all Portuguese Universities that have programs in the area of Particle Physics, Astrophysics and Cosmology, and others in Spain, Italy and France.
IDPASC activities include: A yearly school where PhD students from the several areas and institutions get together for one or two weeks with basic interdisciplinary courses; Schools and courses on specific subjects, usually complemented with workshops on the most recent developments and opened to all the researchers in the area; Public lectures mainly dedicated to the last years high school students and teachers as well as to first year University students. Courses organized locally by each member of the network are advertised promoting mobility between the several institutions. The yearly schools are organized according to the European credits system and all schools and courses have a final individual evaluation so that the Universities can recognize the corresponding credits. At the end of their PhD, the students will be granted a certificate.
In addition to the basic research education programs, LIP participates in the organization of advanced training for young Portuguese graduates in large international scientific organizations like CERN, ESA and ESO, in technological areas which are of strategically importance for the increase in competitiveness of Portuguese companies. The Outreach program of the laboratory is mostly devoted to high school students and teachers, and encompasses a yearly course, co-organized with CERN, on particle physics and related areas, for high school teachers of Portuguese speaking countries. These activities are described in the next sections.

### 7.3.3 Objectives

The main objectives for 2011 were:

- The consolidation of the IDPASC network, with the joining of new partner institutions, the realization of the yearly and thematic network schools and workshops, and the attribution of the first grants of the FCT/ IDPASC PhD program.
- The pursuing of the usual LIP activities in what regards both the inclusion of graduate students and the completion of Thesis works, and the teaching of advanced courses in Particle (and Astroparticle) Physics, Experimental and Simulation Techniques, Data Acquisition.
- The consolidation of the LIP unit at University of Minho, bringing together research in experimental particle physics and education activities, allowing, for a first time, the establishment of our research areas at Minho and a close collaboration with the MAP-Fis PhD network.

### 7.3.4 Achievements

The most recent LIP unit, at Universidade do Minho, is being consolidated and becoming more multidisciplinary. It now has eight members within three PhD holders and students. The basic research areas include quark top properties and new physics at LHC and high energy astroparticle physics, with important activities being developed also in advanced computing, outreach and education.
IDPASC grew with new institutions, namely the European Gravitational Observatory (EGO), the Centro Brasileiro de Pesquisas Fisicas (CBPF) and the Universities of Paris VI, Savoie, Padova and Bari. Specific courses on Statistics and the Standard Model of Particle Physics were organized in Lisbon, and one week schools on Higgs Boson Physics (September, Foz do Arelho) and on Dark Matter (December, Évora) joined together students from several institutions in the network, with international researchers in these areas. The two first batches of FCT/IDPASC PhD grants were attributed in January and July. The jury considered around forty applications and 11 grants were given to students to work in different home institutions and research areas.

# Chapter 8

# Scientific Conferences and Seminars

## 8.1 Seminars

**Seminars**

- *Little Bangs at ATLAS/LHC*
  presented by on 2011-01-13
  — LIP Lisbon.
- *Looking beyond the Standard Model at LHC: SUperSYmmetry & the case for stop*
  presented by on 2011-02-03
  — LIP Lisbon.
- *Detection of the Crab pulsar above 25 GeV and its consequences in pulsar physics*
  presented by on 2011-02-10
  — LIP Lisbon.
- *Top flavour as a window to new physics*
  presented by on 2011-02-17
  — LIP Lisbon.
- *Laser Spectroscopy of the Lamb-Shift in Muonic Hydrogen – Determination of the Proton Radius*
  presented by Joaquim M. F. dos Santos (Centro de Instrumentação, D. F. U. Coimbra) on 2011-03-17
  — LIP Lisbon.
- *Charm Semileptonic decays in the BaBar experiment*
  presented by on 2011-04-07
  — LIP Lisbon.
- *Surprises at Ultra High Energies: the cosmic ray neutrino connection*
  presented by Angela Olinto (U. Chicago) on 2011-04-14
  — LIP Lisbon.
- *First measurement of the top quark mass at the LHC*
  presented by on 2011-04-21
  — LIP Lisbon.
- *Measurement of the ttbar production cross section in pp collisions at sqrt=7 TeV with the CMS detector*
  presented by on 2011-05-05
  — LIP Lisbon.
- *Overview of ATLAS performance and physics results in 2010 and prospects for 2011*
  presented by Daniel Froidevaux (CERN) on 2011-05-12
  — LIP Lisbon.
- *Search for the MSSM Higgs boson at the LHC with the CMS detector*
  presented by on 2011-05-26
  — LIP Lisbon.

- *Astrophysical Uncertainties in Dark Matter Searches*
  presented by on 2011-06-02
  — LIP Lisbon.

- *The Search for the Neutron Electric Dipole Moment*
  presented by Simon Peeters (U. Sussex) on 2011-06-16
  — LIP Lisbon.

- *Ocupação Científica de Jovens em Férias*
  presented by Raios Cósmicos de Energia Extrema com o Observatório Pierre Auger por André Graça, Miguel Correia, Pedro Baião e Thomas Pimenta e *Fontes de baixa tensão do Tilecal/ATLAS em análise - qual se desligou primeiro? por Ana M on 2011-07-08
  — LIP Lisbon.

- *Search for new physics in hadronic decays of B mesons at the LHCb experiment*
  presented by Cibran Santamarina Rios (U. Santiago de Compostela) on 2011-09-15
  — LIP Lisbon.

- *Search for a resonant SM Higgs boson in CMS using diphoton decays*
  presented by on 2011-09-21
  — LIP Lisbon.

- *Cosmic rays: a partly untold story*
  presented by on 2011-09-29
  — LIP Lisbon.

- *Search for charged Higgs boson in the decay of top quark at CMS*
  presented by on 2011-10-06
  — LIP Lisbon.

- *Some innovations in positron emission tomography under investigation at the molecular imaging instrumentation laboratory at Stanford University*
  presented by Craig Levin (Molecular Imaging Instrumentation Laboratory, Stanford Schoolf of Medicine) on 2011-10-19
  — LIP Lisbon.

- *Ettore Majorana meets his shadow - the NEXT experiment*
  presented by J. J. Gomez-Cadenas (IFIC Valencia) on 2011-10-20
  — LIP Lisbon.

- *Bayes versus frequentism: the continuing statistical battle*
  presented by Louis Lyons on 2011-10-27
  — LIP Lisbon.

- *Patenting in the field of High Energy Physics - why, when and how*
  presented by Telma Mantas (CERN) on 2011-11-03
  — LIP Lisbon.

- *Topics on Gamma-ray astrophysics*
  presented by Nicola Giglietto and Francesco Giordano (University of Bari and INFN) on 2011-11-04
  — LIP Lisbon.

- *Quarkonium physics at the LHC: capabilities, achievements and perspectives*
  presented by on 2011-11-07
  — LIP Lisbon.

- *COMPASS - a facility to study QCD*
  presented by Eva-Maria Kabuss (Institut fur Kernphysik da Univ. Johannes Gutenberg, Mainz) on 2011-12-19
  — LIP Lisbon.

- *The spin structure of proton and its 3D picture*
  presented by Krzysztof Kurek (National Center for Nuclear Research) on 2011-12-20
  — LIP Lisbon.

## 8.2 Conferences

- *IDPASC: O Modelo Padrão das Partículas Elementares*
  Conference, FCUL, Lisbon, 2011-06-14
- *IDPASC Higgs School - 2011*
  Workshop, Foz do Arelho, Portugal, 2011-09-06
- *IDPASC: Statistics Course*
  Workshop, LIP Lisbon, 2011-10-24
- *IDPASC Dark Matter School*
  Workshop, Évora, Portugal, 2011-12-14
- *IDPASC Dark Matter Workshop*
  Workshop, Évora, Portugal, 2011-12-17
- *Celebration of the 25th anniversary of LIP*
  Outreach Event, Coimbra, 2011-05-09
- *IDPASC: Frontiers in Particle and Astroparticle Physics*
  Outreach Event, FCUL, Lisbon, 2011-05-11
- *IDPASC: O Bosão de Higgs*
  Outreach Event, Auditório da Esc Sec Rafael Bordalo Pinheiro, Caldas da Rainha, Portugal, 2011-09-08
- *IDPASC: Dark Universe, o que se esconde para além daquilo que vemos...*
  Outreach Event, Évora, Portugal, 2011-12-15