Laboratório de Instrumentação e Física Experimental de Partículas

Work Plan

2013

Contents

Chapter 1

Introduction

1.1 Introdução

A Universidade de Coimbra, a Universidade de Lisboa, a Universidade do Minho e o Instituto Superior Técnico tornaram-se associados do LIP a partir de 1 de Janeiro de 2012, fortalecendo assim velhos laços de cooperação. O mais recente pólo do LIP, na Universidade do Minho, já em pleno funcionamento, está focado na colaboração estreita entre físicos teóricos e experimentais com vista à exploração dos dados do LHC, especialmente na experiência ATLAS.
Em 2012, o LIP participou na descoberta de uma nova partícula - candidata a ser o bosão de Higgs, partícula prevista no Modelo Padrão da Física de Partículas - nas experiências ATLAS e CMS do LHC, o grande colisionador de hadrões do CERN. A conceção, construção e comissionamento de ATLAS e CMS dominaram os esforços do LIP nos últimos 15 anos, e hoje participamos ativamente, em ambos os casos, na manutenção, na tomada de dados e na respetiva análise.
Em 2013, o complexo de aceleradores do CERN vai estar parado para melhoramentos no LHC, que permitirão aumentar a energia e luminosidade do acelerador. Esta paragem representa ainda a oportunidade de trabalhos de manutenção e melhoramento nos detetores ATLAS e CMS e desenvolvimentos no Sistema de Controlo de Dados (DCS) de COMPASS - experiência instalada no acelerador SPS - nos quais as equipes do LIP estão diretamente envolvidas. Este tempo será também utilizado na análise dos dados recolhidos até agora pelas várias experiências, e na preparação de novas análises para futuras condições de operação, e uma nova configuração no caso do detetor de COMPASS. O LIP têm ainda responsabilidades na operação do sub-detetor RPC-TOF e na análise de dados numa outra experiência com aceleradores - HADES, no GSI - que tomará dados em 2013.
Estão previstos para 2013, avanços significativos nas experiências de Astropartículas em que o LIP participa: a publicação dos primeiros resultados do detector de raios cósmicos AMS, na Estação Espacial Internacional a partir de Maio de 2011; o final da instalação e primeiros testes das experiência SNO+ - um detetor de neutrinos no SNOLAB, Canadá e de LUX - um detector de matéria escura na Sanford Underground Research Facility, EUA, que deverá ter já os primeiros dados de física. A equipa do LIP do Observatório Internacional Pierre Auger (instalado na Argentina) lidera o trabalho de I&D da colaboração com vista à futura instalação de detetores de RPC que funcionarão ao ar livre e prossegue uma atividade sistemática de colaboração internacional, designadamente com instituições do Brasil - a instalação dos primeiros protótipos permitira testes in-situ em 2013. As atividades em torno da radiação espacial continuam centradas em projetos da Agência Espacial Europeia, com a validação de ferramentas de simulação e análise, assim como o desenho de monitores de radiação.
O papel inovador do LIP no trabalho de I&D em câmaras de placas resistivas (RPC) é hoje reconhecido internacionalmente, e diversos projetos no LIP as utilizam para diferentes aplicações. Para além dos detetores de muões para funcionarem ao ar livre durante longos períodos, um "TOF-tracker"capaz de medir tempo e posição com precisão elevada, o design e produção de um inovador detetor de tempo de voo para neutrões rápidos e um protótipo de tomógrafo RPC-PET de baixo custo, para pequenos animais estão a ser desenvolvidos. Para 2013 está prevista uma grande publicação de revisão sobre a física das RPCs.
Além destas, o LIP manterá atividades voltadas para o desenvolvimento de detetores de radiação e para aspetos fundamentais da Física da Radiação subjacente. Trata-se de uma área fortemente implantada em Coimbra desde há várias décadas que permanece promissora. Para além de estudos de Monte-Carlo que são essenciais para antever o desempenho de futuros detetores, desenvolvem-se atividades diversas que se estendem por exemplo a otimização da determinação de energia e posição em câmaras de Anger, ou à deteção de neutrões térmicos.
As aplicações à Física Médica continuarão, por um lado com os testes clínicos de protótipos do "ClearPEM", um Tomógrafo por Emissão de Protões para Mamografia e deteção do cancro da mama, e, por outro, os testes

do scanner RPC-PET animal e a montagem do primeiro protótipo do novo scanner RPC-PET de corpo inteiro, uma alternativa válida à configuração-padrão baseada em cristais. Além dos dois projetos PET, continua a cooperação com diversas outras instituições, nomeadamente o ICNAS e dois hospitais em Coimbra, para o desenvolvimento de uma instalação para estudos de radiobiologia com o feixe de protões do acelerador que produz radio-isótopos, e de métodos avançados de monitorização de radioterapia. Tais estudos envolvem a construção de protótipos e poderão resultar em pedidos de patentes.
Nas tecnologias de computação, o LIP continuará centrado na operação dos clusters de GRID - nomeadamente na manutenção da GRID-nacional, e a sua integração na rede ibérica e europeia. Serão estudadas novas estratégias para o armazenamento de dados no Tier-2 português.
A Oficina Mecânica, fundada em 1986 e instalada em Coimbra, contará em 2013 com compromissos importantes com as colaborações do Observatório Pierre Auger e de SNO+, além de diversas encomendas de Câmaras de Faíscas para demonstração pública de Raios Cósmicos; no entanto mantém disponibilidade para serviços externos que procura ativamente.
As atividades de divulgação e ensino prosseguirão como habitual, mantendo o LIP o compromisso de integrar estudantes aos diversos níveis nos seus grupos de investigação, e de acompanhar a maior parte das reuniões científicas e outras oportunidades, com sessões públicas dedicadas ao público em geral, e ao público escolar, em particular. O trabalho de divulgação é essencialmente baseado em atividades regulares que visam, principalmente, professores e estudantes do ensino secundário. No CERN, a Escola de Professores em Língua Portuguesa criada pelo LIP envolve agora professores de ciências do ensino secundário de todos os países da CPLP. A rede de doutoramento internacional IDPASC, impulsionada pelo LIP, continuará as suas diversas atividades neste ano com um esforço significativo de ainda maior integração das diversas Universidades portuguesas com ação na área da Física de Partículas, Astrofísica e Cosmologia.

1.2 Introduction

The University of Coimbra, the University of Lisbon, the Institute of Technology of Lisbon and the University of Minho joined LIP as full members on January 1, 2012, strengthening our long-term cooperation. The most recent LIP branch at the Minho University is now fully established with a focus on strengthening the collaboration between theoretical and experimental physicists in view of the LHC results, especially in the framework of the ATLAS experiment.
In 2012, LIP was involved in the discovery of a new particle — candidate for the Higgs boson, the only particle missing in the Standard Model of Particle Physics — by the ATLAS and CMS experiments at the LHC, the Large Hadron Collider at CERN. The design, construction and commissioning of ATLAS and CMS have dominated LIP´s efforts for the last 15 years, and today LIP actively participates in the maintenance, data taking and data analyses for both experiments.
In 2013, the accelerator system at CERN will be shut down for LHC upgrade in order to increase the energy and luminosity of the accelerator. The technical stop will still allow for maintenance and upgrade works on the ATLAS and CMS detectors and for development works on the Detector Control System of the COMPASS experiment which is installed at the SPS accelerator. Teams from LIP will be directly involved in all these works. The time of shutdown will also be used for the analysis of the data acquired so far for the different experiments, and for the preparation of the analysis within the future operating conditions, and a new configuration in case of the COMPASS detector. LIP still has responsibilities for the operation of the RPC-TOF subdetector and for data analysis in another accelerator experiment, HADES at GSI, which will continue taking data in 2013.
Concerning our participation in Astroparticle physics experiments, a lot of significant progress is expected in 2013: the publication of first results from the cosmic ray detector AMS that runs at the International Space Station since May 2011; the deployment and first tests of the SNO+ experiment, a neutrino detector at SNOLAB in Canada, and of LUX, a dark matter detector at the Sanford Underground Research Facility, USA, that is expected to give first physics results. The LIP team at the Pierre Auger Observatory in Argentina is leading the collaboration efforts in R&D for future installation of RPC open air detectors and follows a systematic approach to international collaborations, notably with institutions in Brazil. The installation of the first prototypes will allow in-situ tests in 2013. LIP´s activities about Space Radiation will continue to be concentrated within projects of the European Space Agency, on the validation of simulation and analysis tools as well as radiation monitor design.
LIP plays an internationally recognized role in the R&D of new Resistive Plate Chambers (RPC), and various LIP projects do use them for different applications. Besides the muon detectors that are capable of operating in open air during extended periods of time, a new TOF tracker with accurate time of flight and position measurement, the design and production of an innovative and inexpensive fast neutron TOF and a new small animal RPC-PET tomographer are being developed. For 2013, a big review publication is planned on the

physics of RPSs.
In addition, LIP will continue its activities on the development of radiation detectors and on the fundamental aspects of the underlying radiation physics. This field is strongly implemented in Coimbra since many decades and continues to give promising results. Besides Monte-Carlo studies that are essential in order to foresee the performance of future detectors, various activities are ongoing like the optimization of energy and position determination in Anger cameras or the detection of thermal neutrons.
Medical Physics applications will continue, with clinical tests with the "ClearPEM" prototype, a Proton Emission Tomographer for Mammography and breast cancer detection, and the tests of the RPC-PET animal scanner and the installation of the first whole-body RPC-PET scanner, as an alternative to the standard crystal based setting. In addition to these two PET projects, the cooperation with various other institutions like ICNAS and two hospitals in Coimbra will continue, on the development of an equipment for radiobiology studies using a proton beam coming from an accelerator to produce radioisotopes, and on advanced methods of radiotherapy. These studies involve the construction of prototypes and might result in patent registrations.
Concerning computing technologies, LIP will continue to concentrate on the operation of the GRID clusters, especially on the maintenance of the Nacional GRID and on its integration into the Iberian and European network. A new technological solution for the Tier-2 storage will be established, addressing issues such as power efficiency and scalability.
The Mechanical Workshop, founded in 1986 and installed in Coimbra, will have important commitments in the framework of the Pierre Auger Observatory and SNO+, in addition to various orders of spark chambers for public display of cosmic rays. Nevertheless the workshop will be open to external services that are actively seeked.
The outreach and training activities will continue, having LIP keeping the commitment of integrating students at various levels into its research groups, and of offering public sessions dedicated to the general public, and also to school students, during the major part of its scientific meetings and at other opportunities. Our outreach work is essentially based on regular activities aiming mainly at high school teachers and students. The CERN Portuguese Language Teachers Program involves now science teachers from all Portuguese speaking countries in the world. The international IDPASC network for PhD students will continue its vast activities driven by LIP during this year with a significant effort to integrate the various universities in Portugal active in the fileds of Particle Physics, Astrophysics, and Cosmology.

1.3 Human resources (people)

Project	Researchers	Technicians	Post-Docs	Students			
				D	M	G	O
ATLAS	15	1	4	11	3	1	1
CMS	5	2	3	4			2
COMPASS	3	1	3	2			
HADES	3	2	2				
LHC Phenomenology	11		3	1	2		1
GRID	6	3	1				
AMS	1		2		2		
SNO+	5	5					
Dark Matter Search	5	2	4	1			
HECR	13	2	3	5			1
Space	5		1	1			
PET - Mammography	2	2	1	5			
Human PET	5	7					
MC in Medical Physics	7			1	4	1	
OrthoImaging	1			1			
Gamma Cameras	6		2	2			
RAD4LIFE							
RD51	5	10		1			
NeuLand - R3B	3	8					
GEMs	5			1			
DUAL	7			2			
NEXT	6			1			
Ion Transport Processes	6		1				
ICNAS	3			1			
OUTREACH	9	2	2				
TTN-ILO		1					
Education							
Totals:	83	20	25	37	11	2	5

Legend:

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

FTE: Full Time Equivalent

1.4 Human resources (FTE)

Project	Researchers	Technicians	Post-Docs	Students				total
				D	M	G	O	
ATLAS	7.95	0.50	3.20	9.43	2.59	0.33	1.00	27.33
CMS	4.25	1.75	2.50	4.00			1.40	14.90
COMPASS	3.00	1.00	2.00	2.00				9.00
HADES	1.00	0.65	1.00					2.65
LHC Phenomenology	3.45		1.75	0.50	1.20		1.00	7.90
GRID	4.48	3.00	1.00					8.48
AMS	0.85		1.80		2.00			4.65
SNO+	1.85	0.75						3.35
Dark Matter Search	2.14	0.60	3.64	0.50				6.88
HECR	6.30	0.80	2.85	4.15			0.65	14.90
Space	0.73		0.99	1.00				2.72
PET - Mammography	1.10	1.05	1.00	5.00				8.15
Human PET	0.80	0.70						1.50
MC in Medical Physics	3.50			0.80	1.90	0.30		6.50
OrthoImaging	0.50			1.00				1.75
Gamma Cameras	1.85		0.40	0.80				3.05
RAD4LIFE								
RD51	1.10	1.50		0.70				3.30
NeuLand - R3B	0.70	1.45						2.15
GEMs	1.40			1.00				2.40
DUAL	2.20			1.60				4.30
NEXT	1.55			0.60				2.35
Ion Transport Processes	1.35		0.15					1.90
ICNAS	0.50			1.00				1.75
OUTREACH	1.60	0.32	0.10					3.42
TTN-ILO		1.00						1.00
Education								
Totals:	54.15	15.07	22.38	34.08	7.69	0.63	4.05	

Legend:

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

FTE: Full Time Equivalent

1.5 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

Alexandre Moita, Américo Pereira, Carlos Manuel, Carlos Silva, Christophe Pires, Emir Sirage, 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 do bosão de Higgs. De facto, os dados de 2011 e 2012 já permitiram a descoberta de uma nova partícula que, como foi anunciado mundialmente pelas experiências ATLAS e CMS no dia 4 de Julho de 2012, é compatível com o bosão de Higgs do Modelo Padrão. A estrutura do detector permite também ser sensível a sinais de nova Física que se poderão manifestar a altas energias, como por exemplo o modelo da Supersimetria que pode explicar a abundância de Matéria Escura no Universo.
As nossas actividades estão concentradas em estudos de Física e desempenho do detector com análise dos acontecimentos do LHC, mantendo as nossas responsabilidades a nível de operação e especialmente melhoramento do detector, área esta que conta com várias actividades em curso durante a paragem prolongada do LHC em 2013-14.
Estão em curso estudos para a pesquisa do bosão de Higgs tanto no canal de decaimento H->WW como no H->b-bbar em associação com bosões W/Z ou com um par t-tbar, utilizando-se nestes os investimentos anteriores feitos no estudo das propriedades do W, dibosões, quark top e reconstrução de jactos.
Os estudos de Física tais como a reconstrução do bosão W e o quark top são fundamentais, tanto no estudo da Física Modelo Padrão como na optimização do funcionamento do detector.
As secções eficazes de produção de W/Z+bjet serão medidas de forma a melhorar as previsões de QCD para a produção de jactos de quarks pesados em colisionadores hadrónicos. Estes processos são ainda um fundo importante para as pesquisas do bosão Higgs, medições de propriedades do quark top e pesquisas de Física além do Modelo Padrão (SM).
Prosseguiremos com os estudos do quark top, no contexto do SM e para além do SM. Em particular, e na ausência de um sinal de nova Física, serão estabelecidos novos limites na taxa de decaimento do top através de correntes neutras com troca de sabor (FCNC), e serão realizadas medidas de assimetrias angulares no seu decaimento, permitindo determinar a estrutura do vértice Wtb com precisão. Estando já várias das medidas das propriedades do quark top limitadas pelas incertezas sistemáticas, serão determinantes estudos detalhados destas fontes de incerteza. Além do estudo das respectivas propriedades, o quark top é importante para a calibração em energia e é um fundo importante em várias pesquisas de Física. No domínio da pesquisa de nova Física associada a quarks pesados será efectuada a pesquisa de quarks vectoriais previstos por diversas extensões do Modelo Padrão.
O programa de Iões Pesados continuará após o sucesso obtido nos runs anteriores, com destaque para a validação e qualidade dos dados.
As responsabilidades no TileCal e Trigger/DAQ serão mantidas.
As actividades em calorimetria hadrónica estão focadas em estudos de desempenho e calibração da escala de energia de jactos no segundo nível de trigger (LVL2), pela qual somos responsáveis, utilizando dados de colisões, bem como no desenvolvimento de melhorias no trigger de jactos no LVL2. A melhoria da reconstrução da energia transversa em falta é também um objectivo, estudando-se em particular o efeito do empilhamento de sinais.
No TileCal, continua o estudo do ruído correlacionado nas células em ambiente de elevado empilhamento

de sinais. Mantemos o nosso envolvimento no Sistema de Controlo (DCS) do TileCal que sofreu melhorias significativas recentemente a nível de desempenho e passou a contar com um simulador de hardware para treino, testes e desenvolvimento. Serão instaladas no detector novas fontes de alimentação de baixa tensão durante a paragem prolongada do LHC e vamos investir agora no desenvolvimento de uma nova geração do sistema de alta tensão do TileCal. Quanto ao laser de monitorização/calibração será testado o novo sistema. O software de análise de dados do sistema de monitorização com o laser continuará a ser melhorado.
Mantemos ainda uma pequena participação nos detectores "forward"de ATLAS. No detector de fibras cintilantes para medição da luminosidade (ALFA) continuaremos o desenvolvimento de software do respectivo sistema de controlo (DCS). Exploraremos as possibilidades de física dos detectores AFP para identificação de protões, em particular para a detecção de acoplamentos quárticos anómalos de bosões de gauge.
Continuaremos a contribuir para a divulgação.

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 of the ATLAS experiment is to study the fundamental properties of matter, mainly the nature of the electro-weak symmetry breaking mechanism and the origin of mass, through the search for the cornerstone of the Standard Model, the Higgs boson. In fact, the 2011 and 2012 data have allowed the discovery of a new particle that, as announced worldwide of the 4th of July 2012, is compatible with a Standard Model Higgs boson. During the current LHC shutdown, the data analysis will be improved to test as many properties of this new particle as possible. The general purpose detector structure will also allow the precise measurements of the SM predictions and the searches for new Physics, such as Supersymmetry, that could explain the abundance of Dark Matter in the Universe.
Our activities are centered in Physics analysis and Performance studies with data of the LHC collision events, but keeping our commitments and responsibilities in detector operation, maintenance and development/upgrade, activities that will be substantially increased in 2013 during the LHC shutdown.
The discovery of a Higgs boson candidate was a major discovery. Now, the study of the decay channels H->b-bbar and H->WW, in which we are involved, are in progress to determine the new particle couplings to fermions and vector bosons and infer its properties for a better determination of its nature. Our investment in W bosons and jet physics and performance will continue.
Top quark studies, in the context of the SM and beyond, have been a long time investment of our group. New limits will be determined for the top decay rate via Flavour Changing Neutral Currents, and measurements of angular asymmetries on its decay will be continued. The study of systematic sources of uncertainty will play a crucial role in the study of top quark properties. In addition to the study of its properties, the top quark is important also for the energy scale calibration and as a background in several Physics studies such as the Higgs boson searches in the H->b-bbar and H->WW decay channels. Within the new physics searches associated to heavy quarks, the search for vector-like quarks will be continued.
The search for fermions beyond the Standard Model has recently started. The LIP group is involved in the development of multilepton analysis devoted to the search of new heavy quarks couplings mainly to the third generation of the Standard Model.
Pb+Pb collisions at the LHC provide an excellent opportunity to create Quark Gluon Plasma (QGP). One of the major goals is the understanding of the QGP effects on jets. Analysis of transverse energy imbalance between the leading jets, as well as validation of data and quality control are some of our tasks.
Our responsibilities in the ATLAS hadronic calorimetry, either in the TileCal detector or in the trigger system, will continue.
In TileCal our contribution is centered on the study of correlated noise in the cells in an environment of significative pile-up, in the Laser system optimization and development of monitoring software and in the integration of the three calibration systems. We maintain our strong involvement in the TileCal Detector Control System (DCS) and a contribution in the project of the new low voltage power supply units to be installed during the 2013 long LHC shutdown. We have been working in the development of a Mobile Drawer Integrity Check System - MobiDICK 4 to be used during the shutdown for the test of the front end electronics, mainly in the optical links and communication interfaces. For the longer term upgrades, we will invest now in the develpoment of the new High Voltage system.
On the Trigger-DAQ side, we will focus on the performance, validation and improvements of the second level jet trigger, and support of the NODE2 histogram retrieval application.
In addition, our involvement in the ATLAS forward detectors will continue with the development of the DCS software for the ALFA detector and exploring the physics capabilities of the AFP forward proton tagging detectors, in particular for the detection of anomalous quartic gauge boson couplings.

The contribution to outreach in these exciting years of LHC physics is also very important.

2.1.3 Objectives

Exploitation of the full physics potential of the ATLAS/LHC experiment at CERN is our final goal.
The ATLAS detector will be off for upgrade in parallel with a major LHC upgrade, but data analysis will continue.
Higgs boson properties searches in the channels H->WW and H->b bbar with this last one in association with a vector boson or a t-tbat pair are some of the main goals. Both the standard methods and multivariate techniques will be used in this analysis.
The W benchmark tool for W related analysis, in particular for W->mu nu channel will be exploited and the measurement of the production cross section of the W boson and dibosons will be updated. W+bjets production cross section 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 trigger level 2 system and respective performance study.
Operation and maintenance activities in TileCal including laser upgrade, LVPS replacement, correlated noise studies and DCS system activities, as well as High Voltage power supplies development for upgrade phase 2 and respective demonstrator prototypes, and in Trigger-DAQ tasks include mainly the support of NODE2 histograms browser and associated infrastructure are part of our long term responsibilities.
It is planned to continue the DCS development in the ALFA luminosity detector. Participation in several outreach activities, such as Masterclasses, seminars and the School for portuguese language teachers at CERN is also foreseen.

2.1.4 Team

Project coordinator: Amélia Maio

Name	Status	%of time in project
Ademar Delgado	PhD student (LIP/FCT)	100
Agostinho Gomes	Researcher (LIP)	85
Alberto Blanco	Researcher (LIP)	15
Alberto Palma	PhD student (LIP/FCT)	100
Alexandre Lopes	Master student (LIP)	100
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 (FCT)	100
Carlos Marques	Researcher (LIP)	100
Emanuel Gouveia	Student (LIP)	100
Emiliano Pinto	Master student (LIP)	75
Ester Simões	Master student (LIP)	84
Filipe Martins	Master (LIP)	33
Filipe Veloso	Post-Doc (LIP/FCT/FCTUC)	90
Guiomar Evans	Researcher (FCUL)	15
Helena Santos	Researcher (LIP)	100
Helmut Wolters	Researcher (LIP/FCTUC)	40
Joana Miguéns	PhD student (LIP/FCT)	100
João Carvalho	Researcher (FCTUC)	35
João Gentil	Post-Doc (LIP/FCT)	100
José Domingos Alves	Graduate student (LIP)	33
José Maneira	Researcher (LIP)	70
José Silva	PhD student (LIP)	50
José Soares Augusto	Researcher (IST/INESC/FCUL)	30
Juan Espinosa	PhD student (LIP/FCT)	100
Lourenço Lopes	Master (LIP/FCUL)	100
Luís Gurriana	Technician (LIP)	50
Luís Seabra	Master (LIP)	100
Manuel Maneira	Researcher (LIP/FCTUNL)	15
Mário Sargedas Sousa	PhD student (LIP/FCT)	100
Miguel Won	PhD student (LIP)	13
Nuno Anjos	Post-Doc (LIP/FCT)	100
Nuno Castro	Post-Doc (LIP/FCT)	30
Patricia Conde	Researcher (LIP)	85
Pedro Jorge	PhD student (LIP/FCT)	80
Rute Pedro	PhD student (LIP/FCT)	100
Susana Santos	PhD student (LIP/FCT)	100

2.1.5 Academic Training

PhD Theses

- *Measurement of the W -> mu nu production cross section with the ATLAS detector*
  Pedro Jorge, (on-going)
- *Non-standard Higgs and top-quark production and decay at the Large Hadron Collider: a collaboration between theory and experiment*
  Miguel Won, (on-going)
- *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)

- *Measurement of the WW Production in 7TeV pp Collisions at the LHC with the ATLAS Detector*
  Joana Miguéns, (on-going)
- *Search for the Higgs boson at ATLAS/LHC, in associated production with a Z boson*
  Mário Sargedas Sousa, (on-going)
- *Search for the Higgs boson at ATLAS/LHC in WH associated production and decay to b quark pairs*
  Rute Pedro, (on-going)
- *Development of boosted jet triggers for Higgs searches at the ATLAS experiment at the LHC/CERN*
  Ademar Delgado, (on-going)

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 CMS no LHC a alta luminosidade (HL-LHC).

2.2.2 Abstract

LIP is a member of the CMS experiment at the Large Hadron Collider at CERN.
The goal of the experiment is the investigation of the most fundamental properties of matter through the study of very high-energy collisions of protons and nuclear beams. In particular, the questions addressed include 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 quark-gluon plasma (QGP) through measurements of quarkonia production;
4) Research and development in view of the upgrade of the CMS trigger system at high luminosity.

2.2.3 Objectives

The objectives of the project are:

- Operation and maintenance of the ECAL Trigger/DAQ hardware and online software in the CMS experiment during the LHC Physics Run in 2015-16 and during the detector upgrade operations in 2013-2014.
- Analysis of the data collected in 2011 at 7 TeV (luminosity 5/fb) and in 2012 at 8 TeV (luminosity 19/fb) in the following physics areas:
    1. Higgs physics: a) charged Higgs in top quark decays; b) Higgs decays in two photons;
    2. Top quark: a) measurement of top properties (Vtb); b) measurement of the top quark pair cross section (with taus);
    3. SUSY: search for the supersymmetric partner of the top quark;
    4. measurement of quarkonia properties in heavy ion and proton collisions.
- Detector upgrade:
    1. Prototyping , production of pre-series and installation of high speed optical links for the upgrade of the CMS calorimeter trigger system.
    2. Development of the concept and simulation of the CMS Pixel Trigger (FP7 INFIERI project)

The program of activities in 2013-14 is centered on the detector upgrades in preparation for the physics data-taking operation expected to start again in 2015, and on the physics exploitation of the data collected by the CMS detector in the 2011-2012 runs. The LIP/CMS project is organized along the following lines:

1. CMS detector and offline computing;
2. proton-proton physics;
3. heavy-ion physics;

4. trigger developments for HL-LHC.

The first line corresponds to the work on the detector and trigger commissioning and operation, as well as in offline computing. An effort to guarantee the presence at CERN of team members involved in the detector maintenance and operation is required. The team members will also be requested to take the required fraction of CMS shifts (ECAL and Trigger). The prototyping and production of high-speed optical links for the upgrade of the CMS calorimeter trigger system is also part of our program.
The analysis of the data collected in 2011-12 (with a total luminosity of 24/fb), including the new data from Pb-Pb and p-Pb collisions, will be pursued. The integrated luminosity collected by the end of the 2012 run confirms the perspective of a rich physics program.

Physics program
The LIP/CMS p-p physics program in 2013-14 is a natural evolution of the analysis work carried out in 2011-12. Our plan for data analysis is based on two guidelines:

1. give priority to the search of new physics profiting from the large luminosity offered by LHC;
2. fully exploit the competences acquired by the group in the analysis of the 2011-12 data.

Higgs physics
We plan a strong involvement in the Higgs physics given its relevance in the LHC context.
The participation in the search for the Higgs decay in two photons was initiated in the beginning of 2011, profiting from the experience acquired in the measurement of the single photon production cross-section, and culminated in the group members´ direct participation to the discovery of a new scalar boson with properties similar to the standard model (SM) Higgs boson in July 2012. This is a very important final state at LHC since it is one of the most sensitive decay channels for the low-mass SM Higgs boson. The LIP group was initially leading the development of the vertex identification algorithms in the multi pile-up environment, an important ingredient to achieve the best two-photon mass resolution, and in 2012 started an analysis to determine the spin of the newly discovered boson in the two-photon final state. Members of the LIP group were in charge of editing the common analysis note and of the management of the common analysis code. The planned work for 2013-2014 will continue along these guidelines.
We will continue pursuing the search for charged Higgs in top decays or in association with top quark production, extending the search sensitivity by using additional channels. Several extensions of the SM may alter the rates of known physics processes. One of such instances is given by the charged Higgs boson which can be present in top decays and could be detected through an anomalously large production of tau leptons. Alternatively, for charged Higgs boson masses larger than the top quark mass, associated production of the charged Higgs with the top quark can also be sought.
The aim is to tackle the production of minimal MSSM charged Higgs bosons in top quark pair events, starting from the event selection and tools developed for the measurement of the top quark pair cross section in the tau dilepton channel. The final state is similar as in tau dilepton events with one W boson is replaced by the charged Higgs.
The search is focused on charged Higgs up to masses of approximately 300 GeV. In the mass range of 100-160 GeV, exclusion limits in the branching ratio t->H+b significantly better than those already obtained at the Tevatron have been obtained for an integrated luminosity of 5/fb. With the full dataset, the limits can be extended to the higher mass region, where the main constraint is given by the limited statistics of the samples.

Top Physics
In 2011-12, several thousand top quark events have been produced and collected with the approximately 24/fb of data (5/fb at 7 TeV, and 19/fb at 8 TeV). Top quarks have been used to re-establish the SM measurements and, at the same time, may provide indication of new physics if deviations from the SM expectations are found. So far, the measurements performed show no indications of deviations from the SM expectations. In a few cases the measurements are not yet at the level of the required precision to test deviations from the SM, either due to limited statistics or to large systematic uncertainties yet to be reduced. More data together with the experience gained with the data analysis will allow further refinement of the measurements. Improved sensitivity to new physics is expected already with the data collected up to now.
The LIP group has measured the cross section in the tau dilepton channel, where one of the two leptons in the final state is a tau. In the first 2/fb of data at the LHC, a few hundreds of these events have been selected after reconstruction and event selection. A simple and robust event selection, together with data-driven methods to determine tau lepton fake rates have been developed and used for the first measurement with proton collision

data. The measurement will be extended to the full dataset collected at 8 TeV using refined analysis techniques, and the cross section ratio between the tau dilepton and the standard dilepton channel will allow an additional test of the SM, with reduced systematic uncertainty.
The LIP group is continuing the study of the dilepton channel to measure the ratio R=BR(t->Wb)/BR(t->Wq), where q=d,s,b. In the framework of the SM, the ratio R can be expressed in terms of the CKM matrix element, R≈Vtb^2. The methods for determination of the heavy flavor content in top events were first studied at LIP with simulated data and later the measurement was performed with data and approved in CMS. The estimation of the probability of misassignment of b-jets from data was developed and validated with a sophisticated and robust data-driven technique, and the measurement of Vtb (or of the b-tagging efficiency assuming R=1) was assessed. The results are the most accurate to-date and will be further refined for the publication of these results using the full dataset. Further extension of the analysis will lead to additional constraints on the SM parameters and will also be pursued in 2013-2014.

SUSY Searches
We plan to extend our top activities in the area of SUSY by performing a search for the supersymmetric partner of the top quark. The mass splitting between pairs of squarks is proportional to the mass of the SM quark partner; this gives the lightest SUSY partner of top (stop1) a robust reason to be the lightest squark, thus the most easily observable. In the first phase, the search will concentrate on the channel with direct production of a stop pair, decaying in top-antitop quark pairs and neutralinos. The topology of these events is top-like and therefore the top quark mass reconstruction methods already developed find here a good application since top production is the main background in stop searches.
An analysis of the final states with one lepton using 7 TeV data was concluded in 2012. The analysis uses neural networks for signal and background discrimination and a specific data driven method for background estimation. The analysis is being extended to the 8 TeV data. According to the CMS plans, the LIP analysis with be integrated with the cut-and-count analysis of the UCSB/FNAL groups in the final publication expected this summer.

Heavy-ion physics
The group will pusue the activities in the quarkonia and b-physics analysis group (PAG).
The main lines of work exploiting the 2011-12 data will be:
- Measurement of the J/psi polarization
- Measurement of the prompt and non-prompt J/psi´s
- Measurement of the polarization of the Chi_c and Chi_b states

This work will be mainly based on the methodology introduced by this group. It should be emphasized that this methodology is now being considered in theoretical and experimental studies both within and outside CMS.

Experiment work

Trigger and Data Quality Monitoring (DQM) studies
The group performed in 2011-12 various trigger studies in the framework of the L1 Trigger DPG (Detector Performance Group). These studies included the measurements of the trigger timing and synchronization using data from CMS delay scans, measurement of the calorimeter trigger efficiencies (electrons, jets, energy sums), a study of the expected rates and efficiencies of the ECAL spike rejection algorithm in the L1 trigger, and a study of the energy scales of ECAL and HCAL trigger primitives. Significant contributions to the L1 Trigger Prompt Analysis to monitor the performance of the trigger during operations were also done. The studies were used to characterize the trigger performance with data, and have been implemented for automatic quality tests to monitor and certify the trigger performance.
Furthermore, studies of Data Quality Monitoring (DQM) were performed with the goal of implementing the certification of the data collected in 2012, and used in all CMS analyses. Preparation and implementation of the DQM algorithms have been developed. Continuation of this work and further finalization of these algorithms are planned for 2013-2014. The algorithms are to be used for the final certification and reconstruction of the 2012 data, and will be in place for the start of the data-taking operation in 2015.

CMS detector and off-line computing
The main objectives of this activity for the next two years are the preparation for the upgrade, maintenance of the detector, and preparation for the operation of the ECAL trigger and data acquisition hardware and online

software in the CMS experiment. The exploitation of GRID facilities and the interface with the Portuguese Tier-2 are also part of our program.

Upgrade: Triggers at High Intensity LHC and HL-LHC

CMS has submitted in 2011 the Technical Proposal on the first large Detector Upgrade in view of the High Intensity LHC. This Upgrade concerns the Hadronic Calorimeter, the Muon Detectors, the Pixel Detector and the L1 Trigger, and it is expected to take place during the first two LHC long shut-downs (starting in 2013 and in 2017).
The Technical Design Report (TDR) of the L1 Trigger Upgrade will be submitted in April 2013.
The upgrade in the Trigger system is aimed at improving the trigger algorithms such that the trigger is able to sustain the high luminosity and event pile-up until LS3. While the ultimate HL-LHC aims at luminosities approaching 10ˆ35cm-1s-1, which could only be achieved after the LS3, it is foreseen that after 2015 the LHC luminosity could exceed its initial specifications (10ˆ34 cm-2s-1) by a factor up to 3 or 4. Therefore there is a strong motivation for a partial upgrade of the Trigger system in 2015, which would concern the calorimeter trigger, and a second upgrade phase in 2016 involving the muon and global triggers. The upgrade of the calorimeter trigger would allow keeping acceptable trigger rates of the electron/photon and tau triggers with the relatively low thresholds required by the Higgs physics analysis.
The LIP group has been involved in the system upgrade design and in the development of prototypes of an optical trigger interface (oSLB) between the ECAL and HCAL calorimeters and the regional calorimeter trigger, replacing the SLB interface that was developed in the past by our group. Prototypes are being developed and tested successfully in 2013, and will be used for extensive testing in the CMS Electronics Center (building 904) together with trigger prototype modules developed by other collaborators. The production of about 500 oSLB boards is foreseen in 2013.
In 2013 we will initiate the development of the concept and simulation of the CMS Pixel Trigger (FP7 INFIERI project) in collaboration with Pisa and Paris groups.

2.2.4 Team

Project coordinator: João Varela

Name	Status	%of time in project
André Tinoco Mendes	Researcher (LIP)	100
Andrea Barisone	Technician (LIP)	75
Cristóvão Silva	PhD student (LIP/FCT)	100
Federico Nguyen	Post-Doc (LIP/FCT)	100
João Pela	PhD student (LIP/Imperial)	100
João Rodrigues Antunes	PhD student (LIP)	100
João Seixas	Researcher (LIP/IST)	50
João Varela	Researcher (LIP/IST)	75
José Carlos Silva	Technician (LIP)	100
Marcelo Vicente	Student (LIP)	90
Michele Gallinaro	Researcher (LIP)	100
Pedrame Bargassa	Researcher (LIP)	100
Pedro Manuel Silva	Post-Doc (LIP/FCT)	50
Pedro Parracho	Collaborator (LIP/AdI)	100
Pietro Faccioli	Post-Doc (LIP/FCT)	100
Pietro Vischia	PhD student (LIP/FCT) *	100
Rogério Jorge	Student (LIP)	50

2.3 Collaboration in the COMPASS experiment at CERN

2.3.1 Resumo

A experiência COMPASS dedica-se essencialmente ao estudo da estrutura do nucleão, nomeadamente das contribuições de gluões e quarks para o seu spin total. Na primeira fase, que decorreu até 2011, COMPASS dedicou-se, através da difusão inelástica profunda de muões na matéria, ao estudo da polarização do gluão (usando 2 canais independentes: a produção de charme e a física de elevado p_T), bem como à medida das funções de estrutura dependentes do spin, nos modos longitudinal e transverso, de modo a separar as suas componentes de sabor. Têm ainda vindo a ser estudadas as funções de fragmentação, através das multiplicidades dos hadrões carregados.
Actualmente, na sua segunda fase, COMPASS dedica-se ao estudo das funções de estrutura dependentes do momento transverso (TMD PDFs), através do processo de Drell-Yan polarizado, bem como das funções de estrutura tridimensionais (GPDs), a tomografia do nucleão, através do processo DVCS (Deep Virtual Compton Scattering). Por outro lado, COMPASS tem por objectivo o estudo de algumas questões de actualidade relativas à espectroscopia hadrónica, como a produção de novos hadrões, bem como de mesões, nomeadamente exóticos ou híbridos. Em 2012 efectuou-se o estudo experimental das polarizabilidades de piões e kaões, usando o processo de Primakoff.
Neste contexto, 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 front- end e num sistema distribuído de event-builders, especialmente concebidos para tratar grandes volumes de dados. De facto, o programa de muões com alvo de 6LiD, que decorreu de 2002 a 2007 perfez um total de 1700 TB. E no programa de hadrões, levado a cabo em 2008 e 2009, os dados adquiridos totalizaram 1300 TB. Em 2010 e 2011 decorreram as últimas tomadas de dados com feixe de muões e com alvo de amónia (respectivamente polarizado transversalmente e longitudinalmente), o que permitiu concluir este programa polarizado de Difusão Inelástica Profunda Semi-Inclusiva (SIDIS). Em 2012 a segunda fase do programa de COMPASS iniciou-se com uma tomada de dados com feixe de hadrões para estudo das polarizabilidades do pião e do kaão.
A farm de processamento de dados de COMPASS, devido ao seu grande volume de dados adquiridos (≈5 PB), 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, na vertente técnica, atingido em anos anteriores, era o desenvolvimento de uma nova arquitectura para o DCS de COMPASS. Mas continuadas evoluções 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 do LIP tem também levado a cabo um conjunto de tarefas relativas à análise de dados e à extracção dos seus resultados físicos, de grande importância para a Colaboração COMPASS e para o próprio grupo. No que respeita ao offline, desenvolveram-se estudos de geradores físicos e sua simulação no detector, com vista à sua concordância com os dados experimentais. Em relação à análise de dados propriamente dita, foram desenvolvidos estudos nos canais físicos mais importantes do programa de Difusão Inelástica Profunda de COMPASS. Foram, nomeadamente, feitos estudos independentes sobre a polarização do gluão, tanto através do processo de charme aberto (o "Golden Channel"de COMPASS), como através de eventos de grande p_T . Estudaram-se ainda as assimetrias de sabor do mar do nucleão, bem como as multiplicidades dos hadrões.
A partir do início de 2010, o grupo do LIP-Lisboa assumiu um papel de destaque na preparação do próximo

Programa experimental de COMPASS, no que concerne aos estudos de transversidade através do processo de Drell-Yan polarizado. Neste contexto, o grupo tem vindo a participar activamente nos estudos de adaptação e optimização do espectrómetro, nomeadamente sobre o absorvedor de hadrões e sobre o trigger de dimuão.

2.3.2 Abstract

The COMPASS experiment is dedicated to the study of the structure of the nucleon, namely of the contributions of gluons and quarks to its total spin. In its first phase, which last till 2011, COMPASS was devoted, through the deep inelastic scattering of muons, to the gluon polarization (using 2 independent channels: open charm photoproduction and high p_T physics), as well as to the measurement of spin dependent structure functions, both in the longitudinal and the transverse modes, in order to disentangle their flavour components. The study of fragmentation functions, through the charged hadron multiplicities, has also been addressed.
In the present phase, COMPASS aims to the study of the transverse momentum dependent structure functions (TMD PDFs) through the polarised Drell-Yan process, as well as the three dimensional structure functions (GPDs), the so-called nucleon tomography, through the DVCS process (Deep Virtual Compton Scattering).
On the other hand, COMPASS studies also some important hadron spectroscopy issues, such as the production of new hadrons, as well of mesons, namely exotics or hybrids. In 2012, the experimental measurement of the polarisability of pions and kaons, using the Primakoff process, was addressed.
In this context, COMPASS uses high intensity beams, that is, a polarized muon (or hadron) beam impinging on a longitudinally or transversely polarized target (or a 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 Cherenkov detector (RICH) for particle identification. The data acquisition system is based on a parallel read-out of the front-end electronics, followed by a distributed set of event-builders, specially designed to cope with huge data volumes. In fact, during the muon program with a 6LiD target, from 2002 to 2007, COMPASS collected a total of 1700 TeraByte of data. And, in the hadron program, from 2008 to 2009, the data taken totalised 1300 TB. The years 2010 and 2011 were dedicated to the two last data takings with a muon beam and an ammonia target, respectively polarised in the transverse and longitudinal modes, allowing to finalise this polarised program of Semi-Inclusive Deep Inelastic Scattering (SIDIS) with muon beams. In 2012 the COMPASS second phase was initiated, with a data taking using a hadron beam, aiming to the study of pion and kaon polarisabilities.
The COMPASS data processing farm, due to the huge data volume to handle, 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 full responsibility of the Detector Control System (DCS) taken by the LIP-Lisbon group at the time of its ingress in COMPASS, in the late 2002, 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 technical 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, the COMPASS 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 a very 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 data analysis task and the physical results extraction is being performed, with a major contribution of the LIP group in the COMPASS Collaboration. This includes the development of new physics generators and their simulation through the detector, as well as the overall compatibility studies with the experimental data. In what concerns the analysis of the most important physics channels in the COMPASS Deep Inelastic Scattering program, independent studies were performed on the gluon polarisation, from the open charm process (the COMPASS "Golden Channel") and through high p_T events. Also addressed was the study of flavour asymmetries of the nucleon sea, as well as of the hadrons´ multiplicities.
From the begining of 2010 on, our group has taken an important role in the preparation of the next COMPASS experimental physics Program, in what concerns transversity studies through the polarised Drell-Yan process. In that view, our group has actively participated, since then, in the spectrometer upgrade and optimisation studies, namely in the design of the hadron absorber and of the dimuon trigger.

2.3.3 Objectives

Concerning general Detector Control System activities, in view of the next COMPASS experimental physics Program, and profiting from the CERN shutdown, the DCS main task will be a global step forward of the supervisor level software, changing from the old PVSS 3.8 version to the new WinCC OA 3.11, which implies major compatibility developments of the new JCOP and the COMPASS Framework packages, as well as of the front-end software, namely OPC servers. From the DCS hardware point of view, the change to 64 bit machines will also take place, together with the installation of the new Linux SLC6 and Windows 7 operating systems. As a consequence of these major changes, deep studies concerning the stability and performance of the new DCS system will be performed. Also, a higher level of monitorisation of the polarised target will be developed.
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With respect to our other commitments in COMPASS, besides the general tasks, attributed to each member of the Collaboration, we will continue to contribute with an important role in the offline and in the analysis effort. Thus, in 2013 our tasks will be the following:

- gluon polarisation extraction, using a new method based on high p_T of single hadron;
- study of fragmentation functions in view of the strange quark polarised parton distribution measurement;
- to continue the studies on the COMPASS setup upgrade, including the new dimuon trigger requirements, and on its optimisation, in view of the polarised Drell-Yan process experiment;
- to optimize the COMPASS reconstruction program due to the major setup changes imposed by the Drell-Yan program;
- to continue the spin asymmetries study concerning low x_Bj and low Q2 physics;
- to continue the new analysis of the 2009 data taking test run with absorber, in view of the spectrometer optimisation for the Drell-Yan program;
- to participate in the Collaboration and in the monthly analysis meetings;
- to be a member of the COMPASS internal Publications Committee (M. Stolarski).

2.3.4 Team

Project coordinator: Paula Bordalo

Name	Status	%of time in project
Catarina Quintans	Researcher (LIP)	100
Celso Franco	Post-Doc (LIP/FCT)	50
Christophe Pires	Technician (LIP)	100
Gonçalo Terça	Master (LIP/AdI)	100
Luis Silva	Post-Doc (LIP)	50
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/FCT)	100

2.3.5 Academic Training

PhD Theses

- *Study of asymmetries with polarised proton target at low Q2*
  Sofia Nunes, (on-going)
- *Polarised Drell-Yan studies in COMPASS*
  Márcia Quaresma, (on-going)

Master Theses

- *AdI TECHNICAL TRAINING: Development of tools for the COMPASS DCS*
  Gonçalo Terça, (on-going)

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.
O objectivo fundamental da experiência, a medida de colisões entre núcleos de ouro, teve lugar em Abril-Maio de 2012. Outras experiências complementares seguir-se-ão. Nesta experiência o detector RPC teve um desempenho sem falhas e foi demonstrada uma excelente performance. O LIP participa agora na análise dos dados de física resultantes da experiência.

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 nuclei 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 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.
The fundamental goal of the experiment, the measurement of the collisions between gold nuclei, was achieved in April-May 2012. Other complementary experiments will follow. The RPC detector has shown flawless operation and excellent performance. LIP participates now in the analysis of the physics data thus produced.

2.4.3 Objectives

HADES RPC TOF WALL

Still some details are to be finished in the integration of the RPC in the HADES systems, but these do not compromise the operation. Namely: software integration of the readout of the reference chambers for gas monitor proposes and readout of the temperature sensors in the motherboard of the front-end electronics.
The RPC calibration procedures, although already bringing the system performance to levels comparable to the RPC intrinsic performance, still miss one correction: the time as a function of position, which will improve the resolution by 10 to 15 ps. Additionally, the RPC calibration procedure should be made much more automatic and user friendly, so that the calibration code could be used easily by future members of the group. Furthermore, the code responsible for generating the input for the GEANT digitizer should be also turned user friendly to allow creating this input as fast as possible for different running conditions, e.g., beam energies.
Implementation of the embedding code in the RPC software. This is an important piece of software responsible for merging real and simulated events. This will soon become an important tool, as it is used for corrections in advanced phases of data analysis.

PARTICIPATION IN THE PHYSICS PROGRAM

One of the main goals of the LIP-HADES group is the determination of the invariant mass spectrum of e-e+ pairs corresponding to the whole of leptons from the fireball of the Au+Au collision. The short-lived fireballs produced in HADES are unique worldwide: very dense hadronic media at low temperature. These lepton pairs are a clean probe of the nuclear modifications that occur within the fireball. The ultimate goal is to study the nuclear mechanism responsible by most of the mass of hadrons, which can be inferred by measuring the modifications in the above mentioned mass spectrum.
The properties of the ´strange´ particles within the fireball are the second analysis topic of the LIP-HADES group. This issue is still a very hot topic and a matter of on-going debate mainly because of the uncertainties related to the kaon production mechanism. Moreover, theoretical models predict a slightly repulsive kaon nucleon potential for K+ and an attractive one for K-. To explain the kaon production mechanism, dedicated studies on distributions of physics parameters related to the produced kaons will be performed.

2.4.4 Team

Project coordinator: Paulo Fonte

Name	Status	%of time in project
Alberto Blanco	Researcher (LIP)	15
Alessio Mangiarotti	Researcher (LIP)	50
Celso Franco	Post-Doc (LIP/FCT)	50
Luís Lopes	Technician (LIP)	50
Luis Silva	Post-Doc (LIP)	50
Paulo Fonte	Researcher (LIP/ISEC)	35
Ricardo Caeiro	Technician (LIP)	15

2.5 Phenomenological Studies at the LHC

2.5.1 Resumo

Por forma a cobrir o campo de física aberto pelo programa do LHC, é fundamental um importante esforço conjunto da comunidade experimental e teórica. Este esforço deve ser concentrado não apenas no estudo dos melhores observáveis físicos disponíveis no LHC, para realizar testes de precisão do Modelo Padrão (SM) da Física das Partículas Fundamentais, mas também no desenvolvimento de novas ideias para a física para além do SM. Neste projecto serão tratados alguns aspectos específicos do programa de física do LHC, tanto do ponto de vista experimental como teórico.
No seguimento do trabalho previamente desenvolvido pelo grupo experimental, a inclusão de novos membros da área da física teórica de altas energias permite o desenvolvimento em Coimbra e na Universidade do Minho, de um grupo de Física de Partículas especialmente dedicado à física do LHC. Uma ênfase especial será colocada na formação de estudantes de doutoramento e na motivação de estudantes de licenciatura.
O projecto em si tem tido o mérito de atrair vários estudantes (quer de universidades portuguesas quer estrangeiras) e proporcionou um ambiente favorável que deu origem à elaboracao de várias teses de mestrado e doutoramento quer na área da fisica experimental quer teórica. O projecto tem o mérito de juntar as comunidades experimental e teórica sob um tema comum de investigação, com o objectivo, a longo prazo, de explorar de uma forma eficiente os dados adquiridos no LHC. Tal como foi feito no passado, estão previstos encontros regulares durante a execução do projecto, e serão realizados seminários para motivação da comunidade científica para o potencial da física de LHC.
Particularmente relevante e´ o desenvolvimento de um grupo de Fisica de Particulas e Astroparticulas na Universidade do Minho, no recem criado Polo do LIP na Universidade do Minho, LIP-Minho. Esta iniciativa, que se iniciou em Fevereiro de 2010 conta com a colaboracao de 5 Doutorados, 2 estudantes de doutoramento e 5 estudantes de Mestrado

2.5.2 Abstract

Several tasks are expected to be developed during the course of the project:
1. Top quark FCNC Processes
The main goal is to study signals of physics beyond the SM in top quark 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 will be studied. Several contributions of this team were already included (gg->tq, gq->tg, qq->tq) in a general purpose generator like TopRex. Results show that these new contributions cannot be neglected when compared with the direct single top production process. Following this experience, a new dedicated Monte Carlo based on CalcHep and interfaced with the LHC experiment simulations will continue to be developed. Pythia will be used to perform the parton level particles hadronization. This new Monte Carlo will include the new contributions already calculated from the strong and electroweak sectors (and their interferences). New contributions associated to top quark production and decay through the Higgs channel will be calculated and included in the generator.
2. Non Standard Higgs Production
All Higgs sectors have self-interactions between Higgs states, and these are notably different from model to model. The simplest self-interaction is the SM triple-coupling. To look for trilinear self-interactions at the LHC one ought to search for final states with two Higgs bosons (chiefly, involving the lightest Higgs state available in the model). This analysis was done not only for the SM by several groups but also for some parameter regions of the MSSM and THDM in the decoupling limit, for Little Higgs Models, Extra Dimension Models, Fermiophobic Models, etc. It was shown that searches for pair-produced Higgs boson at the LHC in the framework of the SM and MSSM can be very challenging in the accessible mass regions. In contrast, the results are very promising for some regions of general THDM. However, until a thorough experimental analysis is performed it will be very hard to distinguish between the different models proposed. The main goal is to be able to say, for a chosen set of luminosities (from the first year of data taken at the LHC to the full Super-LHC sample), which models can be tested and for which regions of the parameter space of each specific model. Together with the theoretical group at NExT (University of Southampton), cross sections and branching ratios will be calculated for those models where this is not already done. All tools readily available (for some models, like for instance the MSSM, there are already a lot of tools, like FeynHiggs or HDECAY which are ready to be used) will be used and similar ones will be created for the remaining models. The next step will be to incorporate the missing channels to standard Monte Carlo (MC) event generators (such as PYTHIA and/or HERWIG) as additional core processes or through suitable interfaces (like SLHA and/or MadGraph/MadEvent and/or CompHep/CalcHep). Then, identify the channels that cover as many models as possible and together with the LHC groups at the University of Coimbra

and University of Minho, and Rutherford Appleton Laboratory, discuss the feasibility of a possible analysis (production modes, decay channels, signatures, triggers, cuts, etc.) and identify the backgrounds generated by the SM in the different extended models.
3. Top Quark Couplings
The LHC will be a top factory. This fact allows for the measurement of the Wtb vertex and the couplings of the top quark. Although the double top production is insensitive to the V_tb 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 vector and tensor like couplings can be introduced within an effective lagrangian approach, which can be probed at the LHC. A new software package, called TopFit, will be made available to the physics community, which performs a global fit to the top quark observables (or related to top) in order to extract the best limits on the anomalous couplings (assuming the SM). During the execution of the task two different issues will be adressed. The first is related to the limits from indirect measurements (e.g. the radiative b decay, b->s gamma) which set very stringent limits on VR and gL (but not on gR). The second issue is related to the measurement of asymetries in top quark decays which set very stringent limits on gR (but not on VR or gL). A combination of all measurements, using also the results from the Tevatron collider (CDF and D0) will be performed to simultaneously set limits on all parameters with TopFit. Given the expected measurements of the ATLAS, CMS and Tevatron experiments, a combination of the results is expected to be explored using TopFit.
4. Tri-leptons and the see-saw mechanism
In this project we propose to explore the clean tri-lepton signals to probe the seesaw mechanism at LHC. This study has great interest because a positive answer would unveil the neutrino mass generation mechanism, which is an important step towards a theory of flavour, which is one of the standing problems in particle physics. On the other hand, trilepton final states appear in other new physics models. They are produced in the decay of new heavy vector-like quarks with charges 2/3, -1/3 or 5/3, which are predicted in several models of extra dimensions with custodial symmetry. Studying trilepton signals will also allow us to probe these models, and to establish the identity of the new particles, if discovered.
5. New physics in models of strong EWSB.
In the presence of fermion custodians, new vector resonances of the strong sector become very broad and have large branching fractions into the custodians. Thus, a good knowledge of the properties of the custodians is crucial as they are the ideal probe to search for the vector resonances that characterise the strong sector responsible for EWSB. Current studies use tops as a final state in the search of new vector resonances, neglecting a large fraction of events that decay in the fermion custodians. The goal is to implement a simplified model that incorporates the main features of models of strong EWSB but has enough freedom to parametrize a large class of models. The model will be based on deconstruction of models with warped extra dimensions, which are dual to quasi conformal models of strong EWSB. Then we will study the potential at the LHC to use top and/or light quark custodians to search for new vector resonances of the strong sector.
6. Theoretical Models and Monte Carlo Generators
One of the required tasks in this project is the development of theoretical models for the different topics under study and the implementation of dedicated Monte Carlo generators. For the single top production via FCNC, a complete calculation of cross-sections and branching ratios (eletroweak+strong and t->qX,X=gluon,gamma,Z and H) must be provided by the theoretical physicists in order to be implemented in the Monte Carlo generator under development (based on CalcHep and interfaced with Pythia and LHC detector simulations). This is the natural continuation of the previous project were it was shown that, apart from the direct single top production via FCNC at the LHC, there are other contributions that must be considered, if a complete view of the FCNC processes in the single top production is wanted. For the study of the Wtb vertex structure and angular asymmetries in top quark decays, the correct parametrization of the phase space should be provided by the theoreticians, together with the dependence on the new vector and tensor like couplings that could exist at the vertex. The dependence of the NNLO corrections to the b->s gamma branching ratio must also be provided (and calculated) by the theoreticians as a function of the new anomalous couplings. A new Monte Carlo generator (which is already under test within the members of the group) called PROTOS will be made available to the community. This generator has implemented the correct parameterization of the anomalous couplings for ttbar and single top production. All couplings are on-mass shell. A new Monte Carlo generator (based on CalcHep and interfaced with Pythia and the LHC experiments simulations) is under development for the study of top quark electroweak couplings (ttgamma and ttZ) for the LHC.

2.5.3 Objectives

In order to address the physics potential of the LHC program, a significant joint effort of the experimental and theoretical 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. In the present project, specific topics of the physics program of the LHC are addressed from both the experimental and theoretical points of view.
Following the work previously developed by the experimental team at the LHC, the inclusion of new members from the field of theoretical particle physics allow us to develop a High Energy Physics group specifically dedicated to the physics at the LHC. The aim of this project is to support this group giving special emphasis to the training of MSc and PhD students and motivation to new undergraduate students.
The project was very successful in the past in attracting students (from Portuguese and foreign universities) and provided the correct framework for the development of several MSc and PhD thesis already, both in experimental and theoretical physics. The project in itself is very valuable once it brings together the experimental and theoretical communities under a common goal of research, with the long term objective of exploring in an efficient way the data that will be collected at the LHC. As was done in the past, regular meetings are foreseen in the course of the project, and seminars are expected to be held in order to motivate the scientific community to the physics potential of the LHC.
Particularly relevant is the fact that a new branch of LIP (LIP-Minho) is under development at the University of Minho, North of Portugal, bringing the field of High Energy Particle Physics and Astroparticle Physics to the Northern Universities of Portugal. This initiative started February 2010 and counts with the collaboration 5 senior PhD members, 2 PhD student and 5 Master students.

2.5.4 Team

Project coordinator: António Onofre

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

2.5.5 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, 2013-03-07

Chapter 3

Computing

3.1 Grid Computing

3.1.1 Resumo

A análise dos dados do LHC requer capacidades de processamento e armazenamento extremamente elevadas, e constitui um enorme desafio tecnológico. Para enfrentar este problema o CERN e as colaborações das experiências do LHC desenvolveram novas tecnologias de computação distribuída baseadas no paradigma da computação grid. Este esforço de I&D resultou na criação do *Worldwide LHC Computing Grid* (WLCG), a infraestrutura de computação distribuída à escala global que suporta o processamento e análise de dados provenientes do LHC.

Um memorando de entendimento para a colaboração no estabelecimento e exploração do WLCG foi assinado pelo CERN e seus países membros. No âmbito deste acordo Portugal assumiu a responsabilidade de operar um centro nacional de computação tipo Tier-2 integrado no WLCG. O Tier-2 Português é critico para a participação nacional nas experiências ATLAS e CMS a decorrer no LHC.

Os centros Tier-2 fornecem capacidade de armazenamento e processamento acessível através de serviços de computação grid, suportando tarefas de análise e simulação. O tier-2 Português é um instrumento fundamental para a participação dos investigadores nacionais na análise dos dados provenientes das experiências do LHC. O Tier-2 Português disponibilizou mais de 40 milhões de horas de CPU normalizado (referência 1K SI2K) desde 2010, representando cerca de 1.2% da capacidade total das experiências ATLAS e CMS. O Tier-2 Português é um serviço federado que faz uso de recursos disponibilizados por três centros de processamento de dados (LIP-Lisbon, LIP-Coimbra e NCG) operados pelo LIP. A operação e suporte são assegurados por uma equipa multidisciplinar de investigadores do LIP. Esta equipa possui uma extensa experiência em ambiente de computação distribuída, obtida através de onze anos de participação em projetos de I&D internacionais. Desta forma o LIP constituiu um núcleo de competência em e-Science único no país.

Portugal (tal como outros países) é responsável por garantir o financiamento necessário à boa operação do tier-2 de forma a cumprir o fornecimento da capacidade acordada e garantida ao CERN. Este acordo inclui capacidade de processamento, armazenamento, conectividade e recursos humanos. O cumprimento do acordo é essencial para que Portugal possa tirar partido de um investimento científico de mais de 20 anos no LHC.

Para maximizar o retorno do investimento, a capacidade do Tier-2 é partilhada com outras comunidades de investigação nacionais e internacionais de múltiplos domínios científicos. Para tal o LIP participa na Iniciativa Nacional Grid, Iniciativa Ibérica Grid (IBERGRID) e na Iniciativa Europeia Grid (EGI). Estas iniciativas operam infraestruturas que permitem a partilha de recursos computacionais a nível nacional, Ibérico e internacional. Os domínios suportados incluem entre outros: Astrofísica, Ciências da vida, engenharia e Ciências da Computação.

No contexto da Iniciativa Nacional grid, o LIP coordenada uma infraestrutura de computação distribuída composta por centros de Universidades e institutos de investigação. Estes centros estão integrados através de computação grid para permitir a partilha da sua capacidade. Esta infraestrutura que inclui o Tier-2 foi estabelecida em resultado de projetos de investigação do LIP, e segue os mesmos princípios das suas congéneres internacionais.

Também neste contexto o LIP gere o nó central grid (NCG), um centro de computação estabelecido em parceria com a FCCN e o LNEC que disponibiliza capacidade de processamento à comunidade científica. O NCG disponibiliza metade dos recursos do Tier-2 nacional, e partilha a sua capacidade com outras comunidade cientificas através das iniciativas IBERGRID e EGI.

A participação no EGI é crucial para o LHC e para as outras comunidades suportadas. O EGI coordena

os serviços que permitem a integração de recursos nacionais e/ou regionais a nível internacional. O CERN estabeleceu o WLCG sobre os serviços de operação grid do EGI. Desta forma os centros (tiers) do WLCG na Europa fazem parte da infraestrutura grid Europeia coordenada pelo EGI. A participação do LIP no EGI é fundamental para a integração do Tier-2 nacional no WLCG.
O LIP participa nestes importantes projetos e iniciativas com o objetivo de assegurar que a investigação e análise de dados do LHC possa continuar, e que os investigadores Portugueses possam beneficiar da integração de recursos disponibilizada pela grid. Ademais o LIP participa nos organismos de coordenação do WLCG tais como o *grid deployment board*, no EGI *council*, e no *executive board* da fundação EGI.eu.
No contexto do EGI, o LIP continuará a disponibilizar recursos e a atuar como agente de ligação assegurando a coordenação entre os utilizadores nacionais, centros de recursos e a grid Europeia. O LIP possui ainda responsabilidades em tarefas globais do EGI tais como a coordenação do middleware a nível Europeu e a disponibilização de serviços técnicos. Através do IBERGRID estas atividades são executadas em colaboração com centros de investigação Espanhóis tais como o IFCA, CESGA, IFIC e UPV. Ainda no contexto do IBERGRID, o LIP participa no desenvolvimento de novos serviço de computação em nuvem (cloud computing) que permitirão explorar ainda mais a capacidade dos centros Ibéricos. Este serviço será disponibilizado em 2013.
O Tier-2 nacional é um motor de desenvolvimento, apoia diretamente a investigação em Física de Partículas, assim como noutros domínios científicos que beneficiam da sua capacidade. Devido à sua natureza o Tier-2 requer inovação constante. As atividades de I&D ligadas ao Tier-2 incluem tópicos como a eficiência energética, eficiência dos serviços e virtualização.

3.1.2 Abstract

LIP has a strong participation in the data analysis of the ATLAS and CMS experiments at the CERN Large Hadron Collider (LHC). The LHC data analysis requires huge processing and storage capacity and constitutes a major technological challenge. To address this problem CERN and the LHC collaborations developed innovative distributed computing technologies based on the grid computing paradigm. This R&D effort resulted in the creation of the Worldwide LHC Computing Grid (WLCG) a global distributed e-infrastructure that supports the LHC data processing.
A Memorandum of Understanding to collaborate on the deployment and exploitation of the WLCG was signed between CERN and the member countries. Under this agreement Portugal assumed the responsibility of funding a national Tier-2 computing centre integrated in WLCG. The Portuguese WLCG Tier-2 is of critical importance to the national participation in the ATLAS and CMS experiments.
The Tier-2 centres provide well-managed, grid-enabled disk storage and processing capacity for tasks such as simulation, and analysis. It constitutes the fundamental technological support for local Portuguese researchers to access, process and analyse the experiments data. The Portuguese Tier-2 has delivered 40 million hours of normalized CPU time (reference 1K SI2K) since 2010 representing 1.2% of both ATLAS and CMS collaborations. The Portuguese tier-2 is a federated service that makes use of resources provide by three data-centres operated by LIP (LIP-Lisbon, LIP-Coimbra and NCG). The operation and support is ensured by a multidisciplinary team of LIP computing researchers and physicists with extensive experience in large distributed computing environments, gathered from eleven years of participation in large international distributed computing research projects. Through this effort LIP has built a core of e-Science competence that is unique in the country.
Alike other countries, Portugal is responsible for ensuring the pledged tier-2 capacity as agreed with CERN. The pledges include computing capacity, storage capacity, manpower and network connectivity. The fulfilment of this agreement is essential to enable data analysis by Portuguese researchers, and thus to take advantage of a scientific investment of more than 20 years in the LHC.
To maximize the return of investment, the Tier-2 capacity is shared with other national and international research communities from multiple scientific domains. This is achieved through participation in the Portuguese Grid Initiative, Iberian Grid Initiative (IBERGRID) and European Grid Initiative. These initiatives operate e-infrastructures that enable computing resource sharing at national, Iberian and international level. Currently the supported communities include among others: Astrophysics, Life Sciences, engineering and ICT.
On behalf of the Portuguese Grid Initiative, LIP coordinates a grid infrastructure composed of computing centres from national Universities and research institutes. These centres are integrated by means of grid computing technologies to share capacity. The infrastructure that includes the Tier-2 data-centres was established as a direct result of the LIP computing research, and follows the same world class standards as its international counterparts.
Also in this context LIP is managing the main node for grid computing (NCG) a large scientific computing facility built in partnership with FCCN and LNEC to provide grid computing capacity to the research community. NCG provides half of the Portuguese Tier-2 capacity. In addition NCG is the largest grid provider to other scientific communities. NCG is part of the Iberian grid computing infrastructure and European Grid Initiative (EGI).

The participation in EGI is crucial both to LHC and other communities. EGI provides the glue that binds together national and regional grid infrastructures across Europe. In fact CERN has established WLCG on top of the EGI grid operations services. The WLCG computing centres (tiers) in Europe are part of grid infrastructures that are integrated and coordinated through EGI. Therefore the LIP participation in EGI and IBERGRID are critical to the operation and integration of the Portuguese Tier-2 in WLCG.
LIP will continue to participate is these important projects and initiatives so that LHC physics research can continue, and Portuguese researchers can benefit from the integrated resources provided by the grid. Furthermore LIP will participate in WLCG coordination bodies such as the resource review board and grid deployment board, in the EGI council and in the EGI.eu foundation executive board.
In the European Grid Initiative context, LIP will continue to provide resources and act as national liaison ensuring proper coordination between the Portuguese grid users, grid sites, and the European infrastructure. Furthermore LIP has major responsibilities in EGI global tasks such as the middleware deployment coordination and the provisioning of technical services. Through IBERGRID, these activities are performed in close collaboration with Spanish research organizations such as IFCA, CESGA, IFIC and UPV. Also in the IBERGRID context a new cloud computing service is being developed to further explore the capabilities of the Iberian scientific computing centres. This service will become available in 2013.
The Portuguese Tier-2 is an innovation engine as it provides direct support for cutting edge research in High Energy Physics and in many other domains that benefit from its computing capacity and expertise. Due to its demanding nature the Tier-2 itself requires continuous R&D activities. These include activities in energy efficiency, IT services efficiency, consolidation of services and virtualization.

3.1.3 Objectives

The IT services that support the LIP research activities and the institutional services are largely supported by the LIP computing centres in Lisbon and Coimbra. In terms of IT services the operation of these centres will be a core activity. The Tier-2 and Tier-3 services for ATLAS and CMS are largely provided by these centres.
The LIP computing strategy is being adapted to the challenging funding conditions. The consolidation of the centres and reduction of costs is of utmost importance for the sustainability of the LIP research programme. The LIP Lisbon datacentre is being downsized and its tier-2 capacity is being shifted to the NCG centre. This operation will allow a reduction of the IT costs in Lisbon and will enable an improvement of the remaining IT services. This will also contribute to restore the pool of spare hardware necessary to keep the IT services operational. The Tier-2 downsize is aiming at improving sustainability. The ongoing reduction will affect mostly the pledged storage capacity which is being decreased by 15%.
The LIP computing group has applied to funding with an R&D project to sustain and improve the WLCG Tier-2 services hosted at LIP premises. This project has been recommended for funding with an evaluation of "outstanding"and is expected to start soon. For 2013, the project will focus on establishing a new technological solution for the Tier-2 storage that will address issues such as power efficiency and scalability. The equipment itself will be acquired in 2014.
The importance of the NCG centre has been reinforced by the funding authorities and LIP will continue operating this national service that has been established in partnership with FCCN and LNEC. The current economic situation is expected to increase even more to the demand for the computing services provided by NCG. A new cloud service is being developed and will become available at NCG in 2013. This service will be fully integrated in the IBERGRID and EGI infrastructures.
LIP will continue operating the national grid infrastructure in the context of the Iberian Grid Initiative and European Grid Initiative. These activities will be much dictated by the new EGI strategy strongly focused in innovation in domains such as cloud computing. LIP will continue to provide global services to EGI namely the middleware rollout coordination, middleware acceptance criteria/verification and the EGI CRM system. The evolution and planning of the EGI infrastructure beyond the EGI-Inspire project will be an important topic. With the election of Jorge Gomes to the Executive Board of the EGI.eu foundation in the Netherlands, LIP will be more involved in the EGI upper management and future strategy.
The LIP computing team will continue searching and working on further project proposals in its domains of competence. The so called big data challenge is gaining attention and is likely to play an important role along 2013 both in terms of services provisioning and new opportunities for collaboration.

3.1.4 Team

Project coordinator: Jorge Gomes

Name	Status	%of time in project
Carlos Manuel	Technician (LIP)	100
Gaspar Barreira	Researcher (LIP)	40
Gonçalo Borges	Researcher (LIP)	100
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)	8
Nuno Ribeiro Dias	Researcher (LIP)	100

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 com o suporte experimental a descoberta 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, actualmente observa-se nos raios cósmicos que são detectados na Terra 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 por partículas neutras e carregadas que atravessam a Galáxia em todas as direcções. Um melhor entendimento dos mecanismos da sua aceleração e propagação requer uma medida dos fluxos tão precisa quanto possível e abrangendo o maior intervalo de energias. O detector AMS, instalado na Estação Espacial Internacional (ISS) 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 subdetector RICH. Desde então, o grupo tomou parte em actividades de construção do detector, da sua simulação, de desenvolvimento de métodos de reconstrução dos anéis de Cherenkov e de análise de dados recolhidos durante os testes de um protótipo. Em particular, o grupo é responsável por um dos algoritmos de reconstrução de carga eléctrica e velocidade do subdetector RICH. Desde a instalação de AMS na ISS o grupo tem estado envolvido em actividades de monitorização do desempenho do detector, em especial do RICH, e também em actividades de análise de dados. Na actividade de reconstrução de carga eléctrica e velocidade com dados da ISS, o grupo tem desenvolvido trabalho com o objectivo de corrigir efeitos ditos sistemáticos e que resultam de variações de temperatura, de variações da reflectividade do espelho cónico e de variações na eficiência de detecção à escala do pixel do fotomultiplicador. Na actividade de análise de física, o grupo está envolvido em:

- estudos de modulação dos fluxos de raios cósmicos primários devido à actividade solar (tese de mestrado em Física, IST Julho 2012)
- estudos de separação isotópica de núcleos leves (tese de mestrado a decorrer)
- estudos de avaliação do impacto da polarização da radiação de Cherenkov na reconstrução da carga eléctrica (tese de mestrado a decorrer)
- estudos da fracção de positrões com grande aceitância geométrica (detectores RICH e TRD) feitos a baixa energia (< 10 GeV)

O grande fluxo de dados gerados na experiência tem permitido a integração no grupo de novos estudantes com o objectivo de realizar tese de mestrado e dinamizar novos tópicos de estudo.
Os membros do grupo têm participado ainda nas actividades de monitorização contínua da experiência no Payload Operation Control Center localizado 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 experi
mental 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 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 matter of which the Universe is composed. More than 90% of 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 acceleration mechanisms and propagation requires a measure of cosmic-ray fluxes as accurate as possible and over a wider range of energies. The AMS detector, installed on the International Space Station (ISS) on 19th May 2011, will allow to search for the existence of antimatter and dark matter with an unprecedented accuracy.
Since 1997, the AMS/LIP group has been actively taking part in the AMS experiment, and in particular in the subdetector RICH activities. During this time, the group took part in the subdetector construction and simulation as well as in the development of reconstruction methods for Cherenkov rings and data analysis with data collected with a RICH prototype. In particular, the group is responsible for the development of one of the algorithms aiming charge and velocity reconstruction. Since the installation of AMS 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. The activities in the charge and velocity reconstruction with the AMS data include the study of corrections for the so-called systematic effects, due to namely temperature variations, mirror reflectivity variations and photon detection efficiency variations at the scale of the photomultiplier pixel. In physics analysis the group is involved in the following topics:

- particle fluxes modulation studies of primary cosmic rays and their correlation with the solar activity (master thesis, IST July 2012)
- isotopic separation of light nuclei (ongoing master thesis)
- evaluation of the impact of Cherenkov radiation polarization in the reconstruction of the electric charge (ongoing master thesis)
- measurement of the positron fraction at low energies (<10 GeV) and with a large detector acceptance by using both the RICH and TRD detectors

The large amount of AMS data allowed to integrate new students in the group aiming to perform master thesis and promoting the study of new physics topics.
The group members took also part in the task common to all collaboration, of continuously monitoring the experiment from the Payload Operation Control Center located at CERN.

4.1.3 Objectives

The AMS detector assembly was finished in 2010 at CERN. 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 and instalation aboard the ISS in May 2011. 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.
Since installation a large amount of data have been collected, at a rate of approximately 40 million events per day. Until now more than 28×10ˆ9 events have been collected.
For the year 2013 the following activities are foreseen:

RICH performance and data reconstruction

The LIP group is responsible for the development and ongoing improvement of one of the two sets of reconstruction algorithms for the RICH subdetector (LIP algorithms). The LIP algorithms provide measurements of particle velocity and electric charge based on Cherenkov ring patterns observed in the RICH. Recent work on algorithm improvements was mainly focused on addressing several sources of systematics due to non-uniformities in RICH detector components such as radiator tiles, the mirror and detection cells. Algorithm refinement and

testing is expected to continue in 2013. One of the issues currently being addressed is the effect of Cherenkov polarization mentioned below. In addition, photomultiplier gain drifts and temperature gain variations have to be monitored and its effects corrected, if needed.

Impact of the Cherenkov radiation polarization on the electric charge reconstruction

The Cherenkov electromagnetic radiation is of polarized nature. The photon path from radiation point to detection includes two interfaces: the radiator-vacuum and the vacuum-light guide. The transmission efficiency depends on the photon polarization. Therefore, the effect of the polarization has to be evaluated for both radiator materials, aerogel and sodium fluoride and compared to the unpolarized case that is currently implemented in the charge reconstruction algorithms developed by the LIP group. The resulting correction is being evaluated in the framework of a master thesis currently being done and if significant, a correction to the charge reconstruction needs to be implemented.

Solar modulation of primary cosmic rays

AMS works as a continuous monitor of the cosmic ray fluxes up to one TeV, placed out of the atmosphere. The solar magnetic field, embedded in the solar wind, is responsible for cosmic-ray modulation at low energies ($<$ 10GeV), affecting both their flux and their energy. It imposes a long term time modulation of $\approx$11 years (polarity inversion) and short time effects due to the solar rotation period ($\approx$27 days). The AMS launch took place during a minimum of solar activity (beginning of 24th cycle). The large acceptance of the AMS detector will allow a precise knowledge of the primary fluxes with a fine granularity in time. The study and monitoring of the proton and electron rates or fluxes, is the subject of a master thesis currently going on in the group. The energy spectrum allows to derive the solar modulation effective parameter and therefore, characterize the solar activity. The measured fluxes can be compared with predictions from cosmic rays propagation in the heliosphere, described by the so-called Parker Equation. Different ways of solving the transport equation were already studied by the group and numerical methods (1D and 2D) were explored.

Measurements with light nuclei isotopes

The study of secondary particles coming from the interaction of primary particles with the interstellar medium is of major importance to validate the available cosmic-ray propagation models in our Galaxy. Deuterons, which are formed from helium nuclei collisions with the interstellar medium matter or from p-p collisions, are one of the most interesting particle species since they are rare in astrophysical terms but relatively abundant in cosmic rays. The major difficulty in their detection arises from proton background separation. A new mass separation method using the geomagnetic cutoff and the very precise determination of the velocity within AMS is currently being explored and applied to ams data. This topic is also the subject of an ongoing master thesis.

B/C ratio and other light nuclei measurements

Like the deuteron/proton ratio, the boron/carbon ratio is one of the most important probes for information on cosmic-ray propagation. Carbon nuclei present in cosmic rays are typically primaries, but fluxes of lighter nuclei above helium (Li, Be, B) are dominated by secondaries due to the comparatively low abundance of these elements in astrophysical sources. In particular, boron nuclei should essentially be the result of interactions of carbon primaries with the interstellar medium.
The precise charge measurements obtained from AMS data, and in particular from the RICH detector, will allow to determine elemental abundances in cosmic rays with an unprecedented accuracy. While several AMS subdetectors (e.g. Tracker, TOF, RICH) provide information on particle charge, it is essential to have a reliable result from the combination of such subdetector measurements, since fragmentation of incoming nuclei inside the AMS detector is non-negligible and may lead to significant changes in apparent abundances of rarer species if not properly addressed.

Measurement of e+/e- ratio and fluxes at low energies

The main AMS analysis on positron identification relies on observables measured by the electromagnetic calorimeter (ECAL) and the Transition Radiation Detector (TRD). At low energies (E$<$10 GeV), positron identification can be done with a larger detector acceptance by using the RICH and the TRD. Therefore, a factor of 4 to 5 more events can be collected at these low energies when compared with an analysis purely done with

ECAL and TRD. Positron separation with the RICH detector uses both the velocity and signal independent measurements.
The LIP positron identification method is based on the definition of velocity and RICH signal probability density functions (PDFs) for every particle kind and for every event with a given rigidity measured by the Silicon Tracker. This method started being used in late 2012 and will be applied in the next LIP studies on e+/e- identification.

Participation in the AMS detector monitoring (shifts)

The mission´s POCC (Payload Operations and Control Center) operations are headquartered at CERN since June 2011. LIP team members participate in the AMS mission control activities, performing shifts and acting as on-call experts for the RICH subdetector. LIP shifters are responsible for monitoring the RICH, TOF and ECAL subdetectors and reporting any anomalies to shift leaders and on-call experts assigned to each specific subdetector. When acting as on-call experts, they are responsible for reporting the RICH detector´s behaviour to the collaboration in its daily briefings and performing contingency procedures if any issues occur with the RICH.

4.1.4 Team

Project coordinator: Fernando Barão

Name	Status	%of time in project
Bruno Santos	Master student (LIP)	100
Fernando Barão	Researcher (LIP/IST)	85
Luisa Arruda	Post-Doc (LIP/FCT)	80
Pedro Nunes	Master student (LIP)	100
Rui Faísca Pereira	Post-Doc (LIP/FCT)	100

4.1.5 Academic Training

Master Theses

- *Thesis in AMS*
  Bruno Santos, (on-going)
- *Thesis in AMS*
  Pedro Nunes, (on-going)

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 Boro-8, medido por interacção de correntes neutras (sensível a todos os sabores de neutrinos), e simultaneamente a diminuição da taxa de neutrinos do eletrão, medida por correntes carregadas - confirmando a oscilação de neutrinos e resolvendo o chamado Problema dos Neutrinos Solares.
O detector SNO consistia numa esfera central de 12 m de diâmetro, rodeada por cerca de 9500 PMTs montados numa estrutura geodésica, instalada a uma profundidade de 2km no SNOLAB, Canadá. O grupo do LIP teve um papel importante na calibração ótica do detector e na medida de precisão dos parâmetros de oscilação dos neutrinos - que resulta na mais precisa medida do ângulo de mistura θ_{12}. Este trabalho originou uma tese de doutoramento defendida este ano na Universidade de Lisboa.
SNO+ adapta o detetor de SNO, substituindo o alvo e meio ativo de água pesada por cerca de 800 ton de cintilador líquido, com múltiplos objetivos científicos, 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; para estas medidas estão previstas diferentes fases de tomada de dados primeiro com e depois sem dopagem com um isótopo para 0NDBD.
A instalação dos novos componentes do detetor está a ser completada, e em 2013 o detector será primeiro enchido com água ultra-pura para primeiros testes antes do enchimento com cintilador líquido.
A calibração em tempo e carga dos fotomultiplicadores (PMTs) é fundamental para a reconstrução de posição e energia dos eventos detetados. Em colaboração com a Universidade de Sussex (UK), desenvolvemos um novo método de calibração não invasivo, baseado em vários cabos longos de fibra ótica, com ligação sequencial a um conjunto de LEDs externo ao detetor. As fibras serão instaladas em posições fixas no detetor, reduzindo a necessidade de introdução de fontes dentro do volume interno de cintilador. Para o desenvolvimento e testes dos 110 cabos de fibras duplas do novo sistema foram utilizadas as instalações do grupo ATLAS no Centro de Física Nuclear da Universidade de Lisboa. Todas as partes mecânicas para inserção das fibras no detetor e a sua colocação nos pontos requeridos foram construídas nas oficinas do LIP em Coimbra. Um terço das fibras foram já instaladas em 2012, as restantes serão instaladas por barco durante o enchimento do detetor com água em 2013.
Recentemente, o LIP tornou-se também responsável pelo desenho e contrução dum novo sistema de colocação de fontes de calibração em SNO+. Este é um sistema complexo que requere estanquicidade (para evitar a contaminação do cintilador com radão externo) e um controlo preciso das tensões sobre as cordas de suporte e os cabos de ligação à fonte. O desenho e construção deste equipamento foi encomendado por SNO+, e será pago com fundos canadianos da colaboração.
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 atualizar o software e desenvolver o plano de análise.
Assim, nos próximos dois anos, as nossas atividades serão centradas nos sistemas de calibração, com a preparação das análises de física para os anos seguintes.
Em termos organizativos, o responsável pelo grupo do LIP assegurou (por eleição) a presidência da "Collaboration Board", entre Setembro de 2011 e Agosto de 2012, depois de um ano com a vice-presidência. Membros do grupo do LIP asseguram a coordenação dos subgrupos de Calibração Ótica e de Física de Antineutrinos, e estão representados no "Analysis Coordination Committee". Em 2010 organizámos a reunião de colaboração em Lisboa. Em 2009 foi assinado o Memorando de Entendimento entre a FCT, o LIP, SNO+ e SNOLAB. A participação do LIP em SNO+ é apoiada financeiramente pela FCT, num projecto a 3 anos que se iniciou em Janeiro 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), and integrated since 2006 the proposal for its successor experiment SNO+.
The SNO detector consisted of a 12m diameter spherical vessel, surrounded by about 9500 PMTs mounted on a 17m diameter geodesic structure, installed at a depth of 2 km in SNOLAB, Canada. The SNO results simultaneously confirmed the predicted total flux of 8B solar neutrinos flux and demonstrated neutrino oscillations,

solving the so-called Solar Neutrino Problem. The LIP group had a strong role in the optical calibration of the detector and in the precision measurement of the neutrino oscillation parameters. These results provide the world´s best precision on the neutrino mixing angle θ_{12}. In 2012, a PhD thesis containing this work was presented to the University of Lisbon.
The SNO+ experiment is adapting the SNO detector, in order to use isotope-loaded liquid scintillator as the active medium. SNO+ has multiple scientific goals, the main one being the search for neutrinoless double beta decay, the most promising signature for the possible Majorana character of neutrinos and for the absolute neutrino mass. Measurements of neutrinos from the Sun, the Earth, Supernovae and nuclear reactors are additional goals of the the experiment, for which further data-taking phases with unloaded scintillator are planned. The installation of new detector components is now being completed and the commissioning phase will start in 2013, during the water fill, followed by the scintillator fill.
Timing and charge calibration of the PMTs is fundamental for the position and energy reconstruction of any detected events. In collaboration with the University of Sussex (UK), we have developed a new method for PMT calibration that does not require the insertion of sources in the detector, since it is based on a set of optical fibers transmitting light from external LEDs. Initial design tests and the final quality control of the full 110 double-fiber cables was carried out at the ATLAS group lab at Centro de Física Nuclear da Universidade de Lisboa. All the mechanical parts for feeding the fiber cables into the detector and attaching them in their mount points were designed and built at the LIP-Coimbra workshop. The installation of the first one-third of the system was carried out in 2012, and the remaining fibers will be installed in 2013 during the water fill. Over the next two years, we will focus on finishing the installation and commissioning the system.
The LIP group has also recently taken the responsibility of redesigning and building the source deployment system for SNO+. This is a complex system, requiring gas tightness (to avoid Radon contamination) and an accurate control over the tensions on the source umbilical and support rope. The design and construction of this equipment will be funded by the Canadian SNO+ grant.
Building on the experience acquired in SNO, the SNO+ optical calibration will soon become one of our main tasks. Our group is already responsible for this analysis subgroup, for which we are upgrading the analysis software.
During the next two years, these activities, focused on the commissioning of the calibration systems and analysis software, will be the main goal of the LIP group. Physics data analysis, focused on reconstruction and background reduction, will be the strategic goals for the years to follow.
Focusing on the organizational aspects, JM served the 2011/2012 term as elected chair of the Collaboration Board and members of the group chair the analysis subgroups of Optical calibration and Anti-neutrino Physics. In 2010, the LIP group organized the collaboration meeting in Lisbon. In December 2009, a Memorandum of Understanding for scientific cooperation was signed between FCT, LIP, the SNO+ Collaboration and SNOLAB. The LIP participation in SNO+ is funded by FCT through a 3-year project in the All Scientific Domains call, that started in January 2011.

4.2.3 Objectives

In 2013 the SNO+ detector should start a commissioning phase with water filling. We will participate directly in the following activities:
1) The analysis of the previous (air-filled) data taking is being used to prepare the common data structure for the PMT and optical calibration task and should lead to a publication describing the new system.
2) Before filling the radiopurity of the water must be assessed, and during the filling the remaining optical fibres of the new calibration system will be installed by boat.
3) With the water filled detector, both the PMT and optical calibrations should be performed. These data will allow first tests of the new data structure, hardware, software and calibration algorithms. The analysis will provide the first set of calibration constants for the liquid scintillator phase.
4) The fabrication of the new equipment for source insertion and removal in Coimbra should be completed also in 2013. The present schedule assumes its installation in SNOLAB in the second half of the year.
5) Anti-neutrino sensitivity studies will be continued, with full simulation analysis and including the expected signals from geo-neutrinos.

4.2.4 Team

Project coordinator: José Maneira

Name	Status	%of time in project
Amélia Maio	Researcher (LIP/FCUL)	15
Carlos Silva	Technician (LIP)	15
Dimpal Chauhan	Master (LIP)	75
João Carvalho	Researcher (FCTUC)	15
Joaquim Oliveira	Technician (LIP)	15
José Maneira	Researcher (LIP)	30
Luís Gurriana	Technician (LIP)	15
Nuno Barros	Researcher (LIP/FCT)	100
Orlando Cunha	Technician (LIP)	15
Rui Alves	Technician (LIP)	15
Sofia Andringa	Researcher (LIP)	25

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

4.3.1 Resumo

Em 2013, as actividades do LIP na área da detecção directa de matéria escura vão continuar com a participação na experiência Large Underground Xenon (LUX).
A experiência LUX constitui um passo decisivo na procura da matéria escura na forma de "Weakly Interacting Massive Particles"(WIMPs). LUX utiliza um detector de xénon de duas fases, técnica bem comprovada pelas experiências ZEPLIN e XENON, introduzindo, no entanto, avanços cruciais relativamente a estas duas experiências, como por exemplo, um aumento muito significativo da massa de xénon (350 kg comparada com 6,5kg e 100 kg em ZEPLIN-III e XENON, respectivamente), avanços nas técnicas de blindagem e de criogenia, redução do fundo de radiação residual, o que permite melhorar a sensibilidade para ≈2×10ˆ-10 pb para 100 GeV/cˆ2 após uma aquisição de dados de 300 dias efetivos). Esta sensibilidade vai permitir testar muitas extensões do Modelo Standard que preveem a existência de WIMPs e no caso de os detector vai permitir acumular um número significativo de eventos (15 eventos no intervalo de energia de 5 a 25 kVnr, assumindo uma secção eficaz de 10ˆ-9 pb para 100 GeV/c2).
Para além da sua muito elevada sensibilidade e do seu consequente potencial para detectar WIMPs, LUX serve também de "balão-de-ensaio"de tecnologias necessárias à próxima geração de detectores de WIMPs: 1) Utilização de fotomultiplicadores maiores e com menor radioactividade; 2) Um sistema criogénico que utiliza termosifões que permite arrefecer o detector de forma compacta e muito eficiente; 3) crióstato e detector em titânio de baixa radioactividade; 4) imersão do crióstato num tanque de água ultra-pura, equipado com fotomultiplicadores, em vez das blindagens de chumbo e de polietileno habitualmente utilizadas; 5) Fontes de calibração gasosas (Kr-83m e H-3) introduzidas diretamente no xénon.
A Colaboração LUX é constituída por 14 instituições de 3 países (EUA, Portugal e UK), num total de cerca de 70 indivíduos. O LIP é membro da colaboração LUX desde Dezembro de 2010.
De Novembro de 2011 a Fevereiro 2012, nas instalações de superfície do complexo de Stanford - o Sanford Research Facility (SURF), em Homestake, SD, EUA - validaram-se individualmente os vários sub-sistemas e a sua integração na experiência. Durante estes testes o detector esteve imerso num tanque de água para reduzir o efeito dos raios cósmicos. Alguns componentes da experiência LUX envolvem novas soluções técnicas que beneficiaram destes testes em condições muito próximas das finais. É o caso da técnica de arrefecimento, da circulação de gás, dos sistemas de purificação, dos sistemas de controlo e de segurança, da aplicação de alta tensão ao cátodo, ânodo e grelhas do detector, e do sistema de aquisição de dados. Um segundo objetivo destes testes de superfície, com o detector numa configuração muito próxima da final, era permitir uma avaliação preliminar do desempenho do detector e dos sistemas auxiliares.
Em Julho de 2012, experiência LUX foi transportada para o laboratório subterrâneo de SURF. A instalação e integração de todos os subsistemas no laboratório subterrâneo começou de imediato, tendo ficado finalizada em Dezembro de 2012. No ínicio de Janeiro irá iniciar-se o teste do detector cheio de xénon gasoso, ao que se seguiu o seu arrefecimento. Após a condensação do xénon no alvo estar finalizada (o que se espera que aconteça no final de Fevereiro), iniciar-se-á uma campanha de purificação xénon até se obter o nível de impurezas desejável (pretende-se alcançar uma vida média dos electrões livres de pelo menos 0.2 ms, resultado obtido nos testes de superfície). O detector será então calibrado com fontes radioactivas, internas e externas, emissoras de radiação gama e de neutrões.
LUX planeia realizar uma primeira tomada de dados durante 60 dias e publicar os resultados (ou comunicá-los publicamente) durante o ano de 2013. O objectivo desta tomada de dados é obter um exposição que permita melhorar o actual limite superior para a secção eficaz de interacção independente do spin entre WIMPs e nucleões para massas dos WIMPs superiores a 10 GeV/c2
LUX é o maior detector de duas-fases de xénon a ser usado numa experiência de matéria escura.

4.3.2 Abstract

In 2013, the LIP activities in the area of dark matter search will continue centered in the participation in the LUX experiment.
LUX experiment constitutes a large step forward in the search for dark mater in the form of Weakly Interacting Massive Particles (WIMPs). Based on the well proven dual-phase xenon detector technology in the ZEPLIN and XENON detectors, it adds improvements in key areas, such as a much larger xenon mass (350 kg compared with 6.5 kg of ZEPLIN-III and 100 kg of XENON100), improvement of shielding and cryogenics, reduction of backgrounds, and boost sensitivity to an expected ≈2×10ˆ-10 pb for 100 GeV/cˆ2 after 300 live-days of data taking. This will allow to test many extensions of the Standard Model that predict WIMPs, and in case of

detecting a WIMP signal, it will allow to accumulate WIMP statistics in a reasonable time frame (15 events/year within the energy window from 5 to 25 kVnr and at 10ˆ-9pb for 100 GeV/c2).
Apart from its potential of discovery, LUX is also very important because it introduces technological innovations required to major scale-up to the ton-scale detectors and beyond: 1) Larger, low activity photomultipliers. 2) A cryogenic system using liquid nitrogen thermosyphons that compactly and economically provides high capacity cooling heads. 3) A low-background titanium cryostat. 4) Immersion of the cryostat in an ultra pure water shield instead of Pb/polyethylene shields more suitable for small experiments. 5) Gas calibration sources (Kr-83m and H-3) introduced directly into the liquid xenon.
LUX Collaboration comprises 16 institutions from 3 countries (USA, Portugal and UK) and about 70 individuals. LIP formally joined LUX in December 2010.
From Nov 2011 to Feb 2012, a surface run conducted with the detector immersed in a water tank validated the various sub-systems and verified the integration of the entire system in preparation of the underground deployment. Some LUX components involve novel technical solutions that benefited from realistic testing, including the cooling, gas circulation and purification systems, the control and safety systems, high voltage delivery, and the data acquisition system. A second aim of the run was to allow a preliminary assessment of the radiation-detection performance of the experiment.
LUX detector and its ancillary systems were moved underground at Sanford Underground Research Facility (SURF), Homestake, SD, US, in July 2012. Underground integration and commission of the LUX detector and all the subsystems started promptly and were completed in December 2012. There will be a short test data taking period with the detector filled with warm gas followed by its cooling down. After xenon condensation in the target is finalized (what is expected to happen by the end of Feb), a xenon purification campaign will start until the desirable purity is achieved (at least it must equals the free electron lifetime of 0.2 ms achieved in the surface run). The detector will then be calibrated with various internal and external gamma and neutron radioactive sources.
LUX Collaboration expects to conduct a preliminary WIMP search run (60 live-days), and release the paper or make an announcement of the results within 2013. The goal of this WIMP run is to get sufficient exposure to exceed the sensitivity of all previous direct detection experiments (for WIMP masses >10 GeV/cˆ2).
LUX is the largest two-phase xenon dark matter detector in the world and is the first xenon TPC deployed in a water shield.

4.3.3 Objectives

Our activity in 2013 will be centered in the following tasks:

1. Complete the construction and commission of a motorized system for automatic calibration of the detector with external radioactive sources. A prototype of this system was already constructed and tested and the software for its control was already developed. We have full responsibility for this system.

2. To complete slow control upgrade and be responsible for its maintenance.

3. Participation in the development of tools for LUX data processing and analysis. Apart from other smaller tasks, this includes to develop a standalone package for reconstruction of event energy and position, crucial for background rejection as it allows to select a low activity region in the center of the detector and to reject multi-interaction events. This package will be integrated in the data analysis chain.

4. Participation in the analysis of the data that will be taken during purification campaign, calibration of the detector and first science run (60 live-days data taking).

5. To participate in the xenon purification campaign, calibrations and science run operations by maintaining always a person from LIP onsite.

6. Measurement of the reflectivity of LUX reflector (PTFE) at low temperature and immersed in liquid xenon (the measurements done so far have been at room temperature and in a gaseous atmosphere).

4.3.4 Team

Project coordinator: Isabel Lopes

Name	Status	%of time in project
Alessio Mangiarotti	Researcher (LIP)	15
Alexandre Lindote	Post-Doc (LIP)	88
Américo Pereira	Technician (LIP)	35
Cláudio Silva	Post-Doc (LIP/FCT)	84
Filipa Balau	PhD student (LIP)	50
Francisco Neves	Post-Doc (LIP)	92
Isabel Lopes	Researcher (LIP/FCTUC)	57
José Pinto Da Cunha	Researcher (LIP/FCTUC)	28
Luiz de Viveiros	Post-Doc (LIP)	100
Nuno Carolino	Technician (LIP)	25
Vitaly Chepel	Researcher (LIP/FCTUC)	30
Vladimir Solovov	Researcher (LIP)	84

4.4 High Energy Cosmic Rays

4.4.1 Resumo

As actividades do LIP na área dos Raios Cósmicos de Energia Extrema continuaram, em 2013, centradas na participação no Observatório Pierre Auger (Auger). Nomeadamente, na preparação de MARTA – "Muon Auger RPC for the Tank Array- um projecto para a instalação de RPCs no detector de superfície de Auger.
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.
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. Em 2013, o projecto MARTA marcará seguramente o trabalho do grupo, quer em actividades de R&D e testes de protótipos, quer na preparação das análises para extração de resultados na sua configuração futura.

4.4.2 Abstract

The LIP activities in the area of high energy cosmic rays will continue, in 2013, centred in the Participation in the Pierre Auger Observatory (Auger). Namely, the preparation of MARTA – "Muon Auger RPC for the Tank Array- a project for the installation of RPCs in the Auger surface detector.
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 Malargue, province of Medonza, Argentina is in operation since 2003. It combines the sampling of air showers arriving at the Earth surface (in the Surface Detector, SD) with the observation, in moonless nights, of the UV light emitted in the interaction of cosmic ray showers with the atmosphere (in the Fluorescence Detector, FD). 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 galactic 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) = 57 TeV) showing a remarkable agreement with the extrapolation of recent LHC measurements for proton-proton (sqrt(s) = 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. In 2013, the group work will be focused on the MARTA project, in R&D activities and prototype testing and in the preparation of the analysis to extract the best results in their future configuration.

4.4.3 Objectives

Our activities for 2013 will be centred in the present data analysis in terms of mass composition and hadronic interaction model testing, and on the development of the proposal for an Auger upgrade that can disentangle the two, through a better assessment of the muonic component, including RPC muons detectors. Blow we summarize the main lines for 2013 within each task.
Task 1- Tools and studies for light propagation and detection
In the last years we have already developed several tools for these systematic studies. Now, we will focus on the analysis of the impact of the scattered light on the extraction of the electromagnetic profile shape variables.
Task 2- Measurement of electromagnetic and muonic shower profiles
In Auger, the FD images the electromagnetic component; while the SD is sensitive to muons coming directly from the decay of charged pions and other mesons along the shower. We try to cover both with the following analysis:
a) Measurement of the average electromagnetic shower profile and its interpretation.
b) Measurement of the average muon production depth as a function of energy.
c) Measurement of the total number of muons and its fluctuations.
d) Study the impact of RPCs in the above muon measurements and on the energy estimation with the Auger surface detector.
Task 3 - Search for Exotic and Rare Events
The search for exotic and rare events in high energy air showers may be a unique, although difficult, window for new physics at energy scales above the LHC. We´ve developed a framework for classifying each air-shower in a wide set of non-exclusive event classes, with a fairly complete coverage for both FD and SD data. The LIP group also has the responsibility to keep a web-based tool where information on interesting events can be shared.
Task 4 - Theory and Models for High Energy Interactions
The Auger results are not easy to explain in terms of the "standard"Astrophysics or Particle Physics models and a rich field of predictions for new effects waits to be confronted to data. This task is the follow up of the many years collaboration between Portuguese experimental and theoretical particle physicists to build a coherent picture that accommodates both recent Auger and LHC data, as well as to explore possible "New Physics"scenarios.
Task 5 – R&D for the next generation of high energy cosmic ray experiments
This task will be central in 2013. The complete development of a proposal for the installation of RPCs in Auger implies a full program for laboratory hardware tests, prototype construction and in-situ tests. The detailed simulation already available will be adapted for each of the proposed tests and detector optimization studies. It will be used also as a base for the development and testing of the future analysis and to evaluate the expected impact on the Auger results.
An international collaboration has been set-up to explore MARTA – "Muon Auger RPC for the Tank Array". This group is led by LIP and comprises four institutions in Brazil, plus other from the Czech Republic, Spain and Italy.

4.4.4 Team

Project coordinator: Mário Pimenta

Name	Status	%of time in project
Alberto Blanco	Researcher (LIP)	20
Alessandro de Angelis	Researcher	35
Américo Pereira	Technician (LIP)	15
Bernardo Tomé	Researcher (LIP)	80
Catarina Espírito Santo	Researcher (LIP)	80
Eva Santos	PhD student (LIP/FCT)	100
Francisco Diogo	PhD student (LIP/FCT)	100
João Espadanal	PhD student (LIP/FCT)	100
Jorge Dias de Deus	Researcher (LIP/IST)	15
Jorge Romão	Researcher (LIP/IST)	15
José Micael Oliveira	PhD student (LIP)	100
José Milhano	Researcher (LIP/IST)	15
Liliana Apolinário	PhD student (LIP)	15
Lorenzo Cazon	Researcher (LIP)	80
Luís Mendes	Student (LIP)	65
Mário Pimenta	Researcher (LIP/IST)	85
Miguel Ferreira	Technician (LIP)	65
Patrícia Gonçalves	Researcher (LIP)	50
Pedro Abreu	Researcher (LIP/IST)	65
Pedro Assis	Post-Doc (LIP/FCT/IST)	85
Pedro Brogueira	Researcher (LIP/IST)	15
Raul Sarmento	Post-Doc (LIP/FCT)	100
Ruben Conceição	Post-Doc (LIP/FCT)	100
Sofia Andringa	Researcher (LIP)	75
Thomas Schweizer		15

4.4.5 Academic Training

PhD Theses

- *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)
- *Medição da secção eficaz de raios cósmicos de alta energia no Observatório Pierre Auger*
  Francisco Diogo, (on-going)
- *Particle Physics at 100 TeV with the Pierre Auger Observatory*
  José Micael Oliveira, (on-going)

4.5 Space Radiation Environment and Effects

4.5.1 Resumo

As actividades desenvolvidas no âmbito deste projecto tiveram início na aplicação da ferramenta de simulação Geant4 a experiências de astropartículas no espaço, no âmbito de um primeiro contrato com Agência Espacial Europeia (ESA) em 2003. As actividades desenvolvidas têm vindo não só a possibilitar a integração de estudantes com interesse no Espaço, como também se têm revelado uma fonte de colaboração entre o LIP e outros institutos, empresas e com a indústria e também com cientistas externos ao LIP

A maior parte das actividades têm vindo a ser desenvolvidas no âmbito de contratos com a ESA, quer individualmente quer em consórcio, mas, no entanto, as áreas científicas de base do projecto "Space"foram definidas pelo conhecimento pré-existente de ferramentas que permitem simular a interacção entre as partículas e a matéria, neste caso o Geant4, e de métodos de detecção de radiação e de instrumentação em Física Experimental de Partículas. Dada a especificidade dos problemas apresentados pelo ambiente de radiação no Espaço, a actividade abrange também o estudo dos efeitos da radiação em componentes electrónicos (EEE) e também nas tripulações de missões espaciais e das estratégias de mitigação correspondentes. As actividades desenvolvidas podem ser classificadas como as relacionadas com contratos com a ESA e as de carácter mais geral, de investigação e desenvolvimento num determinado tema.

Quanto aos contratos com a ESA, existe um contratos em curso, uma proposta em preparação em resposta a um concurso aberto pela ESA (ITTs) e actividades previstas de preparação de propostas.

O contrato em curso é o projecto CODES (COmponent Degradation Simulation tool), cuja terceira extensão está na fase final de implementação da ferramenta CODES num ambiente de utilização integrado e de fácil acesso e utilização.

Até 8 de Fevereiro de 2013 será submetida uma proposta para as fases de desenvolvimento e demonstração do RADEM, um monitor de electrões (mas também de protões e iões) com design "radiation-hard"para a missão da da ESA Juice às Luas geladas de Jupiter, que será lançada em 2022. A proposta encontra-se a ser preparada por um consórcio liderado pela RUAG(CH), de que fazem parte o LIP (PT), a EFACEC (PT), PSI(CH) e a IDEAS(NO) e o resultado da sua availação pela ESA deverá ser conhecido em Junho/Julho de 2013.

Está prevista a preparação de duas propostas em resposta a dois ITTs, que e deverão ser abertos pela ESA em 2013, no âmbito do programa TRP (Technology Research Programme): *AlphaSat TDP-8 MFS Particle Spectrometer Data Analysis* e *Verification of 60Co TID testing representativeness for EEE components flown in the Jupiter electron environment*, este último proposto como medida especial para Portugal, para negociação directa com o LIP.

No âmbito do programa Horizon 2020 da Comissão Europeia, o LIP tem vindo a colaborar com o UNINOVA (um instituto de R&D com instalações no Campus da Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa) na preparação de uma proposta para uma actividade transversal com o título *Multispectral Data Analytics for Planetary Missions*, que tem como tema a exploração de dados de missões espaciais. Pretende-se que esta actividade venha a ter a participação de outras equipas europeias.

Os temas de investigação e desenvolvimento que fazem parte dos objectivos deste projecto são:

- Estudo e modelização do ambiente de radiação em ambientes planetários, nomeadamente nos casos da Lua, Luas de Jupiter e asteroides, assim como a melhoria e validação com dados reais dos modelos desenvolvidos pelo LIP para o ambiente de radiação em Marte.

- O acompanhamento da evolução dos modelos de propagação dos acontecimentos SEP (Solar Energetic Particle events), que se iniciou com o projecto *Portuguese Participation in the Helisopheric Network*.

- Estudo e desenvolvimento de conceitos para futuros monitores de radiação. Explorar novos conceitos e diferentes princípios de detecção, utilizando quer detectores de Si, quer cintiladores.

- Estudo dos efeitos da radiação nas tripulações de futuras missões espaciais.

- LIP foi convidado a participar nas equipas científicas de dois instrumentos propostos para o *payload* científico do *European Lunar Lander*: o L-REM, um monitor de radiação, proposto pela DLR e o DRONE, um espectrómetro de alfas, proposto pelo Institut de Recherche en Astrophysique et Planetologie (IRAP) em França. Entretanto, o programa do *European Lunar Lander* foi suspenso no conselho inter-ministerial entre estados membros da ESA, em Novembro de 2012, mas espera-se que os instrumentos em desenvolvimento possam ser utilizados em oportunidades futuras e que as oportunidades de colaboração que se estabeleceram possam ser concretizadas.

4.5.2 Abstract

The field of space applications in LIP is centered in the study of the radiation environment in space and of its effects. The activities developed at LIP were triggered by the application of the Geant4 simulation toolkit to astroparticle experiments in a first contract celebrated between LIP and ESA in 2003. Since then, the activities developed in this project have been supported mainly by contracts between LIP and the European Space Agency, LIP being either responsible for the project or for parts of the project. These activities have come not only to enable the integration of students with interest in Space, but also have proved a source of collaboration between LIP other institutes, companies and the industry, and also of collaboration with external scientists.
In this project, most activities have been performed in the framework of ESA contracts, but the baseline scientific areas of the project were defined by the pre-existing know how at LIP in the areas of radiation interaction simulations, namely with application of the Geant4 simulation toolkit to Space, and radiation detection and experimental particle physics instrumentation. Given the specificity of the problems presented by the radiation environment in space, this activity includes the study of the effects of the radiation environment in Space in EEE components and in astronauts, and of the corresponding mitigation strategies. The activities developed can thus be divided into ESA contracts related activities and into more general R&D activities. Concerning ESA contracts, there are ongoing contracts; submitted proposals in response to ESA ITTs (Invitation To Tender,) and foreseen activities corresponding to ESA Intended Invitations To Tender, not yet issued but, whose calls are foreseen to occur in 2013.
The ongoing activity under an ESA contract is CODES (COmponent Degradation Simulation tool. The CODES III project is in a final phase of implementation of the CODES tool in an integrated and user friendly environment to be made available by ESA after the end of the contract.
There is one submitted proposal in response to an ESA ITT, concerning the development and deminstration of the "RADEM: Radiation-Hard Electron Monitor for the Jupiter Environment"for the ESA Juice mission to Jupiter. For this purpose, LIP participates in an international consortium, lead by RUAG (CH), with EFACEC(PT), PSI(CH) and IDEAS(NO), which is preparing a proposal to be submitted to the ESA before the 8th February 2013. The outcome of the proposal should be known in June/July 2013.
It is foreseen that during 2013, two ITTs may be issued in the framework of the ESA TRP (Technology Research Program), for which LIP will prepare its proposals:*AlphaSat TDP-8 MFS Particle Spectrometer Data Analysis* and *Verification of 60Co TID testing representativeness for EEE components flown in the Jupiter electron environment*, the latter proposed in the ESA TRP as a Special Measure for Portugal, for Direct Negotiation (due to the Specialization area) with LIP.
Also, and in this case in the the framework of the future Horizon 2020 program, LIP is collaborating with the UNINOVA institute (an R&D institute located in the premisses of the Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa Campus) in the preparation of the proposal for a cross-cutting activity, with the title *Multispectral Data Analytics for Planetary Missions*, with the focus in exploitation of space data.
Research and development themes:

- Study and model the radiation environment in planetary environments, namely in the Moon, Europa, Ganymede and in asteroids, as well as the improvement and validation with real data of the LIP models developed for Mars.

- Follow up of the models for SEP (Solar Energetic Particle events) propagation, that started with the project *Portuguese Participation in the Heliospheric Network*.

- Study and develop concepts for future radiation monitors. Explore new detector concept, using both silicon planes and/or scintillating crystals.

- Study biological effects of the radiation environment in space. LIP was invited to collaborate with the German Aerospace Center (DLR) team in the exploitation of the data of MATROSKA (an anthropomorphic phantom on the ISS).

- LIP is part of the scientific team of two instruments included in the ESA July 2012 call for declarations of interest for instruments for the European Lunar Lander payload: L-REM, a radiation monitor proposed by DLR, and DRONE, an alpha particle spectrometer, proposed by the Institut de Recherche en Astrophysique et Planetologie (IRAP) in France. Although the European Lunar Lander programme was suspended in the November 2012 inter-ministerial meeting between ESA member states, the development of these instruments, should in principle be continued, in view of future opportunities.

4.5.3 Objectives

ESA contracts

In what concerns ESA contracts, the objectives for 2013 are finalizing and closing the CODES contract in March 2013, and initiating the *RADEM protoflight model for the JUICE mission* in mid 2013:

The CODES III project is in a final phase of implementation, and was scheduled to finish in 2012. However, given the promising results of the activity, an extension was suggested to implement and optimized stand alone version of the tool to be available for radiation harness assurance purposes. This extension of 5 months, will end in March 2013.

JUICE is a mission to Jupiter and its icy moons. The mission concept is based on multiple flybys of a number of Galilean Moons prior to eventually entering into orbit around Ganymede. A payload suite of 11 instruments including remote-sensing and in-situ suites will provide new insight into the Jovian system. RADEM stands for RADiation-hard Electron Monitor for the Jupiter environment, for the ESA JUICE (JUpiter ICy moons Explorer) mission to Jupiter. After the preparatory time and definition of a partnership consortium, LIP has participated in the preparation of a proposal to Phase B2, C and D of the development of the RADEM instrument. In this project LIP is to be responsible of the optimization of the High Energy Particle (HEP) instrument and by the development of an electron Directionality Detector (DD). The preliminary design of the DD included in the proposal submitted to ESA, in the beginning of 2013, was developed by LIP in close collaboration with PSI.

Horizon 2020

The preparation of the project *Multispectral Data Analytics for Planetary Missions* in collaboration with UNINOVA will continue, including networking activities with already identified european partners, which will be developed.

R & D activities

The objectives for 2013 are to continue following the established lines of activity, if possible with the realization of Master Degree and PhD theses, and to establish networking activities with other institutes and with the industry.

The publication of the first measurements of the radiation environment at the Martian surface, performed by the Curiosity mission, on Martian soil since august 2012, is awaited for a validation of dMEREM (the detailed Martian Radiation Environment Model developed at LIP) predictions. This comparison analysis will be published in an international magazine and submitted to international conferences.

4.5.4 Team

Project coordinator: Patrícia Gonçalves

Name	Status	%of time in project
Alessandro de Angelis	Researcher	10
Ana Keating	Post-Doc (LIP/FCT)	99
Bernardo Tomé	Researcher (LIP)	10
Bruno Morgado	PhD student (LIP)	100
Catarina Espírito Santo	Researcher (LIP)	7
Patrícia Gonçalves	Researcher (LIP)	41
Pedro Brogueira	Researcher (LIP/IST)	5

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 based on Scintillating Crystals"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 partículas elementares.

5.1.2 Abstract

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

5.1.3 Objectives

Clinical evaluation of the ClearPEM and ClearPEM-Sonic scanners
The LIP group will pursue in 2013 the participating in the clinical studies of breast cancer detection with the ClearPEM machines.
The study of breast cancer detection using alternative tracers to FDG will be undertaken by ICNAS, under a ICNAS project recently funded by FCT. A small funding for scanner maintenance and LIP participation will be provided by ICNAS.
The plan to adapt and use the available ClearPEM scanner at ICNAS as a national infrastructure for small animal imaging will be pursued. It is planned to have the small animal infrastructure operating this summer, after a small animal MRI is delivered to ICNAS.
The ClearPEM-Sonic machine presently in Marseille will be moved to the Unita´ Operativa Medicina Nucleare, Ospedale San Gerardo, under Director Prof. Cristina Messa. The INFN/Milan group of the ClearPEM-Sonic collaboration, will take in charge the re-installation of the machine with the support of LIP and INEGI. An independent evaluation of beast cancer detection with ClearPEM is the main goal of this activity.
Funding for LIP participation in these activities will be requested to FCT. The lack of appropriate funding is the most pressing problem affecting this activity.

EndoTOFPET-US project
The EndoTOFPET-US funded by FP7 will be pursued until end 2014. The main goal in 2013 is the assembly of the first complete prototype system.
Detector modules for the external detection plate, using Hamamatsu SiPM arrays coupled to LIP TOFPET integrated electronics, will be assembled and tested.
Two research students funded by the Marie-Curie ITN PICOSEC project are integrated in this activity.
The re-design of the TOFPET chip in cheaper UMC technology will be undertaken in collaboration with Torino.
A twin version of the chip for silicon strips will be used by the Torino group in the PANDA experiment.

PET/MRI
The evaluation of small PET prototype based on ClearPEM modules will be pursued at EPFL Lausanne.

PEM industrialization
The efforts of industrialization of the PEM technology will be pursued. Two directions are now being exploited:
a) The startup PETsys has applied to a funding round of Portugal Ventures, to build a new PEM scanner based on SiPMs and optimized in cost/performance. The pre-selection phase was passed successfully.
b) A possible project in collaboration with Brasil, involving the HEP group in Rio de Janeiro, is now in discussion.

5.1.4 Team

Project coordinator: João Varela

Name	Status	%of time in project
Carlos Gaston	Researcher (LIP)	100
Catarina Ortigão	Post-Doc (LIP/FCT)	100
Cláudia Sofia Ferreira	PhD student (LIP/FCT)	100
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	PhD student (LIP)	100
Rui Pereira da Silva	Technician (LIP)	100
Viesturs Veckalns	PhD student (LIP)	100

5.1.5 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, 2013-07-01
- *Development of advanced data acquisition technologies for PET applications*
  Ricardo Bugalho, 2014-01-10
- *Integrated Circuit Design for Picosecond Timing measurements on Radiation Detectors*
  Manuel Rolo, 2014-01-15
- *New technologies and algorithms for high-performance local processing of large scale sensor data in high energy and medical physics*
  Viesturs Veckalns, 2016-01-09

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 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.
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[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

Our activities will be developed in the framework of the approved project PTDC/SAU-BEB/104630/2008 - "RPC-PET - A novel technology for single-bed whole-body human molecular imaging with higher sensitivity

and resolution".
Owing to the project budgetary constraints, the number of detector layers will be restricted to one, with 10 gas gaps, yielding an efficiency of only 2% per photon, instead of the 20% that will be needed for the full instrument. It must be realized that we are trying to develop a new technology that may replace with advantage an instrument that costs commercially approximately 1.5MEUR. It is clear that such development cannot take place in full within the budgetary limits of the present project.
The proposed strategy will allows us to develop all components in full-size, but in a quantity smaller by a factor 10, allowing savings by approximately the same factor. The developed technology may be later scaled up to a full instrument (10 detector layers). It is expected that this reduction will allow us to obtain results on parameters (NEC, TOF resolution, scatter,etc) that may, with the help of simulations, be scaled up to draw firm conclusions about a full instrument.
The project is structured in the individual tasks:

- System design
- Detector design and construction
- Analogue readout electronics development
- Data acquisition infrastructure development
- Integration, testing and assessment
- Image reconstruction and data corrections

The team congregates 3 institutions with complementary capabilities:

- LIP - Laboratório de Intrumentação e Física experimental de Particulas - a large "associate laboratory"with capabilities in elementary particle detectors and high energy physics, participating in numerous international collaborations in this field;
- ICNAS - Instituto de Ciências Nucleares Aplicadas à Saúde - an institute of the University of Coimbra devoted to nuclear medicine and hosting an isotope-producing accelerator, PET and SPECT scanners and a very qualified academic staff;
- ADDF - Associação para o Desenvolvimento do Departamento de Física – associated with the physics department of University of Coimbra, which provides capabilities in digital electronics design.

The bulk of the team has already collaborated in the framework of a finished project under the same theme ("Affordable, very-high sensitivity human PET: feasibility studies", POCI/SAU-OBS/61642/2004), which established the basic feasibility of the RPC-PET concept.
Furthermore, the project counts with the collaboration of individual researchers from GSI - Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany (www.gsi.de) - a large nuclear research institute and from the Jagiellonian University in Cracow, Poland (http://www.uj.edu.pl). These researchers are deeply involved in the new data acquisition (DAQ) system of the HADES experiment (www-hades.gsi.de) at GSI, which is of a very modern design, based on field-programmable hardware. Therefore, this system may be adapted to the project needs and provide a very large part of the necessary DAQ infrastructure. This valuable contribution is equivalent to many man-years of R&D.
In 2013 we will build a 4-head full-body system, still slightly simplified from the detectors point of view, but complete from the electrical point of view. This will allow us to measure all the important quantities and perform full tests of the readout electronics.
The extension of the scanner to 3 layers is one of the research lines of the "RAD4LIFE"project in the framework of the EU QREN program approved to take place between July 2013 and December 2015.

5.2.4 Team

Project coordinator: João Lima

Name	Status	%of time in project
Alberto Blanco	Researcher (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/FCTUC)	5
Paulo Fonte	Researcher (LIP/ISEC)	25
Ricardo Caeiro	Technician (LIP)	10
Rui Alves	Technician (LIP)	10
Rui Marques	Researcher (LIP/FCTUC)	10

5.2.5 Academic Training

PhD Theses

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

5.3 Detectors and Monte Carlo in Medical Physics

5.3.1 Resumo

As actividades do projecto irão desenvolveram-se segundo as seguintes linhas:
1. Microdosimetria com feixes de partículas alfa emitidas pelo gás radão e seus descendentes :
Relativamente à microdosimetria iremos proceder à realização, de estudos in vitro com células pulmonares radiosensíveis sujeitas a partículas alfa oriundas de fontes particulares, contribuindo para a determinação da sensibilidade dessas células às partículas alfa. Iremos igualmente colaborar num estudo epidemiológico, na área da saúde pública, levado a cabo pelo Hospital de Sousa Martins da Guarda e pela Associação Portuguesa de Doenças Respiratórias. Esse estudo, deverá ter como objetivo principal o conhecimento da taxa de incidência de tumores radioinduzidos na região da Guarda a figurar no Registo Oncológico Regional (ROR). Procederemos ainda à simulação Monte Carlo de modelos de dose-resposta no acino pulmonar humano com o objetivo de estimar o risco de desenvolvimento de tumores linfáticos originados nesta região do pulmão. Propomos ainda estudar a contribuição da radiação gama para o cálculo da dose efectiva anual média na região da Beira Interior, através do reconhecimento geológico e georeferenciação da distribuição da dosimetria gama no território com produção de cartografia, bem como do estudo dos materiais que são mais usualmente utilizados na construção.
2. Estudo de dose dadas a pacientes sujeitos a radiografia dental panorâmica:
Continuação da pesquisa sobre os efeitos do paciente em proteção radiológica. Estudo da radiação absorvida e dispersa pelo paciente com equipamentos dentários. Quantificação da dose recebida por pacientes pediátricos e adultos em exames de ortopantomografia, com incidência especial na dose recebida nas glândulas salivares, tiroide, olhos e medula óssea.
3. Desenvolvimento de dosimetros de cintiladores plásticos para o estudo de doses dadas a pacientes sujeitos a exames de tomossintese:
Desenvolvimento de sistema portátil de leitura dos dosimetros de cintilador plástico e construção dos dosimetros. Realização de testes dos dosimetros de cintiladores plásticos em ambiente clínico em exames radiológicos de radiografia dental panorâmica e tomossintese.
4. Utilização de simulação Monte Carlo para a determinação quantitativa de metais pesados em amostras biológicas por fluorescência de raios-X:
Aplicação da técnica de análise EDXRF auxiliada por simulação Monte Carlo à determinação elementar de amostras de interesse do património cultural.

5.3.2 Abstract

1. On what concerns microdosimetry we will proceed with in-vitro studies with radio-sensitive lung cells subject to alpha particles originating from radon sources and their progeny, contributing to the determination of the sensitivity of these cells to alpha particles. We will also collaborate on an epidemiological study in the area of public health, conducted by the Hospital de Sousa Martins at the city of Guarda. The main goal of this study is the knowledge of the incidence of tumors in the region induced by exposition to radon. We will proceed with the Monte Carlo simulation dose-response models in the human lung cell in order to estimate the risk of developing lymphatic tumors in the lung area. We also propose to study the contribution of gamma radiation to the average annual effective dose in the region of Beira Interior, through the geology of the area and the most commonly used construction materials.
2. We will continue the research on radiation protection of the patient. The study of the radiation produced by dental equipment and absorbed and scattered by the patient will be made. Quantification of the dose received by pediatric and adult patients in panoramic radiography examinations, with emphasis on the dose received in the salivary glands, thyroid, eyes and bone marrow will also be made.
The development of a portable dosimetric system based on plastic scintillators and its construction will be made. These plastic scintillator dosimeters will then be tested in the clinical environment of dental radiography examinations.
3. A new dosimetry system based on plastic scintillator will be developed for the mammographic scans. The system is constituted by a set of small plastic scintillators coupled to optical fibers allowing for a real-time dose measurement simultaneously in several points. The dosimeters will have a minimum impact in the image quality due to their size (a few milimeters) and building material (plastic).
4. Combining EDXRF measurements with MC techniques and standard quantification methods, we expect to obtain reliable quantitative analysis of various kinds of samples. Although in this project we will implement this approach to a particular EDXRF spectrometer, the methodology can be
extended to any other XRF system used for quantitative analysis. As first test we will apply the analysis to of samples of pigment on paper. The model samples will replicate the simple stratigraphy of a layer of pigment applied on paper, simulating artworks commonly studied in Cultural Heritage applications. Stratigraphied

samples are a good example where MC methods might improve significantly the quantitative analysis when compared with current standard quantification methods.

5.3.3 Objectives

1. Microdosimetry with beams of alpha particles emitted by radon and its progeny.
2. Study of radiation dose given to patients undergoing dental panoramic radiographs.
3. Development of plastic scintillators dosimeters to study doses given to patients examined for tomosynthesis.
4. Use of Monte Carlo simulation for the quantitative determination by energy dispersive X-ray fluorescence of elemental composition of samples of cultural heritage value.

5.3.4 Team

Project coordinator: Luis Peralta

Name	Status	%of time in project
Alina Louro	PhD student (LIP)	80
Ana Campos	Master student (FCUL)	50
Conceição Abreu	Researcher (LIP)	50
Florbela Rego	Researcher (LIP)	80
Jorge Sampaio	Researcher (CFA/FCUL)	20
Luis Peralta	Researcher (LIP/FCUL)	80
Marta Dias	Master student (FCUL)	20
Patrick Sousa	Researcher	20
Pedro Gabriel Almeida	Researcher (UBI)	20
Rui Carvalhal	Graduate student (LIP)	30
Sandra Soares	Researcher (LIP/UBI)	80
Sónia Dias	Master student (FCUL)	20
Yoenls Bahu	Master student (FCUL)	100

5.3.5 Academic Training

PhD Theses

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

Master Theses

- *Estudo da atenuação da radiação ionizante em materiais heterogéneos usados na construção de barreiras de proteção radiológica*
  Sónia Dias, (on-going)
- *Simulação Monte Carlo de um sistema de tratamento de braquiterapia intra-uterina*
  Ana Campos, (on-going)

5.4 Orthogonal Ray Imaging for Radiology and Radiotherapy

5.4.1 Resumo

O LIP e a Universidade de Coimbra converteram o registo provisório de patente submetido ao INPI (Instituto Nacional da Propriedade Industrial) no ano anterior em pedido de patente internacional. O pedido de patente 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. Novos resultados de simulação (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). A dose no alvo/paciente é potencialmente muito reduzida.
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 Orthogonal Ray Imaging 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), o Serviço de Radioterapia dos Hospitais da Universidade de Coimbra, a Universidade Técnica de Delft na Holanda (TU Delft), e o HIT (Centro de Radioterapia com Partículas de Heidelberg) na Alemanha.

5.4.2 Abstract

Last year´s provisional patent application, submitted to INPI (Instituto Nacional da Propriedade Industrial) by LIP, has been converted by the University of Coimbra in an international patent request. The patent addresses 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.). The simulations also show that these results are obtained with a very small dose.
Prior to engaging into OrthoCT, our team has also proposed and equally verified experimentally that such orthogonal ray 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 Orthogonal Ray Imaging, 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 Department of Radiotherapy of Coimbra University Hospitals, Delft University of Technology (TU Delft) in The Netherlands, and the Heidelberger Ionenstrahl-Therapiezentrum (HIT) in Germany.

5.4.3 Objectives

We are showing by Monte Carlo simulation the potentialities of RTmon and OrthoCT in real treatment-like scenarios. For example, the capability of RTmon to follow both the breathing cycle as well as tumor swelling/shrinking in radiotherapy is being addressed. First results seem encouraging.

5.4.4 Team

Project coordinator: Paulo Crespo

Name	Status	%of time in project
Hugo Simões	Master (LIP/FCTUC)	25
Patrícia Cambraia Lopes	PhD student (LIP/TU-Delft/FCT)	100
Paulo Crespo	Researcher (LIP/FCTUC)	50

5.4.5 Academic Training

PhD Theses

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

5.5 Adaptive methods for medical imaging with gamma cameras

5.5.1 Resumo

A Cintilografia e a Tomografia Computorizada de Emissão por Fotão Único (SPECT) são as duas modalidades de imagiologia médica mais usadas. Em ambos os casos o detector de radiação usado é a Câmara Gama, que tipicamente consiste num cristal cintilador acoplado ópticamente a uma matriz de fotomultiplicadores (PMTs) e num colimador que projecta no cintilador a distribuição de um marcador radioactivo no corpo do paciente. As posições de interacção de cada um dos raios gama no cintilador são reconstruídas a partir da distribuição da luz na matriz de PMTs.
A posição de interacção é normalmente determinada usando uma versão modificada do algoritmo do Centro de Gravidade (CdG) originalmente proposto por Anger em 1958. Este algoritmo é ainda amplamente usado apesar de algumas desvantagens, como a não linearidade da imagem reconstruída (distorção), em especial na periferia do cintilador, ou a incapacidade de distinguir entre eventos únicos e multiplos. Alternativamente ao CdG existem algoritmos que usam uma aproximação estatística, como o da Verosimilhança Máxima (VM) ou o dos Mínimos Quadrados pesados (MQ). Estes algoritmos não sofrem das desvantagens atrás mencionadas para o CdG, mas requerem um conhecimento detalhado das Funções de Resposta à Luz (FRL) para cada um dos PMTs, que são difíceis de medir.
Outra problema serie relacionado com a operação das Câmara Gama é a deriva, ao longo do tempo, do ganho dos PMTs e das propriedades de colecção de luz dos diversos elementos ópticos. Este problema é actualmente mitigado de duas formas:
- desenvolvimento (pelos fabricantes) de sistemas automáticos de monitorização e ajustamento do ganho dos PMTs;
- recalibração regular (pelo pessoal médico) seguindo procedimentos bens definidos;
Apesar do considerável esforço dos fabricantes em I&D para a automatização dos sistemas, continuam a ser necessárias recalibrações frequentes pelo pessoal médico para manter a qualidade das imagens.
No decorrer da nossa investigação, desenvolvemos um método para reconstrução das FRL e determinação do ganho relativo dos PMTs num detector de cintilação usando dados de calibração obtidos com fontes de raios gama não colimadas. É de salientar que para este método não é essential que a fonte de calibração seja mono-energética ou isotrópica, mas apenas que o detector seja irradiado na totalidade. Tencionamos aplicar este método ao problema de determinação da posição e monitorização automática dos ganhos em câmaras gama. Com isto pretendemos:
- desenvolver a tecnica de reconstrução dos FRLs e assim fazer os métodos estatísticos para determinação de posição através mais atraentes;
- possibilitar a determinação dos factores de ajuste dos ganhos dos PMTs usando os dados adquiridos para a própria reconstrução da imagem;
- simplificar os procedimentos de recalibração regular e de determinação de qualidade. Adicionalmente, como os métodos estatísticos fornecem informação acerca incompatibilidade entre o modelo e os dados, será possivel a monitorização automática da qualidade da reconstrução da imagem.
Presentemente, existem membros da nossa equipa que participam activamente em projectos baseados em detectores de cintilação sensíveis à posição de interacção:
- Câmaras de duas fases de xénon líquido para detecção de matéria negra (colaborações ZEPLIN-III e LUX);
- Câmaras Anger de cintilação de gas para detecção de neutrões (colaboração FP7 NM13-WP22);
Em ambos os casos, o principio subjacente é semelhante à câmara gama – a luz de cintilação é detectada por uma matriz de PMTs e a posição de interacção é determinada usando a distribuição de luz.
Desde 2004 que o nosso grupo vem desenvolvendo métodos para estimar a posição e deposição de energia em câmaras de cintilação usando xénon líquido, tendo por isso desenvolvido as competencias necessárias para a resolução do problema acima.
Neste projecto tencionamos extender a aplicabilidade dos algoritmos adaptativos para estimar a posição de interacção – desenvolvidos pela nossa equipa no âmbito de detectores de matéria negra baseados em xénon líquido e detectores de neutrões usando câmaras Anger – a câmaras gama para uso médico.
Apesar de os principios básicos de funcionamento serem comuns a estes três tipos de detectores, a extensão destes algoritmos não é trivial. Enquanto que nos primeiros a luz é gerada por cintilação secundária limitada a um plano (2D), no caso da câmara gama para uso médico a luz de cintilação primária é gerada no interior do cristal (caso 3D).
Este projecto está dividido em quatro tarefas:
- Desenvolvimento e um módulo de simulação Monte Carlo (MC)
- Desenvolvimento dos algoritmos de reconstrução baseados na FRL, e software associado.

- Usar um arranjo experimental dedicado (constituído por uma fonte de luz isotrópica e uma matriz de PMTs) para emular uma câmara gama.
- Efectuar testes usando câmaras gama reais, incluindo uma câmara gama para I&D existente no ICNAS

5.5.2 Abstract

Scintigraphy and Single Photon Emission Computer Tomography (SPECT) are the two most widely used modalities of functional medical imaging. Gamma camera, a radiation detector used for both of these modalities, typically consists of a scintillator crystal optically coupled to an array of photomultiplier tubes (PMT) and a collimator that projects the distribution of a radiotracer in the patient´s body onto the scintillator. The positions of individual gamma-ray interactions in the scintillator are found from the distribution of the scintillation light across the PMT array.
To determine the position of an interaction, a modified version of the Centre of Gravity (COG) algorithm originally proposed by Anger in 1958 is still widely used despite several drawbacks, such as the image nonlinearity (distortion) especially on the periphery of the scintillator and inability to discriminate between single and multiple events. As an alternative to COG, there are algorithms that use statistical approach, such as Maximum Likelihood (ML) and weighted Least Squares (LS). These algorithms do not suffer from the drawbacks mentioned above, but require detailed knowledge on the light response function (LRF) for each PMT which is difficult to obtain.
Another major problem related to the operation of gamma cameras is the drift of PMT gains and light collection properties of the optical elements over time. This problem is currently mitigated using two approaches:
- development of automatic systems for gain monitoring and adjustment by the manufacturers;
- regular re-calibration according to well-defined procedures by the medical staff.
Despite the considerable R&D efforts pursued by the manufacturers along the first approach, frequent re-calibration is still required to maintain the image quality.
We have developed a method for reconstruction of the LRFs and determination of the relative PMT gains in a scintillation detector from the calibration data obtained with a non-collimated gamma source. The constraints on the isotropy of emission and energy spectrum of the calibration source are quite mild, it is only essential that the whole detector is irradiated. Our intention is to apply this method to the image reconstruction (including automatic gain monitoring) in gamma cameras. If successful, this will:
- provide a reliable technique of obtaining LRFs which will make statistical methods of position estimation much more attractive;
- make it possible to extract the actual gain factors of the PMTs during the image reconstruction;
- simplify regular calibration and quality assessment procedures for gamma cameras. Additionally, since the statistical methods provide information on the deviation of the measured PMT signals and ones reconstructed using LRFs, it will be possible to implement procedures of automatic quality control.
Several members of our team are currently participating in projects exploiting position-sensitive scintillation detectors:
- liquid xenon dual phase dark matter detectors (ZEPLIN-III and LUX projects)
- gas scintillation Anger camera neutron detectors (FP7 NMI3-WP22 collaboration).
In both cases, the underlying principle is similar to that of a gamma camera - the scintillation is detected by a PMT array and the event position is found from the distribution of the PMT signals. Our group has been working on the problem of position and energy estimation in liquid xenon scintillation cameras since 2004, therefore, we have expertise to solve the problem described above.
In this project, we are going to extend applicability of adaptive algorithms for event position estimation, developed by the team for liquid xenon dark matter detectors and Anger camera neutron detectors to medical gamma cameras. While the basic principles of operation of these three types of detectors is similar, this extension is not straightforward since in the former two types of the detectors the light was generated in secondary scintillation limited essentially to a 2D plane whereas in medical gamma cameras the primary scintillation light is generated in the bulk of the crystal (3D case). Four tasks will be executed in the framework of this project:
- Development of a Monte Carlo simulation module that will provide a "sandbox"for the development and testing of adaptive position estimation algorithms. The module will also serve as a powerful tool for design of new gamma cameras.
- Development of light response reconstruction algorithms and associated software.
- Emulating a gamma camera using a dedicated workbench with isotropic light source and array of photomultipliers to test the reconstruction algorithms in well-controlled environment.
- Tests with real gamma cameras, including a research gamma camera at ICNAS and a small scale gamma camera which we are going to design using our MC simulation package.

5.5.3 Objectives

The main goal of this project is to extend applicability of adaptive algorithms for event position estimation, developed by the team during work on two-phase dark matter detectors with optical readout and anger camera neutron detectors to medical gamma cameras. While the basic principles of operation of these three types of detectors is similar, this extension is not straightforward since in the former two types of the detectors the light was generated in secondary scintillation limited essentially to a 2D plane whereas in medical gamma cameras the primary scintillation light is generated in the bulk of the crystal (3D case).

As the first step we plan to perform detailed Monte Carlo simulations of gamma camera and use the obtained results as the input data for the adaptive reconstruction algorithms. Due to the flexibility of the detector design in MC simulations, this approach offers an excellent "sandbox"for development of the algorithms: in this way the performance and robustness of the algorithms can be established and the requirements on the minimum sample size and any limitations on the detector parameters can be established. As the next step we intend to verify performance of the algorithms on a dedicated gamma camera emulation setup in which the crystal is replaced with a well characterized uniform light source (submillimeter size). The light will be collected by an array of PMT like in traditional gamma cameras. As the final step, we intend to verify adaptive algorithms using raw data collected at real gamma cameras: a commercial gamma camera of a traditional design (the only modification is the ability to read raw data from PMTs) and a self-made small-scale gamma camera utilizing modern photo-detector (SiPM).

The research plan comprises four tasks. First a dedicated Monte Carlo simulation module for gamma cameras will be developed (Task 1). The group possess practical experience with this type of software development (see e.g. [5] which reports on ANTS - a MC simulation package for anger camera neutron detectors). Work on this task will be organized in two phases: In the first phase only the minimum required functionality of the MC module will be created in order to interface it with the module developed in Task 2, which performs estimation of the detector response and event localization. Then, in the second phase the MC module will be upgraded to include all relevant physical and technical aspects of realistic gamma cameras.

Task 2 is dedicated to the development and optimization of the adaptive position estimation algorithms for gamma cameras. In part, the algorithms can be inherited from the previous work but since the extension involves transition from 2D emission plane to 3D crystal bulk, we must allocate time for proper formalization and optimization of the strategy of practical realization. This work will be done while the Task 1 is progressing in the first phase, and as soon as the MC module will generate event data, a study of the performance of the algorithms can be started. The algorithms will be characterized by the difference between the estimated response of the photodetectors as well as the event locations compared to the actual response/locations used in the simulations.

In Task 3 the performance of the algorithms will be investigated with the data provided by the Anger camera evaluation workbench which is under development since October 2010 by a member of the team (Luis Pereira) in the framework of his PhD studies. The workbench utilizes a fully characterized sub-millimeter size isotropic light source mounted on a precision XYZ table and an array of PMTs to collect the light. Using the data obtained in this setup it is possible to test the algorithms in a very controllable environment where several physical and technical aspects relevant for gamma cameras can be adjusted in a broad range (e.g. position of the source, detector geometry, number of photons per pulse, scattering/reflective properties of the boundaries etc). Since the position of the source is known to high precision and the detector response can be accurately measured, validation of the reconstruction algorithms can be easily performed.

The second step in verification of the algorithms will be performed with real gamma cameras (Task 4). Due to cooperation with ICNAS we will have access to a commercial gamma camera used for research. It is planned to perform necessary modifications of this camera to be able to extract raw PMT signals in the digital form by implementing a CAMAC-based read-out system. This step will allow to implement fully the adaptive reconstruction algorithms to the data recorded with the camera. Also, a small scale gamma camera equipped with a modern SiPM sensor will be build. The design of the camera will be similar to one presented in [Maj11] for endorectal prostate imaging. The choice of the crystal and geometry will be made based on the results of MC simulations performed with the software package developed in this project in order to maximize effectiveness of the adaptive reconstruction algorithms. Due to the modular design of SiPMs, the results obtained with this small scale device will be also extendable to large area gamma cameras.

5.5.4 Team

Project coordinator: Vladimir Solovov

Name	Status	%of time in project
Alessio Mangiarotti	Researcher (LIP)	20
Alexandre Lindote	Post-Doc (LIP)	20
Andrey Morozov	Researcher (LIP)	50
Filipa Balau	PhD student (LIP)	50
Francisco Fraga	Researcher (LIP/FCTUC)	15
Francisco Neves	Post-Doc (LIP)	20
Isabel Lopes	Researcher (LIP/FCTUC)	20
Luís Pereira	PhD student (LIP)	30
Vitaly Chepel	Researcher (LIP/FCTUC)	30
Vladimir Solovov	Researcher (LIP)	50

5.6 Rad for Life

5.6.1 Resumo

"Rad for Life"(Radiação para a Vida), é um projecto submetido pela Universidade de Coimbra em parceria com o LIP. Financiado com cerca de 1 milhão de Euros pelo QREN Mais Centro, este projecto com uma extensão de até 30 meses a iniciar em 1 de Julho de 2013, visa explorar aplicações à área da saúde – nomeadamente na imagiologia e na monitorização e controlo de radioterapia – de tecnologias de detecção de radiação surgidas na Física de Partículas.
De facto, nas experiências de Física de Partículas e no longo trabalho de I&D levado a cabo pelas equipas do LIP, tem-se desenvolvido uma série de tecnologias e arquitecturas que provaram ter amplo potencial de aplicação em áreas de interesse para a sociedade, nomeadamente na saúde e na segurança.
Contemplando a contratação de seis doutorados – um deles como Professor Auxiliar da FCTUC – o projecto "Rad for Life"irá permitir, neste período de grandes constrangimentos, manter uma equipa capaz de potenciar algumas das linhas de trabalho científico que têm vindo a ser seguidas pelo LIP, criando condições para progredir em diversas frentes:

- Aplicação à PET (Tomografia por Aniquilação de Positrões) de detectores de placas resistivas (RPC), com o desenvolvimento e teste de protótipos de scanners de PET-Animal e de PET-Humano;
- Exploração em SPECT (Single Photon Emission Computed Tomography) dos avanços conseguidos nas técnicas de localização da interacção de fotões em meios cintiladores;
- Desenvolvimento de técnicas inovadoras de monitorização (e melhoria de eficácia) da radioterapia e estudo de novos dosímetros à base de fibras de cintilantes;
- Aplicações de detectores gasosos de xénon a alta pressão e com grande área de detecção aos campos da saúde e da segurança.

5.6.2 Abstract

"Rad for Life"(Radiation for Life), is a project submitted by the University of Coimbra in partnership with LIP. Funded by QREN Mais Centro in about 1 M€, this project with a duration of up to 30 months starting from July 1st, 2013, aims at exploring applications to the biomedical area – namely imaging and radiotherapy control and monitoring –radiation detection technologies emerging from Particle Physics.
Indeed, in the Particle Physics experiments and long and reknown R&D work carried on by the LIP-Coimbra teams, a series of detection technologies and architectures have been developed which are potentially beneficial in areas of general interest for society, particularly in health and in homeland security. In a period of great financial constraints "Rad for Life"will allow the contract of six PhDs, one of them in a position of Assistant Professor at the University of Coimbra, thus maintaining a team capable of enhancing some lines of work that have been successfully followed by LIP and creating conditions for progressing in various fields:

- Application to PET (Positron Emission Tomography) of resistive plate detectors (PRC), through the development and test of prototype scanners for animal and human PET;
- Exploring in SPECT (Single Photon Emission Computed Tomography) progresses made in techniques for localization of the interaction point of photons in scintillators;
- Developing innovative techniques for monitoring (and improving the effectiveness) of radiotherapy and for studying new dosimeters based on scintillating fibers;
- Applications of high pressure and large area gaseous xenon detectors to homeland security.

5.6.3 Objectives

It is the consortium´s conviction that the scientific program of this research line speaks for itself. Radiation detection is one of the most dynamic fields in physics today, as a necessary tool to probe the most intricate details of energy and matter in sophisticated High-Energy and Particle Physics. CERN is the world´s leading institution in this field, and LIP is the institution that coordinates the Portuguese participation in the organization. As an active member of the Particle Physics community,, LIP has been developing some of the most challenging detection devices in landmark experiments such as ATLAS, CMS, and COMPASS, but also in experiments elsewhere, from GSI (HADES) to SNO, ZEPLIN, LUX and, recently, AUGER. In the course of

those experiments, LIP has developed a number of technologies and architectures that have proven to have a wide potential of applications in other areas of society. Of particular interest are the areas of healthcare and national security.
In the course of the Rad for Life proposal, LIP will show the large body of scientific work that has been done in the fields of RPC detectors and their application to PET imaging, improved photon localization for SPECT, new monitoring techniques for radiotherapy and fiber-based scintillation dosimeters, and high pressure xenon detectors. Their applications to different fields of healthcare and national security will be discussed, along with the prototypes that LIP plans to build around those detectors.
LIP is a Portuguese recognized Associated Laboratory, and it has consecutively received an evaluation of Excellent in the four evaluations by teams of international evaluators commissioned by the Portuguese Science and Technology Foundation to assess the level of excellence of the Portuguese research entities. With over 200 people in total, of which about 80 hold a PhD, LIP is one of the most vibrant research institutions in Portugal, with an impressive body of published articles in all the leading journals in the fields of Particle Physics and associated technologies (e.g., radiation detectors, data acquisition and control electronics, advanced computing or medical physics). LIP papers are often cited by leading research teams in the field, and the lab is often invited to participate in world class experiments in high-energy physics, astroparticle physics, physics of rare events, and application of technologies to medicine.
The Rad for Life program is well within the capabilities of the LIP groups involved in the research since it is part of an ongoing program with very encouraging early results. Most of the component parts that will be part of the final prototypes have already been lab tested with very good results. Furthermore, a lot of the technology was first developed for particle physics experiments, where it has been thoroughly tested. So, it is safe to say that the most expensive part of the research has been done, and it is now a matter of reaping the benefits of that research towards real world applications. It is thus, for the most part, an integration work, which, while important and human-intensive, is not expected to hold many surprises. Given that most of the capital investment in components, devices, laboratories, and a clean room has already been invested in the course of past programs, the project does not have any significant capital investments. The requested funding is, for the most part, meant to hire highly qualified human resources, at standard rates in the Portuguese scientific system. With the help of the University of Coimbra´s budget participation, it is expected that those new jobs can be kept well beyond the end of the program.
The economic and social valuation of the knowledge developed in the course of the Rad for Life project is a strongest point. Given LIP´s extensive body of knowledge in the field of detectors, it would be unethical not to transfer the benefits of that knowledge to society as a whole, trough applications to Healthcare and National Security.
Healthcare is one of the leading concerns of modern societies, given the rapidly ageing population, the increasing number of chronic diseases, and the rampant cost overruns of most health systems. Modern imaging systems, while proving invaluable in the early detection of serious health conditions, have become a major source of expend, stressing many national health budgets. A good example is the PET scanner, where installation costs alone can exceed over 5 million Euros. LIP´s contribution has the potential to substantially reduce the cost of a complete setup, while improving the resolution and allowing, for the first time, a whole-body exam to be performed.
On the national security side, terrorism prevention has been a leading concern in the whole world during the last decade. One of the most common nightmare scenarios is the free circulation of radioactive materials across the world, leading to the creation of so-called dirty bombs and, in a worst-case scenario, the deployment of a nuclear explosive device. The development of large scale sensors capable of being deployed in the form of portals where passengers, luggage, and even container trucks can go through is a major breakthrough that will allow a more effective monitoring and the prevention of illegal transportation of radioactive sources.
The Rad for Life project will be responsible for the direct creation of 6 new highly-skilled scientific positions (for PhDs). Due to LIP´s protocol with the University of Coimbra, at least one position of "Professor Auxiliar"(Assistant Professor) will extend beyond the time frame of the project, thus giving rise to a medium to long-term scientific career. LIP routinely hires new researchers from the international scientific market, with existing researchers coming from as far away as Russia, Spain, Brazil, Germany, and Italy. The job creation allowed by the Rad for Life project, however, is not limited to the six new positions. Because it is the stepping stone towards other scientific projects to be submitted at the European level, we expect it to have a multiplying factor along the next 5 years.
Furthermore, the project is meant to have an exploitation phase after the prototypes are completed, and that phase will be done in cooperation with other Portuguese companies, namely ISA-Intelligent Sensing Anywhere. It is thus expected to foster new economic activity in the region and give rise to a number of new highly skilled jobs. As an example, in the past 5 years, ISA has created over 50 new highly qualified jobs as a result of the exploitation partnerships it has established with other research groups.

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 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

The 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

In 2013 we will continue to work to fulfill our commitments towards the collaboration.
For WG2-T2, the large review paper in RPC physics will be published.
For WG3 the construction of a first prototype of the animal RPC-PET scanner will be terminated and tested.

6.1.4 Team

Project coordinator: Rui Marques

Name	Status	%of time in project
Américo Pereira	Technician (LIP)	15
António Gonsalves	Researcher (FCTUC)	15
Carlos Silva	Technician (LIP)	15
Joaquim Oliveira	Technician (LIP)	15
Luís Lopes	Technician (LIP)	15
Marta Gomez	Researcher (FCTUC)	15
Nuno Carolino	Technician (LIP)	15
Nuno Filipe Silva Dias	Technician (LIP)	15
Orlando Cunha	Technician (LIP)	15
Paulo Fonte	Researcher (LIP/ISEC)	25
Paulo Martins	PhD student (LIP/FCT)	70
Ricardo Caeiro	Technician (LIP)	15
Rui Alves	Technician (LIP)	15
Rui Marques	Researcher (LIP/FCTUC)	35
Sílvia Alexandre	Technician (FCTUC)	15
Susete Fetal	Researcher (LIP/ISEC)	20

6.1.5 Academic Training

PhD Theses

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

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 0º, 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 Universidade 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 0º. 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 (γ,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

Approaching the global aim of thist project, triggered by the future NeuLAND detector, the evaluation of the new concept of a detection system for neutrons with kinetic energy of the order of 1 GeV based on RPC will be completed.
Following the simulation studies carried out (by our Lisbon collaborators) essentially during the first year of the project, the prototypes were built in Coimbra during 2012 and were then tested in beam at GSI (experiment S406) in November.
The final evaluation of results, already under way, will be accomplished during the third year of the project. Furthermore, these final results will be published.

6.2.4 Team

Project coordinator: Rui Marques

Name	Status	%of time in project
Alberto Blanco	Researcher (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

Recentemente, a procura de detectores de neutrões para aplicações de segurança causou um severo esgotamento do estoque existente de 3He e um aumento de custo por um fator de 25. As palavras-chave na evolução de detecção de neutrões são agora "alternativas"3He
Em 2012, apresentámos um projeto para pedido de finaciamanto à FCT "RPCs revestidas a boro para detectores de neutrões térmicos "EXCL/FIS-NUC/0389/2012. O objectivo desta proposta é o desenvolvimento de tecnologias de detecção novos baseados em câmaras de placas resistivas para detectores de neutrões térmicos utilizando conversores sólidos. A principal ênfase está nos detectores de imagem de grande área (da ordem dos metros quadrados), com resolução média ($\approx$ 3 mm) a ser utilizado em experiências de espalhamento. Nestes detectores são normalmente utilizados tubos de alta pressão de 3He e não há actualmente substituição possível para estes.
Pelas suas características, é um projeto prospectivo, combinando duas tecnologias conhecidas para resolver um problema existente em imagens de neutrões térmicos causados pela escassez de 3He.
O projeto foi avaliado como outstanding em três critérios com valor de ponderação de 90% e Excelente em único item de ponderação 10% pelos avaliadores internacionais da FCT, mas não foi financiado. Pedimos uma reavaliação da decisão e aguardamos a decisão.

6.3.2 Abstract

Recently the demand of neutron detectors for security applications caused a severe depletion of the existing 3He stockpile and a cost increase by a factor of 25 , from 80 €/l up to 2000 €/l. The key words in neutron detection developments are now "3He alternatives"
In 2012 we submitted a project to the FCT "Boron coated RPCs for thermal neutron detectors"EXCL/FIS-NUC/0389/2012. The aim of this proposal is the development of new detector technologies based on Resistive Plate Chambers for thermal neutron detectors using solid converters. The main emphasis is in large area (over a square meter) imaging detectors, with medium resolution ($\approx$3mm) to be used in scattering experiments. These detectors typically used high pressure 3He tubes and there is no possible replacement for them.
For its characteristics, it is a prospective project, combining two known technologies to solve an existing problem in thermal neutron imaging caused by the shortage of 3He.
The project was evaluated as Outstanding in three criteria weighting 90% and Excellent in a single item weighting 10% by the FCT international reviewers, but was not funded. We asked for a re-appraisal of the decision.

6.3.3 Objectives

The project is split in two tasks:
Task 1 Design and assembly of a prototype RPC with a 10Bo solid converter with an area of 10x10cm2 (active area 7x7cm2) . We will evaluate the current designs and materials existing at LIP to choose a few candidates to build three small size prototypes for this study. A simulation will be carried in GEANT of the neutron capture efficiency, gamma rejection and neutron scattering in the detector.
The 10Bo coating will be carried at one the known current facilities have experience in this operation that have reported good results in a recent conference – either the Linköping University, the CERN workshop or Helmholtz-Zentrum Geesthacht, Centre for Materials and Coastal Research, GKSS. However, considering the small size and the prospective characteristic of this work we will also ask local institutions carrying research in materials with facilities for material deposition using RF sputtering or low pressure vapour deposition techniques such as Laboratório de Filmes Finos of the Departamento de Engenharia Mecânica, Universidade de Coimbra, or GRF Functional Coatings Group, CFUM-Center of Physics from University of Minho, for the possibility carrying this work locally.
Task 2 Data taking and analysis at detector experiments carried with sources and at neutron beams. Three aspects should be addressed in these studies. The neutron efficiency and space resolution will be tested in the LIP laboratory using an AmBe neutron source and cadmium masks. Readout will be carried using the existing CAMAC system. The gamma rejection will be studied using gamma laboratory sources of 60Co, 133Ba and 137Cs using the standard procedure used at the ILL Grenoble. All these results depend on the gain of operation of the device and a systematic study of their variation versus gain must be carried.
In order to measure the neutron scattering in a multilayer detector at less two RPC modules have to be build and should be taken to a beam line at the ILL Grenoble. We will have the support of the Detector Development Group of the ILL for a short test, and we will use their development technical line for some short tests using high rates.

The two tasks outlines will be carried in an interactive way. The RPC assembly is simple, cheap and rugged enough to allow changes in the design of a detector in a fast and uncompromised way.
Deliveries At the end of this project we should have a report with the values for efficiency, dead time, resolution, gamma sensitivity and uniformity of the prototypes. The results will be presented at one Conference and published in appropriate scientific journals with referee.

6.3.4 Team

Project coordinator: Francisco Fraga

Name	Status	%of time in project
Andrey Morozov	Researcher (LIP)	50
Francisco Fraga	Researcher (LIP/FCTUC)	50
Luís Pereira	PhD student (LIP)	100
Margarida Fraga	Researcher (LIP/FCTUC)	10
Paulo Mendes	Researcher (LIP/FCTUC)	20
Rui Marques	Researcher (LIP/FCTUC)	10

6.4 Gamma-Ray Polarimetry with Fermi and DUAL Space Missions

6.4.1 Resumo

Desenvolvimento de um polarímetro para futuras Missões Espaciais

Em 2012 o nosso grupo prosseguiu o desenvolvimento de um plano focal de CdZnTe (CZT) optimizado para a observar emissões polarizadas de raios gama no espaço que devera ser submetida à próxima chamada do programa Cosmic Vision da ESA. 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. O desenvolvimento de sensores para ambiente espacial requer uma série de teste progressivos até à sua qualificação pela ESA. Nesse âmbito tem vindo a ser 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.

Desenvolvimento do instrumento principal da Missão XIPE

A 15 de Junho de 2012, o nosso grupo integrou a proposta XIPE (X-ray Imaging Polarimetry Explorer) submetida ao concurso para missões S (small missions) da ESA. O nosso contributo para a missão centra-se no desenvolvimento do instrumento principal, constituído por Contadores Gasosos Pixelizados (GPD: Gas Pixel Detectors), em particular na optimização das misturas gasosas (Xénon, Árgon, etc.) tendo em vista a realização de medidas polarimétricas baseadas no efeito fotoeléctrico. O estudo deste instrumento tem vertentes teóricas e experimentais. Foram por nós estudadas através de um programa de simulação pelo Método de Monte Carlo baseado em Fortran, as prestações polarimétricas em função da energia (até 20 keV) de um GPD com Xénon a uma atmosfera. Análise dos dados obtidos permitiu-nos concluir que as potenciais prestações polarimétricas deste tipo detectores são compatítiveis com as exigências de sensibilidade de instrumento a ser enviado para o espaço. Do ponto de vista experimental, testámos um GPD com xénon a uma atmosfera irradiado por uma fonte de radiação polarizada entre os 5 e os 15 keV, tendo sido obtidos resultados que, dentro da margem de erro experimental, verificam os resultados obtidos nas simulações.

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 a space gamma-ray observatory equiped with Laue lens. 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: 10ˆ-6 photons/(cmˆ2.s.keV) detection sensitivity between 100 keV and 1 MeV, energy resolution of $\approx$1% and minimum detectable polarization $< 1\%$ for a Crab source equivalent and for 10ˆ-6s.

XIPE mission main instrument development

XIPE (X-ray Imaging Polarimetry Explorer) mission proposal was submitted to ESA call for S missions by June 15th, 2012. Our group will contribute to the main instrument development composed by GPD (Gas Pixel Detectors), specifically in the gaseous mixtures optimization (Xénon, Árgon, etc.) for photoelectric based polarimetry. Instrument development will be performed both by experimental and simulation work. Up to the present a Fortran Monte Carlo simulation program was developed that allows to analyse the polarimetric performances of a GPD filled with Xenon at 1 atmosphere up to 20 keV. The preliminary results show that

the performances of this type of detectors are potentially compatible with XIPE mission requirements. Experimentally, a GPD filled with xenon at one atmosphere was tested under a partially polarized X-ray beam in an energy range between 5 and 15 keV. The results obtained are in agreement with the results obtained in the performed simulations.

6.4.3 Objectives

Even though XIPE mission was select by ESA, it was a top three ranked mission. Therefore, the development of a GPD instrument to observe the X-ray polarization of celestial objects will be pursued since the next ESA call for S missions proposals will occur by 2015.
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 be developed and tested.

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 Academic Training

PhD Theses

- *Simulations of Mass Models of Gamma-Ray Detectors*
  Colin Paul Gloster, (on-going)
- *Experimental CdTe Polarimeter development*
  José Marques, (on-going)

6.5 High Pressure Xenon Doped Mixtures for the NEXT Collaboration

6.5.1 Resumo

A Colaboração Internacional NEXT (Neutrino Experiment with a gas Xe Time Projection Chamber) Envolve maisde 50 investigadores de 9 instituições diferentes, incluindo 6 investigadores do LIP-Coimbra.
O objectivo da experiência NEXT é a detecção do deacimento beta duplo sem neutrinos do Xe-136 (para determinar se o neutrino é uma partícula Majorana) através da identificação do pico no final do espectro de decaimento beta duplo e, simultaneamente, medir a vida média do deacimento.
O método experimental é baseado na medida do rendimento de electroluminescência (também chamada de cintilação secundária ou proporcional) de modo a obter uma resolução em energia inferior a 1% para a detecção do pico de 2,547 MeV correspondente à soma das energias dos dois electrões numa Time Projection Chamber (TPC) de grandes dimensões com xenon a 20 atm.
Há um conjunto de assuntos para os quias uma decisão ainda não foi tomada e que requerem investigação, alguns dos quais fora atribuídos à nossa equipa. Um deles é a questão de escolher entre Xe puro, para o qual o tracking dos electrões é limitado por baixas velocidades de deriva e elevados coeficientes de difusão, e Xe dopado com gases moleculares como TMAE, CH4, CF4, N2 ou outros gases cuja adição pode aumentar a velocidade de deriva e minimizar a difusão e eventualmente agir como conversor de corrente de comprimento de onda, sem, no entanto comprometer significativamente o rendimento de electroluminescência (EL) e suas flutuações, comparadas com xenon puro.
Coeficientes de difusão baixos e elevadas velocidades de deriva, são altamente desejáveis já que os electrões vão deslocar-se grandes distâncias de deriva (1m) até chegar á região de electroluminescência da TPC. Baixa taxa de recombinação e de attchmente são também desejáveis e terão de ser avaliados. Foi projectado um sistema que albergará os dois detectores que trabalharão em paralelo permitindo confirmação independente dos fenómenos observados.

6.5.2 Abstract

The NEXT (Neutrino Experiment with a gas Xe Time Projection Chamber) International Collaboration involves more than 50 researchers from 9 different institutions, including 6 researchers from LIP-Coimbra. 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 experimental method is based on the measurement of the electroluminescence (also called proportional or secondary scintillation) yield, 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 20 atm. There are a number of issues that are still open to discussion, which require further some of which have been assigned to this team. One of 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 TMAE, CH4, CF4, N2 or other gases, whose addition may improve electron drift velocity and minimize electron diffusion, and eventually act as a wavelength shifter without jeopardizing electroluminescence (EL) yields and their fluctuations 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 and needs also to be assessed. We have projected a system where two detectors will be connected. These detectors will work in parallel allowing for an independent cross checking of the phenomena observed.
Work carried out:
- Design, construction and assembly of the detectors (gas proportional scintillation counter and proportional counter) and gas system (with purification) where both detectors are connected;
- purifications systems fully assembled and tested.
- Test of gas system and detectors;
- Results with detectors.
- Calibration of both detectors.
The experimental set-up is now fully tested and calibrated for pure gases. he system has two set of purifiers: one to use with pure noble gases and the other to use with molecular gas mixtures.
In order to study fluctuations in the electroluminescence of mixtures of Xe and CH4 and CF4 (potential candidates for the Xe based mixtures) and compared them to the fluctuations in pure Xe, Monte Carlo simulations have been performed. The electroluminescence performances in cylindrical and planar geometry were also studied. The simulation studies have already been published.

The Master Degree thesis of Alexandre Garcia has been submitted.
During the last months of 2012 and in 2013 we will be performing measurements with different mixtures considered plausible candidates. There are other fields of investigation related to the present work (high pressure and external electric fields) that we intend to pursue, either within the scope of this project or in a following one, already submitted to FCT.

6.5.3 Objectives

Since the experimental set up is complete, tested and fully working, with two different types of gas purifiers to use in pure gases and in mixtures with molecular gases, and both detectors also fully working (gas proportional counter and gas proportional scintillation counter), the objectives for this final period of the project are to finish all the experiments proposed. Namely, experiments with the gas mixtures have already begun and are in good progress. The purpose of these experiments is to assess the influence of the very low concentration molecular additive in the scintillation yield at different total gas pressures. Molecular additives are CF4, CH4 and TMA. The first gas beeing tested is CH4, whose behaviour at moderate concentrations is known, in order to have a guideline. CF4 will follow and in the end TMA.

6.5.4 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

6.6 Ion Transport Processes in Gaseous Detectors for Particle Physics

6.6.1 Resumo

O estudo do transporte de iões em gases continua a ser um tema com muito interesse para diversas áreas, como a área dos detectores gasosos de radiação, nomeadamente os detectores para física das altas energias. Nos detectores gasosos de radiação baseados em processos de avalanche, a amplitude do impulso do sinal de saída tem duas componentes, uma devida à deriva dos electrões, e outra devida à deriva dos iões. Embora a velocidade de deriva dos iões seja muito menor do que a dos electrões, a sua contribuição para a formação do impulso induzido é frequentemente predominante. Geralmente, é apenas considerado um único tipo de ião, mas muitas vezes, para misturas gasosas do tipo gás nobre/gás molecular utilizadas em detectores para física das altas energias, mais do que um tipo de ião tem que ser considerado no processo de deriva.
O presente projecto tem duas componentes principais:

1. Cálculo teórico de secções eficazes integrais e diferenciais de colisão elástica ião-átomo/molécula e cálculo dos parâmetros de transporte dos iões utilizando técnicas de Monte Carlo.

2. Introduzir melhorias num sistema experimental já existente, baseado em técnicas originais desenvolvidas por investigadores da equipa para a medição de mobilidades de iões em gases, de modo a possibilitar a medida da mobilidade com maior resolução temporal, e a sua utilização para a identificação dos iões presentes.

No que diz respeito aos cálculos teóricos, e na sequência do trabalho anteriormente realizado por investigadores da equipa para gases nobres, serão estendidos estes cálculos a moléculas orgânicas com interesse para detectores para física das altas energias como CH4 e C2H6. As secções eficazes, integrais e diferenciais, de colisão elástica serão calculadas pelo método das ondas parciais, com desvios de fase calculados pelo método de JWKB e potenciais de interacção derivados de resultados de pesquisa bibliográfica. As secções eficazes serão calculadas para energias, no centro de massa, entre 0.001 e 10 eV, nomeadamente para iões de Ar e de CH4 com átomos neutros de Ar e moléculas neutras de CH4.
Estas secções eficazes serão utilizadas para calcular, utilizando técnicas de Monte Carlo, os parâmetros de transporte dos iões (velocidades de deriva e coeficientes de difusão longitudinal e transversal) para campos eléctricos reduzidos até ao limiar para ionização por electrões. Os resultados obtidos serão comparados com os dos limites clássicos de Langevin e, sempre que possível com os da teoria de Chapman-Enskog.
Durante os primeiros meses de 2013, procurar-se-á introduzir algumas melhorias no sistema experimental, anteriormente concebido e implementado pela equipa de investigação, que permitam medir com mais precisão as velocidades de deriva de iões em gases e eventualmente a identificação desses iões. O sistema experimental é baseado nas técnicas originais desenvolvidas por investigadores da equipa. Uma lâmpada VUV de Xe pulsada liberta electrões da superfície de um foto-cátodo de CsI depositado num GEM, electrões esses que ao colidir com os átomos do gás produzem os iões positivos a estudar. Os iões são recolhidos numa grelha colectora, blindada electrostaticamente por uma grelha de Frisch, dando origem a um impulso que permite calcular a velocidade de deriva.
O sistema experimental será usado para medir as velocidades de deriva de iões positivos presentes em misturas gasosas (nomeadamente Ar/CH4 e Ar/C2H6) e quando possível para identificar esses iões e medir taxas de reacção para a formação de iões mais complexos.

6.6.2 Abstract

The study of the transport of ions in gases is subject of great interest in many fields, like the field of gaseous radiation detectors, namely high energy physics detectors. Indeed, for gaseous detectors based on electron avalanches, the output pulse amplitude has two components: one due to the drift of electrons and another due the drift of the ions. Although the drift velocity of the ions is much slower than that for electrons, their contribution to the induced pulse is often predominant. Usually, only one type of drifting ion is considered, but often in gaseous mixtures like noble gas / organic gas mixtures used in high energy physics detectors, more than one type of ion contributes to the drifting processes.
The present project consists of two main parts:

1. Theoretical calculations of low energy ion-atom/molecule elastic scattering cross sections and calculation of ion transport parameters using Monte Carlo techniques.

2. Improvements of an experimental technique that was already implemented by researchers of the team for the measurement of ion mobilities in gases, making possible the measurement of these parameters with better time resolution, and its use for identification of the different ions present.

Concerning the theoretical calculations, we will continue the work carried out before by the team researchers for noble gases and extend it to organic molecules of interest for high energy physics detectors like CH4 and C2H6. The differential and integral elastic collision cross sections will be calculated by the partial waves method, with phase-shifts calculated using the JWKB approximation and potentials derived from literature searches. The cross-sections will be calculated for centre-of-mass energies at least in the 0.001 eV to 10 eV range, namely for Ar and CH4 ions with Ar and CH4 neutrals.
The cross-sections will be used to calculate, by detailed Monte Carlo techniques, ion transport parameters (drift velocities, longitudinal and transversal diffusion coefficients), for reduced electric fields up to about the threshold for electron ionization. The results will be compared with Langevin´s classical limits and whenever possible with Chapman-Enskog theory.
During the first months of 2013, we will continue to improve the experimental system, designed and constructed before by the research team, for the tentative identification of positive ions in gases and the measurement with improved accuracy of their drift velocities. The experimental system, based on original techniques, uses a pulsed Xe UV lamp that releases electrons from a CsI covered GEM which start an avalanche producing a variety of positive ions that drift towards a collecting grid shielded by a Frisch grid. A time-of-flight spectrum generally allows positive ion identification and the determination of their drift velocities.
The experimental system will be used to measure the drift velocities of the positive ions present in the gas mixture (namely Ar/CH4 and Ar/C2H6) and whenever possible their identification and the measurement of their reaction rates.

6.6.3 Objectives

The main objectives for 2013 include:

- Calculation of Ar-CH4+ and Ar-C2H6+ elastic collision cross sections for centre of mass energies in the 0.001 to 10 eV range using the JWKB approximation and interaction potential taken from the literature. Calculation of drift velocities, transversal and longitudinal diffusion coefficients using Monte Carlo techniques for reduced electric fields, E/N, up to about 100 Td.

- Experimental measurements of drift velocities of the ions present in different noble gas/organic gas mixtures with interest for high energy physics gaseous detectors namely Ar/CH4 and Ar/C2H6 and identification of the ions.

6.6.4 Team

Project coordinator: João Barata

Name	Status	%of time in project
Alessio Mangiarotti	Researcher (LIP)	20
Alexandre Fonseca Trindade	Master (LIP)	40
Carlos Conde	Researcher (LIP)	20
Filipa Borges	Researcher (LIP)	20
Filomena Santos	Researcher (LIP)	15
João Barata	Researcher (LIP/UBI)	40
Pedro Neves	Post-Doc (ATP-Group)	15
Teresa Dias	Researcher (LIP)	20

6.7 Beam Monitoring System for Cyclotron Proton Beams at ICNAS

6.7.1 Resumo

O grupo do LIP que desenvolve este projecto juntamente com o ICNAS avançou em várias frentes no âmbito da instrumentação para medições de correntes do feixe de protões do ICNAS. O intuito final é o de potenciar experiências no âmbito da dosimetria e radioterapia com pequenos animais irradiados com feixes de protões.
O projecto tem por fim providenciar ao futuro utilizador a capacidade de trabalhar tanto na área da radioterapia (dose no alvo da ordem do Gy às dezenas de Gy) bem como na área da radioprotecção (dose da ordem das dezenas de mGy ou inferiores).

6.7.2 Abstract

The group at LIP that develops this project in collaboration with ICNAS has already moved forward in its goals in several aspects related to the instrumentation for proton beam measurements at ICNAS. The final goal of the project is to provide the end user with a setup offering the possibility of carrying out dosimetric experiments together with small-animal radiotherapy studies. One of the goals of the project is to allow studies in the field of radiotherapy (comprising total doses between a few Gy to a few tens of Gy), as well as studies in the field of radiation protection (hence comprising doses of the order of a few tens of mGy or less).

6.7.3 Objectives

The two institutions involved in the project, LIP and ICNAS, are already making plans for the installation of the final dosimetric setup, with dose rates and total dose on target being customizable by the end user.

6.7.4 Team

Project coordinator: Paulo Crespo

Name	Status	%of time in project
Francisco Fraga	Researcher (LIP/FCTUC)	10
Hugo Simões	Master (LIP/FCTUC)	25
Paulo Crespo	Researcher (LIP/FCTUC)	30
Rui Marques	Researcher (LIP/FCTUC)	10
Sharif Ghithan	PhD student (LIP/FCT)	100

6.7.5 Academic Training

PhD Theses

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

6.8 Detector Lab / Mechanical Workshop

6.8.1 Resumo

A oficina mecânica (OM) do LIP foi estabelecida em 1986 para apoiar as atividades experimentais a realizar em colaboração com o CERN. Foi na altura equipada com equipamento moderno de maquinação CNC e pessoal qualificado. O equipamento disponível, recentemente complementado com máquinas-ferramentas de alto desempenho e CAD-CAM, mais o pessoal técnico altamente qualificado, permitem atualmente assegurar uma larga gama de serviços mecânicos, desde a conceção e desenho, à maquinação, montagem e testes. Paralelamente o laboratório de detetores (LD) foi também criado logo na fundação do LIP para apoiar as atividades 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. O equipamento disponível e a especialização do pessoal técnico permitem atualmente prestar una larga gama de serviços, nomeadamente: Conceição, desenho, construção e reparação de equipamentos eletrónicos. Conceição, desenho, construção e teste de detetores. Conceição, desenho, construção e reparação de sistemas de gases e de vácuo.
A experiência de duas décadas, garante-nos que na ausência da OM/LD não teria sido possível realizar com a elevada qualidade atingida, nem o trabalho de I&D em detetores gasosos centrado em projetos autónomos ou em pequenas colaborações, nem os compromissos assumidos no âmbito de medias e grandes colaborações internacionais (nomeadamente CP-LEAR, DELPHI, HERA-B, ATLAS, HADES, AUGER). São igualmente incontestáveis os benefícios para a comunidade nacional de I&D que a intervenção da OM/LD do LIP trouxe aos seus projetos, tanto no plano local e nacional, como em colaborações internacionais.

6.8.2 Abstract

The Mechanical Workshop (MW) of LIP was established in 1986 to support the experimental activities to be performed in collaboration with CERN. At this time it was equipped with modern CNC equipment and qualified personnel. At present, the equipment available, recently improved with high performing machine tools and CAD-CAM software, and the highly qualified staff allows the MW to perform a large spectrum of mechanical services, from the design project to the production and testing. In parallel, the detector laboratory (DL) was also created at the beginning of the LIP foundation with the main aim of supporting the experimental activities developed at LIP. The laboratory has been continuously updated according to general needs but also due to specific needs of the research groups. The available equipment and technical staff, allow a variety of services: Design, construction and reparation of electronic circuits. Design, construction and test of detectors. Design, construction and reparation of gas and vacuum systems.
A two-decades experience assures us that, in the absence of the LIP MW/DL, it would not have been possible to perform with the same high level of quality the R&D in gaseous detectors performed in the framework of autonomous projects or small collaborations, or the responsibilities undertaken within medium and large international collaborations (CP-LEAR, DELPHI, HERA-B, ATLAS, HADES, AUGER). Equally evident are the benefits to the national R&D community of the intervention of the MW/DL in its projects, at the local and national level.

6.8.3 Objectives

During this year it is expected that the Mechanical Workshop and detector laboratory reinforces its present capabilities, while widespreading its recognition in the research community. Special efforts will be dedicated to full integration and exploitation of workshop modern machine tools, with a continuous effort put in the use of the TOPSOLID software and try to acquire capabilities in the field of FPGA devices.
Important projects, which will require an important portion of the available resources, will be SNO++ (construction of the mechanics for the PMT calibration system), AUGER (construction of RPCs for cosmic ray detection) and spark chamber (construction of four spark chambers for the outreach project) projects.

Chapter 7

Outreach

7.1 Particle physics education and public outreach

7.1.1 Resumo

O LIP promove o avanço do conhecimento científico para o público em geral, estudantes e professores do ensino secundário, além do treino avançado nas suas áreas de actividade específicas. O grupo de Divulgação Científica é constituído por investigadores do LIP que sentem a necessidade de promover a literacia científica na sociedade e de procurar, motivar e treinar os cientistas de amanhã. Este grupo trabalha de perto com todos os projectos de investigação do LIP, ajudando a explorar as possibilidades de divulação e promovendo novas actividades, organizando também acções regulares que vão além do trabalho específico de cada projecto.
As suas actividades abrangem diferentes áreas e diferentes públicos alvo, embora se foque principalmente nas comunidades escolares (alunos, professores e famílias), principalmente ao nível das escolas secundárias. As actividades regulares podem ser agrupadas em:
1) Seminários de divulgação por convite das escolas ou em sessões públicas organizadas à margem de eventos científicos promovidos pelo LIP;
2) Actividades ao longo do ano escolar, nomeadamente as enquadradas no projecto de Radiação Ambiente, que funciona há vários anos num número crescente de escolas.
3) Participação no Programa de Ocupação Científica de Jovens em Férias, em que diferentes projectos no LIP recebem alguns estudantes para estágios de uma ou duas semanas;
4) As "Masterclasses"Internacionais em Física de Partículas, uma actividade de um dia inteiro em que os estudantes seguem as tarefas de um cientista, com palestras, análise de dados e discussão dos seus resultados. As "Masterclasses"envolvem anualmente milhares de estudantes em todo o país e em coordenação internacional pelo IPPOG;
5) O Programa do CERN para Professores em Língua Portuguesa, em que professores dos países de língua oficial portuguesa passam uma semana no CERN, com aulas de actualização sobre Física de Partículas e o Universo, sessões práticas experimentais e visitas ao complexo de aceleradores e experiências do CERN, acompanhados por investigadores portugueses;
6) Participação em grupos internacionais dedicados à Divulgação e Comunicação, nomeadamente o IPPOG - Grupo Internacional de Divulgação da Física de Partículas - e o EPPCN - Rede Europeia de Comunicação em Física de Partículas - dedicado à divulgação das actividades do CERN nos seus países membros;
7) Criação e adaptação de Comunicados de Imprensa, editados pelo CERN ou outros relacionados com a Física de Partículas e Astropartículas para os meios de comunicação social portugueses.
Em conjunto, o Programa de professores do CERN e o Projecto de radiação ambiente já colocaram em contacto próximo com a ainvestigação recente, várias centenas de professores. Permitiram-nos assim criar uma rede de escolas, espalhada pelo país, em contacto ou com facilidade de acesso aos investigadores e vice-versa, o que consideramos fundamental para a generalização e o impacto das outras acções de divulgação.
O Programa de Professores em língua portuguesa é um exemplo para o próprio CERN, já que foi estendido a todos os outros países de língua portuguesa, dando também a possibilidade aos professores participantes de partilhar experiências com colegas de outras realidades.
Nas masterclasses participam anualmente cerca de dois milhares de estudantes, e várias dezenas de professores. É uma das acções de maior impacto directo e tem sido alargada a todo o país, contando com a colaboração de investigadores do LIP e também de outros investigadores nas instituições locais de Ensino Superior.
É já uma prática corrente que todos os grandes eventos organizados pelo LIP sejam acompanhados por uma sessão pública ou uma pequena exposição dedicada às escolas e ao público em geral. A comunicação com os

parceiros internacionais, no sentido de procurar as melhores práticas, e com a comunicação social portuguesa, complementam as actividades do grupo de Divulgação.

7.1.2 Abstract

LIP promotes the advancement of scientific knowledge for the general public, high school students and teachers, and advanced training within its specific areas of activity. The LIP Outreach Group is constituted by LIP researchers engaged with the necessity to promote scientific literacy in the society, and to find, motivate and train the scientists of tomorrow. It works in close connection with all other groups in LIP to help exploring their outreach opportunities and promote new activities, and additionally organizes specific regular actions that are beyond the specific scientific projects.
Our activities spread over different areas and for different targets, although we mainly focus in the school communities (teachers, students and families). The regular activities can be grouped in:
1) Outreach seminars, either by invitation from schools, or in public sessions at the side of any scientific event organized by LIP;
2) Year long activities with schools, in particular with the Environmental Radiation Project, which exists already for several years with growing numbers of schools;
3) "Science in the Summer"Occupational Youth program from Ciência Viva, in which different LIP projects host a few students in one or two weeks internships;
4) International "Master classes"in Particle Physics, a one full day activity in which the students follow the path of the scientist with lectures, data analysis and discussion of the results. The masterclasses reach thousands of students across the country in coordination with other countries through IPPOG ;
5) CERN Portuguese Language Teachers Program, in which teachers from Portuguese speaking countries spend a week at CERN, having update classes of particle physics and the Universe, experimental hands-on sessions, and visits to the CERN´s complex and experiments, accompanied by Portuguese researchers.
6) Participation in international groups about Outreach and Communication, namelly IPPOG - International Particle Physics Outreach Group - dedicated to the outreach of particle physics worldwide, and EPPCN - European Particle Physics Communication Network - dedicated to the proper communication of Particle Physics and CERN within its member states;
7) Creation or adaptation of Press Releases issued by CERN or related to Particle and Astroparticle Physics for the Portuguese media.
Together, the CERN Portuguese Language Teachers Program and the Environmental Radiation Project have put by now several hundreds of teachers in close contact with present day research. They allowed us to create a network of schools spread all over the country, in close contact or easy access to researchers and vice-versa, which is fundamental for the generalization and impact of our other outreach actions.
The CERN Portuguese Language Teachers Program is an example at CERN, as it was extended to all other Portuguese speaking countries, which creates also the opportunity for teachers to share experiences with colleagues from different realities.
In the International Master classes two thousand students and dozens of teachers participate each year. It is one of the actions with largest direct impact and is being extended to all the country, counting not only on LIP researchers but also researchers in the local Universities.
It is common practice that all major events that LIP organizes are accompanied by a public lecture or small exhibition dedicated to the school and general public. The communication with international partners, in search for best practices, and with the Portuguese media complement the activities of the Outreach group.

7.1.3 Objectives

The objectives for the LIP Outreach group are always to increase the awareness of Particle and Astroparticle Physics in the Society, and to reach a larger sector of the population, both in number of persons and in geographical dispersion. Separated in the above topics the objectives for 2013 are:
1) To give around 70 public seminars in 2012/2013, mostly related to the Higgs boson analyses and profiting from international meetings held in Portugal;
2) To extend the Environmental Radiation Project to include a new task related to cosmic rays.
3) To provide new activities for the students in "Science in the Summer"Occupational Youth program from Ciência Viva, and to enlarge the number of participants to around 20.
4) To organize the International "Master classes"in Particle Physics in 14 locations (in one case in two different dates), to comply with the very strong demand. In particular, the Masterclasses will be held for the first time in Açores.
5) To receive 80 teachers, from all 8 Portuguese speaking countries, in the

CERN Portuguese Language Teachers Program.
6) In 2013 is of particular importance the EPPCN´s Communication Plan for the presentation of the European Strategy for Particle Physics prepared by CERN to the European Commission, in the middle of 2013, to which LIP will contribute also its experience with the CERN´s multicultural and international Portuguese Language Teachers Program.

7.1.4 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		20
Ana Fernandes	Collaborator	20
Ana Keating	Post-Doc (LIP/FCT)	5
Ana Maria Pinto	Collaborator (FCUL)	20
António Onofre	Researcher (LIP/UMinho)	10
Carlos Bernardino	Collaborator	20
Carmen Oliveira	Collaborator (LIP)	20
Conceição Abreu	Researcher (LIP)	40
Fernando Barão	Researcher (LIP/IST)	5
Florbela Rego	Researcher (LIP)	10
Luis Peralta	Researcher (LIP/FCUL)	20
Maria do Anjo Albuquerque	(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

7.2 Technology Transfer Network and Industrial Liaison Office

7.2.1 Resumo

O HEPTech conseguiu evoluir de um conceito para uma rede ativa de nodos que se interligam numa área comum que é a transferência de tecnologia. Esta rede vai continuar a captar a atenção das principais instituições na Europa (CEA/DSM, CPAN, CERN, Chalmers, Universidade de Copenhaga, CNRS/IN2P3, DESY, EPFL, GSI, INFN, JSI, PSI, STFC, Universidade de Sofia, INFN, CTU, ILL, WIS e ESS), que operam na área de Física de Partículas, Astrofísica e Física Nuclear. O estabelecimento dos "Termos de Referência"do HEPTec, consolida o modo de operação da rede e para 2013 várias iniciativas estarão em curso de realização através de 6 grupos de trabalho, designadamente nas seguintes áreas: 1) Tecnologia para Aceleradores, 2) Sistemas de Controlo, 3) TIC, 4) Detectores e duas áreas relacionadas com a transferência do conhecimento, nomeadamente: 5) Boas práticas e 6) Suporte a gabinetes de transferência de tecnologia. Estes grupos de trabalho, principalmente os de 1) a 4), irão ter um ênfase comum que será a organização de eventos AIME "Academia Industry Matching Events"onde a ciência encontra a indústria para se explorarem colaborações orientadas à comercialização de tecnologias para a criação de novos produtos e serviços. O LIP acompanhará estas as várias iniciativas não só através da sua participação como nodo da rede mas também através da contribuição "in-kind"que realizou para o HEPTech.
Actividades do ILO
O mandato de ILO mantém a mesma estratégia para 2013, que visa em apoiar e promover activamente a indústria nacional e instituições de I&D, para o CERN, ESO, ESRF e contribuir para o seu sucesso no processo de aquisições, e na divulgação de novas oportunidades de projectos e tecnologias disponíveis*, por forma a garantir um retorno industrial sustentável para Portugal. O ILO prosseguirá 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 projectos e tecnologias disponíveis* significa: anúncio de documentos técnicos sobre oportunidades de concursos para o fornecimento de bens e serviços, tecnologias disponíveis que incluem patentes, know-how, software, projectos de I&D ou colaborações)

7.2.2 Abstract

The HEPTech managed to evolve from a concept to an active network of nodes that are connected in a common area that is technology transfer. This network will continue to capture the attention of the leading institutions in Europe (CEA / DSM, CPAN, CERN, Chalmers University of Copenhagen, CNRS/IN2P3, DESY, EPFL, GSI, INFN, JSI, PSI, STFC, University of Sofia, INFN, CTU, ILL, WIS and ESS), which operate in the field of Particle Physics, Astrophysics and Nuclear Physics. The establishment of "Terms of Reference"for the HEPTec, consolidates the operating mode of the network for 2013 and several initiatives are being implemented through six working groups, particularly in the following areas: 1) Technology for Accelerators, 2) Control Systems, 3) ICT, 4) Detectors and two areas related to Knowledge Transfer, namely: 5) Good practices and 6) Support to Technology Transfer Offices. These working groups, mainly from 1) to 4) will have a common goal that is the organization of Academia Industry Matching Events (AIME) where science meets industry to explore collaborations with a strong emphasis on commercialization of technologies for the creation of new products and services. The LIP will follow these various initiatives not only through its participation as network node but also by its "in-kind"contribution for the HEPTech.
ILO activities
The mandate of the ILO will maintain the same strategy for 2013, aiming to support and actively promote national industry and R&D institutions, to CERN, ESO, ESRF and contribute to the success in the procurement process, and disseminate new project opportunities projects and technologies available*, to ensure a sustainable industrial return for Portugal. The ILO continues to work closely with the FCT Space Office and the Portuguese delegation at the European Space Agency (ESA) for industrial matters.
(project opportunities and technologies available* means: announcement of technical documents on procurement opportunities for the supply of goods and services, available technologies that include patents, know-how, software, R&D projects or collaborations)

7.2.3 Objectives

HEPTech project
- Ensure that an autonomous and dedicated web-page about Technology Transfer at the LIP Outreach main page is established with the support of LIP "in-kind"contribution to the HEPTech project.

- As a node member in HEPTech, promote among the LIP community and participate, as deemed possible, on AIME "Academia Industry Matching Events"in the following areas: 1) Technology for Accelerators, 2) Control Systems, 3) ICT, 4) Detectors, 5) Good practices and 6) Support to Technology Transfer Offices.
- Organize, at least, one forum with LIP researchers (in Lisbon and Coimbra) about Intellectual Property and Technology Transfer matters, leveraging on the experience of the HEPTech network.
ILO activities
- Ensure that the Industrial Liaison Officer function for CERN, ESO, ESRF is integrated as an official operational unit in the FCT internal structure.
- The goal is the creation of a database (as a CRM information system helping the ILO with matters related to project opportunities and available technologies* at CERN, ESO, ESRF and ESA) of national companies and R&D institutions will be considered in a wider FCT internal ICT project, regarding the creation of an integrated information management system.
- Establish as much as possible, company presentations to technical departments and/or groups at CERN, ESO, ESRF. Always involve, as deemed possible, Portuguese staff at these venues.
- Continue with the national road-show initiative to present CERN, ESO, ESRF to Portuguese companies. And, along with the FCT Space Office have an integrated approach towards the companies operating in the space sector, mainly for ESA.
- Organize and/or participate at industrial events to promote companies at CERN, ESO and/or ESRF, such as: Visit of firms @ CERN, Industry day @ ESO and Industry day @ ESRF.
- Attend, when possible, industry trade-shows and/or targeted events (nationally and internationally) to carry through targeted assessments about the different industrial sectors in Portugal that can contribute to the ILO activities.
(project opportunities and available technologies* means: announcement of technical documents on procurement opportunities for the supply of goods and services, available technologies that include patents, know-how, software, R&D projects or collaborations)

7.2.4 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 Abstract

The continuous training of scientists and the integration of young scientists in our research programs is one of the main objectives of the overall LIP activity. In all areas, but primarily the basic research ones, the maintenance of strong links to higher education is a clear priority reinforced, in the last years, with the enlargement of the IDPASC network.
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, Slovenia, 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 speciyic 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 yirst 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 yinal individual evaluation so that the Universities can recognize the corresponding credits. At the end of their PhD, the students will be granted a certiyicate.
The LIP teams involve students at different levels. Several scientific profiles co-exist, however, to all students a minimum common scientific background is provided. This common background also favours the future mobility and employment of the students either in scientific research projects and institutions or in the society at large. 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 beneyiting from the inputs and discussion within large international collaborations.
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, specifyic agreements exist with each University for the sharing of resources, and LIP has created specifyic laboratory equipment for educational purposes.
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.

7.3.2 Objectives

The main objectives for 2013 are:
* 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 yirst time, the establishment of our research areas at Minho and a close collaboration with the MAP-Fis PhD network.
* 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 approval and attribution of the PhD grants of the IDPASC-Portugal PhD program.
In the beggining of 2013 a proposal entiteled IDPASC-Portugal was presented to FCT. This proposal puts together the main Portuguese Universities with a relevant activity in the IDPASC areas, as well as LIP which is the main centre for experimental particle and astroparticle physics in Portugal. The complementarity between these fields has been clearly established. In the past it was usual that a student had a monochromatic education in one of these fields; this is no longer possible. A solid background in all these areas is, nowadays, mandatory. In these terms an effective collaboration of the proponent and participating institutions can provide the ideal environment for the training of students enabling as well the mobility and the collaboration between their researchers.