LIP

Laboratório de Instrumentação e Física Experimental de Partículas

ACTIVITY REPORT

2003

LIP-LISBOA
and ALGARVE POLE

Introduction

During 2003, the main lines of activities were:

A strong commitment at CERN, namely in the LHC experiments, ATLAS and CMS; in the COMPASS Collaboration; and in the research and development of radiation hard detectors;

An increasing involvement in space related activities, not only as a member of the cosmic rays experiments AMS and EUSO to be installed in the International Space Station, but also through contracts concluded with ESA to develop GEANT4 simulation tools.

An important role in GRID computing activities in the context of the LHC computing GRID and as a full partner in European Union dedicated projects.

An ambitious participation in medical physics research projects namely in the development of PET technology applied to the detection of breast cancer and in solid state detectors for digital gamma ray imaging.

A constant worry concerning Particle Physics Education and Public Outreach namely developing a project of cosmic ray detection in Secondary Schools.

In 2003, LIP opened two three-year research positions for experimental particle physicists in the framework of the contract as Laboratório Associado. Nine candidates applied to the position and six were pre-selected. On 12th February 2004, the pre-selected candidates were invited to present a seminar at LIP before the Jury. Two candidates were selected.

The funding granted to the projects can be seen in the following table:

PROJECT	REFERENCE NUMBER	FUNDING 2002	REFERENCE NUMBER	FUNDING 2003
CALORIMETRY	CERN/FNU/43715/01	235.000€	POCTI/FNU/49527/02	227.000€
CMS	CERN/FNU/43654/01	235.000€	POCTI/FNU/49481/02	260.000€
DELPHI	CERN/FNU/43674/01	120.000€	POCTI/FNU/43674/02	90.000€
NA50	CERN/FNU/43727/01	100.000€	POCTI/FNU/43727/02	80.000€
COMPASS			POCTI/FNU/49501/02	104.000€
ROBOTIZATION	CERN/FNU/43707/01	85.000€		
PROC. & TRANS. TECHNOL	CERN/FNU/43668/01	75.000€		

MEDICAL PHYSICS	CERN/FNU/43672/01	60.000€	POCTI/FNU/43672/02	55.000€
MODELOS BREMSTRAHLUNG			POCTI/FNU/49497/02	15.000€
CMS -DAS	CERN/FNU/43670/01	50.000€		
SILICON DETECTORS	CERN/FNU/43681/01	25.000€	POCTI/FNU/43681/01	20.000€
AMS	DIV 1179	149.600€	DIV 1179	149.600€
EUSO	POCTI/FNU/43515/01	80.000€	POCTI/FNU/43515/01	40.000€
GEANT4			ESTEC/17097/03	50.000€
TRC – Ciência Viva	PV-0124	55.300€	PV-0124	94.339€
PRSATLHC			HPRN-CT-2002-00326	54.540€
PET - ADI				163.000€
CROSSGRID	IST-2001-32243	55.900€	IST-2001-32243	62.307€
	TOTAL	1.325.800€	TOTAL	1.544.786€

The academic training program included in the projects can be summarised in the following table:

	PhD in progress	Master in progress	Master concluded	PhD concluded
ATLAS	1	3		1
DELPHI	1	2		1
MEDICAL PHYSICS	3	2	1	
SILICON DETECTORS	1			
NA50	2			1
CMS	1			
EUSO		1		
AMS		2	1	
Total	9	10	2	3

Human Resources

	December 2002	December 2003	Março 2004
Administrative Staff	5	5	5
Technical Staff	4	5	6
Researchers	14	15	16
Post-doc Fellowships	8	11	11
PhD Students	12	16	16
BIC/BTI Fellowships and Master Students	18	18	16
TOTAL	61	70	70

This table includes LIP Lisbon and LIP Algarve staff

Administrative Staff:
Lina Barata, Claudia Delgado, Sandra Dias, João Vargas, Natália Antunes

Technical Staff:
José Carlos Nogueira, José Carlos Aparicio, João Paulo Conceição, José Carlos da Silva, Miguel Ferreira (since May 2003), Nuno Dias (since February 2004)

Researchers:
Amélia Maio, Conceição Abreu*, Fernando Barão, Gaspar Barreira, João Cruz, João Varela, Jorge Gomes, José Mariano Gago, Luis Peralta, Mário Pimenta, Paula Bordalo, Pedro Abreu, Sérgio Ramos, Rui Ribeiro, Luis Bernardo, Adarsh Jain (since February 2004)

Post-Doc Fellowships:
Agostinho Gomes, Bernardo Tomé, Catarina Quintans, Catarina E. Santo, Mário David, Patricia Gonçalves, Pedro Rato*, Reyes Alemany Fernandez, Maria Jesus Varanda (since June 2003), João Bastos (since June 2003), Aleksandar Mishev (since May 2003),

PhD Students:
Andreia Trindade, Gonçalo Borges, Helena Santos, José Manuel Silva, Nuno Almeida, Nuno Anjos, Patrick Sousa*, Pedro Rodrigues, Sandra Moreno, Teresa Claudino, Catarina Ortigão (since September 2003), Pedro Assis (since October 2003), Rui Moura (since October 2003), Maria Luisa Arruda (since October 2003), Nuno Castro (since October 2003), Ana Keating (since October 2003)

BIC – BTI Fellowships and Master students:

Carlos Marques, Fernando Carmo, Filipe Veloso, João Borges, João Pina, João Saraiva, Sónia Rodrigues*, Marco Quintero*, Bruno Carriço*, Dário Passos*, Rui Pereira* (since July 2003), David Sora (since July 2003), Gustavo Ordonez Sanz (since September 2003), João Pires (since September 2003), Pedro Ribeiro (since September 2003), Miguel Paulos (till December 2003), Filipe Cardoso (till January 2004), Ana Rita Araújo (till February 2004), Sandra Bráz* (since March 2004)

(*) LIP Algarve Staff

PROGRESS REPORT (2003)

Project Title: AMS

Team

Gaspar Barreira	Senior scientist	10%
Mário Pimenta	Senior scientist	10%
Fernando Barão	Senior scientist, Coordinator	75%
Patrícia Gonçalves	Senior scientist (Post-Doc)	60%
Luísa Arruda	Student (Phd)	100%
Rui Pereira	Student (Degree)	100%
João Borges	Student (Master)	100%
Fernando Carmo	Student (Master)	35%

Resumo:

O modelo standard da cosmologia (modelo do Big Bang) baseia-se na expansão do Universo a partir de um estado inicial muito quente e denso e tem como suporte experimental, as descobertas do movimento de recessão das galáxias por Hubble em 1929 e da radiação cósmica de fundo por Penzias e Wilson em 1964. No estado inicial do Universo, iguais quantidades de matéria e antimatéria terão sido produzidas. No entanto, o que se observa actualmente nos raios cósmicos que são detectados na Terra é uma clara assimetria na sua composição de matéria e antimatéria. A procura de eventuais aglomerados de antimatéria no Universo e o entendimento do mecanismo que produziu esta assimetria são questões essenciais na astrofísica actual. Outra questão fundamental é a compreensão da natureza da matéria que compõe o Universo. Mais de 90% da matéria existente é não-luminosa, isto é, matéria escura, mas a sua composição permanece um mistério. Os raios cósmicos são compostos de partículas neutras e carregadas que atravessam a galáxia em todas as direcções. Um melhor entendimento dos mecanismos de aceleração e propagação requer uma medida dos fluxos de raios cósmicos tão precisa quanto possível e no maior intervalo de energias. O detector AMS, a ser instalado na Estação Espacial Internacional por um período de três anos em 2007, permitirá prospectar a existência de antimatéria e matéria escura com uma precisão nunca antes alcançada.

State of art:

The standard model of cosmology (Hot Big Bang model) is based on an expansion of the universe from a singular initial state hugely dense and hot. Experimental evidences for this kind of model are the Hubble discovery of the galactic recession (red-shifts) on 1929 and the discovery of the cosmic microwave background by Penzias and Wilson on 1964. Equal amounts of matter and antimatter should have been produced initially but what is nowadays observed on the cosmic rays arriving at earth is a clear asymmetry. The quest for antimatter or for an evidence of a primordial mechanism causing this asymmetry is one of the astrophysics puzzles. Another outstanding question is understanding the nature of the matter that constitutes the universe. More than 90% of the matter on universe is non luminous – darkmatter, but its nature remains a mystery. Cosmic rays are energetic neutral and charged particles which cross the galaxy in all directions. For a better understanding of the acceleration and propagation mechanisms, cosmic ray fluxes shall

be measured as accurately as possible and in an energy range as wide as possible. The AMS experiment, a particle physics detector to be installed on the International Space Station for three years, will provide the best sensitivity for antimatter and darkmatter searches.

Summary of activities:

AMS (Alpha Magnetic Spectrometer) is a particle physics experiment to be installed in the future International Space Station Facility (ISS). The main physics objectives will be the search for antimatter and dark matter. In addition, it will study the propagation and confinement of cosmic rays in the galaxy.

The capabilities of the AMS spectrometer, compared to the one which flew in the Discovery shuttle in 1998, were largely improved and extended through the inclusion of new detectors: a Ring Imaging Cerenkov Detector (RICH), an Electromagnetic Calorimeter (ECAL) and a Transition Radiation Detector (TRD). The RICH will provide both an independent measurement of the particle velocity and of the electric charge. A velocity goal resolution for singly charged particles of the order of 10^{-3} is envisaged. Such a resolution together with an improved measurement of the particle rigidity due to a higher magnetic field (0.9T), will allow to obtain a very good isotopic separation on a large kinetic range (up to 10 GeV per nucleon).

The RICH is a conical shaped detector with a dual radiator index configuration on the top made of aerogel (n=1.03) and sodium fluoride (n=1.33), a matrix of photodetectors on the bottom and an enveloping outer mirror of very large reflectivity.

The Portuguese team is involved in the RICH simulation and has developed algorithms for velocity and charge reconstruction.

Reconstruction of particle velocity has to deal with an essentially flat background from photomultipliers noise and photon scattering on aerogel radiator. Additionally, complex photon patterns can be set at the detector plane due to the mirror. A least squares and a likelihood method were developed and compared leading to a velocity determination for protons with a resolution less than 0.1%.

A method for charge reconstruction with the rich detector was also implemented. The existence of background photons, uncorrelated with the cerenkov photon ring, which differ from event to event due to the ring geometrical acceptance and event kinematics implied a charge reconstruction method based on an overall efficiency estimation on a event by event basis. The efficiency estimation relies on a semi-analytical method. A typical charge resolution (_Z) of the order of 20% is obtained for protons.

A RICH prototype made of a radiator and 96 photomultipliers separated by an expansion volume similar to the final one, was assembled at the Institut de Sciences Nucléaires (Grenoble). Following previous tests with cosmic data (2001,2002) and a fragmented Lead ion beam of 20 GeV per nucleon (October 2002, Cern), a new prototype run was performed with a fragmented Indium beam of 158 GeV per nucleon (October 2003, Cern). New readout electronics and new readout settings (tunning of the signal peaking

time) were tested. The physics program included the testing of different aerogel radiators, the testing of the mirror material and the reconstruction of inclined particles.

The optical and surface quality of the aerogel radiator are a crucial issue for the radiator final selection. The aerogel transparency and homogeneity are evaluated with data taken at the test beam. The 2002 test beam data showed the existence of a cerenkov photon component forward scattered. For a full understanding of such a component, a detailed study of the aerogel surface with a AFM microscope is being done together with its simulation through the Geant4 package.

The activities where the group was involved along the year 2003 were the following:

Velocity and charge reconstruction algorithms developed by the group were used for:
Velocity and charge reconstruction studies with the test beam data.
Optimization of a dual radiator configuration for the RICH.
Study of the performance of the different radiators tested.

Integration and test of the velocity reconstruction algorithm in the full AMS simulation

Development of a standalone reconstruction method fully based on the RICH signal for determining the velocity and particle direction

Characterization of the aerogel surface with a AFM microscope and its simulation with the Geant4 package

2003 test beam:
Calibration of the two scintilator counters and of the Cerenkov counter used on the prototype test beam setup
Calibration of the prototype photomultiplier matrix
Data analysis

Academic Training:

Degree Thesis:
Development of a standalone reconstruction method for determining the velocity and direction of cosmic rays in the RICH detector of the AMS experiment
Rui Miguel Pereira
December 2003 – Instituto Superior Técnico (Lisboa)
Supervisor: Fernando Barão

Master Thesis:
Cerenkov ring acceptance in the RICH detector of the AMS experiment; Optimization of a dual radiator configuration
Luisa Arruda
June 2003 – Instituto Superior Técnico (Lisboa)
Supervisor: Fernando Barão

Publications:
The AMS-RICH prototype: test beam results

AMS-Note 2003-08-02
Rich Collaboration

Cerenkov angle and charge reconstruction with the RICH detector of the AMS experiment
F. Barão et al.
NIM A502 p310 (2003)

Conferences:
A double radiator configuration for the rich detector of the AMS experiment; implications on the study of isotopic separation of helium and beryllium nuclei
L. Arruda
XIII Encontro Nacional de Astronomia e Astrofísica (2003, Coimbra)

Colaboração portuguesa na experiência AMS: Reconstrução de velocidade com o detector RICH da experiência AMS
J. Borges
XIII Encontro Nacional de Astronomia e Astrofísica (2003, Coimbra)

RICH standalone reconstruction: an algorithm for finding the particle direction and velocity from a set of 2-dim points
R. Pereira
XIII Encontro Nacional de Astronomia e Astrofísica (2003, Coimbra)

PROGRESS REPORT

Project Title: Calorimetry for ATLAS/LHC

Team

Project Coordinator: Amélia Maio

PhD:

Amélia Maio	45%
João Carvalho	20%
António Onofre	50%
António Amorim	5%
Helmut Wolters	5%
Manuel Maneira	4%
Viriato Esteves	25%
Agostinho Gomes	100%

PhD students:

Maria de Jesus Varanda	100%
José Silva	90%

Master students:

João Pina	100%
João Gentil	100%
João Santos	10%
Carlos Marques	100%

Technical Staff:

José Pinhão	10%
Rui Alves	40%
Luis Raposeiro	5%
Américo Pereira	40%
José Carlos	5%
Carlos Silva	25%
Alexandre Moita	40%

Resumo:

O detector ATLAS é um dos dois grandes detectores de objectivos múltiplos que vão funcionar no grande colisionador hadrónico (LHC), acelerador de protões que está a ser construido no CERN. O objectivo principal do ATLAS é a descoberta do bosão de Higgs, partícula fundamental responsável pelas massas de todas as partículas, ou fornecer pistas que indiquem modelos alternativos e pesquisa de nova física. O grupo português participa na construção do detector ATLAS, tendo participado desde o início no projecto e construção do sub-detector TILECAL, detector cuja função principal é a medição da

energia de cascatas hadrónicas (calorímetro hadrónico). Durante a construção dos módulos do TILECAL o grupo português foi responsável pela preparação de grande parte dos componentes ópticos, com particular relevo para as fibras ópticas WLS, canais de acoplamento entre os cintiladores e as fibras, fibras ópticas transparentes para sistema de monitorização com laser e conectores. Actualmente o detector está a ser montado na caverna de ATLAS, e as actividades do grupo têm-se centrado na calibração do calorímetro, no sistema de controlo do mesmo, e na preparação dos estudos de física a ser efectuados com o detector ATLAS. Para tal são efectuados testes em feixe de partículas no CERN, preparam-se testes em laboratório, desenvolve-se e adapta-se software de controlo e realizam-se simulações de Monte Carlo.

Summary of activities:

1. Introduction

The Portuguese group participates since 1982 in the R&D of calorimeters with scintillating optical fibres, scintillators and wavelength shifter fibres for High Energy Physics Experiments at CERN. The group collaborated in the R&D projects for LHC, namely the SPACAL/LAA, RD1 and RD34 projects. In 1992 the group signed the ATLAS Letter of Intent. In December of 1994 the group, enlarged with the participation of several other Portuguese institutions, signed the ATLAS Technical Proposal.
The activities of the Portuguese group have been centered in the TILECAL, the ATLAS barrel hadron calorimeter. TILECAL is an iron, scintillator and WLS fibres sampling calorimeter, with longitudinal tile configuration. Several prototypes were built since 1993 and tested at CERN. Since 1999 the group participated in the production of the TILECAL calorimeter, being responsible for the production and quality control of most of the optical components, activities that have been fulfilled with success. Our involvement in the Tilecal Detector Control System (DCS) started in 2002 and now is a strong component of our activities in ATLAS and one element of the group coordinates the Tilecal DCS. Progressively our participation in the physics simulation and software development is increasing to become one priority in our project, together with our responsibility in the maintenance of TILECAL during the ATLAS experiment runs.
The activities developed in the frame of this project are the following:

- Construction of the TILECAL Calorimeter, including tests of modules with high energy beams at CERN, data analysis and physics simulation
- Production of optical components (PMT components including the QC of such components, laser fibres, connectors, etc)
- Instrumentation/assembly of the TILECAL modules at CERN
  Tilecal Detector Control System Physics Simulation of the top quark, low energy muon detection in the TILECAL calorimeter and width and mass studies of the W boson in the Atlas detector
- Outreach activities

2 The TILECAL/ATLAS construction

The TILECAL Calorimeter is a scintillator sampling hadron calorimeter with longitudinal tile configuration with prototypes built from 1993 to 1995 and Barrel and Extended Barrel Modules 0 from 1996 to 1998. The mechanical and optical instrumentation of all

the Tilecal modules but 3 of them was finished in 2002. This calorimeter fulfils the request of the LHC hadron physics. The technology of this calorimeter is based on a sampling technique using steel absorber material and scintillating plates (tiles) read by WaveLength-Shifting (WLS) optical fibres. An innovative feature of this design is the orientation of the scintillating tiles, which are placed in planes perpendicular to the colliding beams and staggered in depth. This orientation provides good sampling homogeneity when placed behind an electromagnetic calorimeter, offering good performance, fast readout, relatively low cost and simple assembly procedure. The main requirements in the calorimeter design were achieved, namely an energy resolution better than:

$$\frac{\sigma_E}{E} = \frac{50\%}{\sqrt{E}} + 3\%$$

The Portuguese group shared a large responsibility both in the R&D/prototyping and in the final construction of the TILECAL calorimeter. These activities are centred on the calorimeter optics physics performance, including hardware and software tasks. During 2003, the focus of our activity was the calibration of the calorimeter modules that were already produced and the Tilecal detector control system development and implementation.

In previous years, several prototypes and Modules 0 with real dimensions were built and successfully tested, in stand-alone mode or in combination with the Liquid Argon electromagnetic calorimeter. The production of modules for the calorimeter is almost finished, remaining for instrumentation only the 65^{th} module of each cylinder (spare), and part of the modules was already calibrated using cesium radioactive sources and high energy particle beams. Two of the three cylinders were already pre-assembled at surface in building 185 at CERN. In the last few months we also started the preparation of an ATLAS combined testbeam that will take place during next year at CERN and will include all the ATLAS subdetectors.

2.1 Profiles and WLS fibres

A small stock of profiles and WLS fibres is kept for the possibility of future needs for repairs of modules, and the aluminization machine and the robot for fibre insertion are ready to use if needed.

2.2 Photomultipliers

A set of 140 photomultiplier tubes was tested during 2003. Work to change the PMT quality control testbench to a PMT ageing testbench is in progress, with work going on at the level of software adaptation.

2.3 Laser calibration system

The following tasks were already done:

- Distribution connectors for the clear fibres of the laser calibration system were installed in the modules of barrel and extended barrel of the Tilecal at CERN.
- Clear fibers with a length of 100 meters were prepared for tests in the cosmic ray setup at CERN.

3 Summary of the optical components production

Other Optical Components	Total Quantity	Enterprise		Start Production	Already Produced (total)		Comment
		Name	Place		Quantity	%	
Bundle Tubes	10 132	3D-Tech M. Grande	Portugal	July 1999	10132	100	
QC of the Bundle Tubes	~200	LIP-Coimbra	Portugal	July 1999	200	100	
Components for PMT blocks	10 400	3D-Tech M. Grande	Portugal	June 1999	10 400	100	
Clear fibres	63 Km	MITSUBISHI	Germany	March 1999			
Bundles of clear (short) fibres	400 (~45 or 16 fibres each)	LIP-Coimbra	Portugal	May 1999	400	100	
QC of the Clear fibre bundles	400	LIP-Coimbra	Portugal	July 1999	400	100	
Distribution connectors	400	3D-Tech M. Grande	Portugal	May 1999	400	100	
QC of dist. connectors	400	LIP-Coimbra	Portugal	July 1999	400	100	
Adjustable connectors	400		Portugal	2004	0	0	
QC of adj. connectors	400	LIP-Coimbra	Portugal	2004	0	0	
Long clear fibres	400	Mitsubishi	Germany	2003	4	1	purchased, 4 prepared for testing in real scale at cosmic ray setup
Patch-pannels			Portugal	2004	0	0	

4 R&D on scintillators and WLS fibres

Due to severe budget restrictions, we were forced to suspend most of the activities in the field of ageing and characterisation of raw polystyrene. Two papers were published.
Light collection maps of scintillating tiles and WLS fibres were made for the re-evaluation of the light budget in the several cells of the calorimeter, taking into account the several types of polystyrene used in the production of the tiles.

5 Test beam: data acquisition and analysis

The group participated in the 2003 test-beam data taking at CERN. The aim of the tests is to calibrate and certificate ~10-15% of the production modules and to gain knowledge and experience for the calibration of the remaining modules (192 in total). Four Barrel and six Extended Barrel modules were submitted to high energy particle beams in June, early July and August for calibration purpose, and in September for a combined run to test the combined data acquisition system. One additional Barrel and two Extended Barrel modules were also prepared for a late July calibration test but were not tested due to absence of beam for more than one week - we profited from these unexpected circumstances to make systematic studies of the DCS and succeeded to understand the "peaky" trends observed in the low voltage monitoring system.
The group participates in the analysis of the tests with electron, muon and pion beams, and is developing methods to improve and cross-check the calibrations. We have been calculating the number of photoelectrons per GeV (photostatistics), and the results obtained show values of the order of ~80 npe/GeV for tiles made of PSM115 polystyrene and of the order of ~100 npe/GeV for tiles made of BASF polystyrene, well above the Tilecal minimum requirements. The number of photoelectrons per GeV was calculated for several Barrel and Extended Barrel modules. Another test that was performed was a partial scan along the central line of the tiles of some modules to study the uniformity of the signal along the modules, and the analysis is in progress.
The group has also been working in the preparation of the combined testbeam that will take place this year and will include all the subdetectors of ATLAS, and in the cosmic muon commissioning setup, having the responsibility of the detector control system development, implementation, monitorization and coordination.

6 Tilecal DCS

The Tilecal DCS activities started in the second half of 2002 and became an important part of our activities. We are involved in the design, implementation and maintenance of Tilecal DCS software for test beam and for ATLAS and one researcher of the portuguese team is the TILECAL DCS coordinator.

6.1 Design, implementation and maintenance of Tilecal DCS

Most of the design and development work is done at the testbeam setup at CERN. We prepared the migration from PVSS version 2.11.1 to 2.12.1, implemented and maintained the high voltage alarms, made temporary changes in the software to read high voltage values from temporary files, made the setup of the high voltages for the testbeam periods and maintained the system during the January/December expert weeks and the 4 testbeam periods.
The DCS system was interfaced with a prototype of conditions database and some data was transferred and stored in the database.
We have also replaced the old Embedded Local Monitor Boards (ELMB) used in the cooling system by ELMBs of new generation, after finding that the old ones became very unstable. The powering configuration of the ELMBs and CANbus was changed, passing from a system with one power supply to a system with 2 independent power supplies.

The stability of the ELMBs of the cooling and low voltage systems was studied and a systematic search of the LV changes to explain the LV fluctuations was done with success in almost all the known cases.
The high voltage system was also studied in detail, namely the high voltage trip offs and the stability of the HV channels. The HV channels have shown quite good stability with rms of the order of 0.1 V, which will allow to prepare strategies to decrease the rate of data point elements update at the level of the PVSS software, resulting in better performance of the system.
Work followed in parallel at CERN buildings 175 and 185 where smaller DCS systems were also implemented, and recently in the preparation of this year Atlas subdetectors combined testbeam.

6.2 DCS coordination

A long effort has been made to make the Tilecal DCS a uniform, coherent and simple system, using ATLAS common hardware and software as much as possible for easy maintenance. The several calibration systems were asked to study the respective relationship with the DCS, and that study is underway. The high voltage control system evolved from a complicated VME-PC and CORBA-PVSS system to a much simpler system based only in PCs and PVSS, and a new prototype is expected for the combined testbeam of this year. The combined DCS is being prepared, as well as the installation and commissioning of the Tilecal DCS in the Atlas pit.

7 Participation in the ATLAS installation: pre-assembly of Tilecal

Tilecal is composed of 3 cylinders, each one made of 64 modules. We have participated in the pre-assembly of the first extended barrel and of the barrel cylinder in building 185 at CERN.

8 Physics simulation and software development

The physics simulation in which we participate is focused in three main subjects, low energy muon detection using the Tilecal calorimeter, measurement of the W mass and width using the Atlas detector and top quark studies.

8.1 Detection of low energy muons to improve physics trigger

Simulation studies were done to access the possibility of detection of low p_T muons (2 GeV < p_T <6 GeV) using the Tilecal calorimeter. These studies have shown that the Tilecal is able to detect low p_T muons in the |_| < 1.4 range which can be used, in the 1st level trigger, for the construction of a robust low p_T muon trigger in the Atlas detector, and, in the 2nd level trigger, for either low p_T muon trigger or b-tagging. The key for detection of these muons is the last compartment of the Tilecal calorimeter. In the first case, the Tilecal can be used to improve the potential for the detection of some B-physics channels in the Atlas detector, which are triggered in the first level with an inclusive muon trigger. Using the channel B_d -> J/_(_ $^{+}$_ $^{-}$)K^0, and with a 65% efficiency to trigger muons in Tilecal, the fraction of events triggered in Atlas would increase from 8% to ~14%.

This work is reported in an Atlas technical note and in a PhD thesis.

8.2 Measurement of W mass and width

The W mass and width of the W boson are some of the important precision measurements to be held at ATLAS/LHC collider. So it is very important to evaluate the achievable precisions on both measurements, comparing or combining different methods for the best possible result. The work started with the statistical error study, for which, about 60 million events were generated with Pythia and processed with the ATLFAST simulation of the detector. A study with a function that replicates the transverse mass spectrum was made with 10^9 events. The statistical error was 1.6 MeV. The uncertainty in the E-p scale, which is expected to be the main contribution, was found to be 8 MeV. The width statistical error is currently under study. This study is performed in the high mass tail (above 100 GeV), with the current statistics (one month of ATLAS at low luminosity) the statistical error is 110 MeV.

8.3 Top quark studies

To study the double production of top quarks with anomalous couplings at LHC, a modified version of the PYTHIA generator was developed.
The correct parametrization of the spin correlations of the top quarks was implemented and the forward-backward assymetries were studied at the generator level. The events were then passed through the ATLFAST simulation program and stored in the ntuples used by the analysis program under development. Analysis is in progress.

9 Outreach

This project includes also an outreach component. A video production (3D animation) is being finalised and the first version was well received by the ATLAS community that asked to continue it.

10 Publications

10.1 PUBLICATIONS IN INTERNATIONAL REVIEWS

“A measurement of the photonuclear interactions of 180 GeV muons in iron”,
C. Alexa et al, Eur.Phys.J.C28, 297-304 (2003)

“Optical properties of injection moulded polystyrene scintillators. I. Processing and optical properties”,
J. A. Martins et al, Journal of App. Polymer Science, Vol 88, Issue 11, 2003

"Optical properties of injection moulded polystyrene scintillators. II. Distribution of dopants",
J. A. Martins et al, Journal of App. Polymer Science, Vol 88, Issue 11, 2003

10.2 CONFERENCE PROCEEDINGS

"The aluminization of 600K WLS fibres for the TileCal/ATLAS/LHC",
J. G. Saraiva et al, to be published in proceedings of IEEE NSS MIC RTSD workshop, Portland, USA, 2003

"Finger doses received during FDG injections calculated with Monte Carlo simulations", C. Alves, A. Maio, L. Gonzalez and A. Gomes, to be published in proceedings of IEEE NSS MIC RTSD workshop, Portland, USA, 2003 *(spin-off activity)*

10.3 TECHNICAL NOTES

"Trigger of low p_T muons with the Tile hadronic calorimeter", M.J. Varanda et al, ATLAS Internal Communication, ATL - TILECAL-2003-006

"Choice of the WLS fibres for the Tilecal/ATLAS Calorimeter", M. David et al, ATLAS Internal Note, ATL – TILECAL-2003-001

11 THESIS

"The contribution of the Tilecal for b-tagging in ATLAS with a low p_T muon trigger" – PhD thesis, Maria Varanda, F.C. Univ. Lisbon, June 2003.

In progress

"Monitorization and intercalibration of the Tilecal/ATLAS calorimeter, and PMT qualification",- PhD thesis José Silva, in progress.

"Influence of the HV gain in the Tilecal performance", Master thesis, João Pina, finishing (~Mar 2004)

"Contribution for the calibration of the Tilecal calorimeter", Master thesis, João G. Saraiva, finishing (~Mar 2004)

"W mass and width measurement at LHC using the ATLAS detector", Master thesis, Carlos Marques, in progress.

PROGRESS REPORT

Project Title:

Collaboration in the CMS experiment at CERN

Project Coordinator:

João Varela	LIP/IST	

PhD:

João Varela	LIP/IST	50%
Paula Bordalo	LIP/IST	8%
Sérgio Ramos	LIP/IST	8%
Reyes Alemany	LIP	100%
Alexander Mishev	LIP	100%
Marcelino Santos	INESC/IST	20%
Carlos Almeida	INESC/IST	20%
João Paulo Teixeira	INESC/IST	25%
J. Augusto	INESC/IST	25%
F.M. Gonçalves	INESC	20%
Isabel Teixeira	INESC/IST	25%

Students:

Nuno Almeida (PHD student)	LIP	100%
Gustavo Ordonez	LIP	100%
Pedro Ribeiro	LIP	100%

Technical Staff:

José Carlos Silva	LIP	100%
Nuno Cardoso	LIP	100%
Miguel Ferreira	LIP	50%
Jorge Semião	INESC	20%
Octávio Dias	INESC	10%

Resumo:

O LIP em colaboração com o INESC-ID participa na construção da experiência Compact Muon Solenoid (CMS) que se iniciará em 2007 no acelerador LHC do CERN. A actividade portuguesa centra-se no desenvolvimento do sistema de selecção, filtragem e aquisição de dados do calorímetro electromagnético. O calorímetro é um detector de electrões e de fotões de alto desempenho composto por 80'000 cristais cintilantes $PbWO_4$ com um volume de cerca de 10 m^3 . A digitização e leitura de dados do calorímetro é realizada por um sistema electrónico complexo, integrando 20'000 módulos de digitização no detector, 10'000 ligações ópticas de alta velocidade e 250 cartas de processamento dedicadas à seleção e filtragem de dados.
Em 2003, o grupo português concluíu o teste do protótipo final do módulo de sincronização de dados, construíu o protótipo final da carta de filtragem e aquisição de dados de acordo com o calendário previsto, e concluíu com sucesso o teste das ligações ópticas. Em colaboração com a empresa portuguesa Chipidea e o CERN, concluíu o desenho e fabrico do protótipo final do conversor analógico-digital de alta velocidade a integrar nos módulos de digitização. Finalmente, o grupo concluíu a primeira fase do desenvolvimento do software de aquisição e iniciou um programa de preparação da pesquisa de dimensões suplementares nas colisões de protões no LHC.

1. Introduction

This project concerns the Portuguese participation in the CMS experiment. The LIP activity is centered on the development of hardware and software for the readout and trigger system of the electromagnetic calorimeter. The project is carried on in collaboration with INESC-ID.
The Electromagnetic Calorimeter (ECAL) is an electron and photon detector composed by eighty thousand high purity PbWO4 crystals. The extremely fine granularity and the excellent energy resolution makes this instrument very well suited for the measurement of electrons and photons at the LHC. The readout system is responsible for collecting data from 80000 channels.
The calorimeter trigger and readout system of the CMS/LHC experiment at CERN is a high performance electronics and computing system which processes on-line the detector data, about one hundred thousand calorimeter channels, to select electrons, photons, taus, jets and missing energy events, and which reads the detector data following a trigger accept.
A high degree of innovation is required in the project. For the first time a large number of optical data links is used in HEP. The integration scale required and the complexity of the on-line data selection and trigger algorithms is a real challenge for the electronics development. The dimension of the system requires the use of the most advanced quality control and testing techniques.

The complete re-design of the ECAL trigger and readout electronics initiated in mid-2002, aiming at a substantial reduction of the system cost, is now a major success. The Portuguese group has important responsibilities in the project. New prototypes of the trigger and data acquisition hardware were designed and built in 2003. A new 12-bit ADC in 0.25-micron rad-hard technology was developed by Chipidea under contract with

LIP, and is now integrated in the ECAL front-end.

Portuguese construction responsibilities in the CMS experiment:

Development and construction of the trigger synchronization circuits and the trigger high-speed links (construction of 1000 Synchronization and Link Boards for ECAL and HCAL).
Development and construction of the ECAL Data Concentrator Card (construction of 60 DCC 9U VME boards).
Development of data acquisition software for the ECAL readout modules.

In collaboration with Portuguese industry, Portugal is responsibly to deliver:

Grease Pads for the magnet barrel wheels (concluded)
Prototype of Muon Alignment Barrel carbon fiber structures (MABs) (concluded)
Design of a high-performance 40 MHz 12-bit ADC (concluded)

Bibliographic references are available at: http://cmsdoc.cern.ch/docnotes.shtml

2. Synchronization and Link Board (SLB)

LIP has concluded a long-term effort aiming at a Synchronization Circuit for the calorimeter trigger primitive data. This circuit is the heart of a method developed and demonstrated by LIP to achieve synchronization of the calorimeter trigger pipeline system. This circuit is integrated in the Synchronization and Link Board (SLB), together with the Giga-bit trigger link (Vitesse 7216).

Following the ECAL electronics re-design decided in 2002, the SLB was re-implemented in 03 in a more compact form factor. Prototypes of the new SLB mezzanine were distributed for validation to the ECAL and HCAL groups using it.

A new SLB-Tester board was developed and produced. This board houses five SLB mezzanines allowing simultaneous testing of five boards. This feature will reduce the test time of 1000 SLBs needed.

A SLB test system integrating the various components is now installed at CERN. It includes the SLB-Tester (transmitter) and the STC board (receiver, developed in Wisconsin), and a TTC test system. A complete software package for production tests is now being finalized, as well as the final BIST of the synchronization FPGAs.

3. Data Concentrator Card (DCC)

Following the re-design of the ECAL electronics decided in 2002, the specifications of the DCC were reviewed. The new module will receive 72 high-speed optical links from the detector front-end boards (instead of electrical input) and will include an additional input stage responsible for data filtering. This board is the major component of the ECAL data acquisition system.

A prototype of the final DCC with full performance and complete functionality was built in 03. The DCC has a high-speed optical input stage based on 6 NGK 12-channel optical receivers, followed by 72 de-serializer circuits integrated in 9 Virtex FPGAs. These FPGAs include also the data filtering algorithms and the input memory. Three event-builders working in parallel allow an integrated bandwidth of 4.2 Gbit/s. The board collects also trigger data through LVDS high-speed links. In addition, it interfaces to four external systems, namely the central Selective Readout Processor (SRP), the Trigger Timing and Control system (TTC), the Trigger Throttling System (TTS) and the central Data Acquisition system (DAQ), using different data transmission technologies.

A dedicated VME-9U board called DCC-Tester was build in 03. The DCC-Tester emulates all the inputs of the DCC, in particular the 72 high-speed optical links. The high-speed transmitters are implemented in Optical Boards, each carrying 24 transmitters. The DCC-Tester motherboard houses 3 Optical Board mezzanines. The Optical Board transmitters are based on the GOL rad-hard serialiser developed at CERN/MIC and used in the ECAL front-end and on NGK optical transmitters. The DCC-Tester emulates also the SRP inputs and controls the TTC system. It allows to generate random triggers (Poisson) at programmable rate, initiating the transmission of events. On-board memory allows the storage of about 1000 complete simulated events (using CMS ORCA detector simulation).

The critical part of the design is the high-speed stage integrating 72 giga-bit optical links. The high-speed links require a very pure clock, with a jitter well below 100 ps, which is not provided by the TTC system. Our group was among the first to recognize this problem. A dedicated circuit to clean up the TTC clock (QPLL chip) was designed by the CERN MIC group.

Delays in the delivery of the GOL and QPLL chips (August 03) didn't allow concluding yet the tests of the DCC. At this point, the high-speed optical input stage was tested with very good results, which is reassuring.

The DCC-Tester motherboard and optical boards were tested successfully. A second DCC-Tester was produced and debugged for usage by the Palaiseau group in testing their trigger boards.

At present, we have discussions with the RPC Muon detector and with the Preshower detector groups aiming at the integration of the ECAL DCC board in their data acquisition systems.

4 Control and Monitoring Software

The development of ECAL Readout and Control Software and of the software for SLB and DCC Test Systems is proceeding according to the plans. In 2003 the following developments were concluded:

Complete software package for the DCC test system, including generation of test data, control of the DCC-Tester hardware, smooth integration in the data acquisition system, remote graphical user interfaces and access to remote configuration database (Oracle).

Complete software package for the SLB test system, including control of the SLB-Tester hardware and of the STC card, remote graphical user interfaces and access to remote configuration database.

Crate Controller Package for the ECAL test-beam data acquisition system and the final CMS experiment, including remote control capabilities and access through graphical user interfaces, access to remote configuration and equipment management databases, automatic crate scan and configuration, crate hardware monitoring, local data acquisition and monitoring, easy access to the hardware test software.

5.Modeling and Simulation

In order to guarantee that the required functionality and performance of the ECAL data acquisition system is achieved, a model, at system level, of its constituting modules has to be developed and simulated. This need comes from the fact that it is not possible to prototype all modules and interfaces of such a complex system. Thus, the use of system-level simulation is mandatory for achieving this purpose.

In previous phases of this project, a model of the ECAL readout and trigger system was implemented using Rational ROSE RT (Real Time). A complete simulation of the DCC was achieved, putting emphasis on the validation of the event builder design and communication protocols.

The activity in 03 was considerably delayed due to funding restrictions and late availability. In particular, the adaptation of the simulation to the new design of the ECAL electronics was not achieved.

6 Physics Reconstruction and Selection

The activities in Physics Reconstruction and Analysis were substantially incremented in 03. A dedicated team integrating two PhDs and two PhD students was created with the aim of preparing the group for the future data analysis in CMS.

Two major steps in this direction were given:
The creation of a CMS computational basis at LIP, having installed and checked the complete CMS simulation and reconstruction tools.
The identification of an area of physics analysis, namely the physics beyond the standard model based on the hypothetical existence of extra dimensions in space-time.

7 Boundary Scan

The development of boundary scan tools, which we have been consistently pursuing in the last years, was concluded. The set of hardware and software boundary scan tools produced in this sub-project will be extremely valuable for testing and diagnosing hundreds of electronics modules under our responsibility, in the production phase and latter when installed in the experiment.

In the past years we have built a VME based boundary scan controller board, developed

the software implementing the bi-directional link between the SVF format and the VME BS controller and installed the commercial BS software adopted by CERN. Special attention was paid to the application of boundary scan to in-situ re-programming of FPGAs. Two VME test boards, emulating real readout/trigger boards, were built and used to validate our boundary scan test system.

The production of the Boundary Scan Controllers was delayed due to the departure in 03 of the main design engineer. Replacement could not be materialized due to the long delays in funding availability.

8 Development of ADC 40 MHz-12bit

In the framework of the ECAL electronics redesign, the ECAL community decided in August 2002 to sub-contract the design of IP block with a 40 MHz 12-bit ADC in 0.25 micron radhard technology. This IP block was intended to integrate an analog-digital ASIC with 4 ADCs and a dynamic digital range selector.
With this objective, LIP established a design contract with the Portuguese company Chipidea. The CERN microelectronics group integrated the IP block in a 4-fold ADC chip. The first chip samples were received and tested. The measured performance fulfils the ECAL physics requirements. A second submission was done recently in order to improve the chip performance and to solve minor design problems.

9 CMS Trigger and Detector Controls Coordination

The CMS Trigger Control System designates the set of interfaces, protocols and dedicated central control hardware and software modules, which aims the integration in a coherent system of the various trigger components and subdetector readout systems in the overall CMS experiment. This integration activity is coordinated by the CMS Trigger Technical Coordinator in the framework of working groups with representatives of the various sub-detectors.

The CMS Detector Control System (DCS) is responsible to provide the tools necessary to operate the CMS detector and monitor its performance. It is organized as a coherent set of sub-systems each corresponding to the major CMS sub-detectors. The development of DCS is coordinated by the Detector Controls Coordinator.

These CMS positions are held by one member of the LIP group (J. Varela).

10. Publications in 2003

Data Concentrator Card and Test System for the CMS ECAL Readout,
N. Almeida, J.C.Da Silva, R.Alemany, N.Cardoso and J.Varela, *LIP,Lisbon, Portugal,* 9th LECC 2003 Workshop, Amsterdam, Holland, September 2003.

The Fast Merging Module (FMM) for readout status processing in CMS DAQ,

E. Cano, S. Cittolin, A. Csilling, S. Erhan, D. Gigi, F. Glege, M. Gulmini, J. Gutleber, C. Jacobs, M. Kozlovszky, H. Larsen, I. Magrans, F. Meijers, E. Meschi, S. Murray, A. Oh, L. Orsini, L. Pollet, A. Racz, D. Samyn, P. Scharff-Hansen, C. Schwick, P. Sphicas, J. Varela, Presented at: LECC 2003, Amesterdam, Netherland, September 29 - October 03, 2003.

The CMS High Level Trigger,
V. Brigljevic, C. Schwick, G. Bruno, E. Cano, S. Cittolin, S. Erhan, D. Gigi, F. Glege, J. Gutleber, C. Jacobs, M. Kozlovszky, I. Magrans De Abril, F. Meijers, E. Meschi, S. Murray, A. Oh, L. Orsini, L. Pollet, A. Racz, D. Samyn, P. Scharff-Hansen, R. Gomez-Reino Garrido, M. Gulmini, P. Sphicas, J. Varela, Presented at: IEEE NSS 2003, Portland, USA, October 15-19, 2003.

FEDkit: A Design Reference for CMS Data Acquisition Inputs,
V. Brigljevic , G. Bruno, E. Cano, D. Gigi, F. Glege, R. Gomez-Reino Garrido, M. Gulmini, J. Gutleber, C. Jacobs, M. Kozlovszky, H. Larsen, I. Magrans de Abril, F. Meijers, E. Meschi, S. Murray , A. Oh, L. Orsini, L. Pollet, A. Racz, D. Samyn, P. Scharff-Hansen, C. Schwick, J. Varela, S. Cittolin, Presented at: 9th LECC 2003 Workshop, Amsterdam, Holland, September 29 to October 3, 2003.

Readout and Trigger Crate Software for the Electromagnetic Calorimeter of CMS, R. Alemany, N. Almeida, J. C. da Silva, J. Varela, CMS IN-2003/048.

A Software Package for the Configuration of Hardware Devices following a Generic Model,
N.Almeida, R.Alemany, J.C. da Silva, J.Varela, *LIP*,*Lisbon, Portugal,* F.Glege, *CERN, Geneva, Switzerland,* accepted as CMS NOTE, to be submitted to Computing Physics Communications.

PROGRESS REPORT

Project Title:	**Collaboration in the COMPASS Experiment**	

Team:

Project Coordinator
Paula Bordalo

PhD

Paula Bordalo	LIP Researcher / IST Professor	60%
Sérgio Ramos	LIP Researcher / IST Professor	60%
Catarina Quintans	LIP Researcher / Post Doc FCT grant	83%
Maria Varanda	LIP Researcher / Post Doc LIP grant	100%(1)
João Bastos	LIP Researcher / Post Doc LIP grant	95%(2)

Technical Staff

David Sora	Software engineer	100%(1)

(1) From July 2003 on
(2) From October 2003 on

Report:

Sumário

Os primeiros estudos sobre a difusão inelástica profunda polarizada foram realizados em SLAC no início da década de 80. As experiências, realizadas a baixa energia e possuindo um domínio cinemático relativamente restrito, confirmaram na altura as regras de soma de Bjorken e de Ellis-Jaffe. Mais tarde, com o advento de feixes polarizados de energias muito mais elevadas (i.e., uma ordem de grandeza superiores), a experiência EMC do CERN/SPS, concebida com um domínio cinemático muito mais lato, descobriu uma clara violação da regra de soma de Ellis-Jaffe. Tal significa, no quadro do modelo dos quarks partões, que a contribuição total dos spins dos quarks para o spin do protão é pequena.

Neste contexto, foi proposta mais tarde no CERN uma experiência sua sucessora, SMC, com o objectivo de medir novamente a difusão inelástica profunda polarizada usando um alvo de protões polarizados, bem como de realizar uma primeira medida usando um alvo de deuterões polarizados. Os seus resultados, combinados com os de EMC, permitiram concluir que tanto a função de estrutura do protão como a do neutrão estão de acordo com a regra de soma de Bjorken e implicam a violação da de Ellis-Jaffe.

Apesar de em SMC já haver um procedimento de selecção de sabor do quark que absorve

o fotão virtual, compreendeu-se que seria necessária a reconstrução total do jet desse quark, nomeadamente para a medida de Delta G através do processo de fusão *fotão - gluão* $\rightarrow c\bar{c}$. Tal implica, de facto, a medida da assimetria de charme aberto, para a qual é necessária a identificação completa dos produtos da reacção.

Outros assuntos, exigindo também medidas semi-inclusivas de difusão inelástica profunda, começaram entretanto a despertar grande interesse na comunidade, nomeadamente a transversidade.

Neste contexto, foi aprovada pelo CERN a experiência COMPASS, cujo objectivo é duplo: o estudo da estrutura de spin do nucleão, nomeadamente a polarização do gluão e a decomposição das distribuições de helicidade dos quarks; o estudo de temas específicos de espectroscopia hadrónica, como sejam a polarizabilidade de partículas instáveis usando a reacção de Primakov, a procura de estados exóticos e híbridos, e a física do charme (nomeadamente a pesquisa de bariões charmosos duplos).

Neste sentido, COMPASS usa (usará) feixes de muões (de protões) de alta intensidade interagindo com um alvo polarizado (alvo de 'microstrips' de silício) ao qual se seguem dois magnetes que, em conjugação, permitem obter uma grande aceitncia geométrica.
Estes são intercalados por conjuntos de detectores de posição (micromegas e GEMS, que suportam alto fluxo; MWPCs, cmaras de deriva planares e de tubos capilares) e de hodoscópios de cintilação, por dois RICHs e dois conjuntos de calorímetros electromagnético e hadrónico (alguns dos quais ainda não construídos).

O sistema de aquisição de dados baseia-se na leitura em paralelo da electrónica de 'frontend' e num sistema distribuído de 'event-builders'.

Na experiência COMPASS, o grupo do LIP-Lisboa tem a responsabilidade total do sistema de controlo dos detectores (DCS).

Summary

The first studies concerning polarized deep inelastic scattering were done at SLAC around 1980. These experiments, working at low energy and dealing with a somewhat restrict kinematical domain, have confirmed the Bjorken and Ellis-Jaffe sum rules. Later, with the disponibility of high energy polarized beams (typically, one order of magnitude higher), the CERN/SPS EMC experiment, conceived with an enlarged kinematical domain, established a clear violation of the Ellis-Jaffe sum rule. This means that, in the framework of the quark-parton model, the total quark spins contribution to the proton spin is small. In this context, a new CERN experiment, SMC, was proposed, with the aim of measuring the polarized deep inelastic scattering using polarized hydrogen and deuterium targets. Its results, when combined with those coming from EMC, allowed to conclude that both the proton and the neutron structure functions are in agreement with the Bjorken sum rule, but imply the violation of the Ellis-Jaffe's one.

Although a flavour tagging procedure of the struck quark already existed in SMC, in was soon realized that the full quark jet reconstruction was necessary in order to measure Delta G through the fusion process *photon-gluon* $\rightarrow c\bar{c}$. This implies, indeed, the open

charm assymmetry measurement, to which the complete identification of the reaction products is necessary.

Meanwhile, other subjects, also needing semi-inclusive deep inelastic scattering measurements, have began deeply interesting the international community, such as transversity.

In this context, the COMPASS experiment was approved at CERN. Its aims are twofold: the study of nucleon spin structure, namely the gluon polarization and the decomposition of the quarks helicity distributions; the study of specific subjects of hadronic spectroscopy: the polarizability of instable particles through the Primakov reaction, the search of exotic and hybrid states and charm physics (namely double charmed bayons).

In this framework, COMPASS uses (will use) high intensity muon (proton) beams impinging on a polarized target (silicon microstrips target) by a double spectrometer allowing to achieve a very good acceptance. The two main magnets are sorrounded by sets of position detectors (MicroMegas and GEMs, which stand high rates; MWPCs, planar and straw drift chambers) and of scintilating hodoscopes, by two RICHs and two sets of electromagnetic and hadronic calorimeters (some of them not yet built).

The data acquisition system is based in a parallel read-out of the front-end electronics plus a distributed set of event-builders.

LIP-Lisbon was approved last year by the COMPASS Group Leader Board to become a member and to have the full responsibility of the Detector Control System (DCS)

Summary of the Activities

Our LIP-Lisbon group has been accepted by the COMPASS Leader Board to become a member and is thus participating in COMPASS activities at CERN since September 2001. COMPASS Leader Board has also attributed to LIP members the full responsibility of the Detector Control System (DCS) of the experiment, which was very slow and not reliable.

During 2003, the COMPASS experiment LIP group carried on the matters related with the working activities, namely:

- General activities
- Full responsibility of the Detector Control System (DCS)
- Offine and data analysis
- Organization of a COMPASS meeting in Lisbon.

General Activities

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

- Participation in the Collaboration meetings
- Participation in the Steering Committee meetings (the Project Leader)
- Participation in the monthly offine and analysis meetings
- Participation in the technical friday meetings
- Participation in the data taking periods.

Detector Control System

The COMPASS DCS system is being redesigned in order to meet the Collaboration requirements of reliability, robustness and speed. In fact, prior to our arrival in COMPASS, no group was responsible for the task, and the system was developed in a casuistic way.

DCS is a complex system, basically formed of two sub-systems, one running in a Linux platform, and interacting with the detectors via VME interfaces, using the SLIC and DIM packages, and the other running on Windows and dialoging via OPC servers. The several computers running these two platforms were too old and had obsolete versions of the operating systems installed, which neither met the CERN security requirements, nor allowed to update the software packages the system uses.

Thus, our first task has been to upgrade the hardware of the main DCS computers. This allowed us to install uptodate operating systems. Then, new versions, supported by CERN, of all the packages used by DCS, namely PVSS II, JCOP Framework, SLIC and DIM could also be installed. This required a major effort, as these previous versions (on top of which we develop our complex system) were several years old and the new ones were never tested together in a realtime environment dealing with thousands of channels.

After this first part, our team could proceed with another kind of activities, namely the development of several software procedures, as data mirroring and data backup into the main CERN storage devices.
Also, some more PVSS II licenses were installed and the process of improving parallelism began, decoupling detectors from some long loop lines in order to speed up the interactions and to allow readings during the beam spill (one of the major request from detectors responsibles).
A redesign of some panels also took place, as well as the begining of the integration of several detectors that had never been controlled by the DCS system.

During the four months of the data taking, our group members accomplished the following tasks:
- online control of the system performance;
- daily help to DCS users;

- immediate assistance to detector people, namely due to hazardous hardware changes implying DCS reconfigurations;

- weekly main backups to CERN storage systems;

- data base management.

One should stress that the DCS system works practically 12 months per year (apart from short shutdown periods), as during no-beam period still part of the systems run, thus requiring control, as is the case of detectors gas systems. This may be an advantage to test some software improvement, apart from scalability issues, but is also a problem, preventing the system to run in standalone mode (as everytime a sub-system is controling some detector).

Offine and Data Analysis

The software programs and libraries concerning the COMPASS code after the reconstruction chain have already been installed at LIP. In that view, some work has been done, namely to get familiar with the software tools and to understand the quality of the reconstructed events.

As the reconstruction efficiency concerning the slow tracks showed to be poor, contacts have been established with the software tools group, which confirmed us that the algorithm is not yet optimised. An effort of our part regarding this question has been agreed and this heavy task is already being developed at LIP.

Communications presented by LIP members:

Several technical presentations to the Collaboration and technical meetings reporting the DCS implementations.

PROGRESS REPORT

Project Title: Collaboration in the DELPHI experiment at CERN

Team

Project Coordinator: Mário Pimenta

PhD:

Mário Pimenta,	35%
António Onofre,	35%
Pedro Abreu,	40%
Maria Catarina Espírito Santo,	40%
Bernardo Tomé,	40%
Patrícia Gonçalves,	20%

Students:

Sofia Andringa (PhD Student),	100%
Nuno Anjos (PhD Student),	100%
Nuno Castro (Master Student),	100%
Filipe Veloso (Master Student),	100%

Technical Staff:

Resumo das actividades realizadas:

O grupo DELPHI do LIP tem desenvolvido as suas actividades segundo o plano de actividades que, após o fim da operação de LEP, consiste essencialmente na obtenção dos melhores resultados possíveis a partir dos dados de DELPHI. As actividades de análise de dados podem ser divididas em dois subgrupos: Pesquisas de sinais de nova física, e Física Hadrónica. Em ambos os casos, a participação dos membros de DELPHI do LIP (membros LIP/DELPHI) teve lugar nos grupos de análise de física associados, bem como na coordenação destes e das respectivas linhas de pesquisa. Alguns membros LIP/DELPHI representam a colaboração nos grupos de trabalho de LEP para a combinação de resultados entre as experiências LEP.

Os canais de física analisados no tema das 'Pesquisas...' correspondem ao estudo de modelos extendendo o Modelo Padrão da Física das Partículas, em particular a supersimetria e modelos exóticos (Bosões de Higgs fermiofóbicos, fermiões compostos, leptoquarks, correntes neutras com troca de sabor, 4ª família de quarks (b'), produção de quarks top via interacções de contacto). Ainda nesta área foram realizadas medidas de secção eficaz dos processos $e^+e^- \rightarrow WW\gamma$ e $e^+e^- \rightarrow \gamma\gamma(\gamma)$.

Relativo à área 'Física Hadrónica', prosseguiu-se no estudo dos efeitos de reconexão de côr entre os quarks e gluões nos acontecimentos WW, e elaborou-se uma contribuição para a secção '*Soft QCD* ', co-coordenada por um membro do LIP/DELPHI, do grande artigo de revisão da QCD em DELPHI, actualmente em preparação. Foi ainda iniciada

uma pesquisa de pentaquarks nos decaimentos hadrónicos do Z^0, em parceria com o grupo DELPHI da Univ. Udine e INFN, Udine, Itália.
No ano de 2003 foram preparados e enviados para publicação 3 artigos, sob responsabilidade ou com contribuições importantes de membros do LIP/DELPHI, e enviaram-se, sob a forma de Notas DELPHI, dez comunicações científicas a conferências internacionais.
A qualidade do trabalho desenvolvido foi reconhecida pela Colaboração, ao escolher dois membros do LIP/DELPHI para apresentarem os seus resultados em conferências internacionais, em representação da Colaboração DELPHI.
Neste período foi ainda concluída e defendida com sucesso uma tese de doutoramento, por Sofia Andringa, no Departamento de Física do Instituto Superior Técnico / Universidade Técnica de Lisboa.

Summary of activities: ***Analysis of DELPHI data***

The group DELPHI of LIP has proceeded along the lines defined in the previous plan of activities which, after the end of operation of the LEP machine, consist mainly in the extraction of the best results possible from the DELPHI data. The activities can be devided in two subgroups: Searches for New Physics and Hadronic Physics. In both subgroups, the participation of the LIP-DELPHI team has taken place in the DELPHI physics analysis concerned, as well as in the coordination of the corresponding physics teams and physics research lines. Members of the portuguese team are also representatives of the DELPHI Collaboration in the LEP Working Groups.
There are 8 final papers in different stages of preparation, under our responsibility or with important contributions from the LIP-DELPHI team. In 2003 LIP members wrote also many communications for international conferences with proceedings, and presented the DELPHI or LEP results in International Conferences, as listed below. During this period, one PhD thesis was concluded and defended with great success, by Sofia Andringa, in the Physics Department of Instituto Superior Técnico / Universidade Técnica de Lisboa.

Searches for New Physics and Electroweak Measurements *(contact person: Mário Pimenta)*

Search for Supersymmetric particles
Search for non-fermionic neutral Higgs bosons
Search for composite and exotic fermions
Search for Leptoquarks
Search for Flavour Changing Neutral Currents
Search for 4th Generation b'-quark
Search for top quark via Contact Interactions
Measurement of the WWγ Cross-Section and Search for anomalous Quartic Gauge Couplings
Search for $\gamma\gamma(\gamma)$ events

Hadronic Physics
(*contact person: Pedro Abreu*)

Interconnection effects in WW events
Review of DELPHI QCD results – section on Soft QCD

Academic Training:

Thesis concluded in 2003
Study of Anomalous Quartic Gauge Couplings and Search for Fermiophobic Higgs at LEP2 – PhD thesis – Sofia Andringa

Publications: (LIP authors are underlined)

Articles

"*Searches for supersymmetric particles in e+e- collisions up to 208 GeV and interpretation of the results within the MSSM* ", J. Abdallah *et al.*, DELPHI Collaboration, CERN-EP/2003-007, 16 January 2003, accepted by Eur. Phys. J. C.

"*Measurement of the* $e^+e^- \rightarrow W^+ W^- \gamma$ *Cross-section and Limits on Anomalous Quartic Gauge Couplings with DELPHI* ", J. Abdallah *et al.*, DELPHI Collaboration, Eur. Phys. J. C31 (2003) 139-147.

"*Search for single top production via FCNC at LEP at sqrt(s)=189-208 GeV* ", J. Abdallah *et al.*, DELPHI Collaboration, CERN-EP/2003-066, 16 September 2003, submitted to Phys. Lett. B.

Reports

DELPHI note 2003-002 PHYS 928, 7 July 2003 M. Espírito Santo, K. Hultqvist, P. Johansson, A. Lipniacka *Search for neutralino pair production at sqrt(s) from 192 to 208 GeV*

DELPHI note 2003-004 CONF 627, 13 March 2003 S. Andringa, M. Espírito Santo, P. Gonçalves, A. Onofre, M. Pimenta, B. Tomé *Search for a fermiophobic Higgs at LEP2*

DELPHI note 2003-021 CONF 641, 5 August 2003 P. Abreu, N. Anjos, J. D' Hondt, N. J. Kjaer *Update on the investigation of Colour Reconnection in WW Pairs using Particle Flow and mW estimators*

DELPHI note 2003-042 CONF 662, 12 June 2003 V. Obraztsov, S. Slabospitsky, O. Yushchenko, S. Andringa, M. Espírito Santo, P. Gonçalves, A. Onofre, M. Pimenta, B. Tomé *Search for single top production via FCNC at LEP sqrt(s)=189-208 GeV*

DELPHI note 2003-043 CONF 663, 24 June 2003 S. Andringa, M. Espírito Santo, P. Gonçalves, A. Onofre, M. Pimenta, B. Tomé *Search for a fermiophobic Higgs at LEP2*
DELPHI note 2003-048 CONF 668, 24 June 2003 S. Andringa, N. Castro, M. Espírito Santo, P. Gonçalves, O. Oliveira, S. M. Oliveira, A. Onofre, M. Pimenta, R. Santos, B. Tomé, F. Veloso *Search for a 4th generation b'-quark at LEP-II at sqrt(s)=196-209 GeV*

DELPHI note 2003-050 CONF 670, 23 June 2003 J. Abdallah, , M. Espírito Santo, , A. J. Washbrook *Searches for supersymmetric particles in e+e- collisions up to 208 GeV and interpretation of the results within the MSSM*
DELPHI note 2003-051 CONF 672, 19 June 2003 S. Andringa, , O. Yushchenko *Measurement of Trilinear Gauge Boson Couplings in e^+e^- collisions at 189-209 GeV*

DELPHI note 2003-059 CONF 679, 24 June 2003

DELPHI Collaboration (, S. Andringa,) *Measurement of the e+e- -> W+W- gamma Cross-section and Limits on Anomalous Quartic Gauge Couplings with DELPHI*

DELPHI note 2003-066 PROG 245, 26 August 2003 S. Andringa, P. Bambade, J. Holt, U. Schwickerath *Implementation of KK for DELPHI (DELKK version 4.14/6)*

Conferences:

Lake Louise Winter Institute, February 2003, Lake Louise, Alberta, Canada Nuno Castro, *Search for a 4^{th} Generation b'-quark at LEP*

Fourth International Conference on Physics Beyond the Standard Model "Beyond the Desert'03", June 2003, Ringberg Castle, Tegernsee, Germany Sofia Andringa, *Searches for Exotica in DELPHI*

PROGRESS REPORT

Project Title: **Collaboration in the EUSO experiment**

Team

Project Coordinator: Mário Pimenta

PhD:

Mário Pimenta,	40%
Maria Catarina Espírito Santo,	60%
Pedro Abreu,	30%
Bernardo Tomé,	30%
António Onofre,	10%
Luís Melo,	10%
Pedro Brogueira,	10%
Jorge Gomes,	10%

Students:

Pedro Assis (undergraduate),	100%

Resumo

A experiência EUSO destina-se a estudar a radiação cósmica de mais alta energia existente no Universo, medindo a sua energia e investigando a sua origem e composição, e podendo assim desempenhar um papel preponderante nos domínios da astrofísica, física de partículas e cosmologia. EUSO vai observar, a partir do Espaço, a luz de fluorescência induzida pela interacção de raios cósmicos de muito alta energia na atmosfera terrestre. Este princípio de observação inovador permite obter um detector de grandes dimensões (a própria atmosfera da Terra) necessário para compensar o muito baixo fluxo de raios cósmicos de energia extrema. O instrumento científico de EUSO é basicamente um telescópio ultravioleta, a ser instalado na Estação Espacial Internacional (ISS) e apontado para a Terra. Neste Plano de Actividades apresentam-se as principais responsabilidades do grupo do LIP em EUSO, bem como as linhas de acção para o ano de 2004. O grupo Português é responsável por todos os estudos referentes ao desenvolvimento do segmento de Terra científico da missão, o SODC-*Science Operations and Data Centre*, e tem neste momento o apoio da colaboração para ser o país de acolhimento deste centro. O grupo do LIP participa ainda num programa de actividades experimentais com o objectivo de medir diversos parâmetros cruciais para EUSO. Entre elas destaca-se o projecto ULTRA-*UV Light Transmission and Reflection in the Atmosphere*, em que o desenvolvimento do sistema de aquisição de dados e do sistema de posicionamento e sincronização são da nossa responsabilidade. ULTRA deverá tomar dados durante o ano de 2004. O grupo do LIP participa ainda no desenvolvimento do software de simulação e reconstrução para EUSO, devendo a importância desta actividade crescer em 2004. Encontram-se ainda em curso estudos de viabilidade relativos à utilização de câmaras de infravermelhos em EUSO, dado que o conhecimento das características atmosféricas, em particular da

cobertura de nuvens, é importante para a precisão das medidas efectuadas por EUSO. Finalmente, o grupo participa em actividades de divulgação e comunicação.

Summary of activities:

EUSO, the Extreme Universe Space Observatory, is a mission devoted to the exploration of the highest energy processes present and accessible in the Universe. The detector will be placed in the International Space Station (ISS) pointing towards the Earth, and uses the atmosphere as a *calorimeter* for particles with energies in excess of about $5x10^{19}$ eV. The EUSO instrument will detect these Extreme Energy Cosmic Rays (EECR) and neutrinos, indicative of unknown particle production and acceleration mechanisms in the Universe.
EUSO was approved by the European Space Agency (ESA) for a phase A study as external payload of the european modulus of the International Space Station (Columbus External Payload Facility). The phase A study started in March 2002 and will end in April 2004.
During phase A, LIP is responsible for the coordination of the EUSO Science and Operations Data Centre subsystem (SODC), and participates also in a program of experimental support activities, performing various studies of critical parameters for EUSO, namely the ULTRA project and the BABY experiment. Preliminary studies on atmospheric sounding were performed, and activities for public and education outreach were carried out.

SODC – Science Operations and Data Centre

LIP is, at present, responsible for the coordination of the EUSO Science Operations and Data Centre (SODC). The SODC constitutes the EUSO scientific Ground Segment. It ensures the scientific mission control and planning and addresses the issues of data collection, monitoring, distribution and archiving.
The SODC life cycle will accompany the mission life cycle and can be generically divided into the following phases: definition, design, implementation, validation, commissioning, in-flight operations and post-operation. The SODC should in all phases provide adequate support to the user community.
The main topics for the EUSO SODC phase-A study were:

- identification of the Columbus/ISS operation context;
- preliminary evaluation of data volumes;
- identification of the operation modes and procedures;
- conceptual design of the ground data handling facilities;
- archive and database preliminary planning;
- preliminary evaluation of costs and manpower.

The studies corresponding to these topics were carried out and are summarised in the report "*EUSO operations: flight and ground* ". Starting from the general operations scenario and space/ground interplay, an integrated operations concept for EUSO was outlined. This was essencial for the preliminary definition of the needs in terms of telemetry resources and for the specification of the SODC functionalities. generic level. The basic functional blocks of the SODC can be divided in three basic units:

- Telecommand generation, mission planning and system maintenance;
- Telemetry reception, processing and monitoring;
- Mission archive and database, external database handling, user support.

Each of these units includes a number of different modules and functionalities, which were outlined during Phase A. The EUSO requirements in terms of telemetry resources were then estimated. A preliminary estimation of the SODC budgets in terms of manpower and costs was also performed.
EUSO operations were presented in a parallel session in the 28th International Cosmic Rays Conference that took place in Tsukuba, Japan, in July 2003. The SODC was presented in a poster session in the same conference.

ULTRA – Ultraviolet Light Transmission and Reflection in the Atmosphere

The ULTRA experiment has been designed to provide quantitative measurements of the reflection/diffusion signal produced by EAS impacting on the Earth surface, overcoming the lack of information in this specific field. A scintillator array and UV light detectors will operate simultaneously, to detect EAS in coincidence with the UV light reflected/diffused from its impact on Earth. The atmospheric transmission properties will also be studied using the UV light detectors and a laser emitter.
The LIP team is responsible for the data acquisition system and the synchronisation of the experiment. A prototype PCI-based board for data acquisition and for time-tagging the arrival of the EAS, using Global Positioning satellite System (GPS) receivers was produced. This method enables a wireless synchronization of the cells of the array.
The ULTRA data acquisition system is composed of several units (one unit per station giving a time-tag for each event in that station), and the time differences between the several stations in the same event are computed offline. Each unit consists of a low-cost , commercial, GPS receiver, the developped PCI board and a personal computer. The PCI board performs the fine time-tagging and also acquires the signals from the photomultipliers of the array cells. The signals from the photomultipliers are shaped, amplified and then digitized onboard by a 10 bits flash ADC with a frequency of 100 MHz. A digital trigger enables to implement several online trigger conditions. On a trigger, the data is stored in the onboard memory. The board control and data readout is performed using the PCI bus. The overall time accuracy was estimated to be better than 5 ns. The system has successfully acquired and pre-processed the collected data, in two ULTRA engineering runs that took place in the Autumn of 2002 and in June 2003, in Mont-Cenis in the French Alps.
This method was presented in a poster session in the 28th International Cosmic Rays Conference, that took place in Tsukuba, Japan, in July 2003, and a presentation of the ULTRA experiment was given in a parallel session in the 28th International Cosmic Rays Conference (Tsukuba, Japan, July 2003).

BABY – Balloon experiment for background measurements

BABY was set up by members of the EUSO Palermo group as a calibration experiments to measure the UV background in the atmosphere. Flights took place in 2001 and 2002. BABY looked downwards from about 40 km of altitute over land and sea, in moonless nights. Measuring the light in the 300-400 nm band and in 3 narrow bands centred in the emission lines of the nitrogen molecules, with pairs of photomultipliers using both charge

integration and single photoelectron counting, an estimate of the background over the sea of 300 photons·m^{-2}·sr^{-1}·ns^{-1} was obtained.
The data collected in these runs were analysed with collaboration of LIP members, and the results were presented and discussed in the group. These results were presented in a poster session in the 28th International Cosmic Rays Conference (Tsukuba, July 2003).

Atmosphere Sounding – Studying the Atmosphere properties as an active medium

The knowledge of the atmosphere properties, in particular of the presence and height of clouds, which may obscure part of the fluorescence signal and of the _erenkov signal, are crucial for the accurate measurement of the cosmic ray energy and arrival direction. A preliminary study on the use of infrared cameras in EUSO was carried out, and a report was produced in 2003. The study included also a method to extract the distance from the EUSO/ISS to the cloud by stereoscopic vision (triangulation), based on images of the same cloud taken at two different times. Under general assumptions, an estimate of the error in the determination of the height of clouds of about 500 m was obtained, as well as the dependence of this error on the height of the cloud.
The possible different algorithms for image analysis and processing, namely regarding cloud detection, reconstruction and tracking, were evaluated. Simulation and reconstruction software development is under way.

EUSO - Public Education and Outreach

The EUSO experiment is a project of fundamental science that implies, simultaneously, technical development in the area of electronics, software and detectors. Exploring the highest energy objects ever measured, deeply related to the frontier of our knowledge of the Universe, and using an innovative observation principle from space, EUSO has a large outreach potential. The education and public outreach activities included several seminars for students and teachers, and a collaboration with the project TRC-Cosmic Rays Telescope to run a cosmic ray detector (Scintillating detectors and an acquisition system) in high schools. Other education and public outreach activities are envisaged in the scope of the participation of LIP in the EUSO experiment. A group within the EUSO Collaboration was set-up and has provided a preliminary report of the Education and Public Outreach activities within EUSO (EUSO-EPO-DD-001, June 2003).

Academic Training Program:

"Data acquisition system for the Ultra experiment" – Master Thesis – Pedro Assis, conclusion foreseen in Spring 2004.

Publications: (members of LIP are underligned)

Reports

M. C. Espírito Santo, M. Pimenta,
"EUSO Operations: flight and ground", EUSO-SODC/SP-003-2.A, Sep.2003.
O. Catalano, P. Vallania, D. Lebrun, P. Stassi, M. C. Espírito Santo, M. Pimenta, "ULTRA Technical Report", EUSO-SEA-REP-001-1, Sep. 2003. P. Abreu, A. Anzalone,

O. Catalano, M. Pimenta, "The possible use of IR cameras in EUSO", EUSO-SDA-REP-012-1, May 2003.

Conferences (the speaker/responsible author is underlined):

O. Catalano, M.C. Espírito Santo, G. Gugliotta, M. Pimenta, P. Tua (EUSO Collab.), "EUSO Operations: Flight and Ground", oral presentation in the 28th International Cosmic Ray Conference, Tsukuba, Japan, July '03.

M. C. Espírito Santo, J. Gomes, M. Pimenta (EUSO Collab.), "The EUSO Science Operations and Data Centre", poster presentation in the conference 28th International Cosmic Ray Conference, Tsukuba, Japan, July '03.

P. Assis, P. Brogueira, L. Melo, M. Pimenta, J. C. Silva, J. Varela, "A PCI based Data Acquisition System for Ground Array Detectors with Wireless Synchronization through GPS", poster presentation in the 28th International Cosmic Ray Conference, Tsukuba, Japan, July '03.

G.Agnetta, P.Assis, C.Berat, B.Biondo, P.Brogueira, A.Cappa, O.Catalano, G.D'Alí Staiti, M.C.Espírito-Santo, L.Fava, M.Gabriele, P.Galeotti, S.Giarrusso, G.Gugliotta, D.Lebrun, A.Mangano, L. Melo, M.Pimenta, F.Russo, O.Saavedra, P.Scarsi, J.C. Silva, P.Stassi, D.Teyssier, B.Tomé, P.Vallania, and C.Vigorito (EUSO Collab.), "The ULTRA Experiment: a support activity for the Euso Project", poster presentation in the 28th International Cosmic Ray Conference, Tsukuba, Japan, July '03.

S. Giarrusso, G.Gugliotta, G.Agnetta, P.Assis, B.Biondo, O.Catalano, F.Celi, G.Cusumano, G.D'Alí Staiti, R.Di Raffaele, M.C.Espírito-Santo, M.Gabriele, G.La Rosa, M.C.Maccarone, A.Mangano, T.Mineo, M.Pimenta, F.Russo, B.Sacco, A.Santangelo, P.Scarsi, B.Tomé (EUSO Collab.), "Measurements of the UV Nocturnal Atmospheric Background in the 300-400 nm Wavelength Band with the Experiment BaBy during a Transmediterranean Balloon Flight", poster presentation in the 28th International Cosmic Ray Conference, Tsukuba, Japan, July '03.

PROGRESS REPORT

Project Title: **Collaboration in the NA50 Experiment**

Team:

Project Coordinator
Paula Bordalo

PhD

Paula Bordalo	LIP Researcher / IST Professor	25%
Sérgio Ramos	LIP Researcher / IST Professor	25%
Catarina Quintans	LIP Researcher	17%
Ruben Shahoyan	LIP Researcher	17%
Pedro Rato	LIP Researcher	17%

Students

Helena Santos	PhD Student	100%
Gonçalo Borges	PhD Student	100%
João Cruz	LIP Research Assist / FCUNL Assist	25%

Report:

Sumário

A experiência NA50 é uma colaboração internacional de cerca de 100 físicos oriundos de doze Laboratórios e Universidades Europeus que se desenrola junto do acelerador SPS (Super Proton-Synchroton) do CERN. Estuda colisões ultrarelativistas de feixes de iões de chumbo e protões com alvos pesados, através da produção de pares de muões correlacionados com a energia transversa neutra do evento, com a multiplicidade das partículas secundárias carregadas e com a energia incidente não envolvida na interacção.

NA50 tem por objectivo a pesquisa de um novo estado da matéria, o Plasma de Quarks e Gluões (QGP), através do estudo das suas características, nomeadamente a temperatura e a densidade bariónica correspondentes à transição da fase hadrónica para a de plasma. As assinaturas que têm vindo a ser estudadas são as supressões do ψ e do ψ', o aumento de produção do ϕ, bem como o excesso de dimuões na região de massa intermédia.

A presente Proposta é a continuação dos Projectos anteriormente financiados e visa essencialmente o prosseguimento da análise de dados, nas suas diferentes vertentes.
Os principais resultados obtidos no decurso de anteriores tomadas de dados, bem como na experiência precedente NA38, foram:

- a supressão normal do ψ, i.e., a sua absorção por outras partículas secundárias que o acompanham (comovers, para as quais é preciso postular uma grande densidade, várias vezes superior à densidade nuclear)
- a supressão do Psi', em reacções induzidas por iões (enxofre, urânio), contrastando com a sua produção normal em colisões protão-núcleo
- aumento da produção do ϕ para sistemas de maior número de massa e com a centralidade da colisão
- excesso de produção de dimuões na região de massas intermédias (entre as ressonâncias ϕ e ψ), em relação às fontes conhecidas.

Estes interessantes resultados permitiam antever que a experiência NA50, com o acumular de estatística de qualidade, tanto em interacções centrais como em periféricas, pudesse vir a detectar efeitos da formação do plasma de quarks e gluões.

Na realidade, um importante resultado foi recentemente obtido, nomeadamente um efeito de limiar na supressão anómala do Psi em interacções chumbo-chumbo o que, por si só e também conjugado com os resultados precedentes, obtidos por NA38, e relativos a outros sistemas (p-N, O-U, S-U), é naturalmente explicado no quadro da formação de QGP, e constitui pois um grande desafio para os que tinham proposto explicações hadrónicas 'clássicas' para os efeitos previamente observados em NA38.

Com a análise dos últimos dados adquiridos, em que se usou um alvo de Pb no vácuo, procura-se clarificar melhor o comportamento da supressão do ψ, quer em colisões periféricas, quer em colisões centrais.

Pretende-se ainda, agora que os métodos de análise atingiram a sua máxima sofisticação, fazer um estudo sistemático de todos os conjuntos de dados de NA50.

Summary of Activities

The Lead Beam Acceleration Program started at CERN in 1992, its aim being the search of a new state of matter, the quark-gluon plasma (QGP), as well as the study of nuclear matter at high density. It came after the Exploratory Ultrarelativistic Ion Acceleration CERN Program, whose data taking periods with oxigen and sulphur beams took place from 1986 till 1992. LIP has been participating in these Ion Programs included in the NA38 and NA50 experiments.
Our group represents 20% and 15%, respectively, of the total Collaboration's members.

The study of QGP signals, together with nuclear collective flow phenomena, is performed in NA38/NA50 by means of muon pair detection (muon spectrometer) in correlation with the neutral transverse energy released (electromagnetic calorimeter), the charged particle multiplicity (multiplicity detector) and the spectators' energy (zero degree calorimeter).
The NA50 experiment took data during several years, with ion and proton beams, from 1994 till 2001. The tasks and responsibilities concerning the previous phases of the experiment, concerning its design and run, were already extensively reported.

Here, we just concentrate on the tasks of our responsibility concerning the year 2003:

- Participation in the Collaboration and Steering Committee meetings

- Participation in specific technical analysis meetings

- Contribution to lead and proton induced data analyses:

    - Comparative study of ψ and ψ' production and of the ratio ψ'/ ψ, in p-A, using different targets, and S-U interactions (in order to establish ψ and ψ' baseline productions)
    - Study of charmonia suppression in lead-lead collisions, namely the ψ' production as a function of centrality
    - Comparison among the three years of analysis concerning the low-mass resonances production, as functions of centrality and of transverse momentum.

The two first subjects have lead to communications presented in January to the 2004 Quark Matter Conference (the most important one in our field). The two LIP PhD students working on these subjects have been the only NA50 representatives giving presentations at this important Conference.

Academic Training

- Helena Santos, "Study of high-mass vector-meson production in lead-lead collisions at ultra-relativistic energies", PhD Thesis, in progress.
- Gonçalo Borges, "Study of charmonia production in collisions of protons with different targets and in S-U interactions", PhD Thesis, in progress.

Publications

- " ϕ production in Pb-Pb collisions at 158 GeV/c per nucleon incident momentum", Physics Letters B 555 (2003) 147.
- "Charmonia and Drell-Yan production in proton-nucleus collisions at the CERN SPS", Physics Letters B 553 (2003) 167.

Conferences

- "Transverse momentum and transverse mass distributions of J/psi mesons produced in p-A and Pb-Pb interactions at the CERN SPS", to be published in the

XVI International Conference on Particles and Nuclei, PANIC02, September 2002, Osaka, Japan.

- ”Latest results on J/ ψ anomalous suppression”, to be published in the IX International Symposium on Particles, Strings and Cosmology, PASCOS03, January 2003, Bombay, India.

- ”Recent results on J/ ψ suppression from the NA50 experiment”, to be published in XLI International Winter Meeting on Nuclear Physics, January 2003, Bormio, Italy.

- ”Latest results on J/ ψ suppression”, to be published in the 19th Winter Workshop on

Nuclear Dynamics, February 2003, Breckenridge, Colorado, U.S.A.

- ”The production of ϕ, ω and ρ mesons in p, d, S and Pb-induced reactions at the CERN SPS”, to be published in the 7th International Conference on Strangeness in Quark Matter, March 2003, Atlantic Beach, North Carolina, U.S.A.

- ”Recent results on anomalous J/ ψ suppression in Pb-Pb collisions at 158 GeV/c per

nucleon”, to be published in the XXXVIII Rencontres de Moriond, March 2003, Les Arcs, France.

- ” ψ’ production in nucleus-nucleus collisions at the NA50/SPS CERN experiment”, to be published in Proc. of Quark Matter 2004, January 2004, Oakland, U.S.A. .

1. ”J/ ψ and ψ’ nuclear absorption in p-A and S-U collisions at the CERN SPS”, to be published in Proc. of Quark Matter 2004, January 2004, Oakland, U.S.A. .

PROGRESS REPORT

Project Title: Cosmic Rays Telescope – Ciência Viva

Team

Project Coordinator: João Varela

PhD:

João Varela,	20%
Fernando Barão,	10%

Students:

João Pires (since Sep 03)	100%
Catarina Pereira,	50%
Rui Pereira	50%
Teresa Correia	50%

Technical Staff:

Miguel Ferreira,	50%
José Carlos da Silva,	20%
José Carlos Nogueira,	20%

Resumo:

O objectivo do projecto é a construção, instalação e operação de uma rede de detectores de raios cósmicos em 10 escolas de ensino secundário, formando um telescópio para a observação de partículas cósmicas de muito alta energia que interagem na atmosfera terrestre. Em cada escola a estação de detecção é operada e monitorada por uma equipa de alunos com a supervisão de um ou mais professores.

Durante o ano de 2003, foram concluídos os desenvolvimentos tecnológicos para o protótipo das estações de detecção. A estação central do telescópio foi instalada no telhado do Instituto Superior Técnico e as estações a instalar em 2004 nas escolas foram produzidas e testadas em laboratório. Ao longo do ano realizaram-se vários encontros de trabalho com alunos e professores. Realizou-se ainda um curso de 3 dias com uma forte componente laboratorial baseada nos detectores de raios cósmicos, destinado aos professores participantes no projecto

Summary of activities:

The objective of the project is the construction, installation and operation of a Cosmic Rays detector network in a widely separated set of secondary schools. The detector network allows the measurement of the characteristics of high-energy particles impinging

our planet, looking for long-distance correlations between data collected by the network stations.

In the year 2003, the following activities were carried out:

- Development of the detecting system,
- Comissioning and operation of the central station at the roof of Instituto Superior Técnico,
- Comissioning of the schools stations in the laboratory,
- Development, finalisation and comissioning of the LIP-PAD data acquisition card,
- Development, finalisation and comissioning of the high-voltage supply and temperature monitoring box,
- Development and test of the data acquisition system in LABview,
- Development of the analysis program in the ROOT environment,
- Setup in the laboratory of 6 stations for training purposes,
- Organization of several meetings with teachers and students,
- Organisation of a 3 days course with the participation of 40 high-school teachers.

Project Goals:
To reinforce experimental physics teaching in secondary schools, using relatively simple research equipment;
To introduce front-line research topics in particle physics, astrophysics and cosmology, to secondary school students, based on an experimental approach;
To promote a practice of strong bilateral collaboration between researchers and secondary school teachers;
To give secondary school teachers an opportunity of participation in a scientific project.

Scientific motivation:
The observation and measurement of high energy particles impinging the Earth is a recent research topic, which has motivations both from cosmology and particle physics. The origin of ultra high energy cosmic rays ($>10^{18}$ eV) is unknown and misterious. Gigantic cosmic events, like collisions of galaxies, relics of ultra-heavy particles created in the first moments of the universe expansion, or large scale topological structures in the universe, have been proposed to explain its origin. However, none of these models fully account for all the observations.

Several large scale scientific projects (Auger, Euso) are now in construction or in preparation to study the phenomenon in more detail. Our project fits in this context, mimicking in a smaller scale these large research enterprises. Very high energy cosmic rays can be detected by the Cosmic Ray Telescope providing an opportunity for confrontation of results.

Pedagogical motivation:
The scientific motivations depicted above constitute also an important lever to motivate the participation of high-school teachers and students. In this project their participation was sought with relative success, and ten high-schools have been engaged. Thus an array can be constituted by using the roofs or yards of the high-schools, with the teachers and the students operating the local detecting station.

This project has become an important part of the outreach activities in experimental particle physics, also coordinated by LIP and described elsewhere in this report.

Main developments:
The main developments in 2003 were concentrated in the comissioning and delivery of the detecting stations. After an initial setup built in the roof of Instituto Superior Técnico, used for testing the data acquisition system, the analysis program, and all the mechanics needed to maintain the stability of the detecting station, the characteristics of the local station in each school were determined, and the equipments needed were bought and delivered to the laboratory.
During this period the data acquisition card was designed, developped, and after prototype tests, sent for production by a portuguese electronics company. The card, built to interface the PCI bus of a small personal computer, is able to acquire and pre-process the signals of 6 different photomultipliers, with the possibility of coincidence, has a 100 MHz sampling rate, 10 bits dynamic range, and is able to accept an outside trigger and GPS signals for time-tagging the accepted events.

In October, a 3-days training course was organized, with three theoretical sessions in the mornings, and three 'hands-on' pratical sessions in the afternoons. The course was directed to the high-school teachers, and had the participation of about 40 teachers from the high-schools involved in the project. In the theoretical sessions were addressed the basic principles of particle physics, astrophysics and cosmology, cosmic rays interaction with the atmosphere, and detection of high energy particles (with the help of plastic scintillators and photomultipliers). In the pratical sessions, held in the laboratory with 6 complete stations, the teachers were organized in groups and performed different experiments with the setup, that will be installed later in their high-schools.

Participating Institutions:
Escola Secundária D. Pedro V, Sete Rios, Lisboa
Escola Secundária José Gomes Ferreira, Benfica, Lisboa
Escola Secundária Gil Vicente, Graça, Lisboa
Escola Secundária Maria Amália Vaz de Carvalho, Amoreiras, Lisboa
Escola Secundária da Amadora, Reboleira, Amadora
Escola Secundária Herculano de Carvalho, Olivais, Lisboa
Escola Secundária Luís de Freitas Branco, Paço de Arcos
Escola Secundária de Mem Martins, Mem Martins
Escola Secundária Diogo de Gouveia, Beja
Escola Secundária D. Manuel I, Beja
IST – Instituto Superior Técnico, Lisboa
LIP – Laboratório de Instrumentação e Física Experimental de Partículas

Project Title:
Development of Positron Emission Mammography

Project Coordinator:

João Varela	PhD Physicist, Professor IST, Lisbon

Members LIP-Lisboa:

João Varela	PhD Physicist, Professor IST, Lisbon
Rui Ribeiro	PhD Physicist, Professor FEUP, Porto
Luís Peralta	PhD Physicist, Professor FCUL, Lisbon
Sérgio Ramos	PhD Physicist, Professor IST, Lisbon
Paula Bordalo	PhD Physicist, Professor IST, Lisbon
Pedro Rodrigues	PhD Student Physicist
Andreia Trindade	PhD Student Physicist
Rui Moura	PhD Student Physicist
Catarina Ortigão	PhD Student Physicist

Members LIP-Algarve:

Conceição Abreu	PhD Physicist, Professor Univ. Algarve
Pedro Rato Mendes	PhD Physicist
Bruno Carriço	Master Student Physicist
Patrick Sousa	Physicist

Members LIP-Coimbra:

Francisco Fraga	PhD Physicist, Professor Univ. Coimbra
Susete Fetal	Master Physicist
Filipa Balau	Master Student Physicist

Resumo:

A elevada incidência de cancro da mama e a relativa inadequação dos métodos tradicionais de detecção (em particular a mamografia de raios-X) apontam para a necessidade de técnicas e de equipamentos específicos com desempenho complementar. Este projecto visa responder a esta necessidade, propondo um novo equipamento PET, compacto e económico, baseado na detecção de fotões gama resultantes do decaímento de um átomo emissor de positrões.
O equipamento proposto decorrerá de investigação científica e de desenvolvimento tecnológico desde a investigação até ao pré-protótipo para realização de testes clínicos,

estando envolvidos no projecto cerca de 50 pessoas de 7 instituições. O LIP assegura a coordenação científica do projecto.

O projecto iniciou-se em Janeiro de 2003. O primeiro ano de actividade foi dedicado ao desenvolvimento do conceito do detector e à demonstração dos princípios básicos do sistema utilizando simulação Monte Carlo e medidas experimentais.

1. Introduction

The development of PET (Positron Emission Tomography) technology applied to the detection of breast cancer is the objective of a project being carried out by the Consortium PET-Mammography. The high incidence of breast cancer and the relative inefficiency of the conventional detection methods (X-ray and ultrasound mammography) suggest the need for better imaging techniques and improved equipment. The project answers this need by developing new equipment with higher sensitivity for beast cancer detection.

The project started in January 2003 and it is foreseen to last three years. The first year was dedicated to the development of the detector concept and to prove the basic principles by simulation and experimental methods.

2. Project Description

Breast cancer is the most frequent malign neoplasm in women. According to the American Cancer Society, 1 in 9 women will develop invasive breast cancer during their life. Conventional X-ray mammography has detection limitations especially in dense breast tissues. According to published results, the overall sensitivity for cancer tumor detection is around 80%, depending on the type of breast. For dense breasts the sensitivity drops to 70% with a lower limit in size for a detectable tumor of 10 to 20 mm. The same limitations occur with complementary approaches as ultrasound imaging. On the other hand, current methods have a high rate of false positive results: 60 to 85% of the biopsies following an imaging indication obtained with X-rays or ultrasounds do no correspond to malign pathology.

The Positron Emission Mammograph (PEM) prototype developed in this project is intended to evaluate PET technology in the diagnosis of malign neoplasm in the breast and of ganglion loco-regional invasion. PET (Positron Emission Tomography) is an image technique used in the detection and characterization of malign carcinoma. It consists in the injection of a substance labeled with a positron emitter (usually ^{18}F-fluoro-deoxy-glucose, FDG) and in the detection of photons emitted in opposite directions. Since there is an increase in glucose consumption in cancer cells, FDG is an indirect marker of cell proliferation. The detection of the emitted photons allows the reconstruction of an image revealing the dimension and position of the tumor.

In what concerns breast cancer diagnosis, results obtained so far with whole body PET equipments and the FDG tracer are very positive despite of poor statistics. For localized breast cancer, the sensitivity varies between 77% and 100%, and the specificity between 88% and 100%, independently of breast density. However whole body PET systems are expensive and bulky and not adapted to a systematic screening. Because of their open geometry they are also very sensitive to the background emitted from the chest which reduces the detection sensitivity in the breast. Moreover, the spatial resolution and rate performance are still poor.

Relative to whole body PET, the dedicated Positron Emission Mammograph is expected to improve significantly the sensitivity to breast cancer in particular to small tumors. The new equipment is expected to have an image resolution of the order of 1-2 mm and to achieve a very high data acquisition rate, improving the detectability of small (~ 1 mm) tumors by more than two orders of magnitude. The expected performance of the device will allow also to reduce the injected doses and to shorten considerably the examination time, when compared to the present PET exams. Furthermore, the Positron Emission Mammograph is a compact equipment, more economic that the present whole body PET systems.

Technological developments in various complementary areas are underway. High density and fast scintillation crystals coupled to special photosensors are exploited to achieve the desired performance. Dedicated low-noise electronics and high-rate data acquisition systems allow boosting the sensitivity in a compact mechanical construction. Digital techniques are investigated to improve the time resolution and the rejection of uncorrelated photons. New image reconstruction algorithms adapted to the PEM geometry are being developed. Validation of the PEM technology will be obtained with clinical tests carried out with the new equipment.

3. Consortium PET-Mammography

The project *Development of Positron Emission Mammography* is a scientific and technological R&D activity carried out by the consortium PET-Mammography. The consortium, created in December 2002, is formed by seven institutions specialized in the areas of nuclear medicine, radiation detector physics, biophysics, medical engineering, electronics, computing and mechanical engineering.

LIP (Laboratory of Instrumentation and Particle Physics) assures the scientific coordination, and Tagusparque SA (Managing company of Taguspark-Lisboa Science and Technology Park) is the consortium promoter. The nuclear medicine and obstetrics departments of Hospital Garcia de Orta provide medical and clinical expertise. IBEB (Institute of Biophysics and Biomedical Engineering) of the Lisbon Faculty of Sciences and IBILI (Institute for Research in Medical Imaging) of the Coimbra Faculty of Medicine contribute with expertise in medical imaging systems and techniques. INOV (Institute of New Technologies) and INESC-ID (Institute of Systems and Computers Engineering - Research and Development) develop the electronics and data acquisition systems, and INEGI (Institute of Industrial Management Engineering) is responsible for the mechanical and electro-mechanical systems. Table 1 summarizes the functions of the consortium members. Figures 1 and 2 show the structure of the project coordination boards. There are about 50 people involved in the project, from research students to physicist, engineers and medical doctors.

The laboratory tests of the PEM equipment will be done in TagusLIP, a new laboratory being installed in Taguspark and dedicated to the development of medical equipment. The detector characterization is accomplished in LIP-Coimbra and LIP/Pólo Algarve. The clinical tests will be done in Hospital Garcia Orta.

The consortium collaborates with CERN in the framework of an international scientific collaboration named Crystal Clear. The Crystal Clear Collaboration is organized as a federation of national projects connected to a coordination center at CERN. The head office at CERN assures the coordination between the national projects and provides scientific and technological support.

The consortium is financed by AdI (Innovation Agency) and POSI (Operational Program for Information Society) in Portugal, through a research contract signed in July 2003.

Table1 – Functions of the members of the consortium PET-Mammography

Consortium PET-Mammography	
Institution	Functions
Tagusparque SA	Promoter. Project management. Organization of the clinical tests and certification of the PEM equipment. Technology transfer.
LIP	Scientific coordination. Simulation. Detector modules. Module quality control. Laboratory tests of prototypes. Specification of electronics and data acquisition systems. High voltage system. Temperature monitoring.
HGO	Clinical requirements of PEM equipment. Clinical tests.
IBEB	Image reconstruction software. Image visualization software. Clinical tests follow-up.
IBILI	Data acquisition and operation software. Image reconstruction software. Procurement of PET tracers.
INESC-ID/INOV	Development of the front-end electronics. Development and construction of the data acquisition system hardware.
INEGI	Design and construction of the mechanical structures. Electro-mechanical control system.

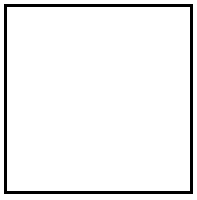

Figure 1 – Management Board

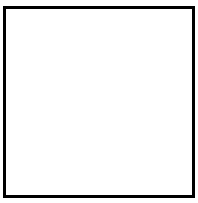

Figure 2 – Technical Board

4. Activities in 2003

4.1 Clinical Specifications

Based on the outcome of the International Workshop on Positron Emission Mammography organized in Lisbon in July 2002 and on further detailed analysis of the clinical aspects of PEM, a consortium internal document on the clinical specifications was produced.

4.2 Simulation

The PEM simulation framework based on Geant4 was developed. The system includes the phantom simulation (in particular a 3D breast phantom based on MRI images), detector simulation with a detailed description of the detector geometry and materials, and the simulation of the electronics signal processing, digitization, trigger and data acquisition.

Preliminary results of the PEM performance were obtained with a simplified geometrical description of the detector. Results on sensitivity, resolution and random coincidences, confirm the performance required by the clinical specifications. New results with the detailed simulation are now being obtained.

4.3 Prototypes development

Measurements performed in collaboration between LIP-Lisbon and LIP-Coimbra show a precision of the order of 1 mm in the determination of the photon detection coordinates. The photon detection is based on a new technique developed in the project and aiming at high-resolution and high-sensitivity Positron Emission Mammography (PEM).

These laboratory measurements confirm the results obtained previously with a computational model and show that in principle it is possible to achieve high-resolution PEM images. At this stage the measurements alone do not constitute a proof that PEM

will have one millimeter resolution. However, they validate a necessary and very important condition for the final goal to be achieved.
Detector characterization was carried out at LIP-Algarve. The test system was installed and the first measurements of a LYSO crystal matrix and of the Hamamatsu APD array S8550 were carried out successfully.

4.4 Analog Electronics

The specification of a front-chip appropriate for PEM was produced by LIP. The chip design started in September at INESC-ID. Low power consumption and low noise are major requirements for the front-end electronics. The circuit diagram includes several analog blocks (input amplifier, analog memory, comparator, output amplifier) and digital block for control.

4.5 Data Acquisition Electronics

The specification of the data acquisition and trigger system was produced by LIP. The system design is developed at INESC-ID and the architectural design was concluded. The system is based in two PCI buses and two auxiliary buses implementing an asynchronous architecture. Design and simulation of the FPGAs implementing data acquisition and trigger algorithms was well advanced. Simulations showed a performance above the design frequency of 100 MHz.

4.6 Mechanical Systems

Based on the clinical specifications document, the design of the mechanical systems was started at INEGI. The first studies aimed at a better understanding of the required detector movements.
In parallel, a detailed concept for assembling the detector plates was developed by LIP in collaboration with INEGI.

4.7 Reconstruction Software

An iterative image reconstruction method (ART) suitable for parallel plates was developed at IBEB. The first implementation tested with simulation data of a simplified detector version showed improved performance relative to the standard FBP method. LIP participated in this work preparing the simulation files needed for the reconstruction tests.

4.8 TagusLIP

LIP and Taguspark joined efforts for the installation of a new laboratory facility dedicated to the development of medical imaging equipment. A proposal for funding was submitted to the program LisAction and was approved. The certification of the infrastructure for work with radioactive materials was requested to the appropriate authorities.

Publications

[1] *Electronics and Data Acquisition in Radiation Detectors for Medical Imaging,*
J. Varela, invited talk, 2nd International Conference on Imaging Technologies in Biomedical Sciences (ITBS2003), Milos Island, Greece, May 2003. Accepted for publication in Nuclear Inst. and Methods in Physics Research, A.

[2] *Breast Imaging with a dedicated PEM*
R. Ribeiro, C. Abreu, P. Almeida, F. Balau, P. Bordalo, N.C. Ferreira, S. Fetal, F. Fraga, P. Lecoq, M. Martins, N. Matela, R. Moura, C. Ortigão, L.Peralta, S. Ramos, P. Rato, P. Rodrigues, A.I. Santos, A. Trindade, J. Varela, presented to 2nd International Conference on Imaging Technologies in Biomedical Sciences (ITBS2003), Milos Island, Greece, May 2003.

[3] *Clear-PEM: A dedicated PET camera for improved breast cancer detection,*
L. Peralta, C. Abreu, P. Almeida, F. Balau, P. Bordalo, N. C. Ferreira, S. Fetal, F. Fraga, M. Martins, N. Matela, R. Moura, S. Ramos, P. Rato, R. Ribeiro, P. Rodrigues, A.I. Santos, A. Trindade, J. Varela , submitted to 7th Portuguese Conference on Biomedical Engineering (BioEng'2003), Lisbon, June 2003.

[4] *ClearPEM - A new prototype for dedicated positron emission mammography,*
M. C. Abreu, P. Almeida, F. Balau, P. Bordalo, N. C. Ferreira, S. Fetal, F. Fraga, P. Lecoq, M. Martins, N. Matela, R. Moura, C. Ortigão, L. Peralta, S. Ramos, P. Rato Mendes, R. Ribeiro, P. Rodrigues, A. I. Santos, A. Trindade, J. Varela, submitted to 7th International Conference on Inorganic Scintillators and Industrial Applications (Scint2003), Valencia, 08-12 September 2003.

[5] *Clear-PEM: Monte Carlo Performance and Image Reconstruction Studies,* A. Trindade, P. Almeida, F. Balau, N. Ferreira, S. Fetal, F. Fraga, M. Martins, N. Matela, P. Mendes, R. Moura, C. Ortigão, L. Peralta, R. Ribeiro, P. Rodrigues, J. Varela, poster at IEEE-Medical Imaging Conference, Portland, October 2003.

[6] *GEANT4 Applications and Developments for Medical Physics Experiments,*
P. Rodrigues, R. Moura, L. Peralta, M. Grazia Pia, A. Trindade and J. Varela, submitted to IEEE-Nuclear Science Symposium, Portland, October 2003.

PROGRESS REPORT

Project Title: Development of radiation hard silicon detectors

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Team

Project Coordinator: Pedro F. P. Rato Mendes

PhD: Maria da Conceição Abreu (25%), Pedro Rato Mendes (25%)

PhD. Student: Patrick Sousa (25%)

M. Sc. Student: Sónia Rodrigues (100%)

Technical Staff: José Mariano (25%)

Sumário:

O projecto "Desenvolvimento de detectores de silício resistentes à radiação" é da responsabilidade do LIP - Laboratório de Instrumentação e Física Experimental de Partículas - no âmbito das actividades do laboratório do LIP sito na Universidade do Algarve, em Faro.

No campo dos detectores resistentes à radiação foi prosseguido o esforço iniciado pelo LIP em 1999 no âmbito da Colaboração RD39 do CERN, com o objectivo de avaliar quais os melhores materiais e electrónica de leitura para realizar detectores capazes de funcionar em ambientes de muito elevada radiação, como os previstos para os futuros colisionadores de física de altas energias. Este esforço faz parte de um projecto de investigação financiado pela FCT, do qual o Bolseiro é, desde Janeiro de 2002, o Investigador Responsável pela equipa portuguesa, tendo sido recentemente nomeado Basic Research Project Leader dentro de RD39, passando agora a fazer parte do comité executivo da Colaboração.
O trabalho realizado consistiu, na sua maior parte, na caracterização de várias amostras, nomeadamente díodos de silício irradiado e não-irradiado, com tratamentos de resistência à radiação como, por exemplo, a engenharia de defeitos no cristal de silício. As amostras foram caracterizadas a várias temperaturas e condições experimentais de modo a determinar quais os valores ideais dos parâmetros de operação, tendo-se chegado à conclusão que a temperatura optimal, para qual a eficiência de recolha de carga é a mais elevada, é próxima de 130 K, tendo detectores oxigenados uma eficiência superior a detectores normais em condições idênticas. Os novos dados recolhidos este ano confirmam a evidência já observada anteriormente.

Summary of activities:

1. Introduction

The main objective of the project "Development of radiation hard silicon detectors" is the characterization of sensors for tracking detectors capable of operating in extremely harsh radiation environments as those expected at future high-luminosity upgrades at the CERN LHC, such as the SuperLHC.

Presently, the research and development in the field of radiation-hard tracking detectors at CERN is being carried out by three large collaborations, all with the same final purpose but different methodologies: RD39 "Cryogenic tracking detectors", RD42 "Development of diamond tracking detectors for high luminosity experiments at the LHC" and RD50 "Radiation hard semiconductor devices for very high luminosity colliders". This project is part of the RD39 Collaboration effort, whose approach to the development of radiation-hard detectors is based on the so-called "Lazarus effect" [1,2] and the operation of silicon devices at cryogenic temperatures, typically 130 K. While RD42 and RD50 exploit new materials (diamond, silicon carbide) and techniques of defect engineering (introducing controlled defects into sensor materials), RD39 profits from the low-temperature properties of standard silicon. The possibilities of this approach have been well demonstrated in the past after microstrip detectors were operated at accumulated doses of 90 Grad [3] and pad detectors were shown to be still operational after fluences in excess of 10^{15} 1-MeV eq. neutrons per cm^2 [4].

The present and future program of RD39 considers three main lines of research, namely: Device Physics, Basic Research and Cryogenic Detector Modules [5,6]. The activities being carried out are, essentially, the characterization of new sensors at low temperatures and different irradiations (for example, oxygenated detectors or simpler sensors), the deeper understanding of the physics of radiation damage and cryogenic operation, and the development and construction of fully operational cryogenic detector modules, in collaboration with CERN experiments.

The LIP group contribution to the RD39 Collaboration program, made through this project, consists on the following: characterization of new sensor samples, understanding of polarization effects (time dependence of the charge collection efficiency in heavily irradiated silicon); development of edgeless detectors (that is, detectors without guard-ring structures on one side) to be used for charged particle tracking very close to the beam line, in collaboration with the TOTEM experiment at CERN; and (starting in 2003) using the data from charge collection efficiency measurements at low temperatures as a new technique for spectroscopy of deep levels in irradiated silicon, based on the Lazarus effect and polarization models [7,8].

2. Development of radiation hard silicon detectors

The activities related to the development of radiation hard silicon detectors are reported here for project tasks 1, 2 and 3.

Task 1 – "Instrumentation upgrade" and Task 3 – "Upgrade of cryogenic equipment"

The budget request presented with this research project featured a considerable fraction of funding for new instrumentation, as both the first and the third tasks proposed an upgrade of the existing experimental setup. This upgrade was duly justified by the fact that most instruments used by the LIP group belonged to the University of Algarve and were not always available when needed, and the requirements imposed by the new kinds of measurements foreseen, such as higher operating voltages and excitation of samples by x-rays instead of charged particles.

The budget allocated to this project for years 2002 and 2003 considered no significant funding for equipment, suggesting that such funding should be found elsewhere. The group requests were added to the LIP general re-equipment proposal submitted to FCT in April 2002, which still got no reply. Therefore, during 2003 all measurements were made with the existing equipment, no instrumentation upgrade being performed.

Task 2 – "Measurement and characterization of irradiated detectors"

The existing setup for measurement and characterization of irradiated detector samples at the LIP laboratory at the University of Algarve consists of a small volume cryostat (similar to the one described in [9]), readout electronics and an automated data acquisition system controlled by a PC running LabVIEW 6i from National Instruments. Presently, measurements can be made from room temperature down to 95 K with better than 0.1 K stability precision, at bias voltages up to ± 210 V.

The sample is placed inside the cryostat, sandwiched between a 0.1 mCi $^{90}Sr/^{90}Y$ beta source and a standard silicon diode acting as trigger, so that when a highly energetic electron from the source reaches the trigger diode, it has necessarily crossed the sample under study. The charge generated by ionization in the sample is then collected and sent to a PCI Multi Channel Analyzer card housed inside the PC. The charge spectrum thus accumulated is fitted with a Landau distribution (thin absorber limit) and compared with a reference spectrum taken from a non-irradiated detector of the same thickness, allowing an absolute determination of the charge collection efficiency (CCE) of the sample under study.

Several samples have been characterized at different temperatures and bias voltages using this technique, and data has been analyzed in the framework of the Lazarus and polarization models. The current-voltage characteristics of the samples were also measured at different operational conditions, and some of the samples have been characterized by TCT and DLTS within the RD39 Collaboration, namely by the Brookhaven National Laboratory (New York, USA) and Ioffe Physico-Technical Institute (St. Petersburg, Russia) groups.

a) CCE temperature dependence of irradiated samples

The results obtained from measuring the CCE of irradiated samples as a function of temperature indicate a general trend, with a maximum value observed at about 130 K, confirming the behavior already observed by the LIP group and other groups within RD39 in the past. A new feature of the data, observed firstly by the LIP in the beginning of 2001, has been confirmed during 2003 by other groups, namely the existence of a second high- efficiency peak at a temperature of about 175 K, separated from the 130 K

maximum by a low-efficiency valley at about 150 K. The interpretation of this more complex behavior has been addressed by the theoreticians from S. Petersburg, and is due to be published shortly.

At reverse bias, the bulk current decreases exponentially with the decreasing temperature, becoming low enough at 200 to 250 K (depending on the sample irradiation) to allow CCE measurements. Discarding polarization effects (to be addressed in the next section) the CCE increases with decreasing temperature, reaching a maximum at about 130 K for all kinds of samples and irradiations.
The absolute value of the CCE for the observed optimal temperature decreases with increasing fluence for similar samples, and is up to 30 % higher for oxygenated samples with respect to standard ones irradiated at the same equivalent fluence. For a given sample, the CCE increases with the applied bias because of the widening of the depletion layer with voltage and the consequent increase in the active detection volume.

Highly irradiated samples (fluences larger than 10^{14} 1-MeV eq. neutrons per cm^2) were also studied under forward bias – this type of operation being possible because of the high resistivity of the irradiated silicon bulk at low temperatures – yielding the same general behavior that was observed at reverse bias under the same conditions.

The collected data, together with other data by the RD39 Collaboration, demonstrated the existence of a general temperature dependence of the CCE of irradiated detectors. The theoretical modeling of the Lazarus effect was further developed, leading to a successful explanation of the observed data. The local maximum observed at about 130 K is believed to be due to the contribution of two processes in the silicon bulk as the temperatures decreases from room temperature to cryogenic values: a reduction in the charged fraction of radiation-induced deep levels and an increase in carrier trapping. The first process leads to a decrease of the absolute value of the effective charge density N_{eff}, with a consequent widening of the depletion layer up to full depletion – increasing CCE – while the second traps more and more carriers generated by ionization as the temperature is lowered – thus decreasing CCE. The competition of both processes leads to the observed maximum of CCE at about 130 K [7].

b) CCE time dependence of irradiated samples

Together with the observed recovery of the CCE for irradiated silicon at low temperatures – known as the Lazarus effect – another behavior was observed: the CCE of reverse biased samples decreased in time when exposed to a constant flux of minimum ionizing particles. The original data, taken each 5 minutes, was fitted with a single exponential but no detailed explanation was given [4].

This polarization effect was eventually explained by members of the RD39 Collaboration to be due to the deep-level trapping of carriers in the silicon bulk at low temperatures, increasing N_{eff}, with the consequent decrease of the depletion depth – and the active volume – for a given reverse voltage [8].

When used in real particle physics collider experiments, silicon tracking detectors will be exposed to an almost continuous flux of minimum ionizing particles and operating under reverse bias, therefore a deeper understanding of the polarization mechanism is needed.

For this reason, a systematic study of the time dependence of the CCE was performed together with the temperature dependence measurements, both for reverse and forward bias voltages applied, data being taken each 15 seconds for 30 minutes (up to 90 on some cases).

The CCE time dependence data has been analyzed, and found to be in good agreement with the polarization model for detectors under reverse bias, which states that for times shorter than the polarization time constant, the CCE is inversely proportional to time. Under forward bias, a slight decrease of the CCE with time at fixed bias and temperature was observed. In this case, the charge created by ionization in the silicon bulk is compensated by the injection of minority carriers through the p-n junction, which maintains the electric field stable in time, with the consequence of a good and very slightly decreasing CCE. Forward bias operation of pre-irradiated silicon detectors may thus be a good technique to have radiation-hard sensors with good and stable CCE characteristics.

The detailed analysis of the data taken will be used in order to further understand the mechanism of CCE degradation observed for charged particle detection and to find ways of minimizing this effect, such as injecting minority carriers with light thus compensating the non-homogeneous electric field in the bulk [5,10]. Work on this is being developed by the S. Petersburg group within RD39.

c) A new deep level spectroscopy technique for heavily irradiated silicon

Using data from CCE time and temperature dependence of two sets of irradiated samples (standard and oxygenated silicon at two different fluences), a new technique for the spectroscopy of deep levels in silicon based on the Lazarus and polarization was proposed by the LIP group. This technique uses both these models to fit the experimental data and thus extract parameters from the irradiated material, such as the densities of defects responsible for the Lazarus effect at low temperatures, the temperature of maximum CCE and the densities of trapping centers for both electrons and holes. This work is under way, with presentations at the 9th Pisa Meeting on Advanced detectors in May and the IEEE Nuclear Science Symposium in October. A paper has also been submitted to the IEEE Transactions on Nuclear Science.

d) Edgeless silicon detectors

A silicon detector in high-energy physics is a piece of a silicon wafer, usually n-type, where p-n junctions were implemented on one or both sides, by diffusion or ion implantation, operated at a reverse bias voltage high enough to fully deplete its volume.

Each p-n junction defines an independent detector cell, and, in order to avoid electric field distortions close to the physical edges of the device and collect surface currents, one or more p-n junctions are used to enclose the detector's active volume. These particular junctions are called *guard rings* and are omnipresent in all detectors, from simple pads or diodes to more complex microstrip or pixel designs.

In those cases when one wants a detector to be sensitive all the way to the edge with no dead areas – for example when detecting particles traveling very close to a high intensity

beam – it is desirable to use detectors with no guard ring, but such devices usually present high surface currents which renders them non-operational at room temperature.

The RD39 Collaboration, exploiting the behavior of silicon at cryogenic temperatures, is developing edgeless silicon detectors to be used in the roman pots of the TOTEM Experiment. This activity involves the development of both cryogenics and mechanics, as well as the characterization of the sensors, a task on which the LIP group participates.

In the past year, several silicon diodes have been diced with different methods (laser, scribing) and electrically characterized at Brookhaven National Laboratory, after which were sent to the LIP group for CCE measurements. The combined results, together with some previous tests made in 2001 of irradiated diced diodes, showed that these "edgeless" detectors behave as standard detectors, with a small but tolerable increase in leakage current. The CCE for non-irradiated detectors reaches 100 % below 270 K, while the temperature dependence of the irradiated samples shows the same behaviour as normal diodes, that is, a maximum for about 130 K [11].

Although diced diodes behave as detectors, the shape of the electric field in the silicon bulk, and its distortions close to the diced edge are not yet fully understood. When considering highly segmented devices such as pixel or microstrip detectors, it is very important to know the CCE close to the edge. Distortions observed in the shapes of the measured charge spectra of edgeless diodes indicate a loss of CCE when compared with standard diodes, as Landau-like curves are more and more distorted towards low collected charges. Offline analysis of the spectra shapes may give a qualitative insight on the amount of charge loss, but no correlation between CCE and distance to detector edge is possible to be evaluated with our existing setup.

In order to have a quantitative estimate of the CCE at different distances from the edge, two tests with beam have been performed at CERN during the summer of 2002 and 2003, using silicon detectors before and after a cryostat with two edgeless detectors (diodes in 2002, microstrips in 2003) operating at low temperatures. The analysis of data is under way and a paper is being written on this subject. The results indicate that the detectors are effectively sensitive all the way to the cutting edge, but the data gives no information on the CCE as a function of position, so that it is not possible to know if there is a loss of efficiency close to the edge.

For 2004, a new cryostat for measurements during irradiation with beam is being developed within RD39, which will incorporate instrumentation for TCT and CCE measurements at low temperatures. This system will allow to further study both standard and edgeless sensors in terms of the generation mechanisms of radiation-induced defects by monitoring defect-related variables in real-time during irradiation.

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[10] E. Verbitskaya et al. (RD39 Collaboration), “Optimization of electric field distribution by free carrier injection in silicon detectors operated at low temperatures”, IEEE Trans. Nucl. Sci. 49 (2002) 258-63

[11] Z. Li et al., “Electrical and transient current characterization of edgeless silicon detectors diced with different methods”, IEEE Trans. Nucl. Sci. 49 no.3 (2002) 1040-1046

Academic Training:

- one Ph.D. student
- one graduate student

Publications:

- P. Rato Mendes et al., “A new technique for the investigation of deep levels on irradiated silicon based on the Lazarus effect”, accepted for publication by IEEE Trans. Nuc. Sci.

- P. Rato Mendes et al., “Silicon strip detectors for two-dimensional soft x-ray imaging at normal incidence, Nucl. Instr. Meth. in Phys. Res. A509 (2003) 333-339

- K. Borer et al. (RD39 Collaboration), “RD39 Status Report”, CERN-LHCC-2003-060 (2003) 28 pp.

Conferences:

Presentations to conferences by LIP group members:

- P. Rato Mendes et al., “A new technique for the investigation of deep levels on irradiated silicon based on the Lazarus effect”, IEEE Nuclear Science Symposium and Medical Imaging Conference 2003, Portland OR, USA, 19-25 October 2003
- P. Rato Mendes et al., “Charge collection efficiency of irradiated silicon diodes at low temperatures”, 9th Pisa Meeting on Advanced Detectors for Advanced Physics, La Biodola, Italy, 25-31 May 2003

PROGRESS REPORT

Project Title: THE GRID PARADIGM: PROCESSING AND TRANSMISSION TECHNOLOGIES FOR PHYSICS EXPERIMENTS

Team:

Project Coordinator: Jorge Gomes (100%)

PhD: Mario David (100%), Luis Bernardo (5%)

Students: Ana Simões

Technical Staff: João Martins (70%) , José Aparício (10%)

Resumo:

As redes computacionais (computing grids) permitem a partilha de recursos de cálculo e armazenamento entre organizações, independentemente das suas características e localização. As redes computacionais baseiam-se numa camada de software e serviços que esconde as especificidades dos vários recursos, permitindo que estes sejam disponibilizados através de uma única interface de acesso igual para todos os utilizadores. Esta camada permite ainda optimizar o acesso e utilização dos recursos de acordo com a sua disponibilidade e com as necessidades dos utilizadores.
O LIP participa no LHC (Large Hadron Collider) através de dois grupos de investigação envolvidos nas experiências ATLAS e CMS. As experiências LHC escolheram o paradigma de computação grid como base para a sua infra-estrutura de cálculo. Neste sentido o CERN criou o projecto LCG (LHC Computing Grid) para coordenar e apoiar a computação grid no âmbito do LHC.
A actividade do LIP nesta área tem como objectivo principal integrar os seus recursos de cálculo na infra-estrutura grid do LCG e contribuir para o seu desenvolvimento. Para este efeito o LIP encontra-se directamente envolvido no projecto LCG e também nos projectos EGEE e CrossGrid. O projecto Europeu EGEE é coordenado pelo CERN e tem por objectivo fomentar e suportar à computação grid na Europa através da integração de recursos e criação de comunidades virtuais de utilizadores. O projecto Europeu CrossGrid tem por objectivo o desenvolvimento de software para computação grid interactiva.

Summary of activities:

According with the established plans the activities developed by the project have been developed in the framework of international research and development projects. The project aims to obtain know-how, develop and support the LIP grid computing infrastructure for the LHC experiments.

The activities foreseen have been severely affected by the lack of proper funding. Although approved by the Operational Programme for Information Society the funds to support most of the computing activities foreseen for 2002/2003 were never transferred. This affected mostly the improvement of the main LIP grid computing infrastructure in Lisbon and the extension to Coimbra. The involvement in new activities was also left out in favor of the fulfillment of previously assumed responsibilities.

During 2003 the activities have been centered in the collaboration with the international projects EU-DataGrid (coordinated by CERN) and EU-CrossGrid. Both projects aim to develop the grid middleware support for High Energy Physics and other scientific disciplines and are focused on different technical aspects of grid computing. LIP participation in DataGrid has been unfunded, while in CrossGrid LIP is a full partner with 50% of co-funding. With the national funding affected most of the activity was limited to the participation in the CrossGrid project where LIP has increased responsibilities as a full partner.

In CrossGrid LIP consolidated its position in the testbed infrastructure coordination in collaboration with CSIC while contributing for the initially established tasks covering the testbed verification, quality control, infrastructure support, integration with DataGrid and testbed setup. In this context one of the most successful achievements was the deployment and maintenance of the most important CrossGrid testbed central services by LIP (VO/VOMS, II, RB, MyProxy). The relevant services have been hosted at the LIP Computer Centre and at the Portuguese Academic Research Network (FCCN) operations center where better network connectivity is available. Similarly LIP is playing an important role in the infrastructure support and in the testbed verification and quality control where LIP is task leader.

Also in 2003 LIP worked in the preparation of the EGEE project proposal. EGEE is an European project coordinated by CERN that aims to build the first European wide production-level grid computing infrastructure for science. EGEE will provide the infrastructure management services for the LHC Computing Grid using middleware based on the developments by DataGrid, CrossGrid and others. The project was submitted and approved by the EU after negotiations carried out in October of 2003. LIP will be a full partner of EGEE and a member of the Southwest federation jointly with Spain.

At national level LIP established contacts with the Portuguese academic research network (FCCN) and with several universities (UP, FCT-UNL, UA, UAL and Lusiada) fostering the collaboration with national groups with interests in this area and aiming to a future interconnection of resources in the country in the context of EGEE.

In parallel with the grid activities the computer center production services based on non-grid technologies have been maintained in order to support the current activities of the LIP physicists.

Activities within DataGrid:

- Participation in the EDG Certification Authorities Coordination Group enabling the authentication and recognition of LIP systems and user certificates in the international testbeds.
    - Establishment of a new policy for the LIP CA.
    - Review of the policies of new CAs.
    - Participation in CA coordination activities.
- Monitoring.
    - Validation of the EDG-2 RB monitoring developed at LIP.
    - Monitoring of EDG Resource Brokers.
- Joint test with CrossGrid of the releases:
    - EDG-1.5, EDG-2.0 and EDG-2.1.
- Joint test with CrossGrid of the components:
    - R-GMA, VOMS, RLS, RM, LCFGng etc.

Activities within CrossGrid:

Testbed set-up and incremental evolution

- International testbed infrastructure coordination in collaboration with CSIC.
    - The LIP project leader is deputy for the testbed.
    - Coordination of testbed activities.
- Participation in the crossgrid CA work group.
- Deployment and maintenance of the CrossGrid central systems hosted at LIP and FCCN:
    - Information Index
    - Resource Broker
    - VO/VOMS
    - MyProxy
    - Etc.
- Infrastructure usage statistics.
- Security.
    - Automated verification of security issues.
    - Contribution to security procedures.
    - Contribution to the tracking and elaboration of security patches.
- Integration of software:
    - Technical support for the integration efforts.
    - Maintenance of the integration requests web site.
    - Integration of software components.
    - Contribution to the project developer’s guide.
- Deployment and maintenance of the LIP local grid infrastructures:
    - Validation systems.
    - Development systems.
    - Production systems.
- Elaboration of technical documents.

Integration with DataGrid

- Follow DataGrid developments.
- Follow LCG developments.
- Test of EDG releases and components.
- Test of LCG releases.
- Participation in the EDG Certification Authorities Coordination Group.
- Participation in monitoring related activities.
- Participation in coordination activities and workshops.

Infrastructure support

- User's support.
- Developer's support.
- Site administrator's support.
- Testbed web pages development and maintenance.
- Maintenance of selected topics of the project knowledge database.
- Monitoring of systems, services and network.

Testbed verification and quality control

- Coordination of the task.
- Review of the integration and validation procedures.
- Tested site and systems validation.
- Verification of testbed services functionality.
- Verification of testbed systems configuration.
- Production of monthly testbed quality assurance reports.
- Development of validation tools.
- Middleware validation including CrossGrid, DataGrid and LCG software.
- Validation of CrossGrid software.
- Validation of basic middleware (Globus and DataGrid and LCG).
- Quality assurance reports:
- Elaboration of monthly testbed quality assurance reports.
- Development of software for the testbed QA.
- Participation in the project Internal Review Board:
- Coordination of reviews.
- Participation as reviewers.

Other grid related activities:

- Preparation of the LIP participation in EGEE.
- Establish contacts and perform dissemination.
- Maintenance of the LIP CA.

Other general activities:

- Improvement of the LIP Computer Centre network connectivity.
- Maintenance of central systems and services including the LIP production farm.
- Maintenance of the experiments systems and services.
- User support.

Academic Training:

Development of a web portal for file management – graduation project in progress –
Ana Simões

Publications:

CG4-D4.6-v1.3-CSIC016-WP4-Testbed-Status: WP4 Testbed Status;
J. Marco, J. Gomes, M. Hardt, F. Fassi, S. Gonzalez, J. Astalos, A. Garcia

CG-4.6-D4.6-v1.3-LIP014: Testbed Infrastructure Status Report;
J. Gomes

CG4-D4.5-v1.6-CSIC014-WP4-Testbed-Status: WP4 Testbed Status;
J. Marco, R. Marco, J. Gomes, C. Fernandez, D. Rodriguez, J. Villauso

CG4-D4.4-v1.0-LIP013-CrossGridTestbed: Testbed Extension and Site Status;
J. Gomes

International Grid CA Internetworking, Peer Review and Policy Management through the European DataGrid Certification Authority Coordination Group;
Journal of Grid Computing
D.P. Kelsey, J. Astalos, R. Cecchini, B.A. Coghlan, R.D. Cowles, J. Gomes, et. al.

Conferences:

Deployment of an Interactive Physics Analysis Application in the CrossGrid Project Testbed; GGF Berlin March 2003;
C. Martinez, J. Marco, D. Rodriguez, J. Gomes, M. David, J. Martins, L. Bernardo, et. al.

Test and validation in WP4
CrossGrid Poznan workshop
J. Gomes

CrossGrid Testbed Status
CrossGrid Poznan workshop
J. Gomes

Impact of EDG 2 in CrossGrid
CrossGrid Poznan workshop
J. Gomes, M. David

Testbed Status
CrossGrid Cyprus integration meeting
J. Gomes

REPORT

MONTE CARLO TECHNIQUES AND DETECTOR DEVELOPMENT APPLIED TO MEDICAL PHYSICS

Team:
PhD: Luis Peralta 40%, M.Carmo Lopes (IPO) 50%, M.Conceição Abreu 25%, Pedro Rato 20%.
Students: Andreia Trindade 100%, Pedro Rodrigues 100%, Catarina Ortigão 100%, Adérito Chaves (IPO) 70%, Carla Oliveira (IPO) 70%, Patrick Sousa 50%.

Resumo:

O presente projecto tem duas vertentes i) pretende desenvolver programas de simulação Monte Carlo que serão aplicados na determinação de doses fornecidas por fontes de radiação ionizante a meios biológicos ii) pretende participar no desenvolvimento de detectores de radiações ionizantes para aplicações na medicina. Estes são importantes domínios de transferência tecnológica da área da Física de Altas energias para as Ciências da Saúde Humana.

As técnicas de simulação Monte Carlo são reconhecidas como uma importante ferramenta no cálculo de doses de radiação absorvida em vários problemas ligados à Medicina. Contudo muitos dos físicos que trabalham nestas áreas não se encontram familiarizados com estas técnicas. Estas competências podem ser encontradas na comunidade de Física de Altas Energias, onde vários dos programas e técnicas utilizados podem ser adaptadas à Física aplicada à Medicina. Um exemplo paradigmático é o da Radioterapia Externa, onde grandes benefícios podem ser alcançados com a utilização destas técnicas. A simulação Monte Carlo pode ajudar uma determinação mais rigorosa das doses efectivamente fornecidas ao volume tumoral, contribuindo desta forma para um combate mais eficaz do cancro. Mas a radioterapia não é a única área de aplicação. Outras técnicas que utilizam radiações ionizantes podem beneficiar dum cálculo de doses mais rigoroso, usando as técnicas de simulação Monte Carlo.

Juntamente com as simulações MC, este projecto participa no desenvolvimento e construção de um protótipo de um detector híbrido para radiação gama para ser utilizado em aplicações médicas. Esta participação será possível com recurso ao know-how da tecnologia de detectores existente no âmbito da colaboração ISPA do CERN. Nos últimos anos tem existido um aumento continuo do desenvolvimento de detectores para aplicações médicas usando técnicas nascidas no seio da Física de Altas Energias. Um exemplo, são os detectores de silício e de determinados tipos especiais de cintiladores em imagiologia com base em raios-X ou gama. Este tipo de materiais usados correntemente em Física de Altas Energias, podem melhorar significativamente o contraste e resolução das imagens obtidas. Permitem também, de uma forma simples, a obtenção e tratamento de imagens digitais.
No decurso deste projecto serão consolidados os conhecimentos adquiridos com o protótipo actualmente em construção e será feita uma iteração sucessiva com o

desenvolvimento e a implementação de um sistema de imagem dual baseado em detectores ISPA, com sensores para raios-x e raios-gama, permitindo a aquisição simultânea de imagens morfológicas e funcionais de alta resolução.
A modularidade do sistema e a cadeia electrónica de leitura única permitirá uma fácil e imediata integração, sobreposição e tratamento dos dois tipos de imagens obtidas.

Summary of activities:

The project aims are the development of Monte Carlo simulation programs in the computation of radiation transport problems applied to medicine, and the development of solid-state detectors for digital gamma ray imaging in nuclear medicine.

1. Introduction

Monte Carlo techniques are nowadays widely used for physics applications in medicine. Its grow started at the late 80's, and as the computing power increased the technique found more application areas. In radiotherapy many of the dose calculations done in an empirical approximate way, are now done in a more accurate way using Monte Carlo simulations [1]. Many of the people involved in this evolution came from areas like Nuclear or High Energy Physics, where codes for radiation transport like EGS4, GEANT3, MCNP4 have been developed. These codes have been adapted or developed to include the specific needs of low energy physics, used in medical applications. This is the case of GEANT4 that is developing a low energy section that extends the energy range down to 250 eV.

Regarding diagnostic imaging tools, namely in nuclear medicine, gamma ray cameras have slowly improved since its first invention by Anger in 1958 [2]. A wide variety of commercial gamma cameras systems are available in a wide range of designs, but they still consist of upgrades of the standard one, limited in spatial and energy resolution. Due to their bulky size and significant dead space around the periphery of the camera, those "all-purposes" systems are not optimized to improve diagnostic accuracy in nuclear medicine imaging for specific procedures and applications. The existing alternatives are oriented on dedicated systems through compact gamma cameras based on new imaging semiconductors technology. They are compact devices suited to high resolution planar gamma imaging. Several prototypes of such imaging probes are currently under development in laboratories [3-5], and some of them already in the market financed through a company project, namely DIGIRAD, OY AJAT, ACRORAD, LABLOGIC, INTRAMEDICAL, SIEMENS, IMARAD, Saint-GOBAIN, etc.
In the framework of the ISPA (Imaging Silicon Pixel Array) Group at CERN [6], and taking advantages on the existing technology for high particle physics, the new gamma camera we are developing is a position sensitive photon detector based on the hybrid technology which combines compactness and portability with high spatial resolution.
The significant achievements of this underway work for our 2003 group activities are presented in this report.

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[6] T. Gys *et al.*, "A new position-sensitive detector based on an imaging silicon pixel array (ISPA-tube)", *Nucl. Inst. Meth. in Phys. Res.*, vol. A355, p.386, 1995.

2. MC Calculations in External Radiotherapy

Basic dosimetry of radiosurgery narrow beams using Monte Carlo simulations – a detailed study of depth of dose maximum

Dose measurements of narrow photon beams used in radiosurgery are complicated by the lack of lateral electron equilibrium which is a requirement namely for ionometric methods. The details of basic dosimetry for these narrow beams are still quite unknown. To overcome this difficulty Monte Carlo simulation is a privileged tool to assess the processes of the energy deposition phenomena in such narrow photon beams. Some simulations had already been performed to calculate percent depth doses in a water phantom of the narrows beams used in our hospital (Centro Regional de Oncologia de Coimbra-Portugal) and the agreement with experimental data was good [1]. A more specific analysis of the calculated and experimental dose measurements in the build-up region revealed that the depth of the dose maximum d_{max} increases with the size of the additional collimators which is the opposed behavior presented by radiotherapy conventional radiation fields [2]. To fully understand this phenomenon, Monte Carlo simulations are performed in order to verify if it is due to processes occurring in the generation of the narrow photon beams or in processes occurring in the water phantom. The Monte Carlo code used in these studies is MCNP-4c [3], the accelerator is a Siemens Mevatron KD2 in 6MV photon mode and the size of the additional collimators goes from 5mm to 23mm (geometrical dimension).

Through this detailed analysis, we have concluded that characterizing the photon and electron spectra in air is not sufficient to explain the increase of d_{max} with the increase of the size of the additional collimator. Only the processes occurring in water explain this behavior.

References

[1] Chaves A., Lopes M.C., Oliveira C.,."Monte Carlo simulation applied to radiosurgery narrow beams using MCNP-4C", Sociedade Portuguesa Protecção Contra Radiações, Radioprotecção, Vol.I, Nº8 e 9, 149-57 (Dezembro 2000-Maio 2001)
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This work has been submitted to the International Symposium on Standards and Codes of Practice in Medical Radiation Dosimetry, 25-28 November 2002, Vienna- Austria, and was presented in poster. Was also presented at the BioEng2003 Bioeng´2003: 7th Portuguese Conference on Biomedical Engineering Fundação Calouste Gulbenkian Lisbon-Portugal June 26-27 2003 as a Poster.

This work has been published in the Medical Physics: "Basic dosimetry of radiosurgery narrow beams using Monte Carlo simulations: A detailed study of depth of maximum dose", Med. Phys. 30 (11) 2003, 2904-2911.

Development and validation of a multiple source model for radiosurgery.

In the past few years, MC simulations appear as powerful tool to access photon beam characterization in radiotherapy. These detailed studies have lead to the development of multiple source models. These models are based on the fact that particles originated in the same component of the accelerator head have similar distributions: position, direction, energy, weight. A reconstructed radiation beam is then composed by particles from various virtual sources representing each relevant component of the accelerator head. The application of this idea to radiosurgery narrow photon beams seems attractive since the reduction in time and data storage is particularly important. The goal of this work is to develop a multiple source model for radiosurgery narrow photon beams. The model will be validated through comparisons with measurements in a water phantom. MCNP4C code was used to produce the phase space data (PSD) of each additional collimator. Eight photon relevant virtual sources were extracted from an extensive characterization of these PSDs. These virtual sources were introduced in the very fast MC code DPM for dose calculations in a water phantom. The size of the voxels in water was fixed to 1mm x 1mm x 5mm. Calculated depth dose curves and profiles were compared with measurements in water for all the additional collimators. Results are within accepted international tolerances.

This work was presented to the

Bioeng´2003: 7th Portuguese Conference on Biomedical Engineering Fundação Calouste Gulbenkian Lisbon-Portugal June 26-27 2003 (Poster presentation)

7th Biennal ESTRO Meeting on Physics in Clinical Radiotherapy, 13-18 Sept.2003 Genève Suisse. (Oral presentation)

3. Detectors for Medical Physics - Participation in the ISPA Group

The work of the LIP group on the development of detectors for medical imaging can be grouped into two main lines of activity:

Characterization and MC simulation of radiation sensors (ISPA tubes);

Design of electronics cards for detector front-end and data readout;

Characterization and simulation of radiation sensors (ISPA tubes)

The Monte Carlo simulation of a _-camera based on YAP:Ce crystals coupled to an ISPA (Imaging Silicon Pixel Array) tube has been done. This study allowed a deeper understanding of the performance and potential benefits of this new kind of detectors which can be used in Nuclear Medicine. Such _-camera represents an excellent tool to improve pediatric thyroid gland and small organs imaging maintaining a low administered dose, being also suitable for Molecular Biology studies. Intraoperative imaging system to assist surgeon in some surgical procedures is foreseen.

Alternative configurations were explored in order to optimize detector arrangement, namely different crystal coatings and reflector properties, several surface treatments and polish types. Some collimator designs were also studied to evaluate the system spatial resolution and sensitivity.

Basically, an ISPA tube consists of a silicon chip anode for photoelectrons readout implemented in a vacuum-sealed cylinder with an optical entrance window (YAP:Ce crystal) on the inner face of which a photo-cathode is evaporated [1,2].

A reliable Monte Carlo simulation study is of significant importance to evaluate the performance of a YAP-ISPA _-camera and search for compromises between energy resolution, spatial resolution and sensitivity. The developed simulation package, based on GEANT3 [3], has allowed an accurate radiation transport description including photon attenuation in high-Z collimators. The tracking of optical photons due to scintillation inside the crystal is also taken in account by simulation.

Monte Carlo results were evaluated in order to achieve the best compromise between spatial and energy resolution. For crystal coating the following cases were explored: total absorption or black material; specular reflector, like aluminum (85% and 95% reflectivity) and diffuse reflector or white material (80% and 98% reflectivity). These were compared with the absence of any coating (air). The best performance was obtained with the aluminum coating configuration. For the surface treatment it was simulated from 100% polished to completed roughness (0.05% polished). The best case was achieved with the most polished crystal, although lower polishing had also good results and is less expensive.

Several crystal matrices and planar crystal thicknesses were simulated for different applications. As expected the thinner crystals achieve better spatial resolutions but have

lower sensitivities. With crystal matrices it is possible to increase the camera active surface.

The introduction of a beryllium window was also appraised. This improvement allows the crystal to be under vacuum within the tube. Simulation results showed that below 3mm thick Be windows can be considered without affecting the detector performance.

The spatial resolution of the system combined with high resolution collimators is 3 to 10 times better than conventional NaI:Tl imaging systems.

References

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These results were presented in the Master thesis of C. Ortigão, in March 2003

This work has been presented at

Bioeng´2003: 7th Portuguese Conference on Biomedical Engineering Fundação Calouste Gulbenkian Lisbon-Portugal June 26-27 2003 (C. Ortigão, Oral presentation).

IPEM Annual Scientific Meeting & IBEX 2003 Exhibition, 15-17 Set. 2003, University of Bath, UK, (C. Ortigão, Oral presentation)

Design of electronics cards for detector front-end and data readout

The current gamma camera readout system operating at CERN laboratories, consists of an ISPA-tube, a full-custom front-end readout card, a discrete analogue system based on NIM modules, different power supplies to provide threshold and bias voltages, a VME-based data acquisition board and a Linux workstation. This laboratory setup is very useful for testing but it is obviously too large and complex to allow usage inside clinical environment.

Reasons to provide easier set-up and utility of the ISPA-tube for clinical studies and basic research, lead us to re-design new electronics for full control and real-time processing of ISPA-tubes.
The new readout system consists of a compact printed circuit board (PCB) to connect the ISPA-tube, and two main electronics cards, one plugged onto the other.
The first one is an upgrade of an existing prototype for high energy physics experiments at CERN [1], and performs the first analysis of the data. The second one, whose layout was achieved within the ISPA Group, was specially design for phototube readout and data acquisition. Those cards were both placed and ordered at CAEN (Costruzioni

Apparecchiature Elettroniche Nucleari) and were already available for this past year 2003.

Through this readout system overview, we have concluded the assembly of a PCB to substitute the present analogue front-end by integrated components and the two electronic cards are currently in the final phase of their programming for communication and control tests at CERN laboratories. Several contributes of the LIP group in this task were performed, but the significant achievement work underway is the implementation of the parallel port protocol for external communication. These allow the card to manage the interface with a standard personal computer through which the user is able to control the system and acquire data. This task is the responsibility of LIP.

References

[1] CAEN S9007 User's manual

This work has been presented at

Bioeng´2003: 7th Portuguese Conference on Biomedical Engineering Fundação Calouste Gulbenkian Lisbon-Portugal June 26-27 2003 (P. Sousa, Poster presentation).

IEEE 2003 Medical Imaging Conference, Portland, USA, Oct 19-25, 2003 (P.Sousa, Poster Presentation)

4. Academic Trainning:

On going Thesis

Adérito Chaves, PhD thesis - Conclusion foreseen in 2004
Patrick Sousa, PhD thesis – Conclusion foreseen 2005
Sandra Moreno, PhD thesis- Conclusion foreseen 2006
Sandra Brás, master thesis – Conclusion foreseen 2005
Sónia Rodrigues, master thesis – Conclusion foreseen 2005

Concluded Thesis

Catarina Ortigão, Master Thesis, "Simulação Monte Carlo de um detector SPECT protótipo de alta Resolução", IST - Technical University of Lisbon, March 2003

5. Publications:

Publications in journals

Gamma Spectroscopy and Optoelectronic Imaging with Hybrid Photon Detector, C. D'Ambrosio, M. Abreu, V. Cencelli, F. Cindolo, F. De Notaristefani, H. Leutz, J. Mares, M. Nikl, D. Piedigrossi, D. Puertolas, P. Rato Mendes, E. Rosso, P. Sousa, Nucl. Instr. Meth. A 497 (2003) 186-197

Basic dosimetry of Radiosurgery narrow beams using Monte Carlo simulations :A detailed study of depth of maximum dose , A.Chaves, M.C.Lopes, C.C.Alves, C.Oliveira , L.Peralta , P.Rodrigues, A.Trindade , Med. Phys. 30 (11) 2003, 2904-2911.

Fast Electron Beam Simulation and Dose Calculation in Radiotherapy, A. Trindade, P. Rodrigues, L. Peralta, M.C. Lopes, C. Alves, A. Chaves, Accepted for publication in NIM A.

A powerful simulation tool for medical physics applications: GEANT4", Barca G, Castrovillari F, Chauvie S, Cuce D, Foppiano F, Ghiso G, Guatelli S, Lamanna E, Lopes MC, Peralta L, Pia MG, Rodrigues P, Trindade A, Veltri M, Nuclear Phys. B-proceedings supplement, 125 (2003) 80-84

Submitted papers

Application of GEANT4 Monte Carlo toolkit to dose calculations on homogeneous and anthropomorphic phantoms, submitted to Applied Radiation and Isotopes.

A Monte Carlo multiple source model applied to radiosurgery narrow photon beam, A.Chaves, M.C.Lopes, C.C.Alves, C.Oliveira, L.Peralta, P.Rodrigues, A.Trindade, submitted to Medical Physics

Oral and Poster presentations to Conferences:

Basic dosimetry of radiosurgery narrow beams using monte carlo simulations – a detailed study of depth of dose maximum, A. Chaves, M.C.Lopes and C. Oliveira, International Symposium on Standards and Codes of Practice in Medical Radiation Dosimetry, 25-28 November 2002 Vienna- Austria. (Poster presentation)

A Monte Carlo Study of a YAP:Ce _-camera coupled to an ISPA tube, Bioeng´2003: 7th Portuguese Conference on Biomedical Engineering Fundação Calouste Gulbenkian Lisbon-Portugal June 26-27 2003 (C. Ortigão, Oral presentation).

Readout electronics development for the ISPA-tube, Bioeng´2003: 7th Portuguese Conference on Biomedical Engineering Fundação Calouste Gulbenkian Lisbon-Portugal June 26-27 2003 (P. Sousa, Poster presentation).

Problems and solutions to face radiosurgery dosimetry and calculation, Bioeng´2003: 7th Portuguese Conference on Biomedical Engineering Fundação Calouste Gulbenkian Lisbon-Portugal June 26-27 2003 (Adérito Chaves, Poster presentation).

Development and validation of a multiple source model for radiosurgery, 7th Biennal ESTRO Meeting on Physics in Clinical Radiotherapy, 13-18 Sept.2003 Genève Suisse (A. Chaves, Oral presentation)

A Monte Carlo Study of a YAP:Ce _-camera coupled to an ISPA tube, IPEM Annual Scientific Meeting & IBEX 2003 Exhibition, 15-17 Set. 2003, University of Bath, (C. Ortigão, Oral presentation)

Further developments on a nuclear imaging system with an ISPA-tube, IPEM Annual Scientific Meeting & IBEX 2003 Exhibition, 15-17 Set. 2003, University of Bath, (C. Ortigão, Oral presentation)

Readout Electronics Development for the ISPA-tube, P.Sousa et al., NSS & MIC (Nuclear Science. Symposium and Medical Imaging Conference), Portland, USA, Oct 19-25, 2003 (Patrick Sousa, Poster Presentation)

Internal Notes

Electron beam adjustment in PLATO RTS 2 including the effect of air gaps, LIP/02-03, EXT-2002-069

Application of GEANT4 radiation transport toolkit to dose calculations in anthropomorphic phantoms, LIP/03-01, EXT-2003-044

Fast Electron Beam Simulation and Dose Calculation, LIP/03-02, EXT-2003-049

REPORT

Low Energy Bremsstrahlung Models for GEANT4

Team:
PhD: Luis Peralta 25%
Students: Andreia Trindade 50%, Pedro Rodrigues 50%

Resumo:
O objectivo deste projecto foi o desenvolvimento do modelo para a geração de fotões de bremsstrahlung na região das baixas energias para o sistema de cálculo GEANT4. O código GEANT4 constitui um sistema de Simulação Monte Carlo de uso geral para o transporte de radiação, sendo implementado na linguagem C++ e tecnologia de programação Orientada por Objectos. Quando foi efectuada a migração do sistema GEANT3 (código Fortran) para o sistema GEANT4 foi adoptada uma simplificação do gerador de bremsstrahlung adoptado por GEANT3. Esta parametrização tinha a característica de ser rápida mas apresentava uma distribuição angular errónea para electrões de energias inferiores a 500 keV. Este é um problema severo para aplicações do GEANT4 à região das baixas energias (como sejam as aplicações à medicina) onde a geração de fotões de bremsstrahlung de baixo ângulo pode ser grandemente sobrestimada.. O nosso objectivo foi o de implementar em GEANT4 um módulo de geração de fotões de bremsstrahlung que siga a chamada distribuição 2BN, mas recorrendo a um algoritmo bastante mais rápido que os usados até agora.

Summary of activities:

The project objective is the development of low energy bremsstrahlung models for the GEANT4 package. The GEANT4 code is developed by an international collaboration where CERN is one of the main partners. This project was the first work done by our group in collaboration with the LowE GEANT4 Working Group.

1. Introduction

Monte Carlo techniques have become the method of choice for the evaluation of different topics in Medical Physics, from dose calculations in Radiotherapy and Brachyterapy to the performance assessment of X–ray and Nuclear Medicine imaging devices. One of the most currently used Monte Carlo codes for medical applications is the GEANT4 radiation transport toolkit [1]. Its applicability in Medicine has been demonstrated by a large number of applications [2], [3]. Some of the factors responsible for the increasing use of GEANT4 are its modularity, flexible infrastructure and the Low Energy Electromagnetic Physics Process (LowE) category, which provide alternative models for electrons and photons transport down to 250 eV [2]. Recent developments include the re–implementation of PENELOPE physics process in GEANT4 and the on–going revision of final state generators for low energy bremsstrahlung.

In this project the implementation of a precise and alternative low energy bremsstrahlung angular generator in the GEANT4 Low Energy Electromagnetic Physics category, has been done.

2. The 2BN bremsstrahlung angular generator

Monte Carlo radiation transport codes, like MCNP4 [4], EGS4 [5], GEANT3 [6] lack dedicated models for low energy (electron kinetic energy less than 500 keV) bremsstrahlung photon angular distributions. EGS4 provides as an option the 2BS Koch and Motz [7], [8] distribution while GEANT3 and current GEANT4 release uses a parameterization of Tsai double differential cross section [9]. However, for low energies both approaches give rise to deviations that could reach 25-30 degree on the most probable photon emission angle. This can have a significant impact in the accurate simulation of electron bremsstrahlung in very thin targets, like some of the current targets for X–ray imaging units. Recently EGSnrc [10]and PENELOPE [11] codes have incorporated respectively, modified 2BS versions (which converges to 2BN distribution also from Koch and Motz) and analytical distribution with adjustable parameters determined from fitting Kissel wave shape functions [12], based on the work of Tseng and co-workers [13]. In the framework of the activities of the GEANT4 Low Energy Physics Working Group the implementation of a new design that will allow the user to chose, in a transparent way, the best concrete implementation depending on simulation time, precision and/or energy range is underway. For the first iteration a design based on a strategy pattern was chosen, which performs the interface with different angular generators concrete implementations. One of the concrete implementations with the 2BN distribution, using an exact fast sampling algorithm was recently developed in this project.

Since the 2BN cross–section is a 2-dimensional non-factorized distribution it cannot be separated into two functions, one that depends on the photon emitted energy and the other on polar angle. In this case the inverse–transform method [11] traditionally used to sample random number according to a given distribution can not be applied. Nevertheless the acceptance-rejection technique can still be used in this case if some basic requirements are met. Using this technique we were able to build a fast 2BN distribution generator, which has a high sampling efficiency in the low energy region.

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[8] A. F. Bielajew, R. Mohan, C.–S. Chui, ‘ “Improved bremsstrahlung photon angular sampling in the EGS4 code system”, *Report NRCC/PIRS-0203* 1989.

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[12] L. Kissel, C. A. Quarls, R. H. Pratt, “Bremsstrahlung from electron collisions with neutral atoms”, *At. Data Nucl. Data Tables*, vol. 28, pp. 382, 1983.

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3. Publications:

Publications in journals

A powerful simulation tool for medical physics applications: GEANT4”, Barca G, Castrovillari F, Chauvie S, Cuce D, Foppiano F, Ghiso G, Guatelli S, Lamanna E, Lopes MC, Peralta L, Pia MG, Rodrigues P, Trindade A, Veltri M, Nuclear Phys. B-proceedings supplement, 125 (2003) 80-84

GEANT4 Applications and Developments for Medical Physics Experiments, P. Rodrigues et. al., accepted for publication to IEEE Transactions on Nuclear Science

Oral and Poster presentations to Conferences

GEANT4 LowE Bremsstrahlung Angular Generators, L. Peralta, P. Rodrigues, A. Trindade, GEANT4 LowE Electromagnetic Physics Meeting, INFN Genova 15-16 April 2003

G4 LowE Bremsstrahlung Angular Generators, L.Peralta, P. Rodrigues and A. Trindade , Oral Presentation at GEANT4 2003 Workshop, 2-6 September 2003, TRIUMF, Vancouver, Canada.

GEANT4 Applications and Developments for Medical Physics Experiments, P. Rodrigues et. al., Poster Presentation, *IEEE Nuclear Science Symposium and Medical Imaging Conference, Portland, October 19–25, 2003.*

Internal Notes

Monte Carlo Generation of the 2BN Bremsstrahlung Distribution, *L. Peralta, P. Rodrigues, A. Trindade, LIP / 03-05*

Manuals

A section describing the 2BN generator has been written an included in the GEANT4 users-manual.

Software code

The software code of the 2BN generator written in C++ has been included in the GEANT4 package.

PROGRESS REPORT

Project Title: Outreach of Experimental Particle Physics

Team

Project Coordinator: Conceição Abreu / João Varela

PhD:
Conceição Abreu 10%
João Varela, 10%
Pedro Abreu 10%

Summary of activities:

The outreach activity has become a very important issue in experimental particle physics, to promote the field and explain the scientific achievements made for the money invested in the experiments. This much has been recognized at CERN and elsewhere, and a set of concerned people have set-up a working group devoted to the public awareness of particle physics (EPOG – European Particle physics Outreach Group).

The portuguese representative in this group had the responsabilities of participating in its meetings, reporting the local activities related to the outreach of particle physics, coordinate the local implementation of the CERN training program "HST – High School Teachers at CERN", and maintain the WEB site located at LIP. The project coordinator changed in September 2003.

Most of the activities involving high school teachers and students had the support of the "Ciência Viva" program, and/or were organized in the framework of the program "Ocupação Científica de Jovens no Verão" of the Ministry of Science and Superior Education.

Members of LIP, not directly related to this project, have also performed seminars in high schools promoting particle physics and astroparticle physics.
LIP members have also actively participated in the organization of exhibitions related to particle physics, namely the Research Centres "Open Days", the "Forum Ciência Viva", and the exposition "Radioactivity" to appear soon.
The LIP/Atlas group have also invested some important resources (money, people and time), in preparing educational films about the group's activities, which are now an important part of the educational resources of the Atlas experiment at CERN.

PROGRESS REPORT

Project Title: Radiation Interaction Simulation Tools for ISS High-Energy Astrophysics Experiments EUSO and AMS

Team

Project Coordinators: Mário Pimenta and Bernardo Tomé

PhD:

Mário Pimenta,	20%
Maria Catarina Espírito Santo,	20%
Bernardo Tomé,	35%
Patrícia Gonçalves,	20%

Students:

Pedro Rodrigues (PhD Student),	10%
Andreia Trindade (PhD Student),	10%

Summary of activities:

The GEANT4 Monte Carlo radiation transport toolkit, developed by the RD44 and GEANT4 Collaborations, aims to become a tool of generalized application in high energy physics, nuclear physics, astrophysics and medical physics research. Due to its Object-Oriented design, GEANT4 is ideal for the development of flexible simulation applications. A wide energy range coverage both for electromagnetic and hadronic physics processes is offered. GEANT4 provides also an optical physics process category, allowing the production and propagation of scintillation and Cherenkov emitted light to be described. Such capabilities are well tailored for the requirements of the new generation of astrophysics experiments to be installed on the International Space Station (ISS), like EUSO and AMS. The following paragraphs summarise the GEANT4 related activities at LIP in 2003, performed under a contract celebrated between LIP and ESA (ESA/ESTEC contract No. 17097/03/NL/LvH/bj). The first part of this project consisted on the development of a GEANT4 based simulation and analysis framework, able to accommodate the different applications foreseen. Applications to EUSO and AMS have followed.

Framework design, simulation cross-checks and improvements

One of the general requirements that guided the development of the GEANT4 based framework was its ability to accommodate different geometry organizations. This was accomplished by introducing an interface class in which the user can plug-in the concrete geometry implementation. For the primary event generation, the General Particle Source was used to sample primary cosmic-ray distributions (ISS orbit or Earth's surface) or phase-space data describing accelerator beams. Physics lists include the standard electromagnetic physics processes for muons, electrons, positrons, photons and charged

hadrons. Since optical transport of scintillation and Cherenkov optical photons was required, the processes of scintillation, Cherenkov production, Rayleigh scattering and light absorption were also included. Optical surfaces have been defined according to the specifications required by the GEANT4 UNIFIED optical model. Since an accurate validation of Monte Carlo results against experimental data requires taking into account the influence of different readout electronics arrangements, data acquisition systems and trigger algorithms, a previously developed digitization module was adapted to the application. At the end of the event, the information stored in this collection of hits is made persistent and then streamed with the ROOT I/O mechanisms.

EUSO analysis and simulation

EUSO will look downwards toward the Earth's dark atmosphere to detect the faint UV traces produced by extreme energy cosmic rays. The EUSO instrument consists of a wide-angle optical system (Fresnel lenses) and a large and highly segmented focal surface. Within the EUSO experiment there is an on-going program of experimental activities for critical parameter studies. The detection of the Cherenkov light associated with the Extensive Air Showers (EAS), measuring UV light diffusion coefficients of different types of media at the surface of the Earth, is the main goal of the ULTRA project. The ULTRA detector is a hybrid system consisting of a UV detection system, the UVscope, and an array of scintillation detectors, the ETscope. The UVscope is used to detect the diffused Cherenkov light from EAS, in coincidence with the ETscope array.
The simulation of the ULTRA experiment components within GEANT4 was performed, allowing the detailed study of the expected performances and capabilities. In particular, in the case of the UVscope, this simulation was crucial for the tuning and validation of several detector parameters and configurations.
Concerning the ETscope, the detailed description of one detector unit was included (geometry, materials and physical processes). A preliminary digitization module, based on the digitization framework described above, was also implemented. The scintillation photons produced by a particle crossing the detector are tracked through the various materials until reaching the surface of the photocathode. Propagation inside the scintillator, passage across the interface between the scintillator and the air, reflection or absorption in the painted walls, are taken into account in the photon tracking.
Concerning the UVscope, the detailed geometry of the object was simulated, including the description of the geometry of the a Fresnel lens, making use of the object parameterisation/replication capabilities. The definition of the relevant optical boundaries, parameters and processes is also included, allowing the detailed ray tracing within the detector.
An *Advanced Example* for GEANT4 users based on this work is currently being prepared and should be included in future GEANT4 releases.

AMS radiator and light guide simulations

The main objectives of AMS are the search for antimatter and dark matter and the study of the propagation and confinement of cosmic rays in the Galaxy. The AMS RICH, built with a low refractive index radiator, will provide an independent measurement of the particle velocities and will be essential for isotope separation. The chosen solution is a conical shaped detector on the top, photodetectors on the bottom and an enveloping outer

mirror of very high reflectivity. The RICH is a complex detector and performance assessment depends critically on the correct modeling of the light production, transmission and collection.
A simplified design of the AMS RICH radiator setup, consisting of aerogel tiles supported by a plexiglass foil, was implemented in the GEANT4 based simulation framework. The implemented aerogel properties (refractive index, absorption length, and clarity) correspond to the AMS RICH radiator setup description. Simulation plays a crucial role in efficiency determination and pattern reconstruction.
A simulation of a Cherenkov counter, used in RICH prototype beam tests in order to obtain an independent measure of the charge of the incident beam particles, was also implemented.
Surface effects in the aerogel are very important for the detailed understanding of the detector response. Aerogel surface maps were obtained using an atomic force microscope and are being modeled within this simulation framework. The modeling of surfaces using user defined maps implied an improvement in GEANT4 itself.

Publications: (members of LIP are underligned)

M.C. Espírito Santo, P. Gonçalves, M. Pimenta, P. Rodrigues, B. Tomé, A. Trindade,
"GEANT4 Applications for Astroparticle Experiments",
Accepted to be published by IEEE Trans. Nucl. Sci.

Conferences (the speaker/responsible author is underlined):

M.C. Espírito Santo, P. Gonçalves, M. Pimenta, P. Rodrigues, B. Tomé, A. Trindade,
"GEANT4 Applications for Astroparticle Experiments",
Nuclear Science Symposium, Portland 2003 IEEE Conference.

M.C. Espírito Santo, P. Gonçalves, R. Moura, L. Peralta, M. Pimenta, P. Rodrigues, B. Tomé, A. Trindade, J. Varela,
"GEANT4 Applications for Medical and Astrophysics Experiments at LIP",
GEANT4 Collaboration 2003 Workshop, TRIUMF, Vancouver.

LIP-COIMBRA

LIP COIMBRA

Introduction

For LIP-Coimbra, the year of 2003 was mainly devoted to:

Increasing the preparation of the team for the involvement in the ATLAS physics activities, in close collaboration with LIP-Lisboa;

Continuation of the development of the Liquid Xenon detectors in view of assessing their application in gamma-ray calorimetry and dark matter search;

Further development of fast RPCs for both the application to particle identification (HADES experiment, at GSI) and the assessment of their performance in a PET system;

Development of GEM detectors, in particular aiming at track determination by measurement of the structure of light output;

Starting measurements of scintillation of nitrogen under controlled temperature and pressure, in the framework of the EUSO (ESA/NASA) experiment.

One position for a research position ("tenure track") in the framework of the contract as Laboratório Associado was advertised and open, upon appointment of the members of the selection committee. Six applications were received. The assessment of the applications will take place in early 2004.

The funding granted to the projects can be seen in the following table:

PROJECT	*REFERENCE NUMBER*	*FUNDING 2002*	*REFERENCE NUMBER*	*FUNDING 2003*
HERA-b	CERN/FNU/43701/2001	130.000,00	POCTI/FNU/49491/2002	56.000,00
Câmaras Resistivas	CERN/FNU/43723/2001	60.000,00	POCTI/FNU/49513/2002	40.000,00
Cintiladores Gasosos	CERN/FNU/43735/2001	50.000,00	POCTI/FNU/43735/2002	40.000,00
WIMPs	CERN/FNU/43729/2001	140.000,00	POCTI/FNU/43729/2002	70.000,00
Praxis - 2ª Fase	POCTI/SAU/1342/95	33.574,99	POCTI/SAU/1342/95	33.575,02
CAMCAO	POCTI/FNU/43843/2001	123.230,00	POCTI/FNU/43843/2001	114.670,00
	TOTAL	536.804,99	TOTAL	354.245,02

PROJECT	*REFERENCE NUMBER*	*TOTAL FUNDING*
n-TOF	FIKW-CT-2000-00107	148.842,00
	TOTAL	148.842,00

The academic training program related to the ongoing projects is summarised in the following table.

	Graduation reports	Master in progress	Master concluded	PhD in progress	PhD concluded
Liquid Xenon		1		1	1
RPCs	1		1		
HERA-b		2		1	1
GEMs	1			2	

HUMAN RESOURCES

RESEARCHERS

	JANUARY 2003			DECEMBER 2003	
Name	*Position*	*Position*	*Name*	*Position*	*Position*
	LIP	Other Institution		LIP	Other Institution
Armando Policarpo	LIP Directorate	FCTUC	Armando Policarpo	LIP Directorate	FCTUC
M. Salete Leite	Collaborator	FCTUC	M. Salete Leite	Collaborator	FCTUC
Rui Ferreira Marques	LIP Directorate Researcher	FCTUC	Rui Ferreira Marques	LIP Directorate Researcher	FCTUC
Ermelinda Antunes	Collaborator	FCTUC	Ermelinda Antunes	Collaborator	FCTUC
Francisco Fraga	Researcher	FCTUC	Francisco Fraga	Researcher	FCTUC
M. Isabel Lopes	Researcher	FCTUC	M. Isabel Lopes	Researcher	FCTUC
Margarida Fraga	Researcher	FCTUC	Margarida Fraga	Researcher	FCTUC
J. Pinto da Cunha	Researcher	FCTUC	J. Pinto da Cunha	Researcher	FCTUC
João Carvalho	Researcher	FCTUC	João Carvalho	Researcher	FCTUC
António Onofre	Researcher	UCP-FF	António Onofre	Researcher	UCP-FF
Vitaly Tchepel	Researcher	FCTUC	Vitaly Tchepel	Researcher	FCTUC
Helmut Wolters	Researcher	UCP-FF	Helmut Wolters	Researcher	UCP-FF
Paulo J.R. Fonte	Researcher	ISEC	Paulo J.R. Fonte	Researcher	ISEC
Paulo J.B. Mendes	Researcher	FCTUC	Paulo J.B. Mendes	Researcher	FCTUC
			Vladimir Solovov	Researcher	LIP

STUDENTS

	JANUARY 2003			DECEMBER 2003	
Name	*Position*	*Position*	*Name*	*Position*	*Position*
	LIP	Other Institution		LIP	Other Institution
Luís Margato	PhD Student	FCT	Luís Margato	PhD Student	FCT
João Bastos	PhD Student	FCT	Francisco Neves	PhD Student	FCT
Francisco Neves	PhD Student	FCT	Vasco Amaral	PhD Student	FCT
Vladimir Solovov	PhD Student	FCT	Alexandre Lindote	PhD Student	LIP
Vasco Amaral	PhD Student	FCT	Susete Fetal	Researcher	ISEC

Alexandre Lindote	PhD Student	LIP	João Batista	PhD Student	LIP
Susete Fetal	PhD Student	LIP	Luis Silva	MsC Student	LIP
João Batista	PhD Student	LIP	Luís Lopes	MsC Student	LIP
Luís Silva	MsC Student	LIP	Filipa Balau	MsC Student	LIP
Pedro Amado	Graduate Stud	LIP	Luís Fazendeiro	MsC Student	LIP
Luís Lopes	Graduate Stud	LIP	Rui Meleiro	Graduate Stud	LIP
Filipa Balau	Graduate Stud	LIP	Cláudio Silva	Graduate Stud	LIP
			A. Catarina Fonseca	Graduate Stud	LIP
			Patrícia Maduro	Graduate Stud	LIP
			Rui Matos	Graduate Stud	LIP

ADMINISTRATIVE AND TECHNICAL STAFF

JANUARY 2003		DECEMBER 2003		
Name	*Position*	*Name*	*Position*	*Lab. Assoc.*
	LIP		LIP	%
Teresa Marques	Secretary	Teresa Marques	Secretary	0
Elisabete Neves	Secretary	Elisabete Neves	Secretary	0
José Pinhão	Mech. Eng.	José Pinhão	Mech. Eng.	50
Rui Alves	Mech. Eng.	Rui Alves	Mech. Eng.	50
Rui Fernandes	Mech. Eng.	Rui Fernandes	Mech. Eng.	50
Alberto Blanco	Engineer	Alberto Blanco	Engineer	100
Joaquim Oliveira	Mechanician	Joaquim Oliveira	Mechanician	50
Carlos Silva	Mechanician	Carlos Silva	Mechanician	50
Jorge Moita	Mechanician	Jorge Moita	Mechanician	50
Nuno Carolino	Lab. Techn.	Nuno Carolino	Lab. Techn.	50
Américo Pereira	Lab. Techn.	Américo Pereira	Lab. Techn.	50
João Silva	Computer Techn.	João Silva	Computer Techn.	100

Activity Report of LIP-Coimbra Mechanical Workshop in 2003

		Man-Power (%)	(HH)	Cost (€)	Charged Value (€)
LIP-Lisboa	ATLAS	2,16%	75	571,8	571,8
	TRC	3,49%	122	1.106,2	1.106,2
		5,65%	*197*	*1.678,0*	*1.678,0*
LIP-Coimbra	RPC	5,27%	183,5	1.927,1	1.927,1
	DET. GASOSOS	0,91%	31,5	457,8	457,8
	XENON LIQ.	41,04%	1428	12.292,5	12.292,5
	ESO - CAMCAO	9,08%	316	4.292,0	4.292,0
		56,30%	*1.959*	*18.969,5*	*18.969,5*
Maintenance		*7,79%*	*271*	*2.526,1*	
Dep. de Física		*6,29%*	*219*	*4.566,2*	
Other clients		*23,97%*	*834*	*13.196,2*	*13.827,2*
	TOTAL	*100,00%*	3.480	40.936,0	34.474,6

Upon conclusion of mass production work for CERN project “Tilecal – ATLAS”, in the previous year, the workshop personnel now remains the same as before 1999, apart of one Mechanical Engineer as project designer.

The most relevant work in 2003 was the construction of aluminium and stainless steel chambers with thin walls (0.8 and 0.4 mm respectively) for liquid Xenon. For this job we had to make dedicated equipment for longitudinal and peripheral TIG welding and a lot of experimental work.

We already started the mechanical construction of the cryogenic Pulse Tube for “ESO-CAMCAO” project of Infra-Red Camera and the main workshop commitment for next year is the IR camera construction.

We plan to start working in 2004 with Computer Aided Machining (CAM) with the new CAD-CAM software (Solidworks), acquired in the framework of the ESO-CAMCAO project.

The question of aged equipment of the workshop deserves some attention, as it is becoming apparent that some machine tools need replacement and others are badly needed– e.g., automated mini-TIG welding system.

PROGRESS REPORT

Project Title: Active gaseous scintillators for detecting neutron and other radiations CERN/FNU/43735 /2002 (2nd year)

Project Coordinator: Francisco Amaral Fortes Fraga (40%)
PhD Researchers : Armando José Ponce de Leão Policarpo (10%), Rui Ferreira Marques (10%), Ermelinda Pedroso de Lima (10%), Maria Margarida Feteira Ribeirete de Fraga (10%), Paulo Jorge Baeta Mendes (20%)
PhD Students: Luís Manuel Silva Margato (100%), Susete Fetal (100%)
MsC Student: Filipa Balau (100%)
Technical Staff: Americo Pereira (20%), Nuno Carolino (20%), João Silva (20%)

Resumo:

As vantagens da utilização de detectores com leitura óptica são bem conhecidas e está provado que os cintiladores gasosos activos usando GEM ("gas electron multiplier") exibem características promissoras - elevado número de fotões emitidos nas regiões do UV e visível, algumas ordens de grandeza superior ao emitido pelos cintiladores típicos, elevada resolução, impulsos rápidos e boas propriedades de detecção. Além disso, espera-se que a fotónica seja uma das tecnologias com mais rápido crescimento nos próximos anos, pelo que esta investigação virá a beneficiar dos dispositivos de leitura óptica em rápido desenvolvimento.

O projecto em curso contempla detectores para áreas diversas tais como a imageologia de neutrões térmicos (industrial e científica), espectrometria de neutrões rápidos e polarimetria de raio-X (astrofísica).

Introduction:

During the second year of the project we decided to allocate much of our resources to the readout of light using photon counting devices, which recent results were beyond expectations. Medical applications (scintillation screen for radiotherapy) still have been idling due to project rearrangement, although we have enrolled a PhD student for this task, that has been working mainly in other tasks (3M GEMs, polarimeter studies and DOI in scintillator crystals studies).

During this period we participated in the elaboration of two proposals that were submitted to the EU 6th Framework Progamme (FP6): one in the field of neutron detection and another in generic instrumentation (TPCs) for astrophysics. The former was selected by the European Commission and our group is responsible for the task 4 related to option#2 (Gas Scintillating Proportional Chamber with light readout) of the Integrated Infrastructure Initiative for Neutron Scattering and Muon Spectroscopy JRA2 "Millimetre Resolution Large Area Neutron Detector" (MILAND).
Thermal neutron detection: in order to establish the viability and the optimal geometry of the PMT readout we developed a simulated model using four 50 mm diameter PMTs placed side by side. This work resulted in the graduation thesys of a student and its

outcome was also valuable to the development of a X-rays polarimeter based on GEM scintillation readout.
Optimization of GEM scintillation - p-terphenyl coating : we have shown that evaporating a coating of wavelenght converter inside the holes of the GEM an "active" wavelenght converter can be developed.
Neutron spectrometer - experimental determination of the recoils: we have now determined that the energy resolution of the recoil interaction is better than 3% and the accuracy of determination of track angle is typically 2 degree, using only the PMT readout. These results will have application in TPC readouts and the other projects underway.
GEM quality control Tests of GEM foils manufactured by the 3M company. So far, the tested GEMs show a better gain consistency and fewer deffects than the GEMs manufactured at CERN.
Medical applications - Depth of Interaction (DOI) in crystals. A measuring system was assembled in our laboratory and the most recent results using 2x2x20mm crystals have shown a resolution of 2 mm.

Academic Training:
Filipa Balau got her graduation in December 2003.
Susete Fetal and Luís Margato proceed on their PhD work

Publications after the 1st of January 2003:

"Dose imaging in radiotherapy with an Ar-CF_4 filled scintillating GEM", S.T.G. Fetal, C.W.E. van Eijk, F.A.F. Fraga, J. de Haas, R. Kreuger, T.L. van Vuure and J.M. Schippers, Nucl. Instr. and Meth., A513(2003)42-46.

"Luminescence and Imaging with Gas Electron Multipliers", F.A.F. Fraga, L.M.S. Margato, S.T.G. Fetal, M.M.F.R. Fraga, R. Ferreira Marques and A.J.P.L Policarpo, Nucl. Inst. and Meth. A513(2003)379-387.

"The scintillation of GEMs coated with wavelength shifters", F.A.F. Fraga, S.T.G. Fetal, M.M.F.R. Fraga, E.F.S. Balau, L.M.S. Margato, R. Ferreira Marques, A.J.P.L Policarpo e F.Sauli, submitted to Nucl. Inst. and Meth.

"Performance of an optical readout GEM based TPC", L.M.S. Margato, F.A.F. Fraga, S.T.G. Fetal, M.M.F.R. Fraga, E.F.S. Balau ,R. Ferreira Marques and A.J.P.L Policarpo, submitted to Nucl. Inst. and Meth

"A Gas Proportional Scintillator Counter for thermal neutrons instrumentation", G. Manzin, B. Guerard, F.A.F. Fraga and L.M.S. Margato , submitted to Nucl. Inst. and Meth.

Conferences after the 1st of January 2003:
IMAGING 2003, International Conference on Imaging Techniques in Subatomic

Physics,Astrophysics, Medicine, Biology and Industry, Stockholm, Sweden, 24 – 27 June 2003 , "The scintillation of GEMs coated with wavelength shifters", F.A.F. Fraga, S.T.G. Fetal, M.M.F.R. Fraga, E.F.S. Balau, L.M.S. Margato, R. Ferreira Marques, A.J.P.L Policarpo e F.Sauli

IEEE Nuclear Science Symposium and Medical Imaging Conference, Portland, Oregon October 19 – 25, 2003, "ClearPEM Performance Studies", A. Trindade, P. Almeida, F. Balau, N. C. Ferreira, S. Fetal, F. Fraga, M. Martins, N. Matela, P. R. Mendes, R. Moura, C. Ortigão, L. Peralta, R. Ribeiro, P. Rodrigues and J. Varela

10th Vienna Conference on Instrumentation, Vienna, Austria - February 16 - 21, 2004 "Performance of an optical readout GEM based TPC", L.M.S. Margato, F.A.F. Fraga, S.T.G. Fetal, M.M.F.R. Fraga, E.F.S. Balau ,R. Ferreira Marques and A.J.P.L Policarpo,
10th Vienna Conference on Instrumentation, Vienna, Austria - February 16 - 21, 2004 "A Gas Proportional Scintillator Counter for thermal neutrons instrumentation", G. Manzin, B. Guerard, F.A.F. Fraga and L.M.S. Margato .

PROGRESS REPORT

Project Title: Collaboration in the HERA-B experiment (POCTI/FNU/49491/2002)

Team

Project Coordinator: João Carlos Carvalho (40%)

PhD: Armando Policarpo (5%), António Amorim (10%), Helmut Wolters (20%)

Students: João A. Bastos (70%), Vasco Amaral (100%), António Oliveira (50%), João Batista (100%), Luis Silva (80%), Rui Matos (20%), Matilde Castanheira (20%)

RESUMO

A colaboração HERA-B estuda a colisão de protões de elevada energia (920 GeV) em alvos fixos de diferentes materiais (Carbono, Alumínio e Tungsténio). Nessas interacções são criados quarks pesados, como o "charm" (c) e o "bottom" (b), que após formarem hadrões decaiem muito rapidamente. O detector da experiência reconstrói as trajectórias e vértices de decaimento, identifica as partículas resultantes das colisões e, a partir dessa informação, obtem distribuições das quantidades cinemáticas relevantes (como a massa invariante, a quantidade de movimento transversa e o ângulo relativamente à direcção inicial do feixe) que permitem extrair informação acerca da produção e decaimento desses quarks pesados.
A experiência HERA-B está agora na fase de análise de dados, após ter terminado a sua recolha em 2003, e estuda a dependência da produção de quarks pesados com o número de massa do material do alvo (em particular a produção do mesão J/Psi, uma ressonância c-anti-c), a secção eficaz de produção de pares de quarks b-anti-b, e o estudo da produção e decaimento de mesões com o quark c. Estas medidas permitem testar as previsões da Cromodinâmica Quântica (QCD, a teoria das interacções fortes) e de modelos alternativos. O grupo português está envolvido na análise de dados, em particular na determinação da luminosidade dos dados (do número de interacções registadas), e da secção-eficaz b-anti-b a partir de decaimentos semileptónicos duplos de hadrões B. Participa ainda na manutenção da base de dados da experiência, desenvolvida e implementada pelo grupo, no controlo de qualidade de reconstrução dos dados, e no desenvolvimento de um novo paradigma de análise de dados baseado na tecnologia e linguagem de bases de dados. Um ponto importante neste projecto prende-se com a formação de estudantes, de mestrado e doutoramento, para futuras experiências de física de partículas e para a indústria de software e serviços.

Summary of activities:

In the year 2003, the HERA-B collaboration finished the data acquisition. The acquired data has higher quality, and the detector performance is much better than in 2000, thanks

to the repair and improvement of the different sub-detectors and the final installation of some pieces of equipment.

The Portuguese team is responsible for the experiment database system, which is fully operational with the integration of information from all the sub detectors. The system worked as required and it was used both online, in data acquisition, and offline, in data analysis. Its performance and functionality were improved. The database system was monitored and maintained, and new alignment constants were released whenever needed, to increase the data quality.

The group is also involved in the RICH detector. This system work as expected and its design parameters were achieved. The group participated in the detector operation and in the test of the particle identification algorithms, using different types of likelihood probabilities.

In data simulation and analysis, the Portuguese team was involved in the measurement of the branching ratio of the omega meson into two muons, that was published for the first time only in 2002, and for which the experiment has a clear signal. This decay is compared with the known branching ratios of omega into two muons and a neutral pion, implying the reconstruction of a neutral pion, and of the phi meson into two muons, where it is necessary to know the relative production cross sections. Other important work was the measurement of the b-bbar cross section from double semileptonic B meson decays. The semileptonic channels have a larger branching ratio than the J/Psi channels. The new data allowed to increase the statistics in this channel in a very significant way, resulting in a measurement of the b quark production cross-section at the HERA center of mass energy. There was also work in the luminosity determination, fundamental for the measurement of absolute cross sections, for which a new statistical method was developed and applied. This method counts the number of empty events in two independent sub-detectors, from which it fits the probability of an empty event. This probability is related with the interaction ratio by Poisson statistics. One of us is the convener of the luminosity working group. Finally there was the definition and test of a new framework of data analysis, with the use of databasing technology and data query languages, with a prototype being developed and tested with the HERA-B data sample.

Academic Training:
João Bastos - Ph.D. thesis finished in 2003.
Vasco Amaral - Ph.D. thesis conclusion foreseen in 2004.
João Batista - M.Sc. Thesis conclusion foreseen in 2004.
Luis Silva - M.Sc. Thesis conclusion foreseen in 2004.
Matilde Castanheira - graduation thesis conclusion foreseen in 2004.

Publications:
"Inclusive V^0 production cross sections from 920 GeV fixed target proton-nucleus collisions" I.Abt et al., DESY-02-213, DEC. 2002, *Eur.Phys.J.C29:181-190,2003,* hep-ex/0212040

"J/Psi production via Chi_C decays in 920 GeV pA interactions" I.Abt et al., DESY-02-187, Nov. 2002, *Phys.Lett.B561:61-72,2003,* hep-ex/0211033

"Measurement of the B anti-B production cross-section in 920-GeV fixed target proton nucleus collisions" I.Abt et al., DESY-02-076, May 2002, *Eur.Phys.J.C26:345-355,2003,* hep-ex/0205106

"HERA-B RICH" S. Korpar for the HERA-B RICH Collaboration, 4th Workshop On RICH Detectors: Dedicated To The Memory Of Tom Ypsilantis (RICH 2002), Pylos, Greece, Nucl.Instrum.Meth.A502:41-45,2003

“Particle identification with HERA-B RICH” M. Staric for the HERA-B RICH Collaboration, 4th Workshop On RICH Detectors: Dedicated To The Memory Of Tom Ypsilantis (RICH 2002), Pylos, Greece, Nucl.Instrum.Meth.A502:289-293,2003

PROGRESS REPORT

Project Title: Development of liquid xenon and liquid argon detectors for WIMPS search and CERN n-TOF project (POCTI/FNU/43729/2002)

Team

Project Coordinator:	
Maria Isabel Silva Ferreira Lopes	30%
PhD:	
Armando Policarpo	10%
José Pinto da Cunha	40%
Paul Baeta Mendes	20%
Rui Ferreira Marques	10%
Vitaly Chepel	30%
Vladimir Solovov (PosDoc)	100%
Students:	
Alexandre Lindote	100%
Ana Catarina Fonseca	50%
Francisco Neves	100%
Rui Miguel Meleiro	50%
Cláudio da Silva	50%
Technical Staff:	
Américo Pereira	25%
José Pinhão	10%

Resumo:

Do movimento das estrelas e das galáxias, assim como de outras observações do domínio da astronomia e da astrofísica, conclui-se que a matéria bariónica (i.e., a matéria constituída por protões, neutrões e electrões) constitui apenas cerca de 5% da massa total do Universo, sendo 1% matéria luminosa e cerca de 4% matéria não luminosa bariónica. A constituição dos restantes 95% da matéria do Universo é presentemente um problema central da Cosmologia. Actualmente, pensa-se que 23% são constituídos pela chamada matéria escura (não-bariónica) e 72% pela energia escura.

A natureza da matéria escura é um dos problemas actuais da Cosmologia. Os WIMPs (Weakly Interacting Massive Particles) são apontados como possíveis constituintes de parte dessa matéria escura. Estas partículas podem eventualmente ser detectadas por observação dos recúos nucleares produzidos por colisão elástica com os núcleos constituintes de um meio detector. A baixa probabilidade destas colisões e a baixa energia dos recúos nucleares que produzem tornam esta observação muito difícil. Além disso, a separação dos sinais devidos aos WIMPs (muito raros) dos sinais devidos a toda a radiação cósmica e ambiente (muito frequentes) é um requesito de importancia crucial.

Para comprovar a existência de WIMPs desenvolvem-se detectores optimizados para este fim e que são colocados em laboratórios subterrâneos para minimizar o ruído constituído pela radiação cósmica e ambiente.
Um dos objectivos deste projecto é a participação no desenvolvimento de um detector de xénon líquido para a pesquisa de WIMPs no âmbito da colaboração internacional UKDMC (UK Dark Matter Collaboration). Fazem parte do programa de trabalho o estudo de alguns dos problemas relevantes para a concepção do detector. A resposta do detector à interacção de WIMPs é estudada usando neutrões de energia adequada (tipicamente alguns MeV) que produzem por colisão elástica recúos nucleares com energia semelhante à esperada das interacções elásticas dos WIMPs.
Para efectuar estes estudos, concebeu-se e construiu-se um detector de xénon líquido e o sistemas para purificação, manipulação e liquefação do xénon. Desenvolveu-se a electrónica para processamento dos sinais do detector. Montou-se o sistema de aquisição de dados para efectuar as medidas com radiação gama e com o feixe de neutrões. Realizou-se a simulação completa não só da resposta do detector a radiação gamma e a neutrões, como das condições experimentais no feixe de neutrões. Estão em curso várias medidas utilizando radiação gamma e em breve terão início os estudos com um feixe de neutrões.
Para além do estudo da resposta do xénon líquido a recúos nucleares, realizaram-se ou estão a decorrer estudos relacionados quer com as opções tecnológicas quer as propriedades fundamentais do xénon líquido com vista à optimização do detector.
Este projecto tem também em simultâneo um outro objectivo central: o desenvolvimento de um detector de xénon líquido para a detecção de cascatas de raios-gamma produzidos em experiências de captura de neutrões como aquelas que são efectuadas no âmbito da colaboração n-TOF no CERN e na qual o nosso grupo participa. Neste caso, o sinal com interesse é devido aos raios-gamma e o ruído é devido à interacção dos neutrões que atingem o detector. Assim, a maior parte dos estudos feitos com vista a atingir o primeiro objectivo referido são também indispensáveis ao desenvolvimento deste outro detector.

Summary of activities:

The project concerns the development of liquid Xe detectors for searching dark matter WIMPs (Weakly Interacting Massive Particles), and for detection of gamma rays from n-capture events in experiment PS213 at CERN carried out by n-TOF. In the framework of the project, the scintillation signals from liquid xenon due to gamma-rays and to neutrons of suitable energy in view of the applications referred above are studied. The interest in investigating the liquid xenon scintillation produced by neutrons is twofold: i) the elastic scattering of neutrons of suitable energy produce nuclear recoils that mimic those expected from WIMP interactions; ii) for the detection of gamma-rays in n-capture cross section measurement experiments, the interaction of neutrons with liquid xenon constitutes a source of background which has to be investigated.
This report refers to the scientific activity developed in the period from 1st May 2003 (beginning of the project) to 1st February 2004. During this period, the following main tasks were carried out:

1. TESTS OF THE PHOTOMULTIPLIER R2154-07MOD HAMAMATSU DOWN TO LIQUID NITROGEN TEMPERATURE. This PMT, with bialkali photocathode, was chosen for being

used in the chamber. Tests were done with both continuous and pulsed light sources in order to study the saturation of response, due to accumulation of charge in the resistive bialkali photocathode, as a function of the light intensity.

2.ASSEMBLING AND TESTS OF A 3 LITER CHAMBER EQUIPPED WITH 7 PHOTOMULTIPLIERS. The chamber and its thermal isolation design, as well as the liquefaction and cooling technique, were conceived having in view the need to minimize the amount of material around the liquid xenon volume. The chamber is made of stainless steel to meet the high purity requirement, the walls having 0.5 mm thickness while the bottom is 4 mm thick. An array of 7 photomultiplier tubes, (2 inch diameter each), are mounted on a 10-inch CF-flange. In order to improve the light collection, a fiducial volume of xenon surrounded by Teflon was created inside the chamber. For thermal isolation, the chamber is placed in a vacuum vessel, made of aluminum and with 0.5 mm thick walls. The thin walls were reinforced by a carbon fiber external coating. The voltage dividers and the preamplifiers for the PMTs were mounted on the top of the chamber, inside the vacuum vessel.

The whole chamber was assembled after having been vaccum and pressure tested, cleaned and baked at -120ºC during several days. After having been assembled, it is being baked at –70ºC for further outgassing.

3.ASSEMBLING AND TESTS OF A NEW COOLING AND LIQUEFACTION TECHNIQUE SUITABLE FOR THE MEASUREMENTS IN A NEUTRON BEAM. This technique uses an auxiliary system – the condenser- composed by a serpentine inside a cooling bath placed above the chamber. The xenon gas condenses in passing the serpentine and drops into the chamber. The temperature of the chamber is maintained by the liquid xenon itself and by the vacuum thermal isolation surrounding the chamber. Such system was tested and proved to work reliably. A condensation rate of ~300 cm^3/h was obtained.

4.DEVELOPMENT AND PRODUCTION OF FRONT-END ELECTRONICS. As the project budget was not enough for buying commercial preamplifiers and shaping amplifiers for the PMT signals, they were developed and implemented in the framework of this project. This consumed extra time and man-power, which was not forseen in the initial project.

The main characteriscs of the developed preamplifier are the following: *gain*: 150 mV/pC; *risetime*: 2.5 ns (adjustable); *decay time*: 500 ns; *noise* (with semi-gaussian shaping of _ = 250 ns at the amplifier): ~6000 e rms; *output*: one, with 50 ohms; *power supply*: bipolar, ±5..7 V; *current consumption* (for full bandwith): 20 mA. Eight preamplifiers were assembled.

A multichannel amplifier unit was produced with 8 channels, each of them with the following characteristics: i) each channel consists of fast inverter, CR–$(RC)^2$ shaper with _ = 250 ns and adjustable gain amplifier; ii) input: 50 ohm BNC; iii) Fast output: gain of approx. 1 and risetime < 5ns; iv) Slow (shaped) output: gain between 1 and 20, adjustable with screw on the front panel; both outputs are inverting, capable of driving a 50 ohm load. iv) an output with the sum of the slow outputs of all the 8 channels; v) power consumption: 250 mA from +6V and 250 mA from –6V; vi) everything is packed in one single-with NIM module.

5.XENON PURIFICATION. Four liters of xenon from Praxair (grade Xenon 4.6) started to be purified in the portable purification system constructed for these experiments. After just a few freezing-and-pumping cycles and one passage of the gas through the Oxisorb column, the electron lifetime was equal to 7 μs. Further purification of xenon is in progress.

6.BEAM TESTS IN A NEUTRON FACILITY (Demokritos Tandem Accelerator, Athens, Greece). Neutron beam tests were done to assess the experimental conditions and perform

preliminary tests in view of carrying out the measurements referred above. These tests included the following: i) testing and fine tuning the n-γ discrimination with the BC501 liquid scintillator; ii) determination of the efficiency of the neutron detector; iii) determination of the beam profile and flux; iv) evaluation of the background conditions in the experimental area in respect to both neutrons and gamma rays; v) study of the efficiency of the available shielding materials; vi) simulation of the n-scattering in LXe detector with a 5"x5" (height x diameter) NaI(Tl) detector.

7.MONTE CARLO SIMULATION OF THE XE CHAMBER OPERATING AT THE DEMOKRITOS NEUTRON SOURCE FACILITY. A detailed Geant4 Monte-Carlo simulation of the response of the liquid xenon chamber under neutron irradiation and, in particular, of the experimental conditions at Demokritos neutron facility has been developed. The neutron generation, neutron transport in the detector and the physical processes were fully simulated. Among the issues studied, one counts: i) the light collection efficiency in the chamber with and without the fiducial volume surrounded by teflon; ii) detector response to nuclear recoils resulting from elastic scattering of neutrons with Xe nuclei; iii) impact of multiple elastic and inelastic scattering of neutrons in the liquid xenon detector and the chamber walls on the measurements of the detector response to nuclear recoils; iv) feasibility of the discrimination of the inelastic scattering events in the chamber by the measurement of the time-of-flight of the scattered neutron; v) effect of an energy cutoff at the energy spectrum measured by the liquid xenon chamber on the discrimination of the inelastic scattering events; vi) in view of the large gamma-ray background existing in the experimental of Demokritos neutron facility, two shielding possibilities were simulated aiming at evaluate their impact on the measurements: to place a small lead sheet directly in front of the neutron beam (best suited for the gamma-rays coming from the neutron source), or to surround the xenon chamber by a lead structure (best suited for an uniform distribution of gamma-rays in the area); the effect of each solution, from the point of view of both gamma-shielding and source of disturbance of the neutrons reaching and interacting in the detector, was studied.

This simulation is providing essential indications to set the irradiation conditions concerning neutron energy, neutron scattering angles selection, neutron collimation, background shielding. It will also be crucial for the future data analysis.

As a final remark, it should be noted that almost the whole effort of the team was concentrated in the tasks necessary and preliminary to make the measurements planned in the project and assess the performance of the detectors purposed. Such tasks are very time and man-power consuming, but do not originate publications by themselves.

It should also be mentioned that there were unexpected technical difficulties which delayed considerably (several months) the conclusion of the construction of the chamber and forced to repeat the pressure and vacuum tests many times, which consumed extra time. Those technical problems had to do with the welding of the thin stainless steel walls of the chamber. There were also problems with the carbon fiber coating of the thermal isolation vessel of the chamber.

Academic Training:

Rui Meleiro e Ana Fonseca are undergraduate students that are doing their graduation project (graduation in Physical Engineering) in the framework of this project. They have "research fellowships" paid by the project.

Alexandre Lindote finished the work and the writing of the thesis in order to get the Master Degree. He is waiting for the examination.
Francisco Neves is doing his Ph.D. work in the framework of this project.
Vladimir Solovov receives a Pos-Doc fellowship from FCT since February 2004.

Thesis:
"Simulation study of a liquid xenon detector with application to the detection of dark matter" , Alexandre Lindote (Master thesis).

Communications:
in the Collaboration Meetings of UKDMC
"Dark Matter search with liquid xenon: activities at Coimbra " presented by V. Chepel , in the UKDM Collaboration Meeting in Sheffield, UK, June 2003.
"Dark Matter search with liquid xenon detectors : R&D activities in Coimbra" presented by M. I. Lopes in the UKDM Collaboration Meeting in Edinburgh, UK, 12-14 January 2004.
in the Collaboration Meetings of nTOF
"R&D of a Liquid Noble Gas Calorimeter: present status " presented by R. Ferreira Marques in the nTOF Collaboration Meeting in Vienna, Austria, December, 2003.

Publications
"Low temperature study of 35 photomultiplier tubes for the ZEPLIN III experiment" H.M. Araujo, A. Bewick, D. Davidge, J. Dawson, T. Ferbel, A.S. Howard, W.G. Jones, M. Joshi, V. Lebedenko, I.Liubarsky, J. Quenby, T. Sumner, F. Neves, (to be published in Nucl. Instrum. Methods A 521 (2004) pp.411-419)

PROGRESS REPORT

Project Title: Applications of timing Resistive Plate Chambers

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Team

Project Coordinator: Paulo J. R. Fonte

PhD: Paulo Fonte, M. Isabel Lopes, Rui Ferreira Marques and Armando Policarpo

Students: Luis Lopes, Pedro Amado

Technical Staff: Alberto Blanco, José Pinhão, Rui Alves, Nuno Carolino

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Resumo:

As Câmaras de Placas Resistivas são detectores de partículas elementares particularmente adequados para a medida do tempo de voo das partículas – uma técnica de identificação de partículas comum em Física Nuclear e de Partículas. A medida de tempos de voo tem também relevância para a técnica de imagiologia por emissão de positrões (PET) utilizada em Medicina Nuclear.

Estas câmaras foram desenvolvidas conjuntamente pelo INFN-Bolonha, CERN, ITEP-Moscovo e LIP-Coimbra no decurso da fase de R&D da experiência ALICE no CERN/LHC [1]. Desde então o LIP-Coimbra tem procurado activamente aplicar a tecnologia em experiências de Física das Altas Energias, no CERN e noutros locais, tendo também sido desenvolvidas aplicações em imagiologia de radioisótopos.

[1] Nuclear Instruments and Methods A 443 (2000) 201-204

Summary of activities:

This report concerns the activities that took place in 2003.

Developments in RPC-PET
The RPC-PET prototype was further explored and the point-like source reconstruction accuracy was improved to 0.6 mm FWHM without any image enhancement. This work was presented at the RPC2003 workshop.
Efforts were initiated to develop a suitable image reconstruction algorithm that may perform full 3D reconstruction (in view of a full size small-animal PET) and image enhancement.

Developments within the HADES experiment (GSI)
A prototype comprising 3 full-size counters with corresponding electronics and DAQ (test versions) was built and beam-tested at GSI. The detector has shown very small

crosstalk, very good uniformity and reasonable count rate capability, seeming to fulfil the HADES requirements. A follow-up test is foreseen for 2004.
The CIEMAT institute in Madrid has agreed to take part in the development of the final front-end electronics and the Department of Mechanical Engineering of the Escola Superior de Tecnologia e Gestão do Instituto Politécnico de Leiria has agreed to take in charge the preparation of the necessary mechanical parts (counter electrodes and enclosing box).

Developments within the CBM collaboration at GSI

High rate timing RPCs

The operation of timing RPCs at 25kHz/cm^2 (one order of magnitude higher than current maximum rates) was demonstrated. The tests were performed at Instituto Tecnologico e Nuclear (ITN), Sacavém, Portugal.
However the electrode material chosen, an anti-static plastic called ENSITAL, proved to be an ionic conductor and therefore must be discarded as a viable solution.
These results were presented at the RPC2003 workshop

Aging in timing RPCs

Our aging test accumulated over eight years of equivalent running time. Deposits were found over the glass surfaces and analysed by x-ray fluorescence. However the counters have shown no adverse effects arising from such deposits. These results were presented at the RPC2003 workshop.

Detector Physics studies

An analytic model of timing RPC timing properties was developed, including the effects of gas electronegativity. The model highlights the main factors influencing the time resolution of RPCs, which are actually only two: the value of the first Townsend coefficient multiplied by the electrons drift velocity and the number of effective primary charge clusters. These results were presented at the RPC2003 workshop.

Developments within the FP6 and INTAS initiatives

Our group became during this year involved in a JRP (*Advanced Time-of-Flight (ATOF)*) within the I3 Hadron Physics project of the EU Sixth Framework Program. This project was recently approved.
We are also participating in the INTAS project Ref.Nr. 03-54-3891 *Development of the high rate RPC TOF detector for particle identification in the CBM experiment.*

Academic Training:

A project fellow, Luís Lopes, concluded his graduation seminar on the theme of “Aging in RPCs”.

Publications:

Results concerning understanding and applications of timing GRPCs, Finck, C; Fonte, P; Gobbi, A; Nuclear Instruments and Methods in Physics Research A 508 (2003) 63 – 69.

Single-gap timing RPCs with bidimensional position-sensitive readout for very accurate TOF systems, Blanco, A; Ferreira Marques, R; Finck, Ch; Fonte, P; Gobbi, A; Policarpo, A; Nuclear Instruments and Methods in Physics Research A 508 (2003) 70 – 74.

Perspectives for positron emission tomography with RPCs, Blanco, A; Chepel, V; Ferreira-Marques, R; Fonte, P; Lopes, M.I; Peskov, V; Policarpo, A; Nuclear Instruments and Methods in Physics Research A 508 (2003) 88 – 93

Resistive plate chambers for time-of-flight measurements, Blanco, A; Fonte, P; Lopes, L; Mangiarotti, A; Ferreira-Marques, R; Policarpo, A; Nuclear Instruments and Methods in Physics Research A 513 (2003) 8 – 12.

Conferences:

A study of aging in timing RPCs, presented at the VII Workshop on Resistive Plate Chambers and Related Detectors. Submited to Nucl. Instrum. and Meth.

Performance of shielded timing RPCs in a 12C fragmentation experiment, presented at the VII Workshop on Resistive Plate Chambers and Related Detectors. Submited to Nucl. Instrum. and Meth.

Development of high-rate timing RPCs, presented at theVII Workshop on Resistive Plate Chambers and Related Detectors. Submited to Nucl. Instrum. and Meth.

An RPC-PET prototype with high spatial resolution, presented at the VII Workshop on Resistive Plate Chambers and Related Detectors. Submited to Nucl. Instrum. and Meth.

Exactly Solvable Model for the Time Response Function of RPCs, presented at the VII Workshop on Resistive Plate Chambers and Related Detectors. Submited to Nucl. Instrum. and Meth.