

The CRESCERE Muon's Lifetime Experiment

J. Santos^{*,1,2,3,5}, J. Augusto¹, A. Gomes^{2,3}, L. Gurriana^{2,3}, N. Lourenço⁴, A. Maio^{1,2,3},
C. Marques^{1,2,3}, J. Silva^{1,2,3}

¹ Faculdade de Ciências da Universidade de Lisboa, Lisbon, Portugal.

² Centro de Física Nuclear da Universidade de Lisboa, Lisbon, Portugal.

³ Laboratório de Instrumentação e Física Experimental de Partículas, Lisbon, Portugal.

⁴ Instituto Superior Técnico, Lisbon, Portugal.

⁵ Instituto Politécnico de Beja, Escola Superior de Tecnologia e Gestão, Beja, Portugal.

In this paper we present the *Muon Lifetime on-line experiment* implemented within *CRESCERE - Cosmic Rays in an European School Environment: a Remote Experiment* – project, as part of the initiative *Researchers in Europe*. It is a real particle physics experiment prepared for the general public that can be remotely operated with only a simple web browser. The basis of the experiment and setup used are explained as well as the concepts behind this e-lab implementation

Keywords Apache; e-learning; e-labs; HTTP server; instrumentation; MySQL; particle physics; PHP; Web; remote experiment.

1. Introduction

The *Muon's Life Time Experiment* [1] is one of the three on-line particle physics experiments provided by *CRESCERE – Cosmic Rays in an European School Environment: a Remote Experiment* – [2]. These are real particle physics experiments, prepared to measure cosmic rays properties, with modern detectors of the same type that are presently used in the High Energy Physics community. They are directed to the general public, allowing to operate the detectors through common web browsers and to communicate with tutors through chat lines. Experimental data were analysed by the participants, discussed with the experts, and published on the Web. *CRESCERE* was a joint project between Italy, Portugal and Romania, in which four leading scientific institutes participated: Laboratori Nazionali di Frascati dell'INFN, Faculdade de Ciências da Universidade de Lisboa, Laboratório de Instrumentação e Física Experimental de Partículas, National Institute of Physics and Nuclear Energy “Horia Hulubei”. It aimed to promote a better understanding of the european researches activities, to improve public awareness of researchers activities in the development of modern society, to stimulate the curiosity in day-by-day research activities and to encourage young people to take up a scientific career [3] and was part of the 2005 European multi-faceted awareness initiative “*Researchers in Europe*” [4].

2. Cosmic muons

The muon is an unstable particle, similar to the electron but with a mass ~200 times greater, that decays into an electron and two neutrinos Cosmic muons are produced through the collision of high energy cosmic rays – primary cosmic rays, mainly protons and heavier nuclei - with the Earth's upper atmosphere (about 20 km from the ground) and may reach the surface. When primary cosmic rays collide with the atmosphere they lose their energy by creating a jet of particles – protons (p), neutrons (N) and pions (π) - which carries on traveling in almost the same direction as the primary cosmic ray. The particles in the jet can themselves create more particles as they hit other nuclei in the air. This jet is called an extensive air shower and keeps on growing until the particles in the shower run out of energy and are absorbed in the atmosphere. The pions produced decay into two photons, if neutral (π^0), or into a

* Corresponding author: e-mail: jsantos@lip.pt, Phone: +351 7973880

muon (μ^\pm) and a neutrino (ν), if charged (π^\pm). The muons decay later into an electron (e) and two neutrinos. The processes of muon production and decay are:

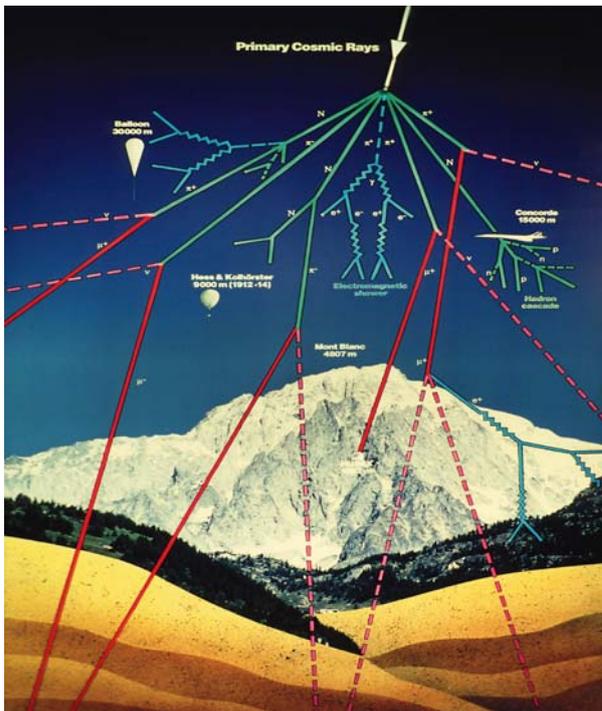
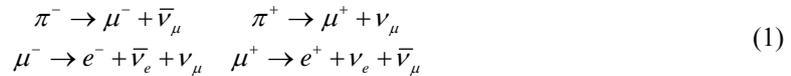


Fig. 1 [5] When primary cosmic rays hit the upper atmosphere they lose their energy by creating a jet of particles which carries on traveling in almost the same direction. The particles in the jet can themselves create more particles as they hit other nuclei of oxygen or nitrogen in the air. This jet is called an extensive air shower and keeps on growing until the particles in the shower run out of energy and are absorbed in the atmosphere. collisions produce charged pions that decay into muons. The muons can reach the earth's surface, if they do not decay before losing almost their kinetic energy.

3. Muon lifetime measurement

The experiment is designed to measure the muon lifetime, in this case the lifetime of cosmic muons that reach the earth's surface. The principle is to obtain a time distribution, consisting of consecutive pulse pairs coming from a detector. Such a time distribution will contain an exponentially decaying component, corresponding to muon decays, from which the muon lifetime is extracted.

A simplified scheme of the system is shown in the figure 2. It consists of a plastic scintillator block ($10 \text{ cm} \times 20 \text{ cm} \times 20 \text{ cm}$), with a layer of lead above to increase the rate of cosmic muons that decay inside the scintillator. These scintillator block is made of plates of injection moulded polystyrene doped with fluorescent dyes, of the same type used in the ATLAS/LHC [6] detector at CERN. When muons are captured inside the scintillating material, and then decay, two flashes of light are produced that will be converted into two electric signals. The first is given by the flash produced by the muon when it passes through the scintillator and the second from the electron resulting from the muon decay. The light flashes from the scintillator are read by optical wavelength shifter (WLS) fibres, and guided to two photodetectors located in each side of the scintillator block. The optical fibres are made of polystyrene doped with fluorescent dyes. In the case of the WLS fibres the dye absorbs in the blue region of the spectrum and emits in the green. The photodetectors are photomultipliers (PMT), light sensors of extreme sensitivity (detecting quantities of light such as one single photon). The output signals are fast electric pulses, which in this case need to be amplified. In order to select pulses of certain amplitude a discriminator is used. The signal from the discriminator is logic, contrary to the signal output of the amplifier, which is analogue. To suppress the noise or uncorrelated signal a coincidence unit based on logic

AND is used. This prevents non correlated signals to be driven to the data acquisition system. All this signal conditioning is made with NIM modules.

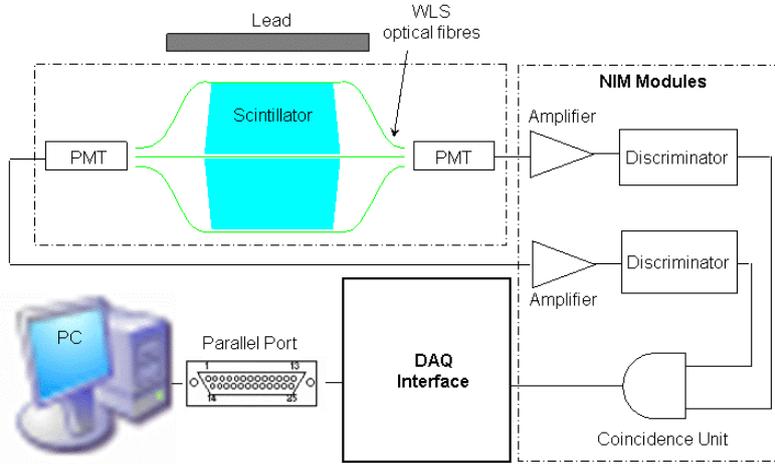


Fig. 2 Scheme of the system for the muon lifetime determination.

The logic signal from the coincidence unit drives the data acquisition interface (DAQ), a dedicated electronic circuit using standard components that was developed [7] for this purpose. It consists of a NIM to TTL converter and a digital clock, connected to the PC through the parallel port. A simplified scheme of the interface is shown in the figure 3. The digital clock is essentially composed by a monostable multivibrator that rejects signals spaced less than 100 ns, a mainly synchronous state machine and a 10 MHz oscillator, that activate an 8 bit counter with the time (in units of 100 ns) between the start and stop signals produced by two successive pulses. The time difference between the signals from the two flashes is given by the number in the counter, which is sent to the PC through the parallel port. Only when the first flash of a pair corresponds to a muon entering the detector, and the second to the decay of a muon which stopped in the detector we obtain an event contributing to the exponential decay.

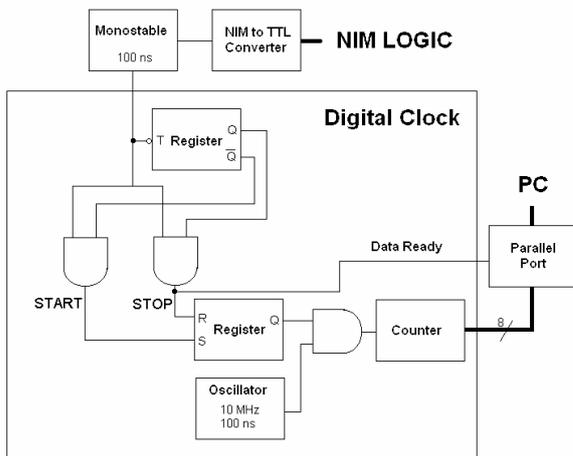


Fig. 3 Functional block diagram of the data acquisition interface. This interface consists basically of a digital clock with 100 ns resolution that measures the time between two subsequent flashes of light. If these flashes are produced by a muon and the electron of its decay, the time events follow an exponential distribution from which the muon lifetime can be extracted.

The DAQ interface is connected to the Status and the Control ports of the parallel interface (figure 4). A data acquisition application polls the bit 7 of the status port, connected to the data ready line. In case of data ready, the 8 bit counter is read in two steps with a 2/1 multiplexer through the bits 3 to 6 of the same

port. The reading procedure is controlled by the application through bit 1 of the Control port. When the event acquisition is completed the application resets the digital clock through the bit 2 of this port and stores the event in a table of a MySQL database. The data acquisition is performed currently on a windows platform (AMD 64 Athlon, with Windows XP Professional) and the application was developed in C with MinGW [8].

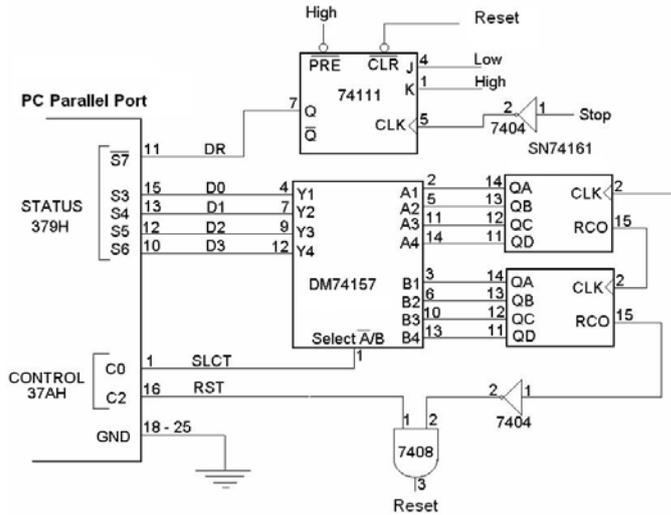


Fig. 4 Details of the interface to the PC parallel port. The data acquisition and the control of the DAQ circuit is done through the Status and Control ports of the parallel port.

4. The remote experiment

This is a classic experiment to measure the muon lifetime, implemented in university laboratories. The innovative character of this work is to be remotely controlled with Web browsers, without needing any special client software. The PC that controls the instrumentation works as an HTTP server, running Apache. A Web site [1] was developed in PHP that describes the experiment, provides access to the on-line lab (e-lab) and allows registered participants to control the experiment, and guides on the analysis of data. The participants can communicate with a tutor/researcher via a Web-cam and a chat e-learning suite. Participation is activated through a previous Web booking and password attribution system. A table in the database keeps parameters that define the state of the detector. PHP scripts change these parameters according to the participant commands and the DAQ application reads them and controls the detector accordingly. All the other relevant information of the experiment (session ID, participant contacts, session password,...) is manipulated through the database. Figure 5 presents the scheme of this e-lab architecture and figure 6 a detail of the online lab user interface.

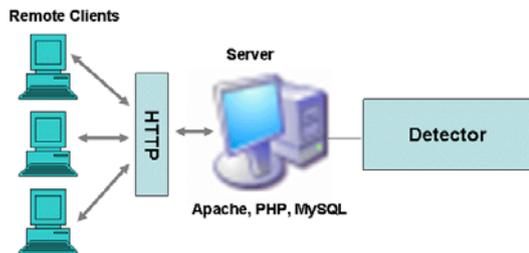


Fig. 5 The remote lab architecture: a PC acts as the instrumentation controller, database server and web server. Control parameters are manipulated through the MySQL database by data acquisition software that controls the instruments and by PHP scripts that allow the control by the users.

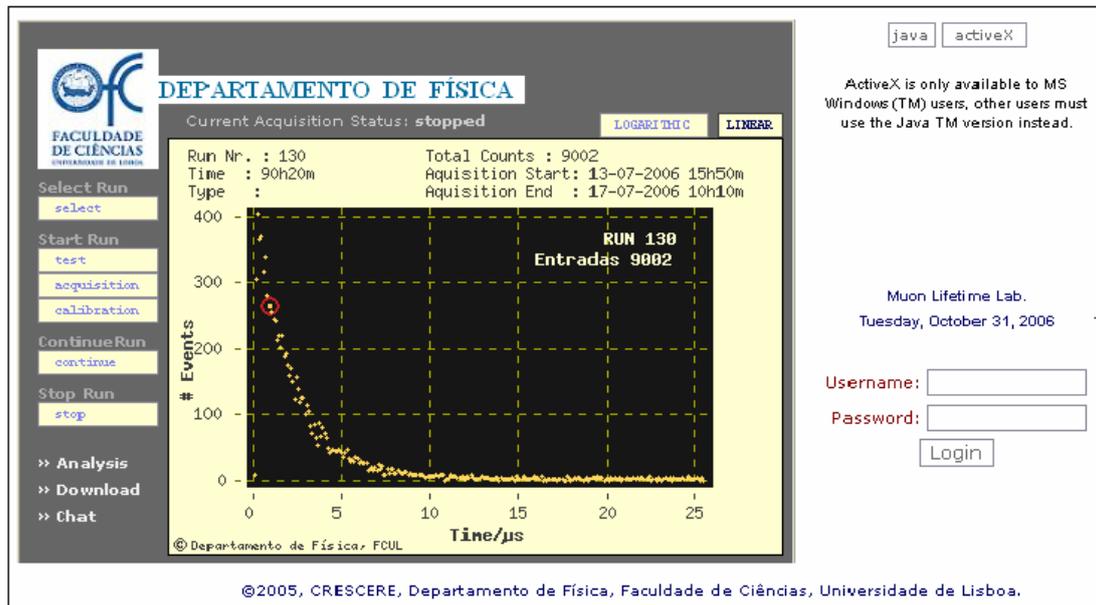


Fig. 6 The user interface of the The Muon Lifetime Experiment remote laboratory. An experimental muon time spectrum obtained in a run of ~90 hours. A fit to the exponential component of this distribution allows to obtain the muon lifetime: $\tau_{\mu} = 2.2 \mu\text{s}$.

5. Conclusions

The remote lab design presented proved to be simple and robust. It doesn't require any special software – only a web browser. As the needs for processing power are mainly on the server side, there's a negligible load in client machines, making it adequate to general public access. The participation in the experiment was very satisfactory and the results obtained for the muon lifetime are coherent with the tabulated values, as described in another paper in this conference [9].

References

- [1] <http://crescere.fc.ul.pt>.
- [2] <http://www.scienzapertutti.net>.
- [3] CRESCERE Booklet, CRESCERE Project (2005).
- [4] FP6-2004-Mobility-13 Project N° FP6-019653.
- [5] CERN Photo: CERN-DI-9905005.
- [6] ATLAS Collaboration, *ATLAS tile calorimeter technical design report*, CERN-LHCC (1996).
- [7] N. Machado, J. Santos, J. Silva, *Projecto de Dispositivo para a Medição da Vida Média de Muões Cósicos com Aquisição de Dados num Computador Pessoal*, Trab. Mestrado Eng. Física, FCUL (1998).
- [8] MinGW - Minimalist GNU for Windows, <http://www.mingw.org>.
- [9] B. Dias *et al.*, *Introduction to particle physics at High School with a remote experiment*, Proceedings of the IV International Conference on Multimedia and Information & Communication Technologies (2006).