

Muon Lifetime Measurement in Chiapas and the Escaramujo project

Luis Rodolfo Pérez Sánchez¹ and Federico Izraelevitch²

¹Faculty of Sciences in Physics and Mathematics and Mesoamerican Centre for Theoretical Physics of Autonomous University of Chiapas (FCFM-MCTP-UNACH)

²National University of San Martín, Argentina and Fermilab (Fermi National Accelerator Laboratory)

E-mail: rperez@mctp.mx

Abstract.

Escaramujo is a project with the goal of promote scientific development and integration regarding science for Latin America. It consists of a series of Laboratories and Workshops for High Energy Physics, astroparticle and instrumentation, given by Federico Izraelevitch. Escaramujo has been conducted at several institutions in Latin America. In this work, the muon mean lifetime measurements performed during the workshop held in Chiapas are presented. The results are compared with the corresponding value reported by the Particle Data Group (PDG).

1. Introduction

The activities performed during the workshop were based on a Cosmic Ray (CR) detector, designed specifically for the project. The students assembled, ran and controlled the detector, they also performed data acquisition from several measurements. The detectors are designed specifically to provide a reasonably priced detection system on a scale which is suitable for classroom or personal use. After each course, a device remained in the academic institution to be used by teachers, students and researchers [1]. The principal goal, reported in this document, is to study the muonic component from an Extensive Air Shower (EAS), induced by CR.

The CR arrive to our planet and interact with the molecules in the atmosphere creating a shower of secondary particles. Those particles can be detectable at ground level by surface detectors or can be seen from their fluorescence traces on their way passing through the atmosphere, by means of Fluorescence telescopes and related techniques.

When primary CR, which are mainly protons (a relatively small fraction of them consist on heavier nuclei, such as Fe, He, Li, Si, N, photons, among others) produce secondary particles in the atmosphere, those particles are mainly pions (π^\pm, π^0) and kaons (K^\pm, K^0). Muons (μ^\pm) are produced by interaction of charged pions (π^\pm). The π^\pm decay into a μ^\pm and its related neutrino (ν_μ) or anti-neutrino ($\bar{\nu}_\mu$), see equations 1 and 2.

The μ is a massive elementary particle that belongs to the second generation of leptons [2]. Its mass is 200 times the electron mass, and its mean lifetime is longer than other unstable



particles. It does not interact with matter via the strong force but through the weak and electromagnetic forces and with gravity.

The μ^- decays into an electron (e^-), the μ^+ into positron (e^+) with its related neutrino (ν_l) and anti-neutrino ($\bar{\nu}_l$), see equations 3 and 4.

$$\pi^- \longrightarrow \mu^- + \bar{\nu}_\mu \quad (1)$$

$$\pi^+ \longrightarrow \mu^+ + \nu_\mu \quad (2)$$

$$\mu^- \longrightarrow e^- + \bar{\nu}_e + \nu_\mu \quad (3)$$

$$\mu^+ \longrightarrow e^+ + \nu_e + \bar{\nu}_\mu \quad (4)$$

1.1. Plastic Scintillator and Photodetector

The instruments used for this experiment are scintillation detectors, made by special materials that radiate when ionized and emit a small flash of light. This phenomenon occurs when the radiation interacts with matter by the excitation and ionization of a large number of atoms and molecules [2]. When they return to their ground state emits photons with energy range in the visible spectrum or near to it.

Escaramujo uses three plates of plastic scintillator *EJ-200*¹ which combines the two important properties: long optical attenuation length and fast timing, which makes it particularly useful for time-of-flight systems using scintillators greater than one meter long. Table 1 shows the properties of the plate EJ-200. The signal produced by the secondary particles in the scintillator are measured by Silicon Photomultipliers (*SiPM*²), one per plate.

The *EJ-200* and the *SiPM* are enclosed with EMI/Static shield (Type 1, Class 1) to exclude ambient light from getting into the SiPM, see figure 1.

Table 1. Properties of the plate EJ-200

PROPERTIES	EJ-200
Scintillation Efficiency (Photons/1 MeV e^-)	10000
Wavelength of Maximum Emission (nm)	425
Light Attenuation Length (cm)	380
Rise time (ns)	0.9
Decay time (ns)	2.1
Polymer Base	Polyvinyltoluene
Refractive index	1.58

The *SiPM* has a surface of 6 mm x 6 mm, type *MicroFC-60035-SMT-SensL*³, this collects the light produced in the scintillator and data acquisition is performed with a high performance

¹ <http://www.eljentechnology.com/index.php/products/plastic-scintillators/ej-200-e-j-204-ej-208-ej-212>

² Detector built from a photodiode matrix, working in avalanche mode, also known as Geiger Mode

³ <http://sensl.com/estore/microfc-60035-smt/>

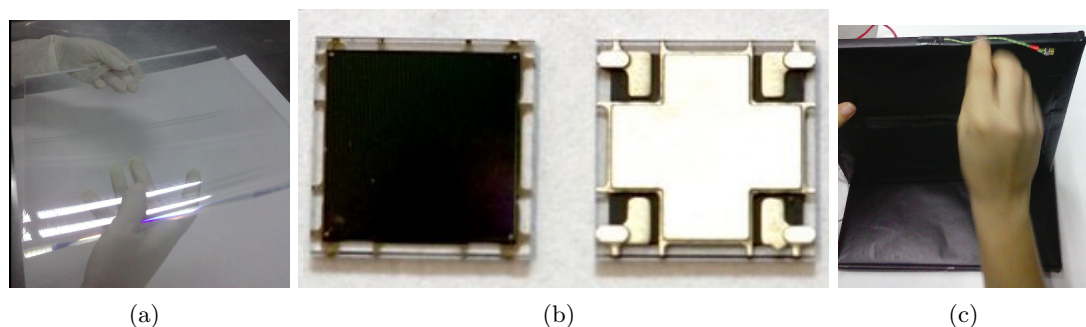


Figure 1. Components of Escaramujo: (a) EJ-200 size of 25 cm x 25 cm x 1 cm, before packaging, (b) Silicon photomultipliers of 6 mm x 6 mm, (c) Placing the *SiPM* in the scintillator after a careful packaging process

analog to digital converter (DAQ) (Quarknet board evaluation version 1.12). The SiPM are insensitive to the electromagnetic fields (EMF), it gives another option for the use of radiation detection and medical physics [3].

The DAQ card for the school-network CR detectors provides a low-cost alternative for its use in standard particle and nuclear physics fast pulse electronics modules, it produces trigger time and pulse edge time data for 2 to 4-fold coincidence levels. Individual detector stations (consisting of 4 scintillation counter modules, front-end electronics and a GPS receiver, produce a stream of data; ASCII text strings in a set of distinct formats for different functions). The DAQ has been designed with Leading and Trailing edge (relative) arrival times, measured with ~ 1 ns precision [4].

The card includes a low-cost GPS (Ublox ANN-MS-2-005 GPS Antenna) receiver module, which allows time stamping for event triggers up to ~ 50 ns absolute accuracy in UTC [5] between widely separated sites; the data are collected with a minicomputer Raspberry PI 2 model B.

2. Experimental Setup

Figure 2 shows the experimental setup for recording the pulse produced in the scintillator. Three plastic scintillator stacked gapless, on one side the SiPM adhere, BNC⁴ cables were used to make the connections between the channels and the DAQ card, see Fig. 2 (a); the plates are not outdoor exposed, they are under concrete slabs from the building where the Escaramujo Detector (DE) is located. The concrete slabs have an approximate density of ~ 2.300 g/cm³[6]. The EJ-200 plates, have a photomultiplier of silicon for detectors A, B and C. Figure 2 (b) shows an example of one of the most common detected events done with this configuration, namely a muon decay in Plate B.

The μ^- has a high probability of being captured by the positive charged nuclei of the detector. Here the events are coincidences between plates A and B or the trigger between A and B. The two neutrinos scape from the apparatus and, due to their low interaction probability, they will go directly through the Earth without stopping. The electrons emit light going through the scintillator [5].

⁴ Bayonet Neill-Concelman

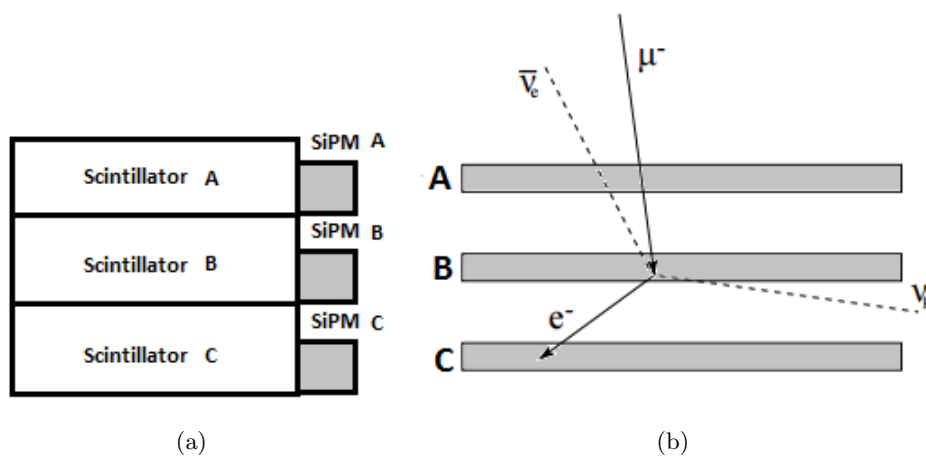


Figure 2. (a)The experimental setup for recording the pulse and geometric configuration of the three scintillation detectors. (b) Plates A, B and C; μ decay on Plate B.

The experiment is an approach to get the μ mean lifetime. For this, after the detector assembly, data acquisition was done during 95 hours and 30 minutes. A Time Window (veto) to 400 ns, between the channel A and B was adjusted. Also a bias voltage of -30 mV and a threshold of 10 mV for the three channels has been used. The gate width is 40.960×10^3 ns, this represents the amount of time allowed between hits considered as coincident.

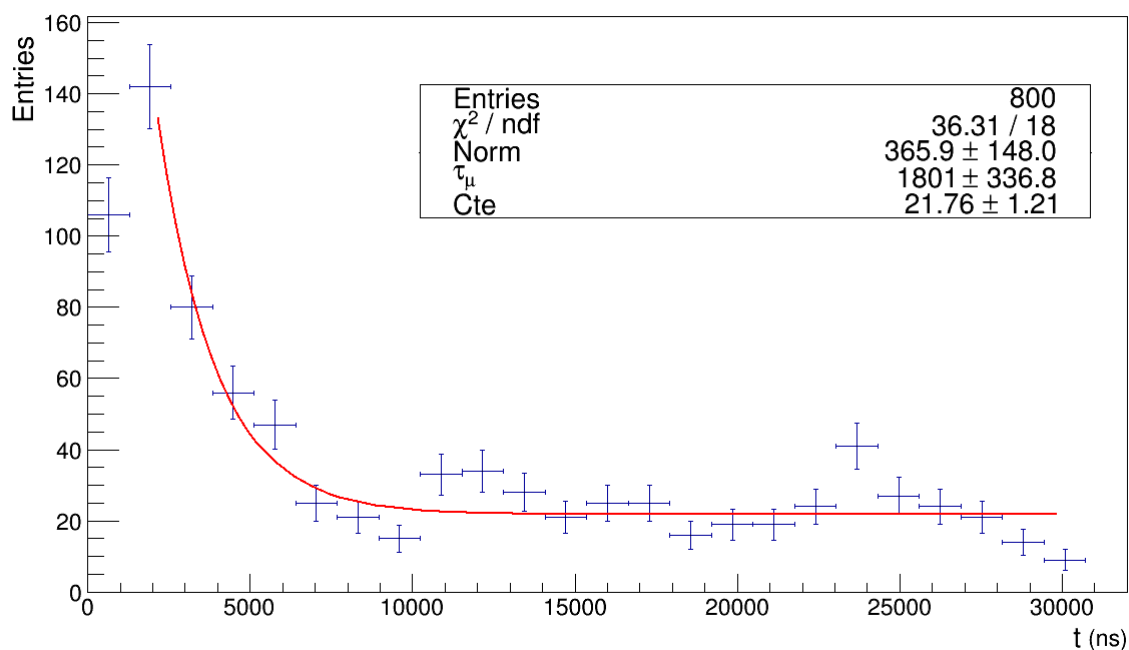


Figure 3. Muon decay. X-axis shows the time differences between the succeeding triggers, expressed in nanoseconds.

3. Results

To obtain the μ mean lifetime, its decay is used. It is supposed that for some time t an amount of $N(t)$ μ 's is registered. If the probability for a μ to decay within some small time interval dt , is λdt , where λ is the decay rate (a constant), the change dN is $dN = -N(t)\lambda dt$ or $dN/N(t) = -\lambda dt$. Integrating $\int_{N_0}^{N(t)} dN/N(t) = -\int_0^t \lambda dt$ it is obtained $N(t) = N_0 \exp(-\lambda t)$, where $N(t)$ is the number of remaining ("survived") muons at time t and N_0 is the number of muons at $t = 0$. The muon mean lifetime (τ_μ) is inversely proportional to λ , $\tau_\mu = \frac{1}{\lambda}$. In the presented experiment a value of $\tau_\mu = 1801 \pm 366.8$ ns has been obtained, which is in a reasonable agreement with the value reported by the Particle Data Group[8]. To perform the corresponding muon decay histogram, a C++/Root [9] program was developed, the histogram is shown in Fig. 3.

4. Conclusions

The Escaramujo Project has been a success at UNACH. The measurement of the muon lifetime, performed in the City of Tuxtla Gutierrez, Chiapas, at an altitude of 522 m. a. s. l. is $\sim 1.80 \times 10^{-6}$ s, this result is in a good agreement with the value reported by the Particle Data Group of 2.197 ± 2.2^{-6} s. This corresponds to muons, μ^\pm , which decay in Plate B due to the veto conditions between A and B. We achieved a correct assembly of the DE components, this means it can be used to calibrate the Cherenkov Detector (LAGO)[7], which is being developed in Chiapas.

5. Acknowledgment

Thanks to the Escaramujo Team in Chiapas, Mexico and to Dr. Arnulfo Zepeda (MCTP Director) for his unconditional support for all the scientific activities.

References

- [1] <http://es.escaramujo.net/>.
- [2] GLENN F. KNOLL *Radiation Detection and Measurement*. Professor of Nuclear Engineering and Radiological Sciences. University of Michigan.
- [3] ERIKA GARUTTI, PETER SCHLEPER. *Study of the Silicon Photomultipliers and Their Applications in Positron Emission Tomography*, zur Erlangung des Doktorgrades des Department Physik der Universität Hamburg.
- [4] STEN HANSEN JORDAN, T. KIPER, DAN CLAES, et. al, *Low-Cost Data Acquisition Card for School-Network Cosmic Ray Detectors*, Fermi National Laboratory, Batavia IL, Univ. of Nebraska, Lincoln, NE. Univ. of Washington, Seattle, WA.
- [5] JEFF RYLANDER, T. JORDAN, J. PASCHKE & HANS-GERD BERNIS. *QuarkNet Cosmic Ray Muon Detector User's Manual Series "6000" DAQ*, Version 1.1, 1-53, January 2010.
- [6] DONALD E. GROOM, NIKOLAI V. MOKHOV & SERGEI I. STRIGANOV, *Muon Stopping power and range Tables 10 Mev-100 Tev*, Atomic Data and Nuclear Data Tables **78**, 183356 (2001)
- [7] M. ALARCÓN, F. ALCARAZ, J. BARRERA, A. ZEPEDA, ET. AL, *Calibration and monitoring of water Cherenkov detectors with stopping and crossing muons*, Nuclear Instruments and Methods in Physics Research A 420 (1999) 3947.
- [8] K. A. Olive *et al.* [Particle Data Group Collaboration], Chin. Phys. C **38**, 090001 (2014). doi:10.1088/1674-1137/38/9/090001
- [9] <https://root.cern.ch/>.