SOCIETY OF PHYSICS STUDENTS

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SPS Chapter Research Award Proposal

Project Proposal Title	Construction of a low-cost Muon Detector
Name of School	Universidad Autónoma de Ciudad Juárez
SPS Chapter Number	3291
Total Amount Requested	$1892.31

Abstract

A group Engineering Students are motivated to build a low-cost muon detector. The objective of the project is to construct a detector capable of measuring cosmic muon rate and muon lifetime, while encouraging research projects among students and enhancing the way in which particle physics is taught at our university.

Proposal Statement

Overview of Proposed Project

High-quality muon detectors are expensive. With this project, students will have a low-cost alternative to achieve useful measurements about cosmic muons to help their understanding about quantum phenomena. Using a thermal can with two photomultipliers (PMT) and plastic scintillators, helped by a DAQ to acquire data, the muon detector can be made.

The main idea is that cosmic muons produce Cherenkov radiation as they travel through the can filled with water. A photomultiplier tube will be placed inside the can, which will detect the photon produced by Cherenkov radiation of the incident muon inside the can and its possible decay, then a carefully-covered scintillating plastic will be placed under the can connected with optical grease to a second photomultiplier tube, which will act as discriminator triggered by the incident muon, telling us that it did not decay inside the can. A muon that is detected by the first photomultiplier tube and not by the second, indicates a possible decay inside the can, allowing us to measure its lifetime with the data collected by the DAQ over time.

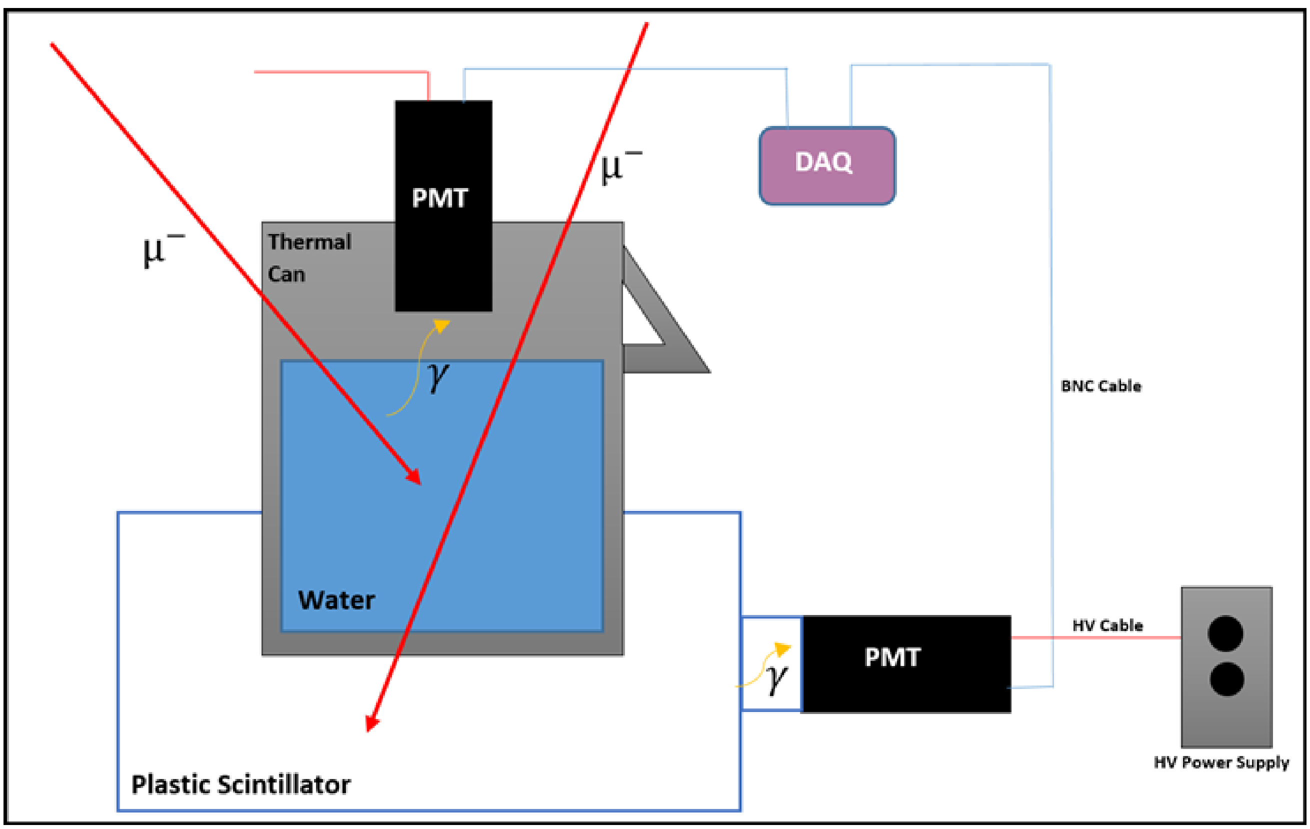

Figure 1. Diagram of the detector

Background for Proposed Project

The muon was one of the first elementary particles discovered and it did not belong to the conventional elementary particles that we knew back then. It was discovered by Carl Anderson and Seth Neddermeyer in 1936, and later J.C .Street together with E.C. Stevenson confirmed its existence, while studying cosmic radiation in a cloud chamber, by detecting the presence of particles that curved when passing through an electromagnetic field, whose trajectory had a different shape from that of electrons and other known particles, and being somewhat between the electron and the proton cuvatrues.

On December 12, 1936, Carl Anderson received the Nobel Prize in Physics for the discovery of the positron. At the end of his speech, he mentioned a mysterious penetrating radiation that was neither electrons nor positrons. The announcement of the new particle would come later and its discoverers gave it the name of mesotron, however, this changed when Conversi, Panini and Piccioni demonstrated in 1945 that the muon does not interact strongly and therefore cannot be said meson.

The muon is denoted by the Greek letter μ, it belongs to the second generation of leptons. Its spin is ½, it has a negative electric charge, its mass is 200 times greater than that of the electron.

The muon is an unstable particle that decays into lighter particles through the weak nuclear force. While the muon has several decay modes, the most common are shown in equations (1) and (2):

$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu \qquad (1)$$

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu \qquad (2)$$

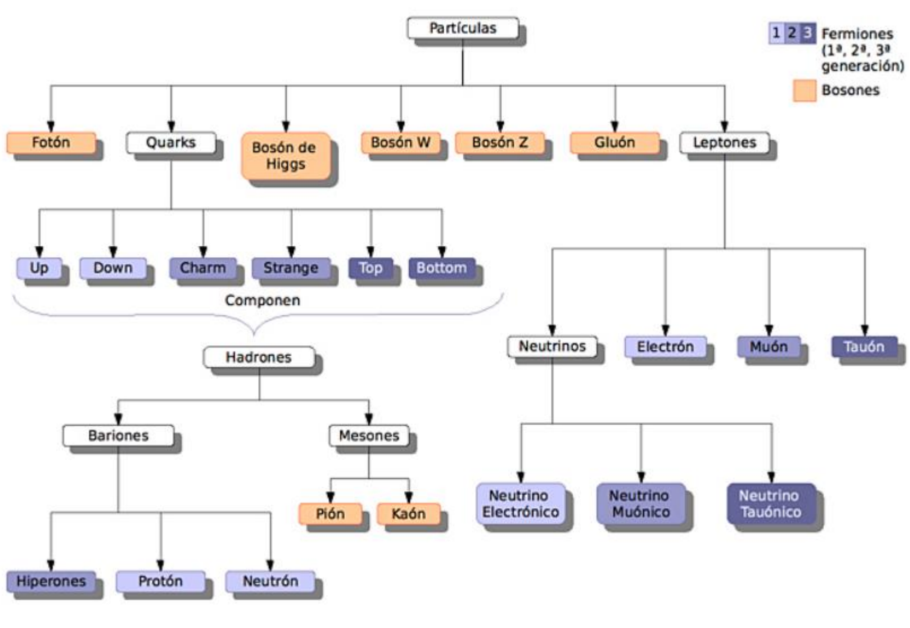

Figure 2. Table of known fundamental particles

Muons can be found in cosmic rays and laboratories. It does not exist permanently in the universe, as its existence is very short-lived (2.2 microseconds). Millions and millions of these particles are found in the Earth's atmosphere every day, coming from outer space, so elusive that we live surrounded and flooded by them, without even feeling a scratch or gentle caress, without even suspecting their subatomic company.

The atmospheric muons produced by cosmic rays are one of the natural forms of radiation to which we are exposed daily. Muons can go through practically everything before them. For years, physicists have studied this radiation to try to understand what causes it and what its characteristics are. Meanwhile, practical applications are being sought. One of the first applications of atmospheric muons was made by the American Nobel laureate Luis Álvarez, who used them to make an X-ray of the pyramid of Khafre in Giza, Egypt.

It is important to understand what cosmic rays are. Cosmic rays are particles that arrive from space and constantly bombard the Earth from all directions. Most of these particles are protons or nuclei of atoms. Some of them are more energetic than any other particle observed in nature. Ultra-energetic cosmic rays travel at a speed close to the speed of light and have hundreds of millions of times more energy than the particles produced in the most powerful accelerator built by man. Cosmic radiation is distinguished by two types:

- Primary: Those that come external to the earth.
- Secondary: Those that originate from the interaction with the atmosphere.

In a way, the atmosphere protects us from primary cosmic rays, which can be very energetic. Secondary cosmic rays again interact with the atmosphere and create more secondary particles, this continues until the newly created particles no longer have enough energy to interact and create new particles. Not all secondary cosmic rays reach the surface. The vast majority lose a lot of energy and are diverted or absorbed by the atmosphere or decay in other products [1].

Muon lifetime.

The first measurements of the lifetime of the muon were carried out by Rasetti in 1940 using the muons of cosmic radiation. The experimental apparatus basically consists of 3 coincident scintillation containers, between carbon blocks that allow absorbing the energy of the muon, the first S1 and S2, allow to detect the passage time t_{12} of the muon, while the third S3 measures the passage time t_3 of the emitted electron in the disintegration of the muon. The lifetime can be obtained from the curve that results from drawing the number of electrons observed as a function of the time difference seen in equation (3):

$$\triangle t = t_3 - t_{12} \tag{3}$$

The results that have been reached today with great precision both mass and half-life of the muon:

$$m_{\mu =} 105{,}658357\ MeV$$
$$\tau_\mu = 2.19703\ \mu s$$

Since then, muons have been used for several applications, such as imaging the structure of volcanoes and trying to predict eruptions. But what Guz Jonkmans has recently proposed is to use muons to analyze nuclear waste or to try to discover nuclear material hidden in large containers.

Expected Results

Once this project is built, the following results are expected:

- Engineering Physics students taking experimental courses related to particle physics will acquire knowledge about muon physics as well as understanding the experiment design.
- Undergraduate's abilities to obtain experimental measurements and data analysis will be enhanced.
- Students will have the necessary equipment, that can be expanded for future projects.
- The project will serve as an example of how particle physics detectors work.

Description of Proposed Research - Methods, Design, and Procedures

The muon detector will be mounted within the university facilities. We will use a thermos can full of water, we will place a photomultiplier (PMT) carefully in contact with the water and we will seal the upper part of the can in such a way that no light can enter. Then, we will place a base of scintillator material under the same jug and, in the same way, we will seal the scintillator so that no light can enter except in one part, the part in which we will connect with a small cylinder of scintillator material, that in turn will be connect to the secondary PMT. Both PMTs will be connected to a DAQ card (PicoScope), which will be connected to a computer. It is estimated that the data collection will take days, perhaps several weeks. After enough data has been collected, the data will be analyzed with the help of the PicoCosmo software.

What we hope to see in this experiment is that, if the muon manages to enter the tank with water, it will produce light that will be detected by the first PMT, which will produce a negative current pulse in the oscilloscope and this signal will be sent to the card of data acquisition, if the muon does not decay within the time it is in the water, it will be detected by the PMT that is stuck in the scintillating material. From the measurement of double pulses, the lifetime of a muon can be estimated (knowledge of exponential decay is necessary but quite manageable in out team). These double-pulses occur if the muon decays close to the can, as both the muon and the electron from the decay cause a signal in the can.

Plan for Carrying Out Proposed Project

If the project is approved, five UACJ Engineering Physics students will be involved in it: Edwin Vela, Leonardo Gonzales, Emma Castillo, Giselle Venancio and Daniel Eleuterio will carry out the development of the detector advised by Dr. Jesús Sáenz. Once the parts are available, the team will meet at the university labs, and the photomultiplier tubes will be tested to see they are working properly. Once this is done, the detector will be assembled in the physics laboratory. Once assembled, the software to be used will be prepared and the data acquisition carried out. After some 20 days of data collection of the cosmic muons, with the help of Dr. Sáenz, an analysis will be carried out to extract the muon rates and its lifetime. This project will be available to future generations as it will be available in the laboratory for its use in the modern physics and introduction to nuclear and particle physics courses.

Project Timeline

Activity	January	February	March	April	May	June	July	August	September	October	November	December
Team reviews documentation of software and equipment that will be used	■	■										
Buy components to start assembly	■	■	■									
Finish the equipment installation			■									
Software tests				■	■							
Submit interim report						■	■					
First test runs								■	■			
Data acquisition									■			
Analyze all data acquired									■	■	■	
Submit final report												■

Budget Justification

The budget that we are requesting is destined to acquire the necessary equipment for the construction of the detector and the collection of the collected data. All the required equipment will be obtained through eBay, which are two Hamamatsu PMTs, a square and cylindrical scintillation plastic, a DAQ Picoscope 2204A, optical grease, black tape, and a thermal can. With this material, in addition an ORTEC power crate, and two ORTEC power supplies to feed the PMTs, it will be possible to carry out the project and the measurements. We believe that with this experimental equipment, a closer contact with cosmic-ray physics will be possible, to us and other students, and thus motivating the study of modern physics, awakening the interest of both university and high school students about particle physics.

Bibliography

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- [4] Andreas Düdder, Matthias Schott, Günter Quast, Lars Vielsack, Self-Made Particle Detectors for High Schools and Universities, (2018), JGU Mainz https://indico.cern.ch/event/667667/contributions/2878598/attachments/1678305/2695407/SlidesDuedder.pdf.