The Detection of Cosmic Rays at Chicago State University
Final Report

Chicago State University SPS Chapter
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Investigative Researchers
Melissa Rangel
Macario Cervantes
Jamall Davis
Maria Elena Perales

Chapter Advisor
Dr. Edmundo Garcia

INTRODUCTION

The research of our SPS chapter is part of the experimental high energy nuclear physics program at CSU. Our work takes place in a detector lab dedicated to, among other things, the construction of a muon tracker detector to measure cosmic ray flow for several applications [1]. Under the direction of Dr. Garcia, physics professor and chapter advisor, we are using the SPS Research Award to construct a prototype of the muon tracker. The prototype will consist of an array of four scintillators and four photomultiplier tubes (the equipment needed to process and analyze the signal is part of Dr. Garcia's lab). The evaluation of the performance of the prototype detector will enable us to finalize the design of the muon tracker detector.

METHODOLOGY

THE SCINTILLATION DETECTOR

As muons, which are electrically charged, traverse the scintillating crystal they produce luminescence. This light travels to the phototube, where the signal is amplified via a series of dynodes and gives an electrical pulse proportional to the number of photons detected. The light then emerges from the optical fiber as an electrical pulse. The electrical pulse is stored in electronic equipment and then read into a computer for analysis.

The first phase of the project consisted of understanding the principles of the muon detection techniques and obtaining experimental benchmarks for the measurements that we will perform using the tracker prototype, which we will build this Fall. To this end, we used the detector array and electronics shown in Figure 1. The detectors consist of thick scintillators attached to phototubes, and we use several NIM (nuclear instrument modules) to process the signals from the phototubes and count the number of muons that hit the detectors in coincidence.

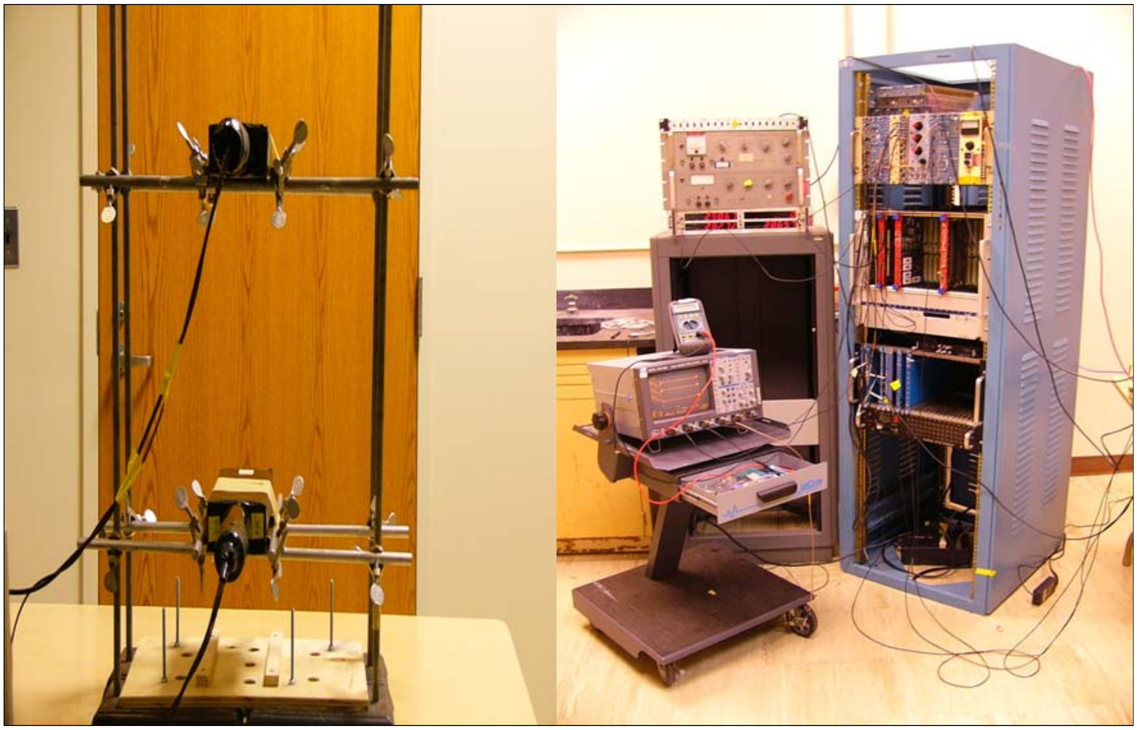

Figure 1*: Detectors (left) and instrumentation (right) used for bench mark measurements.*

VERTICAL FLUX MEASUREMENTS

In order to study the vertical flux, we used a coincidence between 2 detectors and varied the distance between them. By setting up a coincidence we were able to factor out noise and also limit the solid angle so that we get mostly vertical muons. We also connected the output to a discriminator in order to set an energy threshold for the incoming muons.

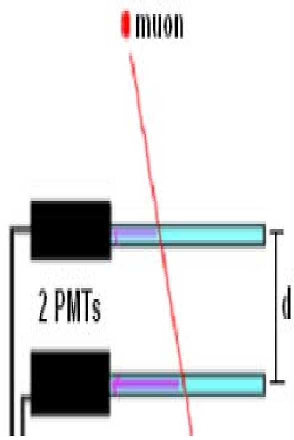

Figure 2: *Principle of Vertical Flux*

For our flux calculations, we employed an approximation that is widely used for a setup involving 2 flat detectors:

$$F_{\mu} = \frac{(\text{count rate})\, d^2}{(\text{area of top panel})\,(\text{area of bottom panel})}$$

We compared our values to the PDG (Particle Data Group) theoretical value, which basically states that muons reach the Earth with a typically constant flux of 1 per square centimeter per minute.

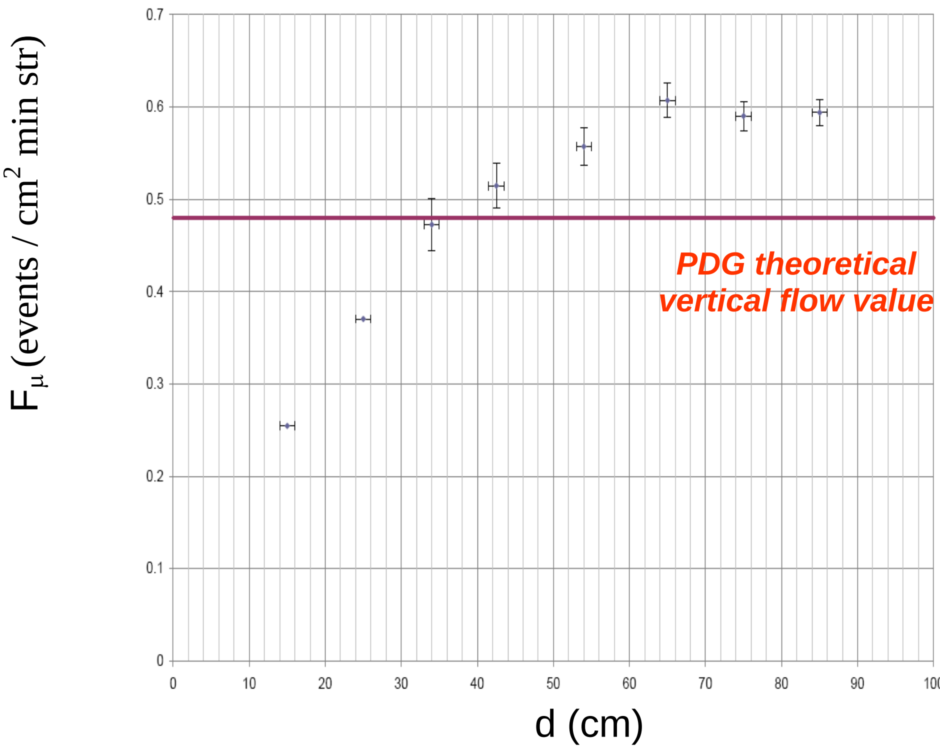

Figure 3*: Vertical Flux for specified distances*

We found that the vertical flux results are within 20% of the PDG value. The error may be due to the approximation used to calculate the flux, where we assume that we are using detectors that are very thin in comparison to the distance between them. To a lesser degree, the error may be also due to the lack of discrimination for completely vertical muons.

However, when we compared our values to the correlation plot of:

$$Rate \propto \frac{1}{d^2}$$

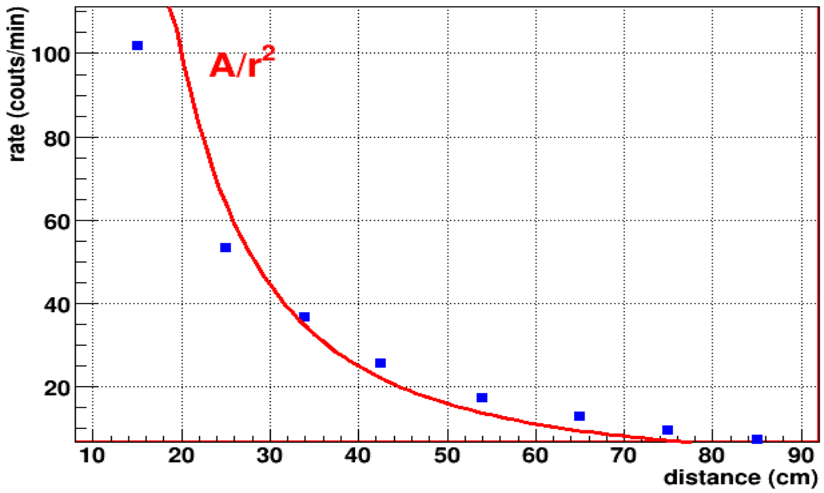

Figure 4*: Muon rate as a function of distance*

We found that the results are within estimates of the correlation plot. This led us to believe that the reason that our data did not agree with the PDG expected values was that the vertical flux has a geometrical dependence.

ZENITH ANGLE DEPENDENCE

In order to study the zenith angle dependence, we used a coincidence between 2 detectors placed a distance of 40 cm apart. We varied the zenith angle by varying the height of one side of the base, as shown in figure 5 below.

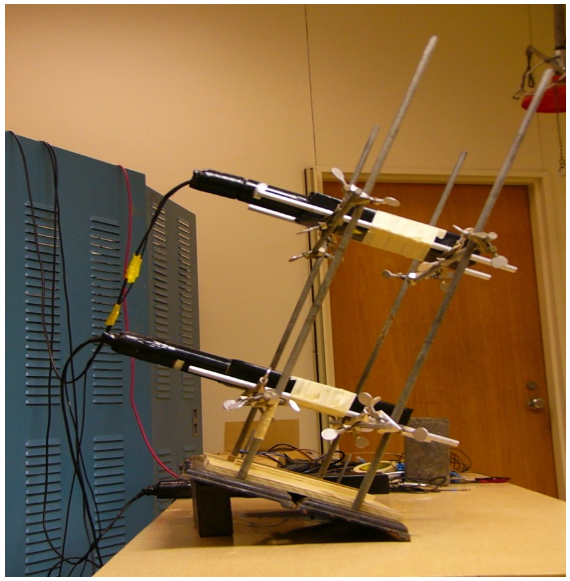

***Figure 5**: Principle of Zenith Angle Dependence*

We compared our values to the PDG theoretical value of proportionality, that the change in flux with changing azimuthal angle θ is proportional to COS ^{2} θ. We found that the dependence corresponds to the expected COS ^{2} θ and is off by about 2%.

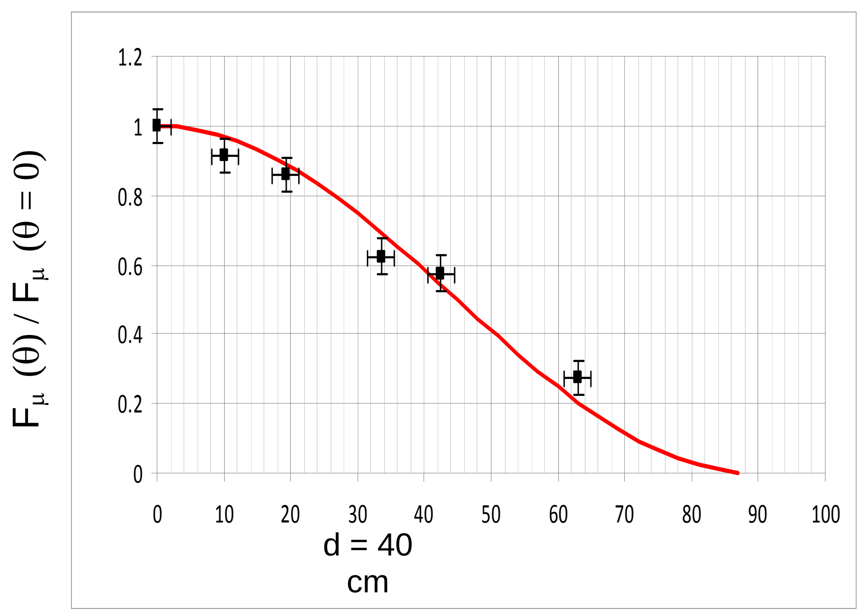

***Figure 6**: Flux as a function of azimuthal angle, at a separation distance of 40 cm*

SPEED OF THE MOUN MEASUREMENT

Another interesting benchmark we have performed is the measurement of the muon speed. This has been an important step in getting familiar with the instrumentation because it required processing the signals in a data acquisition system (DAQ). This system consist on a series of components that take the signal from the tube and digitize it, giving as an output a time interval with respect to an event (time digital conversion or TDC), or the digitization of the area of pulse coming from the phototube (analogue to digital conversion ADC). The area of the pulse is proportional to the amount of light (or number of photons) that the muons produce when they cross the scintillators. The DAQ system that we used was developed for QuarkNet [2].

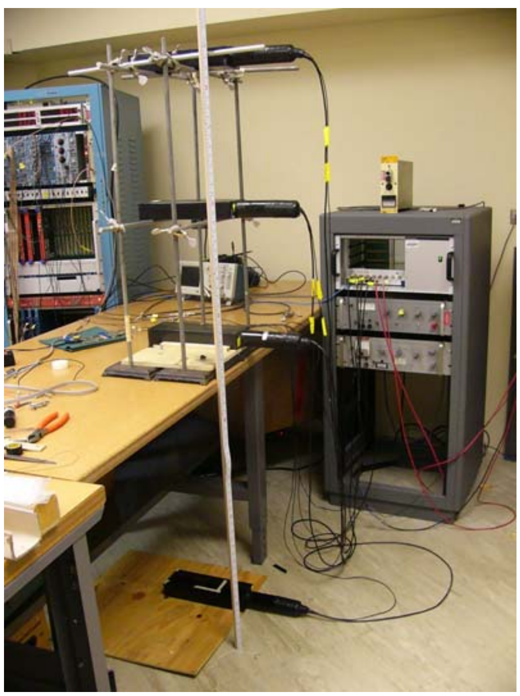

Figure 7. Experimental setup for the moun speed measurement.

The experimental setup is shown in the next Figure 7. We measured the distance between a pair of scintilator detectors using a ruler, and then the time difference between one two hits in different detectors within a very small time window (coincidence). The time measurement was done with the TDC of the QuarkNet DAQ, we measured around 6000 events, and the histogram of the time distribution is shown in Fig. 8.

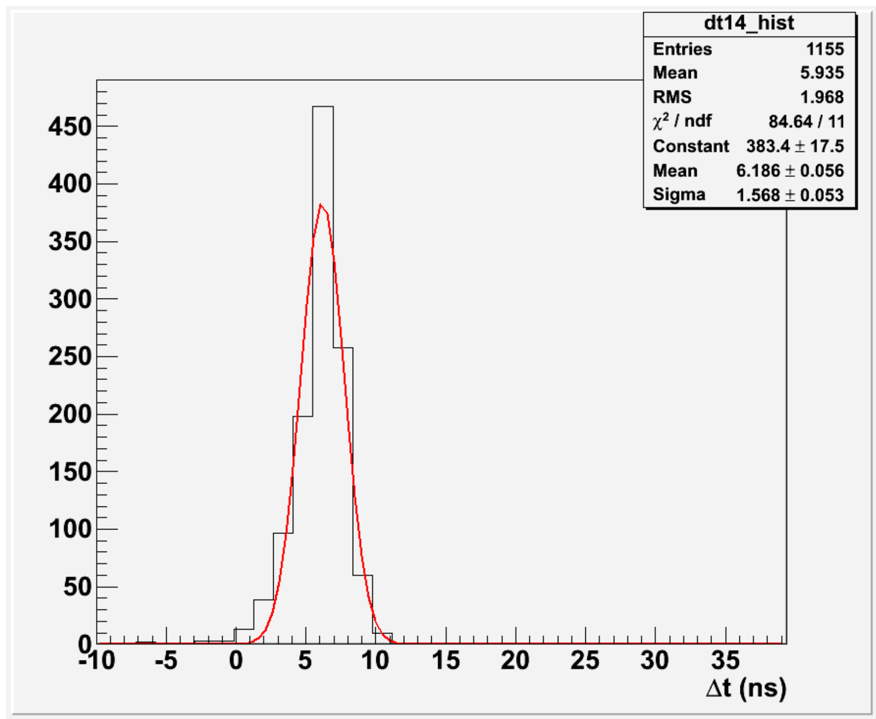

Figure 8. Time difference histogram for muon speed experiment.

The time difference we got was 6.187 ± 1.57 ns, the distance between the detectors was 1.795 m, so the speed of the moun we got was 2.90 x 10^8 m/s or 0.97 ***c***. The result found in the literature for this measurement.

DISCUSSION

Having achieved standard base line measurements with our equipment, and with a better understanding of it, we started the measurements that would lead to the design parameters for the tracker detector we want to build. Among these parameters is the amount of light that muons produce when crossing a scintillator of a given width, and the amount of the light that remains if we use a light guide between the scintillator and the phototube. To this end we purchased few scintillators of different widths and two phototubes (with the award, listed in the budget at the end of the section). For the first measurement we put two slats of 1 and 2 cm width in coincidence with a small finger scintillator as shown in Figure 9.

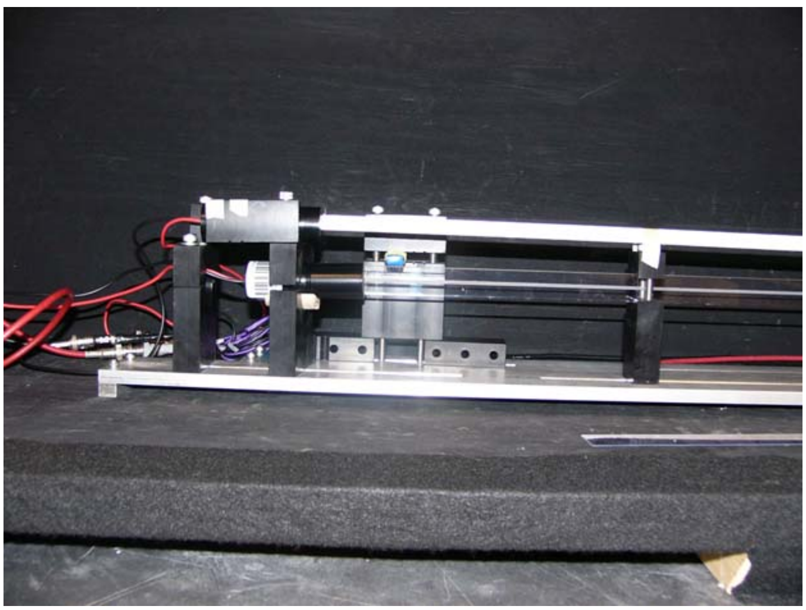

Figure 9. Experimental setup to measure the amount of light produced by muons crossing scintillator slats of different geometries.

The phototubes we used were of the same kind and they were operated at the same gain. The data (ADC) for both scintilators was recorded only for particles that crossed the two slats and the finger scintillator between the slats (blue in the picture). This was done to make sure that we recorded the light from the muons that are crossing vertically both slats. The histograms shown in Fig 10 summarize the results: on the left is the ADC from the 1 cm scintillator, and on the right the ADC for the 2 cm scintillator. To our surprise, the difference in the amount of light measured from the two scintillators is not significantly different, the of light produced by charged particles when they interact with scintillators should be roughly proportional to the width of the scintillator.

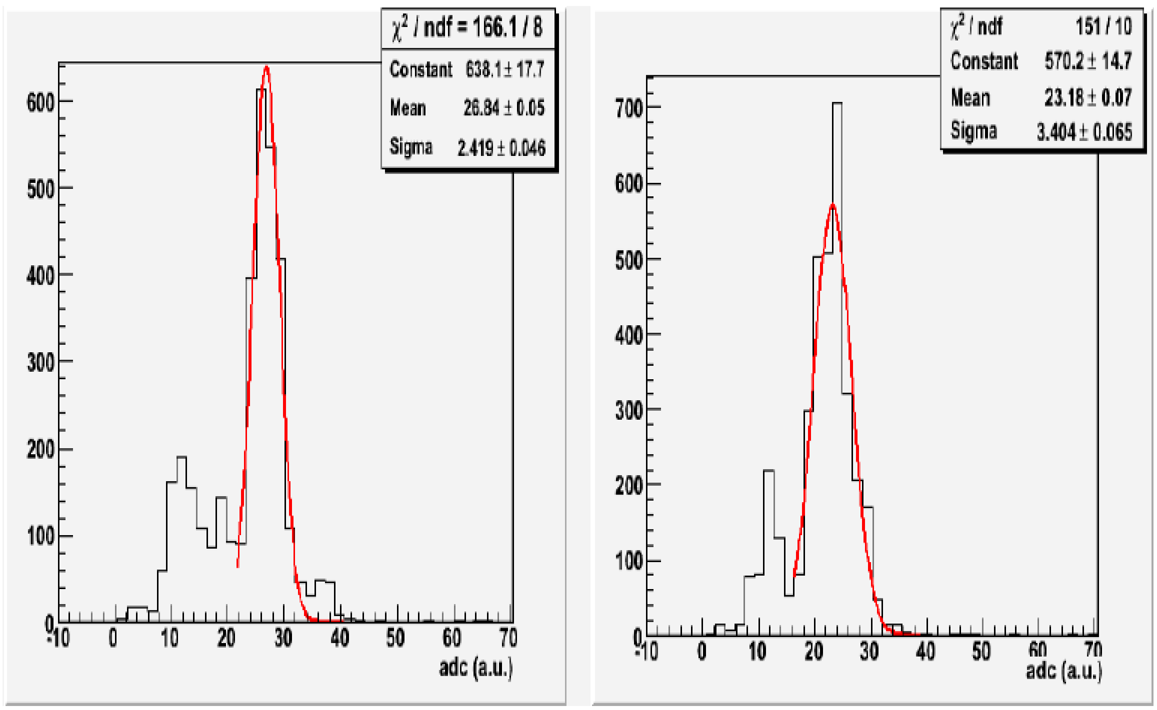

Figure 10. Histograms of ADC measurements for 2 cm width scintillator slat (left) and 1 cm width scintillator slat (right).

CURRENT WORK

Our work to date has been presented at The Women in Physics Conference at UIUC on 01/18/09 and I-LSAMP Conference for Undergraduate Research on 02/28/09, we plan to present the results also at the Washington D.C. AAPT meeting in February. We plan to continue our research, using what we have learned so far and expanding upon it.

Although we are confident of our instruments when using the QuarkNet DAQ card for the time measurements, the ADC measurements seem strange. The size or shape of the signal may not be compatible with the design parameters of the card. We want to verify the signal shape measurements, to this end we would like to build a DAQ from “scratch”. Our plans are to use a CAMAC system. We have a crate controller and a ADC and TDC module. We are planning to use LavView to manage and retrieve the dat a from the controller.

After we verify the ADC measurement, we will with continue towards our goal of finalizing the design of the tracker prototype. For this, we will use different combinations of fibers and scintillators. For each arrangement fibers and slats we will measure the number of photons produced by the muons when they cross the material. Our objective is to find the configuration that optimizes the amount of light that is detected. We hope to accomplish this by the Spring 2011, this will be possible with the recent support that SPS gave us through the 2010 undergraduate research award for our chapter. With the award we will be able to purchase an updated version of LabView and a Laptop to build a DAQ.

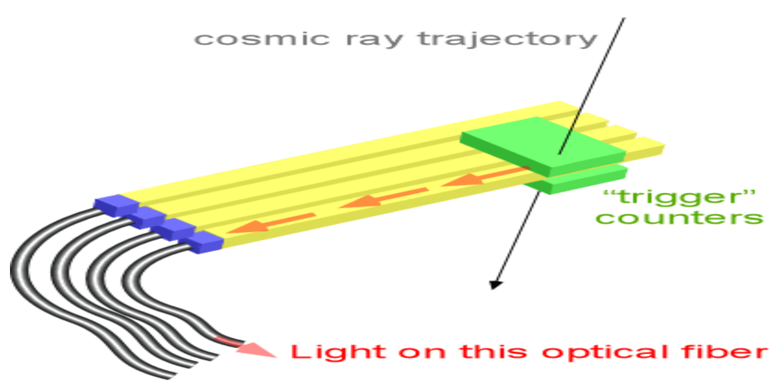

Figure 11: Muon tracker prototype.

FINANCIAL REPORT

The funds requested cover the elements needed to construct two scintillator and phototube detection modules: Hamamatsu H4211A phototubes, connectors, high voltage and signal cables, crimping tool to make the cables, and the scintillators. As mentioned in the text we used a QuarkNet DAQ card to process and digitize the signal from the phototubes. The award funds covered partially these items, the rest the was matched by the Department of Chemistry and Physics.

Qty.	Materials	Unit Price	Price
2	Scintillators BC400 from Saint-Gobain Crystals	$432.00	$864.00
2	Phototubes Hamamatsu H5211A	$712.00	$1424
	Connectors, cables crimping tool	$1623.00	1623.00
		Total:	$3911.00
	SPS Funds used towards the project		$2000.00
	Chemistry and physics matching funds		$1911.00

BIBLIOGRAPHY

1. E. Garcia, Measurement of Cosmic Ray Absorption To Search For Chambers in Mesoamerican pyramids, Productive Affinities Symposium: Successful Collaborations Between Museums and Academia. Evanston, IL (Oct. 2008)
2. For the QuarkNet project:

   http://webs.csu.edu/~egarcia/quarkNet/CSUQuarkNet.html

   For the specifics of the DAQ card:

   http://neutrino.phys.washington.edu/~walta/qnet_daq/