Design, construction, characterization, and use of a detector to measure time of flight of cosmic rays

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Abstract. In the study of cosmic rays, measurements of time of flight and momentum have been used to identify incident particles from its physical properties, like mass. In this document we present the design, construction, characterization, and operation of a detector to measure time of flight of cosmic rays. The device is comprised of three small plates of plastic scintillator arranged in vertical straight line, coupled to one photomultiplier tube. The analogical output has been connected to a data acquisition system to obtain the number of digital pulses per millisecond. We present details of design, construction, operation, and preliminary results.

1. Introduction

Cosmic rays were discovered in 1912 by Victor Hess [1], at the highest level of the Earth’s atmosphere. They consist of stable charged particles and nuclei with lifetimes of order 10⁶ years or longer [2]. When cosmic rays collide with atmospheric atoms they produce secondary particles, mainly pions. Muons are emitted in pion decay, they penetrate below ground, and interact weakly with matter [1].

There are several techniques to detect cosmic ray radiation:

2. Scintillation

This method is used to detect radiation in general. It applies photomultipliers coupled to scintillators, which produce a light flash when interacting with radiation. The flashes are detected by the photomultiplier tubes, so the output pulses are electrical pulses proportional to the amount of energy deposited by the incident particles [3].
Plastic scintillators belong to the organic group of scintillators, with maximum scintillation emission around 425 nm, they are sensitive to X-rays, gamma rays, and charged particles [4].

3. **Time of flight detectors**

Scintillation technique is applied in time of flight detectors to measure the velocity of particles from the difference of time obtained with plastic scintillators counters [3]. Velocity can be combined with measures of momentum to determine the mass of particles, and identify them [5].

4. **Motivation**

The aim of designing, constructing, using, and characterizing a detector to measure the time of flight, is to identify the type of particles that interact with it. Furthermore, a better understanding of the physical functionality of plastic scintillators and photomultiplier tubes can be acquired developing this device.

5. **Design**

The main components of the detector are three plates of plastic scintillators produced by Sumitomo Chemical, arranged in a vertical straight line, separated by one meter using two extensor aluminum plates as is shown in figure 1.

The plastic scintillators are connected to the photomultiplier tube Hamamatsu (H10493-012) showed in figure 2, which has a photosensitive area of 25 mm diameter [6], optical fibers of 3.15 m long were used for the two scintillators at the ends, and a guide of light for the one in the middle part.

![Figure 1. Design of the detector.](image1)

![Figure 2. Photomultiplier tube Hamamatsu H10493-012.](image2)

6. **Plastic scintillators**

The dimensions of the plastic scintillators are 5 cm length, 0.6 cm width, and 5 cm height. They are covered with a box made of aluminum plates to block out external light, and protect them from damage, this is showed in figure 3.
The inside walls of aluminum boxes are polished to mirror level to reflect photons inside, and ensure that most of them are guided toward the photomultiplier tube. For each box, one rectangle face has a perforation that is used to connect the optical fibers and the guide of light.

6.1.1. Supports. Three pieces with a set square form were designed as a support to place the plastic scintillators over them, and fixed them to the extensor aluminum plates. Figure 4 shows the supports for the upper and lower plastic scintillators, the central one has the same shape as the upper.

![Figure 3. Design of the boxes for the plastic scintillators.](image1)

![Figure 4. Support for plastic scintillators.](image2)

7. Middle part of the detector
The base for the photomultiplier tube is in the center of the detector. As it can be seen in figure 5, one aluminum tube is used to put inside the photomultiplier tube, it is placed over three aluminum base plates, and two setsquares are used to hold it. There are another two setsquare pieces used that keep fixed the larger plates to the middle part. Two aluminum squares have the function of covering both sides of the tube, but one of them has three perforations to place the two optical fibers and the guide of light.

![Figure 5. Middle part of the detector.](image3)

8. Construction
The three plates of plastic scintillators were cut using a laser cutter machine. The guide of light was cut using a hacksaw and the edges were polished with sandpaper. All the aluminum pieces were cut using a bandsaw, a plate 1.6 mm thick was used to draw the flat parts of the design, an angle for the supports, and a tube.

The aluminum plates of the boxes for the plastic scintillators were polished until dimensions were appropriate, this is shown in figure 6. The next step was making 45° cuts on the edges of each plate.
using a Belt Disc Sander. Three rectangular plates were drilled, two with a perforation of 16.00 mm diameter, 3.20 mm height, and the last one with a perforation of 25.00 mm of diameter, 3.00 mm height.

In order to polish one face of each plate to mirror finish, sandpapers of different grit sizes were used in the following order: 320, 600, 1000, and 2000. Finally, the plates were polished with a microfiber towel and metal polish cream. The final result is shown in figure 7.

The boxes for the aluminum plates were assembled as it follows: the rectangle plates were stuck together in pairs making a right angle using epoxy adhesive, and fixed with an angle press tool. After one hour, the two angles were glued into a frame.

Then, a square plate was stuck below the frame and the plastic scintillator was put inside. This process is shown in figure 8. Finally, another square plate was glued on the top completing the box. The epoxy adhesive on the surface of the aluminum plates was polished with sandpaper, the finished boxes are shown in figure 9.

Figure 7. Aluminum plates with 45° cuts on edges and mirror finishing.
Figure 8. Assembling of the boxes for the plastic scintillators. a) Angle press tool used to stick two rectangle plates. b) Frame of the box. c) Box with plastic scintillator inside.

Figure 9. Finished boxes with the plastic scintillators inside. From left to right, the first box is for the middle and the latest two are for the up and down part of the detector.

The edges of the boxes were covered with aluminum tape, the final dimensions were 54.0 cm length, 1.0 cm width, and 54.0 cm height. The same process for the boxes of plastic scintillator was applied to the aluminum plates of the guide of light.

Screws of 1/4 in shank hole size were used to set the extensor aluminum plates to the middle part of the detector. For the aluminum base plates and supports of the plastic scintillators the shank size of the screws was 1/8 in.

Square perforations 4.2 cm length and 4.2 cm height were made in the extensor aluminum plates; they were needed for the input window of the photomultiplier tube.

The photomultiplier tube was put inside the aluminum tube and covered with the aluminum plate, in the output cable was added a SMA connector. Finally, the optical fibers were connected to the plastic scintillators and the photomultiplier tube, so it was the guide of light. All the pieces were assembled. The middle part of the detector is shown in figure 10.

Figure 10. Middle part of the detection system.
The detector was fixed to a cabinet using aluminum tape, which was also used to cover the parts of the detector to block out external light. The complete detector is presented in figure 11.

![Figure 11. Complete system of detection.](image)

Figure 11. Complete system of detection.

Figure 12. Block diagram for the connection of the detection system.

9. Tests

The block diagram for the connection of the detector is shown in figure 12. The materials used for tests were the following: three power suppliers TENMA 72-8335A, an oscilloscope Tektronix TDS 1001C-EDU, a discriminator board V3 of four channels, BNC coaxial cables, CompactRIO, a computer, and a multimeter.

![Figure 13. Oscilloscope display for the detector signals. Digital output is channel 1 at the top. Analogical output is channel 2 at the bottom.](image)

Figure 13. Oscilloscope display for the detector signals. Digital output is channel 1 at the top. Analogical output is channel 2 at the bottom.

The sensitivity adjustment method used for the photomultiplier was the voltage programming suggested in the data sheet. The analogical signal of the detector was connected to the discriminator board, whose voltage supply was -5 V, and + 5 V. The digital signal obtained was connected to the data acquisition system, it means the CompactRIO of National Instruments that was programmed to obtain the number of counts per millisecond.

The operation voltages applied were: Low Voltage Input (Red) +14.01 V, Low Voltage Input (Green) -14.04 V, Vcont Input (White) +1.135 V, and Trigger +266.9 mV.
10. Results
Data recordings were done using the CompactRIO. Analog and digital outputs are shown in figure 13, where the oscilloscope configuration parameters were: channel 1 (digital) 2.00 V, channel 2 (analogic) 200 mV, and time 1.00 μs. Data of a 30 minutes recording is shown in figures 14, and 15.

![Figure 14](image1.png) ![Figure 15](image2.png)

**Figure 14.** Frequency distribution of digital pulses per millisecond in a recording of 30 minutes.

**Figure 15.** Counts per millisecond vs time in a recording of 30 minutes.

11. Conclusion
In the first tests, analogic signals with amplitudes close to 400 mV in a time scale of 1μs were observed. Modifications in the design are needed to reduce the noise caused by the leak of electromagnetic radiation to the plastic scintillators and the photomultiplier tube. New tests should be done to probe if there were improvements in the operation of the detector.

Furthermore, a faster acquisition system is required to measure the difference in time of the three digital pulses produced by plastic scintillators, because this difference is in the nanosecond range.

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