Design, Construction, Test, Operation and Simulation of a Four Channel Cosmic Ray Detector

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Abstract. Cosmic ray detectors are constructed to fit many purposes, different materials and geometries. To test materials and to measure the flux of cosmic rays, we planned, designed, constructed, tested and operated a 4 channel cosmic ray detector based on 2.54 cm X 10.32 cm X 20.64 cm Aluminum block and two 0.6 cm X 10.32 cm X 20.64 cm plastic scintillators completely covered with 0.2 cm thick Aluminum foil. The signal, produced by the passage of cosmic rays, was read out using a Hamamatsu photomultiplier in both the Aluminum block and plastic scintillator. The performance of this detector was simulated using GEANT 4. The efficiency of the cosmic ray detector was measured to give 85% approximately. Details of construction, operation, simulation, and preliminary results are presented.

1. Introduction
Today, research in cosmic rays represents an opportunity to study the physical interactions between matter and particles such as electrons, muons and neutrinos, which deposit energy within sensitive materials with which they interact. In order to quantify the deposited energy it is necessary to use particle detectors. Besides being used to measure the energy of the detected radiation, they can be also used to measure other important physical attributes such as momentum, spin and electric charge [1].

2. Planning
It is intended to build, operate and simulate a four channel cosmic ray detector based on plastic scintillator and Aluminum. Also, it is necessary to make a comparison between the experimental data with Monte Carlo simulations performed with Geant 4 [2].

3. Design
The design of the experimental prototype was made using the software Sketchup [3]. Below (figure 1) a side and a front view of detector are shown.
Figure 1. Side and front view of the detector. The discriminator and electronics channel boards are shown (left). The three boards are located at the bottom part of the detector (right).

The cosmic ray detector is based on three blocks, one block of Aluminum with dimensions $25.32 \text{ cm} \times 10.16 \text{ cm} \times 2.54 \text{ cm}$ is symmetrically placed inside two plastic scintillator blocks with dimensions $22 \text{ cm} \times 10.16 \text{ cm} \times 0.6 \text{ cm}$, covering almost all the Aluminum block surface. To detect the light produced inside of the detector, a Hamamatsu avalanche silicon PMT [4] was attached at both ends of the Aluminum block and at one end of each of the plastic scintillator blocks. The geometry of the detector was simulated with Geant 4.

4. Construction

The first step consisted in sanding and polishing twelve aluminum plates, of different dimensions, used to cover the plastic scintillator. Then, a hole was drilled to place the photodiodes in both the aluminum block and scintillator detectors. Each photodiode per channel was welded to an electronic card to be connected to the main electronics boards array, composed by a discriminator card and two electronics cards which supply voltage to the photodiodes (figure 2). In these electronic cards, an RC circuit has been established for each detection channel, in order to obtain an analog signal with exponential decay and a very small decay time (figure 3).

Figure 2. Particle detector experimental setup (left). Geant 4 simulation (right). A side view of the geometry of the simulated detector is shown. The block of aluminum was painted yellow, while the Aluminum plates covering the plastic scintillators were painted with navy blue, cyan and pink respectively.
Figure 3. RC circuits on the electronic cards that supply voltage to the photodiodes.

5. Development
The operation of the four detection channels was tested, that is, using an oscilloscope was checked that an analogic signal was obtained. Also, the operation of the discriminator card was tested and subsequently it was added to the experimental setup. Doing this, both the analog signal and the digital signal were observed (figure 4). The digital signal obtained depends on the analog signal that entered the discriminator card and the threshold voltage set in that electronic board (figure 5). This threshold voltage was set so that be three times the noise of the analog signal [5].

Figure 4. Oscilloscope screen showing analog (plot that has an exponential decay) and digital (square signal) signal for channel 1. Similar signals were obtained on the other channels. The fact that it has been observed both analog and digital signal pointed out that the detector works properly.

Figure 5. Relationship between the digital signal, the trigger voltage of the discriminator card and the analog signal. The number 1 enclosed in a circle represents different trigger voltages set on the discriminator card, T A and T B respectively; the number 2 represents the analog signal read on the oscilloscope; the number 3 represents the resulting digital signal.
As can be seen in figure 5, as a result of having set different trigger voltages and of the form of the input analog signal, different digital signals are obtained. In other words, if the trigger voltage is set near the peak of the analog signal (T\textsubscript{A}), the time window of the digital signal is small, in contrast, if the trigger voltage is set in T\textsubscript{B}, the time window of the digital signal is large.

On the other hand, the discriminator card was connected to a 32 channels data acquisition system (figure 6). Currently, the calibration of the detector is not within our aims, we plan to include it until we have reached a post-thesis research stage; in addition, by now, we do not have an artificial source of radiation, which could help us to calibrate the detector.

Once the proper operation of the detector and the electronics system was verified, we collected several cosmic ray data events with horizontal and vertical atmospheric muons within a time window of 1 ms.

Now, regarding the simulation, the geometry and materials that make up the detector, the primary particle gun and the relevant physical processes have been established. There were 50 events generated, generating in each of them 1000 primary particles, assigning to each of the primary particles an initial energy that is multiple of 100 and that is in the range of 100 to 5000, in units of MeV. Likewise, it was considered that E\textsubscript{i} < E\textsubscript{i+1}, where E\textsubscript{i} is the initial energy of a primary particle that was generated at an event i, and E\textsubscript{i+1} is the initial energy of a primary particle that was generated in a later event i+1, where i goes from 0 to 49. By the other hand, all primary particles were negative muons generated in two different event runs; in an event run, the primary particles had an initial direction of momentum perpendicular to the detector, while in the other event run the particles were shot parallel to the detector. The particles were fired from a distance of 1 mm from the detector with a uniform random spatial distribution.

**Figure 6.** Experimental setup. 1: Data acquisition system, 2: Low voltage power supply, 3: BNC to BNC cables, 4: Power supply cable of the discriminator card, 5: SMA to SMA cables, 6: Mechanical press, 7: Stacking of the detection materials (Top and bottom: plastic scintillators. Middle: aluminum block), 8: Aluminum plate used to place the main electronics boards array, 9: Discriminator card, 10: Electronics cards which supply voltage to the photodiodes, 11: Bicolor cables used to connect the photodiodes with the electronics cards which supply voltage, 12: Bicolor cable used to connect the electronics cards which supply voltage with a high voltage power supply.

### 6. Results

In the simulation, the detector efficiency, defined as the number of detected muons divided by the number of incident muons, as function of the incident muon energy, was computed. We considered a muon as detected to the one that deposited energy in the 3 detection materials. If the muon only deposited energy in at most two of the detection materials, the muon was not considered as detected.
Therefore, only if all the primary particles (those coming out of the simulated particle gun) deposited some of its energy in the 3 detection materials, we could say that we have a 100% acceptance or efficiency in the detector. In reviewing the verbose information output of Geant 4, it was noted that the ionization process was not always produced in the 3 detection materials, that is, there were events in which a primary muon produced ionization only in 1 detection material. In other events, the primary muon produced ionization in only 2 of the 3 detection materials; there were also events in which a primary muon produced ionization in the 3 detector materials. It should also be added that in all the considered energy range (100-5000 MeV), there was always scintillation radiation and Cerenkov effect in the plastic scintillators, that is, there was always some loss of energy in the scintillating plastics as a result of the scintillation process or Cerenkov effect. By the other hand, based on the verbose information output of Geant 4, the only processes observed in the Aluminum block were the transport of particles and ionization, being the ionization a process of energy loss. The transportation process move the particles in space and time, either with or without physical fields; there is no loss of energy in the transportation process. Therefore, in order to obtain a 100% acceptance, this would imply that, of all the primary particles that are generated per event, all of them must deposit or lose some of their energy in the Aluminum block, but, in view of the before said, an acceptance of 100% could not be obtained. It is considered that the randomness of occurrence of the ionization process that was observed in the detector materials could contribute to the efficiency of the detector being maintained above 85% (see figure 7), regardless of the initial energy of the primary particles. Such randomness could be caused by the way physical processes are simulated in Geant 4. Likewise, one has the assumption of that in most events ionization was produced. That is believed to be the cause for the efficiency of the detector to remain practically constant. In order to give a more precise answer, more research is needed. However, in this work, the only energy losses that matter to us are those due to scintillation radiation and Cerenkov effect, this is because the detection channels we are using are optical channels, so the energy losses due to ionization are irrelevant. Although ionization energy losses are currently considered in the simulation, and more specifically in the efficiency of the detector, in the near future, it is planned to conserve energy losses due only to scintillation radiation and Cerenkov effect, taking into account also possible losses of energy by Cerenkov radiation in the block of Aluminum. Currently, it has only been possible to simulate the Cerenkov effect in the plastic scintillators.

As a result of the interaction of the muons with the detection materials, electrons, scintillation photons and Cerenkov photons were produced in the simulation. Qualitatively, we observed some things already known, that is, the isotropic spatial distribution of the scintillation radiation and the appearance of the Cerenkov radiation cone. It was also observed that some of the ionized electrons radiated Cerenkov light.

Now, returning to the efficiency of which we have talked, we cannot say that it is a result with which we agree completely because that result is preliminary, reason why it is necessary to make improvements in the simulation program, in addition, not having an artificial source of radiation in the laboratory, we cannot determine the efficiency of the real-life detector (not simulated) in the way it was obtained in the simulation. However, we could say that the simulated efficiency we have obtained is a good result if we take into account what was stated in the book *Measurement and Detection of Radiation* [6]. In that text, it is said that charged particle detectors have an efficiency of practically 100%, regardless of the size or density of the detector materials. Likewise, it is said that for charged particles, the detection efficiency is practically independent of particle energy except for very low energies, which is when the particles could be stopped by the detector. On the other hand, it must be said that in the simulation of our detector it was never observed that the primary muons were stopped by the detector materials.
Figure 7. Efficiency of the simulated detector. Uncertainties were estimated using the error propagation approach.

On the other hand, using the data acquisition system of the laboratory, it was possible to obtain the number of counts per detection channel, that is, the number of particles detected has been obtained. This has been done per unit of time and for an extended interval of time. In our case, the number of counts for all detection channels has been recorded for 7200000 ms. Then, through the Root software, the number of counts versus statistical frequency (without units) was plotted in order to be able to observe the frequency distribution of the number of counts of each channel. In other words, we have obtained the histogram of the number of counts of each channel, obtaining at the same time the average number of counts for each channel. In order to compare the counts of all channels, the corresponding histograms have been normalized and overlapped in a single plot (see figure 8).

Because the histogram was normalized to 1, this implies that the sum of the statistical frequencies associated with each bin is equal to 1, and therefore, that the statistical frequency of each of the bins is less than 1.

Figure 8. Histogram of the number of counts.
The detector has not yet been characterized, so we would not expect to observe a similar behavior in the channels, as can be seen in figure 7. In that figure, channels 1 and 2 represent channels located on the aluminum block, while channels 3 and 4 represent channels of the plastic scintillators. The arrangement of the detector channels is shown in figure 9.

![Image of detector](image_url)

**Figure 9.** Arrangement of the detector channels. Channels 1 and 2 are located on the aluminum block, while channels 3 and 4 are located on the lower and upper plastic scintillator, respectively. Channel 1 on the Aluminum block is located on the back of the detector.

7. Conclusions

We have planned, designed, constructed, tested and operated a four channel cosmic ray detector; it works properly. We have simulated the constructed detector and measured the detector efficiency.

This cosmic ray detector can be used to detect photons having a wavelength that is in the spectral range of the photodiode, from 320 to 900 nm. The physical processes that can generate such photons could be Cerenkov effect, scintillation radiation, transition radiation, etc.

Because it is a small and low-weight detector, it can be easily moved from one location to another, in case it is required to make data collection with another data acquisition system, calibrate the detector with different sources of radiation, etc. The design of the detector makes possible to obtain auto-coincidences (no other device required) both horizontal and vertical ones. Likewise, such a detector has the advantage that requires a low maintenance, is of a safe operation, does not require of special components and is of easy construction. On the other hand, despite our detector is a cosmic ray detector, this detector does not allow us to detect neutrinos, which are also cosmic rays. However, it is important to say that neutrino detection is not one of the aims of this research.

Finally, the improvements that could be made to the detector are several, for example, ionization channels could be added to measure the ionization produced in the detector, it could be used photodiodes that extend the spectral range of the photodiodes being used, it could be created and used a single electronic card that includes both the discriminator card and the electronic cards that provide voltage to the photodiodes, etc.

8. References

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