

# Design, construction, characterization, and operation of a hybrid cosmic rays detector based on an electron gas

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**Abstract.** There are several sources that produce very energetic cosmic rays that interact with the Earth's atmosphere and create new particles. To detect them there are different methods such as the ionization of a material and Cerenkov radiation, among others. In this work a hybrid cosmic ray detector of 6 channels was designed, built, tested and operated. Being hybrid is possible to validate the signal with the two detection methods. Three Copper bars were used as detection material, each with an ionization and a Cerenkov radiation detection channel. To detect the Cerenkov radiation, Hamamatsu silicon photodiodes were used, and for the ionization channels an RC circuit was developed to measure the signal. The number of signals was counted using discriminator boards, which digitize the signal. With the counts the cosmic rays flux can be measured. The six channels were tested simultaneously. Data collections and analysis were performed. Details of the design, characterization, testing, operation, data analysis and preliminary results are presented.

## 1. Introduction

Cosmic rays consist of particles that come from the outer space, large numbers of them interact with the atmosphere of the earth. Such particles are very energetic, of a few GeV's. These particles are classified into primary and secondary. The primary particles are those created in an astrophysical source. The secondary ones are those that are generated by the interaction between primary cosmic rays and the atmosphere of the planet [1].

Ionization takes place when a particle has enough energy to ionize an atom of a material, which results in an electron and an ion generating a flow of current. This flow of current is amplified if it is immersed in an electric field.

It is thought that Cerenkov radiation only occurs in a dielectric when a particle travels faster than the electromagnetic radiation in the corresponding medium [2].

The Cerenkov radiation detectors are generally developed using materials that are transparent to visible light. On the other hand, detectors that work by ionization normally use a gas. In spite of that, a prototype with an opaque detection material, and that can be ionized, a solid metal that due to the large number of electrons we consider it as an electron gas, was developed.

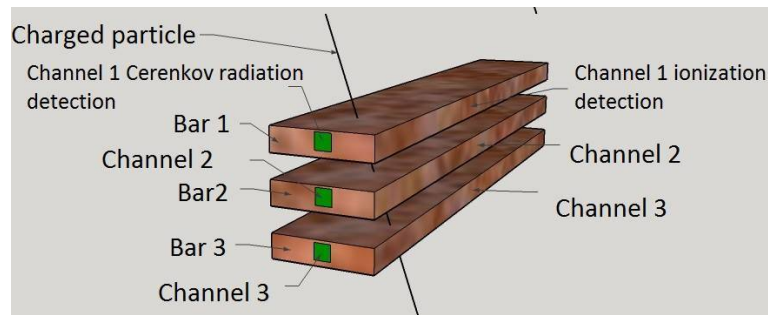


To measure the flux of cosmic rays, a hybrid detector was developed using the two techniques mentioned (ionization and Cerenkov radiation). Using both techniques at the same time it is possible to validate the obtained signal. The identification of incident particles is not considered in planning this detector, it is not of interest in this project. Normally, for the detection of Cerenkov radiation a photodiode [3] is used. A photodiode is a device that transforms light signal into voltage signal or electrical current. For the detection by ionization we use an RC circuit that operates when a pulse is produced by a particle interacting with the material immersed in an electric field. To achieve the data analysis, digital signals are used, however the output of the RC circuit is an analog signal. To transform it from analog to digital a discriminator card is used. When the discriminator receives a voltage higher than the control voltage, which is adjusted in the board using a variable resistor, a digital one is obtained, that is, 5 volts, otherwise a 0 is produced.

## 2. Motivation

To build a detector using ionization detection and Cerenkov radiation, Aluminum was first used. After some tests the material was changed to Copper, since it is approximately three times denser ( $Al=2.699$  g/ml,  $Cu=8.960$  g/ml) [4]. So it is more likely that the particles interact with the material. The ionization energy of the aluminum is less than that of Copper, however, that is not considered a drawback. Cosmic rays energy spectrum is very wide.

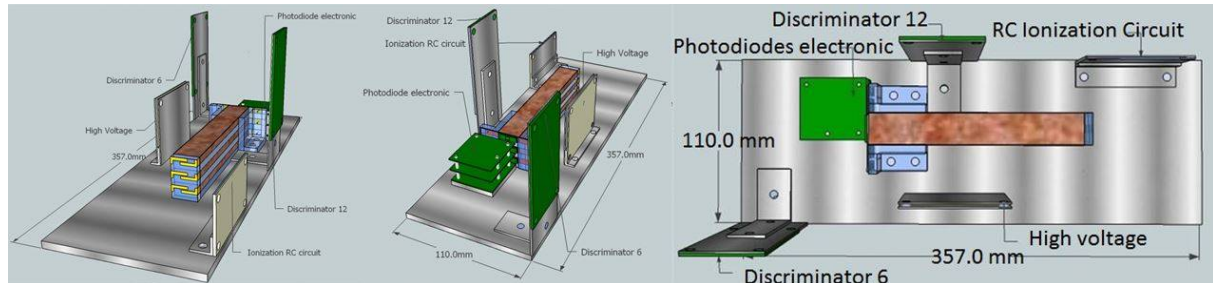
Taking advantage that our device is a hybrid detector, the information is validated using two different detection channels in the same bar. An array of three bars, one on top of the other is also used to validate the information. In bar 2 when bar 1 and 3 have signal as shown in Figure 1. With this arrangement it's possible to know if the particle travels from top to bottom or vice versa, depending on the time of detection in each channel.



**Figure 1.** Corroboration system scheme.

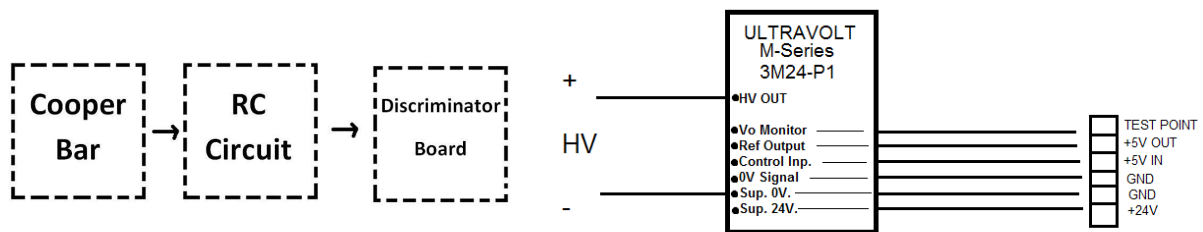
## 3. Design

The design for the prototype was developed using the commercial software SketchUp 2013. The design consists of three Copper bars, one on top of the other, separated by an acrylic bar, to isolate the Copper electrically, as shown in Figure 2. Copper collectors were placed on the sides of the Copper bars that collect the signal and transport it to the RC circuit. As it can be seen in Figure 3. The circuit was fixed to an Aluminum base shaped as a bracket that is screwed to the base system.



**Figure 2.** Design on SketchUp.

The electric field is produced using a high voltage source Ultravolt 3M24-P1 M SERIES [5] with the configuration specified in Figure 4. To fix the electronic board to the Ultravolt voltage source, we used an Aluminum bracket. Two acrylic brackets screwed to the base, were used to maintain the Copper bars in place, and to facilitate the high voltage connection.



**Figure 3.** RC circuit scheme.

**Figure 4.** Configuration of high voltage board.

The Hamamatsu photodiode *S12572-100P* [6] was fixed to the Copper bars, making contact with the surface, welded to a phenolic board that has the pins that connect the photodiode to the voltage source and amplification board. To keep in place the photodiode, a small Aluminum rectangle with an orifice the size of the optical sensitive area was made. Electrical insulating tape was used to isolate the photodiodes electrically and Aluminum tape was placed on top.

The voltage source and amplification board that were used in the *hamamatsu photodiode electronic*, to activate the photodiodes and couple the signal, so that the discriminator can process it. To adjust the level of the *hamamatsu photodiode electronic*, we used an Aluminum base glued to the general base and board separators, so that they could be connected without cables to the photodiodes pins. To fix the discriminator to the whole system, Aluminum brackets were used.

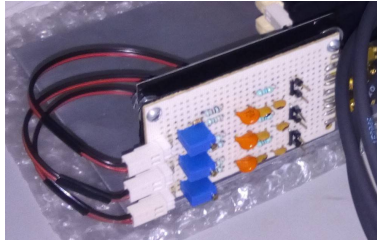
#### 4. Construction

As already mentioned, a prototype using Aluminum was first made using a 5 cm x 5 cm x 1 cm Aluminum bar. The bar was polished and cleaned. An RC circuit was constructed so that it gives a signal with exponential decay, with the shortest decay time possible.

For the Copper detector a Copper plate was used. The plate was cut with a waterjet device into three bars with 22 mm x 6 mm x 151 mm bars, then they were polished using sand paper and cleaned.

Three bars of transparent acrylic were cut with the same dimensions as the Copper bars, sanded on the edges and cleaned. They were glued with instant transparent glue in an interleaved way with the Copper bars, with an acrylic bar in the bottom and a Copper bar on the top.

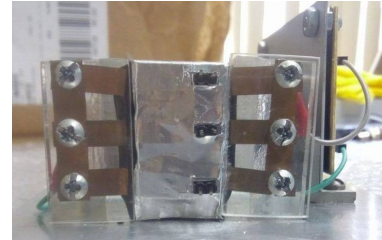
The RC circuit for the ionization channels [Figure 5] was constructed as follows: The high voltage source UltraVolt 3M24-P1 M SERIES was weld to a phenolic board, as seen in Figure 6.



**Figure 5.** Ionization RC circuit.



**Figure 6.** Source of high voltage (UltraVolt).



**Figure 7.** Frontal view of optical channels.

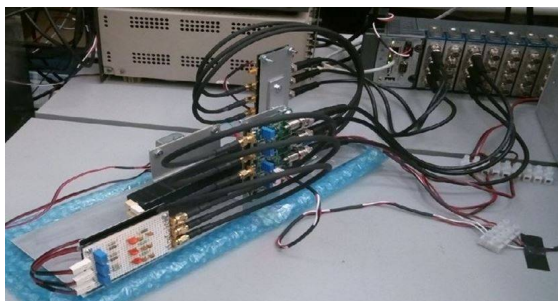
The RC circuit for the ionization channels [Figure 5] was constructed as follows: The high voltage source UltraVolt 3M24-P1 M SERIES was weld to a phenolic board, as seen in Figure 6.

For the optical channels, a phenolic plate of 6 x 22 mm was cut and two guides were drawn to weld two pins and the photodiode. Three Aluminum plates, with a square orifice at the center, the size of the photodiode, were made. At the edges of the orifice a black liquid electrical insulator was applied. These plates were glued with instant transparent glue to the bare Copper, on the opposite side to the RC circuit. Subsequently the photodiodes were placed and electrical tape was used to isolate the photodiodes electrically and from visible light. To isolate from other kinds of electromagnetic radiation, Aluminum tape was placed on top as shown in Figure 7. Electrical insulating tape was used to avoid electric arcs with the electrodes. The only thing left exposed are the pins.

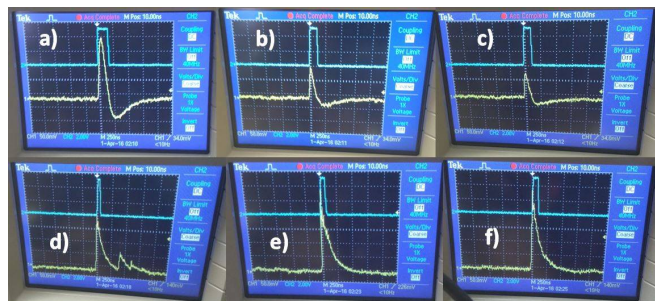
To place the cards that activate the photodiode at the right height, five Aluminum plates were cut, perforated, cleaned and glued together to the base. Board spacers were used to match the cards with the photodiode pins. For the RC circuits, the two discriminatory cards and the high-voltage source, L-shaped Aluminum pieces were made as a vertical support for the circuits and screwed to the base.

## 5. Operation

We verified the correct operation of the Copper detector (Figure 8), starting with the optical channels. Next, we connected the ionization channels, the high applied voltage was approximately 2933 V. The expected signal was visualized on the oscilloscope, obtaining the pulses shown in Figure 9.



**Figure 8.** Detector connected to the CompactRIO.



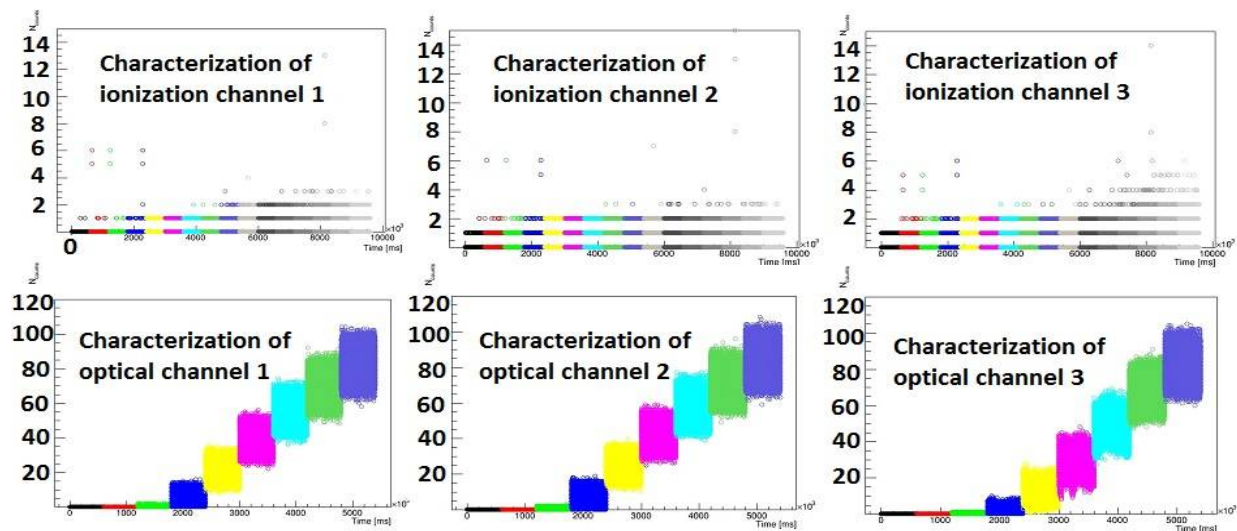
**Figure 9.** Signal on oscilloscope. Vertical axis voltage, horizontal axis time. Ionization channels: 1 → a), 2 → b), 3 → a); Optical channels: 1 → d), 2 → e), 3 → f).

Having the six channels functioning properly at the same time, the output signal was disabled and connected to a 32 channels data acquisition system (CompactRIO), which works with a 40MHz clock. When the six channels were connected, the output signal was enabled and the reference voltages, that was adjusted for each channel in the discriminator board, to about 3 times the noise level. The obtained values can be seen in Table 1.

## 6. Characterization

The detector characterization consisted of modifying the voltage supply value for the photodiode in the optical channels and the high voltage for the ionization channels, making runs of 10 minutes to obtain data using the CompactRIO. The ionization voltage was modified from 1222.22 V (2 V in the source) to 3055.55 V (5 V in the source) with increments of 0.2 V in the source. The voltage of the optical channels was changed from 60 V to 100V with increments of 5 V in each run.

The graphs obtained with the characterization data are shown in Figure 10. As it can be seen, each channel has a different voltage with which a region with stable counts is obtained, these voltage values can be observed in the Table 1.



**Figure 10.** Graphics of characterization, vertical axis counts, horizontal axis time (each color represents 10 minutes).

**Table 1.** Operation and trigger voltage.

Channel	Trigger Voltage (mV)	Operation Voltage (V)
1 Ionization	50.0	1700 to 1800
2 Ionization	60.0	1700 to 1800
3 Ionization	80.0	1700 to 1800
1 Optical	50.0	70 to 75
2 Optical	50.0	70 to 75
3 Optical	50.0	70 to 75

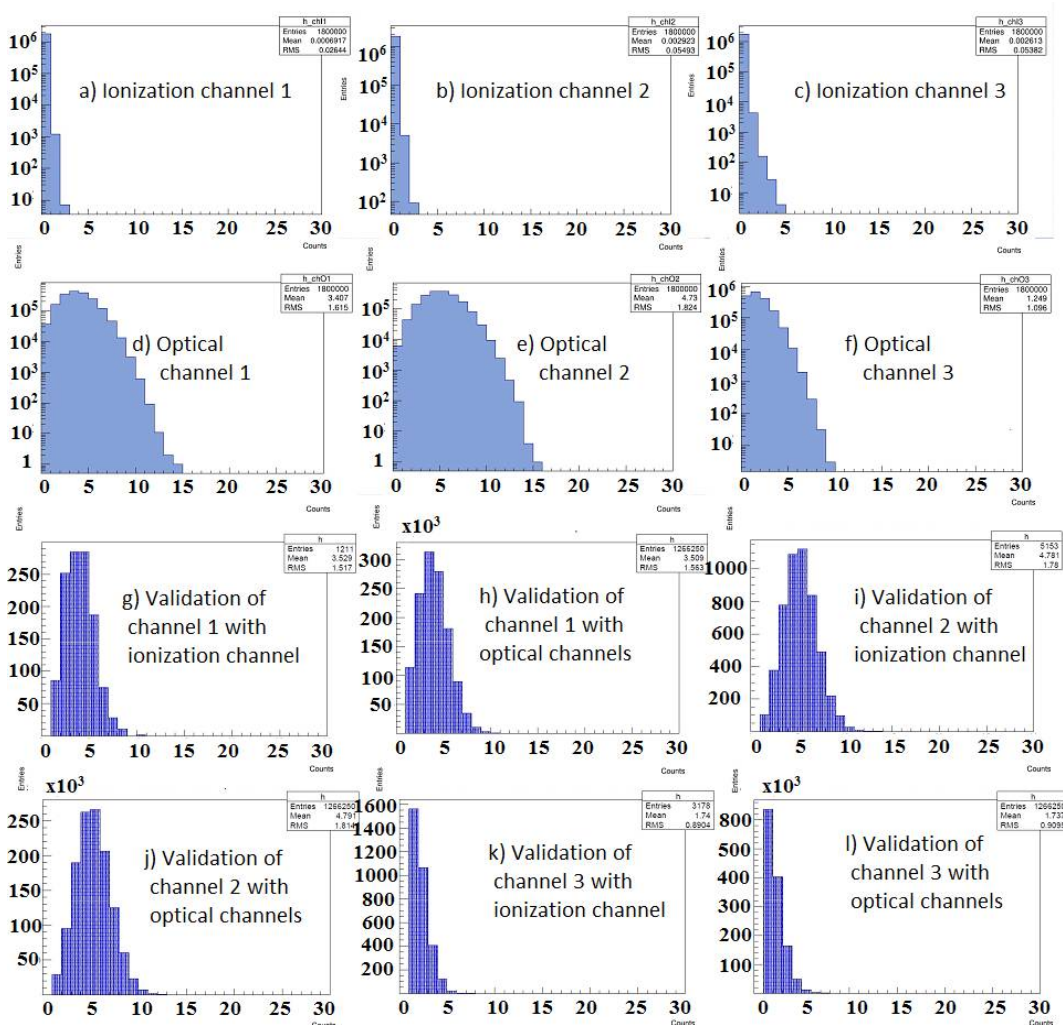
## 7. Results

With operating voltages of 2750 V and 75 V, a run of 30 minutes was performed and the following distributions of frequencies for each channel were obtained: Figures 11 (a, b, c, d, e, f).

The signal of channel 2 was validated in two different ways, first using the 3 optical channels, by having signal in bar 1 and 3 the signal is validated in bar 2, obtaining what is shown in figure 11 (j). The other validation was done using the ionization and optical channel of bar 2, where the optical signal is validated if a signal is detected in the ionization channel (figure 11 (i)). Channel 1 and 3 were validated in the same way (figures 11 (g, h, k, l)).

## 8. Conclusion

It was possible to design, build and characterize a detector with 6 channels functioning at the same time, and obtaining signal simultaneously. A similarity between the 3 optical channels is observed when plotting the frequency distribution. The same happens between the 3 ionization channels. This makes us assume that the 6 channels are functioning properly. The calibration of the detector will be performed using a known radiation source, this will allow us to measure the flux of cosmic rays.



**Figure 11.** Histograms, vertical axis frequency, horizontal axis counts.

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