DESIGN, CONSTRUCTION AND CHARACTERIZATION OF A THREE-CHANNEL COSMIC RAY DETECTOR BASED ON ALUMINUM BLOCKS ELECTRONICS

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Resumen

Actualmente los físicos estudian e investigan los rayos cósmicos; en el mercado se puede adquirir la tecnología de detección de rayos cósmicos, pero con limitaciones en el espectro de detección y en la rapidez. El reto actual es diseñar, construir, y probar la electrónica de detección, y el sistema de adquisición de datos para adquirir continuamente (sin ventana de tiempo). En este trabajo reportamos el diseño, la construcción, la caracterización y las pruebas de las tarjetas electrónicas de un detector de rayos cósmicos de tres canales basado en tres barras de Aluminio de 2.54 x 5.08 x 20.32 cm (diseño novedoso y único) y en un fotodiodo Hammatsu MPPC, S12572-100P por canal. Para adquirir datos se usó el modelo compactRIO de National Instruments por su alta tasa de muestreo, embebido, y basado en tecnología FPGA. Se presentan detalles del diseño, de la construcción, y de la caracterización de la electrónica de detección y resultados físicos preliminares.

Palabras Claves: Embebido, FPGA, rayos cósmicos.

Abstract

Currently physicists study and research cosmic rays; cosmic ray detection technology can be purchased at the market, but with limitations in detection range *and speed. The challenge in these days is to design, build, and test the detection electronics and the data acquisition system for to continuously acquire data (no time window). In this work we report the design, construction, characterization and electronic board testing of a three-channel cosmic ray detector based on Aluminum blocks (innovative and unique design), each one attached to a MPPC, S12572-100P Hamamatsu photodiode. To acquire data it was used the National Instruments CompactRIO model for their high rate sampling, embedded, and based on FPGA technology. The details of the design, construction, and preliminary physical results are presented and discussed.*

***Keywords*:** *Cosmic ray, embedded, FPGA.*

1. Introduction

The scientists around of the world investigate cosmic rays; different types of cosmic rays detectors have been developed to achieve this goal [Morello, 2010]. The applications are mineralogy, spectroscopy, medicine (free X ray), radiography [Durham, 2015], security scanning, earthquake research, etc. In Mexico there are small scientific groups in experimental high energy physics. Particularly, the students and professors from Laboratory for elementary particles (laboratorio de partículas elementales [Félix, 2005]) design, construct, and run their own cosmic ray detectors [Félix, 2015].

The cosmic ray detector presented in this work is home designed and constructed with passive and active electronic parts to activate Hamamatsu avalanche photodiode S12572-100P [Hamamatsu, 2015], figure 1.

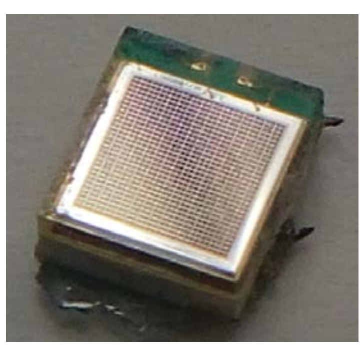

Figure 1 S12572-100P photodiode.

The data acquisition system selected was 9025 CompactRIO [National Instruments, 2015] cRIO of National Instrument, the core of this device is based with Field Programmable Gate Array "FPGA" technology.

2. Methods

In this work, were worked the following steps: design (electronics, using OrCAD), construction (local workshop), test (oscilloscope, LabVIEW and cRIO), characterization (power suppliers, LabVIEW and cRIO), and run (power suppliers, LabVIEW and cRIO).

Design

The one-channel cosmic ray detector is assembled with five stages and its material detection –Aluminum block for this report-, device sensitive to light -avalanche photodiode-, passive electronics board, discriminator board, and data acquisition system with PC-Host. The figure 2 displays the diagram block of one-channel cosmic ray detector.

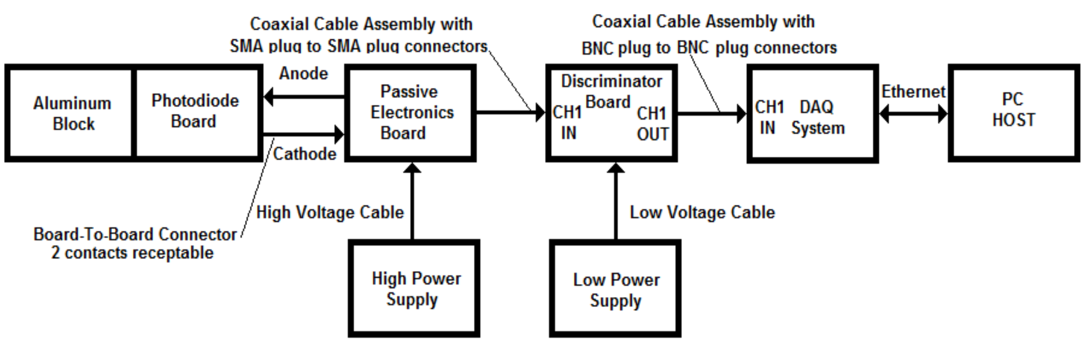

Figure 2 Diagram block of one-channel cosmic ray detector.

Electronic Boards

Photodiode board, the photodiode is soldered on top layer, and connection terminal anodes and cathodes are soldered on bottom layer. Its function is to attach photodiode to the Aluminum block on one of its polished 2.54 x 5.08 cm ends.

The figure 3 and 4 display the bottom and top layer, respectively.

Figure 3 Photodiode board bottom layer.

Figure 4 Photodiode board top layer.

The figure 5 displays photodiode board isolated optically with one layer of Aluminum tape 3311, the figure 6 displays one front end 2.54 x 5.08 cm Aluminum block polish and the figure 7 displays the Aluminum block attached with a photodiode board and isolated optically with four layers of Aluminum tape 3311.

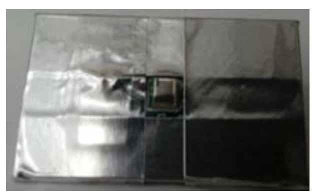

Figure 5 Photodiode board isolates optically.

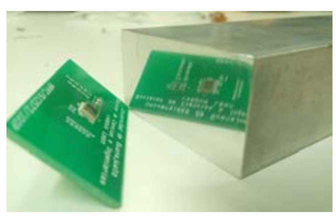

Figure 6 Aluminum block polished.

Figure 7 Aluminum block and photodiode isolated optically.

Passive electronic board, the photodiode is enabled by high voltage, and for the readout of the signal was implemented a RC circuit. The photodiode requires reverse polarity for working. The C3 capacitor is charged when the cosmic ray hits Aluminum block and generates Cerenkov radiation and photodiode detects it, and the C3 capacitor discharges through R7 resistor, analogue signal is obtained, positive decay exponential form is obtained. The readout signal is obtained at J1 SMA connector or a test point.

The figure 8 displays passive electronic board diagram schematic and figure 9 displays the passive electronic board.

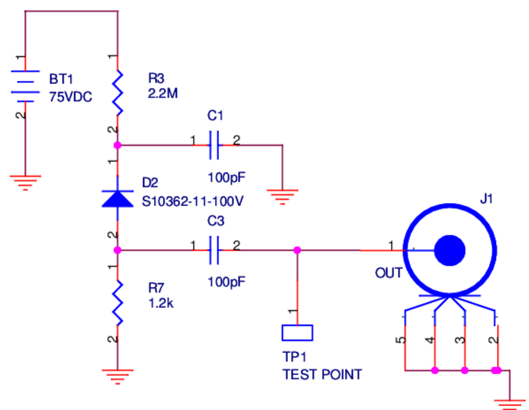

Figure 8 Passive electronic board diagram.

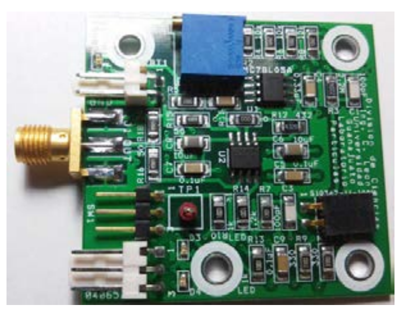

Figure 9 Passive electronic board with photodiode connector.

Discriminator board, its function is to compare analog signal coming from the passive electronic board, with a fixed trigger voltage defined by the final user and give out the digital signal. If the input signal is higher in amplitude than the fixed trigger, the discriminator turned on -one logical state-, otherwise, turns off -zero logical state-. For this board was selected a single integrated circuit CMP401 of Analog Device [Analog Devices, 2002], with 23 ns propagation delay, quad comparators and compatible with 5 V logic. The figure 10 and 11 display the one channel discriminator board diagram schematic and four channel discriminator board, respectively.

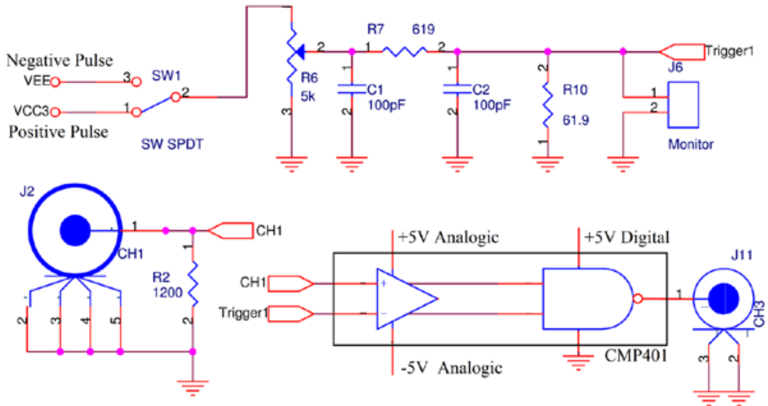

Figure 10 One channel discriminator board schematic diagram.

Figure 11 Four channel discriminator board.

The trigger voltage circuit is made up of three stages: First, polarity voltage selector -the SW1 switch selected only one voltage 3 or -5 V-. Second, voltage adjustment -R6 variable resistor-. Third, voltage divider by ten -divided voltage 3 or – 5 V, obtaining fine adjustment in mV-, and go to the comparator invert input, similarly, J2 SMA connector is for analogue signal from to passive electronic board to comparator non-invert input.

The trigger has wide input range positive of 0 volts to 300 or -470 mV, the end user can measured trigger voltage with J6 board-to-board connector and 2 contacts header.

The J11 BNC connector is for the digital signal output, obtained by comparison of the analogue signal input and trigger voltage defined by final user.

Data Acquisition System

The cRIO is assembled with 9025 embedded controllers, with NI-9402 four-channel, LVTTL digital input/output module [National Instruments, 2016] and one rack. The figure 12 displays assembled cRIO. Finally, the cRIO is connected to the PC HOST via Ethernet cable with one number port.

Figure 12 Assembled cRIO with 32-channel digital input.

The cRIO requires programming in LabVIEW-FPGA and the PC HOST accept only LabVIEW program.

The LabVIEW-FPGA program reads for each channel the digital input signal every 25 ns from C module, submits the digital signal to an edge detector with rise polarity configured for searching digital rise pulse (the digital rise pulse is a possible cosmic rays). If the digital rise pulse is detected, the unsigned 64-bits (U 64-bits) counter increases by one and the digital rise pulse complement is discriminated (to avoid count the same digital signal), this is a parallel process and individual for each channel. The figure 13 displays a block diagram of LabVIEW-FPGA program.

Every 1 ms, LabVIEW-FPGA program copies the three counters results and the time in ms to Direct Memory Access First Input First Output (DMA FIFO) memory with interleaving method, clears the three counters and LabVIEW-VHDL program begins again. Automatically, the DMA FIFO memory information is transferred for Ethernet port to PC HOST by embedded controller.

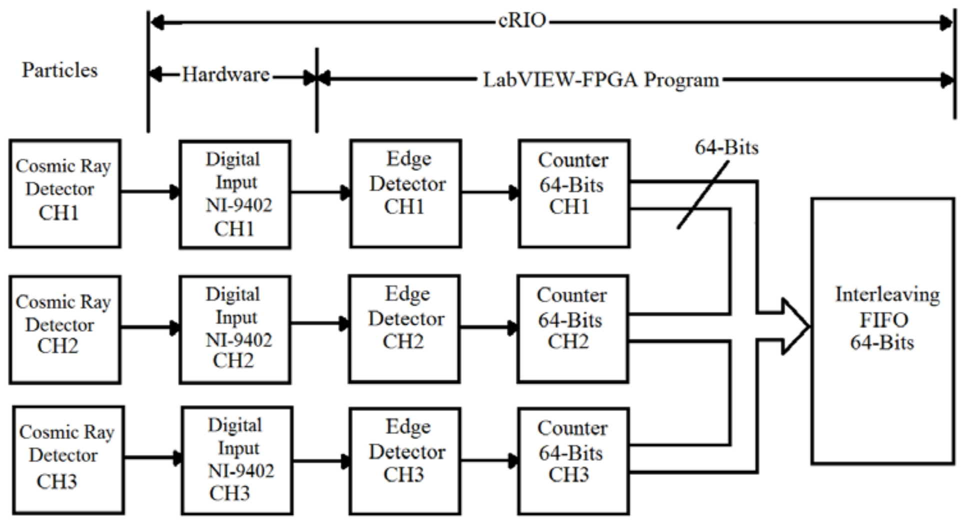

Figure 13 Block diagram of LabVIEW-FPGA program.

Construction

There were implemented three 2.54 x 5.08 x 20.32 cm Aluminum blocks, with only one 2.54 x 5.08 cm end polished to mirror for each Aluminum block. Each photodiode board was attached to the Aluminum block on the polished end, and isolated optically with four layers of Aluminum tape 3311.

A 25 x 35 cm Aluminum plate was used as a main board for some three Aluminum blocks and electronics assemble. On the main board was installed the first Aluminum block and it was connect with the first passive electronic board, it was fixed with four-inch screws and nuts. This process is repeated for the next two channels in stack arrangement and fixed only with nuts.

The discriminator board was fixed at the main board one edge. The top, middle and bottom output channels were connected to 1, 2 and 3 input channels discriminator board with SMA plug to SMA plug coaxial cable. The figure 14 displays the three channels detector final assembly.

The XLN10014 BK Precision and 72-8335A Tenma were used high and low power supply, respectively. The low and high voltage cables were implemented 22 AWG size with wire-board receptacle MC34 series Molex, three contacts for low power and two contacts for high power.

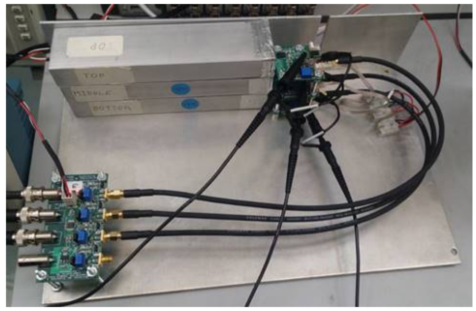

Figure 14 Three channel detector final assembly.

Test

The correct operation of each channel of the cosmic ray detector was verified using TDS1001C-EDU Tektronix oscilloscope. The oscilloscope channel one was connected to the passive probe to passive electronic board test point and oscilloscope channel two was connected to the BNC plug to BNC plug coaxial cable to discriminator board signal output. The figure 15 displays the oscilloscope test to three channel detector.

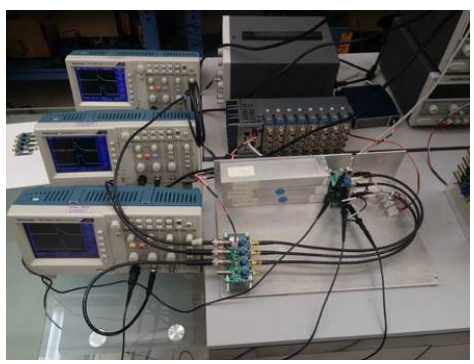

Figure 15 Oscilloscope test to three channel detector.

Characterization

The PC-host has a total control for automatic characterization process. The PC-Host uses a USB2.0 interface to control the high power supply -XLN10014 from BK Precision [BK PRECISION, 2014].

To define the high voltage range and the maximum current, to turn on the PC-Host program is necessary. The sequence is defined in five step: first, output turn on of the high voltage supply with the minimum defined voltage; second, to stabilize the new high voltage, a time delay of 10 seconds from the PC-Host is applied; third, a text file and records for ten minutes is created; fourth, the text file is closed; fifth, the PC-Host program checks if it has reached the maximum voltage defined. If it is true, the PC-Host terminates its execution and disenables the output high power supply; if it is false, the PC-Host increases the voltage by 5 volts, and jumps to second step. The figure 16, displays hardware automatic characterization system blocks diagram.

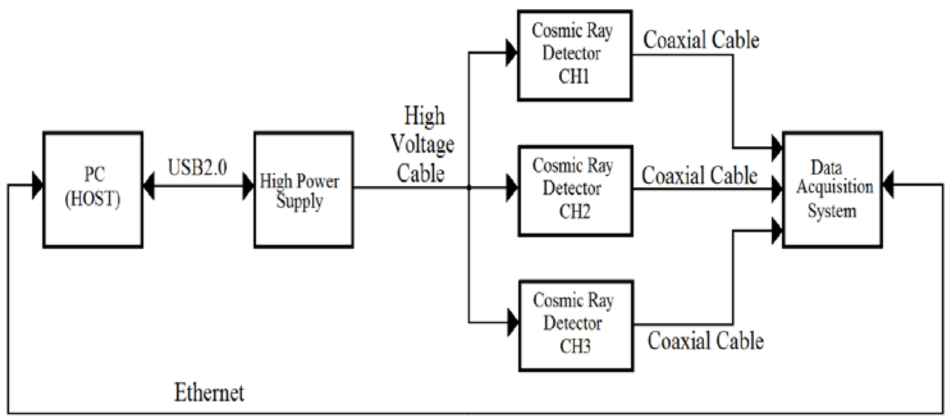

Figure 16 Characterization process block diagram.

3. Results

Test Results

The analogue signal noise was 20 mVpp and the configuration parameters were 75 Volts for operation voltage and 100 mV of threshold for the discriminator board. The analogue signal amplitude is variable, with duration of 200 ns pulse width, and exponential decay positive form.

The figure 17, 18 and 19 display top, middle and bottom Aluminum block output signal tests respectively. The oscilloscope channel one displays analogue output signal of a passive electronic board; the oscilloscope channel two displays the digital version of the analogue signal coming from discriminator board.

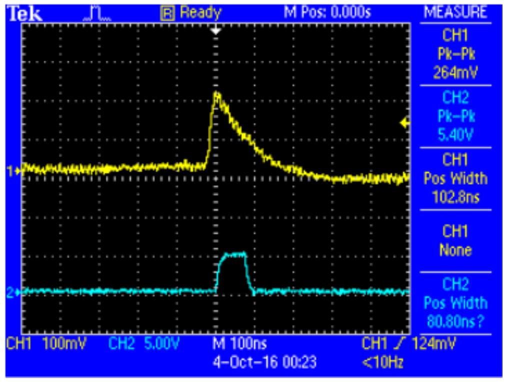

Figure 17 Top Aluminum block oscilloscope output signal test.

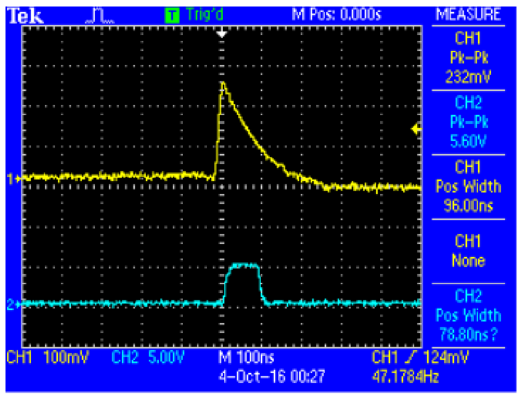

Figure 18 Middle Aluminum block oscilloscope output signal test.

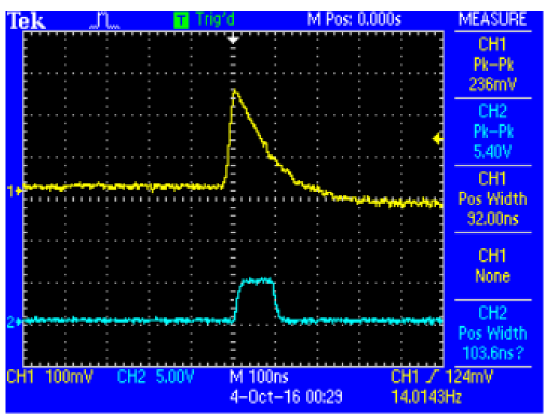

Figure 19 Bottom Aluminum block oscilloscope output signal test.

Characterization Results

The output counts as function of applied high voltage for each channel are displays in figures 20, 21 and 22. The recording interval began at 60 volts and finished at 100 volts in steps of 5 volts each. Nine ten-minute-text files were generated. Figure 20 corresponds to the results of top Aluminum block. Figure 21 corresponds to the result of middle Aluminum block. And figure 22 corresponds to the result of bottom Aluminum block. For 75 volts and higher the number the counts increases lineally with applied voltage.

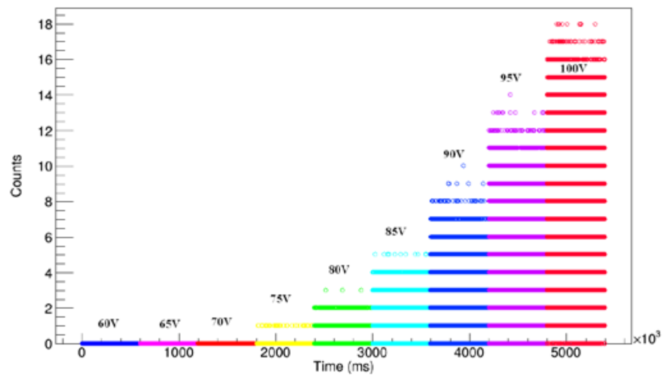

Figure 20 Top Aluminum block characterization result.

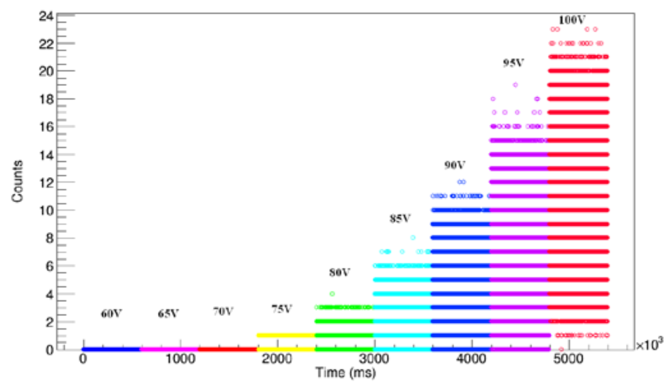

Figure 21 Middle Aluminum block characterization result.

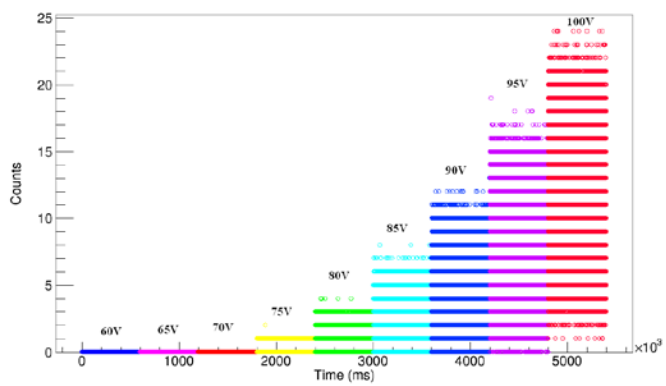

Figure 22 Bottom Aluminum block characterization result.

Results

The configuration parameters were 75 Volts for operation voltage and 100 mV of threshold for the discriminator board.

The figure 23, 24 and 25 display the number of counts vs time for top, middle and bottom channels, respectively. The figure 26, 27 and 28 display frequency vs counts histograms for top, middle and bottom channels, respectively. The recording time length was 30 minutes for each file.

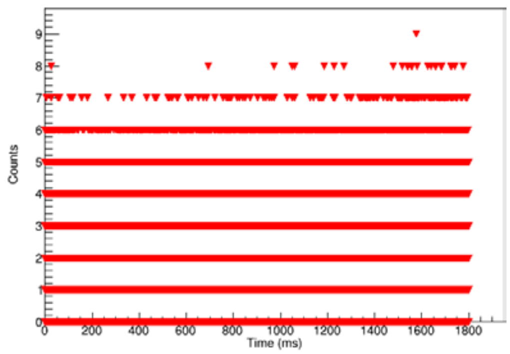

Figure 23 Counts vs time of top Aluminum block.

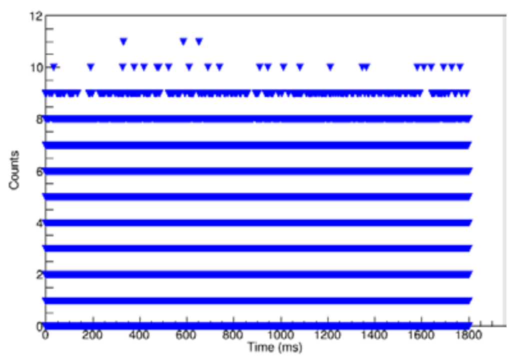

Figure 24 Counts vs time of middle Aluminum block.

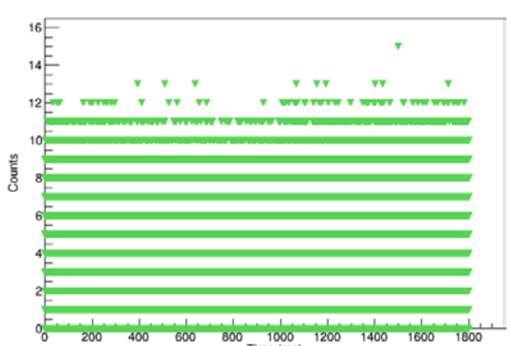

Figure 25 Counts vs time of Bottom Aluminum block.

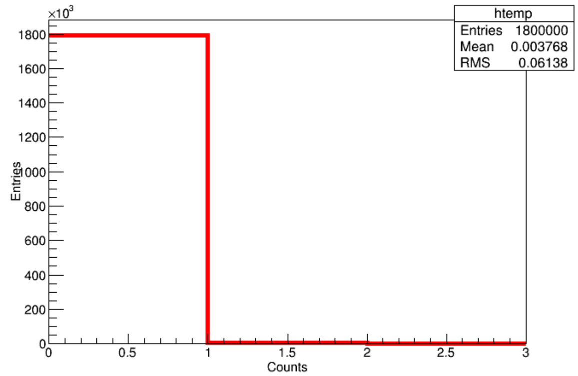

Figure 26 Frequency vs counts of top Aluminum block.

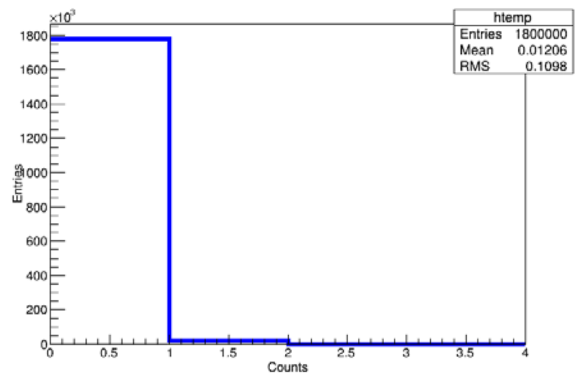

Figure 27 Frequency vs counts of middle Aluminum block.

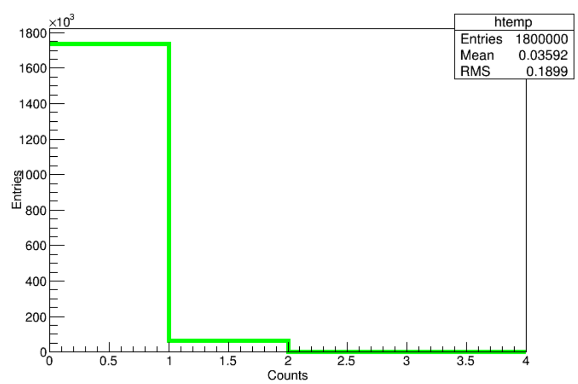

Figure 28 Frequency vs counts of bottom Aluminum block.

4. Discussion

We have planned, designed, constructed, tested and characterized a 3 Aluminum bar cosmic ray detector readout electronic board. It works fine. And the collected data, with a cRIO from NI, is reasonable good.

5. Conclusions

It was designed, constructed, tested, and characterized a three channel cosmic ray detector. The photodiode board, passive electronic board, discriminator board, the data acquisition system work properly. It was characterized the cosmic ray detector to obtain a linear function of the counts vs applied high voltage. The distributions of counts vs time are almost flat, for the three channels of the cosmic ray detector. The distributions of frequency vs counts are almost a Poisson distribution, for the three channels of the cosmic ray detector.

6. Bibliography and References

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