

Abstract

Cosmic ray detection can be achieved by recording ionizing particles or the light produced during their interaction with material media. In this study, a modular detector was developed based on a cylindrical polymethyl methacrylate (PMMA) rod instrumented with four photomultiplier tubes to record light generated via the Cherenkov effect or scintillation. Additionally, experimental characterization and a Monte Carlo simulation using Geant4 were performed. The results show consistency between the experimental and simulated responses, demonstrating the feasibility of using PMMA-based Cherenkov detectors for cosmic radiation detection applications.

Introduction

Cosmic radiation consists of high-energy elementary particles and atomic nuclei that, upon interacting with Earth's atmosphere, generate secondary particles detectable at sea level. Among these, muons constitute the most abundant charged component.

One detection method involves recording photons produced via the Cherenkov effect when charged particles traverse a dielectric medium at speeds exceeding the speed of light within that material. In this study, a PMMA-based detector was developed for the study of muons.

Detector

The detector consists of a cylindrical PMMA rod with a length of 60.09 cm and a diameter of 10.16 cm, instrumented with photomultiplier tubes (PMTs) strategically positioned according to the calculated Cherenkov emission angle for muons.

Modular supports were designed using 3D printing, and an optical and electromagnetic isolation system was implemented using black felt paper and an aluminum coating.



Figure 1: Detector constructed with coupled photomultipliers.

Characterization

The experimentally determined optical and physical properties were:

Density: $\rho = 1.15 \pm 0.002 \text{ g/cm}^3$

Refractive index: $n = 1.47 \pm 0.35$

Attenuation coefficient: $\mu = 0.0052 \pm 0.0015 \text{ cm}^{-1}$

Cherenkov angle: $\theta = 47.76^\circ$

The response times and amplitudes of the photomultiplier tubes were also calibrated to discriminate signals associated with particles incident from opposite directions.

Geant4 Simulation

A Monte Carlo simulation was developed using Geant4, incorporating the system's optical properties and the complete experimental geometry.

The results show agreement between the experimental and simulated responses, enabling the identification of temporal and spectral distributions associated with Cherenkov photon detection.

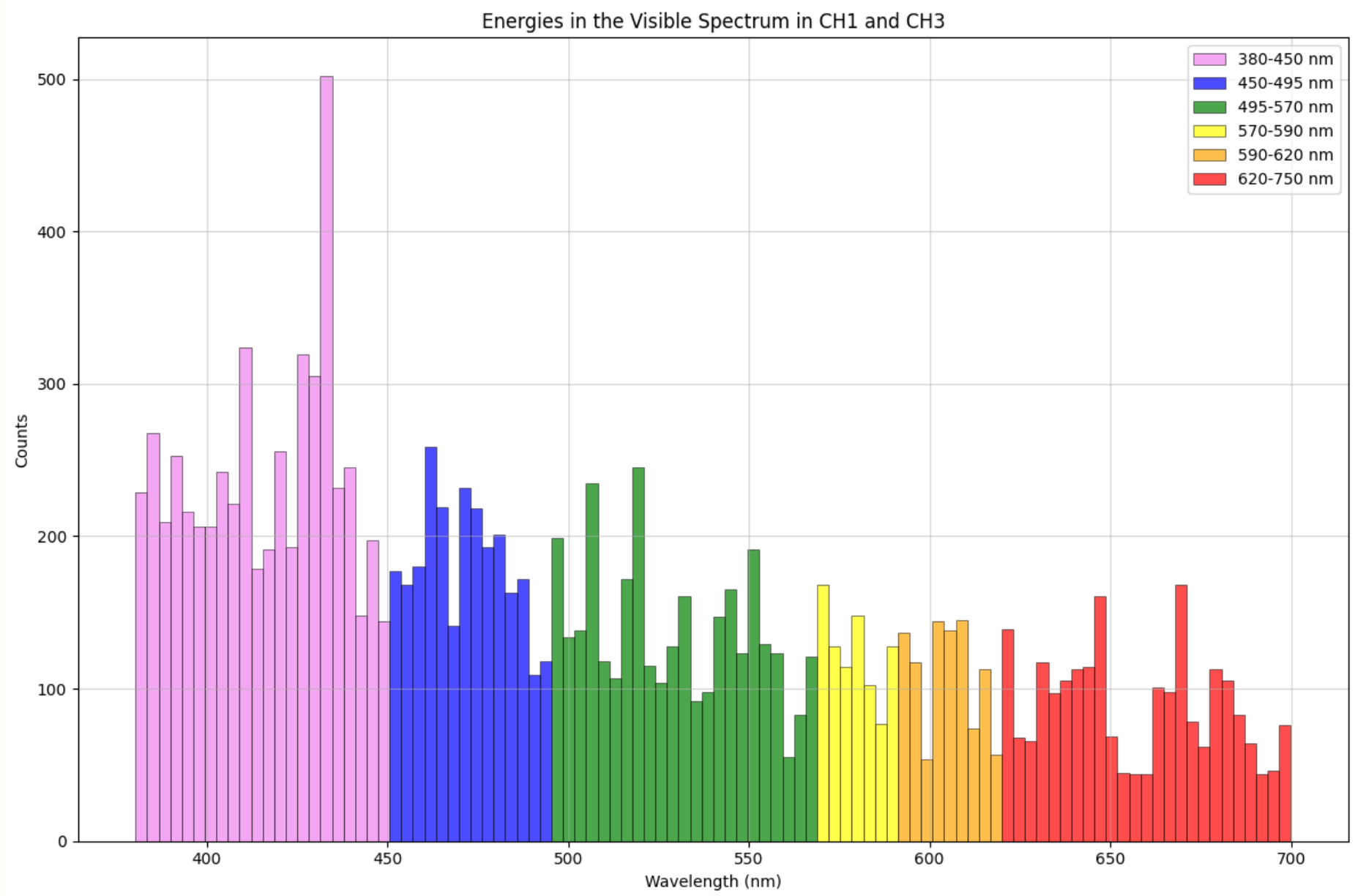


Figure 2: Energy spectrum within the visible range collected in channels 1 and 3. A total of 7541 photons satisfy both the time and energy conditions.

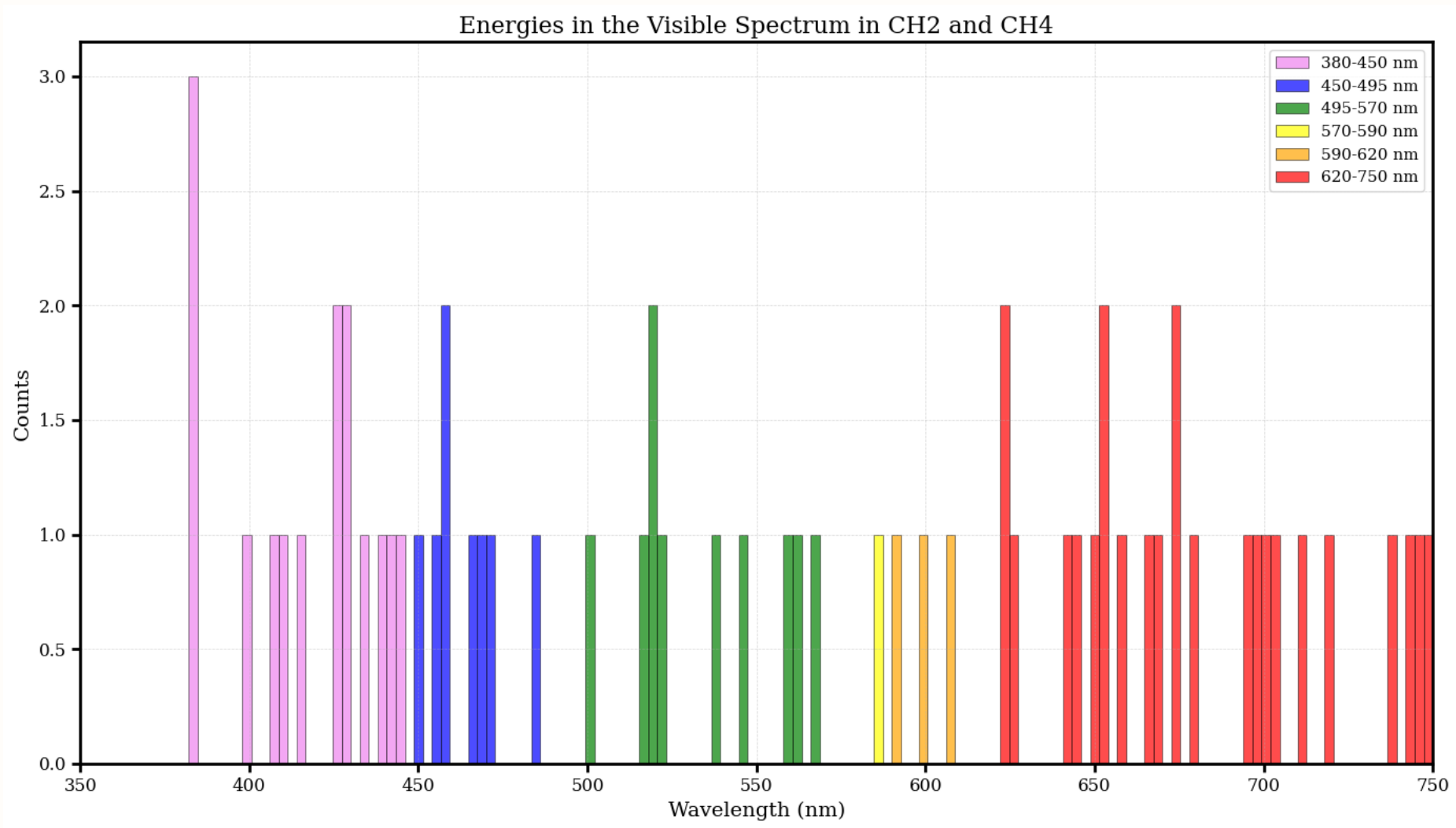


Figure 3: Energy spectrum within the visible range collected in channels 2 and 4. A total of 66 photons satisfy both the time and energy conditions.

Laboratory Results

Signals were recorded using criteria based on amplitude and temporal coincidence between channels. The selected events exhibit characteristics consistent with the detection of Cherenkov photons and show behavior consistent with the expected detector response and the results obtained through simulation.

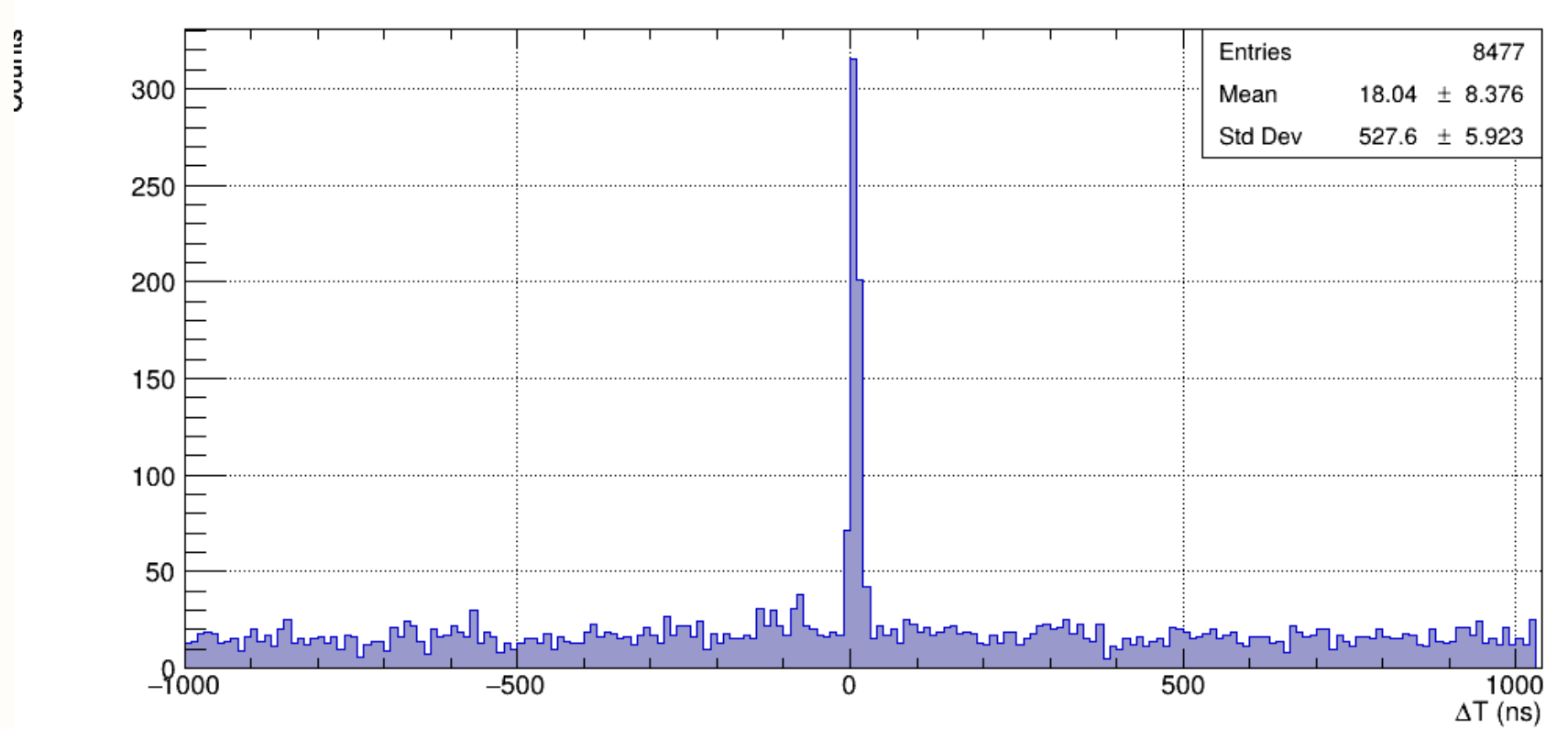


Figure 4: Delay time ΔT between channels 1 and 3 recorded with the CAEN DAQ. Image captured using the CAENCompass software.

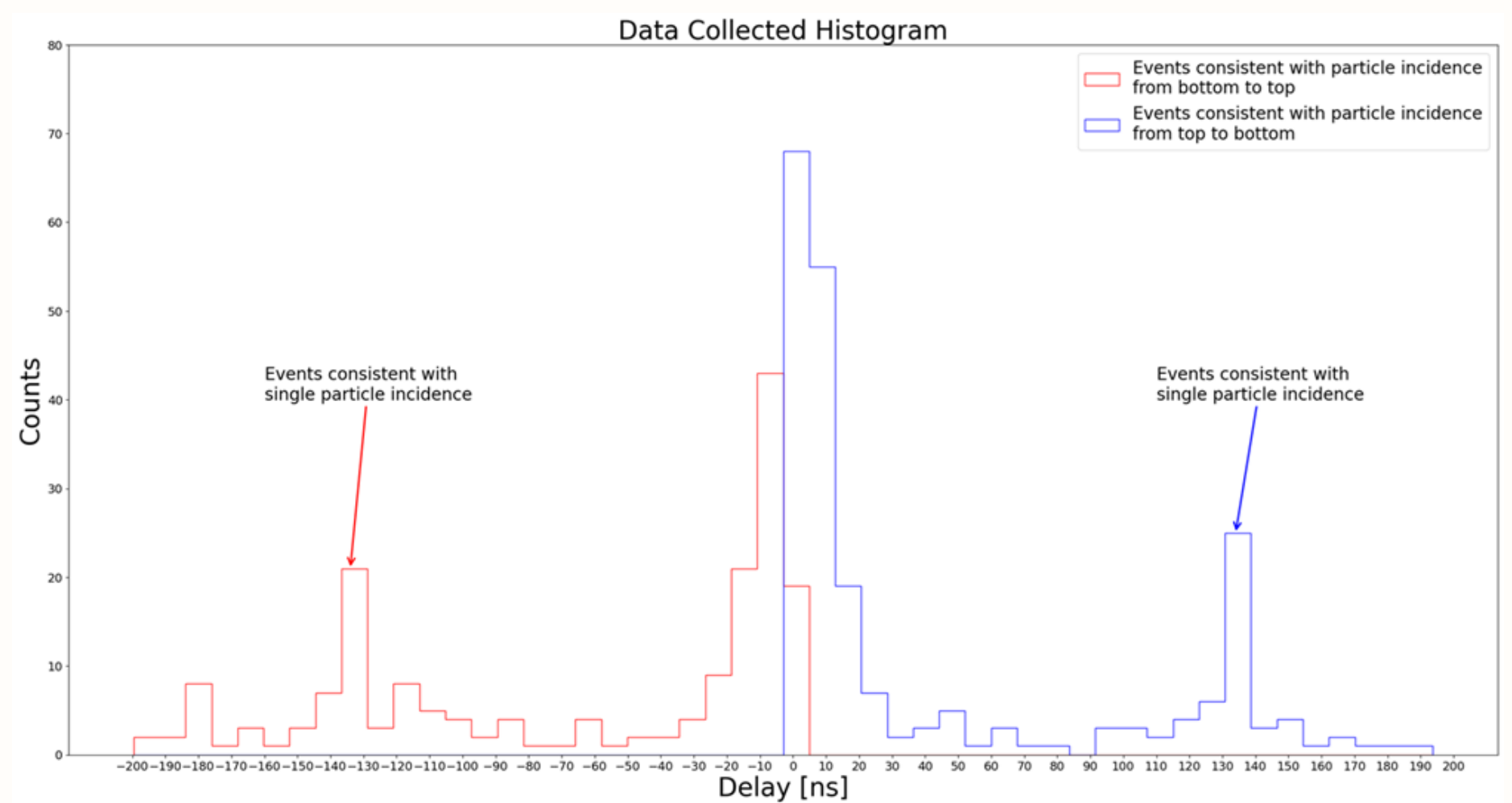


Figure 5: Graph of the events recorded in channels 2 y 4.

Conclusions

A modular Cherenkov detector based on a PMMA bar instrumented with photomultiplier tubes was designed, constructed, and characterized for cosmic radiation detection. The experimental results show behavior consistent with Geant4 simulations, enabling the identification of events associated with the detection of photons produced via the Cherenkov effect.

The developed system represents a scalable, low-cost alternative for applications involving cosmic radiation detection, education, and scientific instrumentation. Future work aims to incorporate veto detectors and continuous data acquisition systems to enhance event identification and selection capabilities.

Bibliography

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