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Prototype Setup for the DUCK

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Abstract. This article covers the prototyping activities for the DUCK (Detector system of Unusual Cosmic ray casKades). The primary goal for the DUCK system is to observe the unusual cosmic events reported by other collaborations, and to look at the possibilities of adding innovations to the EAS (Extensive Atmospheric Shower) analysis methods of the EAS disk measurements at the observation level. The prototyping process has helped to choose between various design possibilities in the process of the optimization of the individual detector design.

1 Introduction

Extensive Atmosphere Showers are still of high interest as they offer insights into the workings of the universe without the use of a particle accelerator and constitute a separate ‘window’ into space other than light and gravity. Detecting cosmic rays is crucial for comprehending their nature, origins, and interactions with the atmosphere. The DUCK [1] system aims to contribute to the methodology of EAS event analysis and serve as a verification tool for detecting "unusual" cosmic ray events identified by the Horizon-T [2] detector system. This pursuit represents a vital step towards unravelling the mysteries of cosmic rays and their profound impact on our understanding of the universe.

The design of the DUCK [3] considers both the need for the high-speed of digitization of the signals as well as the nanosecond-level time resolution that is needed to study the applicability of the EAS disk width to the data analysis and the simulation checking for this parameter as well.

2 Prototype Design

The design of the prototype module is a truncated pyramid (the shape is adopted from [4] following the Horizon-T choice) with the Hamamatsu [5] H11284-30 (former R7723) PMT at the top and the plastic scintillator (0.5 x 0.5 x 0.024 m) at the bottom as shown for the partially completed module in Figure 1 (left). The PMT photocathode is about 55 cm above the scintillator for the prototype. Figure 1 (right) shows the schematic with the PMT and the secondary Hamamatsu 1.3 mm^2 Multi-Pixel Photon Counter (MPPC) photosensor placement positions. The interior and exterior are lined with foil that is covered by Tyvek [6]. The entire system output is recorded by the CAEN [7] DT5730 Flash Analog-to-Digital Converter (FADC).

The MPPC and LED are the elements of the module calibration system that still needs to be tested with the fully completed module. The LED is connected to Rigol [8] DG2102 Waveform Generator. These elements have not yet been fully implemented at this time.

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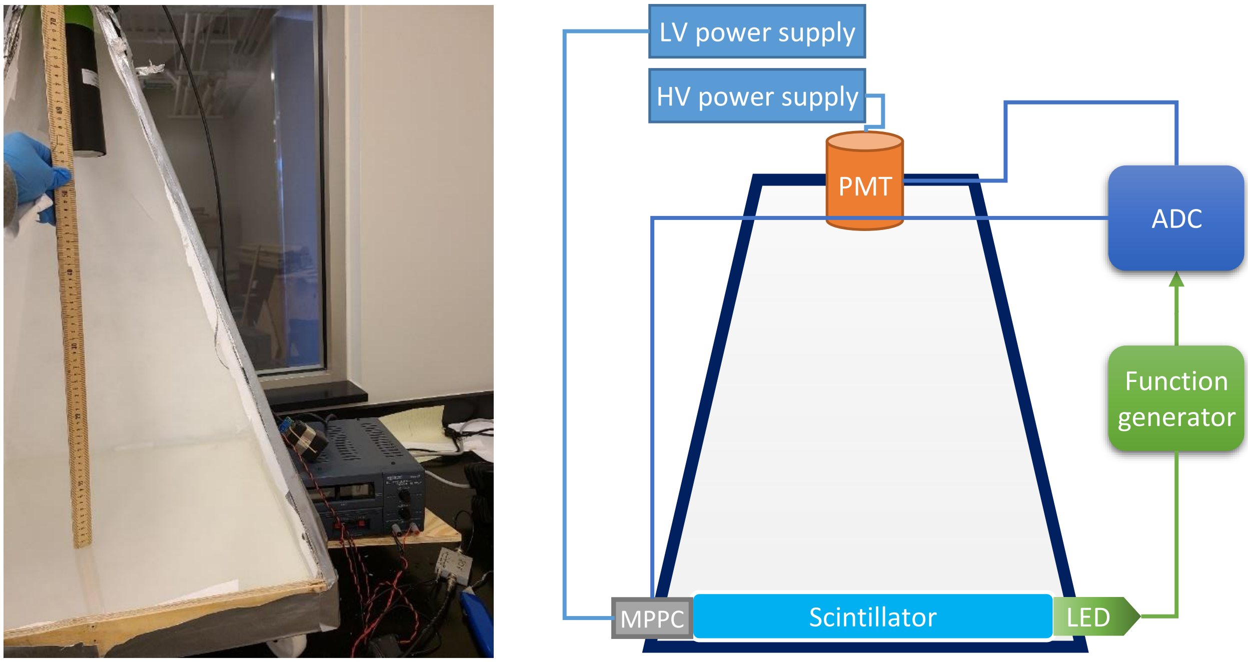

Fig. 1. Left: Progress of prototype module construction. **Right:** General design of the DUCK detector module prototype.

2.1 Paddles Design and Construction

Scintillator paddles form the hodoscope for the cosmic muon calibration coincidence scheme. Figure 2 (left) shows the completed paddle and Figure 2 (right) shows all the layers exposed before completion. The paddle is also done from the 2.4 cm thick scintillator with the square part of the paddle being about 25 x 35 cm. The PMT connector part is 3D-printed. The scintillator is covered by Tyvek for higher light yield. Additionally, aluminium foil, insulation tape, and duct tape were added for both light insulation and structural support. Same model PMTs are used as for the detector modules. Two paddles were constructed for the use in double coincidence scheme.

Fig. 2. Left: Completed paddle detector. **Right:** Paddle construction in progress with layers visible.

3 Detector Calibration

3.1 PMT Bias Calibration

The first test that was done to the newly constructed detectors was to set the bias voltage as well as to set the initial threshold at that bias voltage. For this test, a detector was connected to the discriminator and a counter, then, values were recorded at different bias voltage and threshold values. Figure 3 is a plot of the log of average number of counts per second (i.e. frequency) vs. the threshold value for different biases for the detector prototype module shown as an example. The region, where the fast-decreasing noise counts transition into the signal counts that start to be cut but further threshold increase, can either be short or form a plateau. The threshold is typically chosen closer to the right side of this plateau for a given bias.

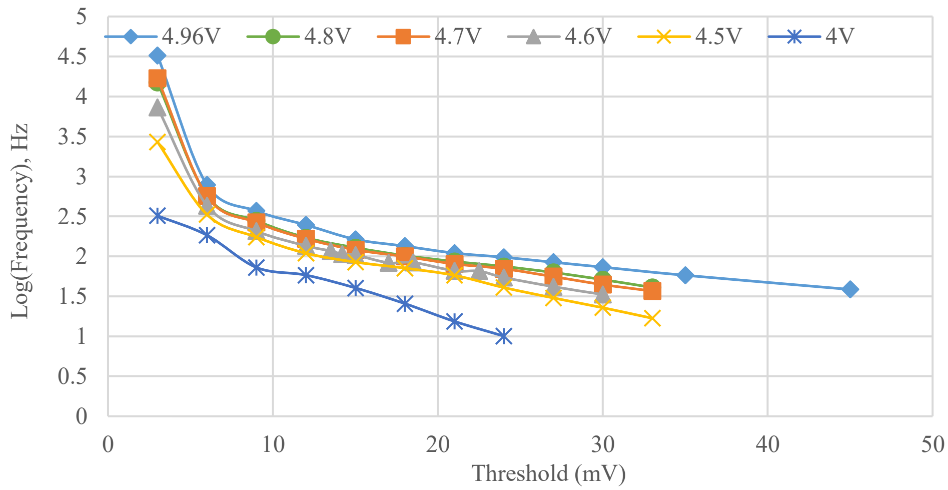

Fig. 3. Count frequency at different threshold values and bias voltages.

The frequency of the noise is important for the double coincidence triggering scheme as within the coincidence window two noise signals can randomly appear creating a false detection of the cosmic event. For this case, the frequency of these false triggers can be estimated using the Eq. 1:

$$f_{False} = f_{noise_1} * f_{noise_2} * w_{coin} \qquad (1)$$

Here, f_{noise} is the average noise of each paddle (in Hz) for the threshold and bias values chosen, and w_{coin} is the width of the coincidence window in seconds. With the typical noise around 300 Hz and the coincidence window of about 50 ns (adjustable), the rate of these false coincidences will be around 1 event in 220 seconds.

3.2 Initial Calibration with Cosmic Rays

A very important detector calibration and performance assessment test is done using the Minimally Ionizing Particles (MIP) that are typically cosmic rays muons. To conduct this test, two paddle detectors are placed above and below the detector being tested, and the FADC is set to detect the double coincidence events as defined by these paddles. Then data is analyzed to determine various properties of the detector response to the MIP signal, such as a sample amplitude as shown in Figure 4. The resulting histogram is fitted with a Landau curve to determine the MPV value for the distribution. As the data is still being taken and analyzed, a detailed description of the results will be reported at a later time. As FADC has a range of 2V and a resolution of 14 bits, the value in ADC bins should be divided by 2^{13} to get the amplitudes in volts.

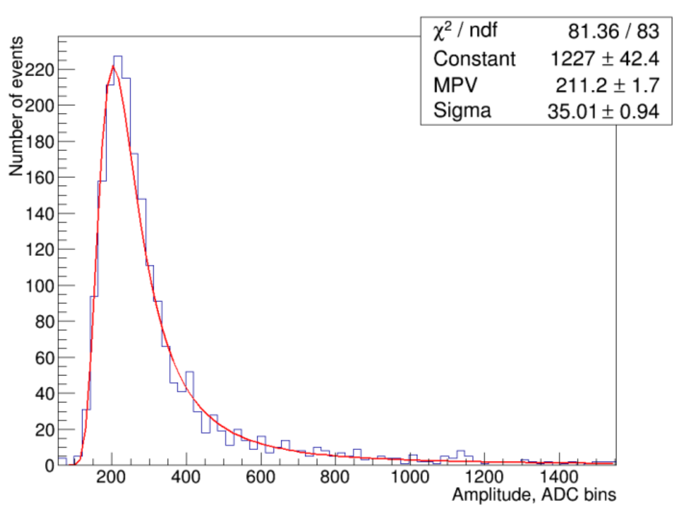

Fig. 4. Amplitude distribution and fit results for the test cosmic run of the prototype detector.

4 Conclusion

In conclusion, the design and prototyping of the DUCK system have demonstrated high performance along the expected characteristics. The prototyping has provided valuable insights into the necessary modifications required to enhance the efficiency of detecting Ultra-high Energy Cosmic Rays in the final design. Additionally, the procedure for PMT calibration can be used to determine the most optimal thresholds and voltages for our data collection in the final design as well. In part, the DUCK hardware was used to support the small project on random numbers [8].

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