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Final Steps of Construction of DUCK System

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Abstract. The update includes the information on the calibration, design, construction and deployment of core modules of DUCK (Detector system of Unusual Cosmic-ray casKades), a cosmic-rays detector system aimed to study the Extensive Air Shower disk thickness as compared to CORSIKA simulations, to join the efforts in the search for the Cosmic Ray Ensembles and to further study the latest advances in the cosmic-rays field, like studying the multi-modal cosmic ray events. The project involves computer simulation activities, design and construction, data acquisition system design, data collection and analysis, allowing participation of students pursuing not only physics but also other STEM fields, such as Chemistry, Engineering and Computer Science.

1 Introduction

One of the few open questions in the High Energy Physics (HEP) field is about the origin and composition of the Ultra-high Energy Cosmic Rays (UHECRs) that originate well outside of the Solar system, maybe even outside of the galaxy. They carry the information that could help us better understand the universe around us and provide insight into the fundamental building blocks of our universe. The primary goal of the Detector of Unusual Cosmic casKades (DUCK) [1-3] is to detect and verify the existence of unusual cosmic events initially discovered by the Horizon-T collaboration [4]. Moreover, it can help innovate EAS (Extensive Atmospheric Shower) analysis methods and participate in other collaborations such as CREDO [5]. Another emerging mystery is the possibility that the origin of the 'knee' in the cosmic rays spectrum might be due to the Galactic center black hole [6]. This article described the conclusion of the construction progress of the DUCK detector system and highlights the instrument calibrations and other activities conducted at Clayton State University.

2 Design Introduction

The design of the DUCK project [7-10] calls for the basic 4 modules that have been completed. Individual detectors were designed based on [11] and consist of the 1x1x0.05m EJ200 Eljen [12] scintillator and the Hamamatsu [13] H11284-30 photomultiplier tubes (PMT) that are connected to the CAEN [14] DT5730 Flash Analog-to-Digital Converter (FADC). Hamamatsu H11284-30 (former R7723) PMT is chosen for the large area of the photocathode (2") and fast output pulse. The Hamamatsu 1.3 mm2 Multi-Pixel Photon Counter (MPPC) photosensors are used as secondary detectors for the calibration purposes only.

The schematic design for a single module is shown in Figure 1, and three completed modules are in Figure 2. For the small parts of each detector, such as the top piece in the Figure 1, the PMT holder and the MPPC fiber ferrule, the 3D printing technology is used. A special design was made by students for all the parts mentioned. Figure 3 shows the 4th detector module under construction with the 3D-printed parts at the top.

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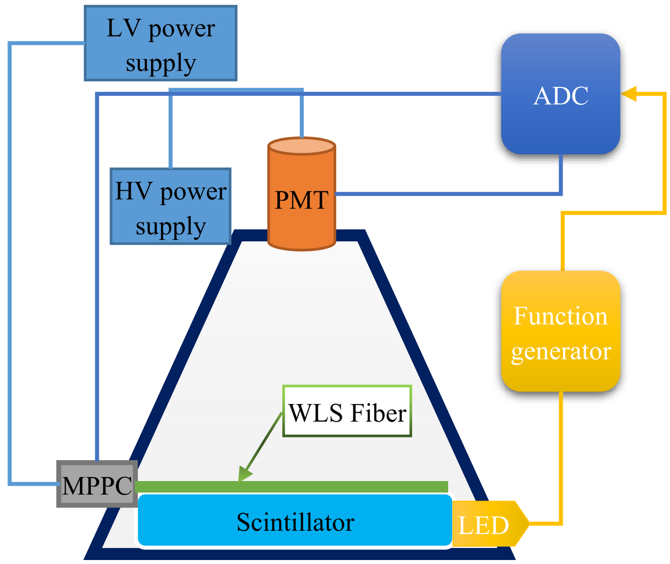

Fig. 1. General design of the DUCK detection module.

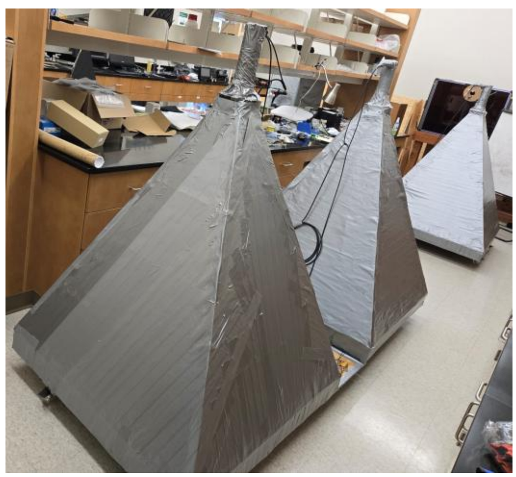

Fig. 2. Three completed DUCK modules.

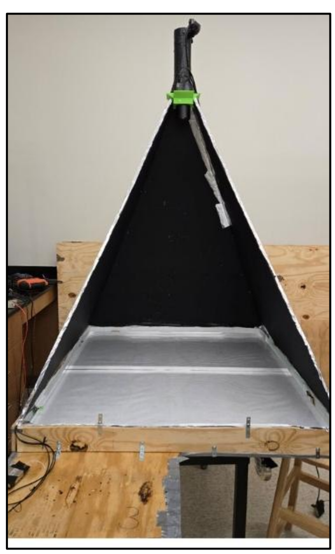

Fig. 3. Detector module 4 under construction. The 3D-printed PMT holder is at the top.

The new 3D printer and the house-built anti-vibrational table are shown in Figure 4. The model shown can also do the CNC and laser-cutting in addition to the 3D-printing with 2 filaments.

Fig. 4. 3D printer and laser cutter on a new table

3 Project Progress

The following lists the current progress of the project:

- Modules 1, 2 and 3 are completed and are under calibration.
- Last module #4 is being finalized and will go under calibration soon.
- The power supplies for the modules are complete and outfitted with controls (Figure 5).
- Modules need to undergo rigorous testing and calibration process after completion.
- Calibration automation software development has been completed [15, 16].

The information is recent for the time of the material presented at the cSTEM symposium on March 26, 2026.

Fig. 5. Power supplies for modules 3 and 4 (for both the PMT and the MPPC).

4 Calibration Automation Software

The calibration of the detector module starts with finding the biasing voltage for the two photosensors used – PMT and MPPC. The initial stage of this process involves measuring the noise rate vs the biasing voltage at each device.

The process involves counting the noise rate at multiple threshold values for each bias voltage amount. The counting is done by the oscilloscope, and the threshold settings need to be updated at each measurement. Bias voltage is updated at the power supply. Therefore, software that updates the threshold and saves the values in a convenient format (.csv) is an asset.

Figure 6 (left) shows the screenshot of the software main window. The functionality allows to initialize the oscilloscope, to set the threshold, to read the count value after a preselected time period, manipulate and plot the data, and save it as a .cvs file format. A possibility to save a .ROOT file directly from the plot also exists if needed. The calibration software uses the pyvisa interface to issue commands to the oscilloscope (VISA stands for Virtual Instrument Software Architecture).

ROOT is used for plotting the data as its being collected and for the possibility of saving into the .root file format [15, 17, 18]. The preference is given to the .cvs format for the data as the datafiles are small and the .cvs format is more flexible and easier to work with.

Figure 6 (right) shows plot of base-10 logarithm of noise rate from MPPC photosensor measured at different voltage threshold. The characteristic steps with plateaus indicate the pixel nature of this device (total of about 1200 pixels) – lowest threshold step only one pixel firing, second highest step at higher threshold is 2 pixels firing almost simultaneously, third step is three pixels and so on.

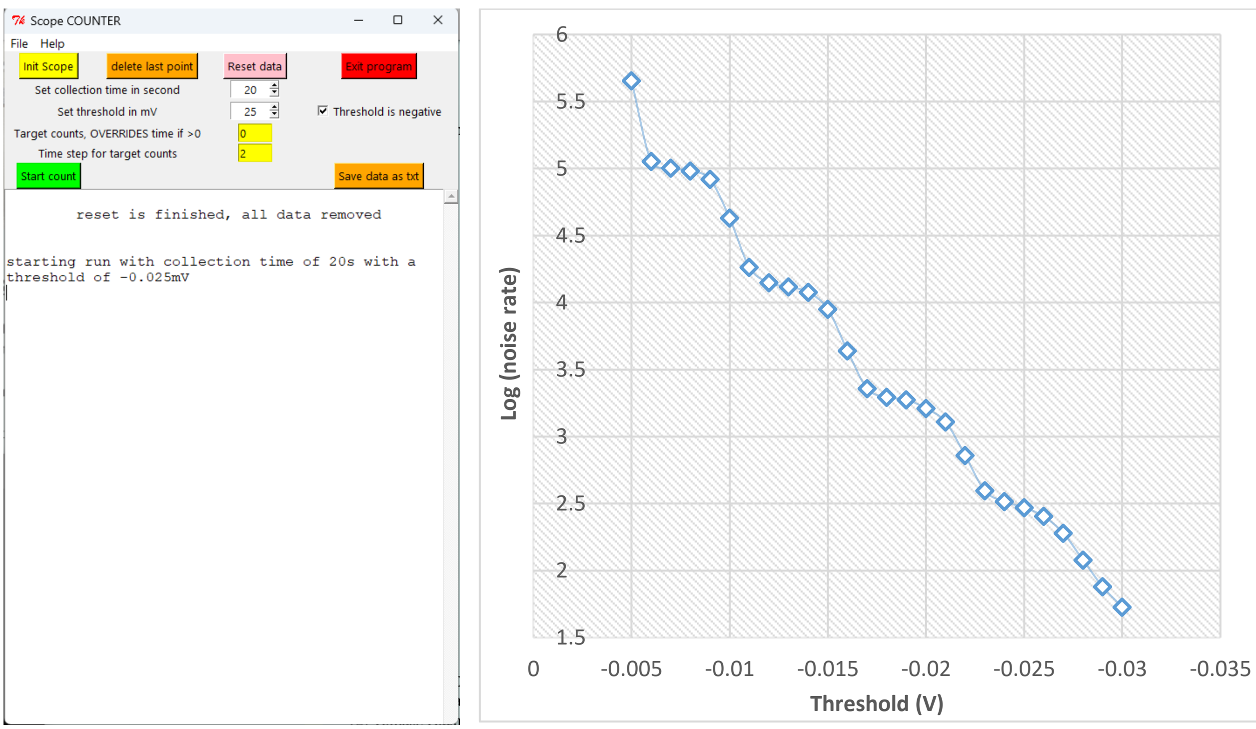

Fig. 6: Left -the main window of the calibration software. Right - the MPPC log of noise rate vs the threshold for 67.6V bias.

5 Conclusions and Future Plans

At the moment, three detector modules have been completed and are under testing and calibration process. The DAQ software and file format for the detector data have been implemented and are functioning. All electronic components have been acquired and soldered with controls and ready for the installation. Calibration automation software is near completed. The future plans are listed below.

The following immediate tasks are needed for the completion of the DUCK project:

- Finish the assembly of module 4
- Complete all calibration activities
- Prepare long signal cables for the physics separation test
- Implement and test LED calibration automation
- Start initial runs using 2 modules at the time (i.e. separation curve test)
- Prepare for the modules placement and physics run

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