PROCEEDINGS OF SCIENCE

Development and Design of New Detector of Unusual Cosmic-ray casKades

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A large mystery that is currently being investigated by the High Energy Physics (HEP) field is the origin and the nature of the Ultra-high energy Cosmic Rays (UHECR). Coming from deep within the Universe, they bring information from afar as well as on possible new physics. This talk reports on the development and design of DUCK (Detector system of Unusual Cosmic-ray casKades), a new cosmic-rays detector at the Clayton State University campus with ns-level detection resolution. The main scientific importance for the DUCK project will be to contribute to the general EAS event analysis methodology novel approach using the full waveform and detector response width, and to an independent verification of the detection of the 'unusual' cosmic ray events by the Horizon-T detector system that may be indicating direction towards the novel physics possibilities.

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1. Introduction

The goals of the presented project include the development, design and construction and deployment of DUCK (Detector system of Unusual Cosmic-ray casKades) core modules [1-3].

The project involves tasks in computer simulation activities, design and construction, data acquisition system design, data collection and analysis, thus allowing for the participation of students pursuing not only Physics but also other STEM fields, such as Chemistry, Engineering and Computer Science. Additionally, the project will extend the research capabilities and update the facilities at CSU to support the overall efforts to develop physics major based on existing minor degree, and to support the newly proposed engineering technology major.

DUCK system is aimed to study the Extensive Air Shower (EAS) disk thickness as compared to CORSIKA [4] simulations, to join the efforts in the search for the Cosmic Ray Ensembles [5] and to further study the latest advances in the cosmic rays by other detectors [6] in the field of unusual cosmic events [7, 8].

2.DUCK Module Design

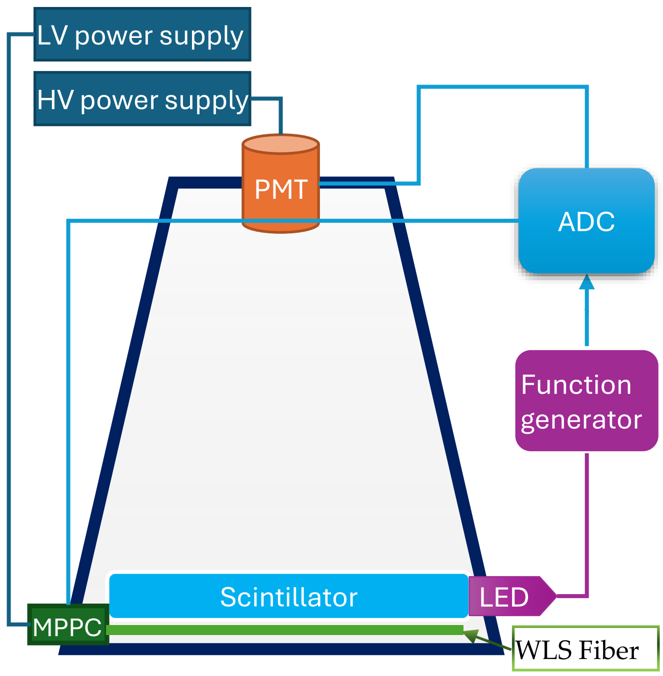

Figure 1. DUCK module schematics.

A total of 4 modules is planned initially, with the scintillator dimensions of $0.05 \times 1 \times 1\ m^3$. A schematic for the module is shown in Figure 1. The module heigh is such that the distance between the PMT (photo-multiplier tube) cathode and the scintillator is ~1m. The use of three or more modules allows to use the chronotron method that is the time difference in EAS arrival at each module, to determine the arrival direction of the EAS. Each module would be calibrated using the MIP (minimally ionizing particles) to provide the particle density.

Fast response of each module makes it possible to record waveform of the signal to look for the unusual events. For that, fast CAEN DT5730 FADC is used (Figure 2 left), with 14-bit resolution and 500 MHz digitization rate that gives a data point every 2ns. For the PMT - a

Hamamatsu H11284-30 (former R7723) model is chosen for the large photocathode (5 cm diameter) and fast pulse characteristics (shown in Figure 2 right). Additionally, the Hamamatsu MPPC photodiode with the WLS fiber will be used for MIP calibration of each module in the stand-alone regime. Module also includes the UV LED for PMT gain monitoring and single photoelectron calibration purposes.

Figure 2. (left) CAEN DT5730 FADC, (right) Hamamatsu H11284-30 PMT.

3. Prototype Module and Calibration Activities

The same H11284-30 PMT was used for the prototype module shown in Figure 3. It has been constructed according to Figure 1 schematic with the scintillator size being 50cm x 50cm x 5cm, and the distance between the PMT photocathode to the scintillator of about 80cm. The experience with the prototype has led to the adjustments to the schematic, Figure 1 is different from earlier versions, like in [2, 3] and the intermediate in [9]. The only difference currently from Figure 1 is that the WLS fiber resides on top of the scintillator as both options will be tested.

Figure 3. DUCK prototype module.

Initially, the bottom and the walls of the prototype were lined with Tyvek (see [9]), next the walls were painted black, next they were covered by black felt as in Figure 3. The response of all three options to MIP were tested. The MPPC and fiber part is still being tested and is not shown.

For the prototype calibration using MIPs, two scintillator counters were constructed using plastic scintillator and same PMT model, with the size of 25 cm x 35 cm [9]. All PMTs were tested to find the optimal bias using counts vs the threshold. This is detailed in [1, 9]. The work has been performed by the students under close supervision for the quality assurance.

For the MIP tests, the counters were placed above and under the prototype module with about 1.5 meters between them. First, tests were carried out with a 2.4 cm thick regular scintillator, after that, a 5 cm thick Eljen EJ200 was acquired. Initially, the EJ200 scintillator was kept in the original transparent wrapping to protect it from multiple configuration changes, in the last test the wrapping is removed so that we can see the effects of it on the MIP response. The following characteristics were studied: response amplitude and area (both are fitted with a Landau curve using ROOT, MPV± Sigma is shown in Table 1); pulse width at 50% and 80% of the area (both are fitted with a Gaussian, Mean ± Sigma is shown in Table 1). The pulse width is defined in the following way – a total area in the window around the pulse is integrated, the tine difference between the 10% of the area and the 50% is taken as the pulse half width and 10% to 80% as full width. The reasons for this choice include reduction of noise introduced by baseline that should integrate to 0, reduction of the pulse start uncertainty between small and large pulses, reduction of the RC effects of the long cables and pulse shape change in them. For the units used, note that 1 mV is 8.192 ADC bins as the total range is 0 – 2 V with 14-bit resolution.

Table 1: The MIP pulse characteristics for different scintillator and walls lining options.

Scintillator, walls	**Amplitude, ADC bins**	**Area, ADC bins * ns**	**Pulse half width, ns**	**Pulse full width, ns**
Generic 2.4cm, Tyvek lined	211.2 ± 35.1	4151 ± 570	11.13 ± 1.86	24.81 ± 3.45
Generic 2.4cm, painted black	47.1 ± 12.3	390 ± 142	4.62 ± 1.67	10.87 ± 4.17
Wrapped, painted black	156.4 ± 29.0	1748 ± 287	5.75 ± 1.36	14.04 ± 3.24
Wrapped, black felt lined	149.6 ± 30.2	1622 ± 288	5.14 ± 1.35	13.42 ± 3.23
Unwrapped, black felt lined	119.9 ± 25.8	1270 ± 232	5.13 ± 1.74	14.08 ± 4.39

From Table 1 data, first we notice that the white lining significantly increases the MIP pulse width as detected by the PMT [10], this is due to the multiple reflections within the detector volume. This increase reduces the ability to resolve the two closely located pulses. Painting walls with black matte paint reduces the pulse width more than twice, but a lot of light is now absorbed. This is remedied by using a thicker scintillator for reliable MIP detection. As the dynamic range is another parameter to consider, the achieved values are acceptable. The slight increase in the pulse width is attributed to the difference scintillator used that has a slower light yield time.

4.Conclusion and Future Plans

The lab capabilities for the research have been established and students are involved in all the steps of the process, such as design, construction, testing and calibration, and software creation. The prototype module has been constructed and in the process some corrections were added to the initial design. Currently, the use of the MPPC for the MIP calibration without external scintillator counters is under testing. The completion of the testing of the prototype will overlap with main module construction start.

Software has been completed for the ADC control. Data analysis will follow. Simulation activities are starting. Data is placed in the repository at https://sos.clayton.edu/DUCK/

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