Construction and calibration of the DUCK (Detector of Unusual casKades) system modules

Dmitriy Beznosko [a,*], **Valeriy Aseykin** [b], **Alexander Dyshkant** [c], **Alexander Iakovlev** [d], **Oleg Krivosheev** [e], **Tatiana Krivosheev** [a], **Vladimir Shiltsev** [c], **Xuong Minh Tran** [a] **and Valeriy Zhukov** [b]

a School of Sciences, Clayton State University,
  2000 Clayton State Blvd., Morrow GA 30260 USA

b P. N. Lebedev Physical Institute,
  Mitin street 3a, Almaty, 050020 Kazakhstan

c Department of Physics, Northern Illinois University,
  1425 W Lincoln Hwy., DeKalb, IL 60115 USA

d Upper School Science Department, Woodward Academy,
  1662 Rugby Avenue, College Park, GA 30337 USA

e Xcision Medical Systems,
  9176 Red Branch Rd STE O, Columbia, MD 21045 USA

  E-mail: dmitriybeznosko@clayton.edu

In the High-Energy Physics field there is an active search of the origin and the nature of the Ultra-high energy cosmic rays. These are messengers that carry information from far into the Universe, and they might also hint on direction towards new physics. This talk presents the overall hardware and software design, and the construction and calibration of DUCK (Detector system of Unusual Cosmic-ray casKades) main modules. DUCK is a new cosmic-rays detector that is being constructed at the Clayton State University campus that has resolution at the ns-level. The main scientific direction for the DUCK project is to contribute to the approach of cosmic ray event analysis using the full waveform and detector response width. Additionally, it aims to provide an independent verification of the detection of the 'unusual' cosmic ray events that were reported by the Horizon-T detector system that may be indicating direction towards the novel physics possibilities.

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[*]Speaker

1. Introduction

A field of physics that still has many unknowns to discover is High Energy Physics (HEP). Among the questions with unknown answers is the origin and composition of the Ultra-high Energy Cosmic Rays (UHECRs). These cosmic rays originate far from the Solar System, possibly even outside of the Milky Way galaxy. They carry information that could help us understand the universe better and provide insight into the fundamental physics principles.

The DUCK detector system [1] will be installed at the ClSU (Clayton State University) campus. It will consist of four scintillator-based particle detectors that will be separated by ~100 m distance to detect the EAS (Extensive Atmospheric Shower) at the ground level. Each detector will consist of the 100 cm x 100 cm x 5 cm plastic scintillator, one 5-cm photocathode diameter PMT (Photo Multiplier Tube) for main readout, an additional photosensor readout for calibration purposes using cosmic muons, and an LED for the gain monitoring. The entire system will be read out by the DT5730 FADC that will also handle the hardware triggering. Additional offline triggers can be applied later. Detailed detector design and view are provided in [2, 3].

The design goal of the DUCK system is to detect and verify the existence of unusual cosmic events [4, 5]. It can eventually further innovate EAS analysis methods by introducing the EAS disk width as one of the parameters. This publication aims to highlight certain topics in development and construction of the detector system at ClSU.

2.Project Status

Out of the four modules envisioned for the DUCK system, modules #1 and #2 have been completed. While module #1 fully corresponds to the previously published specs [2 ,3], module #2 and all consecutive ones will have one minor change in the power supply model.
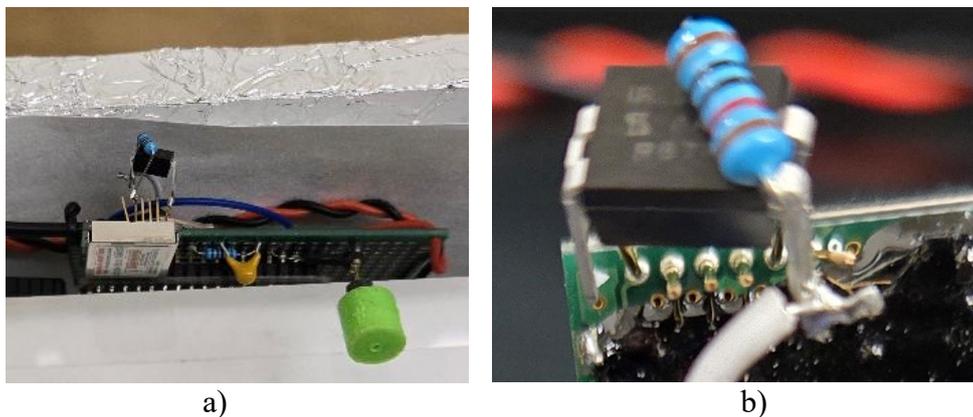
2.1 A Power Supply Saga

Figure 1. a) MPPC board with the power supply. b) The 'reset' circuit.

The original design of the MPPC board calls for the use of the Hamamatsu [6] power supply C11204-01 as shown in Figure 1a. It is powered by 5V, with an output from 40V to 90V. However, during the calibration of the first module and the construction of the second, numerous issues were found when using this power supply:
- COM-port communication only with outdated parity check

- Unnecessarily complicated command structure and parity calculations
- On power loss – loses last setting, starts with default of 40V - added Arduino controller to initialize and monitor the power supply
- With the load present, needs to be 'reset' at start-up: by accident, we discovered to short NC (not connected) pin to ground as shown in Figure 1b, not in the manual anywhere!
- No overload/short protection!

After losing 3 units (one due to accidental short-circuit, two due to reasons unknown – power supply initializes, and outputs 13V even without any load present), it was decided to use robust C9619-01 power supply instead. This supply is rated 400V-2000V, but with the right voltage adjustment voltage from the precision potentiometer, it can provide a stable -70V output. This is advantageous because the MPPC and the PMT outputs are both negative to simplify the data analysis and the ADC (analog to digital converter) settings. The updated MPPC board view is shown in Figure 2. The calibration LED is also visible in the figure. Additionally shown are the WLS fiber and its ferrule on the MPPC sensor.

Figure 2. A new MPPC board. Also shown are the calibration UV LED, ferrule and the WLS fiber.

2.2 Current Status

With the two out of 4 modules completed, the calibration activities are taking place and the start of the construction of the remaining modules. The DAQ software is being prepared and updated to the latest C++ VS compiler. The latest update [7] was for the 2017 VS compiler. The shift to the newer one is going to take some time as the application will need to be migrated to the 64bit platform, and to ROOT v6, which requires significant source code change and a use of new rootcint that has been changed in version 6 for the ROOT into rootcling. Some software and hardware tasks pose an opportunity to be used as student projects in the instructional labs that were recently modified and updated [8].

3. Conclusion

The current plans are to finish construction of Module 3 and 4 with the updated MPPC module and conduct calibration using MIP and LED signals by the end of summer of 2026. The plans also include the start of the separation curve study with two currently available modules given the students' availability.

The software future plans are to complete the ADC-DAQ control with the scripting and remote operations possibilities. The timeline for this project is not set currently.

Acknowledgements

4. References

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