# DUCK Detector System Design

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This article describes the details of development, design, and planned construction/deployment of the DUCK (Detector system of Unusual Cosmic ray casKades). This is a scalable cosmic-rays detector system designed to measure a variety of cosmic event properties. The primary scientific goal for the DUCK project will be an independent verification of the detection of the 'unusual' cosmic ray events by the Horizon-T detector system. A detailed study of events of this type upon verification is a vital step towards understanding the nature of cosmic rays, their origins, and details of interaction with the nuclei in the atmosphere. Further operations as part of other international collaborations will contribute to the continued monitoring of the other types of cosmic events.

*38th International Cosmic Ray Conference (ICRC2023)*
*26 July - 3 August, 2023*
*Nagoya, Japan*

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## 1. Introduction

The immediate physics goal and the motivation for the DUCK (Detector system of Unusual Cosmic ray casKades) [1] is the independent detection, confirmation, and further study of the novel Extended Air Shower (EAS) events, reported by Horizon-T [2] detector system. This detector system is located at TSHASS (Tian-Shan High Altitude Science Station) research facility at the elevation of about 3340 m above sea level and is equipped with the high-speed detectors and electronics. The novel events detected are typically called multi-modal or unusual [3, 4] as they had more than one maximum in one or more detectors. The latest data on these events suggests that such events may be more complicated in nature, as some correlations were noted in the events.

### 1.1 Standard EAS event sample

If shower axis passed near any detection point, there is one high peak and several smaller ones as shown in Figure 1. These signals can be reproduced by superimposing CORSICA [5] simulation output on detection points locations.

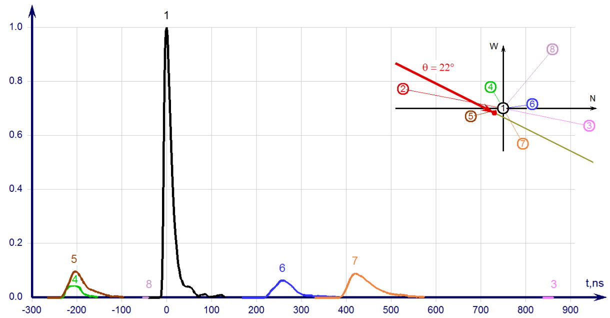


*Figure 1: Standard EAS event. Amplitudes are normalized to detector 1. Red arrow shows the EAS axis.*

### 1.2 Unusual EAS event sample

As illustrated in Figure 2 and Figure 3 that show different detectors outputs of the same event, the outputs feature multiple peaks either fully separated or forming a comb-like structure. The separation of peaks tends to increase with the distance from EAS assumed axis position that is indicated in the figures by the red arrow. The axis position here is assumed due to the absence of the standard analysis methods for such events.

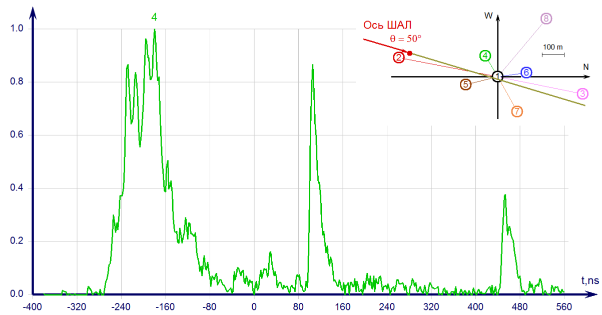


*Figure 2: Unusual EAS event. Amplitudes are normalized. Only detector 4 output is shown.*

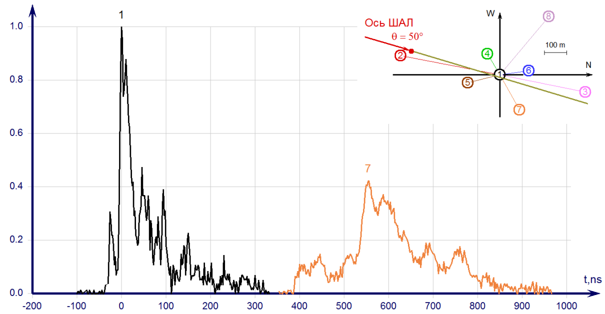


*Figure 3: Unusual EAS event. Amplitudes are normalized. Outputs of detectors 1 and 7 are shown.*

## 2. DUCK design considerations

The following detector system features were considered:

- The overall design should be close to Horizon-T to assure the same detection ability.
  - Waveform recording with ns time resolution must be present.
- Improvements on the original design include:
  - PMT gain monitoring with LED.
  - MIP calibration monitoring (using secondary photodetector).
- Feature scalable design:
  - Can start data collection with fewer modules.
  - Expand per scientific needs and funding availability.
- Ability to pursue other scientific goals:
  - Contribution to CORSIKA EAS disk width studies.
  - Other possibilities?

### 2.1 Current design

The initial detector system is designed with the four detector modules only. This simplifies the requirements for the data acquisition system (DAQ) and removes the need for the timing synchronization between the modules. The initial deployment position of four detector modules will be in a square shape, with modules about 25 - 50 m from each other.

Figure 4 shows the design of the single detector module. The design features the pyramid shape of the protective case with 1 x 1 m inner dimensions of a square base. Plastic scintillator is going to be used with high probability following the liquid scintillator study [6, 7]. The UV LED will be used for the PMT voltage working point calibration and for gain monitoring. LED is embedded in the scintillator and is directly exciting the wave-length shifters in the plastic. The function generator powers the LED by short pulses and provides the trigger to the ADC.

The R7723 OMT assembly will be used as the main detector, with the 1 $mm^2$ MPPC detector as a secondary one. The use of the two detectors allows detector modules to be self-calibrated using double-coincidence and cosmic muons.

The ADC and the function generator will be positioned centrally. The initial deployment position of four detector units will be in a square shape, with units about 25 - 50 m from each other. The DAQ system for the proposed detector system will be largely the same as for the Horizon-T, based on the recently updated ADC CAEN DT5730S Flash ADC. This stand-alone module has 8 channels – 4 channels will be used for the PMTs and 4 for the secondary detectors for MIP calibration. The waveform recorded by each ADC channel consists of at least 5110 data points digitized every 2 ns each, for the total of 10.22 ms. Larger time ranges are possible with up to 2 million data points per event. The internal device memory is used as the event buffer that can hold up to 1024 events when the event length is set to the minimum. The full digitization range of $2^{14}$ bins corresponds to 2 V scale. The compressed binary file size for one event is ~30 Kbyte. ADC is read via USB2 connection by a PC.

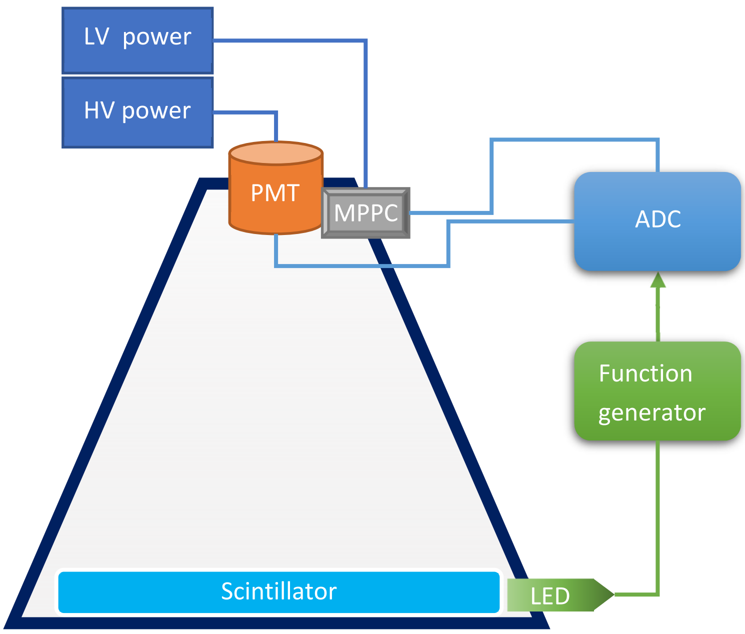


*Figure 4: A detector module design for the DUCK detector system.*

## 3. Conclusion

The design of the DUCK detector system is currently in the development stage and can be updated. Some details are still under investigation, such as the thickness of the scintillator to be used – for this task two smaller prototypes are being constructed. The DUCK system design has a built-in flexibility for easy upgrades and extensions, opening the opportunities for future research topics. One of the possible upgrades is the addition of four to eight detectors at the longer distance from detector center, say ~100 m – 200 m, thus forming two zones: the near and the far.

## Acknowledgements

This work was supported by Clayton State University College of Arts & Sciences UCARE grant, FY 2022-23.

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