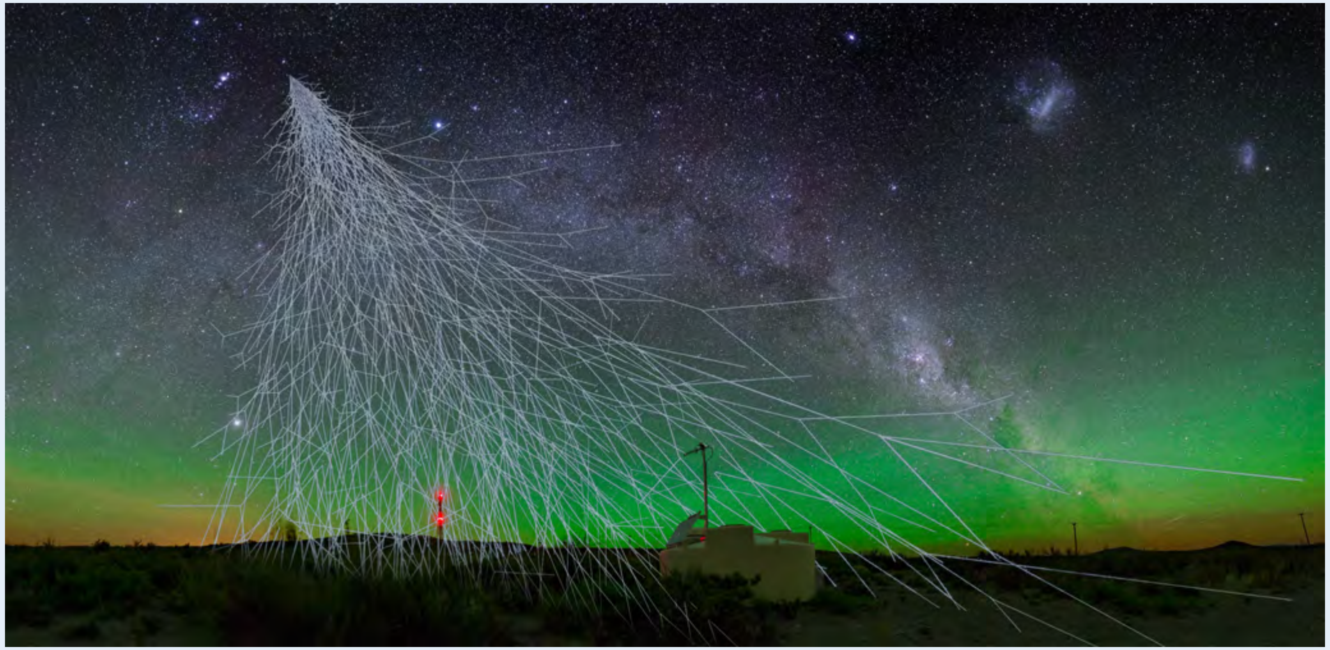
Progress of
Development and Design of DUCK
(Detector of Unusual Cosmic-ray casKades)

APS March 2024 meeting

By: Gerald Harris*, Dmitriy Beznosko, Shriya Chakraborti, Nicholas Muong

CLAYTON STATE UNIVERSITY

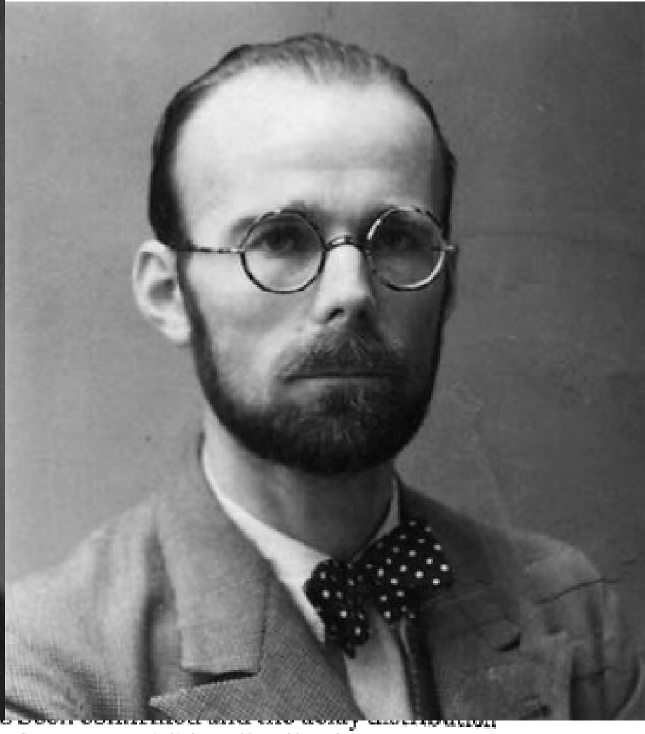


The start of Cosmic Ray Research

- Victor Hess first discovered cosmic rays through a series of balloon experiments from 1911 to 1912. These experiments marked a significant milestone in our understanding of cosmic phenomena.

Extensive Air Showers and Delayed Particles

- From 1927 to 1929 Dmitri Vladimirovich Skobeltsyn discovered cosmic rays are high energy particles[1].
- Shortly after Pierre Auger concluded that these particles generated a cascading shower of particles.



obtained over the range $(3\text{–}70) \times 10^{-8}$ second. This distribution could be represented by an exponential function with half of the delayed particles arriving within $(10 \pm 2) \times 10^{-8}$ second. The total fraction of shower particles that suffer delays in the above range was found to be $(0{\cdot}85 \pm 0{\cdot}05)\%$.

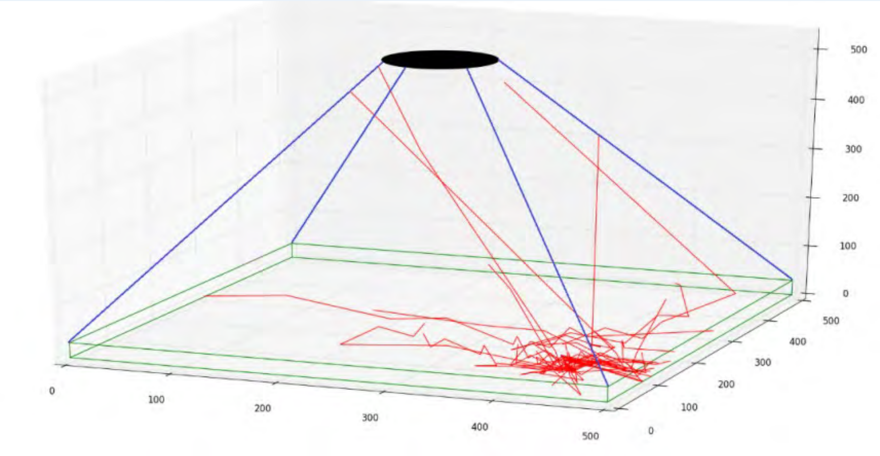
There is evidence that showers with delayed events do not differ in average density from those without such events.

A control experiment was carried out to investigate any spurious effects; this revealed μ–e decay events in the scintillator at approximately the expected rate.

§ 1. Introduction

It has been known for some time (Broadbent and Jánossy 1948, Cocconi *et al.* 1949, McCusker 1950, Mitra and Rosser 1949) that between 1 and 2% of the particles in extensive air showers are penetrating, and further, that of this about three-quarters can be attributed to a non-interacting component (presumed to be μ-mesons) and the remaining quarter to an interacting component (McCusker 1950). We shall henceforward denote the electronic, total penetrating, nucleonic and mesonic components by the symbols e, p, N and μ respectively.

As soon as the presence of the p-component in the showers was demonstrated, it was realized by several workers that the particles composing it might be delayed with respect to the e-component. For if each type of particle has approximately the same average energy, the velocity of the lightest particles will approximate most closely to that of light. If, moreover, a distance of several kilometres, from the higher atmosphere to sea level, is traversed, the difference in time of arrival



Previous Work Done

- Horizon T
  - Similar system to DUCK with eight detection points
  - High altitude
  - Makes use of Hamamatsu R7723 PMT with a secondary trigger detector[2]

- CREDO
  - Global Collaboration
  - Our system is scalable for potential large-scale deployment.

Motivation for continued research in this area

- Discovery of what *causes* this delayed particle effect.
- Discovery of what *are* these particles.

- DUCK system aims to act as a verification of work from the Horizon T detector system
- Contribute to the CREDO collaboration
- Design with nanosecond time resolution for cosmic events
- Study of temporal structure of Extensive Air Showers

Simulation to Support Design

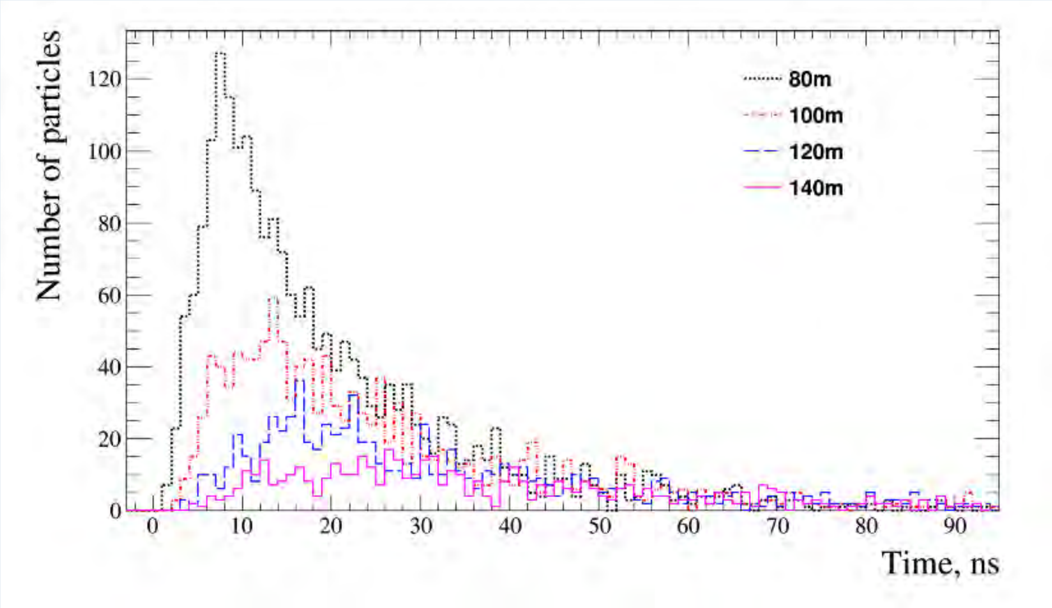


Figure 1. Number of particles arriving at the observation level per 2 ns bins for the virtual detectors placed at various distances from the shower center. Parent particle is 10^{17} eV proton, vertical.[3].

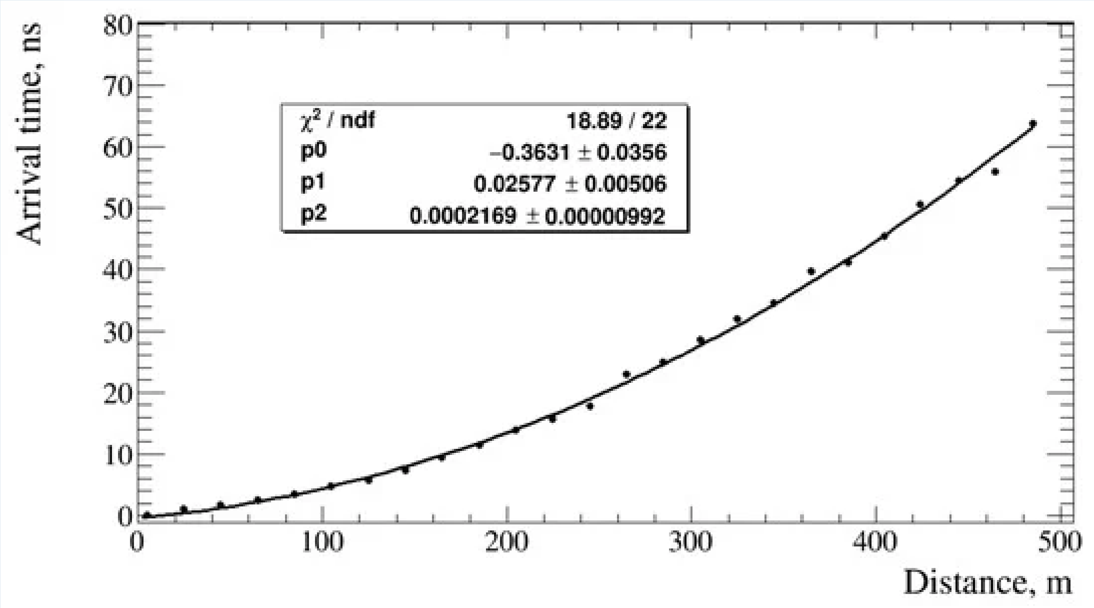
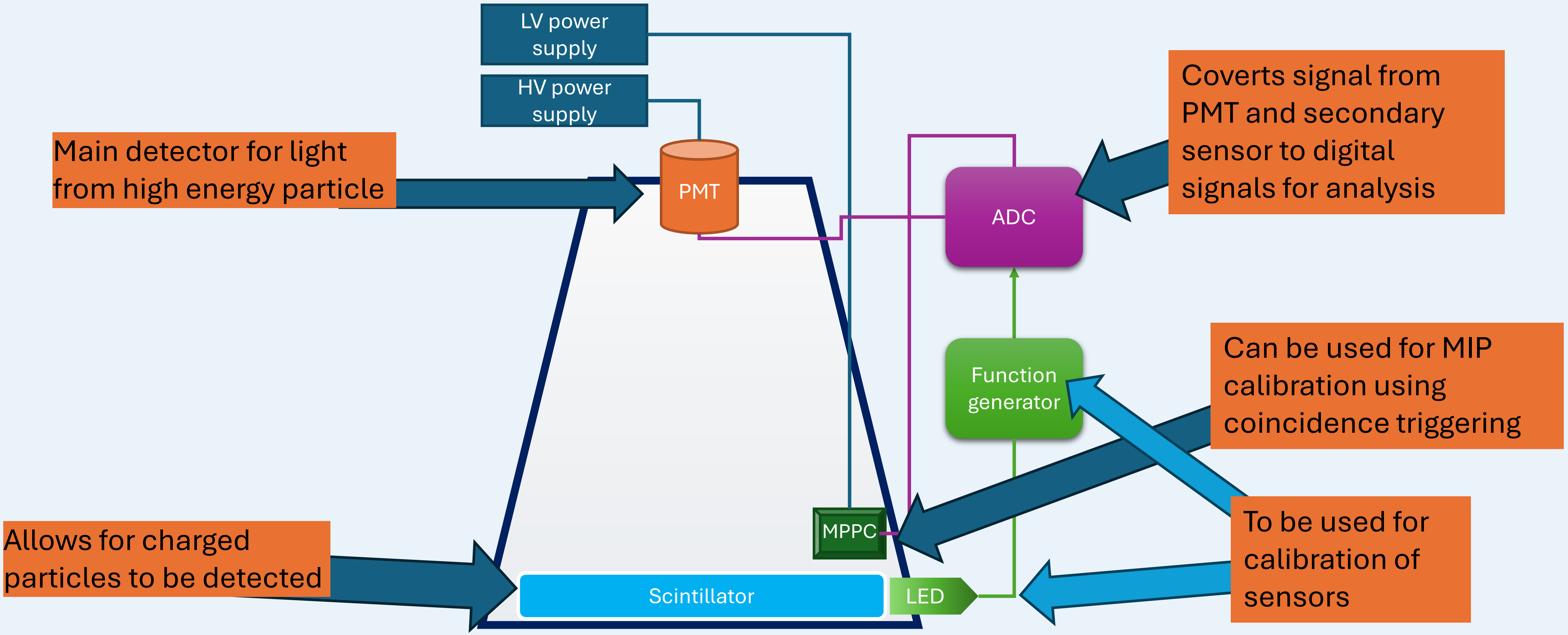
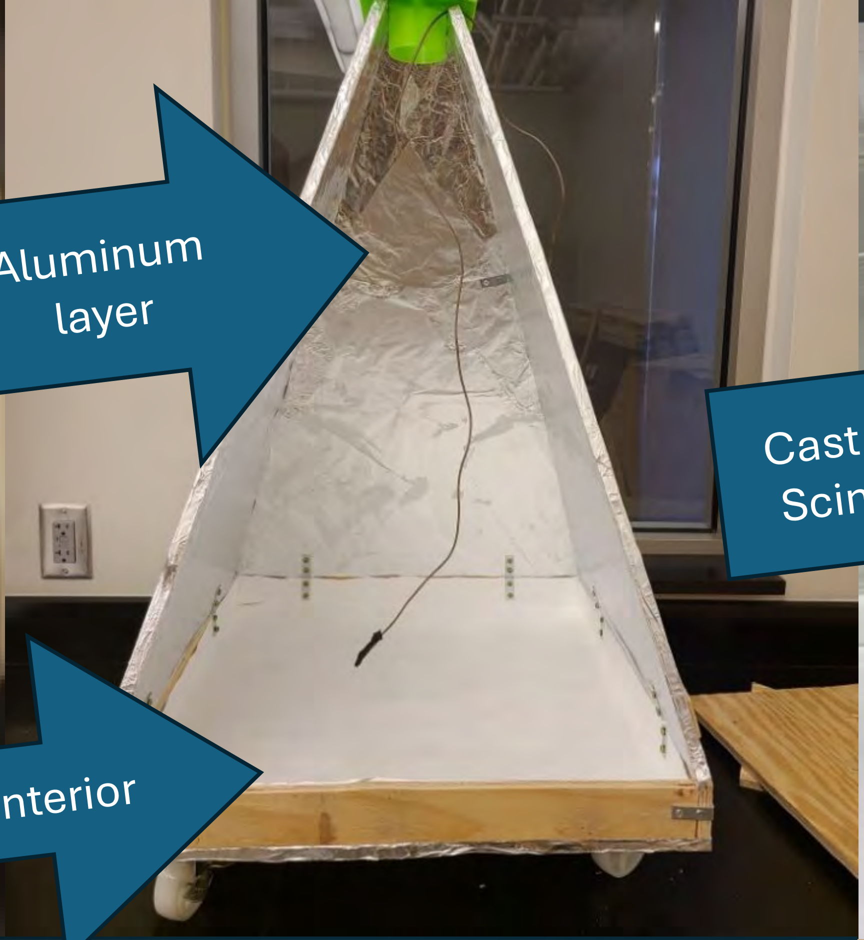


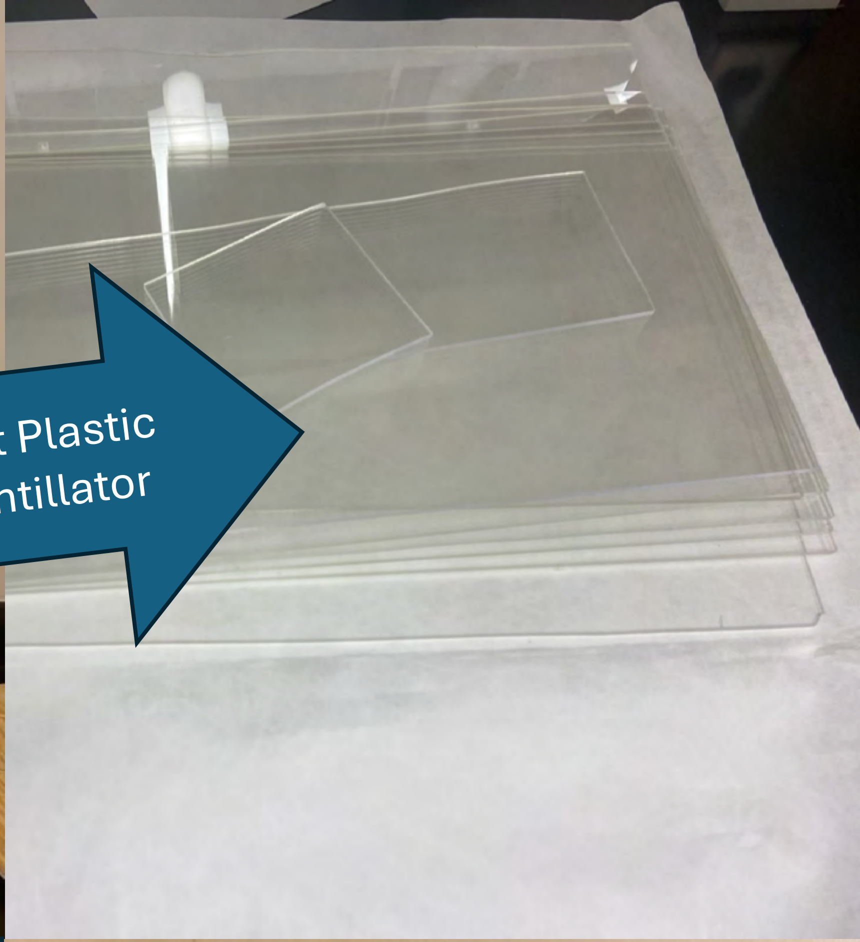
Figure 2. The dependence of the shower disk arrival time on the distance from the center for the same shower as in Figure 3. The fit function used is p0 + p1x + p2x2[3].

CORSKIA* Simulation used to produce model

Initial Layout





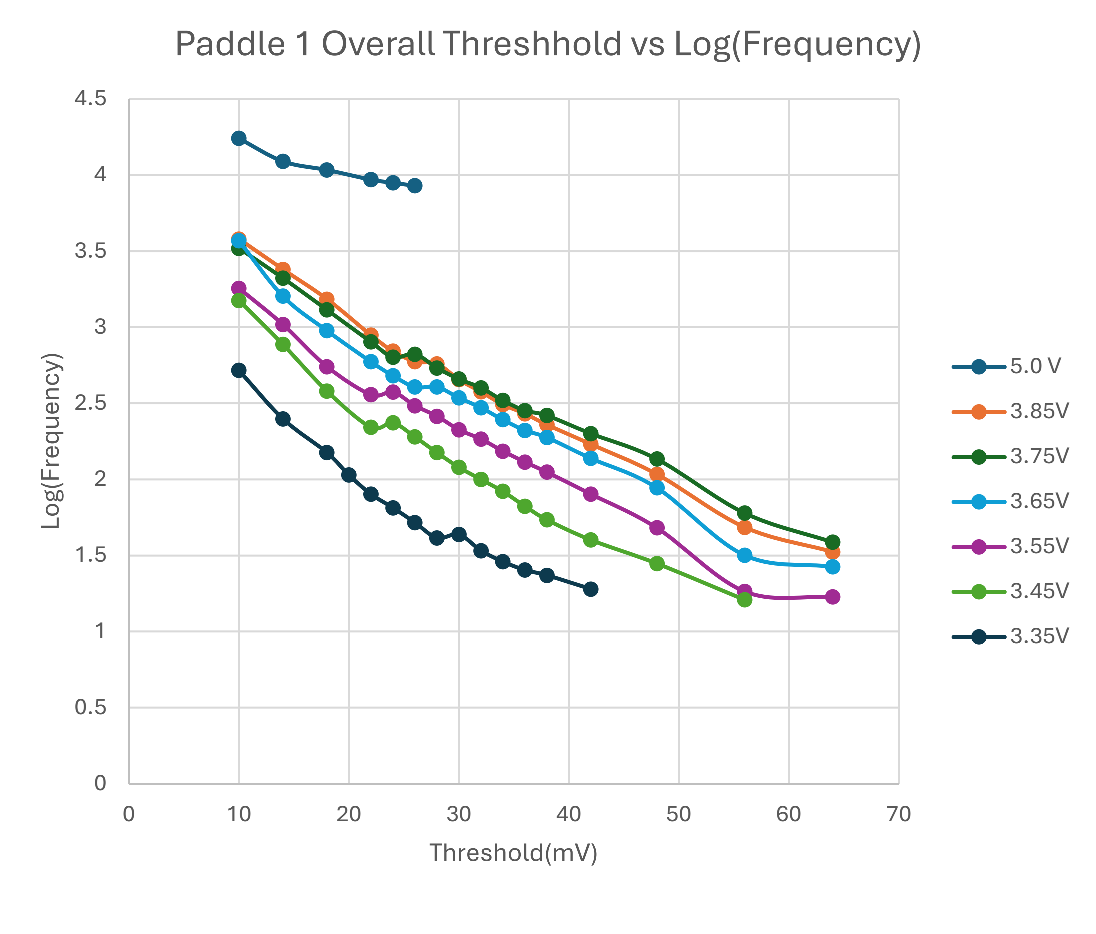


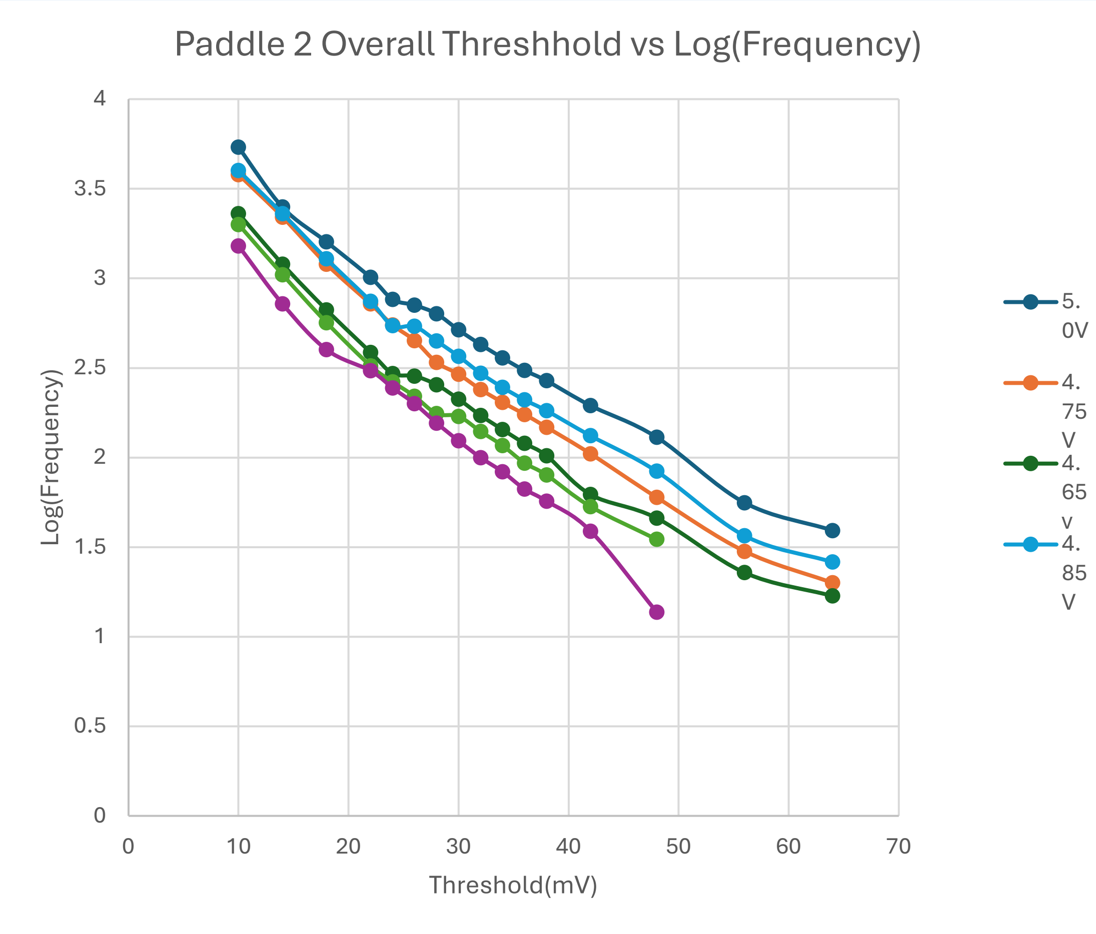
Equipment and Material Used

Characterization of Photomultiplier tubes and “Paddles”

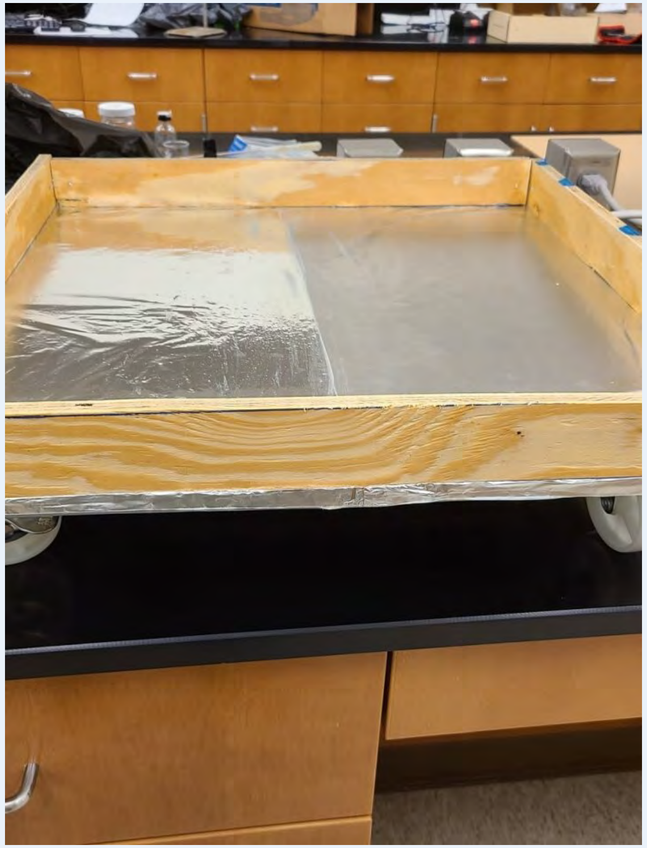
- Done to find the optimal voltages and thresholds for detecting cosmic events.
- Measured the log of frequencies and plotted them against the threshold and identified “plateaus” where the noise is reasonable, and detection is at its highest.

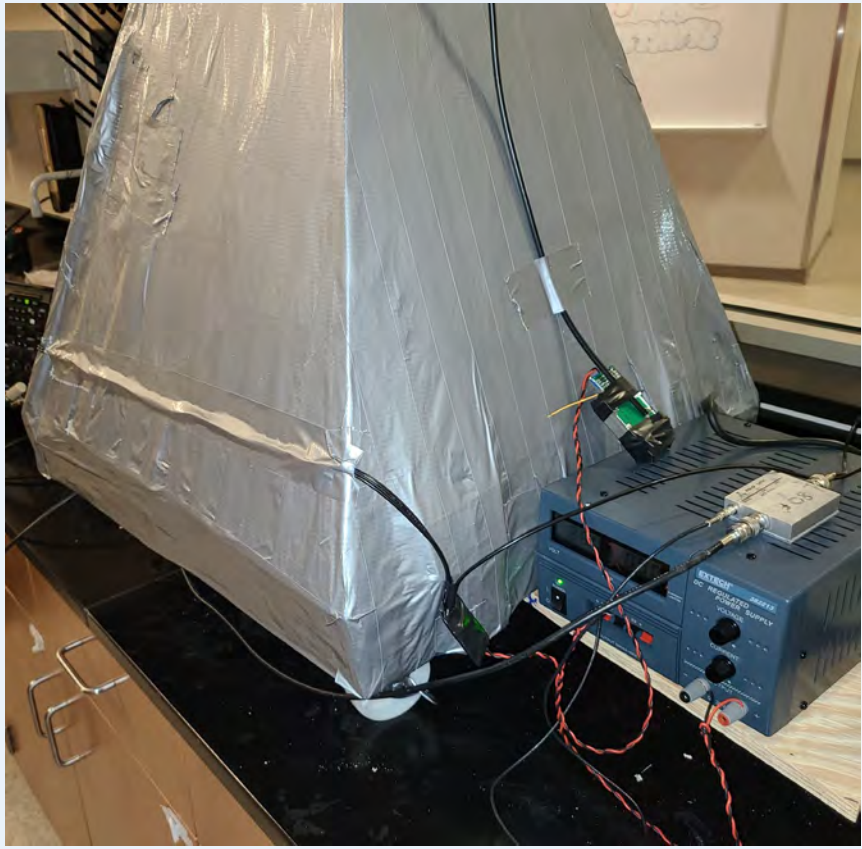
Characterization of the Photomultiplier Tubes





Construction of Prototype Detector

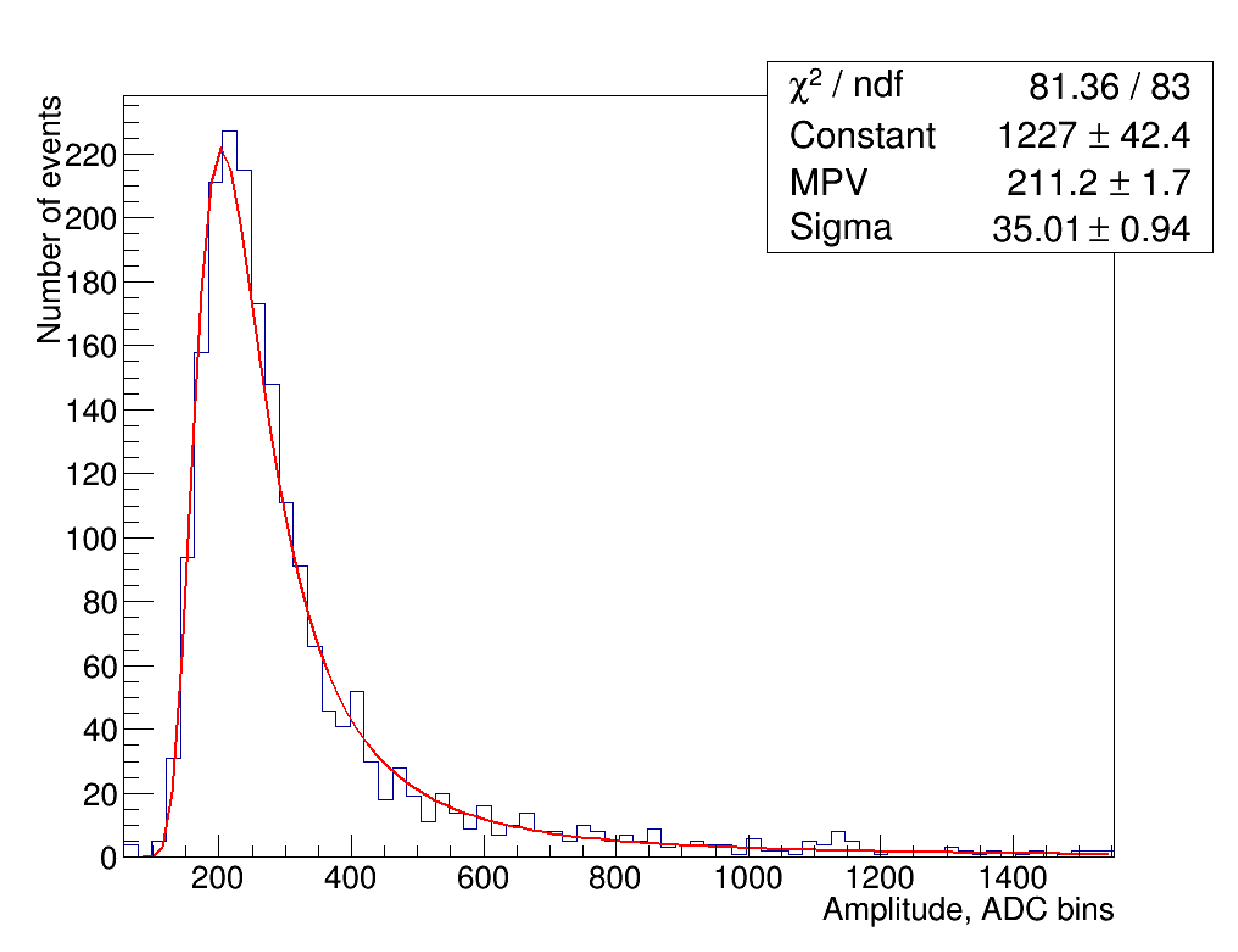




Current Setup

Data Collection

- Data was collected and converted through the analog-to-digital converter (ADC) into ROOT for data analysis.
- Example fit using Landau function in ROOT is shown



Drawbacks/ Challenges

Silicon Sensor displays limited range, needs WLS fiber as a possible fix

Noise from detector needs to be mitigated

Future Considerations for Prototype

- Construction of 3D printed sensor stand for a PMT to improve mechanical strength.
- Reducing reflection of light within the detector housing to potentially mitigant noise.
- Inclusion of fiber optic attachment to MPPC sensor.

Future Goals

- Four large detectors to form the DUCK System
  - Allows for scalability and mass deployment
- Replicable with little cost for mass use in CREDO Collaboration
- Confirm Results from Horizon - T

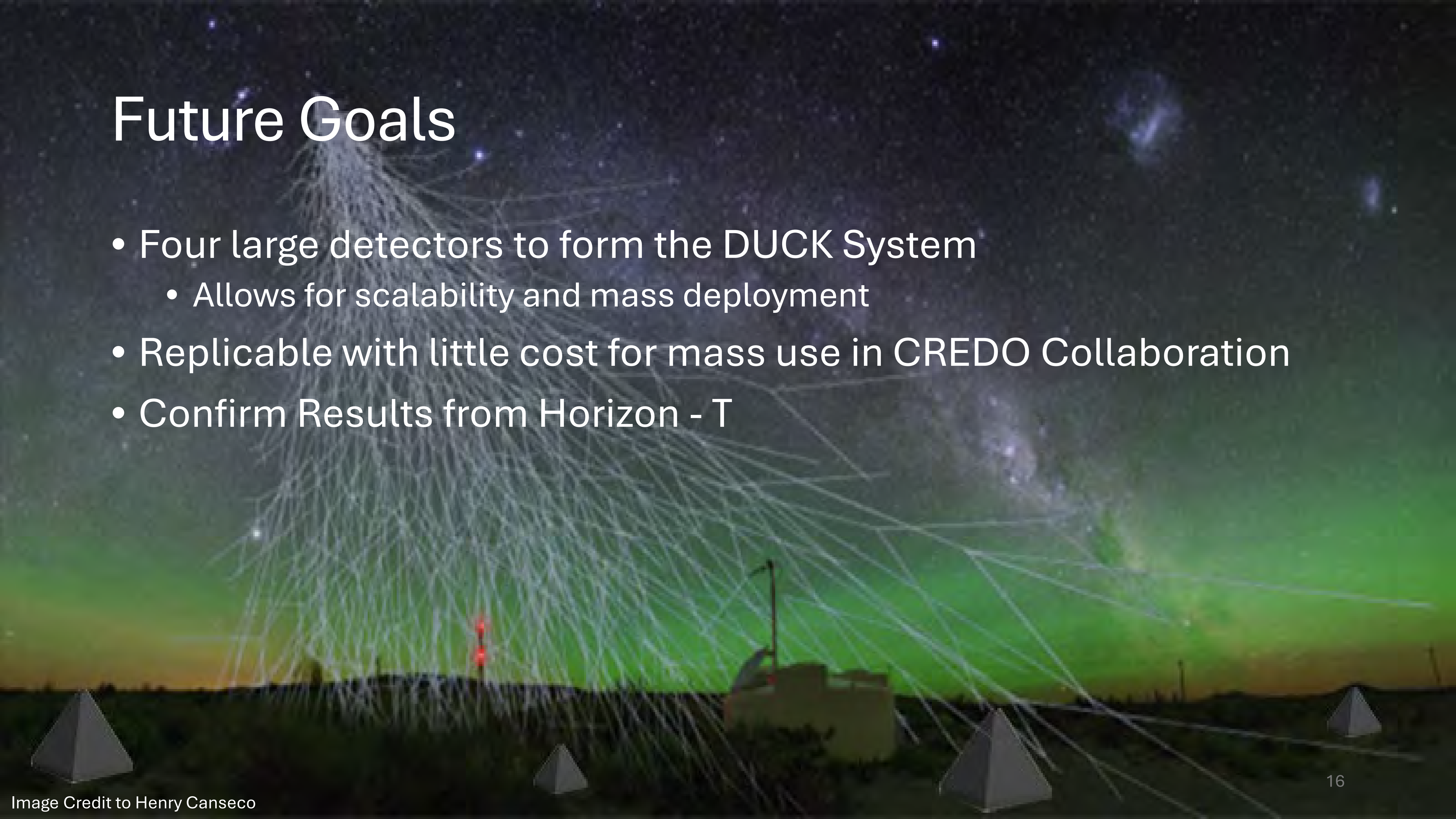


Image Credit to Henry Canseco

Bibliography

[1] G. A. Bazilevskaya, “Skobeltsyn and the early years of cosmic particle physics in the Soviet Union,” Astroparticle Physics, vol. 53, pp. 61–66, Jan. 2014, doi: https://doi.org/10.1016/j.astropartphys.2013.05.007.

[2] J.V. Jelly and W.J. Whitehouse, The Time Distribution of Delayed Particles in Extensive Air Showers using a Liquid Scintillation. Counter of Large Area, Proc. Physical Society A, 66, 5, pp. 454-466, 1953

[3] R. U. Beisembaev et al., “The Horizon-T cosmic ray experiment,” Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 1037, p. 166901, Aug. 2022, doi: https://doi.org/10.1016/j.nima.2022.166901.

[4] D. Beznosko *et al.*, “Design Considerations of the DUCK Detector System,” *Quantum Beam Science*, vol. 7, no. 1, p. 6, Mar. 2023, doi: https://doi.org/10.3390/qubs7010006.

[5] D Beznosko et al., “Horizon-T experiment and detection of Extensive air showers with unusual structure,” Journal of Physics: Conference Series, vol. 1342, no. 1, pp. 012007–012007, Jan. 2020, doi: https://doi.org/10.1088/1742-6596/1342/1/012007.

Acknowledgement:

This work was funded by NSF LEAPS-MPS Grant Award 2316097