The Gas Ring Cherenkov Detector (GRINCH) for Jefferson Lab, Hall A

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CHARTERED 1693

Jefferson Lab

JSA

Gas **RIN**g **CH**erenkov (GRINCH) Detector

The purpose of the GRINCH is to discriminate between pions and electrons in electron scattering experiments in Super BigBite (SBS) program at Jefferson Lab, Hall A.

Installed in Hall A at Jefferson Lab as part of the BigBite electron arm for the Super BigBite Spectrometer summer 2021.

Currently running in the GEn experiment that began in September 2022.

Today we will talk about:

- GRINCH Overview
- Preliminary performance results
  - Cluster Finding Methods
  - Electron efficiency
  - Timing Calibrations
- Next steps and future work

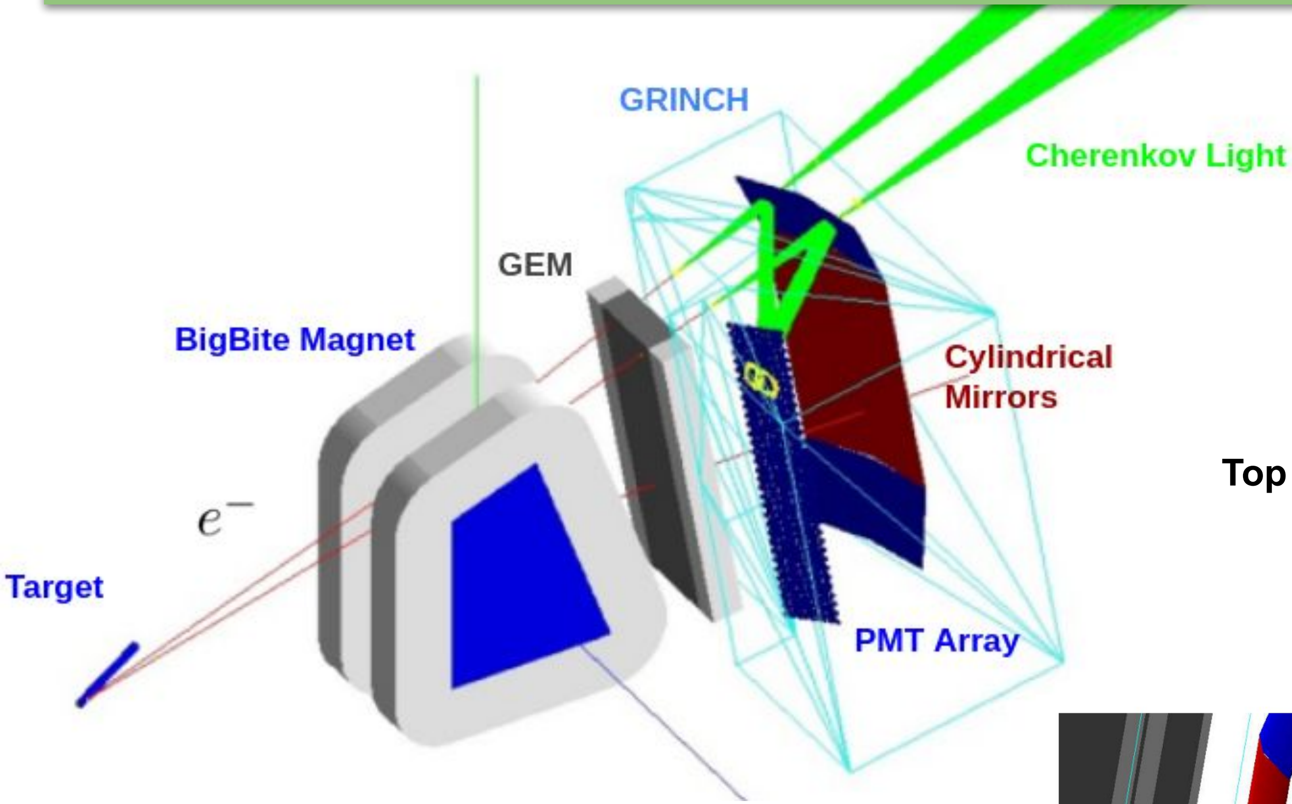
GRINCH

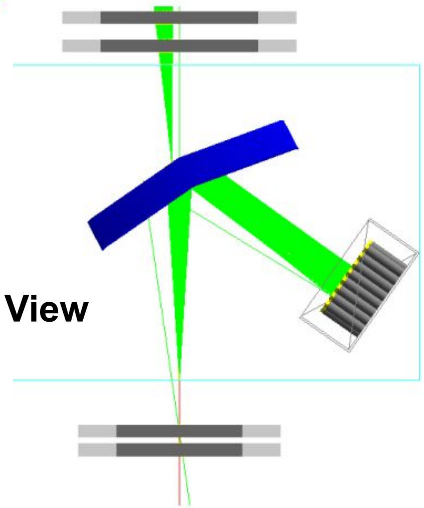
Gas **RIN**g **CH**erenkov detector

- 510 1-inch photomultiplier tubes (PMTs) in a honeycomb array.
- 4 highly reflective cylindrical mirrors.
- Filled with heavy gas C_4F_8
- Pion Threshold of 2.7 GeV.
- Small PMTs and specialized read-out hardware allow data to be collected in a high-background environment.

Todd Averett and the GRINCH in the TEDF high bay, Jefferson Lab.

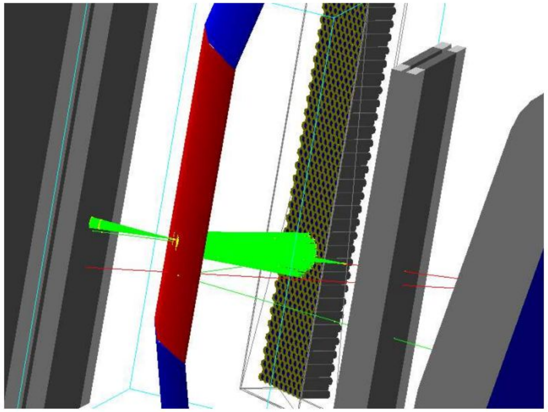
GRINCH Design





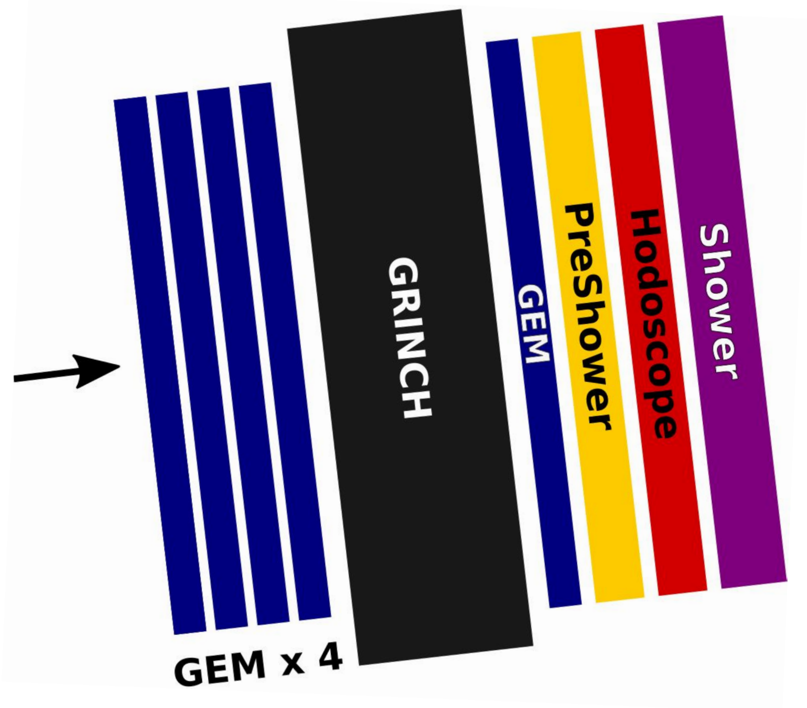
Top View

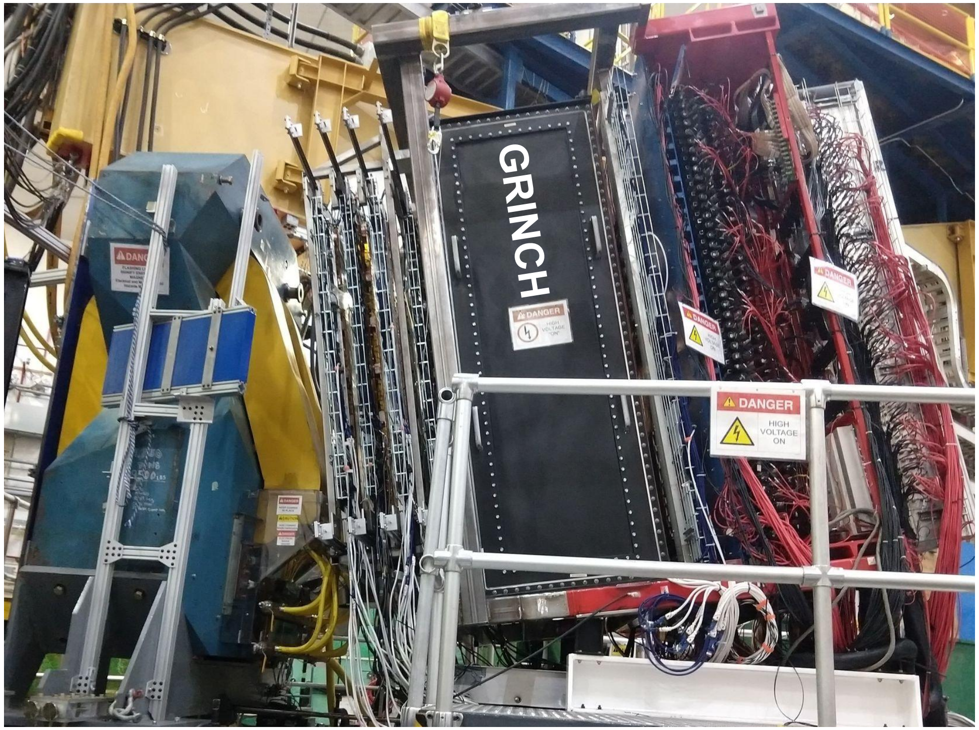
Side View



[1] GEANT4 Simulations

GRINCH in BigBite





BigBite Magnet BigBite Spectrometer

GRINCH PMT Behavior Analysis

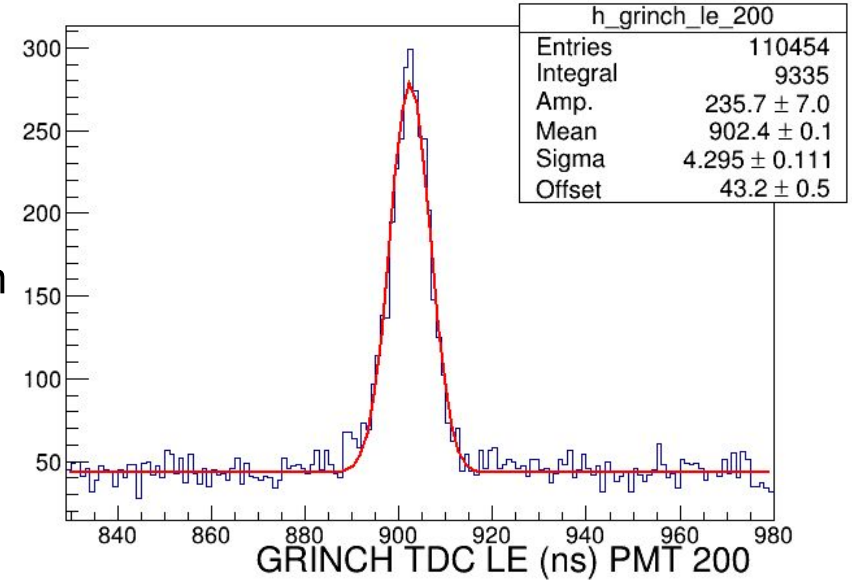
Leading Edge (LE): When the signal crosses the threshold of the time-to-digital converter (TDC).

- Fit each PMT to a gaussian with an offset.

Timing Resolution < 4.5 ns for each PMT. (sigma on gaussian fit)

Background rate 250-450 kHz, depending on the PMT and kinematic setting. Calculated from the offset.

0.25% - 0.45% occupancy on a 10 ns window. (chance that noise will occur during a given time window)



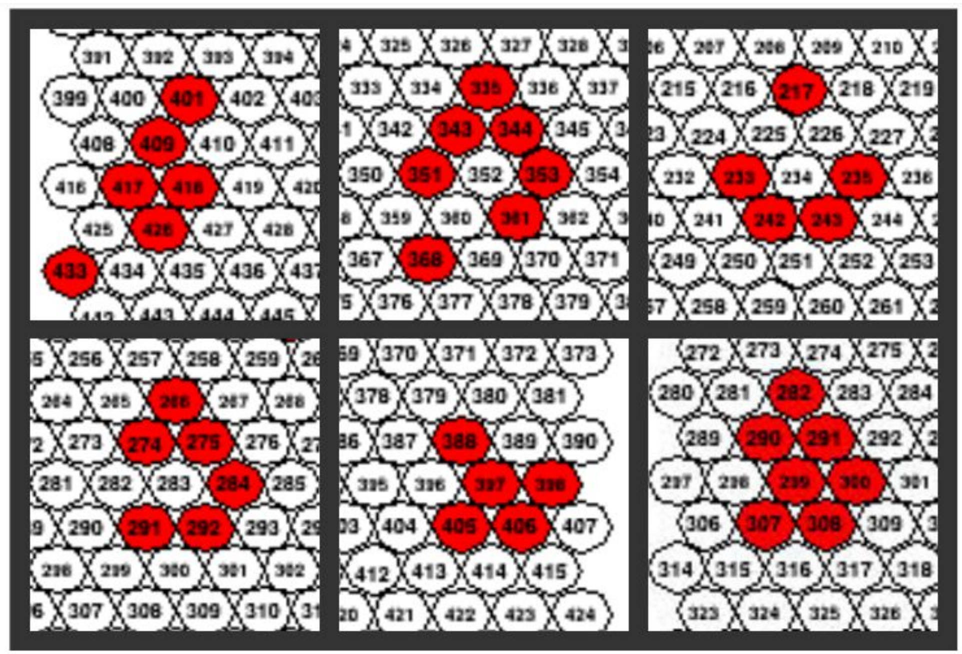
LE spectrum histogram for one PMT.
GMn run 13719.

Cluster Analysis

The Cherenkov light cones from electrons appear as clusters on the PMT array due to the path length of the light cone in the GRINCH.

Algorithm requires 3 or more neighboring PMTs to form a cluster.

[2] PMTs as seen from inside the GRINCH.

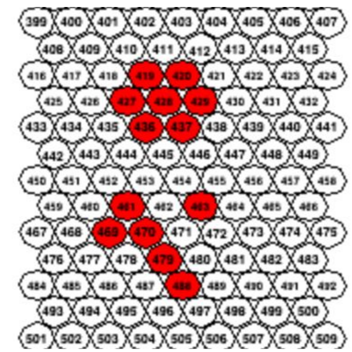


Examples of clusters from electron events, GMn run 13460.

Cluster Analysis: Multiple Clusters

Multiple Groups of PMTs firing within the good time window isn't terribly uncommon (~10% with back-of-envelope calculation).

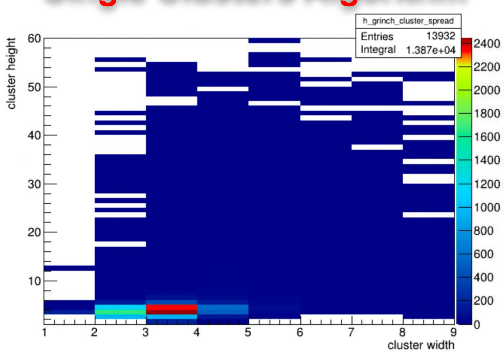
- Previous clustering macro puts everything into one cluster.
    - If a PMT with a hit has two or more neighbors with hits, put it in the cluster.
- Cluster position thus not calculated correctly.
- Possible false positives.



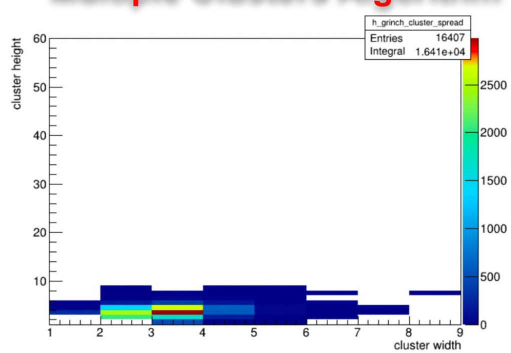
Multiple Clusters developed and implemented a few weeks ago (in my personal macros).

- Utilizes stacks to simulate recursion.
- Spiders through PMTs with hits to map out relationships between them.
- Need to continue verifying that it is working as expected.

Single Clusters Algorithm

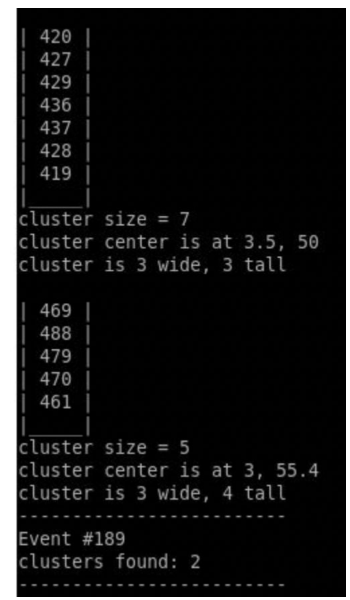


Multiple Clusters Algorithm

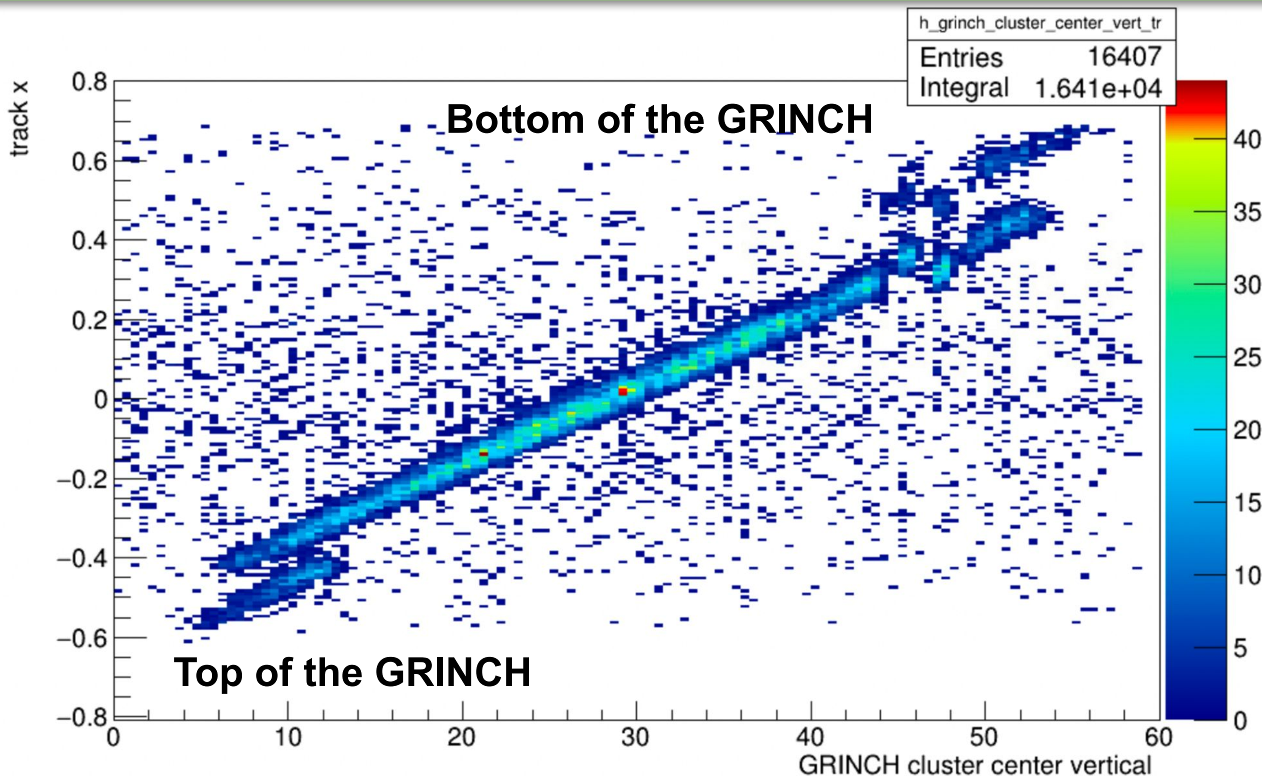


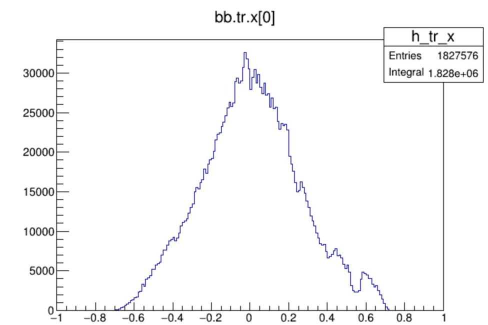
Cluster height and width, GEn run 3038.

Single event display output for above clusters.



Electron Track Correlation*





Histogram of “track x” used in the left histogram.

GEn Run 3038 with a lose electron cut.

*Multiple Clusters used here. Needs to be studied and debugged further.

Why do the top and bottom have strange behaviors? Possible Answers:

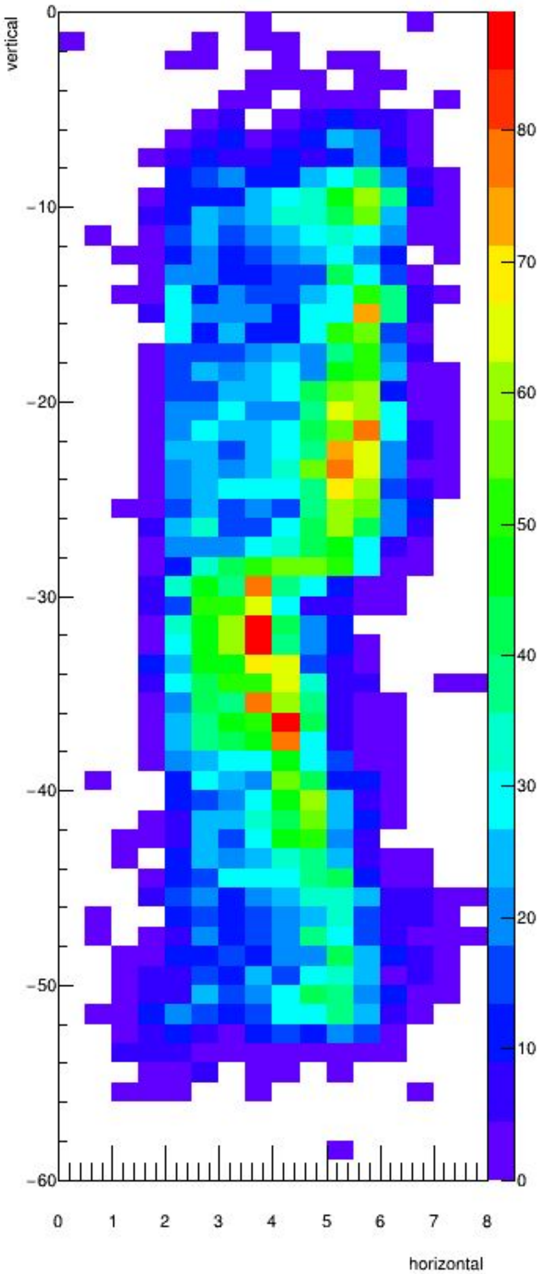
- The extrema of the vertical tracking (bb.tr.x) have an interesting behavior (see histogram).
  - Independent of the GRINCH.
  - When you apply basic theta and phi cuts to the tracks, these ends are cut off.
- The PMTs with the lowest gain are at the bottom of the GRINCH.
- Effects from the boundaries of the GRINCH mirrors.

Electron Detection Efficiency*

Heat Map of cluster centers shows where the Cherenkov light cones hit the PMTs after being focused from the mirrors.

Electron Detection Efficiency

- **85% - 97%** depending on the kinematic settings using clusters of 3 tubes. Increases over time during GMn experiment as the concentration of heavy gas increased with time.
- Tight electron cuts are made on the other detectors and the particle track to find electron events. Then see if the GRINCH saw a cluster.



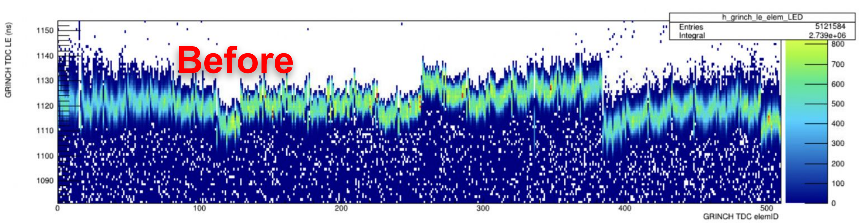
Histogram of cluster centers on the GRINCH PMT array, GMn run 13719.

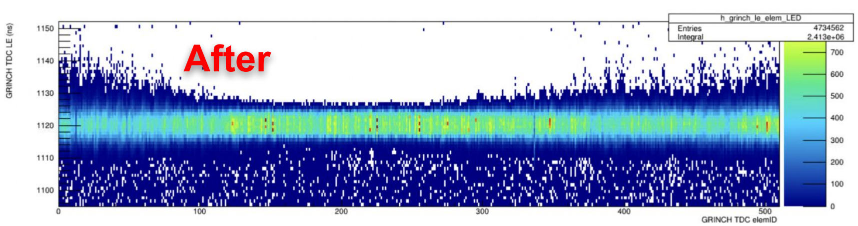
*Not evaluated with multiple clusters.

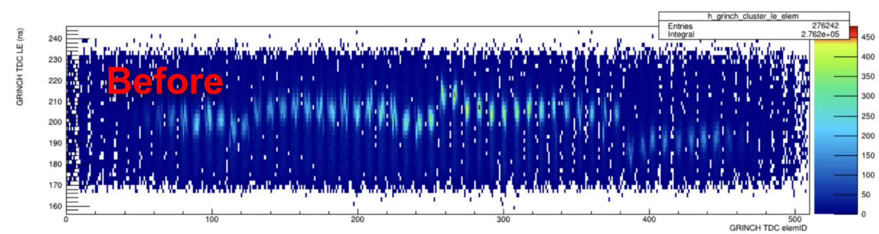
Timing Calibrations

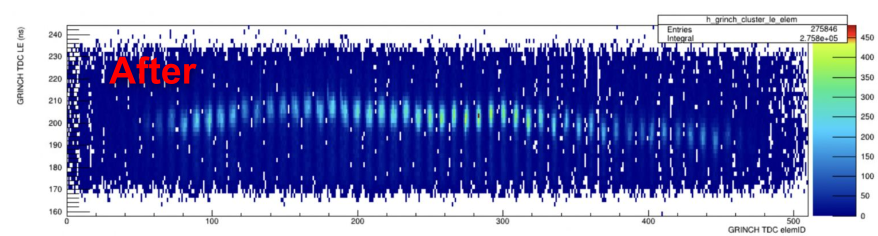
- Need to provide offsets in the software so that the electron signals all come in at the same time across all the PMTs, allowing for tighter timing cuts.
- Unable to calibration using cosmics since it is a cherenkov detector. And many of the PMTs are outside the expected acceptance for electrons.
- Using LED installed inside GRINCH, we can align the Leading Edge (LE) of the TDC signal, then see how that affects the LE from production data.

LED Leading Edge → **Cluster Leading Edge***









GEn runs 3036, 3038.

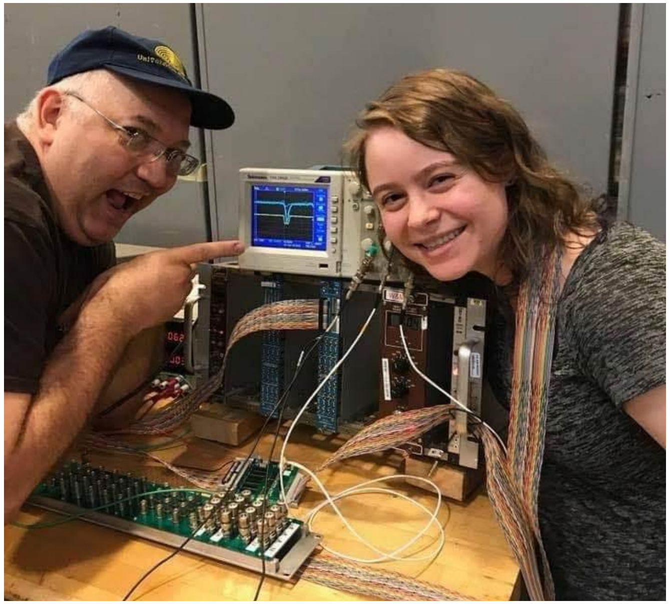
*Multiple clusters not applied yet.

Next Steps and Future Work

- Verify multiple clusters is working as expected.
- Implement GRINCH clustering into SBS_offline (with help of software experts).
- Adjust timing offsets.
- Further investigate the behavior of the mirrors using particle tracks.
- Calculate the electron detection and the pion rejection efficiency across the different kinematics for GMn.
- Analysis and performance in the GEn experiment, which is running now in Hall A.

Thank you! Questions?

Special thanks to Todd Averett and Carlos Ayerbe.



References:

[1] *GRINCH Detector Technical Document v.11, Averett, Yao, Wojtskhowski, 2012*

[2] Carlos Ayerbe, 2018

Carlos Ayerbe and myself seeing PMT signals through the GRINCH front end electronics for the first time in the TEDF. Photo credit: Todd Averett, 2018.

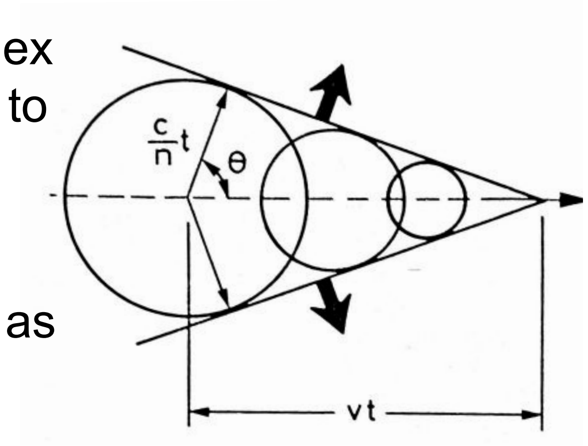
Cherenkov Radiation

Cherenkov Radiation happens when an electromagnetic shock wave is formed when a particle travels faster than the speed of light in the medium.

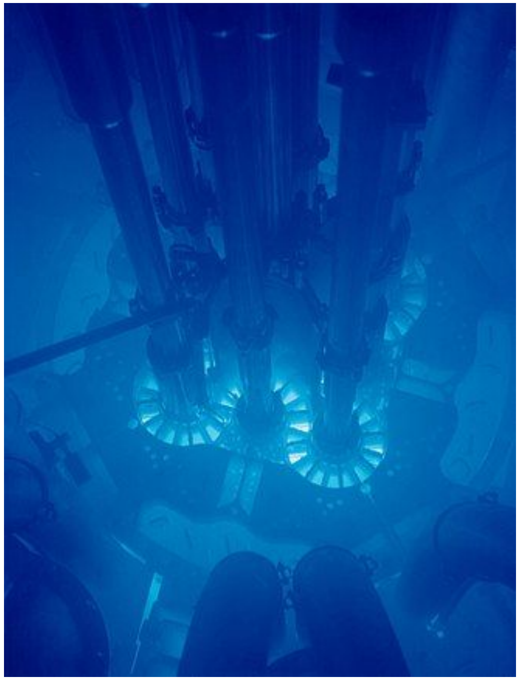
A medium with a certain index of refraction can be chosen to discriminate between velocities.

Light cone can be detected as a ring using photomulitpler tubes (PMTs).

Allows for discrimination between pions and electrons at the same momentum or energy.



Propagation of a Cherenkov light cone through a medium [W.R. Leo].



[Cherenkov light in the Advanced Test Reactor, Idaho National Laboratory.]