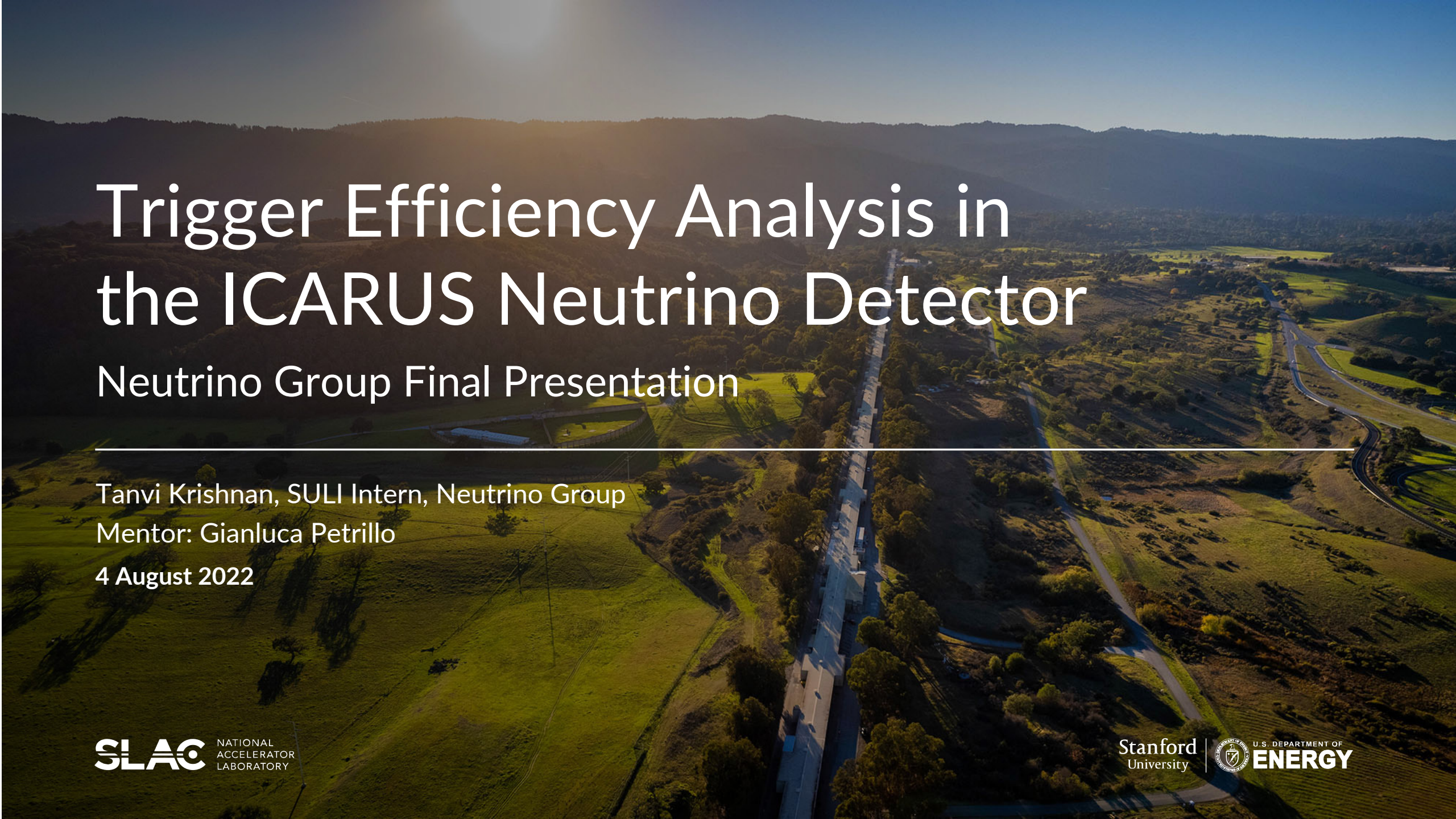

Trigger Efficiency Analysis in the ICARUS Neutrino Detector

Neutrino Group Final Presentation

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4 August 2022

SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

Agenda

1 Detector Overview

2 Trigger System

3 Efficiency Analysis

4 The 2m Track Anomaly

5 Other Possible Considerations

6 Conclusions and Next Steps

1

Detector Overview

ICARUS Detector

Imaging Cosmic And Rare Underground Signals

- Liquid Argon Time Projection Chamber (LArTPC) Detector
  - Creates digital images of neutrino interactions to better understand their properties
- Part of the Short Baseline Neutrino Program at Fermilab
- Composed of two semi-independent cryostats, each containing two LArTPCs

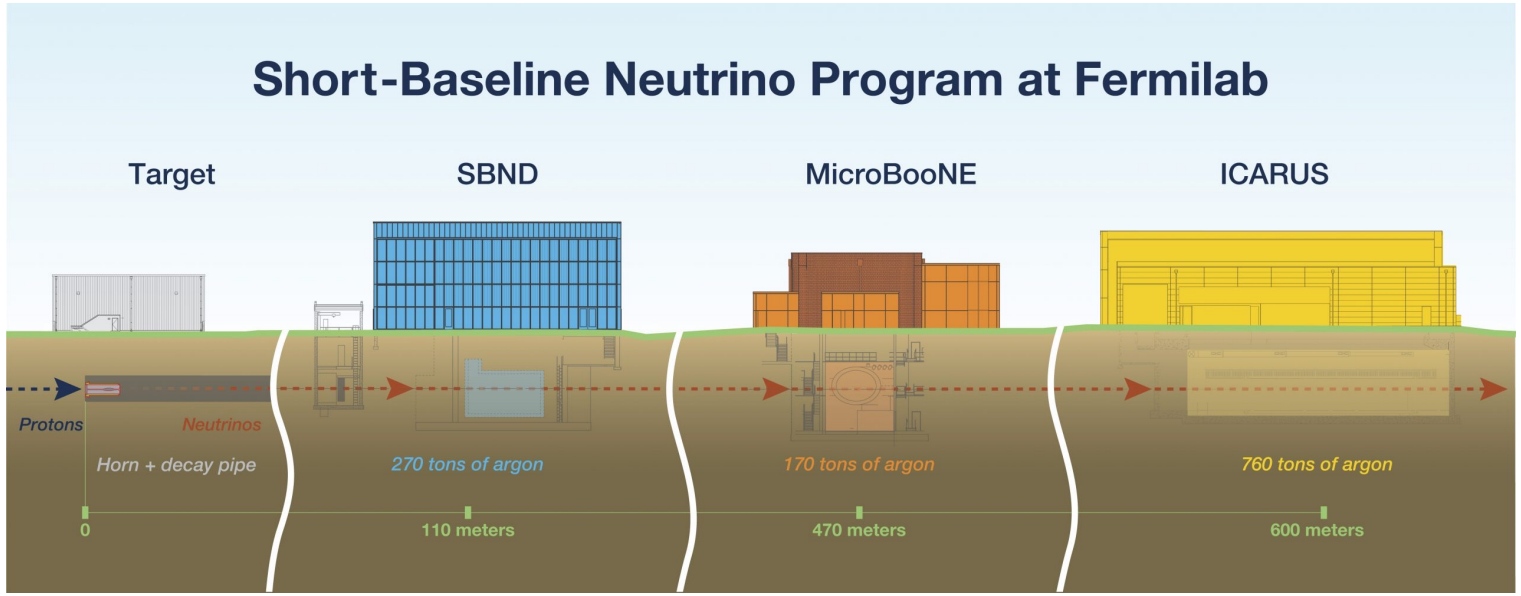


Figure 2. Overview of SBN at Fermilab. Image credits: ICARUS collaboration

ICARUS Detector

Imaging Cosmic And Rare Underground Signals

- LArTPC reads drifting charge → slow! (ms)
- PMTs (photomultipliers) detect light → fast! (ns)
- Within drift time, many cosmic rays pass through detector creating background
- PMTs help us identify cosmic rays

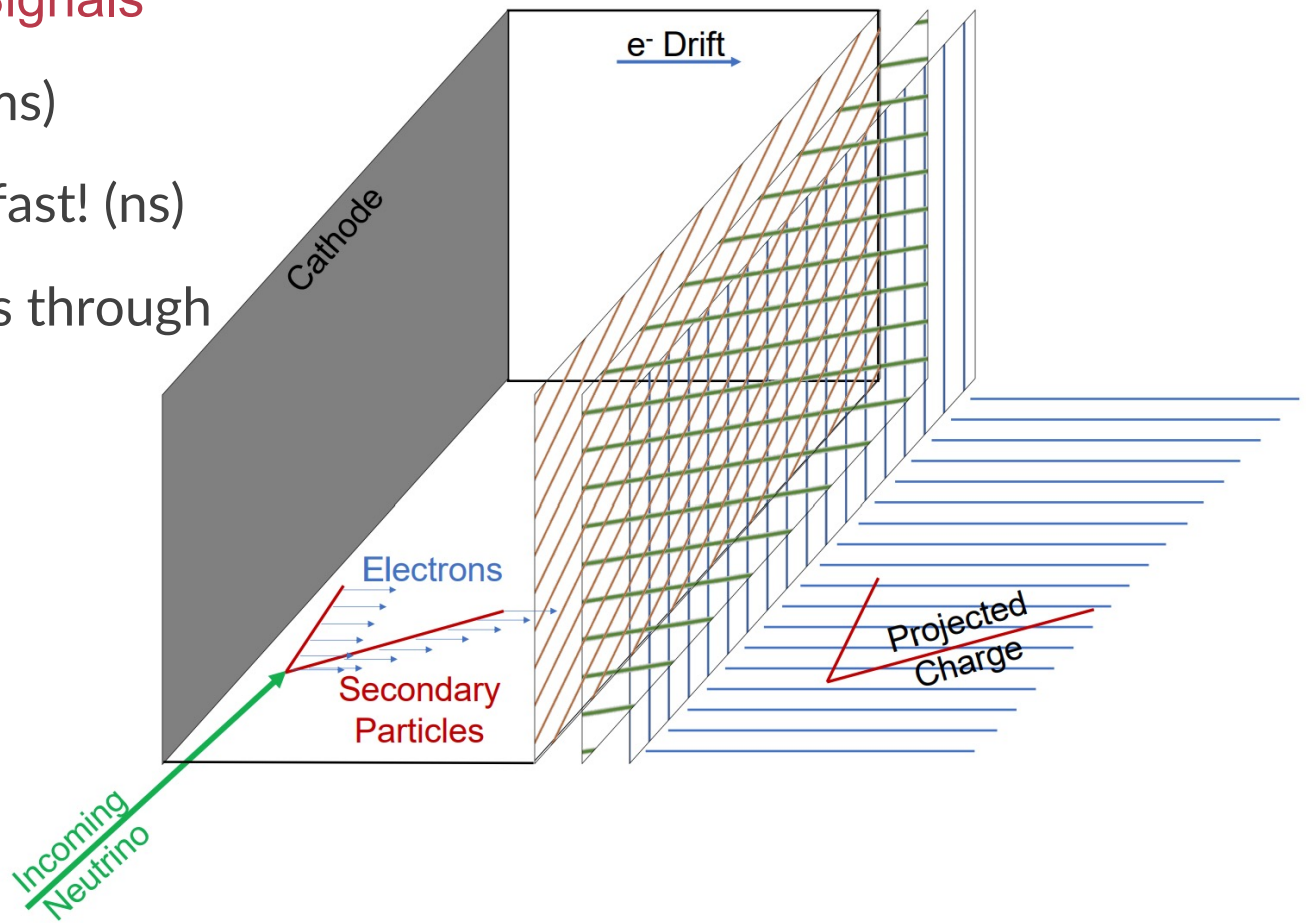


Figure 3. Overview of Liquid Argon Time Projection Chamber (LArTPC). Image Credits: ANL, FNAL.

2

Trigger System Overview

Trigger System

- Hardware system that filters out background in real time
- Test different light requirement levels using software emulation
  - Each pair of PMTs “triggering” means that one detected light above fixed threshold
  - M1: 1 PMT pair triggers within the entire detector
  - S3, S5, S8, S10, S15: # of PMT pairs that trigger within 1 of 3 6m sections of detector
- Select requirement level that maximizes efficiency of recording desired tracks while minimizing the background we accumulate

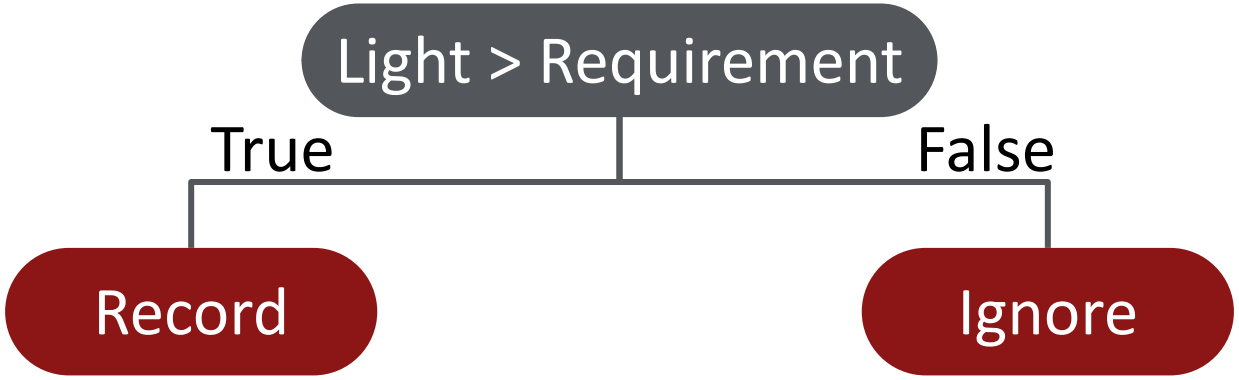


Figure 4. ICARUS Trigger System Logic.

3

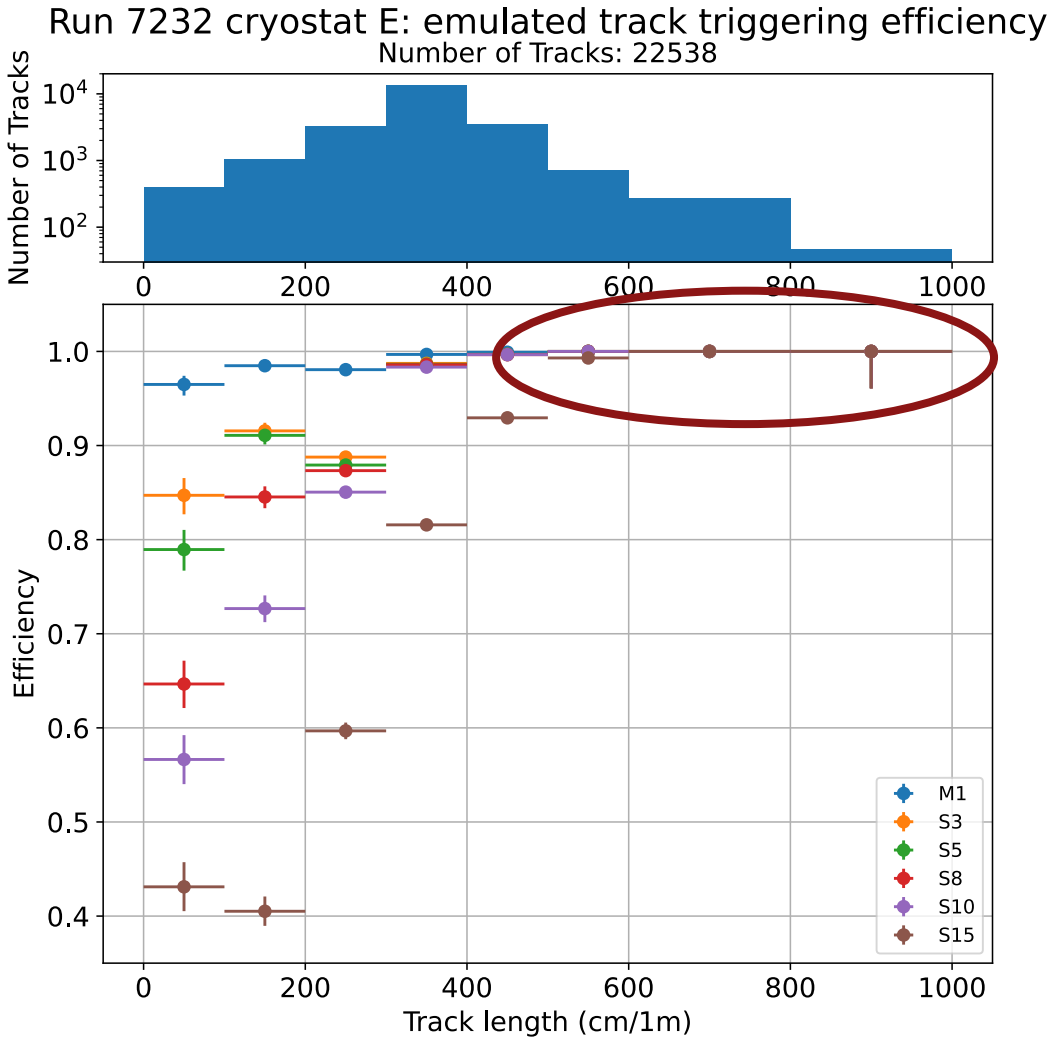
Efficiency Analysis

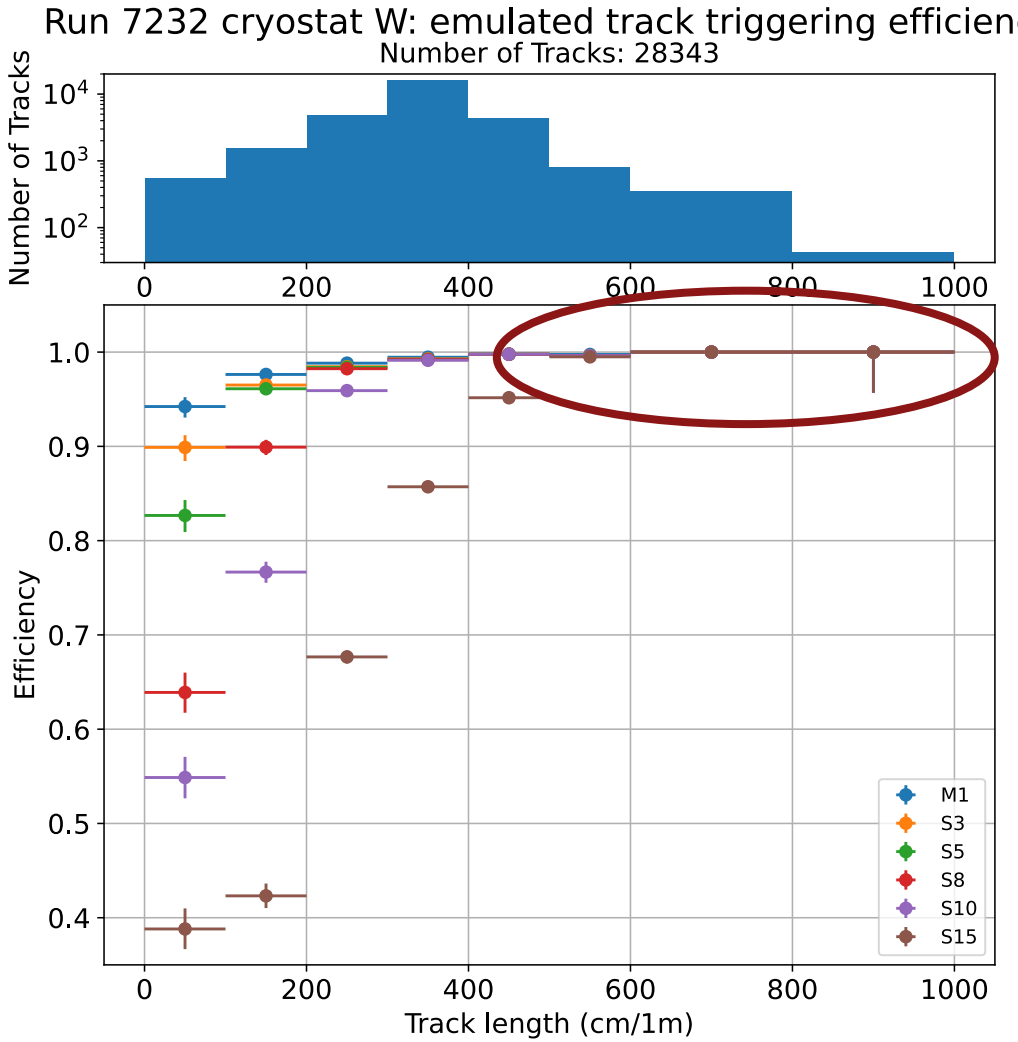
What does our data look like?

- "Minimum bias" run from November 30, 2021
  - Data collected without hardware trigger constraints
  - Software used to emulate trigger performance under different light requirement levels
- Cathode-crossing tracks only
  - Only tracks for which we can reconstruct the time without biasing trigger efficiency measurement
  - Hope to look at tracks that don't cross cathode in the future, reducing sample bias

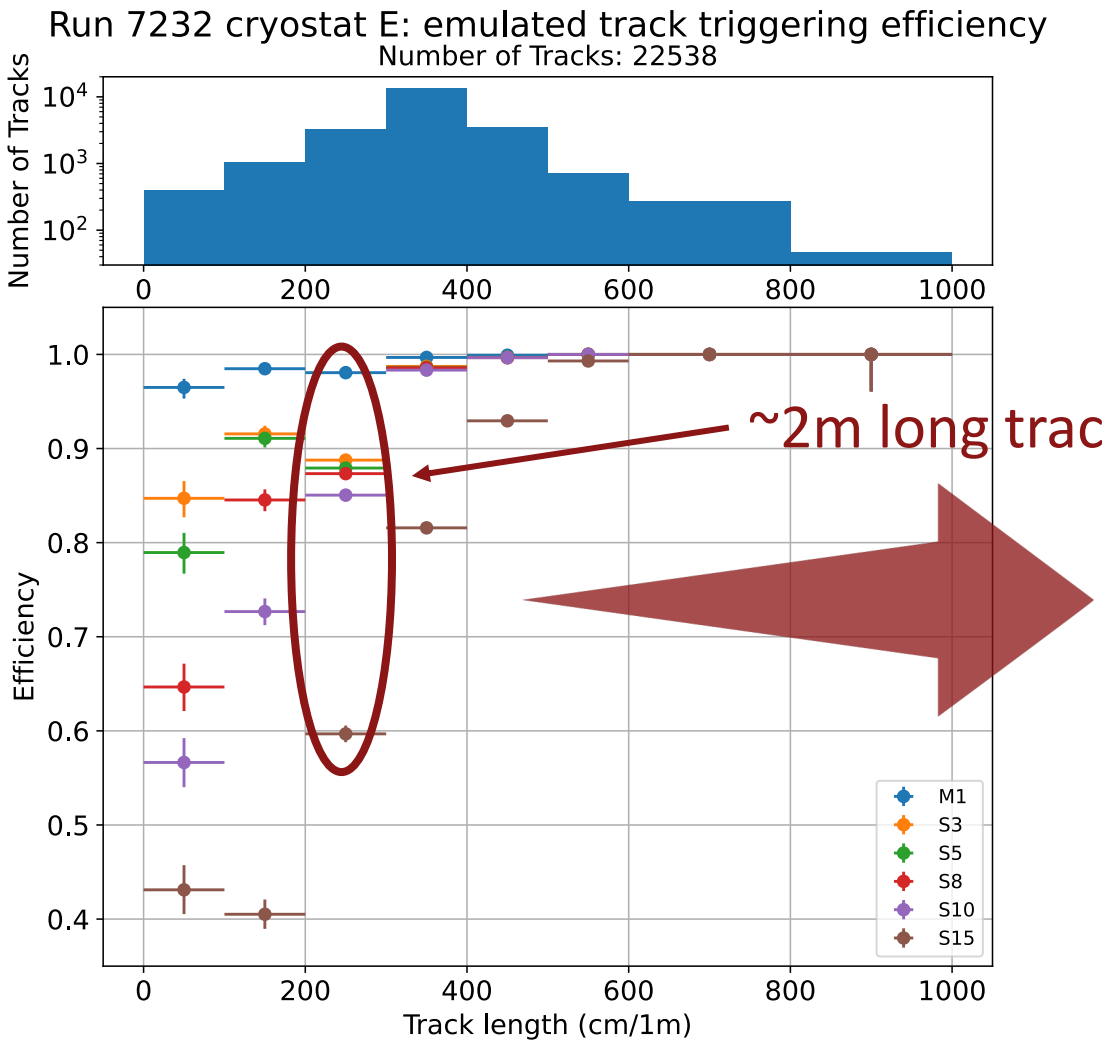
$$\text{Efficiency} = \frac{\text{selected tracks that would trigger}}{\text{selected tracks}}$$

Efficiency of Trigger as a function of Track Length

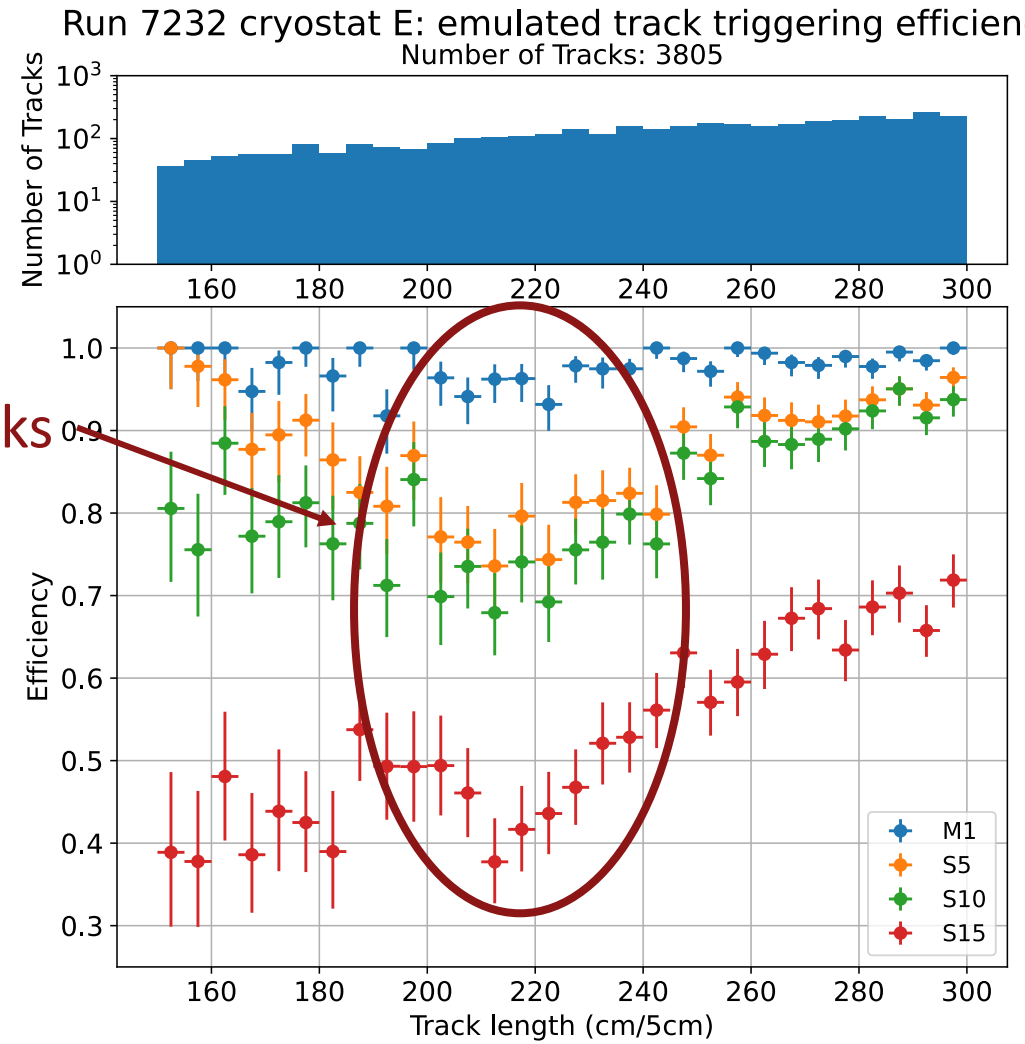




Efficiency of Trigger as a function of Track Length



~2m long tracks



4

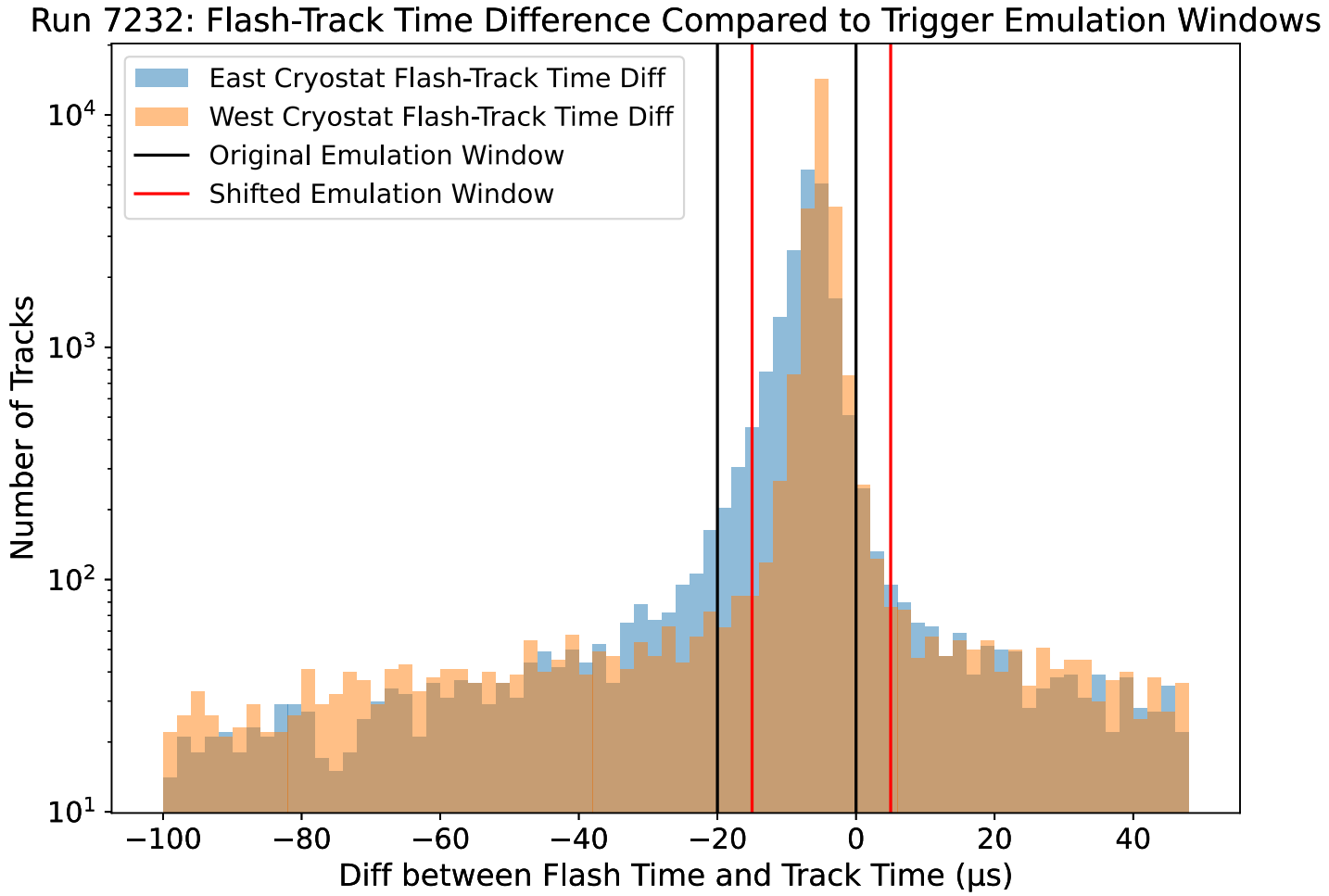
The 2m Track Anomaly

The 2m Track Anomaly

Tracks ~2m in length have a noticeably lower efficiency than slightly shorter or longer tracks

- Especially evident in East cryostat but also present in West cryostat (less severely)
- No noticeable spatial pattern for non-triggering tracks
- Statistics limited for current dataset, hoping a newer run will provide more insight

Shifting the Trigger Emulation Window

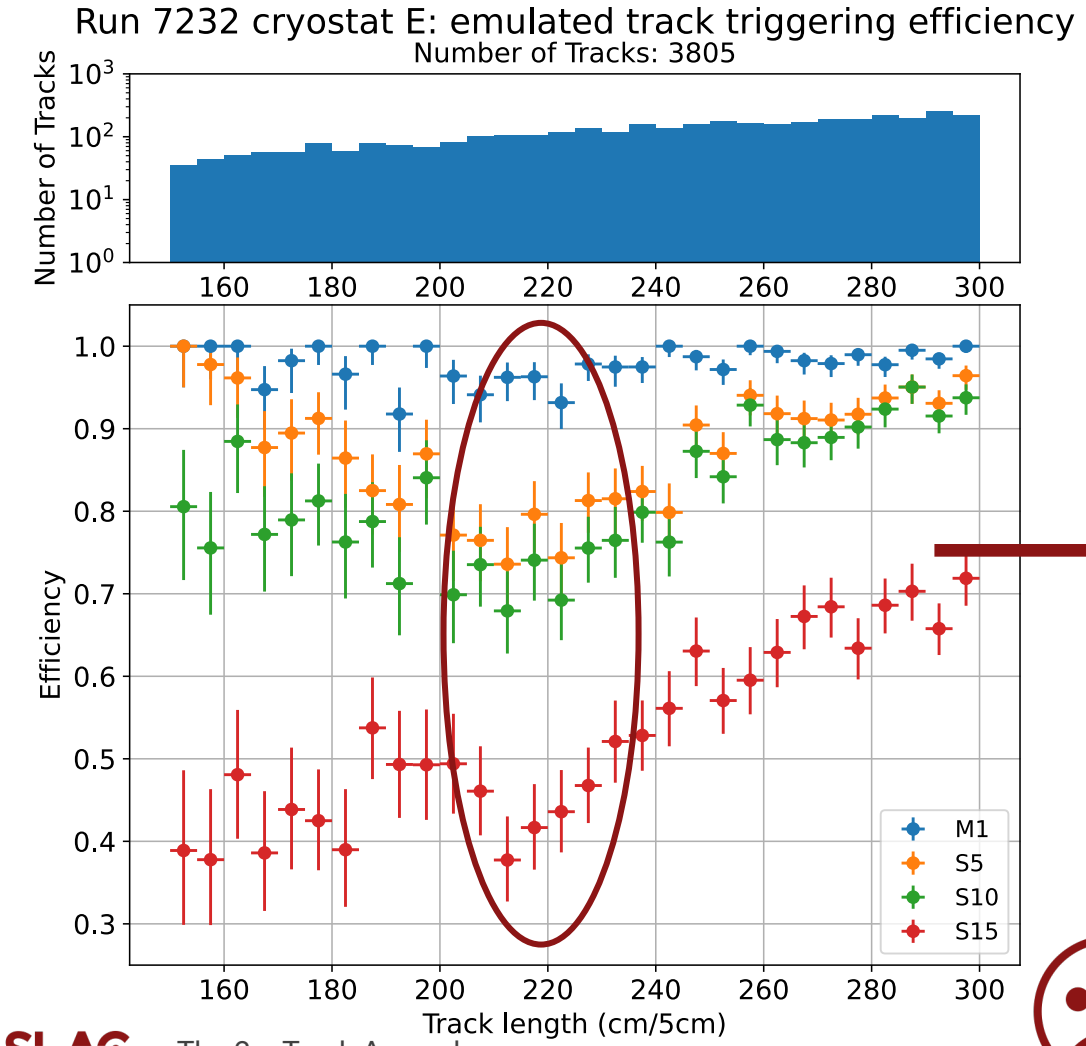


Possible Solution:

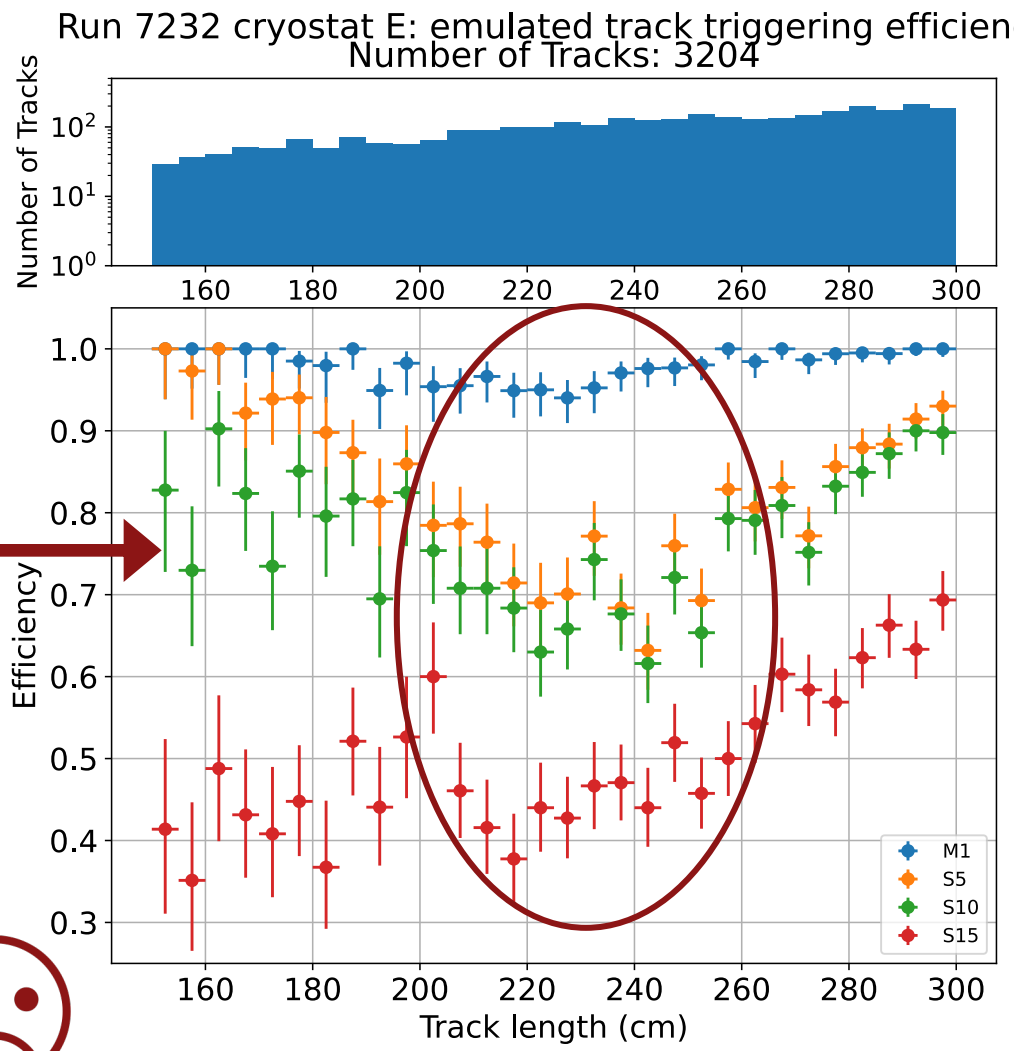
- In Trigger Emulation software, we look for light in a 20 µs window before the track time (t0), and check whether that light exceeds chosen light requirement level
- Most tracks of length ~2m that failed to trigger matched to light occurring <5µs after t0
- Shifted window later by 5 µs to see whether overall efficiency improved

Shifting the Trigger Emulation Window: East Cryostat

Original Emulation Window

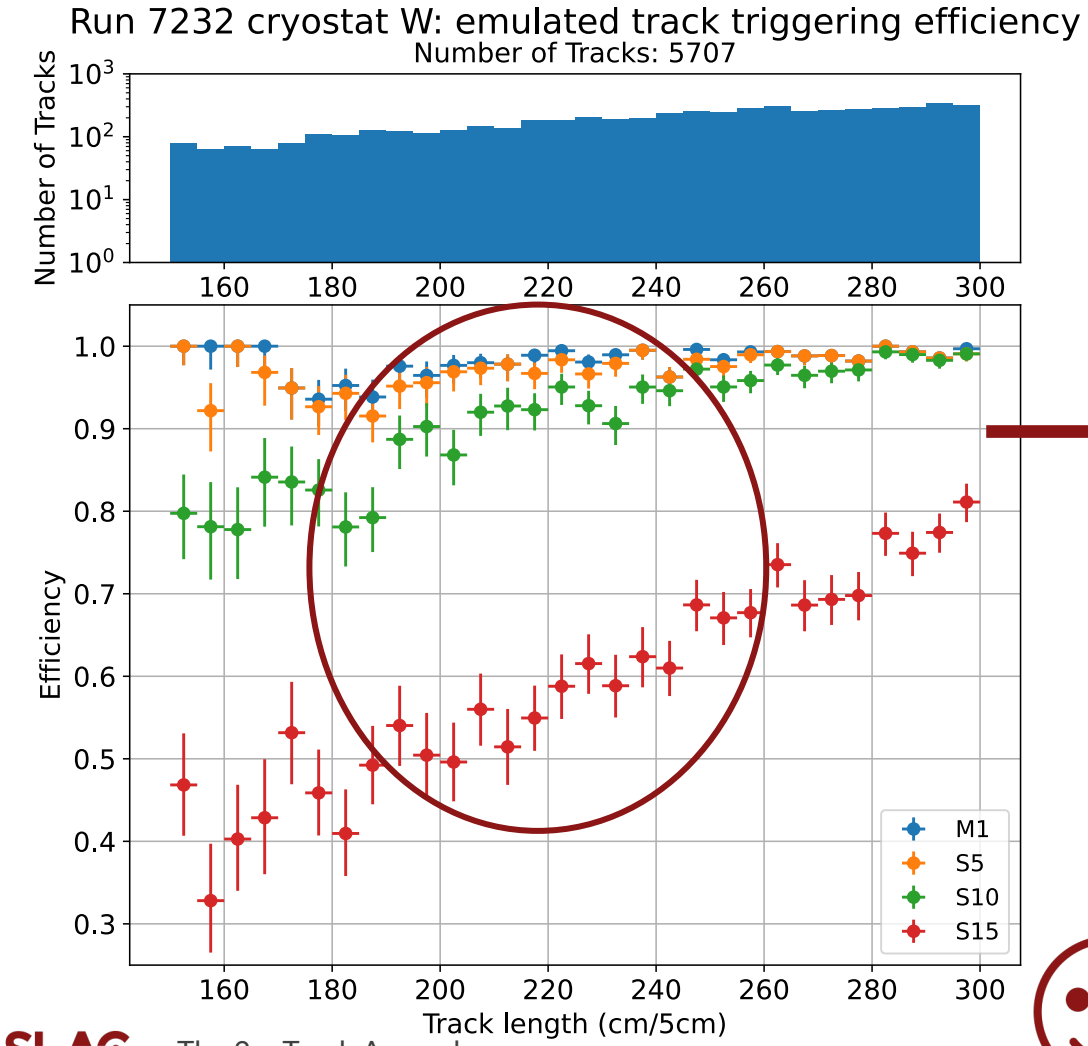


Shifted Emulation Window

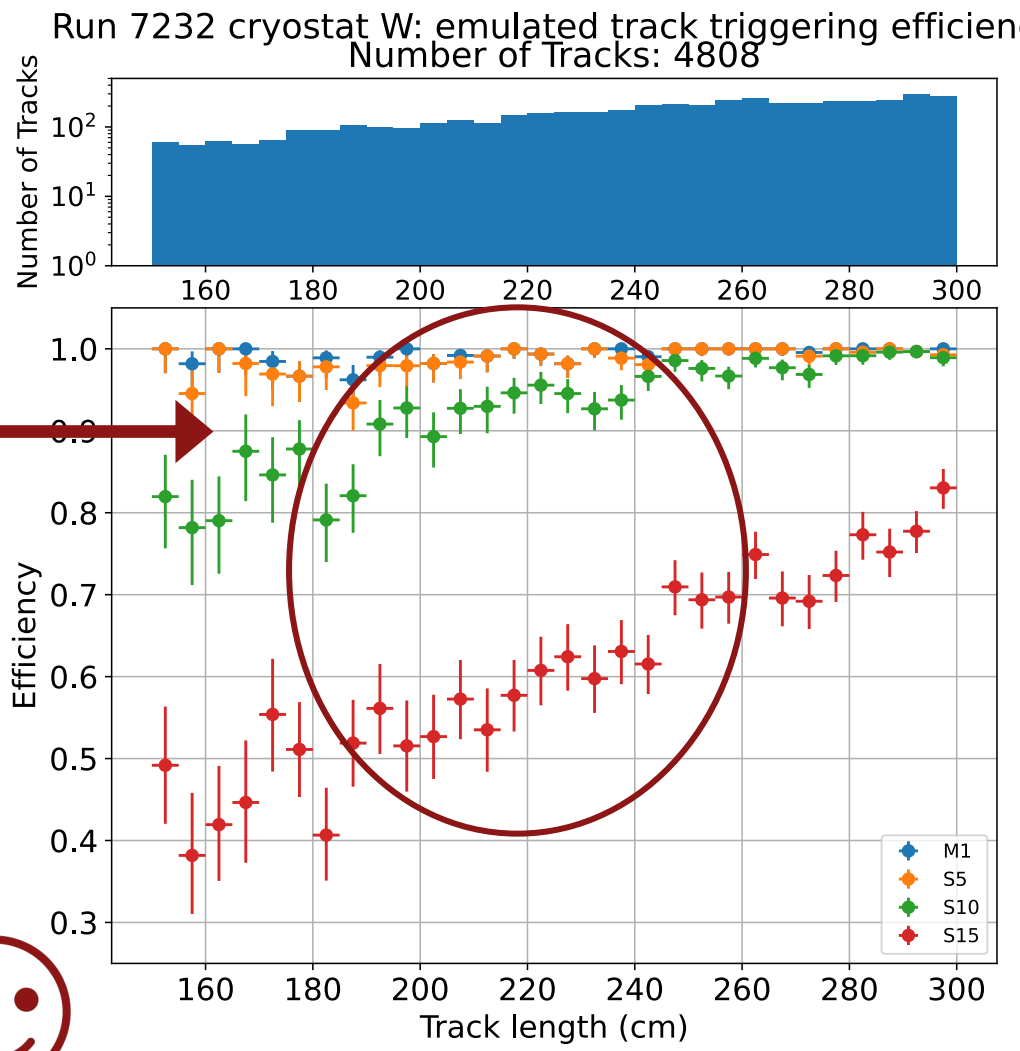


Shifting the Trigger Emulation Window: West Cryostat

Original Emulation Window



Shifted Emulation Window



5

Other Possible Considerations

Potential Causes of the 2m track anomaly

Possible connections

1. Shifting trigger emulation window, t0 reconstruction
    - Somewhat for 2m tracks
2. Length balance ratio of tracks on either side of cathode
3. Smaller track component along the z-axis, large track component along the x-axis
    - Not specific to 2m tracks (geometric bias)
4. Border distortions of electric field
5. Y-axis cathode-crossing position
    - Lower visibility of photons at high y-values
    - Photons lost if they hit the field cage, fewer PMTs at high y-values

Ruled out connections

1. Not time dependent
2. Not from cathode bending
    - Cathode bending shouldn't greatly affect t0 reconstruction
3. Not specific to y-direction of tracks
4. Likely not due to split tracks during track reconstruction
    - From what we saw of the event display (not a statistically significant sample)
    - Also, most tracks appear to go from one edge of cryostat to another (>60% have at least 1 endpoint at an edge of the cryostat)

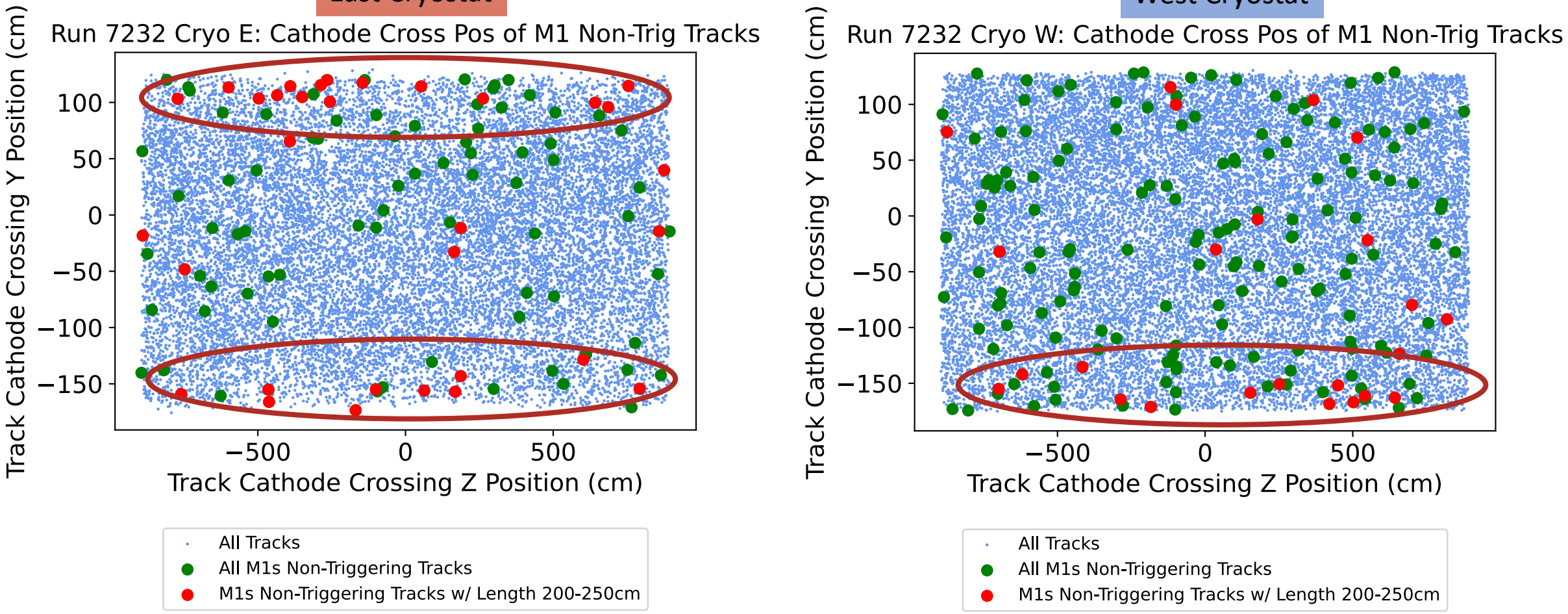
Possible connection:

Y-axis cathode-crossing position

East Cryostat

(-20 µs, 0 µs) Emulation Window

West Cryostat



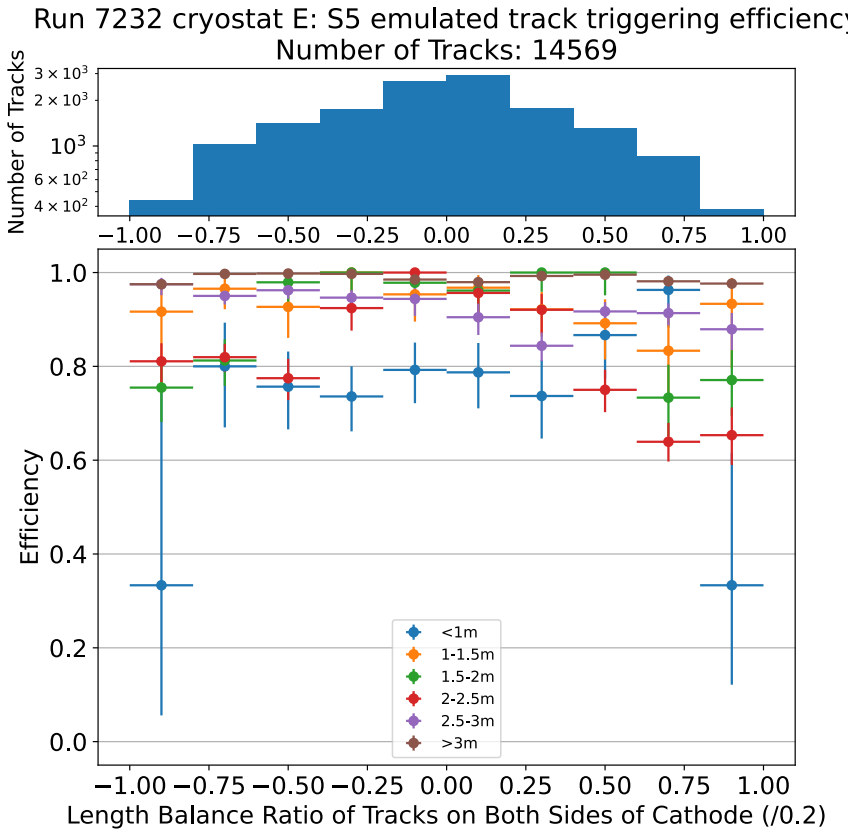
Possible connection:

Length balance ratio of tracks on either side of cathode

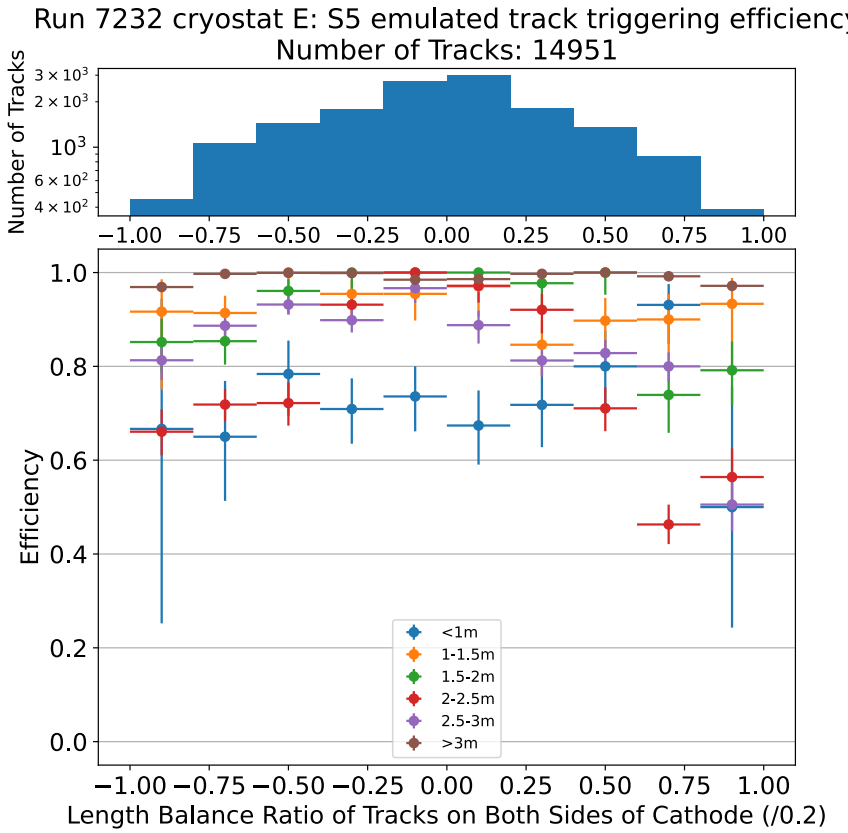
Balance Ratio	≈ -1	≈ 0	≈ 1
Primary TPC of Track	East	Both	West

East Cryostat

(-20 µs, 0 µs) Emulation Window



(-15 µs, 5 µs) Emulation Window



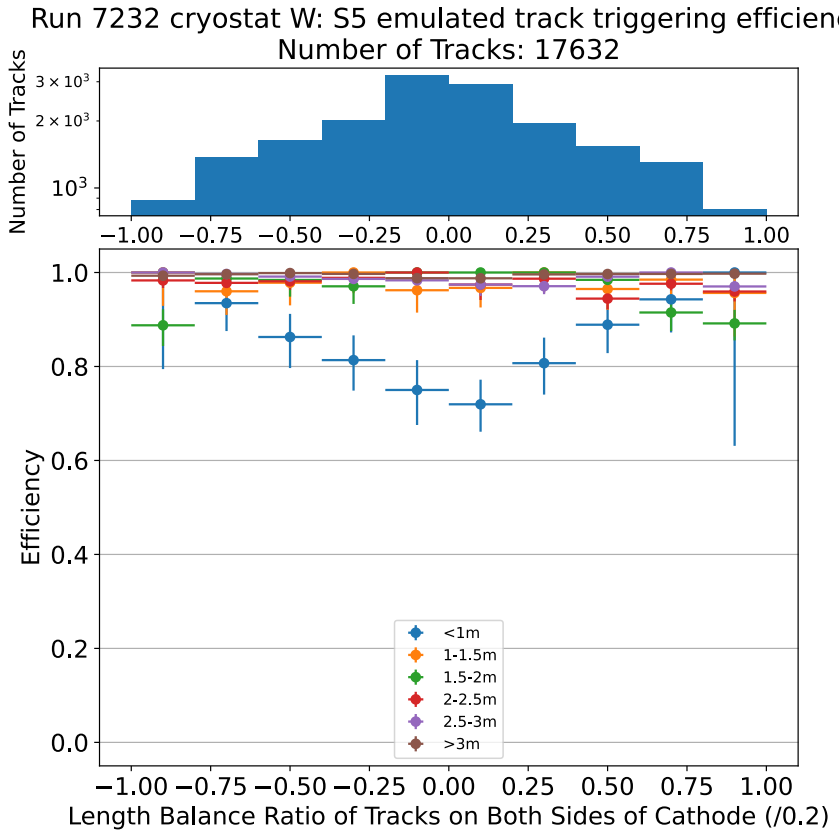
Possible connection:

Length balance ratio of tracks on either side of cathode

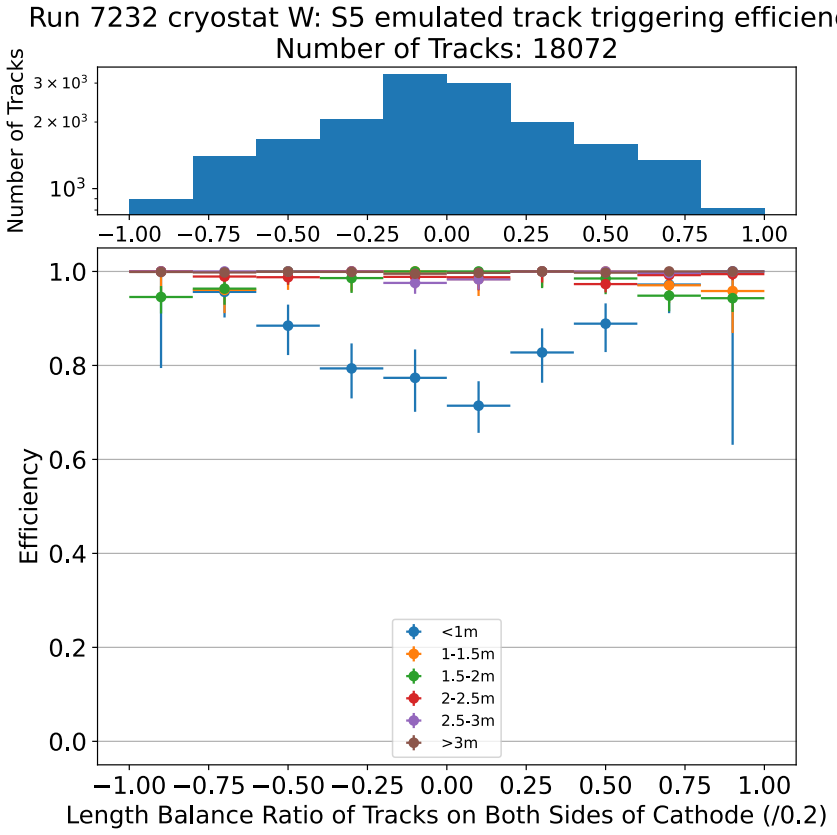
Balance Ratio	≈ -1	≈ 0	≈ 1
Primary TPC of Track	East	Both	West

West Cryostat

(-20 µs, 0 µs) Emulation Window



(-15 µs, 5 µs) Emulation Window

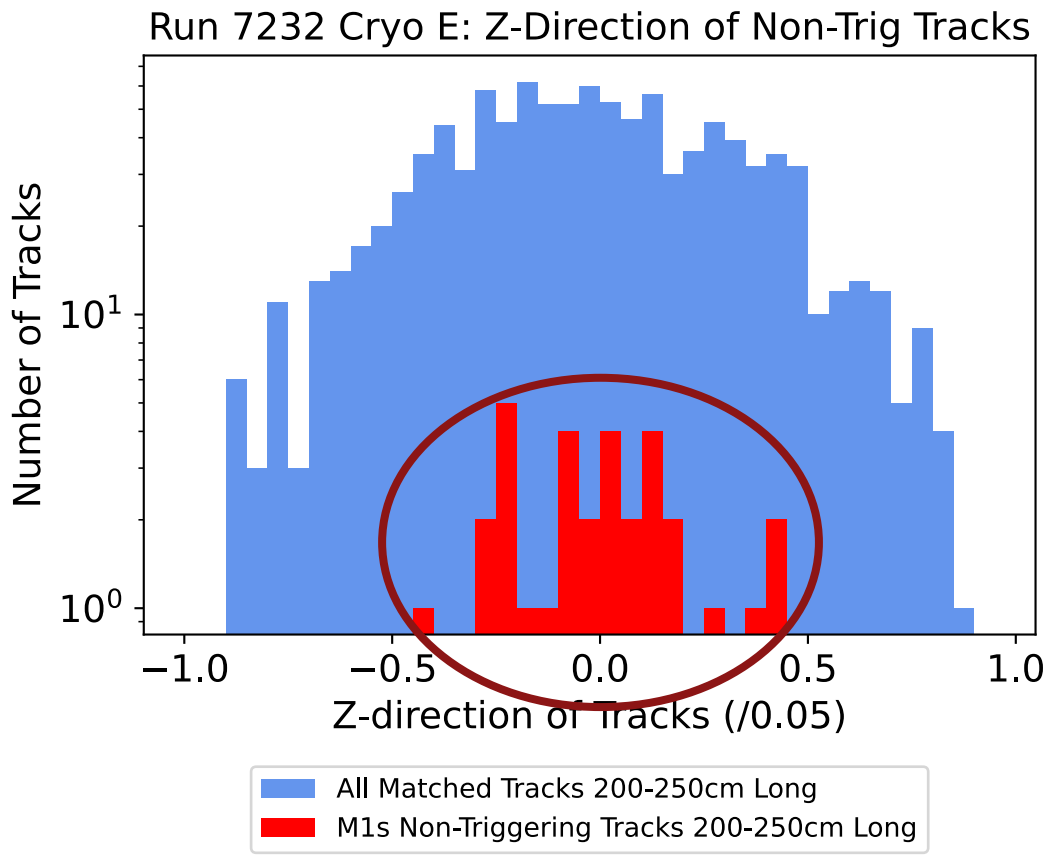


Possible Connection:

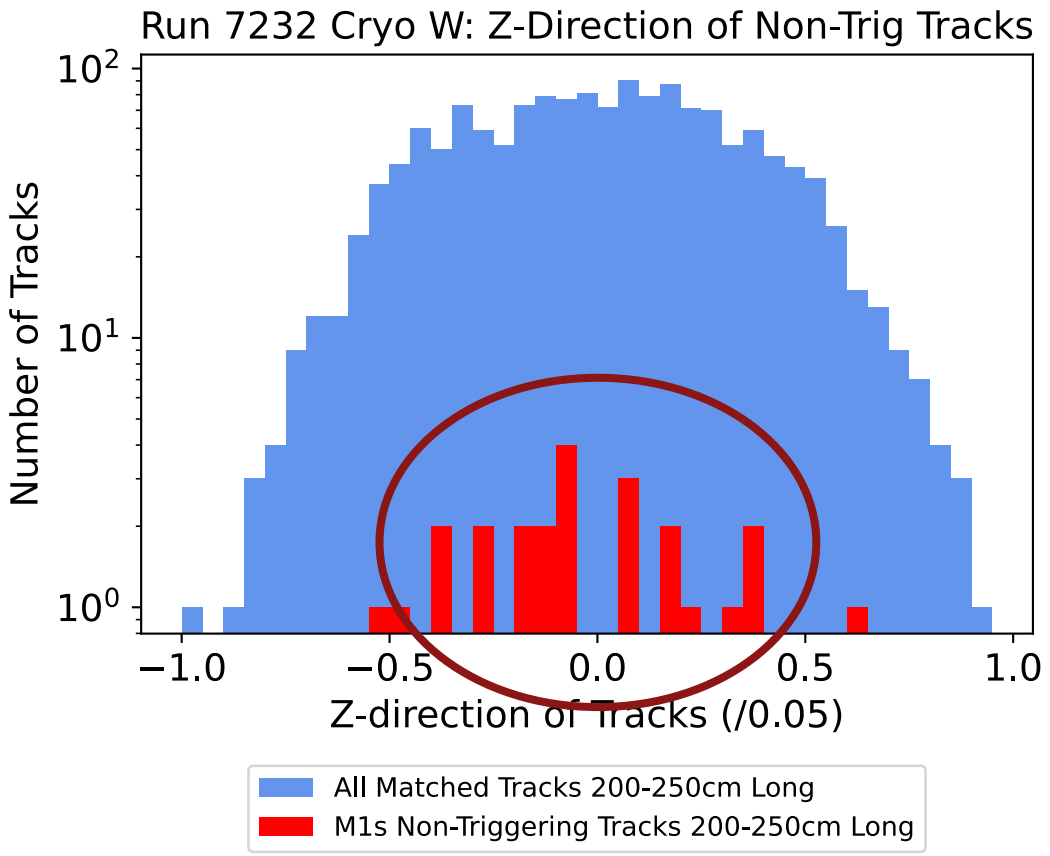
Smaller track angle along the z-axis

(-20 µs, 0 µs) Emulation Window

East Cryostat



West Cryostat

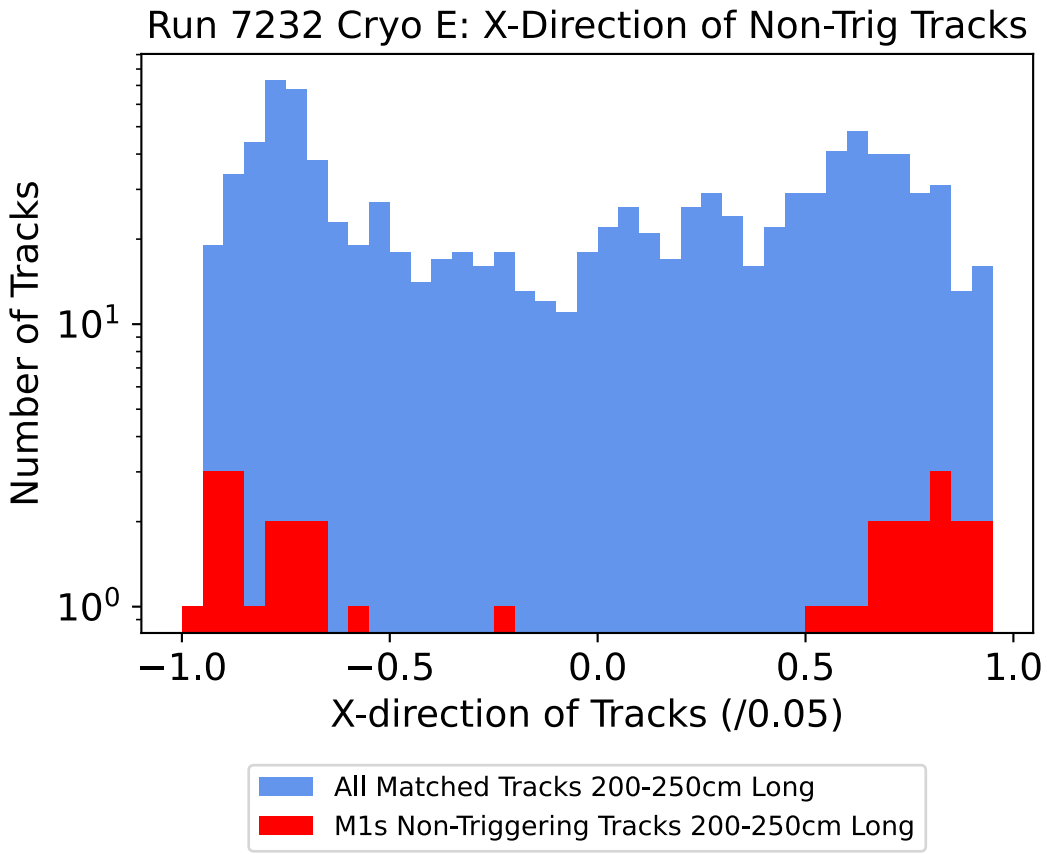


Possible Connection:

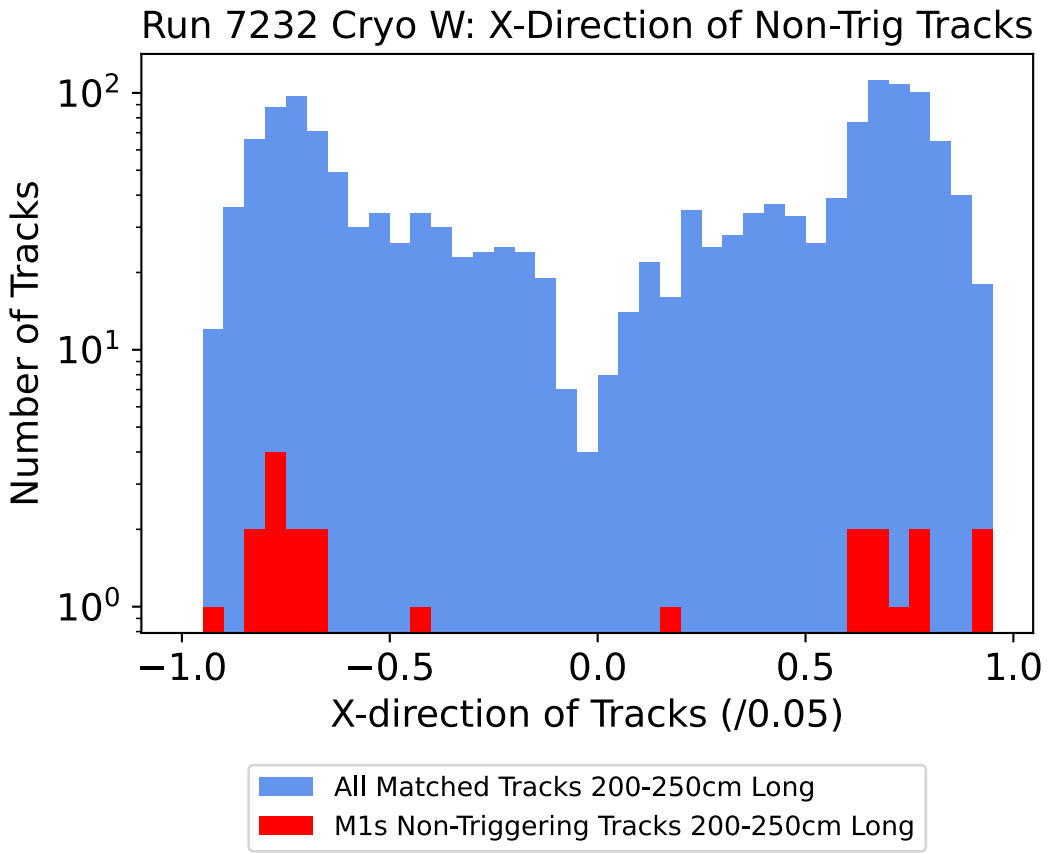
Large track angle along the x-axis

(-20 µs, 0 µs) Emulation Window

East Cryostat



West Cryostat



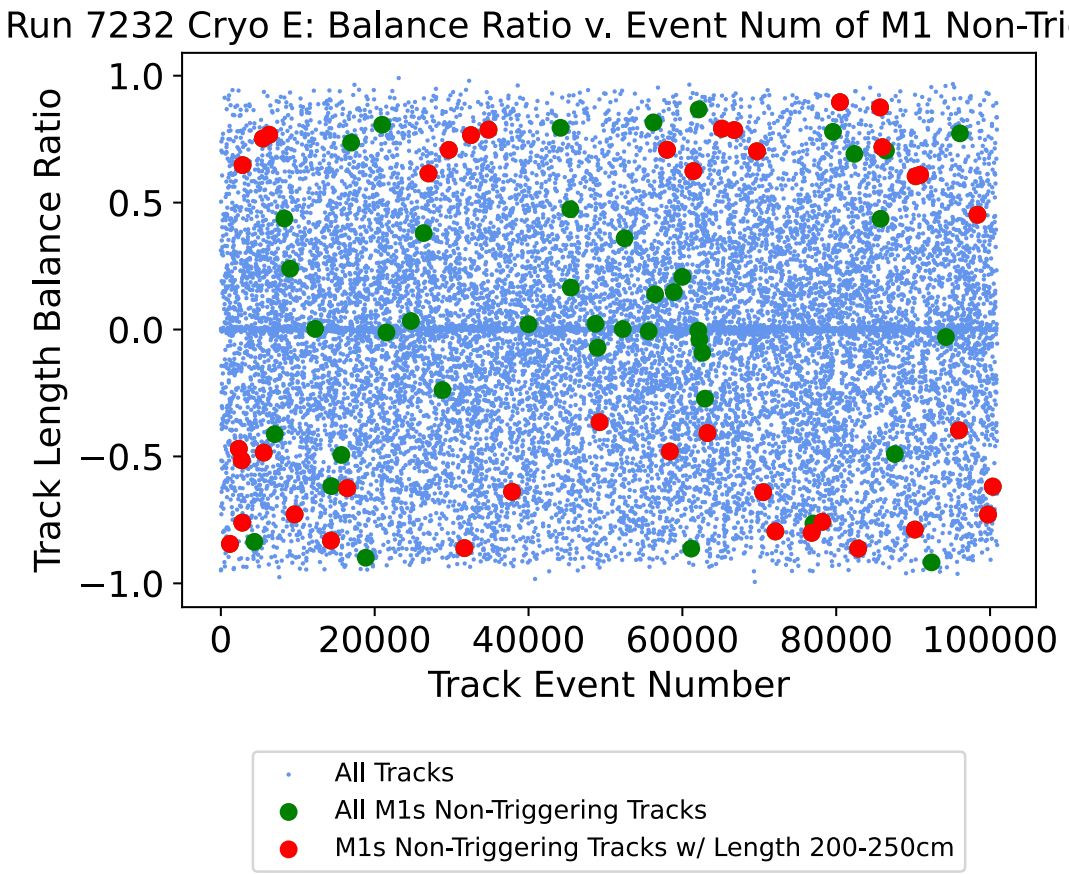
Ruled Out Connection:

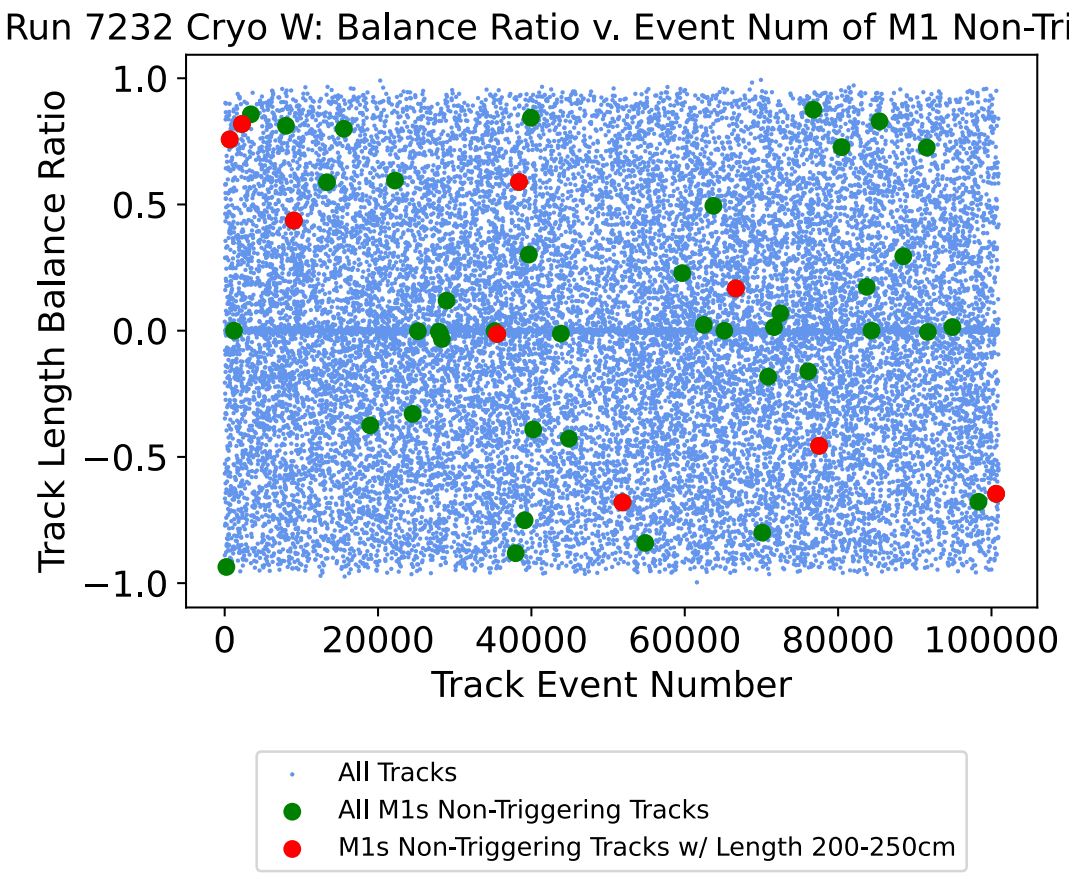
Not time dependent

East Cryostat

(-15 µs, 5 µs) Emulation Window

West Cryostat



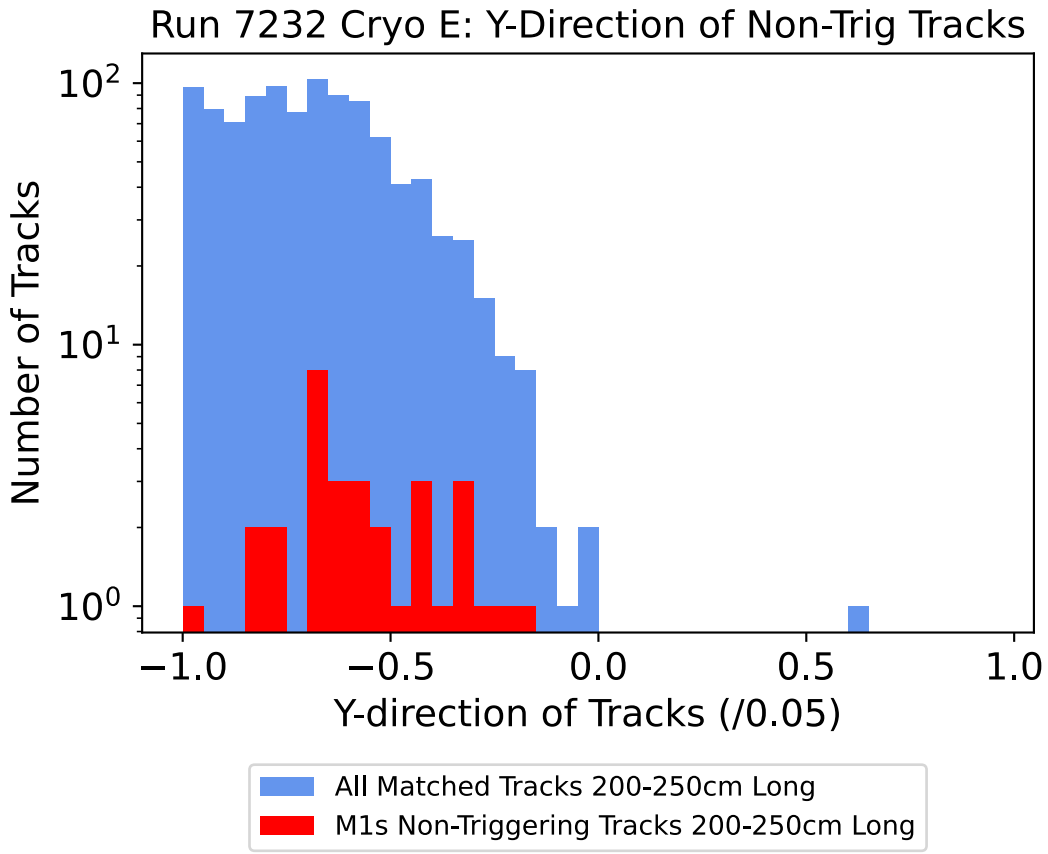


Ruled Out Connection:

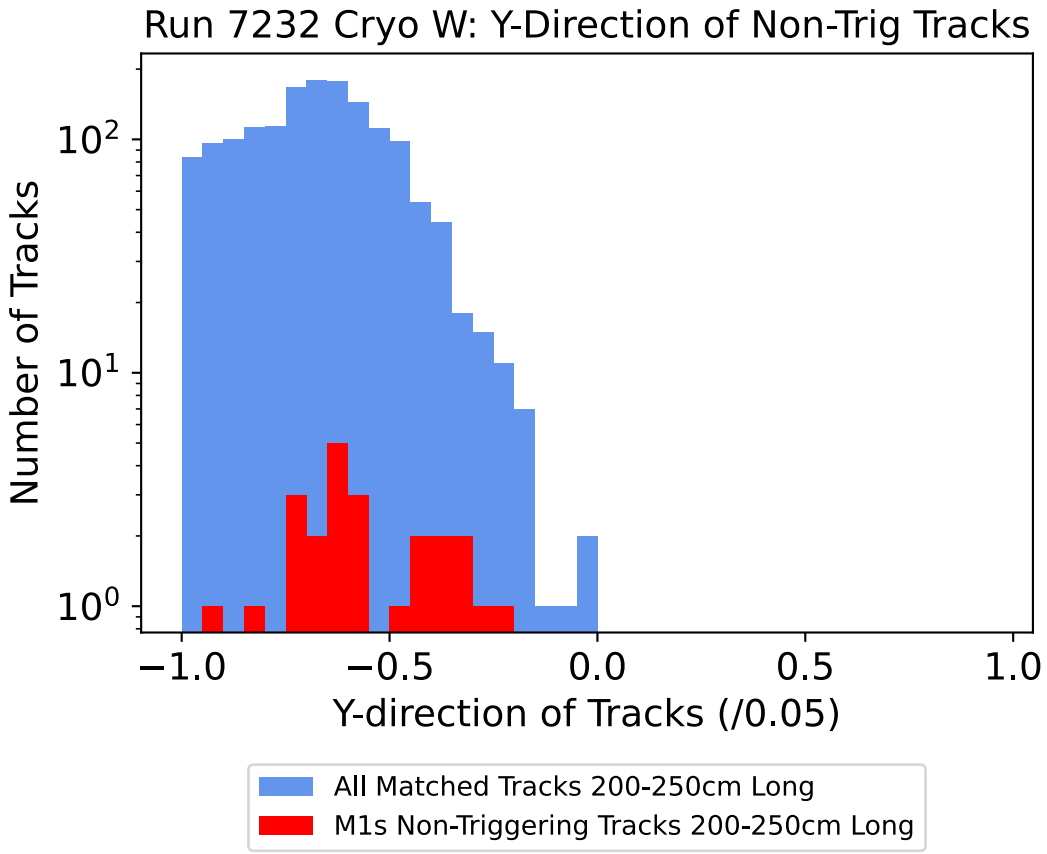
Track angle along the y-axis

(-20 µs, 0 µs) Emulation Window

East Cryostat



West Cryostat



6

Conclusions and Next Steps

Conclusions and Next Steps

- Still investigating the 2m track anomaly
- New minimum bias run (similar to this data) taken last week
  - Repeat these analyses to understand changes
  - Look for efficiency improvements or any new features to study
- Later analyze CRT-matched tracks
  - CRT (Cosmic Ray Tagger) is a set of sensors covering outside of detector
  - Detect cosmic particles entering or leaving the cryostat
  - CRT hits can be matched to tracks within the TPCs and can provide us with time and position information for tracks that don't necessarily cross the cathode

Recap

1 Detector Overview

2 Trigger System

3 Efficiency Analysis

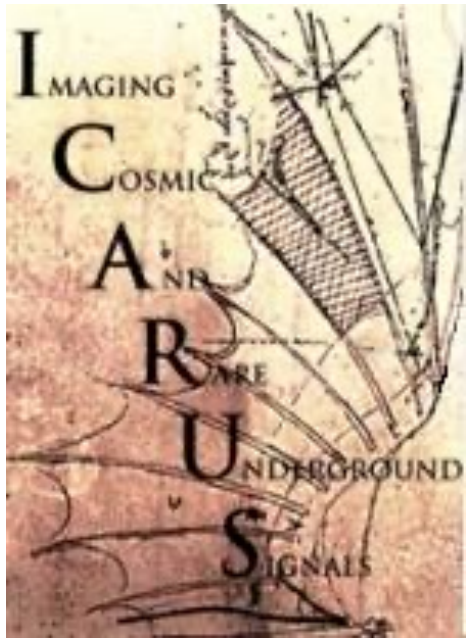
4 The 2m Track Anomaly

5 Other Possible Considerations

6 Conclusions and Next Steps

Acknowledgements

I would like to acknowledge Dr. Gianluca Petrillo, the ICARUS Trigger Working Group, the SLAC Neutrino Group, Erin and Hillary, my fellow interns, and the DOE



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Thank you for listening! Any questions?

Additional Slides

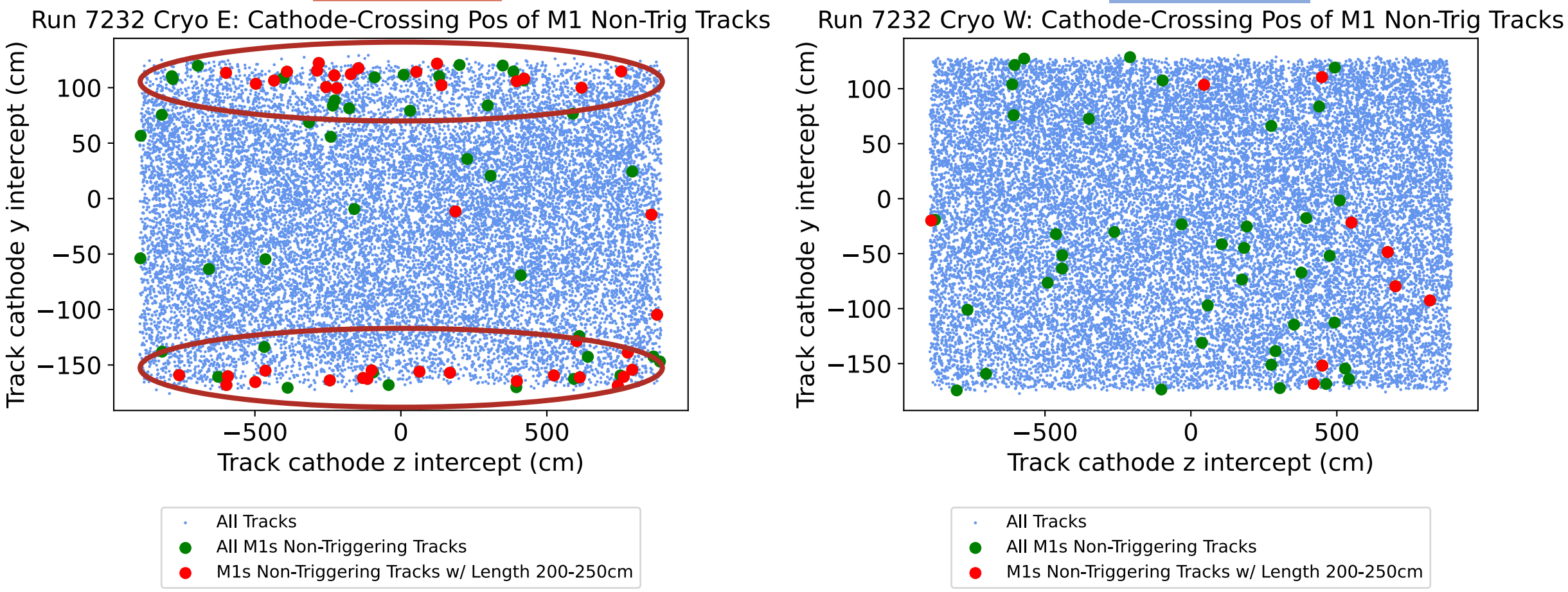
Possible connection:

Y-axis cathode-crossing position

East Cryostat

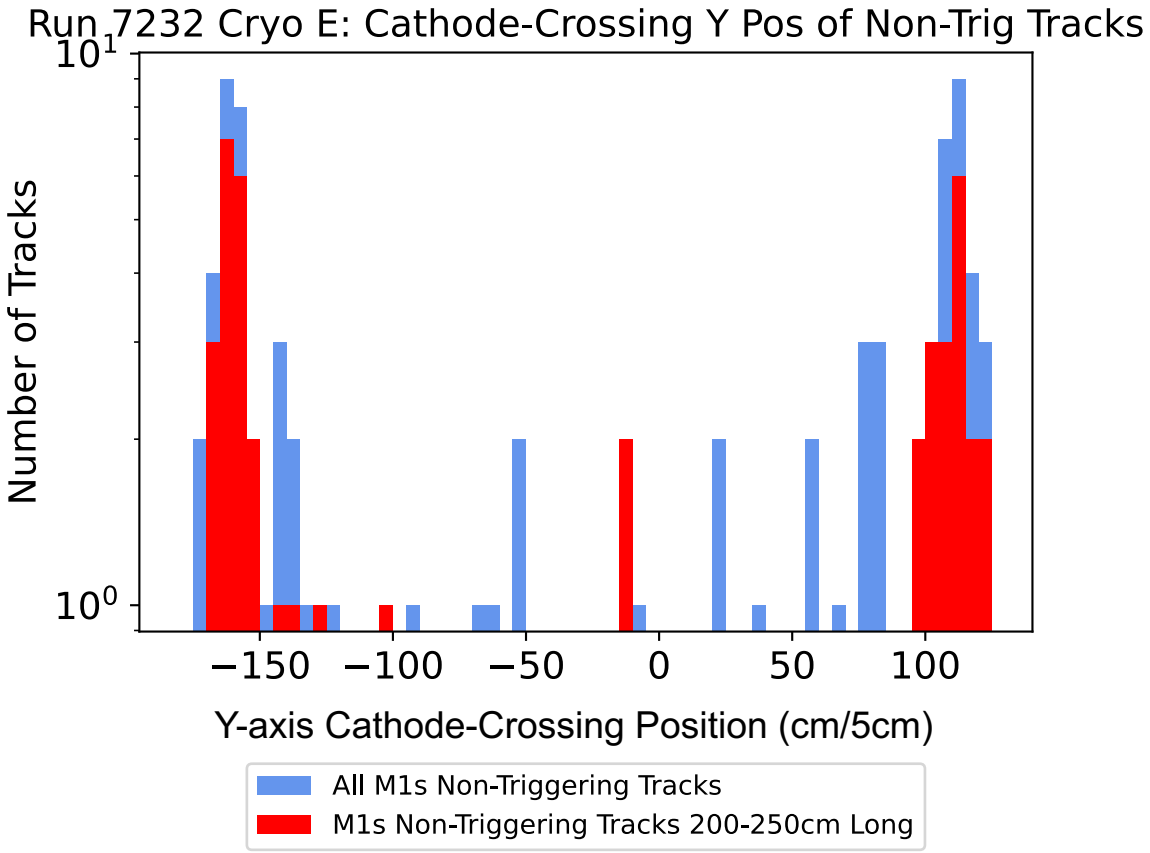
(-15 µs, 5 µs) Emulation Window

West Cryostat



Possible connection:

Y-axis cathode-crossing position



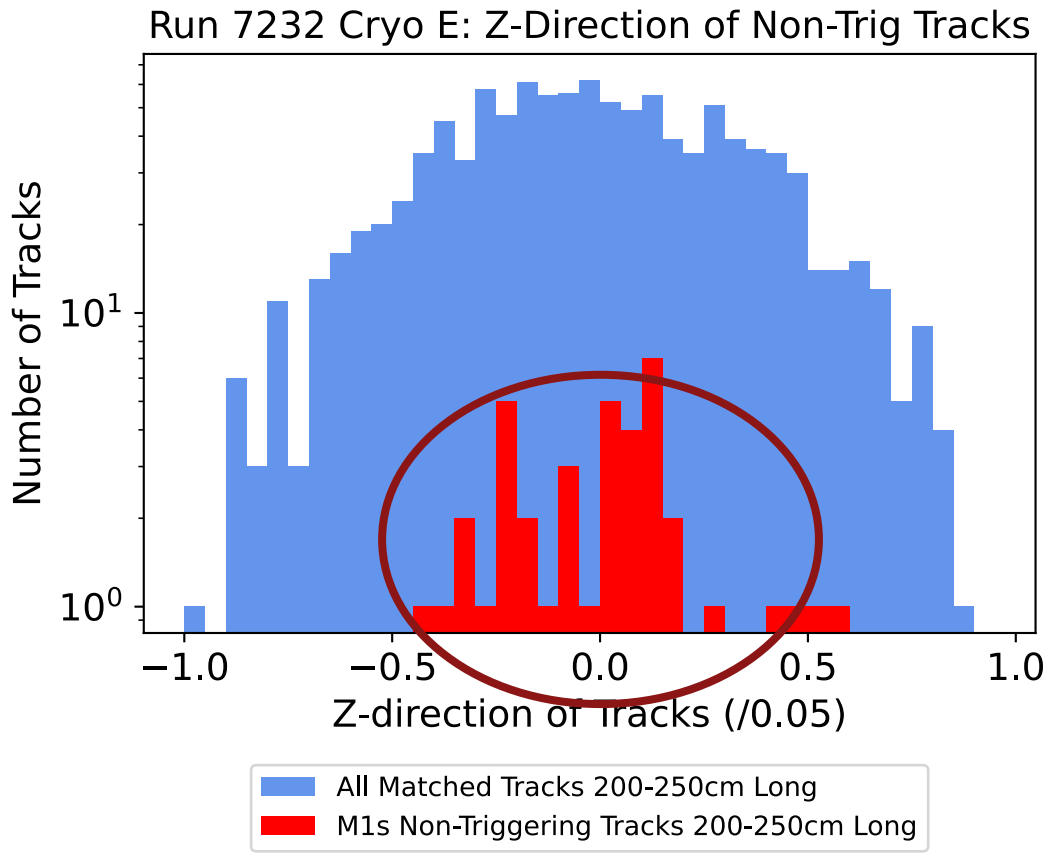
- Proportion of M1 non-triggering tracks with y-axis cathode-crossing position between -150 cm and 90 cm = **0.362**
- Number of M1s non-triggering tracks with lengths 200-250 cm = **42**
- Estimated Number of M1 non-triggering tracks with lengths 200-250 cm with y-axis cathode-crossing position between -150 cm and 90 cm = 0.36 x 42 = **15.2**
- Actual Number of M1 non-triggering tracks with lengths 200-250 cm with y-axis cathode-crossing position between -150 and 90 cm = **6**

Possible Connection:

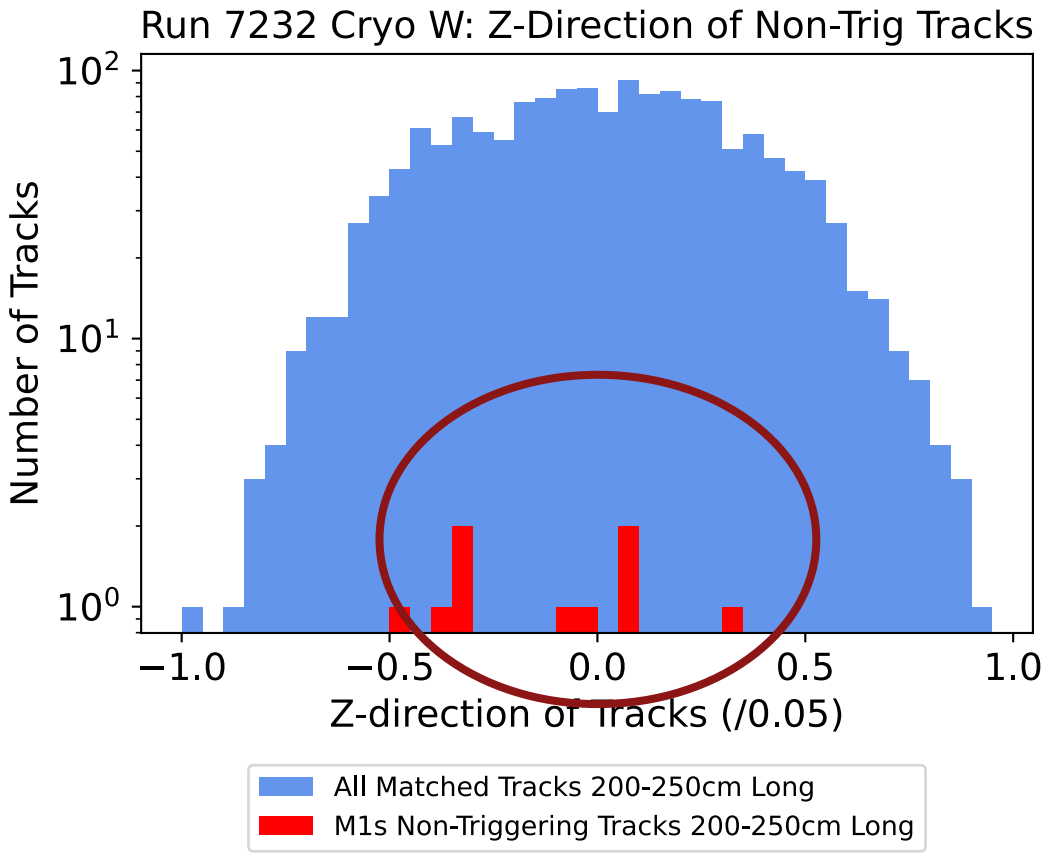
Smaller track angle along the z-axis

(-15 µs, 5 µs) Emulation Window

East Cryostat



West Cryostat

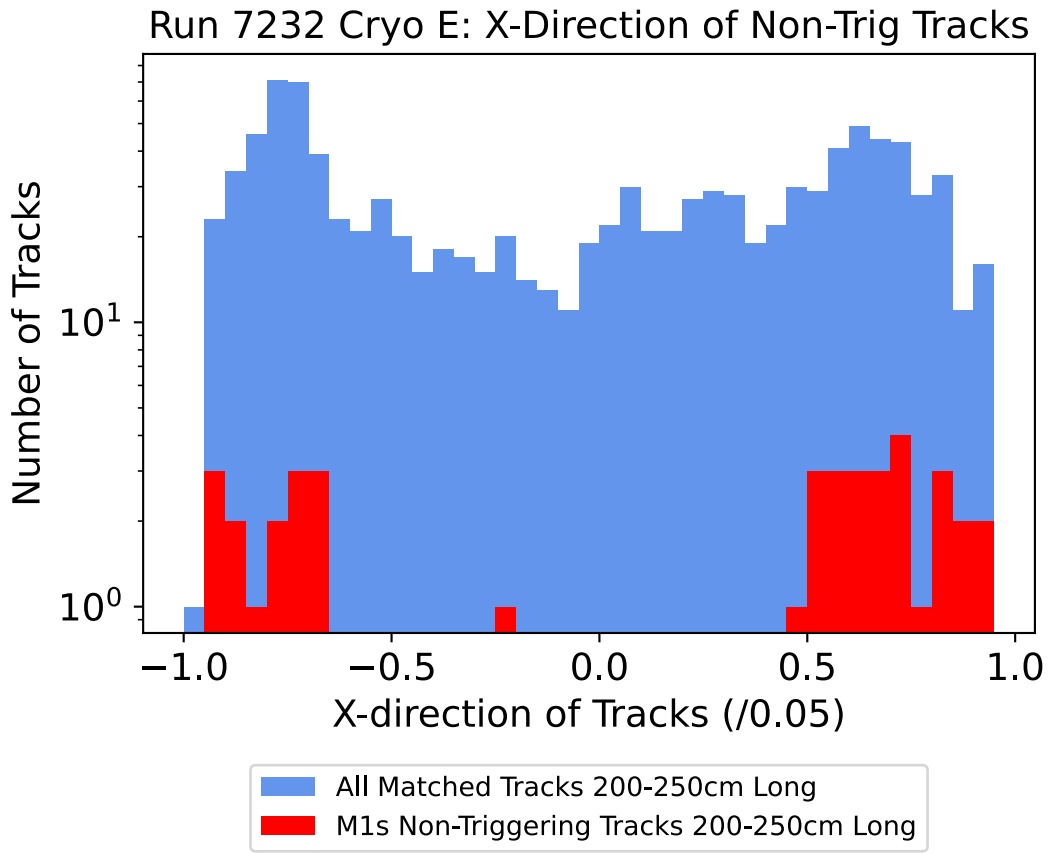


Possible Connection:

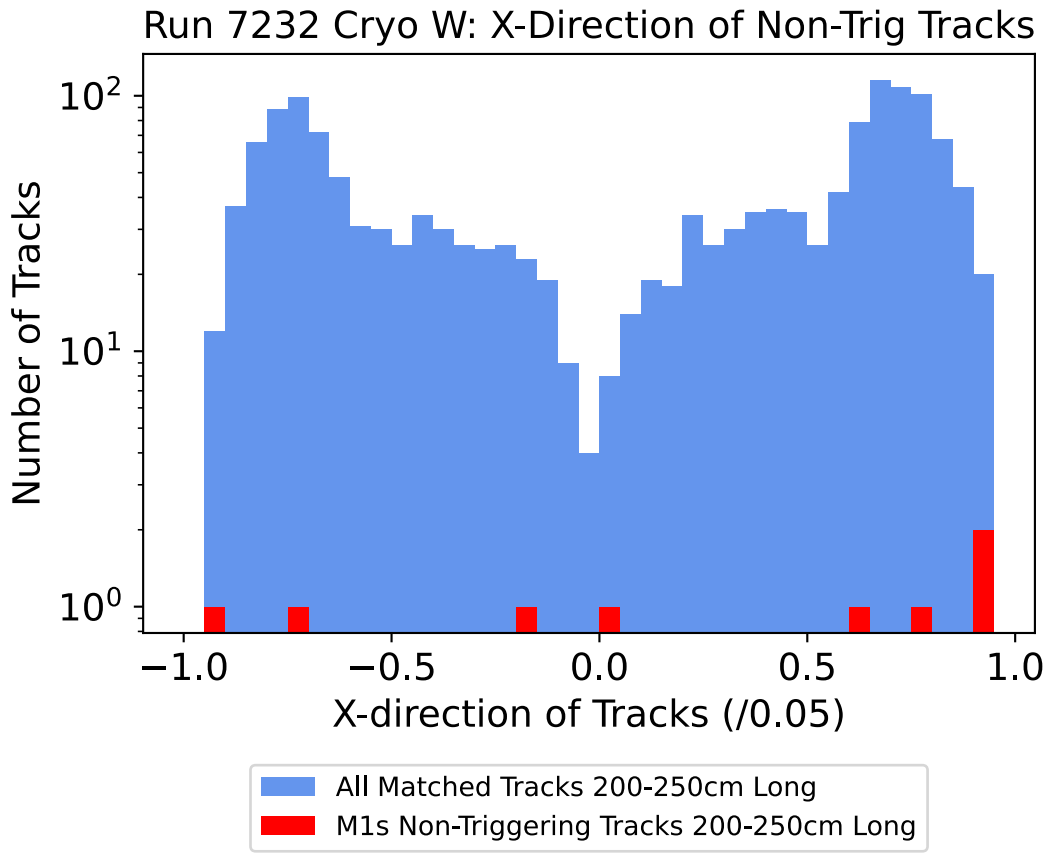
Large track angle along the x-axis

(-15 µs, 5 µs) Emulation Window

East Cryostat



West Cryostat



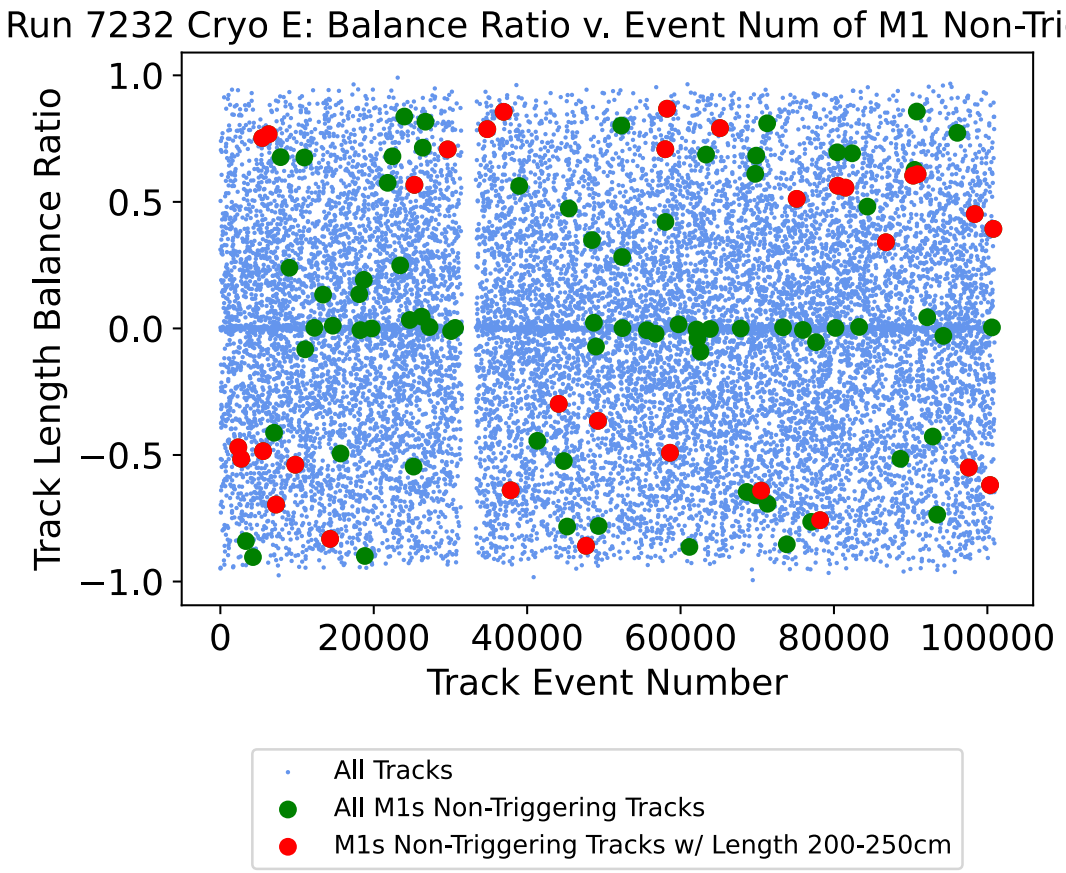
Ruled Out Connection:

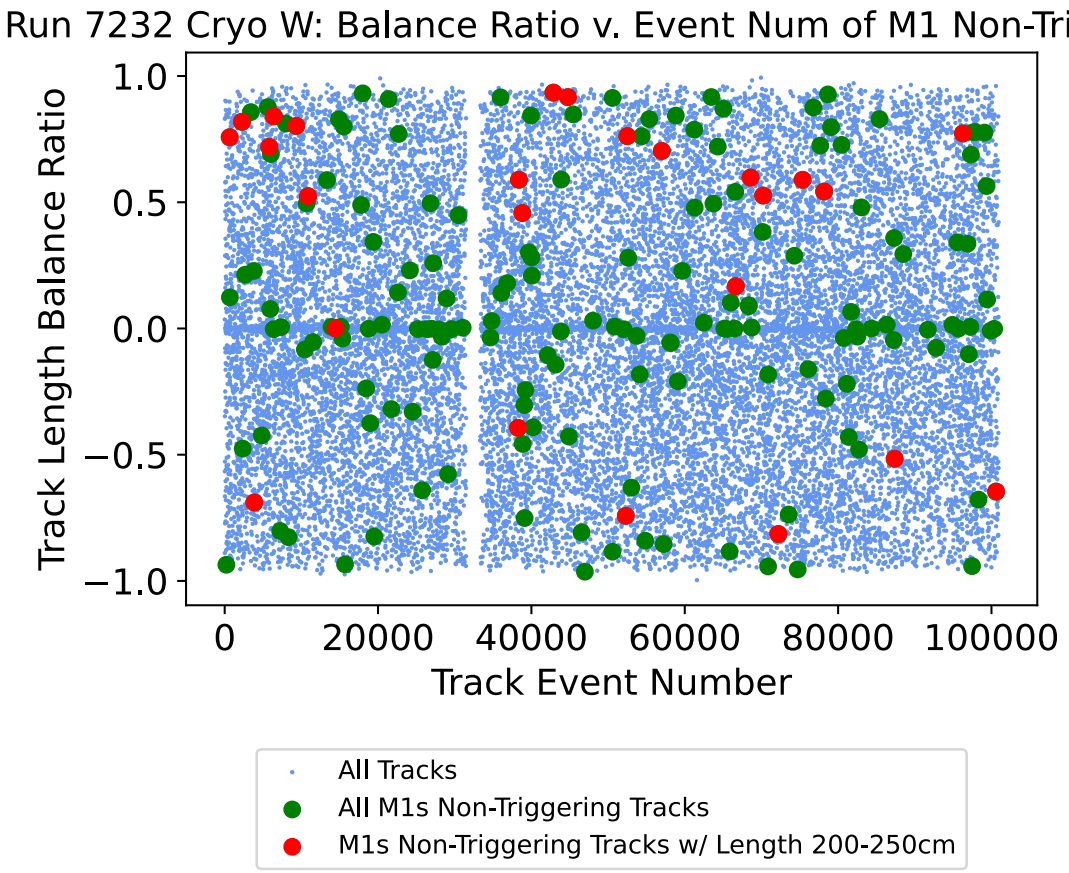
Not time dependent

East Cryostat

(-20 µs, 0 µs) Emulation Window

West Cryostat



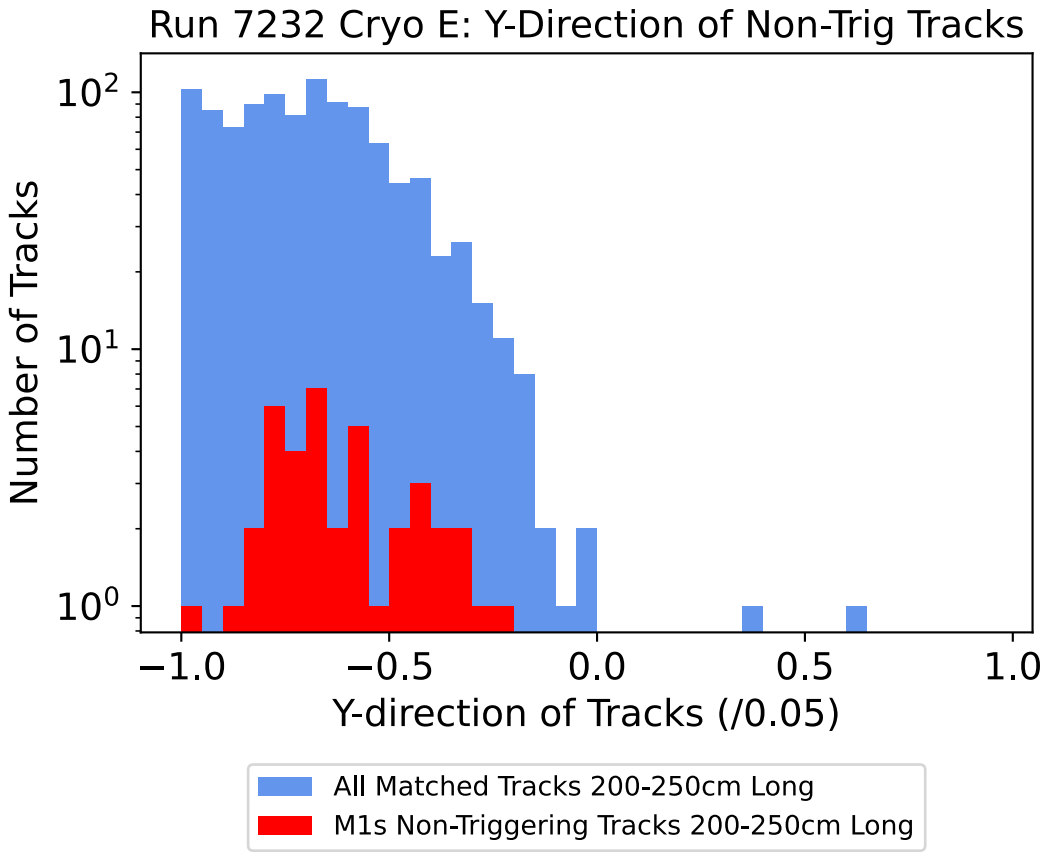


Ruled Out Connection:

Track angle along the y-axis

(-15 µs, 5 µs) Emulation Window

East Cryostat



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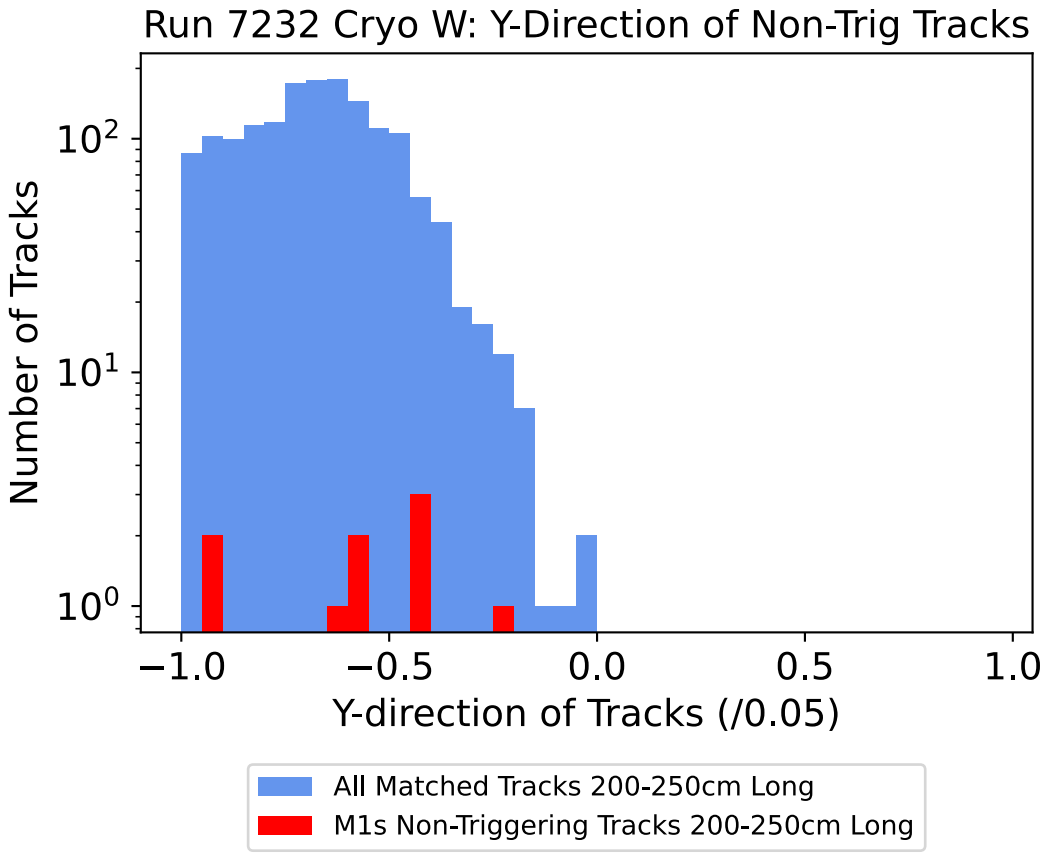
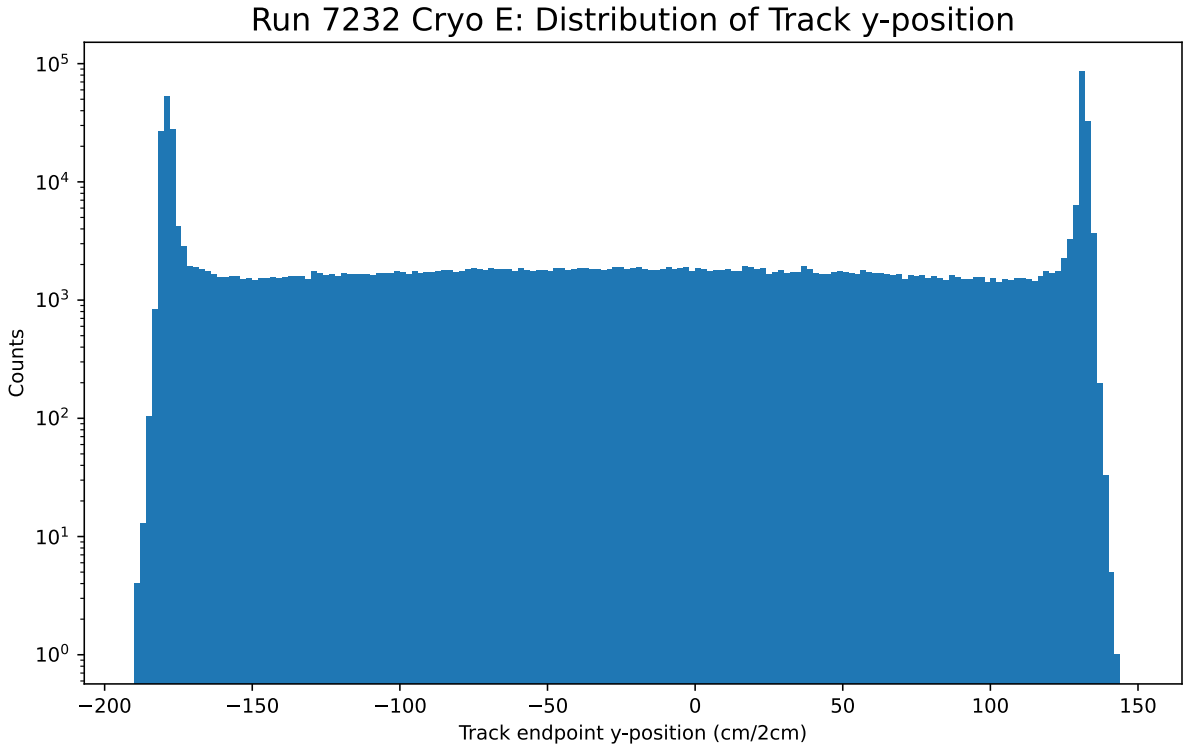
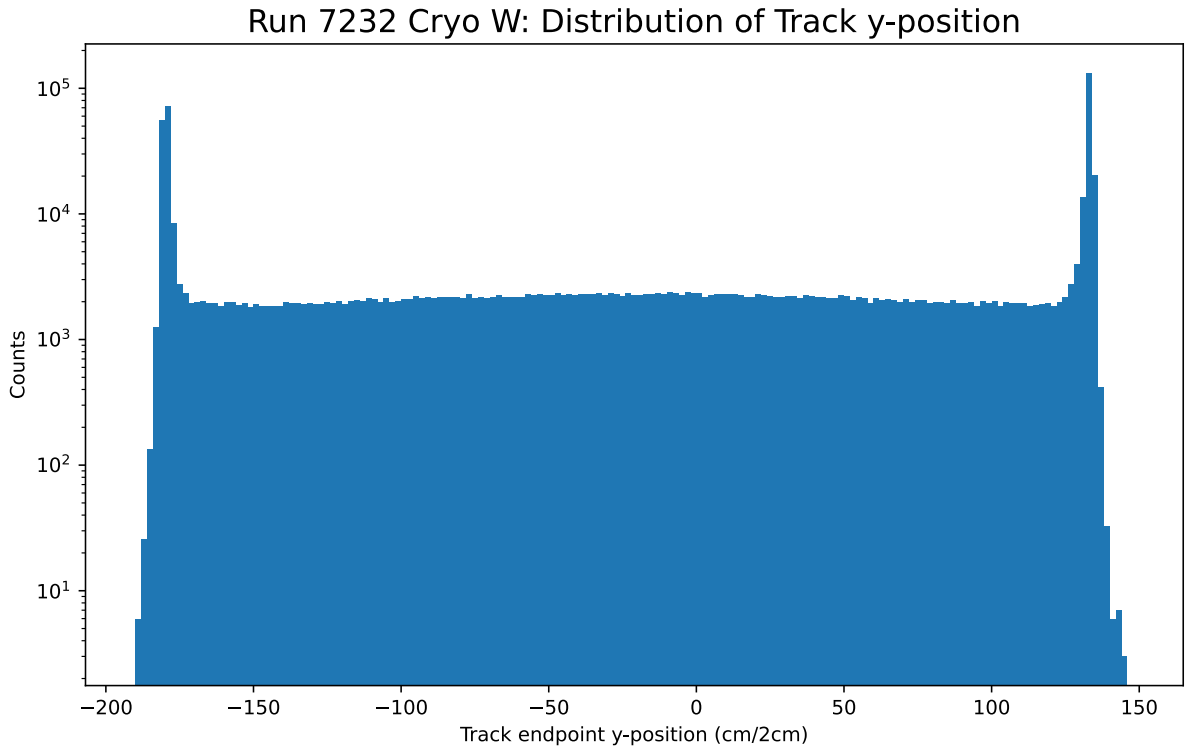


Y-axis Track Endpoint Distribution

East Cryostat



West Cryostat

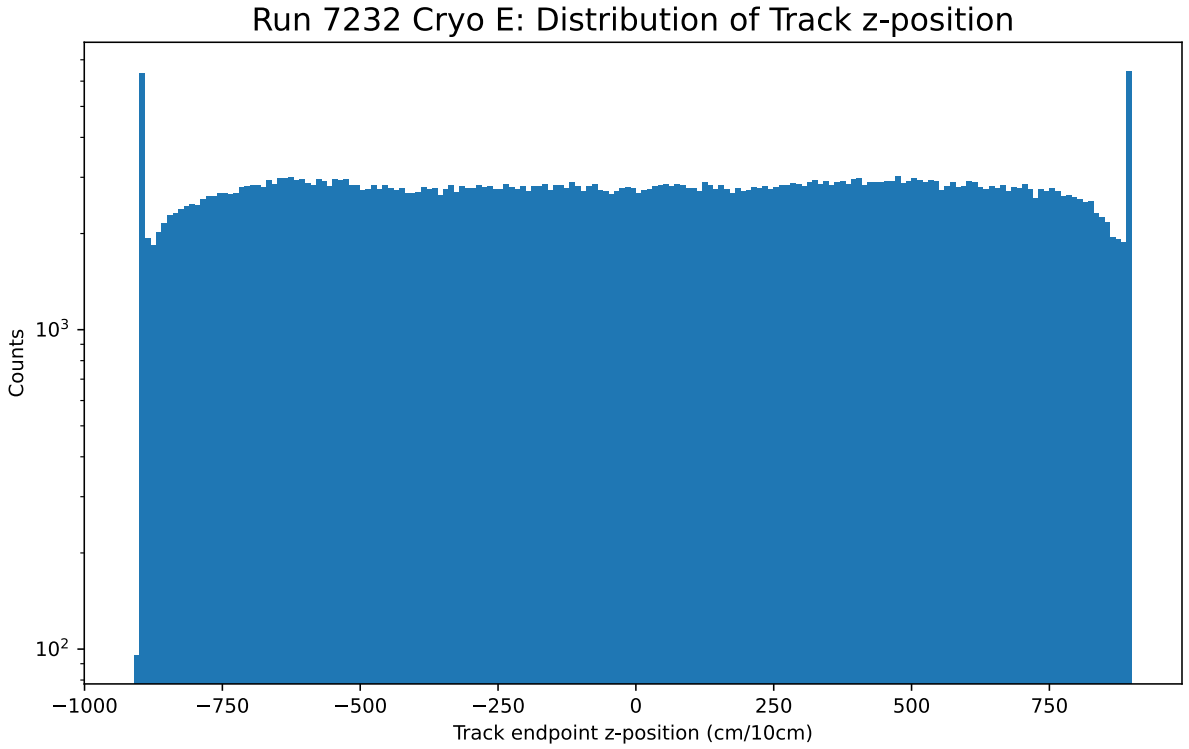


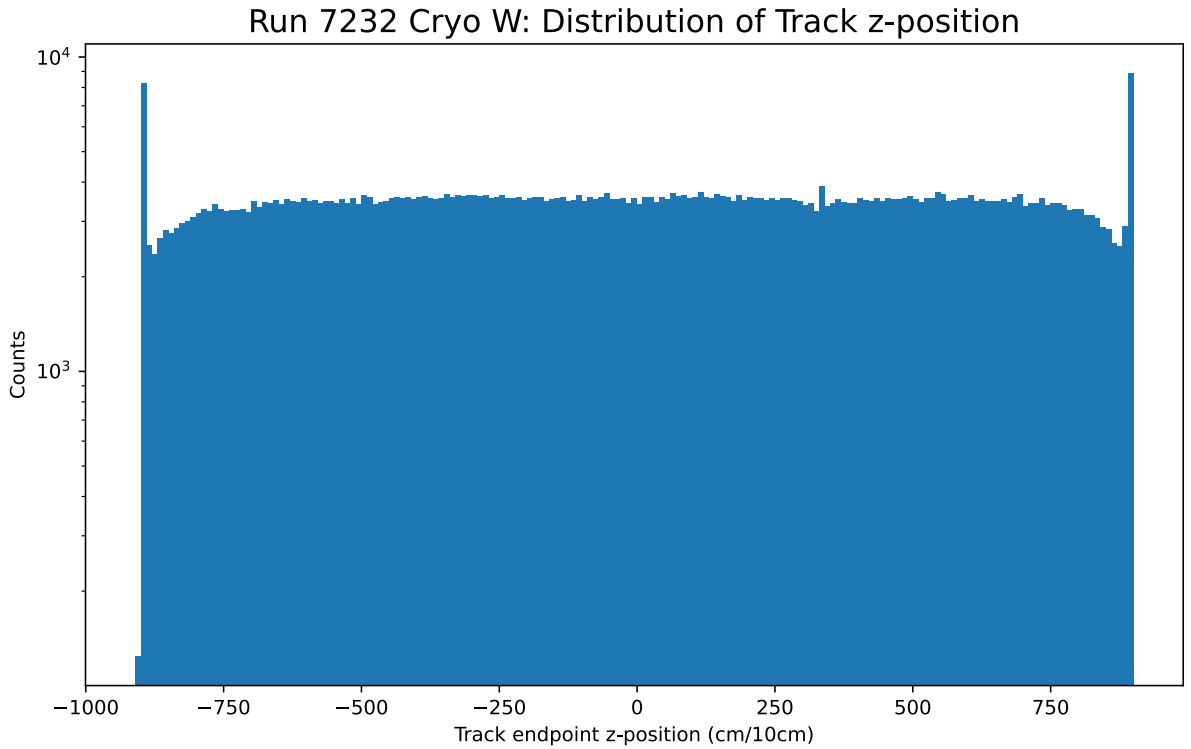
Z-axis Track Endpoint Distribution

East Cryostat

(-15 µs, 5 µs) Emulation Window

West Cryostat





X-axis Track Endpoint Distribution

East Cryostat

(-15 µs, 5 µs) Emulation Window

West Cryostat