Analyzing the Efficiency of the Trigger System in the ICARUS Neutrino Detector

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The ICARUS neutrino detector, a Liquid Argon Time Projection Chamber Detector, is the far detector in the Short Baseline Neutrino Program at Fermilab, which hopes to uncover new and exciting properties of neutrinos that may aid us in utilizing neutrinos to further scientific endeavors such as supernova research. ICARUS employs a trigger system to filter the massive amounts of data collected daily, keeping only the potentially interesting events for further analysis. My work centers around analyzing the efficiency of the trigger system. I use a software emulation of the trigger hardware to analyze the efficiency of different light requirement levels in filtering out background from datasets of particle tracks. I have analyzed the efficiency of the trigger system as a function of different track characteristics and uncovered the 2m track anomaly, a drop in efficiency of tracks roughly 2m in length compared to slightly shorter or longer tracks, which we believe is due to poor reconstruction of track times in the detector for these tracks.

Trigger Efficiency Analysis in the ICARUS Neutrino Detector

SULI Final Presentation

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SLAC NATIONAL ACCELERATOR LABORATORY

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Agenda

What is a Neutrino?

What is a Neutrino?

- Nearly massless, neutrally charged elementary particles that are very difficult to detect
- Formed as a byproduct of nuclear reactions
- Many potential applications, including in nuclear weapons safety and supernova research
- Many properties yet to be understood

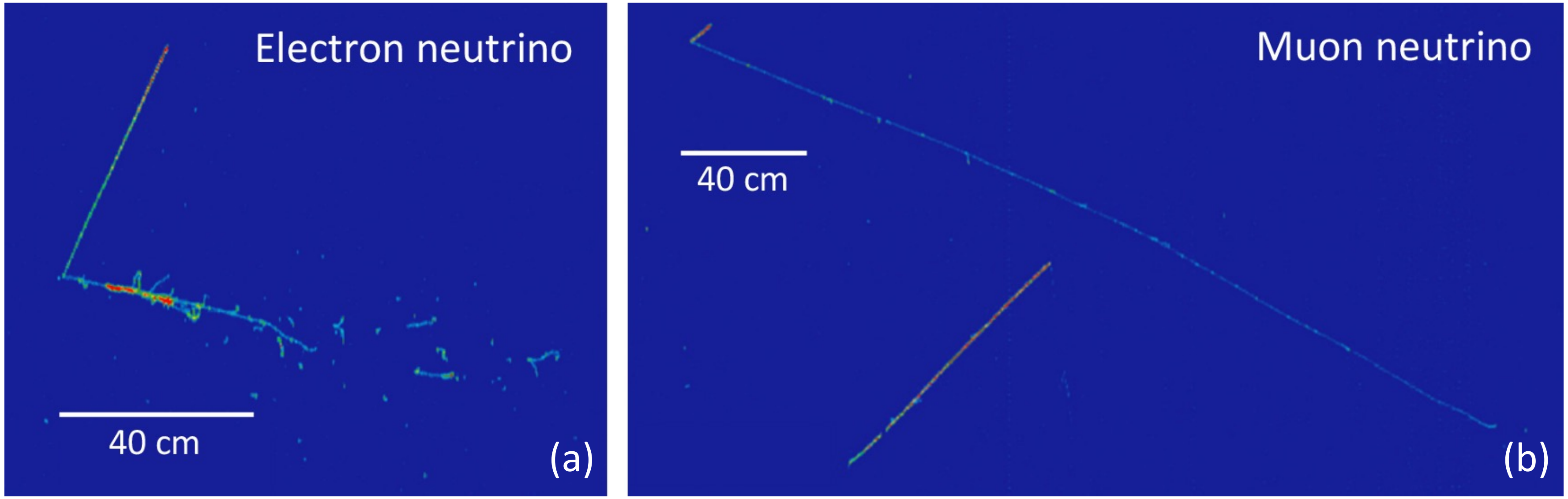

Figure 1. (a) Electron neutrino entering detector from the left, interacting to turn into an electron and a secondary particle. (b) Muon neutrino entering detector from the top left, interacting to turn into a muon (long track) and secondary particle (short track). Image credits: ICARUS collaboration

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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

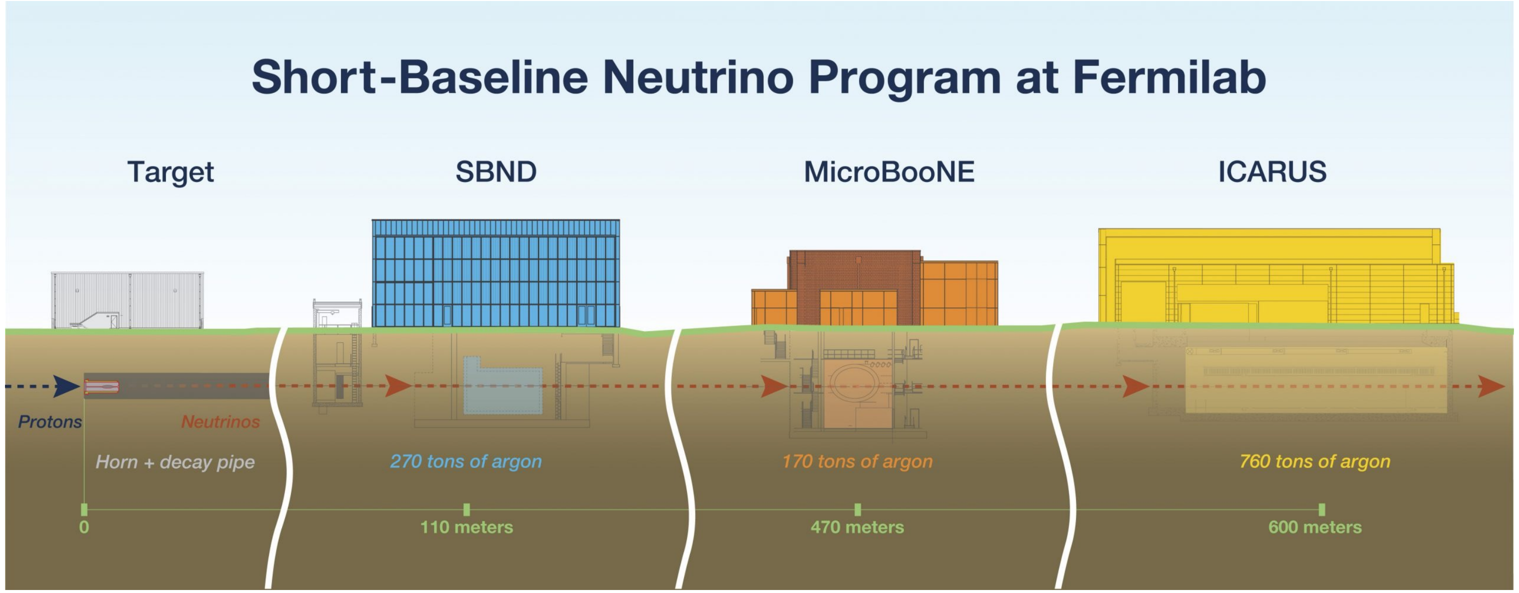

Figure 2. Overview of SBN at Fermilab. Image credits: ICARUS collaboration

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

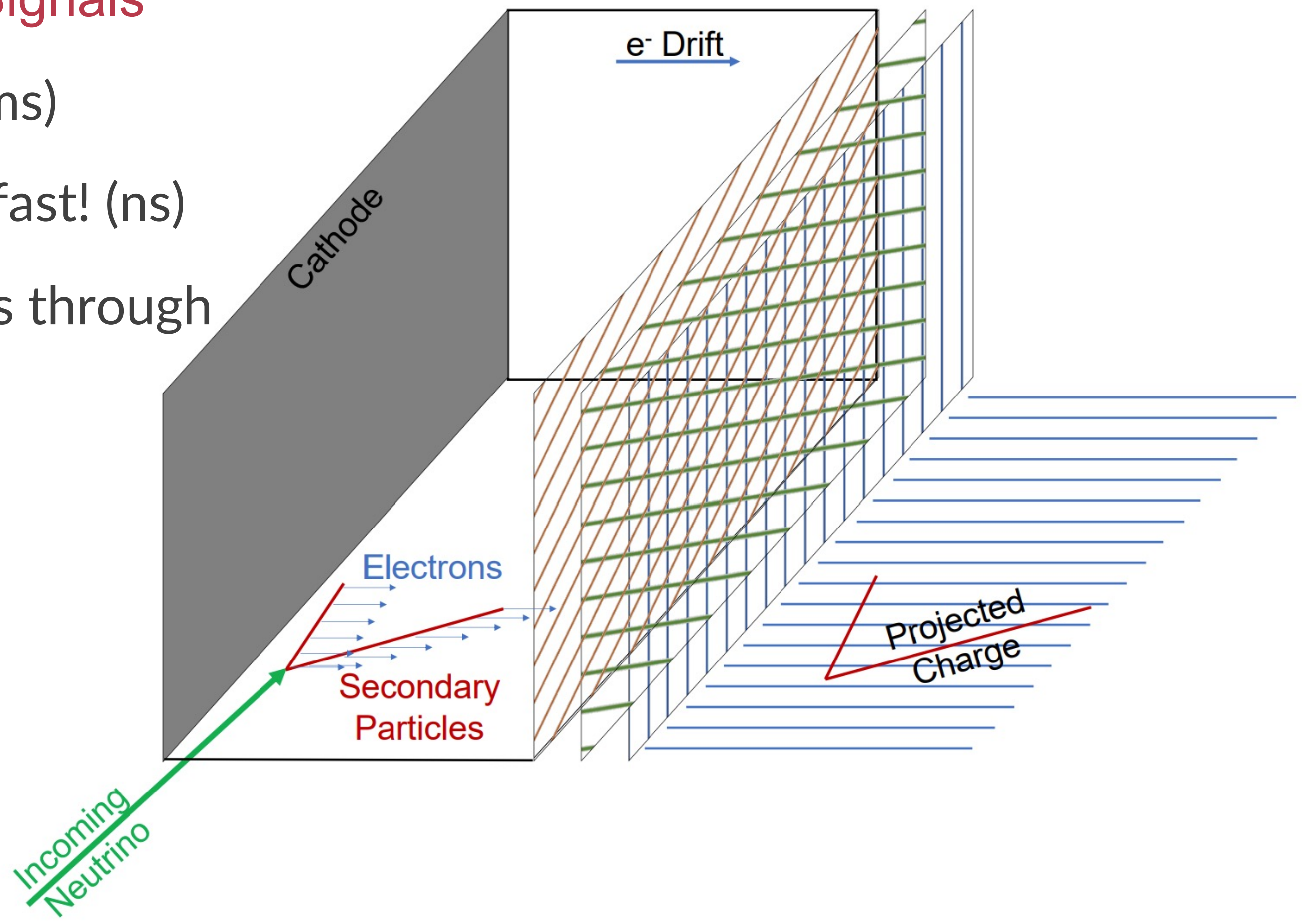

Figure 3. Overview of Liquid Argon Time Projection Chamber (LArTPC). Image Credits: ANL, FNAL.

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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

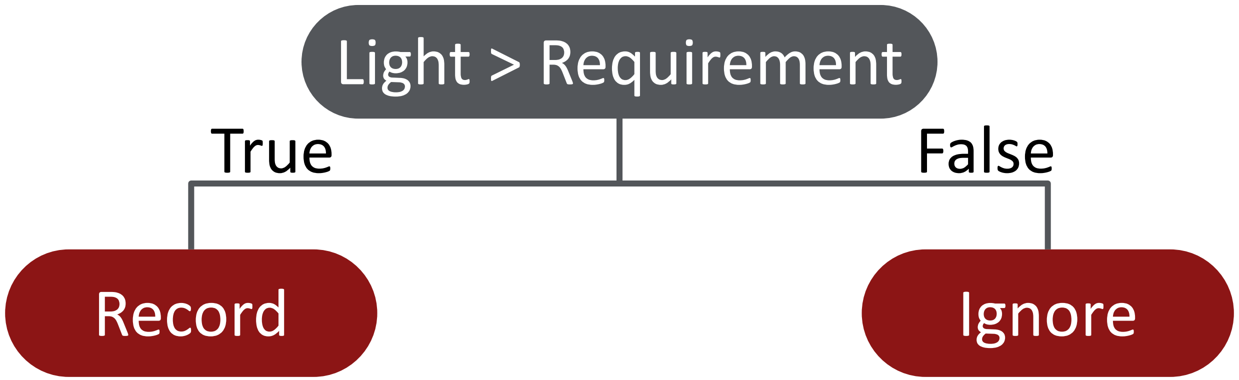

Figure 4. ICARUS Trigger System Logic.

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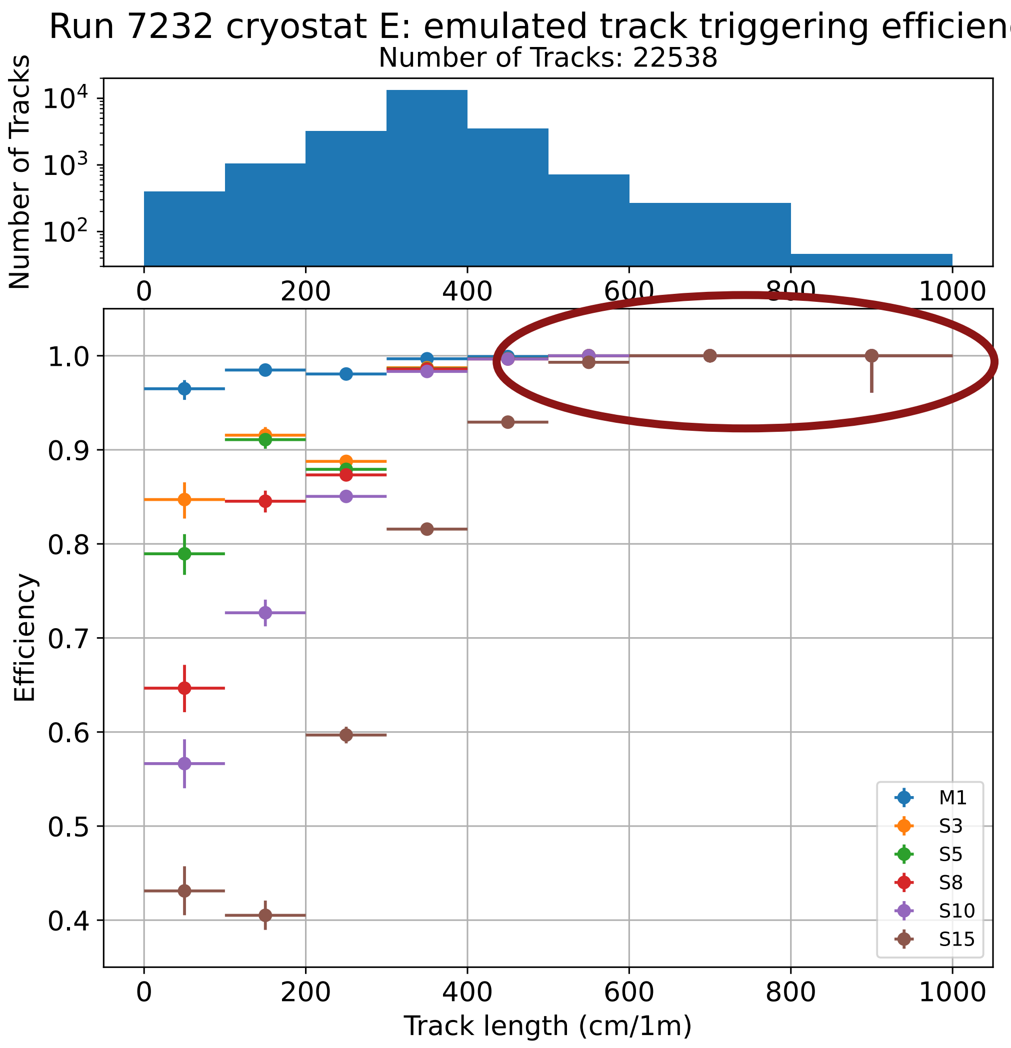
Efficiency Analysis

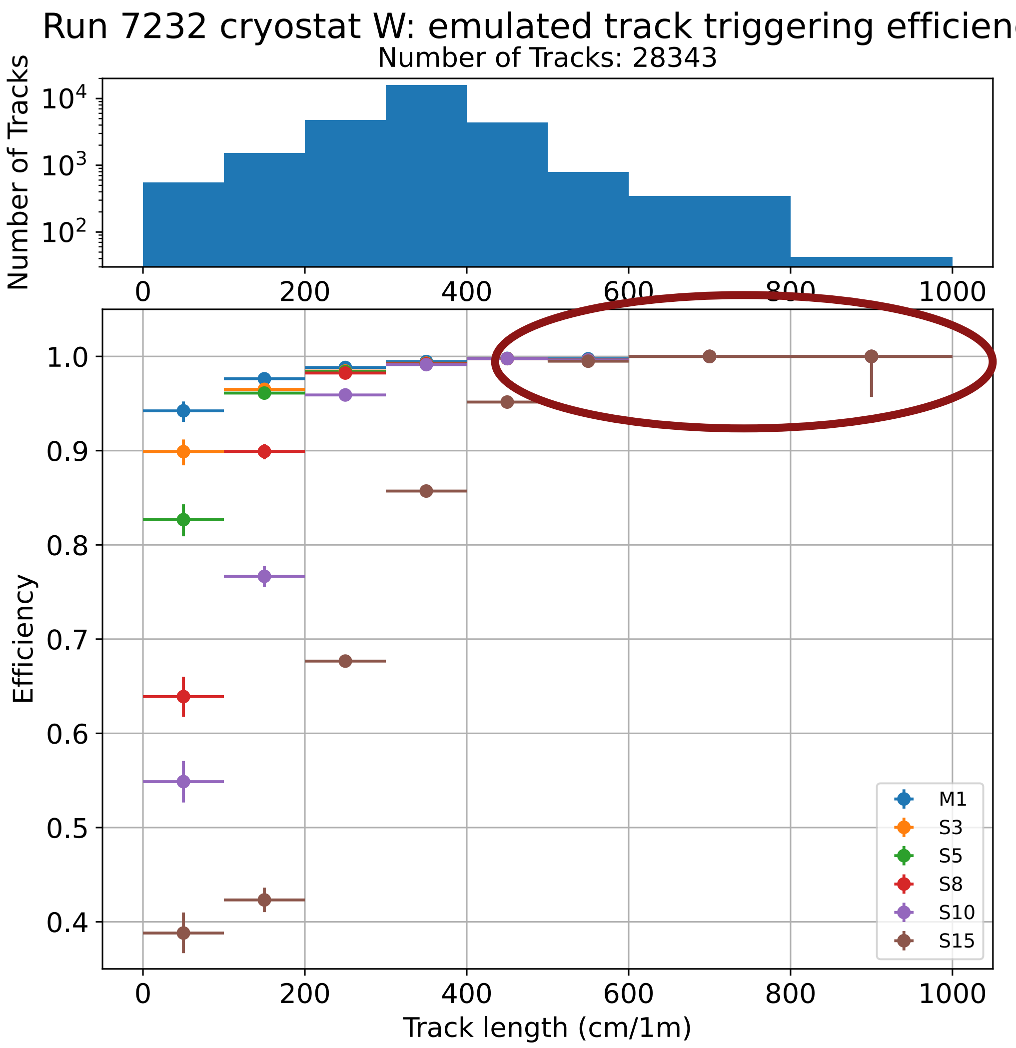
What does our data look like?

- “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

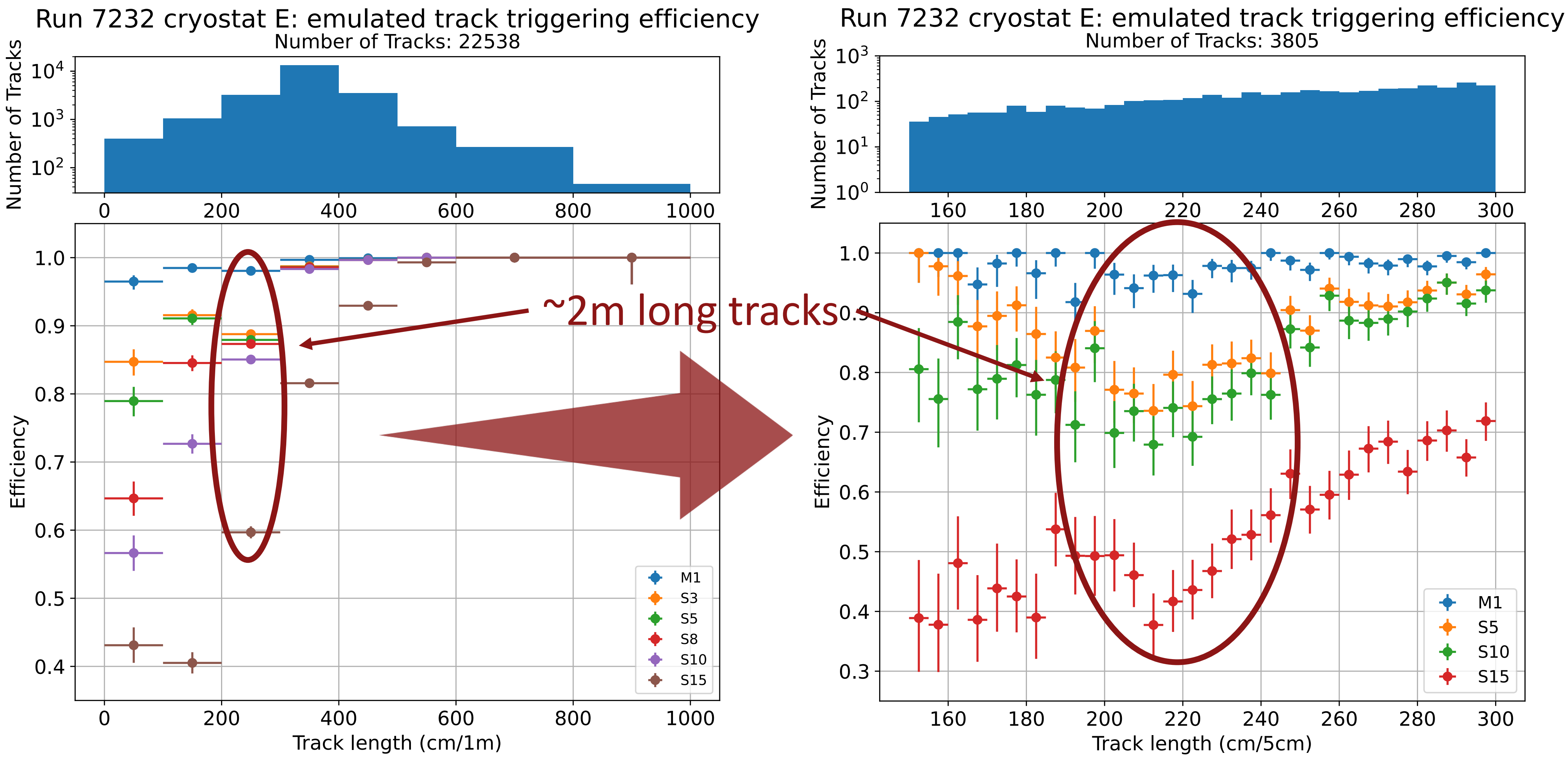
$$\text{Efficiency} = \frac{\text{selected tracks that would trigger}}{\text{selected tracks}}$$

Efficiency of Trigger as a function of Track Length





Efficiency of Trigger as a function of Track Length



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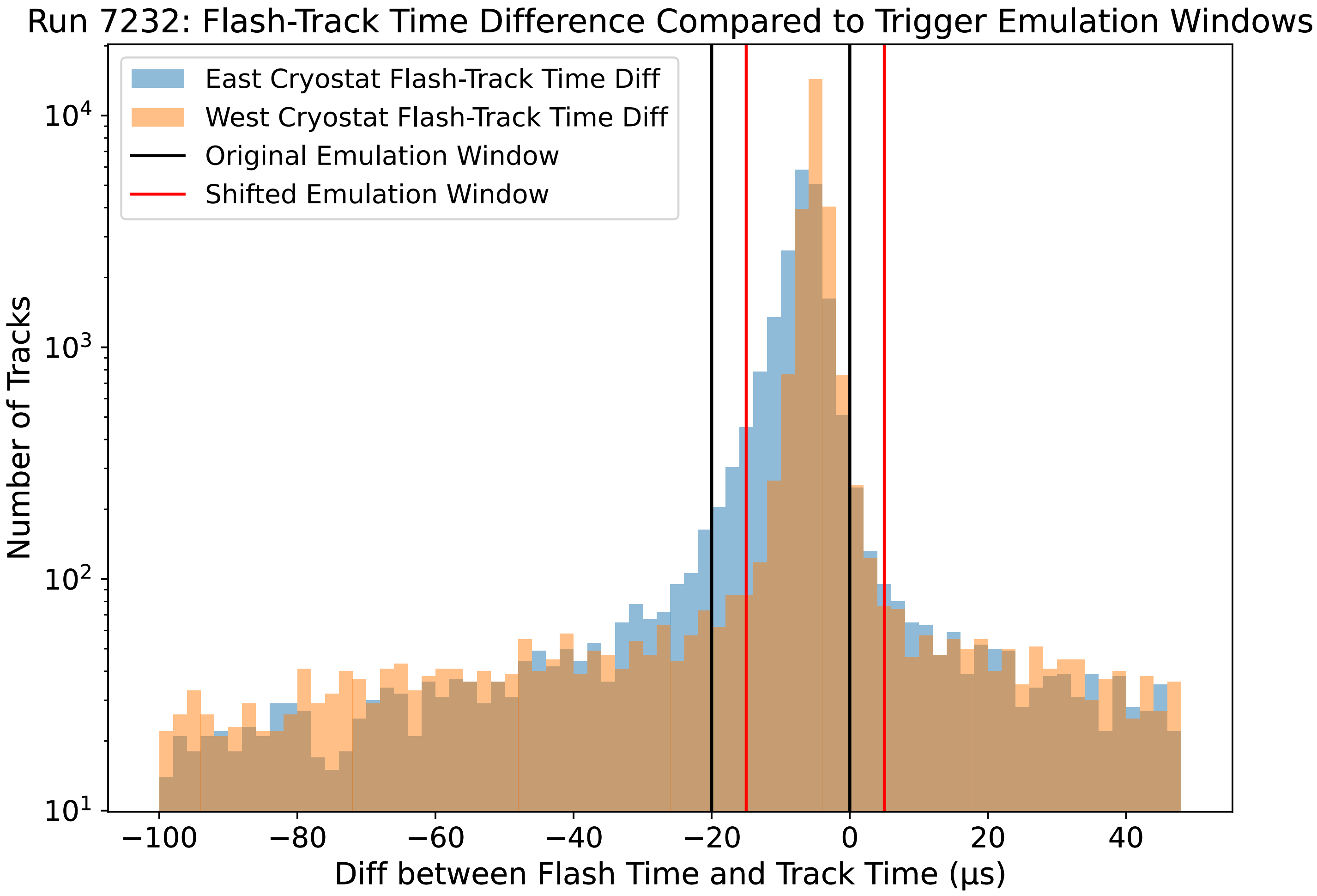
The 2m Track Anomaly

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

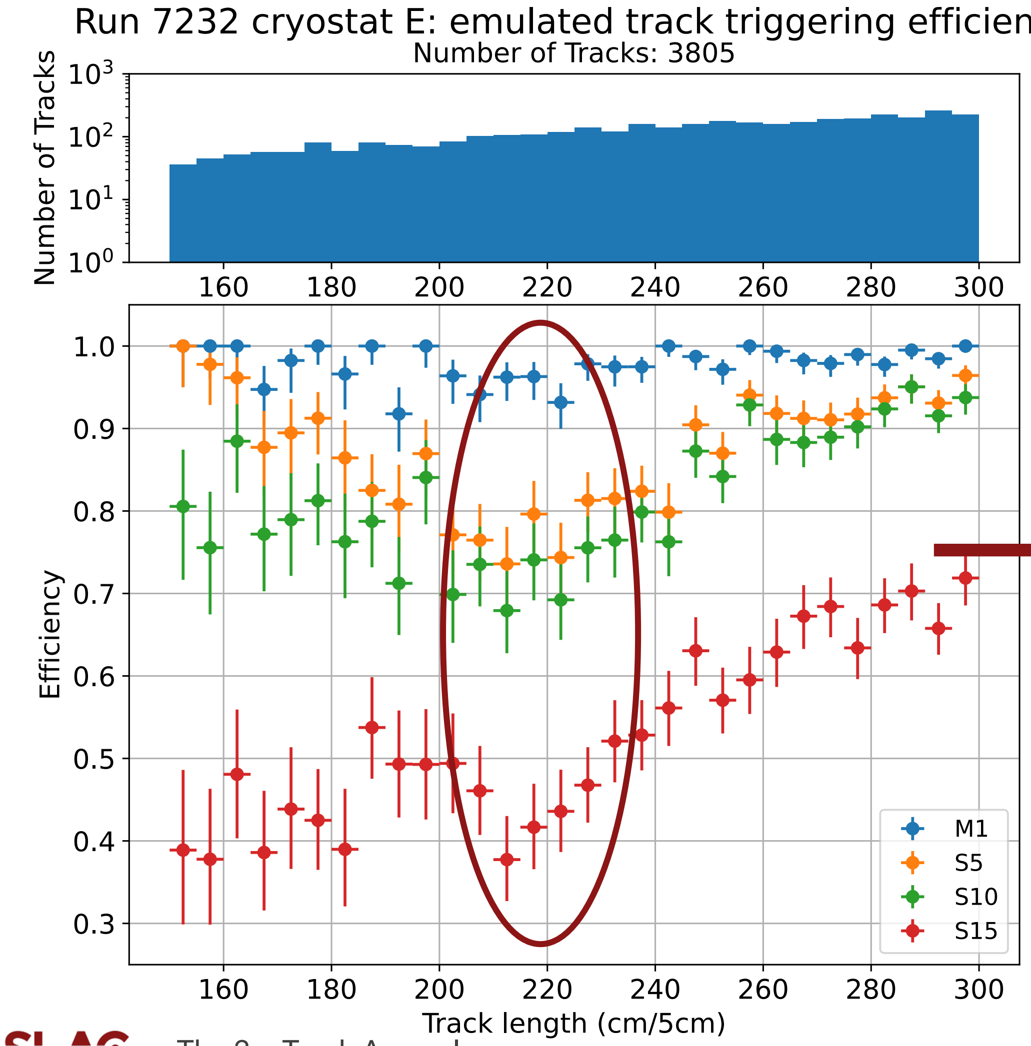


Possible Solution:

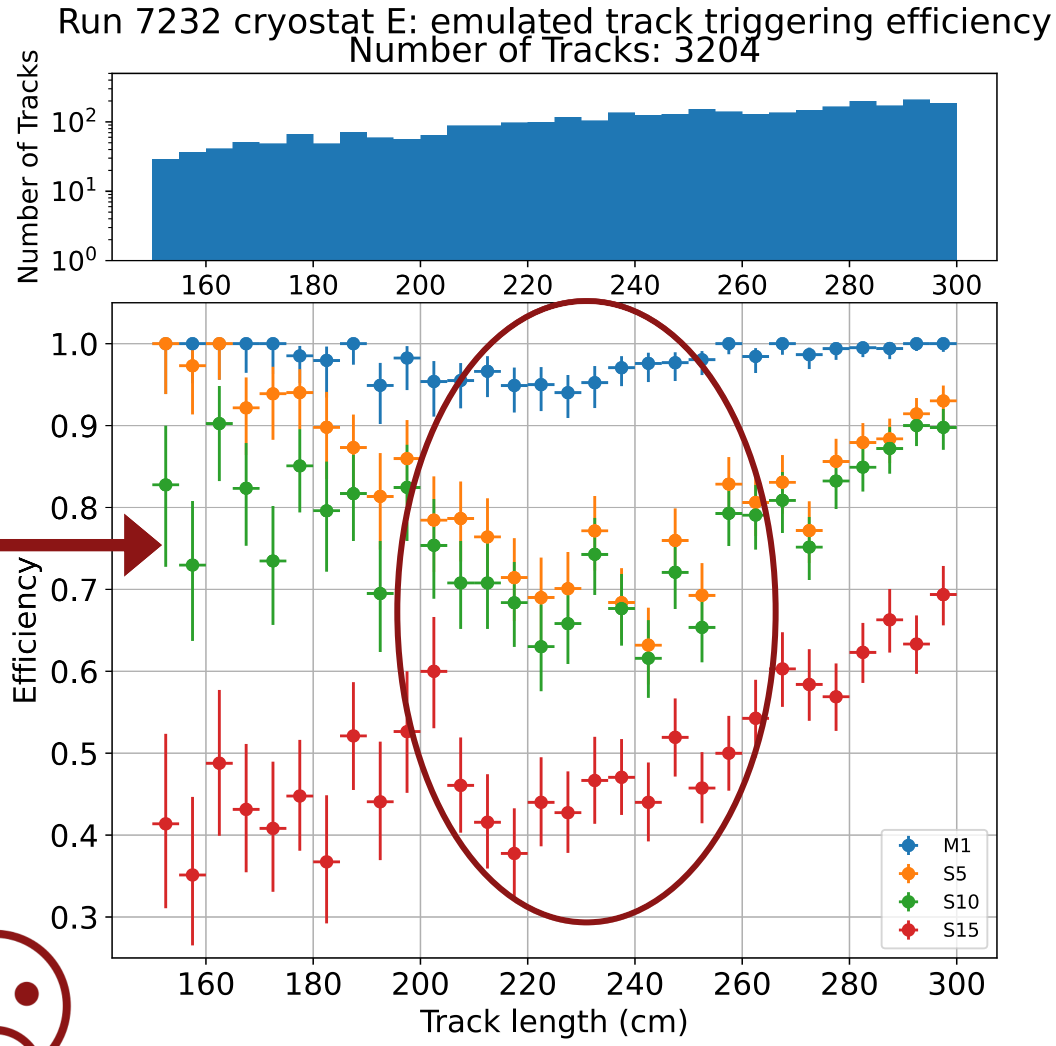
- In Trigger Emulation software, we look for light in a 20 µs window before the track time (t0), and check whether that light exceeds chosen light requirement level
- Most tracks of length ~2m that failed to trigger matched to light occurring <5µs after t0
- Shifted window later by 5 µs to see whether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

Shifting the Trigger Emulation Window: East Cryostat

Original Emulation Window

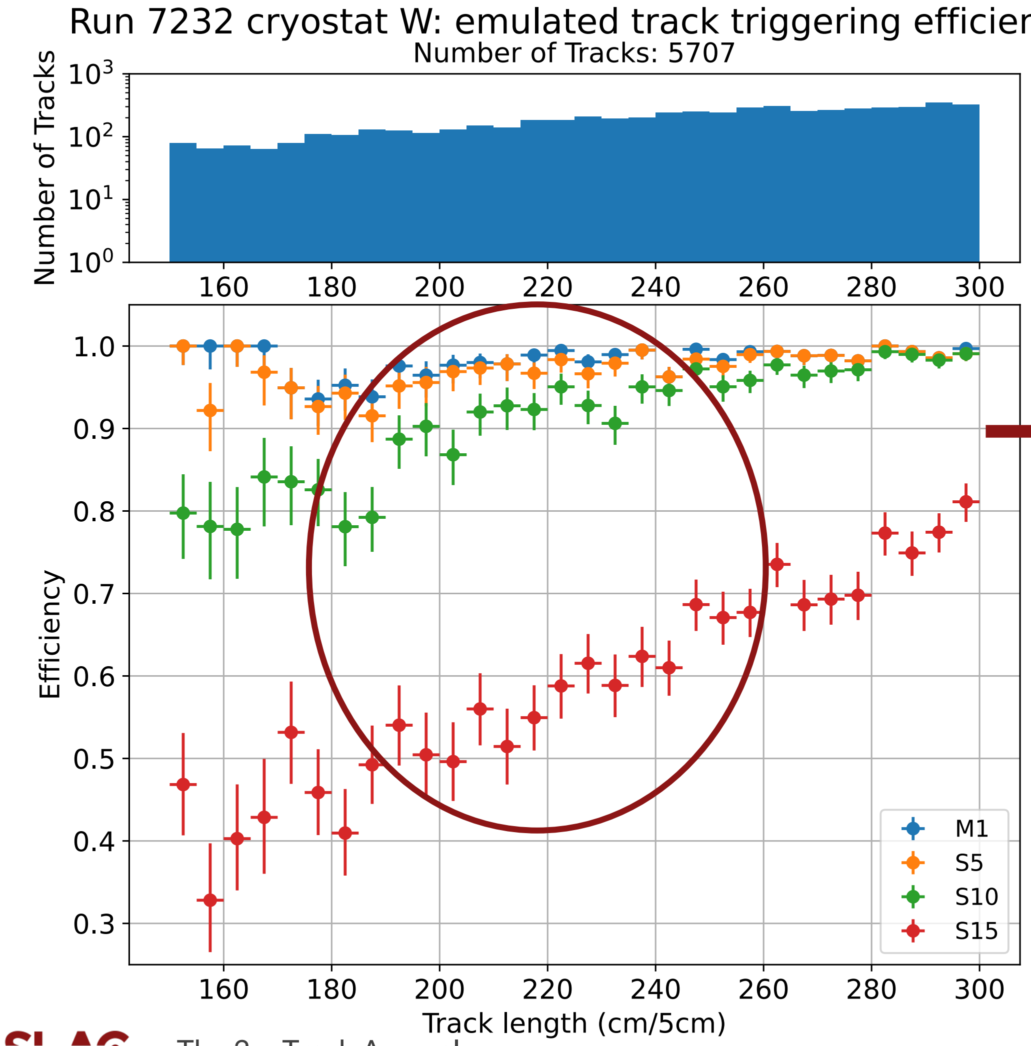


Shifted Emulation Window

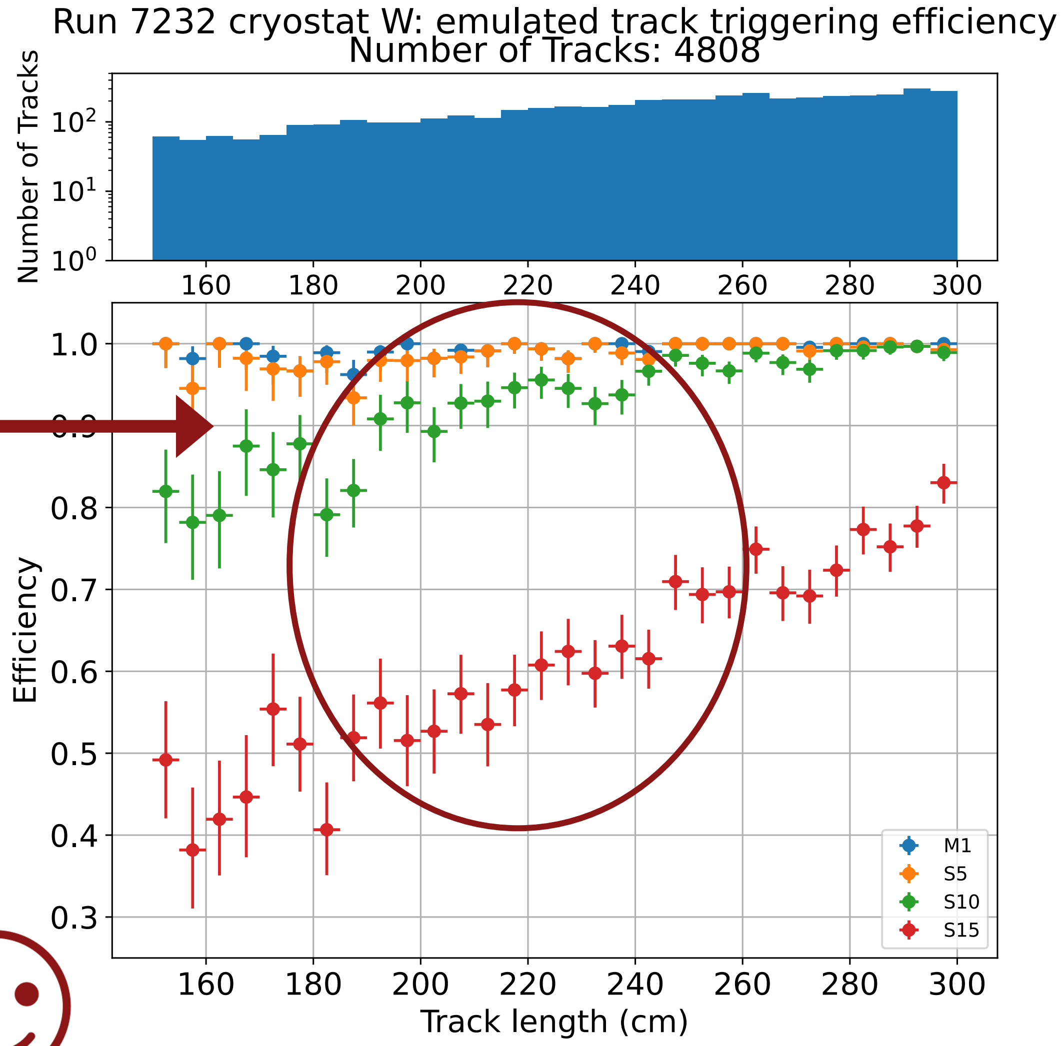


Shifting the Trigger Emulation Window: West Cryostat

Original Emulation Window



Shifted Emulation Window



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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 What is a Neutrino?

2 Detector Overview

3 Trigger System

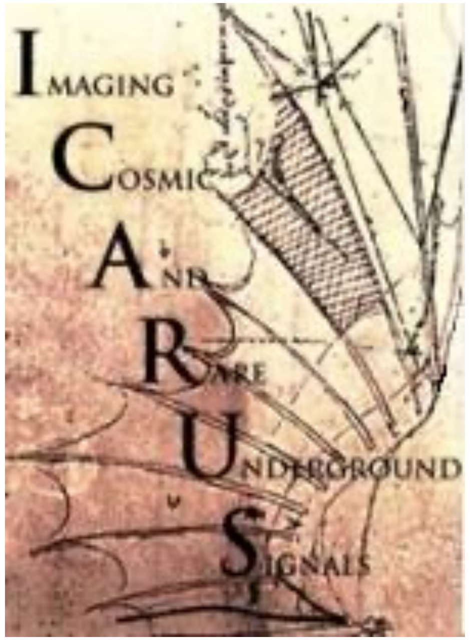
4 Efficiency Analysis

5 The 2m Track Anomaly

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, the DOE, and everyone here for listening to my talk!



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Thank you for listening! Any questions?