Summer Progress Report: Trigger Efficiency Analysis

ICARUS Data-Driven Trigger Efficiency Measurement

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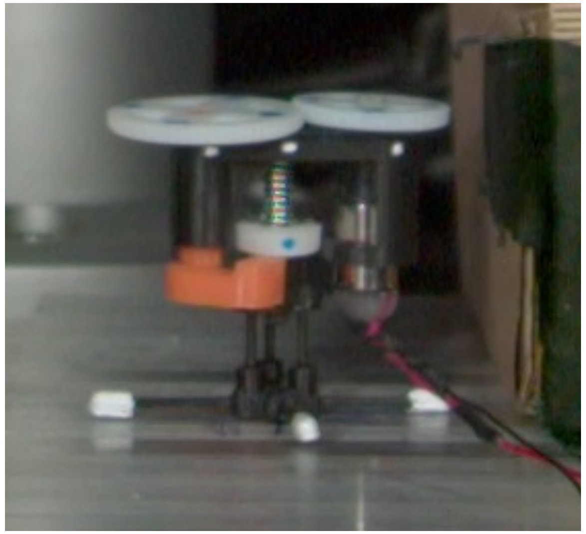
SLAC SULI Intern 2022

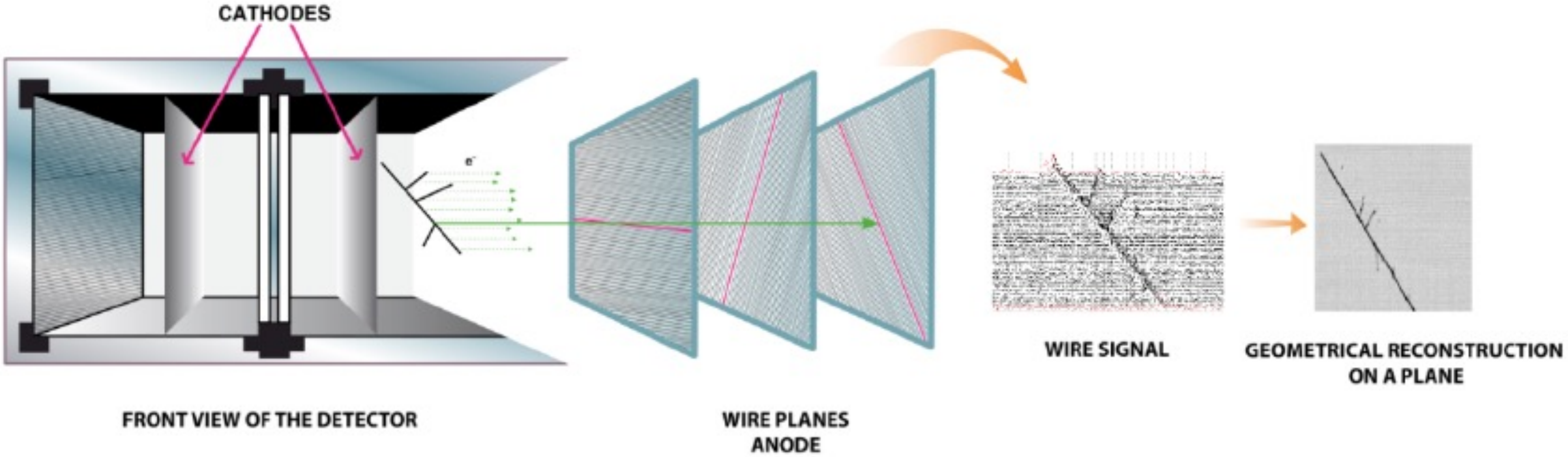
About Me

- I’m a rising Junior at Harvey Mudd College
  - Major: Physics and Computer Science
  - HSA Concentration: Music
- My previous research experience is mostly in robotic biophysics, with a little bit of theoretical particle physics
- In my free time, I like to bake and crochet!



ICARUS

- LArTPC with PMTs and 2 cryostats (East and West)
  - 2 TPCs (East and West) in each cryostat (drift volumes, from cathode to anode)
  - The cathodes are 57% transparent to light
  - Wire planes at the anode to reconstruct tracks



Rubbia, C & Antonello, M. & Aprili, P. & Baibussinov, B. & Baldo-Ceolin, M. & Barze, Luca & Benetti, P & Calligarich, E & Canci, Nicola & Carbonara, F. & Cavanna, Flavio & Centro, Sandro & Cesana, A & Cieslik, Krzysztof & Cline, D. & Cocco, Alfredo & Dabrowska, Anna & Dequal, Daniele & Dermenev, A & Zmuda, J.. (2011). Underground operation of the ICARUS T600 LAr-TPC: first results. Journal of Instrumentation - J INSTRUM. 6. 10.1088/1748-0221/6/07/P07011

Motivation

- The ICARUS detector generates hundreds of terabytes of data daily
- The trigger system filters and keeps only potentially interesting events, reducing the amount of data storage required
  - Trigger logic is based on the collected scintillation light by the PMTs
  - Majority is the number of PMT pairs above a set threshold
- It is important to study the efficiency of the trigger in order to select the optimal level of filtering for the trigger
- We plotted the efficiency as a function of different track characteristics (length, starting and ending x coordinate, starting z coordinate)
- We plotted the efficiency under different emulated trigger settings:

M1: 1 PMT pair trigger	S3: 3 PMT pairs trigger
S5: 5 PMT pairs trigger	S8: 8 PMT pairs trigger
S10: 10 PMT pairs trigger	S15: 15 PMT pairs trigger

  - We use a trigger emulation with a minimum bias run (without the hardware trigger running) so that we have an unbiased sample to analyze with different thresholds

Goals

- Cathode-Crossing Tracks
  - These are currently the only tracks for which we can reconstruct the time of the track (t0), so the only tracks that we can match to the corresponding PMT flashes and emulate the trigger performance for.
  - Recreate efficiency plot v. track length by J. Zettlemoyer
  - Explore trigger efficiency as a function of other variables
- CRT-matched tracks
  - Explore trigger efficiency for a larger variety of tracks (less restrictive sample)
    - The CRT (cosmic ray tagger) is on the outside of the detector, and when we combine the data it collects with the data from the TPCs we can reconstruct the times of tracks that did not cross the cathode. This allows us to analyze a more general sample.
  - This sample is not yet ready, so I have been working with the cathode-crossing track data so far

Methods

- Data from minimum bias run 7232
  - Full TPC readout (1.6 ms), Single PMT buffer readout (150 µs)
  - Data provided by J. Zettlemoyer, the same dataset he used
- Plotted the efficiency of the emulated triggers given by the following formula:

$$\epsilon = \frac{(TPC\ tracks\ with\ light\ info) \cdot (which\ would\ fire\ the\ trigger)}{TPC\ tracks\ with\ light\ info}$$

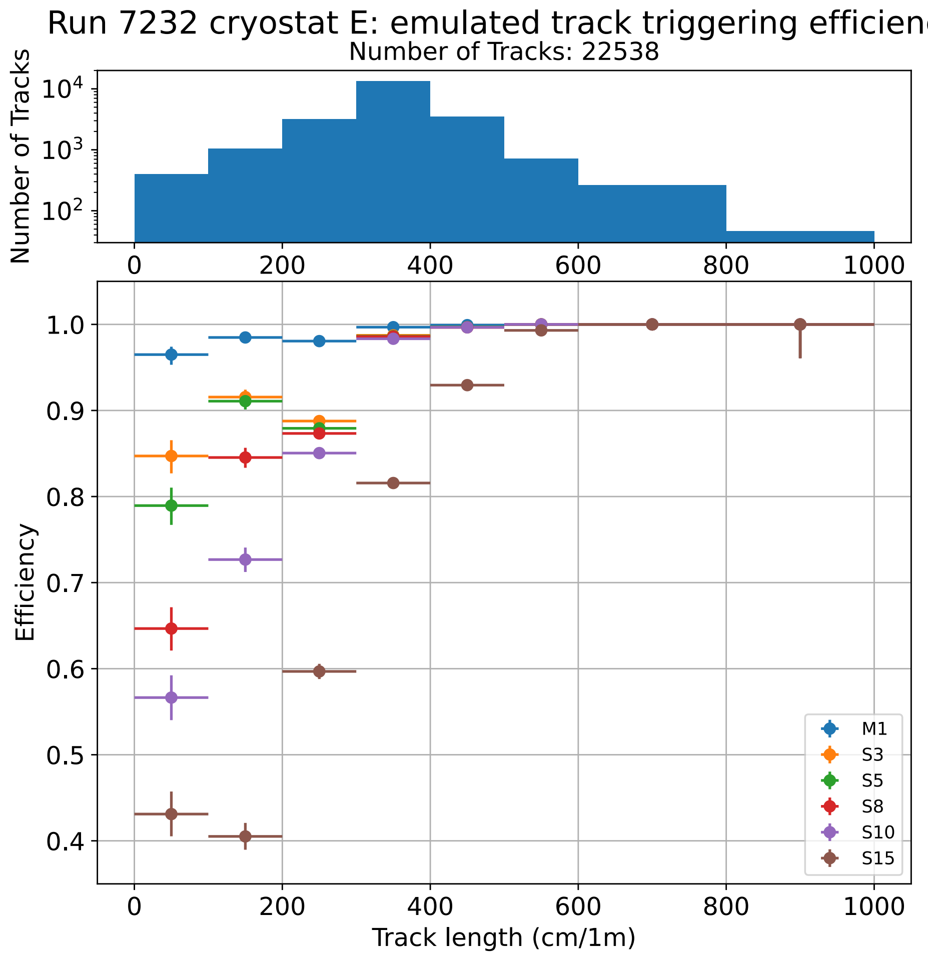
- Only counted TPC tracks with t0 within -55 and 75 µs to fully contain a 20 µs interval for trigger evaluation
- Estimated error in efficiency using an “exact” Clopper-Pearson interval with a confidence level of 68.3%

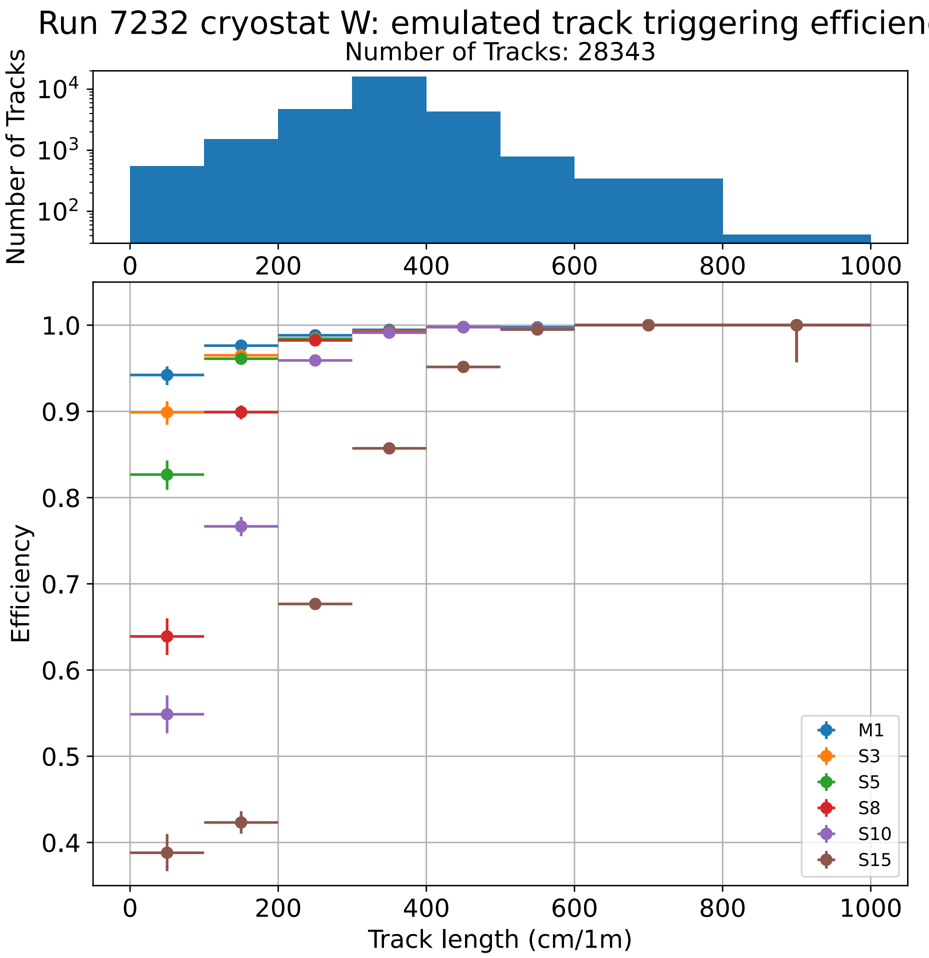
Efficiency Plots

Using reconstructed cathode-crossing tracks from a minimum-bias data run with different trigger emulations, comparing East and West cryostats

Track length

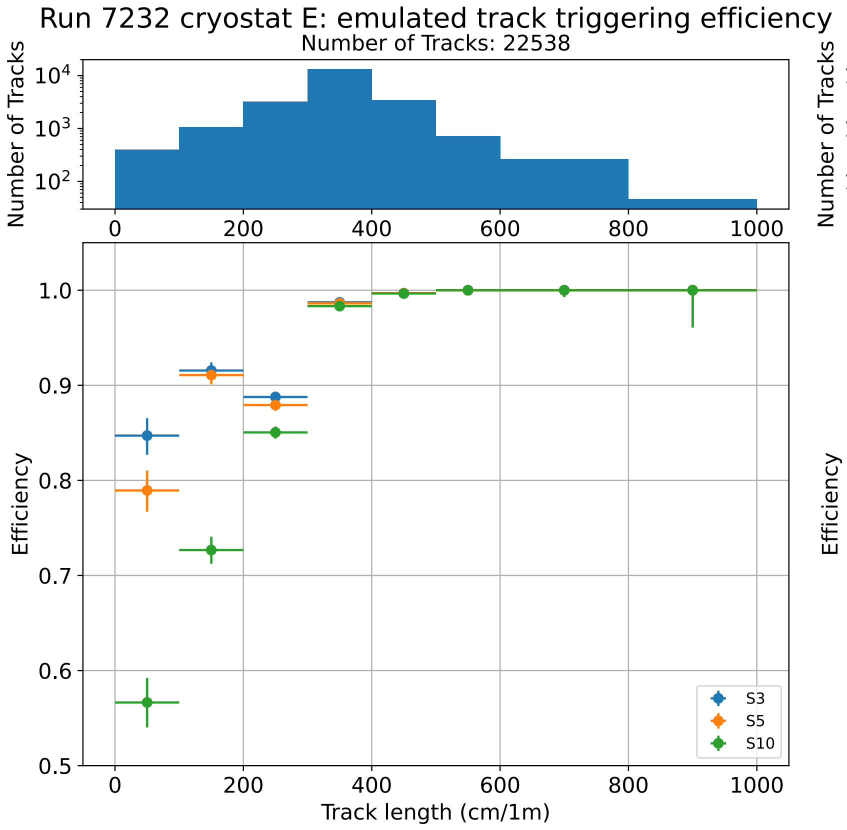
- There were very few (<0.05%) tracks longer than 1000 cm, so I focused on tracks shorter than 1000 cm
- Longer tracks have more energy and so we detect more light from them, so they're easier to trigger
- Cosmic muons are usually long but muons from neutrino events are not necessarily so

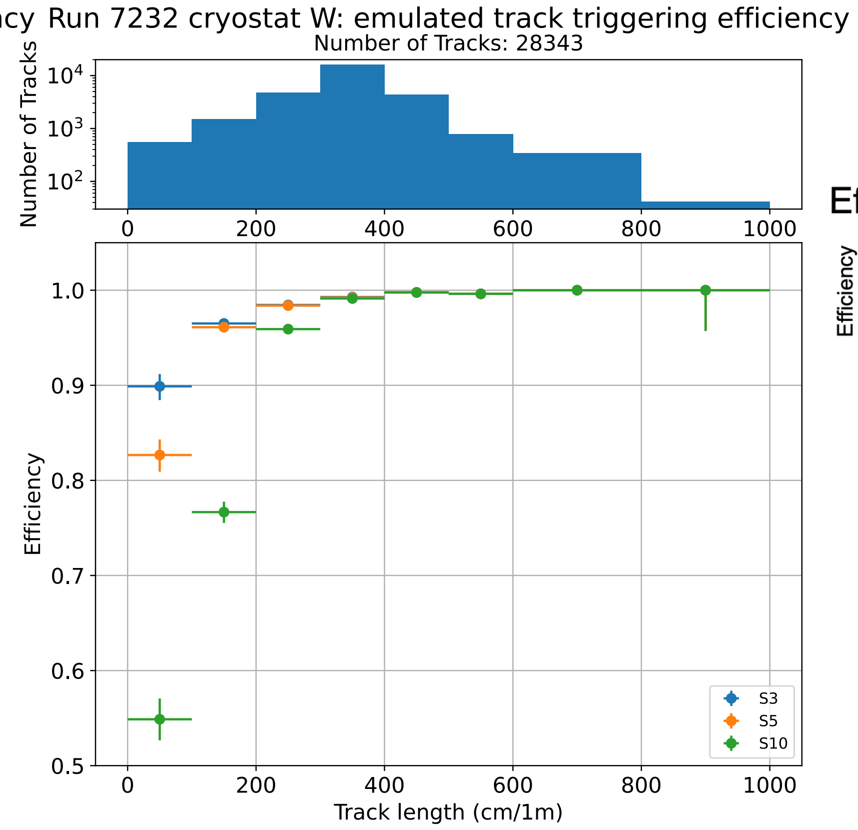


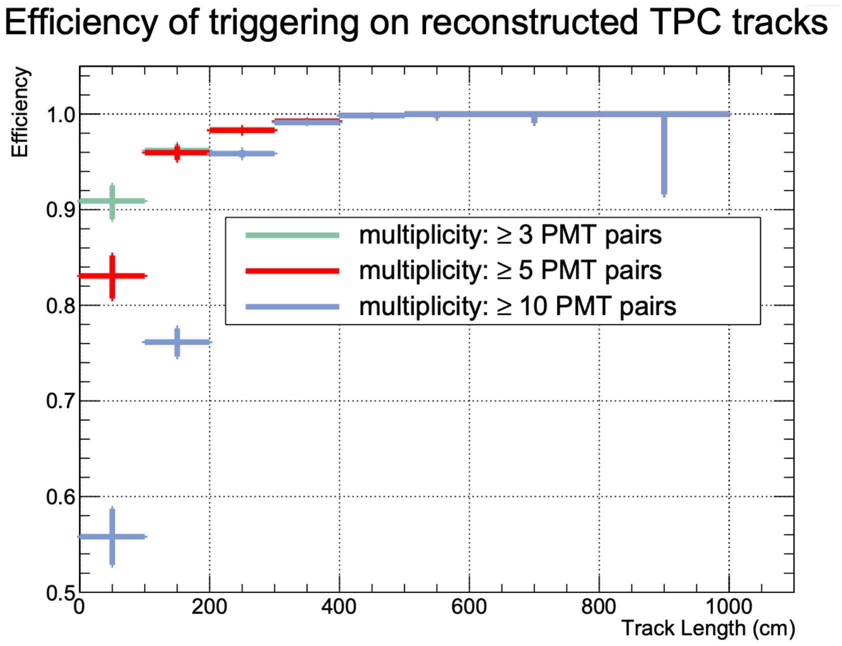


Track length

- Recreated plot of trigger efficiencies by Jacob Zettlemoyer

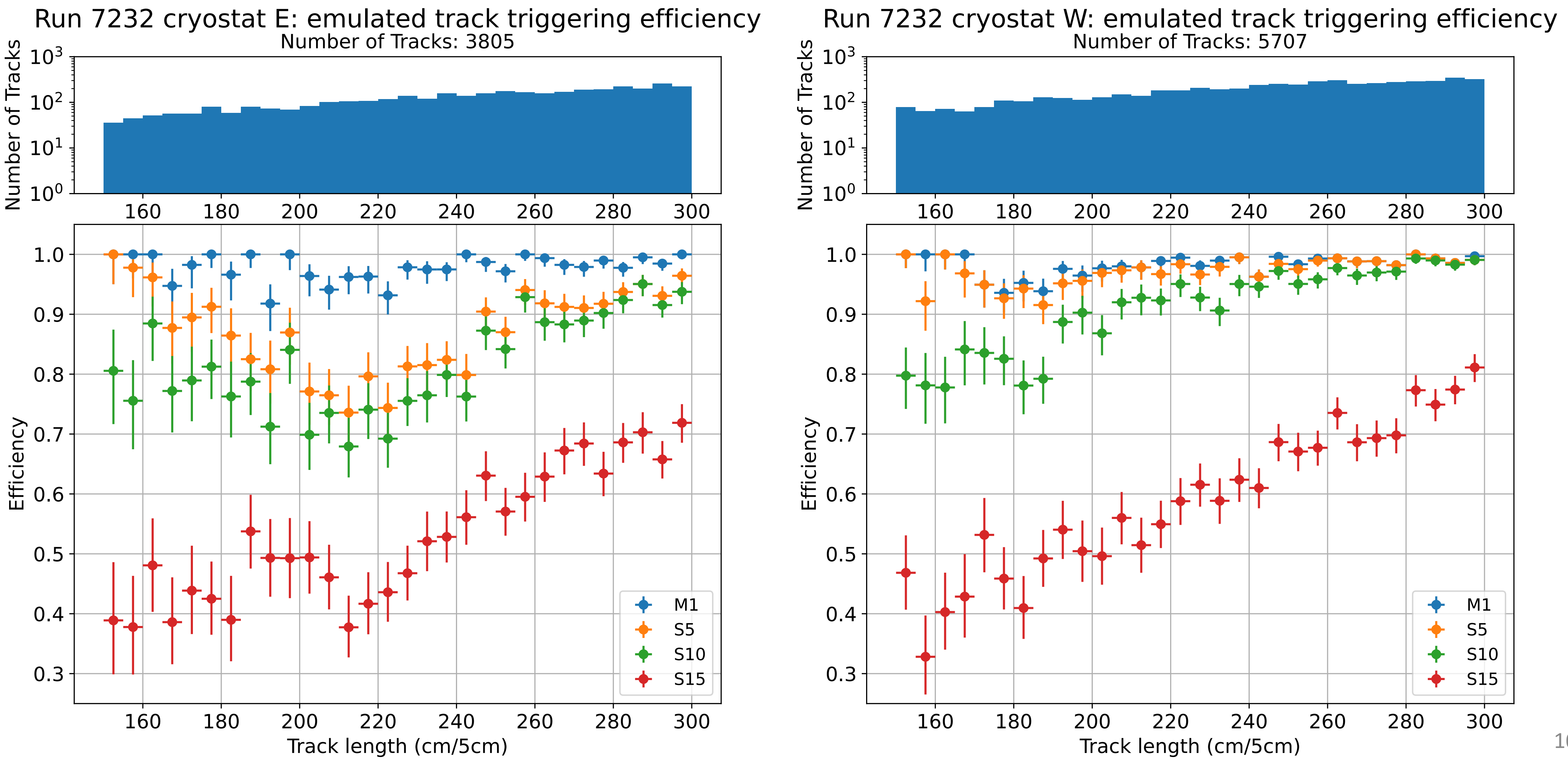






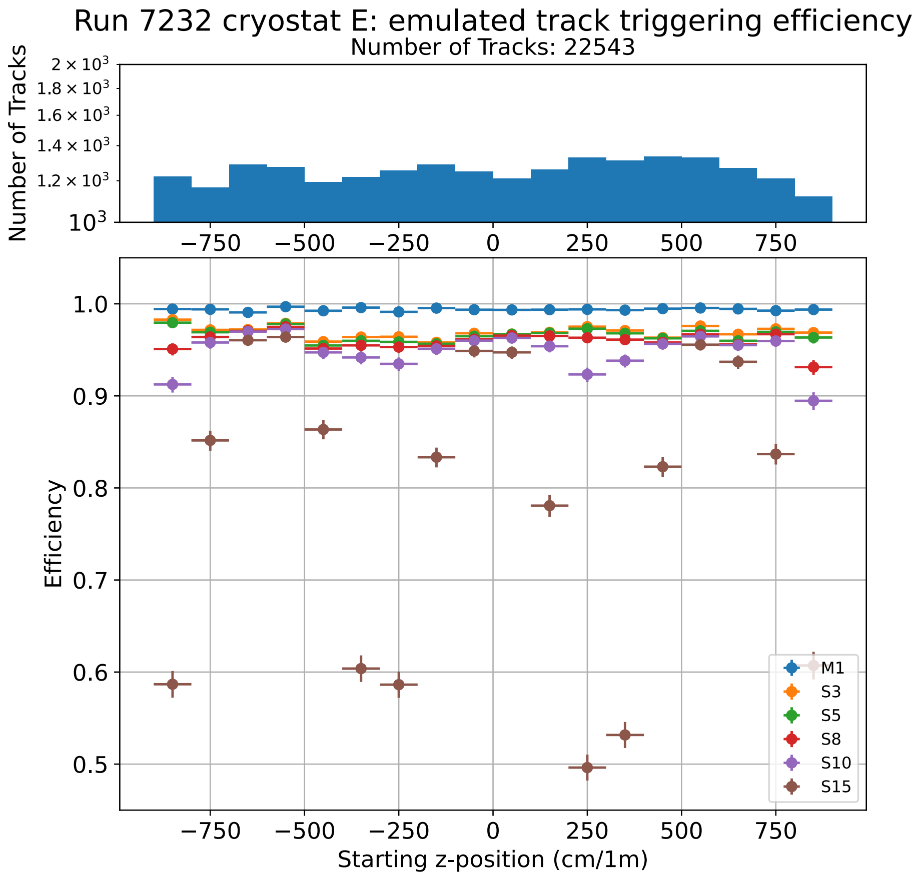
Track length

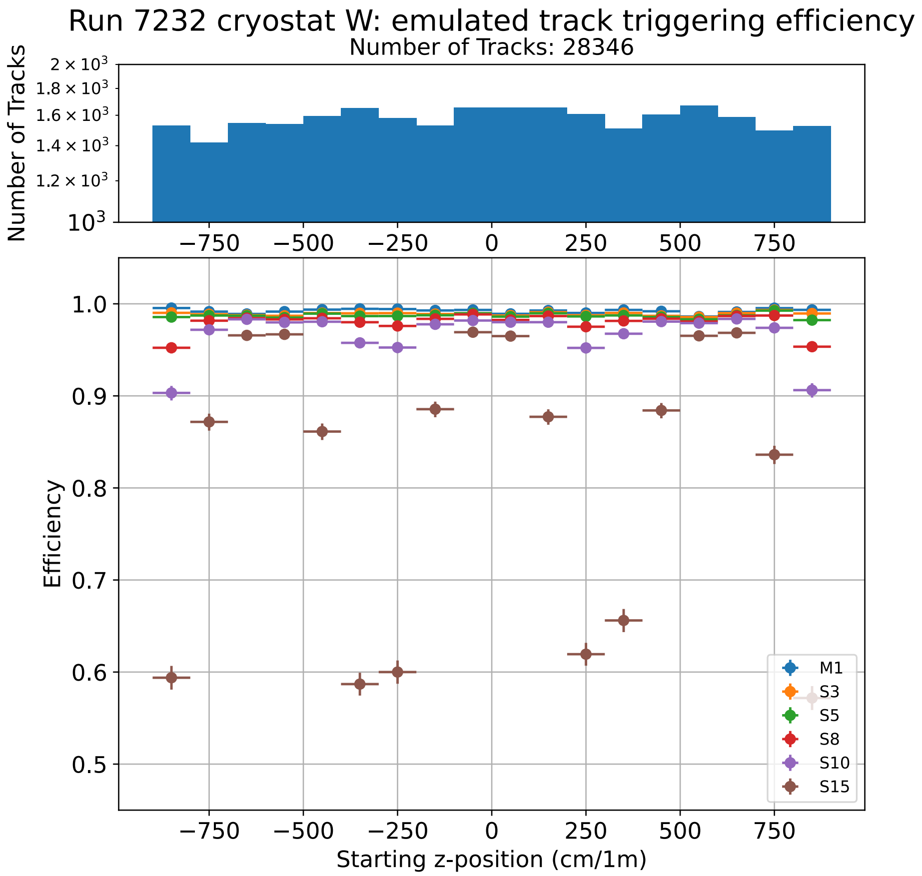
- In both cryostats there’s a drop in efficiency of the emulated triggers for track lengths around 200-240 cm



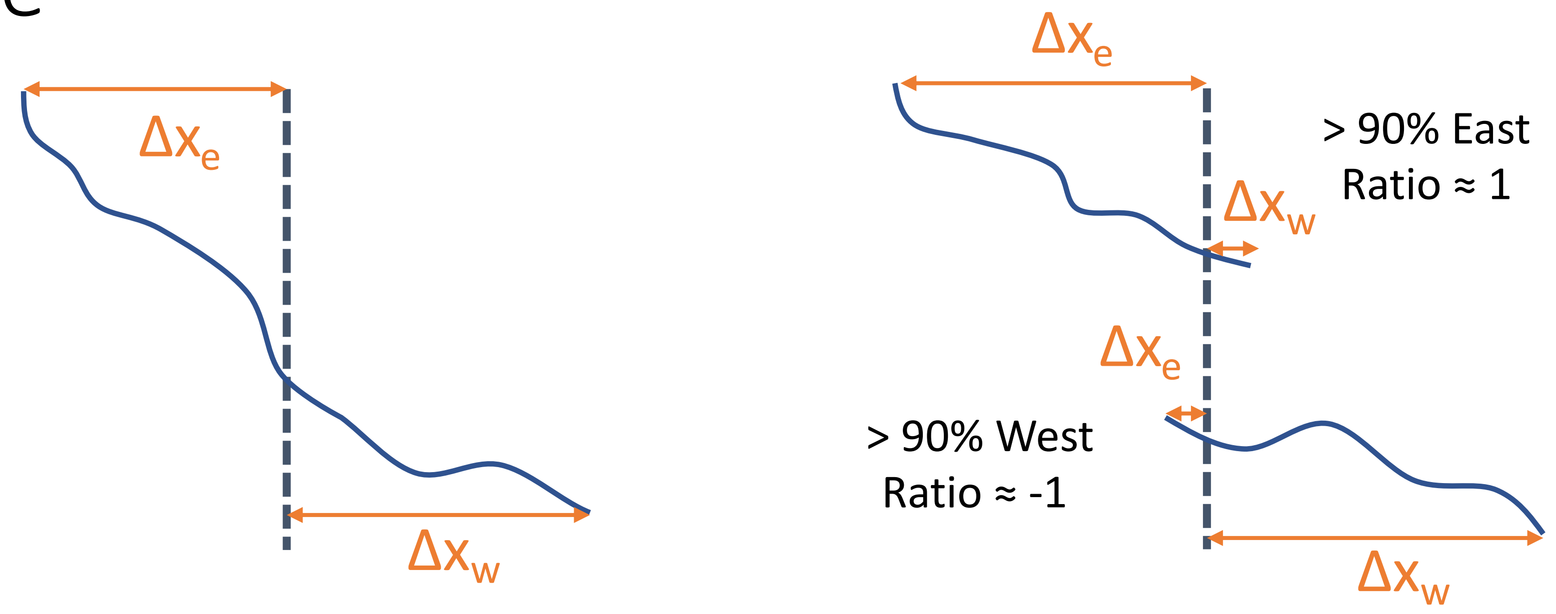
Starting z-position of tracks

- The efficiency appears to have 3 peaks at the centers of the 3 sections of each cryostat (in the trigger emulation) along the z-axis
- Sliding window setup should fix this





X-directional balance of tracks on either side of the cathode



Balance ratio formula: $\frac{\Delta x_w - \Delta x_e}{\Delta x_e + \Delta x_w}$

Δx_e and Δx_w are the x-distances to the cathode from the East and West track endpoints, respectively.

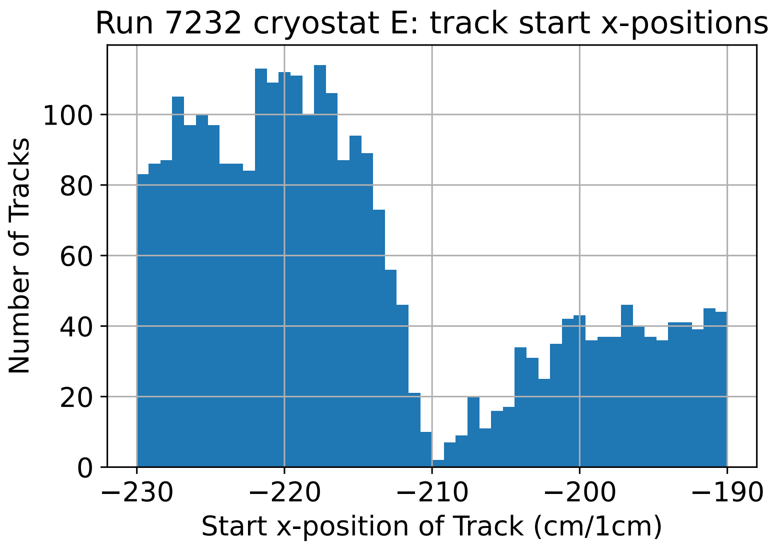
A balance ratio of

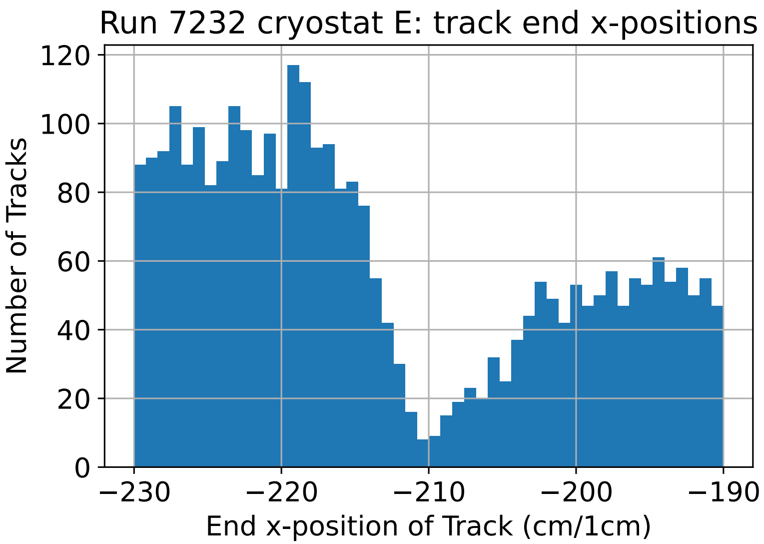
- ≈ 1 ⟶ track mostly lies in the East section of the cryostat (with x-coordinate > $x_{cathode}$)
- ≈ -1 ⟶ track mostly lies in the West section of the cryostat (with x-coordinate < $x_{cathode}$)
- ≈ 0 ⟶ track is balanced evenly between the West and East sections of the cryostat

X-position of the cathode

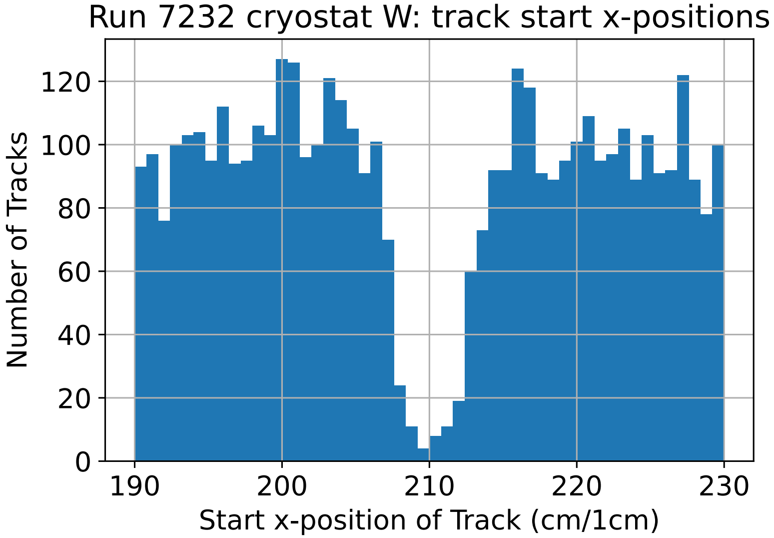
- ”start” and “end” label assigned by TPC pattern recognition (Pandora)
- Cathodes are at x=-210 cm and x=210 cm

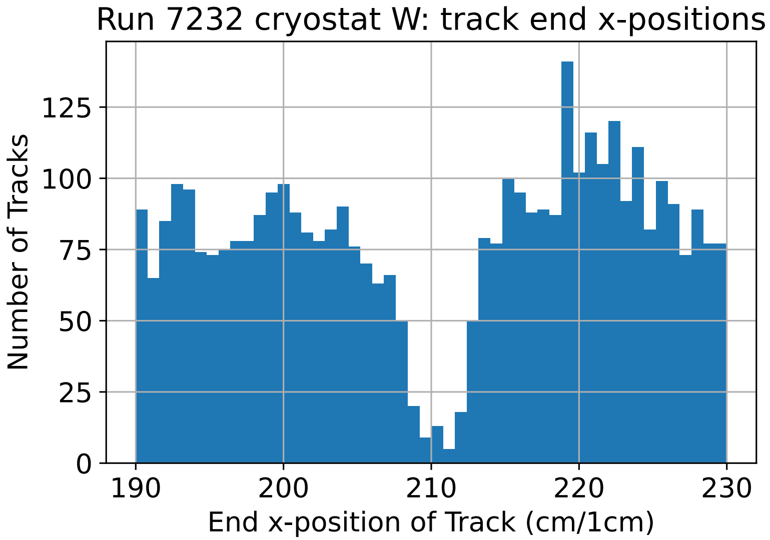
East Cryostat





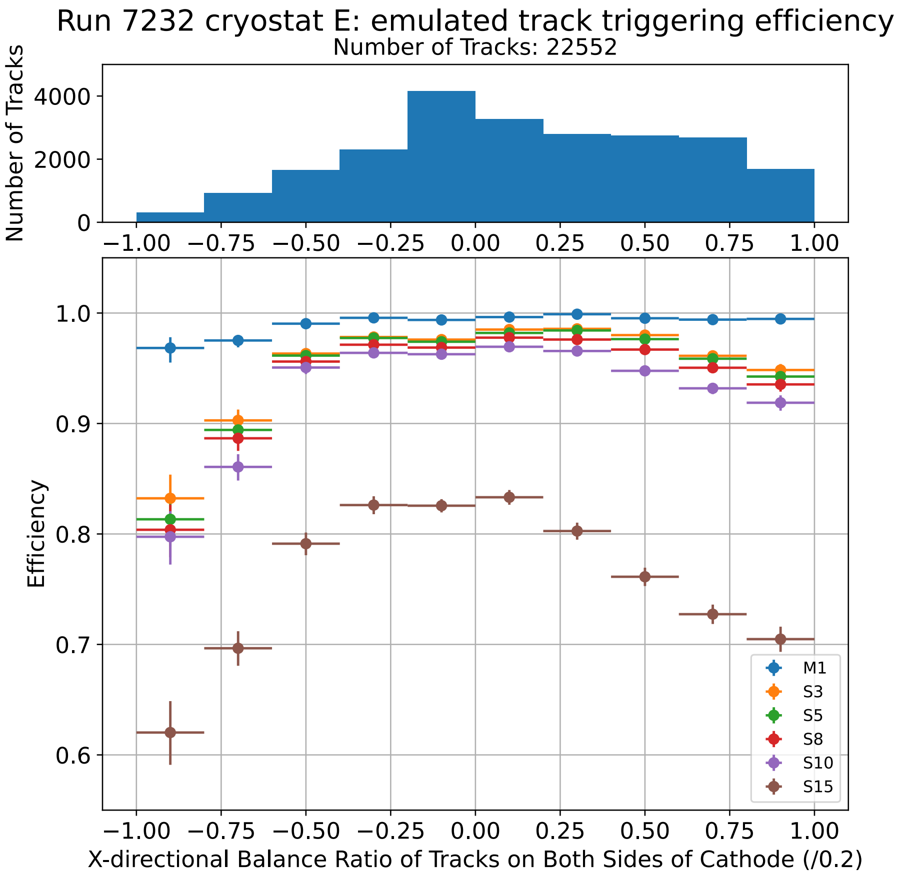
West Cryostat

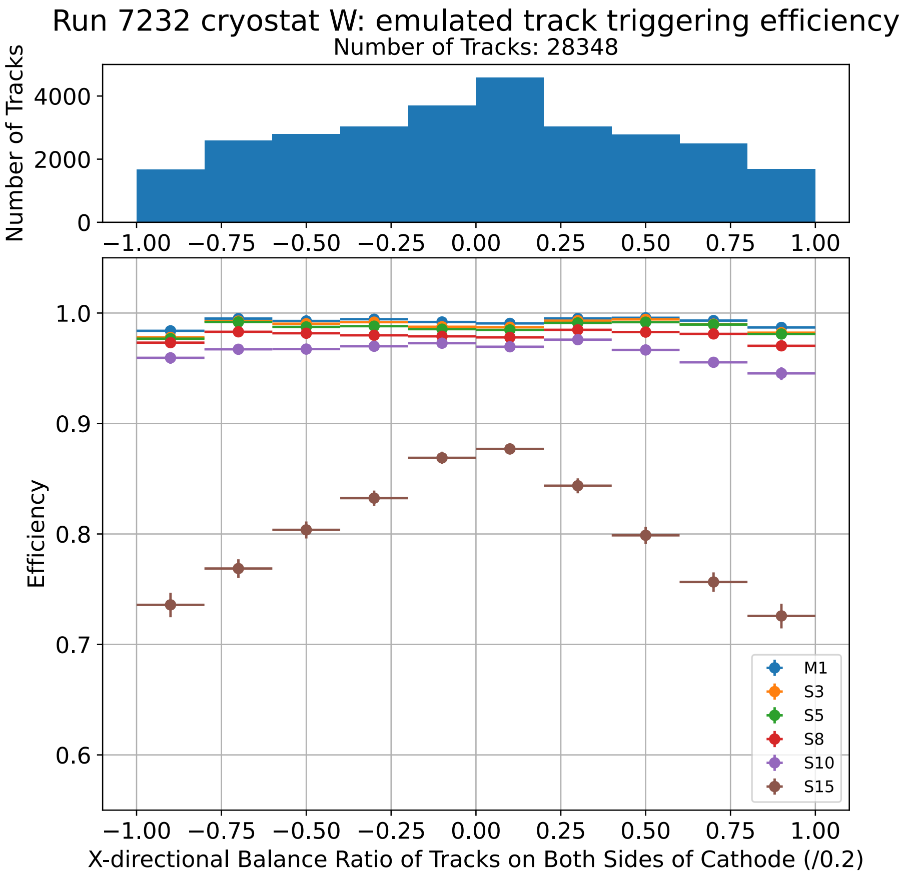




X-directional balance of tracks on either side of the cathode

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





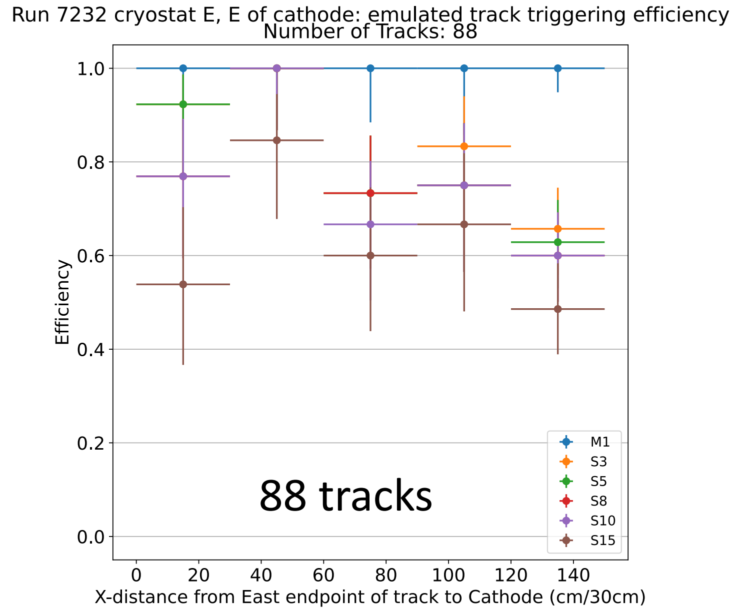
X-distance to Cathode from farther endpoint for tracks primarily on one side of the cathode

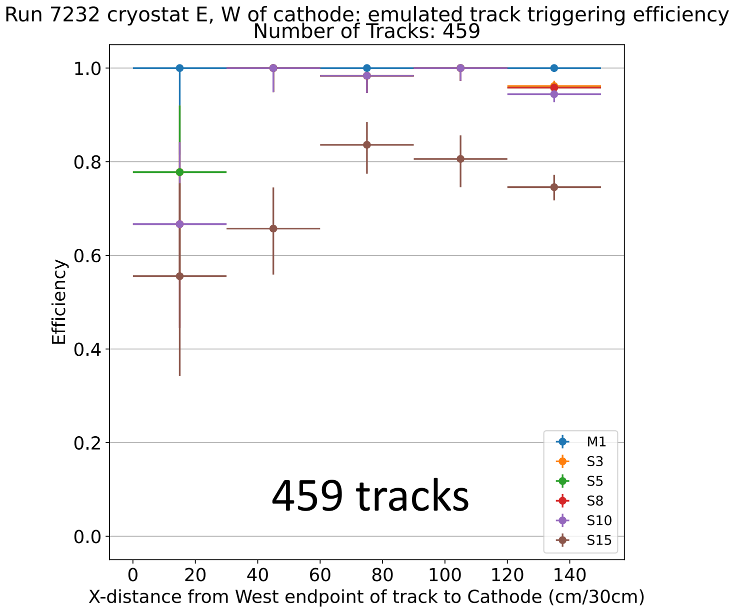
These plots describe tracks with a balance ratio more extreme than 0.9.

East of Cathode

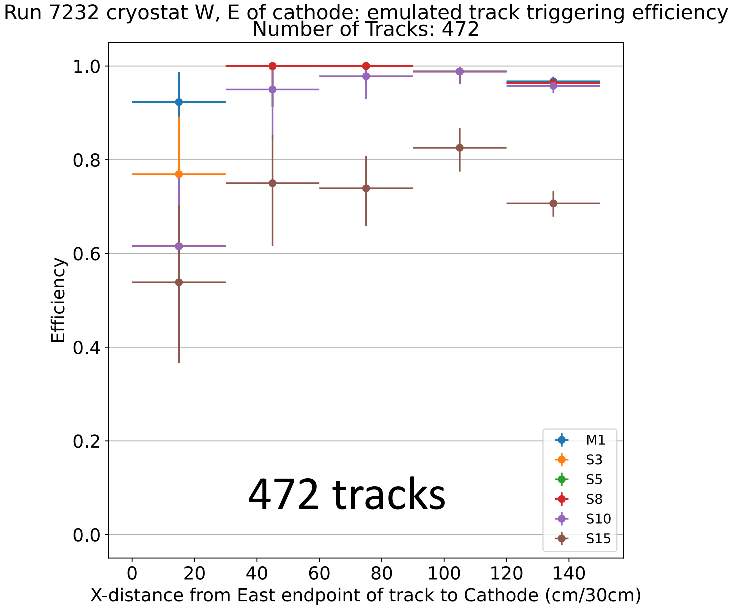
West of Cathode

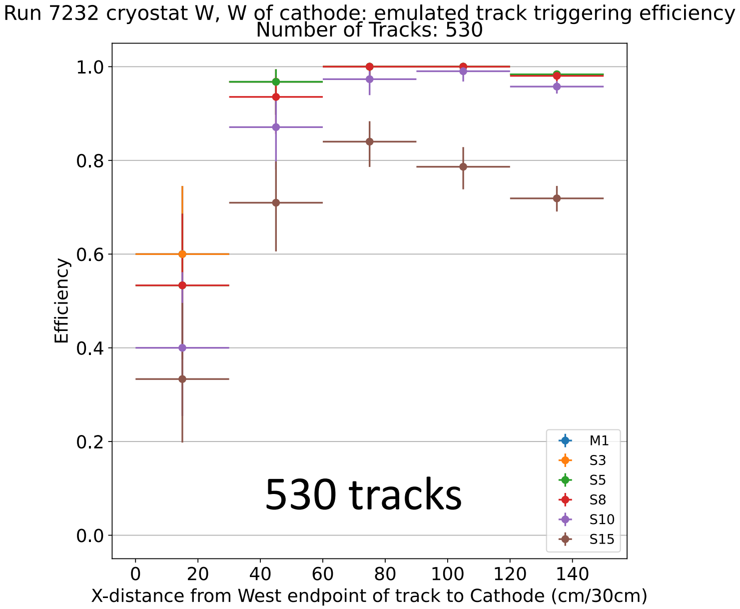
East Cryostat





West Cryostat



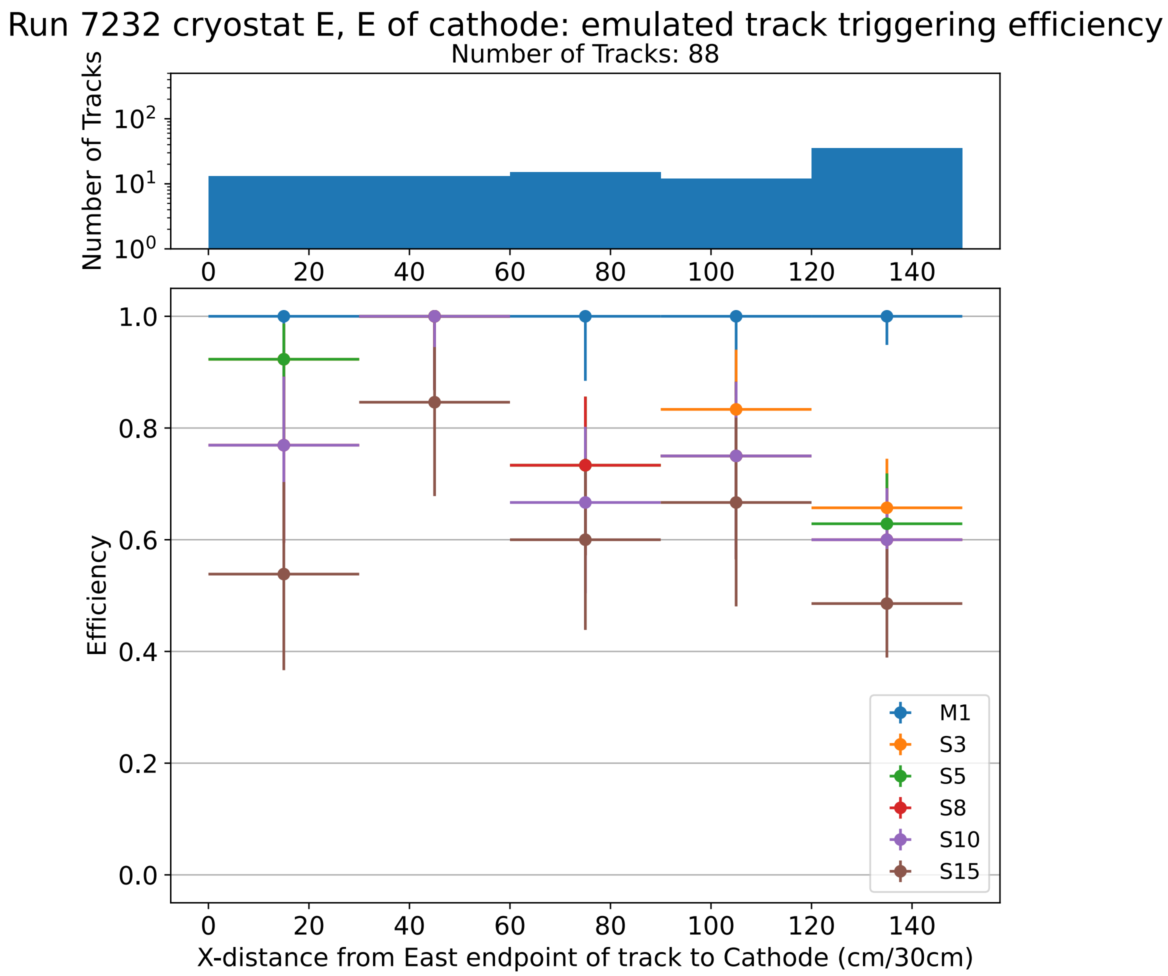


Distance to Cathode from farther endpoint for tracks primarily on one side of the cathode

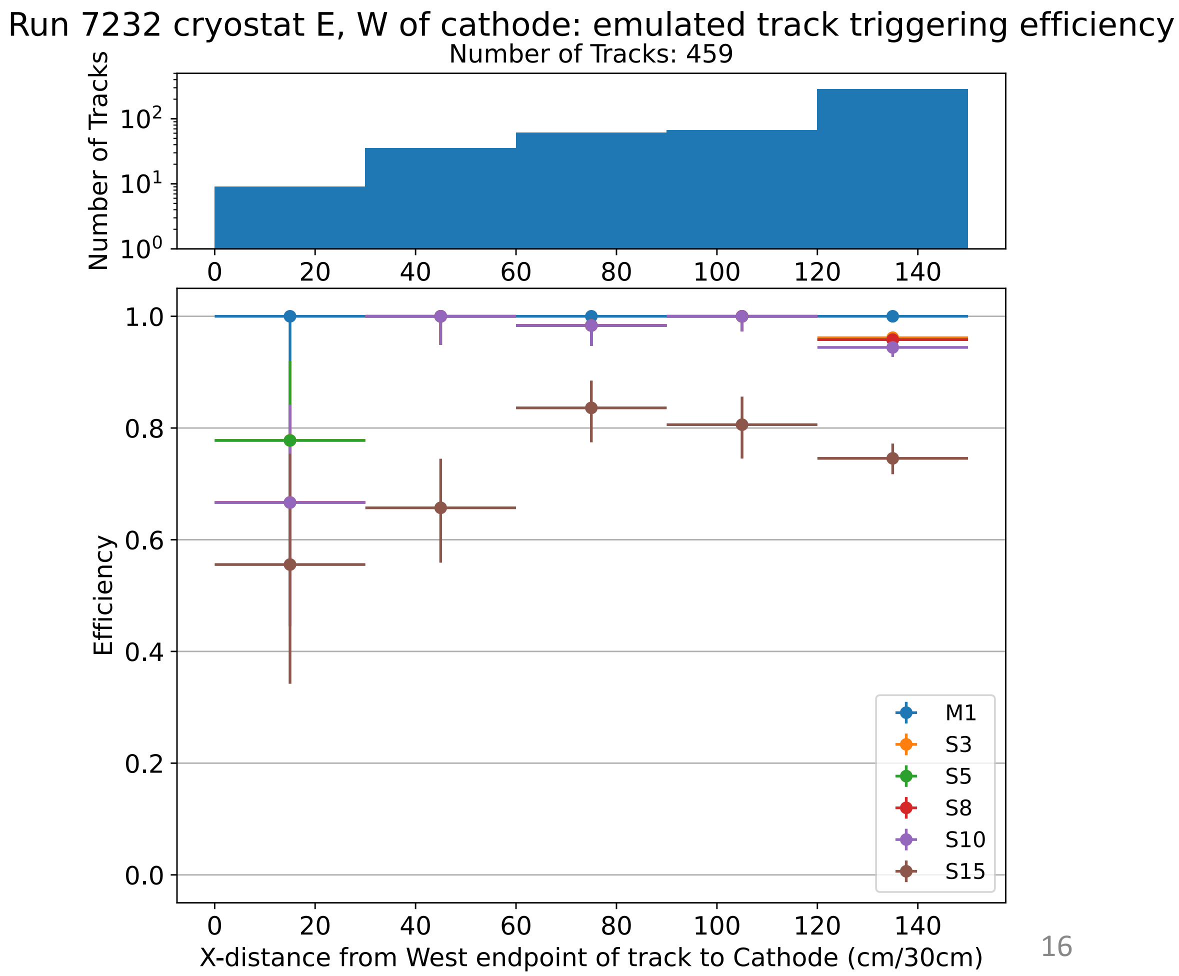
These plots describe tracks with a balance ratio more extreme than 0.9.

East Cryostat

East of Cathode



West of Cathode



Distance to Cathode from farther endpoint for tracks primarily on one side of the cathode

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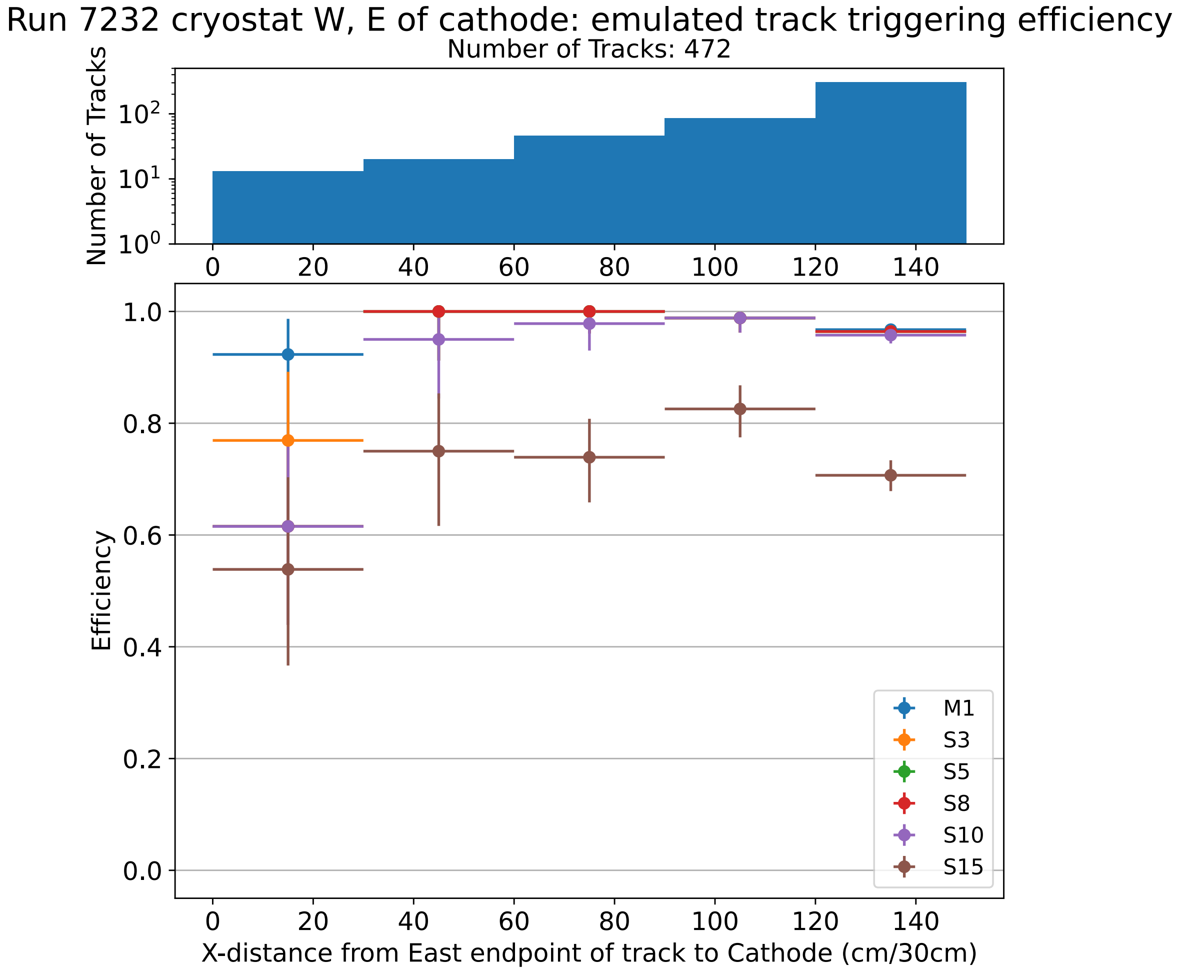
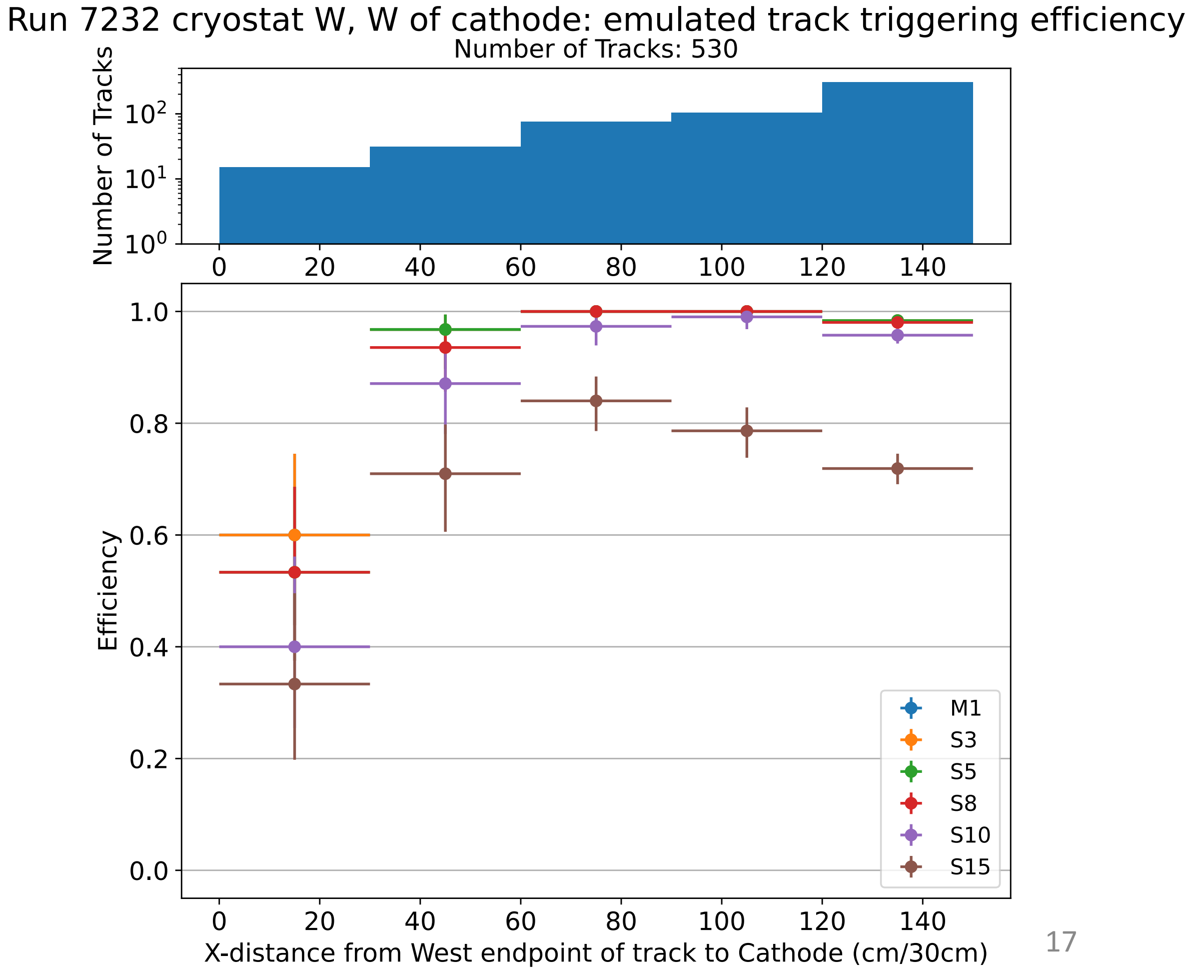
West Cryostat

East of Cathode



West of Cathode



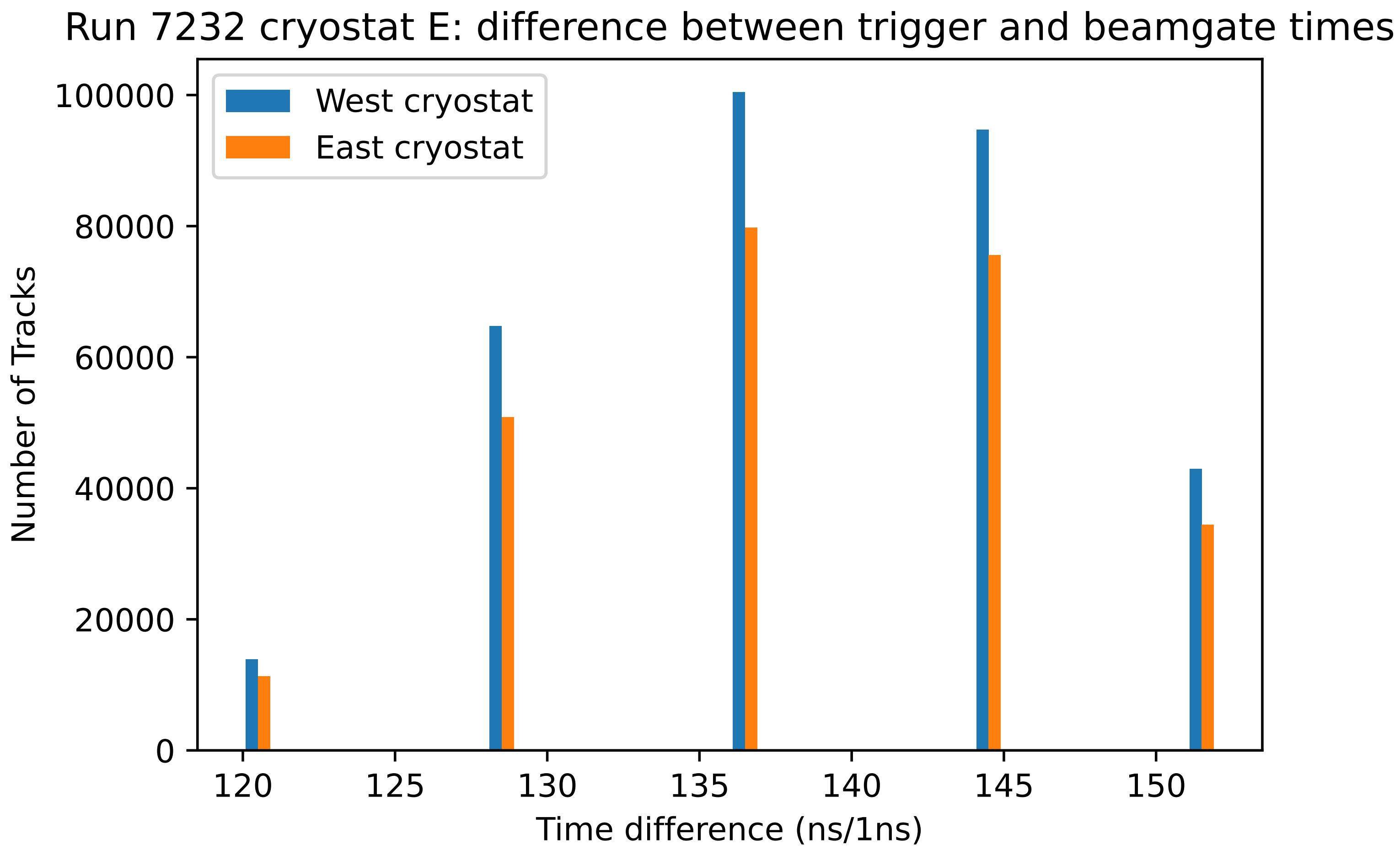
Conclusion/next steps

- CRT sample not ready yet
- Balance ratio is meant to be a measure of the difference in energy deposition of a track on both sides of the cathode, since we are missing the necessary information in the tree to get a better estimate
  - We are looking to see if we could get this information added to the tree
- It would be helpful to add trigger emulation with sliding windows
  - This would eliminate the drop in efficiency seen with the starting z-position plots
- The East cryostat and East TPC looked/behaved differently
  - Much fewer tracks primarily in the East TPC of the East cryostat, and a ~10% drop in efficiency
  - Larger drop in efficiency in the East cryostat for track lengths between 200 – 240 cm
  - Performance differences could be a result of TPC variation on the sides, not only the PMT performance.

Additional Slides

Time Difference between nominal trigger and beam gate

Time difference has 5 possible values, spaced 8 ns apart, from 120 ns to 152 ns. The mean time difference between nominal trigger and beam gate is 138.2 ns. This time difference is due to hardware delays.



Track-Flash Matching Algorithms

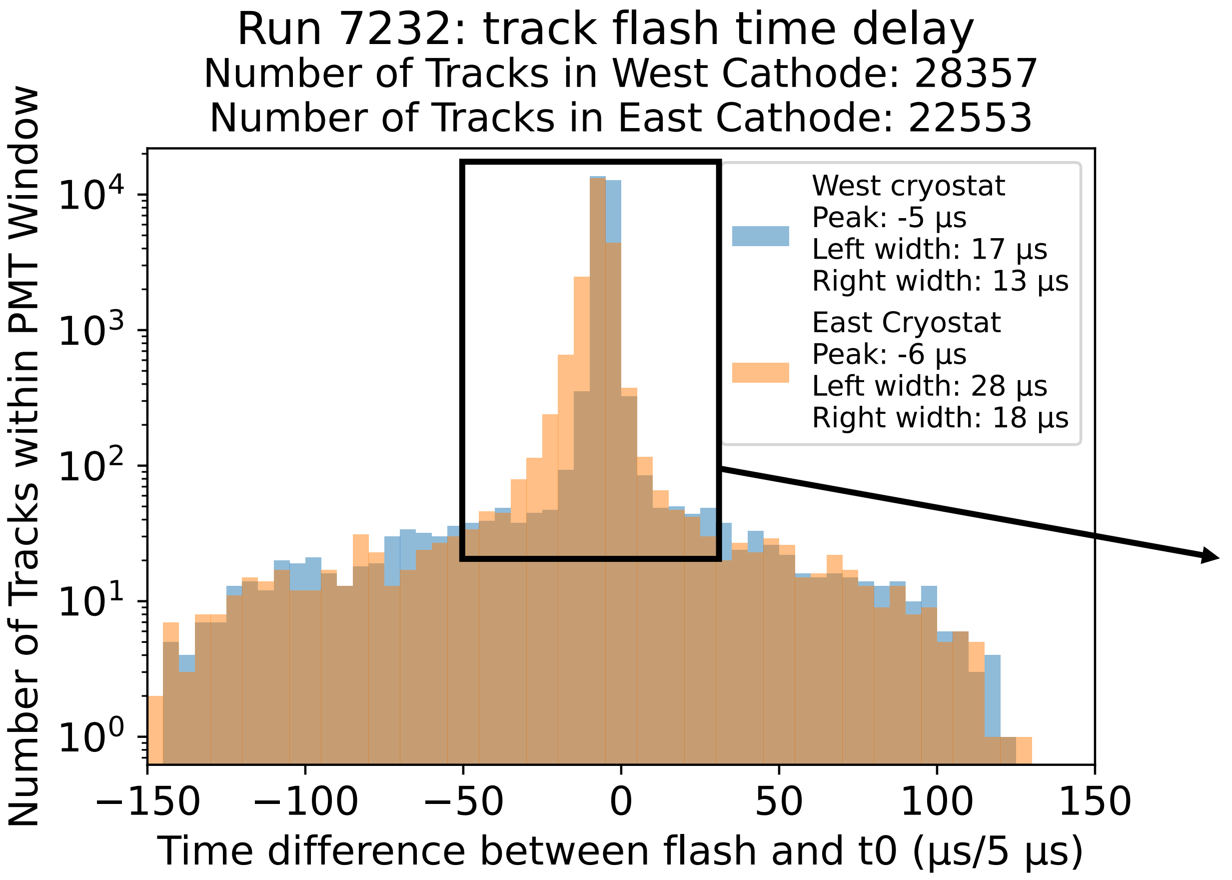
Matching tracks and flashes within a single PMT readout window using location-based and time-based algorithms and comparing the results

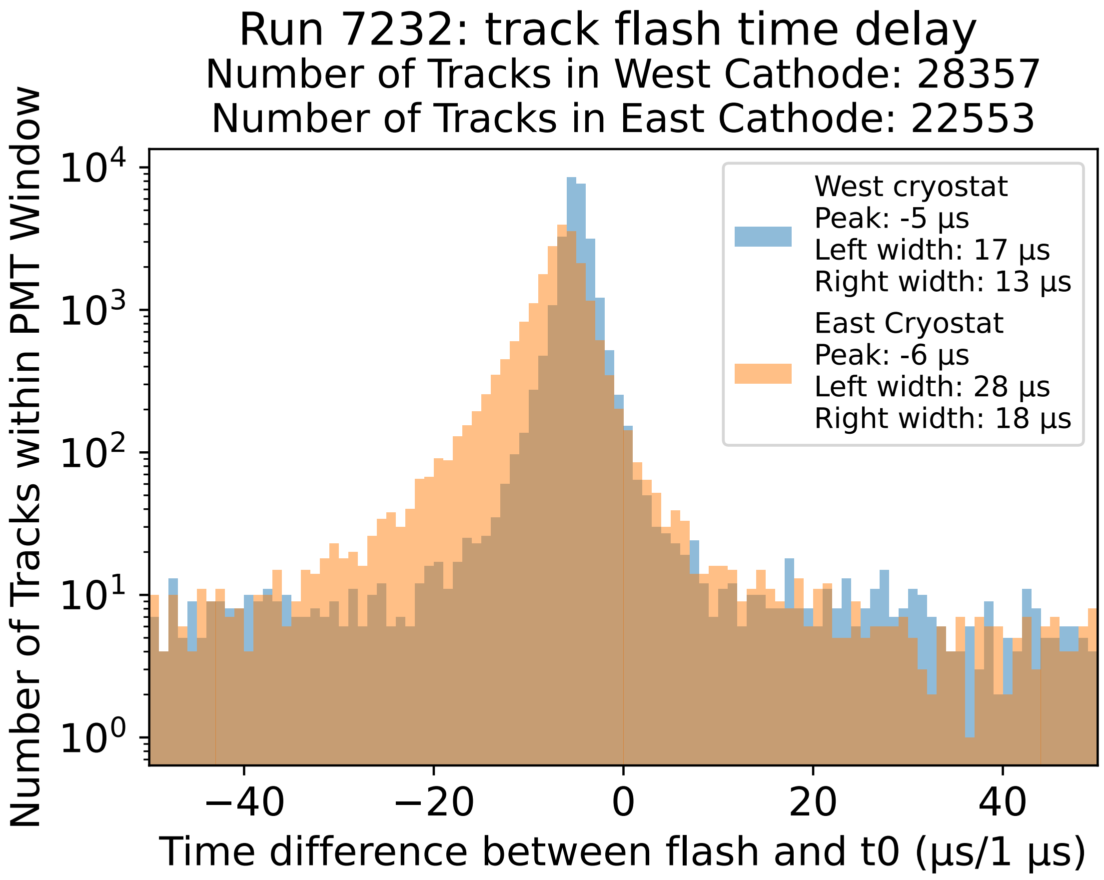
Two matching algorithms: location and time based

- Location Based Algorithm
  - Pick the flash that's closest in y-z position to the track's barycenter/midpoint
- Time Based Algorithm
  - This method
  - Pick the flash that's closest in time to the track time (t0)
  - Keep only tracks with flashes within (t0-40 µs, t0+20 µs)
    - From location-based matching, we found most matched tracks were within this range
- Both Algorithms
  - Allow multiple tracks to match to the same flash
  - Only consider tracks within the PMT readout window, t0 within (-55 µs, 75 µs)
    - This is in order to ensure that we should have the corresponding flash recorded

Matching by Barycenter of Flashes and Tracks

- Pick the flash whose location is closest to the midpoint of the corresponding track
- Below is plotted the time difference between the flash and its matched track

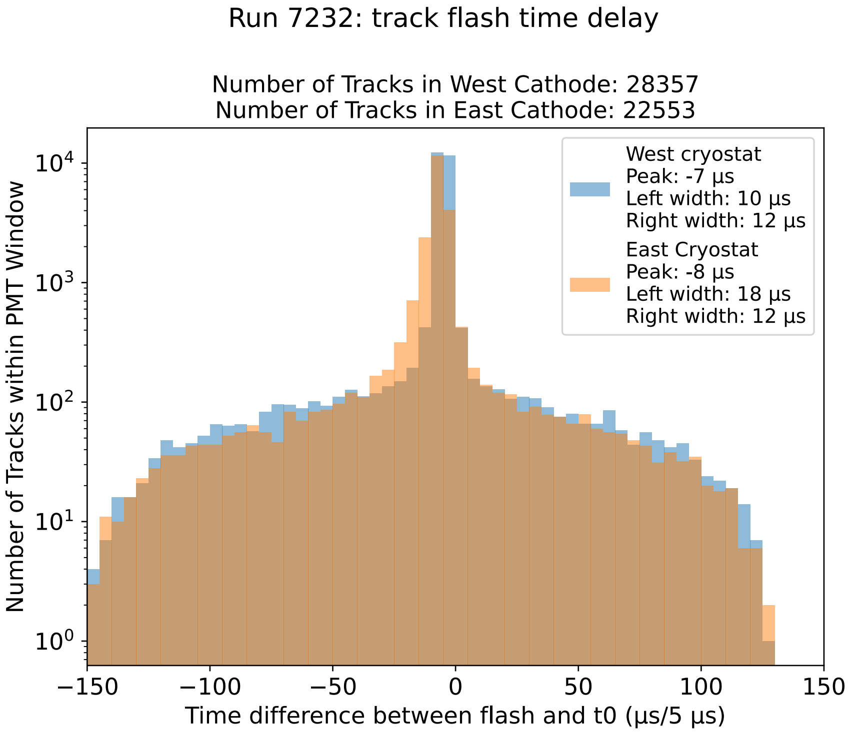




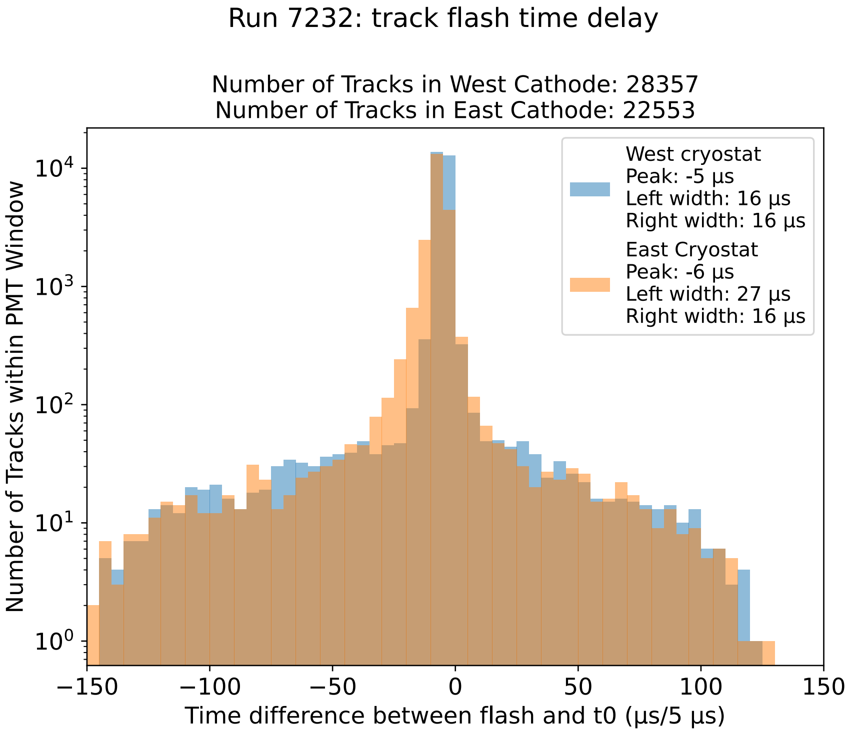
Exploration: Location of Tracks

- We checked whether it makes a significant difference to use the start, end, or midpoint of the track as the track's location
  - "start" and "end" label assigned by TPC pattern recognition (Pandora)
  - Midpoint/barycenter of track calculated using these start and end positions
- While there were slight variations, it didn't significantly affect the plot

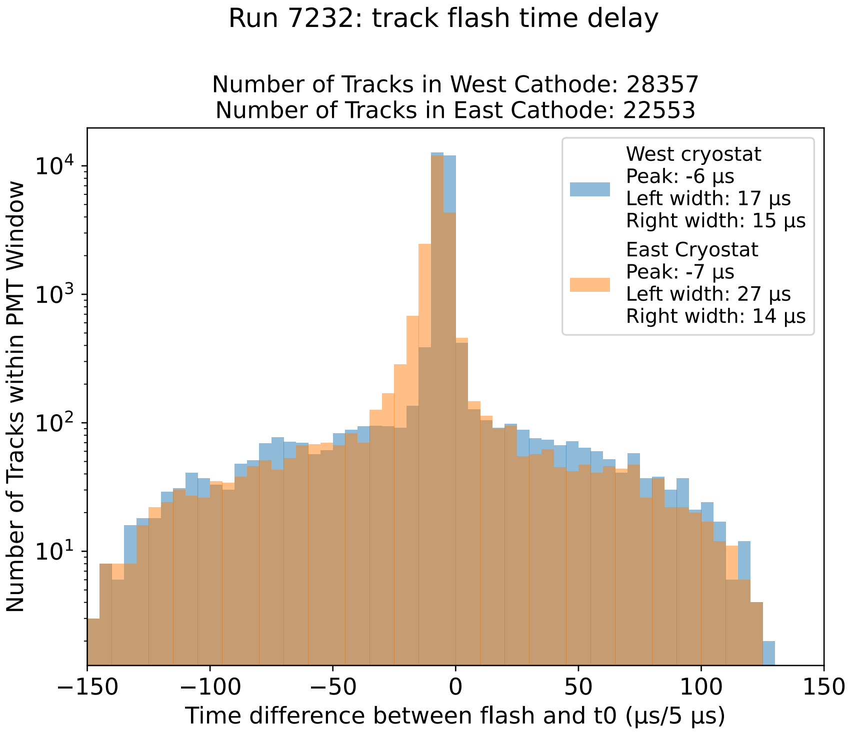
Start



Barycenter

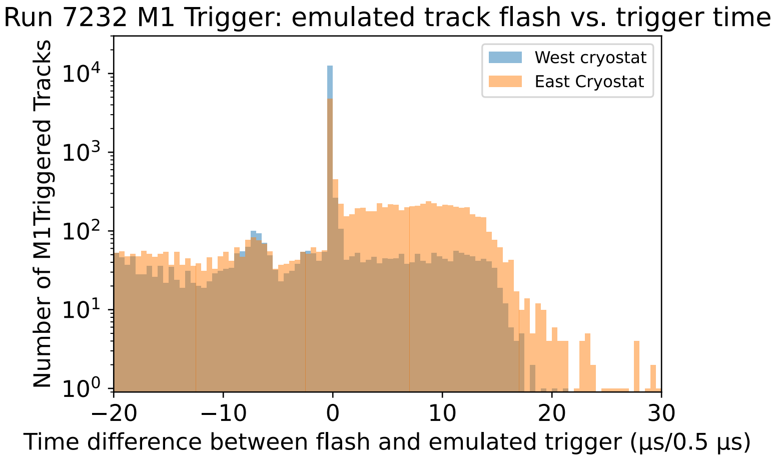


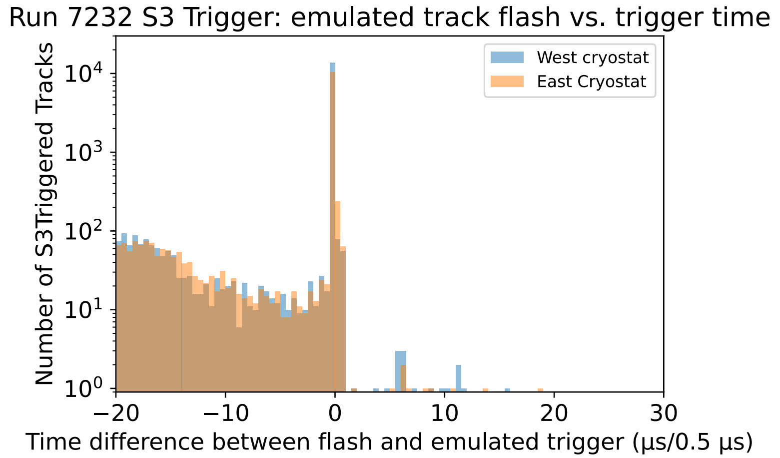
End

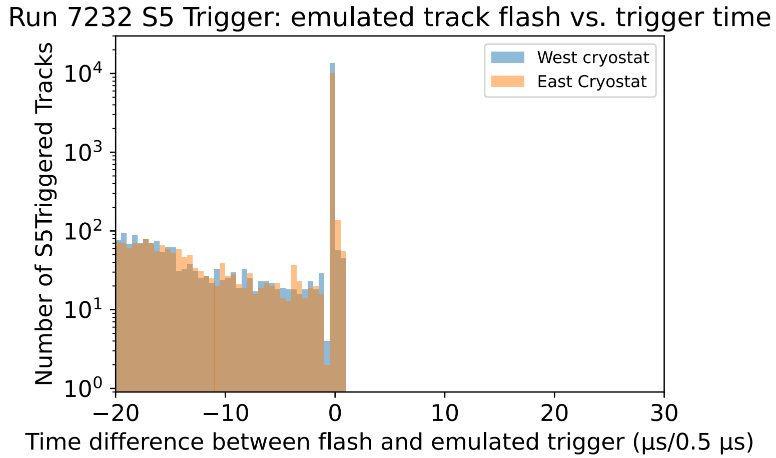


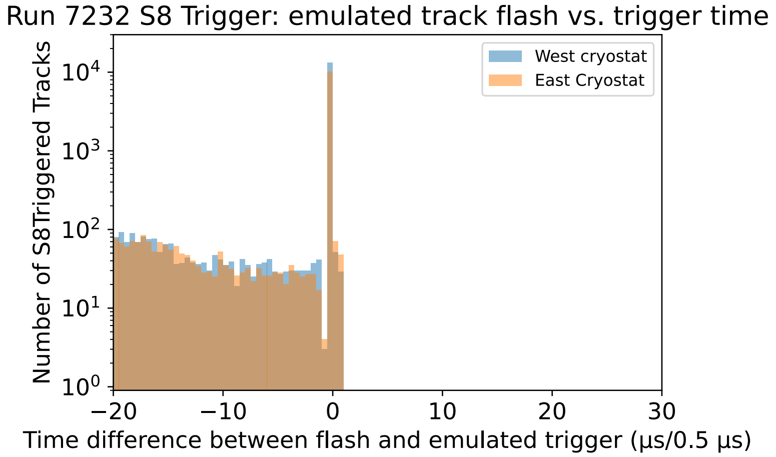
Time Difference between flash and emulated trigger

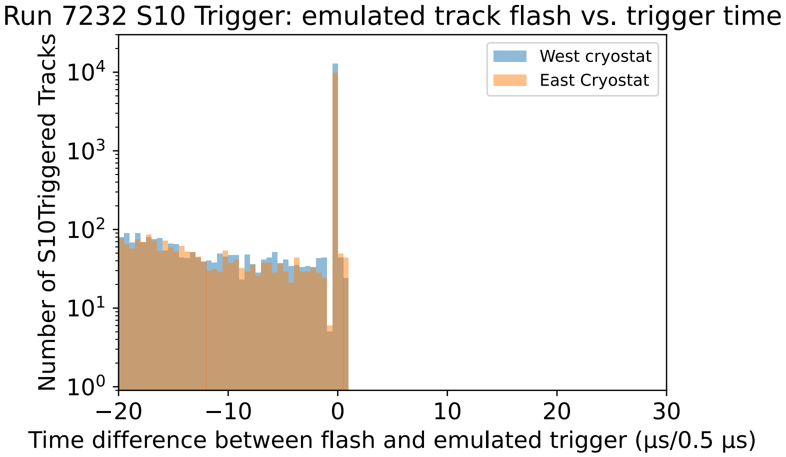
- We used **time-based** flash-track matching for this
- We expect this to mostly be 0, and we do see a large spike at 0
- There are more tracks slightly below 0 than slightly above, so there are more tracks where the flash is slightly before than the emulated trigger than tracks where the flash is slightly after
- In this plot, the time of the flash is already biased by our matching algorithm

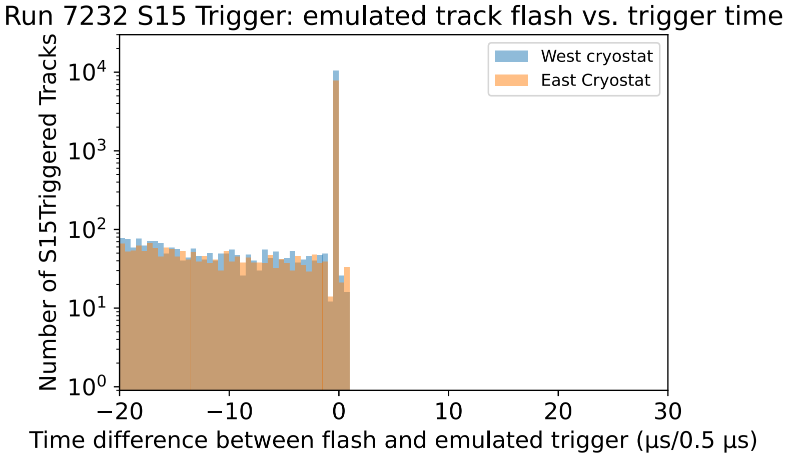






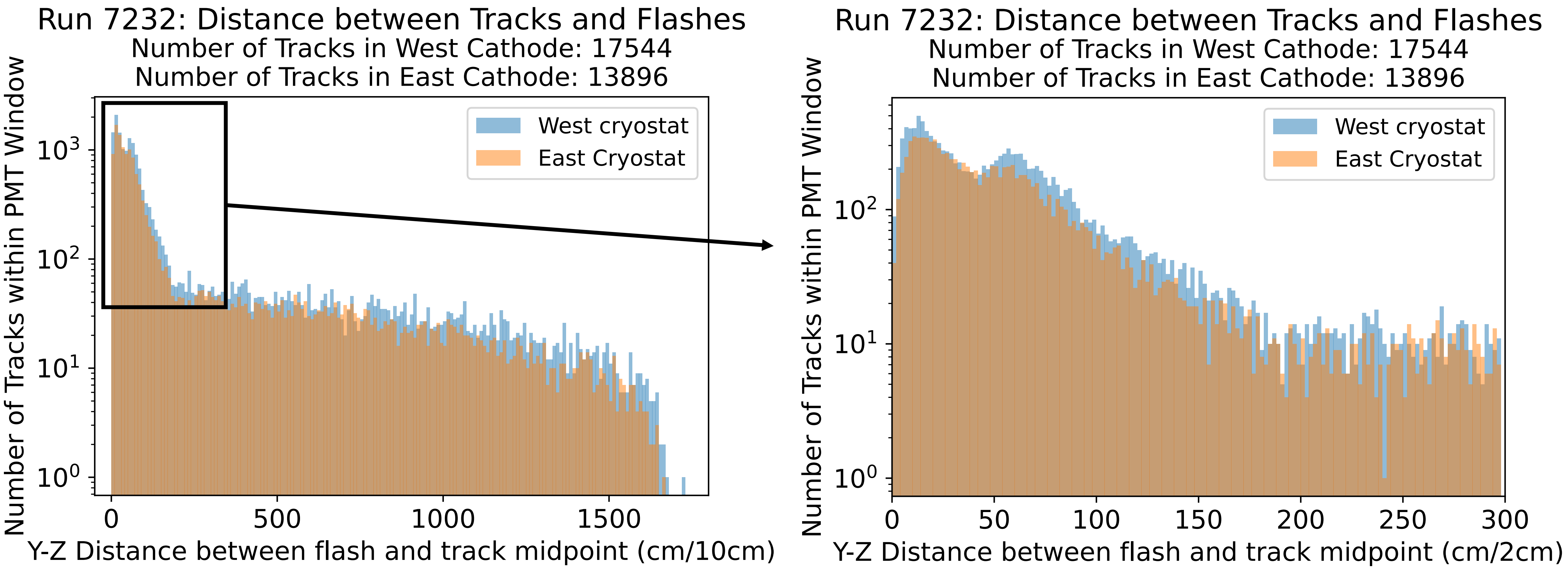






Matching by Time of Flashes and Tracks

- Pick the flash whose time is closest to the corresponding track and within (t0-40 μs, t0+20 μs)
  - We chose this based on the width of the time difference peak when tracks and flashes were matched by time
- Below is plotted distance between flashes and midpoints of tracks



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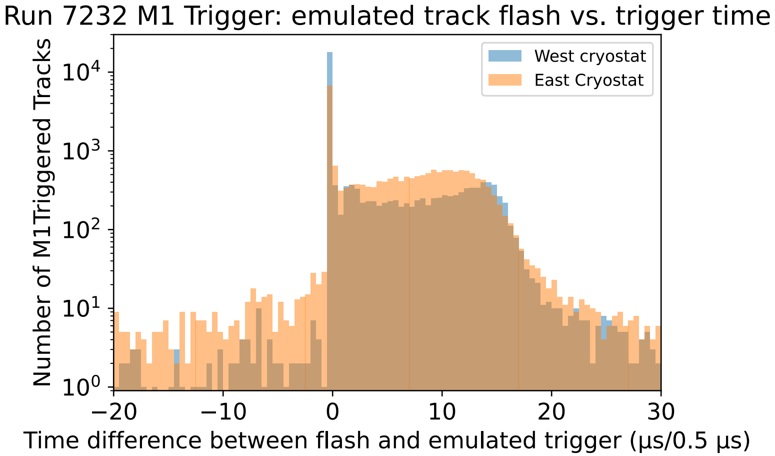
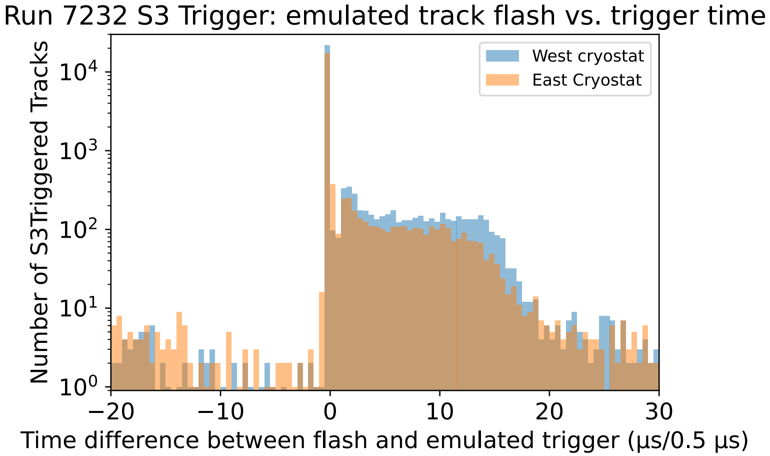
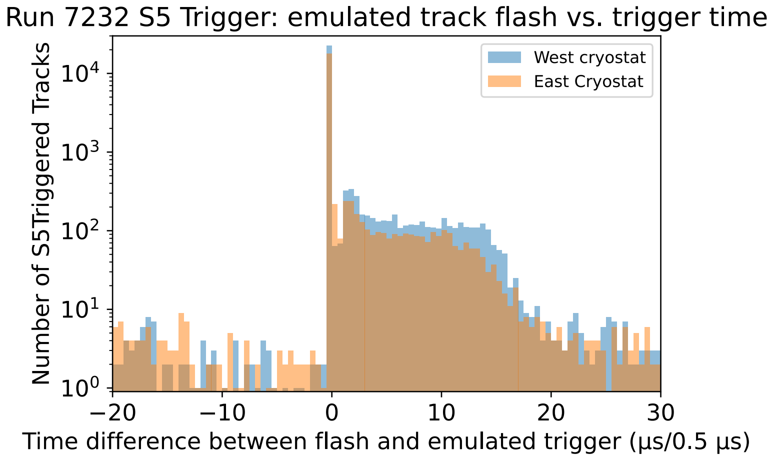
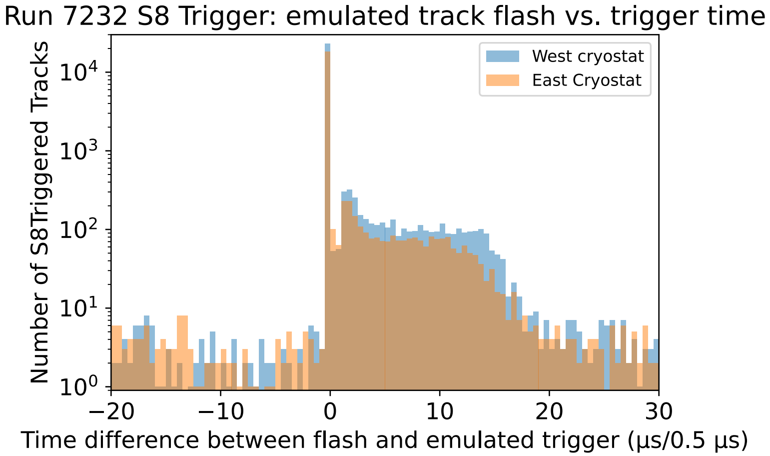
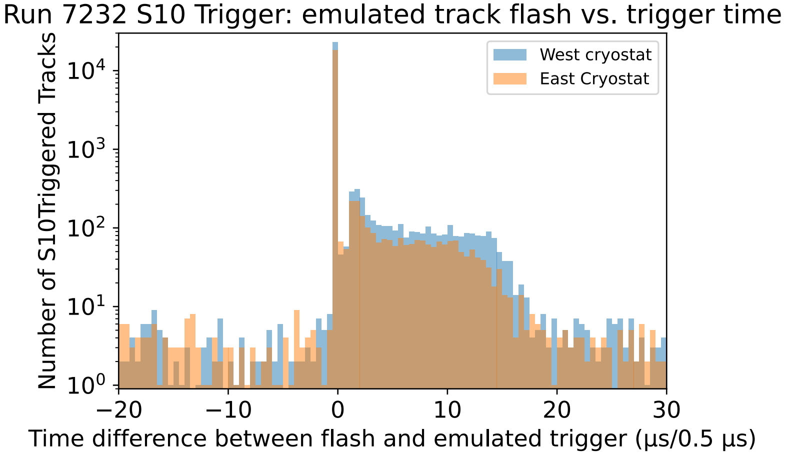
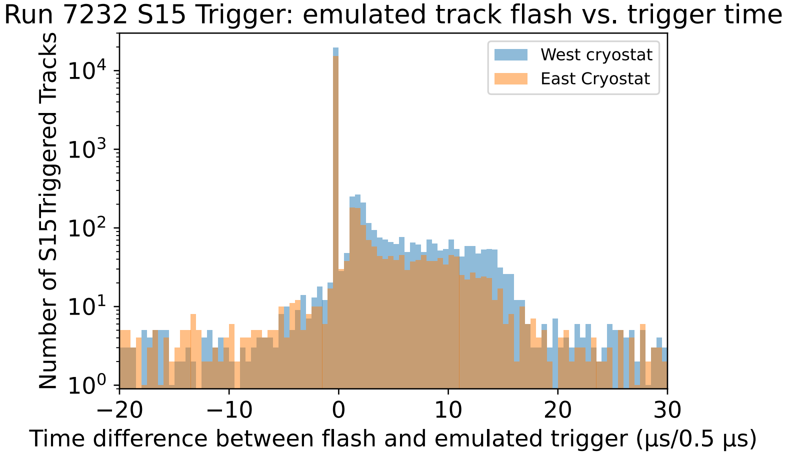






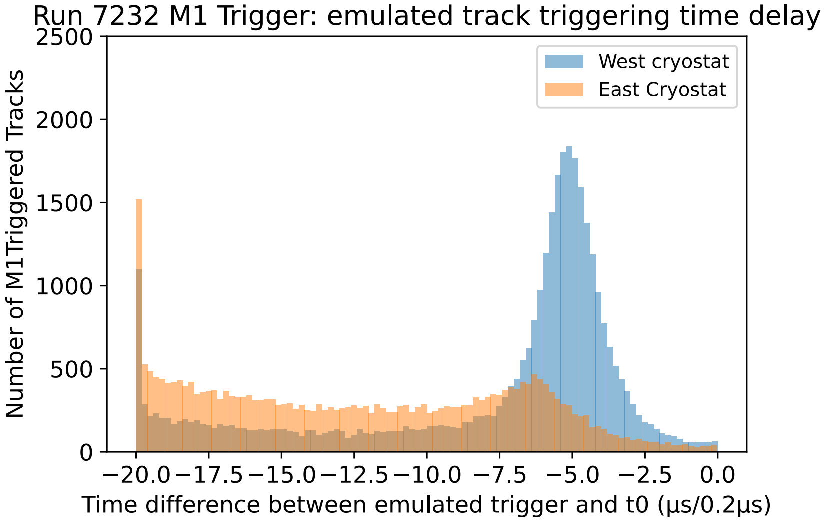


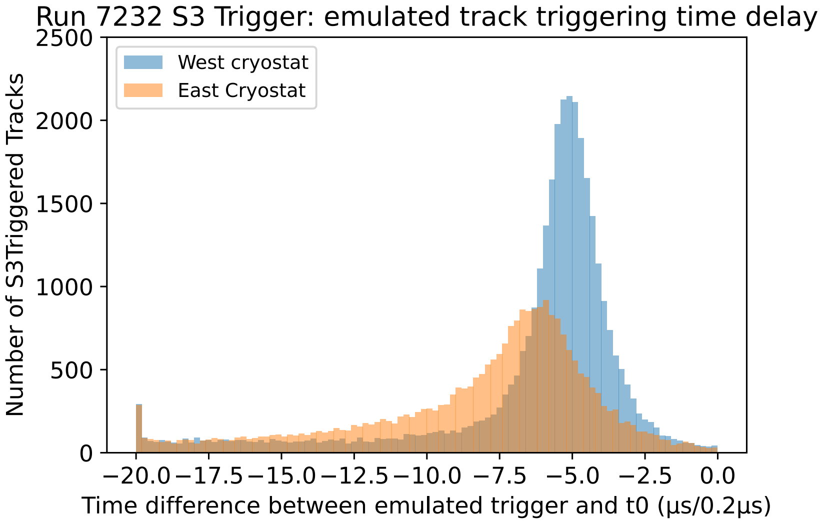


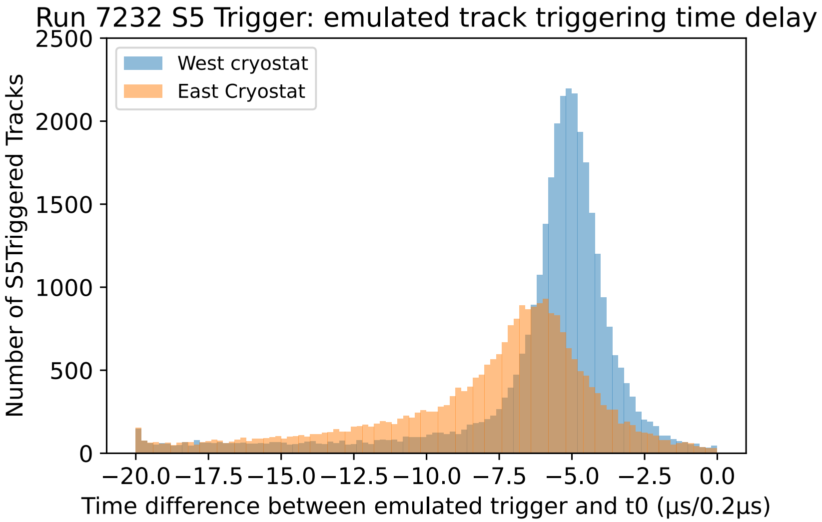


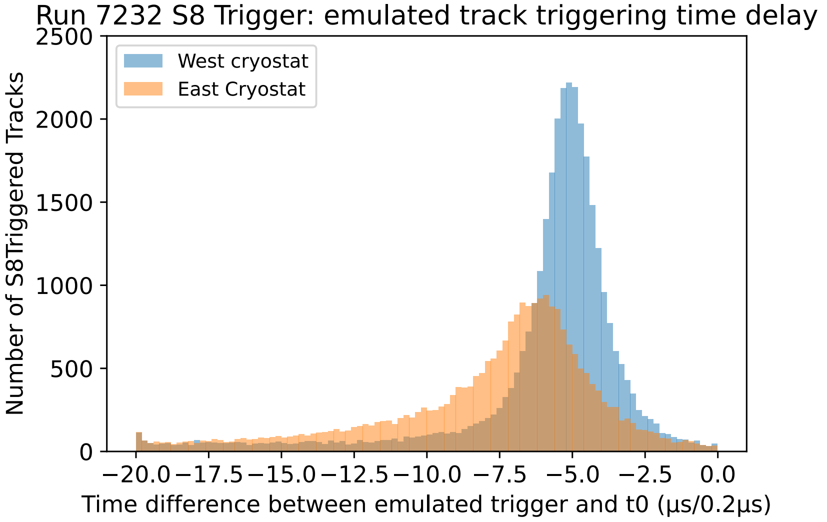
Time Difference between emulated trigger and t0 (track time)

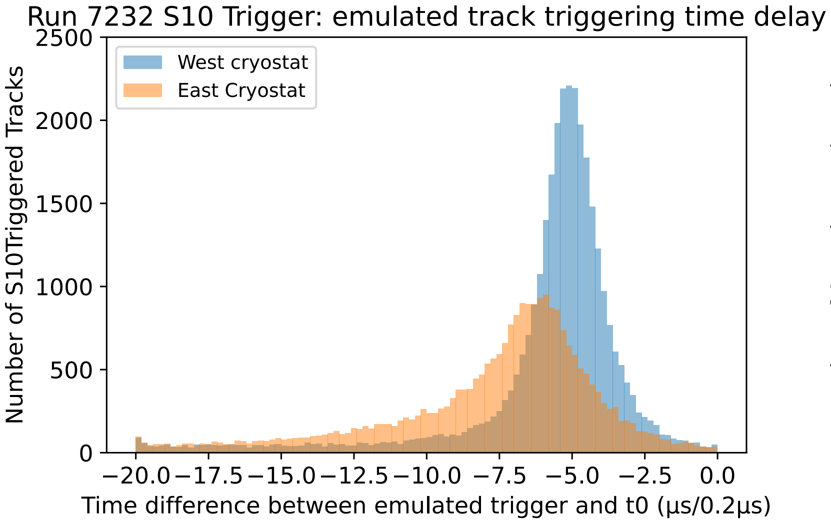
- The time difference should not be negative – this shift is an artifact of the reconstruction
- The wide peak is the average time delay between the track and the trigger
- There is also a peak at -20 µs. We used an interval from t_0 – 20 µs to t_0 to evaluate the trigger response, so any residual light from events before the start of the interval could activate the trigger response immediately upon the start of that interval, as the trigger can only be activated once per spill. This causes the initial spike that can be seen at -20 µs.

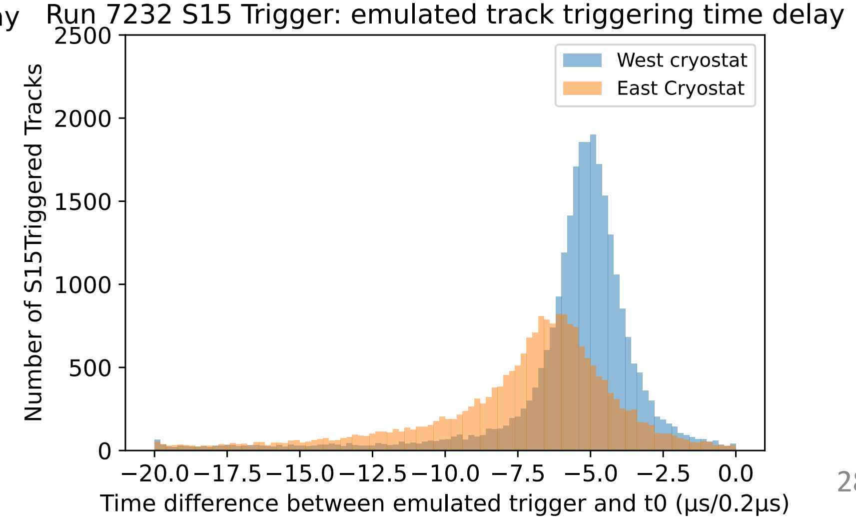






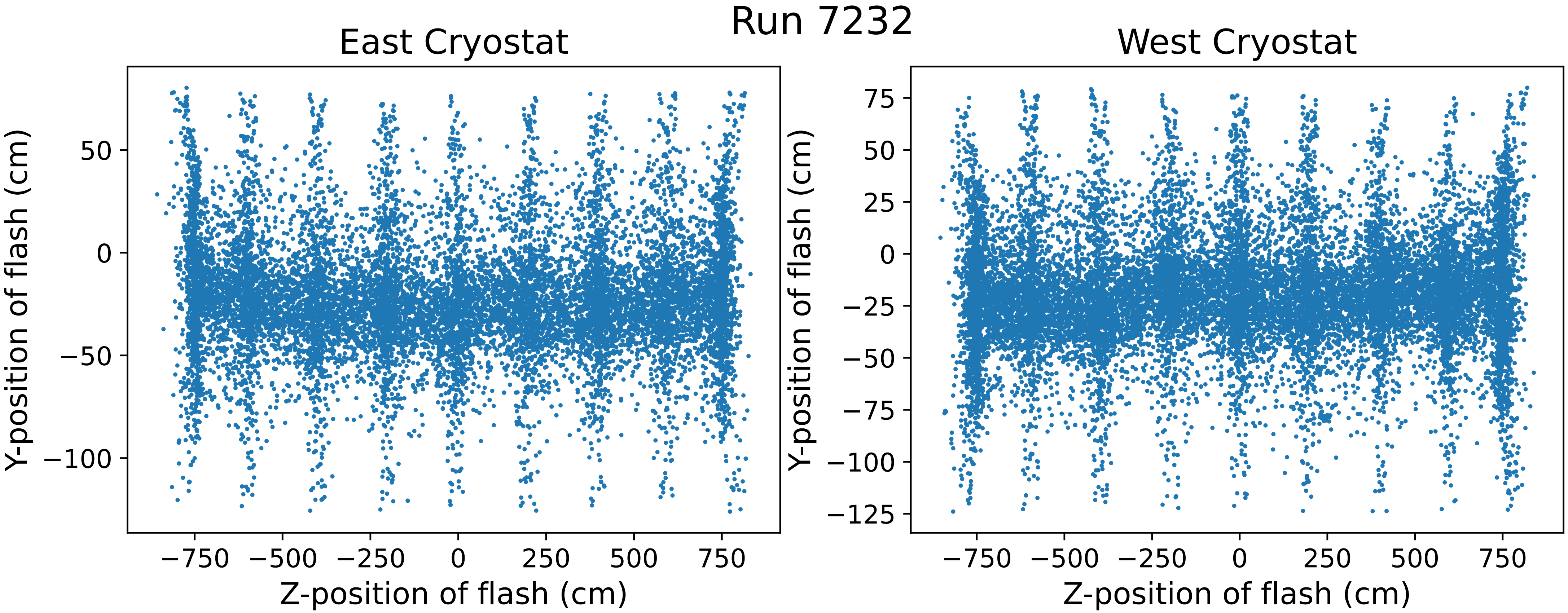






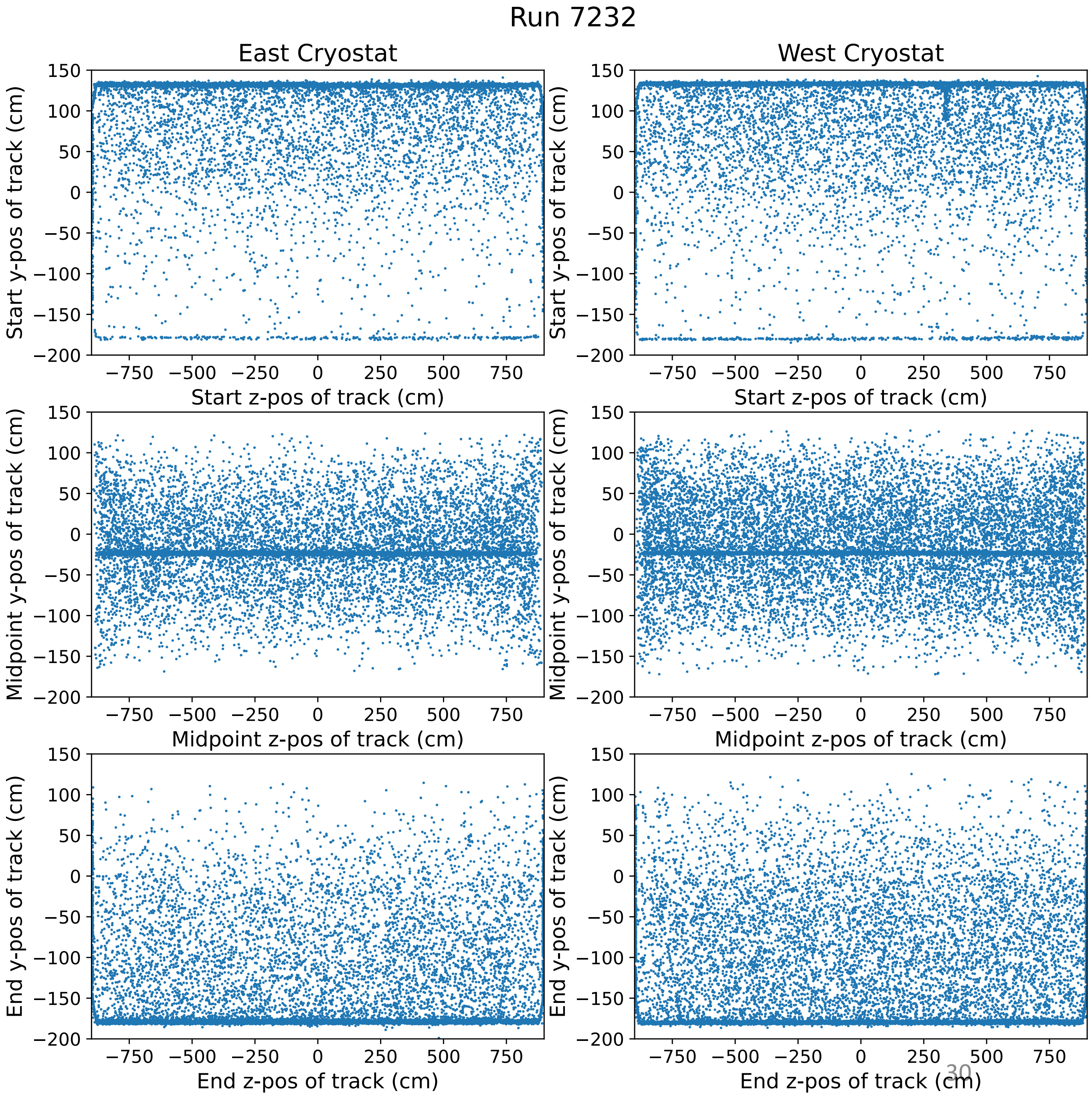
Y-Z positions of flashes in both cryostats

Distribution of flashes is not uniform - it is concentrated close to where the PMTs are located



Y-Z Positions of Tracks

It appears that using the midpoint of position of the track as a measure of the track's location is the most unbiased way to compare it to the flash position, which has a similar distribution



Distance Between track and Flash as a function of z-position of flash

Distance between track and flash peaks at 0-20 cm with a smaller peak at 50-80 cm. We don't fully understand what is causing this second peak, but it is independent of the z-position of the flash.