Investigating Reconstruction Efficiency Using CRT PMT TPC Information

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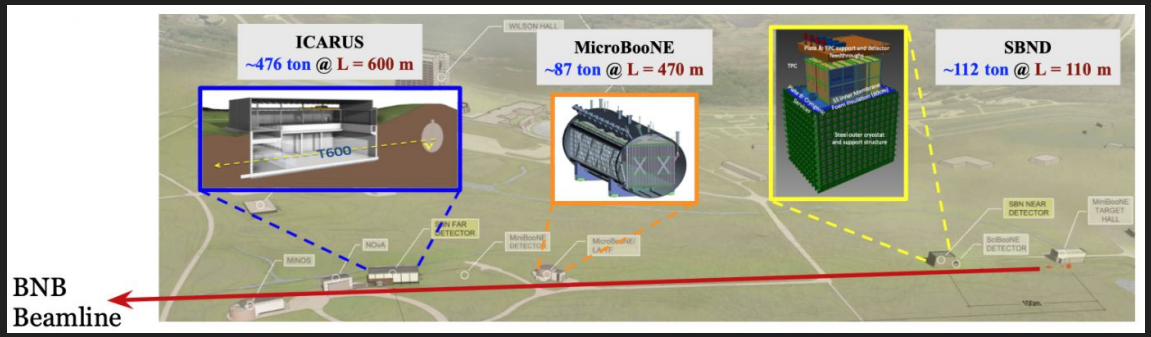
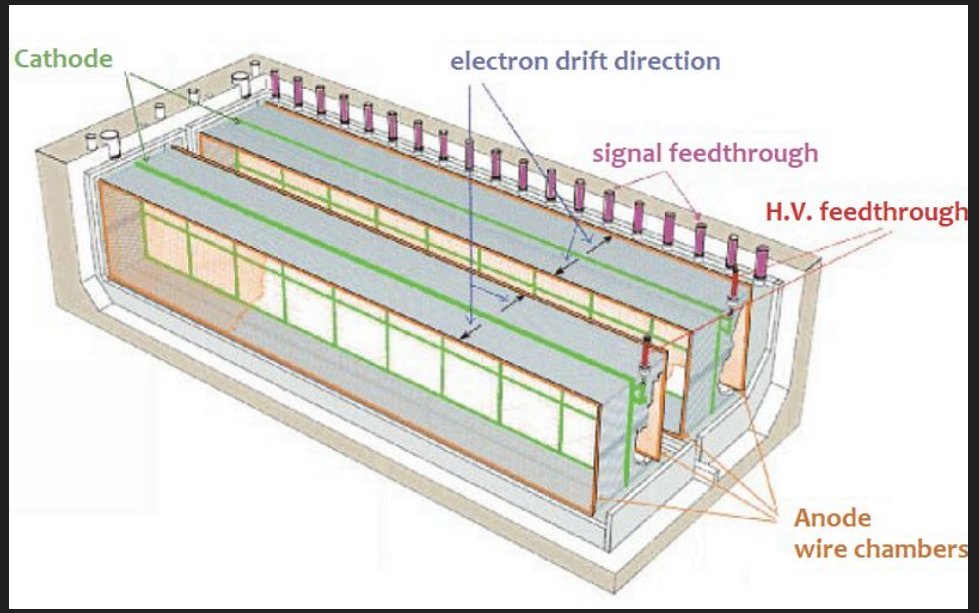
Fermi National Accelerator Laboratory (FNAL)

- World leader in neutrino research.
- Short Baseline Neutrino (SBN) program uses a line of Liquid Argon (LAr) detectors to study high energy physics.
  - MicroBooNE
  - SBND (near detector)
  - ICARUS (far detector)



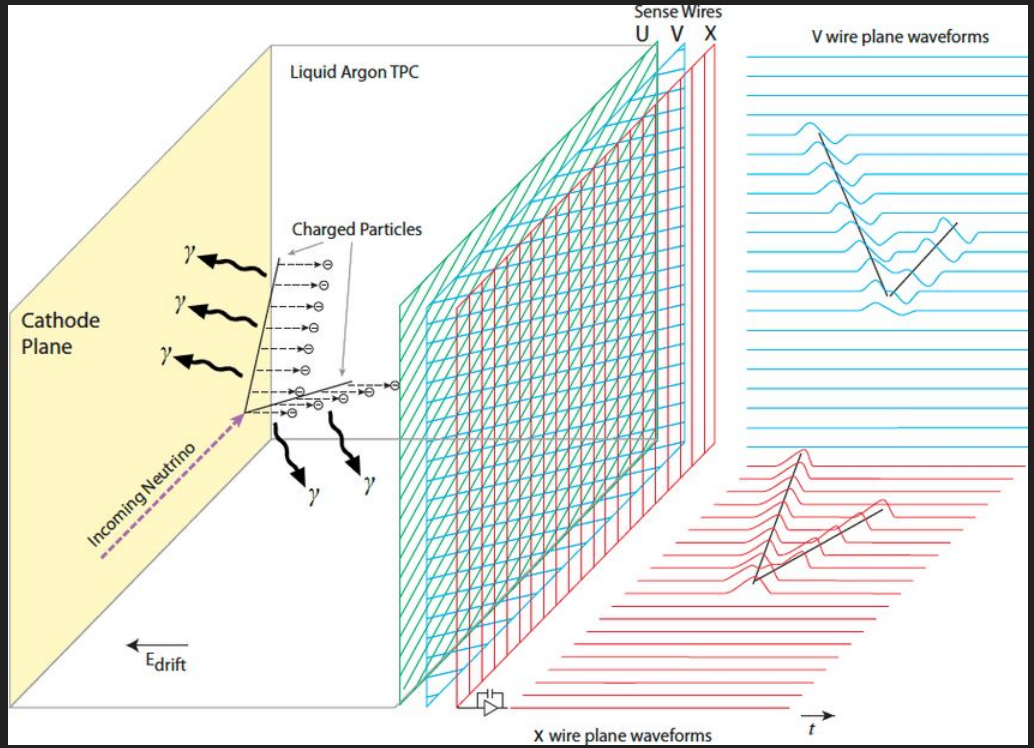
ICARUS Detector

- Neutrino detector
- Filled with 760 tons of LAr
- Measures neutrino cross sections using LAr
- Has three main components
  - Time Projection Chamber
  - Photomultiplier Tube
  - Cosmic Ray Tagger



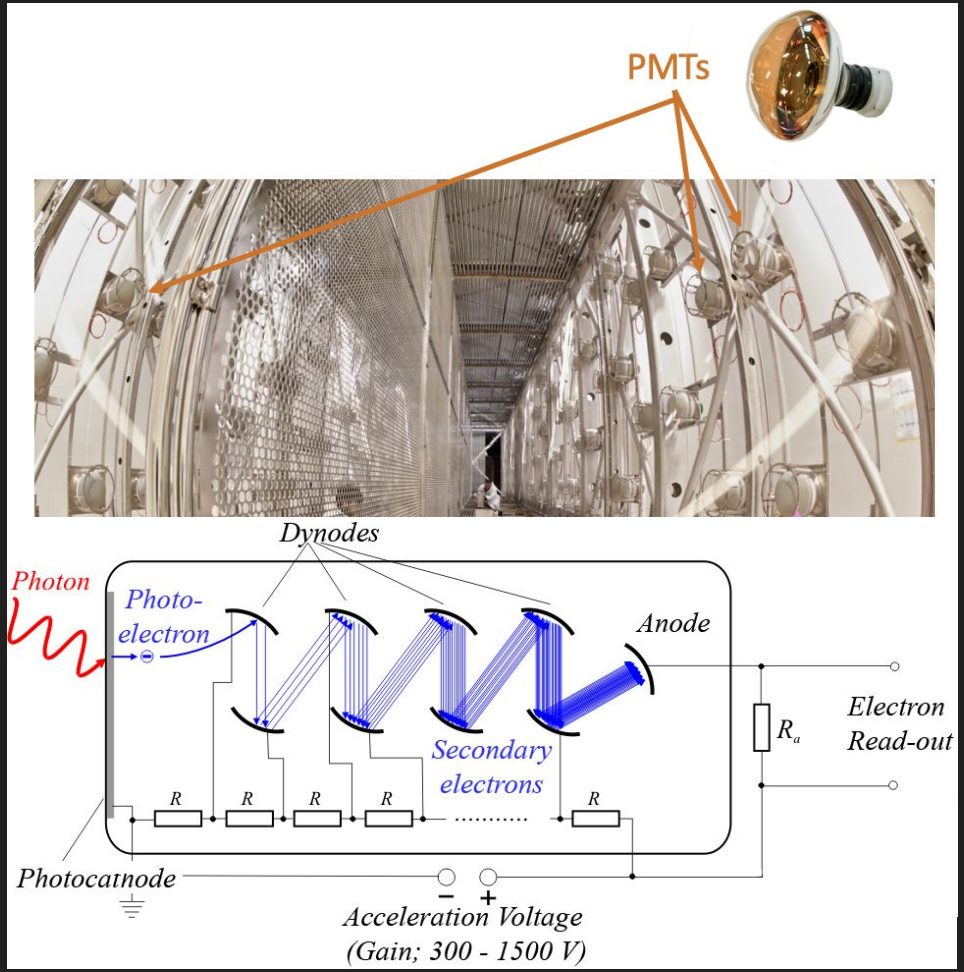
Time Projection Chamber (TPC)

- Neutrino interaction in LAr produces ionization and scintillation light.
- Electric field causes the charged ions to drift away from the cathode plane.
- Read out charges and light are produced using precision wires and PMT's.
- Three wire wires identify how the ion are moving within the medium.



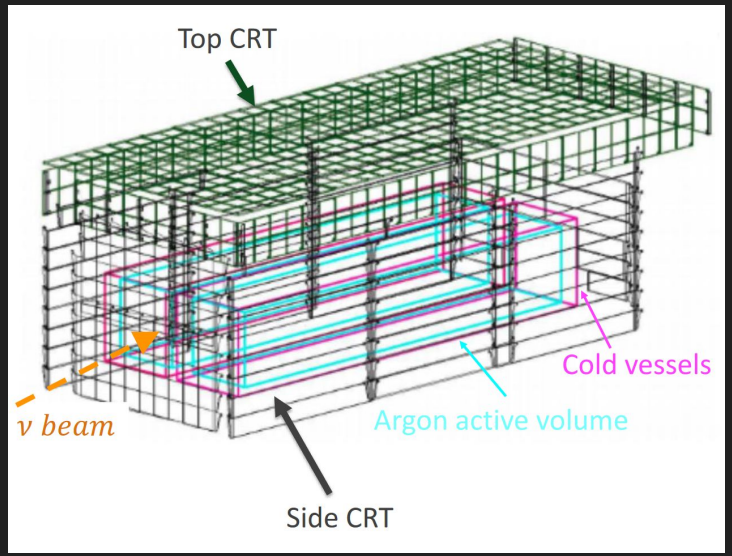
Photomultiplier Tube (PMT)

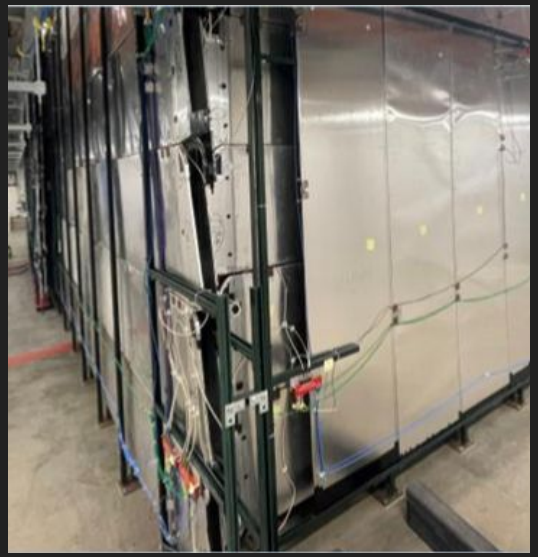
- The PMTs multiply the detection of the light recorded
- Able to reduce the amount of cosmic rays interference.
- When a ionized atom emits a photon to a PMT, the photon is absorbed by the photomultiplier tube's cathode and replaced by an electron that is multiplied throughout the the tube via electrodes.



Cosmic Ray Tagger (CRT)

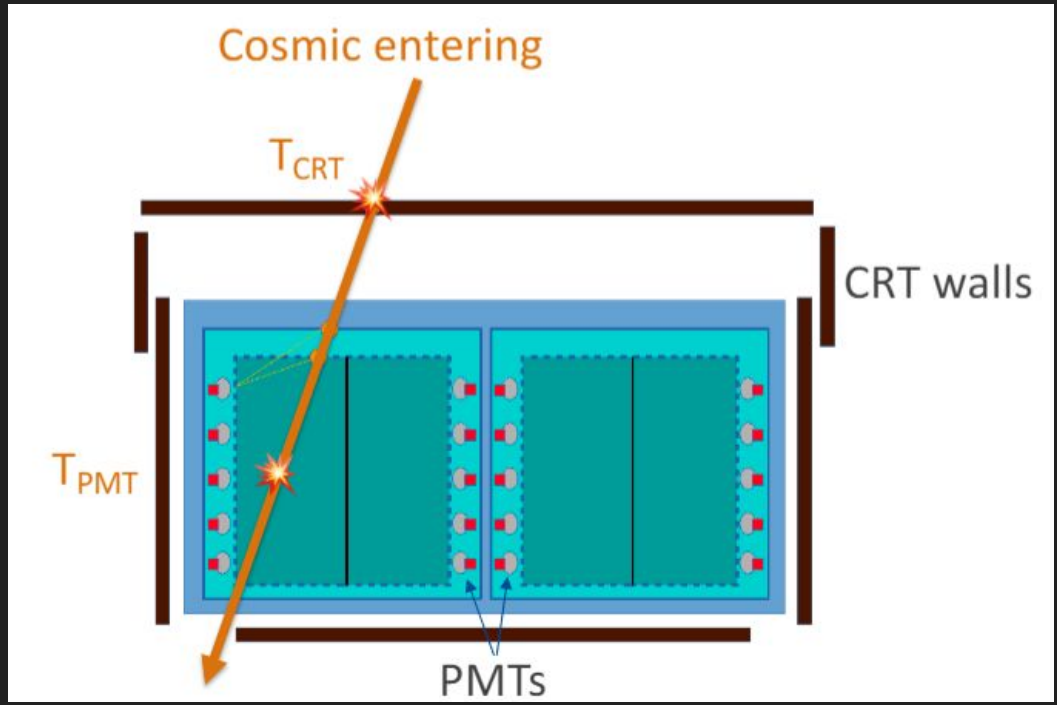
- Main function is to tag muons passing through the cryostats.
- Uses Polystyrene scintillator panels to identify particle hits.
- CRT electronics provide readouts and trigger times.





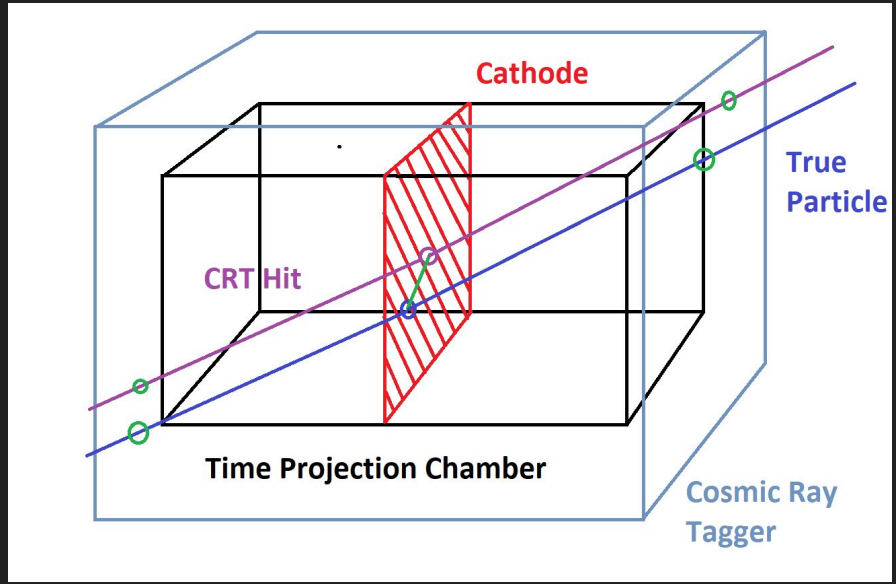
Matching CRT Lines to TPC Tracks

- Start off with first finding two CRT hits that are in time with one another, them we draw a hypothetical line that connects the two.
- We use PMT information to make sure the two hits are within the same cryostat.



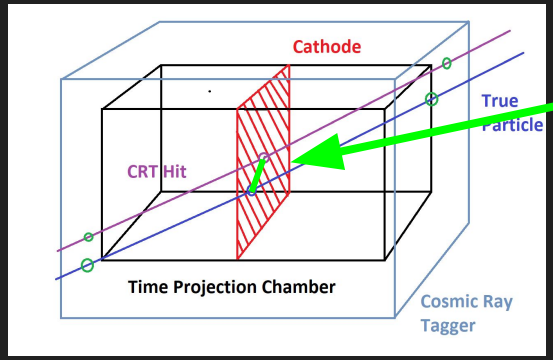
Matching CRT Lines to TPC Tracks

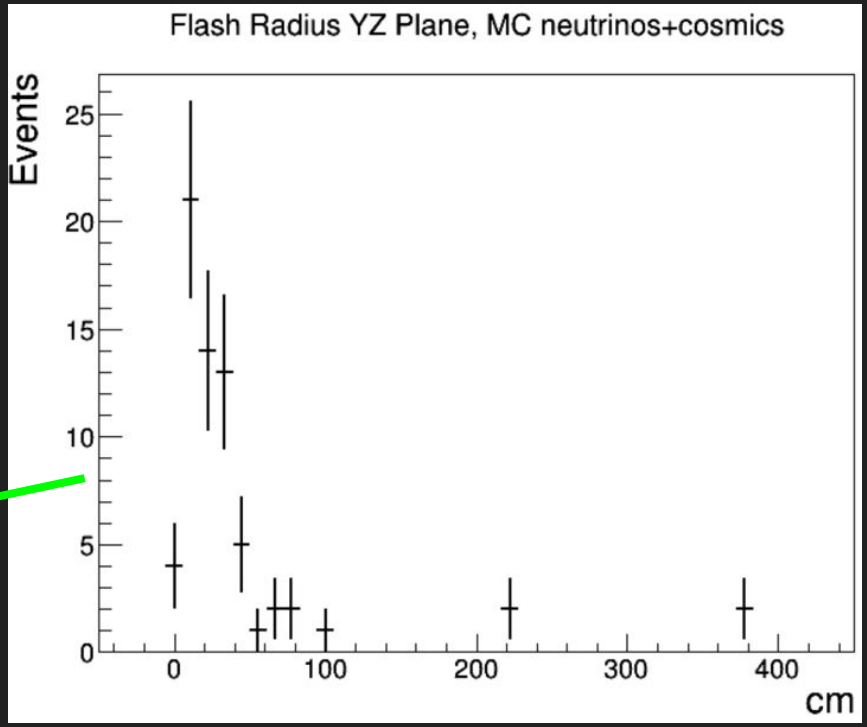
- Once this is done we find where on the cathode the particle crosses using our CRT start and end hit points.
- This is compared to where the true particles hit the cathode.



Comparing Cathode Crossing Particles

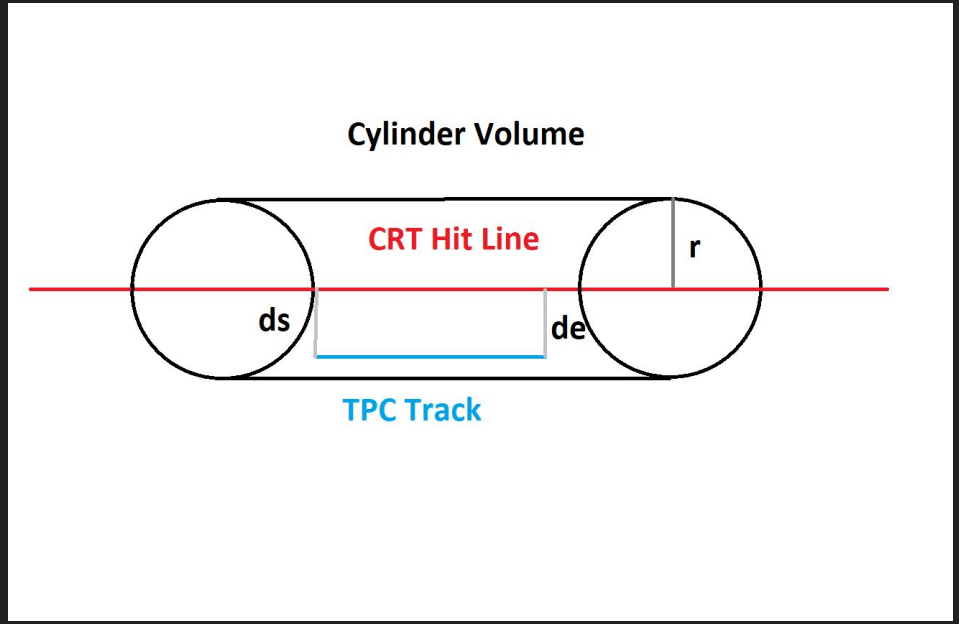
- Measuring the distances between truth and CRT crossings, it was found that the majority of them are within 100 cm of one another.
- Gives a playing field to where we expect our matches should be.





Combining CRT, PMT, and TPC Info.

- Using the CRT line from before, we will draw an imaginary cylinder surrounding it and check if we can find and TPC tracks within it.
- We look for the closest one within the volume of radius r, which is determined form the plot in the previous slide.
- The closest track is found by analyzing de and ds.



Cafe files

- Provides the necessary information from the LArSoft art ROOT files for analysis, selection, truth matching, and more.
- They are produced from stage1 files that are quite heftier.

Checking with Truth MC

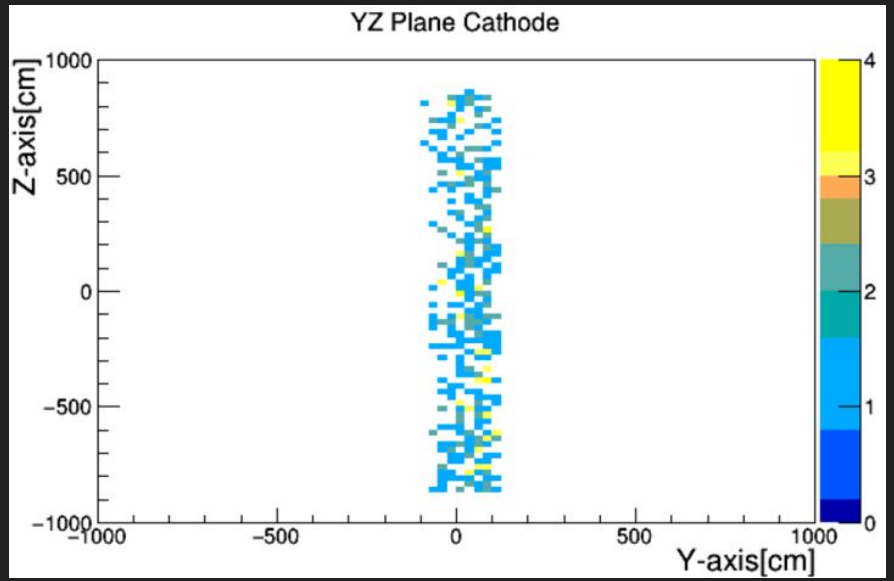
- Look at the total amount of cathode crossers with truth, CRT, and PMT information and comparing it to truth, CRT, PMT, and TPC (that was within our imaginary cylinder).
- **79% efficiency of properly identifying tracks**.
- There is a possibility that some particles cross the cathode at weird angles which could cause imperfect track matching.
- To counter this we tried to look at the efficiency when we remove the perimeter of the cathode (25 cm from the outside to the center).
- **73% efficiency with perimeter removed**.

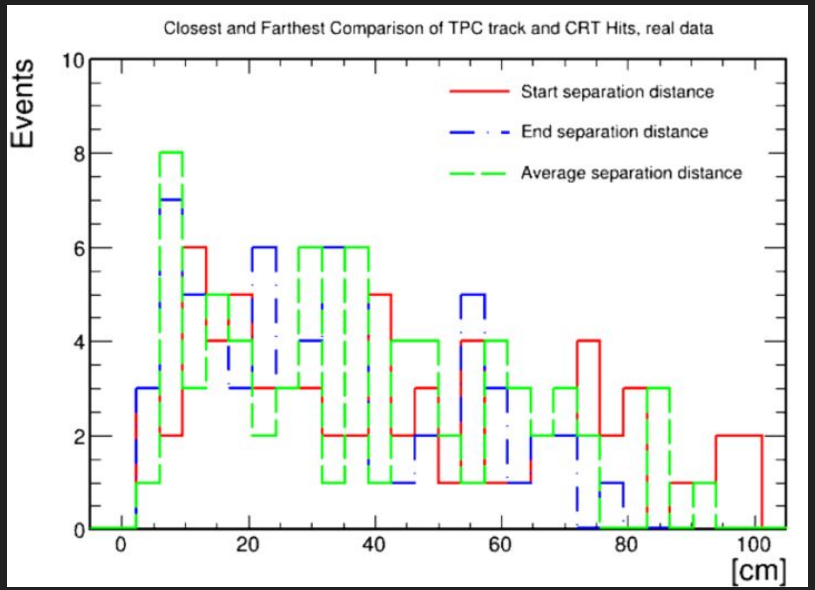
Results of Cosmic Real Data

- With perimeter:
- 495 particles crossing cathode.
- 338 identified within cylinder.
- 68% efficiency.

Without perimeter:

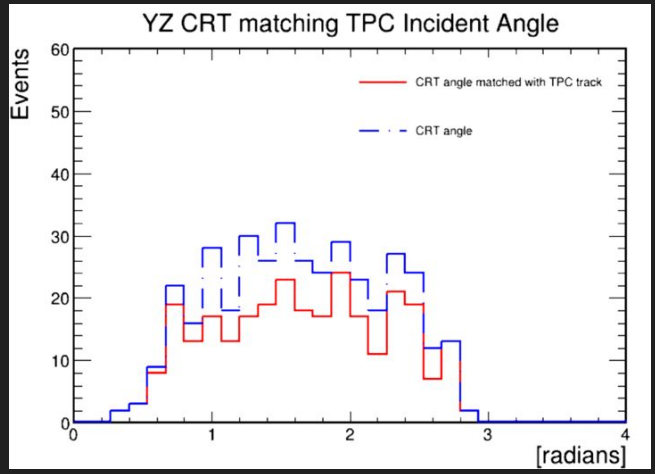
- 384 particles crossing the cathode.
- 265 identified within cylinder.
- 69% efficiency.

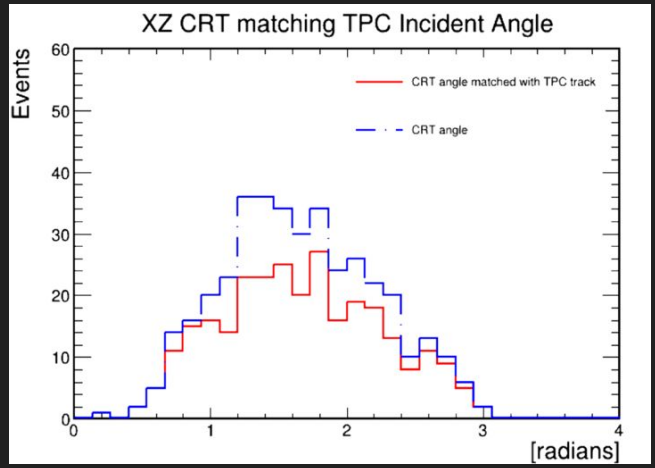




Cosmics Angle Distribution Results

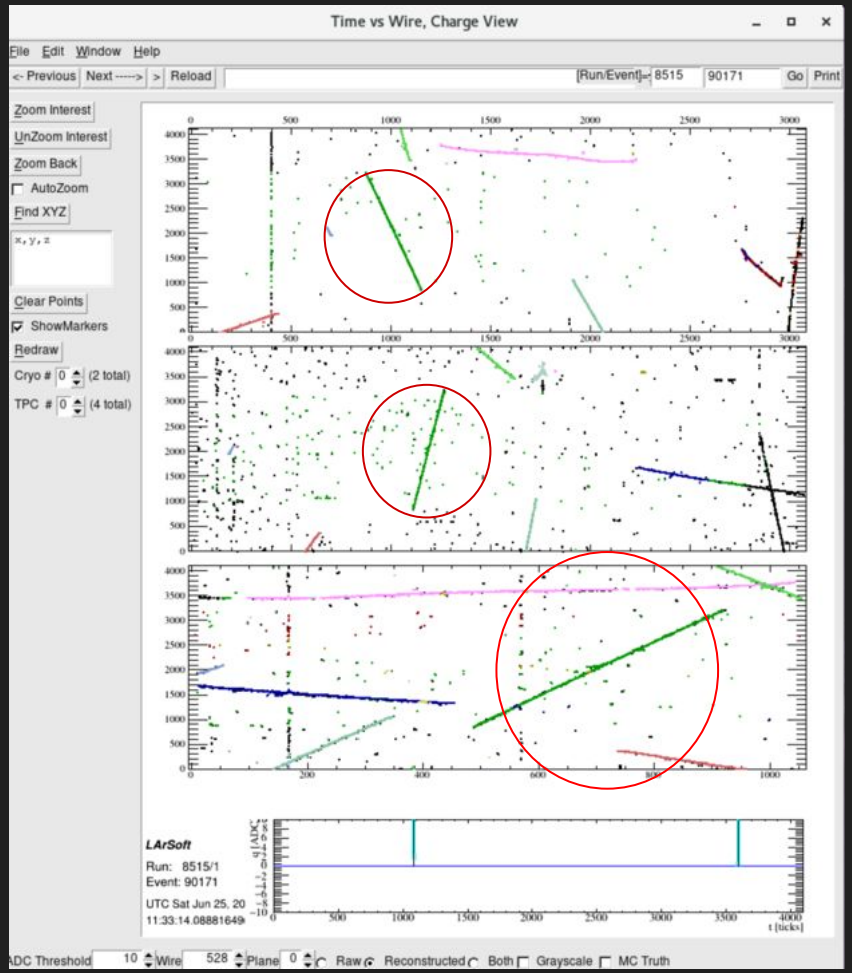
Looking at the incident angles, from a particle, on the cathode can give us a distribution of when a track is found with CRT, PMT, and TPC information, against a particle without the TPC information.





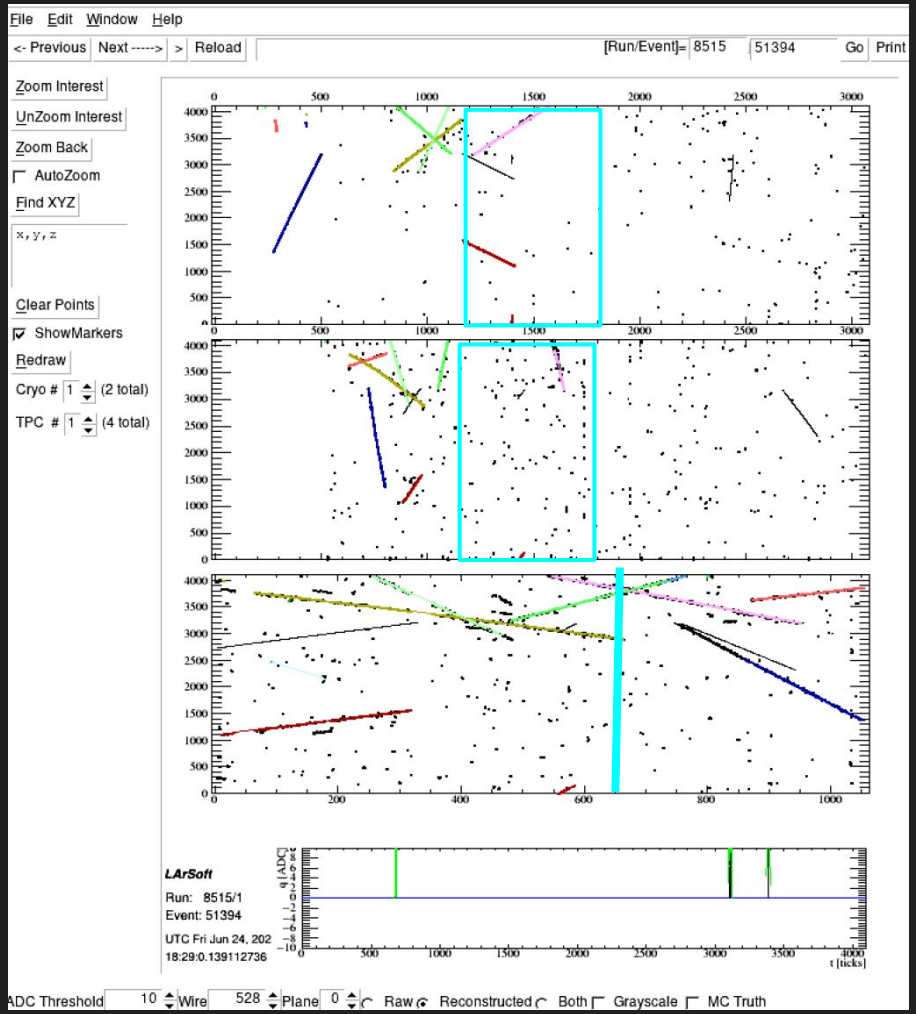
Checking Cosmic Data

- The event display gave us a sanity check.
- Allowed us to see if the track we were looking from the script, was present on the event display and reconstructed.
  - Does it cross the cathode where we expect.
  - Does the track start and end where we expect.
  - Is it in the correct cryostat and TPC.
  - Does it reconstruct properly.
  - Compare it to the Spill reconstruction.



Fake Bias Cosmic Data

- The CRT PMT matching finds a cathode crosser but without a TPC track.
- For the controlled bias group, events with no tracks within the cylinder were prioritized.
- When investigating the controlled “fakes” a bug was found in the way real data was processed for the cafe files.



Visual Scanning

Events with a matching Track									
Event	Match	Slice	Track	Printouts	Event	Match	Slice	Track	Printouts
155861	matched	matched	matched	Matched to 1 tpc	90171	matched	matched	matched	matched one end
		Small Split	Split in 1 TPC	track poorly made					cathode wire off by 20
Event	Match	Slice	Track	Printouts	Event	Match	Slice	Track	Printouts
150809	matched	matched	matched	matched	65465	matched	matched	matchd	no match, one was on track
				cathode wire differs by 100				split	cathode wire matched
Event	Match	Slice	Track	Printouts	Event	Match	Slice	Track	Printouts
10452	matched	matched	matched	matched to 1 tpc	52120	matched	matched	matched	matched, but split
			split	cathode wire differ by 50				split	cathode wire is off by 50
Event	Match	Slice	Track	Printouts	Event	Match	Slice	Track	Printouts
142901	mathced	matched	matched	matched	85851	matched	matched	not matched	no match
			split	cathode wire off by 10					cathode wire match
Event	Match	Slice	Track	Printouts	Event	Match	Slice	Track	Printouts
140225	matched	matched	matched	matched to 1 tpc end	172956	match	matched	no match	matched one end
		minor split	minor split	cathode wire matched			split	one side matched & split	cathode wire match
Event	Match	Slice	Track	Printouts	Event	Match	Slice	Track	Printouts
138173	matched	matched	matched	matched but split	16636	matched	matched	matched	matched
			splits	cathode wire off by 10					cathode wire match
Event	Match	Slice	Track	Printouts	Event	Match	Slice	Track	Printouts
137717	matched	matched	matched	no match	207460	matched	matched	matched	matched but split
			split	cathode wire matched				small splits	cathode is off by 80
Event	Match	Slice	Track	Printouts	Event	Match	Slice	Track	Printouts
3869	matched	matched	matched	matched	199744	matched	matched	matched	matched
				cathode wire off by 40					cathode wire off by 240
Event	Match	Slice	Track	Printouts	Event	Match	Slice	Track	Printouts
112156	matched	matched	not matched	matched	78663	matched	matched to pair	matched	matched
	barely	barely/Split	split/barely	cathode wire match/barely					cathode wire off by 80
Event	Match	Slice	Track	Printouts	Event	Match	Slice	Track	Printouts
113800	match	matched	matched	matched to a split section	191908	matched	matched	matched	within the track, slightly off
			split	cathode wire match					cathode wore off by 100

Summary

- TPC PMT CRT track matching script gave an insight to how well TPC and Spill reconstruction properly identified tracks.
- Script struggled to find tracks where the reconstruction didn’t account for spills which lead to unidentified tracks - brought down efficiency, currently is about 68-70% once they are fixed it could be better (preknown bug).
- Some tracks that were found in the outside of our radius, perhaps a larger radius would be ideal in this case.
- The study found bugs that need to be addressed to improve efficiency.
- Study got the ball rolling for future improvements to the reconstruction process, bad wires, data processing, and the event display.

Special Thanks

These efforts could not be done without the efforts and support of Fermilab faculty:

- Minerba Betancourt
- Bruce Howard (Can’t express how much I am grateful for his help and patience)
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- Anna Heggestuen
- Guadalupe Moreno
- Gianluca Petrillo
- Justin Mueller
- Fermilab facility and resources

References

[1] Collaboration, I. (2023). ICARUS at the Fermilab Short-Baseline Neutrino Program -- Initial Operation. *arXiv (Cornell University)*. https://doi.org/10.48550/arxiv.2301.08634

[2] https://icarus-exp.fnal.gov/at_work/software/doc/icaruscode/latest/namespacecaf.html

[3] https://analytics-hub.fnal.gov/hub