A GRAPH NEURAL NETWORK FOR RECONSTRUCTION OF LArTPC DETECTOR DATA

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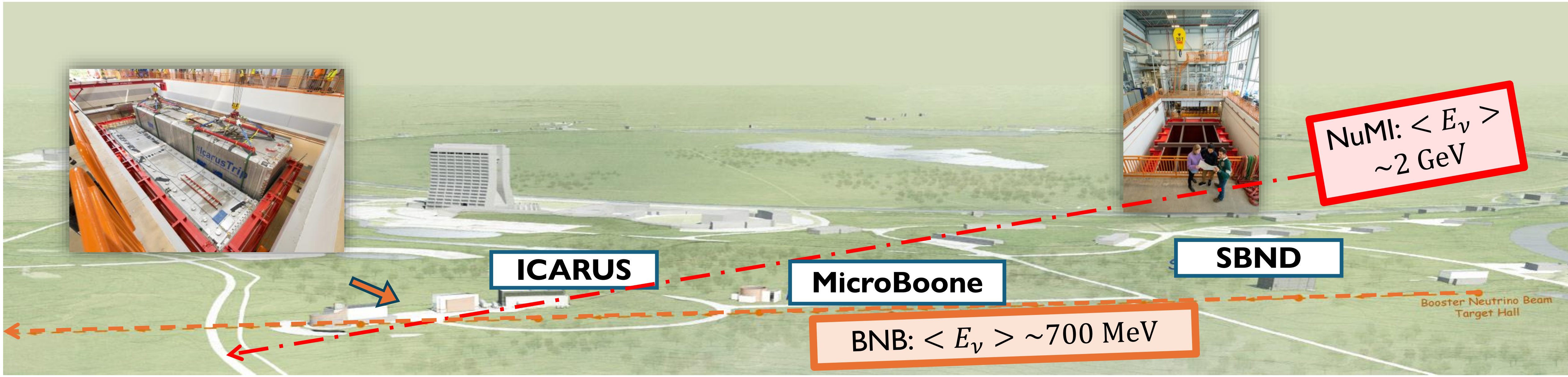
Fermilab

THE SBN PROGRAM



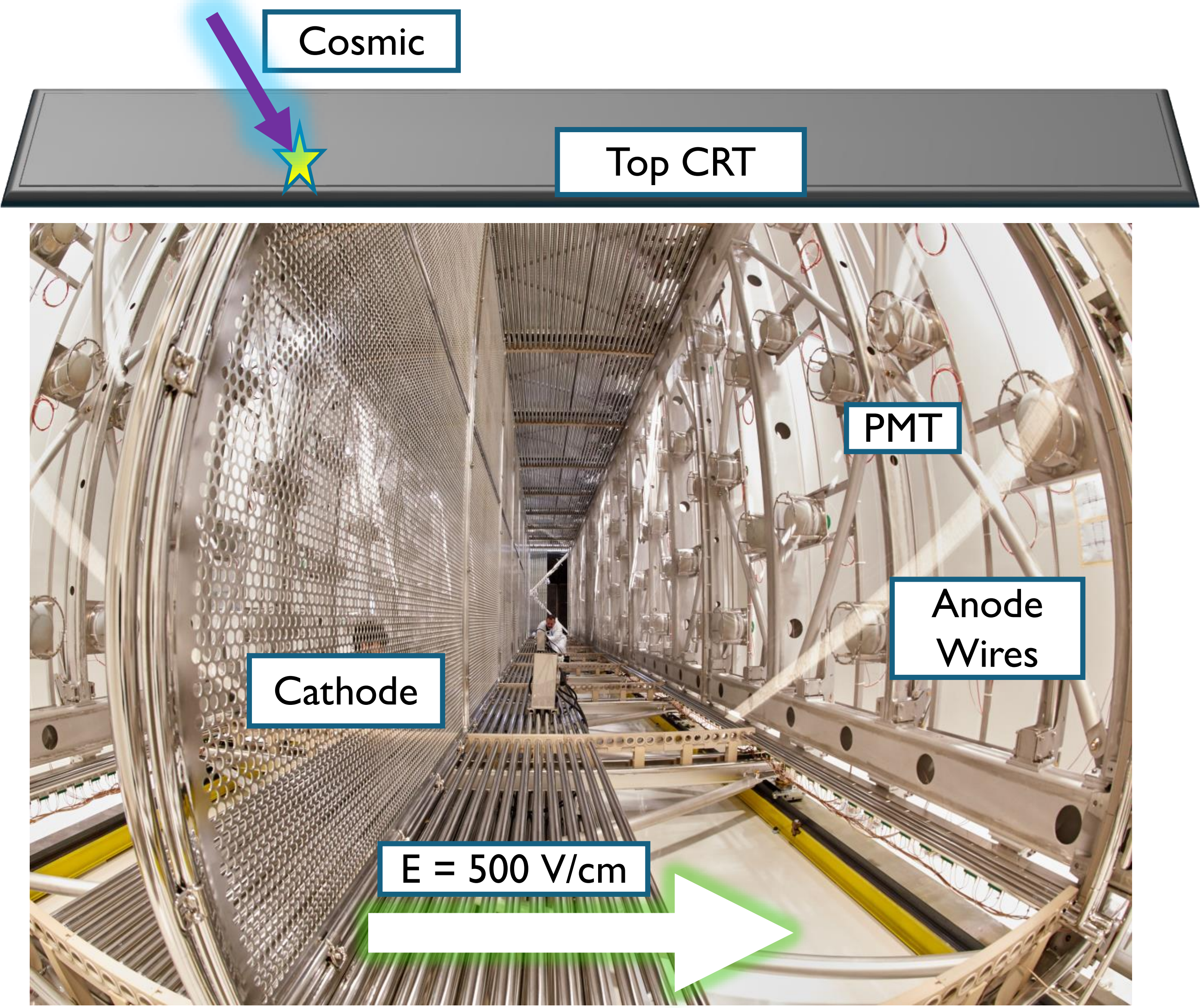
Sterile neutrinos are a possible explanation of the observed anomalies that challenge the standard 3-ν oscillation scenario (Reactor Neutrino, Gallium, LSND and MiniBooNE Low-Energy Excess)

Physics Goals:

- Confirm or rule out sterile neutrinos in the eV scale.
  - -Measure ν_e appearance and ν_μ disappearance rates on the Booster Neutrino Beam (BNB).
  - - ν_e (dis)appearance on NuMI beam.

Near/Far detector joint program reduces systematic uncertantities and increases the sensitivity on the oscillation measurements.

THE FAR DETECTOR: ICARUS

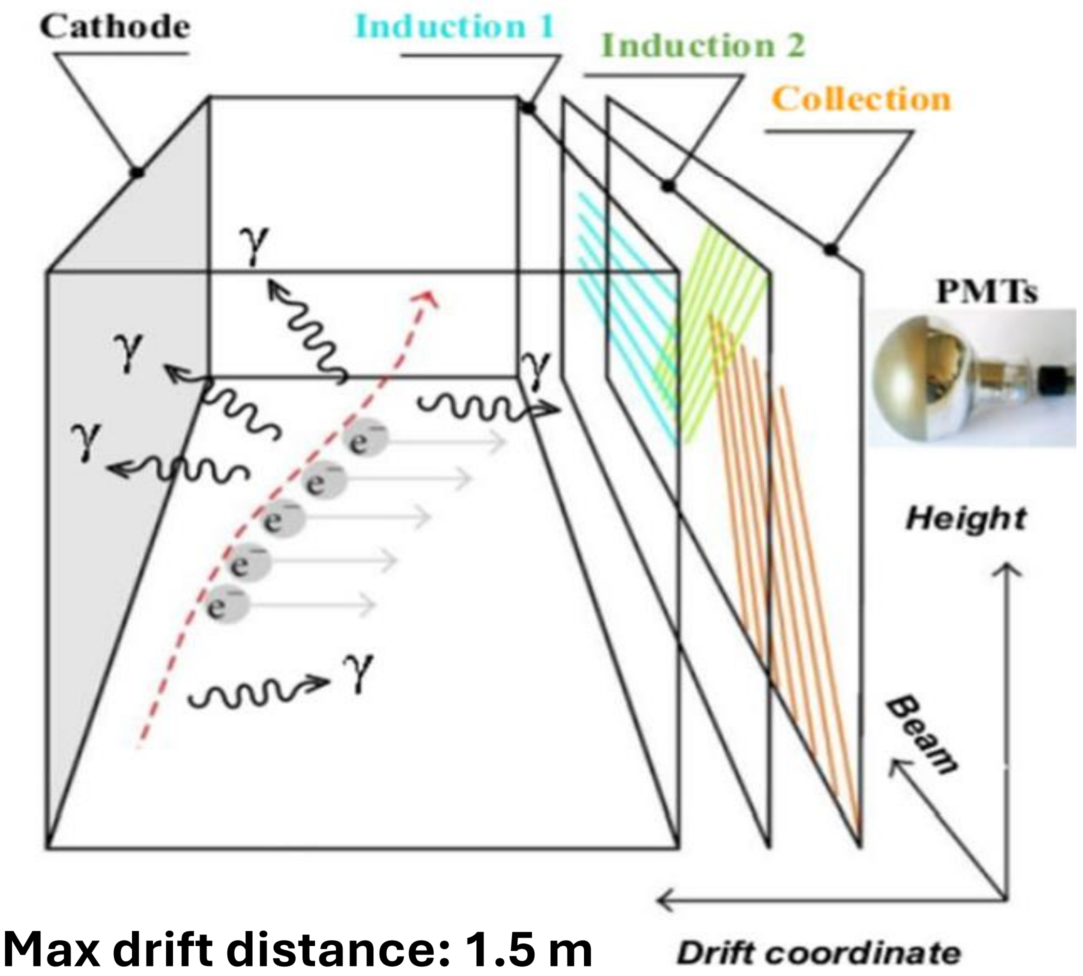


ICARUS has two $3.6 \times 3.9 \times 19.9\ m^3$ cryostats, filled with 760 t of LAr, located at shallow depth 600 meters from the BNB source.

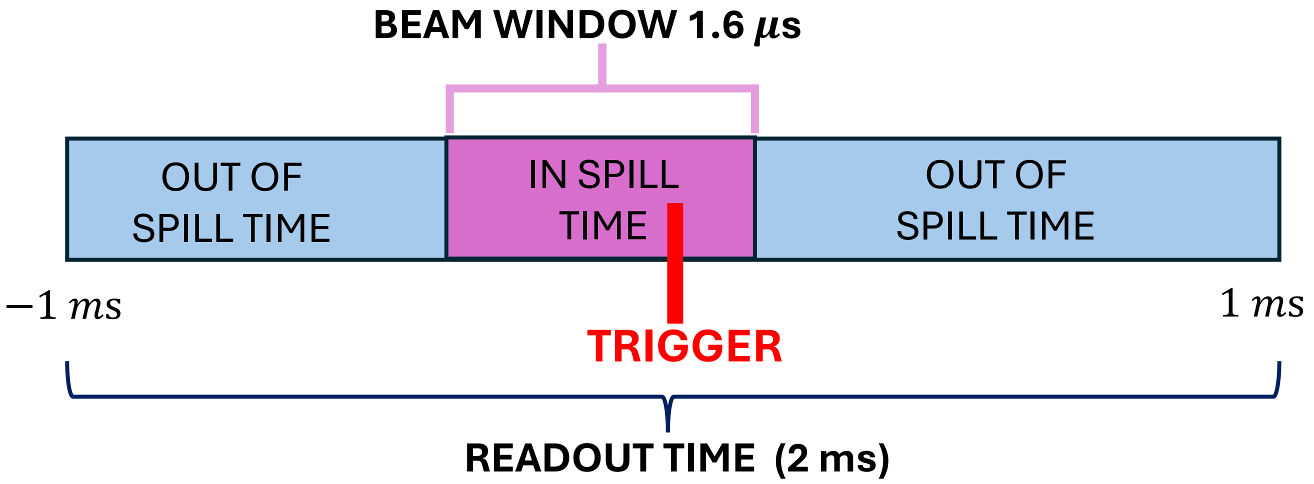
Three subsystems:

- **Time Projection Chamber (TPC)**
  3 readout planes at $0°, \pm 60°$ wr.t. the horizontal.
- **PhotoMultiplier system (PMT)**
  360x 8" PMTs, $\sim 1\ ns$ time resolution
- **Cosmic Ray Tagger (CRT)**
  Top, Side and Bottom scintillator bars
  time resolution ~ 1 ns
  spatial resolution ~ 1 cm

TIME PROJECTION CHAMBER



Max drift distance: 1.5 m
Max drift time: 0.96 ms



- Each cryostat contains 2 TPC systems divided by the cathode with independent coordinates
- Induction 1 wires are split at z=0 on both TPC

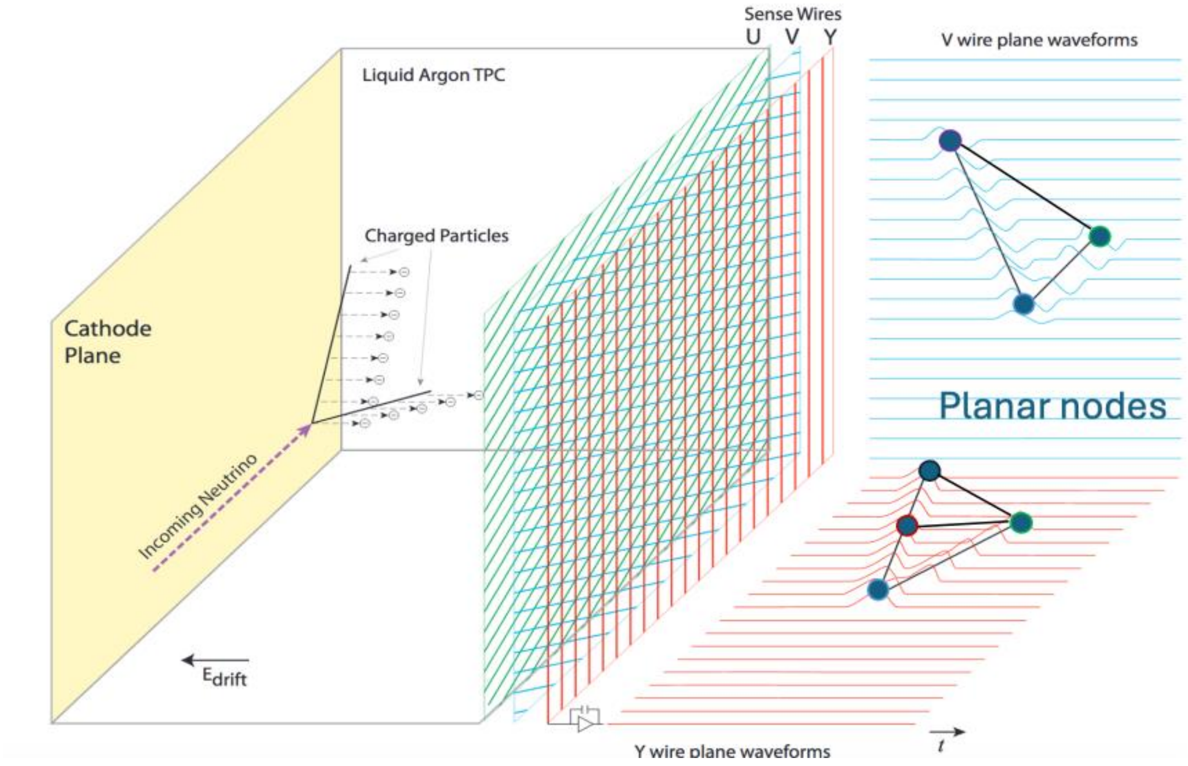
→ The reconstruction algorithm collects deposited charges on each wire and clusters them, forming 3D hits

NuGraph

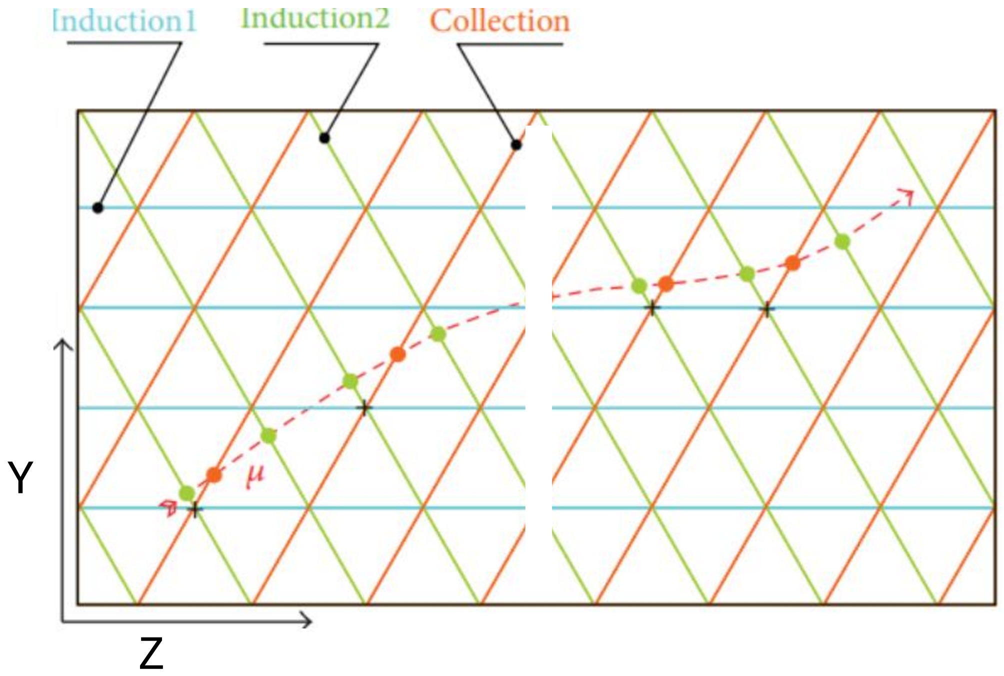
- Nugraph is a Graph Neural Network that takes the hits on each wire and determines the type of particle that originated them.

- The principal inputs are:
  - WireID
  -Peak time
  - charge integral
  -RMS

- Tested on MicroBooNE data and now planned on ICARUS



WIRE MAPPING



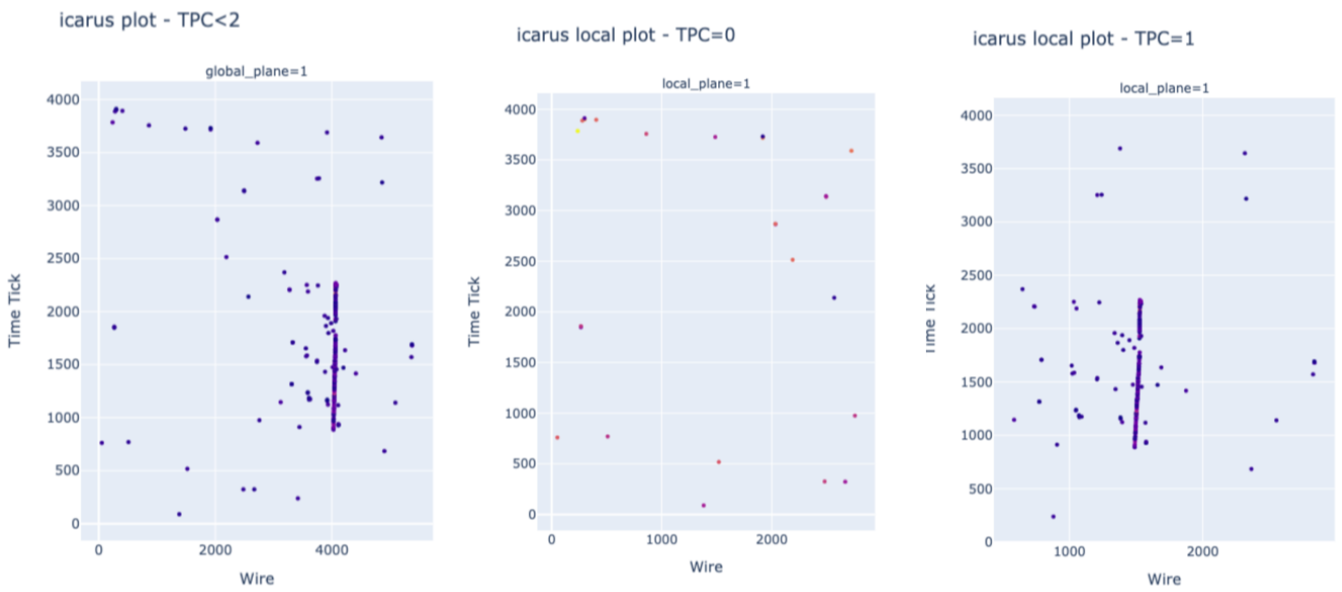
- Induction1 wires keep the same ID on contiguous TPC systems

- Induction2 and collection wires are logically stitched as the last wires of one TPC are connected to the first of the contiguous one.

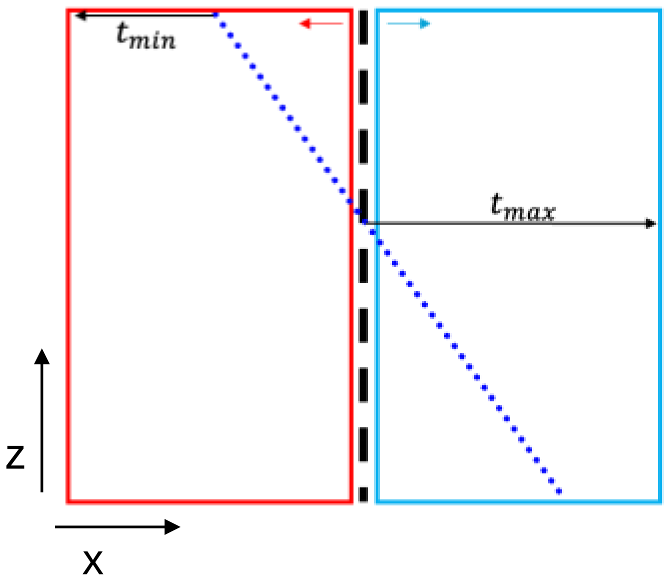
The mapping of the wire labels in planes 1 and 2 is:

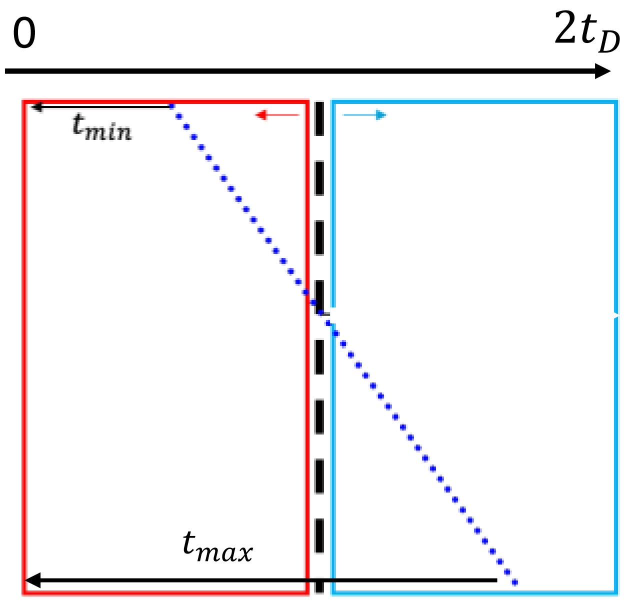
$$WireID \rightarrow WireID + 2536$$

As the wire 2536 of the TPC 0 is stitched with the wire 0 of TPC 1 and so on. Same with TPCs 2 and 3.



TIME MAPPING

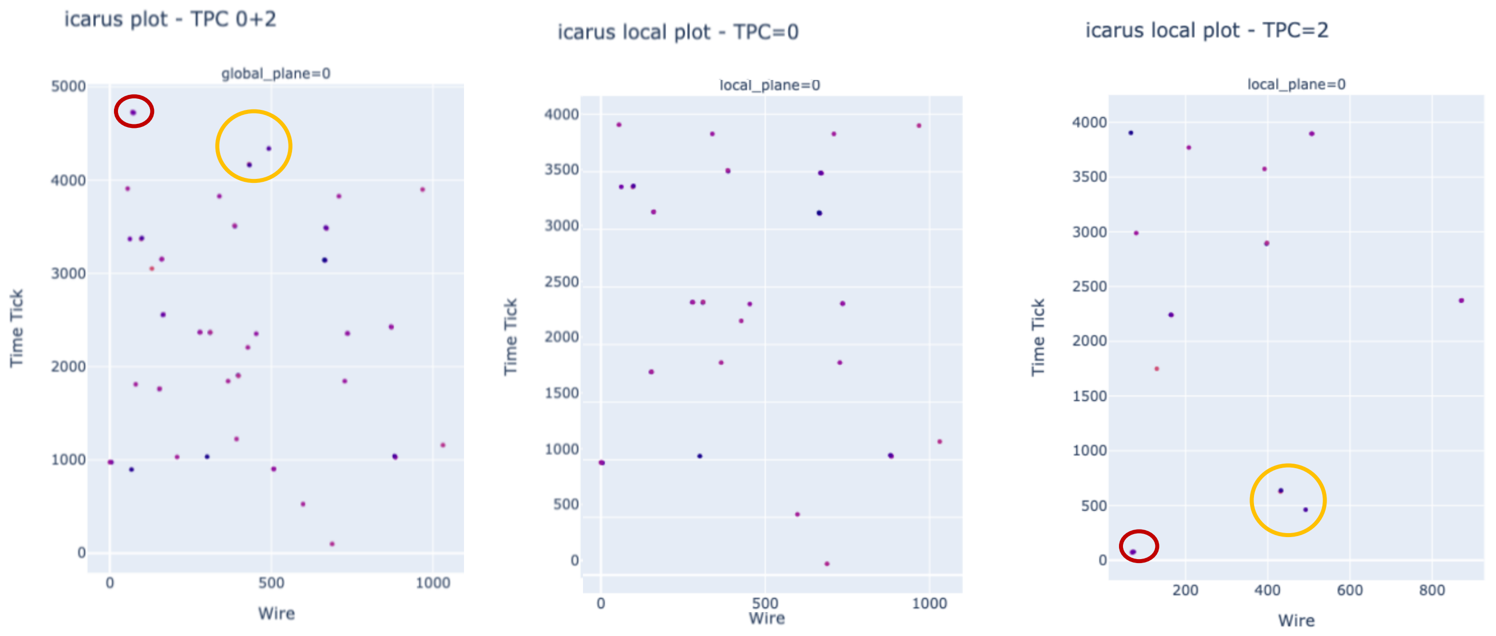




The 0 is set in one TPC plane while at the other the time translation is:

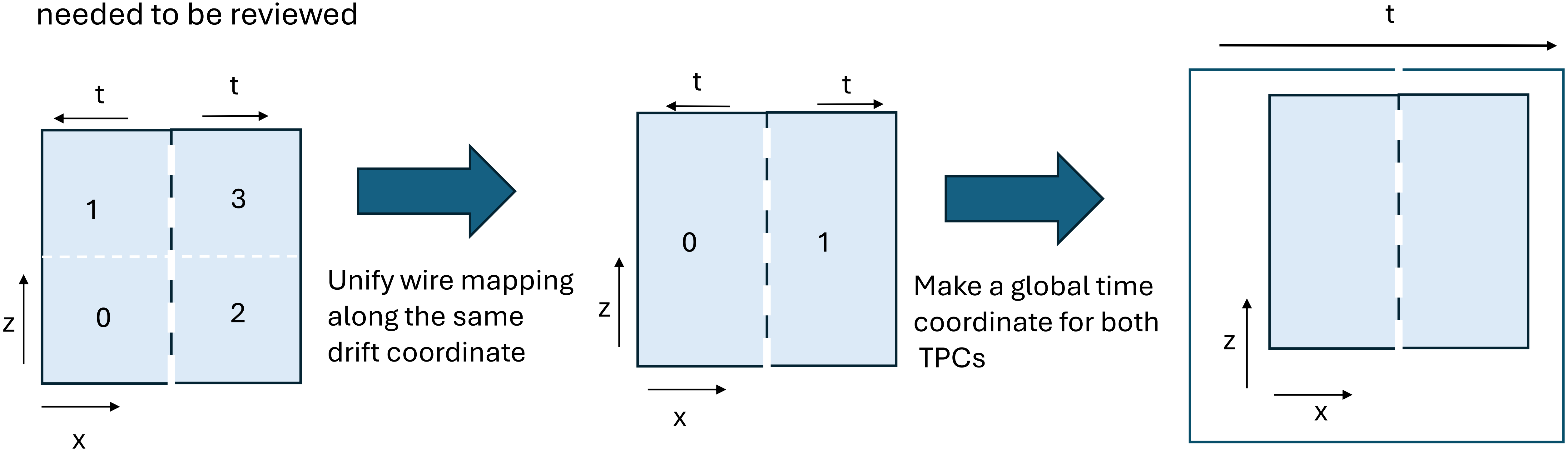
$$t_{hit} \rightarrow \frac{2 * t_D}{0.4} - t_{hit}$$

- Each TPC reconstructs time independently taking the drift distance from the cathode.
- A global timing is set by taking one TPC as reference and scaling the time value to the other TPC



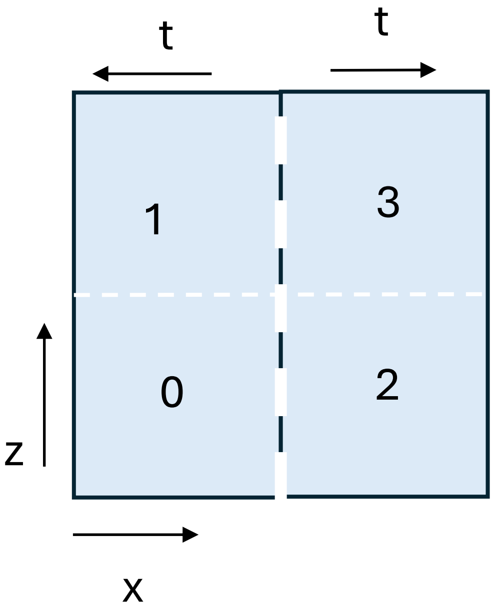
UPDATES ON THE DATASET

After wire and time stitching, the slices of neutrino events are selected by light and charge barycenter matching. Both the time stitching and the barycenter needed to be reviewed

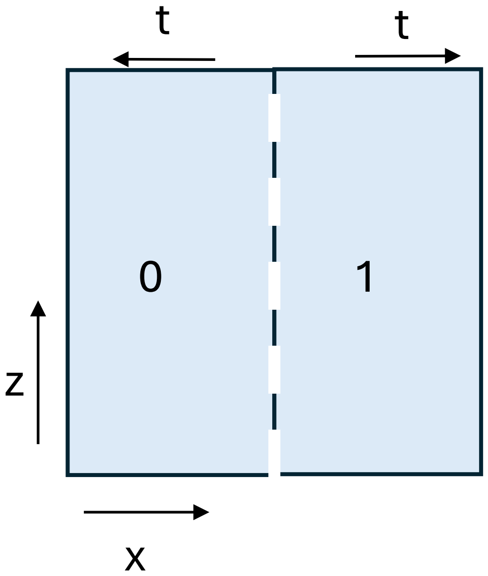


GLOBAL AND LOCAL COORDINATES

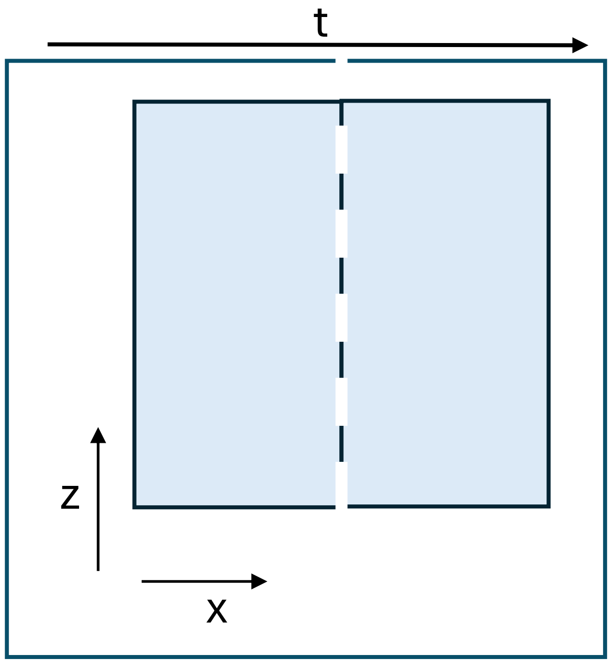
After wire and time stitching are performed the original coordinates of the wire and the timing on each TPC are stored in local and global variables



Unify wire mapping along the same drift coordinate



Make a global time coordinate for both TPCs

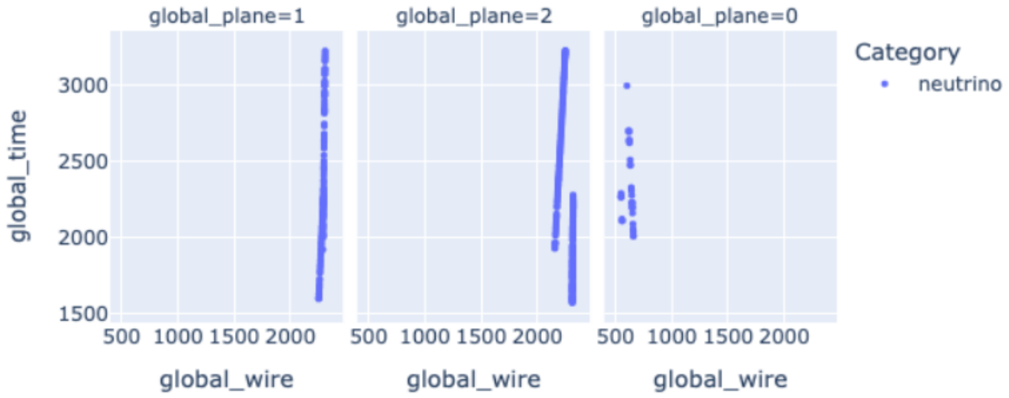


- Local ones correspond to the wire and time on each logical TPC.
- Global to the unified coordinate system

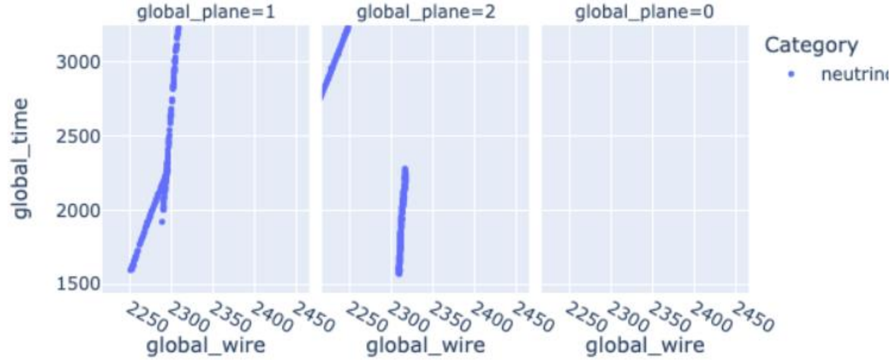
If the stitching is well done, we expect a continuity on all the reconstructed track inside the final virtual TPC

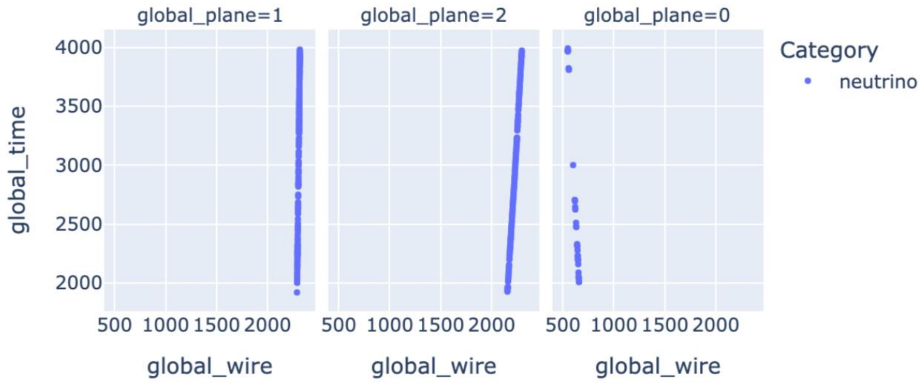
TIME STITCHING

The stitching of the two logical TPCs required not only the mapping of the drift times along the physical TPCs but also the inclusion of the tic offset in the reconstruction of the signals on the wire planes



$$t_{hit} \rightarrow \frac{2 * t_D}{0.4} - t_{hit}$$



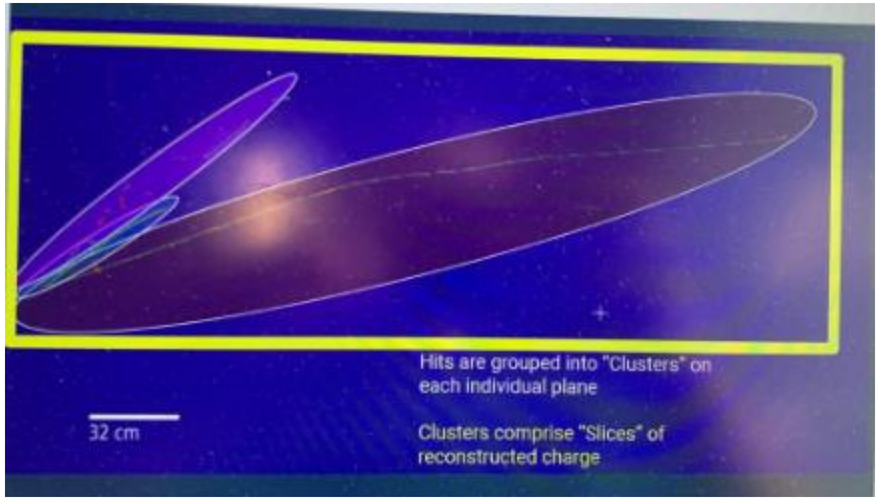


$$t_{hit} \rightarrow \frac{2 * t_D}{0.4} + 1700^{*} - t_{hit}$$

*1700 corresponds to 2 times the tic offset present on the charge reconstruction of the wires performed by Pandora
*Further studies needed

THE NEUTRINO SLICE

- MicroBooNE events are stored in one individual slice, meaning that a neutrino event will be defined in one given slice.
- Each event in ICARUS is reconstructed in multiple candidate neutrino slices, meaning that for each event there are multiple collections of hits that can correspond to the neutrino interaction.
- For a given event in ICARUS, the neutrino interaction will be stored in one slice from all the stored ones.



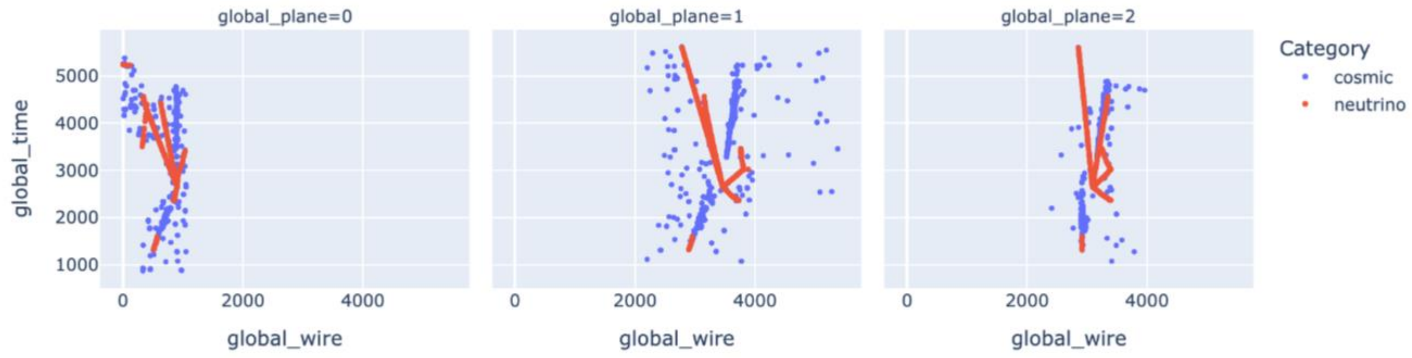
NuGraph is designed to work on one slice, so part of the preprocessing is to select one candidate neutrino slice from each event, this by means of the charge and light barycenter distances.

BARYCENTER DISTANCES

To select the neutrino slice in ICARUS the barycenter of the charges deposited for each hit inside the slice is compared with the one of the flashes within the flashes around 10 μs from the trigger.

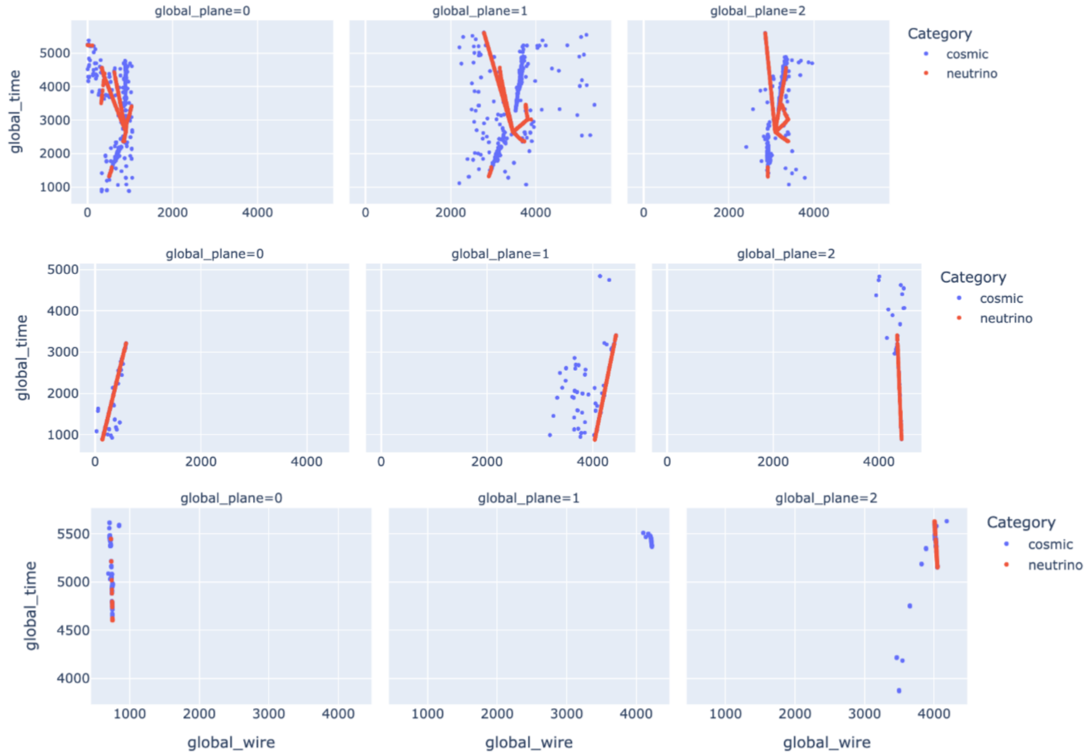
- The coordinates of the hits are given in terms of the wires where the signal is reconstructed. The integral charge is taken from the Collection plane.
- The wire coordinates of the flash are extrapolated from the cartesian ones obtained from the pandora reconstruction.
- The distance is calculated in all 3 planes.

The first approach consisted in taking all the hits corresponding to each slice and calculate the barycenter distance to the flash



BARYCENTER SLICE APPROACH

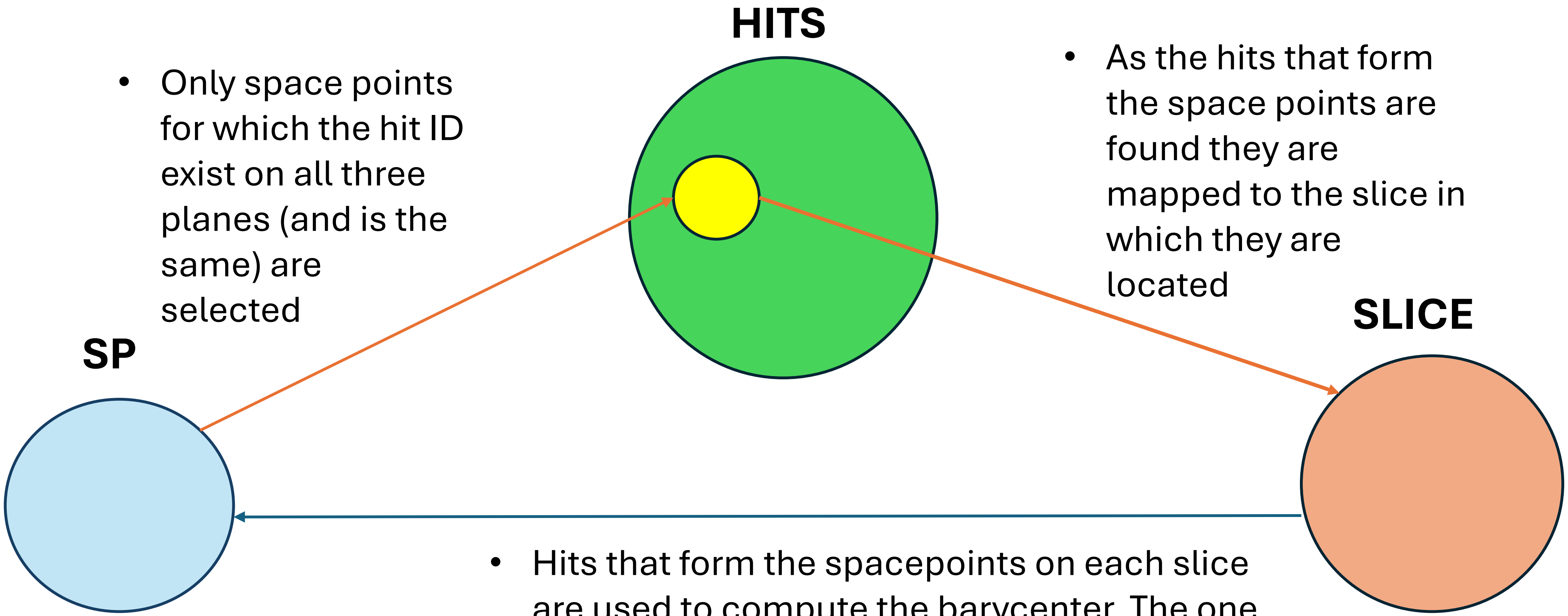
However, collecting all the hits reconstructed per slice includes hits that can correspond to inefficiencies in the reconstruction or that are not associated with a given track; originating miscalculations on the neutrino slice



- Points present in a plane but not in the other 2 correspond to those “scattered” hits that are not correlated to the barycenters on each of the wire planes
- A more precise selection should take in consideration only hits that are present in all 3 planes
- (Some) Hits grouped in spacepoints already fulfill this condition, so the sample can be taken from these objects

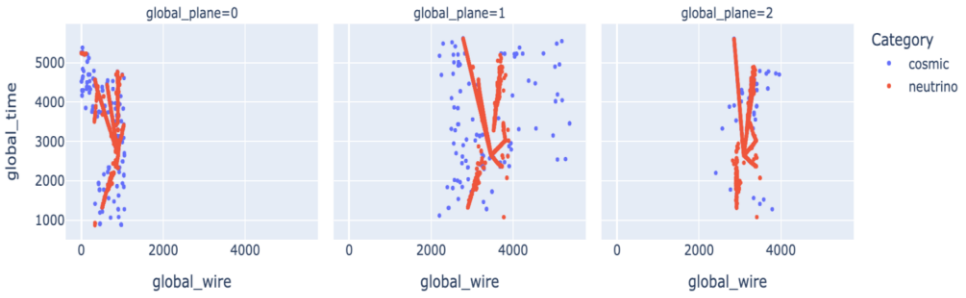
USING THE SPACEPOINT SAMPLE

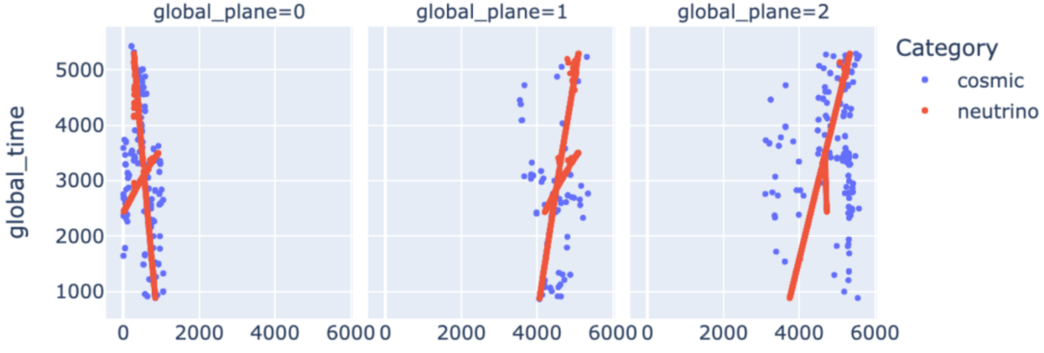
The spaces points are not grouped by slice, so to use their hits as the criteria of selection a map of the Space Points on to the slices is done.

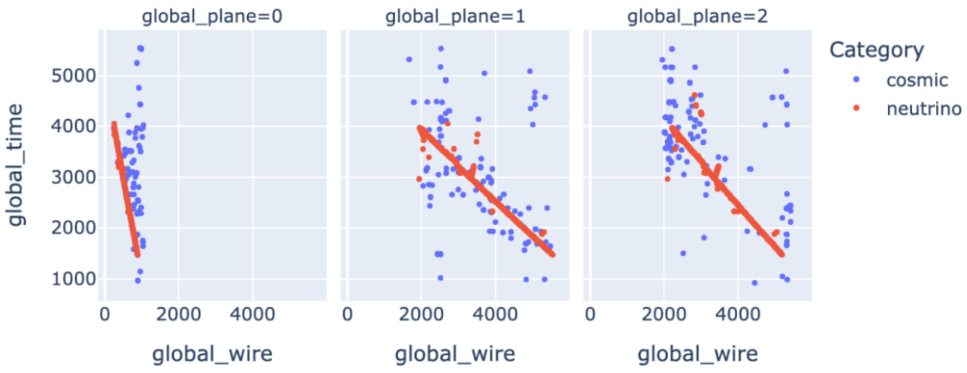


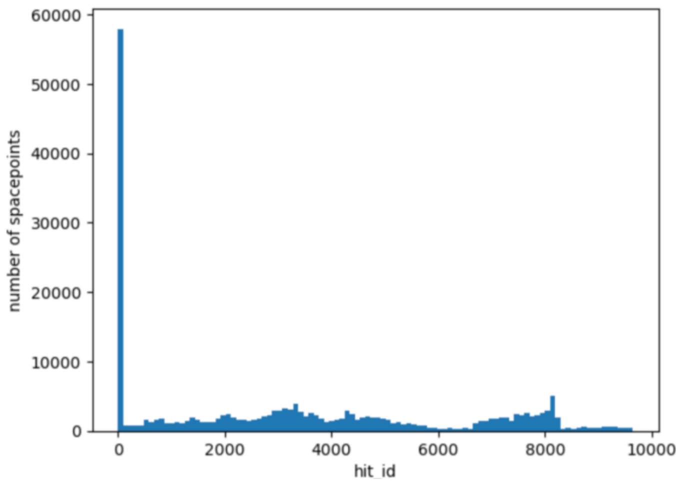
- Only space points for which the hit ID exist on all three planes (and is the same) are selected
- As the hits that form the space points are found they are mapped to the slice in which they are located
- Hits that form the spacepoints on each slice are used to compute the barycenter. The one with shorter distance is selected

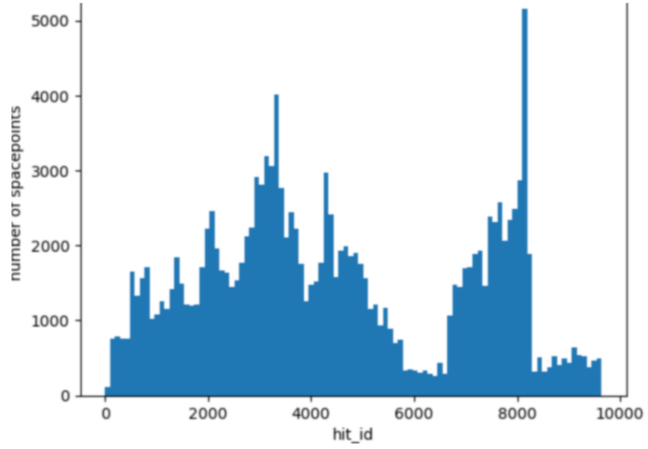
USING THE SPACEPOINT SAMPLE











- Selecting spacepoints for which hits is reconstructed on all planes filters also the hit sample, leaving a sample of hits that are mostly reconstructed correctly (with and ID different than -1). Giving a smaller, more reliable set of points

- The G4ID filter was used to test the number of points that can get selected as neutrino slice in the MC

THE FINAL HDF5 FILES

- The sample of hits collected contains mostly information regarding neutrino candidate tracks correctly mapped into one big virtual TPC. Meaning that is now suited for the pre-training and training of NuGraph on ICARUS data

- A group files (~120) is being produced now for pre-processing and further training on NuGraph

- The first produced files were pre-processed without any issue. Which is a good sign ☺

CONCLUSIONS AND FURTHER WORK

- The adaptation of the ICARUS data sample into a NuGraph-like dataset seems to be complete by now. This is expected to make further stages more direct

- The feature that influences the most the sample corresponds to the 3D reconstruction of the points, filtering more badly reconstructed hits than other variables at a “wire level” as for example the χ^2 of the hits

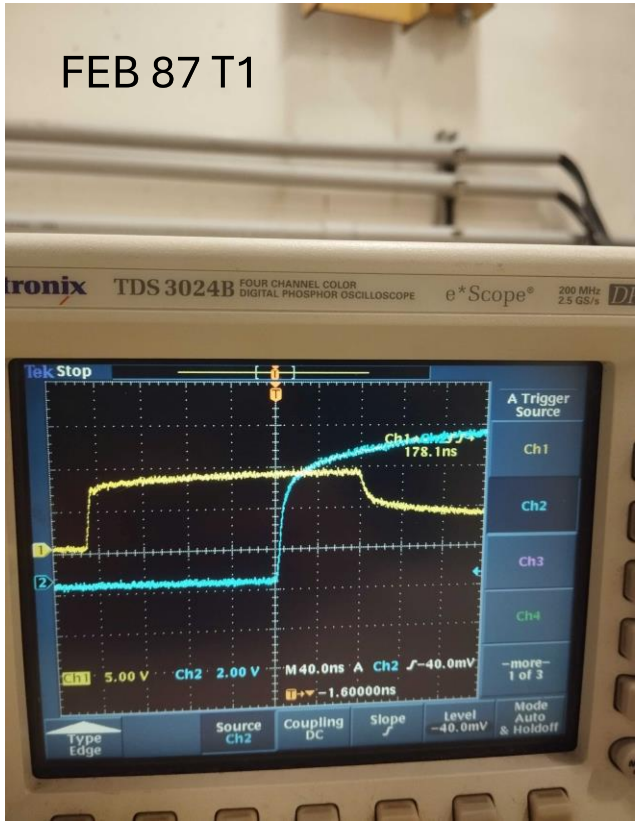
- Next steps consist of the pre-processing and further training of Nugraph with the produced datasets.

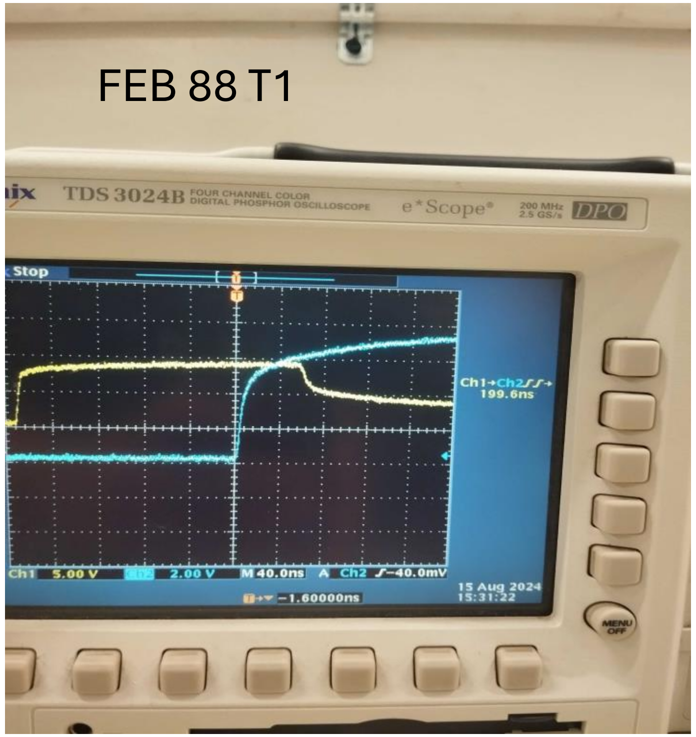
- Hopefully NuGraph performs good on ICARUS too

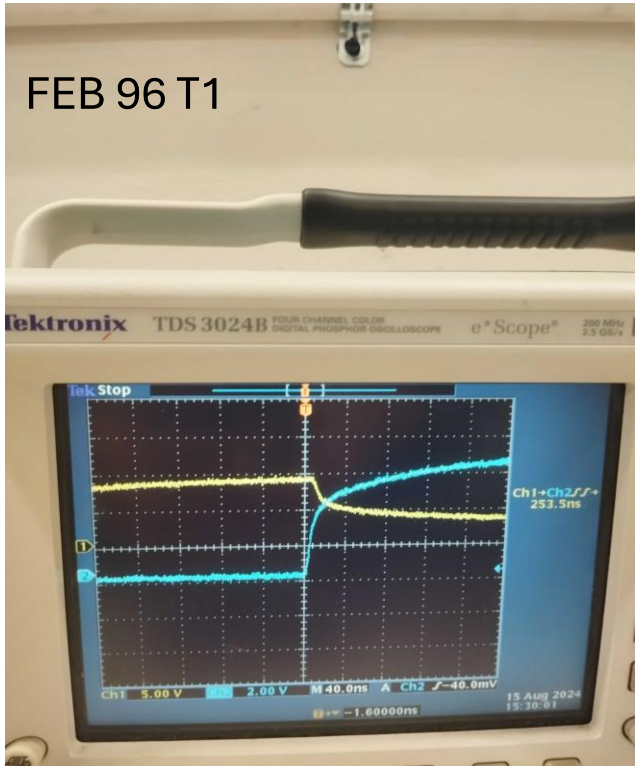
APPENDIX: ICARUS SIDE CRT TIME DELAY

A measurement the delay time on each FEB signal with respect to the global trigger signal.

Reg 45
FEBS: 86-103

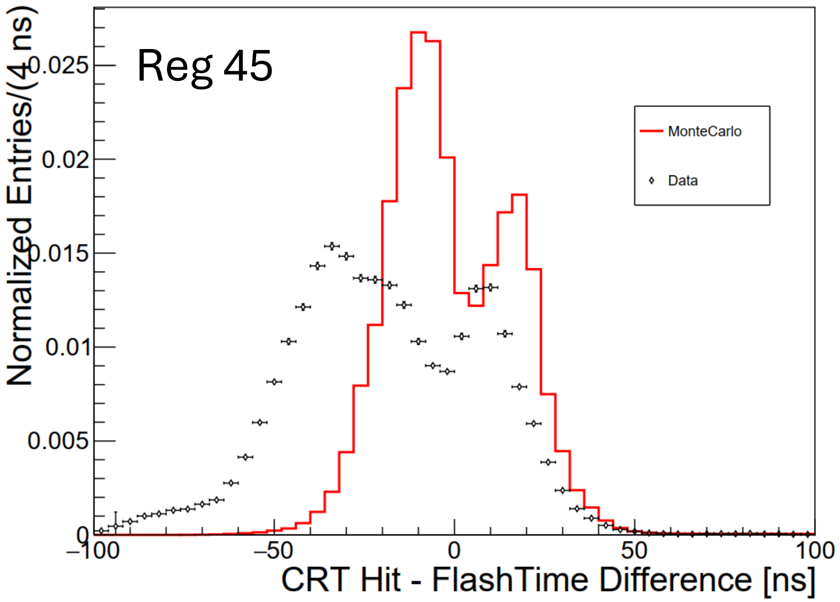


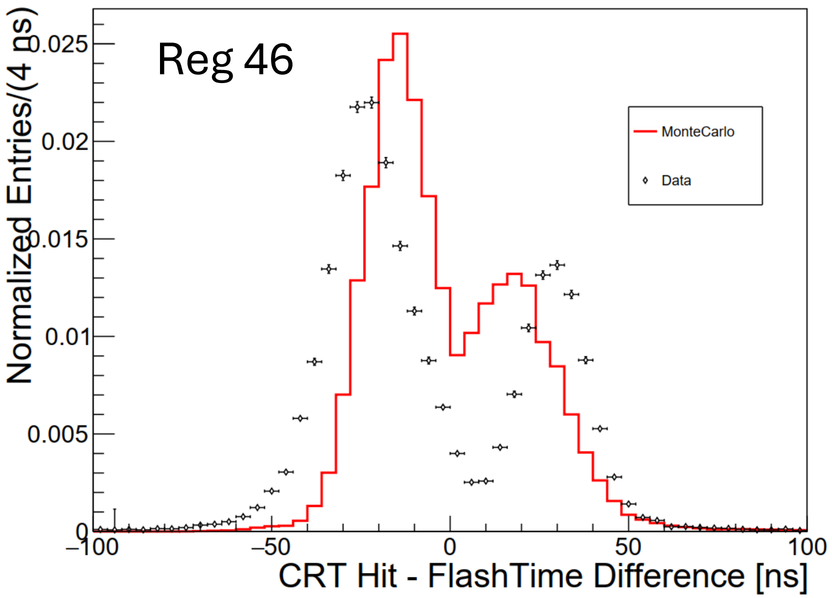


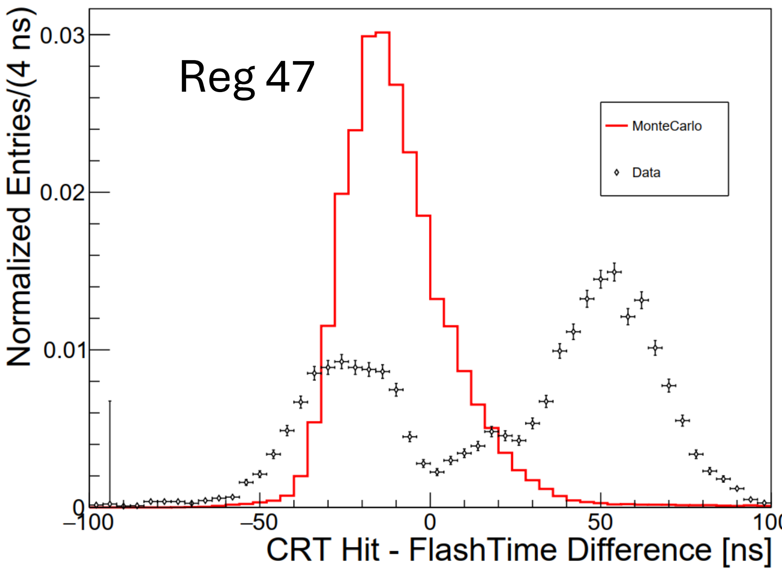


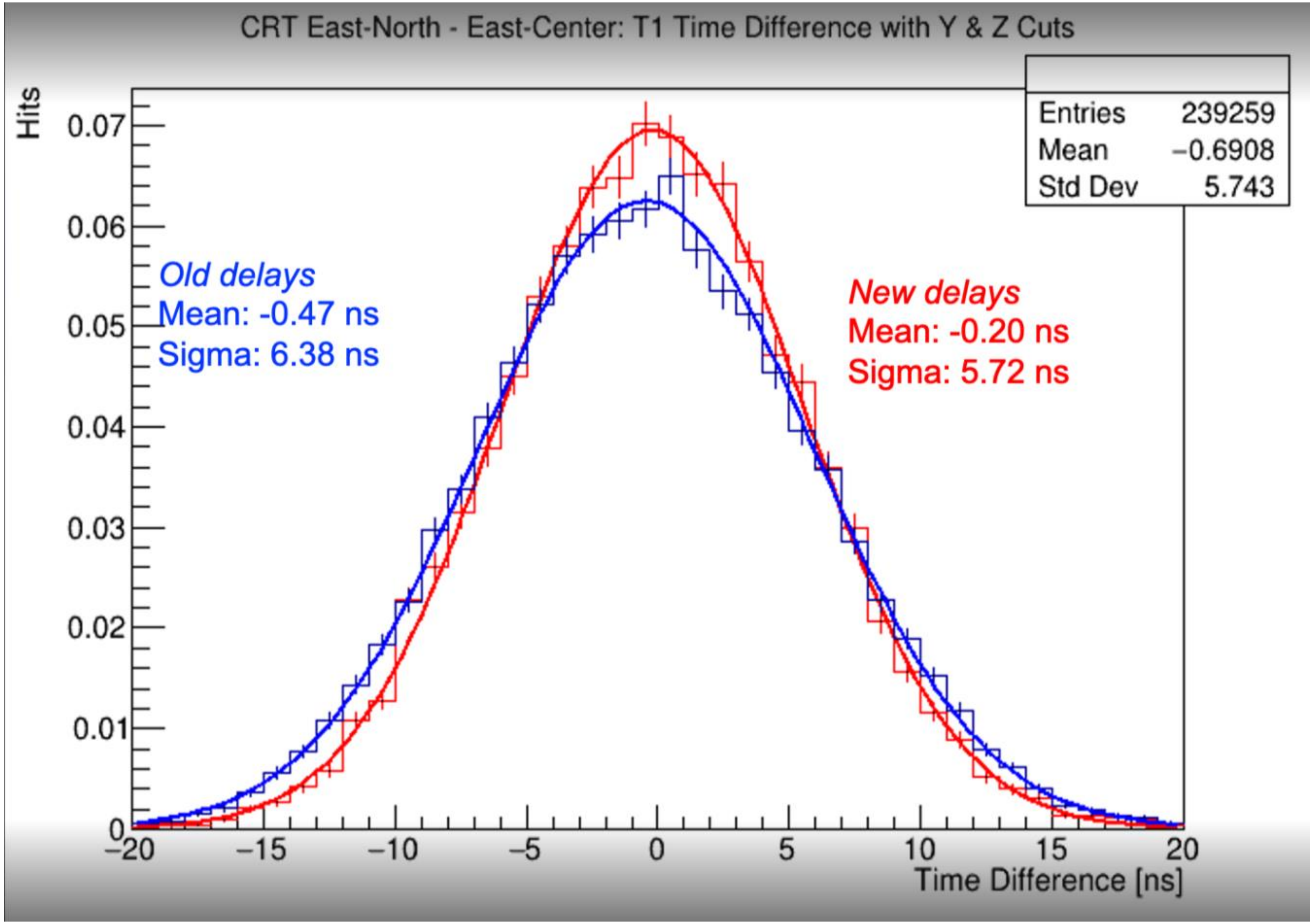
APPENDIX: ICARUS SIDE CRT TIME DELAY

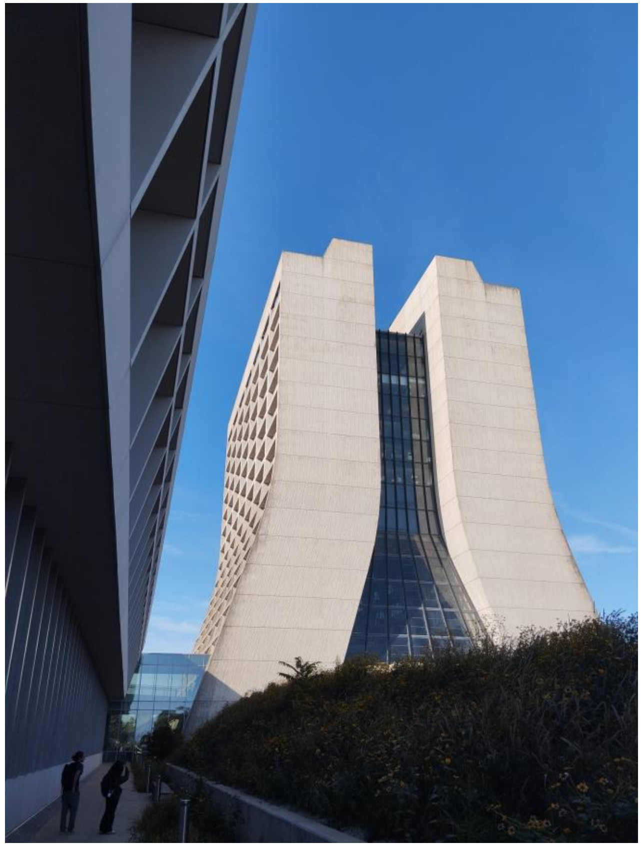
During my thesis work some discrepancias between the Montecarlo simulation and the data for the time difference between the optical flashes and the CRT system were found for the side system.








CRT East-North - East-Center: T1 Time Difference with Y & Z Cuts
Entries 239259
Mean −0.6908
Std Dev 5.743
Hits
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Old delays
Mean: -0.47 ns
Sigma: 6.38 ns
New delays
Mean: -0.20 ns
Sigma: 5.72 ns
−20
−15
−10
−5
0
5
10
15
20
Time Difference [ns]



THANK YOU