First Look at CRT Track Reconstruction at ICARUS

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Abstract

ICARUS will commence its search for evidence of a sterile neutrino jointly with the SBND near detector, within the Short Baseline Neutrino (SBN) program. ICARUS is sitting on the surface and on-axis to Booster Neutrino Beam (BNB) and also exposure to the Neutrino at Main Injector (NuMI) beam will also give the possibility for other physics studies such as light dark matter searches and neutrino-Argon cross-section measurements. As ICARUS is operational on the surface it is prone to a lot of cosmics and main backgrounds for all the physics analysis. 3m concrete overburden and 4π coverage of Cosmic Ray Tagger (CRT) surrounding the Time Projection Chamber (TPC) are installed to mitigate cosmic backgrounds. In this note, we will discuss the CRT track reconstruction and the reconstructed track properties using the real data collected during the detector commissioning.

1 Introduction

ICARUS [1] is a Liquid Argon Time Projection Chamber (LArTPC) operating on the surface at Fermilab. It is the third and the farthest detector of the Short Baseline Neutrino (SBN) Program aimed at providing clarification on the existence of the light sterile neutrino. In addition to which, it will be aimed at studying neutrino-argon interactions using NuMI beam which corresponds to the DUNE energy range.

Since the ICARUS detector operates at the surface, it is prone to a large flux of cosmic radiation, which poses problematic background readouts to the electron-neutrino detection analysis. Hence to identify the cosmic background radiation and tag them, the Cosmic Ray Tagging (CRT) System is set up around the TPC with a 4π coverage to tag the incoming cosmic muons with an efficiency of more than 95%. To avoid maximum incoming cosmic radiation, ICARUS has a 3m thick concrete overburden [2] apart from the CRT which stops the primary cosmics, as well as secondary particles, originating from the primaries. It also helps in reducing the data volume.

2 Cosmic Ray Tagging System

Cosmic Ray Taggers (CRT) [3] are plastic scintillators based on extruded organic scintillator, wavelength-shifting fibers, silicon photomultiplier. As the cosmic rays hit the CRT surfaces, they produce scintillation light and are captured by silicon photomultipliers, which are digitalized by CAEN front-end boards. The ICARUS CRT consists of three subsystems namely the top, side, and bottom surrounding the TPCs (Figure 1). The top part has all newly made plastic scintillator modules covering 400 m^2 above the cryostat and encounters about 80% of the cosmogenic muon flux that enters into the cryostat. Double Chooz modules originally build for the Double Chooz experiment are used in the bottom portion of the CRT. These modules are placed below the cryostat. For the side CRT we recycled modules from the MINOS detector, which had been decommissioned. In total 173 modules were gifted to ICARUS for use in the CRT and these module were extracted from the Soudan Mine and shipped to Fermilab. The side CRT provides enough coverage, about 450 m^2, for the sides of the cryostat

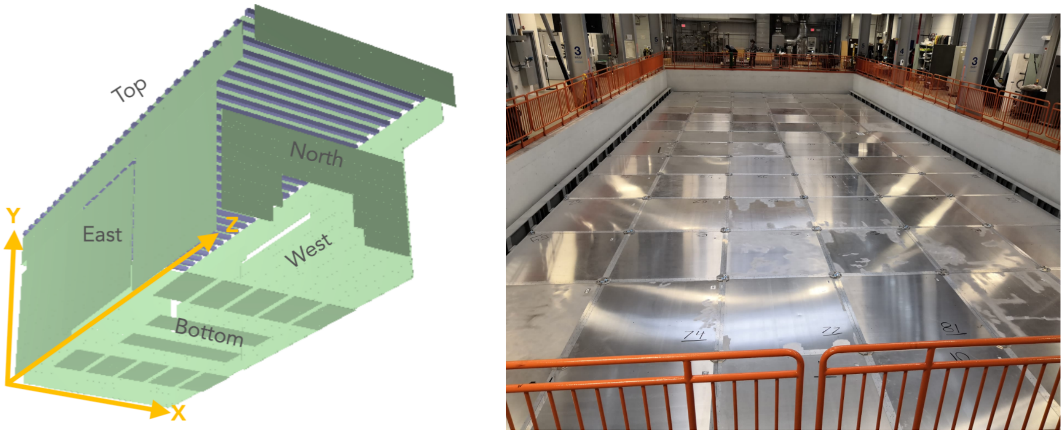

Figure 1: ICARUS CRT Co-ordinate Geometry (left) and top roof of the ICARUS CRT Setup without the overburden (right).

and reduces 20% of intercepted cosmic flux. However on the north side coverage is reduced due to space constraints in the building (Figure 1 (left)). A simulation study reveals that with this coverage a 97% geometric efficiency is achieved for intercepting muons that enter the cryostat. The relevant parameters for the different CRT subsystems are summarized in Table 1.

	Top	Side	Bottom
Scintillator	cast	extruded	extruded
Composition	[v]polystyrene 2% pTP		
0.05(0.03)% POPOP	[v]polystyrene 1% pTP		
0.03% POPOP	[v]polystyrene 1% pTP		
0.03% POPOP			
Reflector	paint	coextruded TiO_2	coextruded TiO_2
LxWxH [cm]	184x23x1(1.5)	800x4x1	322x5x1
Strip Configuration	[v]8 per layer,		
2 layers X-Y	[v]20 1 layer, Y	[v]32 per layer,	
2 layers X-X			
Photodetector	S13360-1350CS (SiPM)	S14160-3050HS (SiPM)	H8804 (MAPMT)
No. of Optical fiber/Strip	2	1	1

Table 1: Various components are summarized for the different ICARUS CRT subsystems.

3 CRT Track Reconstruction

If a particle enters and exits the CRT volume the trajectory can be reconstructed as a CRT track object (Fig:2). Tracks are formed by joining hits within a given time window. Secondary particles from showers and delta rays can cause multiple hits on a tagger, so nearby hits are averaged within a given radius. This radius is currently set at 30 cm to improve the track matching capabilities, this does mean that in events where there are extended showers between the top two planes many tracks can be produced due to the commentaries. The two top planes can be used to create CRT tracks for stopping particles. The algorithm used for CRT track reconstruction is described in more detail below:

Algorithm:

- Create t0 collections for hits within 100 ns of each other.
- For each t0, sort hits by the tagger.
- Average hits within 60 cm on a tagger.

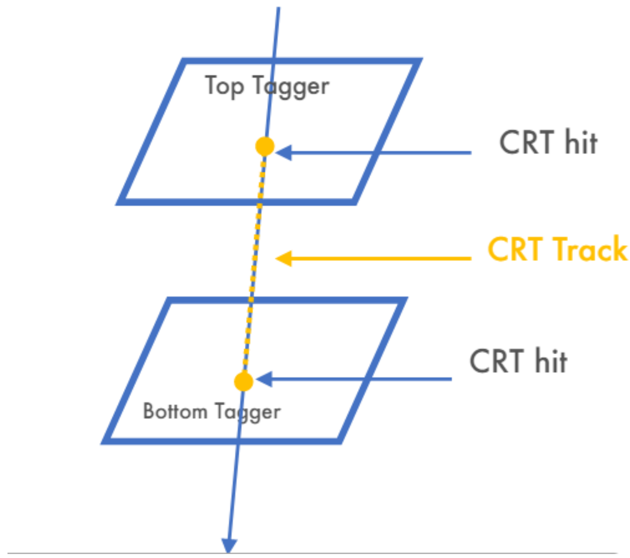

Figure 2: ICARUS CRT Track Reconstruction

  - Take the average position and time of all the hits.
  - Return errors as the maximum possible limits of all the averaged hits.

- Create tracks from averaged hits.
  - Loop over all unique pairs of hits on different taggers.
  - Draw an infinite track between the 2 hits.
  - Loop over all other hits on different taggers and merge into the track if they are within 25 cm.
  - Sort the track candidates by the number of hits.
  - If a candidate has more than 2 hits then create a track and record the hits as used.
  - Do not create tracks with already used hits.
  - If a candidate only has 2 unused hits then create a track but don't record the hits as used.

4 Properties of Reconstructed CRT Track

Once the CRT tracks were reconstructed using the track reconstruction algorithm, they were used to analyze the properties of the data collected from CRT systems. To analyze properties like the Length of the track, time of flight, momentum, angle distribution over the CRT i.e in the x-y and the y-z plane, etc., we made histograms of these properties using the CERN ROOT framework.

CRT Track Distribution

- To get the frequency of CRT tracks crossing the CRT setup from one surface to another we made a 2D graph with the y axis representing the surfaces from which the cosmic muon tracks have exited and the x axis representing the surfaces from which the cosmic muons have entered. The color spectrum represents the number of CRT tracks.

- From this graph, we concluded that most of the tracks enter from the top roof and exit from the top rims followed by side CRT walls. The statistics are low for tracks entering from one of the side CRT walls (east) and exiting through the other wall (west side).

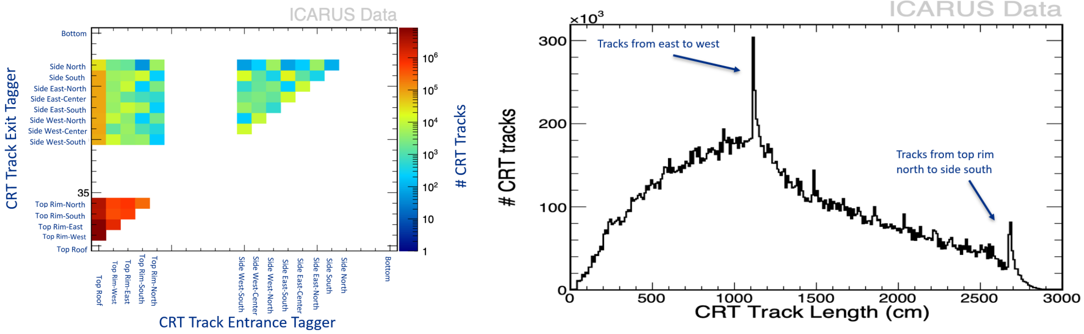

Figure 3: CRT Track Distribution and CRT Track Length.

Length

- All the reconstructed CRT tracks are recorded crossing the CRT volume, and are grouped according to where their hits were recorded on the (length) span of the CRT setup (which is almost 30m long) if the tracks are crossing through an angle other than horizontal. The LArTPC without the CRT itself spans over 19.8m in length.
- From this graph, we observed two spikes near the 1100cm mark which represents the CRT tracks passing from east to the west CRT surface, and the second spike appearing near 2700cm which represents the CRT tracks passing from top rim-north to side south end of the detector.

Time of Flight

- We tracked the CRT hit timing of entrance and the hit timing during exit and subtracted the two timings. Fig: 4(left) shows the time of flight for entrance from the top roof and exit from the sides (specifically the walls of Side West-South, Side West-Center, and Side West-North).
- From this graph, we conclude that most CRT tracks take about 21μs to cross the CRT volume completely. We weren't expecting the number of CRT tracks to be as high as the spikes represent, which again lead to the conclusion that there is further analysis and fine-tuning needed in terms of the algorithm and the creation of false tracks.

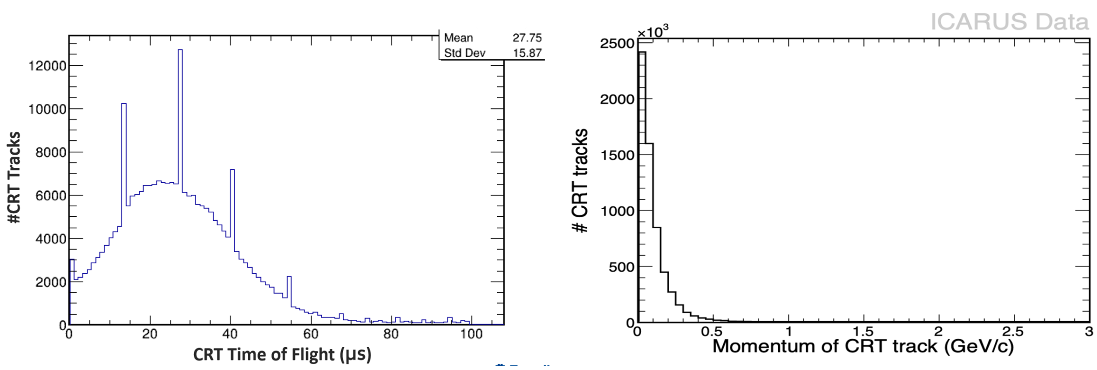

Figure 4: Time of Flight between track trajectories start and end points (left) and momentum of CRT tracks (right).

Momentum

- Momentum of each track is calculated using the given formulas in our algorithm:

$$p=m\gamma\beta$$
$$\beta=v/C$$
$$\gamma = \frac{1}{\sqrt{1-\beta^2}}$$
$$v=\text{Length}/\text{Time of Flight}$$

Where m : mass of the particle, v : velocity of the particle, C : velocity of light.

- The Momentum graphs help us analyze if the particles have undergone an interaction in the detector volume and if so, then how energetic that particle is. From this plot, it has been observed most of the tracks are below 500 MeV. However, we were expecting high energetic cosmics as well.

Angle in the x-y and y-z plane respectively

- Fig:5 represents the number of CRT tracks entering the CRT volume at different angles in the x-y and the y-z plane respectively. Where, θ represents the angle in the x-y plane and ϕ represents the angle in the y-z plane.
- θ and ϕ are conventionally negative towards west(north) and positive towards east(south) sides of the CRT setup. And from these graphs, we can conclude that most tracks are vertical at positive and negative 90° and hence are the least interacting muons coming into detector volume almost perpendicularly.

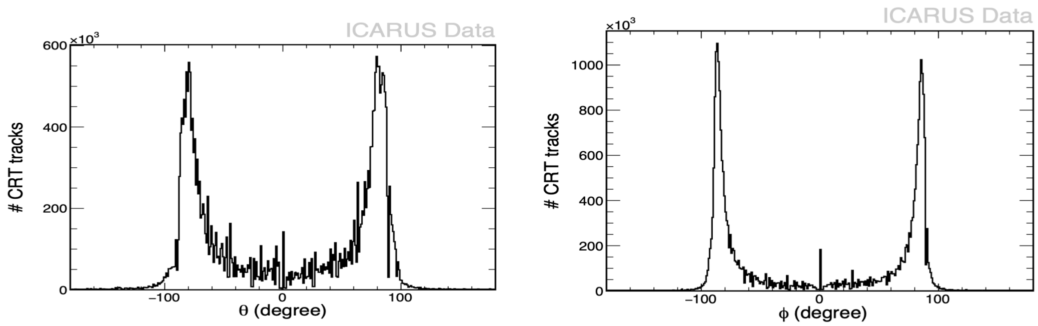

Figure 5: CRT track Angle in the x-y plane(left) and y-z plane (right).

5 Conclusion and Future Work

This project determines and verifies the accuracy of the CRT setup in tagging the cosmic muons and provides insights into the CRT track properties generated using the reconstruction algorithm and the histograms as discussed above. The CRT track reconstruction algorithm works well and we validated using real data, however, needs fine tuning given the spikes in the length graph and the number of CRT tracks observed in some other graphs like the time of flight, hinting at a possibility of the creation of false tracks. The continuation of this research will not only involve improvement in the track reconstruction algorithm but also the quantification of the number of tracks crossing the LArTPC as tagged by the CRT. It will also involve using the CRT system for calibration of the ICARUS detector and to develop an algorithm for CRT-TPC matching to reject the cosmic background with utmost precision for better statistical accuracy.

6 Acknowledgements

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References

[1] C. Rubbia, *Searching for short baseline anomalies with the LArTPC detector at shallow depths.*, [arXiv:1408.6431 (2014)].

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[3] B. Behera, *First data from the commissioned ICARUS side cosmic ray tagger*. PoS NuFact2021 (2022) 201