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Simulation Tuning on the ICARUS Neutrino Detector

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Introduction

The ICARUS detector is a liquid argon neutrino detector in Fermilab's Short Baseline Neutrino Program. One type of interaction from the neutrino beam occurs outside the detector and results in "rock" or "dirt" muons from interaction with the rock surrounding the detector. Previous simulations of the ICARUS detector are based on assumptions for certain factors. A notable factor is the distance outside the detector boundaries that should be considered to include neutrino interactions that occur outside the detector but are still recorded in data. This study compares previous Monte-Carlo-generated data with experimental data considering both the NUMI and Booster neutrino beams to determine an ideal distance beyond the detector boundaries to suggest in future simulations.

Background

The ICARUS detector is comprised of a 60-foot long chamber of liquid argon that operates on both the Boosts rand NUMI neutrino beams. It operates by recording tracks left by neutrino, muon, and other particle interactions caused by a neutrino beam. These interactions leave tracks of ionized argon particles that then "drift" due to an induced magnetic field to data collection frames with orthogonal X and Y orientations and diagonal Z that record where with respect to these directions the track occurred.

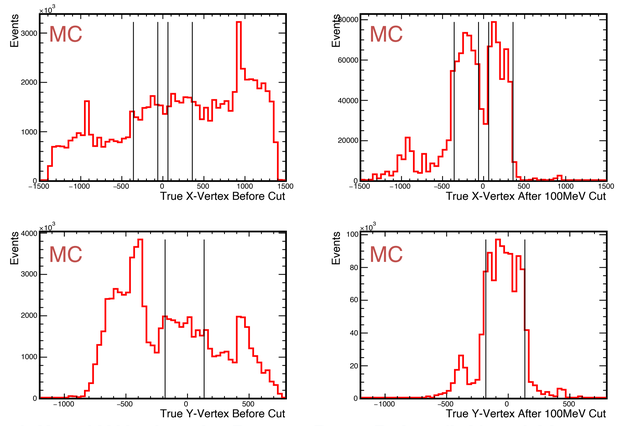
Methodology

Histograms were generated and analyzed comparing data generated by the Monte Carlo simulation with observed data. These were then analyzed to determine at what distance beyond the detector boundaries would include detected interactions outside this boundary.

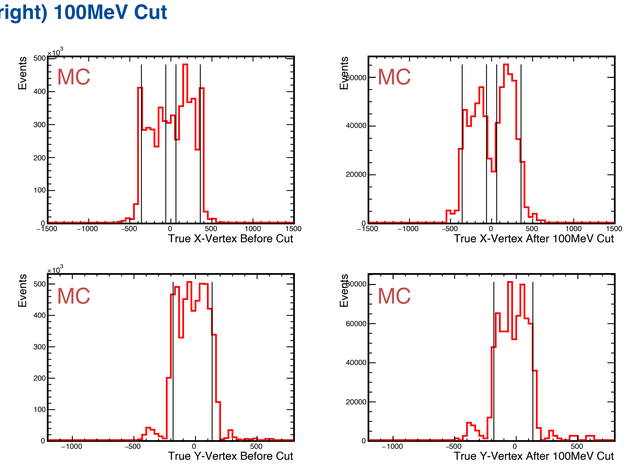
Neutrino Interactions From Rock

The graphs below show the truth vertex in the X and Y directions for a Monte Carlo simulation of the NUMI Neutrino Beam that includes neutrino and cosmic interactions.

Truth X and Y Vertices for NUMI Beam with Neutrino and Cosmic Interactions Before (left) and After (right) 100MeV Cut



Truth X and Y Vertices for Booster Beam Before (left) and After (right) 100MeV Cut

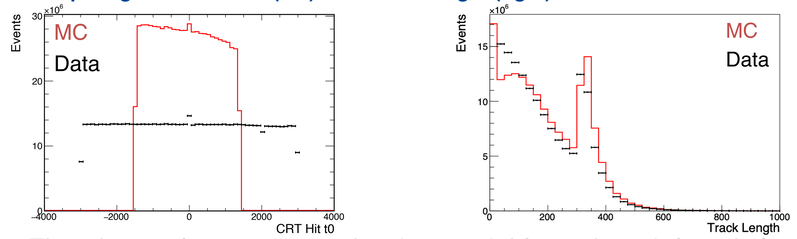


Considering the above plots:

- Vertical lines show the active detector boundaries, statistics outside this line occur outside the detector
- From the left to the right column, a 100MeV cut is applied to ensure interactions are energetic enough to reach and be recorded by the detector.
- We note small peak of events beyond the detector boundary within ± 500cm from the boundary of the detector that should be considered.

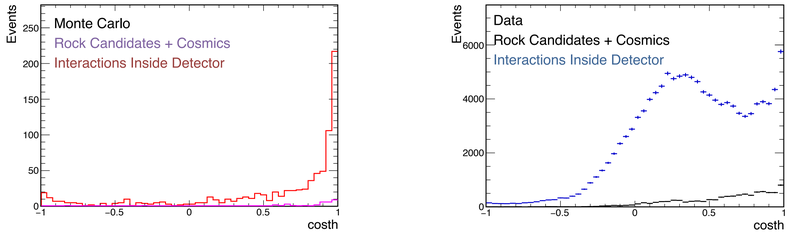
Comparing data and simulation

Comparing Time Variable (left) and Track Length (right)



The above plots compare the time variable and track length for the Monte Carlo simulation (red) and observed data (black). This shows a slight disagreement between the data and Monte Carlo results, indicating that some parameters should be adjusted.

Cosine of Muon Angle for NUMI Observed Data (right) and Monte Carlo (left)



For these two plots of the cosine of the Muon angle with respect to the beam direction:

- Blue (right) and red (left) plots show events with start and end indices within the active detector boundaries
- Magenta (left) and black (right) plots show events with start indices outside the active detector boundaries and end indices within the detector.
- Rock Muons to have a value > 0.95. We notice a peak at 1 for all four plots

Results

Based on the data and histograms analyzed, this study found that 5 meters beyond the detector boundary would include the majority of interactions that occur outside the detector boundary and are recorded by the detector without including more distance that necessary.

Conclusion

Histograms of truth vertices, cosine of the muon angle, the time variable and track length were generated and analyzed to determine the ideal value for simulation factors. This study found that 5 meters beyond the detector boundary would include a significant amount of interactions, including Rock events, for both the NUMI and Booster beams without considering unnecessary distance.

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