

# Cosmic Muon induced EM Showers in NOvA Detector

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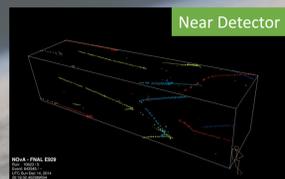
Indian Institute of Technology Guwahati

For the NOvA Collaboration

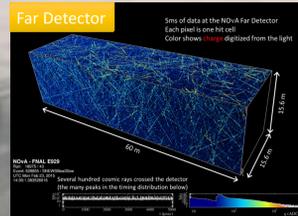
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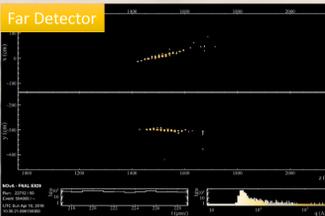
## Introduction and Importance of Cosmic EM Showers in NOvA



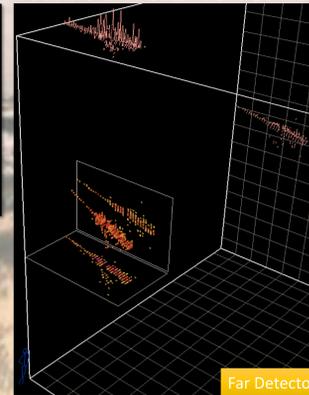
Cosmic rate: 150 kHz



$\nu_e$ -cc electron shower



Cosmic EM Shower: 51Hz

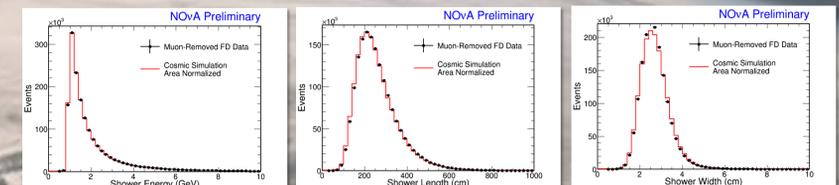


NOvA is a long baseline neutrino experiment with two functionally identical detectors, separated by 810 km, studying  $\nu_\mu$  disappearance and  $\nu_e$  appearance channels.  $\nu_e$ -cc interactions in far detector are tagged by final state electron shower.

Cosmic muon can induce showers through EM interactions. Muon induced and  $\nu_e$ -cc electron showers are very similar.

Cosmic ray-induced showers provide a data-driven test of our simulation and reconstruction of EM showers.

## Data vs MC

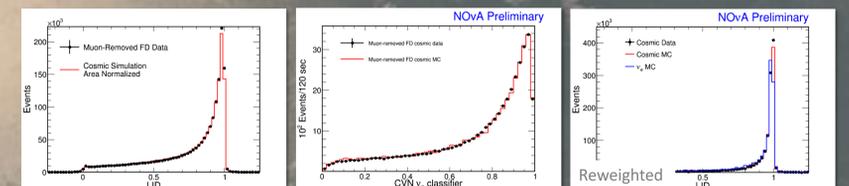


Data and MC (first analysis MC) comparison of cosmic EM shower.

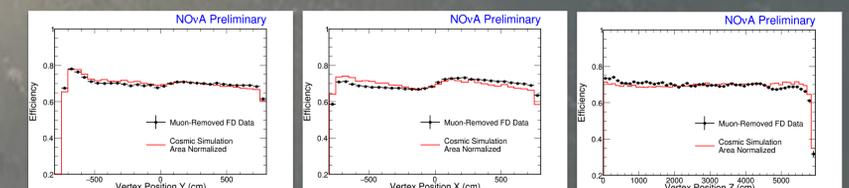
1. A good agreement between Data and MC.
2. Good shower modelling.

## Benchmarking PIDs

dE/dx likelihood based ANN PID and CVN based PID are benchmarked using the cosmic EM shower. LID is the main PID for first analysis and CVN based PID is used for second analysis. Most of the cosmic EM shower are identified as  $\nu_e$ -CC shower. Reweighted sample PID output is very similar to  $\nu_e$ -CC sample PID output.



## Signal Vertex Efficiency



Efficiency is overall flat in X, Y and Z axis along the far detector with less than 5% disagreement between data and MC. Rest of the difference is used as a data driven estimate of a part of the systematic error on the prediction of the signal selection efficiency.

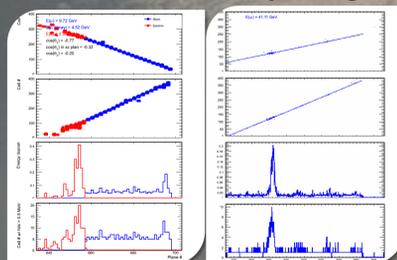
## Summary

- ✓ Using Muon Removal algorithm we find and isolate EM Shower from cosmic data and MC.
- ✓ A good agreement between data and MC.
- ✓  $\nu_e$  reweight method has been developed to make cosmic EM showers resemble beam events.
- ✓ A data-driven technique to benchmark the particle identifications and simulations of EM showers using cosmic EM sample.
- ✓ PID efficiency as a function of positions across the detector are pretty uniform, indicating calibration effects are well controlled.

## Cosmic Shower Extraction

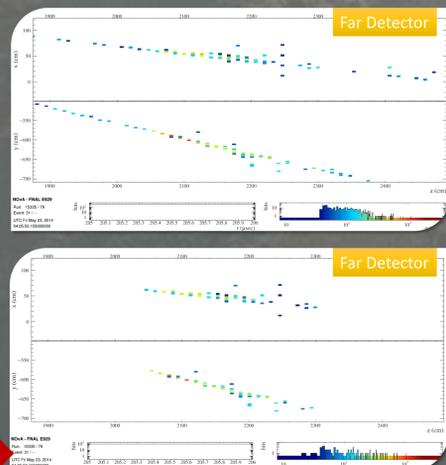
There are two means of producing cosmic EM showers. A Cosmic-ray muon can induce EM showers by photons from bremsstrahlung (brem) and electrons from decay in flight (DiF).

In shower region more energy is deposited per length along the track than muon region. We use this dE/dx property to find shower.



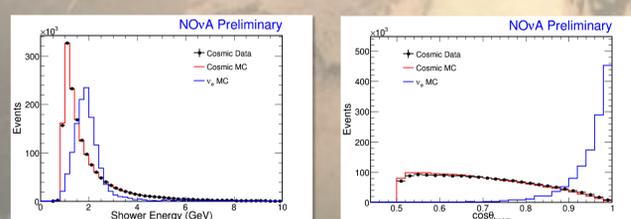
## Muon Removal Algorithm

Based on dE/dx information along the track, the shower region is located. Then muon hits are removed as a MIP fraction of the hits on the track trajectory in the shower region. The leftover hits belong to pure shower.



After muon removal

## $\nu_e$ Shower vs Cosmic Shower



Cosmic induced EM showers are compared with beam  $\nu_e$ -CC electron showers. We use reweighting technique to make shower distributions identical.

## Reweight Shower Sample

We reweight the cosmic induced EM shower to beam  $\nu_e$ -CC shower. The reweighted sample can then be used for various crosschecks of shower modelling or reconstructions or efficiency checks.

