Data-Driven cross checks for ν_e selection efficiency in NOvA

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For the NOvA Collaboration
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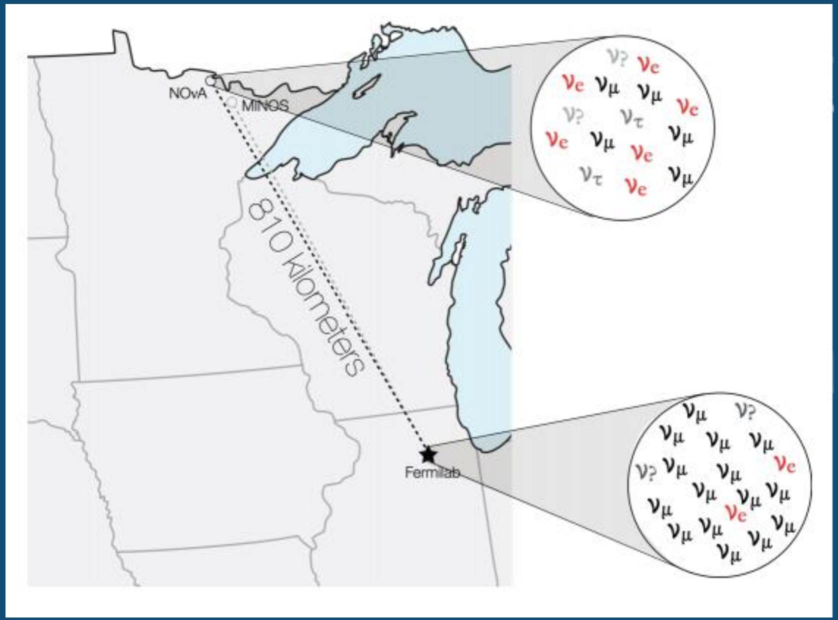
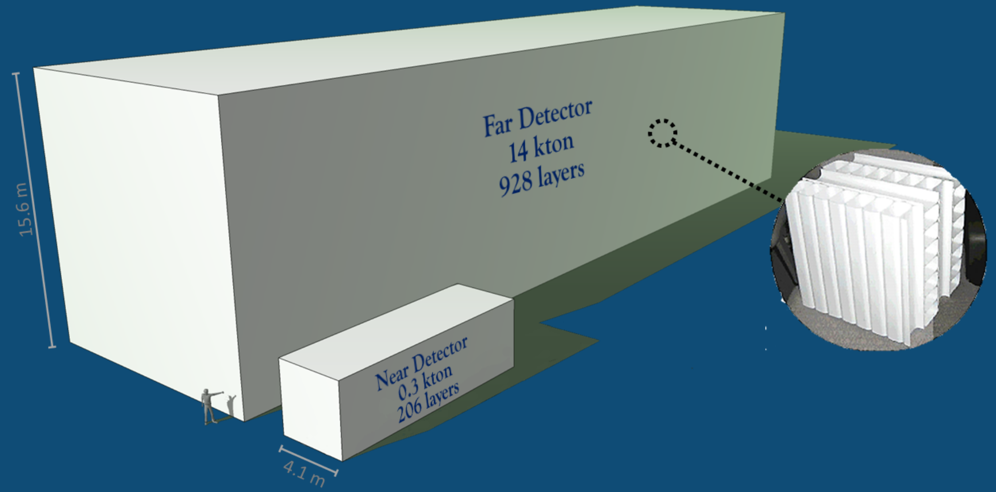
NOvA Experiment

- Long baseline neutrino oscillation experiment that uses Fermilab's NuMI beam



- Consists of two functionally equivalent detectors
  - Near Detector (ND) at Fermilab and the Far Detector (FD) at Ash River, MN
  - Alternating planes made of horizontal and vertical cells for 3D reconstruction



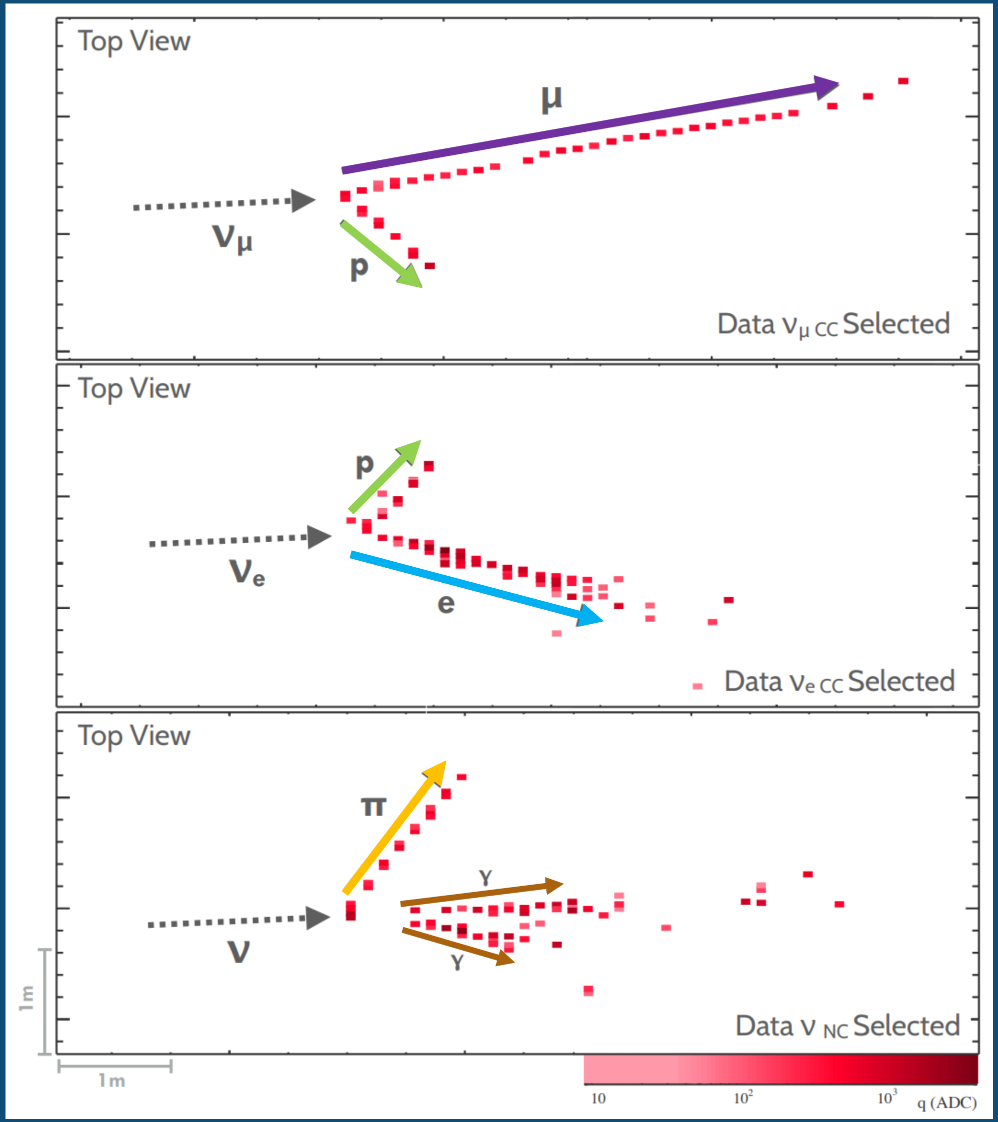
- Primarily look for $\nu_\mu(\overline{\nu_\mu})$ disappearance and $\nu_e(\overline{\nu_e})$ appearance in order to
  - Measure θ_{23} and Δm^2_{23}
  - Probe the neutrino mass hierarchy and CP violating phase

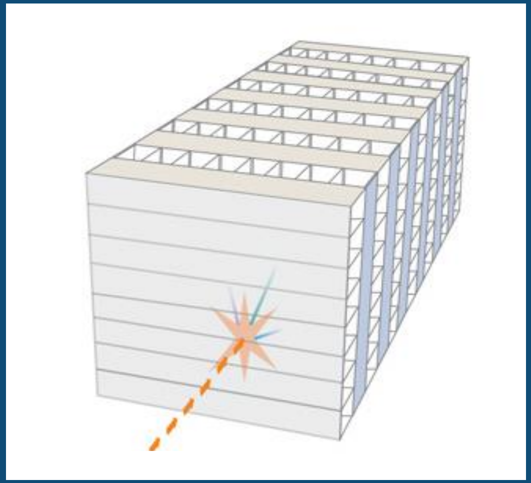
Event Topologies

Long tracks are usually muons

Electrons and photons create electromagnetic showers that span several cells

Heavier particles typically shorter, higher dE/dx tracks.

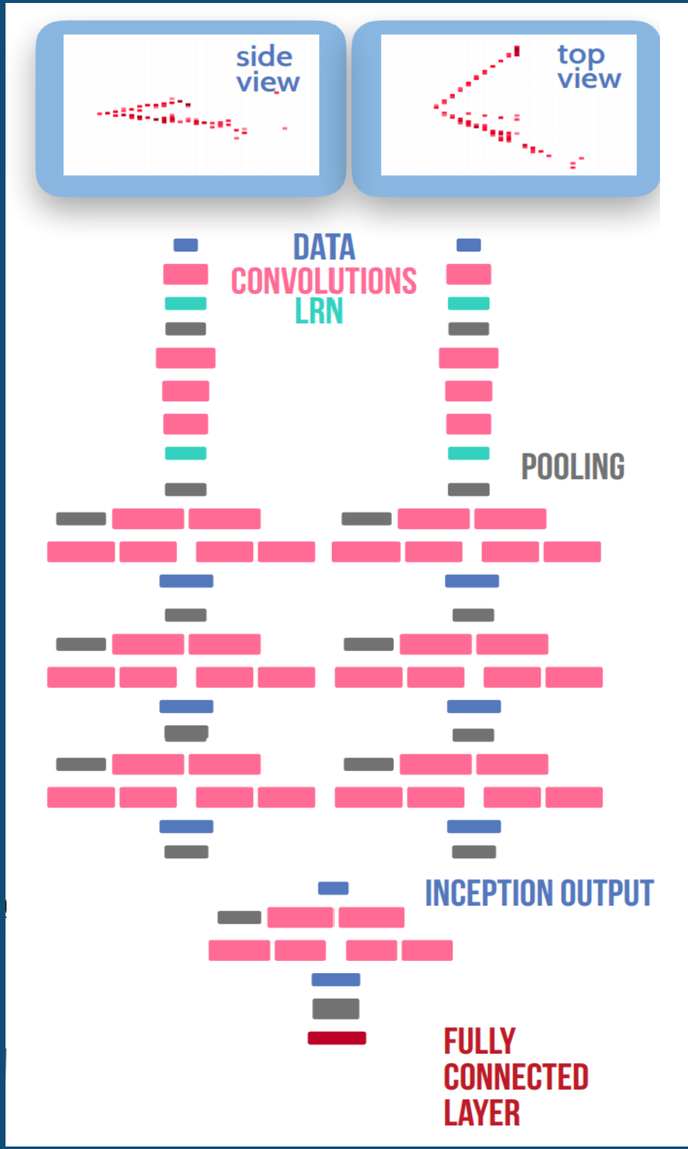




Particle identification for these topologies is done using a convolutional neural network

NOvA's Particle Identifier (PID)

We use a convolutional neural network based on image recognition technology as our PID



- Introduces **convolution filters** to extract features from the pixel maps in each view during the training
- Information of each view is then combined in the final layers of the network
- **Results in IDs for $\nu_e CC$, $\nu_\mu CC$, neutral current, and cosmic background events**
- When first implemented, this PID selector **increased our effective exposure by 30%** compared to traditional ID methods
- After preselection, our charged current identification achieves

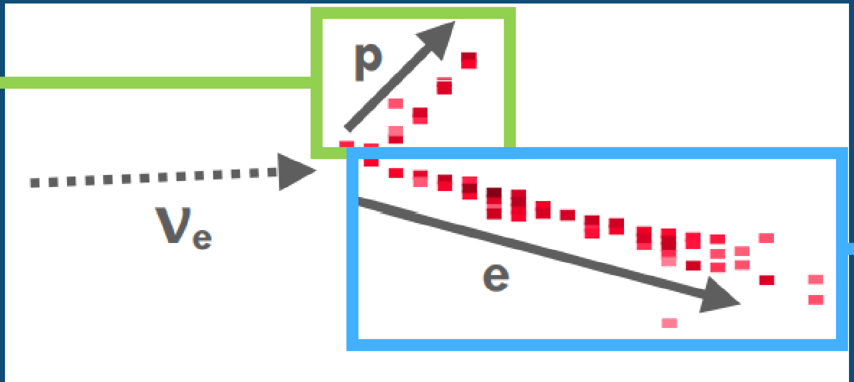
  80-90% efficiency

  80-99% background rejection

Muon Removed Cross Checks

- Because our PID selector is trained using simulated events, there is potential that differences between data and simulation can affect the PID's performance.
- The ν_e's in our ND from the beam have a broader energy distribution than our ν_e signal at our FD making them not very useful in directly checking our PID's ν_e selection efficiency.
- Instead, Muon Removed (MR) Cross Checks are used to compare the selection efficiency of our PID on samples from both data and simulation of easily identifiable and abundant muonic events.
- Selection efficiency = $\frac{PID\ Selected\ Events}{Preselected\ Events}$

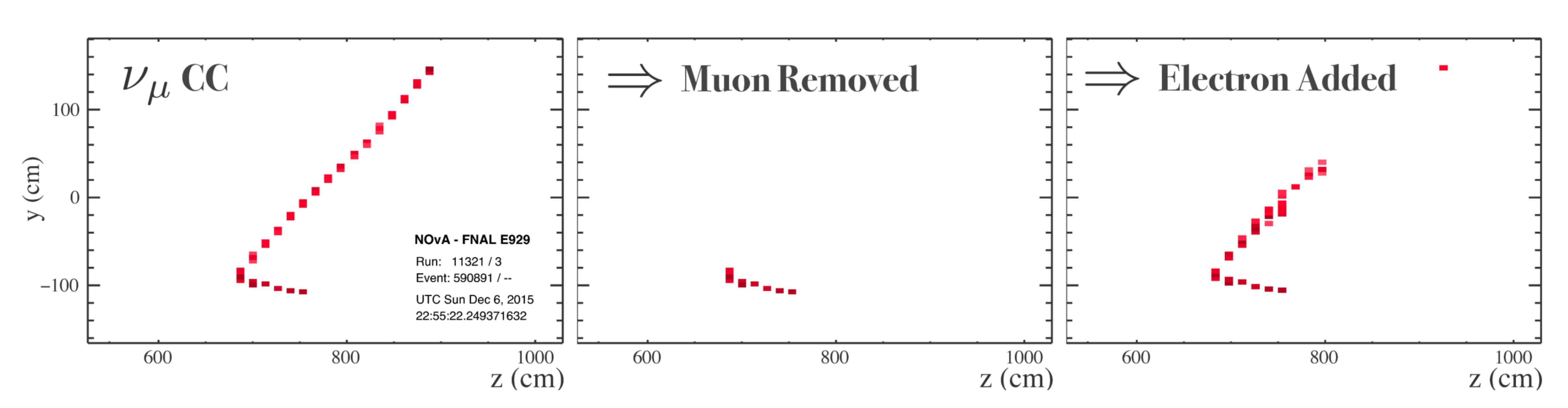
MR Electron-Added studies are used to cross check the modeling of the hadronic component of the signal



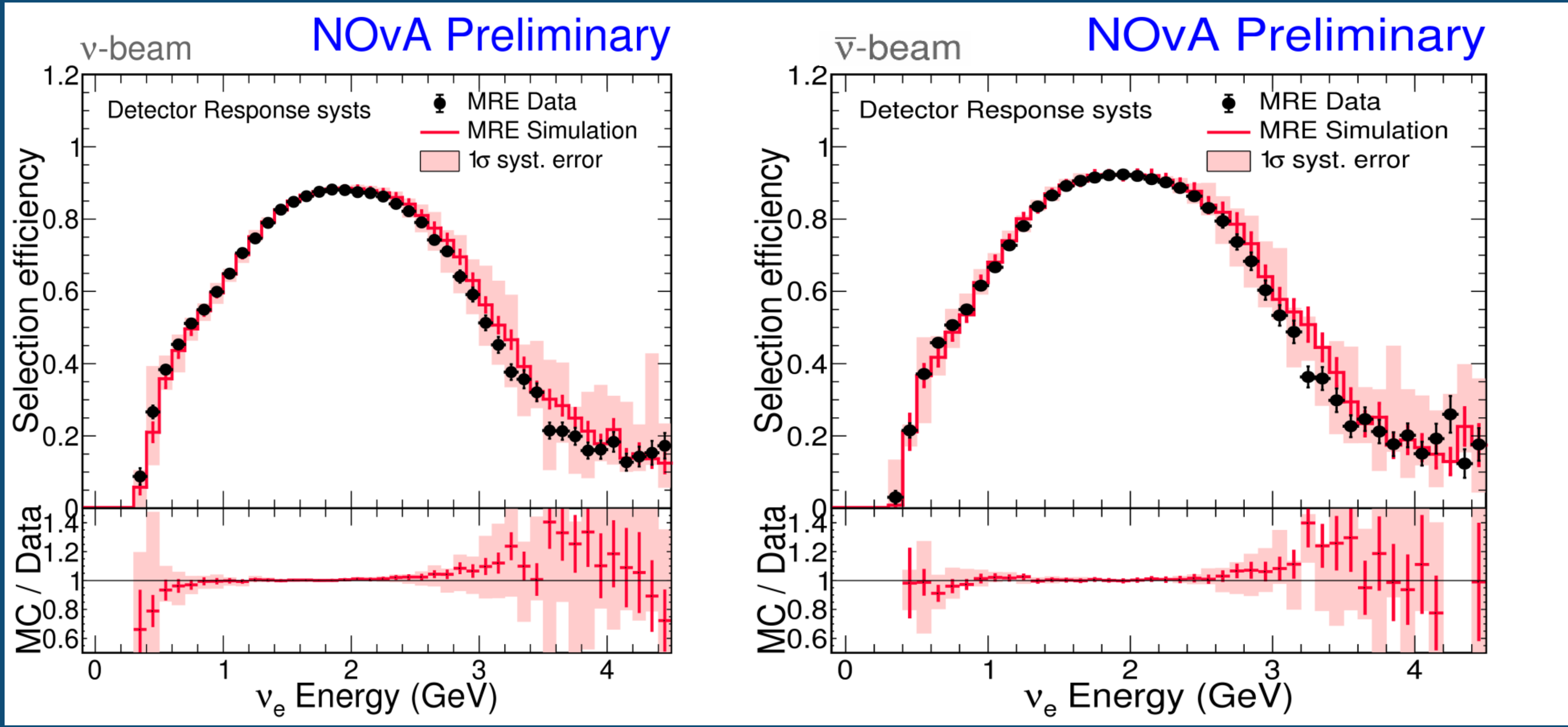
MR Decay-in-Flight studies are used to cross check the EM shower selection efficiency

MR Electron-Added (MRE)

- We take advantage of the large number of ν_μ CC events in our Near Detector for MRE studies
- Once ν_μ CC events have been selected in both data and MC, we remove the muons from those events. Then a simulated electron of similar energy is added in the muons' place
- The resulting hybrid events from the MRE process allows us to study the impact of any mismodeling of the hadronic system on the ν_e selection efficiency



MRE Selection Efficiencies

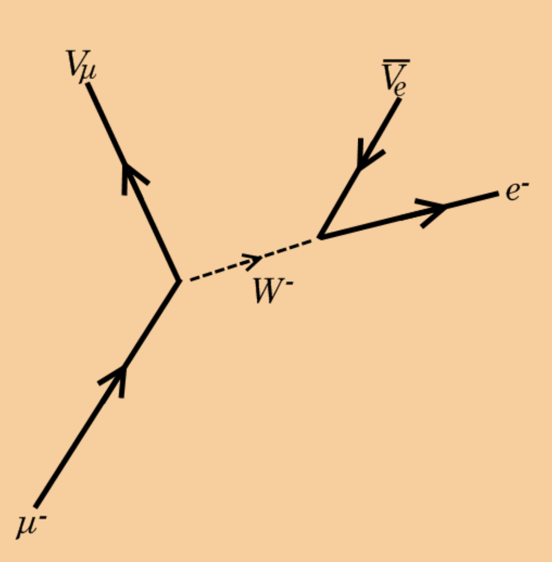


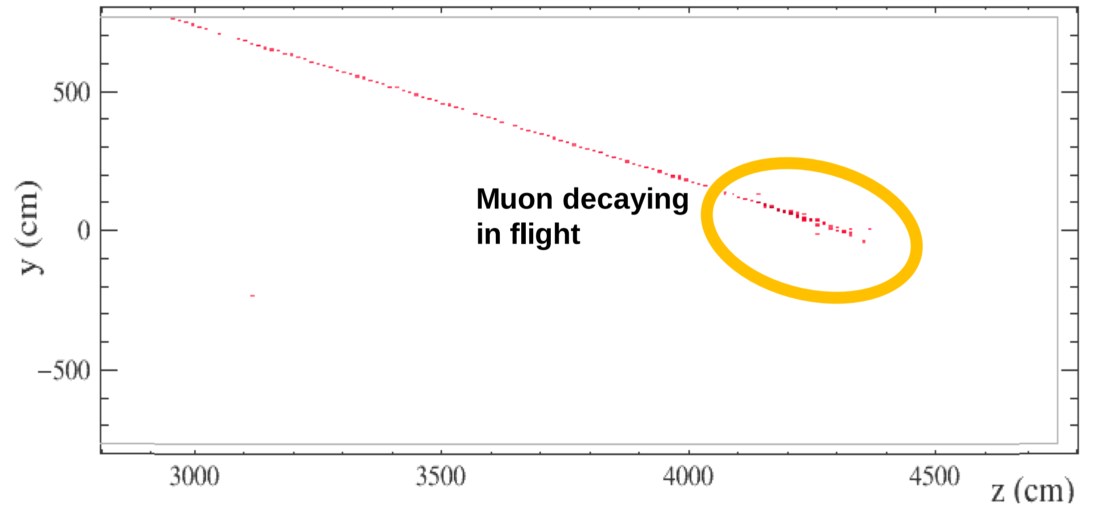
The overall PID selection efficiency agrees between data and MC at the >99% level for MRE events both in neutrino and antineutrino beams.

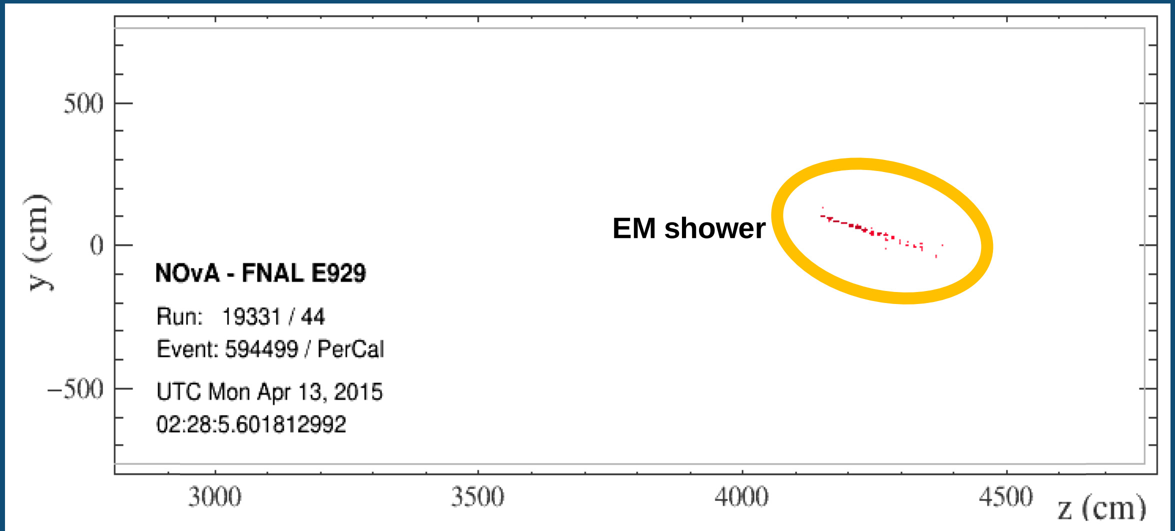
		Efficiency	Difference
Neutrino beam 9.5×10^{20} POT	Data MC	0.796 0.802	-0.76%
Antineutrino beam 11.8×10^{20} POT	Data MC	0.832 0.836	-0.46%

MR Decay-in-Flight (MRDiF)

- Here we take advantage of the approx. 140 kHz of cosmic muons in our Far Detector
- MRDiF looks for muons that decay in flight inside the Far Detector, inducing an EM shower from the resulting electron
- The muon is removed and just the pure EM shower is left







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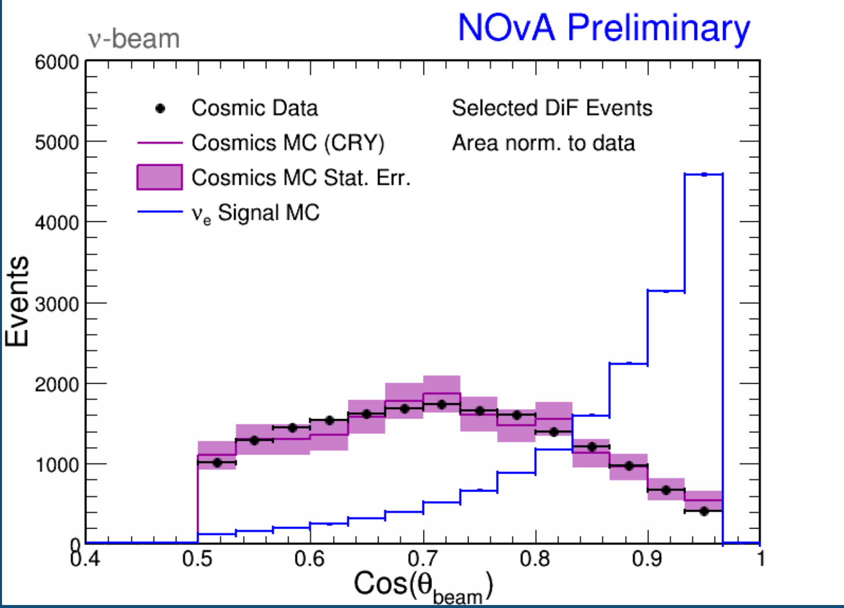
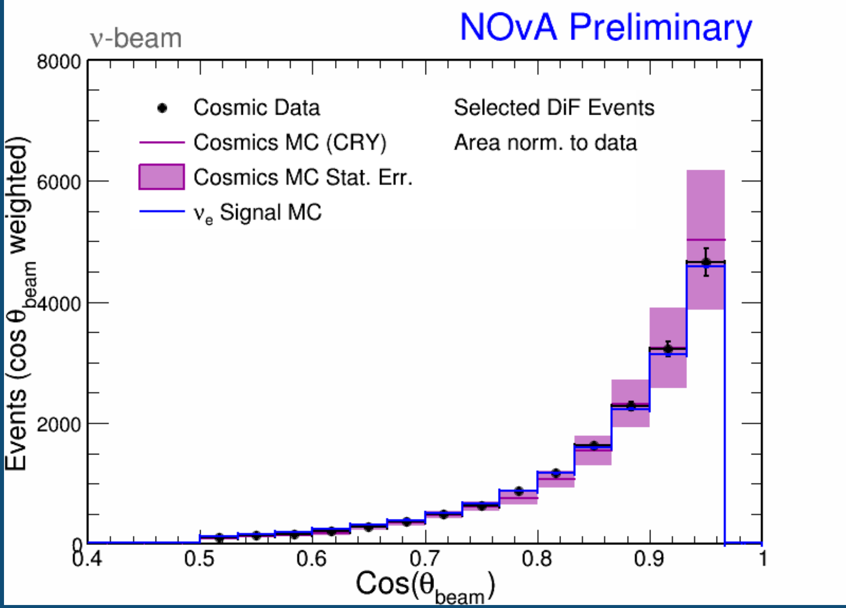
Reweighting the MRDiF Samples

- The induced EM showers from the ν_eCC signal points along the direction of the beam (nearly horizontal)
- Our MRDiF sample is mostly in more vertical directions because they are coming from cosmic muons.
- We reweight the samples by $\cos(\theta_{beam})$ so that we can highlight any discrepancies between data/MC in the region we care about for our signal

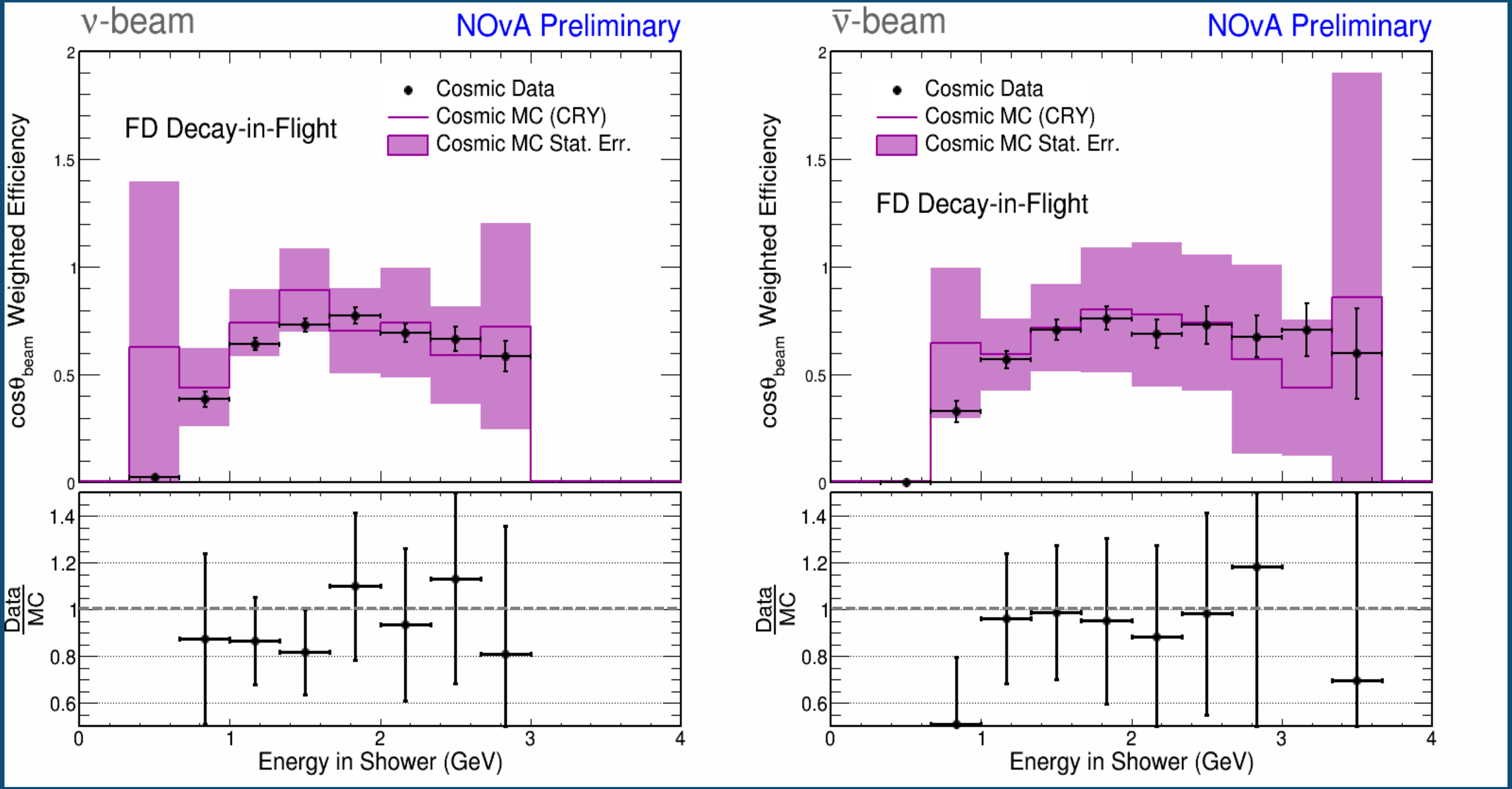


Before reweighting



After reweighting

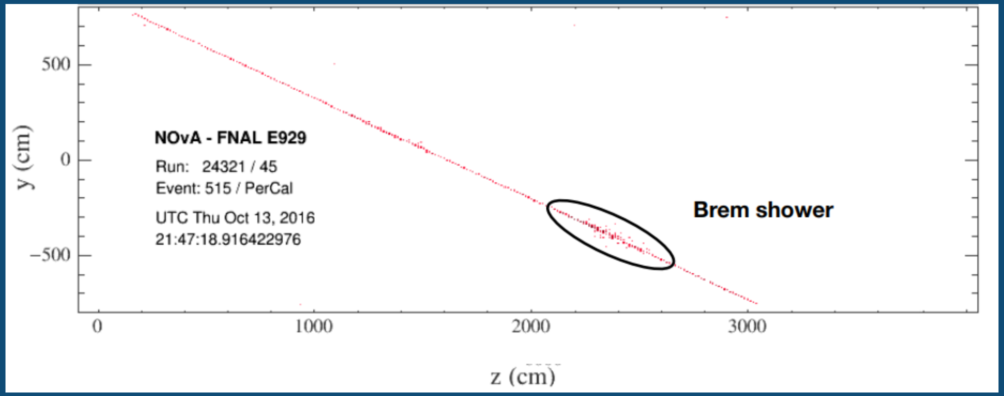
MRDiF Selection Efficiencies



- The overall PID selection efficiency for MRDiF events agrees within our uncertainties between data and MC and both in neutrino and antineutrino beam trained PIDs
- Currently, we are limited in this study by the statistics in our MC sample, but this is being improved for our next analysis

Current and Future Work

- We are currently working on improving the MC statistics for the MRDiF study
- Also plan to reintroduce a study called MR Bremsstrahlung that is similar to the MRDiF study as a second check on the EM shower component



- There are future plans to implement the MRDiF study on our ND data in an effort to directly compare selection efficiencies between our 2 detectors

- The selection efficiency of our PID is implicitly used in our analysis procedure, so work is starting to **implement the MRE study as a correction to that selection efficiency** in addition to its current use as a cross check

Conclusions

- NOvA uses a convolutional neural network for particle identification
- There are 2 data-driven techniques used to cross-check the performance of this PID
  - MRE checks the effect of any potential mismodelling of hadronic systems
  - MRDiF checks the EM showers component of typical $\nu_e(\overline{\nu_e})$ events

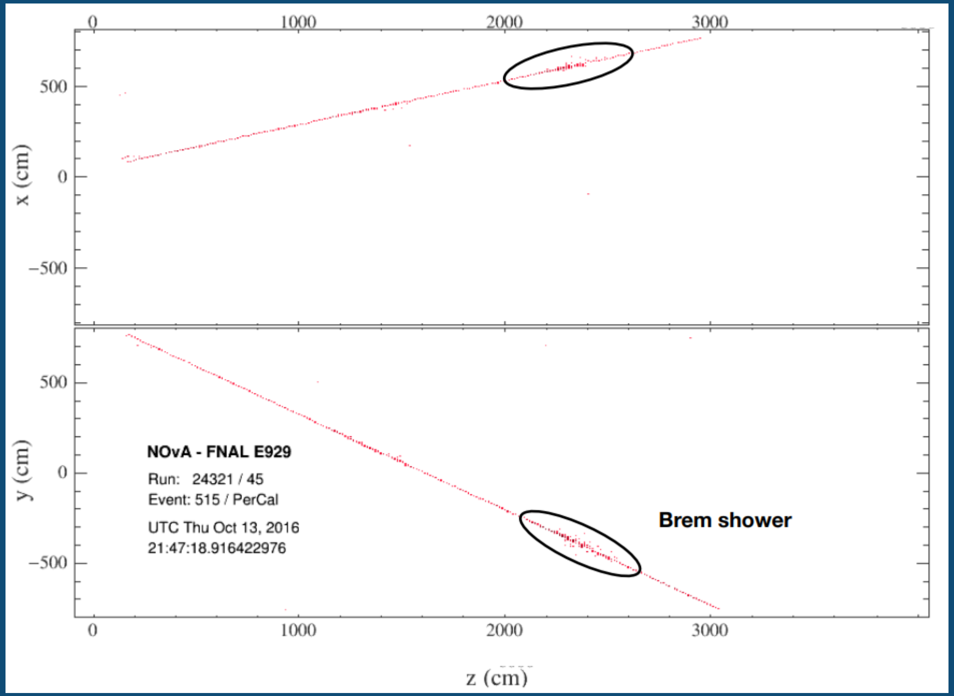
The resulting PID selection efficiency between data and MC from these MR studies show agreement consistent within our uncertainties, meaning our PID selection is generally robust in $\nu_e(\overline{\nu_e})$ CC signal selection

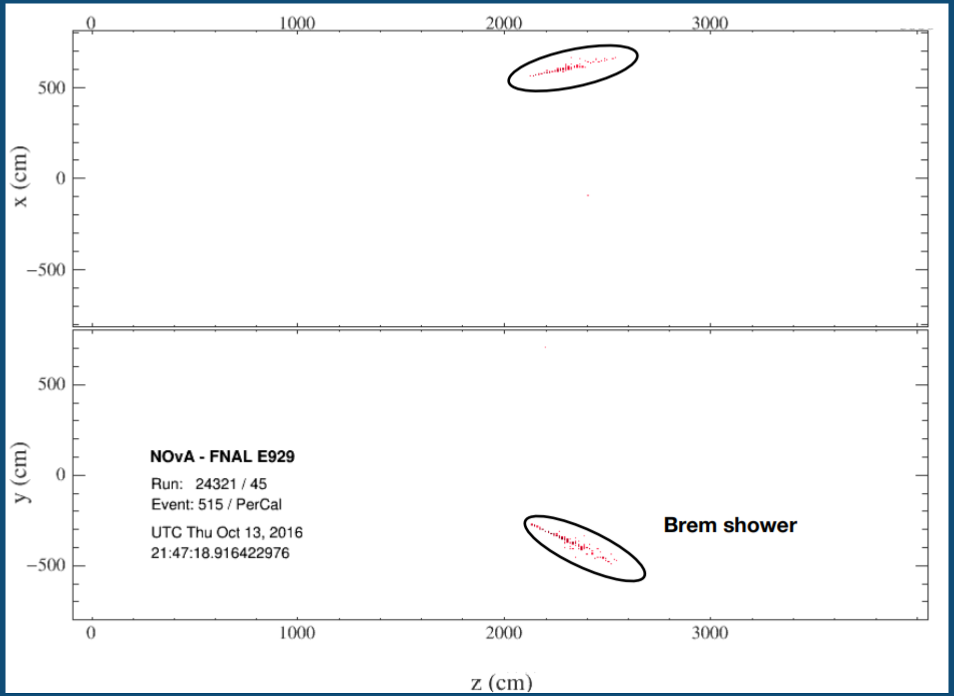
Backups

MR Bremsstrahlung (MRBrem)

- Similar to MRDiF, MRBrem selects muons that have undergone Bremsstrahlung radiation in the Far Detector and again removes the muonic hits, with just the photon induced EM shower remaining

- Was not used in last analysis due to a technical issue, but has been used in previous analyses and we plan to use it again in the future





MRDiF Shower Energy

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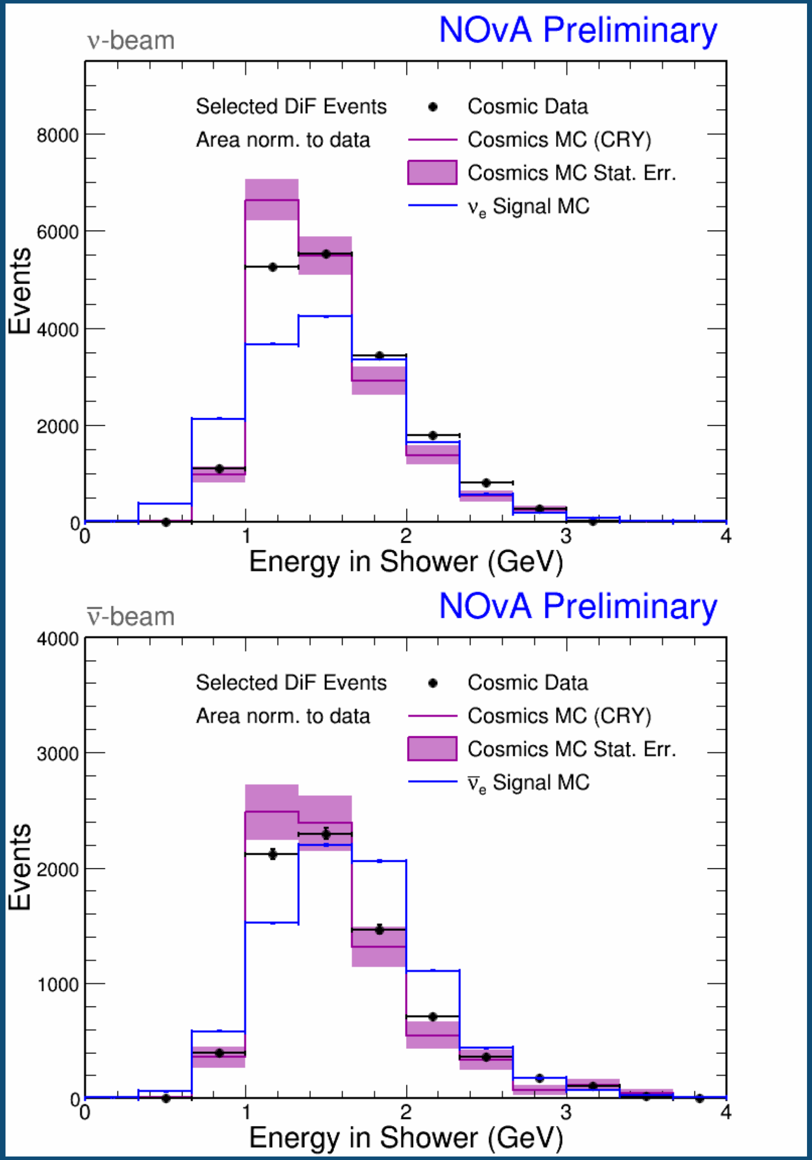

MRDiF and the $\nu_e(\overline{\nu_e})$ signal have mostly similar energy spectras, in particular that both peak between 1-2 GeV

Additionally, reweighting by angle to beam does not too greatly change the overall shape of the shower energy