Status of Muon Remove Electron Study for Neutrino-Electron Elastic Scattering in the NOνA Near Detector

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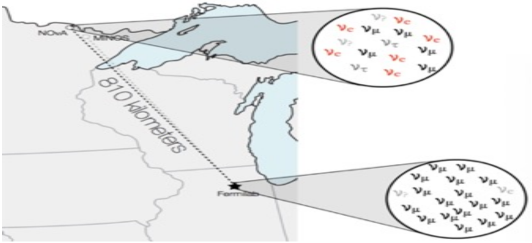
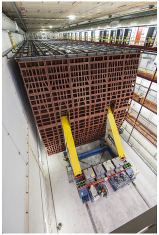
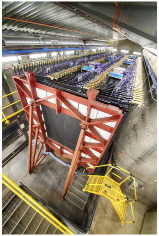
The NOνA Experiment

- NOνA is a long-baseline neutrino experiment
  - 2 detectors, 14 mrad off-axis, 810 km apart
  - optimized for detection of $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu_\mu} \rightarrow \bar{\nu_e}$
- Near Detector receives high neutrino flux which
  - acts as a control for the oscillation analyses
  - provide rich data set for determining cross-sections





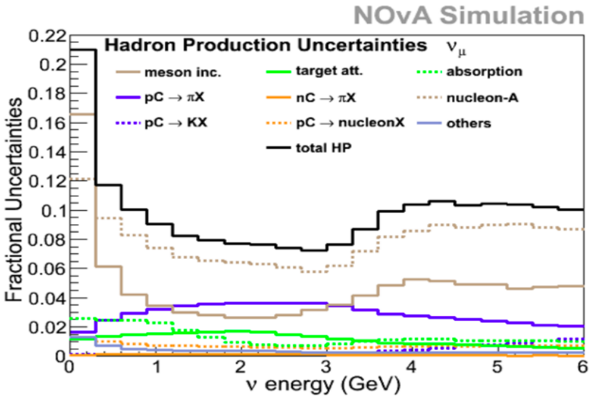
Far Detector



Near Detector

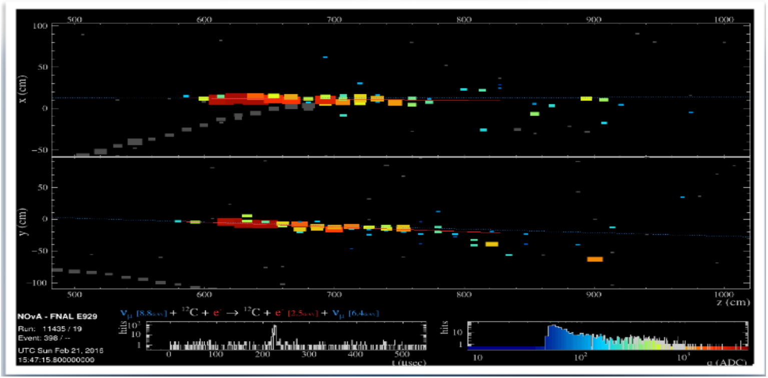
Neutrino Flux

- The accelerator neutrino beams have large uncertainties from hadron productions on targets



- These large uncertainty in the absolute neutrino flux affects the near detector cross-section measurements and far detector oscillation analyses

- Neutrino-electron elastic scattering is a pure leptonic process whose cross-section can be precisely calculated in the standard model.



- Therefore, it will provide a substantial constraint on the neutrino flux prediction to reduce the total uncertainty at NOνA and will also help us to demonstrate a flux constraint method for DUNE.

Event Identification

- $\nu - e$ elastic scattering is an elastic two-body collision, and the kinematics are given by

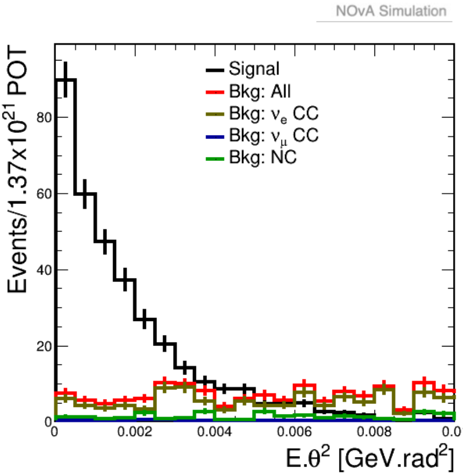
$$E_e \theta_e^2 = 2m_e(1 - y)$$

where E_e is the energy of the most energetic EM shower, θ is the angle w.r.t the beam and y is the ratio of the electron's kinetic energy to the total neutrino energy.

- Since y can vary between 0 to 1. $E_e \theta_e^2$ is less than $2m_e$
- Signal $\rightarrow$ very forward going single prong events with small $E_e \theta_e^2$ peaking around zero.

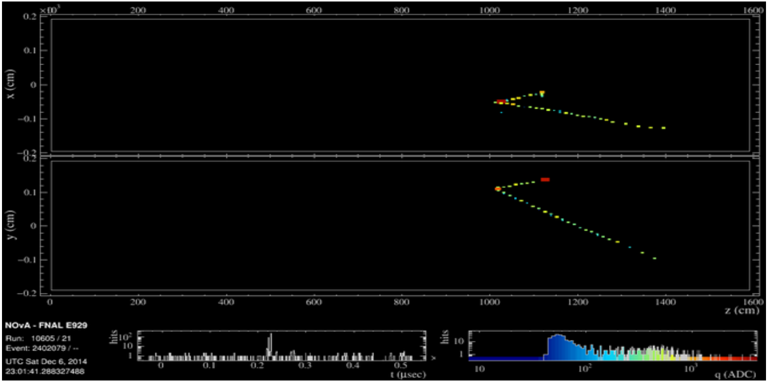
Background Events

- After the electron selection, dominant background $\rightarrow \nu_e$ charged current events.
- Due to large momentum transfer, the $E_e\theta^2$ distribution for ν_e CC events appears to be flat.
- So, the $\nu - e$ elastic scattering signal can be selected with a high background rejection rate by requiring $E_e\theta^2$ to be small.

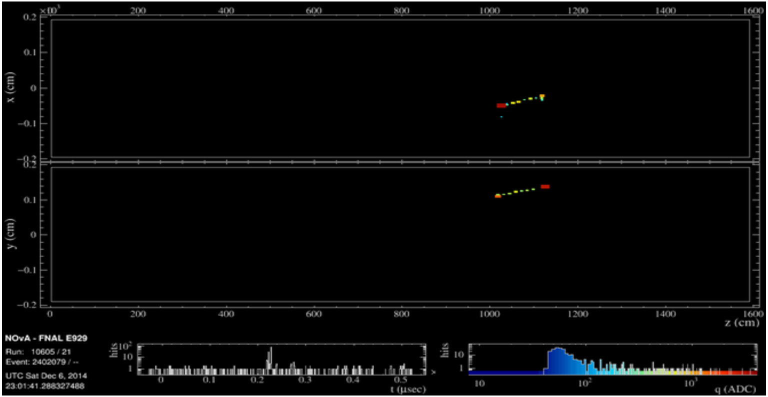


What is MRE?

- MRE stands for Muon-Removed Electron-added
- Constructed by removing hits from reconstructed muon candidate in ν_μ CC interactions and generating an electron in its place
- Muons in NOνA appear as long, clean tracks and are the distinguishing feature of a ν_μ CC interaction

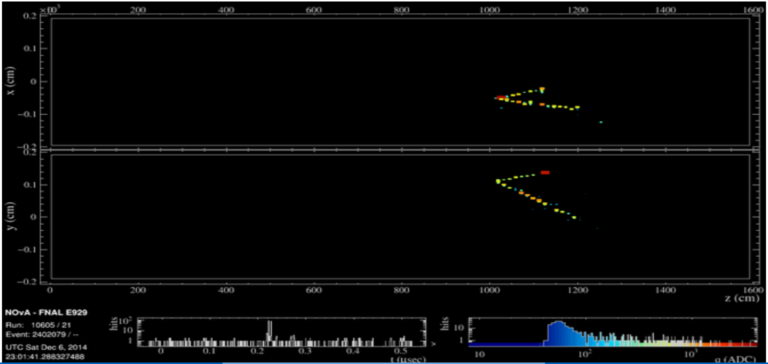


- The removal of information about the outgoing muon in a ν_μ CC interaction produces what is known as a Muon-Removed Charged Current or MRCC event.



What is MRE?

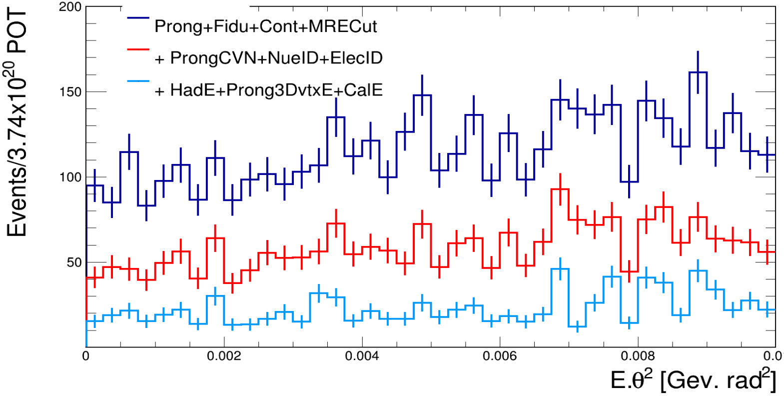
- For each muon removed from the spill, an electron is generated in its place.
- The resulting electron has the same energy as the removed muon, but a different momentum.
- Once the simulated electron hits are generated, they are overlaid with the hits of the MRCC event to get the final MRE event.



MRE Selection Study

- **True Signal Definition**
  - **Interaction Type** (Neutrino Electron Elastic Scatter)
  - **True Fiducial Cut**
    $\rightarrow$ Min X Y Z (cm) : -130, -150, 160
    $\rightarrow$ Max X Y Z (cm) : 155, 160, 1080
- **Pre-Selection**
  - **Single Prong Selection**
  - **Fiducial Volume Cut** $\rightarrow$ ensures all events are well contained within the fiducial volume of the detector
  - **Containment Cut** $\rightarrow$ ensures neutrinos interacted within the detector and rejects cosmic ray background
  - **MRE Cuts** $\rightarrow$ looks out for ν_μ CC interaction on which we can perform MRE procedure
- **Full-Selection**
  - **Pre-selection**
  - **Identifiers Cuts** $\rightarrow$ Electron Prong CVN , Nue ID and Elec ID
  - **Energy Cuts** $\rightarrow$ Hadron Energy, Prong 3D Vertex Energy and CalE energy

MRE Selection



- Nominal MRE MC files are used and plots are normalised to MC POT
- Selections are applied one after another and reduction in background events are noted.

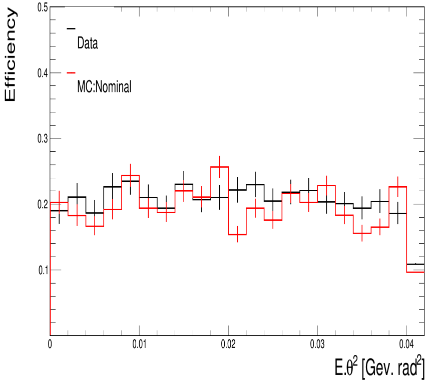
Selection Efficiency Study

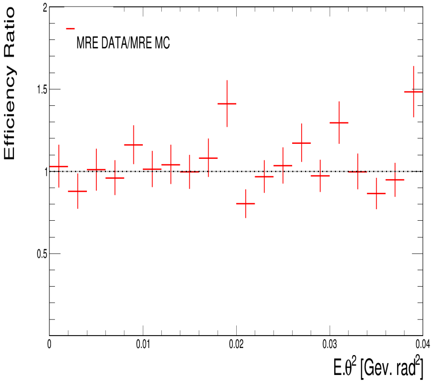
- **Pre-Selection** = Single Prong Selection +Fiducial Volume + Containment Cut + MRE Cut
- **Full Selection** = Pre-selection+ProngCVN+NueID+ElecID+HadE+Prong3DVtx+CalE

File	Pre-Selection	Full-Selection	% Bkg Reduction
MRE-MC	15564.5	3086.13	80%
MRE-Data	13956.1	2922.63	79%
MC Light Up	15242	3096.67	79.7%
MC Light Down	15637.4	3199.13	79.5%
Calib up	14572.9	2713.56	81%
Calib Down	16381.7	3341.81	79.6%
Cheren Up	15450	3181.64	79%
Cheren Down	15599.8	3157.05	79.8%

Efficiency and Efficiency Ratio Study: MC Nominal

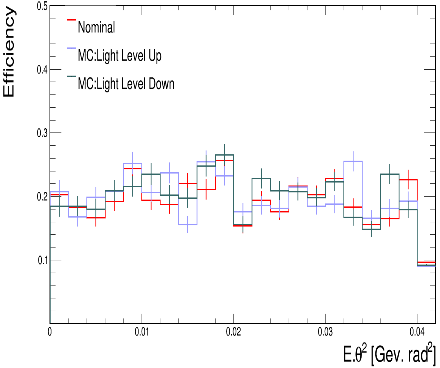
FHC	Pre-Sel	Full-Sel	Efficiency	Difference
DATA	13956.10	2922.63	0.209	
MC	15564.50	3086.13	0.198	+0.011

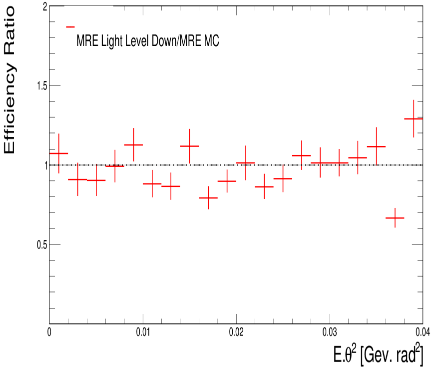




Selection Efficiency: MC Light Level

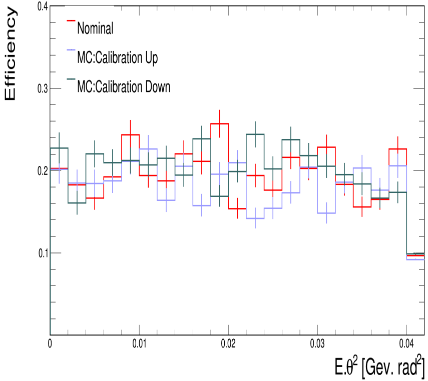
FHC	Pre-Sel	Full-Sel	Efficiency	Difference
MC	15564.50	3086.13	0.198	
lightlevel Up	15242.00	3096.67	0.203	+0.005
lightlevel Down	15637.40	3199.13	0.204	+0.006

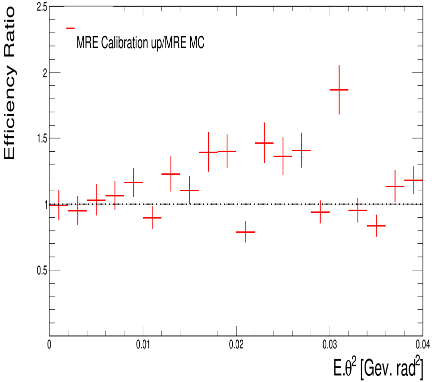




Selection Efficiency: MC Calibration

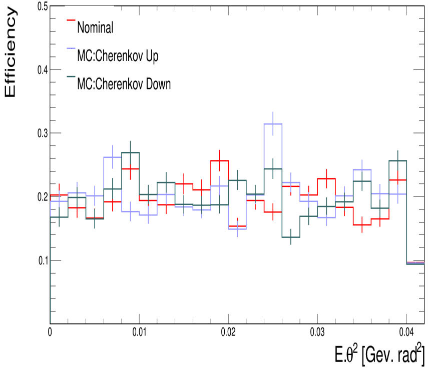
FHC	Pre-Sel	Full-Sel	Efficiency	Difference
MC	15564.50	3086.13	0.198	
Calibration Up	14572.90	2713.56	0.186	-0.012
Calibration Down	16381.7	3341.81	0.204	+0.006

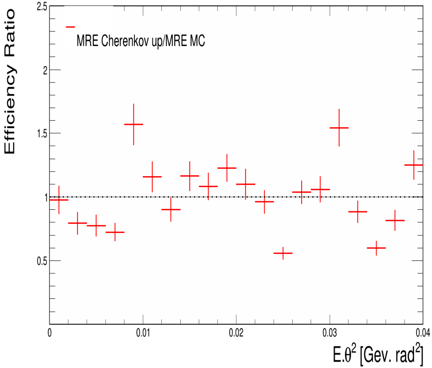




Selection Efficiency: MC Cherenkov

FHC	Pre-Sel	Full-Sel	Efficiency	Difference
MC	15564.50	3086.13	0.198	
Cherenkov Up	15450.00	3181.64	0.206	+0.008
Cherenkov Down	15599.80	3157.05	0.202	+0.004





Summary

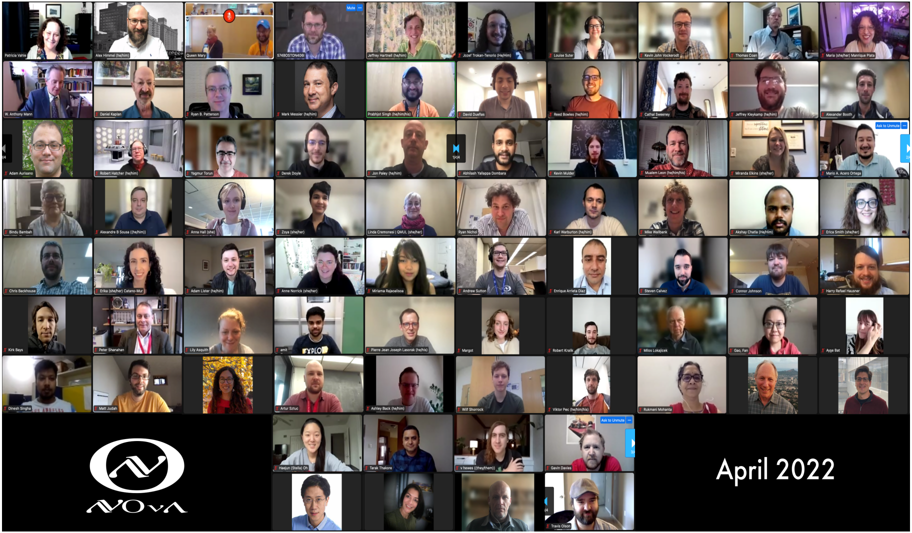
- From the selection efficiency study, here is a summary of all the systematic uncertainty:

<table>
<tr><th>Norm to MRE DATA POT</th><th>MRE Pre-Selection</th><th>Full Selection</th><th>Efficiency</th><th>Difference</th><th>$\frac{N^{D.S}-N^{MC}}{N^{MC}}$</th><th>Uncertainty</th><th>Overall MC Uncertainty</th></tr>
<tr><td>Nominal MC</td><td>15564.50</td><td>3086.13</td><td>0.198</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Lightlevel Up MC</td><td>15242.00</td><td>3096.67</td><td>0.203</td><td>+0.005</td><td>+0.0034</td><td rowspan="2">+0.0366</td><td rowspan="6">0.13</td></tr>
<tr><td>Lightlevel Down MC</td><td>15637.40</td><td>3199.13</td><td>0.204</td><td>+0.006</td><td>+0.0366</td></tr>
<tr><td>Calibration Up MC</td><td>14572.90</td><td>2713.56</td><td>0.186</td><td>-0.012</td><td>-0.1207</td><td rowspan="2">-0.1207</td></tr>
<tr><td>Calibration Down MC</td><td>16381.70</td><td>3341.81</td><td>0.204</td><td>+0.006</td><td>+0.0828</td></tr>
<tr><td>Cherenkov Up MC</td><td>15450.00</td><td>3181.64</td><td>0.206</td><td>+0.008</td><td>+0.0309</td><td rowspan="2">+0.0309</td></tr>
<tr><td>Cherenkov Down MC</td><td>15599.80</td><td>3157.05</td><td>0.202</td><td>+0.004</td><td>+0.0229</td></tr>
</table>

Next Step

- Using all systematic files to estimate the total detector uncertainties
- Working on covariance and correlation matrix
- Next use the MRE results to apply constraint on the background.

Thank You !!



BACKUP SLIDES

Selections

Event Selections

- Single Prong Selection:
  vtx.elastic.fuzzyk.npng $==1$
- Reco Fiducial Volume cuts
  Vertex X, Y, Z min(in cm) $\longrightarrow$ -130, -150, 160
  Vertex X, Y, Z max(in cm) $\longrightarrow$ 155, 160, 1080
- Reco Containment cut
  similar to the nueCC inclusive

Selections

- Electron ProngCVN
  kvProngCVN $>$ 0.89
- Electron ID
  kv5labelElecID $>$ 0.5
- Nue ID
  kvNueID $>$ -0.05
- Hadron Energy
  kCVNhadE $<$ 0.035 [GeV]
- Prong 3D Vertex Energy
  0.0 $<$ kProng3DvertexEnergyVol10 $<$ 0.03 [GeV.rad^2]
- CalE Energy
  kShowCalE $<$ 4.1 [GeV]

Events

- Pre-Selection = Single Prong Selection +Fiducial Volume + Containment Cut + MRE Cut
- Full Selection = Pre-selection+ProngCVN+NueID+ElecID+HadE+CalE+ Prong3DVtx

Selection	MRE MC	MRE Data
Pre-Selection	203910	173340
ProngCVN	78432	72930
NueID	67682	62601
Elec ID	41365	38201
Had E	8625	7668
Cal E	7905	6803
Prong3DVtx	3063	2922