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Wrong Sign Contamination in NOvA

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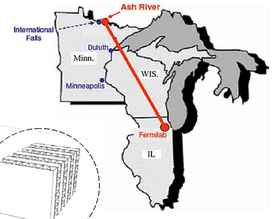
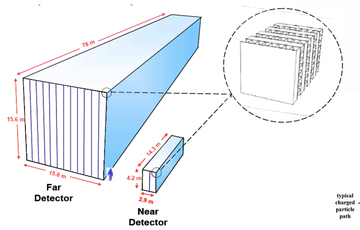
NOvA experiment

- NOvA is an off-axis (14.6 mrad), long baseline (810 km) neutrino oscillation experiment which uses NuMI beam at Fermilab.
- NOvA's main goal is to use muon neutrino disappearance and electron neutrino appearance to probe neutrino mass ordering, Δm^2_{32}, θ_{23} and δ_{cp}.
- NOvA uses two functionally identical liquid scintillator detectors.





Analysis procedure

- The wrong sign fraction is estimated for electron neutrinos and muon neutrinos separately.
- CNN (Convolutional Neural Network) was trained on simulation to identify neutrino and antineutrino events and validated with data.
- A optimal cut value was chosen for Wrong Sign CNN ID based on efficiency and purity to separate the whole sample into wrong sign and right sign enhanced regions.
- Compute the wrong sign fraction using matrix method

$$\alpha B_{RS} + \beta S_{RS} = D_{RS}$$
$$\alpha B_{WS} + \beta S_{WS} = D_{WS}$$

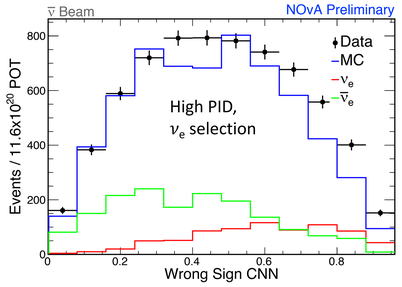
α, β : Fit parameters
D: Data
S: Signal = ν_e , ν_μ CC and NC
B: Background = $\bar{\nu}_e$, $\bar{\nu}_\mu$ CC and NC
RS: Right sign enhanced
WS: Wrong sign enhanced

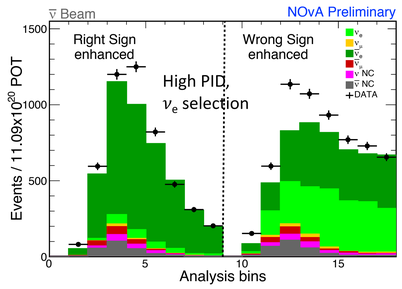
$$Wrong\ sign\ fraction = \frac{\beta(S_{RS} + S_{WS})}{\beta(S_{RS} + S_{WS}) + \alpha(B_{RS} + B_{WS})}$$

$$Wrong\ sign\ error = \sqrt{\frac{C_{22}(S_{RS} + S_{WS})^2}{(D_{RS} + D_{WS})^2}}$$

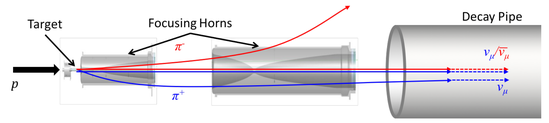
Matrix : $M = \begin{bmatrix} B_{RS} & S_{RS} \\ B_{WS} & S_{WS} \end{bmatrix}$

Covariance matrix : $C = M^{-1} \begin{bmatrix} \sigma_{DRS} & 0 \\ 0 & \sigma_{DWS} \end{bmatrix} M^T$

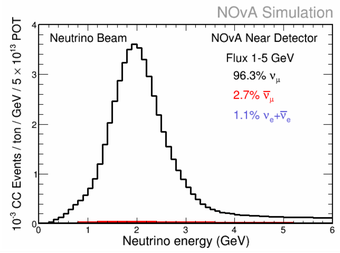


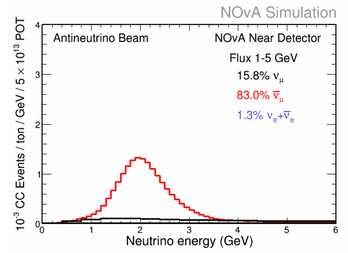


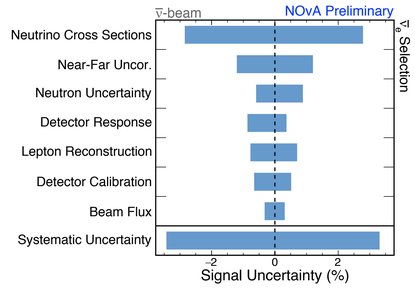
Wrong Sign contamination

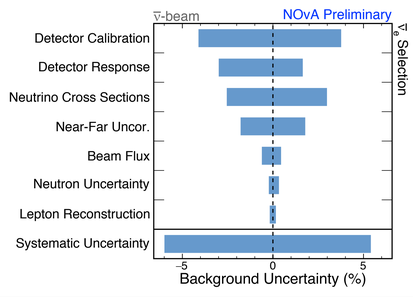


- Wrong sign contamination is fraction of neutrinos/antineutrinos in antineutrino/neutrino beam.
- Wrong sign fraction is higher in antineutrino beam.
- Wrong sign fraction affects our mass hierarchy and δcp. measurements because these parameters are estimated based on difference between ν_e and $\bar{\nu}_e$ appearance.



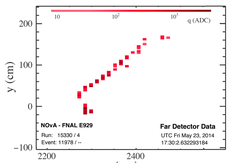




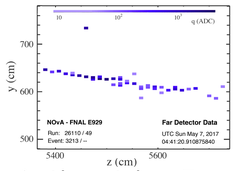


Analysis Methods

- Neutron capture method: Neutrinos are more likely to produce μ^- which gets absorbed in nucleus and produce delayed neutrons while antineutrinos don't.
- Prong CVN score: Identify neutrinos using a single particle classifier for proton identification
- Wrong Sign CNN score: Dedicated CNN for classifying neutrinos and antineutrinos based on topological features



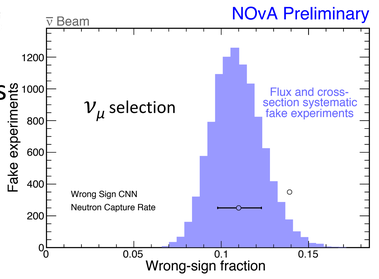
Neutrino Event

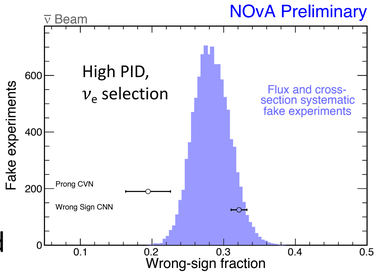


Antineutrino Event

Analysis Results

- All possible wrong sign values for different universes of cross-section, beam and flux uncertainties is shown in blue histogram. Remaining systematics under investigation.
- Currently used as data driven crosscheck but in future can be used for extrapolation.





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