Extraction of the Inclusive Muon Neutrino Charged Current Cross Section at MicroBooNE using Wiener SVD Unfolding

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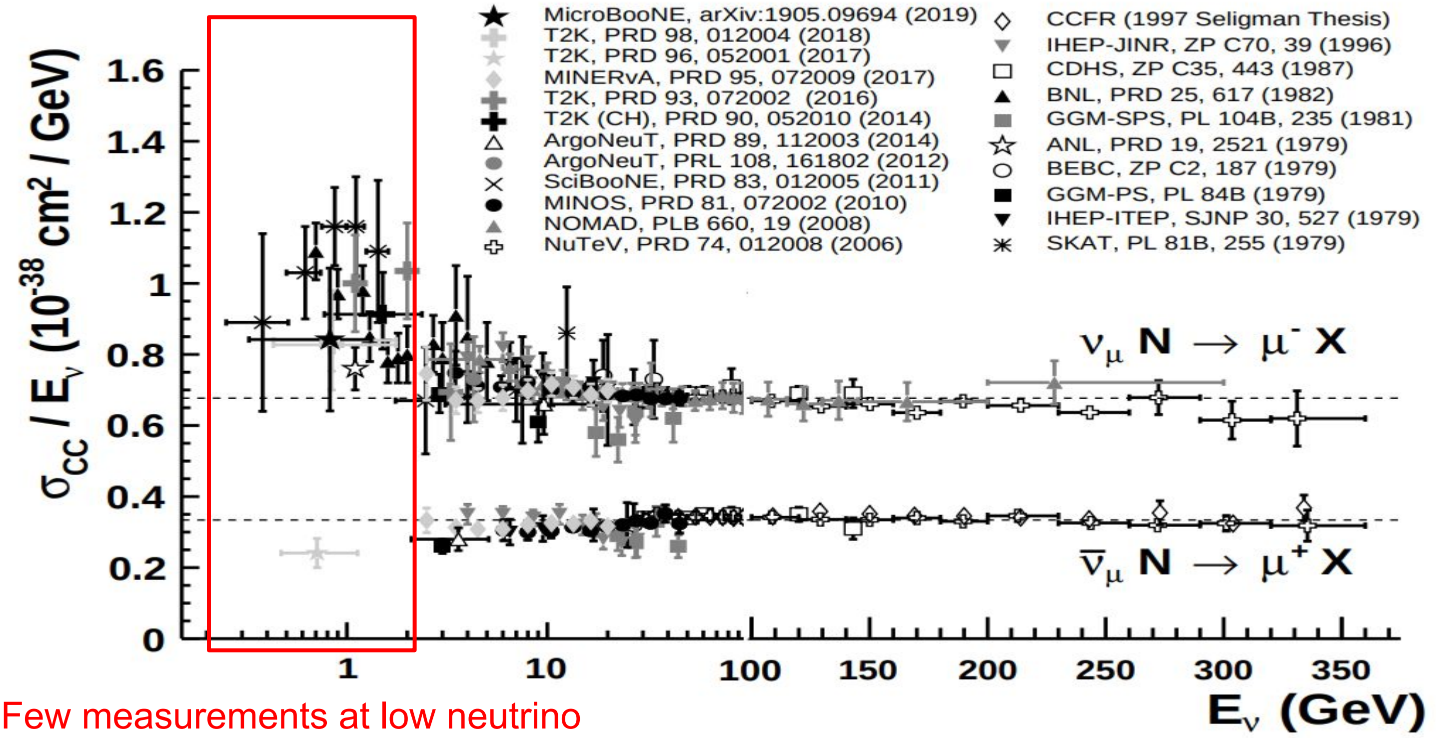
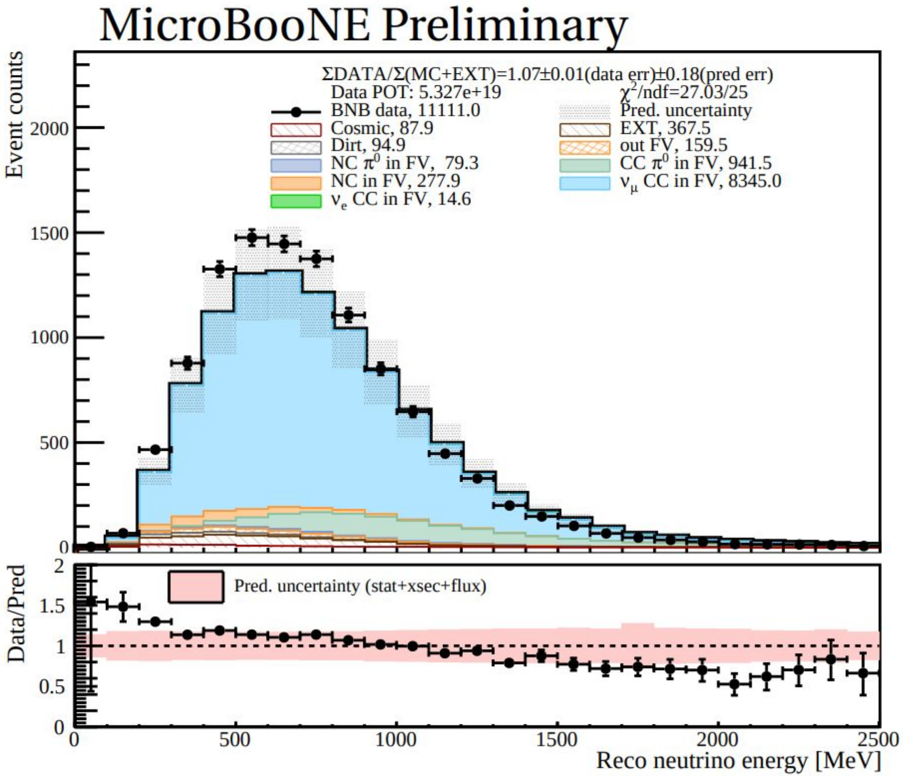
Neutrino Cross Section Measurements



Few measurements at low neutrino energy, especially in Argon.

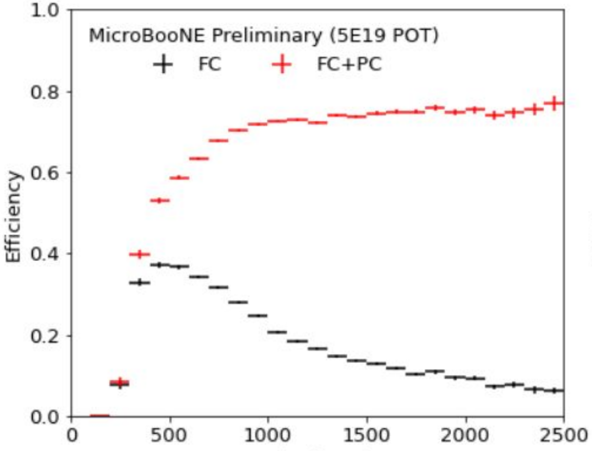
Wire-Cell Generic Neutrino Selection

- Wire-Cell is a fully 3D event reconstruction that arranges charge in a graph structure.
- Wire-Cell has reconstructed an inclusive neutrino selection with high efficiency (64%) and high purity (93%).
- This high efficiency is maintained across the full range of three important kinematic variables for differential cross sections: E_ν, E_μ, and $E_{transfer}$ (aka $\boldsymbol{\nu}$).

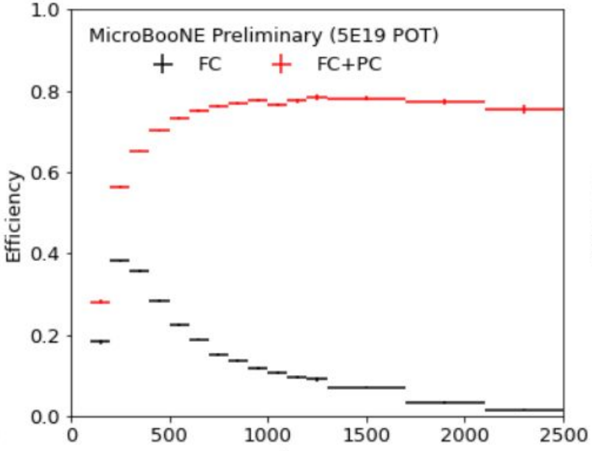


Kinematic Variables for Differential Cross Sections

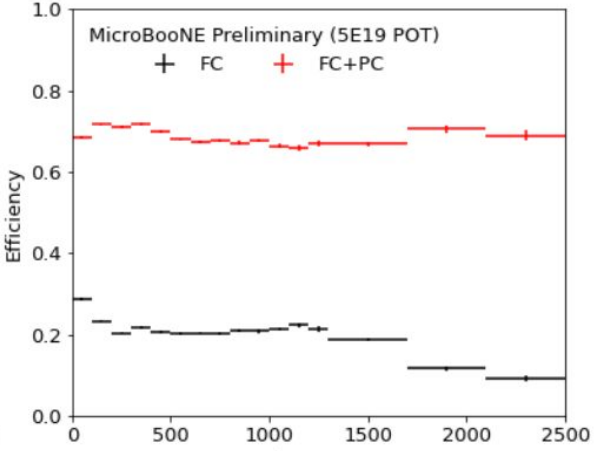
Fully contained (FC) events begin and end inside the detector.
Partially contained (PC) events enter or leave the detector.



E_{ν}^{true}(MeV)



E_{μ}^{true}(MeV)



$E_{transfer}^{true}$(MeV)

ν_{μ}CC selection efficiency as a function of true neutrino energy, true muon energy, and true transferred energy to Ar, respectively.

Measuring the ν_μ CC Cross Section Using Unfolding

Measurement M

Background B

Response matrix R

Signal S

Covariance matrix C

Test statistic $T = (M-B-R\cdot S)^T\cdot C^{-1}\cdot(M-B-R\cdot S)$

$$M-B = R\cdot S$$

Minimize T

$$S = (R^T\cdot C^{-1}\cdot R)^{-1}\cdot R^T\cdot C^{-1}\cdot(M-B)$$

$$C_S = (R^T\cdot C^{-1}\cdot R)^{-1}$$

Allows for cross section to be computed as a function of truth variables.

This standard weighted least squares approach suffers from instability in the computation.

Wiener SVD Unfolding

Measurement M

Background B

Response matrix R

Signal S

Covariance matrix C

Test statistic $T = (M-B-R\cdot S)^T\cdot C^{-1}\cdot(M-B-R\cdot S)+T_{reg}$

$$M-B = R\cdot S \quad \xrightarrow{\text{Minimize } T} \quad S = A_C\cdot(R^T\cdot C^{-1}\cdot R)^{-1}\cdot R^T\cdot C^{-1}\cdot(M-B)$$

$$C_S = (R^T\cdot C^{-1}\cdot R)^{-1}$$

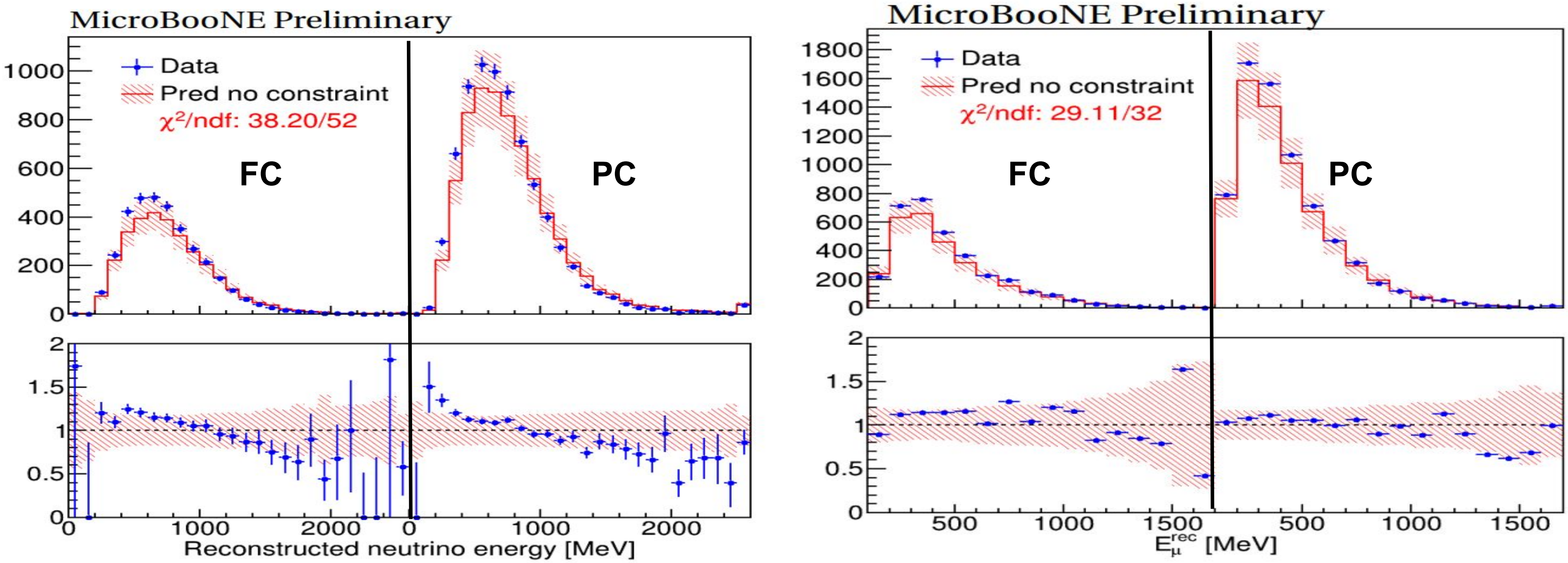
T_{reg} is generated from the MC truth expectation, and helps the fit stability.

The Wiener filter used to generate A_C maximizes signal/noise ratio in the relevant frequency domain.

Assumptions of Wiener SVD Unfolding

- The model used for the regularization term T_{reg} / smearing matrix A_C in unfolding must accurately predict data
- Covariance matrix formalism should accurately describe systematic uncertainties, and these uncertainties should cover any data/MC difference.
- There must be no efficiency gap regions across kinematic variables. (Strength of LArTPC and Wire-Cell).

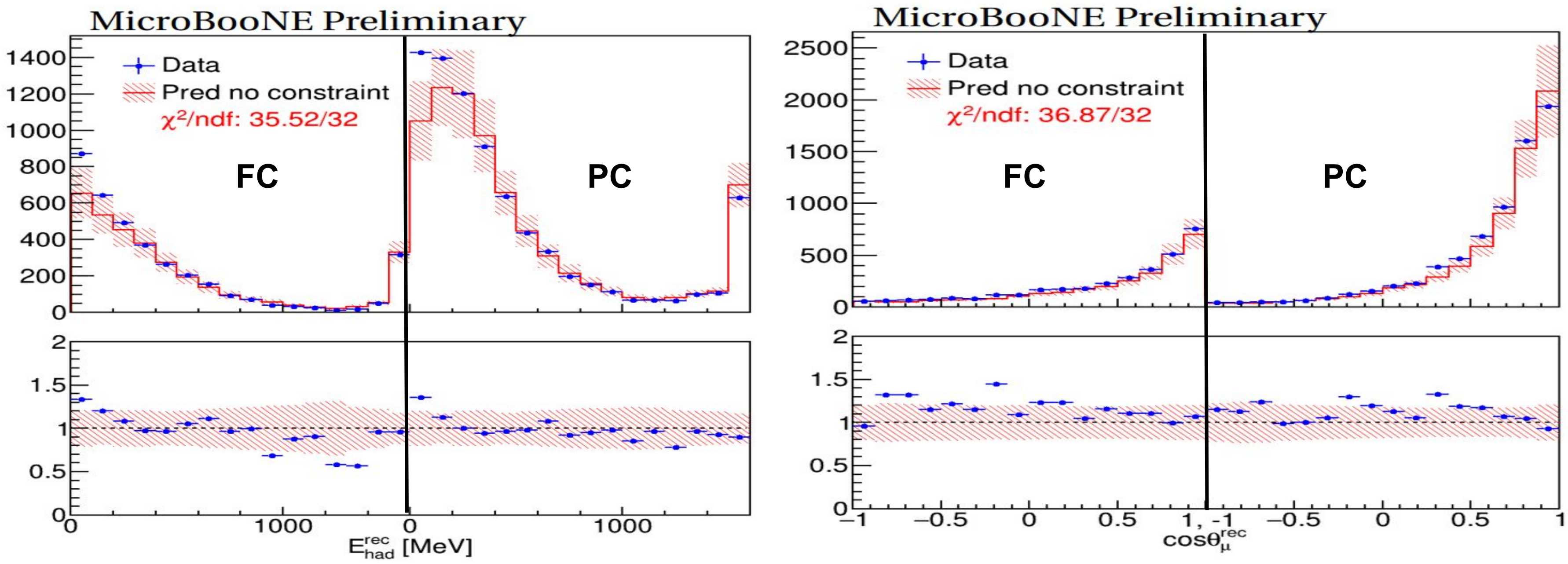
Validation of Model with Goodness of Fit



E_ν E_μ

Fully contained (left) and partially contained (right) events are shown for each variable

Validation of Model with Goodness of Fit



$E_{transfer}$ **$\cos\theta_{\mu}$**

Fully contained (left) and partially contained (right) events are shown for each variable

Summary

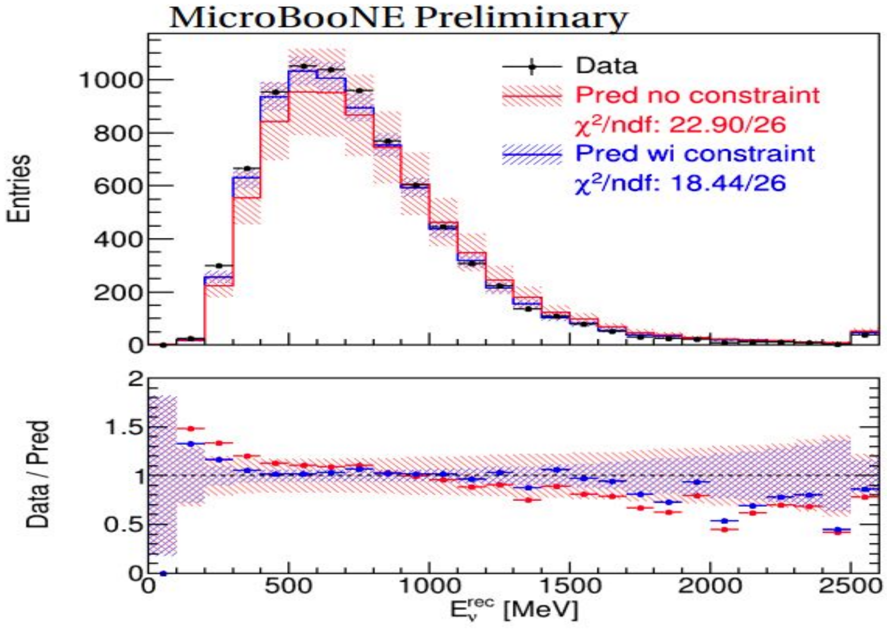
- Unfolding allows for cross sections to be measured as a function of truth variables.
- The high-efficiency, inclusive ν_μ selection provides high statistics for numerous differential cross sections.
- The interaction model is validated with data/MC GoF comparisons to ensure accurate unfolding.
- Multiple cross section measurements are in progress and hope to be published soon!

References

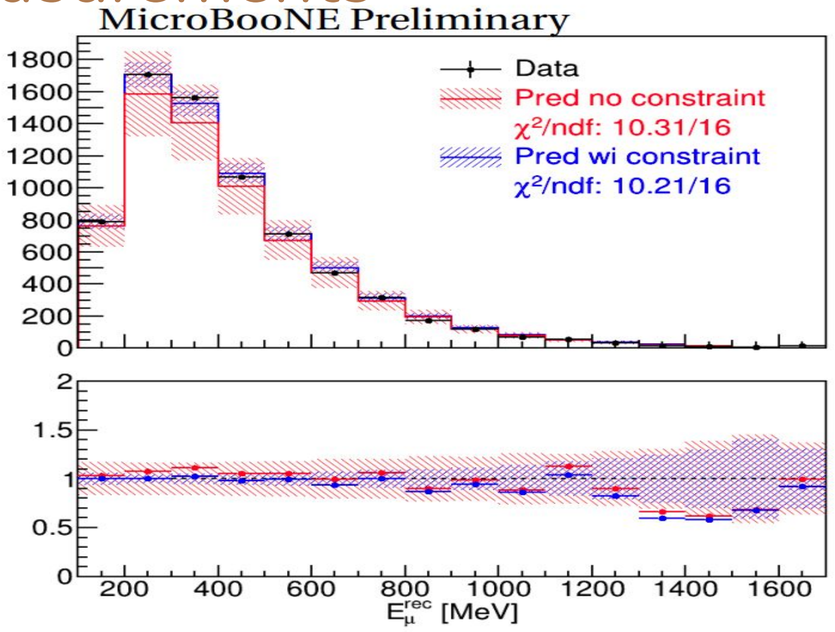
- Wire-Cell Software Package for LArTPC: https://lar.bnl.gov/wire-cell/
- Neutrino Interaction Model and Uncertainties for MicroBooNE Analyses. MICROBOONE-NOTE-1074-PUB
- Wire-Cell Neutrino Selection MICROBOONE-NOTE-1095-PUB
- Data Unfolding with Wiener SVD Method

Backups

Constraining Partially Contained with Fully Contained Measurements



E_ν(PC only)



E_μ

Constraining Hadron Energy with Muon Energy

- Muon energy measurement constraint significantly reduces uncertainty.
- Constrained measurements agree better with MC, improving X^2/ndf.
- This helps reduce worry of hadronic-specific reconstruction issue in data.