Data-Driven Model Validation for Neutrino-Argon Inclusive Measurements at MicroBooNE

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MicroBooNE's Three-Dimensional ν_μ CC Inclusive Measurement

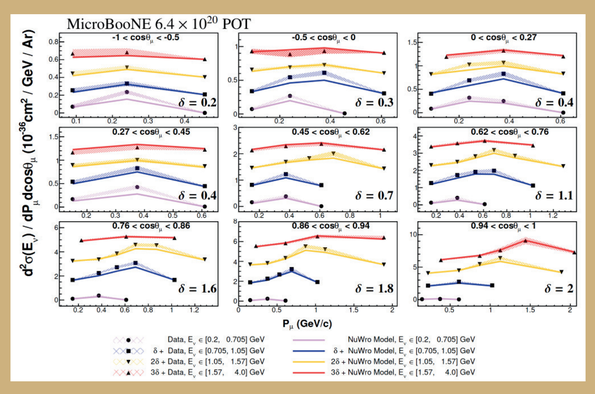
Signal Definition and Event Selection:

- ν_μ CC Inclusive
- 3D phase space: {E_ν , P_μ , θ_μ }
- 68% Efficiency, 92% Purity
- ~110k selected events

Importance of E_ν measurement:

- Separates interaction types: QE/RES/DIS
- Crucial for oscillation physics

Three-Dimensional Cross Section Results

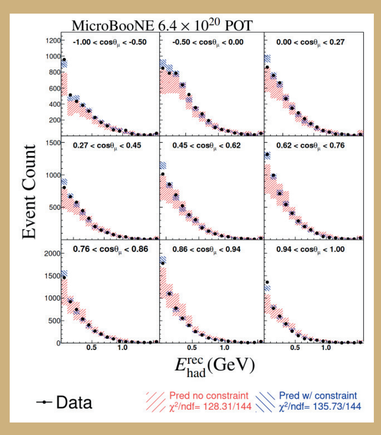


Model	Total χ^2 (138 DoF)
Genie v2	752.2
MicroBooNE Model	329.3
Genie v3 Untuned	324.6
GiBUU	275.2
NEUT	244.3
NuWro	214.1

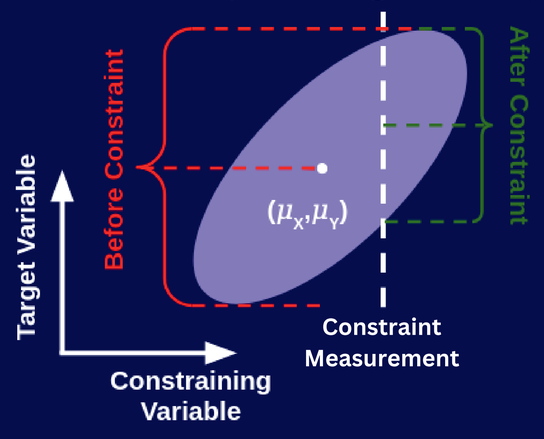
Data-Driven Model Validation

- Tests model w/ data before unfolding
- Increased sensitivity through conditional constraint procedure
  - Sensitive to modeling of missing energy
- Model describes data within uncertainties

Model Validation
{E_{had} , θ_μ} Constrained by {P_μ, θ_μ}



Conditional Constraint Example Diagram



Fake Data Studies using Data-Driven Model Validation

NuWro 19.02.2 Fake Data Study

Xs and Stat Uncertainties Only:

- Model validation detects mismodeling at 3.5 σ
- Unfolded cross section only biased by 1.1 σ

All Uncertainties:

- Neither model validation (p=0.87) nor unfolded cross section (p=0.99) show significant bias

In all cases the model validation tests demonstrate a higher sensitivity to mismodeling than the unfolded cross section

Xs and Stat Uncertainties

All Uncertainties

Distribution over {E_{had}, θ_μ} with and without constraint from {P_μ , θ_μ} for fully and partially contained events using Xs and stat uncertainties (left) and partially contained events using all uncertainties (right).

Scaled E_p Fake Data Study

Xs and Stat Uncertainties Only:

- Model validation detects mismodeling at +-20% E_p
- Unfolded cross section displays significant bias at +- 25% E_p

All Uncertainties:

- Model validation detects mismodeling at +-30% E_p
- Unfolded cross section does not find significant bias

In all cases the model validation tests demonstrate a higher sensitivity to mismodeling than the unfolded cross section

Xs and Stat Uncertainties

All Uncertainties

χ2/ndf (red) and converted σ significant (blue) for model validation GoF tests (dots) and unfolded cross sections (lines) as a function of proton energy scaling fraction.

E_p Scaling (%)	Cross Section & Stat Unc. GoF χ^2 (p-value) 144 DoF	Cross Section & Stat Unc. Cross Section Bias χ^2 (p-value) 138 DoF	All Uncertainties GoF χ^2 (p-value) 144 DoF	All Uncertainties Cross Section Bias χ^2 (p-value) 138 DoF
70	554.6 (2×10^{-49})	240.7 (1.4×10^{-7})	216.4 (9.5×10^{-5})	126.3 (0.753)
75	365.9 (3×10^{-21})	162.1 (0.08)	147.7 (0.40)	85.5 (1)
80	225.4 (1.7×10^{-5})	104.5 (0.985)	95.8 (0.999)	55.5 (1)
85	123.6 (0.89)	60.1 (1)	55.8 (1)	32.6 (1)
90	58.1 (1)	27.4 (1)	29.0 (1)	14.8 (1)
95	17.0 (1)	7.2 (1)	9.2 (1)	3.7 (1)
105	18.7 (1)	7.5 (1)	11.0 (1)	3.8 (1)
110	48.3 (1)	26.8 (1)	26.1 (1)	14.0 (1)
115	96.9 (0.999)	62.3 (1)	52.6 (1)	32.3 (1)
120	152.7 (0.29)	104.3 (0.985)	82.7 (1)	53.7 (1)
125	217.4 (8×10^{-5})	159.2 (0.105)	114.3 (0.967)	81.4 (1)
130	289.5 (9×10^{-12})	229.6 (1.6×10^{-6})	151.4 (0.321)	115.6 (0.917)

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