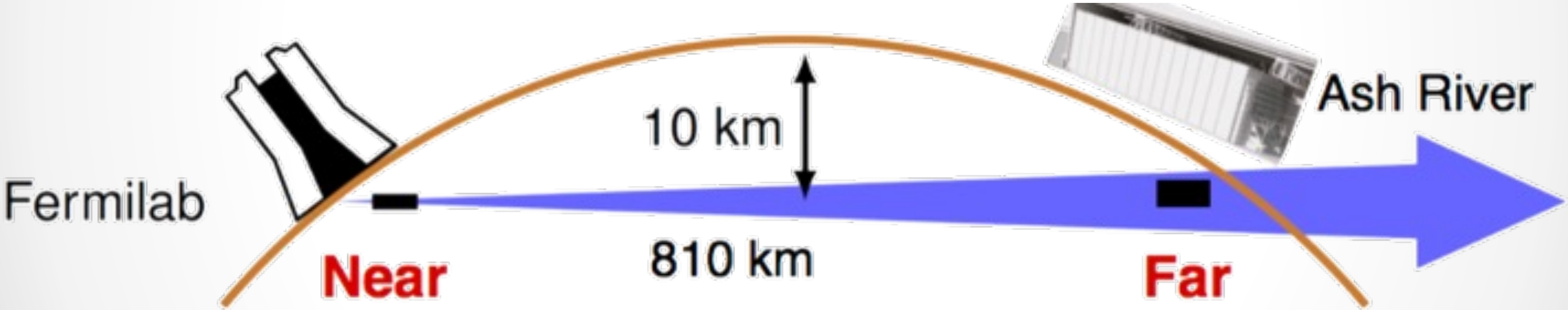
Near Detector Tuning and BSM: NOvA Case Study

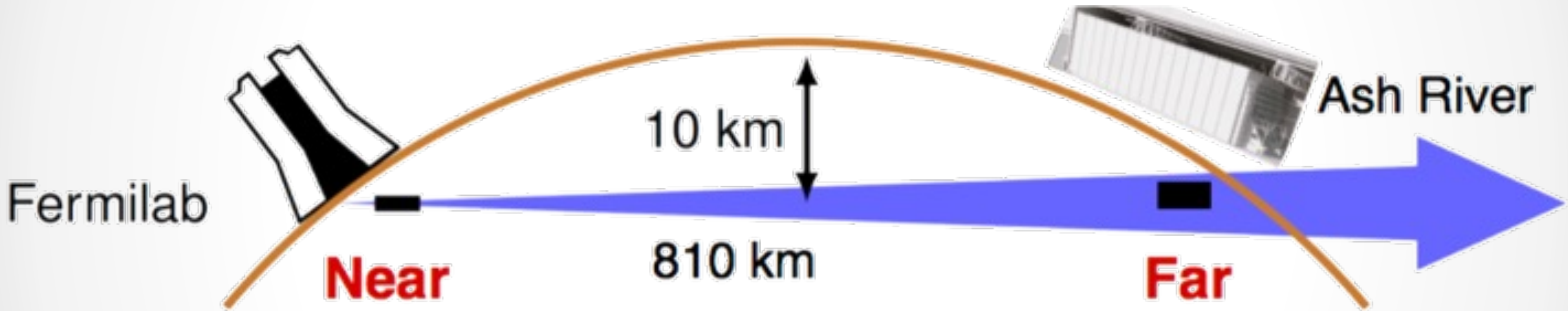


Shirley Li (Fermilab)
With Nina Coyle, Pedro Machado

Neutrino-Nucleus Cross Sections

Experimental Solutions?

Near Detector!



1. How Is It Used? – What Is Near Detector Tuning?
2. What Are the Impacts on Physics Searches?

Why Tuning?

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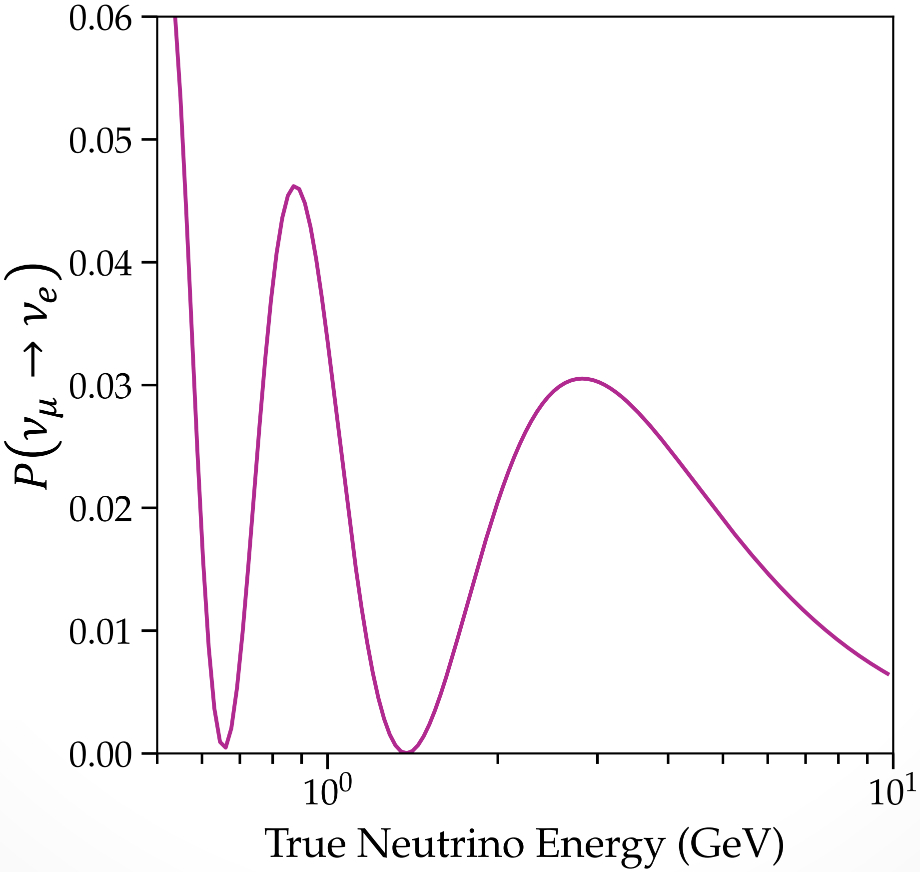
What About Near/Far Cancellation?

Measuring Neutrino Oscillation

With Near Detector, Conceptually



Measuring Neutrino Oscillation

With Near Detector, Conceptually

Far Detector

$$P\left(\nu_\mu \to \nu_e, E_\nu, l = L\right) = \frac{f_e(E_\nu, L)}{f_\mu(E_\nu, 0)} = \frac{N_e(E_\nu, L)/\sigma_e(E_\nu)}{N_\mu(E_\nu, L)/\sigma_\mu(E_\nu)}$$

Near Detector

Cross Section Predictions Doesn't Play A Role?

Near/Far Cancellation

It Does NOT Work Perfectly

Fluxes at Near/Far Detectors Are Different

Not To Scale

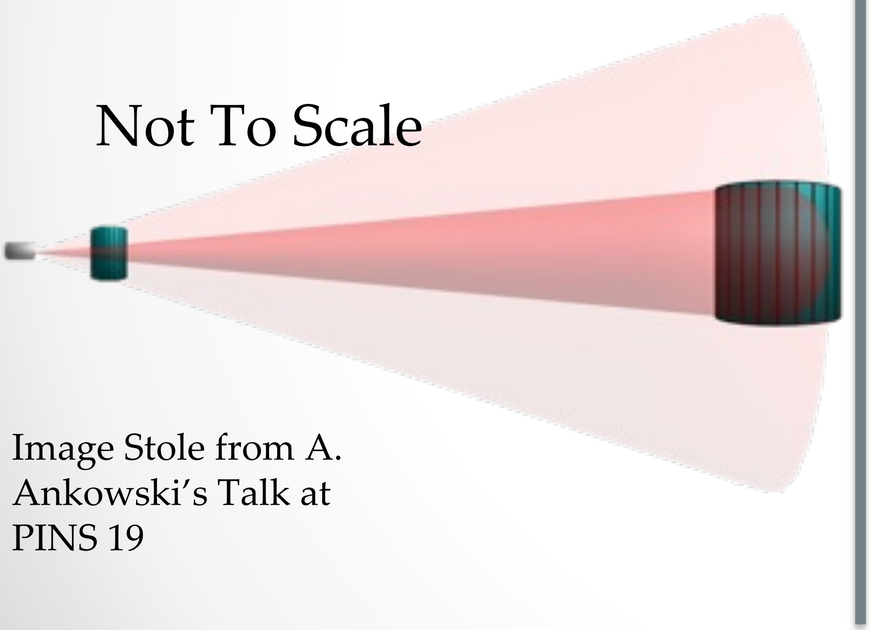


Image Stole from A. Ankowski's Talk at PINS 19

Near/Far Cancellation

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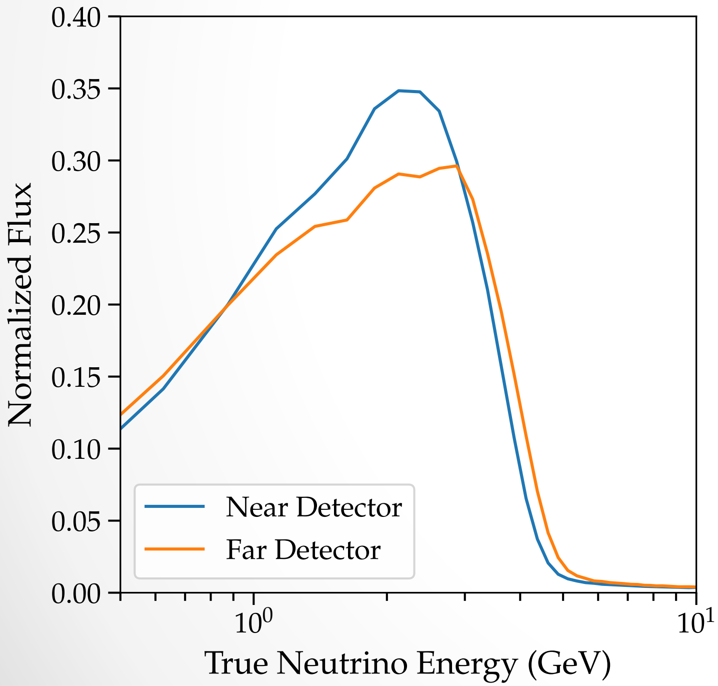

DUNE flux from
https://home.fnal.gov/~ljf26/DUNEFluxes/

Near/Far Cancellation

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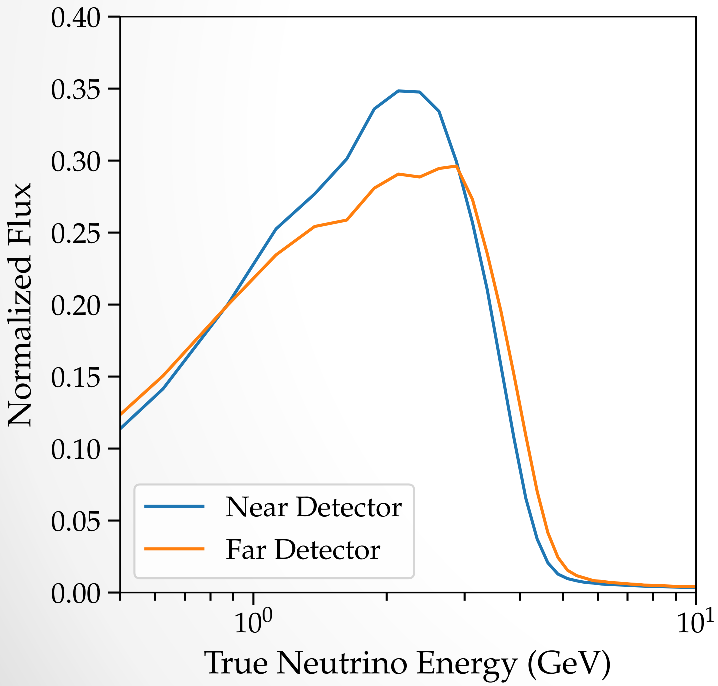

$$P(E_\nu) = \frac{N_e(E_\nu, L)/\sigma_e(E_\nu)}{N_\mu(E_\nu, L)/\sigma_\mu(E_\nu)}$$

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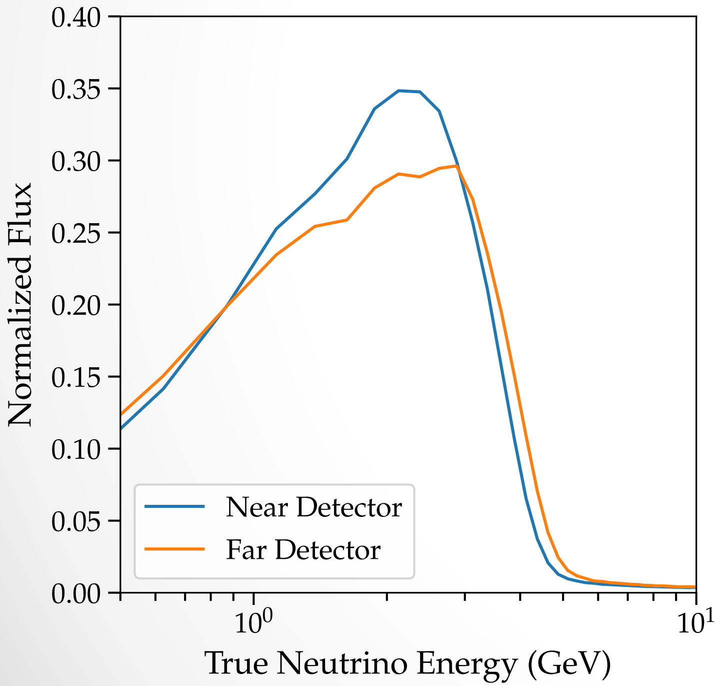

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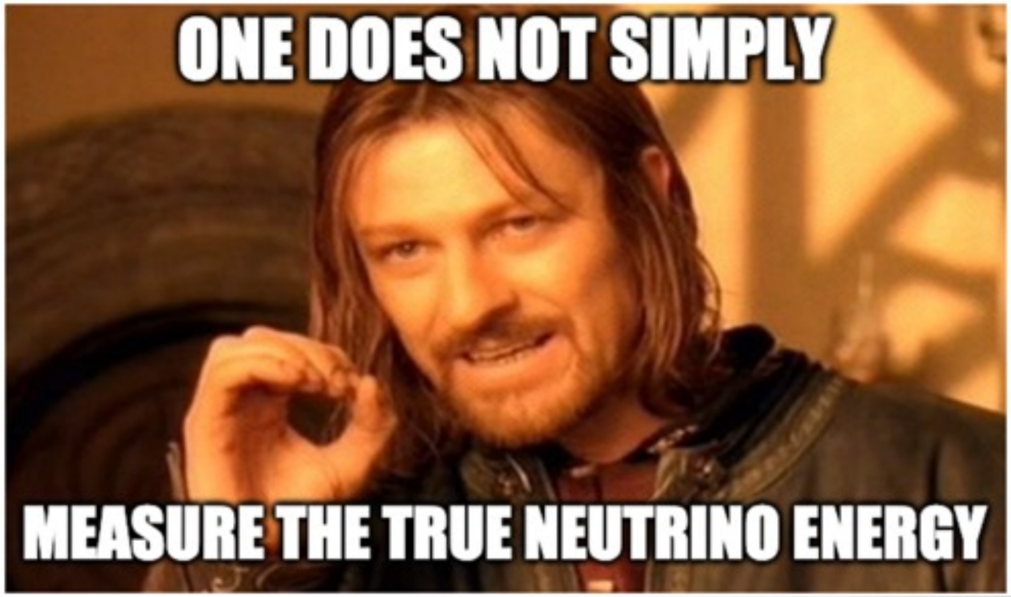

DUNE flux from
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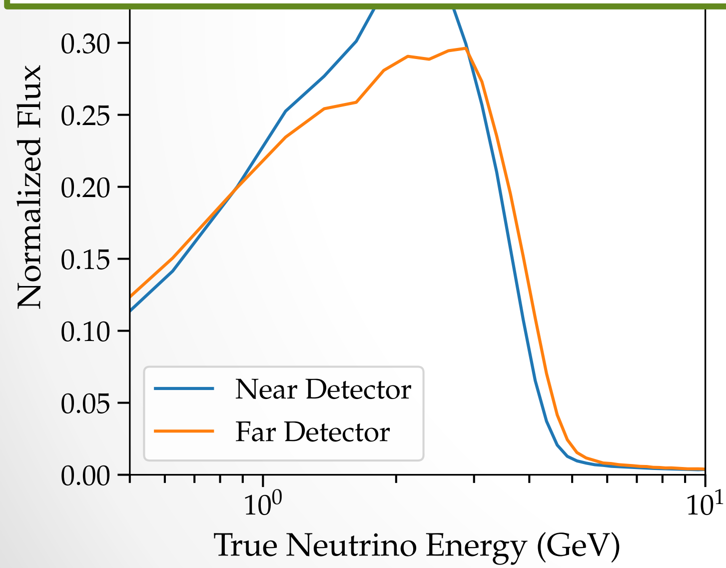
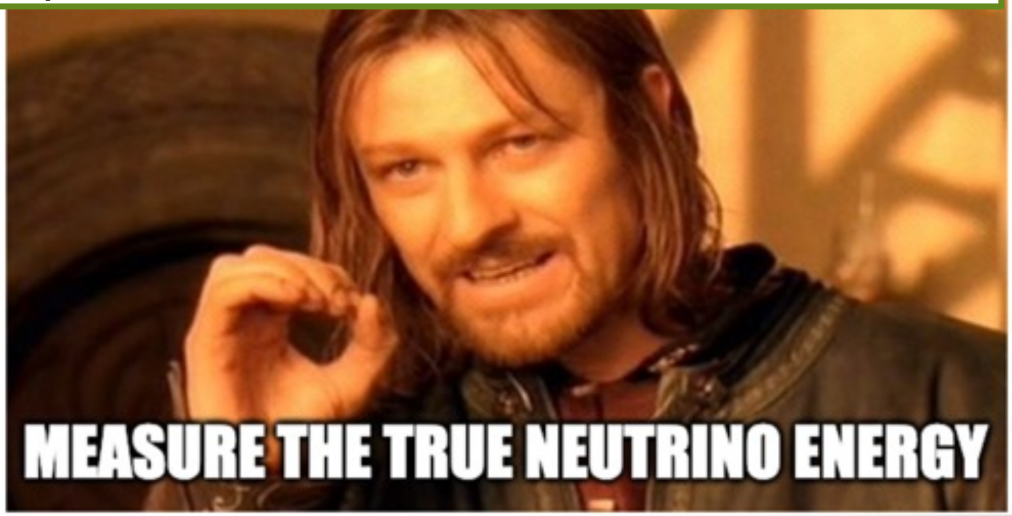
Near/Far Cancellation

It Does NOT Work Perfectly

$$P(\nu_\alpha \to \nu_\beta, E_{\text{rec}}) \approx \frac{\int dE_\nu \frac{dN_\beta}{dE_\nu} D_\beta^{\text{FD}}(E_\nu, E_{\text{rec}})/\sigma_\beta(E_\nu)}{\int dE_\nu \frac{dN_\alpha}{dE_\nu} D_\alpha^{\text{ND}}(E_\nu, E_{\text{rec}}) F_\alpha^{\frac{\text{FD}}{\text{ND}}}(E_\nu)/\sigma_\alpha(E_\nu)}$$





DUNE flux from
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What Is the Analysis Procedure?

Neutrino Event Generator, e.g., GENIE

Simulate Flux

Simulate Detector Response

Near Detector Data Comparison

Tune Model Parameters

Tuned Event Generator

Far Detector Response

Predictions at Far Detector

$$P = \frac{N_e(E_\nu, L)/\sigma_e(E_\nu)}{N_\mu(E_\nu, L)/\sigma_\mu(E_\nu)}$$

What Is Tuning?

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Experiment-Dependent

NOvA Tuning Procedure

NOvA 2020
2006.08727

Step 1: "Fix" Default GENIE (v2.12.2)

1) Adjust m_A from 0.99 to 1.04 GeV
   Reanalysis of ν-deuterium data (Meyer et al., 16)

2) Modify the Momentum Distributions of the Initial Nucleons for QE
   MINERvA study (Gran, 17)

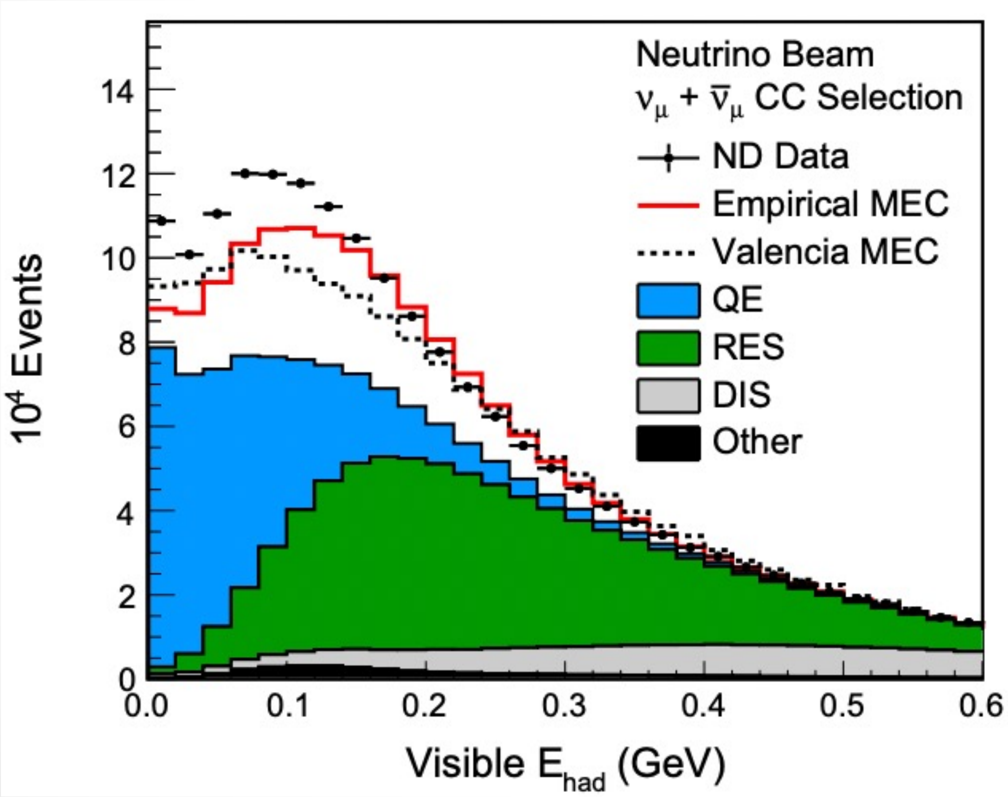
3) Lower ν (and not $\bar{\nu}$) Non-resonance Pion By 57%
   Reanalysis of bubble chamber data (Rodrigues et al., 16)

4) Suppress Resonance Production Low-Q^2 Region
   Motivated by MiniBooNE, MINOS, T2K, MINERvA

NOvA Tuning Procedure

NOvA 2020
2006.08727

Step 2: Identify Theory Data Discrepancy



Data (black points)
vs.
Theory (red line)

Assumes Discrepancy Entirely Due to Mis-Modeling of MEC

NOvA Tuning Procedure

NOvA 2020
2006.08727

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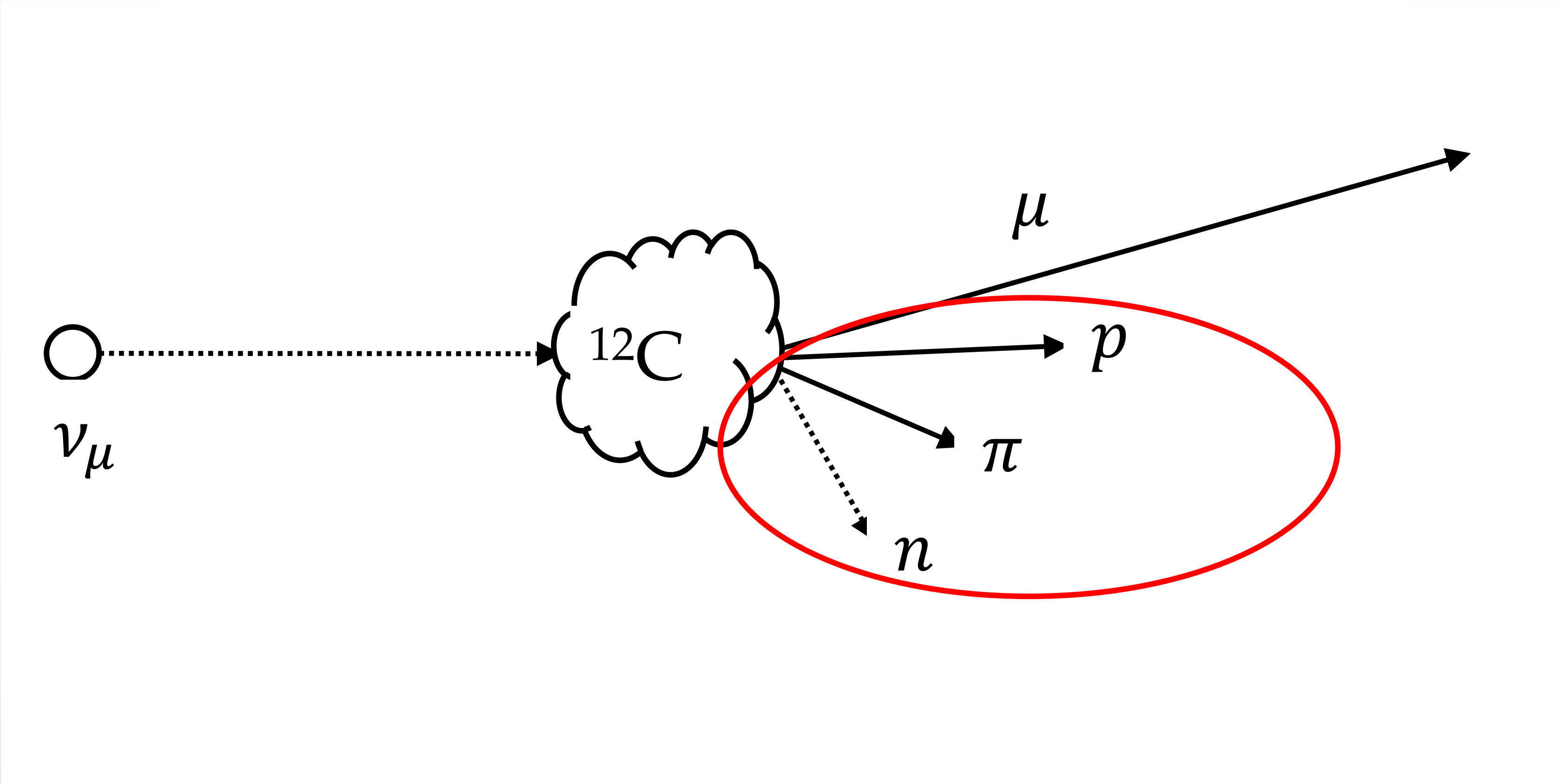

NOvA Tuning Procedure

NOvA 2020
2006.08727

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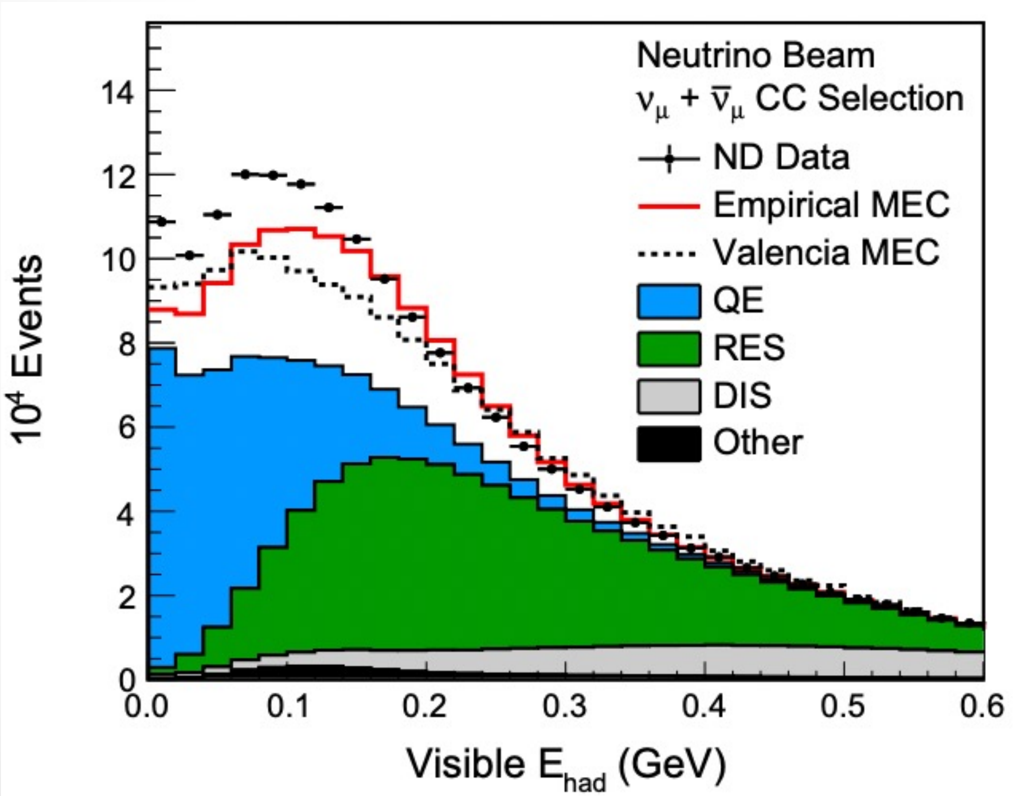

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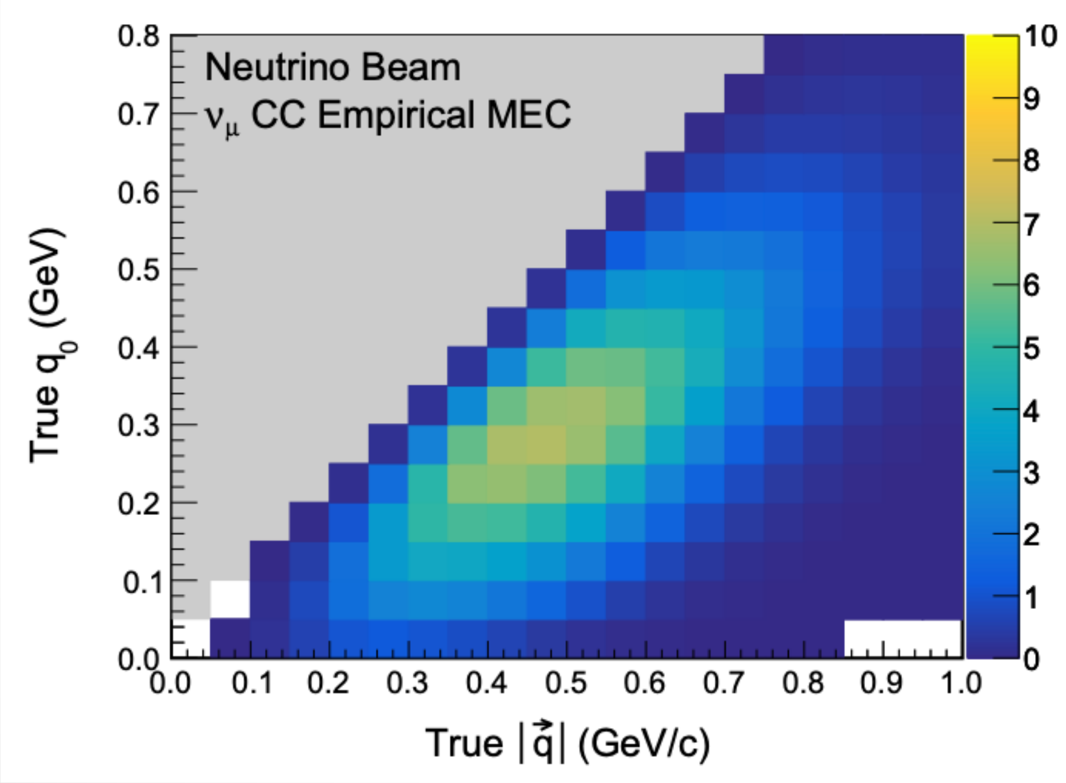
NOvA Tuning Procedure

NOvA 2020
2006.08727

Step 3: Project *Simulated* Events onto $(\vec{q}, q_0)$ Plane



20 * 16 Bins

120 Kinematically Forbidden

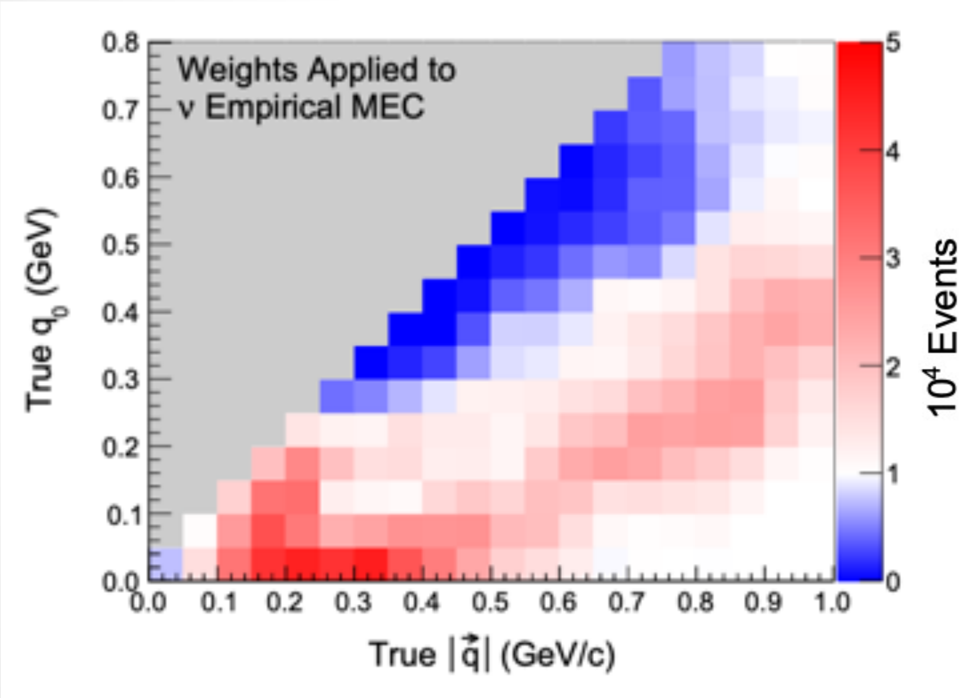
200 Bins Remain

NOvA Tuning Procedure

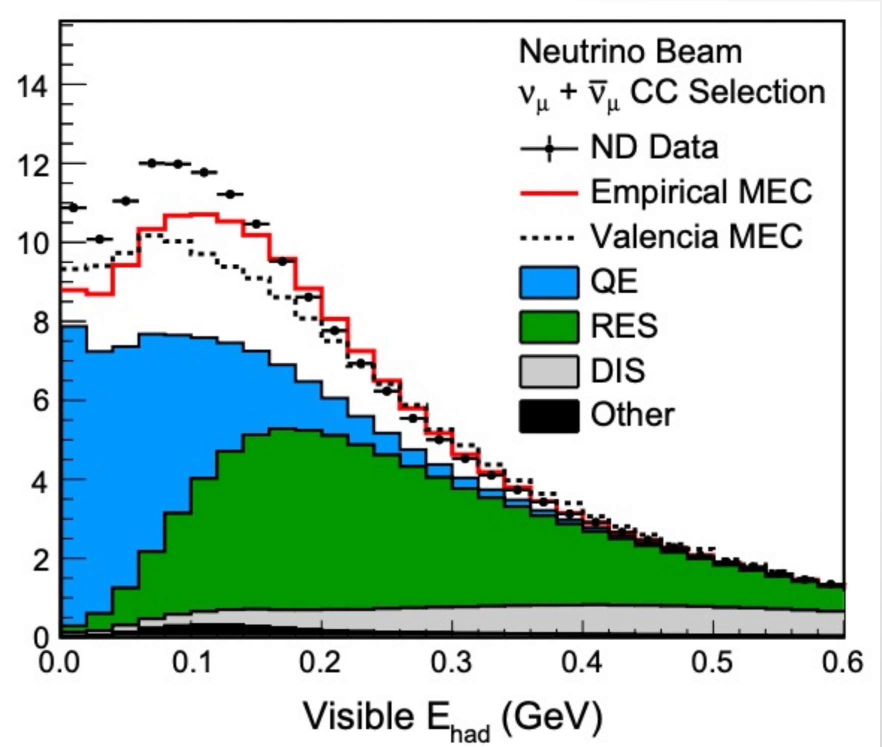
NOvA 2020
2006.08727

Step 4: Reweight

Weights



Data vs. Theory, Pre-Tune



NOvA Tuning Procedure

NOvA 2020
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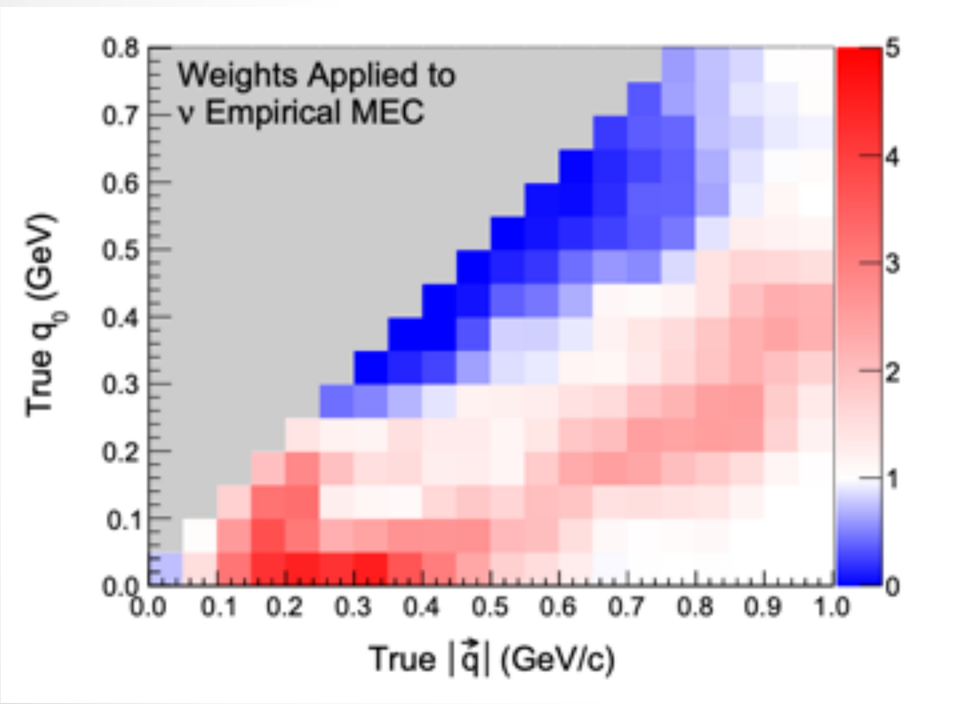
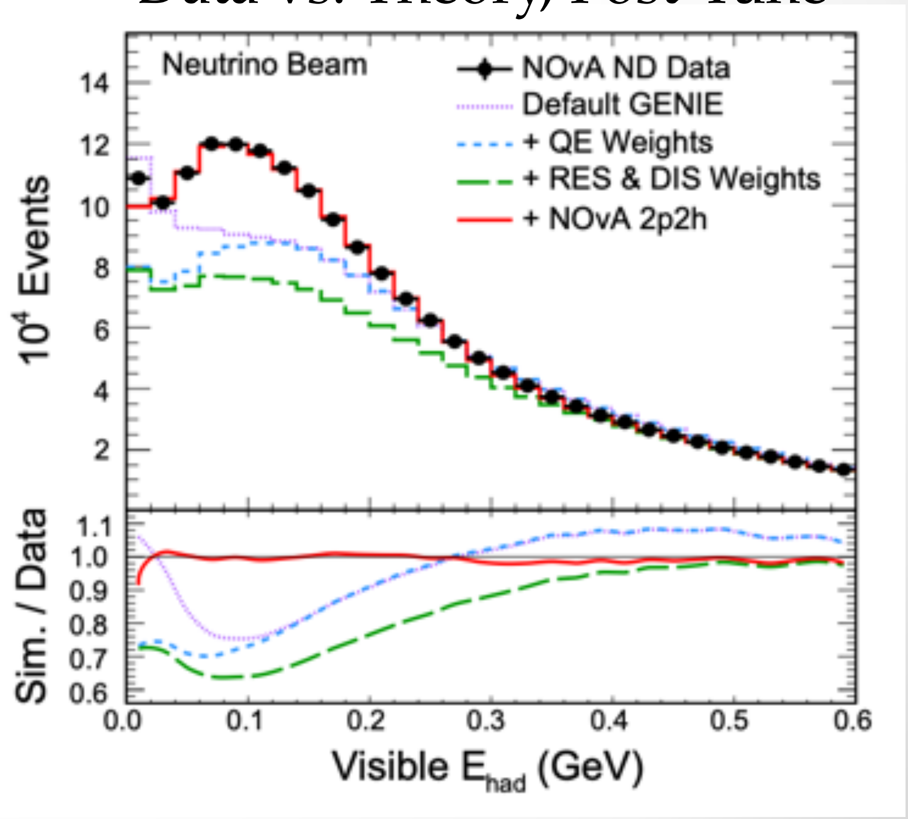
Step 4: Reweight

Weights

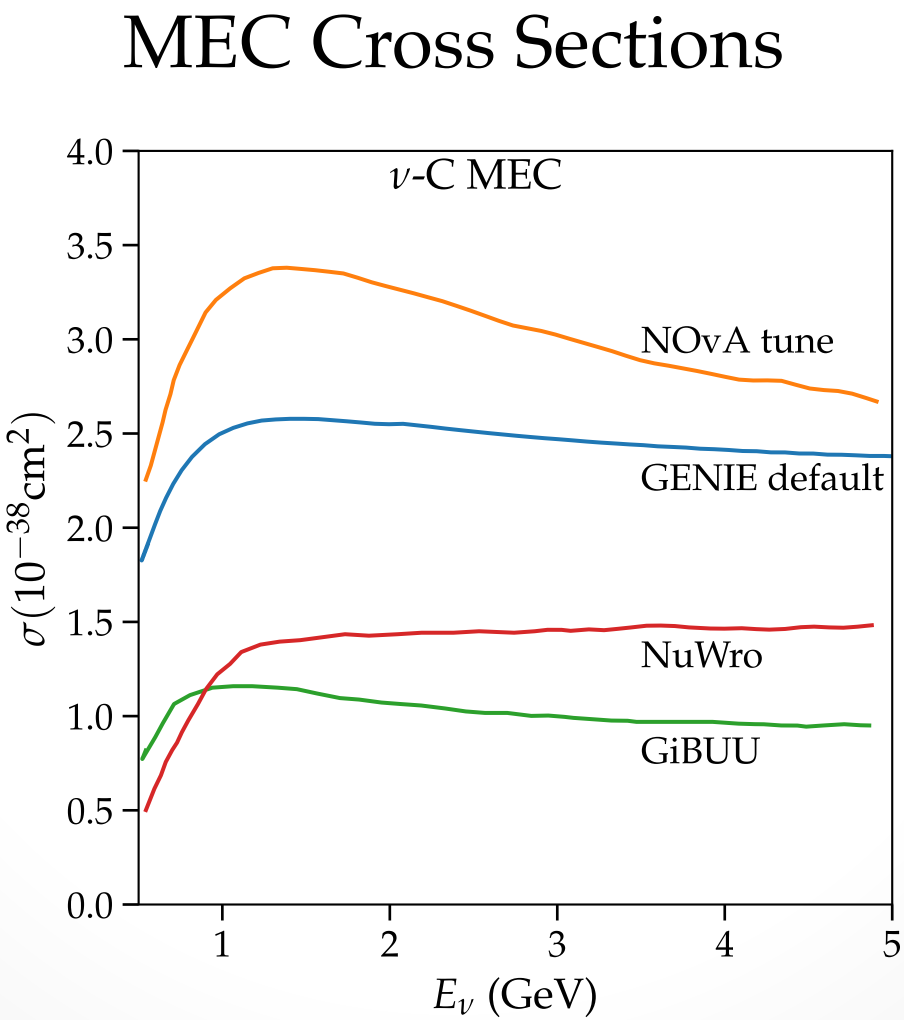


Data vs. Theory, Post-Tune



Big Changes to MEC

Isaacson, Li, Wagman, in prep



Tuning & BSM Searches

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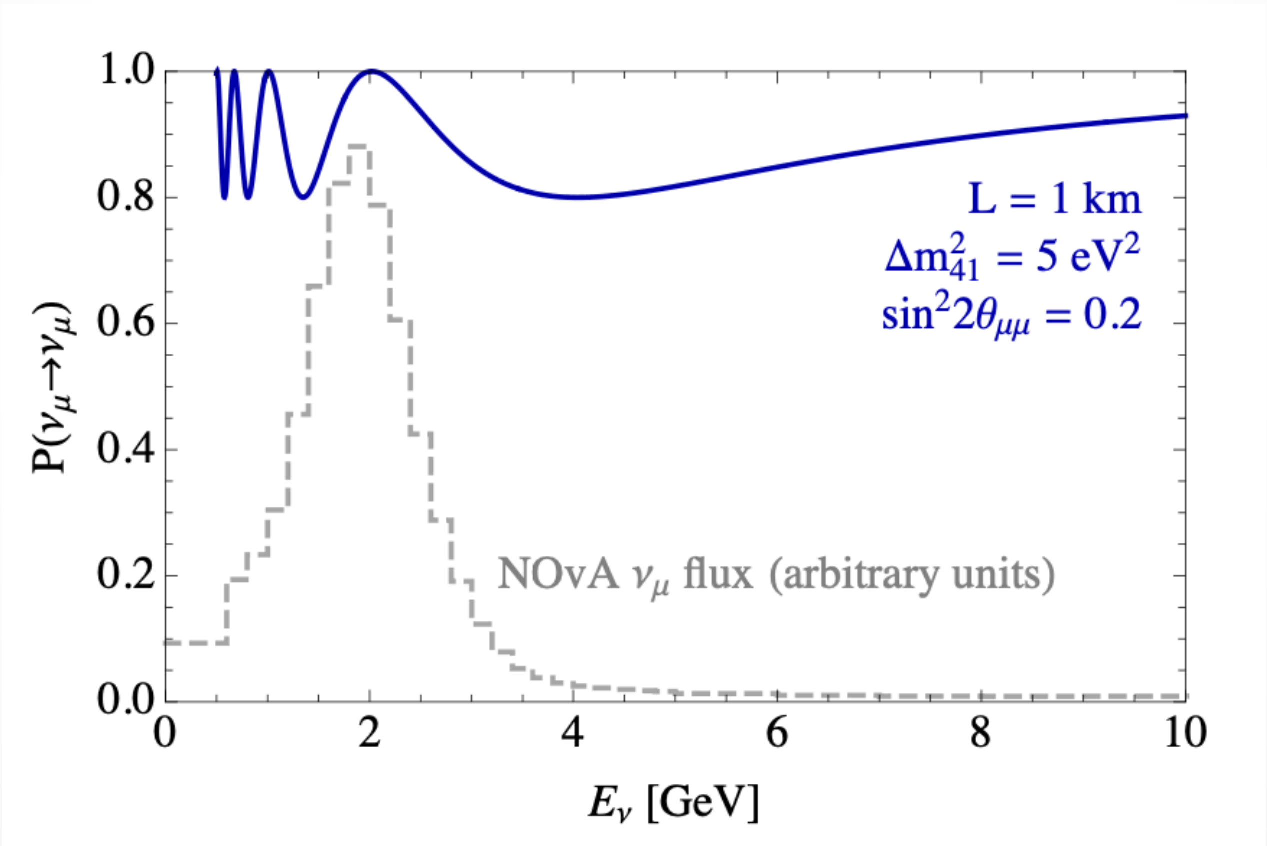
Looking for BSM

Coyle, Li,
Machado, in prep

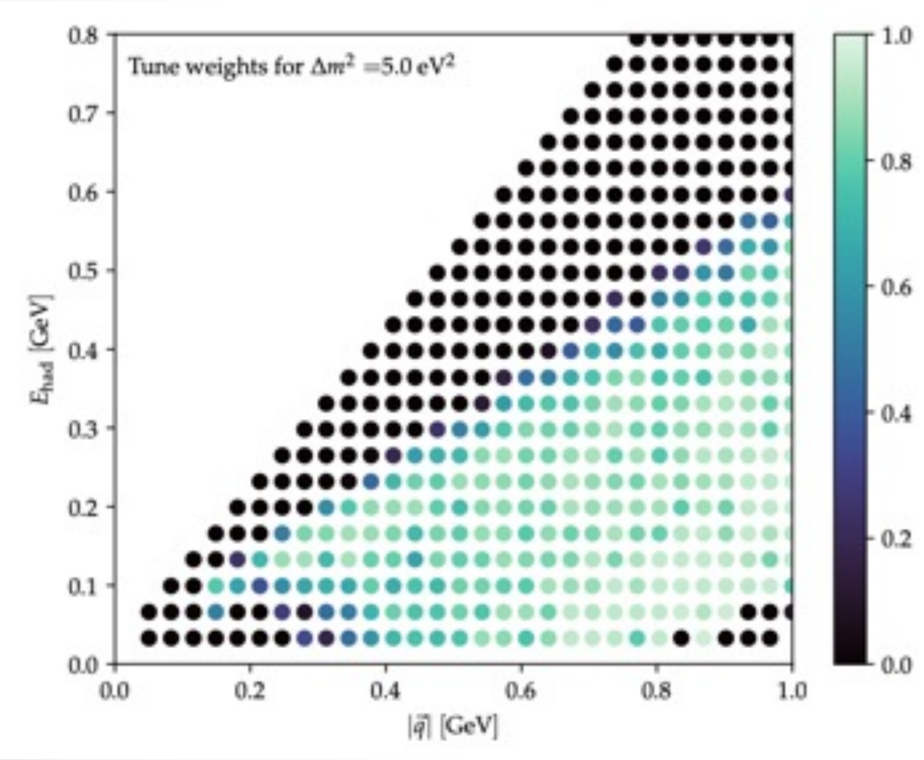
Case Study 1: Sterile Neutrino



Sterile Neutrino Tune

Coyle, Li,
Machado, in prep

Assuming Perfect Knowledge on SM Cross Sections



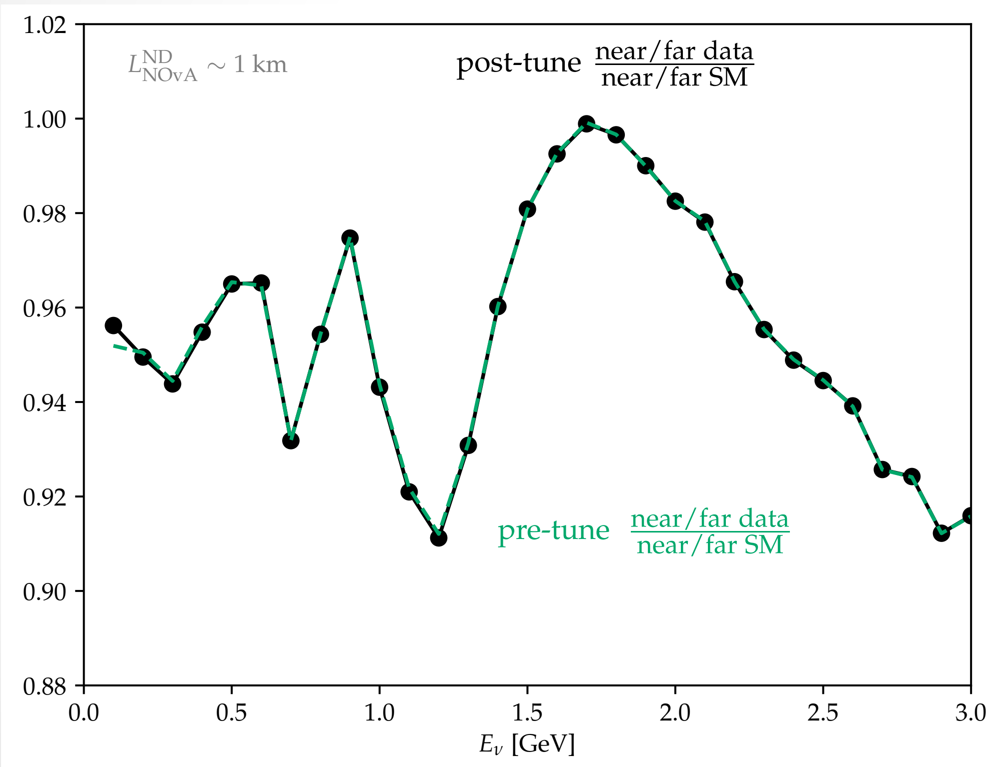
Using GiBUU for ν-C with MEC*2

Data vs. Theory Entirely Due to New Physics

Tuning MEC Component

Sterile Neutrino Post Tune

Coyle, Li,
Machado, in prep



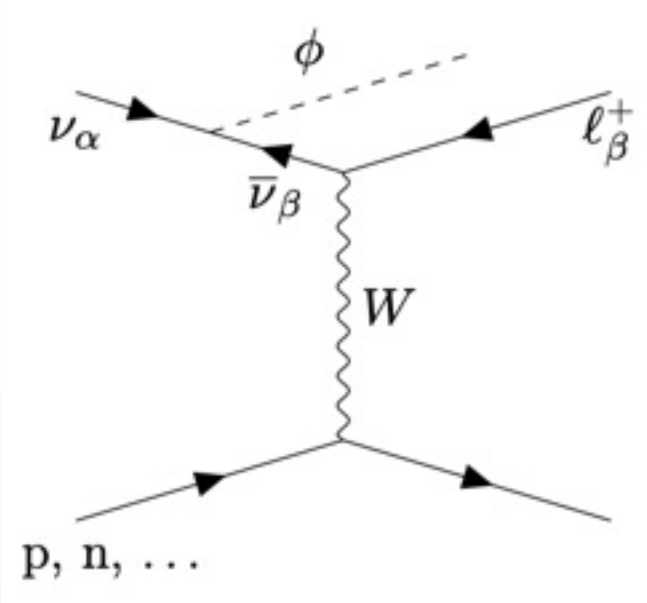
Signature:
Wiggles in Near/Far Ratios

Post Tune:
Slight Shift, Signature Persists

Looking for BSM

Coyle, Li,
Machado, in prep

Case Study 2: Neutrinophilic Scalar



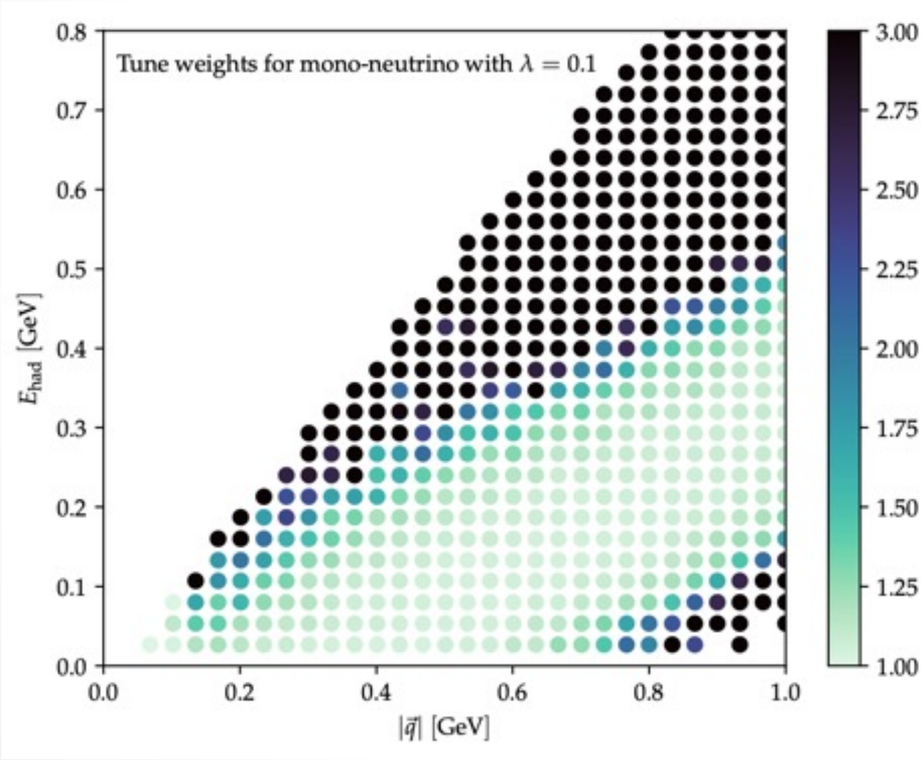
$$\mathcal{O} = \frac{(L_\alpha H)(L_\beta H)}{\Lambda^2_{\alpha\beta}}\phi \to \frac{1}{2}\lambda_{\alpha\beta}\nu_\alpha\nu_\beta\phi$$

Signature: Missing p_T

Missing pT Tune

Coyle, Li,
Machado, in prep

Assuming Perfect Knowledge on SM Cross Sections



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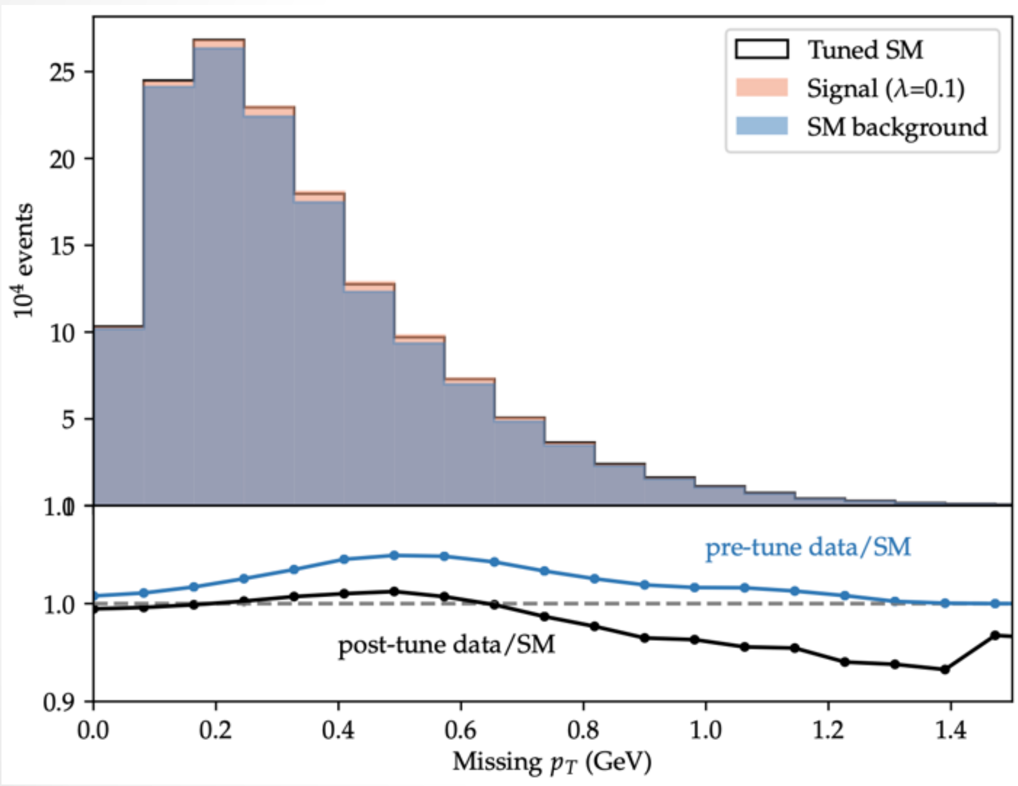
Missing pT Post Tune

Coyle, Li, Machado, in prep



Signature:
Large Missing p_T

Post Tune:
Signature Gone

Comments

- Assuming SM Modeling Is Perfect
- Investigating Robustness of Signals with Alternative Tuning Method
- Investigating Tuning Effects with Different Generators

Take Away

1) Experiments HAVE TO Tune

2) Tuning Introducing Many Degrees of Freedom

3) Some BSM Signatures Seem Robust Against Tuning, Some Are Not

4) Wish List:

Theoretical Guidance to Tuning

Phenomenological Studies of Tuning & BSM Searches

Thank you

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