Neutrino Cross Sections and New Physics Searches

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Fermilab

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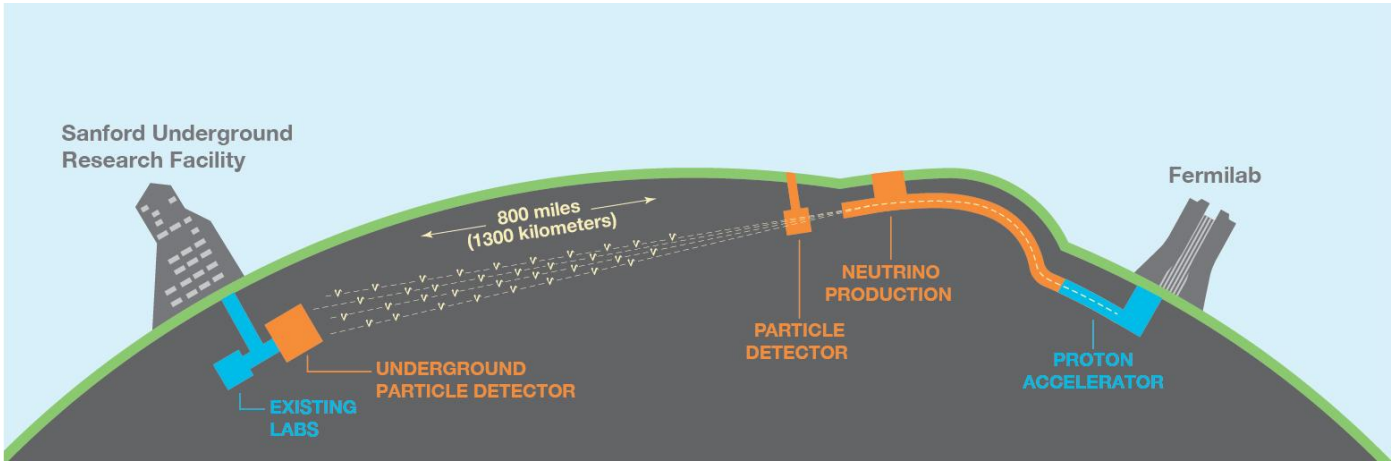
Overview

- Why do we need cross sections?
- Near detector tuning
- Tuning and new physics:
  - Sterile neutrinos
  - Missing energy

Why do we need cross sections?

- Accelerator neutrino experiments aim to measure oscillation probabilities using a near detector (ND) and a far detector (FD)



Why do we need cross sections?

- Accelerator neutrino experiments aim to measure oscillation probabilities:

$$\mathcal{P}_{\alpha\to\beta}(E_\nu, L) = \frac{f_\beta^{\mathrm{FD}}(E_\nu)}{f_\alpha^{\mathrm{ND}}(E_\nu)} = \frac{\frac{dN_\beta^{\mathrm{FD}}}{dE_\nu} \Big/ \sigma_\beta(E_\nu)}{\frac{dN_\alpha^{\mathrm{ND}}}{dE_\nu} \Big/ \sigma_\alpha(E_\nu)}$$

- But it's not so simple! We **can't measure true neutrino energy**, so more realistic is:

$$P_{\mathrm{exp}}(\nu_\alpha \to \nu_\beta, E_{\mathrm{rec}}, L) \simeq \frac{\int dE_\nu \frac{dN_\beta}{dE_\nu} D_\beta^{\mathrm{FD}}(E_\nu, E_{\mathrm{rec}}) \big/ \sigma_\beta(E_\nu)}{\int dE_\nu \frac{dN_\alpha}{dE_\nu} D_\alpha^{\mathrm{ND}}(E_\nu, E_{\mathrm{rec}}) F_\alpha^{\mathrm{FD/ND}}(E_\nu) \big/ \sigma_\alpha(E_\nu)}$$

So we need account for cross sections. How do experiments deal with this?

- Adjust the generator based on data!

Simulate ND using generator

Tune generator to match actual ND data

Use tuned generator in FD analysis

Near detector tuning: NOvA

- Adjust the generator cross sections to **match observed ND spectrum** in visible hadronic energy

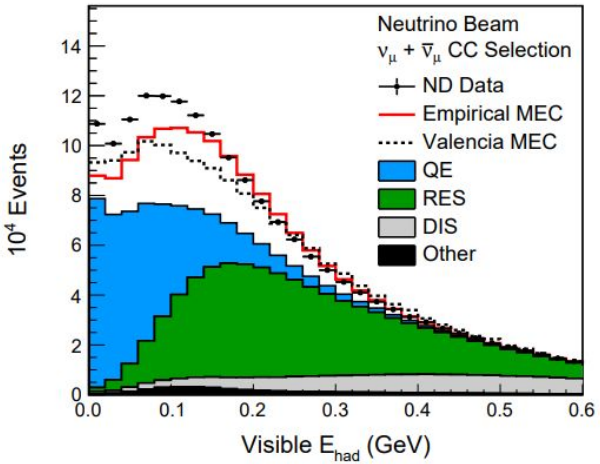
- Start by implementing some changes to the base GENIE based on other experimental results

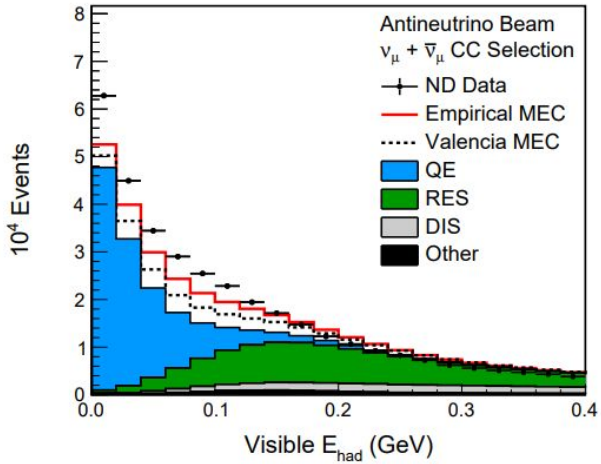
  - Adjust CCQE M_A input value
  - Adjust nuclear model weights using MINERvA data
  - Reduction to non-resonant single pion production

NOvA collaboration, arXiv:2006.08727

Near detector tuning: NOvA

How to account for remaining discrepancy? Adjust the MEC contribution to match **NOvA ND data**





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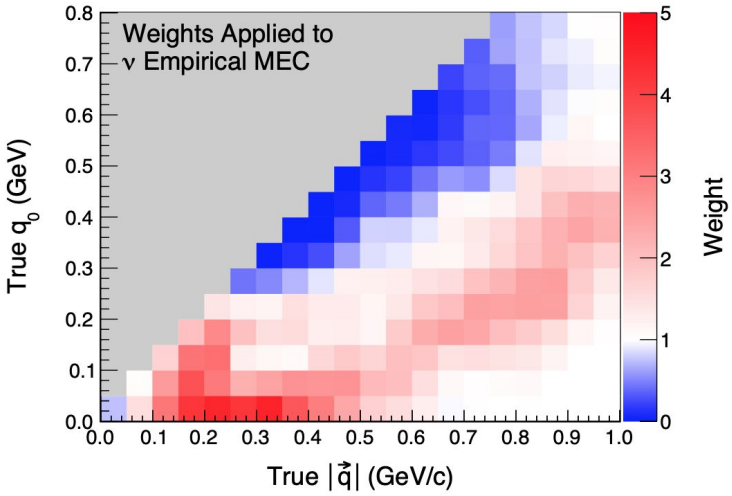

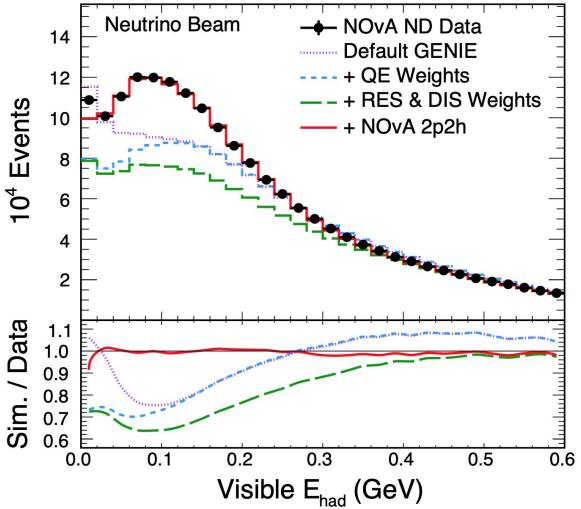

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How does this affect new physics searches?

- Near detectors have much higher flux than far detectors: a good place to search for new physics!

- Light (eV-scale) sterile neutrinos
- Neutrinophilic scalars
- Trident production
- Light dark matter

Do signatures of or searches for new physics survive the tuning procedure?

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Do signatures of or searches for new physics survive the tuning procedure?

Process

- Generate SM prediction using a neutrino generator (GENIE or NuWro)

- Inject new physics signature into the ND simulation

- Perform NOvA MEC tune

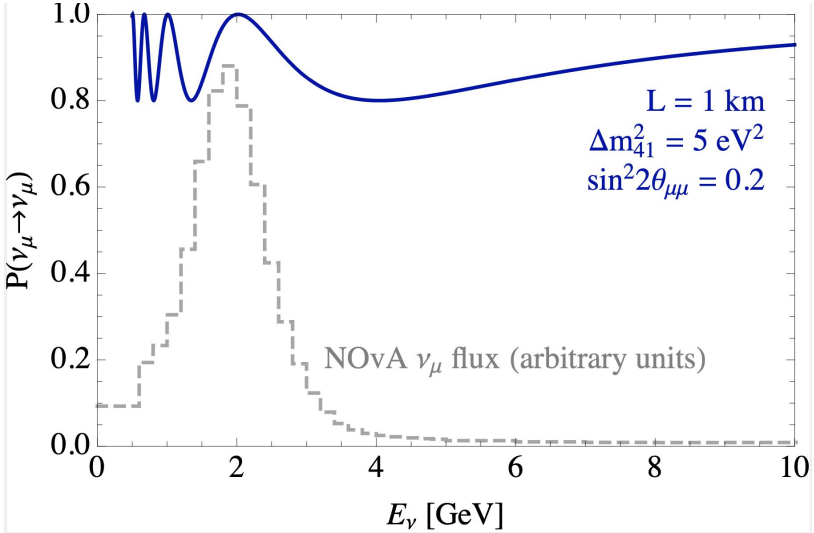
- Examine new physics signature before and after tune

Sterile neutrino signal

- Anomalies point to a potential eV-scale sterile neutrino, although there are some tensions

$$P(\nu_\mu \to \nu_\mu) \simeq 1 - \sin^2 2\theta_{\mu\mu} \sin^2 \left(\frac{\Delta m^2_{41} L}{4E_\nu} \right)$$

- Induce oscillations around L (km) /E (GeV) ~ 1



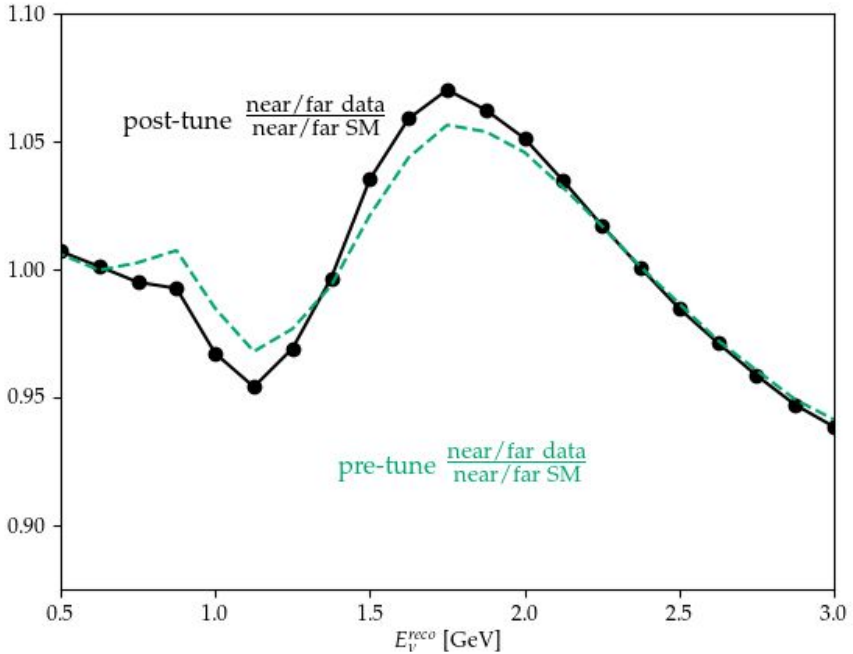
Sterile neutrino signal

- ”Smoking gun” signature: oscillations in ND/FD

- To start: assume only discrepancy between model and data is new physics

- Strength of signal gets modified, but shape remains

- We are not directly tuning to neutrino energy, so we can’t tune away the oscillations!



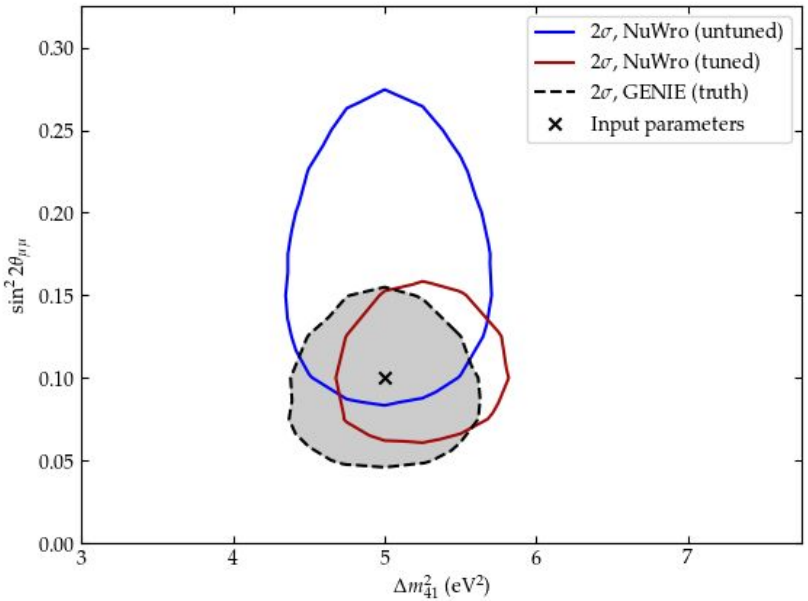
N.C., Li, Machado, in preparation

Sterile neutrino signal: direct fit

- Two different generators: GENIE for data, NuWro for simulated model

- Direct fit to FD and ND rates

- Simultaneous fit and tune



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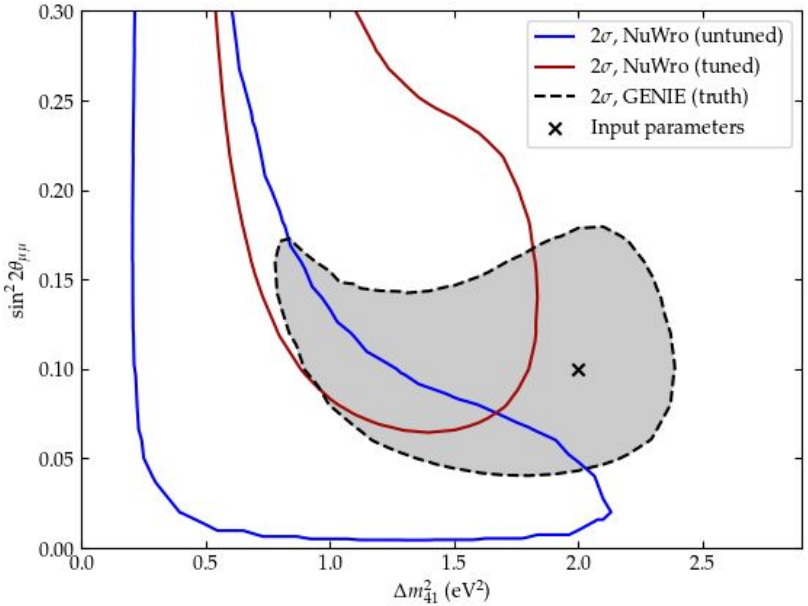
Sterile neutrino signal: direct fit



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Mono-neutrino signal

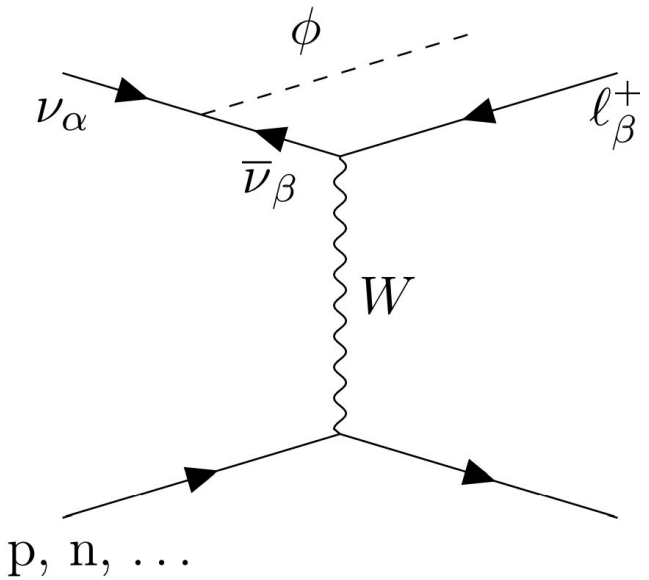
- Neutrinophilic dark matter

- Neutral scalar, showing up as missing pT

- Sub-percent-level fraction of events: requires cuts to see the signal

- Antineutrino beam: cut on 1 proton, 0 pion, with no visible neutrons

- How do cuts affect the tune's impact?



Mono-neutrino signal

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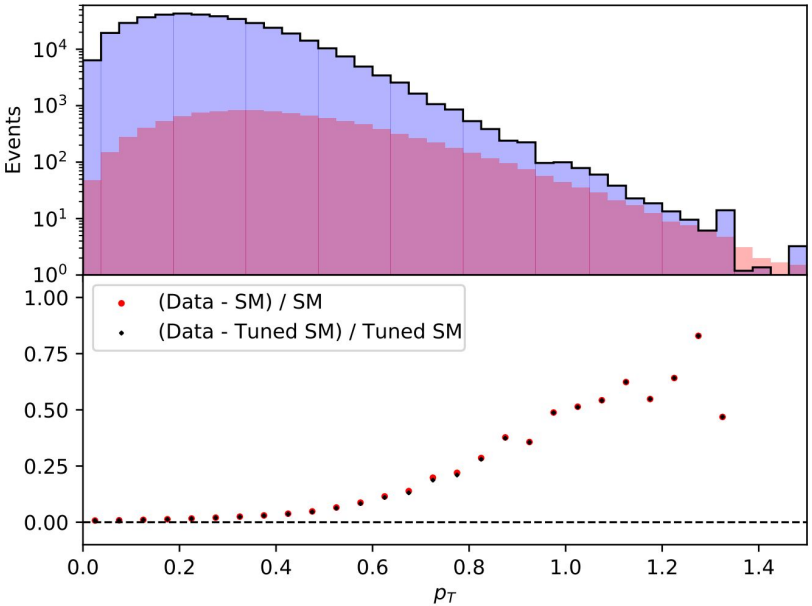
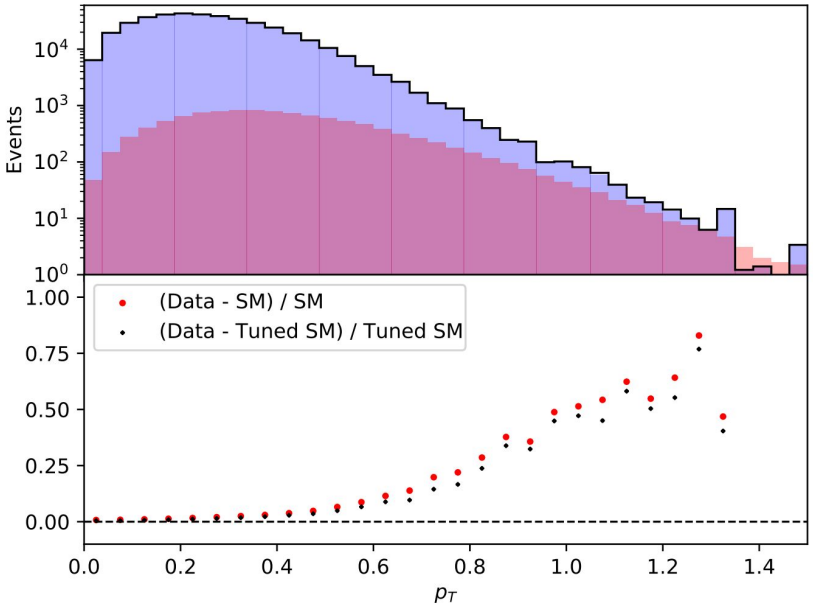
Tune pre-cut



Tune post-cut



Mono-neutrino signal

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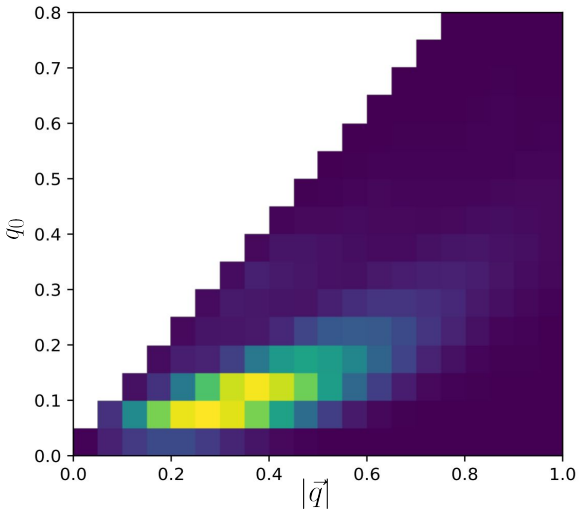
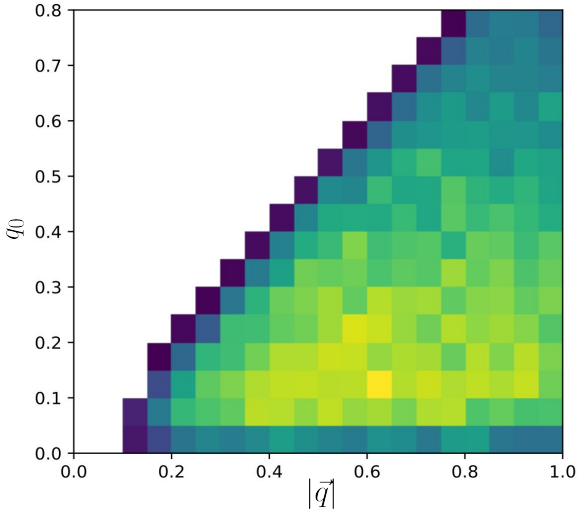
- Important feature: event distribution in the tune plane

Cut SM (QE-like)



Mono-neutrino events



Mono-neutrino signal

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- Still to come: analysis with two different generators

- Cuts can enhance the difference between generators: can tuning account for the difference in generators when cuts are applied?

- Can tuning account for the difference in generators without washing out the signal?

Conclusions

- Cross sections are an important part of neutrino accelerator experiments

- Tuning plays a role in how we interpret observed spectra–we need to understand what impacts it may have

- Impact of cross section uncertainties on BSM searches should be properly estimated

Thank you!