Fermilab

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Joint Group Between Theorists and Experimentalists

Minerba and Andreas, Fermilab

27 September 2017

- A quick reminder about the neutrino program at Fermilab
- Needs for the neutrino community

Neutrino Oscillation Program at Fermilab

Long-BaseLine Neutrino Oscillation Program

CP violation?
Mass hierarchy?

Present 2024

MINOS+ NOvA DUNE

Cross Section Experiment

Present 2018

MINERvA

Short-BaseLine Neutrino Oscillation Program

Sterile Neutrinos?

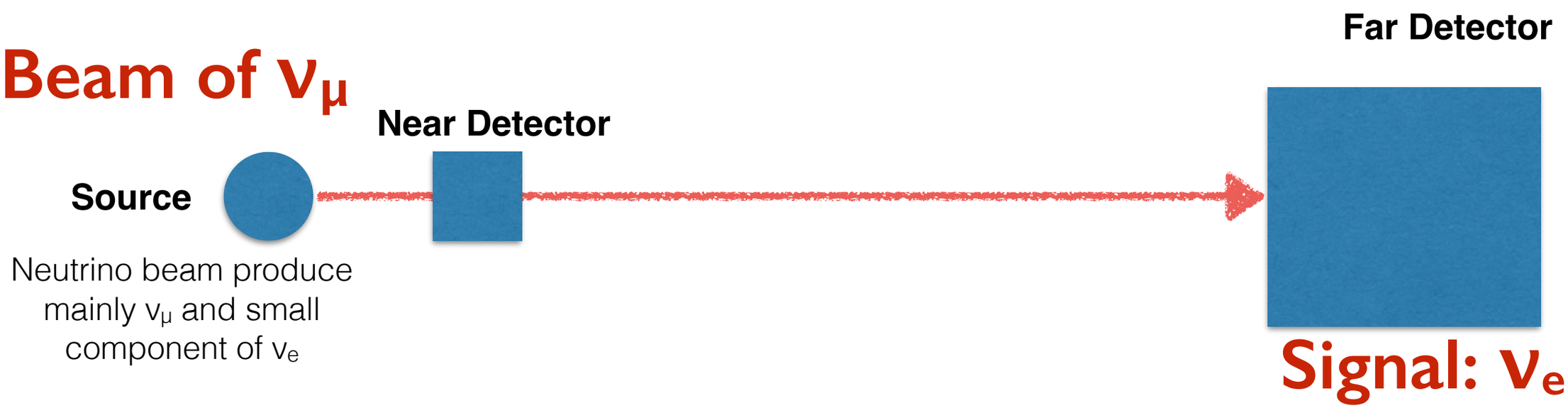
Present 2018 2019

MiniBooNE MicroBooNE ICARUS SBND

Fermilab

Addressing the Remaining Questions

- Is there CP violation in the lepton sector $P[\nu_\mu \to \nu_e] \neq P[\overline{\nu}_\mu \to \overline{\nu}_e]$?
- What is the mass hierarchy? (sign of Δm^2_{32})



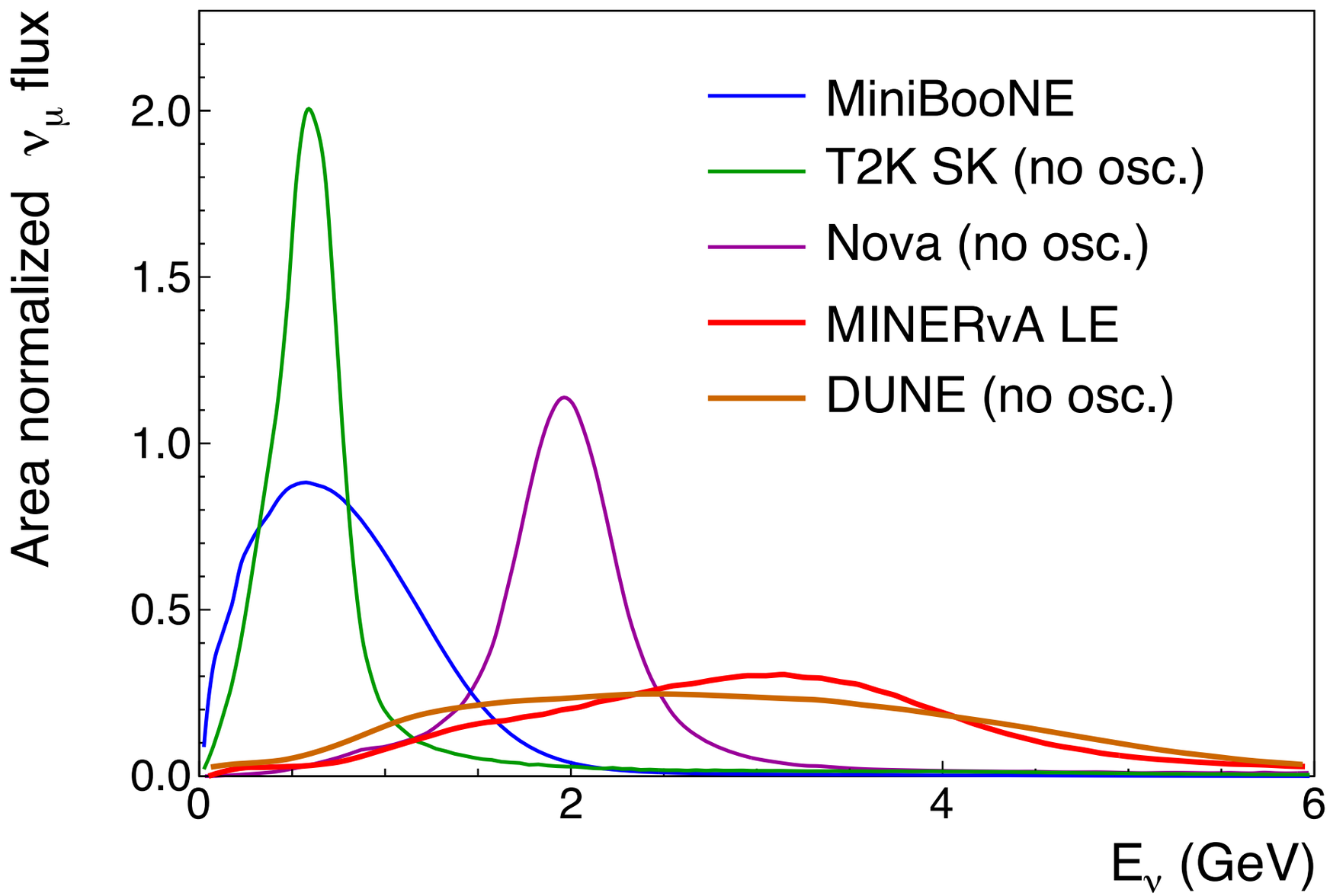
$\phi \times \sigma \times$ **Nuclear Effects**

$\phi' \times \sigma \times$ **Nuclear Effects** $\times P_{\nu_\mu \to \nu_e}$

Nuclear model

- Use simulations to extrapolate from near detector to far detector $\sigma_{\nu\mu} \longrightarrow \sigma_{\nu e}$
- Need a nuclear model to convert from produced to detected energy spectra and topologies in the near and the far detectors
- Need to quantify uncertainty from nuclear models and propagate the uncertainty to oscillation parameters

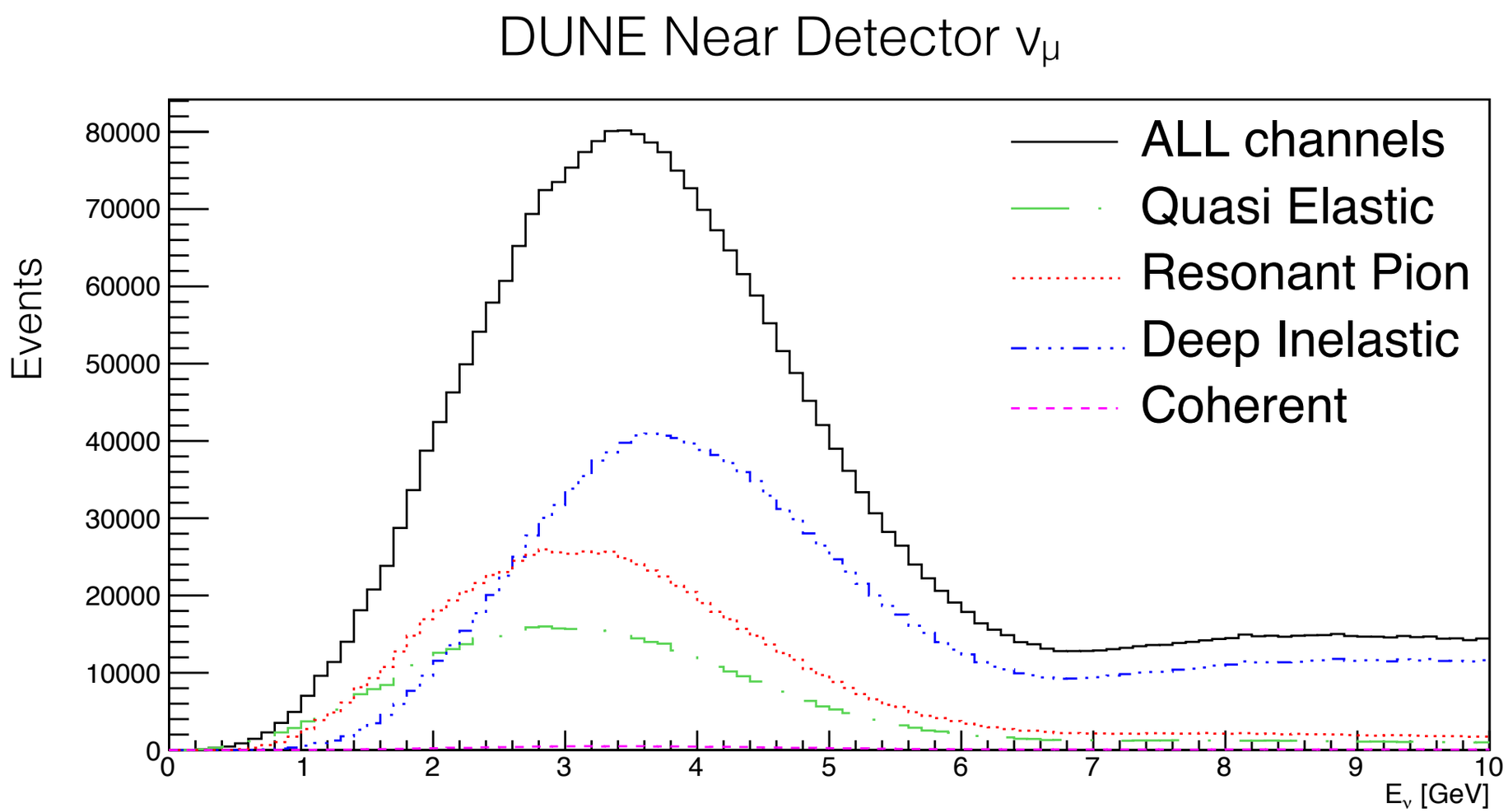
Neutrino Energies for Different Experiments



Plot courtesy of Phil Rodrigues

Muon Neutrino at the Near Detector

GENIE predictions for argon

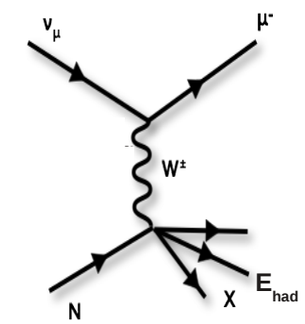


- Use simulations to extrapolate from near detector to far detector $\sigma_{\nu\mu} \rightarrow \sigma_{\nu e}$
- Lean on lepton universality to work out $\sigma_{\nu e}$ from $\sigma_{\nu\mu}$

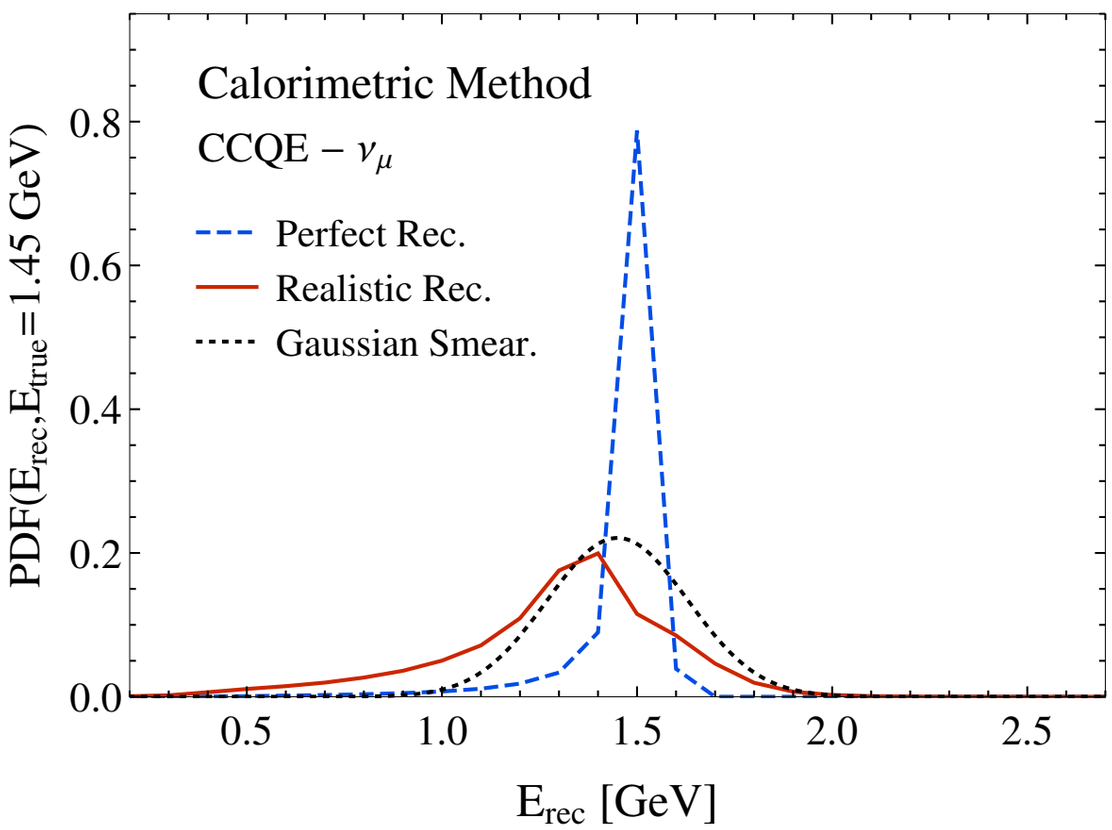
Neutrino Energy

- Oscillation probability depends on neutrino energy E_ν

$$P(\nu_\alpha \to \nu_\beta) \approx 1 - \sin^2 2\theta \sin^2\left(\frac{\Delta m^2 L}{E_\nu}\right)$$



- We need to reconstruct the neutrino energy precisely
- A nice example: Probability distribution functions for an event of energy E_{true}=1.45 GeV to be reconstructed at an energy E_{reco}



A. M. Ankowski, O. Benhar, **P. Coloma**, P. Huber, C.-M. Jen, C. Mariani, D. Meloni, and E. Vagnoni Phys. Rev. D 92, 073014

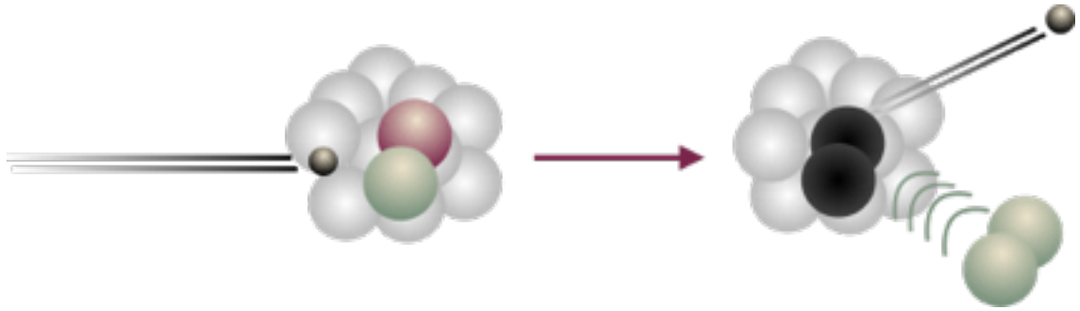
Distributions are asymmetric due to pion absorption in the nuclear medium and the energy carried out by neutron

Perfect Rec.: All produced particles are observed, except the neutron
Realistic Rec.: detector efficiencies and thresholds are taken into account

Monte Carlo Event Generator (GENIE)

GENIE

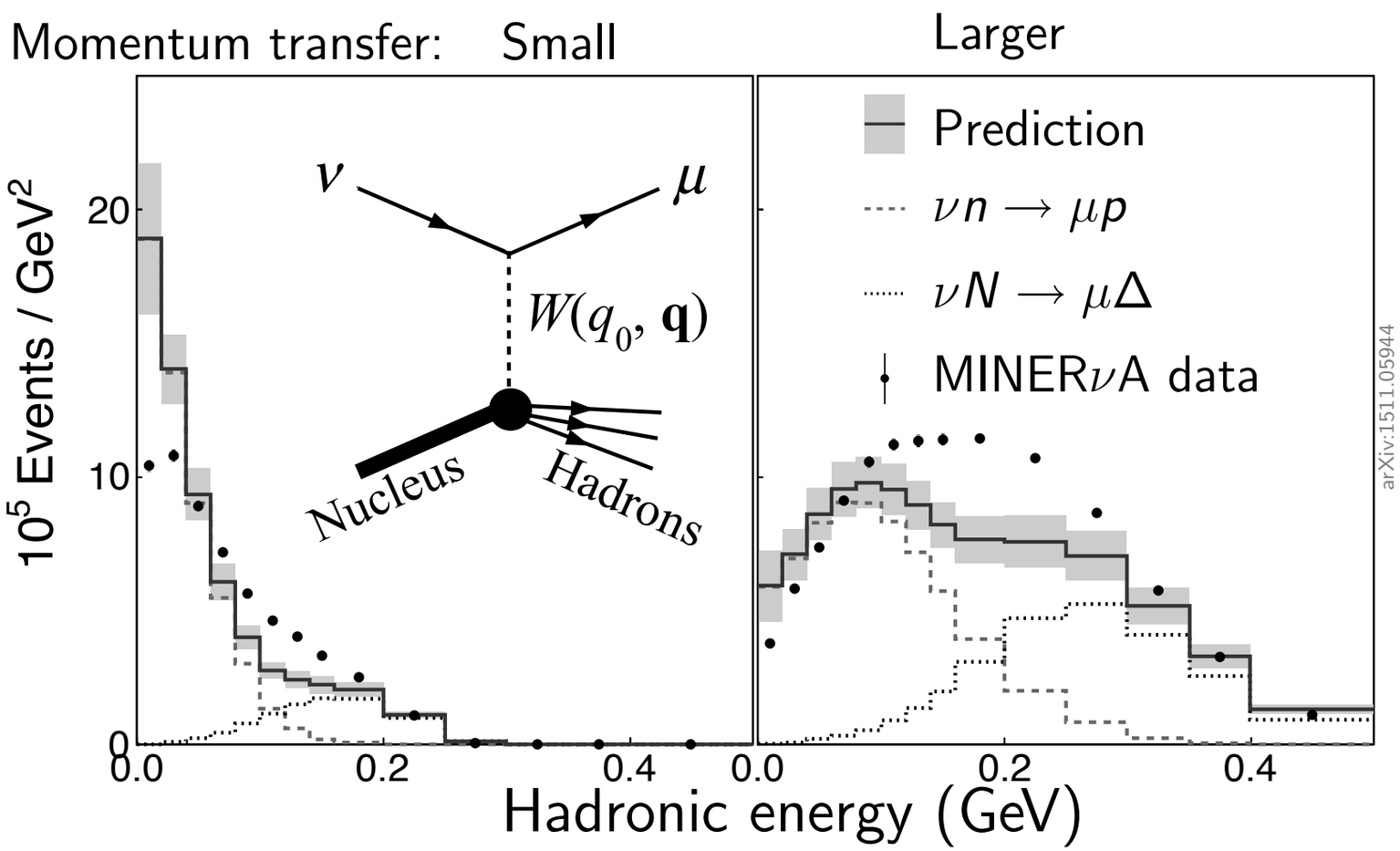
- GENIE is the default Monte Carlo used by all the neutrino experiments at Fermilab
- GENIE has made considerable progress in modeling neutrino interactions lately. Specially for CCQE
  - Inclusion of multi nucleon emission channel (np-nn), J. Nieves, I. Ruiz Simo, and M. J. Vicente Vacas, PRC 83, 045501 (2011)



  - Simulation uses the old dipole axial form factor assumption and axial mass M_A=0.99 GeV
    - We still need to update to the latest model independent axial form factor "z-Expansion" tuned with deuterium data, Aaron M., Richard H., MB, Richard G, Phys. Rev. D93 (2016), 113015
- GENIE has a default model and many alternative models
  - Need flexibility and extensibility to future models
- CCQE is not the dominant channel in DUNE, we need more extensive modeling to treat resonance, deep inelastic interactions and coherent interactions

Nuclear Models and Data

- Recent experimental data is not well described by current nuclear models
- For example, recent data from MINERvA compared with simulations



To reconstruct the energy
$E_\nu = E_{lepton} + hadron$

Phys. Rev. Lett. 116 (2016) 071802

- It is crucial to have a reliable nuclear model in the Monte Carlo generator to take detector quantities back through the nucleus to produced quantities

Cross Section is one of the largest systematics

PRL **116,** 181801 (2016) PHYSICAL REVIEW LETTERS week ending 6 MAY 2016

Measurement of Muon Antineutrino Oscillations with an Accelerator-Produced Off-Axis Beam

Cross section is one of the largest systematic uncertainties for oscillation experiments like T2K as an example

TABLE IV. Percentage change in the number of one-ring μ-like events before the oscillation fit from 1σ systematic parameter variations, assuming the oscillation parameters listed in Table III and that the antineutrino and neutrino oscillation parameters are identical.

Source of uncertainty (number of parameters)	$\delta n_{\mathrm{SK}}^{\mathrm{exp}}/n_{\mathrm{SK}}^{\mathrm{exp}}(\%)$
ND280-unconstrained cross section (6)	10.0
Flux and ND280-constrained cross section (31)	3.4
Super-Kamiokande detector systematics (6)	3.8
Pion FSI and reinteractions (6)	2.1
Total (49)	11.6

T2K's uncertainties, from PRL 116, 181801 (2016)

A new Joint Group Between theorists and experimentalists

What we have

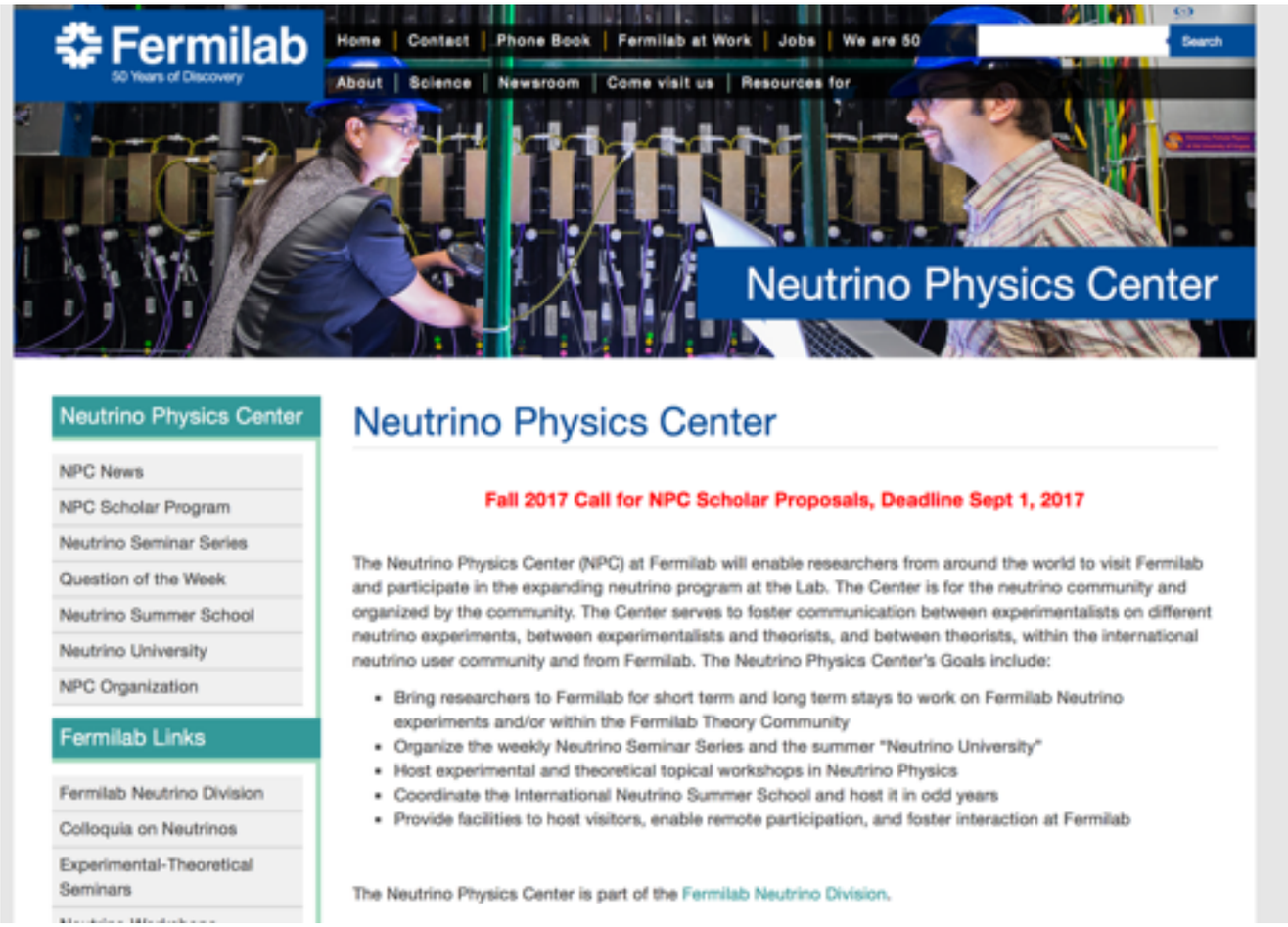
- Rich neutrino program at Fermilab
- Remaining questions of neutrino oscillation
- Neutrino phenomenology
- HEP theory
- Experimentalists
- Software expertise (collider, lattice, ν)

What we need

- Communication between theorists and experimentalists
- Accurate models
- New models to be developed and incorporated in the simulations
- Detailed understanding of each of the component of theory

Group Under the Neutrino Physics Center

- The group will be part of the Neutrino Physics Center
- We will encourage collaborators to apply the NPC Fellows to get support for visits



- We will create a new link with details about the coming meetings

Team

- Fermilab staff, fellows, and distinguished scholars
- Different groups are interested in joining this effort
  - Gil Paz from Wayne State University
  - Saori Pastore (New Intensity Frontier Fellow) and Joe Carlson from Los Alamos
  - Huma Haider (New Intensity Frontier Fellow) from Aligarh Muslim University
- Others as the work developers

Fermilab

Los Alamos NATIONAL LABORATORY EST. 1943

WAYNE STATE EST. 1868

University at Buffalo The State University of New York

University of Kentucky

Next

- Meet once a month to discuss progress and new ideas
- Next meeting will be in October, we would like to hear on the theory-generator interface from collider physics
- Doreen mentioned a follow up workshop for the radiative corrections at the intensity Frontier, we will be happy to coordinate a workshop