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
- Present
- 2024
- MINOS+
- NOvA
- DUNE
- CP violation?
- Mass hierarchy?
- 2019

Cross Section Experiment
- Present
- 2018
- MINERvA

Short-BaseLine Neutrino Oscillation Program
- Present
- 2018
- 2019
- MiniBooNE
- MicroBooNE
- ICARUS
- SBND
- Sterile Neutrinos?
Addressing the Remaining Questions

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

Beam of $\nu_\mu$

Source \hspace{1cm} Near Detector \hspace{1cm} Far Detector

- Neutrino beam produce mainly $\nu_\mu$ and small component of $\nu_e$

$\phi \times \sigma \times \text{Nuclear Effects}$

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

- Use simulations to extrapolate from near detector to far detector $\sigma_{\nu_\mu \to \nu_e}$
- 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

Long-baseline experiments: What can we learn?

- Precision measurements of mixing parameters
- Neutinos mass hierarchy?
- CP Violaton?
- Neutino vs Ant-neutino oscilatons

Nova (Ash river)\hspace{1cm} MINOS (+) (Soudan)\hspace{1cm} DUNE (Home Stake)\hspace{1cm} Fermilab Long-baseline experiments also, T2K in Asia
Neutrino Energies for Different Experiments

Plot courtesy of Phil Rodrigues
Muon Neutrino at the Near Detector

- 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 $\sigma_{\nu\mu}$

**GENIE predictions for argon**
Neutrino Energy

- Oscillation probability depends on neutrino energy $E_\nu$
  \[ P(\nu_\alpha \to \nu_\beta) \approx 1 - \sin^2 2\theta \sin^2 \left( \frac{\Delta m^2 L}{E_\nu} \right) \]

- 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 $E_{reco}$

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

A. M. Ankowski, O. Benhar, P. Coloma, P. Huber, C.-M. Jen, C. Mariani, D. Meloni, and E. Vagnoni Phys. Rev. D 92, 073014
Monte Carlo Event Generator (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
  - Simulation uses the old dipole axial form factor assumption and axial mass $M_A=0.99$ GeV.
- 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**

\[ E_\nu = E_{\text{lepton}} + \text{hadron} \]

- 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

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

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, $\nu$)

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
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