# NuSTEC (Neutrino Scattering Theory Experiment Collaboration)

# Goals and Strategy

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Fermilab
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# What is NuSTEC?

- NuSTEC promotes the collaboration and coordinates efforts between:
  - Theorists (mainly NP) – studying neutrino nucleon/nucleus interactions.
  - Experimentalists – primarily those actively engaged in neutrino nucleus scattering experiments as well as those trying to understand oscillation experiment systematics. e-A experimentalists are certainly welcome.
  - Generator builders – actively developing/modifying the model of the nucleus as well as the behavior of particles in/out of the nucleus within generators
- The main goal is to improve our understanding of neutrino interactions with nucleons and nuclei and, practically, get that understanding in our event generators.
  - The impact of our main goal will be widespread in both hadron and nuclear physics and directly effect oscillation physics.
- Along the way we want to expand support for theorists and encourage a growing theoretical community.

# NuSTEC Board Meeting

## October, 2015

We had a meeting of the NuSTEC Board when we discussed the following issues:

- NuSTEC Board
- NuSTEC By-laws – approved and in force
- NuSTEC Workshops
- NuSTEC Training/Schools
- NuSTEC and Generators
- NuSTEC Communications – Fermilab web page, newsletter
- NuSTEC and Funding Agencies
- NuSTEC Projects
- NuSTEC Publications

# The NuSTEC Board

Ready to expand with theorists willing to work on NuSTEC projects and schools!

## Theorists (9)

- Luis Alvarez Ruso (co-spokesperson)
- Sajjad Athar
- Maria Barbaro
- Omar Benhar
- Natalie Jachowicz
- Marco Martini
- Toru Sato
- Rocco Schiavilla
- Jan Sobczyk (nuWRO)

## Experimentalists (16)

- Steve Brice
- Dan Cherdack
- Steve Dytman (GENIE)
- Rik Gran
- Yoshinari Hayato (NEUT)
- Teppei Katori
- Kendall Mahn
- Camillo Mariani
- Mark Messier
- Jorge G. Morfín (co-spokesperson)
- Ornella Palamara
- Roberto Petti
- Gabe Perdue (GENIE)
- Makoto Sakuda
- Federico Sanchez
- Sam Zeller

# NuSTEC Workshops

- We promote the exchange of information within our community
- **Workshops**: We coordinate and organize community-wide workshops.
  - NuInt – next one in Toronto, CA in June 2017!
    - » organized every18 months.
    - » Comparison of experimental results and nuclear models via event generators
    - » Highlight open problems
  - Topic-specific
    - » to be held in between NuInts
    - » Workshop on Global Fits to Neutrino Scattering Data and Generator Tuning (NuTune2016), July in Liverpool
    - » NuSTEC coordinates multiple workshops to avoid date collisions and unwanted duplication

# NuSTEC Training Programs

- NUSTEC organizes and runs generator and neutrino scattering physics schools/trainings

- **Training**:
  - Long (10-day) schools – one so far, next one to be at Fermilab in 2017.
    - » Every 3 years
    - » Broad, mainly theory with experiment highlights
    - » NuSTEC Training in Neutrino Nucleus Scattering Physics, October 2014, Fermilab with **85** participants.
  - Short (≤ week) schools – two so far
    - » More specific or practical or generator-oriented
    - » Correlated in time and space with NuInt
    - » The Liverpool NuSTEC Nu Generator School associated with NuInt14
    - » NuSTEC School in Okayama, Japan 8-14 November associated with NuInt15.

# Nustec Training in Neutrino Nucleus Scattering Physics – Fermilab, October 2014

- **Electroweak interactions on the nucleon** — **3 hours**
- **Strong and electroweak interactions in nuclei** — **4 hours**
- **The nuclear physics of electron and neutrino scattering in nuclei in the quasielastic regime and beyond** — **9 hours**
- **Pion production** — **3 hours**
- **Exclusive channels and final state interactions** — **3 hours**
- **Inclusive e and ν scattering in the DIS regime** — **3 hours**
- **Impact of neutrino cross section uncertainties on oscillation analyses** — **3 hours**
- **Selected experimental illustrations** — **4 hours**

- **85 registered (paying) participants + ≈ 15-20 sitting in on the courses**
- **Financial support from DOE, NSF, Fermilab, Jlab, CERN, VaTech**
- **WE WILL REPEAT THIS LONG SCHOOL IN OCT/NOV 2017**

# Shorter NuSTEC Schools

- Thus far, two shorter schools.
- Generator-oriented program at Univ. Liverpool in 2014:
  - Series of lectures covering a broad range of neutrino interaction phenomenology topics focusing on the connections between theory, experiment and MC simulations.
  - The Training will also offer extensive hands-on tutorials of the GENIE and NuWro MC
  - 10 hours of theory lectures, 11 hours of hands-on tutorials
- NuSTEC-15 at Okayama in 2015
  - Series of lectures covering a broad range of neutrino interaction phenomenology topics focusing on the connections between theory, experiment and MC simulations
  - 19 hours of theory lectures + 10 hours of tutorials

# NuSTEC15 – Okayama University - Lectures

- Neutrino Physics and Neutrino Interactions (L. Alvarez-Ruso, IFIC, Spain)
- Basics of Nuclear Theory (potential ,current, symmetry) (A. Lovato, ANL)
- Neutrino Oscillation Experiments (T.Katori, Queen Mary University of London)
- Neutrino-Nucleus Scattering from Elastic to Quasi-Elastic Region (M.Sakuda)
- Quasi-Elastic Scattering in Nuclei (S. K. Singh, AMU, India)
- Pion production from nucleons and nuclei , strange particle production, Deep Inelastic Scattering (M.Sajjad Athar, AMU, India)
- Monte Carlo Event Generator (T.Golan, Rochester/Fermilab)
- Electron and Neutrino-nucleus initiałfinal state interactions (A. Ankowski, VTech)
- Water Cherenkov Detector and Neutrino Physics (Y. Koshio, Okayama)
- Liquid Argon Detector and Neutrino Interactions (F. Cavanna, FNAL)
- Liquid Scintillator Detector and KamLAND Latest Result （J.Shirai, Tohoku）
- Reactor Experiment RENO and RENO-50 (S.B.Kim, Seoul National University)
- MINERVA and the Role of the Nucleus in nu-A Interactions (J. Morfin, Fermilab)

# NuSTEC Project – The White Paper / Review

- We address open problems, mainly identified at workshops, by promoting collaboration between theorists and experimentalists
- **There were multiple ideas discussed at the last NuInt15 (Osaka) that would easily become NuSTEC projects.**
- **An important project will be global fits of data to nuclear models**
- **Need to carefully coordinate NuSTEC and Generator-specific projects toward the goal of increasing community and funding agency support for generator work.**
- **Next major NuSTEC project would be the NuSTEC white paper to ultimately be turned into a review paper.**

# Proposed NuSTEC White Paper / Review
## Outline

### Overview Sections of the paper

- **Executive Summary and Bring it Together-** Kendall Mahn, Gabe Perdue, Luis Alvarez Ruso, Jorge Morfin,

- **Overview of the Current Challenges in the Theory of Neutrino Nucleon/Nucleus Interaction Physics** Luis Alvarez Ruso, Maria Barbaro, Natalie Jachowicz, Marco Martini, Toru Sato, Rocco Schiavilla, Jan Sobczyk, (experimentalist)
  1. Initial Interaction Dynamics
  2. Final State Interaction Models

# Proposed NuSTEC White Paper / Review

- **The Impact of Neutrino Nucleus Interaction Physics on Oscillation Physics Analyses** - Dan Cherdack, Kendall Mahn, + …
  - 1. How the cross section model couples to oscillation parameters
  - 2. Description and current systematics of T2K, NOvA
  - 3. Description and projected systematics of SBN / MicroBooNE
  - 4. Description and projected requirements of DUNE, HK

- **Neutrino Event Generators** - Steve Dytman, Yoshinari Hayato, Gabe Perdue, Jan Sobczyk
  - GENIE
  - NuWro
  - NEUT

- **e-A Scattering Input to ν-A:** Maria Barbaro?, experimentalist?

  We obviously are in need of volunteers to address this important issue.

# Proposed NuSTEC White Paper / Review

Each of the following sections will describe an interaction process. It would contain a brief summary (mainly references) to current theoretical and experimental knowledge and generator status. The main thrust would be to motivate open questions, where does the community need to concentrate our theoretical and experimental efforts.

- **Quasi-elastic, quasi-elastic-like scattering** - Maria Barbaro, Rik Gran, Natalie Jachowicz, Teppei Katori, Marco Martini, Ornella Palamara, Federico Sanchez, Geralyn Zeller,
  - 1. QE interactions on the nucleon including axial form factors, non dipole behavior, second class currents, input from lattice QCD
  - 2. 1p1h description of initial and final states in the nucleus, spectral functions
  - 3. 2p2h, initial state and extensions to higher energy transfer, methods to describe 2p2h contribution, double counting considerations, interference.

# Proposed NuSTEC White Paper / Review

- 4. Collective effects (RPA)
- 5. Experimental situation: MINERvA, MiniBooNE, T2K – importance of global fits
- 6. Generator status
- 7. Open questions

- **Resonance model (including pion, photon production)** - Mohammad Sajjad Athar, Steve Dytman, Toru Sato, Jan Sobczyk, Geralyn Zeller
  - 1. Delta-dominant region Model comparisons
  - 2. Higher order resonances model comparisons
  - 3. Non-resonant background
  - 4. Input from Lattice QCD?
  - 5. Experimental situation: MINERvA, MiniBooNE, T2K?
  - 6. Generator status
  - 7. Open questions

# Proposed NuSTEC White Paper / Review

- **Coherent and Diffractive scattering** Luis Alvarez Ruso, Jorge G Morfin
  - 1 Theoretical status
  - 2 Experimental situation: K2K, SciBooNE, MINERvA, T2K
  - 3 Generator status
  - 4 Open questions

- **Shallow Inelastic Scattering and Deep Inelastic Scattering**

  Mohammad Sajjad Athar, Teppei Katori, Jorge G Morfin, Roberto Petti,
  - 1. Low-Q kinematic and dynamic higher twist
  - 2. Nuclear effects
  - 3. Hadronization model
  - 4. Experimental status
  - 5. Generator status
  - 6. Open questions

# Proposed NuSTEC White Paper / Review

Not for the white paper but for the review that contains a section on neutrino flux

- **Neutrino-electron elastic scattering** Jorge G Morfin, Roberto Petti
  - 1. Theoretical status
  - 2. Experimental situation: MINERvA
  - 3. Generator status
  - 4. Using this channel to constrain the flux
  - 5. Open questions

# Discussion

# What do Experimentalists Measure in Detectors

- Measured(E) $\alpha$ Flux(E) $\otimes$ Cross Section(A,E) $\otimes$ Nuclear Effects(A,E)
- Nuclear Effects(A,E) are the energy-dependent, bound nucleon effects on the initial interaction and the final-state interactions of the hadrons traversing the nucleus A.
- Cross Section(A,E) is the energy-dependent cross section for a particular channel on a bound nucleon within the nucleus A.
- Flux(E) is the energy distribution of neutrinos entering the detector. It is considerably different in near and far detectors. This implies there is a very different convoluted combination of cross section and nuclear effects at the near and far detectors.

# Event Generators

Nuclear Model

- Measured(E) $\alpha$ Flux(E) $\otimes$ Cross Section(A,E) $\otimes$ Nuclear Effects(A,E)

- The community models these last two terms in **event generators** that use a particular **nuclear model**.
  - Provide information on how signal and background events should **appear** in our detectors if the model is correct.
  - Provide means for estimating systematic errors on measurements.
  - One of the most important components in the analysis of neutrino experiments.

- The **event generator** used by most of the experimental community!
  - **GENIE** – Used by ArgoNeut, MicroBooNE, MINOS, MINERvA, NOvA, T2K, SBLD, DUNE

# A Step-by-Step Two-Detector LBL Oscillation Analysis

1) Measure detected $E_d$ and event topology in the near detector.
2) Use the **nuclear model** to take the detected $E_d$ and topology back to the initial interaction energy $E_\nu$ and topology.
3) Project this initial interaction $E_\nu$ distribution, perturbed via an oscillation hypothesis that changes flux(E) at the far detector.
4) Following the initial interaction in far detector, use the **nuclear model** to take the initial $E_\nu$ and topology to a detected $E_d$ and topology.
5) Compare with actual measurements in the far detector.

**Critical dependence on the nuclear model**

**even with a near detector**