

---

# NuSTEC Update

**NuInt 2017 – Toronto, Canada**

Jorge G. Morfin

Fermilab

25 June 2017

# NuSTEC: Membership

---

## ◆ THEORISTS

- ◆ Luis Alvarez Ruso (co-spokesperson)
- ◆ Sajjad Athar
- ◆ Maria Barbaro
- ◆ Omar Benhar
- ◆ Richard Hill
- ◆ Patrick Huber
- ◆ Natalie Jachowicz
- ◆ Andreas Kronfeld
- ◆ Marco Martini
- ◆ Toru Sato
- ◆ Rocco Schiavilla
- ◆ Jan Sobczyk (nuWRO)

## ◆ EXPERIMENTALISTS

- ◆ Sara Bolognesi
- ◆ (Steve Brice)
- ◆ Raquel Castillo

- ◆ Dan Cherdack
- ◆ Steve Dytman (GENIE)
- ◆ Andy Furmanski
- ◆ Yoshinari Hayato (NEUT)
- ◆ Teppei Katori
- ◆ Kendall Mahn
- ◆ Camillo Mariani
- ◆ Jorge G. Morfín (co-spokesperson)
- ◆ (Ornella Palamara)
- ◆ Jon Paley
- ◆ Roberto Petti
- ◆ Gabe Perdue (GENIE)
- ◆ Federico Sanchez
- ◆ (Sam Zeller)

( ) indicates advisor

# NuSTEC Web Page

<http://nustec.fnal.gov>

## NuSTEC: Neutrino Scattering Theory Experiment Collaboration

**NUINT 2017**  
25-30 JUNE, 2017  
THE FIELDS INSTITUTE  
UNIVERSITY OF TORONTO

**NuSTEC School 2017**  
7-15 November, 2017  
Fermilab, USA  
[nustec.fnal.gov/school2017](http://nustec.fnal.gov/school2017)

**NuSTEC**  
Neutrino Scattering  
Theory-Experiment Collaboration

### NuSTEC School 2017

NuSTEC school is a training program in the **physics of neutrino-nucleus scattering**, to be held at **Fermilab, Batavia IL, USA in 7-15 November 2017**. Registration will be open soon.

### News

June 12 – Program is fully fixed.

# NuSTEC School 2017 7-15 November

Applications open in a week or two

<http://nustec.fnal.gov/school2017/>

---

## NuSTEC School 2017



## NuSTEC Training in Neutrino-Nucleus Scattering Physics 2017

The NuSTEC school is a training program in the **physics of neutrino-nucleus scattering**, to be held at **Fermilab, Batavia IL, USA in 7-15 November 2017**. Registration will be open soon.

The program will include **33 hours of lectures** and **12 hours of recitation** encouraging questions and discussion on all of the day's lectures. The aim of the program is to provide the necessary theoretical background on the physics of electroweak interactions with nucleons and nuclei. It should allow the participants to understand recent developments and to contribute to this field, which has become very important for the future of neutrino physics. Although this training is ideally suited for experimental and theoretical advanced graduate students and young postdocs, senior researchers may find these lectures informative and are welcome to participate.

# NuSTEC School 2017 7-15 November

## Program with Lecturers fixed

---

### **NuSTEC Training in** **Neutrino Nucleus Scattering Physics**

Fermilab, November 7-15, 2017

	Topic	Hours	Lecturer
0	General introduction	1	P. Huber
1	Introduction to electroweak interactions on the nucleon	3	R. Hill
2	Introduction to neutrino-nucleus scattering	3	J. W. Van Orden
3	Strong and electroweak interactions in nuclei	3	S. Pastore
4.1	Approximate methods for nuclei (I)	2	A. Ankowski
4.2	Approximate methods for nuclei (II)	2	N. Jachowicz
4.3	Ab initio methods for nuclei	2	A. Lovato
5	Pion production and other inelastic channels	3	T. Sato
6	Description of exclusive channels and final state interactions	3	K. Gallmeister
7	Inclusive electron and neutrino scattering in the shallow and deep inelastic regimes	3	J. Owens
8	Systematics in neutrino oscillation experiments	3	S. Bolognesi
9.1	Monte Carlo Methods and Event Generators	3	T. Golan
9.2	Nuisance	2	P. Stowell

- ◆ For details of the content of each lecture series please go to:

**<http://nustec.fnal.gov/school2017/>**

# NuSTEC White Paper

Kendall Mahn and Gabe Perdue

([arXiv:1706.03621](https://arxiv.org/abs/1706.03621))

---

## NuSTEC White Paper: Status and Challenges of Neutrino-Nucleus Scattering

L. Alvarez-Ruso,<sup>1</sup> M. Sajjad Athar,<sup>2</sup> M.B. Barbaro,<sup>3</sup> D. Cherdack,<sup>4</sup> M.E.Christy,<sup>5</sup> P. Coloma,<sup>6</sup>  
T.W. Donnelly,<sup>7</sup> S. Dytman,<sup>8</sup> R. J. Hill,<sup>9, 10, 6</sup> P. Huber,<sup>11</sup> N. Jachowicz,<sup>12</sup> T. Katori,<sup>13</sup>  
A. S. Kronfeld,<sup>6</sup> K. Mahn,<sup>14</sup> M. Martini,<sup>15</sup> J. G. Morfin,<sup>6</sup> J. Nieves,<sup>16</sup> G. Perdue,<sup>6</sup>  
R. Petti,<sup>17</sup> D. G. Richards,<sup>18</sup> F. Sánchez,<sup>19</sup> T. Sato,<sup>20</sup> J. T. Sobczyk,<sup>21</sup> and G. P. Zeller<sup>6</sup>

I. Executive Summary	4
II. Introduction and Overview of the Current Challenges	6
A. Introduction: General Challenges	6
B. Challenges: The Determination of Neutrino Oscillation Parameters and Neutrino-Nucleus Interaction Physics (Section III)	9
C. Challenges: Generators (Section IV)	10
D. Challenges: Electron-nucleus Scattering (Section V)	10
E. Challenges: Quasielastic Peak Region (Section VI)	10
F. Challenges: The Resonance Region (Section VII)	11
G. Challenges: Shallow and Deep-Inelastic Scattering Region (Section VIII)	12
H. Challenges: Coherent Meson Production (Section IX)	13

# NuSTEC White Paper

## Ongoing discussion on publishing the white paper in a journal

---

III. The Impact of Neutrino Nucleus Interaction Physics on Oscillation Physics Analyses	14
A. Neutrino oscillations and the extraction of oscillation parameters	14
B. Event Topology and Experimental Observables	18
C. Benefits and Challenges of Near detectors	19
D. Estimation of neutrino energy	21
E. Calculation of Detection Efficiency	22
F. Current Experimental Program	23
1. Long-Baseline measurements	23
2. New physics searches	25
3. Short-baseline measurements	25
G. Future Experimental Program	26
H. Summary and challenges for oscillation experiments	28
IV. Neutrino Event Generators	29
A. How do neutrino event generators work?	29
B. Cultural concerns	29
C. Theory developments	30
D. Interplay with experiments	31
E. Top challenges	31
V. Electron-nucleus Scattering as input to neutrino scattering	32
A. Introduction	32
B. Experimental input	32
C. Modeling	35
D. Challenges	37

# NuSTEC White Paper

---

VI. Quasi-elastic, quasi-elastic-like scattering	38
A. QE scattering on the nucleon	38
1. Invariant form factors	39
2. Electromagnetic form factors	39
3. Charged current vector form factors	40
4. Neutral current vector form factors	40
5. Axial form factors: charged current	40
6. Axial form factors: neutral current	41
7. Form factor parameterizations	41
8. Practical prospects for lattice QCD	41
B. QE on the nucleus : 1p1h processes	42
C. Multinucleon processes and 2-nucleon knockout	44
D. Experimental situation: results on nucleon, MINERvA, MiniBooNE, T2K	45
E. Relation theory-experiment	49
F. What can be obtained from electron scattering ?	50
G. Generator Status	51
H. Challenges and open questions	52
VII. Resonance Model	54
A. Introduction and Motivation	54
B. Resonance production from the nucleon - Theory	54
1. reaction models of pion production for nucleons	55
2. testing reaction models	56
C. Resonance production from the nucleus - Theory	56
D. Generator status	58
E. Existing Experimental Results	59
1. pion production from the nucleon with neutrinos	59
2. pion production from nuclei with neutrinos	59
3. pion production with electromagnetic beams	61
F. Challenges and Open Questions	61
1. Theory	61
2. Experiment	61



# NuSTEC White Paper

## A living document? – periodically updated?

---

VIII. Shallow and Deep Inelastic Scattering	63
A. Introduction	63
B. Inelastic Scattering off Nucleons	64
1. Quark-Hadron Duality	64
2. Perturbative and Electroweak Corrections	65
3. High Twist Contributions	66
4. Hadronization	67
C. Inelastic Scattering off Nuclei	68
1. Nuclear Modifications of Structure Functions	68
2. Final State Interactions	69
D. Experimental Measurements	69
E. Comparisons between Models and Measurements	70
F. Challenges	72
1. Modeling Issues	72
2. Experimental Issues	73
IX. Coherent and Diffractive Scattering	74
A. Basics of Coherent and Diffractive Processes	74
B. Relevance for oscillation experiments	75
C. Theoretical status	75
1. PCAC models of coherent particle production	76
2. Microscopic models of coherent particle production	76
3. Diffractive contribution to meson production	77
D. Coherent and diffractive scattering in event generators	77
E. Experimental Status: Coherent and Diffractive Meson Production	78
1. Early experiments on CC and NC coherent pion production	78
2. More Recent Coherent Pion Production Experimental Results	78
3. Experimental Isolation of the Coherent Pion Production Signal	78
4. Charged-Current Coherent Kaon Production	79
5. Coherent Photon Production	79
F. Diffractive Pion Production off a Nucleon	80
G. Comparisons between theory and experiment: Open questions	80

# Where do we go from here?

## How do we address these challenges?

---

- ◆ First of all – **what additions and/or changes would you like to see to this review of the status and collection of challenges.** We are establishing a convenient way to collect feedback ( Wiki?).
- ◆ Do we actually need a strategy?
  - ▼ From the recent INT workshop as well as contact with Fermilab Directorate and informal chats with funding agency types – **a strategy of how we as a community want to address these challenges is important.**
  - ▼ Can we as a community decide on the **most important challenges for each topic?**
- ◆ NuSTEC will initiate or continue collaborations of theorists and/or experimentalists to address certain challenges.
- ◆ NuInt is an excellent example of how we do, and can continue to, address these challenges through workshops.

# Addressing the Challenges with Workshops

---

- ◆ Shall we have shorter more focused workshops to address important specific challenges?
- ◆ For example, possible Near Future NuSTEC Workshops:
  - ▼ **Fermilab Theory-Group “Winter Workshop”** A workshop on neutrino-nucleus scattering physics aimed at HEP theorists is being organized in association with our November school.
  - ▼ **Workshop on  $\nu$  – nucleon physics** – A common challenge across topics! Considerable community interest in a new high-statistics  $\nu$  – **N** experiment. What experimental techniques? What can (lattice-gauge) theory bring us?
  - ▼ **Higher-W** – Last INT workshop spent 90% of the time on QE and fundamental nuclear structure (**important across W!**) 10% on Delta production. The community needs an equally probing look at SIS (Delta to DIS) and the DIS regions. Very important for DUNE.

## Addressing the Challenges

---

- ◆ The proposal is to consider these challenges and how to address them as they arise in discussions throughout NuInt.
- ◆ Summarize where we are at the conclusion of NuInt.
- ◆ Gather interested parties post-NuInt for a planning exercise on addressing these challenges..

# Backup

---

# Example Challenges: Theorists

---

- Significant improvements of nuclear models by theorists are essential and should include:
  1. The development of a unified model of nuclear structure giving the initial kinematics and dynamics of nucleons bound in the nucleus.
  2. Modeling neutrino–bound-nucleon cross sections not only at the lepton semi-inclusive cross section level, but also in the full phase space for all the exclusive channels that are kinematically allowed.
  3. Improving our understanding of the role played by nucleon-nucleon correlations in interactions and implementing this understanding in MC generators, in order to avoid double counting.
  4. Improving models of final state interactions, which may call for further experimental input from other communities such as pion-nucleus scattering.
  5. Expressing these improvements of the nuclear model in terms that can be successfully incorporated in the simulation of neutrino events by neutrino event generators.

These steps can most efficiently be accomplished with additional support of theorists working in this area in a well-coordinated international program. It is then vital to have an established procedure that promotes nuclear and high energy theorists joining neutrino interaction generator experts and neutrino experimentalists in working toward this goal. The aim of this program should be to provide more robust models to meet the requirements of the oscillation experiments, and to deepen the engagement between theorists and generator builders so as to speed the implementation of improved models in generators.