NuSTEC White Paper

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Where do we want to go?

Image from: sukanyaramanujan.wordpress.com

How do we get there?

Where do we want to go?

~1% systematic uncertainties for future osc experiments (mountaintop)

Identify challenges. Form a plan. Recruit effort/support. Start climbing.

Image from: sukanyaramanujan.wordpress.com

How do we get there?

Problems from osc. experimentalist's view

For a given process:

- What should the theory be? What uncertainties?
  - How is the theory validated based on e-A or nu-A scattering experiments/near detector data?
- What is in the simulation (generator)? Is it correct?
  - Consistency, double counting
- What is the effect on an oscillation experiment?

If I'm doing something wrong, then I need to find help

A view of the field

Neutrino oscillation experiment

Neutrino scattering experiment

Generators

Electron scattering experiment

HEP theory

Nuclear theory

A view of the (US, DOE) funding

Neutrino oscillation experiment

HEP

Neutrino scattering experiment

Generators

HEP theory

Electron scattering experiment

Nuclear theory

NP

NuSTEC
one tool in the toolbox

Neutrino Scattering Theory Experiment Collaboration

A collaboration of of HEP and NP experimentalists and theorists studying low energy neutrino nucleus scattering

The main goal is to improve our understanding of interactions with nuclei, and get that understanding delivered to experiments (i.e. through even generators)

- Impact on oscillation (long, short baseline) programs
- Impact on cross section measurement programs
- Education and growing the community of involved theorists/experimentalists

NuSTEC Programs

Community wide workshops:

- Main conference: NuInt2017 (Toronto)
- Do we need a modern neutrino + deuterium/hydrogen experiment?

Schools/Training Programs:

- 5-7 day school: 30 students in Okayama (Nov 2015)
- 10 day school: 85 students at Fermilab (Oct 2014)
- Next extended school at Fermilab in Oct/Nov 2017

Projects: Facilitate joint theory-experiment collaboration to address specific issues.

NuSTEC Board

Represent each experiment (+generators) and each school of theory

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

- Plus additional HEP theorists

People in red are at INT

- 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 White Paper

Describe what we don't know to motivate where future effort needs to be

Describe the challenges faced by the field

- Problems span HEP-NP, and theory-experiment
- Include interdependencies and context for problems
- Describe existing tools and knowledge base
- Shows coherence among the community about the issues

Paper provides a means to educate colleagues on the issues

- Establish consistent terminology

Executive summary useful for interactions with funding agencies

- Recruiting support for groups is critical to enable work

NuSTEC White Paper Outline

- **Executive Summary**
- **Overview of the Current Challenges in the Theory of Neutrino Nucleon/ Nucleus Interaction Physics – Coordinators: Jorge Morfín and Jan Sobczyk**
- **The Impact of Neutrino Nucleus Interaction Physics on Oscillation Physics Analyses – Coordinators: Pilar Coloma and Kendall Mahn**
- **Neutrino Event Generators – Coordinator: Gabe Perdue**
- **e-A Scattering Input to ν-A - Coordinators: Maria Barbaro and Eric Christy**
- **Quasi-elastic, Quasi-elastic-like Scattering - Coordinators: Natalie Jachowicz and Federico Sanchez**
- **Coherent and Diffractive Meson Production - Coordinators: Luis Alvarez-Ruso and Jorge Morfín**
- **Resonance Model: Coordinators: Steve Dytman and Toru Sato**
- **Shallow Inelastic Scattering and Deep Inelastic Scattering: Coordinators: Sajjad Athar and Roberto Petti**

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- **Quasi-elastic, Quasi-elastic-like Scattering - Coordinators: Natalie Jachowicz and Federico Sanchez** ***This talk***
- **Coherent and Diffractive Meson Production - Coordinators: Luis Alvarez-Ruso and Jorge Morfín**
- **Resonance Model: Coordinators: Steve Dytman and Toru Sato**
- **Shallow Inelastic Scattering and Deep Inelastic Scattering: Coordinators: Sajjad Athar and Roberto Petti** ***Gabe's talk***

Feedback

- **Are there any major problems/challenges we are missing? What are barriers to progress?**
- **What do we need to know when devising the path forward?**

General Challenges

- Establish priorities based on quantitative criterion based on the goals of current and future experiments
    - Is it possible (and worthwhile) to pursue a systematic benchmarking of models against data?
- Improve connection between modern models and neutrino experiment
    - Comparisons of effects, inclusion of models in event generators. Treatment of the hadronic state.
- Error quantification
    - How do we test the effect of different assumptions on the model for the experiment? How well is the model known?
- Are there any obvious holes experimentally which need to be addressed?
    - New experimental measurements of single nucleon form factors? To what level is needed? What experimental set up is necessary to achieve this goal?
    - Is more pion, photo-production data needed?

Electron scattering (e-A): top challenges

Theoretical:

- How do different nuclear models used in neutrino studies compare to inclusive e-A data?
    - Is it possible (and worthwhile) to pursue a systematic benchmarking of models against data?
- To what extent are universal features from e-A usable as an input to neutrino scattering?

Experimental:

- Are new e-A scattering data needed to test nu-A cross section modelling?
    - Can e-A data help develop robust modeling of the hadronic state?

Generator:

- What is the status of validation of generators used in analyses against electron scattering models/data? What are the difficulties to creating eA interfaces?

Quasi-elastic (QE-like) scattering: top challenges

Theoretical:

- Understand the limitations of the models and the impact of theoretical approach and model parameters
  - Example: scheme dependent separation of 1p1h, 2p2h. Double counting?
  - Example: Role of Delta. How to remove/add to compare to experiment?
- Development of semi-inclusive and fully exclusive channel description

Experimental:

- Establish 2p2h experimentally. Most evidence from muon only.
- Sufficient knowledge of neutrino-nucleon cross sections: assumptions on theory, limitations on experiment?

Generator:

- Implementation of sophisticated microscopic model in MC generators

Summary and Feedback

- NuSTEC is preparing a White Paper to frame the issues in neutrino-nucleus scattering
  - First, agree on the main issues. Useful for funding and eventually strategy.
- Jorge has a hardcopy of the current paper draft.
  - If you are interested in seeing the rough draft, please talk to him and Luis.
- **Are there any major problems/challenges we are missing? What are barriers to progress?**
- **What do we need to know when devising the path forward?**