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The Challenges Facing Neutrino-Nucleus Scattering, Part II

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Overview

- You already know what NuSTEC is…
- You know about the white-paper / review…
- We will talk about a few of the sections and highlight the associated authors' opinions on the most important challenges facing our understanding of:
  - resonant pion production
  - coherent pion production
  - SIS/DIS
  - generators (time permitting)
- Disclaimer: this discussion will be based on email and some conversation with section authors, but it may not all have been reviewed with everyone - so anything strange here is likely due to my misunderstanding, etc.
  - I will present the challenges as offered by the other members of NuSTEC, and then I may follow with some exposition…

Deliberately controversial?… well, maybe

- Breaking the challenges up by reaction channel is an efficient way to survey a large group and focus them on different aspects of the problem, but there is invariably some repetition in this approach, and some questions and concerns are fairly universal.
- Everyone at this workshop understands (at least at some level) what the challenges facing this field are, but we may disagree on priorities.
- Priorities imply working on a topic at the expense of something else.
- That said, the lists provided here are fairly broad. It isn't clear we've really made trade-offs here. Something for the discussion? If nothing else, we are developing a survey of known unknowns. What is missing?
- Of course, we must set priorities based on quantitative criteria. Realistically, this means based on impact on oscillation experiments but we should not ignore more general questions of nuclear structure.

Resonant pion production

- Theory challenges:
  - How to define the optimal nuclear structure?
  - How to nucleon-nucleon correlation effects?
  - What are the best methods for the non-resonant model?
  - What is the optimal mix of theory in generator calculations (and how do we get there)?
- Experiment challenges:
  - We need guidelines for experiments to enable easier comparisons.
  - There is a dire need for new nucleon scattering data - this will require a major new experiment.
  - Neutrino-argon data in the DUNE energy region.

Resonant pion production comments…

- A new nucleon scattering experiment will be a *highly* non-trivial bureaucratic undertaking. It will be important to fully justify the need for such an experiment with detailed calculations illustrating the impact on rest of the international neutrino program.
- It is important to resolve tensions or inconsistencies between measurements and in theory-data comparisons - pion production is particularly problematic in this regard. To what extent is the problem rooted in resonant vs non-resonant production?

Coherent/diffractive pion production

- Theory challenges:
  - Microscopic models must be extended beyond the Delta(1232) region.
  - Incorporate non-resonant contributions to weak pion production on nucleons at high \pi_N invariant masses, capable of describing diffractive (peripheral) pion production.
- Experiment challenges:
  - Perform new measurements of coherent and diffractive scattering to complement MINERvA measurements.
  - Measure the A-dependence of coherent scattering off a range of nuclei and compare data to theoretical predictions.

Coherent/diffractive pion production

- Generator challenges:
  - Microscopic models must be more efficiently implemented.
  - Ambiguities in the predictions of PCAC pion production models implemented in different neutrino event generators should be resolved. A validation criterion could be the ability to describe pion nucleus scattering.
- General challenges:
  - Address coherent gamma production both theoretically and experimentally in the neutrino energy range of interest (presumably DUNE, HK,SBN).
  - For pion and kaon coherent production, it is important to understand if the accuracy goals justify the need for models better than the simple and fast PCAC-based models.
  - Microscopic models must be validated with other reactions: coherent meson photo and electroproduction, meson-nucleus scattering.

Coherent/diffractive pion production comments…

- Coherent pion production is a relatively small part of the total cross section. Weighted by cross section fraction, does it get relatively too much attention? It has the big advantage of relative clarity - we have interesting theoretical models and modern experiments are good at measuring the channel.
- What about other coherent meson production models? Coherent rho production is coming soon in GENIE.

SIS/DIS

- Theory challenges:
  - Optimize the description of the transition region from DIS to resonance production and define the kinematic limits of applicability of the DIS formalism for structure functions and cross sections.
  - Study the interplay of various nuclear effects (Fermi motion and nuclear binding, meson exchange currents, nuclear shadowing, off-shell effects, etc.) in different regions of x_Bj and Q^2 for neutrino and anti-neutrino interactions with bound nucleons.
  - Understand the differences in the nuclear effects for electromagnetic and weak DIS structure functions and cross sections.
  - Study the impact of high twist contributions, F_L structure function and radiative corrections on cross sections.

SIS/DIS

- Experiment challenges:
  - New precise measurements with neutrinos and antineutrinos on free proton and deuteron targets.*
  - New precise measurements with neutrinos and antineutrinos of differential and total cross sections on a variety of nuclear targets with wide x_Bj and Q^2 coverage to compare F_2 and xF_3, as well as F_2_\nu and F_2_L.
  - Model independent measurements of nuclear effects on structure functions by comparing nuclear targets to proton and deuteron targets in the same experiment across x_Bj and Q^2.**
  - Clarify existing discrepancies among existing measurements and between (anti)neutrinos and charged leptons across x_Bj.

* Earlier comments apply

** And again.

SIS/DIS

- Generator challenges:
  - Improve hadronization models used in modern generators for the description of exclusive hadron production at all values of W.
  - Improve the description of FSI and nuclear transport in nuclei.
  - Consistent description of SIS/DIS (anti)neutrino cross sections with respect to recent models/developments.

SIS/DIS comments…

- The transition region offers a good testing ground for exploring differences between generators, but data that explicitly targets it are relatively rare.
- Again it is worth commenting that a new free nucleon experiment will be challenging to get approved (at least in the US). It is interesting to see proton/deuterium ratios to heavier nuclei on the list. If enough of the field gets behind the idea, could we resurrect the MINERvA deuterium target?

Generators

- How do we fully engage the nuclear theory community in the design and implementation of event generators? (A US-specific problem is the HEP-NP DOE divide…)
  - Better, more modern theory underpinnings in generators are beyond crucial at this point. The current mechanisms for improvement have been slow - would direct involvement help?
- When tuning generators, how do we handle “tensions” in datasets? Is it realistic to have the goal of a “universal” tune?
- How do we take best advantage of new and upcoming *ab initio* calculations of the nucleus?
- How do we coordinate efforts between generator groups to minimize duplication of effort but still preserve the advantages of independent approaches and ideas?

Conclusions

- We have many great challenges to overcome… perhaps a cause for concern but also a cause for excitement - we're lucky to have interesting problems to think about.
- Setting priorities requires quantifying the impact of improvements - we need to be able to argue clearly for what will have the largest effects (but without doing all the work first).
- As an organizing framework, what big problems are we missing?