Discussion: Workshop Report and Next Steps

Workshop Report

what do we know?
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what do we need to know?
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What studies can be done at the generator level to quantify the impact of elementary amplitudes? (e.g. with NUISANCE framework)

How can precision scattering data on light nuclei aid the development of nuclear models and computational tools?

Can the uncertainty of nuclear models applied to accelerator neutrino cross sections be quantified?

How can elementary amplitudes and nuclear effects be disentangled in current measurements? How should they be combined in generators?

how will we come to know it?
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What is the best configuration for a future elementary target neutrino experiment? (considerations include data quantity and quality, cost, logistics)

What is the potential impact of lattice QCD for the accelerator neutrino program?

Can precise and reliable elementary amplitude measurements be obtained from subtraction techniques in water or hydrocarbon?

What is the potential for non-neutrino experiments to constrain the elementary amplitudes, and which new and better measurements should be performed?

discussion and report on elementary amplitudes

- preliminaries

  Thanks to all of the speakers and participants !!!

  There are many meetings dedicated to the discussion of the broader program of neutrino nucleus interactions

  Focus attention here on the question of elementary amplitudes

- motivations

  - well defined quantities
  - important component of the error budget
  - necessary to inform and discriminate nuclear models
  - important, fruitful, interesting intersections (lattice, e-p, muonic atoms, …)

- definition of elementary amplitude
    - F_A (too narrow)
    - scattering amplitudes at the nucleon level: $\nu N \rightarrow \ell N$, $eN \rightarrow eN$, $N \rightarrow N\pi$, $NN \rightarrow NN$, etc.
    - inputs to nuclear modeling
    - the initio of ab initio (Carlson, Rocco)
    - any physical quantity that lattice QCD can measure involving one or a few nucleons
    - any physical quantity that can be measured in an elementary target (H or D) scattering experiment

- the questions

  (1) what do we know?

  (2) what do we need to know?

  (3) how can we come to know it?

All questions are difficult, but after normalization, (1)=(3)=easy, (2)=hard

- the questions

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  (3) how can we come to know it?

Probably not enough, but serious attempts to quantify

(talks of Meyer, Morfin, Ruso, Sato, Wilkinson)

- challenges from low statistics and limited data preservation
- open questions on deuteron corrections

- the questions

(1) what do we know?

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New elementary target data (Bross, Kammel)

- underground safety raises the bar for making the physics case
- what can be achieved by subtraction methods using compound targets?

Precision lattice QCD (talks of Kronfeld, Lin, Shanahan)

- F_A within sight
- complementary to scattering data

Electron and positron beams (Crawford, Nakamura), muonic atoms (Kammel), …

Many elements of the physics case (question 2) are common between these paths. Practitioners have strategic interest in helping make this physics case.

- the questions

(1) what do we know?

(2) what do we need to know?

(3) how can we come to know it?

Three levels (at least) of answer

(i) regardless of nuclear model, nucleon-level data tests critical elements of oscillation analyses (e.g. disentangling differences in ν_μ/ν_e from radiative corrections and detector response) (McFarland)

(ii) propagate elementary input errors through a/the default nuclear model and oscillation analysis. Need those errors to be smaller than the desired precision on fundamental neutrino parameters.

(Ashkenazi, Castillo, Himmel, Mahn, Ruterbories)

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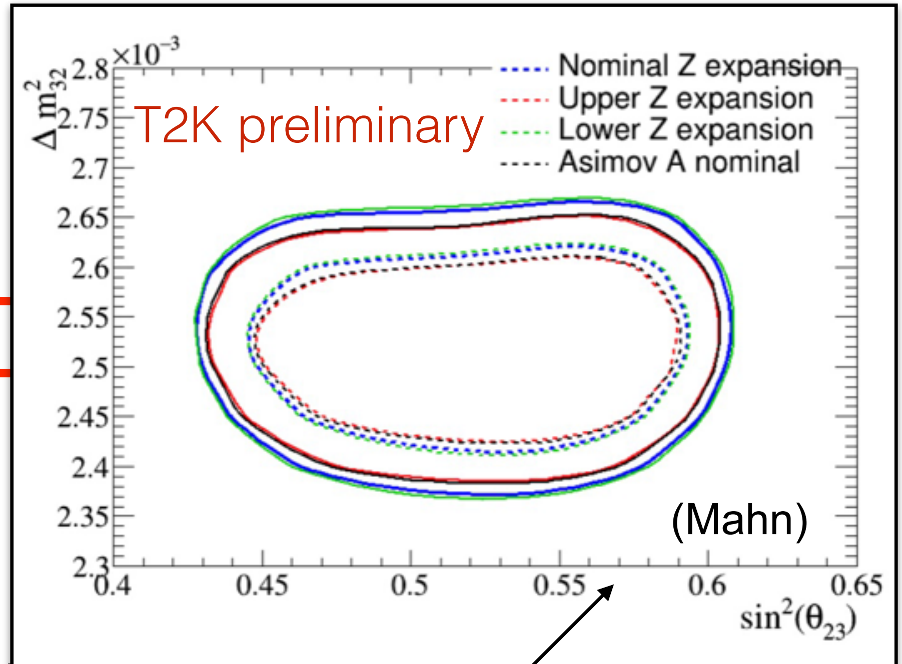

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Three levels (at least) of answer

(iii) the whole shebang

A complete and quantitative answer requires a complete and quantitative nuclear model.

- need to break the circle: improving nuclear models requires better knowledge of the nucleon level amplitudes.

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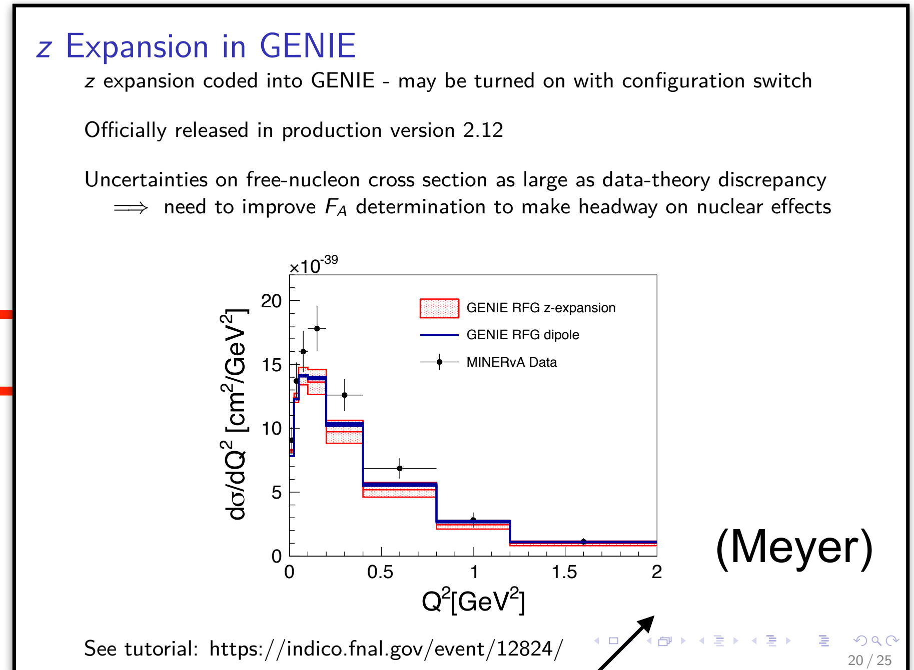

(Meyer)

Three levels (at least) of answer

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- need to break the circle: improving nuclear models requires better knowledge of the nucleon level amplitudes.

- comments

  - It’s a big world - QE, resonance, inelastic processes (Friedland, Morfin). Already at the nucleon level our understanding is rudimentary

  - Parameterizations of things we can’t calculate are fine if they contain the true answer and experimental data are available to constrain them.

Saori, Alex and Kendall Discussion

Physics

- The simplest quantities (fka as “gold plated”) have one hadron in the initial state and zero or one in the final state:
    - proton decay matrix elements: $\langle 0|qqq|N\rangle$ — current status suffices?
    - charges: $g_V = 1$, g_A, g_S, g_T (tensor), … — first full error budgets ≲ now
    - form factors: F_1, F_2, F_A, F_P, F_T (tensor), … — full error budgets ~ soon
    - parton densities, hadron tensor, …, for DIS — rapidly developing
- Resonances are a feature of multi-body states, which poses conceptual and computational challenges: wait (~year) for $B \to K^*(K\pi)l\nu$, then assess realistically.
- Three- and more-body states are a fully open question (need more math).

Andreas and Aaron

Lattice QCD Roadmap: Situation and Plans

Resources (needed for planning)

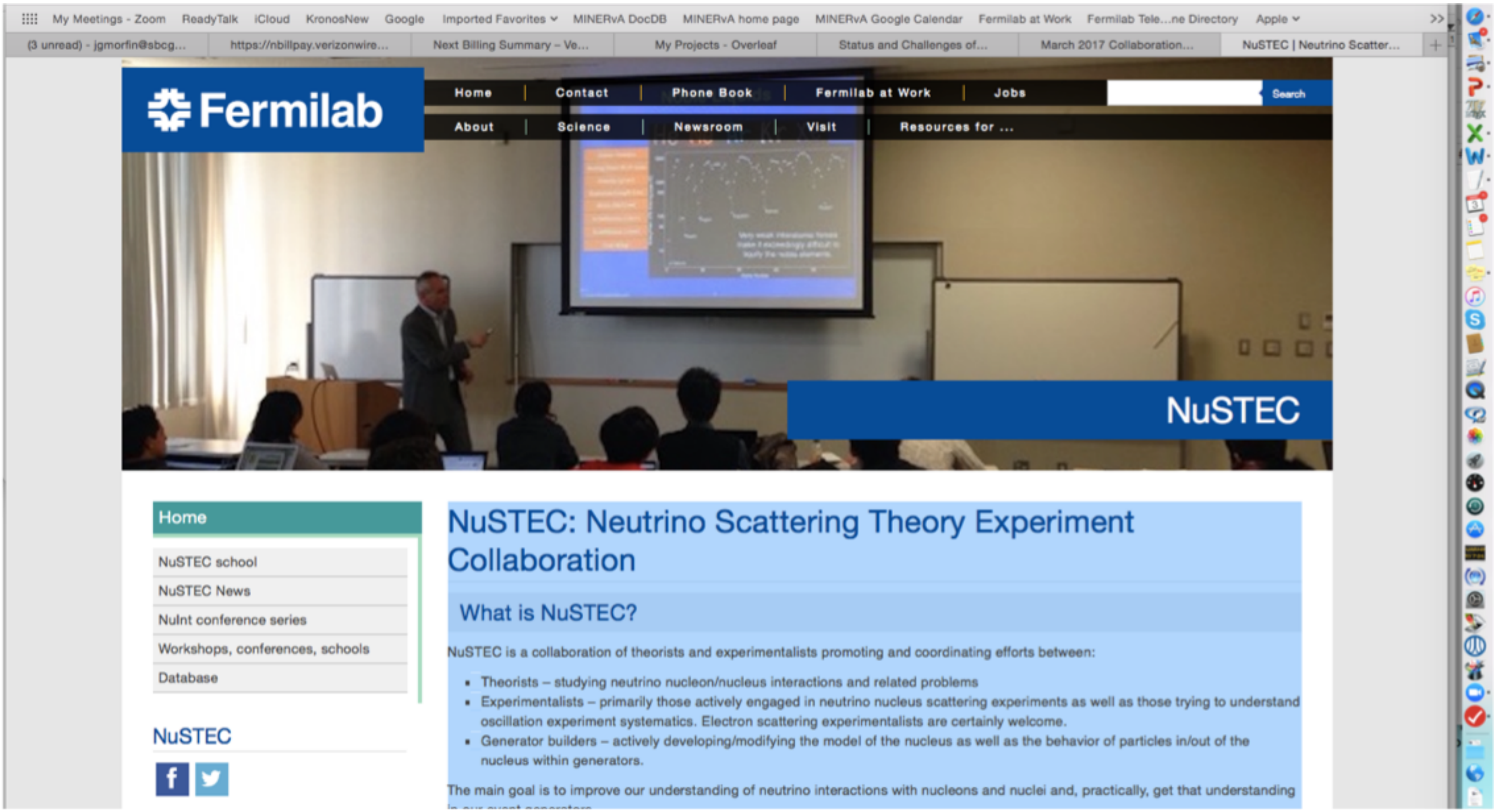
- Large fraction of lattice-QCD research (and funding for resources) is driven by excitement from the experimental program, together with feasibility at any given time:
  - CLEO, BaBar, Belle had a huge influence in the past;
  - Muon g–2 has a huge influence now;
  - in my opinion, the calculations relevant to ν scattering (previous slide) maximize relevance (to HEP), feasibility, and excitement—
    - the hard/impossible have a theoretical attraction.
- Unlike earlier hep-ex oriented work, we now have a three parties in the conversation: experimentalists, lattice-QCD practitioners, and nuclear theorists.
- This week I heard the level of interest needed for ν-scattering problems to rise in priority in the next several years.

Gabe’s Proposal – specific deliverable

- identify interested parties that can actually do work (very hard to arrange!)
- set up a plausible lattice deliverable (with uncertainties)
- have a nuclear theory group help propagate the result into a model and provide uncertainties (especially propagate the lattice uncertainties in a way we can audit their total impact on the final uncertainties)
- code the model into GENIE
  - The last step is highly non-trivial, of course. Maybe we want to code things into a "toy" model (something like an RFG).
  - working on a model with Saori where the underlying ground state model and form factors are subsumed into her calculation
- Goal 1. something "simple" to try to close the loop and iterate with,
- Goal 2. something "more correct" involving a calculation like Saori's - how can we feed this result to her calculation

Neutrino Scattering Theory Experiment Collaboration (NuSTEC)

http://nustec.fnal.gov



NuSTEC: Membership

- <u>THEORISTS</u>
- 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)

- <u>EXPERIMENTALISTS</u>
- 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 Projects

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

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- Two expanded (9 day) and three shorter (5 day) schools on neutrino nucleus scattering physics.
- Input to the present workshop via Richard Hill a co-organizer
- The NuSTEC Workshop on Shallow-and-Deep Inelastic Scattering.
- Multiple collaborative projects between the NuSTEC members reflecting both theory and experimental needs.