Modelling Neutrino Nucleus Interactions

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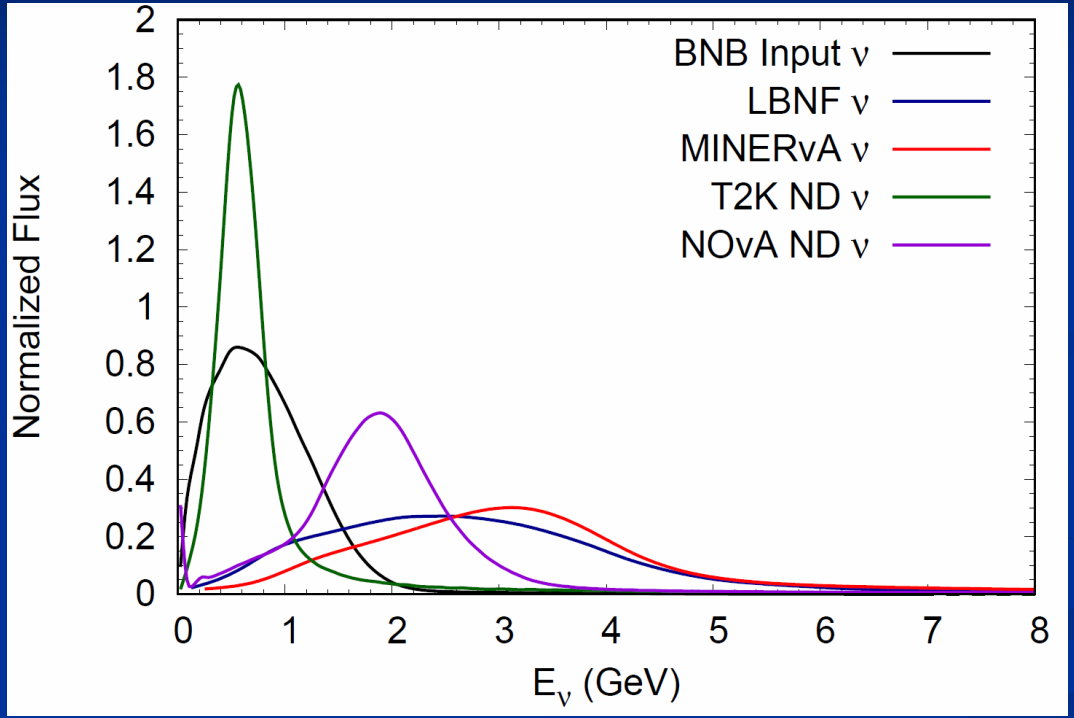
Neutrino-Nucleus Interactions

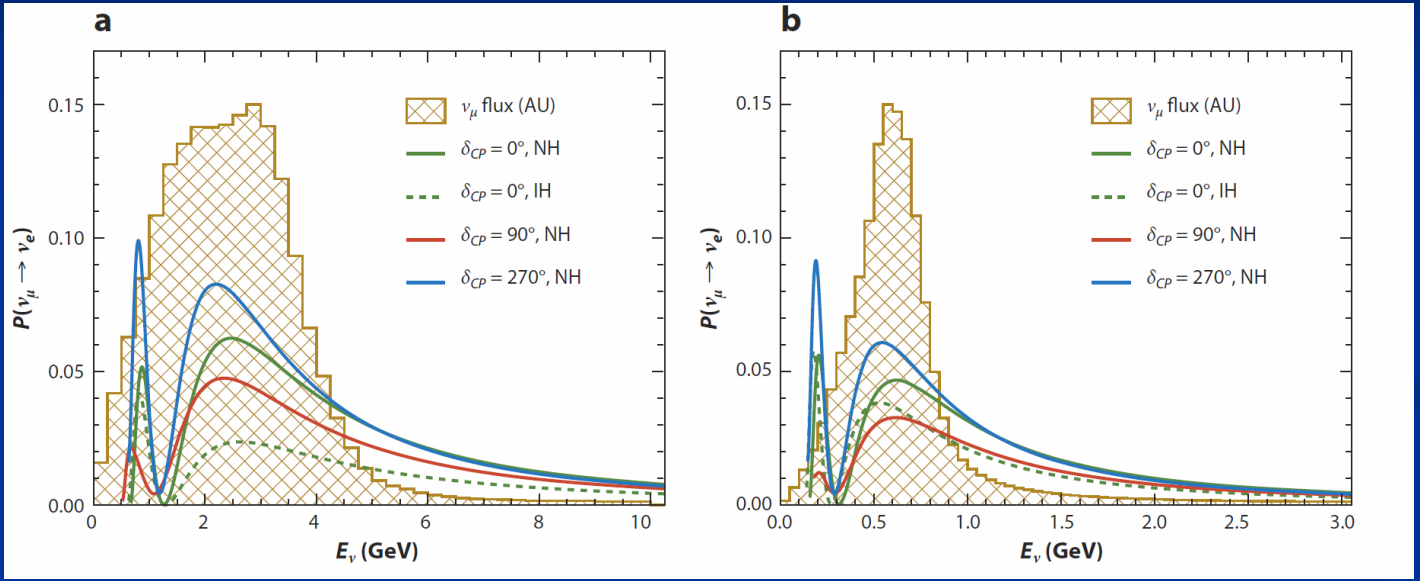
- ‚Inclusives': interest in response of nuclei to electroweak interactions
  Methods: Scaling, GFMC, SF
- ‚Practical': Oscillation epxperiments need control of energy reconstruction
  ➔ Full event description needed, inclusive is not enough!
  Methods: Generators that produce four-vectors of all outgoing particles, must be compatible with the inclusives

Energy-Distributions of Neutrino Beams



Energy must be reconstructed event by event, within these distributions

Oscillation Signals as $F(E_\nu)$



From:
Diwan et al,
Ann. Rev.
Nucl. Part. Sci 66
(2016)

DUNE, 1300 km

HyperK (T2K) 295 km

Energies have to be known within 100 MeV (DUNE) or 50 MeV (T2K)

Ratios of event rates to about 10%

Energy Reconstruction

- Kinematical (QE) method: use only properties of outgoing lepton. Lepton can be measured well, BUT
  - Problem: identify QE in nuclear environment
- Calorimetric method: use energies of all outgoing particles, BUT
  - Problem:
    - detector thresholds and efficiencies
    - Energy of target remnants
- → Have to determine initial energy from computing ‚backwards' from the final state: generators

Generators

- Generators are absolutely essential!
  The best exp. Equipment is useless without them.

- Generators need state-of-the-art nuclear theory, with as little tuning as possible. Tuning may obscure physics.

- Generators thus have to be as good as your latest ^{40}Ar detector → this needs scientific brains + money

Now to the Practical (less fundamental)

- At MINERvA/DUNE all processes, QE + 2p2h+N*+DIS contribute in the same nucleus
- Generators must be able to describe many different reaction types

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Internal Consistency

- Generators are nothing else than encoded nuclear theory, both structure and reactions
- Nuclear Theory has some (trivial) consistency constraints:
  - Nuclei are bound, i.e. nucleons move in potentials
  - Different reaction types all start from the same groundstate
  - Initial electroweak interactions take place on bound, Fermi-moving nucleons
  - Final state interactions happen in the same potential as for the initial interactions
- Requiring this consistency removes many tuning parameters, because of constraints between isi and fsi and different reactions

Two Points of View

1. Exp: A good generator does not have to be ‚right' ‚provided it can be tuned to fit the data
2. Theory: A good generator does not have to fit all the data provided it is ‚right'

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Theory Status

- Inclusives Dilemma:
  1. „Best possible“ theory for inclusives is about 25 years old
  2. The „best modern“ theory (SF, GFMC,…) is still not applicable to actual neutrino experiments.
- Exclusives Dilemma:
  1. The standard MC generators are even older, going back to Bertini cascade (~1970)
  2. Working generators are applied to experiments, but at what prize?

Workshop Goals

- Critically examine:
  - How experiments use the existing generators
  - Physics (and algorithmic) contents of existing generators
  - Possible (necessary) improvements of generators

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