Medium Energy Neutron Detector Response in NOvA

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for the NOvA Collaboration

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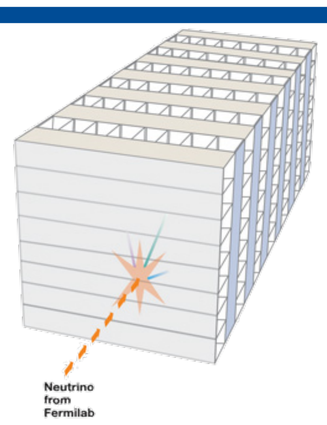
The NOvA Experiment



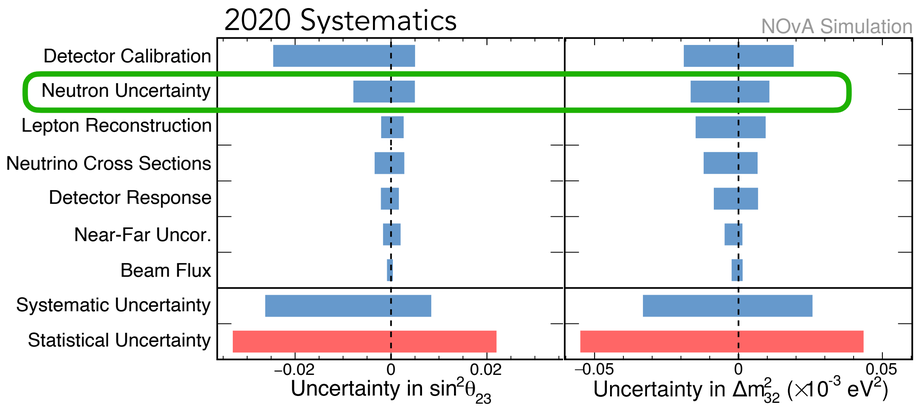
NOvA is a long-baseline neutrino experiment based at FNAL, USA

- Selectable ν_μ or $\bar{\nu}_\mu$ dominated beam
- PVC cells filled with liquid scintillator
  - 67% carbon, 16% chlorine, 11% hydrogen
  - Alternating horizontal and vertical planes result in two views that are merged for 3D reconstruction

Neutron Modeling

Neutron-related uncertainties are a leading systematic

- Neutrons carry away energy unseen
- Degrading neutrino energy estimation performance



Geant4[1]

Detector response is modeled with Geant4 along with a custom light and electronics model

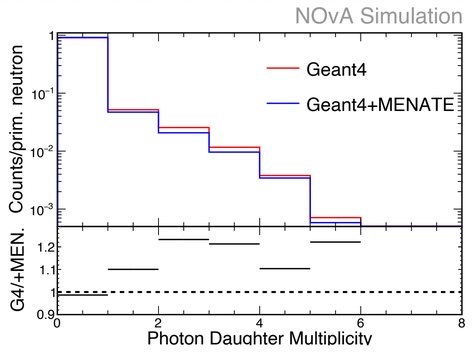
- Geant v4.10.04 with the QGSP_BERT_HP physics list
- Bertini intranuclear cascade statistically produces final state particles

MENATE[2,3]

Alternative medium energy (20-$\mathcal{O}$(100) MeV) neutron-on-carbon inelastic scattering model

- Implemented as a *G4HadronicInteraction* to utilize Geant4's process and model handling
- Final states determined by measured cross-sections

- $^{12}C^* + n' + \gamma$
- $^{9}Be + \alpha$
- $n' + 3\alpha$
- $^{12}B + p$
- $^{11}B + p + n$
- $^{11}C + 2n$

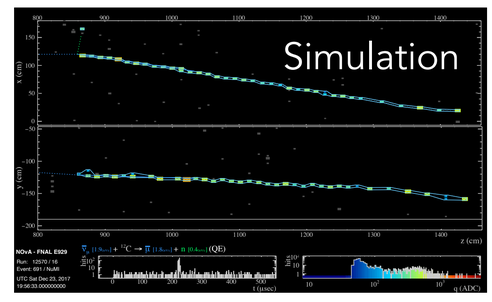


The Visible Neutron Selection

Understanding Neutrons in NOvA

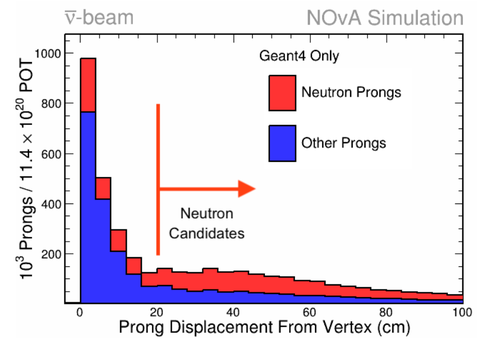
The NOvA ND is comprised of planes of PVC cells

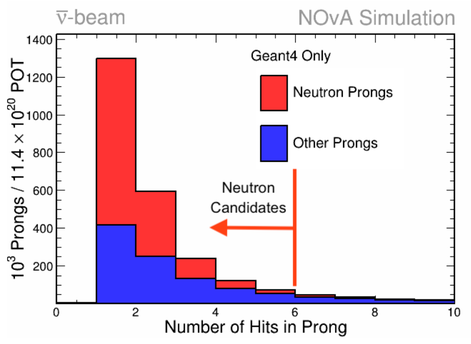
- Related energy depositions in cells are grouped into **"prongs"**.



- Typical mean free path is ~35 cm, driven largely by interactions on ^{12}C
  - Hits will be away from the neutrino interaction vertex
  - Visible energy from inel. scat. is kinematically limited

The Selection Algorithm

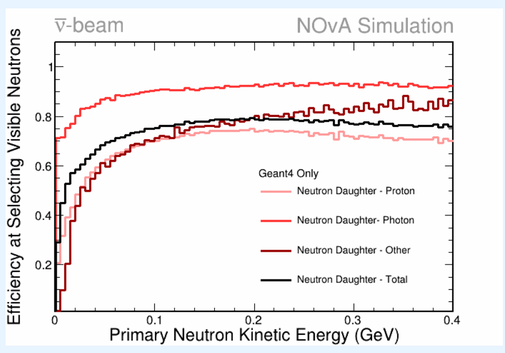


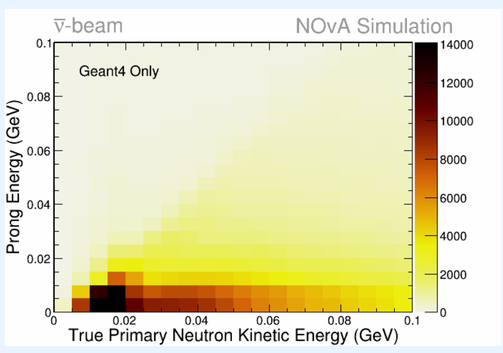


The selection relies on prongs deposited by daughter particles of neutron scatters. The selection keeps:

- Prongs further than 20 cm from the neutrino interaction vertex.
- Prongs with less than 6 cell hits.

Performance on NOvA's Standard Geant Simulation





The neutron prong selection:

- Identifies 72.9% of visible neutrons (44% are visible)
- On average, is 71% efficient and 61% pure. Similar results on the MENATE supplemented simulation.
- Daughters of visible neutrons deposit < 10 MeV

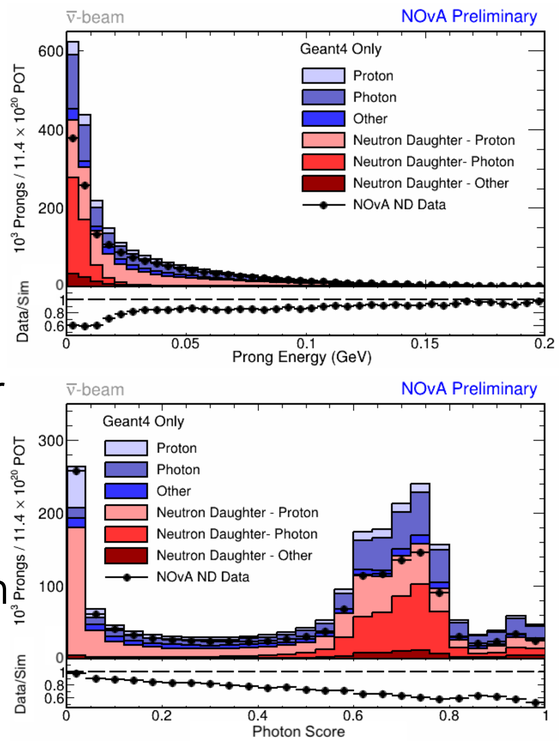
Excess Neutron-Daughter Photons in Geant4

The Geant4 simulation has an excess compared to data.

- Largest for low energy prongs.
- Only where photon-daughter prongs exist.

CNN trained to identify daughter prongs has similar excess.

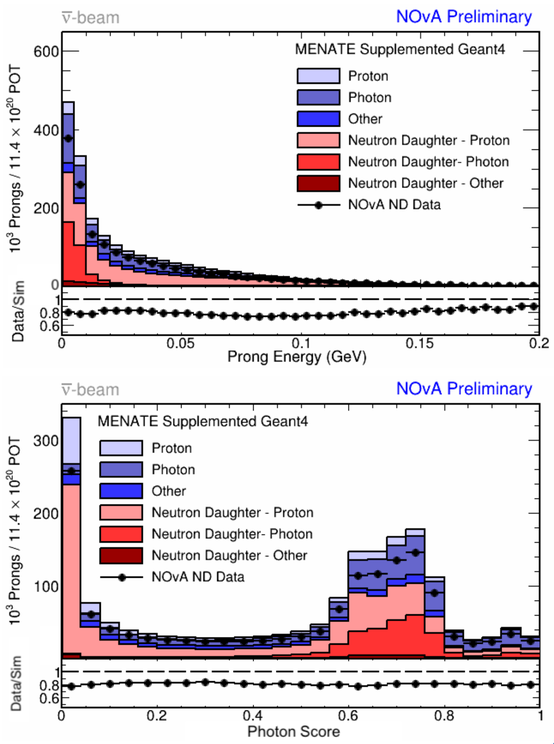
- Double photon peak hints at excess caused by photons from different scattering processes.



MENATE Improves Agreement to Data

MENATE-supplemented simulation has significantly improved agreement with data.

- Nearly-uniform simulation excess across all variable distributions.
- Could be indicative of a neutron yeild from neutrino interaction modeling issue.



Refs. [1] "GEANT4 Physics Reference Manual, Release 10.4; [2] P. Désesquelles, et al., NIM-A 307 (1991) 366-373; [3] Z. Kohley, et al., NIM-A 682 (2012) 59-65