Neutron Cross Sections in ND280

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Outline

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- **Neutron Transport in nd280Geant4Sim:**
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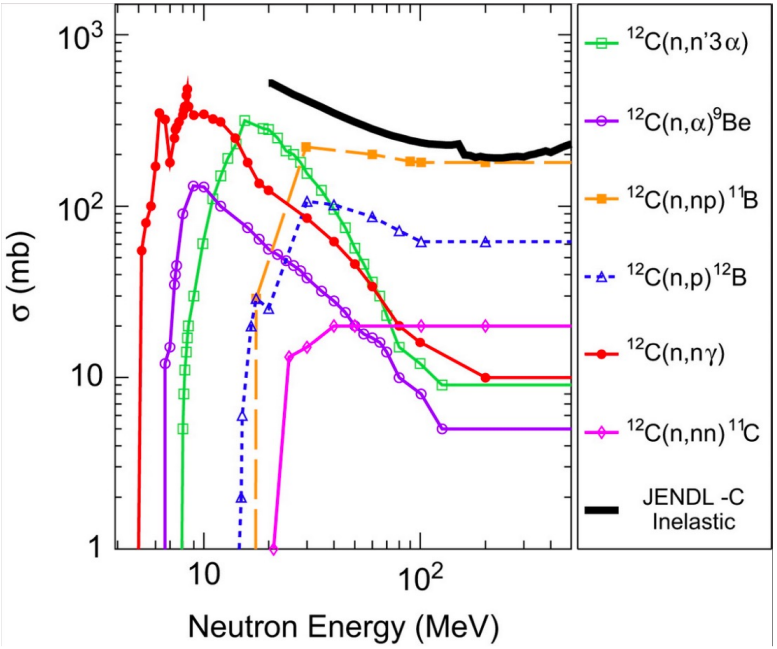
Introduction

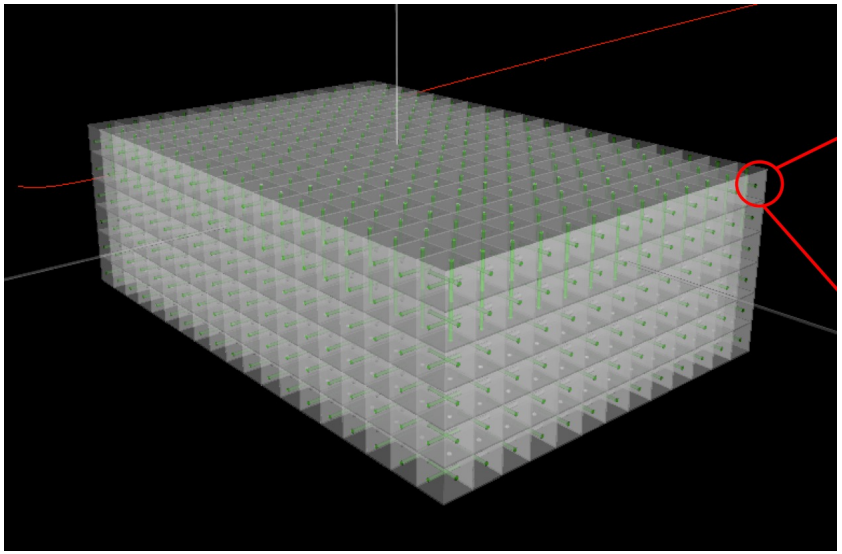
- Neutrons scatter by a variety of mechanisms in polystyrene scintillators; some are visible because they leave energetic charged particles
  - nH-> nH elastic is visible
  - nC-> nC elastic is not
  - nC-> nCgamma (nGamma) is thought to be largely invisible
  - Proton knockout (12Bp) and proton+neutron knockout (11Bnp) are the **leading visible processes**. High energy threshold.
  - Dissociation of C to (threeAlpha)
  - Alpha knockout (BeAlpha)
  - The MoNA experiment collected neutron hydrocarbon scattering data and formed an accurate model



MENATE_R + Geant4 Inelastic cross-sections, and JENDL inelastic [1]

More Introduction

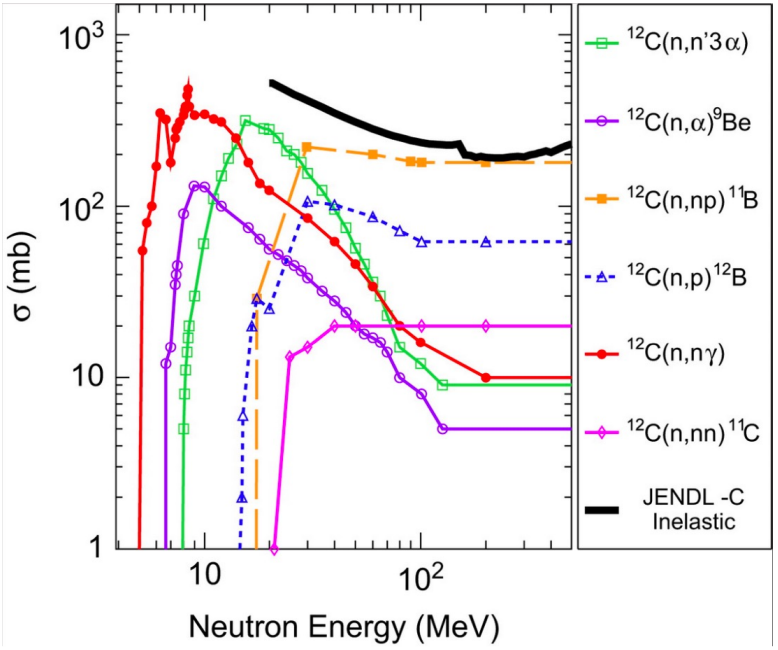
- Accurate neutron transport between 20-300MeV is crucial for MINERvA and SFGD. Neutrons are detected primarily through inelastic events
- MINERvA studied MoNA's model and found that while it agrees with data it did NOT agree with MINERvA's version of GEANT4
- This led to reweighting the MINERvA MC
- SFGD upgrade to ND280 lends itself to a revision of the neutron transport model in ND280Geant4Sim



Schematic concept of the SuperFGD structure. [2]

MoNA and MENATE_R

- MoNA uses Geant4 version 9.4.p01
  - High Precision (HP) Model for KE < 20MeV
  - 20MeV < KE < 300MeV uses **MENATE_R**
- MENATE_R was developed to include additional neutron scattering models to GEANT4
- **Main Differences**:
  - G4-Physics uses JENDL-HE total inelastic n-C XS then simulates each reaction channel with GEANT4 cascade model (BERT)
  - MENATE_R treats n-C XS as discrete reactions sampling from XS data



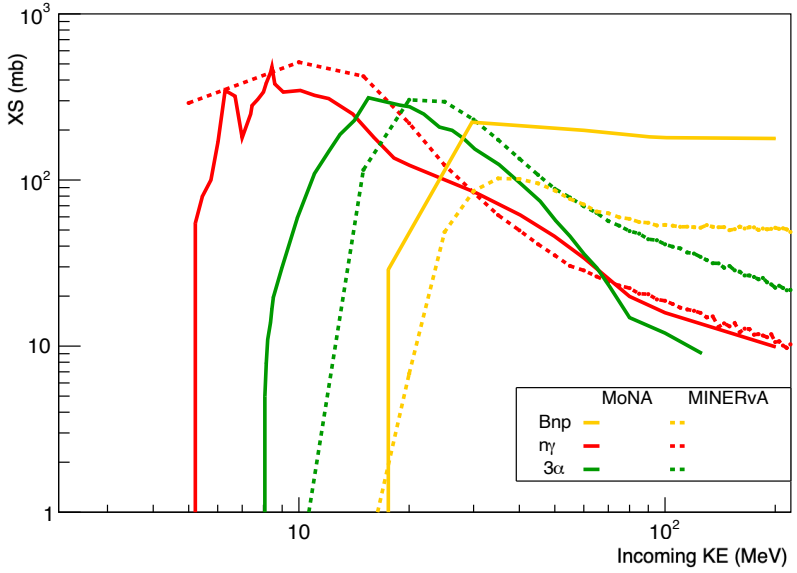
MENATE_R Geant4 Inelastic cross-sections, and JENDL inelastic from MoNA paper [1]

- As of Geant4 11, there is no plan to add MENATE_R as a neutron physics alternative.

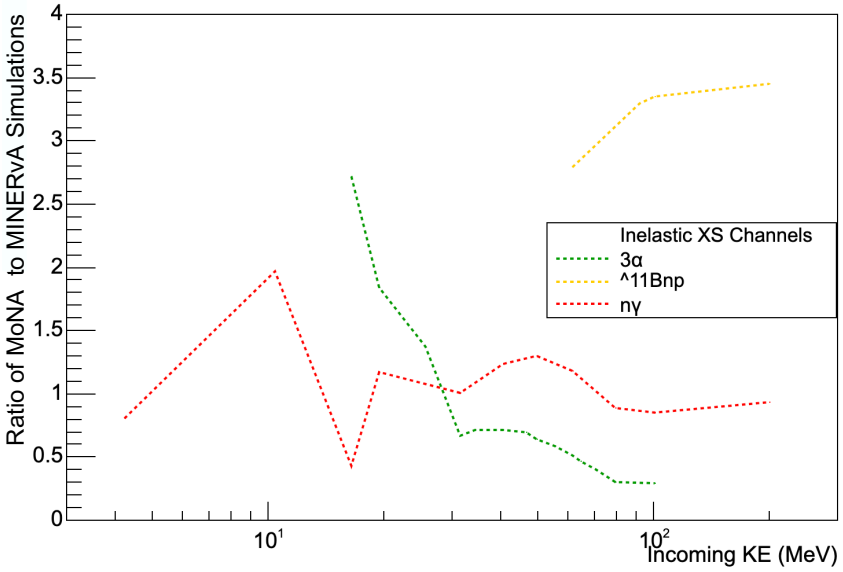
Reweighting MINERvA

Only the nGamma, threeAlpha, and Bnp are reweighted in MINERvA 's **GEANT4 9.04.p02**.

The reweighting used on MINERvA takes a list of neutron cross-section modes and a ROOT file with 'default' cross-sections and reweights those to fit the MoNA's **GEANT4 9.04.p01 + MENATE_R.**



The 3 leading cross sections for MINERvA and MoNA simulations



Ratio of MENATE_R MoNA XS to MINERvA QGSP_BERT XS

MnvHadronReweight/neutronInelasticReweight

"Reweights particles' interaction lengths based on the relative probability of interaction for a given xs.
If specific xs is reduced, events with long tracks are weighted up and short tracks weighted down.
Weight is calculated for each small section in the particle track, and the total product is used for that event.

$$W_{elastic}(X) = \frac{[1 - e^{-\rho X \sigma^{new}_{total}}]\frac{\sigma^{new}_{elastic}}{\sigma^{new}_{total}}}{[1 - e^{-\rho X \sigma^{old}_{total}}]\frac{\sigma^{old}_{elastic}}{\sigma^{old}_{total}}}$$

$$W_{inelastic}(X) = \frac{[1 - e^{-\rho X \sigma^{new}_{total}}]\frac{\sigma^{new}_{inelastic}}{\sigma^{new}_{total}}}{[1 - e^{-\rho X \sigma^{old}_{total}}]\frac{\sigma^{old}_{inelastic}}{\sigma^{old}_{total}}}$$

$$W_{no-interaction}(X) = e^{-\rho X(\sigma^{new}_{total} - \sigma^{old}_{total})}$$

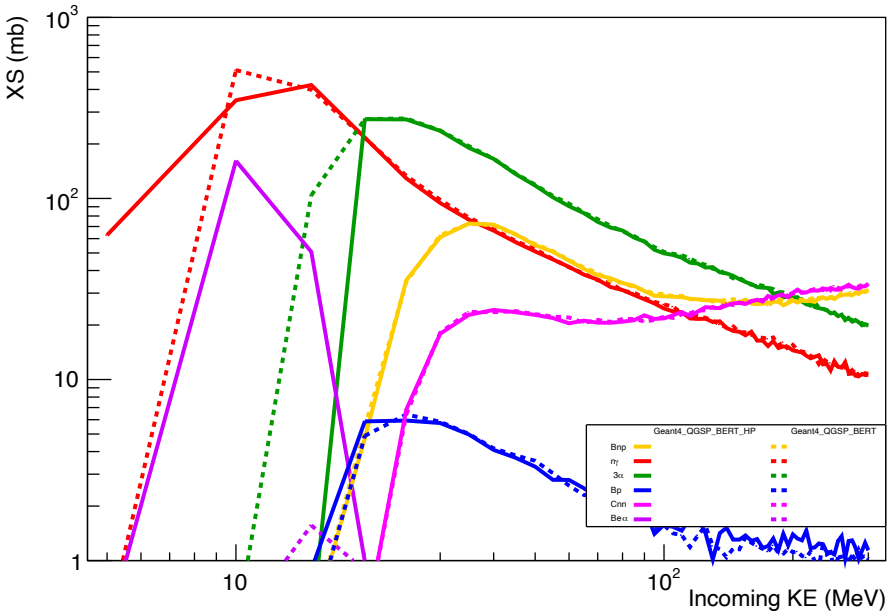
Reweighting the neutron xs changes the number of neutrinos in the sample; an adjustment to keep neutrino xs constant is necessary. Normalization factor N is chosen to keep the total number of neutrinos the same.
The sum of weights for all events is used.

$$\sum W_{original} = N \sum W_{reweighted}$$

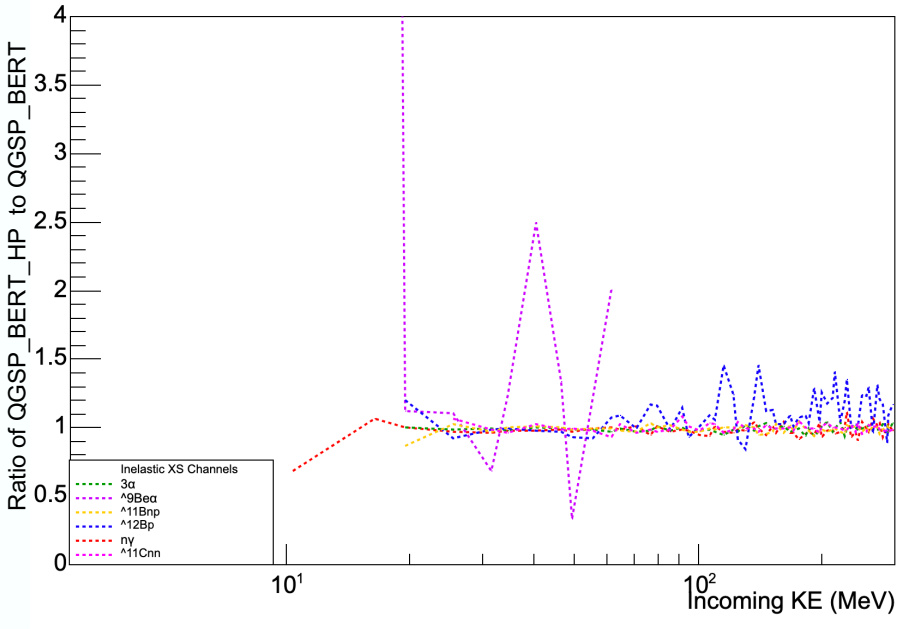
$$W'_{event} = N W_{event}$$

Neutron Transport in nd280Geant4Sim

- nd280Geant4Sim_7.3 uses , **Geant4 10.1.03.04** bertini cascade physics (**QGSP_BERT/QGSP_BERT_HP**) + **neutGeant4CascadeInterface** tune for pions (off by default)
- **QGSP_BERT_HP** is identical to **QGSP_BERT** > 20MeV. Below 20MeV HP samples from neutron xs data
- HP model increases nGamma and BeAlpha, but decreases 3alpha



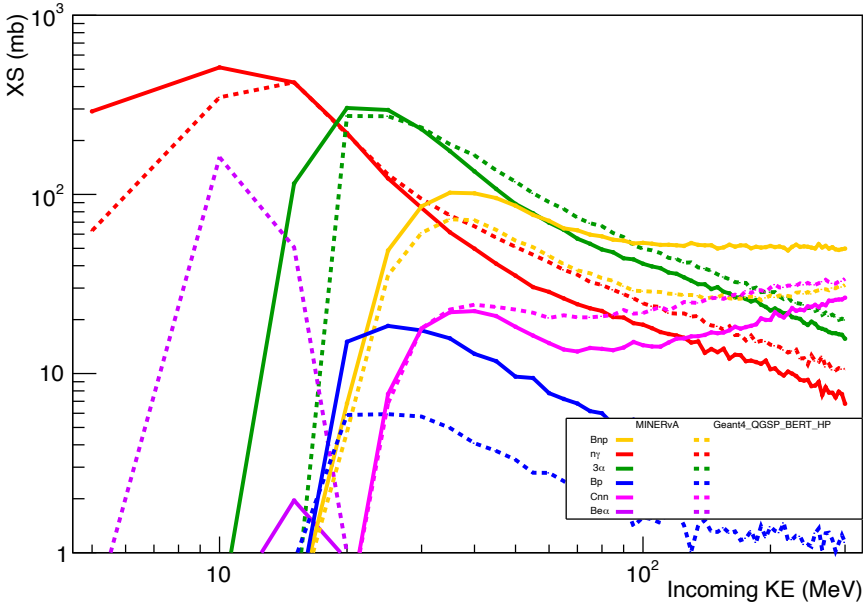
Neutron per channel xs simulated with Geant4 QGSP_BERT



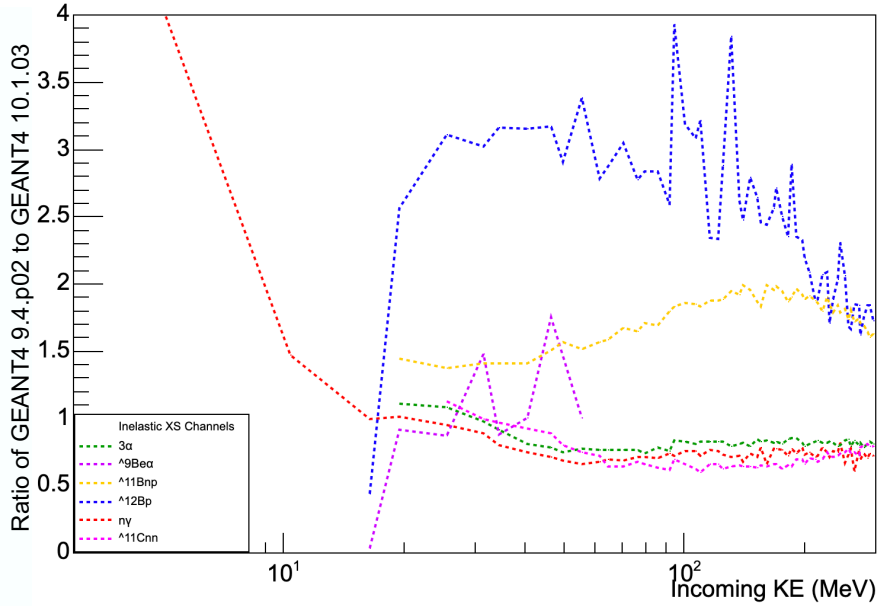
Ratio of High precision physics list to Bertini cascade physics list over 10-300MeV

Difference in GEANT4 Versions

- MINERvA **GEANT4 9.4 (QGSP_BERT)**, ND280 **GEANT4 10.1 (QGSP_BERT_HP)**
- Neutron scattering <20MeV is handled primarily by the **HP** model in **GEANT4 10.1**
- The ratio of **GEANT4 9.4** and **Geant4 10.1** neutron xs is **not 1**



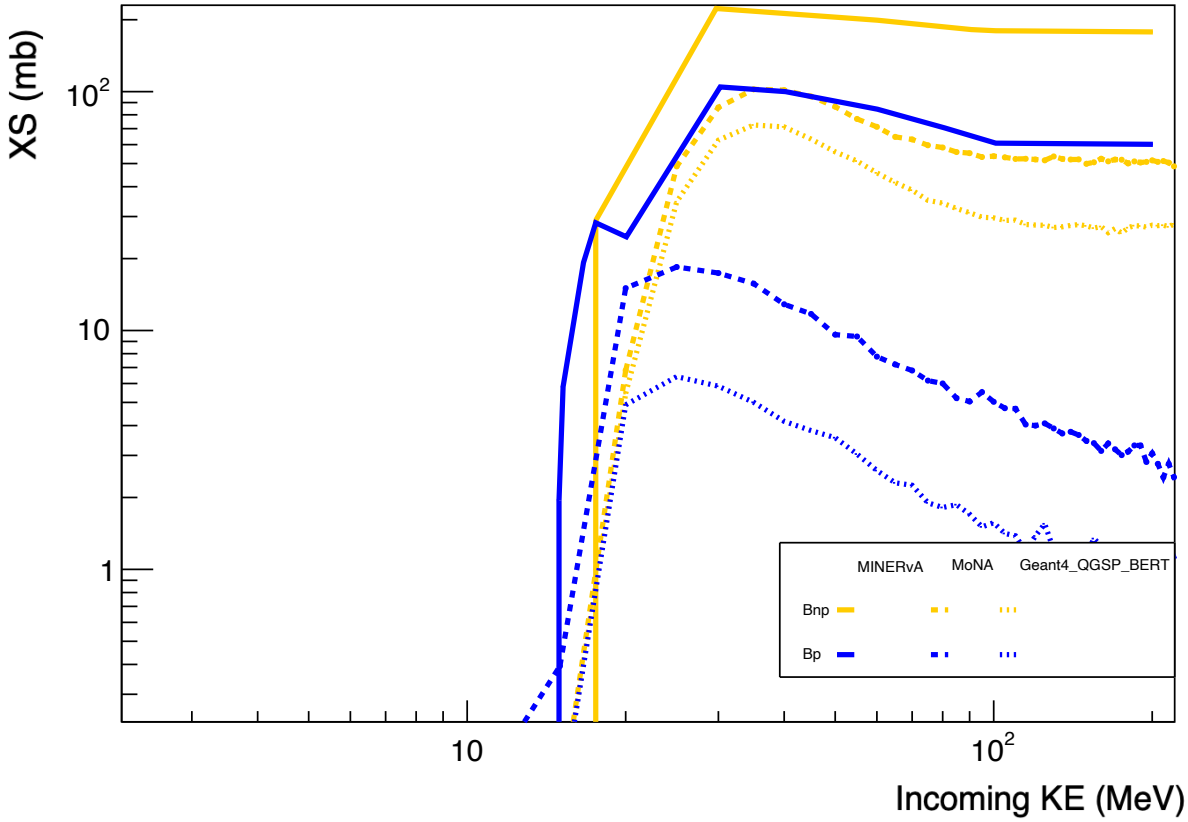
G4 9.4 neutron xs and G4 10.1 HP neutron xs



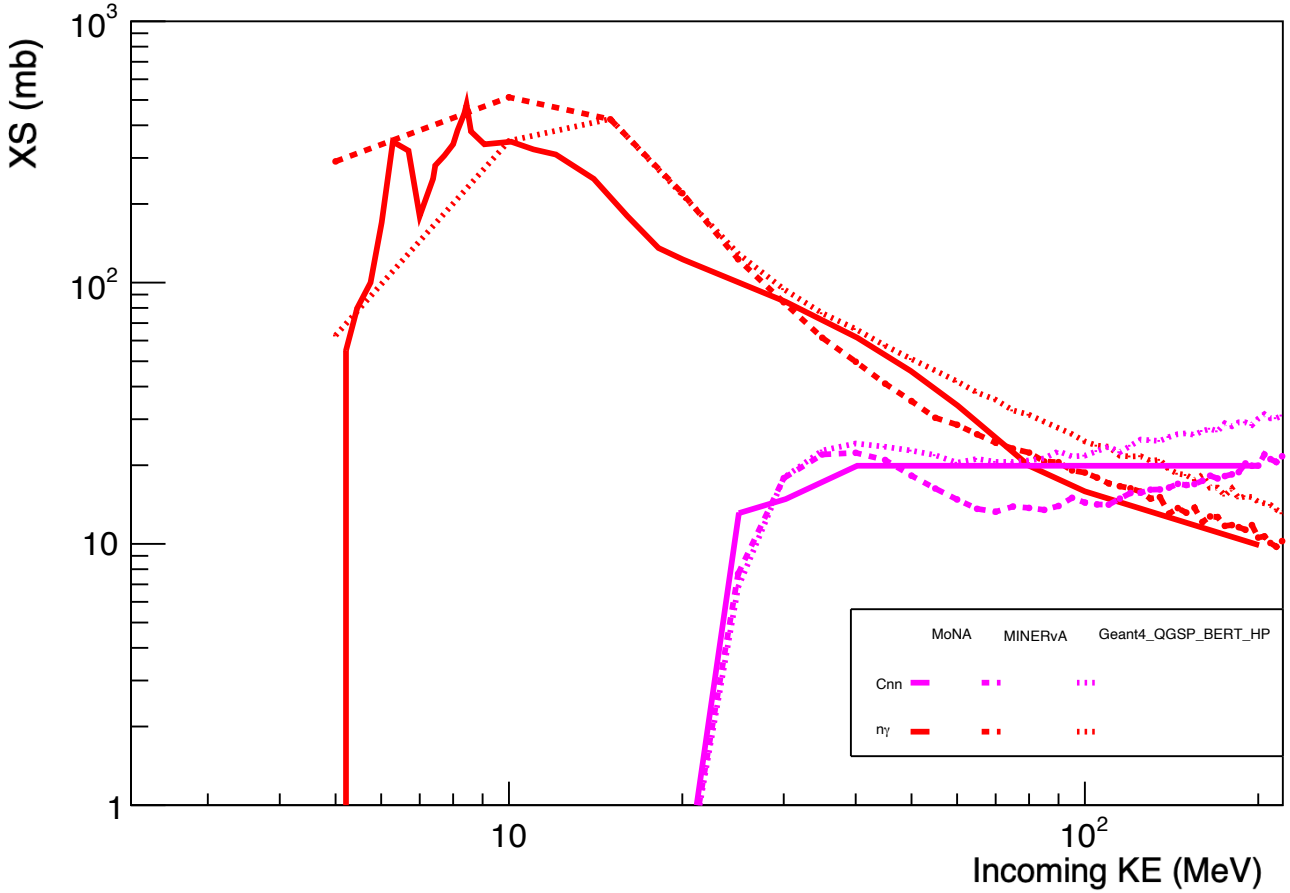
Ratio of G4 9.4 neutron xs to G4 10.1 HP neutron xs

Comparing Leading Visible XS

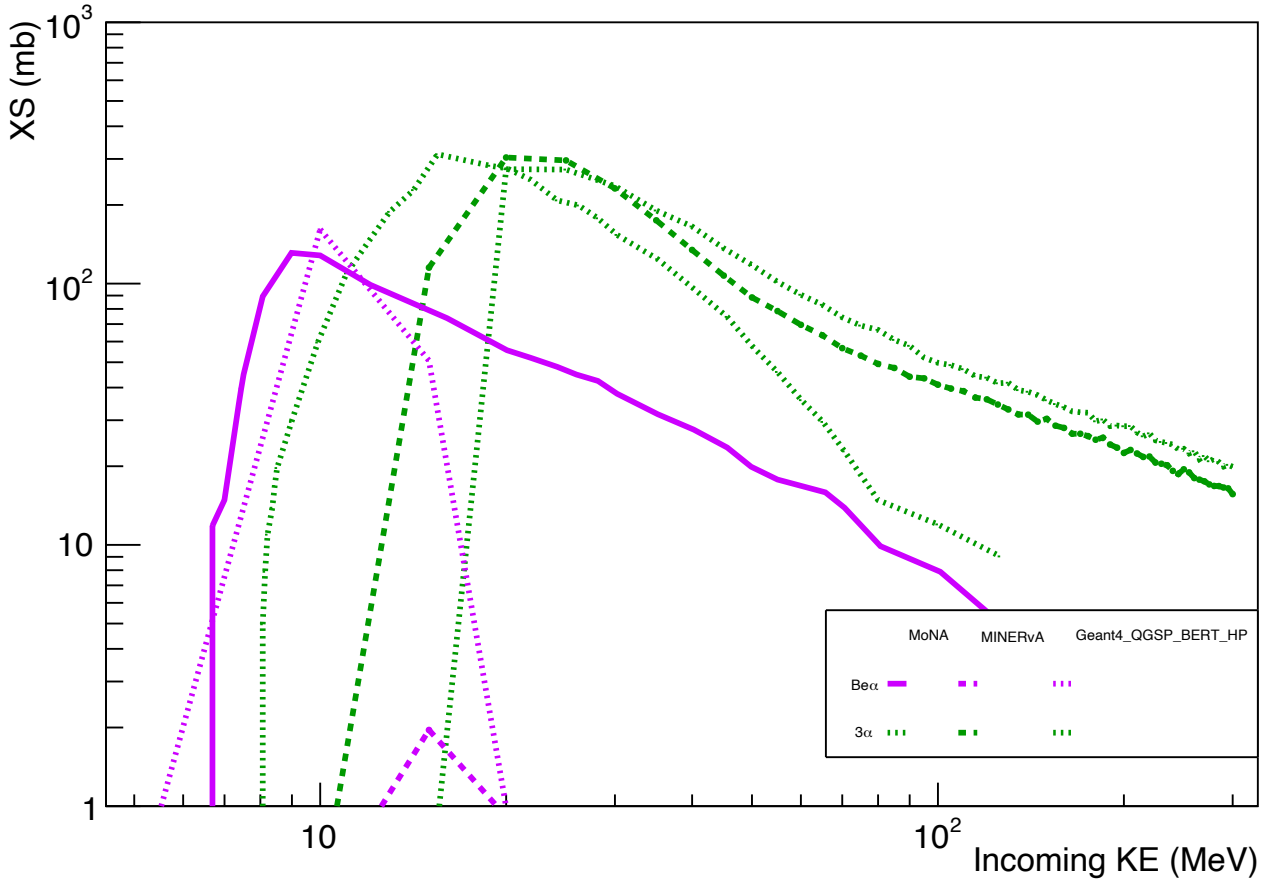
- Leading visible process, 11Bnp, appears with a 50-60% difference between Geant4 Versions
- Both Bnp and Bp lower overall in **Geant4 10.1**
- MINERvA did not reweight Bp, but discrepancy spans ~ an order of magnitude



Cnn and nGamma



Alpha Knockout and 3 Alpha dissociation



Summary

- Accurate neutron model is crucial for MINERvA, MoNA, and ND280
- MoNA's simulation using MENATE_R in GEANT4 does not agree with MINERvA's or ND280's GEANT4 Bertini Cascade Simulations.
- A High Precision Model (QGSP_BERT_HP) fixes problems <20MeV
- Newer versions of GEANT4 appear to have a 'worse' neutron model
  - GEANT4 9.4.p01 (MoNA)
  - GEANT4 9.4.p02 (MINERvA)
  - GEANT4 10.1.03.04 (ND280)
- A reweighting or implementation of MENATE_R into nd280Geant4Sim is necessary to accurate neutron physics
- Current work is focused on testing MENATE_R with GEANT4 10.1

References

[1] Kohley, Z. *et al.* **Modeling interactions of intermediate-energy neutrons in a plastic scintillator array with Geant4**. *Nuclear Instruments and Methods in Physics Research. Section A, Accelerators, Spectrometers, Detectors and Associated Equipment* 682. doi:10.1016/j.nima.2012.04.060 (Apr. 2012).

[2] **T2K ND280 Upgrade -- Technical Design Report.** arXiv:1901.03750.

[3] https://indico.physics.lbl.gov/event/1756/contributions/6251/

[4] Olivier, Andrew. **Neutrons in MINERvA and the Antineutrino Multi-Neutron Production Cross Section**. See GEANT, section 5.5, for cross section reweighting details. PhD Thesis (University of Rochester, Nov. 2022)

[5] Kleykamp, J. ***A-scaling of CCQE-like cross sections at MINERvA***. See GEANT reweighting discussion in section 3.2.1. PhD Thesis (University of Rochester, Sept. 2021).

Backup