Comparison of GENIE with Garino Data

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BNL

In collaboration with Steve Dytman

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Proton propagation in nuclei studied in the $(e,e'p)$ reaction

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Proton propagation in nuclei was studied using the $(e,e'p)$ reaction in the quasifree region. The coincidence $(e,e'p)$ cross sections were measured at an electron angle of 50.4° and proton angles of 50.1°, 58.2°, 67.9°, and 72.9° for ^{12}C, ^{27}Al, ^{58}Ni, and ^{181}Ta targets at a beam energy of 779.5 MeV. The average outgoing proton energy was 180 MeV. The ratio of the $(e,e'p)$ yield to the simultaneously measured (e,e') yield was compared to that calculated in the plane-wave impulse approximation and an experimental transmission defined. These experimental transmissions are considerably larger (a factor of ~ 2 for ^{181}Ta) than those one would calculate from the free N-N cross sections folded into the nuclear density distribution. A new calculation that includes medium effects (N-N correlations, density dependence of the N-N cross sections and Pauli suppression) accounts for this increase.

Introduction

- We want to compare GENIE with the electron-scattering data (MIT-Bates, SLAC, JLAB)
  - e-p elastic channel
  - electroproduction of charged π and ρ, also positive charged Kaon
- Start with Garino et al. (quasi-elastic ep)
  - Electron beam energy: 0.7795 GeV
  - Electrons are detected at 50.4 degrees
  - Protons are detected at 50.1, 58.2, 67.9, and 72.9 degrees
  - Target: 12C, 27Al, 58Ni, and 181Ta

Results from Garino et al.

- Results are presented as ratio of differential cross sections

$$R = \frac{d^2\sigma / d\Omega_e d\Omega_p}{d\sigma / d\Omega_e}$$

vs. proton angles in the lab frame

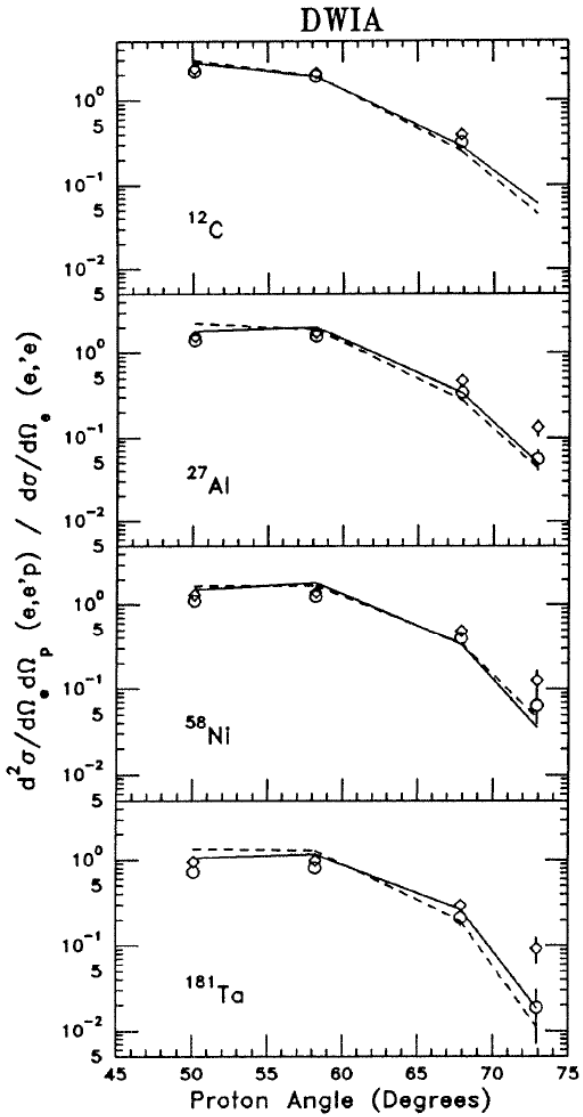


Figure VII.26 *Ratio of integrated coincidence yield to integrated singles yield compared to the DWIA results. Diamonds include radiative corrections only; circles include rescattering effects as well. Curves show DWIA results using initial off-shell prescription and energy dependent (solid) and energy independent (dashed) parameterizations.*

Step I: Run GENIE at Electron Scattering Model

- Update ./src/Conventions/Controls.h
  - kMinQ2Limit = 0.03 GeV^2
  - Electron scattering Xs are much more steeper in terms of Q^2
- Generate Xs splines and events with "–p 11"
  - 1 million events for each target

Step II: Understand Acceptance in Garino et al.

- Electron Arm: OHIPS spectrometer
  - Vertical acceptance +- 1.4 degrees
  - Horizontal acceptance +- 8.1 degrees
  - Momentum acceptance: +- 3.5%
- Proton Arm: BigBite spectrometer
  - Vertical acceptance +- 1.1 degrees
  - Horizontal acceptance +- 2.7 degrees
  - Momentum acceptance: +- 25%

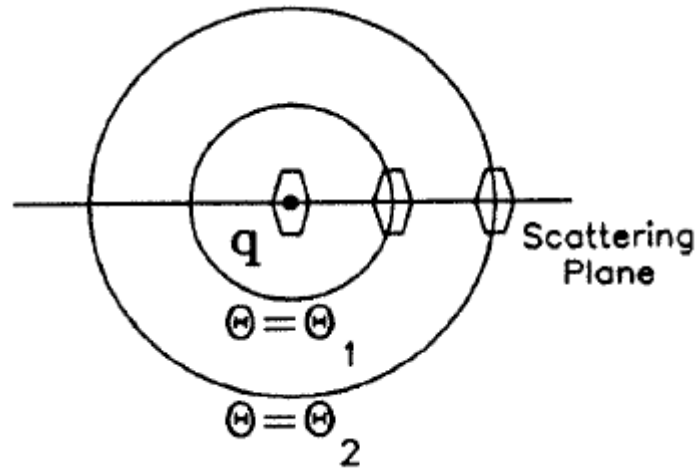
Define Kinematics

- In quasi-elastic process, the data are usually presented in terms of Em

$$p_r = p_{beam} - p_e - p_p$$

$$E = E_{beam} + m_{target} - E_e - E_p$$

$$E_m = m_p + \sqrt{E^2 - p_r^2} - m_{target}$$

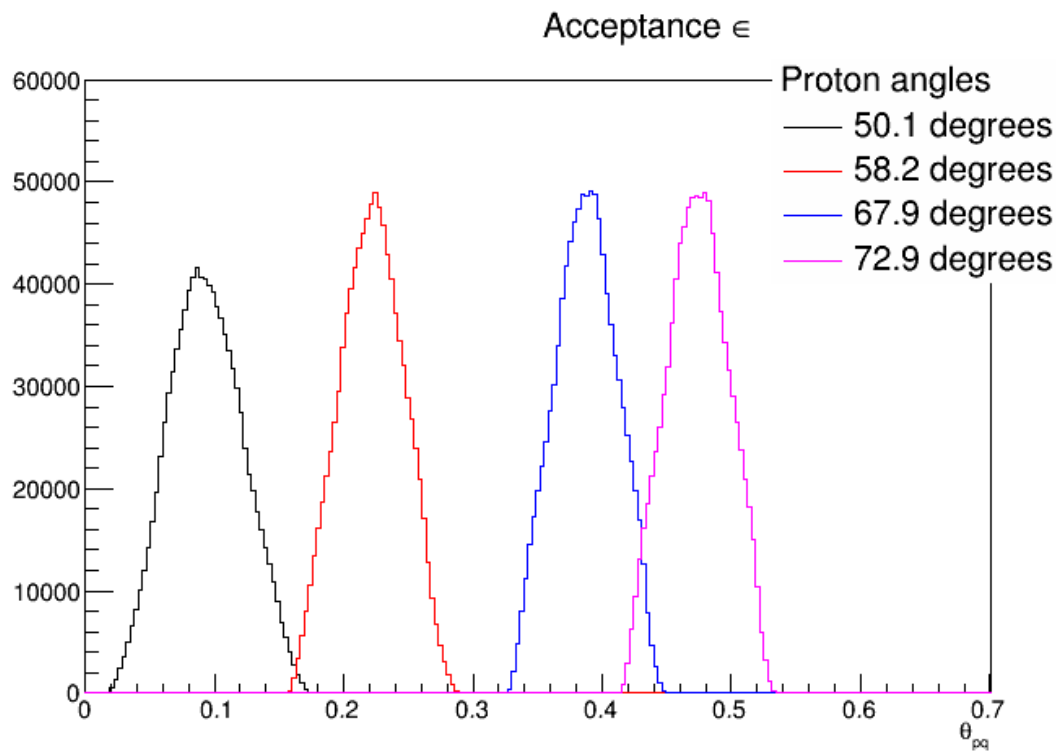


- For recoil proton, the essential kinematics is θ_{pq} the angle between proton and virtual photon (only determined by the electron kinematics)

Acceptance in terms of θ_{pq}

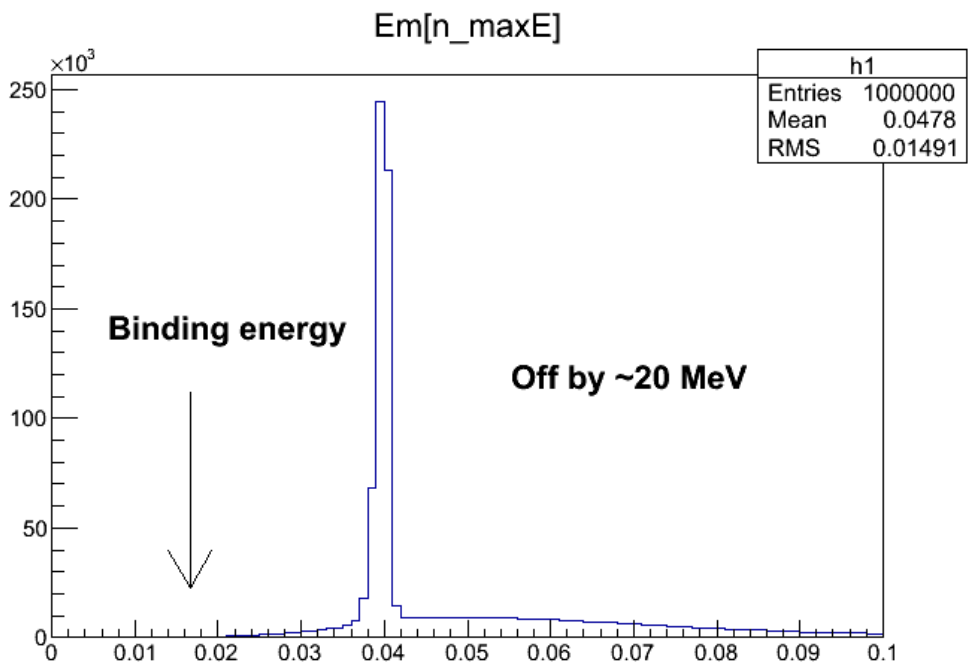
- Given the four proton angles, we modeled the acceptance with a toy MC

These acceptances are essential to perform average of cross sections



Step III: Sanity Checks

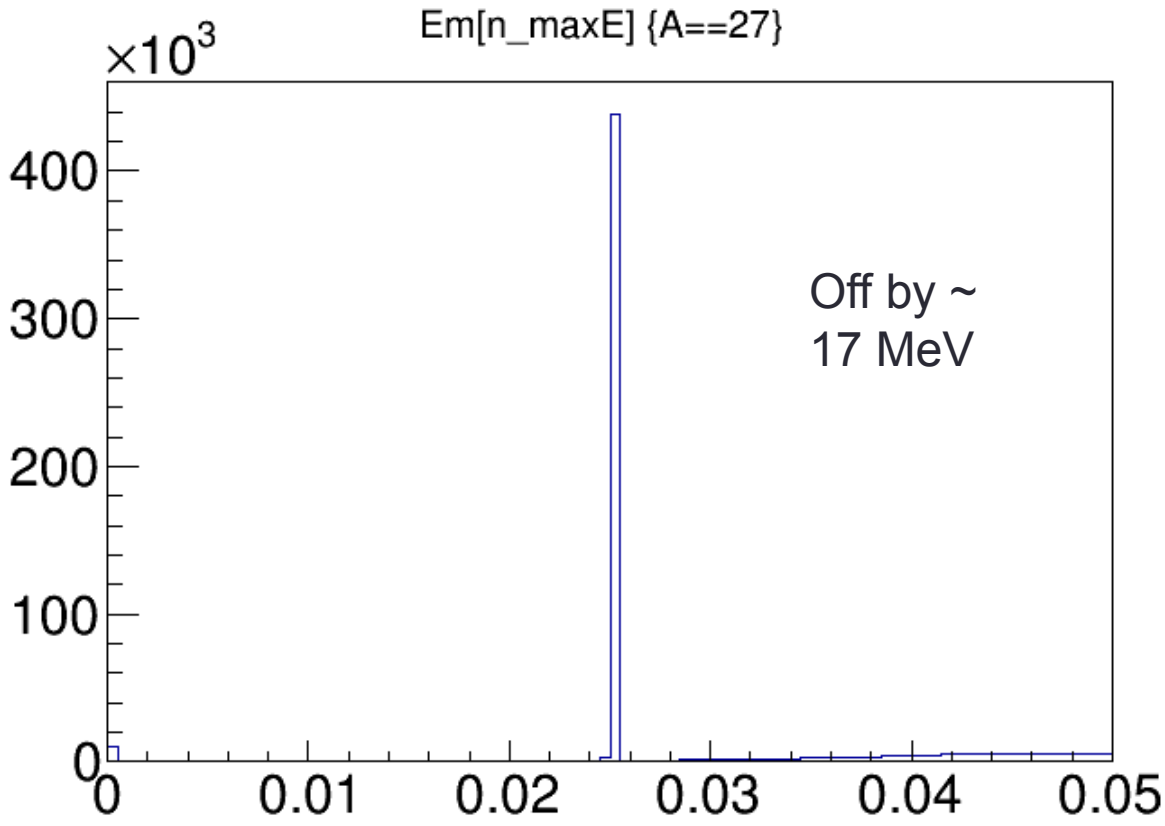
- We checked consistency between calculated Q2 vs. Q2s (from GENIE)
- We checked the binding energy



Carbon, binding energy should be
938.272 + (6*(938.272+939.565) - 938.272 – 76.205) -(6*(938.272+939.565) -92.162) MeV = 16 MeV

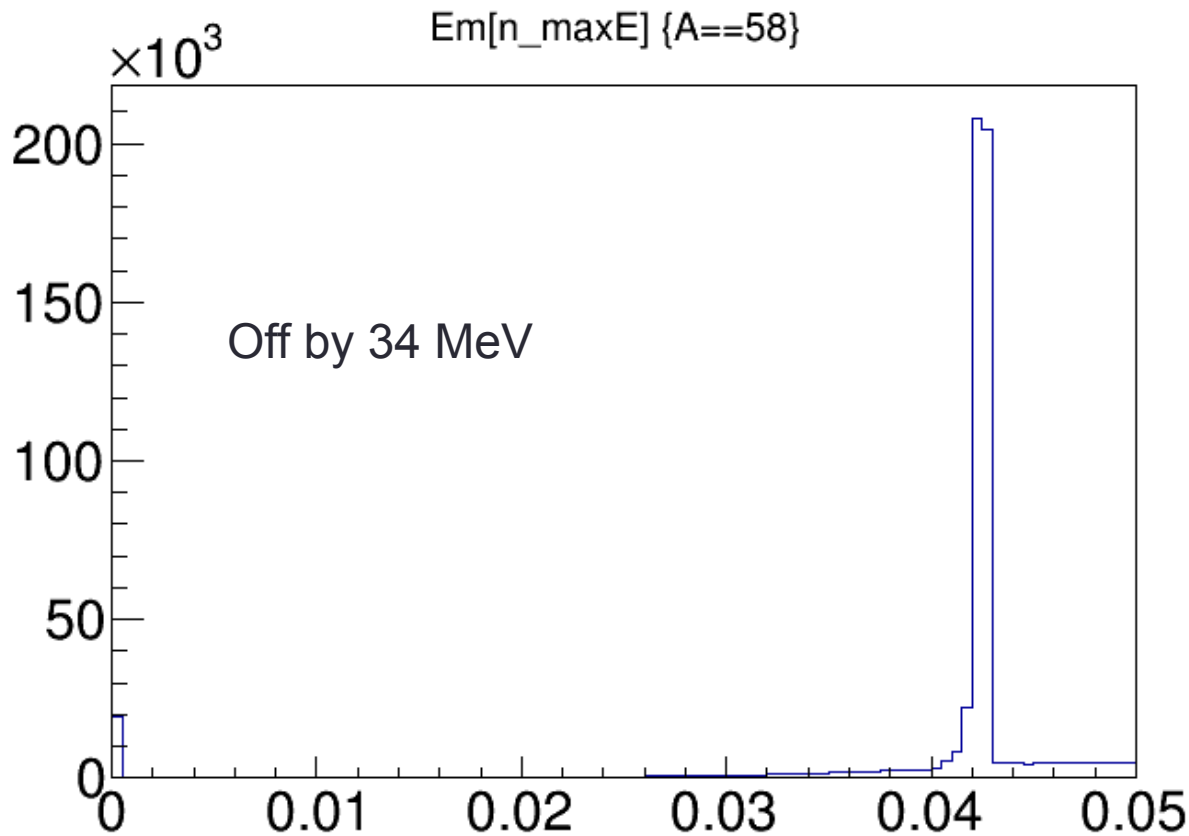
Binding energy of 27Al:

- 224.952 MeV – 216.681 ~ 8.3 MeV

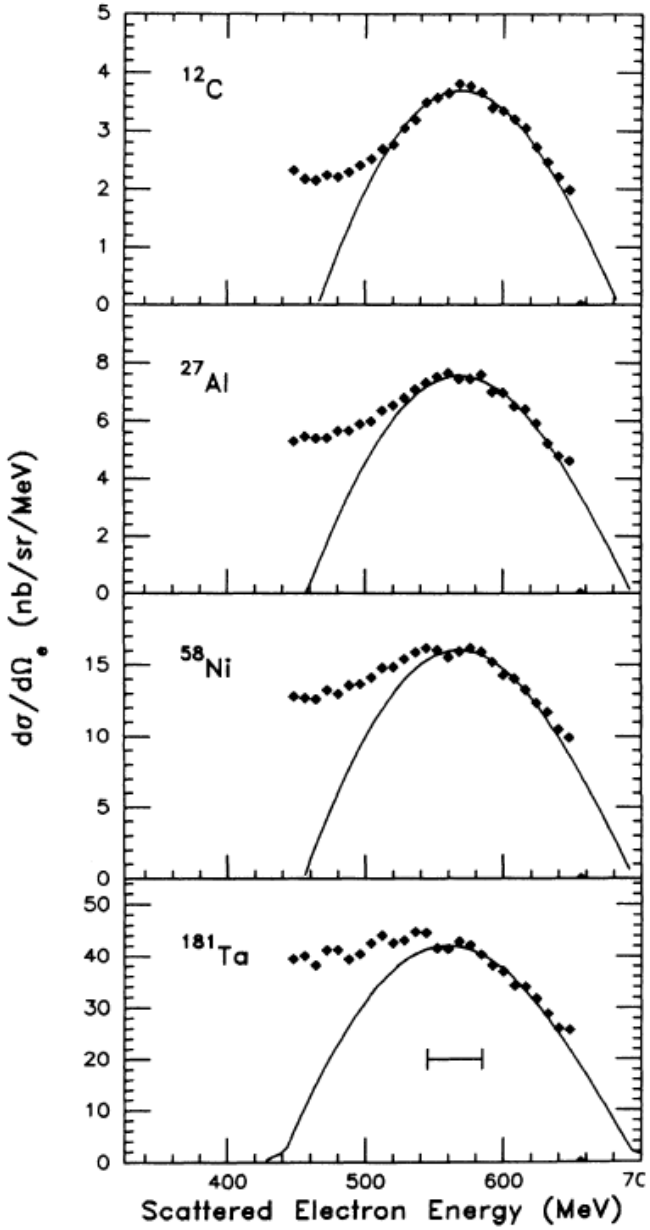


Binding energy of 58Ni

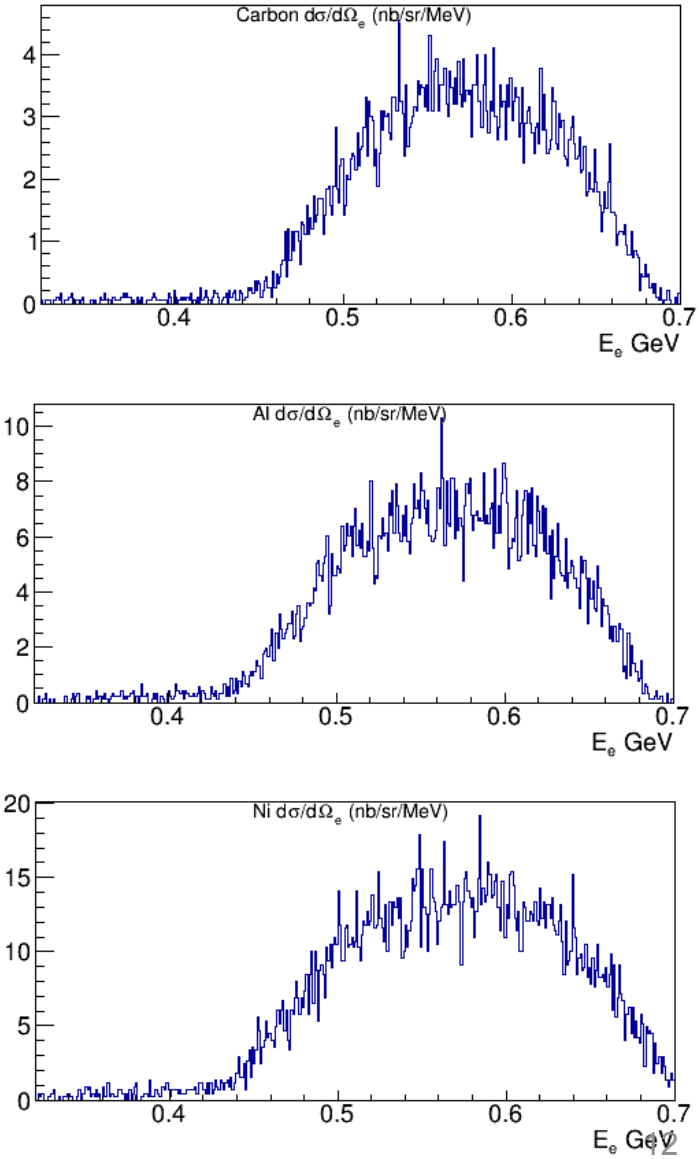
- 506.454 - 498.282 ~ 8.2 MeV



Electron diff Xs



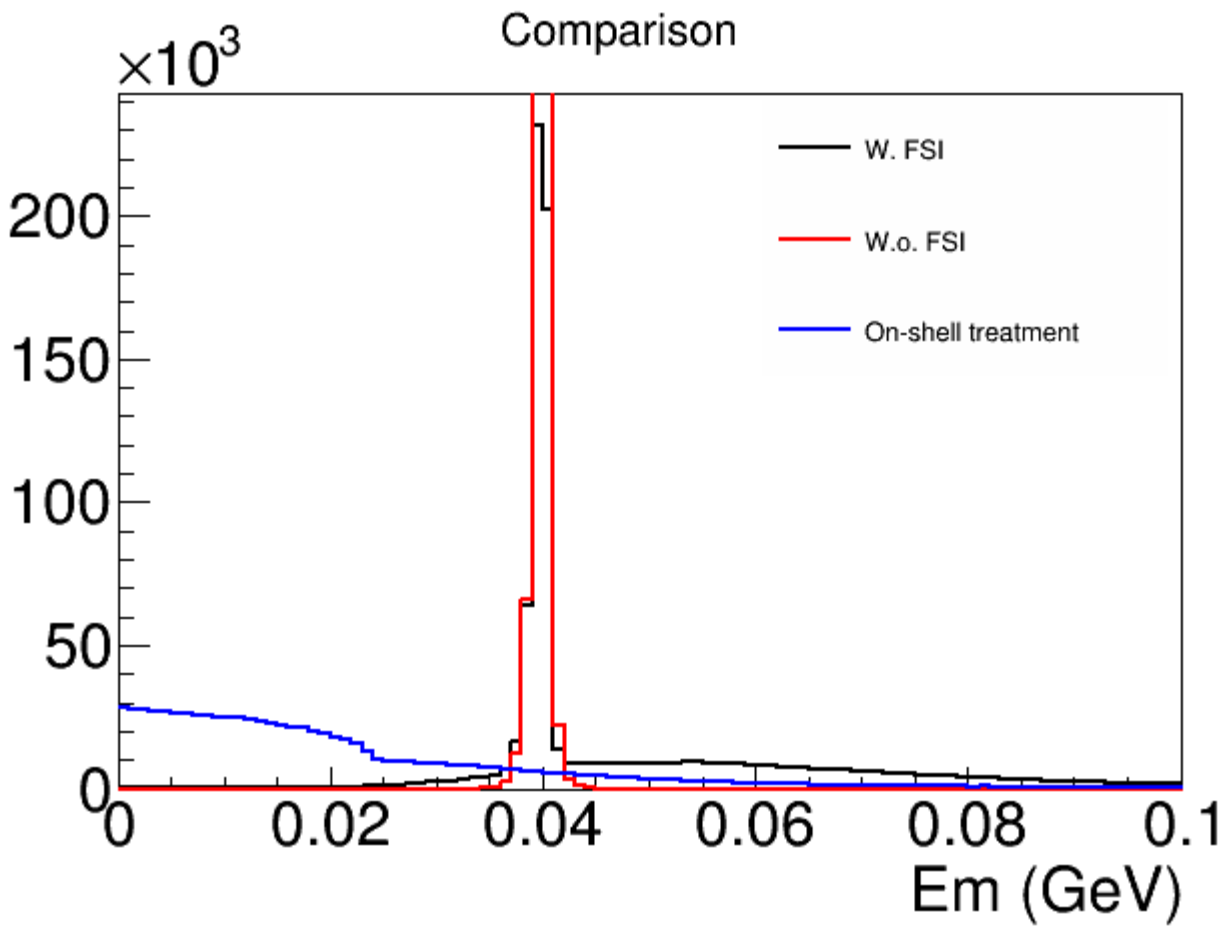
Good agreement



Comments

- It seems that the calculated separation energy is different from the expected ones
  - Need to dig a deeper to find out reasons
- For the differential cross section ratios, we can skip this for now
- Electron inclusive differential cross section agrees well between GENIE and Data

Comparison of Different treatments



On-shell treatment assumes the struck nucleon is on-shell

Method Description

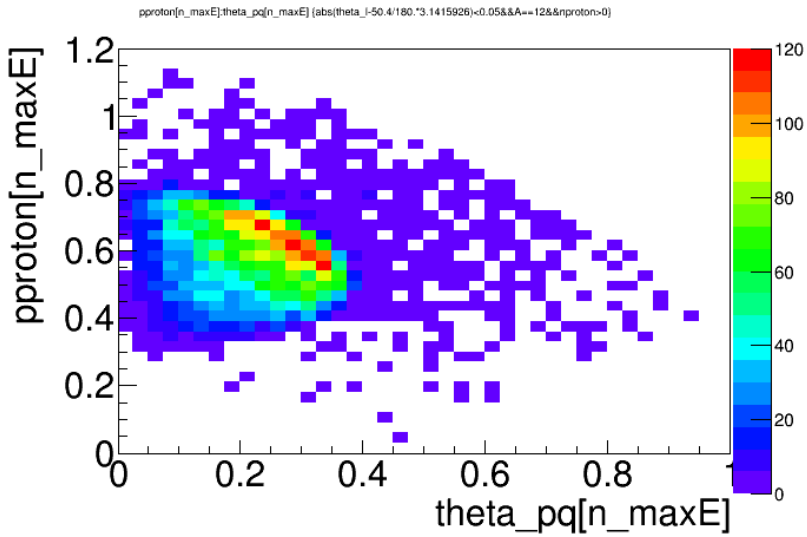
- With GENIE MC data
- Select electrons with 50.4 +- 1.1 degrees and momentum coverage 0.46→0.68 GeV
  - Note: since the results are presented in terms of ratio, a larger electron acceptance will be canceled
  - N_{tot}
- Select the most energetic proton with separation energy < 150 MeV and draw in terms of θ_{pq} : the angle between recoil proton and virtual photon: $N(\theta_{pq})$

Therefore, we have

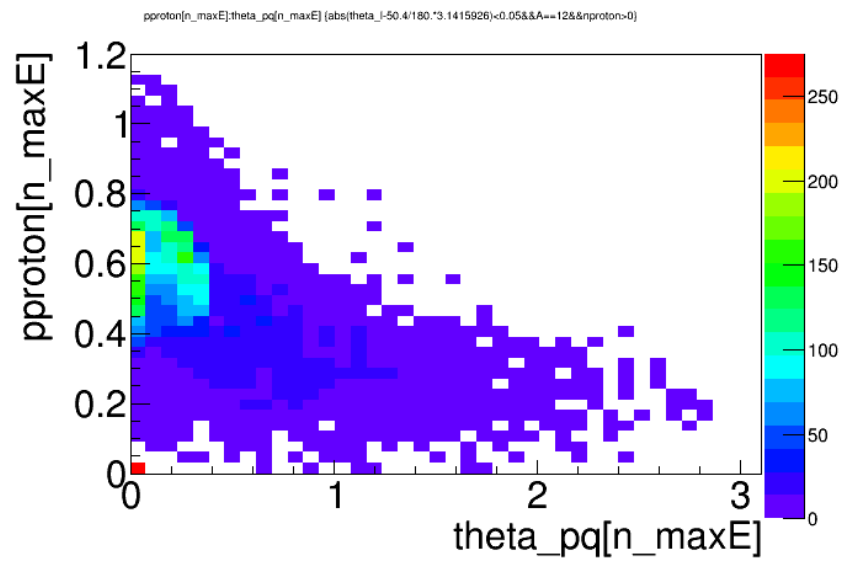
$$R = \frac{d^2\sigma / d\Omega_e d\Omega_p}{d\sigma / d\Omega_e} = \frac{\int N(\theta_{pq}) \cdot \varepsilon(\theta_{pq}) \cdot d\theta_{pq}}{N_{tot} \cdot \int 2\pi \cdot \sin(\theta_{pq}) \cdot \varepsilon(\theta_{pq}) \cdot d\theta_{pq}}$$

- Here, Ntot represents the inclusive electron Xs
- Integral over N is the numerator of double differential Xs
- Integral over sin(theta) is the denominatore of double differential Xs
- By using this formula, we use all possible azimuthal angles

Without FSI



With FSI



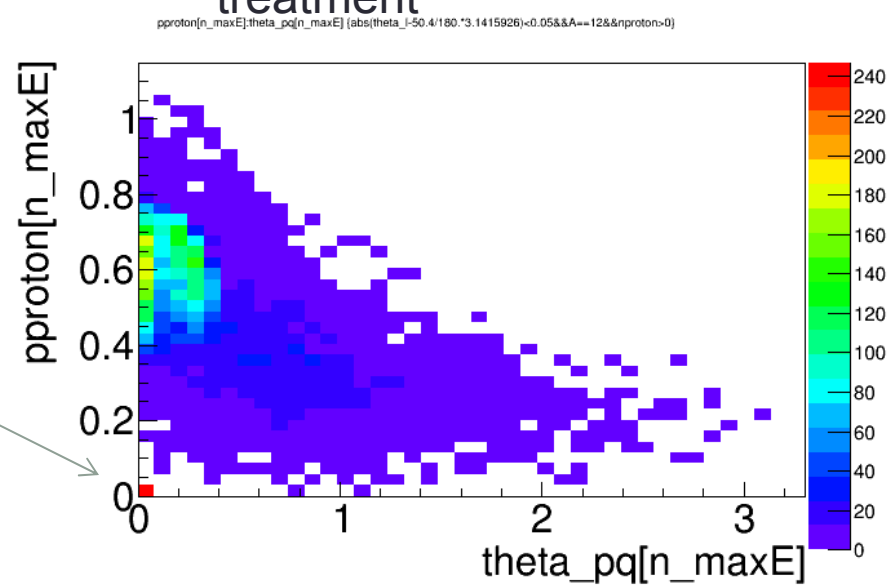
Comments:

Without FSI, the central momentum is about 600 MeV/c corresponding to 180 MeV kinetic energy

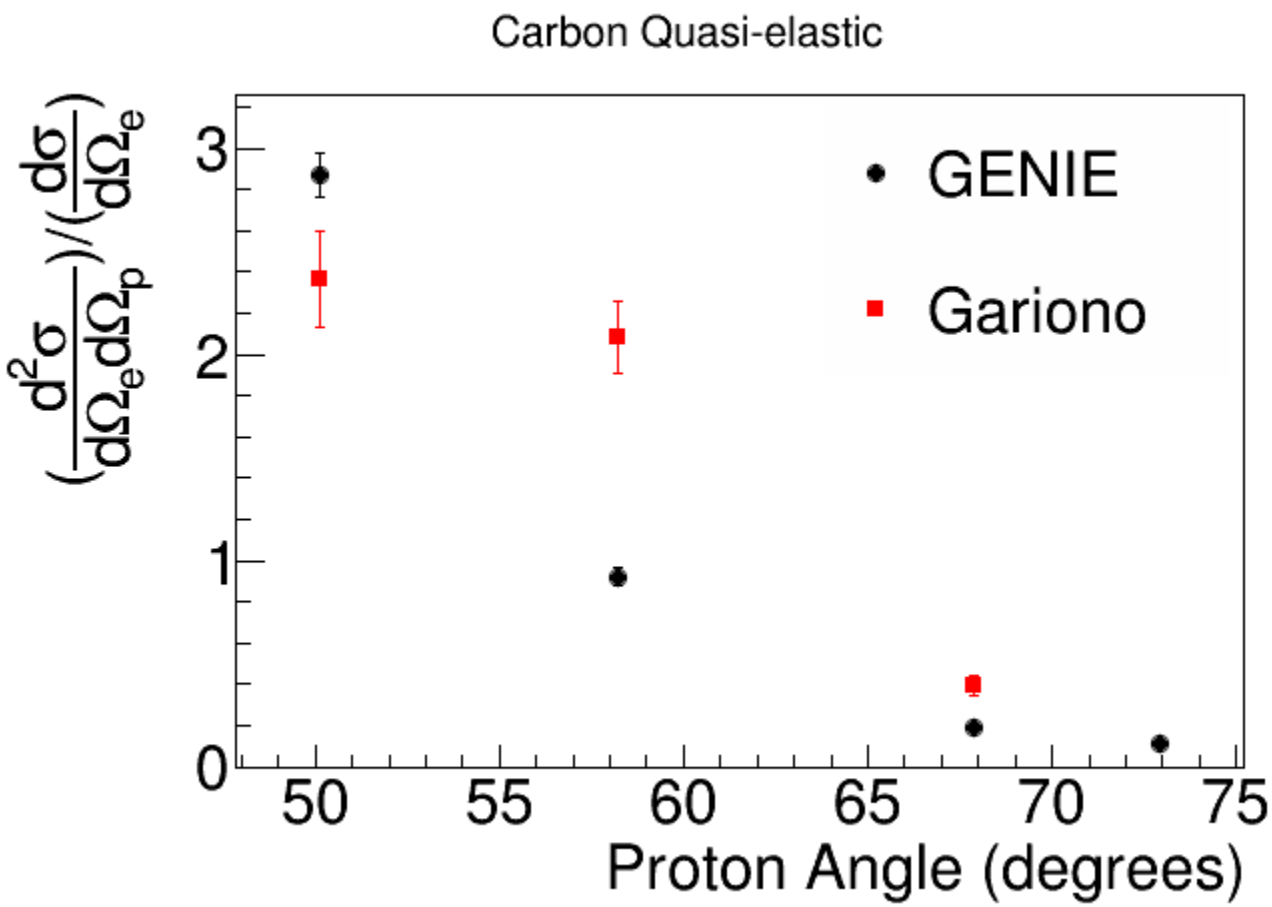
BigBite spectrometer has momentum cutoff about +- 25%

With FSI, there are some protons have energy = 0

With FSI + Onshell treatment

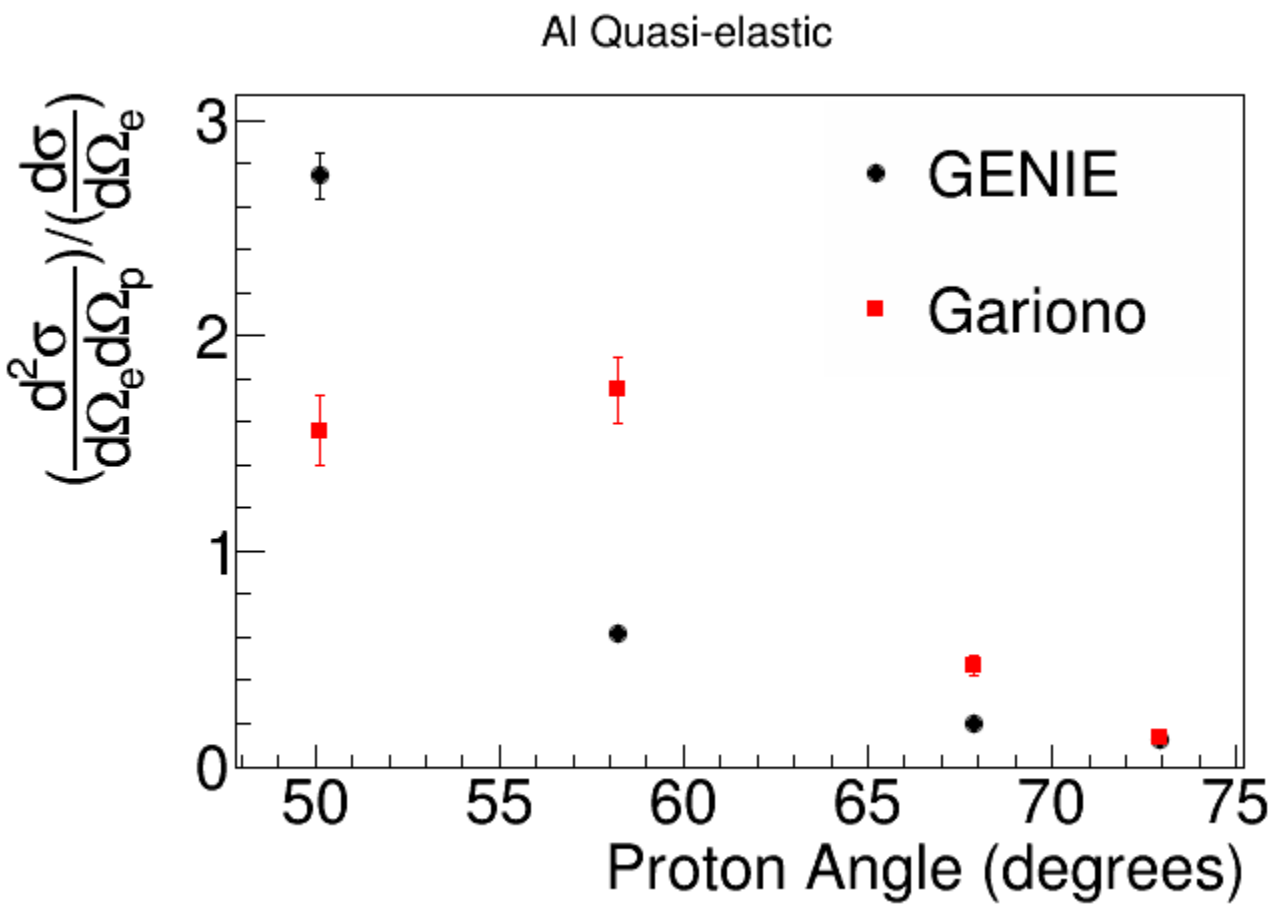


Results of 12C



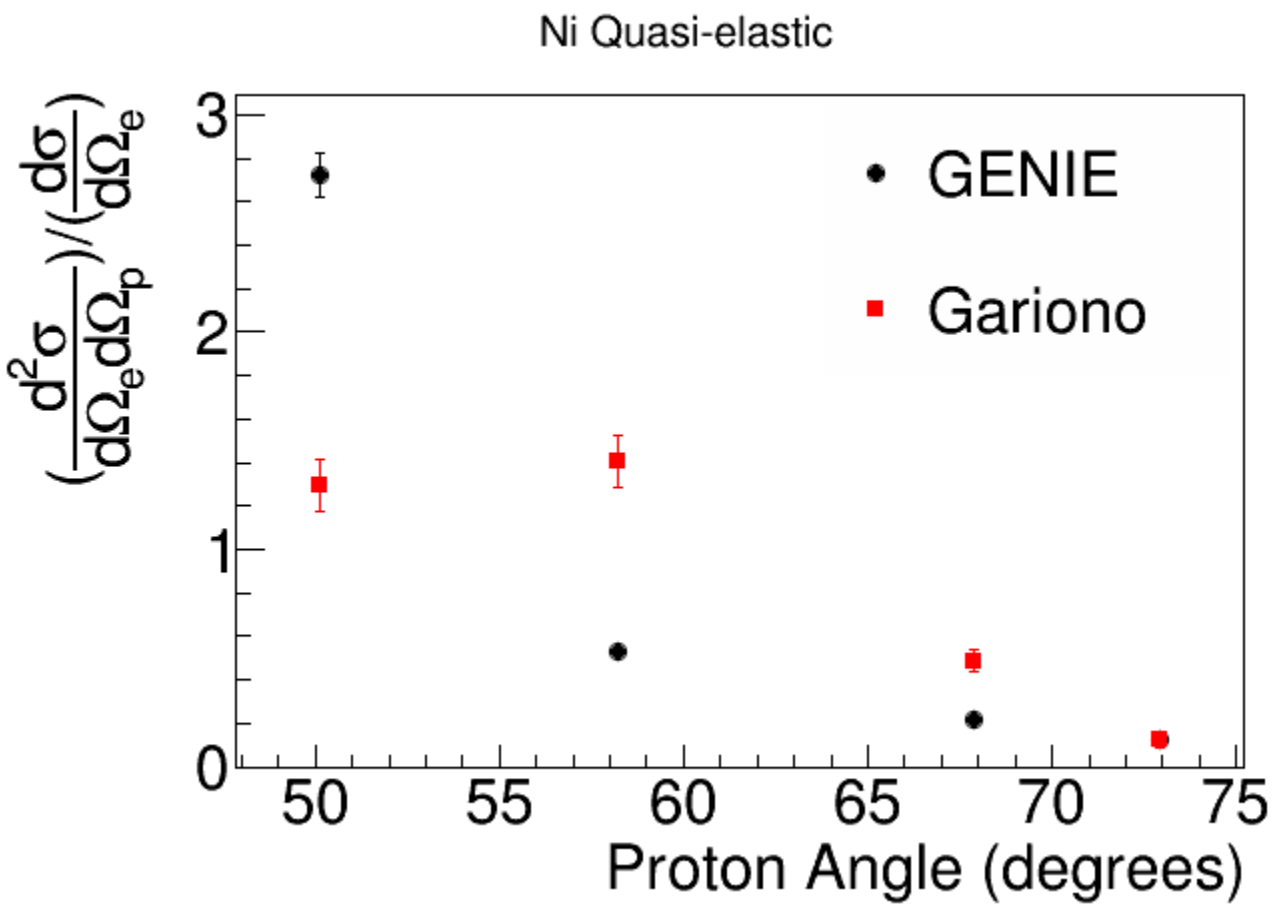
No proton momentum cutoff

Results of 27Al

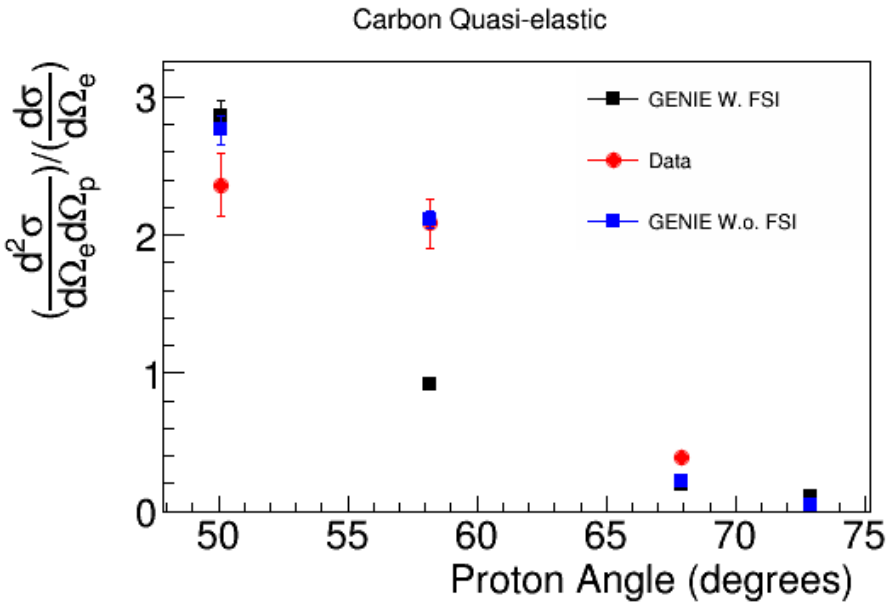


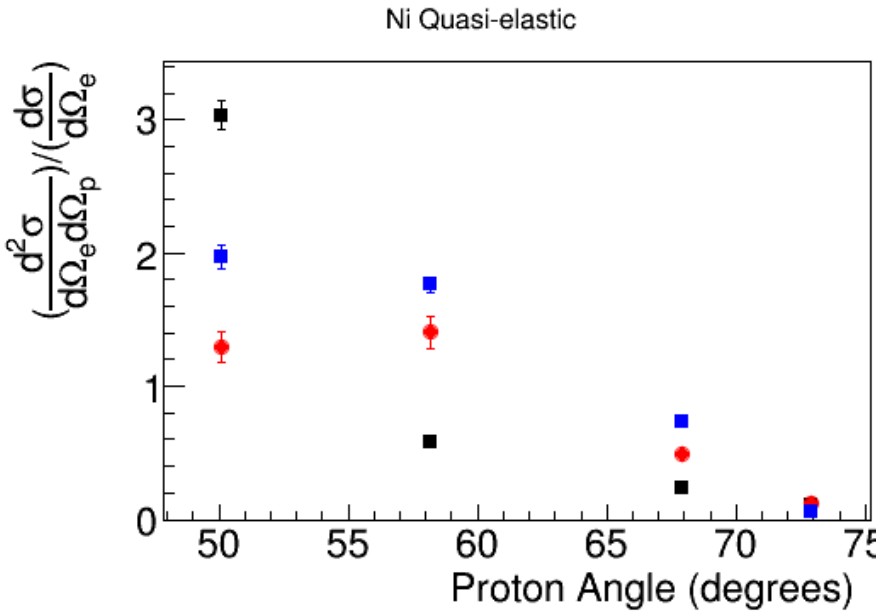
No proton momentum cutoff

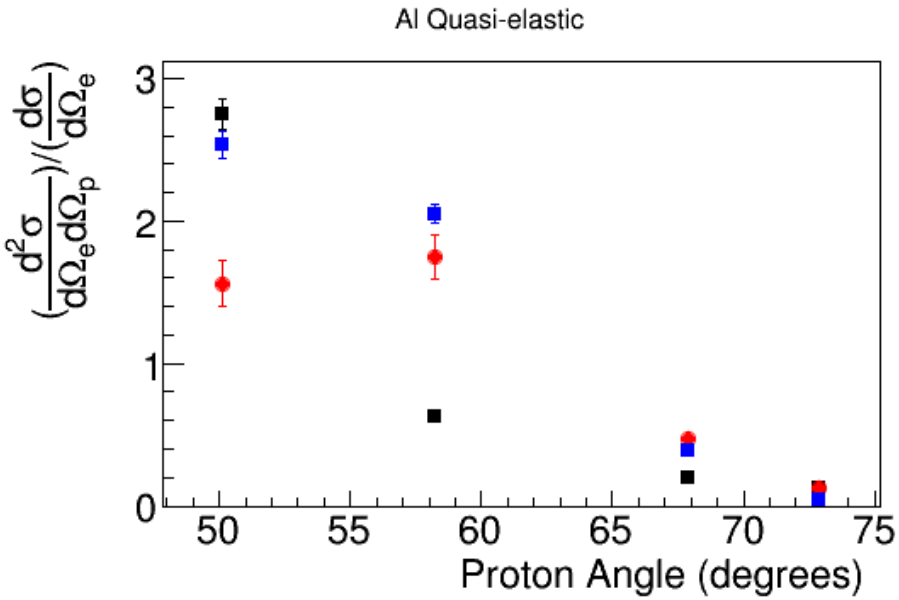
Results of 58Ni



No proton momentum cutoff



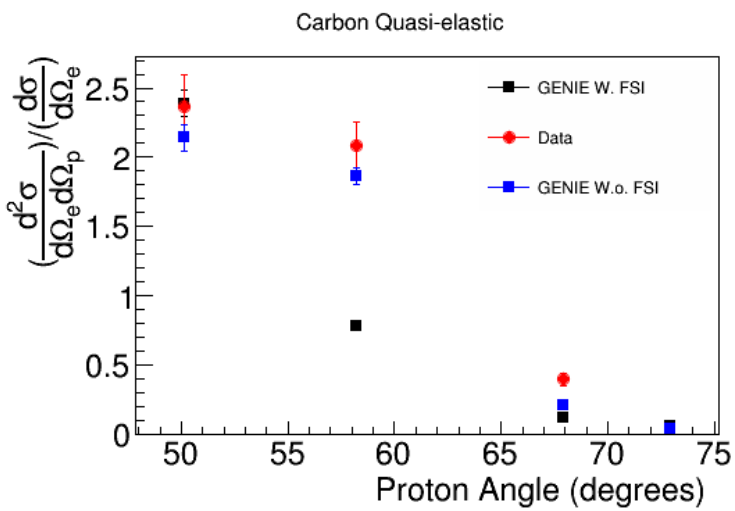


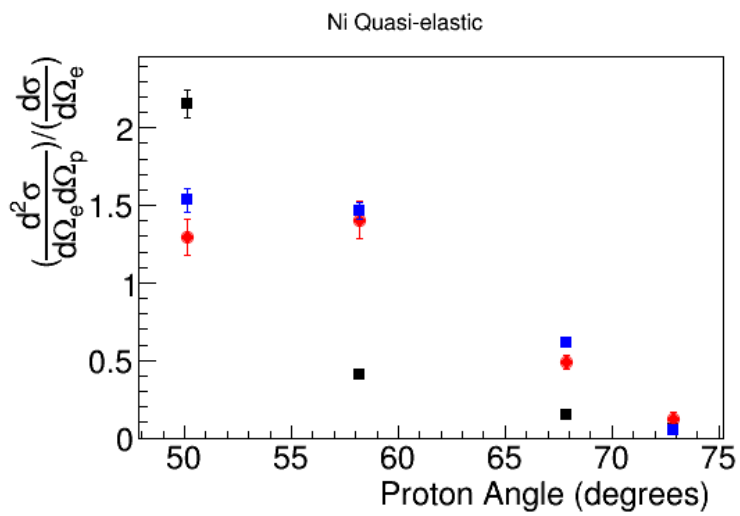


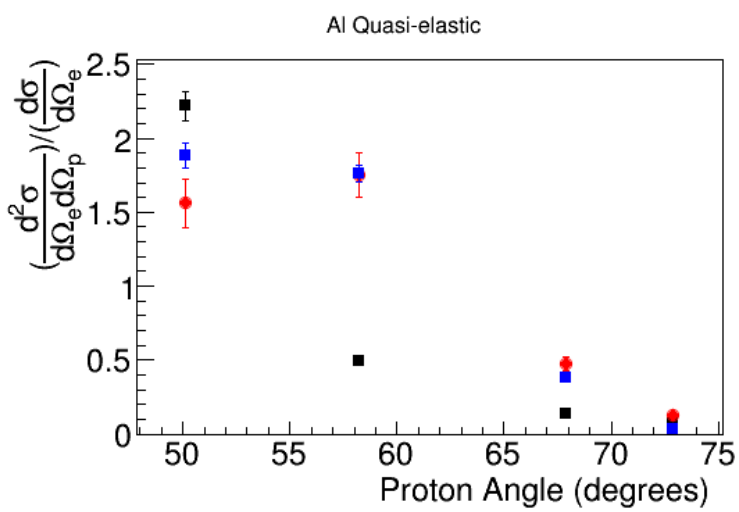
Comparison with different FSI treatments

No proton momentum cutoff

Add a proton momentum cut 450→750 MeV





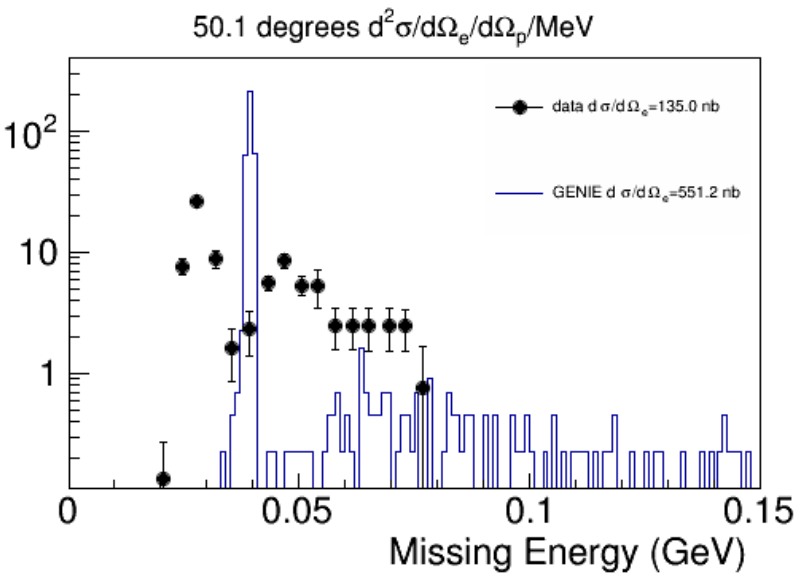


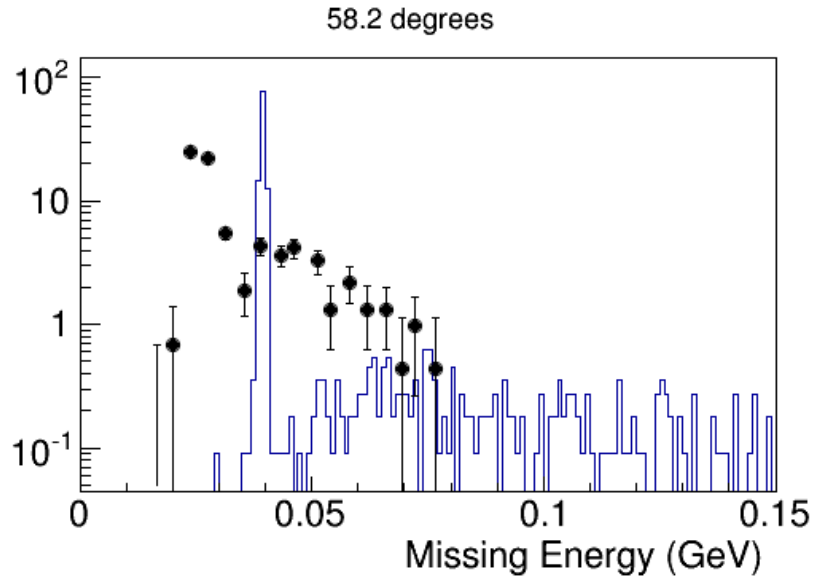
Seems that GENIE without FSI can describe the data better

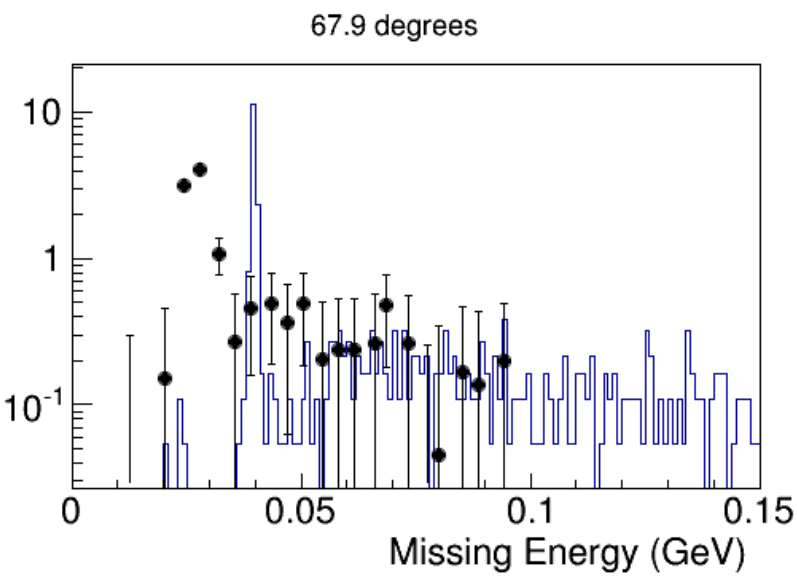
Comments

- Compared with data
  - GENIE's recoil proton with FSI are more aligned with the virtual photon direction
  - GENIE's recoil proton without FSI agrees better with data
    - Part of the problem could be with the final state interaction between recoil proton and medium
    - Could partly due to initial state as well (nucleon-nucleon short/medium/long range correlation)

Carbon Double diff Xs comparison







Data has a momentum cut 545 → 585 MeV for electrons

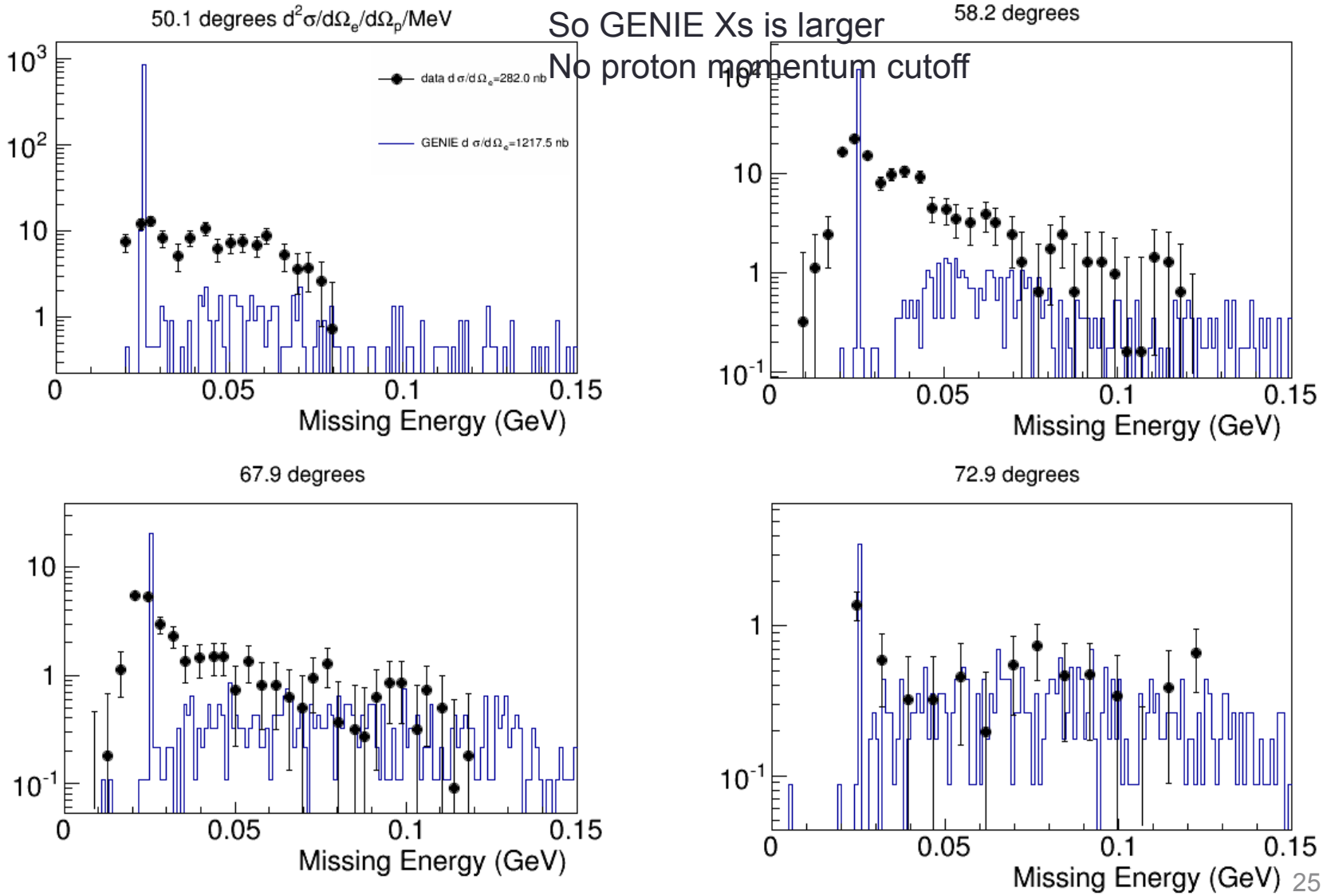
So GENIE Xs is larger

nb/sr/sr/MeV

No proton momentum cutoff

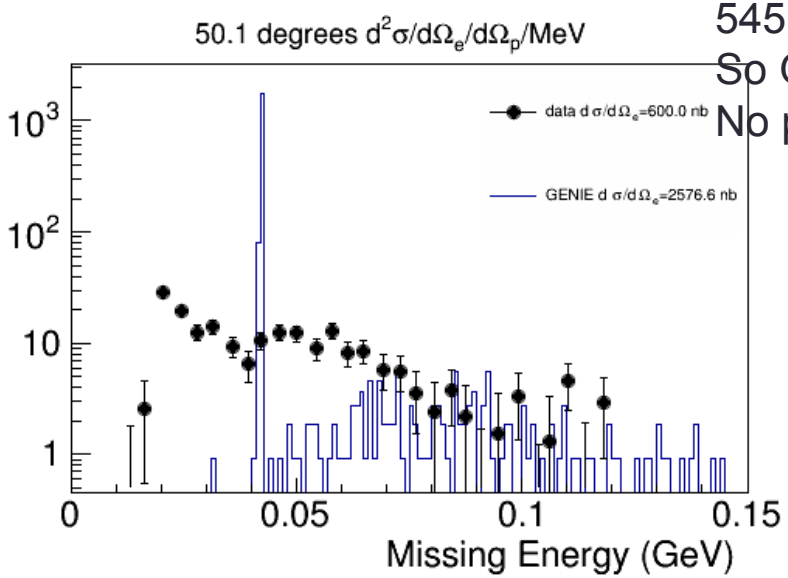
Al double diff Xs comparison

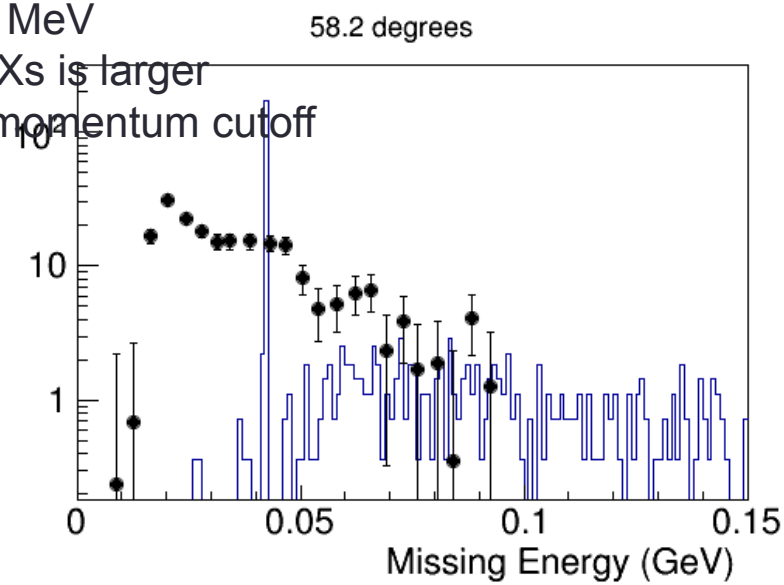
Data has a momentum cut
545 → 585 MeV
So GENIE Xs is larger
No proton momentum cutoff

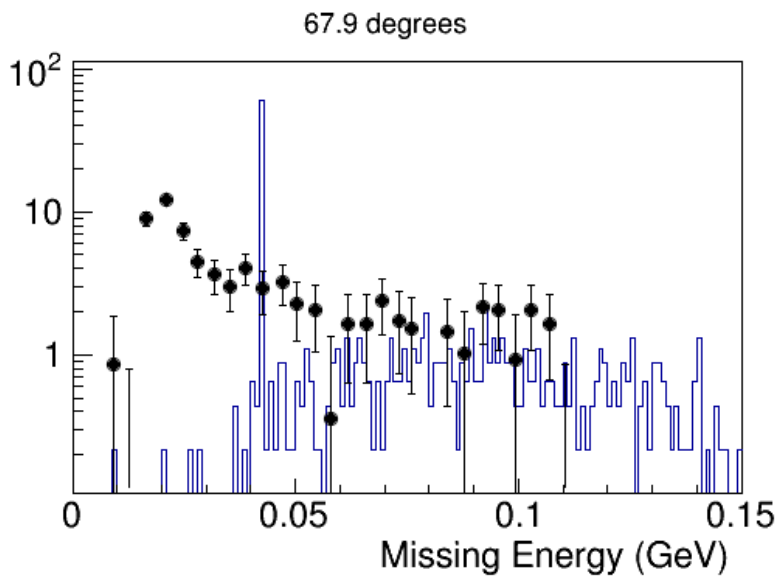


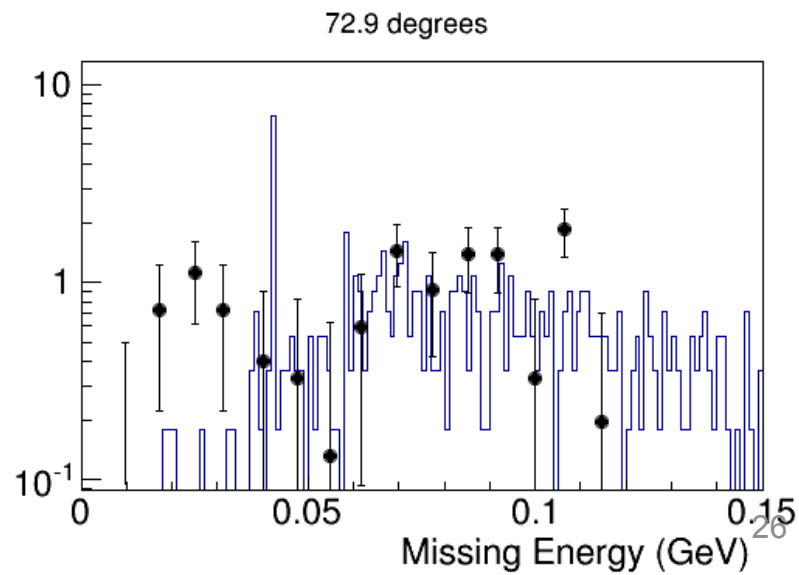
Ni Double diff Xs Comparison

Data has a momentum cut
545 → 585 MeV
So GENIE Xs is larger
No proton momentum cutoff

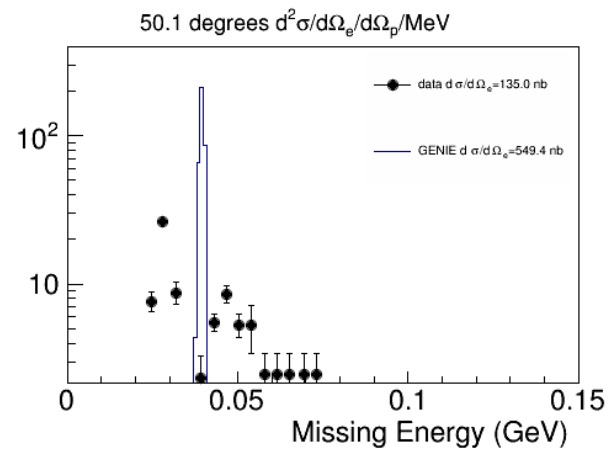


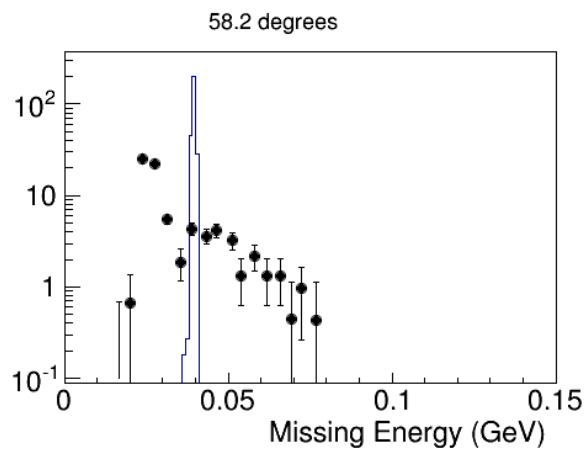


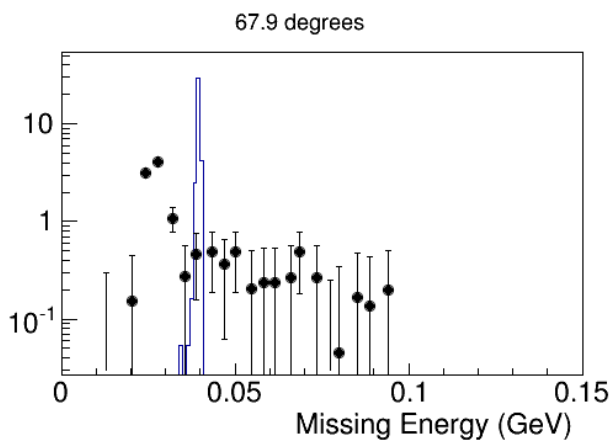




What about GENIE without FSI?

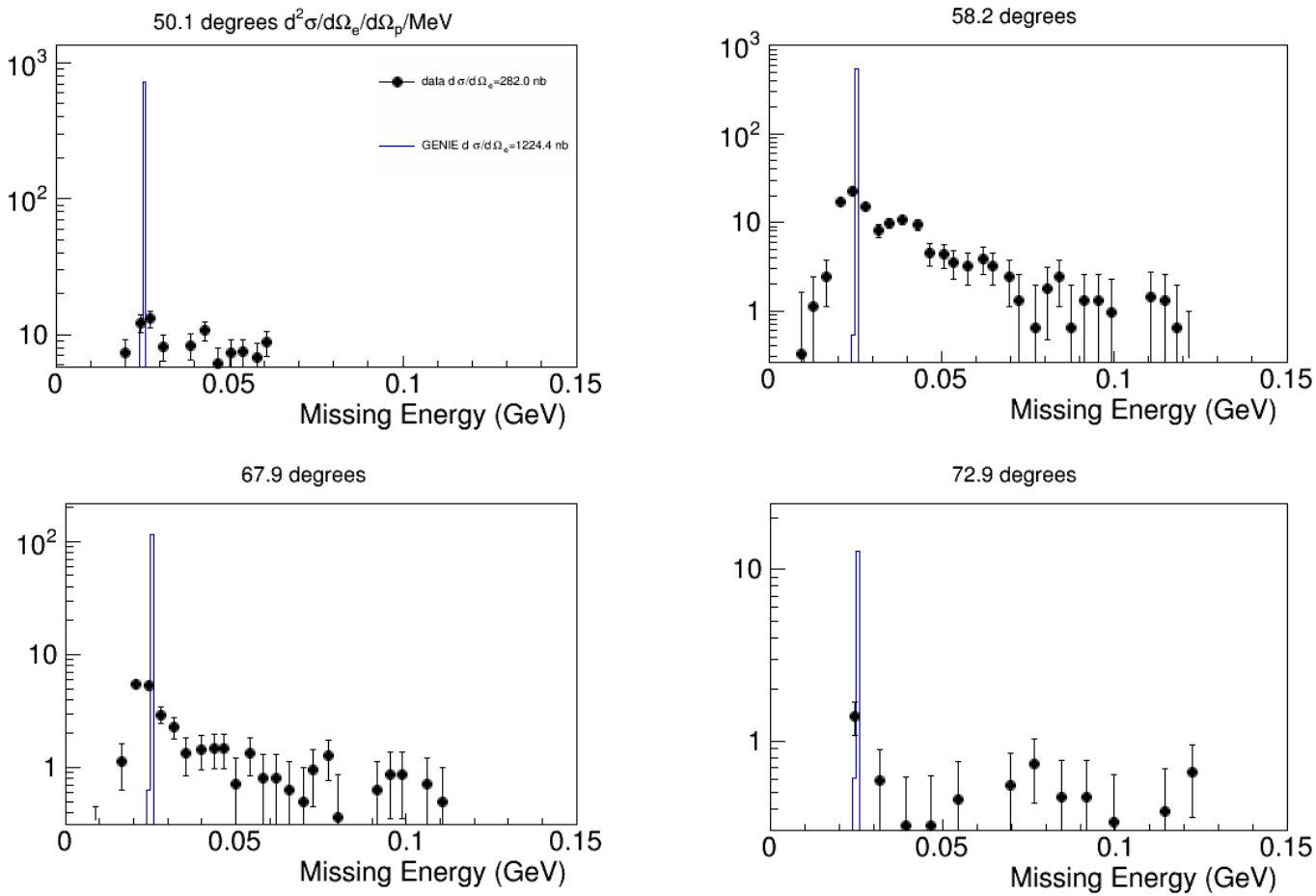




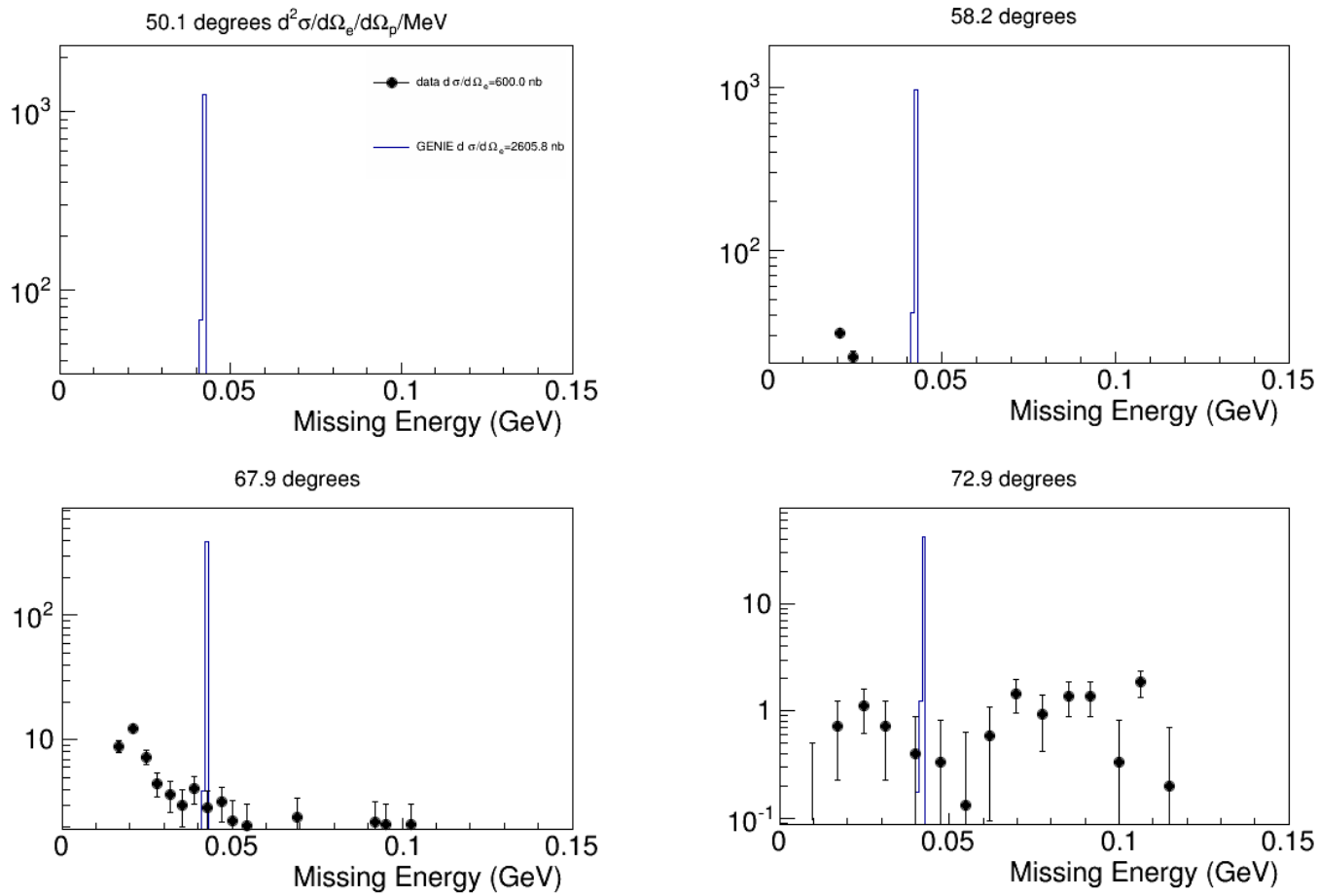


Carbon

Al

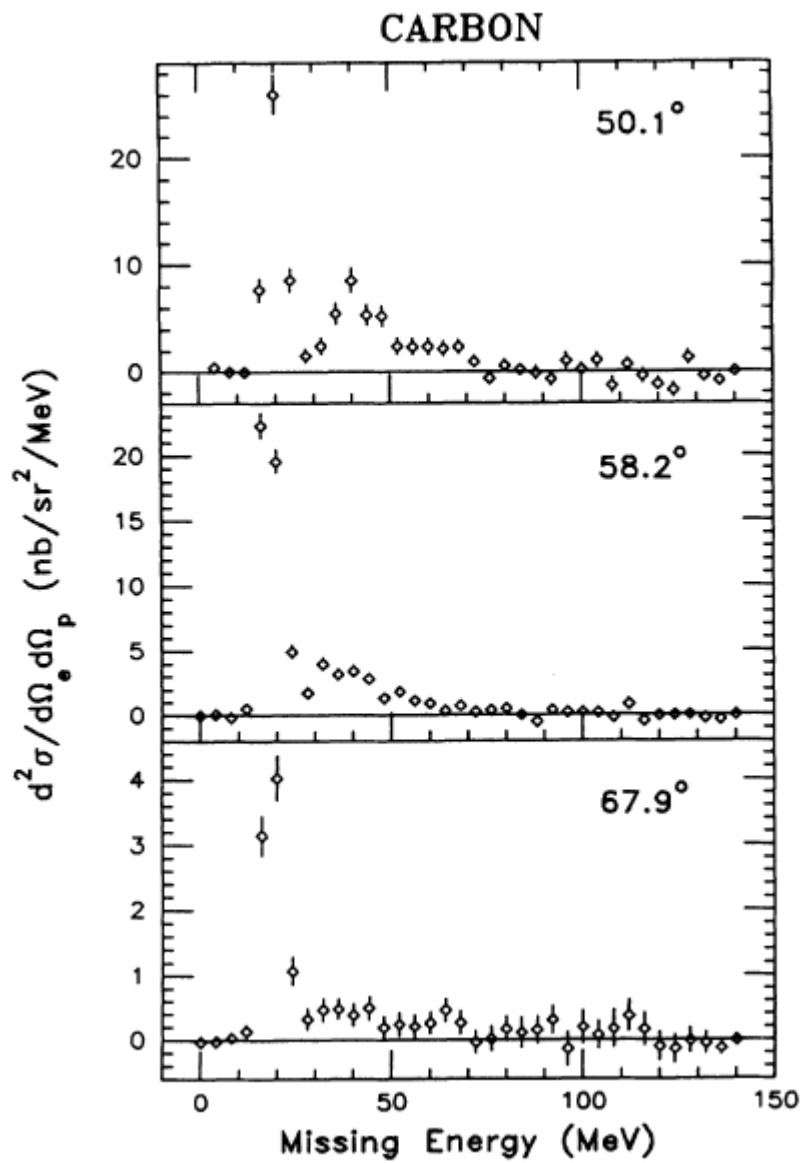

50.1 degrees d²σ/dΩe/dΩp/MeV
data dσ/dΩe=282.0 nb
GENIE dσ/dΩe=1224.4 nb
Missing Energy (GeV)
58.2 degrees
Missing Energy (GeV)
67.9 degrees
Missing Energy (GeV)
72.9 degrees
Missing Energy (GeV)

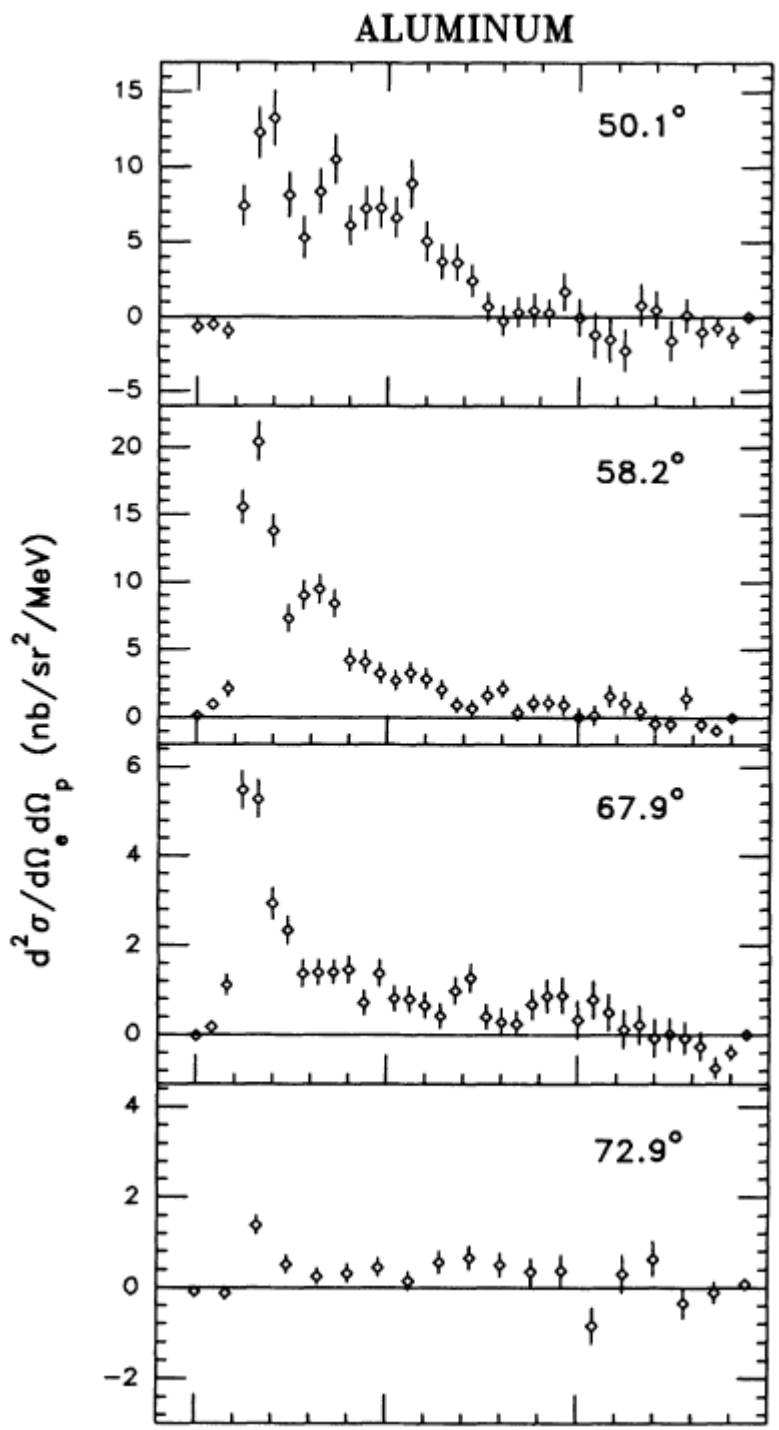
Ni

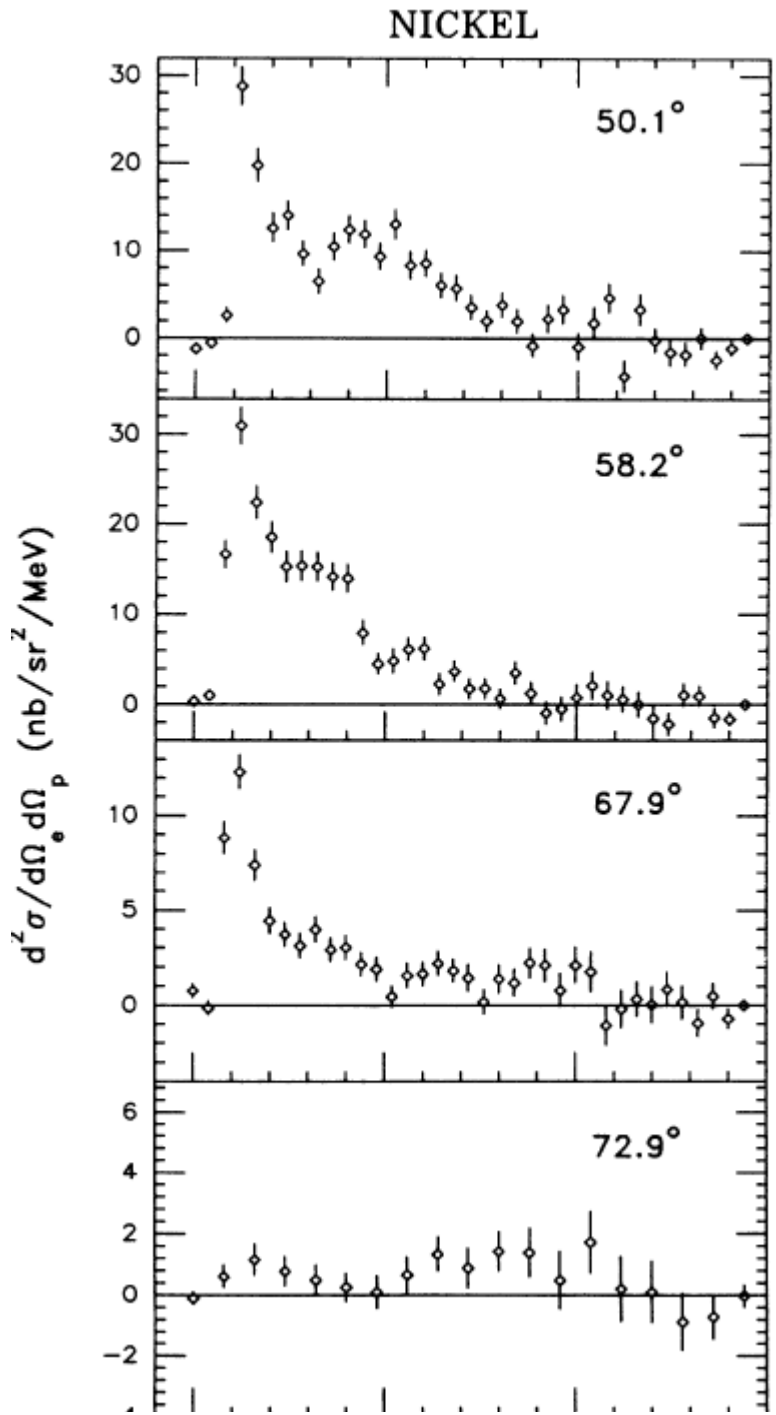

50.1 degrees d²σ/dΩe/dΩp/MeV
data dσ/dΩe=600.0 nb
GENIE dσ/dΩe=2605.8 nb
Missing Energy (GeV)
58.2 degrees
Missing Energy (GeV)
67.9 degrees
Missing Energy (GeV)
72.9 degrees
Missing Energy (GeV)

Summary

- Comparison of GENIE vs. Garino e-p quasi-elastic data is performed
  - Issues with Em (binding energy) need to be investigated further
- Garino Xs ratios agree better with GENIE without FSI than with FSI
- Garino Xs Em dependence does not agree with “without FSI”
    - Part of the problem could be with the final state interaction between recoil proton and medium
    - The other part of the probolem is the initial state as well (nucleon-nucleon short/medium/long range correlation)


CARBON
50.1°
58.2°
67.9°
$d^2\sigma/d\Omega_e d\Omega_p$ (nb/sr^2/MeV)
Missing Energy (MeV)
0
50
100
150


ALUMINUM
50.1°
58.2°
67.9°
72.9°
$d^2\sigma/d\Omega_e d\Omega_p$ (nb/sr^2/MeV)


NICKEL
50.1°
58.2°
67.9°
72.9°
$d^2\sigma/d\Omega_e d\Omega_p$ (nb/sr^2/MeV)