Testing Analysis Algorithms for the $^2H(\vec{e},e'p)n$ Reaction

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PHYSICS MOTIVATION

- An ultimate goal of physics is to understand the transition from hadronic picture of atomic nuclei (Hadronic Model of Nuclear Physics) to the quark/gluon picture (QCD).
- By studying the critical mid-level range of energies, Jefferson Lab plays a critical role in developing our understanding of the transition between the two models. [1]
- We describe here how we performed a computer simulation of the $^2H(e,e'p)n$ reaction in order to test the analysis code used to extract the fifth structure function.
- The fifth structure function represents one of the interference terms in the $^2H(e,e'p)n$ reaction cross section. No measurement of it exists in this energy range so we are exploring new territory of the nucleon-nucleon force.

THE EXPERIMENT

1. The experiment was conducted at Thomas Jefferson National Accelerator Facility [Fig.1] in Hall B using the Continuous Electron Beam Accelerator Facility (CEBAF) Large Acceptance Spectrometer (CLAS).
2. CEBAF is about 7/8 of a mile around, 25 feet underground and is capable of producing electron beams of with energies of 2-6 GeV. The electron beam is accelerated through the straight sections and magnets are used to make the beam travel around the bends. An electron beam can travel around the accelerator up to five times near the speed of light. The beam is sent to one of three halls simultaneously where the beam collides with a target and the debris is measured. [2]
3. CLAS is a 6 sector magnetic spectrometer with a near 4π solid angle coverage [Fig. 2]. Drift chambers measure the trajectory of charged particles, Cherenkov counters are used to separate electrons and pions, scintillators measure time of flight, and calorimeters measure energy. A torroidal magnet is used to measure charged particle momentum. The CLAS spectrometer is designed to measure and identify the debris from a nuclear reaction.
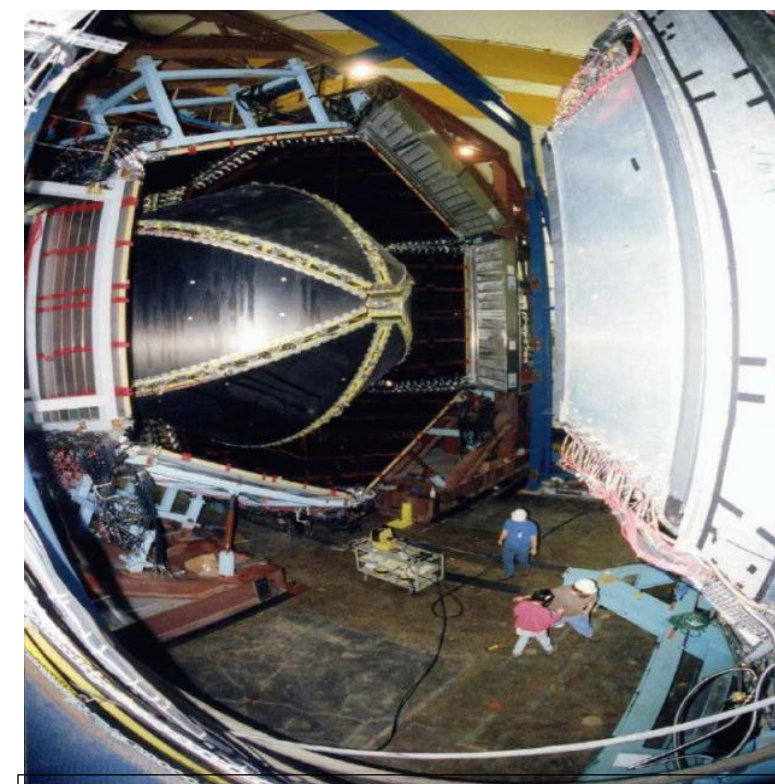
Figure 1. Jefferson Lab accelerator site

Figure 2. The CLAS Detector

THE DATA SET

- Electron beam energies *2.56* GeV and *4.23* GeV, with normal torus polarity (electrons bend towards the beam).
- A third data set at beam energy *2.56* GeV reversed torus polarity in order to reach a low 4-momentum transfer, $Q^2 = 0.2 - 2.0\ (GeV/c)^2$.
- We measured e-p events in CLAS and reconstructed the neutron using missing mass. A cut on W was employed to select quasi-elastic kinematics.

THE FIFTH STRUCTURE FUNCTION

The fifth structure function represents one of the interference terms in the $^2H(e,e'p)n$ reaction cross section, σ'_{LT}. It is formed from the imaginary part of the longitudinal-transverse (LT) interference terms in the probability density, and it is a new insight into the deuteron wave function.

The **cross-section** for the $^2H (e,e'p)n$ reaction is given by,

$$\frac{d^3\sigma}{d\omega d\Omega_e d\Omega_p} = \sigma^{\pm} = \sigma_L + \sigma_T + \sigma_{LT}cos(\Phi_{pq}) + \sigma_{TT}cos(2\Phi_{pq}) + h\sigma'_{LT}sin(\Phi_{pq}) \quad [1]$$

where h denotes the beam helicity. The terms on the right hand side of the equation represent the effective cross-sectional area in the longitudinal (*L*), transverse (*T*), and their respective cross-terms (*LT, TT, LT'*). The angle φ_{pq} is defined in Figures 3. Note that the fifth term is non-zero only for protons ejected out of the scattering plane defined by the incoming and outgoing electron.

The helicity asymmetry A'_{LT} is given by: $A'_{LT} = \frac{\sigma'_{LT}}{\sigma_L + \sigma_T} \quad [2]$

We study the asymmetry because many experimental effects largely cancel in the ratio.
To extract the helicity asymmetry we take advantage of the orthogonality of sine and cosine functions. Consider the following:

$$\langle sin\Phi_{pq}\rangle_{\pm} = \frac{\int_{-\pi}^{\pi}\sigma^{\pm}sin(\Phi_{pq})d\Phi_{pq}}{\int_{-\pi}^{\pi}\sigma^{\pm}d\Phi_{pq}} = \pm\frac{\sigma'_{LT}}{2(\sigma_L + \sigma_T)} = \frac{1}{2}A'_{LT} \quad [3]$$
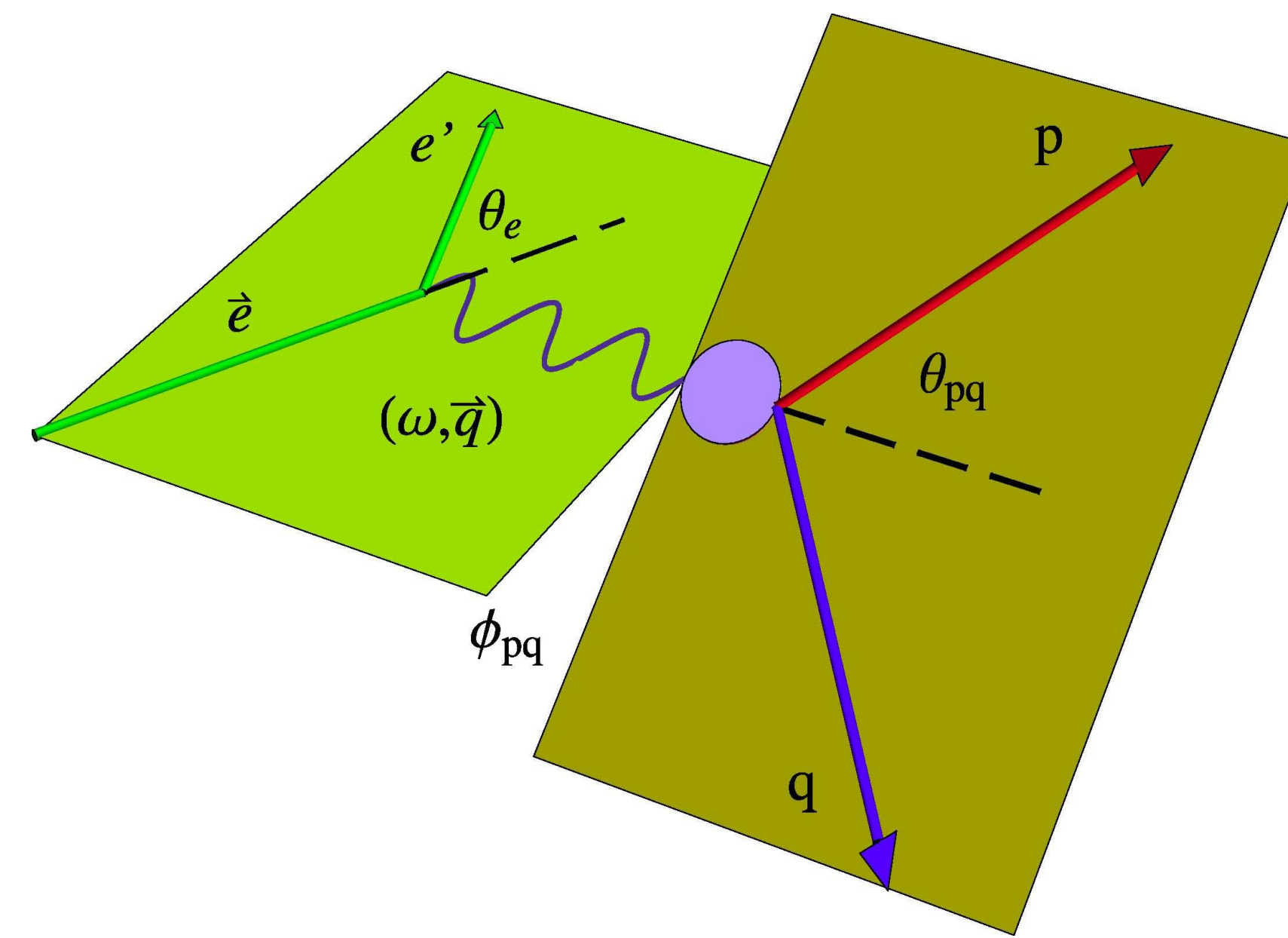
Figure 3. Out-of-plane production.

The differential cross section of the $^2H (e,e'p)n$ reaction with a polarized beam and unpolarized target has a component that is the imaginary part of the interference term between longitudinal and transverse parts of nuclear current. The longitudinal direction points in the direction of the exchanged photon, while the transverse direction is orthogonal to the longitudinal direction. The angle φ_{pq} is the angle between the scattering and reaction planes, while angle ϑ_{pq} is the angle between the longitudinal direction and the direction of the scattered proton.

THE METHOD

1. Extracted the helicity asymmetry as a function of missing momentum using the measured A'_{LT}.

2. To model the reaction, we fitted the measured asymmetry and then implemented the fit into QUEEG (Quasi-Elastic Electron Generator).

3. Hulthen distribution was used to select the magnitude of the internal Fermi momentum of the target nucleon and the direction was chosen isotropically.

4. At high missing momentum we needed to change our process of selecting the internal Fermi momentum to increase the minimum of the probability distribution to get more events in that range. Thus, we were able to achieve better statistics for high missing momentum.

- We generated plots showing the thrown events and the simulated ones so that we could account for the resolution effects in the simulated events.

- Figure 4 shows the resolution effects for high momentum for just a few events (simulated events , red curve, versus the thrown events, blue curve)
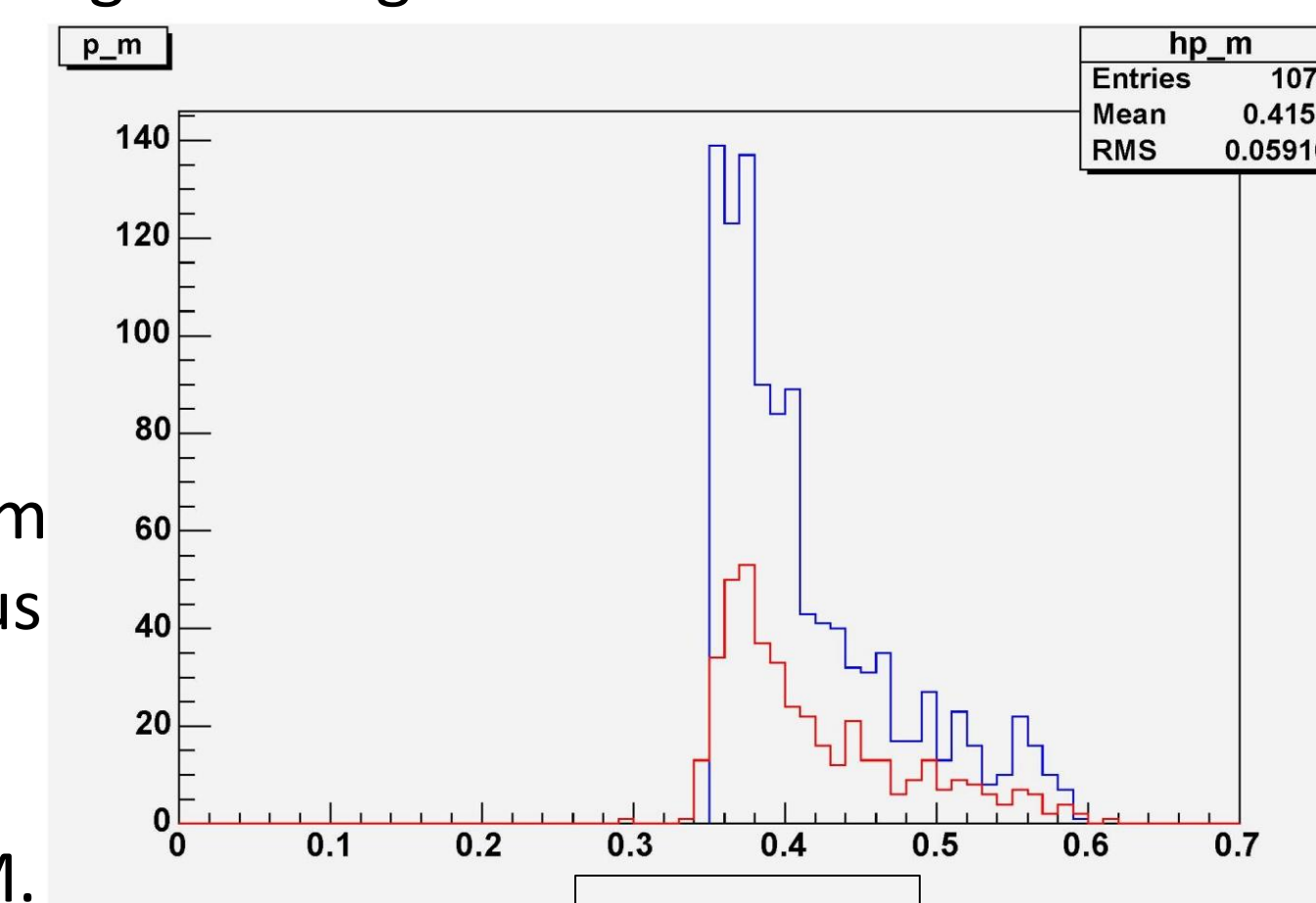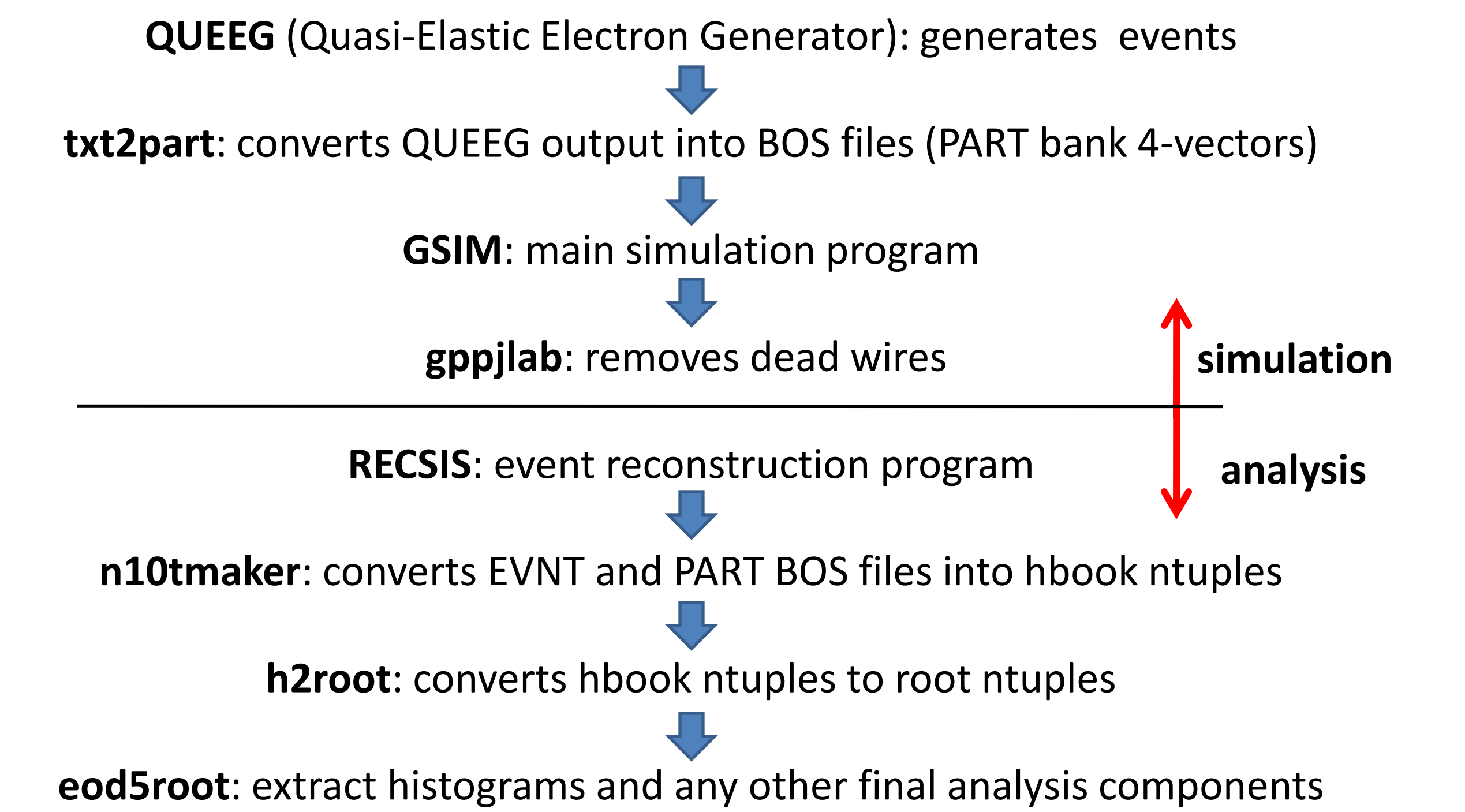
5. Performed a Monte Carlo simulation of CLAS using GSIM.

6. Analyzed the generated events with the same analysis algorithm used to extract the measured fifth structure function.

Figure 4.

REFERENCES

[1] A Precise Measurement of the Neutron Magnetic Form Factor G^n_M in the Few-GeV² Region by J.Lachinet, A.Afanasev, H.Arenhövel, W.K.Brooks, G.P.Gilfoyle, S.Jeschonnek, B.Quinn, M.F.Vineyard, et al. (the CLAS Collaboration) ;
[2] JLAB Thesis Prize Talk by Guy Ron, Weizmann Institute.

SIMULATION

Overview of the sequence of programs used in the simulation of the reaction in CLAS:

QUEEG (Quasi-Elastic Electron Generator): generates events

txt2part: converts QUEEG output into BOS files (PART bank 4-vectors)

GSIM: main simulation program

gppjlab: removes dead wires — simulation

RECSIS: event reconstruction program — analysis

n10tmaker: converts EVNT and PART BOS files into hbook ntuples

h2root: converts hbook ntuples to root ntuples

eod5root: extract histograms and any other final analysis components

RESULTS

1. Our results are shown in Figures 5-6. The black points are the results of the simulation for the two torus polarity setting.

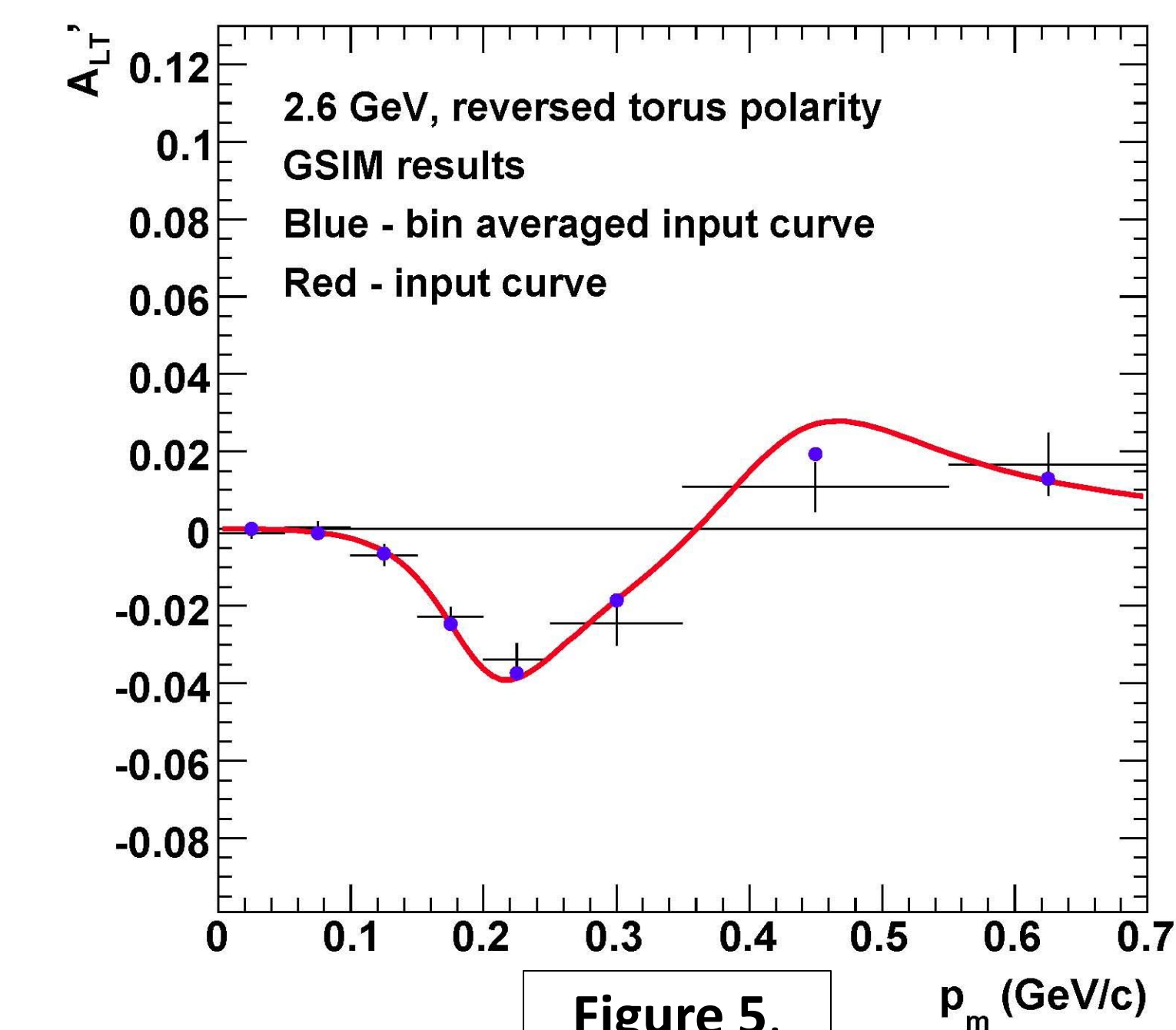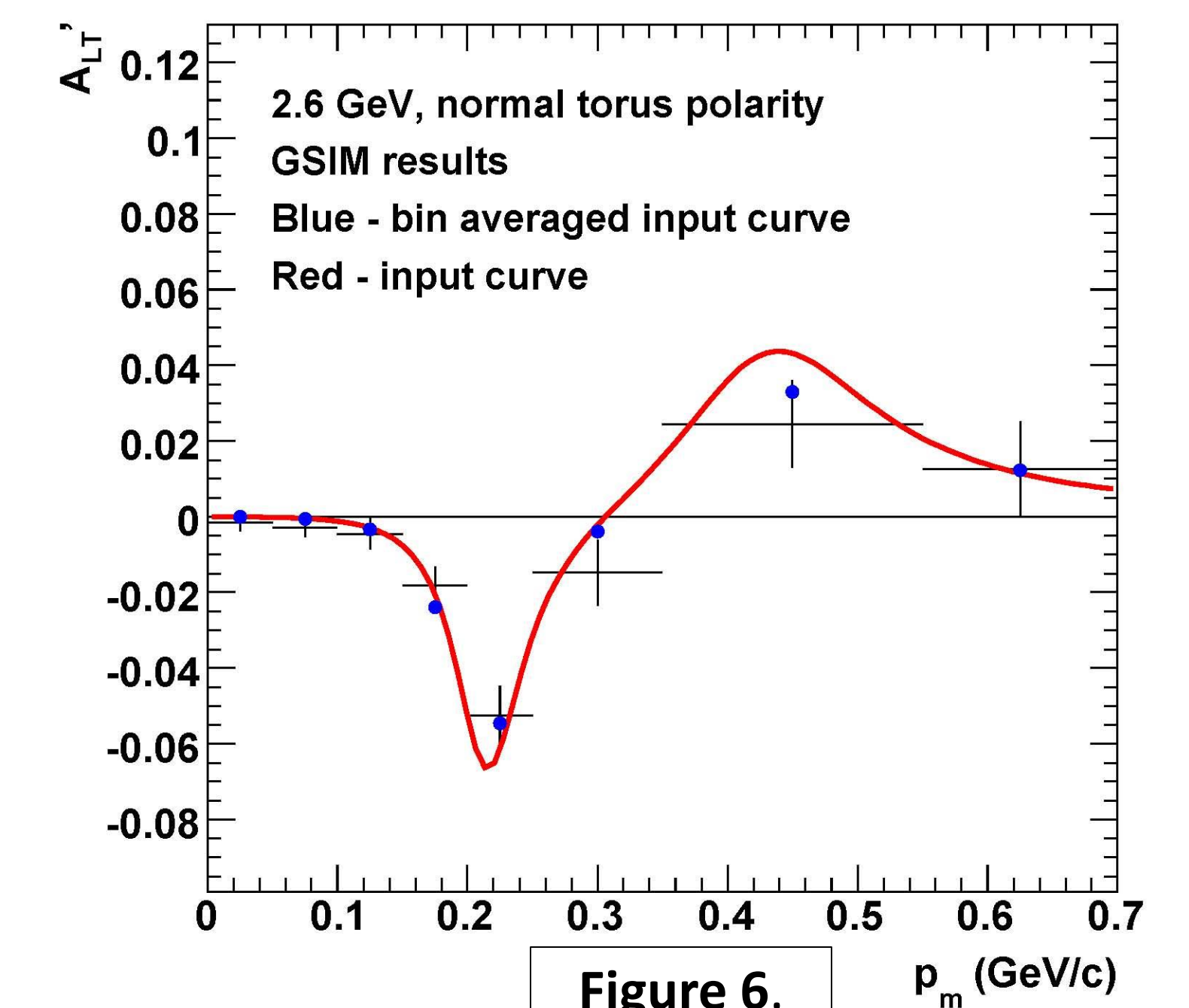**Figure 5.** 2.6 GeV, reversed torus polarity — GSIM results — Blue - bin averaged input curve — Red - input curve

Figure 6. 2.6 GeV, normal torus polarity — GSIM results — Blue - bin averaged input curve — Red - input curve

2. For the reversed torus polarity data set [Fig. 5] the equation used to fit the measured asymmetry is:

$$f(x) = \frac{a_1 x^2 + a_2 x^4}{1 + a_3 x + a_4 x^2 + a_5 x^4 + a_6 x^6} \quad [4]$$

where a_1 = -0.0653, a_2 = 0.5031, a_3 = -11.0388, a_4 = 36.0937, a_5 = -126.685, a_6 = 256.143.
For the normal torus polarity data set [Fig. 6] the equation used to fit the measured asymmetry is:

$$f(x) = \frac{b_1 x^2 + b_2 x^4}{1 + b_3 x + b_4 x^2 + b_5 x^4 + b_6 x^6} \quad [5]$$

where b_1 = -0.0344, b_2 = 0.3204, b_3 = -11.1479, b_4 = 35.4709, b_5 = -119.206, b_6 = 227.042.

3. To properly compare the simulated asymmetry (red curve in Figures 5-6) with the results of the analysis, we averaged over the bins using the equation below,

$$\langle A'_{LT}\rangle_i = \frac{\int_{bin} A'_{LT}(p_m)dp_m}{\int_{bin} dp_m} \quad [6]$$

The bin-averaged input asymmetry is shown as the blue points in Figures 5-6. The black and blue points agree within the uncertainties of the calculation.

CONCLUSIONS

- We have simulated the observed helicity asymmetry in $^2H(e,e'p)n$.
- Monte Carlo events were analyzed with the same code used to extract A'_{LT} from the experimental data.
- The asymmetry extracted from Monte Carlo events is consistent with the input function for the asymmetry within the uncertainties of the calculation.
- This establishes the validity of our analysis algorithms.