Measurement of ^{3}He Elastic Electromagnetic Form Factor Diffractive Minima Using Polarization Observables

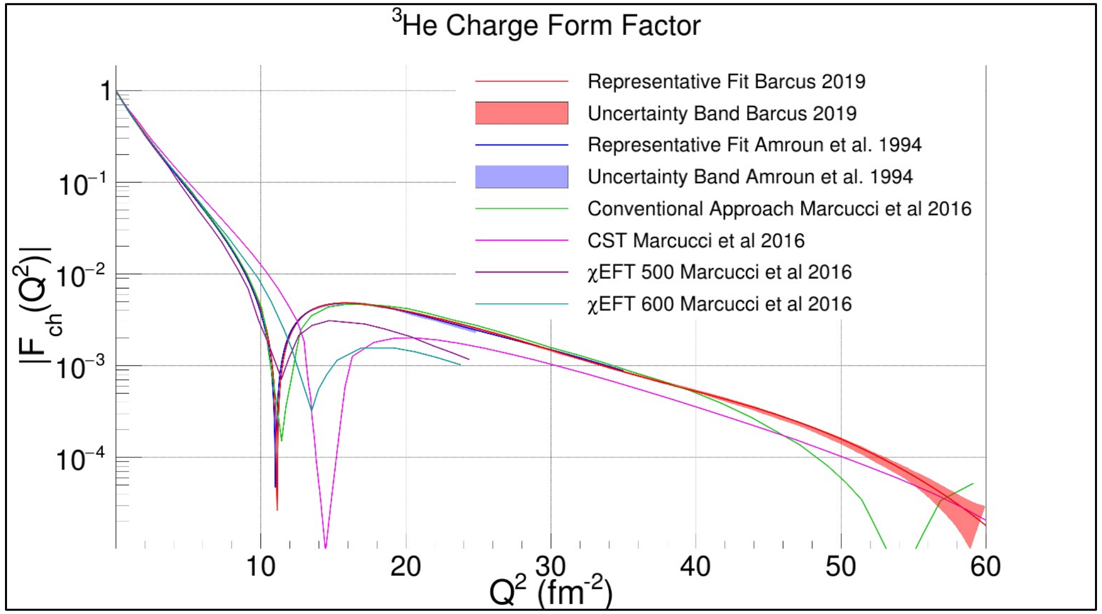
Michael Nycz

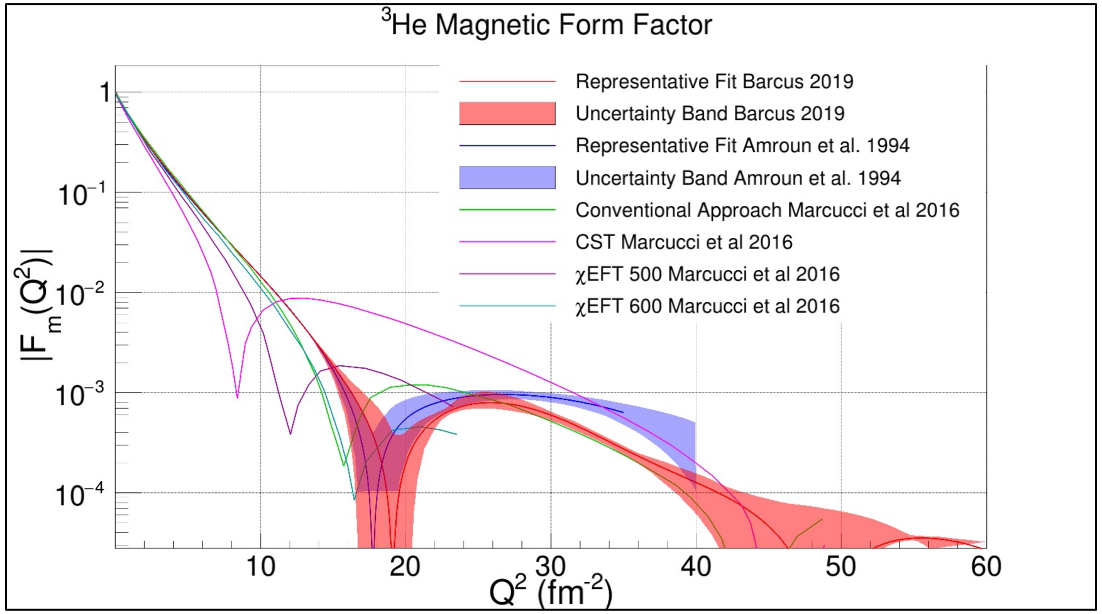
Hall C Collaboration Meeting

February 17, 2022

University of Virginia

Experimental and Theoretical Comparison



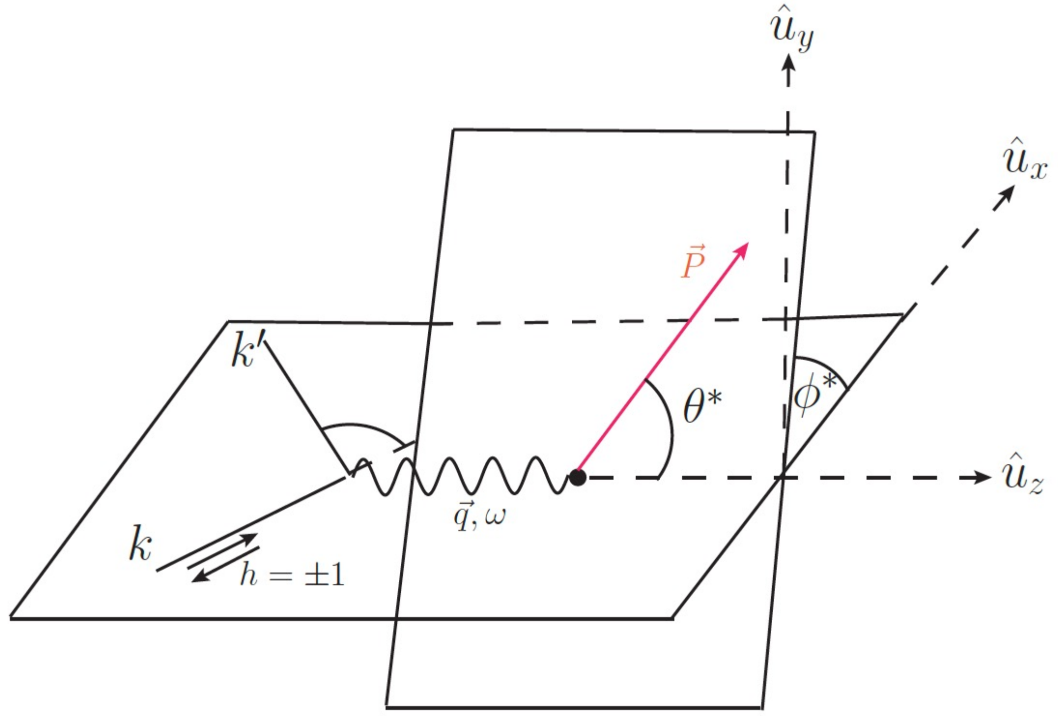


- **Discrepancies in location of minima of the magnetic form factor**
- Rosenbluth separations in diffractive minima are non-trivial
- All high Q^2 ^{3}He Form Factor measurements are from unpolarized elastic scattering
- Differences in EM form factors of the proton between PO and Rosenbluth @ high Q^2

Double-Spin Asymmetry

The Asymmetry can be written as

$$A = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = \frac{\Delta}{\Sigma}$$



- Polarized electron with helicity ±1
- Polarized target

Double-Spin Asymmetry

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Where

$$\Delta = -\sqrt{2} V_{T'} \cos\theta^* G_M^2 - 2\sqrt{2} V_{LT'} \sin\theta^* \cos\phi^* G_E G_M$$

and

$$\Sigma = \frac{\varepsilon G_E^2 + \tau G_M^2}{\varepsilon(1+\tau)}$$

$$v_L = \left(\frac{1}{1+\tau}\right)^2$$

$$v_T = \frac{1}{2}\left(\frac{1}{1+\tau}\right) + tan^2\left(\frac{\theta}{2}\right)$$

$$v_{TT} = \frac{1}{2}\left(\frac{-1}{1+\tau}\right)$$

$$v_{TL} = \left(\frac{-1}{\sqrt{2}(1+\tau)}\right)\sqrt{\left(\frac{1}{1+\tau}\right) + tan^2\left(\frac{\theta}{2}\right)}$$

$$v_{T'} = \sqrt{\left(\frac{1}{1+\tau}\right) + tan^2\left(\frac{\theta}{2}\right)}\,tan\left(\frac{\theta}{2}\right)$$

$$v_{TL'} = \frac{1}{\sqrt{2}}\left(\frac{-1}{1+\tau}\right) tan\left(\frac{\theta}{2}\right)$$

*T.W. Donnelly and A.S. Raskin

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Double Polarization Measurement

$$A_{phys} = \frac{-2\sqrt{\tau(1+\tau)}\tan\left(\frac{\theta}{2}\right)}{G_E^2 + \frac{\tau}{\epsilon}G_M^2}\left[\sin(\theta^*)\cos(\varphi^*)\,G_E\ G_M + \sqrt{\tau\left[1+(1+\tau)\tan^2\left(\frac{\theta}{2}\right)\right]}\cos(\theta^*)G_M^2\right]$$

$$A_{meas} = \frac{N^+ - N^-}{N^+ + N^-}$$

$$A_{meas} = P_t P_l\, A_{phys}$$

Where

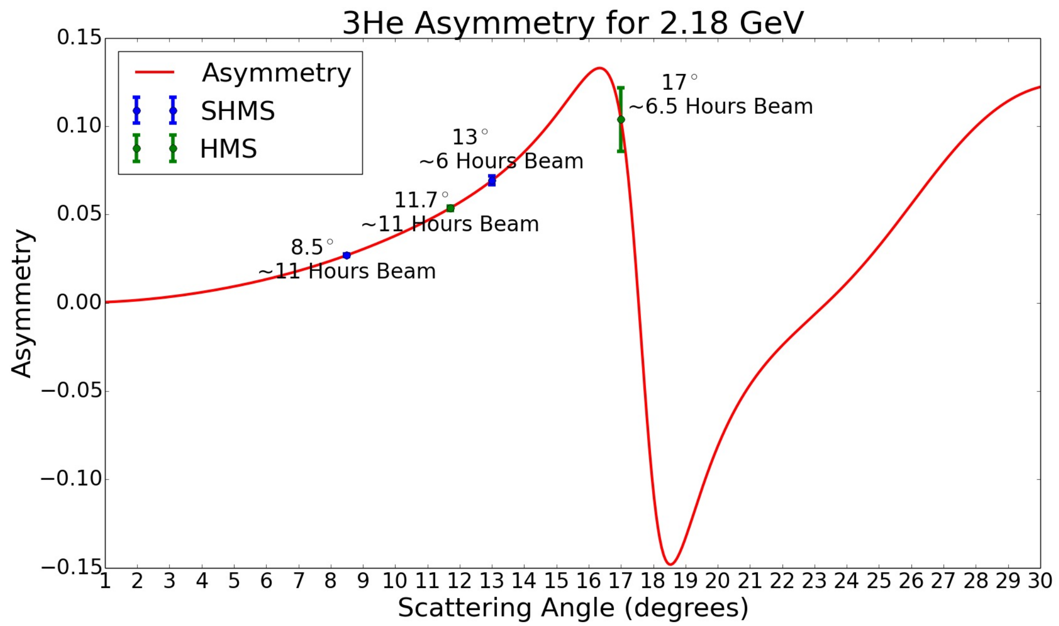
θ^* & φ^* - polar & azimuthal angles of polarization vector of target

P_t & P_l - Polarization of target and electron beam

Experiment E12-06-121A

- Ran parasitically in Hall C during d_2^n
  - Configured with d_2^n planned 1st pass systematic measurements
- Target cells
  - Polarized ^{3}He cell
  - Reference ^{3}He cell
- Beam energy: 2.18 GeV
- Beam current: 30 μA
- Detect elastically scattered electrons independently in both HMS and SHMS
- Collected ≈17 hours of data

Kinematic Settings



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- Target cells
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  (Collimator)
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- Max beam current: 30 μA
- Detect elastically scattered electrons independently in both HMS and SHMS
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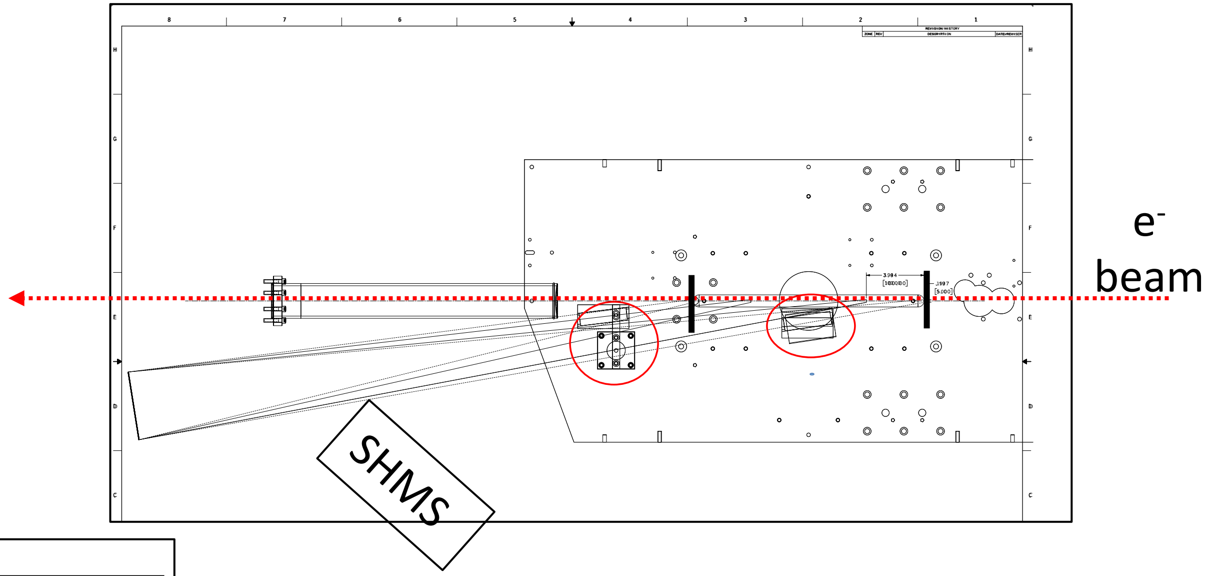
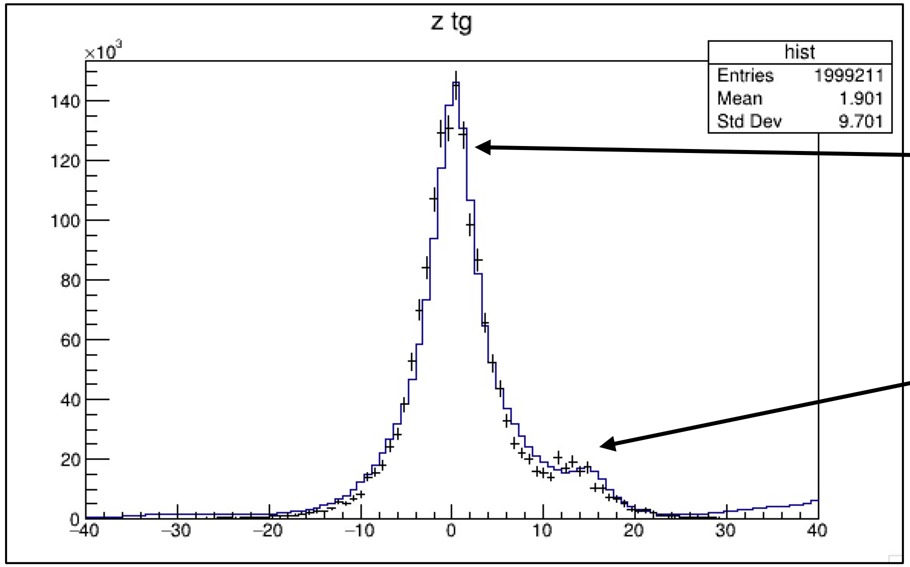
Kinematic Settings

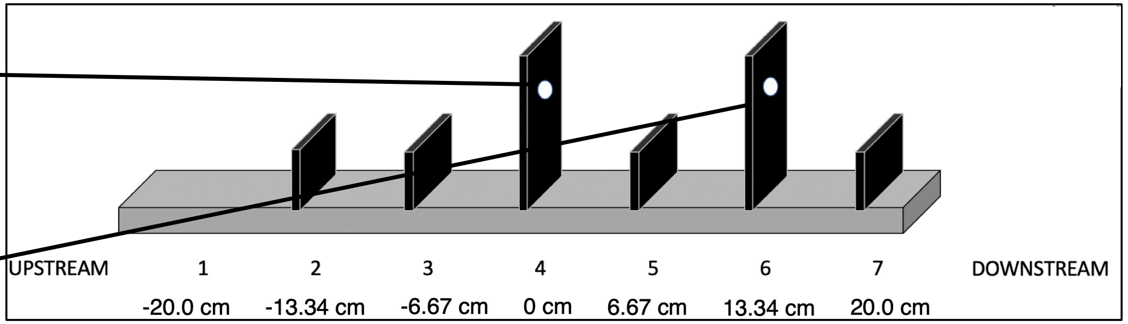
Spectrometer	θ [°]	P_0 [GeV]	Q^2 [fm^{-2}]
SHMS	8.5	2.12	2.60
SHMS	13.0	2.12	6.10
HMS	11.7	2.08	4.88
HMS	17.0	2.08	10.25

1. Collimator positioned on SHMS to limit background
2. Scintillator Paddles optimized on both SHMS and HMS to reduce Quasi-Elastic background

Target Collimator (SHMS)

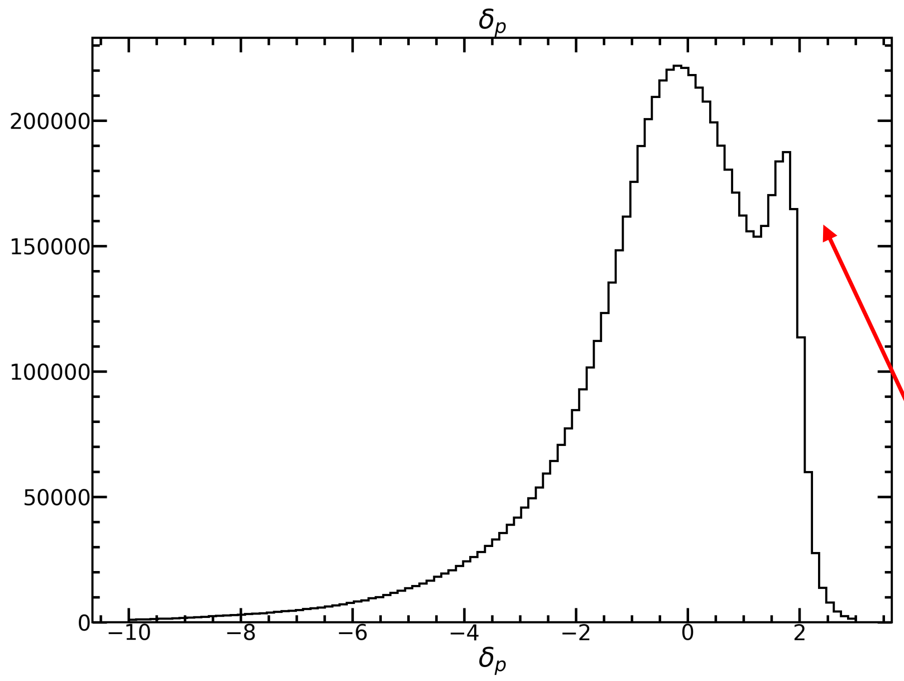




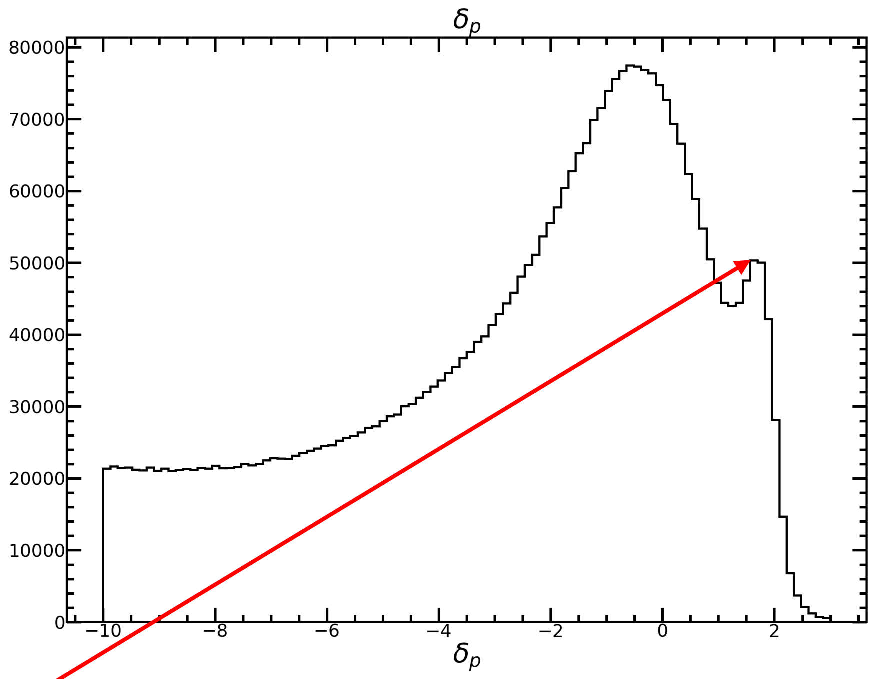


Scintillator Paddle Configurations

Optimized scintillator paddles



All scintillator paddles



Elastic events

Analysis Status and Updates

- Detector calibrations done by A_n^1 and d_n^2 students

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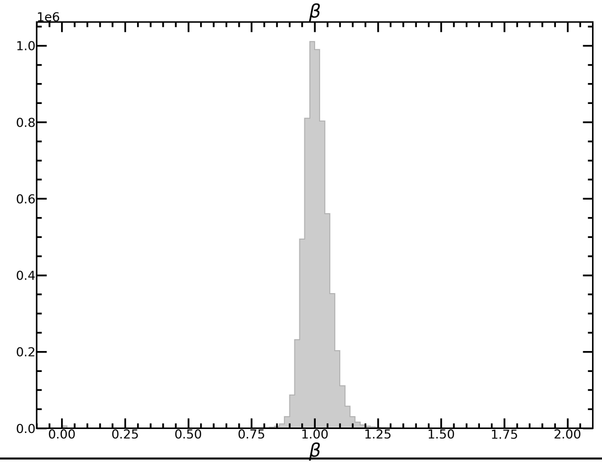
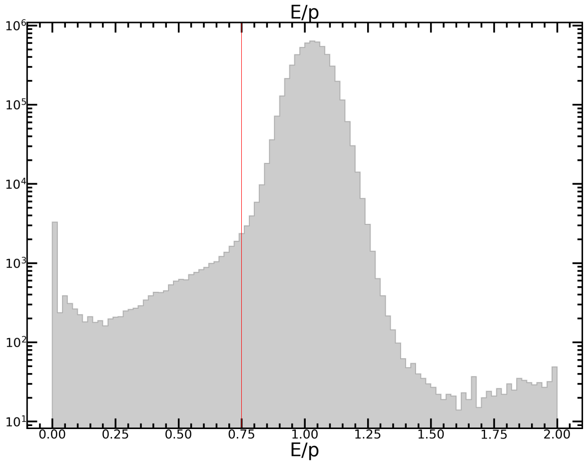
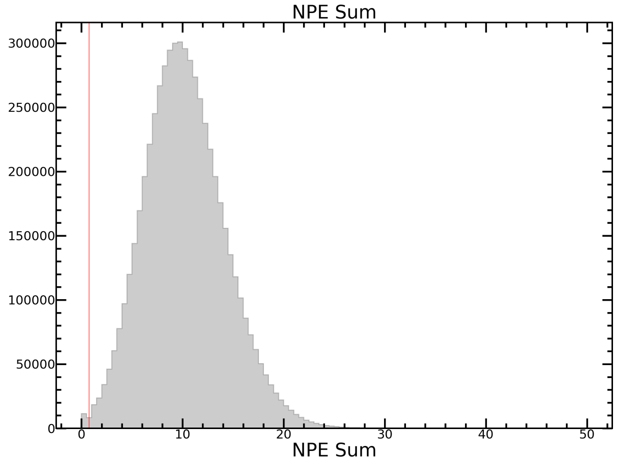
Polarized ^{3}He



Junhao Chen, Mingyu Chen, Murchhana Roy, and Melanie Rehfuss





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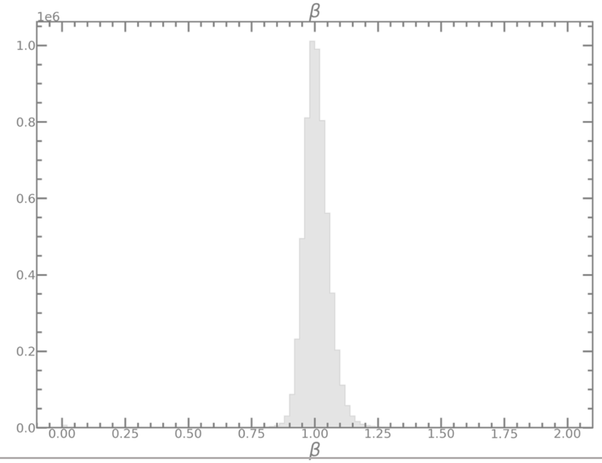

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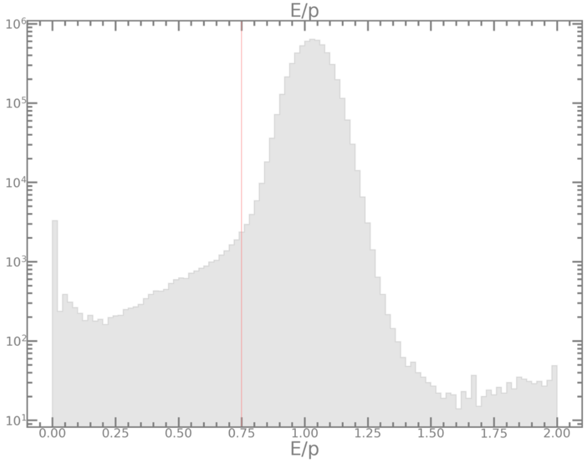
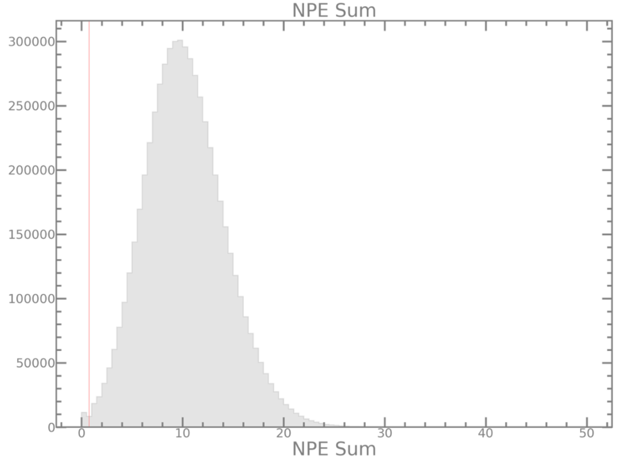
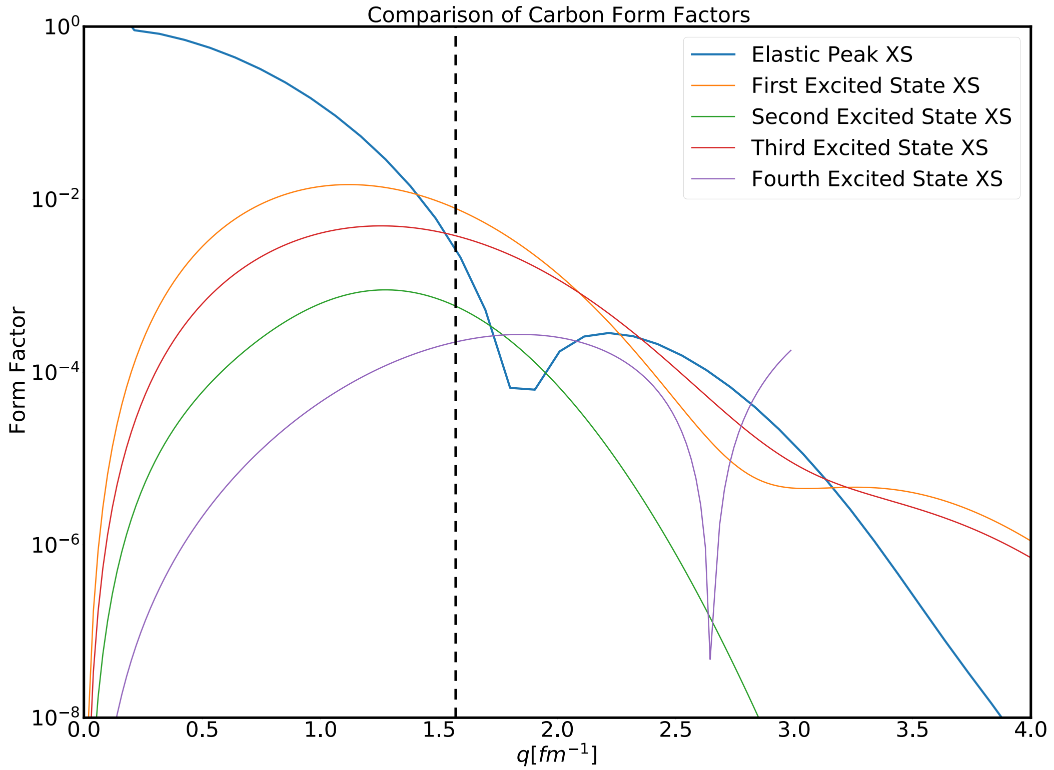


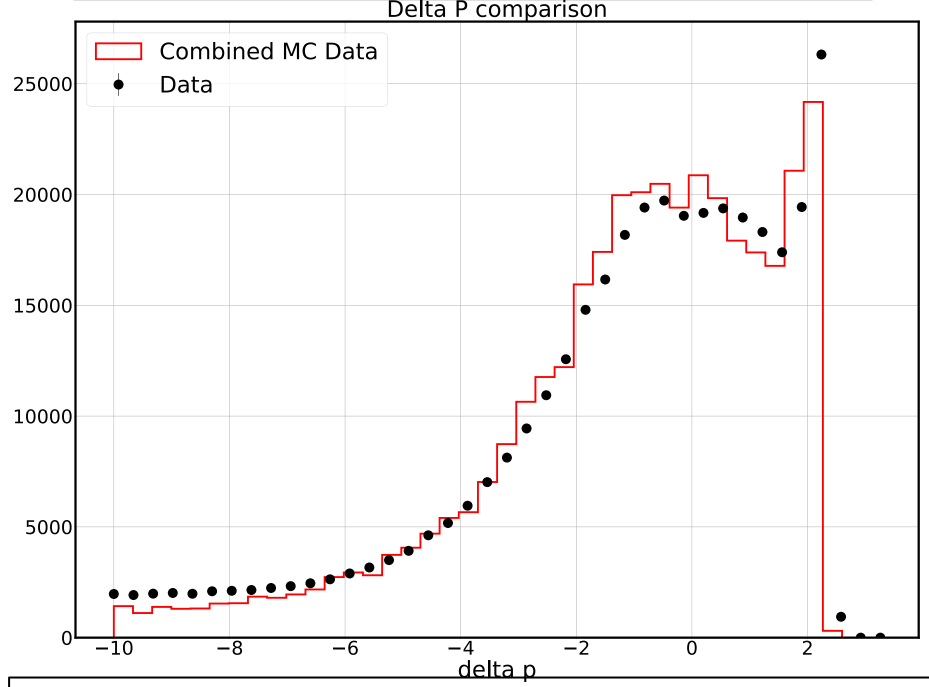


Carbon Foil




```
ff elas at 1.56   : 0.00327133
2+1 ff2 at 1.56   :  0.00806855
3-1 ff2 at 1.56   :  0.00385384
0p2 ff2 at 1.56   :  0.00065325
```

Carbon Foil: SHMS @ 8.5 degrees



Thanks to Michael Paolone and the Coulomb Sum Rule experiment for the helpful suggestions

Analysis Status and Updates

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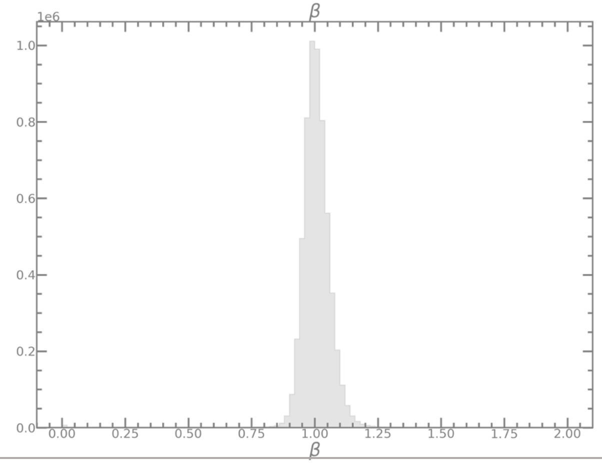
- QE theory calculations

Polarized ^{3}He



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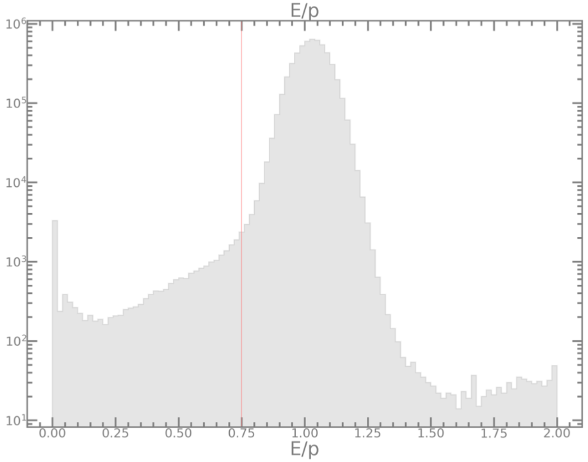
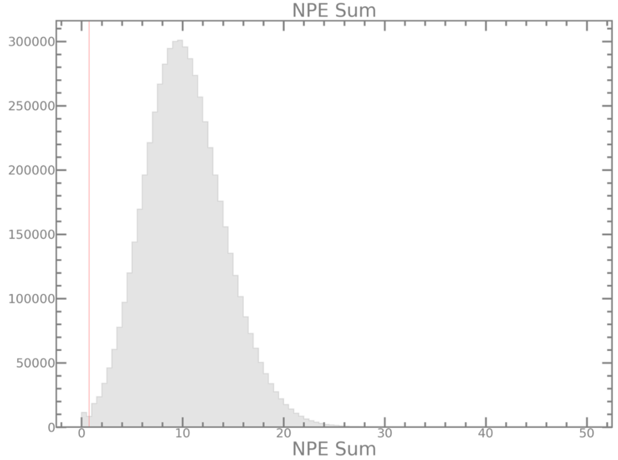
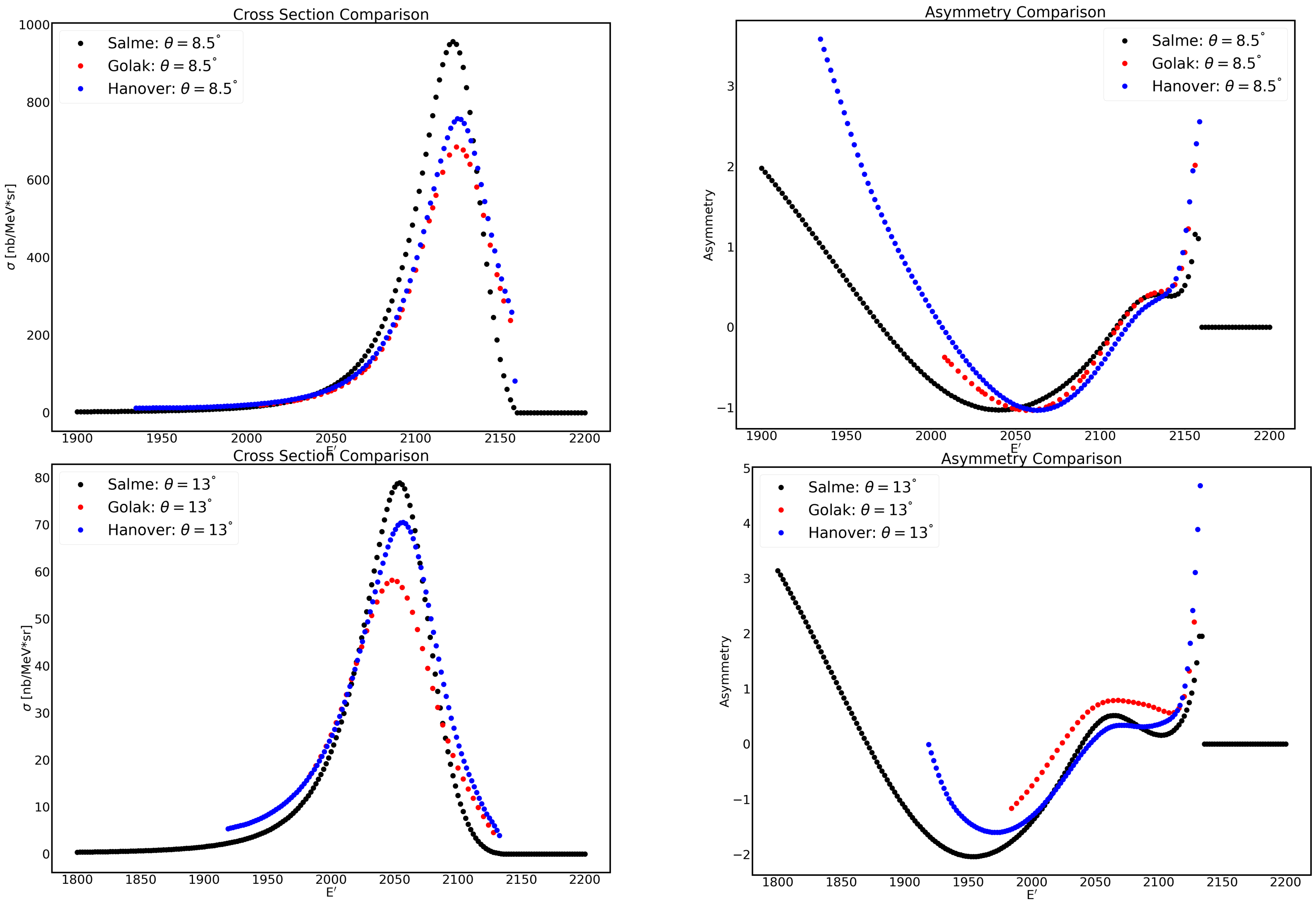




Quasi-Elastic Theory

- Quasi-Elastic calculations from three groups
- Calculations cover kinematic settings



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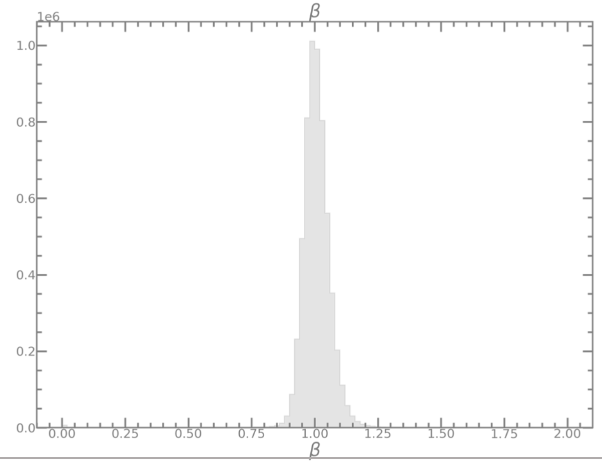
- Comparison of ^{3}He data and Monte Carlo
  - Better treatment of target collimators to account to for “punch through” events
  - Account for a number of paddle configurations at each kinematic

Polarized ^{3}He



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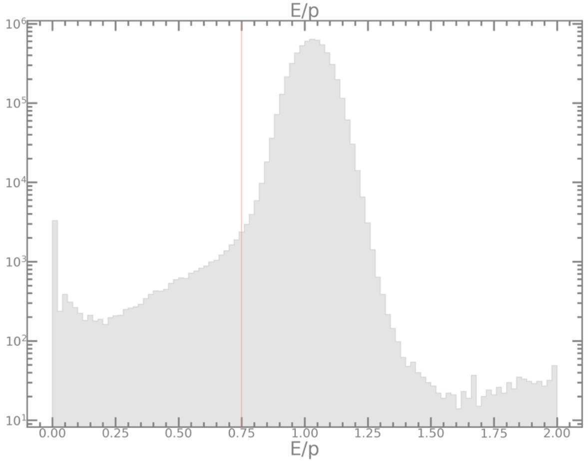
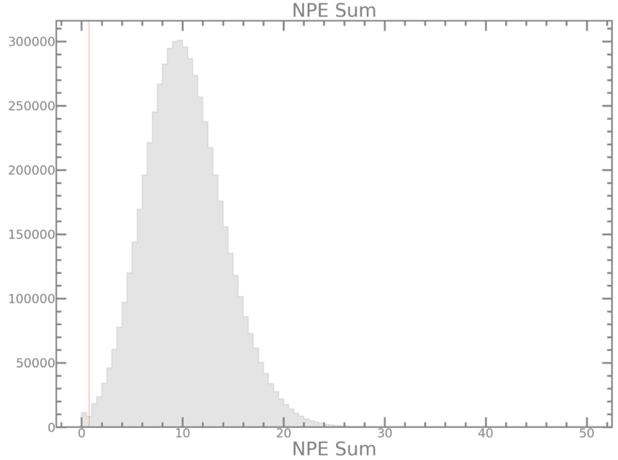
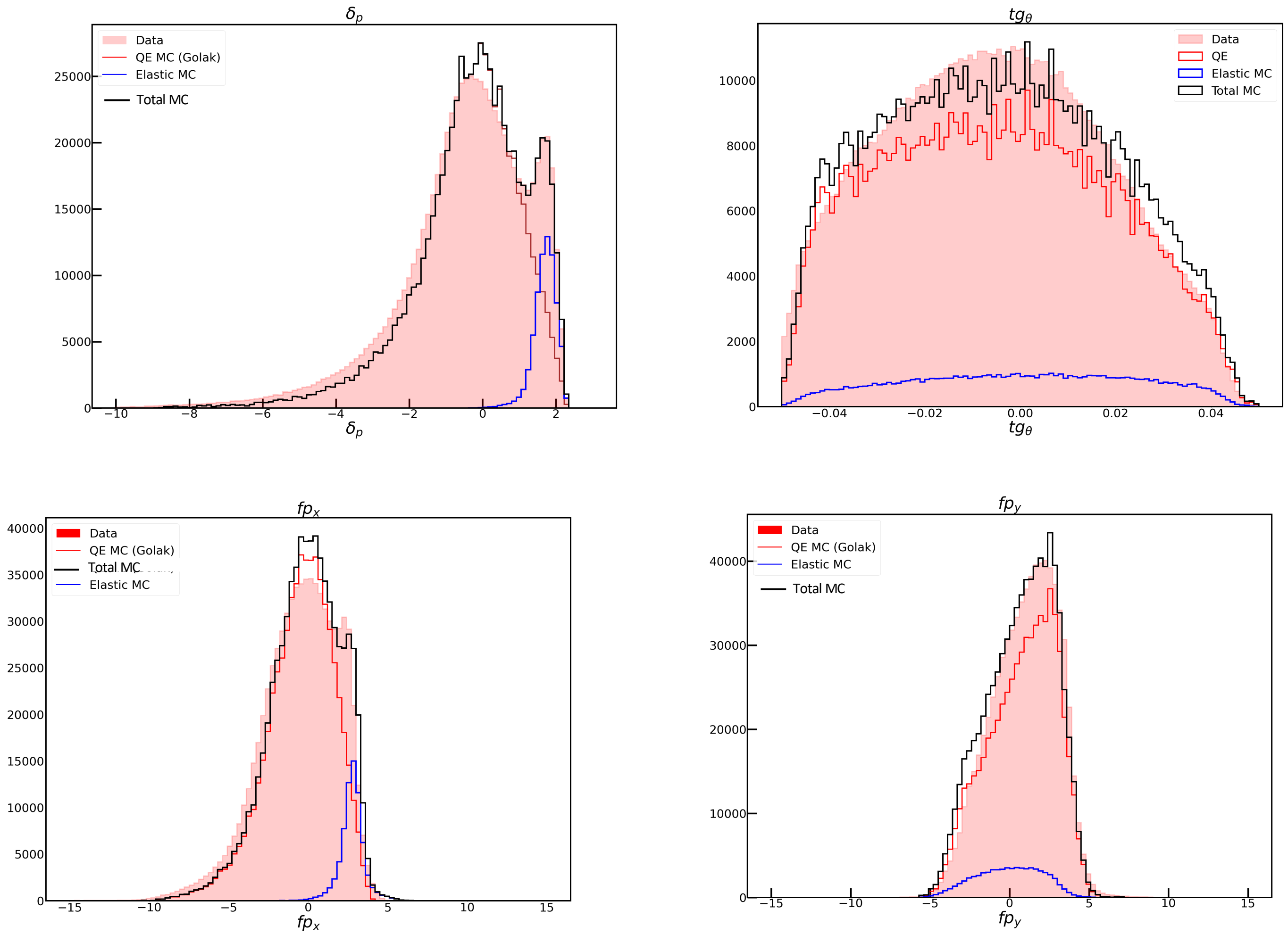




Comparison of Data vs MC

- Observe an overall good agreement between data and MC at both SHMS settings
- Have checked both target and focal plan quantities
- In general, better agreement at 13.0° than 8.5 °

SHMS 8.5 °



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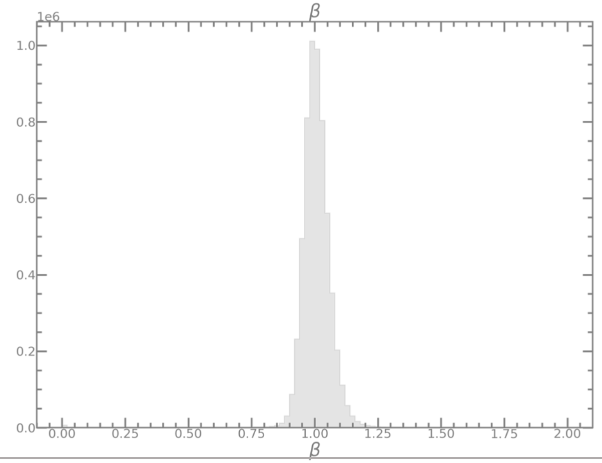
- Comparison of ^{3}He data and Monte Carlo
  - Better treatment of target collimators to account to for "punch through" events
  - Account for a number of paddle configurations at each kinematic
- Preliminary asymmetry for SHMS 8.5° and 13°
  - But…. Final check of the synchronization of helicity dependent quantities
  - Results → soon!

Polarized ^{3}He



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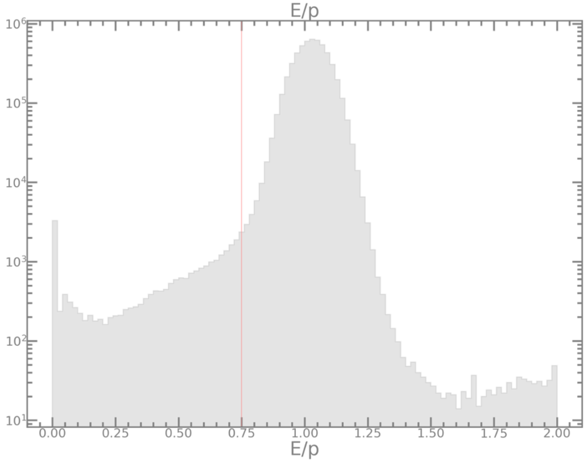
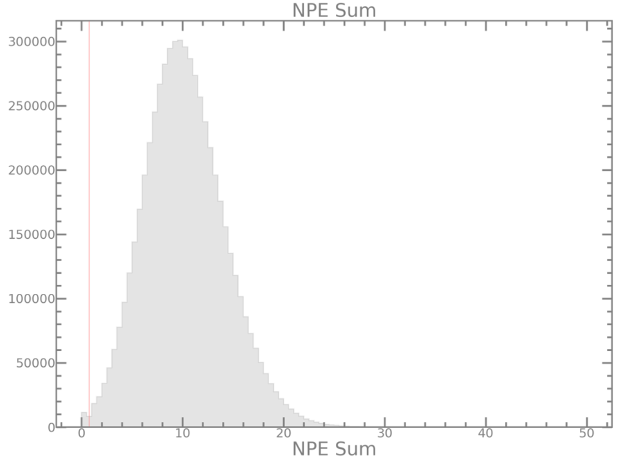
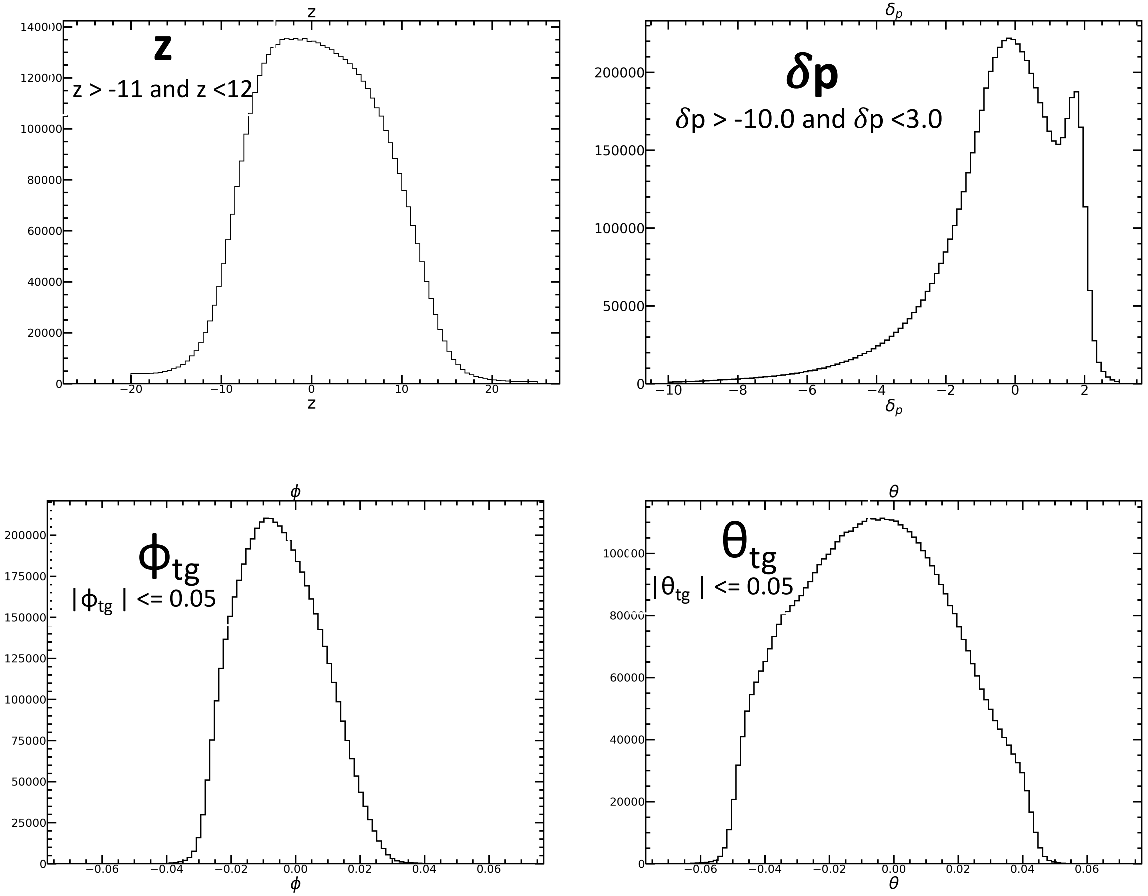




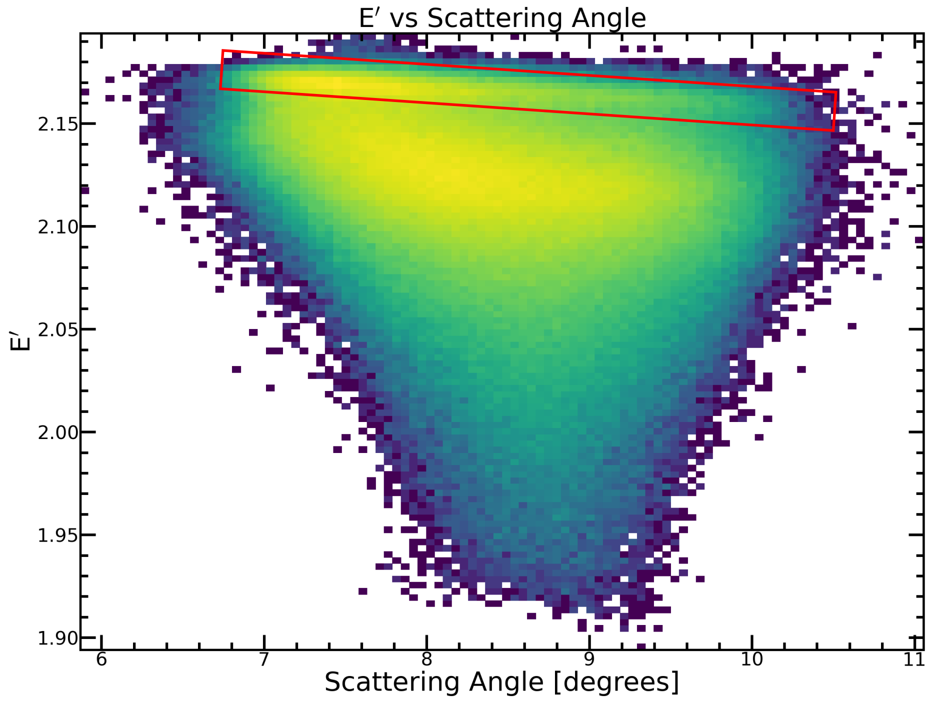
Analysis Cuts



PID:

E/p>0.8
Cherenkov NPE Sum >2.0

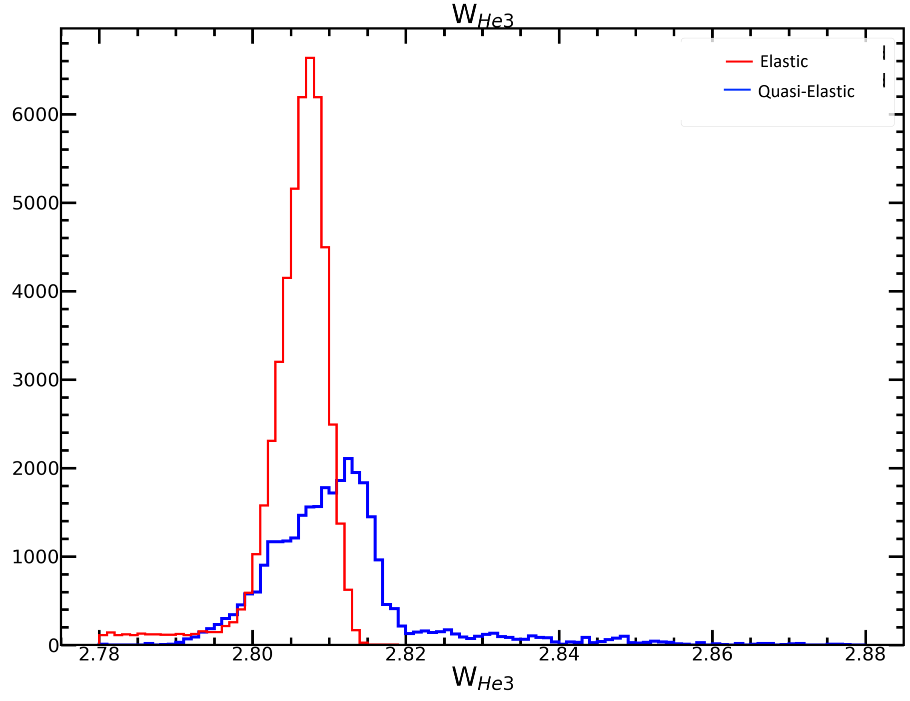
Separate Quasi-Elastic From Elastic Events



Asymmetry (In progress)

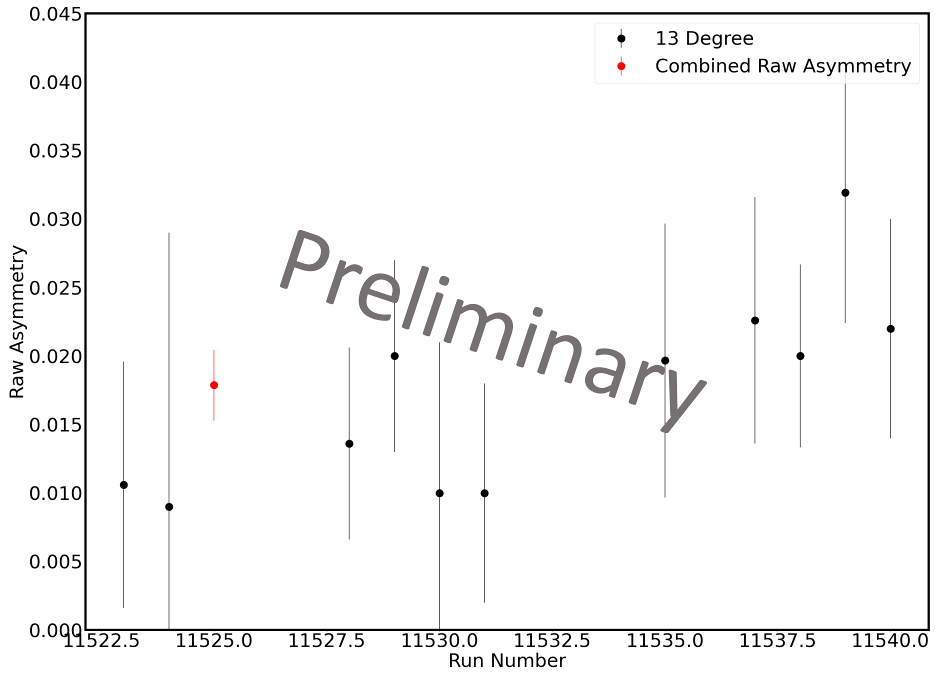
- $A_{raw} = \frac{Y^{+}-Y^{-}}{Y^{+}+Y^{-}}$
  - $Y^{+(-)}$ are the helicity dependent, charged normalized yields
  - $Y^{+(-)} = N^{+(-)}/Q^{+(-)}LT^{+(-)}$
  - Counts (N), charge (Q), and LT are helicity dependent
- Determine A_{phys}:
  - Beam and target polarization
  - QE background and dilutions
- $A_{phys} = \frac{A_{raw}}{P_b P_t}\left(\frac{1}{1-d_{QE}}\right) - A_{QE}\left(\frac{d_{QE}}{1-d_{QE}}\right)$
- d_{QE} : QE background

Quasi-Elastic background: SHMS 8.5 °



Summary

- The 8.5° and 13° (SHMS) settings have been (thoroughly) studied
- Have great theory support!
- Preliminary asymmetries for SHMS settings expected shortly
- Proof of principle



Thank you to the entire Polarized ^{3}He Collaboration

Measurement of ^{3}He Elastic Electromagnetic Form Factor

Diffractive Minima Using Polarization Observables

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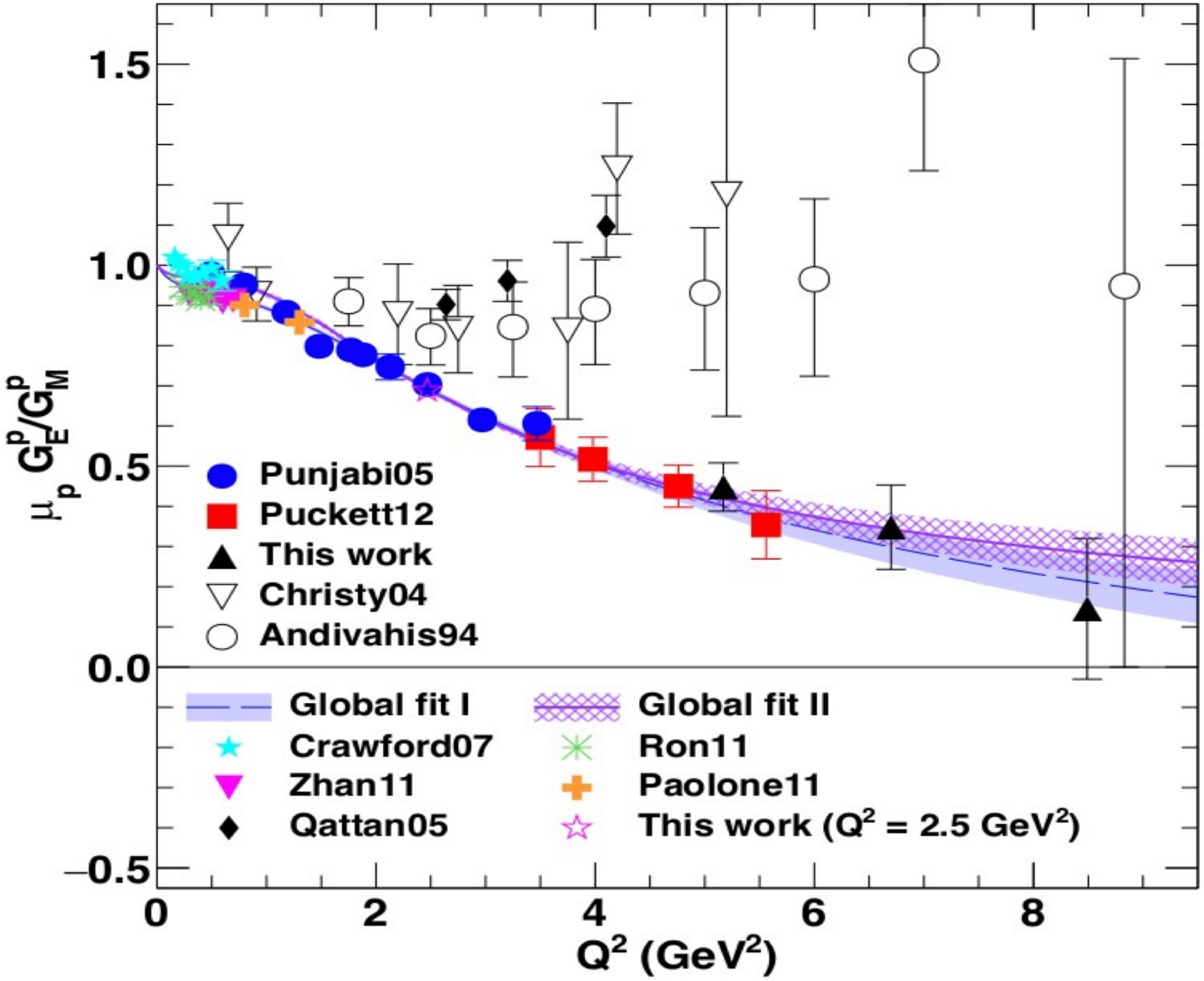
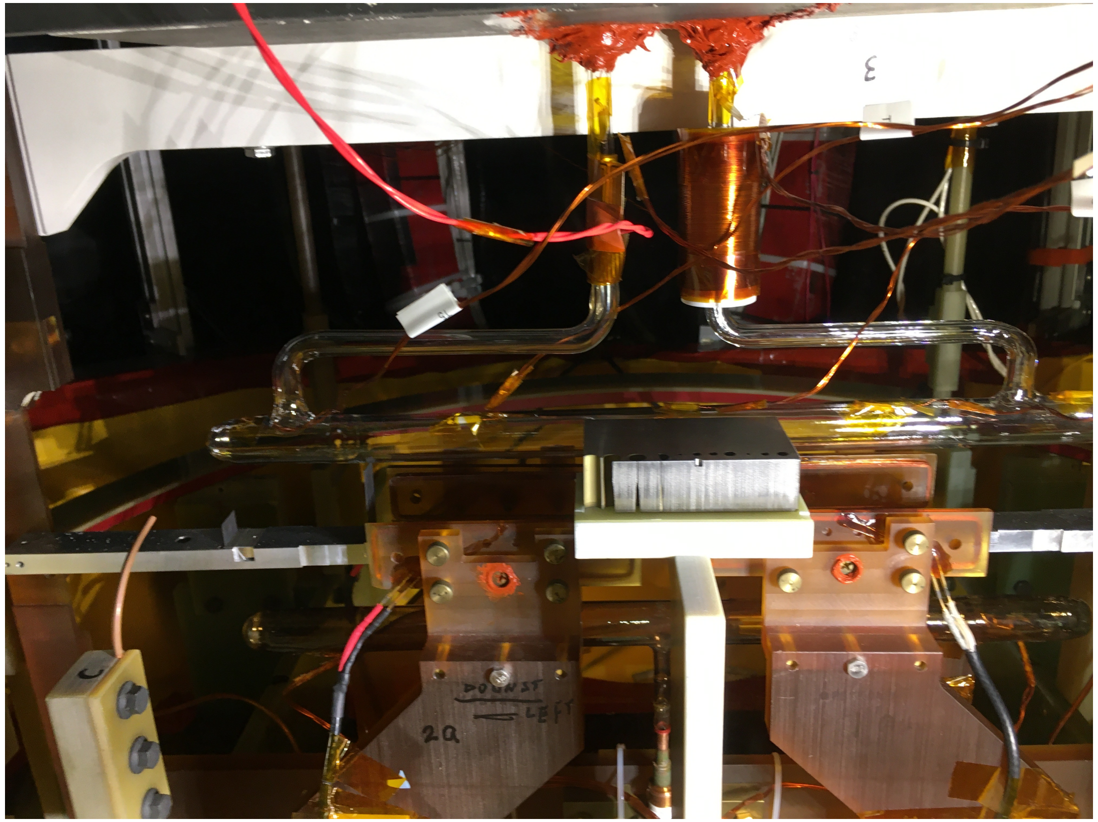
d_2^n Collaboration

JLab Hall C GEP-III PRC 96, 055203 (2017)

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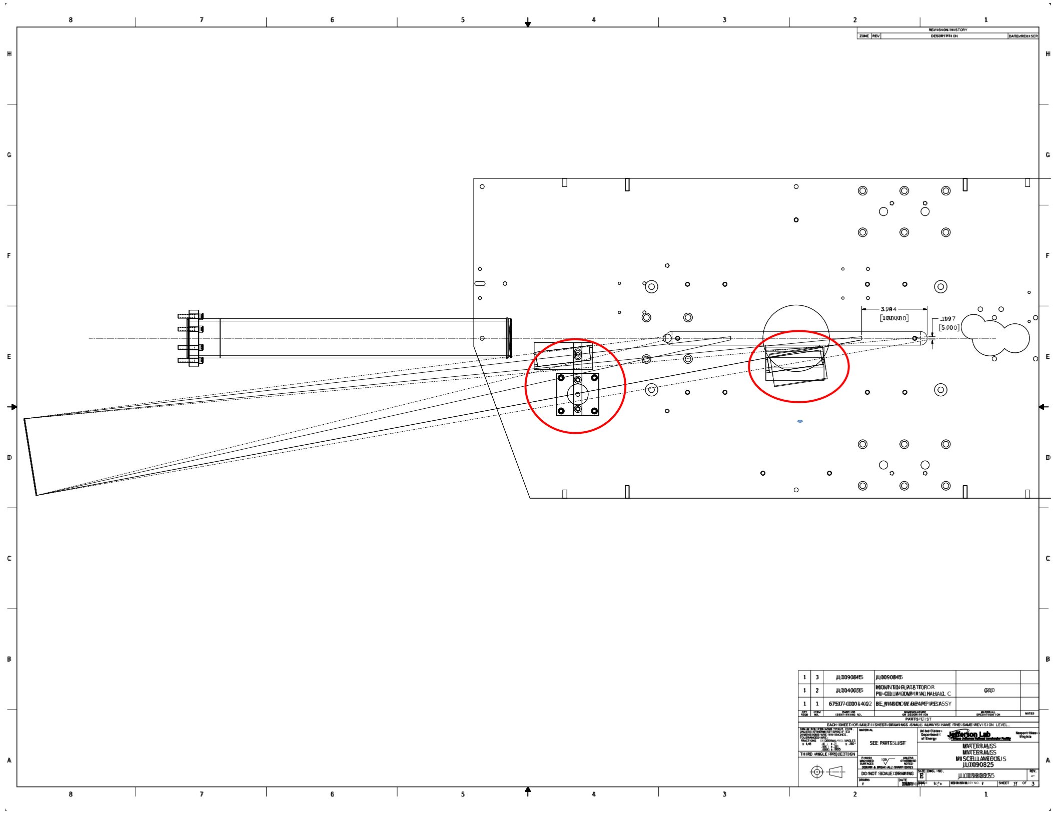
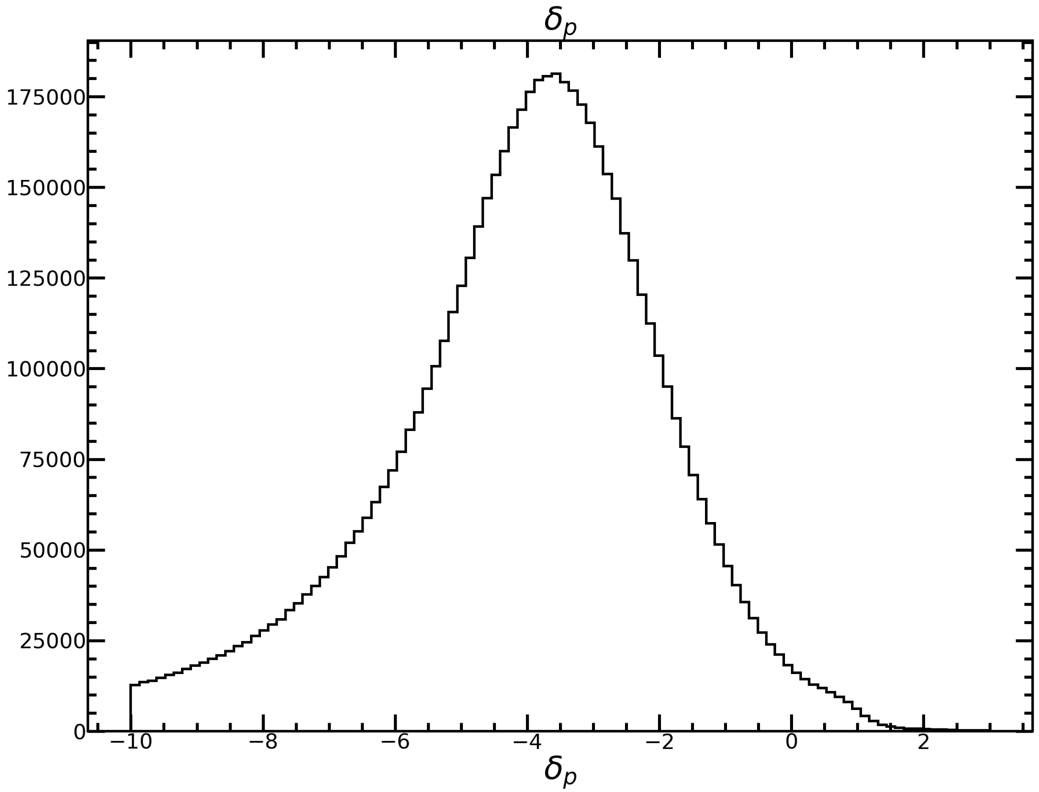
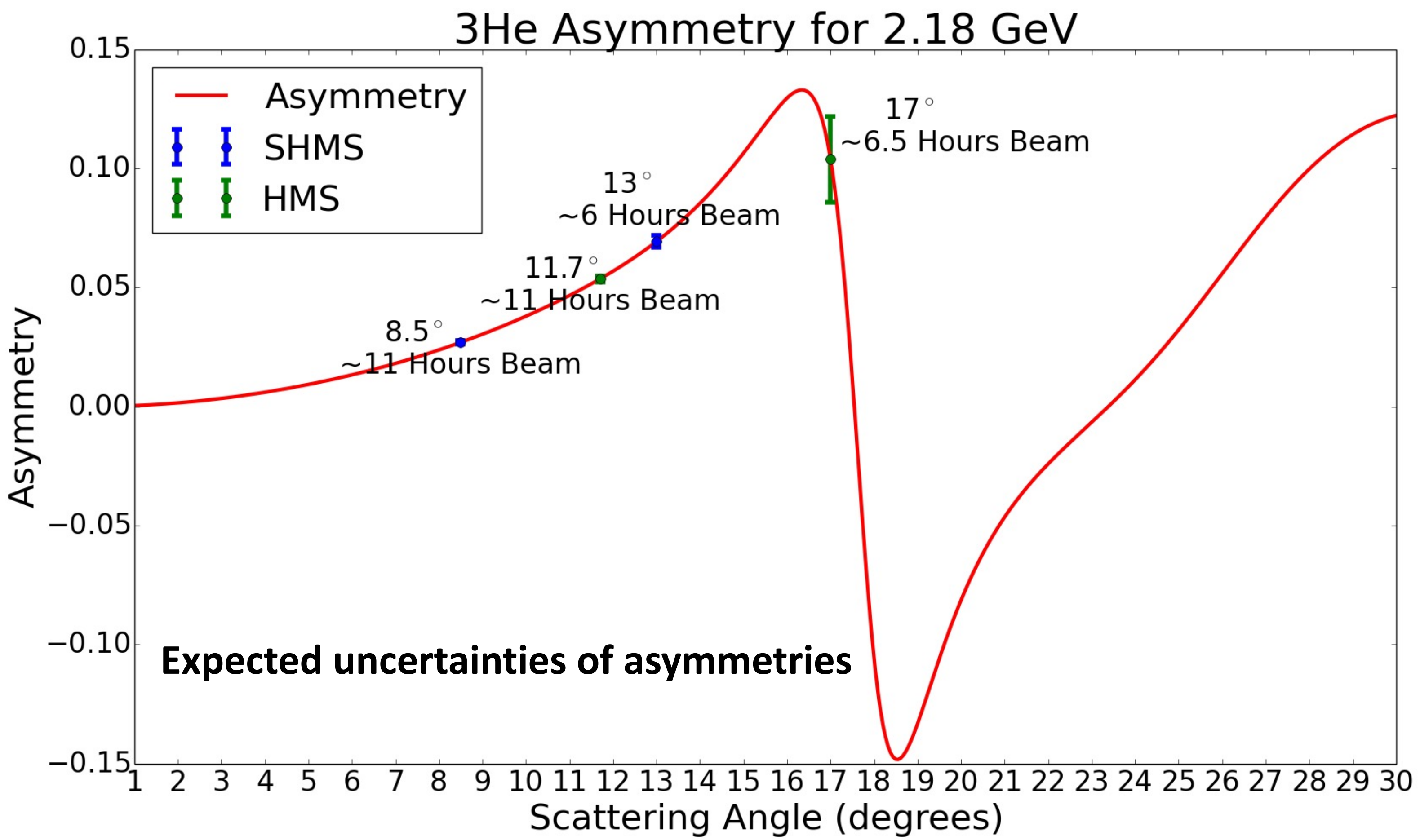

Jefferson Lab
SEE PARTS LIST
THIRD ANGLE PROJECTION
DO NOT SCALE DRAWING


δ_p
175000
150000
125000
100000
75000
50000
25000
0
−10
−8
−6
−4
−2
0
2
δ_p

Measured Kinematic Points

- Will provided further constraints to global fit and better determination of ^{3}He form factors
- Proof of principle



Monte Carlo and Data Comparison: Data Cuts

- SHMS (and HMS) carbon runs dominated by **quasi-elastic** events
- **PID**:
  - E/p>0.8 and E/p <2.0
  - Cherenkov NPE Sum >1.0
- **δp**
  - δp > -10.0 and δp <3.0
- **Acceptance**
  - $|\phi_{tg}| <= 0.05$ and $|\theta_{tg}|<=0.05$
- **z**
  - $|z|< 12$
- Scale factor: $\mathcal{L}_{data} / \mathcal{L}_{MC} = \frac{(6.02e-10) * L_{tg} * \varrho * Q}{(1.602e-13) * A} / \frac{N_{gen}}{\Delta E \Delta \Omega}$

L_{tg}= target length
ϱ = target density
Q= total charge
N_{gen}=# generated events
$\Delta E \Delta \Omega$= phase space