BSA of Coherent π^0 DVMP on Helium-4

Frank Thanh Cao
Advisor: K. Joo
Co-Advisor: K. Hafidi

University of Connecticut

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When embedded in the nucleus,

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Nuclear targets offer two distinct channels:

- Coherent (Nucleus stays intact)
- Incoherent (Nucleon breaks off and traverses nuclear medium)

Enter the CLAS EG6 Experiment

Start with the simplest dense stable nucleus: $^4\mathrm{He}$.

Measure the BSA for exclusive processes to get at nuclear and modified nucleonic FFs and GPDs.

Channel	Process		BSA
Coherent	DVCS:	$\left(e\ ^4\mathrm{He}, e\ ^4\mathrm{He}\ \gamma\right)$	Published[1]
	DVMP:	$\left(e\ ^4\mathrm{He}, e\ ^4\mathrm{He}\ \pi^0\right)$	This talk
		$\left(e\ ^4\mathrm{He}, e\ ^4\mathrm{He}\ \eta\right)$	Stats. too low
Incoherent	DVCS :	$^4\mathrm{He}\,(e, e\ p\ \gamma)\,X$	Under review
	DVMP:	$^4\mathrm{He}\left(e, e\ p\ \pi^0\right)X$	Work in prog.[2]
		$^4\mathrm{He}\,(e, e\ p\ \eta)\,X$	Work in prog.[2]

[1] M. Hattawy Phys. Rev. Lett. 119, 202004 (Nov. 2017)
[2] Perfectly suited for future ALERT detector

Formalism

Generally, the BSA can be expressed in terms of the squared-transition amplitude $\left\langle |\mathcal{M}_\pm|^2 \right\rangle$:

$$BSA = \frac{\left\langle |\mathcal{M}_+|^2 \right\rangle - \left\langle |\mathcal{M}_-|^2 \right\rangle}{\left\langle |\mathcal{M}_+|^2 \right\rangle + \left\langle |\mathcal{M}_-|^2 \right\rangle};$$

$$\left\langle |\mathcal{M}_\pm|^2 \right\rangle = \left(\frac{e^2}{q^2}\right)^2 \mathcal{L}_\pm^{\mu\nu} \mathcal{H}_{\mu\nu};$$

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C. R. Ji's formulation[a] for 0^{-+} meson electroproduction off 0^{++} target

$$\left(e\ {}^4\mathrm{He} \to e\ {}^4\mathrm{He}\ \pi^0\right)$$

$$J_\mu = F_{PS}\epsilon^{\mu\nu\alpha\beta} q_\nu \bar{P}_\alpha \Delta_\beta$$

$$\Rightarrow \mathcal{H}_{\mu\nu} = |F_{PS}|^2\, \epsilon_{\mu\alpha\beta\gamma}\epsilon_{\nu\alpha'\beta'\gamma'} q^{\alpha'} \bar{P}^{\beta'} \Delta^{\gamma'}$$

$$= \mathcal{H}_{\nu\mu}$$

$$\Rightarrow \boldsymbol{BSA \equiv 0}$$

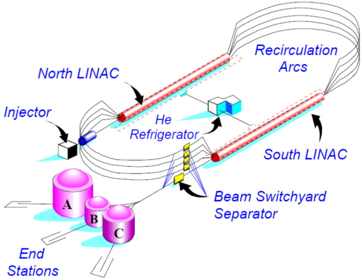
[a] Ji et al., arXiv:1806.01379 (June 2018)

Experiment

CEBAF @ JLab delivers long. polarized 6 GeV electrons to CLAS which detects the scattered electrons:

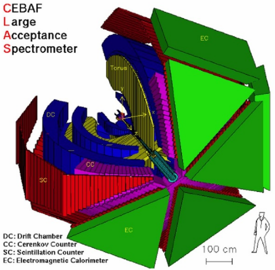
Energy	:	6 GeV
Luminosity	:	10^{34} cm^{2}s^{-1}
Long. Beam Polarization	:	85%

CEBAF



Delivers e

CLAS



Detects e'

$p_{\text{thres}} > 250$ MeV$/c$

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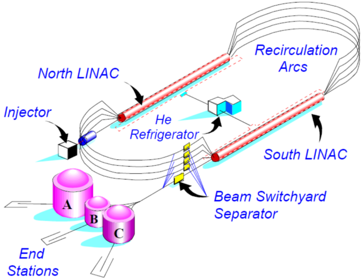

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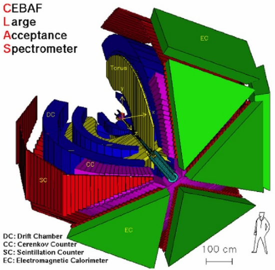


Detects e'

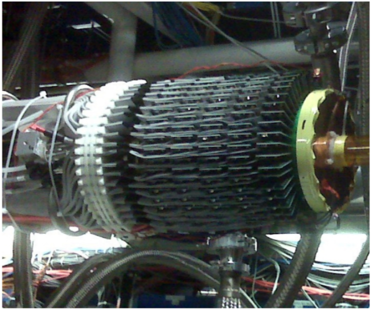
$p_{\text{thres}} > 250$ MeV$/c$

$p_{^4\text{He}} \approx 100$ MeV$/c$

Experiment

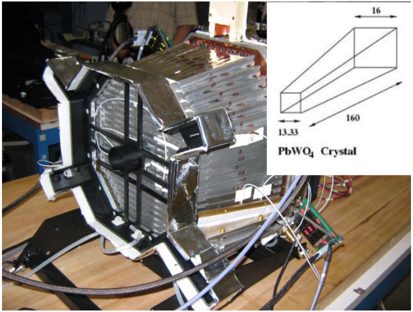
The Jefferson Lab's CLAS EG6 experiment is characterized by its helium gas target, solenoid magnet, and the addition of two detectors:

Radial Time Projection Chamber (RTPC)



Detects $^4\text{He}'$

Inner Calorimeter (IC)



Detects γ

$\theta_\gamma \in (8^\circ, 45^\circ) \bigcup (4^\circ, 15^\circ)$

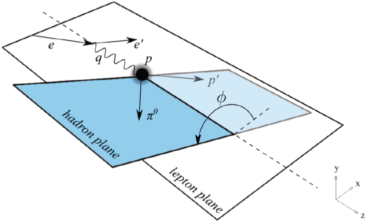
Measuring BSA of π^0 DVMP

We measured the fully exclusive coherent reaction:

$$e\ {}^4\mathrm{He} \to e\ {}^4\mathrm{He}\ \pi^0 \to e\ {}^4\mathrm{He}\ \gamma\ \gamma$$

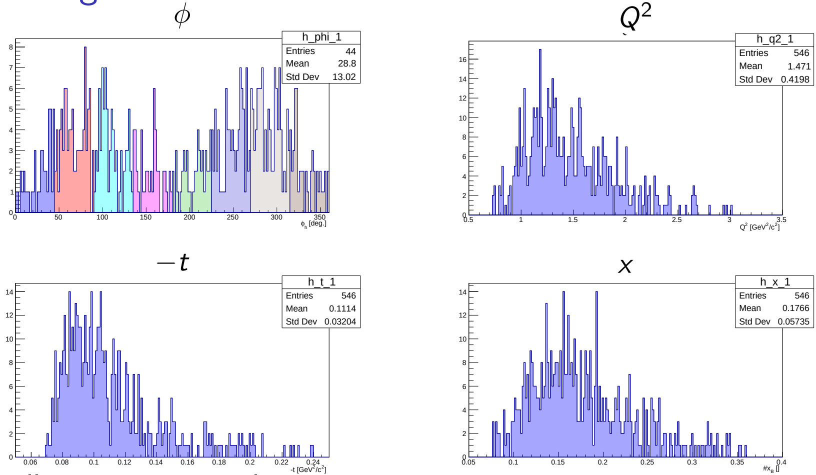
Measure the beam-spin asymmetry (BSA):

$$BSA(\phi) = \left(\frac{1}{P_B}\right) \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)}$$



- Small cross-section $\to$ low statistics
- Relatively large background
- Clean event selection is important!
  - Exclusivity Variable Cuts
  - Kinematic Fitting

Measuring BSA of π^0 DVMP



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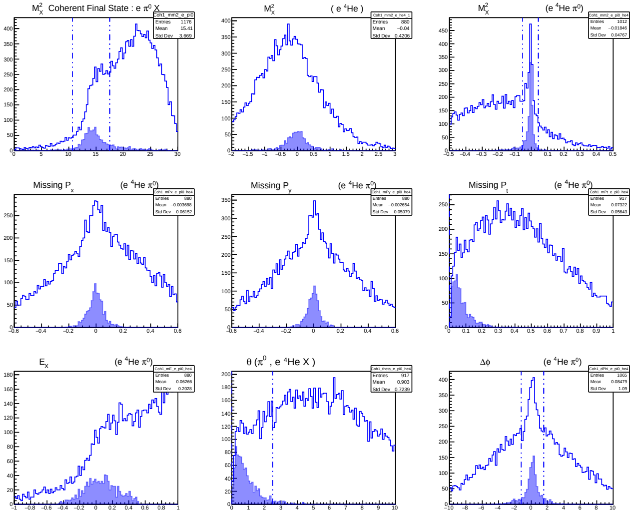

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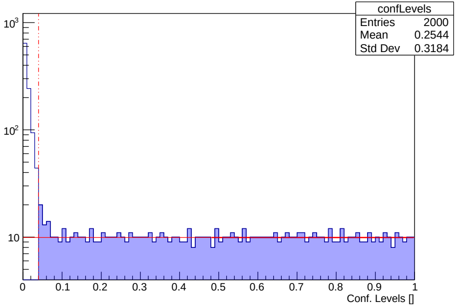
Kinematic Fitting in a Nutshell

Introduce and minimize $\mathcal{L}$, with Lagrange multipliers $\vec{\mu}$:

$$\mathcal{L} = (\vec{\epsilon}^{\,\nu})^T \, C_\eta^{-1} \, \vec{\epsilon}^{\,\nu} + 2\,(\vec{\mu}^{\,\nu})^T \left(A^\nu \vec{\xi}^{\,\nu} + B^\nu \vec{\delta}^{\,\nu} + \vec{c}^{\,\nu} \right) \quad .$$

At the end of the day, there is **one** cut that selects your events:
The Confidence Level Cut (CLC)



(Toy data)

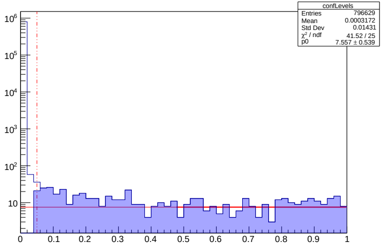
$5C$-Kinematic Fit on EG6: DVπ^0P

$$e\ {}^4\mathrm{He} \to e\ {}^4\mathrm{He}\ \pi^0$$

$$\pi^0 \to \gamma\ \gamma$$

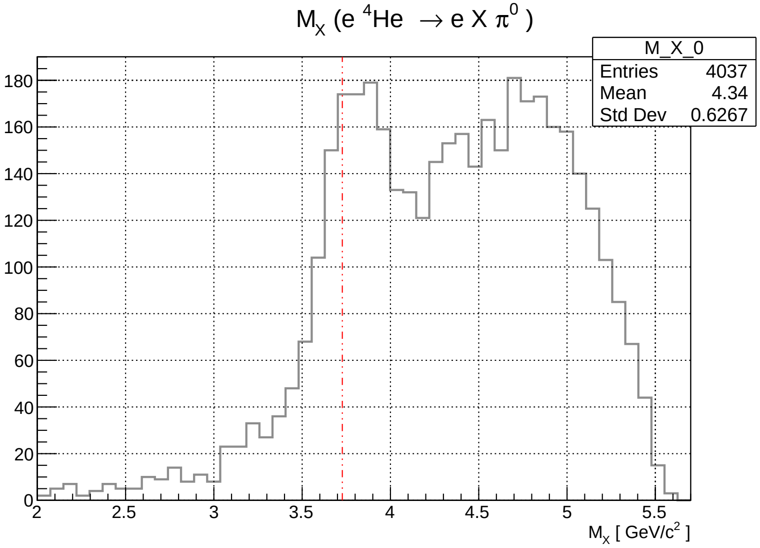
$$5C \Rightarrow \begin{cases} E_{init} - E_{fin} \equiv 0 \\ \vec{p}_{init} - \vec{p}_{fin} \equiv \vec{0} \\ M_{\pi^0} - \sqrt{(E_{\gamma_1} + E_{\gamma_2})^2 - \|\vec{p}_{\gamma_1} + \vec{p}_{\gamma_2}\|^2} \equiv 0 \end{cases}$$

Confidence Level Distribution



CLC = 5%

Kin. Fit Applied



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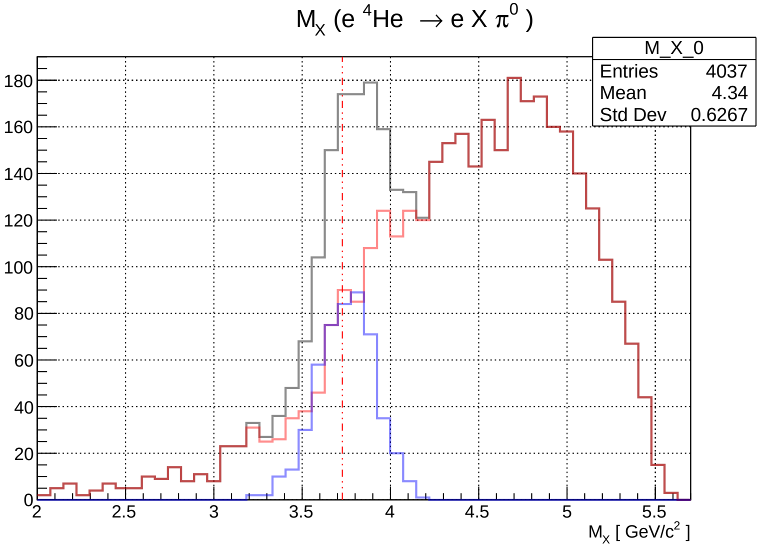
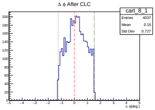


Red : Events failing CLC

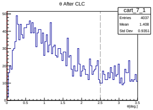
Blue : Events passing CLC

Sequential Exclusivity Cuts Applied

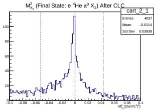
Coplanarity



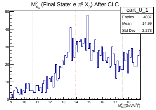
Cone Angle

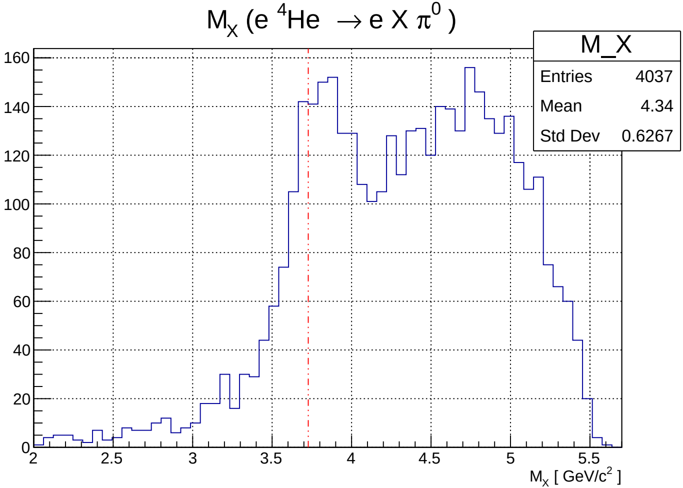


$M^2_{X_{\pi^0}}$



$M^2_{X_{^4\mathrm{He}}}$





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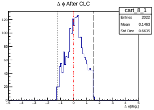

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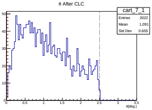

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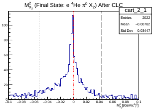

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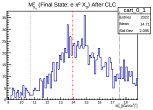

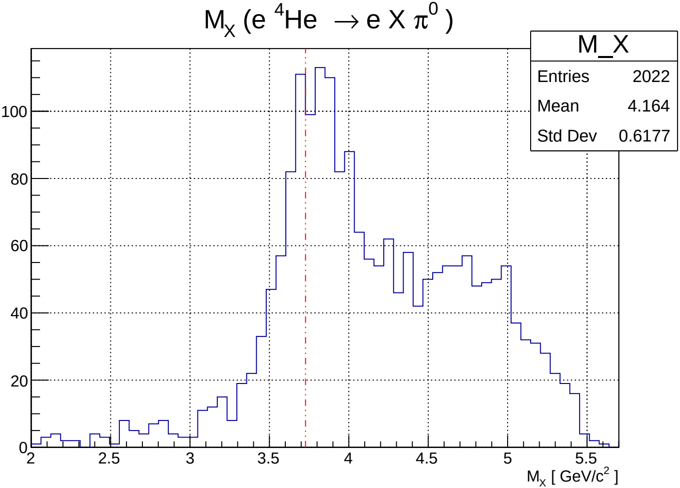

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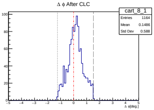

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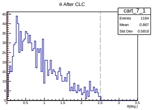

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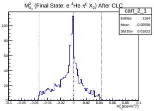

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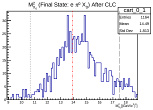

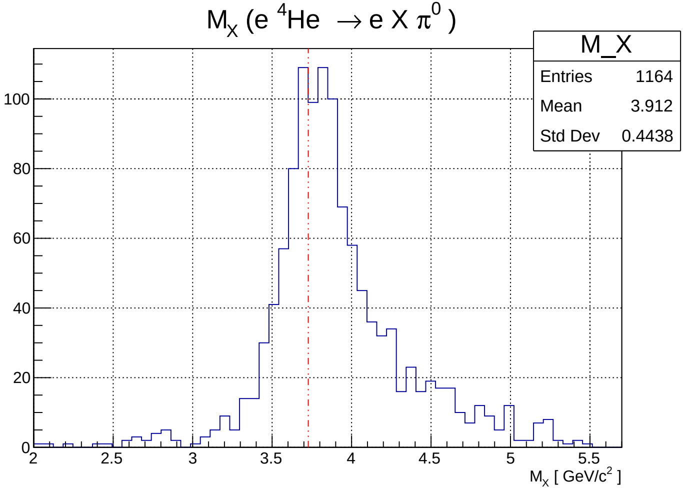

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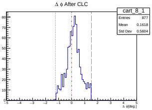

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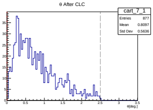

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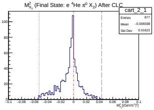

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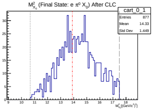
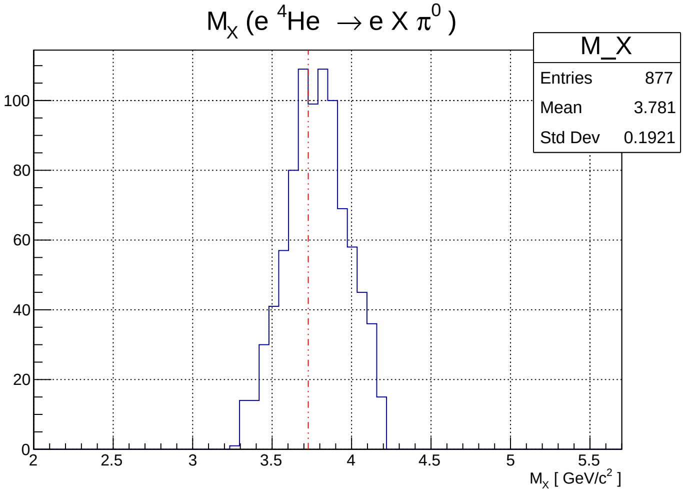
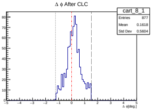




Sequential Exclusivity Cuts Applied

Coplanarity



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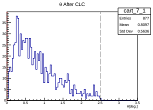

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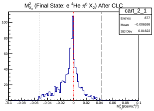

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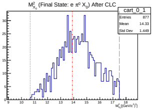
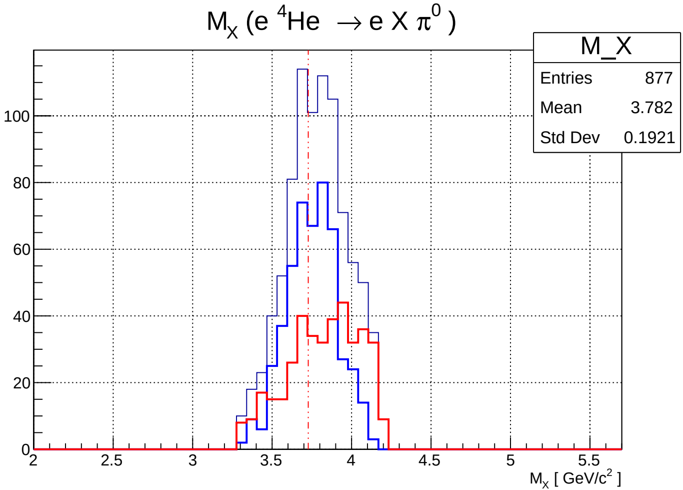




Red : Events failing CLC

Blue : Events passing CLC

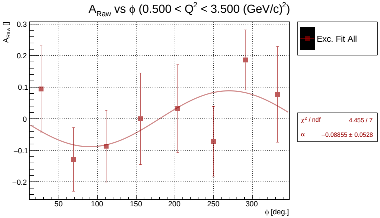
Beam-Spin Asymmetry Comparison

For

$$e\ {}^4\mathrm{He} \rightarrow e\ {}^4\mathrm{He}\ \pi^0 \quad , \tag{1}$$

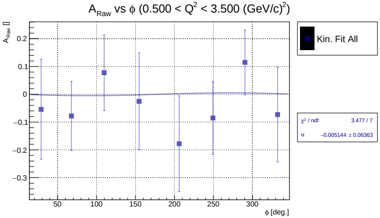
the BSA is obtained from two different event selection methods:

Exclusivity Cuts



BSA = -8.9±5.3 %
(800 events)

Kinematic Fit

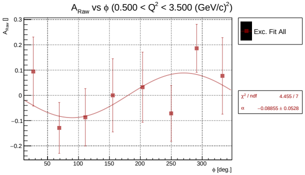


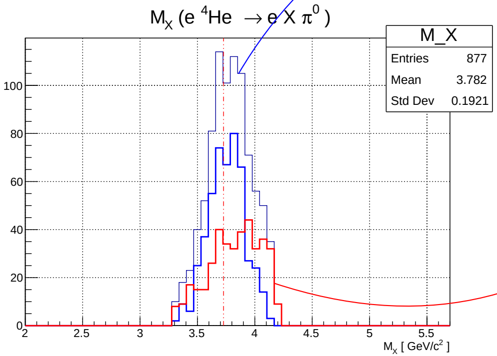
BSA = -0.5±6.3 %
(537 events)

Beam-Spin Asymmetry

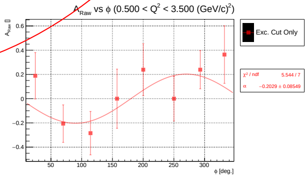
Beam-spin asymmetries for events passing exclusivity cuts *but* failing kin. fitting:

BSA = -8.9±5.3%





BSA = -20.3±8.5 %



Summary

- The BSA of coherent π^0 electroproduction off $^4\mathrm{He}$ is consistent with 0 (-1.08±3.22%)
  - Benchmark measurement for Ji's formulation
- Event selection plays a *crucial* role
- Exclusivity cuts require some cleverness
  - Intimate knowledge of the dataset and reaction needed to remove background and to clean the dataset
- Kin. fitting does not
  - It uses both detector resolutions and conservation law constraints to do a fantastic job in rejecting background
  - Some of these events cannot be rejected by any obvious series of cuts
- Kinematic fitting should be used in more analyses![3]

[3] The repo contains the library, FCKinFitter, with a wiki and working examples to help install, set up, and use kinematic fitting in (hopefully) an intuitive way.