

Coherent and incoherent DVCS and π^0 production on ^{4}He

S. Stepanyan (JLAB)

Nucleon and Resonance Structure with Hard Exclusive Processes

IPN-ORSAY, May 29 – 31, 2017

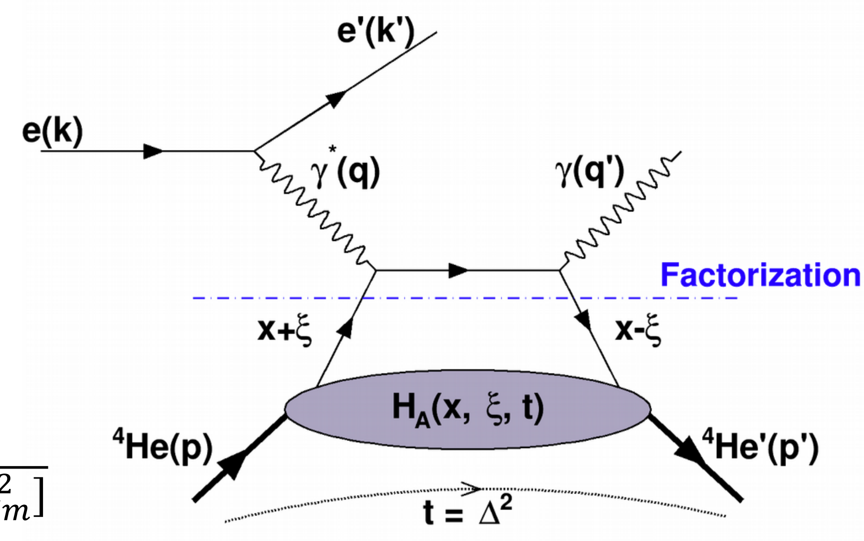
Outline

- DVCS and π^0 production on spin and isospin zero target
- CLAS/EG6 experiment at JLAB
- Radial Time Projection Chamber
- BSA in coherent and incoherent DVCS
- BSA in coherent and incoherent π^0 production
- Future measurements with CLAS12 in Hall-B
- Summary

Beam Spin Asymmetry in DVCS on nuclei

✓ Coherent DVCS, $\vec{e}A \to e'A'\gamma$:

Study the partonic structure of the nucleus. For spinless nuclei (^{4}He, ^{12}C, ^{12}O …), in the forward limit only one chiral-even GPD ($H_A(x,\xi,t)$) is needed to parametrize the nucleus structure and hence the BSA -



$$A_{LU} = \frac{\alpha_0(\phi)\cdot\mathcal{H}_{Im}}{\alpha_1(\phi)+\alpha_2(\phi)\cdot\mathcal{H}_{Re}+\alpha_3(\phi)\cdot[\mathcal{H}_{Re}^2+\mathcal{H}_{Im}^2]}$$

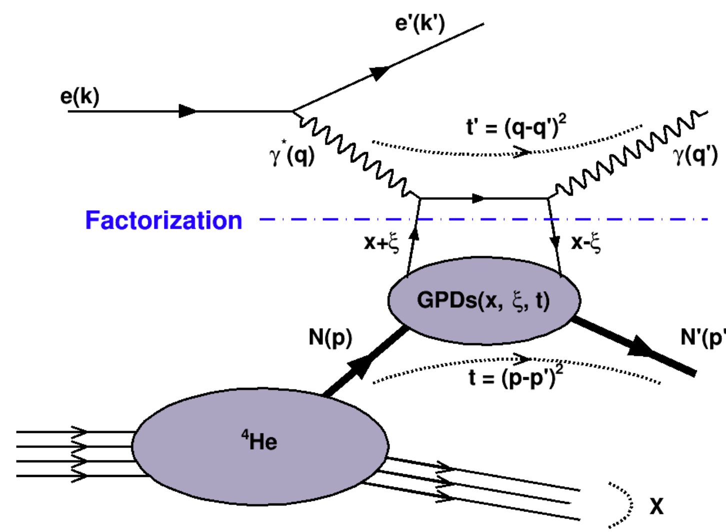
$\mathcal{H}$ – Compton Form-factor

$\alpha_j(\phi)$ – Functions of angle between lepton and hadron scattering planes

✓ Incoherent DVCS, $\vec{e}A \to e'N'\gamma X$:

Study the partonic structure of the bound nucleon. Four ciral-even GPDs $(H(x,\xi,t), \widetilde{H}(x,\xi,t), \mathrm{E}(x,\xi,t), \tilde{E}(x,\xi,t))$

$$A_{LU} \propto \alpha(\phi)\{F_1 H + \xi(F_1+F_2)\widetilde{H} + \kappa F_2 E\}$$



Beam Spin Asymmetry in π^0 production

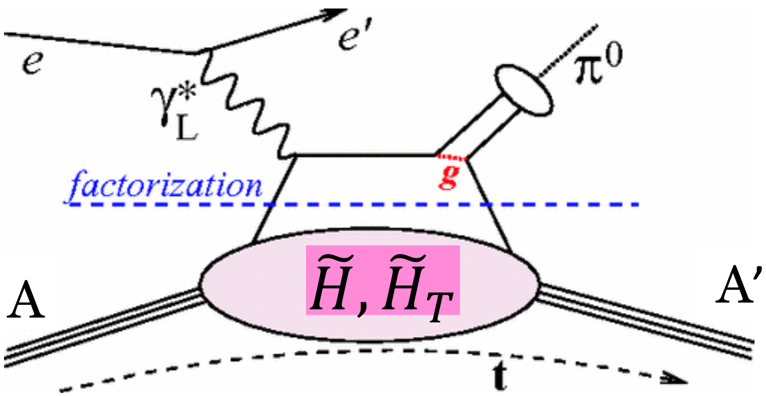
$$\frac{d^2\sigma}{d\varphi dt} = \frac{1}{2\pi}\left[\frac{d\sigma_T}{dt} + \varepsilon\frac{d\sigma_L}{dt} + \sqrt{2\varepsilon(\varepsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\varphi + \varepsilon\frac{d\sigma_{TT}}{dt}\cos(2\varphi) + h\sqrt{2\varepsilon(\varepsilon-1)}\frac{d\sigma_{LT'}}{dt}\sin(\varphi)\right]$$

✓ Coherent π^0 production, $eA \rightarrow e'A'\pi^0$:

At Q^2~few GeV^2, transverse virtual photon contribution dominates the production on the nucleon. Contribution of a longitudinal virtual photon increases in the production on a spinless nuclei, cross section of the photo-production on a spinless nuclei (^{4}He, ^{12}C, ^{12}O …) vanishes with $\vartheta_{cm}\rightarrow 0$:

$$\frac{1}{F^2(t)}\frac{d\sigma_T}{d\Omega} \sim \sin^2\vartheta_{cm}$$

$$A_{LU} \sim \sigma_{LT'} \sim \widetilde{H} * \widetilde{H}_T$$

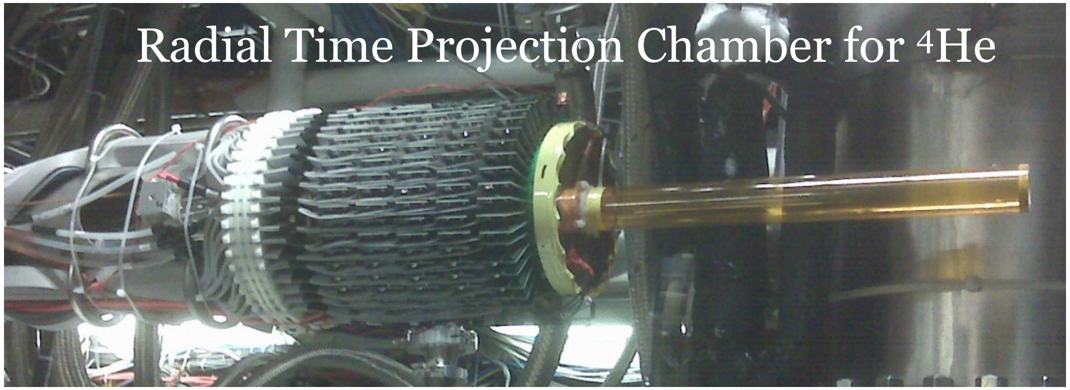


✓ *For the proton target, the flavor structure for π^0 production process is 2*u+d.*
For an isospin zero target, e.g. ^{4}He, the flavor structure is u+d

CLAS/Eg6 experiment, Nov-Dec 2009

- Meson Spectroscopy and DVCS (coherent and incoherent) on ^{4}He
- Both experiments make use of zero spin and isospin of the target to restrict production mechanisms
- Both experiments require detection and identification of recoil α-particles
  - 2nd Generation Radial Time Projection Chamber with 20 cm long, 6 atm, ^{4}He gaseous target located inside of the Hall-B superconducting solenoid magnet

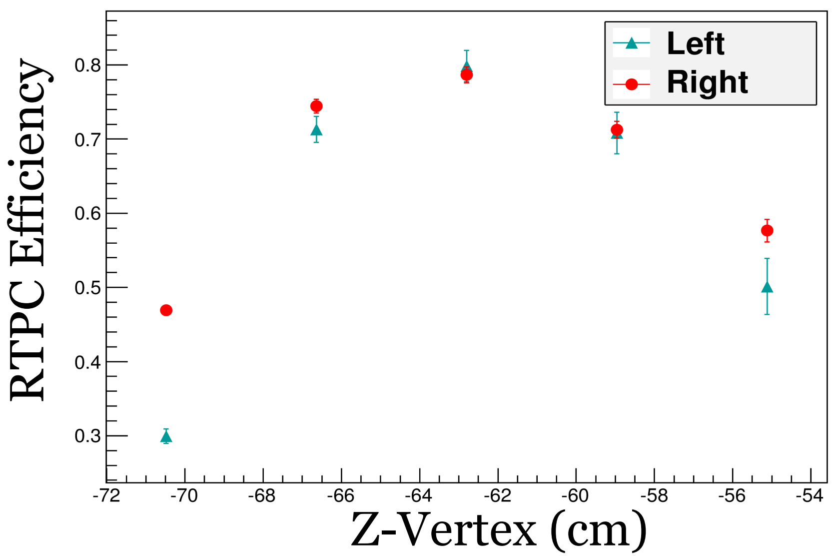
20-cm-long, 15 cm in diameter cylindrical detector positioned around the 6 atm ^{4}He gaseous target. The target cell is a 25-cm-long and 6-mm-diameter Kapton tube with 27-μm-thick walls.



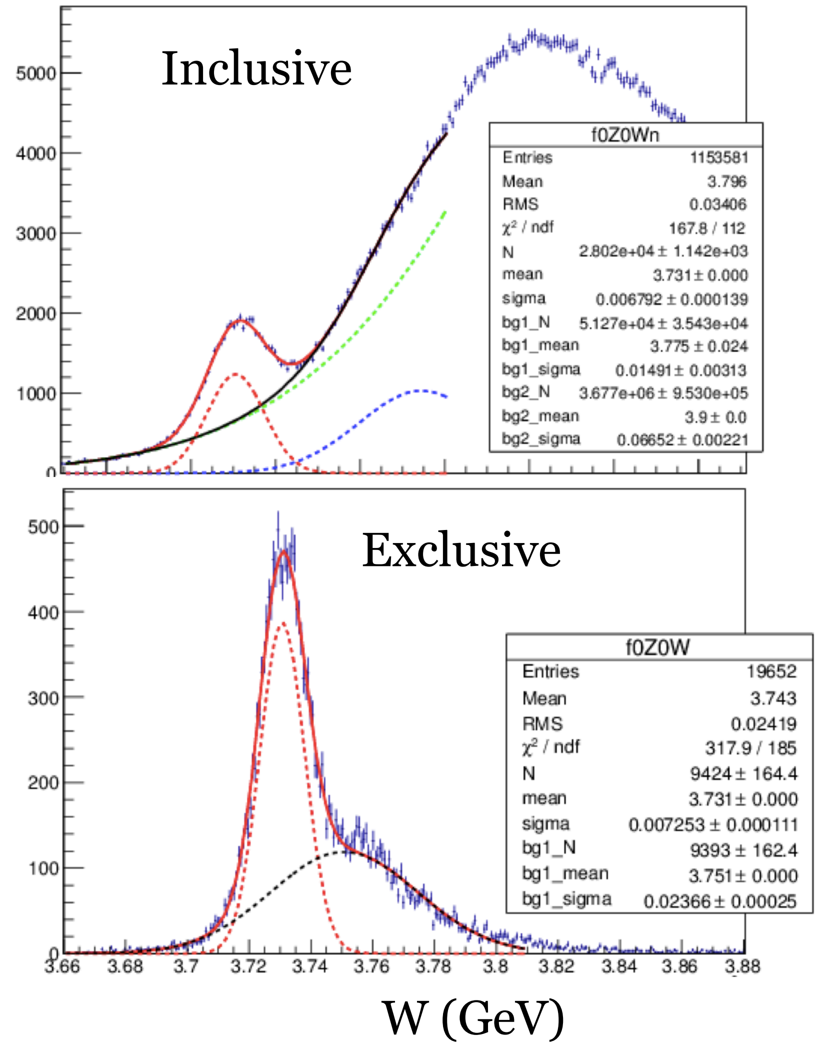
- Production data taking – ~200mC of beam on target (20 PAC days) with 6.06 GeV polarized electrons
- RTPC calibration runs at 1.2 GeV

RTPC Calibration

- Beam energy 1.2 GeV, the same detector configuration as for production data taking
- Both exclusive and inclusive elastic scattering
  - i.e. with and without ^{4}He detection
  - ratio is the RTPC tracking efficiency



Example Fits



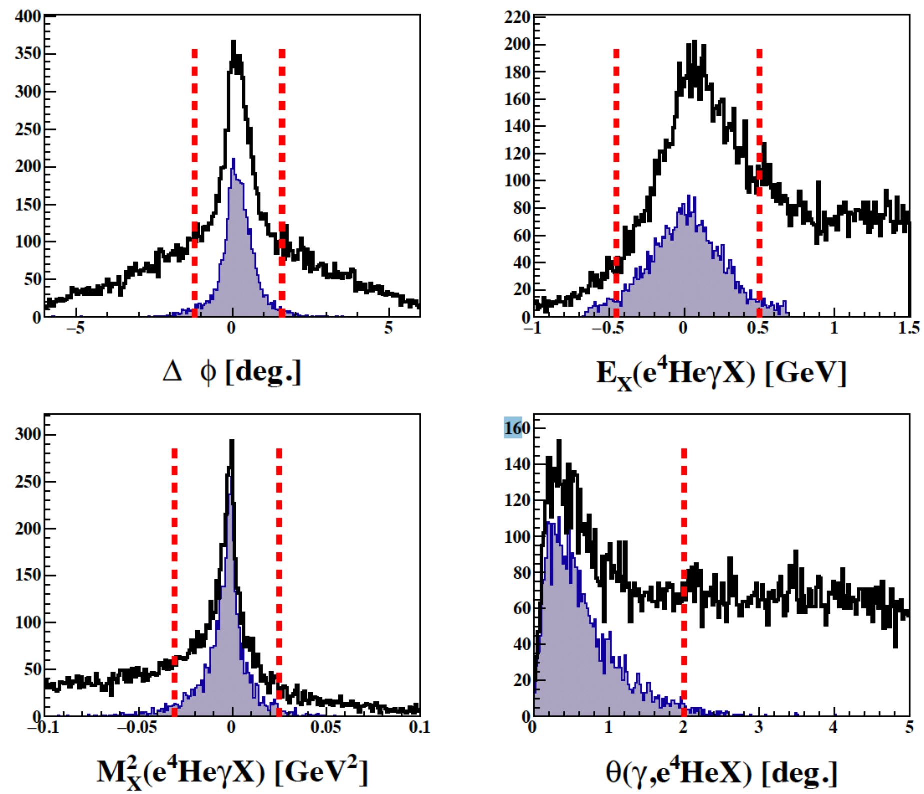
Coherent DVCS analysis

M. Hattawy (ORSAY/ANL)

$$\vec{e}\,^4He \rightarrow e'\,^4He'\gamma$$

- One electron in CLAS, one photon with E>2 GeV in the inner calorimeter
- The recoil α-particles (^{4}He) has been detected and identified in RTPC
- Set of cuts on kinematical variables define the exclusivity of the reaction:
  - the coplanarity angle Δφ between the (γ,γ*) and (γ*,^{4}He′) planes,
  - the missing energy, mass, and transverse momentum of the (e′^{4}He′γ) system,
  - the missing mass squared of the e′^{4}He′ system, and
  - the angle θ between the measured photon and the missing momentum of the e′^{4}He′ system.

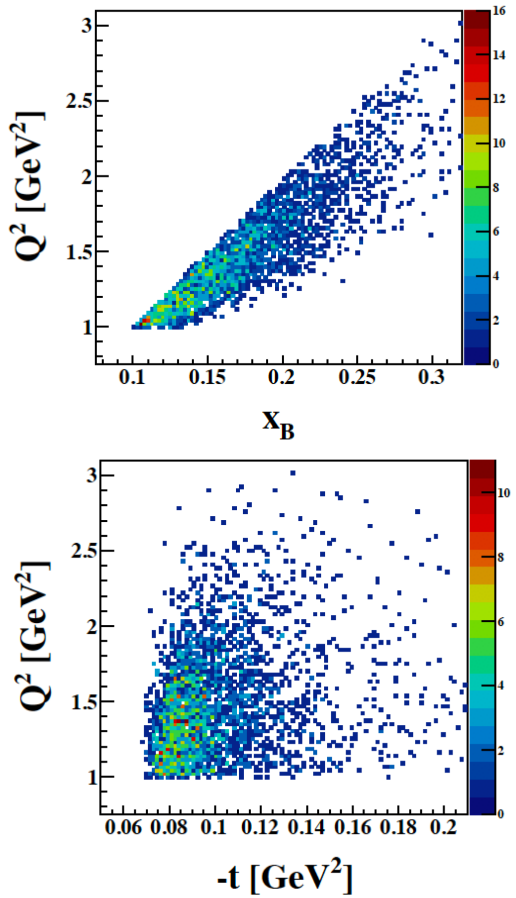
Black - all events, shaded region after all other exclusivity cuts

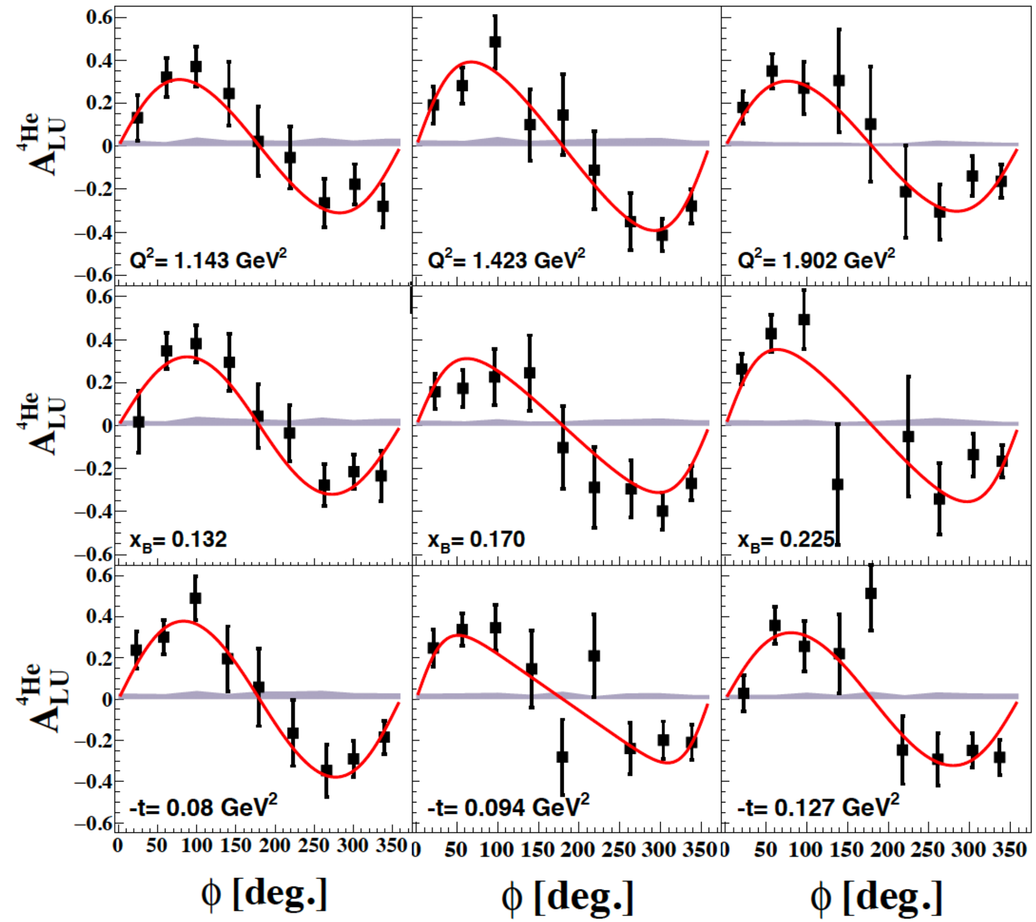


BSA: coherent DVCS

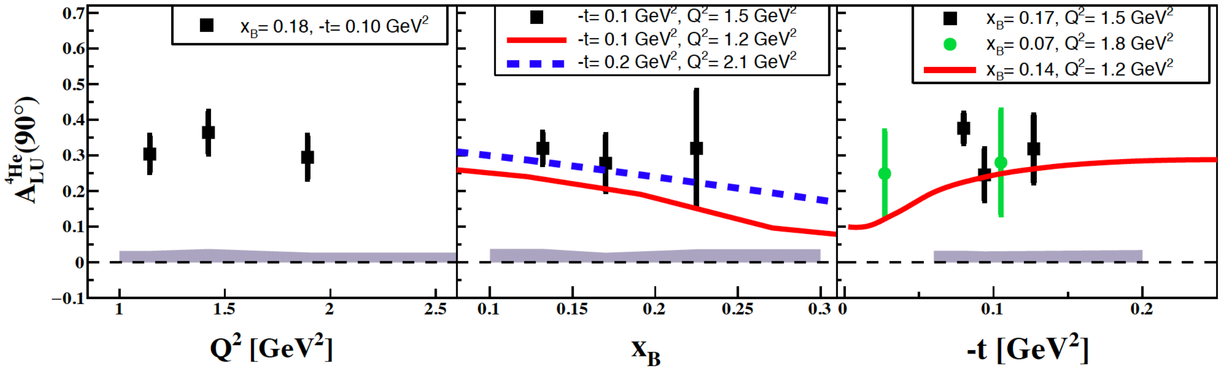
$1 < Q^2 < 2.3$ GeV²
$0.05 < -t < 0.2$ GeV²
$0.1 < x_B < 0.25$

$$A_{LU} = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{1}{P_B}\frac{N^+ - N^-}{N^+ + N^-}$$





ℑm and ℜe parts of the Compton Amplitude



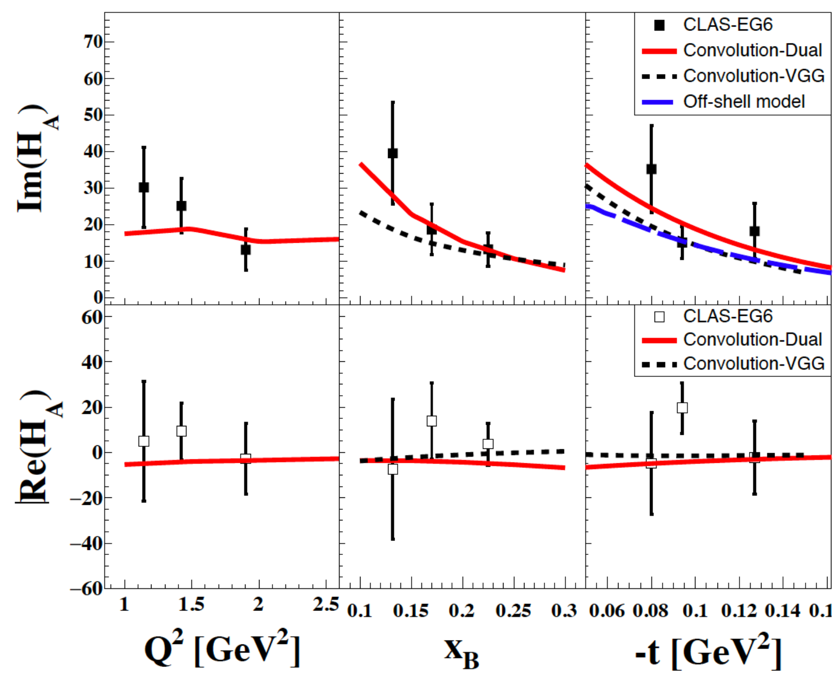
Curves from – *S. Liuti and K. Taneja, Phys. Rev. C 72, 032201 (2005)*

- **HERMES**

Curves:

Convolution-Dual – V. Guzey, Phys. Rev. C 78, 025211 (2008)
Convolution-VGG – M. Guidal, M. V. Polyakov, A. V. Radyushkin and M. Vanderhaeghen, Phys. Rev. D 72, 054013 (2005).
OFf-shell model – J. O. Gonzalez-Hernandez, S. Liuti, G.R. Goldstein and K. Kathuria, Phys. Rev. C 88, no. 6, 065206, (2013).

$$A_{LU} = \frac{\alpha_0(\phi)\cdot\mathcal{H}_{Im}}{\alpha_1(\phi)+\alpha_2(\phi)\cdot\mathcal{H}_{Re}+\alpha_3(\phi)\cdot[\mathcal{H}_{Re}^2+\mathcal{H}_{Im}^2]}$$

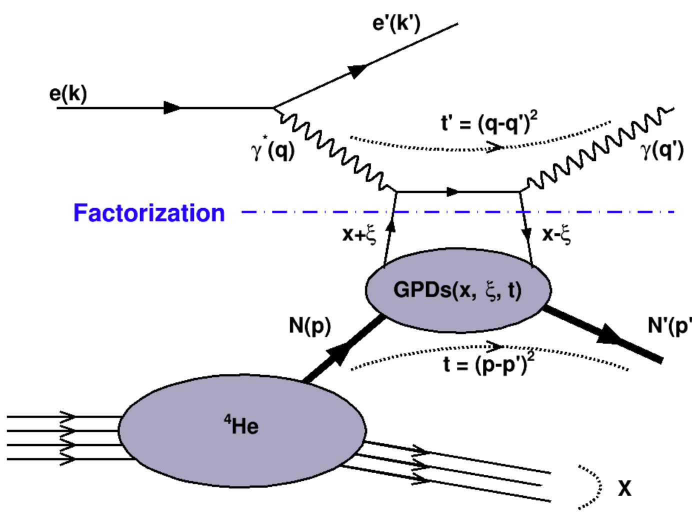


PRL draft is in collaboration review

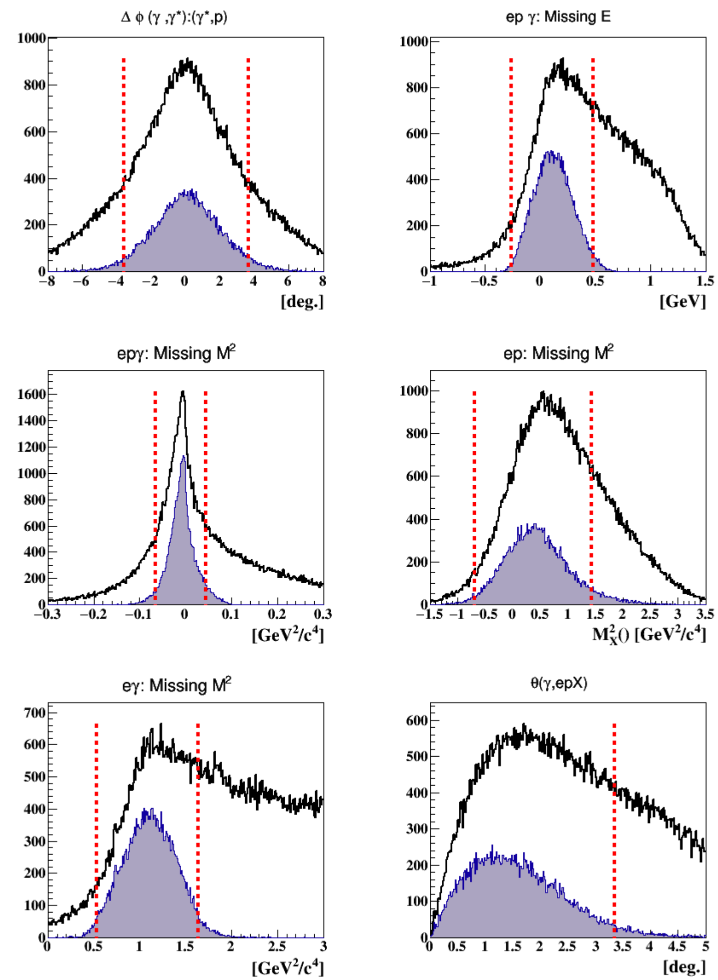
Incoherent DVCS

$$\vec{e}^4He \rightarrow e'p\gamma X$$

- Detected particles: scattered electron and recoil proton in CLAS, DVCS photon with E>2 GeV in the inner calorimeter
- Exclusivity cuts on kinematical variables, similar to hydrogen-DVCS analysis.



Bound nucleon GPDs



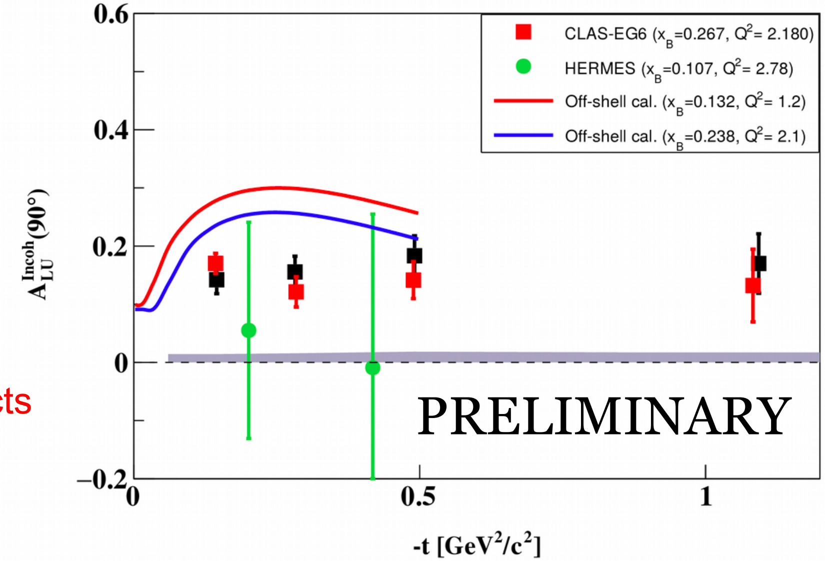
DVCS BSA on bound protons

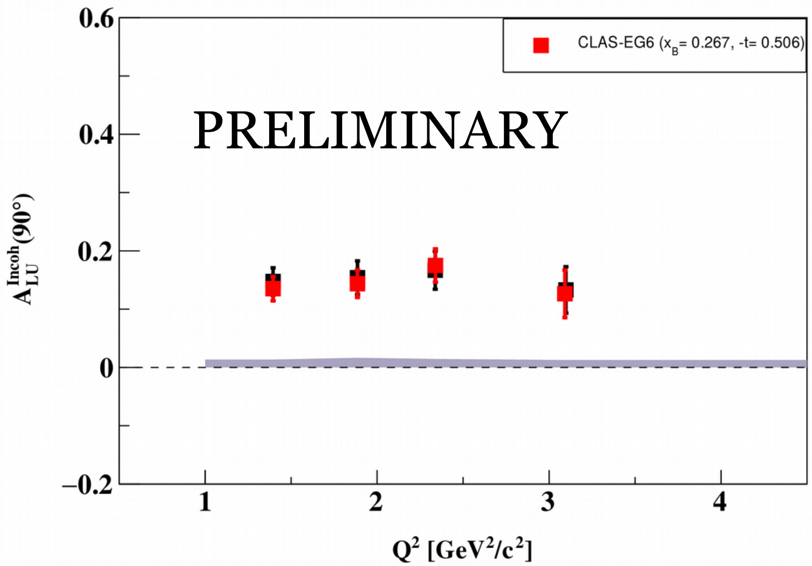
$$A_{LU} = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{1}{P_B}\frac{N^+ - N^-}{N^+ + N^-}$$

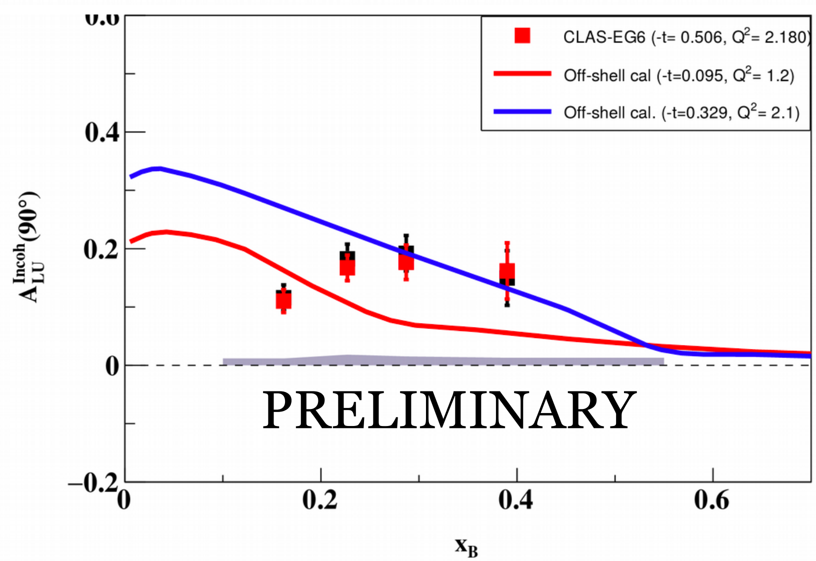
$$A_{LU} \propto \alpha(\phi)\{F_1 H + \xi(F_1 + F_2)\widetilde{H} + \kappa F_2 E\}$$

- ■ bins in $t=(p-p')^2$ - smeared due to Fermi motion
- ■ bins in $t'=(q-q')^2$ - smeared due to radiative effects

Both effects are small in out kinematics

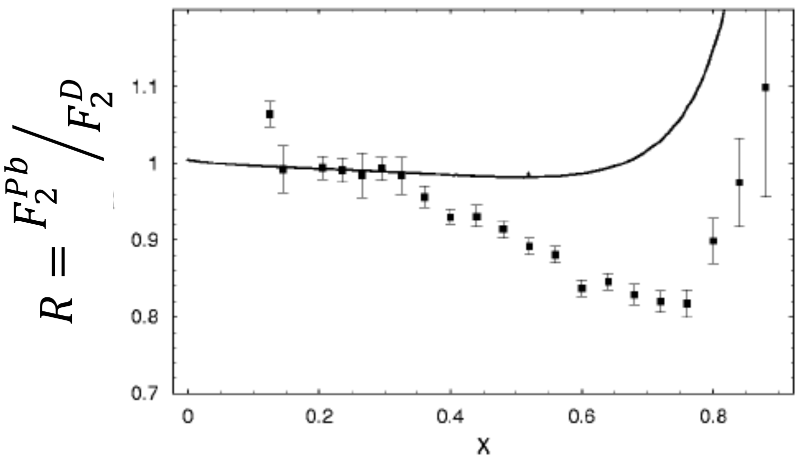


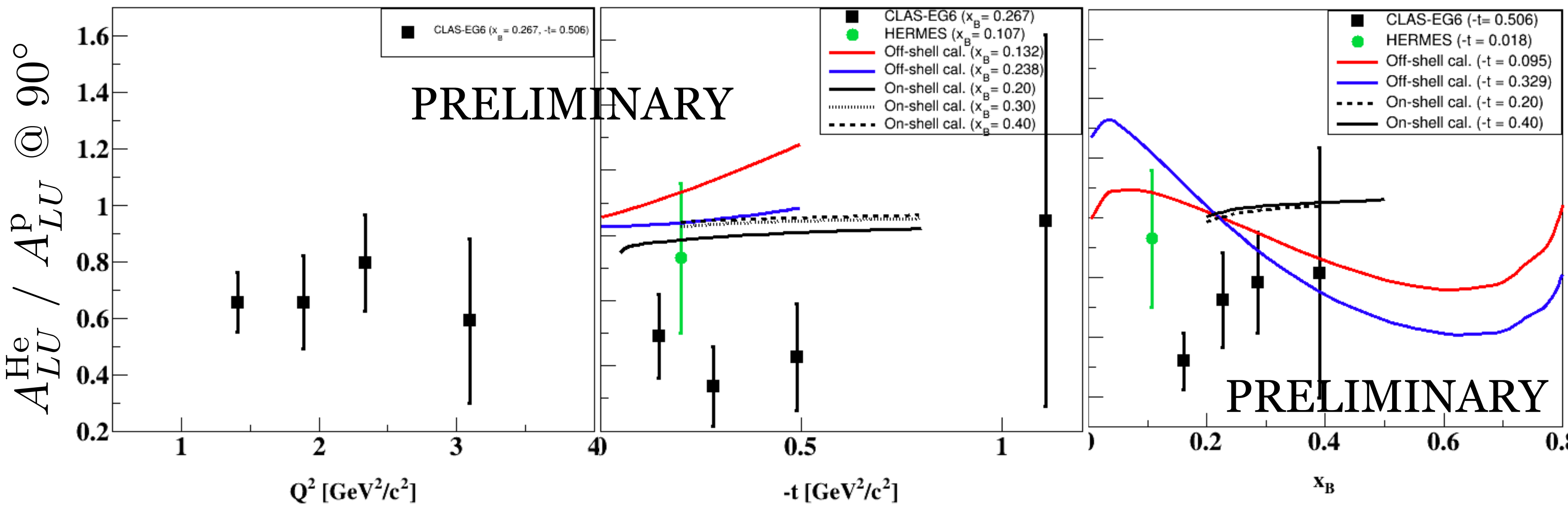




BSA and Generalized EMC Ratio

- EMC effect: nucleon structure is modified.
- Compare BSA measured in incoherent DVCS with the one measured on the hydrogen target.
- Incoherent BSA is dominated by DVCS off of MF protons (no tagging)





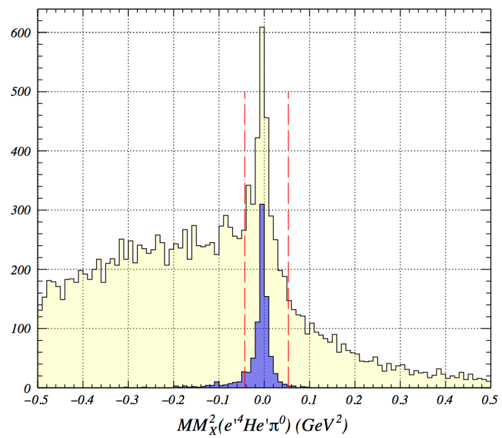
Coherent π^0 Production

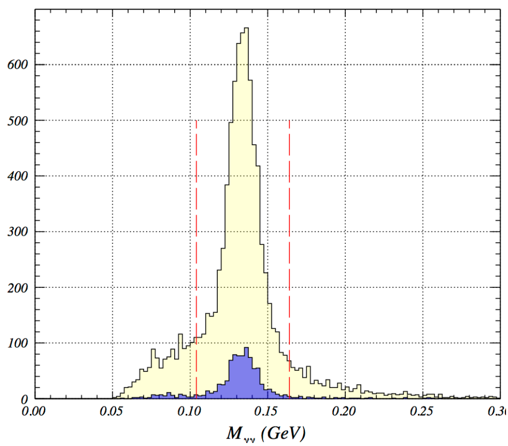
B. Torayev (ODU)

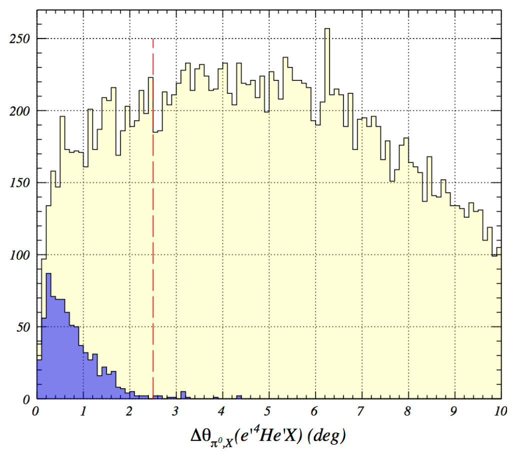
$$\vec{e}\,^4He \rightarrow e'\,^4He'\pi^0$$

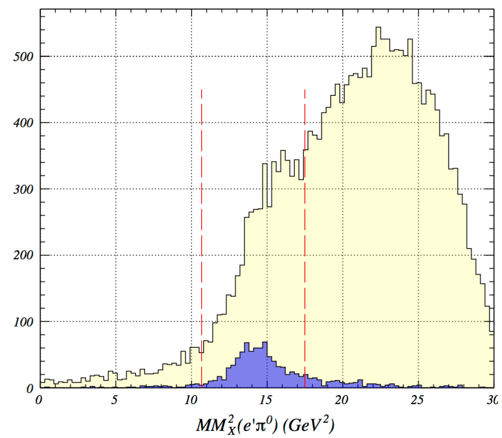
- Detected particles: scattered electron in CLAS, two photons in the inner calorimeter, the recoil ^{4}He is identified in RTPC
- Exclusivity cuts on kinematical variables, similar to coherent-DVCS analysis.

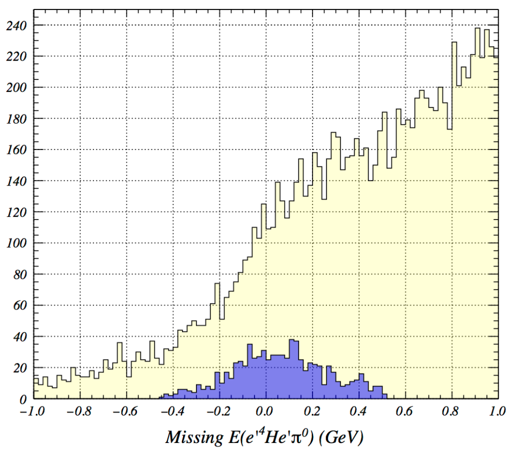
Yellow shaded region - all events
Blue shaded region = after all other exclusivity cuts











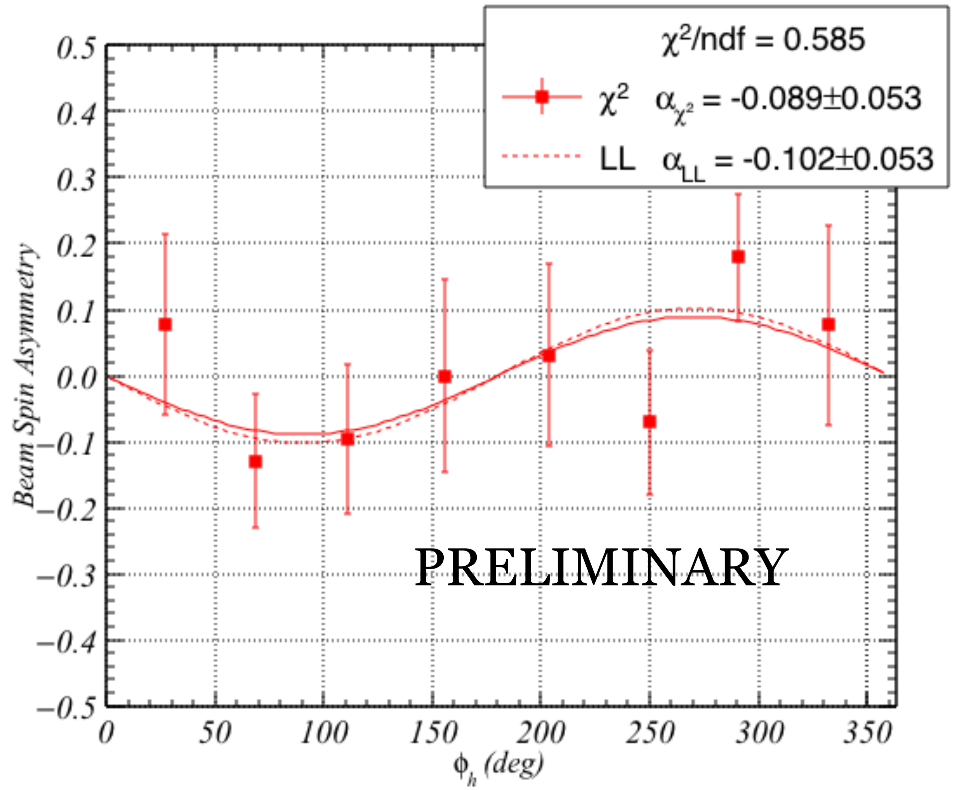
Coherent π^0 Production

Total of ~800 coherent π^0 events.

$$A_{LU}^{\sin(\varphi)} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{1}{P_B}\left(\frac{N^+ - N^-}{N^+ + N^-}\right)$$

$$\Delta A_{LU}^{\sin(\varphi)} = \frac{2}{P_B}\left(\frac{\sqrt{\left(N^-\Delta N^+\right)^2 + \left(N^+\Delta N^-\right)^2}}{\left(N^+ + N^-\right)^2}\right)$$

χ^2 and un-binned maximum log-likelihood fits to BSA ϕ-dependence



$$A_{LU}^{\sin(\varphi)}(\chi^2) = -0.09 \pm 0.05(stat.)$$

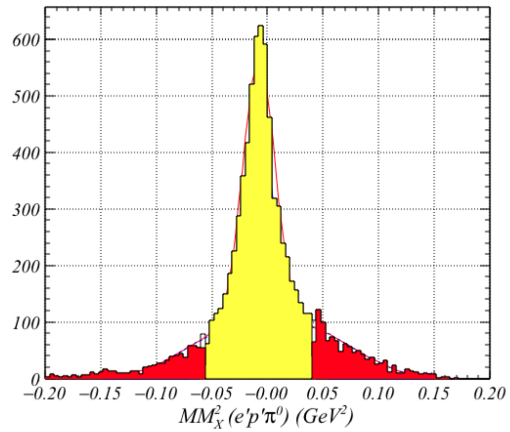
$$A_{LU}^{\sin(\varphi)}(LL) = -0.10 \pm 0.05(stat.)$$

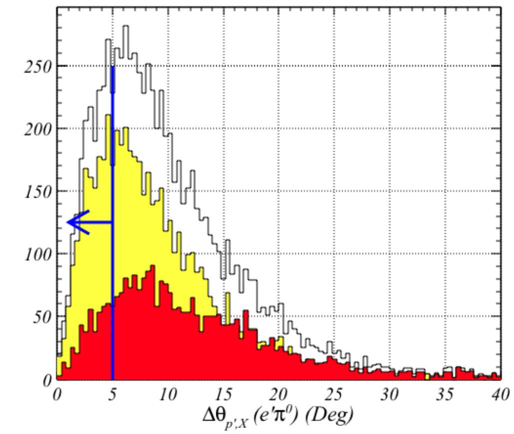
Incoherent "exclusive" π^0 Production

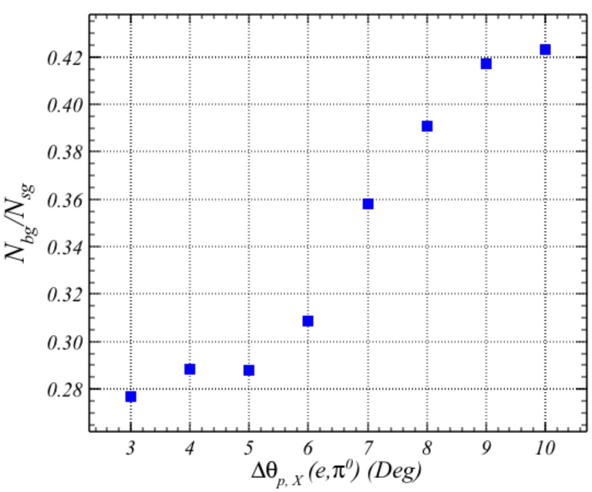
$$\vec{e}\,^4He \rightarrow e'p\pi^0X$$

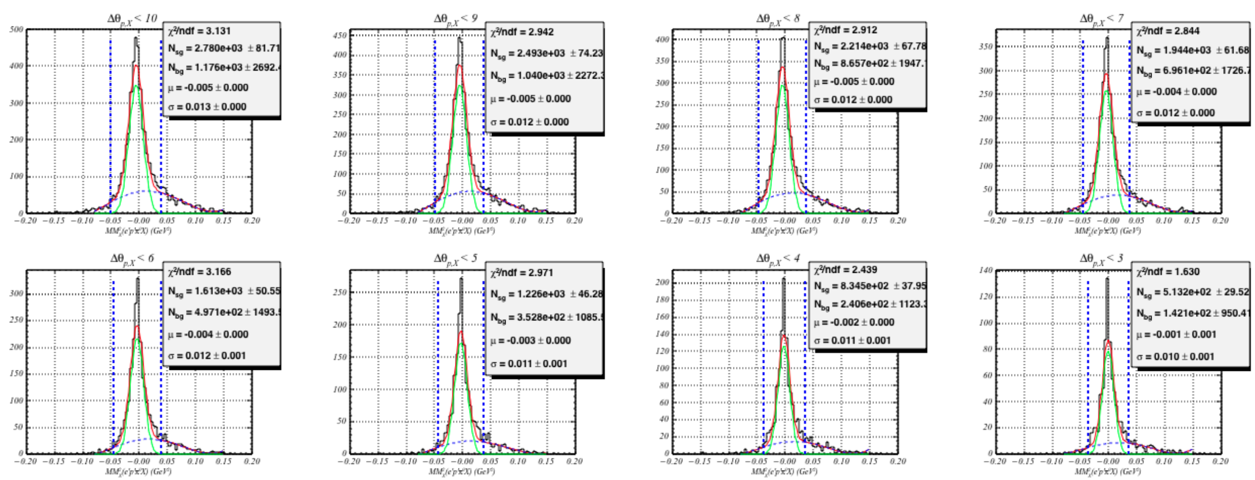
Detected particles: scattered electron and the recoil proton in CLAS, two photons in the inner calorimeter.

Kinematic cuts to optimize signal over background from the fits to the MM-distributions.





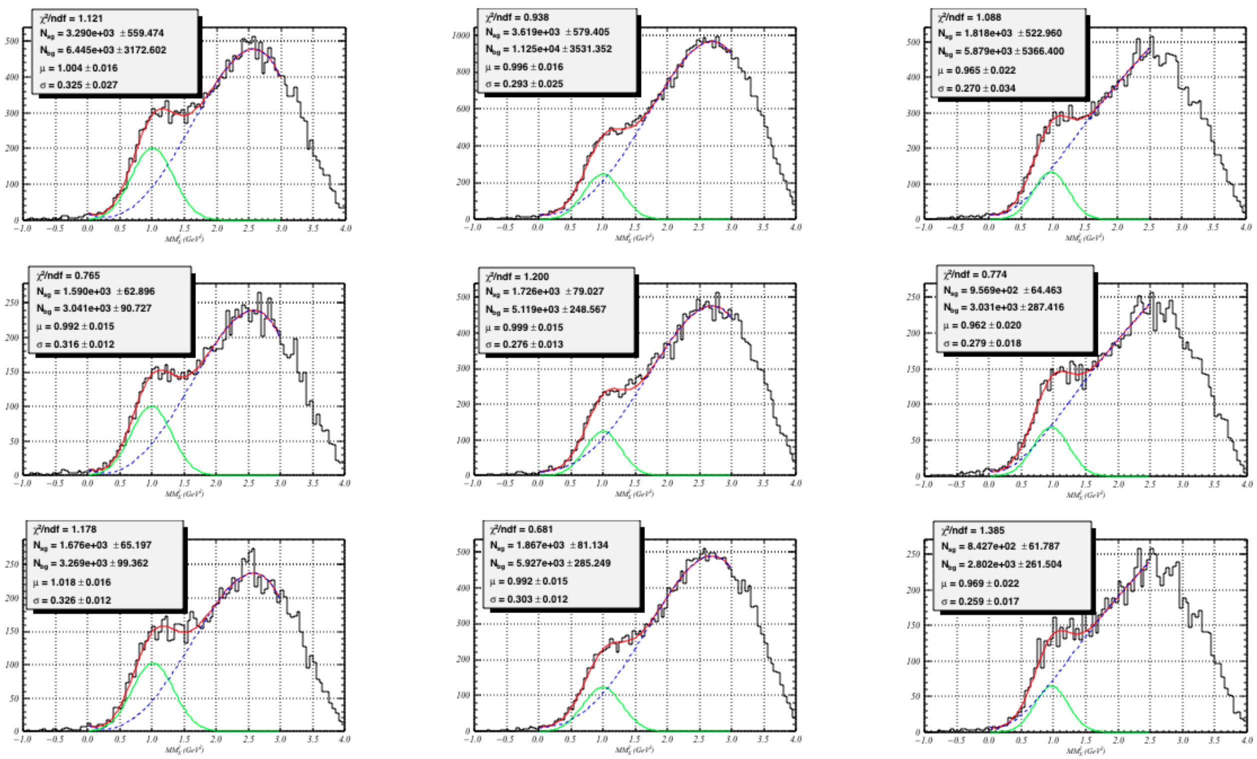




Incoherent “semi-exclusive” π^0 Production

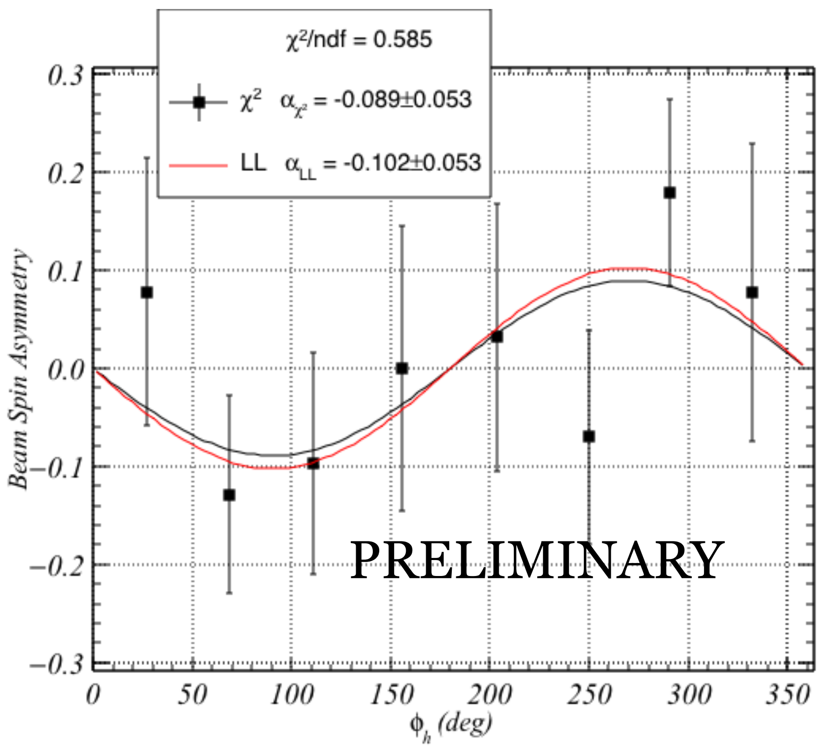
$$\vec{e}\,^4He \rightarrow e'N\pi^0X$$

- Detected particles: scattered electron in CLAS, two photons in the inner calorimeter.
- Number of events in each beam helicity and ϕ-bin is extracted from the fit to the MM distribution of $(e'\pi^0)$ asuuming $\vec{e}N \rightarrow e'\pi^0X$

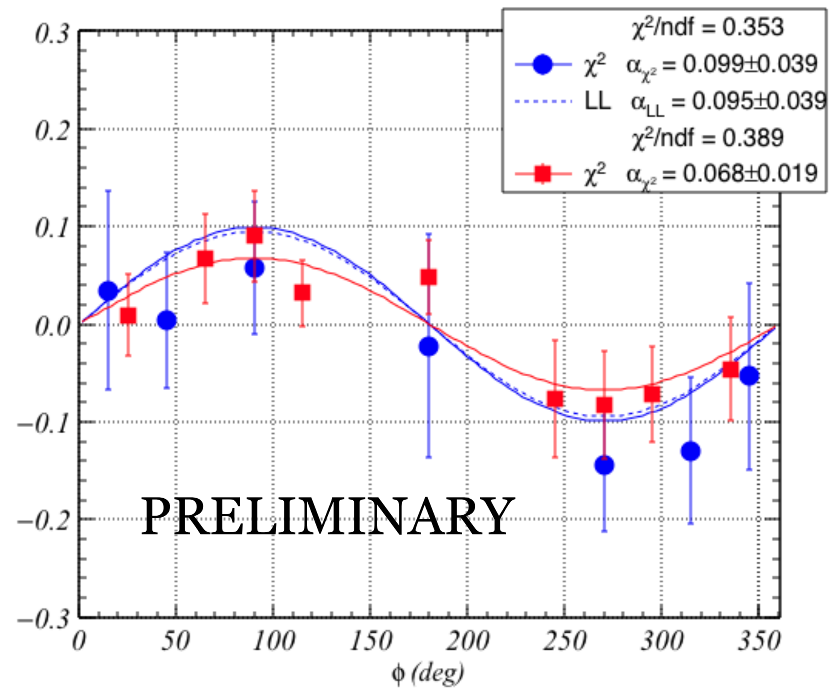


BSA in coherent and in-coherent π^0 production

$\vec{e}\,^4He \rightarrow e'\,^4He'\pi^0$

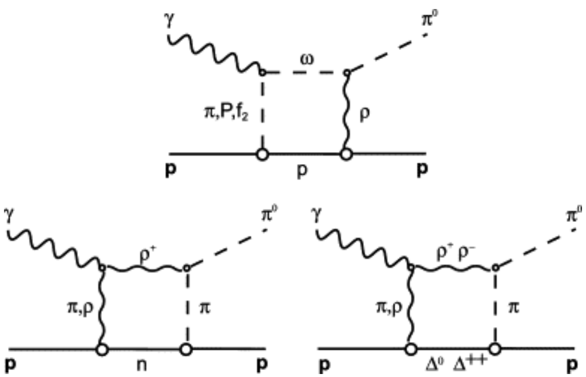


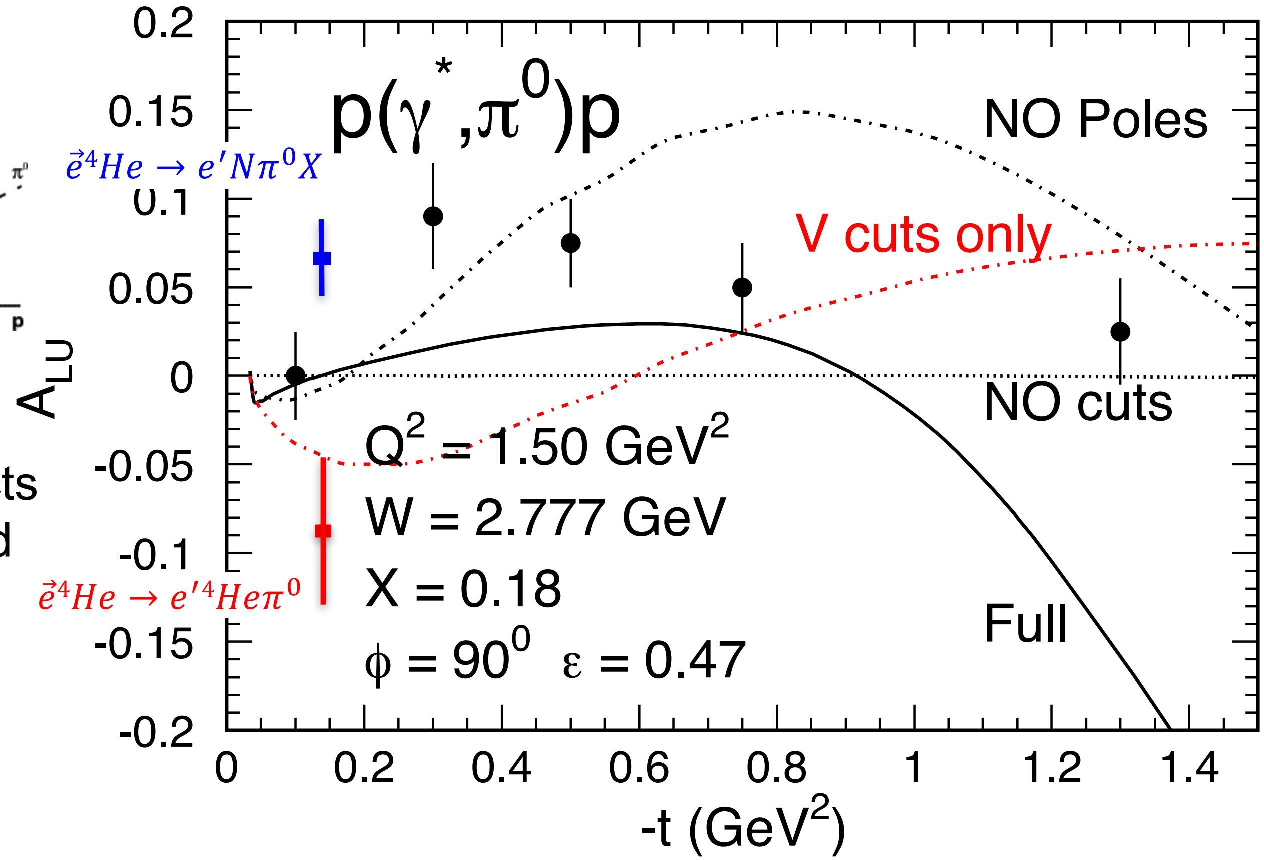
$\vec{e}\,^4He \rightarrow e'N\pi^0X$



Note the asymmetry sign change between spin/isospin zero target and the nucleon

Hadronic exchanges in π^0 production





Production on ^{4}He selects exchanges with spin and isospin =0.

The 2-π exchange has the strongest $J=T=0$ contribution.

J.M. Laget / Physics Letters B 695 (2011) 199–204

Quark degrees of freedom in π^0 production on ^{4}He

The BSA for this process is:

$$A_{LU} \sim \sigma_{LT'} \sim \widetilde{H} * \widetilde{H}_T$$

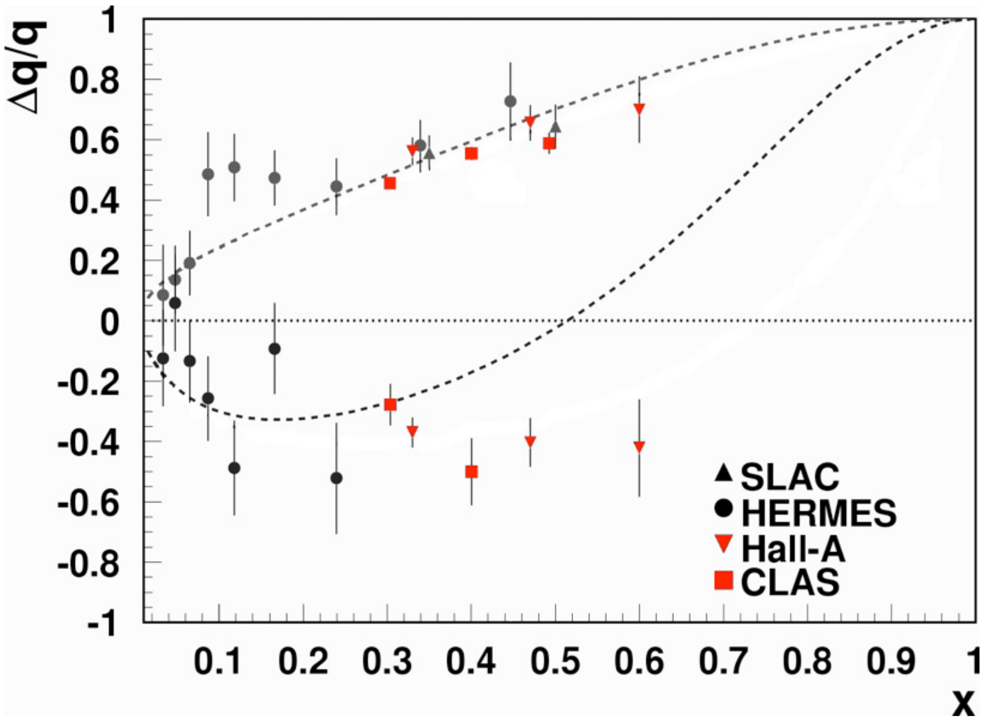
These GPDs are proportional (normalized) to:

$$\Delta q \cdot \Delta q_T$$

where Δq is the polarized PDF and Δq_T is the tensor anomalous moment.

For the proton target, the flavor structure for this process is:

$$2u + d$$



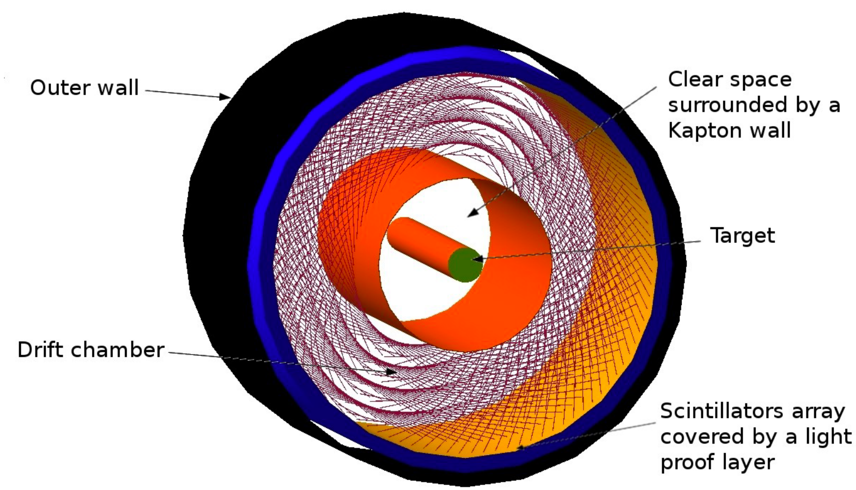
For ^{4}He, the flavor structure is $u + d$. Since Δd and Δu are opposite in sign, the enhancement of the d-quark contribution for ^{4}He should decrease the resulting beam-spin asymmetry relative to the proton case. (*Note clear if this is enough to flip the sign*)

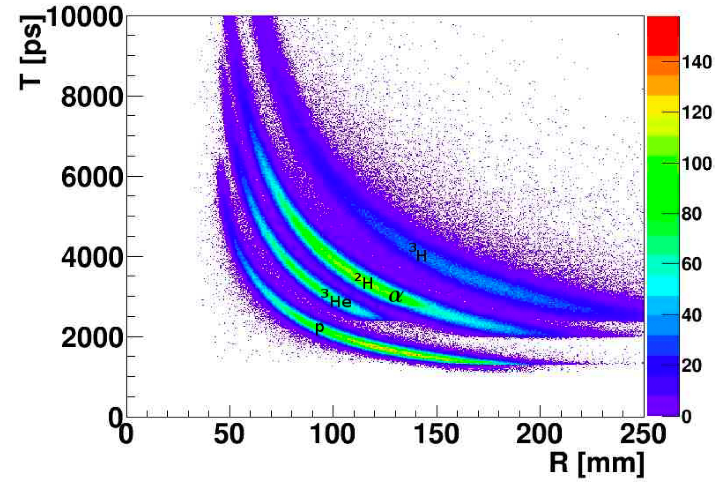
V. Guzay, private communication

Low energy recoil tagging with CLAS12

New proposal to JLAB PAC45 – very ambitious program tuned for studies of partonic structure of light nuclei and bound nucleons using low energy recoil tagging technique.

Measurement	Particles detected	p range	θ range
Nuclear GPDs	^{4}He	$230 < p < 400 MeV/c$	$\pi/4 < \theta < \pi/2$ rad
Tagged EMC	p, ^{3}H, ^{3}He	As low as possible	As close to π as possible
Tagged DVCS	p, ^{3}H, ^{3}He	As low as possible	As close to π as possible



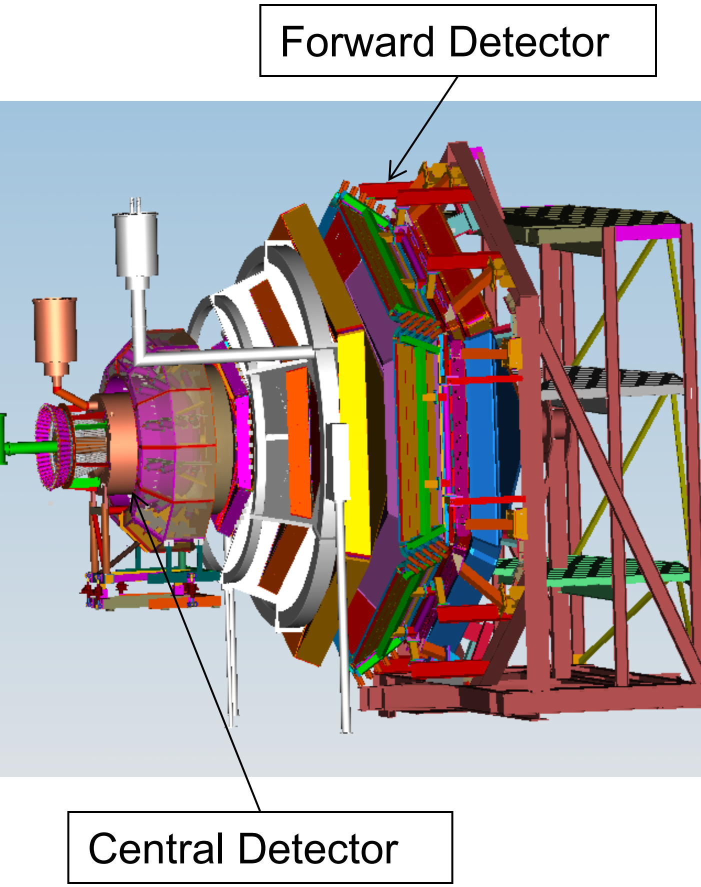


Summary

- CLAS experiment for coherent photo- and electro-production of the photon and mesons on a spin and isospin zero target, **^{4}He**, run in 2009
- Scattering of a 6.06 GeV polarized electrons on a 6 atm., 20 cm long ^{4}He gas target was used to collect data for DVCS and π^0 electroproproduction
- A low energy recoil detector, a cylindrical RTPC, has been deployed for detection and identification of the recoiling α–particles
- BSA in the fully exclusive final state, for the first time, have been measured in coherent DVCS and $\boldsymbol{\pi}^0$ production on ^{4}He. Coherent DVCS allows model-independent extraction of the $\mathfrak{Re}$ and $\mathfrak{Im}$ parts of Compton amplitude. The BSA of π^0 production has different sign of asymmetry than BSA on the nucleon.
- BSA in incoherent DVCS opens up a new opportunities for studying the partonic structure of bound nucleons through spectator tagging
- A new measurements are planned for CLAS12 using up to 11 GeV longitudinally polarized electron beams, a high pressure gaseous target, and a new low energy recoil detector, ALERT, with much improved PID that is very important for spectator tagging (proposal have been re-submitted to PAC45)

Thanks you

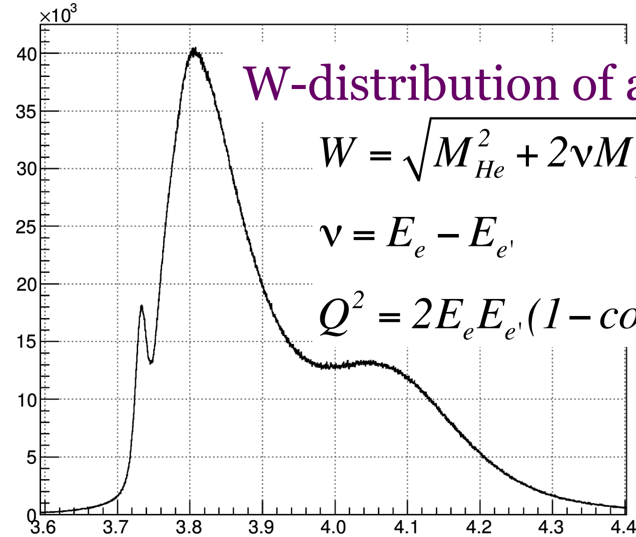
CLAS12 – Design Parameters



	Forward Detector	Central Detector
Angular range		
Tracks	$5^0 – 40^0$	$35^0 – 125^0$
Photons	$2^0 – 40^0$	---
Resolution		
$\delta p/p$ (%)	< 1 @ 5 GeV/c	< 5 @ 1.5 GeV/c
$\delta\theta$ (mr)	< 1	< 10 - 20
$\Delta\phi$ (mr)	< 3	< 5
Photon detection		
Energy (MeV)	>150	---
$\delta\theta$ (mr)	4 @ 1 GeV	---
Neutron detection		
N_{eff}	< 0.7 (EC+PCAL)	n.a.
Particle ID		
e/π	Full range	---
π/p	< 5 GeV/c	< 1.25 GeV/c
π/K	< 2.6 GeV/c	< 0.65 GeV/c
K/p	< 4 GeV/c	< 1.0 GeV/c
$\pi(\eta)\rightarrow\gamma\gamma$	Full range ---	

$$L = 10^{35} cm^{-2} s^{-1}$$

Selection of elastic events

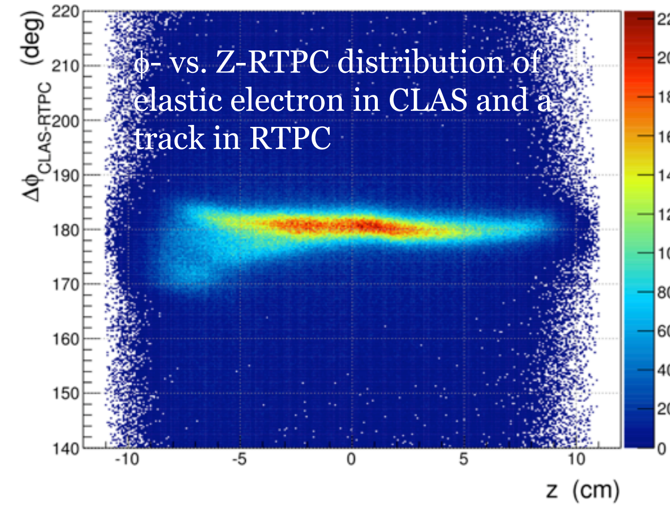


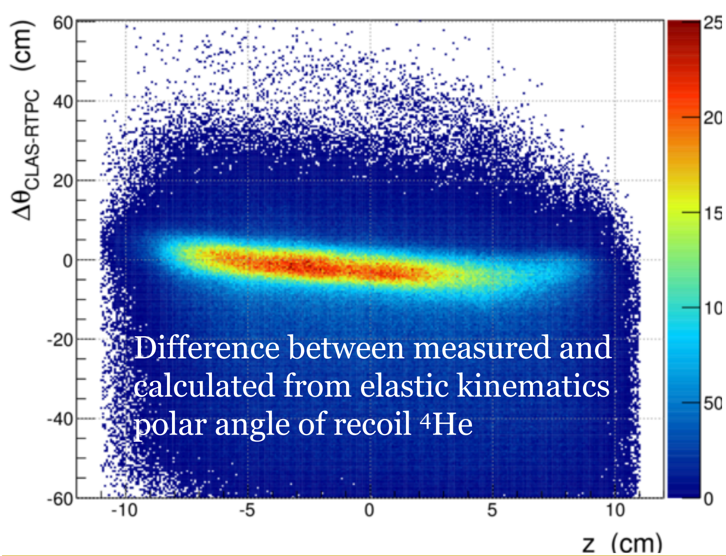
W-distribution of all events

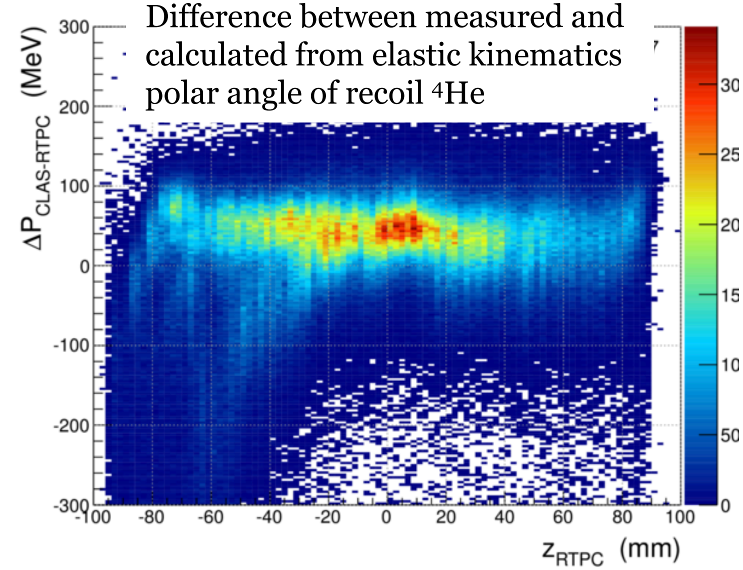
$$W = \sqrt{M_{He}^2 + 2\nu M_{He}^2 - Q^2}$$

$$\nu = E_e - E_{e'}$$

$$Q^2 = 2E_e E_{e'}(1 - \cos\vartheta_{e'})$$

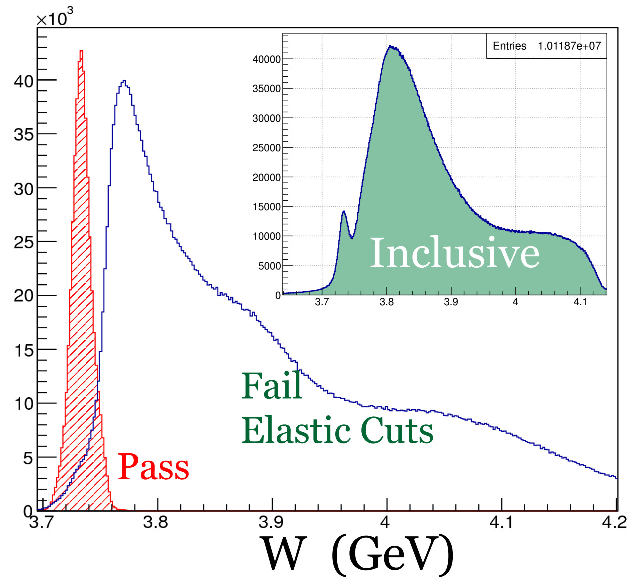


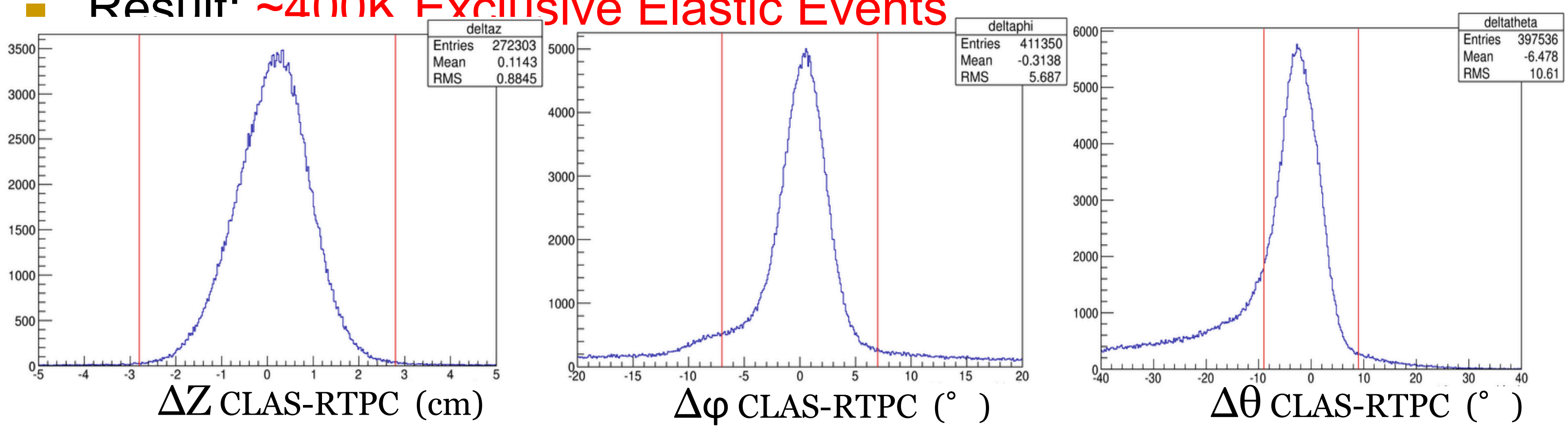




RTPC Efficiency: Detect Elastic ^{4}He

- With electron selected, look for RTPC track with matching vertex and elastic angles
  - Each Δ-quantity below has a cut on the others' peaks
  - Resolutions are roughly 8mm, 2°, 3° on z,φ,θ
- Test cut sensitivity, particularly Δθ
- Result: ~400K Exclusive Elastic Events



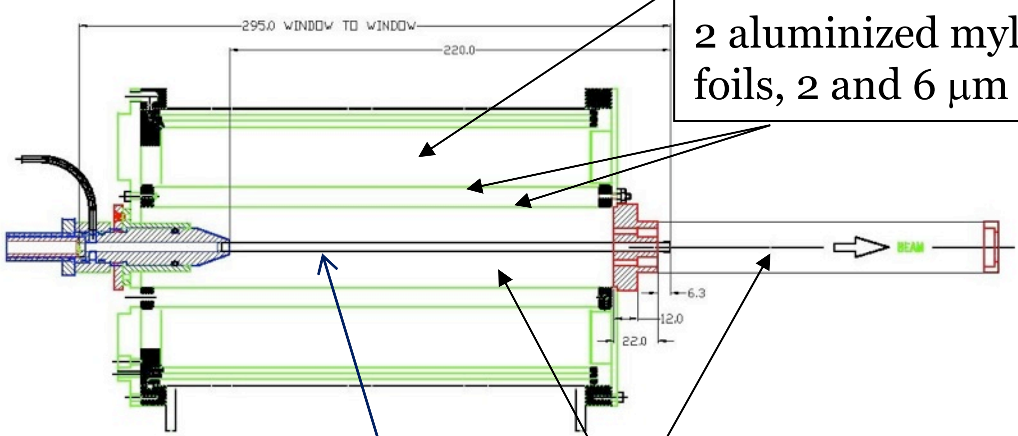


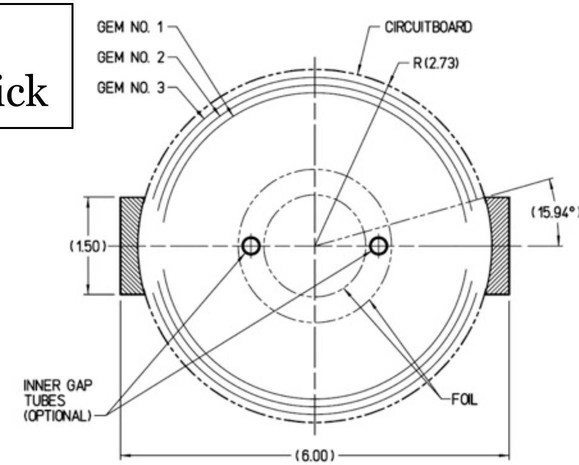
Jefferson Lab
Thomas Jefferson National Accelerator Facility

Target & RTPC assembly for eg6

Working gas, NeDME @ 1 atm

2 aluminized mylar foils, 2 and 6 μm thick





He @ 1 atm

New target cell, 6 mm ID & with 27 μm wall thickness, target gas He @ 6 atm.
(Bonus run with 50 μm thick target cell)

Open geometry (has not been utilized effectively)

Improved backend readout

Total material thickness on the way of particles at 90o is ~39 μm

RTPC calibration

Elastic scattering on ^{4}He at 1.2 GeV