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

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Partons and Nuclei

IPN-ORSAY, June 1 – 2, 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

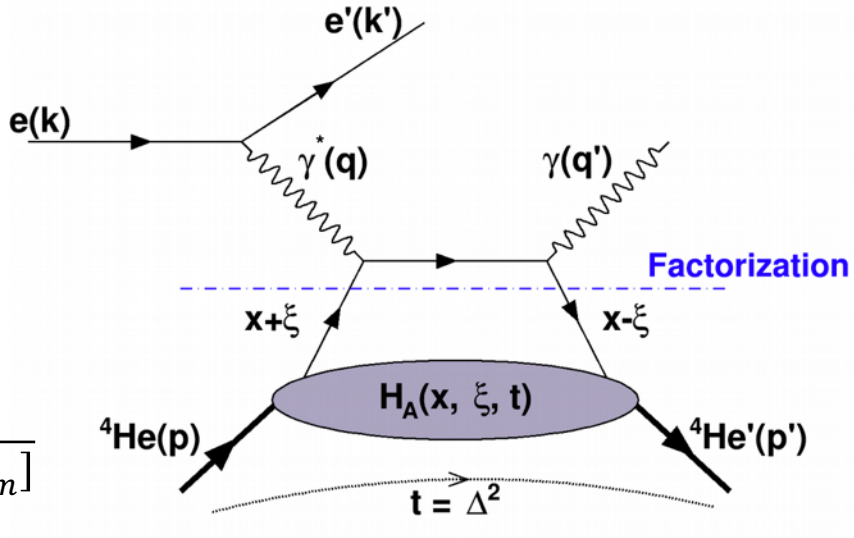
✓ Coherent DVCS, $\vec{e}A \rightarrow e'A'\gamma$:

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

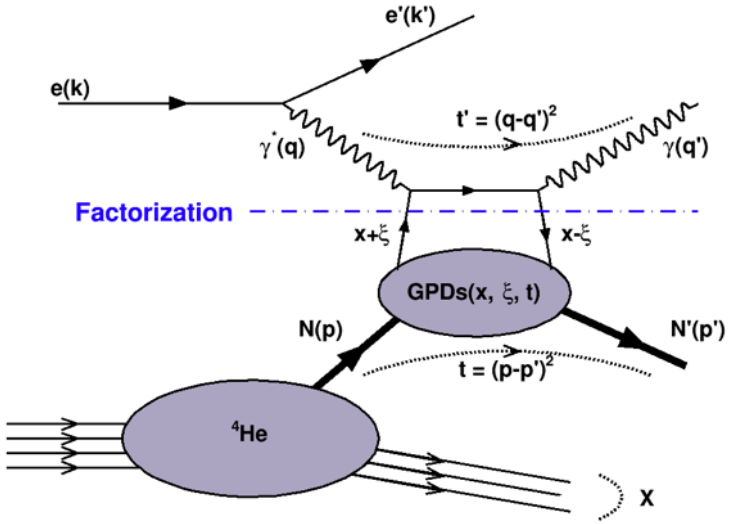
$\alpha_j(\phi)-$ Functions of angle between lepton and hadron scattering planes



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

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

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



Beam Spin Asymmetry in π^0 production

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

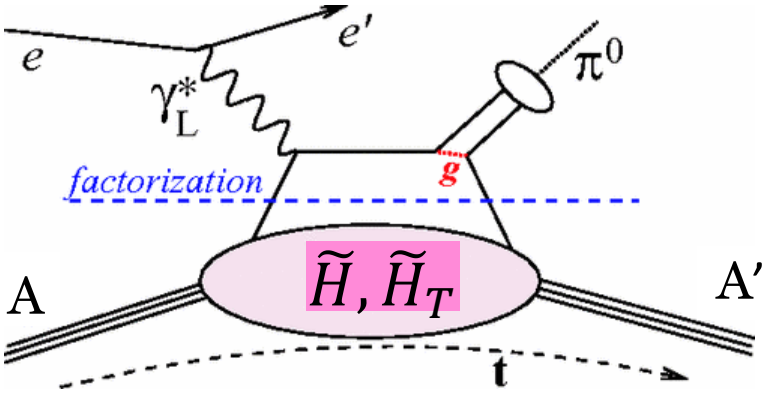
- ✓ Coherent π^0 production, $eA \to e'A'\pi^0$:

  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 $\vartheta_{cm}\to 0$:

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

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

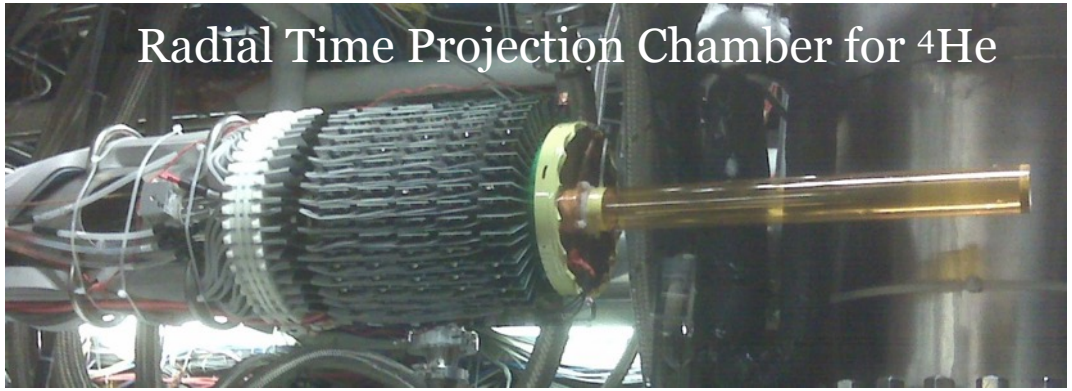
- ✓ *For the proton target, the flavor structure for π^0 production process is 2*u+d.*
  For an isospin zero target, e.g. ^{4}He, the flavor structure is u+d



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

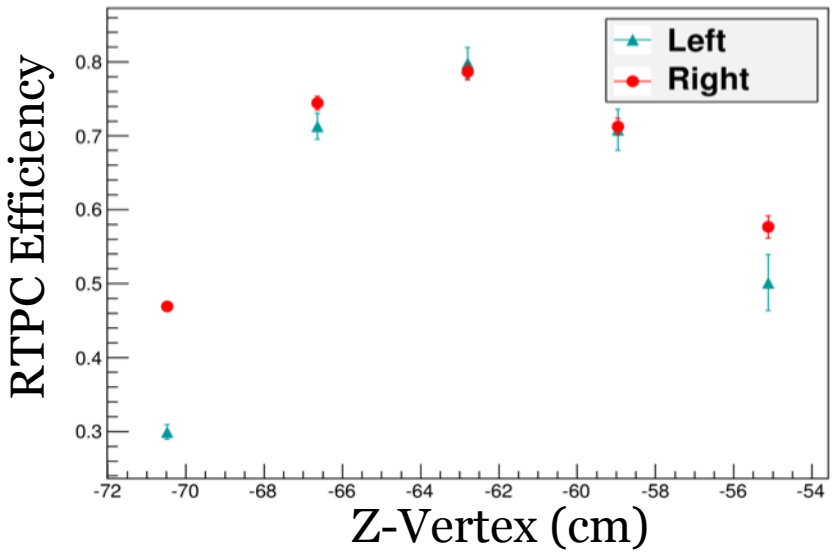
20-cm-long, 15 cm in diameter cylindrical detector positioned around the 6 atm ^{4}He gaseous target. The target cell is a 25-cm-long and 6-mm-diameter Kapton tube with 27-μm-thick walls.



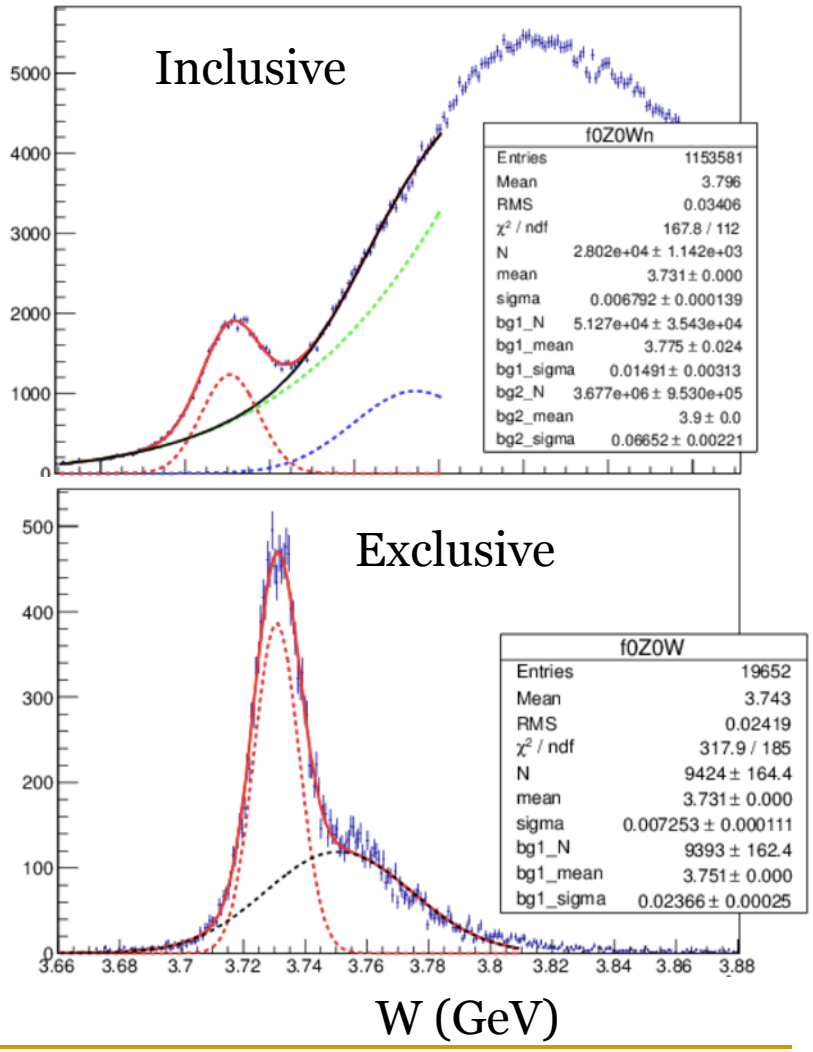
- Production data taking – ~200mC of beam on target (20 PAC days) with 6.06 GeV polarized electrons
- RTPC calibration runs at 1.2 GeV

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

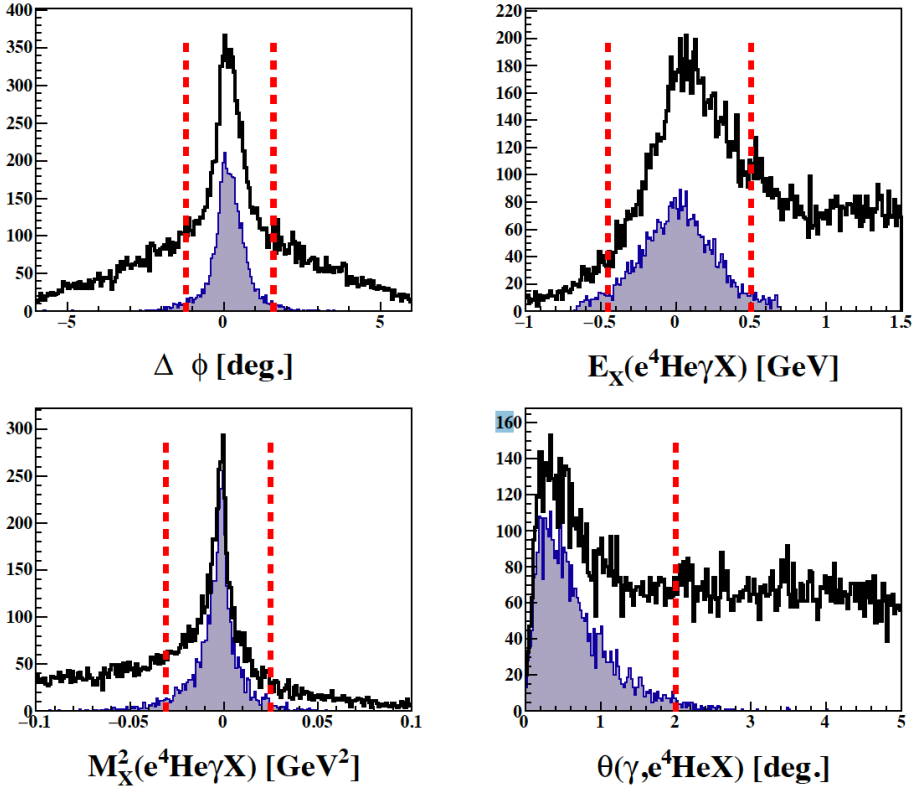
M. Hattawy (ORSAY/ANL)

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

- 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 $\Delta\varphi$ between the (γ,γ^*) and $(\gamma^*,{}^4He')$ planes,
  - the missing energy, mass, and transverse momentum of the $(e'{}^4He'\gamma)$ system,
  - the missing mass squared of the $e'{}^4He'$ system, and
  - the angle θ between the measured photon and the missing momentum of the $e'{}^4He'$ system.

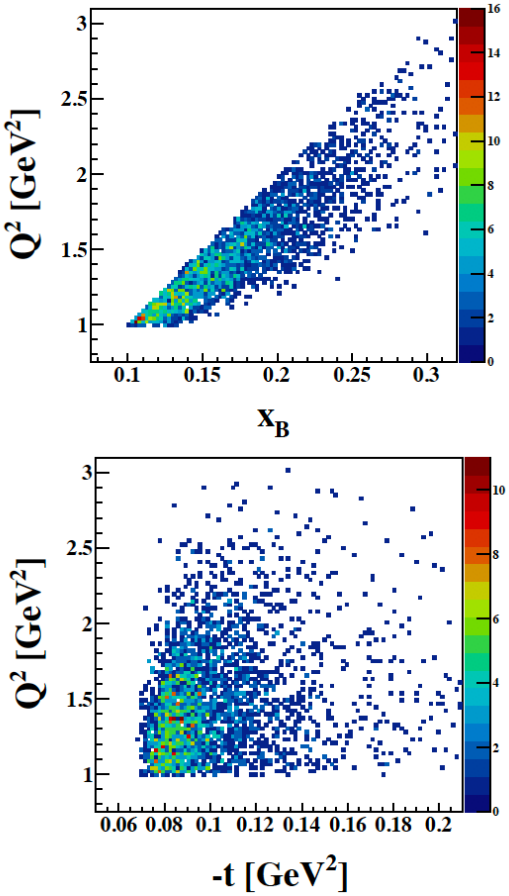
§ *At some point these cuts should be part of global kinematic fit*

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

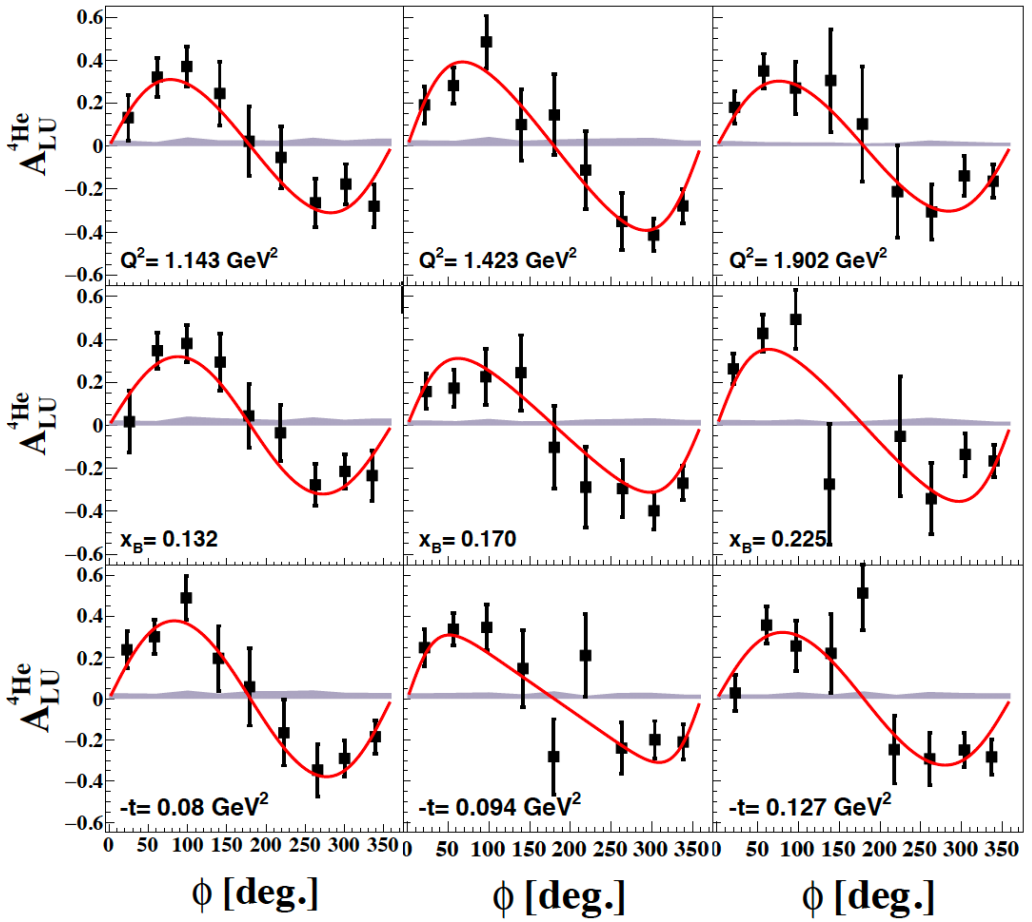


BSA: coherent DVCS

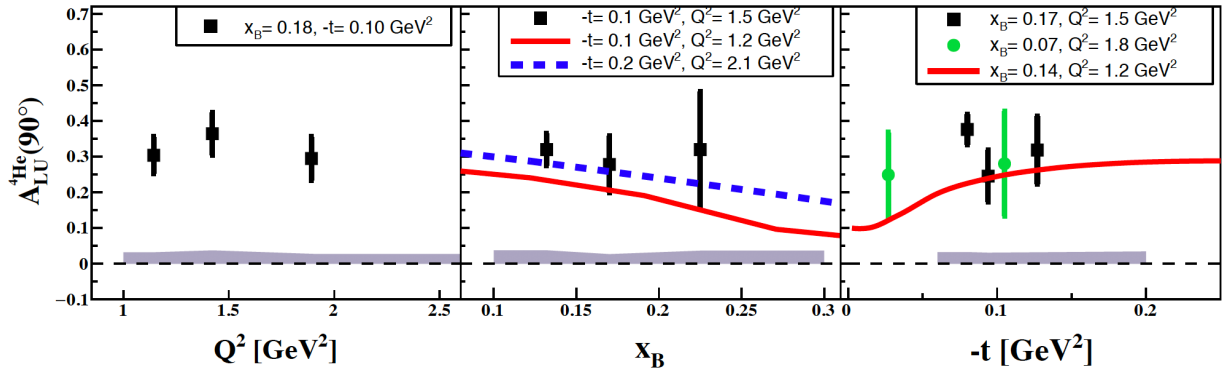
$1 < Q^2 < 2.3$ GeV^2
$0.05 < -t < 0.2$ GeV^2
$0.1 < x_B < 0.25$



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



$\mathfrak{Im}$ and $\mathfrak{Re}$ parts of the Compton Amplitude



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

- **HERMES**

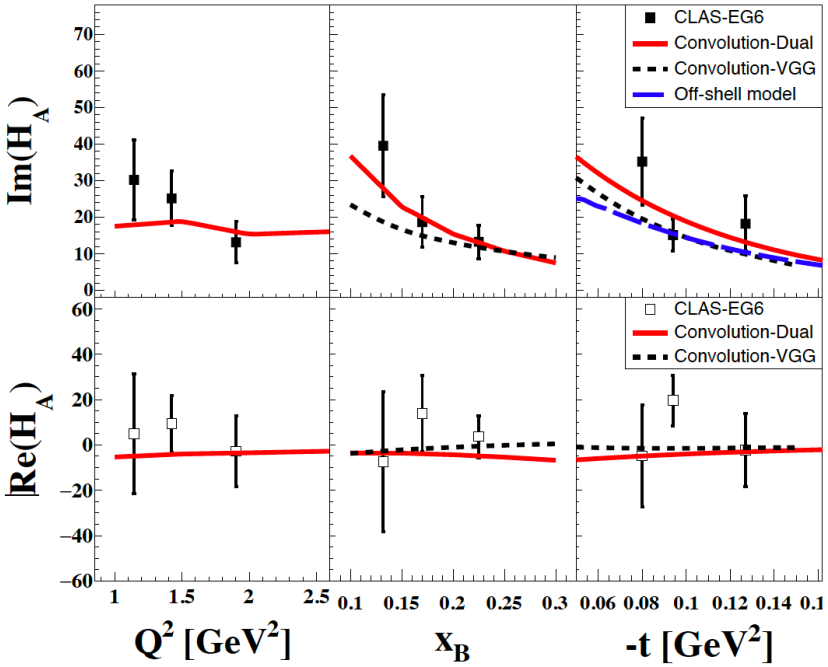
Curves:

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).

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

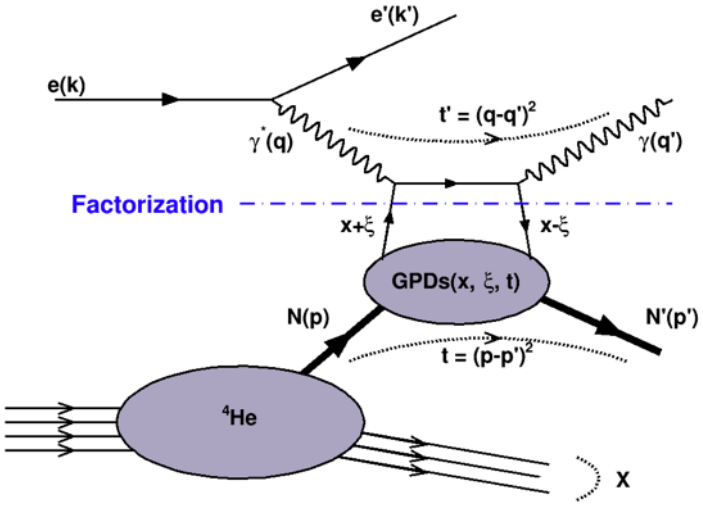


PRL draft is in collaboration review

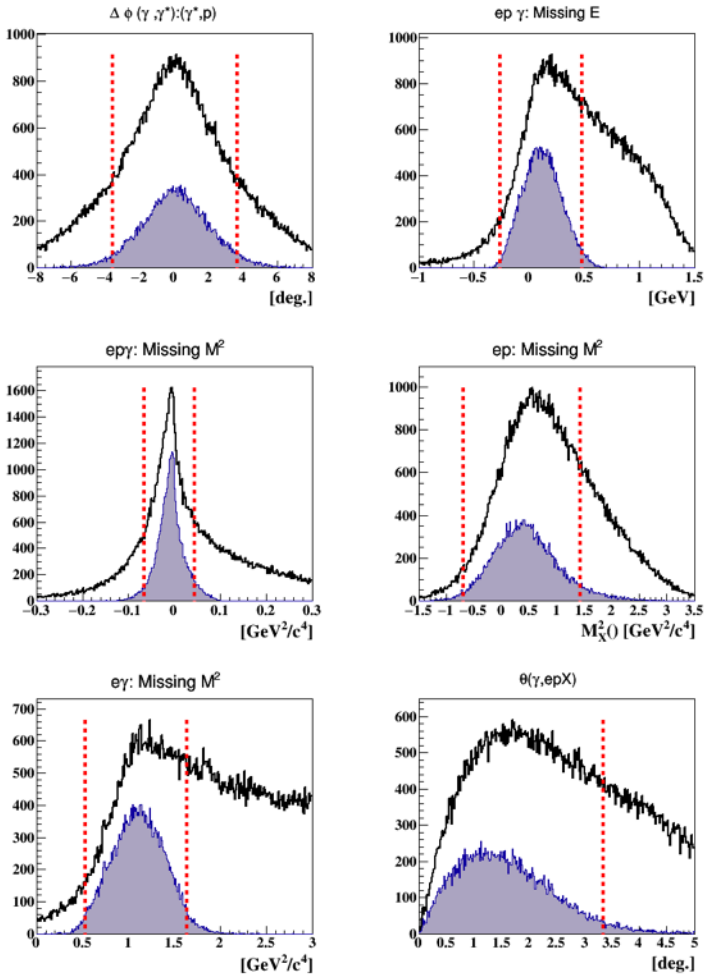
Incoherent DVCS

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

- 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



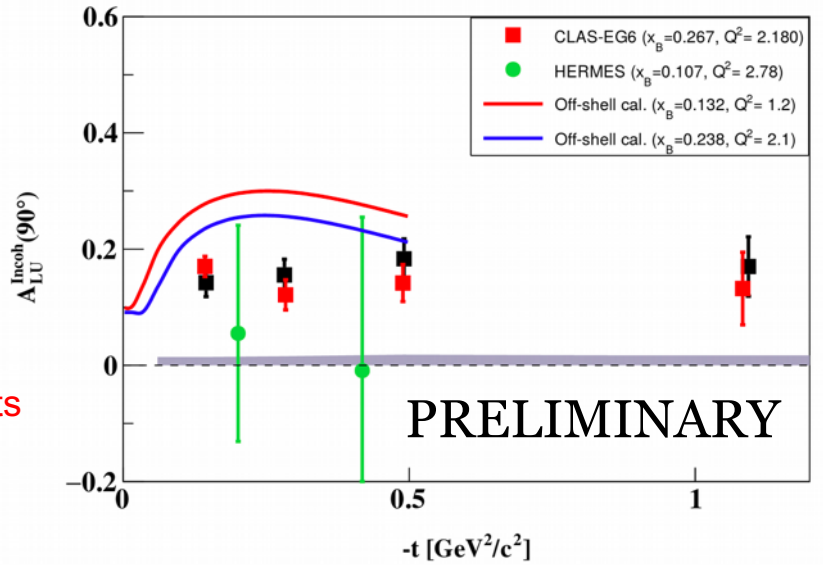
DVCS BSA on bound protons

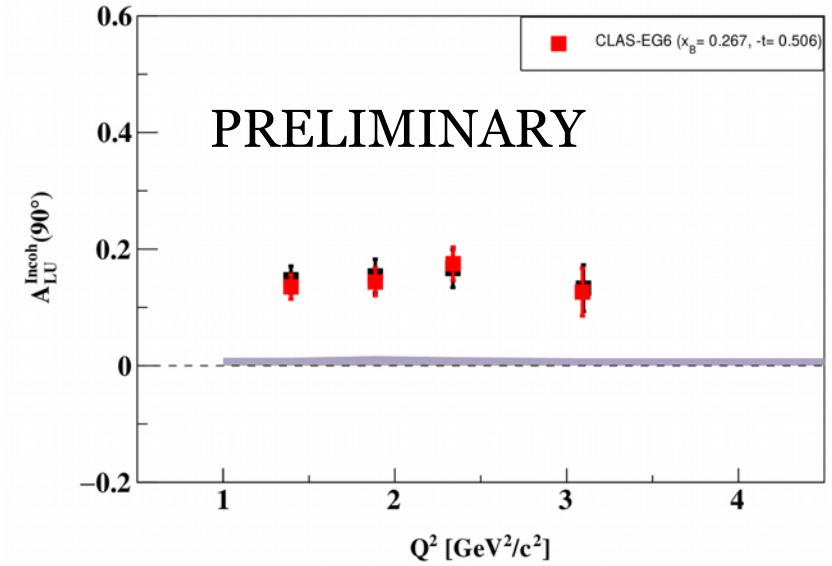
$$A_{LU} = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{1}{P_B}\frac{N^+ - N^-}{N^+ + N^-}$$

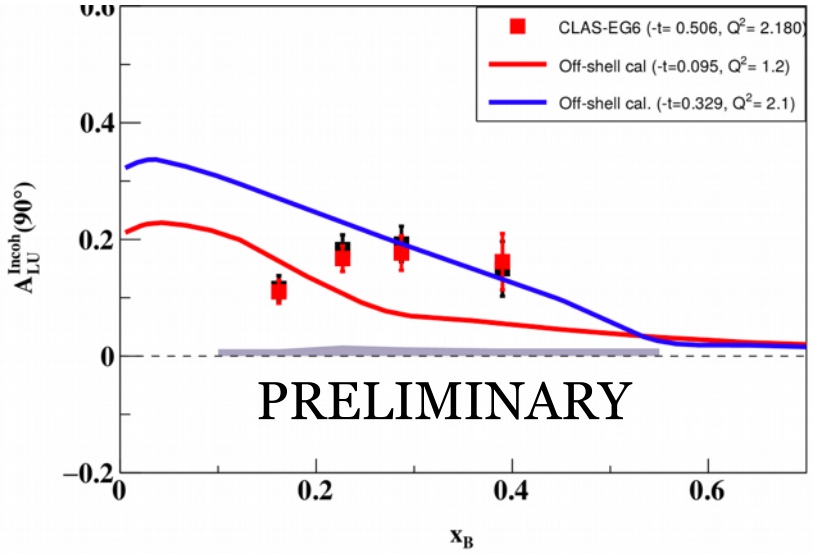
$$A_{LU} \propto \alpha(\phi)\{F_1 H + \xi(F_1 + F_2)\widetilde{H} + \kappa F_2 E\}$$

- 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

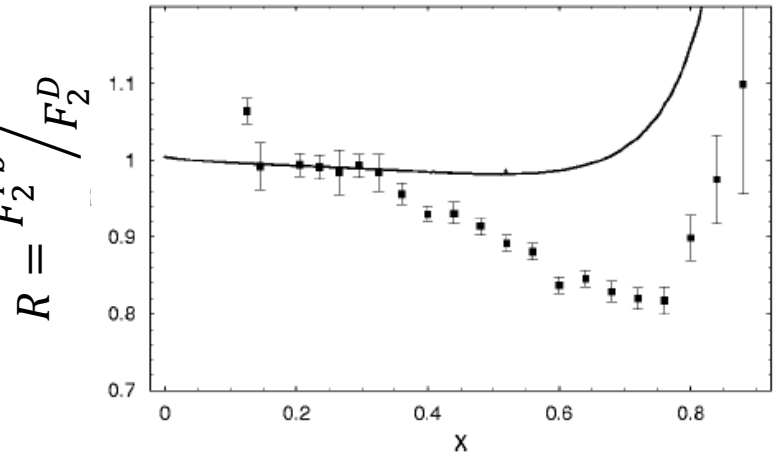


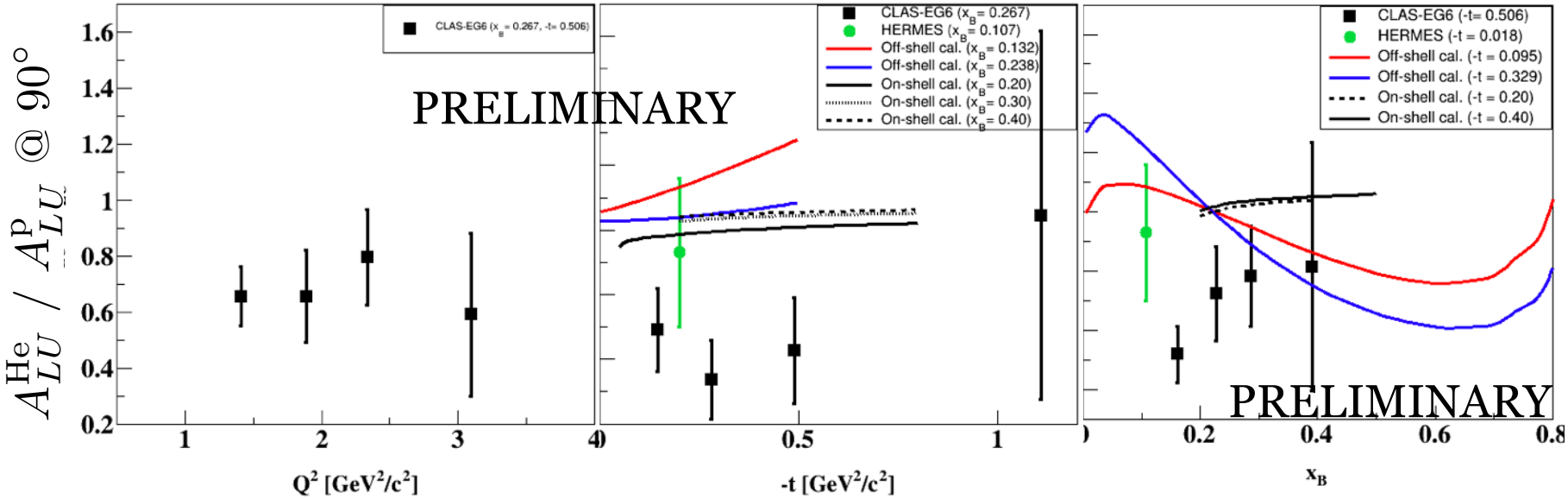




BSA and Generalized EMC Ratio

- 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)

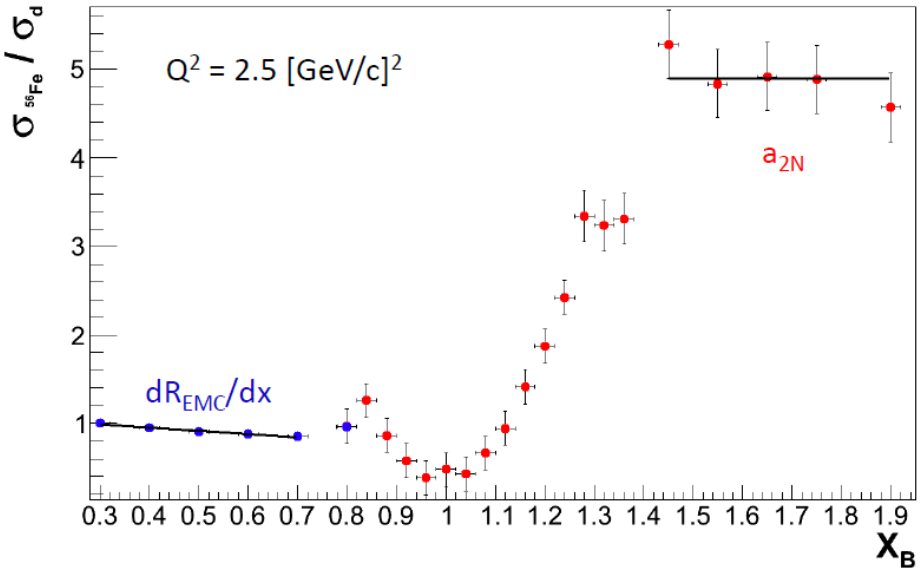




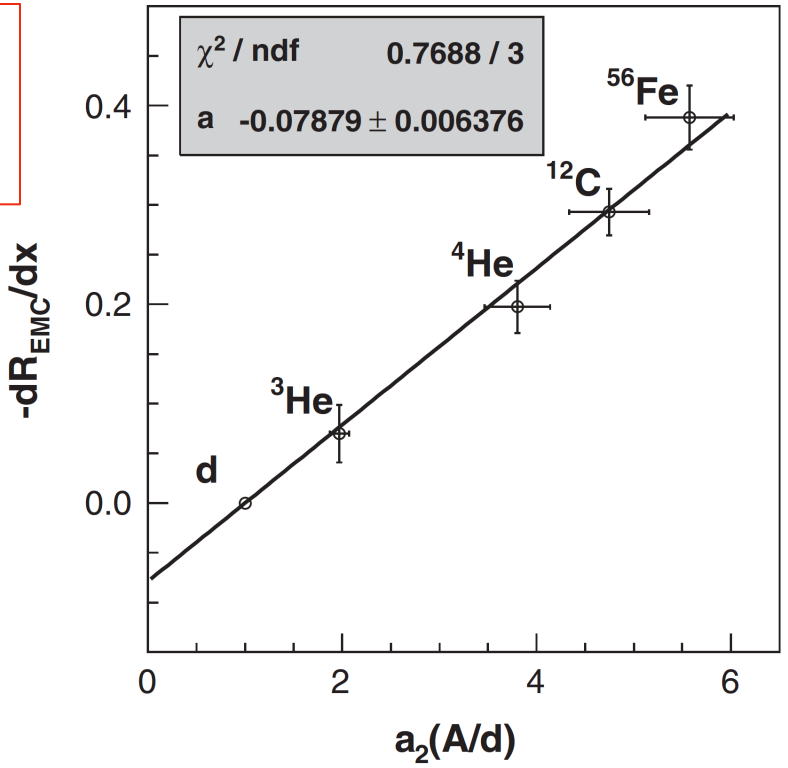
DVCS and NN-short range correlations

DIS probes partonic (quark) structure of hadrons

Inclusive scattering at x>1 probes partonic (nucleon) structure of nuclei.



D. Higinbotham et al., arXiv: 1003.4497



L. Weinstein et al., PRL 106, 052301 (2011)

DVCS with high energy spectator tagging can provide valuable information on the nucleon structure modification through measuring the GPDs of a strongly bound (off-shell) nucleon

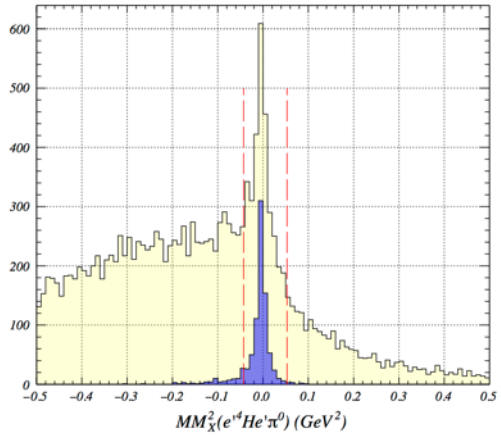
Coherent π^0 Production

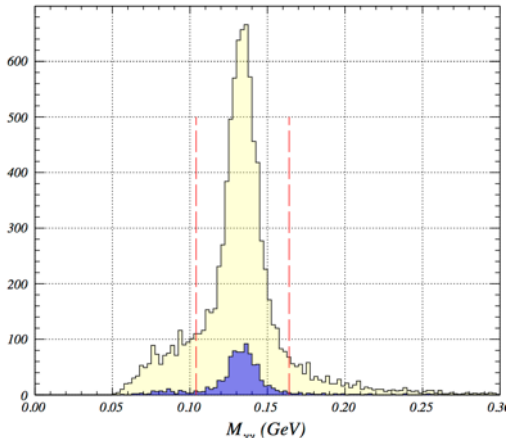
B. Torayev (ODU)

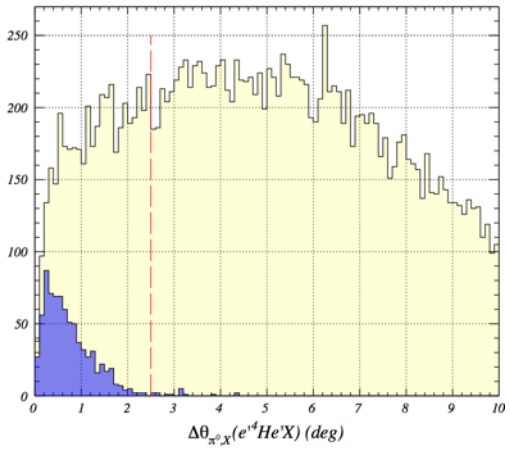
$$\vec{e}\,^4He \rightarrow e'\,^4He'\pi^0$$

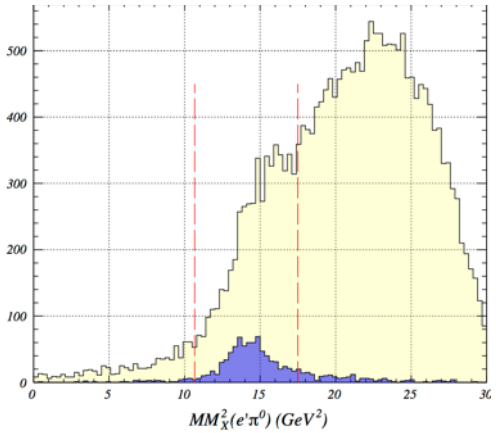
- Detected particles: scattered electron in CLAS, two photons in the inner calorimeter, the recoil ^{4}He is identified in RTPC
- Exclusivity cuts on kinematical variables, similar to coherent-DVCS analysis.

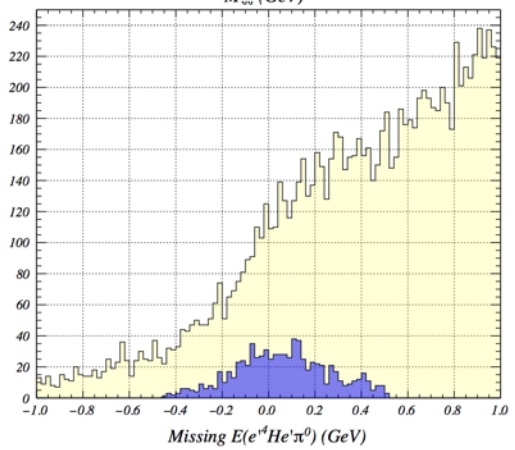
Yellow shaded region - all events
Blue shaded region = after all other exclusivity cuts











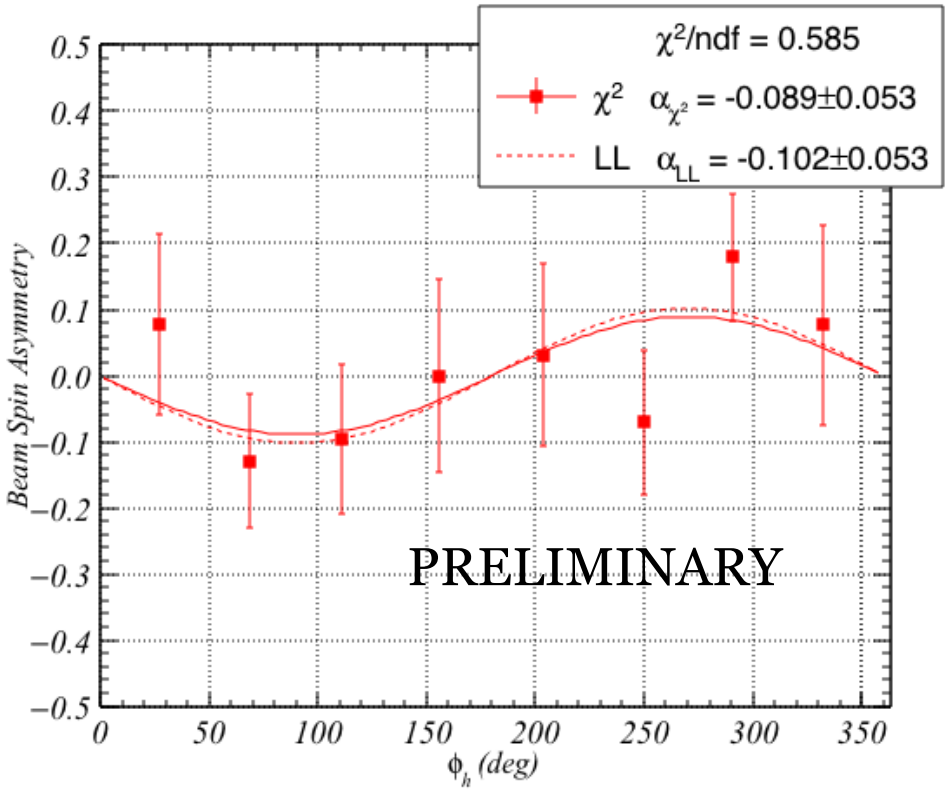
Coherent π^0 Production

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



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

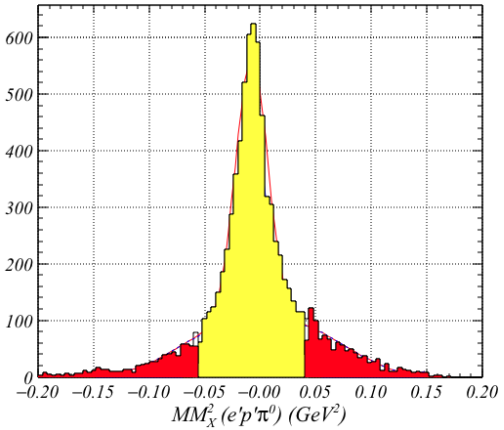
$$A_{LU}^{\sin(\varphi)}(LL) = -0.10 \pm 0.05(stat.)$$

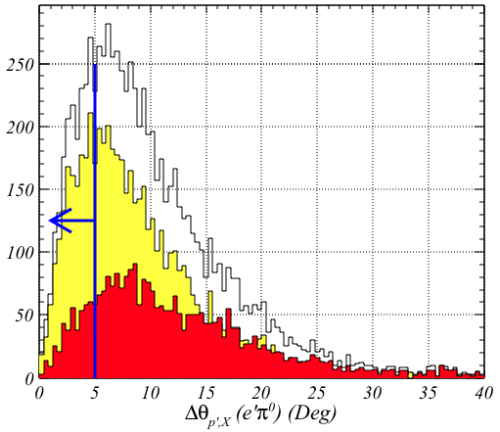
Incoherent "exclusive" π^0 Production

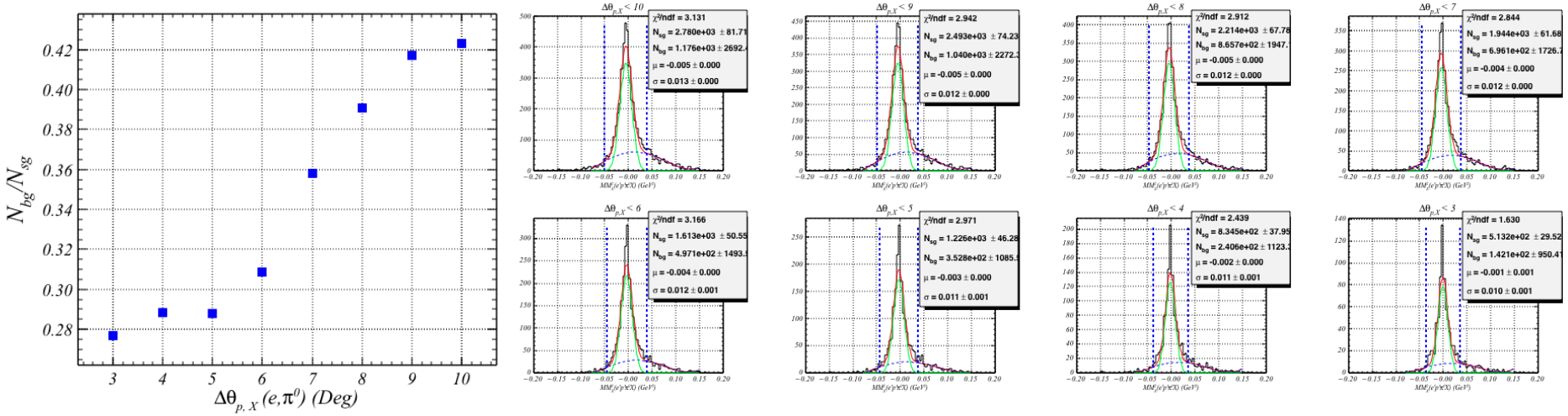
$$\vec{e}\,^4He \rightarrow e'p\pi^0X$$

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.



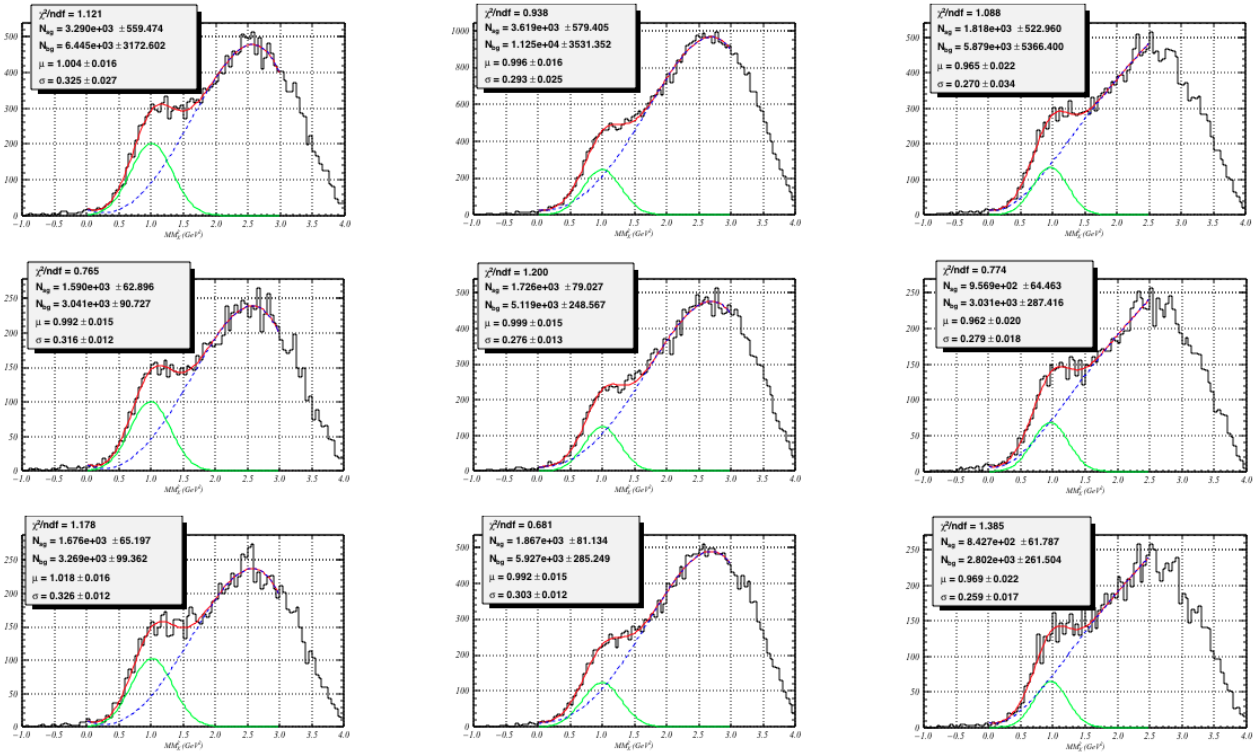




Incoherent "semi-exclusive" π^0 Production

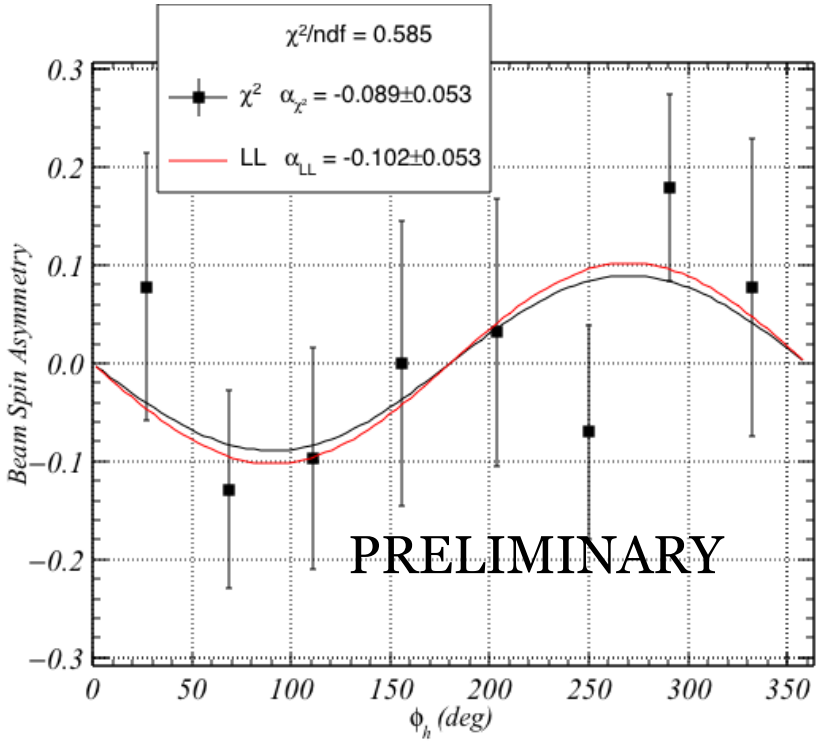
$$\vec{e}\,^4He \rightarrow e'N\pi^0X$$

- 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 $\vec{e}N \rightarrow e'\pi^0X$

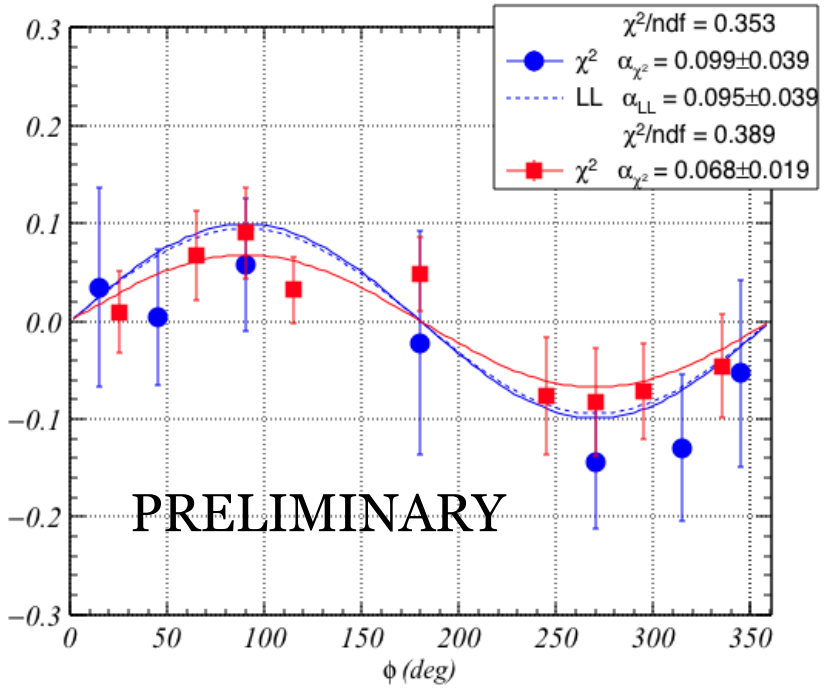


BSA in coherent and in-coherent π^0 production

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

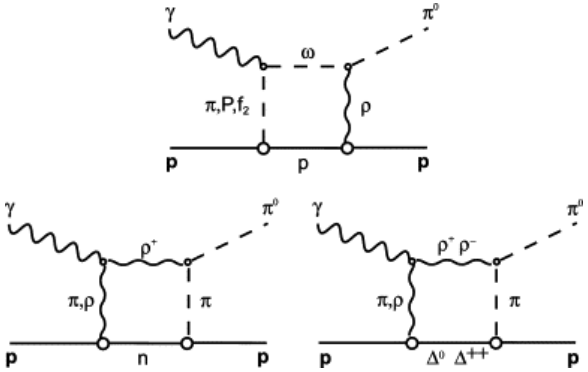


$\vec{e}^4He \rightarrow e'N\pi^0X$



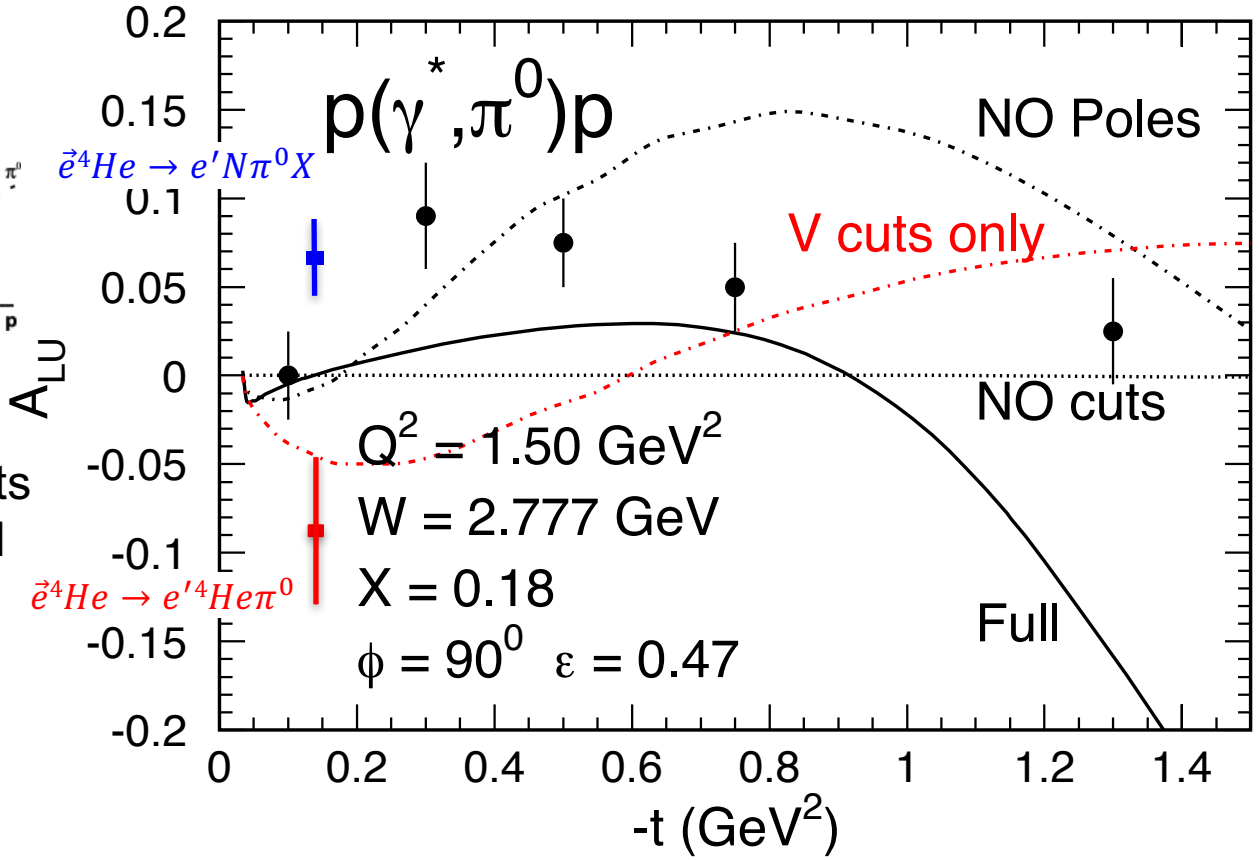
Note the asymmetry sign change between spin/isospin zero target and the nucleon

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.



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

- The BSA for this process is:

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

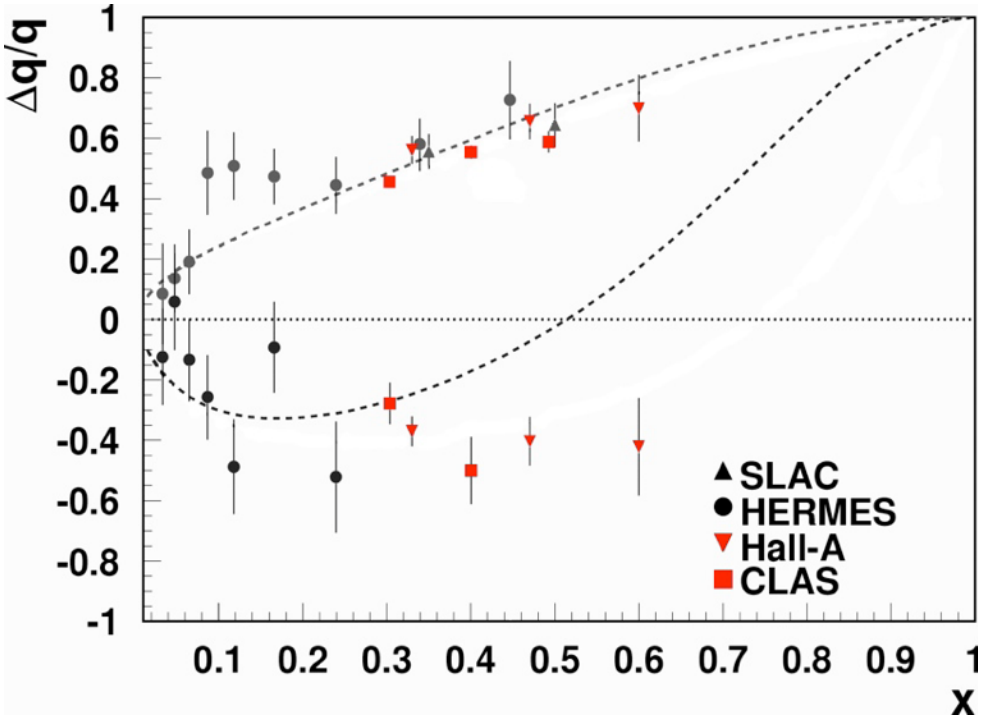
- These GPDs are proportional (normalized) to:

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

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*)

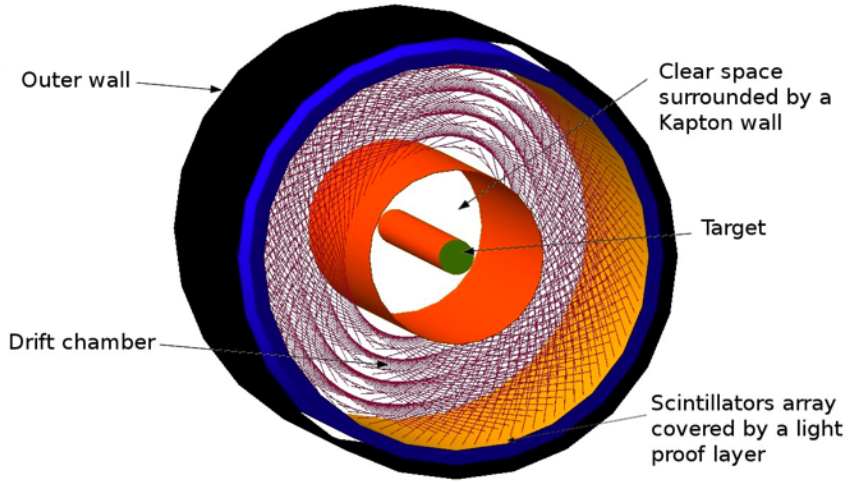
✓ Will be interesting to study BSA in coherent π^0 production on ^{2}H

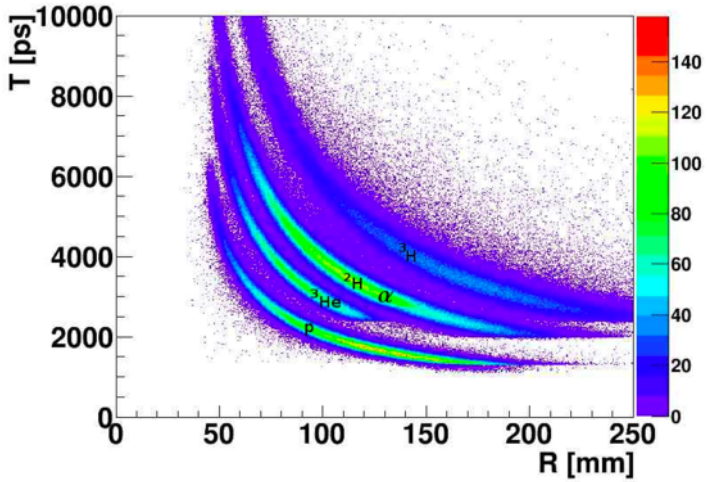
V. Guzay, private communication

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 $\mathcal{Re}$ 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