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Deeply Virtual Compton Scattering off ^{4}He

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(On behalf of the CLAS collaboration)

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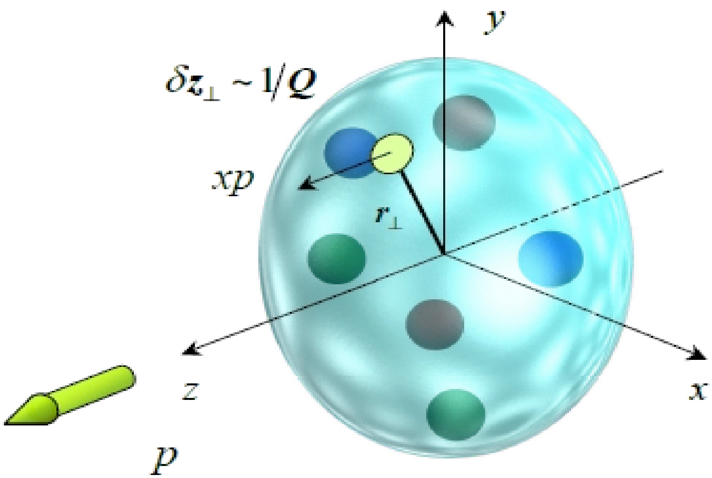
Physics Motivations

◊ Form Factors:

→ Contain information on the quarks transverse spatial distributions
→ They are accessible via elastic scattering

◊ Parton Distribution Functions:

→ Provide the quarks longitudinal momentum distributions
→ Measurable via deep inelastic scattering



◊ Generalized Parton Distributions (GPDs):

- Contain information on:

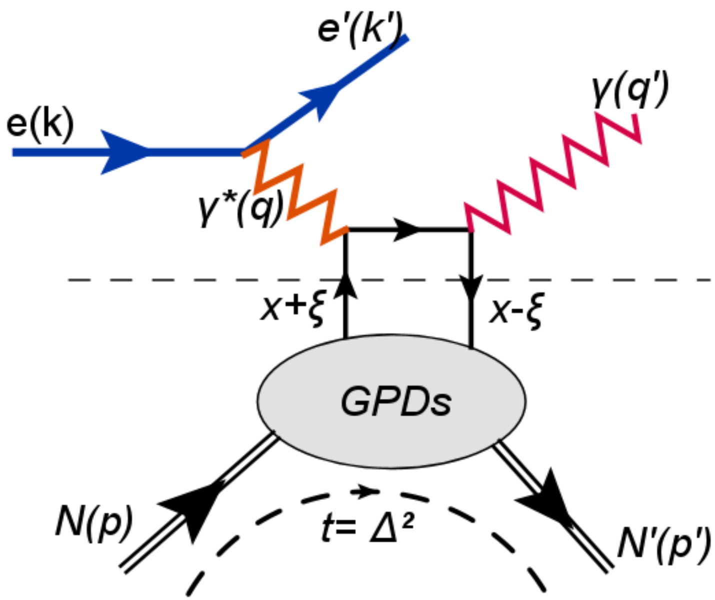
→ Partons correlation
→ Correlation between longitudinal momentum and transverse spatial position of partons

- Accessed via exclusive processes:

→ Deeply Virtual Compton Scattering (DVCS)
→ Deeply Virtual Meson Production (DVMP)

From the theoretical point of view, the DVCS is considered the easiest way to access the GPDs

DVCS Reaction



Hard part (perturbative, calculable in PQED)

Factorization

Soft part (Non-perturbative QCD, parameterized in terms of GPDs)

t : squared momentum transfer

ξ : skewdness parameter

x : longitudinal parton momentum ($x \neq x_B$)

Q^2: photon's virtuality

$$t=(p-p')^2=(q-q')^2$$

$$\xi \simeq x_B/(2-x_B)$$

$$x_B=Q^2/2p.q$$

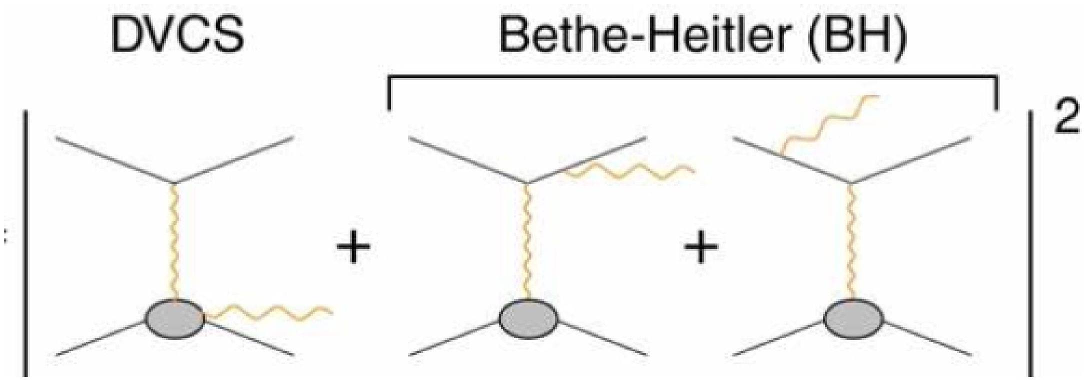
$$Q^2=-q^2=-(k-k')^2$$

→ GPD(x,ξ,t): the probability amplitude of picking up a parton with momentum x+ ξ and putting it back with a momentum x-ξ without breaking the nucleon with a momentum transfer squared t.

→ DVCS amplitude can be accessed in the Beam Spin Asymmetry (BSA) because it interfers with Bethe-Heitler (BH) process.

DVCS and Bethe-Heitler processes

◊ **Experimentally,** the DVCS is indistinguishable from Bethe-Heitler (BH) process. Therefore, the measured photo-production cross-section ($ep \rightarrow ep\gamma$) is:



- The cross-section is dominated by BH in most of the phase space, which is calculable using the elastic form factors
- DVCS signal is enhanced by the interference.

On ^{4}He:

→ The differential cross-section: $d\sigma \propto |\tau_{BH}|^2 + \underbrace{(\tau^*_{DVCS}\tau_{BH} + \tau^*_{BH}\tau_{DVCS})}_{\mathcal{I}} + |\tau_{DVCS}|^2$

→ The coherent DVCS on ^{4}He (SPIN ZERO → ONE GPD IS NEEDED $H_A(x,\xi,t)$):

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

$$\mathcal{H}_{Re}(\xi,t) = \mathcal{P}\int_0^1 dx[H_A(x,\xi,t) - H_A(-x,\xi,t)]\boxed{C^+(x,\xi)}$$

Quark propagator

$$C^+(x,\xi) = \frac{1}{x-\xi} + \frac{1}{x+\xi}$$

$$\mathcal{H}_{Im}(\xi,t) = H_A(\xi,\xi,t) - H_A(-\xi,\xi,t)$$

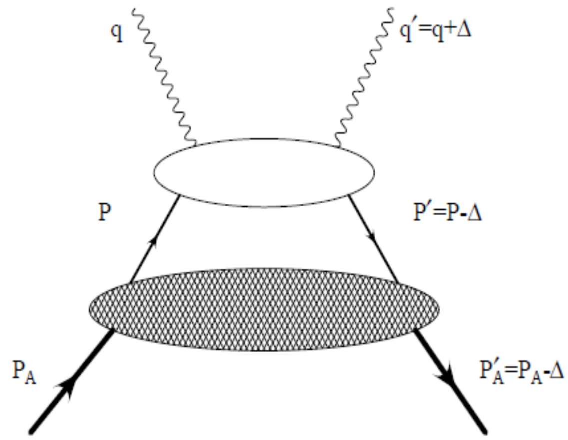
DVCS off nuclei

Nuclear DVCS provides access to two channels:

◊ **Coherent DVCS: $e^- A \rightarrow e^- A \gamma$**

→ Study the partonic structure of the nucleus.

→ One GPD is needed to parametrize the structure of the spinless nuclei (^{4}He, ^{12}C, ^{16}O, ...).

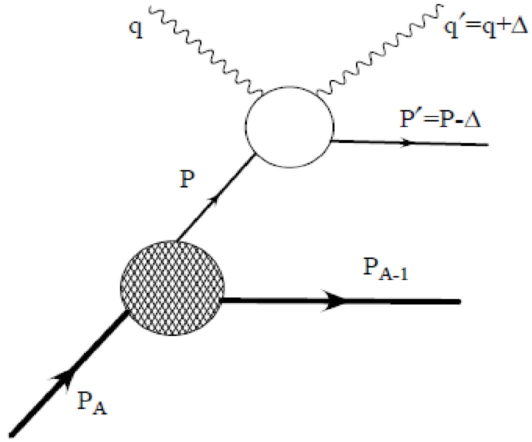


◊ **InCoherent DVCS: $e^- A \rightarrow e^- N X \gamma$**

→ The nucleus breaks and the DVCS takes place on a nucleon.

→ Study the partonic structure of the bound nucleons (4 GPDs are needed to parametrize their structure).

→ Study the medium modifications of the nucleons (EMC effect) in terms of GPDs.



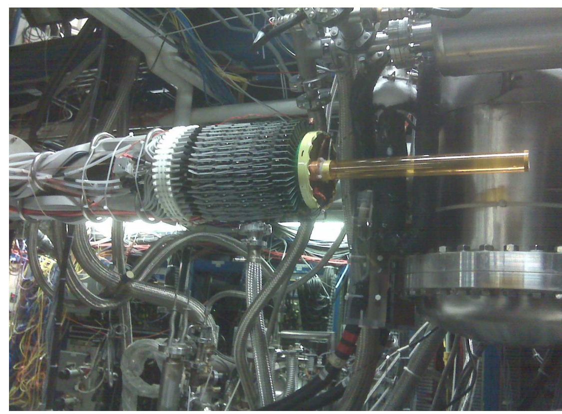
Experimental Setup

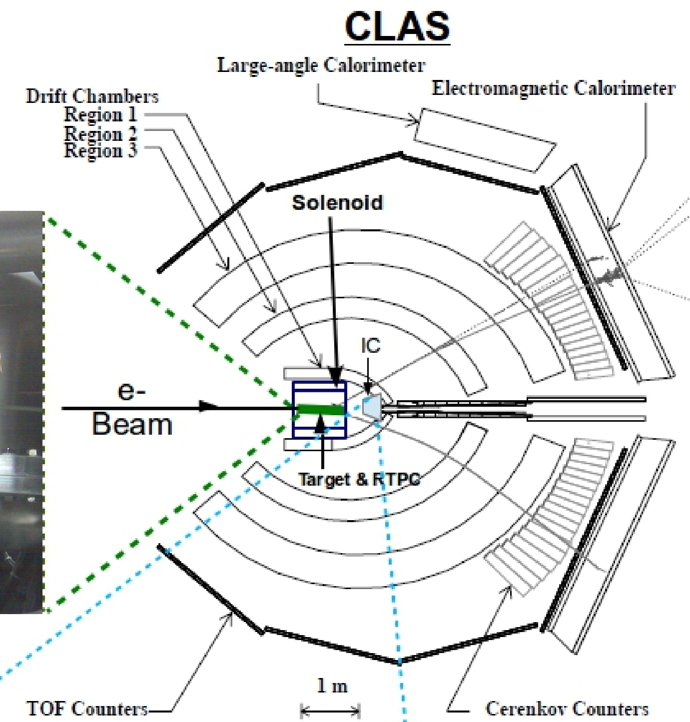
E08-024 experiment, Hall B, JLab (Virginia, USA), 2009.

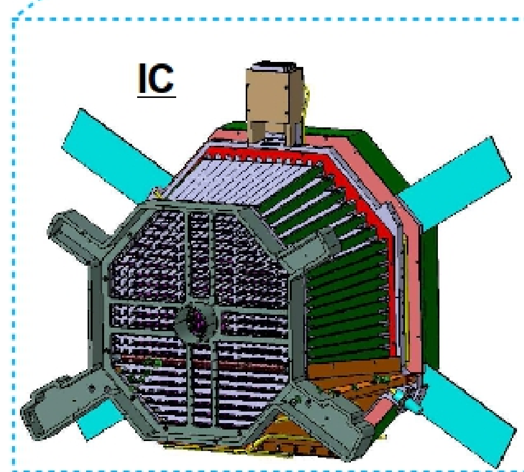
$$e^- \, {}^4He \rightarrow e^- \, ({}^4He/pX) \, \gamma$$

6 GeV,
L. polarized

RTPC







- **CLAS:**
  → Superconducting Torus magnet.
  → 6 independent sectors:
    → DCs track charged particles.
    → CCs separate e^-/π^-.
    → ECs detect γ, e^- and n [8º,45º].
    → TOF Counters identify hadrons.

- **RTPC:** Detects low energy nuclei.

- **IC:** Improves γ detection acceptance [4º,14º].

- **Solenoid:** Shields the detectors from Moller electrons.

- **Target:** ^{4}He gas @ 6 atm, 293 K

DVCS events selection

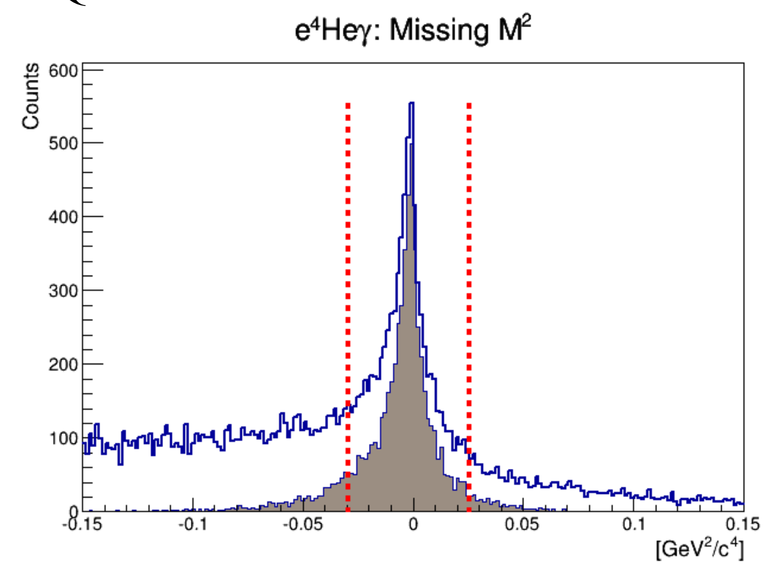
We select events which have:

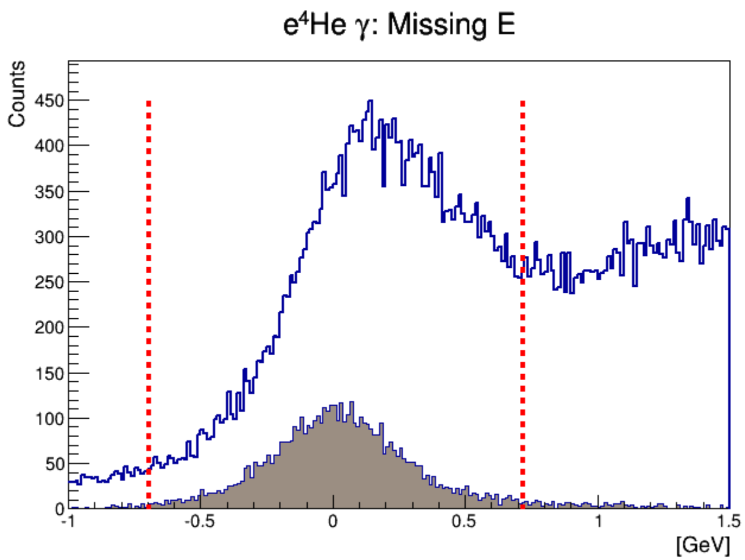
◊ Coherent (InCoherent): Only one good electron, at least one photon and only one good ^{4}He(p).

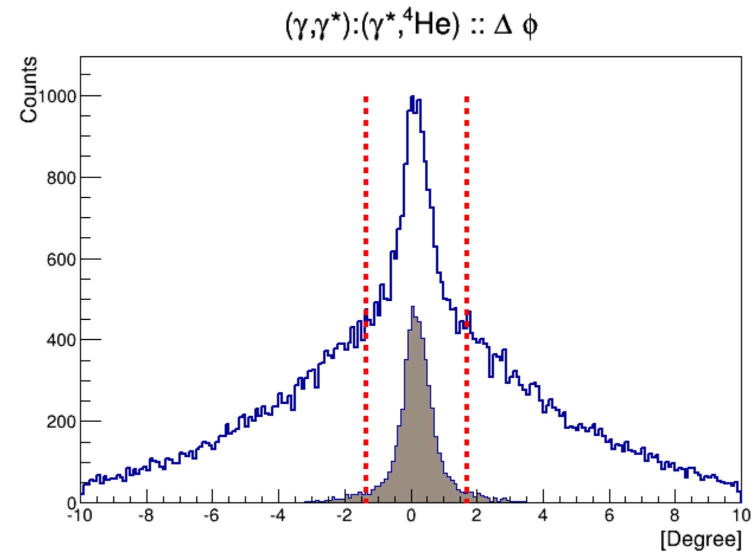
◊ $E\gamma > 2$ GeV, $W > 2$ GeV/c, $(E_b - E_{e'})/E_b < 0.85$ and $Q^2 > 1$ GeV².

◊ Exclusivity cuts (3 sigmas).

- In BLUE, coherent events before all exclusivity cuts.
- In shaded BROWN, coherent DVCS events which pass all the other exclusivity cuts except the ONE ON the quantity itself.







Background Subtraction

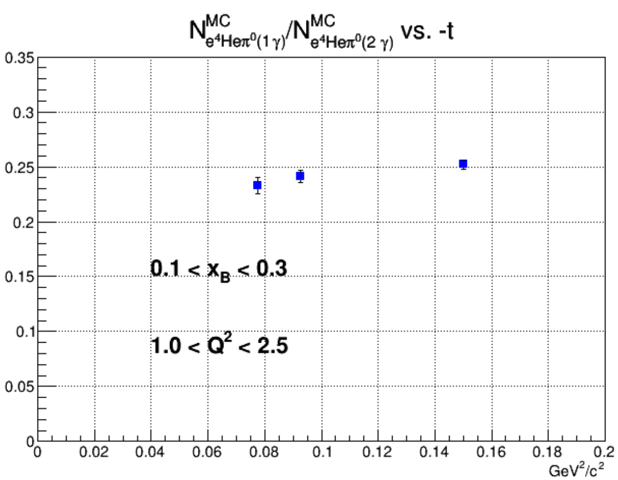
◊ With our kinematics, the main background comes from the exclusive π^0 channel ($e(^4He/p)\pi^0$) in which one photon from π^0 decay is detected and passed the DVCS exclusivity cuts.

◊ We use simulation to compute the contamination of π^0 to the DVCS channels.

$$\overset{\leftrightarrows}{N}_{DVCS/BH} = \overset{\leftrightarrows}{N}^{Exp.}_{eHe\gamma} - \overset{\leftrightarrows}{N}^{Exp.}_{eHe\pi^0(1\gamma)} = \overset{\leftrightarrows}{N}^{Exp.}_{eHe\gamma} - \left(\frac{N^{MC}_{eHe\pi^0(1\gamma)}}{N^{MC}_{eHe\pi^0(2\gamma)}}\right) * \overset{\leftrightarrows}{N}^{Exp.}_{eHe\pi^0(2\gamma)}$$

R ($1\gamma/2\gamma$) × Relative yield of $e^4He\pi^0$ = Relative contamination

→ In -t bins (integrated over φ_h, Q^2, x_B):



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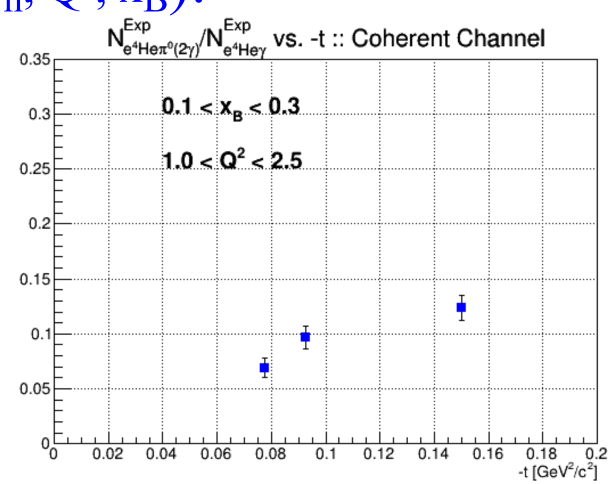

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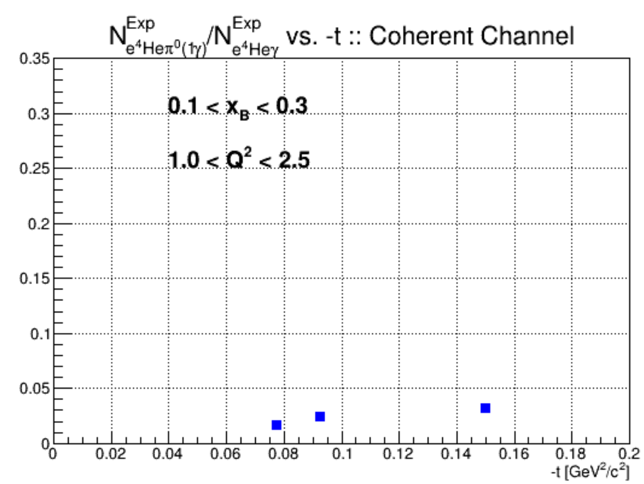


◊ Background yield ratio ~ 2-4% (8-11%) in $e^{-4}He\gamma$ ($e^- p\gamma$) DVCS channel.

Coherent beam-spin asymmetries

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

Beam polarization (P_B) = 83%

→ Probed coherent kinematical regions:

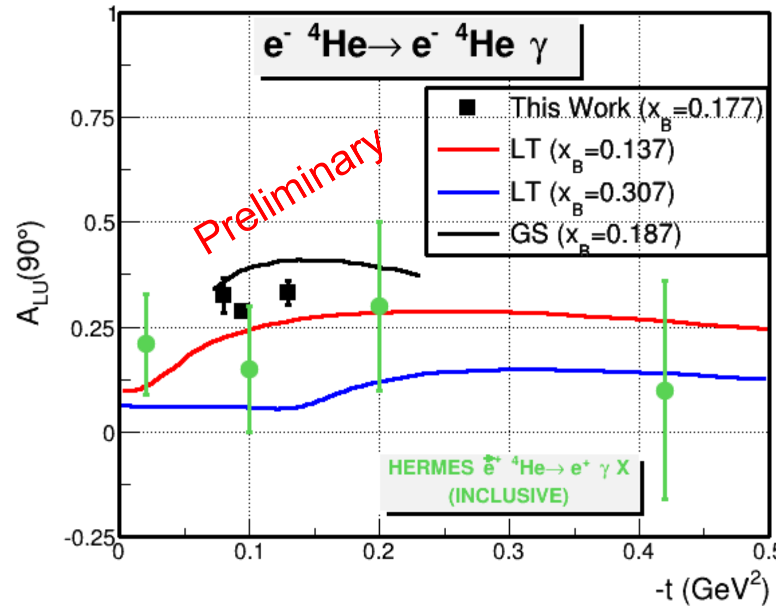
$0.06 < -t < 0.2 \rightarrow \langle -t \rangle = 0.10\ [\mathrm{GeV}^2]$

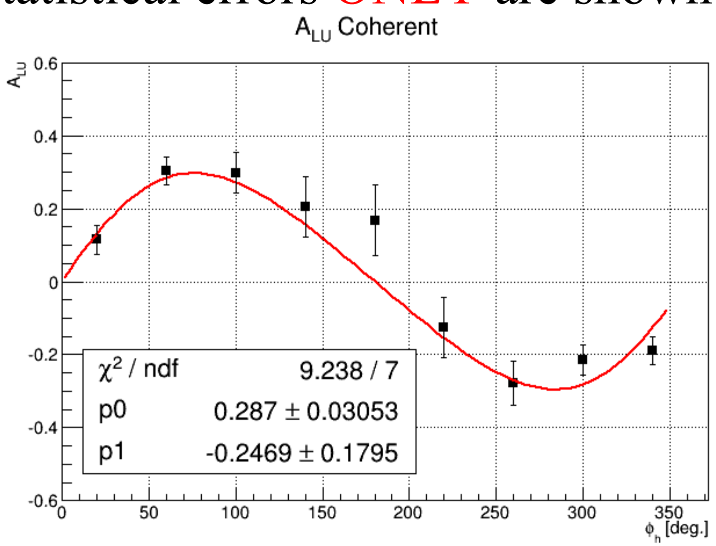
$1.0 < Q^2 < 2.5 \rightarrow \langle Q^2 \rangle = 1.49\ [\mathrm{GeV}^2]$

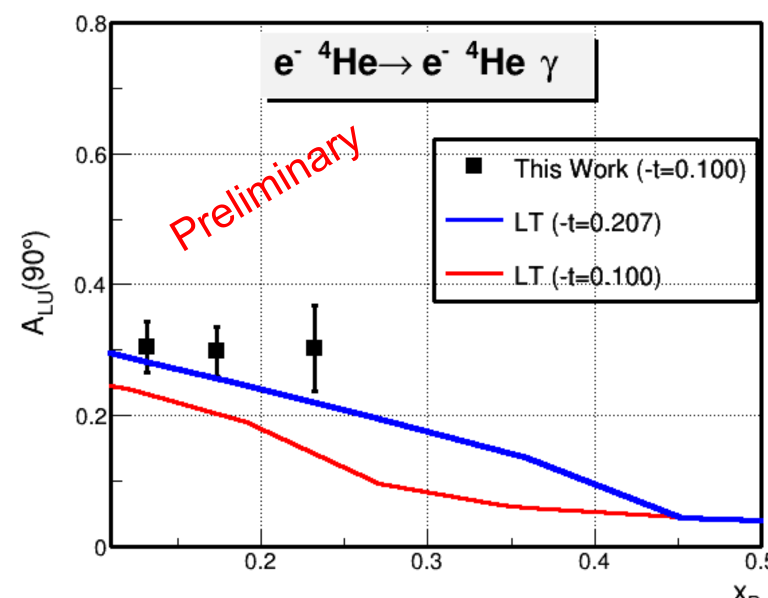
$0.1 < x_B < 0.3 \rightarrow \langle x_B \rangle = 0.18$

- Due to statistical constraints, we constructed 2D bins -t or x_B or Q^2 versus φ
- Fit A_{LU} signals: $p_0 * \sin(\phi)/(1 + p_1 * \cos(\phi))$
- Statistical errors ONLY are shown

A_{LU} @ 90° vs. (<-t>/<x_B>)







[1] LT: S. Liuti and S. K. Taneja.Phys. Rev., C72:032201, 2005.

[2] GS: V. Guzey and M. Strikman. Phys. Rev., C68:015204, 2003.

[3] HERMES: F. Ellinghaus, R. Shanidze, and J. Volmer. AIP Conf. Proc., 675:503–507, 2003.

Compton form factor extraction

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

We are not sensitive to this order

$$\alpha_0 \sim 10^{-2},\ \alpha_1 \sim 1,\ \alpha_2 \sim 10^{-2},\ \boxed{\alpha_3 \sim 10^{-4}}$$

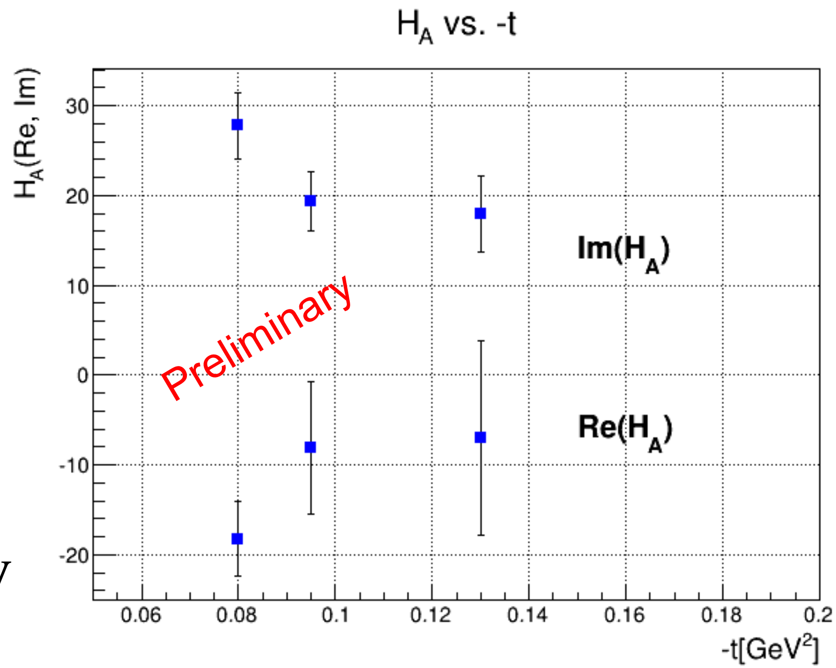
Expected to be small magnitude

$$\begin{aligned} \alpha_0(\phi) &= a\sin(\phi) \\ \alpha_1(\phi) &= b + c\cos(\phi) + \boxed{d\cos(2\phi)} \\ \alpha_2(\phi) &= h + f\cos(\phi) \end{aligned}$$

- Using the kinematical calculable factors (a, b, c, h and f) and the fitted coherent ALU @ 90º vs. <-t>

$$p_0 * \sin(\phi)/(1 + p_1 * \cos(\phi))$$

$\rightarrow$ Extracted the real and the imaginary parts of the Compton form factor.



- We have "significant" trends with t and xB as well.

InCoherent beam-spin asymmetries

◊ Probed kinematical regions:

$0.05 < -t < 2.5$ [GeV²] $\rightarrow$ $\langle -t \rangle = 0.53$ [GeV²]

$1.0 < Q^2 < 4.5$ [GeV²] $\rightarrow$ $\langle Q^2 \rangle = 2.20$ [GeV²

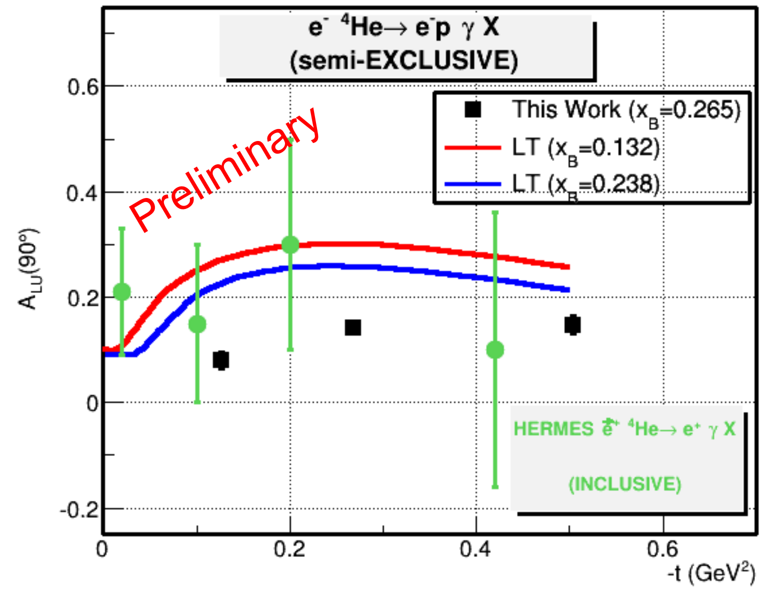
$0.1 < x_B < 5.5$ $\rightarrow$ $\langle x_B \rangle = 0.26$

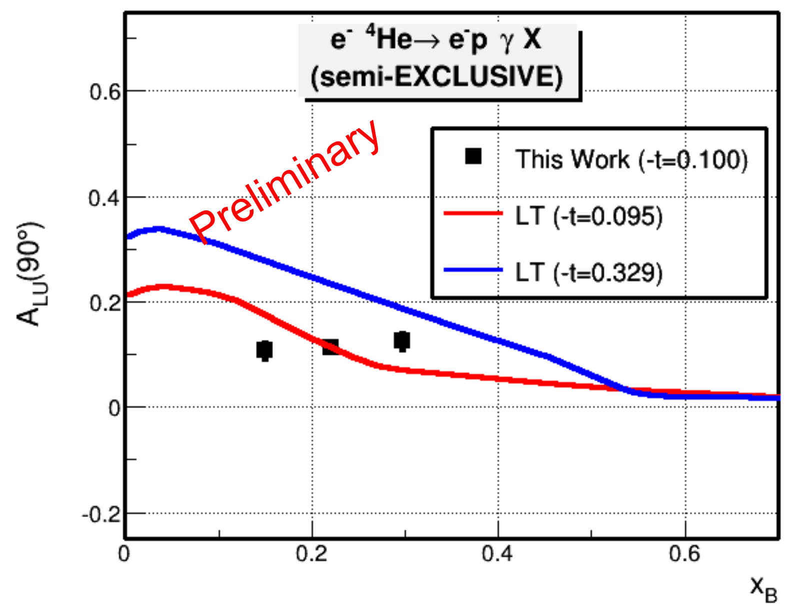
◊ The black points are our measured asymmetries after the background subtraction in which:

- 2D bins ($-t/x_B/Q^2$) vs. Φ
- Fitted with $p_0 * \sin(\phi)/(1 + p_1 * \cos(\phi))$
- Statistical errors ONLY are shown

◊ Theoretical predictions:

- In -t @ x_B=0.132 and 0.238
- In x_B @ -t= -0.095 and 0.326





[1] LT: S. Liuti and S. K. Taneja.Phys. Rev., C72:032201, 2005.
[2] HERMES: F. Ellinghaus, R. Shanidze, and J. Volmer. AIP Conf. Proc., 675:303–307, 2003.

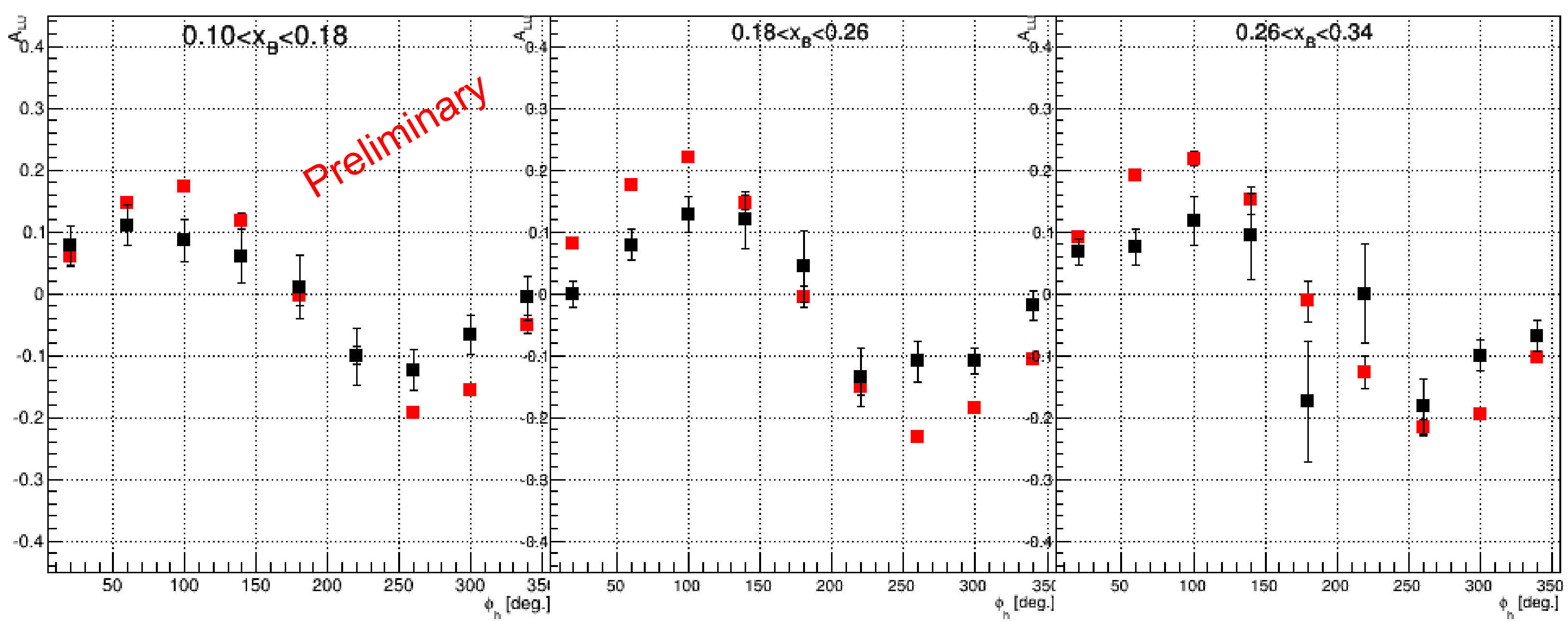
EMC ratio (1/2)

◊ Possible explanation of the EMC effect:
Modifications of the nucleons themselves in the nuclear medium

◊ We compared our measured incoherent asymmetries (Black points) with the asymmetries measured in CLAS DVCS experiment on the proton (Red Points).

A_{LU} vs. φ in x_B bins

*** Integrated over:**
$0.05 < -t < 2.5$
$1.0 < Q^2 < 4.5$



◊ The bound proton shows a lower asymmetry relative the free one in the different bins in x_B.

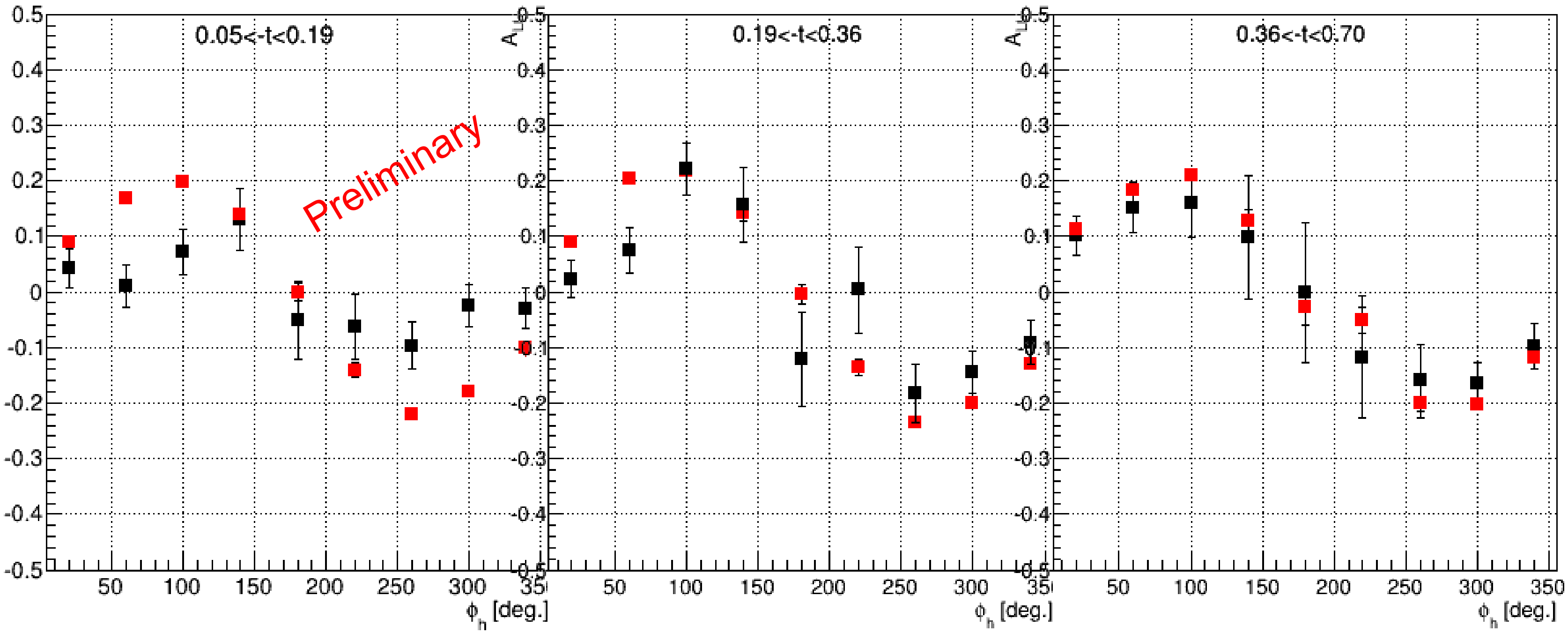
EMC ratio (2/2)

◊ Possible explanation of the EMC effect:
Modifications of the nucleons themselves in the nuclear medium

◊ We compared our measured incoherent asymmetries (Black points) with the asymmetries measured in CLAS DVCS experiment on the proton (Red Points).

A_{LU} vs. φ in -t bins

* Integrated over:
$0.1 < x_B < 0.55$
$1.0 < Q^2 < 4.5$



◊ At small -t, the bound proton shows lower asymmetry than the free one.
◊ At high -t, the two asymmetries are compatible.

Conclusions

◊ The exclusive DVCS off ^{4}He was measured for the first time with our experiment

◊ Preliminary asymmetries were extracted and compared with theoretical predictions

◊ With our available statistics, the bound proton has shown a different trend compared to the free one

◊ Perspectives:

→ Final results soon

→ Proposing a new ^{4}He DVCS experiment with JLab upgrade.

Thanks for your attention

$\alpha_i(\varphi)$ coefficients appearing in the BSA expression

$$
\begin{aligned}
\alpha_0(\phi) &= 8\,K x_A (1+\epsilon^2)^2\,(2-y) F_A\,\sin(\phi)\\
\alpha_1(\phi) &= c_0^{BH} + c_1^{BH}\cos(\phi) + c_2^{BH}\cos(2\phi)\\
\alpha_2(\phi) &= 8\,\frac{x_A}{y}\,(1+\epsilon^2)^2 F_A\left[K(2y-y^2-2)\cos(\phi)\right.\\
&- \left.(2-y)(\frac{t}{Q^2})\Big((2-x_A)(1-y)-(1-x_A)(2-y)^2(1-\frac{t_{min}}{Q^2})\Big)\right]\\
\alpha_3(\phi) &= 2\,\frac{x_A^2 t}{Q^2}\,(2-2y+y^2)\,(1+\epsilon^2)^2\,\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)
\end{aligned}
$$

◊ The Fourier coefficients of the BH amplitude for a spin-0 target can be expressed as:

$$
\begin{aligned}
c_0^{BH} = &\left[\left\{(2-y)^2 + y^2(1+\epsilon^2)^2\right\}\left\{\frac{\epsilon^2 Q^2}{t} + 4(1-x_A) + (4x_A+\epsilon^2)\frac{t}{Q^2}\right\}\right.\\
&+2\epsilon^2\left\{4(1-y)(3+2\epsilon^2) + y^2(2-\epsilon^4)\right\} - 4x_A^2(2-y)^2(2+\epsilon^2)\frac{t}{Q^2}\\
&\left.+8K^2\frac{\epsilon^2 Q^2}{t}\right] F_A^2,
\end{aligned}
$$

$$
c_1^{BH} = -8(2-y)K\left\{2x_A + \epsilon^2 - \frac{\epsilon^2 Q^2}{t}\right\} F_A^2,
$$

$$
c_2^{BH} = 8K^2\frac{\epsilon^2 Q^2}{t} F_A^2,
$$