Deeply Virtual Compton Scattering off ^{4}He:

New results and future perspectives

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(On behalf of the CLAS collaboration)

Next generation nuclear physics with JLab12 and EIC

10-13 February 2016, Florida International University

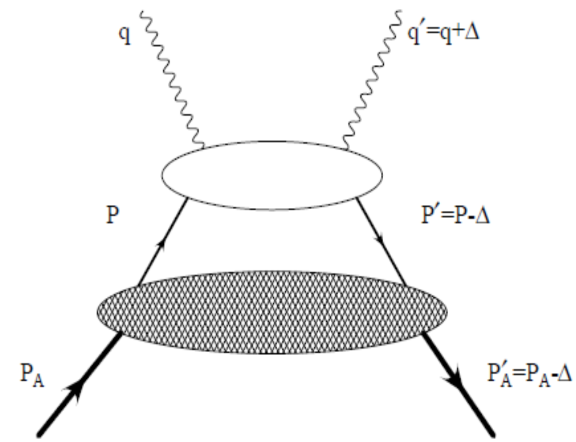
DVCS off nuclei

Two DVCS channels are accessible with nuclear targets:

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

→ Study the partonic structure of the nucleus.

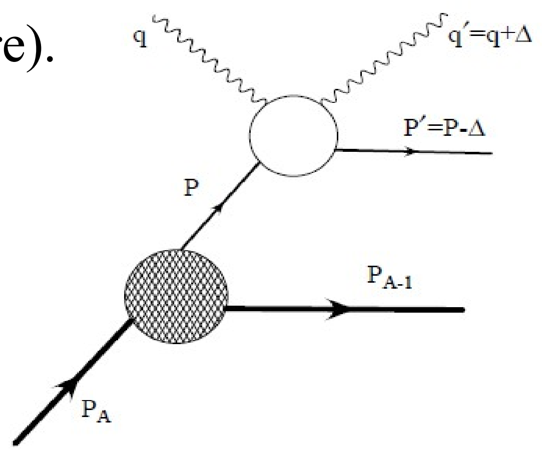
→ One chiral-even GPD (**$H_A(x,\xi,t)$**) is needed to parametrize the structure of the spinless nuclei (^{4}He, ^{12}C, ^{16}O, ...).



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

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

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



conserve nucleon spin

unpolarized { **$H(x,\xi,t)$**, **$E(x,\xi,t)$** }

{ **$\tilde{H}(x,\xi,t)$**, **$\tilde{E}(x,\xi,t)$** } **polarized**

flip nucleon spin

Nuclear spin-zero DVCS observables

The GPD H_A parametrizes the structure of the spinless nuclei (^{4}He, ^{12}C …)

$$\mathcal{H}_A(\xi,t) = Re(\mathcal{H}_A(\xi,t)) - i\pi Im(\mathcal{H}_A(\xi,t))$$

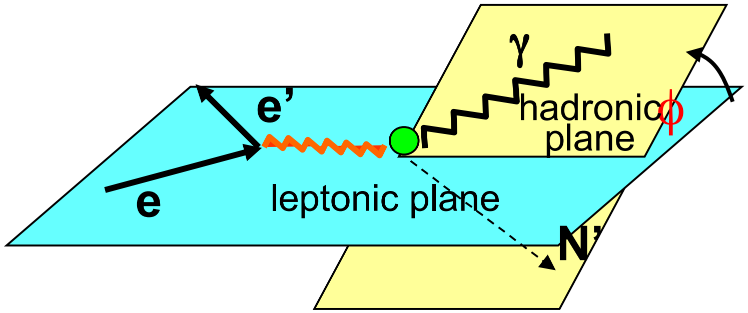
$$Im(\mathcal{H}_A(\xi,t)) = H_A(\xi,\xi,t) - H_A(-\xi,\xi,t)$$

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

Quark propagator

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

→ Beam-spin asymmetry ($A_{LU}(\phi)$) : (+/- beam helicity)

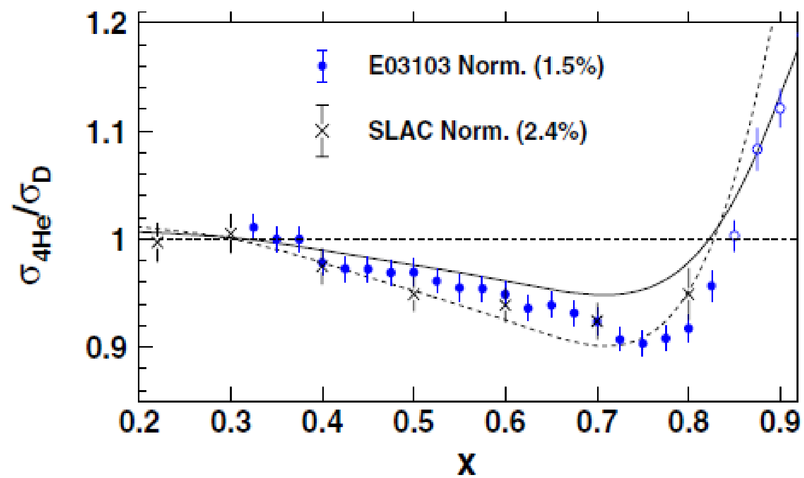


$$A_{LU}(\phi) = \frac{1}{P_B}\frac{N^+ - N^-}{N^+ + N^-}$$

$$= \frac{x_A(1+\epsilon^2)^2}{y} s_1^{INT}\sin(\phi) \Big/ \Big[\sum_{n=0}^{n=2} c_n^{BH}\cos(n\phi) + \frac{x_A^2 t(1+\epsilon^2)^2}{Q^2} P_1(\phi)P_2(\phi)\, c_0^{DVCS} + \frac{x_A(1+\epsilon^2)^2}{y}\sum_{n=0}^{n=1} c_n^{INT}\cos(n\phi)\Big]$$

EMC effect in 4He

EMC effect: the modification of the PDF f_2 as a function of the longitudinal momentum carried by the struck parton.



[J. Seely, A. Daniel, D. Gaskell, J. Arrington et al., Phys. Rev. Let.: PRL 103, 202301 (2009)]

- Nuclear modifications of the DIS cross section measured by CERN, SLAC and JLab
  → Variations with the nuclear properties, i.e. mass & density

- The origin of the EMC effect is still not fully understood, but possible explanations:
  → Modifications of the nucleons themselves
  → Effect of non-nucleonic degrees of freedom, e.g. pions exchange
  → Modifications from multi-nucleon effects (binding, N-N correlations, etc...)

- Clear explanations may arise from measuring the nuclear modifications via other reactions, like DVCS and DVMP …

Theoretical predictions of the EMC in 4He

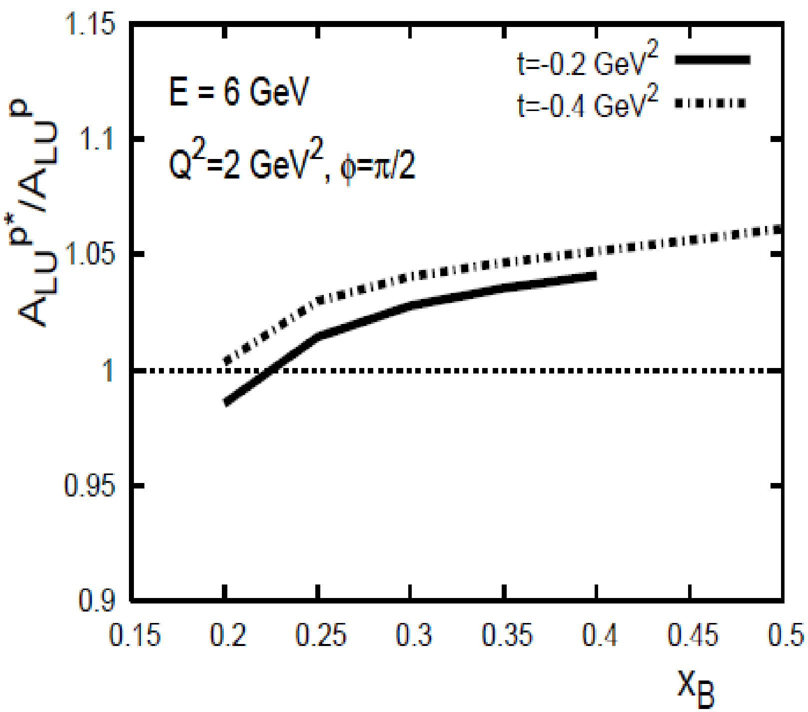
On-shell calculations:

(1) Impulse approximation

$GPD^{4He}(x,\xi,t) = \Sigma$ (free p and n GPDs)$*F_{4He}(t)$

(2) Medium modifications:

$$H^{q/p^*}(x,\xi,t,Q^2) = \frac{F_1^{p^*}(t)}{F_1^p(t)} H^q(x,\xi,t,Q^2),$$



[V. Guzey, A. W. Thomas, K. Tsushima, PRC 79 (2009) 055205]

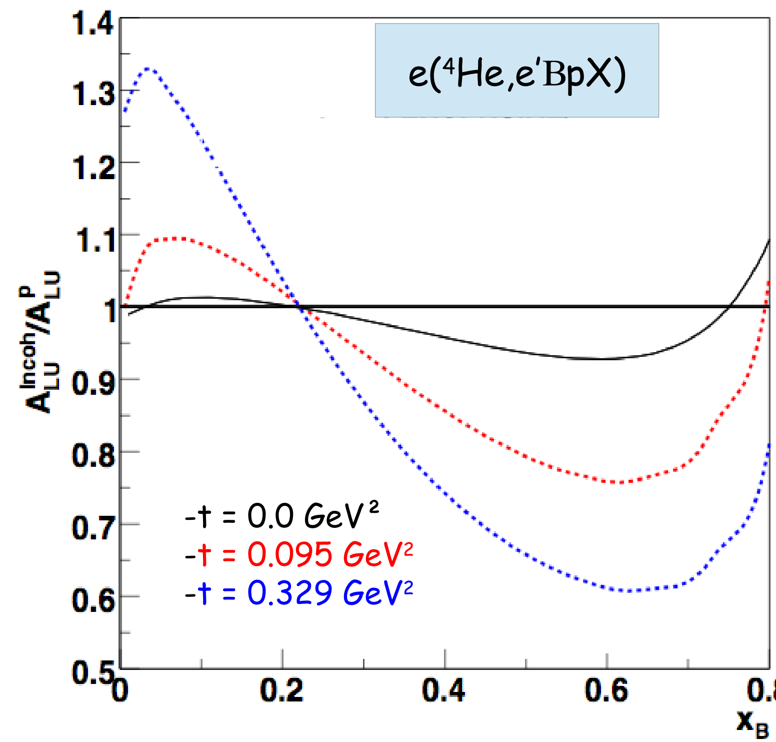
Off-shell calculations:

Nucleus = bound nucleons + nuclear binding effects

$$H^A(x,\xi,t) = \sum_N \int \frac{d^2P_\perp dY}{2(2\pi)^3} \frac{1}{A-Y} A\rho^A(P^2,P'^2)$$

Nuclear spectral function

$$\times \sqrt{\frac{Y-\xi}{Y}} \left[H_{OFF}^N\left(\frac{x}{Y},\frac{\xi}{Y},P^2,t\right) - \frac{1}{4}\frac{(\xi/Y)^2}{1-\xi/Y} E_{OFF}^N\left(\frac{x}{Y},\frac{\xi}{Y},P^2,t\right) \right]$$



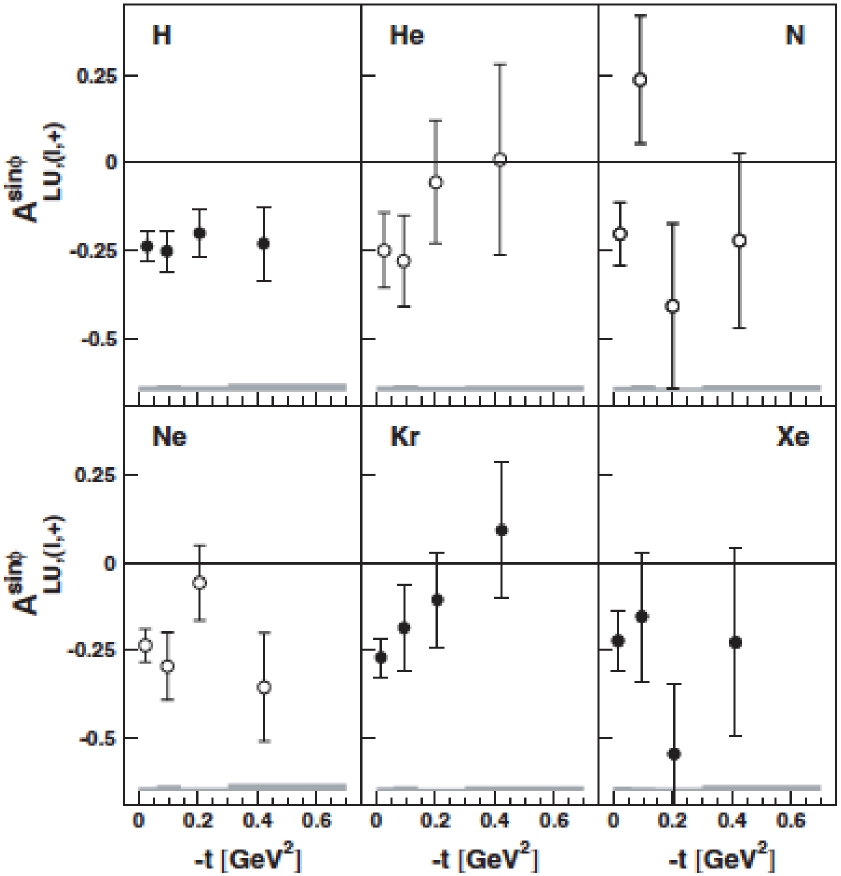
[S. Liuti, K.Taneja, PRC 72 (2005) 034902]

Nuclear DVCS measurements: HERMES

- The exclusivity is ensured via cut on the missing mass of eγX final state configuration.

$$A_{LU}^{sin} = \frac{1}{\pi}\int_0^{2\pi} d\phi \, \sin\phi \, A_{LU}(\phi)$$

- Coherent and incoherent separation depending on -t, i.e. coherent rich at small -t.



[A. Airapetian, et al., Phys Rev. C 81 (2010) 035202]

- Conclusions from HERMES:
  No enhancement of the nuclear asymmetry with respect to the free proton asymmetry.

In CLAS - E08-024, we measure EXCLUSIVE coherent and incoherent DVCS channels off ^{4}He

CLAS - E08-024 experimental Setup

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

6 GeV,
L. polarized

Beam polarization (P_B) = 83%

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

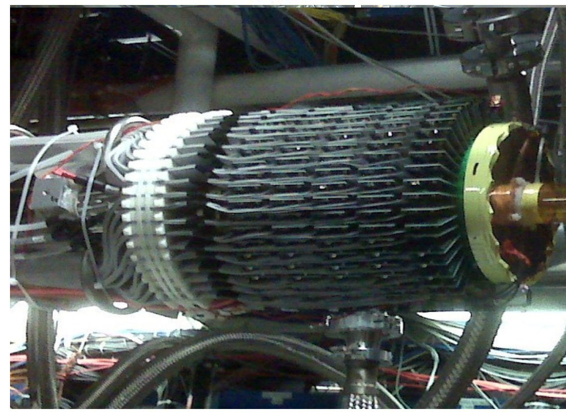
- IC: Improves γ detection acceptance [4°,14°].

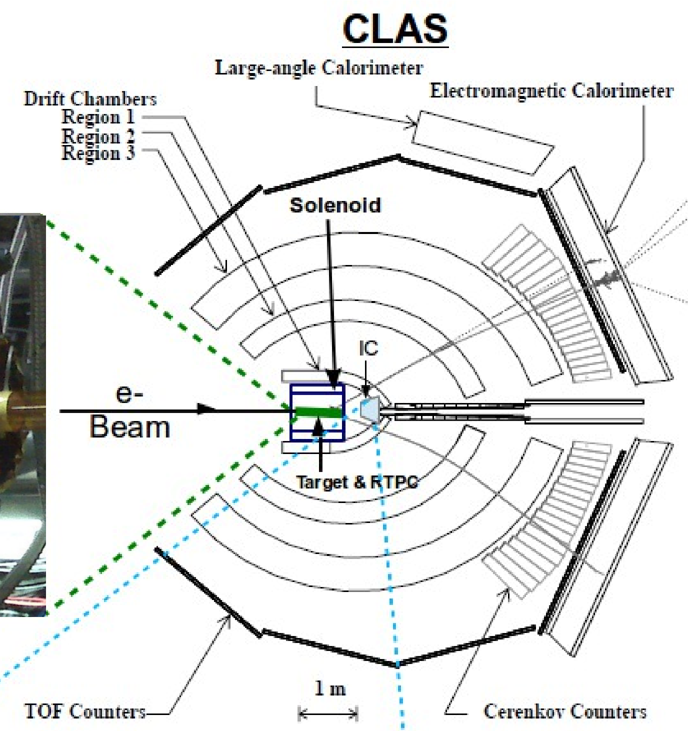
- RTPC: Detects low energy nuclear recoils.

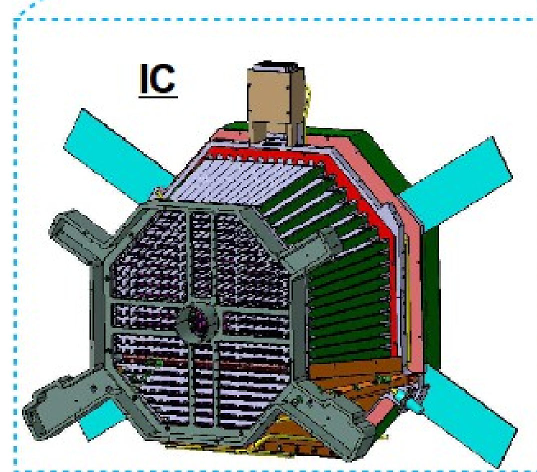
- Solenoid: - Shields the detectors from Møller electrons.
- Enables tracking in the RTPC.

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

RTPC







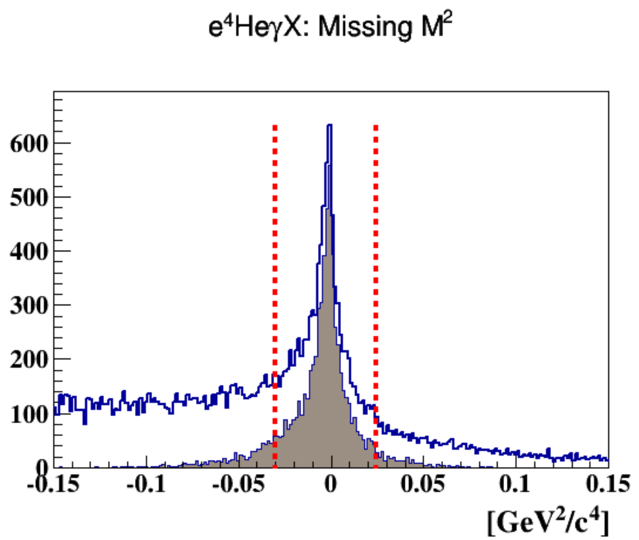
DVCS events selection (1/2)

We select COHERENT events which have:

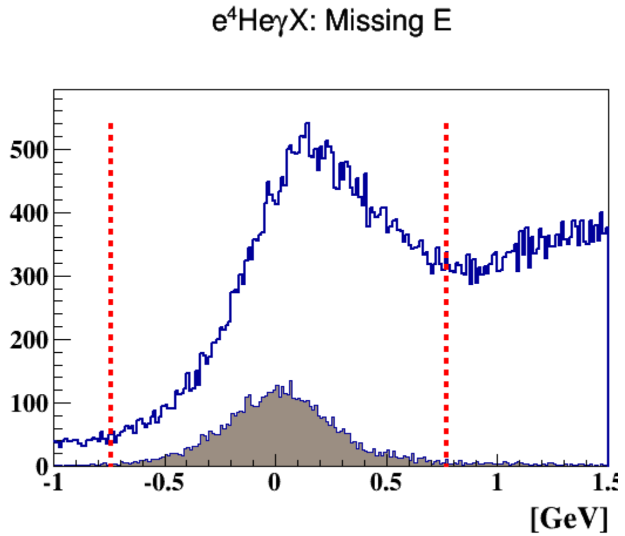
◊ Only one good electron, at least one photon and only one good ^{4}He.

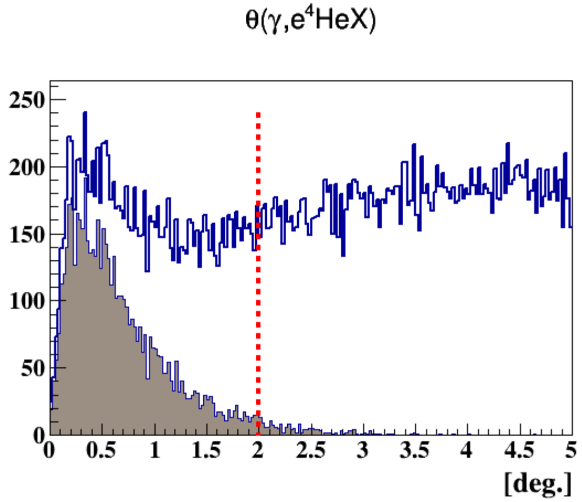
◊ $E\gamma > 2$ GeV, $W > 2$ GeV/c^2 and $Q^2 > 1$ GeV^2.

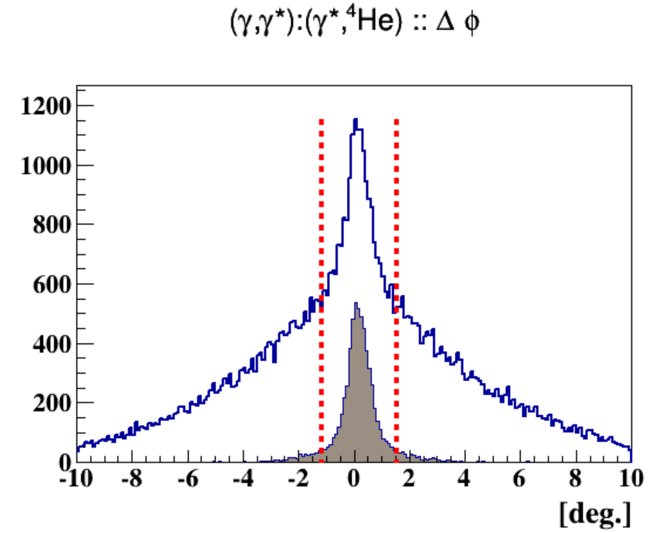
◊ Exclusivity cuts (3 sigmas).



- 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.



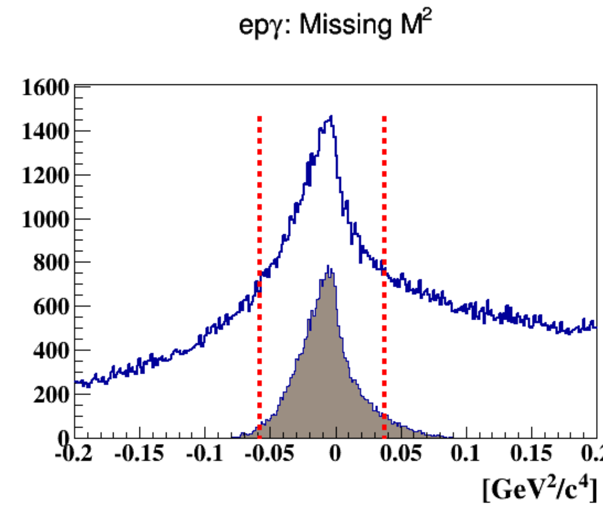




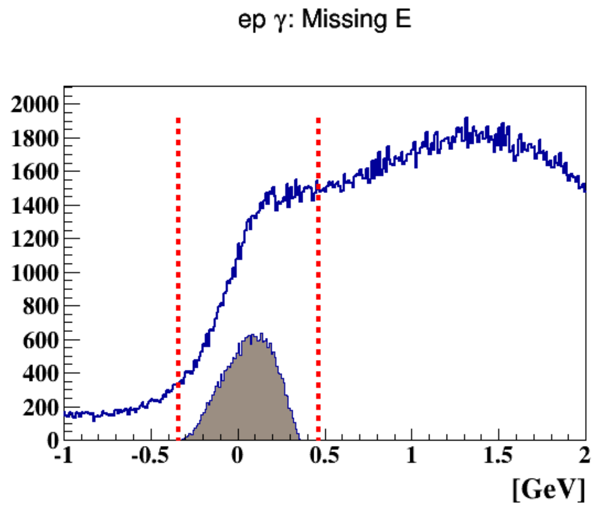
DVCS events selection (2/2)

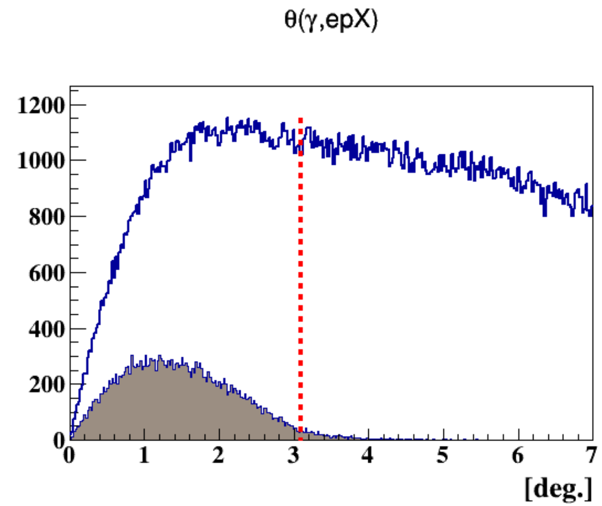
We select INCOHERENT events which have:

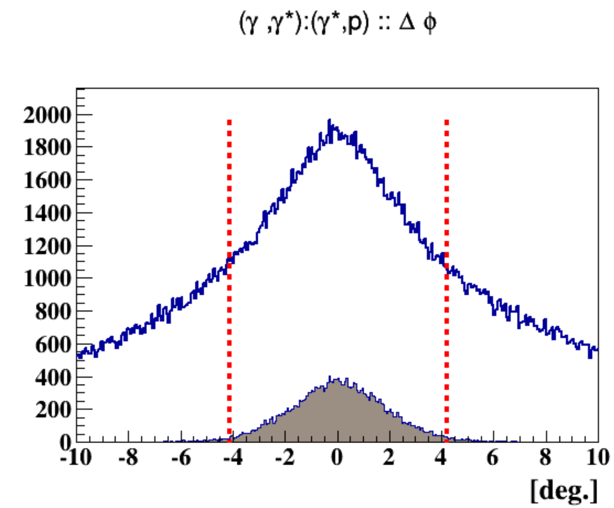
- ◊ Only one good electron, at least one photon and only one good p.
- ◊ Eγ > 2 GeV, W > 2 GeV/c^2 and Q^2 > 1 GeV^2.
- ◊ Exclusivity cuts (3 sigmas).



- In BLUE, incoherent events before all exclusivity cuts.
- In shaded BROWN, incoherent DVCS events which pass all the other exclusivity cuts except the one on the quantity itself.

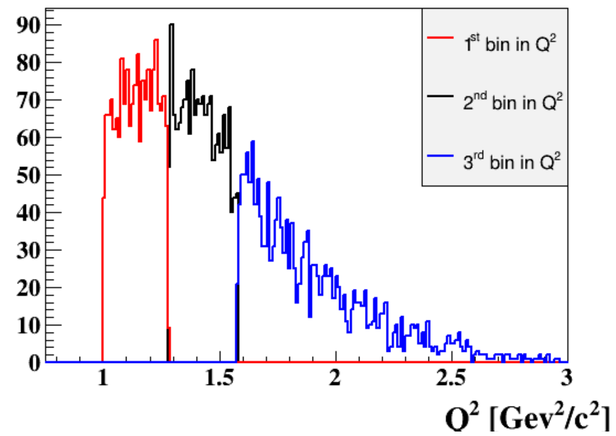


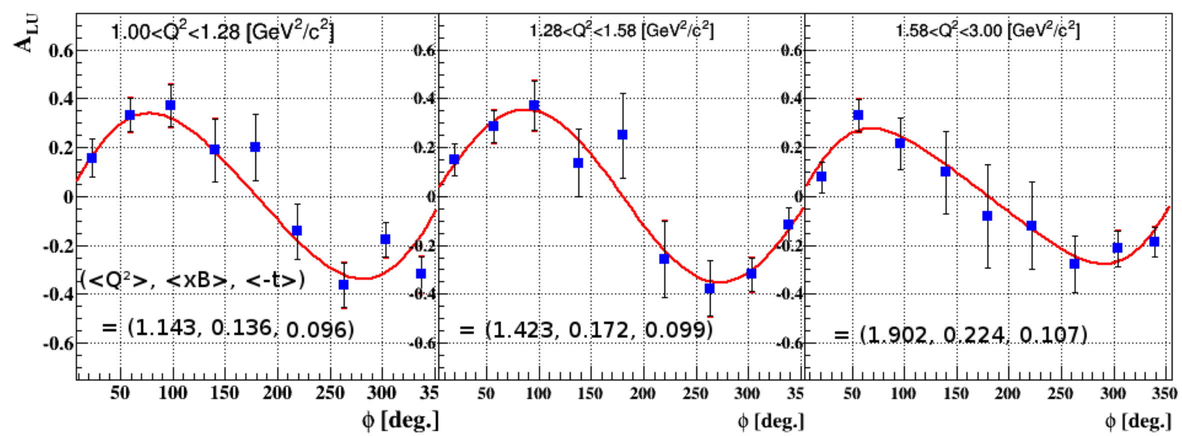


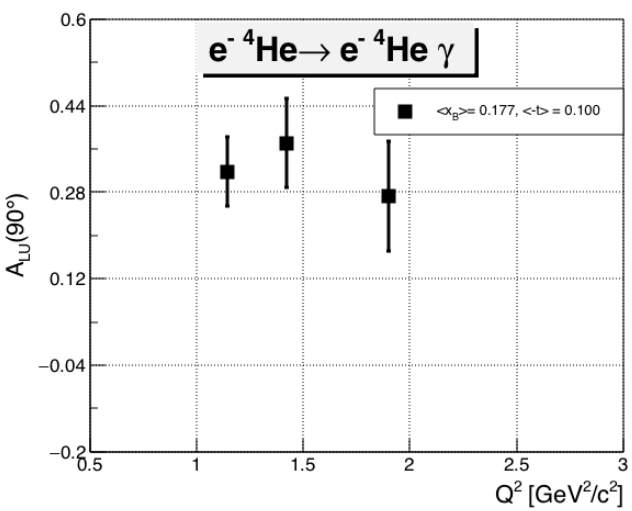


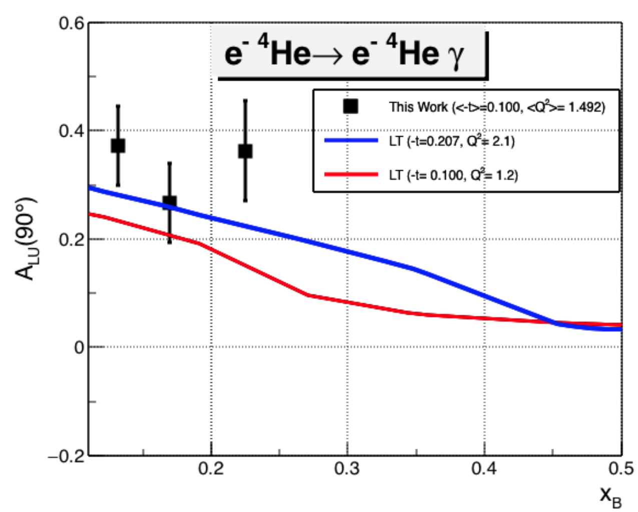
Coherent beam-spin asymmetries

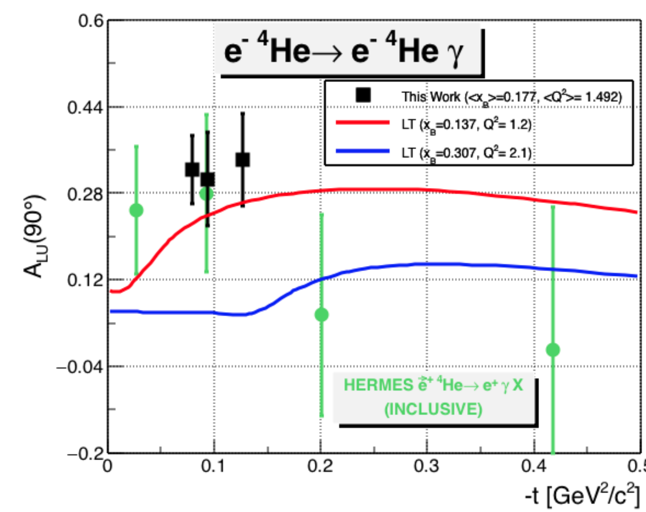
- Due to statistical constraints, we construct 2D bins -t or x_B or Q^2 versus φ
- Fit A_{LU} signals: $\alpha*\sin(\phi)/(1+\beta*\cos(\phi)+\eta*\cos(2\phi))$







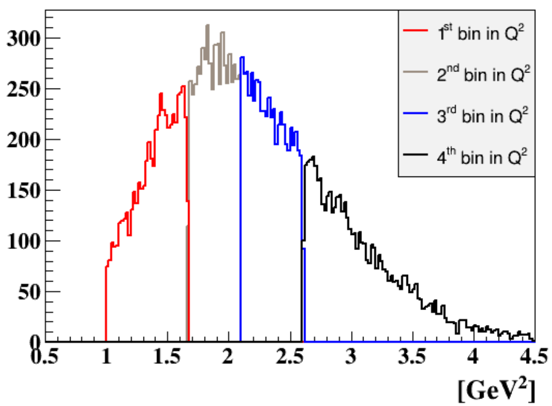


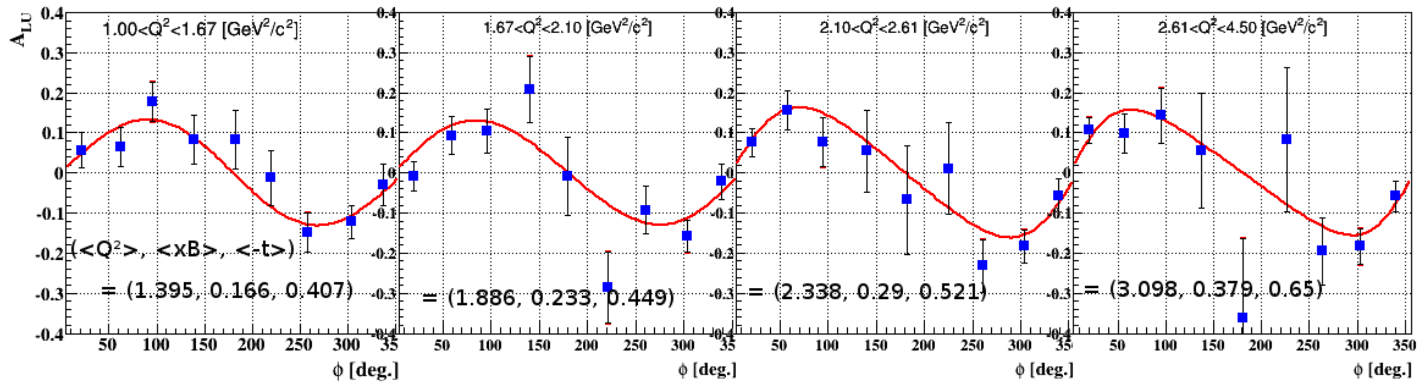


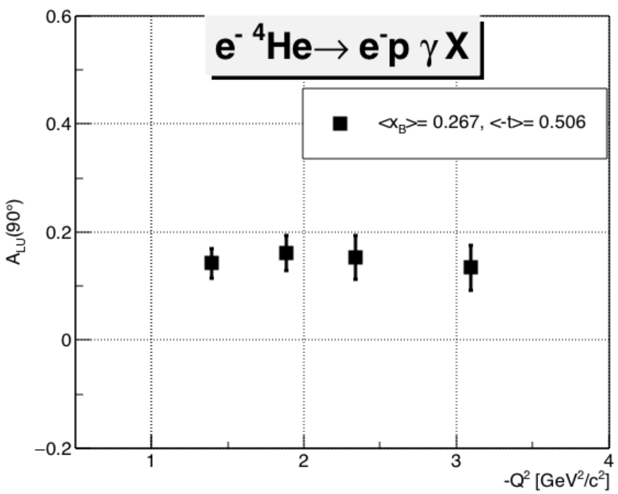
LT: S. Liuti and S. K. Taneja, PRC 72 (2005) 034902.
HERMES: A. Airapetian, et al., Phys. Rev. C 81, 035202 (2010).

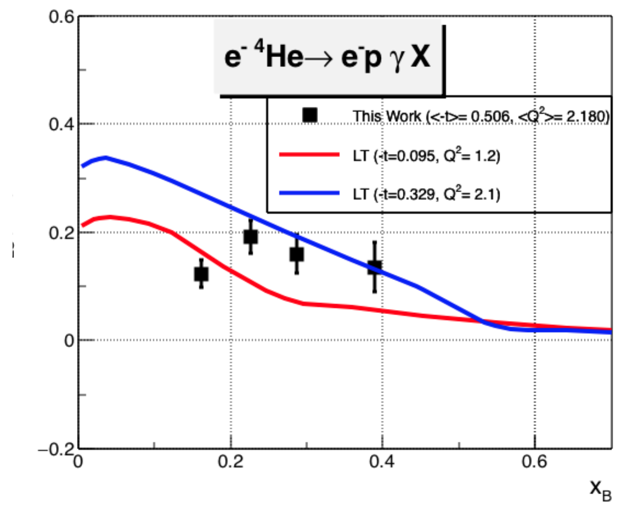
Incoherent beam-spin asymmetries

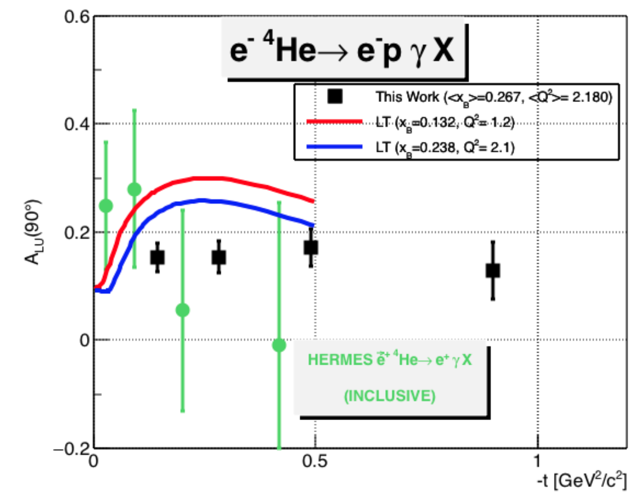
Q² of epγ events







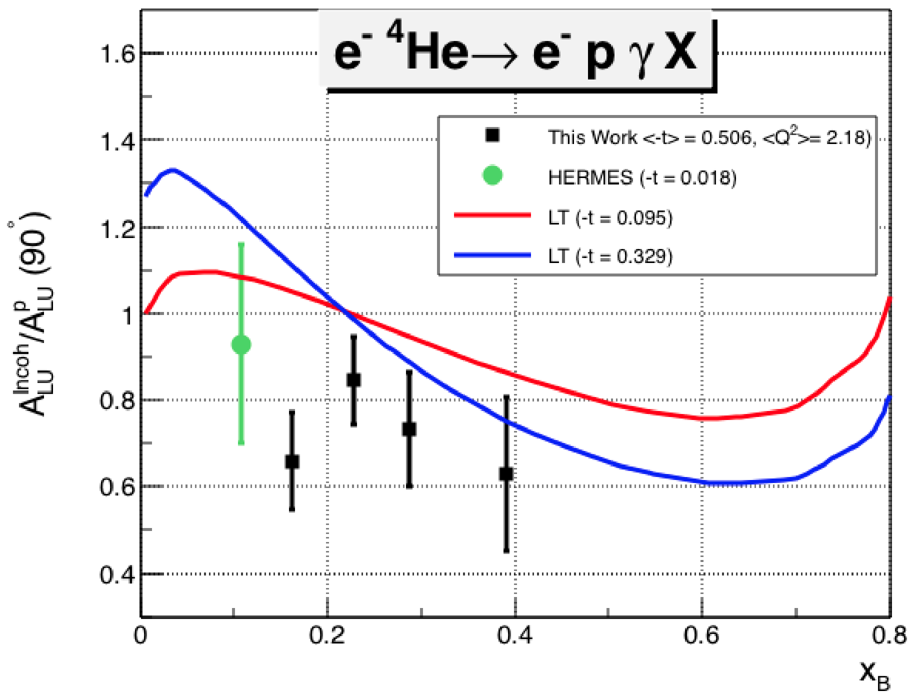


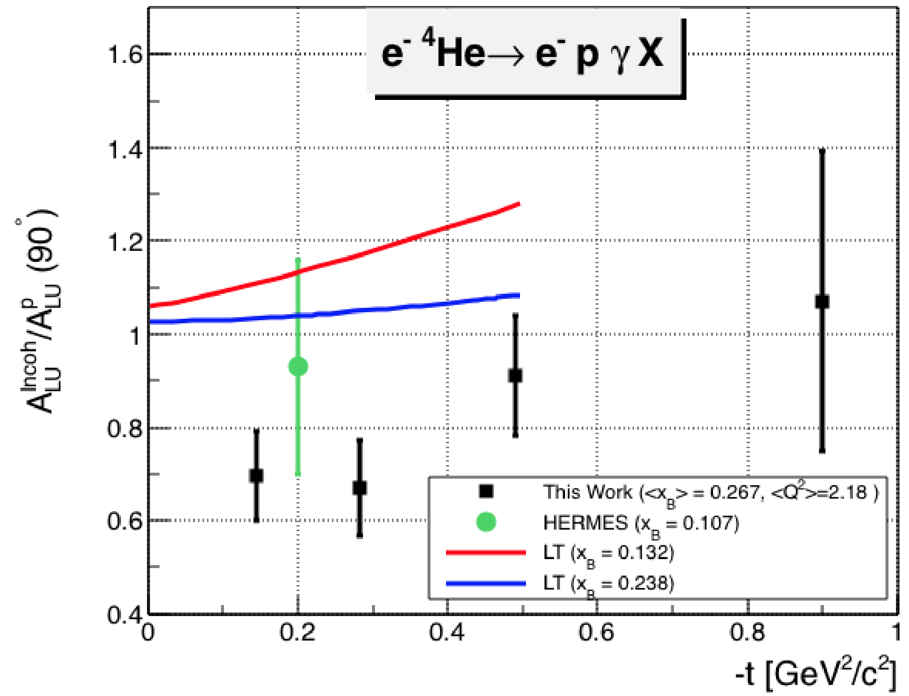


[1] LT: S. Liuti and S. K. Taneja.Phys. Rev., C72:032201, 2005.
[2] A. Airapetian, et al., Phys Rev. C 81, 035202 (2010).

EMC ratio (1/2)

◊ Comparing our measured incoherent asymmetries with the asymmetries measured in CLAS DVCS experiment on the proton.





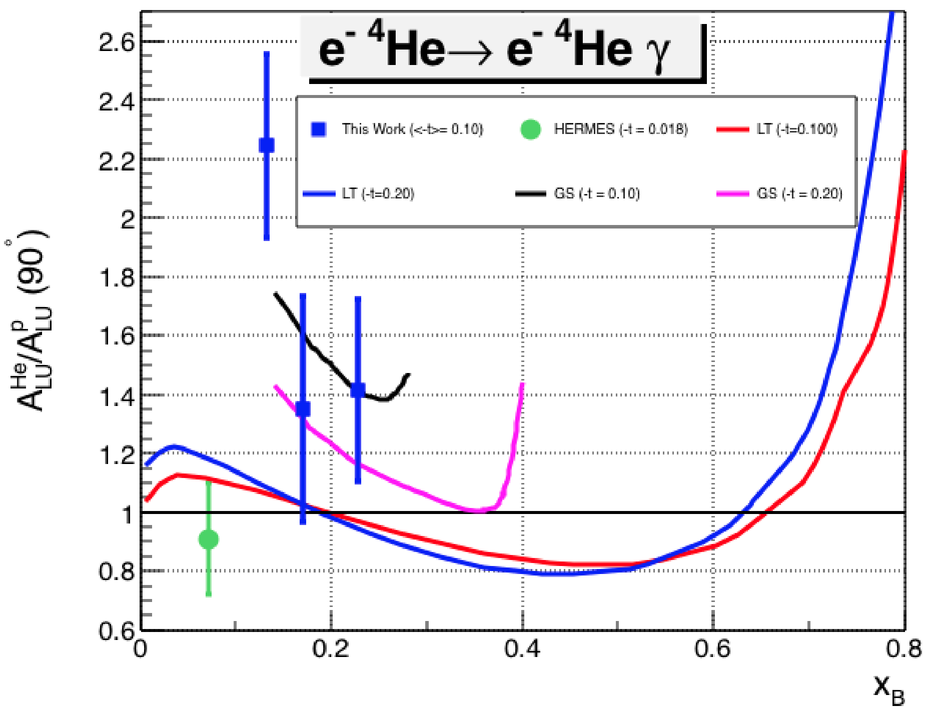
◊ The bound proton shows a lower asymmetry relative to the free one in the different bins in x_B.

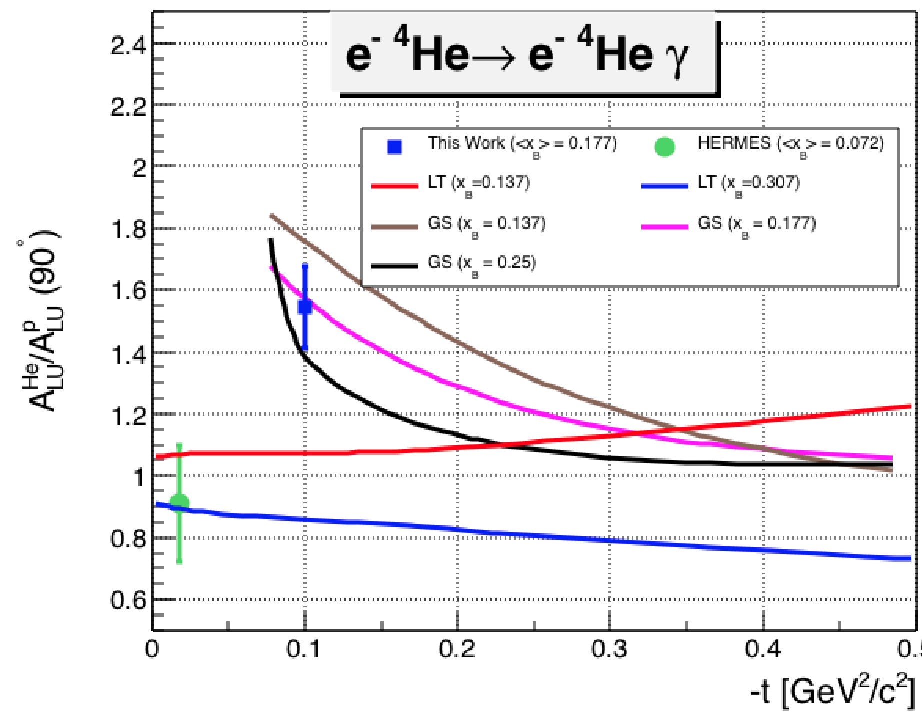
◊ At small -t, the bound proton shows lower asymmetry than the free one.

◊ At high -t, the two asymmetries are compatible.

EMC ratio (2/2)

◊ Comparing the coherent asymmetries to the free proton ones:





→ Consistent with the enhancement predicted by the Impulse approximation model [V. Guezy et al., PRC 78 (2008) 025211]

→ Does not match the inclusive measurement of HERMES.

→ Additional nuclear effects have to be taken into account in the nuclear spectral function calculations. [S. Liuti and K. Taneja. PRC 72 (2005) 032201]

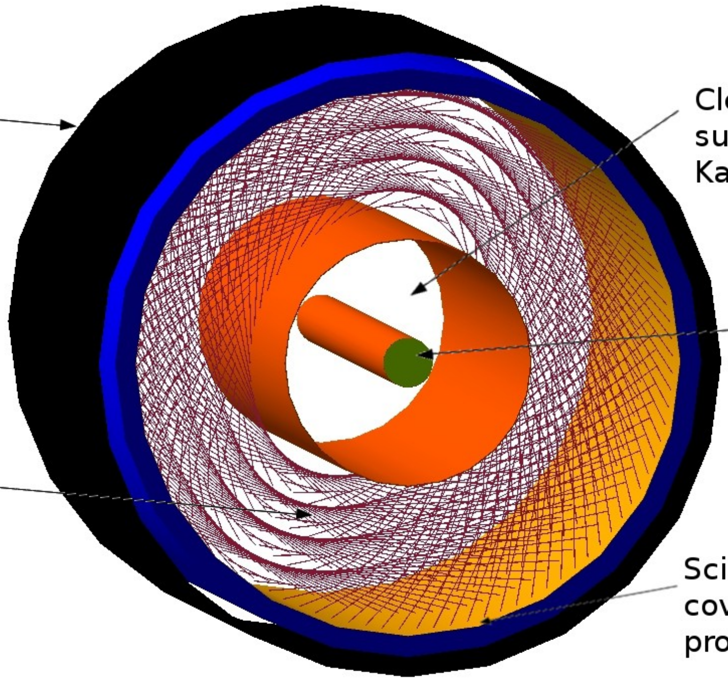
Future perspectives and proposals using “CLAS12 + ALERT” experimental setup

K. Hafidi, N. Baltzell, G. Charles, R. Dupre, M. Hattawy, S. Joosten, A. El-Alaoui, W. Armstrong, A. Accardi, M. Amarian, S. Stepanyan, G. Dodge, Z. E. Meziani, M. Paolone

- Coherent and incoherent DVCS off ^{4}He.
- DVCS on deuterium and neutron.
- Tagged EMC.
- Coherent phi production on ^{4}He.

- 300 mm long
- 90 mm diameter

→ The drift time is short.
→ Can be included in the trigger.
→ Separate protons, deuterium, tritium, alpha, helium-3.
→ Can be used for BoNuS12, tagged EMC and DVCS on He4 ...



Conclusions

◊ CLAS – E08-024 experiment:

→ The first exclusive measurement of DVCS off ^{4}He.

→ The coherent DVCS shows a stronger asymmetry than the free proton as was expected from theory.

→ We extracted EMC ratios and compared them with theoretical predictions.

→ The bound proton has shown a different trend compared to the free one indicating the medium modifications of the GPDs.

◊ Perspectives:

→ Final results soon

→ We will need 12 GeV Jlab to obtain better statistics and wider kinematic coverage.

Monte Carlo simulation

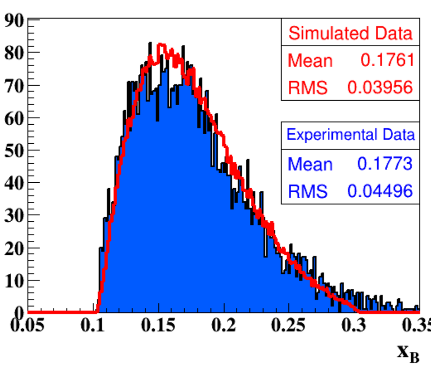
◊ **We use Monte Carlo for two goals:**

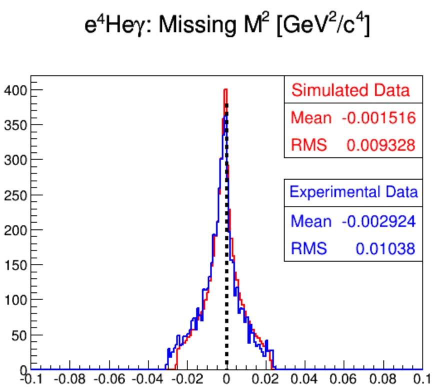
- Understanding the behavior of each particle type in our detectors
- Calculate the acceptance ratio for the purpose of the π^0 background subtraction

◊ **Simulation stages:**

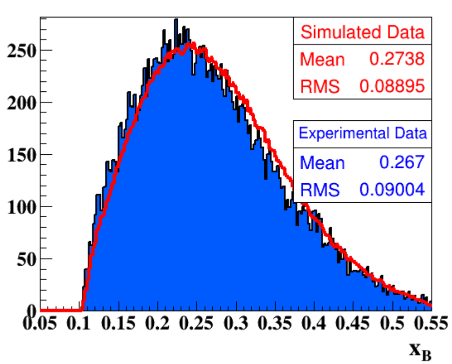
- **Event generator:** $e\ ^4He\gamma$, $e\ ^4He\pi^0$, $ep\gamma$ and $ep\pi^0$ events are generated in their measured phase space (Q^2, x_B, $-t$, ϕ_h) following this parametrization of the cross section.
- **Simulation (GSIM):** GEANT3, describes the detectors' response to the different particles.
- **Smearing (GPP):** Makes the simulation more realistic by smearing the positions, energies and times.
- **Reconstruction (RECSIS):** (ADCs, TDCs) → physical quantities.

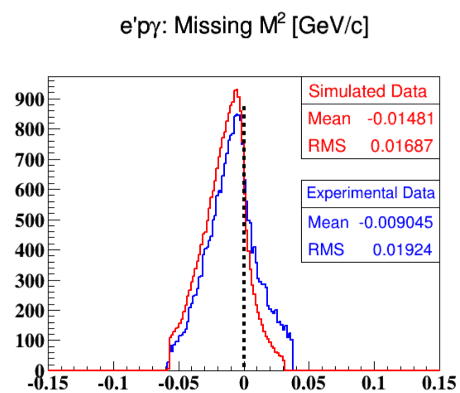
Coherent DVCS





Incoherent DVCS





Adequate agreement between data and simulation

Background Subtraction

◊ With our kinematics, the main background comes from the exclusive π^0 channel,

$$e^4He \rightarrow e^4He\pi^0 \rightarrow e^4He\gamma\gamma \qquad ep \rightarrow ep\pi^0 \rightarrow ep\gamma\gamma$$

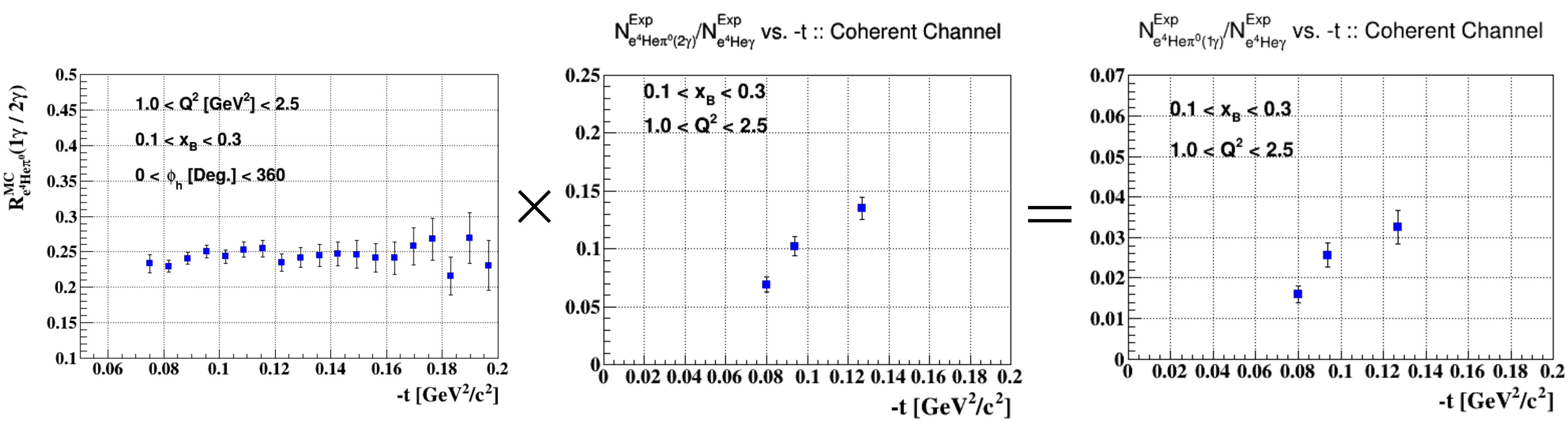
in which one photon from π^0 decay is detected and passes the DVCS selection.

◊ We combine real data with simulation to compute the contamination of π^0 to DVCS.

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

Acceptance ratio (R (1γ/2γ))

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



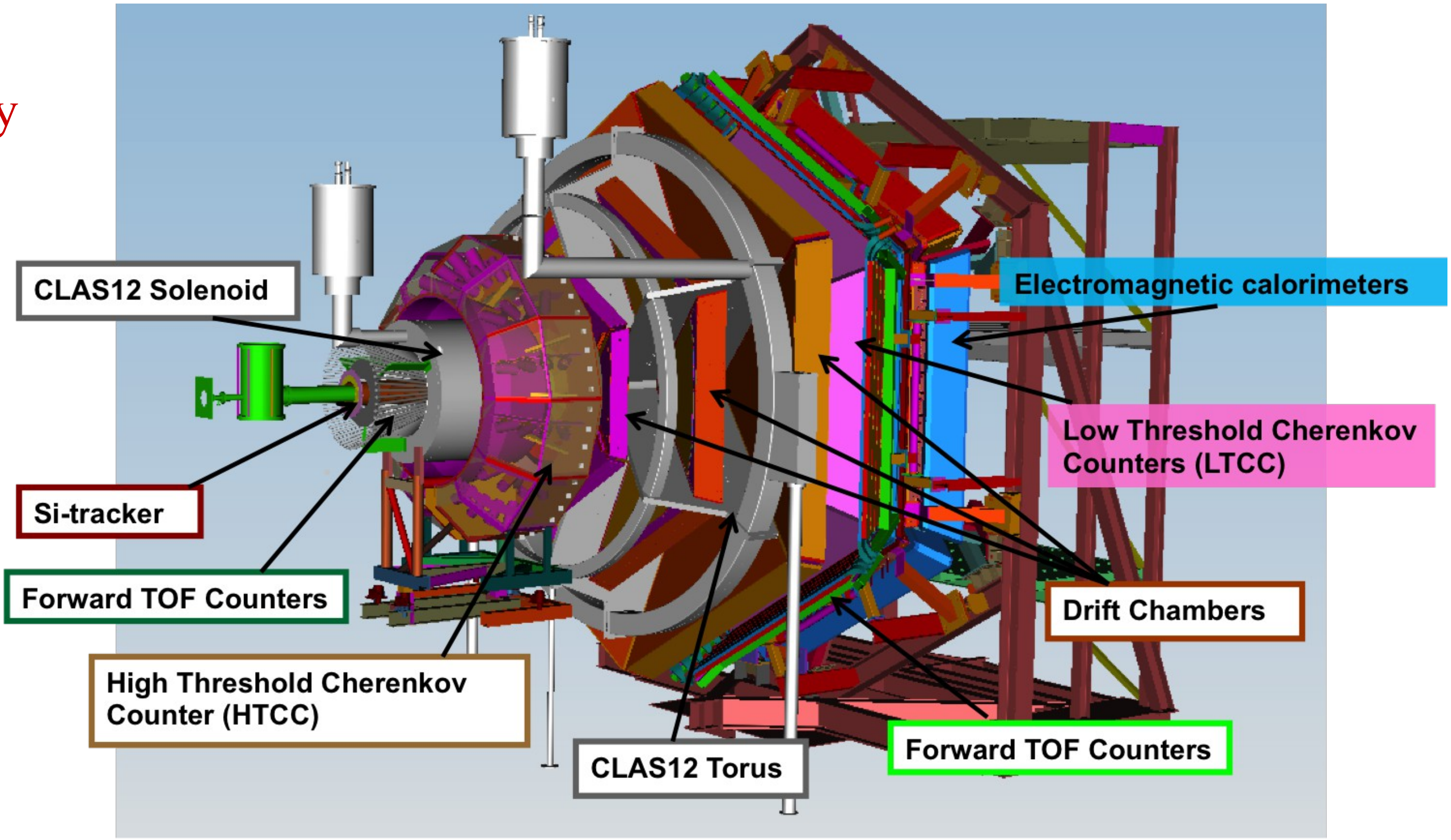
◊ Background yield ($N^{Exp}_{e^4He\pi(1\gamma)}$ / $N^{Exp}_{e^4He\gamma}$) ratio ~ 2-4% (8-11%) in $e^4He\gamma$ ($ep\gamma$) channel.

DVCS with Jlab 12

CLAS12 detector

Design luminosity

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



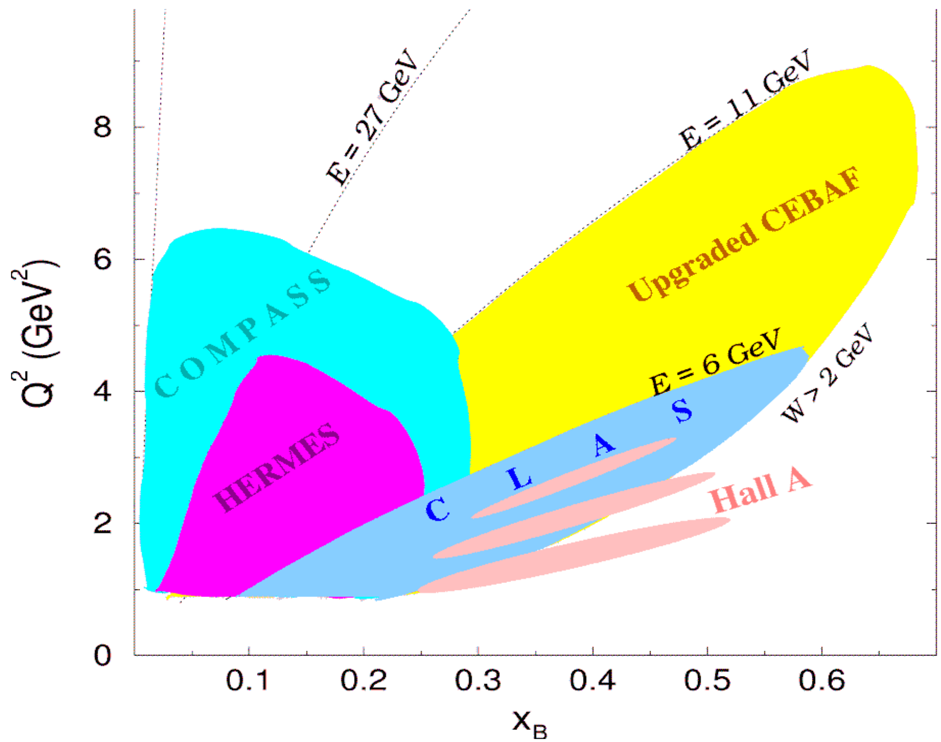
High luminosity & large acceptance:

Concurrent measurement of deeply virtual exclusive, semi-inclusive, and inclusive processes

Design parameters of CLAS12

	Forward detector	Central detector
Angular range		
Tracks	$5-40^{\circ}$	$35-125^{\circ}$
Photons	$2.5-40^{\circ}$	n.a.
Resolution		
$\delta p/p$	$< 1\%$ @ 5 GeV/c	5% @ 1.5 GeV/c
$\delta\theta$	< 1 mr	$<$ 10-20 mr
$\delta\phi$	< 3 mr	< 5 mr
Photon detection		
Energy	> 0.15 GeV	n.a.
$\delta\theta$	4 mr @ 1 GeV	n.a.
Neutron detection		
Efficiency	< 0.7	under dev.
Particle ID		
e/π	Full range	n.a.
π/p	Full range	< 1.25 GeV/c
π/K	Full range	< 0.65 GeV/c
K/p	< 4 GeV/c	< 1 GeV/c
$\pi \rightarrow \gamma\gamma$	Full range	n.a.
$\eta \rightarrow \gamma\gamma$	Full range	n.a.

DVCS worldwide effort



CERN
COMPASS
p-DVCS: X-sec,BSA,BCA, tTSA,lTSA,DSA

DESY	
HERMES	***H1/ZEUS***
p-DVCS BSA,BCA, TTSA, LTSA,DSA	p-DVCS X-sec,BCA

JLAB	
Hall A	***Hall B***
p,n,d -DVCS: X-sec	p-DVCS: BSA,LTSA, DSA, X-sec Helium-4: BSA

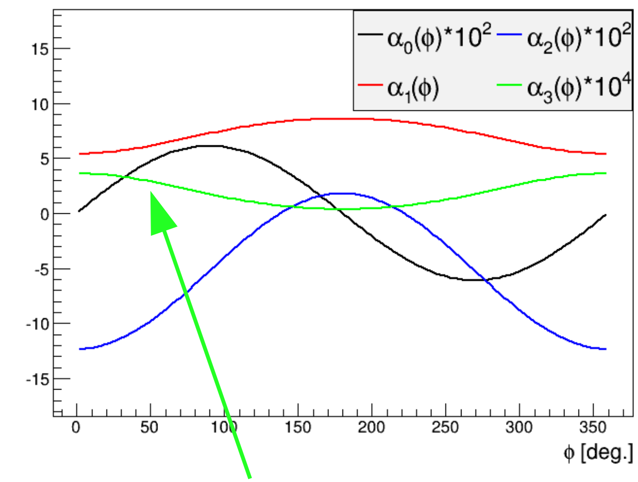
Promising future experiments with JLab upgrade and COMPASSII

He-4 CFF extraction

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

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

Expected to be small magnitude



Suppressed by 2 orders of magnitude

- Using the kinematical calculable factors (a, b, c, h and f) and the fitted coherent

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

→ Extracted the real and the imaginary parts of the Compton form factor from ALU @ 90° vs. <-t>

- We have "significant" trends with t and xB