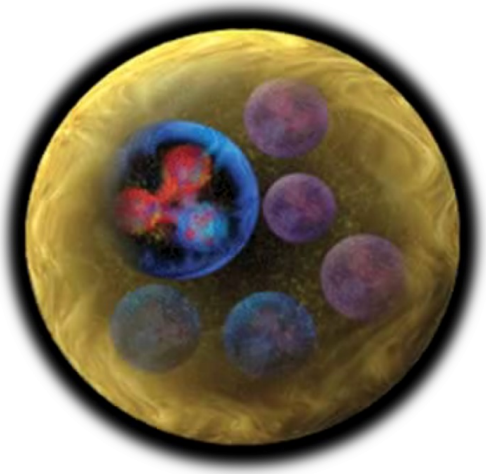
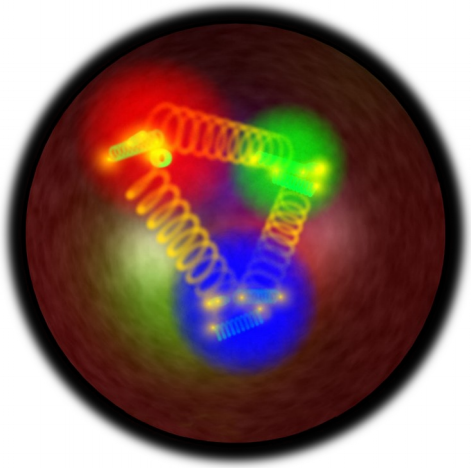
OLD DOMINION UNIVERSITY

Catching a Glimpse of the 3D Partonic Structure of Nucleons and Nuclei

S. Kuhn & M. Hattawy



- **Physics Motivations**
- **Recent Results.**
- **Future Measurements.**



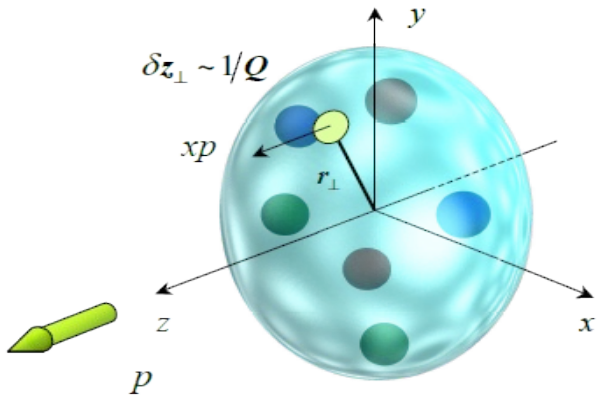
2019 Fall Meeting of the APS Division of Nuclear Physics, October 14-17, 2019

Generalized Parton Distributions

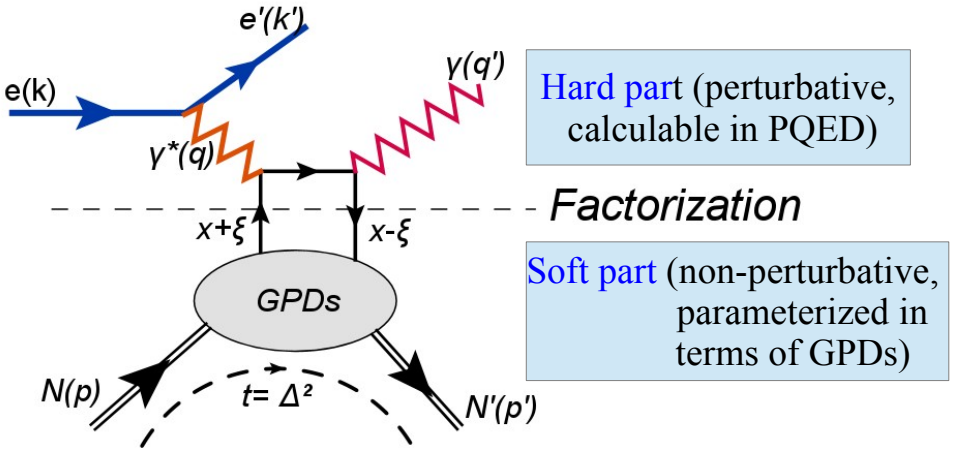
- Contain information on:

→ Correlation between quarks and anti-quarks

→ Correlation between longitudinal momentum and transverse spatial position of partons



- Can be accessed via hard exclusive processes such as deeply virtual Compton scattering (DVCS):



Hard part (perturbative, calculable in PQED)

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

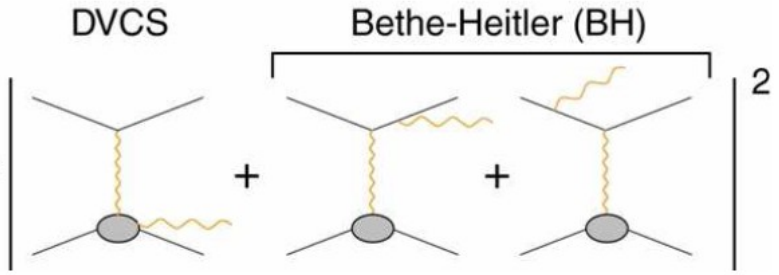
$$\xi \simeq x_B/(2-x_B) \qquad x_B = Q^2/2\mathrm{p.q}$$

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

* At leading order in $1/Q^2$ (twist-2) and in the coupling constant of QCD (α_s).

- **Experimentally,** the measured photon-electroproduction cross section (ep → epγ) is:

$$d\sigma \propto |\tau_{BH}|^2 + \underbrace{(\tau^*_{DVCS}\tau_{BH} + \tau^*_{BH}\tau_{DVCS})}_{\mathcal{I}} + |\tau_{DVCS}|^2$$



- The DVCS signal is enhanced by the interference with BH.

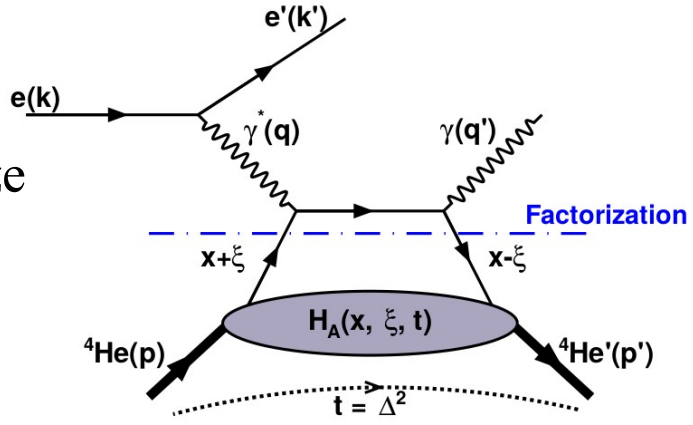
DVCS off Nuclei

Two DVCS channels are accessible with nuclear targets:

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

→ Study the partonic structure of the nucleus.

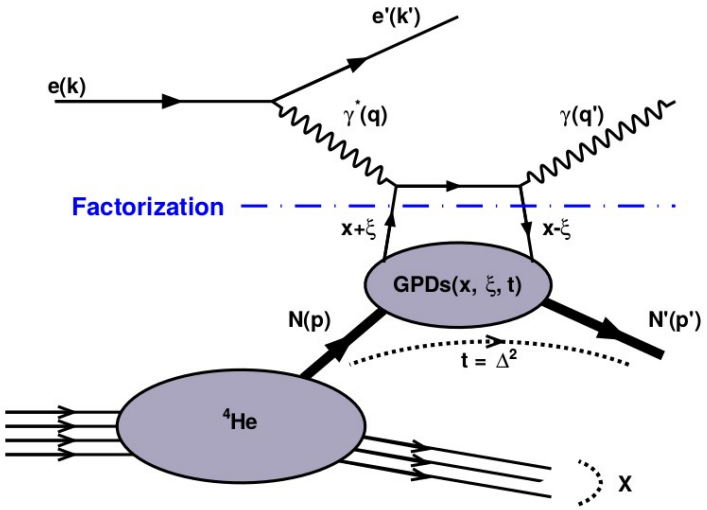
→ One chiral-even GPD ($\mathbf{H_A(x,\xi,t)}$) is needed to parametrize the structure of the spinless nuclei (^{4}He, ^{12}C, ^{16}O, ...).

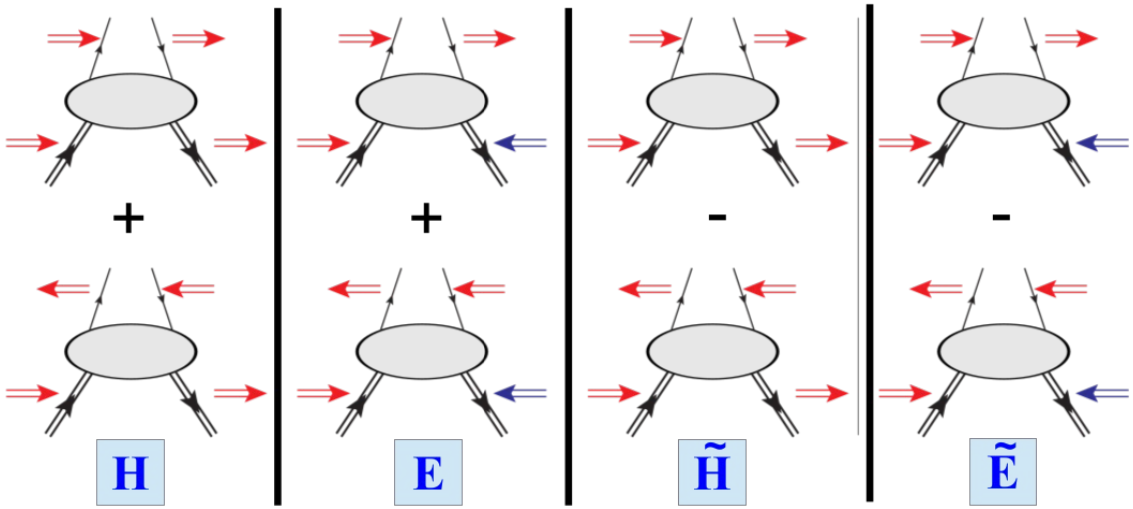


◊ **Incoherent DVCS: $e^- A \to e^- N \gamma X$**

→ 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).

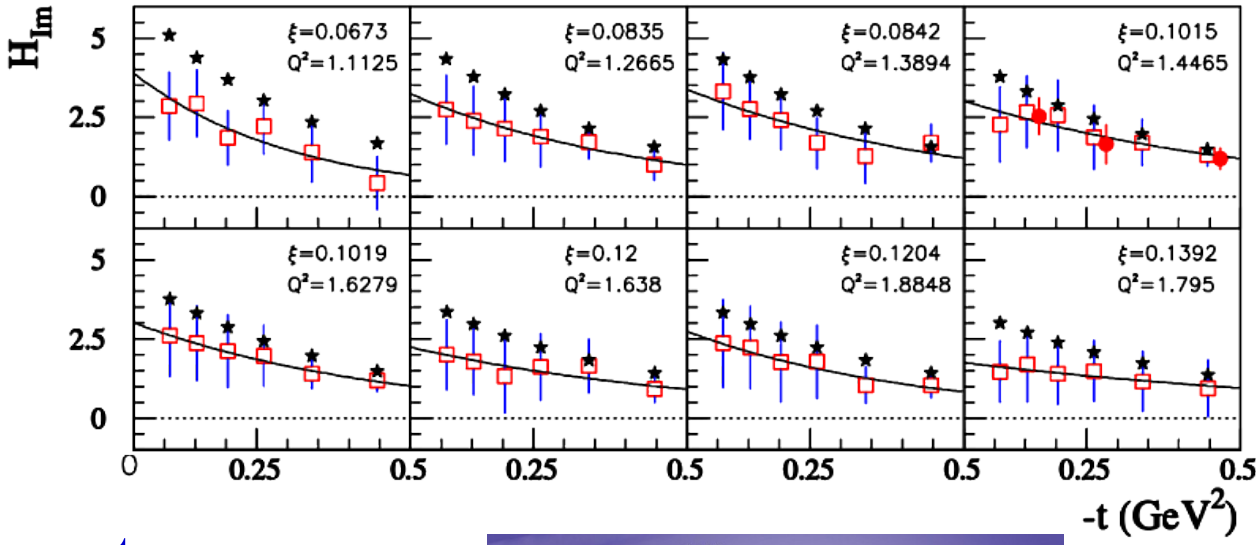




Proton Tomography via DVCS

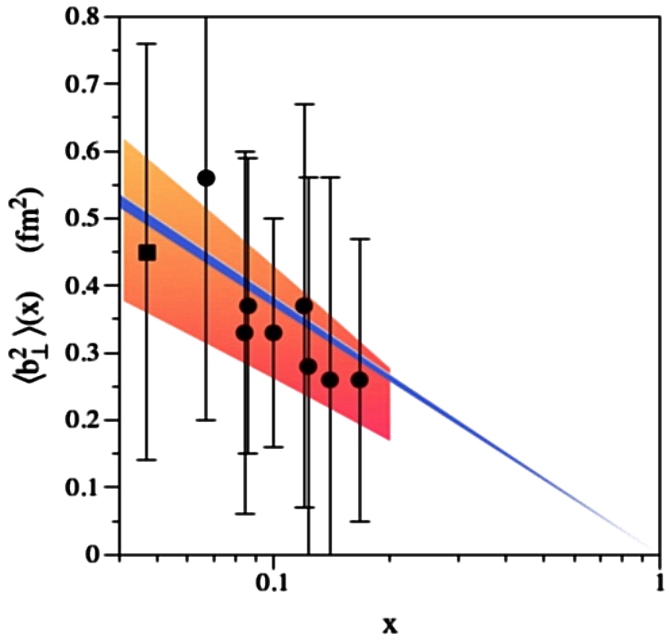
- Local fit of all the JLab data
  - Jlab Hall A (σ, Δσ)
  - CLAS (σ, Δσ, lTSA, DSA)

- Enough coverage to explore the t and x_B (→ξ) dependence of H_{Im}.

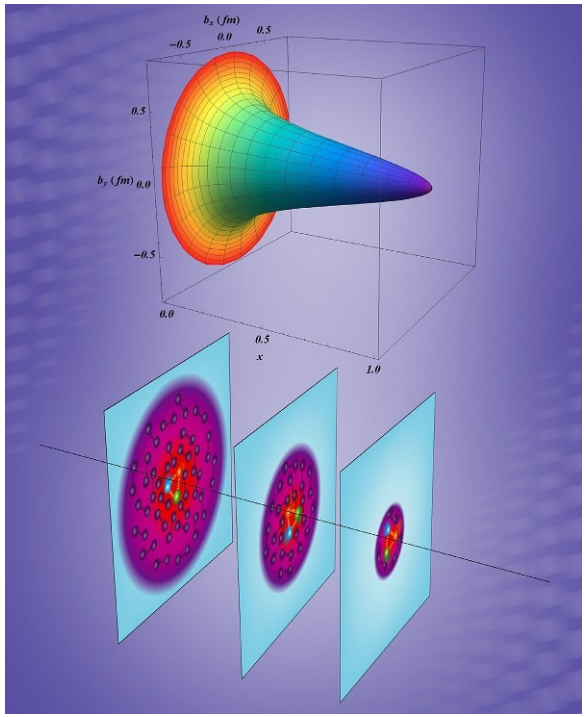


- Obtaining the tomography of the proton

– Represented is the mean square charge radius of the proton for slices of x.



- The nucleon size is shrinking with x.



[R. Dupré et al. Phys.Rev. D95 (2017) no.1, 011501]

CLAS6 Coherent ^{4}He DVCS

1. We select COHERENT events which have:

◊ Events with :
- Only one good electron in CLAS
- At least one high-energy photon (Eγ > 2 GeV)
- Only one ^{4}He in RTPC (p ~ 250-400 MeV).

◊ $Q^2 > 1$ GeV².

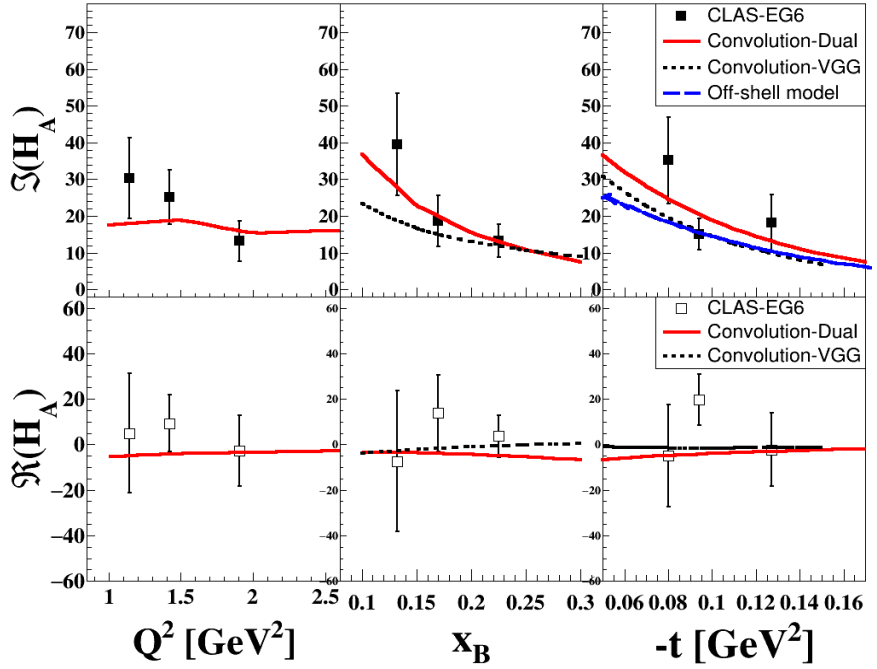
◊ Exclusivity cuts.

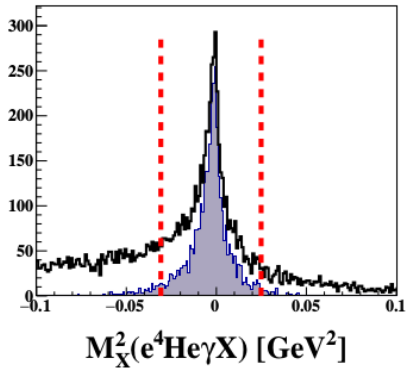
2. Beam-spin asymmetry:

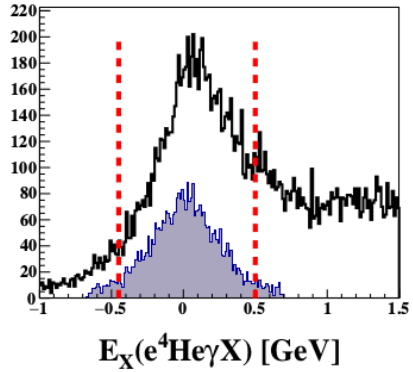
$$A_{LU} = \frac{d^4\sigma^+ - d^4\sigma^-}{d^4\sigma^+ + d^4\sigma^-} = \frac{1}{P_B}\frac{N^+ - N^-}{N^+ + N^-}$$

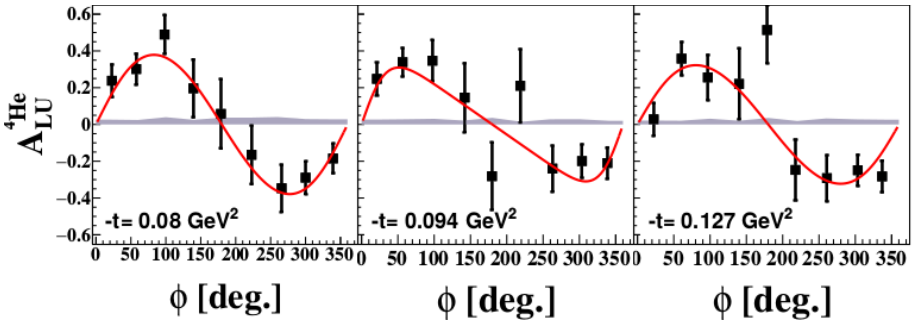
$$= \frac{\alpha_0(\phi)\,\Im m(\mathcal{H}_A)}{\alpha_1(\phi) + \alpha_2(\phi)\,\Re e(\mathcal{H}_A) + \alpha_3(\phi)\,\left(\Re e(\mathcal{H}_A)^2 + \Im m(\mathcal{H}_A)^2\right)}$$

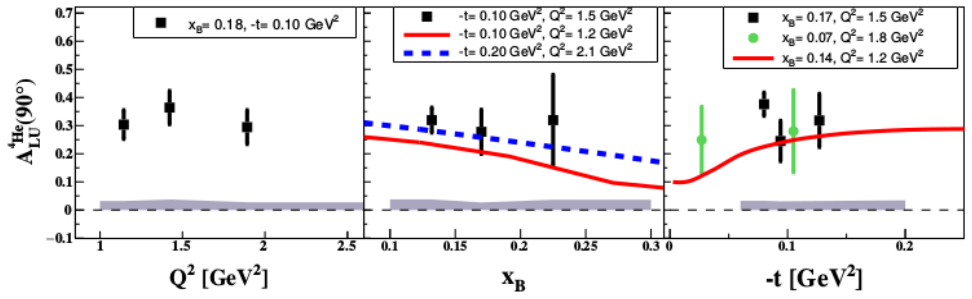
M. Hattawy et al., Phys. Rev. Lett. 119, 202004 (2017)











→A_{LU} in agreement with the available models.

→The first ever experimental extraction of the real and the imaginary parts of the ^{4}He CFF. Compatible with the calculations.

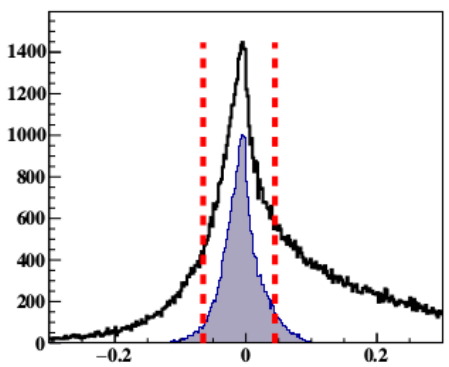
CLAS6 Incoherent p-DVCS off ^{4}He

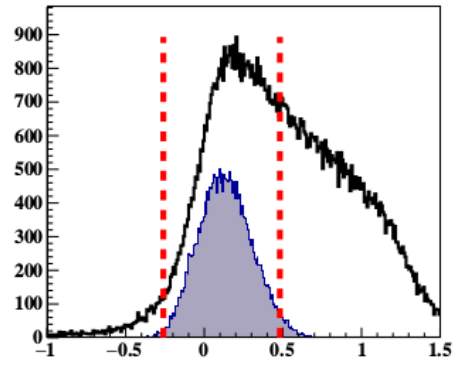
1. We select events which have:

◊ Events with :
- Only one good electron in CLAS
- At least one high-energy photon (Eγ > 2 GeV)
- Only one proton in CLAS.

◊ $Q^2 > 1$ GeV² and W> 2 GeV/c²

◊ Exclusivity cuts (3 sigmas).



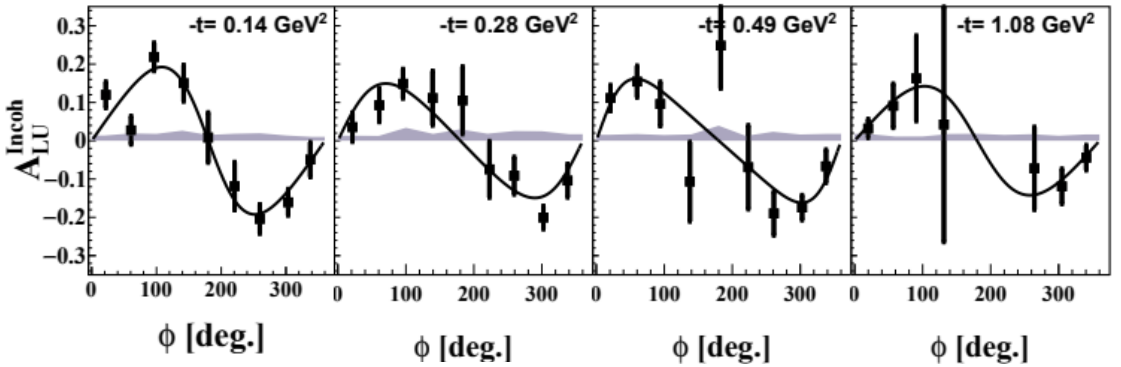


2. π^0 background subtraction (contaminations ~ 8 - 11%)

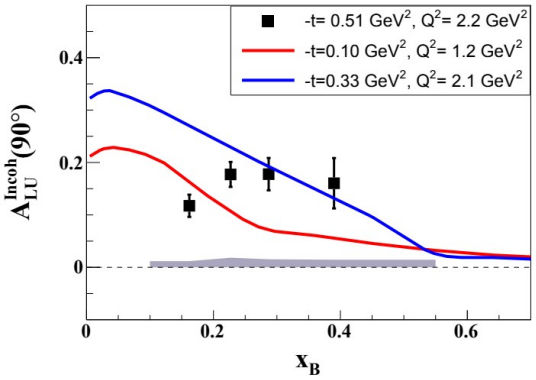
3. Beam-spin asymmetry:

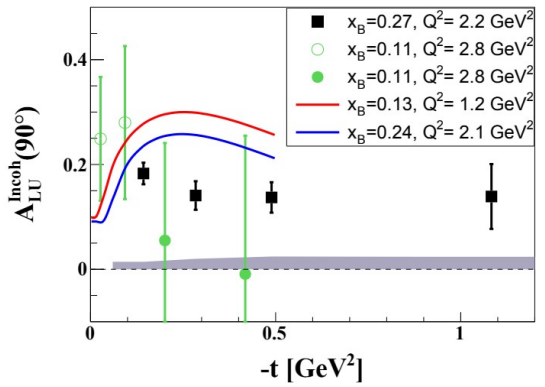
$$A_{LU} = \frac{d^4\sigma^+ - d^4\sigma^-}{d^4\sigma^+ + d^4\sigma^-} = \frac{1}{P_B}\frac{N^+ - N^-}{N^+ + N^-}$$

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



- 2D bins due to limited statistics
- Fits in the form: $\frac{\alpha * \sin(\phi)}{(1 + \beta * \cos(\phi))}$





[M. Hattawy et al., Phys. Rev. Lett. 123, 032502, 2019]

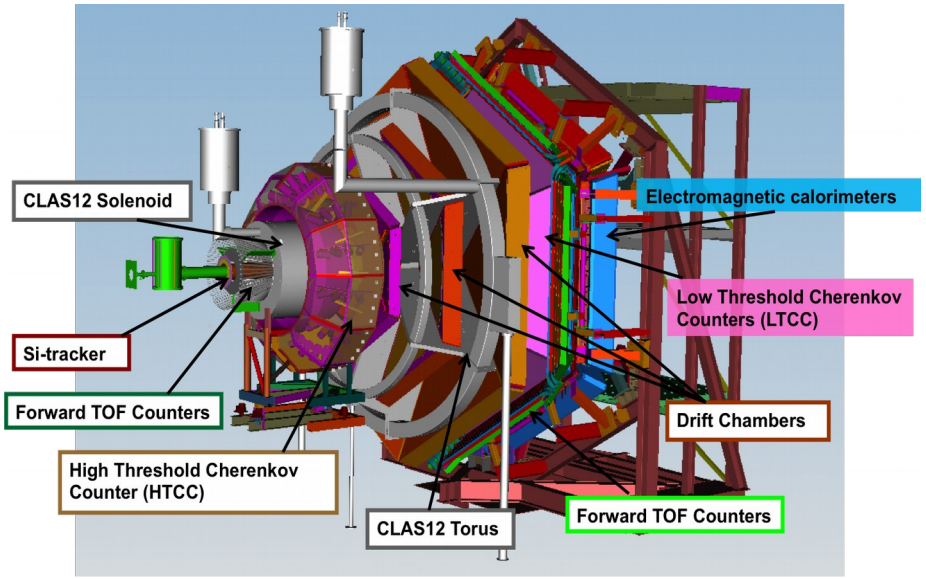
CLAS12-ALERT Program

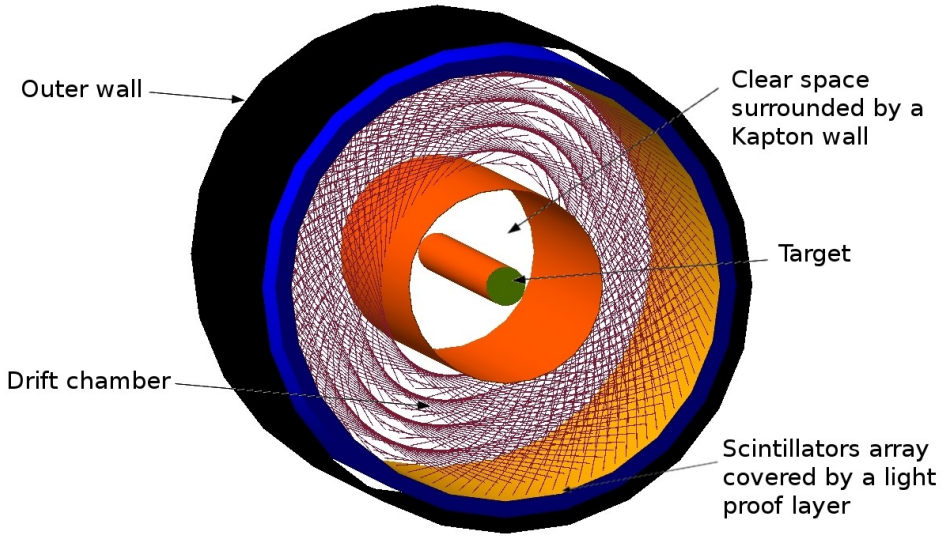
- CLAS12 experimental apparatus:
  - High luminosity & large acceptance.
  - Measurements of deeply virtual exclusive, semi-inclusive, and inclusive processes.
- We proposed to measure with CLAS12:
  - Partonic Structure of Light Nuclei.
  - Tagged EMC Measurements on Light Nuclei.
  - Spectator-Tagged DVCS Off Light Nuclei.
  - Other Physics Opportunities.
- The momentum threshold of the CLAS12 inner tracker is too high to be used for our measurements.
- Approved experimental setup:
  - CLAS12 forward detectors.
  - A Low Eenergy Recoil Tracker (ALERT) in place of CLAS12 Central detector (SVT & MVT).
- CLAS12-ALERT setup will allow higher statistics and wider kinematical coverage.

30/20 days on ^{4}He/D

5 days on H_2

with $L = (3\text{-}6) \cdot 10^{34}$ cm^{-2} sec^{-1}





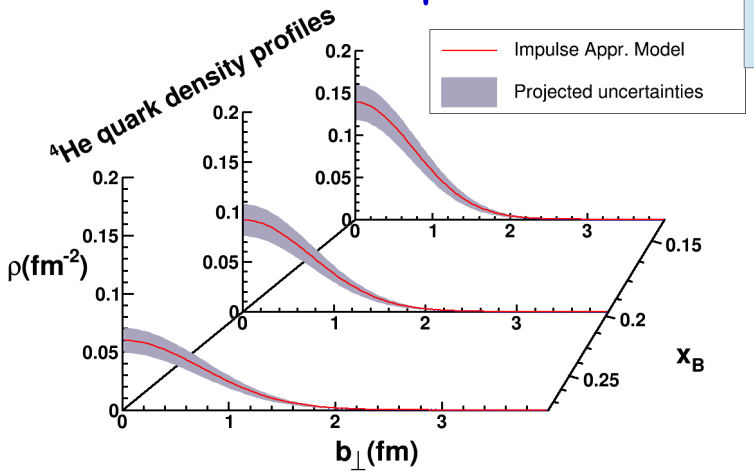
CLAS12-ALERT Proposals

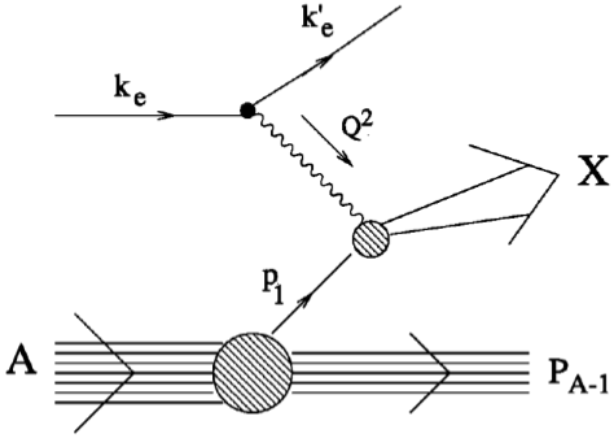
1. Compare the quark and gluon 3D structure of the Helium nucleus

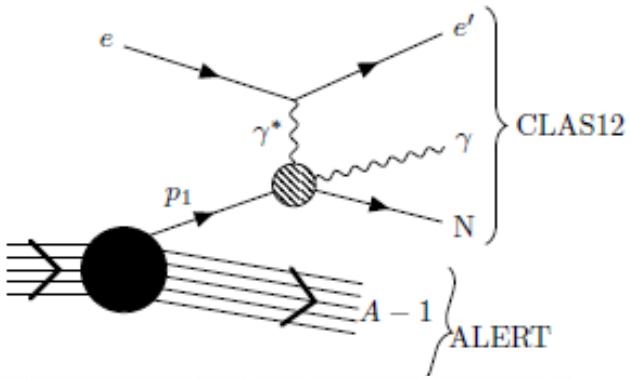
2. Tagged DIS test for:
- FSI models over wide momentum and angle ranges.
- EMC effect models: x/Q^2 scaling.
- d/u ratio changes in medium.

3. Tagged DVCS for:
- Bound proton DVCS
  (Fully detected ep^3H final state)
- Neutron DVCS:
  - $e\,^3He(n)$ / $ep(n)$ final states

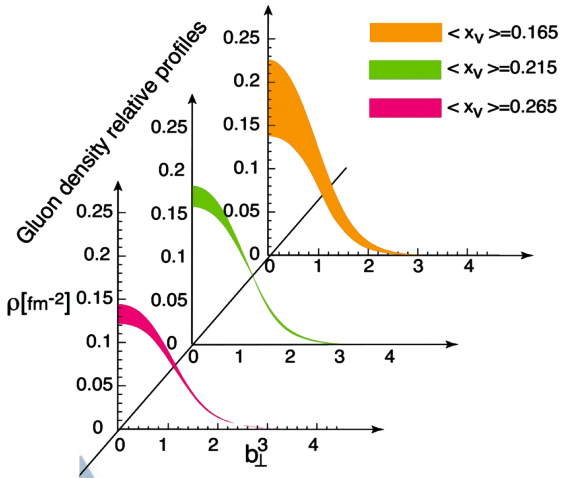
$e\,^4He \rightarrow e`\,^4He`\gamma$:

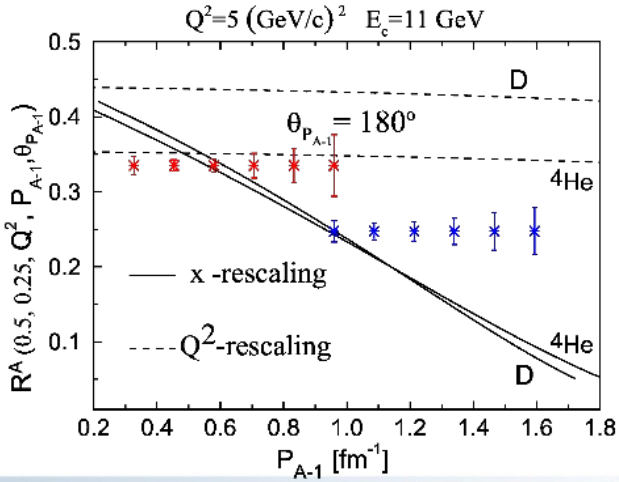


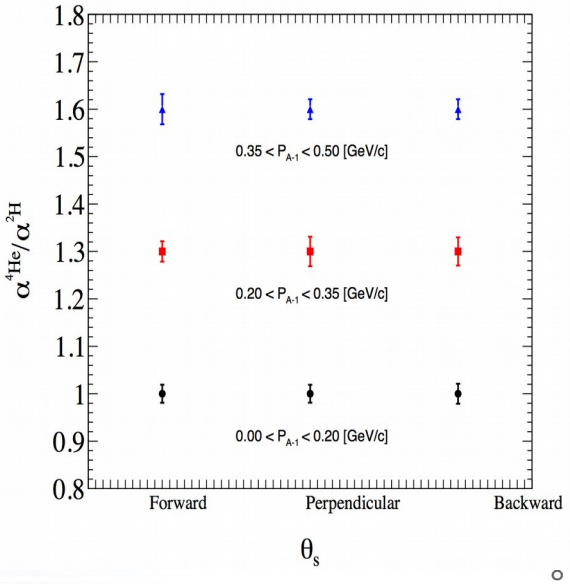




$e\,^4He \rightarrow e`\,^4He`\varphi\,(\rightarrow K^+K^-)$:







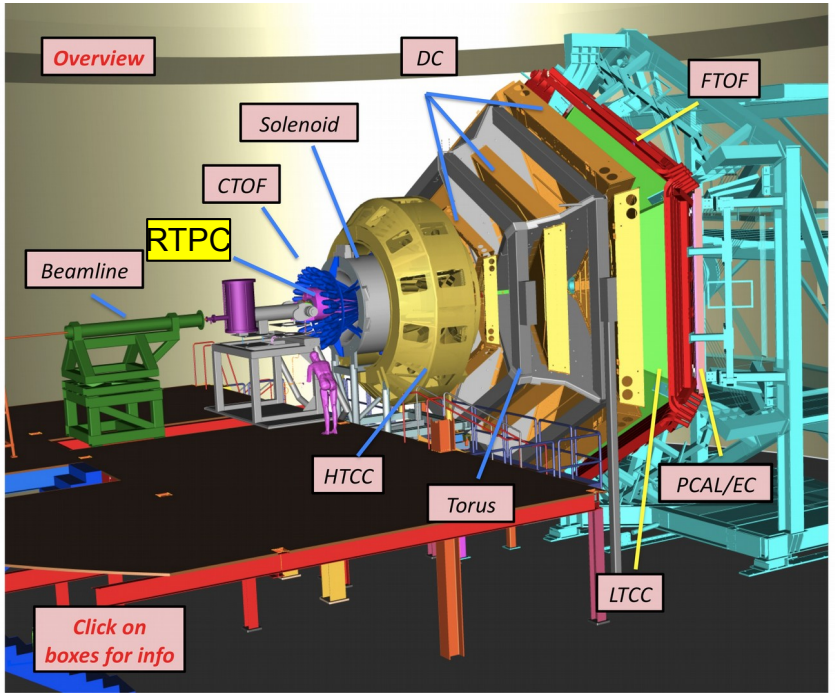
ODU

nDVCS with BONuS12

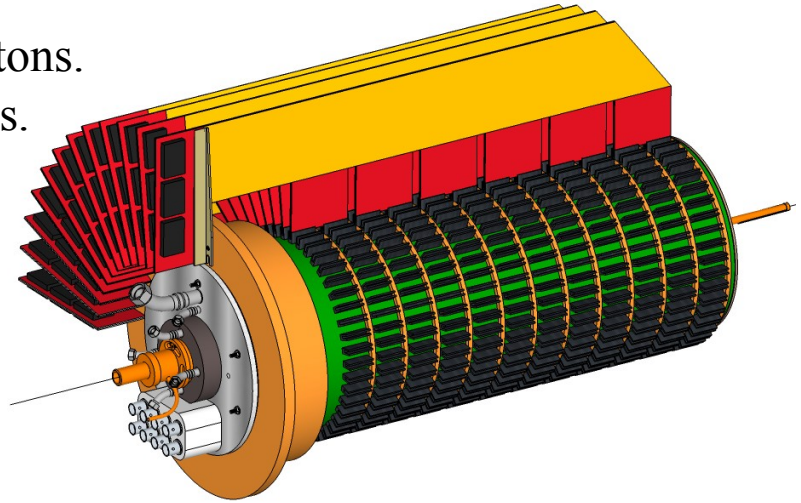
11 GeV

$e^- D \rightarrow e\ p\ \gamma\ (n)$

- **CLAS12 Forward Detector:**
  - → Superconducting Torus magnet.
  - → 6 independent sectors:
    - → HTCC: identifying π^- (p >5.0 GeV/c).
    - → 3 regions of DCs: tracking charged particles.
    - → LTCC: π^- identification (p >3.0 GeV/c).
    - → FTOF Counters: identifying hadrons.
    - → PCAL and Ecs: detecting γ, e^- and n [5°,40°].



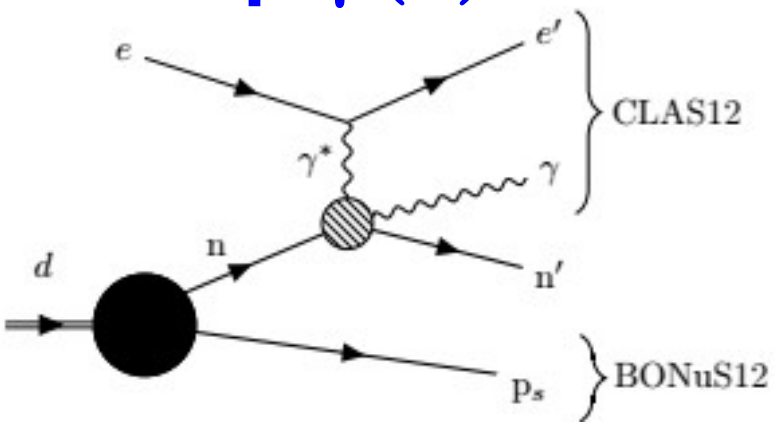
- **Central Detector:**
  - **Target:** D gas @ 7.5 atm, 293 K
  - **BONuS12 RTPC:** Detects low energy spectator protons.
  - **Solenoid:** - Shields the detectors from Møller electrons.
    - Enables tracking in the RTPC.
  - **CTOF, CND, and FMT**

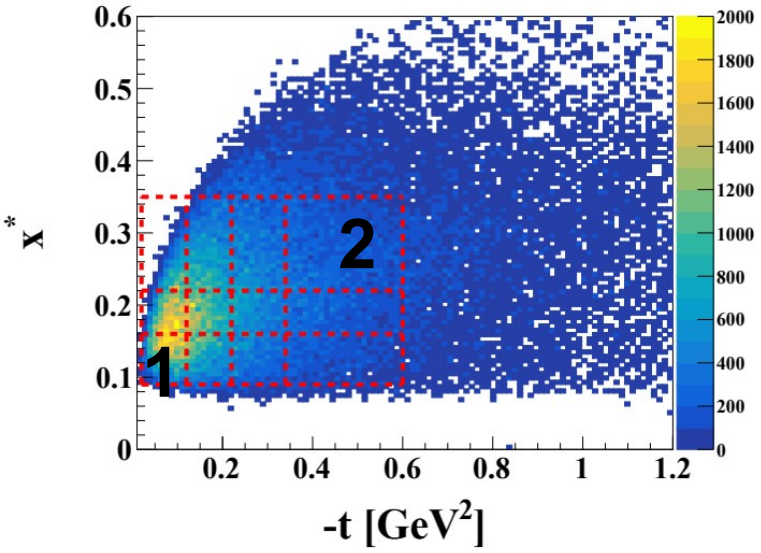


35 days on D
5 days on H_2
with $L = 2 \cdot 10^{34}\ cm^{-2}\ sec^{-1}$

Tagged-proton nDVCS

$e^- D \rightarrow e^- p \gamma (n)$

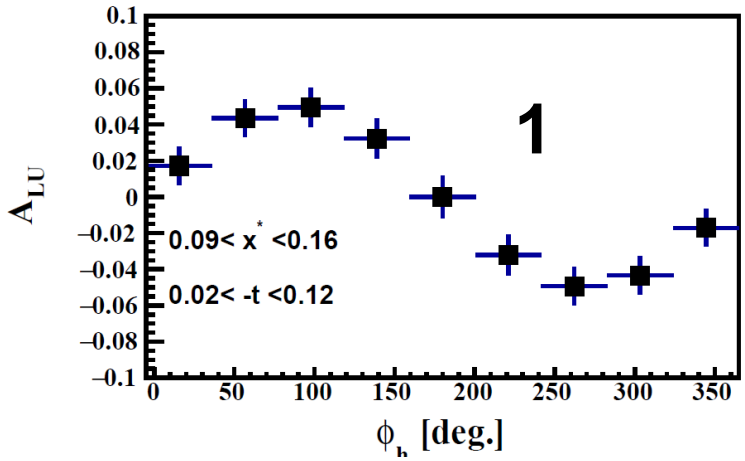


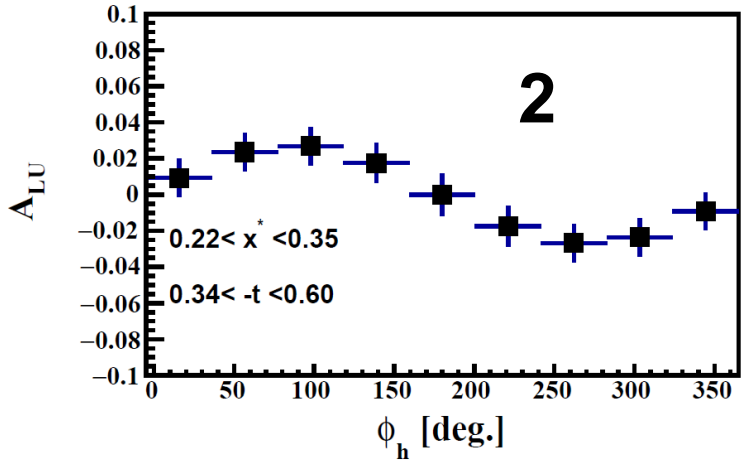


$$x^* = \frac{Q^2}{2M_N E y(2-\alpha_{sp})} = \frac{x_B}{2-\alpha_{sp}},$$

$$\alpha_{sp} = \frac{E_s - p_s^z}{M_N}$$

- ◊ 9M expected events.
- ◊ Total of 108 bins in x* vs. t vs. phi
- ◊ 20% conservative sys. Uncertainities.
- ◊ **Exploring the neutron's CFF via the BSA.**
- ◊ **Compare the nDVCS to Free proton DVCS.**

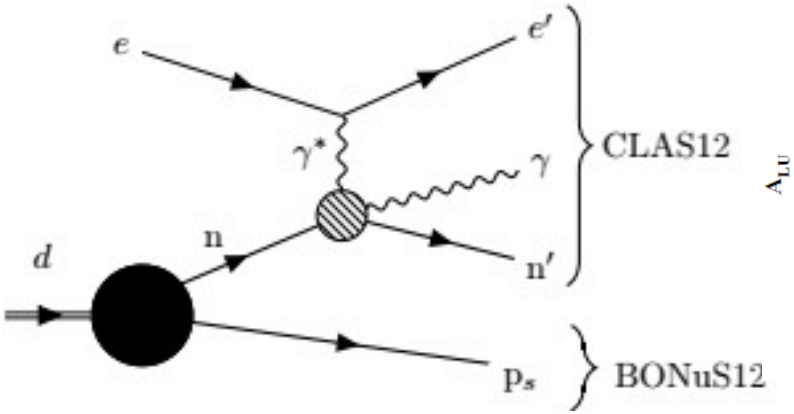


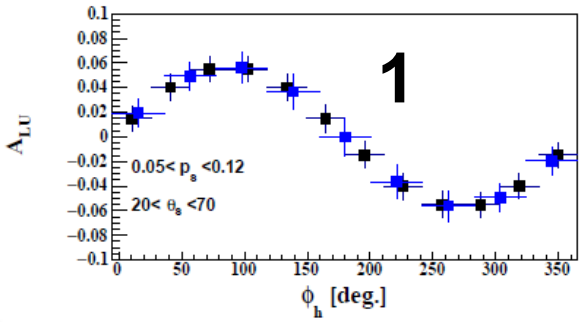


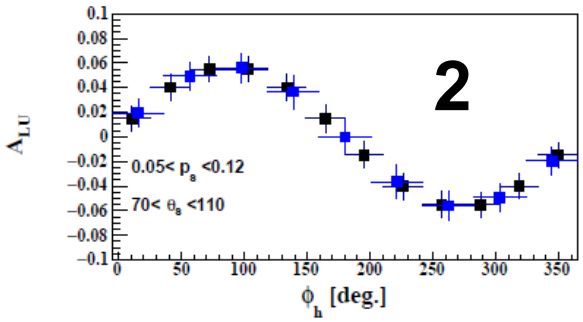
Fully exclusive nDVCS

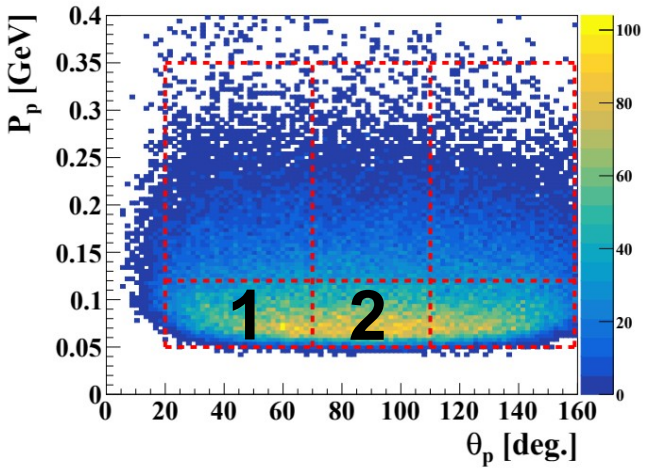
$e^- D \rightarrow e^- n \gamma p$

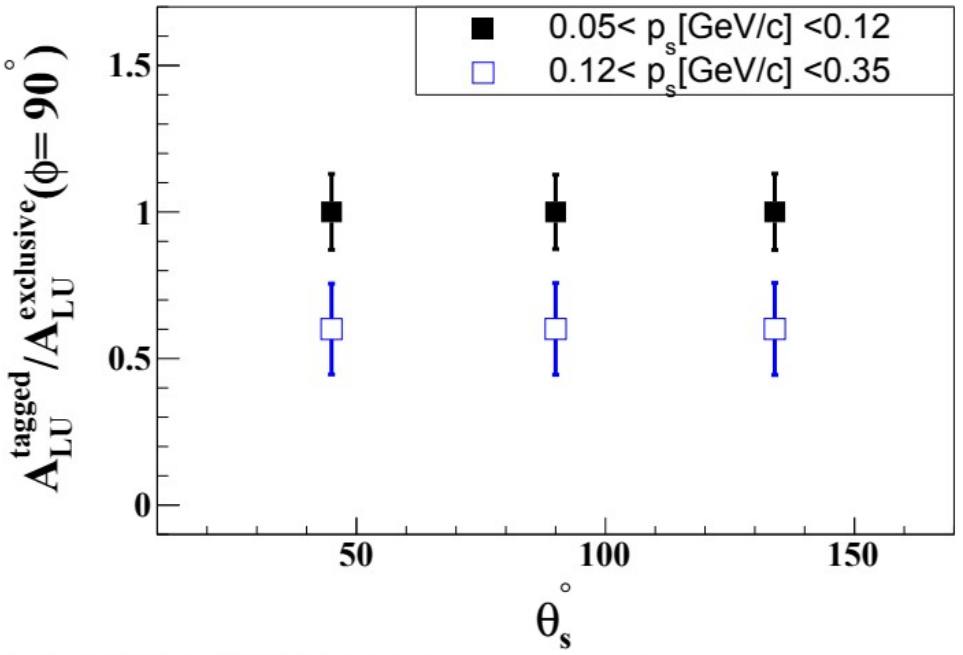
◊ 9M tagged nDVCS events (**black**)
~ 0.8M fully exclusive nDVCS (**blue**).
◊ **Exploring the Fermi motion and FSI effects on BSA.**











Conclusions & Perspectives

◊ **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 performed the first ever model independent extraction of the ^{4}He CFF.
→ The bound proton has shown a different trend compared to the free one indicating the medium modifications of the GPDs and opening up new opportunities to study the EMC effect.

◊ **CLAS12-ALERT** will provide wider kinematical coverage and better statistics that will:
→ Allow performing ^{4}He tomography in terms of quarks and gluons.
→ Allow comparing the gluon radius to the charge radius.
→ Use tagging methods to study EMC effect via DIS measurements.
→ Use Tagged-DVCS techniques to study in-medium nucleon interpretations.
→ Reinforce EIC physics program by proving their usefulness in the valence region.

◊ **CLAS12-RGF** we intend to measure the neutron DVCS beam-spin asymmetry by:
→ Tagging the spectator slow-recoiling proton
→ Measuring the fully exclusive neutron DVCS channel.

Thank you!