DVCS with nuclear targets

Vadim Guzey

Petersburg Nuclear Physics Institute (PNPI),
National Research Center "Kurchatov Institute", Gatchina, Russia

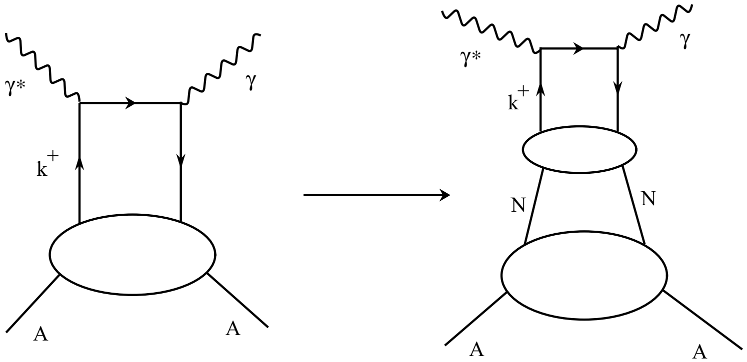
Outline:

1. Enhancement of coherent nuclear DVCS at small t
2. Coherent/incoherent interplay
3. Medium-modified GPDs from quasi-elastic nuclear DVCS
4. Present experiments on nuclear DVCS
5. Tagged nuclear DVCS on Deuterium

DVCS workshop, Bochum, Germany, February 10-12, 2014

Nuclear GPDs in impulse approximation

The nucleus consists of unmodified, uncorrelated, slowly moving nucleons:
nuclear GPDs given by the convolution with free proton and neutron GPDs:



$$H_A^q(x, \xi_A, Q^2, t) = \left|\frac{dx_N}{dx}\right| \Big[Z \Big(H^{q/p}(x_N, \xi_N, Q^2, t) + \frac{t}{4m_N^2} E^{q/p}(x_N, \xi_N, Q^2, t) \Big) + N \Big(H^{q/n}(x_N, \xi_N, Q^2, t) + \frac{t}{4m_N^2} E^{q/n}(x_N, \xi_N, Q^2, t) \Big) \Big] F_A(t), \tag{1}$$

VG, Strikman, PRC68 (2003) 015204; VG PRC78 (2008) 025211
Kirchner, Mueller, EPJ32 (2003) 347

The only nuclear effects included: presence of Z protons and N neutrons and nuclear coherence given by the nuclear form factor $F_A(t)$.

Impulse approximation:

- preserves the baryon number and momentum sum rules in the forward limit
- violates polynomiality (for this, one needs full relativistic treatment of nuclei)
- corrections due to nuclear binding (nucleon motion) can be added and are small.

Nuclear binding for He-3: Scopetta, PRC70 (2004) 015205 and PRC79 (2009) 025207

Coherent nuclear DVCS in impulse approximation

At small |t|, the fact that we scatter on both protons and neutrons enhances the nuclear DVCS amplitude by factor A.

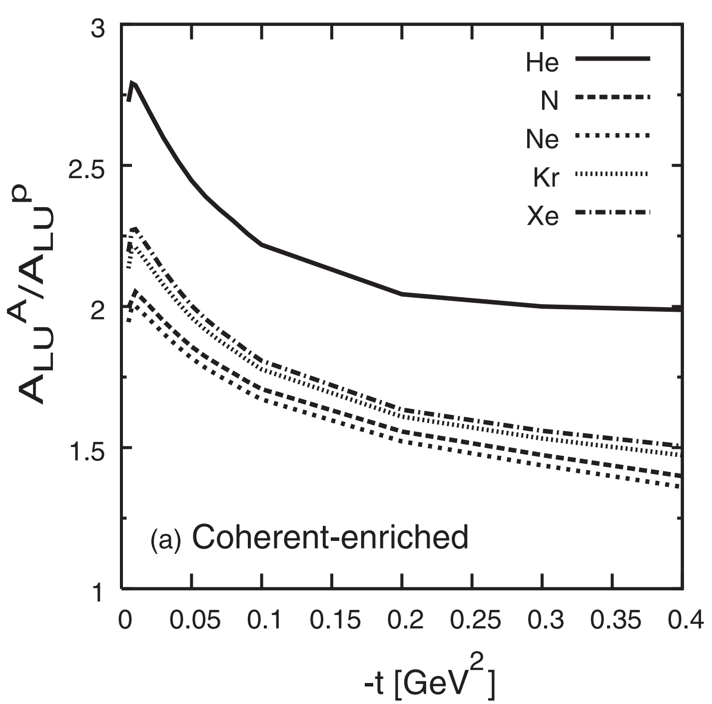
$$\mathcal{T}^A_{\mathrm{DVCS}} = A F_A(t) \mathcal{T}^N_{\mathrm{DVCS}}$$

$$\mathcal{T}^A_{\mathrm{BH}} = Z F_A(t) \mathcal{T}^N_{\mathrm{BH}}$$

The BH amplitude is enhanced only by factor Z.

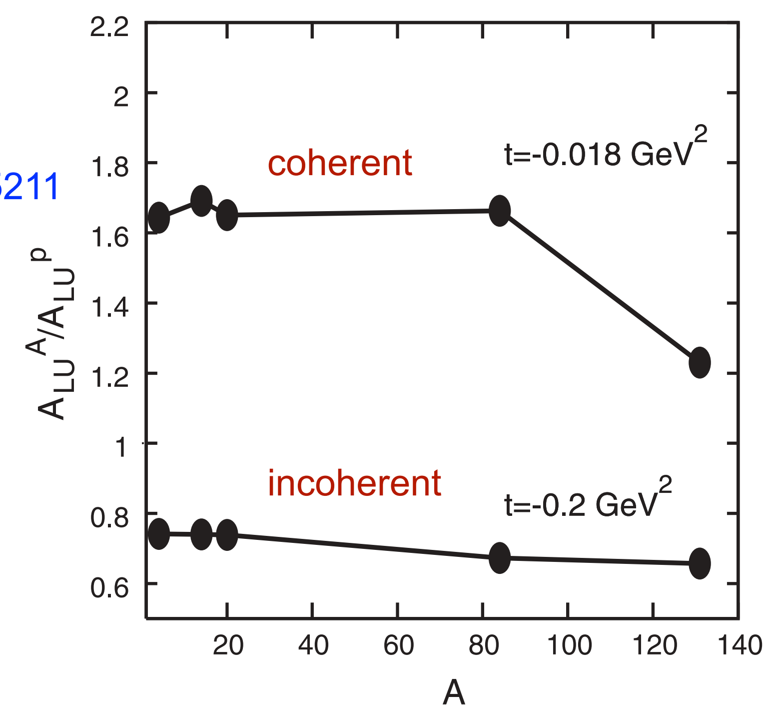
Model-independent statement: DVCS asymmetries in coherent nuclear DVCS are enhanced by factor **~2**.

$$A^A_{\mathrm{LU}}(\phi) \sim \frac{A}{Z} A^p_{\mathrm{LU}}(\phi)$$



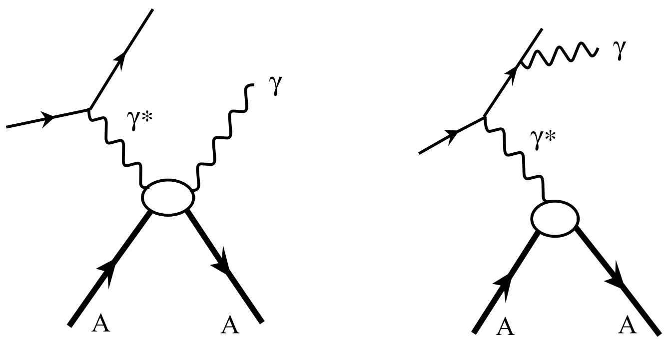
VG PRC78 (2008) 025211

Q^2=1.7 GeV^2
x_B=0.065
ϕ=90°

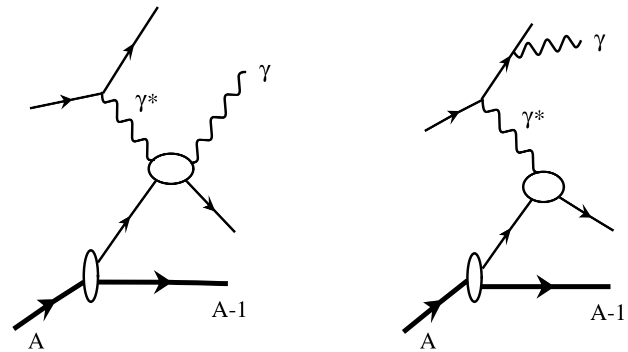


Interplay of coherent and incoherent nuclear DVCS

When final nucleus is not detected, both coherent (nucleus intact) and incoherent (nucleus breaks up) contribute:



coherent DVCS and BH



incoherent DVCS and BH

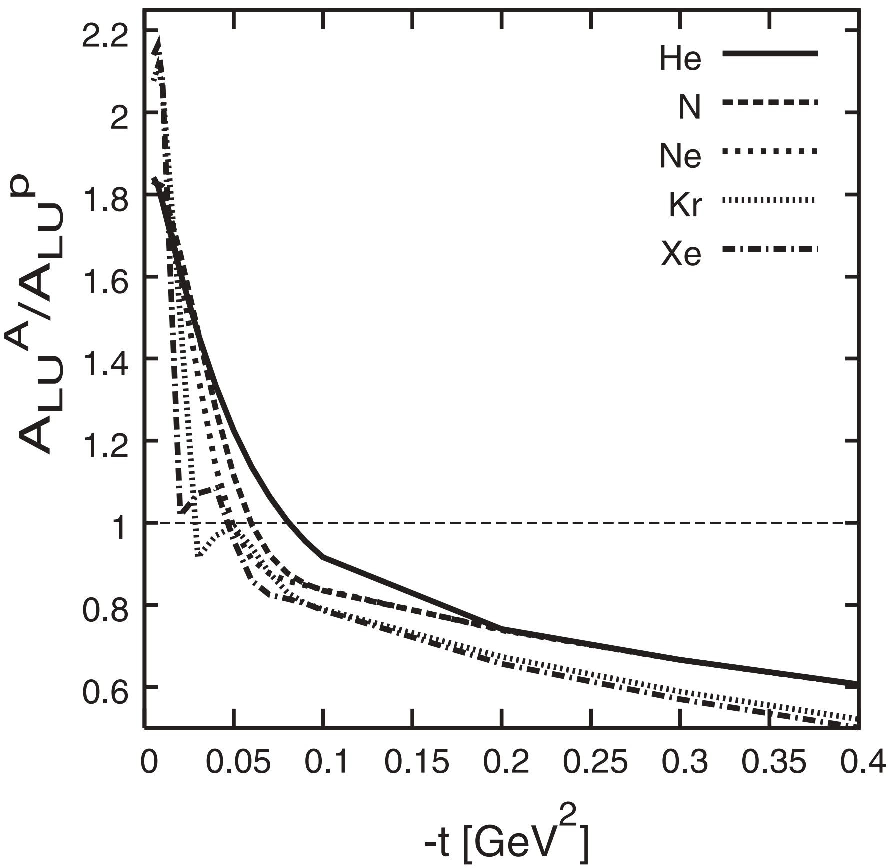
Coherent contribution dominates at small |t|; incoherent – at large |t|:

$$|\mathcal{T}^A_{\rm DVCS}|^2 = (A-1)^2 F_A^2(t) |\mathcal{T}^N_{\rm DVCS}|^2 + Z|\mathcal{T}^p_{\rm DVCS}|^2 + N|\mathcal{T}^n_{\rm DVCS}|^2$$

$$|\mathcal{T}^A_{\rm BH}|^2 = Z(Z-1) F_A^2(t) |\mathcal{T}^N_{\rm BH}|^2 + Z|\mathcal{T}^p_{\rm BH}|^2 + N|\mathcal{T}^n_{\rm BH}|^2$$

$$\mathcal{I}^A = Z(A-1) F_A^2(t) \mathcal{T}^N + Z\mathcal{I}^p + N\mathcal{I}^n$$

Interplay of coherent and incoherent nuclear DVCS (2)



Q^2=1.7 GeV^2, x_B=0.065, ϕ=90°

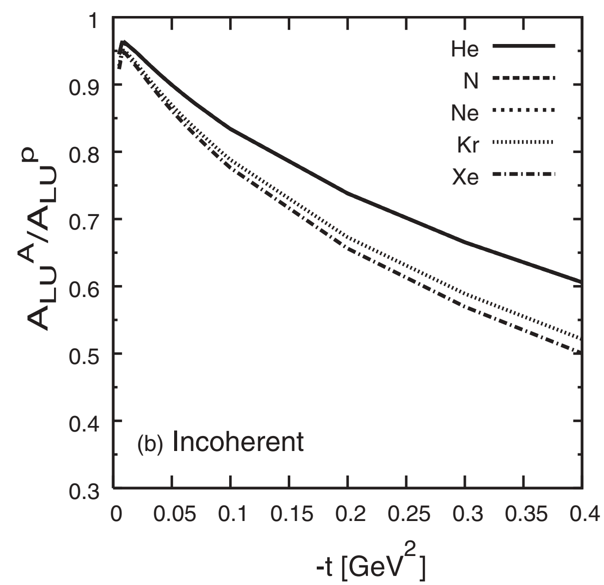
Combinatoric enhancement at small |t| followed by some suppression at large |t| due to neutron contribution.

$$|\mathcal{T}^A_{\rm DVCS}|^2 = (A-1)^2 F_A^2(t)|\mathcal{T}^N_{\rm DVCS}|^2 + Z|\mathcal{T}^p_{\rm DVCS}|^2 + N|\mathcal{T}^n_{\rm DVCS}|^2$$

$$|\mathcal{T}^A_{\rm BH}|^2 = Z(Z-1)F_A^2(t)|\mathcal{T}^N_{\rm BH}|^2 + Z|\mathcal{T}^p_{\rm BH}|^2 + N|\mathcal{T}^n_{\rm BH}|^2$$

$$\mathcal{I}^A = Z(A-1)F_A^2(t)\mathcal{T}^N + Z\mathcal{I}^p + N\mathcal{I}^n$$

At large |t|, one is sensitive to neutron contribution →



VG PRC78 (2008) 025211

Medium-modified GPDs

On top of impulse approximation, model medium modifications of bound nucleon GPDs.

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

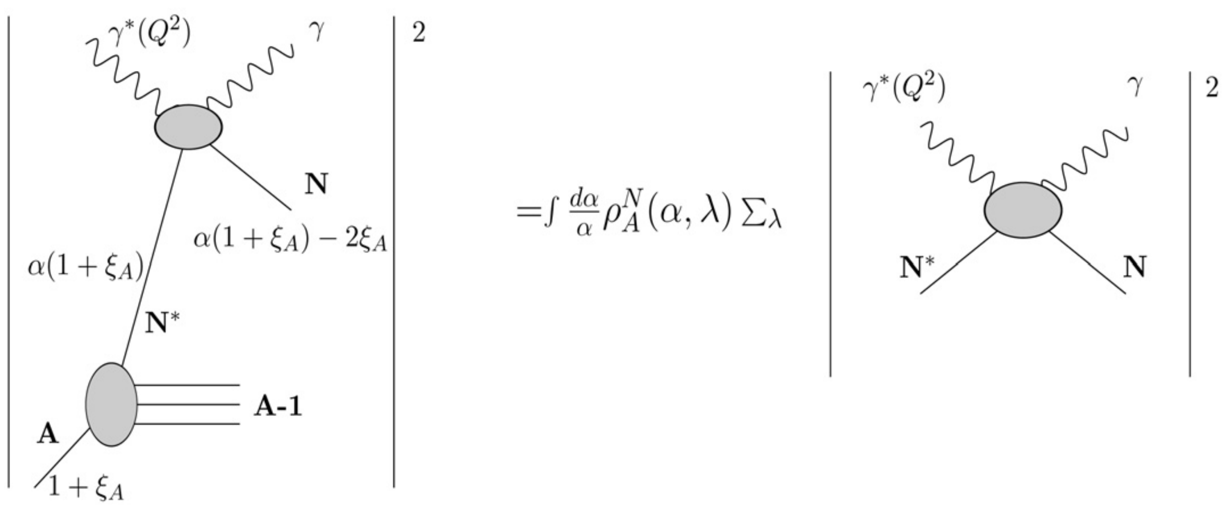
Assume that GPDs are modified in proportion to bound proton elastic form factors:
VG, Thomas, Tsushima, PLB673 (2009) 9

$$E^{q/p^*}(x,\xi,t,Q^2) = \frac{F_2^{p^*}(t)}{F_2^p(t)} E^q(x,\xi,t,Q^2),$$

$$\tilde{H}^{q/p^*}(x,\xi,t,Q^2) = \frac{G_1^*(t)}{G_1(t)} \tilde{H}^q(x,\xi,t,Q^2),$$

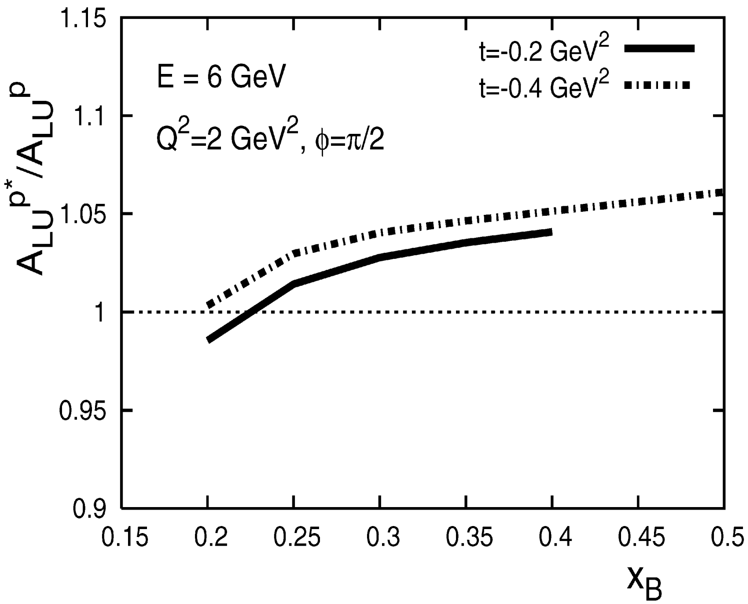
Bound proton FFs modeled using Quark-Meson Coupling (QMC) model consistent with analysis of polarization transfer in ${}^4\mathrm{He}(\vec{e},e'\vec{p})^3\mathrm{He}$ measured at Hall A, Strauch *et al.*, PRL91 (2003) 052301

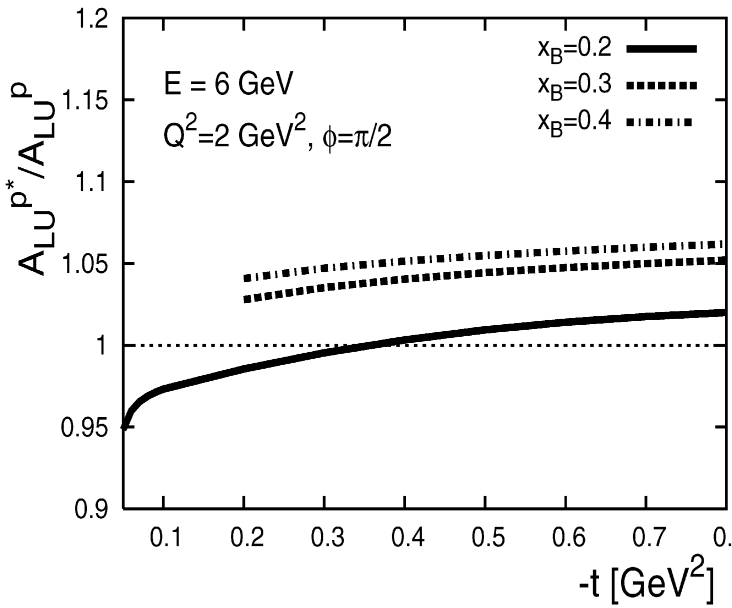
Designed to probe *possible* medium-modifications on bound proton GPDs in quasi-elastic nuclear DVCS:



Medium-modified GPDs (2)

Predictions for He4 in JLab kinematics,
to be tested by completed CLAS experiment

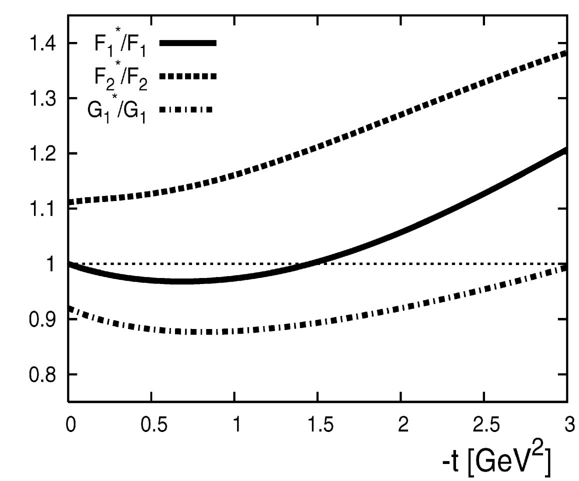




We predict **~5%** enhancement at not too small |t|.

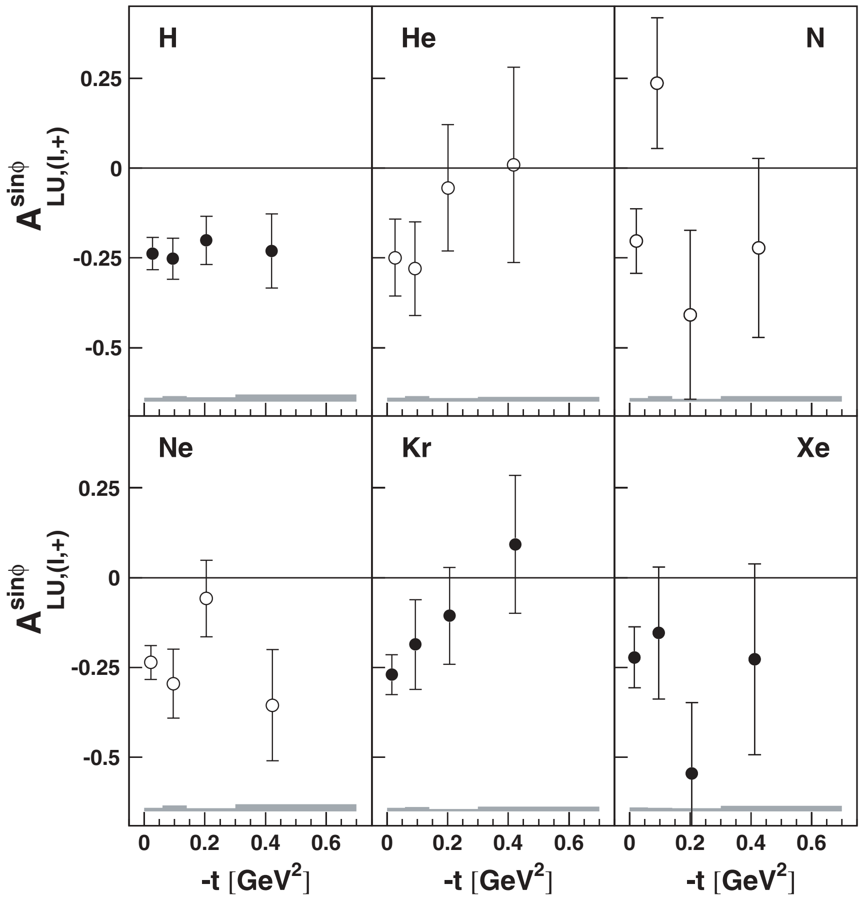
The result can be understood by analyzing medium-modifications of bound proton elastic form factors:

$$A_{\mathrm{LU}}(\phi) \propto \mathrm{Im}\Big(F_1^{p^*}\mathcal{H}^{p^*} + \frac{x_B}{2-x_B}\big(F_1^{p^*}+F_2^{p^*}\big)\tilde{\mathcal{H}}^{p^*} - \frac{t}{4m_N^2}F_2^{p^*}\mathcal{E}^{p^*}\Big) \Big/ f\big(F_1^{p^*}, F_2^{p^*}\big)\sin\phi,$$



Nuclear DVCS: HERMES

Airapetian *et al*. (Hermes) PRC81 (2010) 035202



- The recoiling system is NOT detected:
  exclusivity via cut on missing mass

- Coherent and incoherent separated using
  trick related to t-dependence: approximate

- Main conclusions:
  - no A-dependence
  - for the ratio of asymmetries:

$$R_{\mathrm{LU}} = A^{\sin\phi}_{\mathrm{LU,(I,+),A}} / A^{\sin\phi}_{\mathrm{LU,I,H}}$$

$$R^{\mathrm{coh}}_{\mathrm{LU}} = 0.91 \pm 0.19$$

$$R^{\mathrm{incoh}}_{\mathrm{LU}} = 0.93 \pm 0.23$$

Possible reasons for absence of A-enhancement:

- over-subtraction of incoherent DVCS
- overestimated DVCS on proton (by ~15%) → talk on G. Schnell on Monday
- large theoretical corrections to impulse approximation (FSI for closure approximation, some nuclear shadowing)

Nuclear DVCS on ^{4}He at CLAS at 6 GeV

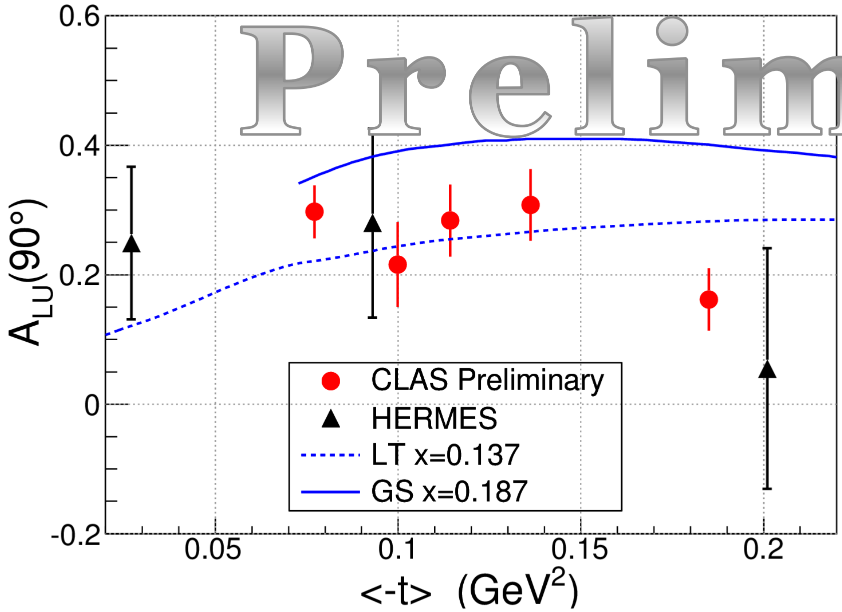
Results: BSA and Generalized EMC Ratio

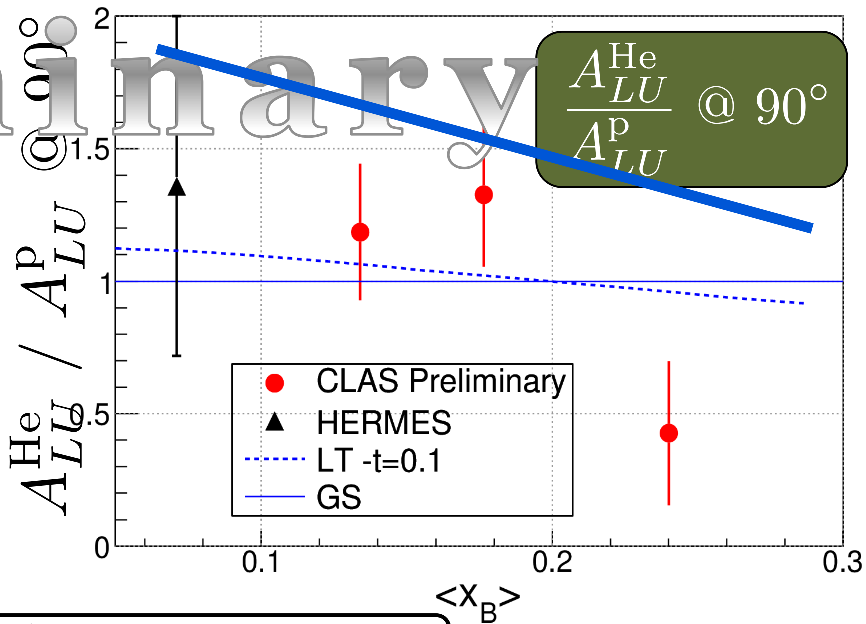
Beam Spin Asymmetry @ 90

- Significantly non-zero and relatively flat ~25%
- Consistent with HERMES ((eγX, no ^{4}He detection)
  - A. Airapetian et al, Phys. Rev. C 81 (2010) 035202

Generalized EMC Ratio

- Binning chosen to match published e1dvcs kinematics for the denominator
- We only cover eg1dvcs's lowest t-bin
- A hint of the predicted behavior



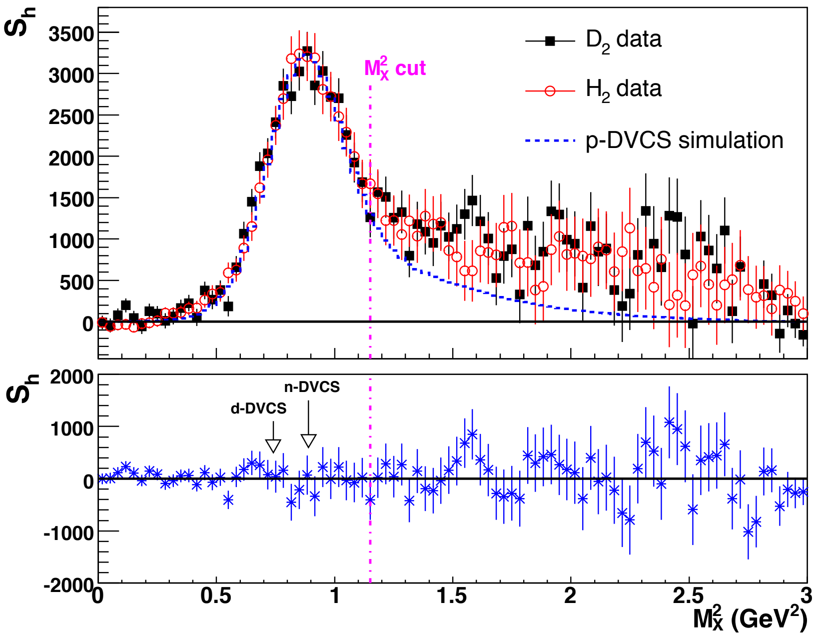


GS: Guzey & Strikman, Phys. Rev. C 68 (2003) 015204
LT: Liuti & Taneja, Phys. Rev. C 72 (2005) 032201

Nuclear DVCS on D: Hall A at JLab

Mazouz *et al.* (Hall A) PRL99 (2007) 242501

Helicity signal



- Exclusivity via cut on missing mass

- $S_h(D) - S_h(p)$ = coherent deuteron + incoherent neutron:

$$\frac{d^5\Sigma_{\mathrm{D-H}}}{d^5\Phi} = \frac{1}{2}\left[\frac{d^5\sigma^+}{d^5\Phi} - \frac{d^5\sigma^-}{d^5\Phi}\right]$$

$$= \left(\Gamma_d^{\Im}\,\Im\mathrm{m}\left[\mathcal{C}_d^I\right]^{exp} + \Gamma_n^{\Im}\,\Im\mathrm{m}\left[\mathcal{C}_n^I\right]^{exp}\right)\sin(\phi_{\gamma\gamma})$$

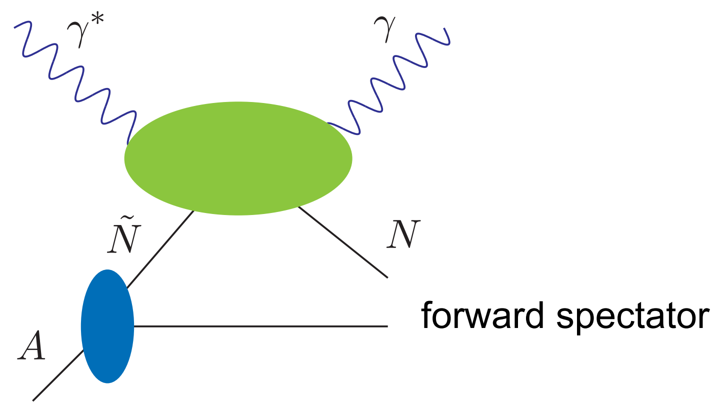
Results:
- extraction of C_d^I and C_n^I at $x_B=0.36$ and $Q^2=1.9$ GeV^2

- coherent D: consistent with theory at large |t| and inconsistent at small t.

- incoherent neutron:
- unlike p-DVCS probing H and H~, n-DVCS essentially sensitive to E
- enhanced sensitivity to d-quark → flavor separation of quark GPDs
- model-dependent constrains on Ju and Jd quark angular momenta

Tagged nuclear DVCS on Deuterium

- Part of project "Physics potential of polarized light ions with EIC@JLab", JLab LDRD grant
- Aimed to study:



  - neutron partonic structure for x < 0.1
  - bound nucleon in controlled nuclear environment
  - multiple scattering (nuclear shadowing)

- Advantage of collider kinematics and tagging:
  - (polarized) ions in colliders for the first time
  - wide kinematics in x_B and Q^2
  - spectator tagging allows for extrapolation to nucleon pole and better control of FSI and shadowing corrections
- Coherent DVCS on heavy nuclei: nuclear coherence via rapidity gap + zero degree calorimeter catching neutrons from nucleus decay

Summary

- Coherent nuclear DVCS is enhanced by factor **~2**.
  - competing prediction of Liuti, Taneja (2005): 10-25% enhancement
  - discrepancy with Hermes analysis
  - broadly consistent with DVCS on ^{4}He at CLAS (analysis under way)

- When the final nucleus is not detected, both coherent and incoherent processes contribute.
  - coherent dominates at small t
  - incoherent dominates at large t; can be used to probe DVCS on the bound neutron.

- Quasi-elastic nuclear DVCS probes possible medium-modifications of bound proton GPDs.
  - the effect is expected to be small, ~5%.

- There is pioneering data on nuclear DVCS from Hermes and JLab
  - analysis of DVCS on ^{4}He at CLAS in progress

- EIC has extensive program for nuclear DVCS and deep exclusive meson production
  - tagged nuclear DVCS on light polarized nuclei (D, ^{3}He)
  - coherent nuclear DVCS on heavy nuclei for small-x physics: nuclear shadowing and gluon saturation