Incoherent DVCS on nuclear targets

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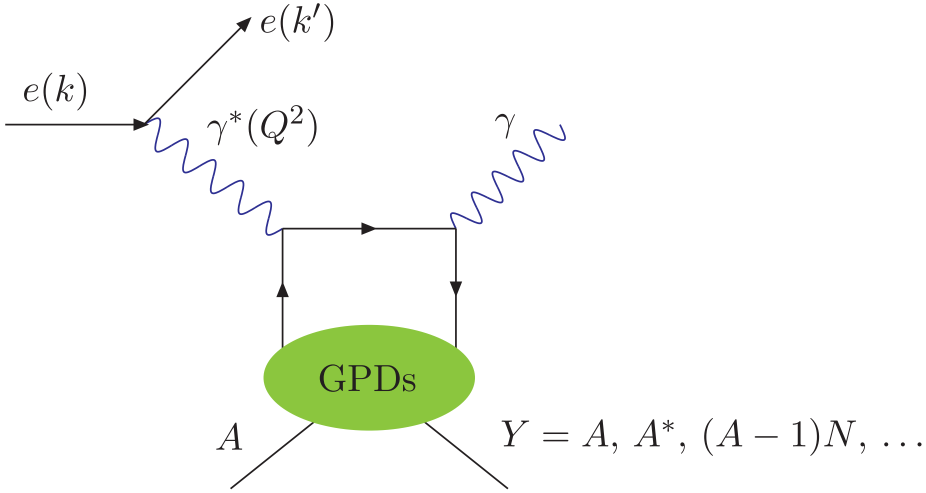
Outline

- Introduction
- Incoherent and coherent nuclear DVCS
- Medium modifications and incoherent nuclear DVCS
- Conclusions and Discussion

Introduction

Deeply Virtual Compton Scattering (DVCS) is the cleanest example of hard exclusive process.

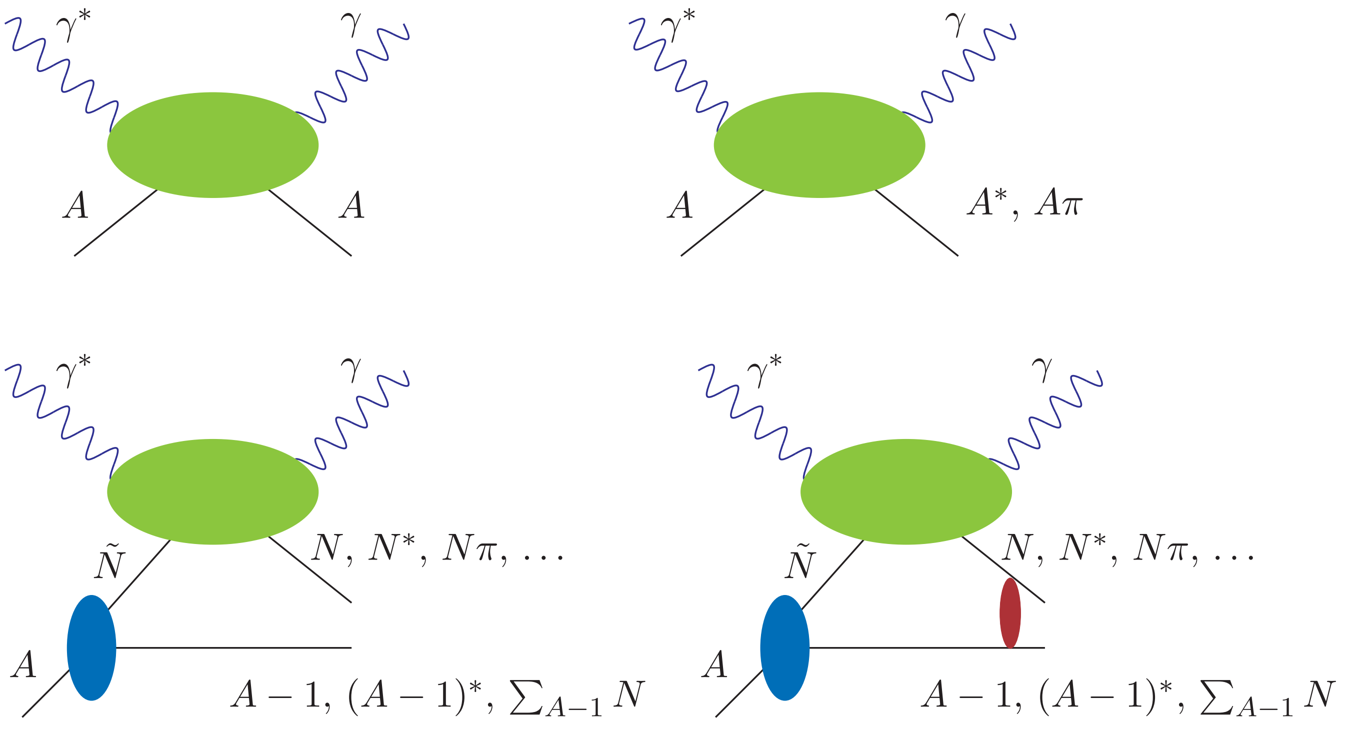


- The QCD factorization theorem for hard exclusive reactions (DVCS, electroproduction of mesons) allows to interpret the measurements in terms of universal generalized parton distributions (GPDs) of the target.

- The GPDs generalize and interpolate between form factors and structure functions and encode information on 3D distributions of quarks and gluons in the target.

DVCS on nuclear targets is more complex and versatile than DVCS on the free proton since:

- many more final states can be excited
- the reaction mechanism is more complex
- different spin and isospin of the target are available.



Important roles of nuclear DVCS:

Nuclear DVCS gives the information on the nucleon GPDs complimentary to DVCS on the free proton:

- theoretical description of nuclear GPDs requires GPDs of the (bound) proton and neutron as input
  VG and Strikman '03, VG '08;S. Scopetta '04; S. Liuti and S.K. Taneja '05

- incoherent DVCS on deuteron accesses almost-on-shell neutron GPDs
  M. Mazouz *et al.* (Hall A), Phys. Rev. Lett. **99**, 242501 (2007)

- DVCS on polarized ^{3}He will probe GPDs of the neutron

- electroduction of pseudoscalar mesons on deuteron is sensitive to non-pole contribution to the GPD $\tilde{E}$
  F. Cano and B. Pire, Eur. Phys. J. A **19**, 423 (2004)

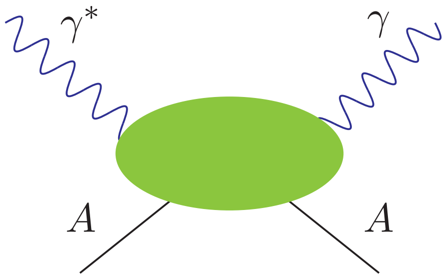
- electroproduction of pseudoscalar mesons on ^{3}He at small t probes GPDs of the neutron ($\gamma^*_{\rm L}+^3$He$\rightarrow \pi^0+^3$He) or proton ($\gamma^*_{\rm L}+^3$He$\rightarrow \pi^++^3$H)
  L. Frankfurt *et al.*, Phys. Rev. D **60**, 014010 (1999)

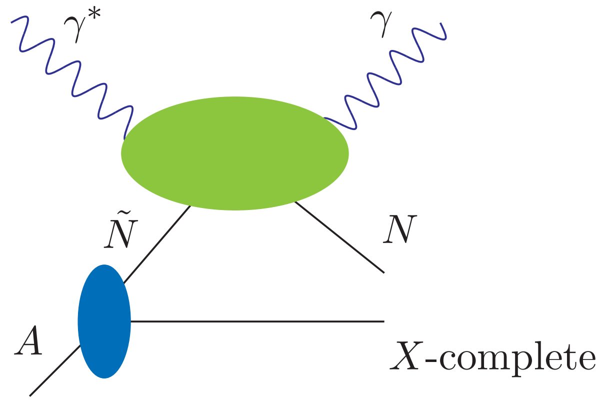
Nuclear DVCS is interesting in its own right:

- Might access novel nuclear effects not present in DIS and elastic scattering on nuclear targets:
  - contribution of non-nucleon (meson) degrees of freedom to the real part of the DVCS amplitude
    M.V. Polyakov, Phys. Lett. B **555**, 57 (2003); VG and M. Siddikov, J. Phys. G **32**, 251 (2006)
  - unexpected pattern of nuclear shadowing for the real part of the DVCS amplitude at high-energies
    A. Freund and M. Strikman, Phys. Rev. C **69**, 015203 (2004)
- Will put stringent constaints on theoretical models of the nuclear structure: covariant description is more important than for nuclear DIS and nuclear form factors
- At high energies, nuclear DVCS is more sensitive to the physics of high parton densities and the parton saturation than inclusive scattering
  M.V.T. Machado, arXiv:0810.3665 [hep-ph]

Incoherent and coherent nuclear DVCS

In theoretical analysis of nuclear DVCS, the analysis is simplest when the final state is simple: elastic or complete set of final nuclear states.





Coherent nuclear DVCS:

– dominates at small t
– $\mathcal{A} \propto A\, F_A(t)$

Incoherent nuclear DVCS:

– dominates at large t
– $\mathcal{A} \propto F_N(t)$

When the final nuclear state is not detected (summed over), both coherent and incoherent contributions are present.

DVCS amplitude: $\mathcal{T}^A_{\rm DVCS} = -\bar{u}(k')\gamma_\mu u(k)\frac{1}{Q^2}H^{\mu\nu}\epsilon^*_\nu$

Hadronic tensor: $H^{\mu\nu} = -\int d^4x e^{-iqx}\langle X|T\{J^\mu(x)J^\nu(0)\}|A\rangle \equiv \langle X|\mathcal{O}(q)|A\rangle$

DVCS amplitude squared:

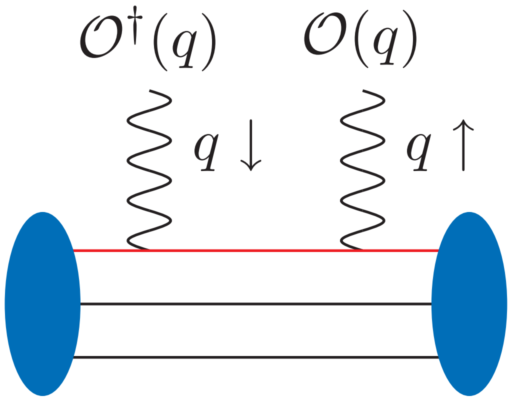
$$|\mathcal{T}^A_{\rm DVCS}|^2 \propto \langle A|\mathcal{O}^\dagger(q)|X\rangle\langle X|\mathcal{O}(q)|A\rangle = \langle A|\mathcal{O}^\dagger(q)\mathcal{O}(q)|A\rangle$$

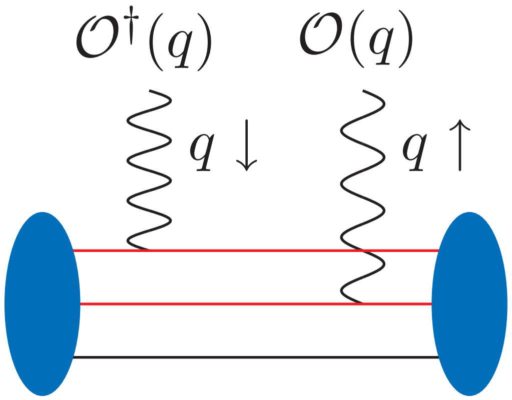
$$= \sum_{i,j}\langle A|N_i\rangle\langle N_i|\mathcal{O}^\dagger(q)\mathcal{O}(q)|N_j\rangle\langle N_j|A\rangle$$

$$= \sum_i |\langle A|N_i\rangle|^2\langle N_i|\mathcal{O}^\dagger(q)\mathcal{O}(q)|N_i\rangle + \sum_{i\neq j}\langle A|N_i\rangle\langle N_i|\mathcal{O}^\dagger(q)\mathcal{O}(q)|N_j\rangle\langle N_j|A\rangle$$

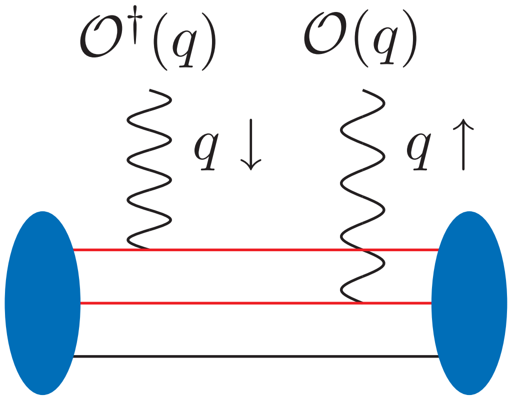
$$= A|\mathcal{T}^N_{\rm DVCS}|^2 + A(A-1)F^2_A(t' = A/(A-1)t)|\mathcal{T}^{A,{\rm coh.enr.}}_{\rm DVCS}|^2$$

L. Frankfurt, G.A. Miller and M.Strikman, Phys. Rev. D **65**, 094015 (2002)

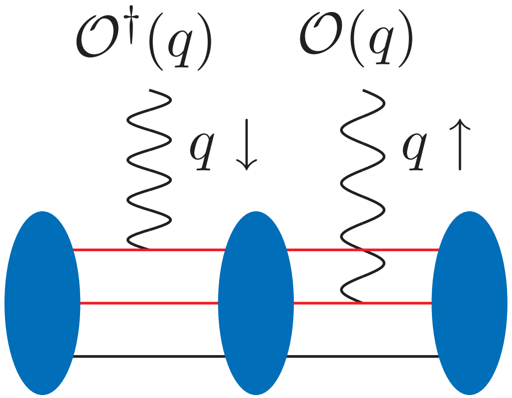




Note the difference between the coherent-enriched and purely coherent contributions



$A(A-1)F_A^2(t')$



$A^2 F_A^2(t)$

Several important comments:

- The assumption of the completeness of final nuclear states (closure approximation) is justified at sufficiently large t so that many final states are possible.

- Both incoherent and coherent nuclear DVCS take place on medium-modified, off-shell nucleons that are subject to Fermi motion.
  For incoherent nuclear DVCS:

$$A|\mathcal{T}_{\rm DVCS}^{N}|^2 \to \int_{\alpha_{\rm min}}^{1} \frac{d\alpha}{\alpha} \rho_A^N(\alpha) |\mathcal{T}_{\rm DVCS}^{N^*}(\xi_N(\alpha)|^2$$

  In my numerical results shown below, these effects are neglected. I only distinguish between protons and neutrons:

$$A|\mathcal{T}_{\rm DVCS}^{N}|^2 = Z|\mathcal{T}_{\rm DVCS}^{p}|^2 + N|\mathcal{T}_{\rm DVCS}^{n}|^2$$
$$A\mathcal{T}_{\rm DVCS}^{A,{\rm coh.enr.}} = F_A(t')(Z\mathcal{T}_{\rm DVCS}^{p} + N\mathcal{T}_{\rm DVCS}^{n}) \equiv AF_A(t')\mathcal{T}_{\rm DVCS}^{N/A}$$

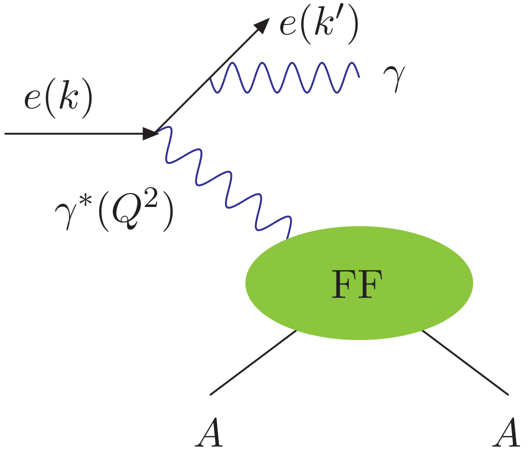
DVCS cross section at the photon level (keeping only the GPD H):

$$\frac{d\sigma}{dt} \approx \frac{\pi \alpha_{\rm em}^2 x_B^2}{Q^4} \left[A(A-1) F_A^2(t') |\mathcal{H}_{N/A}|^2 + Z |\mathcal{H}_p|^2 + N |\mathcal{H}_n|^2 \right]$$

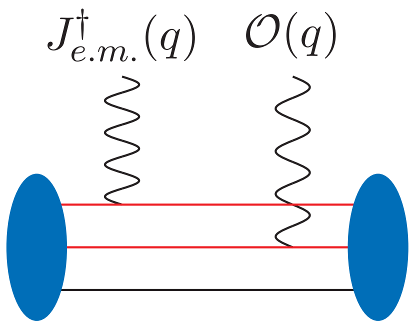
DVCS beam-spin asymmetry $A_{LU}(\phi)$:

$$A_{LU}(\phi) = \frac{\overrightarrow{\sigma} - \overleftarrow{\sigma}}{\sigma^{\rm unp}} = \frac{(A-1) Z F_A^2(t') \Delta \mathcal{I}_{N/A} + Z \Delta \mathcal{I}_p + N \Delta I_n}{Z(Z-1) F_A^2(t') |\mathcal{T}_{N/A}^{\rm BH}|^2 + Z |\mathcal{T}_p^{\rm BH}|^2 + N |\mathcal{T}_n^{\rm BH}|^2 + \dots}$$

Bethe-Heitler process



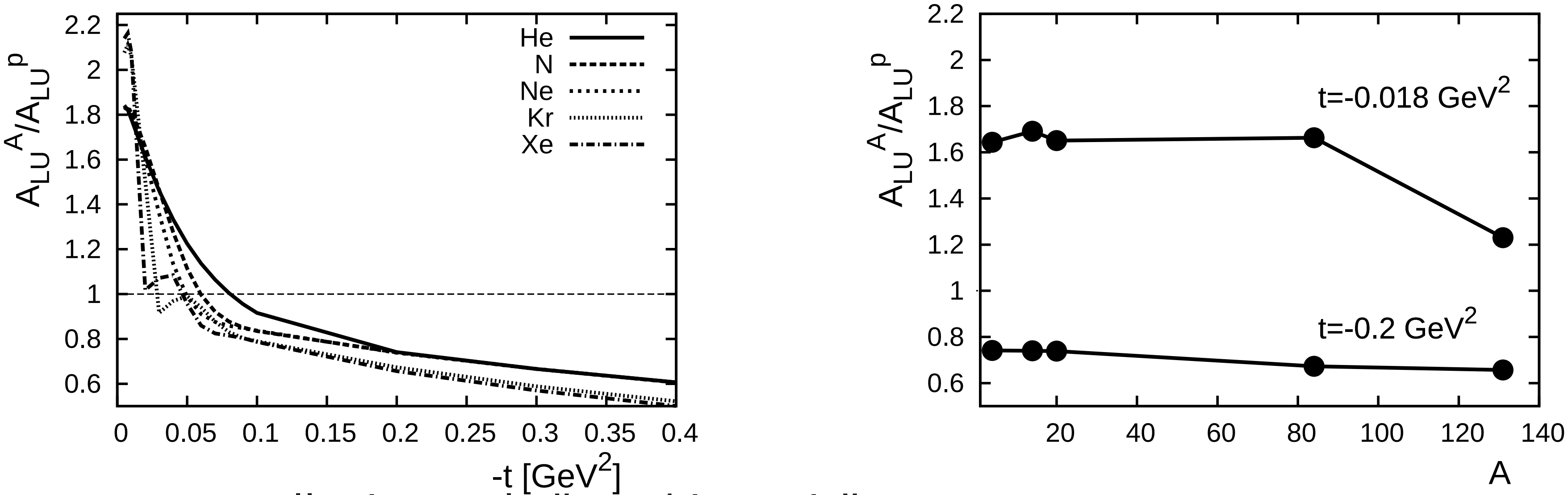
"Counting" for coherent-enriched interference



$Z(A-1) F_A^2(t')$

Predictions for the ratio of nuclear to proton beam-spin asymmetries, A^A_{LU}/A^p_{LU} in HERMES kinematics: $x_B = 0.065$ and $Q^2 = 1.7$ GeV^2 ($\phi = 90^0$)

V. Guzey, Phys. Rev. C **78**, 025211 (2008)



Enhancement at small t is purely "combinatoric":

$$A^A_{LU}/A^p_{LU} \approx 1 + \frac{N}{Z-1}\frac{\Delta\mathcal{I}_n}{\Delta\mathcal{I}_p} \approx 1.65 - 1.85$$

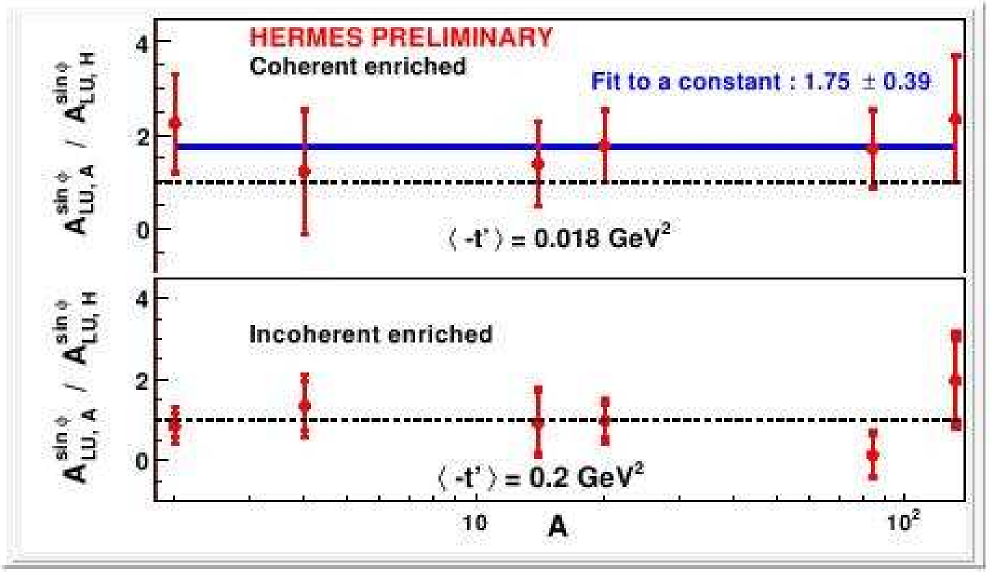
Suppression of incoherent DVCS at large t is due to the neutron contribution.

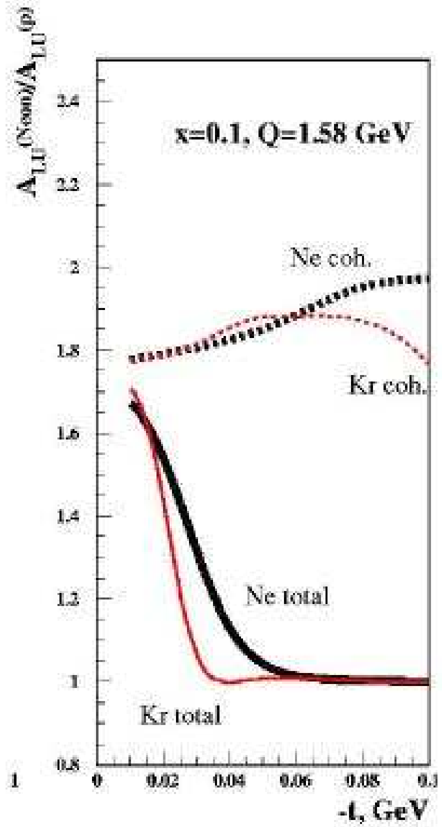
VG and M. Strikman, Phys. Rev. C **68**, 015204 (2003)

A. Kirchner and D. Mueller, Eur. Phys. J. C **32**, 347 (2003).

Original Hermes analysis is consistent with our 2003 predictions.

RATIO A^A_{LU}/A^p_{LU} (METHOD 1)



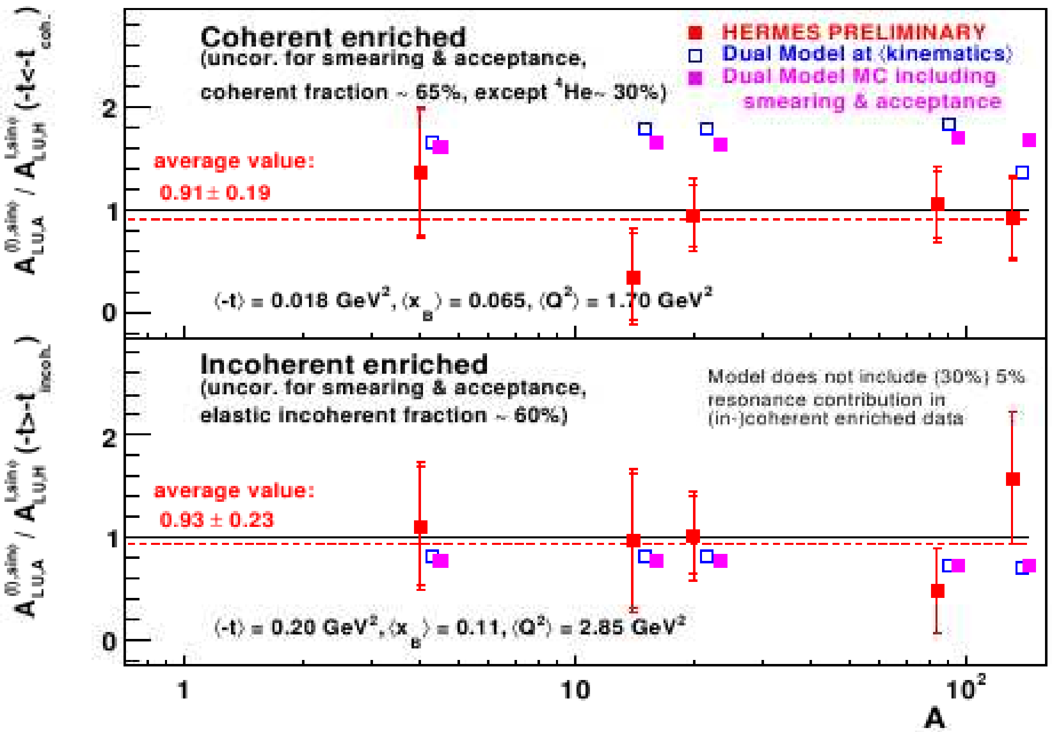


- COHERENT ENRICHED: MEAN RATIO DEVIATES FROM UNITY BY 2σ. CONSISTENT WITH PREDICTIONS BETWEEN 1.8 AND 1.95: GUZEY/STRIKMAN PHYS.REV.C 68 (2003)
- INCOHERENT ENRICHED: CONSISTENT WITH UNITY AS NAIVELY EXPECTED

Frank Ellinghaus, University of Maryland, October 2006 6

New Hermes analysis is inconsistent with coherent enhancement.

Ratio of Leading BSA Amplitude: $A_{LU,A}^{(I),\sin\phi} / A_{LU,H}^{I,\sin\phi}$



- The measured ratio of $A_{LU,A}^{(I),\sin\phi} / A_{LU,H}^{I,\sin\phi}$ is comparable with unity in both (in-)coherent enriched sample
- The results have been corrected for the background and other experimental effects, but not for the smearing (small effect, $\sim$0.01) and acceptance effect

H.Ye, Peking University, Mar. 30, 2008

Possible sources of inconsistency

- Experimental issues:
  - Large experimental errors
  - Incorrect subtraction of the incoherent contribution to obtain coherent-enriched data

- Theoretical issues:
  - Large corrections to the closure approximation, e.g. due to the off-shell effects and final state interactions
  - The correction due to the Fermi motion is not expected to be large
    VG and M. Strikman, Phys. Rev. C **68**, 015204 (2003)
  - Strong medium modifications and off-shell effects?
    S. Liuti and S.K. Taneja, Phys. Rev. C **72**, 032201 (2005); C **72**, 034902 (2005)

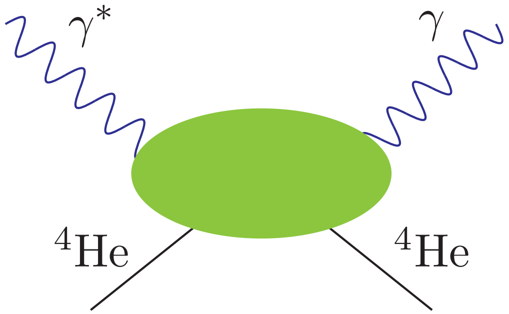
Medium modifications and incoherent nuclear DVCS

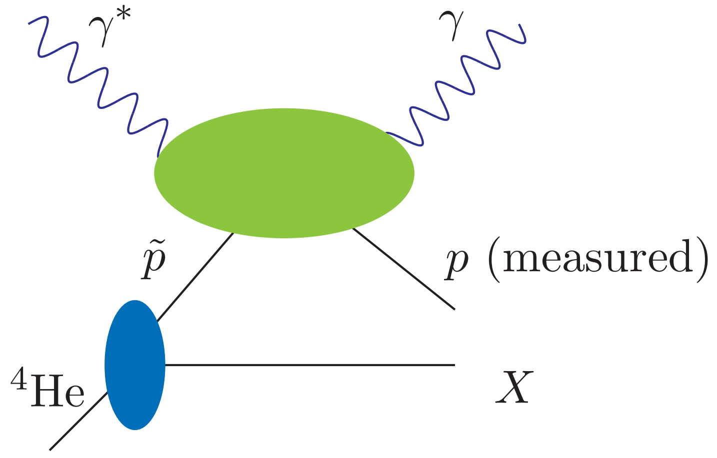
The new Jefferson Lab (CLAS collaboration) experiment on DVCS on ^{4}He will measure

H. Egiyan, F.-X. Girod, K. Hafidi, S. Liuti, E. Voutier *et al.*, Jefferson Lab Experiment E08-024 (2008)

- Purely coherent DVCS on ^{4}He (the final nucleus will be detected using BoNuS detector)

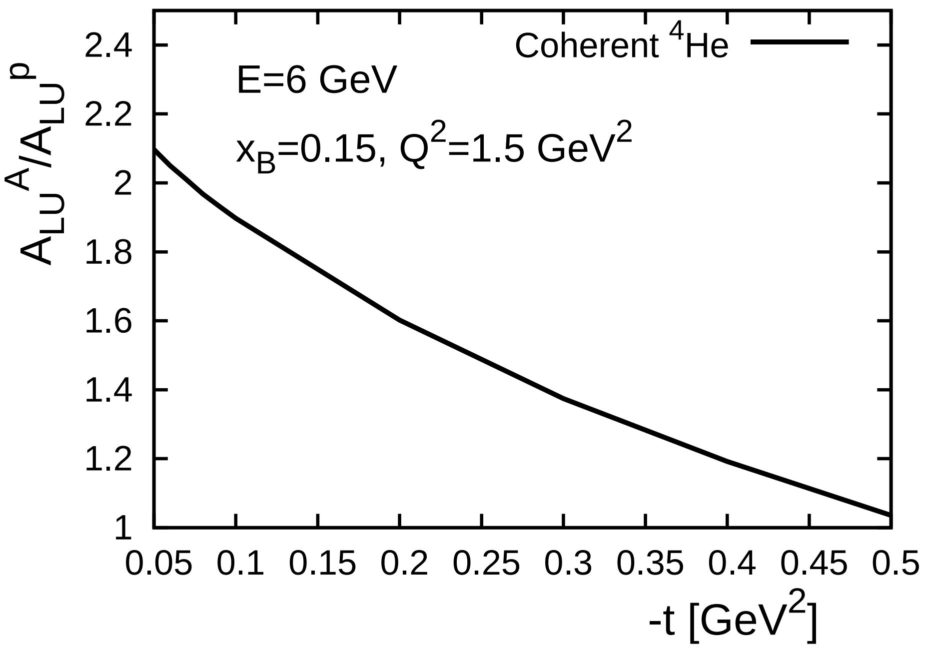
- Incoherent DVCS on the bound proton (the final proton is detected)





Predictions for A_{LU}^{A}/A_{LU}^{p} for coherent DVCS on ^{4}He ($\phi = 90^{0}$)

V. Guzey, Phys. Rev. C **78**, 025211 (2008)



Predictions for the incoherent DVCS on bound proton in ^{4}He

$$\frac{A_{LU}^{p^*}}{A_{LU}^{p}} = 1$$

if the Fermi motion, off-shellness and medium-modification effects are not taken into account.

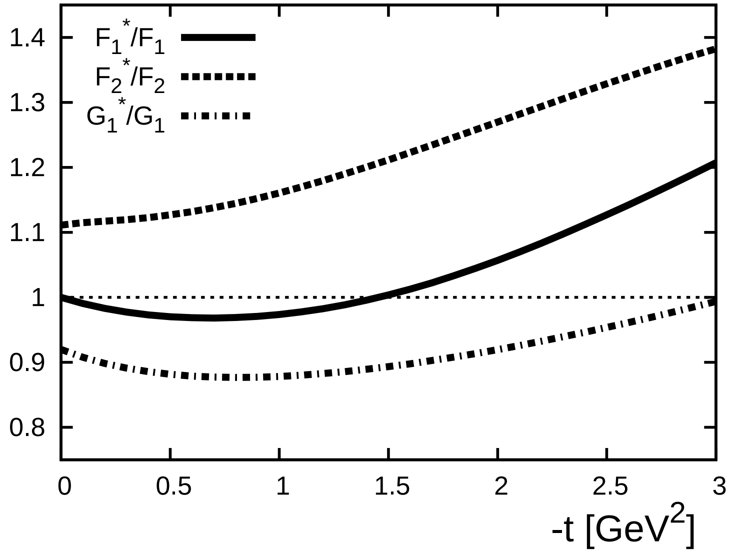
We included the effect of medium-modifications of the bound nucleon assuming that in-medium nucleon GPDs are modified in proportion to the bound nucleon elastic form factors.

VG, A.W. Thomas and K. Tsushima, arXiv:0806.3288

$$H^{q/p^*} = \frac{F_1^{p^*}(t)}{F_1^p(t)} H^{q/p}$$

$$E^{q/p^*} = \frac{F_2^{p^*}(t)}{F_2^p(t)} E^{q/p}$$

$$\tilde{H}^{q/p^*} = \frac{G_1^{p^*}(t)}{G_1^p(t)} \tilde{H}^{q/p}$$

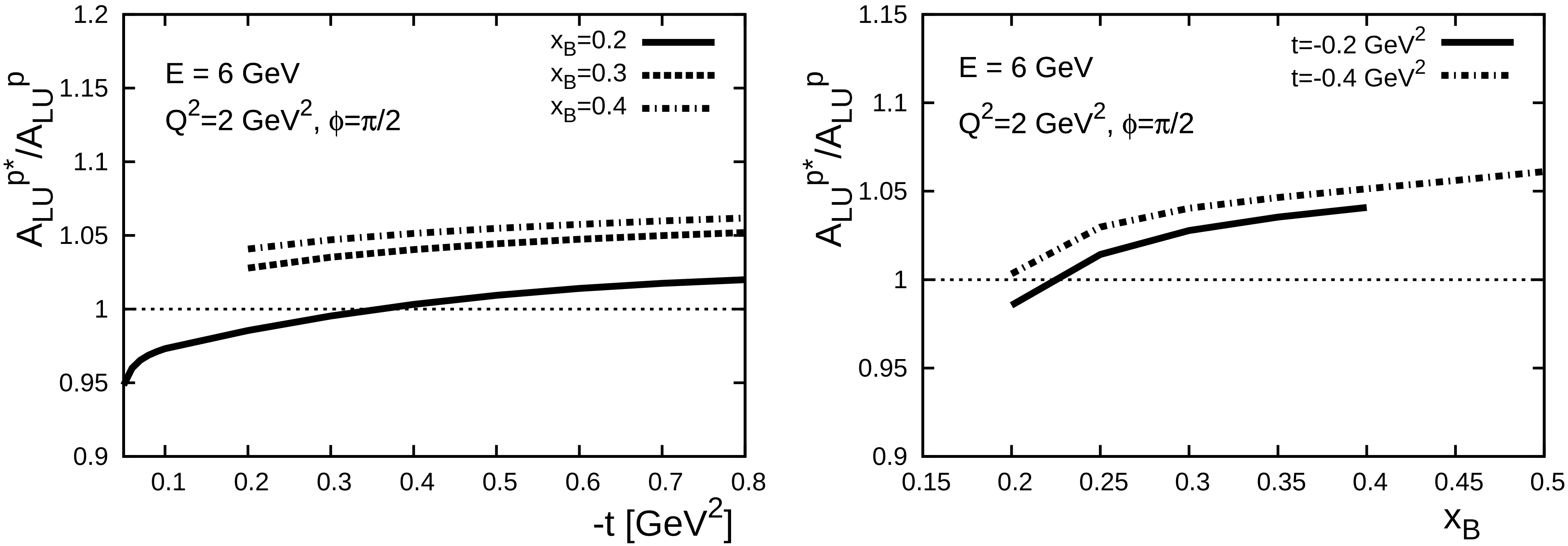


K. Saito, K. Tsushima and A.W. Thomas, Prog. Part. Nucl. Phys. **58**, 1 (2007)

The medium-modified elastic form factors are taken from the Quark-Meson Coupling Model whose predictions are consistent with the polarization transfer measurement $^4\mathrm{He}(\vec{e}, e'\vec{p})^3\mathrm{H}$ (Hall A JLab): S. Malace, S. Strauch, arXiv:0807.2252 (Actually, MM+FM+FSI)

Predictions for the ratio of the bound to free proton DVCS beam-spin asymmetries, $A_{LU}^{p^*}/A_{LU}^{p}$, for incoherent DVCS on $^4\mathrm{He}$

VG, A.W. Thomas and K. Tsushima, arXiv:0806.3288.



- The deviation of $A_{LU}^{p^*}/A_{LU}^{p}$ from unity is as large as 6%
- Our predictions are much smaller in size and different in shape (x_B-dependence) from the predictions of S. Liuti and S.K. Taneja, Phys. Rev. C **72**, 032201 (2005); C **72**, 034902 (2005)

Conclusions and Discussion

- Using the completeness of the final nuclear states, one can derive an expression for nuclear DVCS that interpolates between the coherent-enriched and incoherent nuclear DVCS

- For the coherent-enriched and purely coherent nuclear DVCS, we predict the "combinatoric" enhancement at small t, $A_{LU}^{A}/A_{LU}^{p}=1.65-2$.

- For the incoherent nuclear DVCS at large t, $A_{LU}^{A}/A_{LU}^{p}<1$ due to the neutron contribution.

- The effect of medium-modifications of the bound nucleon GPDs are modelled using results of the Quark-Meson coupling model; the deviation of $A_{LU}^{p^*}/A_{LU}^{p}$ is at most 6%.

- In the above results, we neglected the effects of the Fermi motion and the final state interactions.

- Future work (personal plans): final state interactions for incoherent DVCS on deuteron; DVCS on polarized ^{3}He.