Introduction
Neutron GPDs from nuclear DVCS
Non-nucleonic degrees of freedom in nuclear DVCS
Theoretical challenges of nuclear DVCS
Conclusions

Theory of DVCS on nuclei: Promising observables

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Outline

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Introduction

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- QCD factorization theorem for Deeply Virtual Compton Scattering (DVCS) and for Deep Exclusive Meson Electroproduction (DEMP) on any hadronic target $\longrightarrow$ universal Generalized Parton Distributions (GPDs) of the target
- GPDs interpolate between elastic FFs and PDFs
- GPDs contain information on 3D distributions and correlations of partons in the target

Introduction (2)

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Three roles of DVCS and DEMP on nuclear targets:

- To give information on GPDs of the nucleon complimentary to experiments on H
- To access novel nuclear effects not present in DIS and in elastic scattering on nuclear targets
- To test theoretical models of the nuclear structure:
  - relativistic effects
  - non-nucleonic degree of freedom

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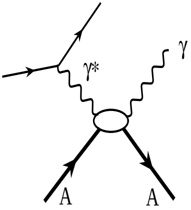
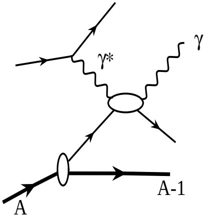
Neutron GPDs from nuclear DVCS

DVCS on nuclei at large $t \to$ nucleon (neutron) GPDs

- coherent
- dominates at small t

- incoherent
- dominates at large t





Both coherent and incoherent are present at all t.

Neutron GPDs from nuclear DVCS (2)

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Generic situation: $\mathcal{A}(t) = \langle A^* | \sum_i^A J_i \, e^{i\vec{\Delta}\cdot\vec{r}_i} | A \rangle$

$$\frac{d\sigma}{dt} \propto$$

$$\propto \sum_{A^*} \langle A | \sum_j^A J_j^\dagger \, e^{-i\vec{\Delta}\cdot\vec{r}_j} | A^* \rangle \langle A^* | \sum_i^A J_i \, e^{i\vec{\Delta}\cdot\vec{r}_i} | A \rangle = \langle A | \sum_{i,j}^A J_j^\dagger \, J_i \, e^{i\vec{\Delta}\cdot(\vec{r}_i - \vec{r}_j)} | A \rangle$$

$$= \langle A | \sum_{i \neq j}^A J_j^\dagger \, J_i \, e^{i\vec{\Delta}\cdot(\vec{r}_i - \vec{r}_j)} | A \rangle + \langle A | \sum_i^A J_i^\dagger \, J_i | A \rangle$$

$$\approx A(A-1) F_A^2(t') \frac{d\sigma}{dt} + A \, \frac{d\sigma}{dt}$$

Frankfurt, Miller, Strikman, Phys. Rev. D 65 (2002) 094015

- $F_A(t')$ is the nuclear form factor ($F_A(0) = 1$)
- $t' = t \frac{A}{A-1}$ (the center of mass effect)
- indistinguishable nucleons

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Neutron GPDs from nuclear DVCS (3)

DVCS cross section (on the photon level, integrated over ϕ)

$$\frac{d\sigma_{\rm DVCS}}{dt} = \frac{\pi \alpha^2 x_B^2}{Q^4\sqrt{1+\epsilon^2}}$$
$$\times \quad \left[A(A-1)F_A^2(t^\prime)|\mathcal{H}_{N/A}(\xi_N,t)|^2 + Z\,|\mathcal{H}_p(\xi_N,t)|^2 + N|\mathcal{H}_n(\xi_N,t)|^2\right]$$

DVCS beam-spin asymmetry A_{LU}

$$A_{LU}(\phi) = \frac{(A-1)Z\,F_A^2(t^\prime)\Delta\mathcal{I}_{N/A} + Z\,\Delta\mathcal{I}_p + N\,\Delta\mathcal{I}_n}{Z(Z-1)\,F_A^2(t^\prime)\mathcal{T}_{{\rm BH},N/A} + Z\,\mathcal{T}_{{\rm BH},p} + N\,\mathcal{T}_{{\rm BH},n} + \cdots}$$

Guzey, Strikman, Phys. Rev. C 68 (2002) 015204

Neutron GPDs from nuclear DVCS (4)

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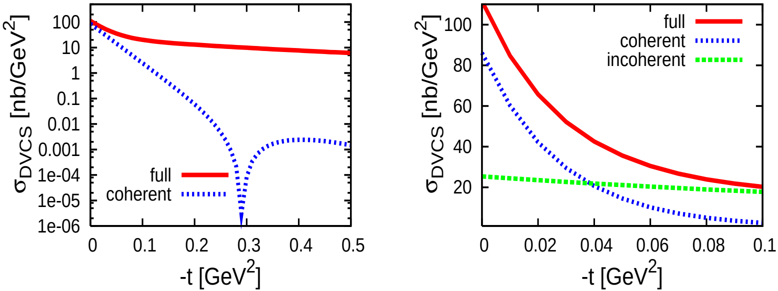
DVCS cross section ($Q^2 = 3$ GeV^2, $x_B = 0.2$)



Prelim. HERMES data

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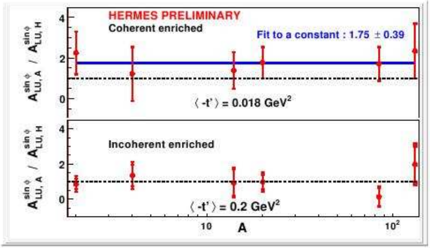
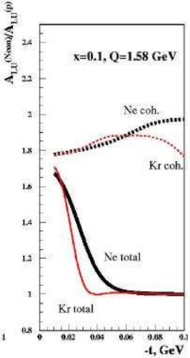
Ratio A^A_{LU}/A^p_{LU} (Method 1)





- 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

Neutron GPDs from nuclear DVCS (5)

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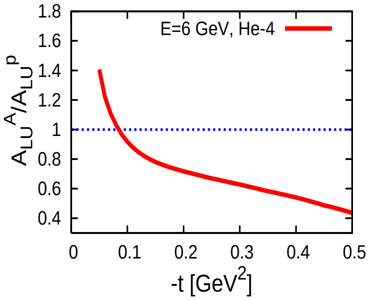
DVCS beam-spin asymmetry $A_{LU}(\phi)$ ($E = 6$ GeV, $Q^2 = 2$ GeV^2, $x_B = 0.2$)



Non-nucleonic degrees of freedom in nuclear DVCS

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- The matrix element of the energy-momentum tensor (any theory with a Lagrangian) between nuclear states (spin-0)

  in the spirit of X.D.Ji, Phys.Rev.D55, 7114 (1997)

$$\langle p'_A|\hat{T}^{\mu\nu}(0)|p_A\rangle = M_2(t)\bar{p}^{\mu}_A\bar{p}^{\nu}_A + \frac{1}{5}d(t)(\Delta^{\mu}\Delta^{\nu} - g^{\mu\nu}\Delta^2)$$

- In QCD, $M_2(t)$ and $d(t)$ are related to nuclear GPDs

$$\int_0^1 dx\, x H^q_A(x,\xi,t) = M_2^{q/A}(t) + \frac{4}{5}\xi^2 d^q_A(t)$$

- $M_2^{q/A}(t=0)$ momentum fraction of the target carried by the quark
- d^q_A so-called D-term

Non-nucleonic degrees of freedom (2)

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- In the Breit frame at $t = 0$

$$d(t=0) = -\frac{M_A}{2}\int d^3r\,(r_j r_k - \frac{\delta_{jk}}{3}r^2)T_{jk}$$

- Calculation in the simple liquid-drop model of the nucleus
  M.Polyakov, Phys.Lett.B555, 57 (2003)

$$d_A(0) = -0.2\,A^{7/3}(1+\frac{3.8}{A^{2/3}})$$

- The A-dependence is faster than expected A^2
- It is a nuclear surface effect
- Related to the distribution of the shear forces in the nucleus ($i \neq j$ of T_{jk} work)

Non-nucleonic degrees of freedom (3)

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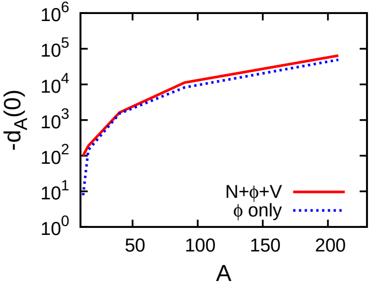
- Explicit numerical calculation in the Walecka model (nucleons N, vector field V, scalar field ϕ)
  V.G. and M.Siddikov, J.Phys.G32, 251 (2006)



- $d_A(0)$ is dominated by ϕ meson
- Fit $d_A(0) = -0.3\,A^{2.26}$
- Consistent with the liquid-drop model calculation $d_A(0) = -0.2\,A^{7/3}(1 + \frac{3.8}{A^{2/3}})$

- Possibility to study meson degrees of freedom thought A-dependence of DVCS observables (d_A^q enters the real part of the DVCS amplitude) of DVCS

Non-nucleonic degrees of freedom (4)

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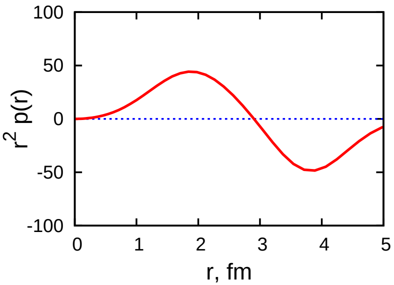
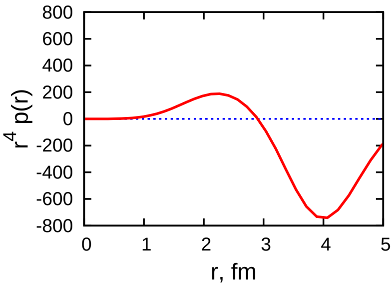
Distribution of pressure inside the nucleus



Distribution of D-term inside the nucleus



- Attractive ϕ meson contribution makes $d_A(0) < 0$
- This is the same mechanism as in χQSM, K.Goeke *et al.*, hep-ph/0702030 (2007)
- $d_A(0) < 0$ seems to be a general feature of any field-theoretical model

Non-nucleonic degrees of freedom (5)

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- Convolution approximation for nuclear GPDs and Walecka model for the distribution of N, V and ϕ

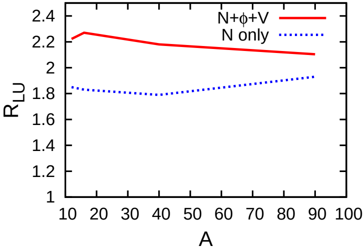
V.G. and M.Siddikov, J.Phys.G32, 251 (2006)

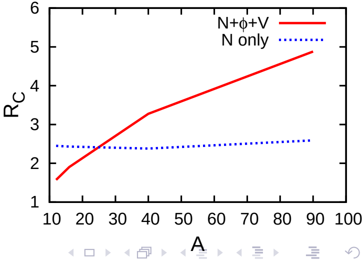
- Ratio of DVCS asymmetries

$$R_{LU} = \frac{A_{LU}^{\sin\phi}(\mathrm{nucleus})}{A_{LU}^{\sin\phi}(\mathrm{proton})}\,, \quad R_C = \frac{A_C^{\cos\phi}(\mathrm{nucleus})}{A_C^{\cos\phi}(\mathrm{proton})}$$

Aver. HERMES kinem.: $x_N = 0.09$, $Q^2 = 2.2$ GeV^2, $t = -0.01$ GeV^2

$R_{LU} \propto 1/A^{0.03}$ $\qquad$ $R_C \propto A^{0.5}$





Theoretical challenges of nuclear DVCS

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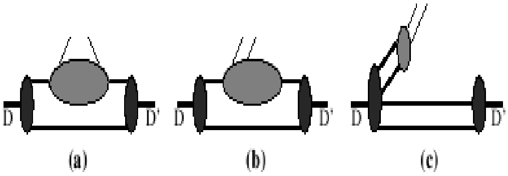
- Current approach to modeling nuclear GPDs: convolution of nucleon GPDs with the generalized distribution of nucleons
- The convolution approximation takes into account only graphs a and b



F. Cano and B. Pire, Eur. Phys. J. A **19**, 423 (2004)

- Neglect of graph c leads to (numerically small) violation of polynomiality (related to Lorentz invariance)
- It is a theoretical challenge to restore polynomiality for nuclear GPDs!

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- To access novel nuclear effects through the real part of the nuclear DVCS amplitude
- To test theoretical models of the nuclear structure:
  - relativistic effects
  - non-nucleonic degree of freedom
  - nuclear shadowing and antishadowing (A. Freund and M. Strikman, Eur. Phys. J. C **33**, 53 (2004); Phys. Rev. C **69**, 015203 (2004))