Generalized parton distributions in nuclei

Vadim Guzey

Jefferson Laboratory

Science and Technology Review
Jefferson Lab, July 15, 2009

Outline

- Introduction: generalized parton distributions (GPDs)
- Motivation to study generalized parton distributions in nuclei
- Two examples of nuclear effects in nuclear GPDs:
  - medium modifications of bound nucleon GPDs
  - nuclear shadowing in nuclear GPDs
- Summary

Introduction: GPDs

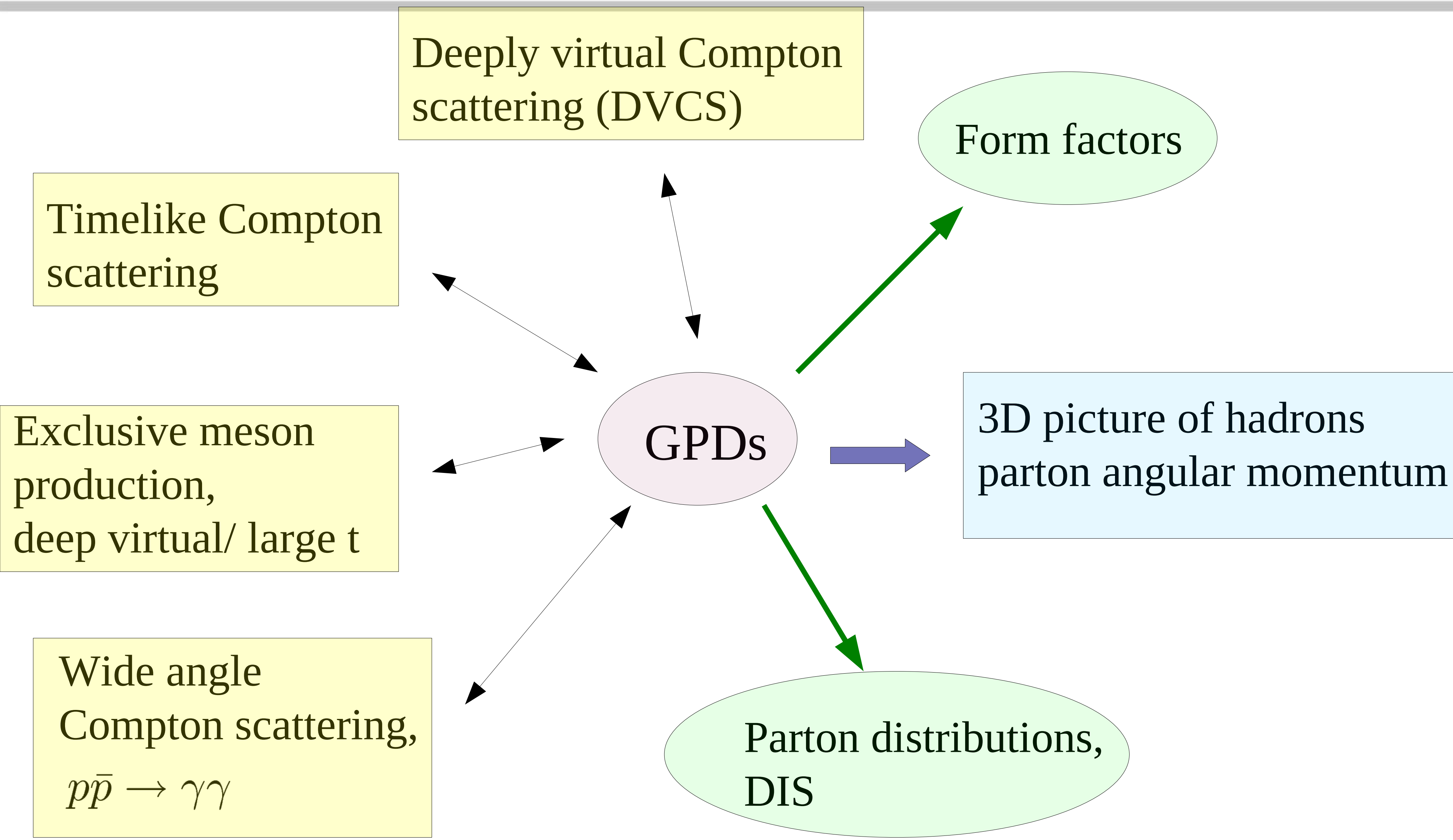
- One of key objective of nuclear physics is to understand the structure of the nucleon and nuclei in terms of quarks and gluons (partons) – the fundamental degrees of freedom of Quantum Chromodynamics, the theory of the strong interactions.

- The partonic structure of hadrons is studied in high energy scattering with a large momentum transfer that enables one to resolve short-distance parton structure of the target.

- Main theoretical tool – factorization theorems that enable to introduce universal (process-independent) distributions of partons in the target.

- Generalized parton distributions (GPDs) are examples of such distributions that can be probed in hard exclusive processes.

Introduction: GPDs (Cont.)



Generalized parton distributions in nuclei

Complimentary to proton GPDs

- nuclear GPDs involve proton and neutron GPDs, i.e. indirect info on nucleon GPDs
- DVCS on quasi-free nucleon in nuclei (incoherent DVCS) probes the nucleon GPDs
- The only way to measure neutron GPDs,

JLab, DVCS on deuteron, 2007

Traditional nuclear effects enhanced

- nuclear binding and off-diagonal EMC effect
- nuclear shadowing

"New" nuclear effects

- medium modifications of bound nucleon GPDs
- non-nucleon degrees of freedom

Medium modifications of the bound nucleon

Properties of bound nucleons in a nuclear medium are expected to be modified:

- structure function $F_{2N}^{*}(x,Q^2) \neq F_{2N}(x,Q^2)$ in DIS with nuclei (EMC effect)

- elastic form factors $F_{1,2}^{*}(t) \neq F_{1,2}(t)$ in quasi-elastic scattering on nuclei

  Recoil polarization in $^4He(\vec{e}, e'\vec{p})^3H$

  S. Strauch et al. [JLab Hall A] PRL 91, 052301 (2003); S. Malace at al, 0807.2252 [nucl-ex]

- axial coupling constant $g_A^{*} < g_A$ in nuclear beta decay

- various static properties (masses, magnetic moments)

It is natural to expect that bound nucleon GPDs should also be modified by the nuclear medium.

Model for medium modifications of bound nucleon GPDs

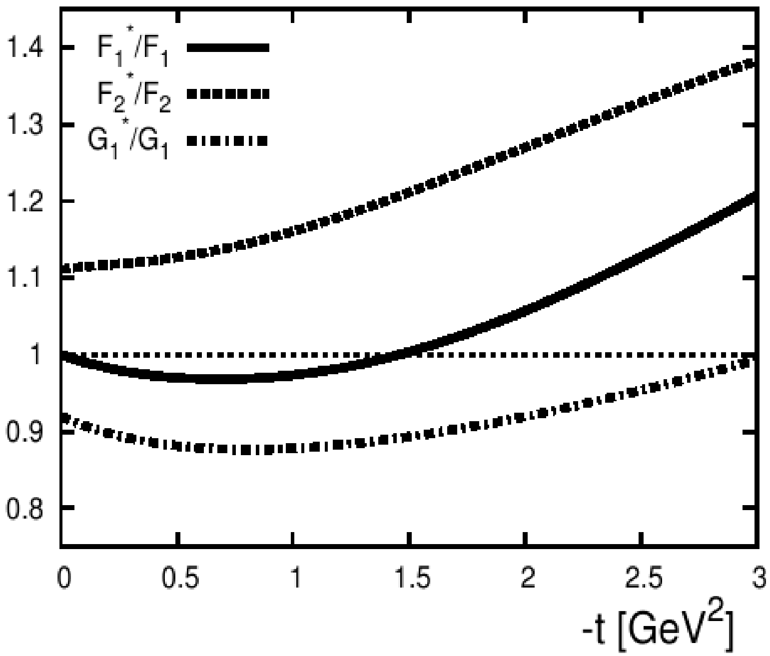
Motivated by results on recoil polarization in quasi-elastic scattering on ^{4}He that indicate that $F_{1,2}^*(t) \neq F_{1,2}(t)$, and by connection of GPDs and elastic form factors, we proposed a model for the *bound nucleon GPDs*,

V. Guzey, A.W. Thomas, K. Tsushima, PLB673 (2009) 9

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

Double distribution for free GPDs
M. Guidal et al, 2005

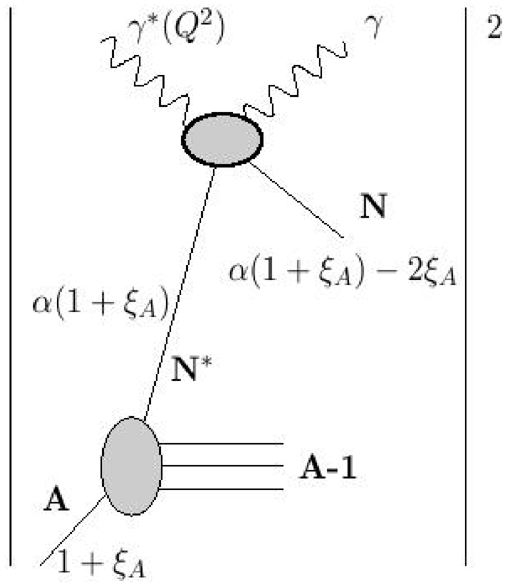
$$E^{q/N^*}(x,\xi,t) = \frac{F_2^{q/N^*}(t)}{F_2^{q/N}(t)} E^{q/N}(x,\xi,t)$$



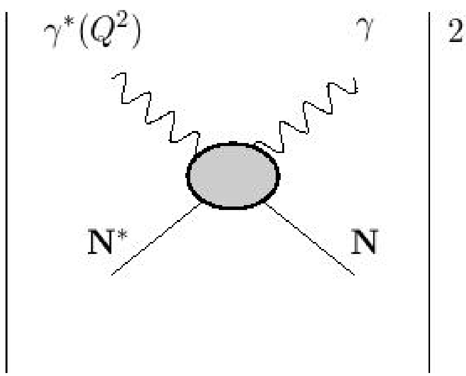
Results of Quark-Meson Coupling (QMC) model for bound proton in ^{4}He
K. Saito, A.W. Thomas, K. Tsushima, 2007.
Consistent with the data on recoil polarization in $^4He(\vec{e},e'\vec{p})^3H$

Medium modifications and incoherent DVCS

GPDs of the bound nucleon can be probed in DVCS on a quasi-free nucleon (*incoherent* DVCS) with nuclei



$$= \int \frac{d\alpha}{\alpha} \rho_A^N(\alpha,\lambda) \sum_\lambda$$



Neglecting Fermi motion:

$$|\mathcal{T}^{^4\mathrm{He}}_{\mathrm{DVCS}}|^2 = \sum_{\lambda} |\mathcal{T}^{p^*}_{\mathrm{DVCS}}|^2$$

Nuclear DVCS, example for 4He

proton polarization

Bound proton

Medium modifications and incoherent DVCS (Cont.)

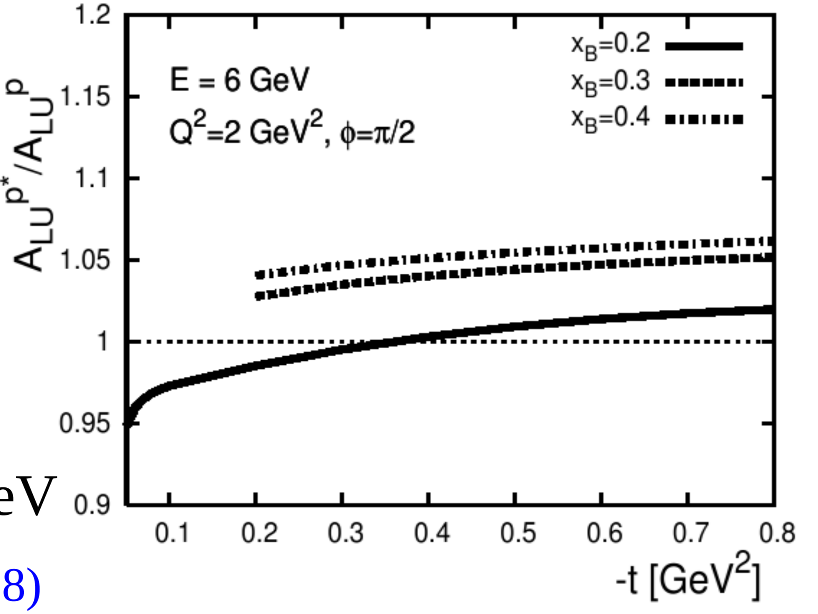
Beam-spin DVCS asymmetry for the nucleon bound in 4He:

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

VG, A.W. Thomas, K. Tsushima, PLB673 (2009) 9

enhancement because $F_2^*(t) > F_2(t)$

suppression because $F_1^*(t) < F_1(t)$



- will be tested by the future JLab experiment at 6 GeV

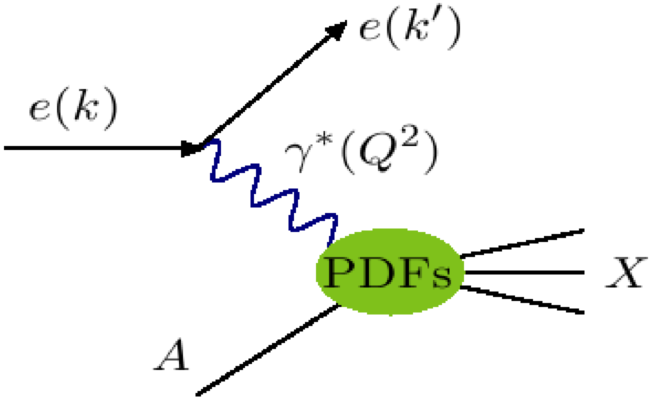
H.Egyian, F.Girod, K.Hafidi, S.Liuti, E.Voutier, E08-024 (2008)

- our predictions are very different from the only other existing model

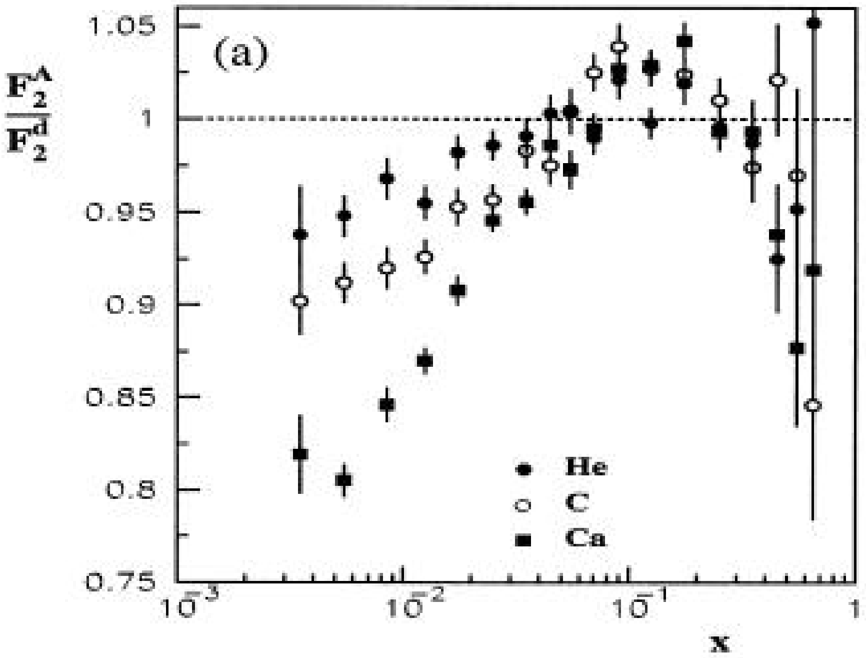
S.Liuti and S.K.Taneja, 2005

Nuclear shadowing in DIS with nuclei

Inclusive DIS with nuclear targets measures nuclear structure function $F_{2A}(x,Q^2)$



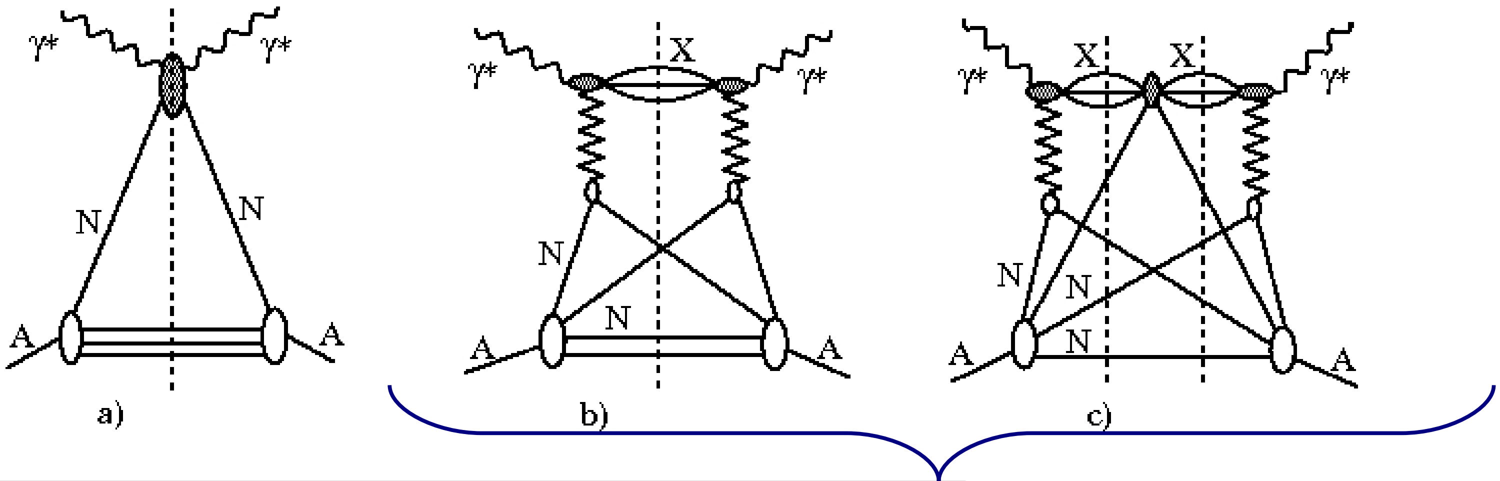
Ratio of nuclear to deuteron structure functions



shadowing

Nuclear shadowing in DIS with nuclei (Cont.)

Nuclear shadowing is well-understood and explained by observing that at small x_B, γ^* interacts with all nucleons:



$$F_{2A}(x,Q^2) = AF_{2N}(x,Q^2) - \text{shadowing corr.}$$

- γ^*N scattering amplitude is predominantly imaginary, and the graphs above contribute with an alternating relative sign:

  Geometric interpretation: one nucleon *shadows* the other one, R. Glauber, 1955

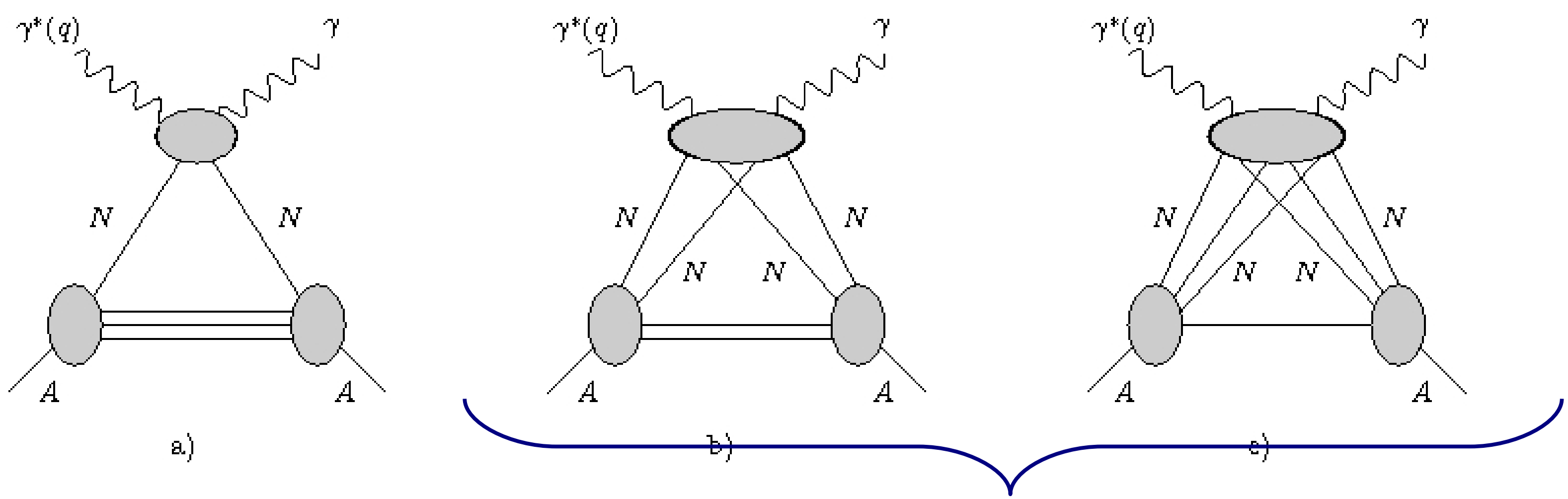
- γ^*N interaction is diffractive: shadowing driven by diffraction.

  V.N. Gribov, 1969; M. Strikman and L. Frankfurt, 1989

Nuclear shadowing in nuclear GPDs

The formalism can be generalized to DVCS and nuclear GPDs at small x_B

K. Goeke, VG, M. Siddikov, PRC 79 (2009) 035210



Born term

Shadowing correction

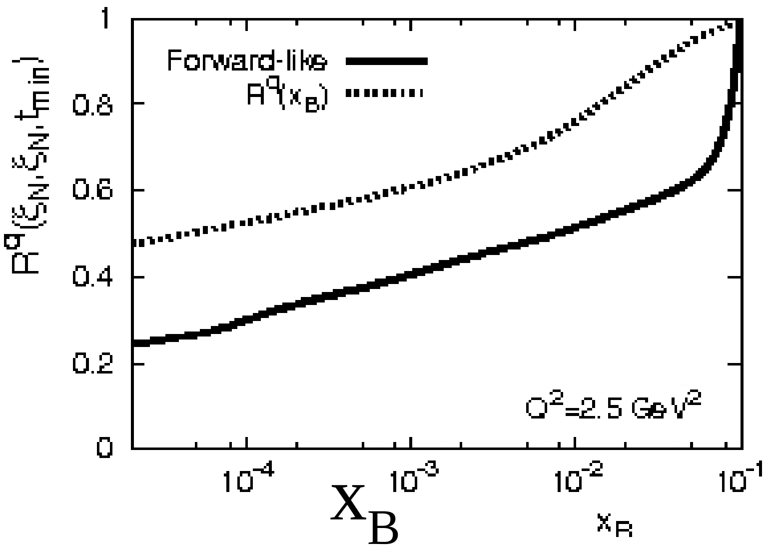
$$H_A^{q,g}(x,\xi,t) = AF_A(t)H_N^{q,g}(x,\xi,t) \quad -H_{IP}^{q,g} \otimes \text{Nucl. Part}$$

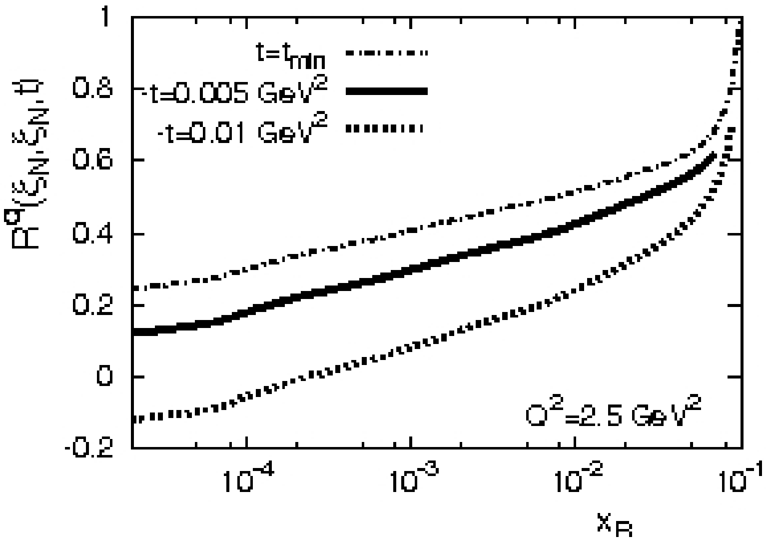
"quark or gluon GPD of the Pomeron"

Nuclear shadowing in nuclear GPDs (Cont.)

$$R^q(x,\xi,t) = \frac{H_A^q(x,\xi,t)}{AF_A(t)H_N^q(x,\xi,t)}$$ at $x=\xi=x_B/(2-x_B)$

K. Goeke, VG, M. Siddikov, PRC 79 (2009)





208Pb

Shadowing for GPDs is larger than for forward nuclear PDFs

Shadowing increases with increasing $|t|$

*Used forward-like model for GPDs

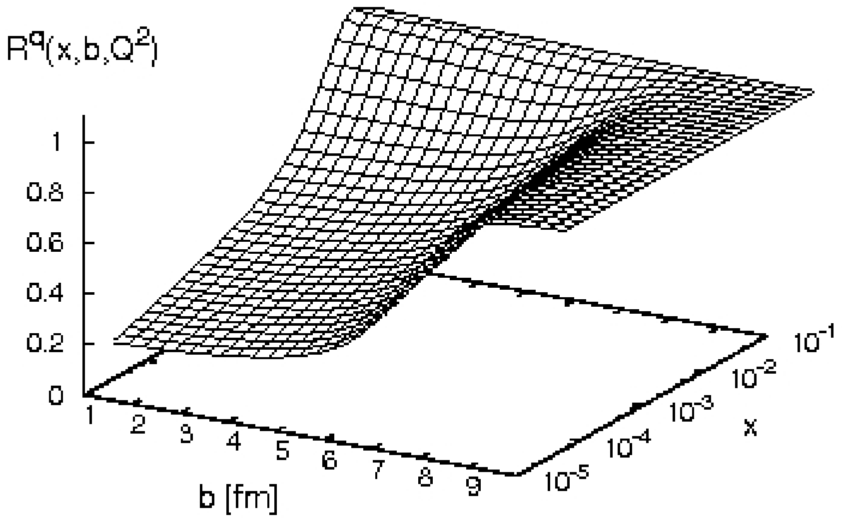
Nuclear shadowing for nuclear GPDs (Cont.)

In the $\xi = 0$ limit, $t = -q^2$, and GPDs have the probabilistic interpretation in the impact parameter **b** space.

$$R^q(x,b) = \frac{H_A^q(x,\xi=0,b)}{AT_A(b)H_N^q(x,\xi=0,b)}$$

Density of nucleons at given b

208Pb

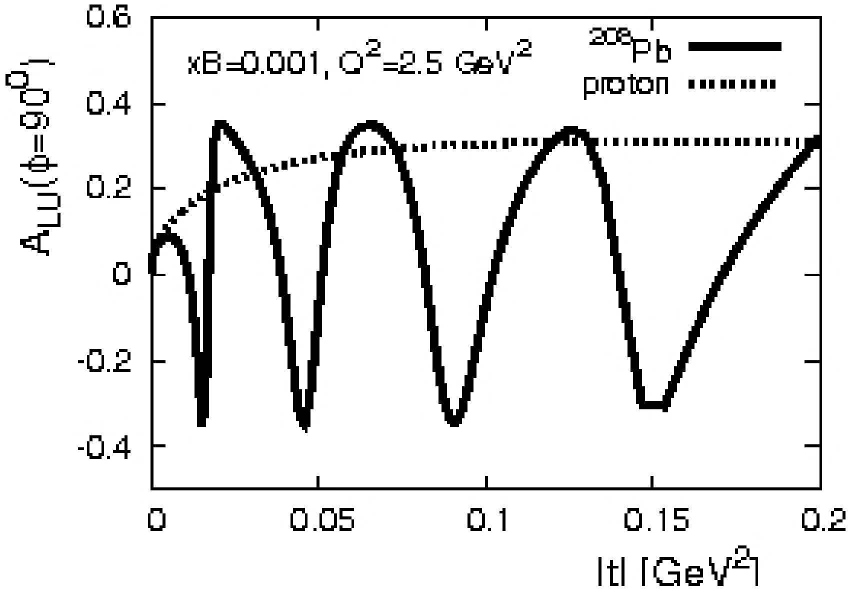


- Nuclear shadowing is larger at small b
- Nuclear shadowing introduces *correlations between x and b*, even if such correlations are absent for the free nucleon GPDs

Nuclear shadowing for nuclear GPDs (Cont.)

Predictions for beam-spin DVCS asymmetry

K. Goeke, VG, M. Siddikov, 2009



208Pb

- Nuclear shadowing leads to dramatic oscillations.
- Can be tested at the future Electron-Ion Collider.

Summary

- Generalized parton distribution (GPDs) parametrize the response of the hadrons when probed in hard exclusive processes.

- GPDs enable one to obtain a 3D image of the target and to study its spin content in terms of quarks and gluons.

- Nuclear GPDs are interesting in their own right:

    - contain complementary info on the nucleon (neutron) GPDs
    - traditional nuclear effects are enhanced (binding, EMC, shadowing)
    - sensitive to "new" (not well-established) nuclear effects (medium modifications of bound nucleons)

- All these aspects of nuclear GPD will be studied at JLab at 6 and 12 GeV and at the future Electron-Ion Collider.