Nuclear GPDs and DVCS in Collider kinematics

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Outline

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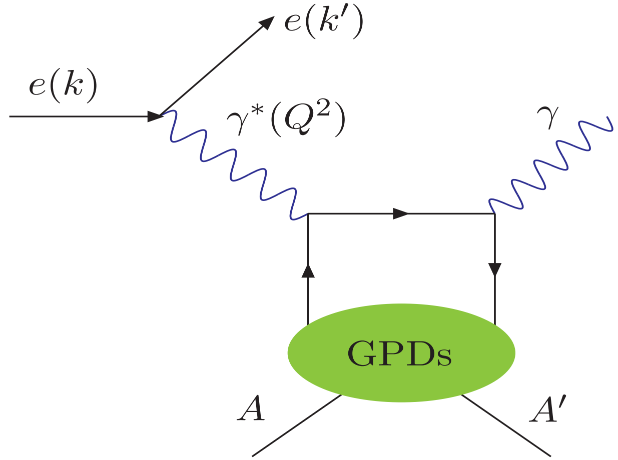
- Nuclear PDFs
- Nuclear GPDs
- Predictions for DVCS
- Conclusions

Introduction

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



In collider kinematics, hard exclusive processes (DVCS) on nuclear targets will address the following physics problems:

- Interaction of small-size $q\bar{q}$ dipoles with nuclear matter, related to the phenomenon of Color Transparency
- Quark and gluon 3D (transverse) imaging through the studies (extraction) of generalized parton distributions (GPDs)
- Approach to the regime of high parton densities (saturation)

Introduction

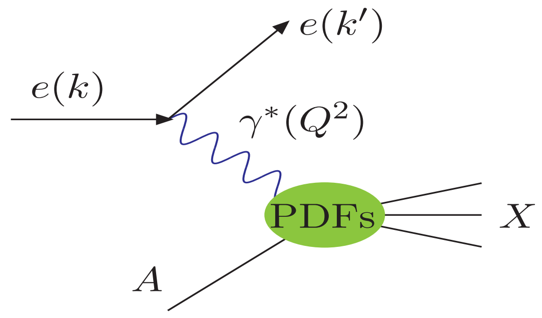
More specifically, DVCS on nuclear targets:

- Will naturally continue studies of nuclear Parton Distribution Functions (PDFs) carried out with fixed nuclear targets
- Will complete studies of DVCS on the nucleon initiated at HERA in DVCS on the proton
- Might access novel nuclear effects not present in DIS on nuclear targets (effects associated with the real part of the DVCS amplitude)
- Will put stringent constaints on theoretical models of the nuclear structure. DVCS is more sensitive to details of small-x physics (shadowing, antishadowing, black disk limit) than inclusive DIS on nuclear targets

In my talk, I will concentrate on the last point.

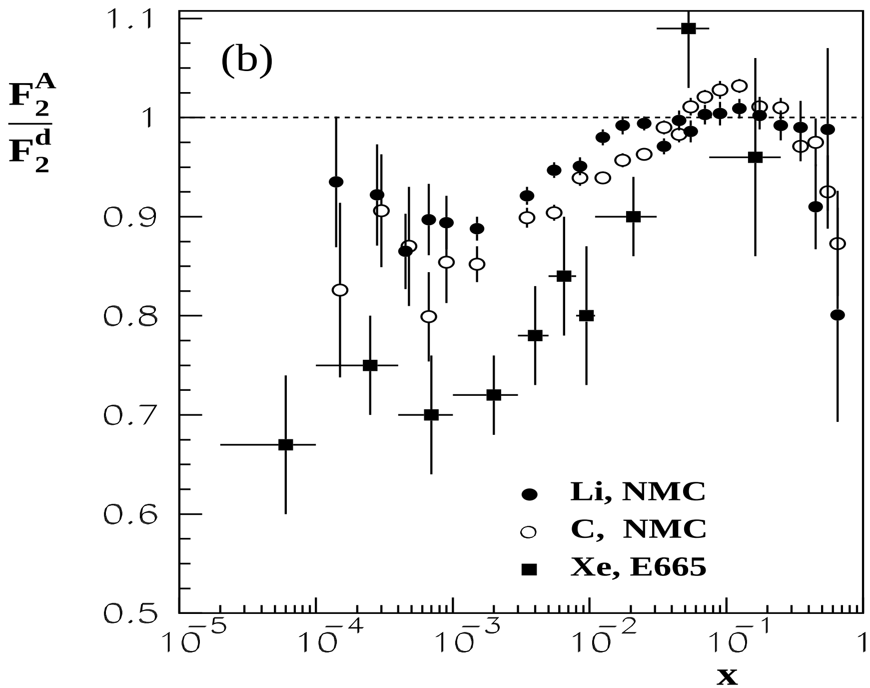
Nuclear PDFs

Unpolarized Inclusive Deep Inelastic Scattering (DIS) measures the structure function $F_2^A(x,Q^2)$



DIS on fixed nuclear targets, $R_{F_2} = F_2^A(x,Q^2)/F_2^D(x,Q^2)$

– nuclear shadowing
– antishadowing
– EMC effect



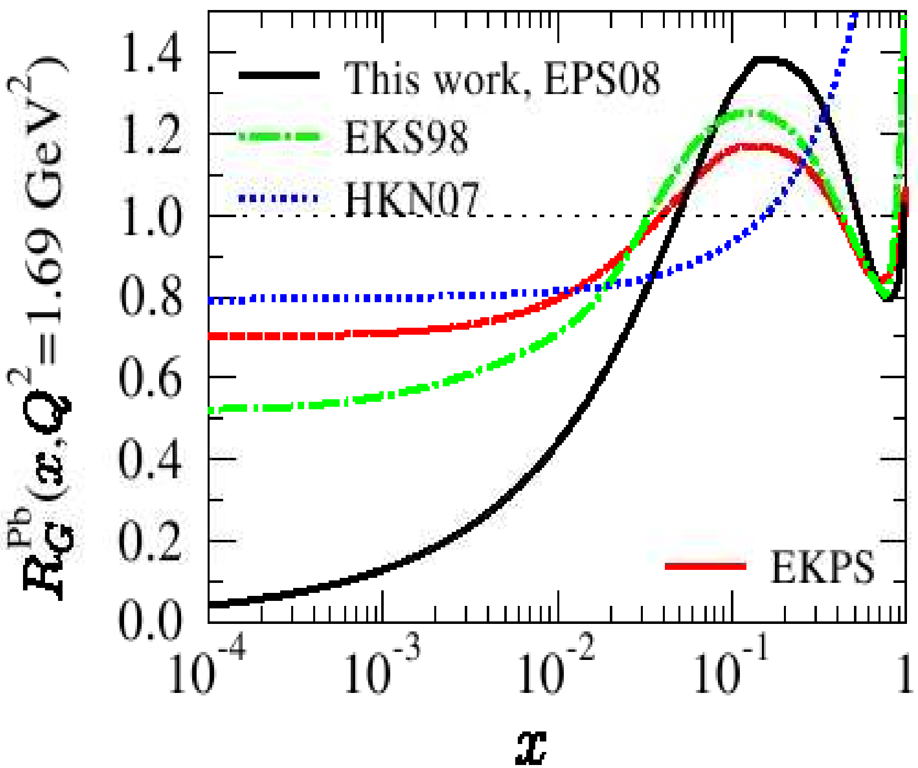
Nuclear PDFs

Using QCD factorization theorem, nuclear Parton Distribution functions (PDFs) can be extracted from $F_2^A(x,Q^2)$ and other data (DY, RHIC) by global fits.

Main drawbacks:

– insufficient kinematic coverage;
– small x correspond to small Q^2. Hence, small-x is either excluded from fits or contain large uncertainty (HT corrections)
$\rightarrow$ large uncertainties at small-x

$$R_G = g_A(x,Q^2)/[A g_N(x,Q^2)]$$



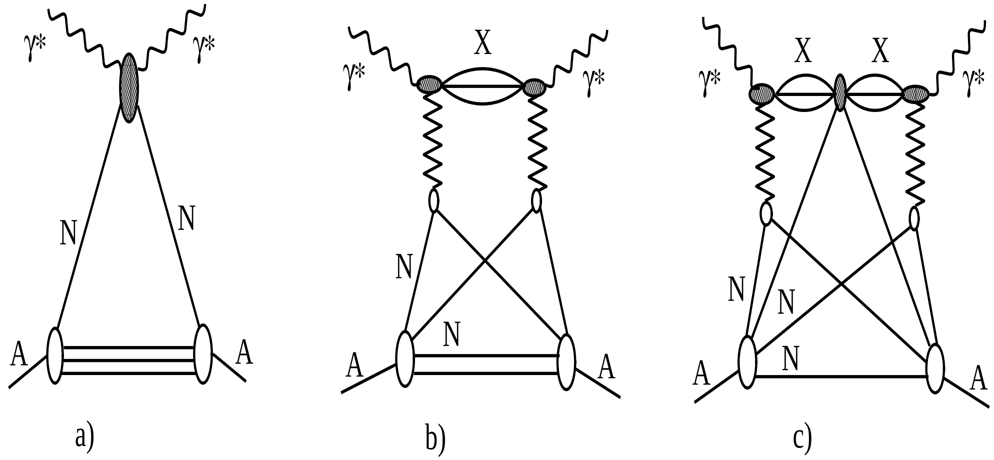
K. Eskola *et al.*, arXiv:0802.0139 [hep-ph]

Nuclear PDFs

An alternative to fitting is the leading twist (LT) model of nuclear shadowing (NS)
L. Frankfurt, V.G, M. Strikman, Phys. Rev. D71, 054001 (2005)

LT model of NS is based on:

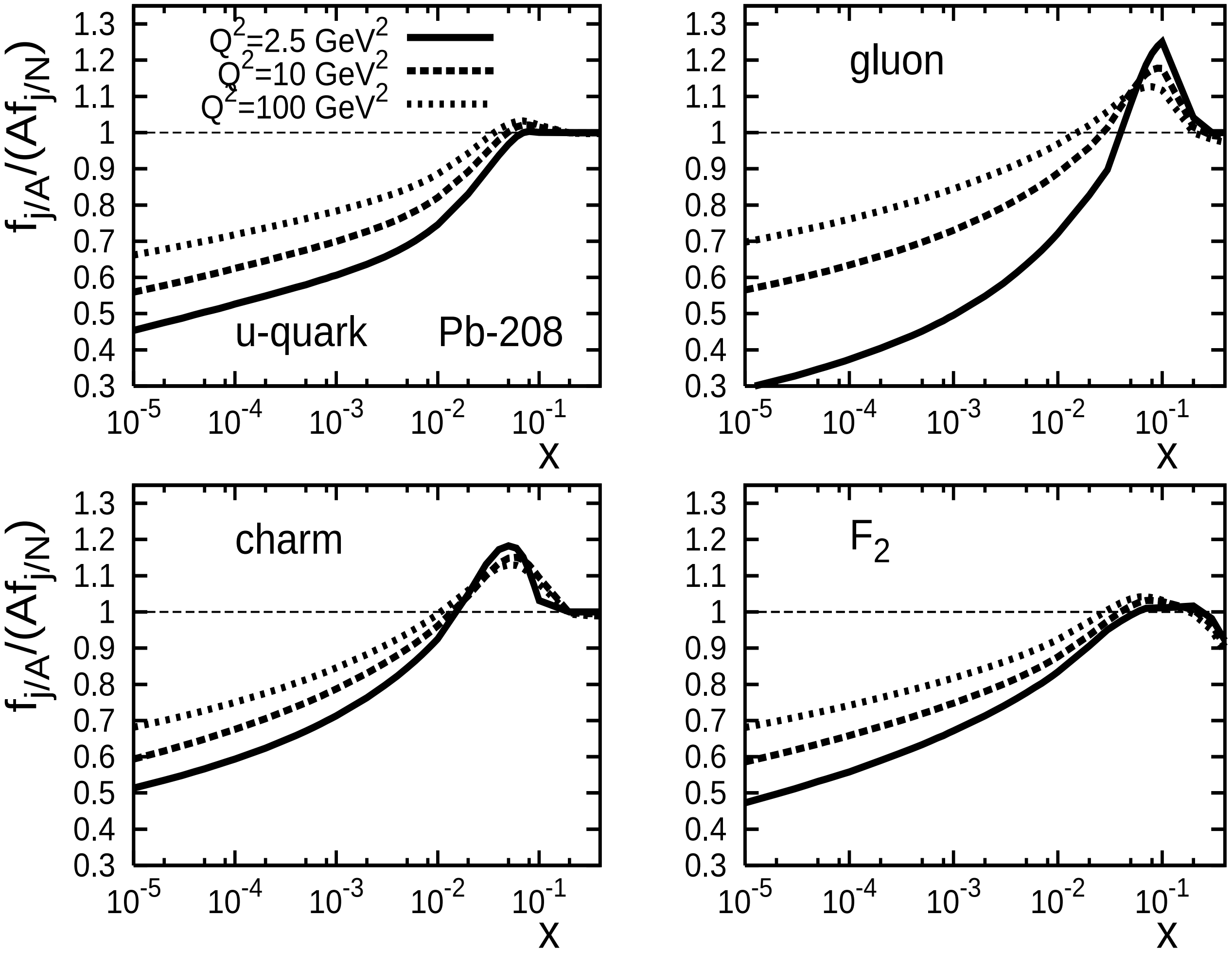
- connection between NS and diffraction due to V. Gribov
- QCD factorization theorem for inclusive and hard diffractive scattering in DIS
- QCD analysis of the HERA diffractive data by H1 and ZEUS



$$
\begin{aligned}
x f_{j/A}(x, Q_0^2) &= A\, x f_{j/N}(x, Q_0^2) \\
&- 8\pi A(A-1)\Re e \frac{(1-i\eta)^2}{1+\eta^2} \int_x^{0.1} dx_{I\!P}\, \beta f_j^{D(4)}(\beta, Q_0^2, x_{I\!P}, t_{\min}) \\
&\times \int d^2\vec{b} \int_{-\infty}^{\infty} dz_1 \int_{z_1}^{\infty} dz_2\, \rho_A(\vec{b}, z_1)\rho_A(\vec{b}, z_2) e^{i(z_1-z_2)x_{I\!P} m_N} \\
&\times e^{-\frac{A}{2}(1-i\eta)\sigma_{\rm eff}^j(x,Q^2)\int_{z_1}^{z_2} dz' \rho_A(\vec{b},z')}
\end{aligned}
$$

Nuclear PDFs

Predictions of LT model of NS,
L. Frankfurt, V.G, M. Strikman, in preparation,
based on 2006 H1 analysis of diffraction at HERA



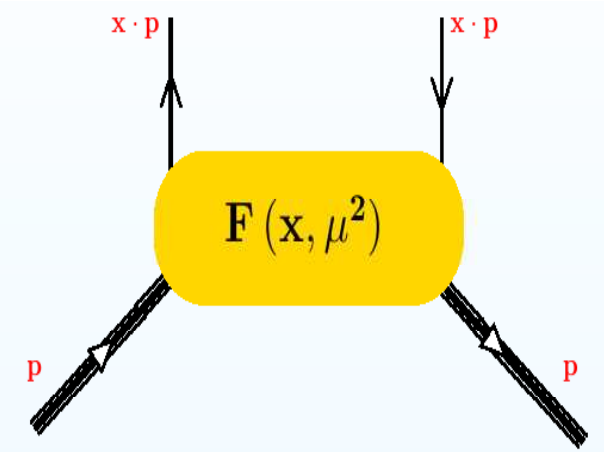
LT model of NS also predicts:

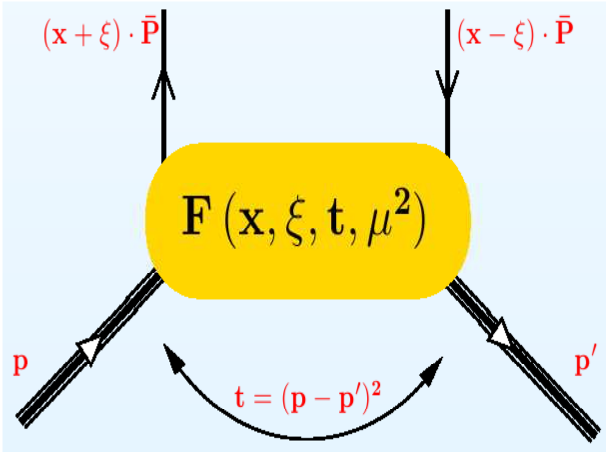
– nuclear diffractive PDFs
– impact parameter dependent PDFs

Nuclear GPDs

Quark GPD of a spinless nucleus

$$H^q(x,\xi,t,\mu^2) = \int \frac{dz^-}{4\pi} e^{ix\bar{P}_A^+ z^-} \langle P'_A | \bar{\psi}\left(-\frac{z^-}{2}\right)\gamma^+ \psi\left(\frac{z^-}{2}\right) | P_A \rangle_{|z^+,\vec{z}_\perp=0}$$





– x longit. momentum fraction
– μ^2 factorization scale

– $\bar{P}_A^+ = (P_A + P'_A)/2$
– $x \pm \xi$ longit. momentum fractions
– $\xi = x_B/(2 - x_B)$
– $\Delta = P'_A - P_A$
– enters via convolution !

Nuclear GPDs

Nuclear impact parameter dependent PDFs are nuclear GPDs at $\xi=0$ (from the definition and from the fact that $\vec{b}$ is conjugate to $\vec{\Delta}_\perp$, M. Burkardt, Int. J. Mod.Phys. A 18, 173 (2003) for proton)

LT theory of NS gives nuclear GPDs at $\xi=0$ "for free".

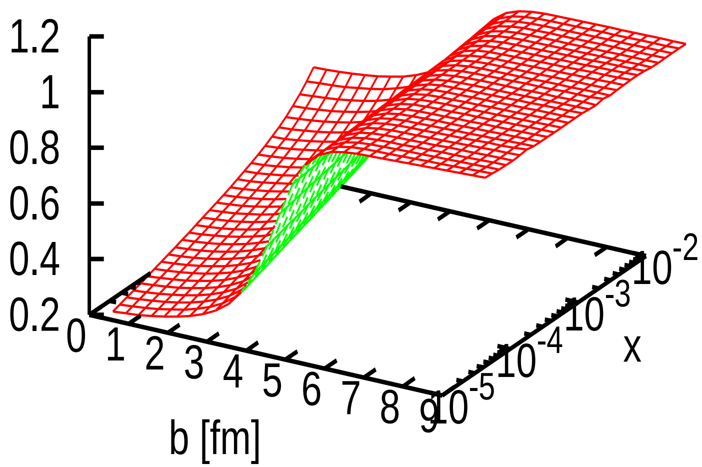
$$R_q = q_A(x,b)/[AT_A(b)q_N(x)] \sim H_A^q(x,\xi=0,b)$$

for ^{208}Pb at $Q_0^2 = 2.5$ GeV^2

Interesting feature:

– NS introduces correlations between x and b

– Such correlations are absent in the nucleon GPDs at small x



Nuclear GPDs

How to nuclear GPDs for $\xi \neq 0$? Two possible ways:

- Generalize the LT theory of NS to the case of off-forward kinematics
  V.G and M. Siddikov, in progress

- Using experience with modeling nucleon GPDs in terms of nucleon PDFs, relate nuclear GPDs to nuclear PDFs
  - Double Distibution
    A. Radyushkin, Phys. Rev. D 56, 5524 (1997)
  - Align-jet model motivated
    A. Freund, M. McDermott, M. Strikman, Phys. Rev. D 67, 036001 (2003)
  - Dual parameterization
    V.G. and T. Teckentrup, Phys. Rev. D 74, 054027 (2006)

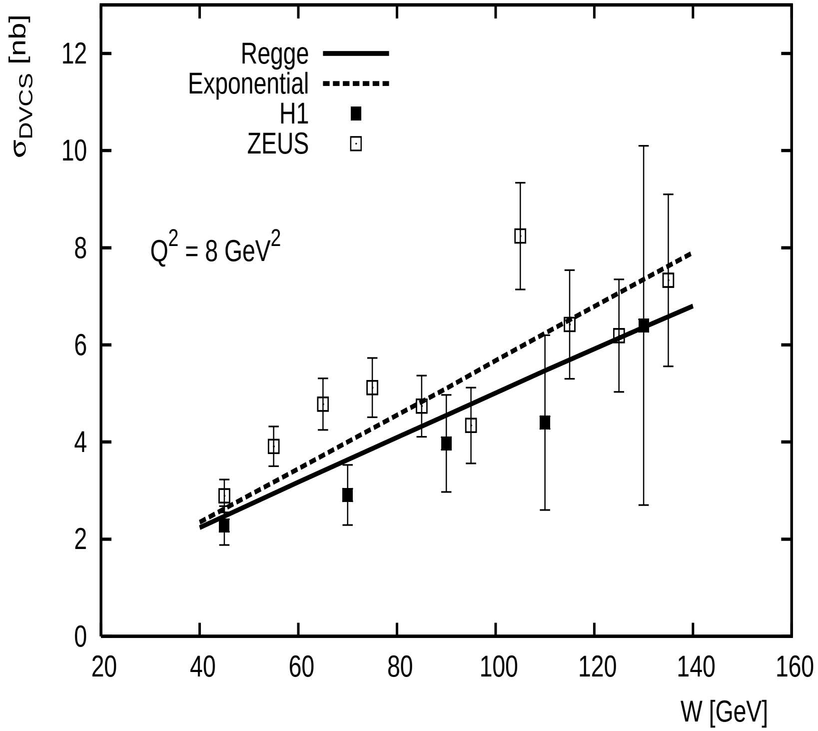
Nuclear GPDs

I will use the dual parameterization, which:

– essensially small-x_B expansion of nucleon GPDs

– simple expressions at LO

– leads to good description of all high-energy DVCS data on proton (HERA, Hermes)
V.G. and T. Teckentrup, (2006)



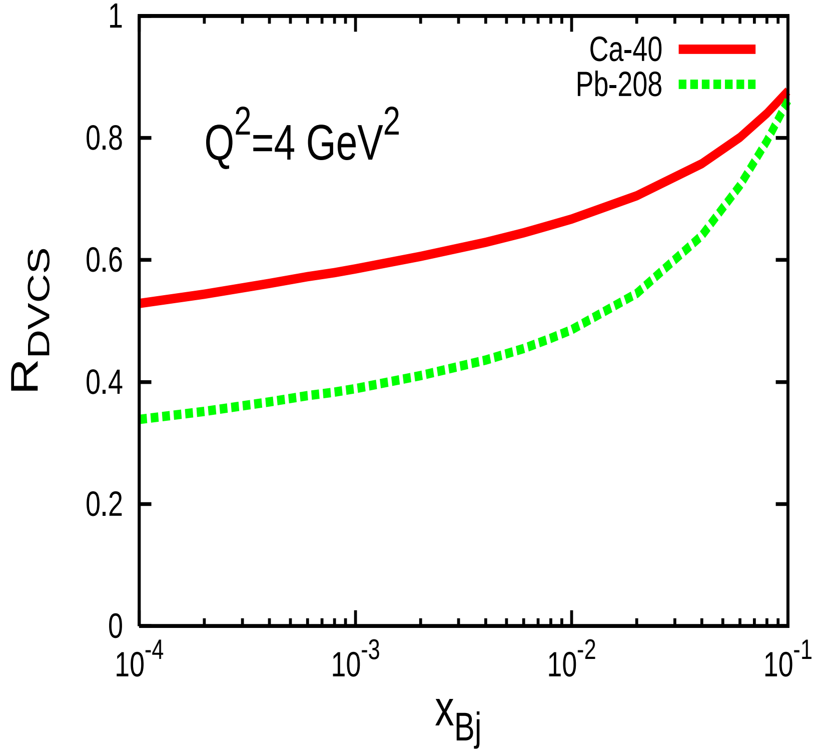
Generalization of the dual parameterization to the case of nuclear GPDs allows to express

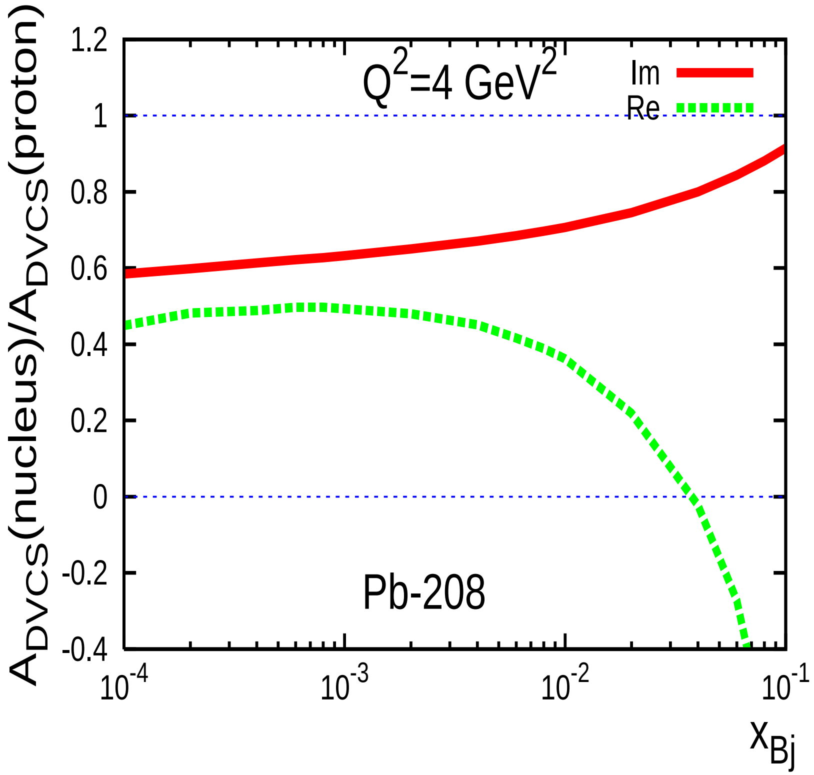
$$\mathcal{A}^{\mathrm{LO}}_{\mathrm{DVCS}}(\xi, t, Q^2) \quad \text{in terms of} \quad q_A(x, Q^2)$$

– $q_A(x, Q^2)$ are given by LT theory of NS

Predictions for DVCS

Predictions of the resulting model of nuclear GPDs for DVCS on nuclear targets





Ratio of t-integrated DVCS cross sections,

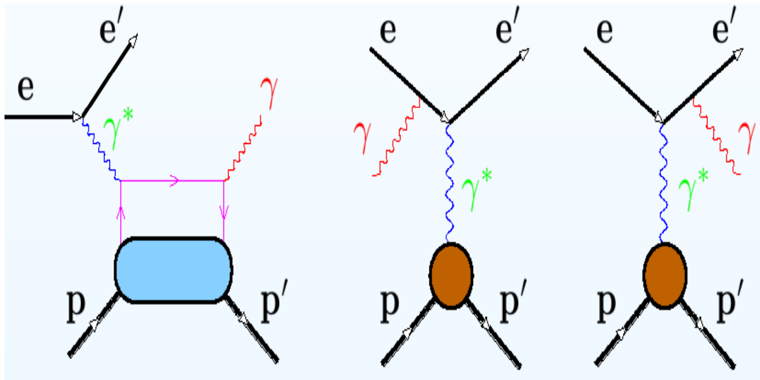
$$R_{\rm DVCS} = \frac{\sigma_{\rm DVCS}}{\sigma_{\rm DVCS}(\text{no NS})}$$

Ratio of nucleus/proton DVCS amplitudes

$$R = \frac{\mathcal{A}^A_{\rm DVCS}(t_{\rm min})}{\mathcal{A}^p_{\rm DVCS}(t_{\rm min})}$$

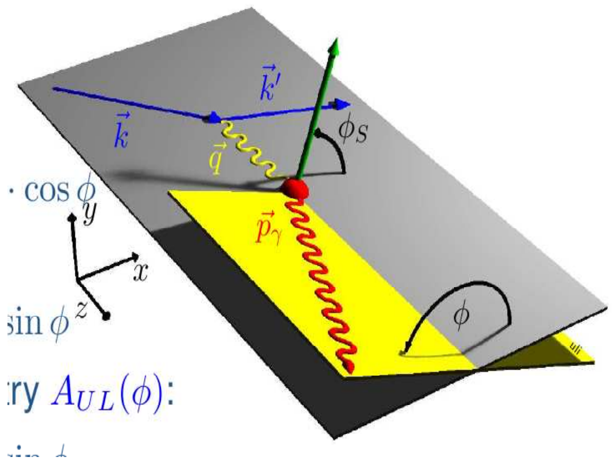
Predictions for DVCS

Contributions of the imaginary and real parts of DVCS amplitudes can be separated by measuring DVCS asymmetries arising due to the interference with the purely EM Bethe-Heitler process:



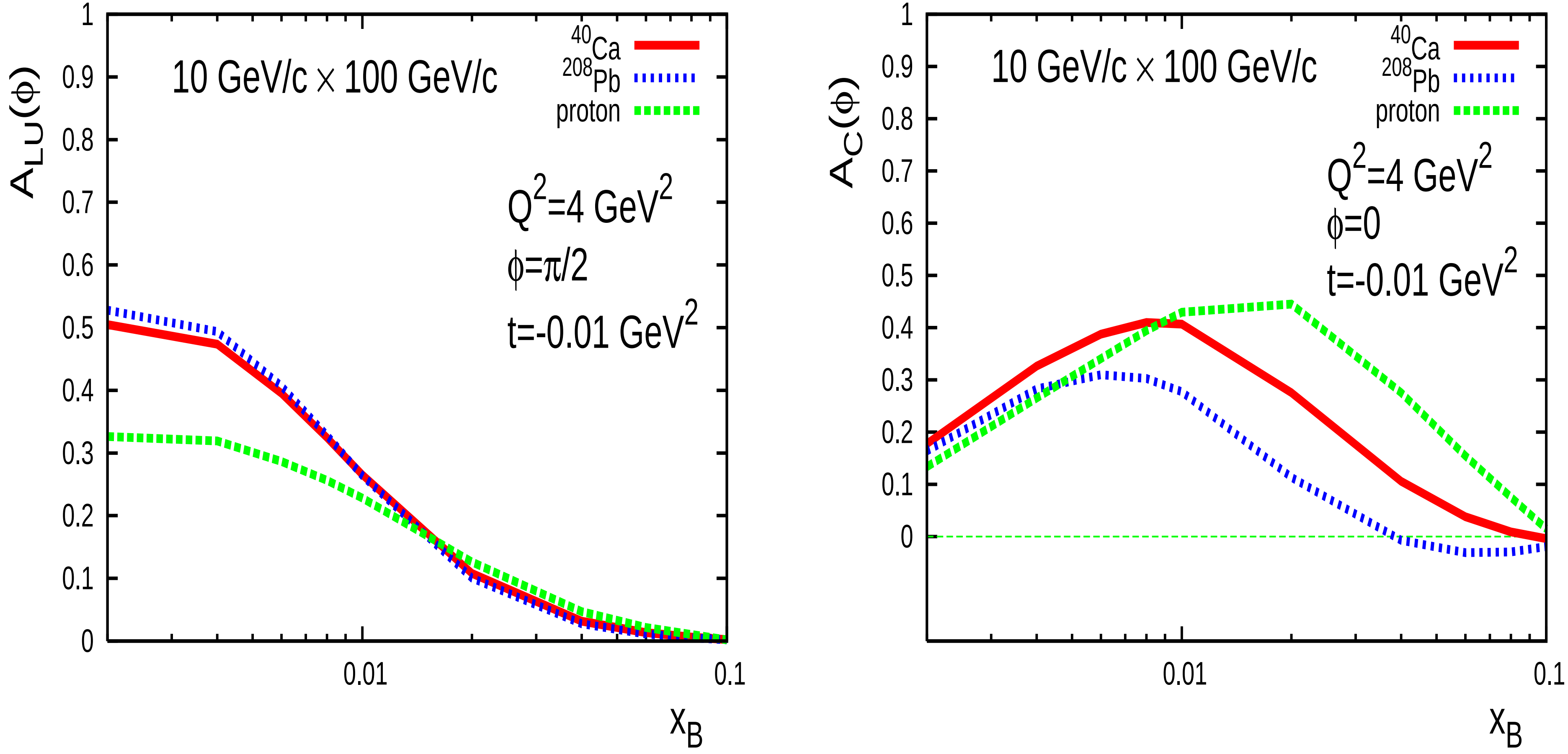
- Beam-spin asymmetry $A_{\mathrm{LU}}(\phi)$:
  $d\sigma(\vec{e},\phi) - d\sigma(\vec{e},\phi) \propto \mathrm{Im}\mathcal{H}\sin\phi$

- Beam-charge asymmetry $A_{\mathrm{C}}(\phi)$:
  $d\sigma(e^{+},\phi) - d\sigma(e^{-},\phi) \propto \mathrm{Re}\mathcal{H}\cos\phi$



Predictions for DVCS

Predictions for $A_{\rm LU}(\phi)$ and $A_{\rm C}(\phi)$



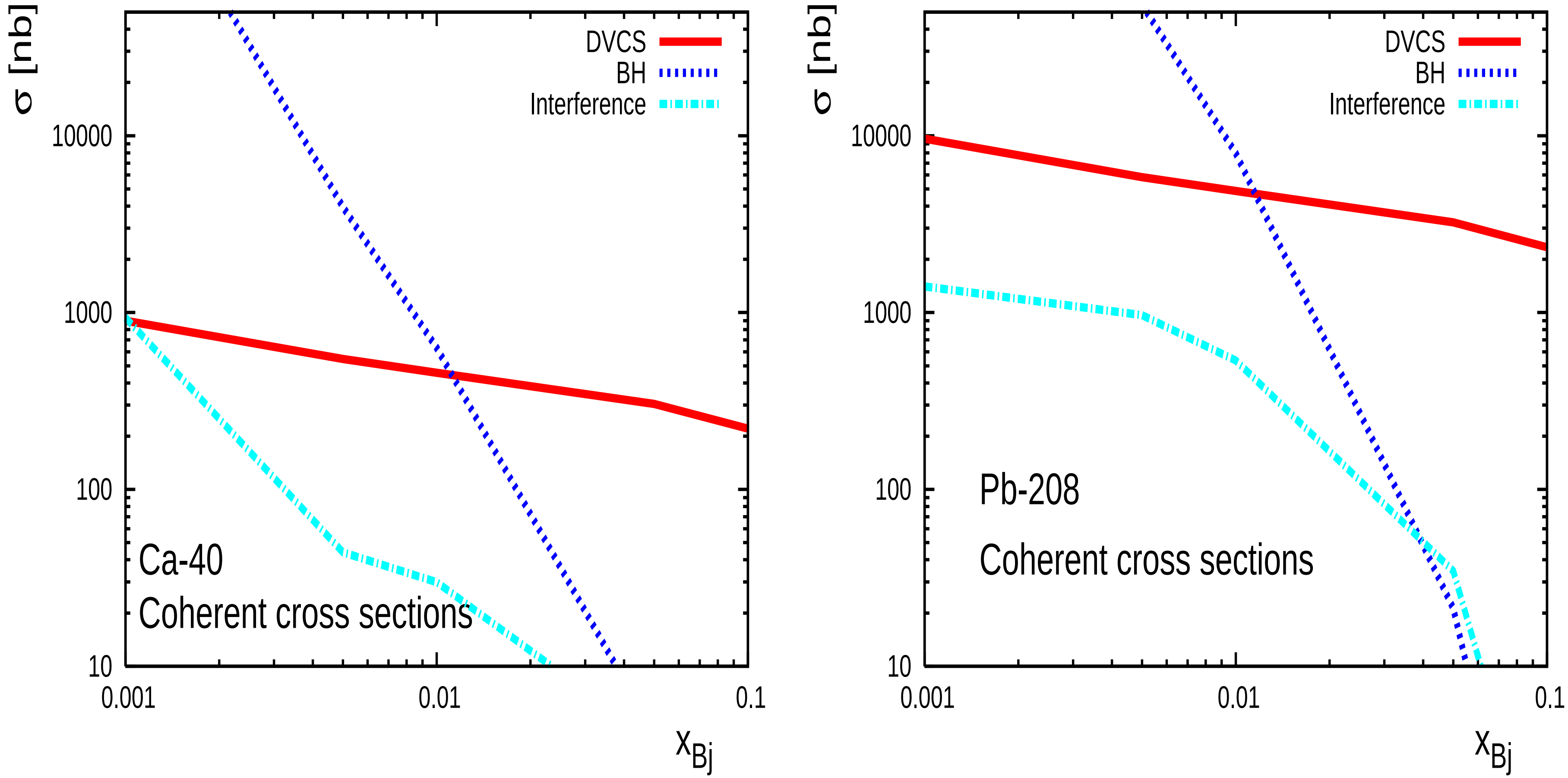
Conclusions

- Studies of DVCS and other hard exclusive processes with nuclei and extraction of nuclear GPDs is a natural continuation of studies of small-x physics with fixed nuclear targets.

- In particular, GPDs contain information on the distribution of quarks and gluons both in the longitudinal and transverse directions.

- DVCS appears to be rather sensitive to LT nuclear shadowing and antishadowing at small-x. This is observed both in DVCS cross sections and in DVCS asymmetries. (A_{C} which probes the real part of DVCS amplitude is especially sensitive.)

Back-up


σ [nb]
DVCS
BH
Interference
10000
1000
100
10
0.001
0.01
0.1
x_{Bj}
Ca-40
Coherent cross sections
Pb-208
Coherent cross sections