Coherent and Incoherent Nuclear Exclusive Processes

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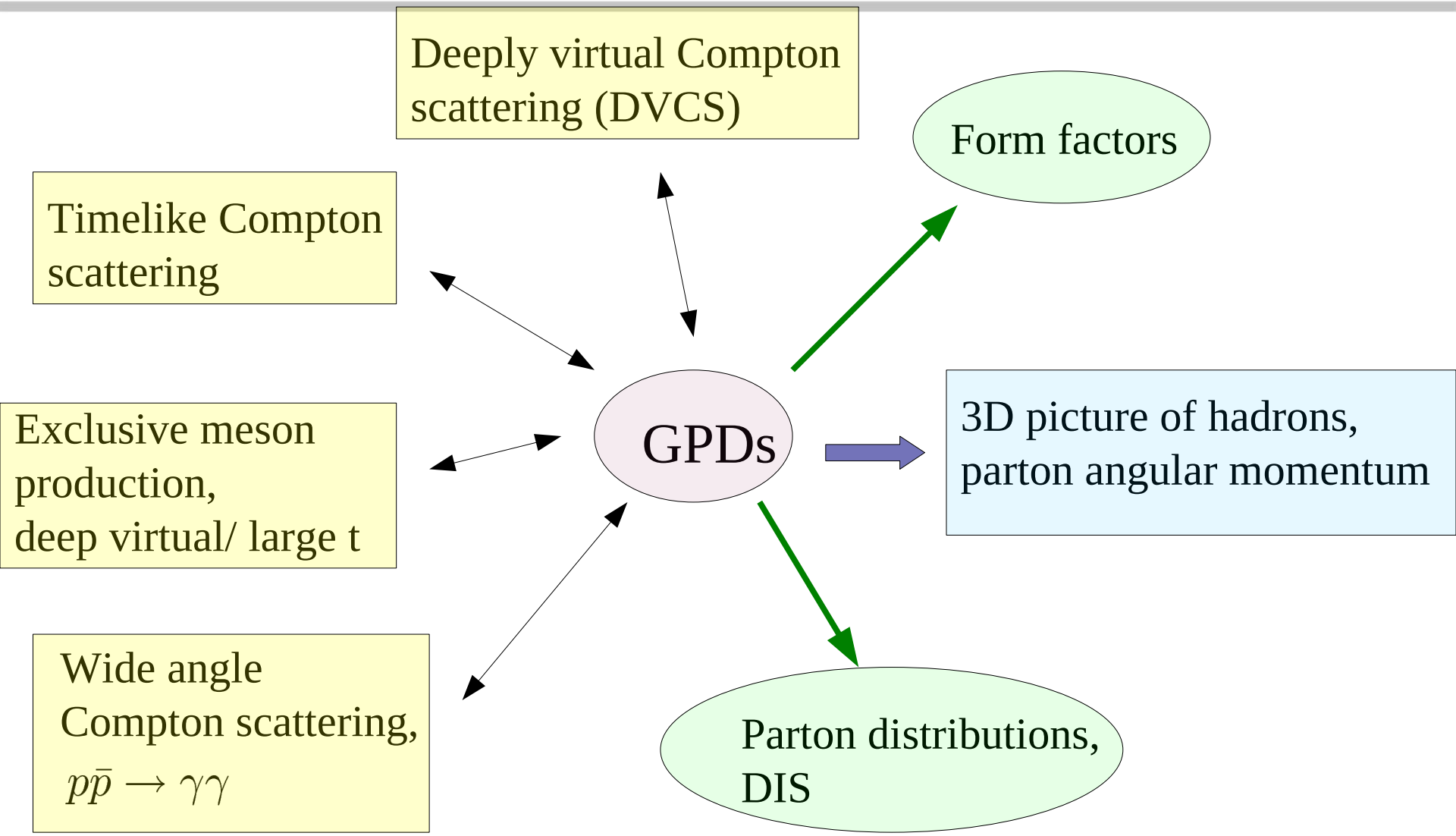
Outline

- Coherent and incoherent nuclear DVCS
- Coherent nuclear DVCS and nuclear shadowing
- Other interesting observations and ideas for nuclear exclusive reactions
- Conclusions

Generalized parton distributions

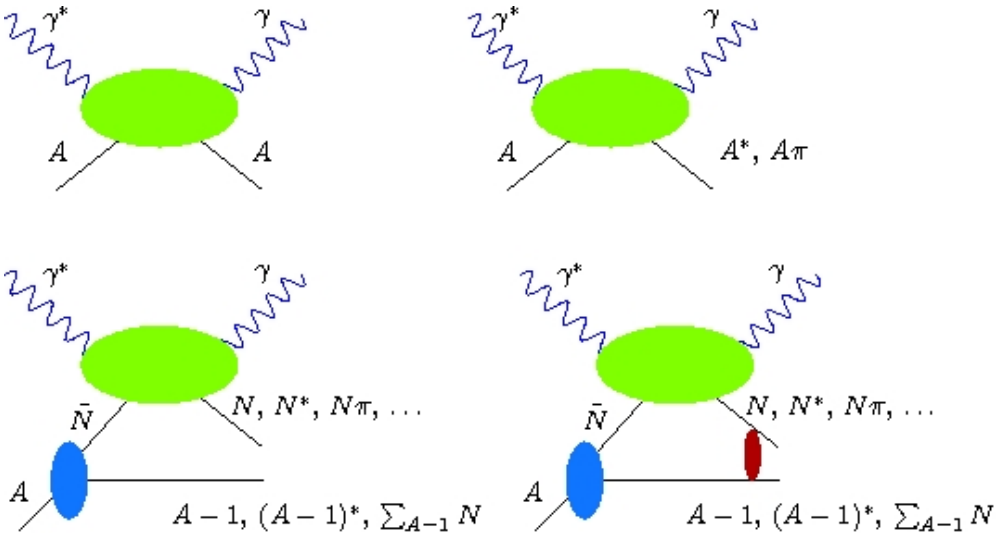


Coherent and Incoherent nuclear DVCS

The cleanest process to study GPD is deeply virtual Compton scattering (DVCS).

Nuclear DVCS is more complex and versatile than DVCS on protons:

- many more final states can be excited: coherent and incoherent DVCS
- hadronic final state interactions
- targets with different spin and isospin



DVCS with nuclei

Complimentary to proton DVCS

- nuclear GPDs involve proton and neutron GPDs -> access to different spin/flavor combinations
- 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

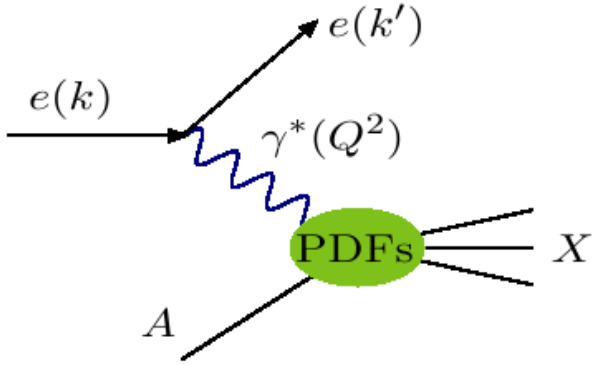
- off-diagonal EMC effect
- nuclear shadowing

"New" nuclear effects

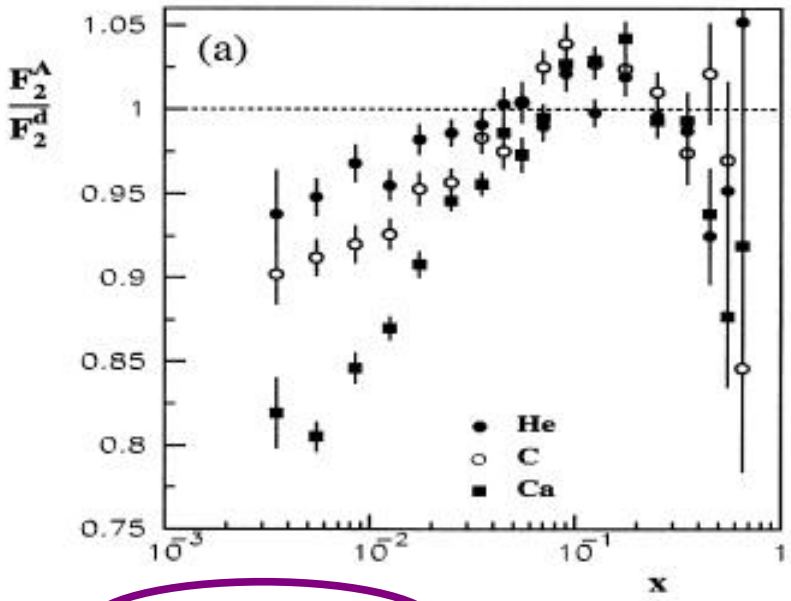
- medium modifications of bound nucleon GPDs
- non-nucleon degrees of freedom

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

- Global fits to extract nuclear PDFs lead to large uncertainties at small x

- Alternative to fitting: dynamical models of nuclear shadowing:
  -- LT theory of nuclear shadowing

  -- dipole models and CGC

Leading twist theory of nuclear shadowing

The leading twist theory of nuclear shadowing is an approach to calculate nuclear parton distributions (PDFs) as functions of x and b at some scale Q_0^2.

The Q^2 dependence is given by DGLAP.

The approach is based on:

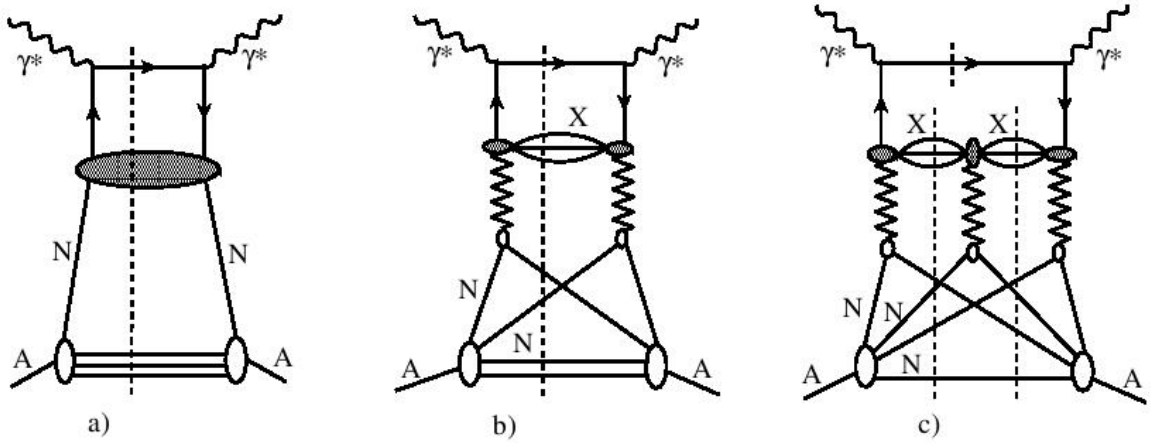
- generalization of Gribov's theory of nuclear shadowing to DIS and to arbitrary nuclei
  Frankfurt and Strikman, '88 and '98

- collinear factorization theorem for inclusive and diffractive DIS
  J. Collins '98

- QCD fits to HERA measurement of diffraction in ep DIS

Leading twist theory of nuclear shadowing-2

Graphical representation for nuclear quark PDFs:



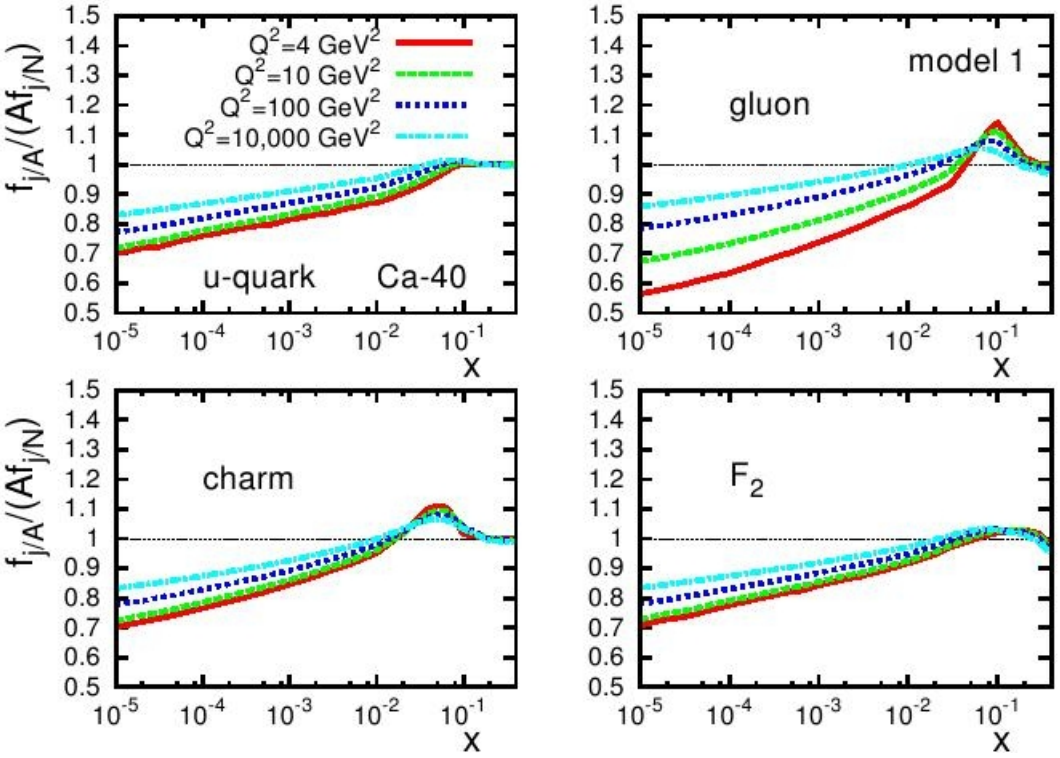
$$x f_{j/A}(x,Q^2) = A x f_{j/N}(x,Q^2)$$

$$- x f_{j/N}(x,Q^2) 8\pi A(A-1)\,\Re e \frac{(1-i\eta)^2}{1+\eta^2} B_{\rm diff} \int_x^{0.1} dx_{I\!P}\, \beta f_j^{D(3)}(\beta,Q^2,x_{I\!P})$$

$$\times \int d^2b \int_{-\infty}^{\infty} dz_1 \int_{z_1}^{\infty} dz_2 \rho_A(\vec{b},z_1)\rho_A(\vec{b},z_2) e^{i(z_1-z_2)x_{I\!P} m_N} e^{-\frac{A}{2}(1-i\eta)\sigma_3^j(x,Q^2)\int_{z_1}^{z_2} dz' \rho_A(\vec{b},z')}, \quad (57)$$

diffractive PDFs and slope B
nuclear density
rescattering cross section

Predictions for nuclear PDFs



Frankfurt, VG, Strikman, 2010 (in preparation)

- shadowing is large
- gluon shadowing > quark shadowing
- large shadowing in $F_L^A(x,Q^2)$
- same approach for nuclear diffractive PDFs

EIC is an ideal place to test these predictions!

Impact parameter dependence

• LT theory of nuclear shadowing also gives impact parameter b dependence of nuclear PDFs:

$$x f_{j/A}(x,Q^2,b) = A\,T_A(b)\,x f_{j/N}(x,Q^2)$$
$$-\,8\pi A(A-1)B_{\rm diff}\,\Re e\frac{(1-i\eta)^2}{1+\eta^2}\int\limits_x^{0.1} dx_{I\!P}\,\beta f_j^{D(3)}(\beta,Q^2,x_{I\!P})$$
$$\times\int\limits_{-\infty}^{\infty} dz_1\int\limits_{z_1}^{\infty} dz_2\,\rho_A(\vec{b},z_1)\rho_A(\vec{b},z_2)\,e^{i(z_1-z_2)x_{I\!P}m_N}\,e^{-\frac{A}{2}(1-i\eta)\sigma_3^j(x,Q^2)\int_{z_1}^{z_2}dz'\rho_A(\vec{b},z')}\,,$$

• Impact parameter dependent nuclear PDFs=nuclear GPDs in the xi=0 limit:

$$f_{j/A}(x,Q^2,b) = H_A^j(x,\xi=0,b,Q^2)\,.$$

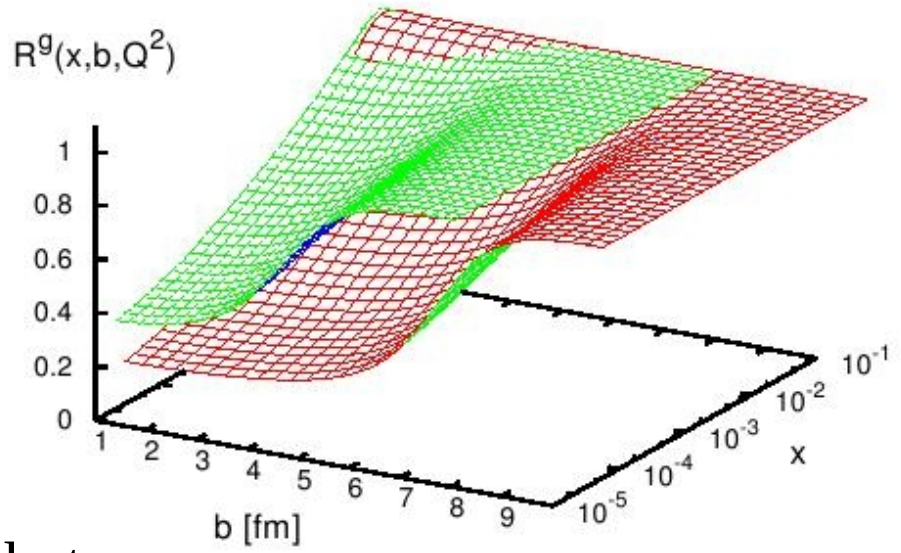
Intuitively clear – M. Strikman
Formal proof – Goeke, VG and M. Siddikov, '09

Nuclear GPDs at xi=0

$$R^j(x,b,Q^2) = \frac{f_{j/A}(x,Q^2,b)}{A\,T_A(b)\,f_{j/N}(x,Q^2)} = \frac{H^j_A(x,\xi=0,b,Q^2)}{A\,T_A(b)\,f_{j/N}(x,Q^2)}\,.$$

Frankfurt, VG, Strikman, 2010 (in preparation)

Density of nucleons at given b



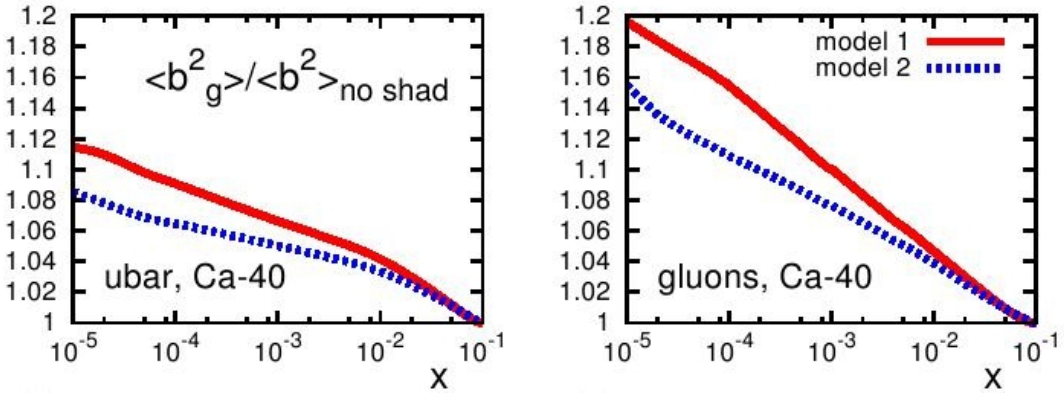
- Nuclear shadowing is larger at small b
- Shadowing introduces correlations between x and b, even if such correlations are absent for free nucleon

Spacial image of nuclear shadowing can be studied using coherent exclusive reactions with nuclei (DVCS, VM production)

Increase of parton transverse size

- Impact-parameter dependent nuclear shadowing leads to an **increase** of transverse size of partons (quarks and gluons) in nuclei

$$\langle b_g^2 \rangle = \frac{\int d^2b\, b^2 g_A(x,Q^2,b)}{\int d^2b\, g_A(x,Q^2,b)} \,. \qquad \langle b^2 \rangle_{\text{no shad}} = \frac{\int d^2b\, b^2 A T_A(b) f_{j/N}(x,Q^2)}{\int d^2b\, A T_A(b) f_{j/N}(x,Q^2)} = \int d^2b\, b^2 T_A(b) \,.$$



- *This has experimentally testable consequences*:
  -- position of the minima of DVCS cross section shifts towards smaller t
  -- dramatic oscillations of DVCS asymmetries

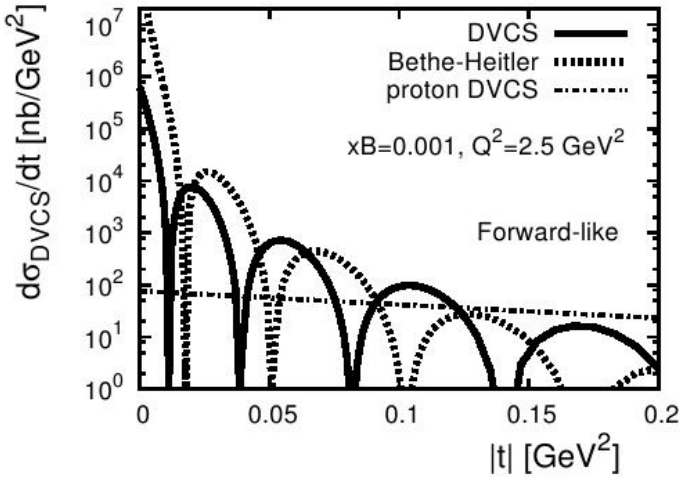
K. Goeke, VG, M. Siddikov, PRC 79 (2009) 035210

LT nuclear shadowing and coherent nuclear DVCS

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

- The DVCS and BH cross sections for Pb-208 integrated over phi

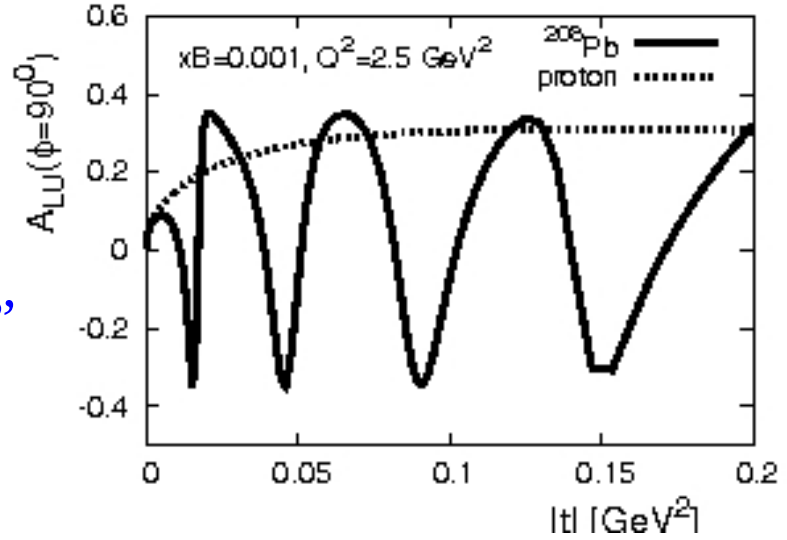
The shift is the measure of nuclear shadowing (In the example, Δt=0.006 GeV^2)



Similar pattern also for diffractive VM production

- The beam-spin DVCS asymmetry

The reason for the oscillations is shadowing, position of nodes measures the strength of shadowing



Interesting observations and ideas for nuclear exclusive reactions

- Nuclear shadowing for CFFs is large.
  The trend of shadowing for the real part of nuclear CFFs is very unexpected.
  A. Freund and M. Strikman, PRC 69, 0152003 (2004)

- Non-nucleon (meson) degrees of freedom seem to be enhanced;
  they leads to fast non-trivial A-dependence of the nuclear D-term
  M.V.Polyakov, PLB 555, 57 (2003); VG and M. Siddikov, J. Phys. G 32, 251 (2006)

- Off-diagonal EMC effect is much larger than in DIS
  S. Scopetta, PRC 70, 015205 (2004) and PRC 79, 025207 (2009);
  S. Liuti and S.K. Taneja, PRC 72, 032201 (2005) and 034902 (2005)

- Bound nucleon GPDs ≠ free nucleon GPDs. Can be tested experimentally
  in incoherent nuclear DVCS
  VG, A.W. Thomas, and K. Tsushima, PLB673, 9 (2009) and PRC 79, 055205 (2009)
  S. Liuti and S.K. Taneja, PRC 72, 032201 (2005) and 034902 (2005)

Interesting observations and ideas for nuclear exclusive reactions-2

- *New suggestion by M. Strikman*: Probe medium modifications of *gluon GPDs* in quasi-elastic J\Psi production on nuclei

- Electroproduction of pseudoscalar mesons on ^{3}He at small t probes GPDs of the neutron (gamma*$_L$+^{3}He -> π^0 + ^{3}He) or proton (gamma*$_L$+^{3}He -> π^++ ^{3}H)
  L. Frankfurt *et al*., PRD 60, 014010 (1999)

- Electro-production of pseudoscalar mesons on deuteron is sensitive to non-pole contribution to the GPD Etilde
  F. Cano and B. Pire, EPJ. A 19, 423 (2004)

- Coherent processes with nuclei sensitive to parton saturation
  M.V.T. Machado, EPJ C 59, 769 (2009)
  K. Goeke, VG, and M. Siddikov, EPJ C 56, 203 (2008)

Summary

- Coherent and incoherent exclusive processes with nuclei contain important and novel info on nuclear GPDs and allow to study traditional and novel nuclear effects in off-diagonal kinematics
(see my summary slide in Introduction).

- The off-diagonal EMC effect, nuclear shadowing and antishadowing (?) can be studied by an EIC.

- Nuclear shadowing in nuclear DVCS and nuclear GPDs is large, and leads to an increase of transverse size of partons in nuclei which is measurable -- the shift of the minima of DVCS cross section and oscillations of DVCS asymmetries.