Nuclear shadowing and nuclear parton distributions

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Outline

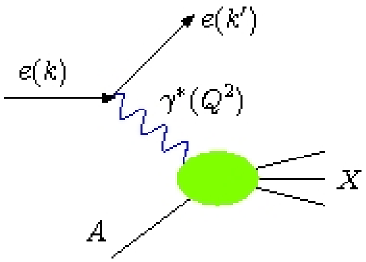
- Nuclear parton distributions
- Leading twist nuclear shadowing and nuclear PDFs
  - usual nuclear PDFs
  - nuclear GPDs
- Summary

Partonic structure of nuclei at EIC

Accessed in hard (large Q^2) processes with nuclei using QCD factorization theorems:

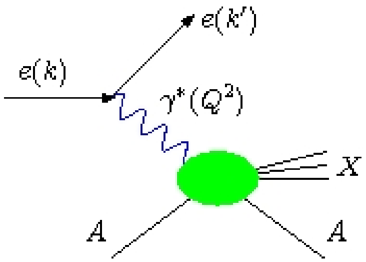
- **Usual** parton distributions

  from $F_{2A}(x,Q^2)$, $F_L(x,Q^2)$ in eA DIS



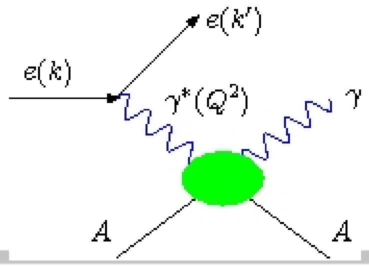
- **Diffractive** parton distributions

  from $F_{2A}{}^{D(3)}(x,Q^2,x_P)$ in diffraction in eA DIS



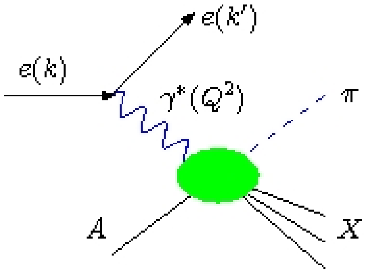
- **Generalized** parton distributions

  from DVCS and meson electroproduction



- **Transverse** moment. dependent

  from SIDIS



Partonic structure of nuclei at EIC-2

- Various PDFs contain fundamental information on different aspects of distribution/correlation of partons in nuclei.
- Modified (expected to be modified) in nuclei compared to free proton due to various nuclear effects, see talk by I. Cloet
- The dominant effect at small Bjorken x – nuclear shadowing

- **Usual nuclear parton distributions**
  - longit. distribution of partons
  - poorly known from fixed-target DIS, nuclear DY and RHIC inclusive pion
  - reliable nuclear PDFs needed for interpretation of RHIC and LHC data on pA and AA (saturation vs. non-saturation; IS vs FS effects)

see talk by L. Zhu

- **Diffractive parton distributions and structure functions**
  - never been measured
  - test for many approaches (LT vs. dipole models)
  - more sensitive to saturation than inclusive DIS

see talks by M. Lamont and L. Frankfurt

Partonic structure of nuclei at EIC-3

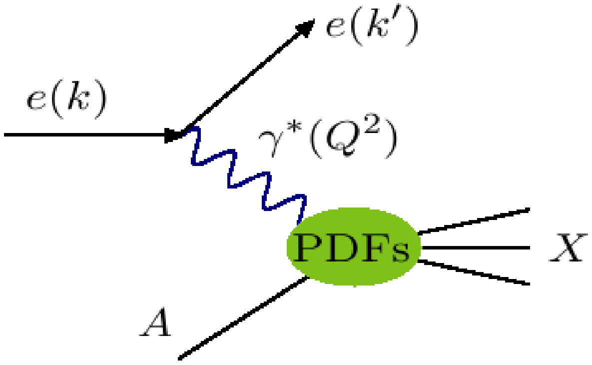
- **Generalized parton distributions**
  - 3D correlations/distributions of partons
  - measured for ^{4}He at JLab 6 GeV, plans for 12 GeV
  - standard nuclear effects enhanced: EMC, shadowing
  - non-standard effects also enhanced: bound nucleon medium modifications, non-nucleon degrees of freedom

see talk by S. Liuti

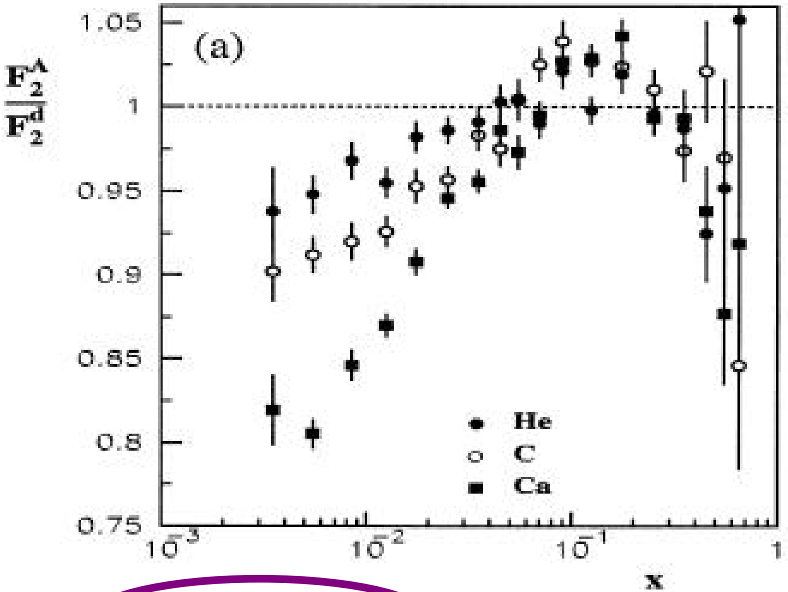
- **TMDs in nuclei**
  - very new idea, see H. Avakian's talk
  - method to access x-kT correlations

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

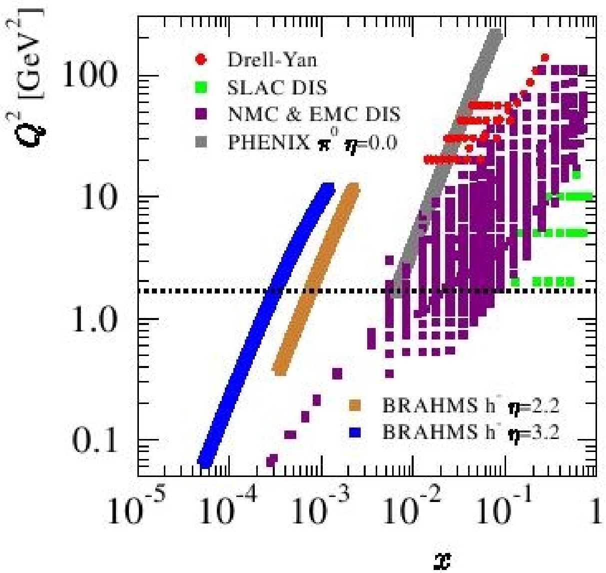
- Global fits to extract nuclear PDFs
  lead to HUGE uncertainties at small x

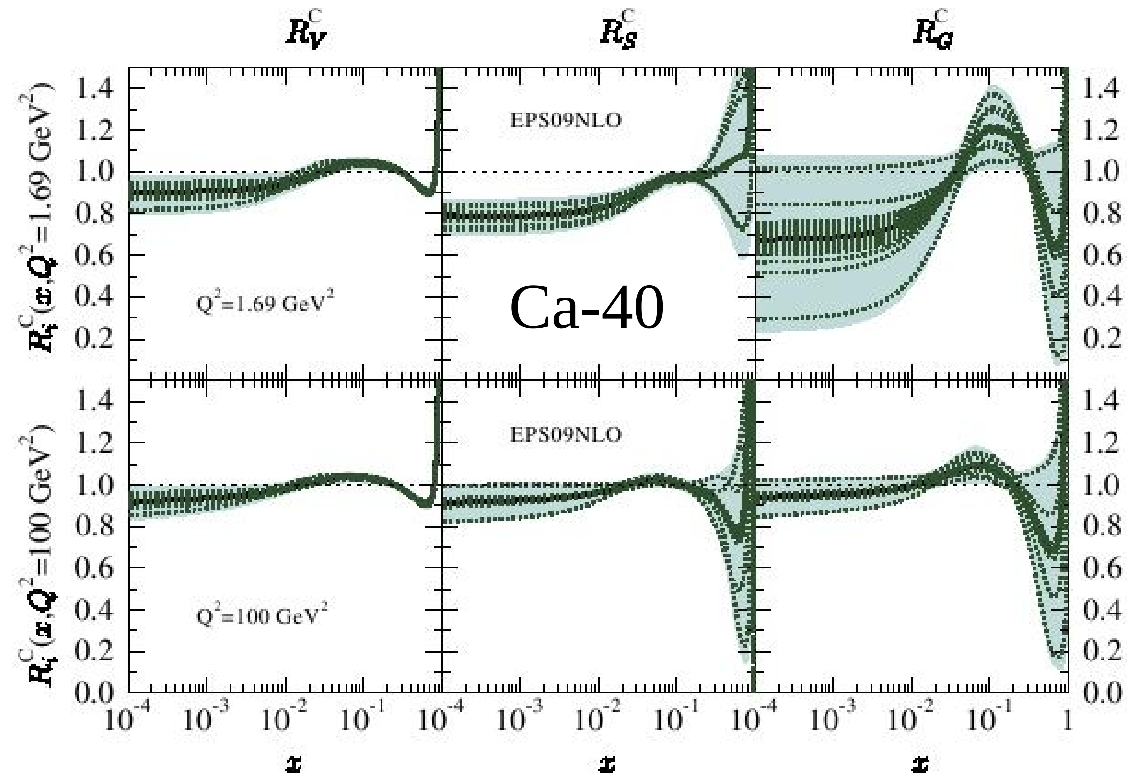
- Dynamical models of nuclear shadowing:
  - LT theory of nuclear shadowing
  - dipole models (LT + HT)
  - HT shadowing

  J.-w. Qiu and I. Vitev, PRL 93 (2004) 262301

EPS09 nuclear PDFs

Example of extraction of NLO nuclear PDFs and their uncertainties from available data, Eskola, Puukkunen, Salgado, JHEP 04 (2009) 065





Before EIC, pA scattering at LHC should help to better constrain nPDFs and resolve discrepancy between different scenarios (shadowing and EMC for glue)
Quiroga-Arias, Milhano, Wiedermann, arXiv: 1002:2537

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:

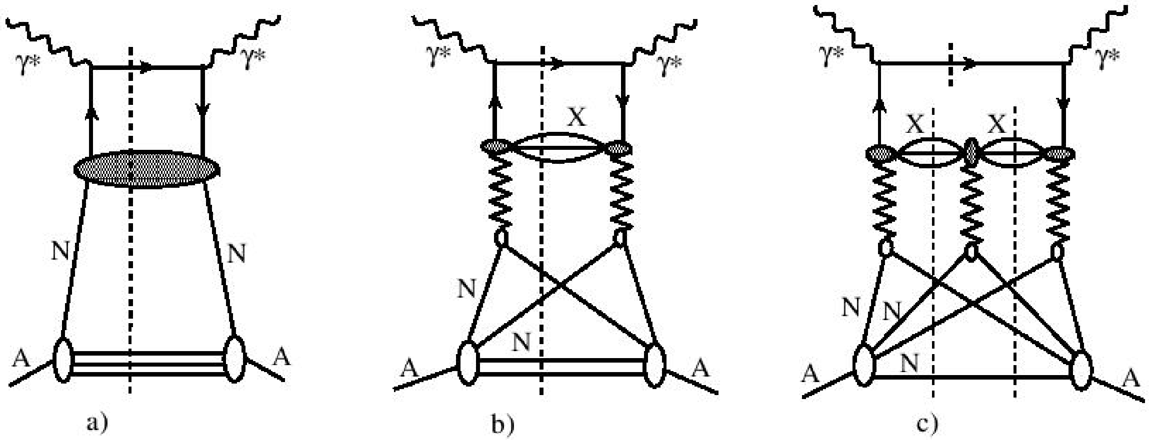
- generalization of Gribov's theory of nuclear shadowing to DIS and to arbitrary nuclei
  Frankfurt and Strikman, '88 and '98

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

- QCD fits to HERA measurement of diffraction in ep DIS
  H1 and ZEUS Collab. 2006

Leading twist theory of nuclear shadowing-2

Graphical representation for nuclear quark PDFs:



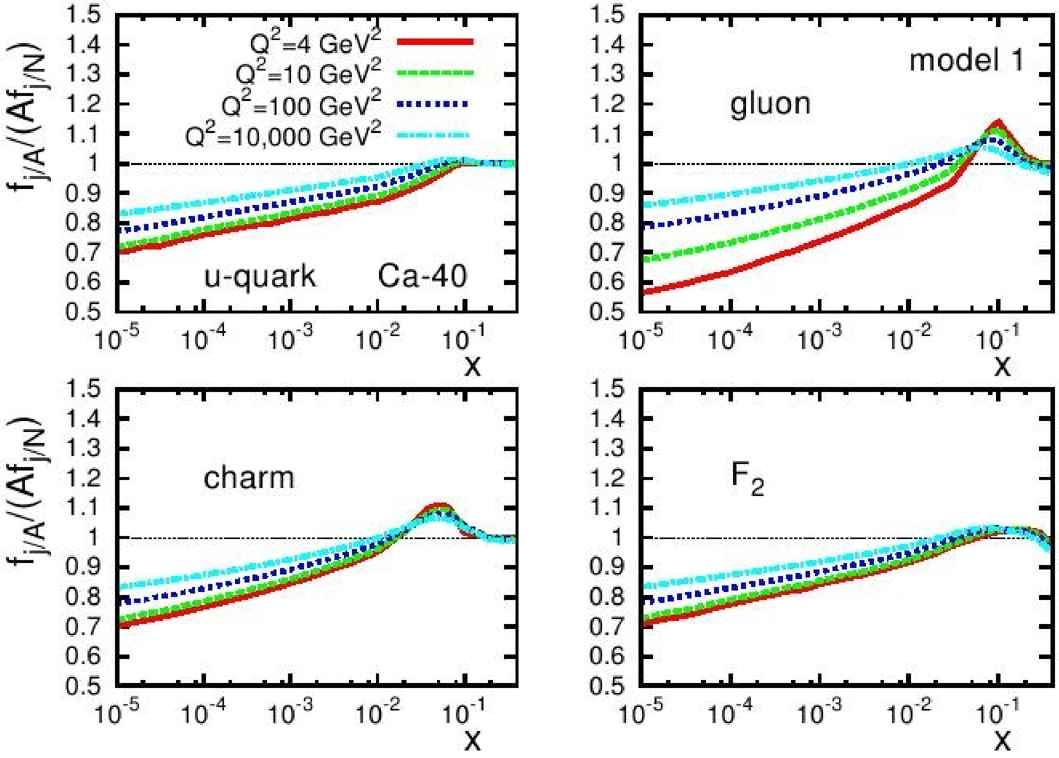
+ interaction with N > 3 nucleons

$$x f_{j/A}(x,Q^2) = A x f_{j/N}(x,Q^2)$$
$$- x f_{j/N}(x,Q^2) 8\pi A(A-1)\,\Re e\frac{(1-i\eta)^2}{1+\eta^2} B_{\rm diff}\int_x^{0.1} dx_{I\!P}\,\beta f_j^{D(3)}(\beta,Q^2,x_{I\!P})$$
$$\times \int d^2b \int_{-\infty}^{\infty} dz_1 \int_{z_1}^{\infty} dz_2\, \rho_A(\vec{b},z_1)\rho_A(\vec{b},z_2) e^{i(z_1-z_2)x_{I\!P} m_N} e^{-\frac{A}{2}(1-i\eta)\sigma_3^j(x,Q^2)\int_{z_1}^{z_2} dz' \rho_A(\vec{b},z')}, \quad (57)$$

Input:

- diffractive PDFs and slope B
- nuclear density
- rescattering cross section for N ≥ 3 nucleons

Predictions for nuclear PDFs



Frankfurt, VG, Strikman, 2010 (in preparation)

- shadowing is large
- gluon shadowing > quark shadowing
- large shadowing in $F_L{}^A(x,Q2)$
- same approach for nuclear diffractive PDFs and GPDs

EIC is an ideal place to test these predictions!

Glauber-Gribov model of shadowing

Capella *et al*., EPJ C 5 (1998) 111
Armesto *et al*., EPJ C 29 (2003) 531

- Similarly to LT theory of shadowing, uses the connection between shadowing and diffraction
- Different modeling of interaction with N≥3 nucleons
- Inconsistent treatment of QCD evolution
- Neglect of effect of coherence length

Tywoniuk *et al*, PLB 657 (2007) 170

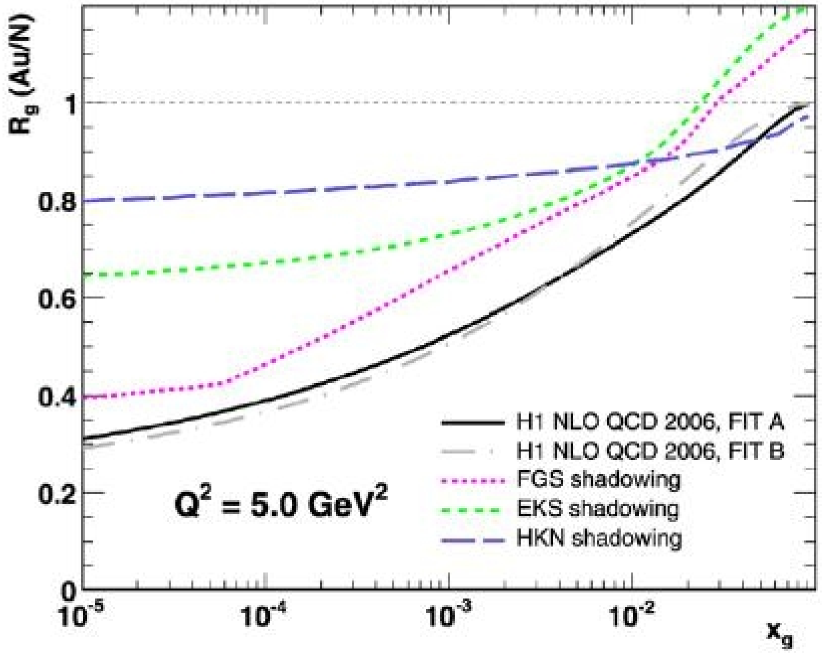
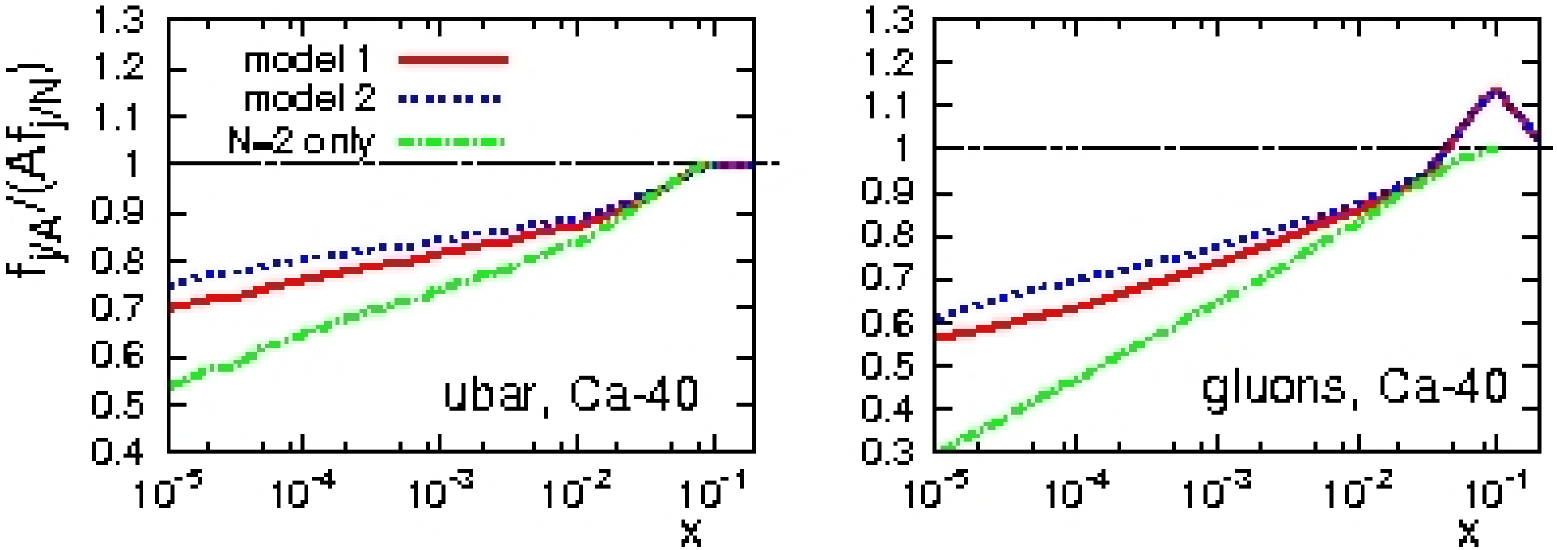


Fig. 5. Comparison of the results of the Glauber–Gribov model with FGS model [24], EKS [33] and HKM [34] parameterizations.

Model-independent shadowing at medium energies

For x > 0.005, double scattering dominates and LT predictions become model-independent.



In this kinematics:

- Measurements of shadowing will test the entire formalism
- Measuring shadowing with one (light nucleus), one can predict for any A
- One can predict HT contribution to shadowing

Impact parameter dependence

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

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

- 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 – K. Goeke, VG and M. Siddikov, '09

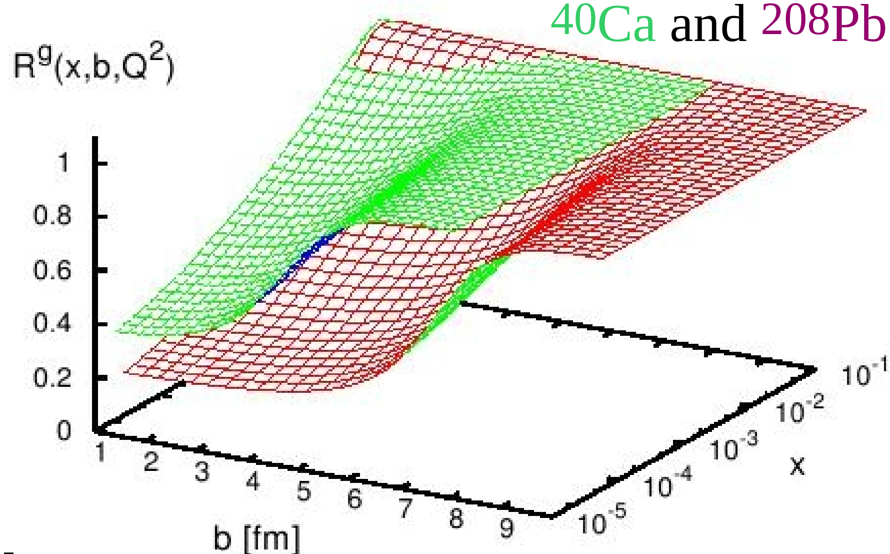
Nuclear GPDs at xi=0

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

Frankfurt, VG, Strikman, 2010 (in preparation)

Density of nucleons at given b

^{40}Ca and ^{208}Pb



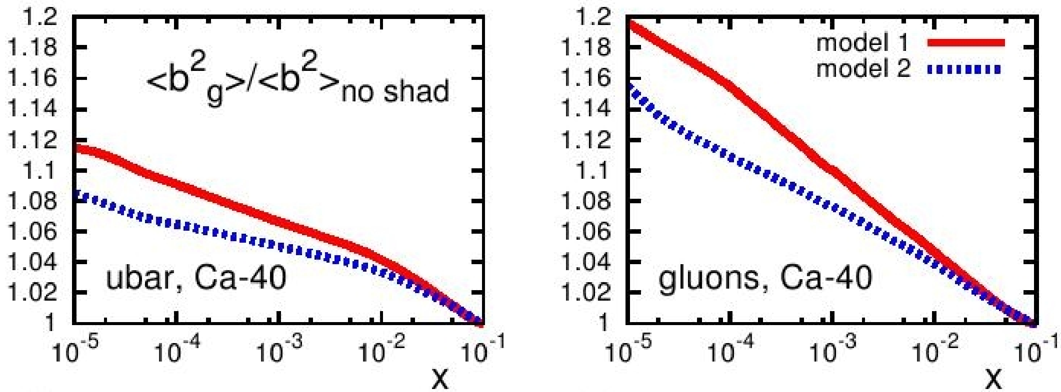
- Nuclear shadowing is larger at small b
- Shadowing introduces correlations between x and b, even if such correlations are absent for free nucleon

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

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



- *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

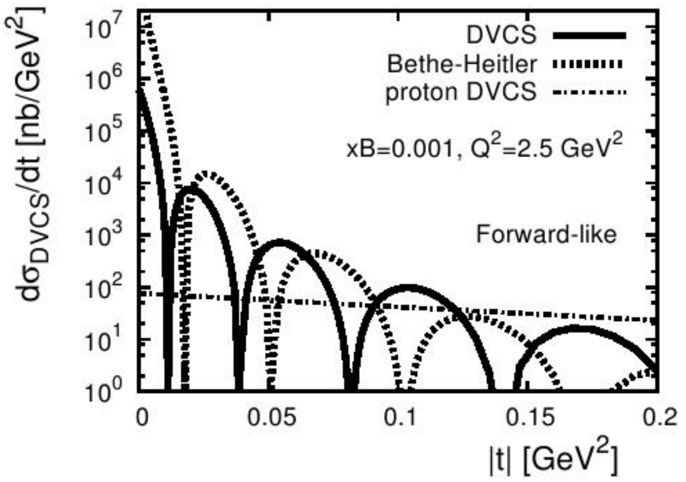
LT nuclear shadowing and coherent nuclear DVCS

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

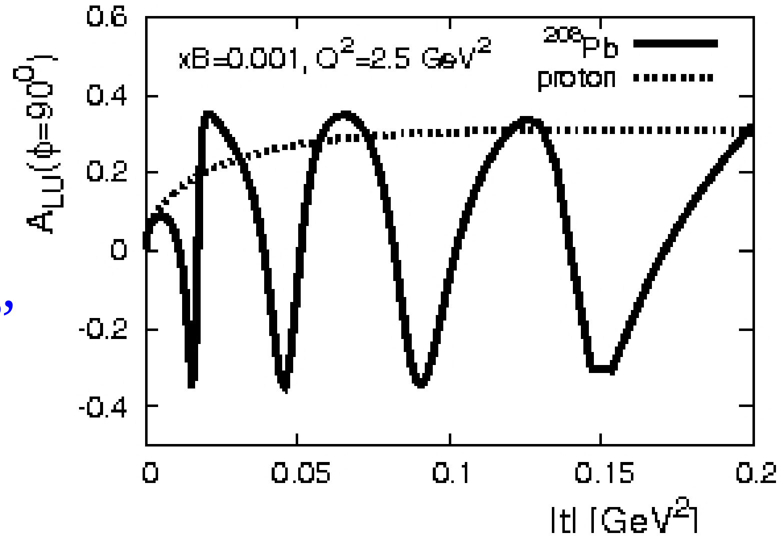
(In the example, Δt=0.006 GeV2)



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



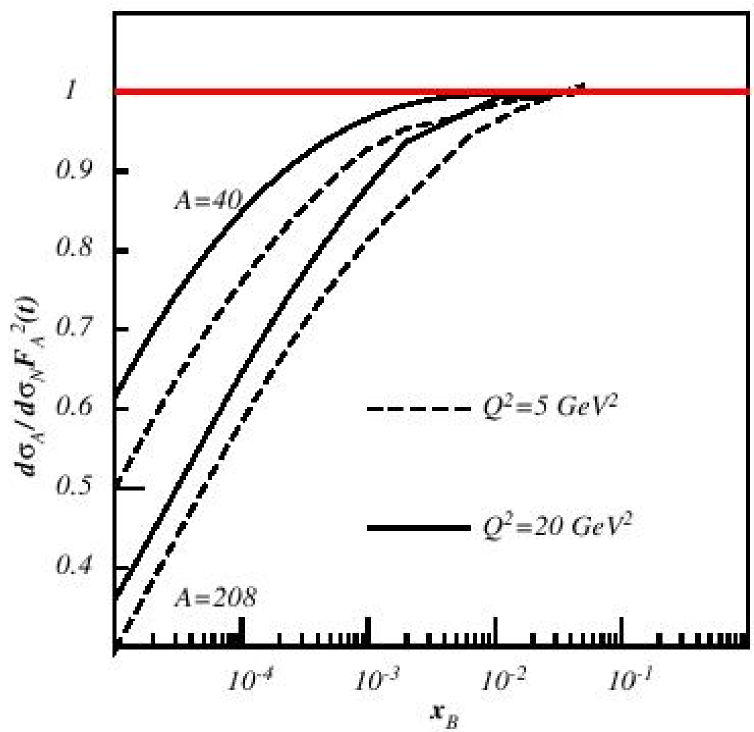
Dipole formalism and shadowing in nuclear DVCS

Predictions of large nuclear shadowing in coherent and incoherent DVCS and real Compton scattering with nuclei in dipole formalism (LT+HT)

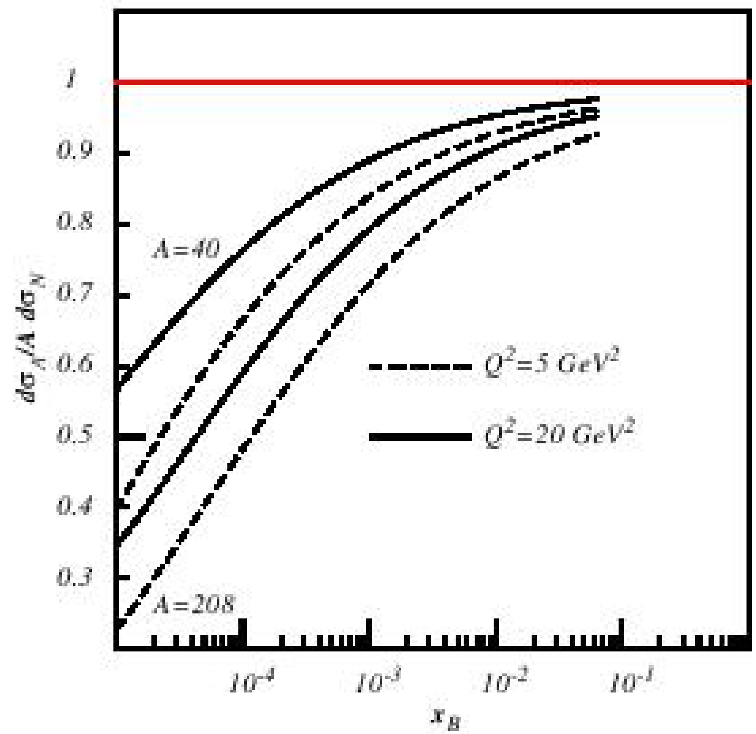
Kopeliovich, Schmidt, Siddikov, arXiv:1003:4188

see also earlier work on nuclear DVCS by Machado, arXiv:0810.3665

coherent



incoherent



Summary

- Fundamental nuclear PDFs are either poorly known or unknown in a wide kinematics region, especially at small values of Bjorken x.

- Nuclear shadowing strongly suppresses all types of nPDFs (usual, diffractive, generalized, TMDs (?))

- Reliable nuclear PDFs in the shadowing domain need for phenomenology of pA and AA at RHIC and LHC and important by themselves (competing models of shadowing, onset of saturation, etc.)

- Nuclear shadowing in nuclear DVCS and nuclear GPDs is large. It leads to an increase of transverse size of partons in nuclei.

EIC in an ideal (only) machine to study nuclear shadowing in different nuclear parton distributions.