Nuclear DVCS

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Outline

Introduction

- 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).
- GPDs are more general than elastic FFs and PDFs.
- GPDs contain information on 3D distributions and correlations of partons in the target.

Introduction

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 on nuclear targets
- To test theoretical models of the nuclear structure (relativistic effects are important for GPDs)

Introduction

Complementarity of nuclear DVCS

- Coherent DVCS on any nucleus at small $t \rightarrow$ test of models of GPDs of the proton and the neutron
- DVCS on light nuclei of D and ^{3}He at large $t \rightarrow$ GPDs of the neutron
- DEMP of pseudoscalar mesons on ^{3}He $\rightarrow$ GPDs of the neutron
- DEMP of pseudoscalar mesons on D $\rightarrow$ non-pole contribution to GPD $\tilde{E}$

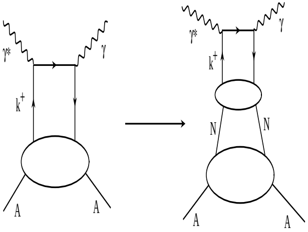
Introduction

Novel nuclear effects in nuclear DVCS

- DVCS on heavy nuclei (^{20}Ne, ^{84}Kr) $\rightarrow$ role of non-nucleon (meson) degrees of freedom
- DVCS on heavy nuclei at large energies ($\xi < 0.1$) $\rightarrow$ nuclear shadowing and antishadowing effects for the real and imaginary parts of the DVCS amplitude

Convolution approximation for nuclear GPDs

Currently, all models of nuclear GPDs rely on the convolution approximation "borrowed" from nuclear DIS.



$$H_A^q(x,\xi,t) = \sum_N \int_x^1 \frac{dy}{y} H_{i/A}(y,\xi,t) H_i^q\left(\frac{x}{y},\frac{\xi}{y},t\right)$$

- $H_{i/A}$ off-diagonal distribution of nucleons in nucleus
- H_i^q free nucleon GPD

Convolution approximation for nuclear GPDs

The convolution approximation for nuclear GPDs

- Gives correct expression for the forward limit of H_A^q (baryon number and momentum sum rules)
- Reproduces the nuclear form factor
- BUT: In general, violates polynomiality of H_A^q, even if H_N^q obey polynomiality
- HOWEVER: Polynomiality violation $\propto 0(p^2/m_N)$, which is the accuracy of the convolution approximation

DVCS on Deuteron

- L. L. Frankfurt, P. V. Pobylitsa, M. V. Polyakov and M. Strikman, Phys. Rev. D **60**, 014010 (1999)
- E. R. Berger, F. Cano, M. Diehl and B. Pire, Phys. Rev. Lett. **87**, 142302 (2001)
- A. Kirchner and D. Mueller, Eur. Phys. J. C **32**, 347 (2003)
- F. Cano and B. Pire, Eur. Phys. J. A **19**, 423 (2004)

DVCS on Deuteron

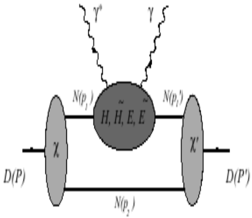
Deuteron with $J = 1$ has nine twist-2 quark GPDs

$$
\begin{aligned}
V_{\lambda'\lambda} &= \int \frac{dk}{2\pi} e^{ix2\bar{P}\cdot n} \langle P', \lambda' | \bar{\psi}(-kn) \hat{n} \psi(kn) | P, \lambda \rangle \\
&= \sum_{i=1}^{5} \epsilon'^{*\beta} V^{(i)}_{\beta\alpha} \epsilon^{\alpha} H_i(x, \xi, t) \\
A_{\lambda'\lambda} &= \int \frac{dk}{2\pi} e^{ix2\bar{P}\cdot n} \langle P', \lambda' | \bar{\psi}(-kn) \hat{n} \gamma_5 \psi(kn) | P, \lambda \rangle \\
&= \sum_{i=1}^{4} \epsilon'^{*\beta} A^{(i)}_{\beta\alpha} \epsilon^{\alpha} \tilde{H}_i(x, \xi, t)
\end{aligned}
$$

- $H_{1,2,3}$ and $\tilde{H}_{1,2}$ related to deuteron FFs
- $H_{1,5}$ and $\tilde{H}_1$ related to deuteron PDFs

DVCS on Deuteron

Convolution approximation

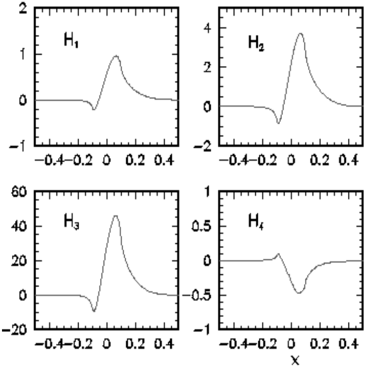


$$V^q_{\lambda'\lambda} = \frac{2}{16\pi^3}\int d\alpha d\alpha' d\vec{p}_{1\perp} d\vec{p}'_{1\perp}\sqrt{\frac{1+\xi}{1-\xi}}\frac{1}{\sqrt{\alpha\alpha'}} \delta^2(\vec{p}'_{1\perp}-\vec{p}_{1\perp}-\Delta_\perp)\delta(\alpha'-\frac{\alpha(1+\xi)-2\xi}{1-\xi}) \sum_{\lambda_1',\lambda_1,\lambda_2}\chi^*_{\lambda'}(\alpha',\vec{k}'_\perp,\lambda_1',\lambda_2)\chi_\lambda(\alpha,\vec{k}_\perp,\lambda_1,\lambda_2) \frac{1}{2}\int\frac{dk}{2\pi}\langle p_1',\lambda_1'|\bar{\psi}_q(-\frac{k}{2}n)\hat{n}\psi_q(\frac{k}{2}n)|p_1,\lambda_1\rangle$$

- χ_λ deuteron light-cone wf (obtained from NR wf)

DVCS on Deuteron

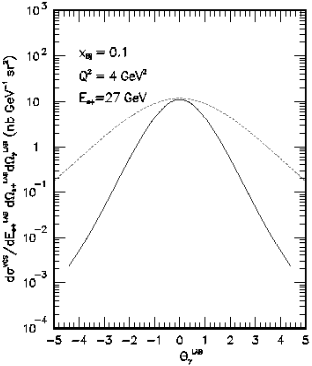
Predictions for Deuteron GPDs
$Q^2 = 2$ GeV^2, $\xi = 0.1$ and $t = -0.25$ GeV^2



- For H_N^q: double distribution model with factorized t-dependence

DVCS on Deuteron

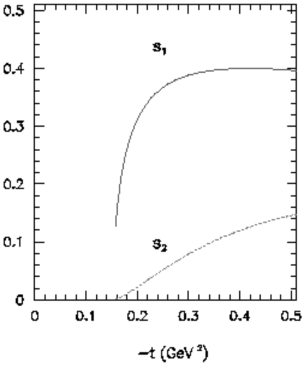
Predictions for the DVCS cross section



- Solid – deuteron; dashed – proton

DVCS on Deuteron

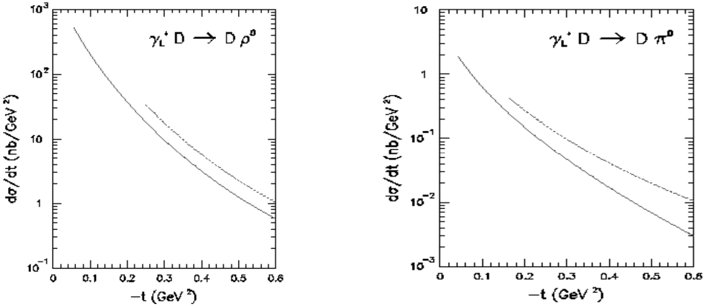
Predictions for DVCS beam-spin asymmetry A_{LU}
$E = 6$ GeV, $Q^2 = 2$ GeV^2 and $x = 0.2$



- $A_{LU} = a_0 + s_1 \sin\phi + s_2 \sin 2\phi$

DVCS on Deuteron

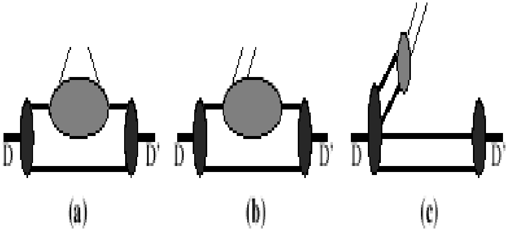
Predictions for DEMP on Deuterium



- Production of pseudoscalar mesons (both neutral and charged) is suppressed due to $I = 0$ of Deuteron (the pion pole thru nucleon GPDs $\tilde{E}$ does not contribute)

DVCS on Deuteron

- The convolution approximation takes into account graphs a and b



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

DVCS on ^{3}He

- L. L. Frankfurt, P. V. Pobylitsa, M. V. Polyakov and M. Strikman, Phys. Rev. D **60**, 014010 (1999)
- S. Scopetta, Phys. Rev. C **70**, 015205 (2004)

DVCS on ^{3}He

Convolution approximation

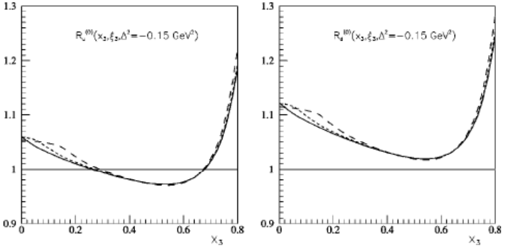
$$H^q_{A=3}(x,\xi,t) = \sum_N \int_x^1 \frac{dz}{z} h^3_N(z,\xi,t) H^q_N(\frac{x}{z},\frac{\xi}{z},t)$$

- $$h^3_N(z,\xi,t) = \int dE \int d\vec{p} P^3_N(\vec{p},\vec{p}+\Delta)\delta(z+\xi-\frac{p^+}{\bar{P}^+})$$
- P^3_N off-diagonal nuclear spectral function.
- P^3_N is a result of rather involved numerical calculation using the exact wf of ^{3}He and exact two-nucleon wf.

DVCS on ^{3}He

Predictions for ^{3}He GPDs

$$R_q(x,\xi,t) = \frac{H^q_{A=3}(x,\xi,t)}{2H^q_p(x,\xi,t) + H^q_n(x,\xi,t)}$$



- $\xi = 0$, 0.1 and 0.2
- Toy model for H^q_N without Q^2-dependence
- No predictions for DVCS observables (yet)

DVCS on ^{3}He

Predictions for DEMP on ^{3}He

- π^0 production at small t

$$d\sigma(\gamma_L^* + {}^3\mathrm{He} \to \pi^0 + {}^3\mathrm{He})/dt = d\sigma(\gamma_L^* + n \to \pi^0 + n)/dt\, F_{A=3}(t)$$

- π^+ production at small t

$$d\sigma(\gamma_L^* + {}^3\mathrm{He} \to \pi^+ + {}^3\mathrm{H})/dt = d\sigma(\gamma_L^* + p \to \pi^+ + n)/dt\, F_{M,A=3}(t)$$

DVCS on heavy nuclei

- V. Guzey and M. Strikman, Phys. Rev. C **68**, 015204 (2003)
  - Interpolation between the coherent and incoherent DVCS
  - Explanation of the non-enhancement of A_{LU} observed at HERMES
- V. Guzey and M. Siddikov, J. Phys. G **32**, 251 (2006)
  - Analysis of meson degrees of freedom in DVCS observables
  - Confirmation of the fast A-dependence of the nuclear D-term
  - Predictions of DVCS asymmetries relevant for the HERMES nuclear DVCS data

DVCS on heavy nuclei

- A. Freund and M. Strikman, Eur. Phys. J. C **33**, 53 (2004)
- A. Freund and M. Strikman, Phys. Rev. C **69**, 015203 (2004)
  - Model of nuclear GPDs including effects of nuclear shadowing and antishadowing
  - Predictions for the real and imaginary parts of the DVCS amplitude at small ξ
  - Observation of very unusual behavior of the real part of the DVCS amplitude

Conclusions

Nuclear DVCS allows us

- to obtain information on GPDs of the nucleon, which is complimentary to that obtained from DVCS on the hydrogen target
- to study novel nuclear effects not present in DIS on nuclear targets (associated with the real part of the DVCS amplitude)
- to test theoretical models of the nuclear structure

Discussion

Nuclear DVCS and GPDs to do list (theory):

- GPDs of ^{4}He
- Nuclear shadowing and antishadowing for nuclear GPDs using the dual parameterization of nucleon GPDs
- Deuteron GPDs with polynomiality