Deeply Virtual Compton Scattering
with CLAS12 at 6.6 GeV and 8.8 GeV
PR12-16-010

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June 17th 2016

Rosenbluth separation across the valence region
of the cross-sections for DVCS and exclusive $\pi^0$
Exclusive Processes and Generalized Parton Distributions

Definition of the Generalized Parton Distributions:

\[ F^q_\mathcal{O}(x, \xi, t) = \int \frac{dz^-}{2\pi} e^{ixP^+z^-} \langle P_2|\bar{q}(-z)\mathcal{O}q(z)|P_1\rangle \bigg|_{z^+=0, z=0} \]

List of GPDs, their corresponding operators, and exclusive reactions in this proposal:

<table>
<thead>
<tr>
<th>GPDs $F_\mathcal{O}$</th>
<th>operator $\mathcal{O}$</th>
<th>type</th>
<th>reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chiral even</td>
<td>$H, E$</td>
<td>$\gamma^\mu, \Delta_\nu \sigma^{\mu\nu}$</td>
<td>vector, tensor</td>
</tr>
<tr>
<td></td>
<td>$\tilde{H}, \tilde{E}$</td>
<td>$\gamma^\mu \gamma_5, \Delta^\mu \gamma_5$</td>
<td>axial-vector, pseudoscalar</td>
</tr>
<tr>
<td>Chiral odd</td>
<td>$H_T, E_T$</td>
<td>$\sigma^{\mu\nu}, \gamma(\mu \Delta_\nu)$</td>
<td>tensor</td>
</tr>
<tr>
<td></td>
<td>$\tilde{H}_T, \tilde{E}_T$</td>
<td>$P(\mu \Delta_\nu), \gamma(\mu P_\nu)$</td>
<td></td>
</tr>
</tbody>
</table>

- At $\xi = 0$, $t = 0$ the GPDs reduce to ordinary PDFs
- The integrals of $H$ and $E$ over $x$ are independent of $\xi$ and reduces to elastic FFs
- The second Mellin moments of the GPDs $H$ and $E$ access gravitational FFs
Physics Content of GPDs

\[
\langle P_2 | T^{\mu \nu} | P_1 \rangle = \bar{u}(P_2) \left[ \frac{1}{2} M_2(t) \gamma^{(\mu P^\nu)} + [2J(t) - M_2(t)] \rho^{(\mu i \sigma^\nu)} \lambda \frac{\Delta \lambda}{4M} + \frac{d_1(t)}{5M} (\Delta^\mu \Delta^\nu - \Delta^2 g^{\mu \nu}) \right] u(P_1)
\]

One can show that these appear in the second Mellin moments of the GPDs \( H \) and \( E \)

\[
\int dx \, x H(x, \xi, t) = M_2(t) + \frac{4}{5} \xi^2 d_1(t)
\]

\[
\int dx \, [H(x, \xi, t) + E(x, \xi, t)] = J(t)
\]
Deeply Virtual Compton Scattering Physics

The Bethe-Heitler and DVCS processes interfere at the amplitude level:

$$|T_{BH} + T_{DVCS}|^2 = |T_{BH}|^2 + |T_{DVCS}|^2 + I$$

In the context of DVCS, the Rosenbluth separation exploits:

$$I \sim 1/y^3, \quad |T^{DVCS}|^2 \sim 1/y^2$$

The coefficients of the $\phi$ harmonic decomposition of the cross-sections are related to the GPDs via the so-called Compton Form Factors:

$$H(\xi, t) = i\pi [H(\xi, \xi, t) - H(-\xi, \xi, t)] + \mathcal{P} \int_{-1}^{1} dx \left[ \frac{1}{\xi - x} - \frac{1}{\xi + x} \right] H(x, \xi, t)$$

The Real and Imaginary parts of the CFFs are related through Dispersion Relations:

$$\mathcal{P} \int_{-1}^{1} dx \left[ \frac{1}{\xi - x} - \frac{1}{\xi + x} \right] H(x, \xi, t)$$

$$\overset{LO}{=} D(t) + \mathcal{P} \int_{-1}^{1} dx \left( \frac{1}{\xi - x} - \frac{1}{\xi + x} \right) [H(x, x, t) - H(-x, x, t)]$$
Deeply Virtual Meson Production Physics

Assuming single photon exchange, the unpolarized $\gamma^* + N \rightarrow \pi^0 + N$ differential cross section writes:

$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi_\pi} = \Gamma(Q^2, x_B, E) \frac{1}{2\pi} \left[ \left( \frac{d\sigma_T}{dt} + \epsilon \frac{d\sigma_L}{dt} \right) + \epsilon \cos 2\phi_\pi \frac{d\sigma_{TT}}{dt} + \sqrt{2} \epsilon (1 + \epsilon) \cos \phi_\pi \frac{d\sigma_{LT}}{dt} \right]$$

The existing 6 GeV data strongly suggest dominance of the transverse part of the cross-section. The $\pi^0$ deep electroproduction is therefore determined by the chiral-odd transversity GPDs:

$$\frac{d\sigma_T}{dt} \sim \frac{1}{Q^8} \left[ (1 - \xi^2) |H_T|^2 - \frac{t'}{8m^2} |\bar{E}_T|^2 \right]$$

$$\frac{d\sigma_{LT}}{dt} \sim \frac{1}{Q^7} \xi \sqrt{1 - \xi^2} \frac{\sqrt{-t'}}{2m} \text{Re} \left[ \langle H_T \rangle^* \langle \bar{E} \rangle \right]$$

$$\frac{d\sigma_{TT}}{dt} \sim \frac{t'}{Q^8} |\bar{E}_T|^2$$

The Rosenbluth separation in this case consists in exploiting the $\epsilon$ dependence of the $\phi$ independent term to disentangle $\frac{d\sigma_T}{dt}$ and $\frac{d\sigma_L}{dt}$.

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DVCS at 6.6 GeV and 8.8 GeV
CLAS12 Detector

- $\mathcal{L} = 1 \times 10^{35} \, \text{cm}^{-2}\text{s}^{-1}$
- 76 nA on 5 cm long liquid H$_2$
- Electrons in the FD
- Protons in the FD and CD
- Photons in the FD and FT
Forward Tagger

- Polar angle coverage $\theta = 2.5^\circ - 4.5^\circ$
- 324 PbWO$_4$ crystals
- $\sigma(E)/E \leq 0.02/\sqrt{E(\text{GeV})} + 0.01$
- Hodoscope and Micromegas for electrons
Background Studies

- 3D rendition of the GEANT-4 simulation model
- DC tracking efficiency requires occupancies ≤ a few%
- Beamline shielding has been optimized
- Occupancies at $\mathcal{L} = 1 \times 10^{35}$ cm$^{-2}$s$^{-1}$ well within safety margins

Drift Chamber Occupancy for new_8.8_GeV_FToff_out
Kinematical Coverage, Exclusivity

- Black boxes example of binning in the $(x_B, Q^2)$ plane
- $\pi^0$ decay with one photon lost contamination to the DVCS sample
- Contamination kept at levels between 5% and 10%
- Cone angle: between the detected and predicted photon
- Missing mass $e p \rightarrow e \gamma Y$
DVCS Projected Results

- Left: cross-sections at fixed kinematics for beam energies 6.6 GeV and 8.8 GeV
- Right: corresponding Beam Spin Asymmetries
- Green: pure Bethe-Heitler
- Red: model fit on 6 GeV data
- Blue: simultaneous fit of the projected data
- Separation of: \( I \sim 1/y^3 \) and \( |\mathcal{T}^{DVCS}|^2 \sim 1/y^2 \)

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**DVCS at 6.6 GeV and 8.8 GeV**
DVCS Rosenbluth separation

- Left: result for the extracted Imaginary part of $\mathcal{H}$
- Right: result for the extracted Real part of $\mathcal{H}$
- Three green curves correspond to three scenarios for the D-term
π⁰ Projected Results

-t = 0.4 GeV²

- \( Q^2 = 6.5 \text{ GeV}^2 \)
- \( Q^2 = 5.5 \text{ GeV}^2 \)
- \( Q^2 = 4.5 \text{ GeV}^2 \)

- \( x_B = 0.35 \)
- \( x_B = 0.45 \)

- Cross-sections vs \( \phi \) for \( E_{\text{beam}} = 8.8 \text{ GeV} \)
- Red curves: Input model
- Green curves: Fit to projected data

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DVCS at 6.6 GeV and 8.8 GeV

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\( \pi^0 \) Rosenbluth separation

- Top rows: \( \phi \) independent \( \sigma_U \) vs \( \epsilon \)
  (n.b. zero suppression. \( \sigma_L \approx 0.1 \sigma_T \))
- \( \epsilon \) dependence fitted to a straight line
- Pure \( \sigma_T \) contribution extracted as intercept lever arm as main systematical uncertainty
- Bottom Left: \( \sigma_T \) vs \(-t\) exponential fit
- Bottom Right: exp. slope parameter vs \( x_B \) proton “shrinks” at large \( x_B \)
Summary and Beam Time Request

- Rosenbluth separation of the Interference amplitudes and pure DVCS squared
- Model dependent Dispersive evaluation of the D-term
- Rosenbluth separation of the transverse and longitudinal parts in $\pi^0$ production
- Provide strong constraint on chiral-odd transversity GPDs
- Beam Time Request:
  50 days at 6.6 GeV and 50 days at 8.8 GeV, at $L = 1 \times 10^{35}$ cm$^{-2}$s$^{-1}$