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

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for the CLAS collaboration

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Rosenbluth separation accross the valence region
of the cross-sections for DVCS and exclusive π^0

Exclusive Processes and Generalized Parton Distributions

Definition of the Generalized Parton Distributions :

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

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

	GPDs $F_{\mathcal{O}}$	operator $\mathcal{O}$	type	reaction
Chiral even	H, E $\tilde{H}$, $\tilde{E}$	γ^μ, $\Delta_\nu\sigma^{\mu\nu}$ $\gamma^\mu\gamma_5$, $\Delta^\mu\gamma_5$	vector, tensor axial-vector, pseudoscalar	$\gamma^*(Q^2)+N\to\gamma+N$
Chiral odd	H_T, E_T $\tilde{H}_T$, $\tilde{E}_T$	$\sigma^{\mu\nu}$, $\gamma^{(\mu}\Delta^{\nu)}$ $P^{(\mu}\Delta^{\nu)}$, $\gamma^{(\mu}P^{\nu)}$	tensor	$\gamma^*(Q^2)+N\to\pi^0+N$

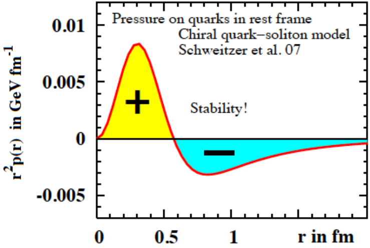
- At $\xi=0, t=0$ the GPDs reduce to ordinary PDFs
- The integrals of H and E over x are independent of ξ and reduces to elastic FFs
- The second Mellin moments of the GPDs H and E access gravitational FFs

Physics Content of GPDs

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

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

$$\begin{aligned} \int \mathrm{d}x \, x H(x,\xi,t) &= M_2(t) + \frac{4}{5}\xi^2 d_1(t) \\ \int \mathrm{d}x \, x \left[H(x,\xi,t) + E(x,\xi,t) \right] &= J(t) \end{aligned}$$



Deeply Virtual Compton Scattering Physics

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

$$|\mathcal{T}_{\mathrm{BH}} + \mathcal{T}_{\mathrm{DVCS}}|^2 = |\mathcal{T}_{\mathrm{BH}}|^2 + |\mathcal{T}_{\mathrm{DVCS}}|^2 + \mathcal{I}$$

In the context of DVCS, the Rosenbluth separation exploits :

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

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

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

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

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

Deeply Virtual Meson Production Physics

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

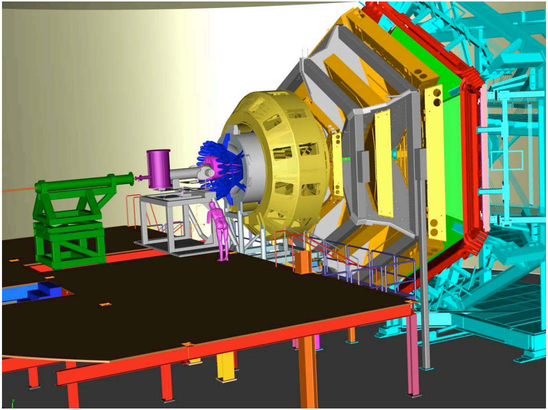
$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi_\pi} = \Gamma(Q^2, x_B, E)\frac{1}{2\pi}\left[\left(\frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt}\right) + \epsilon\cos 2\phi_\pi\frac{d\sigma_{TT}}{dt} + \sqrt{2\epsilon(1+\epsilon)}\cos\phi_\pi\frac{d\sigma_{LT}}{dt}\right]$$

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

$$\begin{aligned}
\frac{d\sigma_T}{dt} &\sim \frac{1}{Q^8}\left[\left(1-\xi^2\right)|H_T|^2 - \frac{t'}{8m^2}|\bar{E}_T|^2\right]\\
\frac{d\sigma_{LT}}{dt} &\sim \frac{1}{Q^7}\xi\sqrt{1-\xi^2}\frac{\sqrt{-t'}}{2m}\,\mathrm{Re}\left[\langle H_T\rangle^*\langle\tilde{E}\rangle\right]\\
\frac{d\sigma_{TT}}{dt} &\sim \frac{t'}{Q^8}|\bar{E}_T|^2
\end{aligned}$$

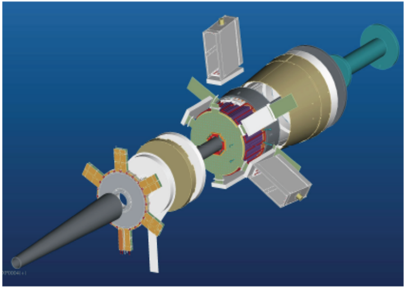
The Rosenbluth separation in this case consists in exploiting the ϵ dependence of the ϕ independent term to disentangle $\frac{d\sigma_T}{dt}$ and $\frac{d\sigma_L}{dt}$.

CLAS12 Detector



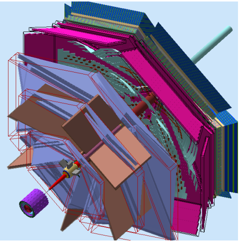
- $\mathcal{L} = 1 \times 10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
  76 nA on 5 cm long liquid H_2
- Electrons in the FD
- Protons in the FD and CD
- Photons in the FD and FT

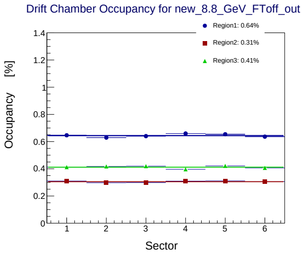
Forward Tagger



- Polar angle coverage $\theta = 2.5^\circ - 4.5^\circ$
- 324 $PbWO_4$ crystals
- $\sigma(E)/E \leq 0.02/\sqrt{E(\mathrm{GeV})} + 0.01$
- Hodoscope and Micromegas for electrons

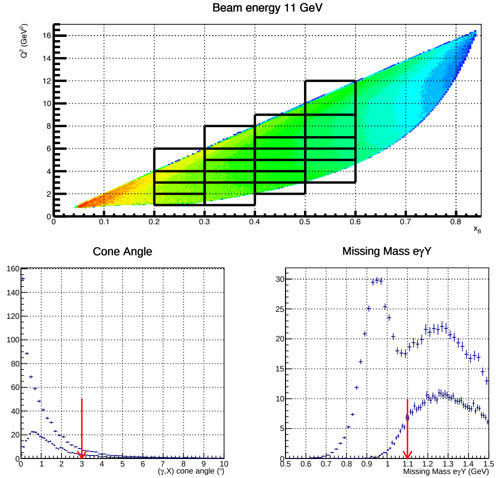
Background Studies





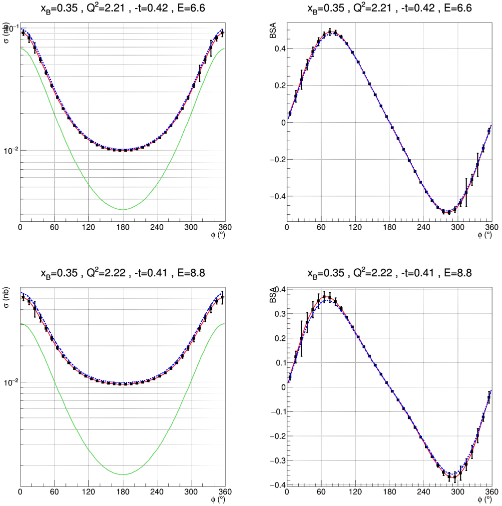
- 3D rendition of the GEANT-4 simulation model
- DC tracking efficiency requires occupancies $\leq$ a few%
- Beamline shielding has been optimized
- Occupancies at $\mathcal{L} = 1 \times 10^{35}$ cm^{-2}s^{-1} well within safety margins

Kinematical Coverage, Exclusivity



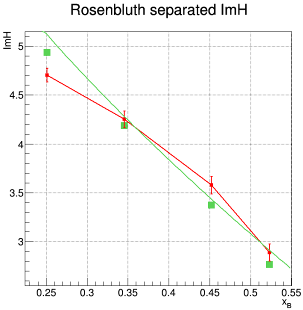
- Black boxes example of binning in the (x_B, Q^2) plane
- π^0 decay with one photon lost contamination to the DVCS sample
- Contamination kept at levels between 5% and 10%
- Cone angle : between the detected and predicted photon
- Missing mass $ep \to e\gamma Y$

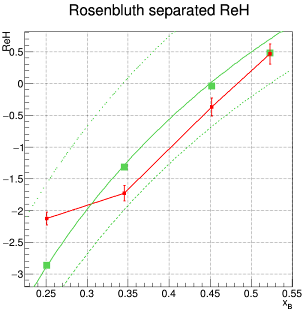
DVCS Projected Results



- 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 : $\mathcal{I} \sim 1/y^3$ and $\left|\mathcal{T}^{\mathrm{DVCS}}\right|^2 \sim 1/y^2$

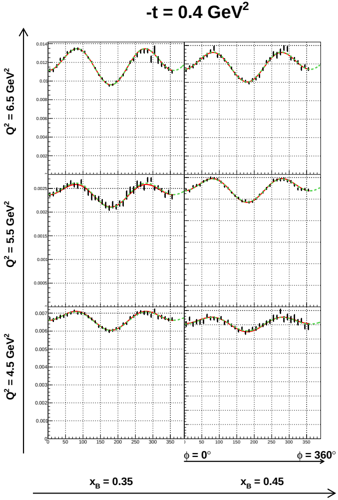
DVCS Rosenbluth separation





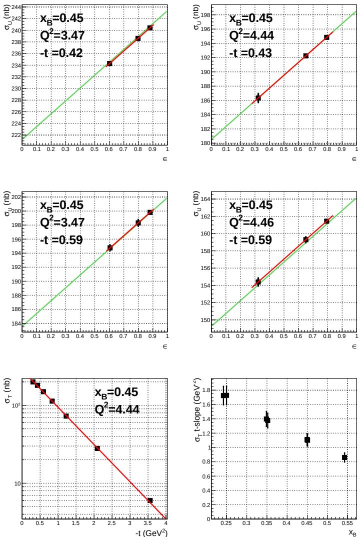
- Left : result for the extracted Imaginary part of $\mathcal{H}$
- Right : result for the extracted Real part of $\mathcal{H}$
- Three green curves correspond to three scenarios for the D-term

π^0 Projected Results



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

π^0 Rosenbluth separation



- Top rows : ϕ independent σ_U vs ϵ (n.b. zero suppression. $\sigma_L \approx 0.1\sigma_T$)
- ϵ dependence fitted to a straight line
- Pure σ_T contribution extracted as intercept lever arm as main systematical uncertainty
- Bottom Left : σ_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 π^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 $\mathcal{L} = 1 \times 10^{35}$ cm^{-2}s^{-1}