Simulation of the exclusive π^0 electroproduction on EicC

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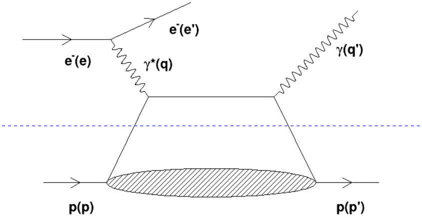
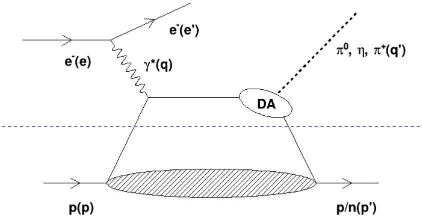
Overview

1. GPDs and deeply exclusive meson productions
2. Deeply virtual π^0 production and transversity GPDs
3. Simulation of deeply virtual π^0 production on EicC (preliminary)
4. Summary and outlook

GPDs and deeply exclusive meson productions





Samilar to DVCS process, hard exclusive meson production (DVMP, deeply virtual meson production) is sensitive to GPDs of partons as well. DVMP can be used to check GPD university, and it is also important for the flavor-separation.

$$Q^2 = -q^2, x_B = Q^2/(2pq), t = (p-p')^2$$

$$\xi = \frac{x_B(1+t/2/Q^2)}{2-x_B+x_B t/Q^2} \text{ (DVCS)}$$

$$\xi = \frac{x_B}{2-x_B}\left(1+\frac{m_\pi^2}{Q^2}\right) \text{ (DVMP)}$$

GPDs and deeply exclusive meson productions

In the scaling region (high Q^2), pseudoscalar meson DVMP is sensitive to the polarized GPDs ($\tilde{H}, \tilde{E}$), vector meson DVMP is sensitive to the unpolarized GPDs (H, E), and heavy vector meson DVMP is sensitive to the gluon GPD. [Xiangdong Ji, J. Phys. G 1998; Vanderhaeghen, Guichon, Guidal, Phys. Rev. D 1999; Goeke, Polyakov, Vanderhaeghen, Prog. Part. Nucl. Phys. 2001; Belitsky, Radyushkin, Phys. Rep. 2005]

$$\tilde{H}_{\pi^0} \sim e^u \tilde{H}^u - e^d \tilde{H}^d$$

$$\tilde{H}_{\pi^+} \sim \tilde{H}^u - \tilde{H}^d$$

$$\tilde{H}_{\eta} \sim e^u \tilde{H}^u + e^d \tilde{H}^d - 2e^s \tilde{H}^s$$

$$H_{\rho_L^0} \sim e^u H^u - e^d H^d$$

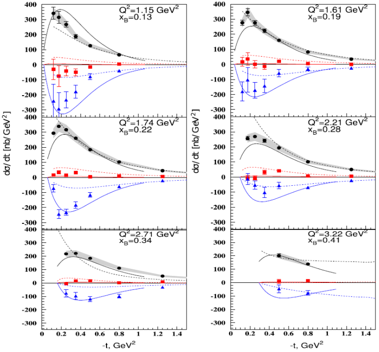
$$H_{\rho^+} \sim H^u - H^d$$

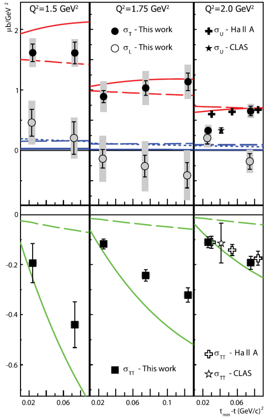
$$H_{\omega_L} \sim e^u H^u + e^d H^d$$

Deeply virtual π^0 production and transversity GPDs

Things become much complicated with nowadays experimental observation and theoretical development. The transversity GPDs is dominated for the pseudoscalar meson production in JLab kinematical region. (Transversity GPDs is actually the chiral-odd GPDs in which the quark helicity flipped.)

$\sigma_U > |\sigma_{TT}| > |\sigma_{LT}|$, and $\sigma_T > \sigma_L$ [CLAS, PRL 2012; JLab HallA, PRL, 2016]





Deeply virtual π^0 production and transversity GPDs

With the assumption that the handbag framework still works, the chiral-odd GPDs of the nucleon are coupled to a twist-3 distribution amplitude of the pion. There are four chiral-odd GPDs: H_T, E_T, $\tilde{H}_T$, and $\tilde{E}_T$ ($\bar{E}_T = 2\tilde{H}_T + E_T$). The chiral-odd GPDs are parameterized using either the double distribution representation or the reggeized diquark model (a connection between the chiral-even and chiral-odd reduced helicity amplitudes). [Ahmad, Goldstein, Liuti, PRD 2009; Goloskokov, Kroll, EPJC 2010; Goloskokov, Kroll, EPJA 2011; Goldstein, Hernandez, Liuti, PRD 2015]

Why measuring π^0-DVMP?

- without pion-pole, it is convenient to extract the transversity GPDs, which is least known.
- the extraction of the tranversity GPDs may constrain the tensor charge and transverse anomalous moment.
  $\int_0^1 H_T^q(X,0,0)dX = \delta^q, \int_0^1 \bar{E}_T^q(X,0,0)dX = \kappa_T^q$
- π^0-DVMP is the background of the DVCS channel if one decay photon of π^0 is not detected

Deeply virtual π^0 production and transversity GPDs

Some formulas,

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

$$\sigma_T = \frac{4\pi\alpha_e}{2k(Q^2, x_B)}\frac{\mu_\pi^2}{Q^4}\left[(1-\xi^2)|\langle H_T\rangle|^2 - \frac{t'}{8m^2}|\langle \bar{E}_T\rangle|^2\right]$$

$$\sigma_{TT} = \frac{4\pi\alpha_e}{2k(Q^2, x_B)}\frac{\mu_\pi^2}{Q^4}\frac{t'}{8m^2}|\langle \bar{E}_T\rangle|^2$$

$$t' = t - t_{\min}, \mu_\pi = m_\pi^2/(m_u + m_d)$$

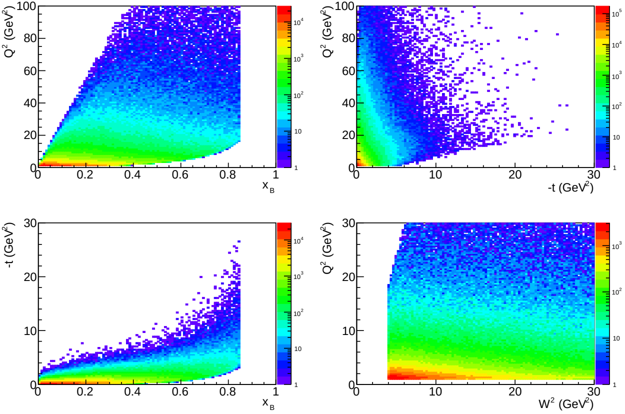
$$A_{LL} = \frac{\sigma^{+-} + \sigma^{-+} - \sigma^{++} - \sigma^{--}}{\sigma^{unpolarized}} = \frac{1}{P_e}\frac{1}{P_p}\frac{N^{+-} + N^{-+} - N^{++} - N^{--}}{N^{+-} + N^{-+} + N^{++} + N^{--}}$$

$$A_{LL}^{const}\sigma^{unpolarized} = \sqrt{1-\epsilon^2}\frac{4\pi\alpha}{\kappa}\frac{\mu_\pi^2}{Q^4}(1-\xi^2)|\langle H_T\rangle|^2$$

$\langle H_T\rangle$ and $\langle \bar{E}_T\rangle$ are the convolutions of the hard process with GPD H_T and $\bar{E}_T$ respectively.

Simulation of deeply virtual π^0 production on EicC (preliminary)

We have known that chiral-odd GPDs are important to the pion DVMP process. It's time to have more data to unveil chiral-odd GPDs.

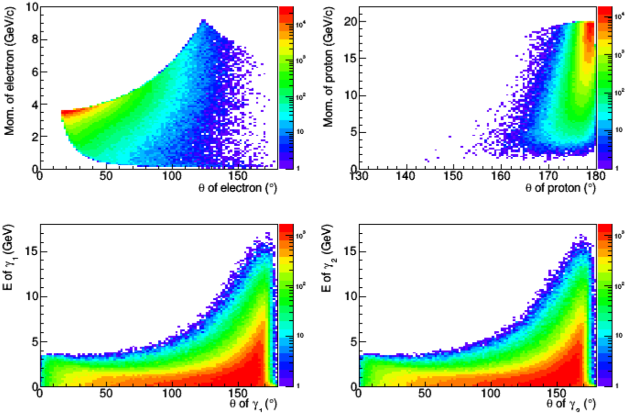


EicC (Electron-ion collider in China) opportunity: 3.5 GeV polarized electron * 20 GeV polarized proton, *lumi.* $=$ 2-5$\times 10^{33}\text{cm}^{-2}\text{s}^{-1}$

The left graph shows the invariant kinematic coverage of EicC (smaller x_B and higher Q^2 compared to JLab experiments).

Simulation of deeply virtual π^0 production on EicC (preliminary)

The energy and θ angle distributions of the final particles.

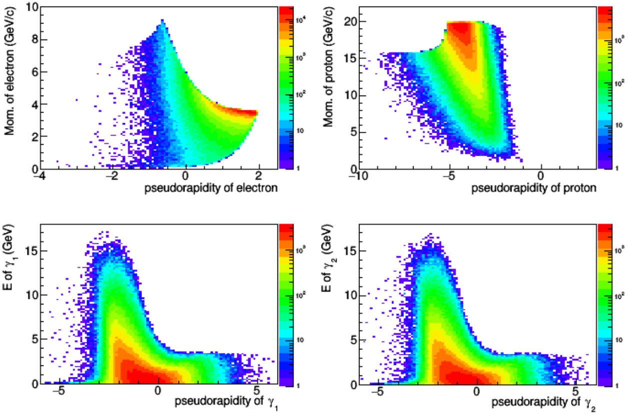


$x_B < 0.85$,
$1 < Q^2 < 100\ \text{GeV}^2$,
$0.05 < |t| < 30\ \text{GeV}^2$,
$W^2 > 4\ \text{GeV}^2$

The electrons go forward. The γ's go backward. The protons go very backward.

Simulation of deeply virtual π^0 production on EicC (preliminary)

The energy and pseudorapidity distributions of the final particles.

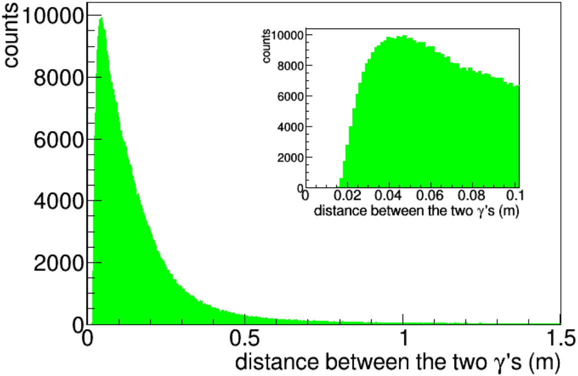


$x_B < 0.85$,
$1 < Q^2 < 100$ GeV^2,
$0.05 < |t| < 30$ GeV^2,
$W^2 > 4$ GeV^2

$|\eta|$ of electron is smaller than 2. $|\eta|$ of γ is smaller than 3. The proton has quite big $|\eta|$.

Simulation of deeply virtual π^0 production on EicC (preliminary)

The distance distribution between the two decay γ's, at one meter away from the interaction point. If we want 100% separation of photons, the spacial resolution should be better than 2 cm.



The Edep-averaged position resolution of the calorimeter is around 0.3 cm. Most of the photons go backward, and they are detected at longer distance ($\gg$ 1meter) from the vertex. So, the resolution of the calorimeter won't be an issue for backward photons.

Simulation of deeply virtual π^0 production on EicC (preliminary)

Let's look at the dynamic of π^0 production on EicC. Total cross-section from MC integral,

$$\sigma_{tot} = (Q^{2,high} - Q^{2,low})(x_B^{high} - x_B^{low})(t^{high} - t^{low})(\phi_\pi^{high} - \phi_\pi^{low})$$

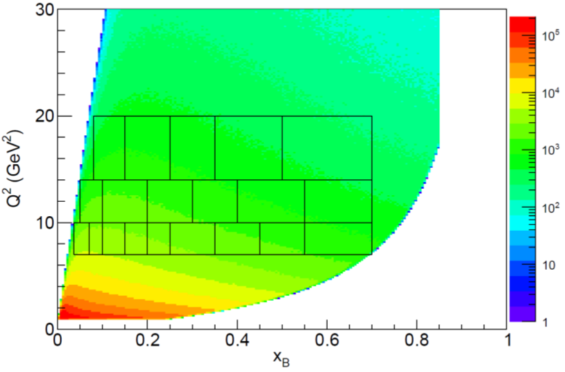
$$\times \frac{\sum_{i=1}^{N^{generated}} \frac{d_i^4\sigma}{dx_B dQ^2 dt d\phi_\pi}}{N^{generated}}$$

[if the sampling point outside of physical volume or mismatch the cuts ($W^2 > 4$ GeV^2, $Q^2 > 1$ GeV^2), $\frac{d^4\sigma}{dx_B dQ^2 dt d\phi_\pi} = 0$]

Total cross-section $= 1.689$ nb.
Number of events $= 1.689$ nb $\times$ 50 fb^{-1} $= 84.5$ million.

Simulation of deeply virtual π^0 production on EicC (preliminary)

The x_B-Q^2 binning strategy is shown below.



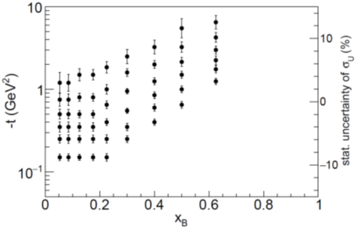
$x_B < 0.85$, $1 < Q^2 < 100$ GeV^2, $0.05 < |t| < 30$ GeV^2, $W^2 > 4$ GeV^2

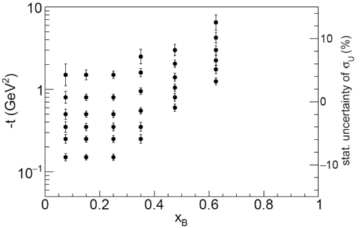
θ-acceptance for electron or γ is [2°, 178°].

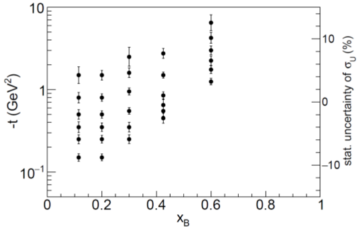
θ-acceptance for proton is [,179.5°]. Energy cut for e or γ is > 100 MeV.

[Assuming 10 photoelectons per MeV (PWO4 crystal), the Poisson fluctuation= $\sqrt{10^3}/10^3 = 3.2\%$ for 100 MeV Edep.])

Simulation of deeply virtual π^0 production on EicC (preliminary)

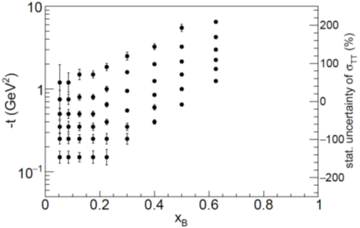


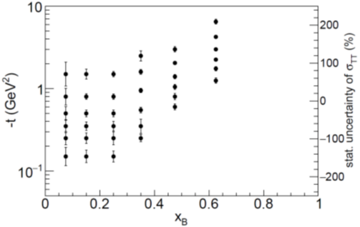


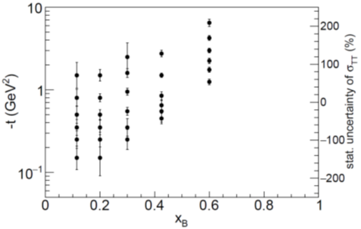


The relative statistic uncertainty of the un-separated cross-section σ_U. From top to bottom, and left to right, the Q^2 ranges are [7, 10], [10, 14], and [14, 20] GeV^2, respectively.

Simulation of deeply virtual π^0 production on EicC (preliminary)



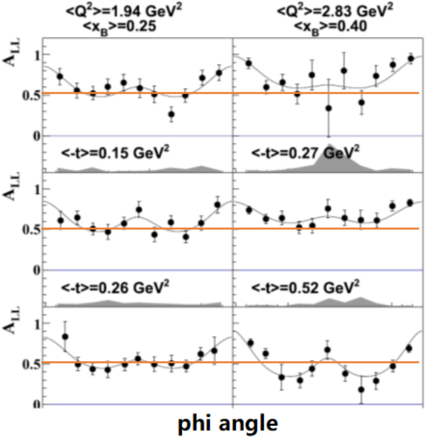


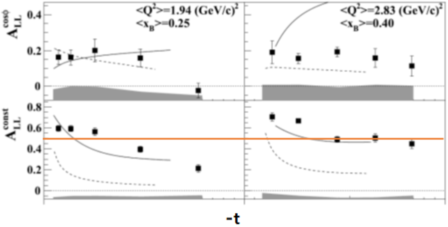


The relative statistic uncertainty of the cross-section σ_{TT}, which is sensitive to $\langle \bar{E}_T \rangle$. From top to bottom, and left to right, the Q^2 ranges are [7, 10], [10, 14], and [14, 20] GeV^2, respectively. The uncertainty is $\sim$ 20% at small x_B; and $\sim$ 5% at big x_B.

Simulation of deeply virtual π^0 production on EicC (preliminary)

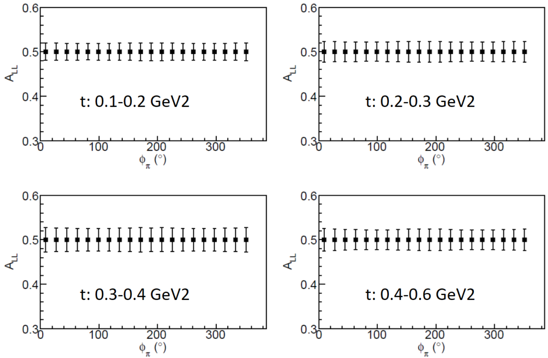
A_{LL} data from clas, [CLAS, Phys. Lett. B, 2017].





A_{LL} of π^0-DVMP is huge, and the A_{LL}^{const} is dominated in the ϕ_π-modulation. $A_{LL} \sim 0.5$ roughly exists when $|t| < 1$ GeV^2.

Simulation of deeply virtual π^0 production on EicC (preliminary)



Assuming $A_{LL} = 0.5$, we have estimated the statistical uncertainty of A_{LL} for the bin of $0.1 < x_B < 0.15$ and $7 < Q^2 < 10$ GeV^2. The uncertainty is calculated using the formulas shown below.

$$A_{LL} = \frac{\Delta N}{N},$$

$$\delta(A) = \sqrt{\left(\frac{\delta(\Delta N)}{N}\right)^2 + \left(\frac{\Delta N}{N^2}\delta(N)\right)^2},$$

$$\frac{\delta(A)}{A} = \sqrt{\left(\frac{\delta(\Delta N)}{\Delta N}\right)^2 + \left(\frac{\delta(N)}{N}\right)^2}.$$

Summary and outlook

Summary:

- With ∼two years of accumulation of the data on EicC (50 fb^{-1}), we would have a decent amount of π^0-DVMP events. And these events are distributed in a wide range of x_B, Q^2, and t (higher Q^2 and smaller x_B compared to the current data).
- The statistical uncertainties of both the differential cross-section and the asymmetry A_{LL} are small, which would well constrain the chiral-odd GPD models.
- Judged by the ϕ_π-dependence, the transeversity part still plays a role in the π^0 production on EicC.

Outlook:

- The feasibility of L-T separation should be investigated.
- The other type asymmetries should also be studied for the EicC domain.
- More studies on the detector capability should be considered.

The End,
Thank you!

backup 1

Parametrization of differential cross-sections, CLAS parametrization,

$$\sigma_T = 814.599 e^{0.447\times k\times t}/(Q^2 + 1.08767)^{1.693},$$

$$\sigma_L = 1404.1 Q^2 e^{0.692\times k\times t}/(Q^2 + 1.08767)^{1.693},$$

$$\sigma_{TT} = -5205.9(t_0 - t)e^{0.987\times k\times t}/(Q^2 + 1.08767)^{1.693}.$$

$$k = 2 \times 1.1 \times log(x_B)$$

backup 2

Illustration of the fit of ϕ_π-dependence, for the bin of $0.1 < x_B < 0.15$ and $7 < Q^2 < 10$ GeV^2. The uncertainties of σ_U and σ_{TT} are given by the minuit fit, TVirtualFitter::SetErrorDef(3.67).