Timelike Compton Scattering with CLAS12 at Jefferson Lab

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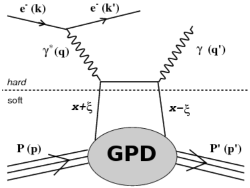
CLAS Collaboration meeting
March 7, 2019

Overview of this talk

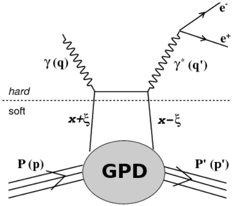
- State of the analysis at DNP 2018
- Validation of $e^+e^-p(e^-)$ Monte Carlo simulation
- MC studies of ee interference and QED background
- Validation of the asymmetry exctraction algorithm

From DVCS to TCS

DVCS ($\gamma^* p \to \gamma p$)



TCS ($\gamma p \to \gamma^* p$)



Compton Form Factors

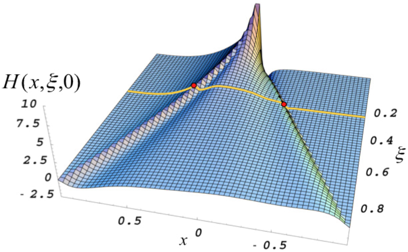
$$\mathcal{H} = \sum_q e_q^2 \left\{ \mathcal{P} \int_{-1}^{1} dx H^q(x,\xi,t) \left[\frac{1}{\xi - x} - \frac{1}{\xi + x} \right] + i\pi \left[H^q(\xi,\xi,t) - H^q(-\xi,\xi,t) \right] \right\}$$

Imaginary part

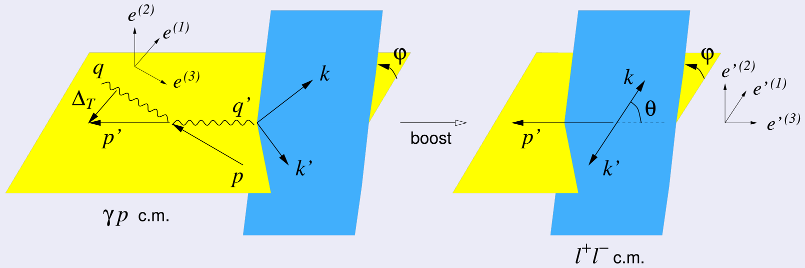
- Measured in DVCS asymmetries

Real part

- Accessible in DVCS cross section
- Accessible in TCS in cross section angular modulation



$\gamma p \to e^+ e^- p$ kinematics



$$Q'^2 = (k + k')^2 \qquad t = (p' - p)^2$$

$$L = \frac{(Q'^2 - t)^2 - b^2}{4} \qquad L_0 = \frac{Q'^4 sin^2\theta}{4} \qquad b = 2(k - k')(p - p')$$

$$\tau = \frac{Q'^2}{2p \cdot q} \qquad s = (p + q)^2 \qquad t_0 = -\frac{4\xi^2 M^2}{(1 - \xi^2)}$$

$\gamma p \to e^+e^-p$ Cross section and CFFs

Interference cross section

$$\frac{d^4\sigma_{INT}}{dQ'^2 dt d\Omega} = -\frac{\alpha_{em}^3}{4\pi s^2}\frac{1}{-t}\frac{m_p}{Q'}\frac{1}{\tau\sqrt{1-\tau}}\frac{L_0}{L}\left[\cos(\phi)\frac{1+\cos^2(\theta)}{\sin(\theta)} Re\ \tilde{M}^{--} + ...\right]$$

$$\to \tilde{M}^{--} = \frac{2\sqrt{t_0 - t}}{M}\frac{1-\xi}{1+\xi}\left[F_1\mathcal{H} - \xi(F_1+F_2)\tilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E}\right]$$

BH cross section

$$\frac{d^4\sigma_{BH}}{dQ'^2 dt d\Omega} \approx -\frac{\alpha_{em}^3}{2\pi s^2}\frac{1}{-t}\frac{1+\cos^2(\theta)}{\sin^2(\theta)}\left[(F_1^2 - \frac{t}{4M^2}F_2^2)\frac{2}{\tau^2}\frac{\Delta_T^2}{-t} + (F_1+F_2)^2\right]$$

Weighted cross section ratio

$$R(\sqrt{s}, Q'^2, t) = \frac{\int_0^{2\pi} d\phi\ \cos(\phi)\ \frac{dS}{dQ'^2 dt d\phi}}{\int_0^{2\pi} d\phi \frac{dS}{dQ'^2 dt d\phi}} \qquad \frac{dS}{dQ'^2 dt d\phi} = \int_{\pi/4}^{3\pi/4} d\theta \frac{L}{L_0}\frac{d\sigma}{dQ'^2 dt d\phi d\theta}$$

Data analysis

$$ep \rightarrow (e)\gamma p \rightarrow (e)\gamma^* p \rightarrow (e)e^+ e^- p$$

Final state

- Use the CLAS12 reconstruction software PID (and cuts on leptons SF)
- Events with e^+e^-pX selected

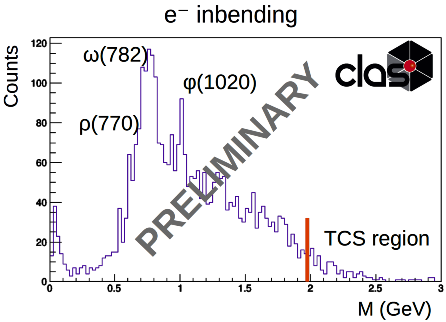
Incoming photon

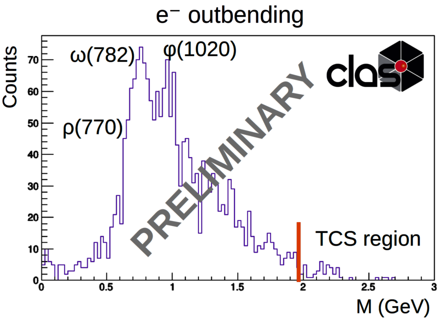
- Make sure the photon is quasi-real
- Cuts on $Xp \rightarrow e^+e^-p$ missing mass

Scattered electron

- Additional cuts on scattered electron
- Look at $ep \rightarrow e^+e^-pX$ system

Lepton-pair spectrum shown at DNP 2018





Next steps

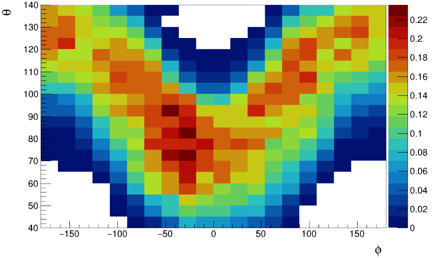
- Mass cut to avoid resonances in the e^+e^- mass spectrum ($\rho(1450)$ and $\rho(1700)$)
- Calculate the acceptance for cross section extraction

R ratio calculation

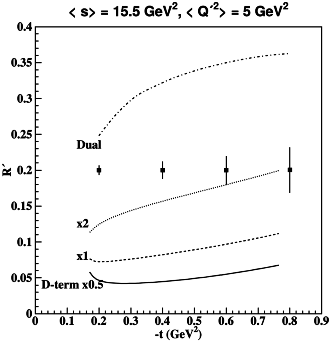
Experimental cross section ratio

$$R(\sqrt{s}, Q'^2, t) = \frac{\int_0^{2\pi} d\phi \; cos(\phi) \; \frac{dS}{dQ'^2 dt d\phi}}{\int_0^{2\pi} d\phi \frac{dS}{dQ'^2 dt d\phi}} \qquad R' = \frac{\sum_{\phi} cos(\phi) Y_\phi}{\sum_{\phi} Y_\phi}$$

$$Y_\phi = \sum_\theta \frac{L}{L_0} N_\theta^\phi \frac{1}{A_\theta^\phi}$$



Acceptance in the θ/ϕ plane
($0.5 \; GeV^2 < -t < 0.7 \; GeV^2$)



Expected results from CLAS12

Monte Carlo Validation

Two $e^+e^-p(e^-)$ Monte Carlo are available :

- GRAPE designed for HERA data (see http://research.kek.jp/people/tabe/grape/)
- MC Generator written by Rafayel Paremuzyan

GRAPE

- Covers large phase space and regimes (elastic and inelastic)
- Includes beam electron, BH and pair production from the beam
- Includes interference between pair and scattered electron
- No GPDs included
- Used in many (>40) HERA publications

R. Paremuzyan Generator

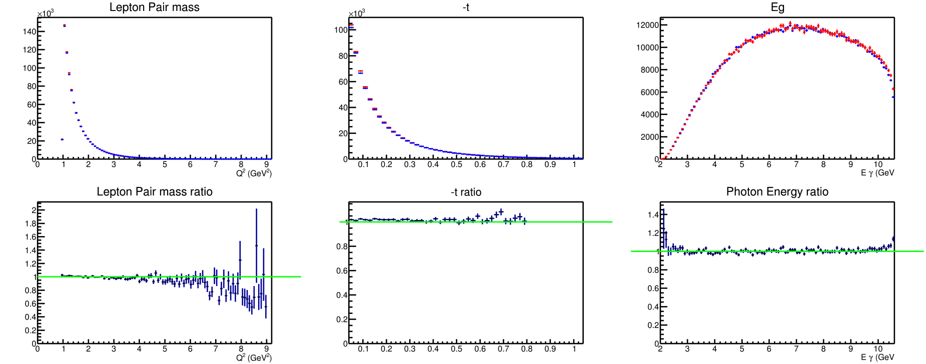
- Includes GPDs and D-term (possibility to vary the D-term strength)
- Does not include beam electron, uses Equivalent Photon Approximation

MC Comparison for BH - Generator Validation

- $Q^2 < 0.05\ GeV^2$
- $0.0 < -t < 1\ GeV^2$
- $\theta_{lab} > 2^\circ$
- $P_{e^+e^-} > 1\ GeV$
- $1 < Q'^2 < 9\ GeV^2$

A bug have been found and corrected in Rafo's Generator. After correction both generators agree for the 5 variables (E_g, t, Q'^2, θ and ϕ)

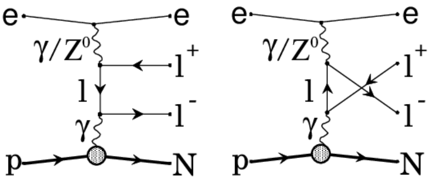
GRAPE **Rafo's Gene**



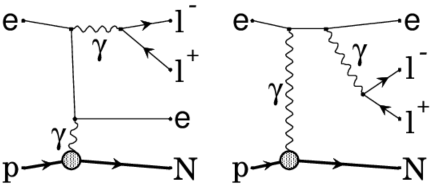
Phi distributions in back-up

Study of Backgrounds from MC

- Interference between pair electron and scattered electron
- QED pair production from beam electron



(a) Bethe-Heitler type diagrams

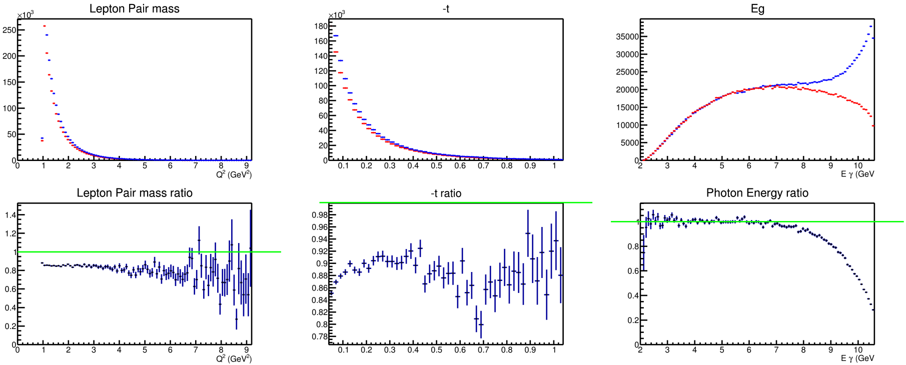


(b) QED-Compton type diagrams

Study of Backgrounds from MC

- Electron (scattered and pair) are now indistinguishable
- "Pair" electron is defined as high θ_{lab} electron, "Scattered" electron is defined as low θ_{lab} electron
- Events simulated with Interference + QED

Direct BH **Int.+QED**

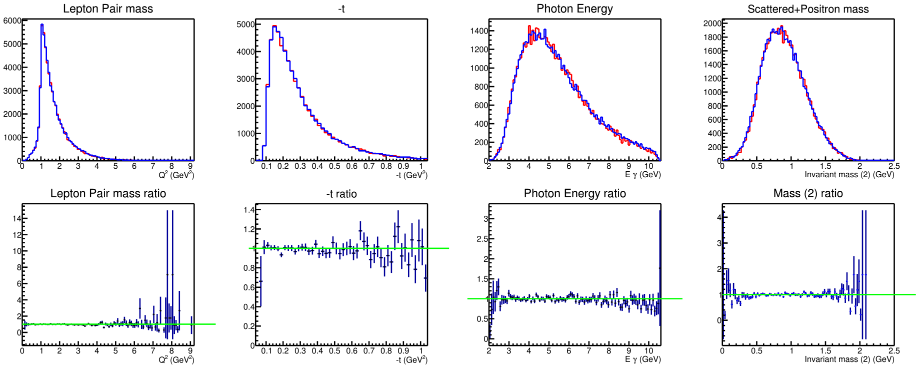


Study of Backgrounds from MC

- After reconstruction distributions are the same.
- Direct BH is the main process contributing for e^+e^-p final state in CLAS12

Direct BH **Int.+QED**

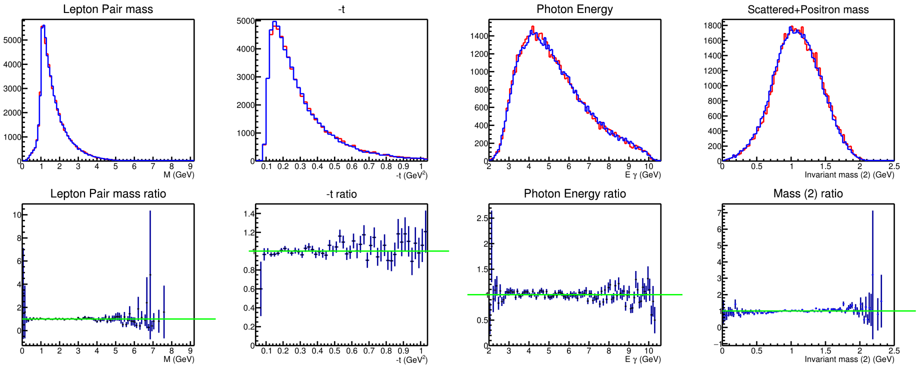
Inbending electrons



Study of Backgrounds from MC

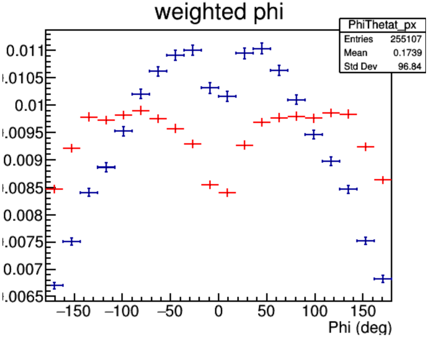
Direct BH **Int.+QED**

Outbending electrons

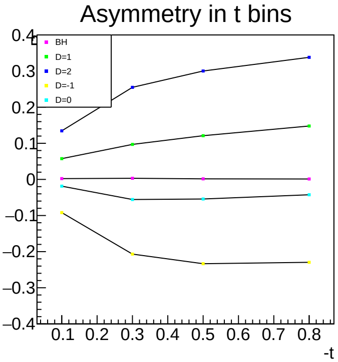


R ratio calculation from generated events

$$R(\sqrt{s}, Q'^2, t) = \frac{\int_0^{2\pi} d\phi \;\; cos(\phi) \;\; \frac{dS}{dQ'^2 dt d\phi}}{\int_0^{2\pi} d\phi \frac{dS}{dQ'^2 dt d\phi}} \qquad R' = \frac{\sum_\phi cos(\phi) Y_\phi}{\sum_\phi Y_\phi} \qquad Y_\phi = \sum_\theta \frac{L}{L_0} N_\theta^\phi$$

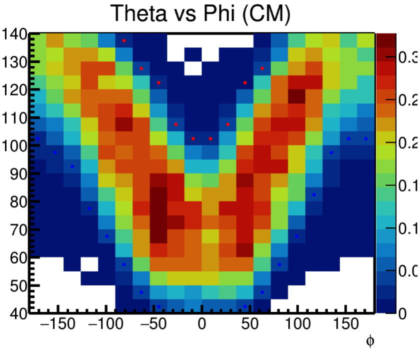


Weighted Phi distribution
$(0.2 \;\; GeV^2 < -t < 0.4 \;\; GeV^2)$
BH **D=1**

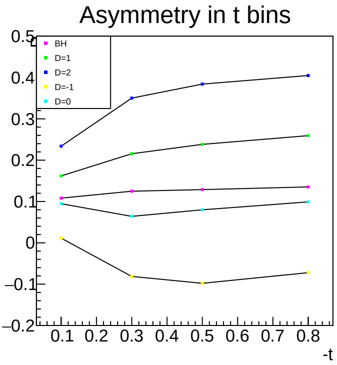


R ratio calculation from generated events within CLAS12 acceptance (inbending)

$$R' = \frac{\sum_{\phi_A} cos(\phi) Y_\phi}{\sum_{\phi_A} Y_\phi} \qquad Y_\phi = \sum_{\theta_A} \frac{L}{L_0} N_\theta^\phi$$

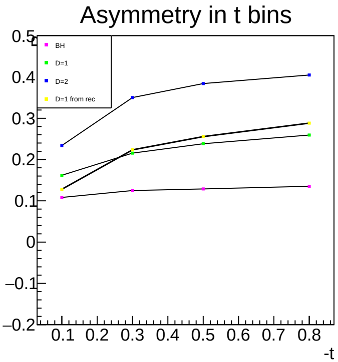


Acceptance in θ *vs* ϕ plane
$(0.2\ GeV^2 < -t < 0.4\ GeV^2)$

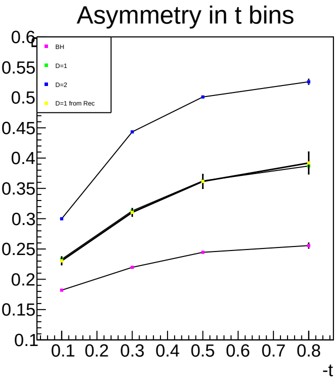


R ratio calculation from reconstructed events within CLAS12 acceptance (inbending)

Acceptance calculated with full cross section (BH and interference term (D=1))



$$Y_\phi = \sum_{\theta_A} \frac{L}{L_0} N_\theta^\phi \frac{1}{A_\theta^\phi}$$



$$Y_\phi = \sum_{\theta_A} N_\theta^\phi \frac{1}{A_\theta^\phi}$$

$\rightarrow$ Need to understand the discrepancy in the weighted asymmetry

Conclusion

- In CLAS12 acceptance, only BH contributes to the e^+e^-p final state, interference between electrons and QED pair production are negligeable.
- The framework to extract the TCS asymmetry is ready. As soon as trains are processed, we can get a first value for the asymmetry.

Outlook

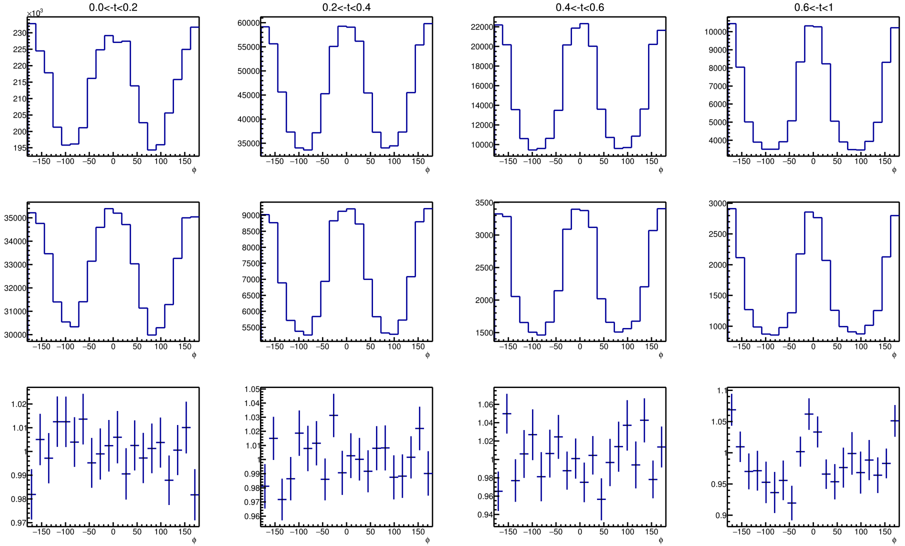
- Understand model dependance of the acceptance.
- Understand weighted asymmetry discrepancy.
- Study background from $e^+e^-(e^+e^-)p$ final state using data.

Thank you !

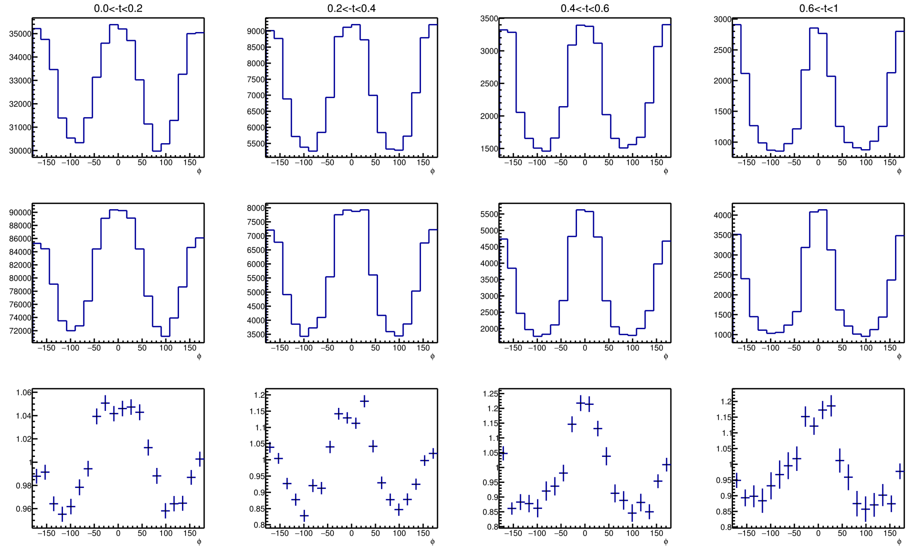
Back up

Phi distributions BH Comparison

First row : Grape   Second row : Rafo's Gene



Gene Phi distributions Direct BH/QED+Int



Rec Phi distributions Direct BH/QED+Int