Timelike Compton Scattering at JLab

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P H O T O N 2 0 1 3

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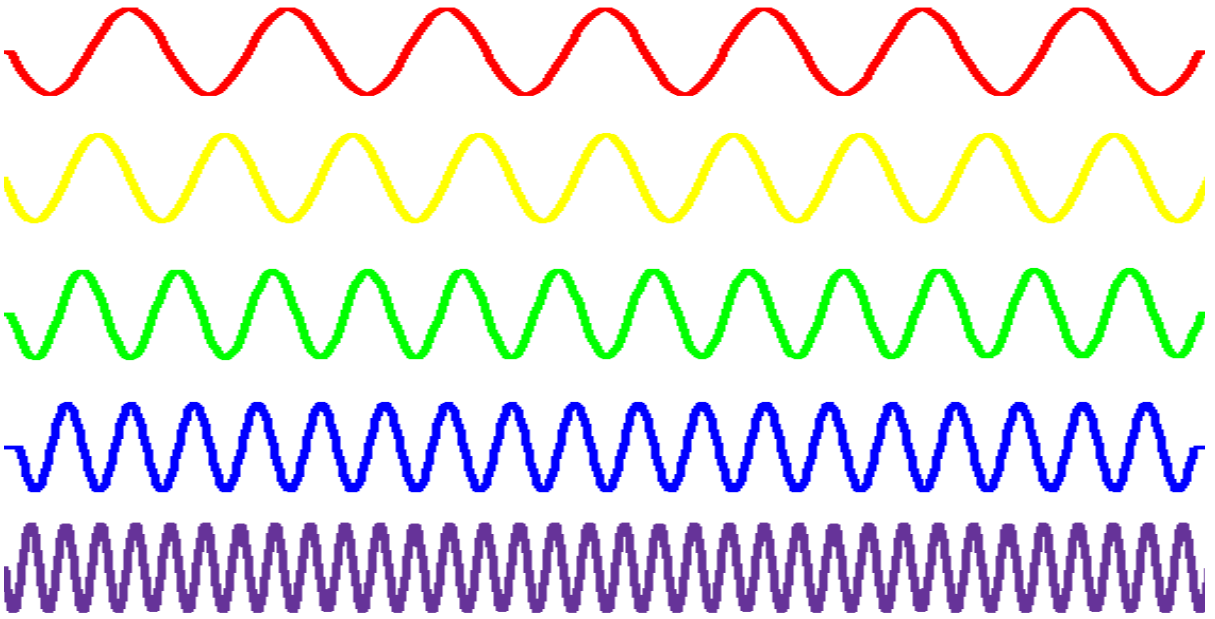
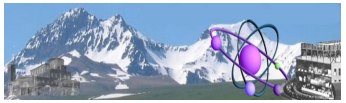


Outline

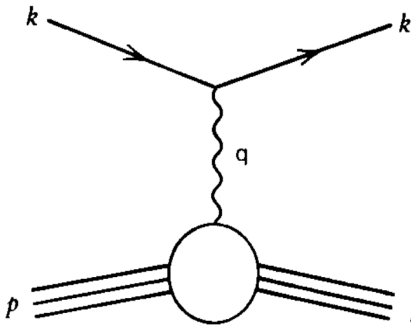
- Nucleon Structure and GPDs
- Phenomenology of lepton pair production
- Preliminary results on e^-e^+ pair production from CLAS
- Future prospects with CLAS12 and upgraded CEBAF machine
- Summary

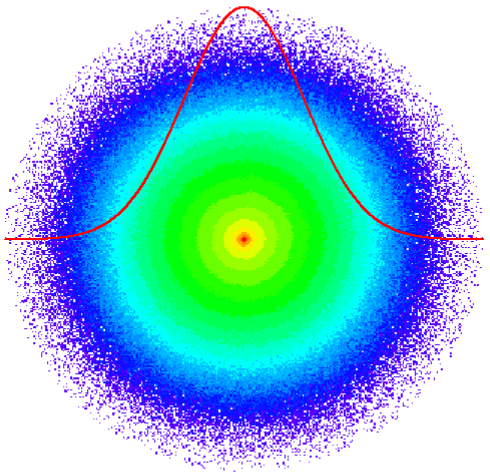


Nucleon structure through elastic and Deep Inelastic Scattering

Elastic: $eN \rightarrow eN$

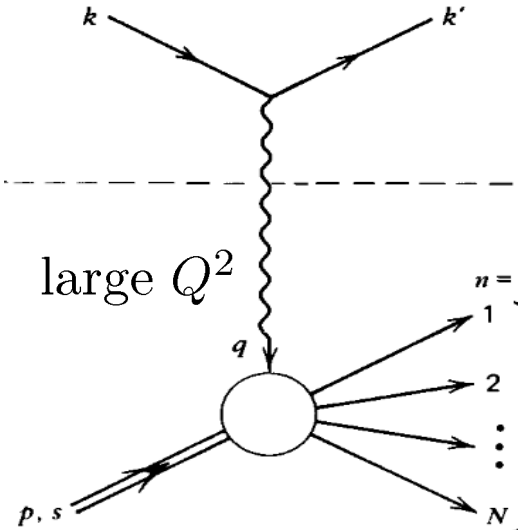
Elastic Form Factors Characterize Charge and magnetization distributions in the impact parameter space

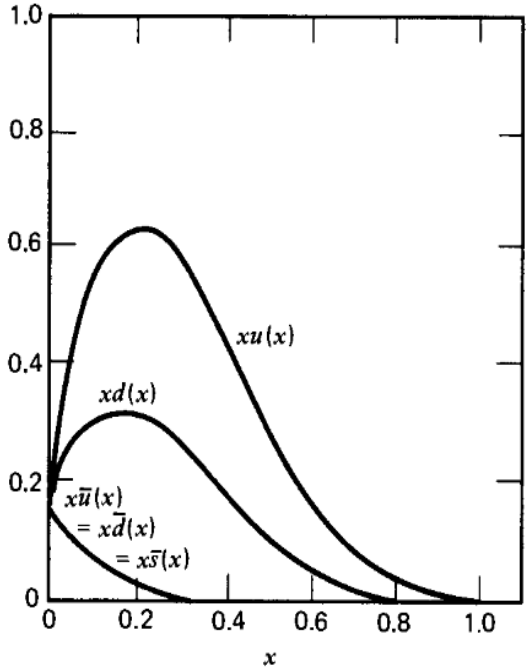




(Un)Polarized DIS : $\vec{e}N \rightarrow eX$

Polarized and unpolarized DIS experiments revealed that quarks carry ~50% of the nucleon longitudinal momentum and ~25% of nucleon SPIN

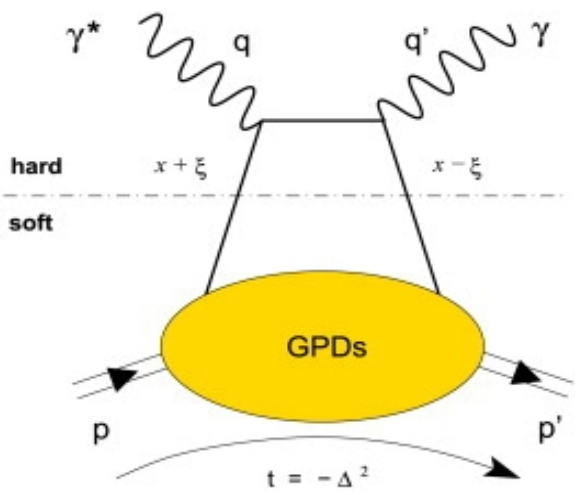




Nucleon structure and GPDs

Hard Exclusive precesses: A new class of reactions provide novel information on the quark and gluon distributions in hadrons

Factorization theorem for exclusive processes:
Allows to express amplitudes of hard exclusive process in terms of process independent 4 nucleon structure functions GPDs $(\mathrm{H},\ \tilde{H},\ \mathrm{E},\ \tilde{E})$ and short distance cross sections for the hard scattering partons, calculable in pQCD.



Basic properties of GPDs

$$k^+ = x\bar{P}^+ \qquad \Delta^+ = 2\xi\bar{P}^+$$
$$t = -\Delta^2$$

In a forward limit (p = p')

$$H^q(x,0,0) = \begin{cases} q(x), & x > 0 \\ -\bar{q}(-x), & x < 0 \end{cases}$$

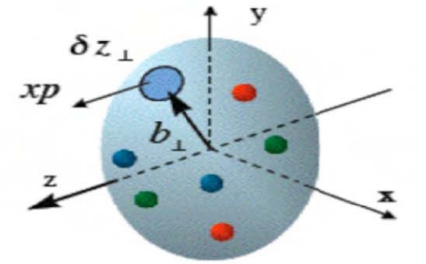
$$\tilde{H}^q(x,0,0) = \begin{cases} \Delta q(x), & x > 0 \\ -\Delta\bar{q}(-x), & x < 0 \end{cases}$$

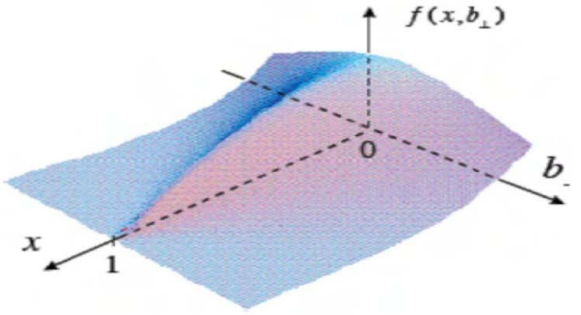
$$\int_{-1}^{1} dx H(x,\xi,t) = F_1(t)$$

$$\int_{-1}^{1} dx E(x,\xi,t) = F_2(t)$$

$$\int_{-1}^{1} dx \tilde{H}(x,\xi,t) = g_a(t)$$

$$\int_{-1}^{1} dx \tilde{E}(x,\xi,t) = h_a(t)$$



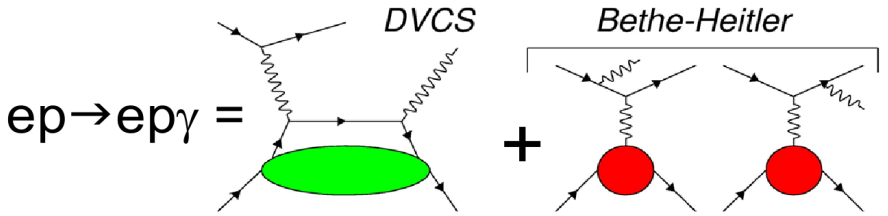


Constructing GPDs

Extraction of GPDs from experimental observables is not a simple task. They enter into Real part of Compton Form Factors as integrals of x, and into Imaginary part at a x = ξ point.

Many experimental observables are needed to constrain models!

DVCS is the Best studied reaction



$$\sigma \propto \left|\mathcal{T}_{BH}\right|^2 + \left|\mathcal{T}_{DVCS}\right|^2 + \mathcal{T}^*_{DVCS}\mathcal{T}_{BH} + \mathcal{T}^*_{BH}\mathcal{T}_{DVCS}$$

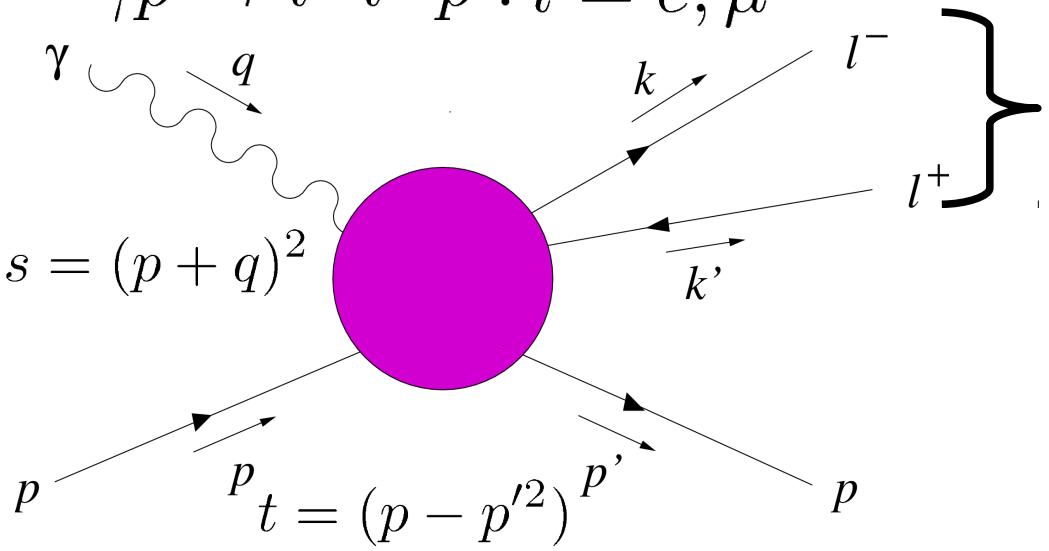
$$\mathcal{H}(\xi,t) = \underbrace{i\pi\left[H(\xi,\xi,t) - H(-\xi,\xi,t)\right]}_{\text{Im}} + \underbrace{\mathrm{P}\int_{-1}^{+1} dx \left(\frac{1}{\xi - x} \pm \frac{1}{\xi + x}\right)\left[H(x,\xi,t) \mp H(-x,\xi,t)\right]}_{\text{Re}}$$

Most of DVCS observables are sensitive to Im part of CFFs. The real part is only accessible through cross section, BCA or double spin asymmetries measurements.

Timelike virtual Compton Scattering

Experimentally: Photoproduction of lepton pairs

$$\gamma p \to l^- l^+ p : l = e, \mu$$



Hard Scale

$$Q'^2 = M^2_{l^- l^+} = (k + k'^2)$$

Analog of ξ in TCS

$$\eta = \frac{Q'^2}{2s - Q'^2}$$

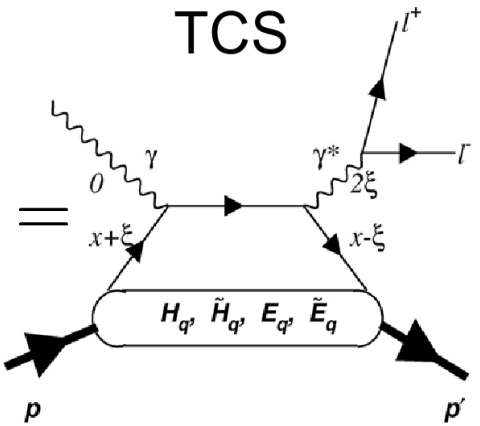
- Inverse to DVCS – serve as a test of universality of GPDs
- simultaneous measurement of the real/imaginary parts of the Compton amplitudes with unpolarized/circularly polarized photon beams

Accessing GPDs experimentally - TCS

TCS

Bethe-Heitler (BH)

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



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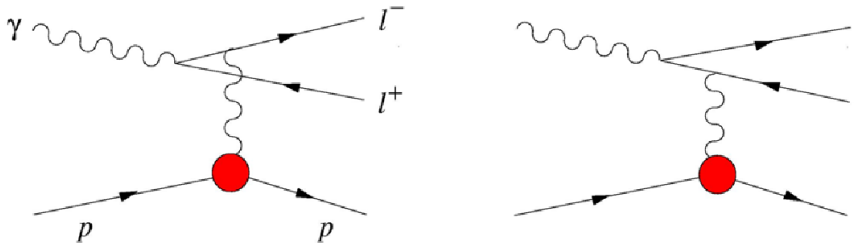


$$\sigma(\gamma p \to e^- e^+ p) = \sigma_{TCS} + \sigma_{BH} + \sigma_{Int}$$

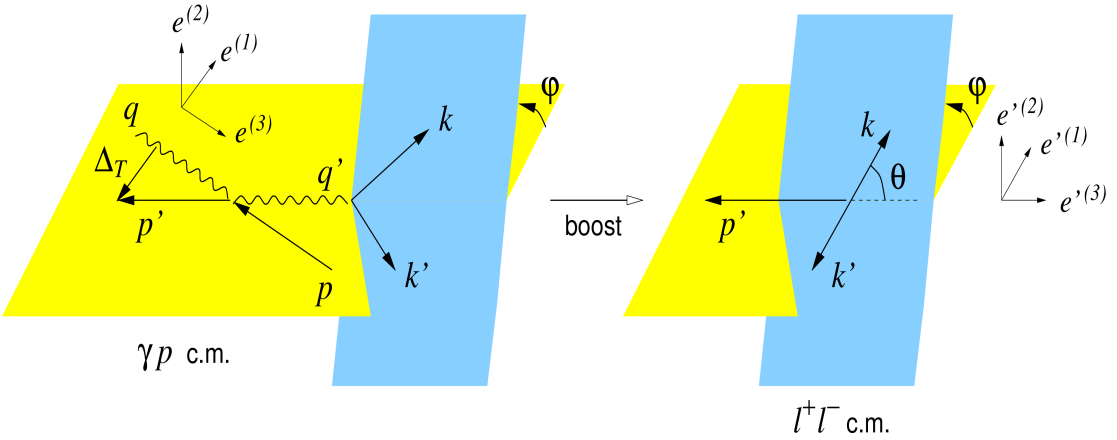
Symmetric

Antisymmetric

$$k \leftrightarrow k'$$

Any observable that changes the sign under lepton pair interchange, will project out the interference term.

Interference term can be extracted through the angular distribution of lepton pair (φ).



Accessing GPDs experimentally - TCS

$$\frac{d\sigma_{INT}}{dQ'^2\,dt\,d(\cos\theta)\,d\varphi} = -\frac{\alpha_{em}^3}{4\pi s^2}\frac{1}{-t}\frac{M}{Q'}\frac{1}{\tau\sqrt{1-\tau}}\frac{L_0}{L}\Big[\cos\varphi\,\frac{1+\cos^2\theta}{\sin\theta}\,\mathrm{Re}\,\tilde{M}^{--} - \cos 2\varphi\,\sqrt{2}\cos\theta\,\mathrm{Re}\,\tilde{M}^{0-} + \cos 3\varphi\,\sin\theta\,\mathrm{Re}\,\tilde{M}^{+-} + O\Big(\frac{1}{Q'}\Big)\Big],$$

Incoming photon polarization

$$- \nu\,\frac{\alpha_{em}^3}{4\pi s^2}\frac{1}{-t}\frac{M}{Q'}\frac{1}{\tau\sqrt{1-\tau}}\frac{L_0}{L}\Big[\sin\varphi\,\frac{1+\cos^2\theta}{\sin\theta}\,\mathrm{Im}\,\tilde{M}^{--} - \sin 2\varphi\,\sqrt{2}\cos\theta\,\mathrm{Im}\,\tilde{M}^{0-} + \sin 3\varphi\,\sin\theta\,\mathrm{Im}\,\tilde{M}^{+-} + O\Big(\frac{1}{Q'}\Big)\Big]$$

$$\tilde{M}^{--} = \frac{2\sqrt{t_0-t}}{M}\frac{1-\eta}{1+\eta}\Big[F_1\mathcal{H}_1 - \eta(F_1+F_2)\,\tilde{\mathcal{H}}_1 - \frac{t}{4M^2}\,F_2\,\mathcal{E}_1\Big]$$

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

Quasi-real photon-production of e^-e^+ pair with CLAS

Beam electrons scattered at small ~0 angle served as a source of quasi real photons.

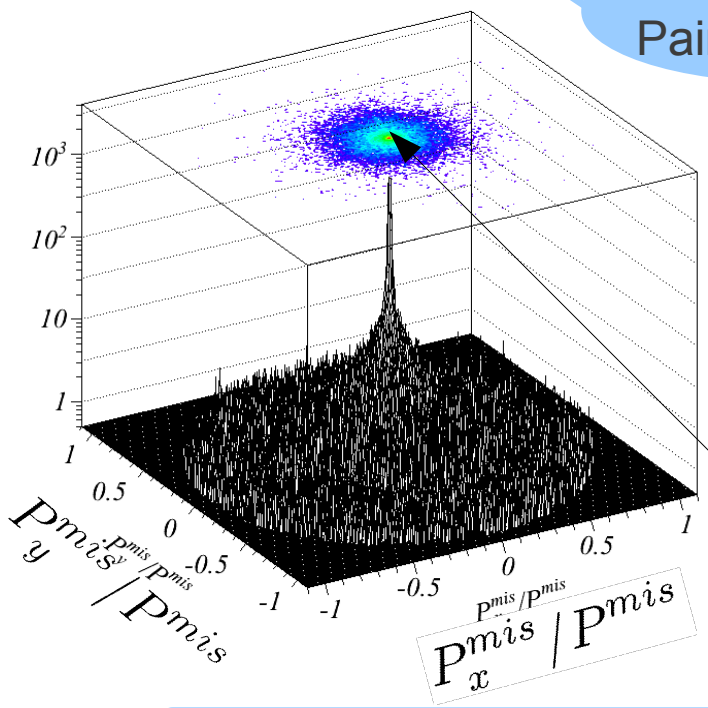
Scattered electron

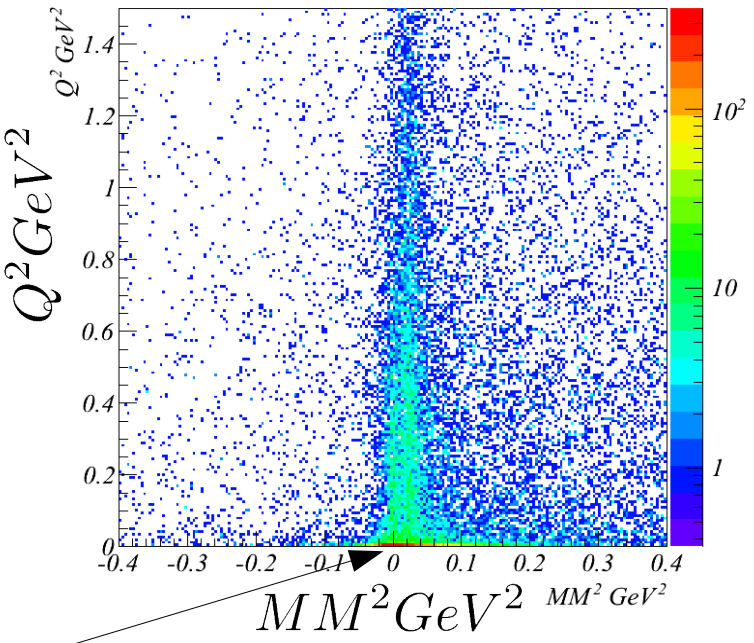
$$ep \rightarrow e' e^- e^+ p'$$

From Pair production

The final state to be analyzed

$$ep \rightarrow e^- e^+ pX$$



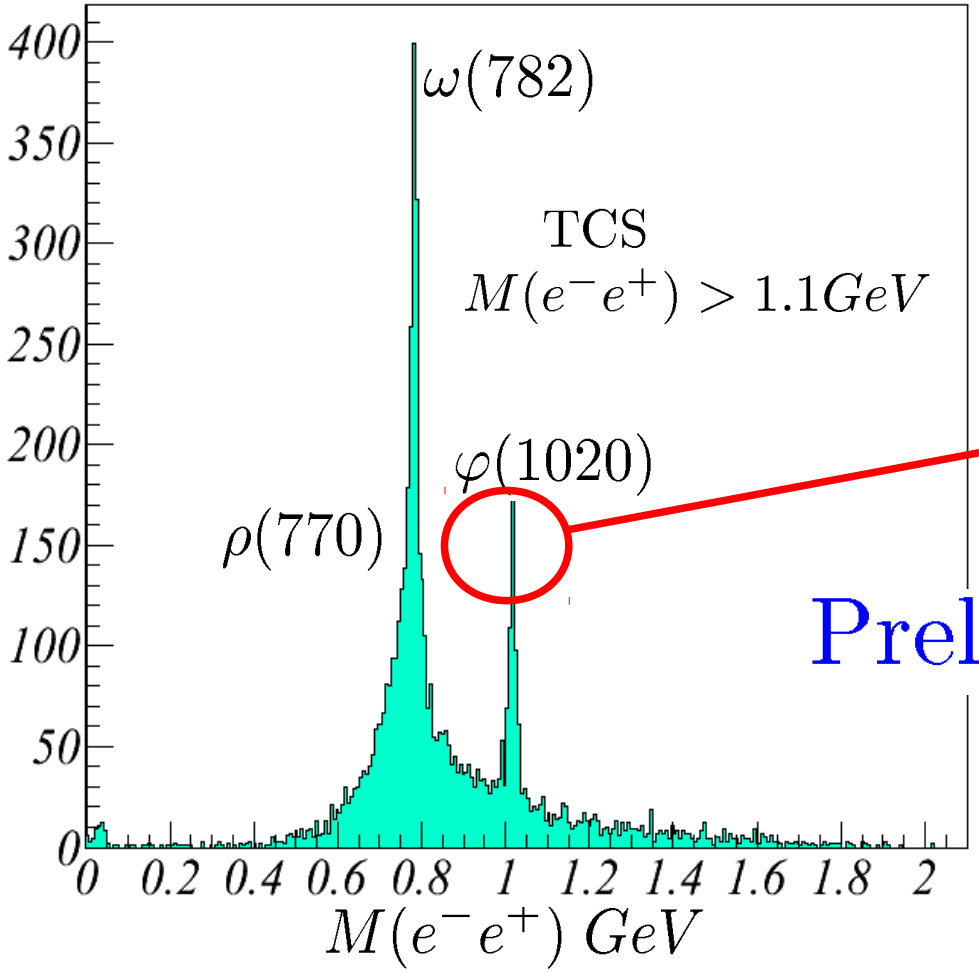


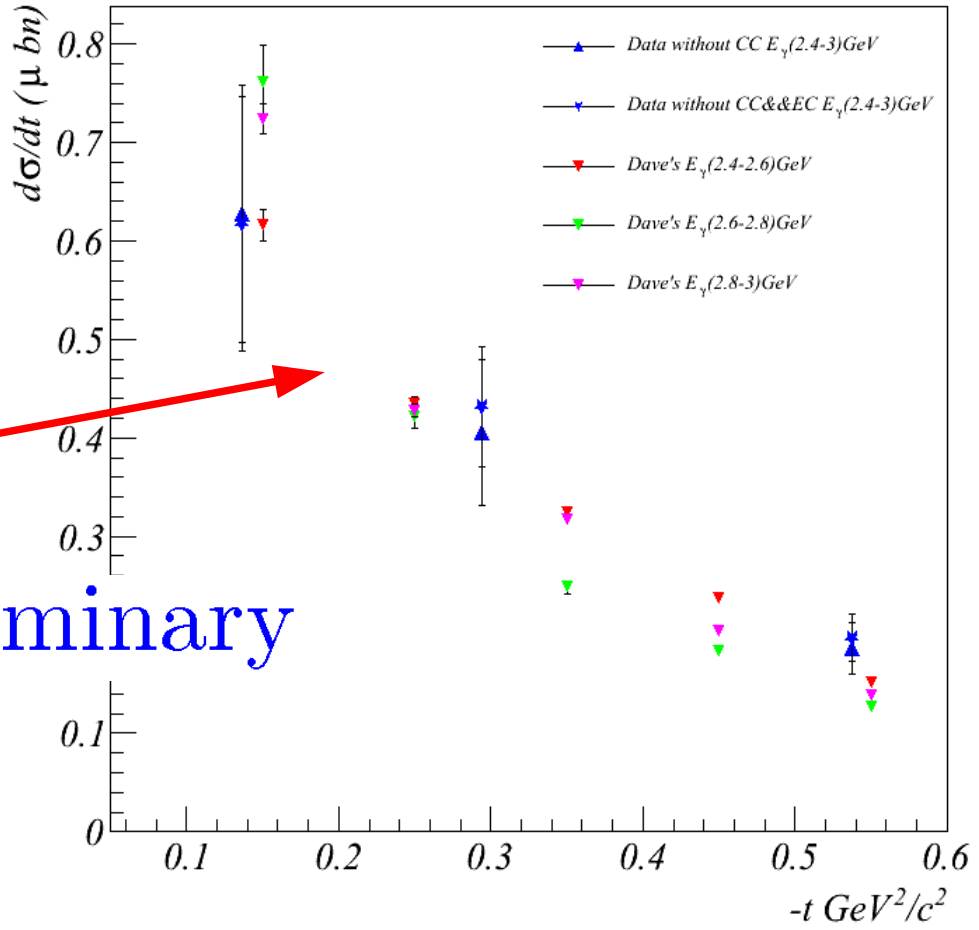
X is identied as a beam electron scattered at 0 degree

$$Q^2 < 0.01 GeV^2 \quad |M_x|^2 < 0.1 GeV^2$$

Photoproduction of lepton pairs

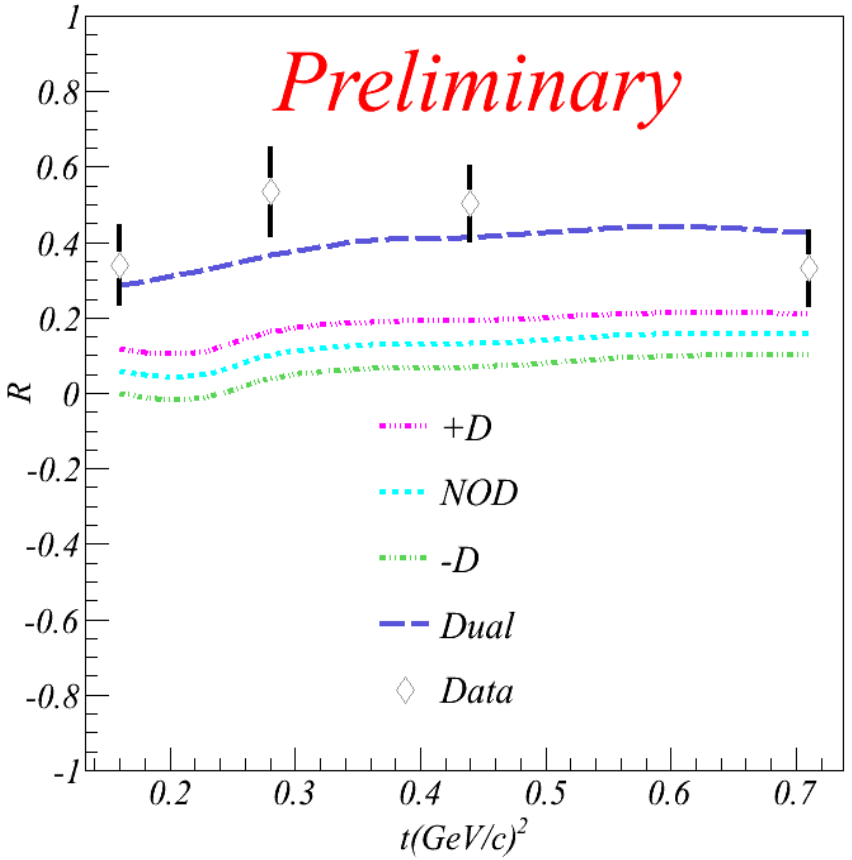
As a check for selection technique and photon flux calculation, φ meson cross section is calculated and compared to real photoproduction data.





Preliminary

Cos(φ) moments from CLAS data



Work is in progress to extract theoretical R

Theoretical R

$$R_{Theory} = \frac{2\int_0^{2\pi} d\phi cos(\phi)\frac{dS}{dQ^2 dt d\phi}}{\int_0^{2\pi} d\phi \frac{dS}{dQ^2 dt d\phi}}$$

$$\frac{dS}{dQ^2 dt d\phi} = \int_{\pi/2-\Delta}^{\pi/2+\Delta} \frac{L(\theta,\phi)}{L_0(\theta)} \frac{d\sigma}{dQ^2 dt d\theta d\phi}$$

E. R. Berger, M. Diehl, B. Pire arXiv:hep-ph/0110062

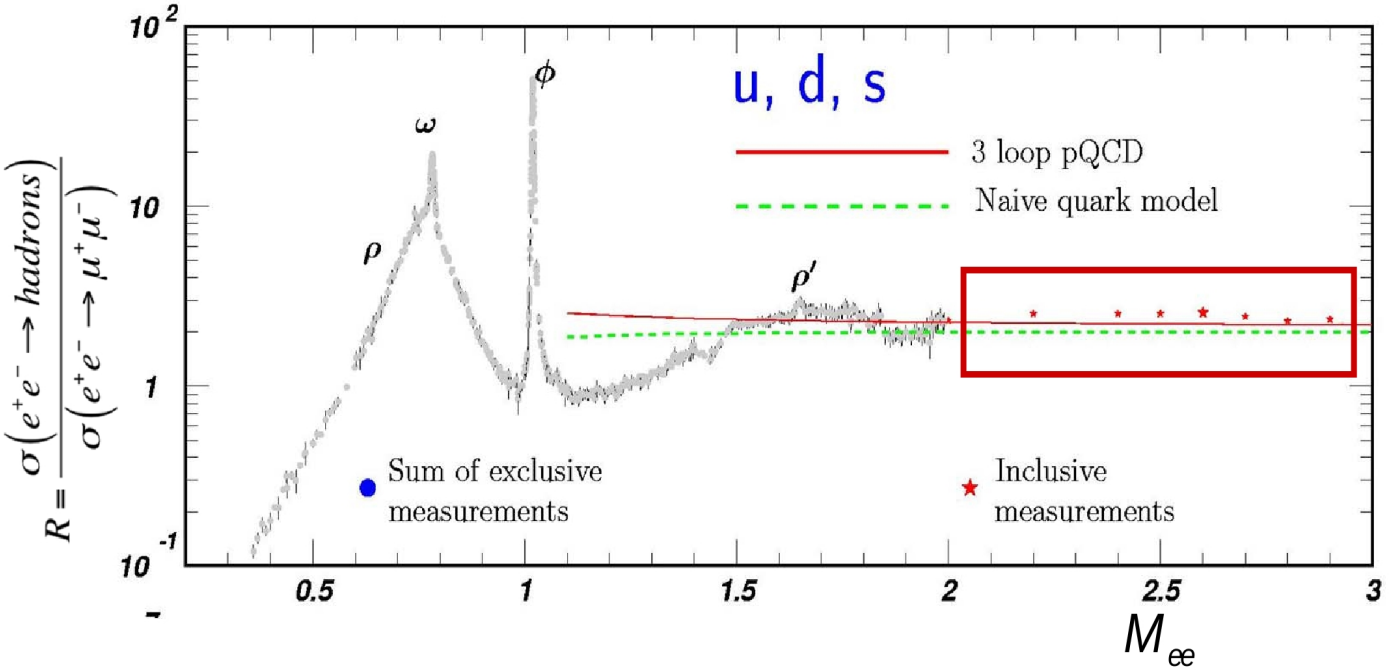
Experimental R

$$R' = \frac{2\sum_{\phi_i} \frac{Y_i}{\Delta Q^2 \Delta t \Delta\phi} cos(\phi)}{\sum_{\phi_i} \frac{Y_i}{\Delta Q^2 \Delta t \Delta\phi}}$$

$$\frac{Y_i}{\Delta Q^2 \Delta t \Delta\Phi} = \sum_{a(\phi)}^{b(\phi)} \frac{L(\theta,\phi)}{L_0(\theta)} N_\theta^\phi \frac{1}{Acc}$$

Prospects with CLAS12 upgrade

- Luminosity increases one order of magnitude 10^{35} cm^{-2} s^{-1}
- With 11 GeV electron beam $M(e^-e^+) < 3.7$GeV is accessible
- The $M(e^-e^+) \subset (2\text{-}3)$GeV resonance free region can be used for TCS analysis



- J/ψ photo-production can be studied in energy range from threshold to 11 GeV

A proposal is approved for studying TCS and J/ψ photo-production using lepton pair photo-production

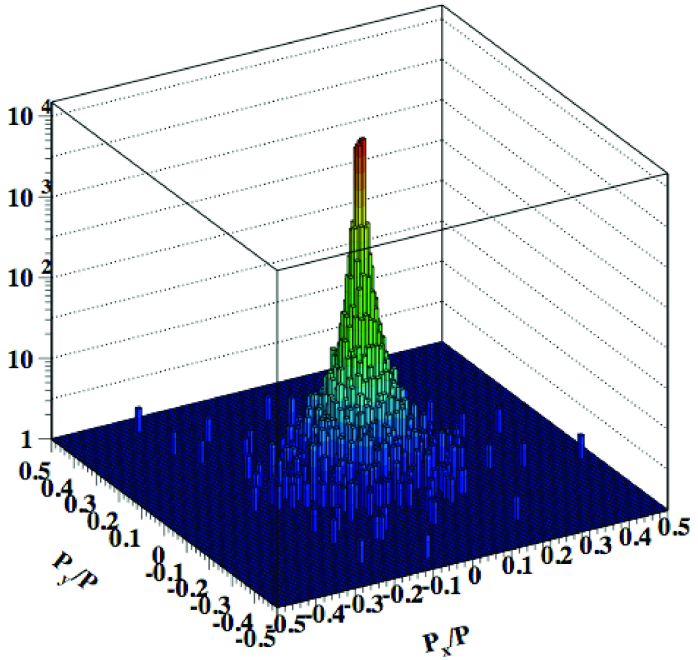
e^-e^+p events in CLAS12

Same missing 4momentum technique will be used to select $e^-e^+p(e')$ events

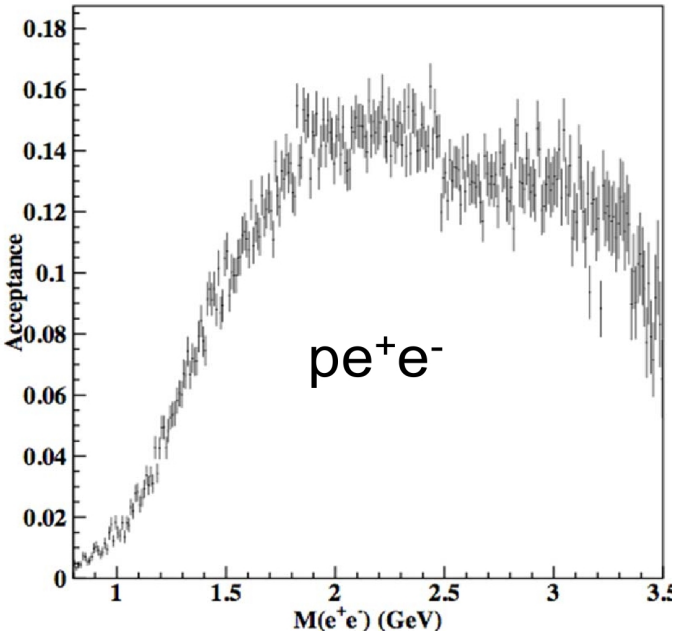
From the $ep \rightarrow e^-e^+p(X)$ reaction

Simulation of $ep \rightarrow BH + \rho + \omega + \varphi + J/\psi\,(e')$ ($\rho+\omega+\varphi+J/\psi \rightarrow e^-e^+$) using FastMC shows that:

CLAS12 momentum and angular resolution is enough for clean selection of quasi-real Photo-production events



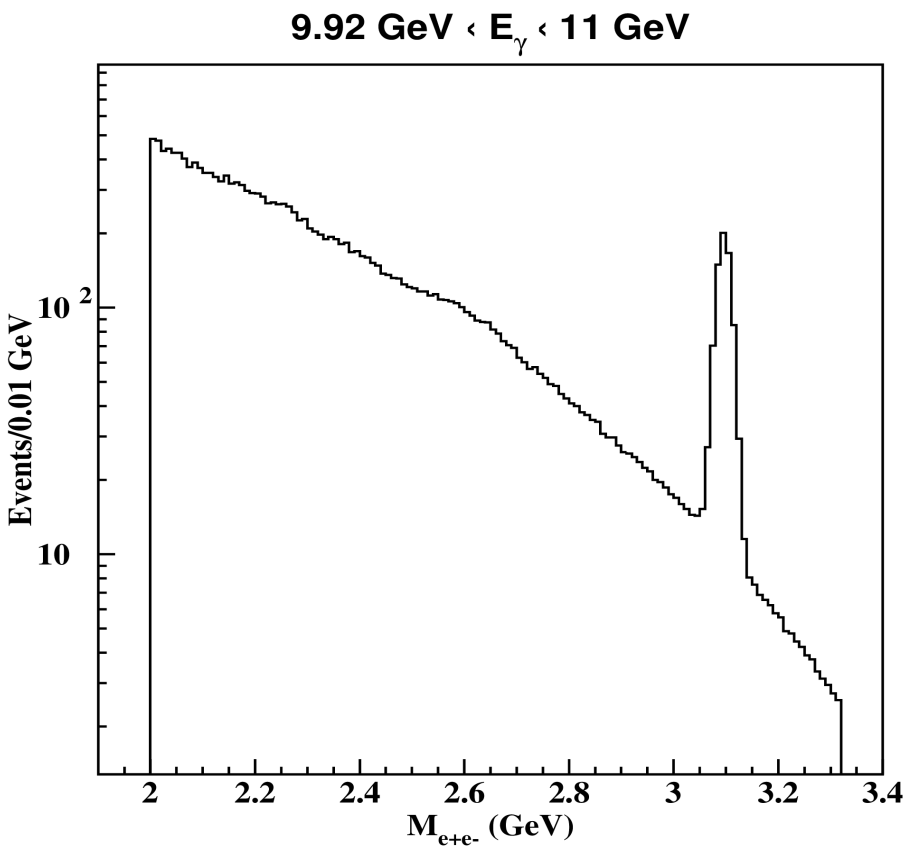
CLAS12 has good acceptance especially at $M(e^-e^+) > 2$GeV region

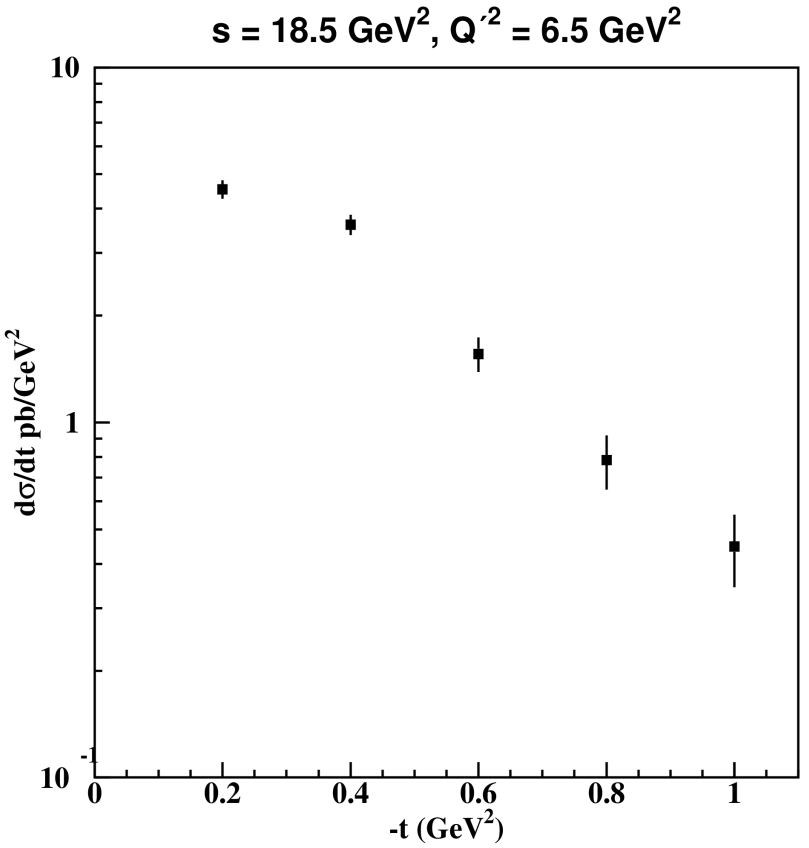


Production Rates

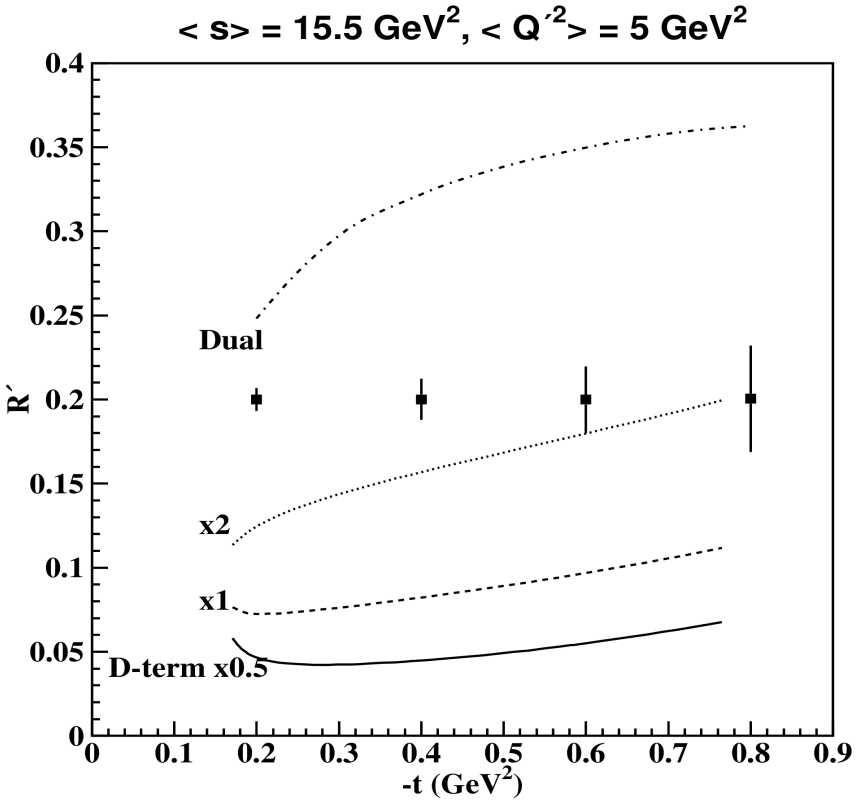
More than 100 PAC days of beam time for electro-production on proton at 11 GeV with CLAS is already approved

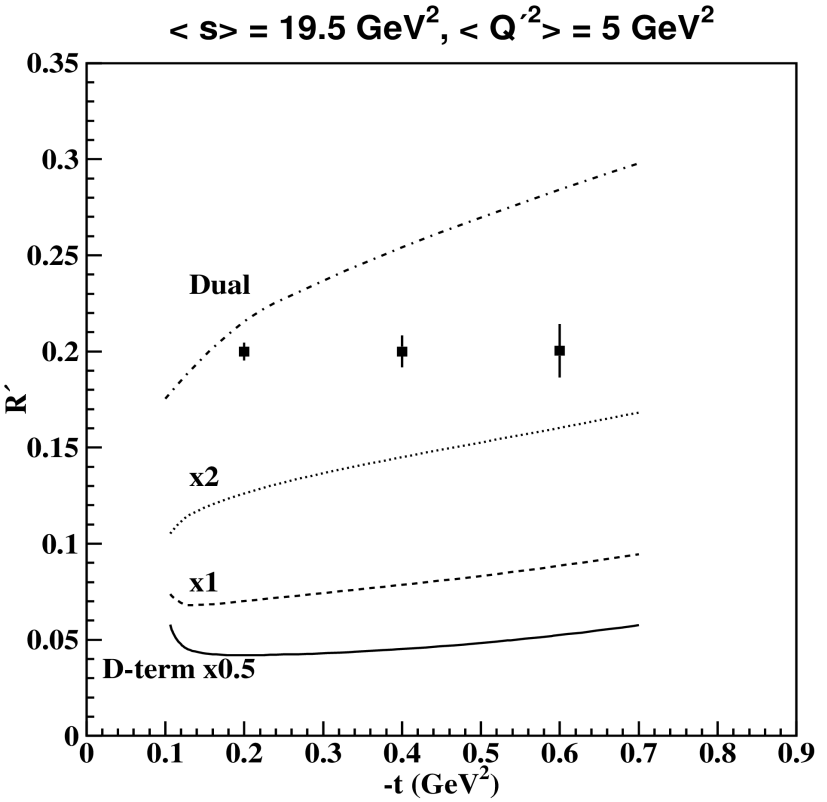
With the luminosity of $10^{35}cm^{-2}sec^{-1}$, expected number of e^-e^+p events in a $4<Q'^2<9$ GeV^2 for 100 days of running will be 30K





Uncertainties on angular moments





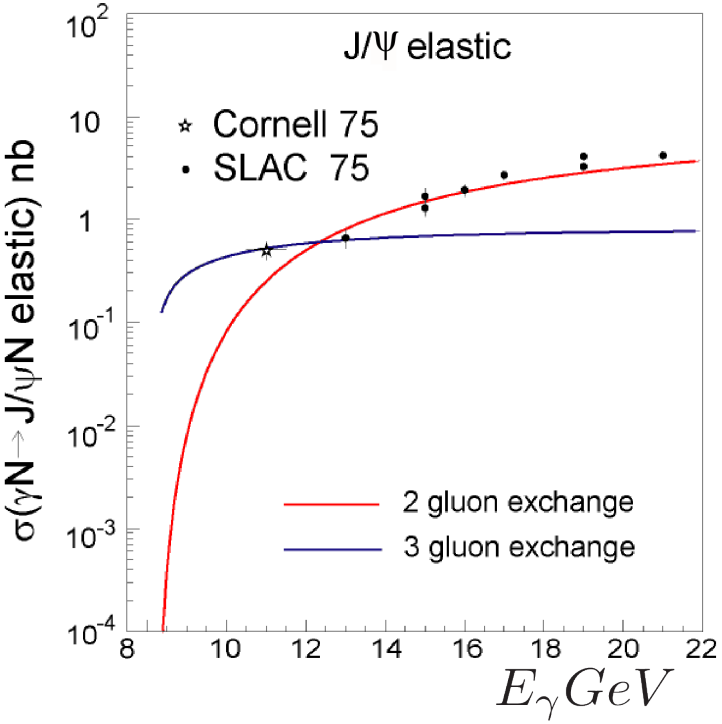
$$R' = \frac{2\int_0^{2\pi} d\phi cos(\phi)\frac{dS}{dQ^2 dt d\phi}}{\int_0^{2\pi} d\phi \frac{dS}{dQ^2 dt d\phi}}$$

$$\frac{dS}{dQ^2 dt d\phi} = \int_{\theta_1(\phi)}^{\theta_1(\phi)} \frac{L(\theta,\phi)}{L_0(\theta)} \frac{d\sigma}{dQ^2 dt d\theta d\phi}$$

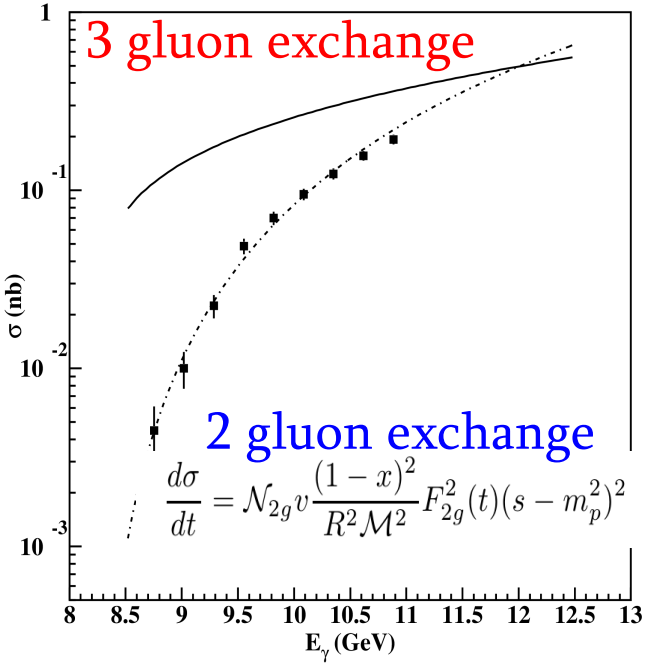
Estimates for J/ψ photoproduction with CLAS12

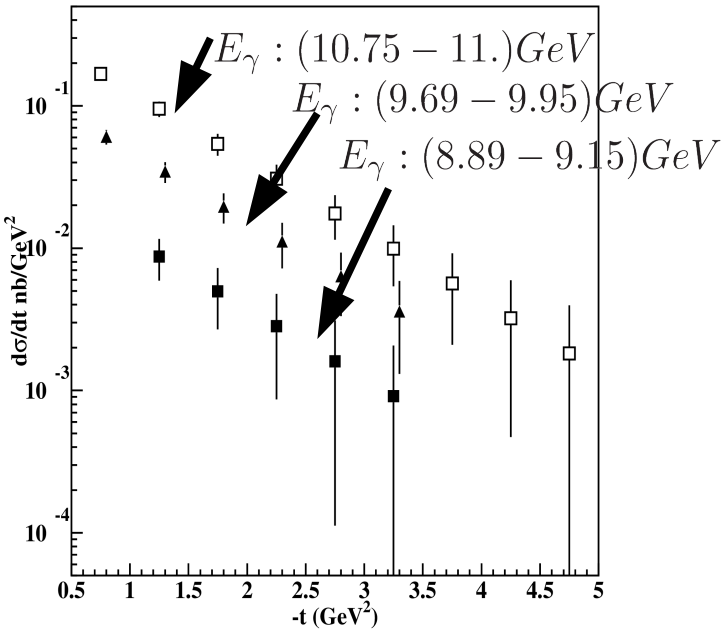
There is no J/ψ photo-production measurement near threshold exits yet.
Could be valuable input to studies on understanding of the J/ψ production Mechanism near threshold.

Rates were estimated with the pessimistic assumption: 2 gluon exchange



$$\frac{d\sigma}{dt} = \mathcal{N}_{3g} v \frac{(1-x)^0}{R^4 \mathcal{M}^4} F_{3g}^2(t)(s-m_p^2)^2$$





Summary

- Timelike Compton Scattering is a complementary way to study GPDs. In particular it gives a direct access to the real part of the Compton amplitudes and will test universalities of GPDs.

- Initial studies using CLAS 6 GeV data showed feasibility of studying quasi-real photo-production of lepton pairs using electro-production experiments.

- 12 GeV upgrade will provide better conditions for studying TCS. In particular high luminosity and wider resonance free region.

- Measurement of J/ψ photo-production near threshold could be one of the first CLAS12 publications, and it will provide important insight on production mechanism near threshold.