

Timelike Compton Scattering at JLab

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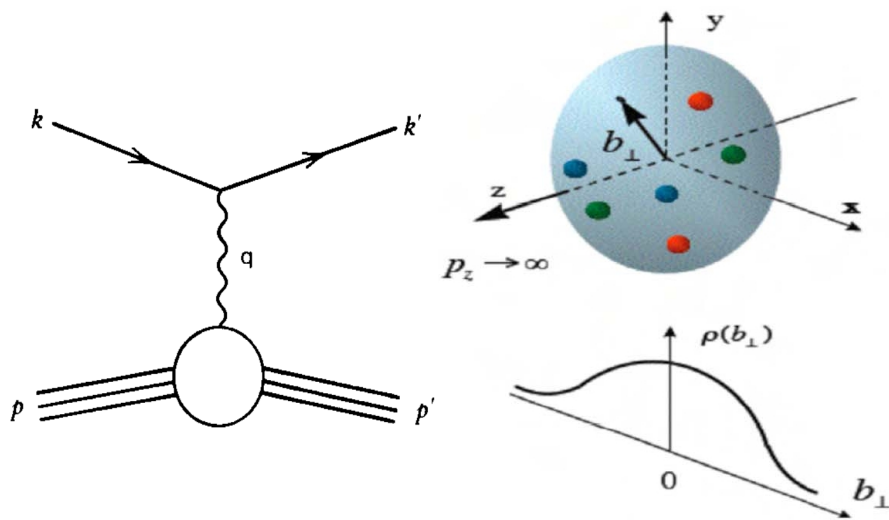
Outline

- ★ 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

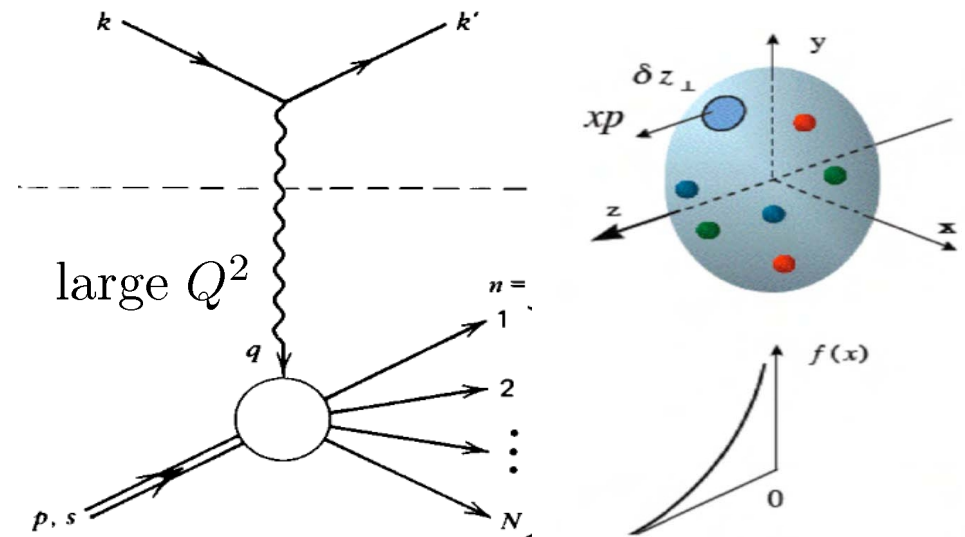
Elastic: $eN \rightarrow eN$

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 $\approx 50\%$ of the nucleon longitudinal momentum and $\approx 25\%$ of nucleon SPIN

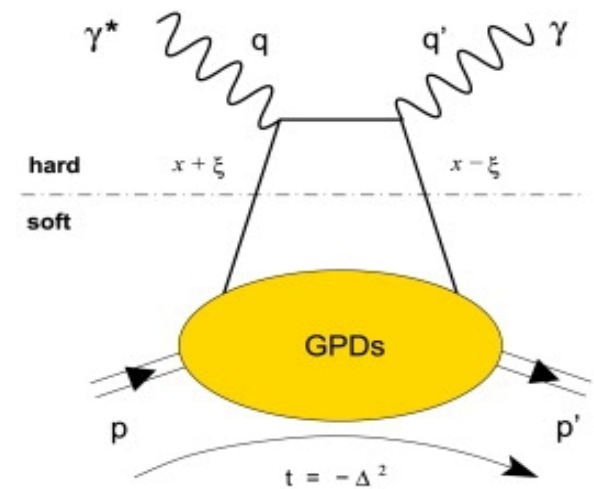


Nucleon structure and GPDs

Hard Exclusive processes: 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 ($H, \tilde{H}, E, \tilde{E}$) and short distance cross sections for the hard scattering partons, calculable in pQCD.



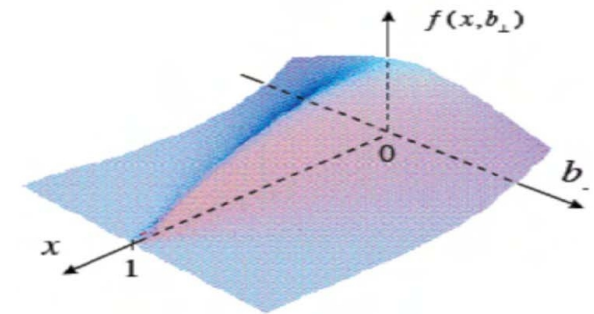
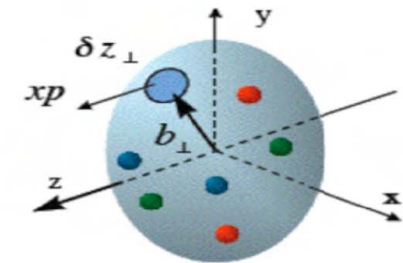
Basic properties of GPDs

$$k^+ = x\bar{P}^+ \quad \Delta^+ = 2\xi\bar{P}^+ \\ t = -\Delta^2 \quad \int_{-1}^1 dx H(x, \xi, t) = F_1(t)$$

In a forward limit ($p = p'$)

$$H^q(x, 0, 0) = \begin{cases} q(x), & x > 0 \\ -\bar{q}(-x), & x < 0 \end{cases} \quad \int_{-1}^1 dx E(x, \xi, t) = F_2(t)$$

$$\tilde{H}^q(x, 0, 0) = \begin{cases} \Delta q(x), & x > 0 \\ -\Delta\bar{q}(-x), & x < 0 \end{cases} \quad \int_{-1}^1 dx \tilde{H}(x, \xi, t) = g_a(t) \\ \int_{-1}^1 dx \tilde{E}(x, \xi, t) = h_a(t)$$



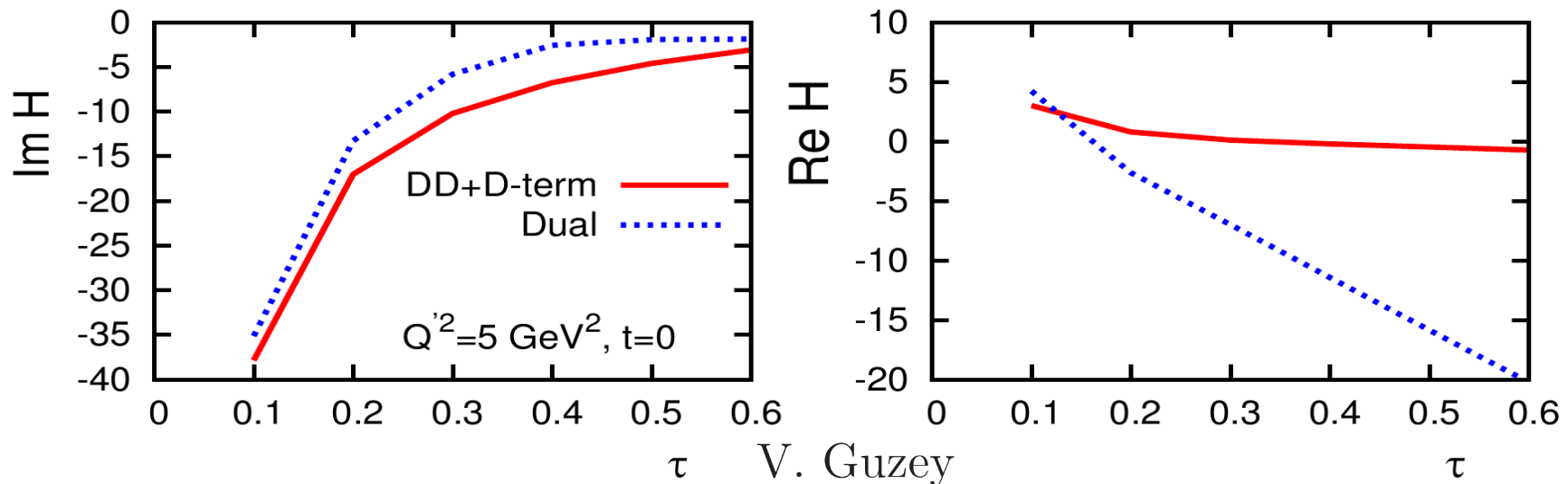
Constructing GPDs

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 $x = \xi$ point.

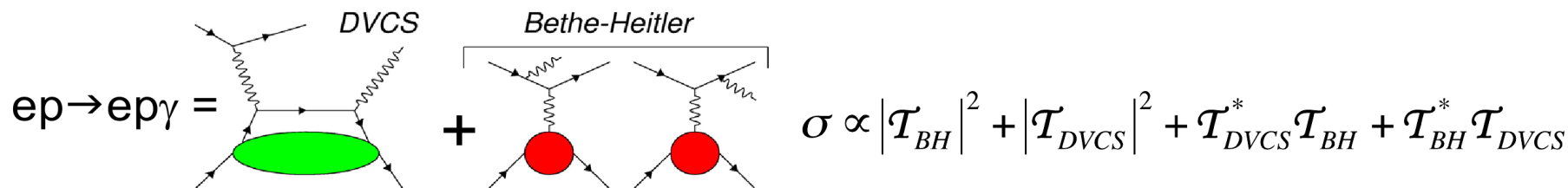
Many experimental observables are needed to constrain models.

The Best studied reaction is DVCS. Most of DVCS observables are sensitive to **Im** part of CFFs. The real part is only accessible through cross section or BCA measurements.

In contrast to **Im** part, **Re** part of CFF H has strong model sensitivity



Accessing GPDs experimentally - DVCS

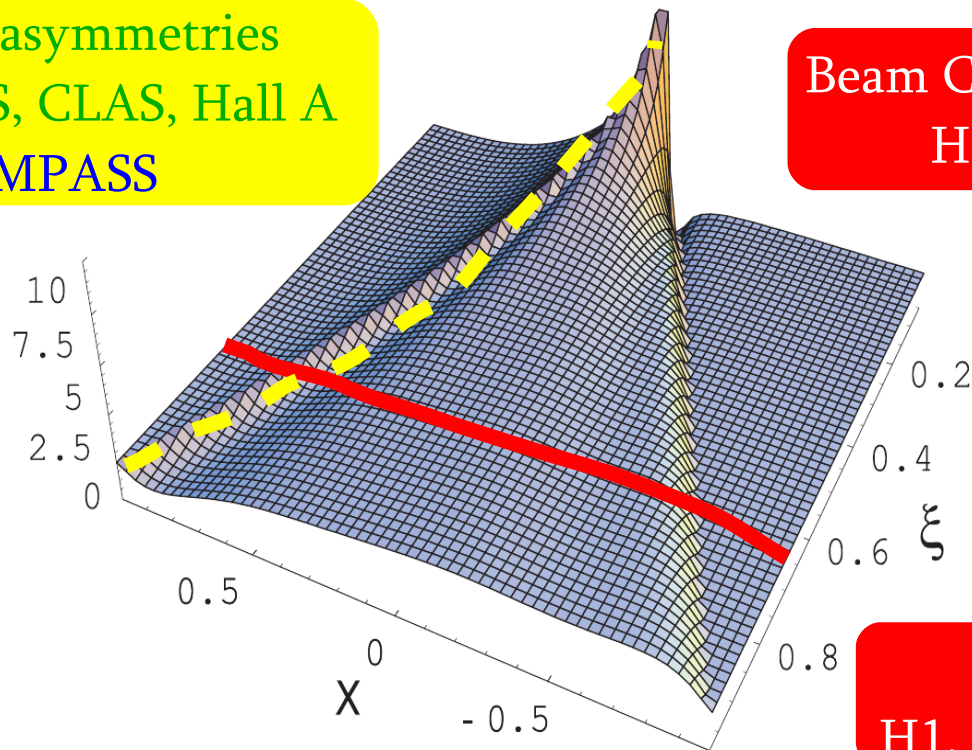


$$\sigma \propto |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + \mathcal{T}_{DVCS}^* \mathcal{T}_{BH} + \mathcal{T}_{BH}^* \mathcal{T}_{DVCS}$$

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

DVCS single spin asymmetries
(Im, $x = \xi$) HERMES, CLAS, Hall A
JLab12, COMPASS

Beam Charge Asymmetry ($|\text{Re}|$)
HERMES, COMPASS

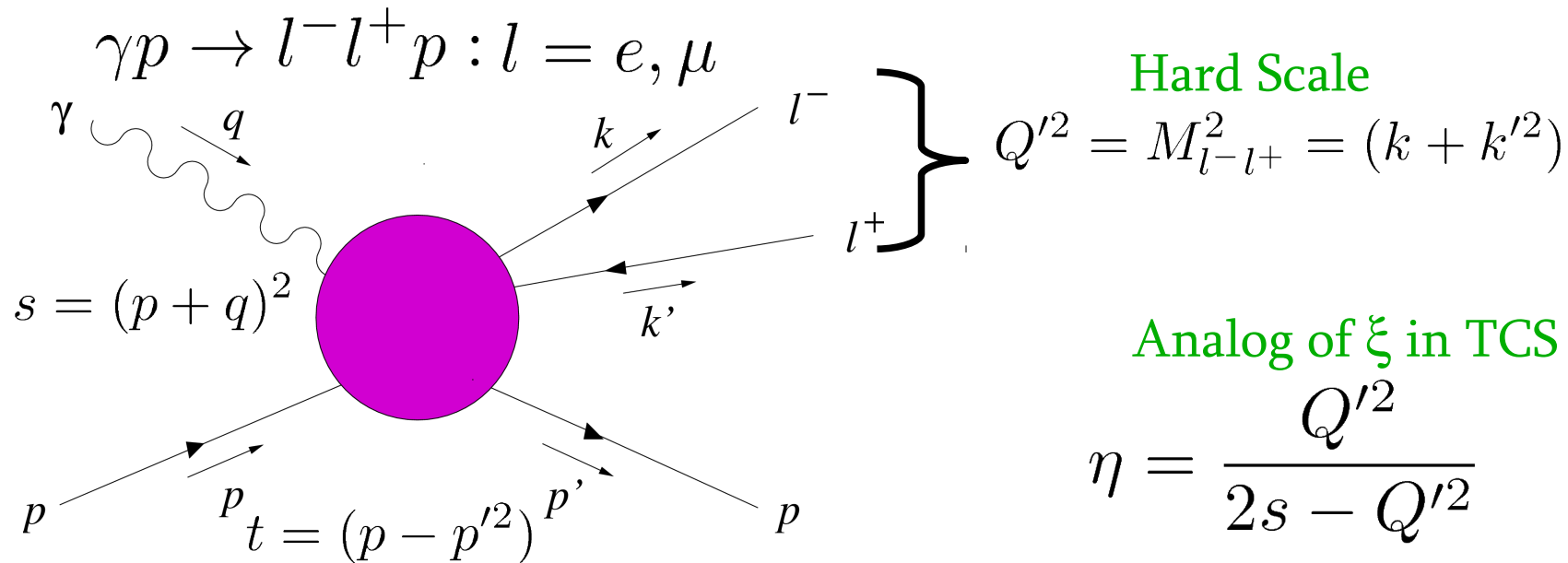


Cross section ($|\text{Re}|^2$)
H1, Hall A, JLAB12, COMPASS

Timelike virtual Compton Scattering

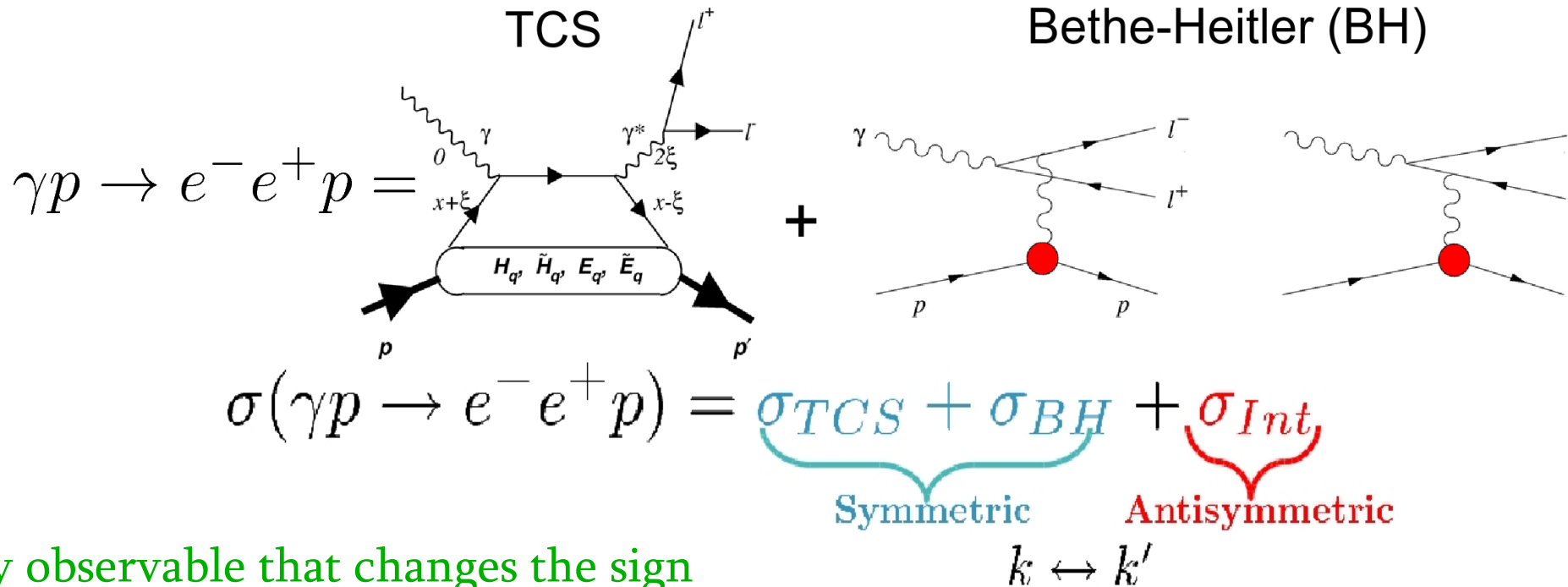
TCS, Photoproduction of lepton pairs, is the inverse process to DVCS. - can be used to test universality of GPDs (as Drell Yan was studied to test unviersality of PDFs obtained from DIS)

Will allow simultaneous measurement of the real and imaginary parts of the Compton amplitudes in photo-production of lepton pairs with unpolarized and circularly polarized photon beams



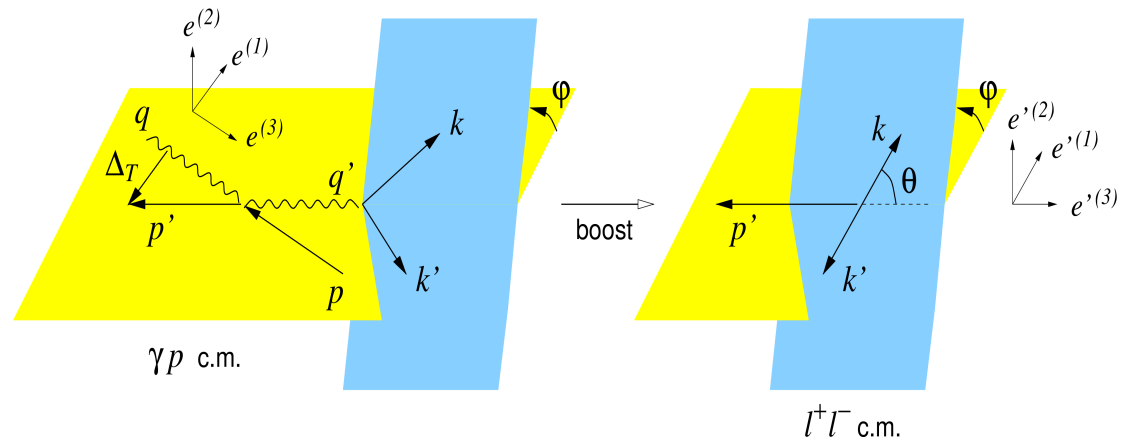
Contribution of higher twists are different for DVCS and TCS processes and hence measuring both will help to obtain stronger constraints on GPDs

Accessing GPDs experimentally - TCS



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

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

Incoming photon polarization

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

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

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

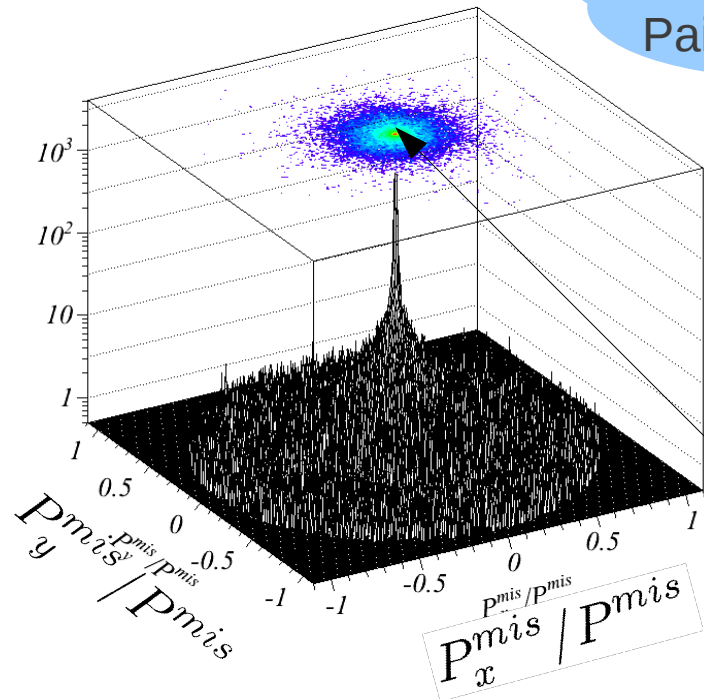
Quasi-real photon-production of e^-e^+ pair with CLAS

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

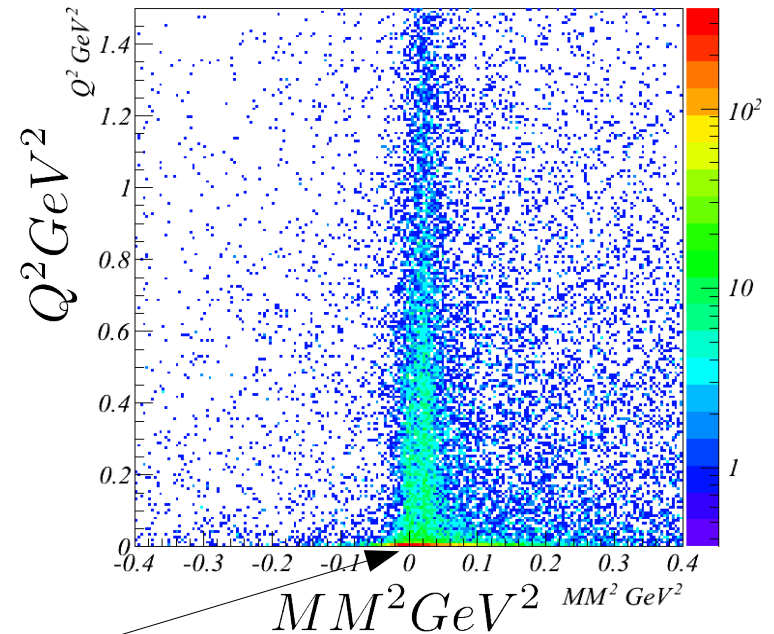
Scattered electron



From Pair production



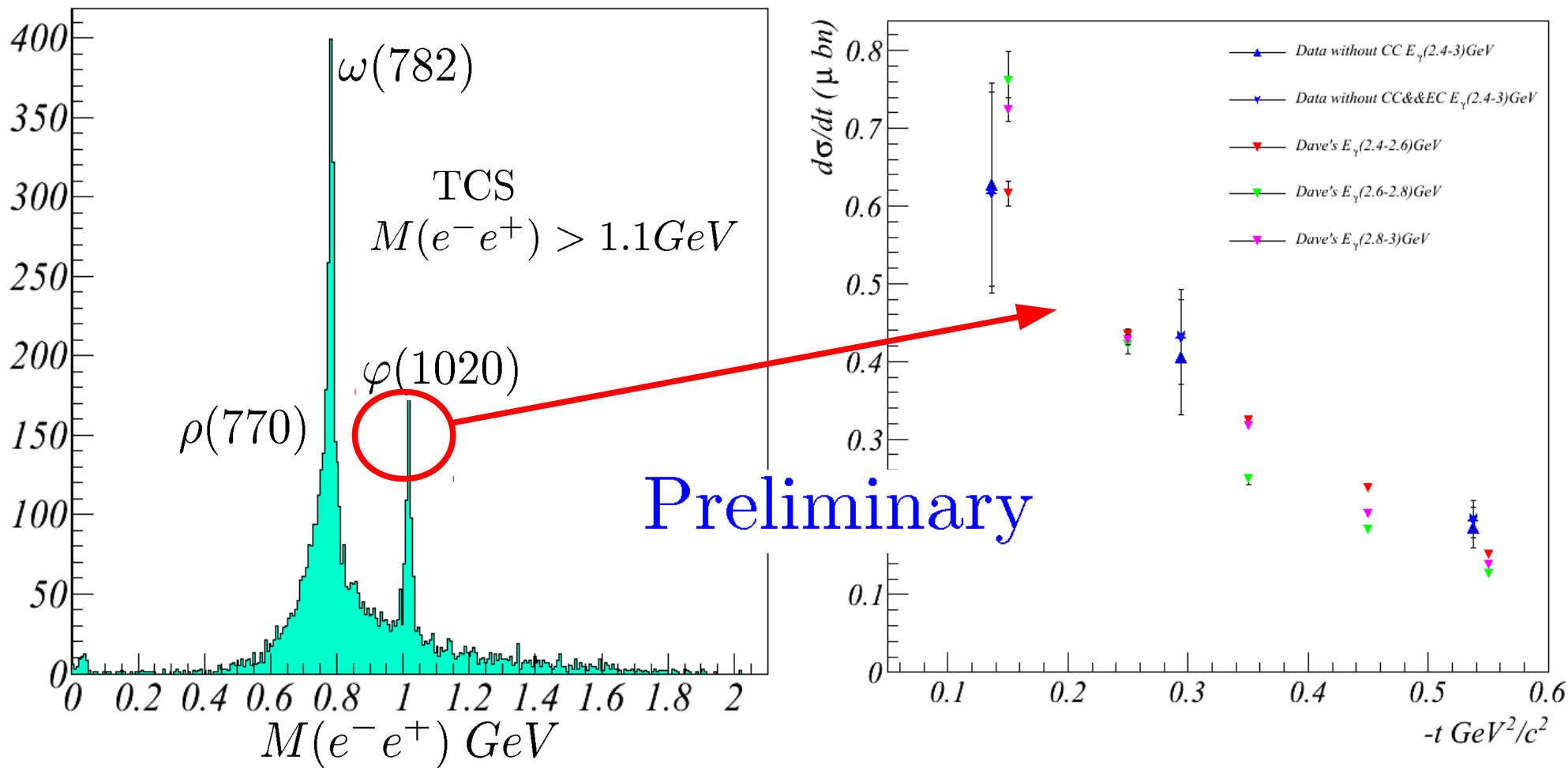
The final state to be analyzed



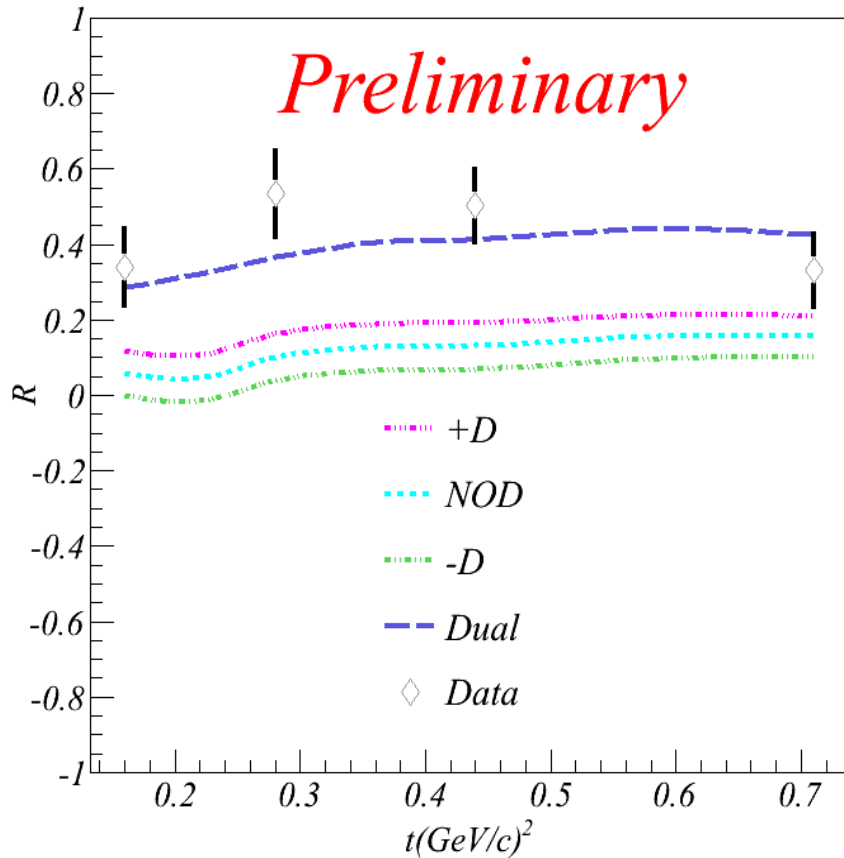
X is identified as a beam electron scattered at 0 degree
 $Q^2 < 0.01 \text{ GeV}^2 \quad |M_x|^2 < 0.1 \text{ GeV}^2$

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.



Cos(ϕ) moments from CLAS data



Work is in progress to
extract theoretical R

Theoretical R

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

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

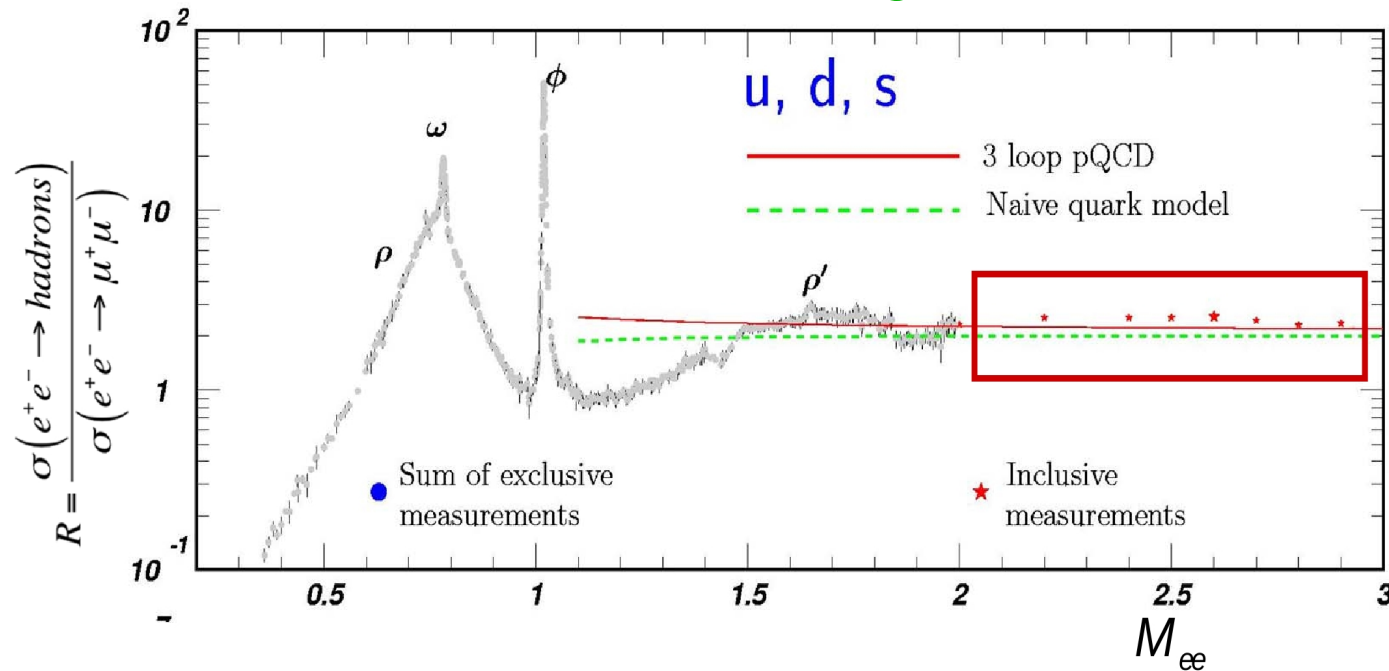
Experimental R

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

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

Prospects with CLAS12 upgrade

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

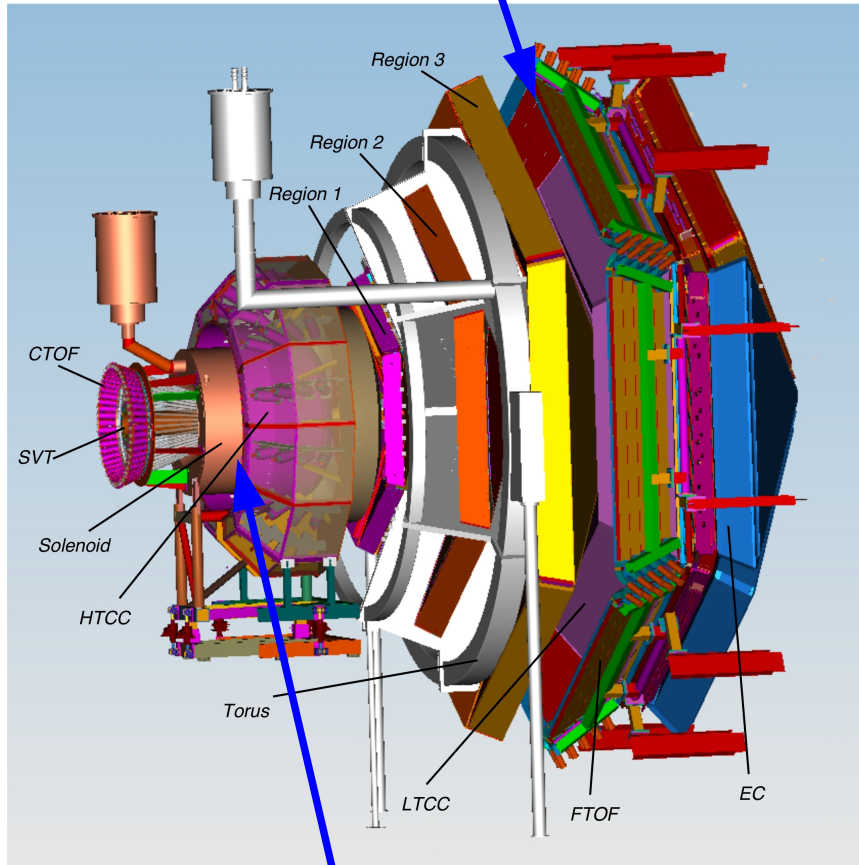


- ★ J/ψ photo-production can be studied in energy range from threshold to 11 GeV

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

CLAS12 – Design parameters

Forward detector



Central detector

$$L = 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$$

Parameters	Forward Detector	Central Detector
Charged tracks:		
polar angular range (θ)	5° to 35°	35° to 125°
resolution:		
polar angle ($\delta\theta$)	< 1 mr	< 10 mr to 20 mr
azimuthal angle ($\delta\phi$)	< 4 mr	< 5 mr
momentum ($\delta p/p$)	< 1% at 5 GeV/c	< 5% at 1.5 GeV/c
Neutral particles:		
angular range (θ)	5° to 40°	40° to 125° (neutrons)
angular resolution ($\delta\theta$)	< 4 mr	< 10 mr
Energy resolution	< 0.1/ \sqrt{E}	< 5%
PID:		
e/ π	full momentum range	NA
π/p	full momentum range	< 1.25 GeV/c
K/ π	< 3 GeV/c	< 0.65 GeV/c
K/p	< 4 GeV/c	< 1 GeV/c

e^-e^+p events in CLAS12

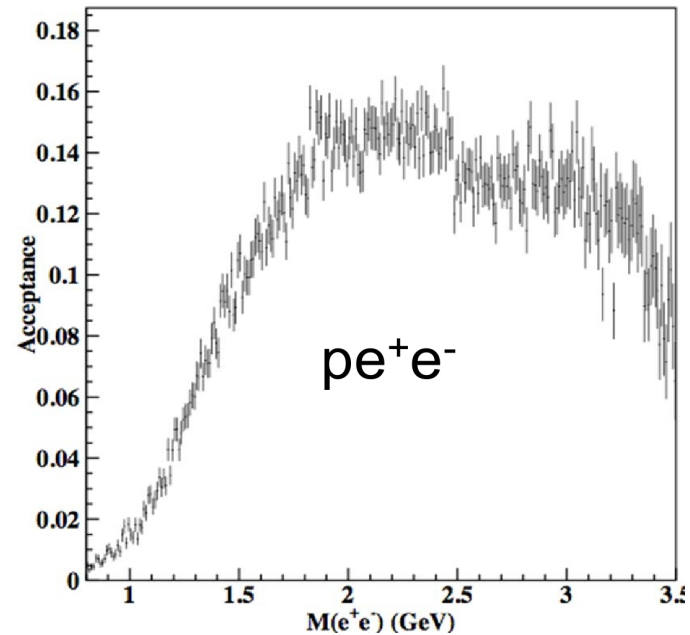
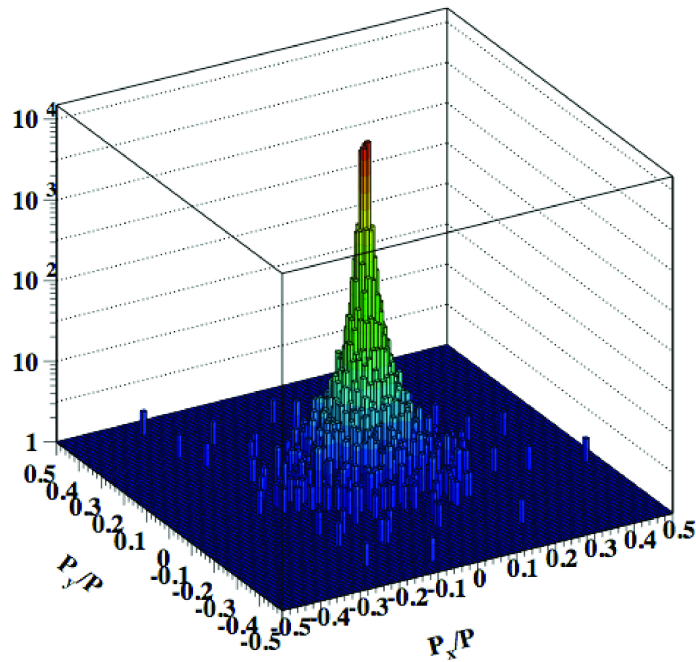
Same missing 4momentum technique will be used to select $e^-e^+p(e')$ events

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

Simulation of $ep \rightarrow BH + \boxed{\rho + \omega + \phi + J/\psi}(e')$ using FastMC shows that:

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

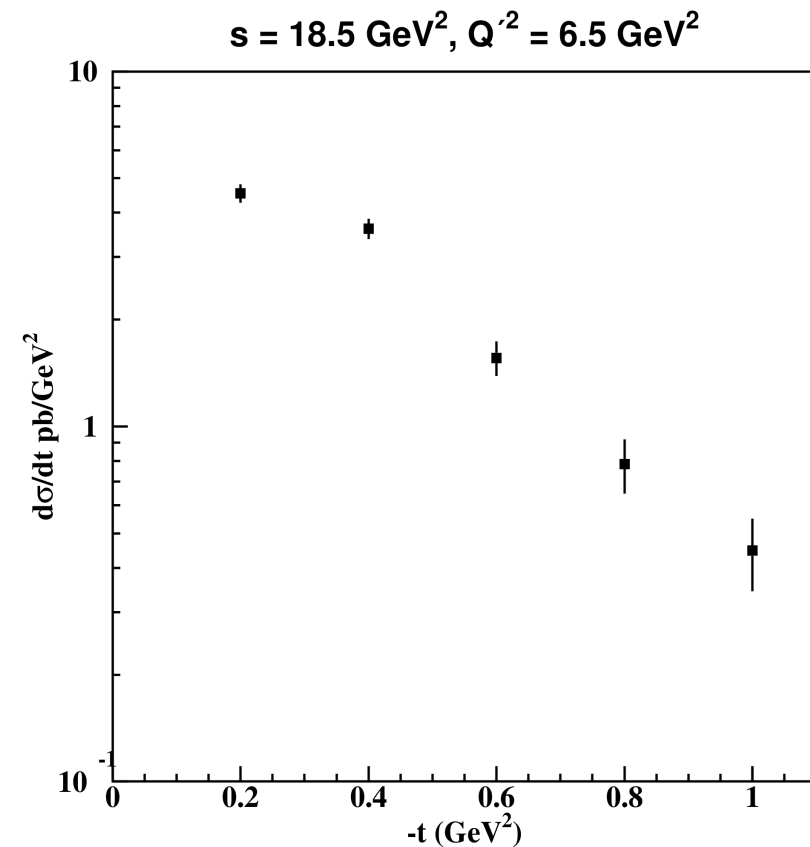
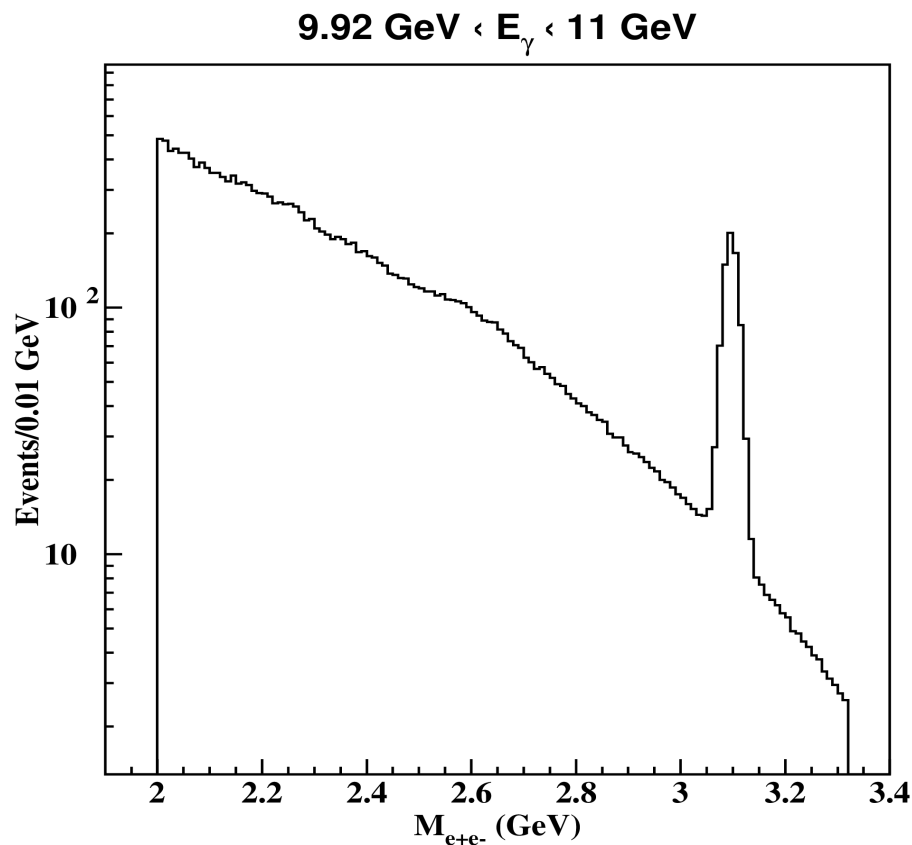
CLAS12 has good acceptance especially at $M(e^-e^+) > 2\text{GeV}$ region



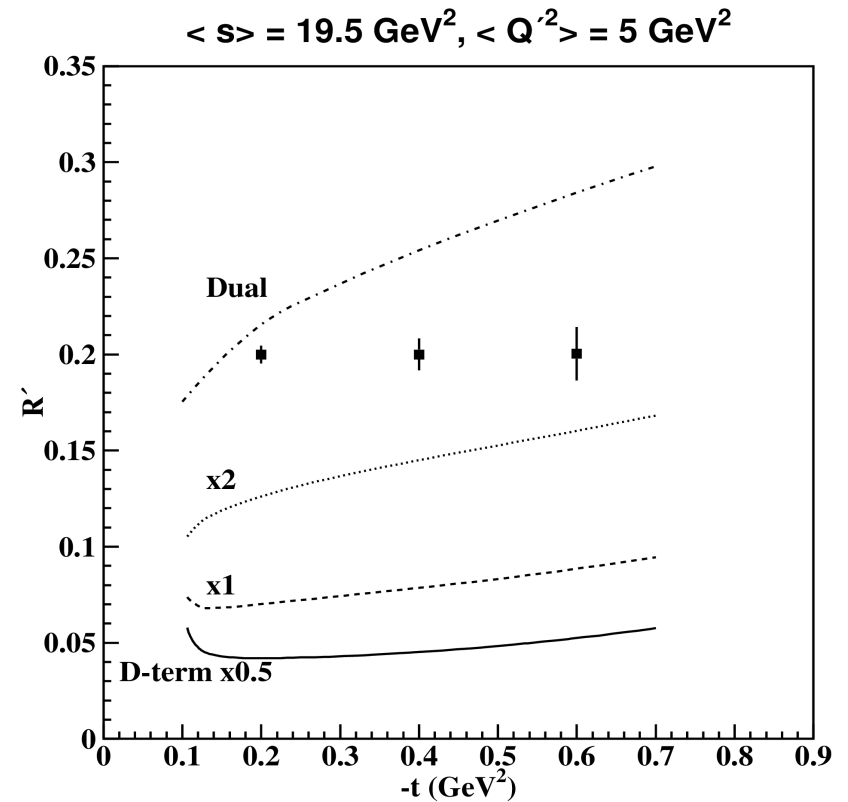
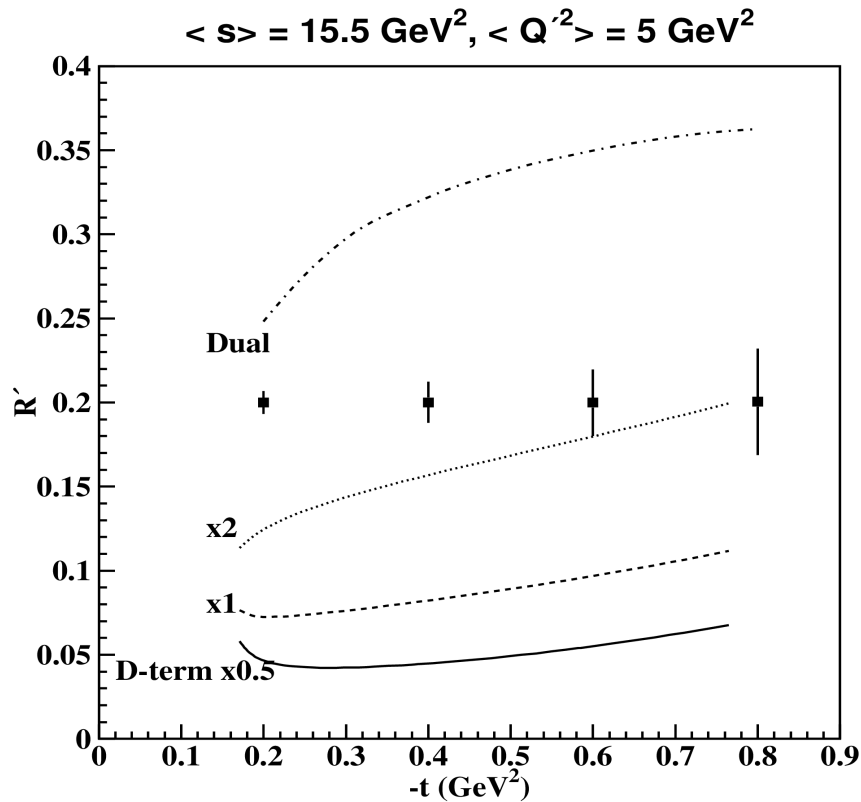
Production Rates

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



Uncertainties on angular moments



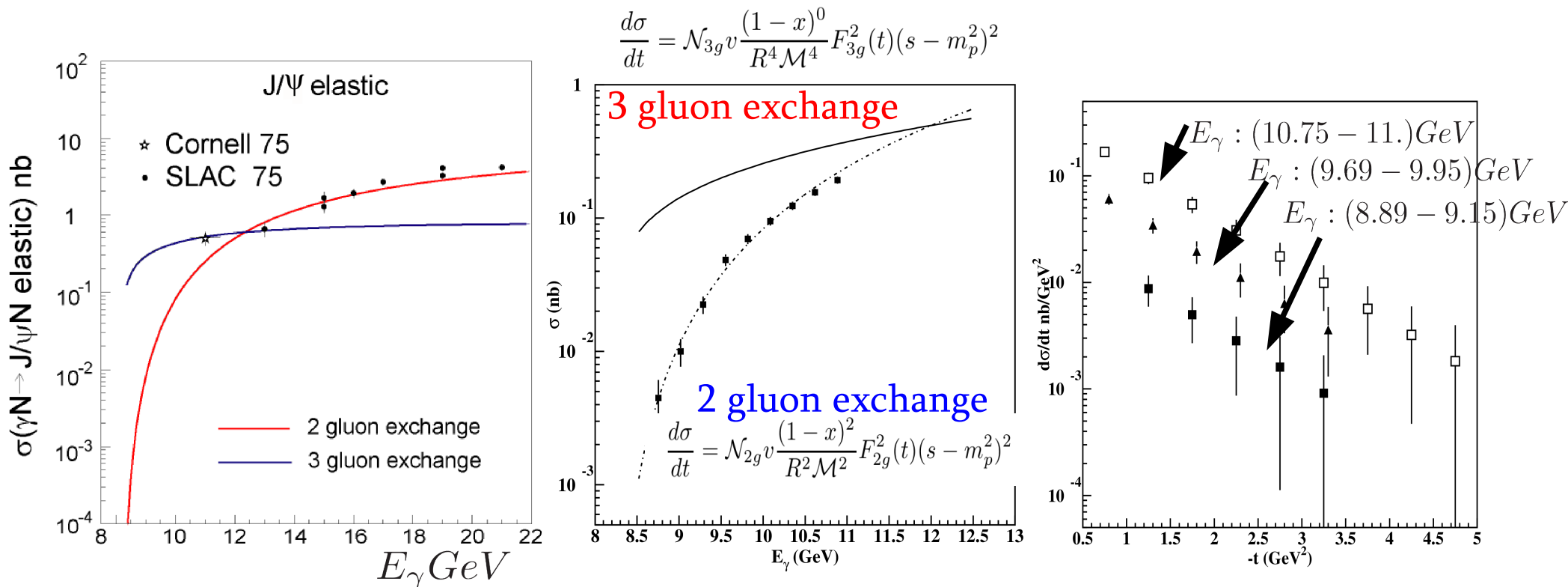
$$R' = \frac{2 \int_0^{2\pi} d\phi \cos(\phi) \frac{dS}{dQ^2 dt d\phi}}{\int_0^{2\pi} d\phi \frac{dS}{dQ^2 dt d\phi}}$$

$$\frac{dS}{dQ^2 dt d\phi} = \int_{\theta_1(\phi)}^{\theta_2(\phi)} \frac{L(\theta, \phi)}{L_0(\theta)} \frac{d\sigma}{dQ^2 dt d\theta d\phi}$$

Estimates for J/ψ photoproduction with CLAS12

There is no J/ψ photo-production measurement near threshold exists 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



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.