Time-like Compton Scattering

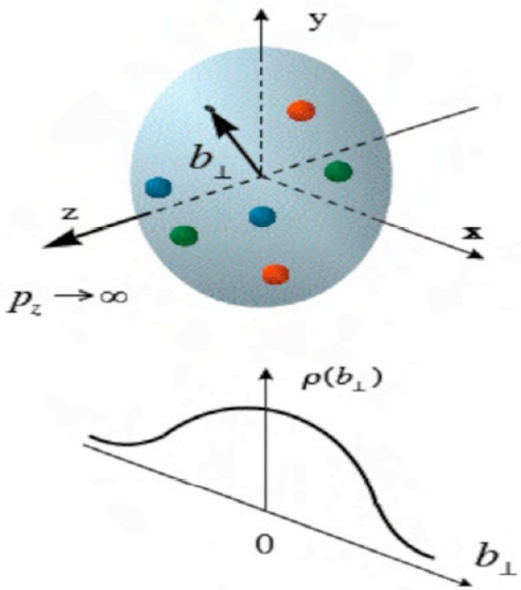
S. Stepanyan (JLAB)

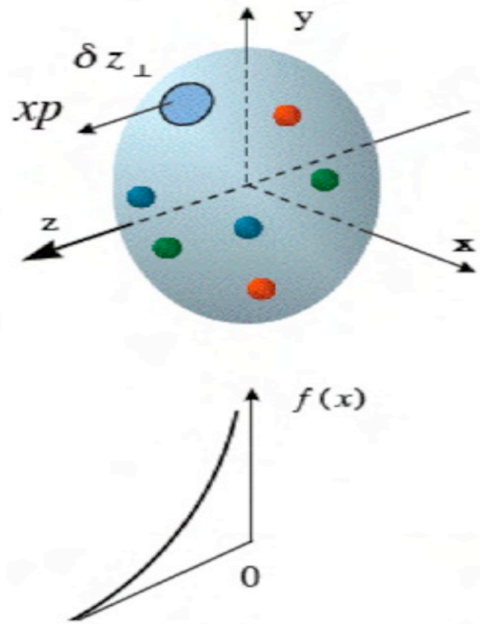
Workshop on probing small-size configurations in high-t photo/electroproduction

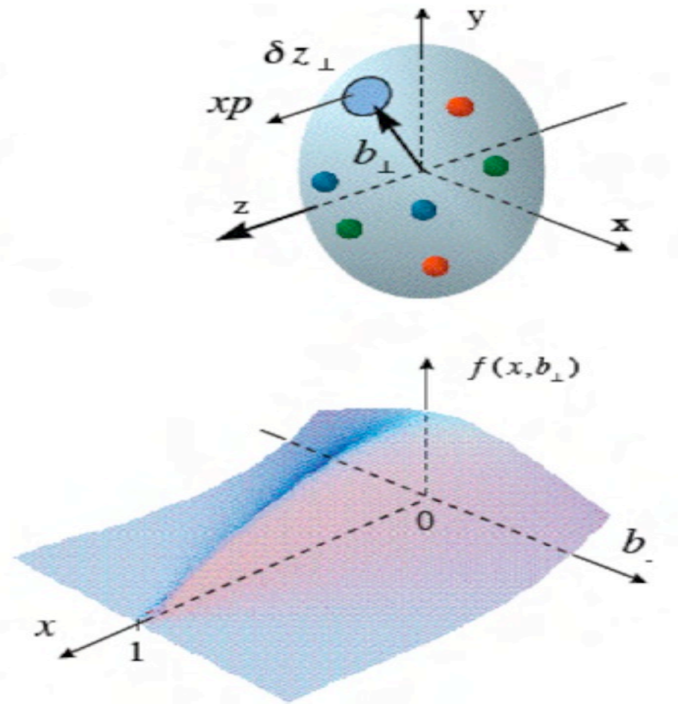
JLAB, March 25-26, 2011

- GPDs, DVCS, and nucleon structure
- Extraction of GPDs from Experimental Data
- TCS phenomenology and observables
- Quasi-real Photoproduction of lepton pairs in CLAS
- Perspectives for CLAS12
- Summary

GPDs and Nucleon Structure





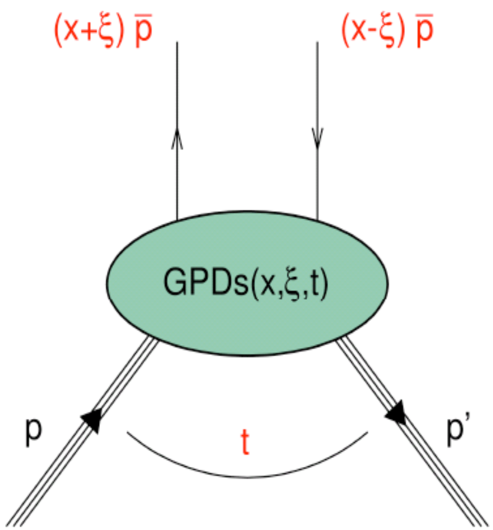


Elastic Form Factors – characterize charge and magnetization distrubutions in the impact parameter space

DIS Parton Distribution Functions - discovery of the quark and gluon substructure of the nucleon, with quarks carrying ½ of the nucleon's momentum and ~25% of its spin

Generalised Parton Distributions – 3-D imaging of the nucleon, the correlation of quark/antiquark transverse spatial and longitudinal momentum distributions, and on the quark angular momentum distribution

Determination of GPDs



Four chiral-even GPDs:

$$H^q; E^q; \widetilde{H}^q; \widetilde{E}^q$$

Boundary conditions

- GPDs → PDFs (in the limite t → 0)

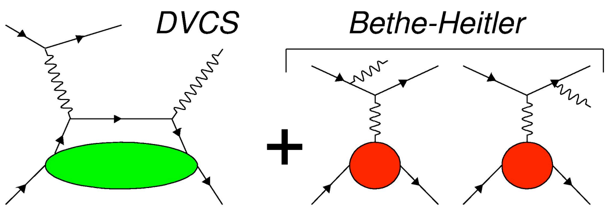
$$H^q(x,0,0) = q(x), -\bar{q}(-x)$$
$$\widetilde{H}^q(x,0,0) = \Delta q(x), \Delta\bar{q}(-x)$$

- GPDs → FFs (first moments of GPDs)

$$\int_{-1}^{+1} dx H^q(x,\xi,t) = F_1^q(t) \quad \int_{-1}^{+1} dx \widetilde{H}^q(x,\xi,t) = g_A^q(t)$$
$$\int_{-1}^{+1} dx E^q(x,\xi,t) = F_2^q(t) \quad \int_{-1}^{+1} dx \widetilde{E}^q(x,\xi,t) = h_A^q(t)$$

Accessing GPDs experimentally (DVCS)

ep' epγ =



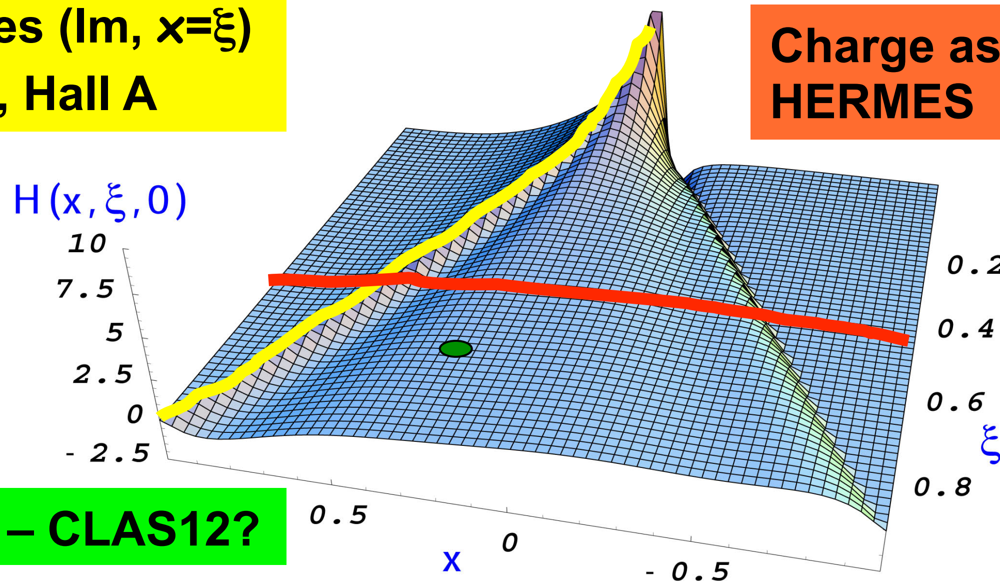
$$\mathcal{T} = |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + \mathcal{T}^*_{DVCS}\mathcal{T}_{BH} + \mathcal{T}^*_{BH}\mathcal{T}_{DVCS}$$

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

Spin asymmetries (Im, x=ξ)
HERMES, CLAS, Hall A

Charge asymmetry (|Re|)
HERMES

Cross sections
(|Re|^2) H1, Hall A



DDVCS (Im, $x \neq \xi$) – CLAS12?

Revealing GPDs

The extraction of GPDs from experimental data will require:

- extensive experimental program [with polarized beam/targets] (CLAS12)

and

- the phenomenological parameterization of GPDs

Commonly used parameterization uses factorized ansatz for the t-dependence: e.g. the Regge parameterization $\sim x^{-\alpha' t}$

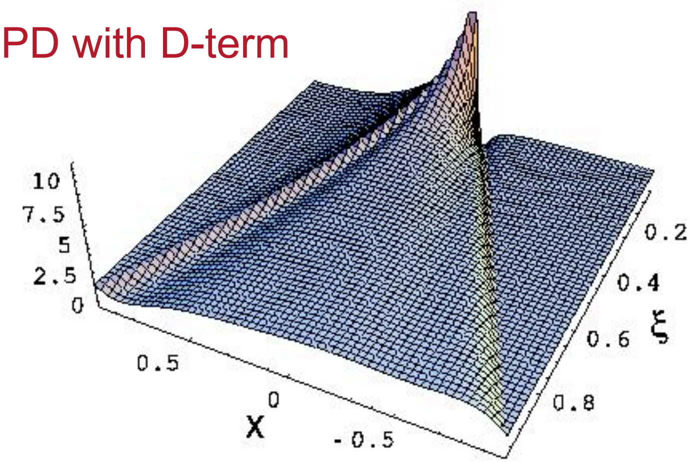
Parameterization of GPDs

DD-distributions

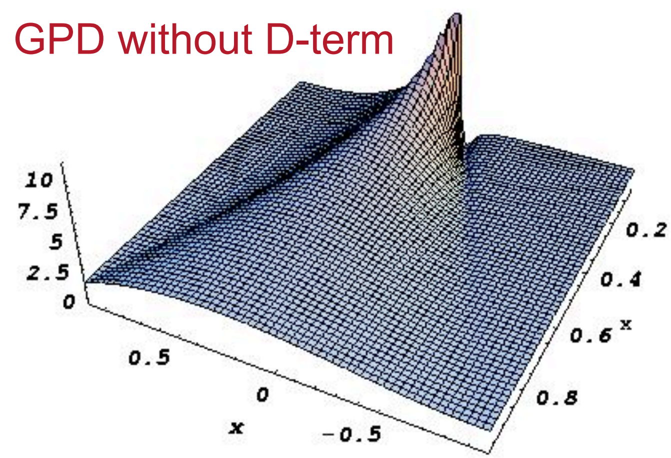
$$H^q(x,\xi) = H^q_{DD}(x,\xi) + \theta(\xi - |x|)\frac{1}{N_f} D\left(\tfrac{x}{\xi}\right)$$

D-term – to satisfy polynomiality of Mellin moments of GPD

GPD with D-term



GPD without D-term



Real part of the Compton amplitude is very sensitive to the D-term

Extracting the GPDs

Global fit to the DVCS data, using models of GPDs - M. Guidal, Eur.Phys.J. **A37**, p319 (2008)

8 independent quantities to be fit -

$$\mathrm{Im}(\mathbf{H}); \mathrm{Im}(\mathcal{E}); \mathrm{Im}(\tilde{\mathbf{H}}); \mathrm{Im}(\tilde{\mathcal{E}})$$

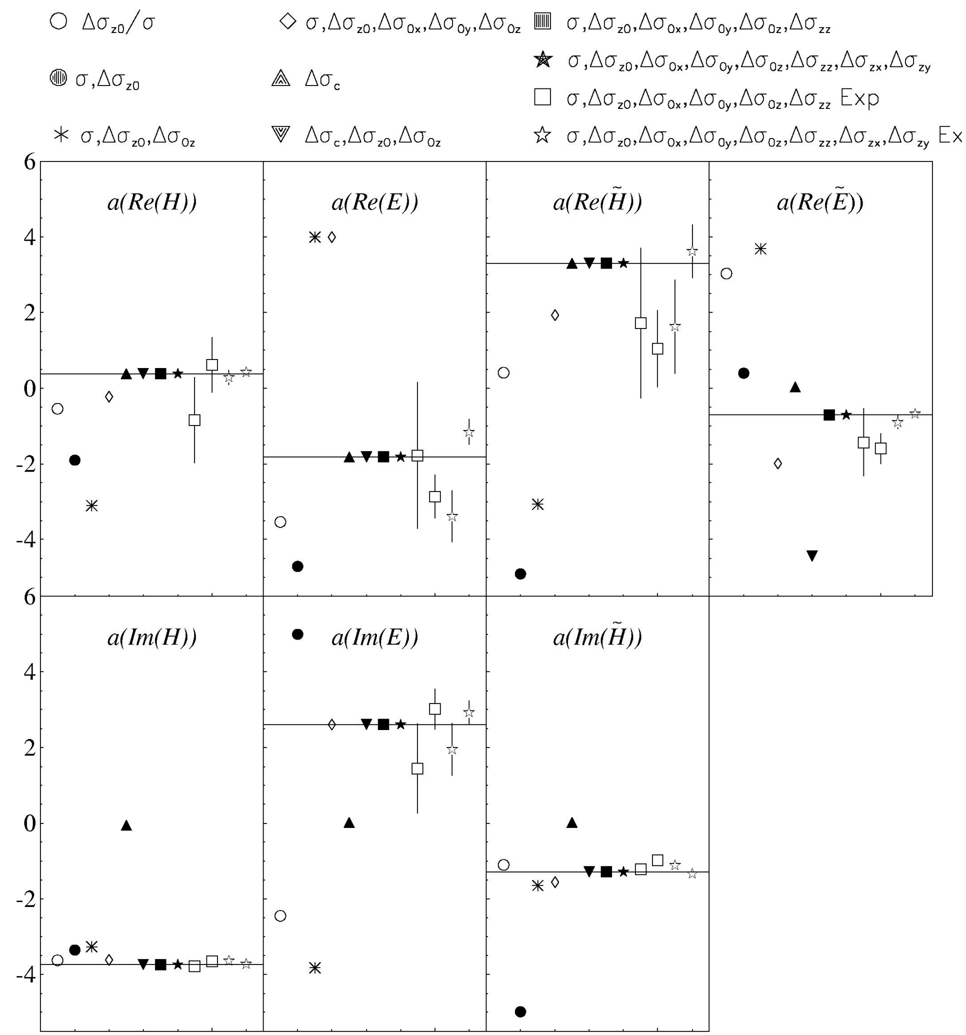
$$\mathrm{Re}(\mathbf{H}); \mathrm{Re}(\mathcal{E}); \mathrm{Re}(\tilde{\mathbf{H}}); \mathrm{Re}(\tilde{\mathcal{E}})$$

Using 9 independent observables -

$$\sigma; \Delta\sigma_{z0}; \Delta\sigma_{0x}; \Delta\sigma_{0y}; \Delta\sigma_{0z};$$

$$\Delta\sigma_{zx}; \Delta\sigma_{zy}; \Delta\sigma_{zz}; \Delta\sigma_{c};$$

Assumption - $\mathrm{Im}(\tilde{\mathcal{E}}) = 0$



Conclusions from the fits

- In general, with enough observables fit was able to constrain seven GPDs

There might be possibilities to reduce the number of independent parameters – dispersion relations or model motivated ansatzes

- Imaginary part of CCFs $\mathcal{H}$ and $\tilde{\mathcal{H}}$ can be reliably extracted from σ, $\Delta\sigma_{z0}$ and $\Delta\sigma_{0z}$ – planned and ongoing experiments at JLAB
- Real parts of the GPDs can be reliably reconstructed
  - from BCA measurements – requires lepton beams of both charges

and/or

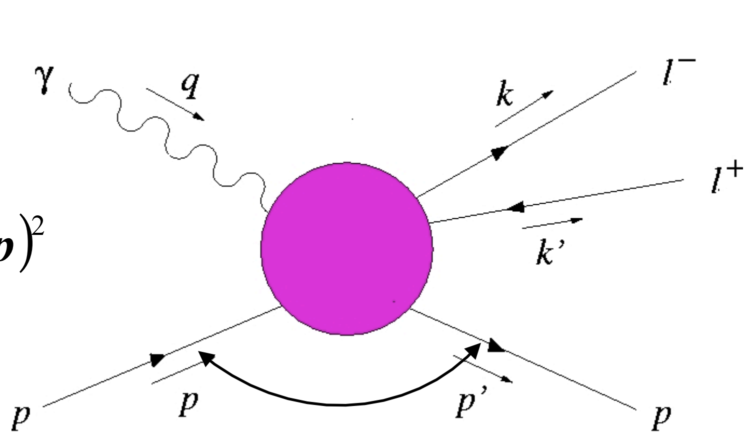
  - in the combined analysis of several (at least 6) beam and/or target spin asymmetry measurements – will potentially have large systematic uncertainties and requires huge amount of data

Time-like Compton Scattering (TCS)

Information on the real (imaginary) part of the Compton amplitude can be obtained from photoproduction (circularly polarized) of lepton pairs

$$\gamma\, p \rightarrow p\, l^+\, l^- \;;\quad l = e, \mu$$

$$s = (q+p)^2$$



$$t = (p-p')^2$$

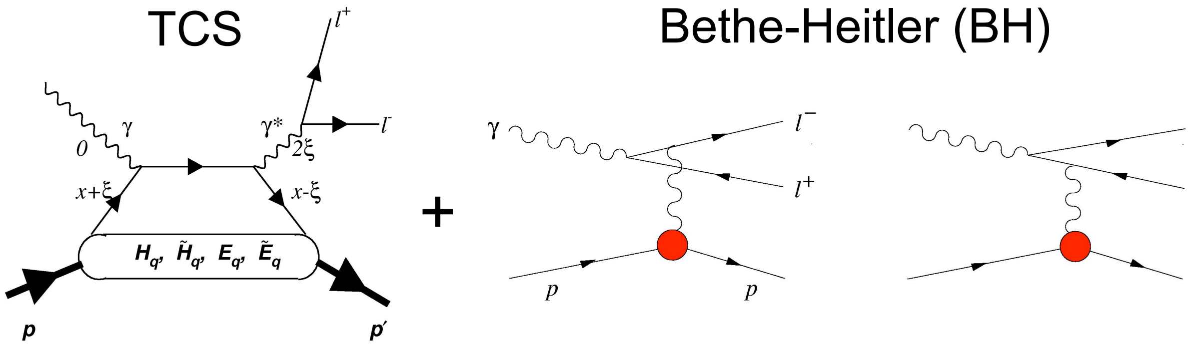
Hard scale

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

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

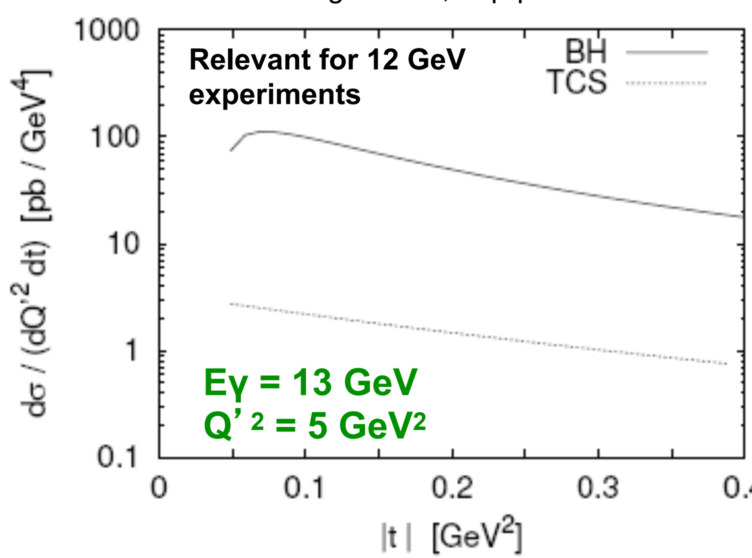
TCS is the inverse process to DVCS. Contributions of higher twists are different for DVCS and TCS processes and hence measuring both will help to obtain stronger constraints on GPDs

Lepton pair photo-production



$$\frac{d^4\sigma}{dx_B dQ^2 dt d\varphi} \propto |T^{BH}|^2 + T^{BH} \bullet \mathrm{Re}(T^{VCS}) + h_{\oplus} T^{BH} \bullet \mathrm{Im}(T^{VCS}) + |T^{VCS}|^2$$

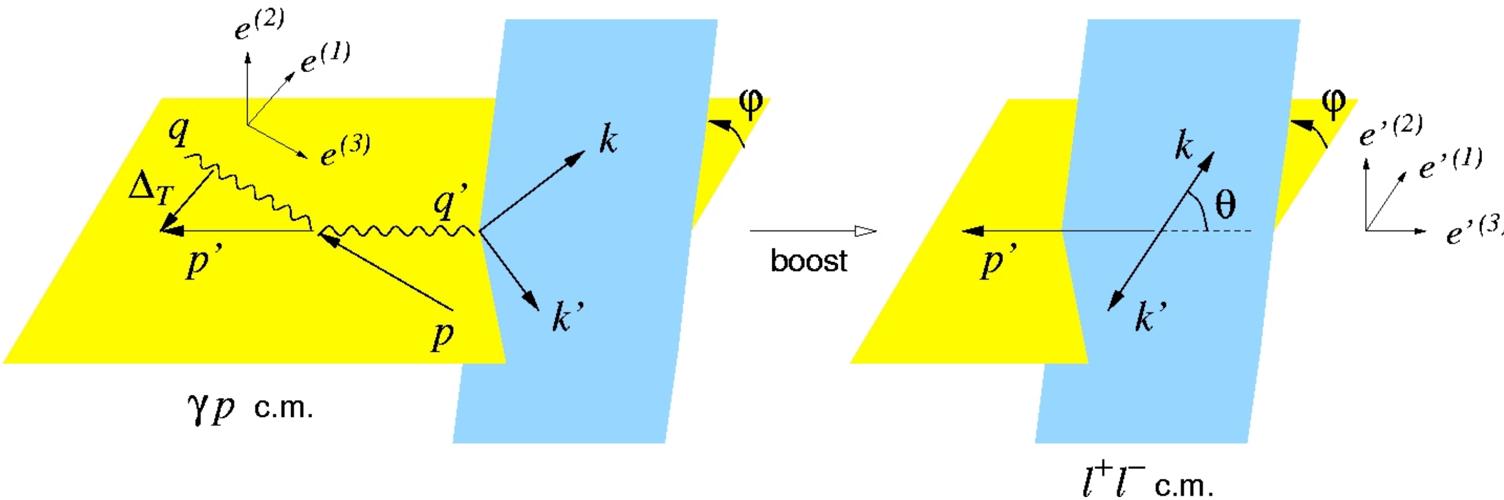
E. Berger et al., hep-ph/0110062



- BH always dominates in the cross section
- lepton pair is produced in C-odd state by TCS and in a C-even state by BH, azimuthal angular dependence will project out the interference – analogous to BCA in DVCS

Interference term and angular harmonics

E. Berger et al., hep-ph/0110062



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

$$\left. -\cos 2\varphi\,\sqrt{2}\cos\theta\,\mathrm{Re}\,\tilde{M}^{0-} + \cos 3\varphi\,\sin\theta\,\mathrm{Re}\,\tilde{M}^{+-} + O\left(\frac{1}{Q'}\right)\right],$$

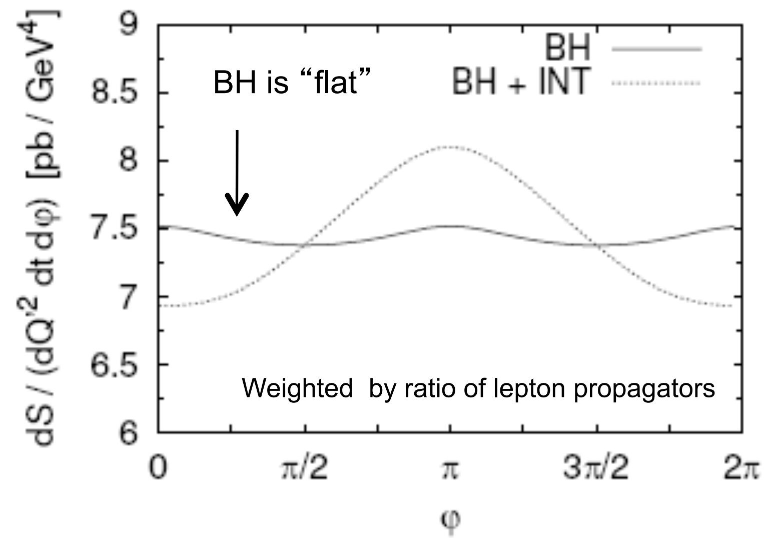
$$-\nu\frac{\alpha_{em}^3}{4\pi s^2}\frac{1}{-t}\frac{M}{Q'}\frac{1}{\tau\sqrt{1-\tau}}\frac{L_0}{L}\left[\sin\varphi\frac{1+\cos^2\theta}{\sin\theta}\mathrm{Im}\,\tilde{M}^{--}\right.$$

$$\left. -\sin 2\varphi\,\sqrt{2}\cos\theta\,\mathrm{Im}\,\tilde{M}^{0-} + \sin 3\varphi\,\sin\theta\,\mathrm{Im}\,\tilde{M}^{+-} + O\left(\frac{1}{Q'}\right)\right]$$

Angular dependence

E. Berger et al., hep-ph/0110062

$$\frac{dS}{dQ'^2\,dt\,d\varphi} = \int \frac{L(\theta,\varphi)}{L_0(\theta)} \frac{d\sigma}{dQ'^2\,dt\,d\varphi\,d\theta}\,d\theta$$



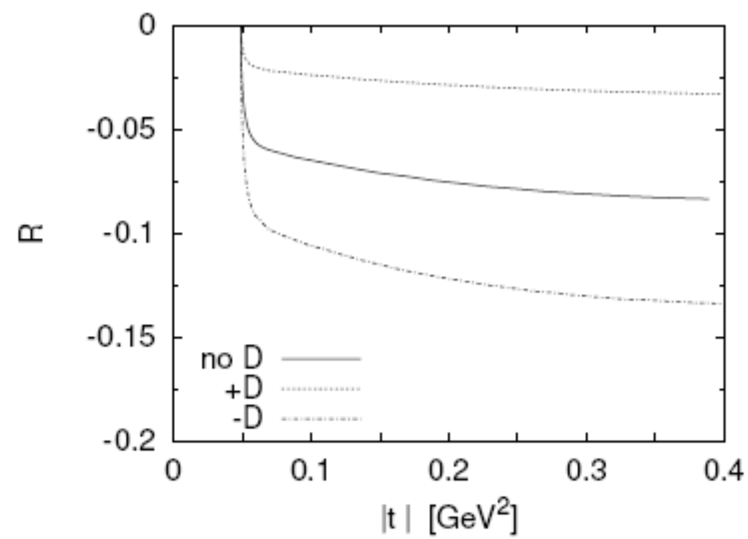
Lepton propagators:

$$L_0 = \frac{Q'^4 \sin^2\theta}{4};$$

$$L = \frac{(Q'^4 - t)^2 - 4\left[(k-k')(p-p')\right]^2}{4}$$

Observable:

$$R = \frac{2\int_0^{2\pi} d\varphi \cos\varphi \frac{dS}{dQ'^2\,dt\,d\varphi}}{\int_0^{2\pi} d\varphi \frac{dS}{dQ'^2\,dt\,d\varphi}}$$



First TCS analysis from CLAS data

Analysis of electroproduction data to select events in the quasi-real photoproduction region, when incoming electron scatters at ~0 degrees

In the production of e^+e^- pair, there are two electrons in final state

scattered electron

$$ep \rightarrow e' \underbrace{e^+ e^-}_{} p'$$

pair production

Final state to analyze

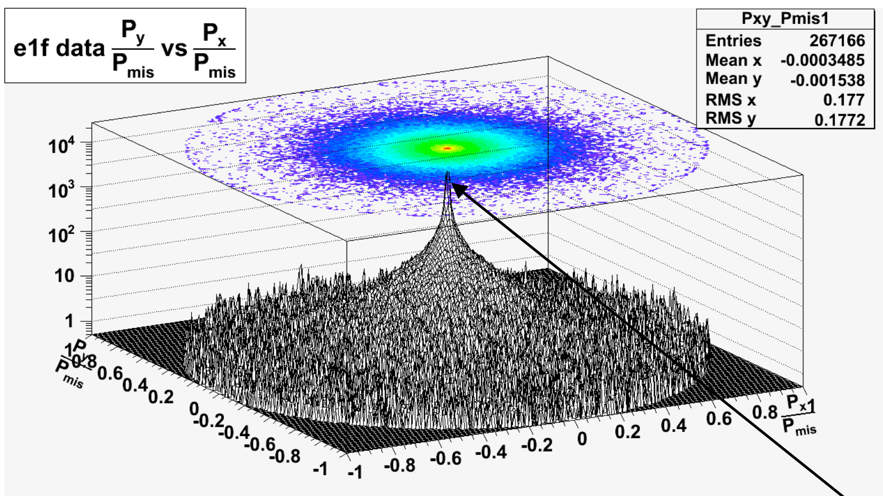
$$ep \rightarrow e^+ e^- pX$$

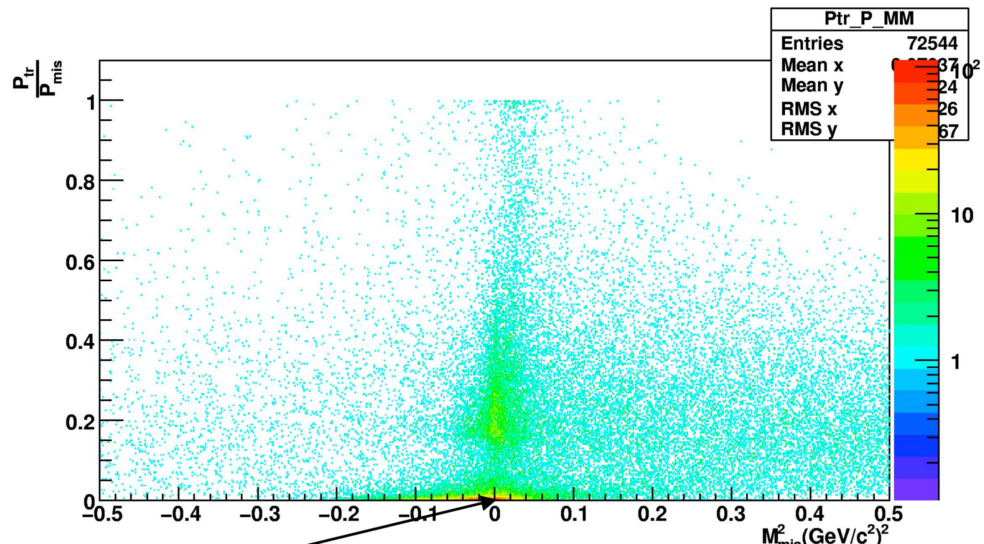
Scattered electron kinematics is deduced from missing momentum analysis

Quasi-real photoproduction of e^+e^-

Missing momentum analysis for final state -

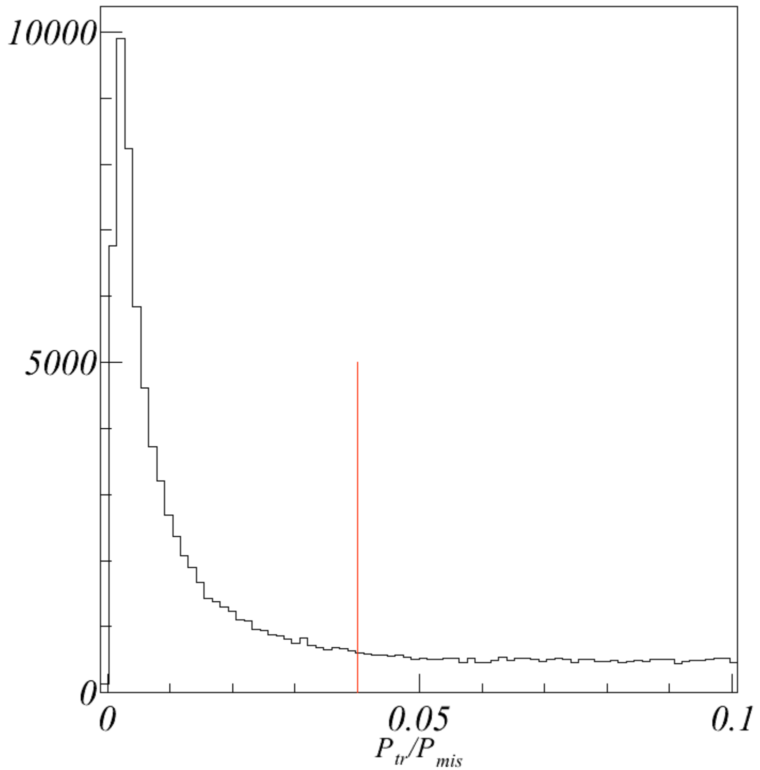
$$ep \rightarrow e^+ e^- pX$$





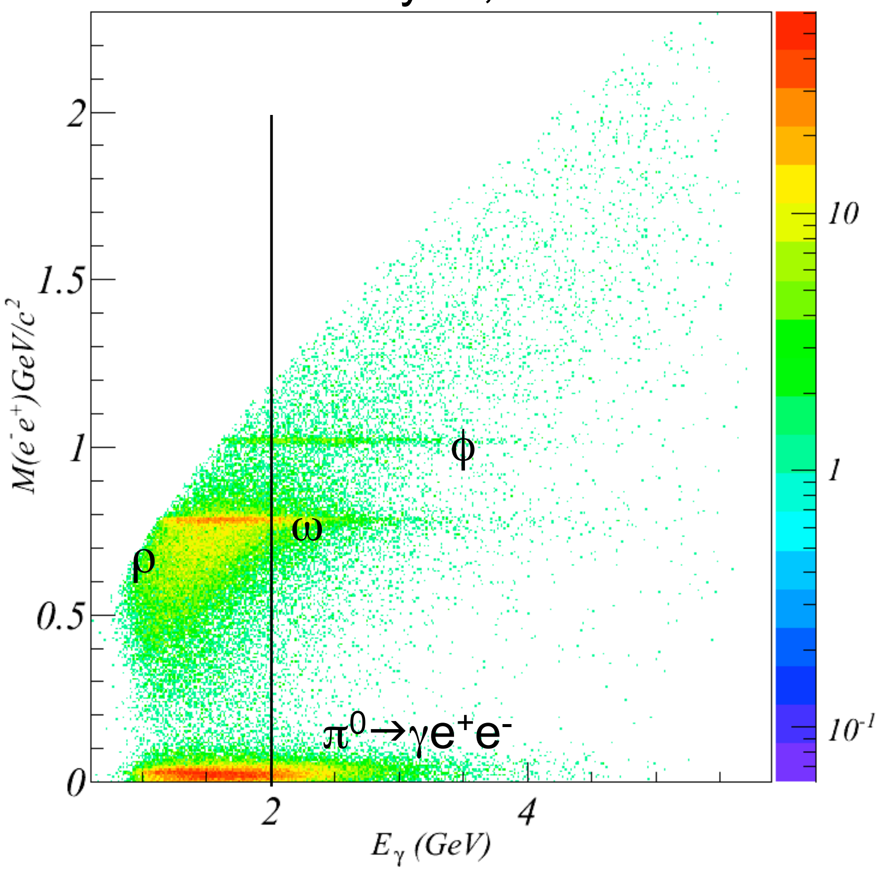
X – is identified as an electron scattered at 0 degrees, $Q^2<0.01\ (GeV/c)^2$ and $|M_X^2|<0.1\ (GeV)^2$

Selection of events for TCS



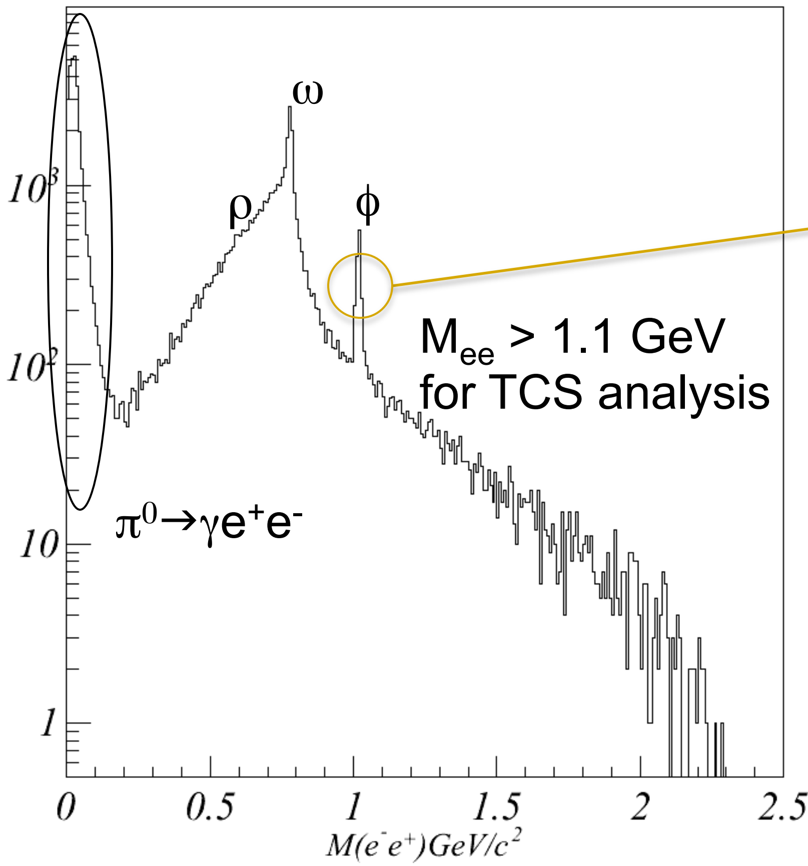
Quasi-real photoproduction – P_t (Q^2) ~ 0, consistent with detector resolution

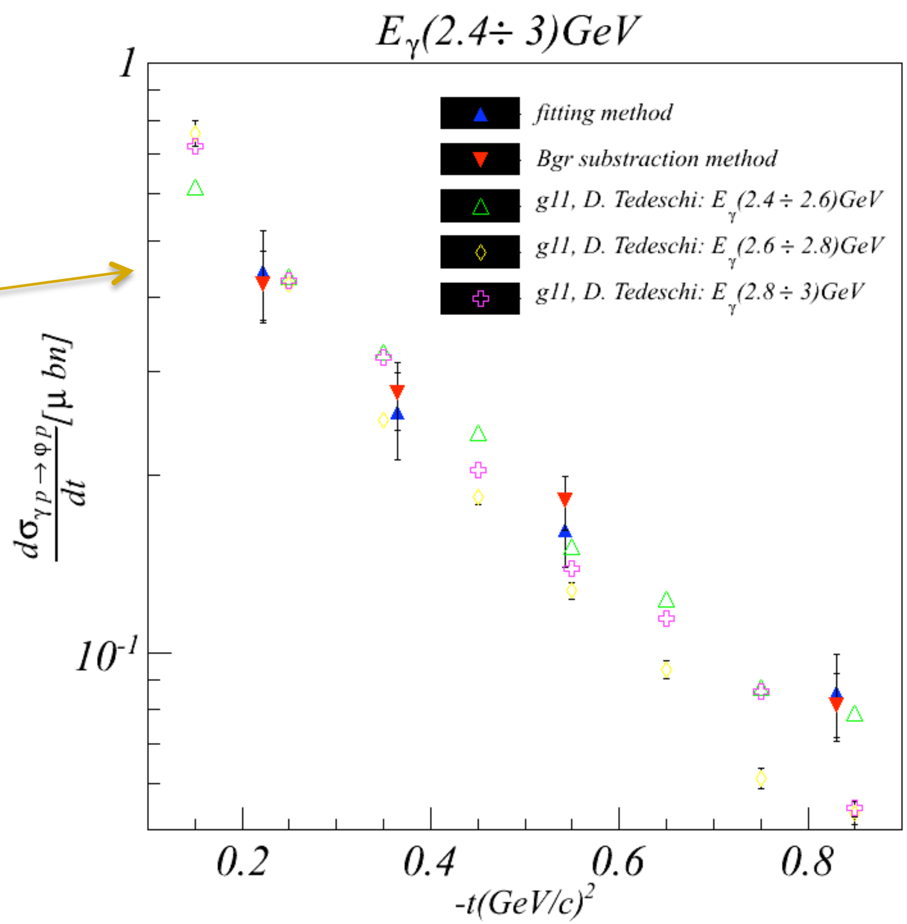
For TCS analysis, $\sqrt{s} > 2.\ GeV$



Photoproduction of lepton pairs

CLAS/E1-6

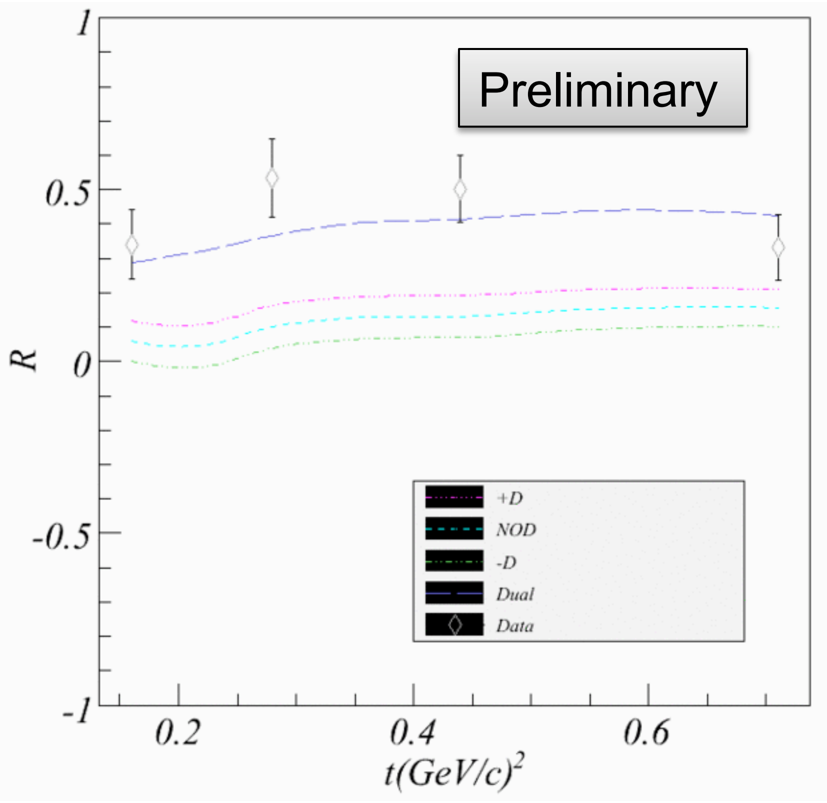




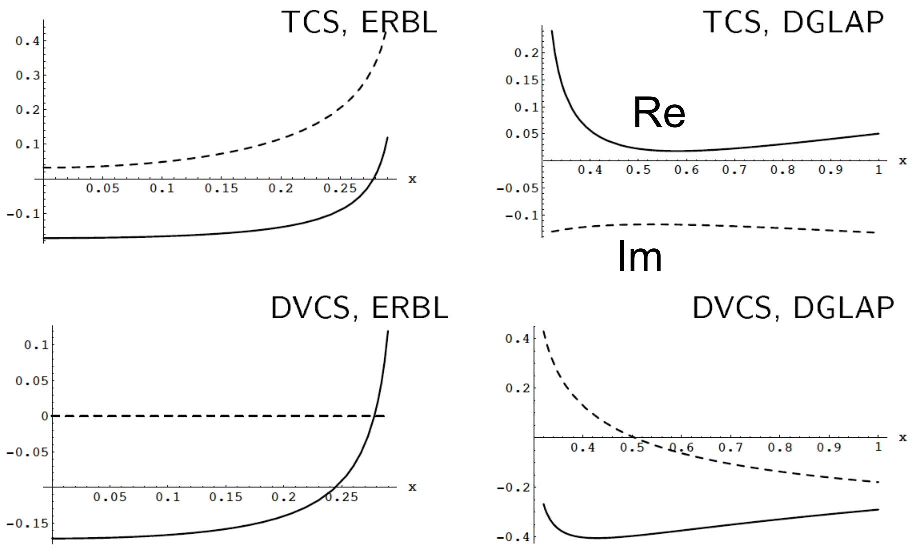
Analysis of CLAS e1-6 and e1f data are underway, R. Paremuzyan

Angular moment from CLAS-6 data

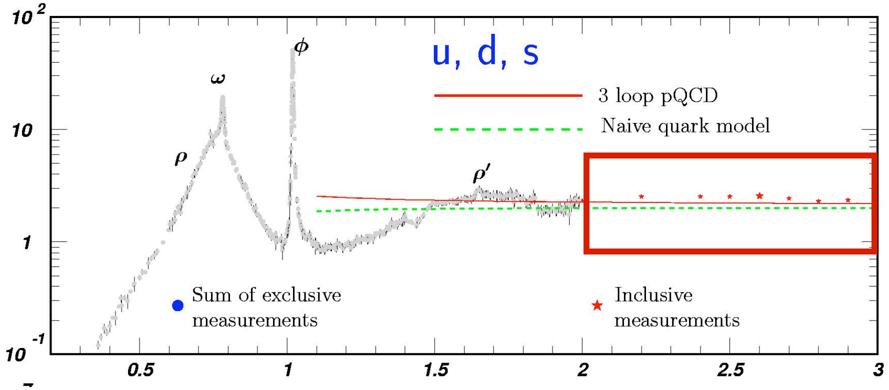
LO calculations (Vadim Guzay per Berger et al.)



NLO contributions (Lech Szymanowski)



TCS with CLAS12

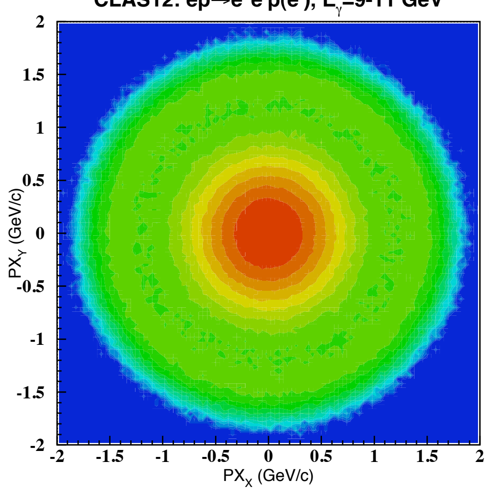


The most suitable region of masses for TCS studies at high energies

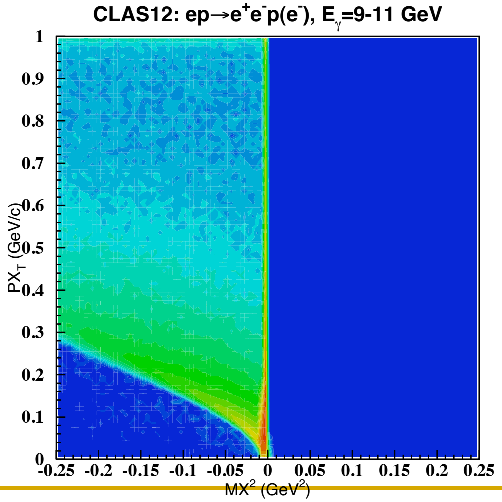
$$\sqrt{s} > 4GeV$$

2 GeV < M_{ee} < 3 GeV

Use electroproduction data to extract exclusive photoproduction reactions e.g. $ep \rightarrow e^+e^-p(e^-)$, (e^-) scattered electron at ~0^o



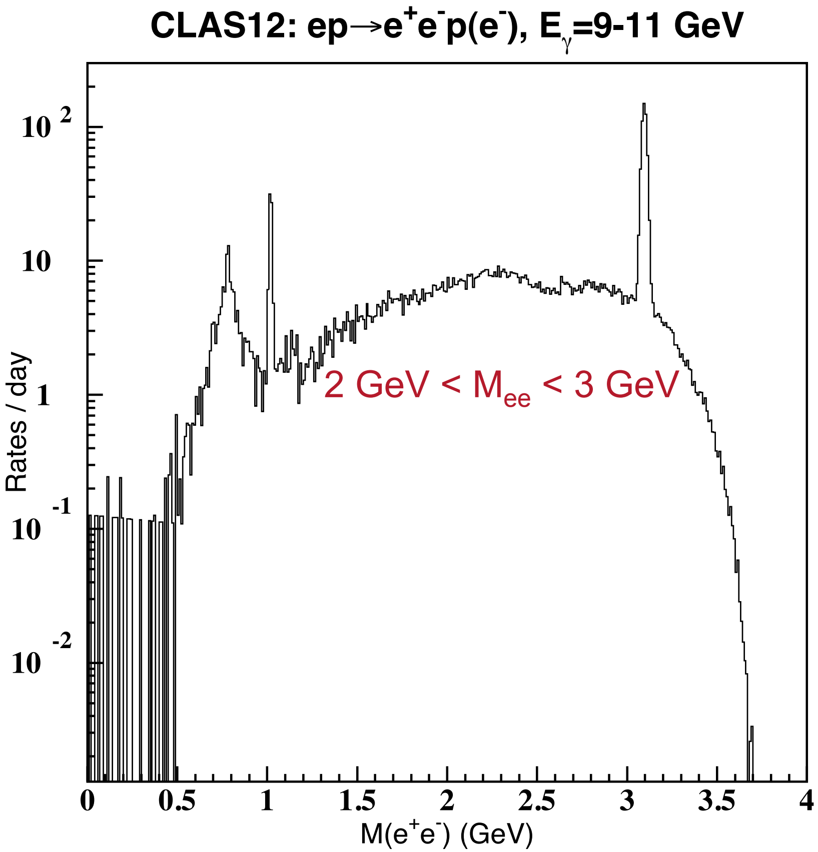
Simulations of the reaction $ep \rightarrow BH$, and ρ, ω, φ and J/Ψ with $\sigma \sim 1/Q^4$ and $\sigma \sim e^{-3t}$

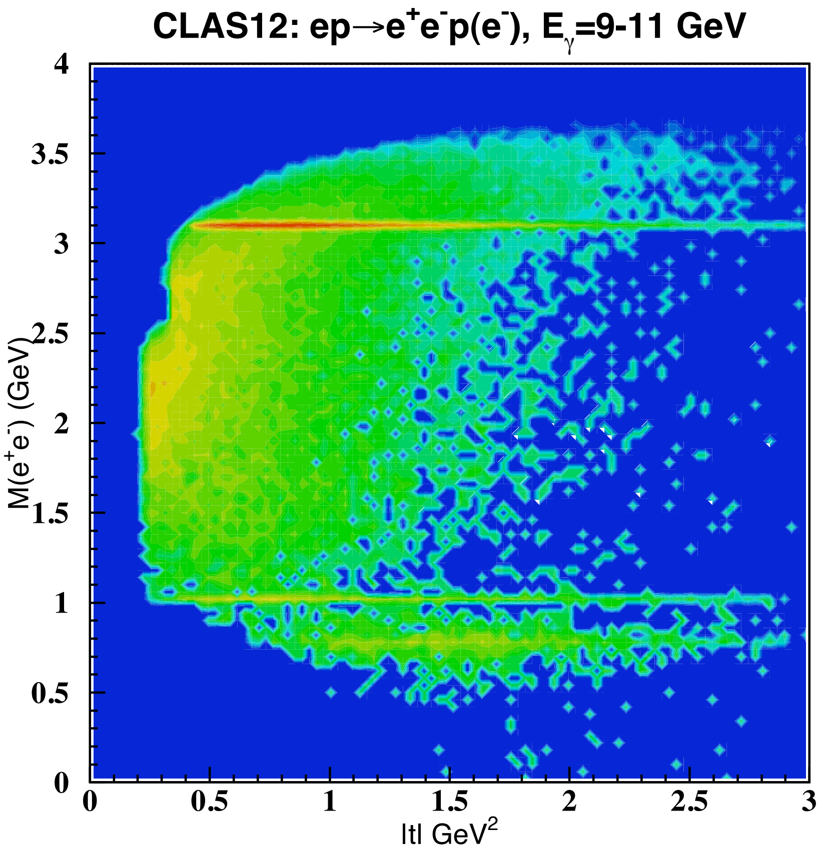


TCS with CLAS12

Simulations include V-mesons decay BR to e^+e^- and photoproduction cross sections

Fiducial acceptance, and momentum and angular smearing of CLAS12 are used





TCS with CLAS12

- No real photon beams will be available with E_{γ}>~6.6 GeV
- The same technique can be used - electroproduction of lepton pairs in the quasi-real photoproduction region
- Significant amount of beam time for electroproduction at 11 GeV with CLAS12 is already approved

Proposal	*Contact Person*	*Physics*	*Energy (GeV)*	*PAC days*	*Parallel Running*	*Target*
PR-09-103	*Gothe, Mokeev*	*N* at high Q^2*	*11*	*60*	*119*	*LH2 TCS & J/Ψ*
E12-06-119a	*Sabatie*	*DVCS pol. beam*	*11*	*80*		
PR-11-005	*Battaglieri*	*Meson Spectroscopy*	*11*	*119*		
E12-06-112	*Avakian*	*$ep \rightarrow e\pi^{+/-/0} X$*	*11*	*60*		
E12-06-108	*Stoler*	*DVMP in π^0,η prod L/T separation*	*11*	*80*	*20 20*	
			8.8 6.6	*20 20*		
E12-06-117 E12-06-106	*Brooks Hafidi*	*Quark Hadronization Color transparency*	*11 11*	*60 60*	*60?*	*NUCLEAR J/Ψ*

Summary

- Huge amount of data with polarized beam and targets will be obtained on DVCS with CLAS12 at beam energies up to 11 GeV
- Nevertheless, DVCS data alone will not be sufficient to fully constrain the GPDs
- Extraction of GPDs from these measurements will require combined analysis, using models of GPDs
- In particular, extraction of the real part of the Compton amplitude will suffer in accuracy if only electroproduction data are used
- The real part of the amplitude can be accessed directly in Beam Charge Asymmetry in DVCS – requires lepton beams of both polarities
- The same information can be obtained from azimuthal asymmetries in Time-like Compton Scattering
- In addition, with enough statistics, TCS will give complementary information on the imaginary part of the Compton amplitude – advantage, e.g., different contributions for higher twist effects

Summary (cont.)

- Preliminary analysis of CLAS 6 GeV electroproduction data showed feasibility of measuring the TCS in electroproduction experiments

va

Theoretical support will be greatly appreciated!

Thanks for Vadim

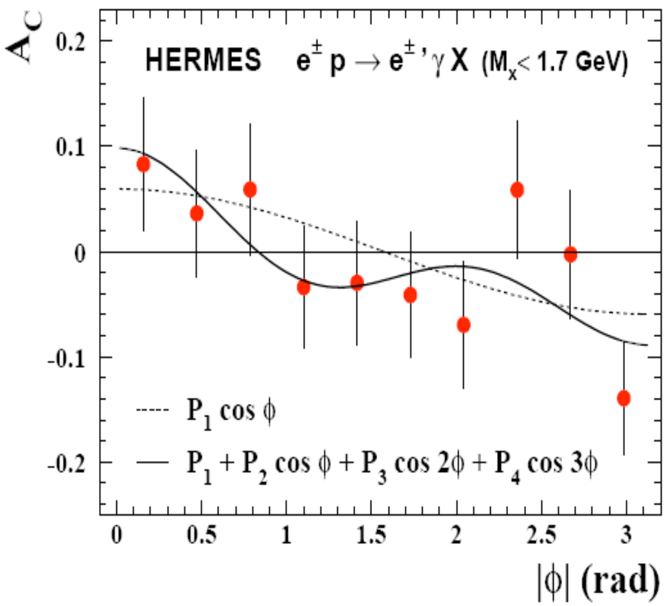
- With CLAS12, data will be available for TCS studies "almost for free" from already approved electroproduction experiments at 11 GeV
- Full proposal for TCS (general $\gamma A \rightarrow e^+e^-$, including J/Ψ) with CLAS12 is in works, may (will) be submitted to PAC 38

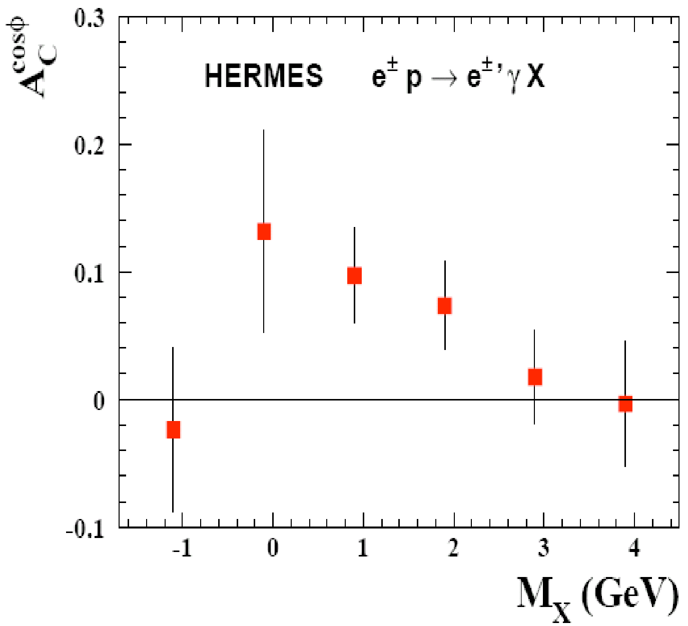
TCS can be also an important reaction to be considered for studying GPDs (gluonic) on EIC, experimentally will be simpler than DVCS

Backups

Beam charge asymmetry

$$A_C(\phi) = \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)} \propto \frac{Re\mathcal{H}}{F_1} \cdot cos\phi$$





A. Airapetian et al., HERMES coll., Phys. Rev. D **75,** 011103(R) (2007)

BCA requires lepton beams of both charges, not available in any of existing facilities