Timelike Compton Scattering

I. Albayrak[1], V. Burkert[2], E. Chudakov[2], M. Guidal[3,*], V. Guzey[2], K. Hicks[4], *T. Horn*[1,*], C. Hyde[5], Y. Ilieva[6], F.J. Klein[2], C. Munoz Camacho[2], P. Nadel-Turonski[2,*,**], M. Osipenko[6], R. Paremuzyan[7], B. Pire[8], F. Sabatie[9], C. Salgado[10], S. Stepanyan[2,*], L. Szymanowski[11], J. Wagner[11], C. Weiss[2].

* spokespersons

** contact person

1) The Catholic University of America, Washington, DC 20064

2) Thomas Jefferson National Accelerator Facility, Newport News, VA 23606

3) Institut de Physique Nucleaire d'Orsay, IN2P3, BP 1, 91406 Orsay, France

4) Ohio University, Athens, OH 45701

5) University of South Carolina, Columbia, SC 29208

6) INFN, Sezione di Genova e Dipartamento di Fisica dell'Universita, 16146 Genova, Italy

7) Yerevan Physics Institute, 375036 Yerevan, Armenia

8) CPhT Ecole Polytechnique, F 91128 Palaisaeu CEDEX, France

9) CEA, Centre de Saclay, Irfu/Service de Physique Nucleaire 91191 Gif-sur-Yvette, France

10) Norfolk State University, Norfolk, VA 23504

11) National Center for Nuclear Research, Warsaw, Poland

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LOI11-106: e^+e^- pair production with CLAS12 at 11 GeV

PAC recommendation

"The physics addressed in this proposal is very relevant for the JLab 12 GeV program. The PAC encourages the development of a full proposal."

Timelike Compton Scattering

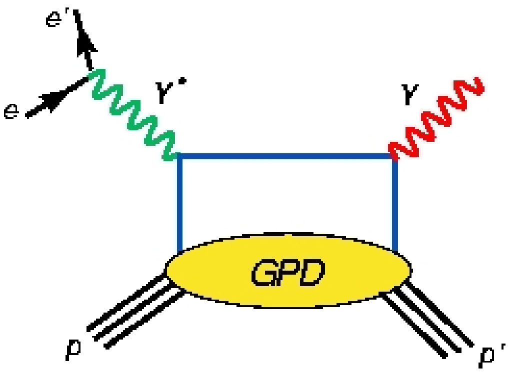
- Proposal will be submitted to the upcoming PAC 39.

J/Ψ

- The first proposal, for production on the nucleon to probe the gluon distribution in the valence region, will be submitted to PAC 40.
  - additional proposals are likely to follow (*e.g.*, nuclear targets, electroproduction)
- There is a dedicated proposal (C12-07-106) for Hall C to study photoproduction on nuclear targets at $t \sim t_{min}$, for which the rates would be better than in CLAS
- A LOI was also recently submitted to take a single high-Q^2 point with very limited statistics in Hall C. This is unlikely to impact the CLAS12 effort.

Compton scattering – nomenclature

- Real Compton Scattering
- Deeply Virtual Compton Scattering (DVCS)
  - Outgoing photon is real
  - Simplest probe of GPDs
- Timelike Compton Scattering (TCS)
  - Incoming photon is real
  - Complementary to DVCS
- Double DVCS
  - Both photons are virtual
  - Experimentally challenging



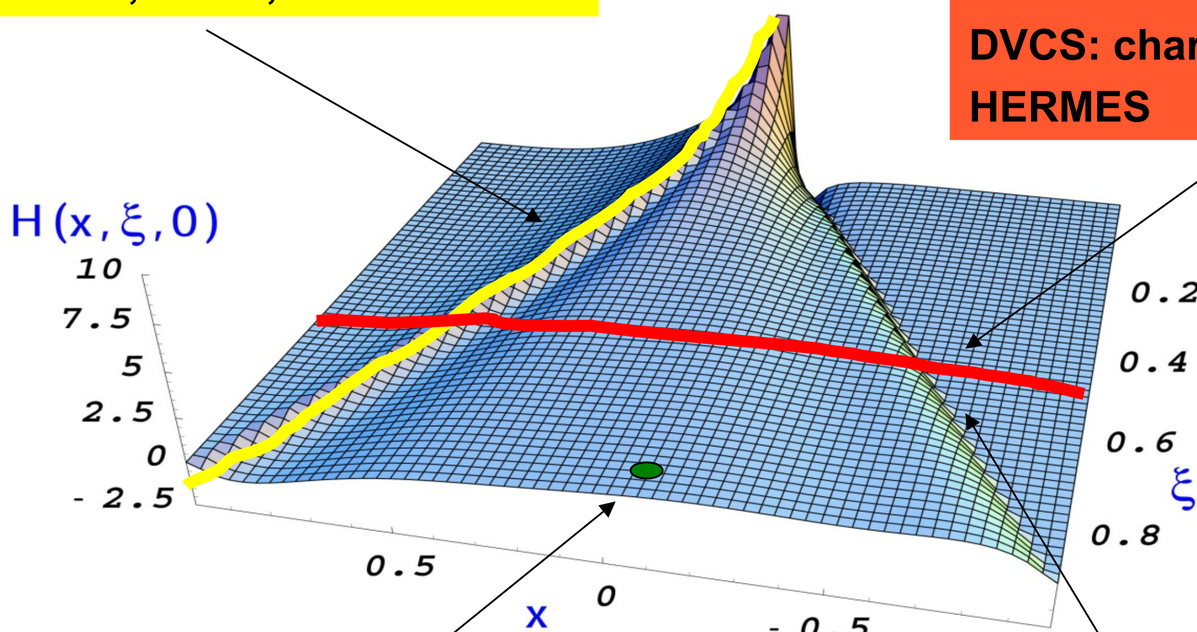
$$\gamma^* + p \rightarrow \gamma^* + p$$

GPDs can be extracted from Helicity Amplitudes or Compton Form Factors

Probing GPDs through Compton scattering

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

(|Re|)
TCS: azimuthal asymmetry
CLAS
DVCS: charge asymmetry
HERMES



(Im, $x \neq \xi$, $x < |\xi|$)
DDVCS

($|Re|^2$)
DVCS: cross sections
H1, Hall A

Why TCS?

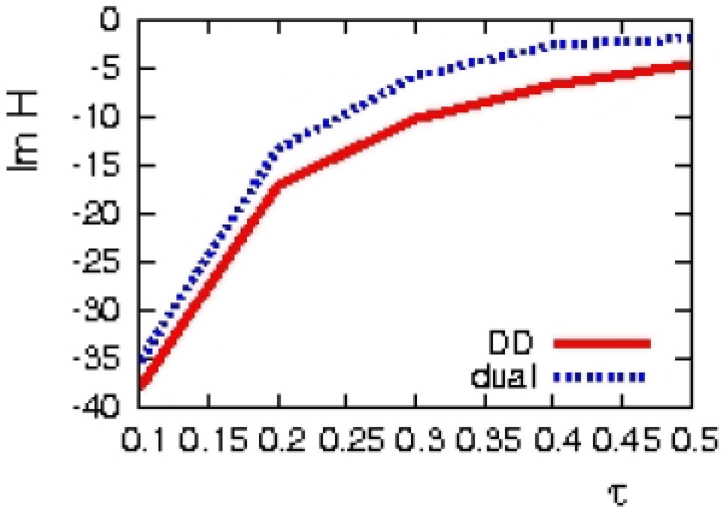
Theory

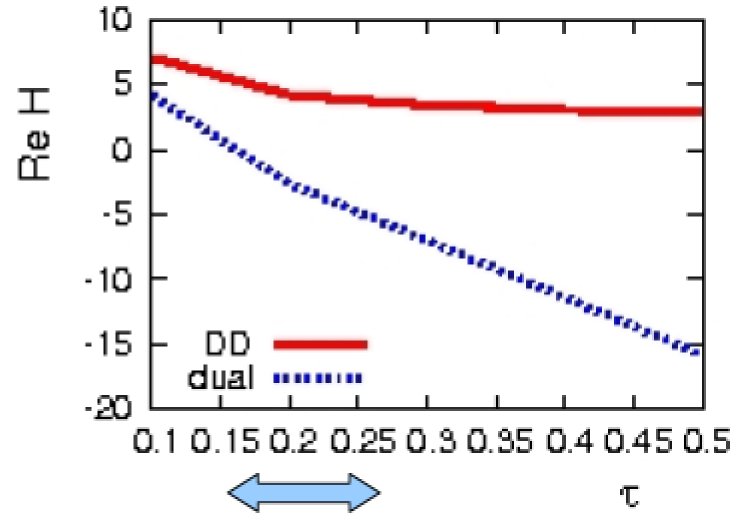
- Straightforward access to real part of amplitudes/CFFs/GPDs
- Impact on global fits for Compton Form Factors (Guidal, Sabatie)
- Dispersion relations – how important is the real part at large x?
- Universality of GPDs extracted from exclusive processes
  - Spacelike – Timelike comparison as for DIS and Drell-Yan
- Interesting behavior of NLO corrections
  - Sensitive to GPD models and potentially to gluons

Experiment

- Challenging to get real part from beam charge asymmetries (electron – positron)
  - And currently no such facility

GPD models sensitive to real part at large x





CLAS

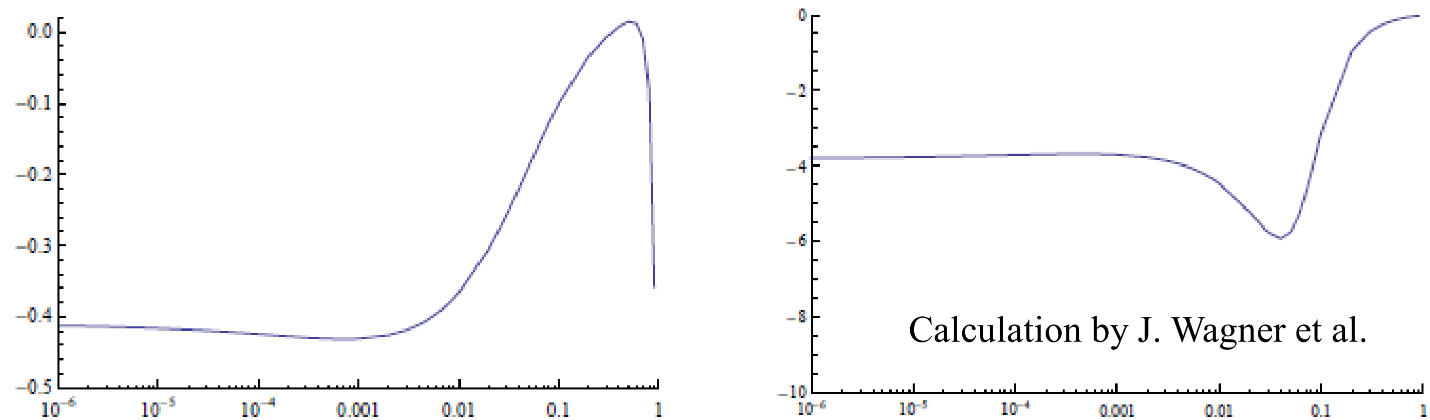
$$\tau = \frac{Q'^2}{s - M_p^2}$$

is the equivalent of Bjorken *x*,
hard scale is given by $Q'^2 = M^2_{e+e-}$

LO cCalculation by V. Guzey
for $Q'^2 = 5$ GeV^2 and $t = 0$

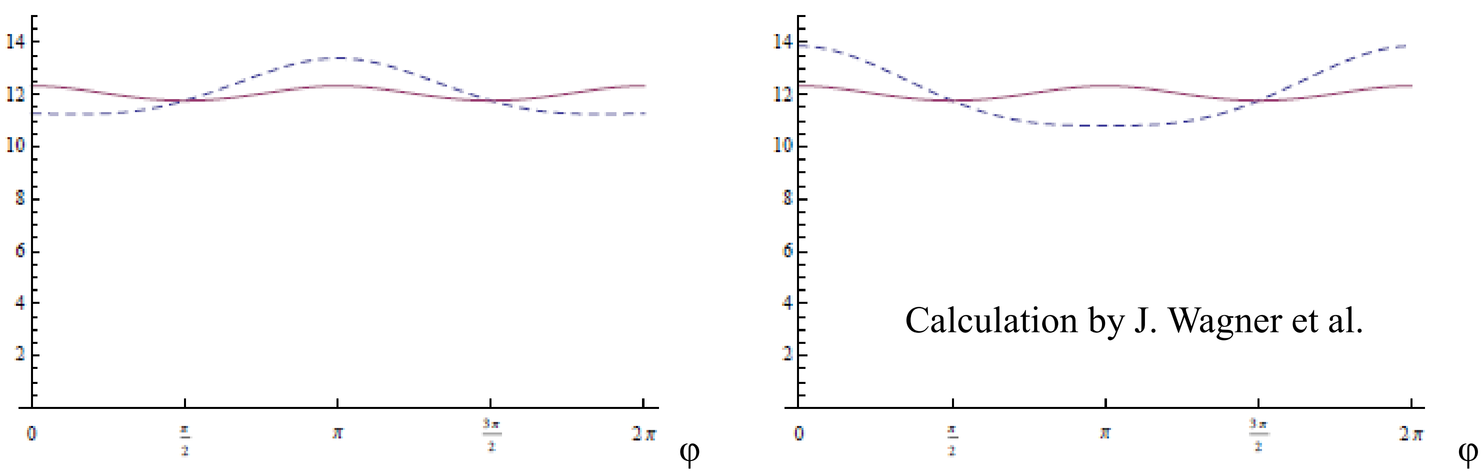
- Model predictions similar for Im H, but large differences for Re H
- Reliable measurements of real part are needed!

NLO corrections



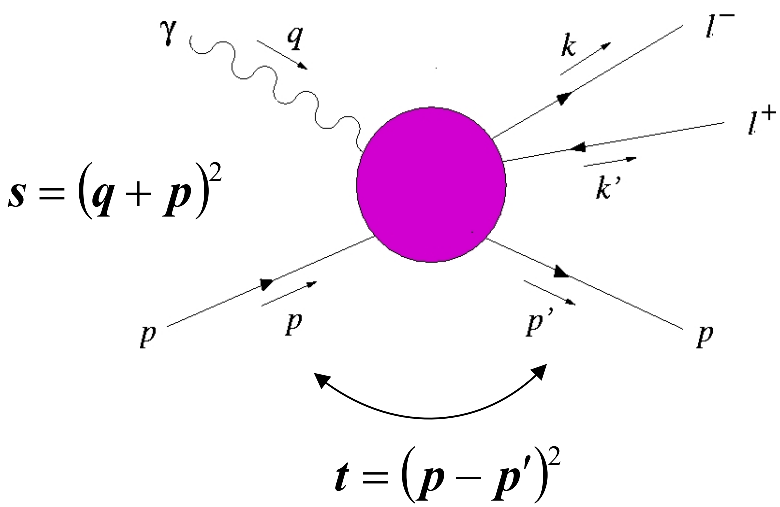
Ratio of NLO correction to the Born term for the imaginary (left) and real (right) part of the CFF H for the Kroll-Goloskokov model, for Q'^2 = 4 GeV^2, t = 0, and μ_F = Q.

The correction on the right is almost entirely due to gluons.

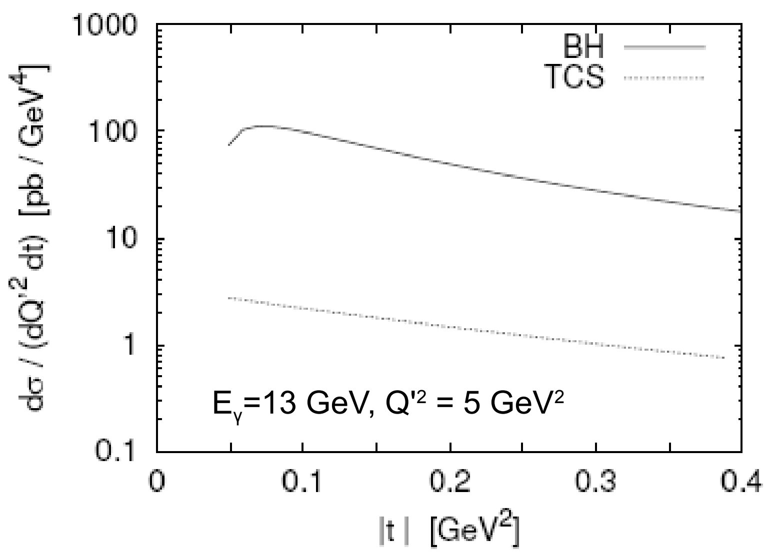


LO (left) and NLO (right) differential cross sections for B-H (solid) and B-H + INT (dashed) for Eγ = 11 GeV, Q'^2 = 5 GeV^2, and t = -0.1 GeV^2.

Photoproduction of lepton pairs

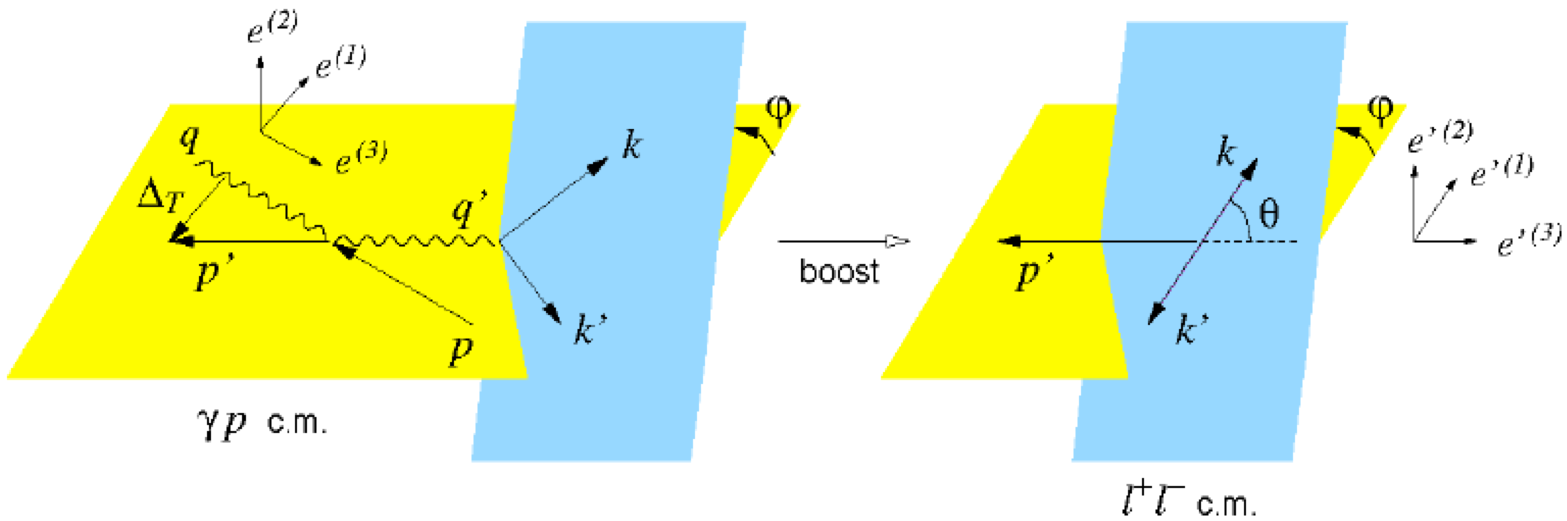


E. Berger *et al.*, Eur. Phys. J. C23, 675 (2002)



- TCS cross section is small compared with Bethe-Heitler (B-H) for all kinematics
  - cannot be accessed directly
- The interference term is, however, enhanced by the B-H and easy to isolate

Kinematics



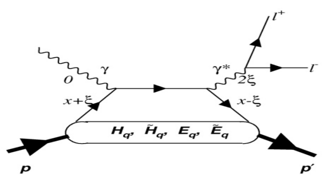
- k,k' = momentum of e^-, e^+
- θ = angle between the scattered proton and the electron
- φ = angle between lepton scattering- and reaction planes

$$\frac{d\sigma_{BH}}{dQ'^2 dt d\cos\theta} \approx 2\alpha^3 \frac{1}{-tQ'^4} \frac{1+\cos^2\theta}{1-\cos^2\theta} \left(F_1(t)^2 - \frac{t}{4M_p^2} F_2(t)^2 \right)$$

- For small Θ, B-H becomes large. A cut is usually applied.

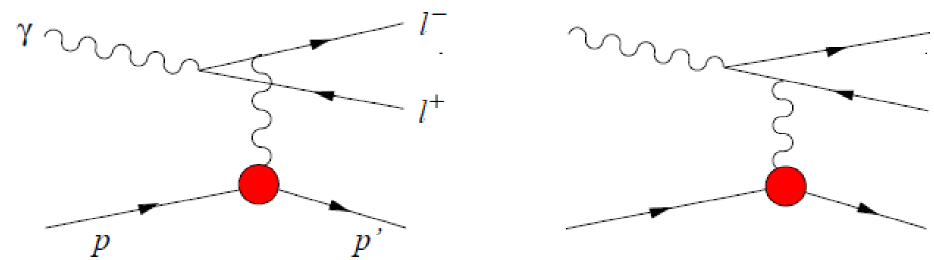
Observables sensitive to the interference term

TCS



+

Bethe-Heitler (BH)



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

- Under lepton charge conjugation:
  - Compton and BH amplitudes are *even*
  - Interference term is *odd*
  - Observables that change sign project out *only the interference term*

- Example of observable: azimuthal angular distribution (φ) of the lepton pair

TCS cross section and the interference term

$$\frac{d\sigma_{TCS}}{dQ'^2 d\Omega dt} \approx \frac{\alpha^3}{8\pi}\frac{1}{s^2}\frac{1}{Q'^2}\left(\frac{1+\cos^2\theta}{4}\right) 2(1-\xi^2)\,|\mathcal{H}(\xi,t)|^2$$

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

$$\tilde{M}^{--} \approx \frac{2\sqrt{t_0-t}}{M}\frac{1-\xi}{1+\xi}\,[F_1(t)\mathcal{H}(\xi,t)]$$

$$\mathcal{H}(\xi,t) = \sum_q e_q^2 \int_{-1}^{1} dx\Big(\frac{1}{\xi-x+i\epsilon} - \frac{1}{\xi+x+i\epsilon}\Big)H^q(x,\xi,t)$$

Full interference term with polarized beams

To leading order, in terms of helicity amplitudes:

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

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

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

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

ν: circular polarization of incoming photon also gives access to imaginary part

$$\frac{1}{2}\sum_{\lambda,\lambda'}|M^{\lambda'-,\lambda-}|^2 = (1-\eta^2)\big(|\mathcal{H}_1|^2+|\tilde{\mathcal{H}}_1|^2\big) - 2\eta^2\,\mathrm{Re}\big(\mathcal{H}_1^*\,\mathcal{E}_1+\tilde{\mathcal{H}}_1^*\,\tilde{\mathcal{E}}_1\big)$$

$$-\Big(\eta^2+\frac{t}{4M^2}\Big)|\mathcal{E}_1|^2 - \eta^2\frac{t}{4M^2}|\tilde{\mathcal{E}}_1|^2,$$

Example: first data from 6 GeV

- Cosine moment of weighted cross sections

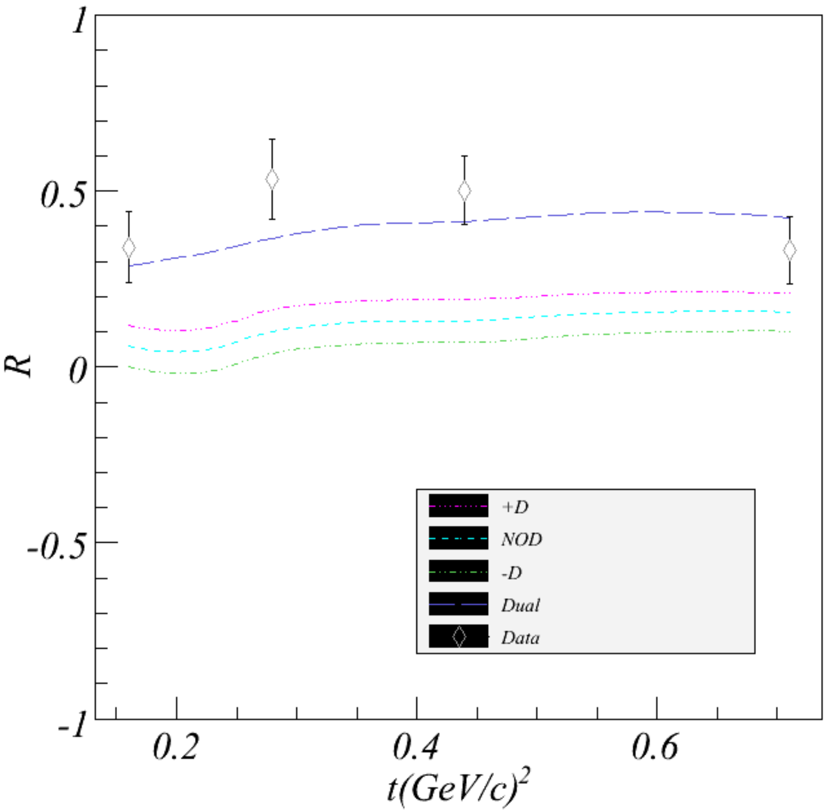
$$\frac{dS}{dQ'^2\,dt\,d\varphi} = \int \frac{L(\theta,\varphi)}{L_0(\theta)} \frac{d\sigma}{dQ'^2\,dt\,d\varphi\,d\theta}\,d\theta$$

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

- Numerator is proportional to Re M^{--}
  - cos φ part of interference term

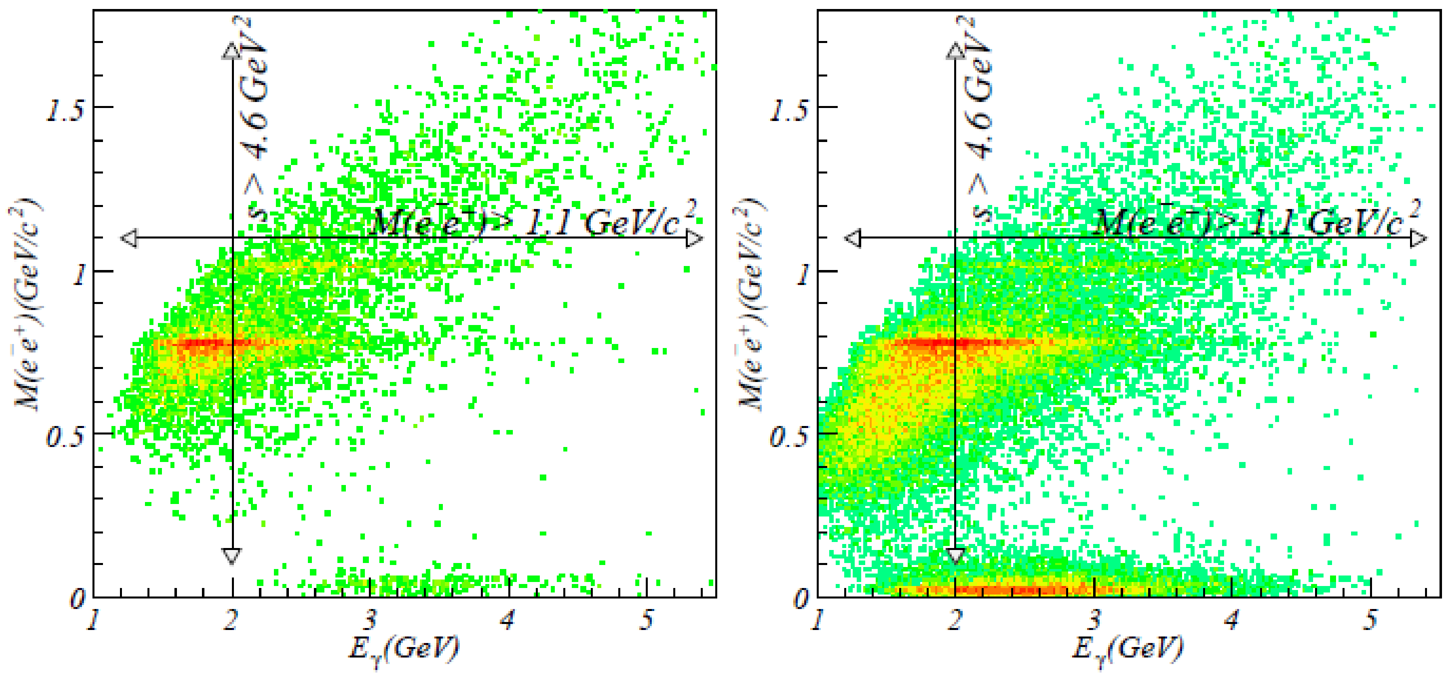
- R can be compared directly with GPD models even in experiments with limited statistics

- Sensitive to Polyakov-Weiss D-term?



Comparison of results from e1-6/e1f with LO calculations by V. Guzey.

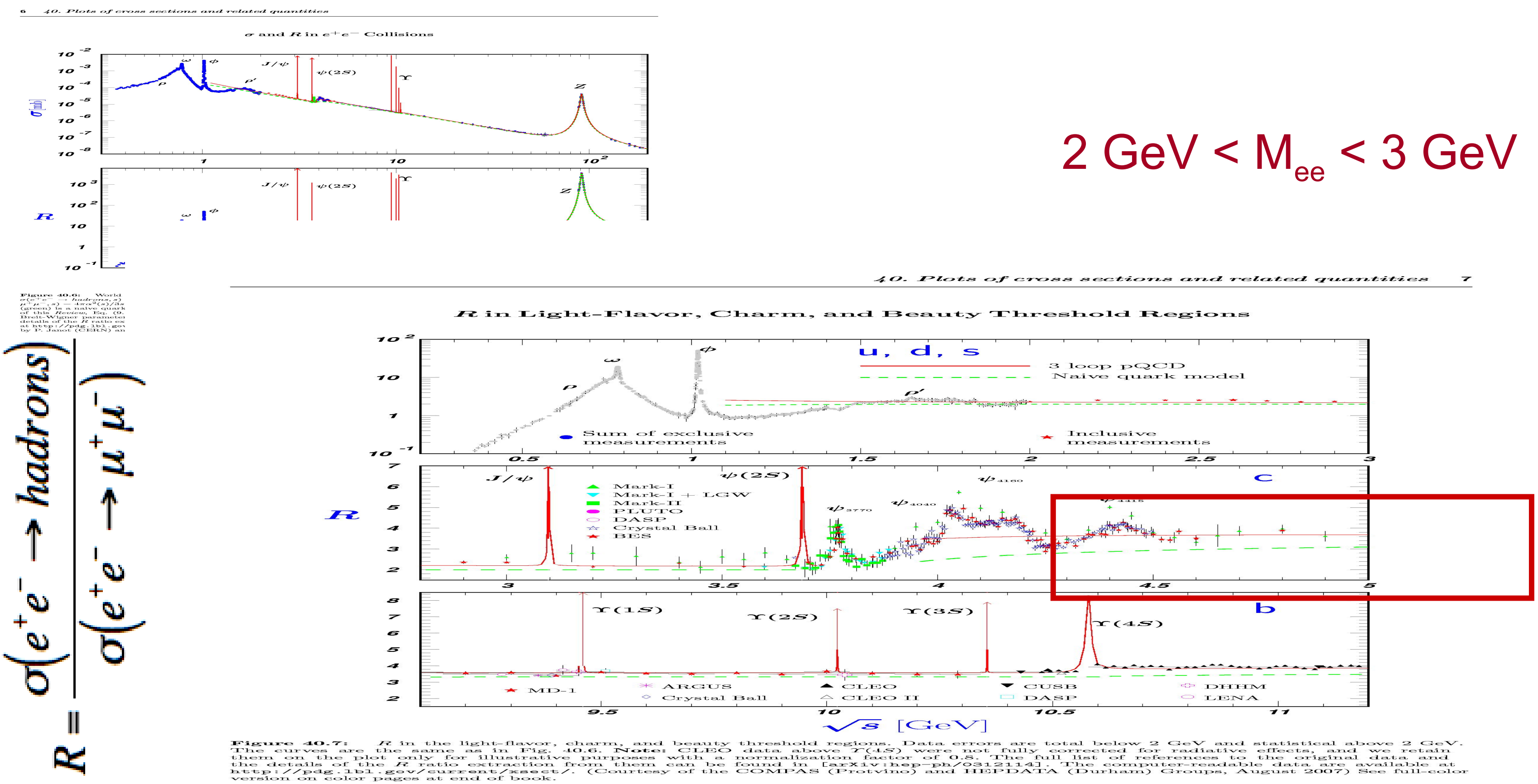
Limited coverage and statistics at 6 GeV



Data from e1-6 (left), e1f (right), and g12 have limited coverage in *s* and $M_{ee} = Q'$.

- Pilot experiments at 6 GeV are important for developing methods.
- 12 GeV will provide
  - A much larger reach in Q'^2 (factorization, x range)
  - More statistics for multi-dimensional binning
  - A possibility to avoid resonances

Resonance-free region at 12 GeV

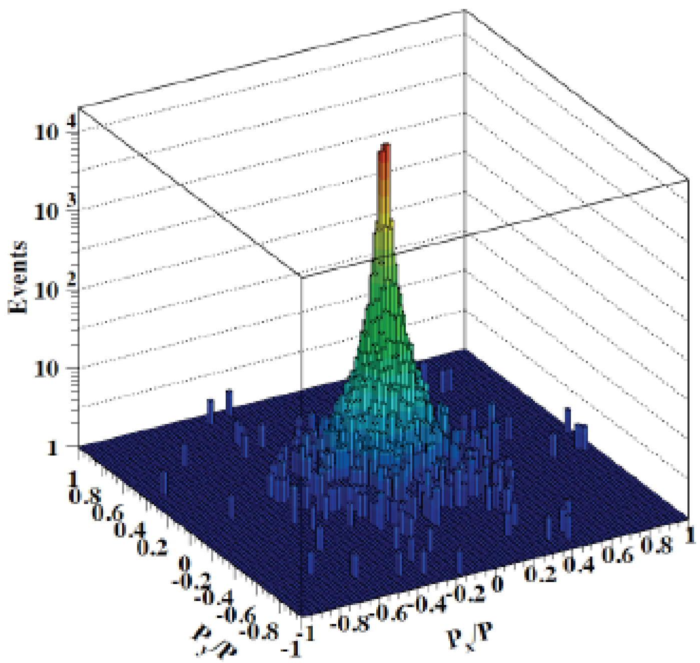


$$R = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

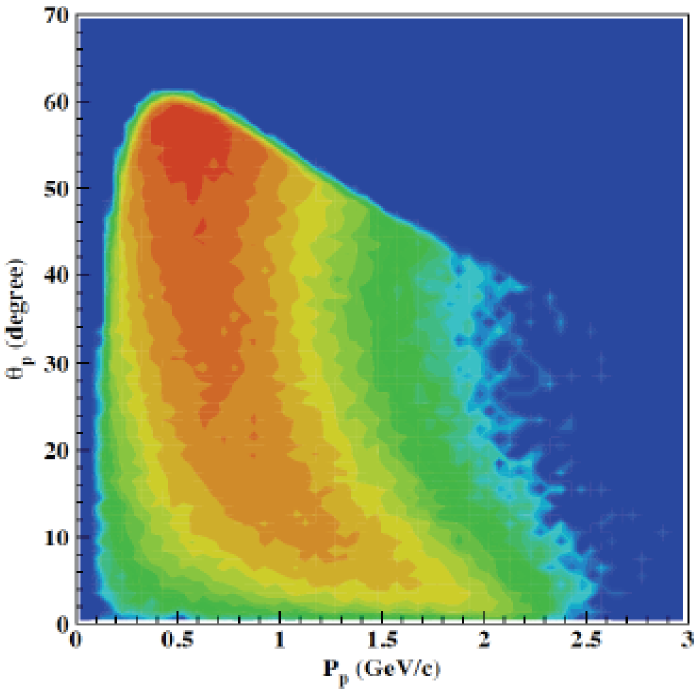
2 GeV < M_{ee} < 3 GeV

- JLab 12 GeV kineamtics are ideally suited for TCS
- Data can be taken in the resonance-free region between ρ' and J/Ψ

Beam electron and recoil proton kinematics

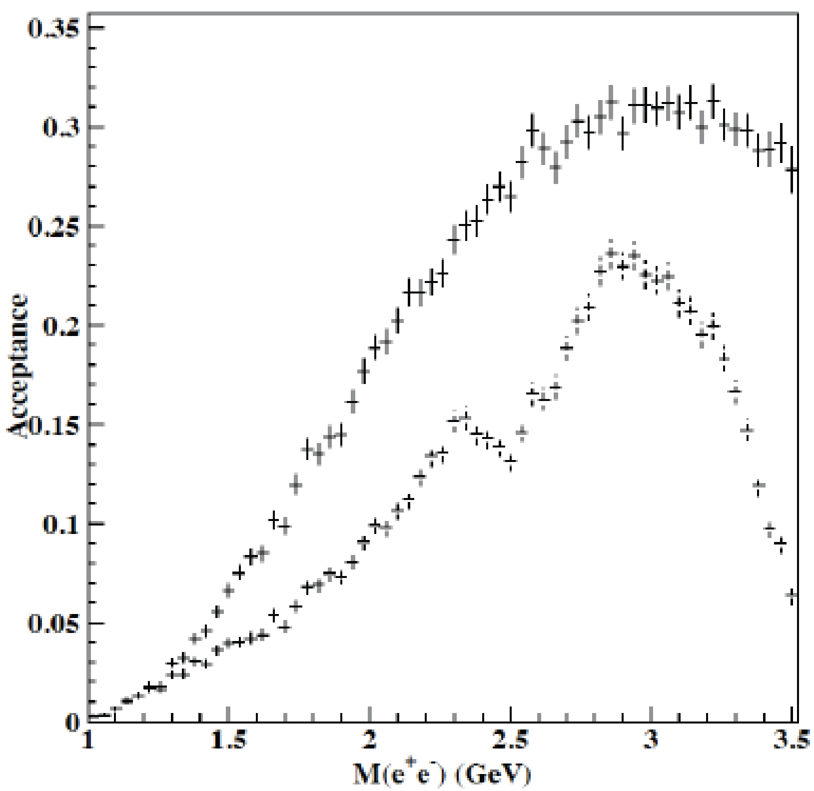


Low-Q^2 events are reconstructed by cuts on the transverse momentum of the missing beam electron



Protons from 9.5-10.5 GeV photons, for M_{ee} > 1.5 GeV

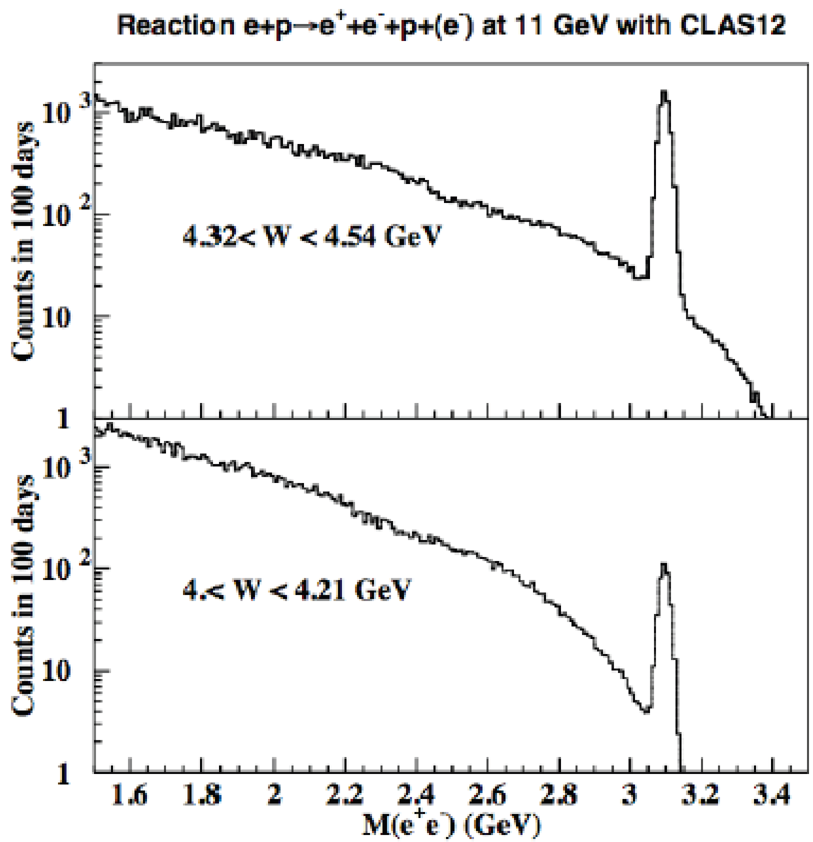
Acceptance (from fast Monte Carlo)



- (Top): only e+e- detected in CLAS
- (Bottom): e+e-p detected in CLAS
- With an untagged beam of quasi-free photons we need all three for complete event kinematics

- Acceptance is good for the most interesting events at high M_{ee} (Q') due to the large lepton opening angle.

Rate estimate



- Counts in 100 days as function of M_{ee} (Q')
- For 2 < Q' < 3 GeV, the upper W = √s bin will have 20k events, and the lower 25k events.
- For analysis, the binning in W may be coarser, but the data will also be binned in t and φ, and a cut will be applied in θ*.

Beam time already approved for CLAS12

Proposal	Physics	Contact	Rating	Days	Group	needed equipment	Energy	Group	Target
E12-07-104	Neutron magnetic form factor	G. Gilfoyle	A-	30	90	Neutron detector RICH IC	11	A	liquid D_2 target
PR12-11-109 (a)	Dihadron DIS production	Avakian		D					
E12-09-007a	Study of partonic distributions in SIDIS kaon production	K. Hafidi	A-	56					
E12-09-008	Boer-Mulders asymmetry in K SIDIS w/ H and D targets	M. Contalbrigo	A-	TBA					
11-003	DVCS on neutron target	S. Niccolai	A	90					
E12-06-108	Hard exclusive electro-production of π^0, η	P. Stoler	B	80	119	RICH IC Forward tagger	11	B	liquid H_2
E12-06-112	Probing the proton's quark dynamics in Semi-Inclusive pion production	H. Avakian	A	60					
E12-06-119	Deeply Virtual Compton Scattering	F. Sabatie	A	80					
E12-09-103	Excitation of nucleon resonances at high Q^2	R. Gothe	B+	40					
E11-005	Hadron spectroscopy with forward tagger	M. Battaglieri	A-	119					
PR12-11-103	DVMP of ρ , ω, φ	M. Guidal		D					
E12-06-106	Color transparency in exclusive vector meson electroproduction off nuclei	K. Hafidi	B+	60	60		11	C	Nuclear targets
E12-06-117	Quark propagation and hadron formation	W. Brooks	A-	60	60		11	D	Nuclear
E12-10-102	Free Neutron structure at large x	S. Bueltman	A	40	40	Radial TPC	11	E	Gas D_2
E12-06-109	Longitudinal Spin Structure of the Nucleon	S. Kuhn	A	80	170	Polarized target RICH IC	11	F	NH_3 ND_3
E12-06- 119(b)	DVCS on longitudinally polarized proton target	F. Sabatie	A	120					
E12-07-107	Spin-Orbit Correl. with Longitudinally polarized target	H. Avakian	A-	103					
PR12-11-109 (b)	Dihadron studies on long. polarized target	H. Avakian		D					
E12-09-007(b)	Study of partonic distributions using SIDIS K production	K. Hafidi	A-	110					
E12-09-009	Spin-Orbit correlations in K production w/ pol. targets	H. Avakian	B+	103					
PR12-11-109	SIDIS on transverse polarized target	M. Contalbrigo		C2		Transverse target	11	G	HD
TOTAL run time				1231	539				

Running conditions and beamtime request

Running conditions

- The TCS proposal requires 11 GeV beam and a LH2 target.
  - There are few other restrictions, and beamtime can easily be shared.

Beam time request

- The TCS proposal will request about 100 days at full luminosity
  - Simulations are still ongoing

Notes

- It would be possible to study TCS on other targets, but there is no obvious motivation for doing so at this point

- The upcoming J/Ψ proposal for the nucleon will request additional time with a reversed field for systematics checks.