Timelike Compton Scattering

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CLAS Collaboration Meeting, JLab, Feb 23, 2012

Timelike Compton Scattering, or timelike DVCS

$$\gamma\, p \rightarrow \gamma^*\, p \rightarrow e+\, e-\, p$$

- Important addition to the CLAS GPD program at 12 GeV

- Complementary to (spacelike) DVCS

- Will test universality of factorization, which makes it possible to probe GPDs in exclusive processes

- Excellent experimental tool for accessing the real part

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

- Physics objectives: Timelike Compton (DVCS), J/Ψ on nucleon and nuclei

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."

PAC 39 Proposal: Timelike Compton Scattering

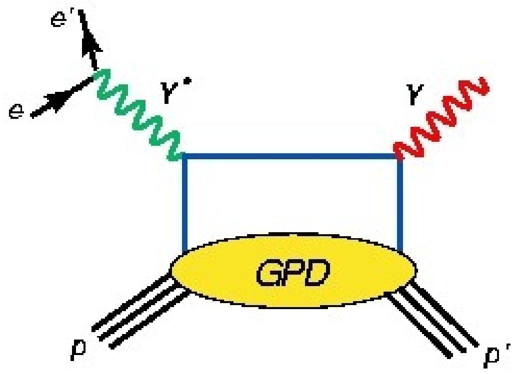
- Important contribution to thee GPD program
- Theory rapidly developing – much progress
- J/Ψ cross section will be measured (→ normalization)

J/Ψ: will be submitted as separate proposal(s)

- Developing physics case: Gluonic structure of nucleon, non-perturbative color forces.
- Workshop Temple University, March 26-28, 2012
  - http://quarks.temple.edu/~npcfiqcd

Compton scattering – overview

- 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

Why TCS?

$\gamma\, p \rightarrow \gamma^*\, p \rightarrow e+\, e-\, p$

Theory

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

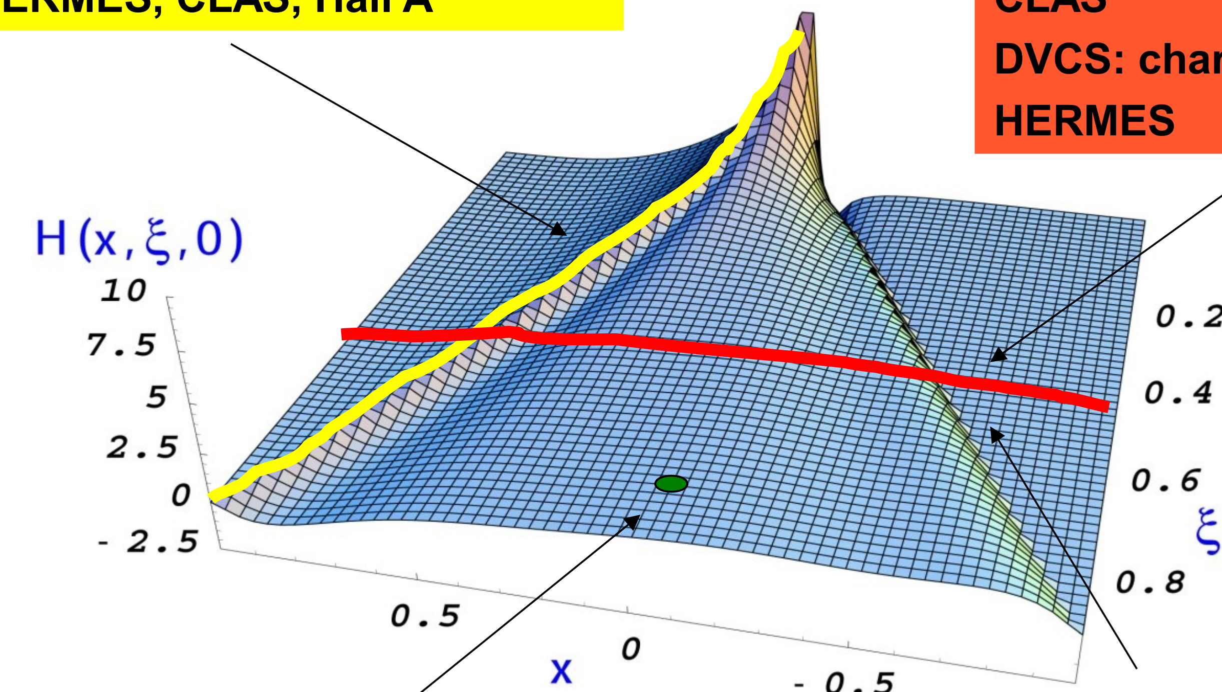
Experiment

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

Probing GPDs through Compton scattering

(Im, x=ξ)
DVCS: spin asymmetries
HERMES, CLAS, Hall A

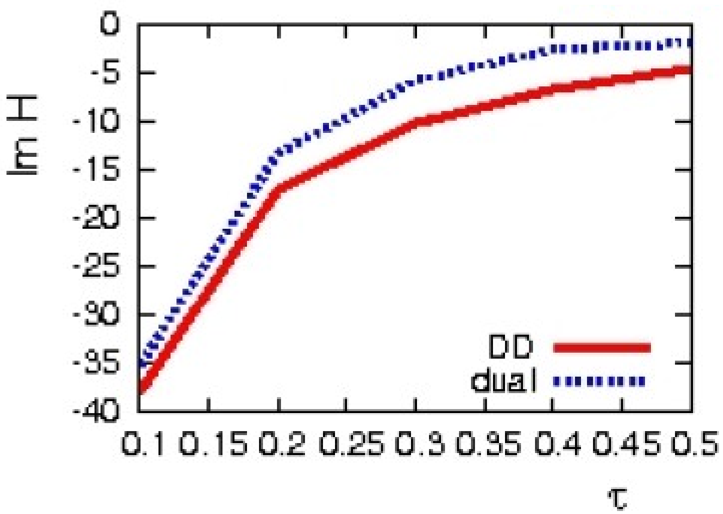
(|Re|)
TCS: azimuthal asymmetry
CLAS
DVCS: charge asymmetry
HERMES

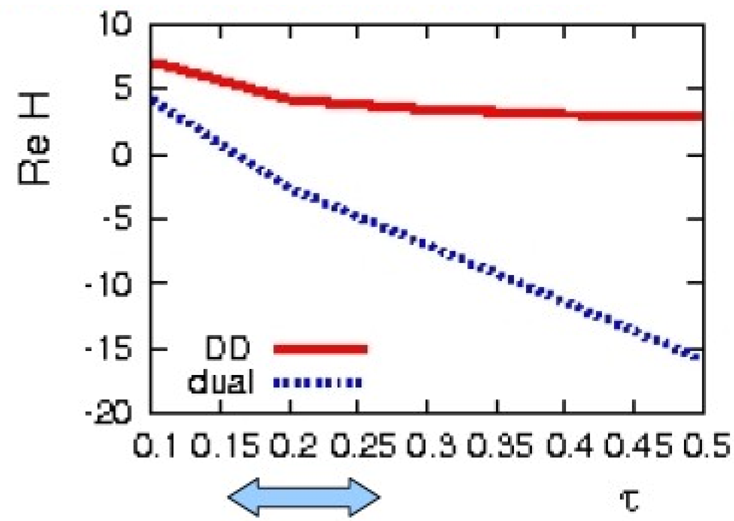


(Im, x ≠ ξ, x < |ξ|)
DDVCS

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

GPD models sensitive to real part at large x





CLAS

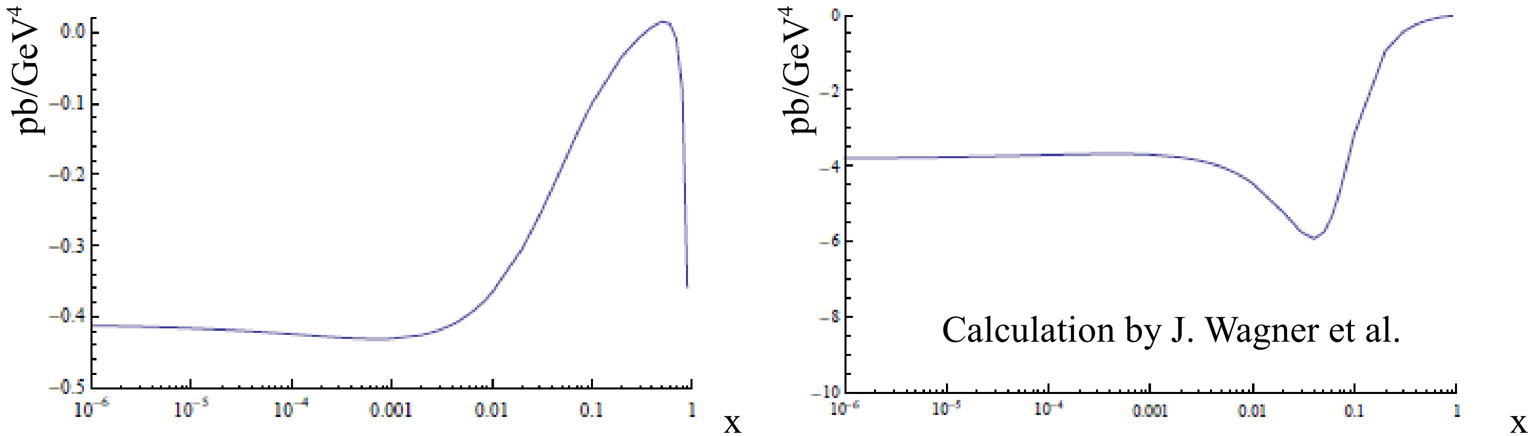
$$\tau = \frac{Q'^2}{s - M_p^2}$$

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 $t = 0$

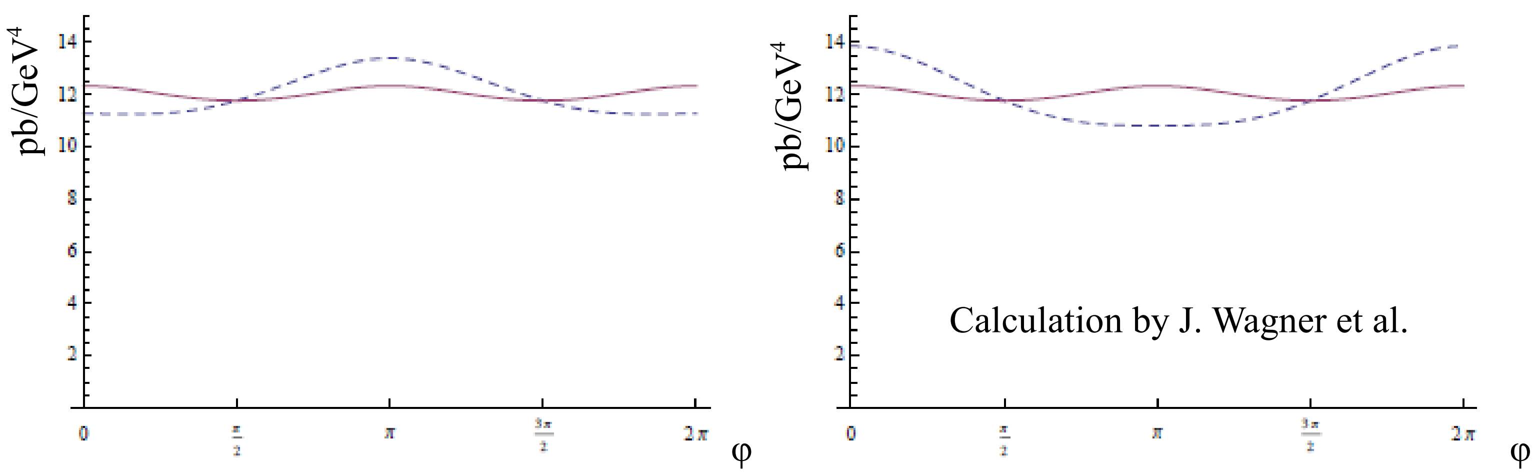
- Model predictions similar for Im H, but large differences for Re H
- Reliable measurements of real part are needed!

NLO corrections – a crucial test for theory



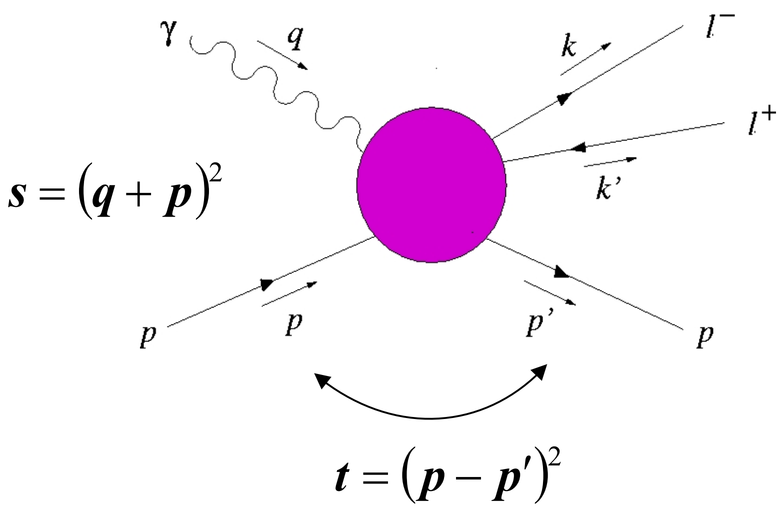
Ratio of NLO correction to the Born term for the imaginary (left) and real (right) part of the CFF H for the Kroll-Goloskokov model, for $Q'^2 = 4$ GeV^2, $t = 0$, and $\mu_F = Q$.

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

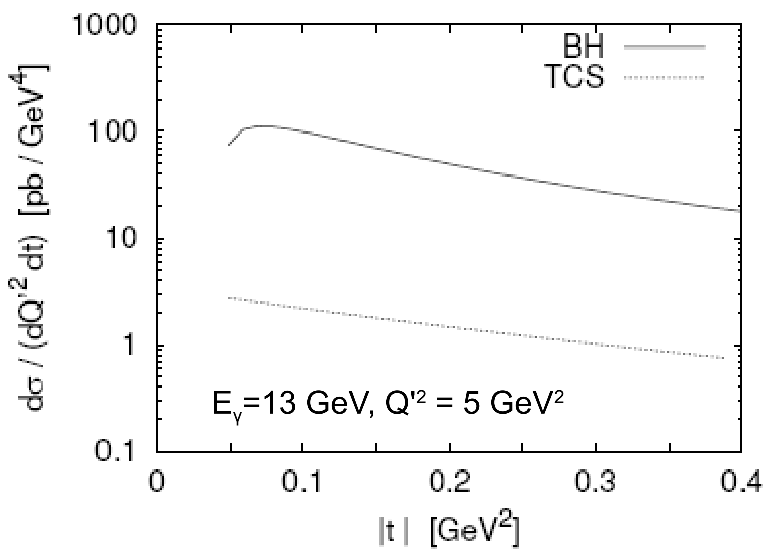


LO (left) and NLO (right) differential cross sections for B-H (solid) and B-H + INT (dashed) for Eγ = 11 GeV, $Q'^2 = 5$ GeV^2, and $t = -0.1$ GeV^2.

Photoproduction of lepton pairs

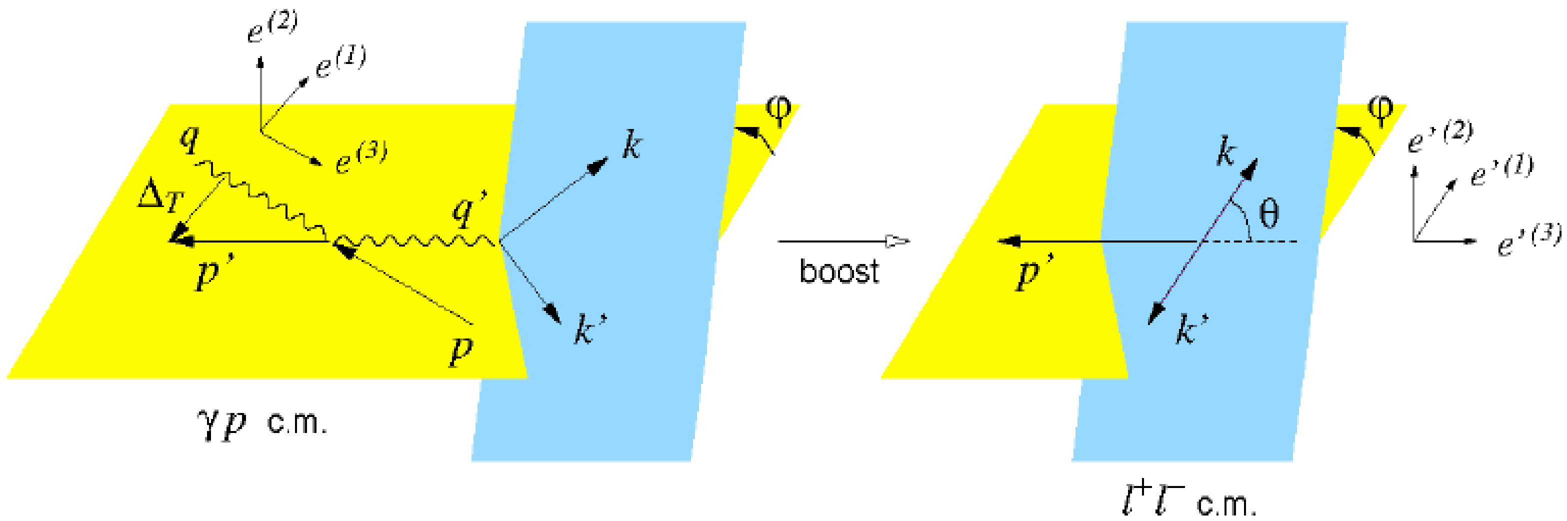


E. Berger *et al.*, Eur. Phys. J. C23, 675 (2002)



- 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

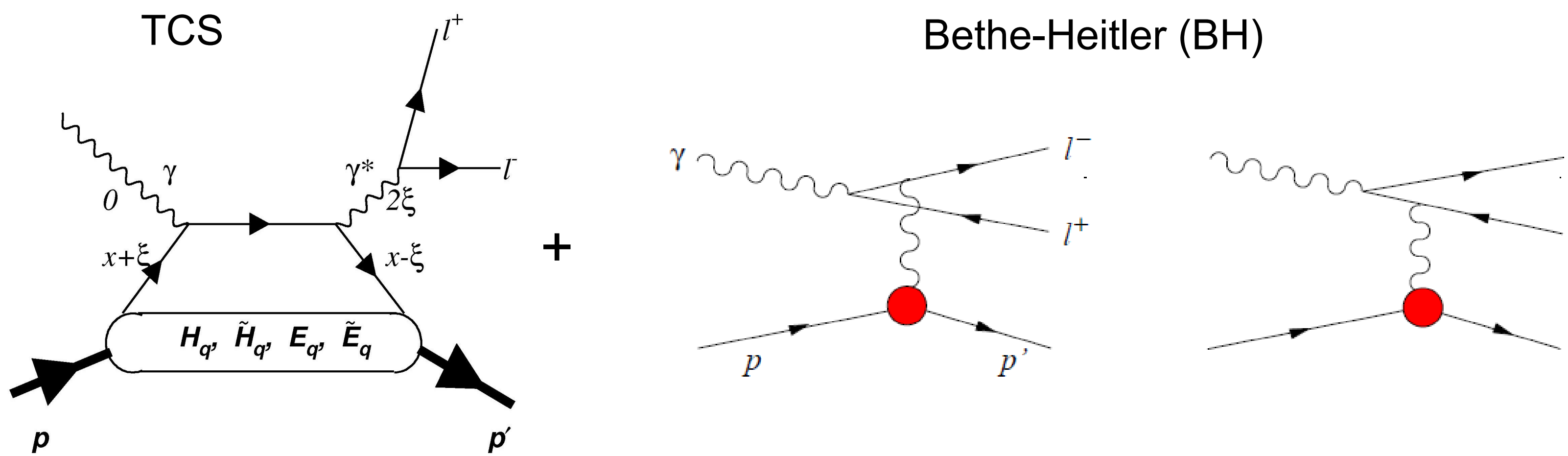


- k,k' = momentum of e^-, e^+
- θ = angle between the scattered proton and the electron
- φ = angle between lepton scattering- and reaction planes

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

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

Observables sensitive to the interference term



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

- 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

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

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

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

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

Full interference term with polarized beams

To leading order, in terms of helicity amplitudes:

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

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

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

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

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

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

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

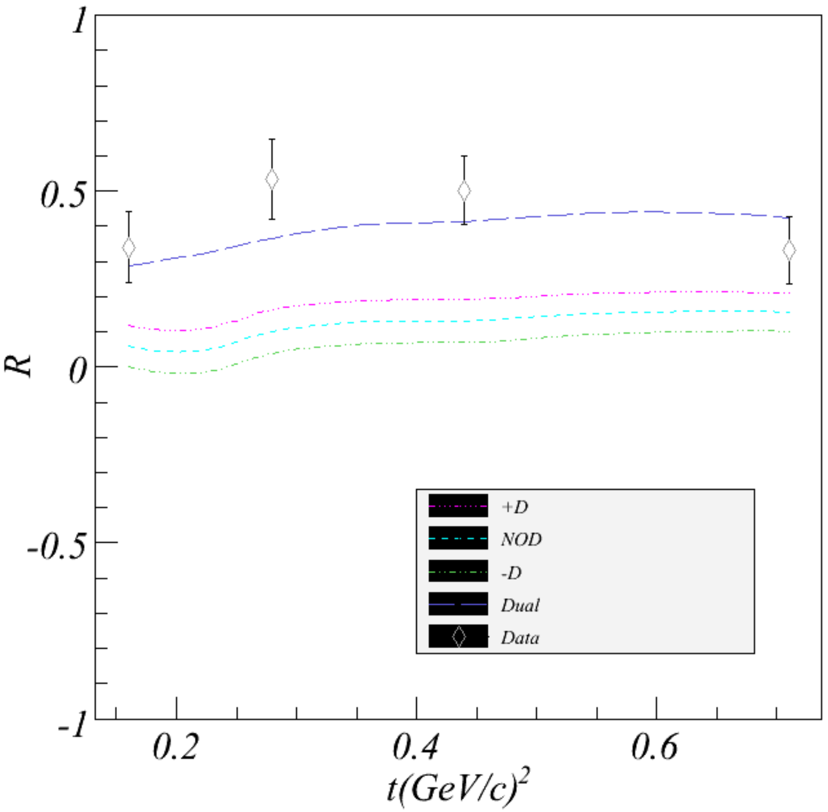
Example: first data from 6 GeV

- Cosine moment of weighted cross sections

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

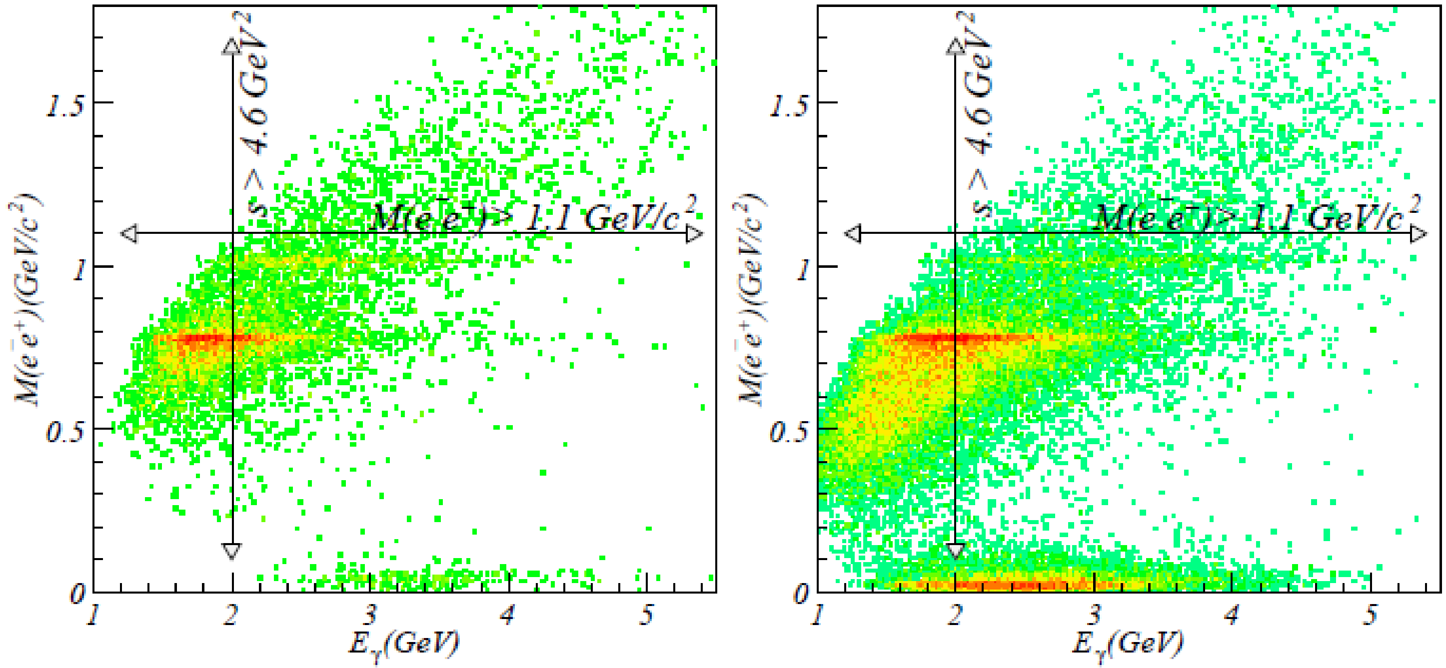
$$R = \frac{2\int_0^{2\pi} d\varphi \cos\varphi \frac{dS}{dQ'^2 dt d\varphi}}{\int_0^{2\pi} d\varphi \frac{dS}{dQ'^2 dt d\varphi}}$$

- 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



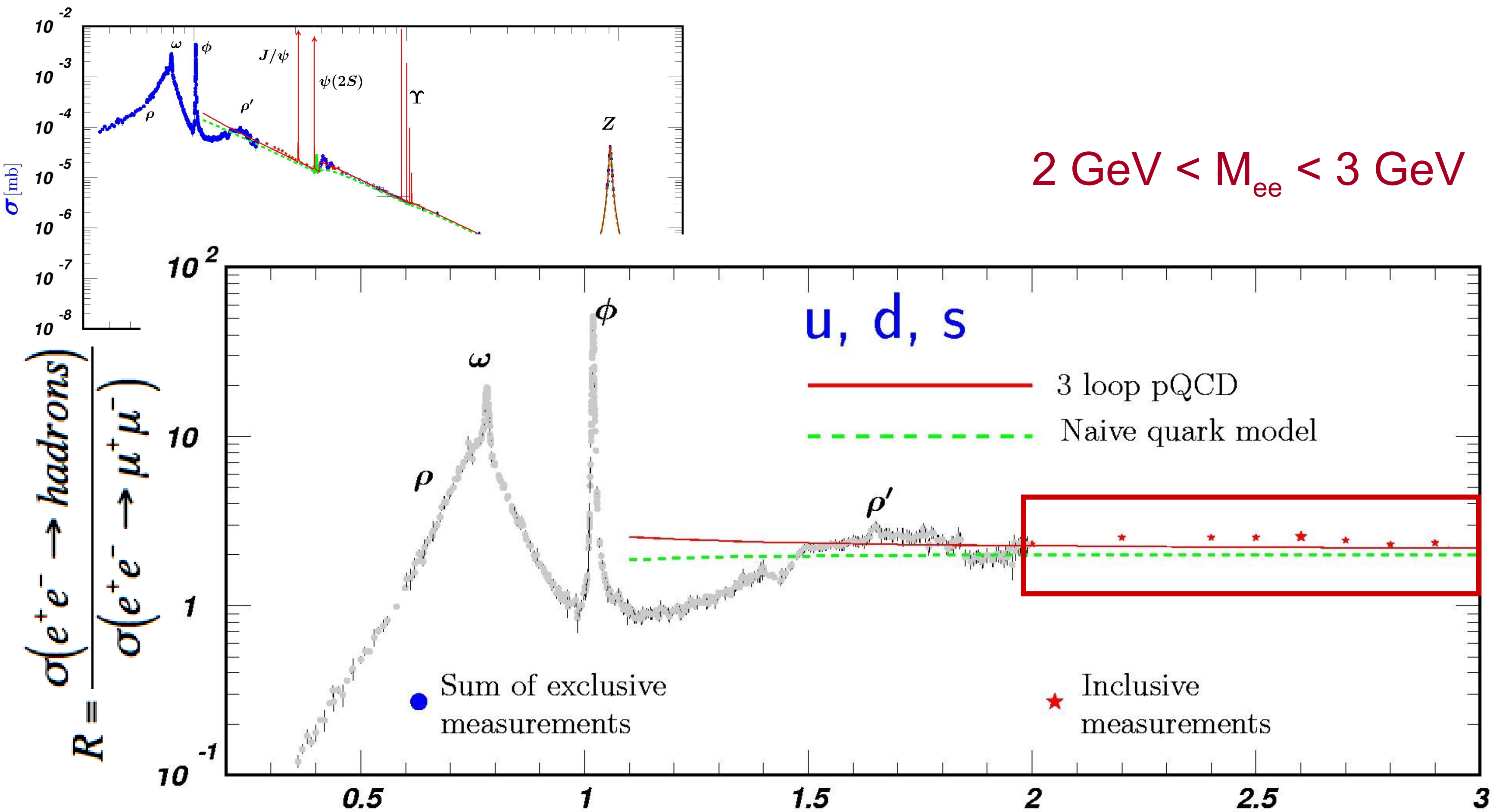
Data from e1-6 (left), e1f (right), and g12 have limited coverage in s and $M_{ee} = Q'$.

- 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

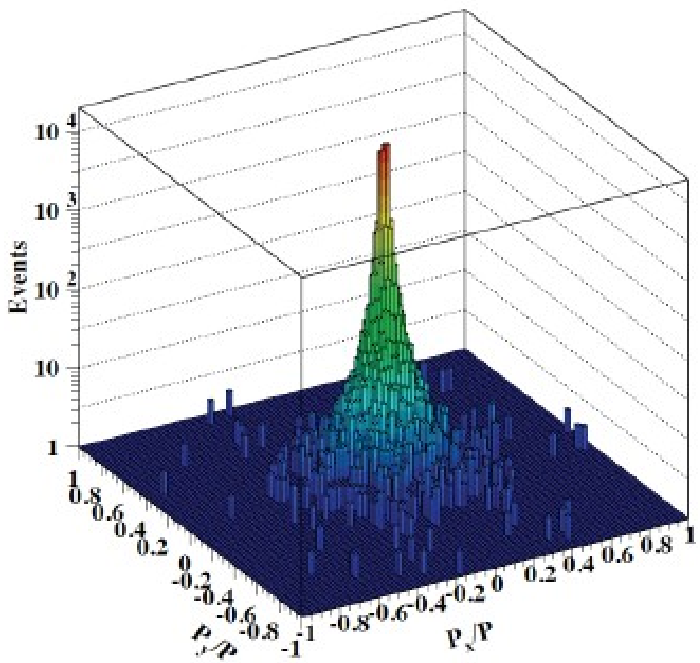
Resonance-free region at 12 GeV

2 GeV < M_{ee} < 3 GeV

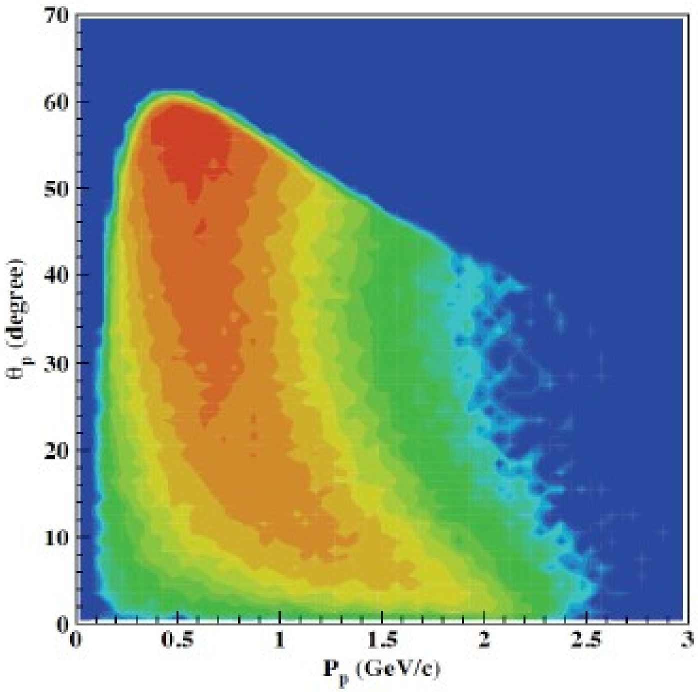


- JLab 12 GeV kineamtics are ideally suited for TCS
- Data can be taken in the resonance-free region between ρ' and J/Ψ

Beam electron and recoil proton kinematics

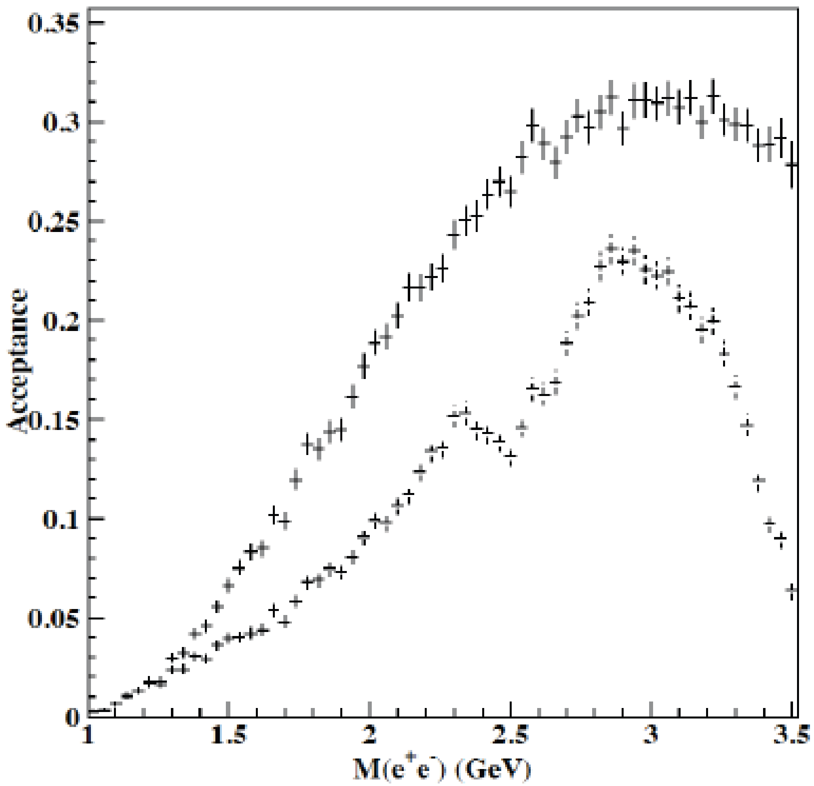


Low-Q^2 events are reconstructed by cuts on the transverse momentum of the missing beam electron



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

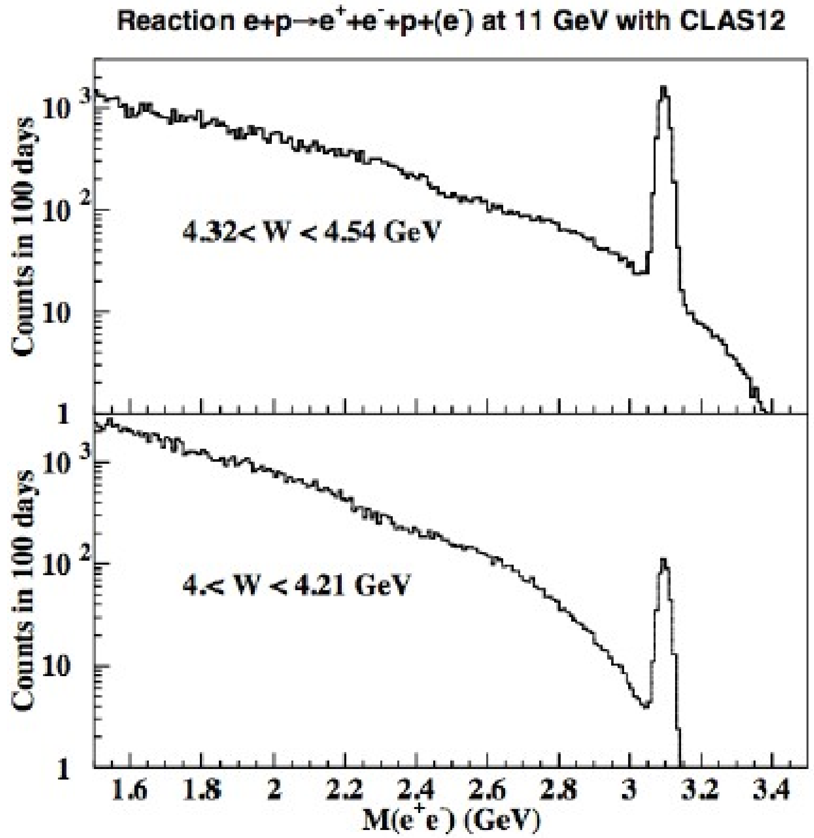
Acceptance (from fast Monte Carlo)



- (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 no other restrictions so beamtime can easily be shared.

Beam time request

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

Notes

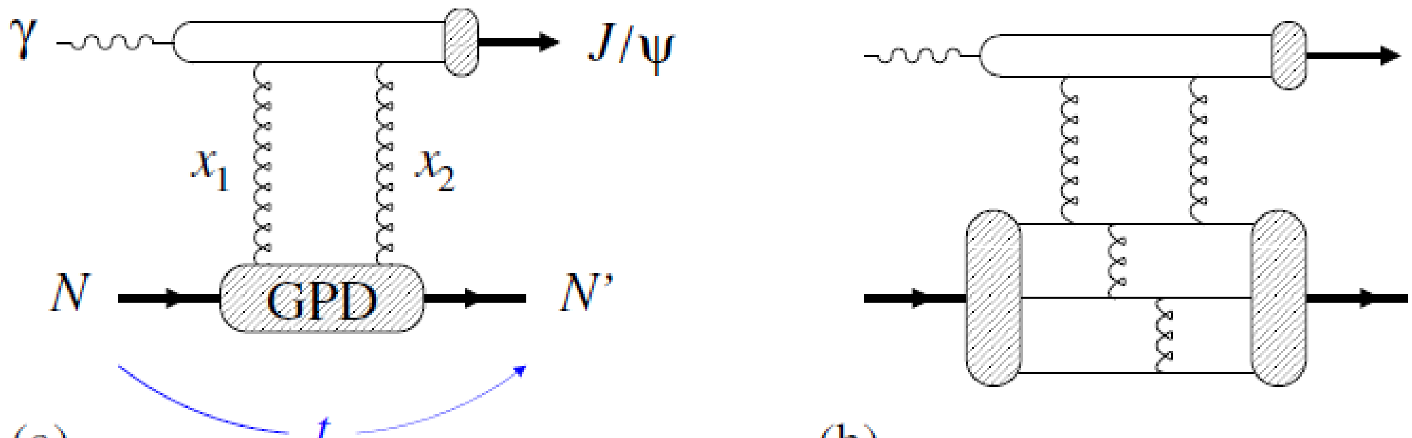
- It would be possible to study TCS on other targets, but there is no obvious motivation for doing so at this point

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


Thank you!

Backup

J/Ψ



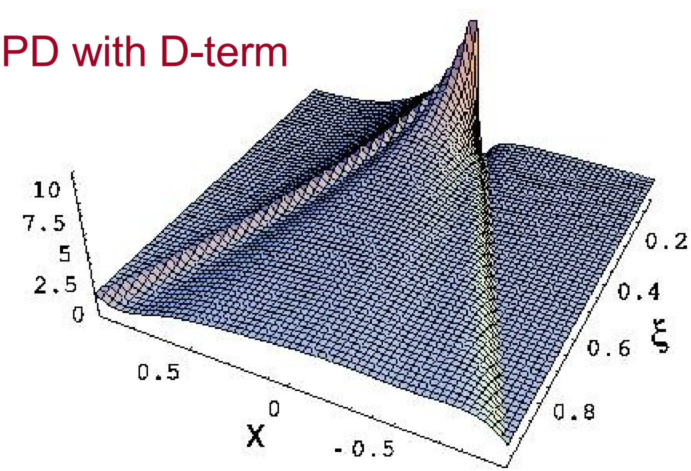
(a) (b)

D-term in DD-parametrization of GPDs

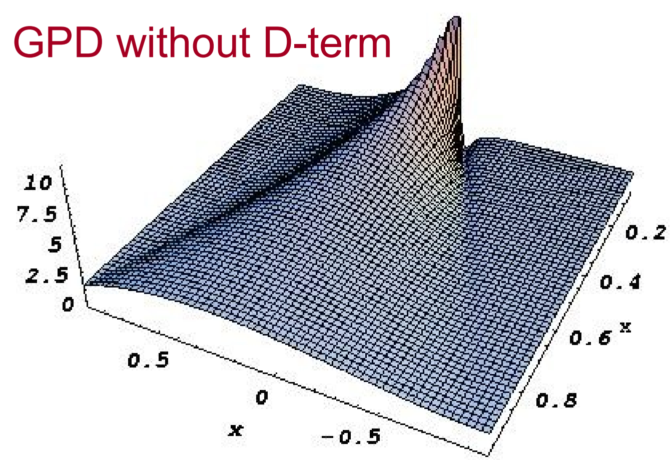
$$H^q(x,\xi) = H^q_{DD}(x,\xi) + \theta(\xi - |x|)\frac{1}{N_f} D\left(\tfrac{x}{\xi}\right)$$

D-term – allows to satisfy polynomiality of Mellin moments of GPDs

GPD with D-term



GPD without D-term



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