Interests of measuring Timelike Compton Scattering off a transversely polarized target for studies of Generalized Parton Distributions

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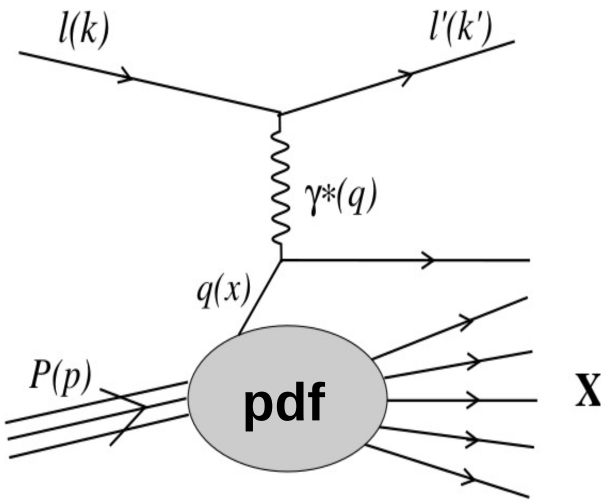
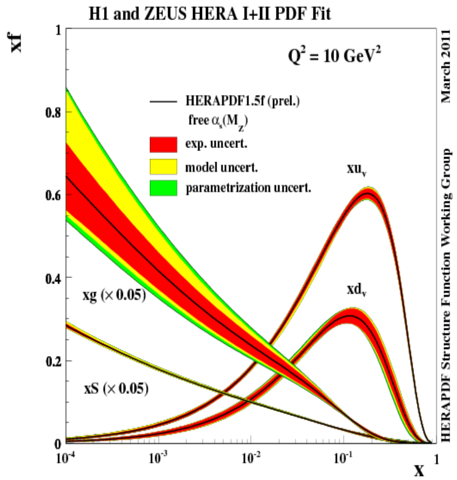
Physics case of PR-12-18-005

February 4th, 2020 - CPS collaboration meeting, Jefferson Laboratory

Toward 3D nucleon imaging

Inclusive: Deep Inelastic Scattering





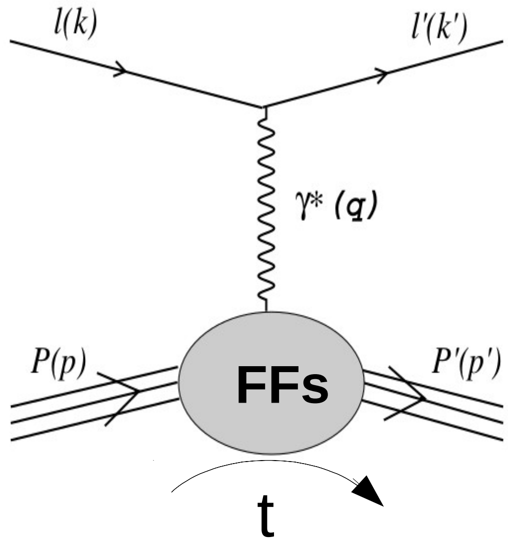
Structure functions f(x), g(x)
⇒ Parton Distributions q(x), g(x)

x dependence : partons longitudinal momentum fraction of the nucleon,
infinite momentum frame: all "forward" boost

Q^2 : scale, also provides a hard scale

No momentum transfer : t = 0
creation/annihilation of quark at different space-time points ⇒ non local, forward matrix element

Exclusive: Elastic Scattering



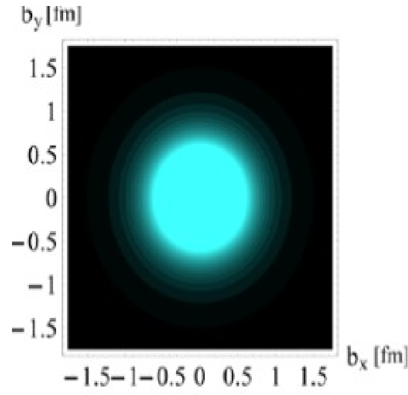


fig. from
M. Vanderhaeghen

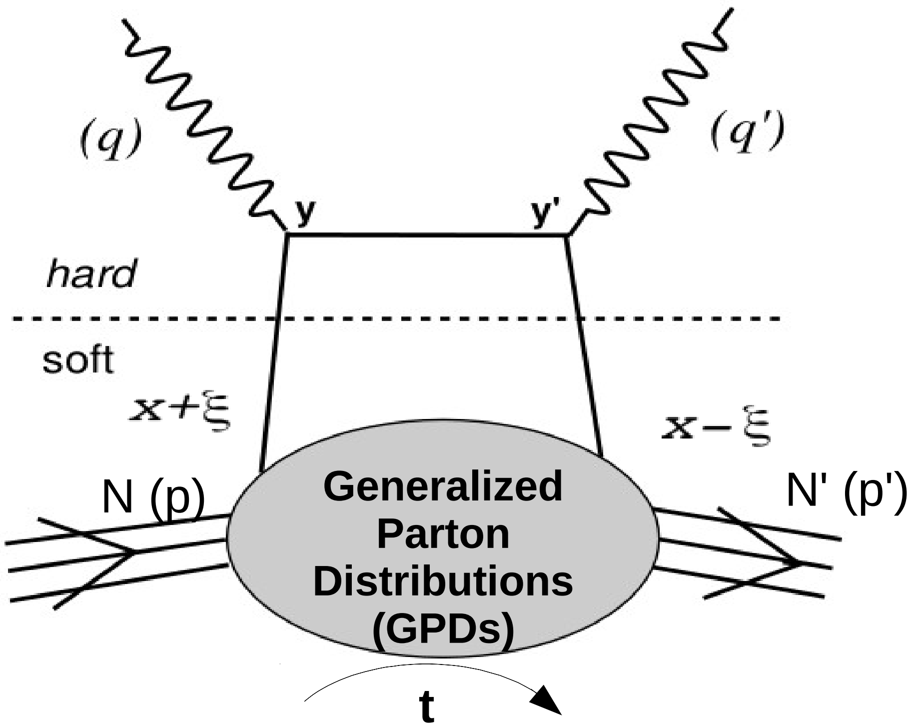
Form factors $F_1(t)$, $F_2(t)$, $G_A(t)$, $G_p(t)$

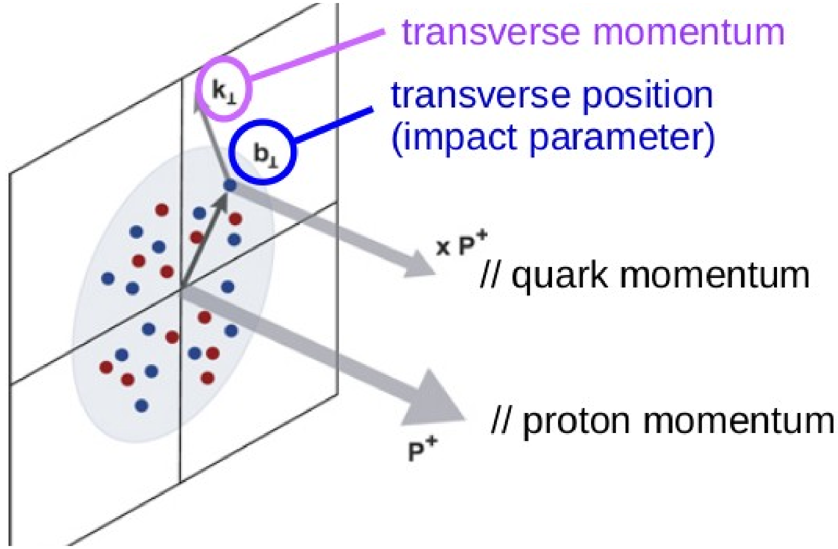
→ FT transverse of charge densities
quarks transverse distribution thanks to "t" dependence

Local operator: quark created/annihilated at same space-time points, off forward: t≠0

Hard exclusive reactions:
exclusive ⇒ access t
hard scale ⇒ struck parton of momentum x

Generalized Parton Distributions





"quark creation/annihilation at different points, + small transverse kick"
⇒ Non local / off forward matrix elements

Hadronic tensor decomposition (X. Ji):
massless quarks, twist 2, spin 1/2 nucleon

vector structure:

$$F^{\mu}_{q}(x,\xi,t,Q^2) = \frac{1}{2\pi}\int d^4y\, e^{ixp^+y^-}\langle N(p')|\bar{\Psi}_q(y)\gamma^{\mu}\Psi_q(0)|N(p)\rangle_{y^+=y_\perp=0} + \mathcal{O}\left(\frac{1}{Q}\right),$$

axial-vector:

$$\tilde{F}^{\mu}_{q}(x,\xi,t,Q^2) = \frac{1}{2\pi}\int d^4y\, e^{ixp^+y^-}\langle N(p')|\bar{\Psi}_q(y)\gamma^{\mu}\gamma^5\Psi_q(0)|N(p)\rangle_{y^+=y_\perp=0} + \mathcal{O}\left(\frac{1}{Q}\right)$$

F.T.

Ji - chiral even GPD decomposition, twist 2 for TCS hadronic tensor:

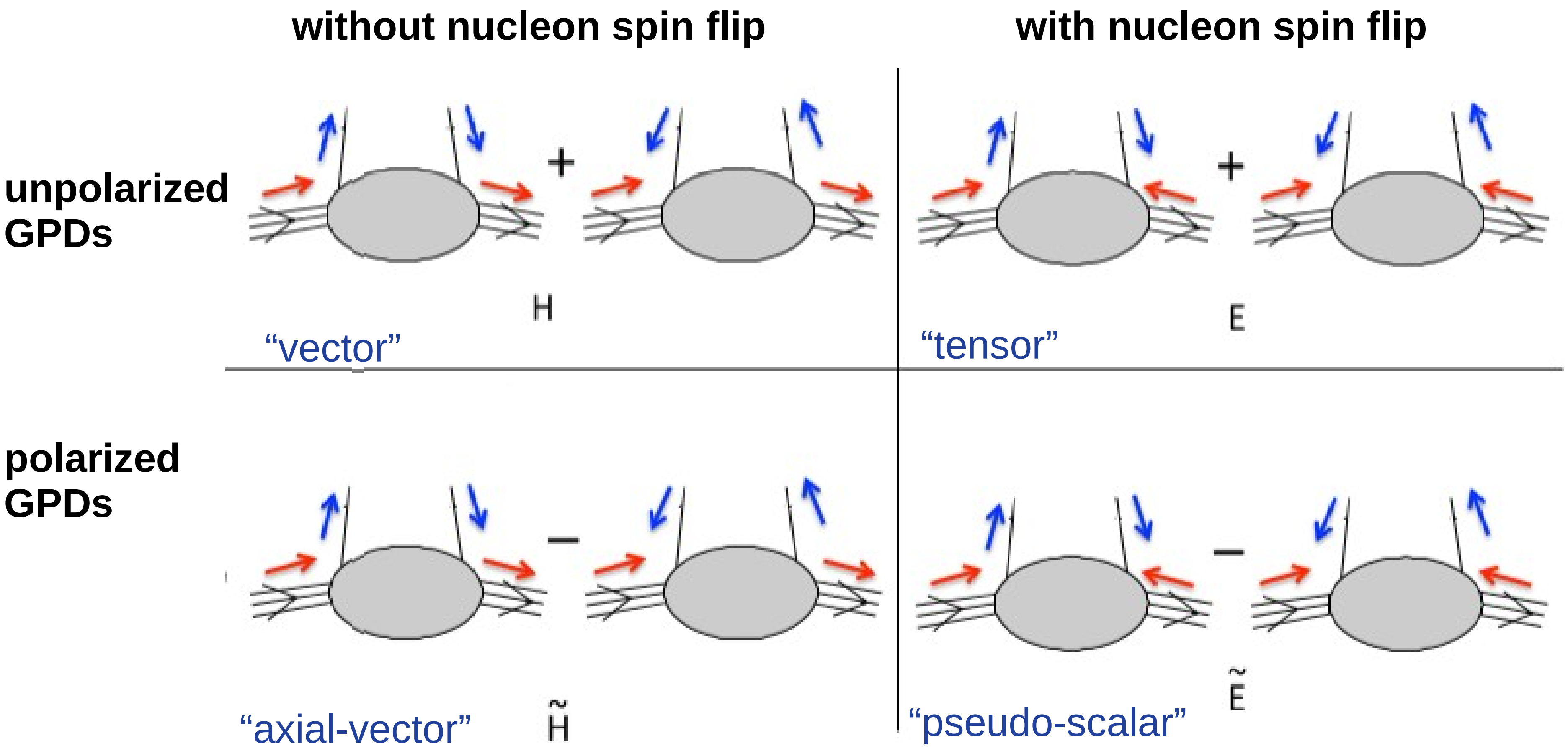
4 quarks chiral-even GPDs, real functions

$$H_{\mu\nu}^{TCS} = \frac{1}{2}(-g_{\mu\nu})_\perp \int_{-1}^{1} dx \left(\frac{1}{x-\xi-i\epsilon} + \frac{1}{x+\xi+i\epsilon}\right) \cdot \left(H(x,\xi,t)\bar{u}(p')\not{n}u(p) + E(x,\xi,t)\bar{u}(p')i\sigma^{\alpha\beta}n_\alpha\frac{\Delta_\beta}{2m_N}u(p)\right)$$

$$-\frac{i}{2}(\epsilon_{\nu\mu})_\perp \int_{-1}^{1} dx \left(\frac{1}{x-\xi-i\epsilon} - \frac{1}{x+\xi+i\epsilon}\right) \cdot \left(\tilde{H}(x,\xi,t)\bar{u}(p')\not{n}\gamma_5\, u(p) + \tilde{E}(x,\xi,t)\bar{u}(p')\gamma_5\frac{\Delta\cdot n}{2m_N}u(p)\right).$$

Generalized Parton Distributions

Chiral-even quark nucleon GPDs :
spin 1/2× spin 1/2



GPDs are associated to various helicity states of the quarks and nucleon spin orientation

- GPDs contain correlation between quark's transverse distribution and their longitudinal momentum
- Distributions of (un)polarized quarks in (un)polarized nucleon

GPD E: unpolarized quarks in polarized nucleon (1 unit of spin flip)

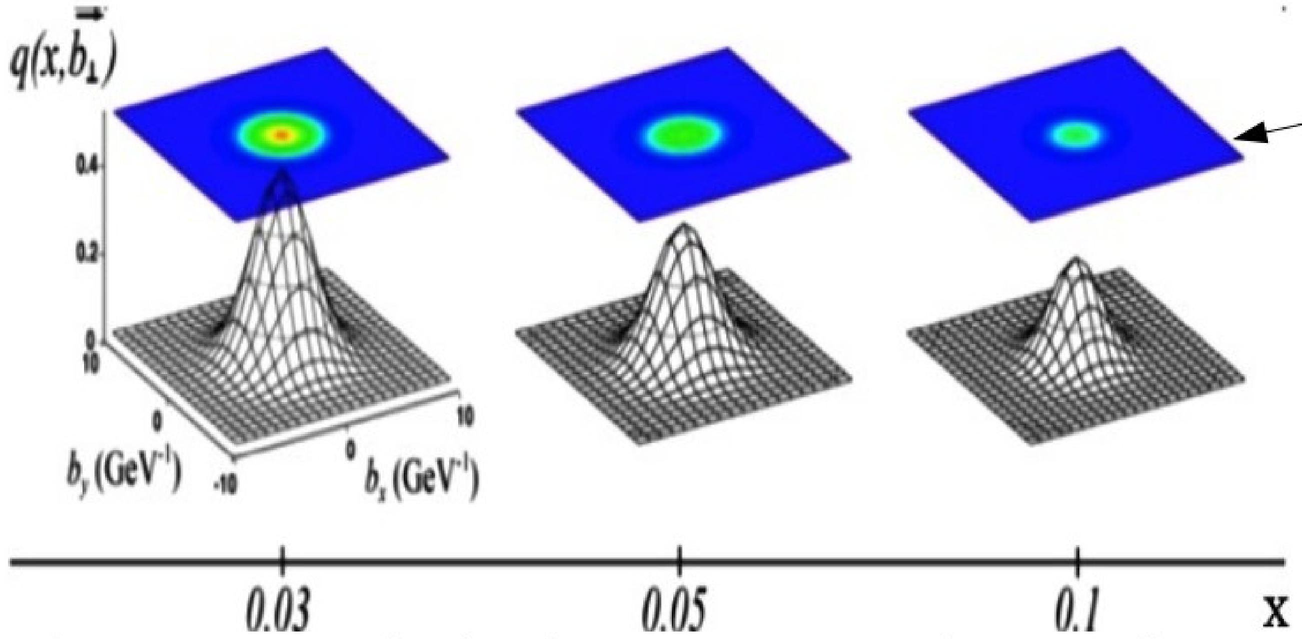
Some interpretations of Generalized Parton Distributions

correlation between quark longitudinal momentum fraction x, and transverse distribution

Nucleon tomography :
FT of GPD H (x, 0, $|t|=\Delta_\perp^2$)

x : longitudinal momentum fraction
t : momentum transfer squared
$b_{x,y}$: transverse distance to CM

Impact parameter space
x-dependent transverse space distributions



transverse charge density also accessed via Form Factors (no x dependence), which are ∫ dx of GPD

x distribution at t=0 correspond to pdf Related to probability of probing q, g...

← gluons, sea quarks dominate valence region →

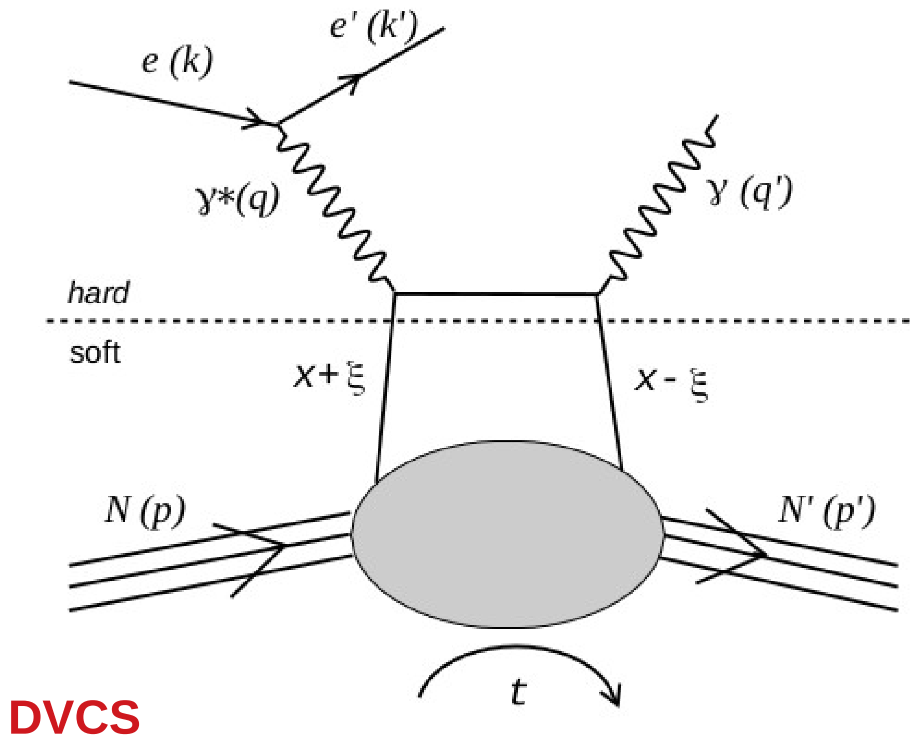
Ji sum rule → access angular momenta through GPDs H and E first moment

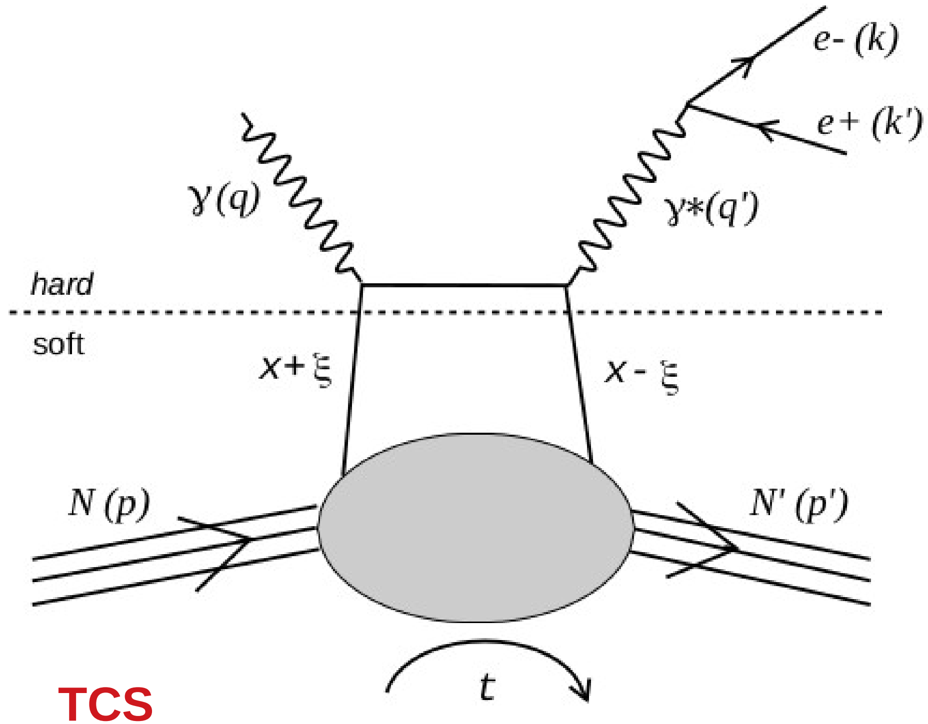
$$J^q(t=0) = \frac{1}{2}\int dx\, x\,[H^q(x,\xi,t=0) + E^q(x,\xi,t=0)] = \frac{1}{2}\Delta\Sigma + L_q \quad (\forall\xi)$$

X. Ji, Phy.Rev.Lett.78,610(1997)

$\Delta\Sigma \approx 0.3$

Timelike Compton Scattering vs Spacelike Deeply Virtual Compton Scattering





- Most of knowledge on GPDs from DVCS and hard exclusive mesons measurement: H1/ZEUS, HERMES, JLab, COMPASS…

- **GPDs are universal! How to demonstrate it?**

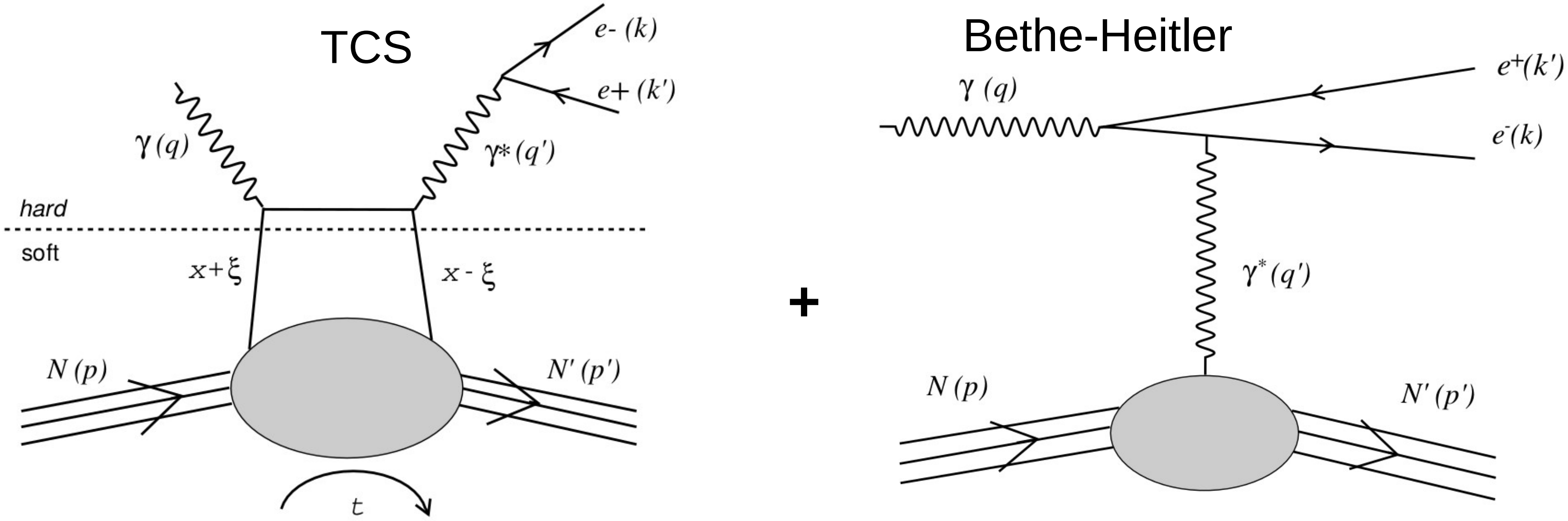
DVCS and TCS have leading order, leading twist complex conjugate amplitudes
⇒ extraction of GPDs from both processes independently
⇒ comparison of "equivalent" spacelike and timelike processes for universality studies
⇒ multi-observables fitting approaches to constrain all CFF simultaneously, assuming universality

TCS experiments are challenging: need of high intensity photon beams, interferences...

Measuring Timelike Compton Scattering

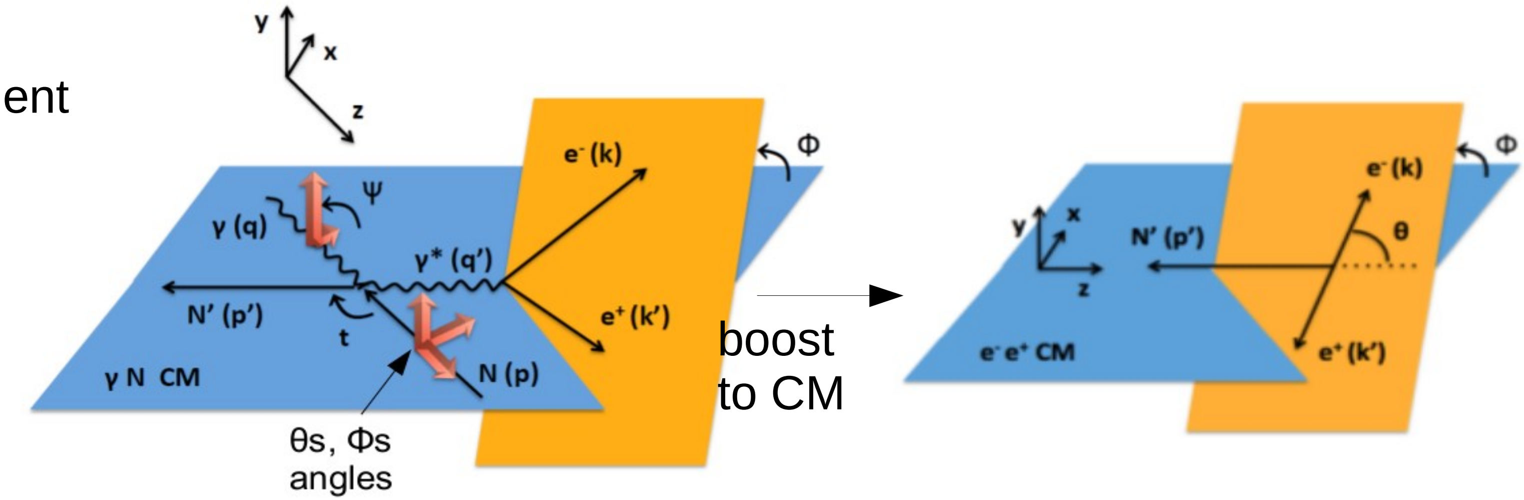
γ N → e⁺e⁻ N

=



dσ: 5 or 6 independent variables

choice:
E or ξ,
t, Q^2, φ, θ,
if spin: φ_s or Ψ_s



φ: (hadronic plane, pair)
θ: (γ*, e⁻)

φ_S, θ_S: (hadronic plane, target spin)
Ψ: (hadronic plane, γ spin)

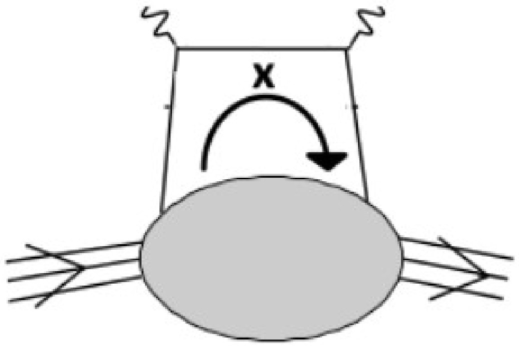
Various unpolarized, polarized cross sections, target and/or spin asymmetries or angular momenta are sensitive to different Compton Form Factors and GPDs

notations: σ (x-section) or A (asymmetry)≡[$\sigma^{\downarrow}$-$\sigma^{\uparrow}$]/[2σ], index 1=beam polar., index 2=target polar.

How to access GPDs?

Extraction via Compton Form Factors (CFFs)

ξ, t = measurable
x = loop
x±ξ = propagator



$$T^{DVCS} \sim \int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi + i\varepsilon} dx + \ldots \sim \underbrace{P\int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi} dx}_{\mathrm{Re}\,(\mathcal{H})} - \underbrace{i\pi H(\pm\xi,\xi,t) + \ldots}_{\mathrm{Im}\,(\mathcal{H})}$$

Compton Form Factor (CFF)
Indirect access to GPDs

(same for DVCS and TCS at asymptotic limit)

Compton Form Factors for quark chiral even GPDs H, E, H̃, Ẽ

H, E ⇒ $$\Re e[\mathcal{F}(\xi,t)] = \mathcal{P}\int_0^1 dx\,[\frac{1}{x-\xi} + \frac{1}{x+\xi}].[F(x,\xi,t) - F(-x,\xi,t)],$$

H̃, Ẽ ⇒ $$\Re e[\tilde{\mathcal{F}}(\xi,t)] = \mathcal{P}\int_0^1 dx\,[\frac{1}{x-\xi} - \frac{1}{x+\xi}].[\tilde{F}(x,\xi,t) + \tilde{F}(-x,\xi,t)],$$

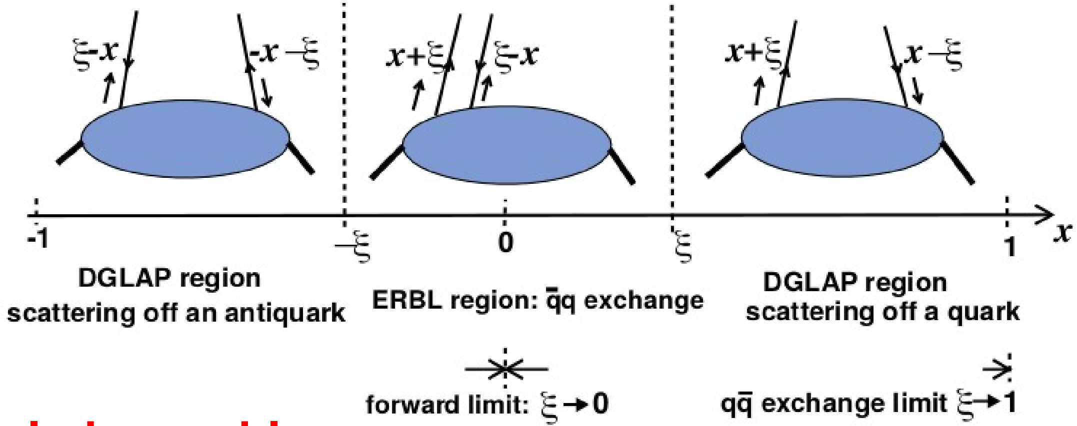
H, E ⇒ $$\Im m[\mathcal{F}(\xi,t)] = \pi[F(\xi,\xi,t) - F(-\xi,\xi,t)],$$

H̃, Ẽ ⇒ $$\Im m[\tilde{\mathcal{F}}(\xi,t)] = \pi[\tilde{F}(\xi,\xi,t) + \tilde{F}(-\xi,\xi,t)],$$

How to access GPDs?

$$T^{DVCS} \sim \int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi + i\varepsilon} dx + \ldots \sim \underbrace{P\int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi} dx}_{\mathrm{Re}\,(\mathcal{H})} \underbrace{- i\pi H(\pm\xi,\xi,t) + \ldots}_{\mathrm{Im}\,(\mathcal{H})}$$

Compton Form Factor (CFF)
Indirect access to GPDs

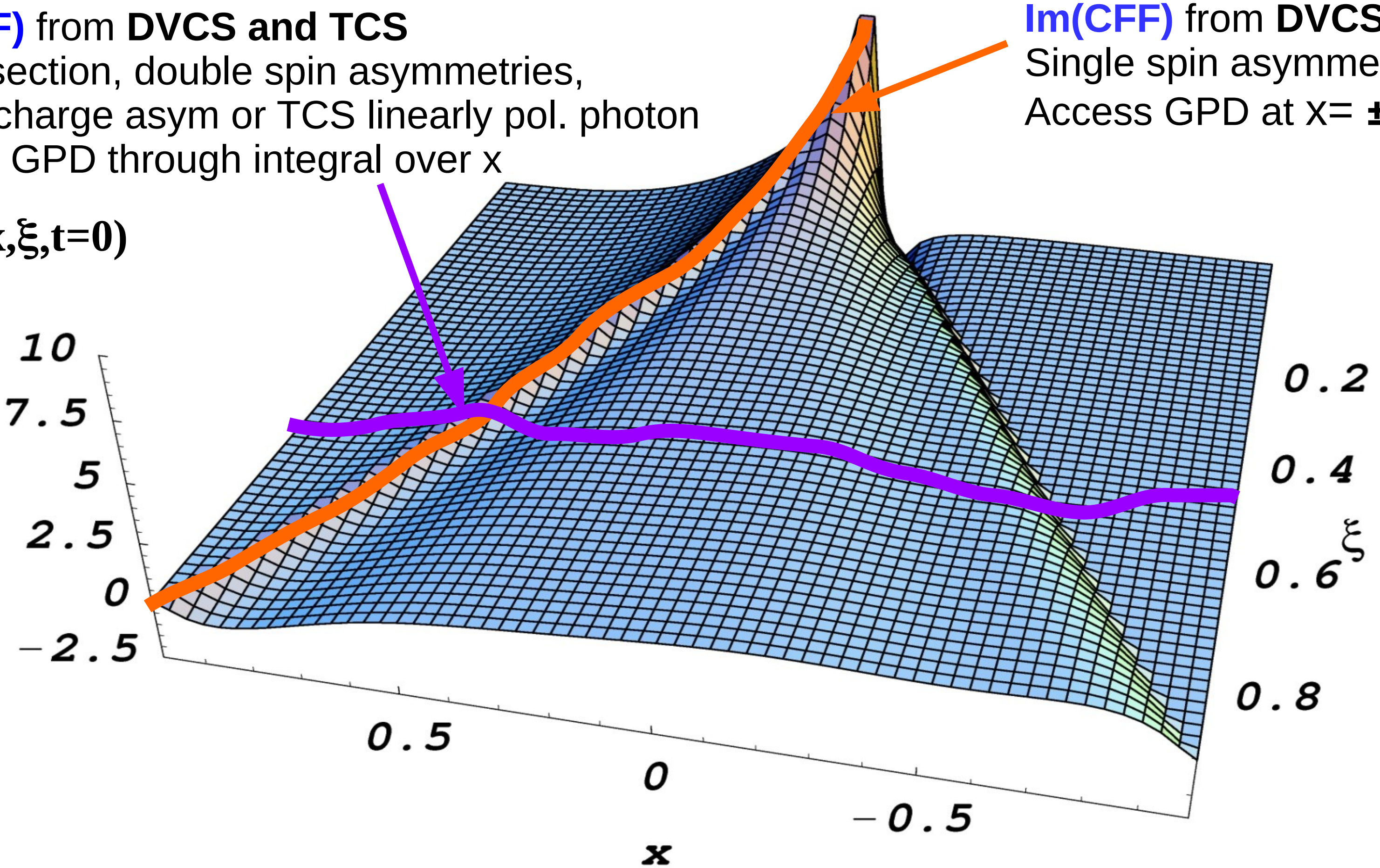


Probing GPD x vs ξ dependence with experimental observables:

Re(CFF) from **DVCS and TCS**
Cross section, double spin asymmetries,
DVCS charge asym or TCS linearly pol. photon
Access GPD through integral over x

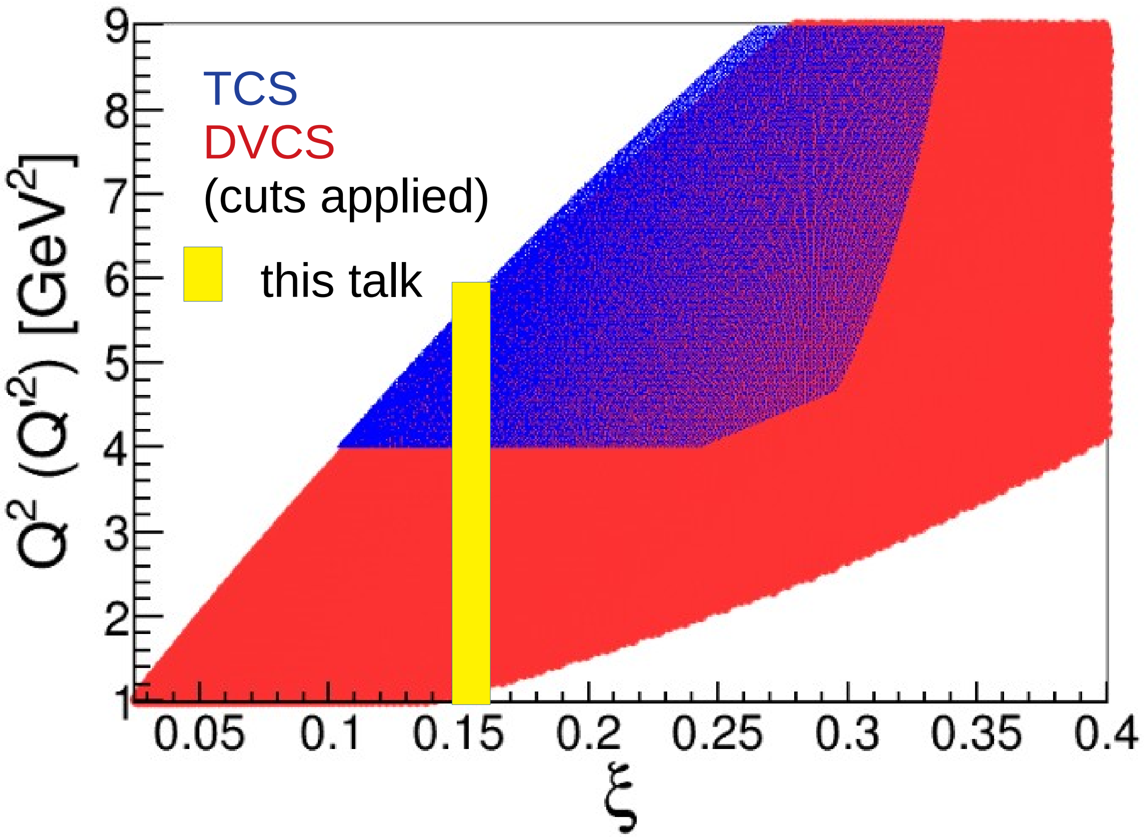
Im(CFF) from **DVCS and TCS**
Single spin asymmetries, cross section
Access GPD at x= **±ξ**

GPD H(x,ξ,t=0)



Im part DVCS and TCS access GPDs at x = ± ξ

Compton Form Factor fits from DVCS and TCS



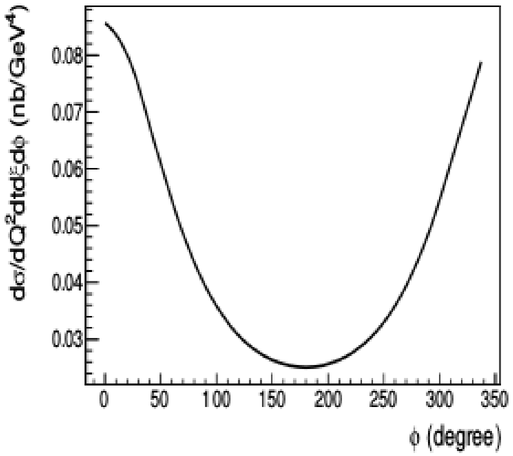
Method:

- Fitting DVCS and TCS observables at same ξ, t kinematics
- 8 CFFs following VGG model formalism (Im and Re associated to each chiral-even twist-2 GPD)
- Observables: unpolarized cross section and polarized x-sec differences in 16 bins in φ
- Uncertainties: 5% error/bin (unpolarized), 7% error/bin (polarized)

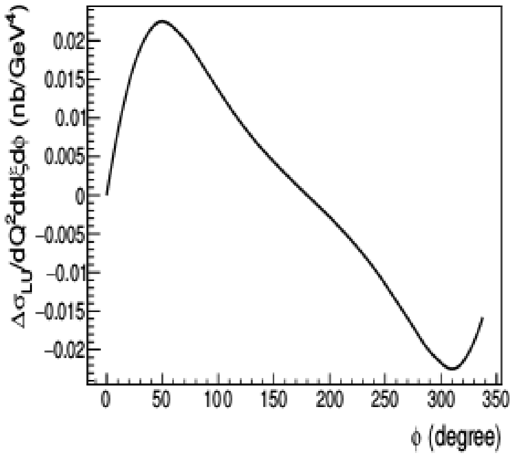
Generated distributions

DVCS

unpolarized cross section



polarized beam: $\Delta\sigma_{LU}$



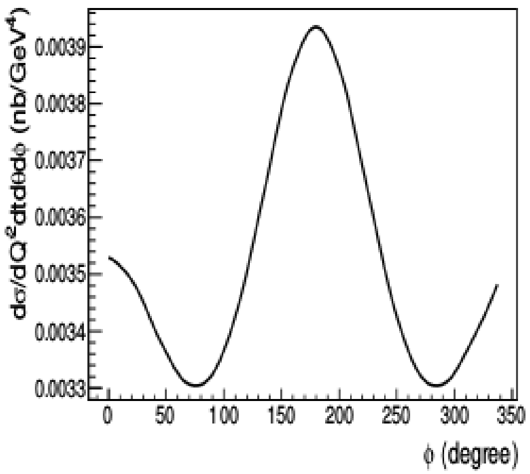
+ 7 more distributions of polarized cross section differences:

// pol target: $\Delta\sigma_{UL}$
⊥ pol target: $\Delta\sigma_{UX}$ (φ_S=0°), $\Delta\sigma_{UY}$ (φ_S=90°)
double pol beam+ target: $\Delta\sigma_{LX}$, $\Delta\sigma_{LY}$, $\Delta\sigma_{LL}$
beam charge: $\Delta\sigma_C$

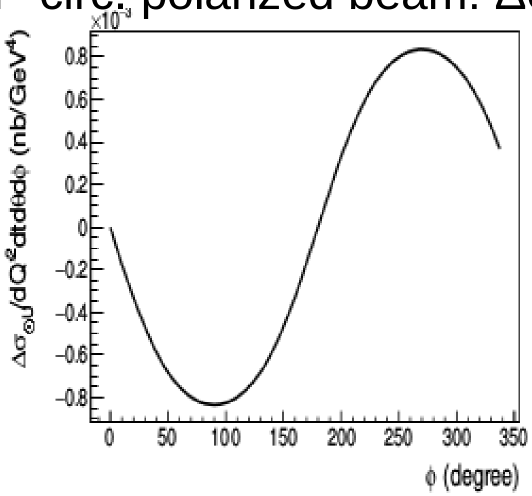
At Q^2 = 2.5 GeV², E = 11 GeV

TCS

unpolarized cross section



circ. polarized beam: $\Delta\sigma_{\odot U}$



+ 7 more distributions of polarized cross section differences:

// pol target: $\Delta\sigma_{UL}$
⊥ pol target: $\Delta\sigma_{UX}$ (φ_S=0°), $\Delta\sigma_{UY}$ (φ_S=90°)
double pol beam+ target: $\Delta\sigma_{\odot X}$, $\Delta\sigma_{\odot Y}$, $\Delta\sigma_{\odot L}$
linearly pol beam: $\Delta\sigma_{LU}$

At Q^2 = 4.5 GeV², θ = 90°

In this talk, in both cases: ξ = 0.15, -t = 0.2 GeV²

Sets of observables

Observables fitted simultenaously from pseudo-data,
corresponding to current and future measurements at JLab at 12 GeV (indicated by letter for the experimental hall in columns 2, 3, 4)

Set of observables	DVCS	TCS	DVCS+TCS	# independent obs. (DVCS/TCS/both)
1) σ, $\Delta\sigma_{LU}$	A, B, C	A, B, C	A, B, C	2/2/2
2) σ, $\Delta\sigma_{LU}$, $\Delta\sigma_{UL}$, $\Delta\sigma_{LL}$	B	-	-	4/4/4
3) σ, $\Delta\sigma_{LU}$, $\Delta\sigma_{UT}$ (x2)	-	C	-	4/4/4
4) σ, $\Delta\sigma_{LU}$, $\Delta\sigma_{UT}$ (x2) $\Delta\sigma_{UL}$, $\Delta\sigma_{LL}$	-	-	-	6/6/6
5) σ, $\Delta\sigma_{LU}$, $\Delta\sigma_{UT}$ (x2) $\Delta\sigma_{UL}$, $\Delta\sigma_{LL}$, $\Delta\sigma_{LT}$ (x2)	-	-	-	8/8/8
6) σ, $\Delta\sigma_{LU}$, $\Delta\sigma_{C}$	-	x	x	3 (DVCS)
6') σ, $\Delta\sigma_{\odot U}$, $\Delta\sigma_{LU}$	x	D ?	x	3 (TCS)
6") 2) of DVCS + 3) of TCS	x	x	B+C	6 (DVCS+TCS)

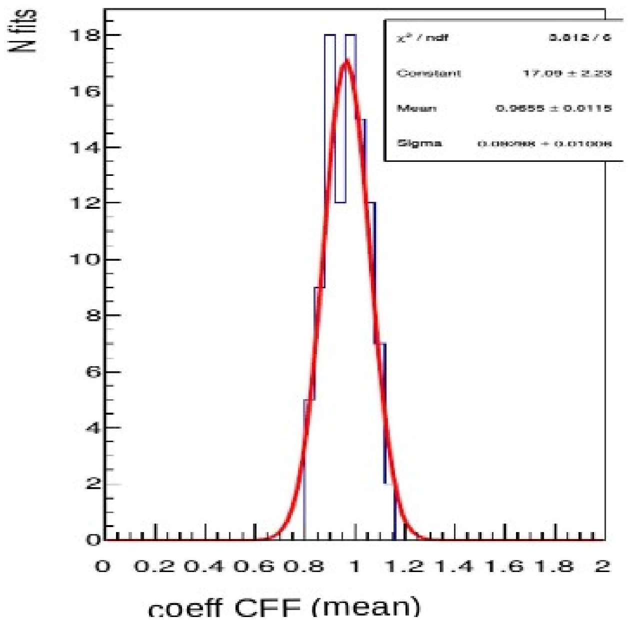
independently (DVCS, TCS) — combined (DVCS+TCS)

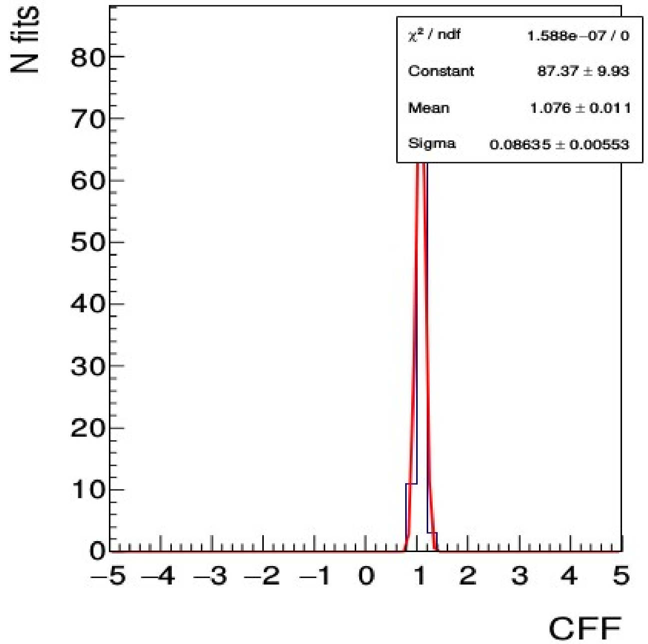
- DVCS experiments: approved or taking data
- TCS experiments 'A', 'B' are approved 'B' started analysis, 'C' is PR-12-18-005

no consideration here about experimental statistics. Assume "realistic" / ideal scenario with future experiments

Systematic studies and extraction of the results

• Stability of results: multiple iterations with random + smearing (1σ), then average mean and errors. Note: uncertainty limits are stable and more relevant than the "mean" value of the fit





Im(H̃) mean value extracted   positive error from MINOS

data set (2) = 4 independent observables. red = average (gaus)

• If system is underconstrained, less than 8 independent observables:
asymmetric uncertainties, need to evaluate uncertainty dependence with correlation to other CFFs (varying phase space limits, generated distributions...)
in this talk: comparison of results using always same input parameters

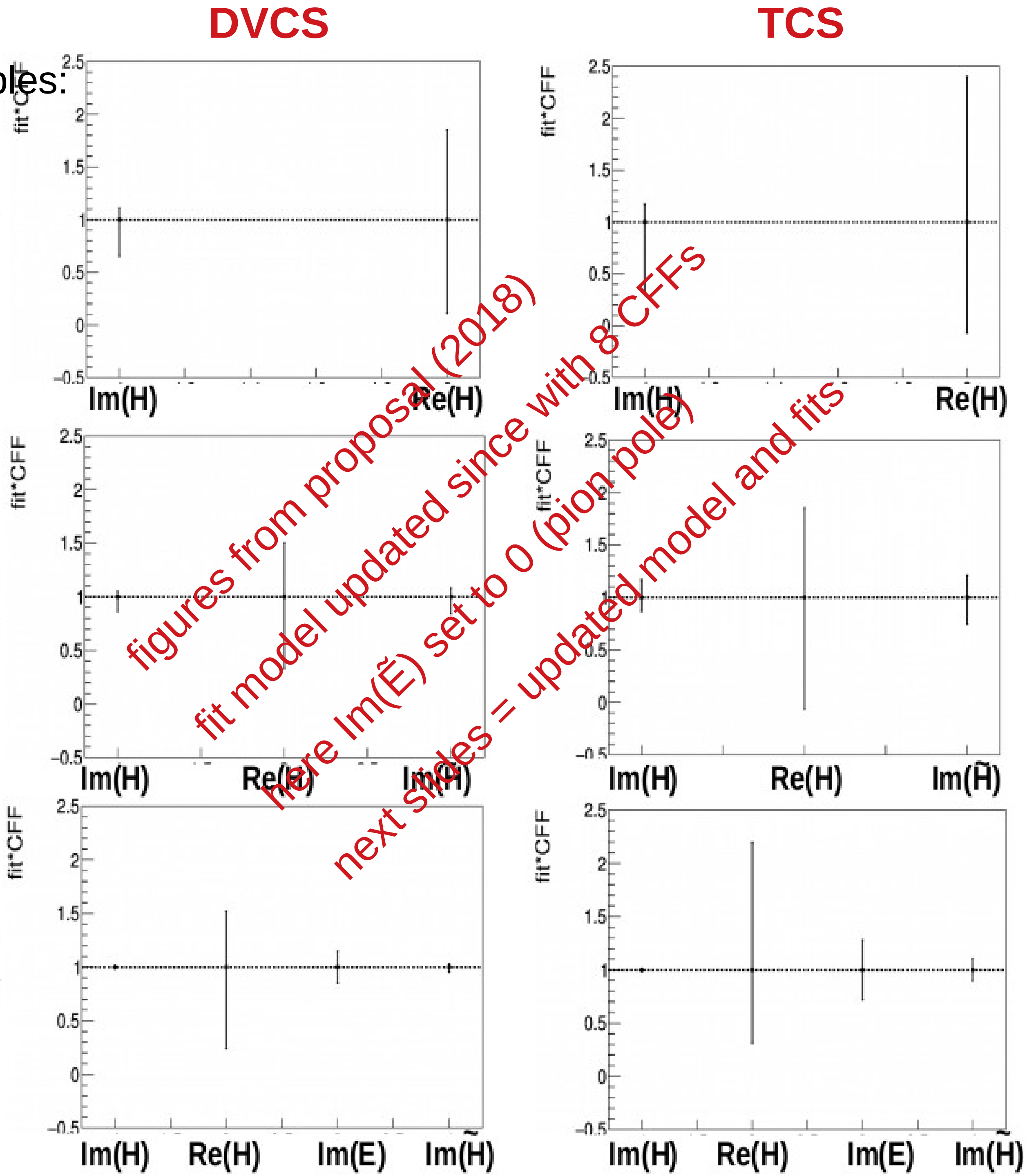
Compton Form Factors extracted from DVCS and TCS at twist 2

Observables:

1) $\sigma, \Delta\sigma_{LU}$

2) $\sigma, \Delta\sigma_{LU}$
$\Delta\sigma_{UL}, \Delta\sigma_{LL}$

3) $\sigma, \Delta\sigma_{LU}$
$\Delta\sigma_{UX}, \Delta\sigma_{UY}$



Pseudo-data with 5% error on unpolarized σ, 7% pol. σ,16 bins φ, 7 params CFFs fits

Comparison DVCS vs TCS

Assuming small higher twist versus fit uncertainties:
- Access same CFFs twist 2
- similar uncertainties for equivalent observables
- complementary if not same CFFs are extracted from DVCS and TCS

• unpolarized+beam: Im+Re($\mathcal{H}$)

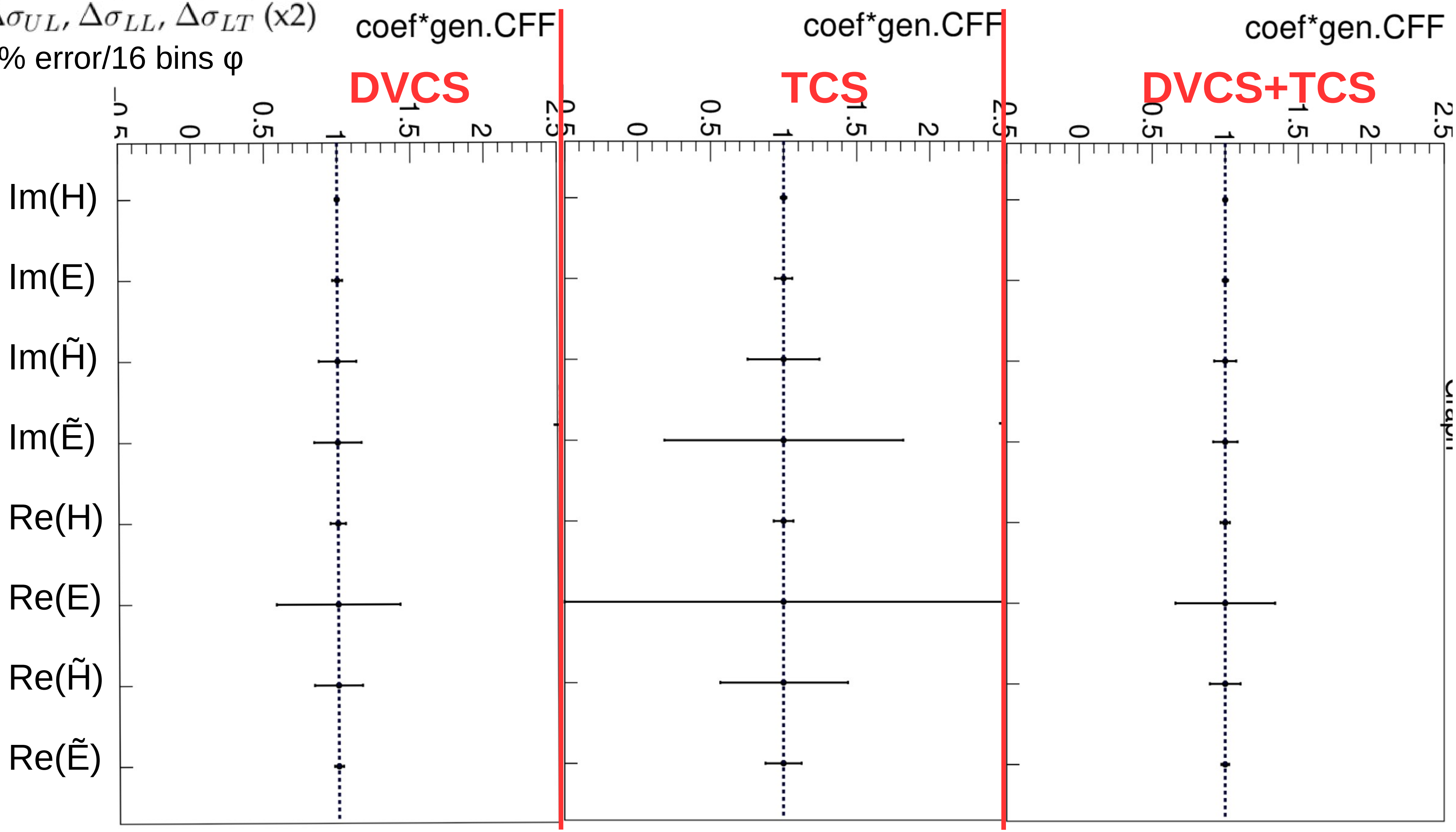
• including longitudinal target: Access Im+Re($\mathcal{H}$) and Im($\tilde{\mathcal{H}}$)

• including transverse target: Im+Re($\mathcal{H}$), Im($\tilde{\mathcal{H}}$), Im($\mathcal{E}$)

Assuming large higher twist versus fit uncertainties:
Universality studies, higher twist observations and timelike vs spacelike structure

Results: 8 parameters, 8 independent observables

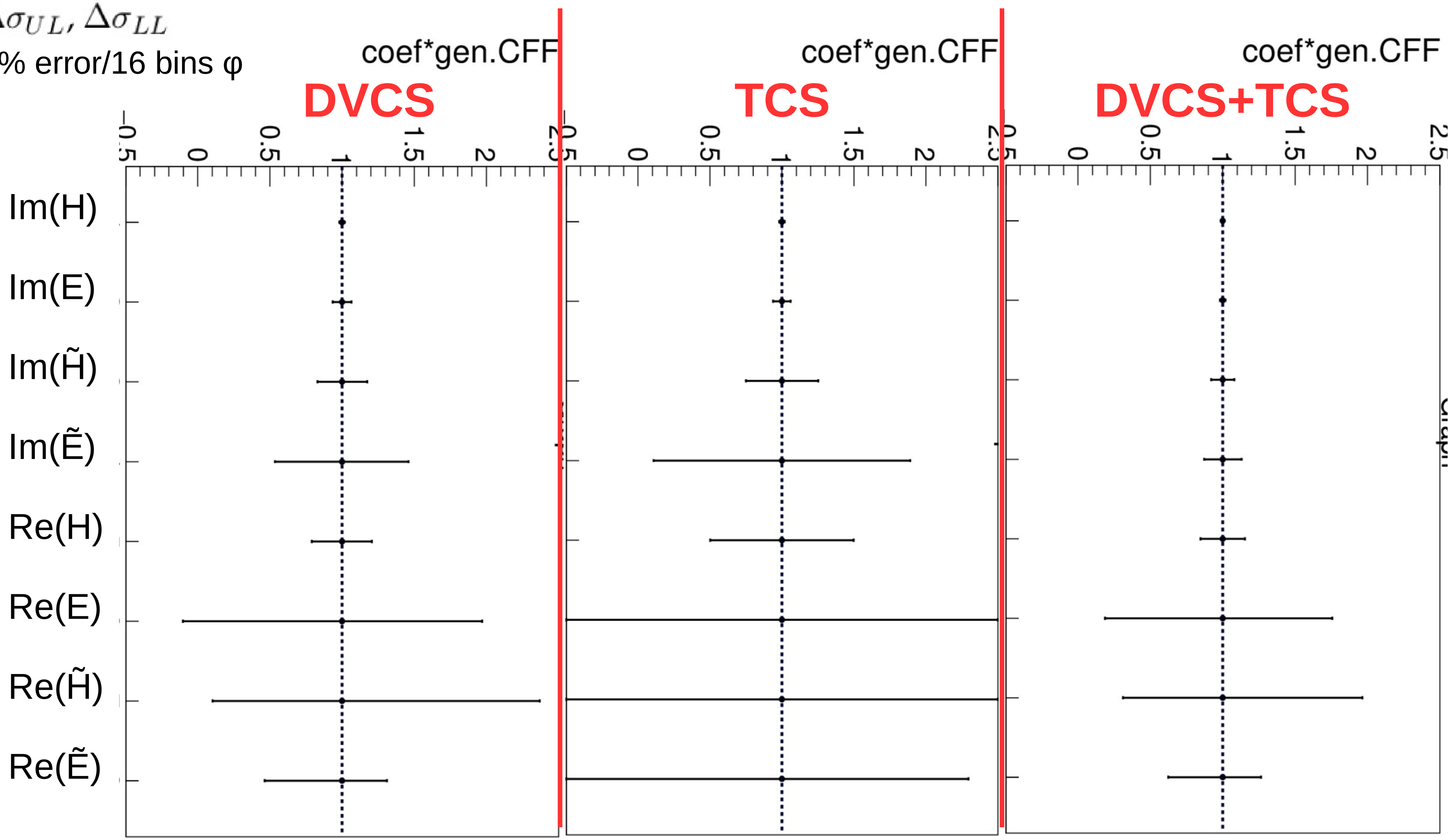
5) σ, $\Delta\sigma_{LU}$, $\Delta\sigma_{UT}$ (x2)
$\Delta\sigma_{UL}$, $\Delta\sigma_{LL}$, $\Delta\sigma_{LT}$ (x2)
7% error/16 bins φ



- **All CFFs extracted from DVCS and TCS, errors of same order** ⇒ comparison, universality
- Lower errors with DVCS vs TCS: TCS/BH < DVCS/BH. "real": higher statistics with DVCS
- DVCS+TCS: "real" scenario expect shift to direction of DVCS solution if shift to opposite directions from higher twists ⇒ combining fits assume GPDs universality + low higher twist/order

Results: 8 parameters, 6 independent observables

4) σ, $\Delta\sigma_{LU}$, $\Delta\sigma_{UT}$ (x2)
$\Delta\sigma_{UL}$, $\Delta\sigma_{LL}$
7% error/16 bins φ



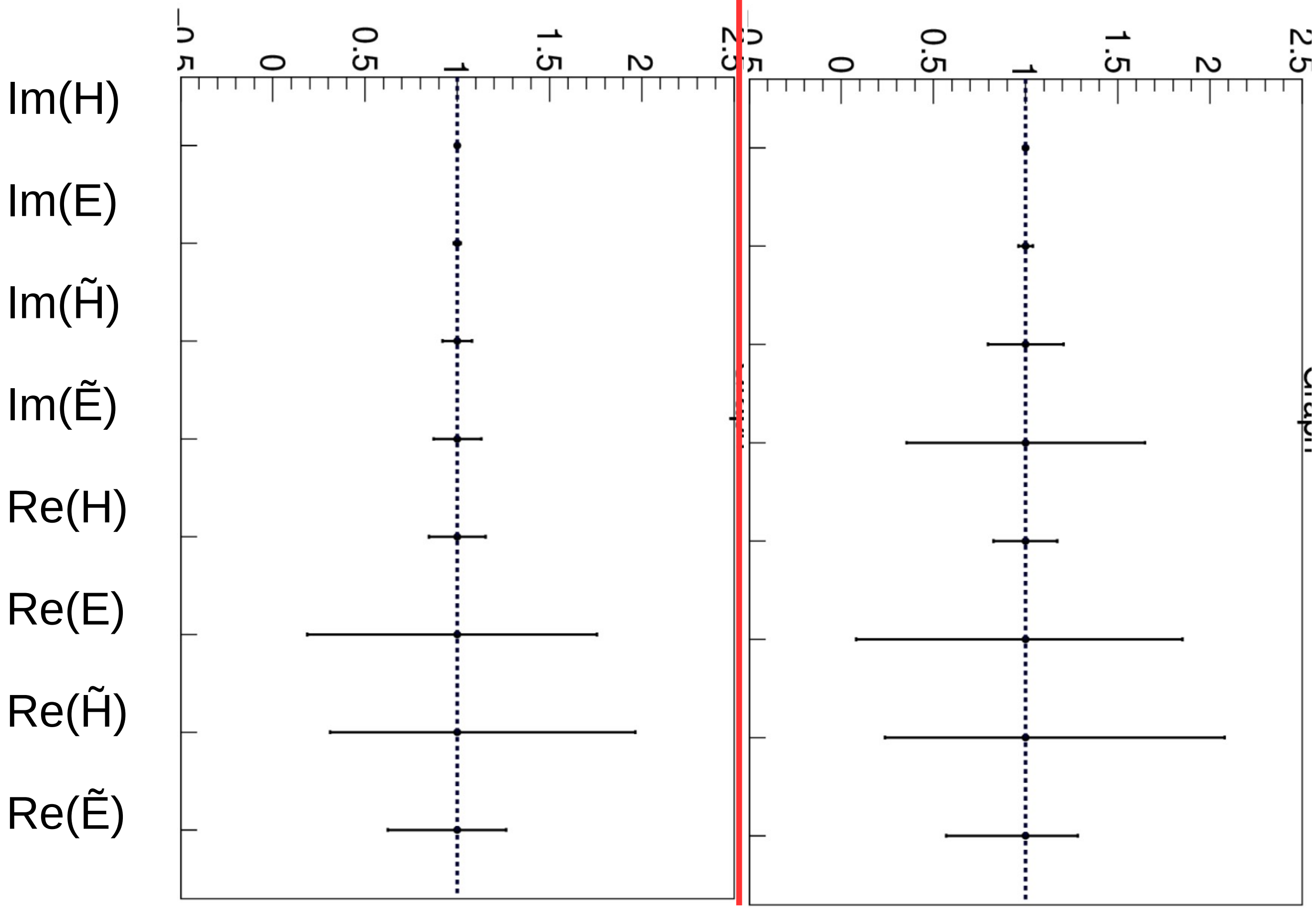
More realistic scenario: hard to measure $\Delta\sigma_{LT}$, large errors expected

- Problem is underconstained → asymmetric errors for Re(CFFs)
- Still possible to **extract all CFFs** (errors larger than scale for TCS real parts)

Combining independent observables from DVCS and TCS

DVCS+TCS (previous slide, 6 obs.): σ, $\Delta\sigma_{LU}$, $\Delta\sigma_{UL}$, $\Delta\sigma_{LL}$, $\Delta\sigma_{U\perp}$

DVCS (4 obs.): σ, $\Delta\sigma_{LU}$, $\Delta\sigma_{UL}$, $\Delta\sigma_{LL}$
+ TCS (4 obs.): σ, $\Delta\sigma_{\odot U}$, $\Delta\sigma_{U\perp}$



4+4 independent observables → 6 independent when combined

Realistic scenario: longitudinal target single+double asym with DVCS, transverse target with TCS

• Similar result combined fits with 4+4 observables than 6+6 observables → **all CFFs extracted**, thanks to independent information brought by the 2 processes

Caveat: assume low higher twist effects, and GPD universality

Dynamic twist corrections for TCS

- leading-twist TCS hadronic part of amplitude with "Ji's" GPDs decomposition

$$H^{\rm TCS}_{\mu\nu} =$$
$$\frac{1}{2}(-g_{\mu\nu})_\perp \int_{-1}^{1} \mathrm{d}x \left(\frac{1}{x-\xi-i\epsilon}+\frac{1}{x+\xi+i\epsilon}\right)$$
$$\cdot\left(H(x,\xi,t)\bar{u}(p')\not{n}u(p)+E(x,\xi,t)\bar{u}(p')i\sigma^{\alpha\beta}n_\alpha\frac{\Delta_\beta}{2m}u(p)\right)$$
$$-\frac{i}{2}(\epsilon_{\nu\mu})_\perp \int_{-1}^{1} \mathrm{d}x \left(\frac{1}{x-\xi-i\epsilon}-\frac{1}{x+\xi+i\epsilon}\right)$$
$$\cdot\left(\tilde{H}(x,\xi,t)\bar{u}(p')\not{n}\gamma_5\, u(p)+\tilde{E}(x,\xi,t)\bar{u}(p')\gamma_5\frac{\Delta\cdot n}{2m}u(p)\right)$$

$$\Delta = (p'-p)$$

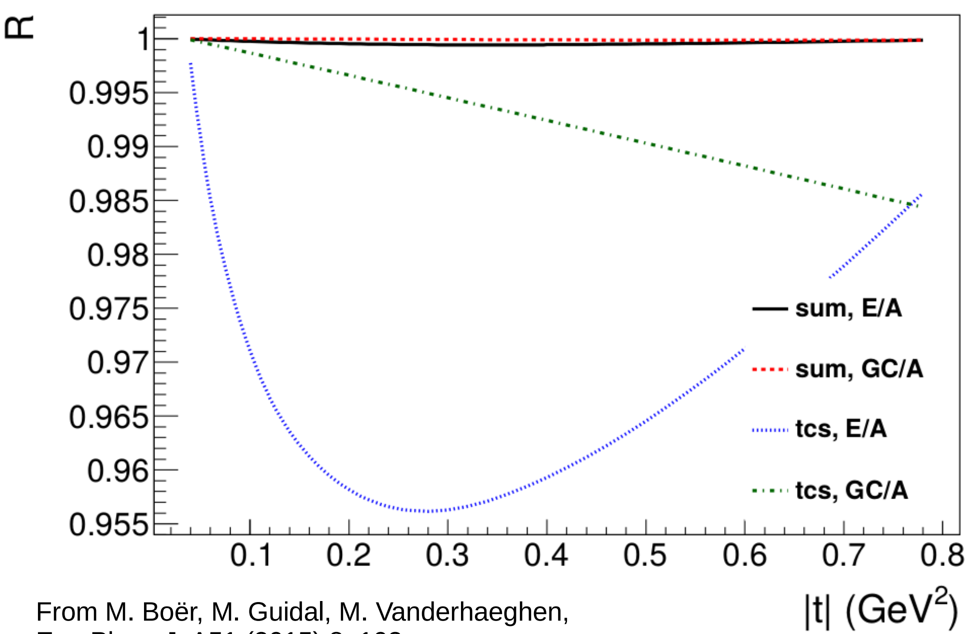
- ad-hoc twist 3 corrections for gauge-invariance

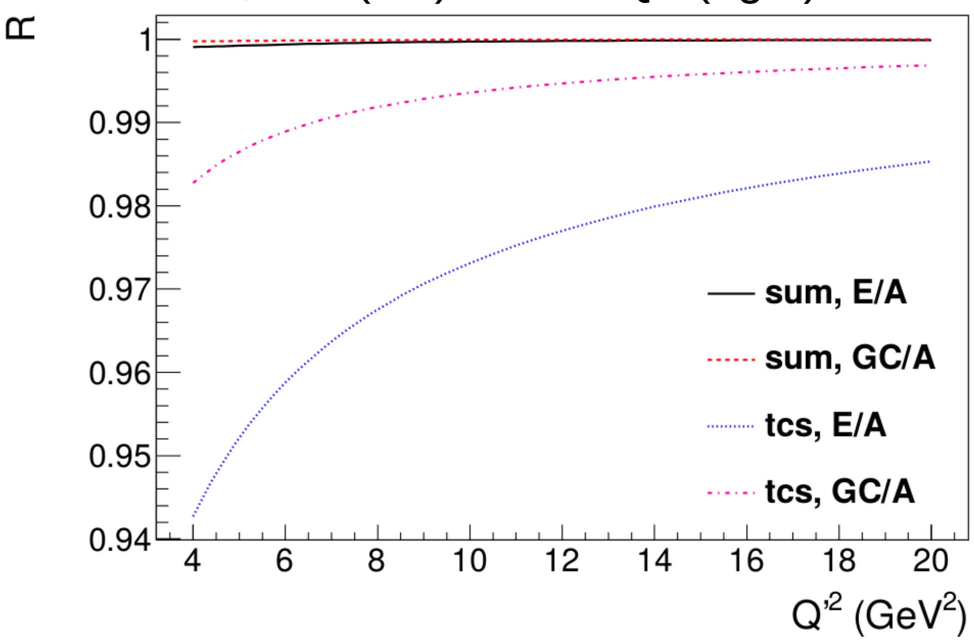
$$H^{\mu\nu} = H^{\mu\nu}_{LO} - \frac{P^\mu}{2P\cdot\bar{q}}\cdot(\Delta_\perp)_\kappa\cdot H^{\kappa\nu}_{LO} + \frac{P^\nu}{2P\cdot\bar{q}}\cdot(\Delta_\perp)_\lambda\cdot H^{\mu\lambda}_{LO} - \frac{P^\mu P^\nu}{4(P\cdot\bar{q})^2}\cdot(\Delta_\perp)_\kappa\cdot(\Delta_\perp)_\lambda\cdot H^{\kappa\lambda}_{LO}$$

- mass and Δ terms in skewness variables, related to light cone momentum fractions

$$\xi' = -\frac{\bar{q}^2}{2P\cdot\bar{q}} = \frac{-Q'^2+\Delta^2/2}{2(s-m^2)+\Delta^2-Q'^2}$$
$$\xi = -\frac{\Delta\cdot\bar{q}}{2P\cdot\bar{q}} = \frac{Q'^2}{2(s-m^2)+\Delta^2-Q'^2}$$

R = corrected / asymptotic unpolarized cross sections, vs t (left) and vs Q'² (right)





From M. Boër, M. Guidal, M. Vanderhaeghen,
Eur. Phys. J. A51 (2015) 8, 103

Impact of dynamic twist corrections on DVCS+TCS fits

- **Corrections applied**: **target mass and restoration of gauge invariance**
- **Impact on CFFs**: **~10% on Re, ~1% on Im, opposite sign in DVCS and TCS**
- **Impact on DVCS+TCS fits: between "twist 2" and "DVCS" results; 1% (Im) to 10% (Re)**

→ **below uncertainties on CFFs**

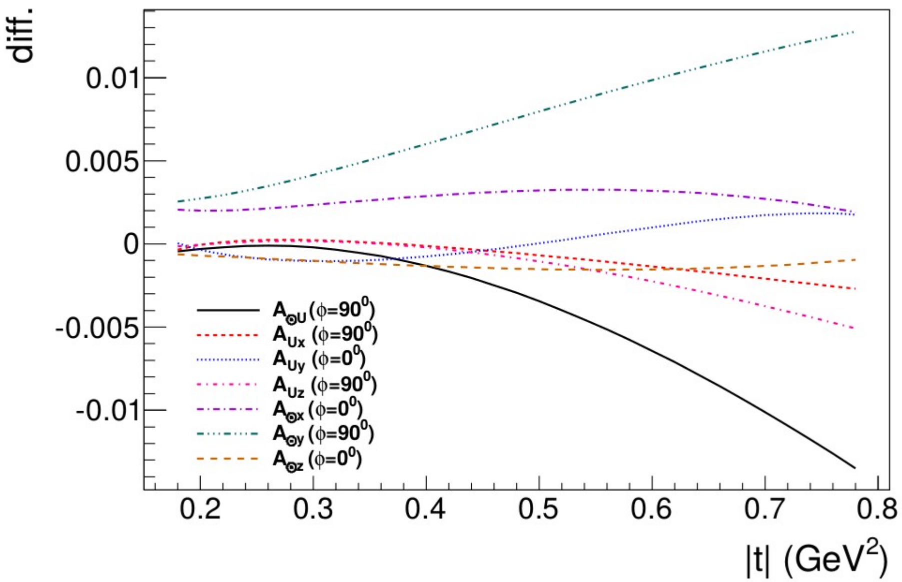
Corrections

mass and Δ=(p-p') in skewness variable:

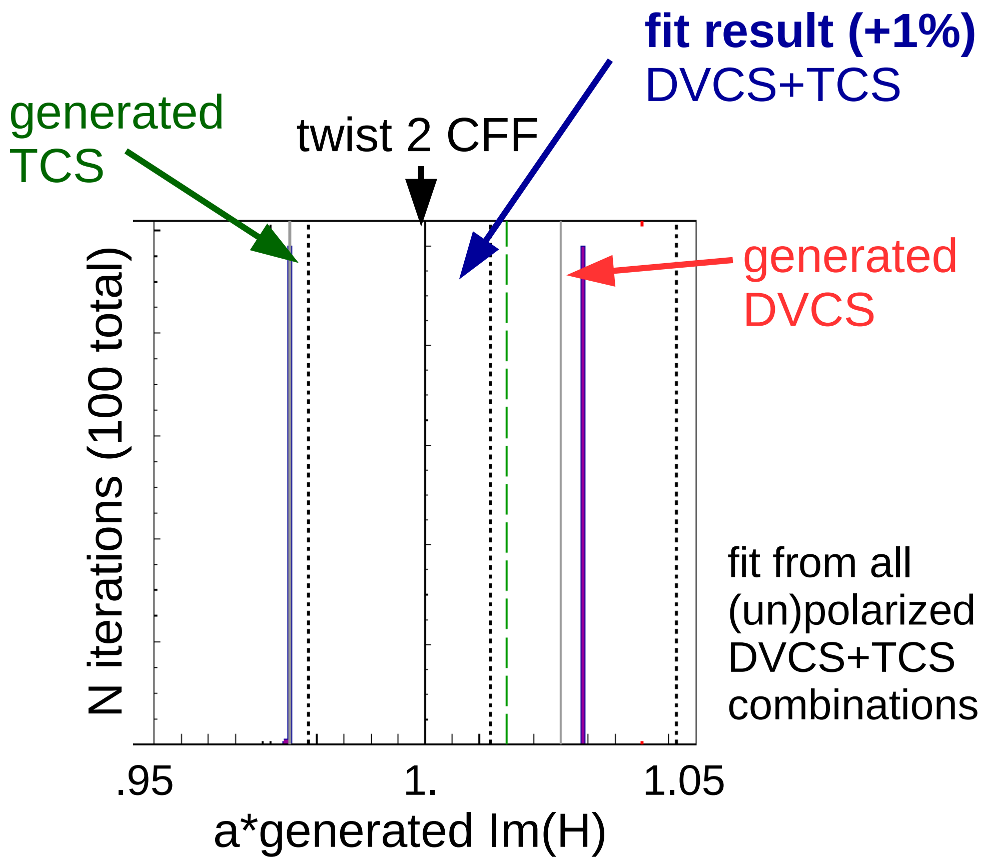
$$\xi' = -\frac{\bar{q}^2}{2P\cdot\bar{q}} = \frac{-Q'^2 + \Delta^2/2}{2(s-m^2)+\Delta^2-Q'^2}$$

$$\xi = -\frac{\Delta\cdot\bar{q}}{2P\cdot\bar{q}} = \frac{Q'^2}{2(s-m^2)+\Delta^2-Q'^2}$$

(corrected - asymptotic) asymmetries



Fit results



fit from all (un)polarized DVCS+TCS combinations

Conclusion from fit results and expected physics

What is expected with experimental measurements:

Depending on size of NLO and higher twist

- small effects: combine DVCS+TCS observables → global fits

- small/moderate effects: independent analysis → constraint on GPD universality

- large effects: observation of higher twist in spacelike (DVCS) vs timelike (TCS)

GPDs universality:
It is possible to independently extract CFFs from TCS and compare with results from DVCS

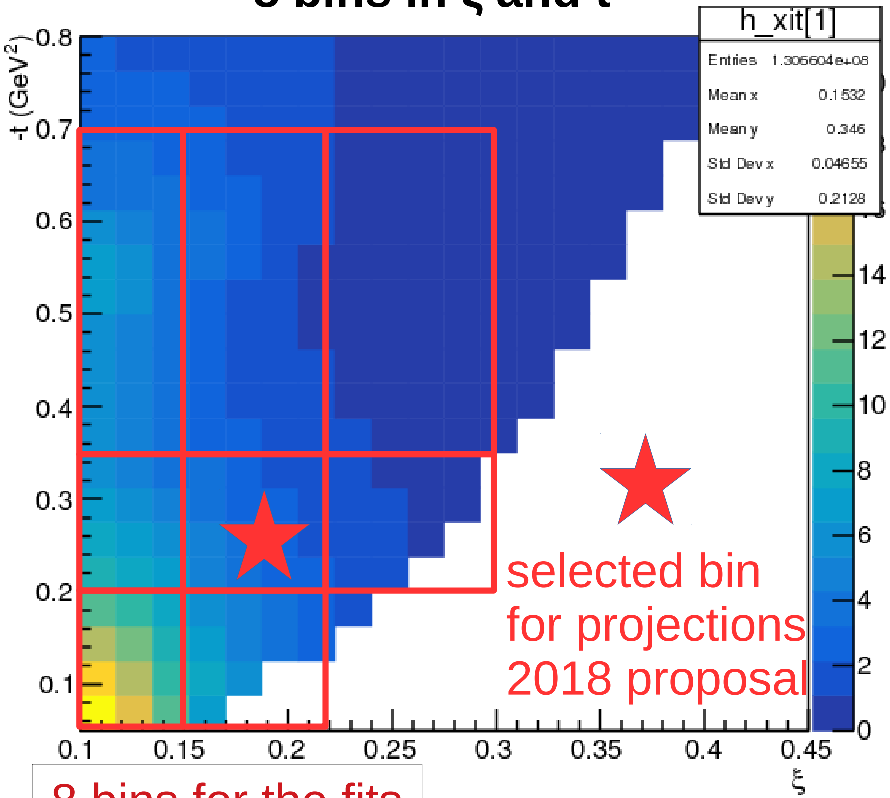
GPD models:
GPD models can be constrained from both DVCS and TCS independently or combining observables

GPD models and E:
TCS can bring constrain on GPD E →poorly constrained from DVCS, link to nucleon spin

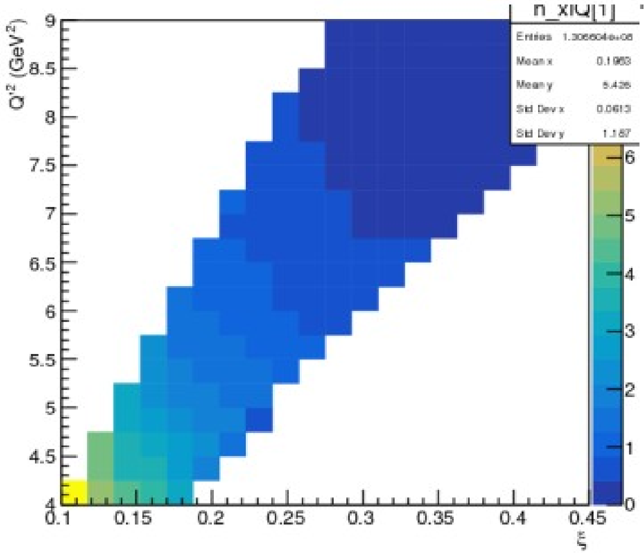
Phase-space choice for GPD studies

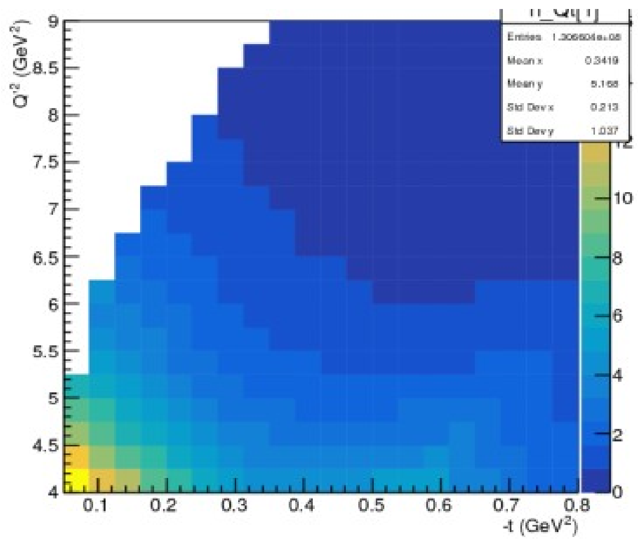
Where can we extract CFFs and GPDs? What is the impact of TCS experiment?

8 bins in ξ and t



8 bins for the fits





Bins in proposal: **8 (Q'², ξ, t), 16 φ bins, 16 φ_S bins, 7.5 <E<11 GeV, kinematic dependent binning in (θ, φ)**

Updates:

- extended phase-space, studies beyond what is in the proposal. Not yet decided what in final version
- Currently: -t up to 2 GeV², 5.5< E <11 GeV
- Next: lower Q'², will also study resonance region
- note: that extensions are not the main of physics case, "best" physics already in 2018 proposal
- note: other experiments (hall B, LHC) extend phase space due to their low statistics, but physics impact limited and lots of assumptions as they have big statistic uncertainties

Physics impact of angular selections

Why angular range in the proposal is drastically limited and we don't show such high statistics as other experiments may suggest (hall B, D): need to cut out BH peaks! no GPD physics there

θ vs φ, leptons CM angles

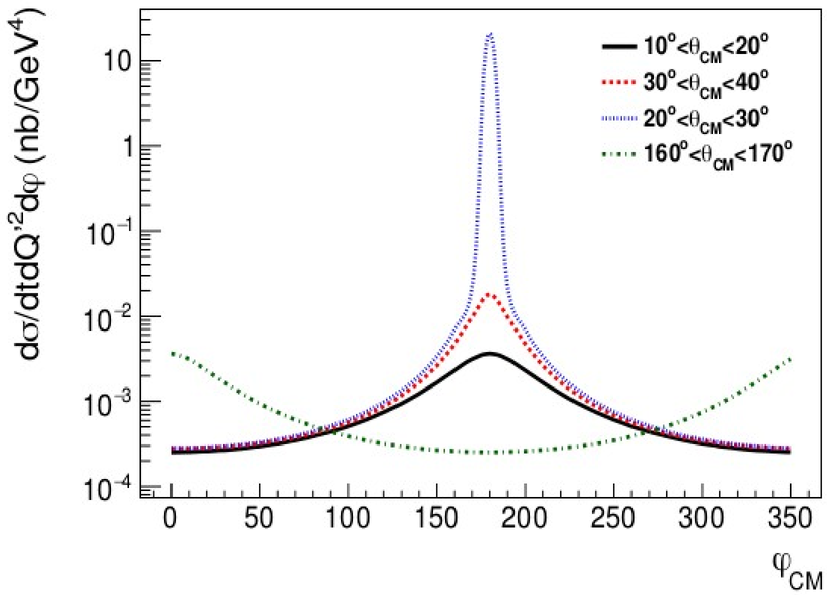
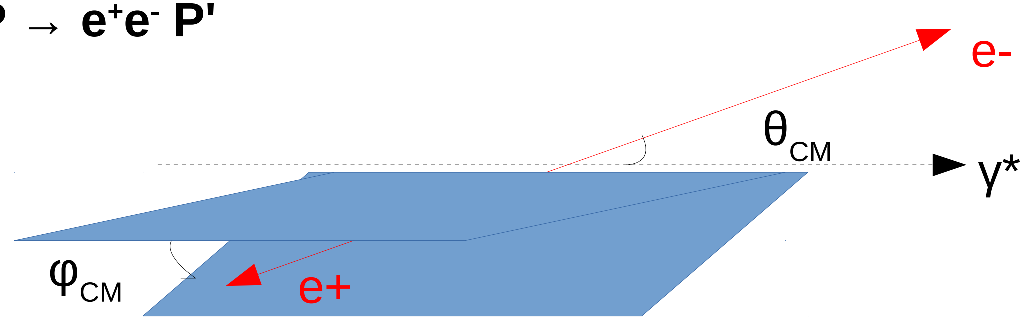


Figure 31: BH cross section as a function of ϕ at Q'^2 = 5 GeV², -t=0.3 GeV², E_γ=9.5 GeV, and integrated over θ_{CM} on various ranges (colored curves).

θ at given kinematics reflects TCS/BH rate

- while TCS angular distributions are smooth, BH presents "near singulariries" ($1/m_e^2$ terms) corresponding to lepton + virtual photon + real photon become "collinear"
- effect to balance with kinematics (γγ* angle)
- reflects experimentally with one lepton taking most of the energy, near beam, and one lepton almost at rest: mostly cut by acceptance, but need to be reduced + interpretations

$\gamma P \rightarrow e^+e^- P'$



-t→0 forward limit:
γ and γ* are collinear, $\Theta_{\gamma\gamma^*} \rightarrow 0$

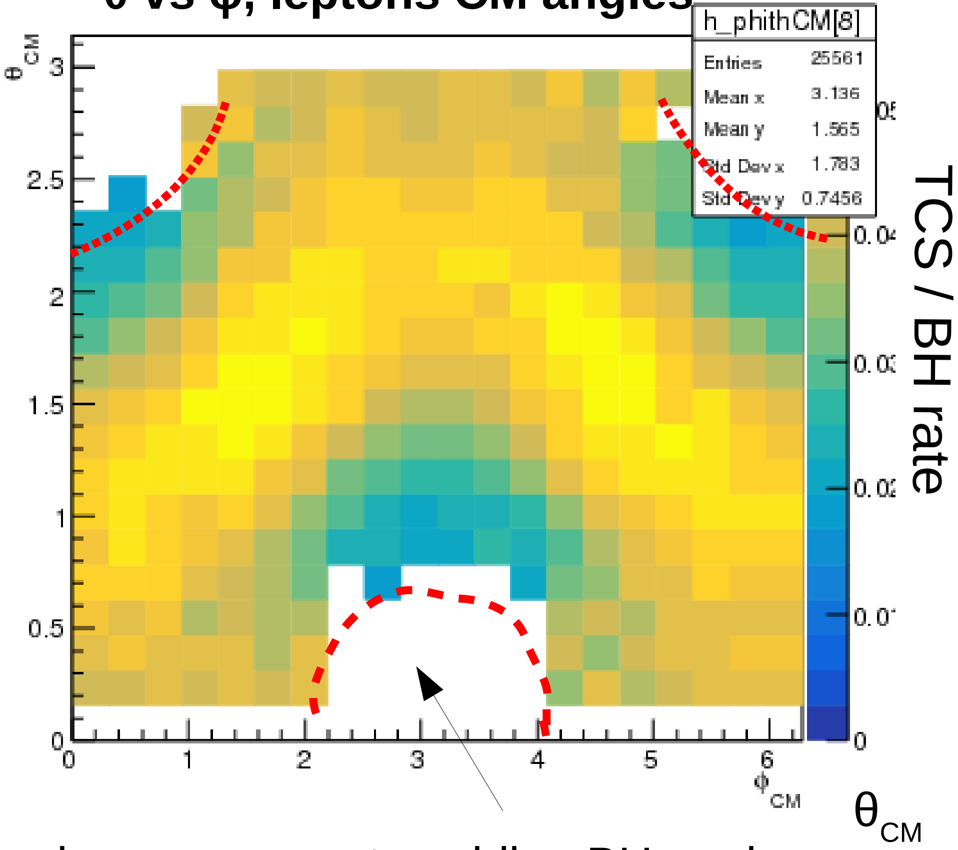
kinematic dependent “near-singularities”:

1) $\theta_{CM} \rightarrow 0$: e⁻ becomes collinear with γ, $\varphi_{CM} \rightarrow \pi$
2) $\theta_{CM} \rightarrow \pi$: e⁺ becomes collinear with γ, $\varphi_{CM} \rightarrow 0$

Physics impact of angular selections

$\gamma P \rightarrow e^+e^- P'$

θ vs φ, leptons CM angles



phase-space cut avoiding BH peaks

kinematic dependent cuts:

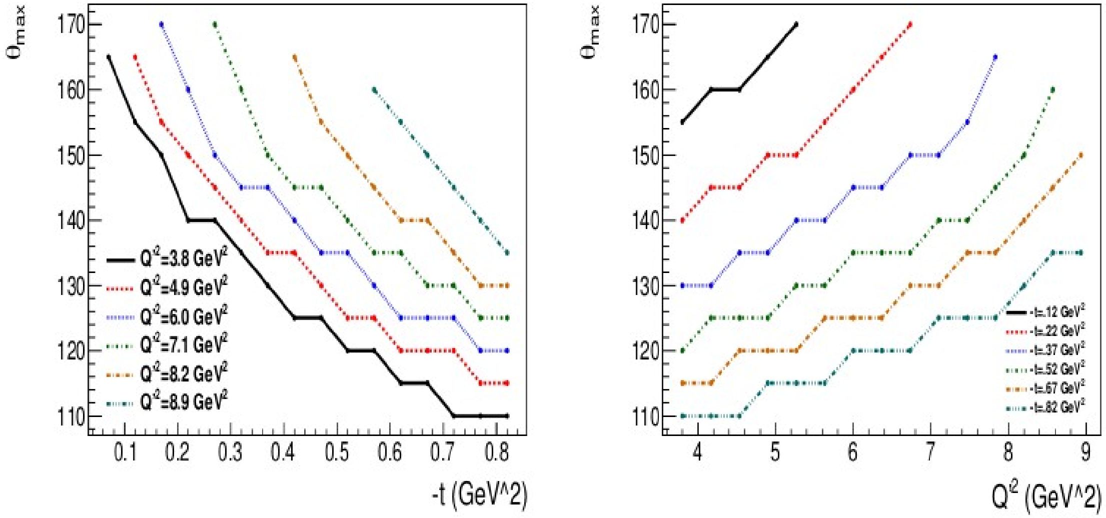


Figure 33: Values of θ_{max} for a fixed beam energy $E_\gamma = 9.5$ GeV, as a function of t for differen values of Q'^2 (left panel) and as a function of Q'^2 for different values of $-t$ (right panel). See tex for details.

Avoiding near beam high energy lepton peaks, not resolvable with limited statistics and bins + not physics we are looking for

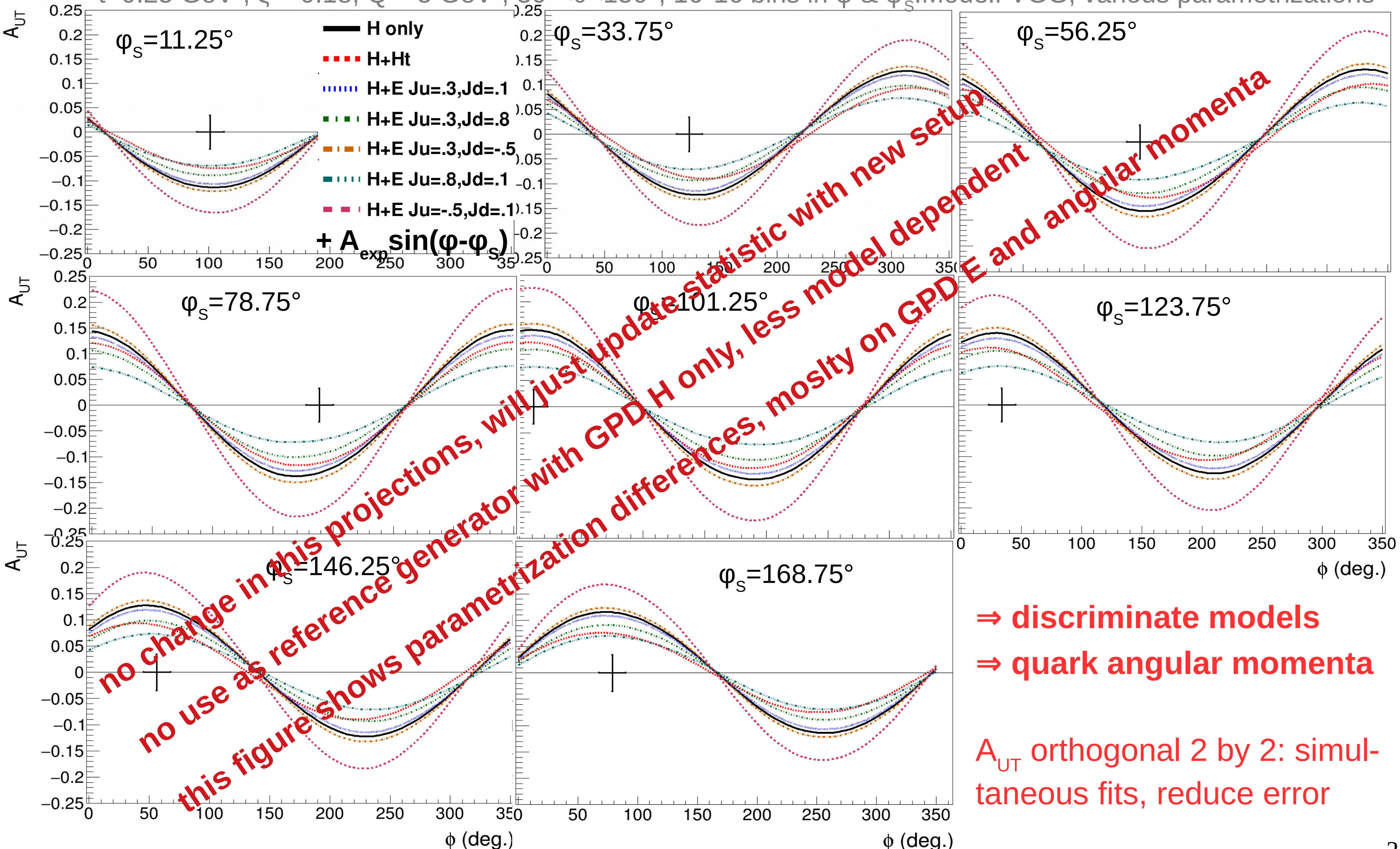
consequence to also increase TCS/BH rate, but statistic being limited, integrals over θ. Projected observables takes that into account. Ideally θ~90°

Remark: extended phase-space and extended measurements + improved statistic from "side bins" in the updated version of the proposal. Angular selection remain the same

A_{UT} versus φ_S: experimental errors and model dependence

Error bars on first moment fit $A*\sin(\varphi-\varphi_S)$ for 8 φ_S bins and one (ξ, t, Q'²) bin versus models

-t=0.25 GeV²; ξ = 0.18, Q'²=5 GeV², 30°<θ<150°, 16*16 bins in φ & φ_S.Model: VGG, various parametrizations



⇒ discriminate models

⇒ quark angular momenta

A_{UT} orthogonal 2 by 2: simultaneous fits, reduce error

- Uncertainties on moment scaled to theory curves, using 43% target dilution, 90% polarization
- Small asymmetries case of "red" scenario using H+H̃ in event generator used for the proposal

Proposal physics case and status

1.2 Brief summary of the science case

The main measurement of our experiment is the transverse target spin asymmetry of the TCS+BH reaction, in addition to the unpolarized cross section and the circularly polarized beam spin asymmetry. For illustration, we display Fig. 4 the expected transverse target spin asymmetry and the statistical uncertainties for a selected bin. The major impacts of the measurements will be:

1. Extraction of the CFF $\Im E$ and parametrization of GPD E. This result will allow for understanding the partition of the nucleon angular momentum among the quarks.

2. Demonstration or proof of violation of GPDs universality by comparative measurement of CFFs extracted from TCS (timelike) and DVCS (spacelike). Fig. 5 shows the precision expected on extracted CFFs from TCS (under some assumptions detailed in the document).

3. Simultaneous fits of CFFs with DVCS and TCS to constrain all CFFs (twist 2) at the same time thanks to new independent observables from TCS, provided the GPD universality is established.

summary in the proposal document

Proposal physics case and status

Theory review

PR12-18-005: *Timelike Compton Scattering off a transversely polarized proton*

T. Rogers, I. Balitsky

The proposed experiment aims at the measurement of various GPDs of the proton using time-like Compton scattering off the transversely polarized target. In particular, the experiment should give us the information about GPD E which is poorly constrained up to now. This GPD together with GPD H determines quark orbital momentum in the proton via Ji's sum rule. The proposed experiment will access the imaginary part of E for the first time. In addition, comparison of GPDs extracted from DVCS and from TCS will give a clear test of the leading-twist approximation at JLab energies since DVCS and TCS amplitudes are complex conjugate at leading order and leading twist (and there is no reason to believe that this property survives at higher twists).

One goal of the measurement is to test the universality of GPDs in TCS as compared with DVCS, using the observation that these processes are related via complex conjugation at $O(\alpha_s)$. One comment is that, since this relation does not hold beyond lowest order, it is important to estimate the error induced by higher order corrections.

Summarizing, the proposed experiment contributes significantly to the GPD program at JLab and, in our opinion, should be pursued.

Proposal physics case and status

PAC review

Summary: The PAC thinks that the physics case of the proposal is strong and nicely complements the extensive program of GPD-related measurements at JLab. However, the goals were not clear, and the proposal should better identify these goals, and at the same time put the experiment in a broader context of other DVCS and TCS measurements. This is necessary in order to estimate more reliably the impact on GPD extractions. An updated proposal should provide a thorough description and simulation of the event selection, including an estimate of the effect from other final states that survive the selection criteria due to the finite energy resolution. The technical questions from the TAC report also need to be addressed.

SUMMARY

Status of physics case:

- Motivations need to be better addressed for the PAC
- Need of demonstration for some statements in the proposal (higher twist...)
- Would benefit from more theory support: input in physics case, new peer-reviewed publications

To do list (only physics case)

- Write it better and involve theorists
- Perspective TCS vs DVCS and other past/future measurements at JLab and worldwide
  - few DVCS projections
  - updating fits with actual DVCS uncertainties, discuss DVCS in proposal
  - more TCS projections and what can really be achieved from full program
- Higher twist impact
  - including higher twist and NLO in fits: some higher twist included, need to be "presentable"
  - theory publications on higher twist
- Strengthen case with publications on fits, calculations, methods
- 2D observables rather than 1D "as HERMES", including fitting maps

Documentation about this talk:

- Hall C note #999 (2019): M.B., Fits of TCS+DVCS caveat: some changes in model since, updated
https://hallcweb.jlab.org/DocDB/0009/000999/001/Note_CFFcombinedfits.pdf (public)
- Hall C note #1000 (2019): M.B., DEEPGen event generator for TCS (and other reactions)
https://hallcweb.jlab.org/DocDB/0010/001000/001/DEEPGenframeworkNote.pdf (public)
- TCS calculations from article: Boër, Guidal, Vanderhaeghen, EPJA 51, no. 8, 103 (2015)
- DVCS calculations and VGG model: Vanderhaegen, Guidal, Guichon PRL 80 (1998) 5064-5067

(+ more articles)