Generalized Parton Distributions studies with Timelike Compton Scattering

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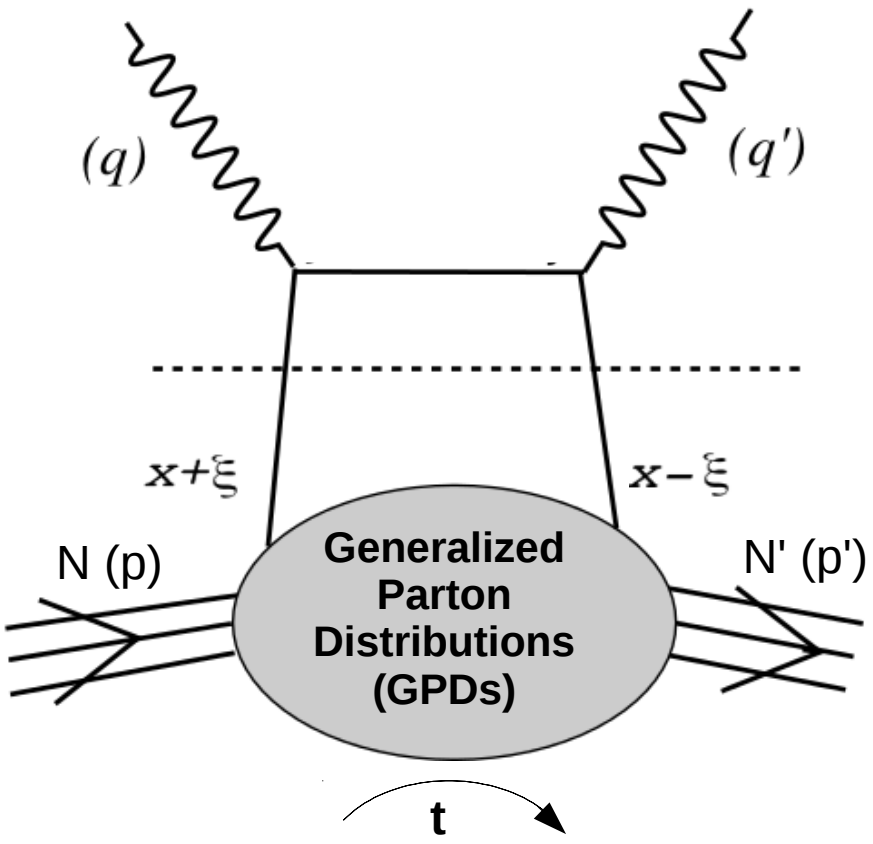
Spacelike and Timelike Deeply Virtual Compton Scattering



2 particular cases of Deeply Virtual Compton Scattering:

Deeply Virtual Compton Scattering (DVCS)

e P → γ* (q) P' → e' P' γ

$q^2 < 0$ and $q'^2 = 0$

Timelike Compton Scattering (TCS)

γ P → γ* (q') P' → e^+e^- P'

$q^2 = 0$ and $q'^2 > 0$

⇒ complex conjugate at LO, twist 2

⇒ complementary studies, accessing the same Compton Form Factors

This talk:

I. Extraction of CFFs from DVCS and TCS

II. What to expect from TCS experiments at JLab

Compton Form Factors and GPDs from DVCS and TCS

DVCS amplitude decomposition into Compton Form Factors (TCS similar):

ξ, t = measurable
x = integrals

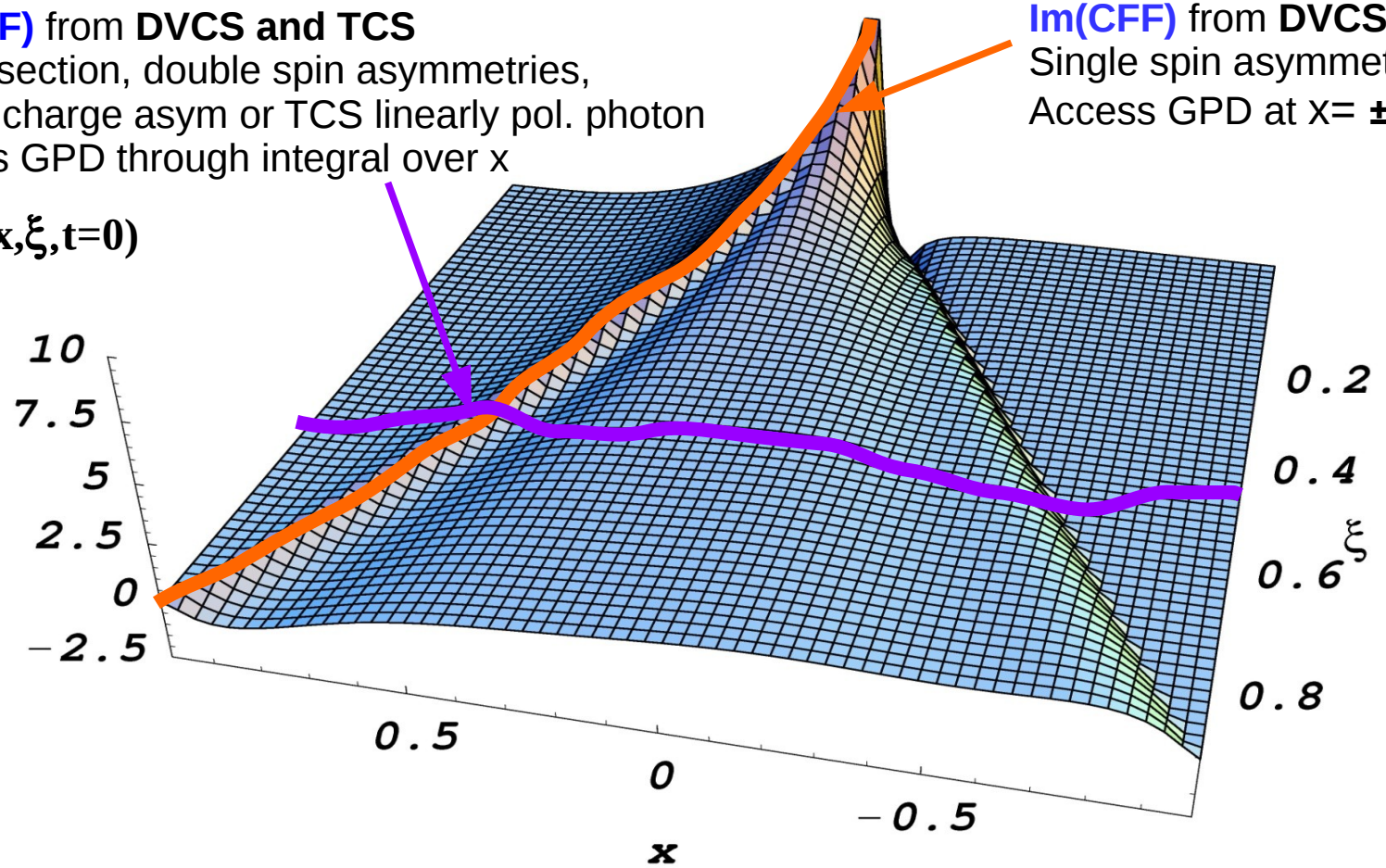
$$T^{DVCS} \sim \int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi + i\varepsilon} dx + \ldots \sim \underbrace{P\int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi} dx}_{\mathrm{Re}(\mathcal{H})} \underbrace{- i\pi H(\pm\xi,\xi,t)}_{\mathrm{Im}(\mathcal{H})} + \ldots$$

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)



CFF extraction from DVCS and TCS

Comparison of sensitivities to CFFs from DVCS and TCS
Method for what is presented in this talk:

- 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)
- cf original method from M. Guidal with DVCS

- Here, the work is done with pseudo-data, having "ideal" constant uncertainties/bin and cross sections are computed at twist 2, LO (VGG model)

- Kinematics and errors are possible scenarii for JLab

What is expected with experimental measurements:

Depending on size of NLO and higher twist

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

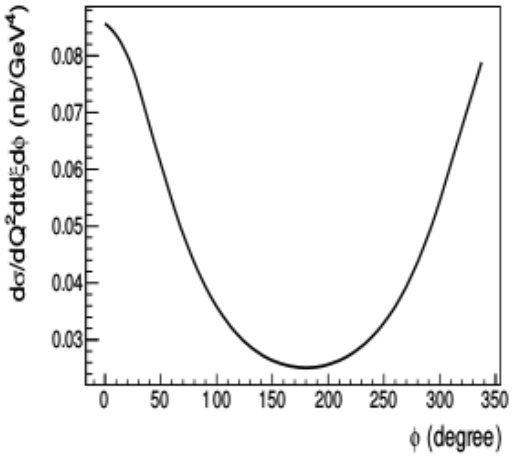
- small/moderate effects: independent analysis → constraint on GPD universality

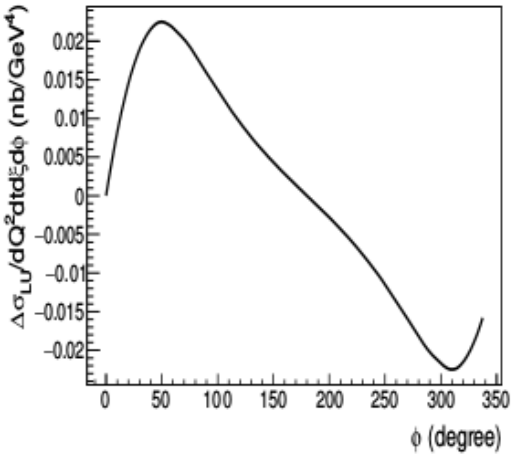
- large effects: observation of higher twist in spacelike (DVCS) vs timelike (TCS)

Generated distributions

DVCS

unpolarized cross section polarized beam: $\Delta\sigma_{LU}$





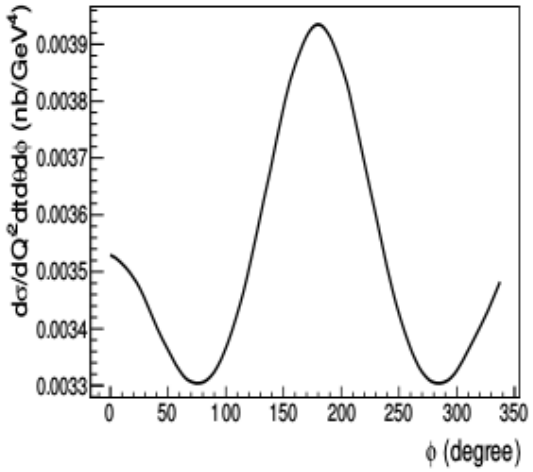
+ 7 more distributions of polarized cross section differences:

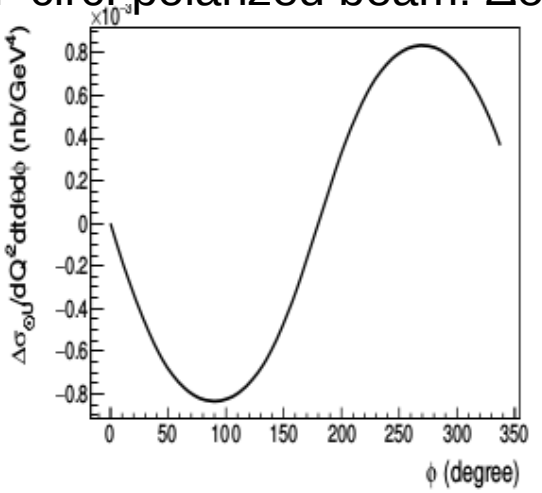
// pol target: $\Delta\sigma_{UL}$
$\perp$ pol target: $\Delta\sigma_{UX}$ (φ_S=0°), $\Delta\sigma_{UY}$ (φ_S=90°)
double pol beam+ target: $\Delta\sigma_{LX}$, $\Delta\sigma_{LY}$, $\Delta\sigma_{LL}$
beam charge: $\Delta\sigma_C$

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: $\Delta\sigma_{UL}$
$\perp$ 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) $\sigma, \Delta\sigma_{LU}$	A, B, C	A, B, C	A, B, C	2/2/2
2) $\sigma, \Delta\sigma_{LU}, \Delta\sigma_{UL}, \Delta\sigma_{LL}$	B	-	-	4/4/4
3) $\sigma, \Delta\sigma_{LU}, \Delta\sigma_{UT}$ (x2)	-	C	-	4/4/4
4) $\sigma, \Delta\sigma_{LU}, \Delta\sigma_{UT}$ (x2) $\Delta\sigma_{UL}, \Delta\sigma_{LL}$	-	-	-	6/6/6
5) $\sigma, \Delta\sigma_{LU}, \Delta\sigma_{UT}$ (x2) $\Delta\sigma_{UL}, \Delta\sigma_{LL}, \Delta\sigma_{LT}$ (x2)	-	-	-	8/8/8
6) $\sigma, \Delta\sigma_{LU}, \Delta\sigma_{C}$	-	x	x	3 (DVCS)
6′) $\sigma, \Delta\sigma_{\odot U}, \Delta\sigma_{LU}$	x	D	x	3 (TCS)
6″) 2) of DVCS + 3) of TCS	x	x	B+C	6 (DVCS+TCS)

independently

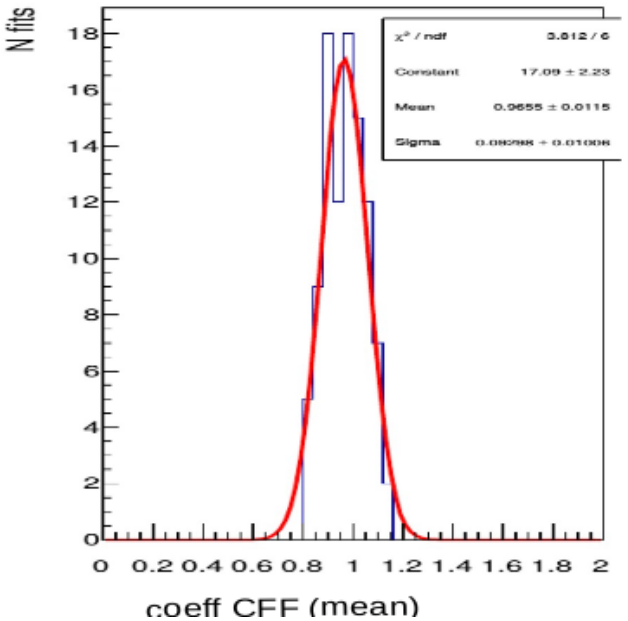
combined

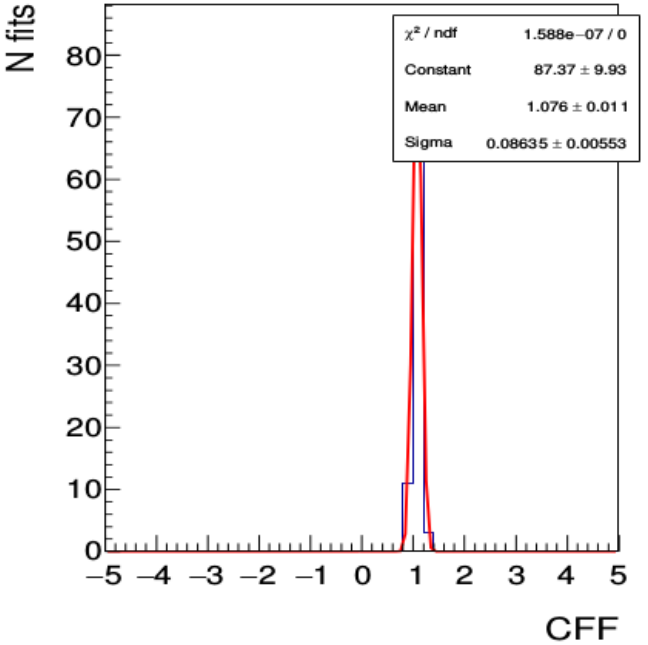
- DVCS experiments: approved or taking data, (not topic of this talk - other measurement possibles in medium to long term, other experiments as well)

- TCS experiments 'A', 'B' are approved, 'C' is conditionnaly approved, 'D' assume future data. 'B' started analysis, however, low statistics

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





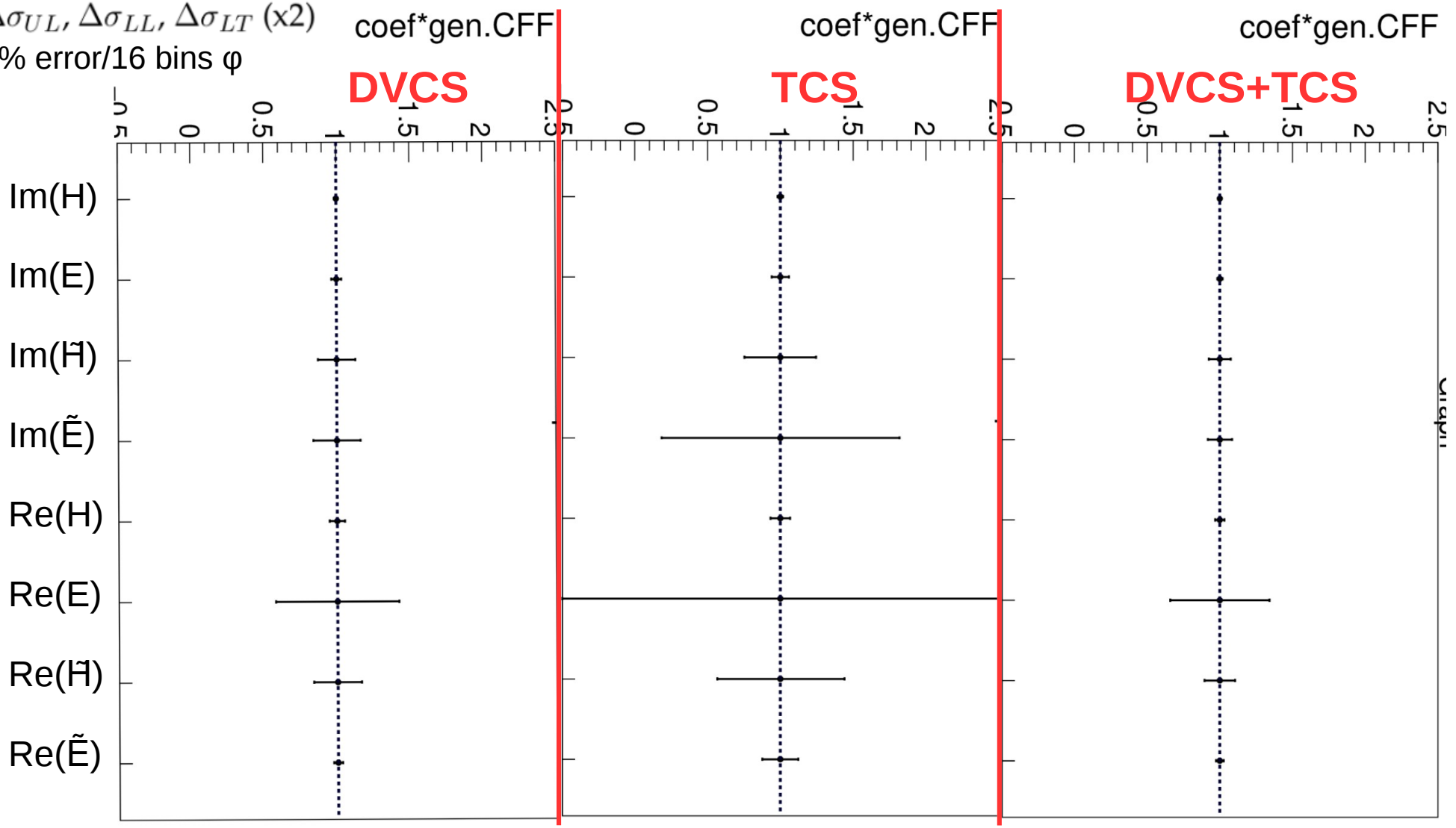
Im(Ħ) mean value extracted positive error from MINOS

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

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

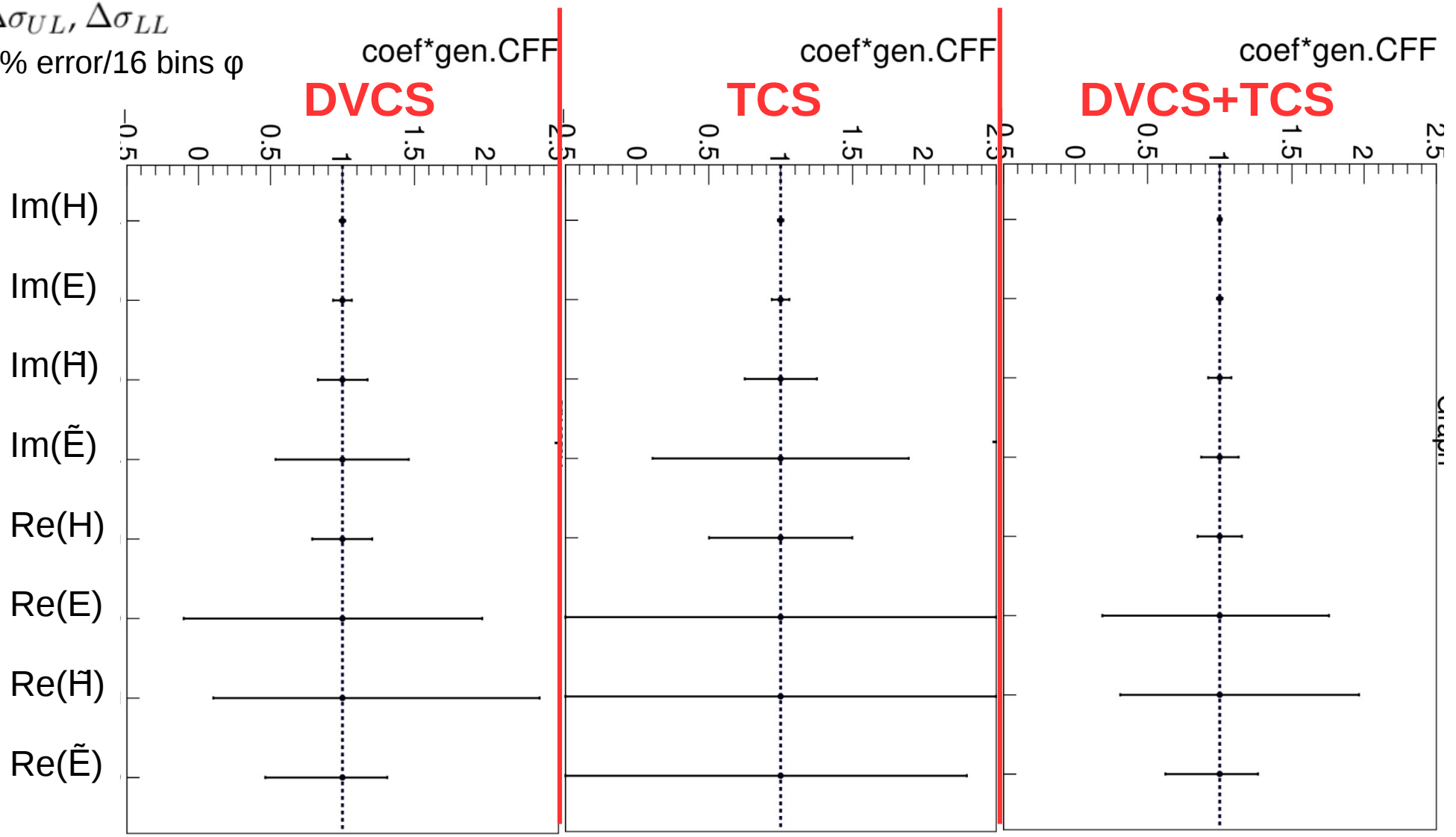


- **All CFFs extracted from DVCS and TCS, errors of same order** ⇒ comparison, universality
- Lower errors with DVCS vs TCS: TCS/BH < DVCS/BH. "real": higher statistics with DVCS
- DVCS+TCS: "real" scenario expect shift to direction of DVCS solution if shift to opposite directions from higher twists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



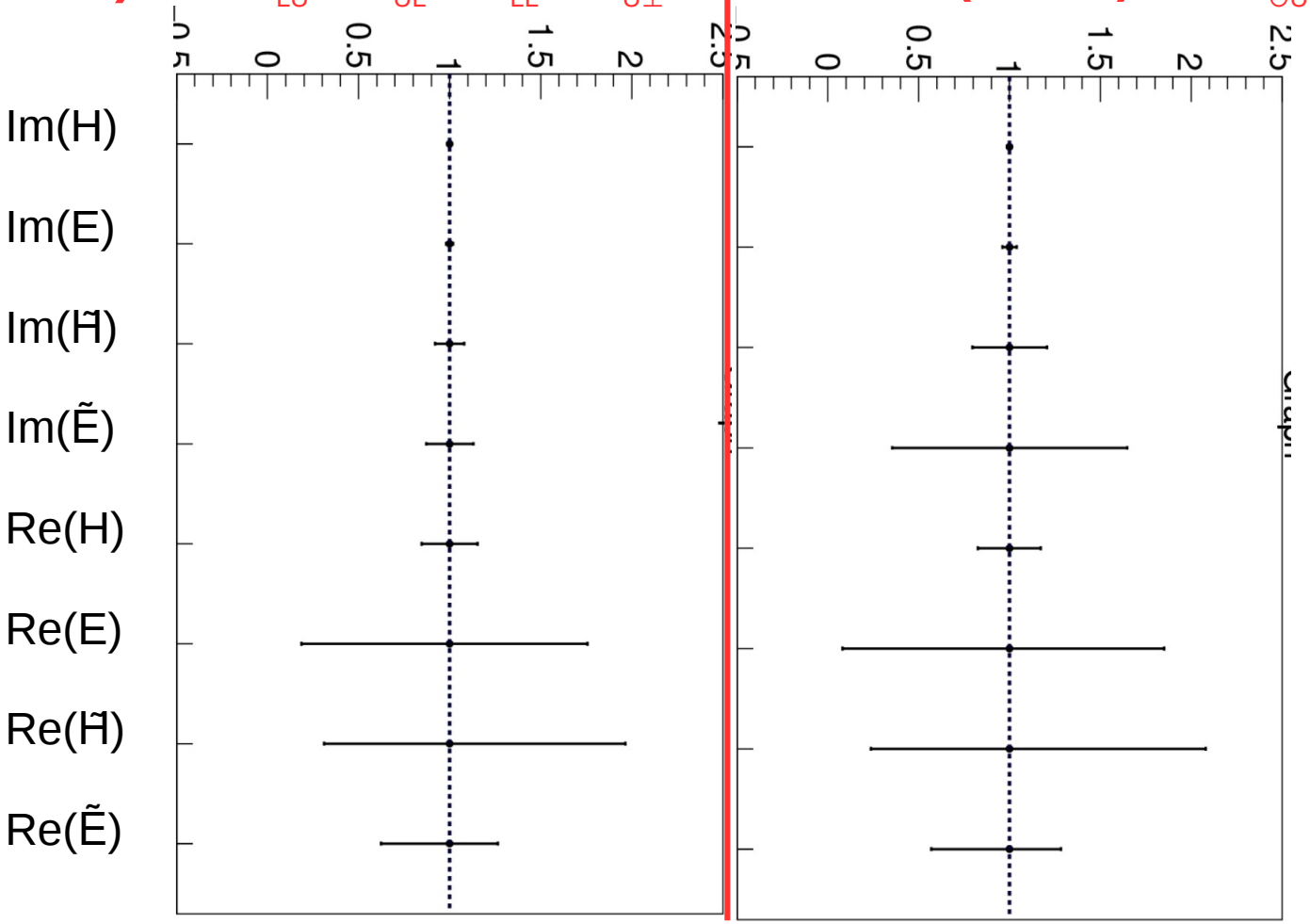
More realistic scenario: hard to measure $\Delta\sigma_{LT}$, large errors expected

- 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.): $\sigma, \Delta\sigma_{LU}, \Delta\sigma_{UL}, \Delta\sigma_{LL}, \Delta\sigma_{U\perp}$

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



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

Discussion: interpretation of extracted results and open questions

• 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
⇒ only 1 configuration in an experiment, unlike pseudo-data that allow for iterations:
CFF result can be anywhere between the limits
→ limits more relevant than the "mean" value extracted?

• Model dependence: Approximations with any method and models. Here assume twist 2 and LO, in principle free of other bias if solution not too far to model parametrization.
Model dependence bias could come from correlations otherwise
how and could all results be affected if one CFF is wrongly parametrized, but still kept as a free parameter of the problem?
→depend method: shift of the results, large uncertainties...

• Avoiding wrong solutions if several options to minimize the problem: taking advantage of correlation between CFF. Method: extracting all 8 at same time, and iterations varying other parameters such as size of parameter space→wrong solutions are unstable, good are stable
ideal exercise with simulations, valid with real data. **Could correlations with higher twist GPDs bias these results?**

• Combining DVCS+TCS (and any other reaction): **need real data to evaluate effect!**

These remarks and questions are based on results of this work, but same questions will come with other fitting methods!

II. Upcoming TCS measurements at JLab

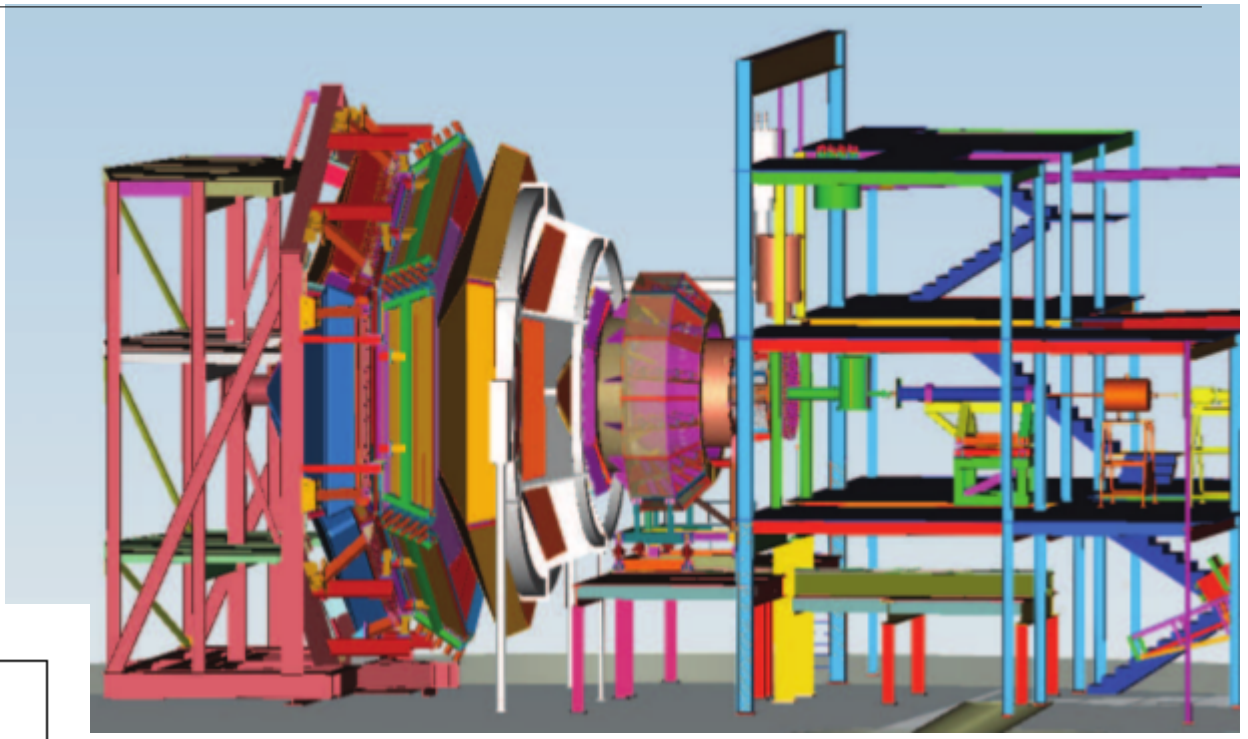
CLAS 12 TCS experiment: unpolarized cross section E12-12-001

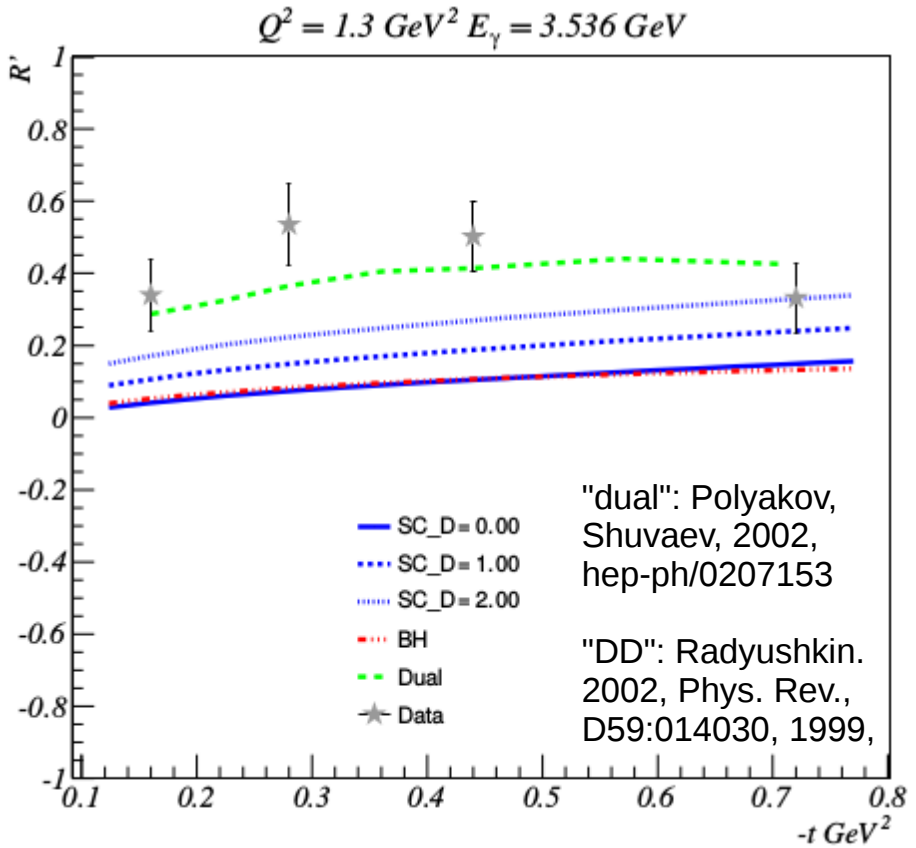
- data on tape, analysis ongoing:
cross section → Im and Re (H)

- first measurement of TCS after exploratory work with CLAS in 2012 at 6 GeV

- from electron beam

Fig: R. Paremuzyan PhD thesis





"dual": Polyakov, Shuvaev, 2002, hep-ph/0207153

"DD": Radyushkin. 2002, Phys. Rev., D59:014030, 1999,

left: exploratory measurement at 6 GeV + models for R (R' = "experimental" R, with sum over bins)

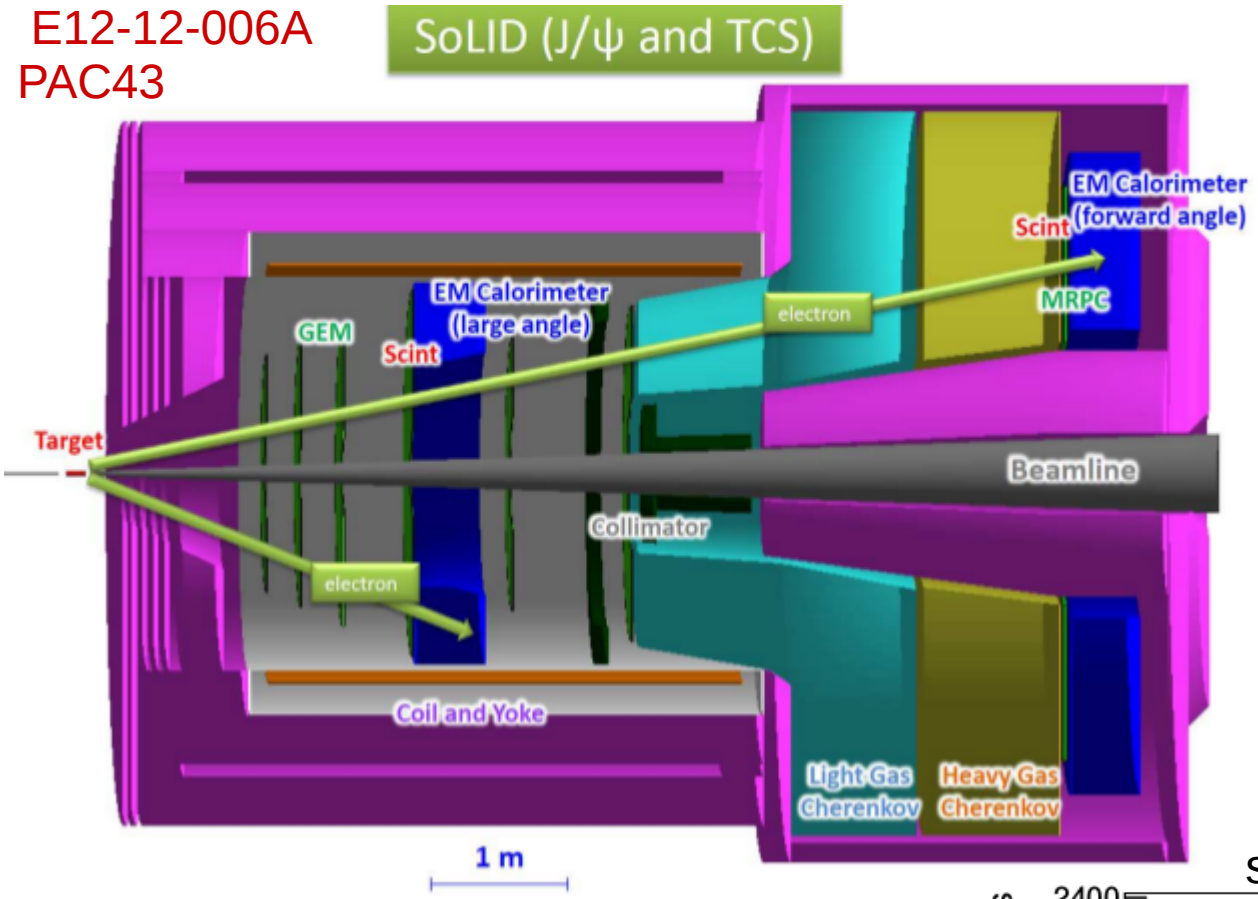
- theory curve for different GPD / D-term models

- could discriminate between "dual" and "double distristribution" type models

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

TCS with SoLID: cross section and BSA with high luminosity

E12-12-006A
PAC43

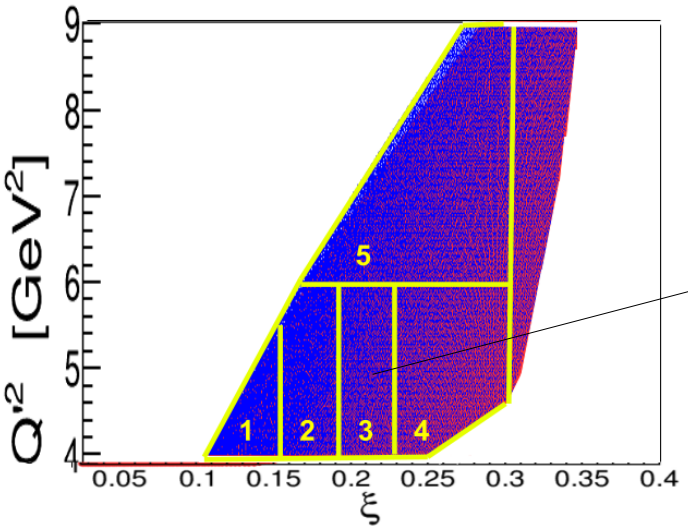


SoLID setup for J/ψ approved exp.
50 days at flux 10^37 $cm^{-2}s^{-1}$
LH2 unpolarized target

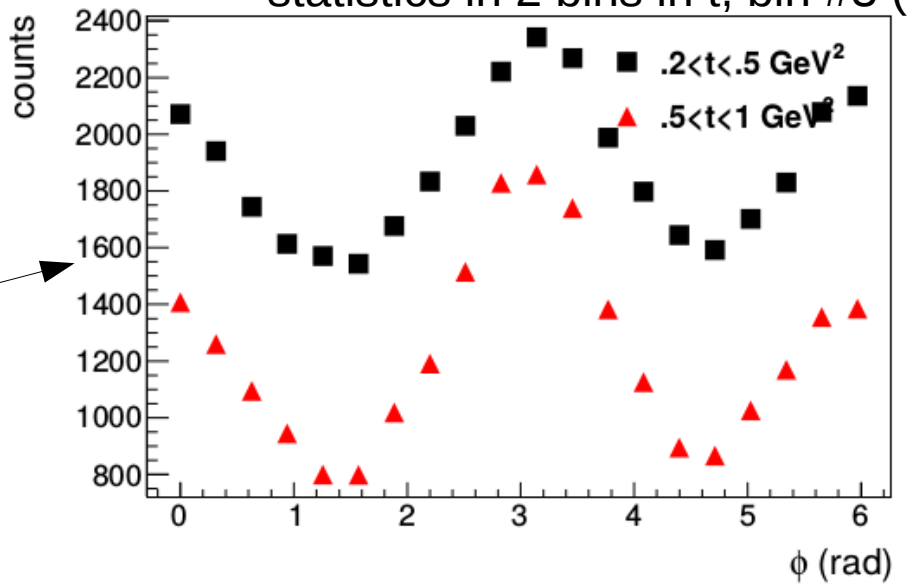
x-sec and BSA with high statistic
→ binning in Q'^2: evolution...
→ studies of GPD universality by comparing H extracted from TCS and DVCS

- from electron beam

statistics in 2 bins in t, bin #3 (Q'^2, ξ)



bin 3



Hall C experiment with a transversely polarized target

Conditionnaly approved, E-12-18-005, PAC 46, 2018

- GPDs universality and higher twist effects,

high level precision to compare with DVCS

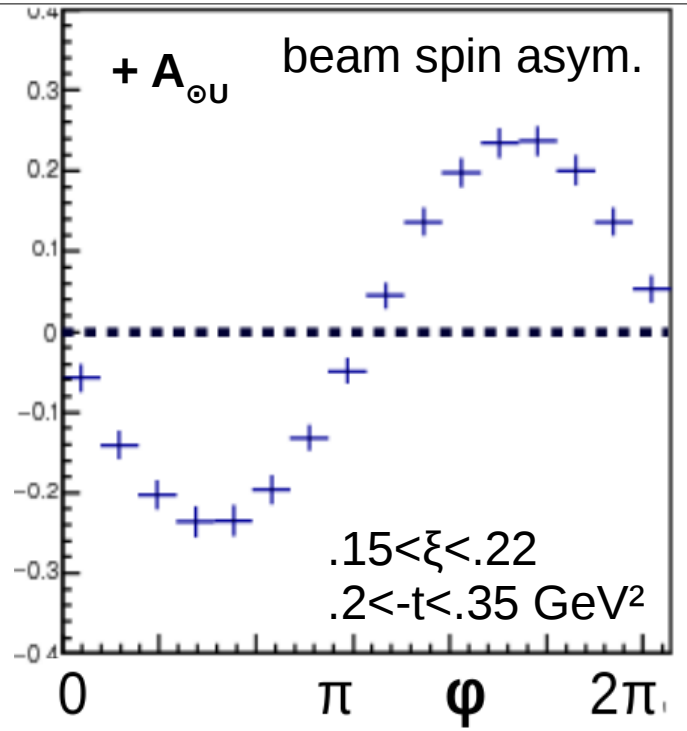
- Im(E) and angular momenta

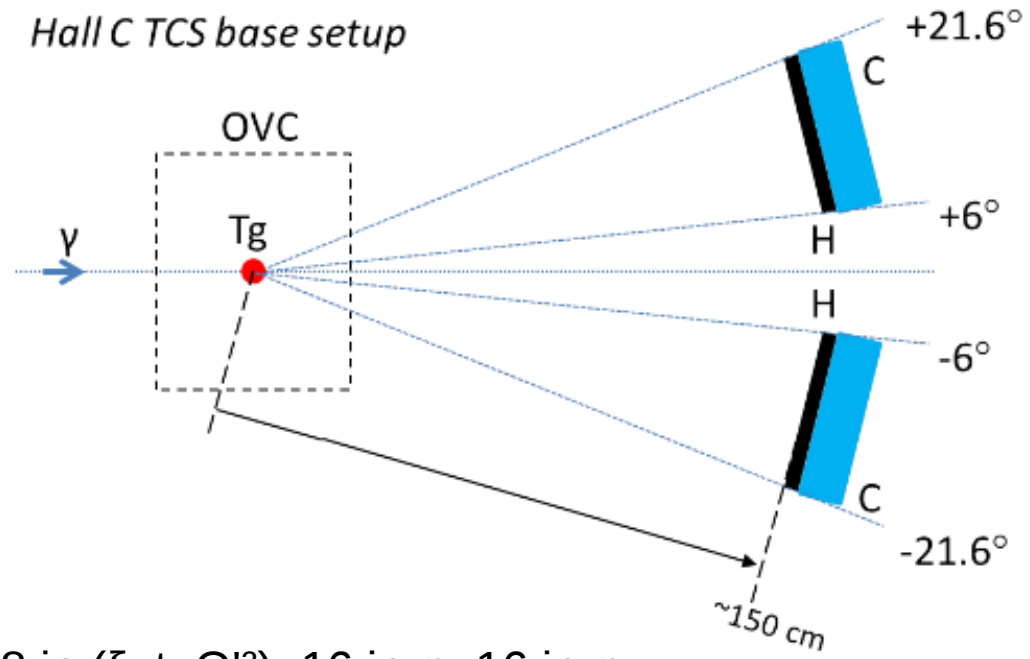
- complementarity DVCS in twist 2 global fit approach

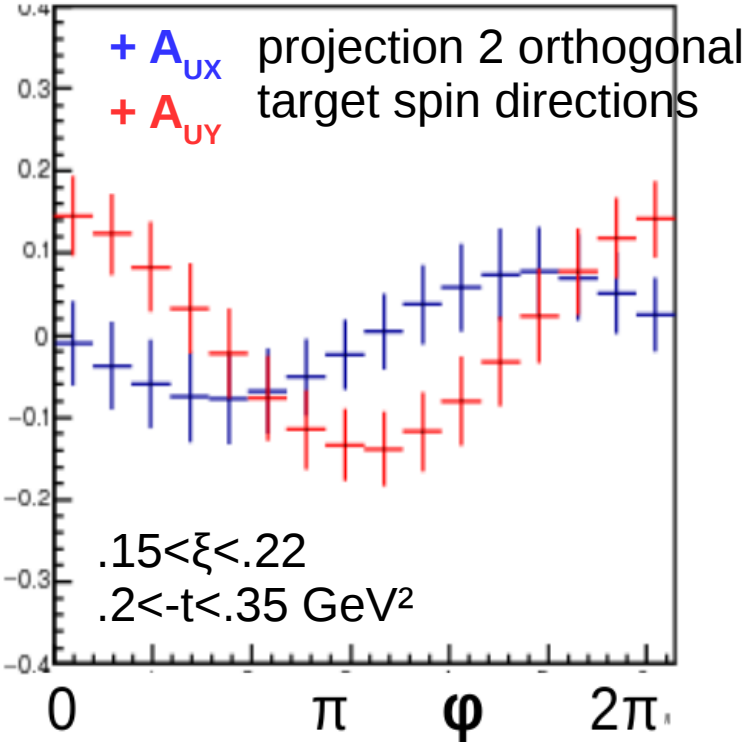
Main advantages:

- transversely polarized target NH_3
- real photon beam, circularly polarized
- high luminosity, ~6e5 pb^{-1} in 35 days
- access 4 independent observables

* Fig. uncertainties statistics + dilution





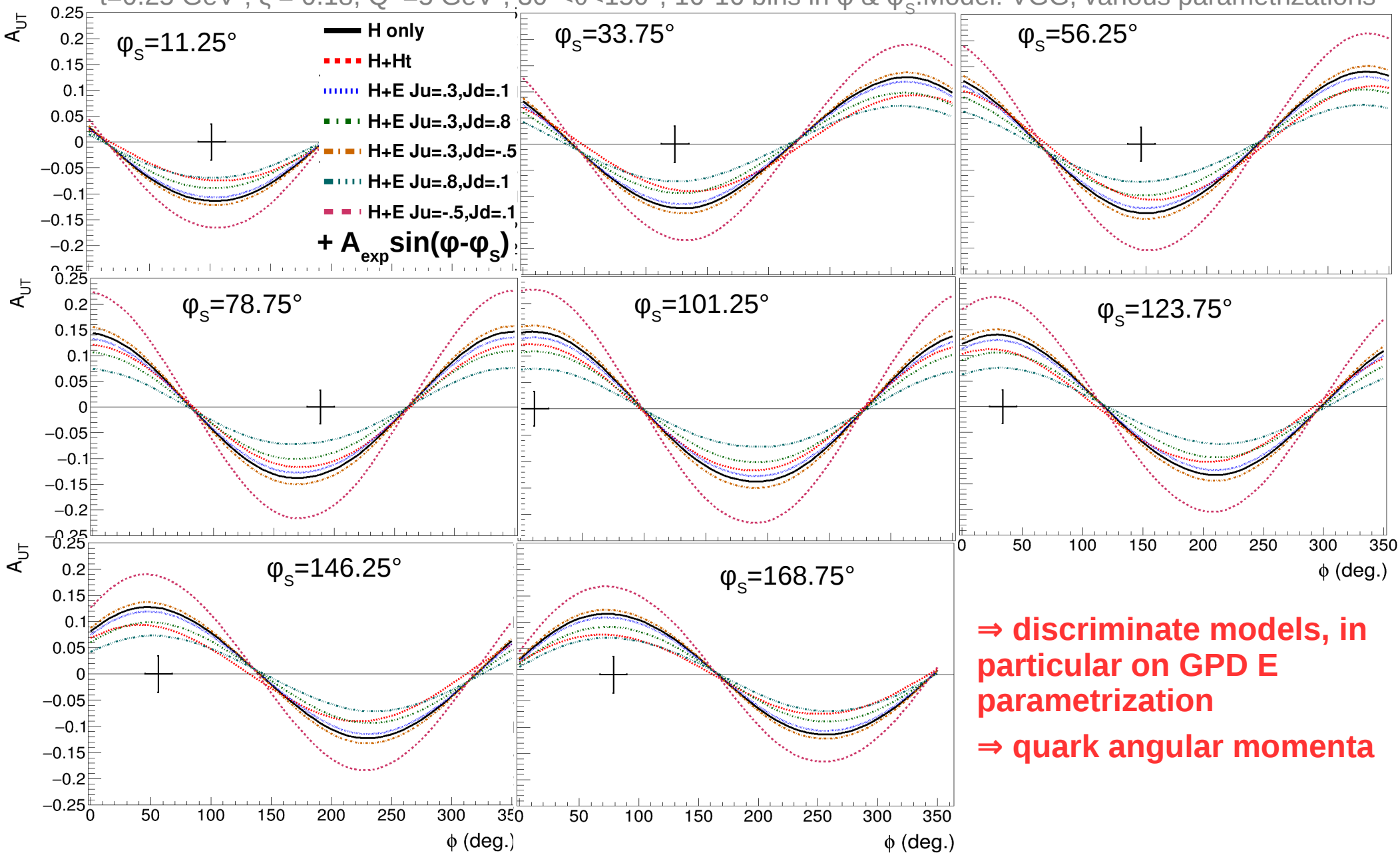


Bins: 8 in (ξ, t, Q'²), 16 in φ, 16 in φ_S

A_{UT} vs φ_s in Hall C experiment: strong sensitivity to model & angular momentum

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, in particular on GPD E parametrization

⇒ quark angular momenta

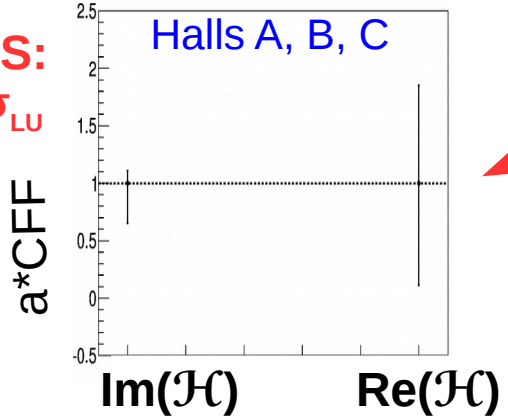
projection of 1 kinematic bin vs angles from 2018 proposal

Compton Form Factors from DVCS and TCS: access at JLab

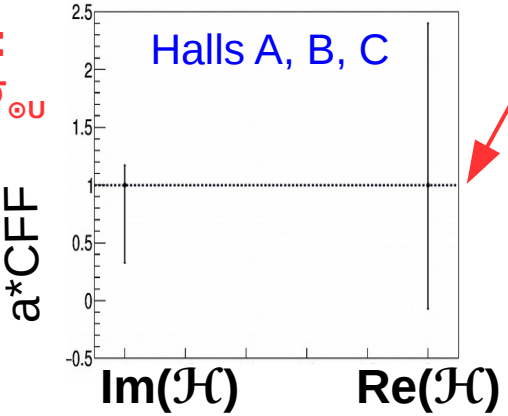
Extracted CFF uncertainties for DVCS, TCS, various sets of observables

Slide for PAC46 2018 summarizing possibilities for CFF extraction with future TCS experiments

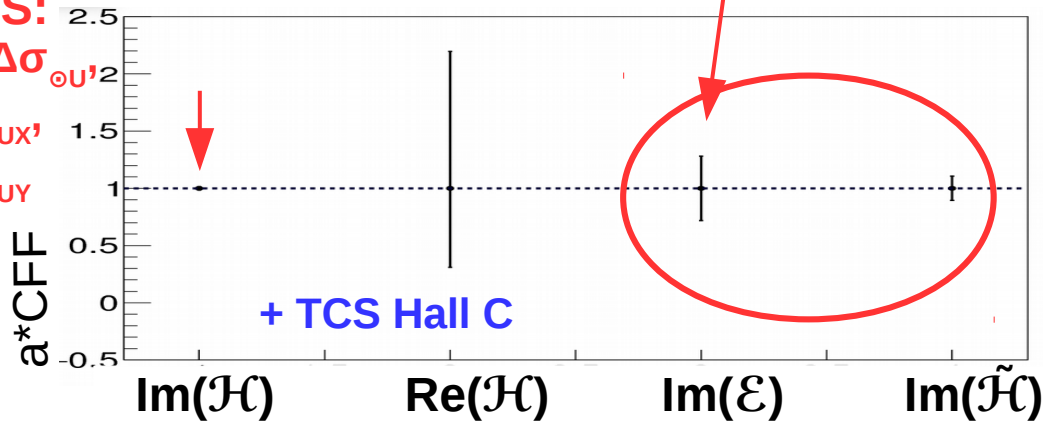
DVCS:
σ, $\Delta\sigma_{LU}$



TCS:
σ, $\Delta\sigma_{\odot U}$



TCS:
σ, $\Delta\sigma_{\odot U}$, $\Delta\sigma_{UX}$, $\Delta\sigma_{UY}$



CFFs from TCS at same level than DVCS

Im($\mathcal{E}$) extracted thanks to transverse target

Interpretation of extracted CFFs:

- global fits → if small higher twist
- GPD universality → if small/medium higher twist
- observation of higher twist spacelike/timelike

• Higher twists: opposite direction in DVCS vs TCS % level effect on Im part, ~10% on Re part of extracted CFFs → lower than CFF uncertainties

Fits of CFFs from DVCS and TCS obs., same (ξ=.1, -t=.2GeV²), leading twist/order
CFFs = functions of GPDs, H → Im($\mathcal{H}$), Re($\mathcal{H}$)
Pseudo-data: 5% error (unpol) or 7% (pol) /16 φ bins, generated a*CFF=1, VGG model with 7 free param.
errors: typical exp scenario without acceptance in φ

SUMMARY

- **Studies of GPD universality from timelike vs spacelike similar processes**

- **Evaluation of higher twist and NLO contributions by comparison TCS vs DVCS**

- **Fits: access same GPDs, combination DVCS+TCS in a multi-observables approach**

- **Important in this approach: having many independent DVCS and TCS observables**

- **Several short term DVCS + medium term TCS measurements at JLab, complementary in different halls. Possible TCS measurements:**
  - **TCS at "low" energy: JLab. ongoing projects, possibility for new dedicated exp.**
  - **TCS at "high" energy: LHC with UPC in pA, EIC from bremsstrahlung in eP and eA**

    → more important NLO contribution in DVCS and TCS than fix target kinematics, different structure in the 2 reactions

    → depending luminosity, but likely measurable, with various polarizations

Open questions for the discussion:

- Improving extraction of CFFs: different methods, evaluation of systematics...

- Future TCS experiments: relevant observables, experimental challenge

* the question was slide #12! Find the GPDs hidden in this picture!