INSTITUT DE PHYSIQUE NUCLÉAIRE
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DIS 2015

XXIII International Workshop on Deep-Inelastic Scattering and Related Subjects

Dallas, Texas
April 27 – May 1, 2015

Timelike Compton Scattering off the nucleon: polarization observables and experimental perspectives for JLab @ 12 GeV

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April 29, 2015

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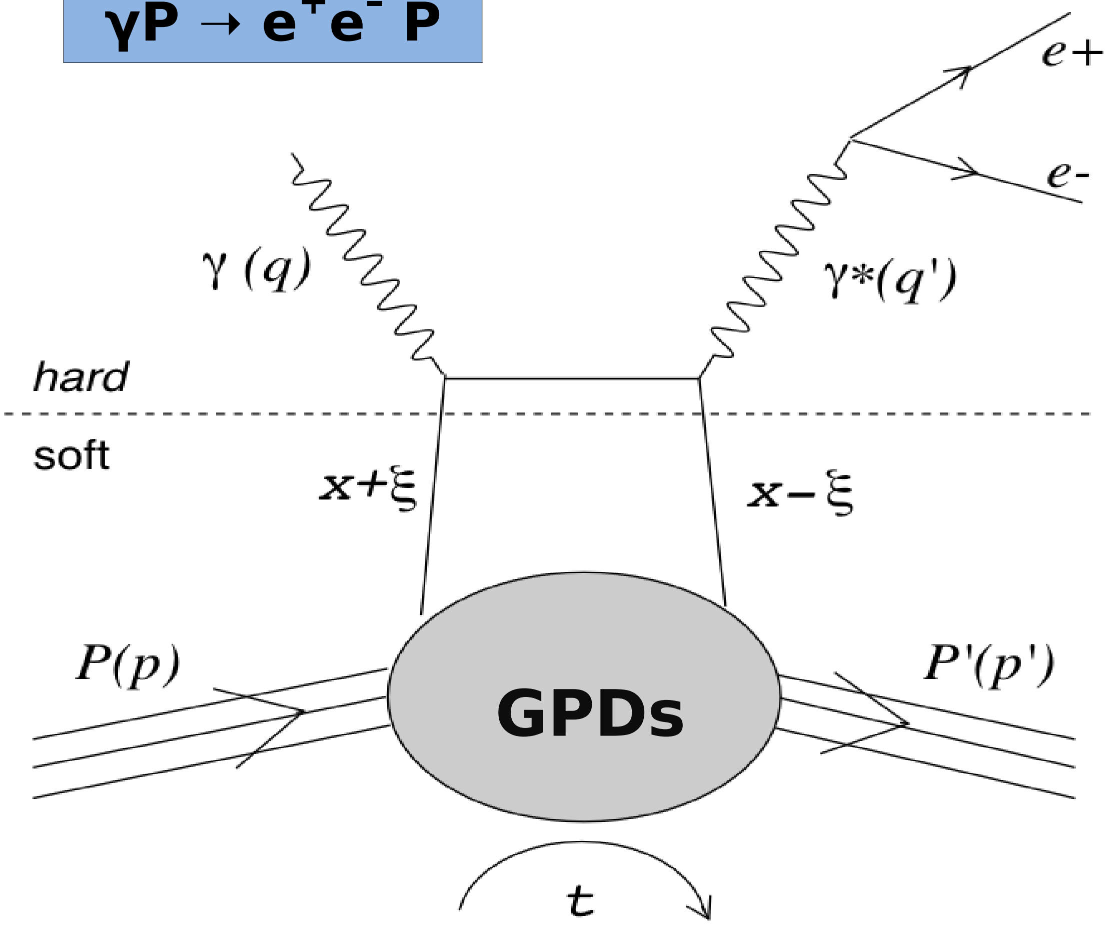
Timelike Compton Scattering

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



x: average longitudinal momentum fraction of the struck quark

ξ: longitudinal momentum transfer

$Q'^2 >> 1$ GeV^2
hard scale

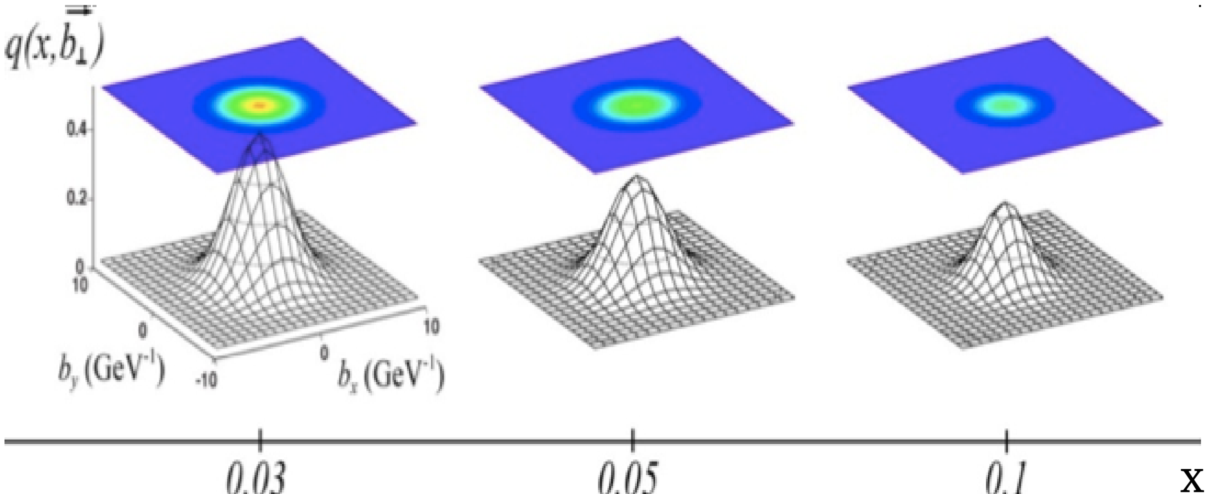
$t << Q'^2$
momentum transfer

Exclusive process: measurement of t and ξ

Soft part: Generalized Partons Distributions → GPD(x , ξ , t ; Q'^2)

Generalized Parton Distributions (GPDs)

Correlation between longitudinal momentum fraction x and transverse charge densities



gluons, sea quarks

valence quarks

Nucleon tomography : $H(x,b_\perp)$

$= \text{FT of } H\ (x,\ \xi=0,\ |t|=\Delta_\perp^2)$

Different GPDs : quark and nucleon helicities

→

unpolarized nucleon (H, E),

polarized nucleon ($\tilde{H}$, $\tilde{E}$),

nucleon helicity flip (E, $\tilde{E}$)

Parton Distribution

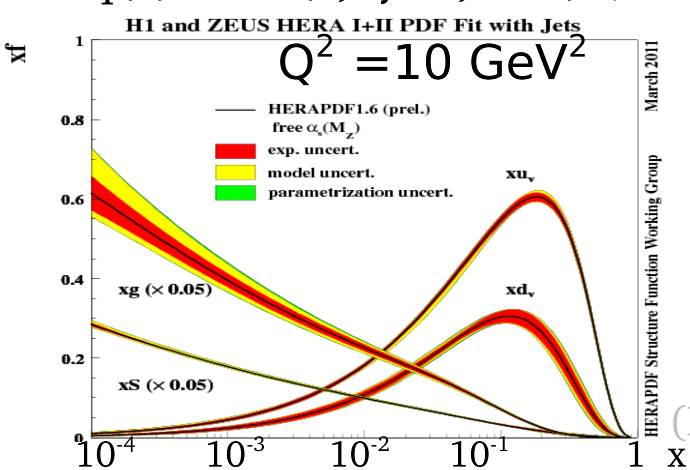
$q(x) = H\ (x,\ \xi=0,\ t=0)$

t = 0

$\int$ dx

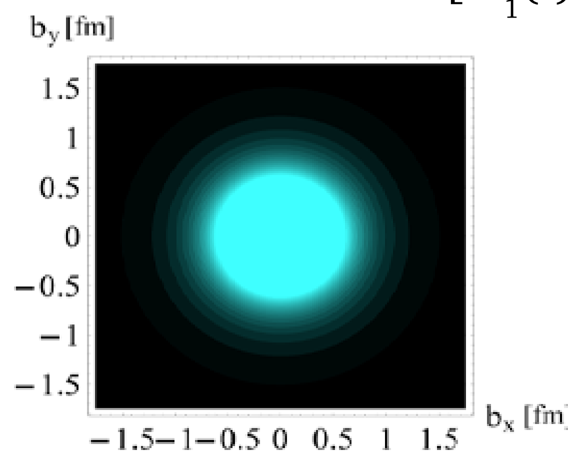
Transverse charge density

Form Factors $\Longrightarrow$ FT[$F_1(t)$]



(HERA pdf)

Carlson, Vanderhaeghen, PRL 100 (2008) 032004

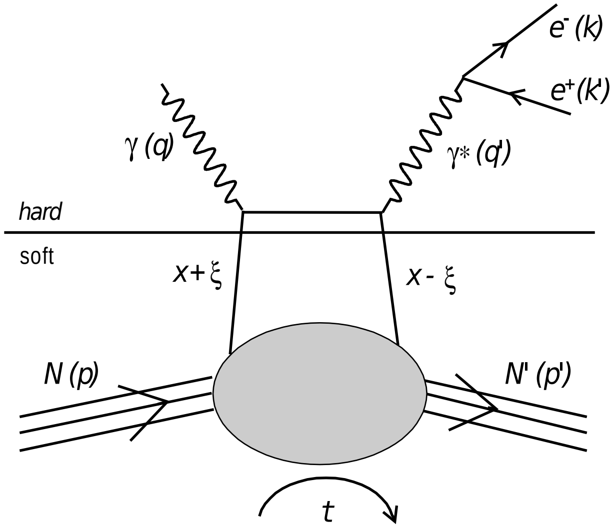


Part I

Theoretical predictions :
- cross sections
- spin asymmetries
- GPD dependencies of observables

TCS in exclusive lepton pair photoproduction

$$\gamma N \rightarrow e^+ e^- N \quad =$$



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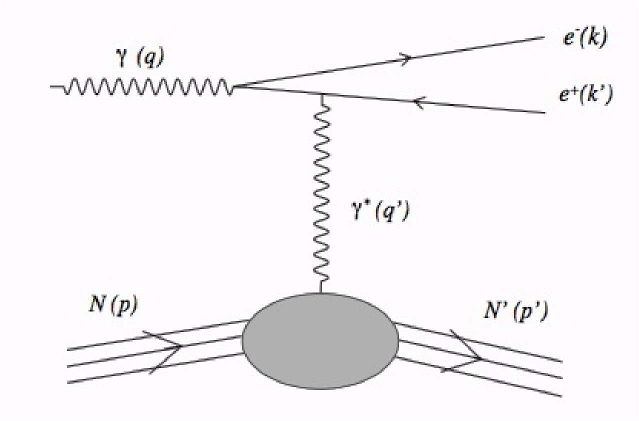


Timelike Compton Scattering (TCS)
sensitive to the nucleon GPDs

Bethe-Heitler (BH)
sensitive to the nucleon Form Factors

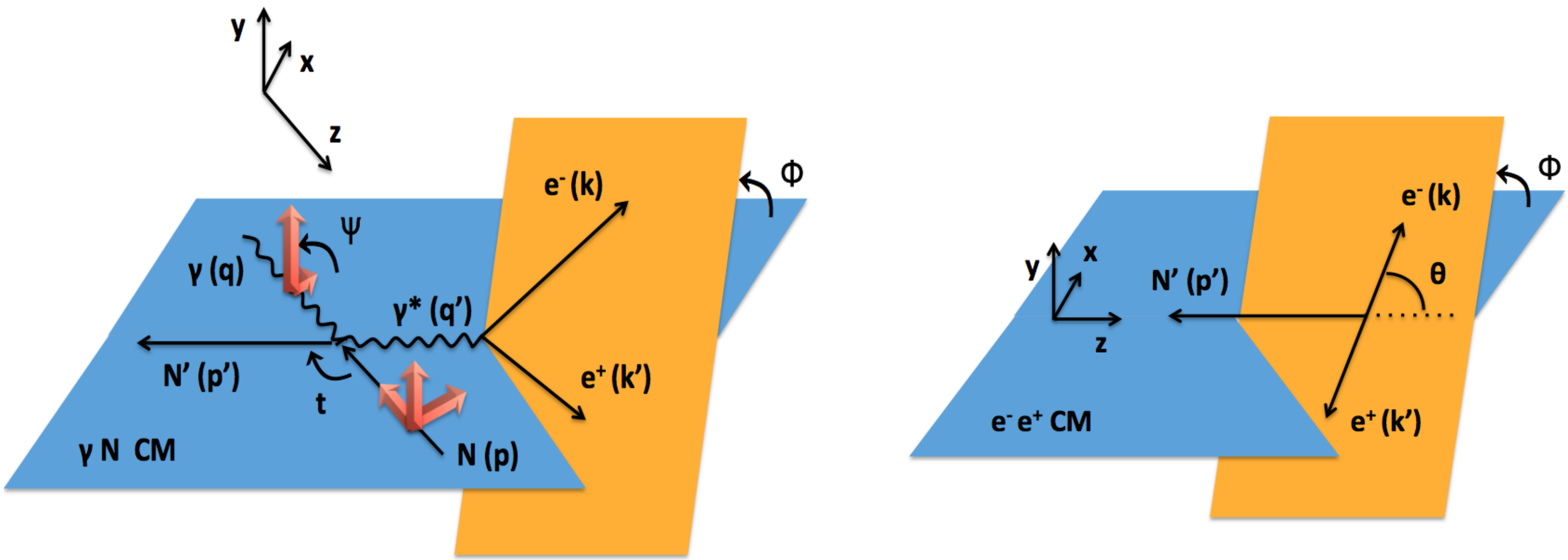
$$\frac{d^4\sigma}{dQ'^2 dt d\Omega}(\gamma p \rightarrow p' e^+ e^-) = \frac{1}{(2\pi)^4} \frac{1}{64} \frac{1}{(2ME_\gamma)^2} \mid T^{BH} + T^{TCS} \mid^2$$

Angles and notations

$\gamma\, N \rightarrow e^+ e^- N$
Fixed beam energy
or **ξ**

$$\frac{d\sigma}{dQ'^2\ dt\ d\phi\ d(cos\theta)}$$

Ψ: (reaction plane, **γ** spin)
φ: (hadronic plane, e^+e^- pair)
θ: (γ^*, e^-)



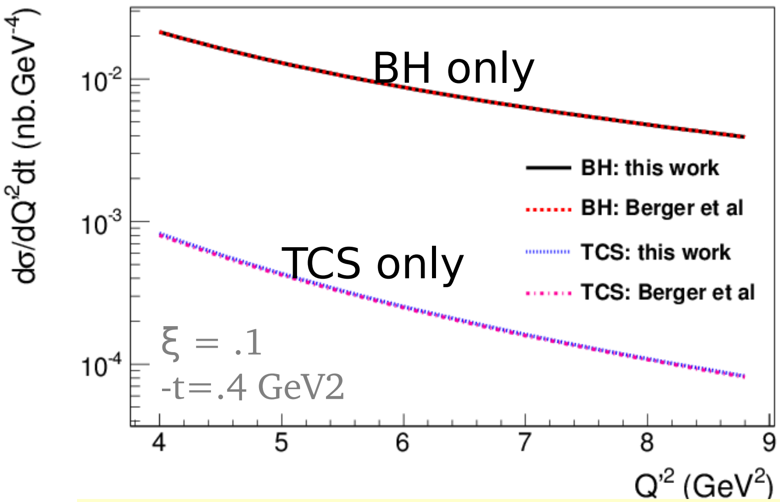
Notations
$\mathbf{A}_{i\,j}$: asymmetry
1st index: photon polarisation, ⊙ = circular, **L** = linear, **U** = unpolarized
2d index: nucleon polarisation, **x** (transverse, in plane), **y** (transverse), **z** (longitudinal)

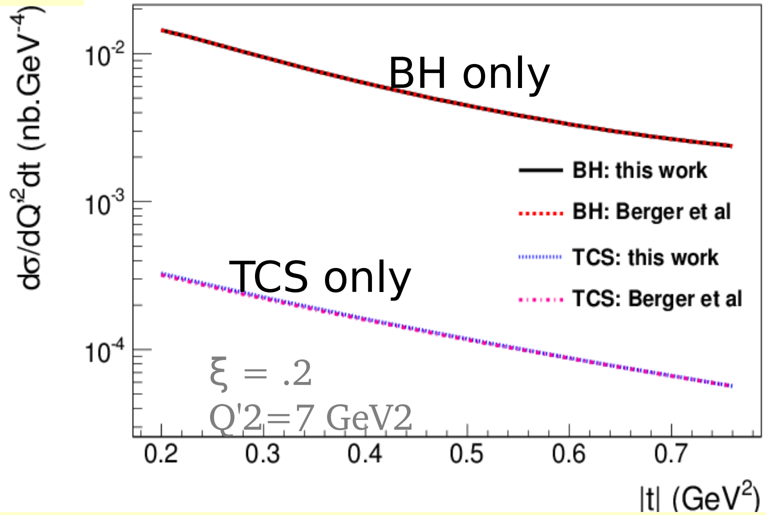
Kinematical dependencies and comparisons

cross sections vs Q'^2 and vs t

integrated over decay angles

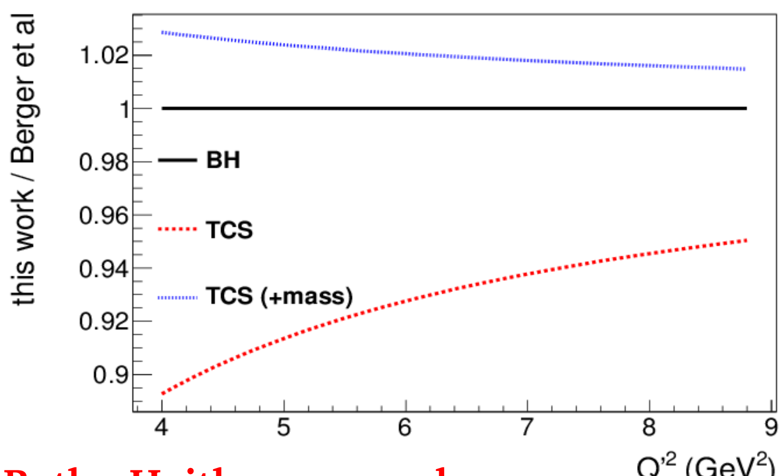
$\theta \in [45°, 135°]$
$\Phi \in [0°, 360°]$

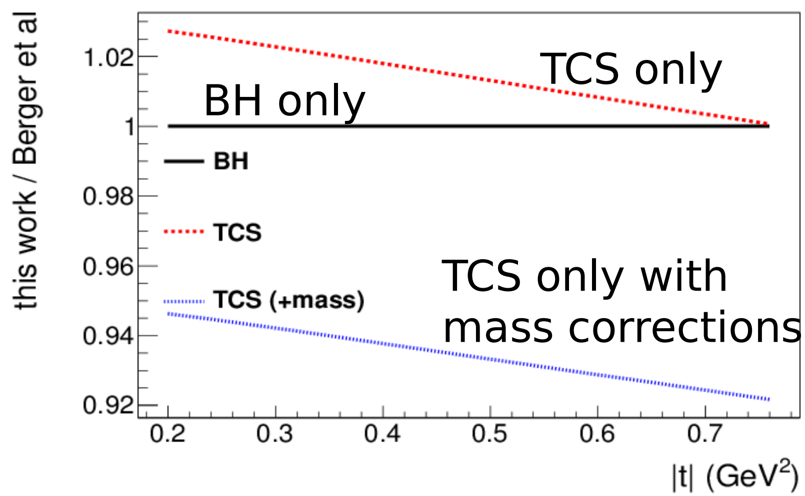




BH >> TCS
order of pb

R = this work / Berger, Diehl, Pire[1] (pioneer theoretical work)





[1]Berger, Diehl, Pire, E.P.J. C23 (2002) 675

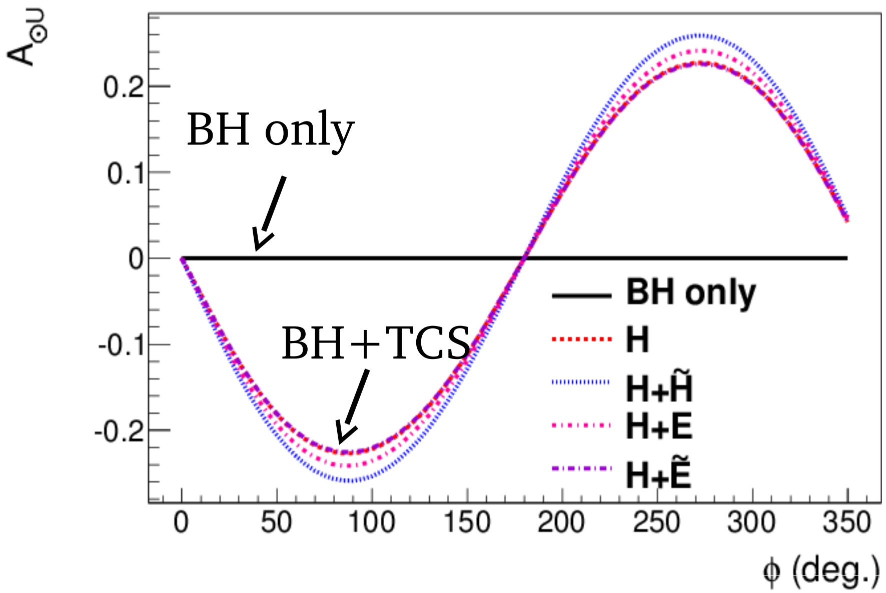
Bethe-Heitler: ≈ equal

TCS: few % at low Q'^2 ⇝ we waived some t/Q'^2 approximations (some higher twist corrections)

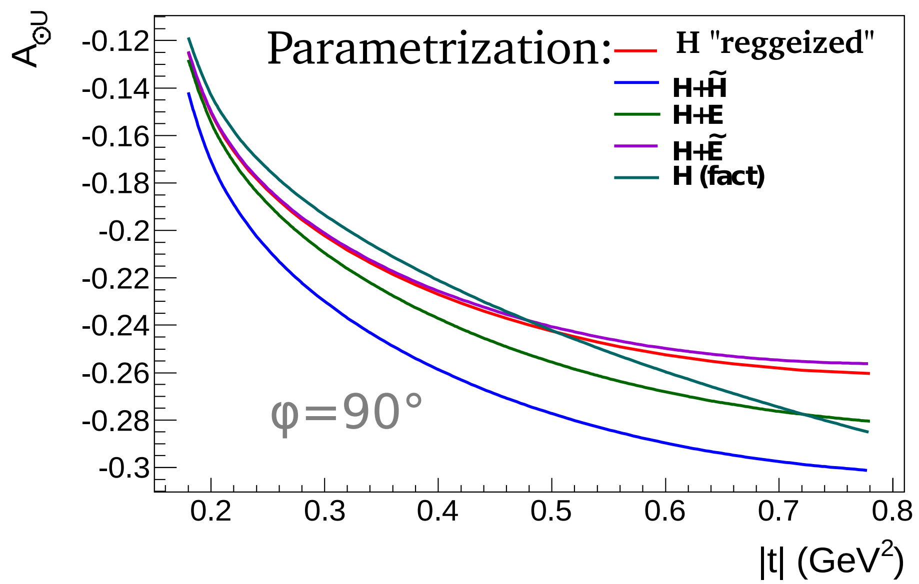
Asymmetries: circularly polarized beam

ξ=0.2, Q′2 =7 GeV2, -t=0.4 GeV2, θ ∊ [45°,135°]

Angular dependence in Φ



Kinematical dependence in -t

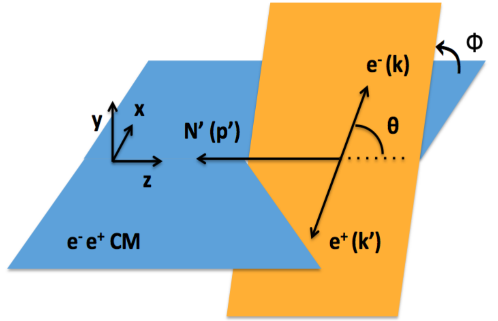


$A_{\odot U}$ ∝ imaginary part of amplitudes ⇒ $A_{\odot U}$ = 0 for Bethe-Heitler

Asymmetry ≈20%

This observable : mostly sensitive to H and H̃

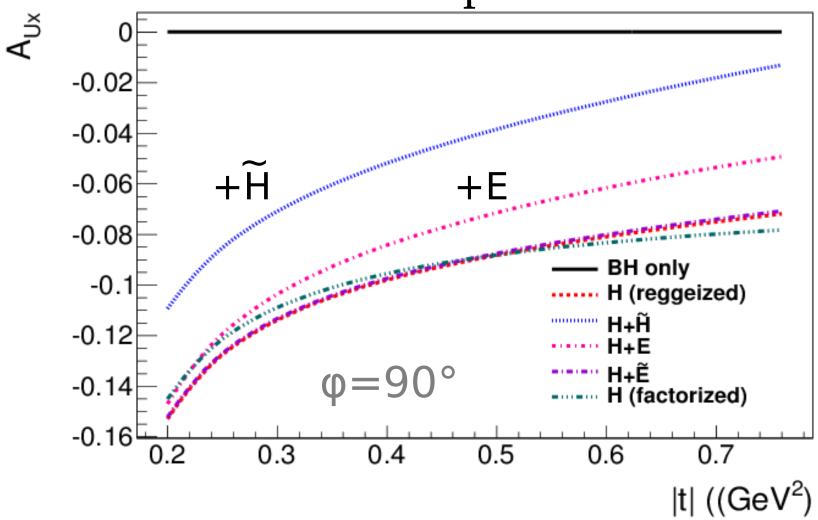
≈ 20% asymmetry coming from interference BH x TCS and sensitive to GPDs



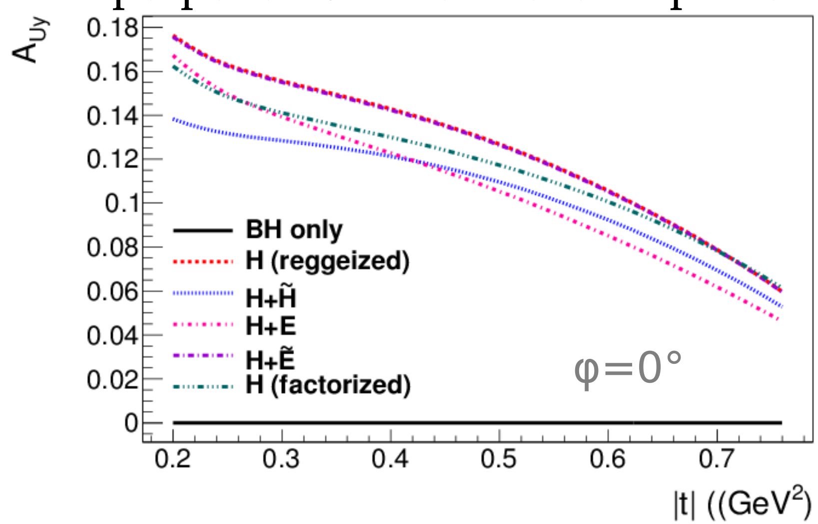
Polarized target : single spin asymmetries

Transversally polarized target asymmetries vs |t|

"in hadronic plane"

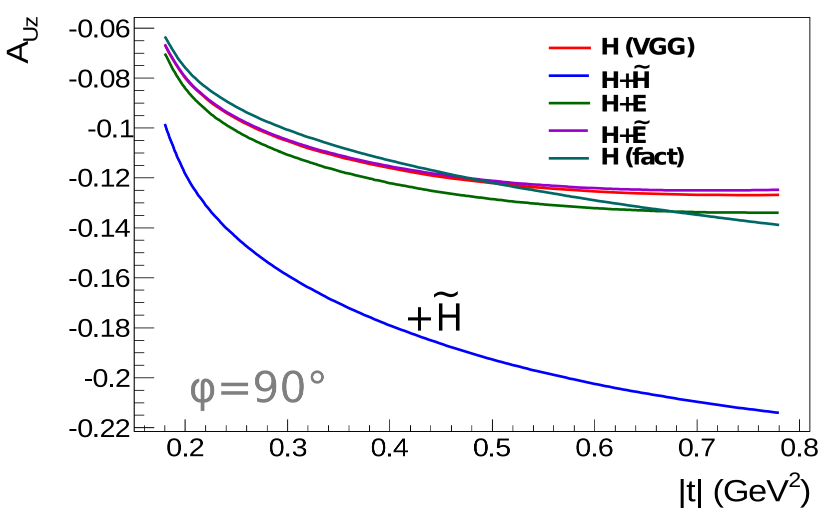


"perpendicular to hadronic plane"



GPD E
+H̃

Longitudinaly polarized target asymmetry vs |t|



GPD H̃

- Im part of amplitudes

$\Rightarrow A_{Ui}$ [BH] = 0

- Sensitive to H, $\tilde{H}$, E

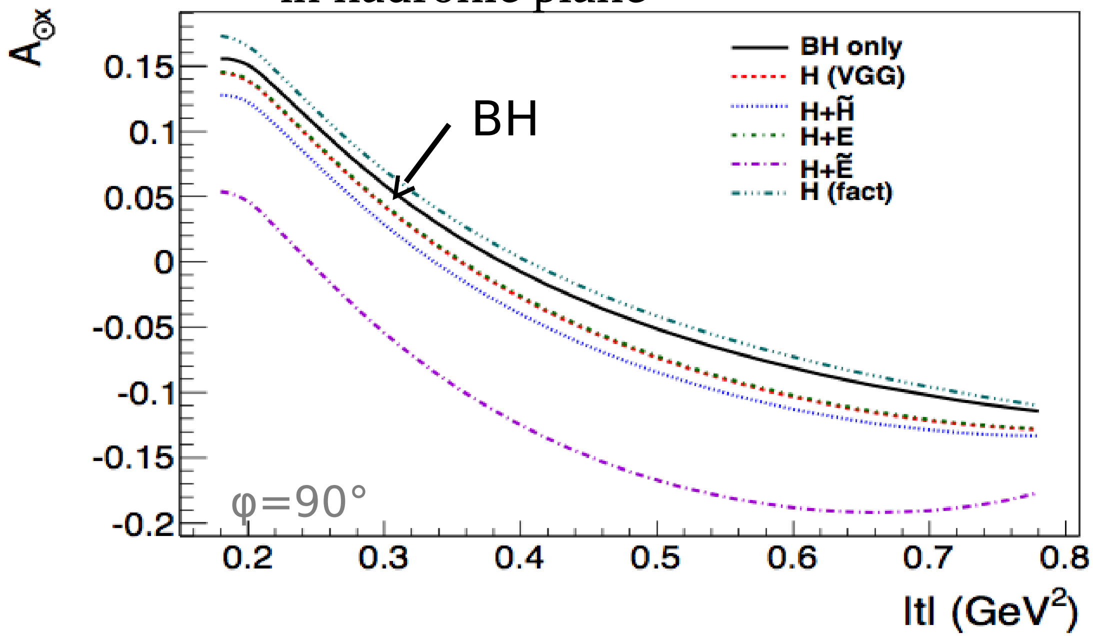
10% to 20% asymmetries

ξ=0.2, Q′2 =7 GeV2, -t=0.4 GeV2, θ ∊ [45°,135°]

Polarized beam and target : double spin asymmetries

Circularly polarized beam and transversally pol. target vs |t|

"in hadronic plane"



ξ=0.2, Q′2 =7 GeV2,
-t=0.4 GeV2,
θ ∈ [45°,135°]

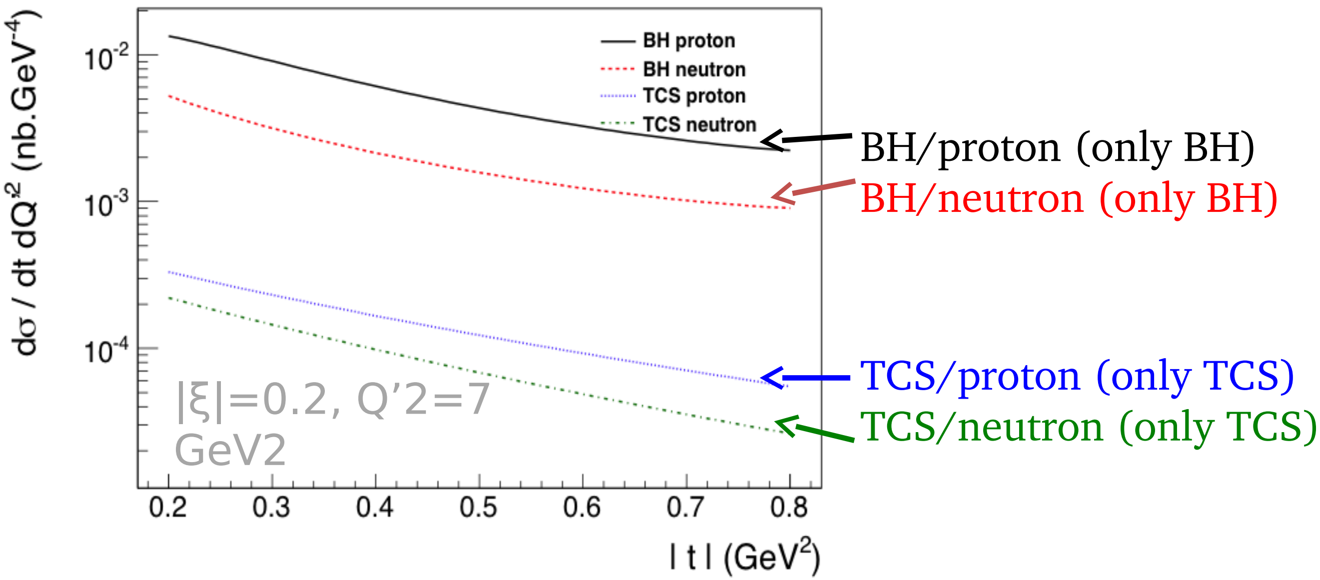
- Very sensitive to the GPDs parameterization
- Sensitive to the real part of amplitudes
- But

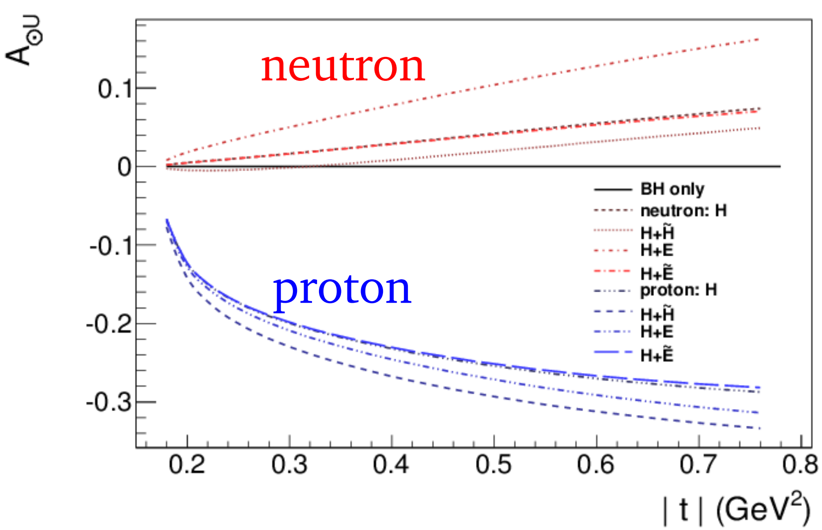
- A[BH]≠0 , few % deviation from TCS signal
- Bins in φ and θ preferable for signal
- Experimental difficulties (stat...)

Other observables : with linearly polarized photon beam (not shown)

TCS off the neutron

unpolarized cross sections TCS and BH





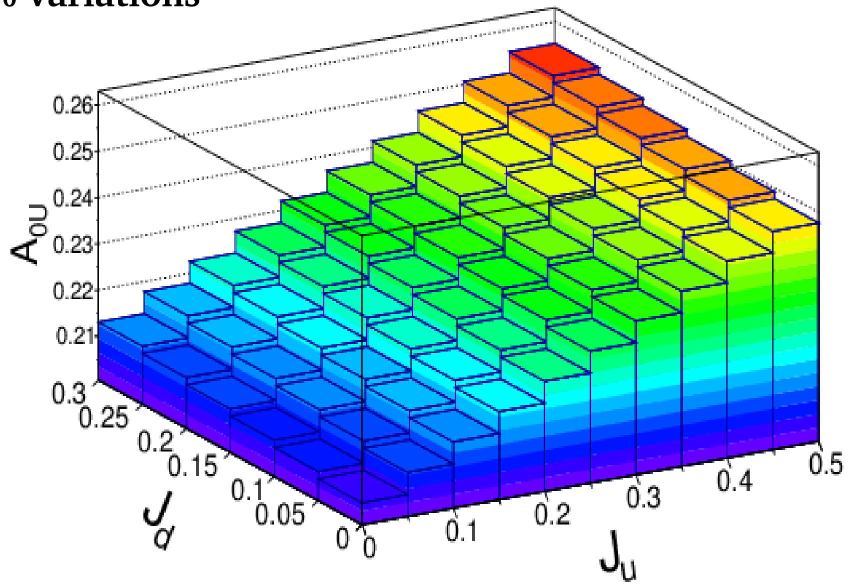
⟹ TCS off neutron is measurable but is more difficult experimentaly
⟹ Asymmetries ≈ same Φ and t dependancies and same magnitudes

- **flavor separation : u and d quarks**
- **GPD E (next slide) => Ji sum rule**

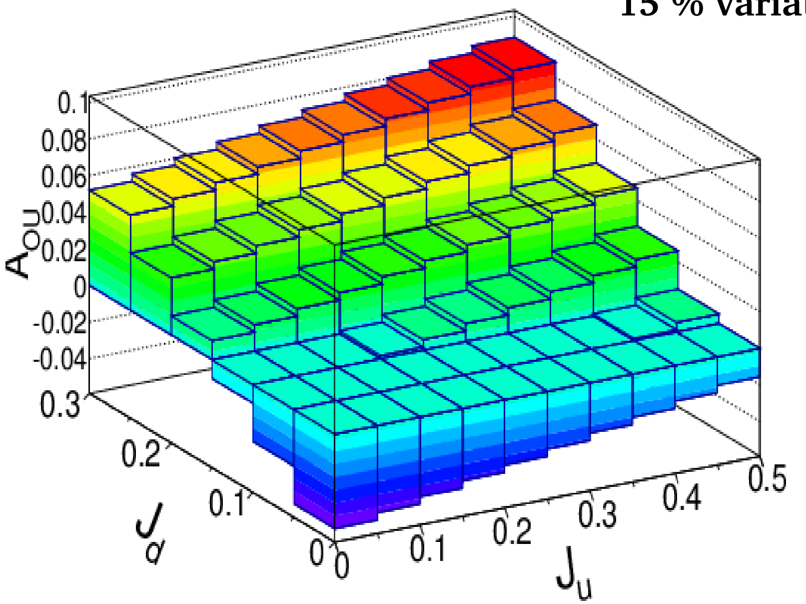
Beam spin asymmetry off the proton and off the neutron

Sensitivity to GPD E in BSA:
BSA as a function of u and d quark angular momenta J_u and J_d
BSA(-t=.4 GeV^2) vs J_u and J_d for proton: **for neutron:**

5 % variations



15 % variations



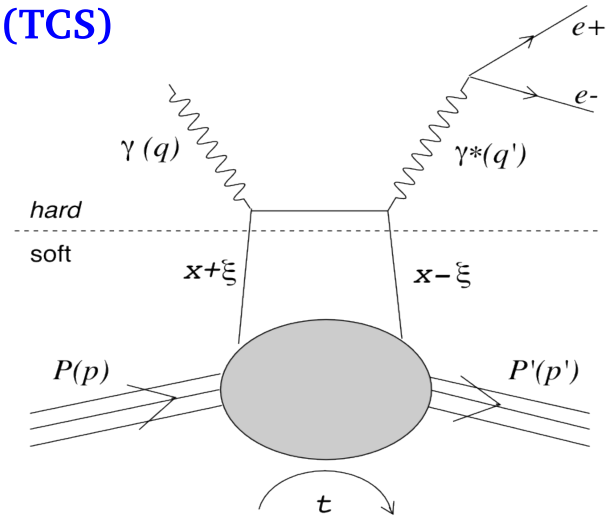
Stronger sensitivity to J_u and J_d + change of sign for BSA off the neutron
→ Ji sum rule... studies of angular momenta of quarks

Part II

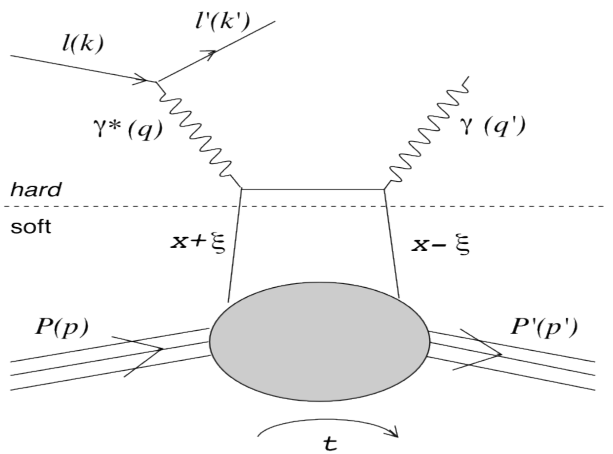
- Extraction of GPDs with TCS
- Experimental perspectives

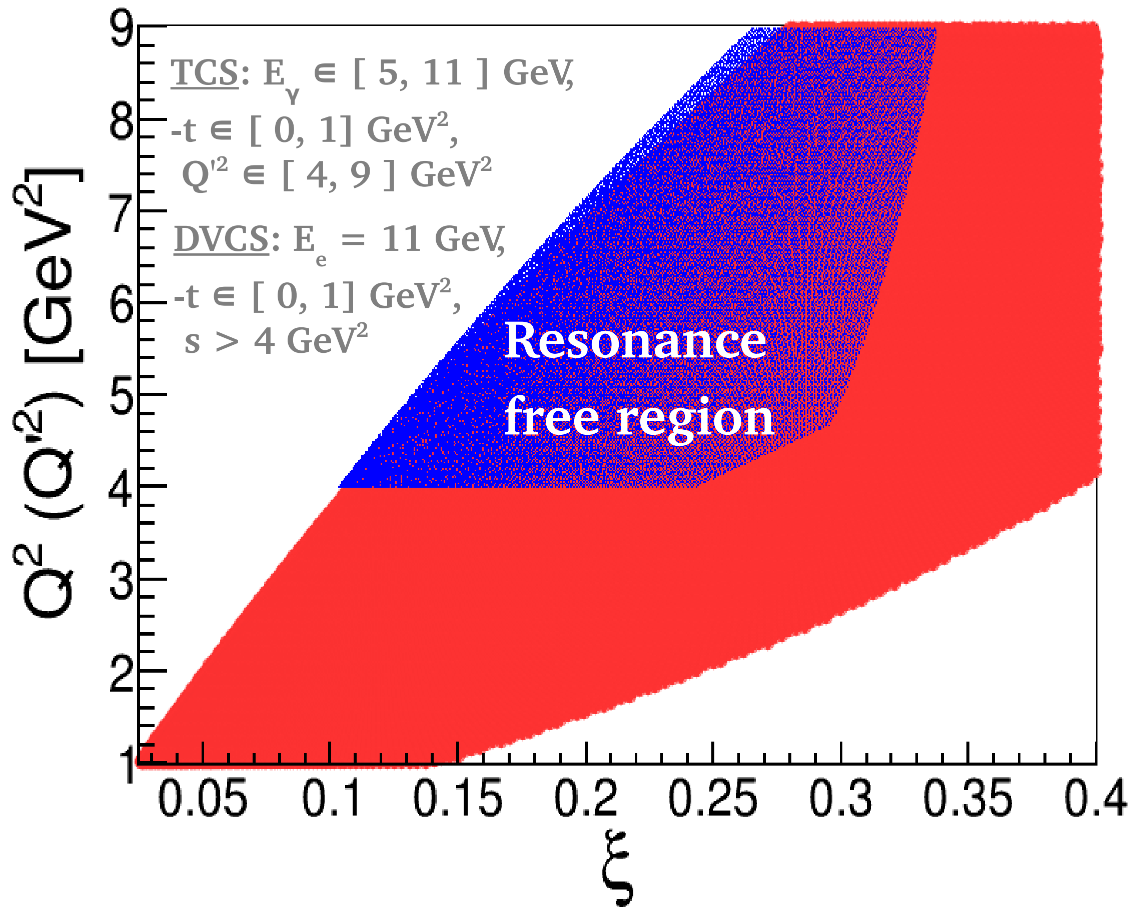
Phase Space for TCS and DVCS at JLab @ 12 GeV

Timelike Compton Scattering (TCS)



Deeply Virtual Compton Scattering (DVCS)
Measurements already published (JLab, HERMES, H1, ZEUS)





Interest of TCS and DVCS in parallel :

- Universality of GPDs
- Complementary observables
- Higher twist and higher order effects

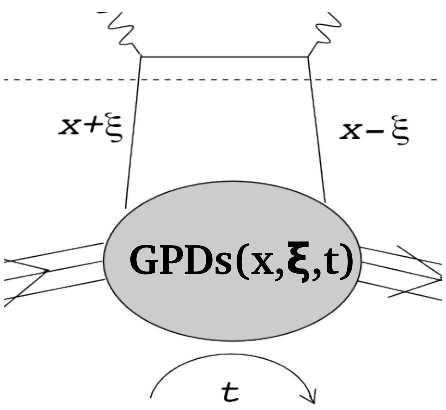
GPDs and Compton Form Factors

GPD (real) **Compton Form Factor (CFF, complex)**

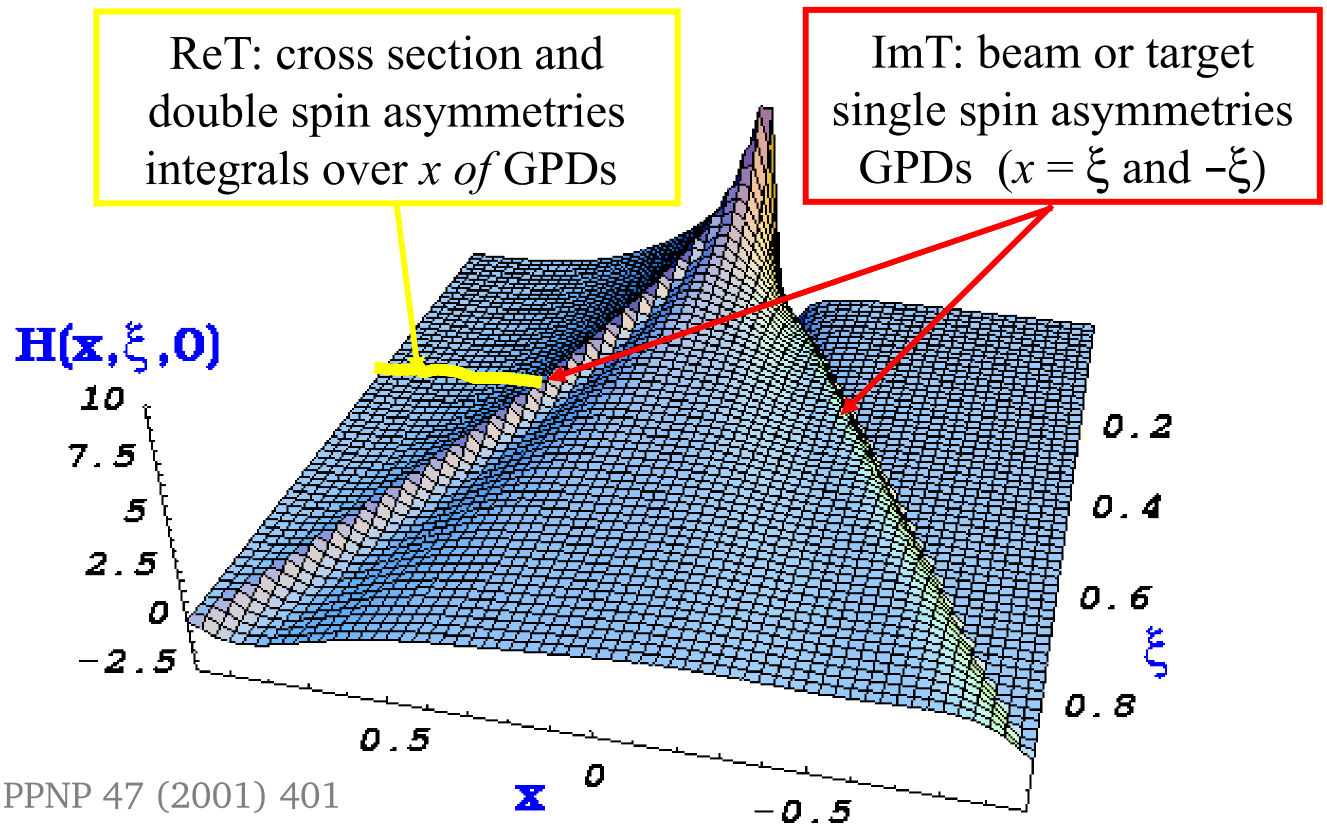
$$T^{DVCS} \sim \int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi + i\varepsilon} dx + \ldots \sim \quad P\int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi} dx - i\pi H(\pm\xi,\xi,t) + \ldots$$

CFFs are measurable:

ξ, t : mesurables
x : loop variable
x±ξ : propagator



→ CFFs(ξ,t)



Goeke, Polyakov, Vanderhaeghen PPNP 47 (2001) 401

Could we extract CFFs from TCS fits ?

- **Pseudo-data based on our TCS calculation**
- **DVCS[1] method is expanded for <u>TCS and TCS+DVCS</u>**
- **Local fits: MINUIT + MINOS**

- several sets of observables, (ξ , t) points fitted independently
- 7 free parameters: CFFs ($\Im$m and Re [H, $\widetilde{H}$, E], Re[$\widetilde{E}$]) , the variation of parameters is limited in parameter space

[1] M. Guidal, EPJA 37 (2008) 319

Compton Form Factors fits with TCS

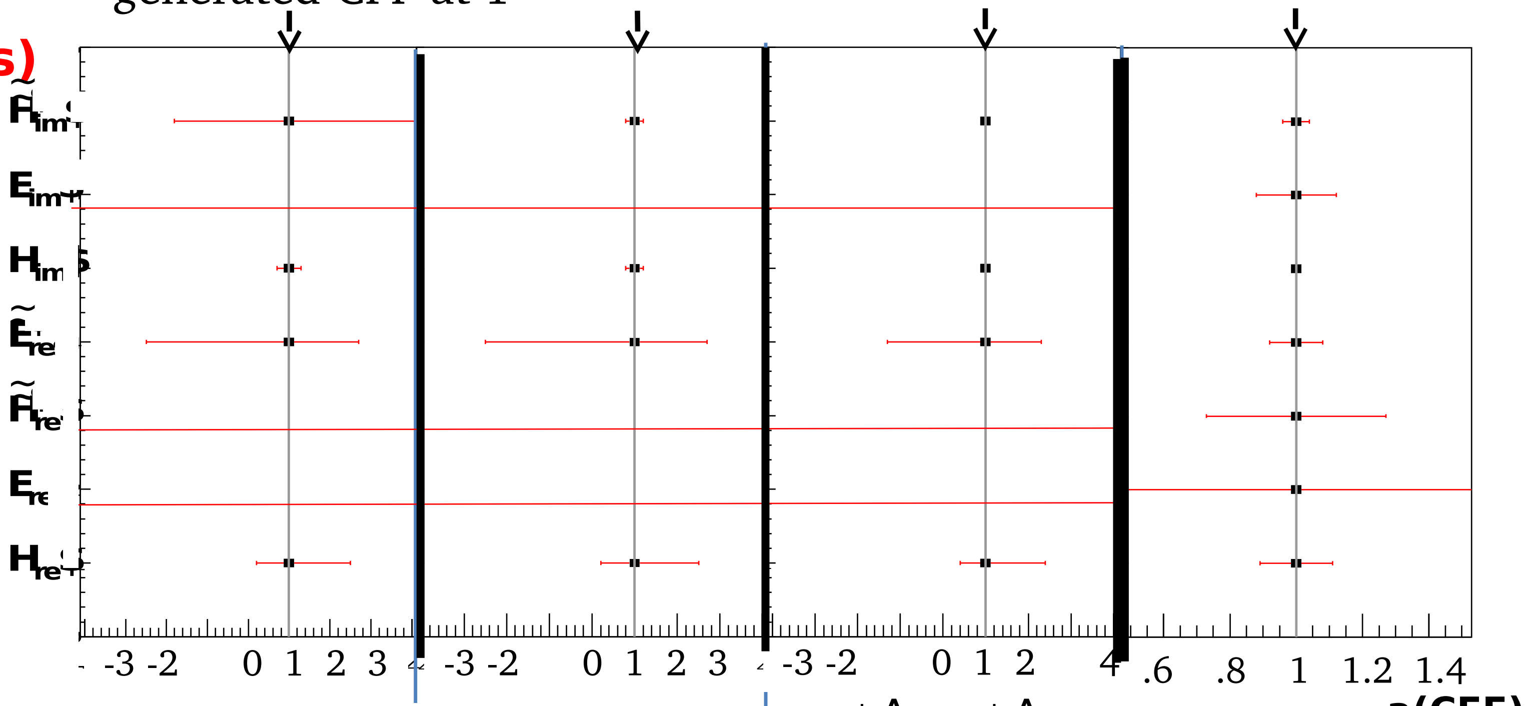
Set of results (uncertainties)

Compton Form Factors (CFFs)

simulations;
without smearing
$\delta\sigma = 5\%$, $\delta\Delta\sigma = 2\%$

generated "CFF" = 1

ξ=0.2, Q′2 =7 GeV2,
-t=0.4 GeV2, θ = 90°



Observables:
With polarized beam and/or target

$\sigma + \Delta\sigma_{\odot U}$

$\sigma + \Delta\sigma_{\odot U} + \Delta\sigma_{UL}$

$\sigma + \Delta\sigma_{\odot U} + \Delta\sigma_{UL} + \Delta\sigma_{Ux} + \Delta\sigma_{Uy}$

$\sigma + \Delta\sigma_{\odot U} + \Delta\sigma_{UL} + \Delta\sigma_{Ux} + \Delta\sigma_{Uy} + \Delta\sigma_{\odot L} + \Delta\sigma_{\odot x} + \Delta\sigma_{\odot y}$

- underconstrained system: some CFFs are extracted: $\Im m(H)$
- 8 independant observables, 7 CFFs: all CFFs are extracted
- single spin asymmetries $\propto$ ImT $\Longrightarrow$ Im(CFFs) are extracted with smaller error bars
- compared to DVCS : more difficult with TCS, but complementary

CFFs can be extracted from TCS fits assuming 5% uncertainties on observables

Experimental perspectives at JLab @ 12 GeV

Hall A SoLID (large acceptance spectrometer, L=10^{37}cm^{-2}s^{-1})
- (LOI in 2013 and proposal in progress) unpolarized target, polarized "quasi-real" photon beam
- near future : polarized target and polarized beam

Hall B CLAS12 (large acceptance spectrometer, Luminosity=10^{35}cm^{-2}s^{-1})
- accepted proposal (2012): unpolarized cross sections with "quasi-real" photon beam
- experimental feasability was shown with analysis @ 6 GeV (R. Paremuzyan PhD thesis)
- (proposal in progress) linearly polarized beam asymmetries (not shown, sensitive to the real part of amplitudes)

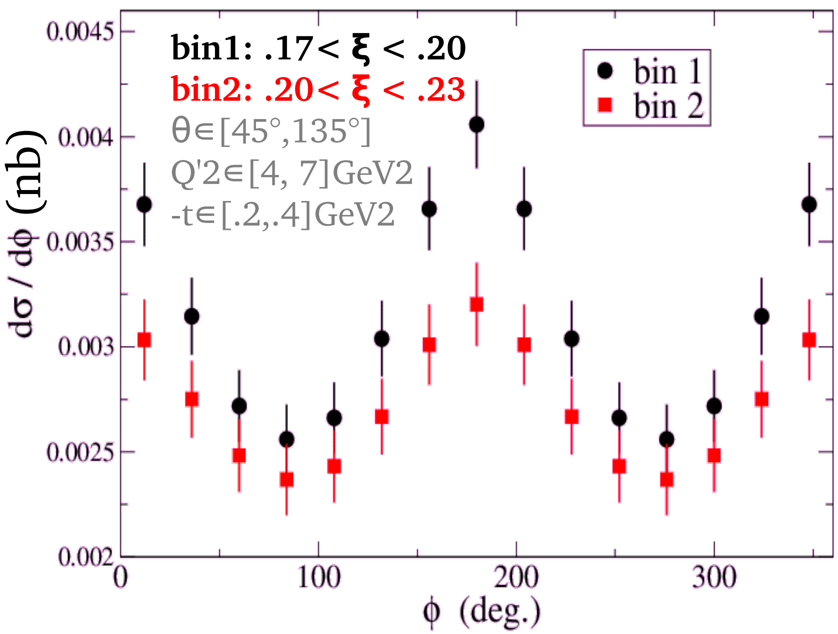
Hall C
- (LOI in progress) dedicated measurement with transversally polarized target and "quasi real" photon beam

Hall D
- studies of faisability, only Hall with a real linearly polarized photon beam

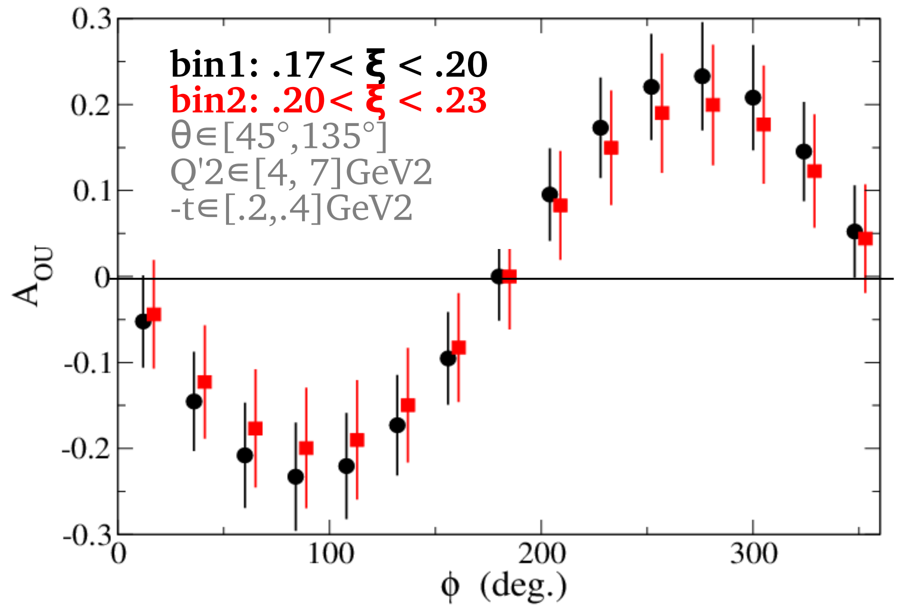
Some predictions for JLab @ 12 GeV with CLAS12

CLAS12 accepted configuration

unpolarized cross section



circ.beam spin asymmetry



~5% statistical error: justification of the 5% error for the fits,

- Observables are measurable
- Extraction of GPD H is possible

100 days, $A \approx 0.2$, L= 10^{35} $cm^{-2}s^{-1}$, E(e–)=11GeV, "quasi-real" photons

Summary

Calculations of unpolarized + beam and/or target polarized cross sections[1]

- Single spin asymmetries (circularly polarized beam or target) most favorable for GPDs, sensitive to the imaginary part of amplitudes
- TCS off the neutron: flavor separation, GPD E, angular momenta of quarks
- Some higher twist corrections taken into account here (not shown)

Fits on pseudo-data and GPD extraction

- CFFs and GPDs can be extracted with TCS
- Comparisons to DVCS in the kinematical range: universality of GPDs, evaluation of higher twist effects...

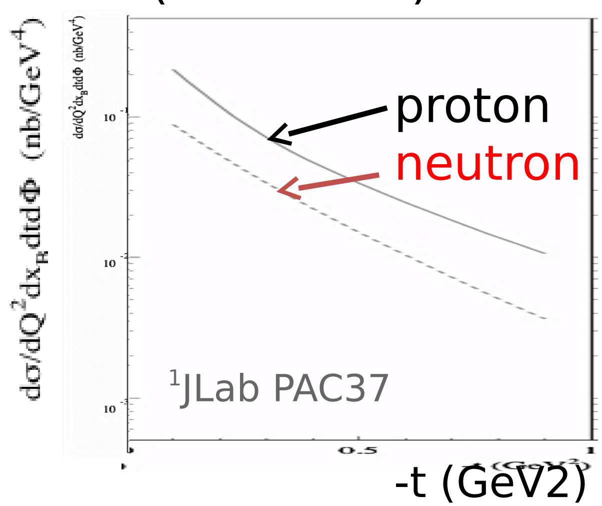
Experimental perspectives for JLab

- Accepted experiment for CLAS12, LOI for SOLID
- New proposals for CLAS12 and SOLID (in progress)
- New LOI for Hall C with transversally polarized target (in progress)

[1] MB, M. Guidal, M. Vanderhaeghen, arXiv:1501.00270 [hep-ph]

Asymmetries	sensitivity of Im or Re part in amplitudes
BSA (circ)	Im
BSA (lin)	Re
TSA (long)	Im
TSA (trans)	Im
BTSA (beam circ)	Re
BTSA (beam lin)	Im

Comparison:
(DVCS+BH)[1]



Photon beam polarization rate