Timelike Compton Scattering: polarization observables and experimental perspectives for JLab at 12 GeV

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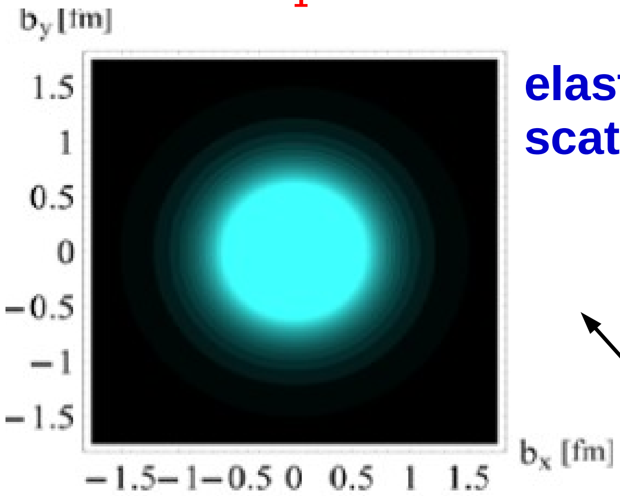
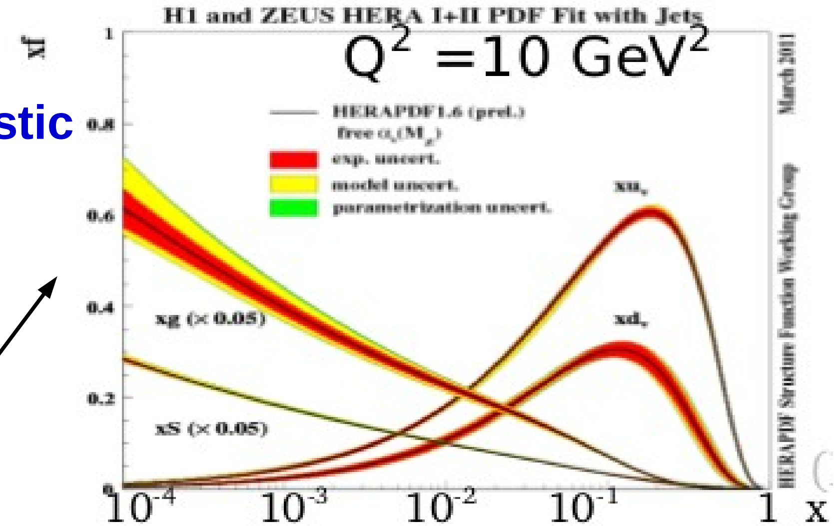
"3D" imaging : Generalized Parton Distributions (GPDs)

Form factors $F_1(t)$ → transverse charge densities



elastic scattering

Parton Distributions q(x)



inclusive deep inelastic

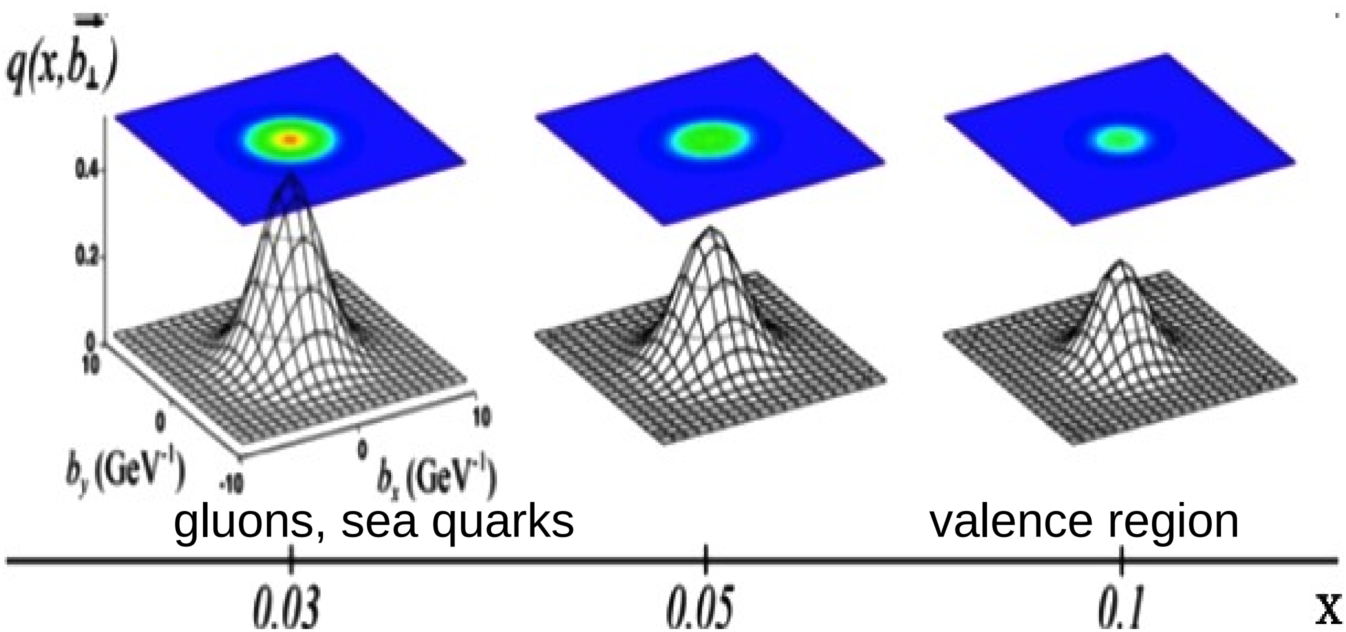
∫ dx

t = 0

hard exclusive processes

Generalized Parton Distributions

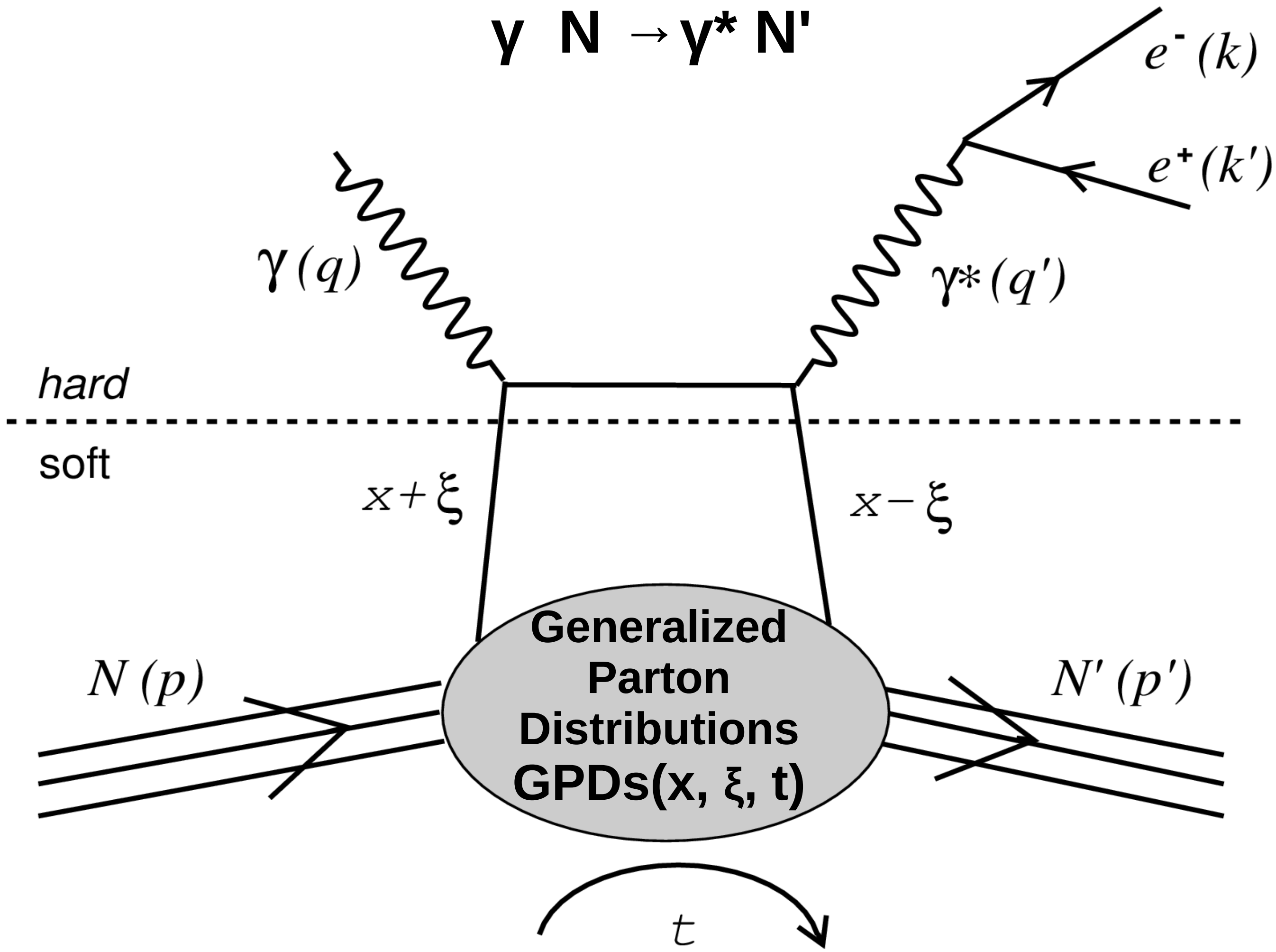
Correlation between longitudinal momentum fraction x and transverse charge densities $b_{x,y}$



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

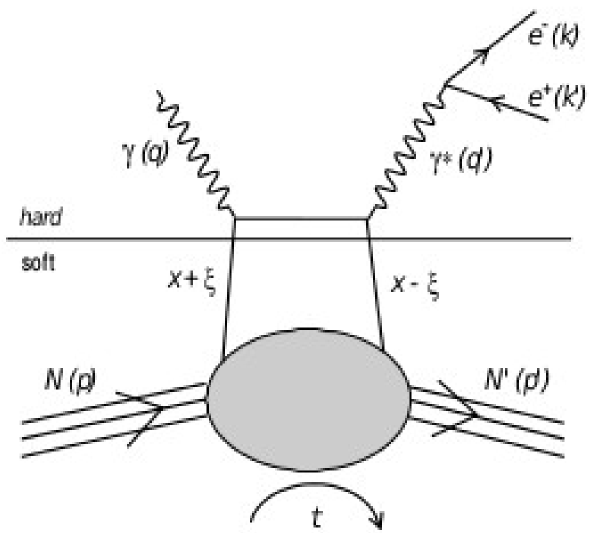
x : longitudinal momentum fraction
t : momentum transfer squared

Timelike Compton Scattering

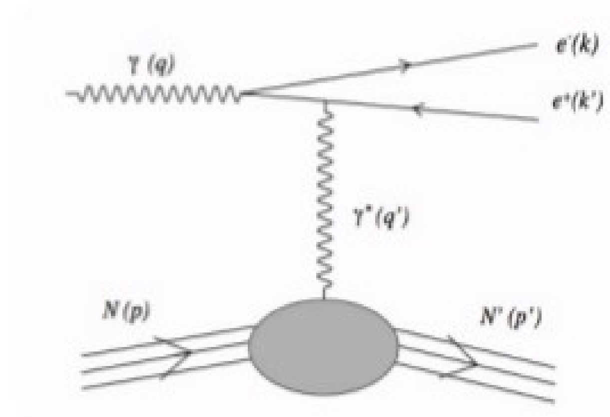


x : average longitudinal momentum fraction of the struck quark
ξ : longitudinal momentum transfer
t : momentum transfer squared
$Q'^2 = +q'^2$: invariant mass of the lepton pair

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



+



Timelike Compton Scattering (TCS)
sensitive to the nucleon GPDs

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

$\gamma\, N \rightarrow e^+ e^- N$

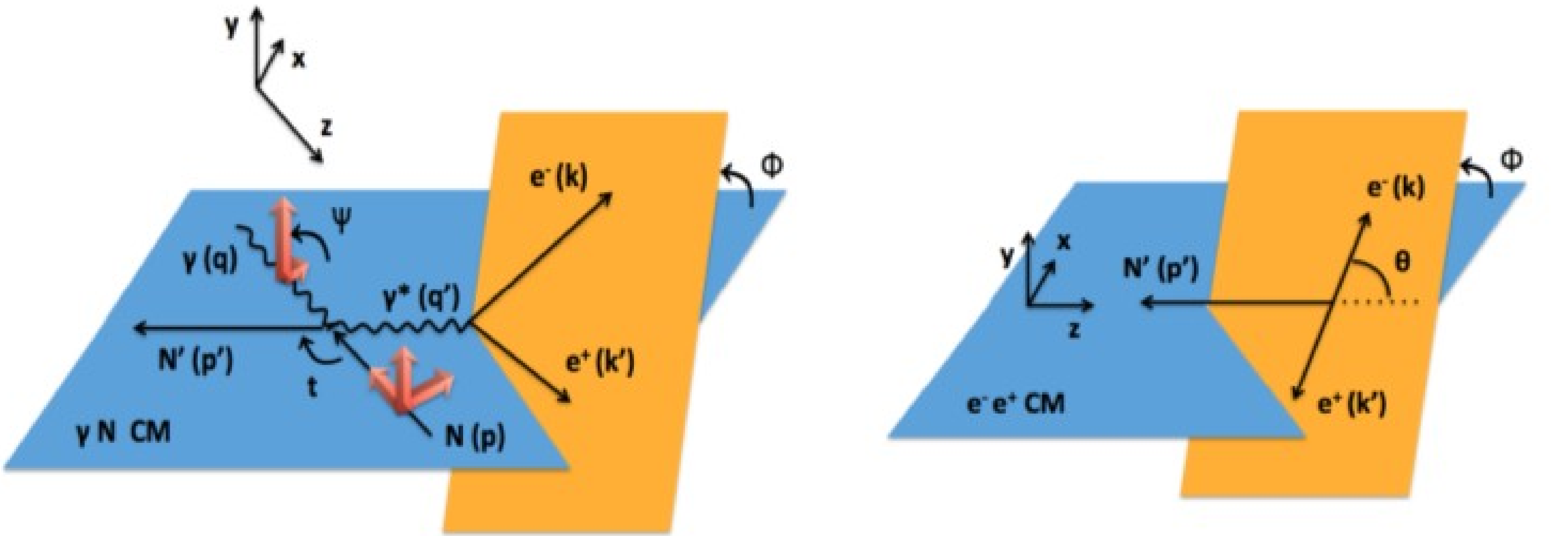
Fixed beam energy or ξ

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

Ψ: (reaction plane, γ spin)

φ: (hadronic plane, e^+e^- pair)

θ: (γ^*, e^-)



Notations

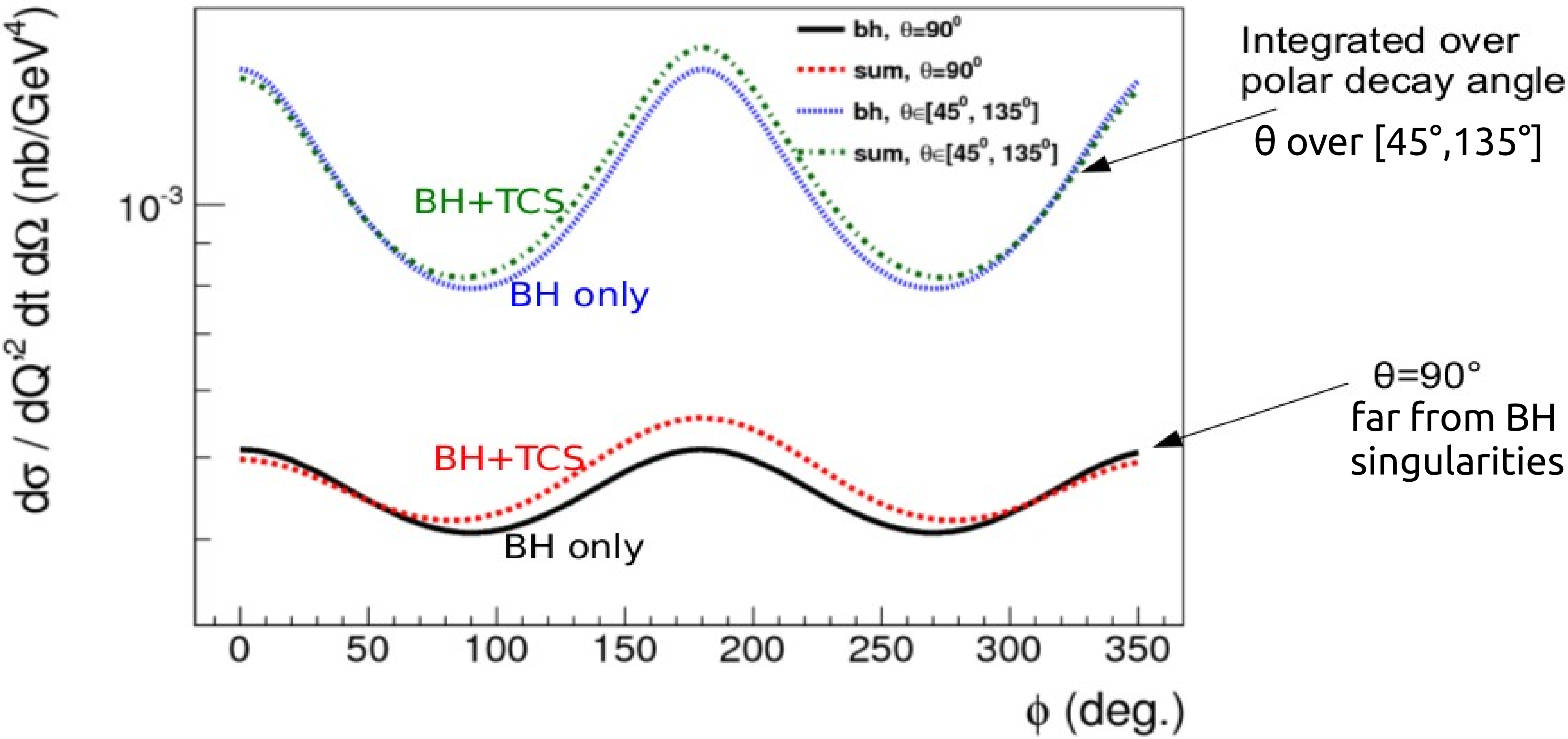
$\mathbf{A}_{ij}$: asymmetry

1st index: photon polarisation, ⊙ = circular, **L** = linear, **U** = unpolarized

2d index: nucleon polarisation, **x** (transverse, in plane), **y** (transverse), **z** (longitudinal)

BH and TCS cross section angular dependencies

BH singularities : **e^- in γ direction (θ → 0°) => singularity at φ=180°**
e^+ in γ direction (θ → 180°) => singularity at φ=0°



BH is largely dominant, only few % from TCS

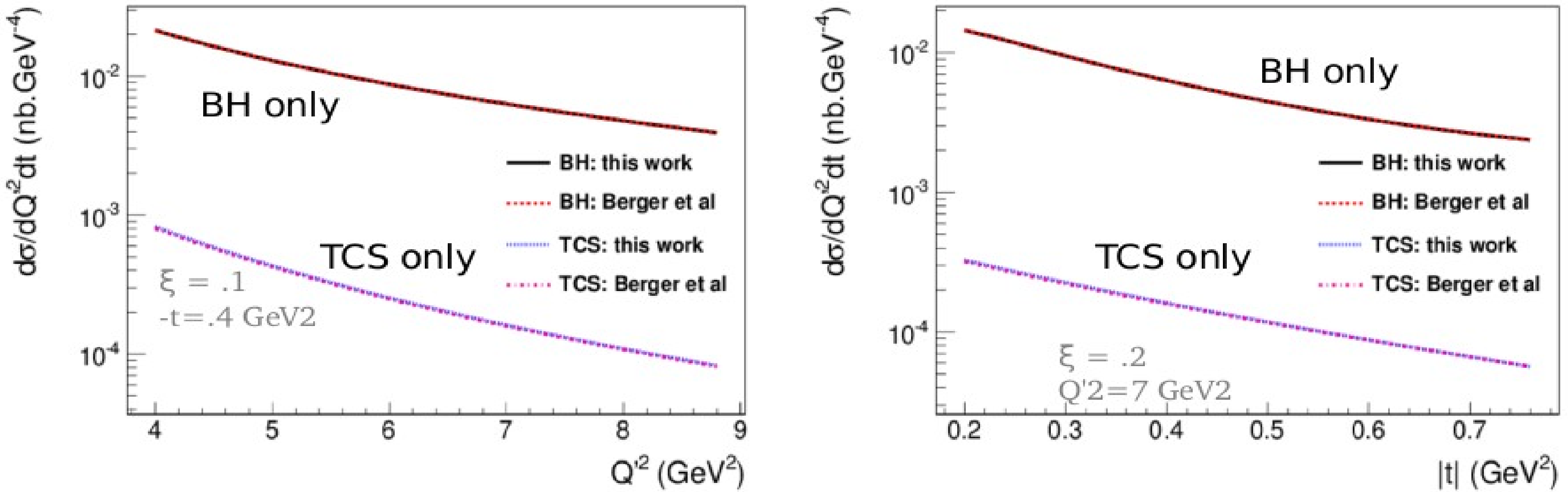
Integrated in all following figures

BH and TCS kinematical dependencies

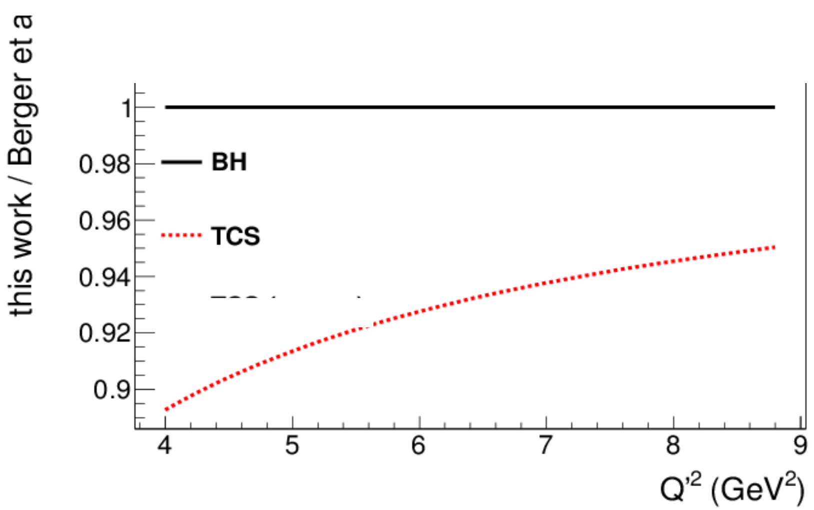
cross sections vs Q'^{2} and vs t

- BH is always 1 or 2 order of magnitude larger than TCS
- order of pb

integrated over decay angles $\theta \in [45°,135°]$, $\Phi \in [0°, 360°]$



Comparison to the pioneering theoretical work
Berger, Diehl, Pire, E.P.J. C23 (2002) 675



Bethe-Heitler: ≈ equal

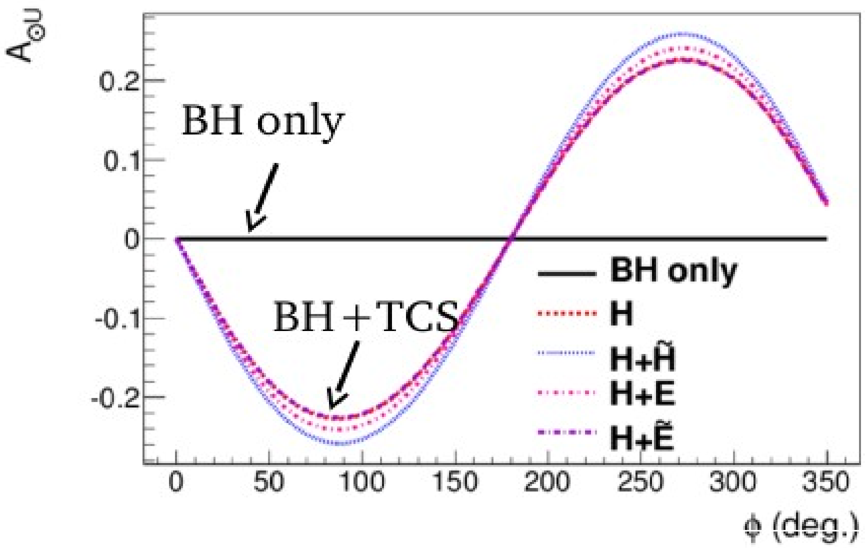
TCS: few % at low Q'^{2}

=> we waived some t/Q'^{2} approximations

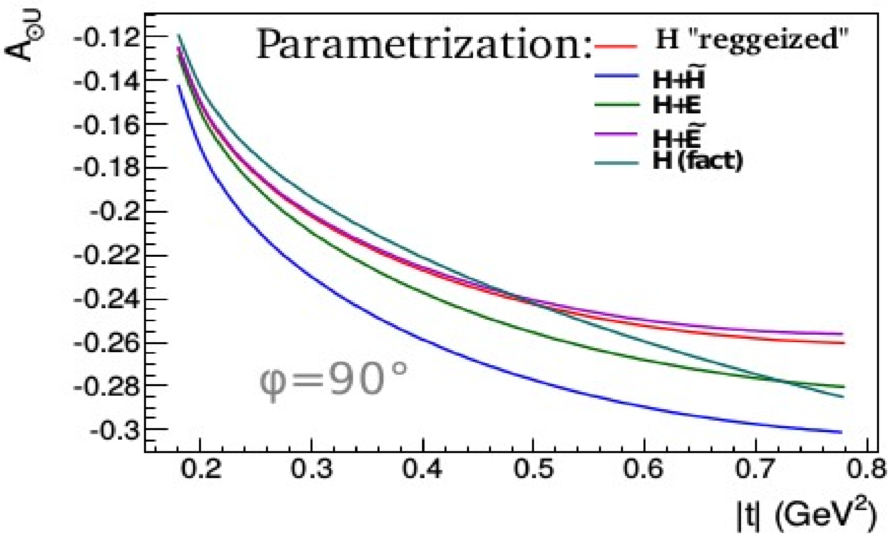
(higher twist corrections, gauge invariance)

Circularly Polarized

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

Hall B CLAS12 proposal
E12-12-01 PAC39 (2012)

Hall A SoLID run group proposal
E12-12-006A PAC43 (2015)

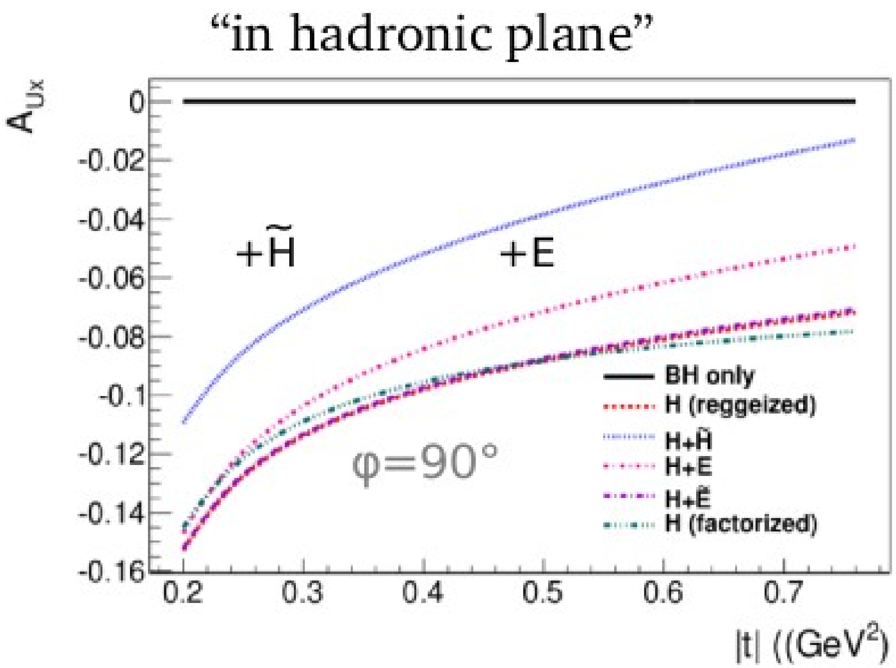
Linearly Polarized

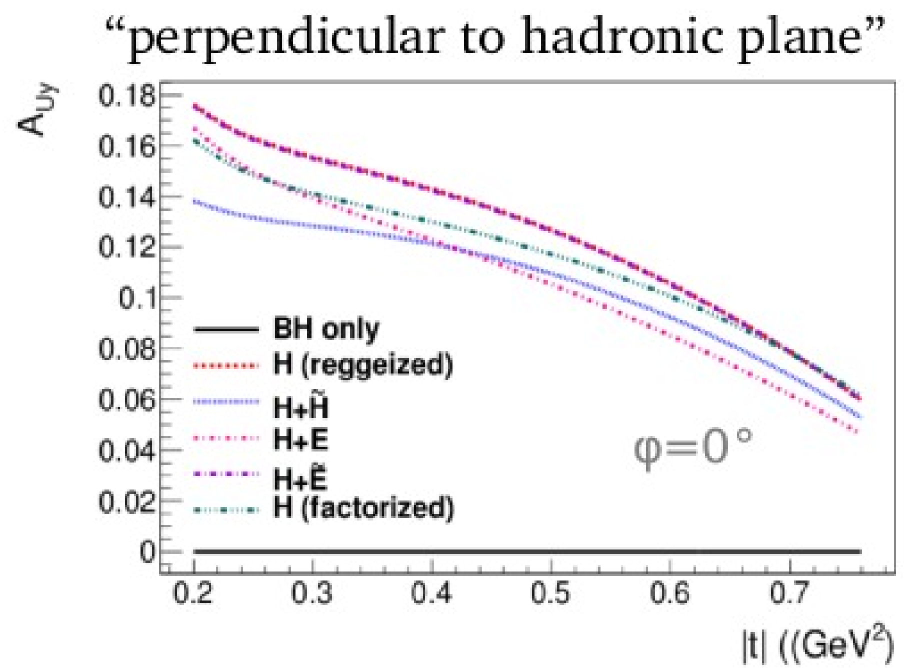
+ sensitive to the real part of amplitudes
- more difficult experimentaly

ξ=0.2, Q'2 =7 GeV2, -t=0.4 GeV2, θ ∈ [45°,135°]

Target Spin Asymmetries (TSA)

Transversally polarized target asymmetries vs |t|





- **Im part of amplitudes ⇒ A_{Ui} [BH] = 0**
- **Sensitive to H, $\tilde{H}$, E 10% to 20% asymmetries**

Hall C LOI 12-15-007
PAC43 (2015)

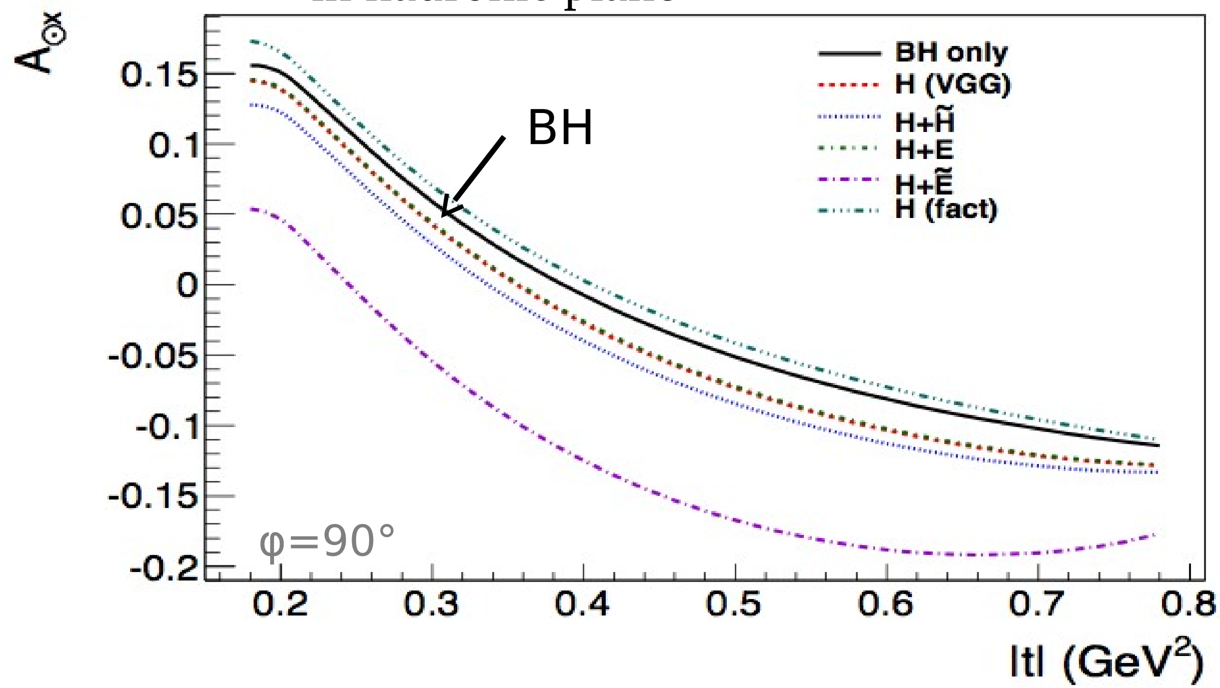
→ Spin physics with GPD E...

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

Double Spin Asymmetries (BTSA)

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

"in hadronic plane"



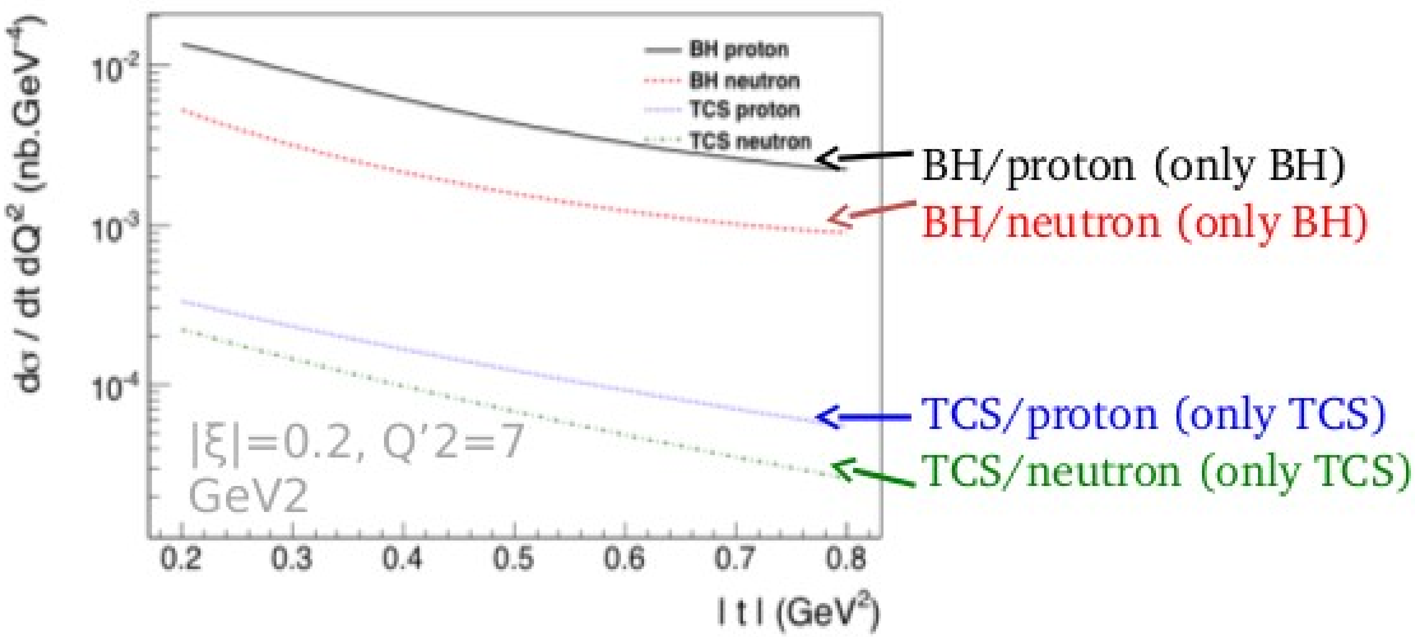
ξ=0.2, Q′2 =7 GeV2,
-t=0.4 GeV2,
θ ∊ [45°,135°]

- 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...)

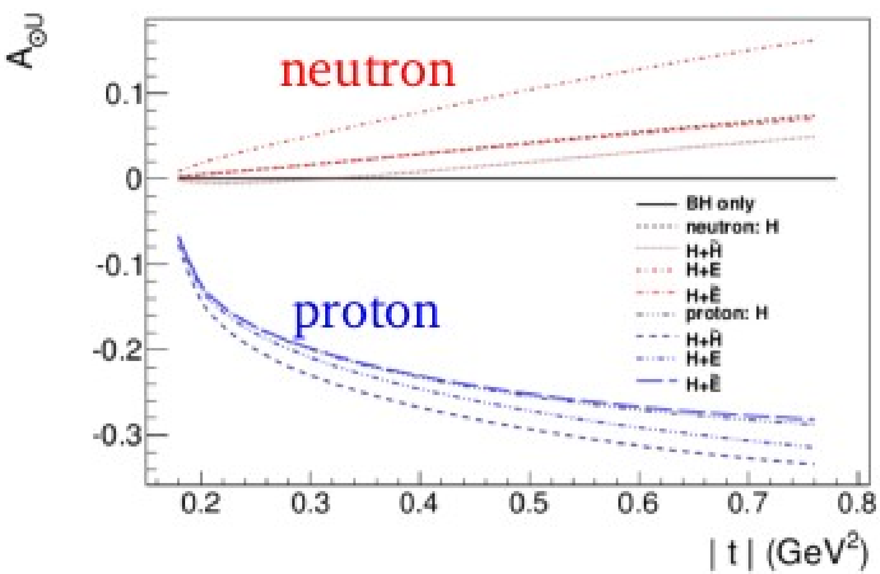
Future
need high luminosity
+ resolution

BTSA with linearly polarized beam : sensitive to imaginary part of amplitudes unpolarized cross sections TCS and BH



<u>Future</u>

JLab Hall A
SoLID ^{3}He target ?



$\Longrightarrow$ TCS off neutron is measurable but is more difficult experimentaly

$\Longrightarrow$ Asymmetries ≈ same Φ and t dependancies and same magnitudes

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

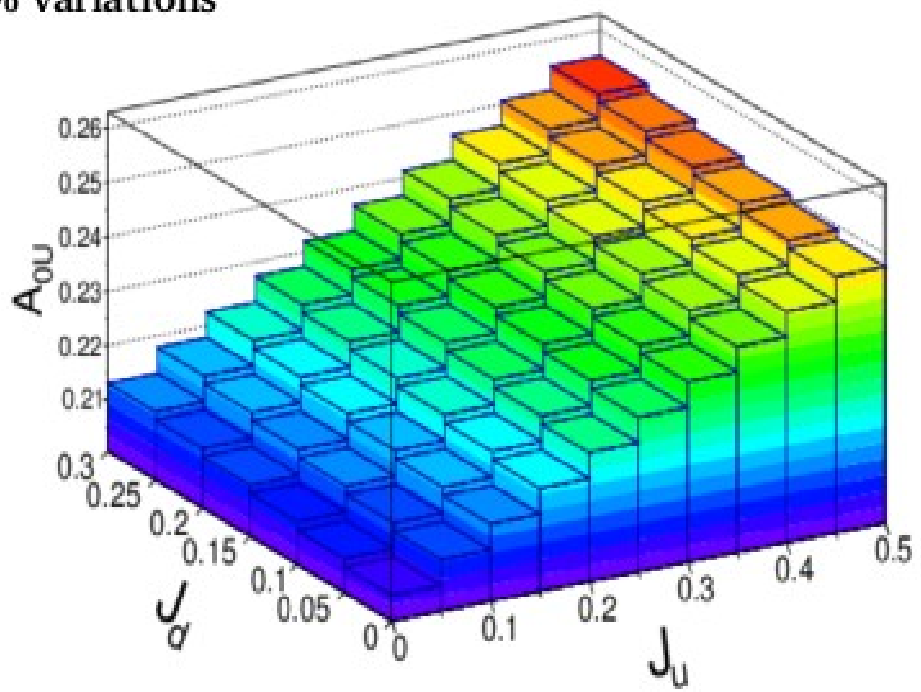
Spin physics with TCS off the proton and off the neutron

Sensitivity to GPD E in BSA:

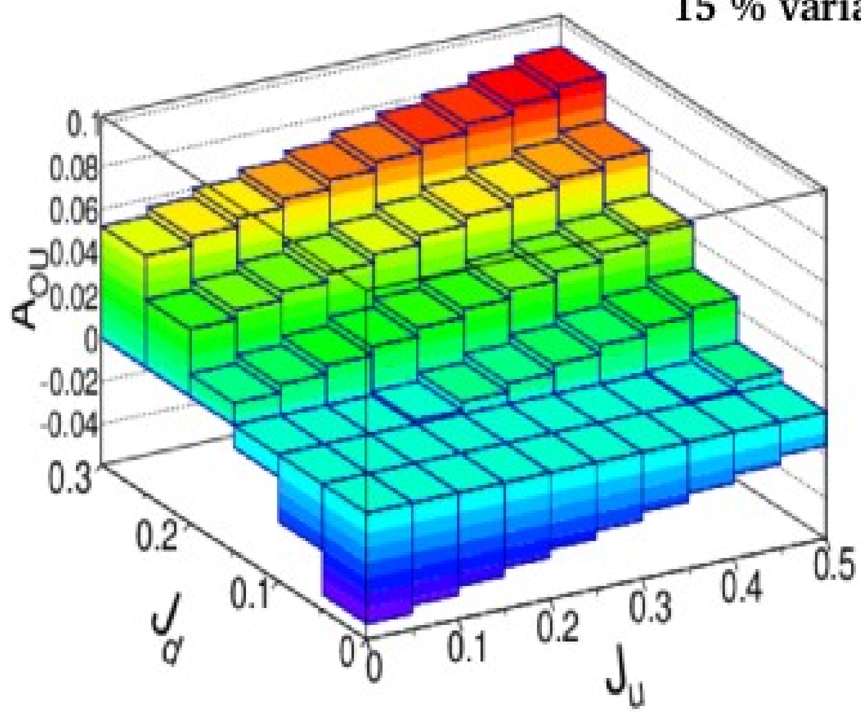
BSA as a function of u and d quark angular momenta J_u and J_d (max amplitude)

BSA(-t=.4 GeV^2) vs J_u and J_d for proton: **for neutron:**

5 % variations



15 % variations

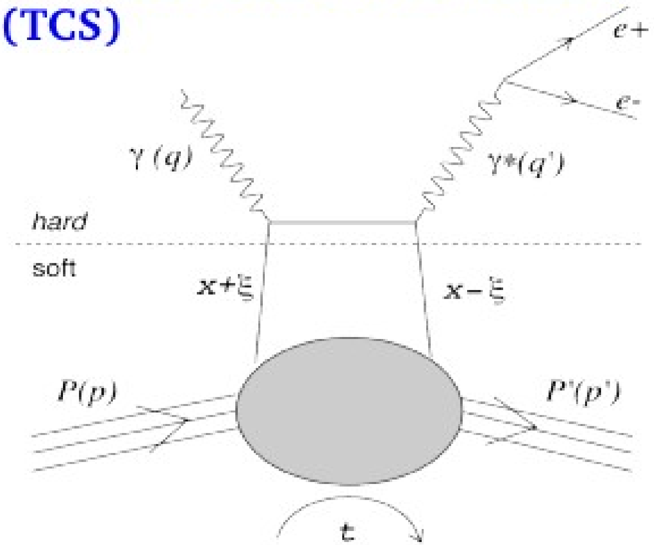


Stronger sensitivity to J_u and J_d + change of sign for BSA off the neutron

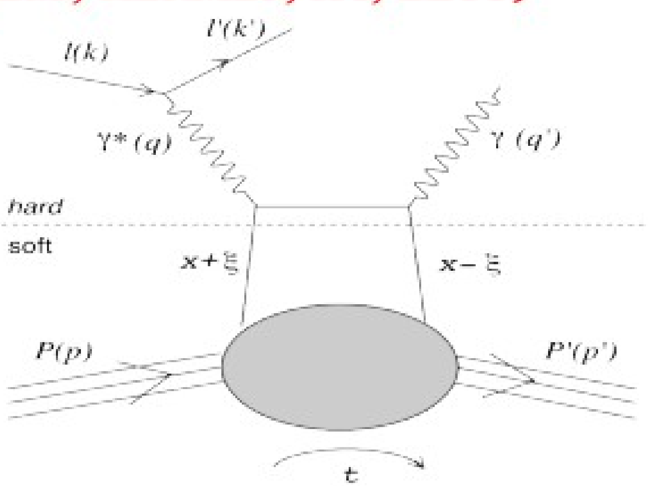
→ Ji sum rule… studies of angular momenta of quarks

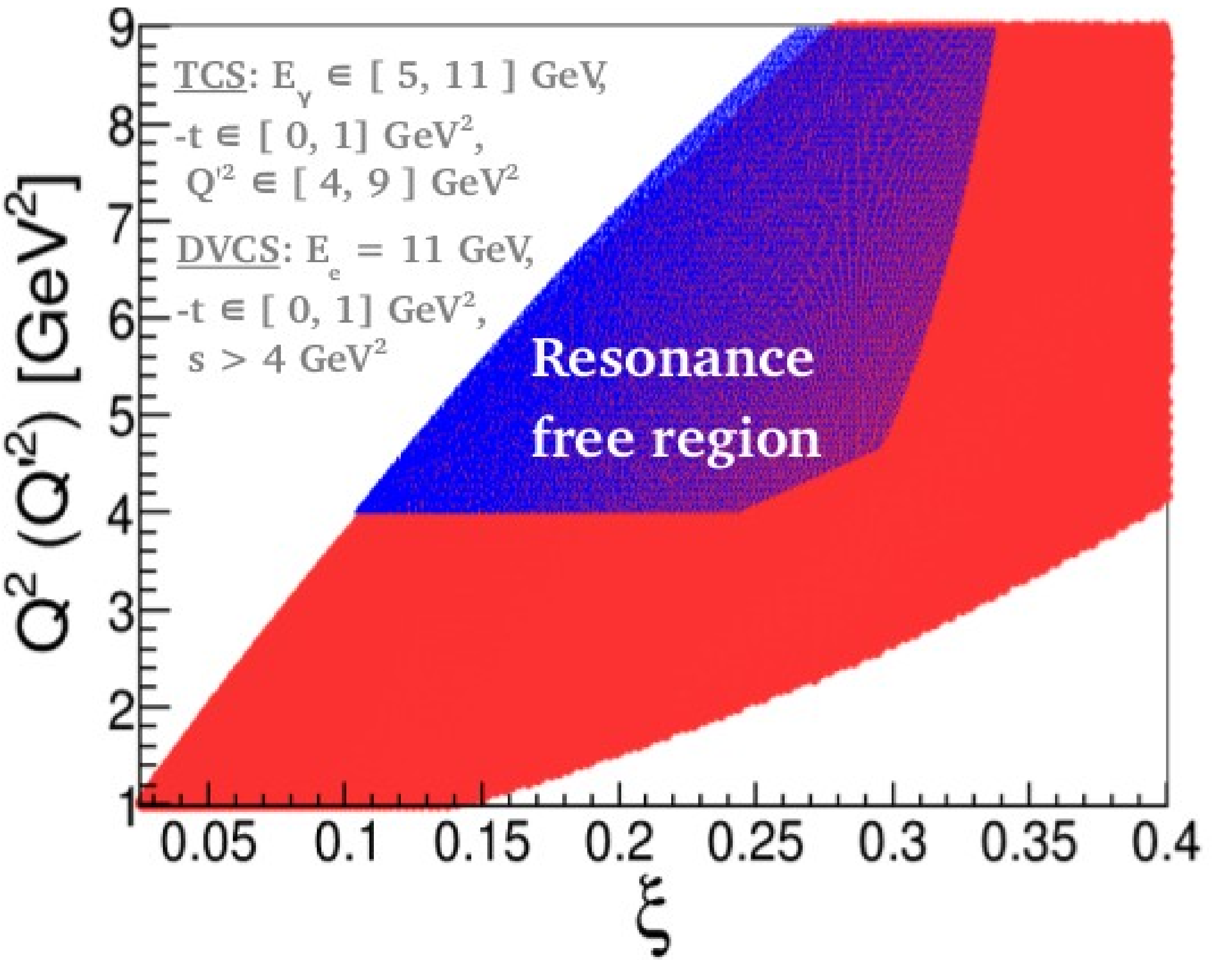
Fits of DVCS and of TCS : phase space for JLab at 12 GeV

Timelike Compton Scattering (TCS)



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





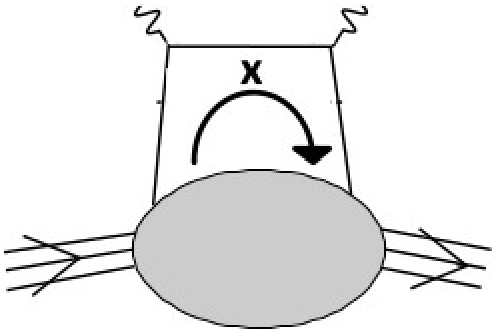
Interest of TCS and DVCS in parallel :

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

See talk of M. Guidal

Accessing GPDs with Compton Form Factors

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



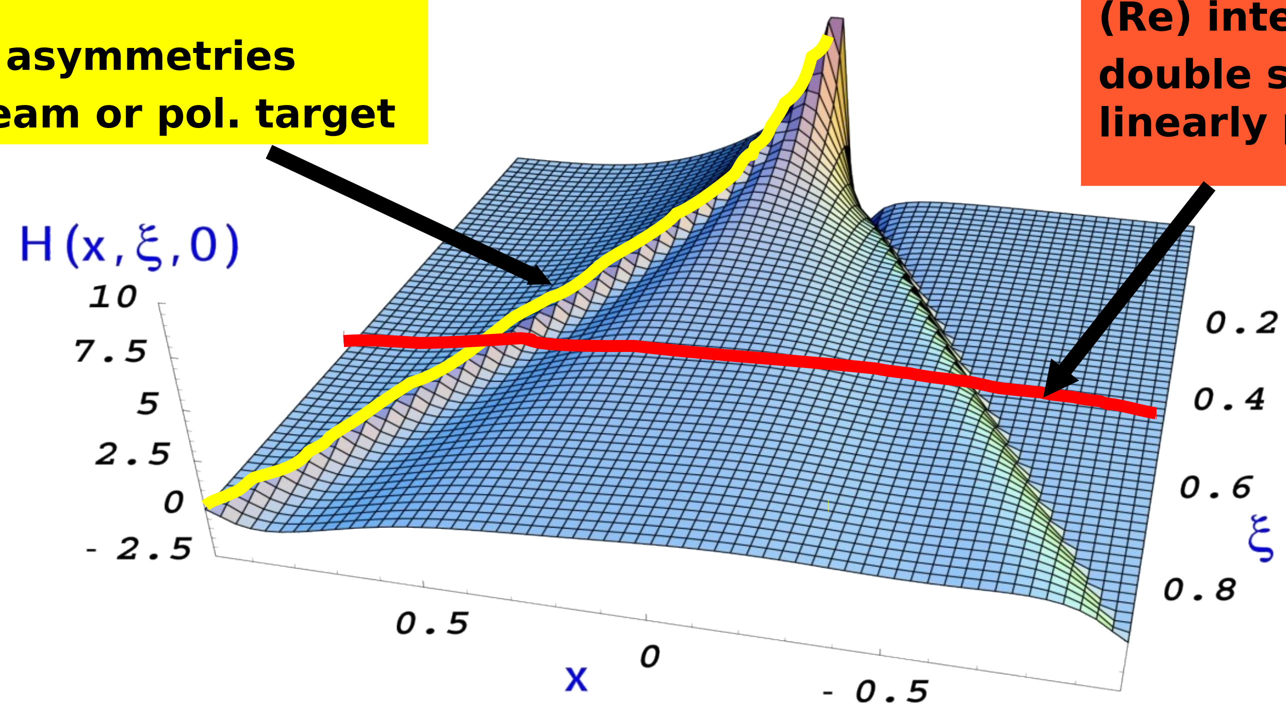
$$T^{DVCS} \sim \int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi + i\varepsilon} dx + \ldots \sim P\int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi} dx - i\pi H(\pm\xi,\xi,t) + \ldots$$

Compton Form Factor (CFF) — Re $(\mathcal{H})$ — Im $(\mathcal{H})$

CFF are extracted from different observables, at different kinematical points:

(Im, x=±ξ)
single spin asymmetries
circ. pol. beam or pol. target

(Re) integrate GPD over x
double spin asymmetries or linearly polarized beam



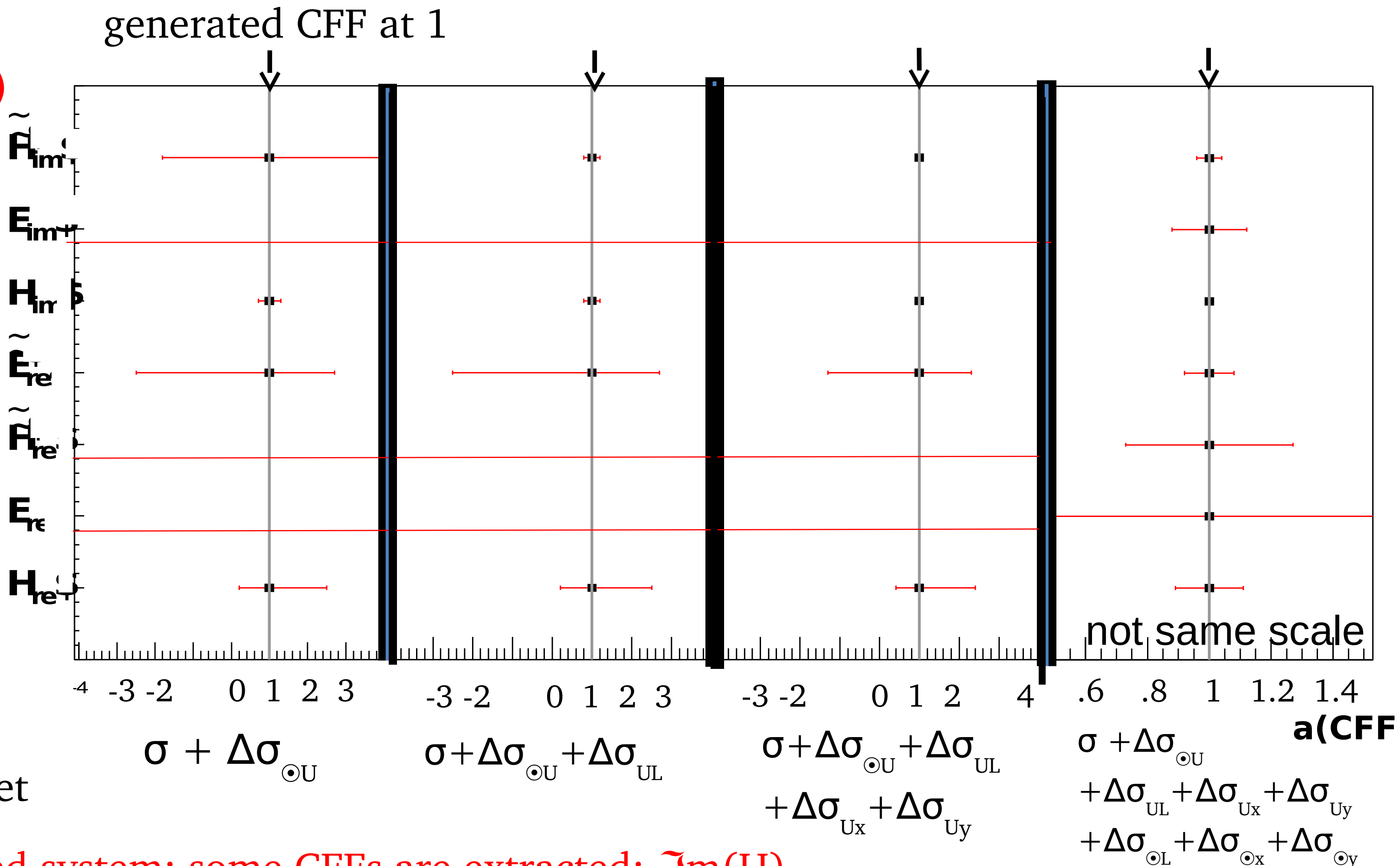
Set of results (uncertainties)

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

- underconstrained system: some CFFs are extracted: $\Im m(H)$
- 8 independant observables, 7 CFFs: all CFFs are extracted
- single spin asymmetries ∝ 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

Summary

- Nucleon "3D" imaging with Generalized Parton Distributions
- TCS signal: through interference with BH, with beam and/or target spin asymmetries
- 2 accepted proposals for JLab at 12 GeV: CLAS12 (Hall B) and SoLID (Hall A), 1 LOI NPS (Hall C)
- Other experimental perspectives : linearly polarized beam, real photon beam, double spin asymmetries, TCS off the neutron..
- Fits : CFFs can be extracted, interests for DVCS+TCS combined fits...