Generalized Parton Distributions measurements with Timelike Compton Scattering off the proton

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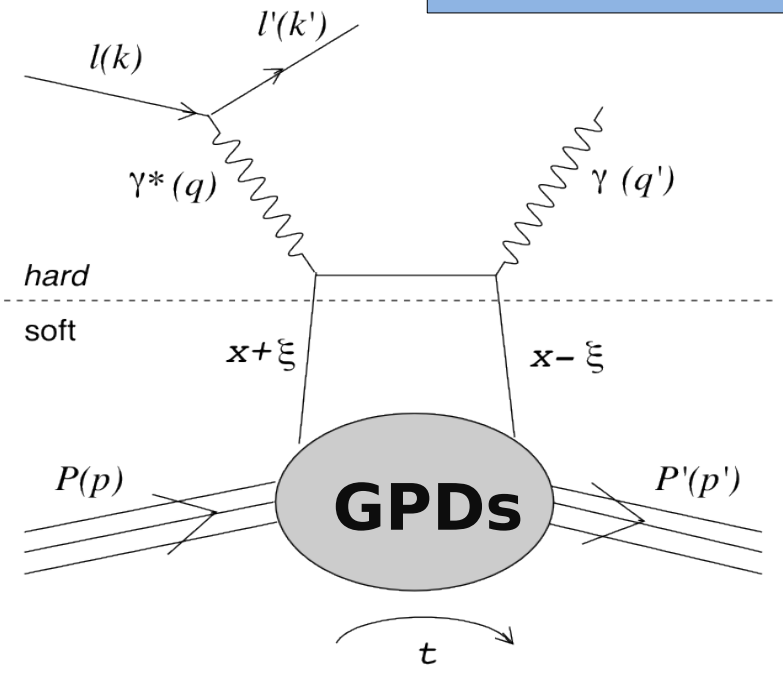
Results from: MB, M. Guidal, M. Vanderhaeghen, arXiv:1501.00270 [hep-ph]

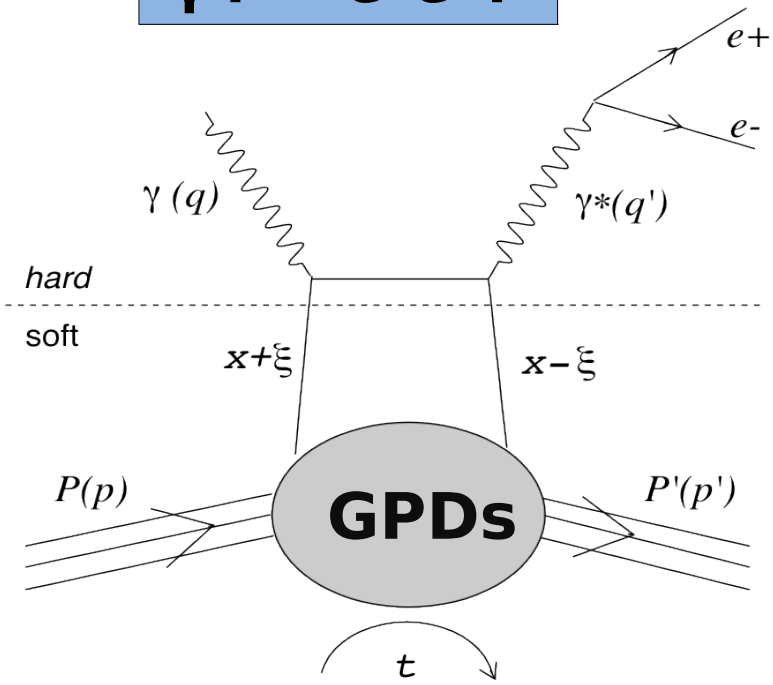
Timelike Compton Scattering

e P→e γ P



Deeply Virtual Compton Scattering

γ P → e⁺e⁻ P



Timelike Compton Scattering

x : average longitudinal momentum fraction of the struck quark

ξ : longitudinal momentum transfer

t << Q'² : momentum transfer

Q'² >> 1 GeV² : hard scale

Exclusive processes:

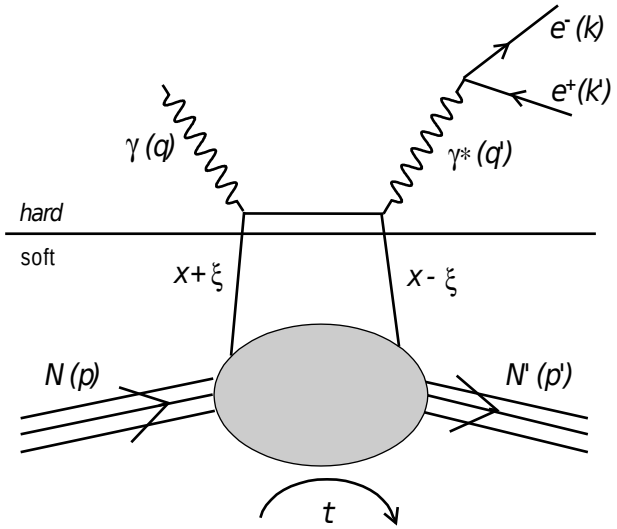
measurement of t and ξ

Soft part: Generalized Partons Distributions

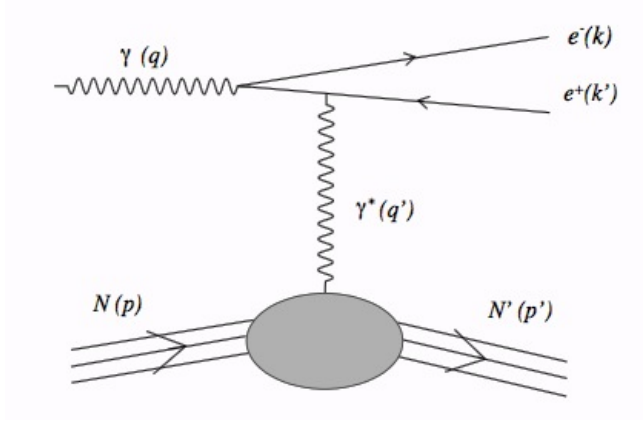
→ GPD(x , ξ , t ; Q'²)

TCS in exclusive lepton pair photoproduction

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



+



Timelike Compton Scattering (TCS)
sensitive to the nucleon GPDs

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

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

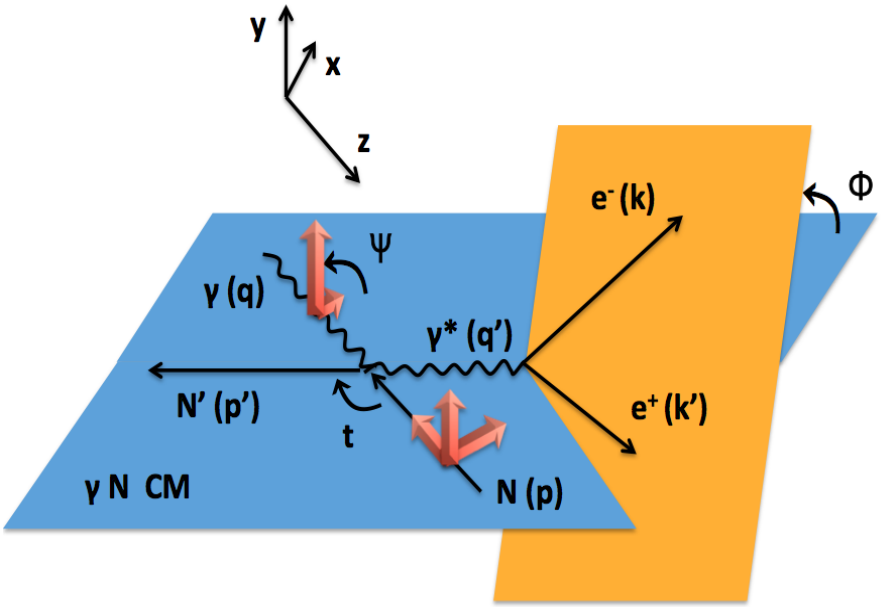
Angles and notations

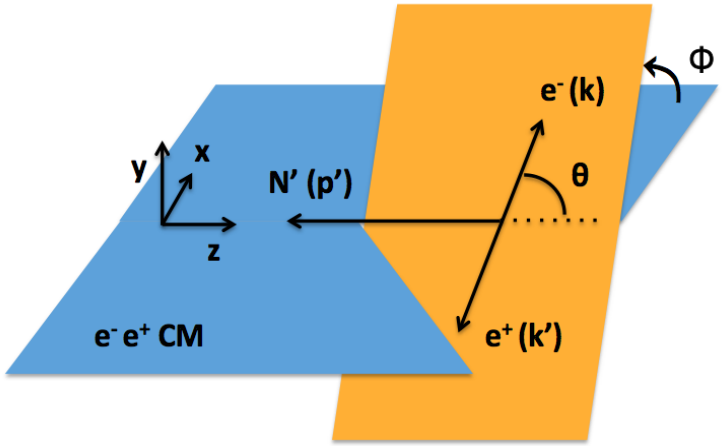
γ N → e⁺e⁻ N

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^-)





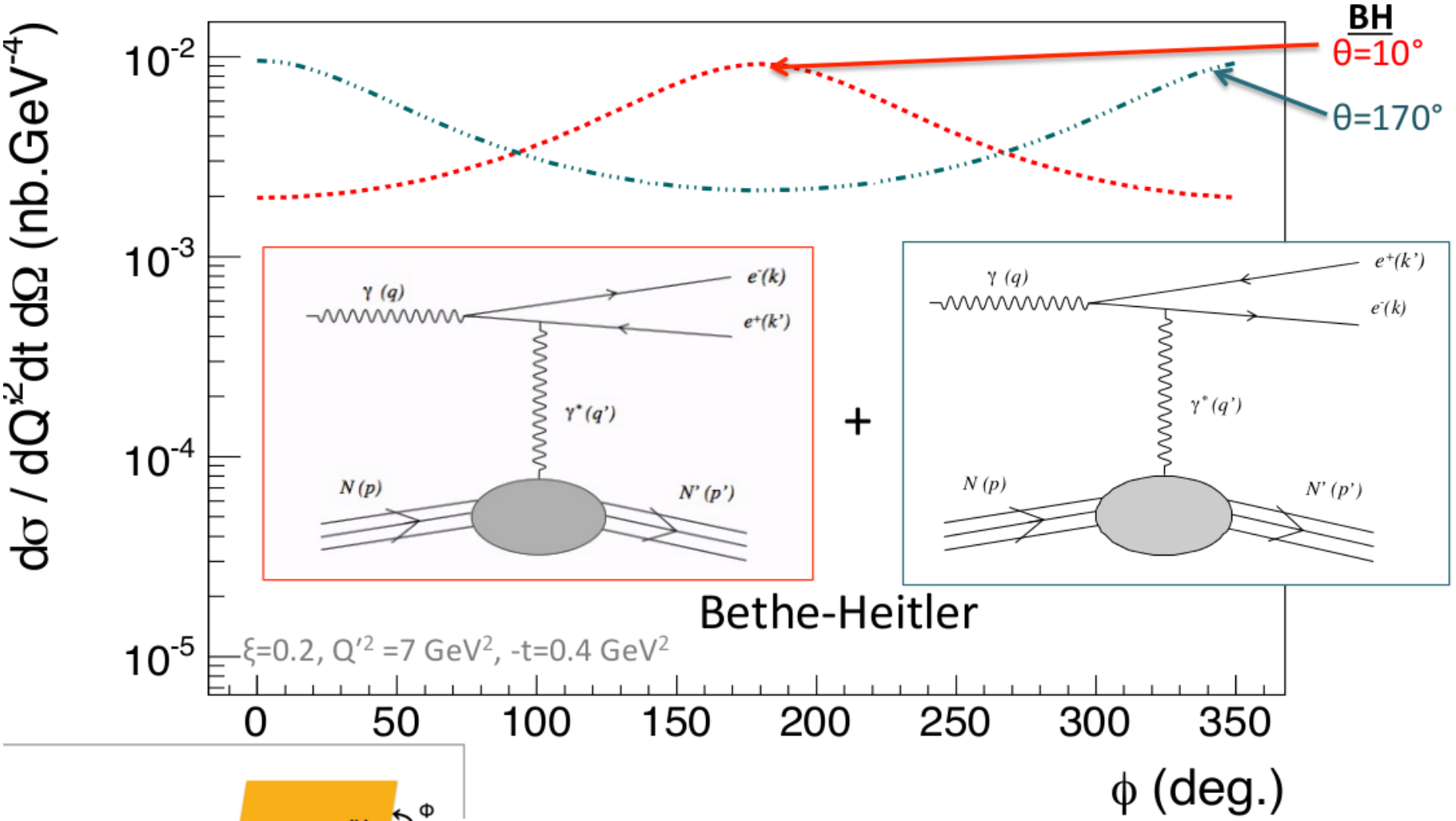
Notations

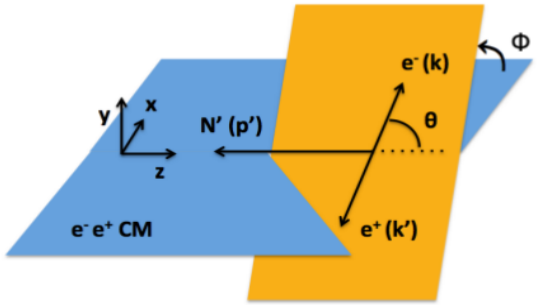
A_{ij} : asymmetry

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

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

Angular dependencies of the cross sections

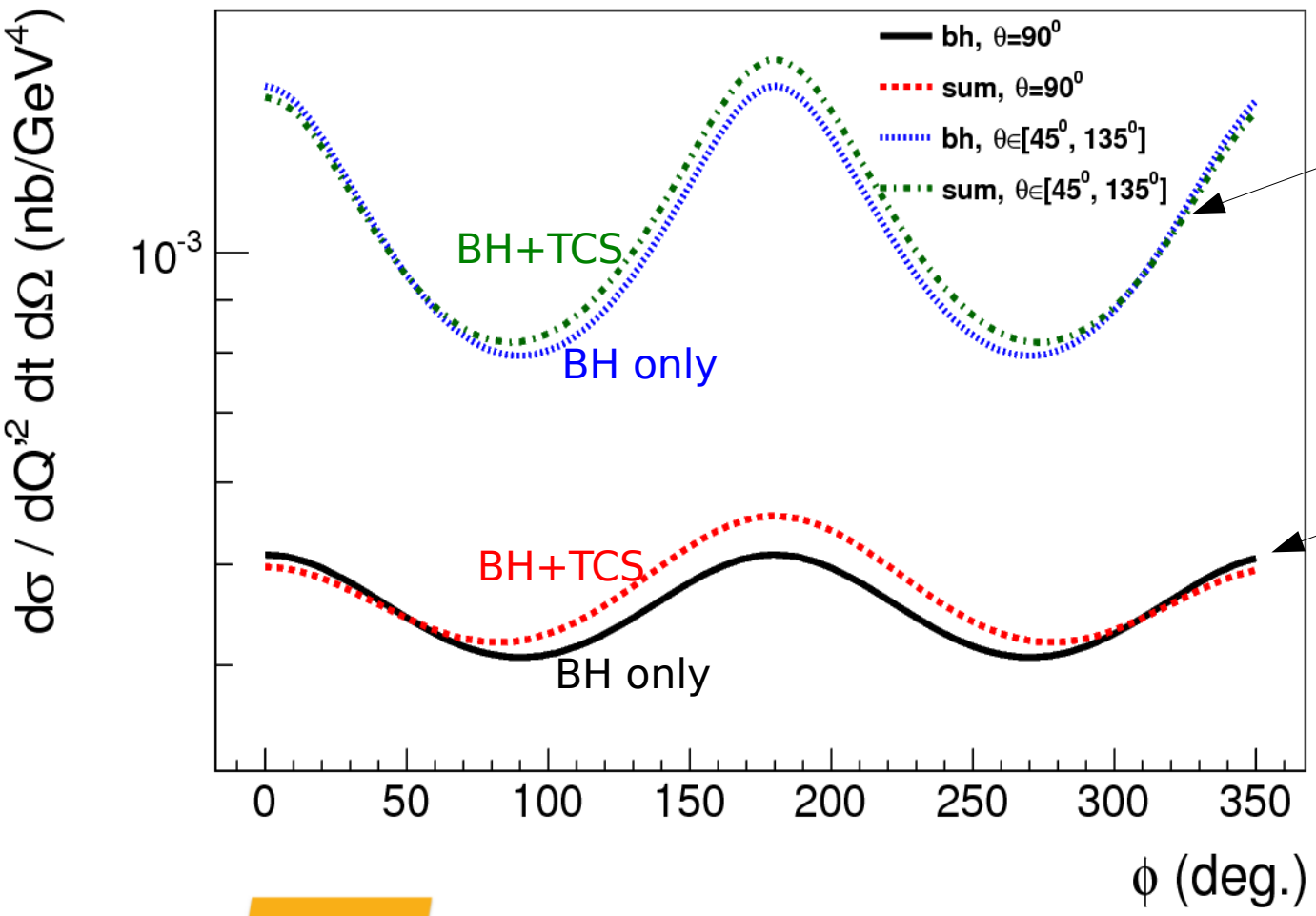




e^- in direction of γ ($\theta \longmapsto 0°$) ➪ Singularity at $\phi=180°$

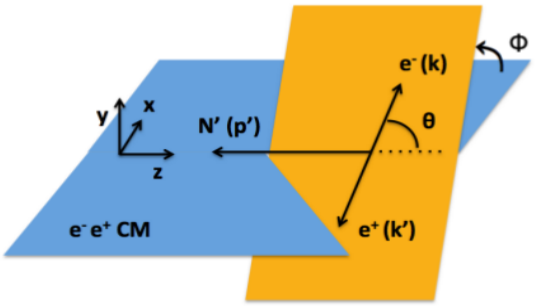
e^+ in direction of γ ($\theta \longmapsto 180°$) ➪ Singularity at $\phi=0°$

Angular dependencies of the cross sections



Integrated over polar decay angle

θ=90°



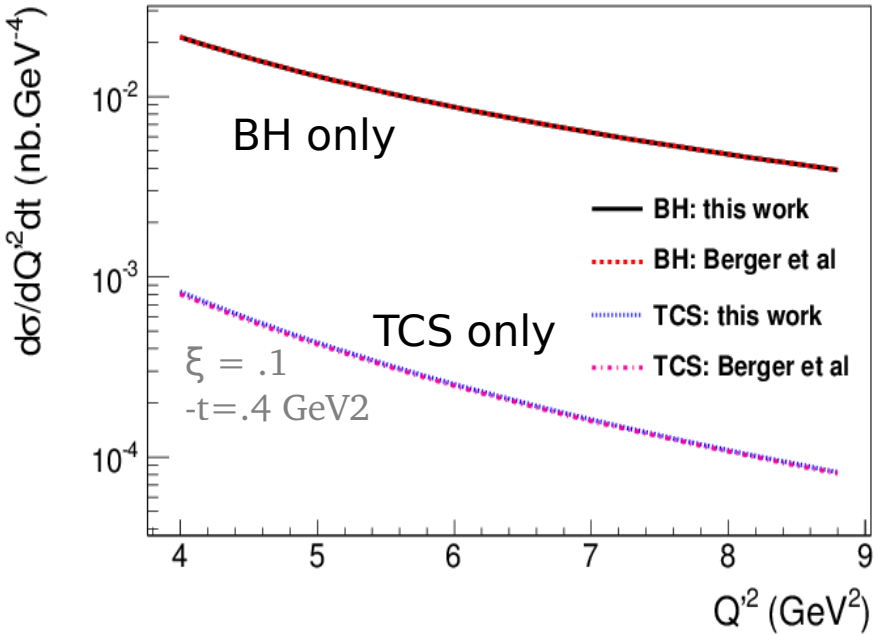
Integration over θ :
- BH singularities
- counting rates

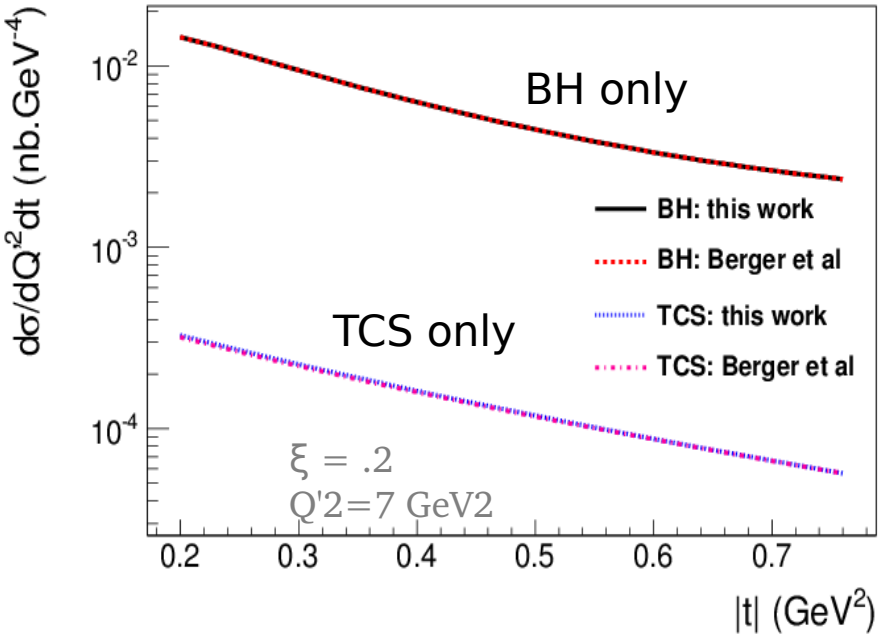
Kinematical dependencies and comparisons

cross sections vs Q'^2 and vs t

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

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

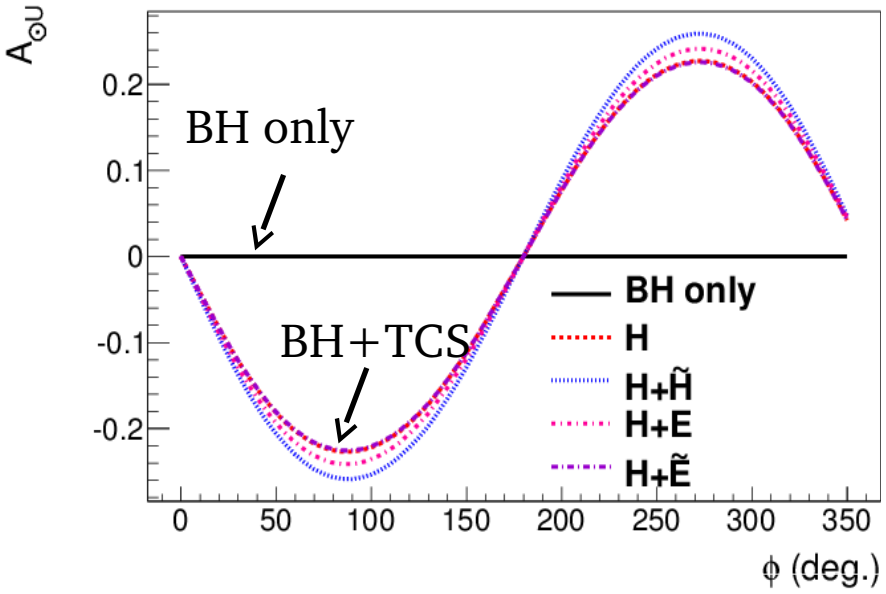




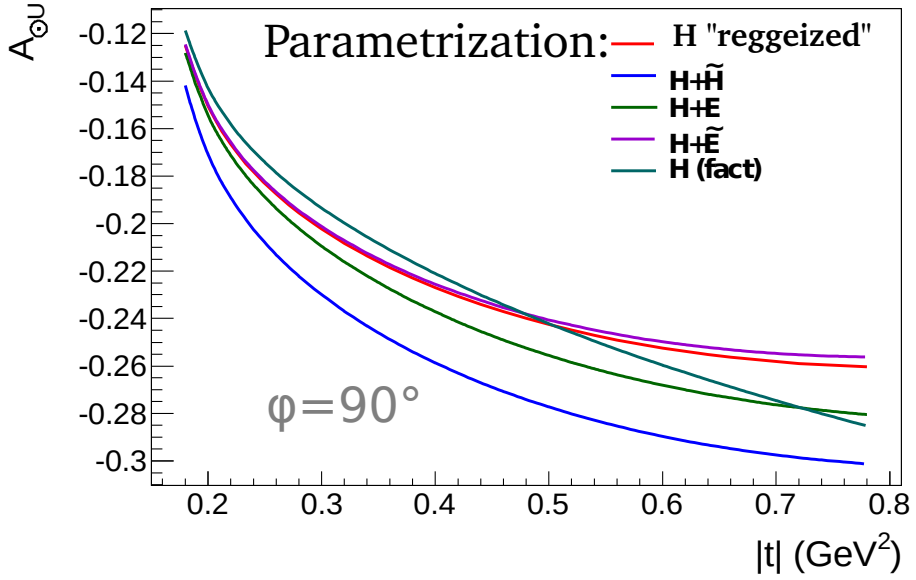
Asymmetries: circularly polarized beam

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

Angular dependence in Φ



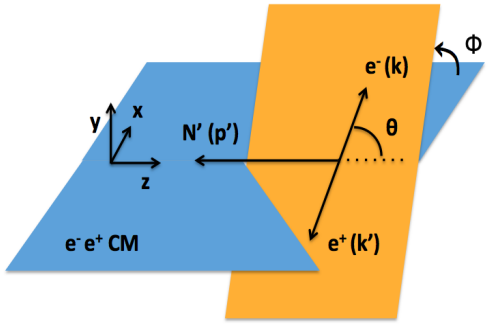
Kinematical dependence in -t



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

Asymmetry ≈20%

This observable : mostly sensitive to H and $\tilde{H}$



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

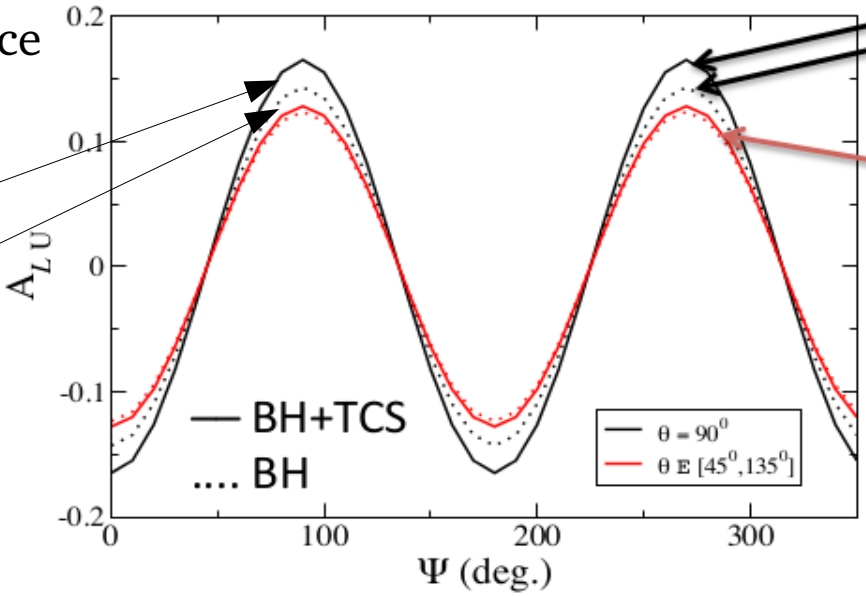
Asymmetries: linearly polarized beam

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

Angular dependence in Ψ

BH+TCS

BH only



BH+TCS (θ=90°,Φ=0°)

BH only

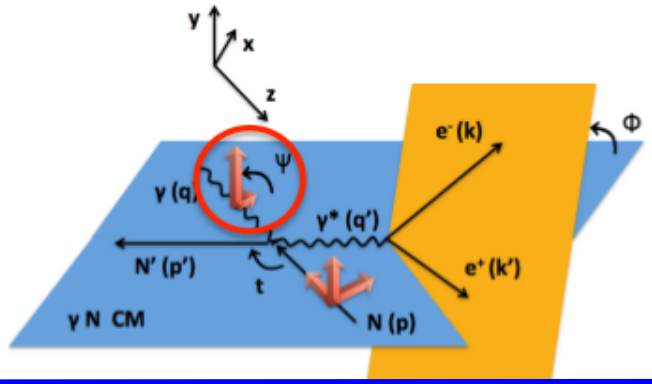
integrated over θ

(BH+TCS ≈ BH)

ξ=0.2, Q'^2 =7 GeV^2,

-t=0.4 GeV^2

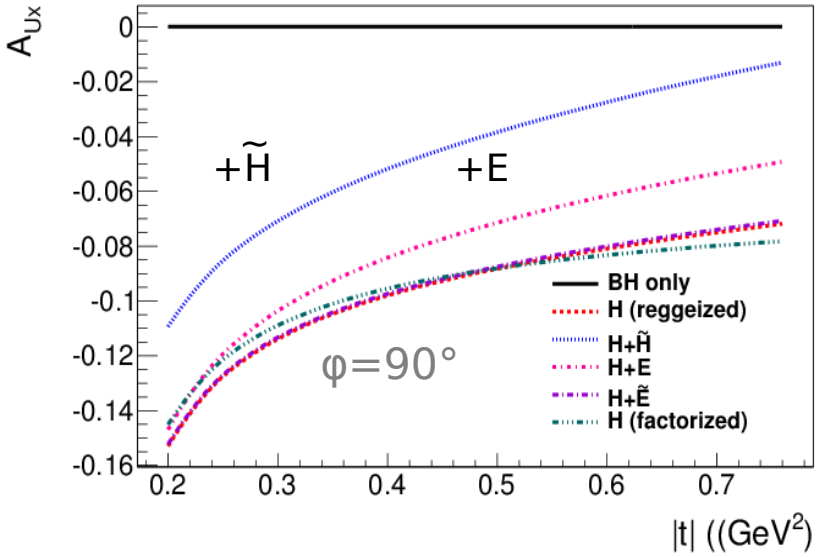
- **Real part of amplitudes ⟹ BH only ≠ 0**
- **Small deviation due to TCS, small sensitivity to the GPDs**
- **Bins in ϕ and θ required**



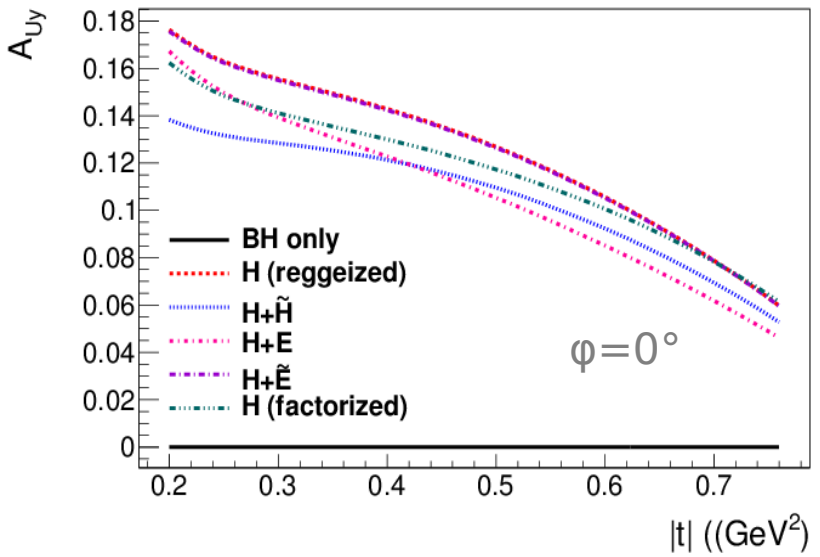
Polarized target : single spin asymmetries

Transversally polarized target asymmetries vs |t|

"in hadronic plane"



"perpendicular to hadronic plane"



- **Im part of amplitudes ⇒ 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°]

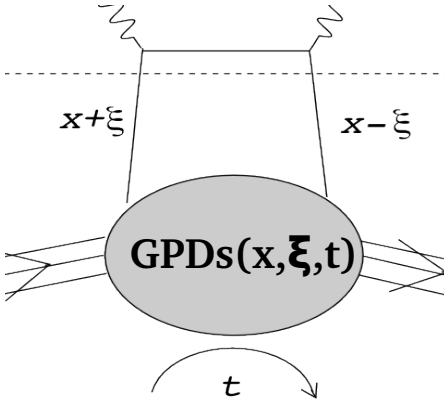
GPDs and Compton Form Factors

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

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

CFFs are measurable:

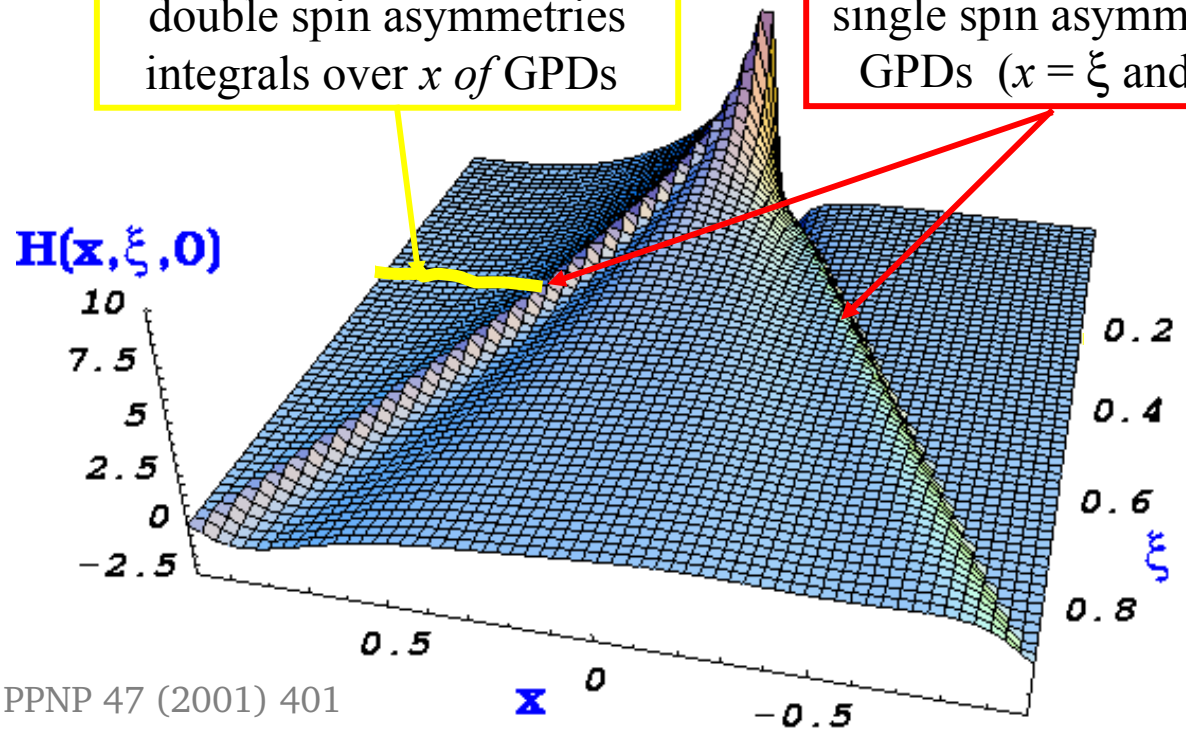
ξ, t : mesurables
x : loop variable
x±ξ : propagator



→ CFFs(ξ,t)

ReT: cross section and double spin asymmetries integrals over *x of* GPDs

ImT: beam or target single spin asymmetries GPDs ($x = \xi$ and $-\xi$)



Goeke, Polyakov, Vanderhaeghen PPNP 47 (2001) 401

Compton Form Factors with TCS fits

Could we extract CFFs from TCS fits ?

What is new with TCS in addition to DVCS ?

- **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

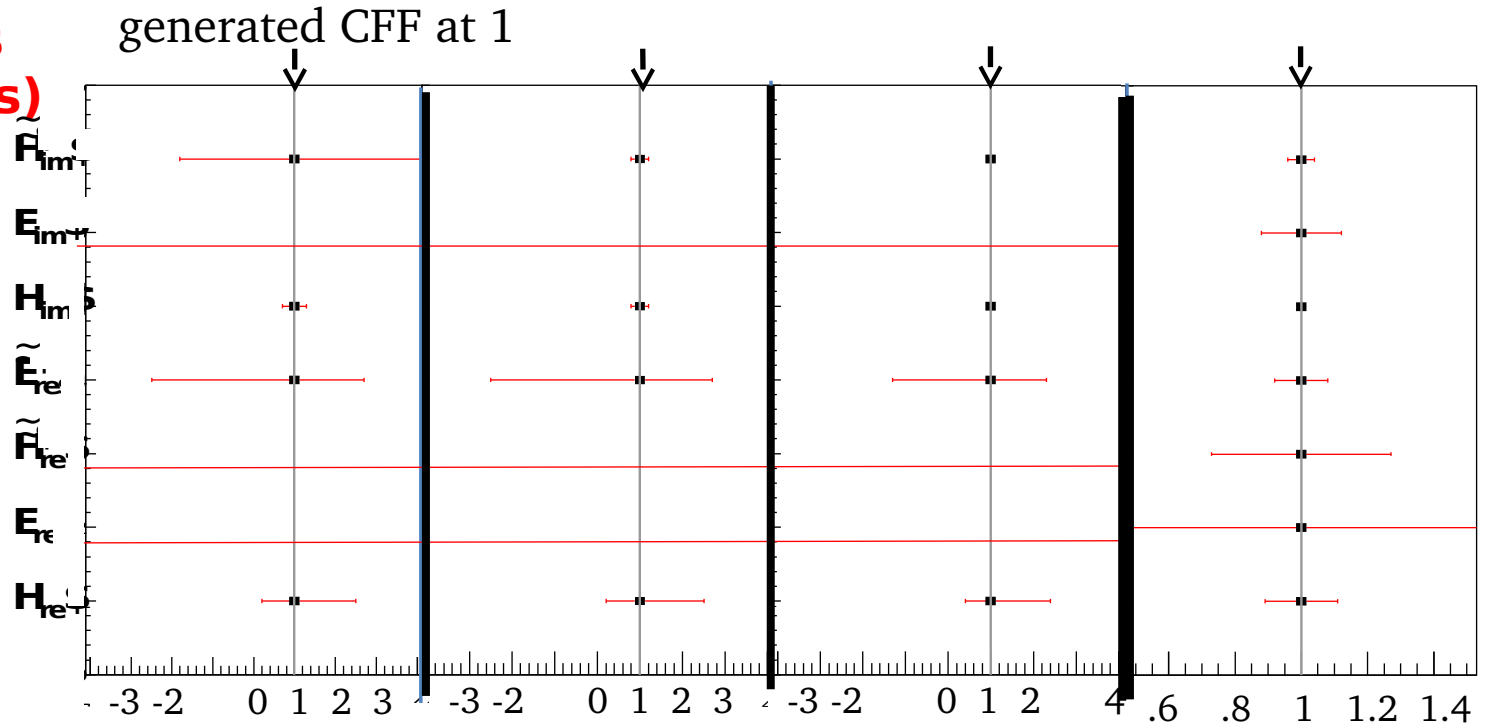
Set of results (uncertainties)

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, $\theta = 90°$



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

Compton Form Factors fits with DVCS+TCS

Set of results (expected uncertainties)

DVCS + TCS in combination in fits.

	$(\sigma, \Delta\sigma_{LU})$ DVCS 5%	$(\sigma, \Delta\sigma_{LU})$ DVCS 5% + TCS_ℓ 15%	$(\sigma, \Delta\sigma_{LU})$ DVCS 5% + TCS_c 15%	$(\sigma, \Delta\sigma_{LU})$ DVCS 5% + TCS_ℓ 5%	$(\sigma, \Delta\sigma_{LU})$ DVCS 5% + TCS_c 5%
$\sigma^+(Re\{\mathcal{H}\})$	+1.21	+0.92	+0.80	+0.54	+0.55
$\sigma^-(Re\{\mathcal{H}\})$	-0.84	-0.79	-0.83	-0.44	-0.45
$\sigma^+(Im\{\mathcal{H}\})$	+0.23	+0.20	+0.15	+0.11	+0.12
$\sigma^-(Im\{\mathcal{H}\})$	-0.50	-0.40	-0.21	-0.27	-0.19
		+TCS $(\sigma+\Delta\sigma_{LU})$	+TCS $(\sigma+\Delta\sigma_{\odot U})$		

Uncertainties are reduced by ~2

Summary

Unpolarized + beam and/or target polarized cross sections

- Single spin asymmetries (circularly polarized beam or target) most favorable for GPDs, sensitive to the imaginary part of amplitudes
- Linearly beam polarized asymmetry and cross section sensitive to the real part

Fits on pseudo-data and GPD extraction

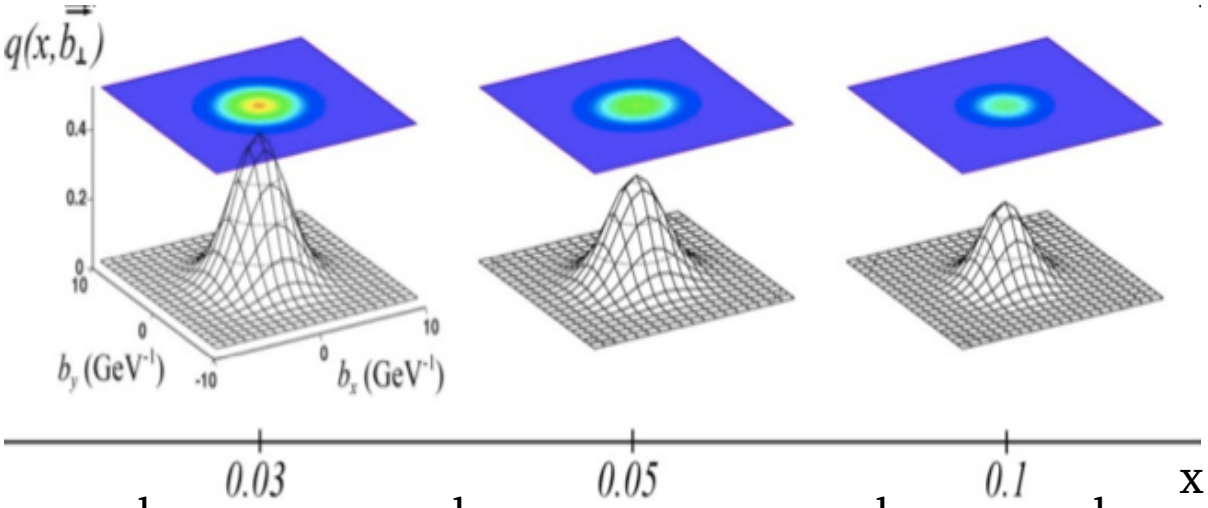
- CFFs and GPDs can be extracted with TCS
- Comparisons to DVCS in the same kinematical range: universality of GPDs, more independant observables...

Experimental perspectives in JLab

- Hall B : approved proposal for CLAS12, unpolarized and beam polarized cross.
- Hall A : SoLID (Z. Zhao's talk)
- Hall C : LOI for a transversally polarized target

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

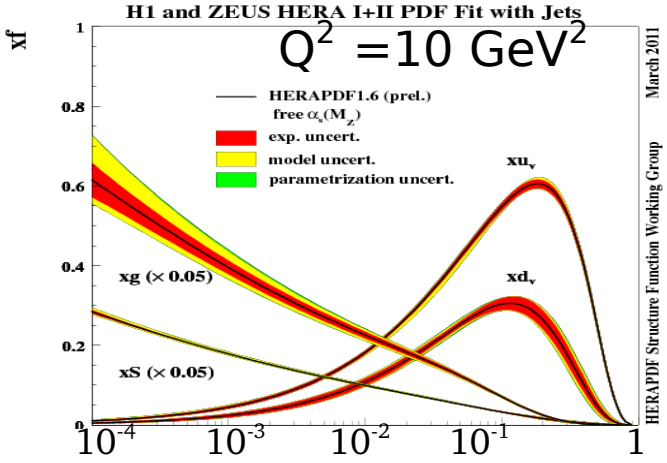
$q(x) = H(x, \xi=0, t=0)$

t = 0

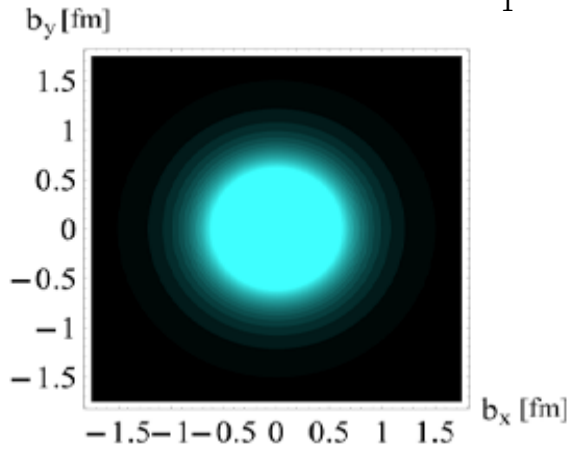
$\int$ dx

Transverse charge density

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



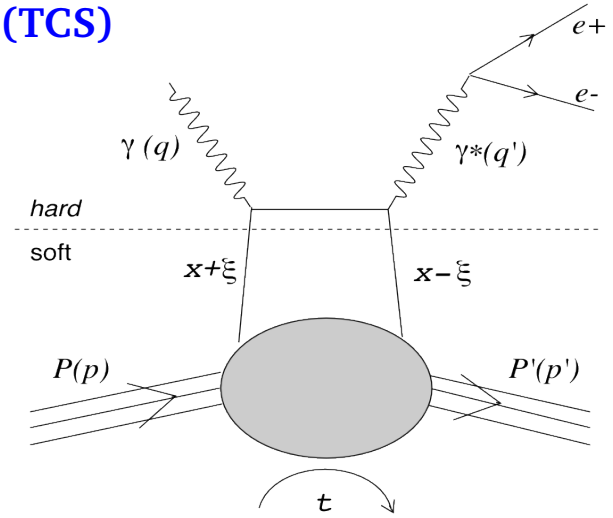
(HERA pdf)



Carlson, Vanderhaeghen, PRL 100 (2008) 032004

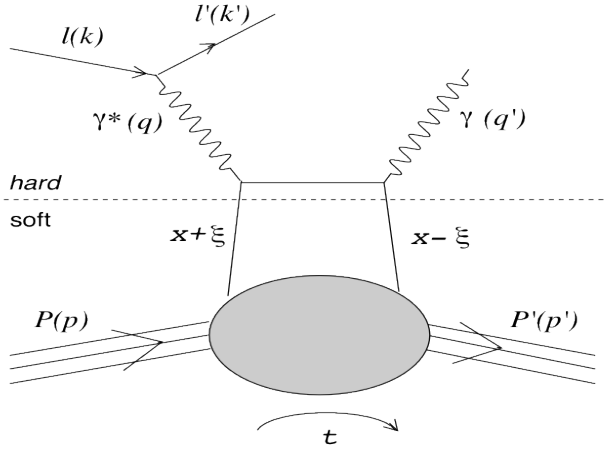
Phase Space for TCS and DVCS at JLab @ 12 GeV

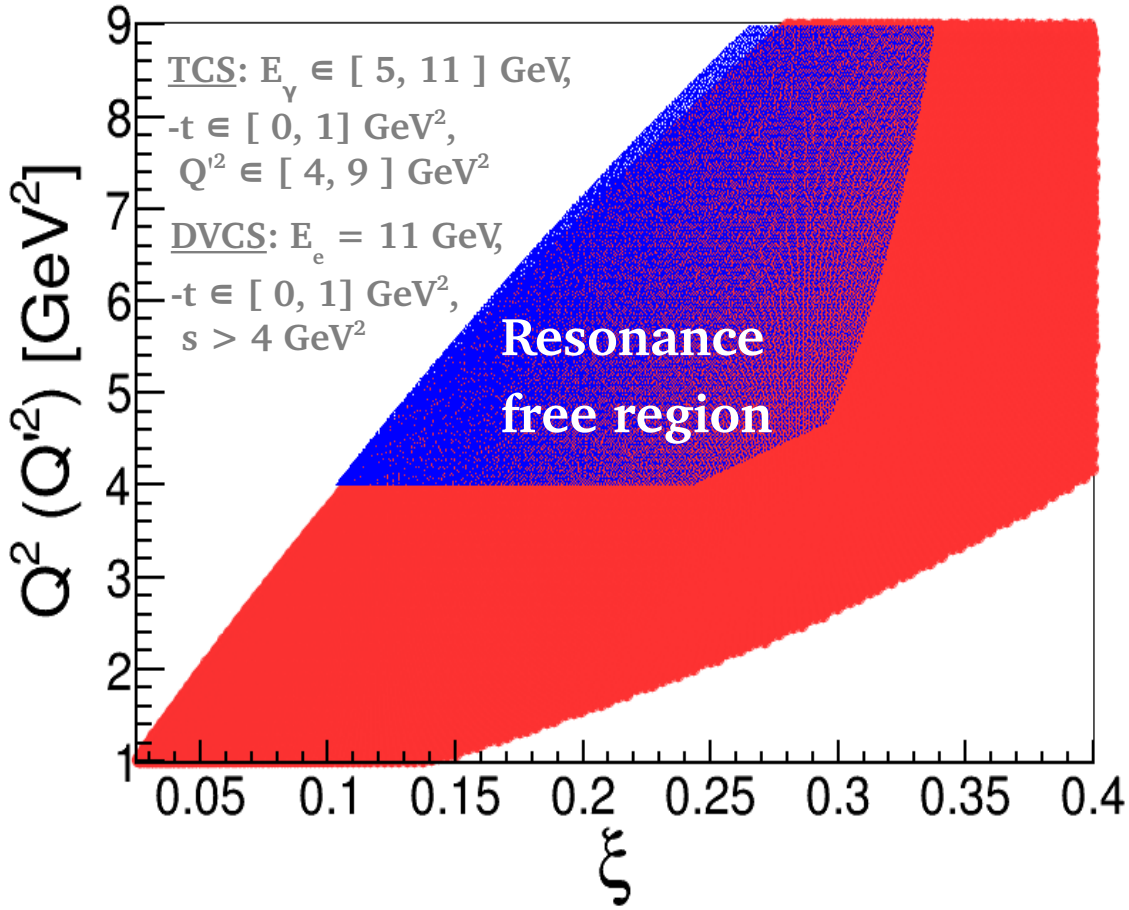
Timelike Compton Scattering (TCS)



Deeply Virtual Compton Scattering (DVCS)

Measurements already published (JLab, HERMES, H1, ZEUS)



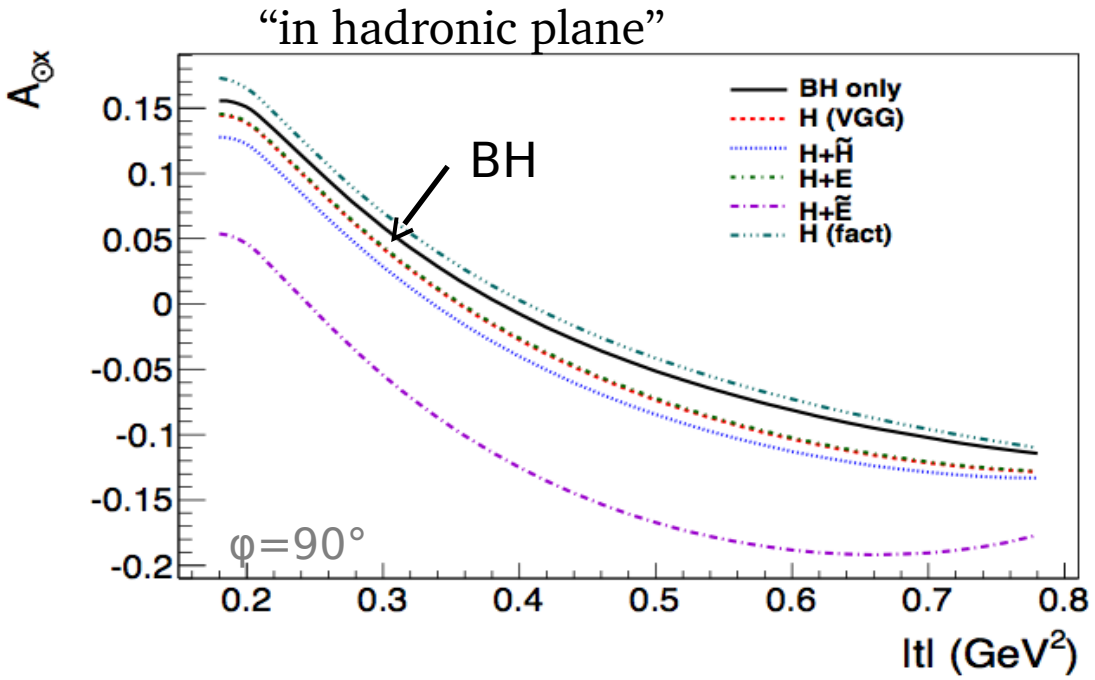


Interest of TCS and DVCS in parallel :

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

Polarized beam and target : double spin asymmetries

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



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

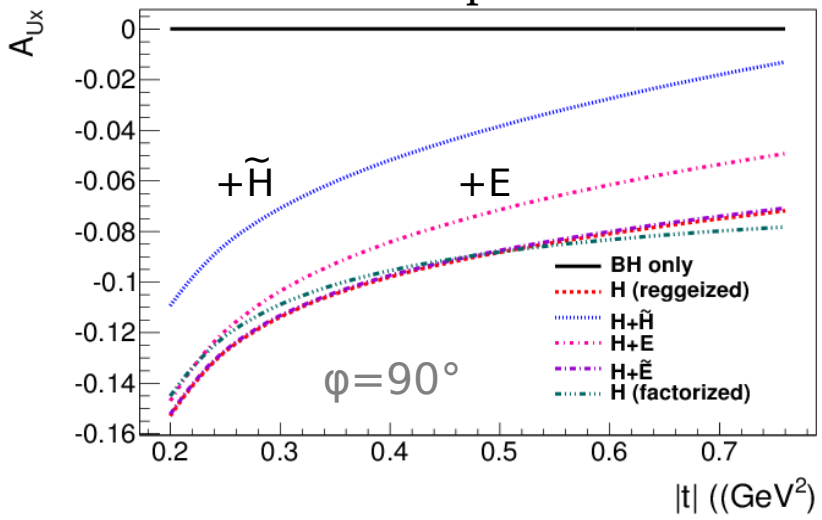
- A[BH]≠0 , few % deviation from TCS signal
- Bins in **φ** and **θ** preferable for signal
- Experimental difficulties (stat...)

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

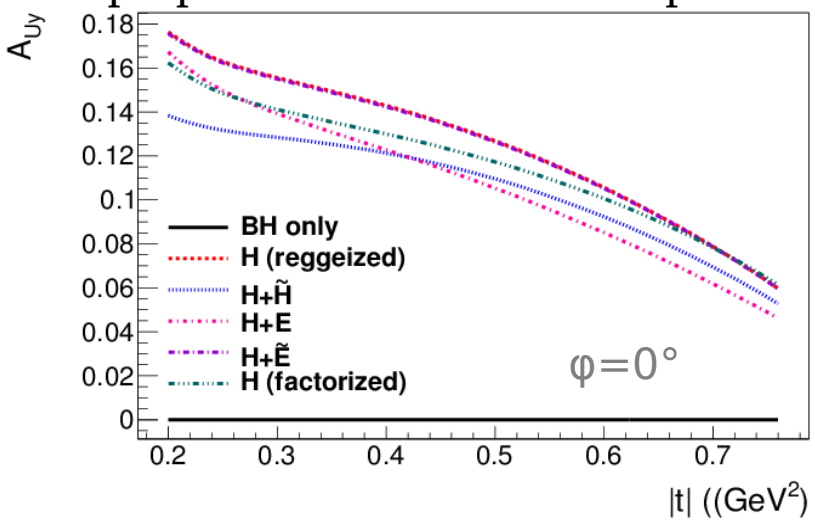
Polarized target : single spin asymmetries

Transversally polarized target asymmetries vs |t|

"in hadronic plane"

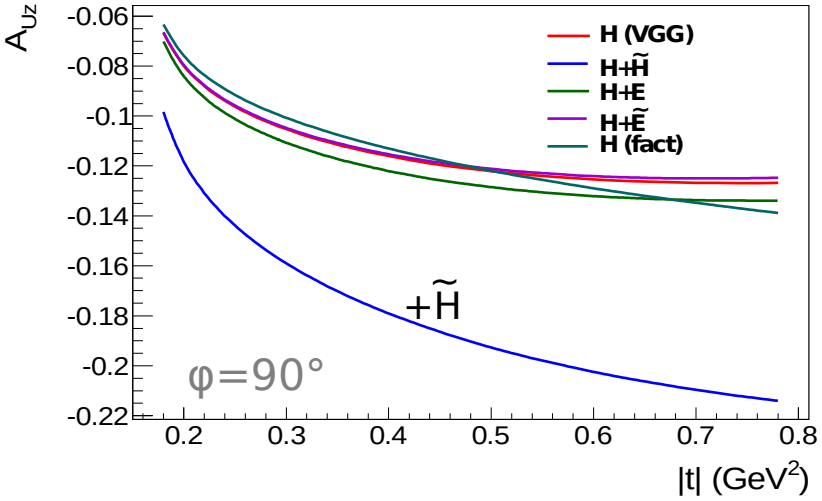


"perpendicular to hadronic plane"



GPD E +H̃

Longitudinaly polarized target asymmetry vs |t|



GPD H̃

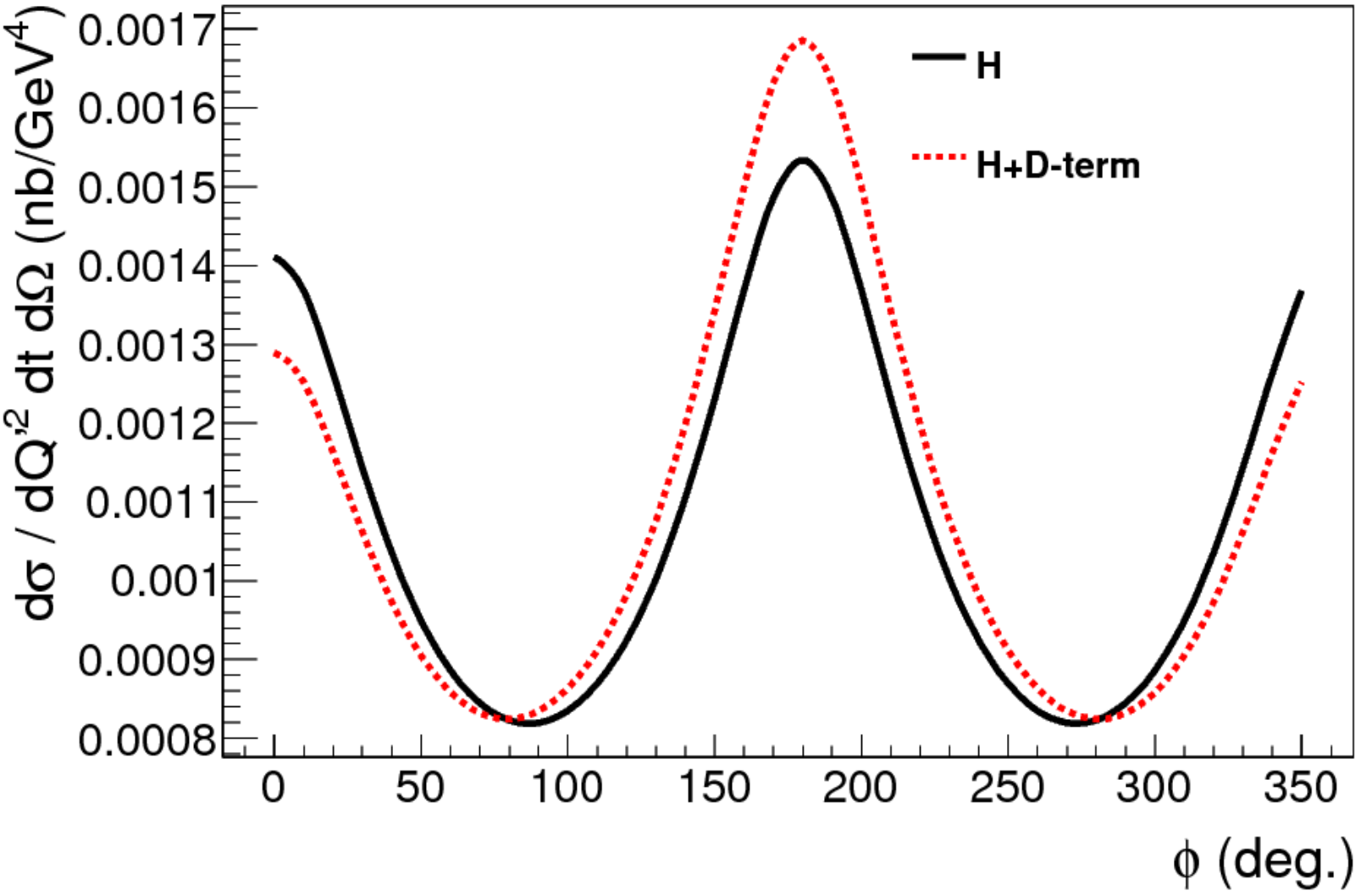
- Im part of amplitudes

⇒ A_{Ui} [BH] = 0

- Sensitive to H, H̃, E

10% to 20% asymmetries

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


0.0017
0.0016
0.0015
0.0014
0.0013
0.0012
0.0011
0.001
0.0009
0.0008
dσ / dQ'2 dt dΩ (nb/GeV4)
H
H+D-term
0
50
100
150
200
250
300
350
ϕ (deg.)

Asymmetries (TCS)	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

Photon beam polarization rate