Deeply Virtual Compton Scattering at Jlab/CLAS

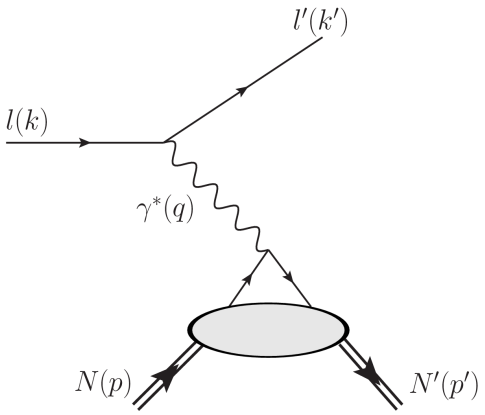
Baptiste GUEGAN

PANDA collaboration meeting 09/10/12

IPN Orsay

Nucleon structure using the electromagnetic probe

Elastic scattering

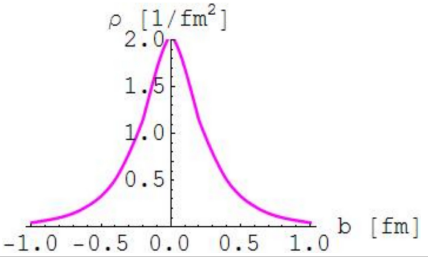


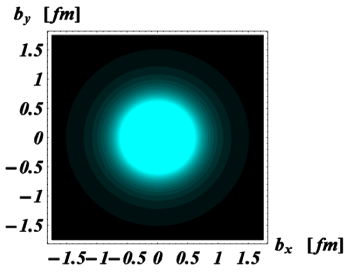
Local non-forward matrix element:

$$\langle p' | \bar{q}(0) O q(0) | p \rangle$$

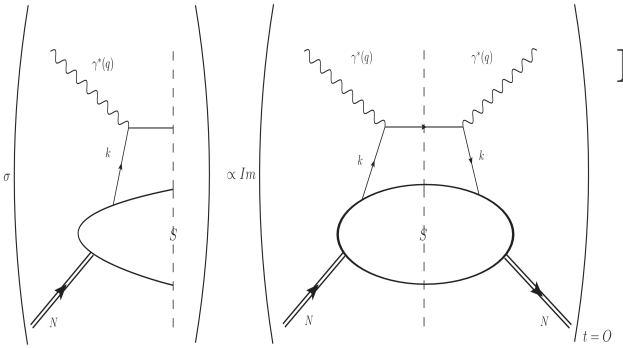
→ Form factors: $F_1(t), F_2(t), G_A(t), G_P(t)$

Interpreted as the transverse localisation of partons in the nucleon (independently of their longitudinal momentum)





Deep inelastic scattering

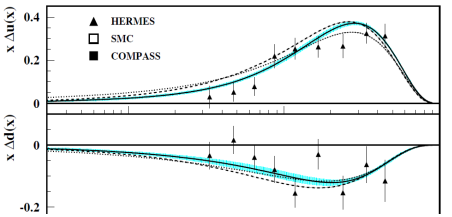


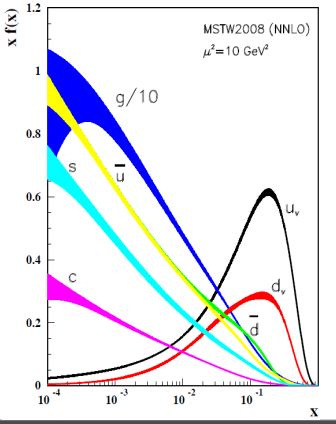
Non-Local forward matrix element:

$$\langle p | \bar{q}(0) O q(y) | p \rangle$$

→ Structure functions: $f_2(x)$, $g_1(x)$

Interpreted as the longitudinal momentum distribution
(no information on the transverse localisation)

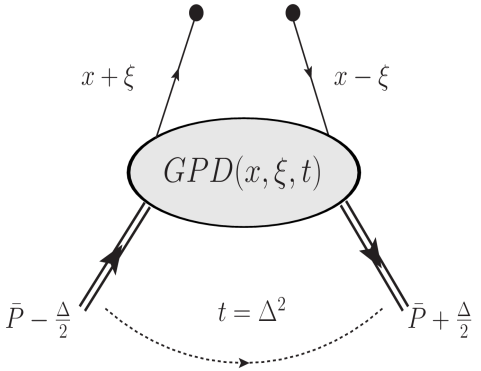




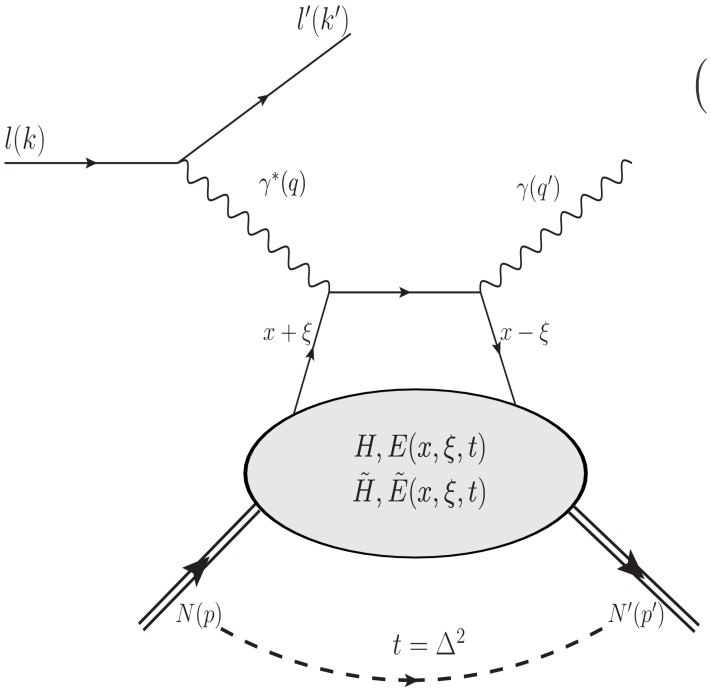
Generalized Parton Distributions

Extension to the non-local, non-forward matrix element:

$$\langle p' | \bar{q}(0) O q(y) | p \rangle$$



Accessed with the Deeply Virtual Compton Scattering :



$(x+\xi)$ and $(x-\xi)$: longitudinal momentum fractions of quarks

$t=\Delta^2=(p'-p)^2$: squared momentum transfer

Unpolarized GPDs :

(quark helicity independent)

- $H(x,\xi,t)$ Vector
- $E(x,\xi,t)$ Tensor

Polarized GPDs:

(quark helicity dependent)

- $\tilde{H}(x,\xi,t)$ Axial - Vector
- $\tilde{E}(x,\xi,t)$ Pseudoscalar

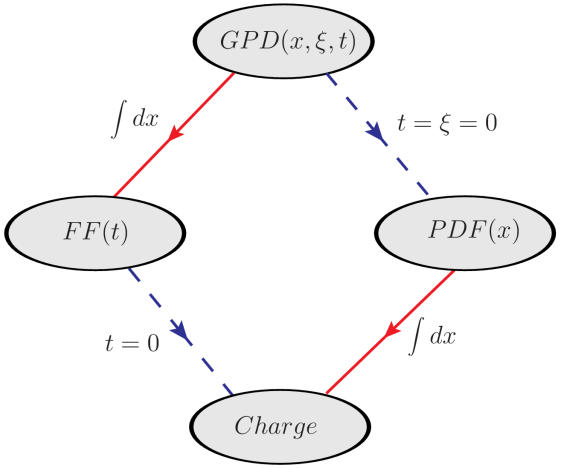
At large Q^2, the process can be factorized and described by 4 Generalized Parton Distributions

GPDs properties

- In the forward limit (t=ξ=0), the GPDs reduce to PDFs:

$$H(x,0,0)=q(x) \qquad \tilde{H}(x,0,0)=\Delta q(x)$$

No similar equations for E and $\tilde{E}$. New information !



- The first moment of the GPDs reduce to the FFs:

$$\int_{-1}^{1} dx\, H(x,\xi,t)=F_1(t) \qquad \int_{-1}^{1} dx\, E(x,\xi,t)=F_2(t)$$
$$\int_{-1}^{1} dx\, \tilde{H}(x,\xi,t)=G_A(t) \qquad \int_{-1}^{1} dx\, \tilde{E}(x,\xi,t)=G_P(t)$$

- The second moment of (E+H) when t → 0 : total angular momentum

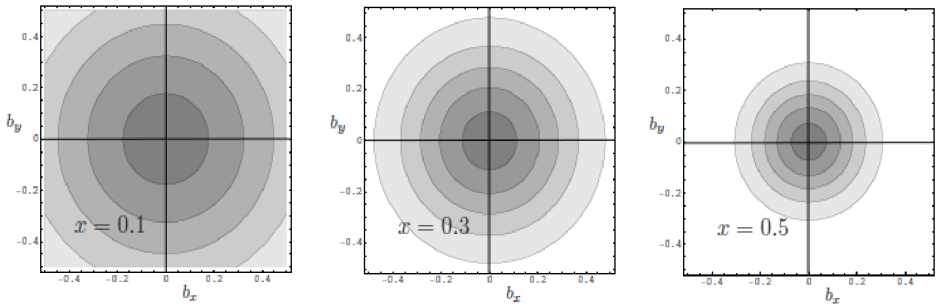
$$\int_{-1}^{1} dx\, x[H^q(x,\xi,0)+E^q(x,\xi,0)]=2J_{quarks}$$

$$\frac{1}{2}=(S_{quarks}+L_{quarks})+J_{gluons}$$

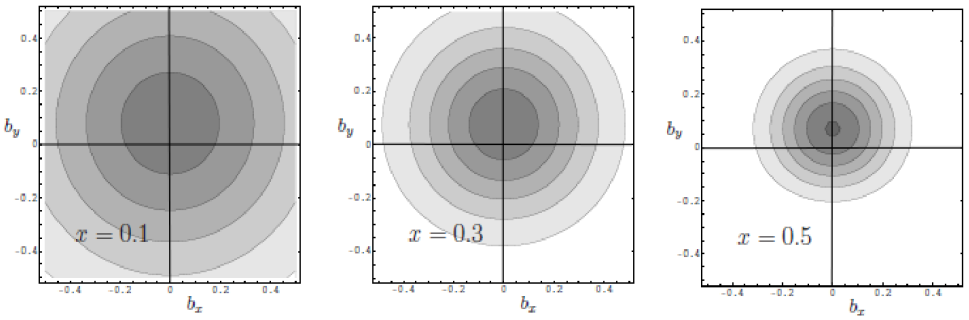
$EMC:\ \approx 30\,\%$

- At ξ = 0, a GPD is a x-decomposition of the form factor:

u-quark distribution in a unpolarized proton



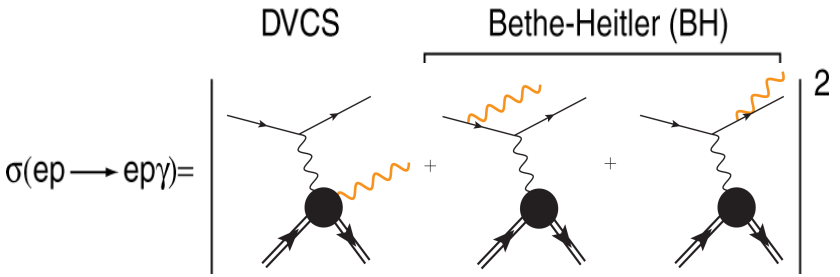
u-quark distribution in a polarized proton



Exclusive electroproduction of a photon

Contribution from both DVCS and Bethe-Heitler (undistinguishable experimentally):

$$\sigma_{(ep\to ep\gamma)} \propto \left|T^{DVCS}+T^{BH}\right|^2$$



- $\mathcal{T}_{BH}$ At low t, the nucleon FFs (Dirac, Pauli) are well known so that $\mathcal{T}_{BH}$ is precisely calculable
- $\mathcal{T}^{DVCS} \propto \int_{-1}^{1} dx \frac{f(x,\xi,t)}{x\pm\xi\mp i\epsilon} = \mathcal{P}\int_{-1}^{1} dx \frac{f(x,\xi,t)}{x\pm\xi} \pm i\pi f(x=\mp\xi,\xi,t)$

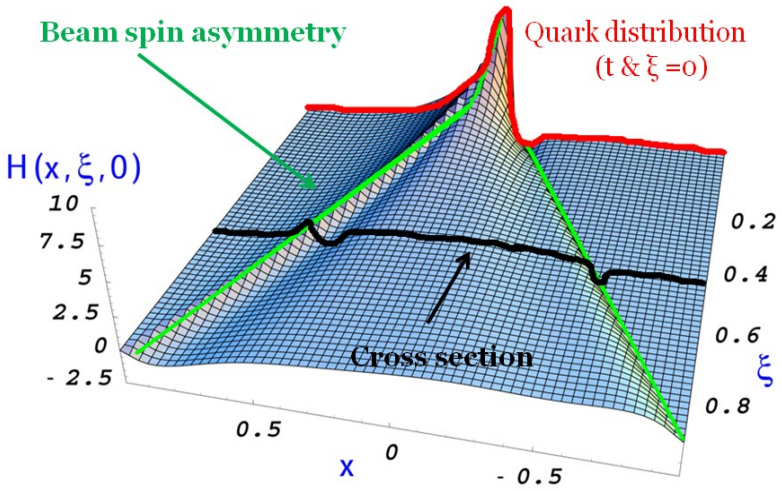
➡ GPDs appear in the **real part** through an integral over x

➡ GPDs appear in the **imaginary part** at the lines $x=\pm\xi$

With a polarized beam and an unpolarized target, one can measure 2 observables:

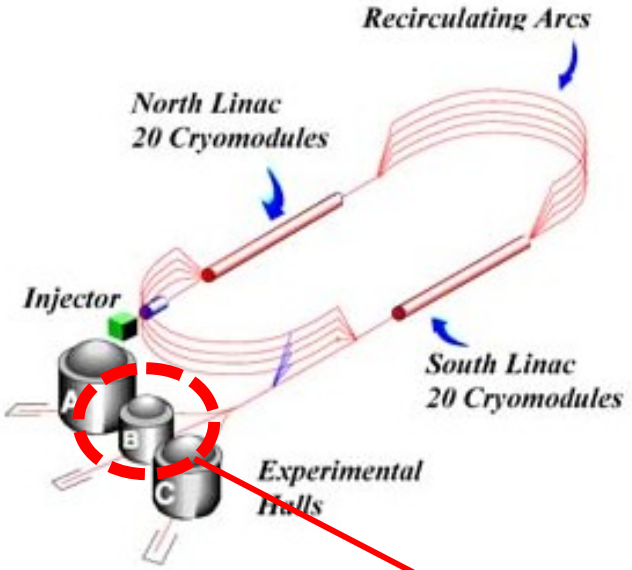
$$\frac{d^4\sigma}{dtdQ^2dx_Bd\phi} \approx \left|T^{BH}\right|^2 + 2T^{BH}.\mathrm{Re}(T^{DVCS}) + \left|T^{DVCS}\right|^2$$

$$\frac{d^4\vec{\sigma}-d^4\overleftarrow{\sigma}}{dtdQ^2dx_Bd\phi} \approx 2T^{BH}.\mathrm{Im}(T^{DVCS}) + \left[\left|T^{\vec{DVCS}}\right|^2 - \left|T^{\overleftarrow{DVCS}}\right|^2\right]$$

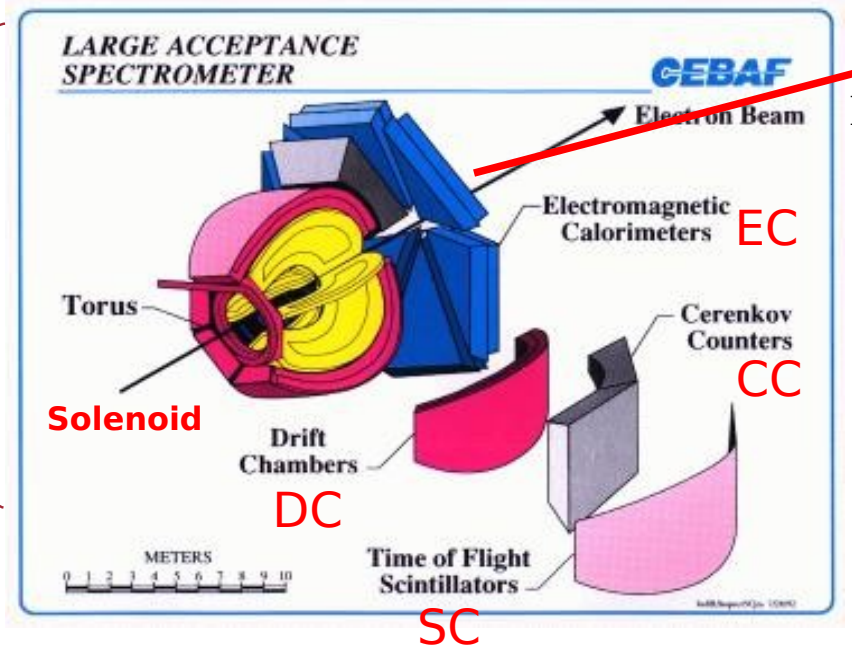


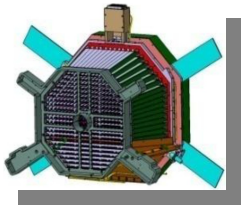
CLAS *(CEBAF Large Acceptance Spectrometer)* @ JLAB *(Jefferson Laboratory)*

MACHINE CONFIGURATION



- 1500 physicists, ~30 countries, operationnal since end 97
- Two LINACs, 3 experimental halls
- Imax=20 nA, Emax= 6 GeV, 100% duty cycle
- Luminosity: Hall B= $10^{34} cm^{-2} s^{-1}$





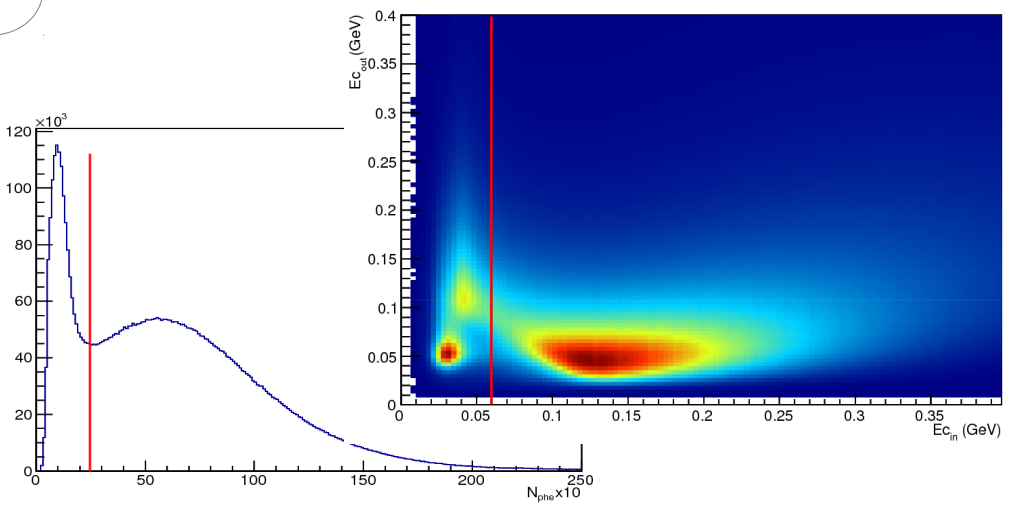
IC

DVCS photons are mostly emitted at forward angles

- Large acceptance detector
- Toroidal magnetic field (2,5 T)

Identification of the final state particles

$ep \rightarrow ep\,\gamma$



➡ **Electron** :

Identification with

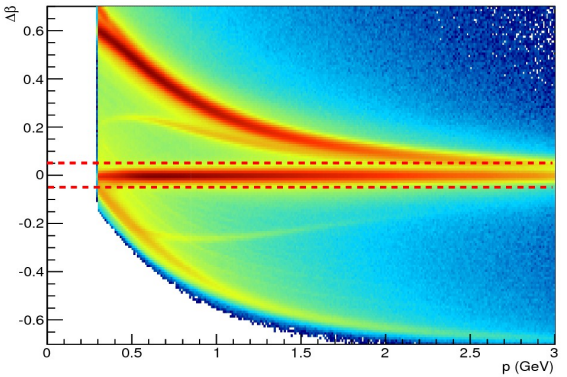
DC + CC + EC

Rejection of the π^- with EC and CC

➡ **Proton**:

Identified with DC + SC

Cut on: $\Delta\beta = \beta^{SC}_{measured} - \beta^{DC}_{calculated}(M_p) = \frac{d}{ct} - \frac{p}{\sqrt{p^2 + M_p^2}}$

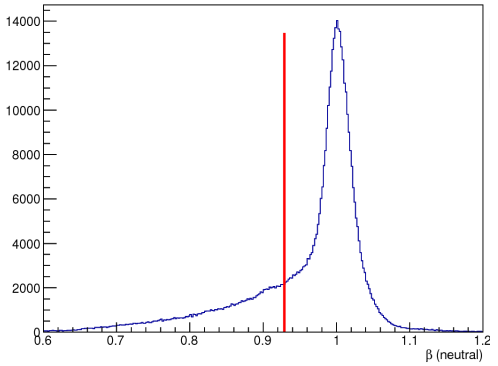


➡ **Photon** :

Identified with IC and/or EC

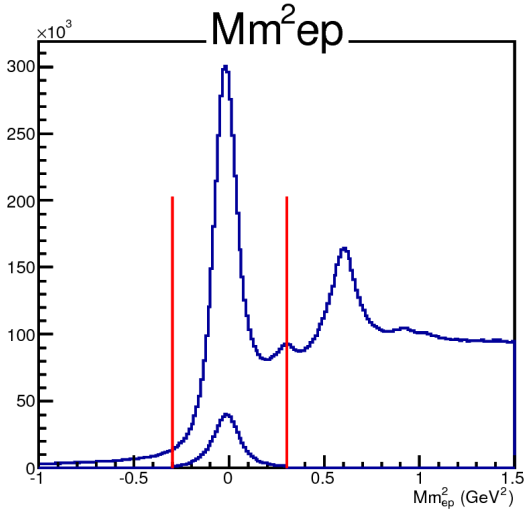
Rejection of the neutrons in EC

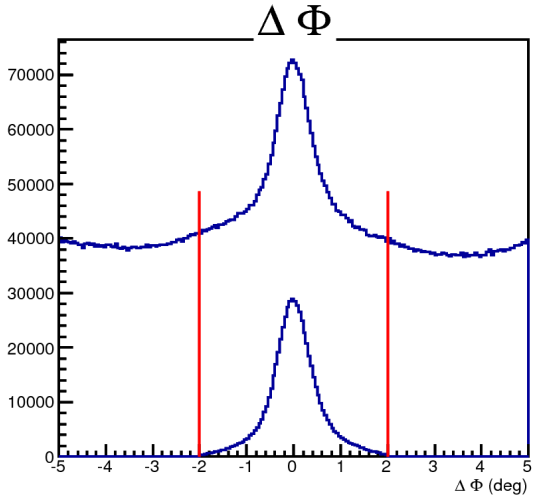
with β neutral $> 0{,}92$

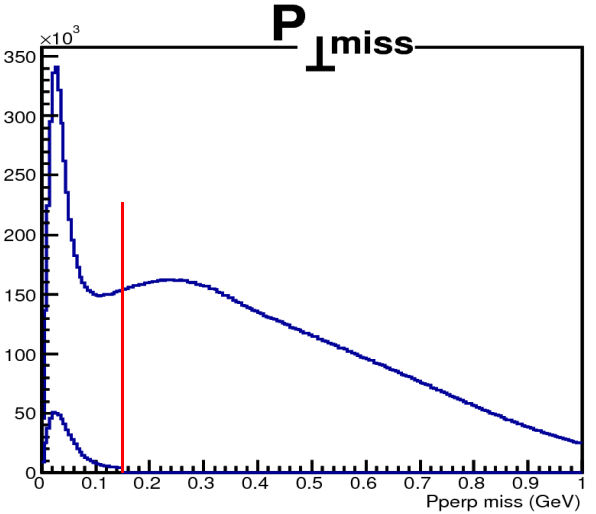


Exclusivity cuts and background

- Additional cuts are applied to ensure the exclusivity of the DVCS process:



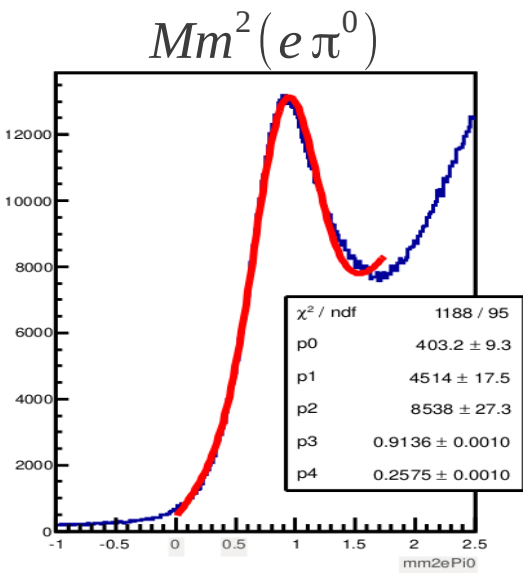


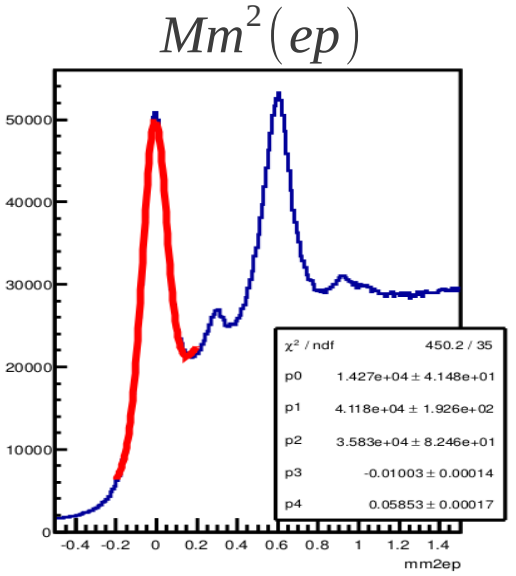


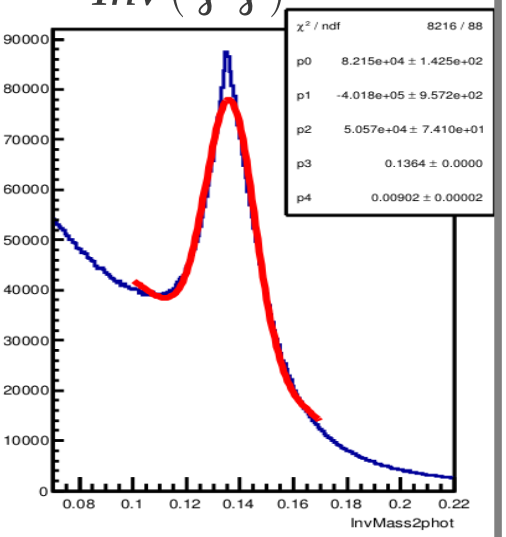
- Background :

$ep \rightarrow ep\pi^0 \rightarrow ep\gamma(\gamma)$

Between 10 to 20 %



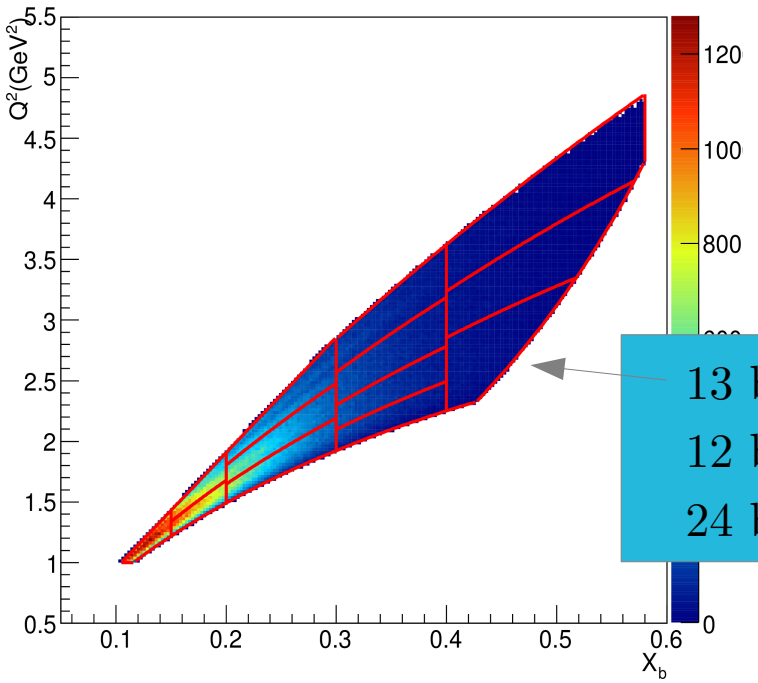




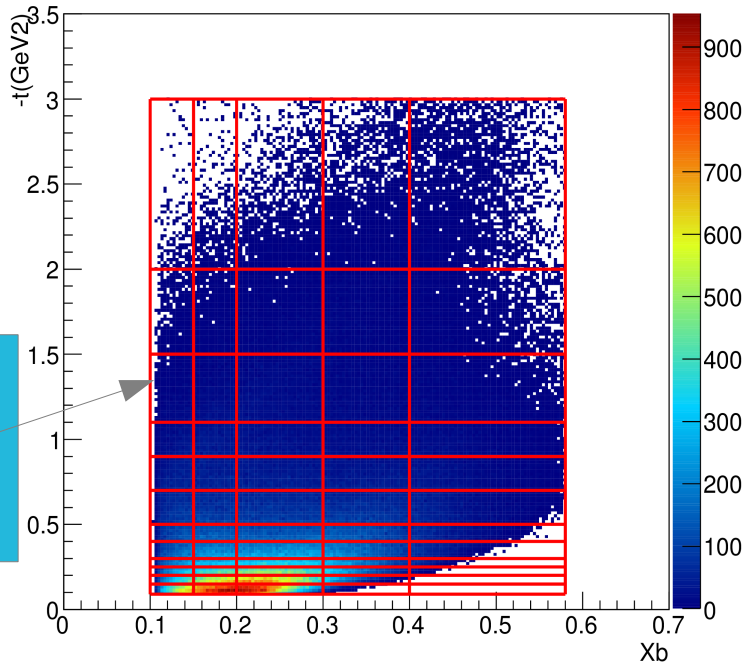
Kinematic coverage of the e1-DVCS data and binning

9

$Q^2>1,\ 0.1<x_B<0.58,\ 21<\theta_e<45,\ p_e>0.8,\ W>2$



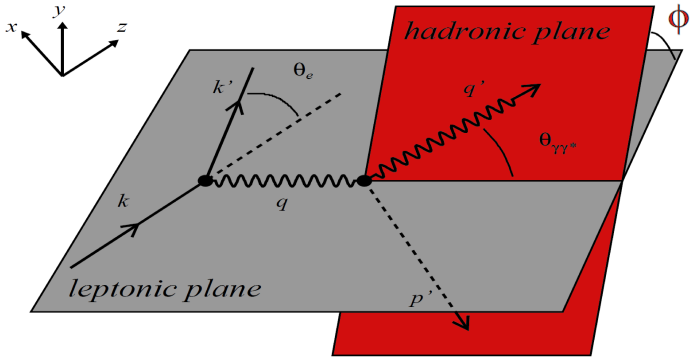
13 bins in (Q^2, x_B)
12 bins in $-t$
24 bins in Φ



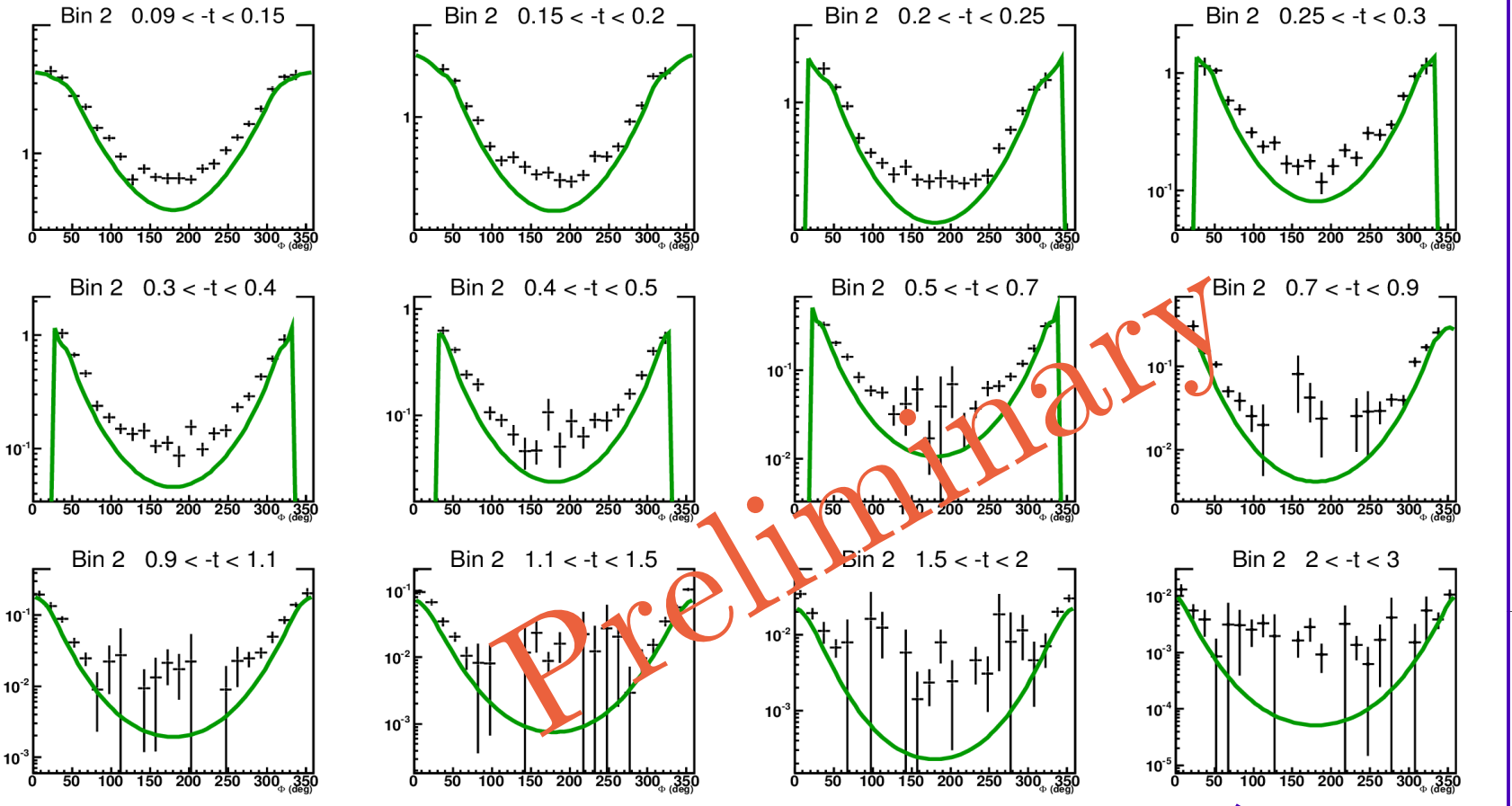
The kinematics of the DVCS reaction is defined by 4 independent variables :

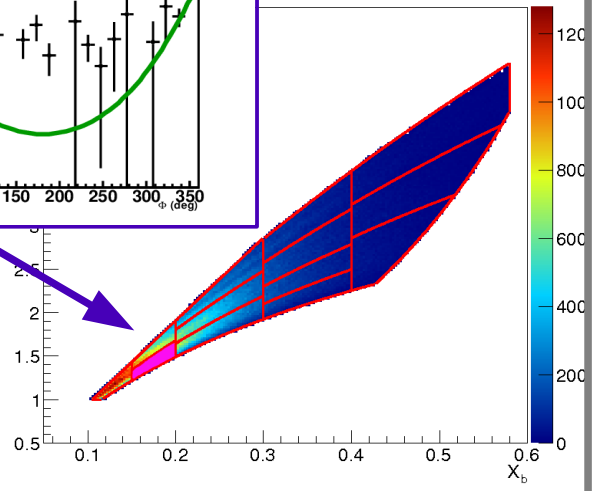
$$Q^2, x_B, -t, \Phi$$

→ 4-dimensional binning



Unpolarized cross sections

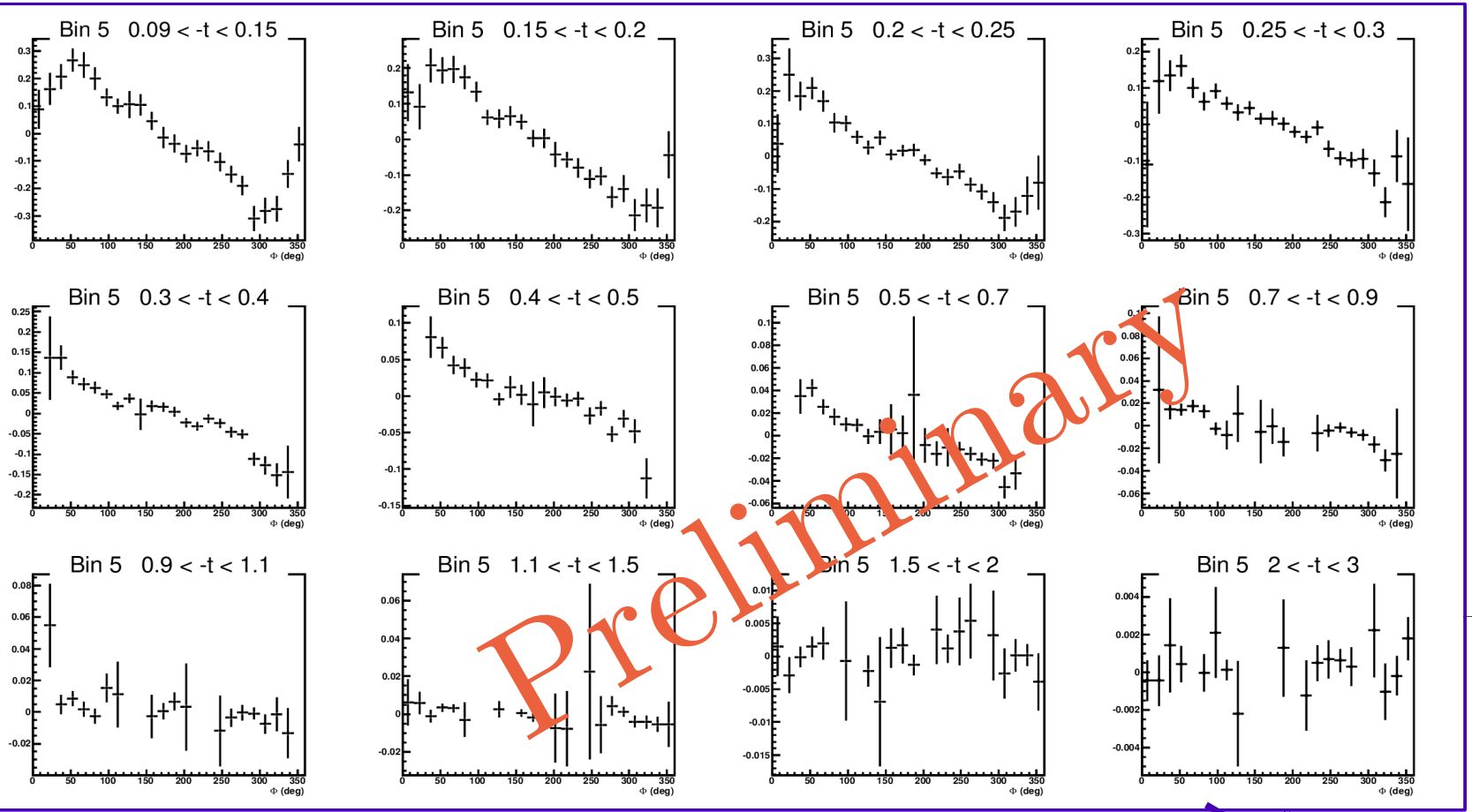




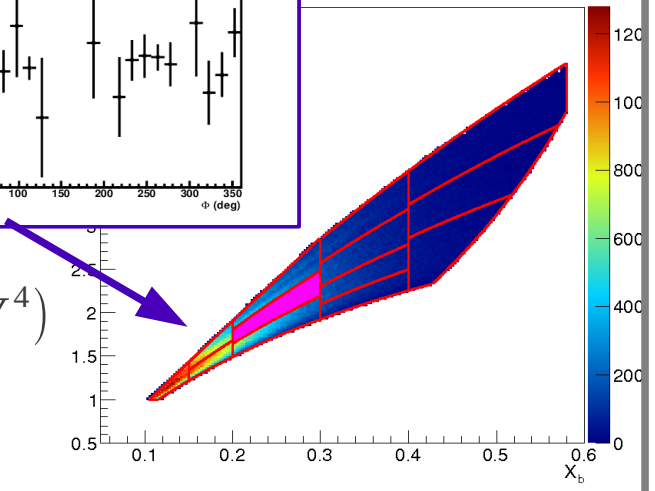
- $\dfrac{d^4\sigma_{ep\to ep\gamma}}{dQ^2\ dx_B\ dt\ d\Phi}\ \left(nb/GeV^4\right)$

Bethe-Heitler integrated over the bin

Difference of polarized cross sections



- $\frac{1}{2}\left(\frac{d^4\sigma^{\rightarrow}_{ep\rightarrow ep\gamma}}{dQ^2\, dx_B\, dt\, d\Phi} - \frac{d^4\sigma^{\leftarrow}_{ep\rightarrow ep\gamma}}{dQ^2\, dx_B\, dt\, d\Phi}\right) \; (nb/GeV^4)$



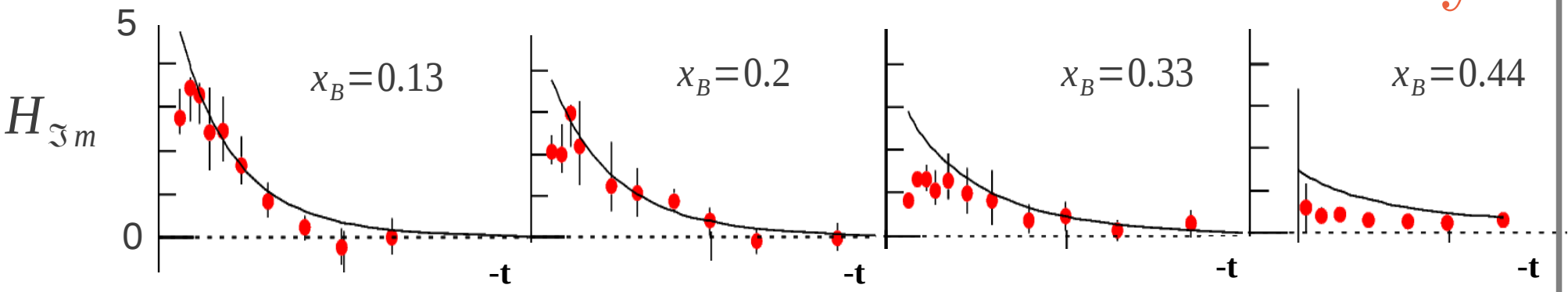
Extraction of Compton Form Factors (CFFs)

Model-independent fitting procedure:

At fixed (Q^2, x_B, t), extraction of the CFFs from the DVCS observables

CFFs are combinations of GPDs

Preliminary



● Results of model-independent fit —— VGG model prediction

$H_{\Im m}$: the t-slope reflects the size of the probed object:

Large t-slope $\Leftrightarrow$ extended object

Small t-slope $\Leftrightarrow$ localized object

➡ The sea quarks (low x) spread to the periphery of the nucleon

➡ The valence quarks (large x) remain in the center

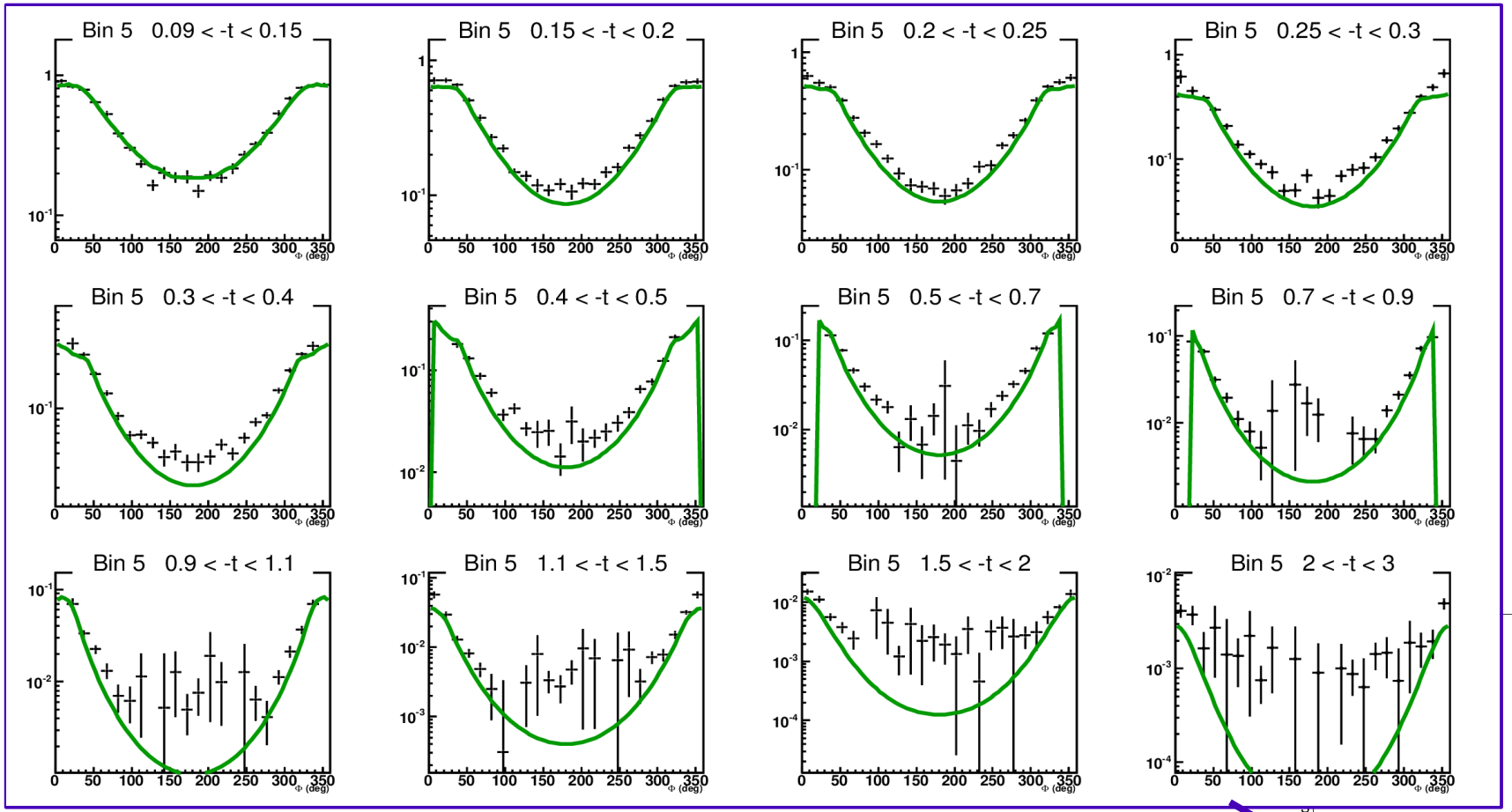
Conclusion

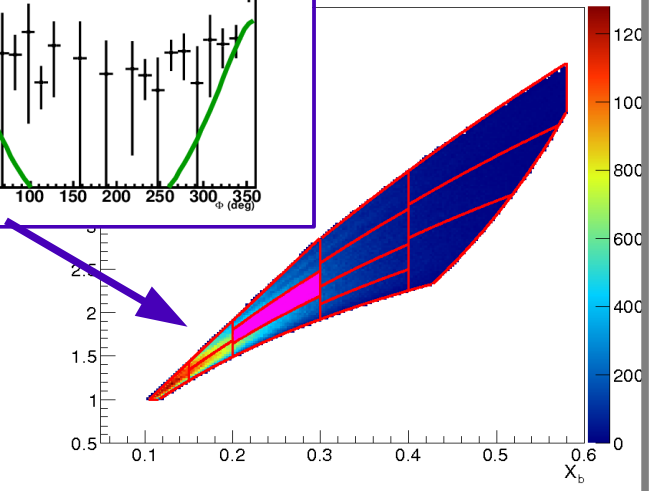
- Extraction of DVCS unpolarized and polarized cross sections in the largest kinematic domain ever explored in the valence region

- Extraction of Compton Form Factors by fitting simultaneously the unpolarized and polarized is in progress

- Dedicated GPD program at Jlab 12GeV :
  - ➡ Target spin asymmetry A_{UT}, A_{LT}
  - ➡ Target spin asymmetry A_{LU}
  - ➡ DVMP: pseudoscalar/vector mesons

Unpolarized cross sections

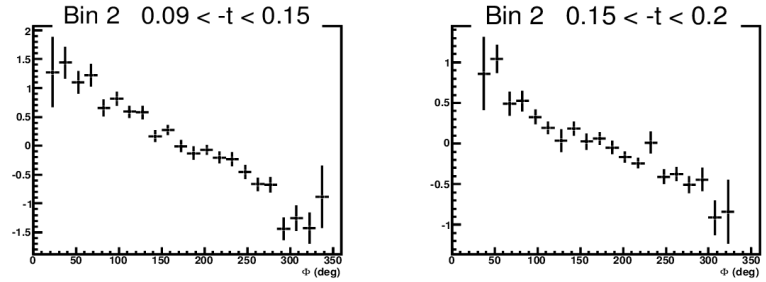


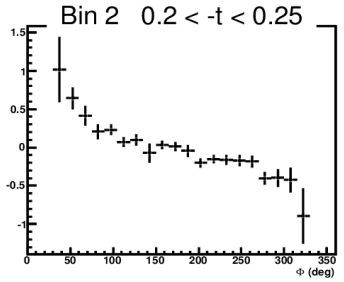


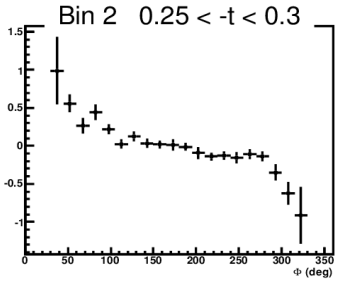
- $\dfrac{d^4\sigma_{ep\to ep\gamma}}{dQ^2\ dx_B\ dt\ d\Phi}\ \left(nb/GeV^4\right)$

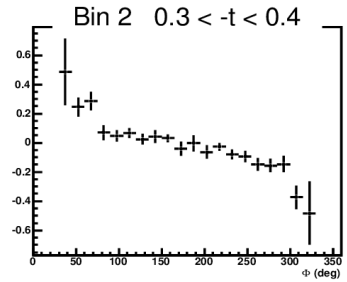
Bethe-Heitler integrated over the bin

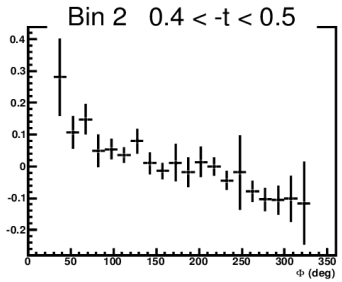
Difference of polarized cross sections

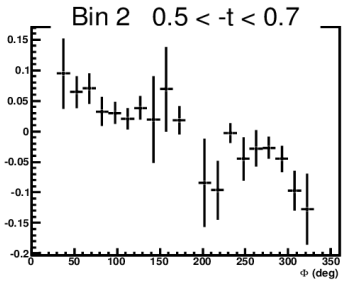


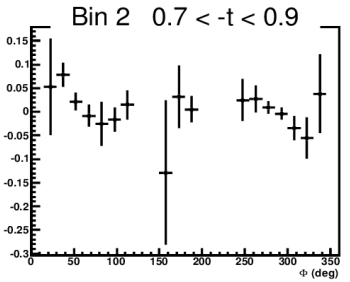


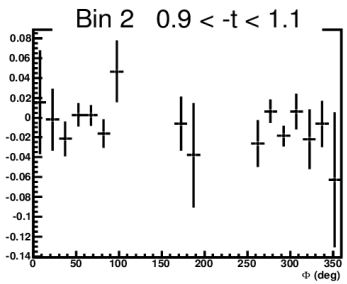


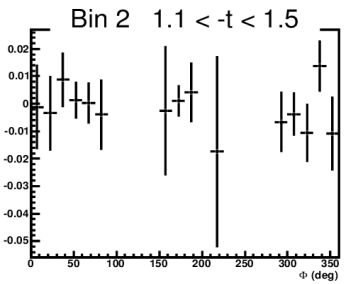


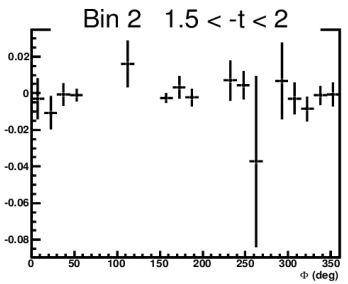


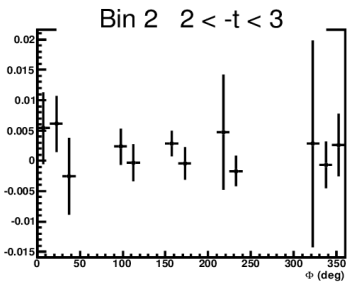




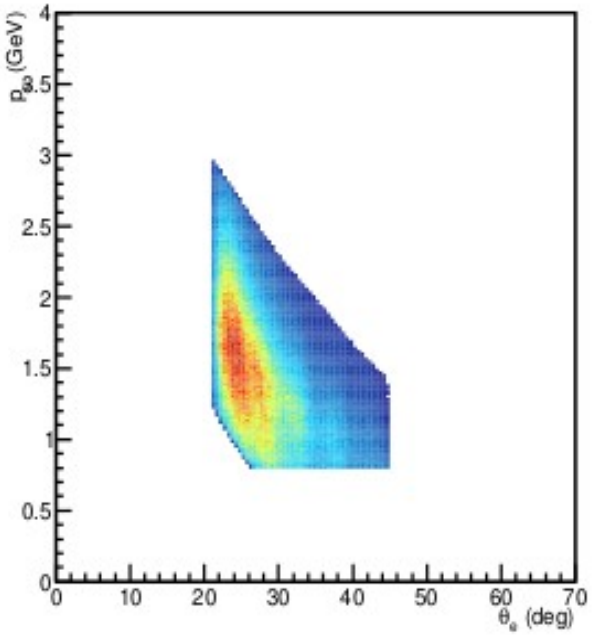


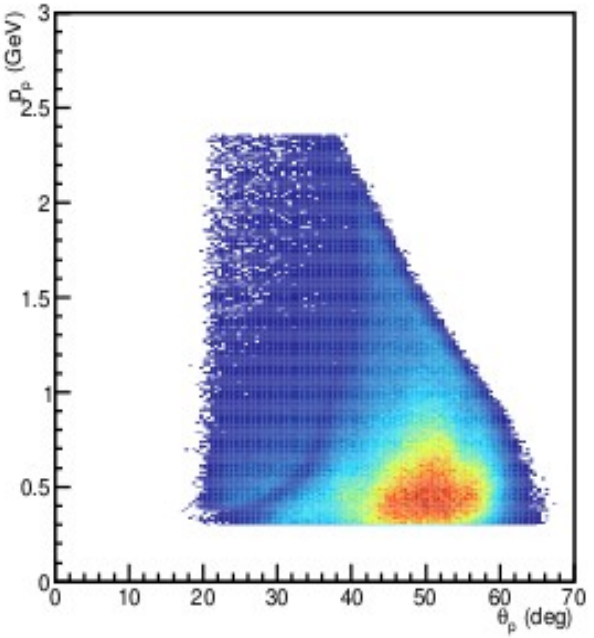


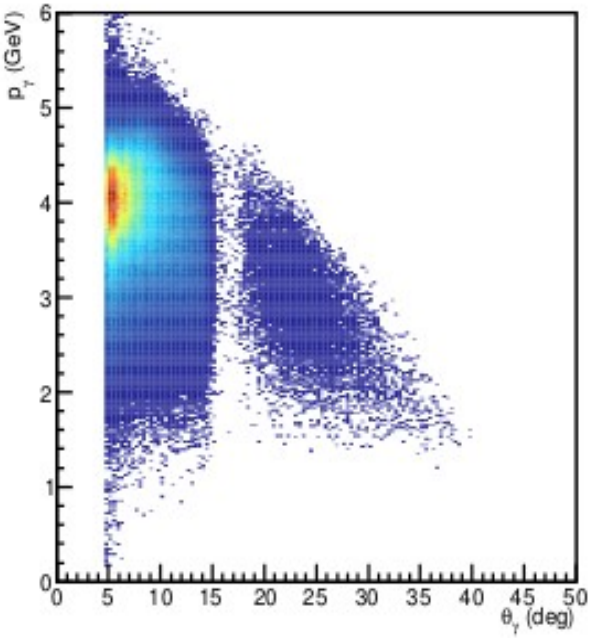


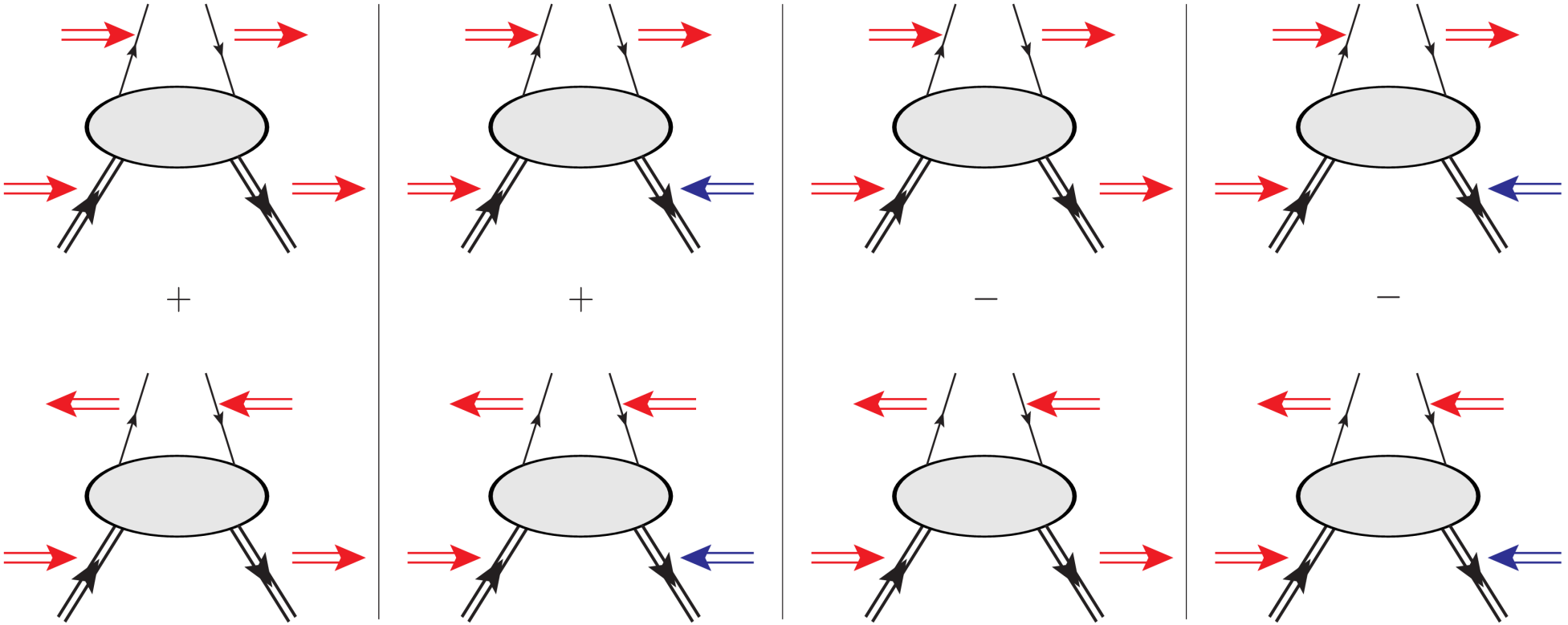


- $\frac{1}{2}\left(\frac{d^4\sigma^{\rightarrow}_{ep\rightarrow ep\gamma}}{dQ^2\ dx_B\ dt\ d\Phi} - \frac{d^4\sigma^{\leftarrow}_{ep\rightarrow ep\gamma}}{dQ^2\ dx_B\ dt\ d\Phi}\right)\ (nb/GeV^4)$

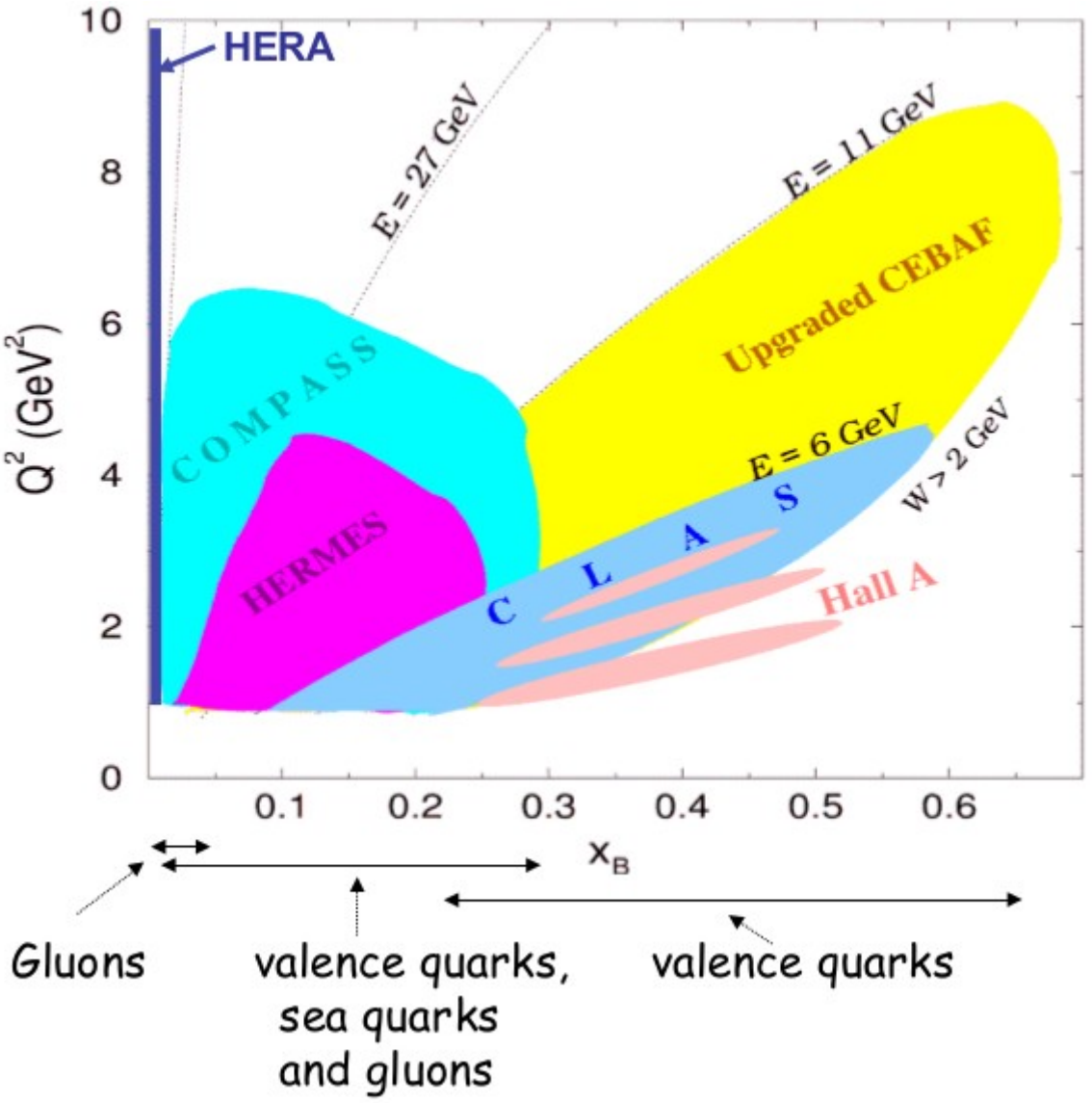

p_e (GeV)
θ_e (deg)


p_p (GeV)
θ_p (deg)


p_γ (GeV)
θ_γ (deg)



Four different possible spin-helicity transition of the nucleon-quark system


HERA
E = 27 GeV
E = 11 GeV
Upgraded CEBAF
COMPASS
HERMES
E = 6 GeV
W > 2 GeV
CLAS
Hall A
Q^2 (GeV^2)
x_B
0
2
4
6
8
10
0.1
0.2
0.3
0.4
0.5
0.6
Gluons
valence quarks, sea quarks and gluons
valence quarks

Extraction of Compton Form Factors (CFFs)

$$\mathcal{T}^{DVCS} \propto \int_{-1}^{1} dx \frac{f(x,\xi,t)}{x \pm \xi \mp i\epsilon} = \mathcal{P}\int_{-1}^{1} dx \frac{f(x,\xi,t)}{x \pm \xi} \pm i\pi f(x = \mp\xi, \xi, t)$$

Real part	Imaginary part
$\mathcal{H}_{Re}(\xi,t) = \mathcal{P}\int_0^1 dx[H(x,\xi,t) - H(-x,\xi,t)]\, C^+(x,\xi)$	$\mathcal{H}_{Im}(\xi,t) = H(\xi,\xi,t) - H(-\xi,\xi,t)$
$\mathcal{E}_{Re}(\xi,t) = \mathcal{P}\int_0^1 dx[E(x,\xi,t) - E(-x,\xi,t)]\, C^+(x,\xi)$	$\mathcal{E}_{Im}(\xi,t) = E(\xi,\xi,t) - E(-\xi,\xi,t)$
$\tilde{\mathcal{H}}_{Re}(\xi,t) = \mathcal{P}\int_0^1 dx[\tilde{H}(x,\xi,t) + \tilde{H}(-x,\xi,t)]\, C^-(x,\xi)$	$\tilde{\mathcal{H}}_{Im}(\xi,t) = \tilde{H}(\xi,\xi,t) + \tilde{H}(-\xi,\xi,t)$
$\tilde{\mathcal{E}}_{Re}(\xi,t) = \mathcal{P}\int_0^1 dx[\tilde{E}(x,\xi,t) + \tilde{E}(-x,\xi,t)]\, C^-(x,\xi)$	$\tilde{\mathcal{E}}_{Im}(\xi,t) = \tilde{E}(\xi,\xi,t) + \tilde{E}(-\xi,\xi,t)$

With: $C^{\pm}(x,\xi) = \frac{1}{x-\xi} \pm \frac{1}{x+\xi}$

Extraction of Compton Form Factors (CFFs)

	Sensitivity	Experiment
$\sigma_{unp} = \sigma^{\rightarrow} + \sigma^{\leftarrow}$	$\propto \mathcal{H}_{Re}$	H1 ((2001), (2005), (2008)) ZEUS ((2003) , (2009)) Hall-A (2006) Hall-B (E1-DVCS experiment: data under analysis)
$\sigma_{pol} = \sigma^{\rightarrow} - \sigma^{\leftarrow}$	$\propto \mathcal{H}_{Im}$	Hall-A (2006) Hall-B (E1-DVCS experiment: data under analysis)
$\mathcal{A}_C$	$\propto \mathcal{H}_{Re}$	HERMES ((2007) , (2008) , (2009))
$\mathcal{A}_{LU}$	$\propto \mathcal{H}_{Im}$	HERMES ((2001) , (2009)) Hall-B ((2001) , (2008))
$\mathcal{A}_{UL}$	$\propto \mathcal{H}_{Im}, \tilde{\mathcal{H}}_{Im}$	Hall-B (2006) HERMES (2010) Hall-B (Eg1-DVCS experiment: data under analysis)
$\mathcal{A}_{LL}$	$\propto \mathcal{H}_{Re}, \tilde{\mathcal{H}}_{Re}$	HERMES (2010) Hall-B (Eg1-DVCS experiment: data under analysis)
$\mathcal{A}_{UT}$	$\propto \mathcal{E}_{Im}$	HERMES (2008) Hall-B proposal
$\mathcal{A}_{LT}$	$\propto \mathcal{H}_{Re}, \mathcal{E}_{Re}$	HERMES (2011) Hall-B proposal

Model-independent fit, at fixed (Q^2, x_B, t) of DVCS observables

with MINUIT + MINOS

8 unknowns (the CFFs), non-linear problem, strong correlations

Bounding the domain of variation of the CFFs (5xVGG)

Extraction of Compton Form Factors (CFFs)

	Sensitivity	Experiment
$\sigma_{unp} = \sigma^{\rightarrow} + \sigma^{\leftarrow}$	$\propto \mathcal{H}_{Re}$	H1 ((2001), (2005), (2008)) ZEUS ((2003) , (2009)) Hall-A (2006) Hall-B (E1-DVCS experiment: data under analysis)
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$\mathcal{A}_C$	$\propto \mathcal{H}_{Re}$	HERMES ((2007) , (2008) , (2009))
$\mathcal{A}_{LU}$	$\propto \mathcal{H}_{Im}$	HERMES ((2001) , (2009)) Hall-B ((2001) , (2008))
$\mathcal{A}_{UL}$	$\propto \mathcal{H}_{Im}, \tilde{\mathcal{H}}_{Im}$	Hall-B (2006) HERMES (2010) Hall-B (Eg1-DVCS experiment: data under analysis)
$\mathcal{A}_{LL}$	$\propto \mathcal{H}_{Re}, \tilde{\mathcal{H}}_{Re}$	HERMES (2010) Hall-B (Eg1-DVCS experiment: data under analysis)
$\mathcal{A}_{UT}$	$\propto \mathcal{E}_{Im}$	HERMES (2008) Hall-B proposal
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