Deeply Virtual Compton Scattering with CLAS12

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for the CLAS collaboration

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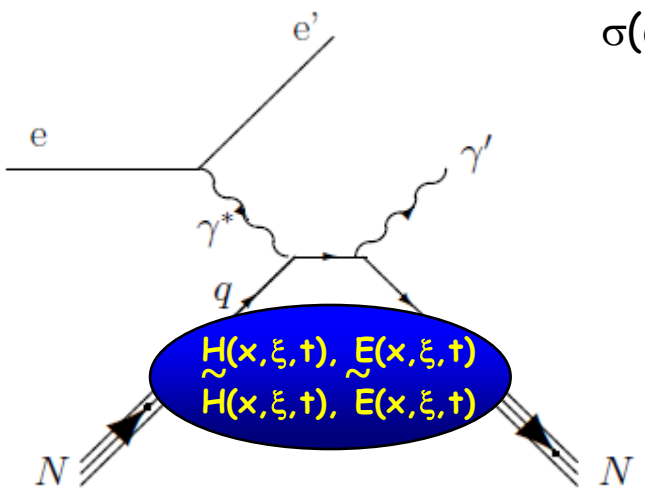
Outline

- Introduction
- The CLAS12 detector
- DVCS on the proton : beam-spin asymmetries
- DVCS on the proton : longitudinally polarized target
- DVCS on the proton : transversely polarized target
- Extraction of Compton Form Factors from proton pseudo-data
- DVCS on the neutron : beam-spin asymmetries
- Summary

Deeply Virtual Compton Scattering (DVCS)

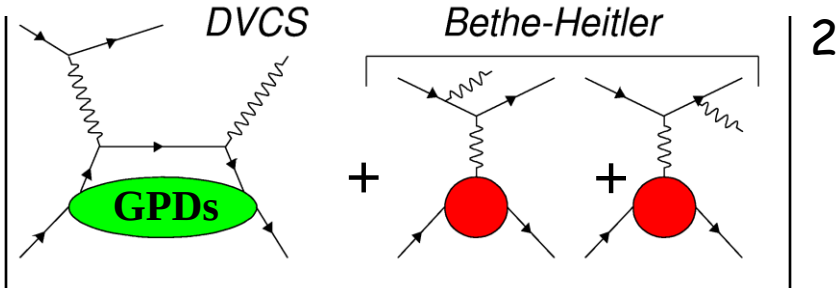
"handbag" diagram (high Q^2, small t, fixed x_B)

DVCS



BH fully calculable in QED

$\sigma(eN \to eN\gamma) =$



DVCS and Bethe-Heitler (BH) experimentally undistinguishable

interference between the 2 processes

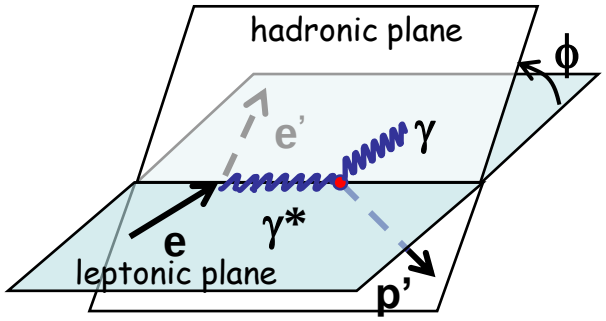
$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi} \approx \left|T^{DVCS} + T^{BH}\right|^2 = \left|T^{DVCS}\right|^2 + \left|T^{BH}\right|^2 + I$$

with $\underbrace{I = T^{DVCS}T^{*BH} + T^{*DVCS}T^{BH}}_{\text{interference term}}$

DVCS is the key reaction allowing to access the GPDs → simplest interpretation in terms of GPDs

The kinematics of the DVCS reaction is defined by 4 independent variables : Q^2, x_B, t and ϕ

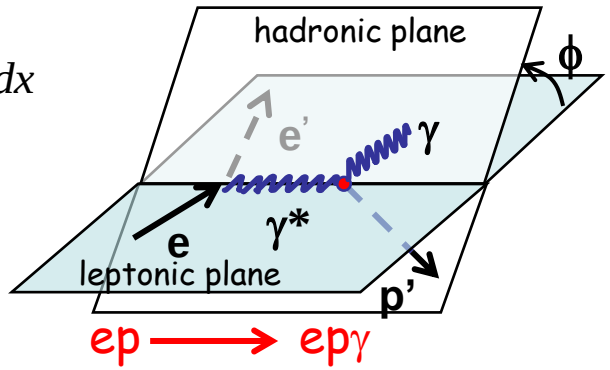
4-dimensional bins = (Q^2, x_B , -t, ϕ)



Extracting GPDs from DVCS observables

Compton Form Factors (CFFs)

$$\begin{cases} Re\mathcal{H}_q = e_q^2 P \int_0^{+1} \left(H^q(x,\xi,t) - H^q(-x,\xi,t)\right)\left[\frac{1}{\xi - x} + \frac{1}{\xi + x}\right]dx \\ Im\mathcal{H}_q = \pi e_q^2 \left[H^q(\xi,\xi,t) - H^q(-\xi,\xi,t)\right] \end{cases}$$



Beam Spin Asymmetry : $A_{LU} = \frac{d\vec{\sigma} - d\overleftarrow{\sigma}}{d\vec{\sigma} + d\overleftarrow{\sigma}} = \frac{\Delta\sigma_{LU}}{d\vec{\sigma} + d\overleftarrow{\sigma}}$

$\xi = x_B/(2-x_B)$ $k = t/4M^2$

Proton	Neutron

- Polarized beam, Unpolarized target

$\Delta\sigma_{LU} \sim \sin\phi\ \mathrm{Im}\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E}\}d\phi$

→ $Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p, \mathcal{E}_p\}$ $Im\{\mathcal{H}_n, \tilde{\mathcal{H}}_n, \mathcal{E}_n\}$

- Unpolarized beam, Longitudinally polarized target

$\Delta\sigma_{UL} \sim \sin\phi\ \mathrm{Im}\{F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + x_B/2\mathcal{E}) - \xi kF_2\tilde{\mathcal{E}} + \ldots\}d\phi$

→ $Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$ $Im\{\mathcal{H}_n, \mathcal{E}_n, \tilde{\mathcal{E}}_n\}$

- Unpolarized beam, Transversely polarized target

$\Delta\sigma_{UT} \sim \cos\phi\ \mathrm{Im}\{k(F_2\mathcal{H} - F_1\mathcal{E}) + \ldots\ldots\}d\phi$

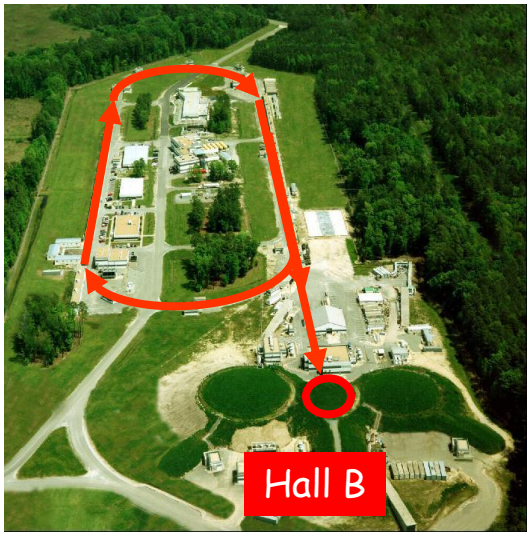
→ $Im\{\mathcal{H}_p, \mathcal{E}_p\}$ $Im\{\mathcal{H}_n\}$

- Polarized beam, Longitudinally polarized target

$\Delta\sigma_{LL} \sim (A + B\cos\phi)\ \mathrm{Re}\{F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + x_B/2\mathcal{E})\ldots\}d\phi$

→ $Re\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$ $Re\{\mathcal{H}_n, \mathcal{E}_n, \tilde{\mathcal{E}}_n\}$

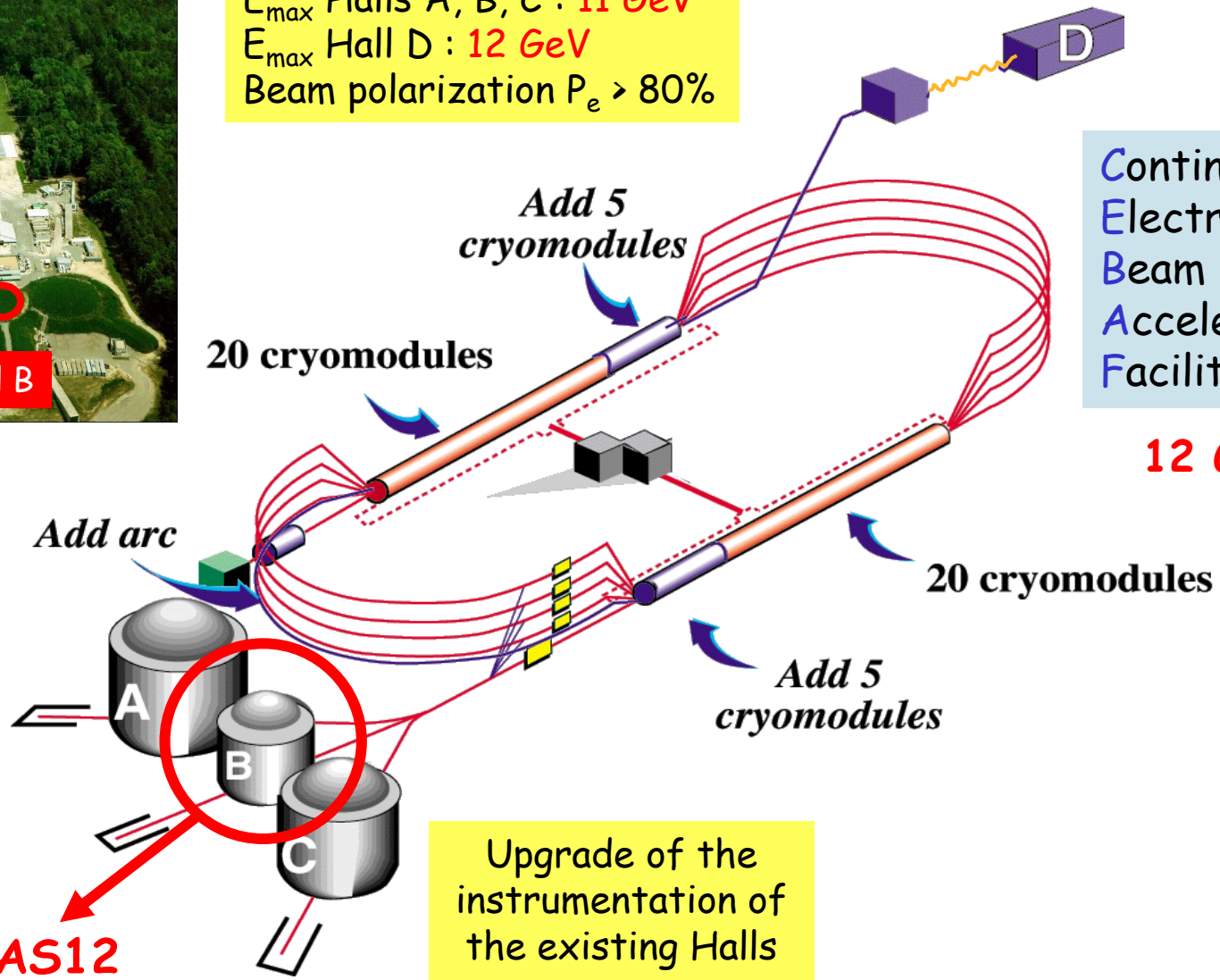
JLab upgrade to 12 GeV



E_{max} Halls A, B, C : 11 GeV
E_{max} Hall D : 12 GeV
Beam polarization P_e > 80%

Continuous
Electron
Beam
Accelerator
Facility

12 GeV



Upgrade of the instrumentation of the existing Halls

Hall B at JLab 12GeV: CLAS12

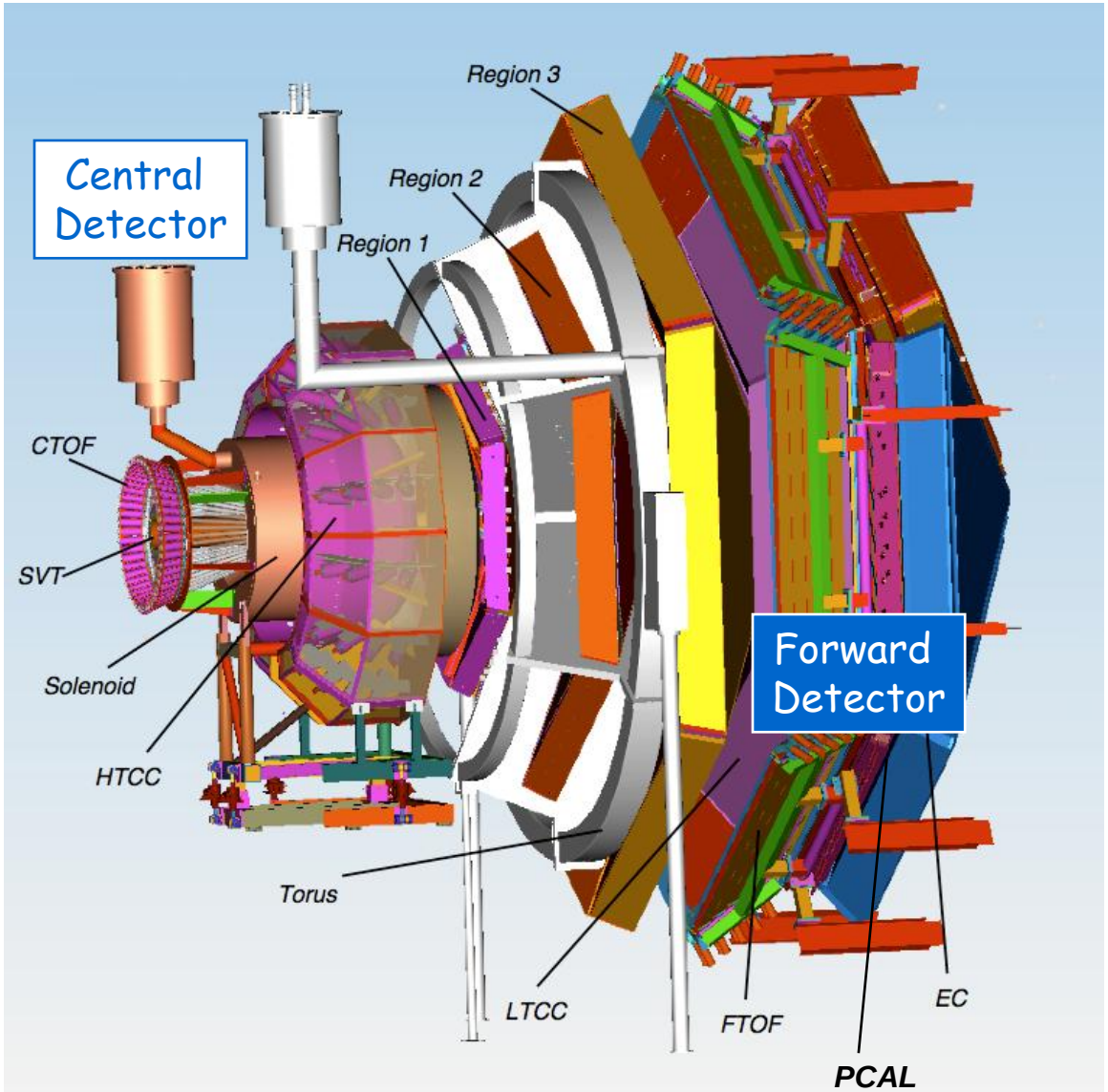
CLAS12

E_{max} = 11 GeV

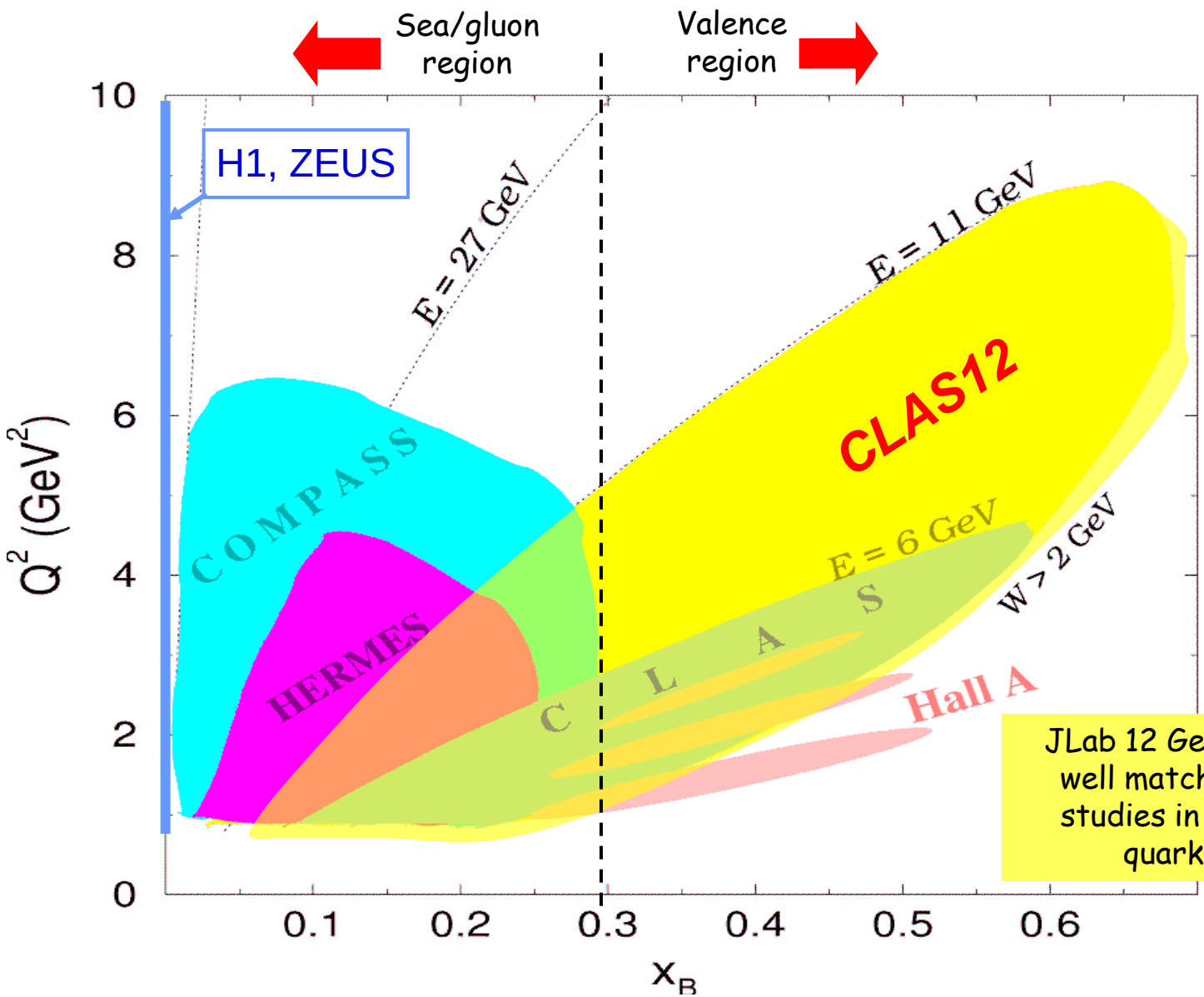
Design luminosity
$L \sim 10^{35}\ cm^{-2}s^{-1}$

Large acceptance

Large kinematic coverage



Kinematic coverage of CLAS12

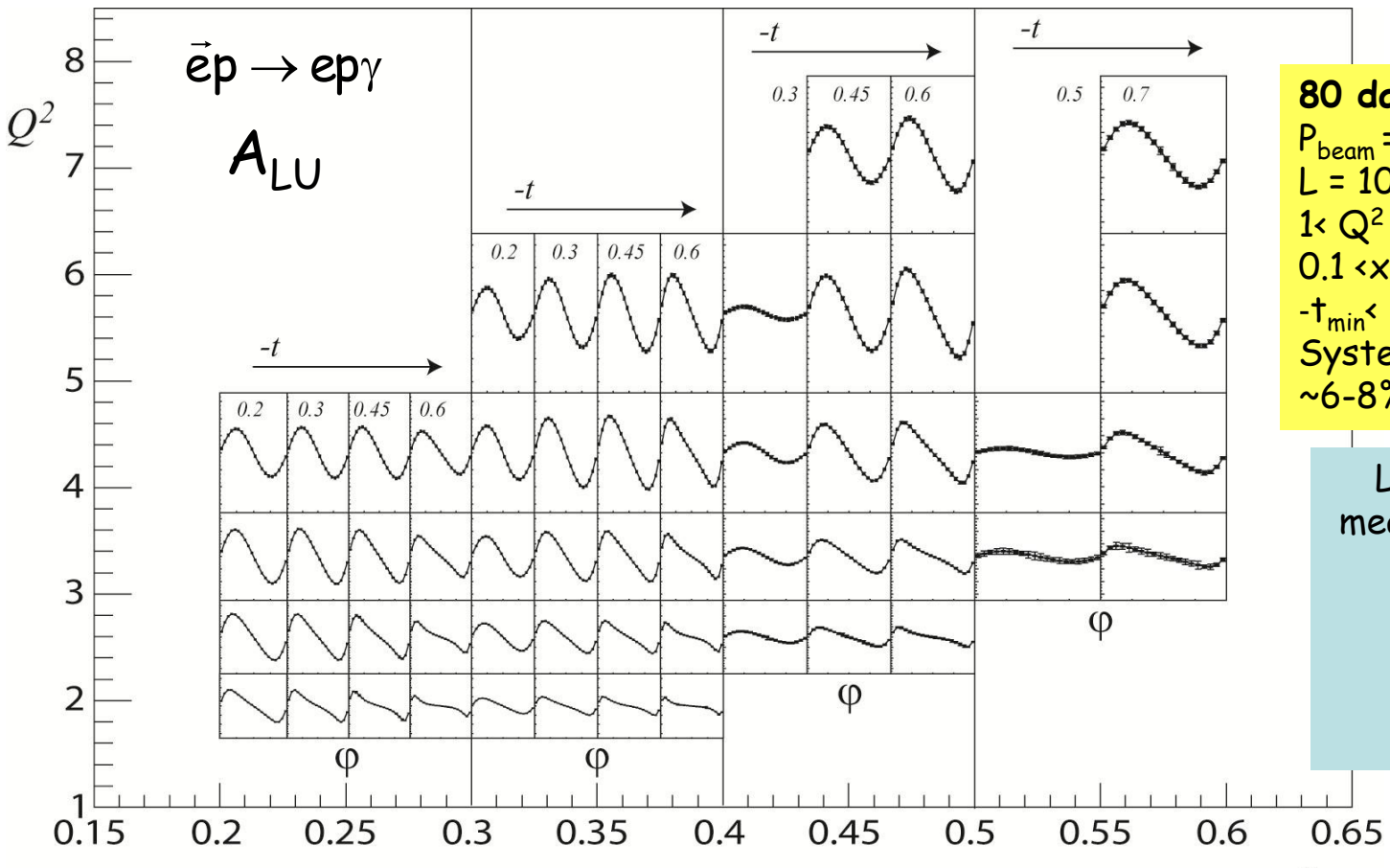


JLab 12 GeV Upgrade is well matched for GPD studies in the valence quark regime

DVCS A_{LU} on the proton

Approved experiment

Projections 80 days – LH_2 target – 10^{35} Luminosity – VGG model



80 days of beam time
P_{beam} = 85%
$L = 10^{35}\ cm^{-2}s^{-1}$
$1 < Q^2 < 10\ GeV^2$
$0.1 < x_B < 0.65$
$-t_{min} < -t < 2.5\ GeV^2$
Systematic uncertainties: ~6-8%

Large acceptance: measurements in large Q^2, x_B, t ranges simultaneously
$A_{LU}(Q^2, x_B, t)$
$\sigma(Q^2, x_B, t)$
$\Delta\sigma(Q^2, x_B, t)$

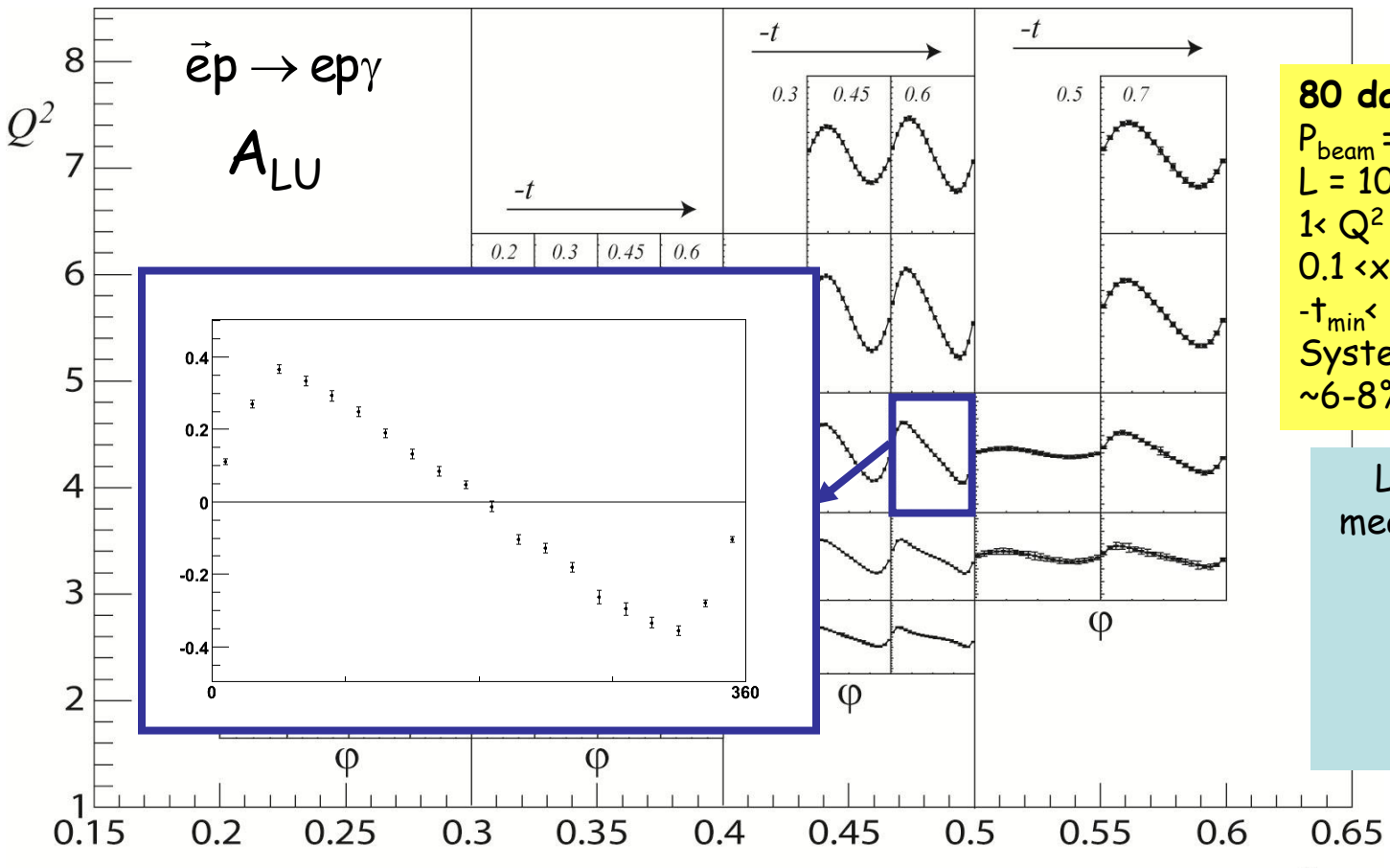
$$\Delta\sigma_{LU} \sim \sin\phi\ \mathrm{Im}\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E}\}d\phi \Rightarrow Im\{\mathcal{H}_p, \mathcal{H}_p, \mathcal{E}_p\}$$

DVCS A_{LU} on proton is mostly sensitive to the GPD H_p

DVCS A_{LU} on the proton

Approved experiment

Projections 80 days – LH_2 target – 10^{35} Luminosity – VGG model



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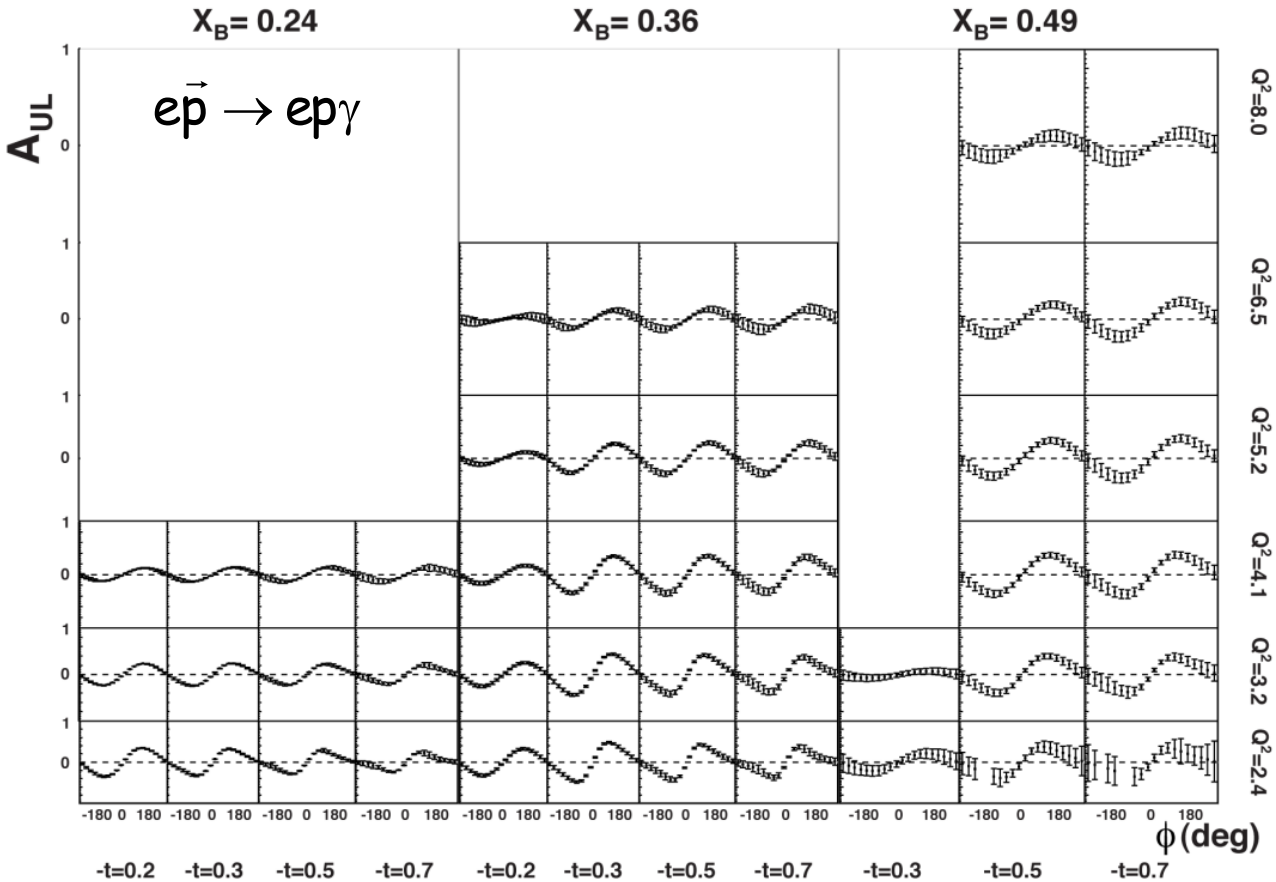
DVCS A_{LU} on proton is mostly sensitive to the GPD H_p

DVCS A_{UL} on the proton

Approved experiment

Projections 120 days – polarized NH_3 target – 2.10^{35} Luminosity – VGG model



120 days of beam time
P_{beam} = 85%, P_{target} = 80%
$L = 2.10^{35}\ cm^{-2}s^{-1}$
$1 < Q^2 < 10\ GeV^2$
$0.1 < x_B < 0.65$
$-t_{min} < -t < 2.5\ GeV^2$
Systematic uncertainties: ~6-8%

Large acceptance: measurements in large Q^2, x_B, t ranges simultaneously
$A_{UL}(Q^2, x_B, t)$

$\Delta\sigma_{UL}$ ⇒ $Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$

$\Delta\sigma_{LL}$ ⇒ $Re\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$

DVCS A_{UL} and A_{LL} on proton is mostly sensitive to the GPDs $\tilde{H}_p$ and H_p

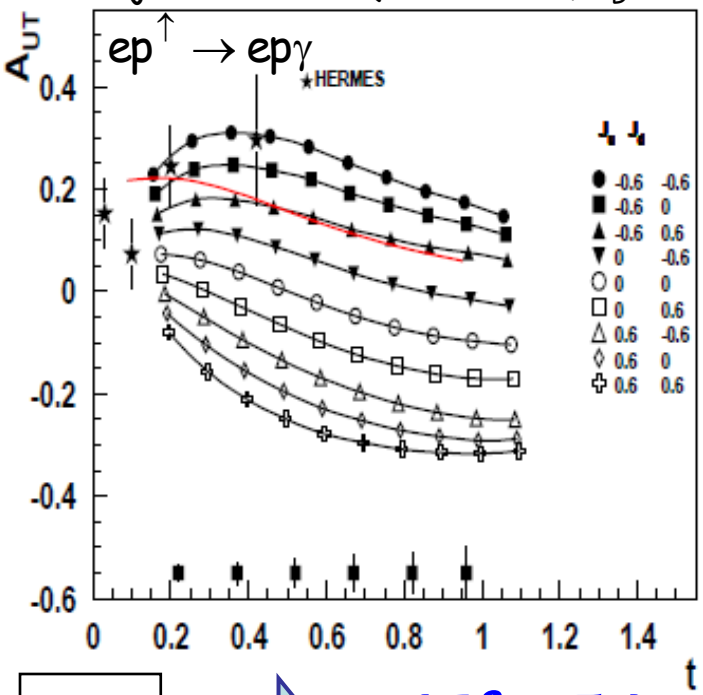
Transversely polarized target : DVCS A_{UT} and A_{LT} on the proton

Proposal submitted to PAC39

polarized HD target $ep^{\uparrow} \rightarrow ep\gamma$

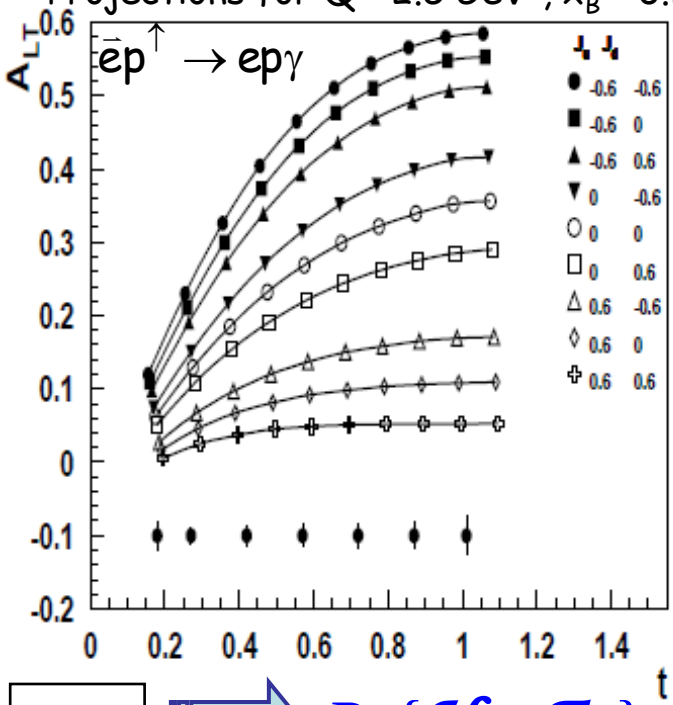
100 days of beam time
P_{beam} = 85%, P_{target} = 60%, L = 5.10^{33} $cm^{-2}s^{-1}$
$1 < Q^2 < 10$ GeV^2, $0.06 < x_B < 0.66$, $-t_{min} < -t < 1.5$ GeV^2
Systematic uncertainties ~8%

Projections for Q^2=2.5 GeV^2, x_B = 0.2



$\Delta\sigma_{UT}$ ⇒ $Im\{\mathcal{H}_p, \mathcal{E}_p\}$

Projections for Q^2=2.5 GeV^2, x_B = 0.2



$\Delta\sigma_{LT}$ ⇒ $Re\{\mathcal{H}_p, \mathcal{E}_p\}$

Transverse-target spin asymmetries are highly sensitive to the GPD E_p

needed to access J^q (Ji's sum rule)

Extraction of Compton Form Factors (CFFs)

8 CFFs

$$\begin{cases} \mathrm{Re}(\mathcal{H}) = P\int_0^1 dx\left[H(x,\xi,t) - H(-x,\xi,t)\right]C^+(x,\xi) \\ \mathrm{Re}(\mathcal{E}) = P\int_0^1 dx\left[E(x,\xi,t) - E(-x,\xi,t)\right]C^+(x,\xi) \\ \mathrm{Re}(\tilde{\mathcal{H}}) = P\int_0^1 dx\left[\tilde{H}(x,\xi,t) + \tilde{H}(-x,\xi,t)\right]C^-(x,\xi) \\ \mathrm{Re}(\tilde{\mathcal{E}}) = P\int_0^1 dx\left[\tilde{E}(x,\xi,t) + \tilde{E}(-x,\xi,t)\right]C^-(x,\xi) \\ \mathrm{Im}(\mathcal{H}) = H(\xi,\xi,t) - H(-\xi,\xi,t) \\ \mathrm{Im}(\mathcal{E}) = E(\xi,\xi,t) - E(-\xi,\xi,t) \\ \mathrm{Im}(\tilde{\mathcal{H}}) = \tilde{H}(\xi,\xi,t) - \tilde{H}(-\xi,\xi,t) \\ \mathrm{Im}(\tilde{\mathcal{E}}) = \tilde{E}(\xi,\xi,t) - \tilde{E}(-\xi,\xi,t) \end{cases}$$

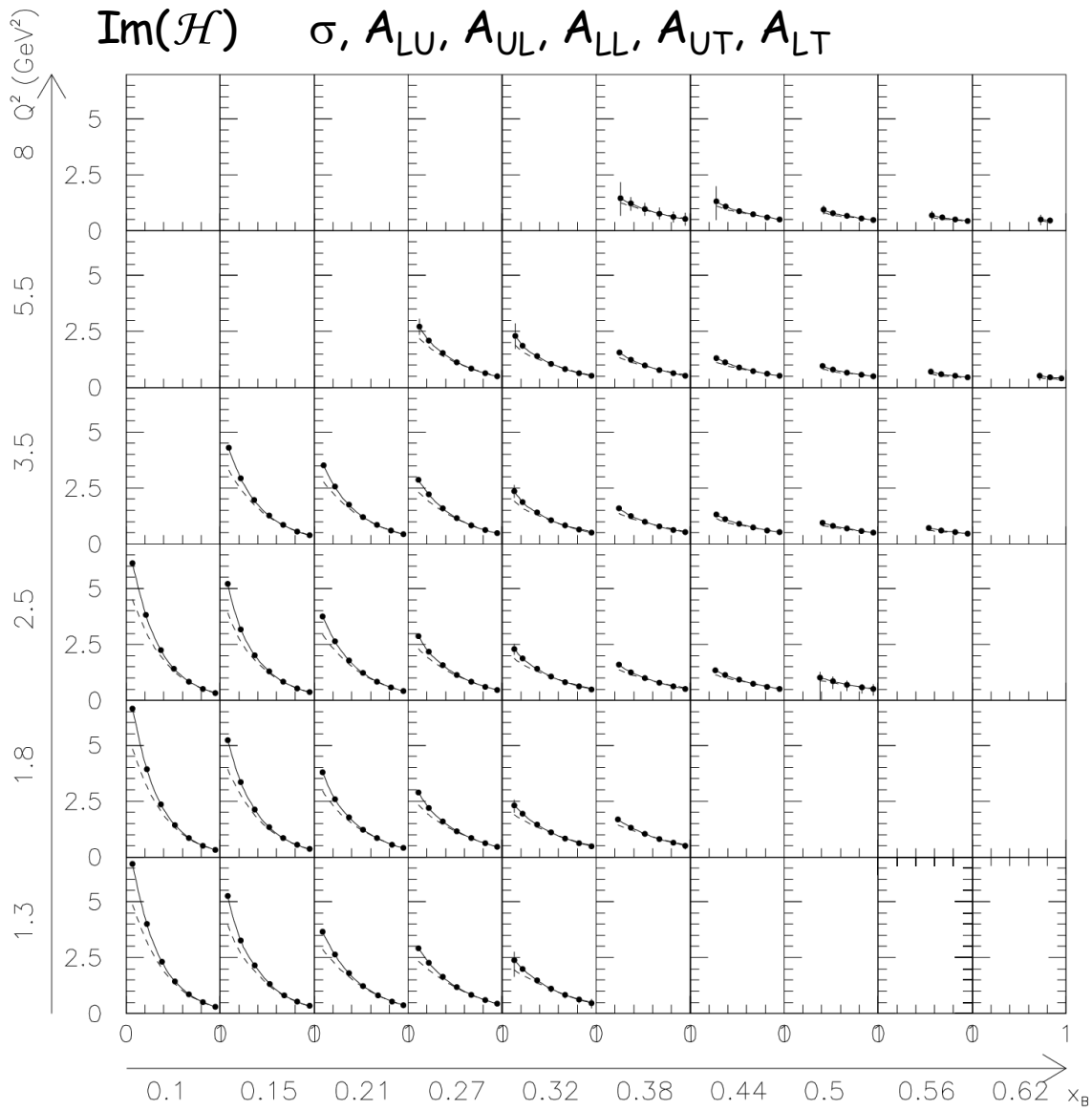
with $C^{\pm}(x,\xi) = \dfrac{1}{x-\xi} \pm \dfrac{1}{x+\xi}$

M. Guidal : model-independent fit, at fixed Q^2, x_B and t of DVCS observables with MINUIT + MINOS

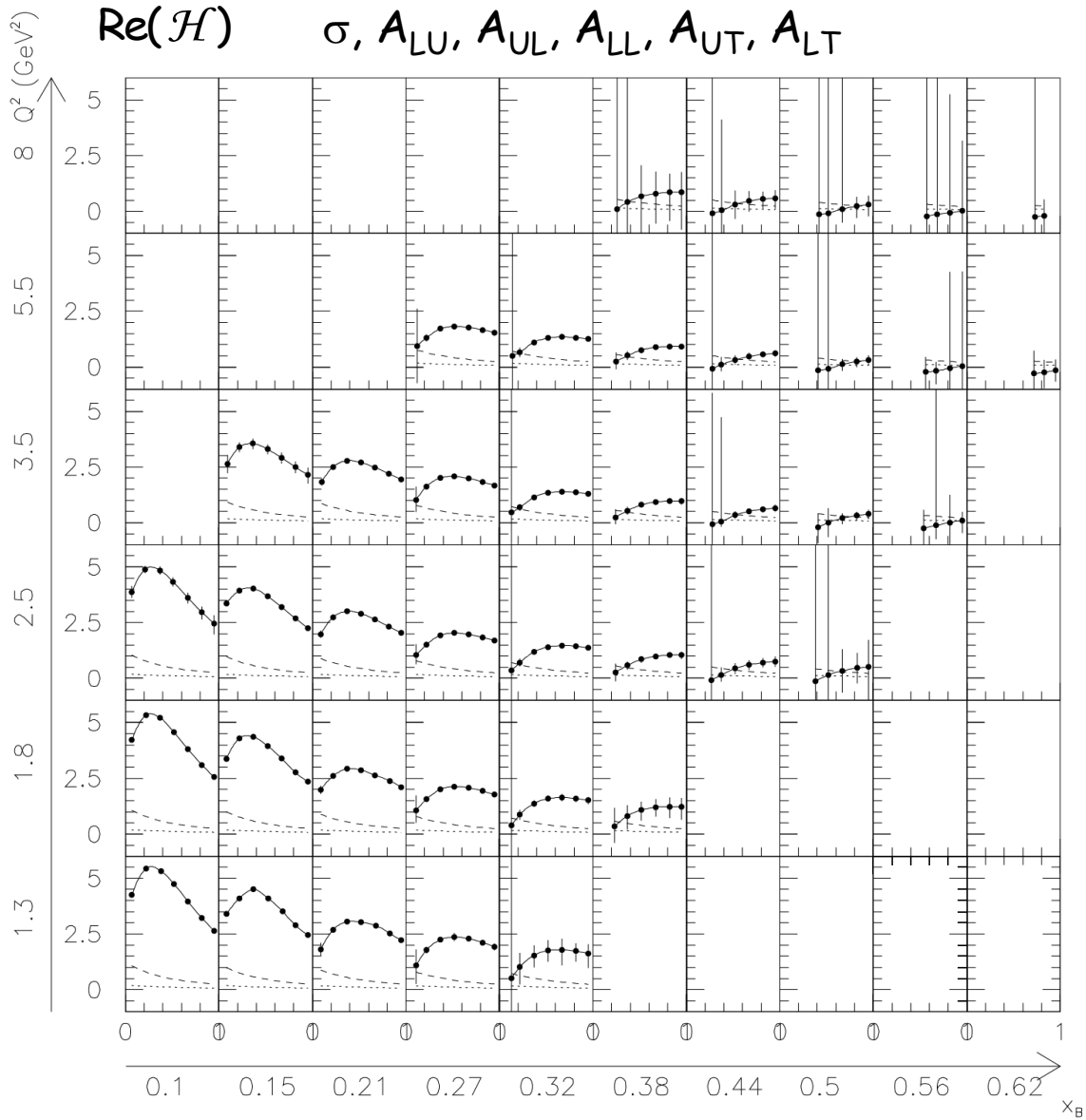
8 unknowns (the CFFs), non-linear problem, strong correlations

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

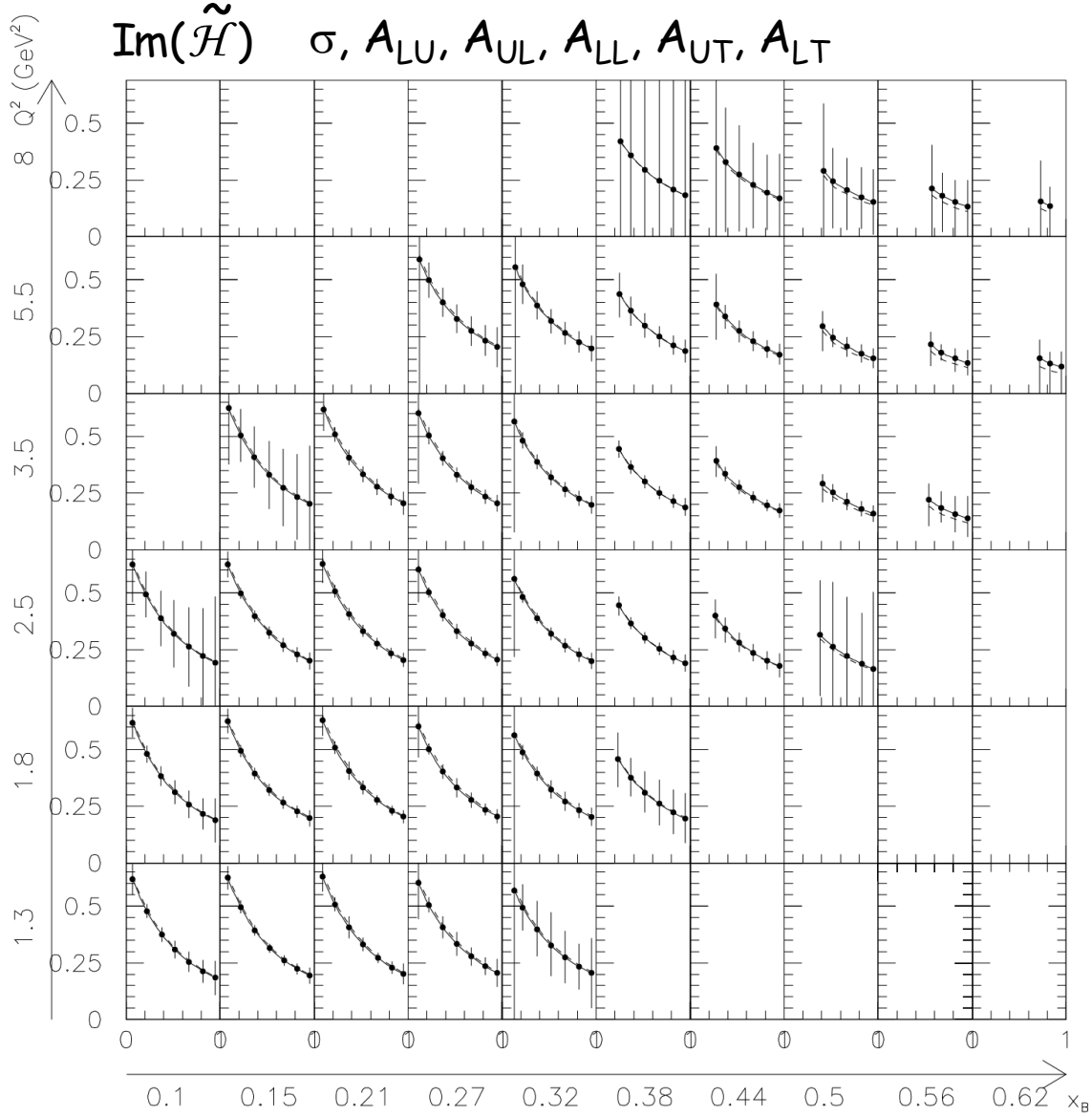
Extraction of Im($\mathcal{H}$) from proton pseudo-data



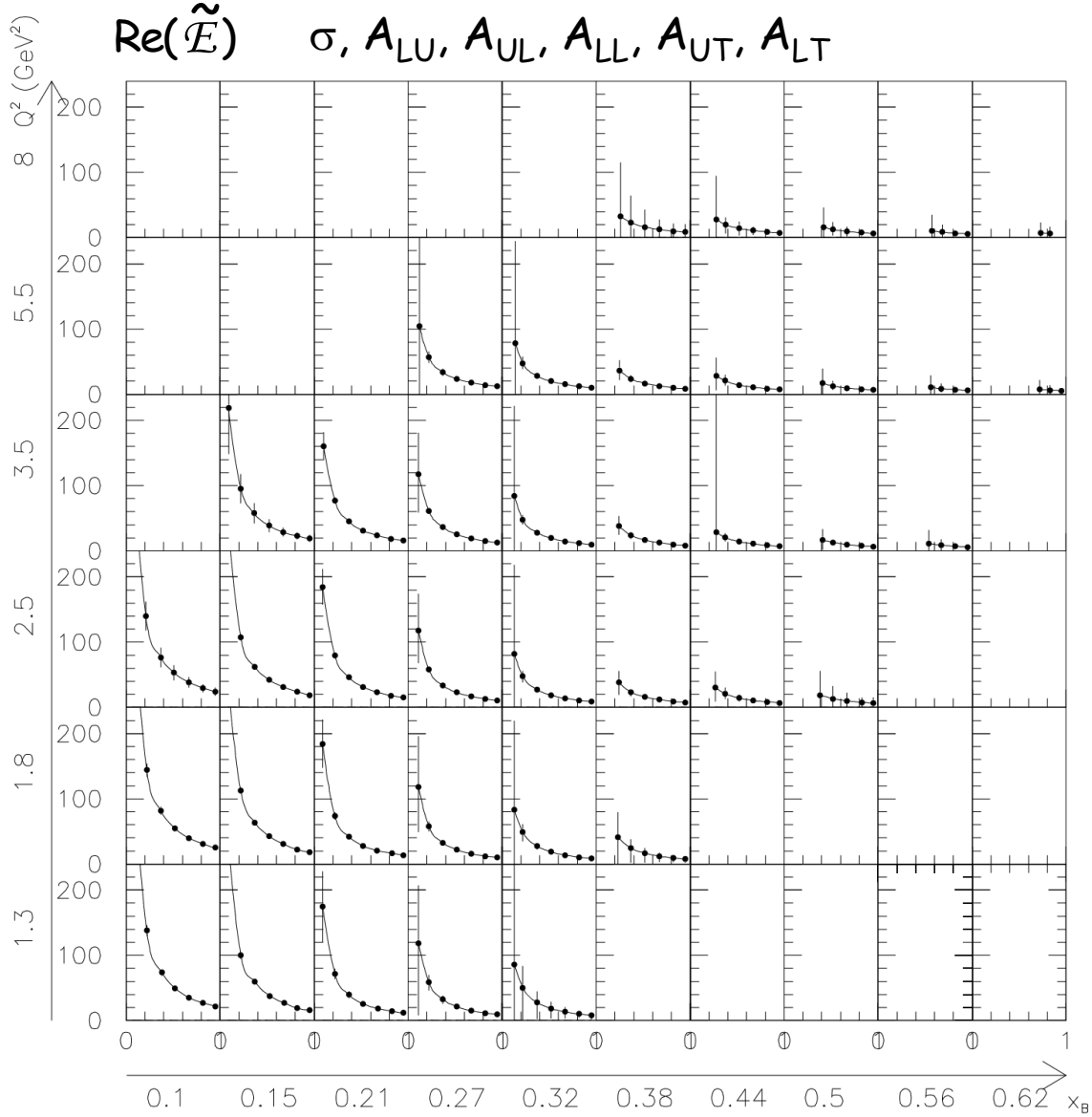
Extraction of Re($\mathcal{H}$) from proton pseudo-data



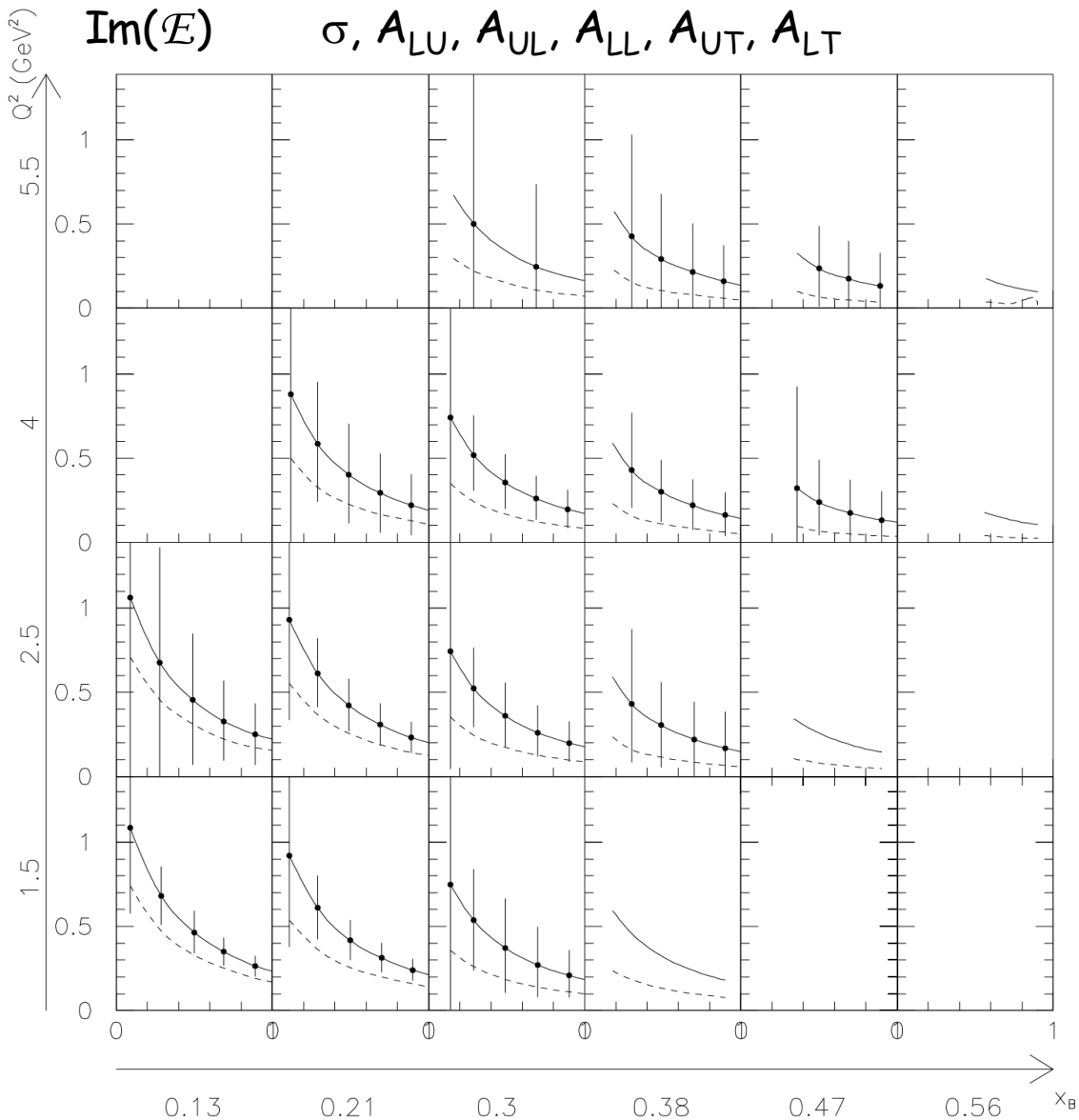
Extraction of $\mathrm{Im}(\tilde{\mathcal{H}})$ from proton pseudo-data



Extraction of $\mathrm{Re}(\tilde{\mathcal{E}})$ from proton pseudo-data



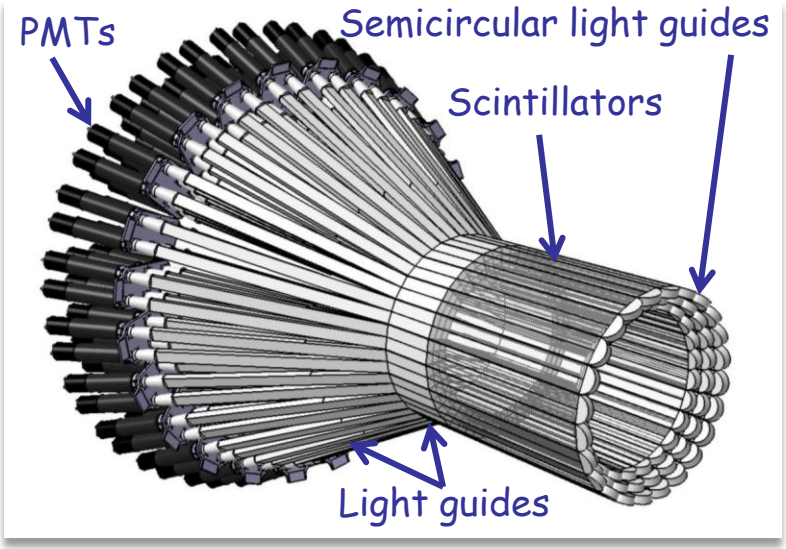
Extraction of Im($\mathcal{E}$) from proton pseudo-data

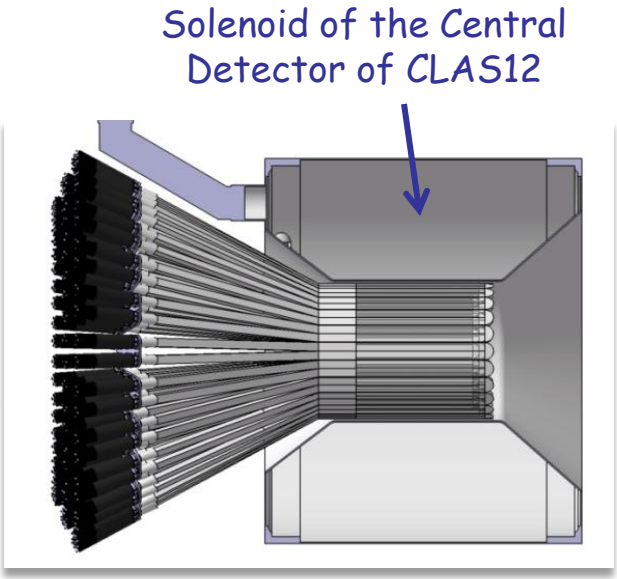


DVCS A_{LU} on the neutron

Approved experiment

This program requires adding a Central Neutron Detector (CND) to the CLAS12 base equipment





Combined analysis of DVCS on proton and neutron allows flavor separation of GPDs

$$(H,E)_u(\xi,\xi,t) = \tfrac{9}{15}\left[4(H,E)_p(\xi,\xi,t) - (H,E)_n(\xi,\xi,t)\right]$$
$$(H,E)_d(\xi,\xi,t) = \tfrac{9}{15}\left[4(H,E)_n(\xi,\xi,t) - (H,E)_p(\xi,\xi,t)\right]$$

$$\Delta\sigma_{LU} \sim \sin\phi \, \mathrm{Im}\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E}\}d\phi$$

$\Rightarrow$ $Im\{\mathcal{H}_n, \mathcal{H}_n, \mathcal{E}_n\}$

DVCS A_{LU} on neutron is mostly sensitive to the GPD E_n

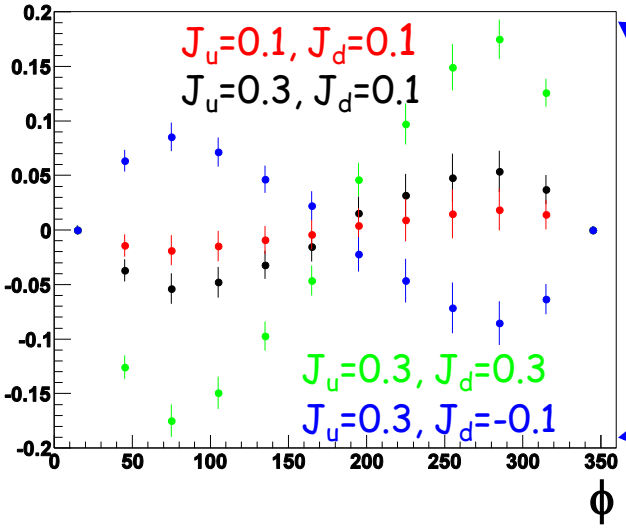
Needed to access J^q (Ji's sum rule)

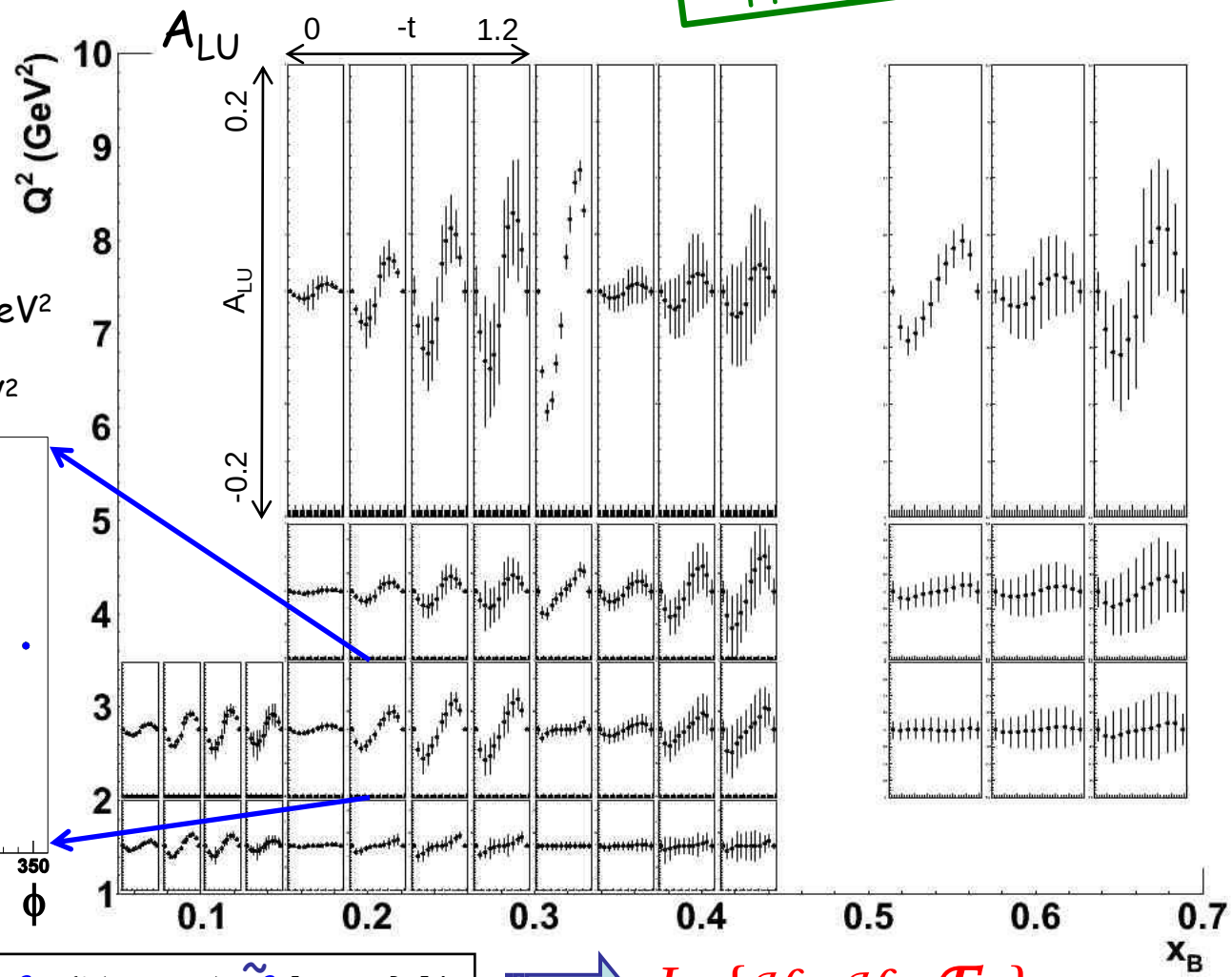
DVCS A_{LU} on the neutron

Approved experiment

80 days of beam time
$L = 10^{35}\ cm^{-2}s^{-1}$

$Q^2 = 2.75\ GeV^2$, $\Delta Q^2 = 1.5\ GeV^2$
$x_B = 0.225$, $\Delta x_B = 0.15$
$t = -0.35\ GeV^2$, $\Delta t = 0.3\ GeV^2$





$$\Delta\sigma_{LU} \sim \sin\phi\ \mathrm{Im}\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E}\}d\phi \Rightarrow Im\{\mathcal{H}_n, \mathcal{H}_n, \mathcal{E}_n\}$$

DVCS A_{LU} on neutron is mostly sensitive to the GPD E_n

Needed to access J^q (Ji's sum rule)

Summary

- JLab 12 GeV will provide high luminosity for high accuracy measurements to test models on a large x_B scale and thus will be a great facility to study GPDs in the valence region and CLAS12 will be perfectly suited for a rich experimental GPD program

- Four experiments proposed to study DVCS (DVCS on the proton/neutron, DVCS with polarized targets,…), among which three have been approved so far

- Extraction of Compton Form Factors (M. Guidal) attempted using pseudo-data by fitting simultaneously the different DVCS observables gives a large set of results in a very large kinematic domain

- Future DVCS results obtained with CLAS12 will provide strong constraints on a very large kinematic domain

Thank you

Backup slides

Extraction of Im($\mathcal{E}$) without transversely polarized target data