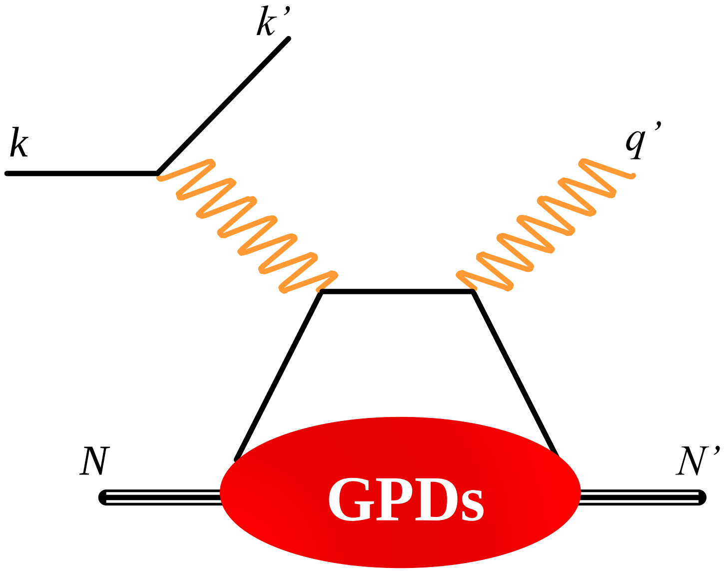
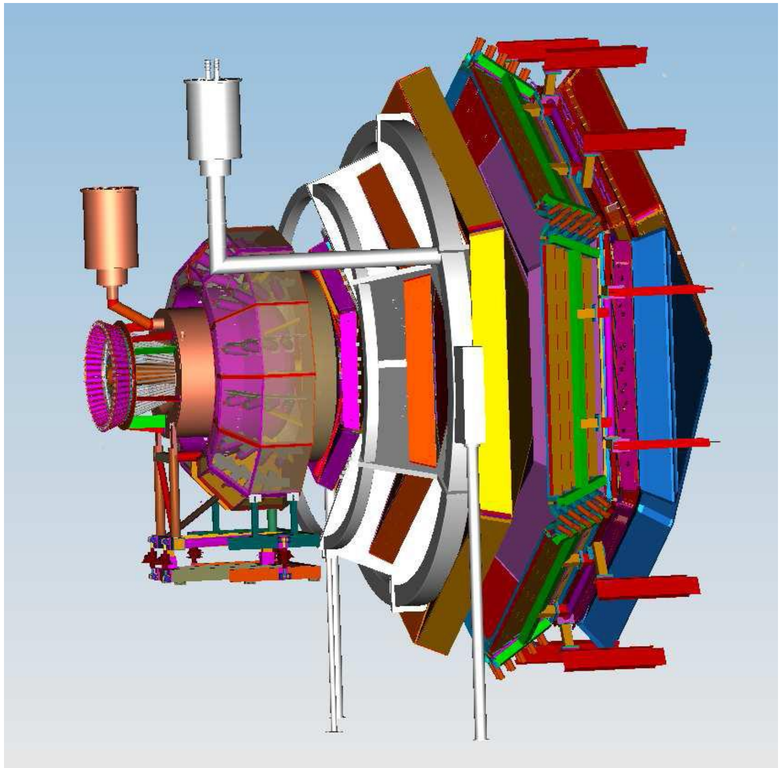
The Generalized Parton Distributions program with CLAS and CLAS12





Silvia Niccolai IPN ORSAY **CLAS Collaboration**

Electron-Nucleus Scattering XII
Marciana Marina (Italia) – June 26th 2012

The Generalized Parton Distributions program with CLAS and CLAS12

• Interest of GPDs

• GPDs and Deeply Virtual Compton Scattering

• The CLAS detector

• DVCS results with CLAS

• GPDs and Deeply Virtual Meson Production

• DVMP results with CLAS

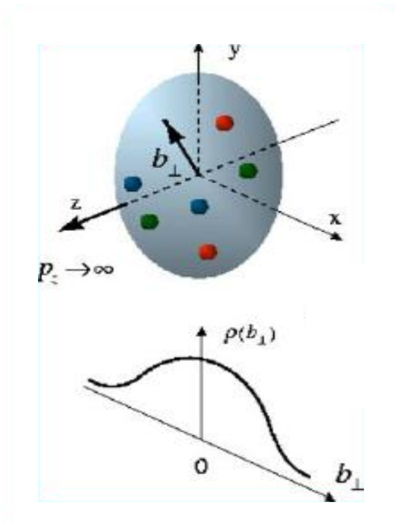
• The JLab 12 GeV upgrade and CLAS12

• Future experiments on GPDs with CLAS12

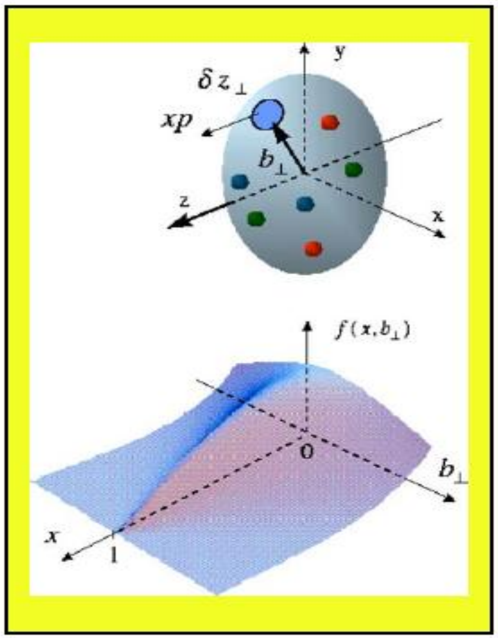
Silvia Niccolai IPN ORSAY **CLAS Collaboration**

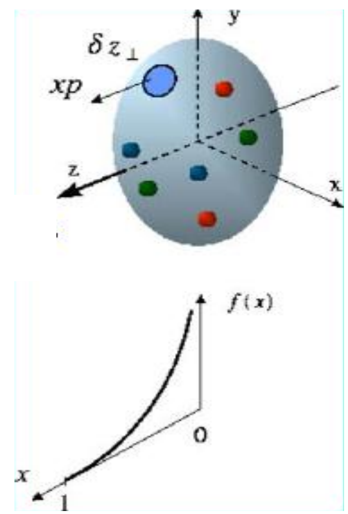
Electron-Nucleus Scattering XII
Marciana Marina (Italia) – June 26th 2012

Electron scattering to unveil nucleon structure



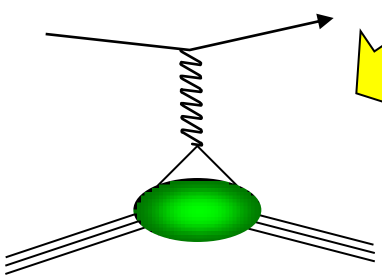
GPDs: H, E, $\tilde{H}$, $\tilde{E}$
Fully correlated quark distributions in both coordinate and momentum space





Form factors: **transverse quark distribution** **in coordinate space**

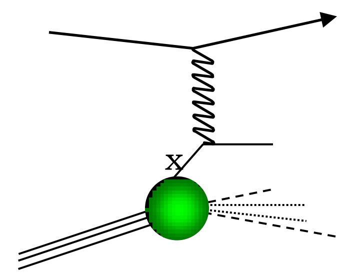
Parton distributions: **longitudinal quark distribution** **in momentum space**



$\int H(x,\xi,t)dx = F_1(t)$ $(\forall\ \xi)$

$\int E(x,\xi,t)dx = F_2(t)$ $(\forall\ \xi)$

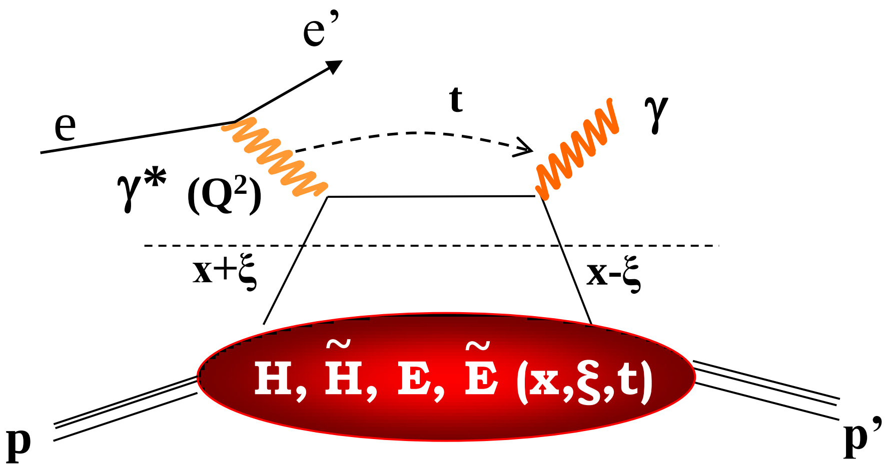
Accessible in hard exclusive processes



$H(x,0,0) = q(x)$,

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

Deeply Virtual Compton Scattering and GPDs



- $Q^2 = -(e-e')^2$
- $x_B = Q^2/2M\nu \quad \nu = E_e - E_{e'}$

- $x+\xi$, $x-\xi$ longitudinal momentum fractions
- $t = (p-p')^2$
- $\xi \cong x_B/(2-x_B)$

At LO, LT, chiral-even, quark sector
→ **4 GPDs for each quark flavor**

« Handbag » factorization valid in the Bjorken regime: high Q^2, ν (fixed x_B), $t \ll Q^2$

conserve nucleon helicity

Vector: $H(x,\xi,t)$ **Axial-Vector: $\tilde{H}(x,\xi,t)$**

Tensor: $E(x,\xi,t)$ **Pseudoscalar: $\tilde{E}(x,\xi,t)$**

flip nucleon helicity

Quark angular momentum (Ji's sum rule)

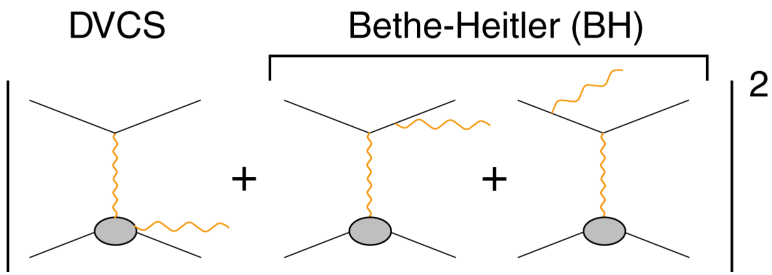
$$J^q = \frac{1}{2} - J^G = \frac{1}{2}\int_{-1}^{1} x\,dx \left[H^q(x,\xi,0) + E^q(x,\xi,0)\right]$$

X. Ji, Phy.Rev.Lett.78,610(1997)

«3D» quark/gluon image of the nucleon

Accessing GPDs through DVCS

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

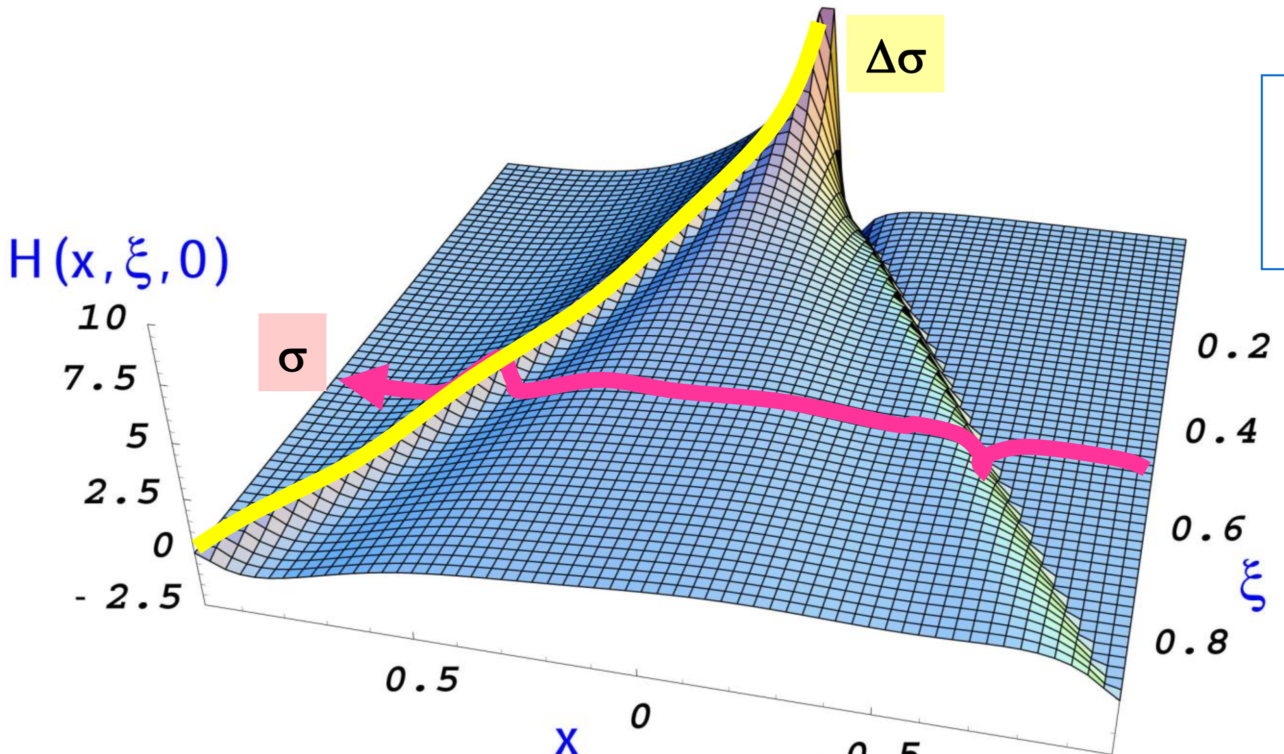


$$\sigma \sim |T^{DVCS} + T^{BH}|^2$$

$$\Delta\sigma = \sigma^{+} - \sigma^{-} \propto I(DVCS \cdot BH)$$

$$A = \frac{\Delta\sigma}{2\sigma} \propto \frac{I(DVCS \cdot BH)}{|BH|^2 + |DVCS|^2 + I}$$

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

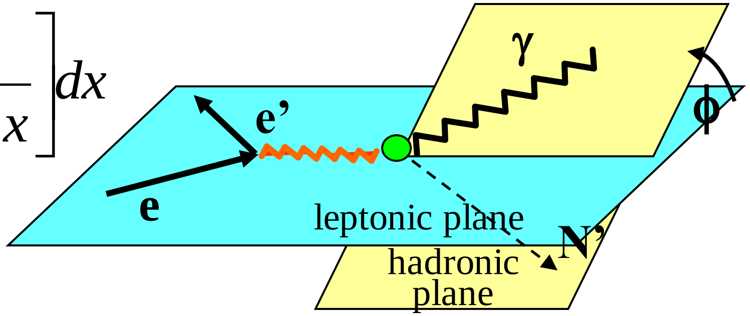


Only ξ and t are accessible experimentally

Sensitivity to GPDs of DVCS spin observables

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

$$Im\mathcal{H}_q = \pi e_q^2\left[H^q(\xi,\xi,t) - H^q(-\xi,\xi,t)\right]$$



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

Proton **Neutron**

Polarized **beam**, unpolarized target:

$\Delta\sigma_{LU} \sim \sin\phi\ \mathbf{Im}\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E}\}d\phi$ ⇒ $Im\{\boldsymbol{\mathcal{H}}_{\mathbf{p}}, \tilde{\mathcal{H}}_p, \mathcal{E}_p\}$ $Im\{\mathcal{H}_n, \tilde{\mathcal{H}}_n, \boldsymbol{\mathcal{E}}_{\mathbf{n}}\}$

Unpolarized beam, **longitudinal** target:

$\Delta\sigma_{UL} \sim \sin\phi\,\mathbf{Im}\{F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + x_B/2\,\mathcal{E}) - \xi kF_2\tilde{\mathcal{E}} + \ldots\}d\phi$ ⇒ $Im\{\boldsymbol{\mathcal{H}}_{\mathbf{p}}, \tilde{\boldsymbol{\mathcal{H}}}_{\mathbf{p}}\}$ $Im\{\boldsymbol{\mathcal{H}}_{\mathbf{n}}, \mathcal{E}_n, \tilde{\mathcal{E}}_n\}$

Polarized **beam**, **longitudinal** target:

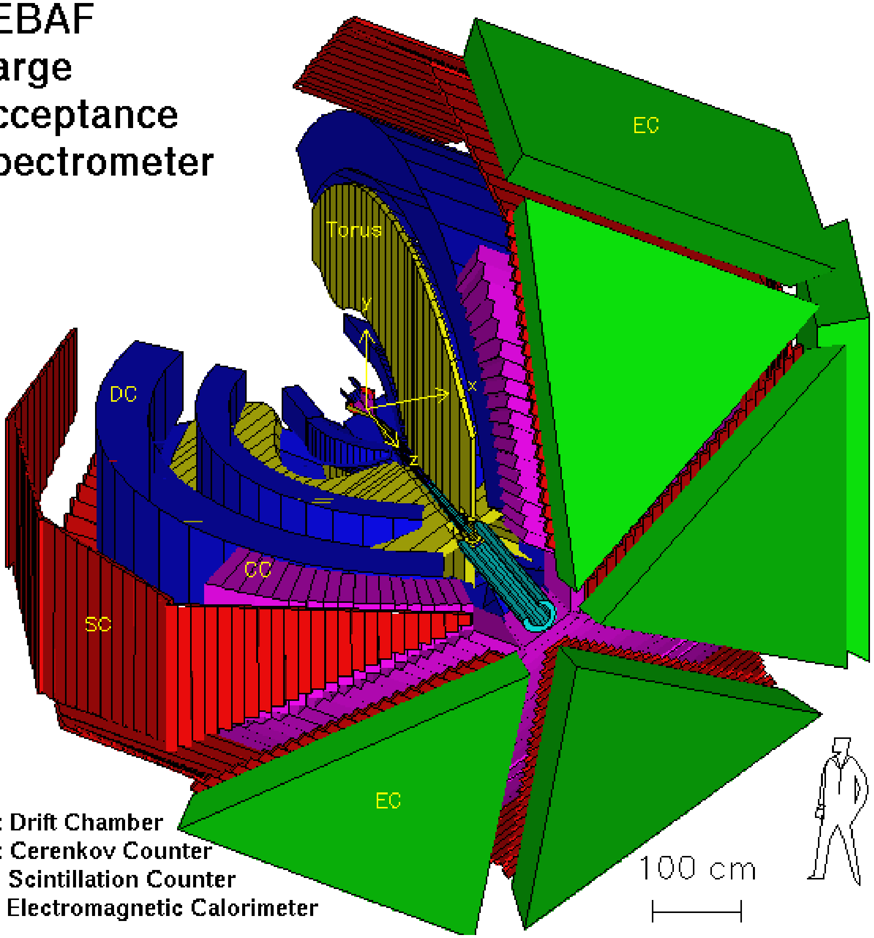
$\Delta\sigma_{LL} \sim (A + B\cos\phi)\mathbf{Re}\{F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + x_B/2\,\mathcal{E})\ldots\}d\phi$ ⇒ $Re\{\boldsymbol{\mathcal{H}}_{\mathbf{p}}, \tilde{\boldsymbol{\mathcal{H}}}_{\mathbf{p}}\}$ $Re\{\boldsymbol{\mathcal{H}}_{\mathbf{n}}, \mathcal{E}_n, \tilde{\mathcal{E}}_n\}$

Unpolarized beam, **transverse** target:

$\Delta\sigma_{UT} \sim \sin\phi\,\mathbf{Im}\{k(F_2\mathcal{H} - F_1\mathcal{E}) + \ldots\}d\phi$ ⇒ $Im\{\boldsymbol{\mathcal{H}}_{\mathbf{p}}, \boldsymbol{\mathcal{E}}_{\mathbf{p}}\}$ $Im\{\boldsymbol{\mathcal{H}}_{\mathbf{n}}\}$

The CLAS detector (Jefferson Lab, Hall B)

CEBAF
Large
Acceptance
Spectrometer



- **Toroidal magnetic field (6 supercond. coils)**
- **Drift chambers (argon/CO_2 gas, 35000 cells)**
- **Time-of-flight scintillators**
- **Electromagnetic calorimeters**
- **Cherenkov Counters (e/π separation)**

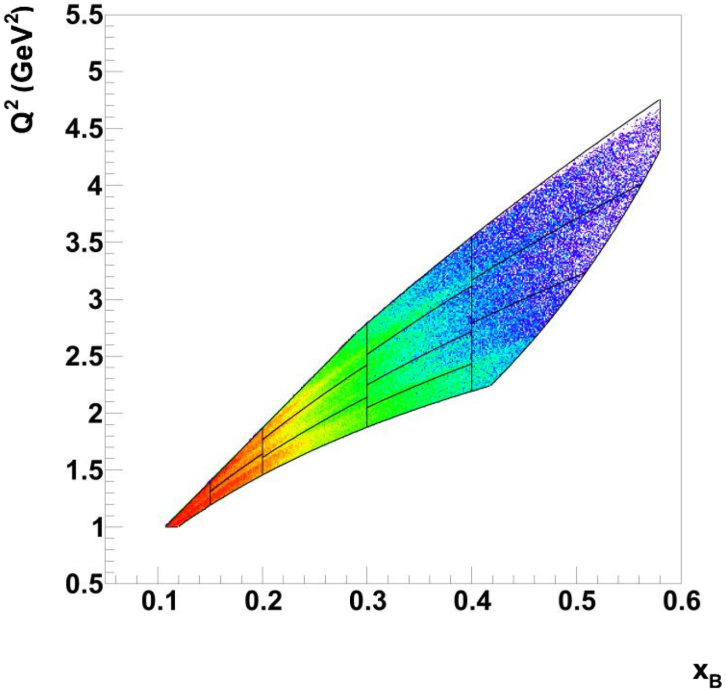
Performances:

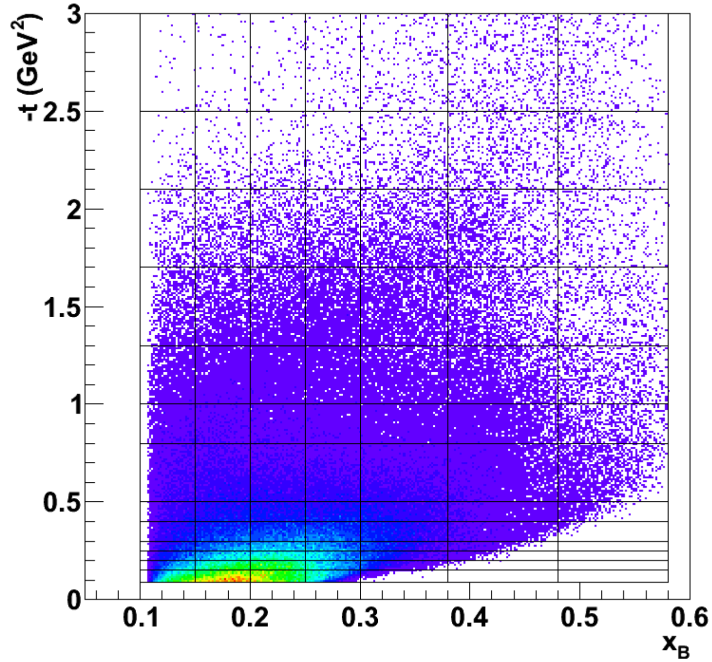
- **large acceptance** for charged particles
  $8° < \theta < 142°$, $p_p > 0.3$ GeV/c, $p_\pi > 0.1$GeV/c
- **good momentum and angular resolution**
  $\Delta p/p \leq 0.5\%$ - 1.5%, $\Delta\theta$, $\Delta\phi \leq 1$ mrad

Optimal for measurements of exclusive reactions with multi-particle final states

After ~15 years of honored service, CLAS has completed its program in May 2012

The e1-DVCS experiment



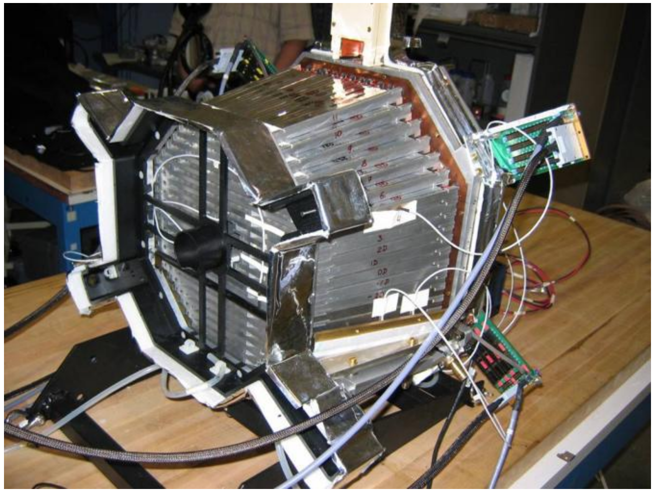


Part 1 of the e1-DVCS experiment:

- Data taken from March 11 until May 27, 2005
- Beam energy ~ 5.766 GeV
- Beam current = 20-25 nA
- Beam polarization ~ 80%
- Integrated luminosity ~ 3.33 x 10^7 nb^{-1}
- Target LH_2

CLAS + Solenoid (Moeller shield) + IC

More data taken in fall 2008, under analysis

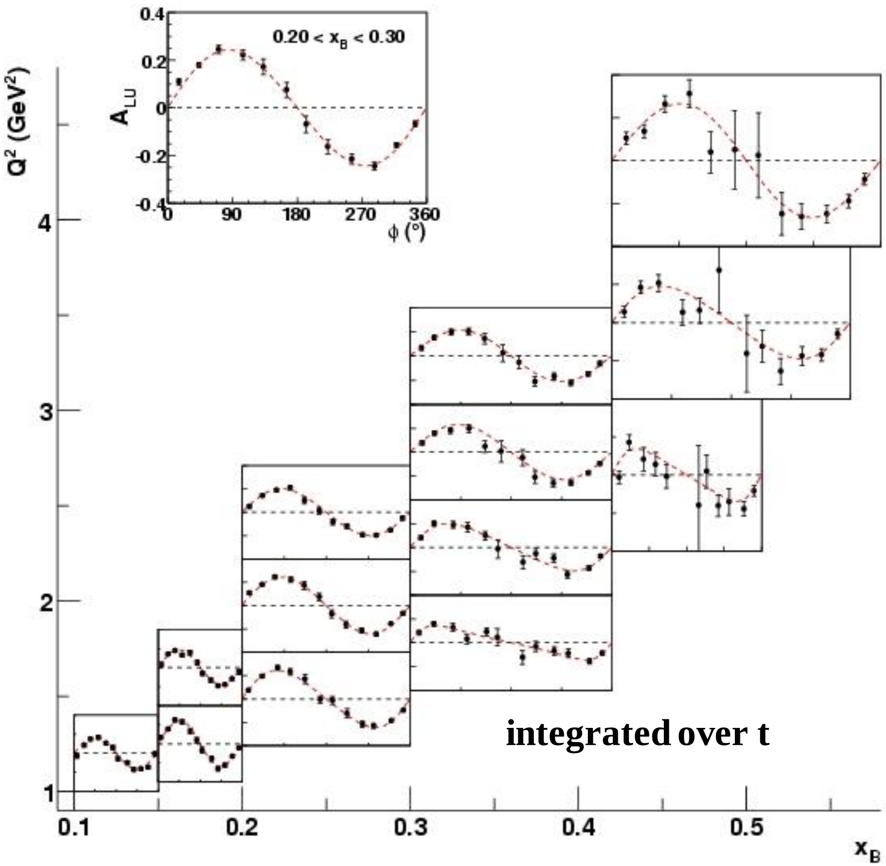


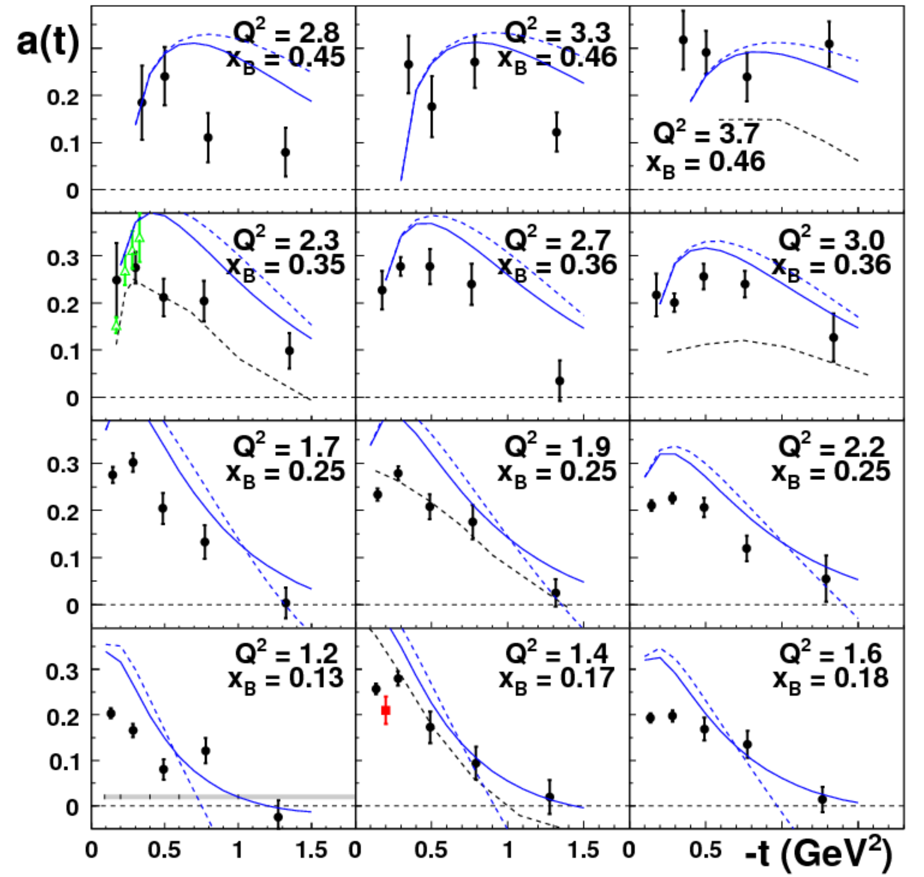
IC (inner calorimeter)
424 lead tungstate crystals + APD readout

DVCS Beam Spin Asymmetries

ep→epγ

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





- CLAS e1-dvcs
- Hall A
- CLAS @ 4.3 GeV²
- VGG(*) twist-2 (DD)
- VGG(*) twist-2 and 3
- Regge model (**)

Fit = a sinϕ/(1+b cosϕ)

F.X. Girod et al., Phys. Rev. Lett. 100, 162002 (2008)

(*) Guidal, Polyakov, Radyushkin, Vanderhaegen, PRD 72 (2005)

(**) Cano and Laget, PL B551 (2003)

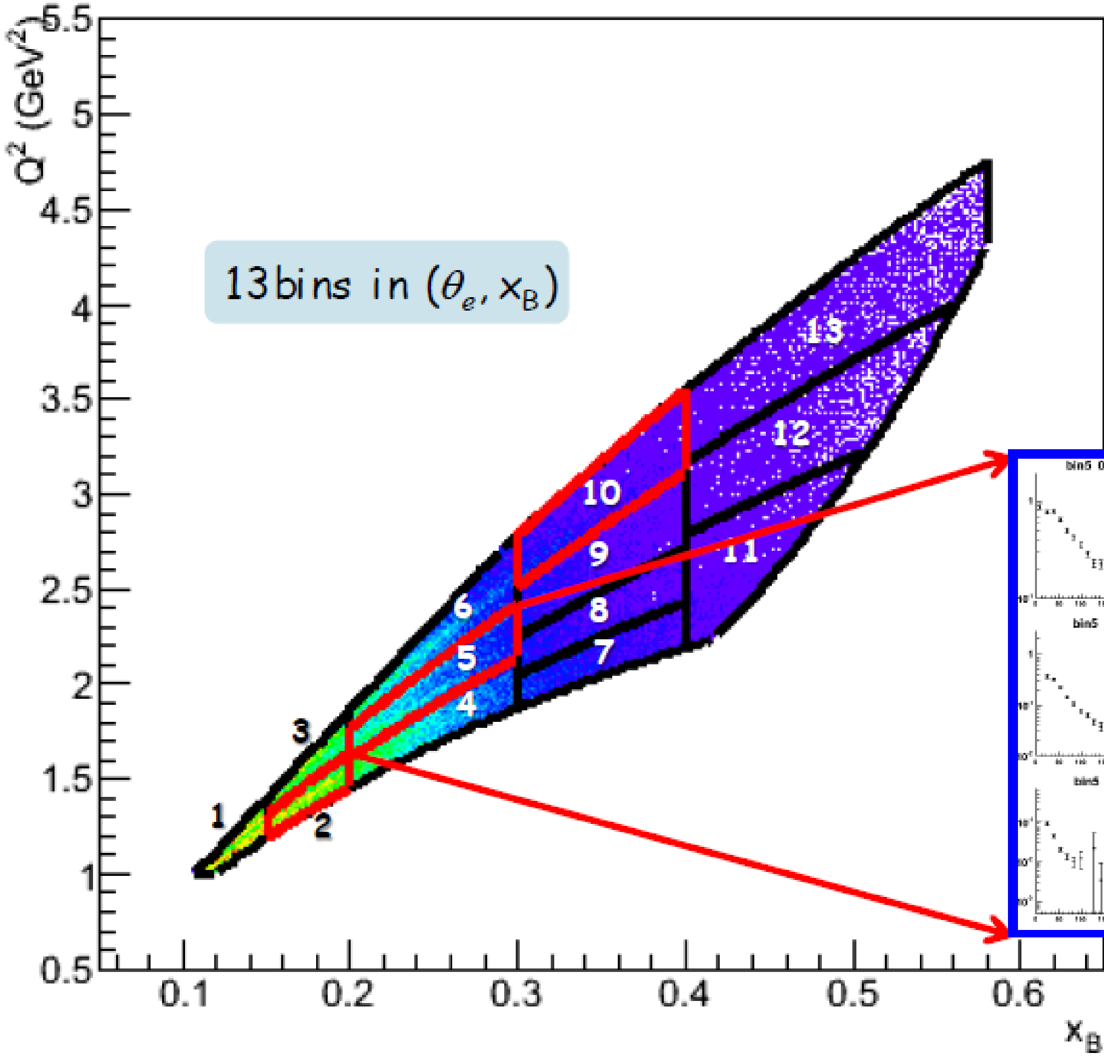
Hyon-Suk Jo, IPNO

DVCS cross sections

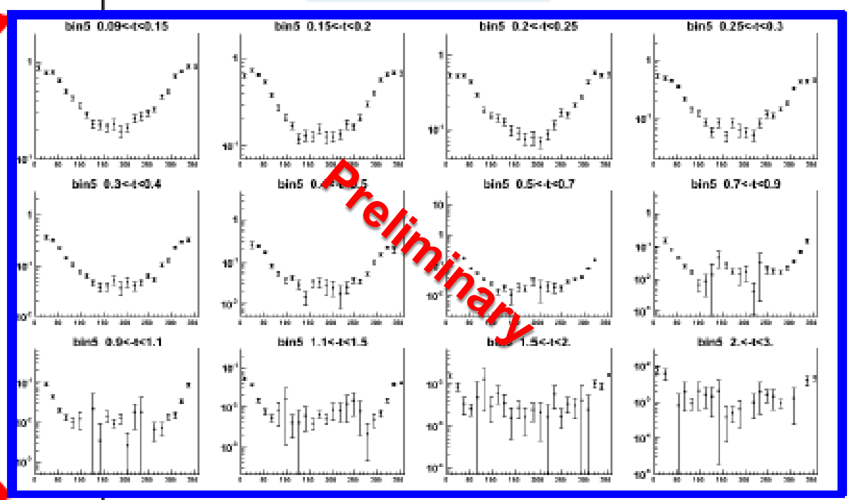
$Q^2 > 1, \; 0.1 < x_B < 0.58,$

$21 < \theta_e < 45, \; p_e > 0.8, \; W > 2$

Extraction of 4-differential cross sections $\frac{d^4\sigma_{ep\to ep\gamma}}{dQ^2 dx_B dt d\Phi}$



12 bins in t



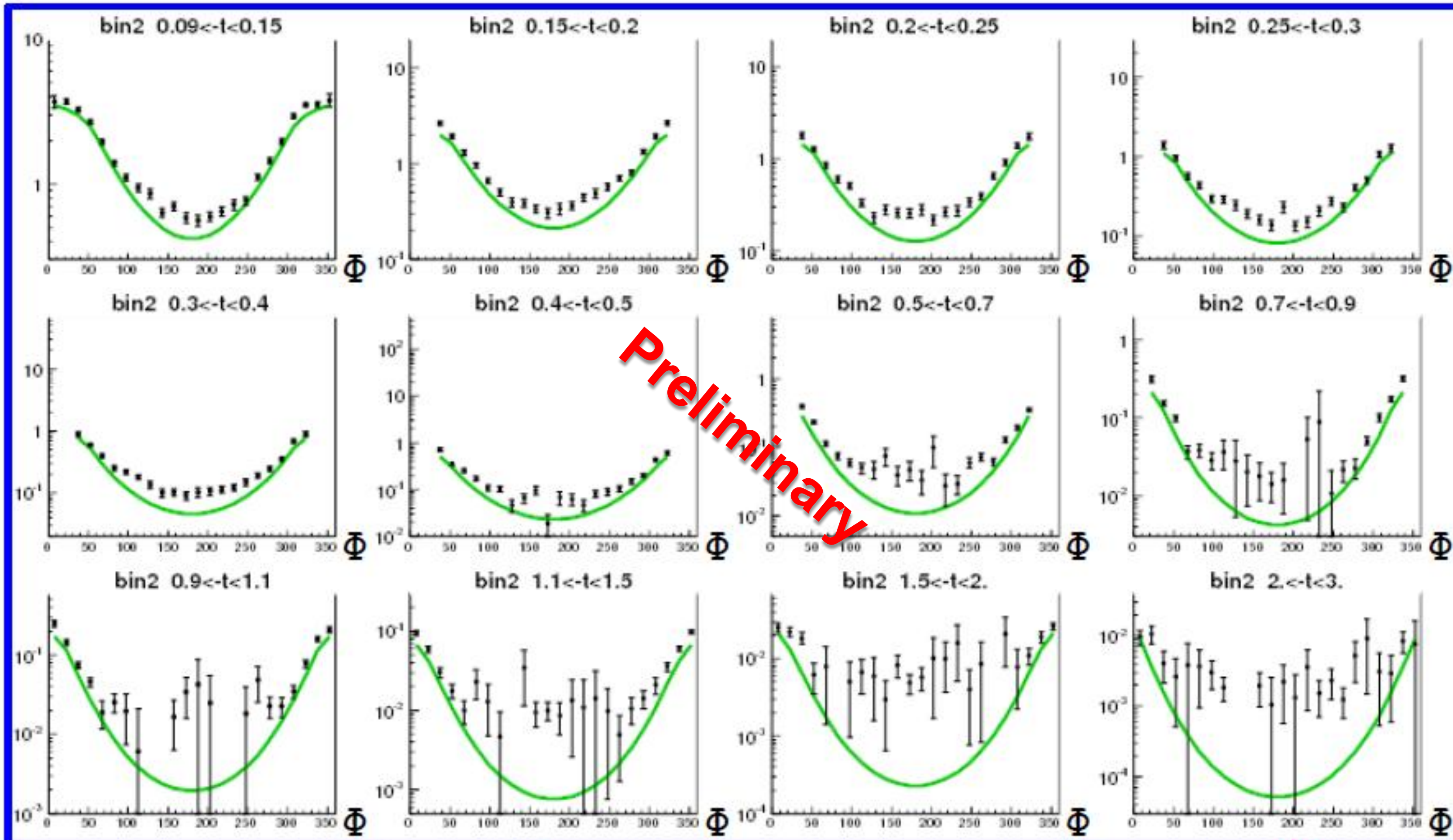
Φ

24 bins in Φ

Beam-polarized cross section differences are also extracted

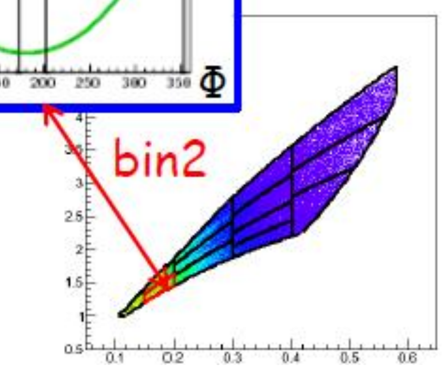
Hyon-Suk Jo, IPNO

DVCS cross sections



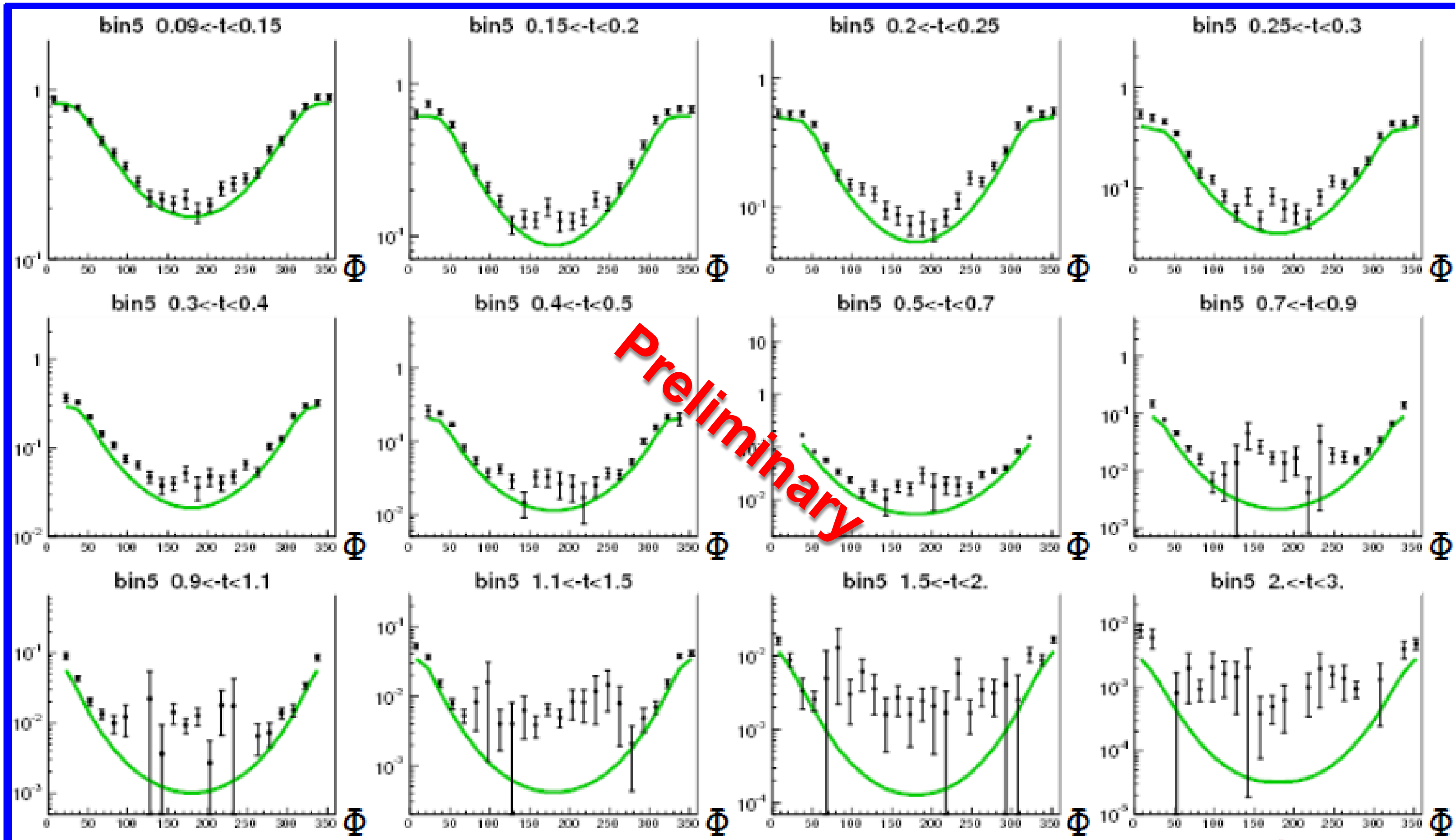
• $\frac{d^4\sigma_{ep\to ep\gamma}}{dQ^2 dx_B dt d\Phi}$ (nb/GeV^4)

— Bethe-Heitler integrated over the bin



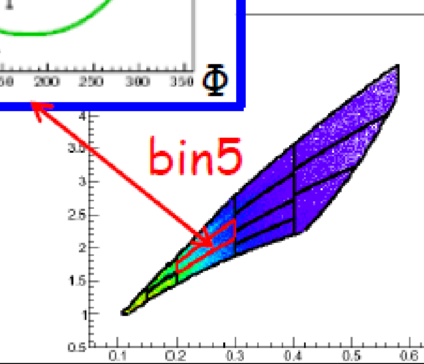
Hyon-Suk Jo, IPNO

DVCS cross sections



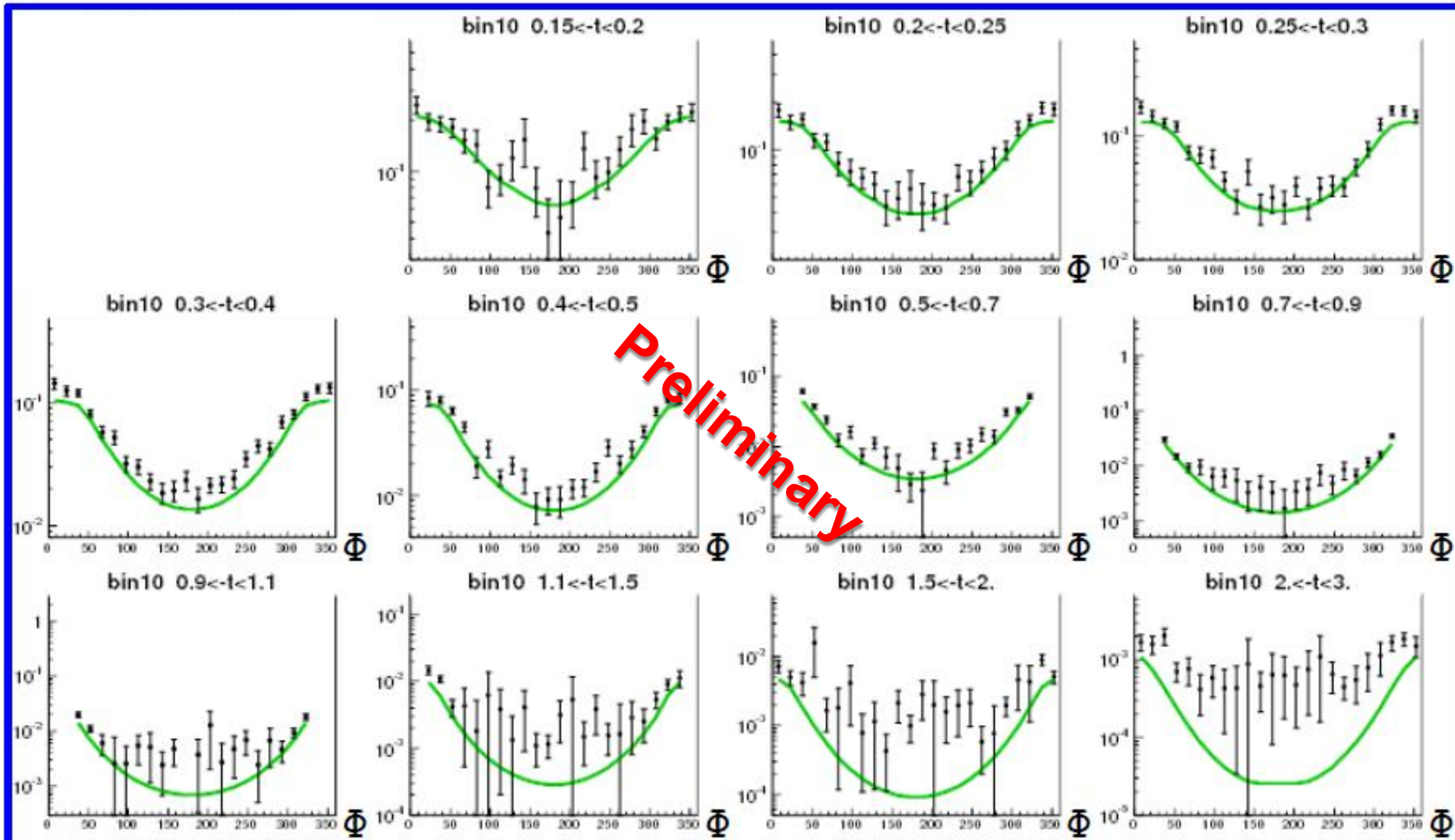
• $\frac{d^4\sigma_{ep\to ep\gamma}}{dQ^2 dx_B dt d\Phi}$ (nb/GeV^4)

— Bethe-Heitler integrated over the bin



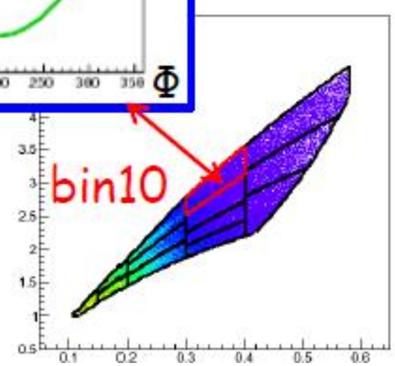
Hyon-Suk Jo, IPNO

DVCS cross sections



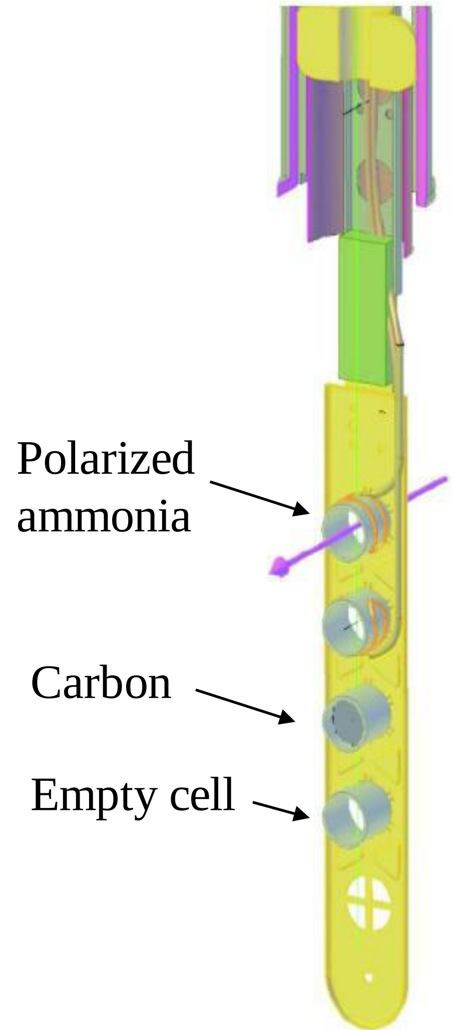
• $\frac{d^4\sigma_{ep\to ep\gamma}}{dQ^2 dx_B dt d\Phi}$ (nb/GeV^4)

— Bethe-Heitler integrated over the bin



The eg1-dvcs experiment at CLAS

- Data taken from February to September **2009**
- Beam energies = 4.735, 5.764, 5.892, 5.967 GeV
- Beam polarizaton ~ 85%
- **CLAS+IC** to detect forward photons
- Target: **longitudinally polarized** via DNP (5 Tesla, 1 Kelvin, 140 Ghz microwaves) $\mathbf{NH_3}$ (~80%) and $\mathbf{ND_3}$ (~30%) – Luminosity ~ $5 \cdot 10^{34}$ cm^{-2} s^{-1}
- Target polarization monitored by **NMR**
- ~75 fb^{-1} on NH3 (parts A, B), ~25 fb^{-1} on ND3 (part C)



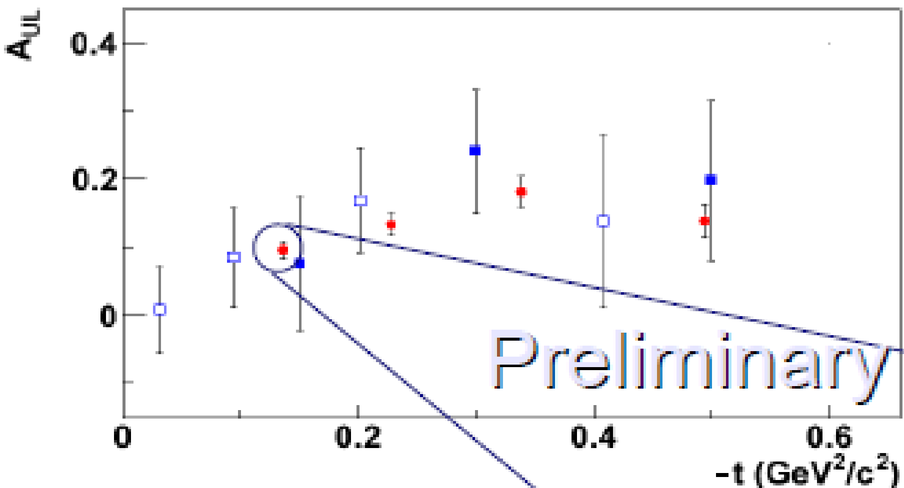
C.D. Keith et al., NIM A 501 (2003) 327

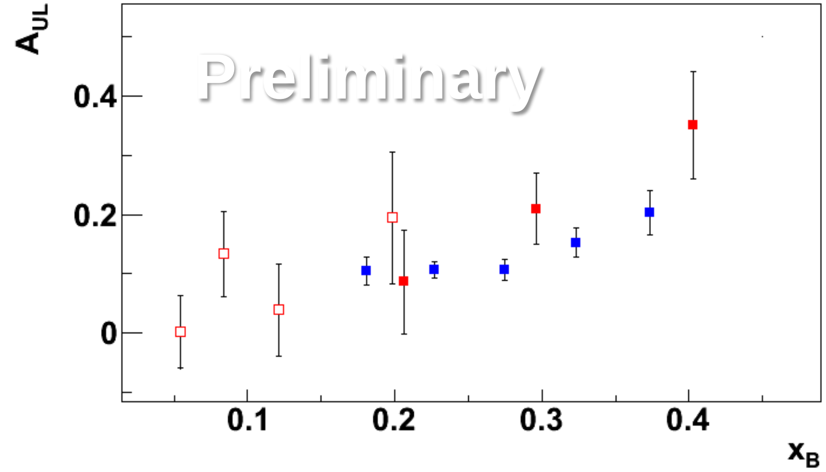
p-DVCS: Target Spin Asymmetry

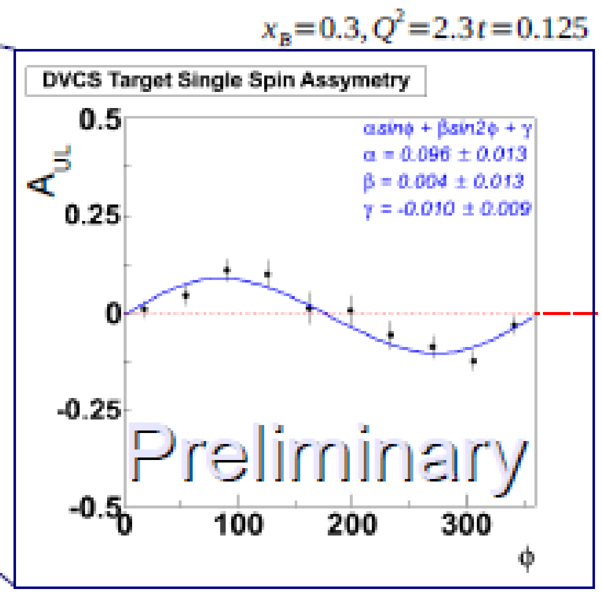
Erin Seder, UConn

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

- ■ CLAS eg1-dvcs
- ■ pioneering measurements from CLAS-eg1b
- □ results from HERMES







Dilution factor: f~ 0.76

Target polarization: P_T=-85%, +90%

Only IC photons included

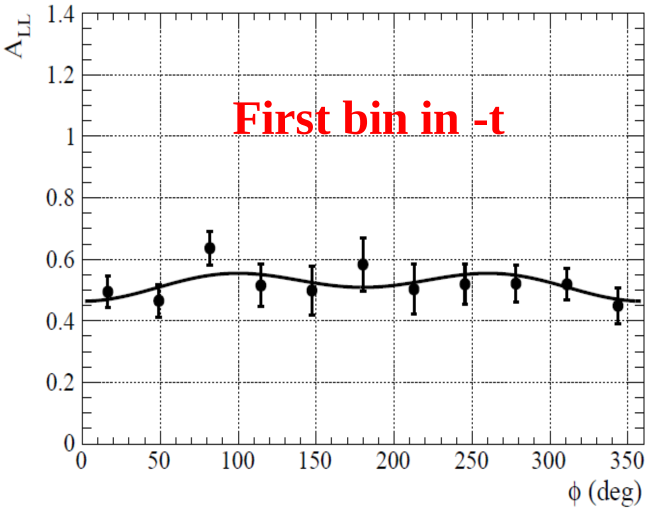
Only eg1-dvcs part B data

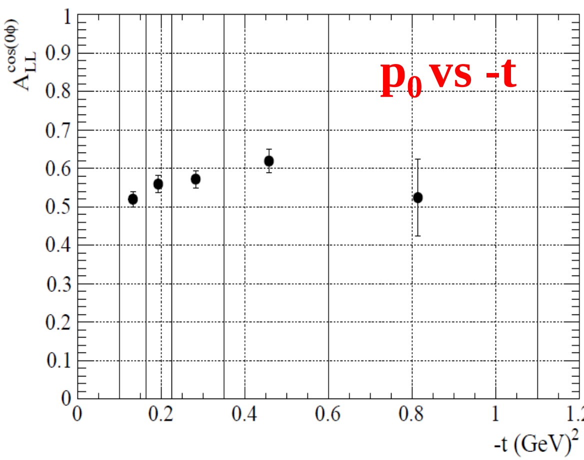
No π^0 background subtraction yet

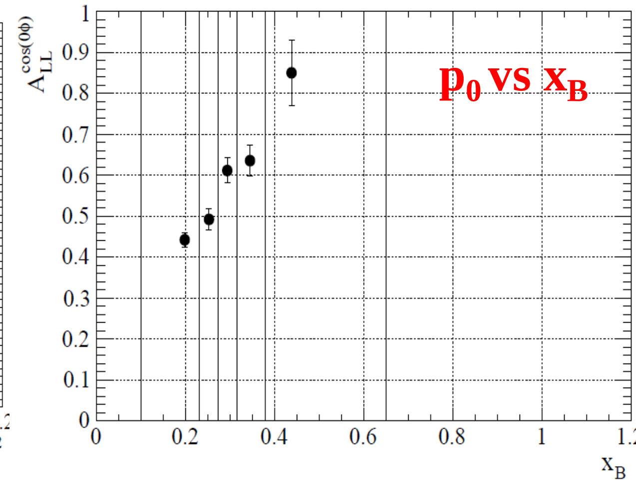
p-DVCS: Double (Beam-Target) Spin Asymmetry

Gary Smith, Glasgow

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







$$A_{LL} = \frac{(N^{++}+N^{--})-(N^{+-}-N^{-+})}{f\cdot P_B P_T(N^{++}+N^{--})+(N^{+-}+N^{-+})}$$

$$Fit = p_0 + p_1\cos\varphi + p_2\cos 2\varphi$$

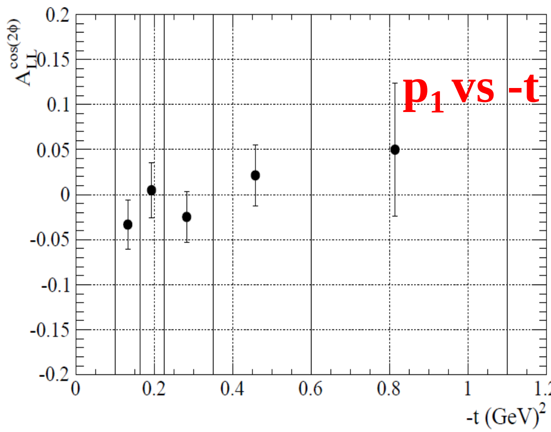
ALL THESE RESULTS ARE VERY PRELIMINARY!

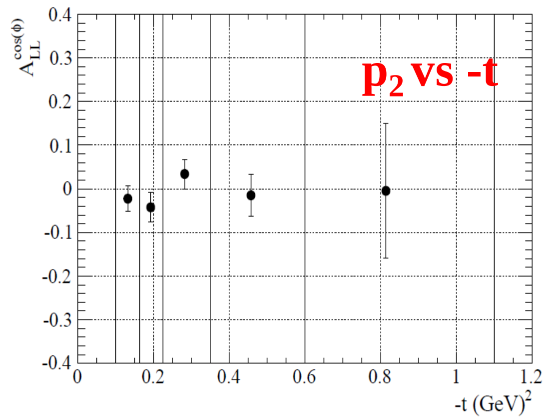
Dilution factor: f~ 0.76

Target polarization: P_T=-85%, +90%

Beam Polarizarion: P_B= 83%

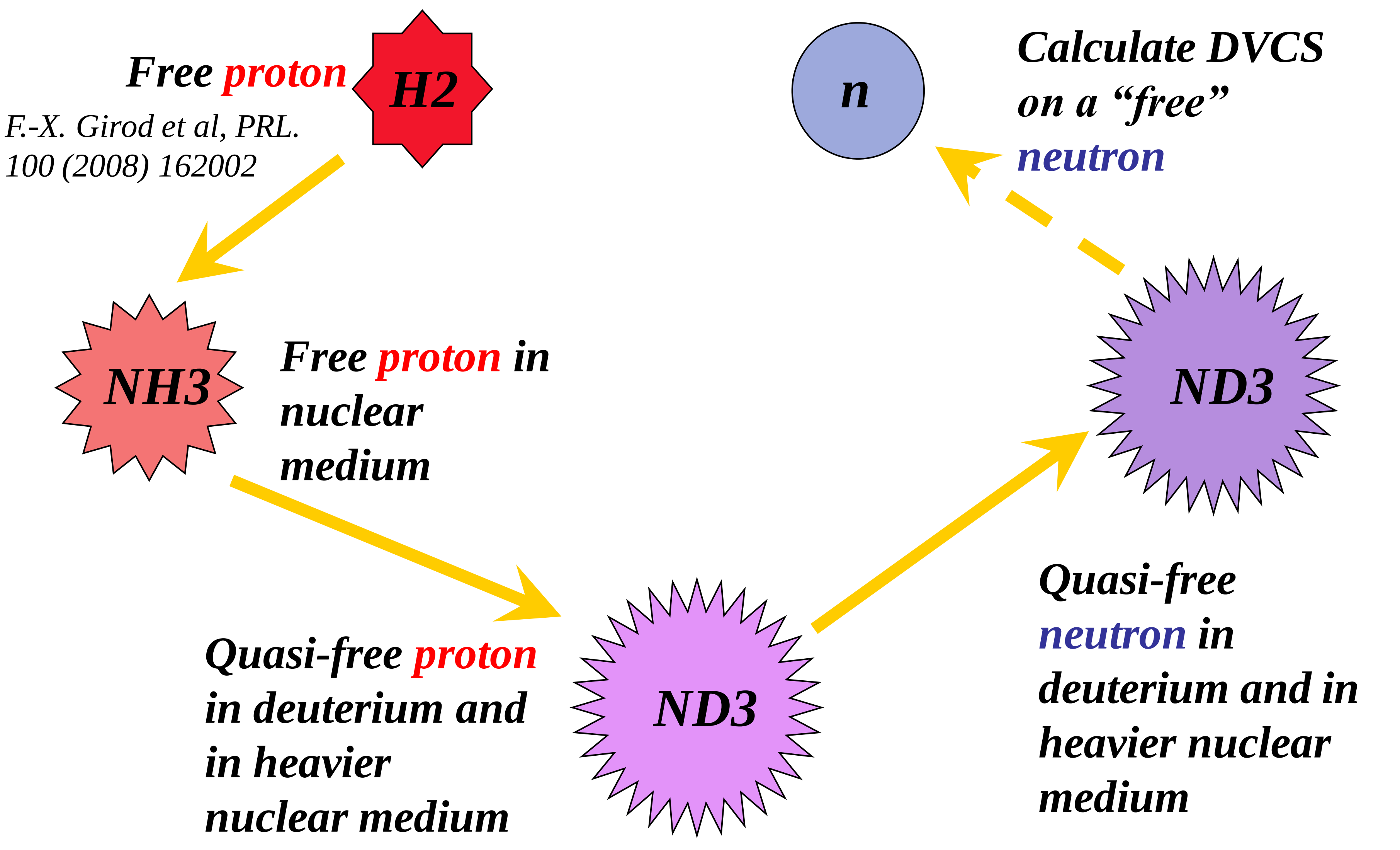
Only IC photons included
only eg1-dvcs part B data
No π^0 background subtraction yet





Extracting n-DVCS from eg1-dvcs data

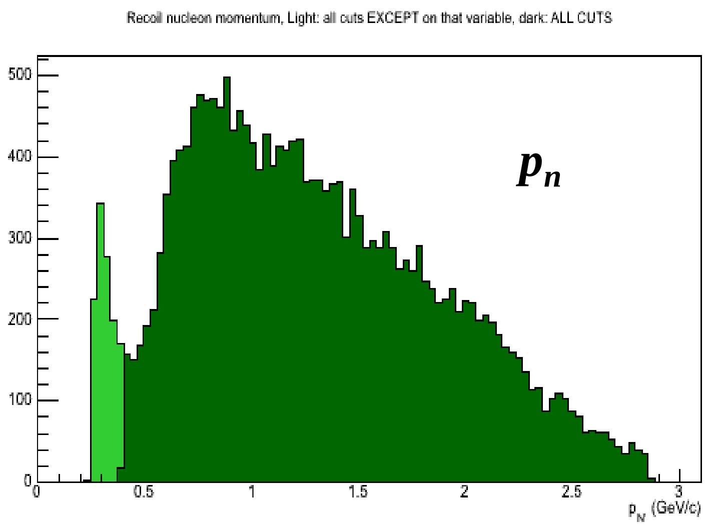
Daria Sokhan, IPNO

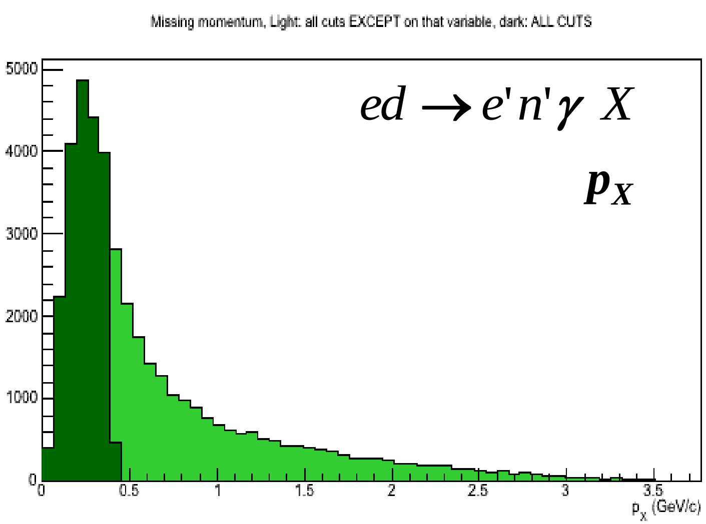


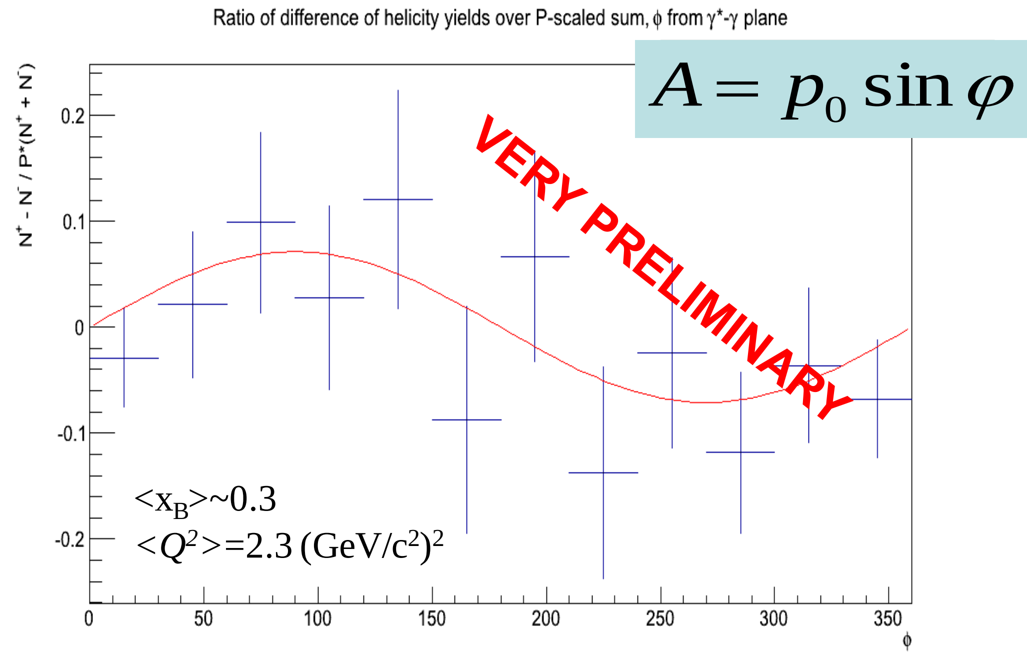
n-DVCS A_{LU} beam-spin asymmetry from ND_3

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

Daria Sokhan, IPNO







Integrated over all kinematics
No π_0 subtraction yet
Statistics very low, but $A_{LU} \neq 0$!
A_{UL} analysis also underway
More data will be taken with **CLAS12** at 11 GeV, on **liquid deuterium target**

Extraction of Compton Form Factors from p-DVCS observables

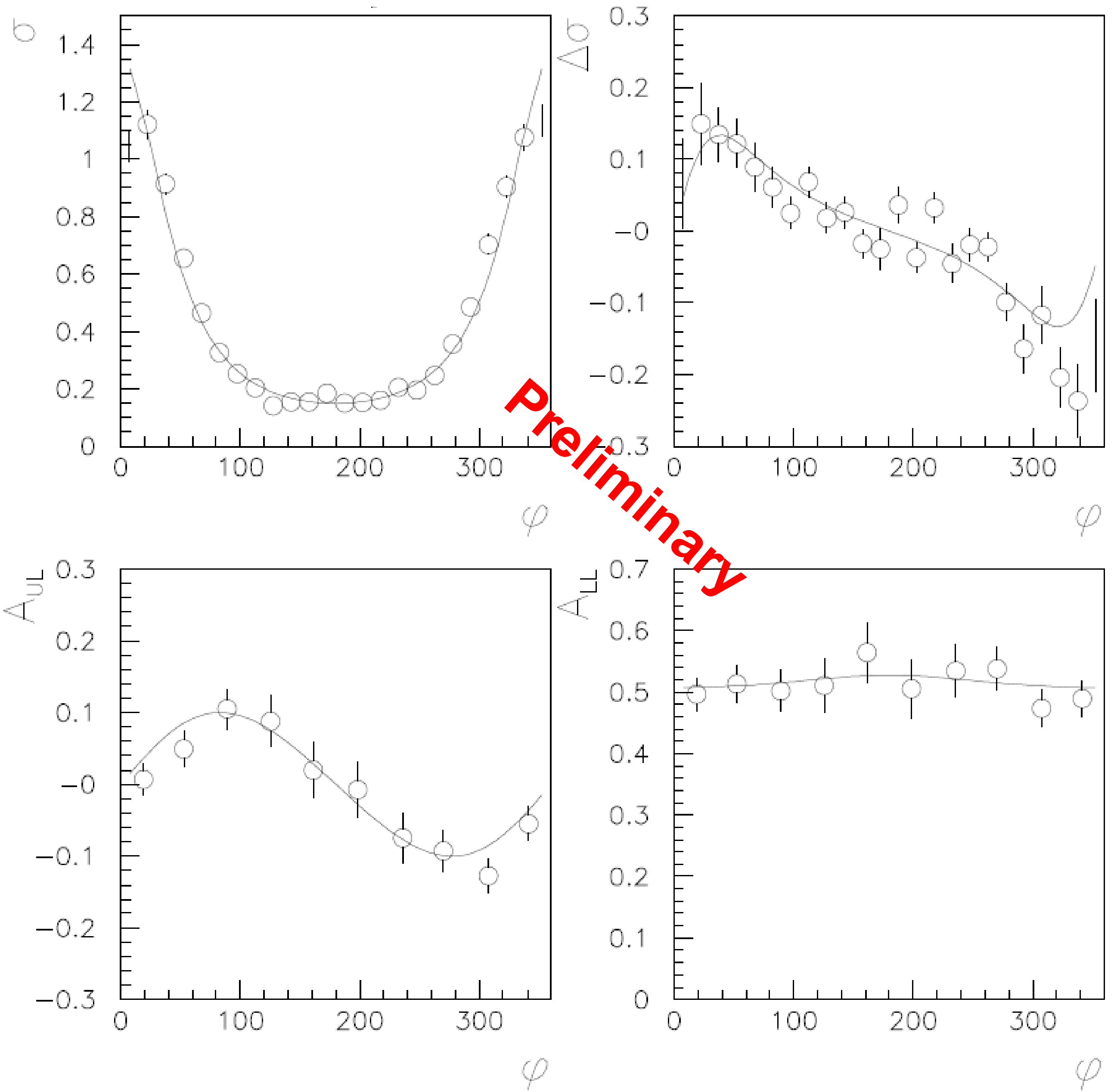
8 CFF

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

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

M. Guidal: **Model-independent fit**, at fixed Q^2, x_B and t of DVCS observables
8 unknowns (the CFFs), non-linear problem, strong correlations
Bounding the domain of variation of the CFFs with model (5xVGG)

Extraction of CFF from the CLAS p-DVCS results

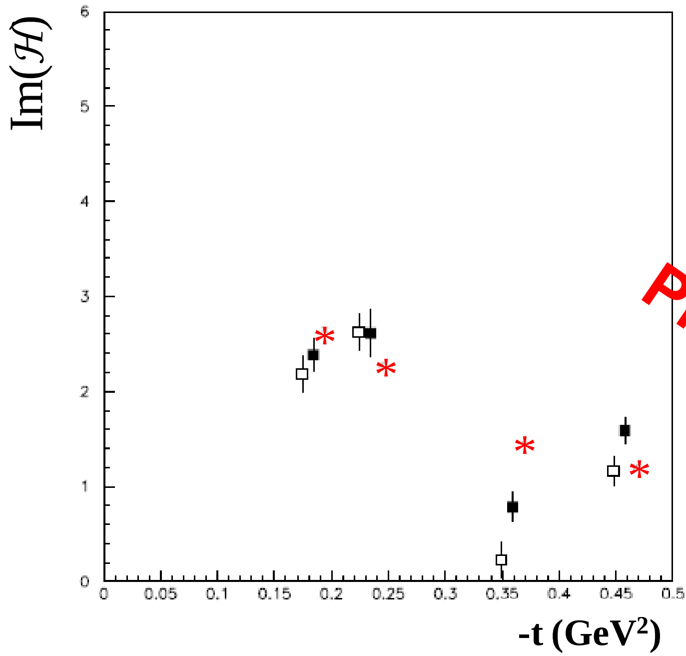


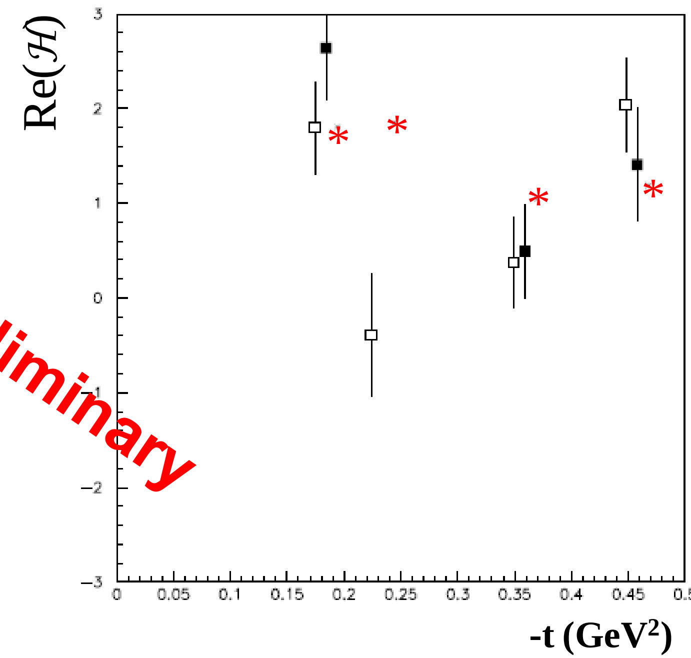
Simultaneous fit of **σ** and **Δσ** from **e1-dvcs** and A_{UL} and A_{LL} from **eg1-dvcs**

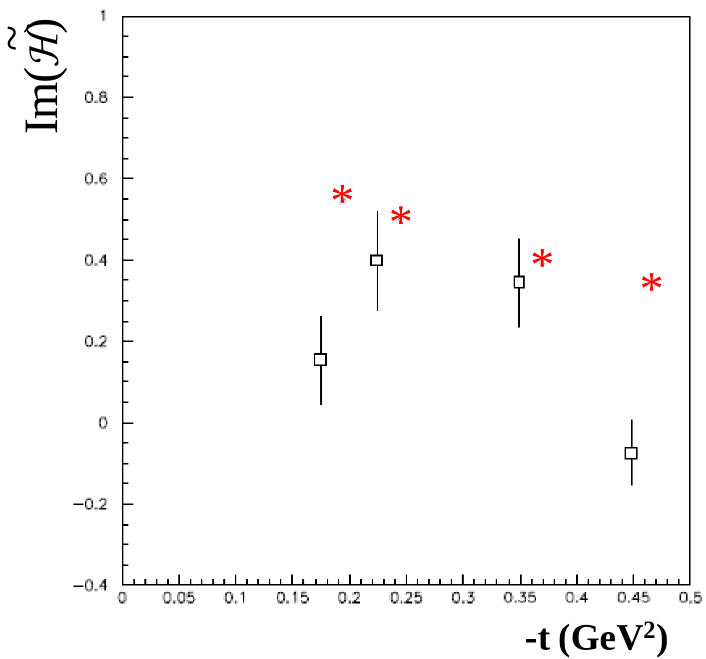
Q^2=1.94 GeV^2
x_B=0.24
-t=0.17 GeV^2

M. Guidal, IPNO

Extraction of CFF from the CLAS p-DVCS results







□ Fit of σ, Δσ, A_{UL}, A_{LL}

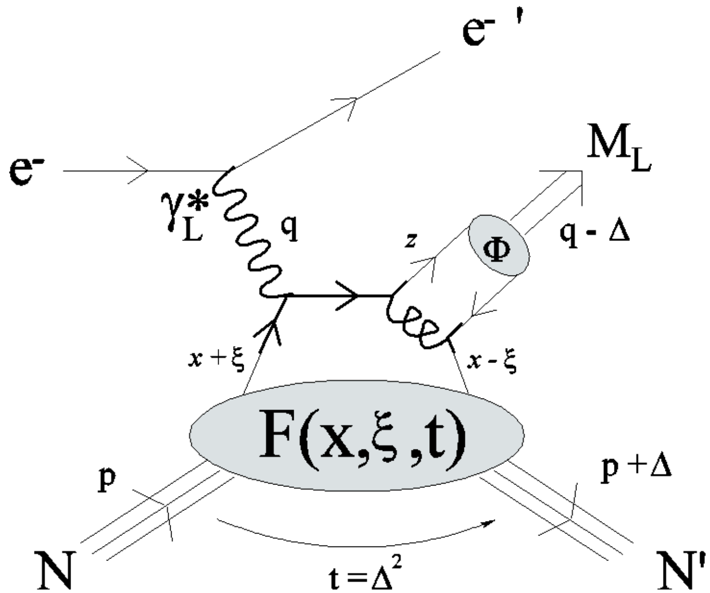
■ Fit of σ, Δσ

* VGG model predictions

ImH has steeper t-slope than ImH̃: is axial charge more concentrated than the electromagnetic charge?

M. Guidal, IPNO

Deeply virtual meson production and GPDs



Different mesons → different sensitivity to GPDs

H	**$\tilde{H}$**
E	**$\tilde{E}$**
↓	↓
Vector mesons (ρ, ω, ϕ)	**Pseudoscalar** mesons (π, η)

π^0	$2\Delta u+\Delta d$
η	$2\Delta u-\Delta d$

ρ^0	2u+d
ω	2u-d
ρ^+	u-d

Factorization only for **longitudinally polarized γ***
σ_T suppressed by **$1/Q^2$** → at **large Q^2**, σ_L dominates

quark flavor decomposition
accessible via meson production

$$A_L = -\frac{2ie}{9}\left(\int_0^1 dz \frac{\Phi(z)}{z}\right)\frac{4\pi\alpha_S(Q^2)}{Q}\int_{-1}^{+1} dx \left\{\left[\frac{1}{x-\xi+i\epsilon}+\frac{1}{x+\xi-i\epsilon}\right]F(x,\xi,t)\right\}$$

Complications: effective scale in the hard scattering process, meson distribution amplitude

Deeply virtual meson production at CLAS

Vector mesons: exclusive ρ^0, ω, ϕ and ρ^+ electroproduction on the proton with CLAS:

K. Lukashin *et al.*, Phys. Rev. C 63, 065205, 2001 **(ϕ@4.2 GeV)** C. Hadjidakis *et al.*, Phys. Lett. B 605, 256-264, 2005 **(ρ^0@4.2 GeV)**	e1-b (1999)
L. Morand *et al.*, Eur. Phys. J. A 24, 445-458, 2005 **(ω@5.75GeV)** J. Santoro *et al.*, Phys. Rev. C 78, 025210, 2008 **(ϕ@5.75 GeV)** S. Morrow *et al.*, Eur. Phys. J. A 39, 5-31, 2009 **(ρ^0@5.75GeV)**	e1-6 (2001-2002)
A. Fradi, Orsay Univ. PhD thesis **(ρ^+@5.75 GeV)**	e1-DVCS (2005)

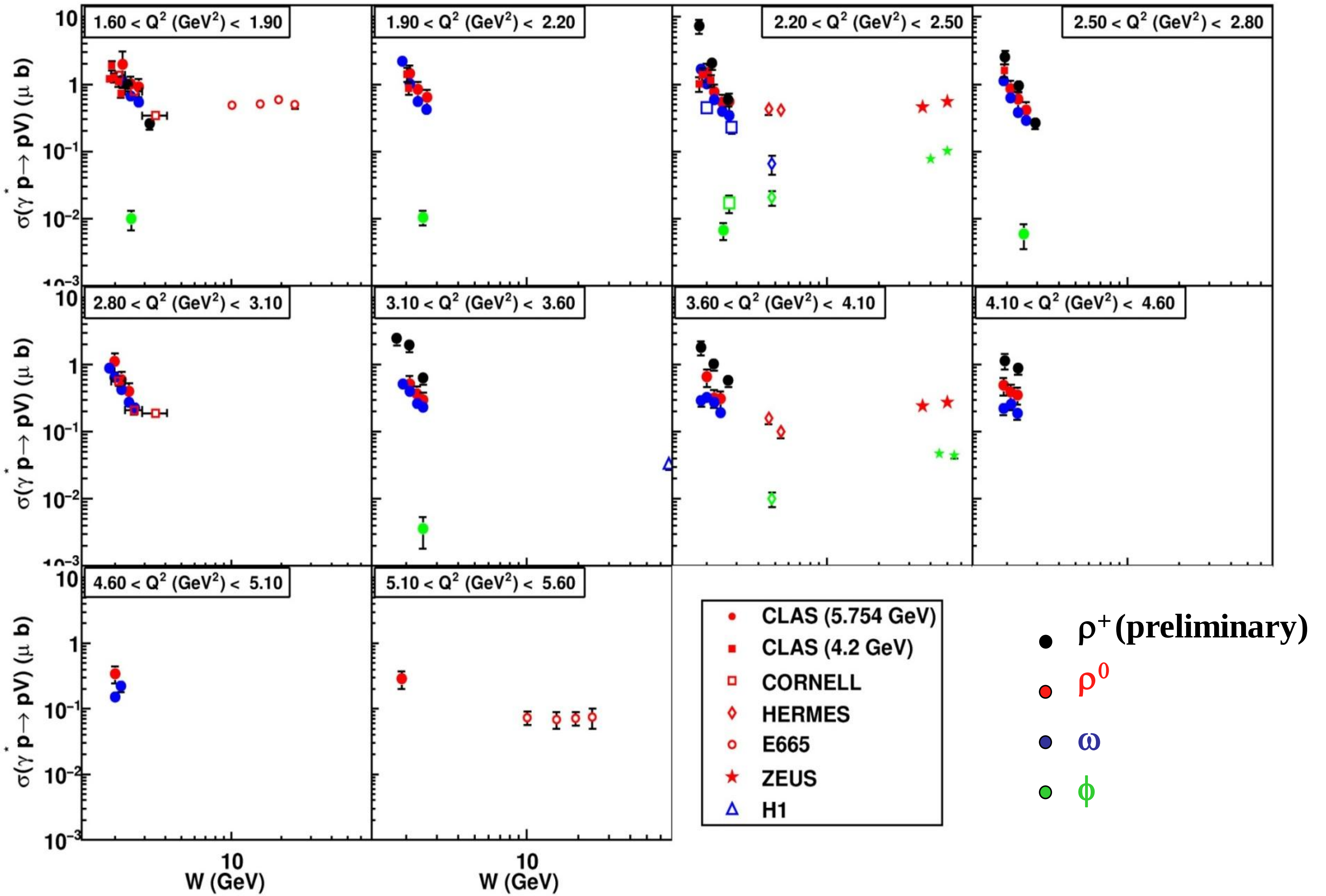
There are also results on **exclusive pseudoscalar meson electroproduction** on the proton with CLAS:

R. De Masi *et al.*, Phys. Rev. C 77, 042201(R), 2008 **(π^0@5.75GeV)**

K. Park *et al.*, Phys. Rev. C 77, 015208, 2008 **(π^+@5.75 GeV)**

I. Bedlinskiy *et al.*, just submitted to PRL **(π^0@5.75GeV)**

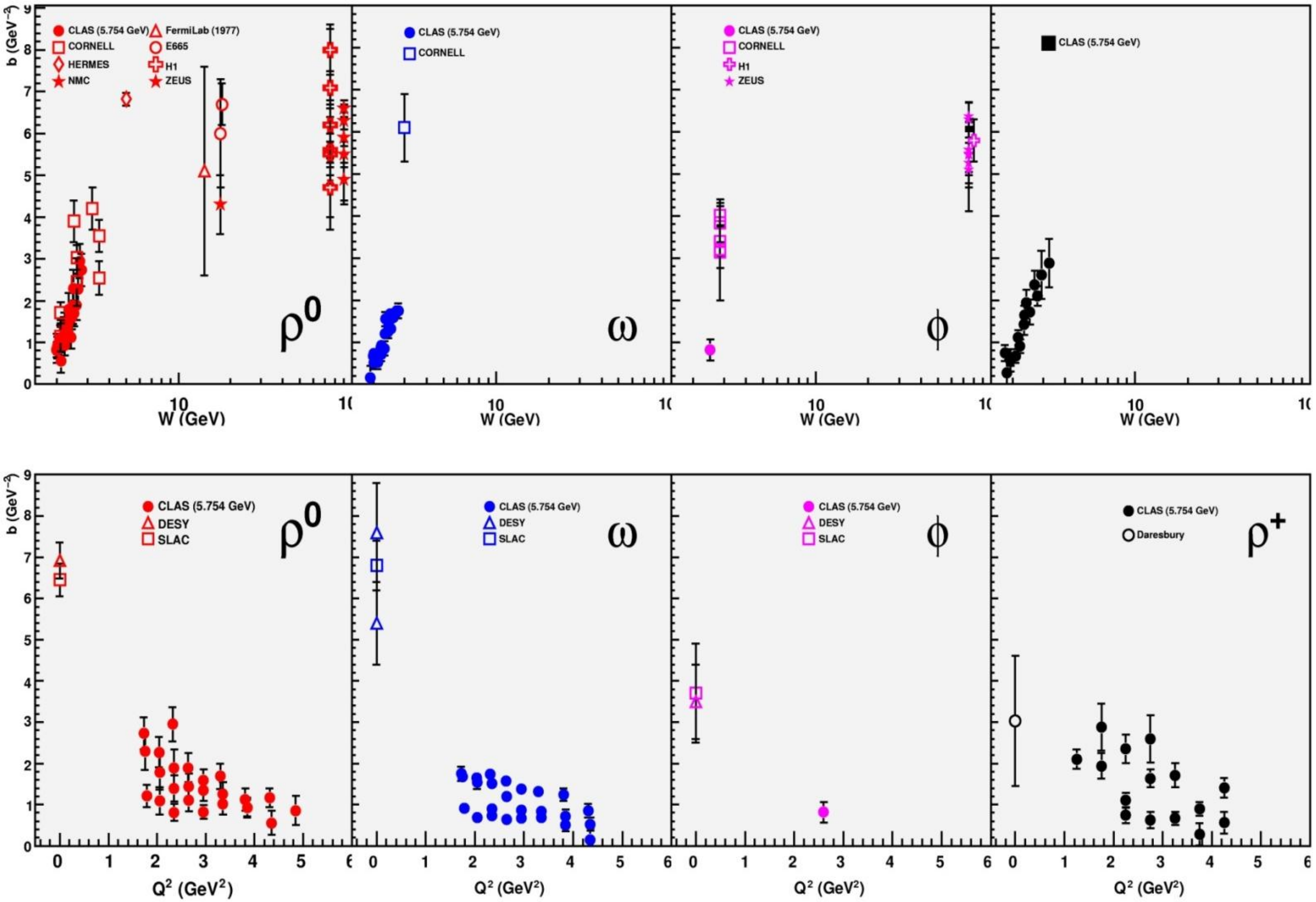
Comparison between vector mesons (σ)



Comparison between vector mesons

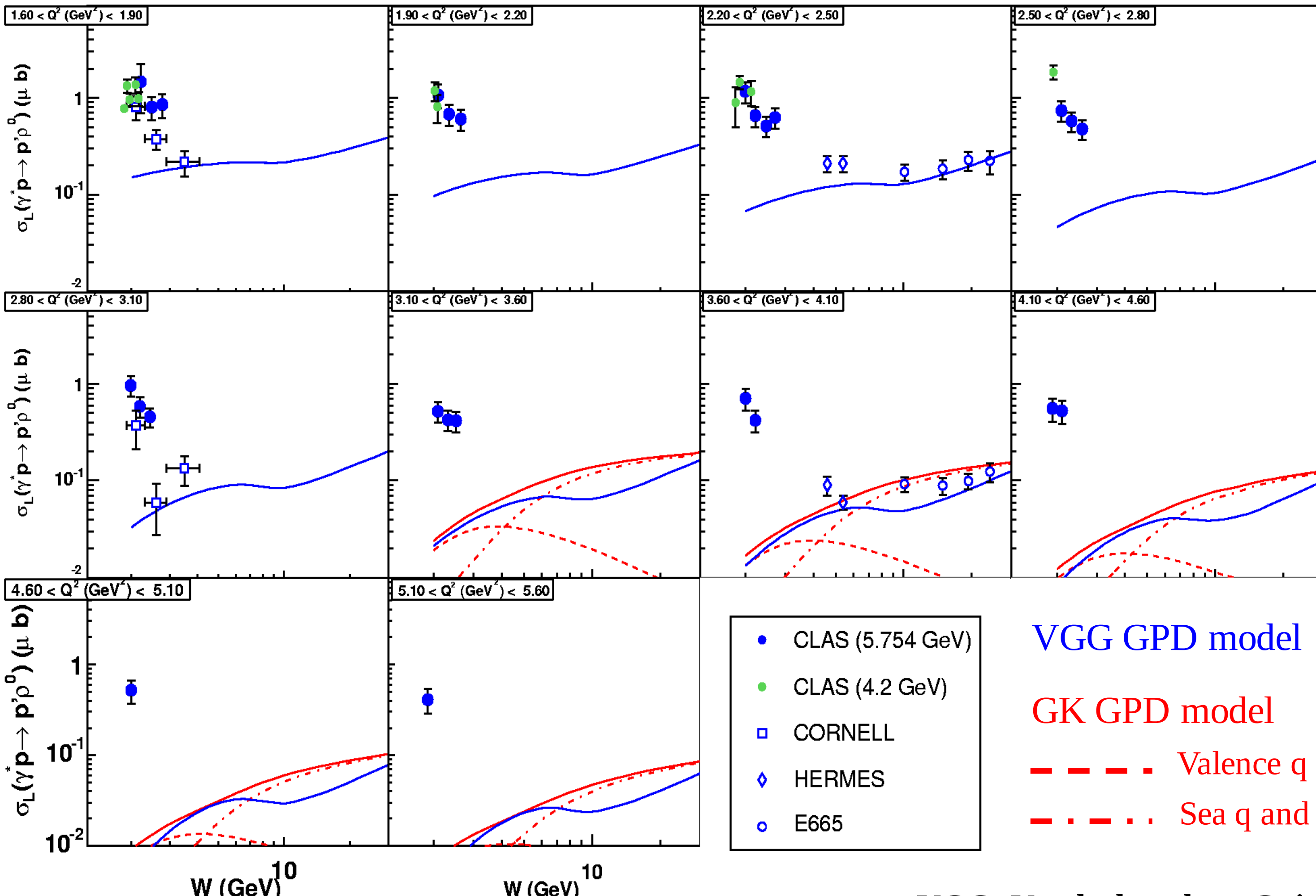
b increases with W (~1/x): valence (fast) quarks in the center and sea (slow) quarks at the periphery of the nucleon

$d\sigma/dt \sim e^{bt}$



b decreases with Q^2: by increasing the resolution of the probe, smaller objects in the nucleon can be seen

Longitudinal cross section $\sigma_L(\gamma^*_L p \rightarrow p\, \rho^0_L)$



The GPD models fail to reproduce the behavior at **low W** (W < 5 GeV)

VGG GPD model

GK GPD model

Valence q

Sea q and gluons

S. Morrow *et al.*, Eur. Phys. J. A 39, 5-31, 2009

VGG: Vanderhaeghen, Guichon, Guidal

GK: Goloskokov, Kroll

Exclusive electroproduction of π^0

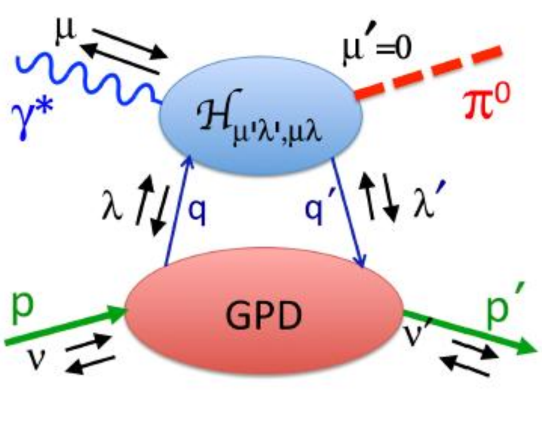
$$\frac{d^4\sigma}{dQ^2 dx_B d\phi dt} = \Gamma(Q^2, x_B)\frac{d^2\sigma}{d\phi dt}$$

$$\frac{d^2\sigma}{d\phi dt} = \frac{1}{2\pi}\left(\frac{d\sigma_T}{dt} + \varepsilon\frac{d\sigma_L}{dt} + \sqrt{2\varepsilon(\varepsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi + \varepsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi\right)$$

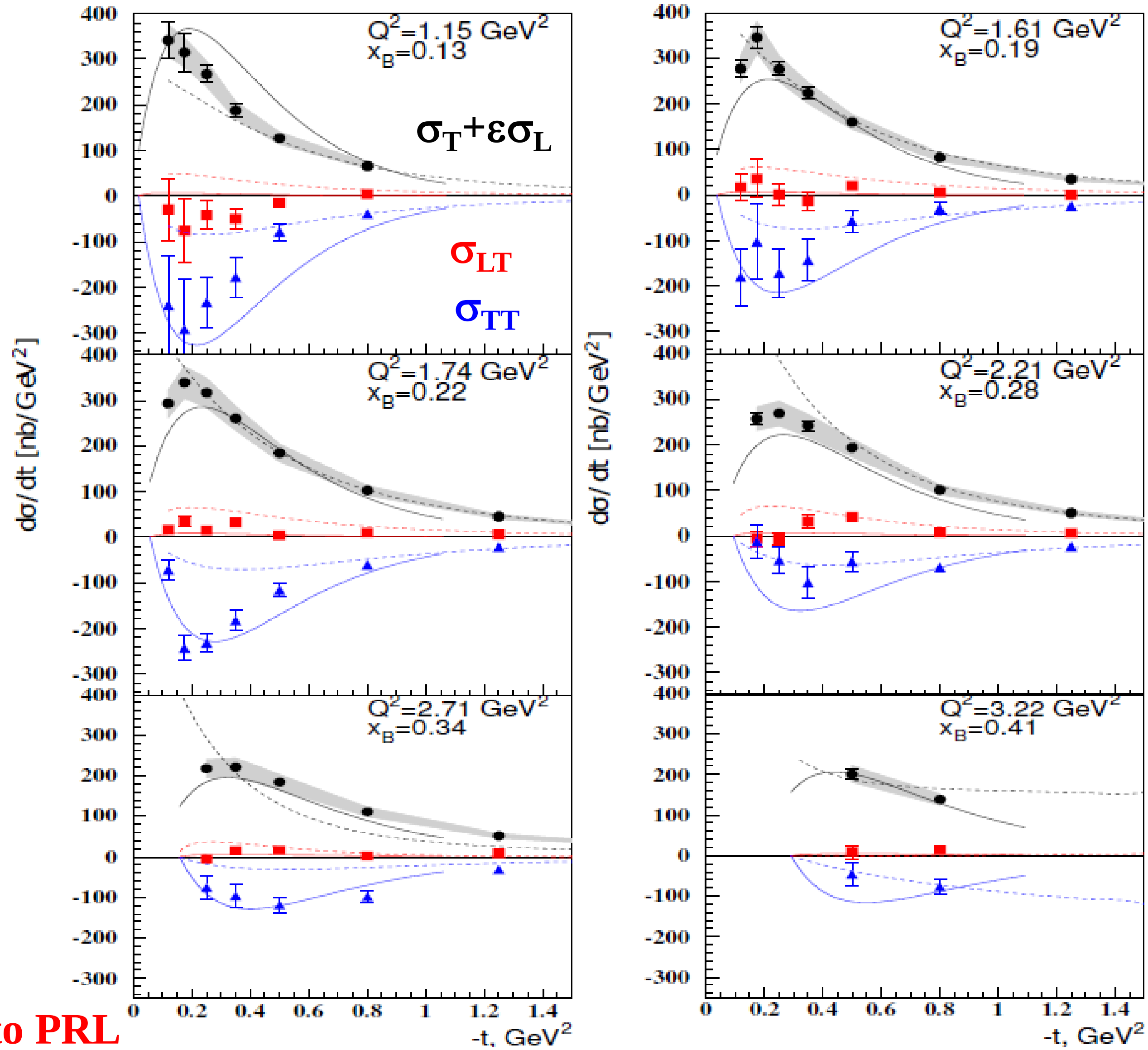
$\sigma_T + \varepsilon\sigma_L \gg \sigma_L$

Solid line: S.V. Goloskokov and P. Kroll, Eur. Phys. J. A 47, 112 (2011).
Dotted line: G. R. Goldstein, J. O. Gonzalez Hernandez and S. Liuti, Phys. Rev. D 84, 034007 (2011).

Models include **transversity GPDs** (chiral-odd, twist 3)



$\mu = \pm 1$; $\lambda' = -\lambda$; $\nu' = \pm\nu$



I. Bedlinsky et al., submitted to PRL

GPDs: where we stand, where we are going

• Dedicated experiments on **DVCS** (Hall A, CLAS), show evidence for **handbag (twist-2) dominance** (asymmetry ~sinϕ) and **unexpected scaling** at **$Q^2 \sim 2$ GeV^2** (Hall A)

• **DVMP** experiments (ρ, ω, π^0) hint that either **scaling cannot be reached** for Q^2 as low as for DVCS or **something is missing** in "standard" GPDs parameterizations

• Model-independent fits need to combine **several observables** measured with **high statistics on a wide kinematic coverage** to constrain GPDs

• Hall A's first attempt to measure **n-DVCS** showed the importance of this channel for **Ji's sum rule** and the extraction of **J_q**

More data needed on DVCS and DVMP:

- **High Q^2 to verify scaling for DVCS on a wider Q^2 range, and to approach GPD validity regime for DVMP**
- **Wide x_B coverage**
- **High accuracy on measured observables (high luminosity required)**
- **Measurements of spin-asymmetries and cross sections on proton and neutron**

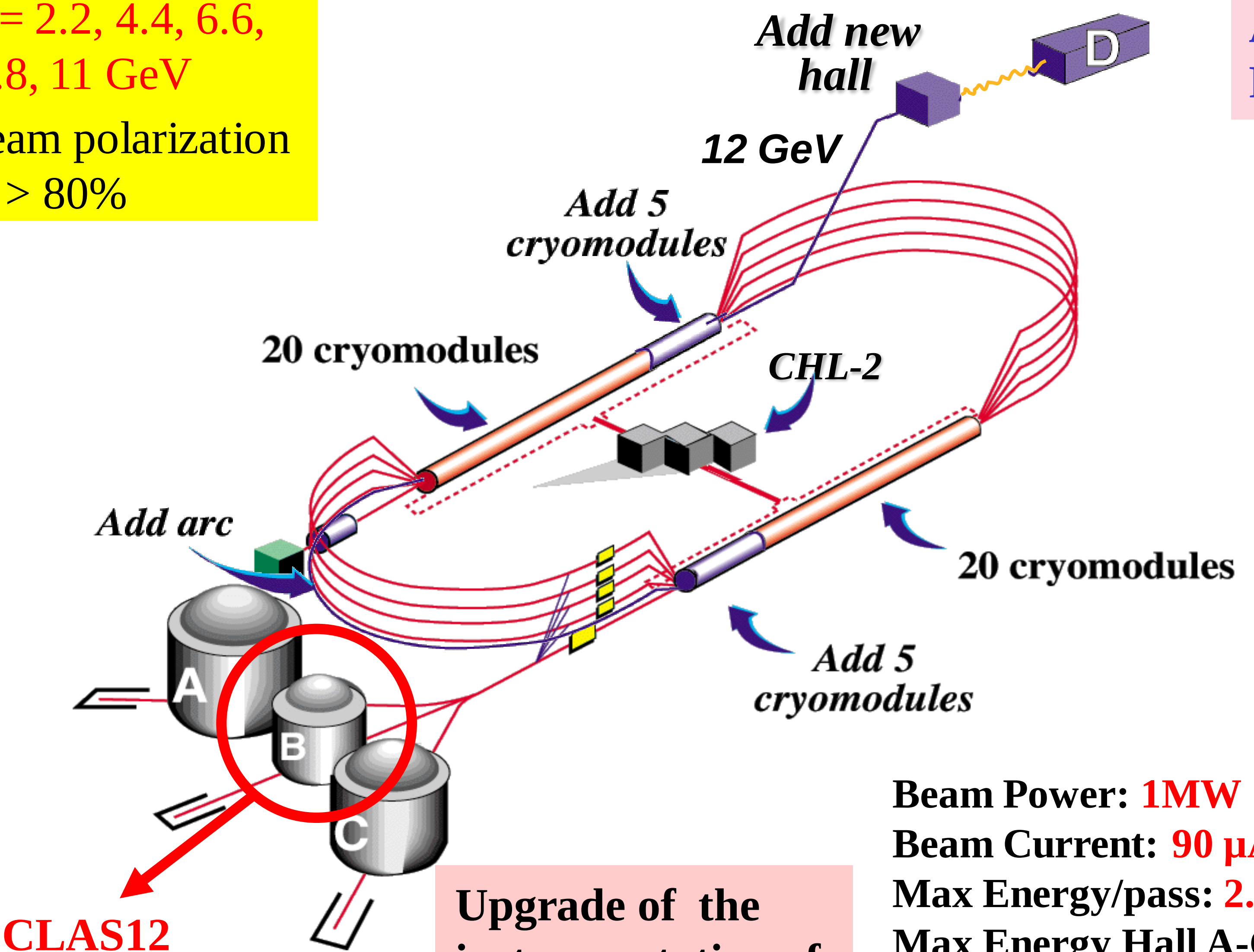
CLAS12 will be the optimal facility for these goals

JLab upgrade to 12 GeV

Continuous
Electron
Beam
Accelerator
Facility

E= 2.2, 4.4, 6.6, 8.8, 11 GeV

Beam polarization
$P_e > 80\%$



Upgrade of the instrumentation of the existing Halls

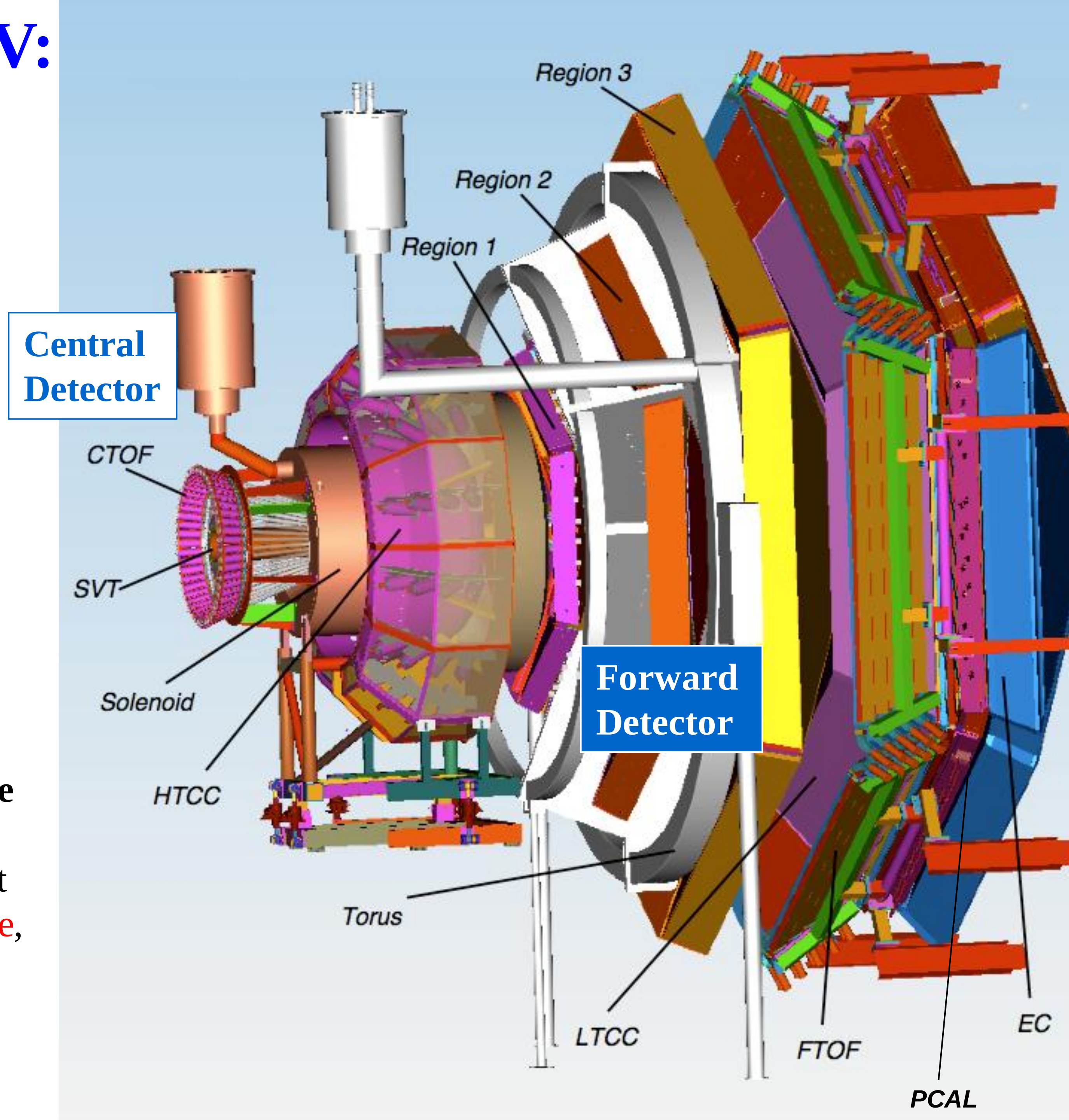
Beam Power: 1MW
Beam Current: 90 µA
Max Energy/pass: 2.2 GeV
Max Energy Hall A-C: 11 GeV
Max Energy Hall D: 12 GeV

Hall B@12 GeV: CLAS12

Design luminosity
L ~ 10^{35} cm^{-2}s^{-1}

Acceptance for charged particles:
- **Central (CD), 40°<θ<135°**
- **Forward (FD), 5°<θ<40°**

Acceptance for photons:
- **IC 2°<θ<5°**
- **EC, 5°<θ<40°**



High luminosity & large acceptance:
Concurrent measurement of deeply virtual exclusive, semi-inclusive, and inclusive processes

Hall B@12 GeV: CLAS12

Forward Detector:

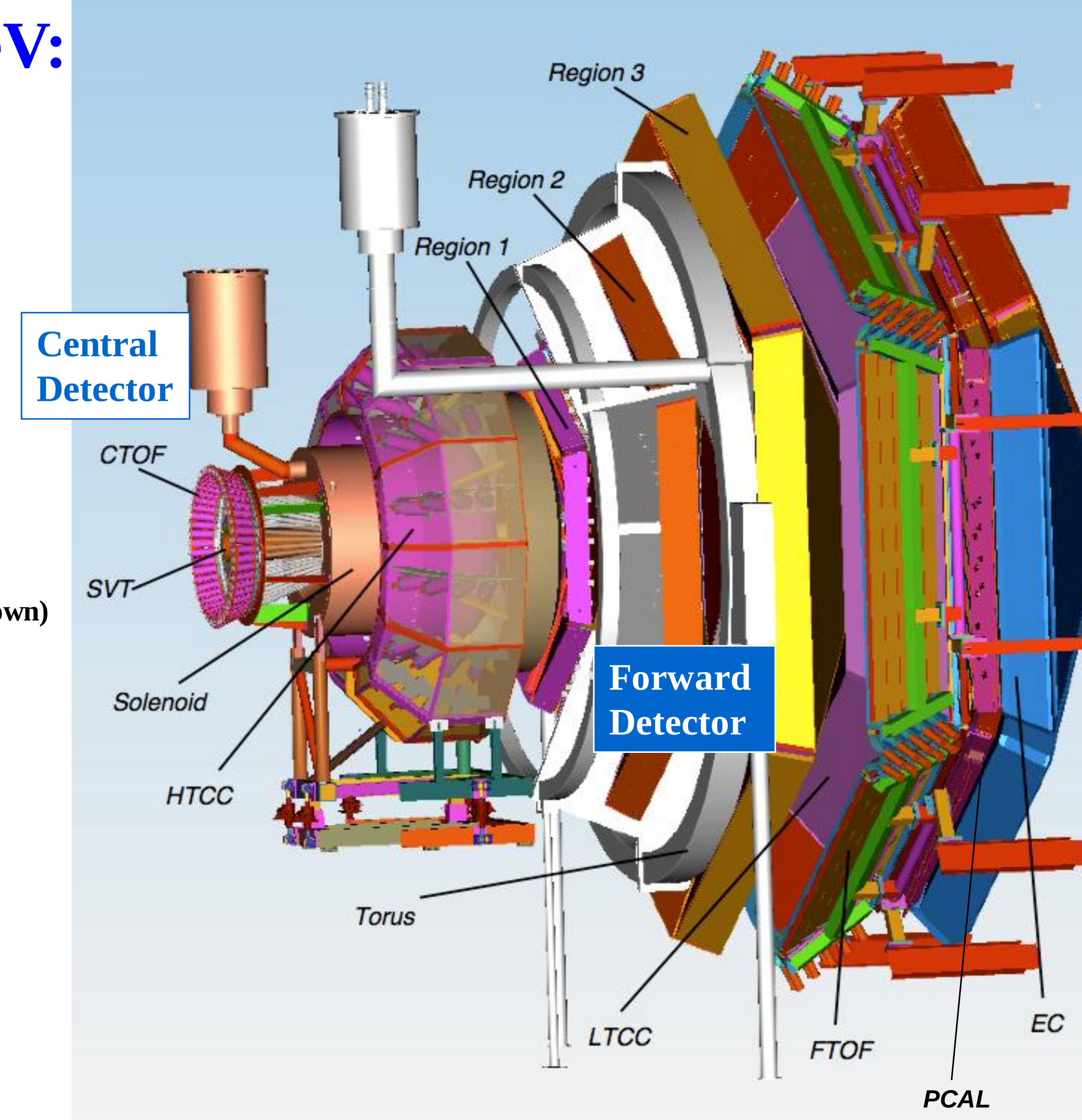
- TORUS magnet
- Forward tracker
- HT Cherenkov Counter
- Drift chambers (3 regions)
- LT Cherenkov Counter
- Forward ToF System
- Preshower calorimeter
- E.M. calorimeter (EC)
- Inner Calorimeter (IC, not shown)

Central Detector:

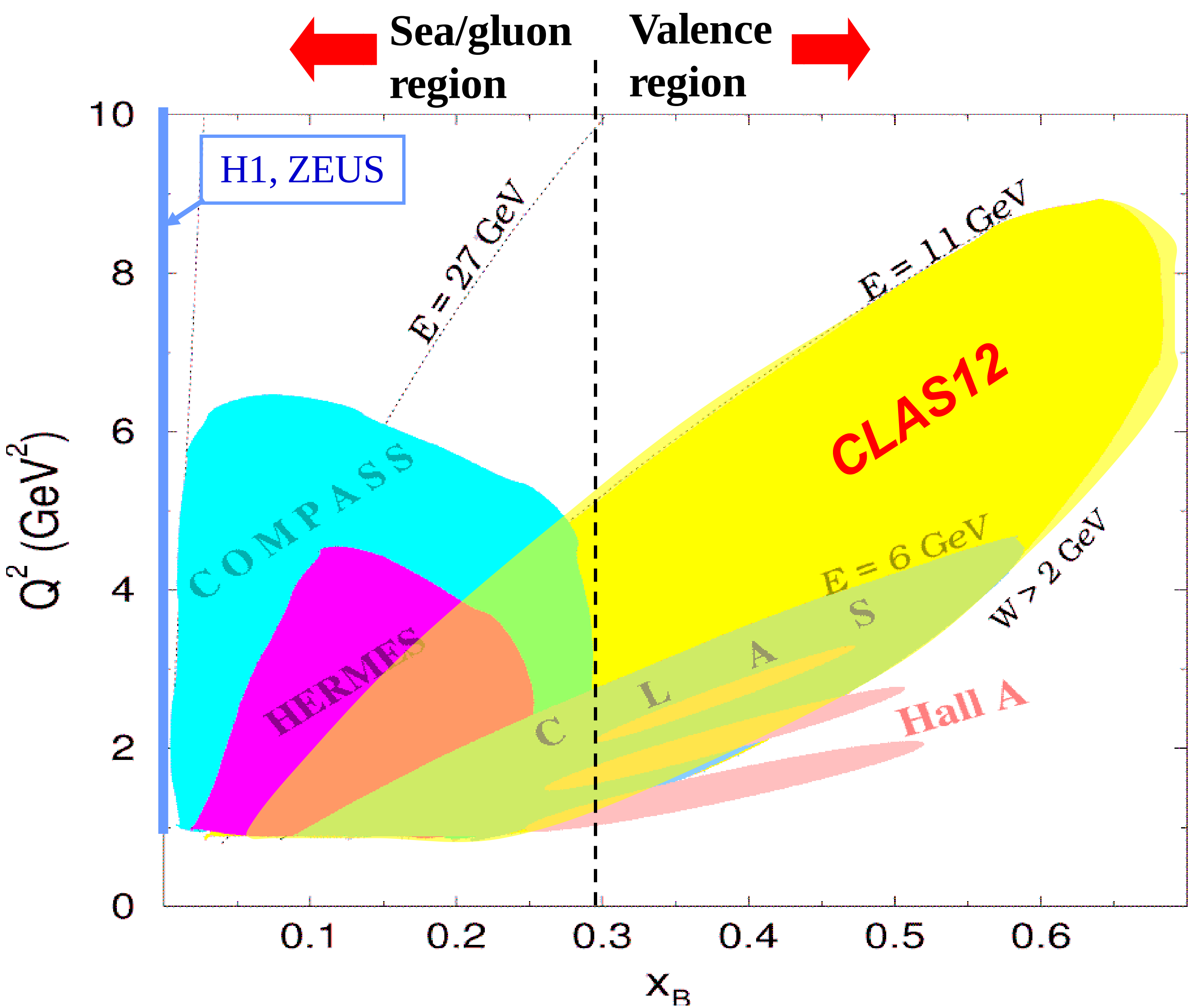
- SOLENOID magnet
- Barrel Silicon Tracker
- Central Time-of-Flight

Proposed upgrades:

- Micromegas (CD)
- Neutron detector (CD)
- RICH detector (FD)
- Forward Tagger (FD)

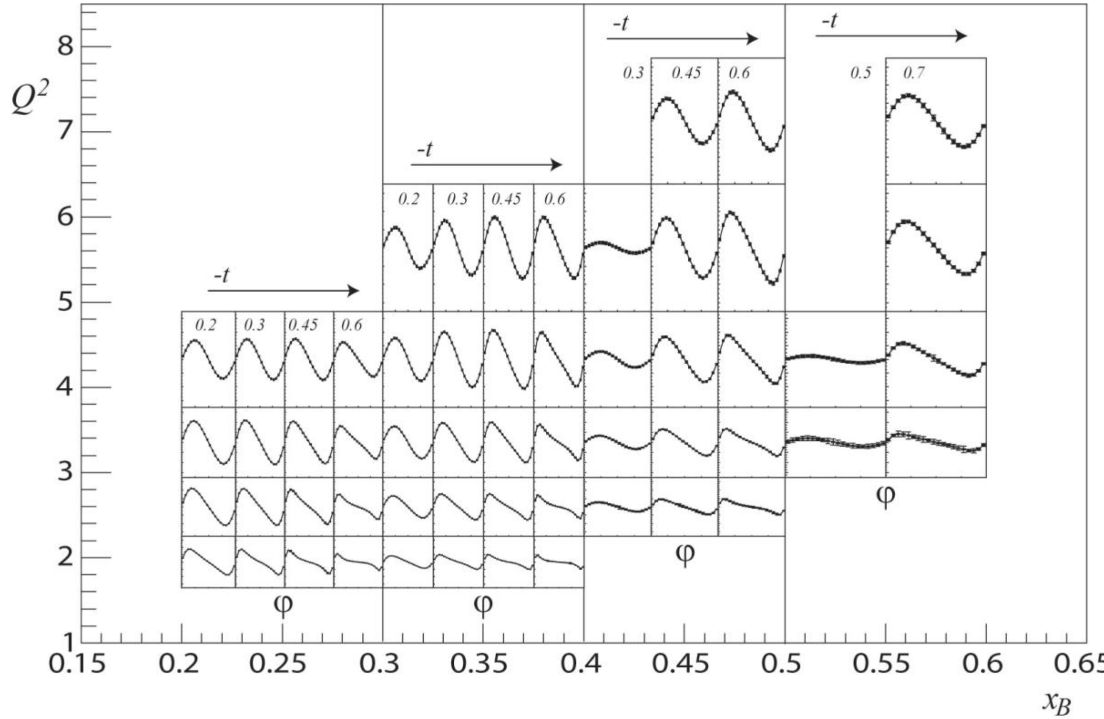


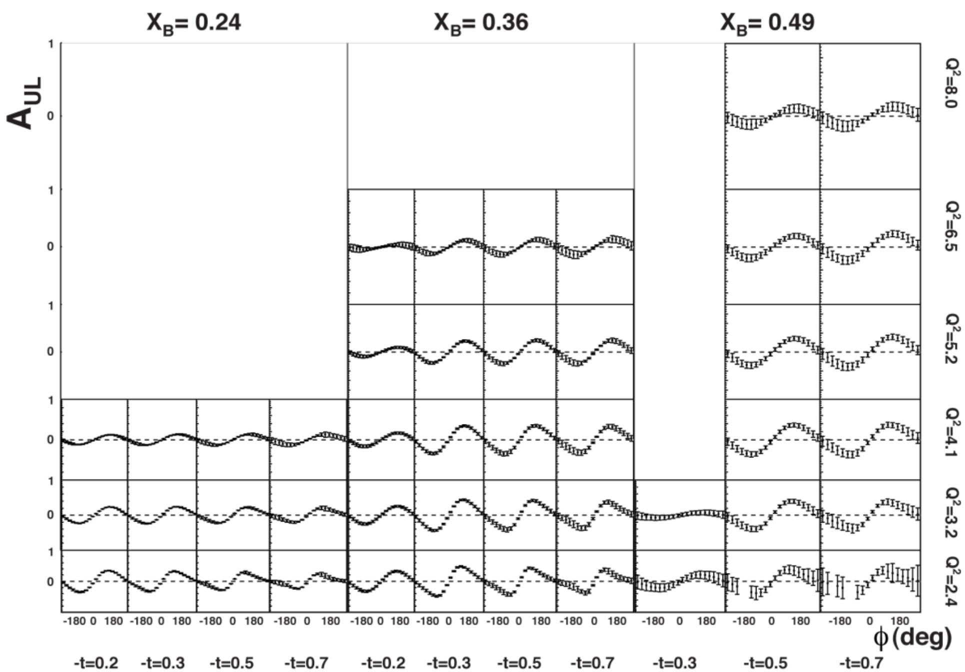
Large phase space (ξ,t,Q^2) and high luminosity



DVCS BSA and TSA with CLAS12 & 11 GeV beam

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

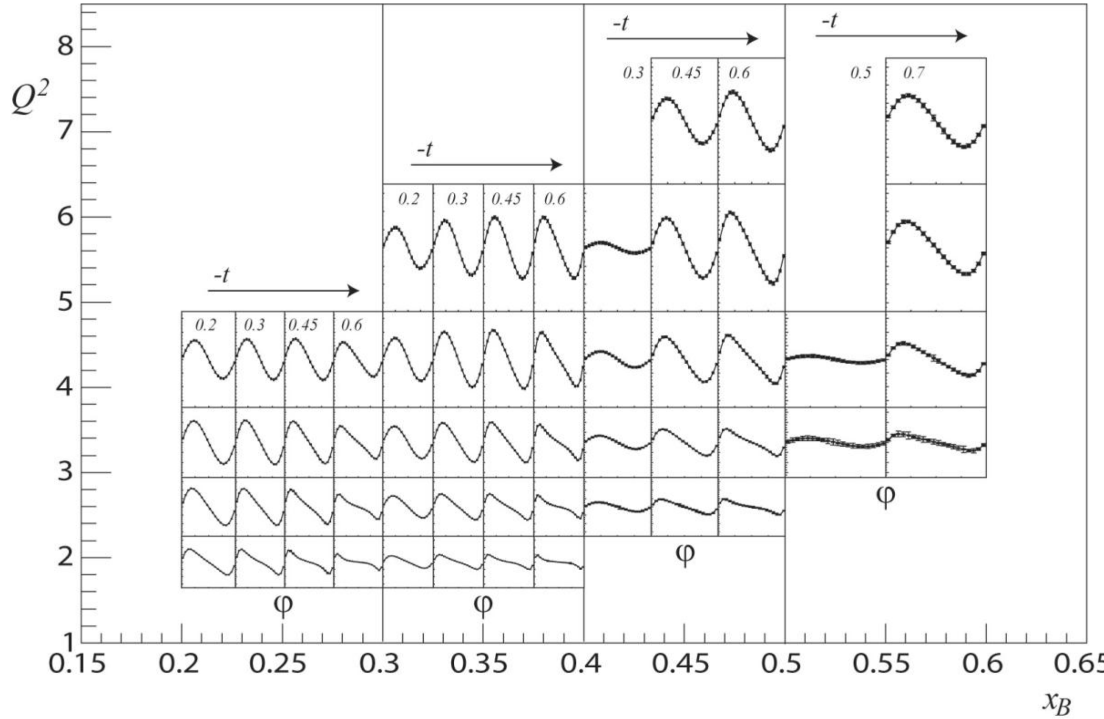


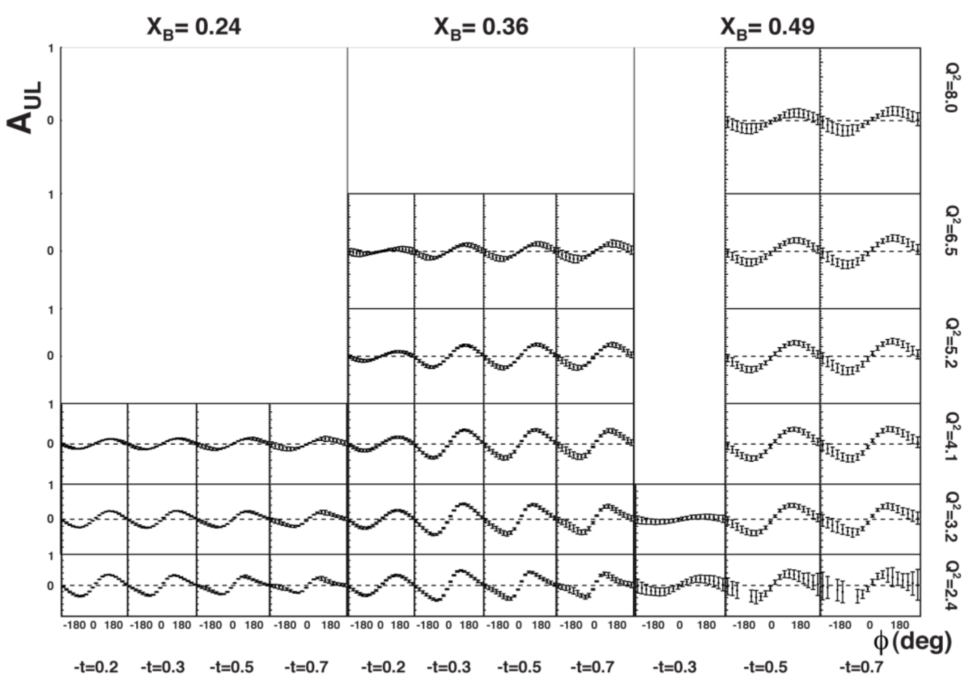


120 days of beam time
$P_{beam} = 85\%$, $P_{target} = 80\%$
$L = 2.10^{35}\ cm^{-2}s^{-1}$
$1 < Q^2 < 10\ GeV^2$
$0.1 < x_B < 0.65$
$-t_{min} < -t < 2.5\ GeV^2$
Statistical error: 2% to 15%
on sinϕ moments
Systematic uncertainties: ~6-8%

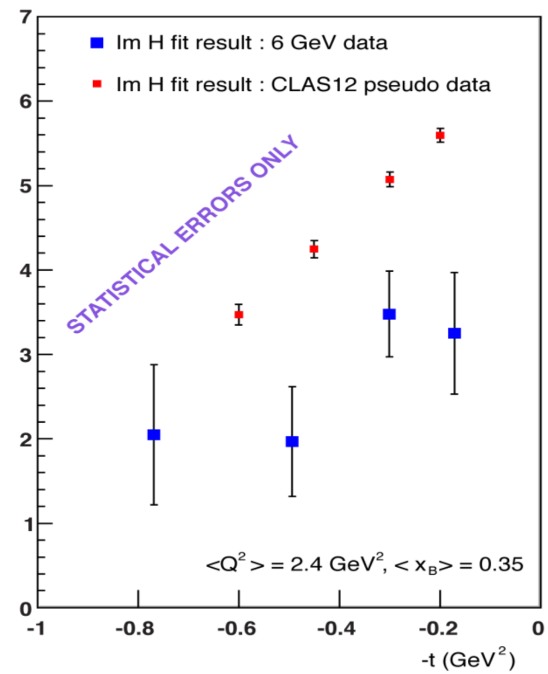
DVCS BSA and TSA with CLAS12 & 11 GeV beam

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





Impact of CLAS12 DVCS-BSA data on model-independent fit to extract Im(H)

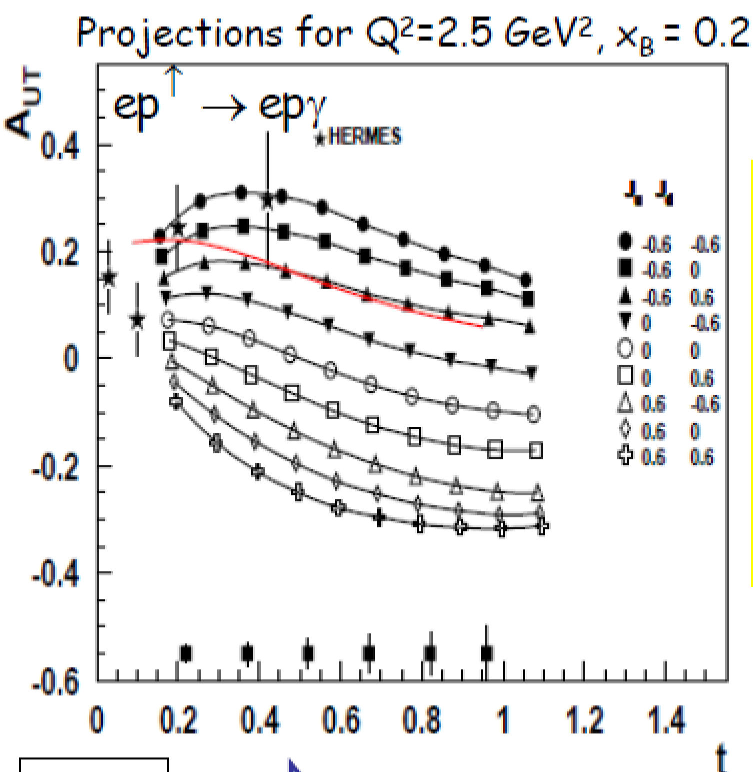


CLAS12: p-DVCS *transverse* target-spin asymmetry

100 days of beam time

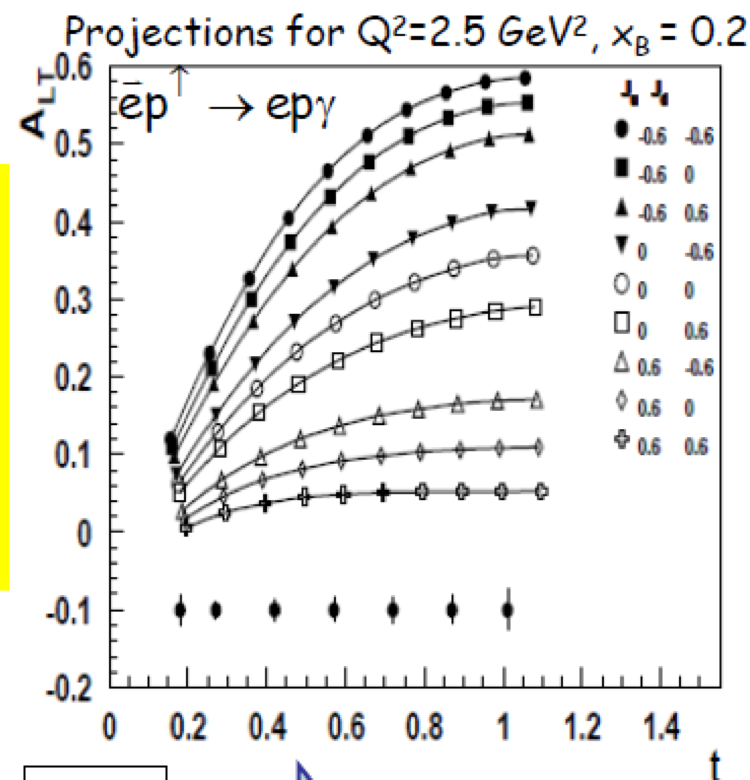
Beam pol. = 80% ; **target pol. (HDIce) = 60%** ; Luminosity = $5x10^{33}$ $cm^{-2}s^{-1}$

$1 < Q^2 < 10$ GeV^2, $0.06 < x_B < 0.66$, $-t_{min} < -t < 1.5$ GeV^2



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

Transverse-target spin asymmetry for p-DVCS is **highly sensitive** to the **u-quark contributions** to proton spin.



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

Proposal conditionally approved by PAC39

BSA for DVCS *on the neutron* with CLAS12

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

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

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

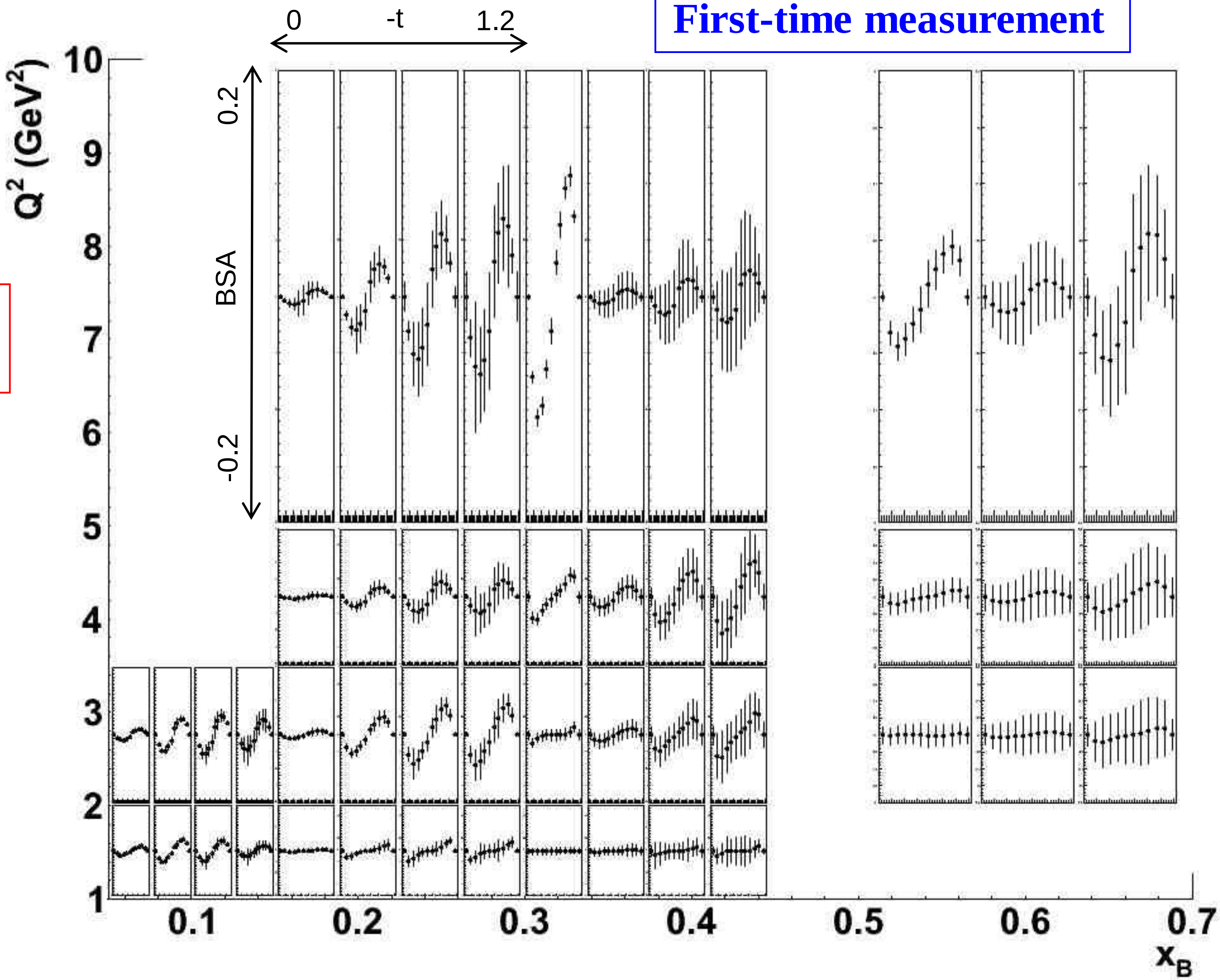
The most sensitive observable to the GPD E

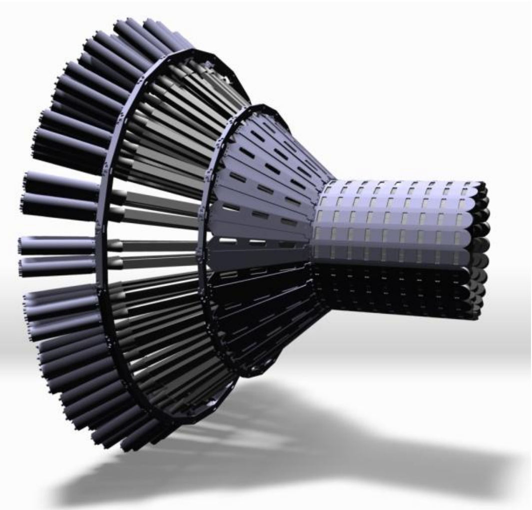
ed→ e(p)nγ

CLAS12 +
Forward Calorimeter +
Neutron Detector

80 days of data taking
L = 10^{35} cm^{-2}s^{-1}/nucleon

First-time measurement





Under construction at IPN Orsay

BSA for DVCS *on the neutron* with CLAS12

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

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

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

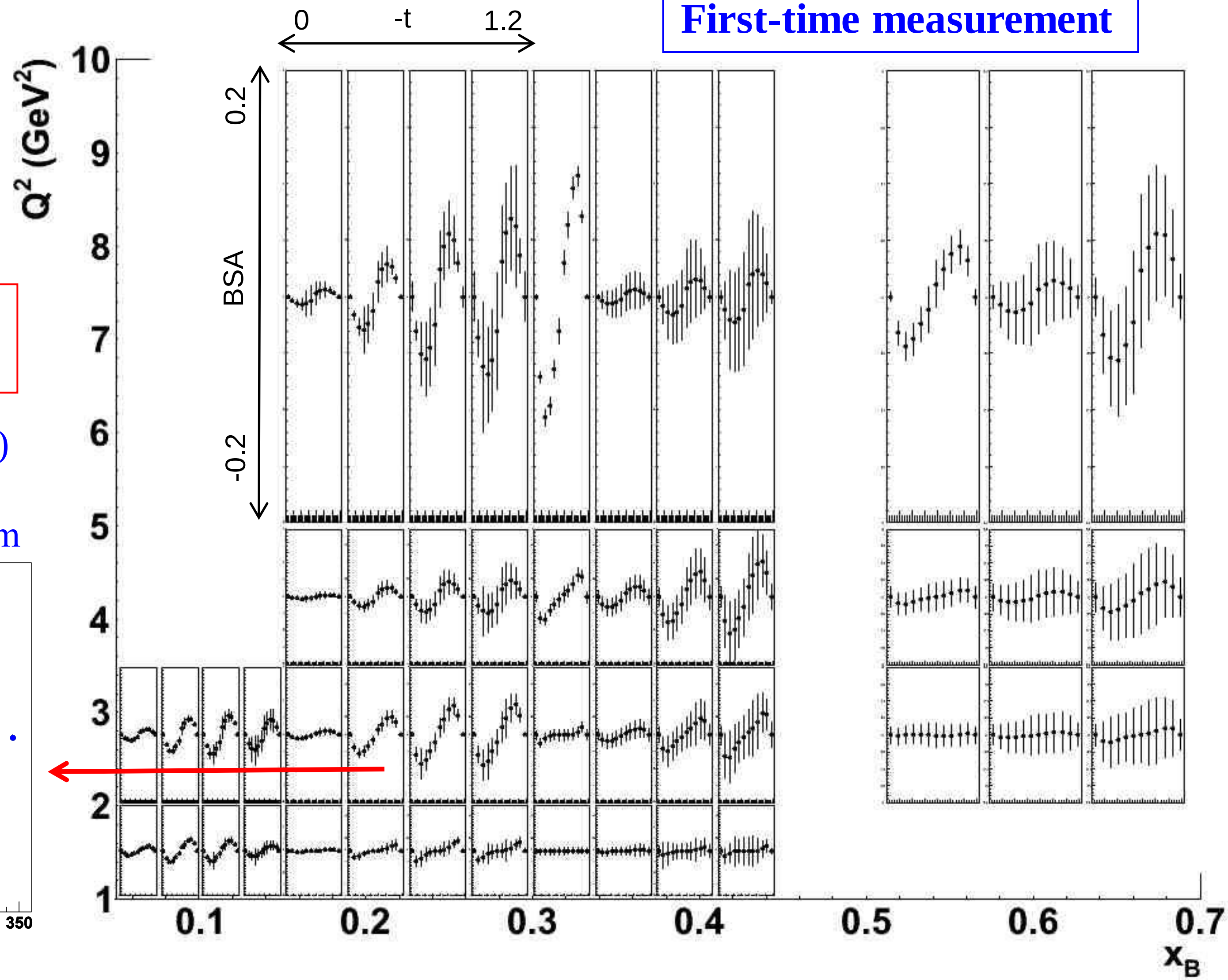
The most sensitive observable to the GPD E

$ed \rightarrow e(p)n\gamma$

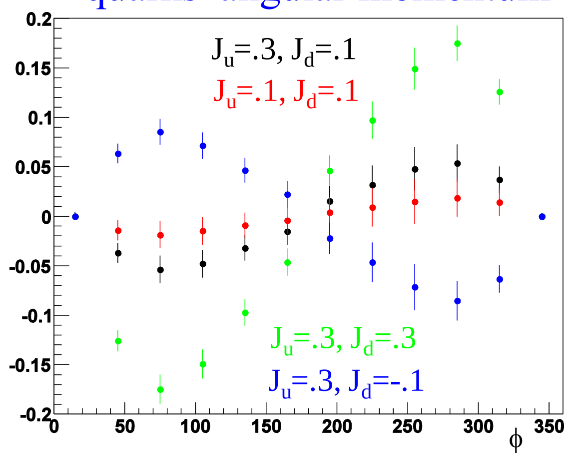
CLAS12 +
Forward Calorimeter +
Neutron Detector

80 days of data taking
L = 10^{35} cm^{-2}s^{-1}/nucleon

First-time measurement



Model predictions (VGG)
for different values of
quarks' angular momentum



Summary

- GPDs are a unique tool to explore the **internal landscape of the nucleon**:
  - **3D** quark/gluon **imaging** of the nucleon
  - **orbital angular** momentum carried by quarks
- Their extraction from experimental data is **very difficult**:
  - they depend on **3 variables**, only two (ξ, t) experimentally accessible
  - they appear as **integrals** in cross sections
- We need to measure **several exclusive channels and observables** over a **wide phase space** to constrain the parametrizations of GPDs
- Very promising **experimental results** on DVCS (BSA, TSA, DSA, σ, $\Delta\sigma$) and DVMP (vector and pseudoscalars) are coming from **CLAS:**
  - **constraints on GPD models**
  - first **model-independent GPD fits**
- The JLab 12 GeV upgrade is essential for the study of **3-D nucleon structure** in the **valence region** with high precision, allowing the measurement of **deeply virtual exclusive processes** (to access GPDs) with polarized beam and polarized targets
- **A complete experimental program for DVCS on proton and neutron has been approved**
- **CLAS12** will be world wide **the only full acceptance**, general purpose detector for **high luminosity** electron scattering experiments, and it will be perfectly suited for the **GPD program**


Many thanks to the organizers for inviting me here!