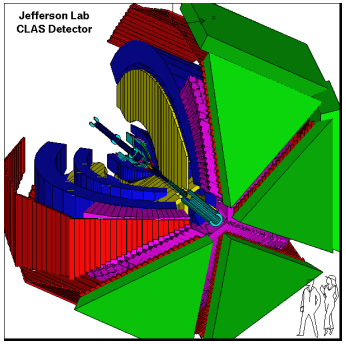
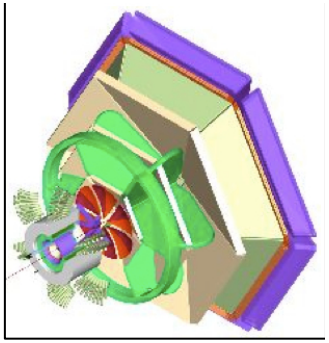


Jefferson Lab
Thomas Jefferson National Accelerator Facility



Vector Mesons and DVCS at Jefferson Lab

Valery Kubarovsky
Jefferson Lab
Newport News, VA

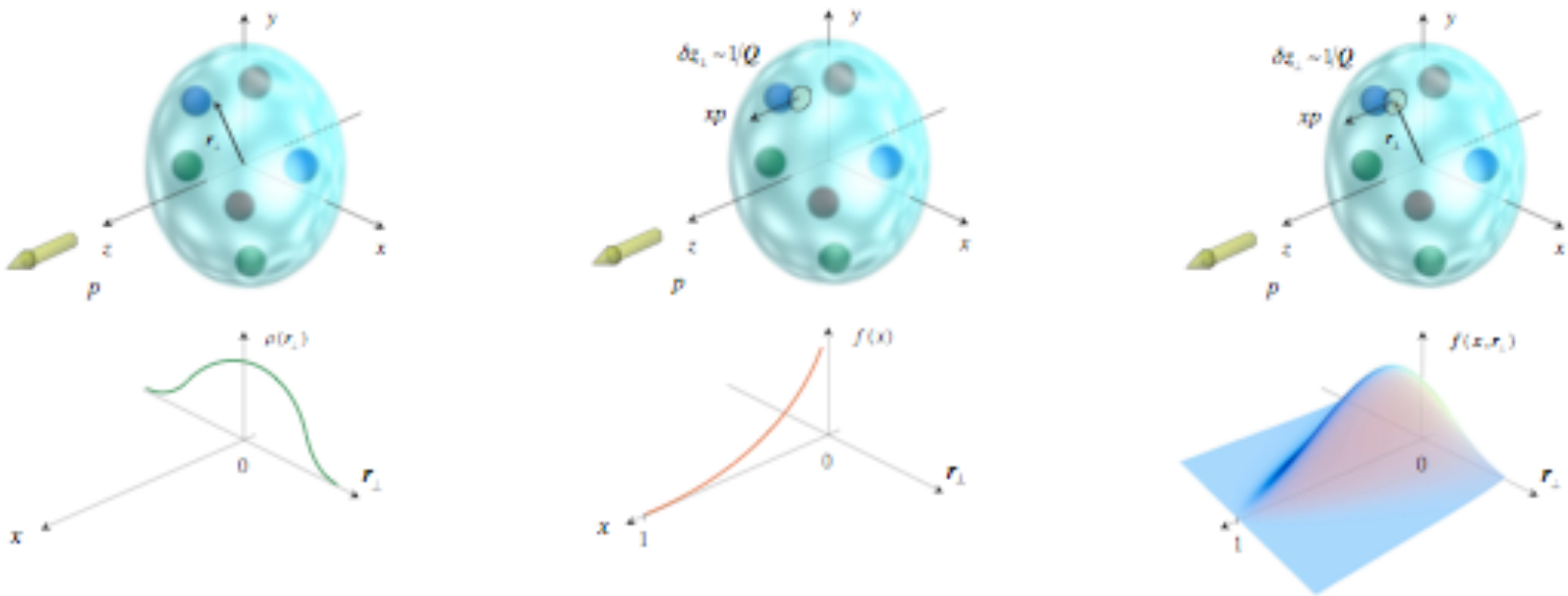
DIS 2011
XIX International Workshop on Deep Inelastic Scattering and Related Subjects

XIX International Workshop on Deep-Inelastic Scattering and Related Subjects

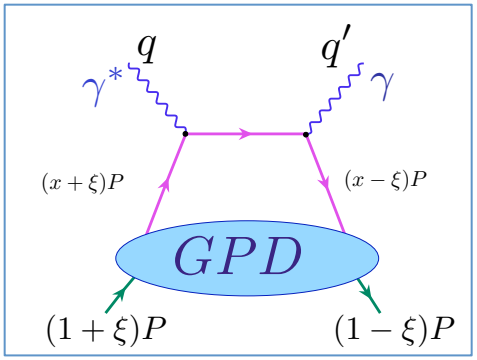
Outlook

- Introduction
- DVCS with unpolarized target
- DVCS with polarized targets
- Vector meson electroproduction
- JLAB 12 upgrade
- Conclusion

Description of hadron structure in terms of GPDs

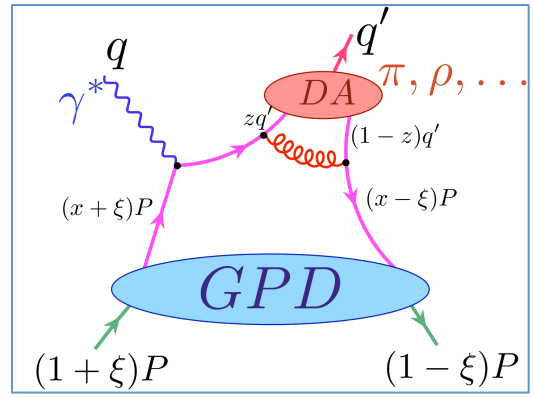


Nucleon form factors transverse charge & current densities	*Structure functions* quark longitudinal momentum (polarized and unpolarized) distributions	*GPDs* correlated quark momentum distributions (polarized and unpolarized) in transverse space



DVCS and DVMP

- Factorization theorem
- Access to fundamental degrees of freedom



DVCS:

- the clearest way to access the GPDs
- Only γ_T photons participate in DVCS
- Interference with BH process

DVMP:

- Factorization proven only for σ_L
  $\sigma_T/\sigma_L \sim 1/Q^2$
- Meson distribution amplitude
- Gluon exchange required
- Vector and pseudoscalar meson production allows to separate flavor and separate the helicity-dependent GPDs form helicity independent.

	Meson	GPD flavor composition
$\widetilde{H}, \widetilde{E}$	π^+	$\Delta u - \Delta d$
	π^0	$2\Delta u + \Delta d$
	η	$2\Delta u - \Delta d$
H, E	ρ^0	$2u + d$
	ρ^+	$u - d$
	ω	$2u - d$

Accessing GPDs through polarization

$$A = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{\Delta\sigma}{2\sigma}$$

$\xi \approx x_B/(2-x_B)$

$k = t/4M^2$

Polarized beam, unpolarized proton target:

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

Kinematically suppressed

$\Rightarrow$ $\mathcal{H}(\xi,t)$

Unpolarized beam, longitudinal proton target:

$$\Delta\sigma_{UL} \sim \sin\phi \, \{F_1 \tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + \xi/(1+\xi)\mathcal{E}) - .. \} d\phi$$

Kinematically suppressed

$\Rightarrow$ $\mathcal{H}(\xi,t)$, $\tilde{\mathcal{H}}(\xi,t)$

Unpolarized beam, transverse proton target:

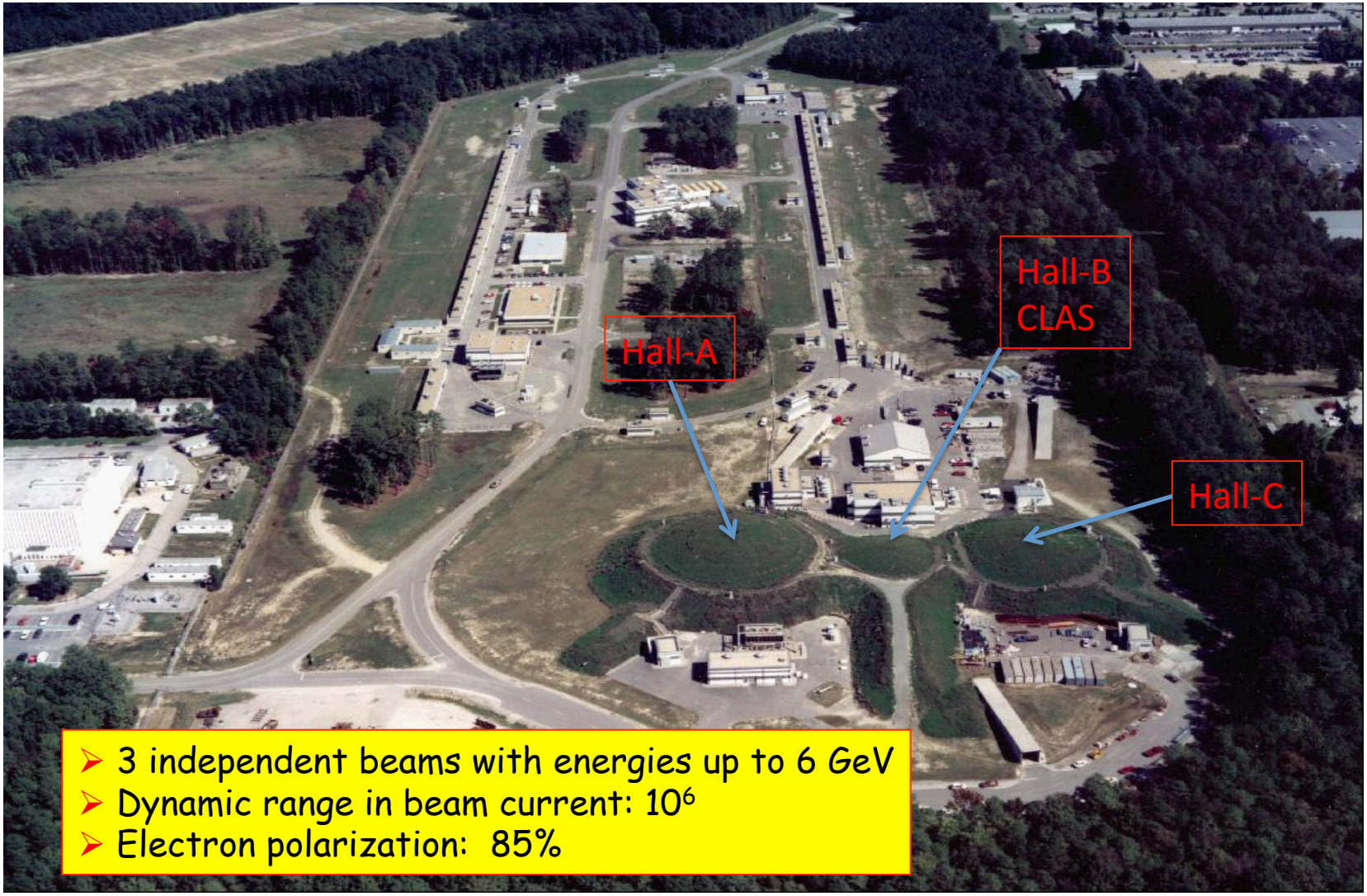
$$\Delta\sigma_{UT} \sim \cos\phi \, \{k(F_2 \mathcal{H} - F_1 \mathcal{E}) + ... \} d\phi$$

Kinematically suppressed

$\Rightarrow$ $\mathcal{H}(\xi,t)$, $\mathcal{E}(\xi,t)$

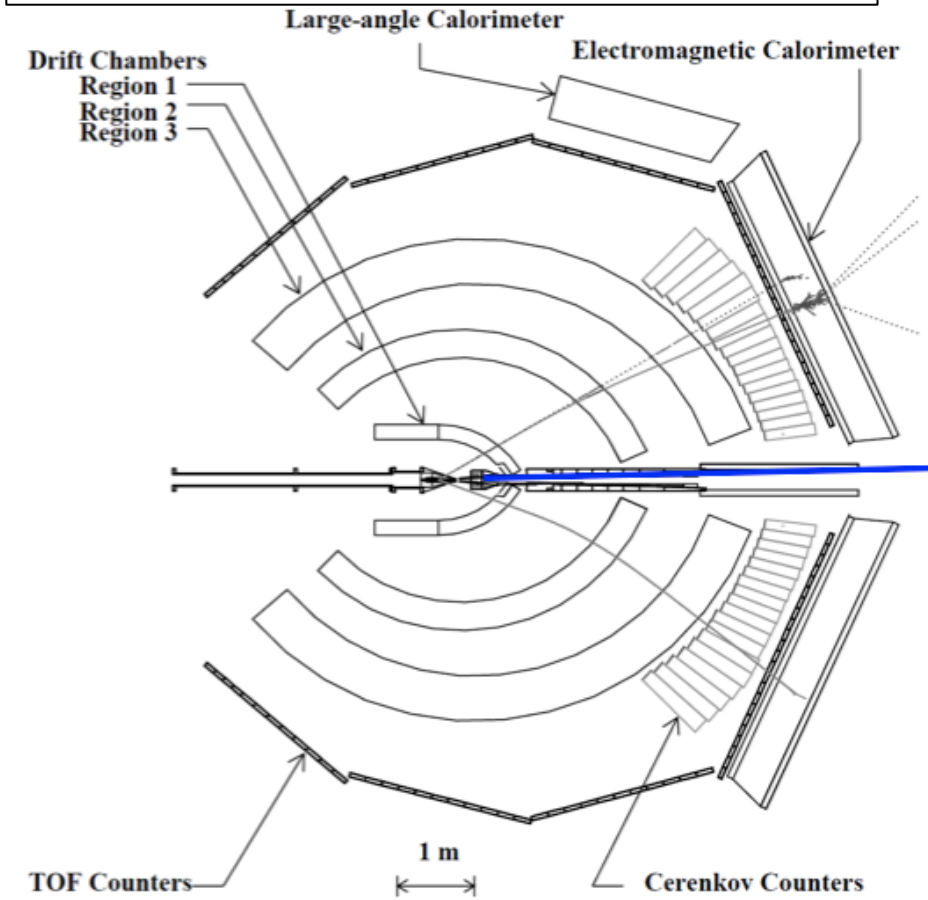
$\mathcal{H}(\xi,t)$, $\mathcal{E}(\xi,t)$… are CFF

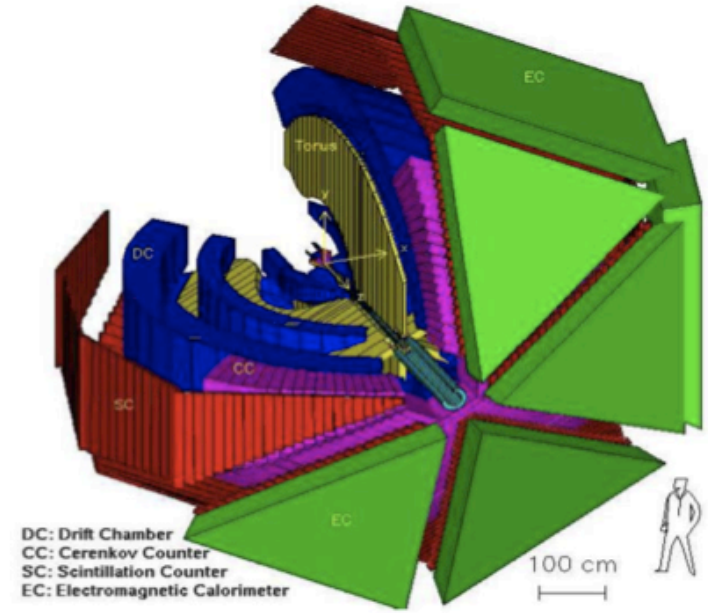
JLab Site: The 6 GeV Electron Accelerator



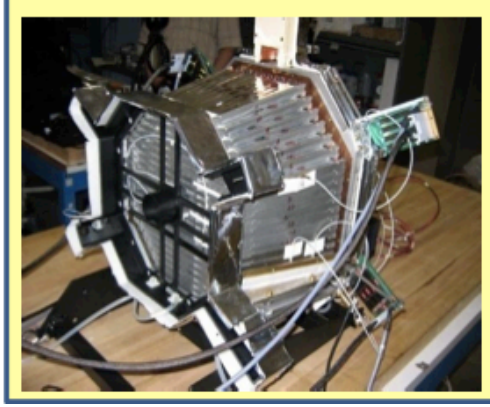
- 3 independent beams with energies up to 6 GeV
- Dynamic range in beam current: 10^6
- Electron polarization: 85%

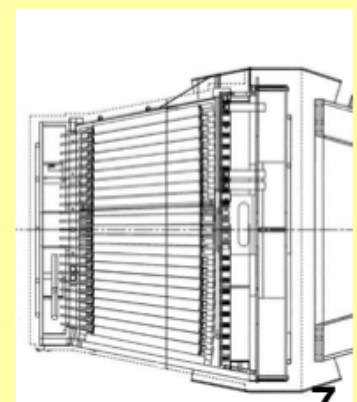
CEBAF Large Acceptance Spectrometer CLAS





Inner Calorimeter





CLAS Lead Tungstate Electromagnetic Calorimeter

424 crystals, 18 RL,
Pointing geometry,
APD readout

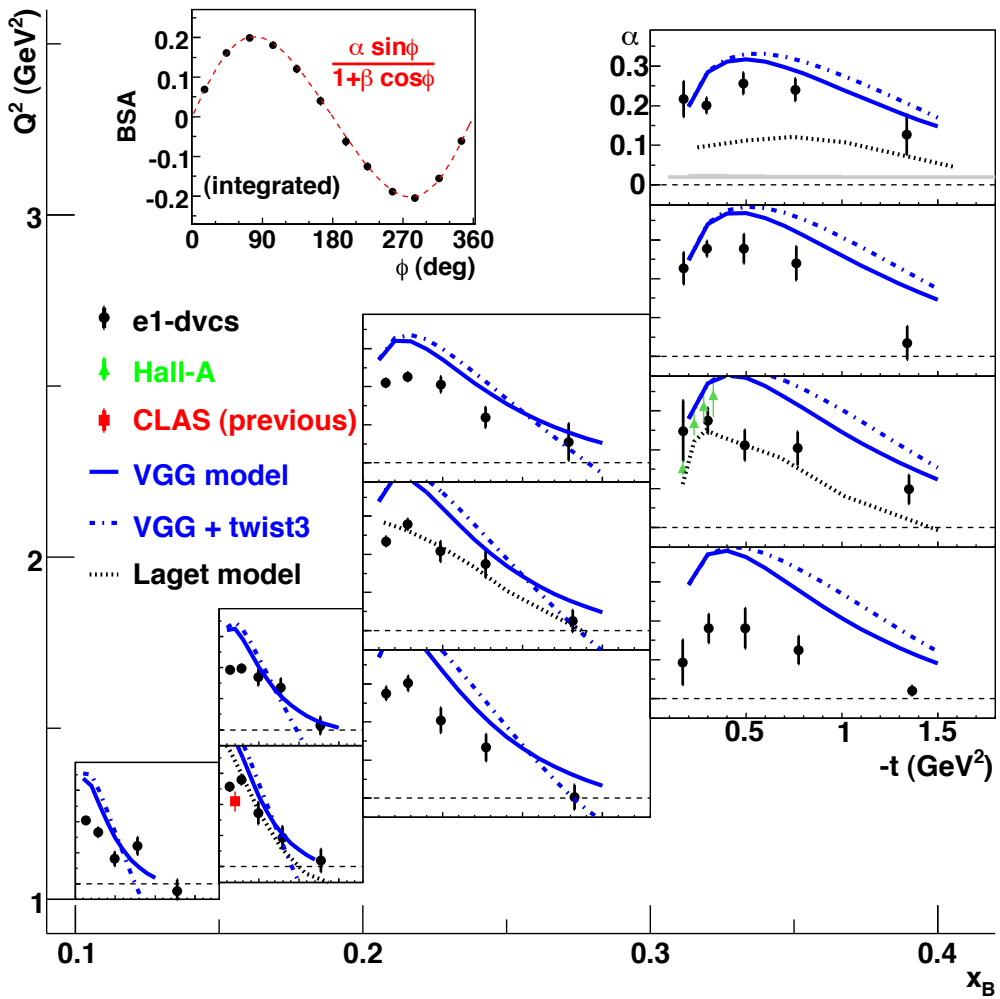
DVCS Beam Spin Asymmetry A_{LU}

$$A_{LU} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{\Delta\sigma}{2\sigma}$$

- VGG parameterization reproduces $-t > 0.5\,\mathrm{GeV}^2$ behavior, and overshoots asymmetry at small t.
- The latter could indicate that VGG misses some important contributions to the DVCS cross section.
- Regge model (J-M Laget) is in fair agreement in some kinematic bins with our results.
- The Regge mode seems to be working at low Q^2 while the GDP approach gets better at larger Q^2. This is expected

F.-X. Girod et al., PRL 100 (2008) 162002

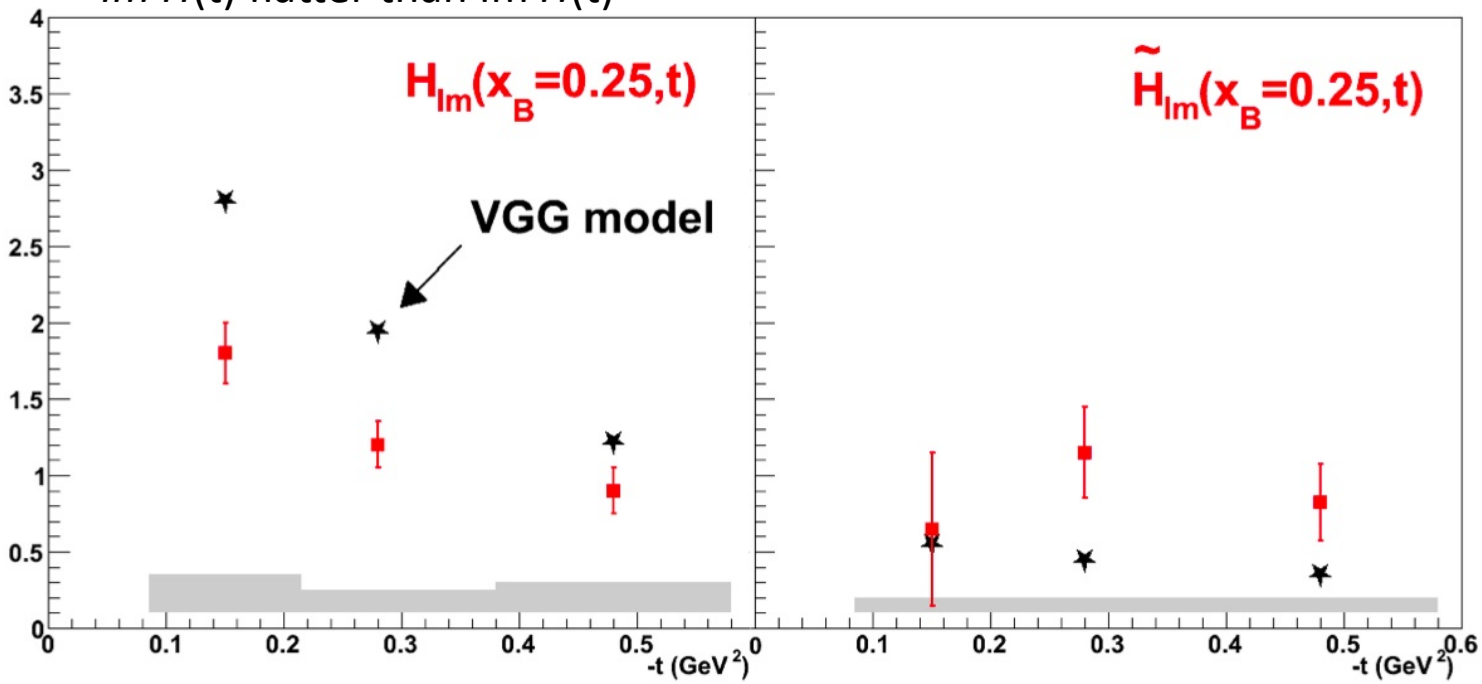
CLAS data



Extraction of Compton Form Factors from CLAS DVCS data

- A_{LU} and A_{UL} CLAS results only
- *Im H*(t) Im $\tilde{H}$(t) are extracted
- *Im* $\tilde{H}$(t) flatter than Im *H*(t)

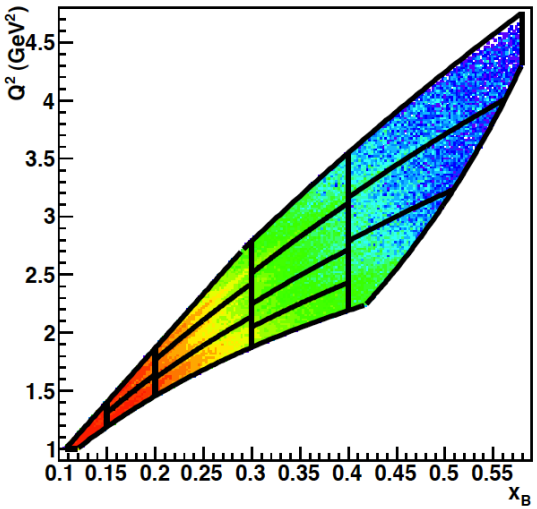
M. Guidal, Phys.Lett.B689:156-162,2010



The fact that $\tilde{H}$ is "flatter" in t than H, hints that the axial charge of the nucleon is more concentrated than the electromagnetic charge. This is related to the fact that the axial form factor is also flatter than the EM form factors. We see that via different formalism (GDPS vs FFs) and reaction (DVCS vs elastic), one reaches the same conclusions.

$\sigma(ep \rightarrow ep\gamma)$

DVCS x-sections from e1dvcs



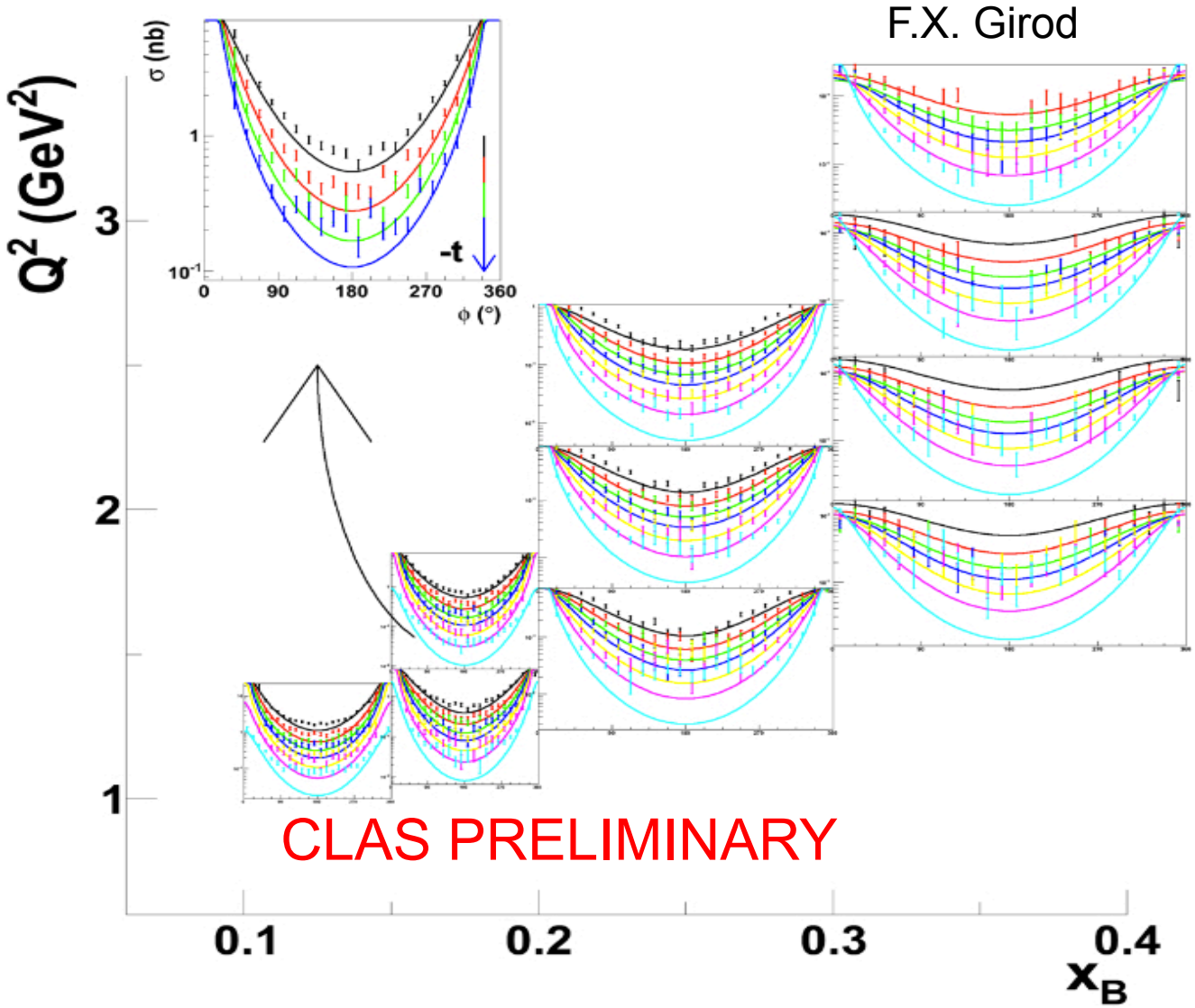
F.X. Girod

Hyon-Suk Jo

Alex Kubarovski

Four dimensional grid
Q^2, x_B, t, ϕ

F.X. Girod

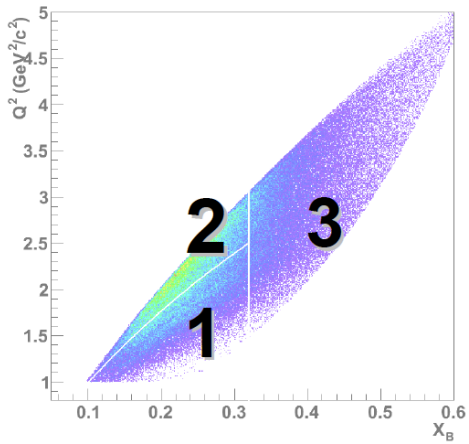


Radiative corrections and π^0 contamination accounted

DVCS target spin asymmetry

$$\sigma(\vec{e}p \rightarrow e\vec{p}\gamma)$$

eg1-dvcs - completed data taking at 2009

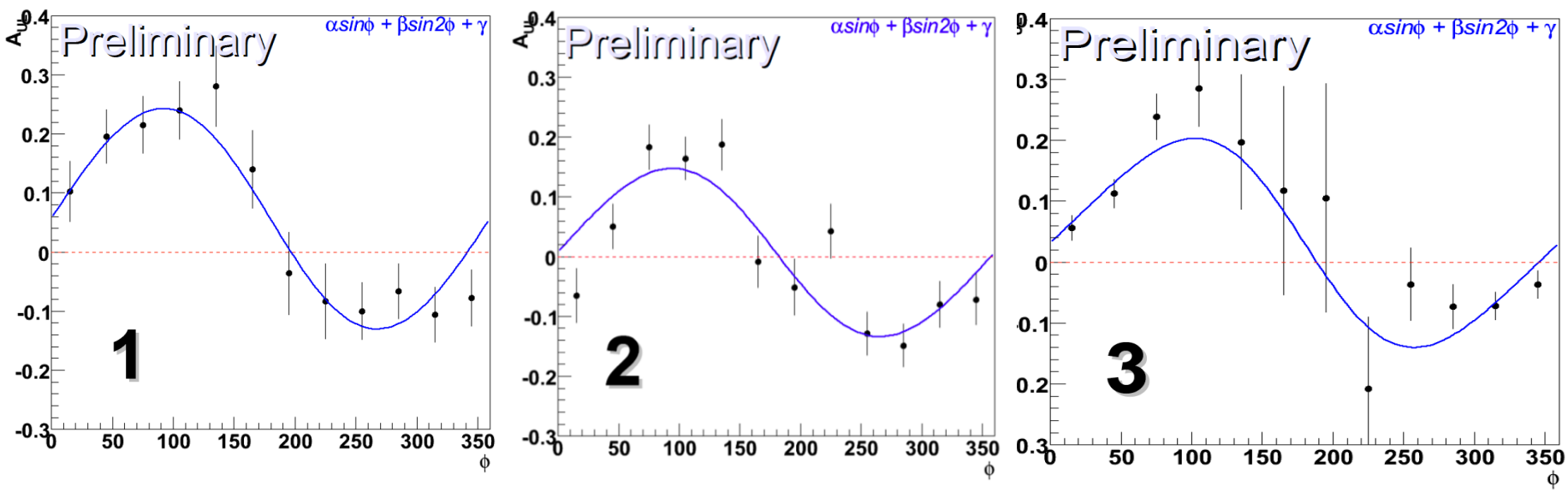


E. Seder

$$A_{UL} = \frac{N^{\Uparrow}(\phi) - N^{\Downarrow}(\phi)}{f\,[P^{\Downarrow}_t N^{\Uparrow}(\phi) + P^{\Uparrow}_t N^{\Downarrow}(\phi)]}$$

Longitudinal Polarized target

- **Polarizations:**
  - **Beam: ~80%**
  - **NH3 proton ~70%**
- **Beam energy ~5.7 GeV**



Longitudinal target SSA will be extracted in bins in Q2, x and t

DVCS double spin asymmetry

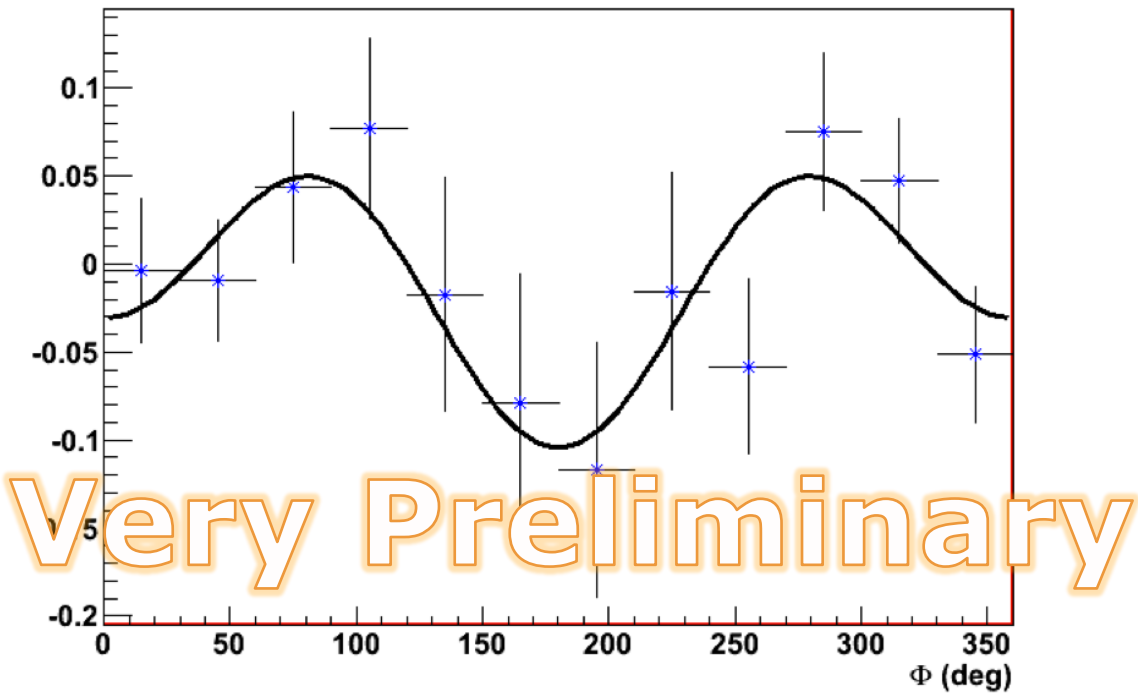
eg1-dvcs - completed data taking at 2009

$$A_{LL} = \frac{(N^{++} + N^{--}) - (N^{+-} + N^{-+})}{f P_{beam} P_{target} (N^{++} + N^{--}) - (N^{+-} + N^{-+})}$$

S. Pisano

Fitting function:

$$A_{LL} = \alpha + \beta cos\varphi + \gamma cos^2\varphi + \delta sin^2\varphi$$

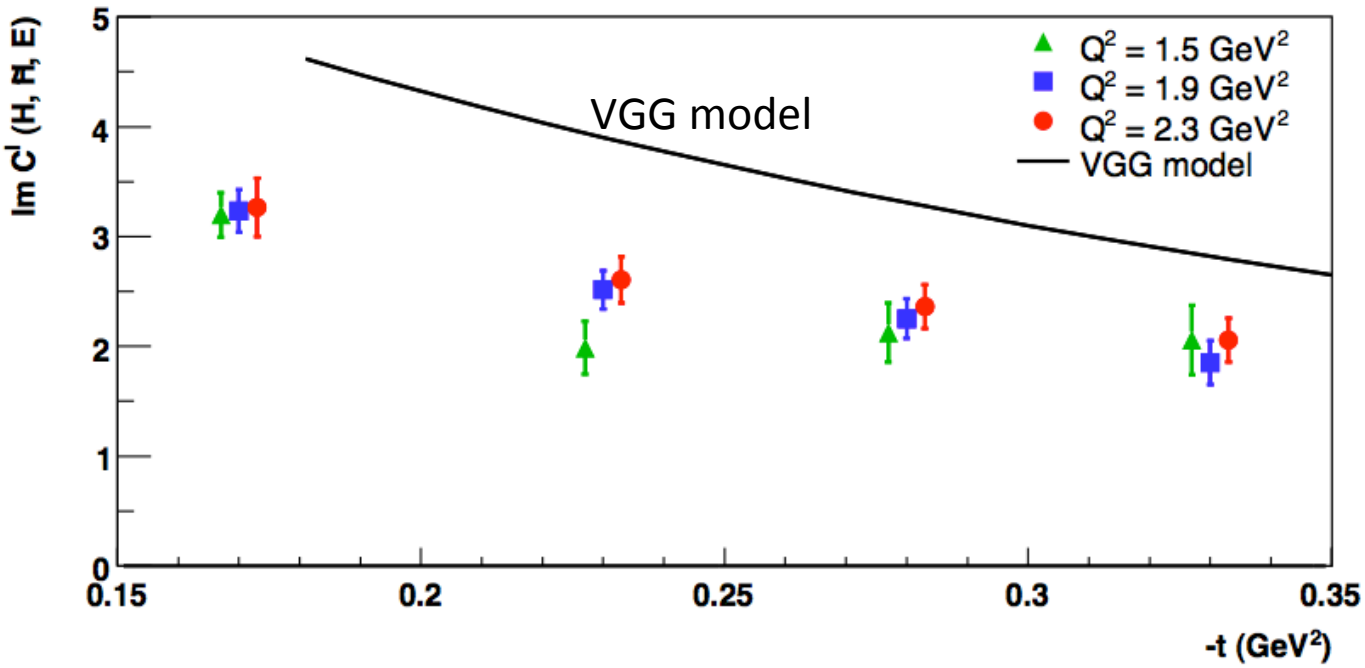


- $N^{+/-}$: number of DVCS events with a positive (negative) target/beam polarization
- $P_{beam/T}$: beam/target polarization
- f: diluition factor

Hall A

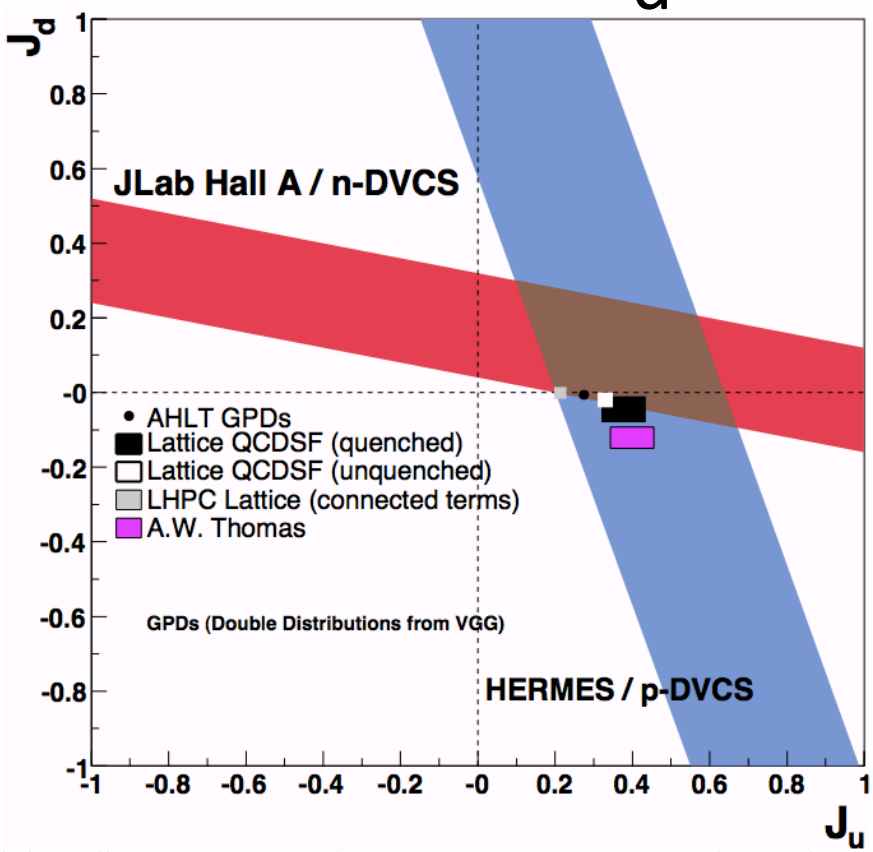
- Proton DVCS, helicity dependent and independent cross sections were measured at
  - Q^2=(1.5, 1.9, 2.3) GeV^2
  - -t=(0.17, 0.23, 0.28, 0.33) GeV^2
  - x_B=0.36
- Neutron DVCS, helicity dependent cross section on deuterium. Sensitive to $E(\xi,t)$
  - Q^2=1.9 GeV^2
  - x_B=0.36
- Completed data taking at 2010, which included measurements of DVCS on proton and deuterium at two different energies with the aim to separate Re [DVCS*BH] and $|DVCS|^2$ terms.

Imaginary Part of the Interference Term



- VGG model agrees in slope with the data but lies 30% above
- Q^2 independent in all t bins
- Provide support for the factorization at Q^2>2 GeV^2

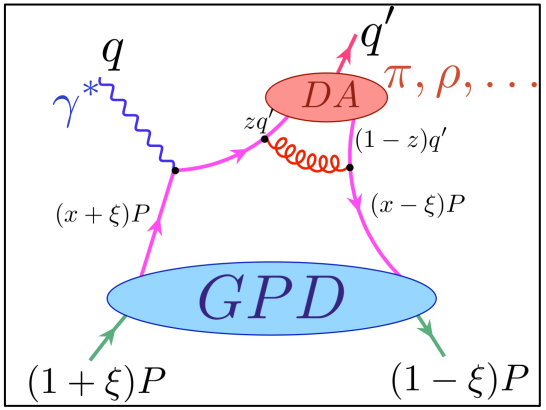
Constraint on J_d and J_u



Helicity-dependent Jlab Hall-A neutron and HERMES transversity polarized proton data constrain in ***a model dependent way*** on the total up and down quark contributions to the proton spin.

$$J_q = \frac{1}{2}\Delta\Sigma_q + L_q = \frac{1}{2}\int_{-1}^{1} x[H_q(x,\xi,t=0) + E_q(x,\xi,t=0)]dx$$

Exclusive Meson Production



Pseudoscalar mesons

$$ep \to en\pi^+$$

$$ep \to ep\pi^0, \quad \pi^0 \to \gamma\gamma$$

$$ep \to ep\eta, \quad \eta \to \gamma\gamma$$

CLAS6: lots of data.
CLAS12: Exp. # E12-06-108

Vector mesons

$$ep \to en\rho^+, \quad \rho^+ \to \pi^+\pi^0$$

$$ep \to ep\rho^0, \quad \rho^0 \to \pi^+\pi^-$$

$$ep \to ep\omega, \quad \omega \to \pi^+\pi^-\pi^0$$

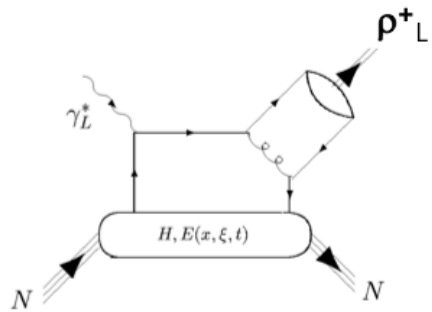
$$ep \to ep\phi, \quad \phi \to K^+K^-$$

New proposal being prepared for PAC 38

K. Lukashin et al., Phys.Rev.C63:065205,2001 (ϕ, 4.2 GeV)
C. Hadjidakis et al., Phys.Lett.B605:256-264,2005 (ρ^0,4.2 G eV)
L. Morand et al., Eur.Phys.J.A24:445-458,2005 (ω, 5.75GeV)
J. Santoro et al., Phys.Rev.C78:025210,2008 (ϕ, 5.75GeV)
S. Morrow et al., Eur.Phys.J.A39:5-31,2009 (ρ^0, 5.75GeV)
A. Fradi, Orsay Univ. PhD thesis (ρ^+ ,5.75 GeV)

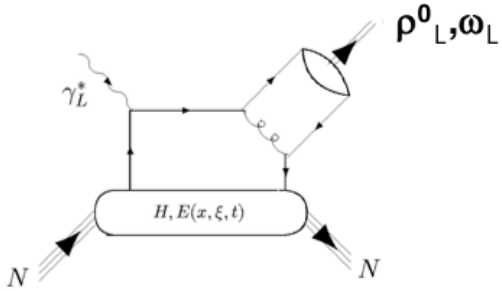
Vector Mesons
Quark and Gluon GPDs

$\gamma^* p \rightarrow n\rho^+$

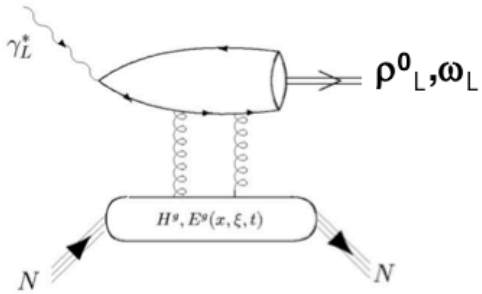


ρ^0	$e_u H^u - e_d H^d$ $e_u E^u - e_d E^d$
ω	$e_u H^u + e_d H^d$ $e_u E^u + e_d E^d$
ρ^+	$H^u - H^d$ $E^u - E^d$

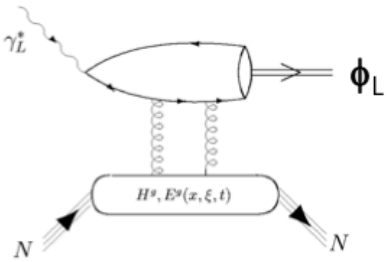
$\gamma^* p \rightarrow p\rho^0$
$\gamma^* p \rightarrow p\omega$



+

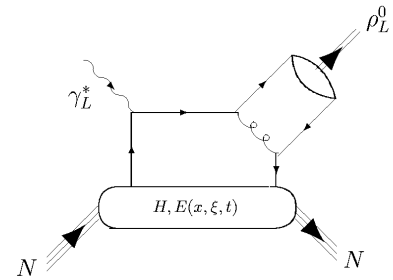


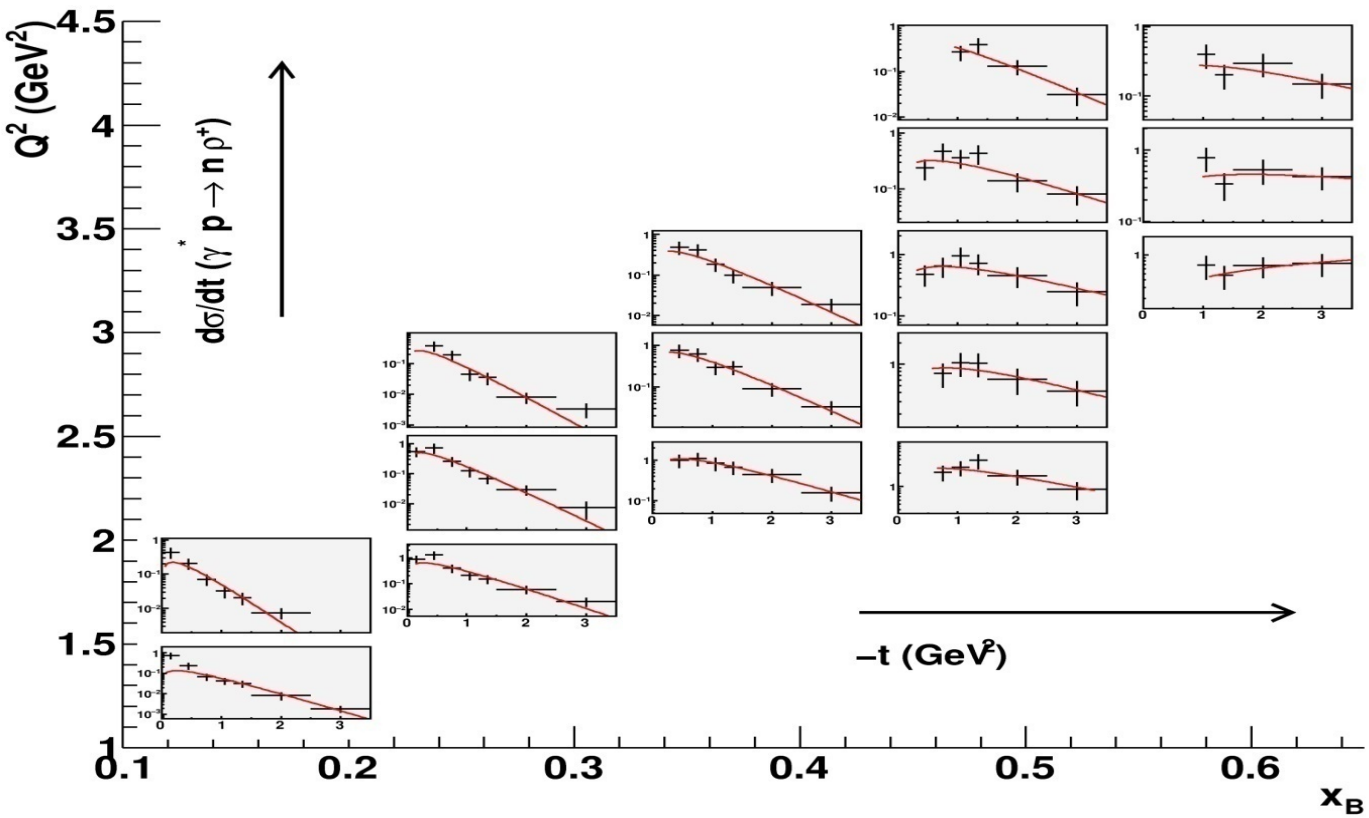
$\gamma^* p \rightarrow p\phi$



$$\frac{d\sigma}{dt}(\gamma^* p \rightarrow en\rho^+) \propto \sqrt{-t}e^{bt}$$

New



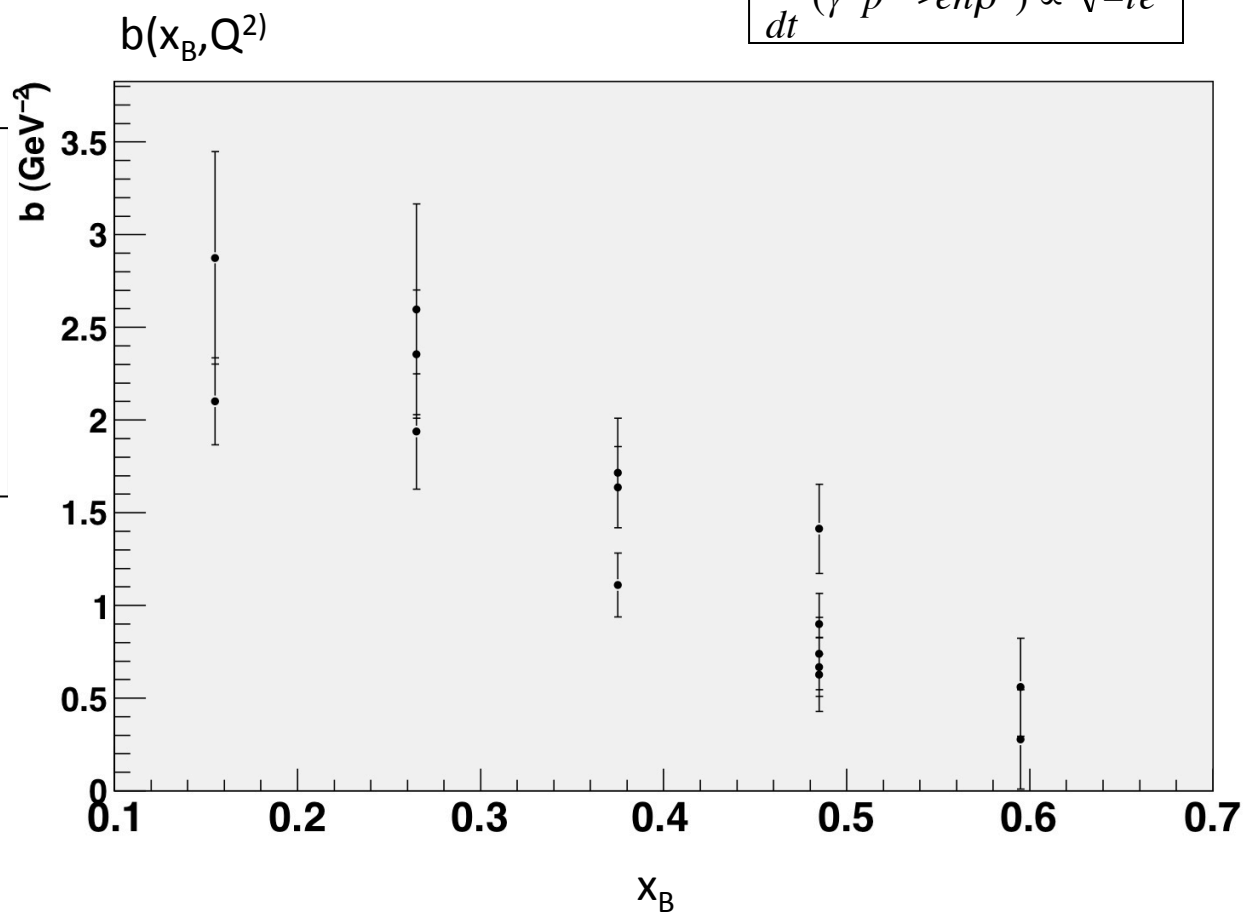


CLAS data. The first measurement of the ρ^+ exclusive electroproduction

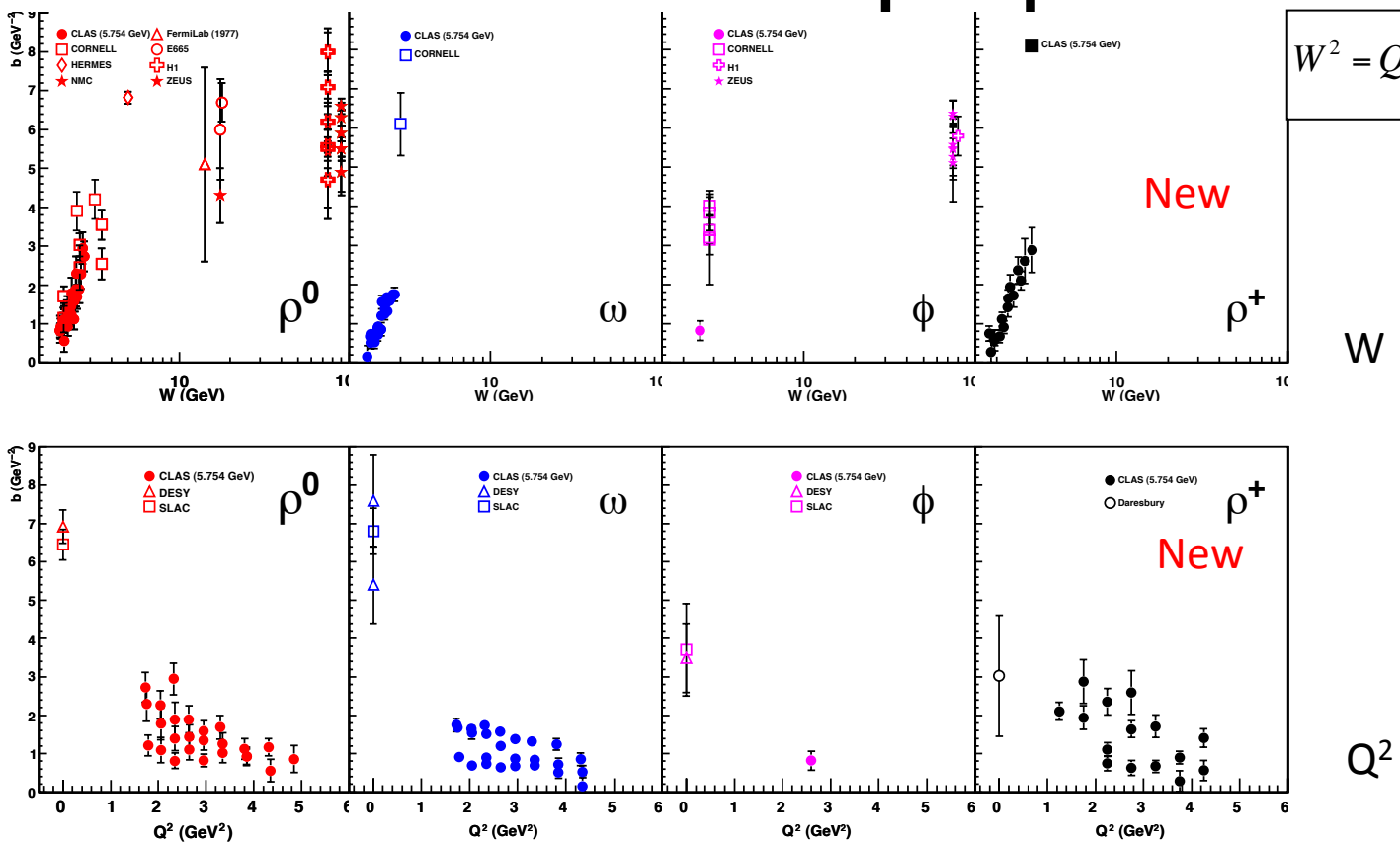
ρ^+ t-slope parameter

$$\frac{d\sigma}{dt}(\gamma^* p \rightarrow en\rho^+) \propto \sqrt{-t}e^{bt}$$

Slope parameter is decreasing with x_B. This indicates that the size of the interaction region decreases as $x_B \rightarrow 1$



Vector mesons t-slope parameter



$$W^2 = Q^2\left(\frac{1}{x_B} - 1\right) + m_N^2$$

W

Q^2

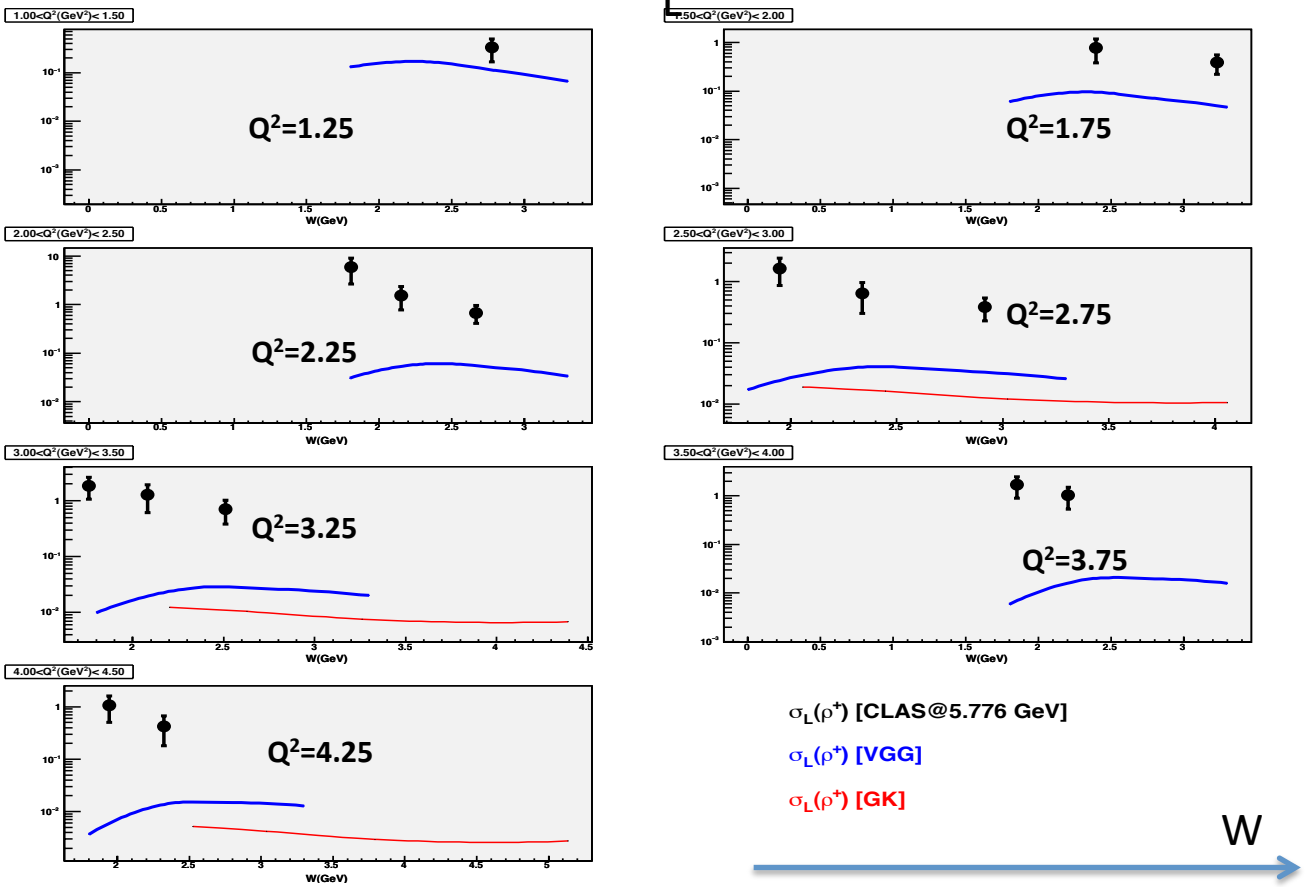
• b increases with W : the size of the nucleon increases as one probes the high W values (i.e. the sea quarks). Sea quarks tend to extend to the periphery of the nucleon.

σ_L, σ_T separation

S-channel helicity conservation

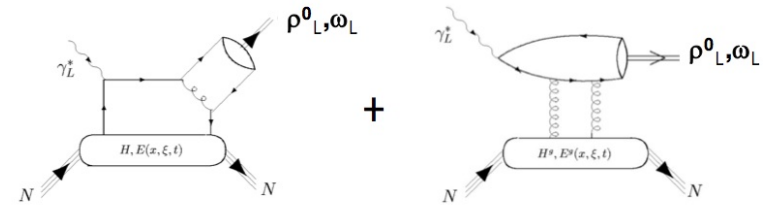
$$\gamma_L^* p \rightarrow n\rho^+$$

σ_L



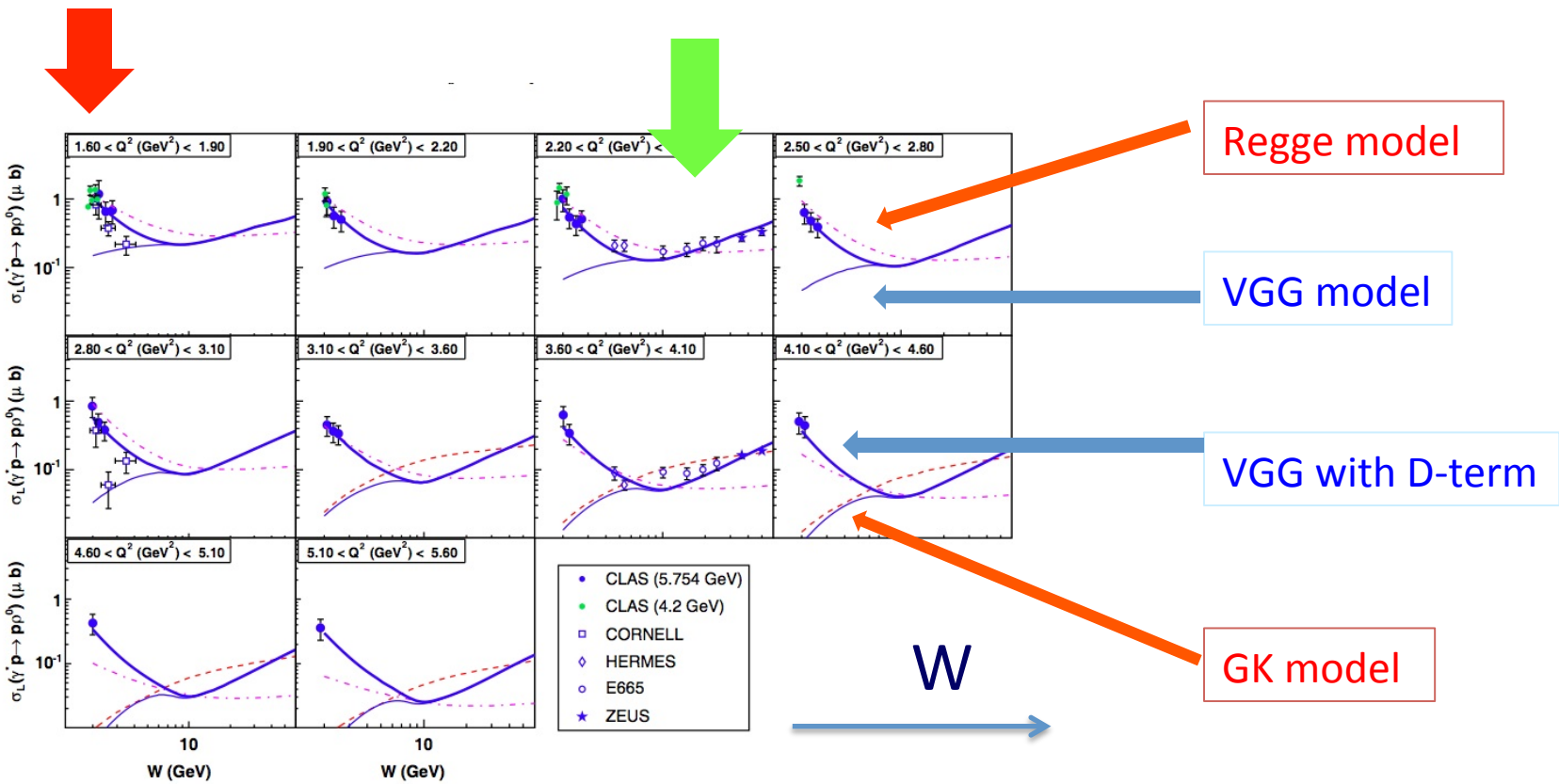
GPD fails to describe data by more than order of magnitude

$$\gamma_L^* p \rightarrow p\rho^0$$



Fails to describe data W<5 GeV

Describes well for W>5 GeV



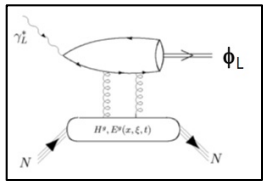
- Popular GK and VGG models can not provide the right W-dependence of the cross-section
- This does not mean that we can't access GPD in vector meson electroproduction
- For example, model with the addition of q-qbar exchange (M.Guidal) together with standard VGG model successfully describes data

$$\gamma_L^* p \to p\phi$$

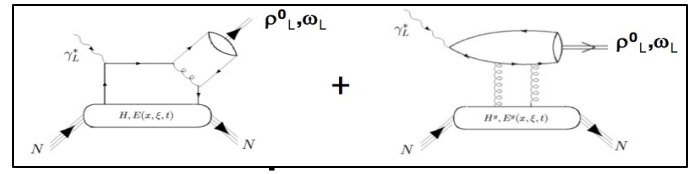
ϕ and ρ^0

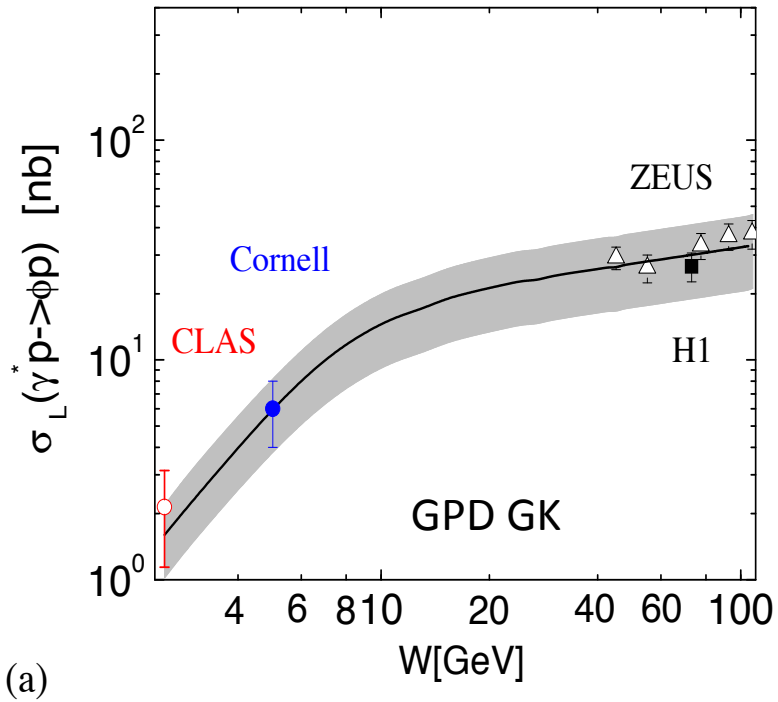
Goloskokov, Kroll

$$\gamma_L^* p \to p\rho^0$$

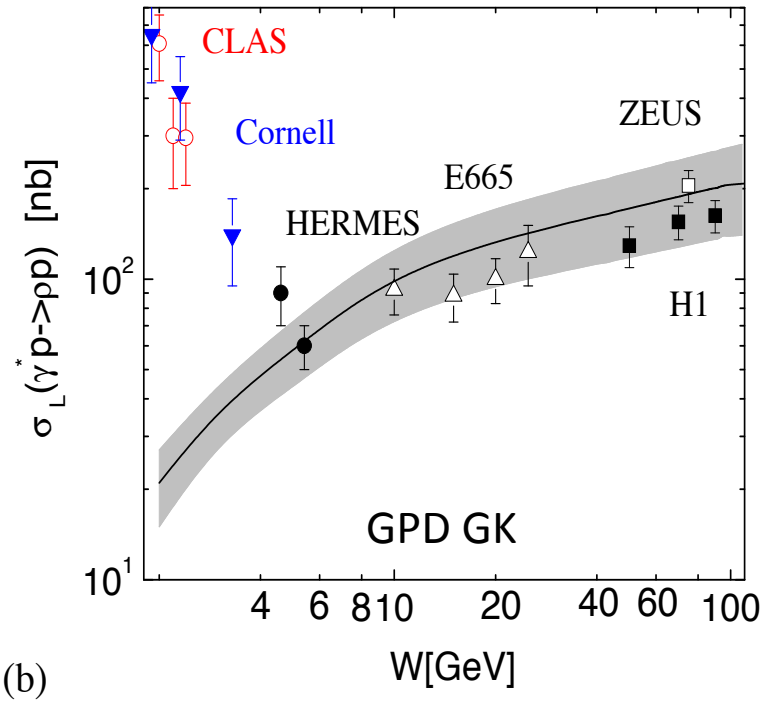


ϕ





(a)



(b)

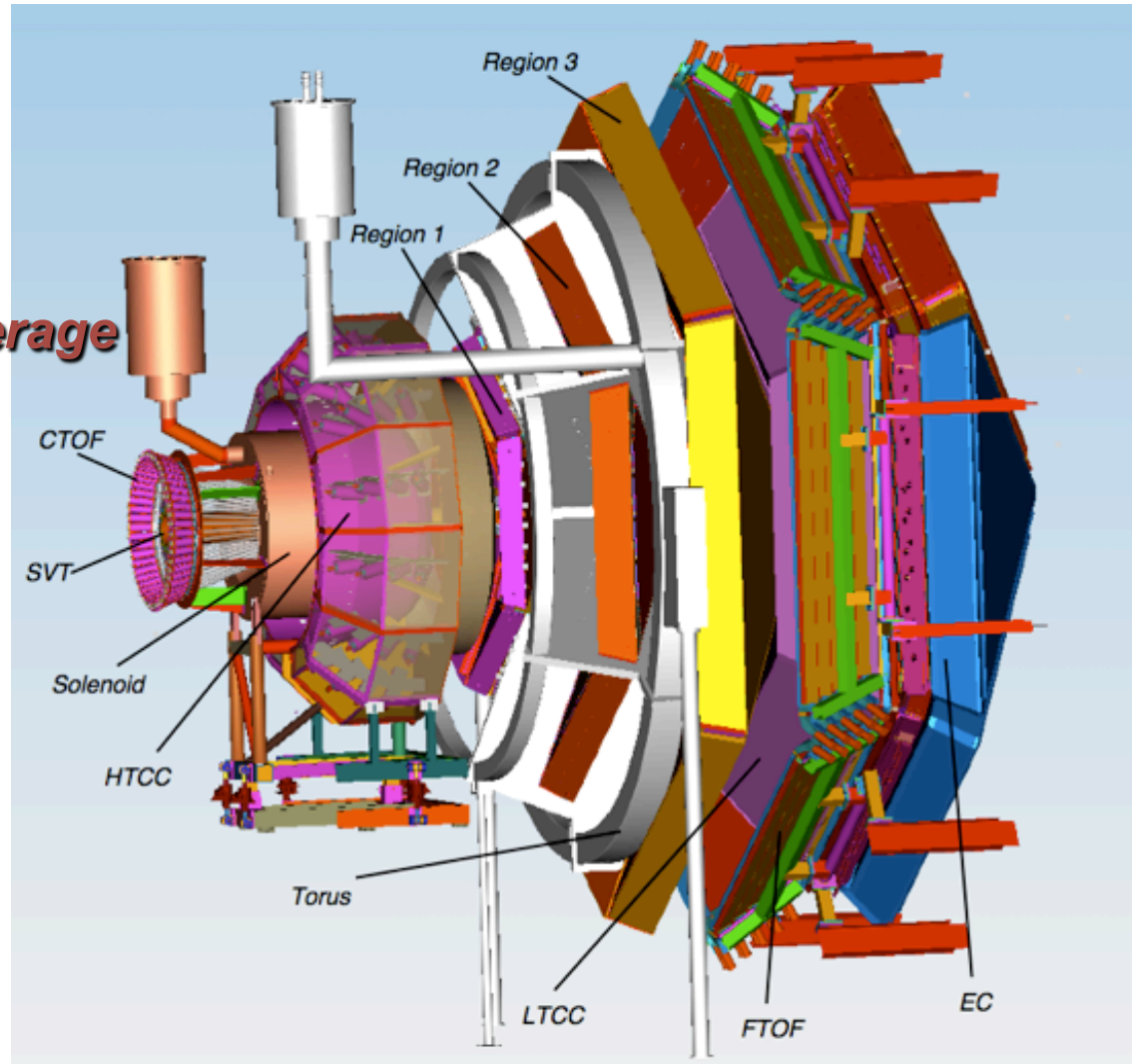
- ϕ mesons - gluon GPD are dominant
- ρ^0 and ω – sea quarks and/or gluons dominant.

GPD approach describes well data for W>5 GeV

JLab 12 GeV Upgrade

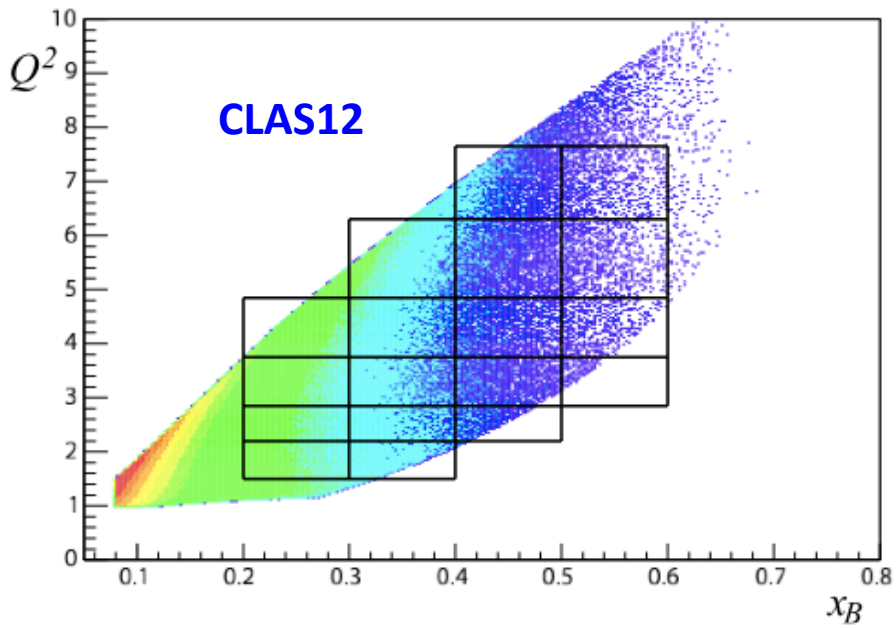
CLAS12

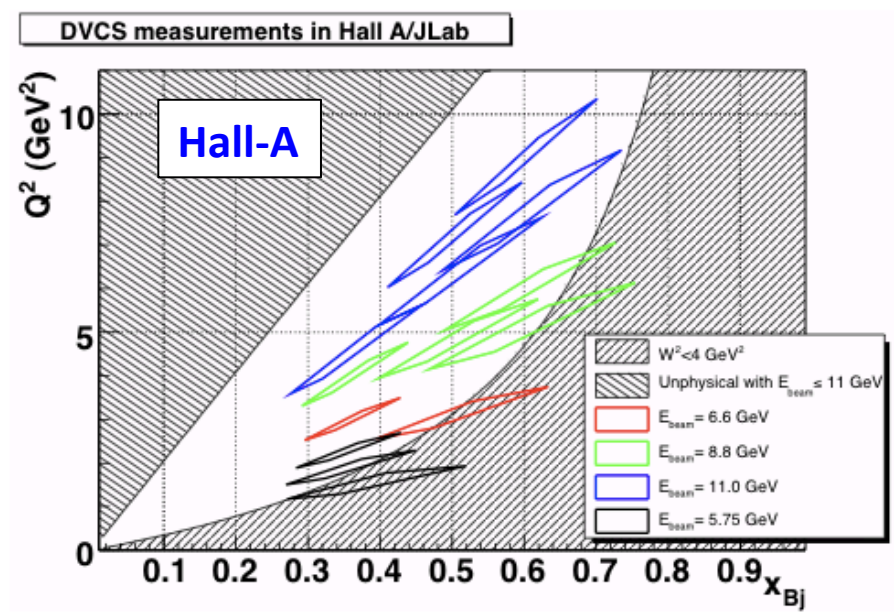
- High luminosity
- Large acceptance
- Wide kinematic coverage
- High precision



The JLab 12 GeV project offers an unprecedented frontier of intensity and precision for the study of deep exclusive scattering.

Kinematic Bins at Jlab 12 GeV





Left: CLAS12 kinematics for DVCS and DVMP on unpolarized H2 and longitudinally Polarized targets. The colors and density are proportional to the relative count rates.
Right: Hall A kinematics for DVCS and π0 electroproduction. Beam time is adjusted for roughly equal counts in all bins.

Jlab Upgrade Program

Deeply Virtual Exclusive Meson Electroproduction

$ep \rightarrow ep\pi^0$	$ep \rightarrow ep\eta$
$ep \rightarrow ep\phi$	$ep \rightarrow ep\rho^0$
$ep \rightarrow ep\omega$	$ep \rightarrow en\rho^+$

Deep Virtual Compton Scattering

$ep \rightarrow ep\gamma$	$en \rightarrow en\gamma$

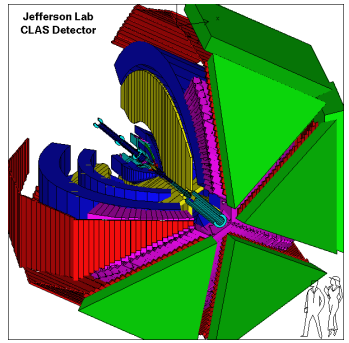
- Kinematics:

  Q^2 from 3 – 10 GeV^2

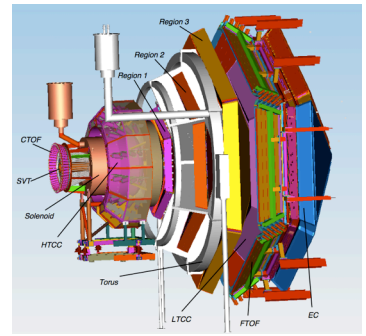
  $-t$ from .5 to 10 Gev^2

  W from 2-4 GeV

Summary



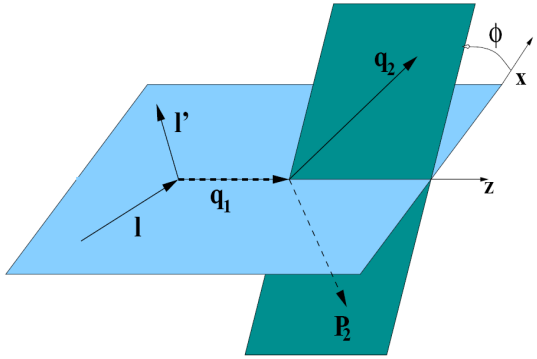
2015

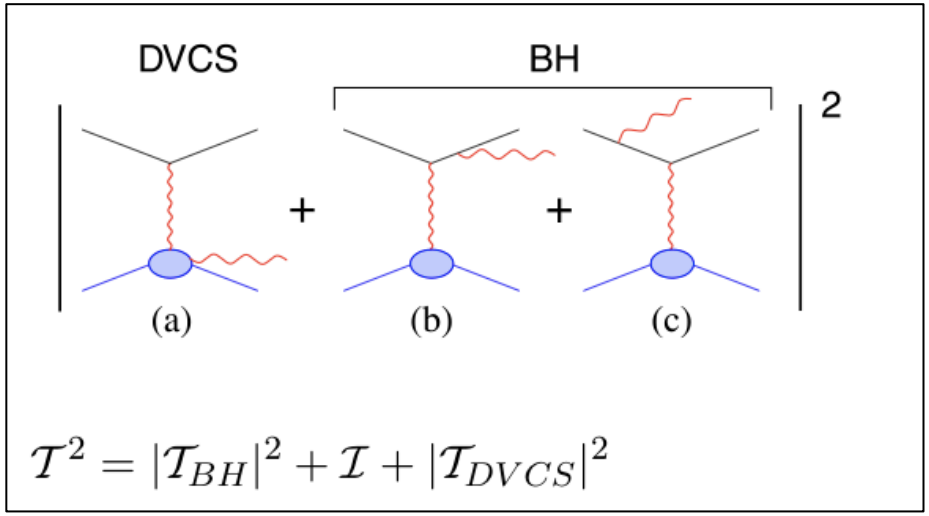


- Jlab DVCS experiments provide important data, crucial for the extraction of GPDs in a wide kinematical region
- DVCS with polarized and unpolarized targets provides precise information on H and $\tilde{H}$
- The most extensive set of π^0, η, ρ^+,ρ^0,ω, and ϕ electroproduction to date has been obtained with the CLAS spectrometer.
- Jlab 12 GeV program of DVCS, pseudoscalar and vector meson electroproduction will provide unique information about the:

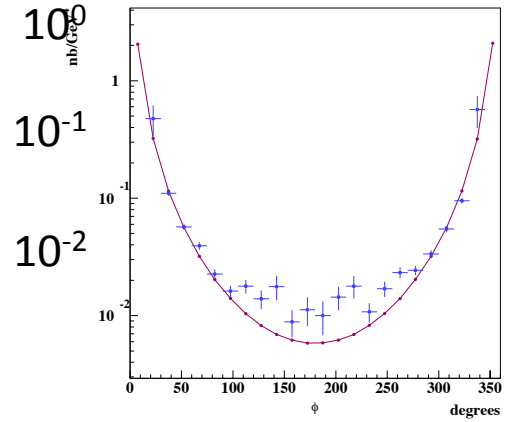
  - transition between soft long-range phenomena and hard short range
  - quark momentum and spin distributions of the nucleons.
  - quark and gluon GPDs

DVCS

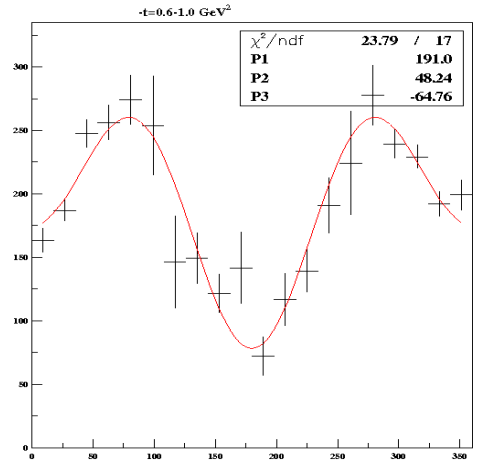




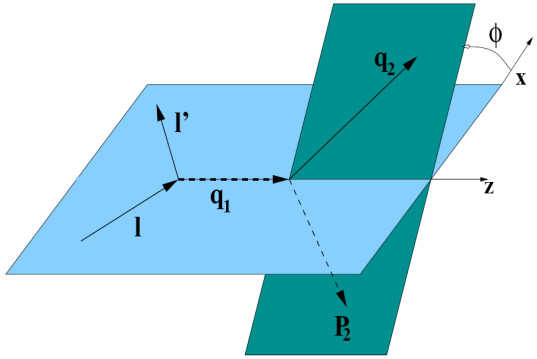
$$\mathcal{T}^2 = |\mathcal{T}_{BH}|^2 + \mathcal{I} + |\mathcal{T}_{DVCS}|^2$$

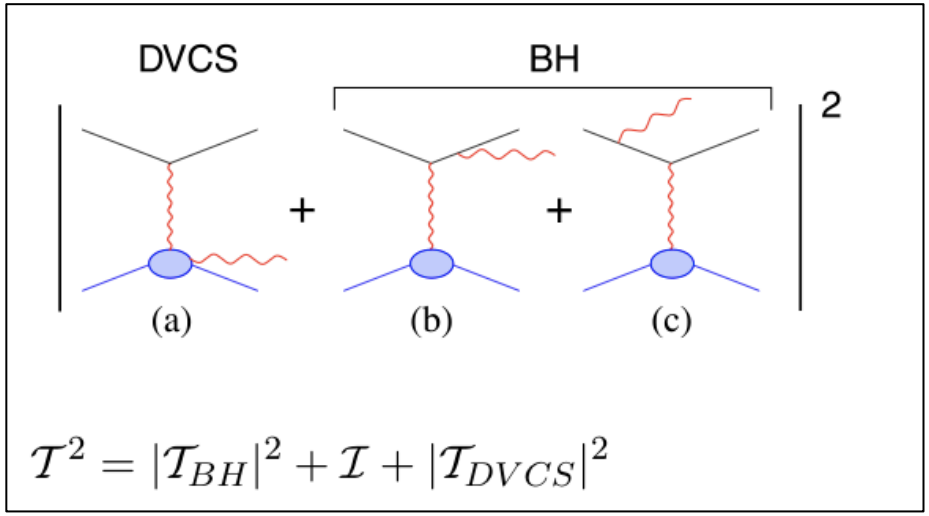


DVMP



DVCS





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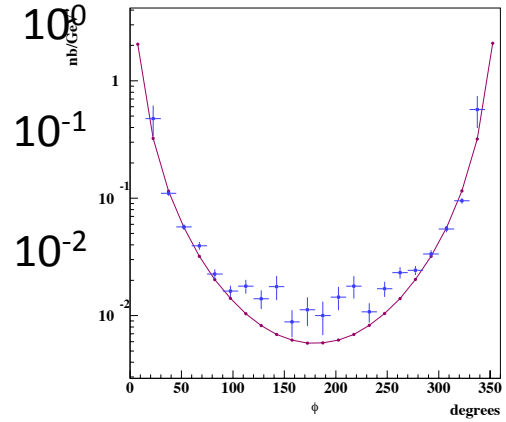
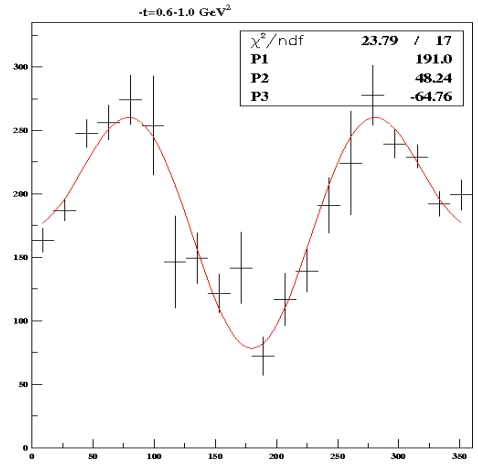


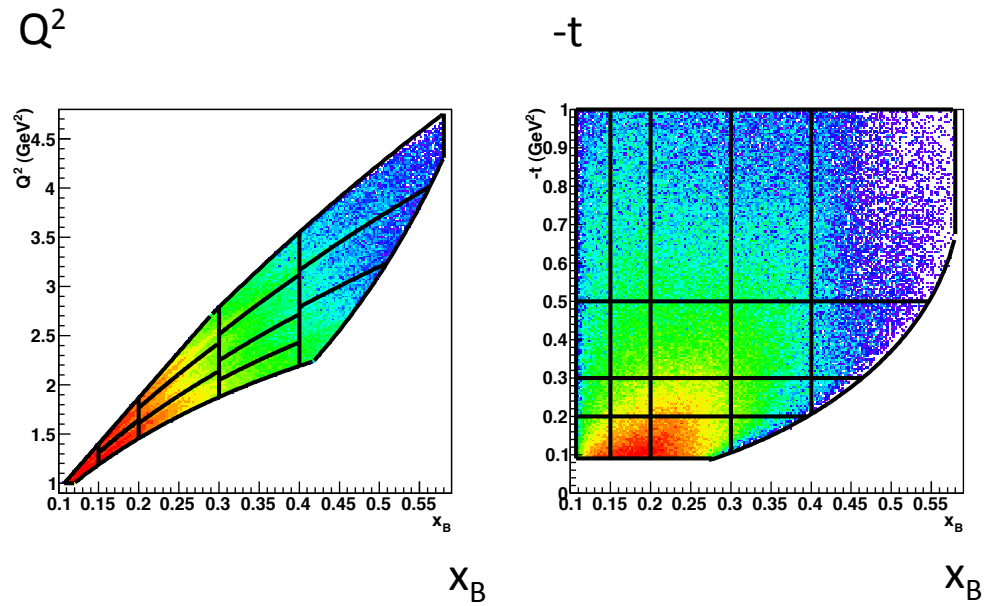
DVMP



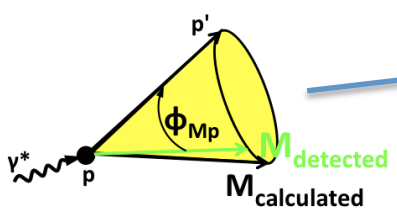
DVCS kinematics

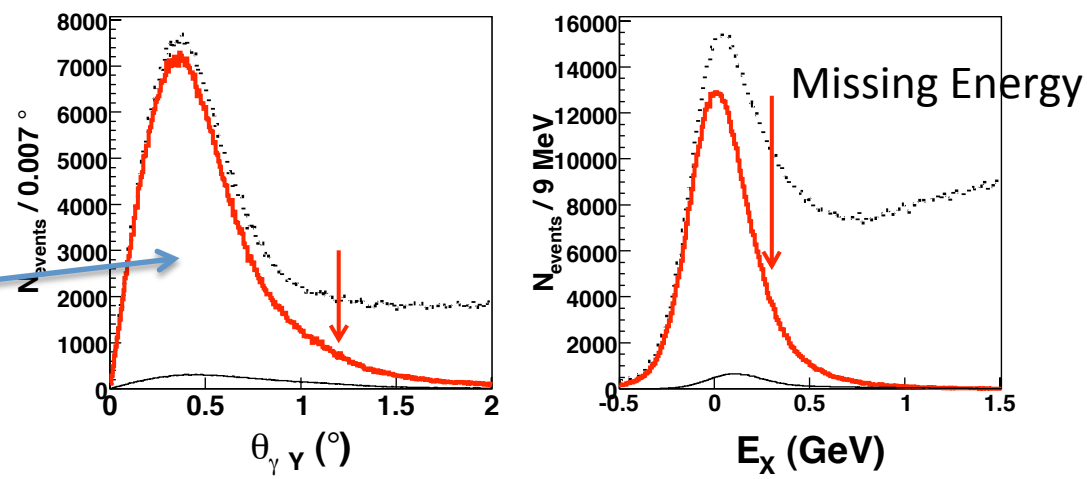
$$\sigma(ep \rightarrow ep\gamma)$$

Kinematical coverage
(x_B,Q^2) and (x_B,-t)



Exclusive cuts
And π^0 subtraction





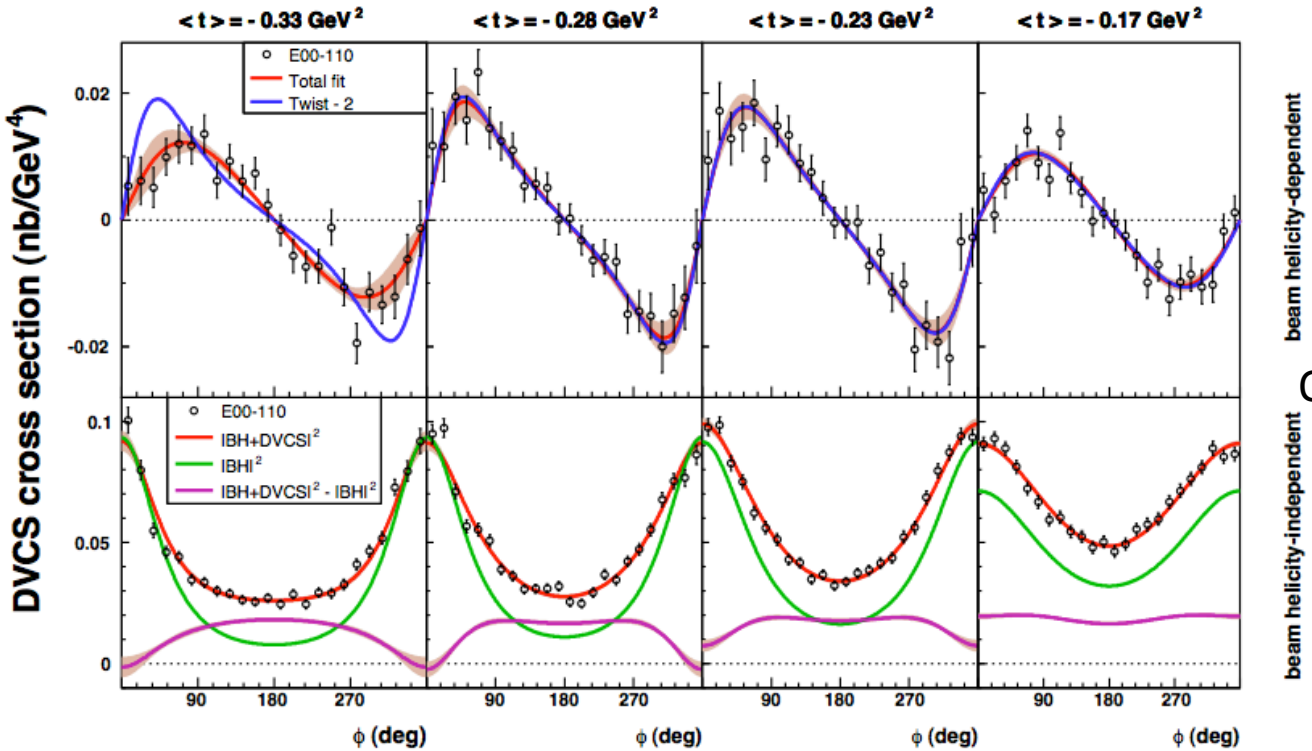
Helicity dependent (top) and independent DVCS Cross sections

Twist-2

Complete fit

BH

Twist-2
Twist-3



Q^2=2.3 GeV^2

The helicity independent cross sections show the significant contribution from the sum of the interference and DVCS terms as compared to the pure BH cross section