

Measurement of GPDs at JLab and in Future at Colliders

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Electron-Ion Collider Workshop March 16

- Physics Motivation
- Exclusive reactions and GPDs
 - DVCS
 - Pseudoscalar mesons
 - Vector mesons
- Summary & Outlook

Physics Motivation

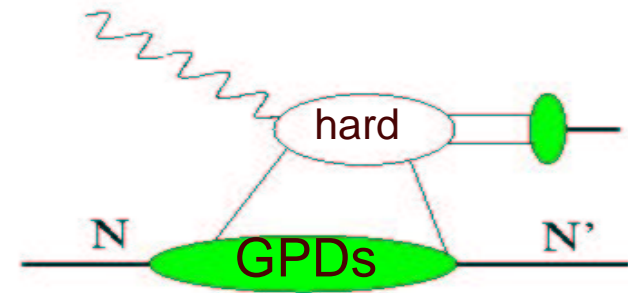
➤ Describe the complex nucleon structure in terms of quark and gluon degrees of freedom.

- parton distributions ← ←
- angular momentum ← ←
- gluon polarization ←

• Exclusive production of photons and hadrons in hard scattering kinematics.

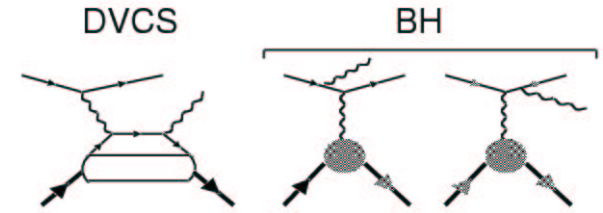
• test QCD based predictions (assuming factorization) for different observables and restrict underlying GPDs.

• studies of applicability of partonic picture in exclusive reactions



$H^q(x, \xi, t)$	\tilde{H}^q	E^q	\tilde{E}^q
H_T^q	\tilde{H}_T^q	E_T^q	\tilde{E}_T^q

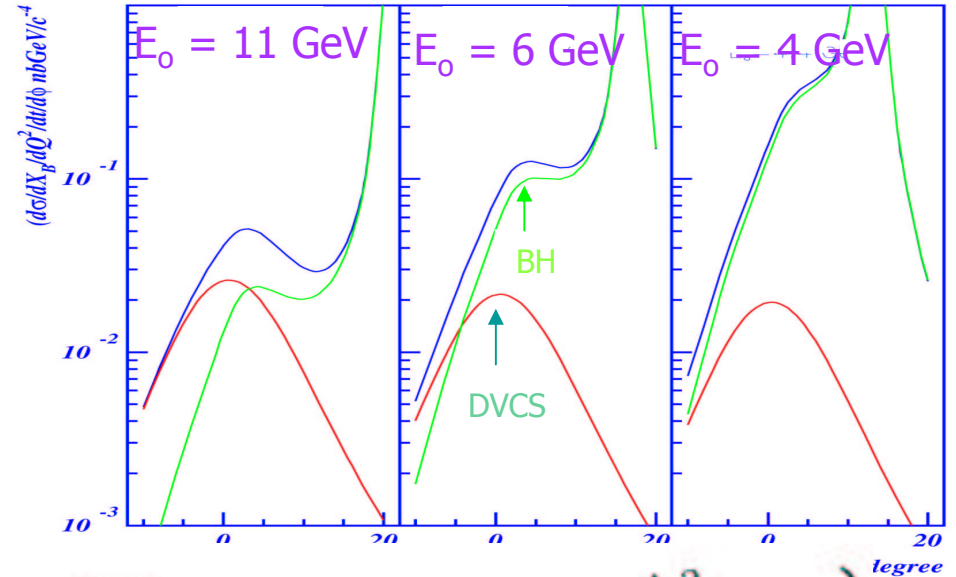
Deeply Virtual Compton Scattering $ep \rightarrow e'p'\gamma$



$$|\mathcal{T}_{\text{BH}}|^2 = \frac{e^6}{x_B^2 y^2 (1 + \epsilon^2)^2 \Delta^2 \mathcal{P}_1(\phi) \mathcal{P}_2(\phi)} \left\{ c_0^{\text{BH}} + \sum_{n=1}^2 c_n^{\text{BH}} \cos(n\phi) + s_1^{\text{BH}} \sin(\phi) \right\}$$

Cross section of $ep \rightarrow e'p'\gamma$ at $Q^2 = 2 \text{ GeV}^2$ and $x_B = 0.35$

$$\mathcal{I} = \frac{\pm e^6}{x_B y^3 \Delta^2 \mathcal{P}_1(\phi) \mathcal{P}_2(\phi)} \left\{ c_0^{\mathcal{I}} + \sum_{n=1}^3 [c_n^{\mathcal{I}} \cos(n\phi) + s_n^{\mathcal{I}} \sin(n\phi)] \right\},$$

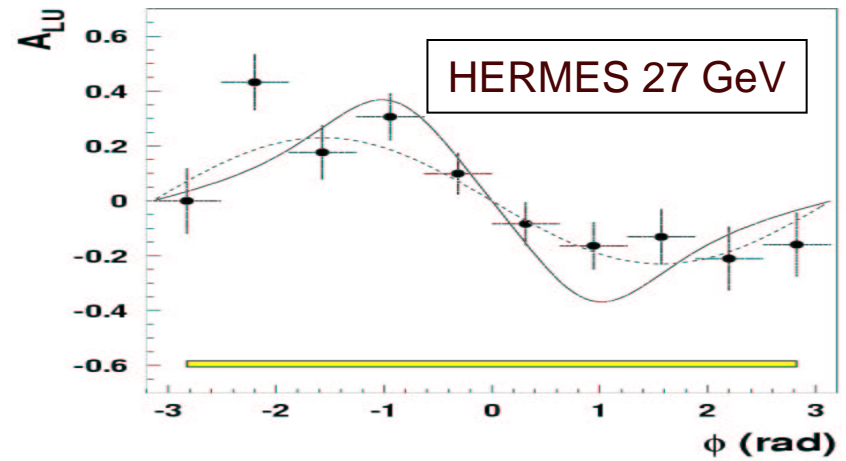
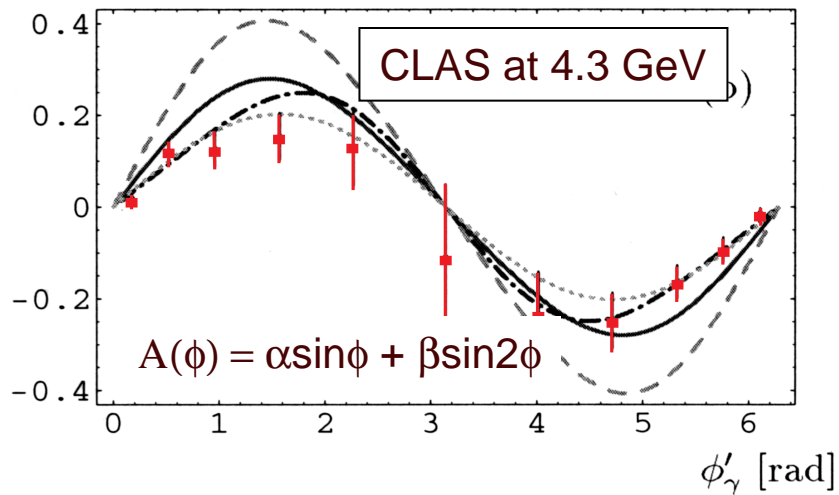
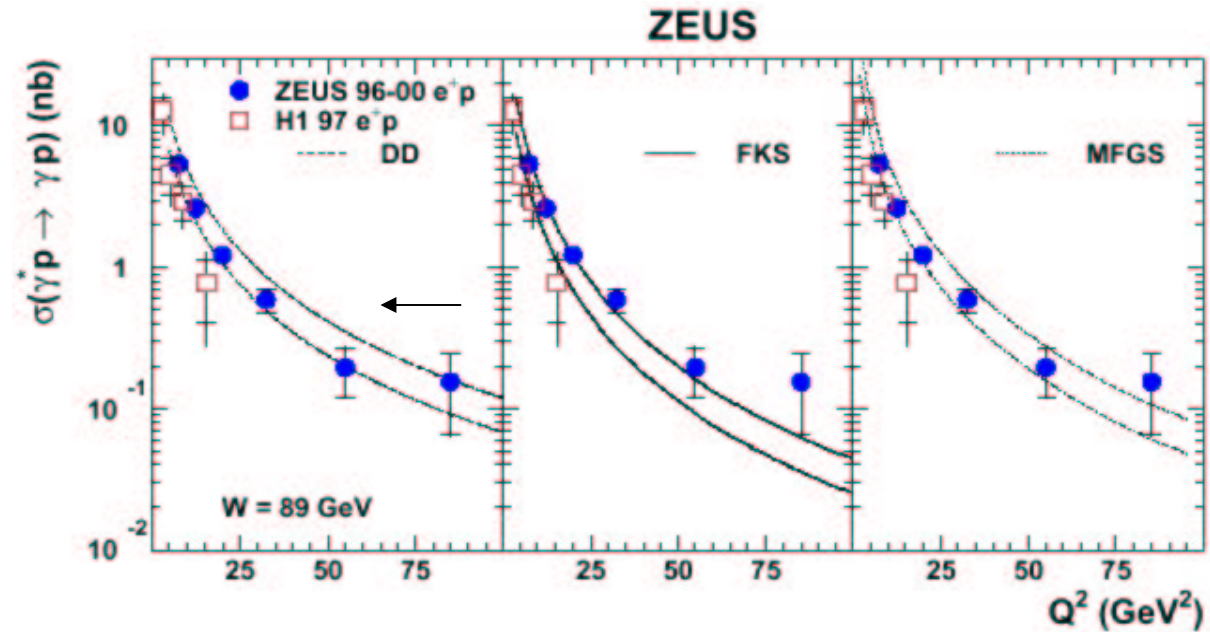


$$A_{\text{LU}} \sim \pm \frac{x_B}{y} \frac{s_{1,\text{unp}}^{\mathcal{I}}}{c_{0,\text{unp}}^{\text{BH}}} \propto \Im \left\{ F_1 \mathcal{H} + \frac{x_B}{2 - x_B} (F_1 + F_2) \tilde{\mathcal{H}} - \frac{\Delta^2}{4M^2} F_2 \mathcal{E} \right\}$$

Interference responsible for SSA, contain the same lepton propagator $\mathcal{P}_1(\phi)$

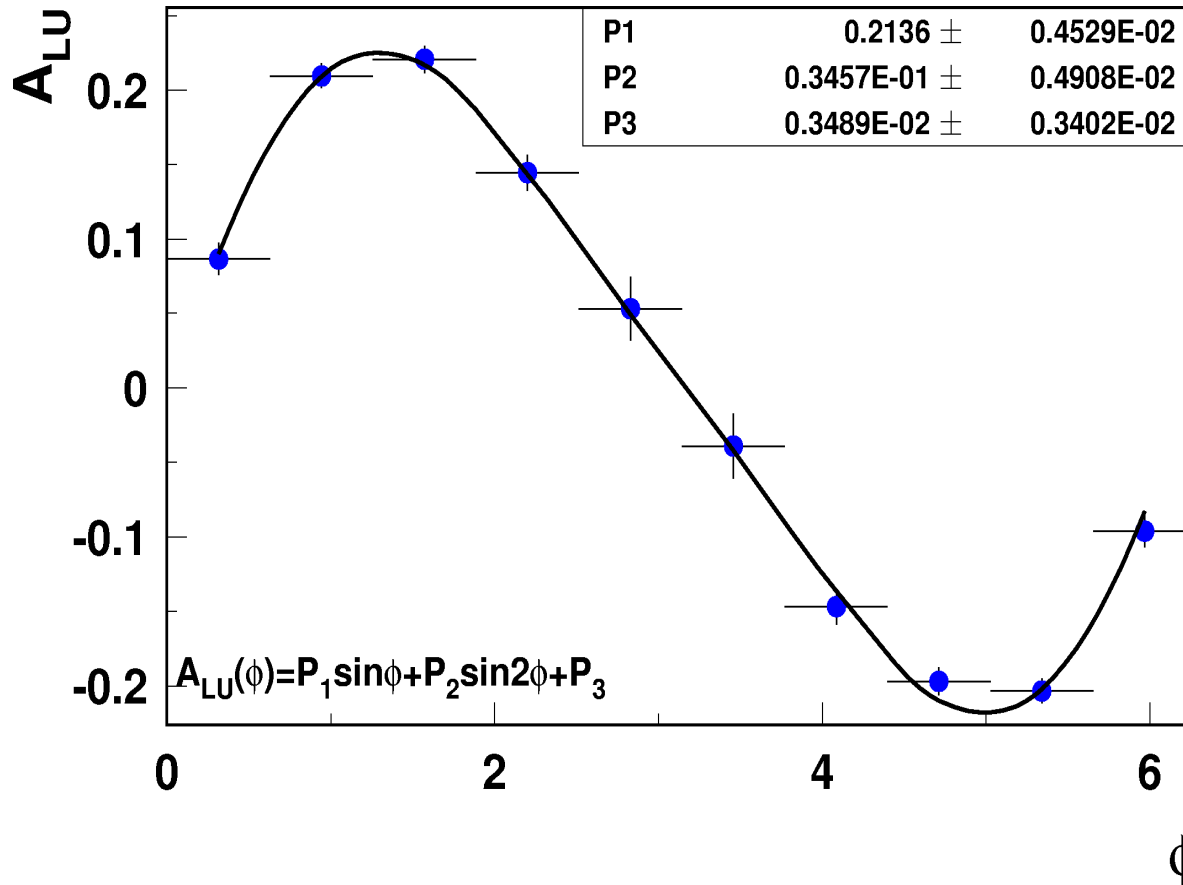
Different GPD combinations accessible as **azimuthal moments** of the total cross section.

Pioneering DVCS Experiments



SSA flips the sign from e^+ to e^-

CLAS 5.7 GeV: DVCS SSA

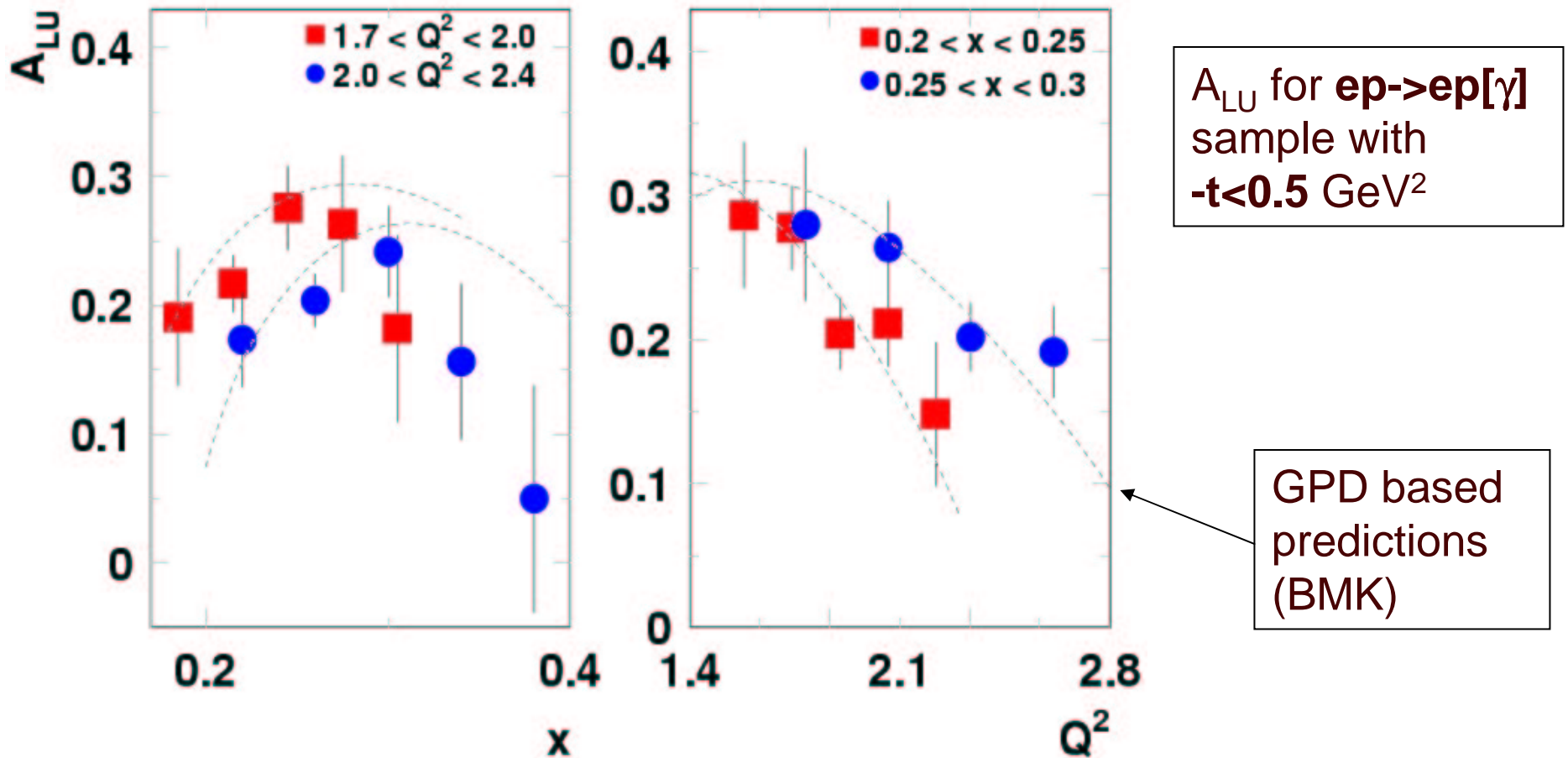


**CLAS 5.7 GeV -
first experiment
with GPDs in mind**

- Kinematic range:
 $0.15 < x < 0.4$
 $1.50 < Q^2 < 4.5 \text{ GeV}^2$
 $-t < 0.5$
 Significant $\sin\phi/\sin 2\phi$

- Higher energy increases kinematics range.
- Higher statistics allows binning of A_{LU} in Q^2 , t , x_B

DVCS SSA kinematic dependences at 5.7 GeV



Fine binning allows to determine the x_B and Q^2 dependence

DVCS ongoing activities with CLAS at 5.7 GeV

- Extraction of kinematic dependences x , Q^2 , t
- Extraction of the $\sin 2\phi$ moment
- Cross section difference
- GPD studies using measured kinematic dependences of SSA
- Measurement of DVCS SSA with longitudinally polarized target at CLAS

DVCS near future measurements at JLAB

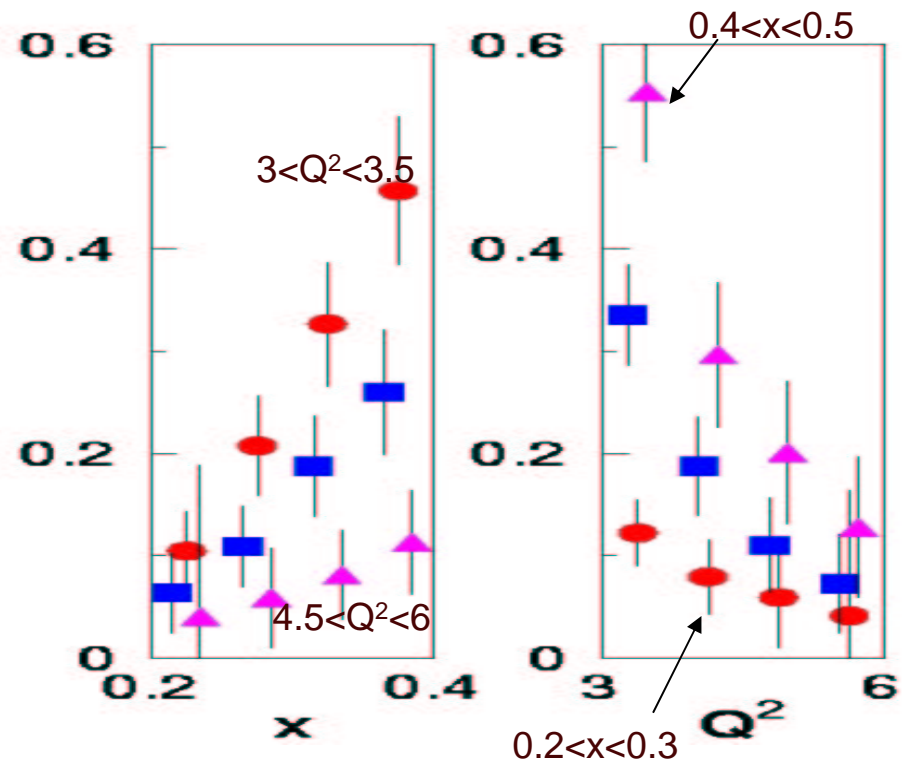
- Reconstructing all 3 final states.
 - HALL-A (2004): Cross section differences ($L=10^{37}\text{cm}^{-2}\text{sec}^{-1}$),
 - HALL-B (2005): SSA and cross section difference over the wide kinematic range ($L=2.10^{34}\text{cm}^{-2}\text{sec}^{-1}$)

DVCS with longitudinally polarized target (CLAS++)

$$A_{UL} \sim \pm \frac{x_B}{y} \frac{s_{1,LP}^I}{c_{0,unp}^{BH}} \propto \frac{x_B}{2-x_B} (F_1 + F_2) \left(\mathcal{H} + \frac{x_B}{2} \mathcal{E} \right) + F_1 \tilde{\mathcal{H}} - \frac{x_B}{2-x_B} \left(\frac{x_B}{2} F_1 + \frac{\Delta^2}{4M^2} F_2 \right) \tilde{\mathcal{E}}$$

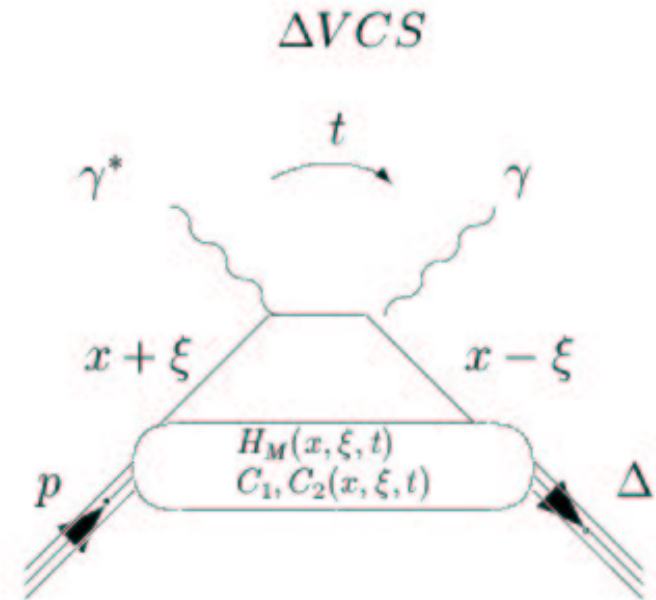
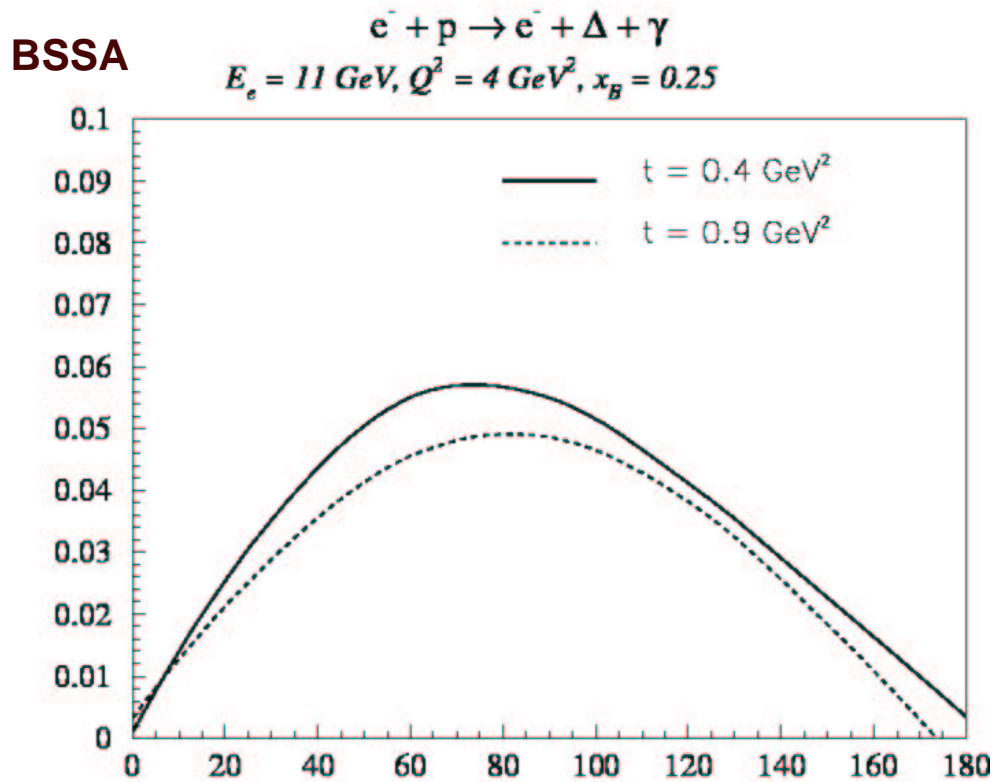
SSA Sensitive to polarized GPDs

- Transverse target DVCS asymmetry is sensitive to GPD E
- Polarized target DVCS SSAs will provide access to different combinations of GPDs important for their separation.



Δ -VCS or $ep \rightarrow e'\gamma\Delta$ at 11 GeV

Frankfurt et al PRL,84(2000)



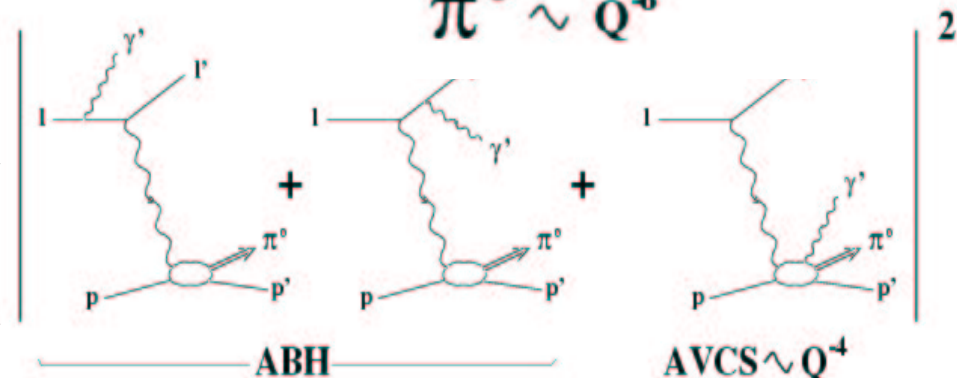
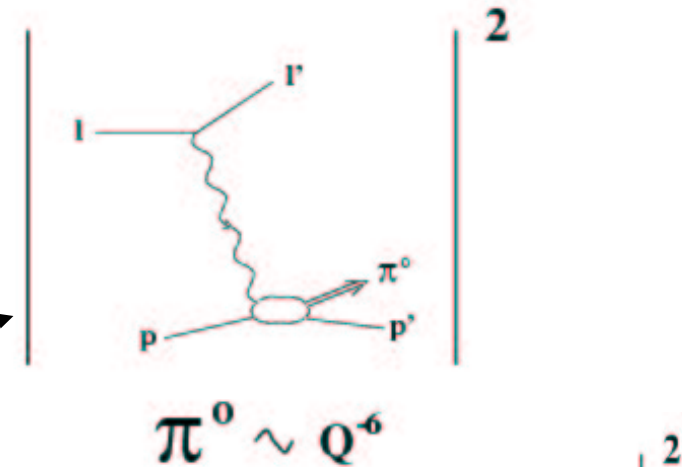
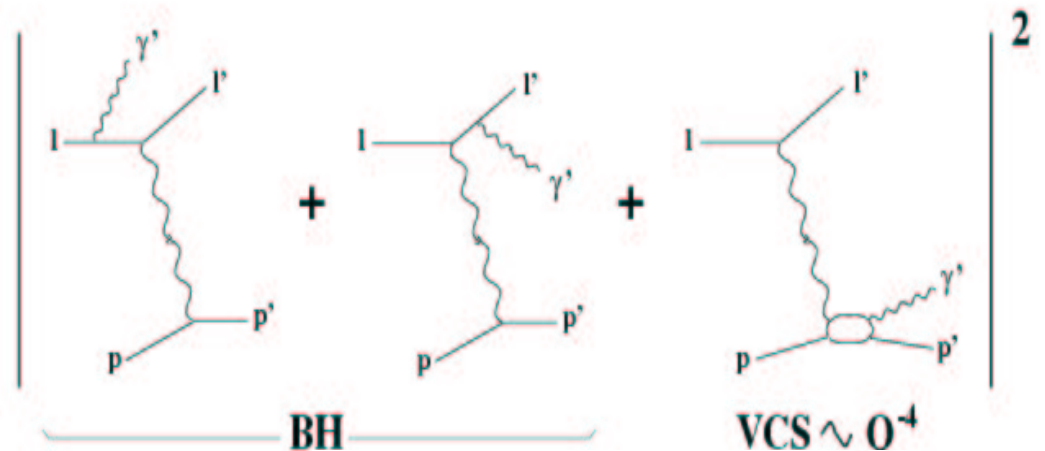
Transition GPDs (large N_c $C_1 \approx \tilde{H}$)
 Background to DVCS
 Background to pion production

GPDs from $ep \rightarrow e'p'\gamma$

Requirements for precision (<15%) measurements of s_2^I and GPDs from DVCS SSA:

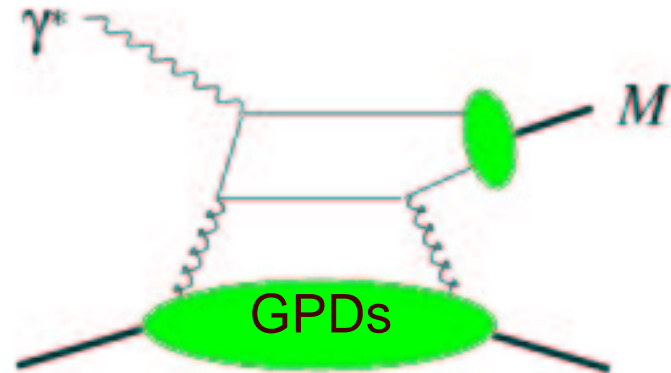
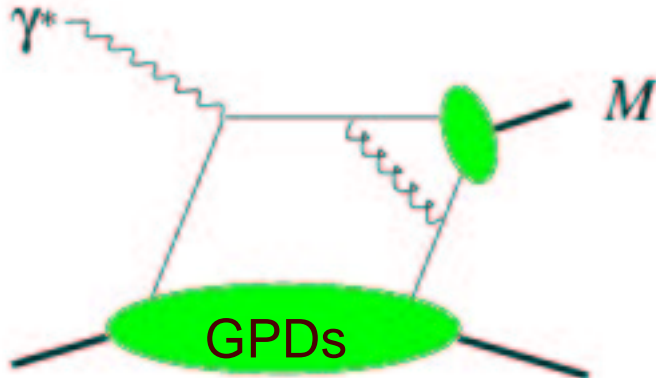
- Define relation between A_{LU} and s_2^I
 - effect of other non-0 moments $\sim 10\%$
 - effect of finite bins $\sim 15-20\%$
- Define background corrections
 - pion contamination $\sim 15\%$
 - ADVCS $\sim 5\%$ at CLAS
 - radiative background

More important when proton is not detected



Meson production in GPD framework

Only longitudinal photons

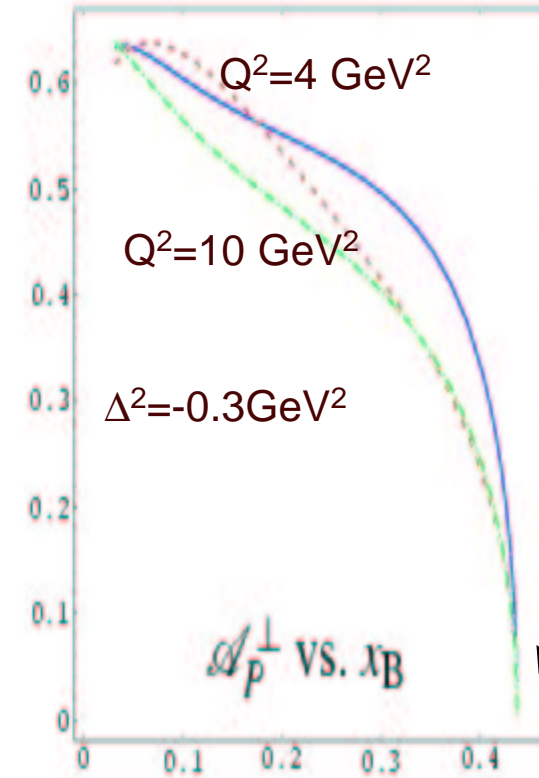
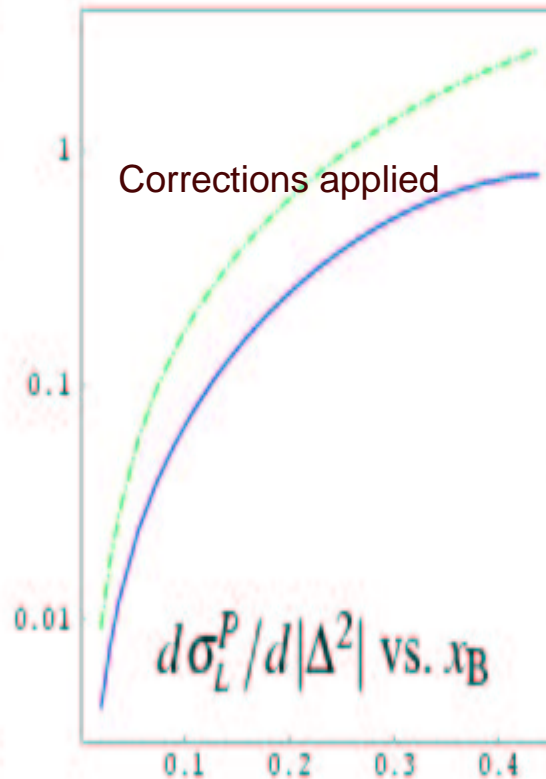
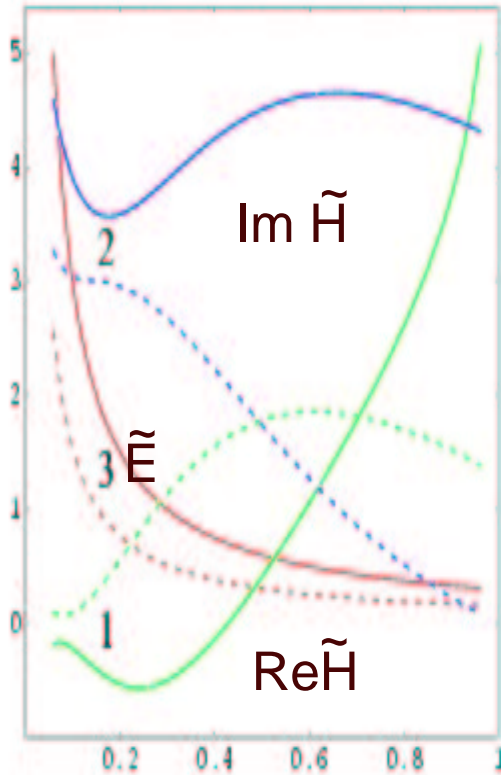


1. Different final state mesons filter out different combinations of unpolarized (H,E) and polarized (\tilde{H}, \tilde{E}) GPDs.
2. Studies at 6-12GeV provide information on how far is the asymptotic regime and guide theory in describing HT.

Meson	GPD flavor composition
π^+	$\Delta u - \Delta d$
π^0	$2\Delta u + \Delta d$
η	$2\Delta u - \Delta d$
ρ^0	$2u + d$
ρ^+	$u - d$
ω	$2u - d$

Hard Exclusive Meson Production(HMP)

Belitsky hep-ph/0307256 ($ep \rightarrow e' \pi + n$)

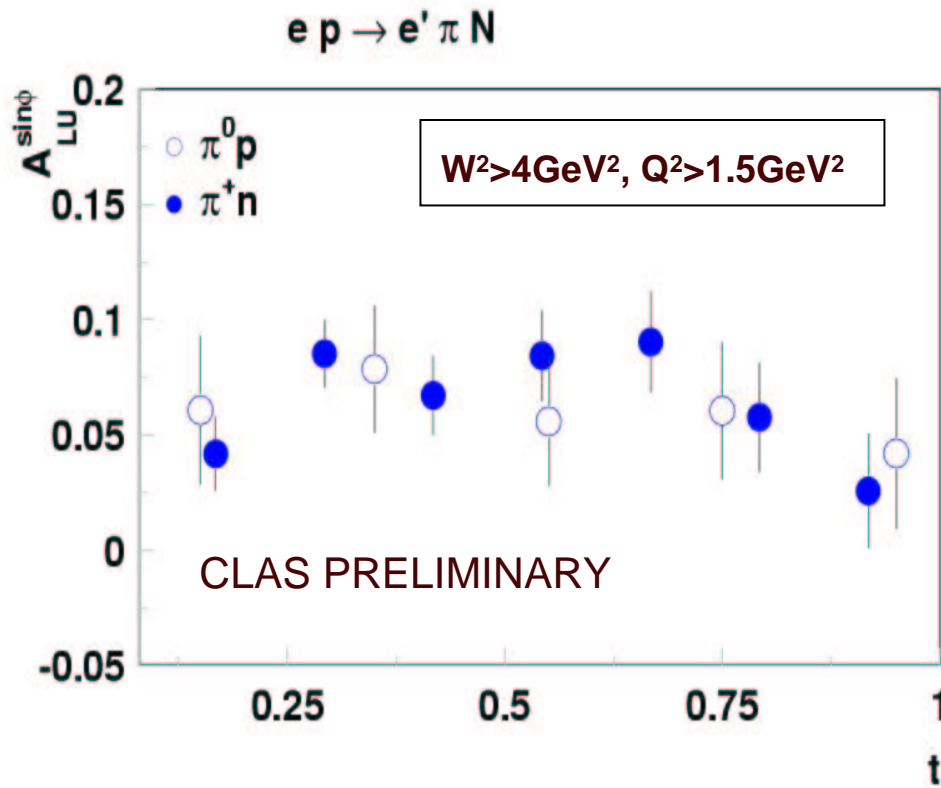


- Only longitudinal cross sections
- Large power correction to cross section

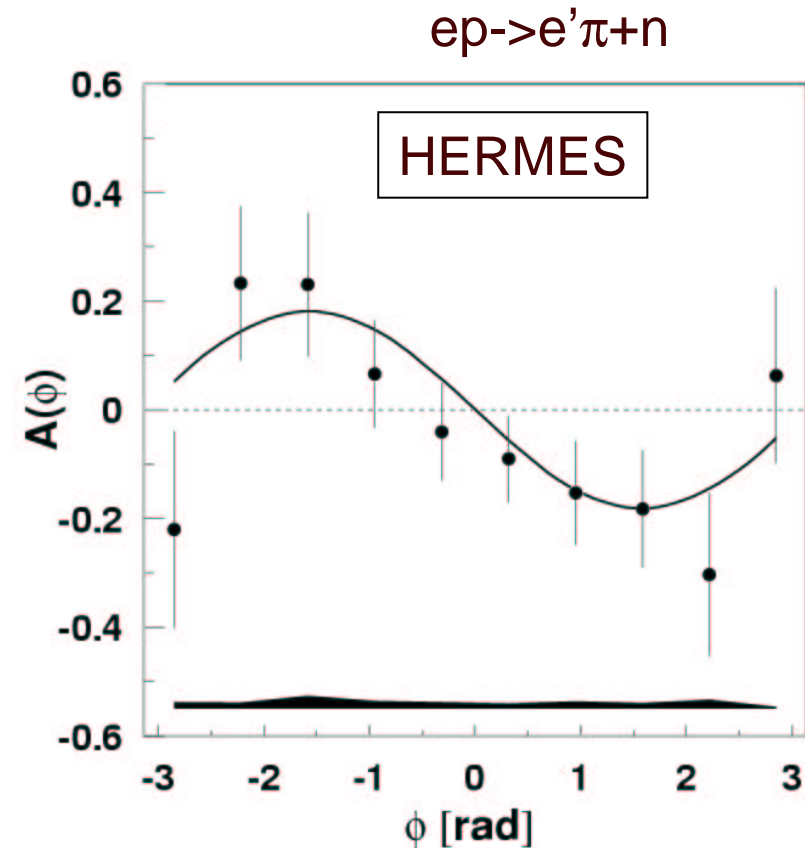
No significant variations in SSA "precocious scaling"

SSA in exclusive pion production

Beam SSA A_{LU} at 6 GeV

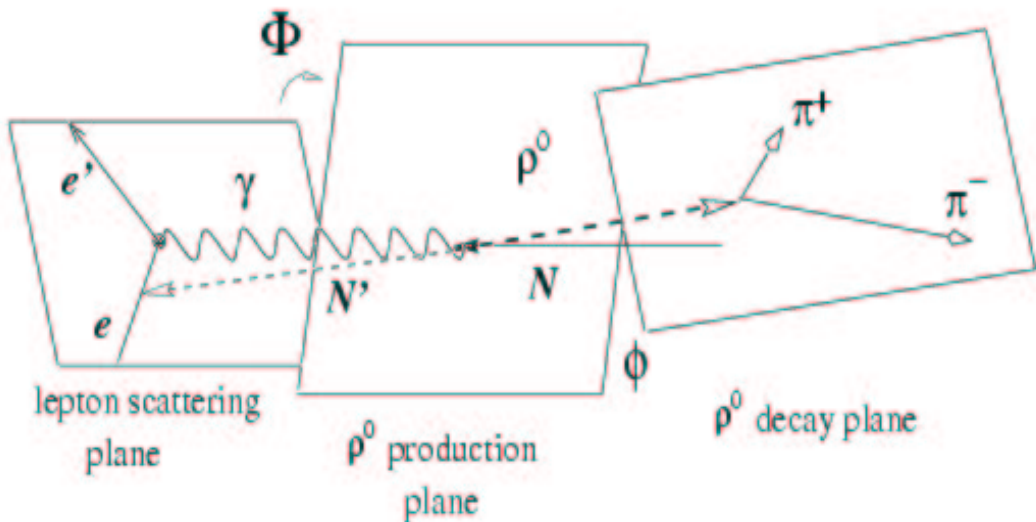


Target SSA at 27.5 GeV

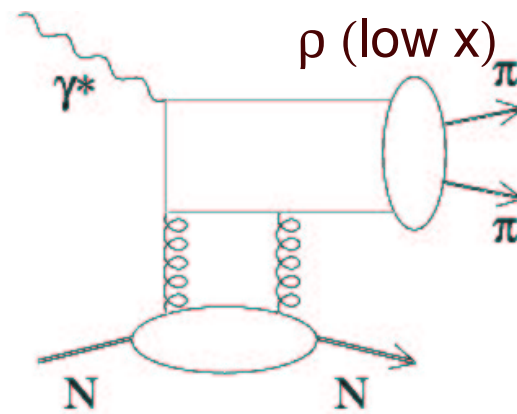
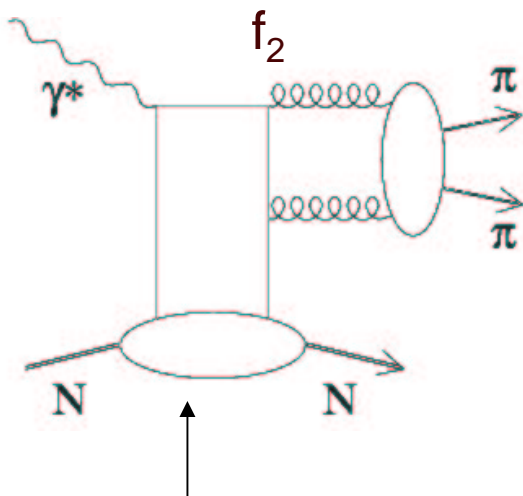
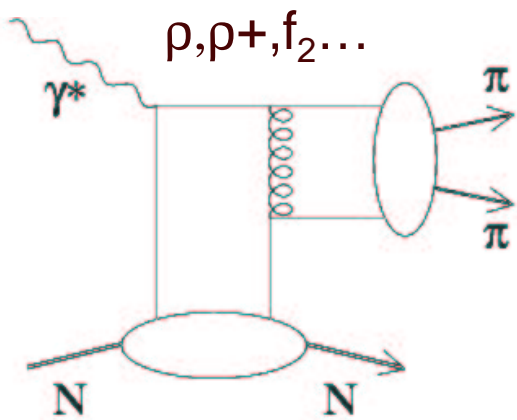
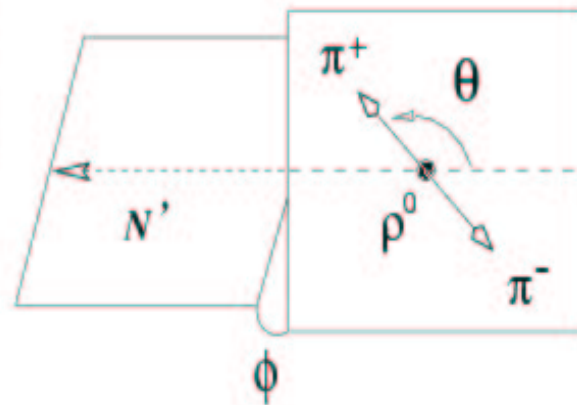


Beam SSA and longitudinally pol. target SSA provide information on HT (0 at leading order)

2 pion electroproduction Kinematics



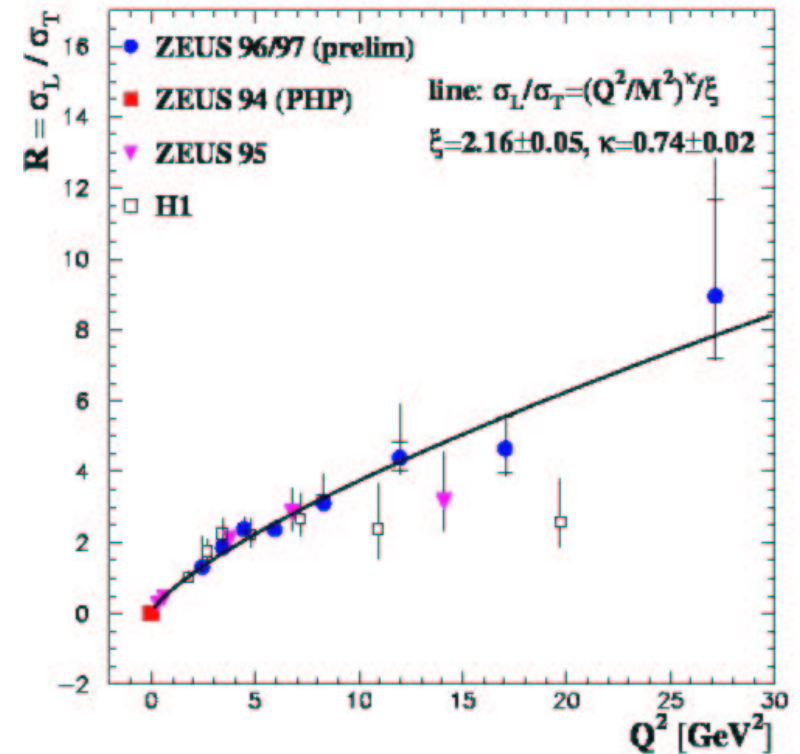
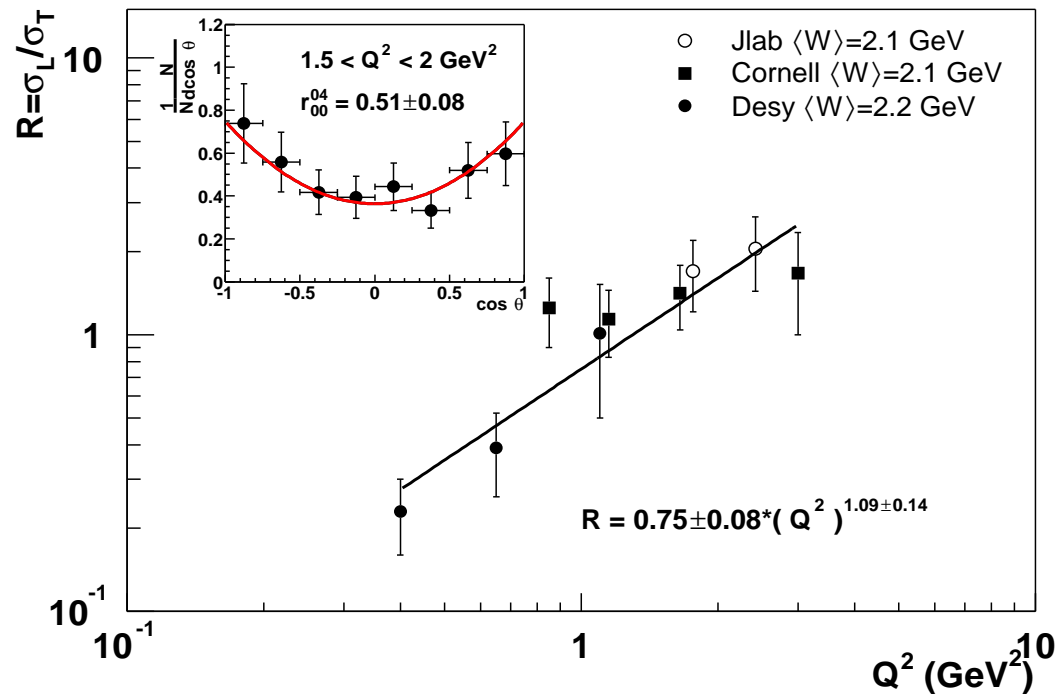
$$t = (p_2 - p_1)^2$$



isoscalar channel accessible in θ distributions of 2 pions (hep-ph/9910310)

Exclusive ρ and L/T ratio

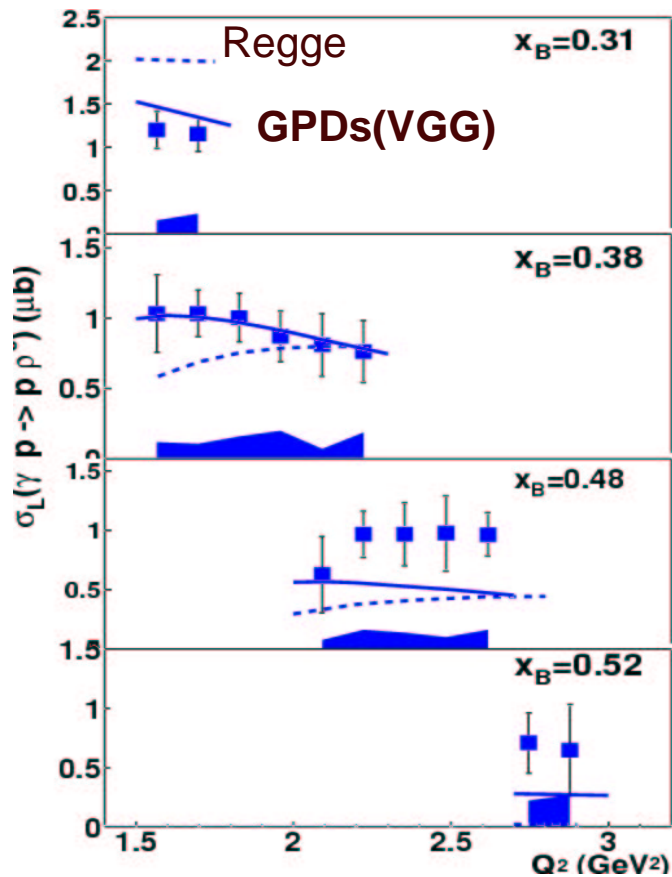
CLAS at 4.3 GeV $e p \rightarrow e p \rho \rightarrow \pi^+ \pi^-$



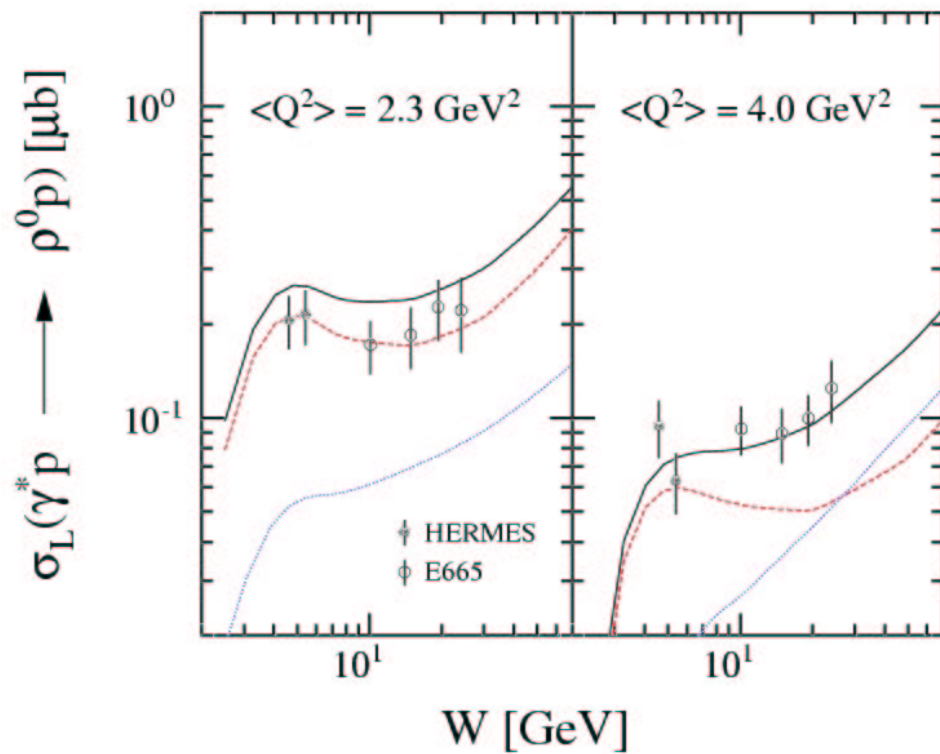
L/T ratio from exclusive ρ data at minimum beam energy where DIS kinematics accessible, is consistent with measurements at higher energies.

Exclusive ρ measurements

CLAS at 4.3 GeV $W > 1.75 \text{ GeV}$

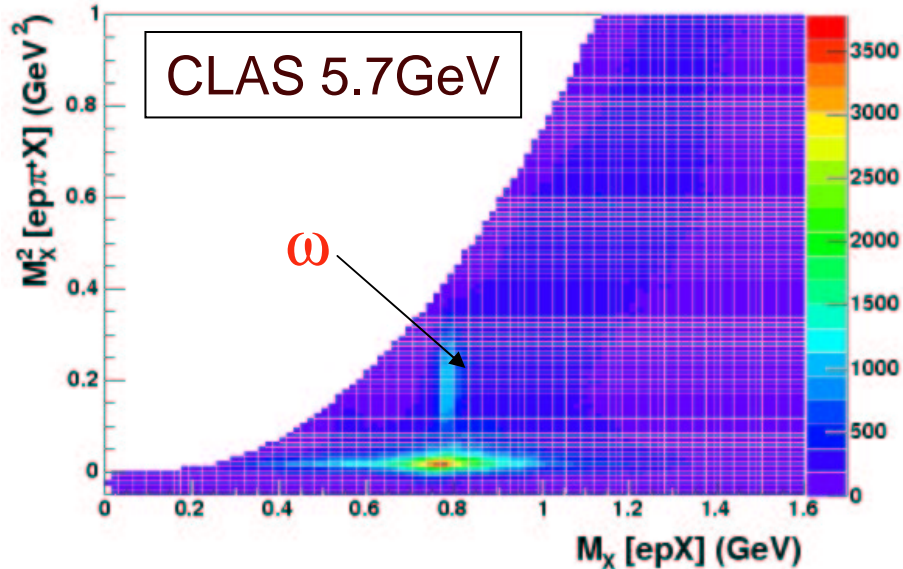


HERMES at 27.5 GeV $W > 2 \text{ GeV}$



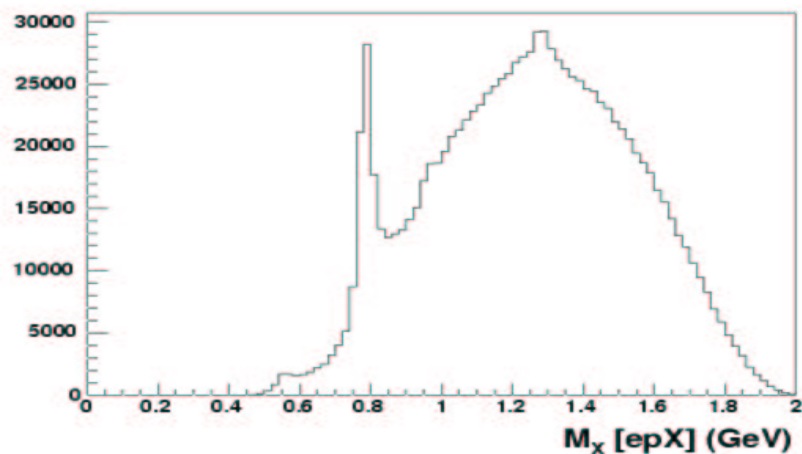
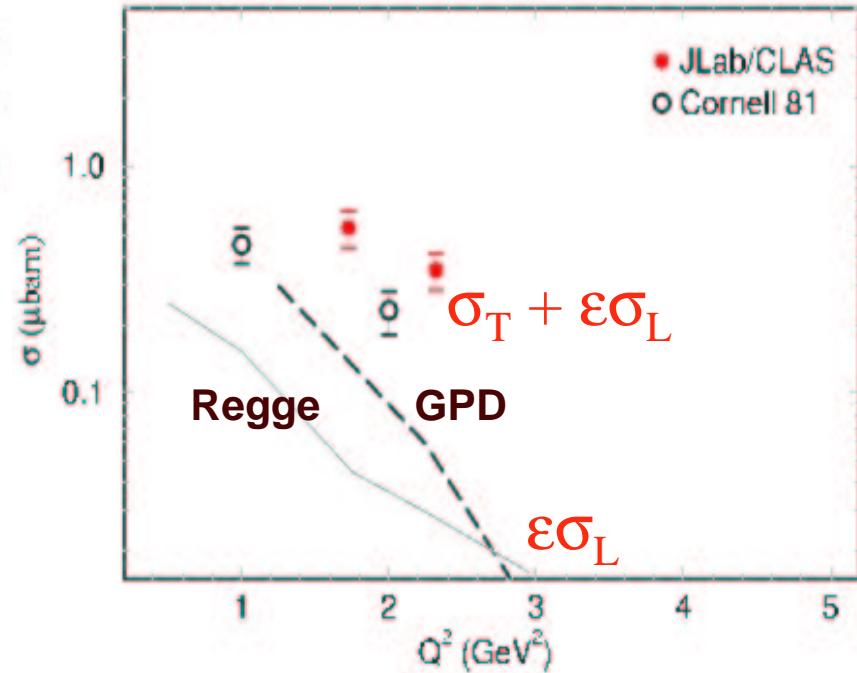
Decent description in pQCD framework
already at moderate Q^2

Exclusive ω production



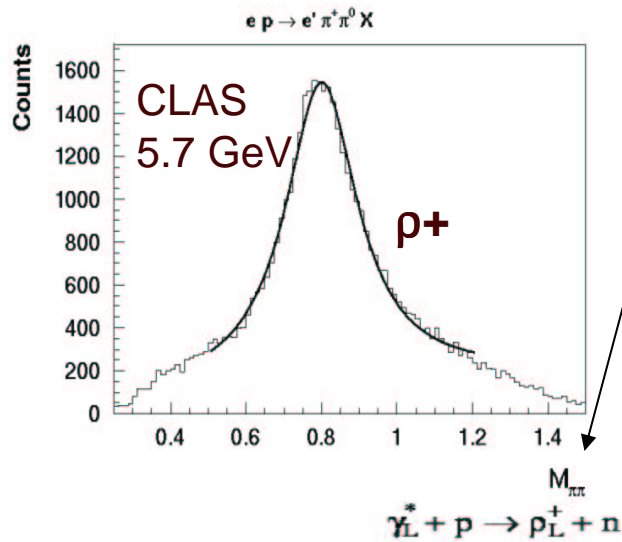
$\omega \rightarrow \pi^+ \pi^- \pi^0$ ($M = 783$ MeV, $\Gamma = 8$ MeV)
 $\rho^0 \rightarrow \pi^+ \pi^-$ ($M = 770$ MeV, $\Gamma = 151$ MeV)

$\langle W \rangle = 2.8$ GeV

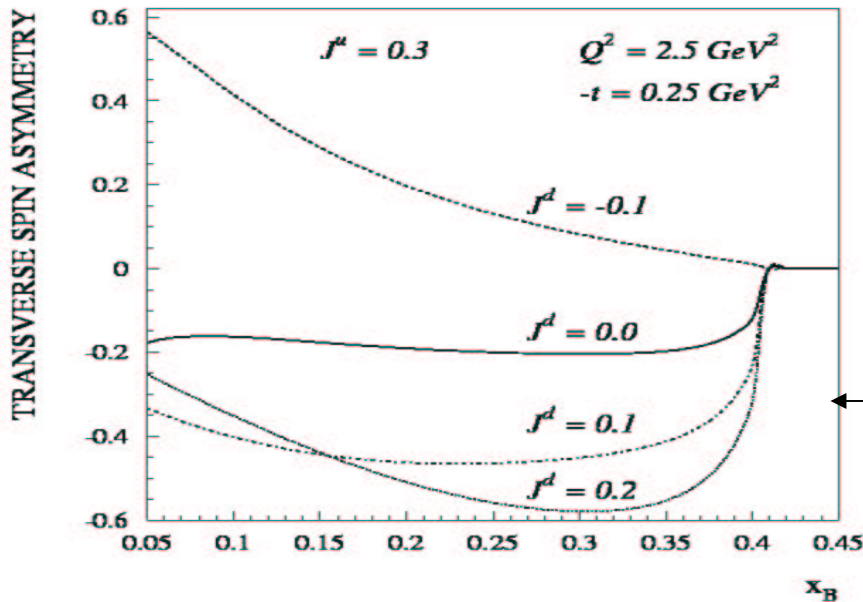
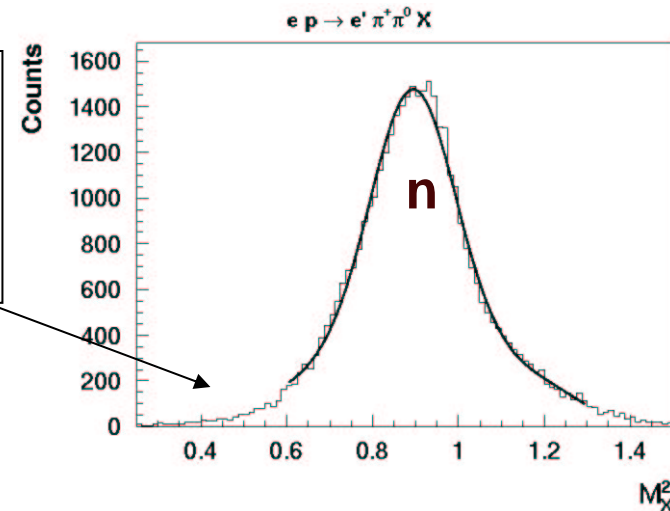


Handbag dominance for ω
 require higher Q^2 and W

Exclusive ρ^+ production



Exclusive ρ^+ and n separated by invariant and missing masses.



Provide access to different combinations of orbital momentum contributions J^u, J^d

$\rho^0 \rightarrow 2J^u + J^d$

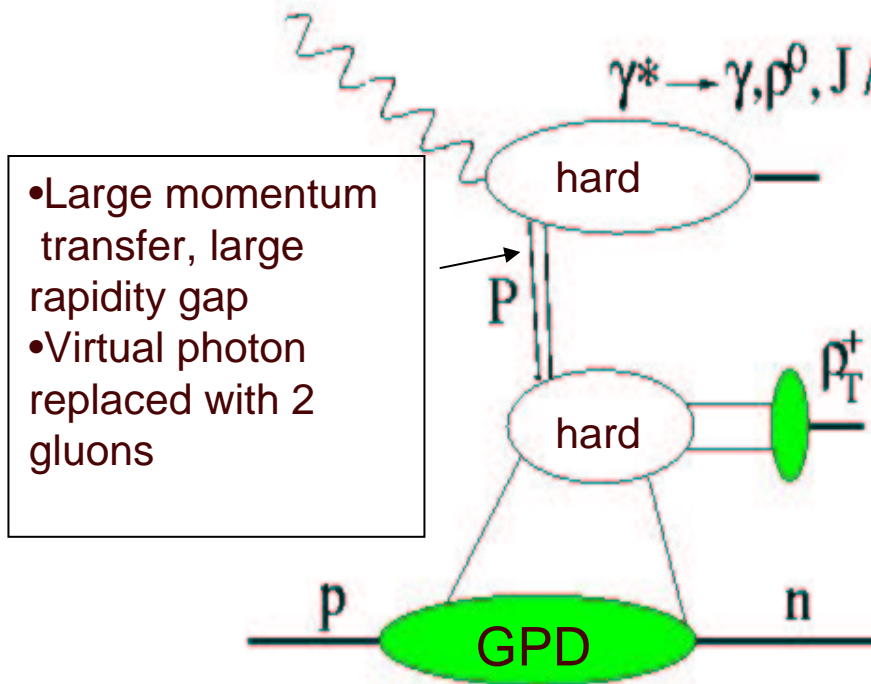
$\rho^+ \rightarrow J^u - J^d$

$\omega \rightarrow 2J^u - J^d$

• Significant transverse target SSA predicted for exclusive ρ^0, ρ^+ (Goeke et al hep-ph/0106012)

Transversity GPDs with exclusive ρ, ρ^+

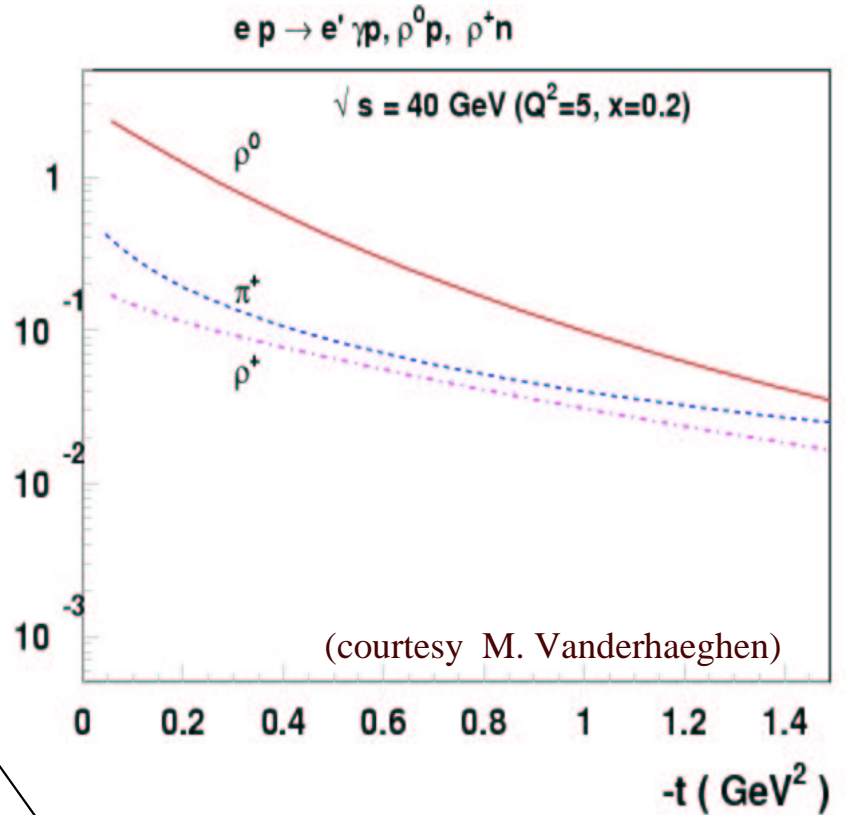
$$\gamma^* N \rightarrow \rho_L^0 \rho_T^+ N'$$



Long distance part described by GPD H_T

Ivanov et al. hep-ph/0401157

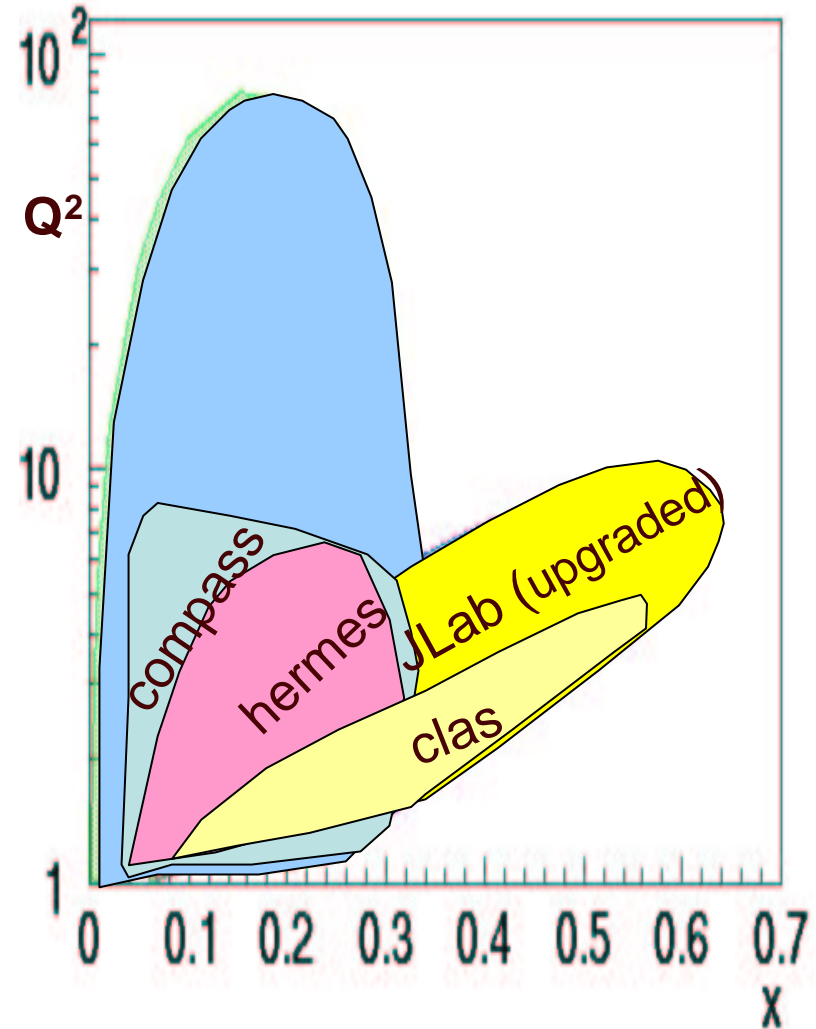
$d\sigma / dQ^2 dy dt$ (nb/GeV⁴)



Smaller rapidity gap
 ρ^+ selects quark antiquark exchange with the nucleon.

Summary

- Exclusive γ and ρ production provided first glimpses of GPDs at moderate energies.
- Global analysis of different exclusive reactions in hard scattering will allow separation and flavor decomposition of different parton distribution functions.
- Collider measurements, requiring high luminosity ($L \sim 10^{35} \text{cm}^{-2} \text{sec}^{-1}$), and wide coverage, will vastly increase the kinematics and the scope of observables providing access to essentially unexplored parton distributions.



DVCS A_{LU} extracted from MC (ep->e'p'[γ])

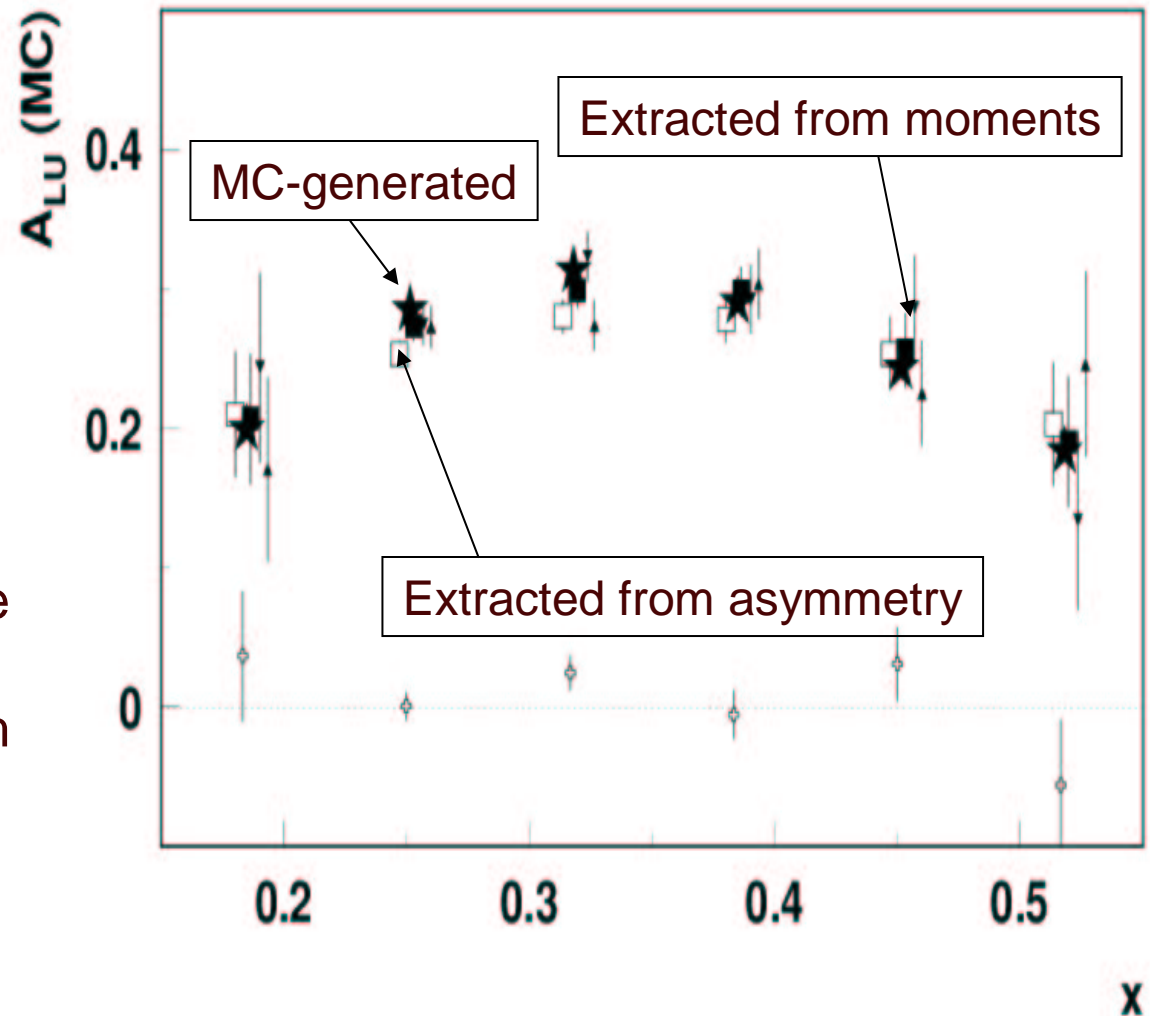
$$y < y_{col} \approx 1 + (1-x) \frac{t}{Q^2}$$

$$-t < 0.5$$

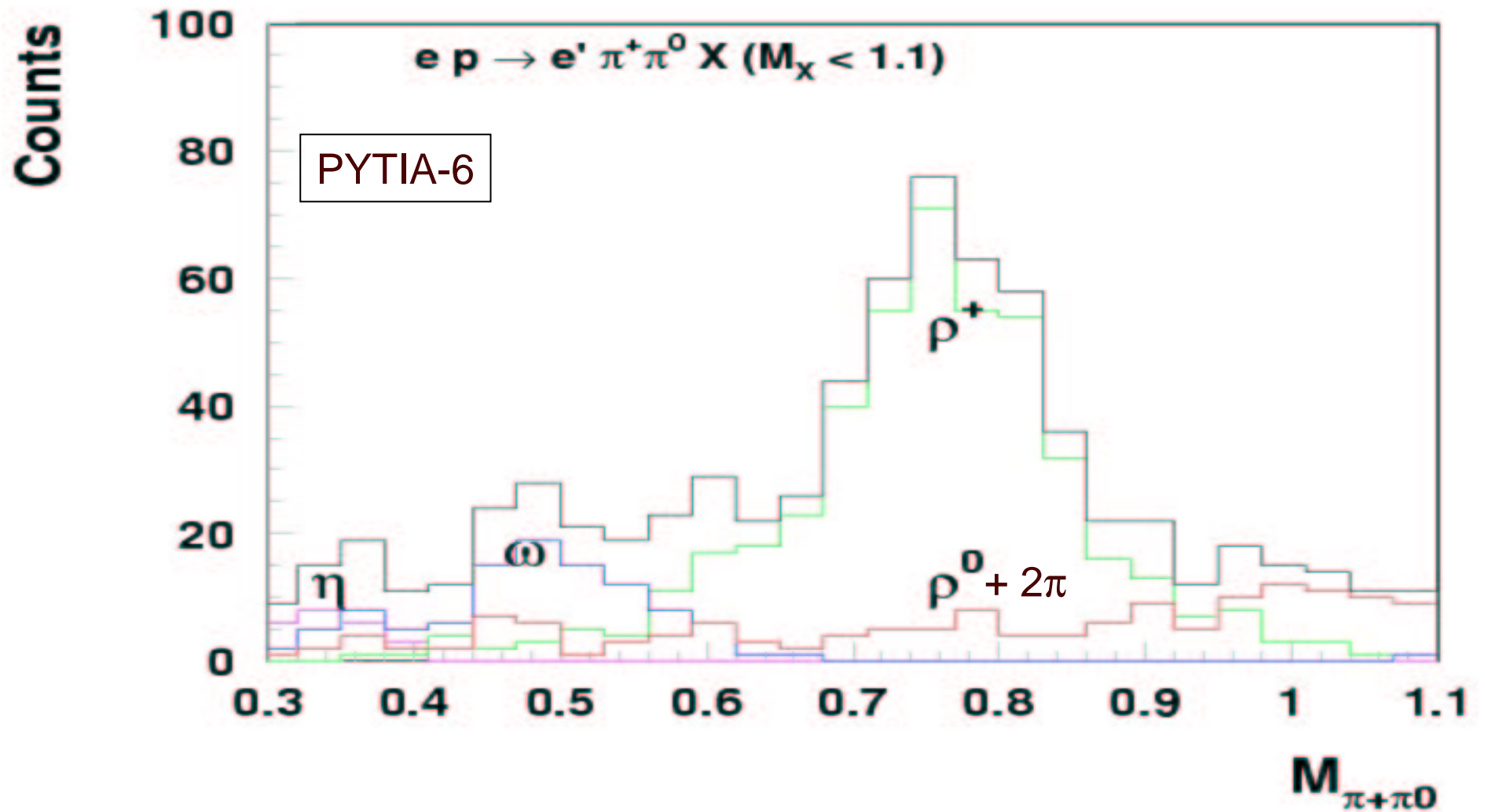
$$W^2 > 4\text{GeV}^2$$

$$Q^2 > 2\text{GeV}^2$$

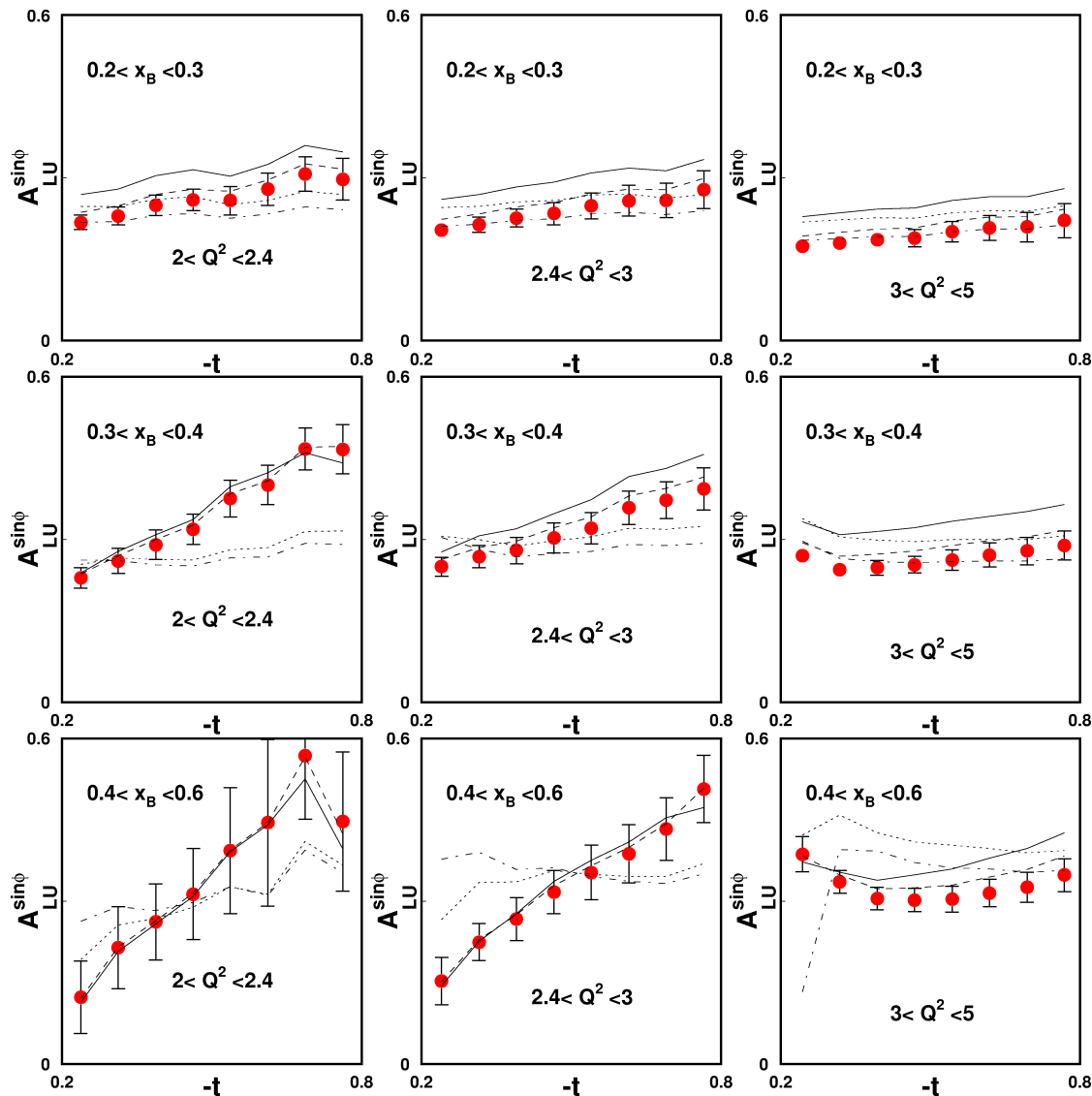
In the kinematics where the lepton propagator $P_1(\phi)$ is not changing rapidly both method recover the DVCS asymmetry within $\sim 10\%$



Exclusive ρ^+ at 6 GeV



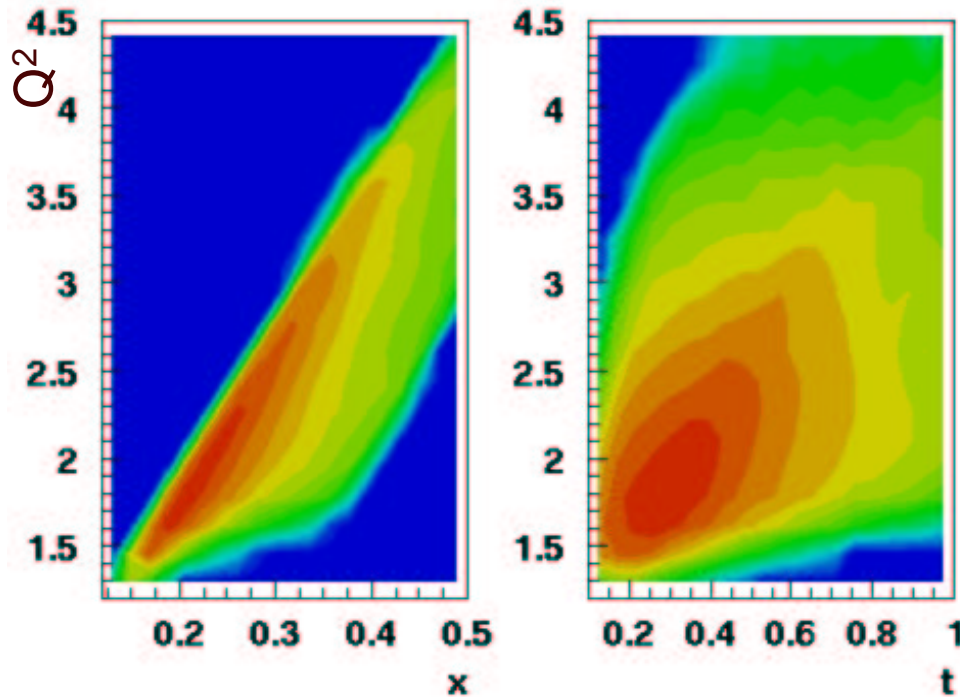
DVCS with polarized beam with CLAS⁺⁺ at 11 GeV



Q^2, x_B, t ranges measured simultaneously.

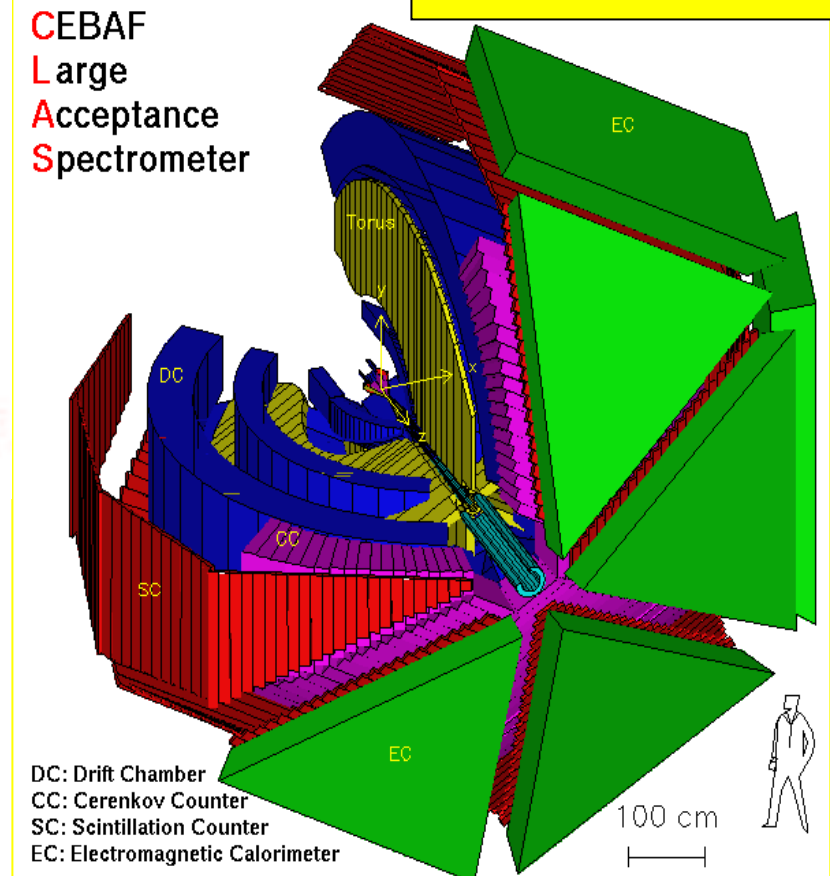
$A(Q^2, x_B, t)$
 $\Delta\sigma(Q^2, x_B, t)$
 $\sigma(Q^2, x_B, t)$

The CLAS Detector

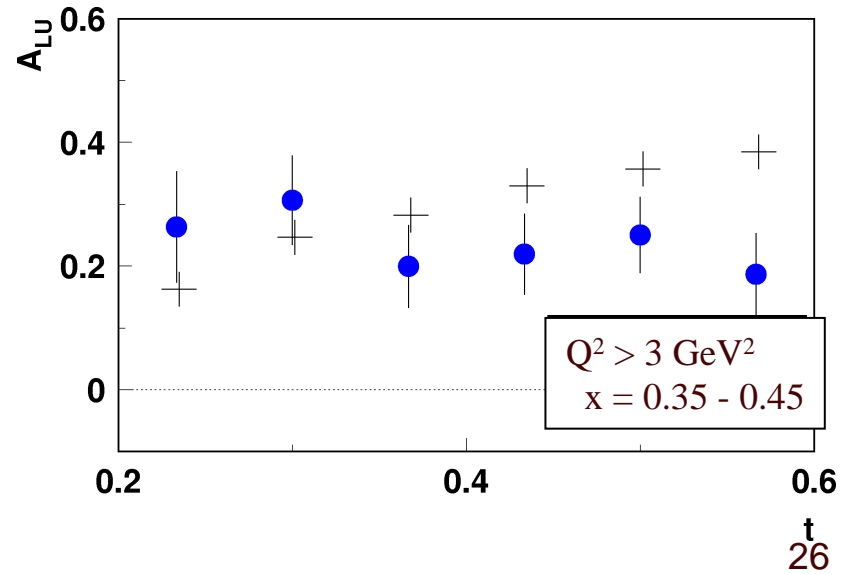
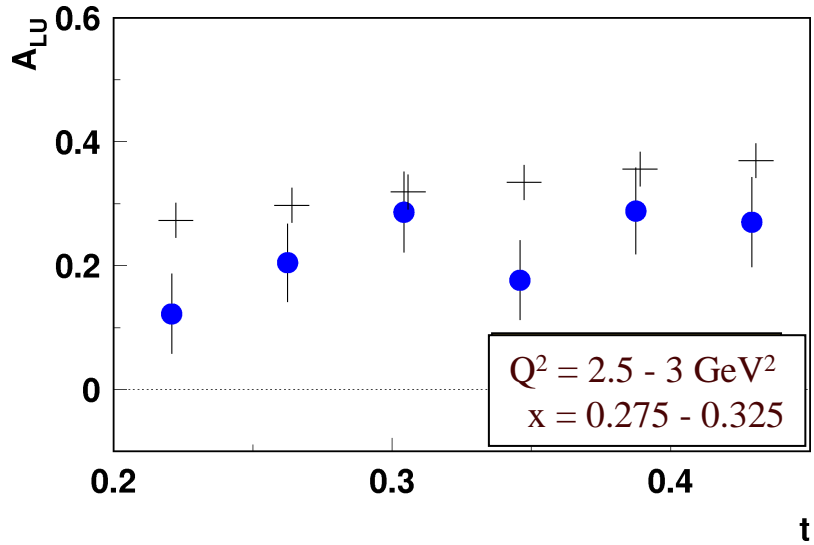
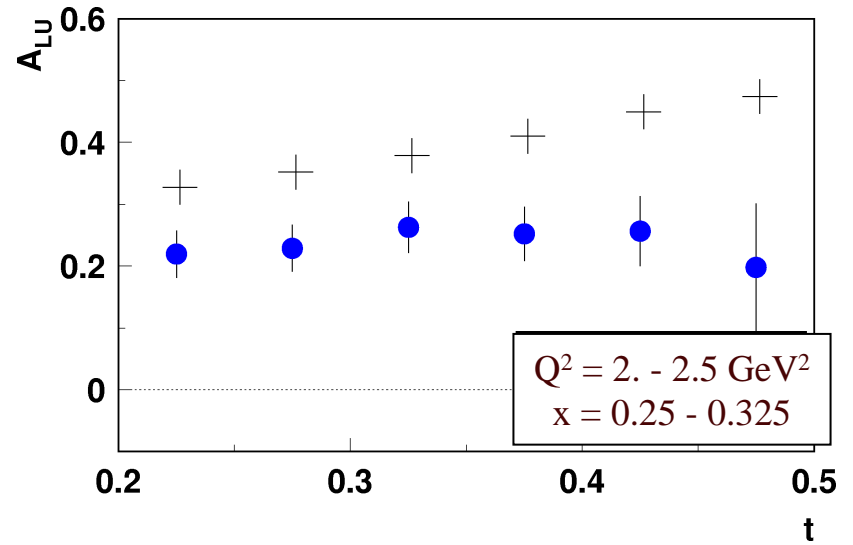
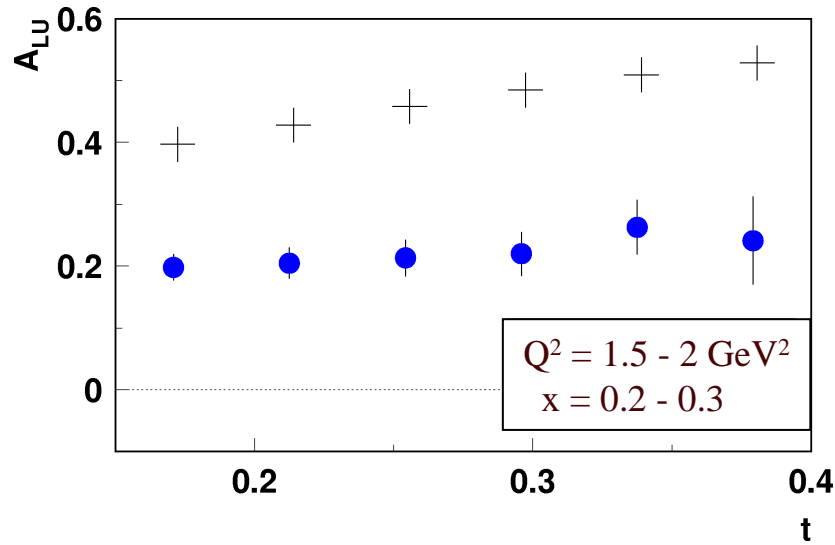


- ◆ high luminosity, wide coverage
- ◆ charged particles:
 - ◆ $p > 0.2 \text{ GeV}/c$
 - ◆ $8^\circ < \theta < 140^\circ$
 - ◆ $\sigma_p/p \sim 0.5\%$ ($\theta < 30^\circ$)
 - ◆ $\sigma_p/p \sim 1-2\%$ ($\theta > 30^\circ$)
 - ◆ $\sigma_\theta = 1 \text{ mrad}, \sigma_\phi = 4 \text{ mrad}$

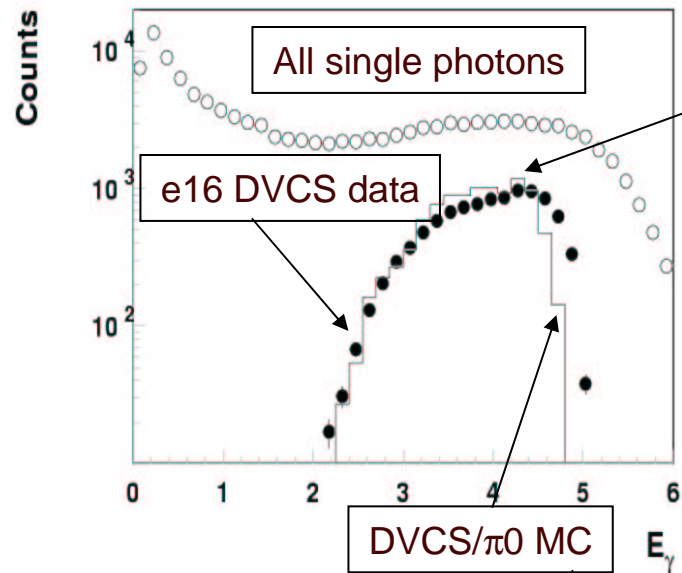
~ 200 physicists
37 institutions



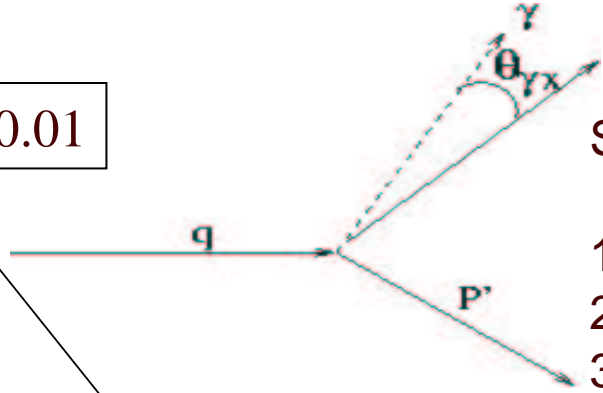
DVCS SSA kinematic dependences at 5.7 GeV



DVCS MC: separating DVCS photons

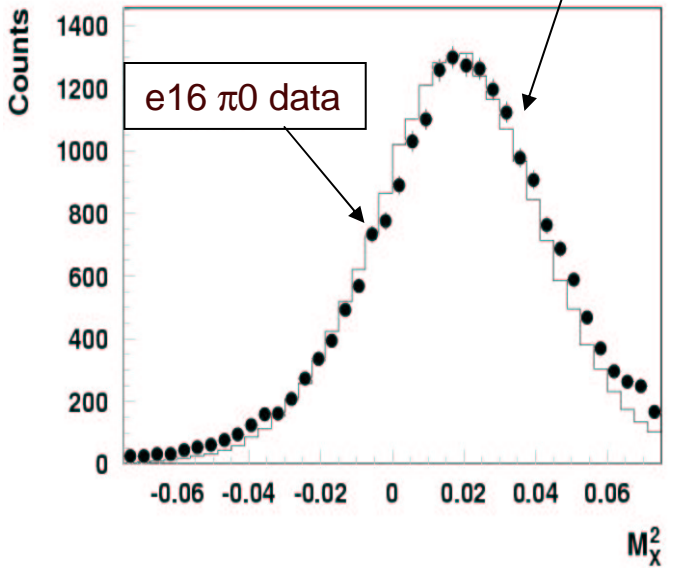


$\theta_{\gamma X} < 0.01$

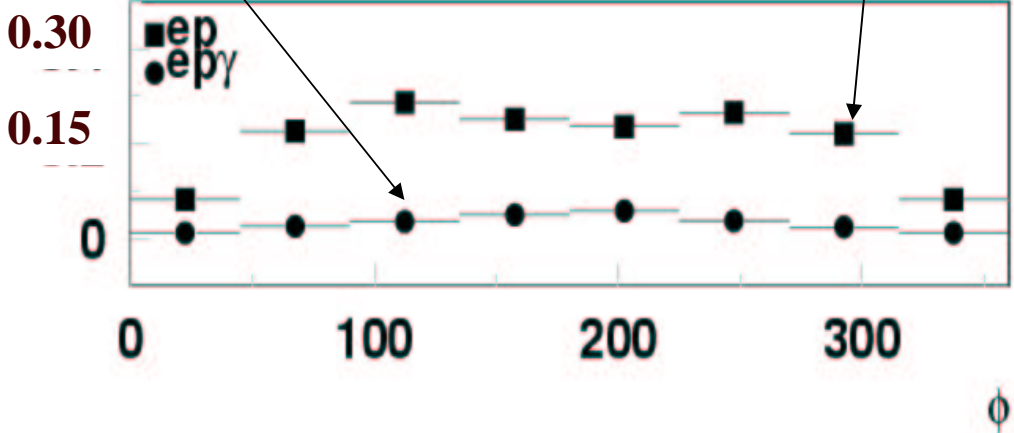


Samples:

- 1) ep (no γ in CLAS)
- 2) ep γ (exc.)
- 3) ep π^0 (exc.)



π^0/γ



π^0 contribution small and under control