Hard exclusive processes at JLab

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Jefferson Lab

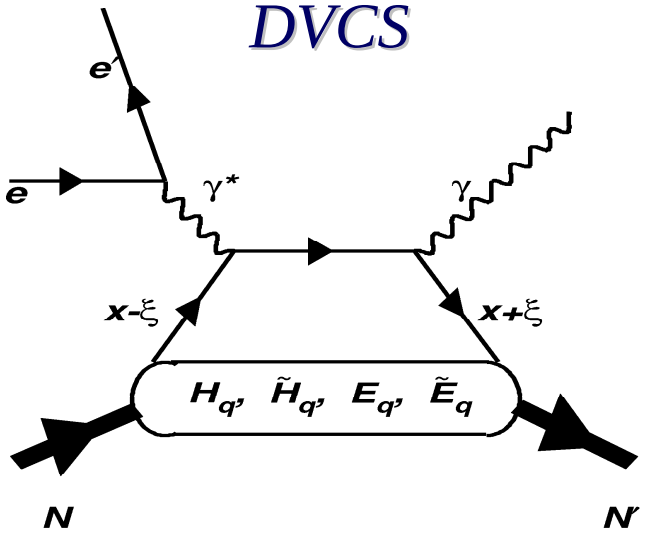
Workshop on Future Prospects in QCD at High Energy, July 20, 2006

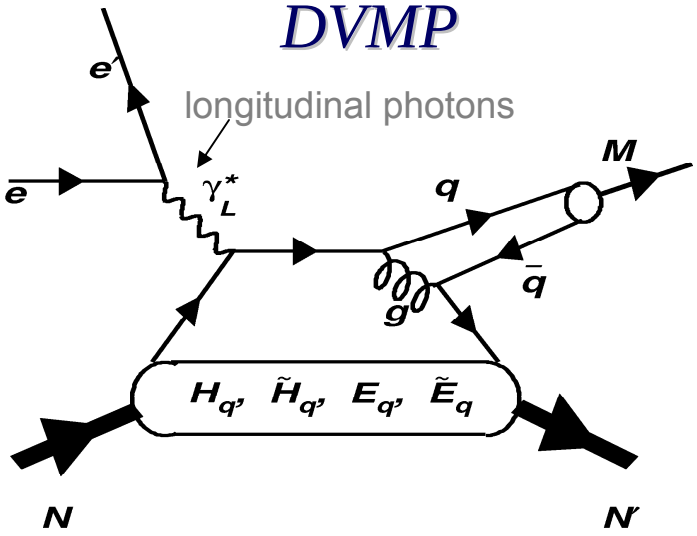
- Introduction
- Exclusive processes
  - Photons (DVCS)
  - Pseudoscalar mesons
  - Vector mesons
  - Lambda production
  - JLab at 12 GeV
- Summary

* In collaboration with V.Burkert and L.Elouadrhiri

Physics Motivation

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





DVCS – for different polarizations of beam and target provide access to different combinations of GPDs H, $\tilde{H}$, E

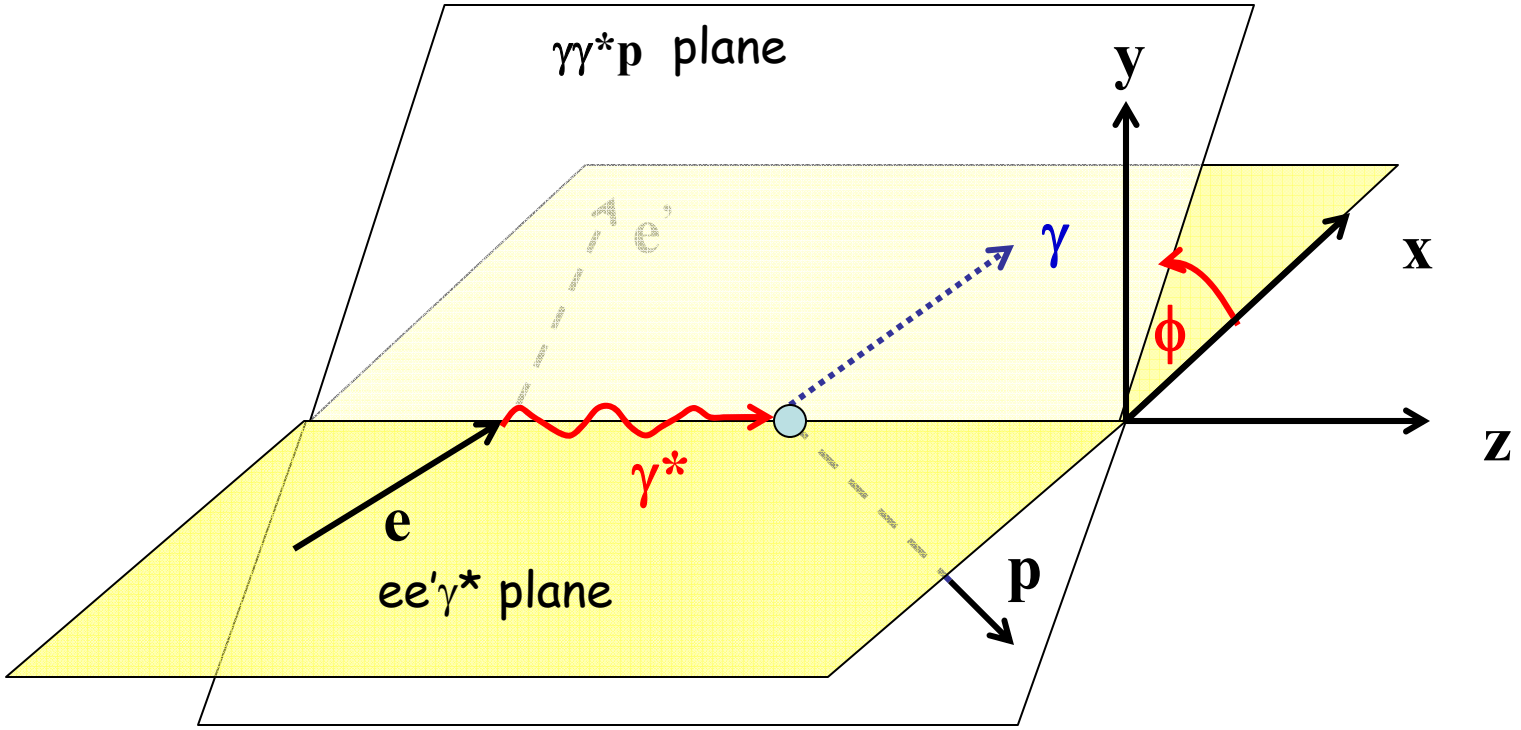
DVMP for different mesons is sensitive to flavor contributions (ρ^0/ρ^+ select H, $\tilde{H}$, E, for u/d flavors, π, η, K select $\tilde{H}$, E)

Study the asymptotic regime and guide theory in describing HT.

Deeply Virtual Compton Scattering

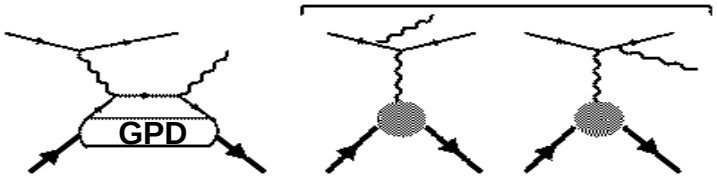
$ep \longrightarrow ep\gamma$

Kinematics

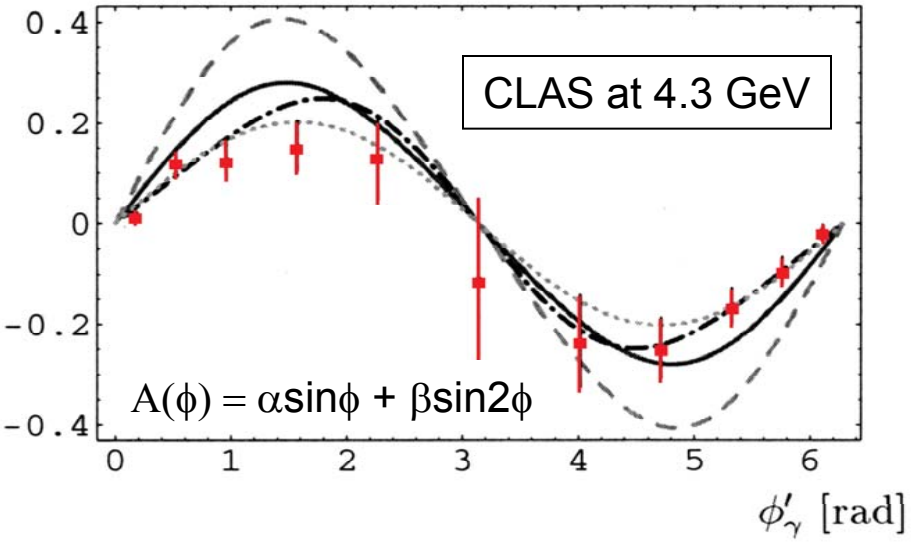


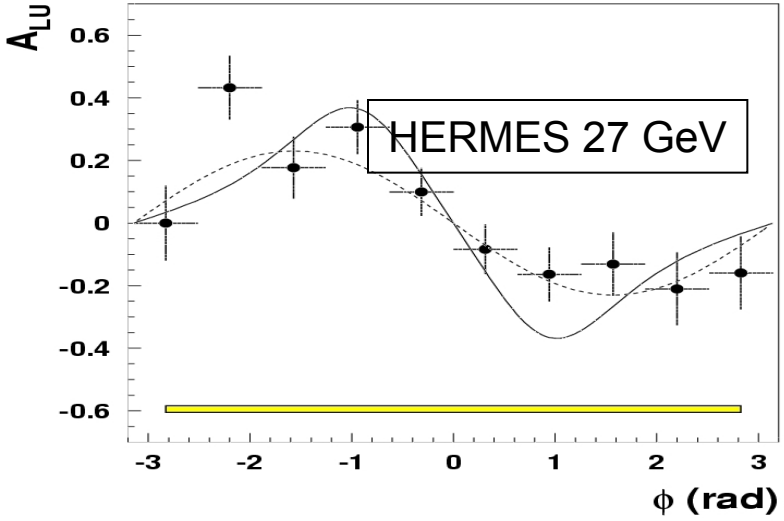
Asymmetry in DVCS Experiments

$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi} \sim |T^{DVCS} + T^{BH}|^2$$



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

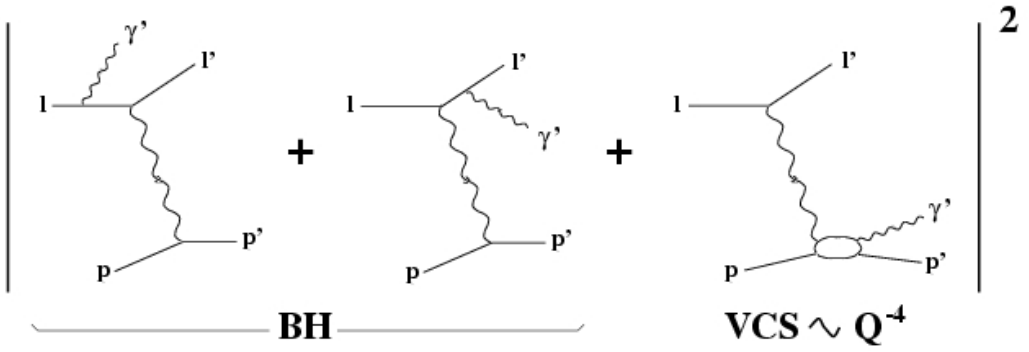




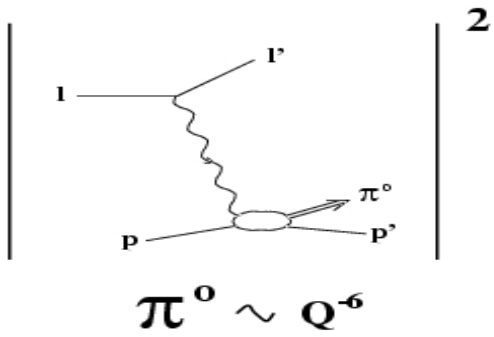
S. Stepanyan et al. Phys. Rev. Lett. **87** (2001)

A. Airapetian et al. Phys. Rev. Lett. **87** (2001)

GPDs from ep->e'p'γ



Requirements for precision (<15%) measurements of GPDs from DVCS SSA:

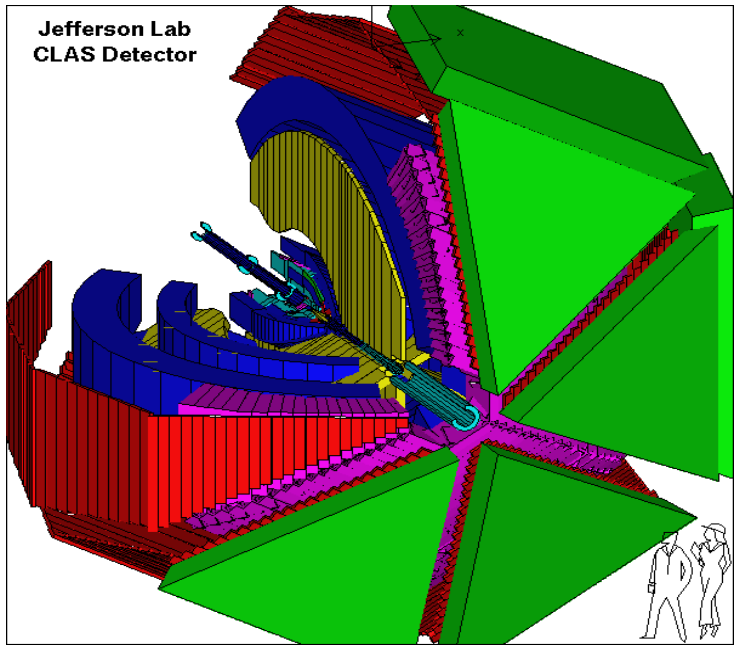


- Define the procedure to extract GPDs from A_{LU}
  - effect of finite bins (prefactor variations) ~10%
  - other moments
- Define background corrections
  - pion contamination ~10%
  - radiative background, ADVCS

A complete MC simulation of the whole chain:

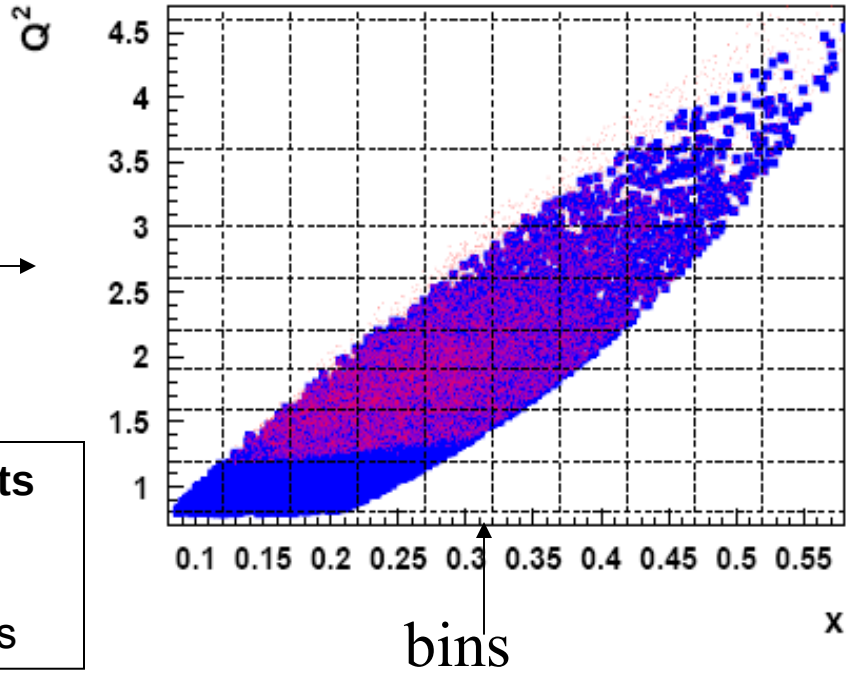
1. Generator (signal+background)
2. Detector response (GEANT)
3. Extraction of GPDs from measured exclusive events (cleaned from background)

CEBAF Large Acceptance Spectrometer



Kinematic coverage of 5.75 GeV(red) and 5.48(blue) CLAS data sets

- High luminosity, polarized CW beam.
- Wide physics acceptance, including exclusive, semi-inclusive processes, current and target fragmentation.
- Wide geometric acceptance, allowing detection of multi-particle final states.

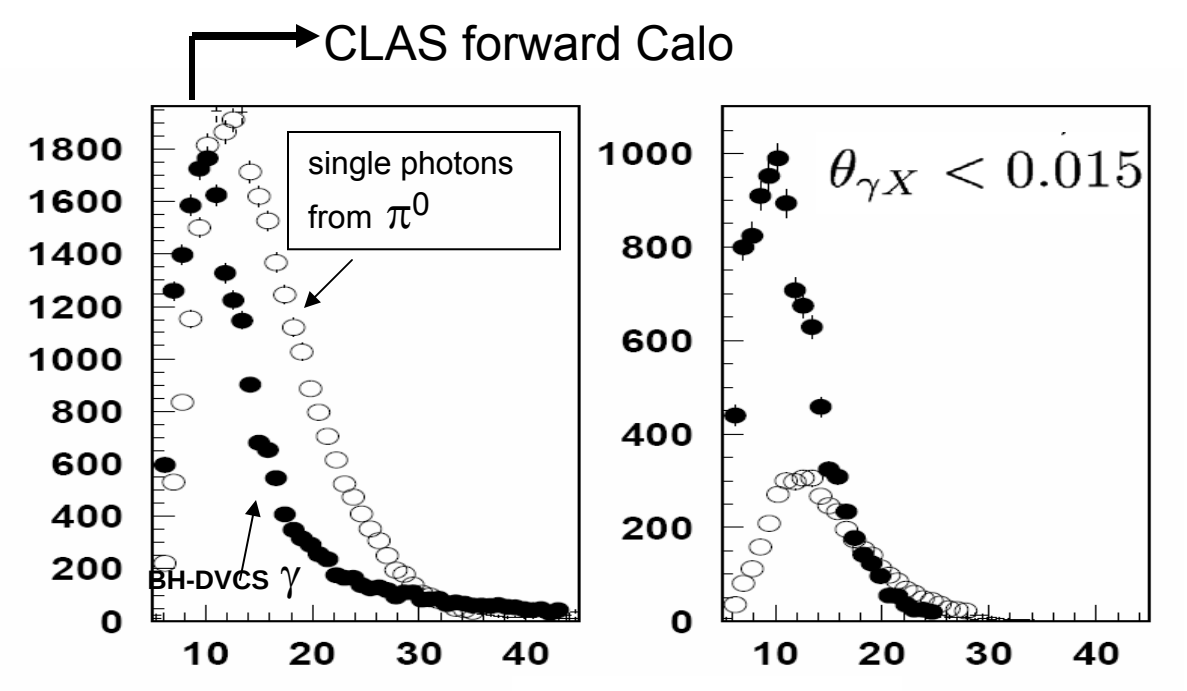


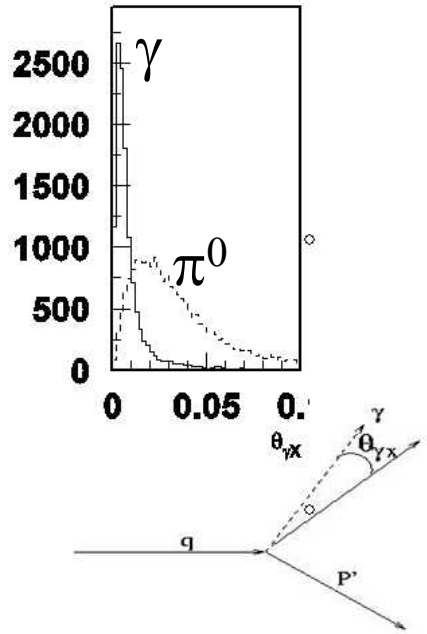
DVCS data sets

1. epγ 1 photon in Calorimeter **~150000 events** + ~500000 from dedicated run.
2. epX 0 photons in CLAS (**~2M events**) tight cuts on PID,missing mass M_X, no other tracks

π^0 contamination of DVCS sample

Use realistic event generators for single γ and π^0 that reproduce the measured yields.

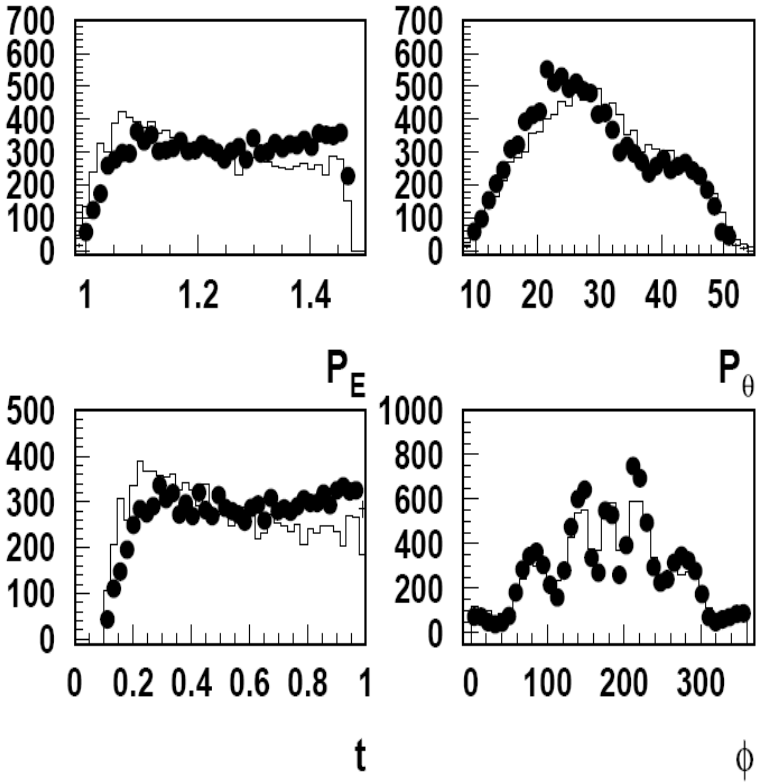


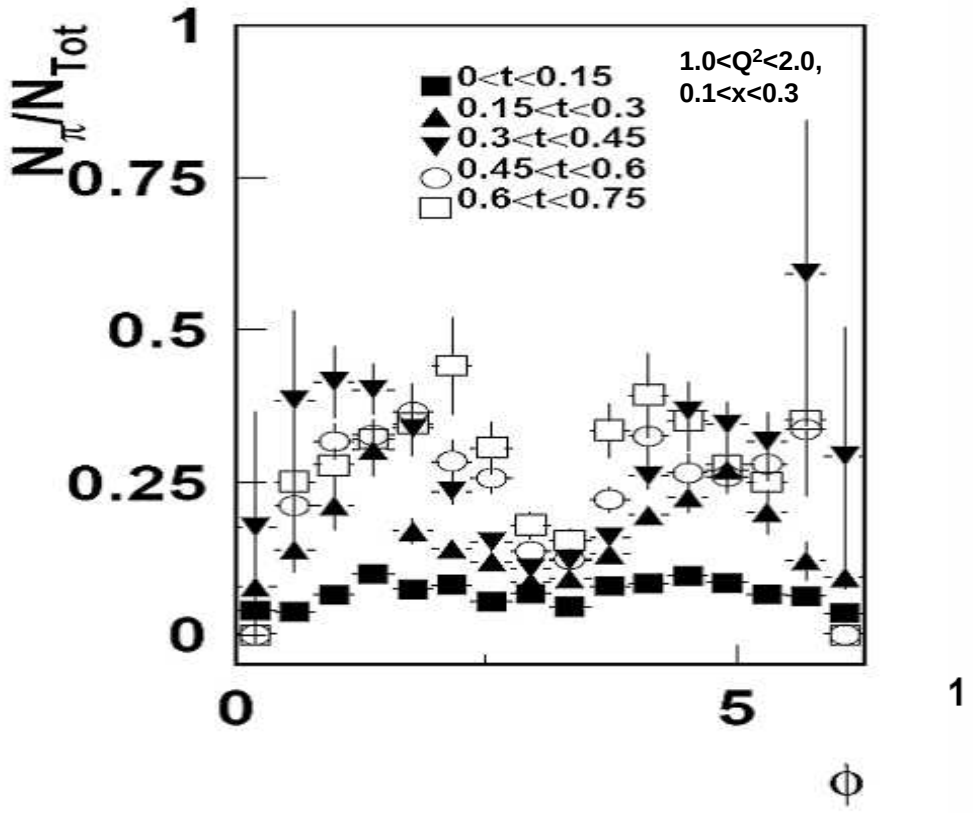


θ (photon lab. angle)

- Cut on the direction of the measured photon significantly reduces the π^0 contamination.
- Contamination strongly dependent on kinematics, and π^0 contribution must be subtracted bin by bin.

π^0 MC vs Data





- Exclusive π^0 production simulated using a realistic MC (PDF based)
- Kinematics distributions in x,Q^2 and t tuned to describe the CLAS data (b=1)
- Define contribution to the single photon sample from π^0

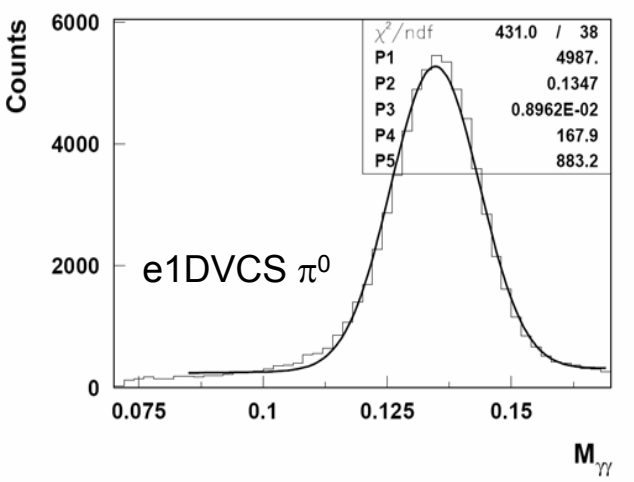
$$N_\gamma^{Data}(\pi^0) = N_{\pi^0}^{Data}\frac{N_\gamma^{MC}(\pi^0)}{N_{\pi^0}^{MC}},$$

π^0 - Beam cross section asymmetry

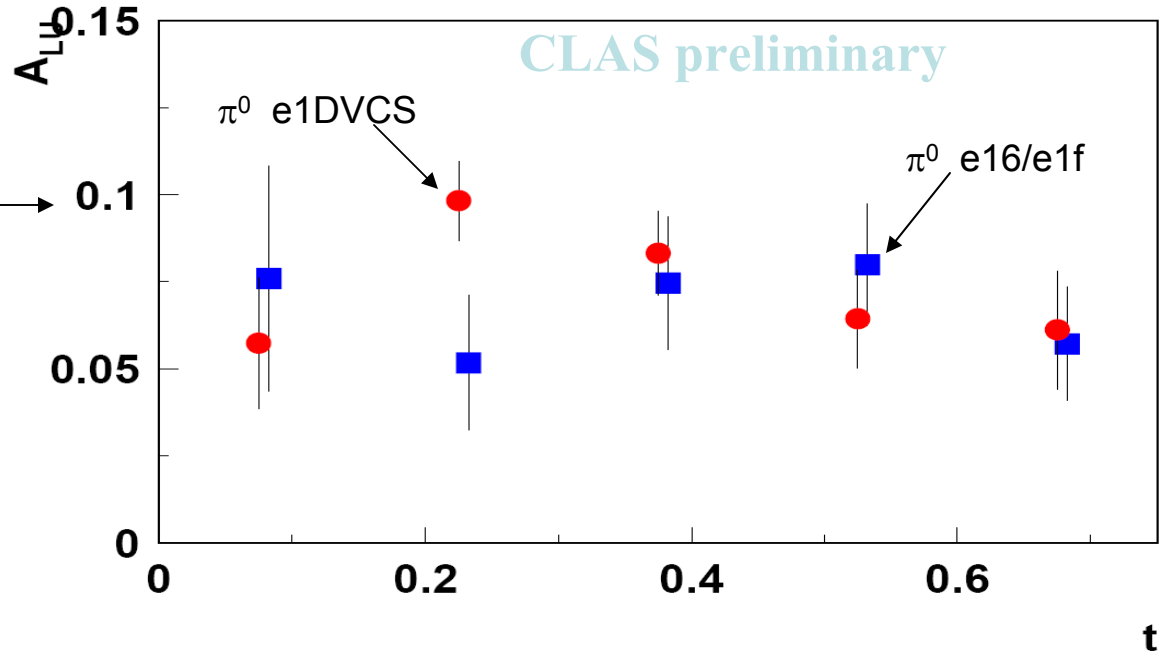
Main unknown in corrections of DVCS SSA is the π^0 beam SSA.

- Use **ep$\gamma\gamma$(π^0)** to estimate the contribution of π^0 in the **epγ** sample.

~150000 exclusive π^0s →

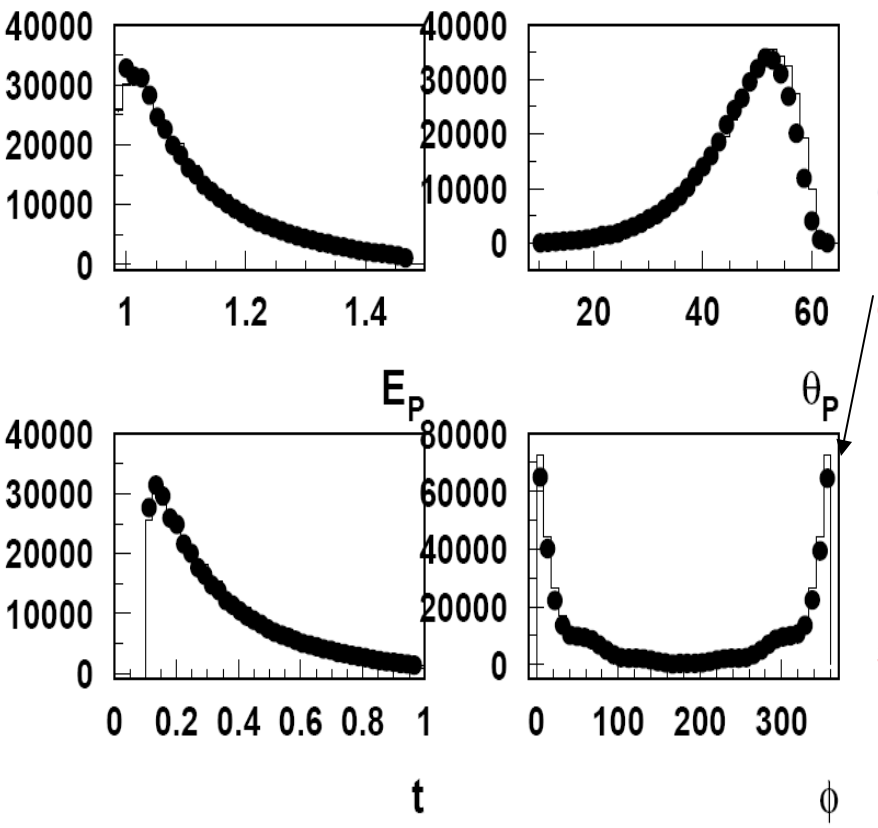


ep → epπ^0



→ π^0 Asymmetry is ~ 1/3 of DVCS-BH asymmetry!

γ MC vs Data



Region where BH totally dominates (small t, small photon θ_{LAB})

- Negligible DVCS x-section, small π^0 contamination
- Rapidly changing prefactors, mainly small ϕ, hard to detect photons

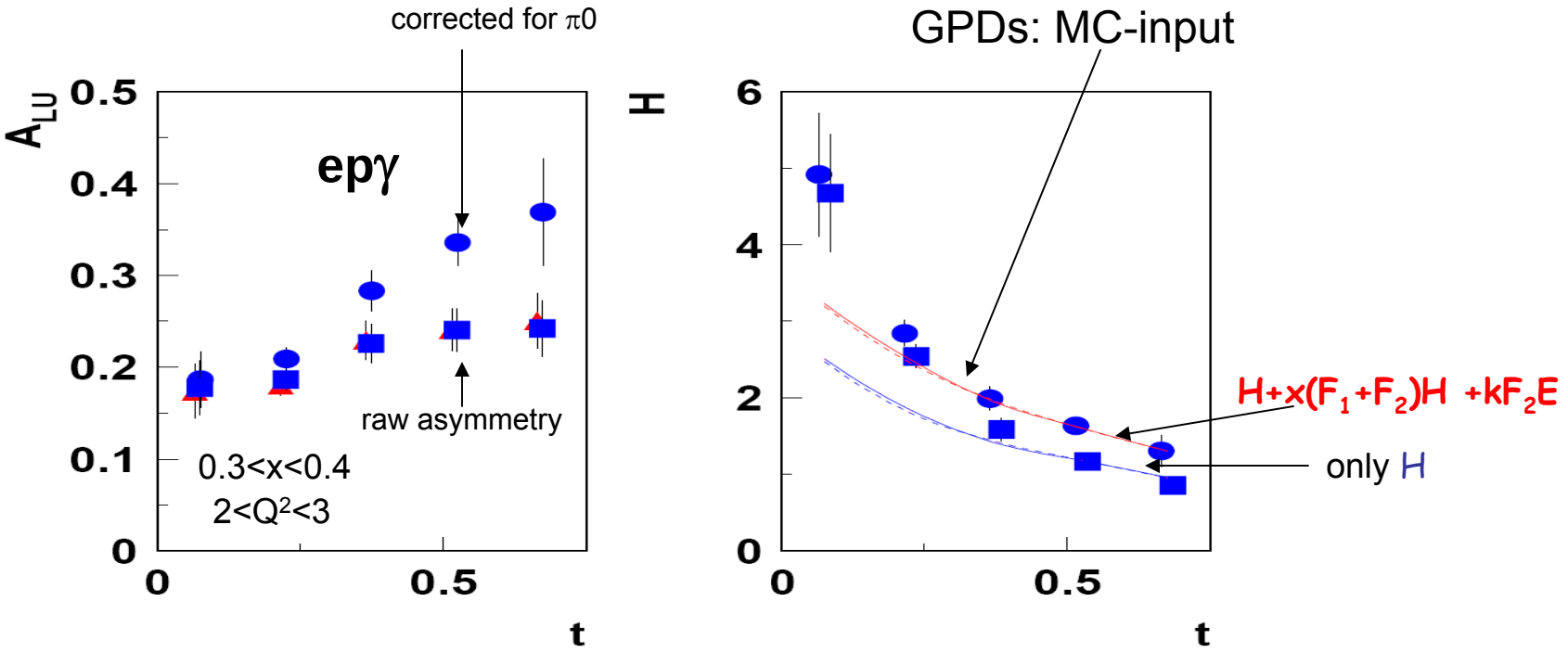
Large angles

- Uniform coverage in angle ϕ, photon measurement less challenging
- DVCS x-section non negligible introduce some model dependence)
- π^0 dominates the single photon sample (in particular at low Q^2 and large t)

- MC Kinematic distributions in x,Q^2,t consistent with the CLAS data

GPD extraction from Beam SSA:MC

$$A_{LU}(\phi) \approx c_{LU} \sin\phi \left\{ \mathcal{H} + \xi\left(1 + \frac{F_2}{F_1}\right)\widetilde{\mathcal{H}} + \frac{t}{4M^2}\frac{F_2}{F_1}\mathcal{E} \right\}, \; c_{LU} \approx \frac{8xK(x,t,Q^2)(2-y)(1+\epsilon^2)^2 F_1}{c_0^{BH}},$$

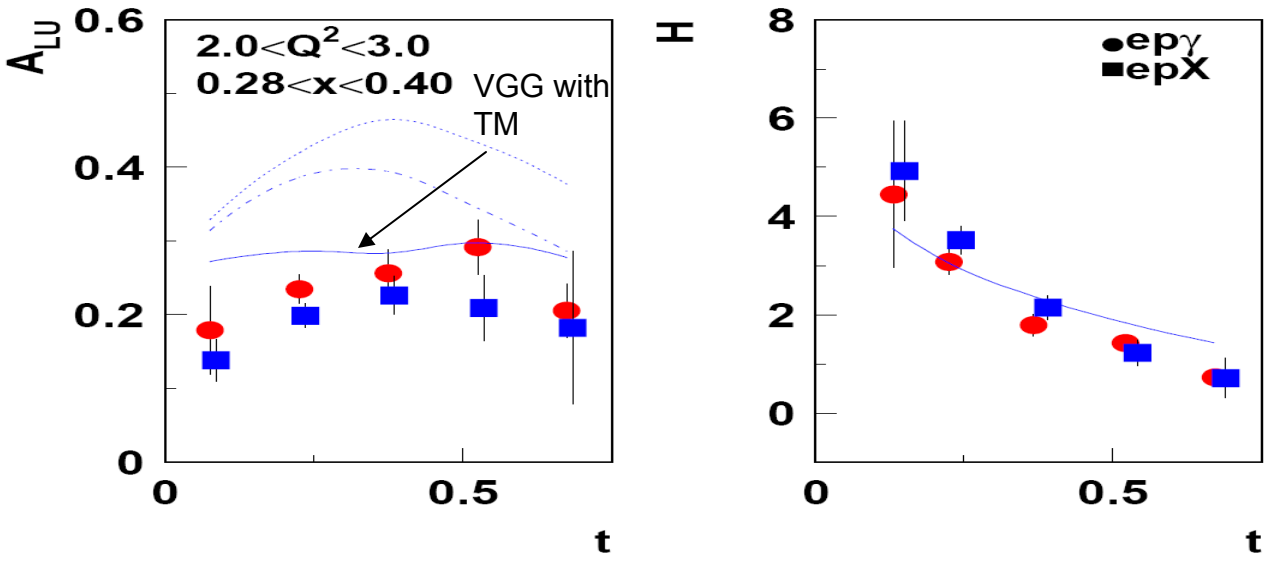


Divide the A_{LU} by the kinematic factor c_{LU} extracted from event by event sum

Extraction procedure tested with GEANT based MC with realistic x-sections for DVCS and pions recover input GPDs

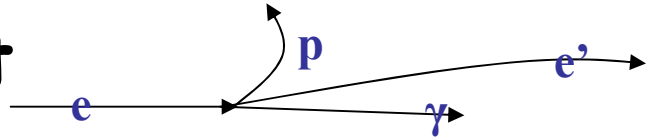
GPD extraction from Beam SSA:Data

- A_{LU} corrected for π^0 (bin by bin)
- H → ratio of the A_{LU} and prefactor c_{LU} calculated for all events in a bin (averaged over ϕ)



GPD sums (H) extracted for two non-overlapping data sets epX(ep0γ) and epγ consistent

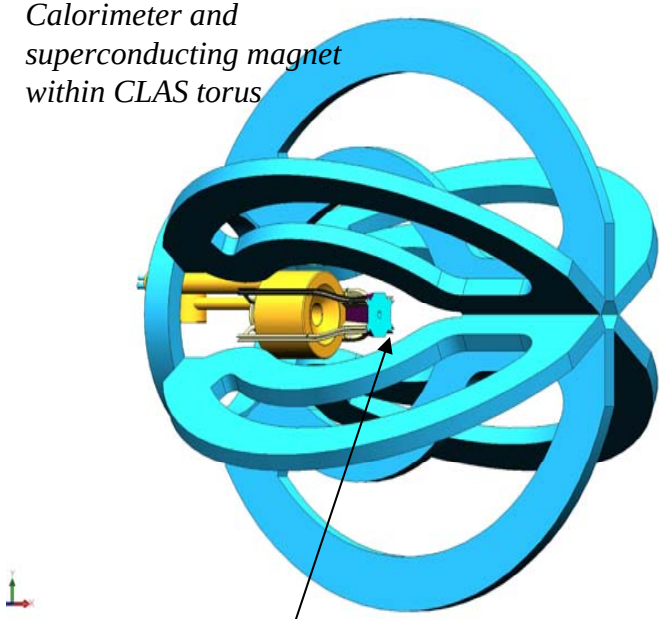
Dedicated CLAS DVCS experiment



→ Detection of 3 particles e, p and γ in final state
→ Large kinematical coverage in x_B and t

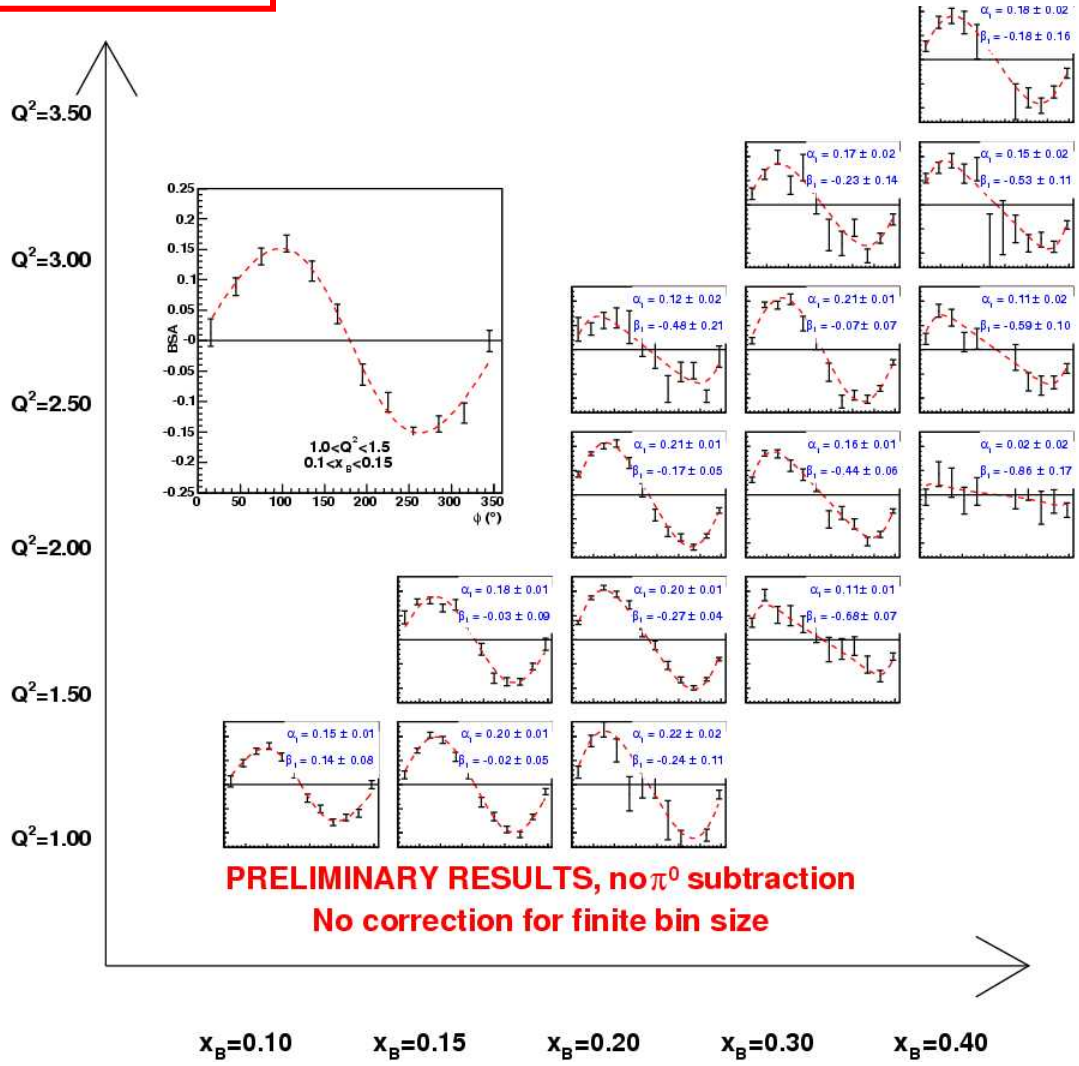
40% of data taken in 2005

Calorimeter and superconducting magnet within CLAS torus



424 PbWO4 crystals

dedicated calorimeter (IC) detect photons from 5°

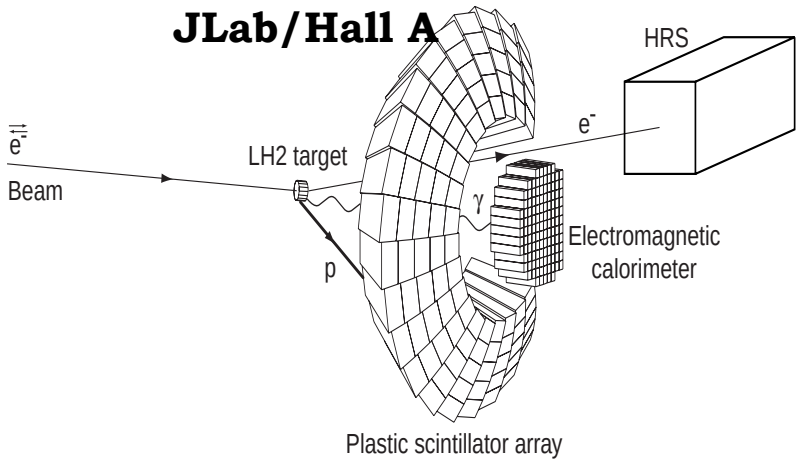


Dedicated DVCS experiment at JLab Hall-A, 2004 - 2005

Dedicated, high statistics, DVCS experiments

→ Detection of 3 particles e, p and γ in final state(cross section difference ~5%)

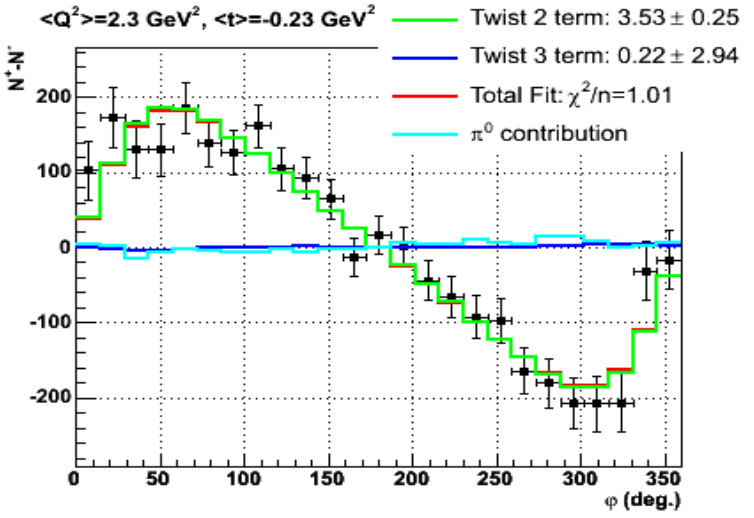
→ Establish scaling laws (up to Q^2 ~ 5 GeV^2), if observed, or deviations thereof understood

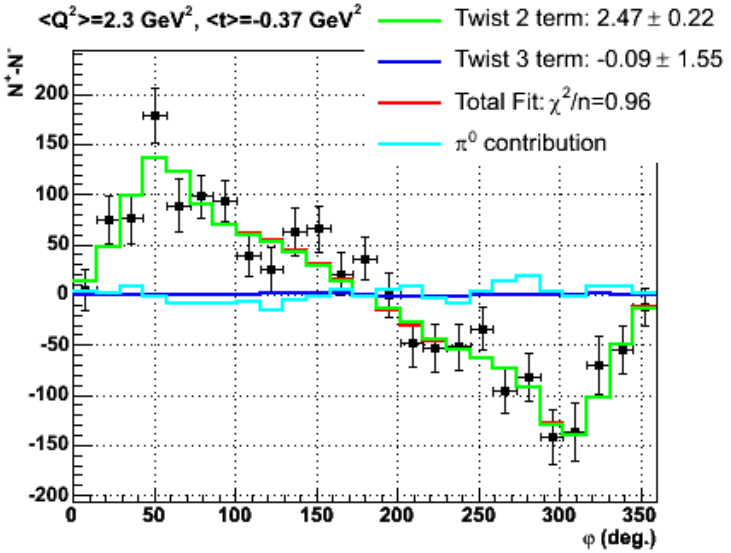


HRS + PbF_2 + Plastic scintillator

H(e,e'γp)

D(e,e'γN)N





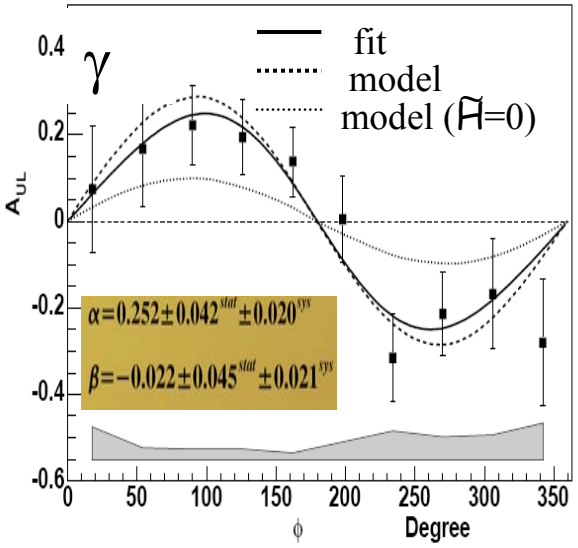
Target Spin Asymmetry (LTSA): t- Dependence from CLAS

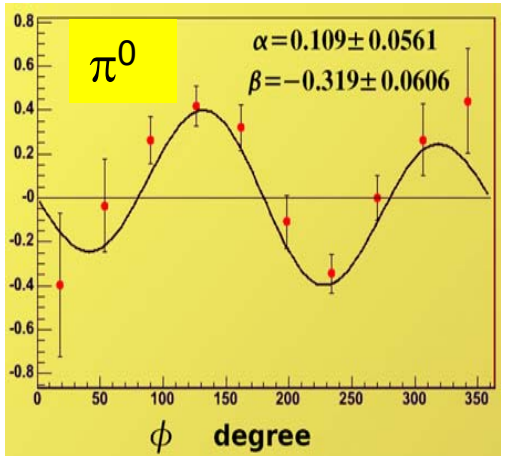
Unpolarized beam, longitudinal target:

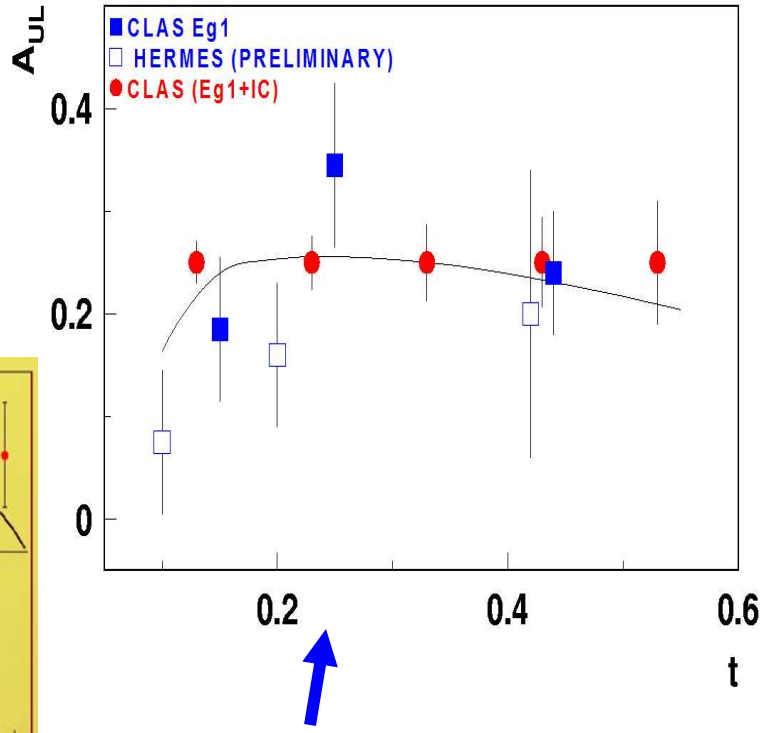
$$\Delta\sigma_{UL} \sim \sin\phi\,\mathrm{Im}\{F_1\tilde{H}+\xi(F_1+F_2)(H+..\}$$
$$\Delta\sigma_{LL} \sim \cos\phi\,\mathrm{Re}\{F_1\tilde{H}+\xi(F_1+F_2)(H+..\}$$

Kinematically suppressed

$\alpha \sin\phi + \beta \sin 2\phi$



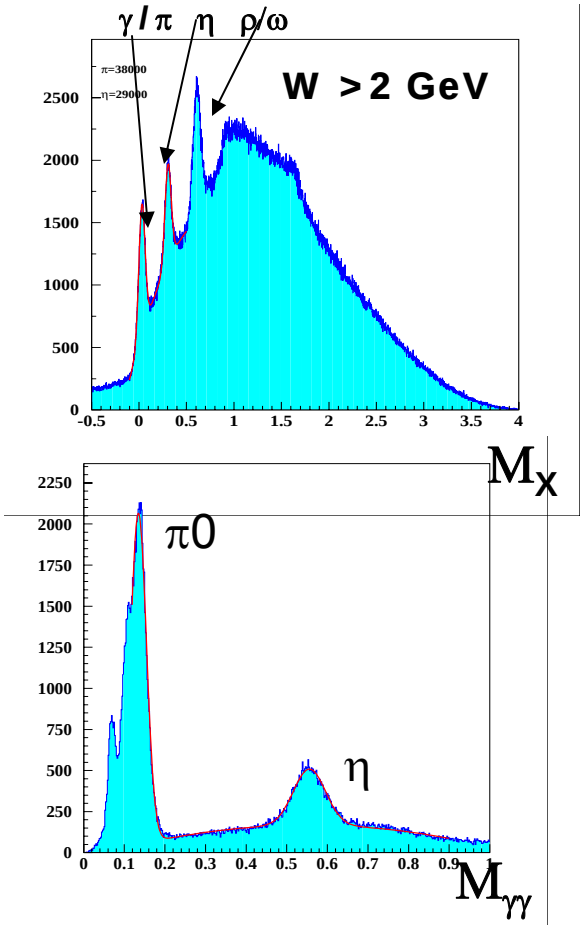




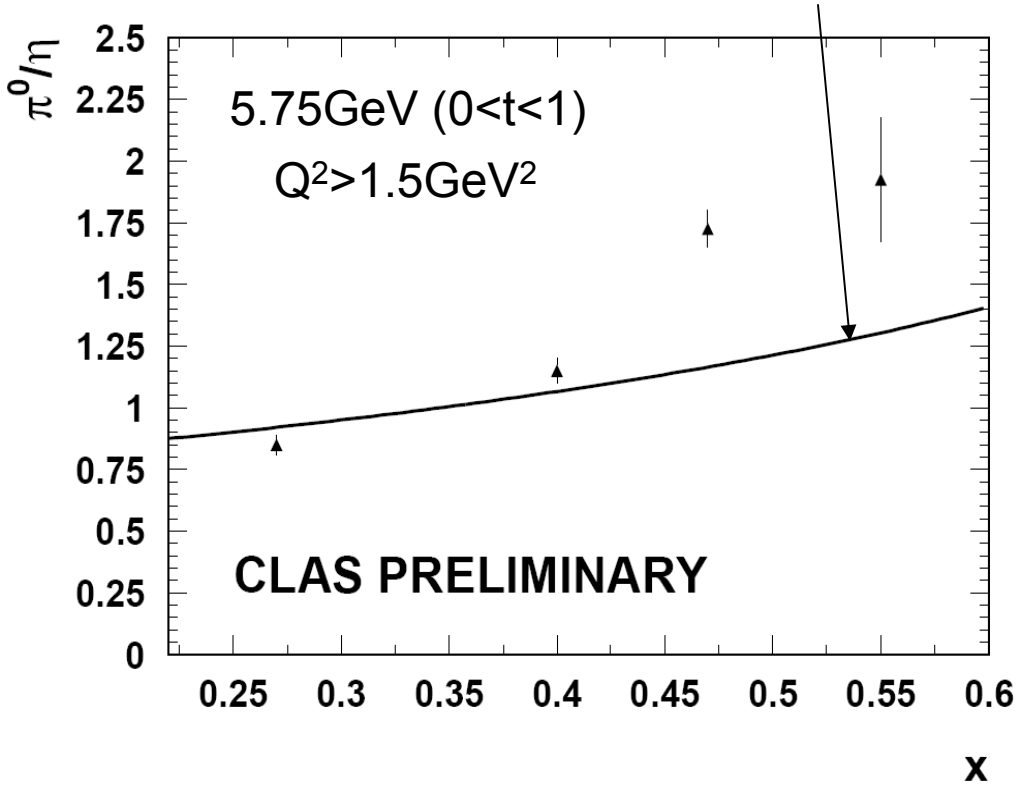
First data available(5 CLAS days), more(60 days) to come at 6 GeV

Measurements with polarized target will constrain the polarized GPDs and combined with beam SSA measurements would allow precision measurement of unpolarized GPDs.

$$e^- p \rightarrow e^- p (\pi^0 / \eta)$$



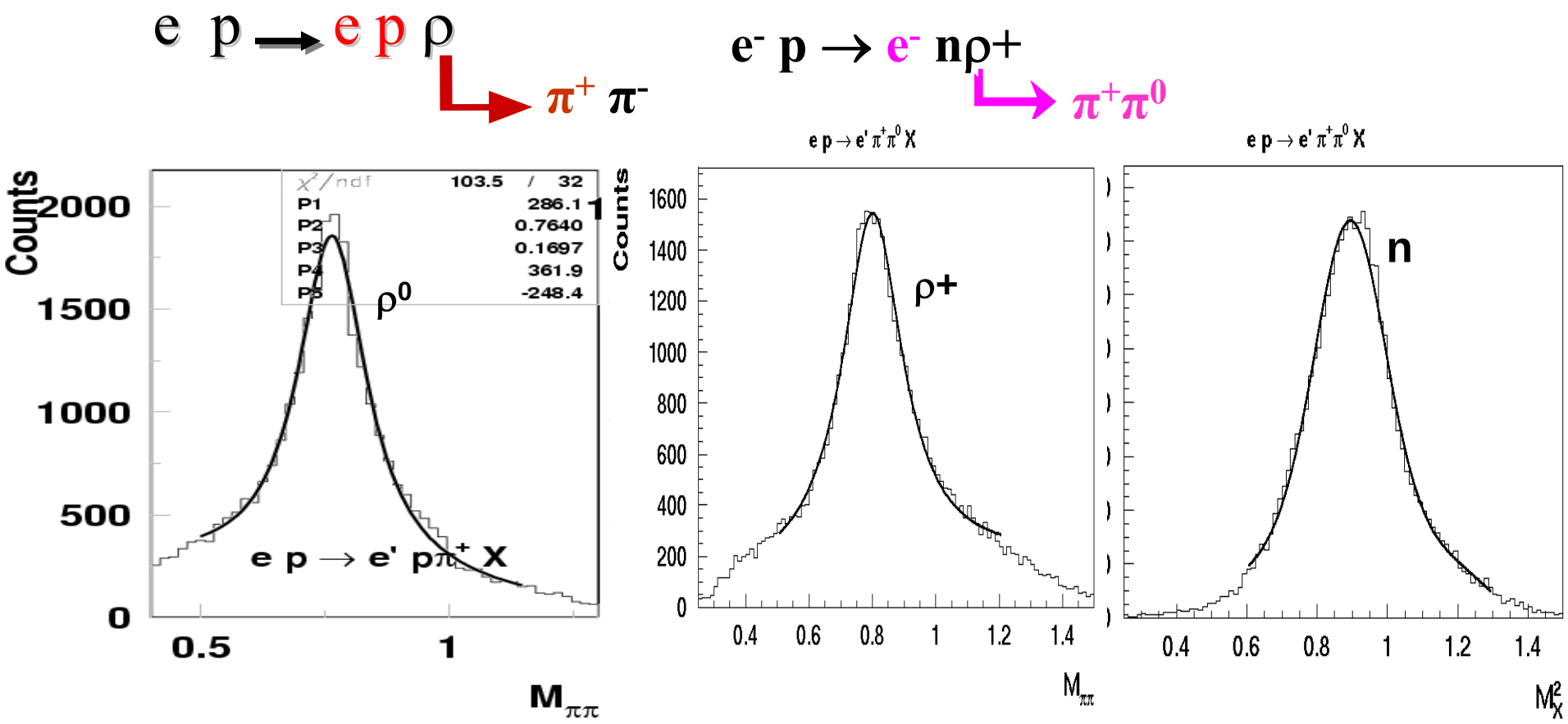
Eides,Frankfurt,Strikman 1998



Ratio $\pi/\eta = \frac{1}{2}\left(\frac{2}{3}\Delta u + \frac{1}{3}\Delta d\right)^2 / \frac{1}{6}\left(\frac{2}{3}\Delta u - \frac{1}{3}\Delta d + \frac{2}{3}\Delta s\right)^2$

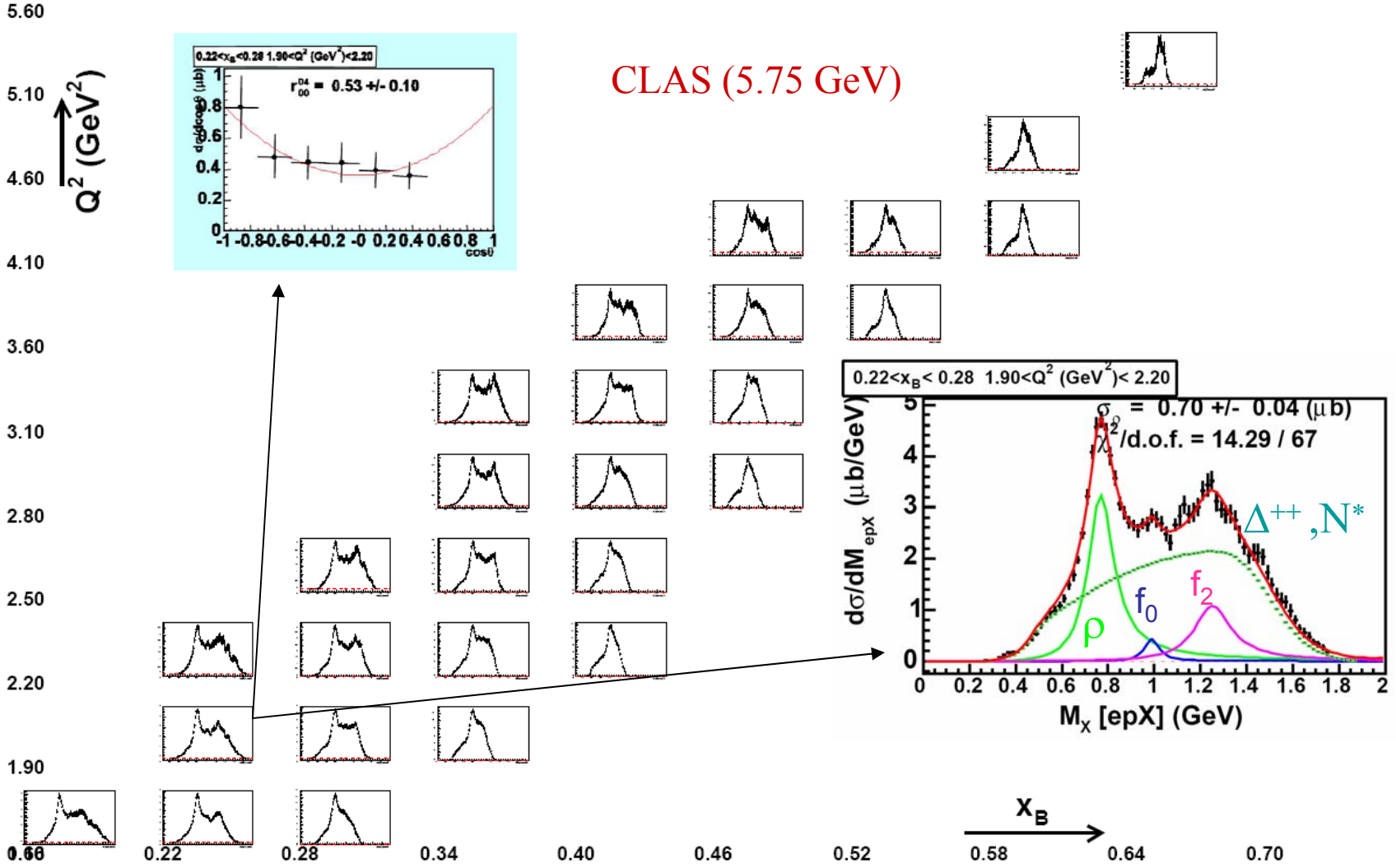
Requires separation of longitudinal and transverse contributions (Hall-C)

Exclusive $\pi^+\pi^-$ and $\pi^+\pi^0$



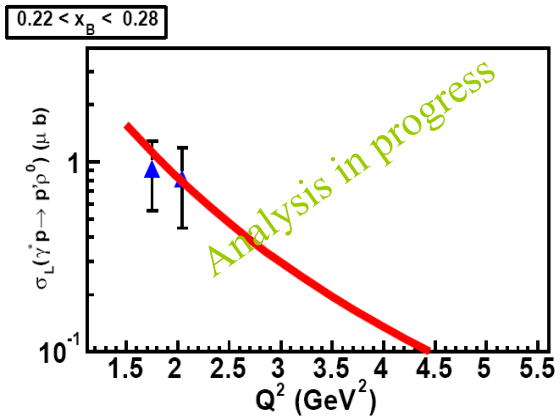
- Provide access to different combinations of orbital momentum contributions J^u,J^d ρ^0 -> $2J^u + J^d$, ρ^+ -> $J^u - J^d$
- Measurements of ratios ρ^+ / ρ^0, ρ^+ / π^+ …

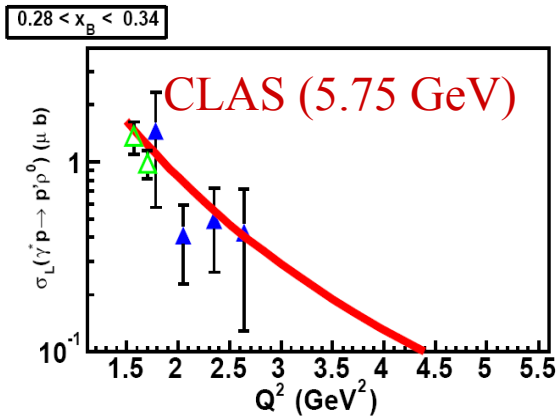
Exclusive 2 pion production: M_X (epX)



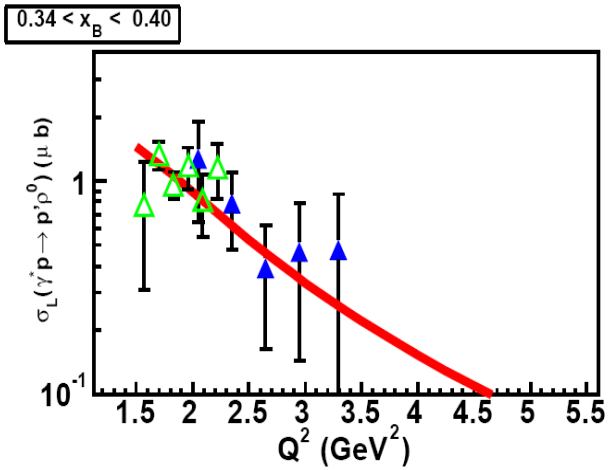
Significant background from exclusive 2 pion production

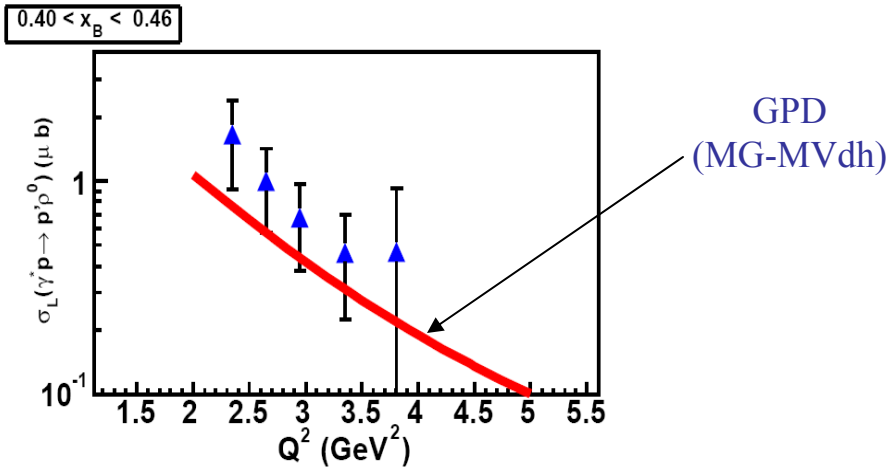
Exclusive ρ meson production: $\gamma^* p \rightarrow p\rho^0$





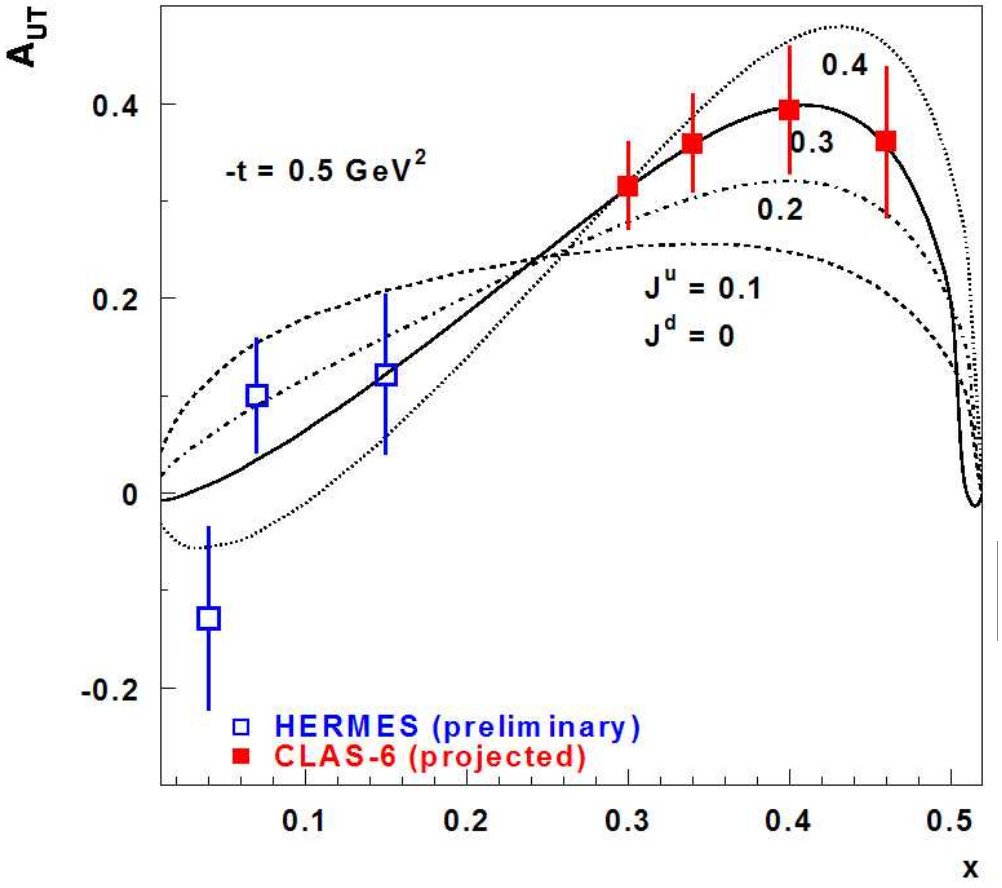
GPD formalism (beyond leading order) describes approximately data for $x_B<0.4$, $Q^2>1.5$ GeV^2





Decent description in pQCD framework already at moderate Q^2

Exclusive ρ^0 production on transverse target



$$A_{UT} = -\frac{2\Delta_\perp(\mathrm{Im}(AB^*))/\pi}{|A|^2(1-\xi^2) - |B|^2(\xi^2+t/4m^2) - \mathrm{Re}(AB^*)2\xi^2}$$

ρ^0

$$A \sim 2H^u + H^d$$
$$B \sim 2E^u + E^d$$

ρ^+

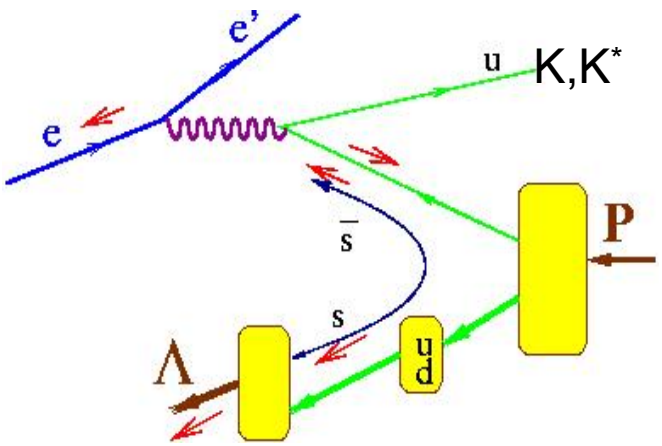
$$A \sim H^u - H^d$$
$$B \sim E^u - E^d$$

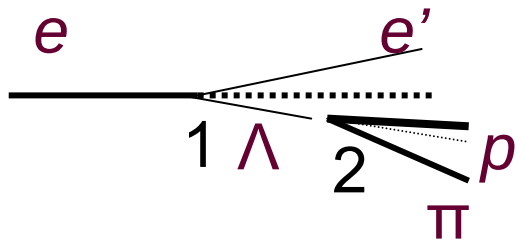
E^u, E^d needed for angular momentum sum rule.

K. Goeke, M.V. Polyakov, M. Vanderhaeghen, 2001

Asymmetry is a more appropriate observable for GPD studies at JLab energies as possible corrections to the cross section are expected to cancel

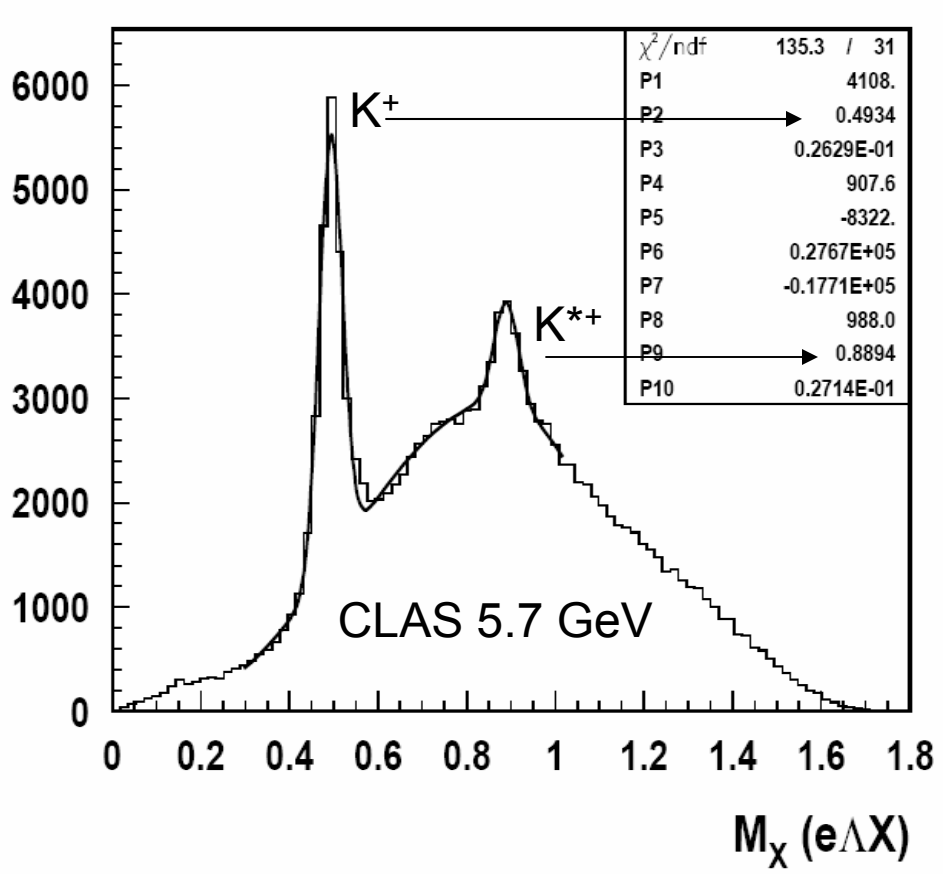
Λ production





$$K^{*+}\Lambda \quad -\frac{1}{\sqrt{6}}\Big(2[2H^u - H^d - H^s] - [2H^{\bar{u}} - H^{\bar{d}} - H^{\bar{s}}]\Big)$$

$$K^{+}\Lambda \quad -\frac{1}{\sqrt{6}}\Big(2[2\tilde{H}^u - \tilde{H}^d - \tilde{H}^s] + [2\tilde{H}^{\bar{u}} - \tilde{H}^{\bar{d}} - \tilde{H}^{\bar{s}}]\Big)$$

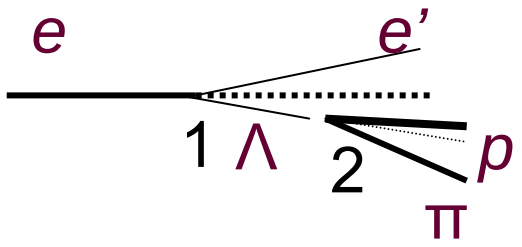


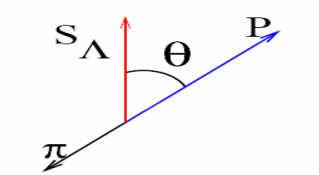
Accessing polarized and strange GPDs with unpolarized target ! (no gluons)

(ud)-diquark is a spin and isospin singlet s-quark carries whole spin of Λ $|\Lambda\rangle = |uds\rangle$

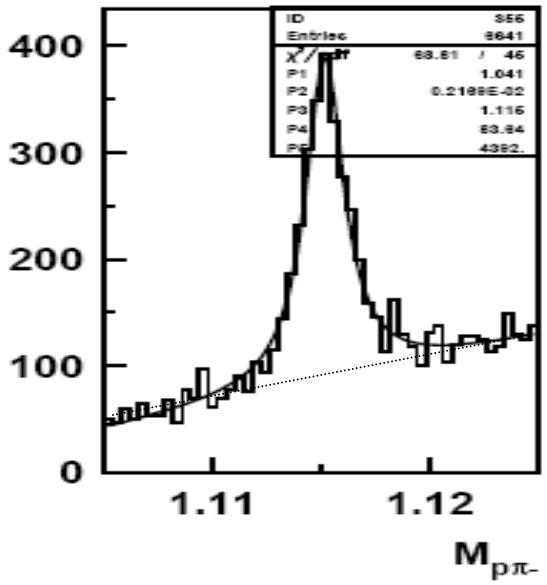
Study ratio observables: K/K*,polarization transfer

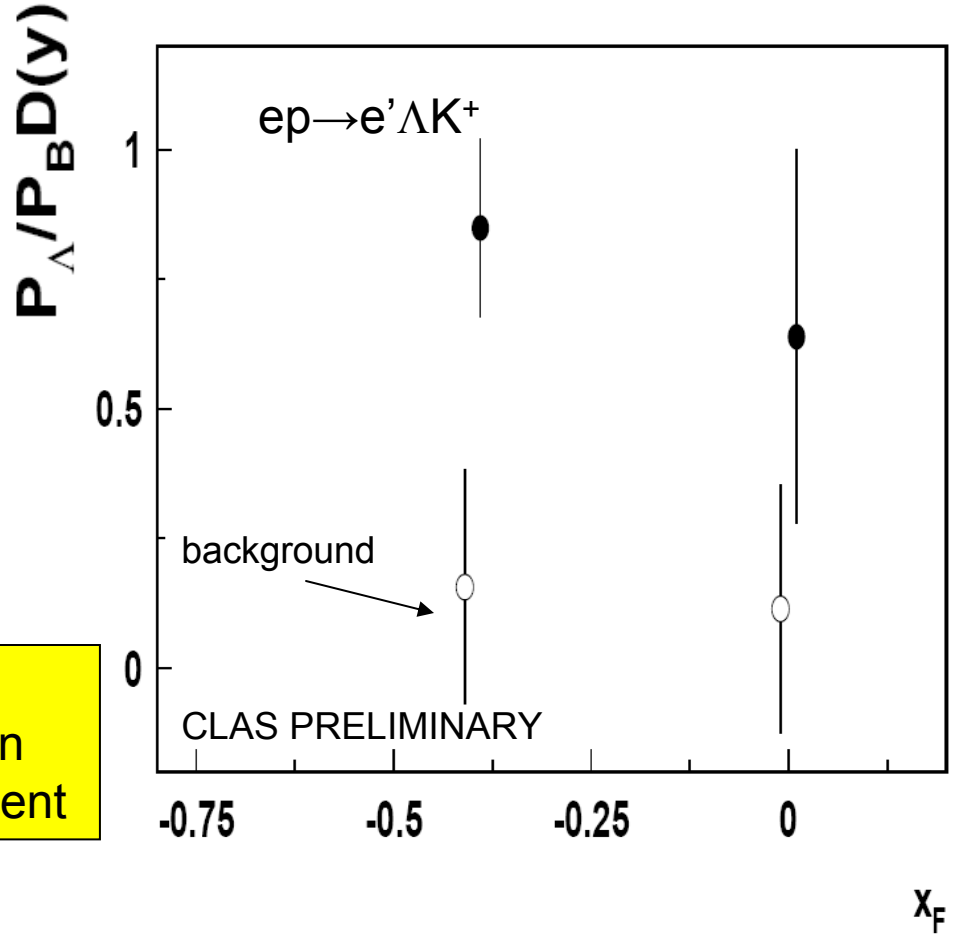
Λ polarization





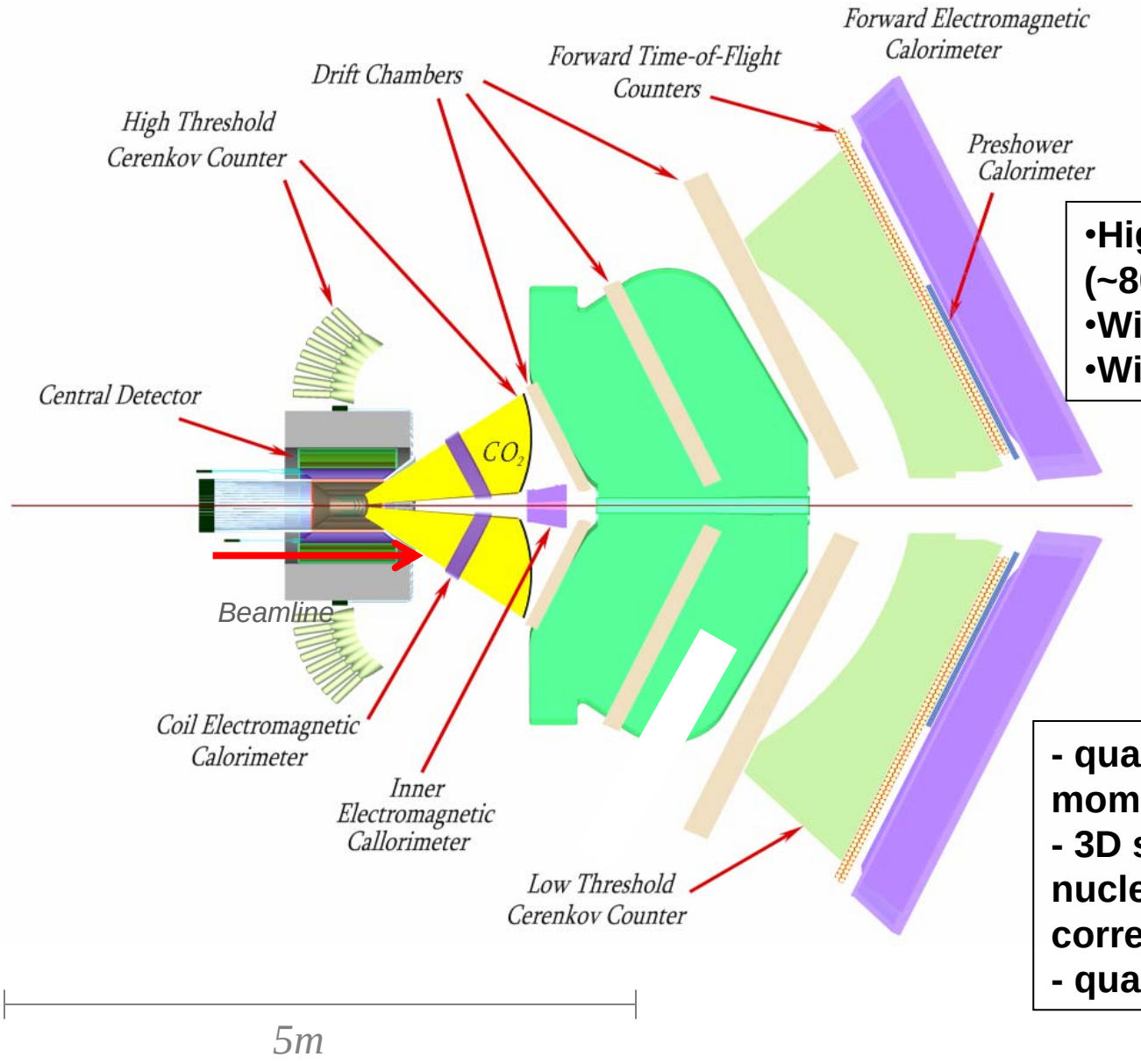
$$d\sigma/d\cos\theta = \sigma_0(1 + \beta P_\Lambda \cos\theta)$$





Polarization transfer in exclusive Λs:
strange sea contribution to proton spin
Ratio observable, less model-dependent

CLAS12



- High luminosity polarized (~80%) CW beam
- Wide geometric acceptance
- Wide physics acceptance

- quark orbital angular momentum contributions
- 3D structure of the nucleon's interior and correlations
- quark flavor polarization

CLAS 12 - Expected Performance

	Forward Detector	Central Detector
Angular coverage:		
Tracks (inbending)	8^o - 40^o	40^o - 135^o
Tracks (outbending)	5^o - 40^o	40^o - 135^o
Photons	2^o - 40^o	40^o - 135^o
Track resolution:		
δp (GeV/c)	$0.003p + 0.001p^2$	$\delta p_T = 0.03 p_T$
$\delta\theta$ (mr)	< 1 (>2.5 GeV/c)	8 (1 GeV/c)
$\delta\phi$ (mr)	< 3 (> 2.5 GeV/c)	2 (1 GeV/c)
Photon detection:		
Energy range	> 150 MeV	> 60 MeV
$\delta E/E$	0.09(EC)/0.04(IEC)	0.06 (1 GeV)
$\delta\theta$ (mr)	4 (1 GeV)	15 (1 GeV)
Neutron detection:		
η_{eff}	0.5 (EC), 0.1 (TOF)	0.04 (TOF)
Particle id:		
e/p	>>1000 (< 5 GeV/c) >100 (> 5 GeV/c)	- -
p/K	< 3 GeV/c (TOF) 3 - 10 GeV/c (CC)	0.65 GeV/c
p/p	< 5 GeV/c (TOF) 3 - 10 GeV/c (CC)	1.2 GeV/c
K/p	< 3.5 GeV/c (TOF)	0.9 GeV/c

CLAS12 - DVCS/BH Target Asymmetry

$e\,p^{\uparrow} \longrightarrow ep\gamma$

Transversely polarized target

E = 11 GeV

$\Delta\sigma_{UT} \sim \sin\phi\,\mathrm{Im}\{k_1(F_2 H - F_1 E) + \ldots\}d\phi$

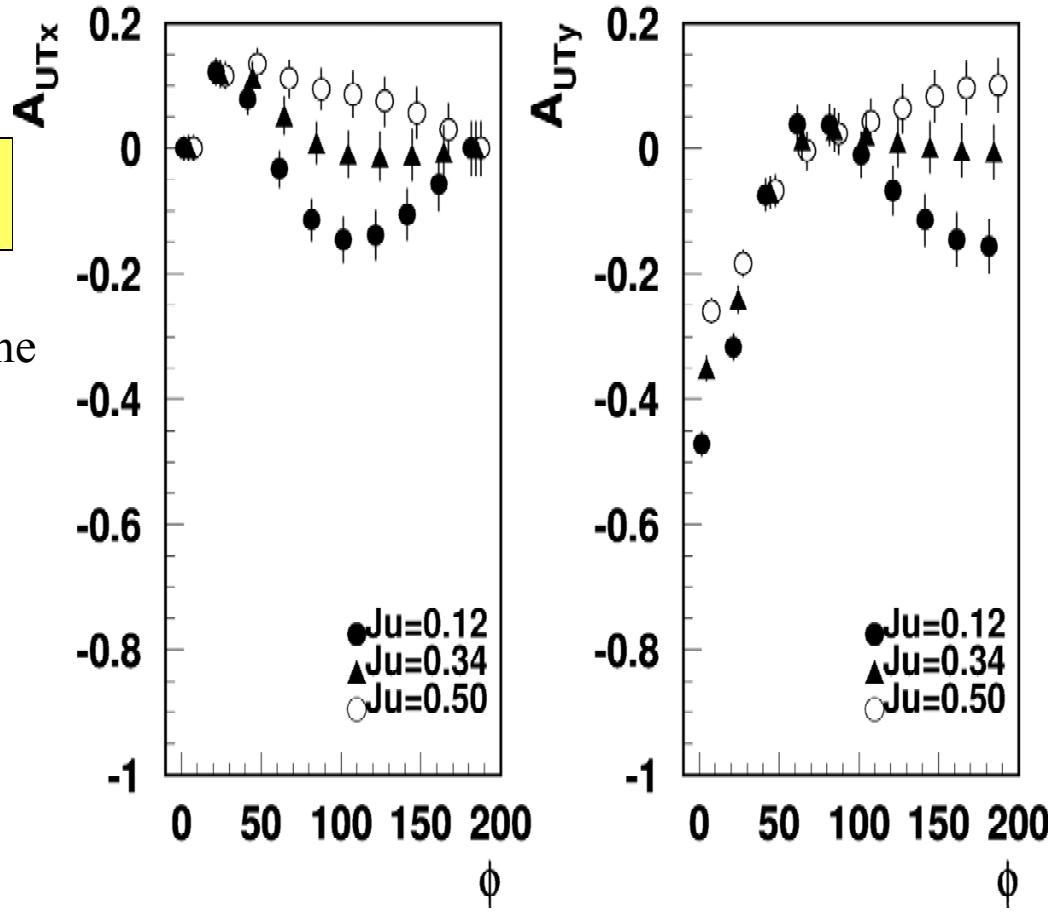
A_{UTx} Target polarization in scattering plane

A_{UTy} Target polarization perpendicular to scattering plane

- Asymmetry highly sensitive to the u-quark contributions to the proton spin.

Sample kinematics

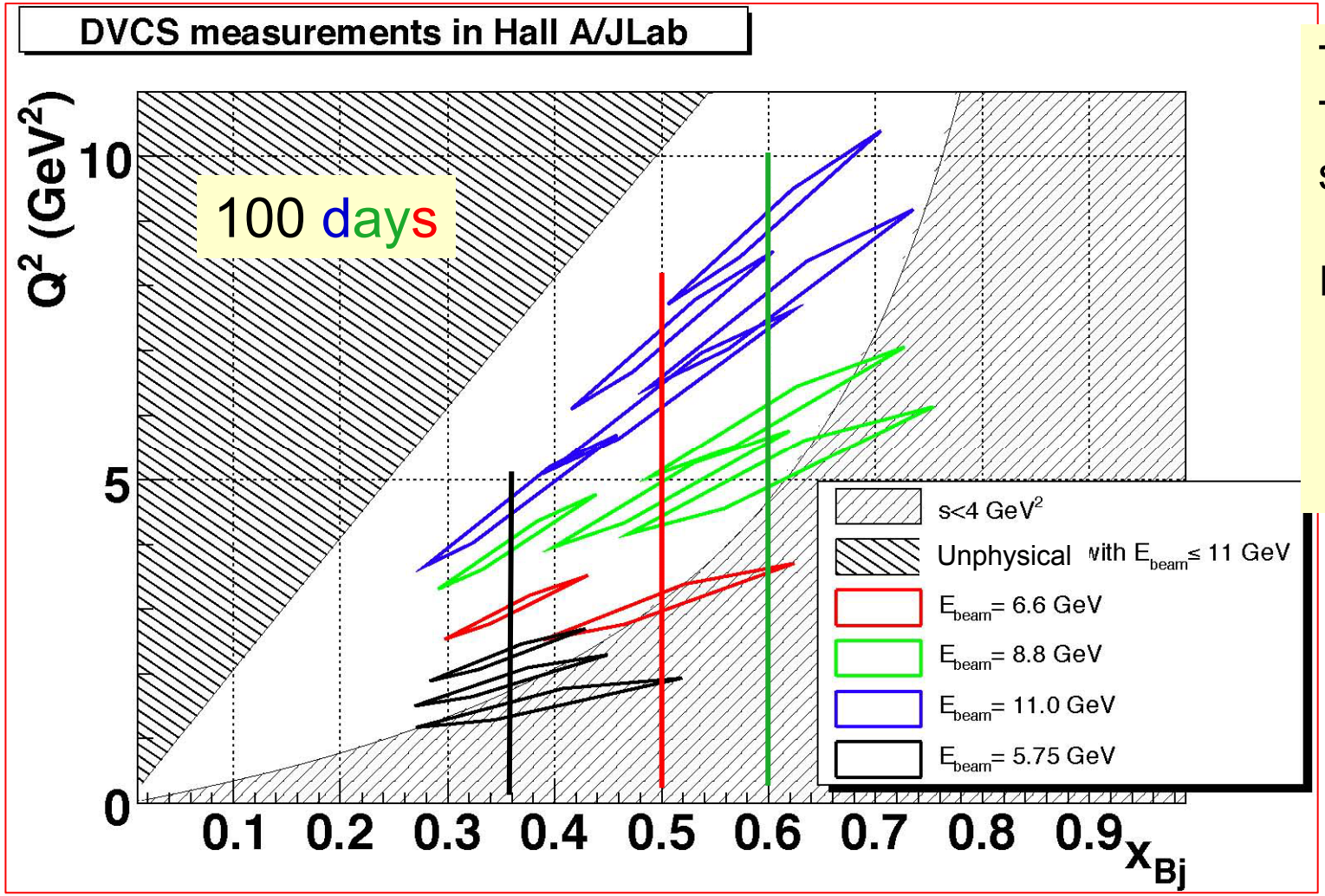
Q^2=2.2 GeV^2, x_B = 0.25, -t = 0.5GeV^2



JLab12: Hall A unpolarized target

H(e,e'γ)p

Absolute measurements: $d\sigma(\lambda_e=\pm1)$
250K events/setup



Twist 2 & Twist 3 separation.

Im{DVCS*BH}+ εDVCS^2

Re{DVCS*BH} +ε'DVCS^2

Summary

- DVCS beam spin asymmetries was extracted from two different CLAS data sets and for two different samples and was used to study GPDs.
- DVCS target spin asymmetry was extracted and compared with GPD based predictions (in publication) .
- Studies of the exclusive π^0 background performed. Beam and target SSA extracted.
- Significant polarization transfer measured in exclusive production of Lambda hyperons

- High luminosity, polarized CW beam, wide kinematic and geometric acceptance allow studies of exclusive meson production in hard scattering kinematics, providing data needed to study GPDs.

Summary-12

➢ *Upgraded JLab:* Combination of full acceptance, general purpose (CLAS12) and high luminosity (Hall-A/C) detectors will provide high precision measurements of 3D PDFs in the valence region.