Spin and Azimuthal Asymmetries in DIS

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Jefferson Lab

Dubna-Spin03 Workshop

- **Polarized semi-inclusive DIS**
- **Factorization studies**
  - **Multiplicities**
  - **Double spin asymmetry**
- **SSAs with polarized target and beam**
- **SSAs in exclusive processes**

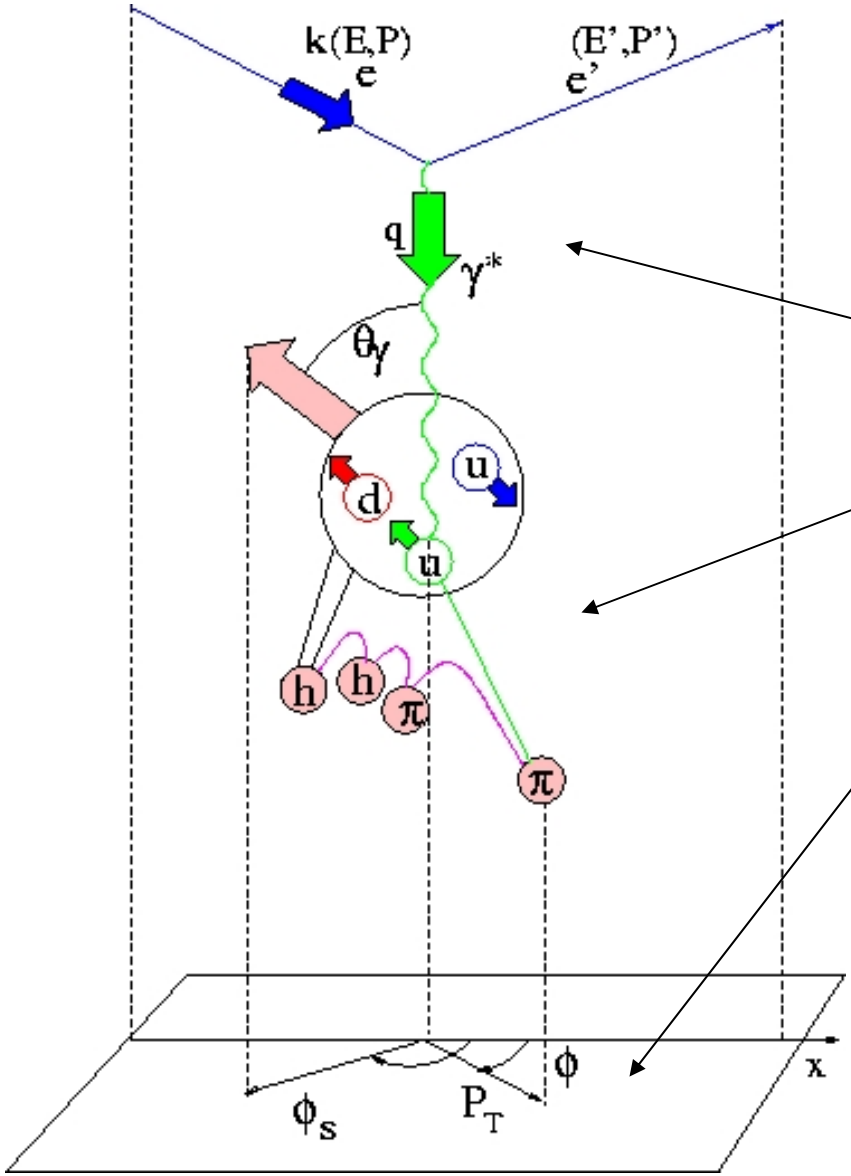
Summary

* Talk presented by Peter Bosted

Studies of Semi-Inclusive DIS at JLab:

- Study x,z dependence for different observables
- compare with measurements at higher energies (HERMES,SMC)
- compare with realistic MC (LUND-MC)
- compare with QCD based predictions (assuming factorization) for different observables, different final states

Single Pion Production Kinematics



Cross section depend on scale variables **x,y,z**

$$
\begin{aligned}
Q^2 &= 4EE'\sin^2(\theta/2) \\
\nu &= E - E' \\
x &= Q^2/2M\nu \\
y &= \nu/E \\
z &= E_h/\nu \\
\sin\theta_\gamma &\approx \frac{2Mx}{Q}\sqrt{1-y} \\
\sin\phi &= \frac{[\vec{q}\times\vec{k}]\vec{P}_\perp}{|\vec{q}\times\vec{k}||\vec{P}_\perp|}
\end{aligned}
$$

Azimuthal moments of the total cross section can be extracted as Spin Azimuthal Asymmetries.

$$
A_{LU}^{\sin\phi} = \frac{<\sin\phi>}{<\sin^2\phi>} = \frac{1}{P^{\pm}} \frac{\sum_{i=1}^{N^{\pm}} \sin\phi_i}{\sum_{i=1}^{N^{\pm}} \sin^2\phi_i}
$$

Spin-Azimuthal Asymmetries

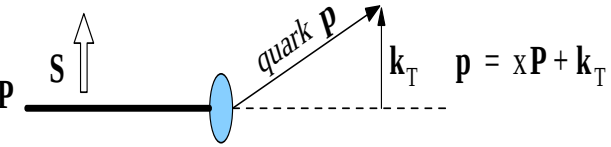
Spin-Azimuthal Asymmetries: Azimuthal modulations of spin asymmetries in semi-inclusive DIS.

Significant progress made recently in studies of Single-Spin Azimuthal Asymmetries (SSA) with longitudinally polarized target (HERMES), transversely polarized target (SMC), and polarized beam (CLAS).

- SSA are sensitive to the orbital momentum of quarks, enable measurements of GPDs and k_T-dependend PDFs (TMDs)
- provide a window to the physics of partonic final and initial state interactions
- model calculations indicate that SSA are not affected significantly by a wide range of corrections.
- Good agreement in SSAs measured in a wide energy range in electroproduction and **pp** scattering.

SSAs: appropriate observable at JLAB beam energies and $\mathbf{Q^2}$

Polarized SIDIS and TMD PDFs



N/q	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1 , $h_{1T}^\perp$

$$\sigma_{UU} \propto (1-y+y^2/2)\sum_{a,\bar{a}} e_a^2 x f_1^a(x) D_1^a(z)$$

$$\sigma_{UU}^{\cos 2\phi} \propto (1-y)\cos 2\phi \sum_{a,\bar{a}} e_a^2 x h_1^{\perp(1)}(x) H_1^{\perp(1)a}(z)$$

$$\sigma_{LL} \propto \lambda_e S_L y(2-y)\sum_{a,\bar{a}} e_a^2 x g_1^a(x) D_1^a(z)$$

$$\sigma_{UL}^{\sin 2\phi} \propto S_L 2(1-y)\sin 2\phi \sum_{a,\bar{a}} e_a^2 x h_{1L}^{\perp(1)}(x) H_1^{\perp(1)a}(z)$$

$$\sigma_{UT}^{\sin \phi} \propto S_T(1-y)\sin(\phi-\phi_{S'})\sum_{a,\bar{a}} e_a^2 x h_1^a(x) H_1^{\perp(1)a}(z)$$

$$\sigma_{UT}^{\sin \phi} \propto S_T(1-y+y^2/2)\sin(\phi-\phi_S)\sum_{a,\bar{a}} e_a^2 x f_{1T}^\perp(x) D_1^a$$

$$\sigma_{LU}^{\sin \phi} \propto \lambda_e y\sqrt{1-y}\frac{M}{Q}\sin\phi \sum_{a,\bar{a}} e_a^2 x^2 e^a(x) H_1^{\perp(1)a}(z)$$

λ_e, S_L, S_T polarizations
$\sum_{a,\bar{a}} \rightarrow$ sum over quarks and anti-quarks.

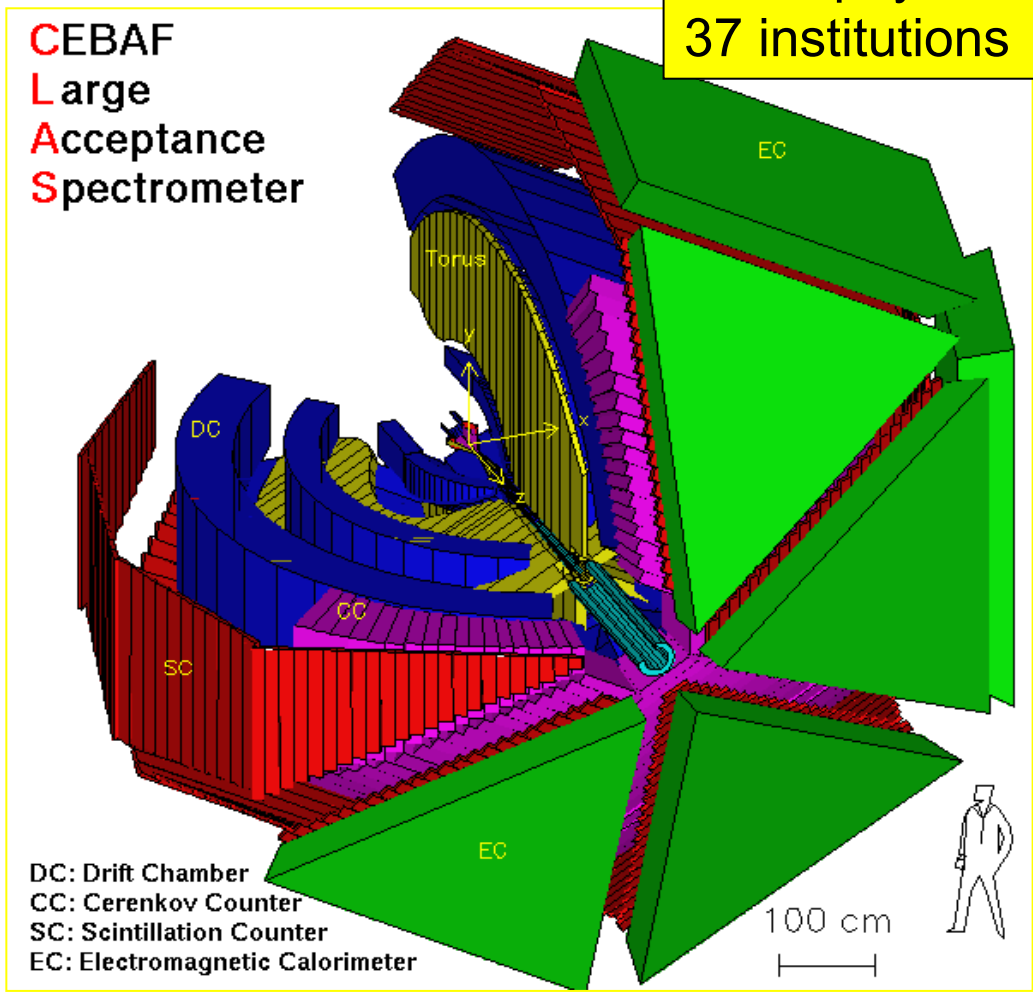
Gauge invariant definition of TMDs discussed by Collins and Belitsky,Ji & Yuan Nucl.Phys. B656 165, 2003

Two fundamental QCD mechanisms (**Collins** and **Sivers**) identified, to generate **SSA**:

The CLAS Detector

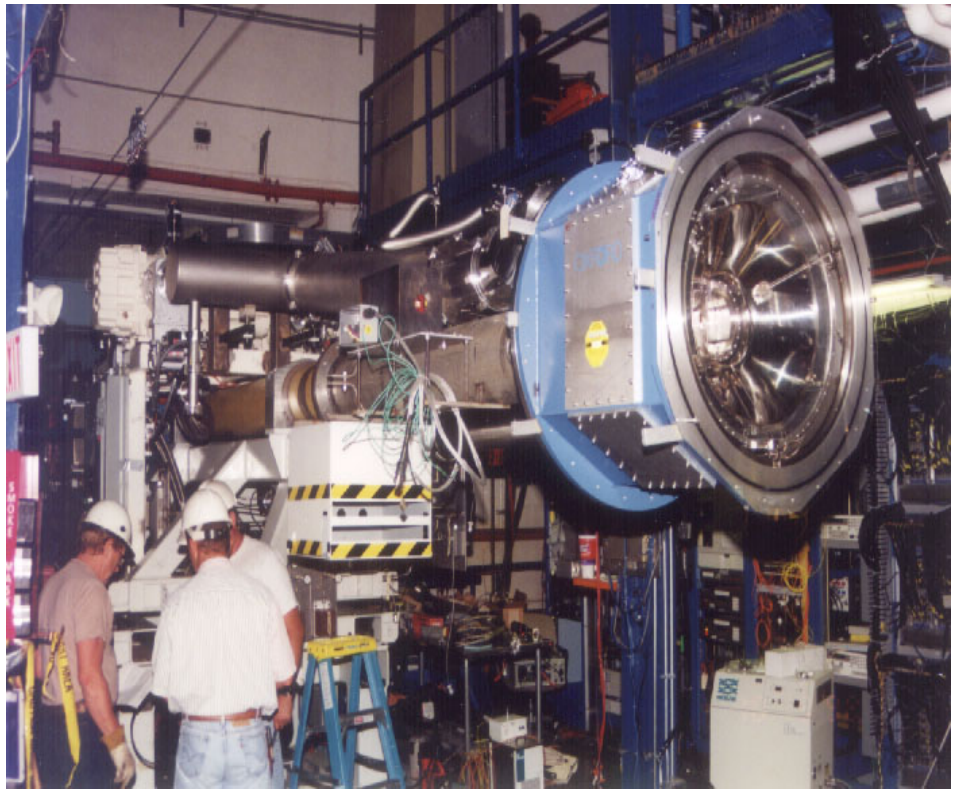
~ 200 physicists
37 institutions

- large kinematical coverage
- high luminosity
- multi-particle final states
  - charged particles:
    - p>0.2 GeV/c
    - $8^o<\theta<140^o$
    - $\sigma_p/p\sim0.5\%$ ($\theta<30^o$)
    - $\sigma_p/p\sim1\text{-}2\%$ ($\theta>30^o$)
    - σ_θ=1mrad
    - σ_ϕ=4mrad



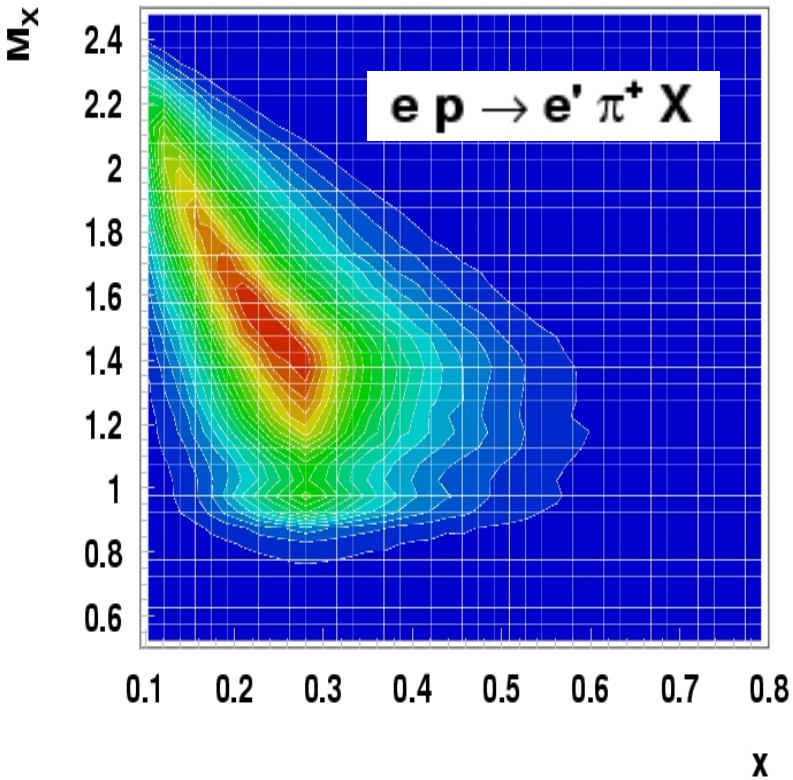
The CLAS Polarized Target

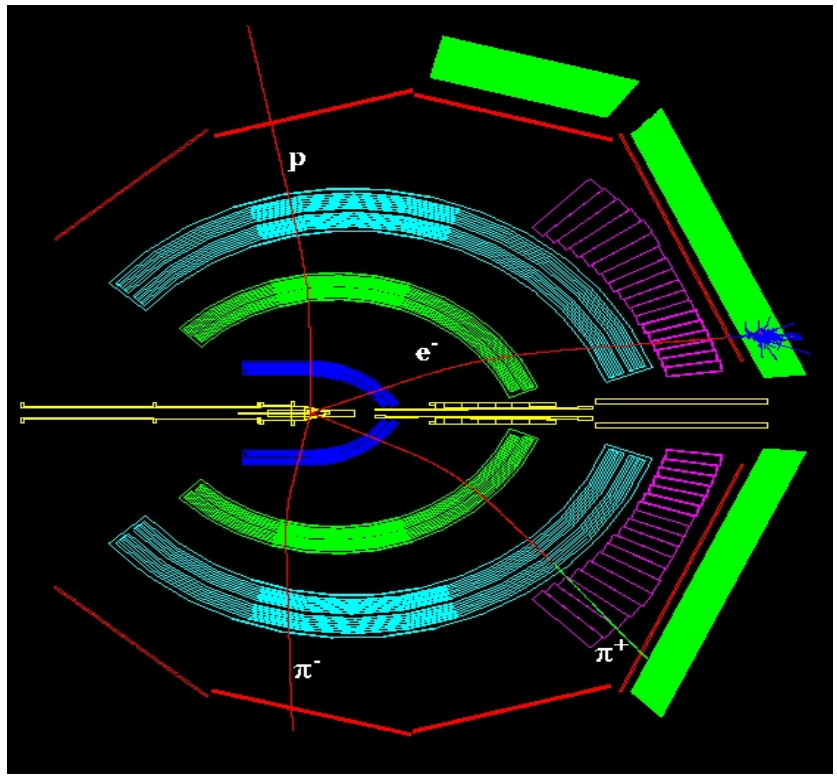
- **solid NH_3/ND_3 target polarized by Dynamic Nuclear Polarization**
- **1 K, 5 T field**
- **proton polarization ~70-80%**
- **high lumi $\rightarrow 2\times10^{34}\ s^{-1}cm^{-2}$**



The CLAS Event Display

Scattering of 5.7 GeV polarized electrons off polarized NH_3 and unpolarized hydrogen



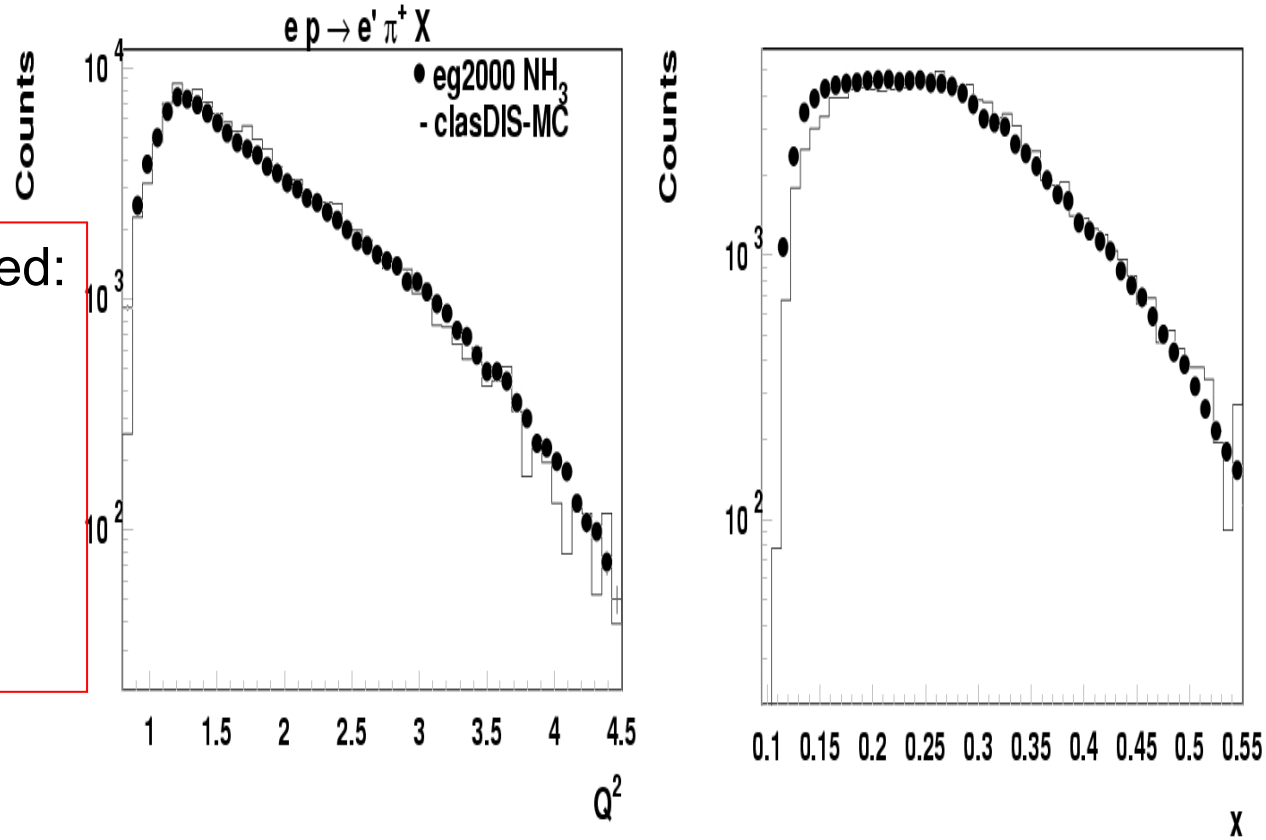


- **~8M π^+ in DIS kinematics, $Q^2>1$ GeV^2, $W^2>4$ GeV^2, $y<0.85$, $0.8>z>0.5$, $M_X^2>1.1$**
- **beam polarization 73%**
- **target polarization 72% (f≈0.2)**

LUND-MC vs Polarized CLAS data

DIS kinematics defined:

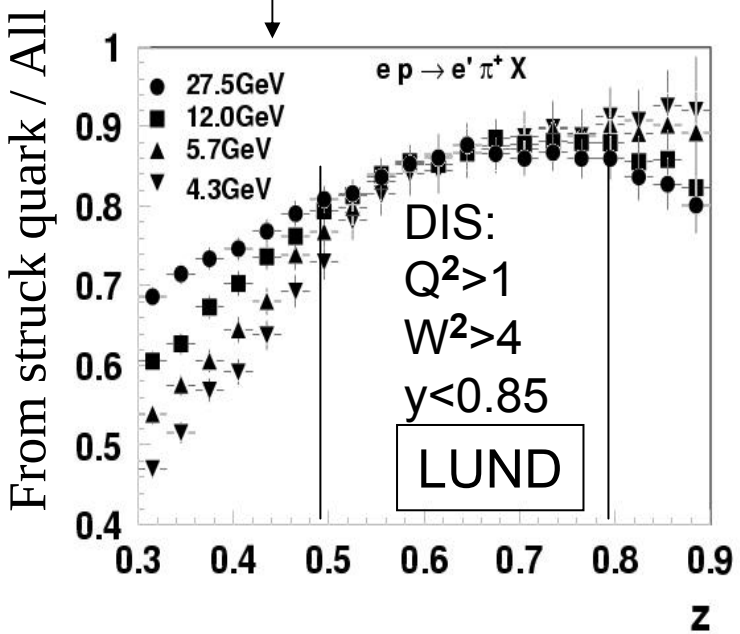
$Q^2>1$ GeV^2
$W^2>4$
$y<0.85$
$0.5<z<0.8$
M_x^2 **>1.1**

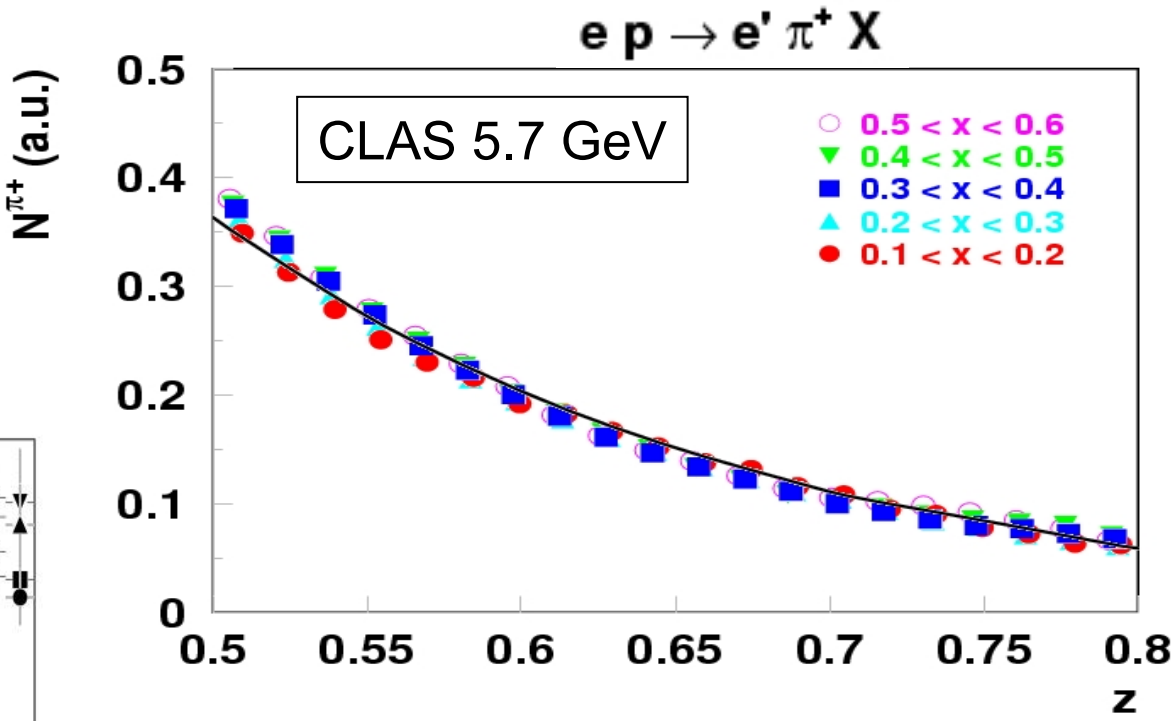


x and **Q^2** distributions from LUND-MC vs 5.7 CLAS NH_3 data.

Factorization studies in CFR at CLAS

The fraction of π from struck quark in a range 0.5<z<0.8 is not changing significantly with beam energy.

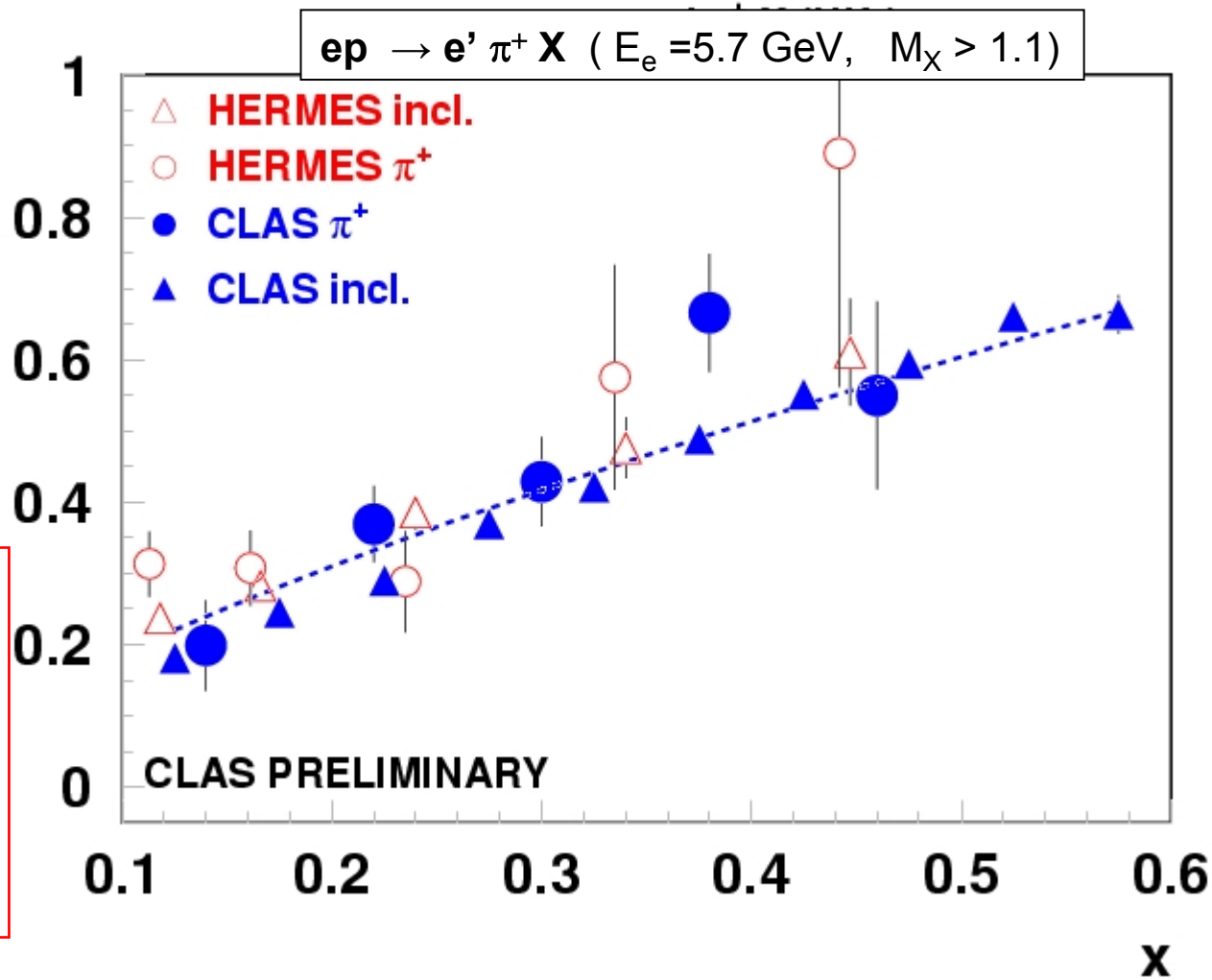




No significant variation observed in z distributions of π+ for different **x** ranges

Polarized target: HERMES vs CLAS at 5.7GeV

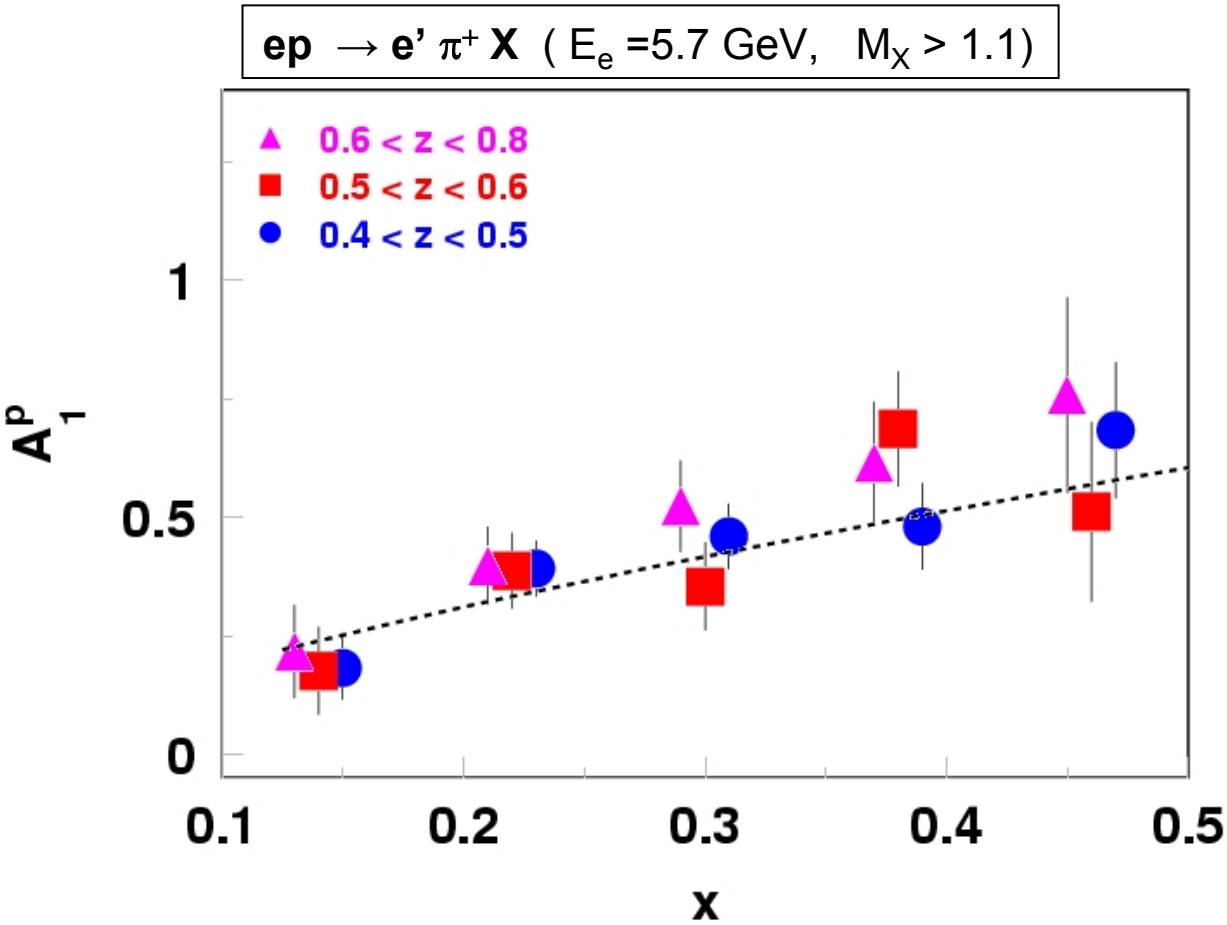
$$A_1^p \approx \frac{1}{P_B P_T f D(y)} \frac{N^{+-} - N^{++}}{N^{+-} + N^{++}}$$



x dependence of CLAS $\mathbf{A_1^p}$ (A_2=0) consistent with HERMES data, world inclusive fit $\mathbf{x^{0.727}}$

Polarized target: x,z factorization studies at 5.7GeV

No significant variation observed in **x** dependence of A_1^p for different **z** ranges.

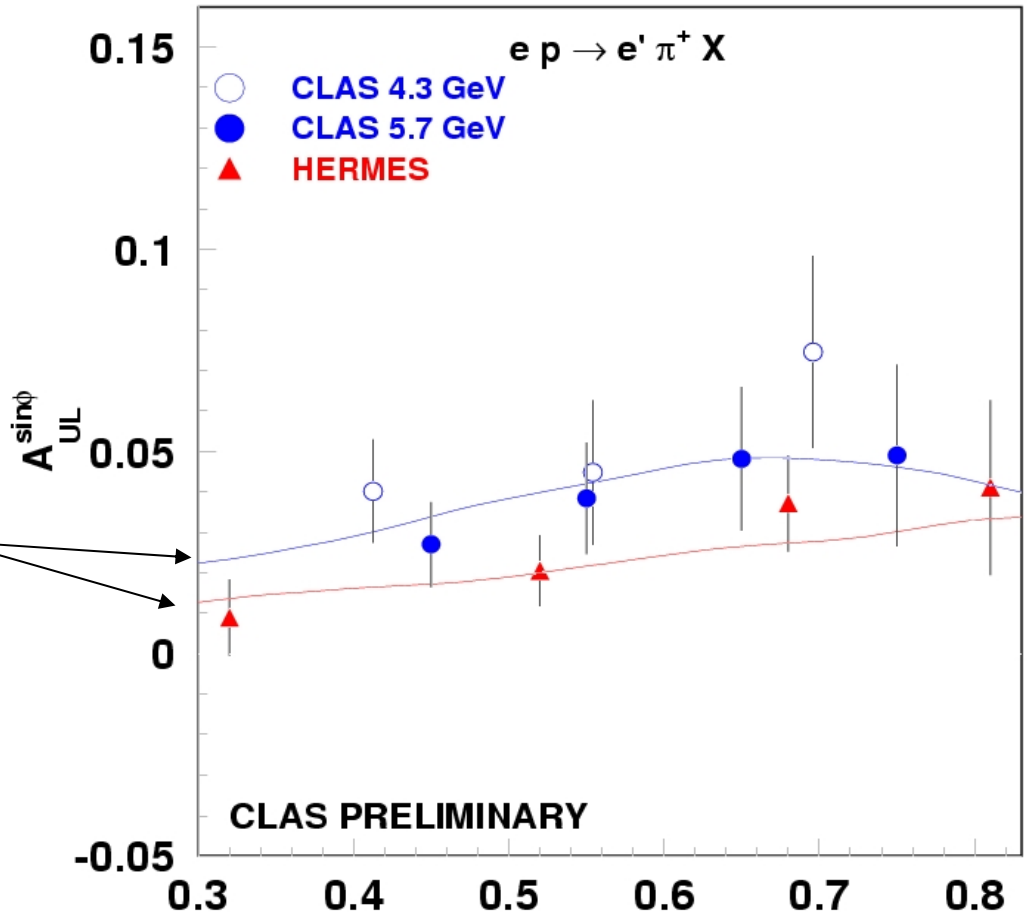


z-independent A_1^p consistent with factorization!

Longitudinally Pol. Target: SSA for π^+

Target SSA: CLAS (4.3 GeV, and 5.7 GeV) consistent with HERMES (27.5 GeV)

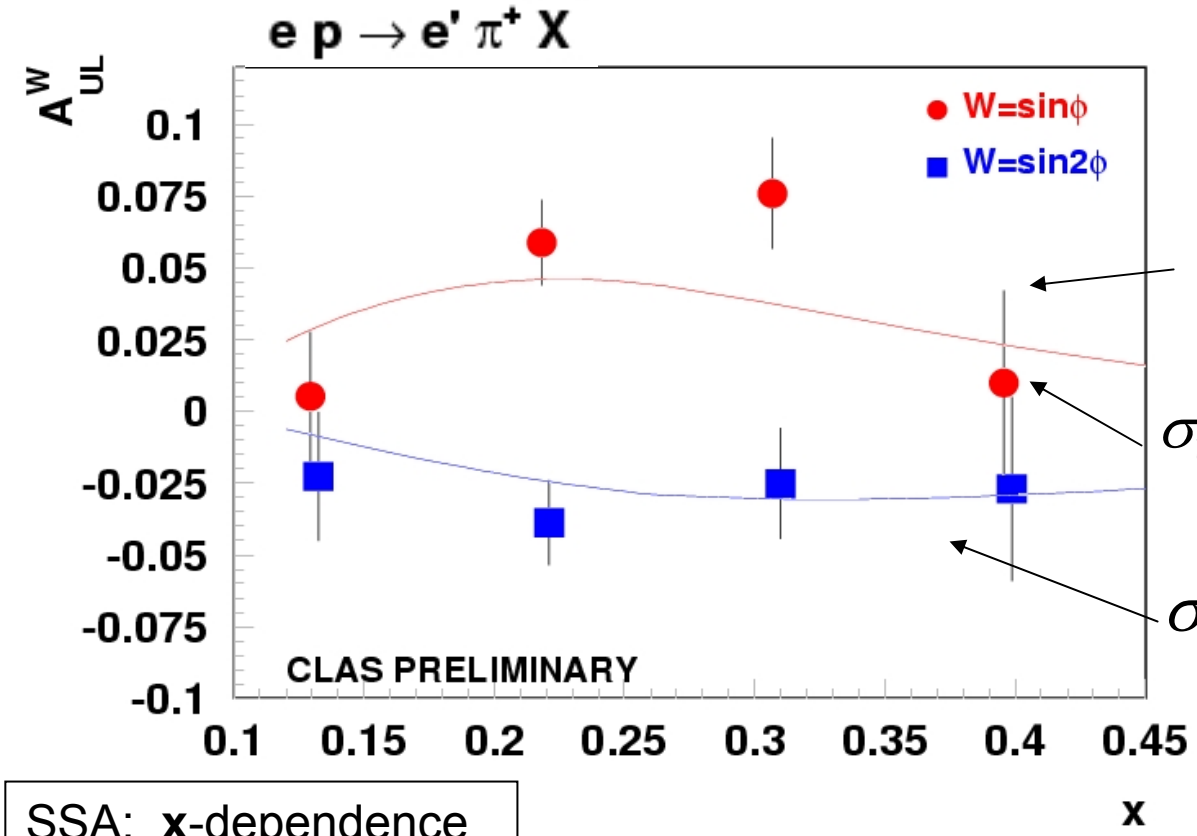
predictions for **Sivers effect** using BHS A_{UT} Phys.Lett.B53099,2002
Sivers only interpretation require large A_{UT}



Note: A_{UL} **z**-dependence also consistent both in magnitude and sign with predictions based on the **Collins mechanism**

$$A_{UL} \propto \sin\theta_\gamma \times A_{UT} \propto \sin\theta_\gamma \frac{f_{1T}^{\perp u}(x)}{u(x)}$$

Longitudinally Pol Target: SSA for π^+



$$\sigma_{UT}^{\sin\phi} \propto S_T \sum_{q,\bar{q}} e_q^2 f_{1T}^{\perp q}(x) D_1^q(z)$$

$$\sigma_{UT}^{\sin\phi} \propto S_T \sum_{q,\bar{q}} e_q^2 h_1(x) H_1^{\perp q}(z)$$

$$\sigma_{UL}^{\sin\phi} \propto S_L \frac{M}{Q} \sum_{q,\bar{q}} e_q^2 x h_L(x) H_1^{\perp q}(z)$$

$$\sigma_{UL}^{\sin 2\phi} \propto S_L \sum_{q,\bar{q}} e_q^2 h_{1L}^{\perp(1)q}(x) H_1^{\perp q}$$

SSA: **x**-dependence CLAS (5.7 GeV) is consistent with predictions for **Collins effect** from Efremov et al. hep-ph/0208124

$H_1^{\perp}$ - Collins FF

- First indication of a non-zero **sin2ϕ** moment (Kotzinian-Mulders asymmetry)
- $A_{UL}^{\sin 2\phi}$ is a clean source of Collins SSA

LI-relations and higher twists

Lorenz invariant relations linking moments of twist-3 and twist-2 functions break down (K. Goeke et al. hep-ph/0302028)

Polarized targets

$$g_T = g_1(x) + \frac{d}{dx} g_{1T}^{(1)}(x)$$

$\downarrow$ $\downarrow$ $\downarrow$

$\langle \cos\phi_S \rangle_{LT}$ $\langle 1 \rangle_{LL}$ $\langle \cos\phi \rangle_{LT}$

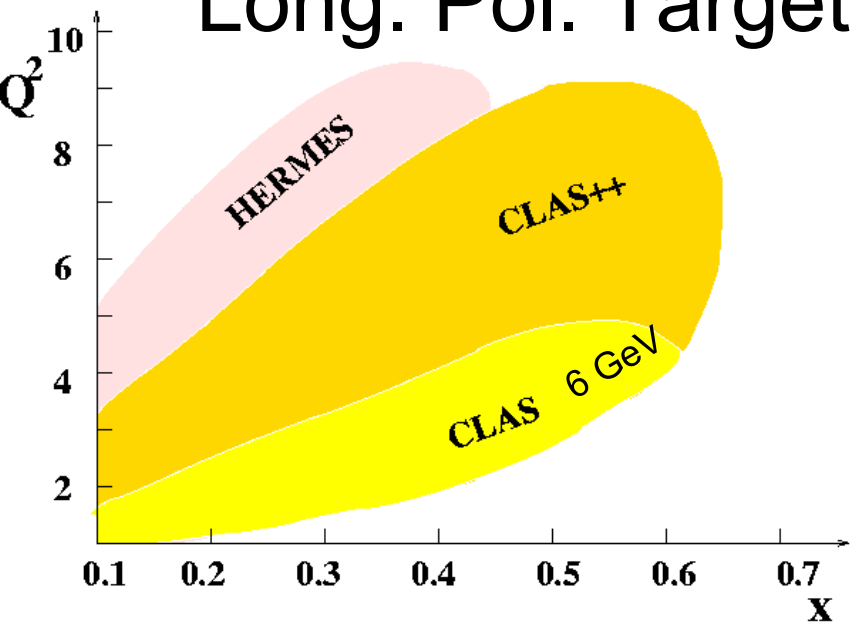
All involved functions are separately accessible in different spin-azimuthal asymmetries

$$h_L = h_1^q(x) - \frac{d}{dx} h_{1L}^{\perp(1)}$$

$\downarrow$ $\downarrow$ $\downarrow$

$\langle \sin\phi \rangle_{UL}$ $\langle \sin\phi \rangle_{UT}$ $\langle \sin 2\phi \rangle_{UL}$

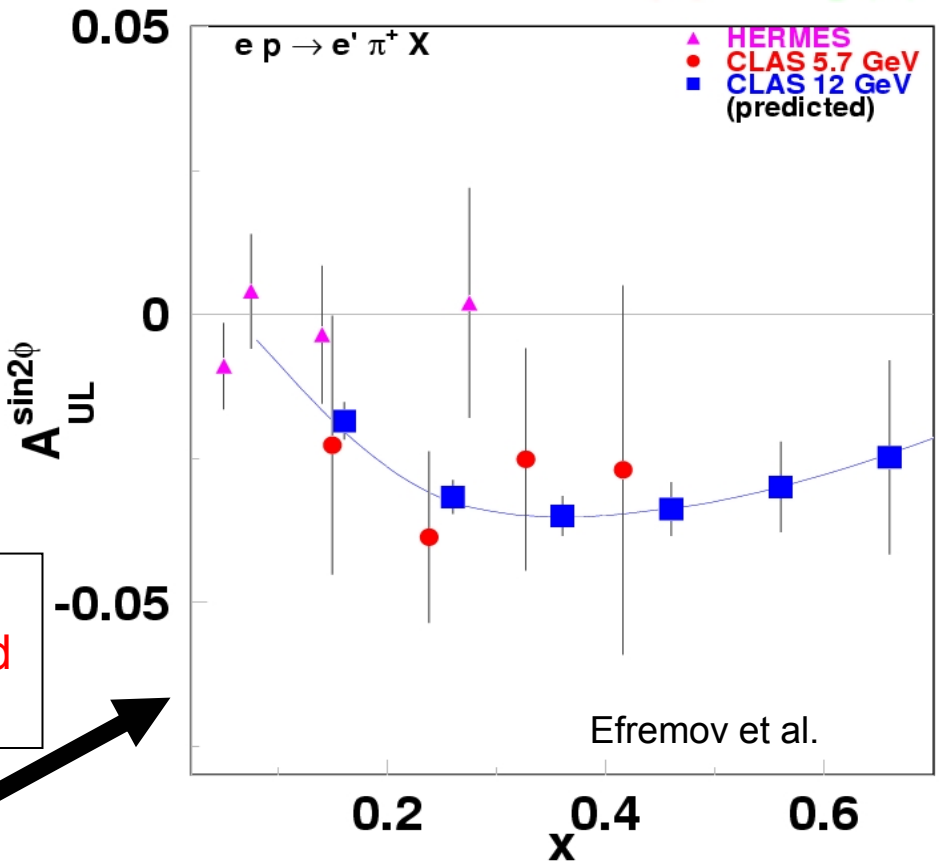
Long. Pol. Target SSA for π^+ at 12GeV



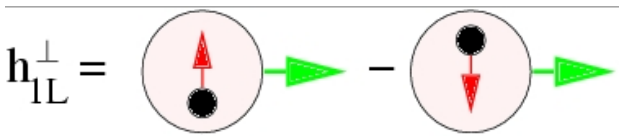
large x + high luminosity

$$A_{UL}^{\sin 2\phi} \propto \frac{h_{1L}^{\perp u}(x)}{u(x)} \frac{H_1^{\perp u}(z)}{D_1^u(z)}$$

The sin 2ϕ asymmetry for 2000 h of projected CLAS++ data.



Direct measurement of first moments of k_T dependent twist-2 distribution and fragmentation functions at CLAS++

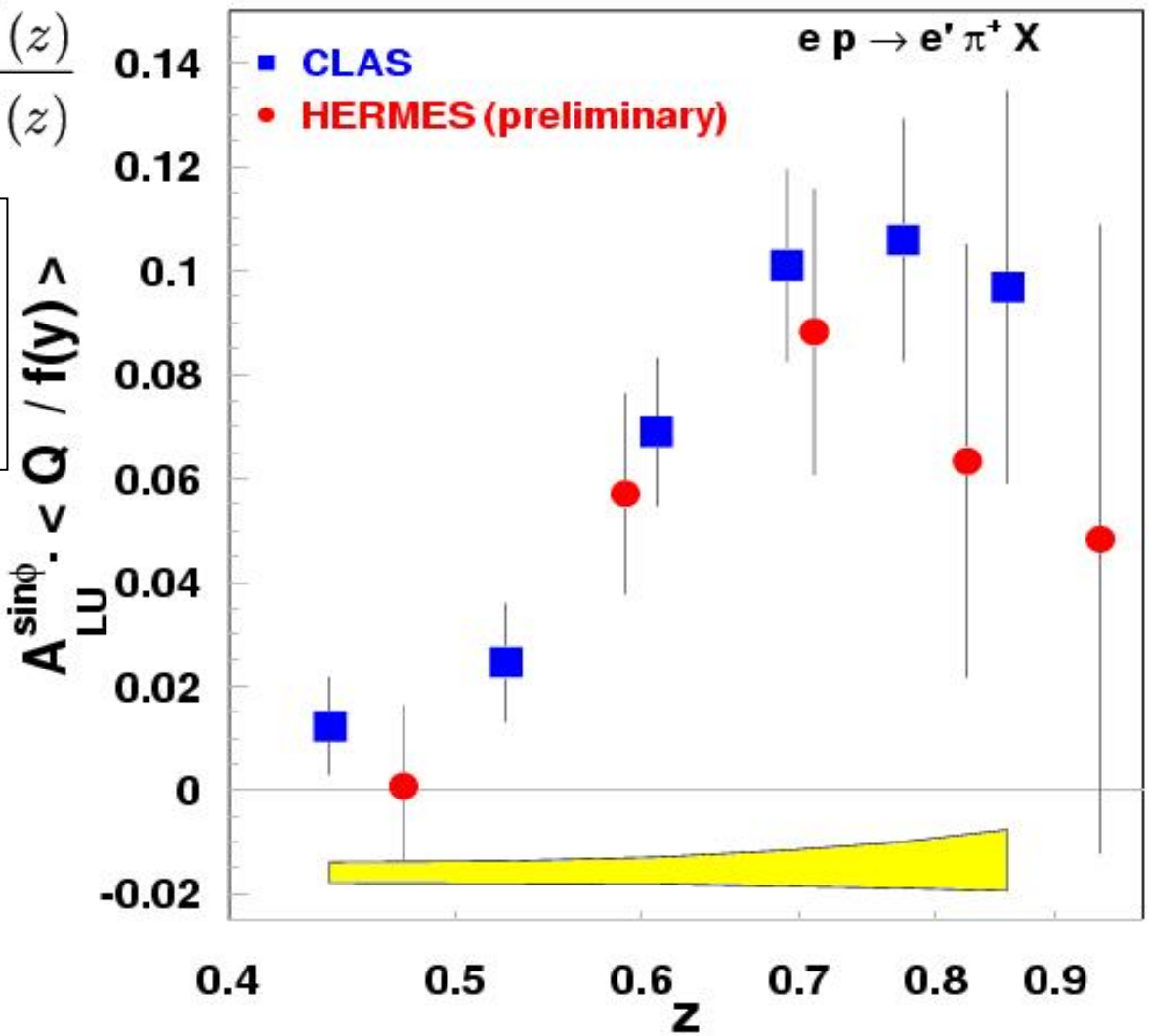


Beam SSA: sinϕ Moment

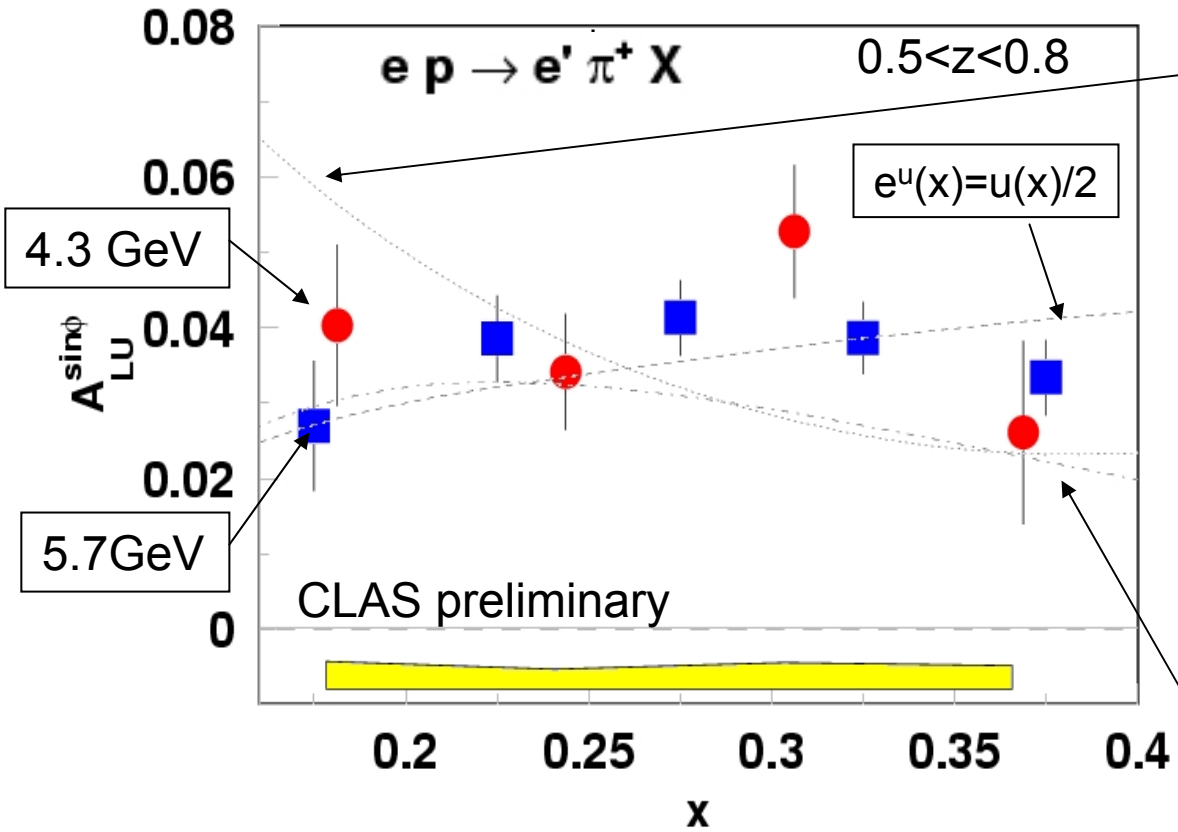
$$A_{LU} \propto \lambda_e \boxed{f(y)\frac{M}{Q}} \frac{H_1^{u,\pi^+}(z)}{D_1^{u,\pi^+}(z)}$$

Kinematic factor to be excluded in comparison (like D(y) depolarization function for g_1/f_1 case in A_1)

Beam SSA measurements for CLAS at 4.3GeV and HERMES (SPIN-2002) are consistent.



A_{LU} x-dependence: CLAS 4.3 vs. 5.7 GeV



Photon Sivers Effect Afanasev & Carlson (using BHS mechanizm)

Sivers contribution in case of beam SSA has the same source (FSI) as in case of target SSA, provides access to essential parameters with less ambiguities

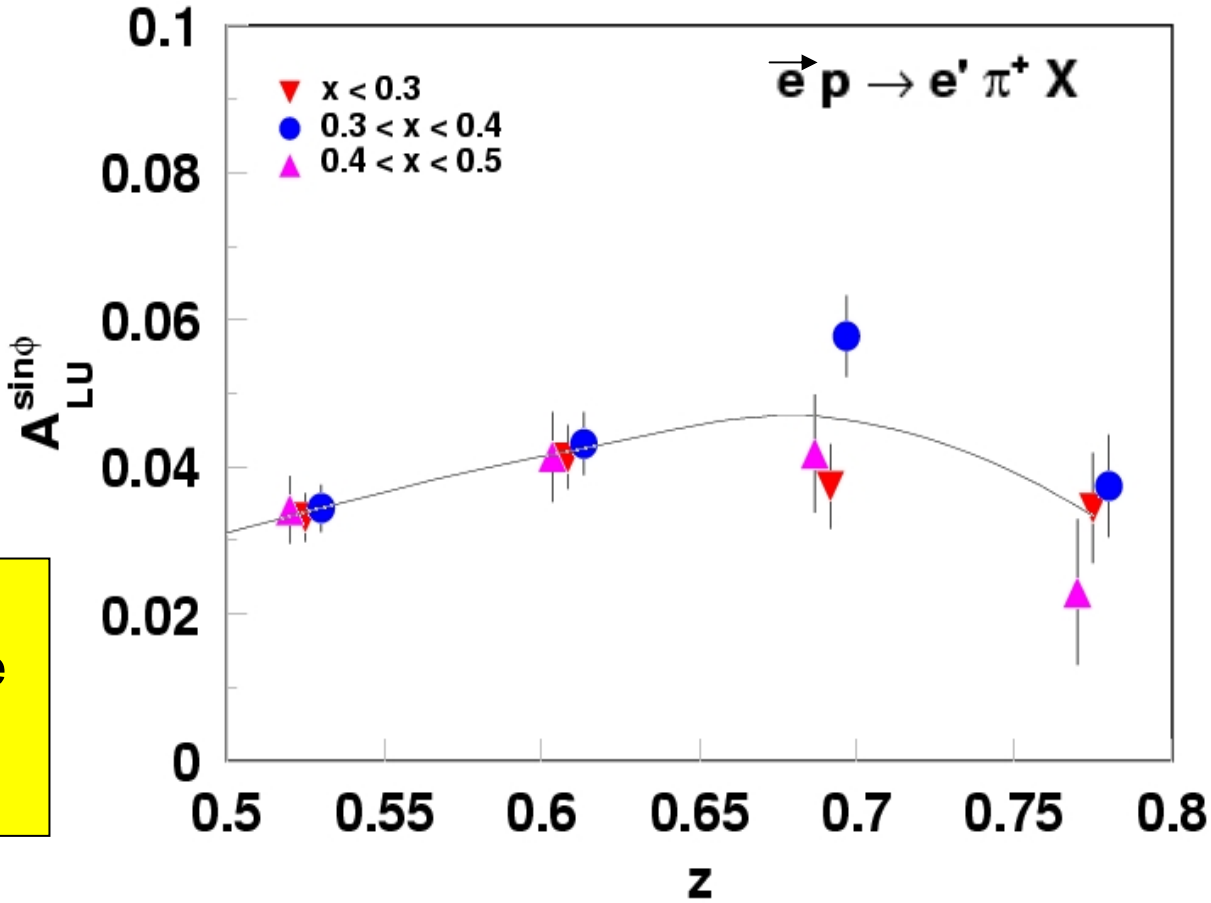
Beam SSA analyzed in terms of the Collins effect by Schweitzer et al. using e(x) from χQSM

4.3 GeV and 5.7 GeV data consistent

Factorization studies in CFR at CLAS

In terms of Collins fragmentation

$$A^{\sin\varphi}_{LU} \propto \lambda \frac{e(x)}{f(x)} \frac{H_1^{\perp}(z)}{D(z)}$$



No significant variation observed in z dependence of A_{LU} for different **x** ranges

First Extraction of e(x) from CLAS Data

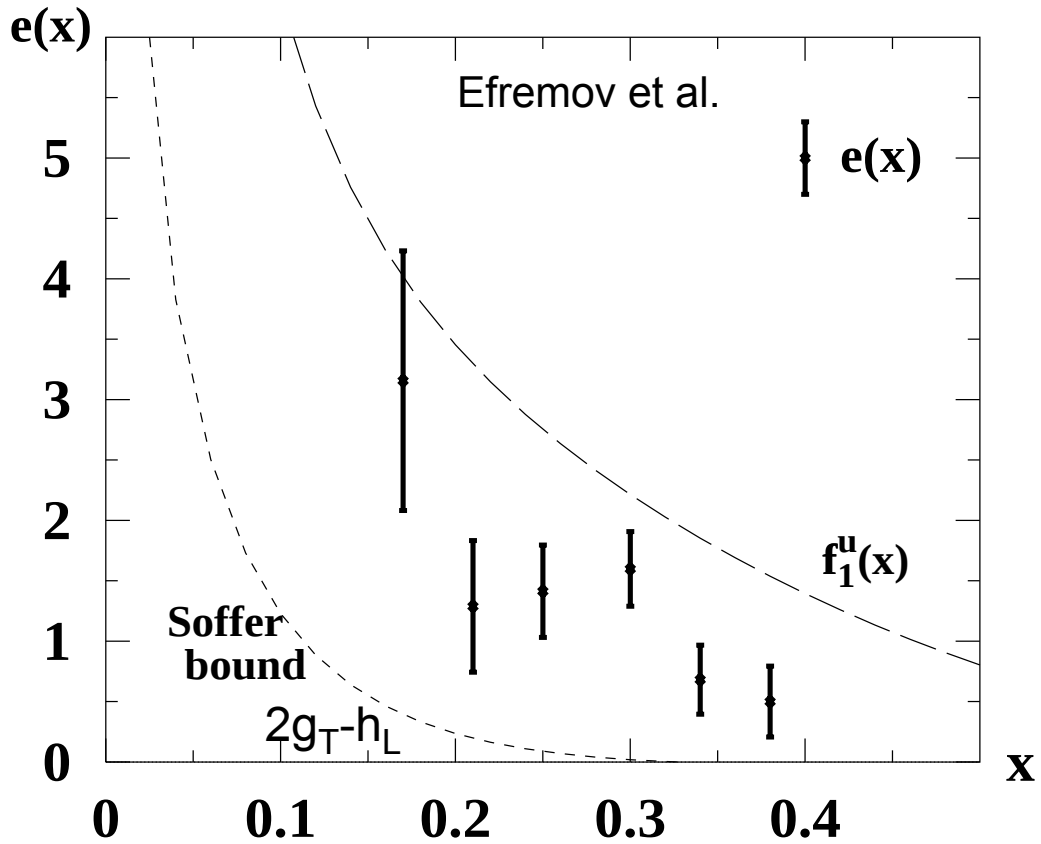
SSA analyzed in terms of the fragmentation effect

x-dependence of CLAS beam SSA (A_{LU})

+

z-dependence of HERMES target SSA (A_{UL})

First glimpse of Twist-3 e(x)



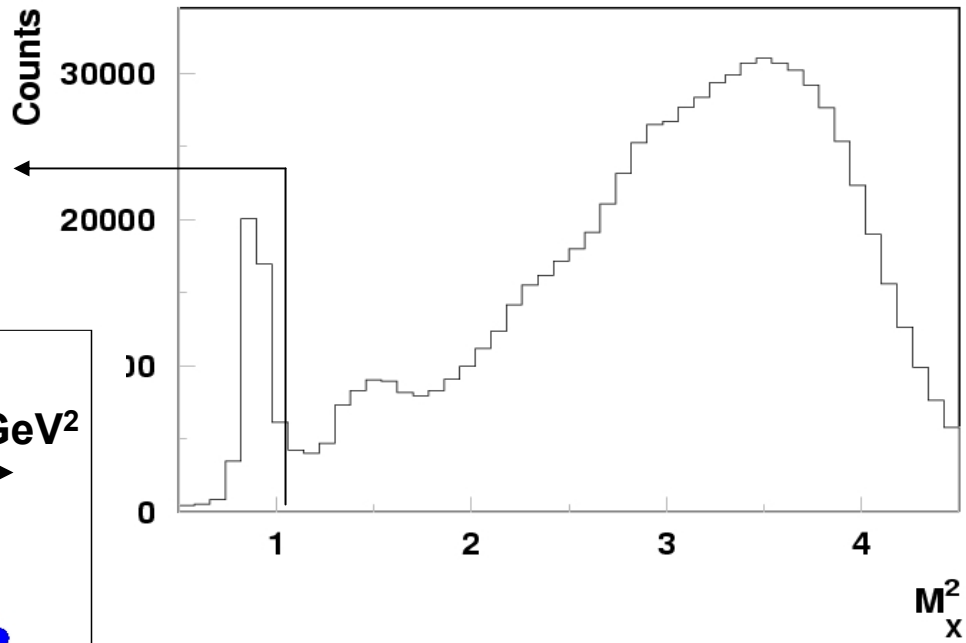
$$\int_0^1 e(x) = \frac{2\sigma_{\pi N}}{m_u + m_d}$$

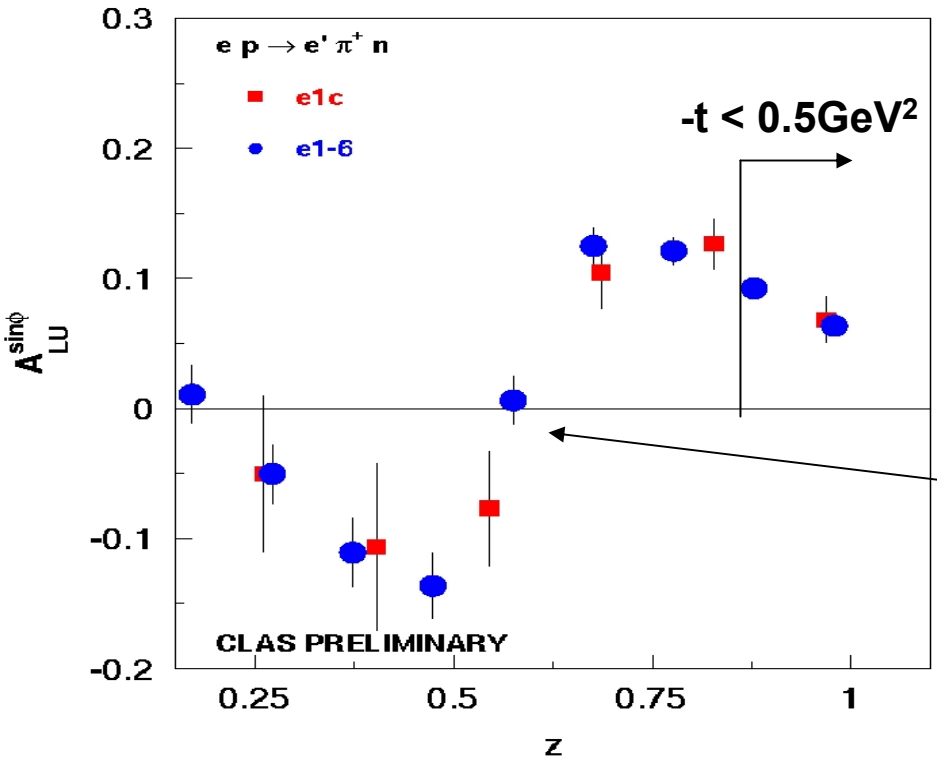
Jaffe,Ji 1992

Hard exclusive processes

$ep \to e'\pi^+ n$

- detect $e'\pi+$
- identify neutron from M_X
- $Q^2>2.5$, $W^2>5$

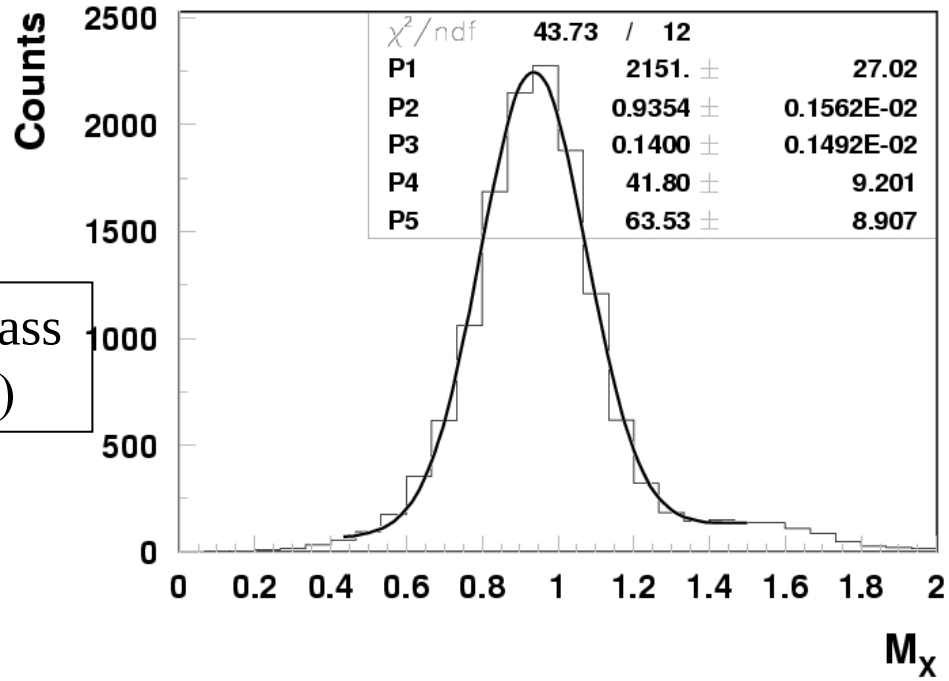




Sign flip at z ~ 0.5 (energy of γ^* shared between n and $\pi+$)

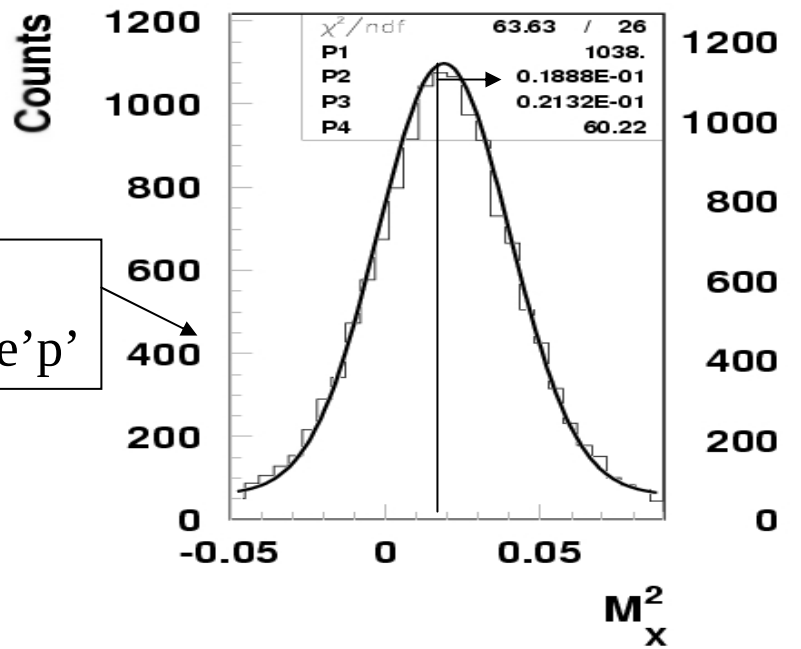
ep->e'pπ^0

missing mass of e'π^0 (2γ)

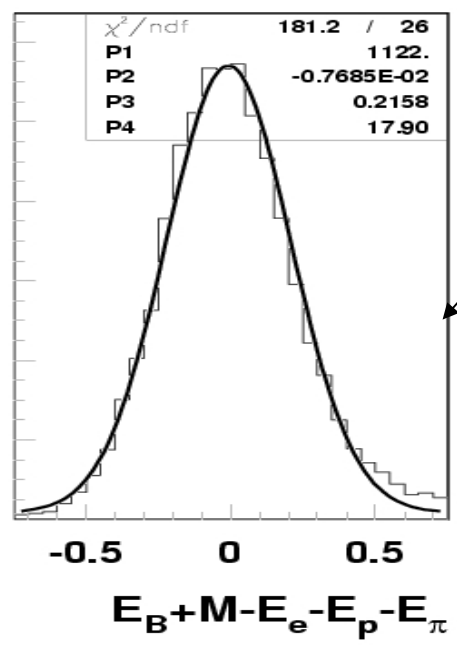


Exclusive production with detection of all final state particles!

missing mass of e'p'

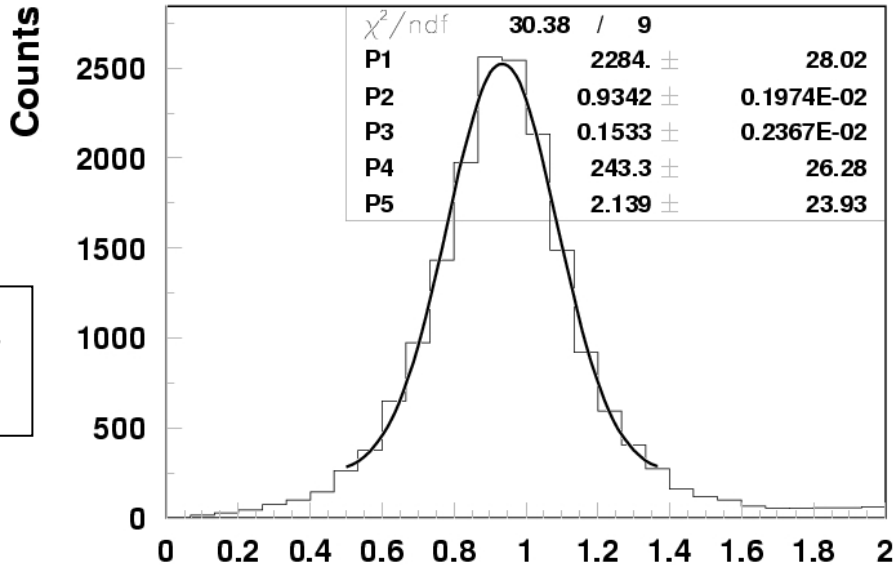


missing energy of epπ^0 (GeV)



ep->e'pγ

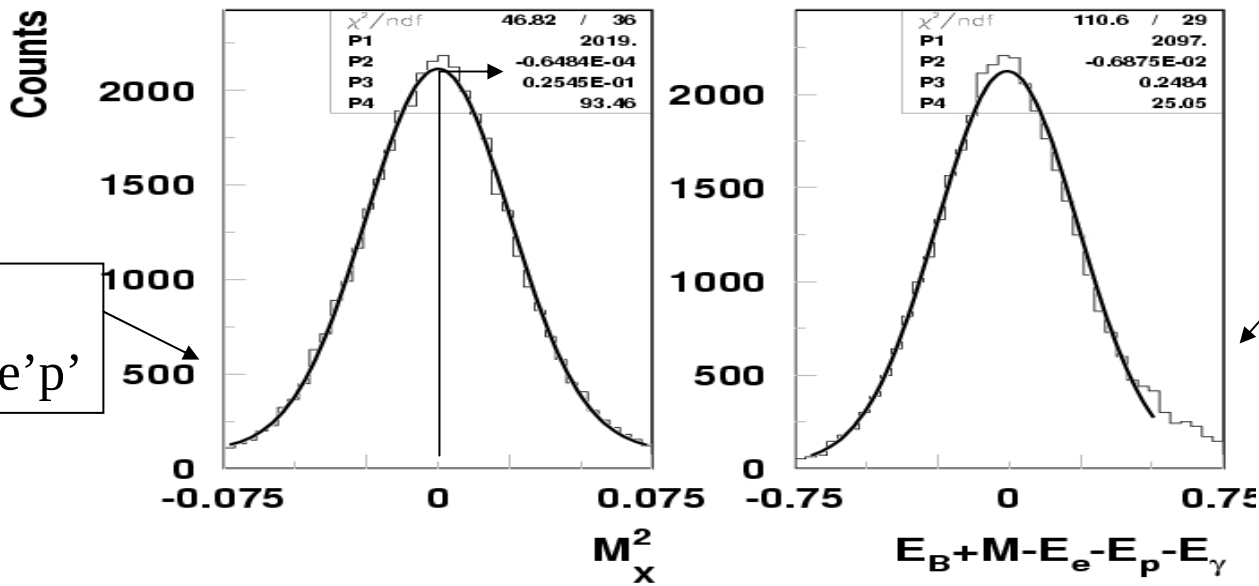
missing mass of e'γ



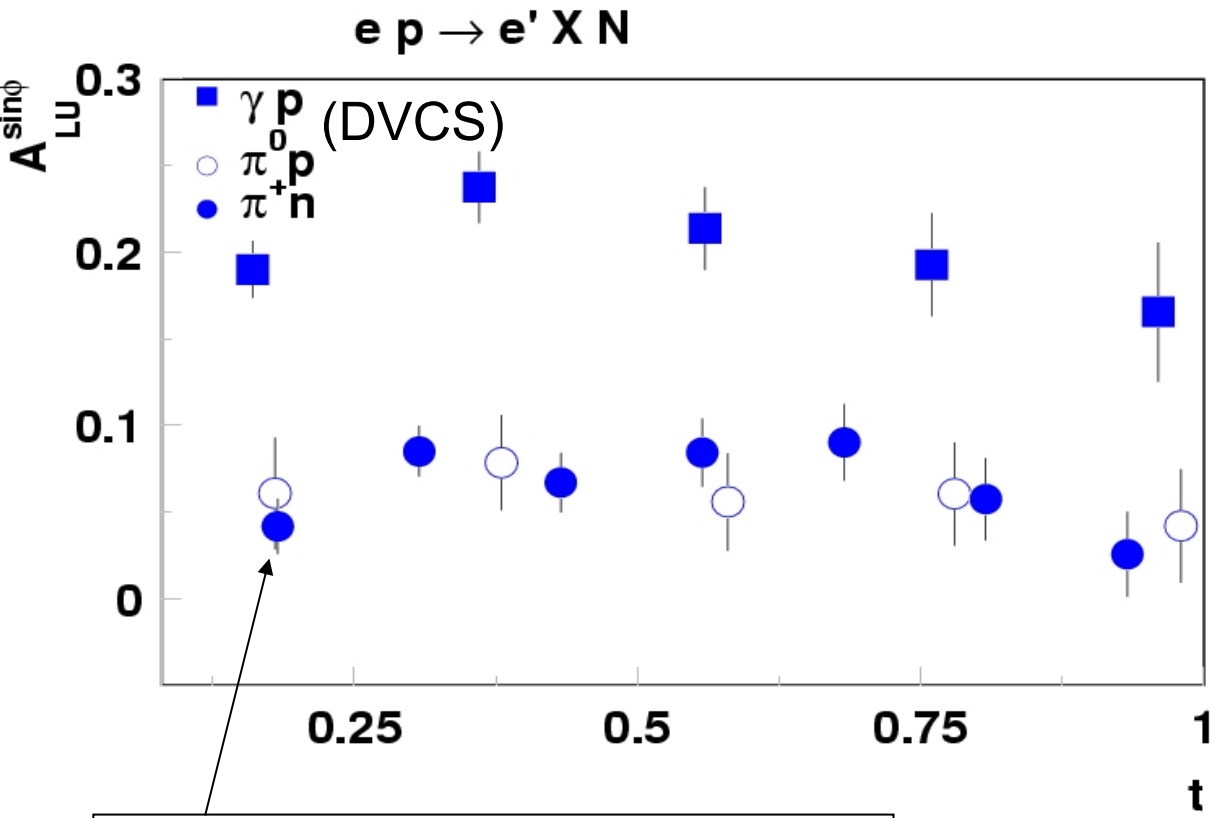
Exclusive production with detection of all 3 final state particles!

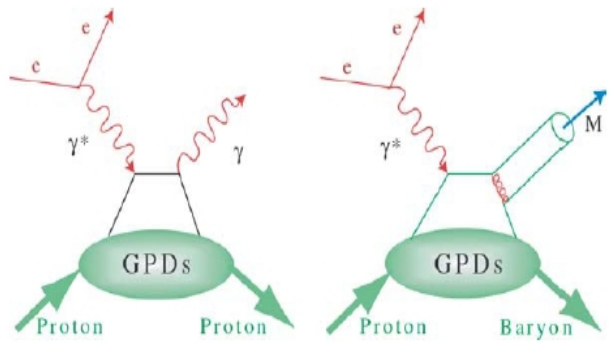
missing mass of e'p'

missing energy of epγ (GeV)



SSA t-dependence (CLAS 5.7GeV)





In SSA, certain cancelation expected for higher order and higher twist corrections. Belitsky hep-ph/0307256

No sign flip in A_{LU} for exclusive π+ compared to SIDIS

More exclusive asymmetries from CLAS in P.Bosted's talk.

Summary

- **Current CLAS data are consistent with a partonic picture, and can be described by a variety of theoretical models**
- **No x/z-dependence observed in single and double spin asymmetry measurements (consistent with factorization).**
- **Single-Spin asymmetries extracted for SIDIS $\pi+$ are in agreement with predictions from χQSM model .**
- **A non-0 $\langle \sin 2\phi \rangle$, measured for the first time, may provide a direct access to Collins fragmentation.**

- **Global analysis of SSA for polarized beam and target needed to separate contributions from different mechanisms and extract corresponding distribution functions.**