Spin and Azimuthal Asymmetries in DIS at CLAS

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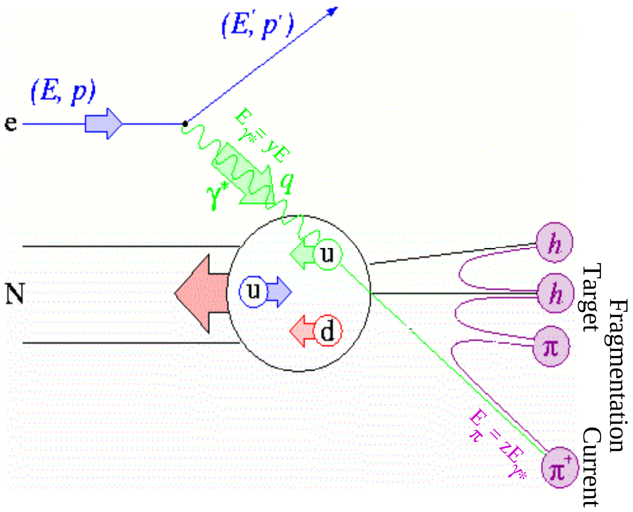
- Physics goals
- The Experiment
- Target & Beam SSA
- Measurements with CLAS++
- Outlook

Polarized Semi-Inclusive DIS



$$
\begin{aligned}
Q^2 &= 4EE'\sin^2(\tfrac{\theta}{2}) \\
\nu &= E - E' \\
x &= \frac{Q^2}{2m\nu} \\
y &= \frac{\nu}{E} = \frac{p\cdot q}{p\cdot k} \\
z &= \frac{E_h}{\nu} \\
x_F &= \frac{p_L^*}{p_{L\,max}^*} \\
\eta &= \frac{1}{2} ln \frac{E+p_L^*}{E-p_L^*}
\end{aligned}
$$

Main goal:

- **Measure single beam and target spin asymmetries in $\vec{e}\vec{p} \rightarrow e'\pi^+ + X$.**
- **Extract information on underlying distribution and fragmentation functions.**

Measured SSA in DIS:

- **Significant target SSA in $e\vec{p}\uparrow \rightarrow e'\pi^+ + X$ at HERMES & SMC**
- **Consistent with 0 beam SSA $\vec{e}p \rightarrow e'\pi^+ + X$ at low z.**

Major sources of SSA:

- **T-odd fragmentation functions (Collins effect)**
- **T-odd distribution functions (Sivers effect)**

SSA in SIDIS

Physics objects accesible in SSA

- The intrinsic transverse momentum of quarks
- The transverse spin of quarks (transversity and other chiral-odd distribution functions) in the fragmentation.
- Time-odd distribution functions.
- Spin dependent fragmentation
- Higher twists and quark-gluon correlations in DIS.
- Transition from semi-inclusive to exclusive

The method:

- Measurement of azimuthal distributions of hadrons in semi-inclusive and semi-exclusive DIS.

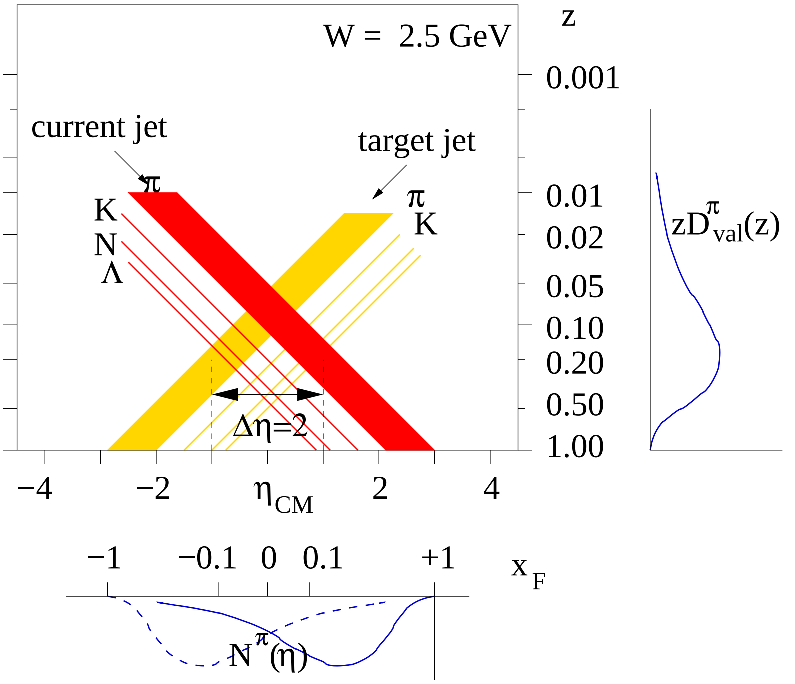
SIDIS kinematics at CLAS

Lower the energy smaller the z-range ($Q^2 > 1, W^2 > 4$).

CLAS 4-6GeV

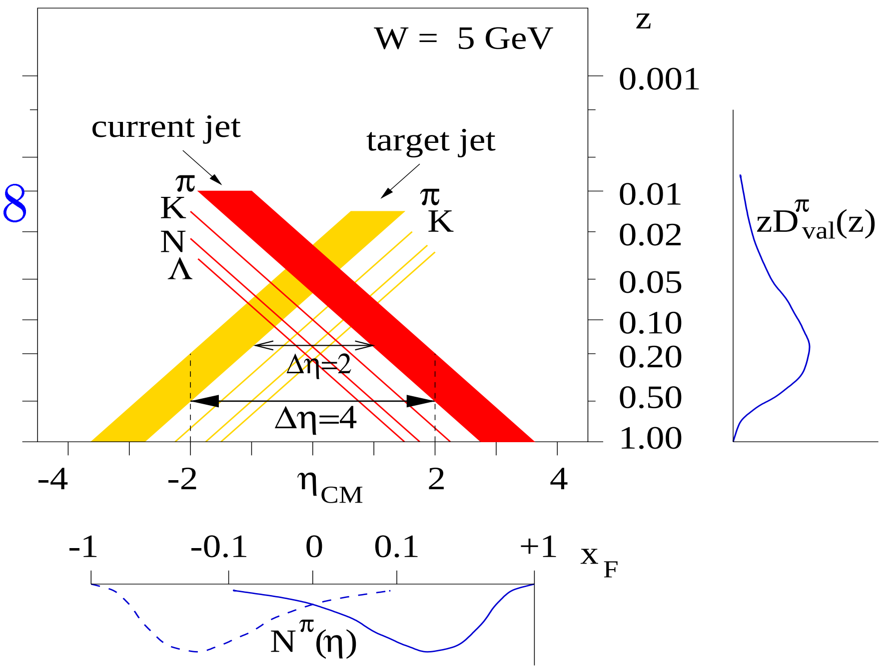
- $0.5 < z < 0.8$
- $x_F > 0.1$

Mulders et al. $\rightarrow$



CLAS++

- $0.3 < z < 0.8$
- $x_F > 0.0$

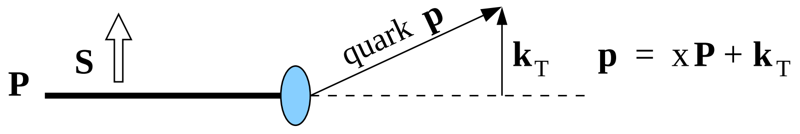


At 12 GeV the kinematical range where the current and target fragmentations could be separated is increasing, making also accessible studies with Kaons.

Classification of distribution functions:

SSA originates from multi-parton correlation and intrinsic quark transverse momentum k_T.

Partons carry a fraction x of proton's longitudinal momentum P and tranverse component k_T



Distribution functions from Mulders & Co.

distribution functions		chirality even	chirality odd
twist 2	U	$\mathbf{f_1}$	$h_1^\perp$
	L	$\mathbf{g_{1L}}$	$h_{1L}^\perp$
	T	$f_{1T}^\perp, g_{1T}$	$\mathbf{h_1}$ $h_{1T}^\perp$
twist 3	U	$f^\perp$	$\mathbf{e}$
	L	$g_L^\perp$	$\mathbf{h_L}$
	T	$\mathbf{g_T}$ $g_T^\perp$	h_T $h_T^\perp$

$f_1(x) \equiv \int d^2k_T f_1(x, k_T)$.

$g_1(x) \equiv \int d^2k_T g_{1L}(x, k_T)$.

$$\boldsymbol{h_{1L}^{\perp(1)}(x) \equiv \int d^2k_T \left(\frac{k_T^2}{2M_h^2}\right) h_{1L}^\perp(x, k_T)}.$$

Contributions to σ in polarized SIDIS

Leading twist

$$
\begin{aligned}
\sigma_{UU} &\propto (1-y+y^2/2)\sum_{a,\bar{a}} e_a^2 x f_1^a(x) D_1^a(z) \\
\sigma_{LL} &\propto \lambda_e S_L y(2-y)\sum_{a,\bar{a}} e_a^2 x g_1^a(x) D_1^a(z) \\
\sigma_{UT}^{\sin\phi} &\propto S_T(1-y)sin\phi_C \sum_{a,\bar{a}} e_a^2 x h_1^a(x) H_1^{\perp a}(z) \\
\sigma_{UL}^{\sin 2\phi} &\propto S_L 2(1-y)sin2\phi \sum_{a,\bar{a}} e_a^2 x h_{1L}^{\perp}(x) H_1^{\perp a}(z) \\
\sigma_{UT}^{\sin\phi} &\propto S_T(1-y)sin\phi_C' \sum_{a,\bar{a}} e_a^2 x f_{1T}^{\perp}(x) D_1^{\perp a}(z) \\
\sigma_{UU}^{\cos 2\phi} &\propto (1-y)cos2\phi \sum_{a,\bar{a}} e_a^2 x h_1^{\perp}(x) H_1^{\perp a}(z)
\end{aligned}
$$

- λ_e, S_L, S_T electron and proton long. and trans. pol.
- $\sum_{a,\bar{a}} \rightarrow$ sum over quarks and anti-quarks.

$D_1, H^{\perp}$ unpolarized and polarized ("Collins") fragmentation functions.

$$H_1^{\perp}(z) \approx a\, z\, D_1(z) \quad \text{with} \quad a = 0.15 \pm 0.03 \;\; .$$

Contributions from T-odd fragmentation $H_1^{\perp a}(z)$ and/or distribution functions $(f_{1T}^{\perp}, h_1^{\perp})$.

Twist-3 contributions to σ in SIDIS

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

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

The twist-3 chiral-odd function $h_L^a(x)$ relevant for a longitudinally polarized proton.

$$h_L(x) = 2x \int_x^1 dy\,\frac{h_1(y)}{y^2} + \overline{h}_L(x)\,.$$

The twist-3 chiral-odd function $e^a(x)$ relevant for a longitudinally polarized lepton beam and unpol. target.

$h_L(x)$ and $e(x)$ are unique windows into quark gluon correlations in the nucleon.

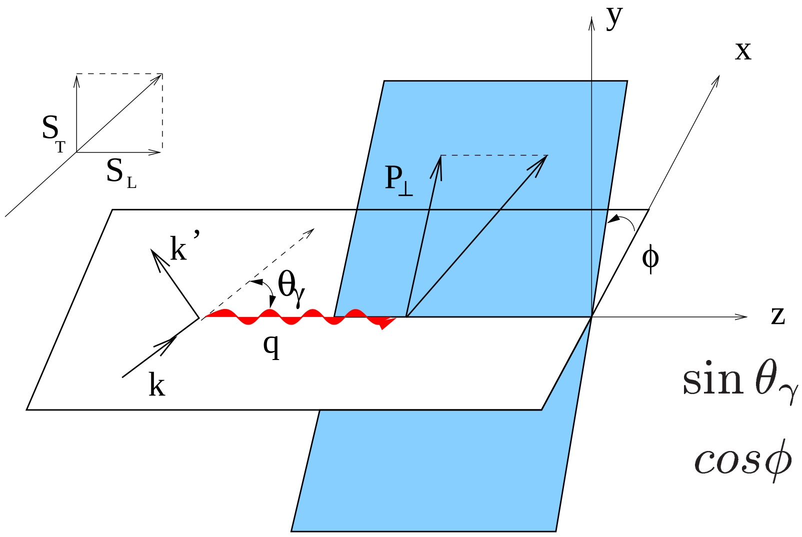
The lower bound for $e(x)$ is given by the Soffer inequality $e(x) > 2g_T - h_L$

Azimuthally Weighted Asymmetries

Analyzing powers for beam (target) longitudinal polarization cases

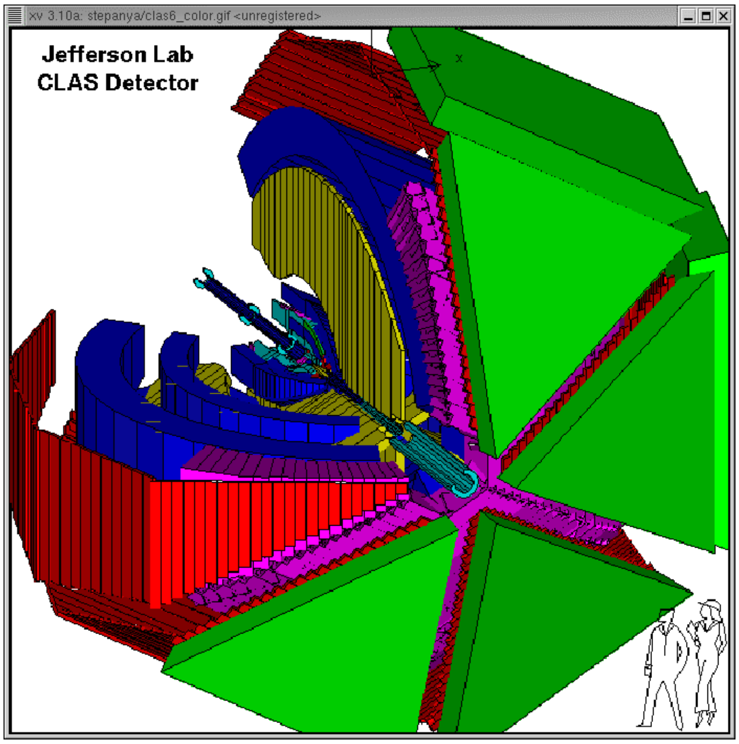
$$A_{LU[UL]}^{\sin\phi}(x) = \frac{\int \mathrm{d}y\,\mathrm{d}z\,\mathrm{d}\phi\,\sin\phi\,\frac{1}{P}\left(\frac{\mathrm{d}^4\sigma^+}{\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z\mathrm{d}\phi} - \frac{\mathrm{d}^4\sigma^-}{\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z\mathrm{d}\phi}\right)}{\frac{1}{2}\int \mathrm{d}y\,\mathrm{d}z\mathrm{d}\phi\left(\frac{\mathrm{d}^4\sigma^+}{\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z\mathrm{d}\phi} + \frac{\mathrm{d}^4\sigma^-}{\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z\mathrm{d}\phi}\right)}$$

the $+/-$ denotes positive/negative helicity of the electron (proton), P lumi weighted polarization.



$$\sin\theta_\gamma \approx \frac{2Mx}{Q}\sqrt{1-y}$$
$$cos\phi = \frac{[\vec{q}\times\vec{k}][\vec{q}\times\vec{P}_h]}{|\vec{q}\times\vec{k}||\vec{q}\times\vec{P}_h|}$$

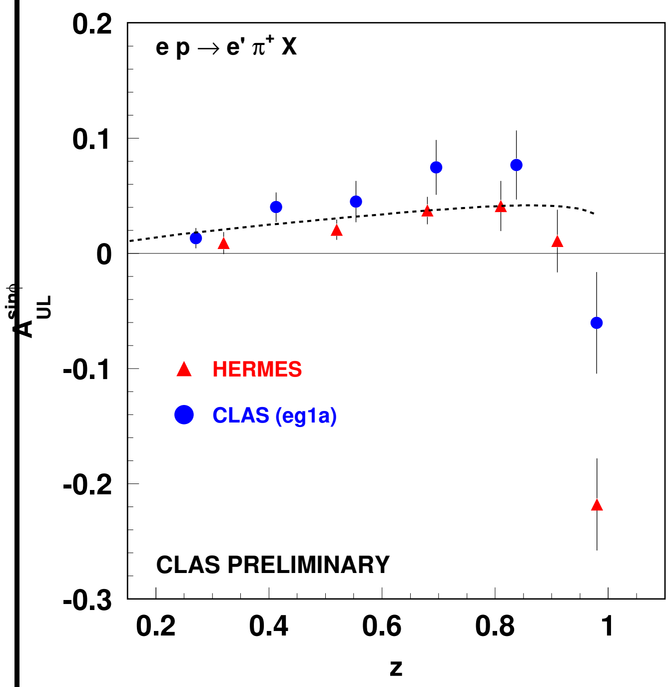
CLAS EG1/E1 experiments

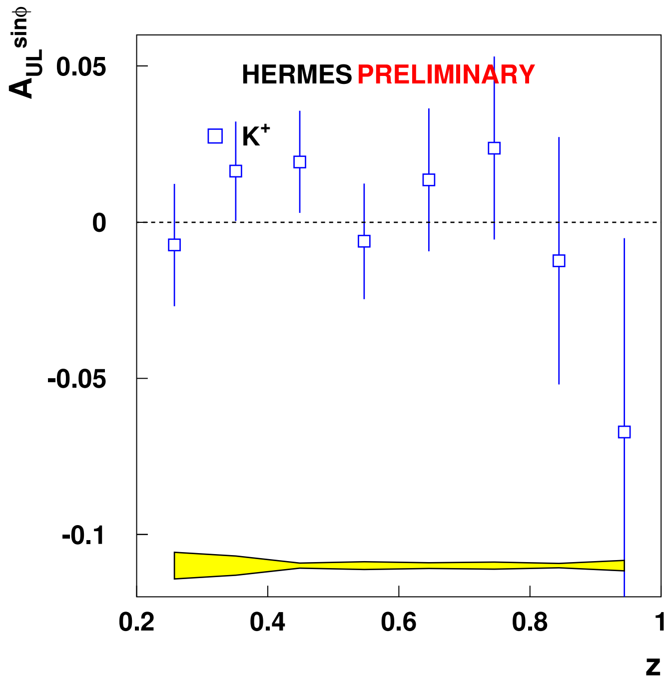


Target **Beam Energy** **Beam Polarization** **Target Polarization**	**hydrogen,NH$_3$** **4.3GeV** 0.65 ± 0.05 **(longitudinal)** 0.5 ± 0.05 **(longitudinal)**
Acceptance in e_θ **Acceptance in** π_θ	$20 < \theta < 50 < e_\theta >= 32^o$ $8 < \theta < 65 < \pi_\theta >= 23^o$
DIS cuts	$Q^2 > 1$ **hard scattering** $W^2 > 4$ **small res. contribution** $y < 0.85$ **small rad. effects**
Cuts on π^+	$0.5 < z < 0.8$ **current fragment.** $M_X > 1.1$ **exclude exclusive ev.** $0.02 < P_\perp < 1.1,\quad \phi$ **well defined**
$\gamma^* p -> \pi^+ + X$	**400K rec. events in e1c** **2.7M rec. events in eg1**

LPol Target SSA for π^+ and K^+

$$A_{UL} \propto D_L(y) \times \frac{h_L^u(x)}{u(x)} \frac{H_1^u(z)}{D_1^u(z)}$$





The z-dependence of target SSA from CLAS is consistent with HERMES measurement.

The behavior of target SSA for π^+ and K^+ is consistent in agreement with factorization and u-quark dominance.

Higher twist contributions

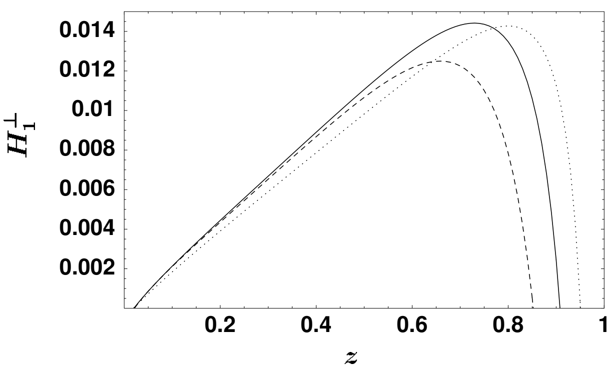
Semi-inclusive

When neglecting the interaction dependent part in distribution function h_L (Boglione & Mulders):

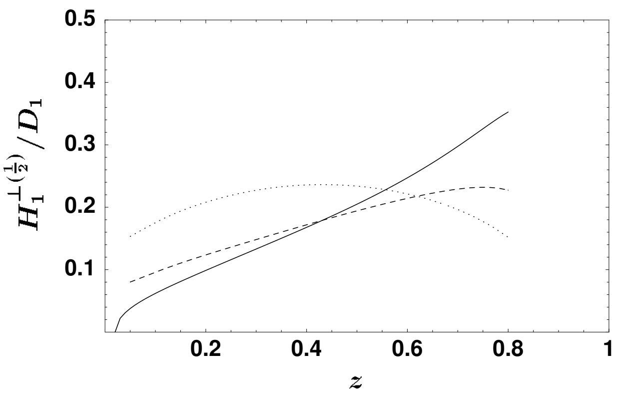
$$A_{UL}^{\sin\phi} \propto x\,\frac{h_L}{f_1}[H_1^{\perp(1)}(z) + \frac{\tilde{H}(z)}{2z}]/D(z)$$

$$\frac{\tilde{H}^a(z)}{z} = \frac{d}{dz}\left(zH_1^{\perp(1)a}(z)\right),$$

the HT term with $\tilde{H}(z)$ gives a contribution with opposite sign



The Collins function for different values of constituent quark mass.

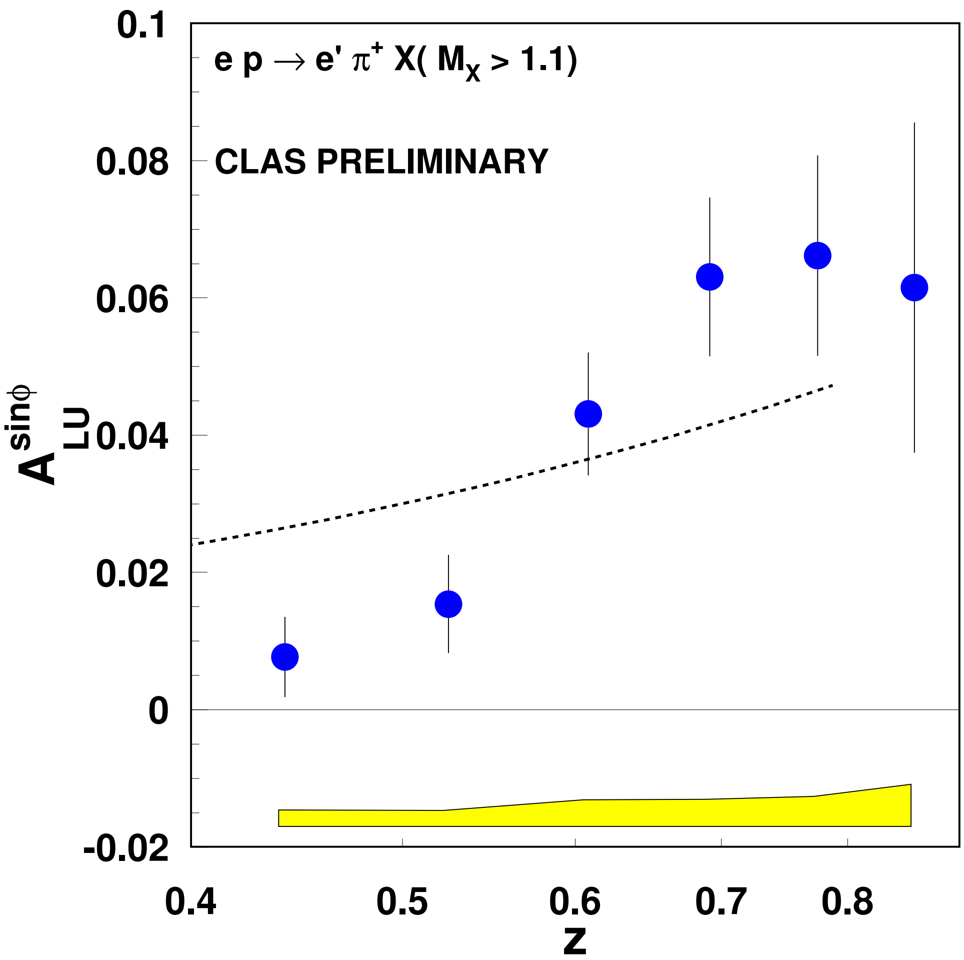


Comparison with different parameterizations based on HERMES data.

The target SSA may have a significant contamination from HT fragmentation function at large z

Beam SSA: $\sin\phi$ moment

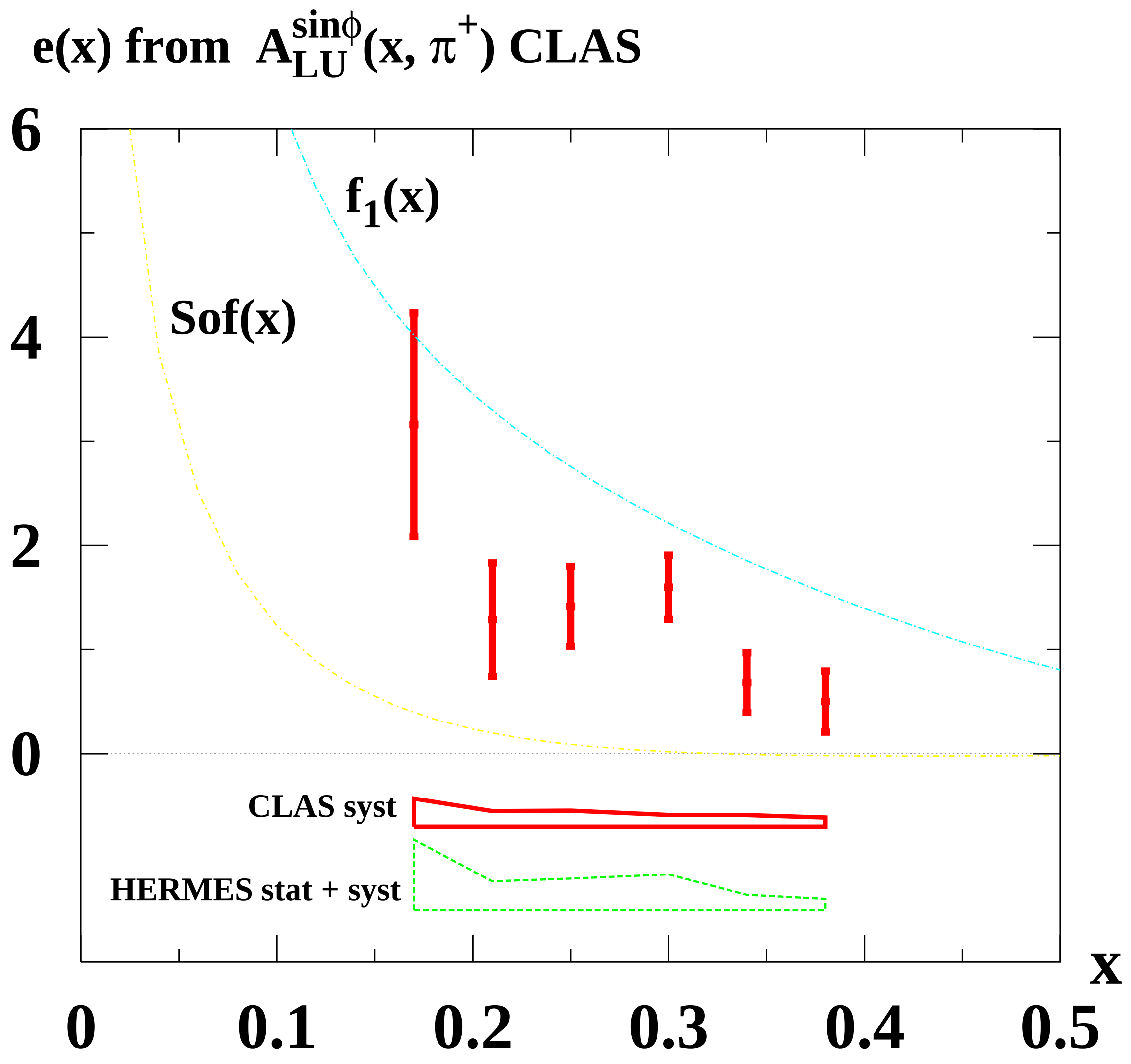
$$A_{LU}^{\pi^+} \propto \lambda_e \frac{H_1^{u,\pi^+}(z)}{D_1^{u,\pi^+}(z)}$$



The z dependence of A_{LU} (CLAS e1c 4.3GeV data), may provide information on the "Collins" function. The dashed line is a fit to Collins function from HERMES A_{UL} data by Efremov et al.

Main contribution to systematic error from acceptance and beam polarization.

First extraction of $e(x)$ from CLAS data

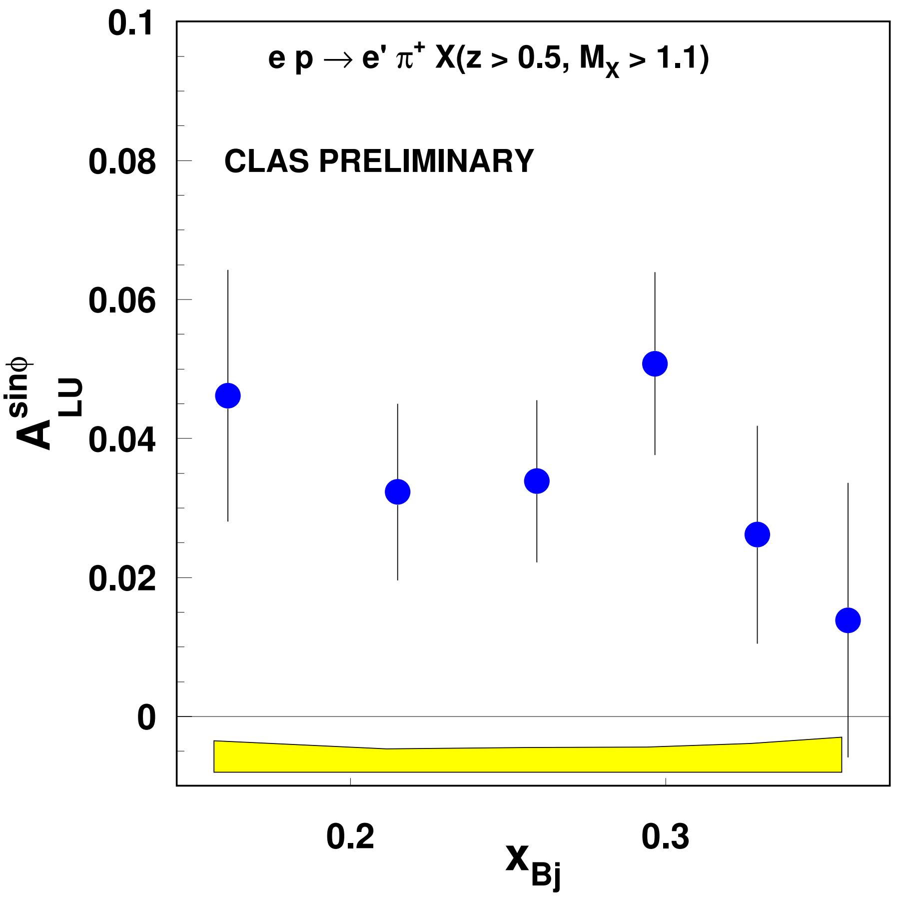


Twist-3 $e(x)$ extraction (Efremov et al.) from CLAS A_{LU} measurement.

Upper and lower curves are for f(x) and lower bound for $e(x)$ given by the Soffer inequality $(e(x) > 2g_T - h_L)$.

Beam SSA: $\sin\phi$ moment

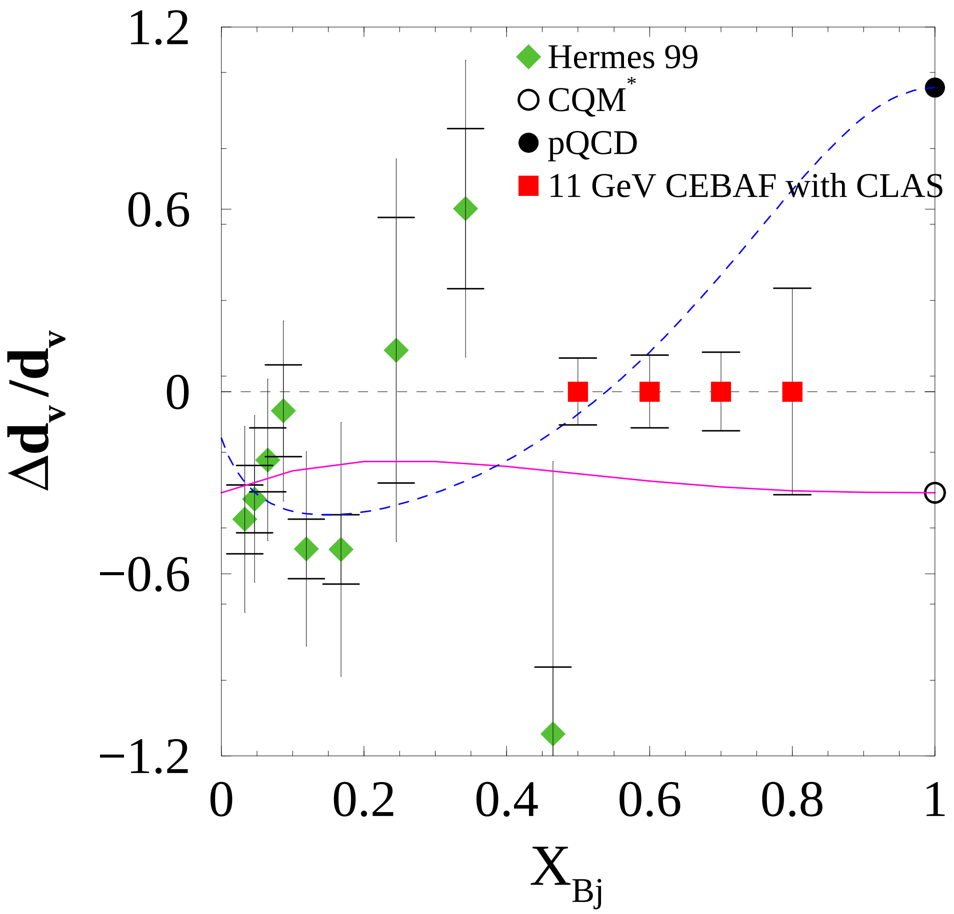
$$A_{LU}^{\pi^+} \propto \lambda_e \frac{e^u(x)}{u(x)}$$



The relatively flat x dependence of A_{LU} (CLAS e1c 4.3GeV data) is consistent with bag model calculations of the twist-3 distribution function $e(x)$ (Signal NP B 497 1997).

DSA: A_{LL}, g_1, D_1 Flavor decomposition

$$A_{LL} \propto \frac{\sum_{a,\bar{a}} e_a^2 g_1^a(x) D_1^a(z)}{\sum_{a,\bar{a}} e_a^2 f_1^a(x) D_1^a(z)}$$

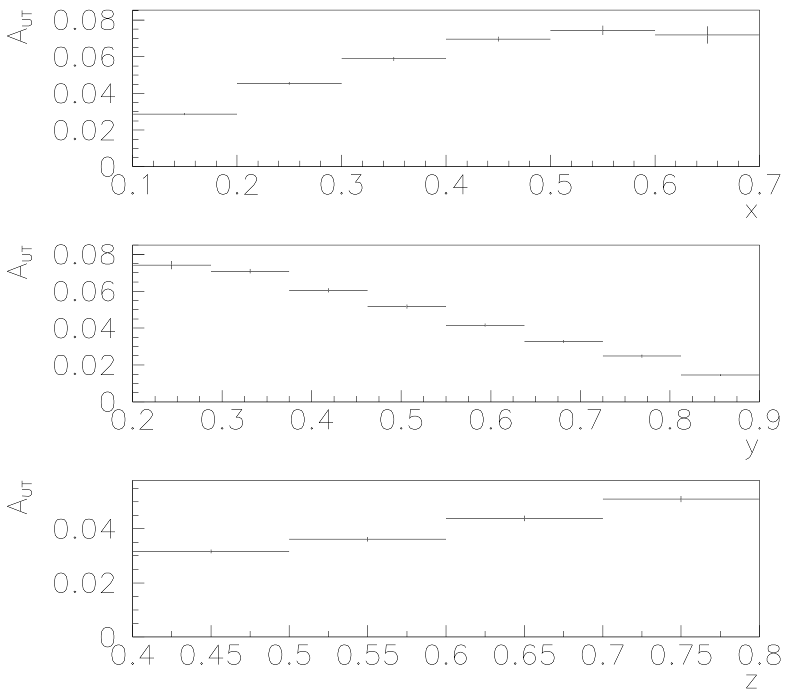


Measurement of A_1 asymmetry for different hadrons and targets allow extraction of helicity distributions (g_1^q, $g_1^u(x) = u(x), g_1^d(x) = d(x)$...)

Transverse Target SSA for π^+

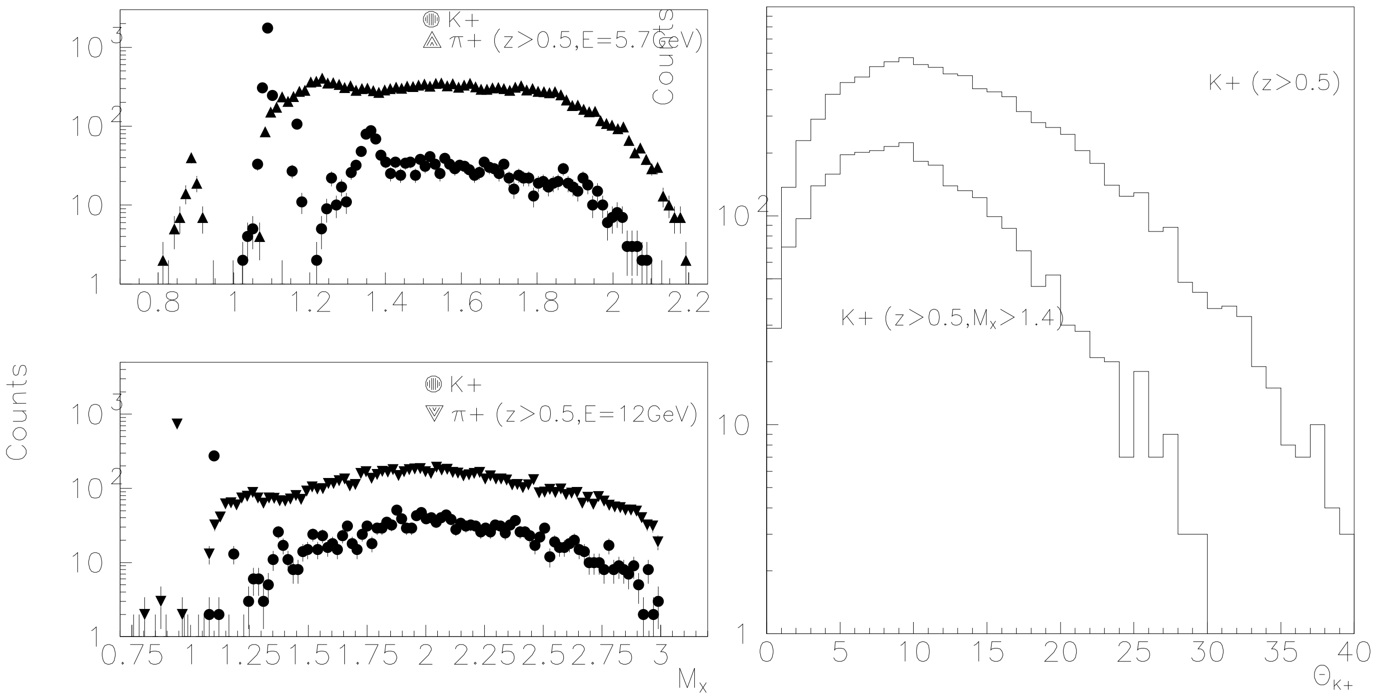
Collins Asymmetry at CLAS++

$$A_{UT} \propto D_T(y) * \frac{h_1^u(x)}{u(x)} \frac{H_1^u(z)}{D_1^u(z)} \leftarrow$$



z-dependence of SSA is important for separation of different contributions (no significant z-dependence expected for Sivers type SSA)

Kinematics at 12 GeV



Missing mass M_X and polar angle θ_{K+} distributions in $\gamma^* p \to h^+ + X$ for leading particles $(z > 0.5)$. The triangles are for K^+ and circles for π^+.

Good e^-/π^- and π^+, K^+, p separation required at scattering angles $5^o < \theta_{LAB} < 30^o$, for flavor separation of different DFs and FFs.

Direct comparison of π^+ and K^+ SSA will provide a test of factorization and u-quark dominance in SIDIS.

Summary

- Sign and magnitude of CLAS target SSA are in qualitative agreement with published data (HERMES 1999-2000).
- Significant single-beam spin asymmetry measured for the first time in π^+ electroproduction in DIS.
- Significant difference observed in the z-depenence of target and beam single spin asymmetries in DIS.
- Measurements of beam and target SSA in DIS region are in progress using CLAS eg1b(polarized NH_3) and e1-6 (unpolarized hydrogen) data with higher energy ($E_e = 5.7GeV$) and much higher statistics (8billion triggers).

  extraction of beam and target SSA for other hadrons (π^0, π^-, K^+, ρ...).

  extraction of Q^2 dependency of beam and target SSA for fixed x

Outlook

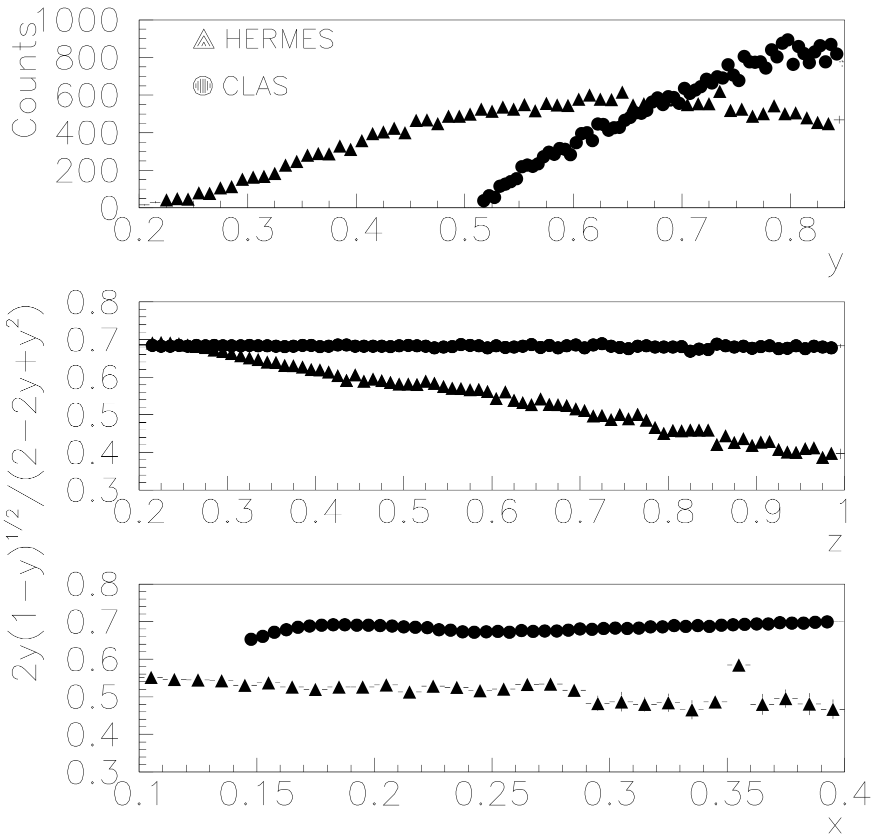
- **There is a wide range of essentially unexplored distribution and fragmentation function which are accessible at CLAS++ in spin and azimuthal asymmetries in hadron distributions in semi-inclusive and exclusive processes on nucleons and nuclei.**
- **Extraction of beam and target single and double spin asymmetries in a wide range of x, z, Q^2 for different hadrons ($\pi^+, \pi^0, \pi^-, K+, \rho$) and targets will provide additional test of factorization and will enable flavor decomposition of different chiral-odd and T-odd distribution and fragmentation functions.**

CLAS++ detector combine high ;uminosity, large acceptance, good PID (separation of e^-/π^- and $\pi^+/K^+, p$) and capability to run with longitudinally and transversely polarized targets required for full-scale SIDIS studies.

Kinematics: A_{LU} vs y

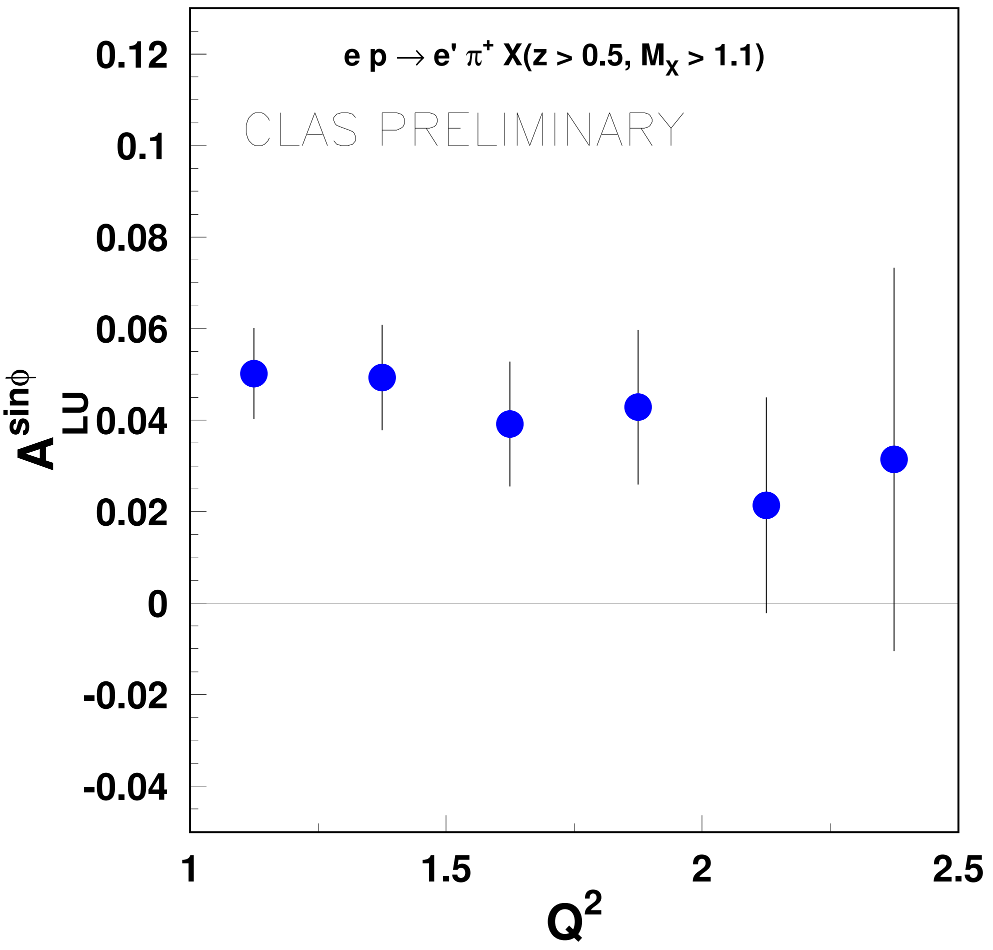
The kinematic factor in beam SSA

$$A_{LU}(y) = \frac{\sigma_{LU}}{\sigma_{UU}} \propto \frac{2y\sqrt{1-y}}{(2-2y+y^2)}$$



Kinematic suppression responsible for the difference in beam SSA from HERMES and CLAS!.

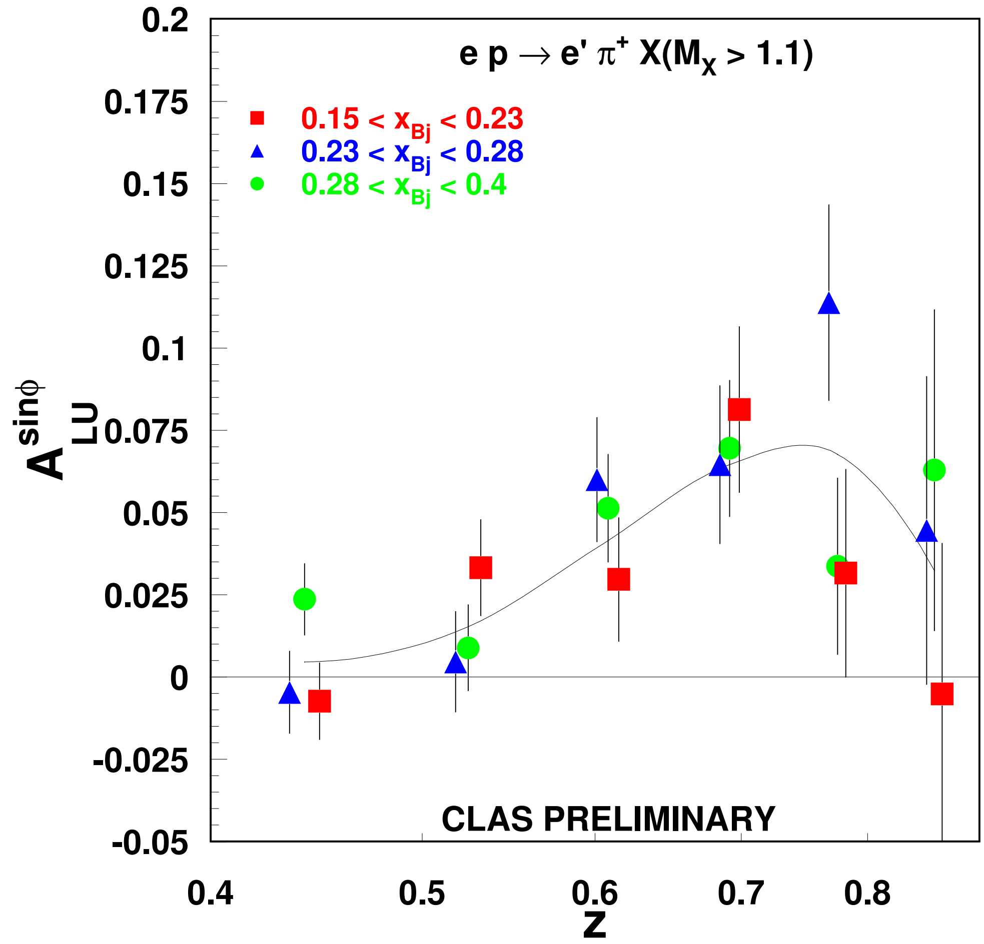
Beam SSA: Q^2-dependence



The beam SSA as a function of Q^2 extracted from the e1c data with 4.25GeV electrons.

More data at large Q^2 needed to define the trend.

Factorizing $A_{LU}(z)$

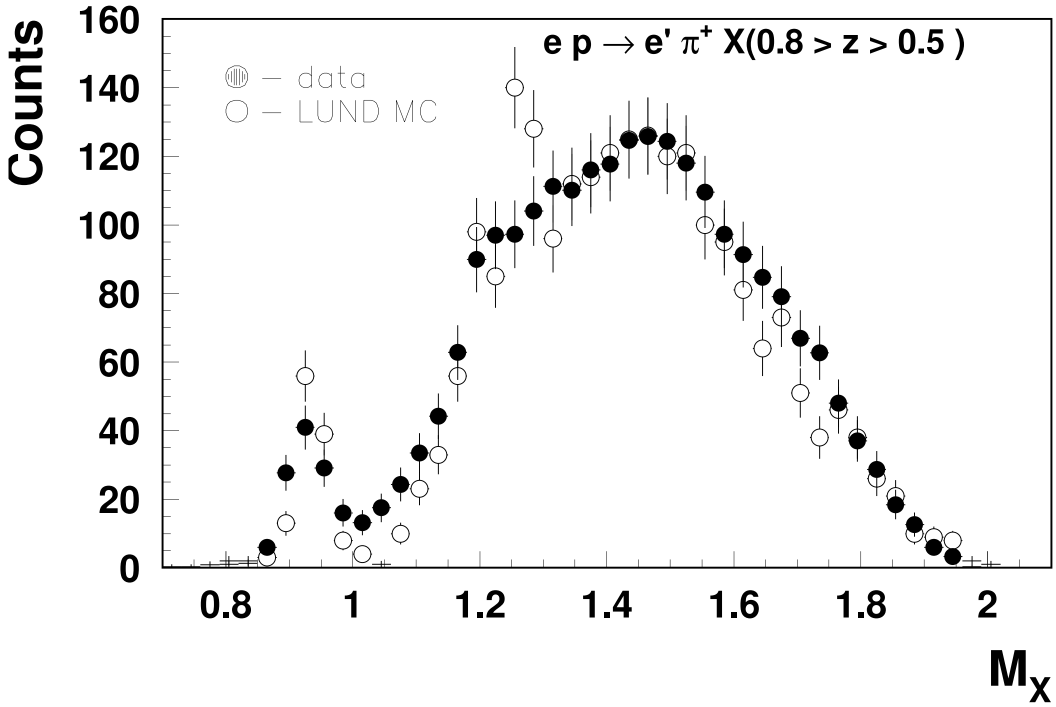


The beam SSA as a function of z for different ranges of Bjorken x from e1c 4.25GeV data. Beam SSA shows no significant variation of z dependence for different x.

MC reconstructed vs data

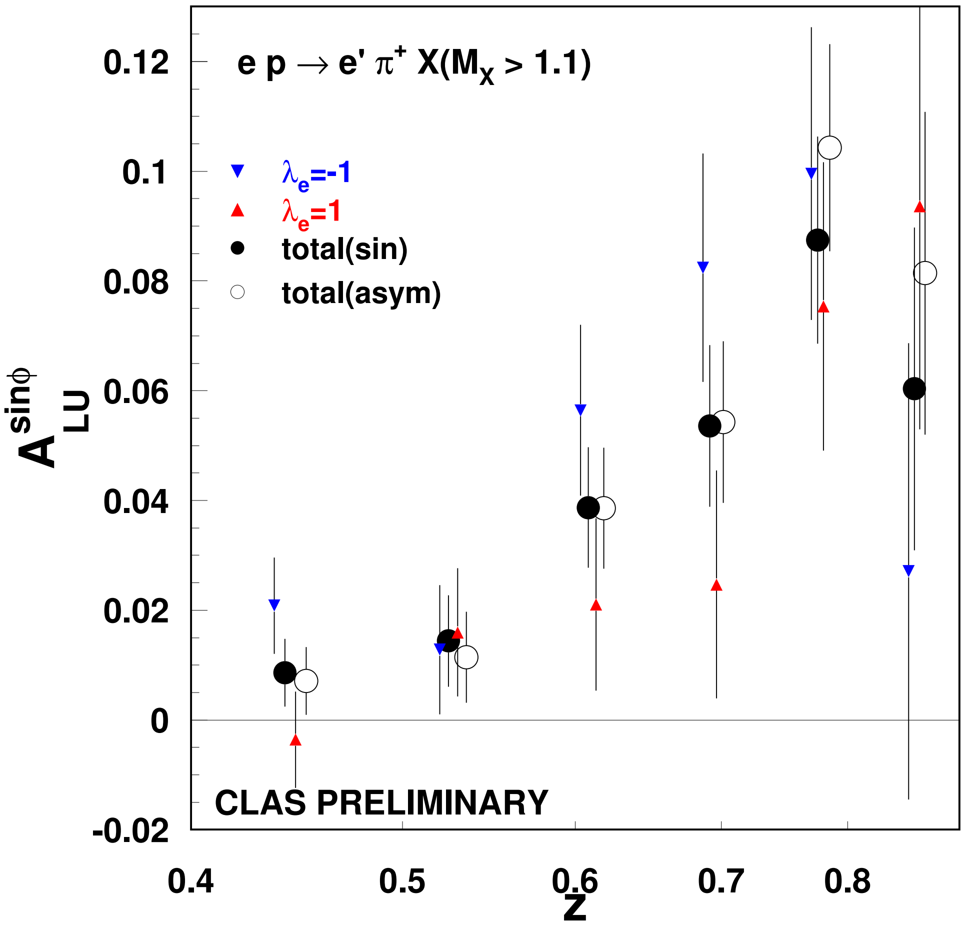
Adjustable parameters in LUND(JETSET) :

- longitudinal string breaking probability
- average transverse momentum
- diquark production parameter



CLAS 4.3GeV data (full circles) and LUND (PEPSI+LEPTO+JETSET) MC.

Beam SSA: e1c 2 spin states



The $\sin\phi$ moment for π^+ (e1c). Triangles up/down and filled circles for positive,negative helicities and their average. Open circles are for a asymmetry type extraction ($\frac{N^+ - N^-}{N^+ + N^-}$). **Two methods of asymmetry extraction are in good agreement.**