Single-Spin Asymmetries at JLAB++

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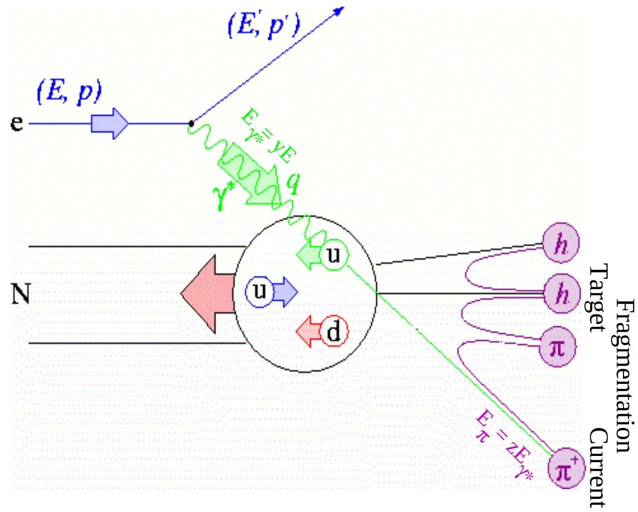
HALL-C Meeting Apr 10

- Physics goals
- Target SSA
- Beam SSA
- Kinematics at 12 GeV
- Outlook

Semi Inclusive Deep Inelastic Scattering



In unpolarized DIS:

- **Distribution function $f_1^u(x)$ probability to find a u-quark with a momentum fraction x.**
- **Fragmentation function $D_{1u}^{\pi^+}(z)$ probability for a u-quark to produce a π^+ with a momentum fraction z.**

We want:

- **Detect final state pions in $ep \rightarrow e'\pi^+ + X$**
- **Extract information about distribution and fragmentation functions.**

$$\sigma^{eH \rightarrow ehX} = \sum_q f^{H \rightarrow q} \otimes \sigma^{eq \rightarrow eq} \otimes D^{q \rightarrow h},$$

Polarized Semi-Inclusive DIS

Main goal:

- **Detect final state e' and π^+ in $\vec{e}\vec{p} \rightarrow e'\pi^+ + X$**
- **Measure single beam and target spin asymmetries.**
- **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**
- **Significant beam SSA $\vec{e}p \rightarrow e'\pi^+ + X$ at CLAS & HERMES.**

Possible sources of SSA in DIS:

- **Final State Interactions (transverse momentum in fragmentation)**
- **Initial State Interactions (transverse momentum in distribution)**

SSA in SIDIS

Physics objects accesible in SSA

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

The method:

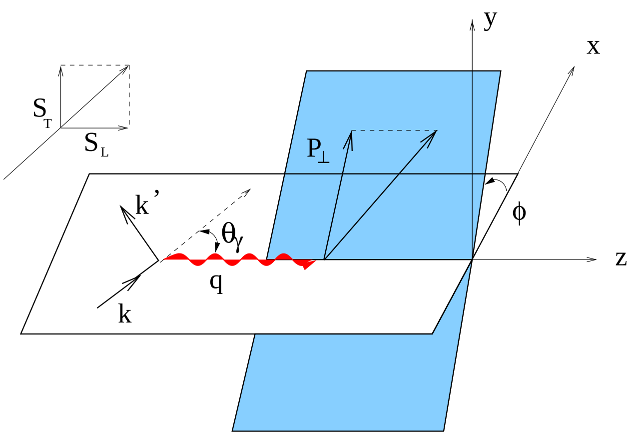
- Measurement of azimuthal distributions of hadrons in semi-inclusive and semi-exclusive DIS.

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.

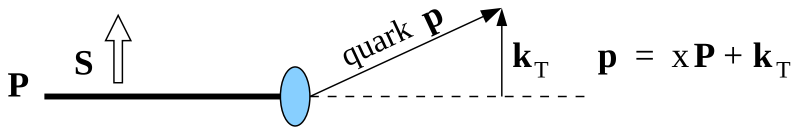


$$\begin{aligned} Q^2 &= 4EE'\sin^2(\tfrac{\theta}{2}) \\ \nu &= E - E' \\ x &= \frac{Q^2}{2m\nu} \\ y &= \frac{\nu}{E} = \frac{p\cdot q}{p\cdot k} \\ z &= \frac{E_h}{\nu} \end{aligned}$$

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	f_1	
	L	g_{1L}	$h_{1L}^{\perp}$
	T	g_{1T}	h_1 $h_{1T}^{\perp}$
twist 3	U	$f^{\perp}$	e
	L	$g_L^{\perp}$	h_L
	T	g_T $g_T^{\perp}$	h_T $h_T^{\perp}$

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

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

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

Classification of distribution functions:

The twist-3 chiral-odd function $g_T^a(x)(g_T = g_1 + g_2)$ relevant for a longitudinally polarized beam and transversely polarized proton.

$$g_T(x) = \int_x^1 dy\, \frac{g_1(y)}{y} + \overline{g}_T(x)$$

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

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

$h_L(x)$ and $g_T(x)$ are considered to be unique windows into quark gluon correlations in the nucleon.

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

$$e^a(x) = \frac{m_a}{M}\frac{f_1^a(x)}{x} + \tilde{e}^a(x).$$

Contributions to σ in polarized SIDIS

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

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

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

$$\sigma_{UL}^{\sin 2\phi} \propto S_L 2(1-y) sin2\phi \sum_{a,\bar{a}} e_a^2 x h_{1L}^{\perp}(x) H_1^{\perp a}(z)$$

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

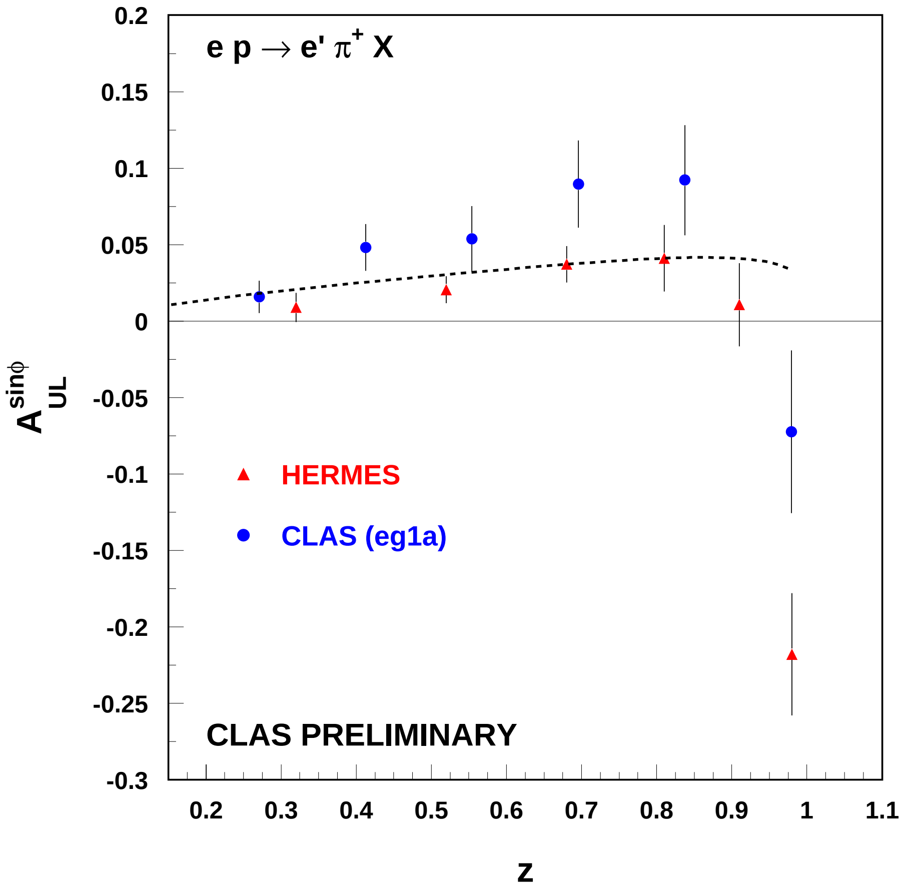
$$\sigma_{LU} \propto \lambda_e sin\phi\, y\sqrt{1-y}\frac{M}{Q}\sum_{a,\bar{a}} e_a^2 x^2 e^a(x) H_1^{\perp a}(z)$$

- 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.

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

Target SSA: CLAS vs HERMES



CLAS target SSA in qualitative agreement with HERMES target SSA (relatively flat z-dependence).

Dashed line H_1/D_1 from Kotzinian et al.

Higher twist contributions

Semi-inclusive

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

$$A_{UL}^{\sin\phi} \propto x^2\, h_L[2zH_1^{\perp(1)}(z) + \tilde{H}(z)]/f_1(x)D(z)$$

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

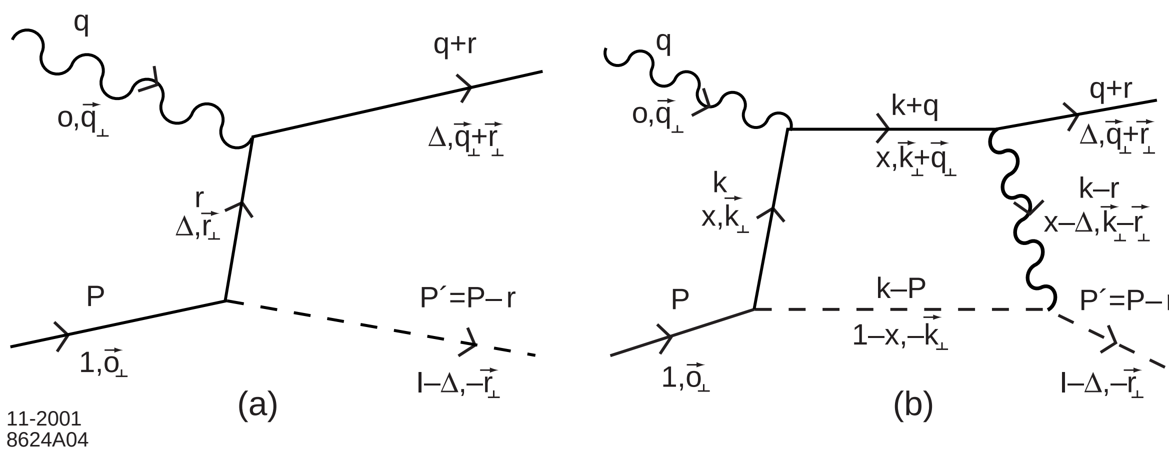
the HT term with $\tilde{H}(z)$ gives a contribution with opposite sign.

Semi-exclusive

Transverse target spin asymmetry $\frac{2}{\pi}A_{UT}^{\sin\phi}$ at $x \approx 0.1$ for the longitudinal electro-production of π^+ +n is predicted ≈ 60% (Frankfurt & Co.)

- $A_{UT}^{\sin\phi}(\pi^+\Delta^0) \approx -0.3\, A_{UT}^{\sin\phi}(\pi^+ n)$.
- $A_{UT}^{\sin\phi}(\pi^-\Delta^{++}) \approx 0.5\, A_{UT}^{\sin\phi}(\pi^+\Delta^0)$.

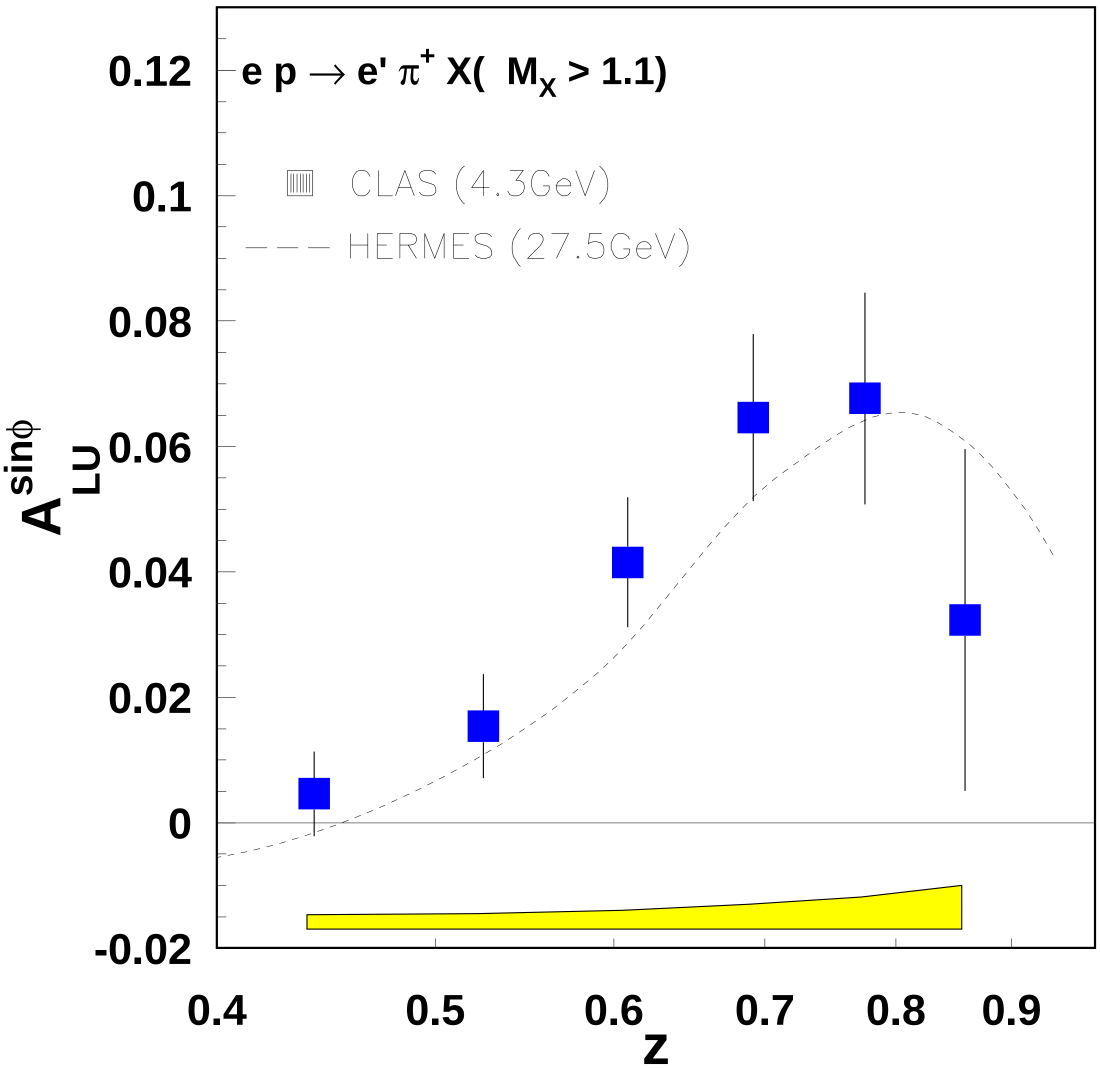
SSA from ISI



SSA is generated as a result of rescattering (interference between hard gluon scattering off a diquark in different orbital momentum states).

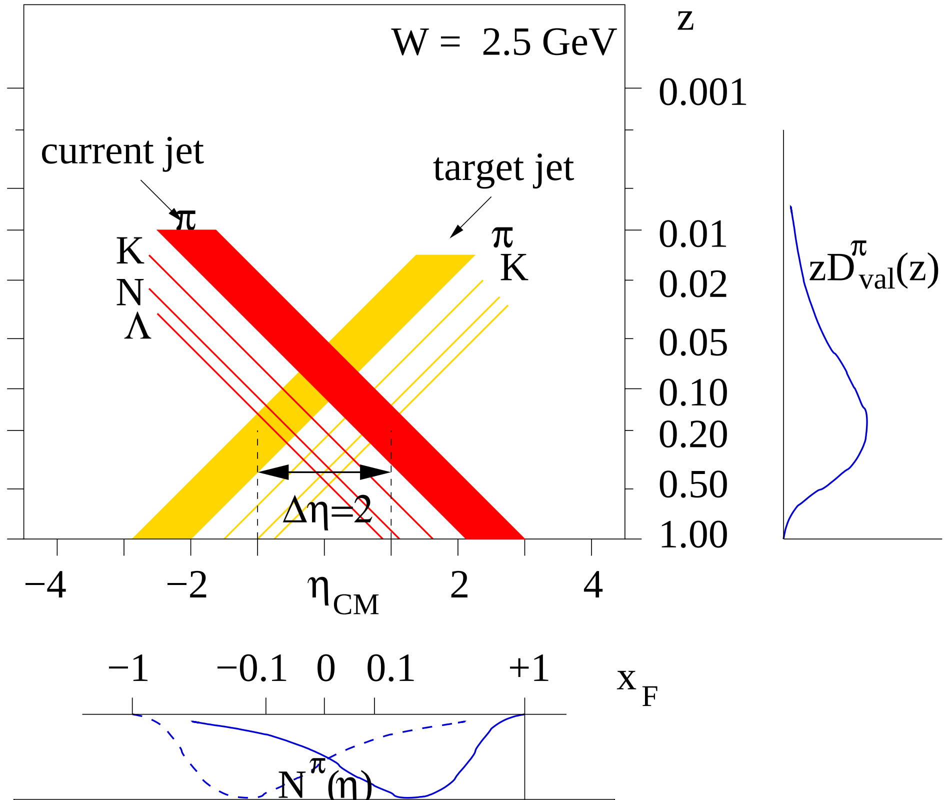
- **Fragmentation is uniform in azimuthal angle**
- **No Q^2 dependence expected for target SSA.**
- **Target SSA are not related to "transversity"**

Beam SSA: CLAS vs HERMES

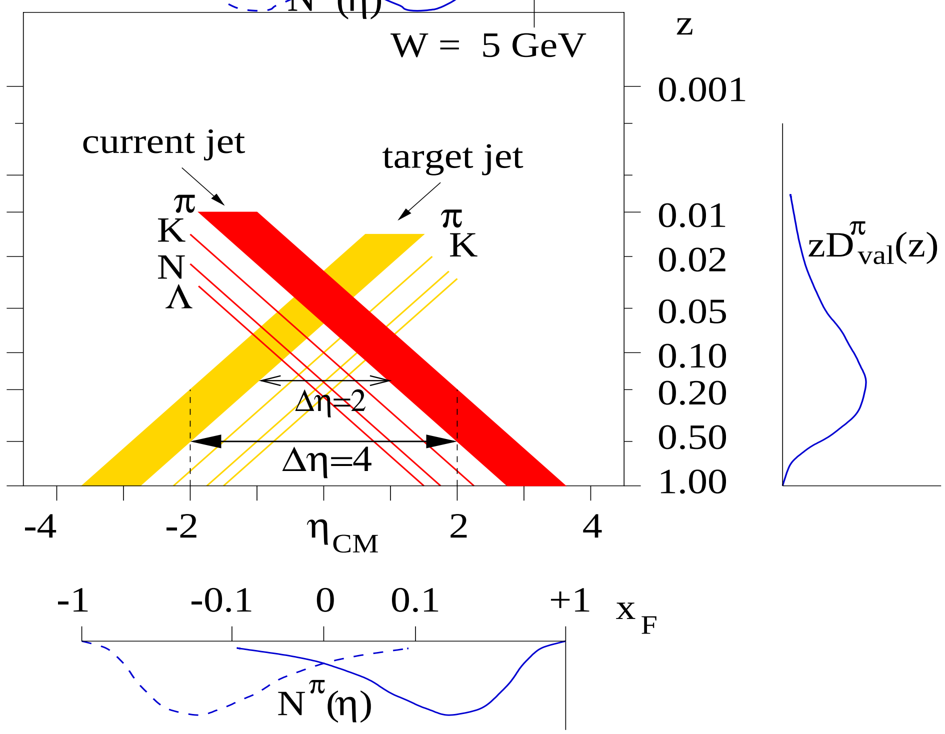


The line is HERMES result corrected for different y-dependent kinematic factor.

JLAB today

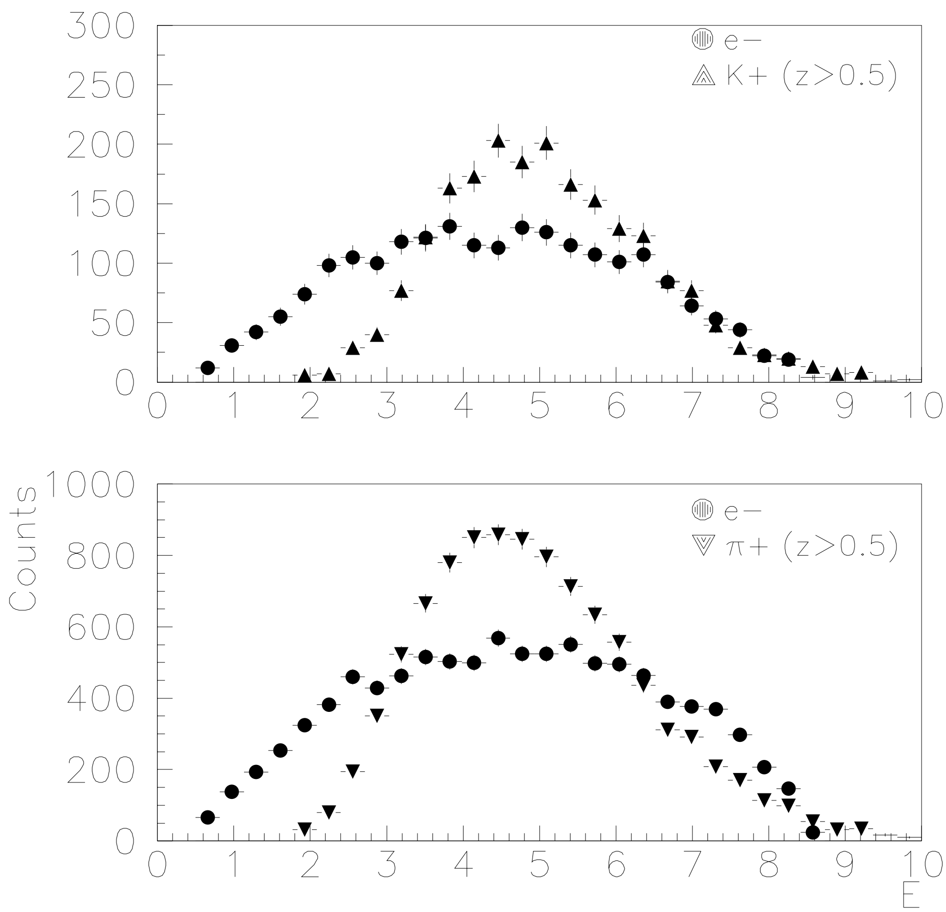


JLAB++



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

Kinematics at 12 GeV



Momentum distributions of scattered electron and leading hadrons in $\gamma^* p \to \pi[K] + X$ at 12 GeV.

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

Outlook

Hard Scattering at JLAB++

- SSA in hadron azimuthal distributions in semi-inclusive and exclusive processes give new insight into the structure of QCD bound states.
- Extraction of x, z, Q^2 dependencies of Beam and Target SSA.

  ▷ extraction of chiral-odd PDF $h_1(x), e(x), h_L(x)$ in the valence region.

  ▷ study of higher twists to shed light on long-range quark-gluon dynamics

  ▷ extraction of unpolarized $D_1(z)$ and polarized $H_1(z)$ fragmentation functions in a wide range of z $(0.3 < z < 0.8)$
- Extraction of beam and target SSA for different hadrons $(\pi^0, \pi^-, K+, \rho)$ will provide additional test of factorization and will enable flavor decomposition of different chiral-odd and T-odd distribution and fragmentation functions.