Spin-Azimuthal Asymmetries in DIS

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for the hermes Collaboration

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- Introduction
- Azimuthal asymmetries in polarized SIDIS
- Interpretation
- π^0 versus π^+
- Summary

Physics goals

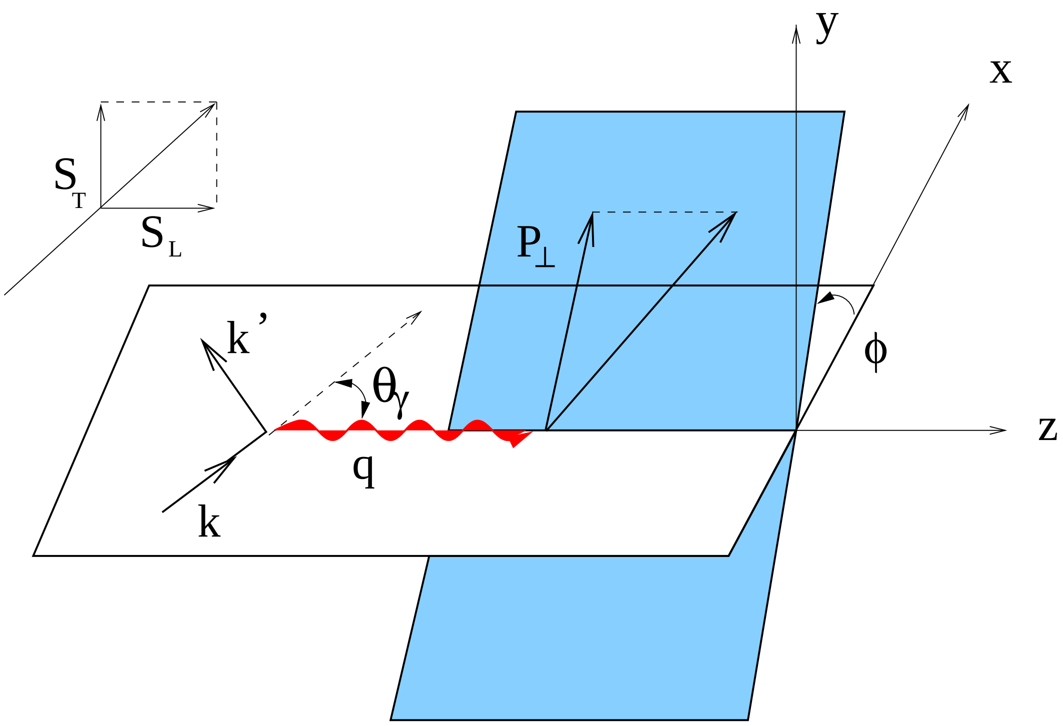
Looking for

- The role of intrinsic transverse momentum of quarks in DIS
- The role of transverse spin of quarks (transversity and other chiral-odd distribution functions) in the fragmentation.
- The role of higher twists in DIS
- Transition from semi-inclusive to semi-exclusive
- Q^2 lower limits for hard exclusive processes

Where ?

- Azimuthal distributions of hadrons in semi-inclusive and semi-exclusive DIS.

SIDIS Kinematics



$$\sin\theta_\gamma \approx \frac{2Mx_B}{Q}\sqrt{1-y},$$

$$x_B = Q^2/2M\nu \;, y = \nu/E \;, z = E_h/\nu,$$

$$\phi = arccos\left(\frac{[\vec{q}\times\vec{k}][\vec{q}\times\vec{P}_h]}{|\vec{q}\times\vec{k}||\vec{q}\times\vec{P}_h|}\right)\frac{\vec{P}_h[\vec{q}\times\vec{k}]}{|\vec{P}_h[\vec{q}\times\vec{k}]|}$$

Lepton cut $Q^2 > 1, W^2 > 4$.

Pion cut $P > 4.9GeV, P_\perp > 0.05GeV$.

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Azimuthally weighted cross Sections

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

$$\sigma^{eH\to ehX} = \sigma_0 + \sigma_1 \sin\phi + \sigma_2 \cos\phi + \sigma_3 \sin 2\phi + \ldots$$

$$\sigma_i = \sigma_i^{UU} + \sigma_i^{UL} + \sigma_i^{LU} + \sigma_i^{UT} + \ldots$$

Unpolarized (U), longitudinally polarized (L) and transversely polarized (T) beam/target

When the cross section is integrated over the final transverse momentum of hadrons the single-spin asymmetries (UL,LU,UT . . .) vanish in the leading order.

$$A_{UL}^{\sin\phi} \equiv \sigma_1^{UL}/\sigma_0 \equiv 2\langle \sin\phi \rangle_{UL}$$

defines the $\sin\phi$ term in the cross section for unpolarized beam and longitudinally polarized target.

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Azimuthally Weighted Asymmetries

The analyzing powers for beam (target) longitudinal polarization are evaluated as

$$A^{W}_{LU(UL)} = \frac{\frac{L^{\uparrow}}{L_P^{\uparrow}}\sum_{i=1}^{N^{\uparrow}} W(\phi_i) \ - \ \frac{L^{\downarrow}}{L_P^{\downarrow}}\sum_{i=1}^{N^{\downarrow}} W(\phi_i)}{\frac{1}{2}[N^{\uparrow} \ + \ N^{\downarrow}]} \qquad (1)$$

the $\uparrow$ / $\downarrow$ denotes positive/negative helicity of the lepton (target), L and L_P luminosity and lumi weighted polarizations.

$$W(\phi) = \sin\phi, \sin 2\phi, \sin 3\phi, \cos\phi, \cos 2\phi \ldots$$

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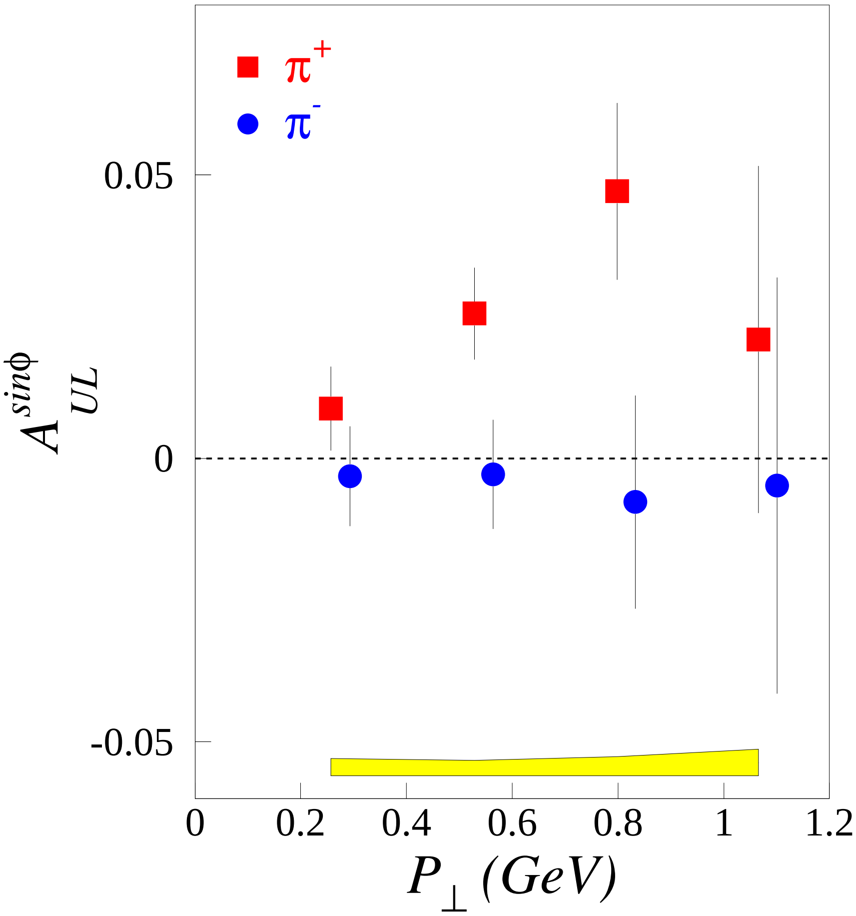
Spin Asymmetries from HERMES

$P_\perp$ dependence (HERMES-published)



$$H_1^\perp / D_1 \propto \frac{M_c p_\perp z}{M_c^2 z^2 + p_\perp^2}$$

$M_c \sim 1GeV$, D_1 is the unpolarized fragmentation function, $H^\perp$ polarized "Collins" fragmentation function.

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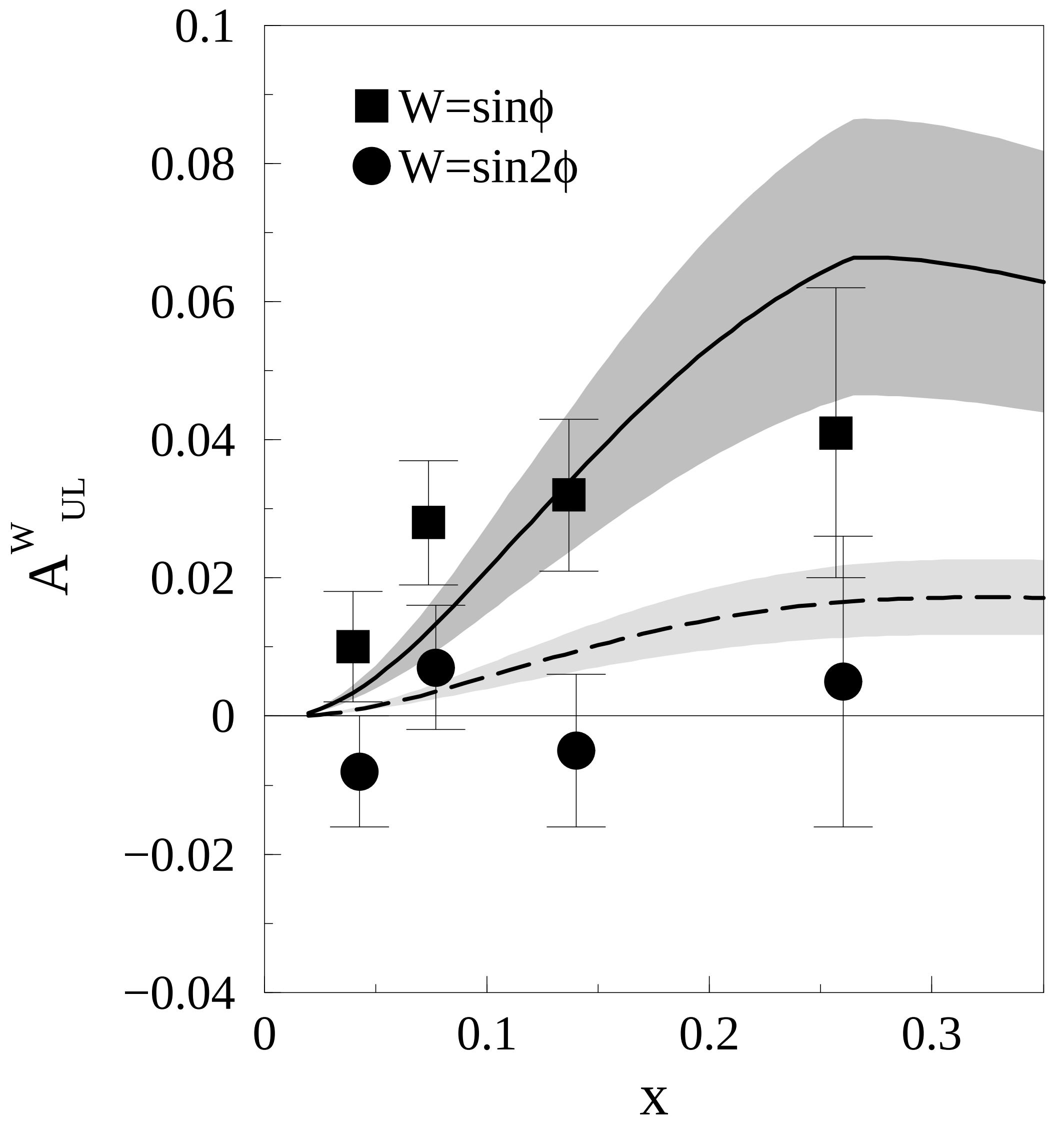
Comparison for $sin2\phi$ & $sin\phi$



Efremov et. al hep-ph/0001119.

- only the favored fragmentation functions $D_1^{a/\pi}$ and $H_1^{\perp a/\pi}$
- $\langle H_1^{\perp}(z)/z\rangle = \langle H_1^{\perp}(z)\rangle/\langle z\rangle$ with $\langle z\rangle = 0.41$
- $\langle P_{h\perp}\rangle \approx \langle p_T\rangle \approx 0.4\, GeV$
- GRV parameterization for $f_1^a(x)$
- h_1 calculated in chiral soliton model

Spin-Azimuthal Asymmetries

Leading twist.

$$A_{UT}^{\sin\phi} \propto |\boldsymbol{S}_T|\ (1-y)\ h_1(x)\ H_1^{\perp(1)}(z),$$

$$A_{UL}^{\sin 2\phi} \propto S_L(1-y)x\ h_{1L}^{(1)}(x)\ H_1^{\perp(1)}(z) \Longleftarrow$$

S_L and $\boldsymbol{S}_T$ proton longitudinal and transverse polarizations

Parton carry a fraction x of proton's longitudinal momentum P and transverse component $\boldsymbol{p}_T$, $\vec{p} = xP + \boldsymbol{p}_T$

$f_1(x) \equiv \int d^2\boldsymbol{p}_T f_1(x, \boldsymbol{p}_T)$.

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

$h_1(x), h_{1L}^{\perp}(x)$, describe the quark transverse polarization in transversely and longitudinally polarized nucleon.

Spin-Azimuthal Asymmetries

Higher twist.

$$A_{UL}^{\sin\phi} \propto S_L\; 2(2-y)\sqrt{1-y}\;\frac{M}{Q}\;x\;h_L(x)\;H_1^{\perp(1)}(z) \Longleftarrow$$

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

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

$$A_{LU}^{\sin\phi} \propto \lambda_e\; 2y\sqrt{1-y}\;\frac{M}{Q}\;x\;e(x)\;H_1^{\perp(1)}(z) \Longleftarrow -0.0047 \pm 0.008$$

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

$A_{UL}^{\sin\phi}$: x,$P_\perp$-dependence

Short summary

- Suppressed $A_{UL}^{\sin\phi}$ for π^- on the proton.

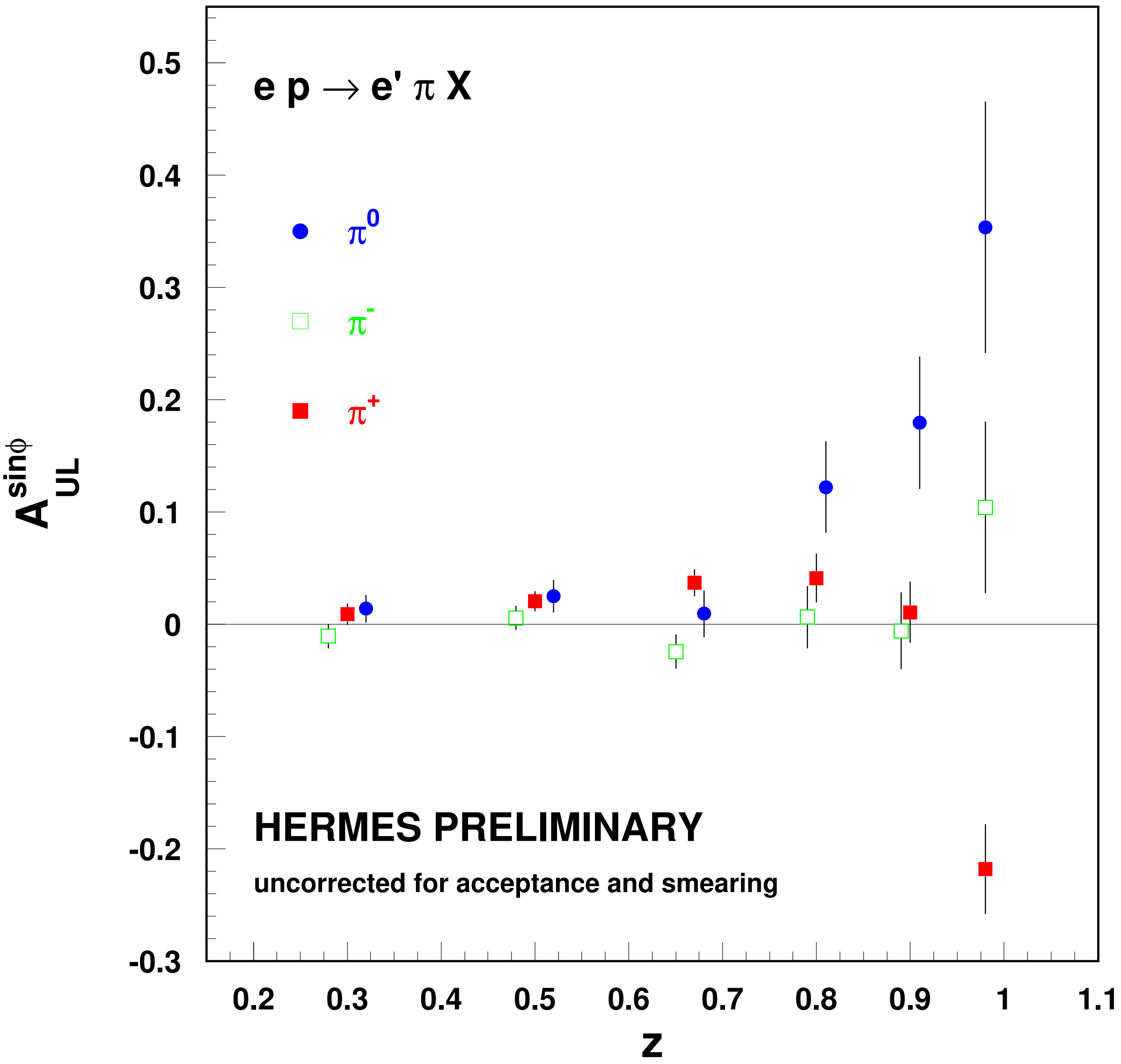
- $A_{UL}^{\sin\phi}$ $x, P_\perp$ dependence for π^+ are consistent with theory.

- The $\sin 2\phi$ asymmetry is suppressed compared to the $\sin\phi$ asymmetry even in the approximation $\overline{h}_L = 0$, which leads to a maximal $h_{1L}^{\perp(1)}$. (Kotzinian et. al,Boglione & Mulders,Efremov et. al).

  More data is needed to define the $h_{1L}^{\perp(1)}$.

- Contribution from the target spin transverse to the virtual photon momentum (h_1 term) is suppressed with respect to the longitudinal part (h_L) in case of longitudinally polarized target (Kotzinian et. al, Boer).

Spin Asymmetries from HERMES



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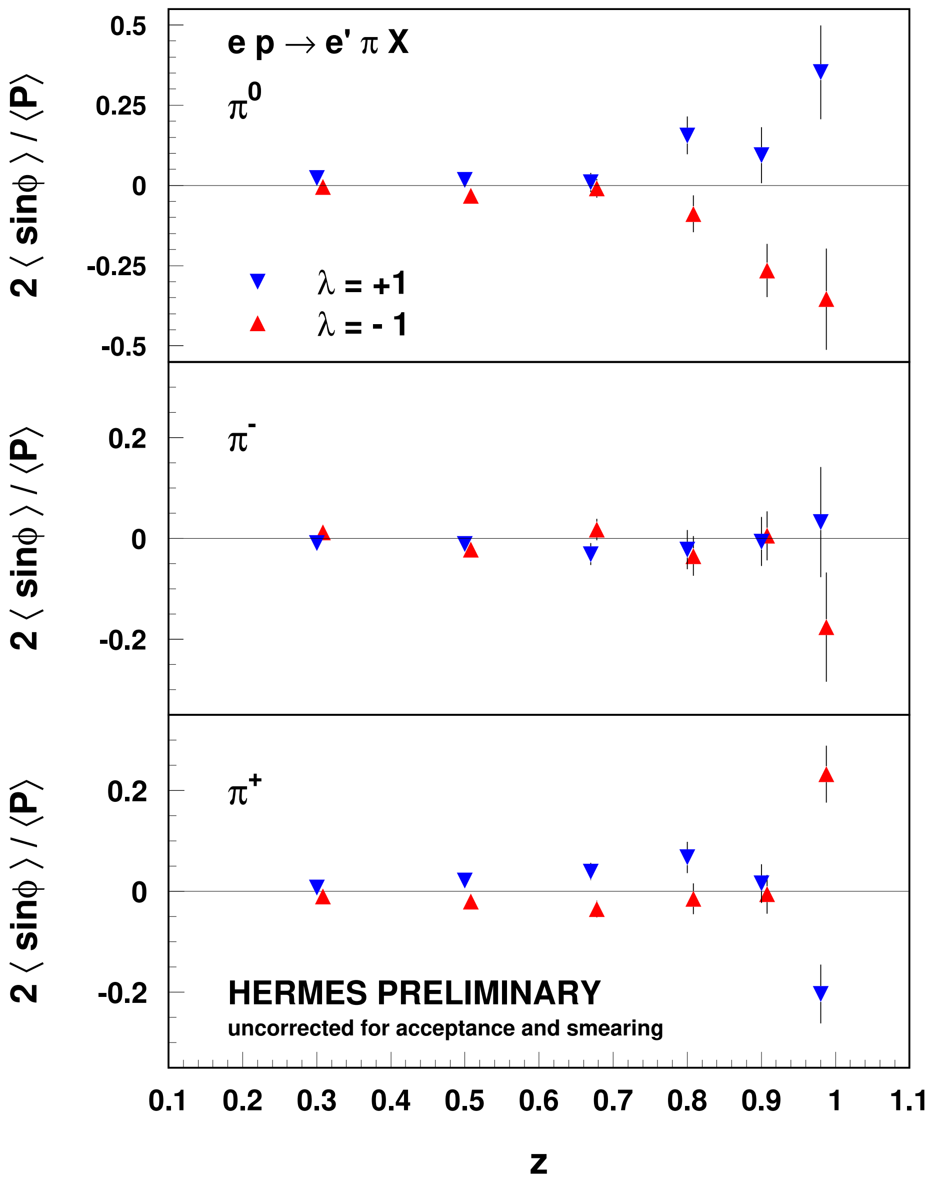
Spin Asymmetries from HERMES



$$\sigma_1 = \sigma_1^{UU} + \sigma_1^{UL} + \sigma_1^{LU}$$

Significant contribution only from σ_1^{UL}.

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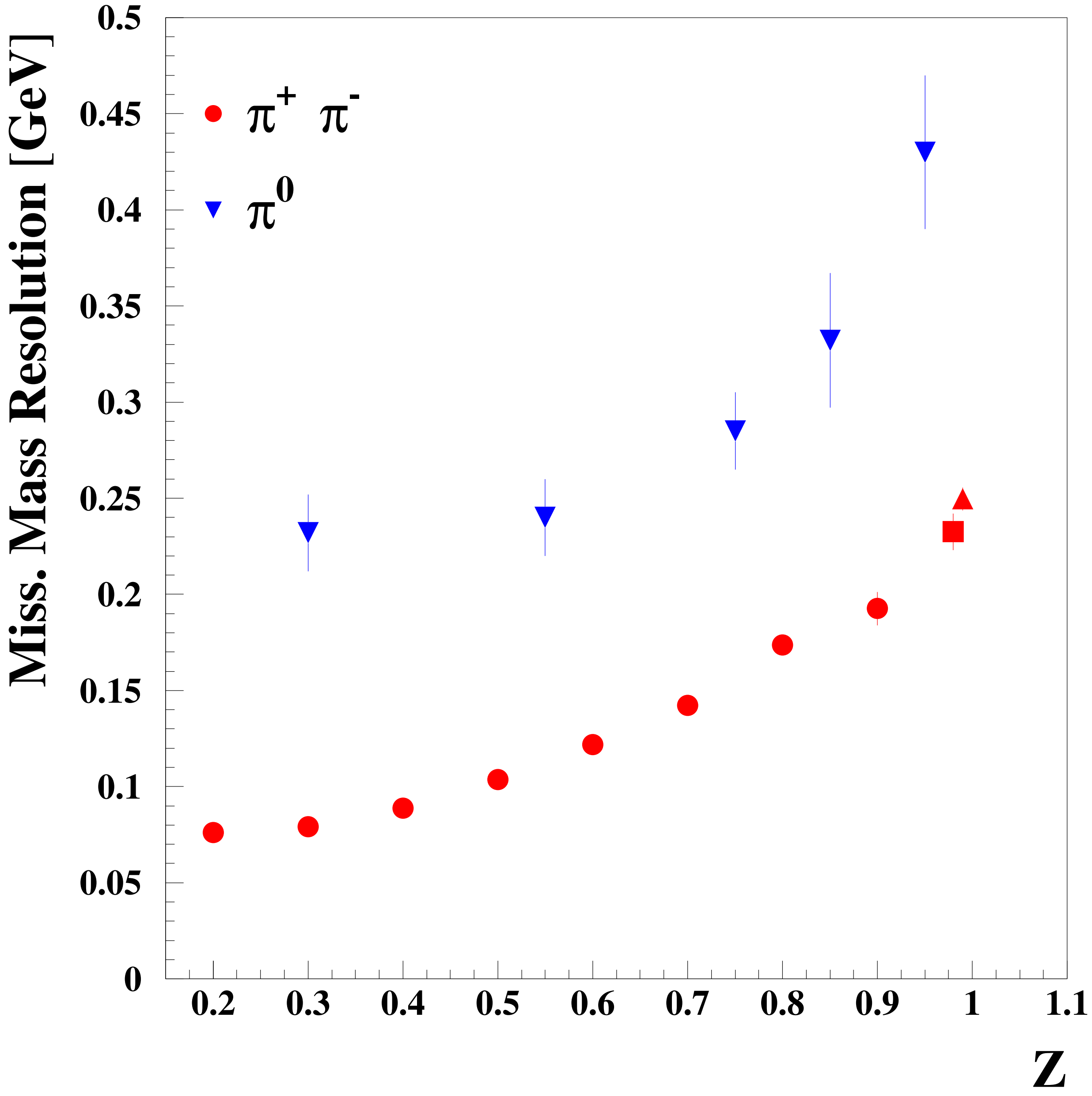
HERMES resolutions



Resolution in z from HERMES MC. Red square is calculated from the data.

Higher twist contributions

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

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

Semi-inclusive

When neglecting the interaction dependent part in distribution function h_L, $h_{1L}^{\perp(1)} = -\frac{x}{2}h_L(x)$ and we have (Boglione & Mulders):

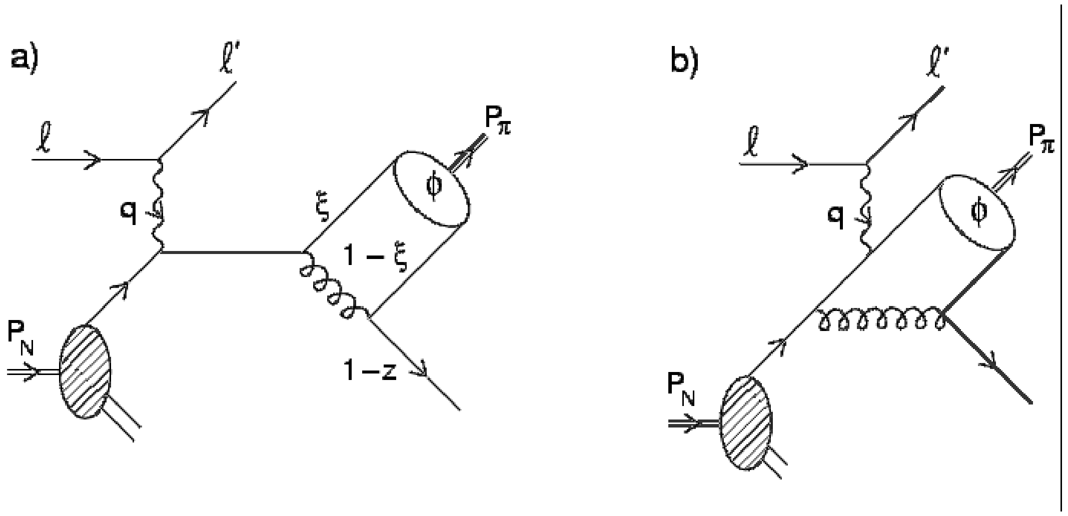
$$A_{UL}^{\sin\phi} \propto x^2\, h_L[2zH_1^{\perp(1)}(z) + \tilde{H}(z)]/f_1(x)D(z)$$

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

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

Semi-exclusive electroproduction

Berger 1980,Brandenburg 1994

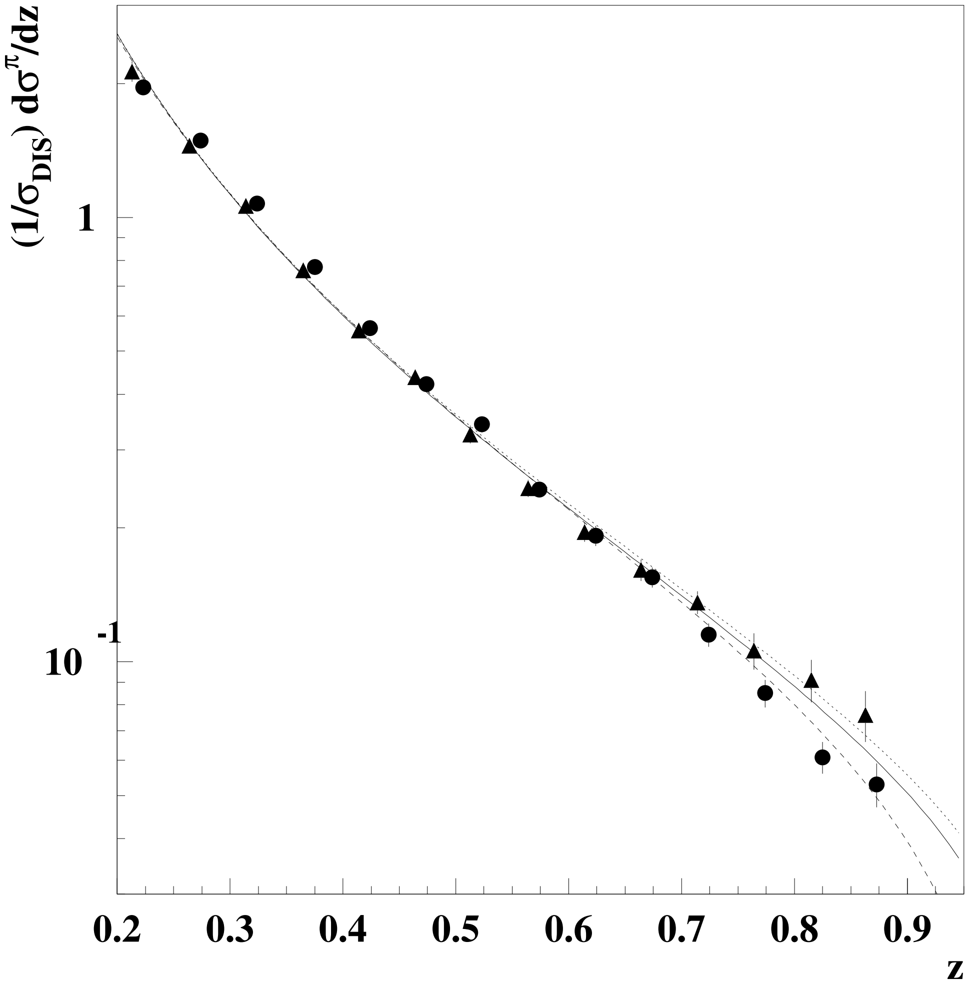


Dominant contribution to the *semi-exclusive pion* production ($u + e^- \rightarrow e^- + \pi^- + d$), with the pion distribution amplitude $\phi(\xi)$.

$D_{\pi/q}(z, Q^2)$ at high z is getting an extra non-scaling term, independent of z(Berger-Z.Phys. C 4,289 (1980))

$$D_{\pi/q}(z, Q^2) \propto D_{\pi/q}(z) + \frac{2}{9}\frac{\langle P_\perp^2 \rangle}{Q^2}$$

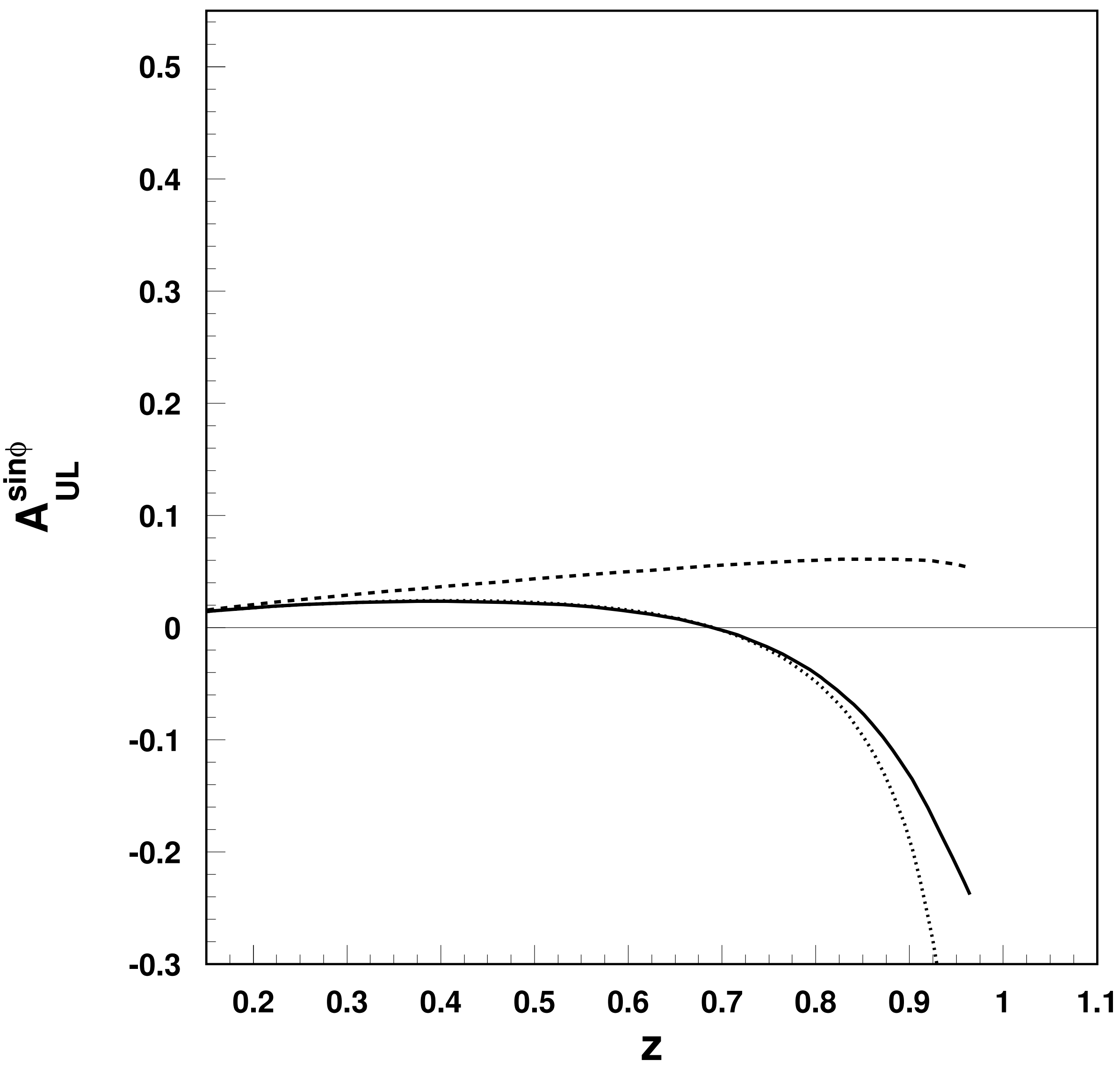
z-distributions from HERMES



Filled circles for π^0 and triangles for $\frac{1}{2}(\pi^+ + \pi^-)$. Curves are fits to $\frac{1}{2}(\pi^+ + \pi^-)$ to BKK formula. The dotted (bottom curve) without any HT correction. Corrections (upper curves) done from the Q^2 and $P_\perp^2$ average values $\langle P_\perp^2 \rangle = 0.25$ and $\langle P_\perp^2 \rangle = 0.18$ (from HERMES data) .

The $\frac{2}{9}\frac{\langle P_\perp^2 \rangle}{Q^2} = D(z)$ gives $z \sim 0.8 - 0.9$ (Q^2=2.5).

Spin Asymmetries from HERMES



The $A_{UL}^{\sin\phi}$ for pions. The upper curve includes only the $H_1^{\perp(1)}$ contribution, the lower with $\tilde{H}$ term added. The middle curve is the same, but with $D(z)$ replaced with $D(z) + \frac{2}{9}\frac{\langle P_\perp^2 \rangle}{Q^2}$

Summary

- The single beam-spin asymmetry for charged pions is consistent with 0, $A_{LU}^{\sin\phi} = 0.0048 \pm 0.008 \pm 0.004$.

- Significant $\sin\phi$ moments are measured for the polarized target in π^+ and π^0 SIDIS cross section, giving access to transversity and spin dependent fragmentation.

- Observables for π^0 SIDIS at high z significantly diverge from the simple sum of π^+ and π^- .

- π^0 multiplicities at high z are lower than for charged pion sum.

- Measured $A_{UL}^{\sin\phi}$ at high z flip the sign for π^+.

- Higher twist contributions might be significant in SIDIS at high z .