Results on Azimuthal Asymmetries from DIS Experiments

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- Introduction
- Single-Spin Asymmetries
  - ▷ semi-incl $\pi \Rightarrow$ New polarised DF and FF
  - ▷ π^0 versus $\pi^{\pm}$
  - ▷ exclusive limit
- Summary-outlook

* Talk presented by W.-D. Nowak, DESY Zeuthen

Single Spin Asymmetries

- Double Spin Asymmetries:
  Polarized Beam and Target.

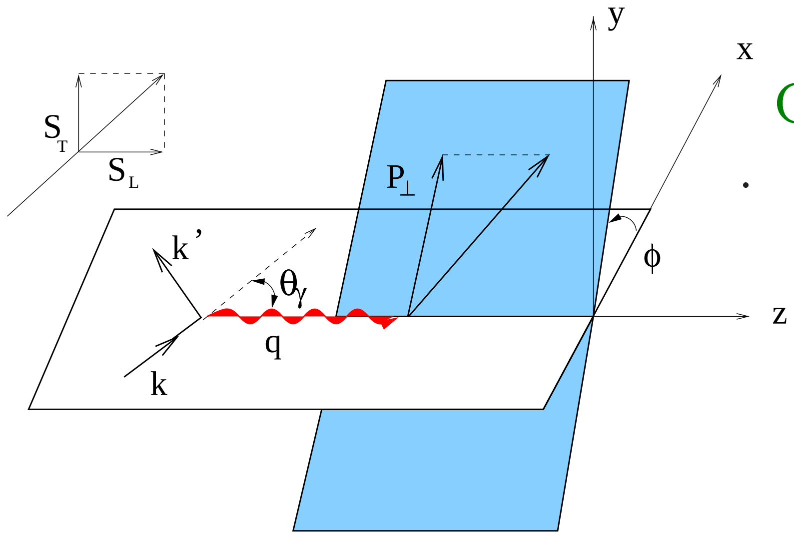
- Single Spin Asymmetry (SSA)
  Polarized Beam or Target.
  - ▷ transverse quark polarization densities
  - ▷ fragmentation of polarized quarks
  - ▷ intrinsic transverse momentum of quarks
  - ▷ GPDF (SPDF, OFPDF..)
  - ▷ higher Twists

Accessible through measurements of

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

Semi-Inclusive DIS

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



Chiral odd, T-even DF

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$\Downarrow$

Chiral-odd T-odd FF

$\Downarrow$

SSA

Naive parton models, non interacting collinear parton
Parity, Angular momentum, Helicity Cons. $\Rightarrow$ SSA $= 0$

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

Azimuthally weighted cross Sections

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

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

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

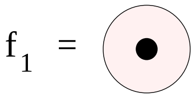
When the cross section is integrated over ϕ of hadrons the single-spin asymmetries (UL,LU,UT ...) vanish in leading order.

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

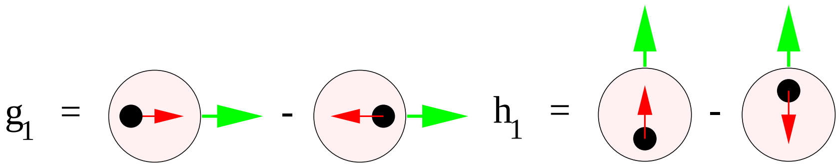
defines the $\sin\phi$ term in the cross section for unpolarized beam and longitudinally polarized target.

Classification of Distribution Functions

The leading twist (subscript:1) description of the nucleon involves 3 types of Distribution Function (+ others at higher level)

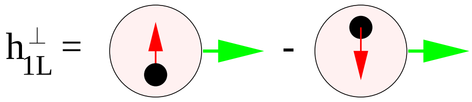


Unpolarized quark in unpolarized nucleon.



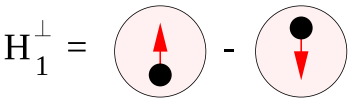
Longitudinal quark in longitudinally and transverse quark in transversely polarised nucleon.

After introduction of transverse momentum of quarks ($p_\perp$):



Transverse quark in longitudinal and longitudinal quark in transversely polarised nucleon.

h_1 is chiral odd $\rightarrow$ can be observed only in combination with another chiral odd structure $\rightarrow$ Collins FF.



Contributions to $\sin\phi$

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

$$< \sin\phi >_{UT} \quad \propto \quad S_T (1-y) \sum_{a,\bar{a}} e_a^2 h_1^a(x) H_1^{\perp a}(z)$$

$S_T \propto \sin\theta_\gamma \approx \frac{2Mx_B}{Q}\sqrt{1-y}$,
h_L: twist-3 DF

In HERMES kinematics and with a *longitudinally* polarized target (above shown) contribution from the S_L term is expected to dominate($\sim 75\%$).

Azimuthally weighted Asymmetries

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

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

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

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

Data selection

Table 1: The HERMES experiment

Target Polarization	hydrogen 0.86 ± 0.05 (longitudinal)
Acceptance in θ_x Acceptance in θ_y	$-0.17 < \theta_x < 0.17$ $0.04 < \|\theta_y\| < 0.14$
DIS cuts	$Q^2 > 1$ $W^2 > 4$ $y < 0.85$
Cuts on hadrons	$z > 0.2$
$\pi^{\pm}$	$4.9 < E_\pi < 14 GeV$
π^0	$E_\gamma > 1.0 GeV, \quad 0.1 < M_{\gamma\gamma} < 0.17 GeV$

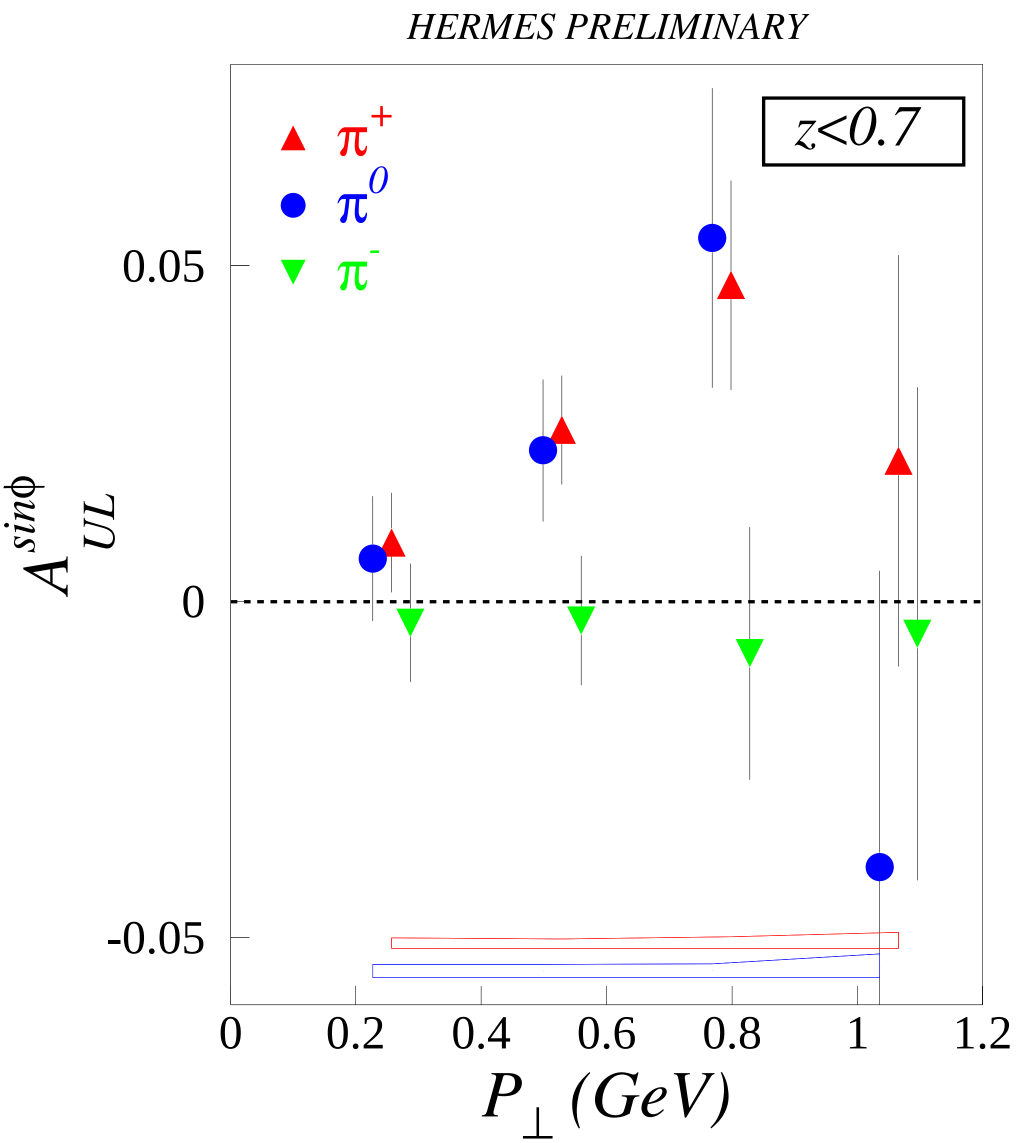
Acceptance and efficiency:

∘ θ_y cut has major influence on the acceptance

Acceptance generated $\sin\phi$ terms:

- Direct: generated $\sin\phi$ term is negligible (MC)
- Indirect: generated $\sin\phi$ (through the $\cos\phi$ term in the acceptance and $\sin 2\phi$ single spin term in the cross section) is under control.

SSA $\mathcal{A}_{UL}$: $P_\perp$ dependence

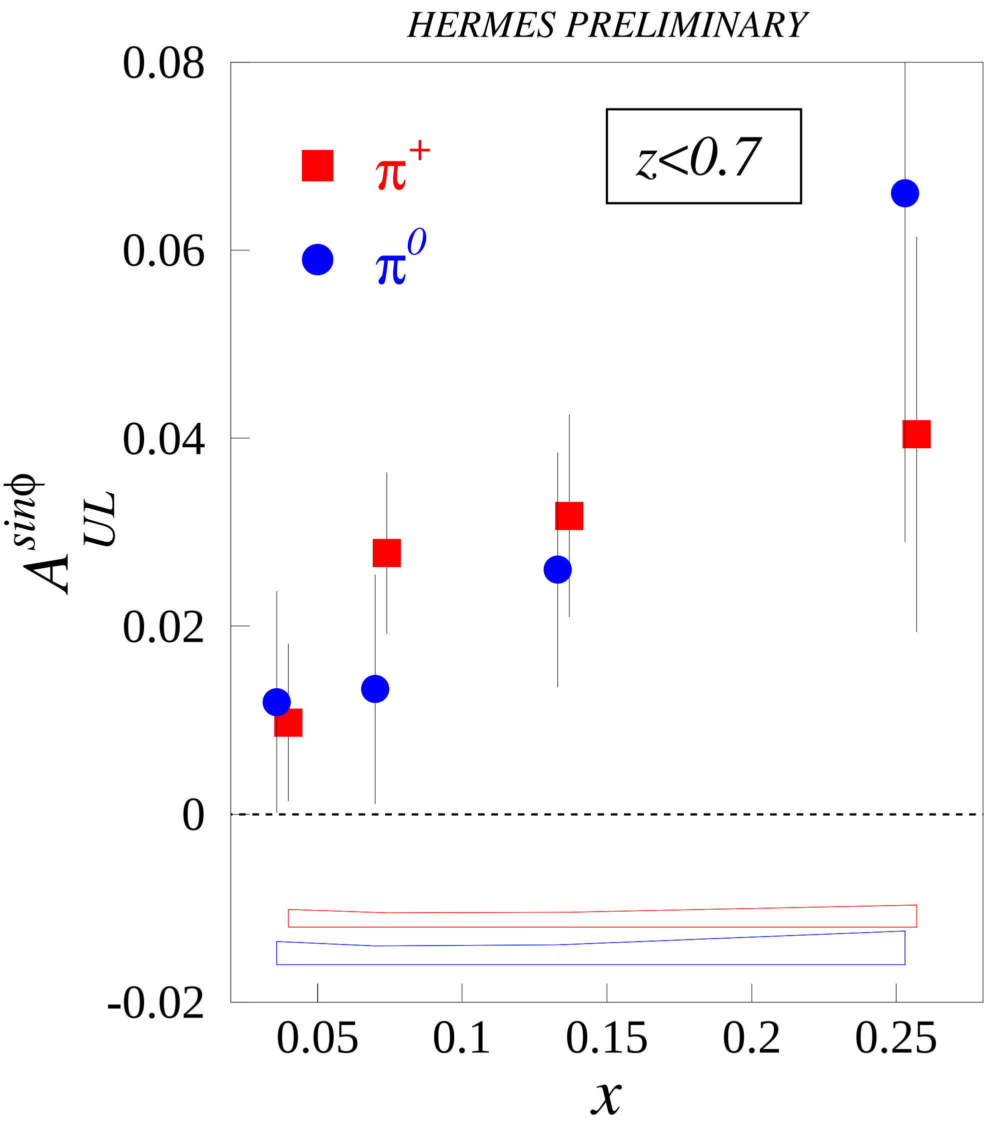


in simple model: $H_1^\perp / D_1 \propto \frac{M_c p_\perp z}{M_c^2 z^2 + p_\perp^2}$

$M_c \sim 1GeV$, D_1 is the unpolarized fragmentation function, $H_1^\perp$ the polarized "Collins" fragmentation function.

$\pi^\pm$ data published in *A. Airapetian et al, Phys. Rev. Lett. 84 (2000) 4047*

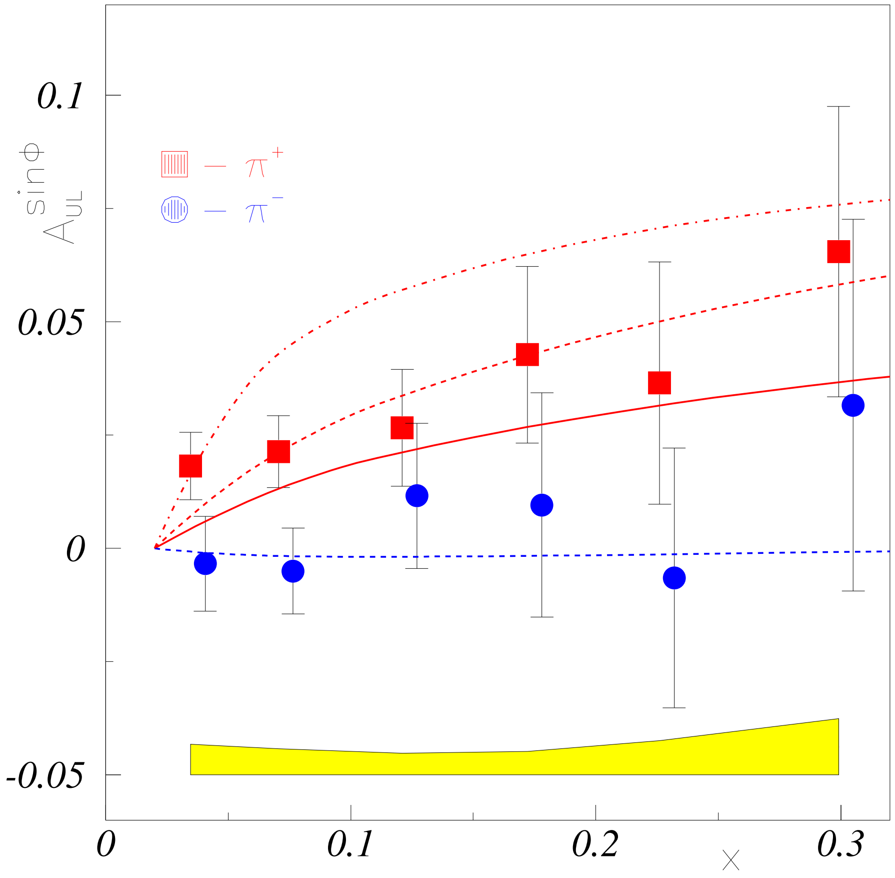
SSA $\mathcal{A}_{UL}$: x dependence



∘ consistent behaviour of π^+ and π^0.

∘ behaviour consistent with increase suggests that the sea contribution does not dominate the effect.

Comparison with theory for $\pi^{\pm}$

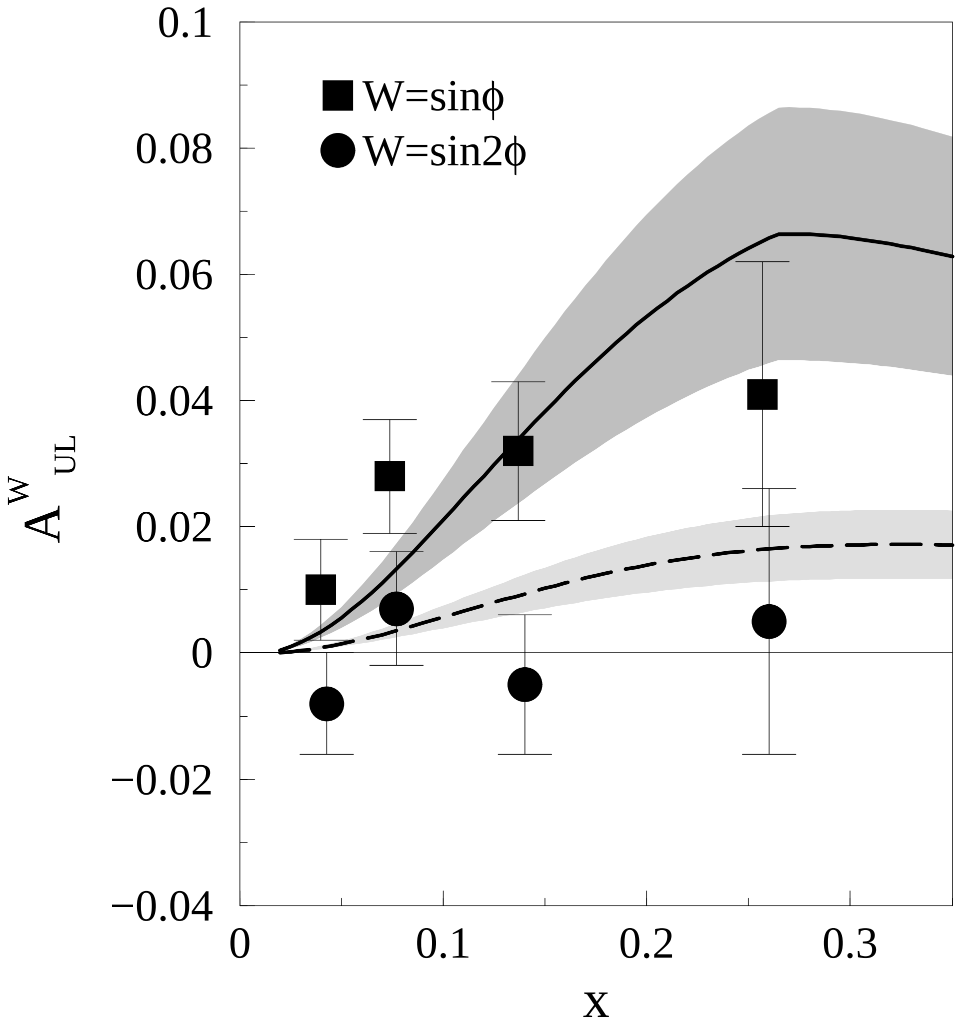


Curves (Kotzinian et al. NP A666,290 2000) correspond to different approximations for h_1 ($h_1 = 0.5(g_1 + f_1)$ for upper and $h_1 = g_1$) and $H_1^{\perp}$ ($M_c = 0.3$ for lower and $M_c = 0.7$).

$$\pi^+ \quad \mathcal{A}_{UL}^{sin\phi} \propto \frac{4}{9} h_L^u \mathbf{H_1^{\perp u \to \pi^+}} + \frac{1}{9} h_L^d H_1^{\perp d \to \pi^+}$$

$$\pi^- \quad \mathcal{A}_{UL}^{sin\phi} \propto \frac{4}{9} h_L^u H_1^{\perp u \to \pi^-} + \frac{1}{9} h_L^d \mathbf{H_1^{\perp d \to \pi^-}}$$

Comparison with theory: *sin2ϕ & sinϕ*



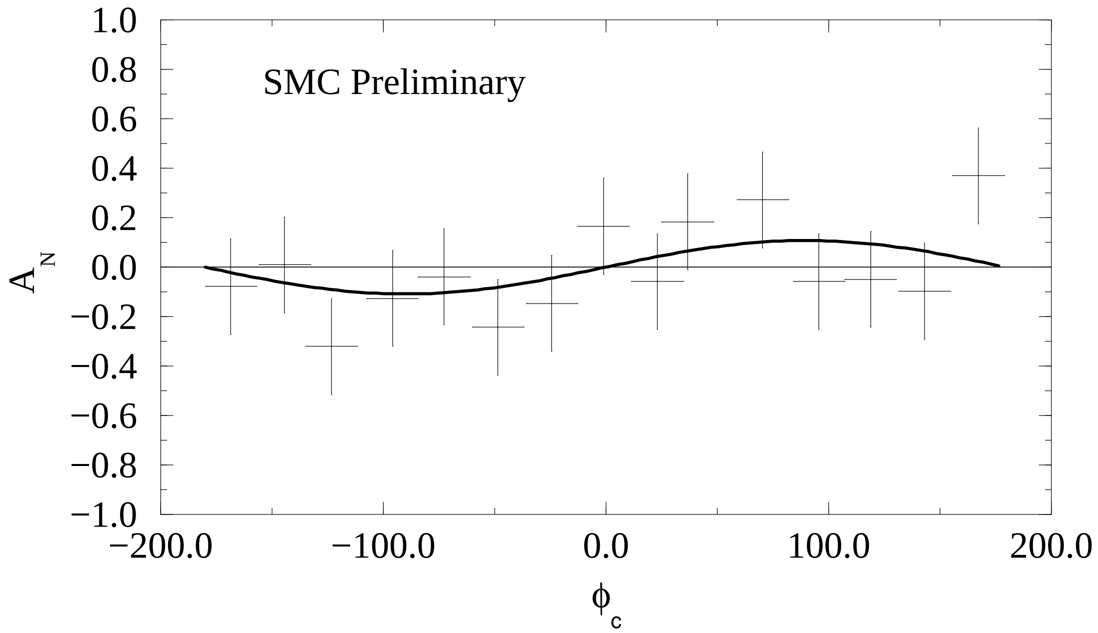
Efremov et. al hep-ph/0001119: ($H_1^{\perp}$ from DELPHI)

- 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

Other Experiments

SMC SSA on *transversely* polarized target

Bravar, DIS99



Best fit value from SMC data:

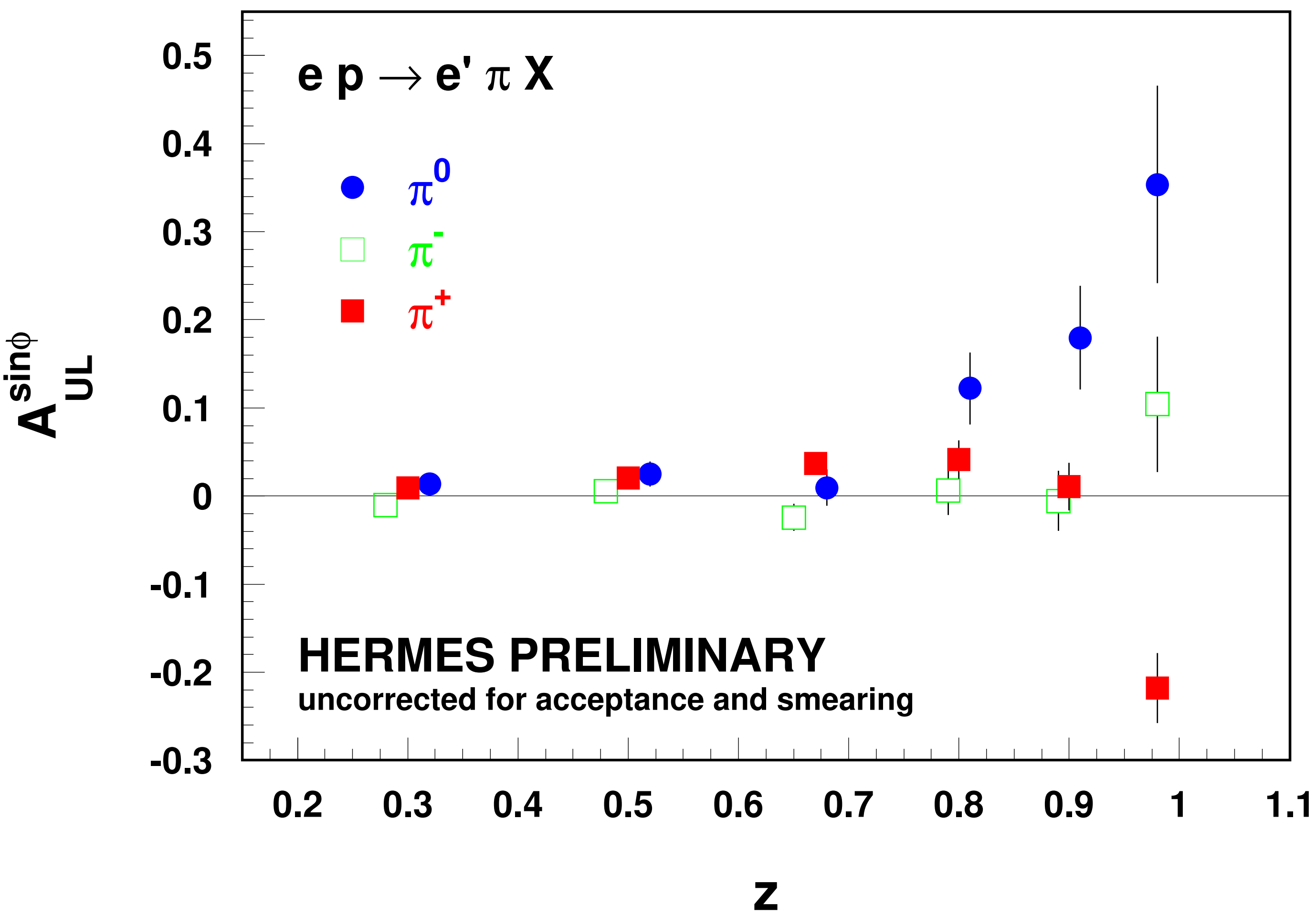
$A_N = 0.11 \pm 0.06$

is consistent with HERMES measurements on *longitudinally* polarized target and also the estimate of the analyzing power given by Efremov et. al.

$$\left| \frac{\langle H_1^{\perp} \rangle}{\langle D_1 \rangle} \right| = (0.063 \pm 0.020)$$

SSA: z-dependence

→ Large SSA in semi-exclusive and esclusive region for π^+ and π^0



→ SIDIS → "SEDIS" → GPDF

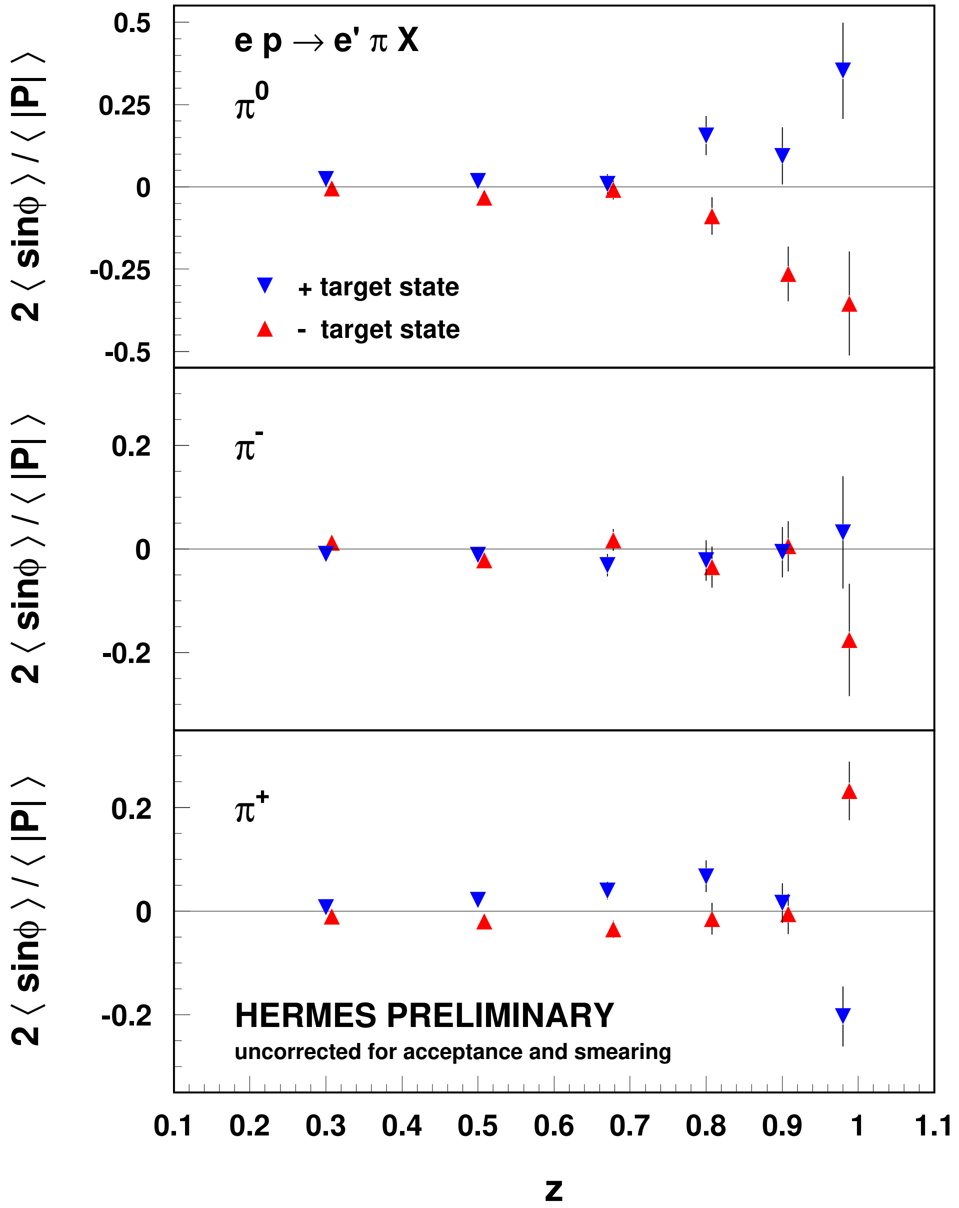
Possible sources for sign flip in π^+ SSA:

▷ HT in SIDIS (Boglione & Mulders)

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

Single Spin Asymmetries for pions

HERMES SSA for separate target spin states



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

∘ significant contribution for π^+ and π^0 from σ_1^{UL}.

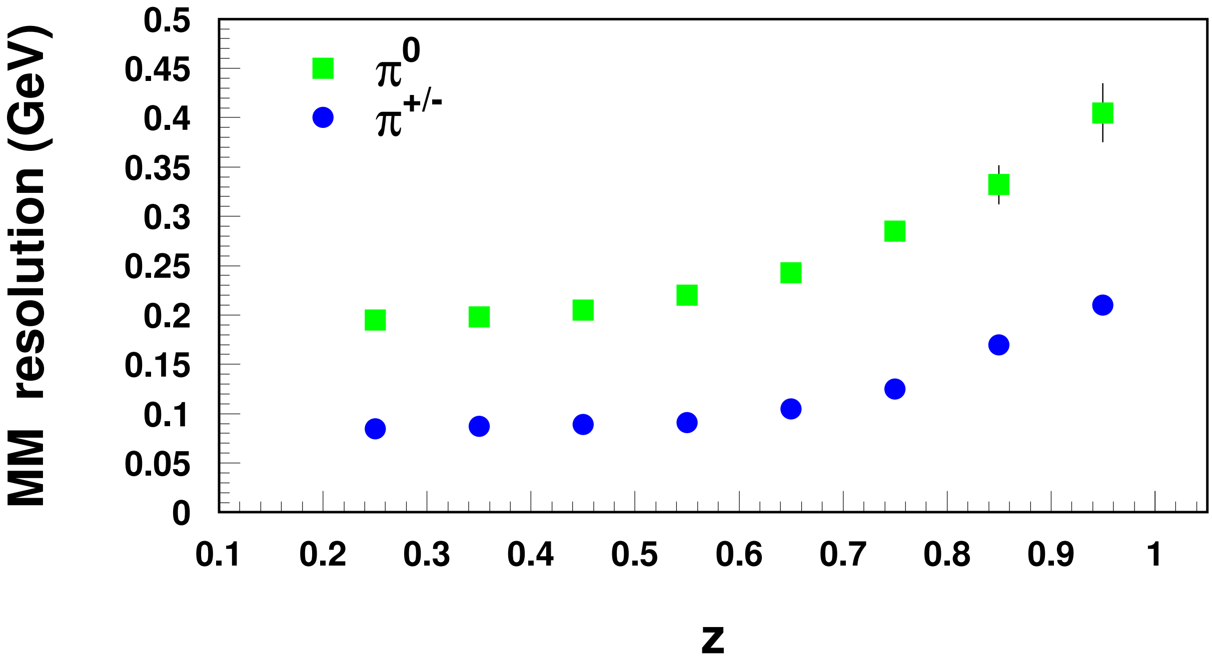
Pions in exclusive limit

Different behavior of π^0 and $\pi^\pm$

- Worse resolution for missing mass for π^0 ($\rightarrow$ fig.)
- Suppression of exclusive π^0 production on proton with respect to π^+(as seen by HERMES)

$\rightarrow$ π^0 in exclusive limit presumably dominated by pure SIDIS events.

HERMES missing mass resolutions



Missing parts of mosaic

- The role of higher twists ($z > 0.7$) and exclusive scattering ($z \approx 1$) in SIDIS

  $\Rightarrow$ need theoretical coverage of full z range

  $\Rightarrow$ need link between SIDIS HT and hard exclusive scattering
- Find kinematic limits (z, Q^2) where SIDIS is still dominating semi-exclusive production.
- Interpretation of SSA differences for charged and neutral pions

Summary

- **Significant x and $P_{\perp}$ dependence of $A_{UL}^{sin\phi}$ observed for π^+ and π^0 SIDIS.**
- **Different behavior for charged and neutral pions in exclusive limit (z→1).**

Improvements in HERMES Detector

- **RICH $\Rightarrow$ clean π and K samples**
- **Λ wheel $\Rightarrow$ improved exclusivity criteria**

Outlook

- **Transversely polarized target (2000+)**
  - ▷ **transversity, h_1**
  - ▷ **Collins fragmentation function**
  - ▷ **2-pion production [Jaffe]**
- **Separation of contributions from different distribution functions through measurements of other moments ($\cos\phi$,$\cos 3\phi$, $\sin 3\phi$...)**