Spin Azimuthal Asymmetries in Semi-Inclusive Pion Electro-Production at HERMES

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(on behalf of the HERMES Collaboration)

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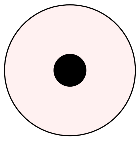
- **Motivations**
- **How to access to transversity ?**
- **Semi-Inclusive SSA for π^+, π^- and π^0**
- **Conclusions**

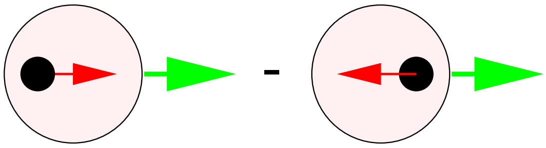
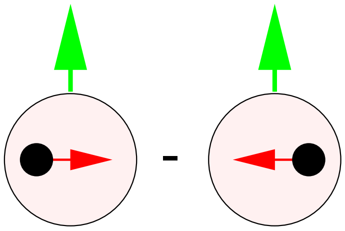
Interpretation of Distribution Functions

The leading twist description of the nucleon involves 3 types of Distribution Functions (+ others at higher level).

f_1 = 

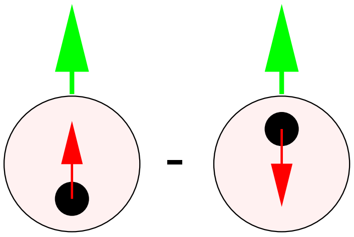
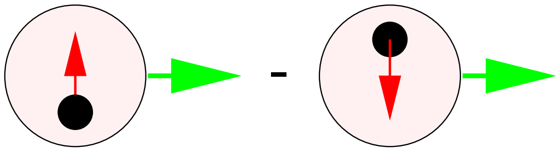
Unpol quark in unpol nucleon

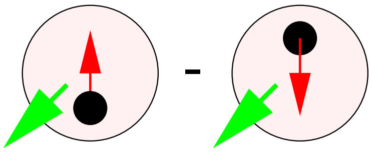
$q(x)$ $\Rightarrow$ **spin average (well known)**

g_1 =  g_{1T} = 

Longitudinal quark in longitudinal and transverse nucleon

$\Delta q(x)$ $\Rightarrow$ **helicity difference (well known)**

h_1 =  $h_{1L}^{\perp}$ = 

$h_{1T}^{\perp}$ = 

Transverse quark in longitudinal and transverse nucleon

$\delta q(x)$ $\Rightarrow$ **helicity flip (unknown)**

Other features of $h_1(x)$:

- **in absence of relativistic effect** $h_1(x) = g_1(x) \rightarrow$ **a measurement of** $h_1(x)$ **indicates the relativistic nature of quarks in the nucleon** $(m_u, m_d \ll m_p)$**.**

- **unlike for** $g_1(x)$**, the gluon polarisation does not mix with quark polarisation in** $h_1(x) \rightarrow$ **different** Q^2**-evolution.**

- $h_1(x)$ **is predominantly sensitive to valence quark polarisation.**

- **first moment of** $h_1(x)$ = **tensor charge of the nucleon** $\rightarrow$ **possible comparison with lattice QCD.**

Chirality Problem

▷ **Double Spin Asymmetries : polarized beam AND target**

$$g_1^n,\ g_1^p,\ \Delta q,\ \ldots$$

Longitudinal quark polarization densities

$\rightarrow$ CHIRAL EVEN $\leftarrow$

▷ **Single Spin Asymmetries (SSA) : polarized beam OR target**

$$h_1,\ h_{1L},\ h_{1T}$$

Transverse quark polarization densities

$\rightarrow$ CHIRAL ODD $\leftarrow$

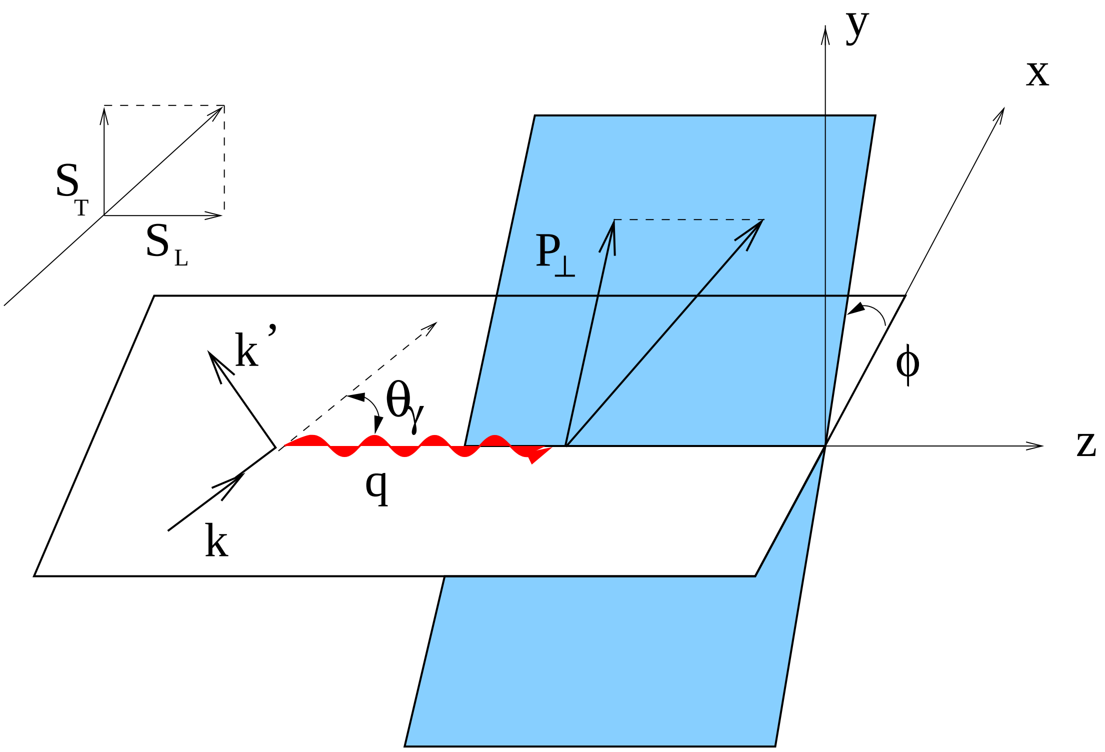
h_1 can be measured only together with another chiral odd function

Semi-Inclusive DIS

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

$\downarrow$ chiral ODD h_1

$\downarrow$ chiral ODD $H_1^{\perp}$ Collins FF



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.

Contributions to $\sin\phi$

$$
\begin{aligned}
< \sin\phi >_{UL} \quad &\propto \quad S_L \sum_{a,\bar{a}} e_a^2 x h_L^a(x) H_1^{\perp a}(z) \\
&+ \quad S_T \sum_{a,\bar{a}} e_a^2 x h_1^a(x) H_1^{\perp a}(z)
\end{aligned}
$$

HERMES, Longitudinally polarized target:
$S_T << S_L$

		T-even DF		T-odd FF	
		chirality even	chirality odd	chirality even	chirality odd
twist 2	U	$\mathbf{f}_1$			$H_1^{\perp}$
	L	$\mathbf{g}_{1L}$	$h_{1L}^{\perp}$		
	T	g_{1T}	$\mathbf{h}_1$ $h_{1T}^{\perp}$	$D_{1T}^{\perp}$	
twist 3	U	$f^{\perp}$	$\mathbf{e}$		$\mathbf{H}$
	L	$g_L^{\perp}$	$\mathbf{h}_L$	$D_L^{\perp}$	E_L
	T	$\mathbf{g}_T$ $g_T^{\perp}$	h_T $h_T^{\perp}$	$\mathbf{D_T}$	E_T

Analysing Powers

The analyzing powers for target longitudinal polarization are evaluated as:

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

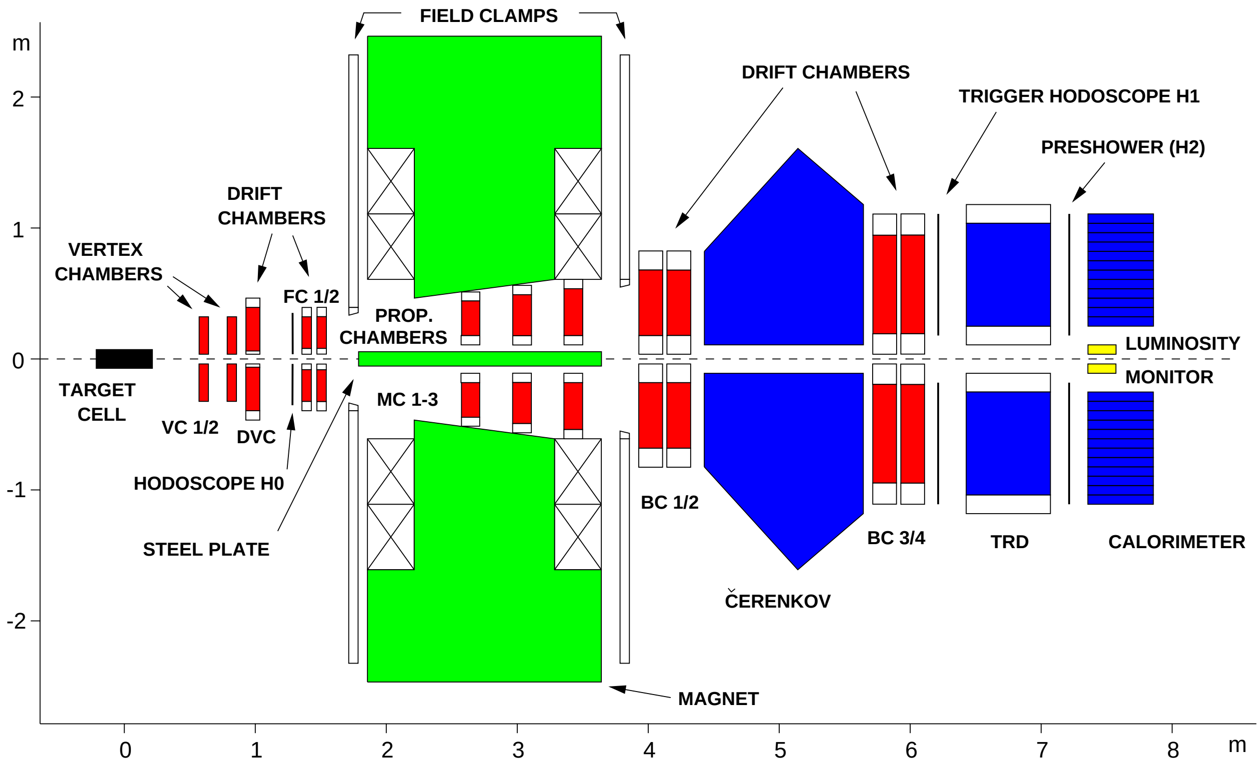
the $\uparrow / \downarrow$ denotes positive/negative helicity of the target, L and L_P are luminosity and lumi weighted polarizations.

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

UL defines unpolarized beam and longitudinally polarized target.

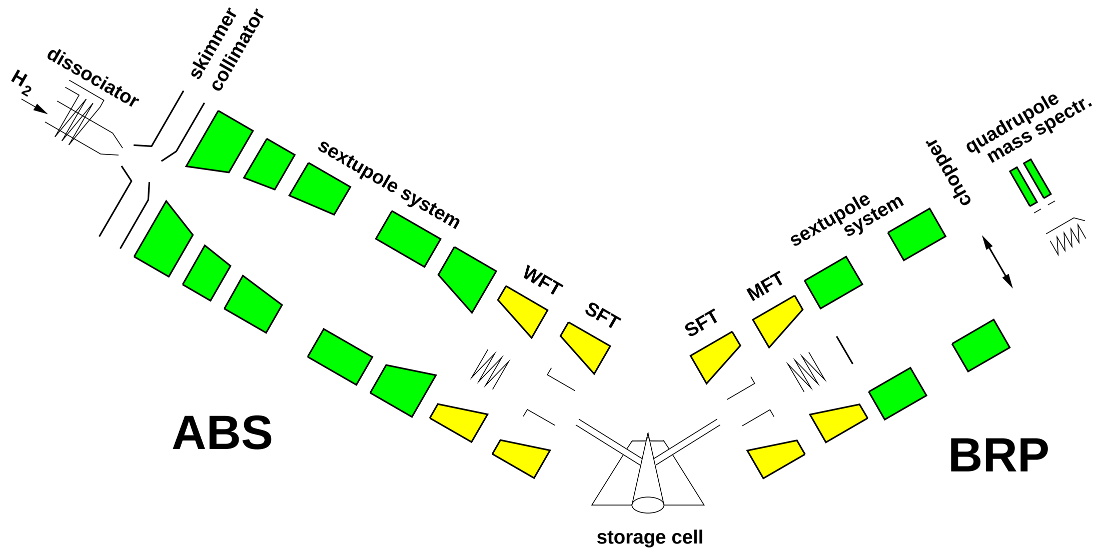
HERMES

• Spectrometer (before ’98)



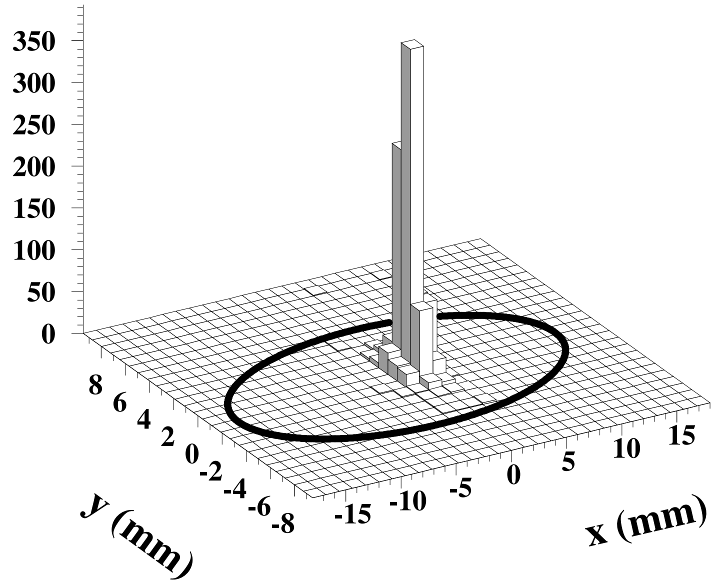
27.5 GeV e^+ (e^-) beam @ 27.5 GeV

• Target



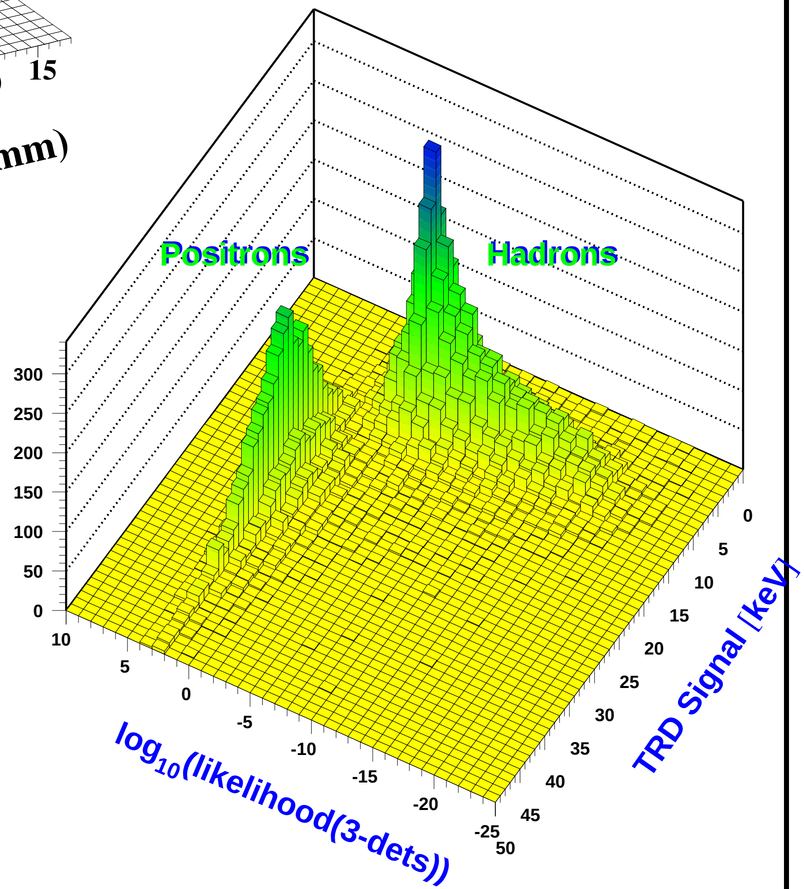
NIM A417 (1998) 230

- **Forward dipole spectrometer: 1.5 Tesla m , 40 mrad $< \theta <$ 220 mrad**
- **Charge particle tracking: 57 tracking planes,** $\delta P/P = (0.7 - 1.3)\%$, $\delta\theta < 0.6$ **mrad**



Vertex reconstruction

PID from $\hat{C}$erenkov, *TRD, Preshower* and *Calo*
h **contamination** $\leq 1\%$
e^+ **efficiency** $\geq 99\%$



$\pi^{\pm}$ identification ('96-'97): $\hat{C}$erenkov threshold detector

$$4\ GeV < P_{\pi^\pm} < 14\ GeV$$

Data selection

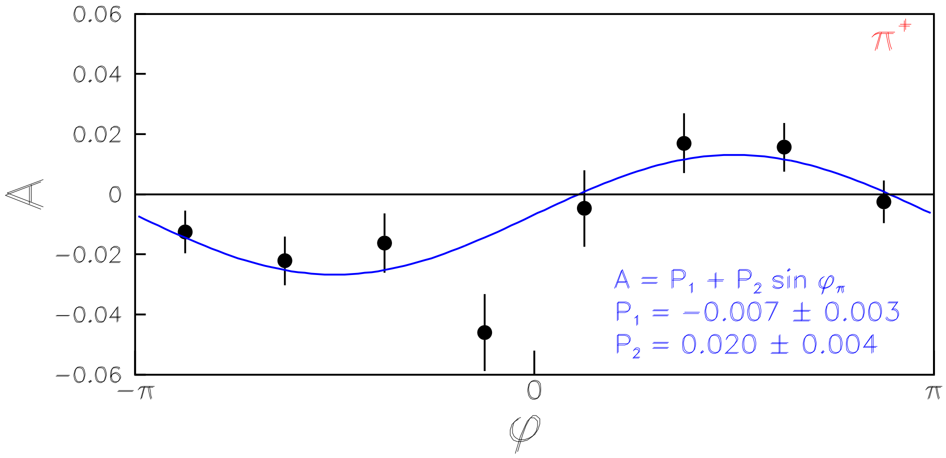
- Target:
  - ▷ $\vec{H}$
  - ▷ $< P_T >= (0.86 \pm 0.05)\%$

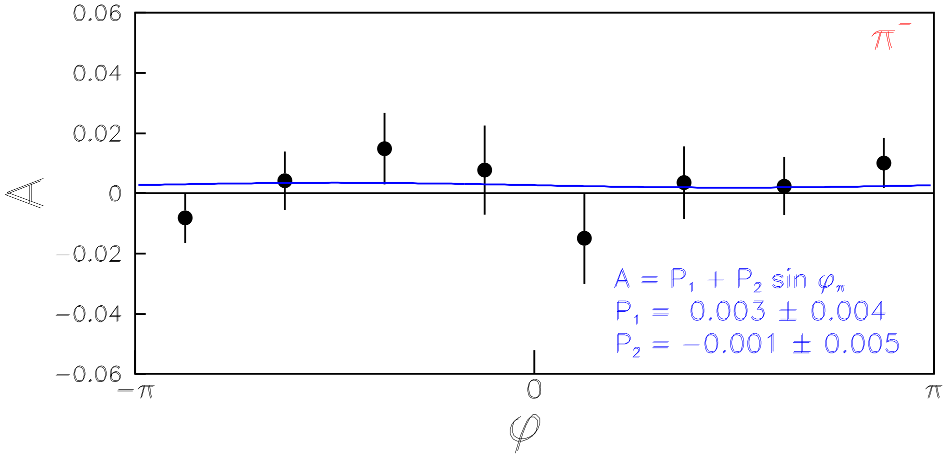
- DIS limits:
  - ▷ $Q^2 > 1\ GeV^2$
  - ▷ $W^2 > 4\ GeV^2$
  - ▷ $y = (E - E')/E < 0.85$

- Semi-Inclusive limits:
  - ▷ $0.2 < z = E_\pi/(E - E') < 0.7$
  - ▷ $\pi^\pm$: $4.5 < E_\pi < 13.5\ GeV$
  - ▷ π^0: $E_\gamma > 1.0\ GeV,\ 0.100 < M_{\gamma\gamma} < 0.170\ GeV$

Cross section Asymmetry

Asymmetry in the cross section: $A(\phi) = \frac{1}{P_H}\frac{N^+ - N^-}{N^+ + N^-}$





$$\pi^+ \quad \mathcal{A}_{UL}^{sin\phi} = 0.022 \pm 0.005(stat) \pm 0.003(syst)$$

$$\pi^- \quad \mathcal{A}_{UL}^{sin\phi} = -0.002 \pm 0.006(stat) \pm 0.004(syst)$$

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

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

SSA Systematics

Main contributions to systematic uncertainties:

Target polarization: 5%

- Target$^{\uparrow/\downarrow}$ $\Rightarrow$ $< sin\phi >^{\uparrow} \simeq - < sin\phi >^{\downarrow}$
- Target^{0} $\Rightarrow$ $< sin\phi >^{0} \simeq 0$

No significant instrumental effect !

Acceptance

- Geometrical accept gives $cos\phi$ contribution < 0.3 (MC)

$$\bigoplus$$

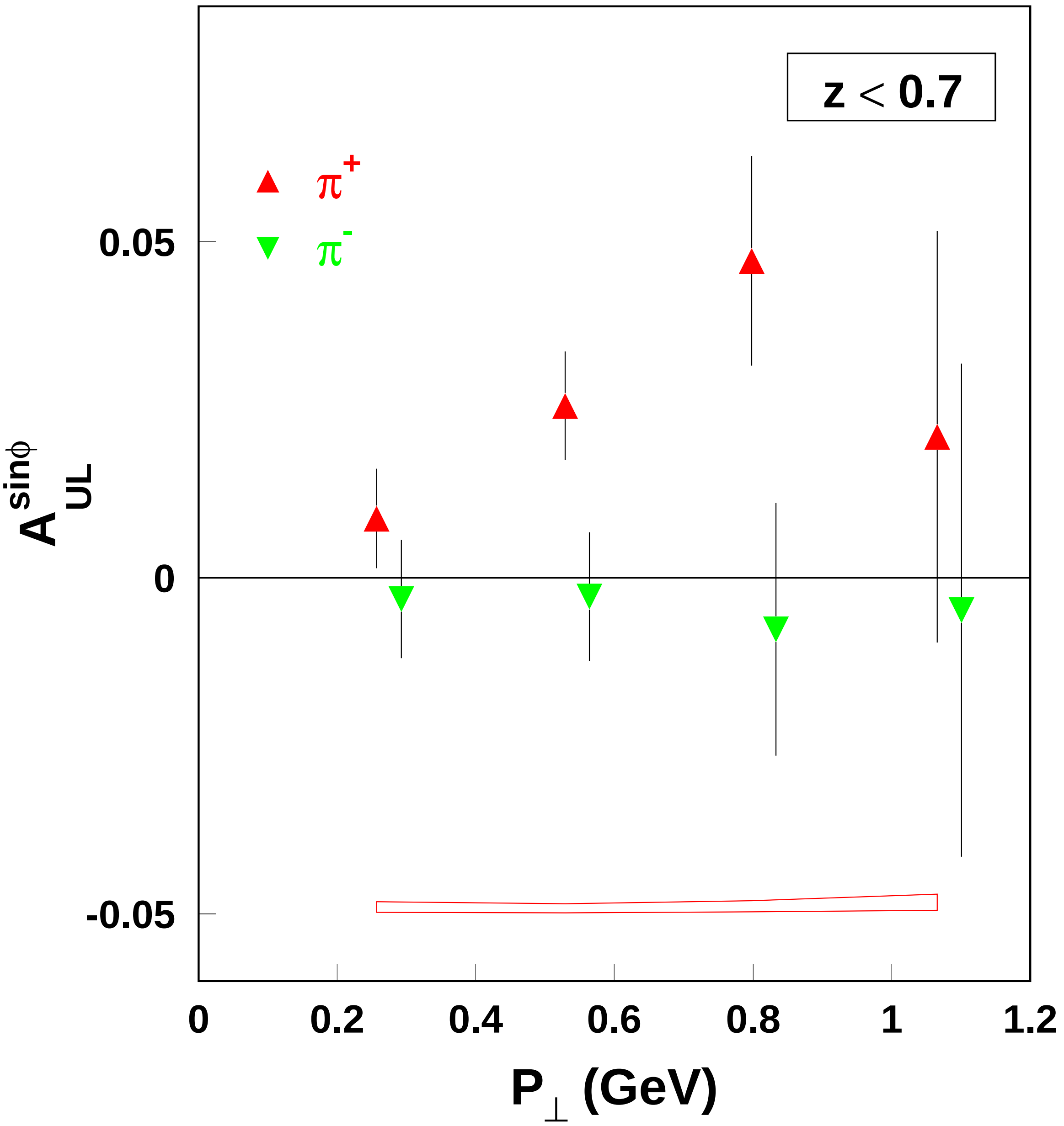
- Cross section has $sin2\phi$ (twist-2) $< 1\%$ (data/theory)

$$\Downarrow$$

- The contribution to $sin\phi$ is 0.003 (15%). It is included in the SSA calculation and in the systematic uncertainties too.

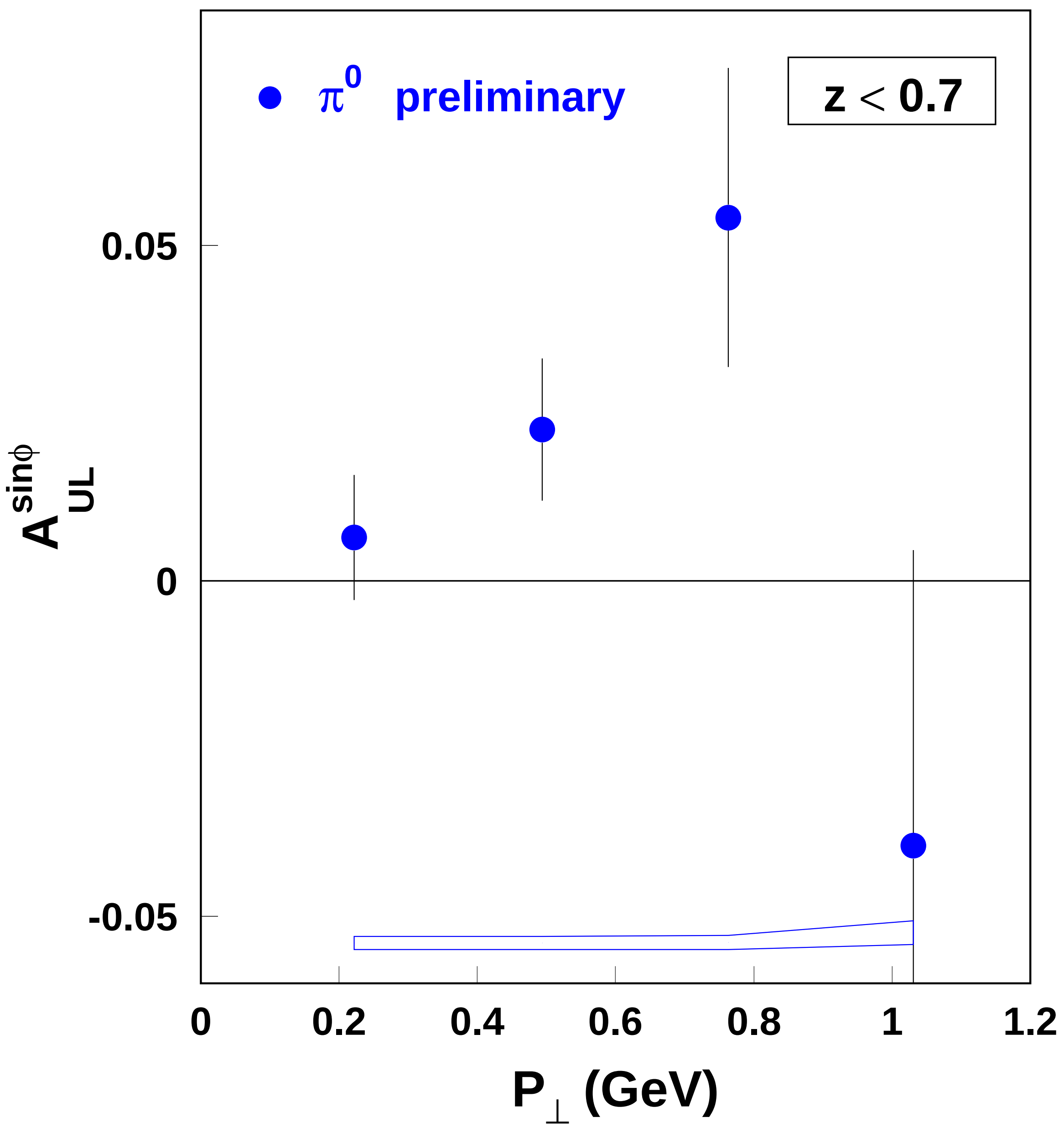
Small acceptance corrections !

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

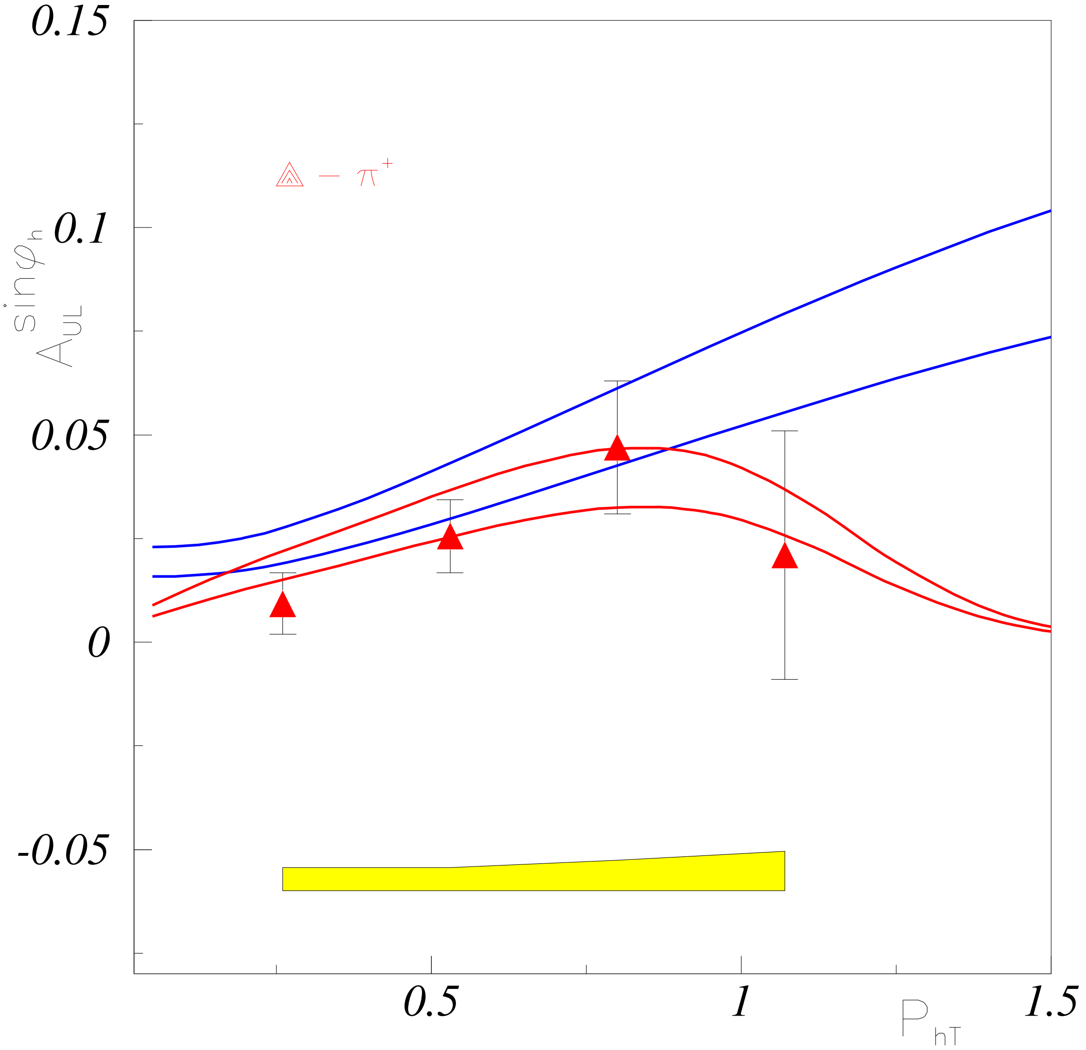


Dominant role of $k_\perp$ when $P_\perp$ remains below a typical hadronic mass (∼1 GeV).

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



$P_\perp$ dependence & theory

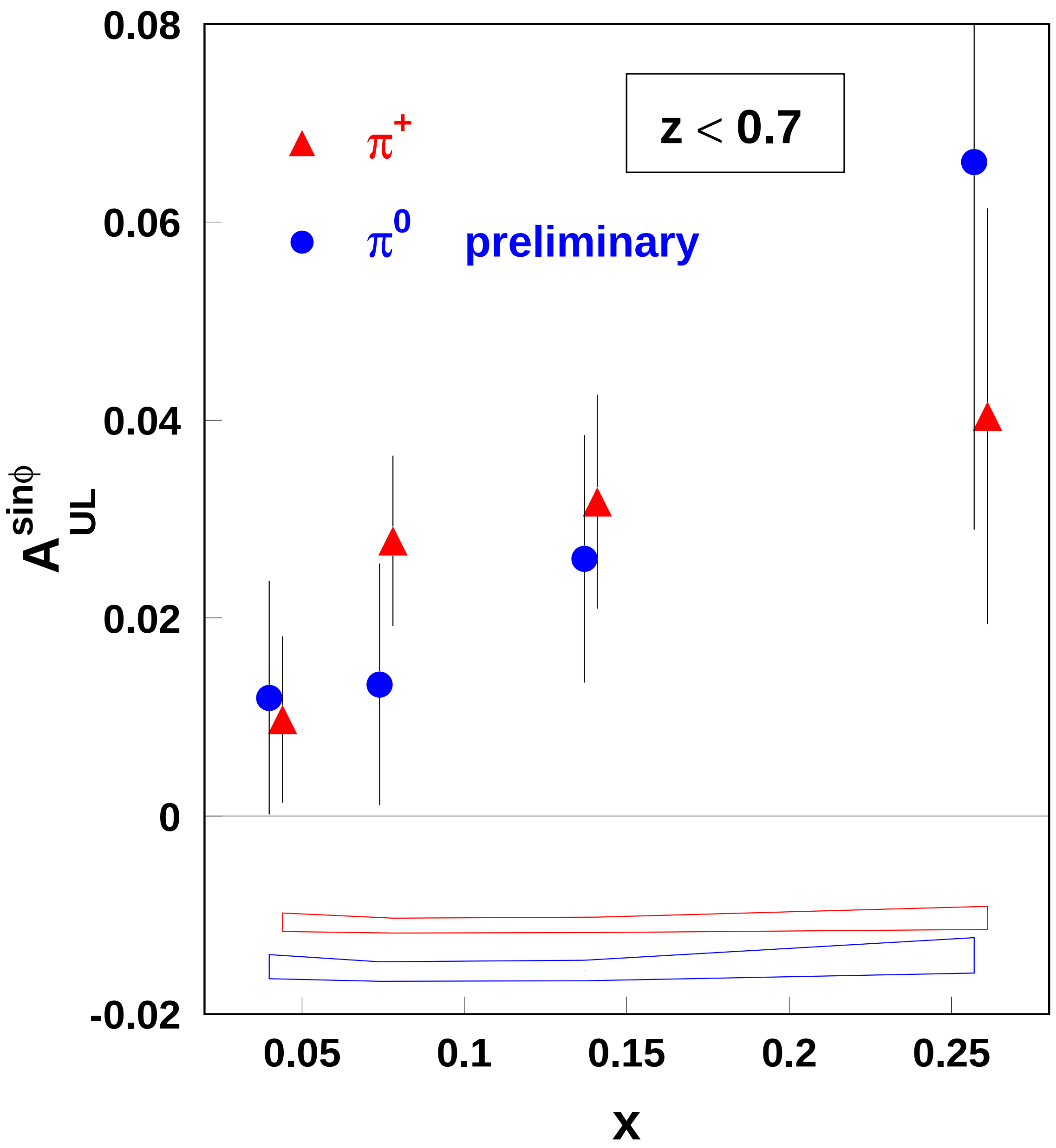


At high $P_\perp$ a not negligible contribution from PQCD arises:

$$\mathcal{A}_{UL}^{sin\phi} = \frac{2\int d\sigma^{(NP)} sin\phi}{\int d\sigma^{(NP)} + \int d\sigma^{(\alpha_s)}}$$

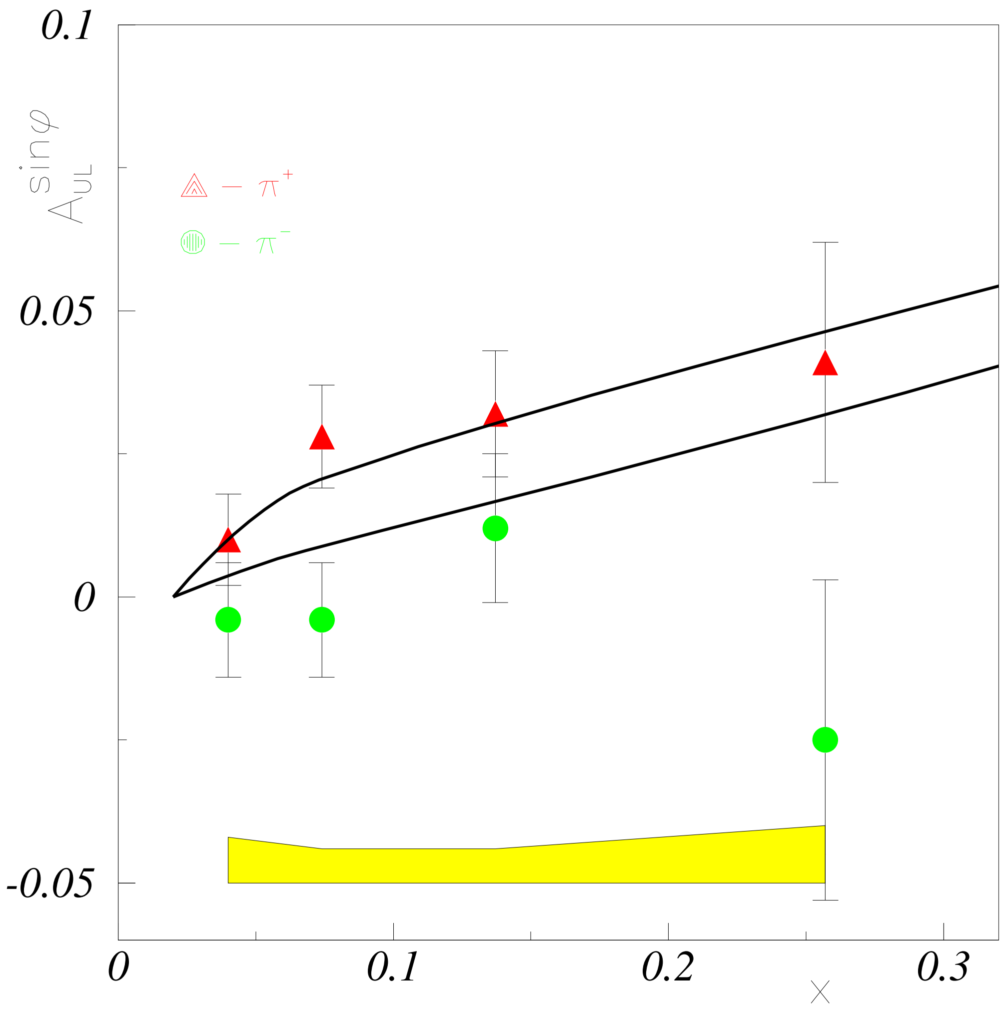
K.A.Oganessyan et al. hep-ph/0010063

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



- consistent behavior of π^+ and π^0.
- behavior consistent with increase suggests that the sea contribution does not dominate the effect.

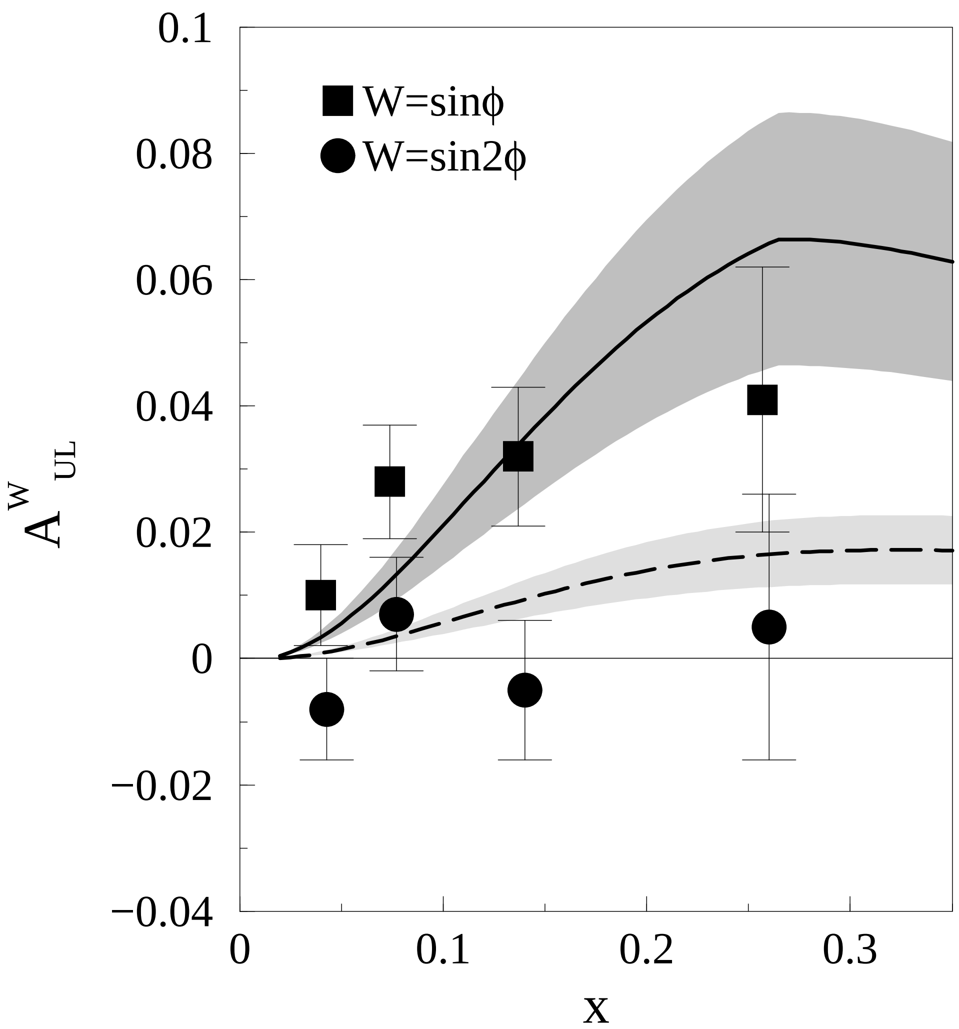
Comparison with theory for π^+



Curves correspond to different approximations for h_1 ($h_1 = \frac{1}{2}(g_1 + f_1)$, $h_1 = g_1$).

K.A.Oganessyan et al. PL B483 (2000) 69

Comparison with theory: $sin2\phi$ & $sin\phi$



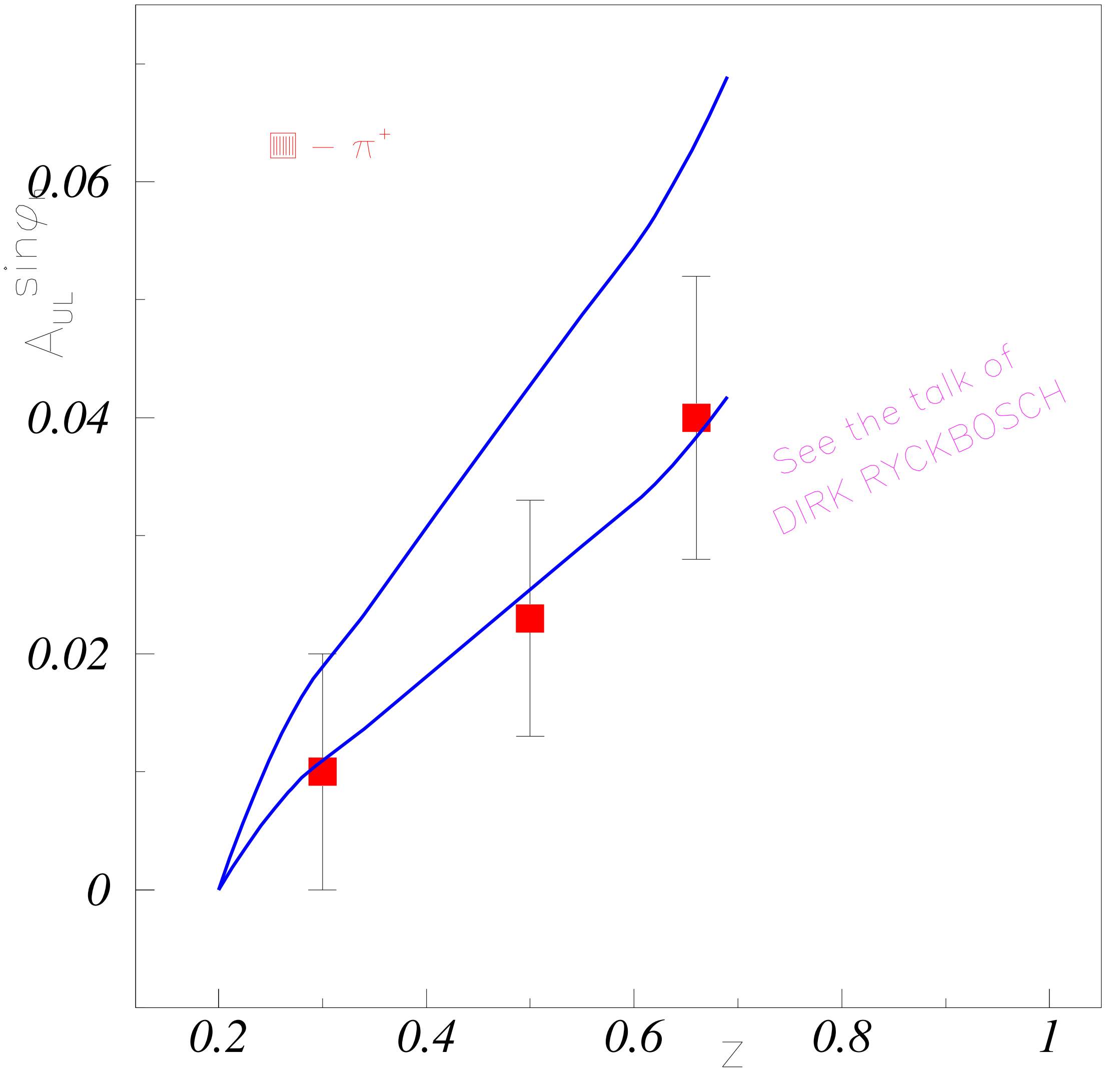
(Efremov et al. PL B478 (2000) 94)

⇒ $sin\phi$ is twist-3;

⇒ $sin2\phi$ is twist-2 but suppressed by a kinematical factor.

$$\pi^+ \quad \mathcal{A}_{UL}^{sin2\phi} = -0.002 \pm 0.005(stat) \pm 0.010(syst)$$
$$\pi^- \quad \mathcal{A}_{UL}^{sin2\phi} = -0.005 \pm 0.006(stat) \pm 0.005(syst)$$

SSA: z-dependence



$z = E_h/\nu$

Different SSA behavior in semi-inclusive and exclusive region for $\pi^{\pm}$ and π^0.

Summary and outlook

- **First observation of a Single Spin Azimuthal asymmetry for semi-inclusive pion electro-production in DIS:**
  - $\triangleright\ \pi^+ : A_{UL}^{sin\phi} = 0.022 \pm 0.005(stat) \pm 0.003(syst)$
- $A_{UL}^{sin\phi}(\pi^-)$ **is suppressed on the proton (u-quark dominance).**
  - $\triangleright\ \pi^- : A_{UL}^{sin\phi} = -0.005 \pm 0.008(stat) \pm 0.004(syst)$
- **Preliminary π^0 results are consistent with π^+;**
- $A_{UL}^{sin\phi}$ **vs x (valence quarks) and $P_\perp$ ($k_\perp$ contribution) constraint theoretical models;**
- $A_{UL}^{sin2\phi}$ **suppressed compared to $A_{UL}^{sin\phi}$;**
  - $\triangleright\ \pi^+ : A_{UL}^{sin2\phi} = -0.002 \pm 0.005(stat) \pm 0.010(syst)$
- **First evidence of transversity effects in longitudinally polarized target.**

More results in 2001+ by the HERMES transversely polarized target:

- **Transversity h_1;**
- **Collins fragmentation function;**
- **Access to different DF and FF ($cos\phi,\ cos3\phi,\ sin3\phi,\ ...$).**