# Tagging the Collins Fragmentation Function at

hermes


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- How to access to transversity ?
- Experimental layout
- Semi-Inclusive SSA for $\pi^+$, $\pi^-$ and $\pi^0$
- Conclusions

# Chirality Problem

▷ Longitudinal quark polarization densities:
$g_1, \ldots \rightarrow$ CHIRAL EVEN

▷ Transverse quark polarization densities (by SSA):
$h_1,\ h_{1L},\ h_{1T} \rightarrow$ CHIRAL ODD

It's a simple quantum mechanics consequence:

$$|{}^{\perp}_{\top}\rangle = \frac{1}{\sqrt{2}}(|+\rangle \pm |-\rangle)$$

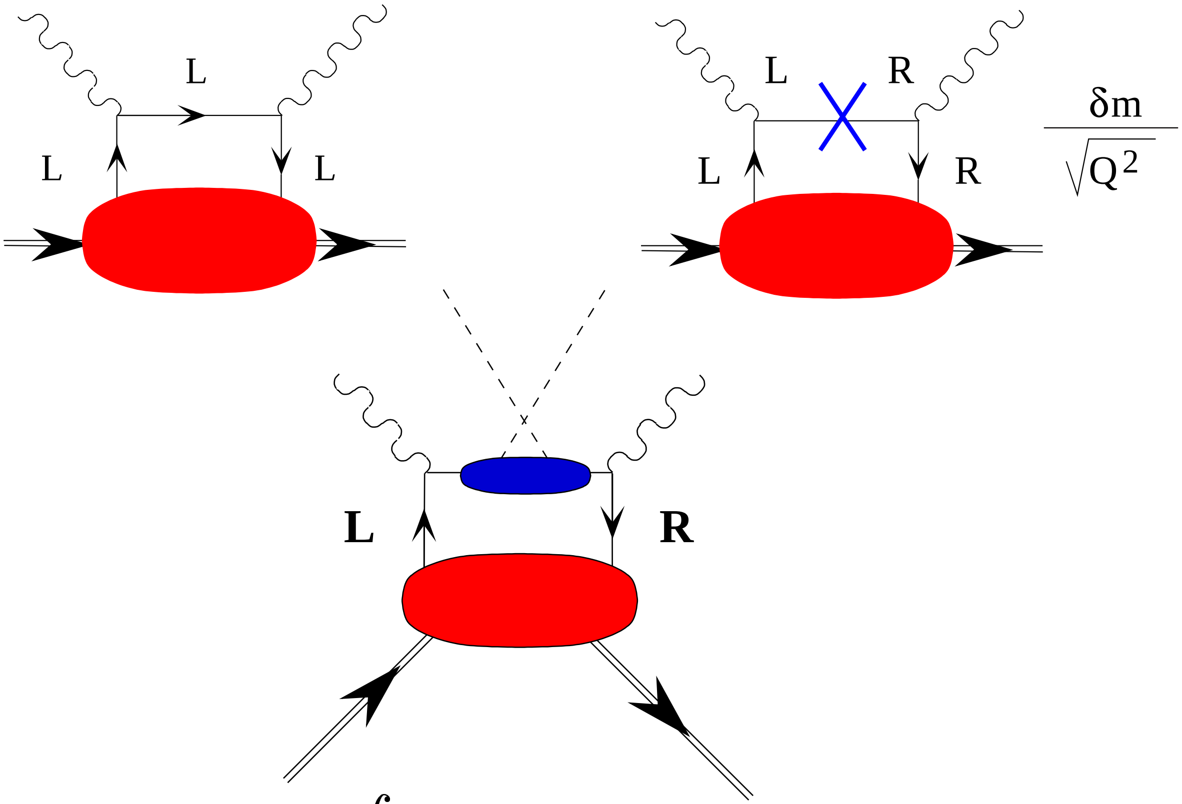
$$d\sigma_{{}^{\perp}_{\top}} \propto \langle {}^{\perp}_{\top}| \cdots |{}^{\perp}_{\top}\rangle$$

$$d\sigma_{\perp} - d\sigma_{\top} \propto \langle +| \cdots |-\rangle + \langle -| \cdots |+\rangle$$

All hard QCD and electroweak processes preserve chirality.

# The Collins FF

To access transversity and preserve chirality, simultaneously, "a good chance" is to involve a *chiral-odd* DF + a *chiral-odd* FF.

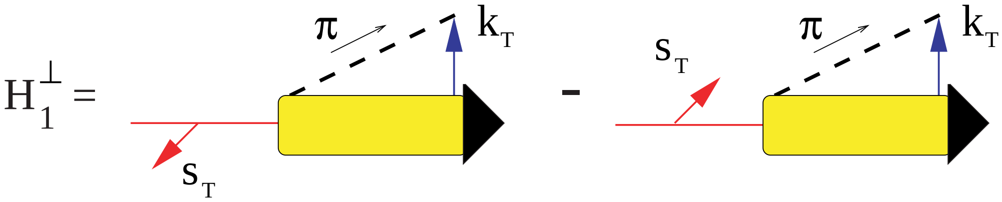



$$H_1^\perp \propto \int d^2p_\perp D_h(z,\vec{p}_\perp) \cos\chi$$

if the target is polarized

$$\cos\chi \propto \vec{k}\times\vec{s}\cdot\vec{p} \qquad \begin{cases} \vec{k} & \textit{initial electron's momentum} \\ \vec{s} & \textit{target spin} \\ \vec{p} & \textit{final hadron's momentum} \end{cases}$$

$H_1^\perp$ is chiral-odd because of $\cos\chi$:




(by D.Boer)

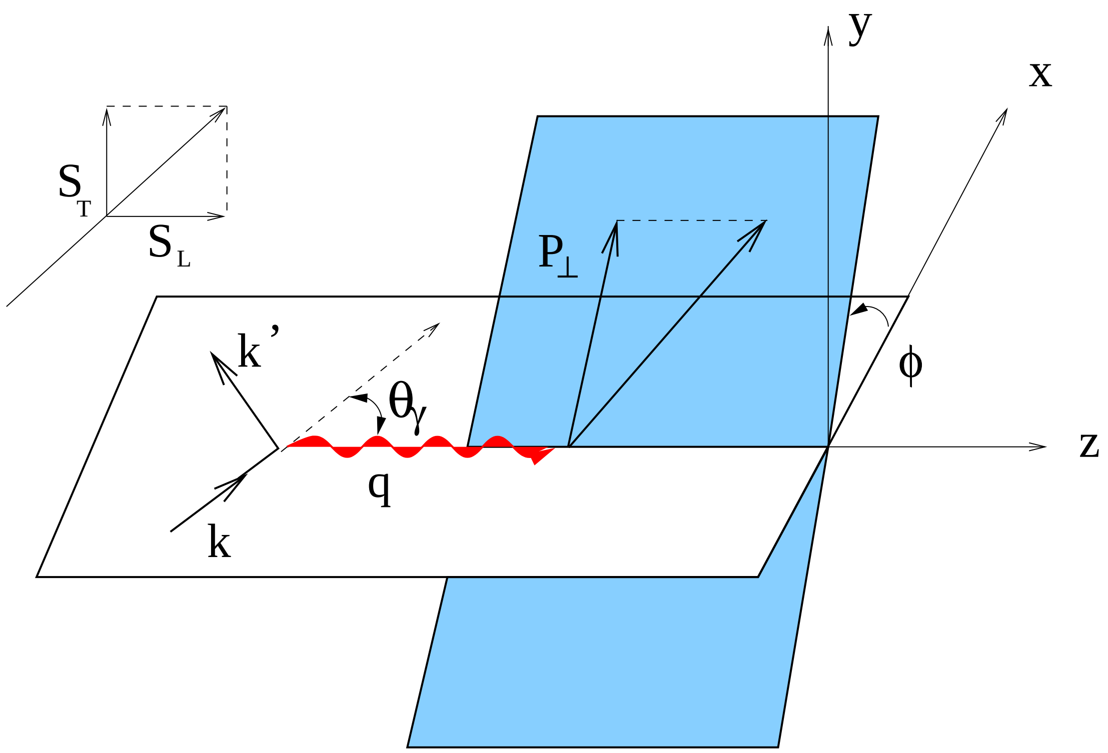
# Semi-Inclusive DIS

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

$$\downarrow \qquad\qquad\qquad \downarrow$$

chiral ODD $h_1$ chiral ODD $H_1^\perp$ Collins FF

If $e\vec{p}_\perp \to e' hX \quad \Longrightarrow \quad \cos\chi = \sin\phi$




We expect a <u>Single Spin azimuthal Asymmetry</u> (SSA), a signature of the transversity DF, originates from intrinsic quark transverse momentum $k_T$ (i.e. from $H_1^\perp$).

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

# Contributions to $\sin\phi$

It is possible to access to $h_1$ and to $H_1^\perp$ by $< \sin\phi >_{UL}$:

$$\begin{aligned} < \sin\phi >_{UL} \quad &\propto \quad S_L \frac{2(1-y)}{Q\sqrt{1-y}} \sum_{a,\bar{a}} e_a^2 x h_L^a(x) H_1^{\perp a}(z) \\ &+ \quad S_T (1-y) \sum_{a,\bar{a}} e_a^2 x h_1^a(x) H_1^{\perp a}(z) \end{aligned}$$

In HERMES $(e\vec{p}_{\parallel} \to e' h X)$ $S_T << S_L$

| | | 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 longitudinally polarized target are evaluated as:

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

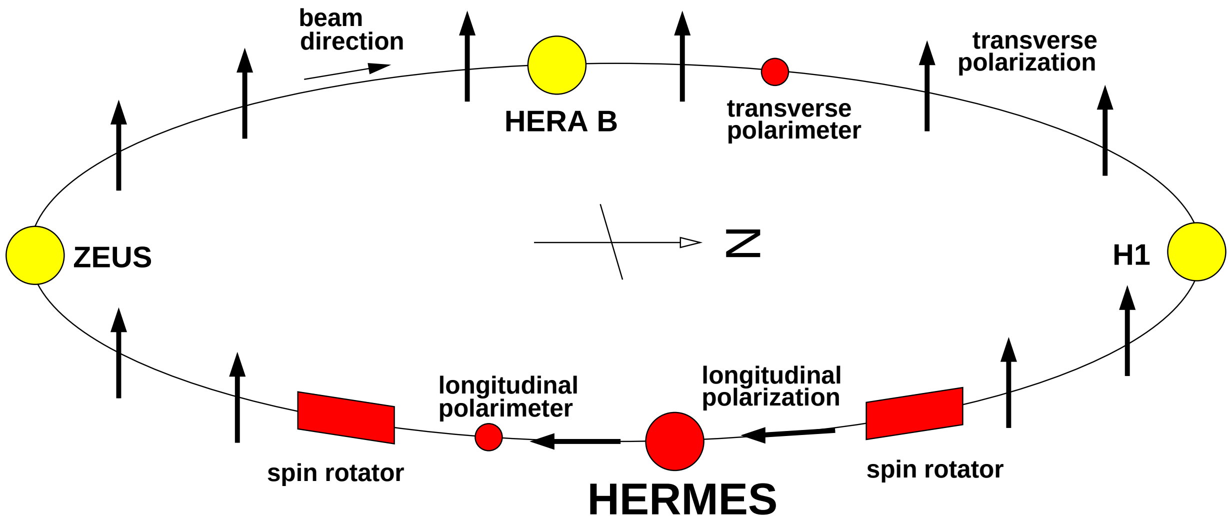
the $\uparrow / \downarrow$ denotes positive/negative helicity of the target, $L$ and $L_P$ are luminosity and lumi weighted polarizations.

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

(e.g. $A_{UL}^{sin\phi} = 2 < sin\phi >$)

UL defines unpolarized beam and longitudinally polarized target.

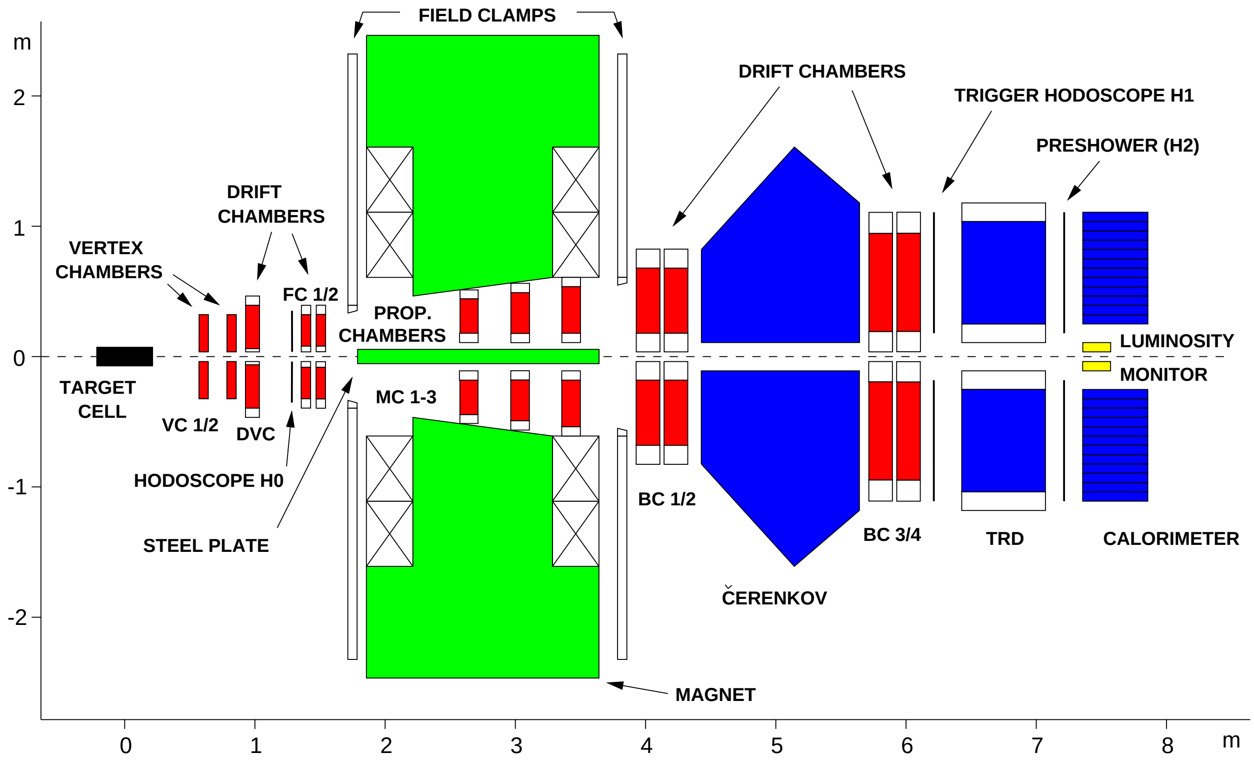
# HERMES at DESY




- 27.5 GeV $e^+$ ($e^-$), I~30-50 mA.
- Self-polarization by emission of synchrotron radiation, $P_b(t) = p_b^{max}[1 - exp(t/\tau)]$.
- Spin rotators $\rightarrow$ longitudinal beam polarization at HERMES IP
- 2 Polarimeters

# SPECTROMETER

(HERMES coll. NIM A417 (1998) 230)



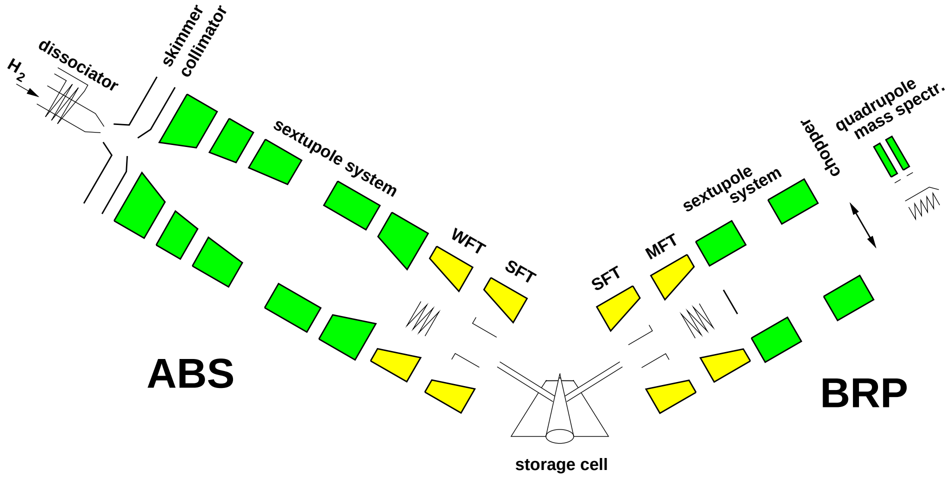

- **kinematic:** $0.004 < x < 0.8$ for $Q^2 > 0.2$, $W^2 > 4$
- **Tracking**: 57 tracking planes, $\delta P/P = (0.7 - 1.3)\%$, $\delta\theta < 0.6$ mrad
- **Particle identification: $\hat{C}$erenkov, TRD, Preshower, e.m. Calorimeter**

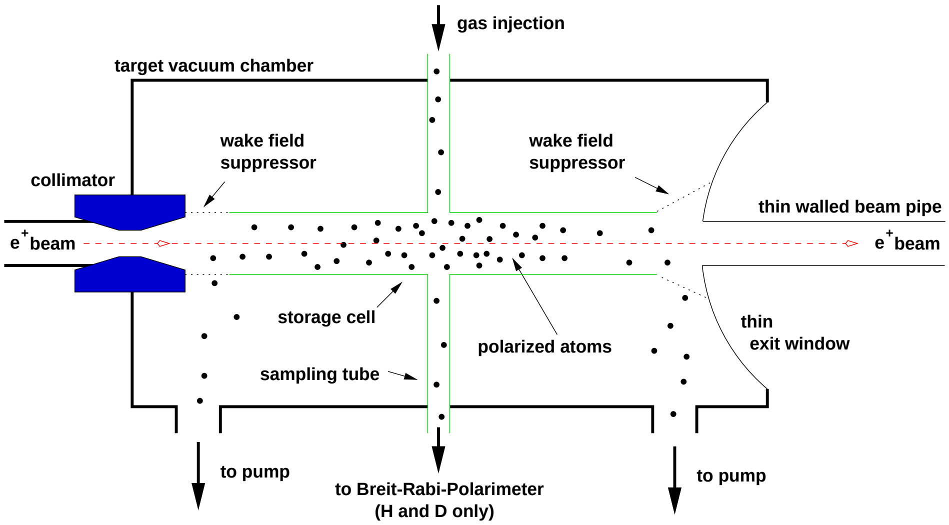
  $e^+$ identification: 99% efficiency and < 1% of contamination

Several upgrades have been performed in the 1998 and 2000.

The following results are related to the 96+97 data taking period.

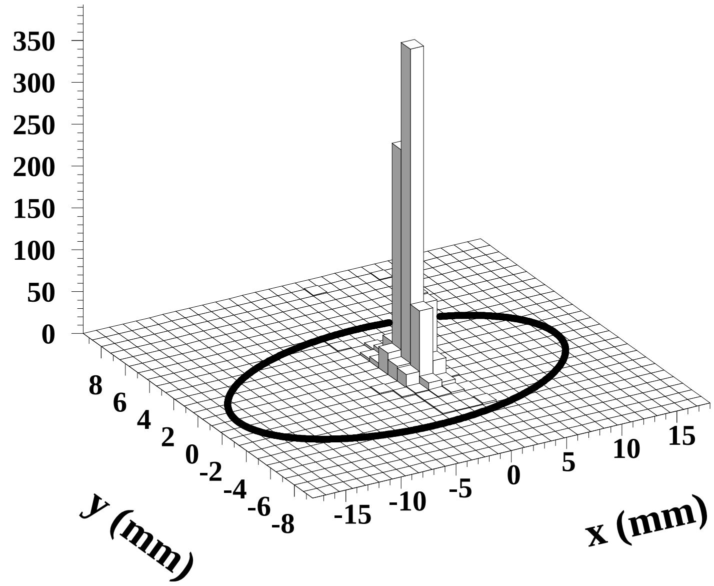
# The Target



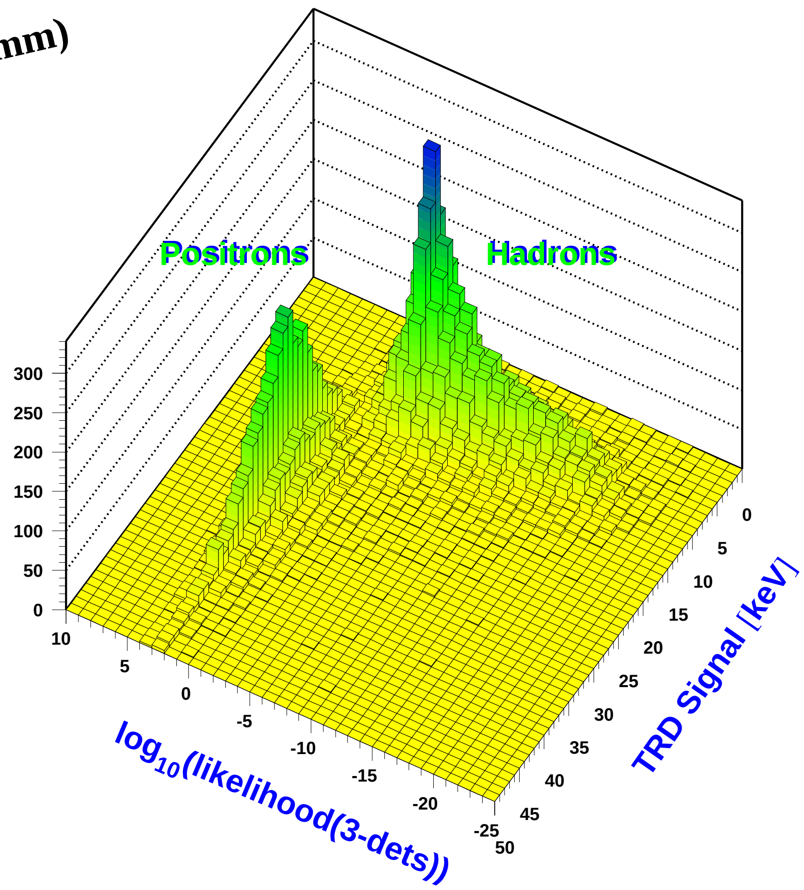

- Internal storage cell.
- No entrance or exit windows $\Rightarrow$ no multiple scattering, low background.
- Atomic beam source for $\vec{H}$ and $\vec{D}$ target with high polarisation ($Pol > 90\%$).
- Pure gas target, no dilution factor.
- Unpolarised high density nuclear targets (H, D, $^3$He, $^4$He, N, Ne, Kr).
- Densities: $\left\{ \begin{array}{rl} 7 \cdot 10^{13}\ Nucl/cm^2 & (polarised) \\ 10^{15} \div 10^{17}\ Nucl/cm^2 & (unpolarised) \end{array} \right.$

# Charged pions




**Vertex reconstruction**

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

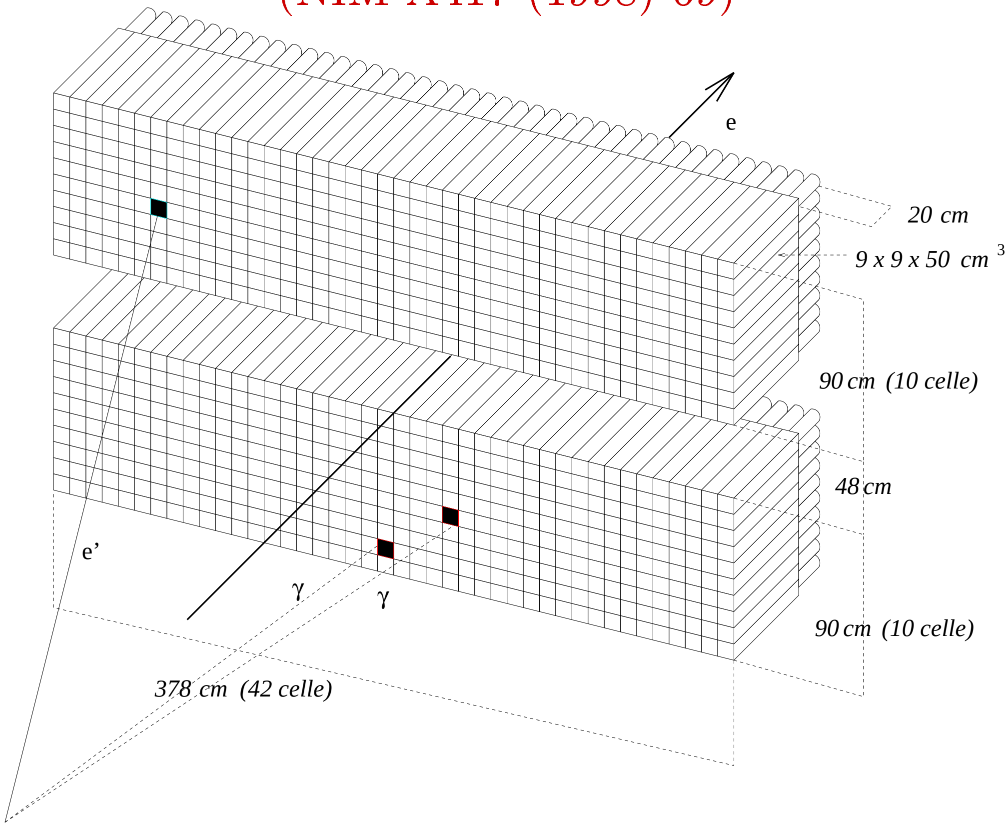


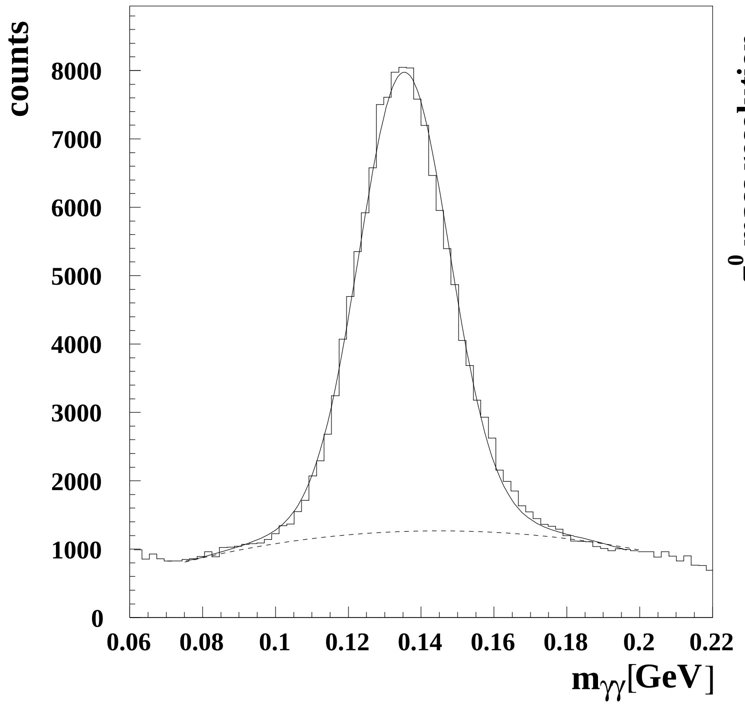

$\pi^{\pm}$ identification (1996-97): $\hat{C}$erenkov threshold detector

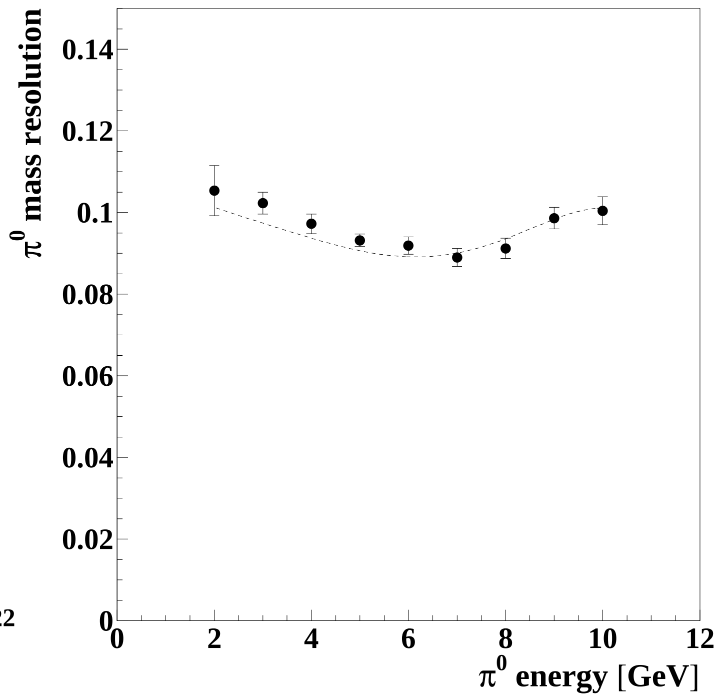
$$4\ GeV < P_{\pi^{\pm}} < 14\ GeV$$

# Neutral pions

(NIM A417 (1998) 69)




$E_\gamma > 1.0$ GeV, $0.100 < M_{\gamma\gamma} < 0.170$ GeV

$$\boxed{M_{\pi^0} = 0.135 \pm 0.012 \text{ GeV}}$$

# Data selection

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

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

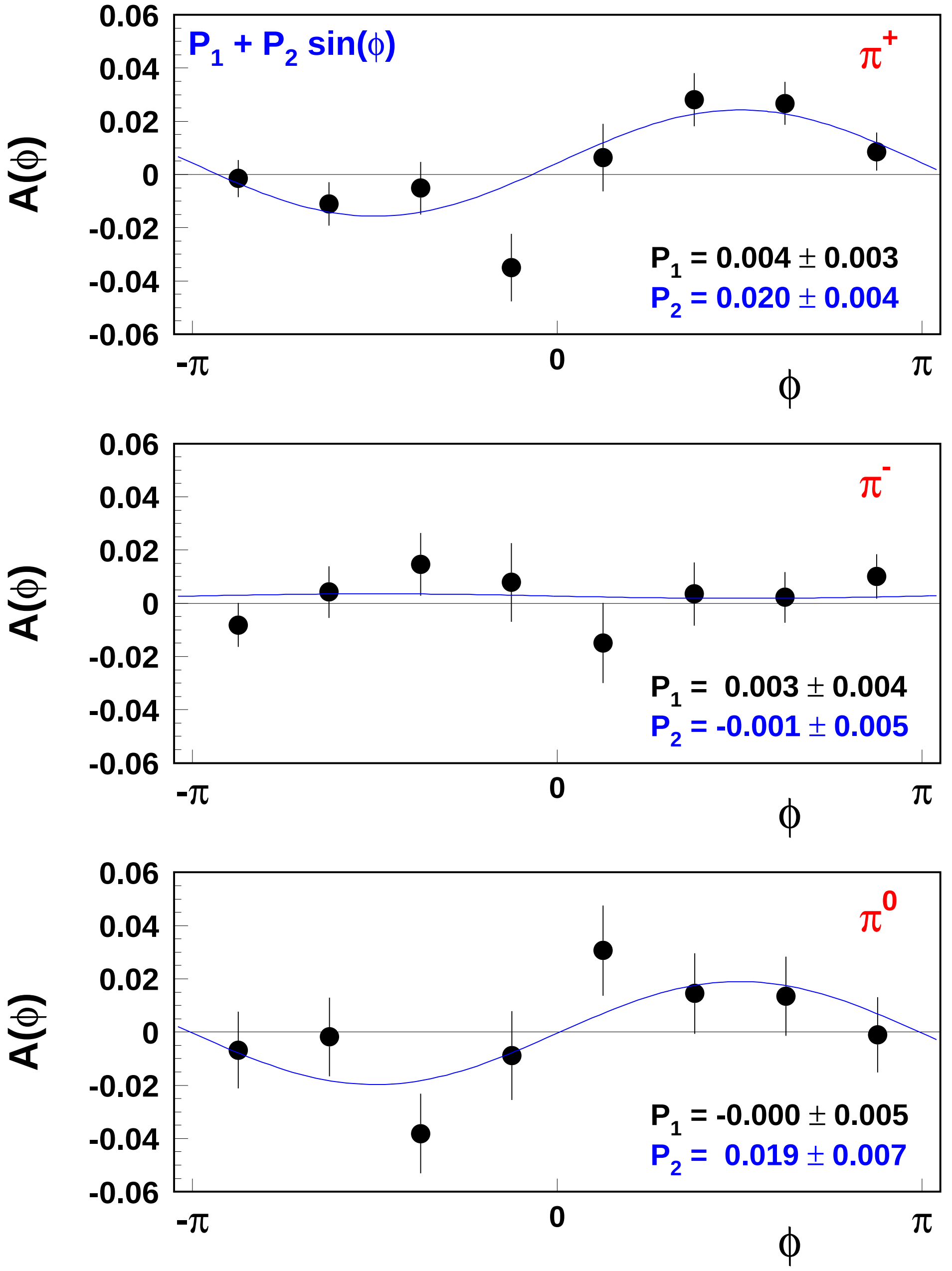
- Semi-Inclusive limits:
  - ▷ $0.2 < z = E_\pi/(E - E') < 0.7$
  - ▷ $\pi^\pm$: $4.5 < E_\pi < 13.5$ GeV
  - ▷ $\pi^0$: $E_\gamma > 1.0$ GeV, $0.100 < M_{\gamma\gamma} < 0.170$ GeV
  - ▷ $P_\perp > 0.050$ GeV

Related HERMES papers:

- Phys. Rev. Lett. 84 (2000) 4047-4051 (hep-ex/9910062)
- Submitted to Phys. Rev. D. (hep-ex/0104005)

# Cross section Asymmetry

$$A(\phi) = \frac{1}{< P_t >} \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)}$$




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

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

$$\pi^0 \quad \mathcal{A}_{UL}^{\sin\phi} \propto \frac{1}{9} (4 h_L^u + h_L^d) H_1^{\perp u \to \pi^0}$$

# 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)

$$\bigoplus$$

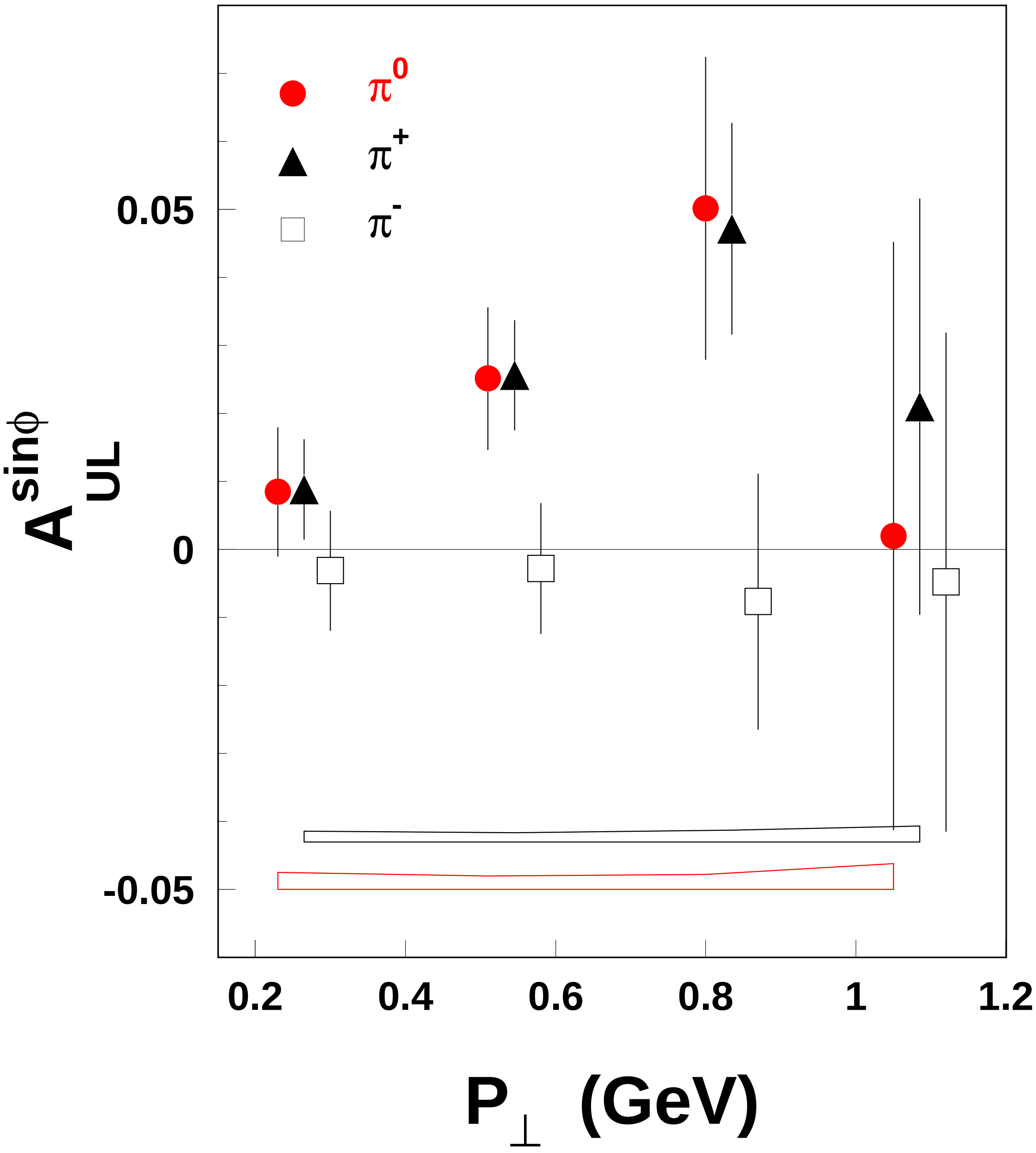
- Cross section has $sin2\phi$ contribution $< 1\%$ (data/theory)

$$\Downarrow$$

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

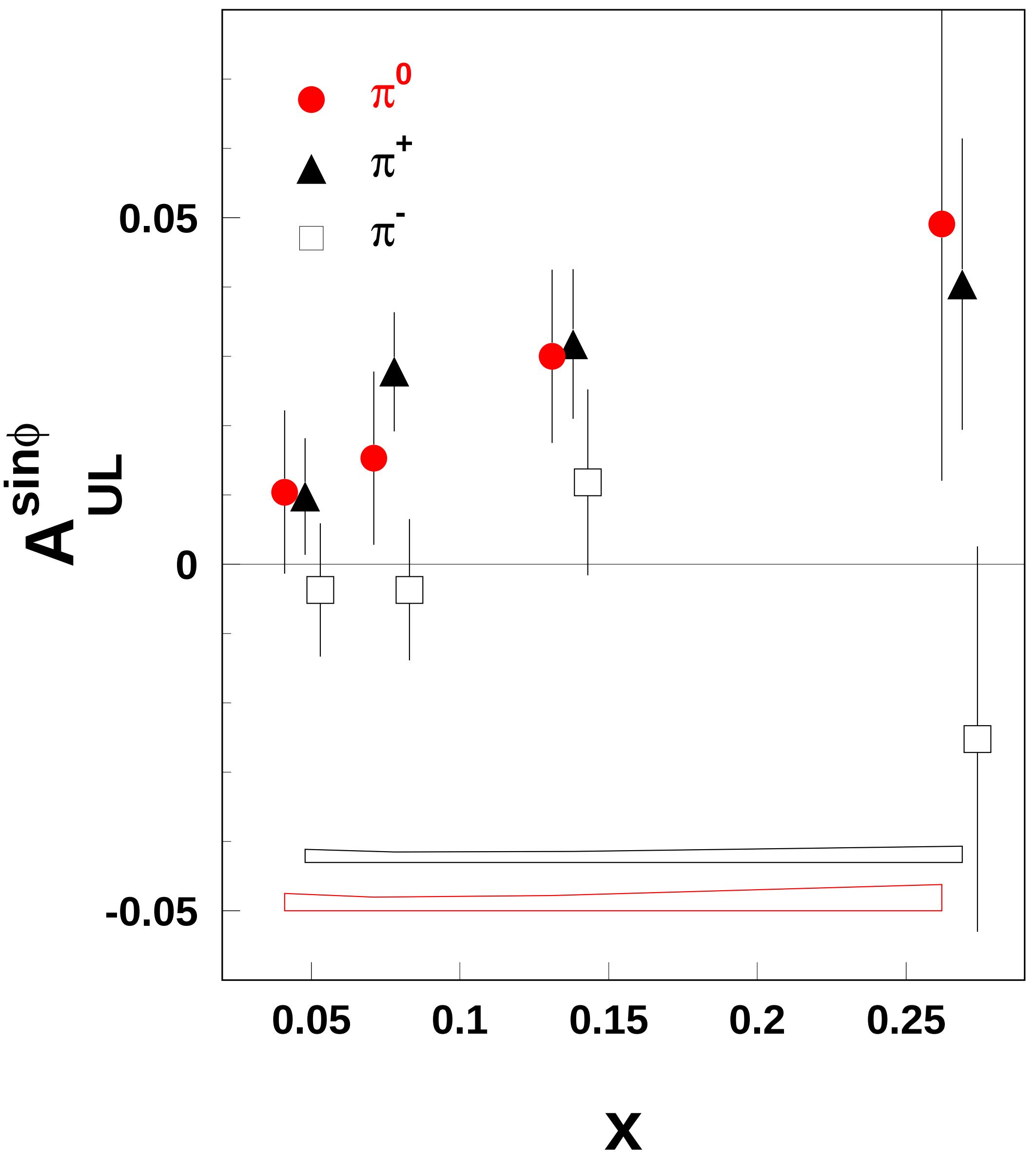
**Small acceptance corrections !**

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




- Similar behavior of $\pi^+$ and $\pi^0$.
- Dominant kinematical role of the intrinsic transverse momentum of the quark when $P_\perp$ remains below a typical hadronic mass ($\sim$1 GeV).

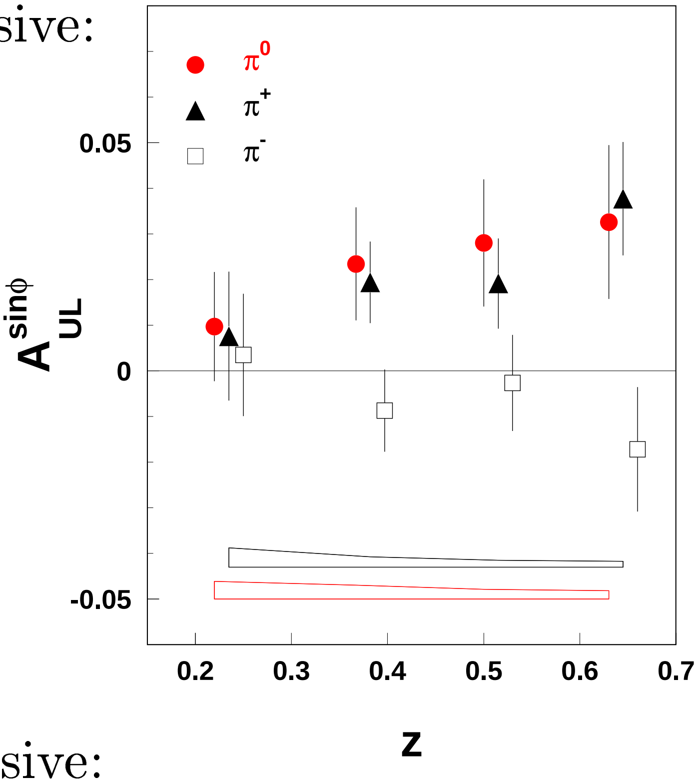
# SSA $\mathcal{A}_{UL}$: $x$ dependence



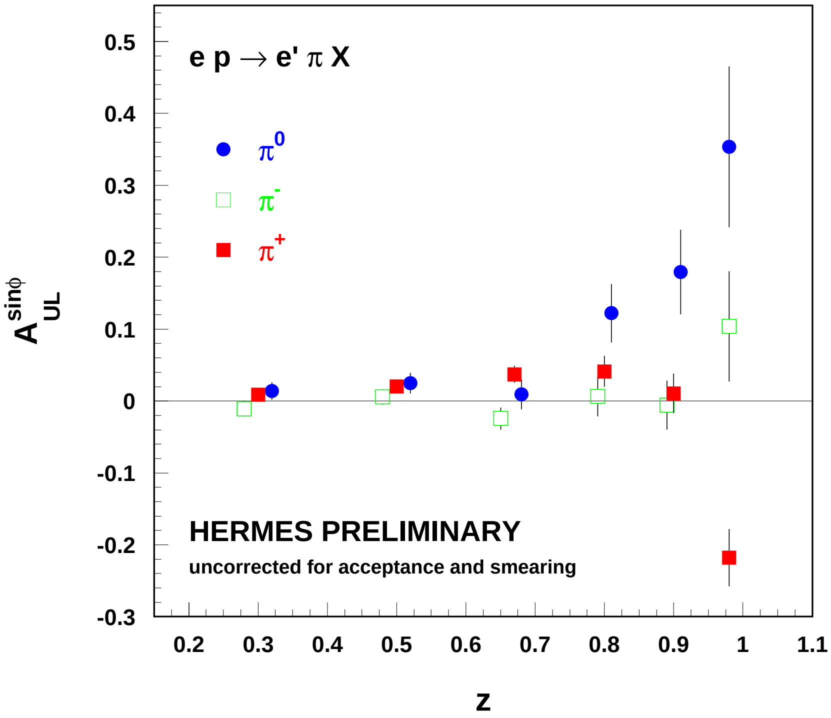

- Similar behavior of $\pi^+$ and $\pi^0$.
- The increasing of the behavior with $x$ suggests that the SSA is dominated by valence quark contributions.

# SSA: $z$-dependence ($z = E_h/\nu$)

Semi-inclusive:



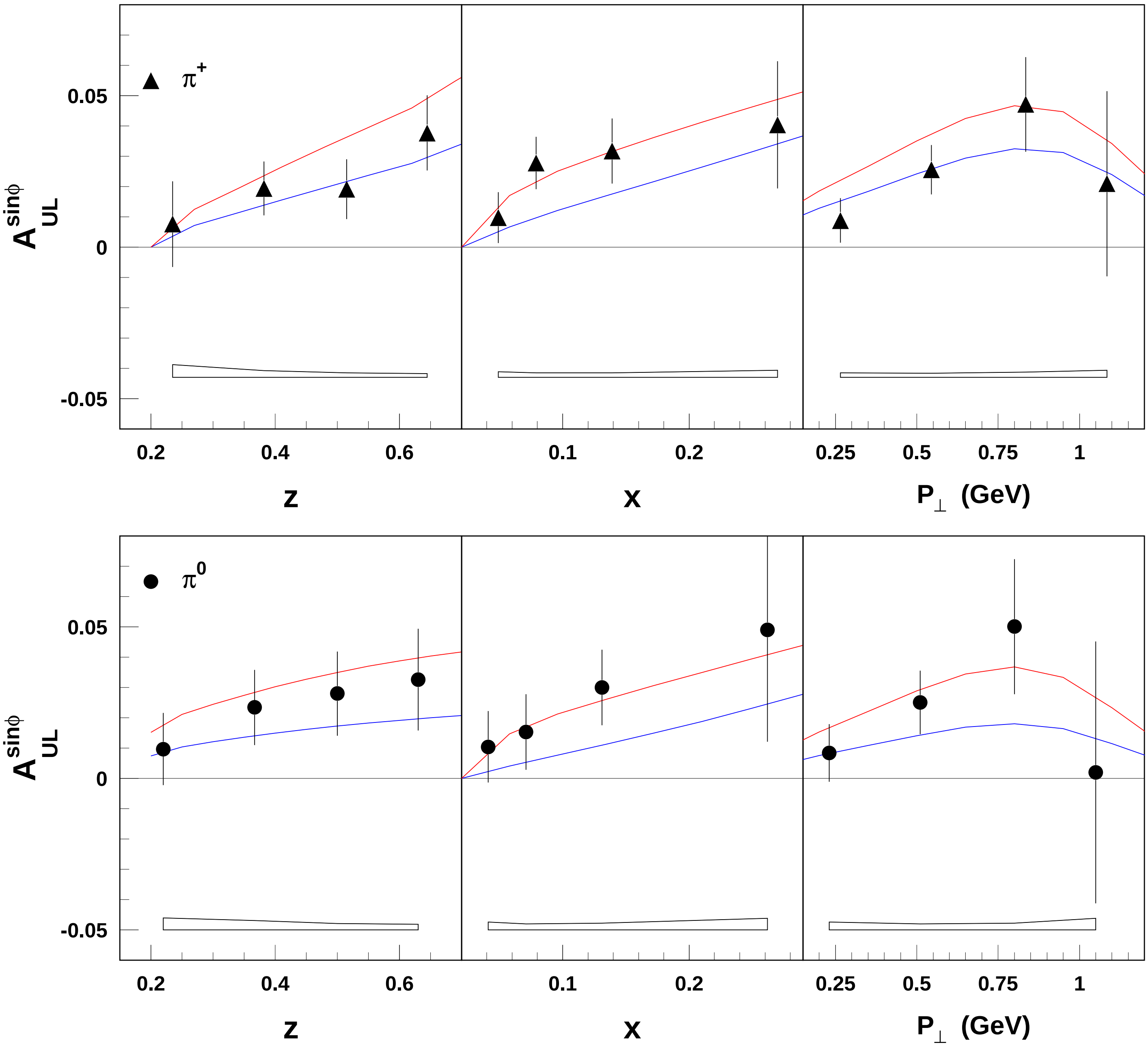

Semi-exclusive:




Exclusive $\pi^+$: $\mathcal{A}_{UL}^{sin\phi} = -0.18 \pm 0.05 \pm 0.01$

Very different SSA behavior in semi-inclusive and exclusive region for $\pi^+$ and $\pi^0$.

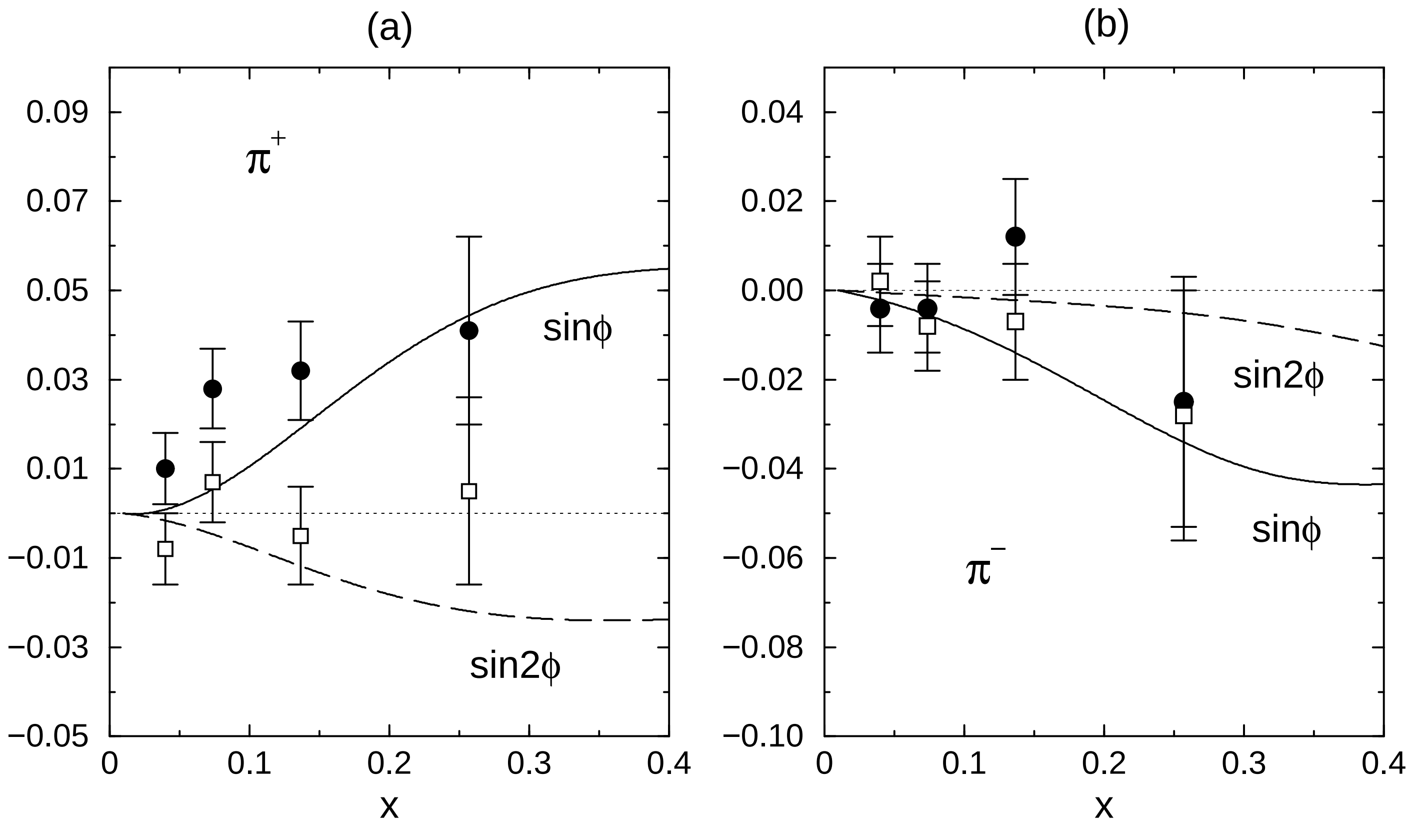
# Data & Theory (1)




Oganessyan et al., hep-ph/9808368 + PLB 483 (2000) 69

- $h_L(x) = h_1(x) - \frac{d}{dx} h_{1L}^{\perp(1)}(x) \sim h_1(x)$
- $g_1$ (n.r. limit) $< h_1 < (f_1 + g_1)/2$ (Soffer in.)
- $A_C(z, k_T) = \frac{|k_T|}{M_h} \frac{H_1^{\perp}(z, k_T^2)}{D_1(z, k_T^2)} = \frac{M_C |k_T|}{M_C^2 + k_T^2}$ (Collins par.)

# Data & Theory (2) ($sin\phi$ & $sin2\phi$)




(For models: M.Wakamatsu, hep-ph/0012331)

⇒ $sin\phi$ is twist-3;

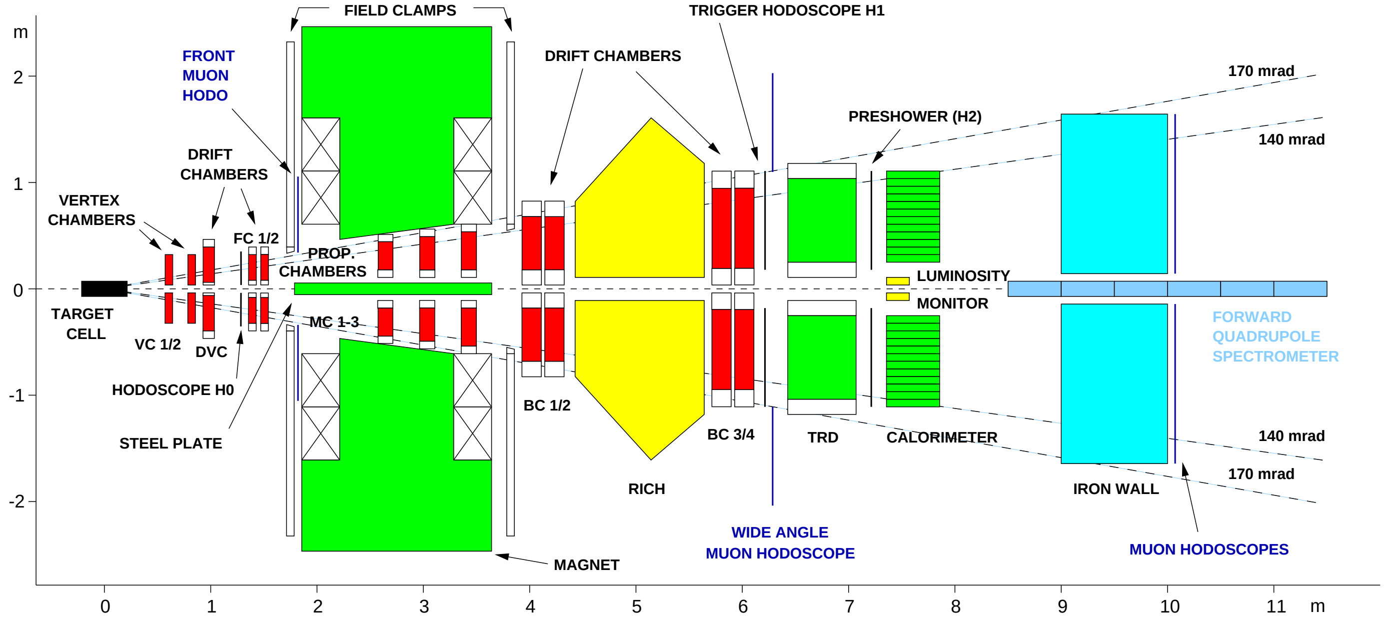
⇒ $sin2\phi$ is twist-2 but suppressed by a kinem. factor.

$$\pi^+ \quad \mathcal{A}_{UL}^{sin2\phi} = -0.002 \pm 0.005 \pm 0.010$$
$$\pi^- \quad \mathcal{A}_{UL}^{sin2\phi} = -0.005 \pm 0.006 \pm 0.005$$
$$\pi^0 \quad \mathcal{A}_{UL}^{sin2\phi} = 0.006 \pm 0.007 \pm 0.003$$

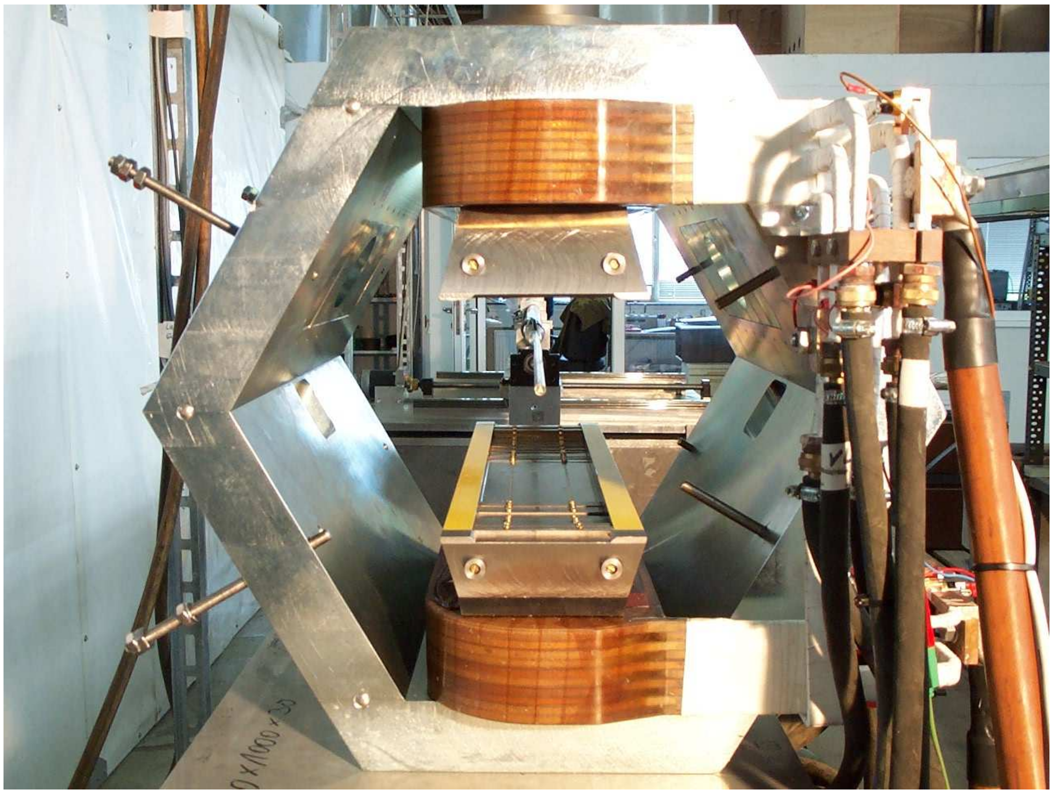
$$\pi^+ \quad \mathcal{A}_{LU}^{sin\phi} = -0.005 \pm 0.008 \pm 0.004$$
$$\pi^- \quad \mathcal{A}_{LU}^{sin\phi} = -0.007 \pm 0.010 \pm 0.004$$

# The new HERMES

Several upgrades have been performed in 1998 and 2000:




The transverse magnet:



# DIS+SIDIS cross section

Mulders and Tangermann, NP B461 (1996) 197

$$d\sigma = d\sigma^0_{UU} + \frac{p_T}{Q}\cos\phi\, d\sigma^1_{UU}$$

$$+\lambda\frac{1}{Q}\sin\phi\, d\sigma^2_{LU}$$

$$+S_L[\sin 2\phi\, d\sigma^3_{UL} + \frac{1}{Q}\sin\phi\, d\sigma^4_{UL}]+$$

$$S_T[\sin(\phi+\phi_S)d\sigma^5_{UT}+\sin(3\phi-\phi_S)d\sigma^6_{UT}+\frac{1}{Q}\sin(2\phi-\phi_S)d\sigma^7_{UT}]$$

$$+\lambda S_L[d\sigma^8_{LL} + \frac{1}{Q}\cos\phi\, d\sigma^9_{LL}]$$

$$+\lambda S_T[\cos(\phi-\phi_S)d\sigma^{10}_{LT} + \frac{1}{Q}\cos(2\phi-\phi_S)d\sigma^{11}_{LT}]$$

# Summary and outlook

- **First observation of a Single Spin Azimuthal asymmetry for semi-inclusive pion electroproduction in DIS:**
  - $\triangleright\ \pi^+ : A_{UL}^{sin\phi} = 0.022 \pm 0.005 \pm 0.003$
  - $\triangleright\ \pi^- : A_{UL}^{sin\phi} = -0.005 \pm 0.008 \pm 0.004$
  - $\triangleright\ \pi^0 : A_{UL}^{sin\phi} = 0.019 \pm 0.007 \pm 0.003$
- **u-quark dominance and $\pi^0 \Leftrightarrow \pi^+$;**
- **Valence quark contribution;**
- **Clear $k_\perp$ contribution (Collins parameterization);**
- **Semi-inclusive $\leftrightarrow$ semi-exclusive differences;**
- **Model predictions consistent with data;**
- $A_{UL}^{sin2\phi}$ **suppressed compared to** $A_{UL}^{sin\phi}$**;**
- $A_{LU}^{sin\phi}$ **compatible with zero.**

**FIRST EVIDENCE OF TRANSVERSITY EFFECTS IN LONGITUDINALLY POLARIZED TARGET.**

**More results in 2001+ by the HERMES transversely polarized target (M.Vincter's talk):**

- **Direct access to $h_1$;**
- **Access to different DF and FF** $(cos\phi,\ cos3\phi,\ sin3\phi,\ ...)$**;**
- **New channels: $\Lambda$ fragmentation, $\pi\pi$, ....**

R.L.Jaffe

opening talk of SPIN 2000, Osaka (Japan)

(SPIN 2000 Proceedings, hep-ph/0101280)

"To my mind the most interesting development in QCD spin physics reported since SPIN98 is the azimuthal asymmetry in pion electroproduction from HERMES."