Transversity and Friends at HERMES

Measurement of novel distribution and fragmentation functions

Naomi C.R. Makins
University of Illinois at Urbana-Champaign
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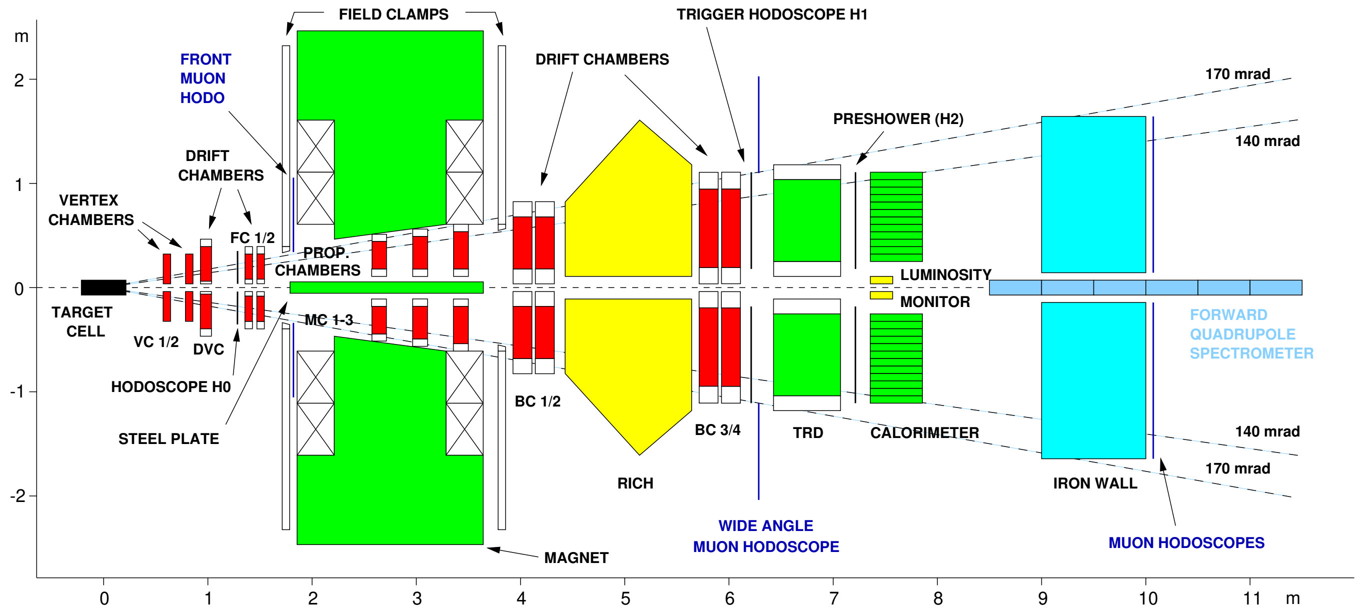
- *Azimuthal Moments of Polarized SIDIS Cross-Section*
- $A_{UL}(\phi)$ *Single-Spin Asymmetry and Transversity*
- *Other Ways to Access Transversity*
- *T-Odd Distribution Functions*
- *Transverse* Λ *Polarization in Photoproduction*

The HERMES Experiment



Polarized Beam and Target

- ***Longitudinally polarized*** $e^{\pm}$ ***beam*** of 27.5 GeV from HERA
- ***Longitudinally polarized targets*** of H, D, and ^{3}He
  $\Rightarrow$ pure internal gas targets with no dilution

Forward Magnetic Spectrometer

- Identical upper and lower halves, with ***large angular acceptance***
  $40 < |\theta_y| < 140$ mr and $|\theta_x| < 170$ mr
- ***Excellent PID*** for electron-hadron separation
  (efficiency $>$ 97% at hadron contamination $<$ 1%)
- ***Pion ID*** via threshold Cerenkov in range $4 < p < 13$ GeV

Upgrades in 1998

- ***RICH detector*** allows $\pi/K/p$ separation at all momenta
- ***Muon identification*** at standard and wide angles

HERMES Data Taking

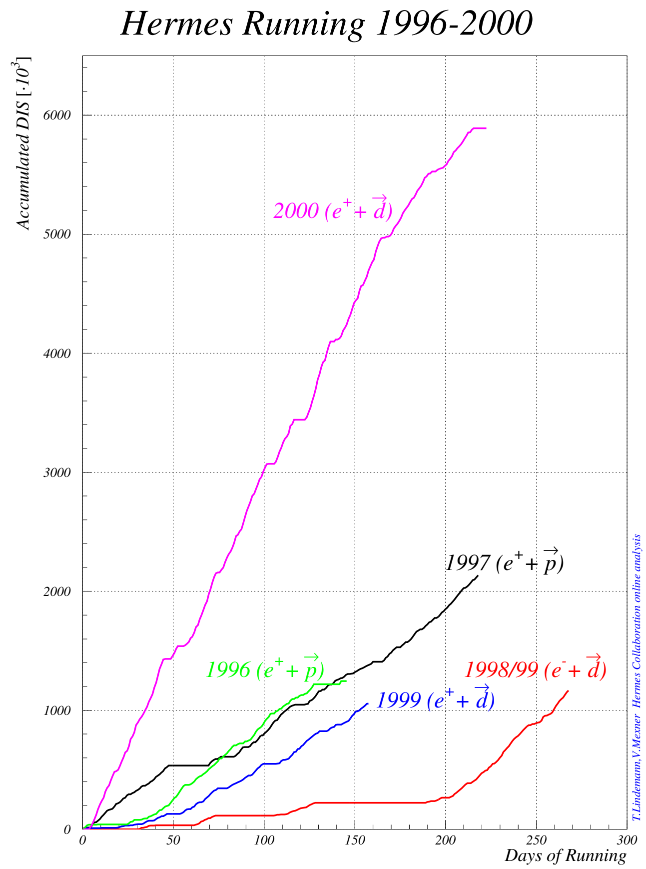
Polarized Data Taking

- 1995: $^3\vec{\mathbf{He}}$ target $\rightarrow$ 3 M DIS
- 1996-97: $\vec{\mathbf{H}}$ target $\rightarrow$ 2.5 M DIS
- 1998-2000: $\vec{\mathbf{D}}$ target $\rightarrow$ ***8 M DIS*** !

Unpolarized Data Taking

- 1996-97: $\mathrm{H, D, {}^3 He}$ $\rightarrow$ 10 M DIS
- 1997: $^{14}\mathrm{N}$ $\rightarrow$ 2.2 M DIS
- 1998-2000: $\mathrm{H, D, {}^4 He, {}^{14} N, {}^{20} Ne, {}^{84} Kr}$

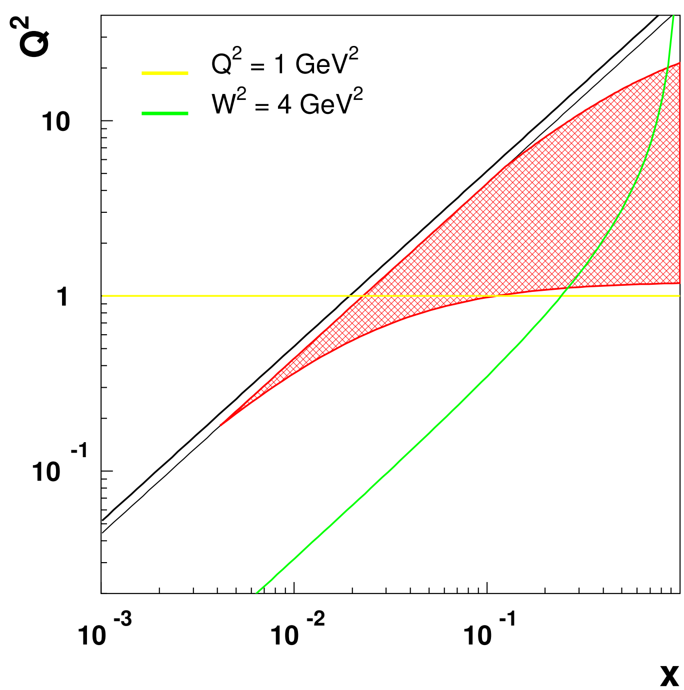
  $\rightarrow$ ***18 M DIS*** !



HERMES Run II (2001 - 2006)

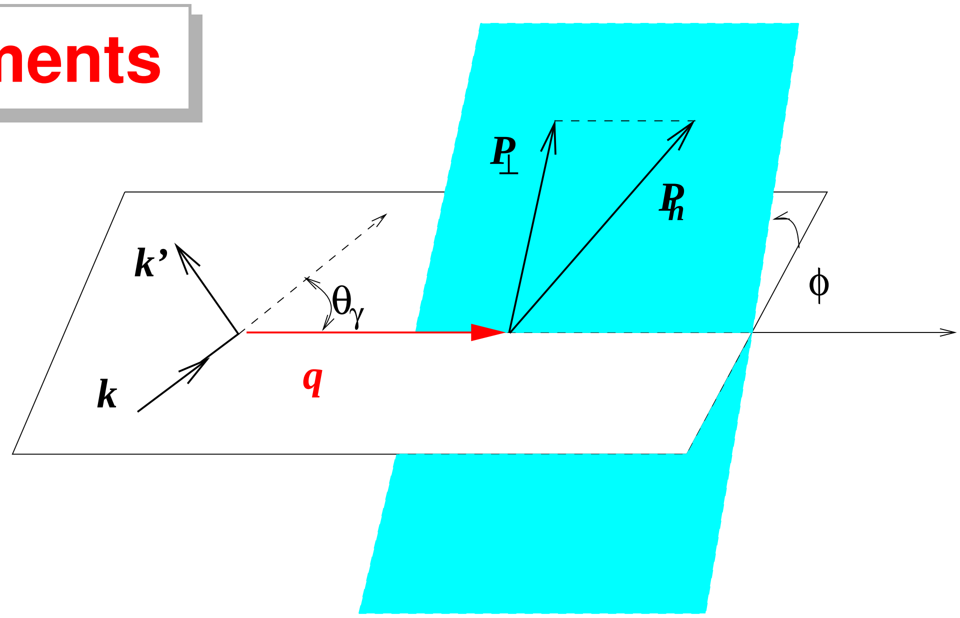
- ***Transversely*** polarized targets (H and D)
- Silicon Λ ***Wheels*** installed
- Silicon ***Recoil Detector*** (2003+) $\Rightarrow$ hard exclusive processes

  $\rightarrow$ talk of K. Rith



Azimuthal Moments

"The Bible":
Mulders & Tangerman,
PLB 461 (1996) 197



Polarized SIDIS xsec at leading order in $1/Q$:

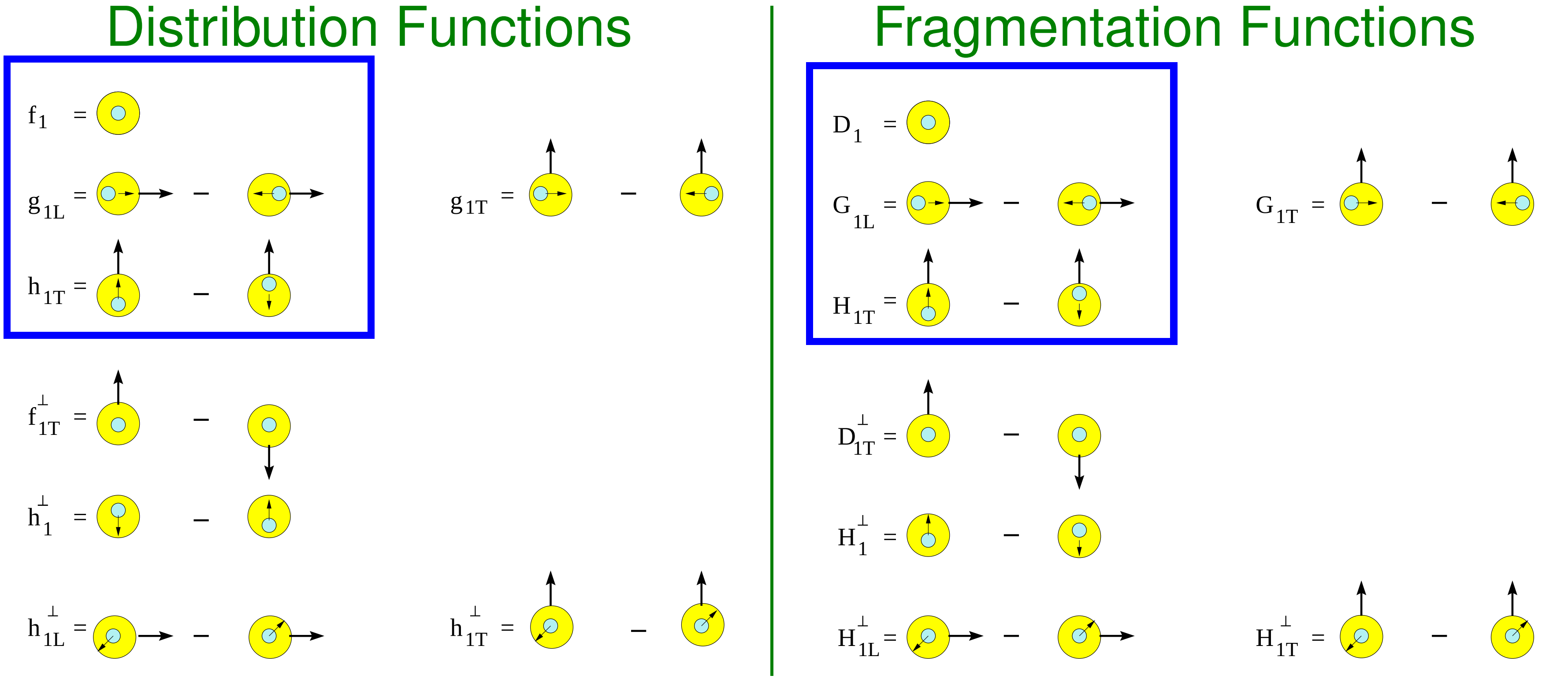
UU	1	$\otimes\ f_1$ =	$\otimes\ D_1$ =
	$\cos(2\phi_h^l)$	$\otimes\ h_1^\perp$ =	$\otimes\ H_1^\perp$ =
UL	$\sin(2\phi_h^l)$	$\otimes\ h_{1L}^\perp$ =	$\otimes\ H_1^\perp$ =
UT	$\sin(\phi_h^l + \phi_S^l)$	$\otimes\ h_1$ =	$\otimes\ H_1^\perp$ =
	$\sin(\phi_h^l - \phi_S^l)$	$\otimes\ f_{1T}^\perp$ =	$\otimes\ D_1$ =
	$\sin(3\phi_h^l - \phi_S^l)$	$\otimes\ h_{1T}^\perp$ =	$\otimes\ H_1^\perp$ =
LL	1	$\otimes\ g_1$ =	$\otimes\ D_1$ =
LT	$\cos(\phi_h^l - \phi_S^l)$	$\otimes\ g_{1T}$ =	$\otimes\ D_1$ =

Functions Surviving on Integration over Transverse Momenta

- The others are sensitive to intrisic $< k_t >$ in the nucleon & in the fragmentation process

Distribution Functions

Fragmentation Functions



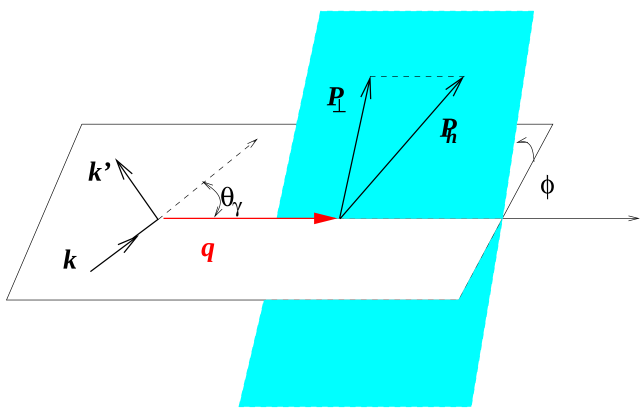
Higher Twist Functions
(no pictures)

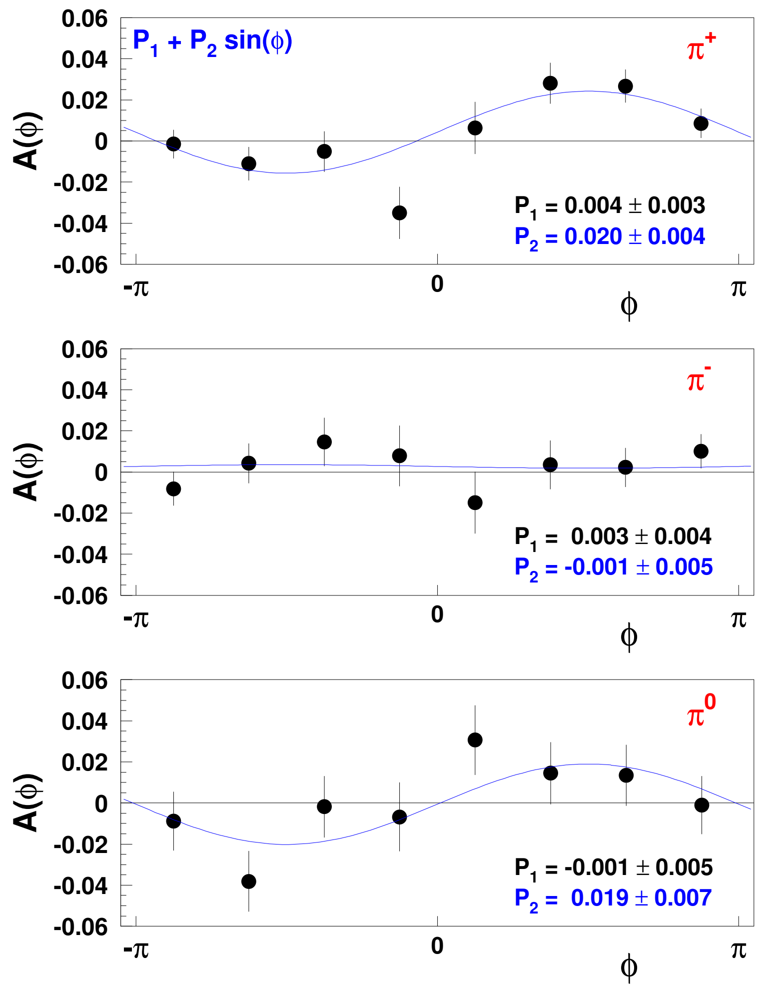
- Sensitive to parton-parton correlations
- Have a twist-2 part ... e.g. $h_L(x) = 2x \int_x^1 dy \frac{h_1(y)}{y^2}$

Spin-Azimuthal Asymmetry A_{UL}

Longitudinal target spin asymmetry:

$$A_{\rm UL}(\phi) = \frac{1}{P}\,\frac{N^-(\phi) - N^+(\phi)}{N^-(\phi) + N^+(\phi)}$$

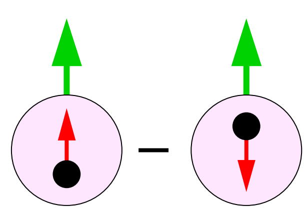




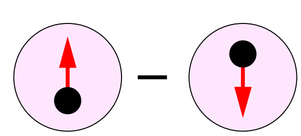
- significant $\underline{\sin\phi}$ dependence observed for π^+ and π^0
- $\underline{\sin 2\phi}$ moment consistent with zero for all pions

$\sin\phi$ ***moment*** $A_{\rm UL}^{\sin\phi}$ ***related to product of transversity*** $h_1(x)$
and Collins fragmentation function $H_1^\perp(z)$

$A_{\rm UL}^{\sin\phi} \sim \mathbf{h_1}$ =

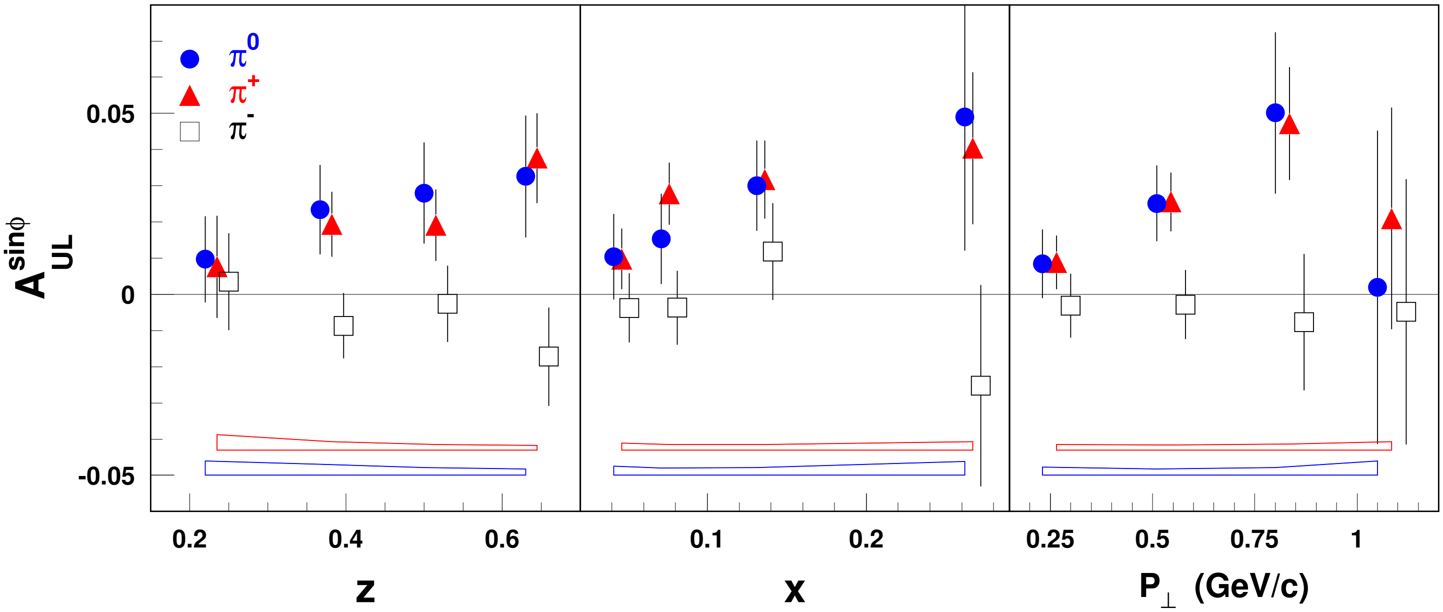


$\cdot\ H_1^\perp$ =



$A_{UL}^{\sin\phi}$ Behaviour

Red squares (blue circles) = π^+ (π^-). *HERMES, hep-ex/9910062*



Original Predictions of Collins

Collins, NP B396 (1993) 161

- Effect should peak at $x \simeq 0.3$ (valence region)
- Effect should be stronger for π^+ than π^- (u-quark dominance)
- Effect should grow with p_T and peak at $p_T \simeq 1$ GeV/c

Similarity between π^+ and π^0

... guess $\delta d \approx -\delta u/2$ ...

Favoured frag. func. $D_1 = D_u^{\pi^+} = D_d^{\pi^-}$

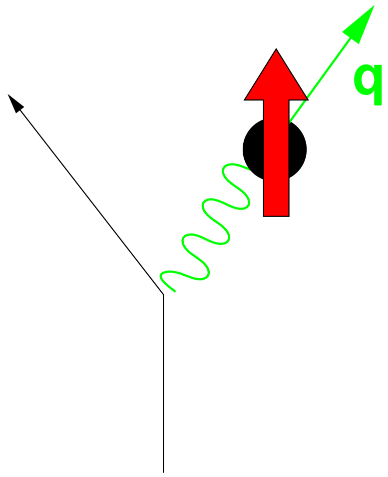
Disavoured frag. func. $D_2 = D_d^{\pi^+} = D_u^{\pi^-}$

$$\rightarrow \quad \eta \equiv \frac{D_2}{D_1} \approx \frac{1-z}{1+z} \approx \frac{1}{3}$$

$$A_p^{\pi^+} \approx \frac{4\,\delta u + \eta\,\delta d}{4\,u + \eta\,d} \approx \frac{\delta u}{u} \qquad A_p^{\pi^0} \approx \frac{4\,\delta u + \delta d}{4\,u + d} \approx \frac{\delta u}{u} - \Delta \qquad A_p^{\pi^-} \approx \frac{4\eta\,\delta u + \delta d}{4\eta\,u + d} \approx 0$$

$A_{UL}(\phi)$ Interpretation

From a theory perspective, longitudinal target has ***2 components*** :



$$A(\phi) = \frac{1}{P_{\text{target}}} \frac{N^{p\rightarrow}(\phi) - N^{p\leftarrow}(\phi)}{N^{p\rightarrow}(\phi) + N^{p\leftarrow}(\phi)}$$

$$= \frac{\mathbf{S_L}\, d\sigma_{\mathbf{UL}}(\phi) + \mathbf{S_T}\, d\sigma_{\mathbf{UT}}(\phi)}{S\, d\sigma_{\mathrm{UU}}(\phi)}$$

with $\boxed{S_L/S \approx 1}$ and $\boxed{S_T/S \approx 1/Q}$

Extract $\sin\phi$ and $\sin 2\phi$ moments:

$$A_{\mathrm{UL}}^{\sin\phi} = \frac{S_L \,\langle \sin\phi \rangle_{\mathrm{UL}} + S_T \,\langle \sin\phi \rangle_{\mathrm{UT}}}{S\,\langle 1 \rangle_{\mathrm{UU}}}$$

Theoretical decomposition at leading and sub-leading order:

$$\langle 1 \rangle_{\mathrm{UU}} \sim f_1(x)\, D_1(z)$$

$$\langle \sin\phi \rangle_{\mathrm{UT}} \sim \mathbf{h_1}(x)\, H_1^{\perp(1)}(z)$$

$$\langle \sin\phi \rangle_{\mathrm{UL}} \sim \frac{1}{Q}[h_{1L}^{\perp(1)}(x)\, H_1^{\perp(1)}(z) \oplus \tilde{h}_L(x)\, H_1^{\perp(1)}(z) \oplus h_{1L}^{\perp(1)}(x)\, \tilde{H}]$$

$$\langle \sin 2\phi \rangle_{\mathrm{UL}} \sim h_{1L}^{\perp(1)}(x)\, H_1^{\perp(1)}(z)$$

$$\text{where } f^{(1)}(x) \equiv \int dp_\perp^2 \frac{p_\perp^2}{2M^2} f(x, p_\perp^2)$$

➡ $\langle \sin\phi \rangle_{\mathrm{UL}}$ ***is*** ***subleading*** ***and involves*** ***interaction-dependent twist-3*** ***functions*** $\tilde{h}_L$ ***and*** $\tilde{H}$ ***...***

$A_{UL}(\phi)$ Interpretation

What to do with the twist-3 pieces ...

From Lorentz invariance,

$$h_{1L}^{\perp(1)}(x) = x^2 \int_x^1 \frac{dy}{y^2} \left[-\mathbf{h_1}(y) + \tilde{h}_L(y) + \frac{m_q}{M} \frac{g_1(y)}{y} \right]$$

① Set $\boxed{\tilde{h}_L(x) = 0}$ (interaction-dependent part) $\Rightarrow$ $h_{1L}^{\perp(1)}(x) = -x^2 \int \frac{dy}{y^2} \mathbf{h_1}(y)$

② Set $\boxed{h_{1L}^{\perp(1)} = 0}$ to match observed $\langle \sin 2\phi \rangle_{\mathrm{UL}} \approx 0$ $\Rightarrow$ $\tilde{h}_L(x) = \mathbf{h_1}(x)$

What to do with Collins fragmentation function $H_1^\perp$ ...

① **Collins parametrization** : *Collins, NP B396, 161*

$$\frac{H_1^\perp}{D_1} = \eta \frac{M_c M_h |k_T|}{M_C^2 + k_T^2}$$

with hadronic scale $M_C \approx 2m_\pi$ to M_p

② **DELPHI data** : *Efremov et al., hep-ph/9812522*

Transverse q, $\overline{q}$ polarization small but ANTI-CORRELATED (@ $\sim$ 50 % level)

$$\left| \frac{H_1^\perp}{D_1} \right| = 6.3 \pm 1.7\,\%$$

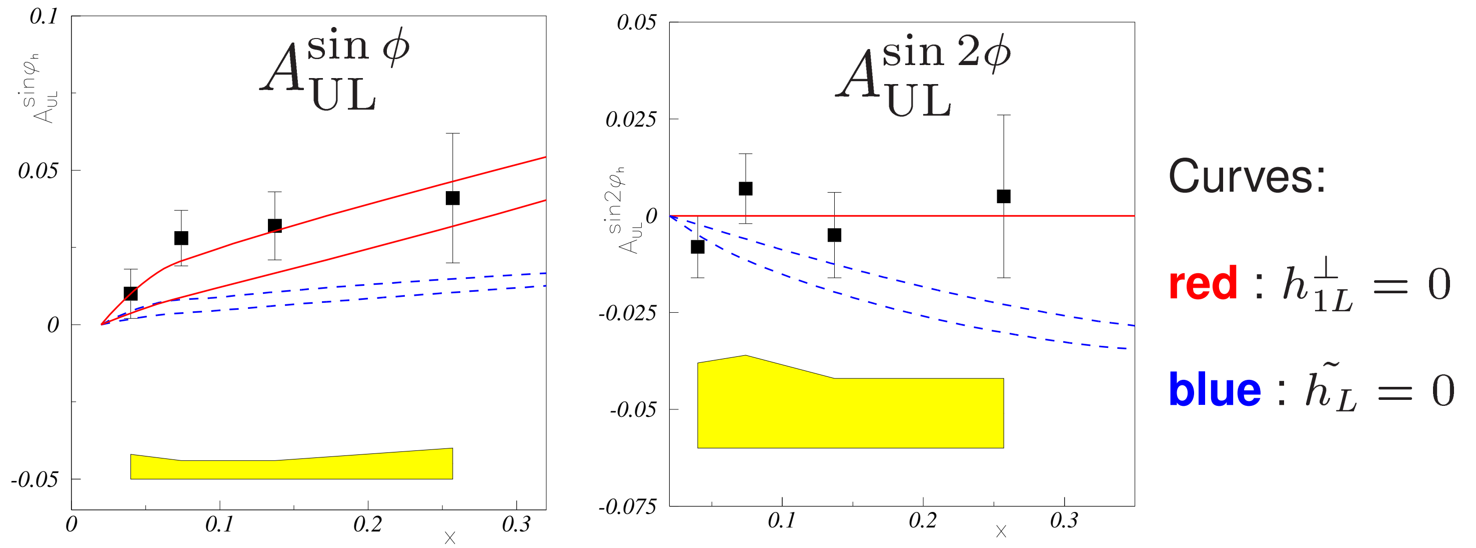
Interaction-dependent fragmentation function $\tilde{H}$ related:

$$\tilde{H} = z \frac{d}{dz} (z H_1^{\perp(1)})$$

Modelling $A_{\rm UL}^{\pi^+}(\phi)$: Simple Ansätze

Try range of $\mathbf{h_1}$: from g_1 to Soffer bound $(f_1+g_1)/2$ ...

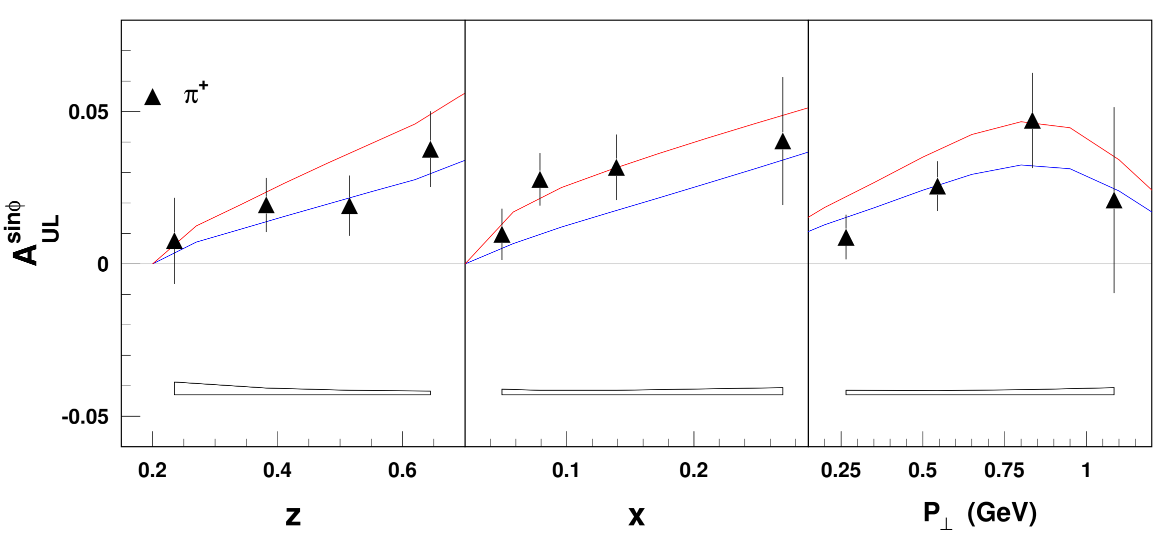
Collins $H_1^\perp$ with $M_C = 0.3, \eta = 0.8$ *K.A. Oganessyan et al, hep-ph/0010261*



75-80% of effect from longitudinal target component ...

Asymmetry more sensitive to twist-3 assumptions than $\mathbf{h_1}$

Collins $H_1^\perp$ with $M_C = 0.3, \eta = 1$ *E. DeSanctis et al, PLB 483 (2000) 29*

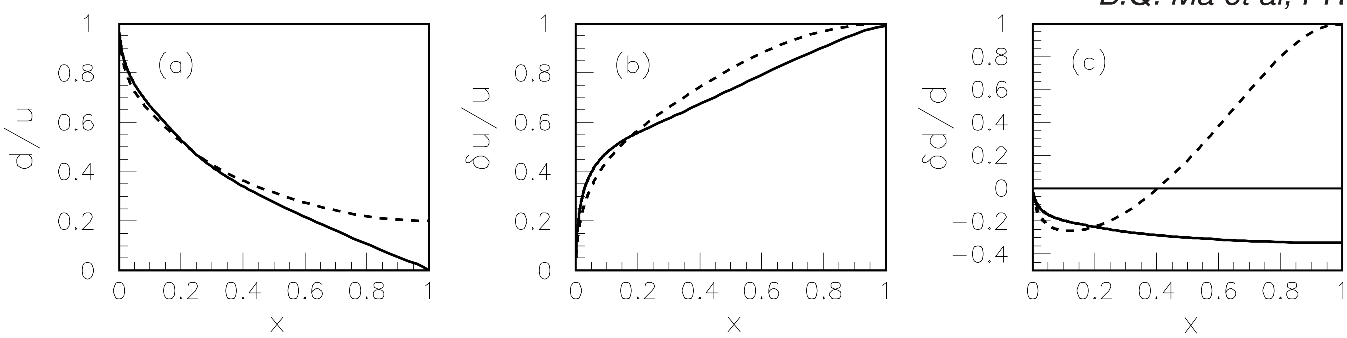


Kinematic dependences well reproduced

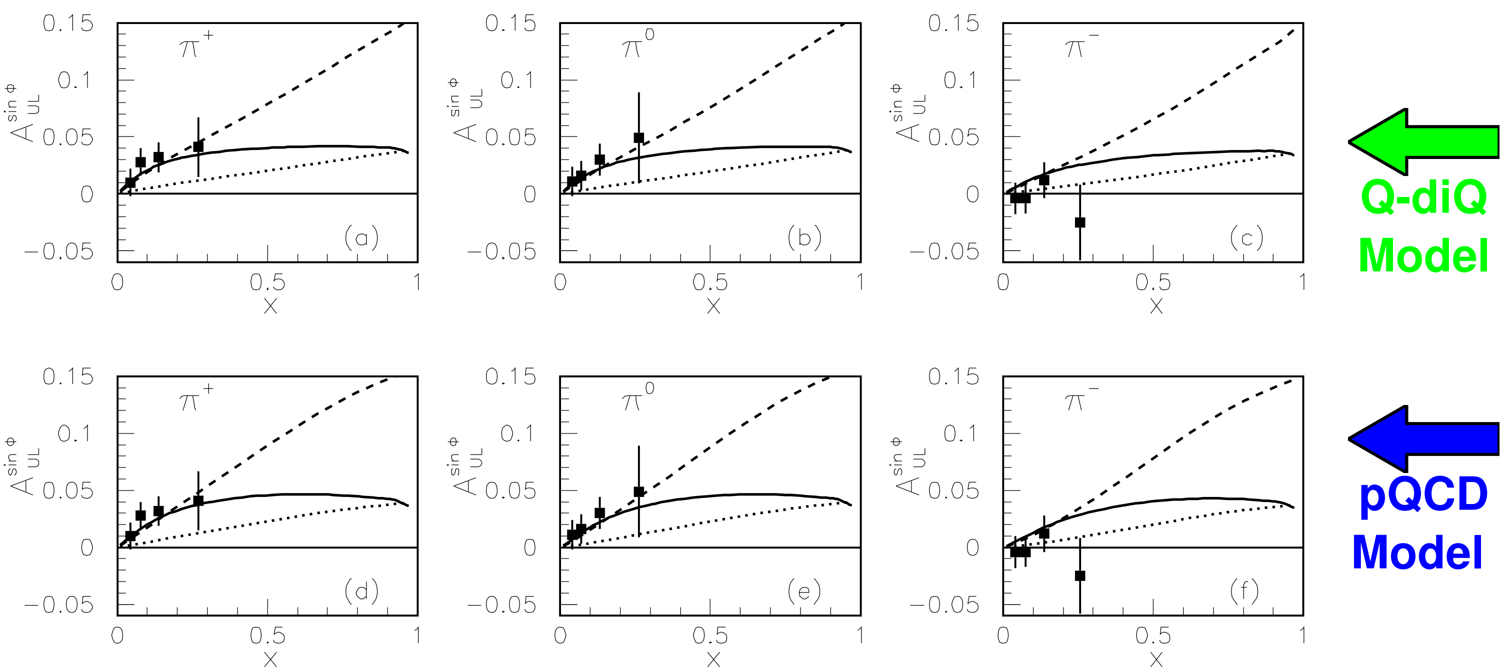
Modelling $A_{\mathrm{UL}}(\phi)$: Phenomenological Models

Try $\mathbf{h_1}$ from quark-diquark (solid) and pQCD-based (dashed) models

B.Q. Ma et al, PRD 65, 034010



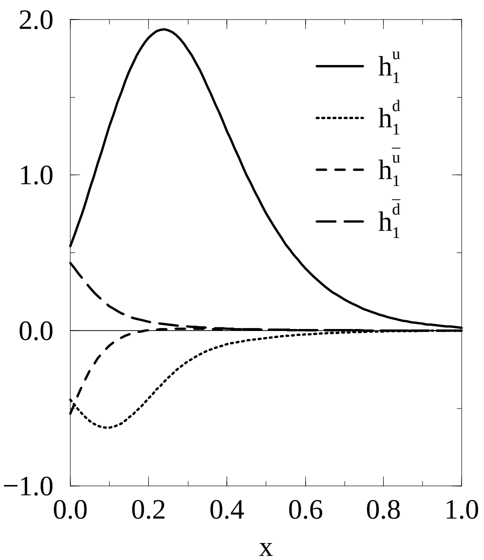
Dot : S_T (transverse) only **Solid** : $\tilde{h_L}, \tilde{H} = 0$ **Dash** : $h_{1L}^{\perp(1)} = 0$



- Again, transverse-component S_T of target not enough
- Suprisingly large π^- asymmetry, due to inclusion of unfavoured fragmentation functions

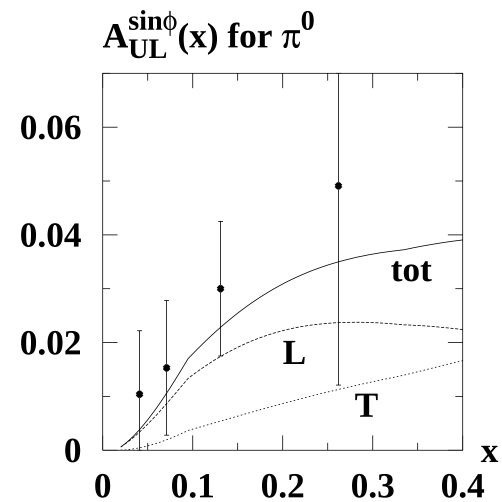
Modelling $A_{UL}^{\pi^+}(\phi)$: Chiral Quark Soliton Model I

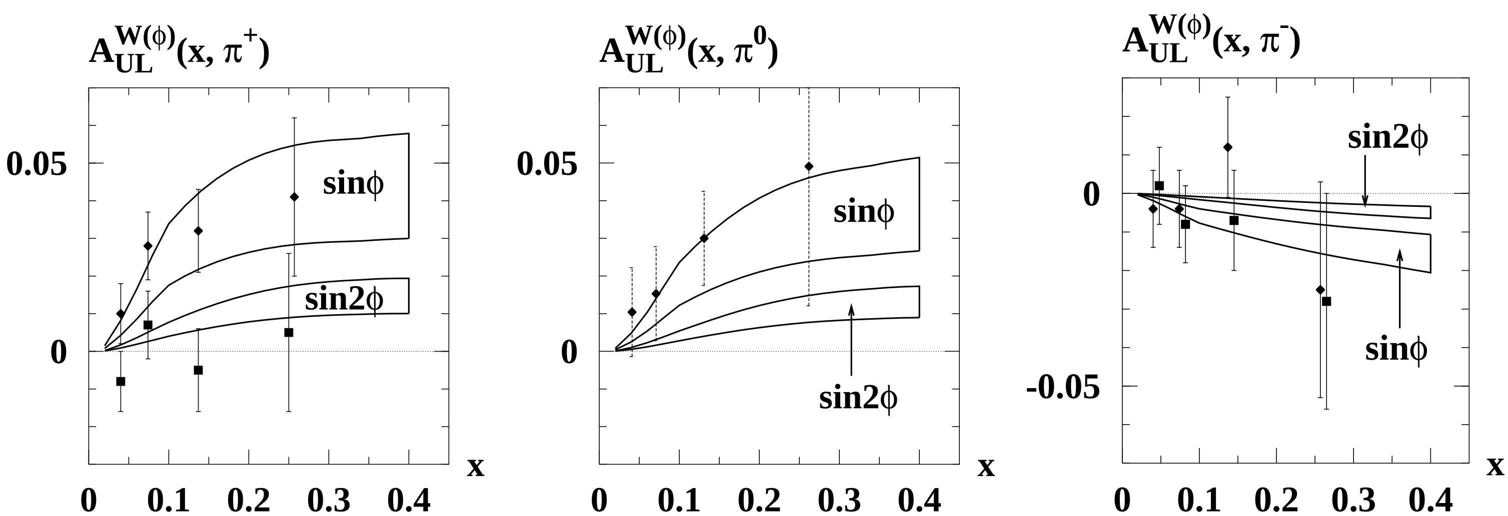
A.V. Efremov et al, PLB 478, 94



Ingredients:

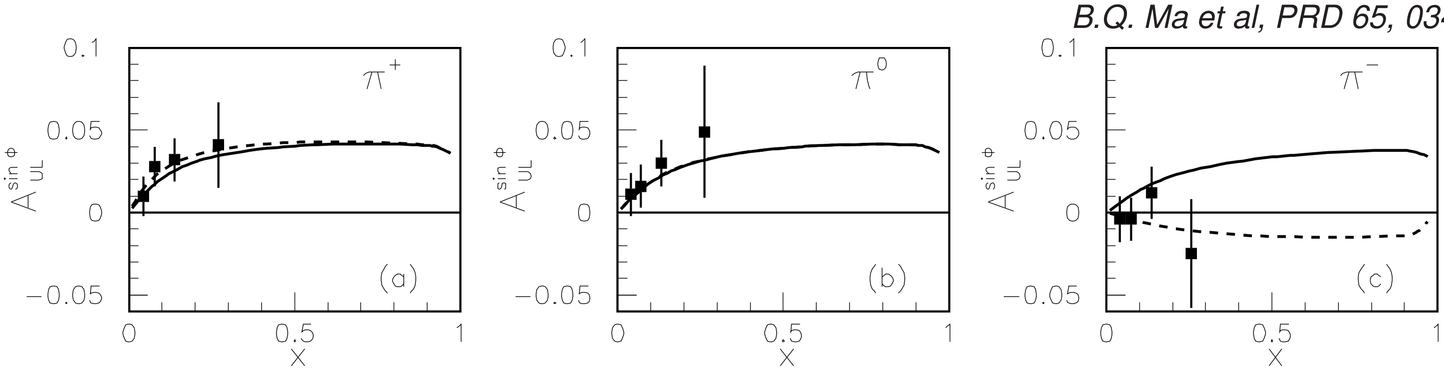
- $h_1(x)$ from χQSM
- Favoured fragment$^{\underline{n}}$ functions only
- $\tilde{h_L}, \tilde{H} = 0$
- $H_1^{\perp}$ from DELPHI





However, ***unfavoured frag func*** ***may be important for*** π^- ***...***

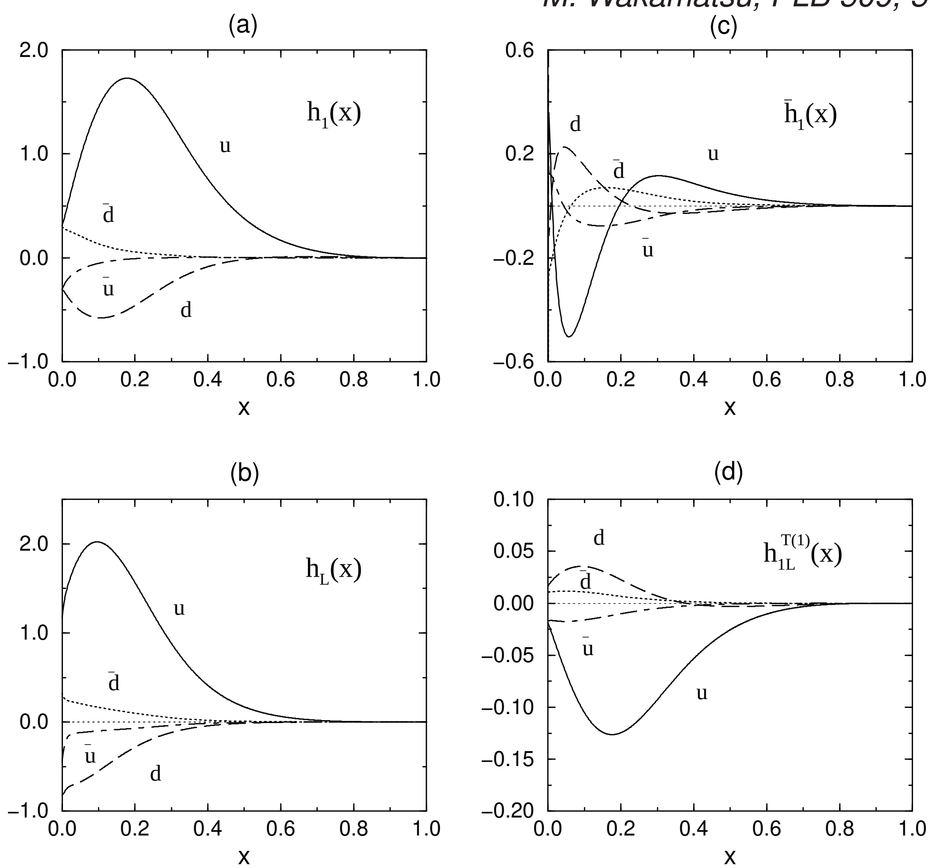
B.Q. Ma et al, PRD 65, 034010



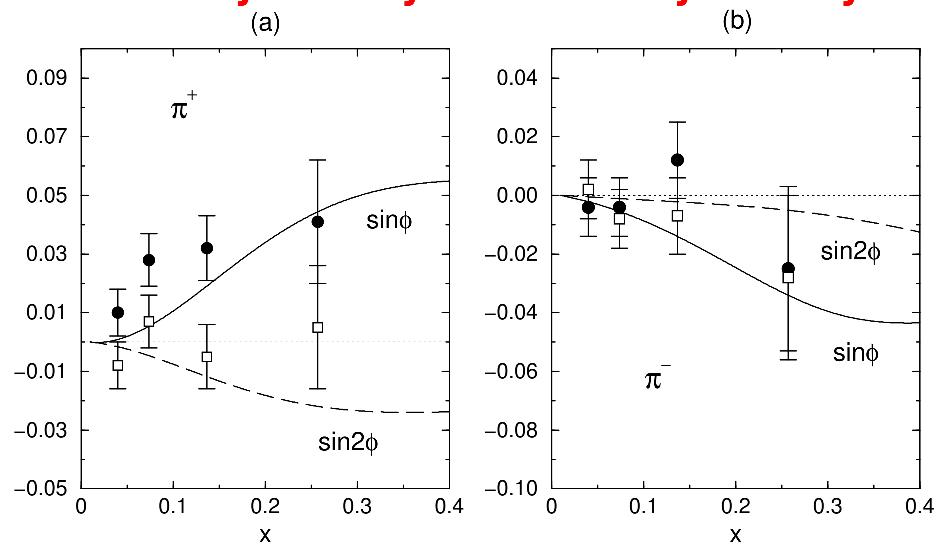
Modelling $A_{UL}^{\pi^+}(\phi)$: Chiral Quark Soliton Model II

Higher-twist calculation in χQSM of $h_L = -\frac{2h_{1L}^{\perp(1)}}{x} + \tilde{h}_L$

M. Wakamatsu, PLB 509, 59



π^+ asymmetry **π^- asymmetry**

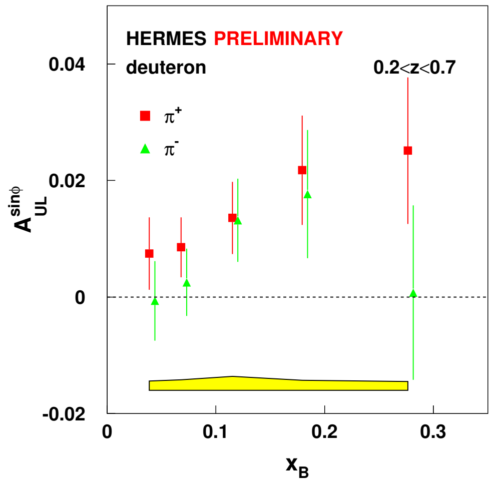


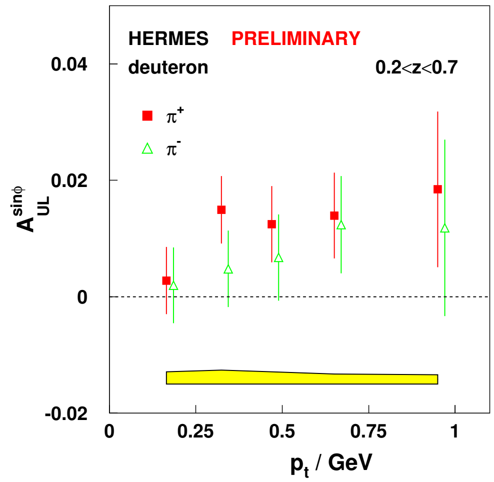
➡ $h_{1L}^{\perp(1)} \approx 0$ indeed better approximation than $\tilde{h}_L \approx 0$

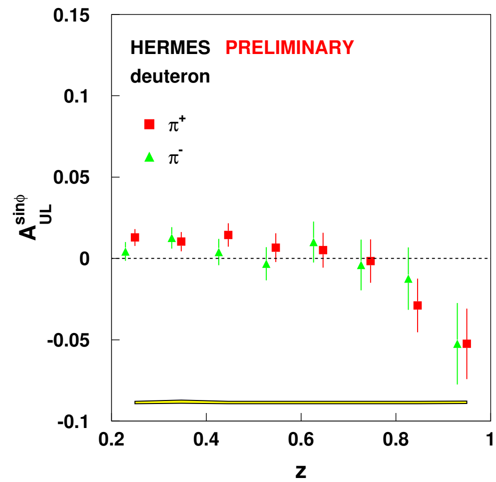
➡ $h_{1L}^{\perp(1)}$ small, but non-zero

New Results on Deuterium

New results from 1998-2000 data set:



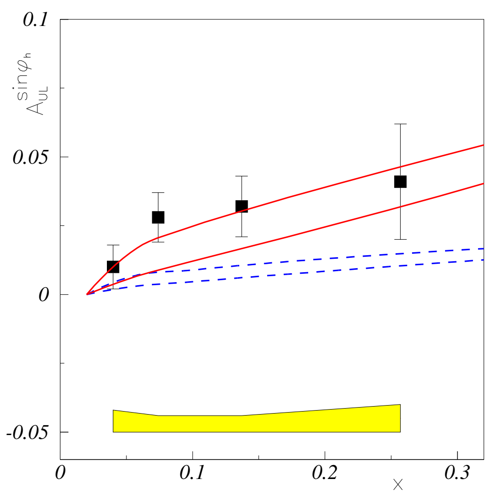




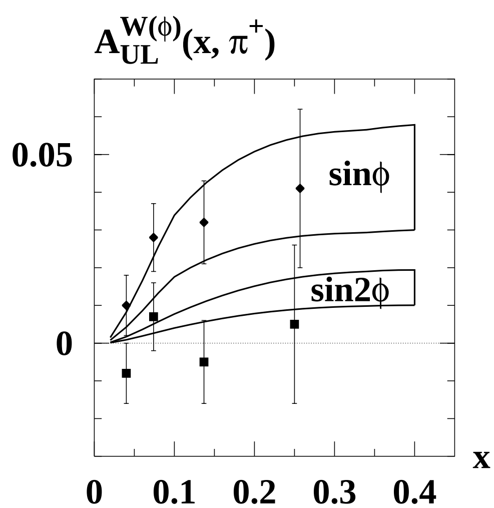
$$A_p^{\pi^+} \approx \frac{4\,\delta u + \eta\,\delta d}{4\,u + \eta\,d} \approx \frac{\delta u}{u} \quad \text{and} \quad A_d^{\pi^+} \approx A_d^{\pi^-} \approx A_d^{\pi^0} \approx \frac{\delta u + \delta d}{u + d}$$

$$\text{With } \delta d \approx -\delta u/3 \text{ and } d \approx u/2 \quad \rightarrow \quad A_d^{\pi} \approx \frac{4}{9}\frac{\delta u}{u} \approx \frac{A_p^{\pi^+}}{2}$$

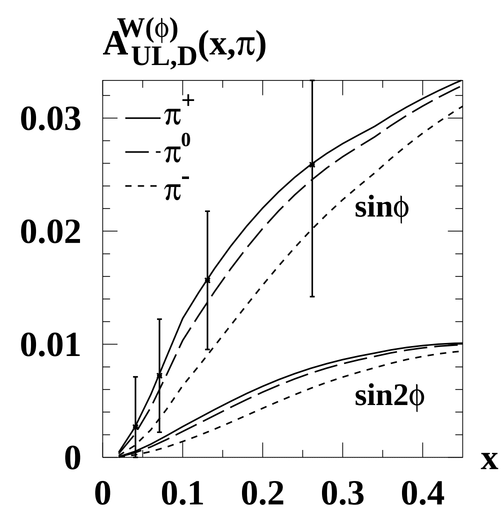
Hydrogen data



χQSM: Hydrogen, π^+



... and Deuterium



Other Ways to Measure $h_1(x)$

① Collins Effect with Transverse Target

Cleanest method is $A_{\mathrm{UT}}^{\sin\phi} \sim \mathbf{h_1}\, H_1^{\perp}$. Since effect already visible using a longitudinally polarized target, good promise for future ***transverse target program*** at HERMES and COMPASS.

② Higher Twist Fragmentation Function $\tilde{E}$

$$d\sigma_{\mathrm{LT}} \sim \cos(\phi_S^l) \left[\frac{Mx}{Q} \cdot g_T(x)\, D_1(z) + \frac{M_h}{zQ} \cdot \mathbf{h_1}(x)\, \tilde{E}(z) \right]$$

... calculation of Ji & Zhu suggests $\tilde{E}(z) = \frac{m_q}{M} z D_1(z) \approx \frac{1}{3} z D_1(z)$

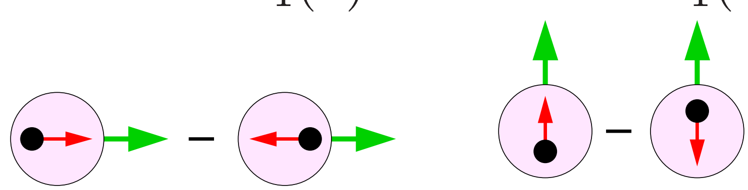
③ Final State Polarization

$$\boxed{d\sigma_{\mathrm{UTT}} \sim \cos(\phi_S^l + \phi_{S_h}^l) \cdot \mathbf{h_1}(x)\, H_1(z)}$$

Method requires significant ***spin transfer*** from ***quark to*** Λ in fragmentation process ...

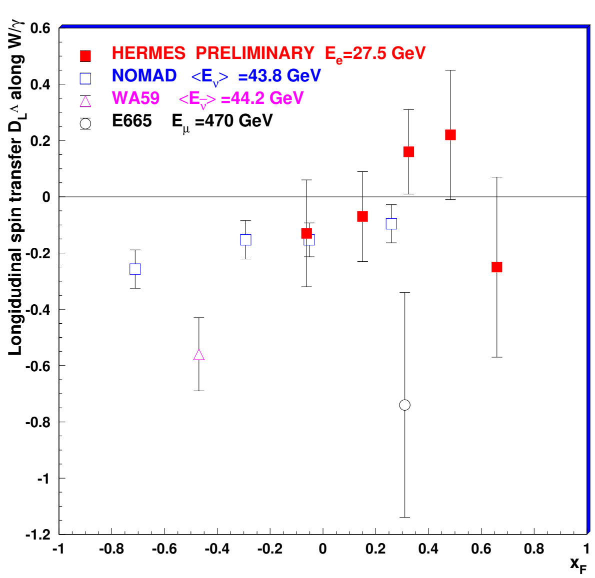
longitudinal spin transfer: $G_1(z)$

transverse spin transfer: $H_1(z)$



⋮

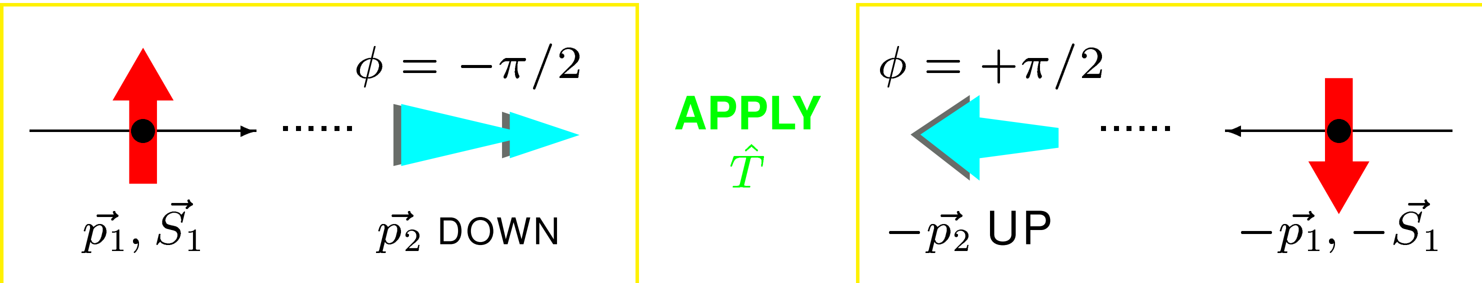
New results from HERMES 2000 data indicate **small** $G_1(z)$ ...



T-Odd Functions

Spin Spin Azimuthal Asymmetry: $\sigma \sim \vec{S_1} \cdot (\vec{p_1} \times \vec{p_2}) \;\sim \sin\phi$

$\Rightarrow$ ODD under time reversal



$\Rightarrow$ $\hat{T}$ transforms ϕ to $-\phi$

But elementary QCD processes are $\hat{T}$-invariant ...

can build $\hat{T}$-odd term in xsec ($\sim \sin\phi$) from **interference**

TOY EXAMPLE

Any amplitude $A = \langle f|\hat{\mathcal{H}}|i\rangle$ for $\hat{T}$-invariant $\hat{\mathcal{H}}$ satisfies

$$A^*(-\phi) = A(\phi)$$

1. No spin flip $\quad A_1 = \langle S_1 =\uparrow |\hat{\mathcal{H}}|\phi, S_2 =\uparrow\rangle \sim e^{i\phi}$
2. Spin flip $\quad A_2 = \langle S_1 =\uparrow |\hat{\mathcal{H}}|\phi, S_2 =\downarrow\rangle \sim 1$

... suppose $\exists$ **PHASE SHIFT** $e^{i\delta}$ *between amplitudes ...*

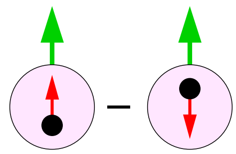
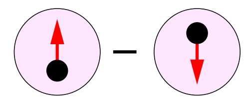
$$\sigma \sim |A_1 + e^{i\delta} A_2|^2 = 2 + 2\mathrm{Re}(e^{i\delta} A_1^* A_2) = 2 + \cos\delta\;\cos\phi - \sin\delta\,\sin\phi$$

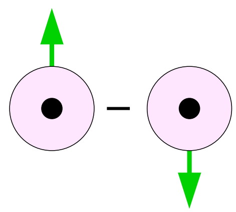
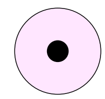
- $e^{i\delta} \Rightarrow$ scattering phase shift, from **final / initial state interactions**
- ... but in high energy π production, surely **many** amplitudes contribute

significant $\hat{T}$-odd frag$^{\underline{n}}$ function $\Rightarrow$ **phase coherence** in fragmentation!

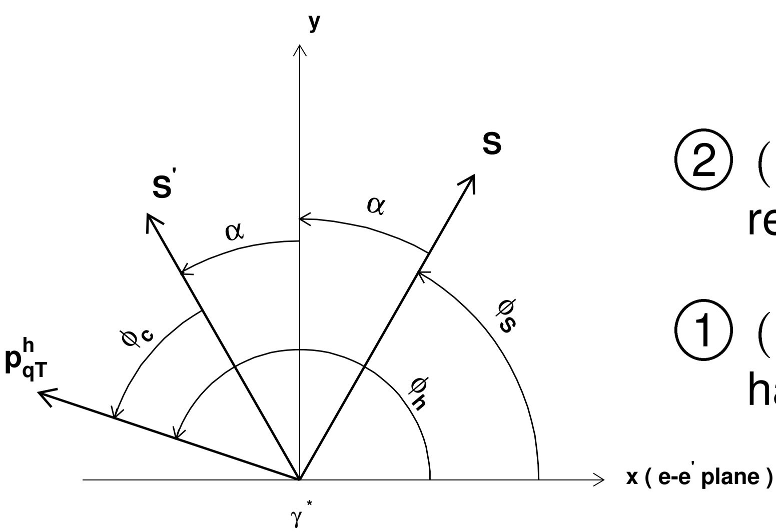
T-odd Distribution vs Fragmentation Function

There are actually **two** similar terms in $d\sigma_{\mathrm{UT}}$ ...

1 $\sin(\phi_h^l + \phi_S^l)$ $\otimes\, h_1$ =  $\otimes\, H_1^\perp$ = 

2 $\sin(\phi_h^l - \phi_S^l)$ $\otimes\, f_{1T}^\perp$ =  $\otimes\, D_1$ = 

$f_{1T}^\perp$ = ***T-odd*** ***distribution function***



2 $(\phi_h^l - \phi_S^l)$ = angle of hadron relative to **initial** quark spin

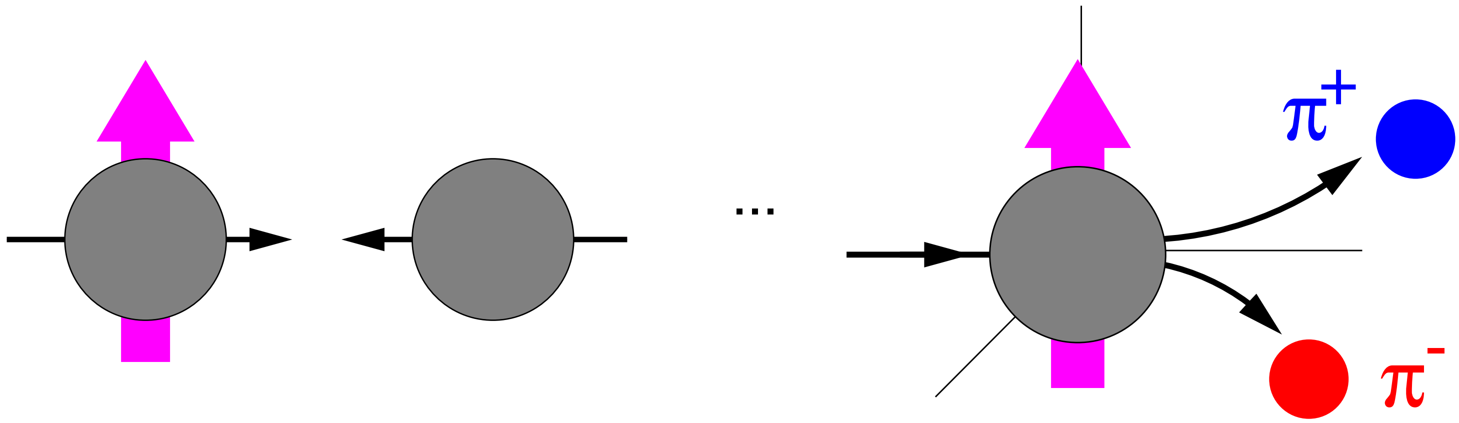
1 $(\phi_h^l + \phi_S^l) = \pi + (\phi_h^l - \phi_S^{l'})$ = hadron relative to **final** quark spin

Cannot distinguish in:

- **longitudinal-target case** ...
  $\rightarrow$ transverse component has $\phi_S^l = 0$.
- **inclusive π production** , e.g. $p^\uparrow p \rightarrow\ \pi X$
  $\rightarrow$ jet axis not known

Single Spin Asymmetries

E704: $p^{\uparrow}p \to \pi X$



From perturbative QCD considerations, it was expected that transverse spin effects would be **small:** $\sim m_q/\sqrt{\hat{s}}$ ...

$$A_N(p^{\uparrow}p \to \pi X) \sim \int h_1(x_a) f_1(x_b) D_1^{\pi}(x_c)\, \hat{a}_{ab} \frac{d\sigma}{dt}(a^{\uparrow}b \to cd)$$

with helicity flip in subprocess asymmetry:

$$\hat{a}_a b = \frac{d\sigma(a^{\uparrow}b \to cd) - d\sigma(a^{\downarrow}b \to cd)}{d\sigma(a^{\uparrow}b \to cd) + d\sigma(a^{\downarrow}b \to cd)}$$

No large effects possible:

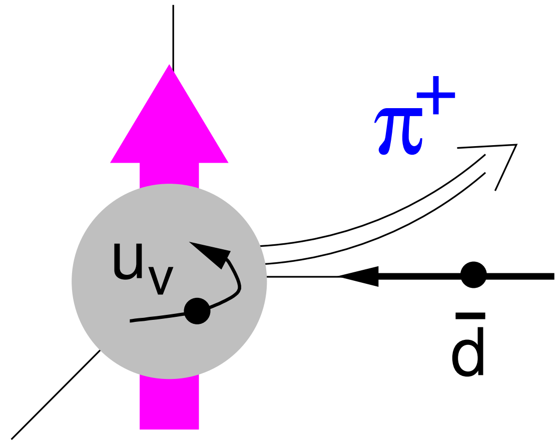
- q helicity flip vanishes in the limit $m_q = 0$
- $\hat{a}_{ab}$ arises from **interference** between a non-flip and a single-flip helicity amplitude ... and no imaginary phases possible at Born level.

Sivers Effect

Chou-Yang Model

Valence quarks = relativistic Dirac particles in central potential

- relativistic quarks in eigenstates of J, which is shared between L and S
- symmetrized wavefunction $\rightarrow \Delta u = +4/3, \Delta d = -1/3$
- forward π^+ produced directly from orbiting u_v quark at front surface of beam proton



Sivers Idea

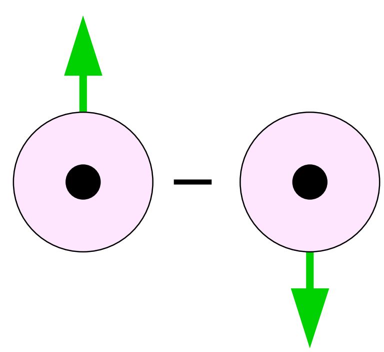
Consider dependence of parton densities on **intrinsic** k_T :

$$A_N \sim \int \boxed{f_{1T}^{\perp}(x_a, \mathbf{k}_{Ta})} f_1(x_b, k_{Tb}) D_1^{\pi}(x_c, k_{Tc}) \frac{d\sigma}{dt}(ab \rightarrow cd)$$

- Unknown soft dynamics absorbed into $f_{1T}^{\perp}$ ... hard subprocess merely transmits the asymmetry to large transverse momentum by kinematics.
- Intrinsic k_T introduces hadronic scale M into the problem: transverse effects of order pT/M (not just pT/s)

New structure function: $f_{1T}^{\perp}(x, \mathbf{k}_T)$

- disappears on integration over $\mathbf{k}_T$
- odd under time reversal ... requires initial state interactions between colliding hadrons

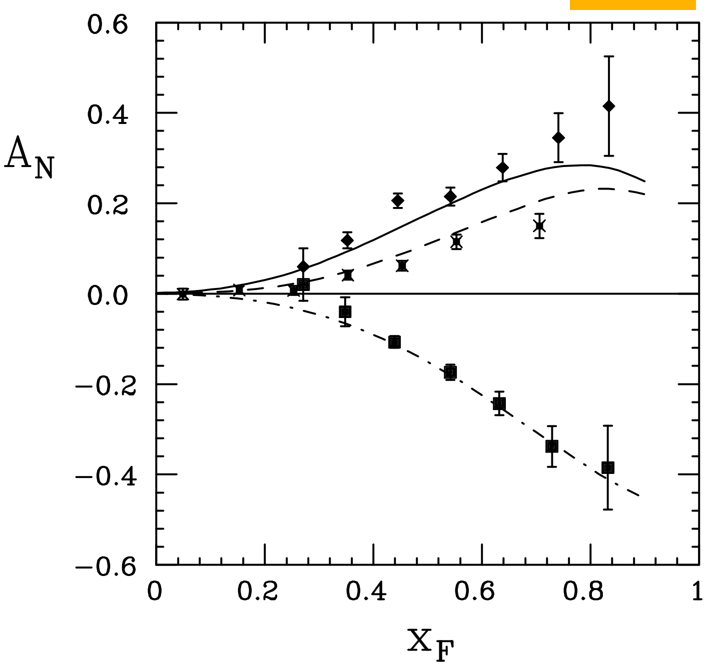


Collins Effect and Transversity

There is another possible explanation ...
the E704 single-spin asymmetry could be due to:

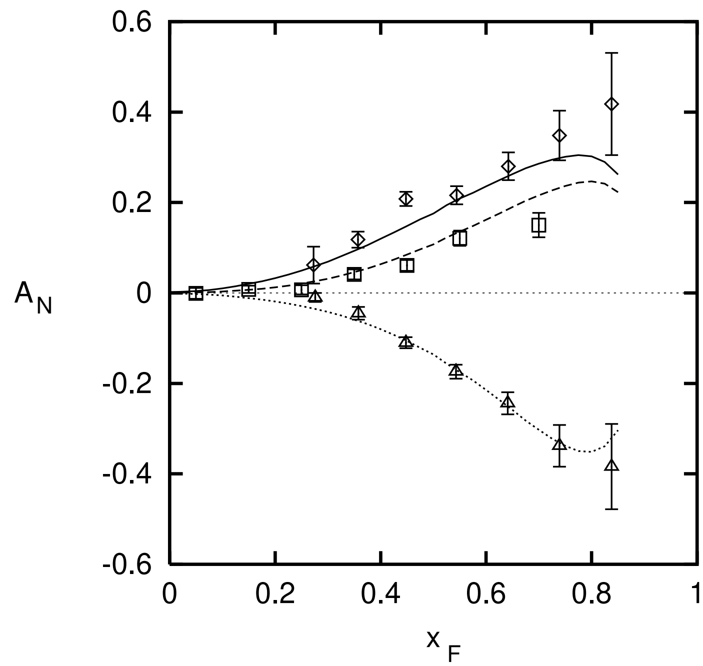
Sivers Effect:

T-odd **distribut$^{\underline{n}}$ function** $f_{1T}^{\perp}$



Collins Effect:

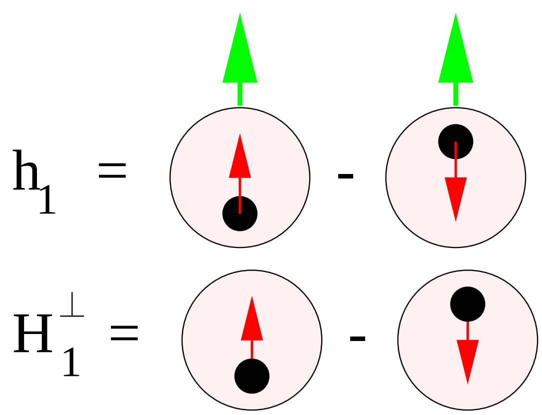
T-odd **fragmentat$^{\underline{n}}$ function** $H_1^{\perp}$



Collins Effect

In this case, $A_N \sim h_1(x)\, H_1^{\perp}(z)$

$\Rightarrow$ access to **transversity!**



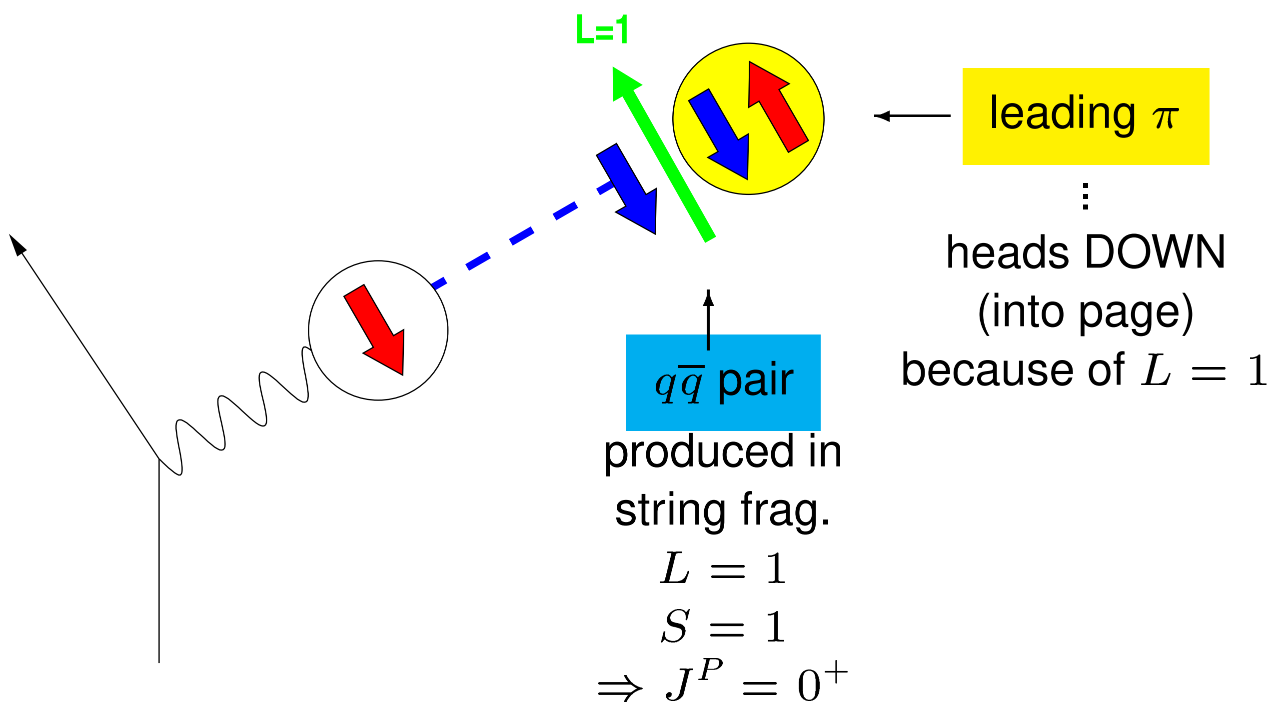
How to separate?

Single Spin Asymmetries in DIS

The Collins Effect in the String Fragmentation Model

Collins Fragmentation Function $H_1^{\perp}(z)$

- **chiral-odd** like $h_1(x)$ ... chiral-odd distribution and fragmentation functions appear in pairs in DIS cross-section
- **T-odd** ... one T-odd function required to produce single-spin asymmetry in semi-inclusive DIS

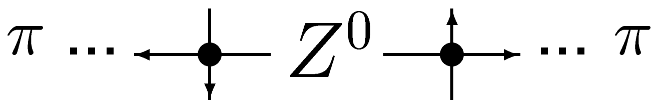


The Collins function is indicative of **phase coherence** in fragmentation
$\Rightarrow$ generate inteference between non-flip and single-flip amplitudes

Size of Collins Function

• DELPHI

Efremov et al., hep-ph/9812522



Transverse q, $\overline{q}$ polarization small but ANTI-CORRELATED (@ $\sim$ 50 % level)

$$\Rightarrow \quad \left|\frac{H_1^\perp}{D_1}\right| = 6.3 \pm 1.7\,\%$$

• HERMES / SMC

Efremov et al., hep-ph/0108213

Fit experimental data for $H_1^\perp$, taking $h_1(x)$ from Chiral Quark Soliton Model (χQSM)

$$\Rightarrow \quad \left|\frac{H_1^\perp}{D_1}\right| = \begin{cases} 6.1 \pm 0.9 \pm 0.8\% \\ \text{(HERMES)} \\ 10 \pm 5\% \quad \text{(SMC)} \end{cases}$$

• E704

Boglione & Mulders, PRD 60 (1999) 054007

Fit experimental data, assuming ONLY Collins effect contributes

$$\Rightarrow \quad \left|\frac{H_1^\perp}{D_1}\right| = 7.6\%$$

There seems to be general agreement

(although results depend on z-range over which averaging performed)

What about the Sivers Function?

- Note: fit to E704 assuming ONLY Sivers effect contributes:

$$\Rightarrow \quad \left|\frac{f_{1T}^\perp}{f_1}\right| = 8.3\% \quad \begin{pmatrix} \text{“max”} \\ \text{size} \end{pmatrix}$$

- MORE DATA NEEDED ... e.g. DIS w transverse target

$$A_{UT} \text{ has term } \sim f_{1T}^\perp\, D_1\, \sin(\phi_h^l + \phi_s^l)$$

Origins of $f_{1T}^{\perp}$

$f_{1T}^{\perp}$ represents ***off-diagonal*** nucleon matrix elements ...
should be zero due to T-invariance of QCD. ***However ...***

• Initial State Interactions

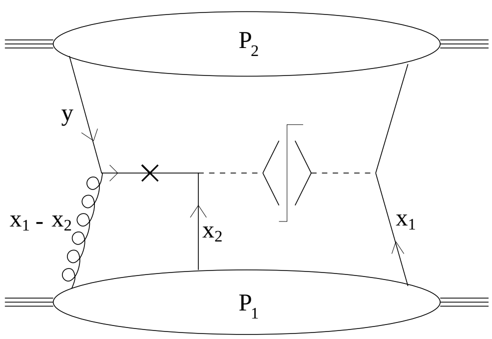
M. Anselmino et al, PRD 56, 6021

Possible in pp scattering (soft gluons); highly suppressed ($\mathcal{O}(\alpha_{em})$) in DIS

This should not contribute in DIS

• Gluonic Poles

Qui & Sterman, PRL 67, 2264; Hammon et al, hep-ph/9611359



+ c. c.

In pp or ep scattering, pole at zero gluon momentum when quark propagator $\times$ on shell

• Spin-Isospin Interactions

Anselmino et al, hep-ph/9703303

Spin-isoposin interaction in e.g. ***chiral model*** mixes states of different flavours under T-reversal ... could produce $f_{1T}^{\perp}$ ***independent of reaction***

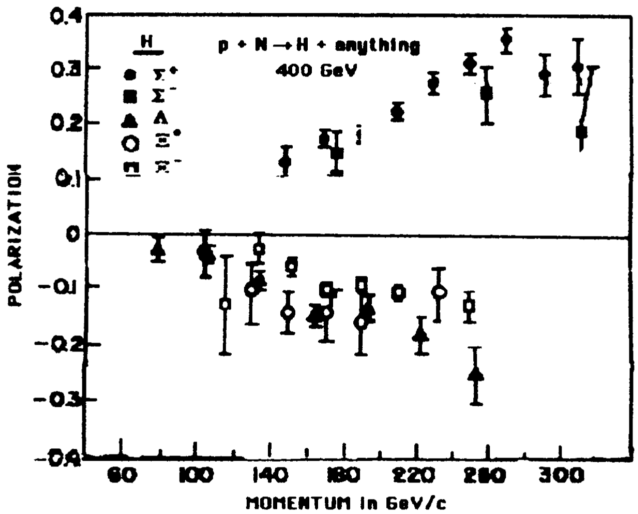
Isolating $f_{1T}^{\perp}$

- $\sin(\phi_h^l - \phi_S^l)$ vs $\sin(\phi_h^l + \phi_S^l)$ behaviour
- **Direct photon** $(pp \to \gamma X) \to$ no fragmentation part
- $(e,p)p \to hX$ with h **collinear** to jet axis ($\vec{q}$) $\to$ no Colllins effect
- **Inclusive DIS** : $d\sigma_{UT} \sim \sin(\phi_S^l)\, f_T\, D_1$, with $f_T = -d/dx\, f_{1T}^{\perp(1)}$

The Wacky World of Hyperon Polarization

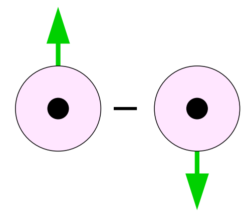
Unpolarized beams on unpolarized targets produce hyperons which are strongly polarized! ... direction is $\hat{n} = \mathbf{p}_{\rm beam} \times \mathbf{p}_Y$

$pp \to Y^{\uparrow} X$



$$d\sigma_{UUT} \sim \sin(\phi_h^l - \phi_{S_h}^l) \cdot$$

$f_1(x)\, \mathbf{D}_{1T}^{\perp(1)}$ =



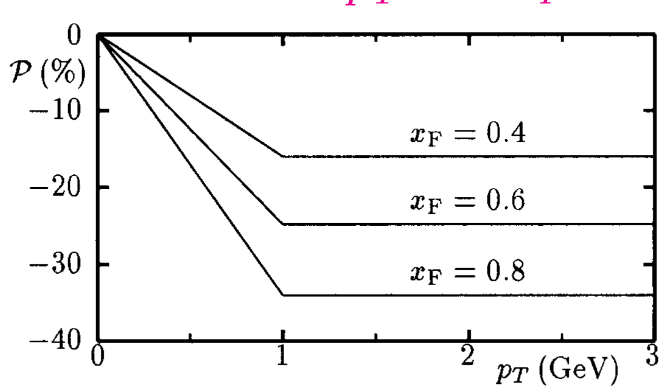
$\Rightarrow$ T-odd fragmentation analogue of $f_{1T}^{\perp}$

The key seems to be **hyperon spin structure** ... in NRQM:

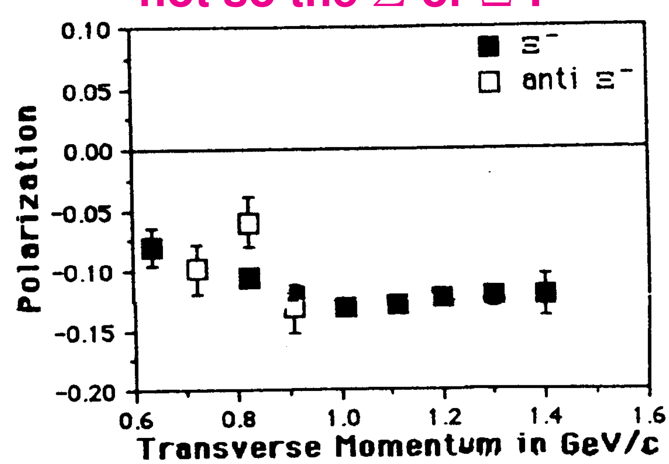
$$\begin{array}{lll} \Lambda & \Delta s = +1, & \Delta u = \Delta d = 0 \\ \Sigma^{\pm} & \Delta s = -1/3, & \Delta u, d = +4/3 \\ \Xi^{\pm} & \Delta s = +4/3, & \Delta u, d = -1/3 \end{array}$$

$\Rightarrow$ sign of polarization is opposite to Δs ...

Kinematic behaviour: linear with p_T and x_F

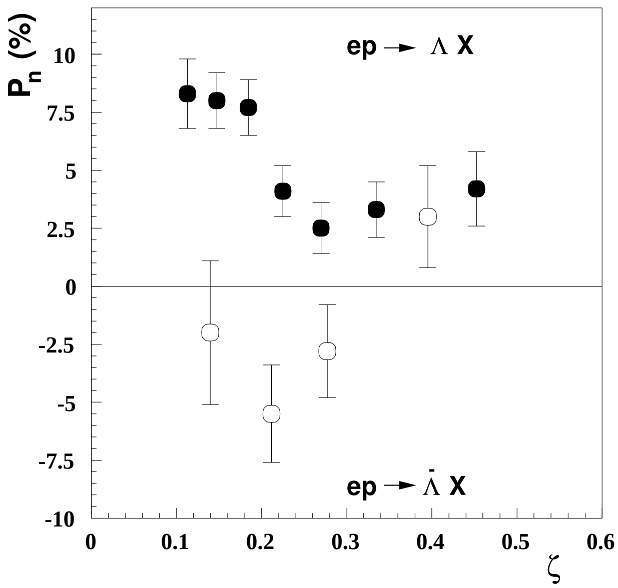


Anti-Λ is unpolarized, but ... not so the $\overline{\Sigma}$ or $\overline{\Xi}$!



Transverse Λ Polarization from γp

ζ dependence



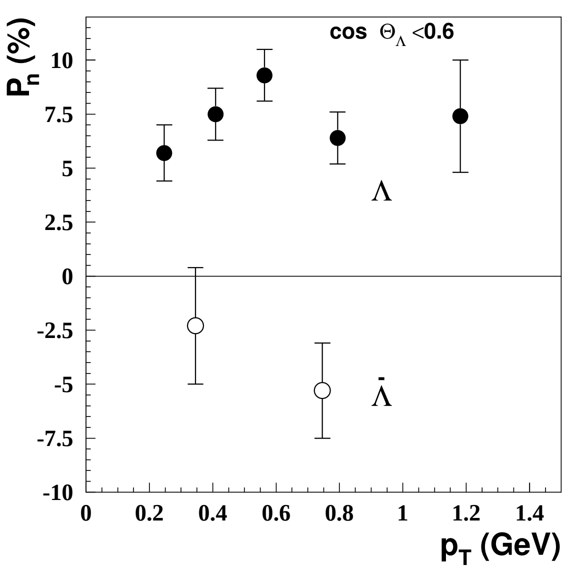
Light-cone fraction

$$\boxed{\zeta \equiv (E_\Lambda + p_{z\Lambda})/(E_B + p_B)}$$

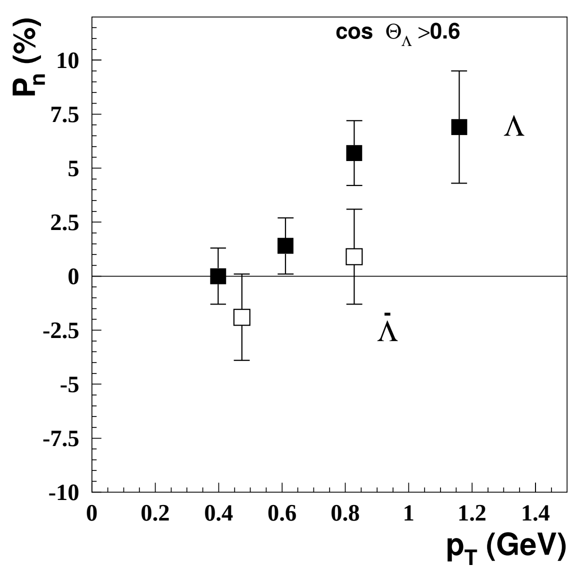
- **Change in behaviour** at $\zeta \approx 0.25$
  $\Rightarrow$ transition from target to current fragmentation region
- **Positive sign** of P_n^Λ, unlike pp case
  $\Rightarrow$ perhaps from $\gamma \rightarrow s\bar{s}$

p_T dependence

backward production



forward production



Qualitative agreement between P_n^Λ ***and*** $P_n^{\bar{\Lambda}}$ in ***forward*** direction, where γ beam does not distinguish between quarks and anti-quarks

Conclusions

Transversity $\mathbf{h_1}$

- HERMES $A_{UL}^{\sin\phi} \Rightarrow$ both h_1 and $H_1^\perp$ significantly non-zero
- ***qualitative concensus*** on magnitudes between
  HERMES, SMC, E704, DELPHI
- best access to h_1: experiments with ***transverse target***
  $\Rightarrow$ HERMES Run 2, RHIC spin, COMPASS

T-Odd Distribution Function $f_{1T}^\perp$

- possible contribution to E704 $pp^\uparrow \to \pi X$ measurement,
  but likely (?) not present in DIS
- $ep^\uparrow$ and $pp^\uparrow$ experiments in near future can ***separate*** from $h_1 \cdot H_1^\perp$
- related to orbital motion of quarks?

Spin Effects in Fragmentation

- T-odd: $H_1^\perp$ clearly non-zero (HERMES) ... along with $D_{1T}^\perp$,
  $\rightarrow$ ***surprising phase coherence*** in fragmentation
- ***spin transfer*** in fragmentation: G_1 clearly non-zero (LEP),
  but net H_1, G_1 effects appear small in SIDIS (HERMES)
- upcoming SIDIS measurement of $D_{1T}^\perp$ (high Q^2) from HERMES
  may shed some light