Transversity: theory vs experiments

- Why transversity? $[h_1, \Delta_T q, \delta q]$
  Experimental access to transversity
- h_1 in $p^\uparrow p^\uparrow$ interactions $[h_1 \otimes h_1]$
- New chiral-odd fragmentation functions
- h_1 in $pp^\uparrow \to \pi X$ or $pp^\uparrow \to \Lambda^\uparrow X$
- h_1 in SIDIS processes:

  $\ell p^\uparrow \to \ell \pi X$

  $\ell p^\uparrow \to \ell \pi \pi X$

  $\ell p^\uparrow \to \ell V^\uparrow X$

  $\ell p^\uparrow \to \ell \Lambda^\uparrow X$

- Access to new frag. functs.

  $e^+e^- \to \pi^+\pi^- X$

  $e^+e^- \to \pi\pi\ \pi\pi X$

- Conclusions

Trieste, 19/2/2002
M. ANSELMINO

Transversity, h_1 or $\Delta_T q$ or δq

q, Δq and h_1 (or $\Delta_T q$, δq):
fundamental leading-twist quark distributions [equally important]

q = quark distribution $(= f_{q/P})$

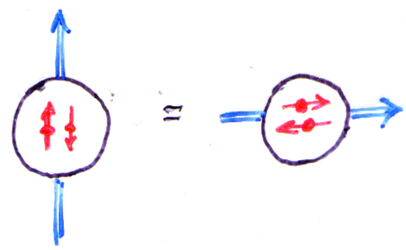
Δq = helicity distribution

$$= q_+^+ - q_-^+ \quad (= f_{q_+/P_+} - f_{q_-/P_+})$$

$\Delta_T q$ = transverse polarization distribution

$$= q_\uparrow^\uparrow - q_\downarrow^\uparrow$$

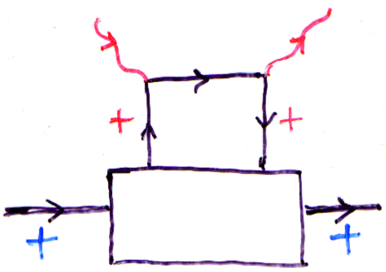
$\Delta_T q = \Delta q$ only at rest



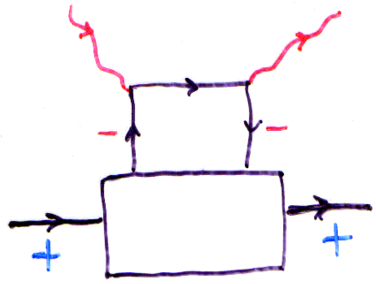
$\Delta q \sim \bar{q}\, \gamma^\mu \gamma_5\, q$ (chiral-even)

$\Delta_T q \sim \bar{q}\, \sigma^{\mu\nu} \gamma_5\, q$ (chiral-odd)

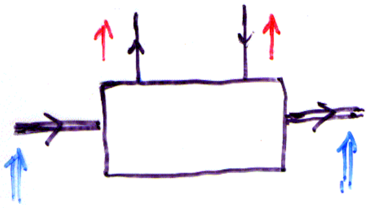
q and Δq can be measured in DIS



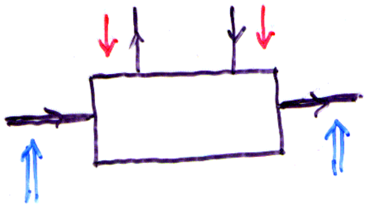
$\pm$



$$= \begin{matrix} q(x,Q^2) \\ \Delta q(x,Q^2) \end{matrix}$$



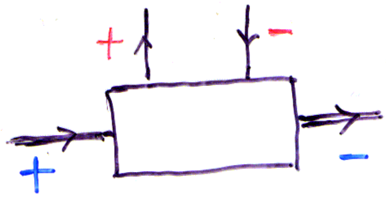
$\pm$



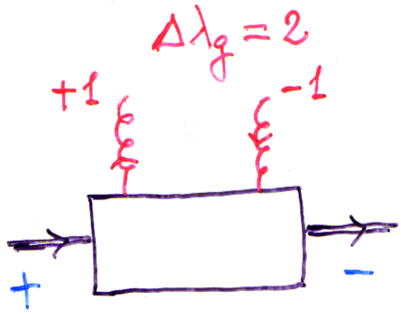
$$= \begin{matrix} q(x,Q^2) \\ \Delta_T q(x,Q^2) \end{matrix}$$

In helicity basis, $\Uparrow, \Downarrow = \frac{1}{\sqrt{2}}\left(|+\rangle \pm i|-\rangle\right)$

$\Rightarrow$

$h_1(x,Q^2) \sim$ 

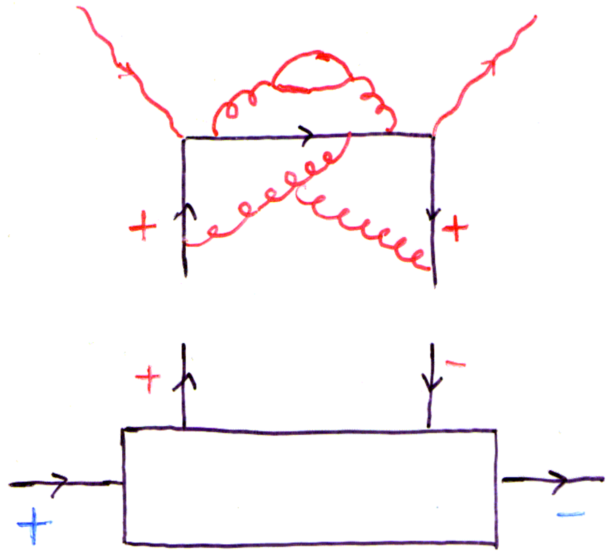
$\Rightarrow$ no gluon contribution to h_1



$\Delta\lambda = 1$

(simple Q^2 evolution)

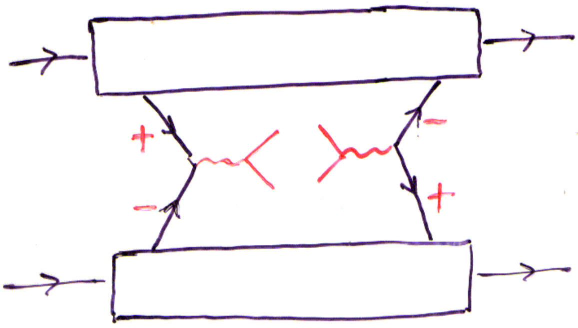
$\Rightarrow$



h_1 decouples from QCD, SM dynamics

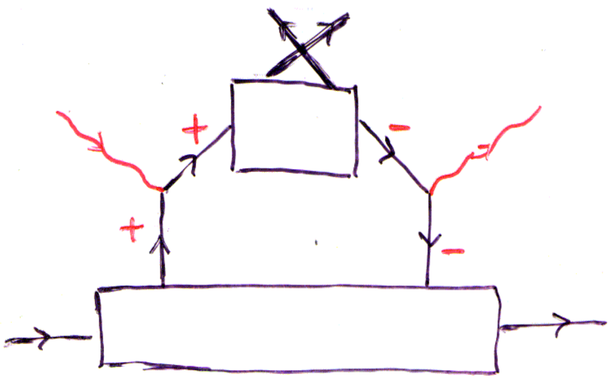
$\Rightarrow$ h_1 must couple to another chiral-odd function. For example:

Drell-Yan processes $(pp \to \mu^+ \mu^- X)$



$\sim h_1 \otimes h_1$

SIDIS $(\ell p \to \ell h X)$



$\sim h_1 \otimes \tilde{D}_{c\text{-}o\ldots}$

h_1 from $p^\uparrow p^\uparrow$ processes

Measure $A_{TT} = \dfrac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}} \equiv \dfrac{\Delta_T \sigma}{\sigma}$

- $p^\uparrow p^\uparrow \to \mu^+ \mu^- X$

very small

$$\Delta_T \sigma^{\mu\mu} \sim \sum_q h_{1q} \otimes h_{1\bar{q}} \otimes \Delta_T \hat{\sigma}$$

- $p^\uparrow p^\uparrow \to \pi^+ \pi^- X$

$$\Delta_T \sigma^{\pi\pi} \sim \sum_{abcd} h_{1a} \otimes h_{1b} \otimes \Delta_T \hat{\sigma} \otimes D_{\pi/c} \otimes D_{\pi/d}$$

no gluon contribution $\Rightarrow$ A_{TT} very small

$$A_{TT} = \frac{\Delta_T \sigma^{\pi^+\pi^+} + \Delta_T \sigma^{\pi^-\pi^-} - \Delta_T \sigma^{\pi^+\pi^-} - \Delta_T \sigma^{\pi^-\pi^+}}{\sigma^{\pi^+\pi^+} + \sigma^{\pi^-\pi^-} - \sigma^{\pi^+\pi^-} - \sigma^{\pi^-\pi^+}}$$

large, but huge statistical errors

(de Florian, Stratmann, Vogelsang)

- $p^\uparrow p^\uparrow \to$ 2 jets $+ X$

A_{TT} small (~ 1 ‰) but very good statistic at RHIC

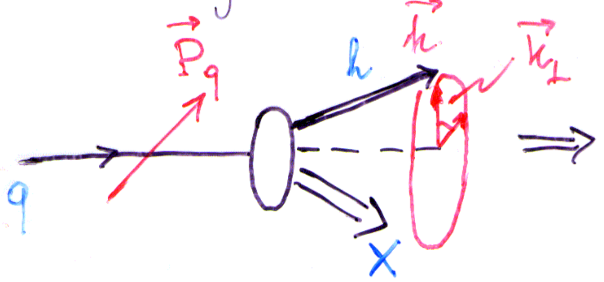
New chiral-odd fragmentation functs.

Access h_1 via chiral-odd f.f.
Which ones?

- Analogue of h_1 for fragmentation

$$\Longrightarrow \quad \Delta_T D = D_{q\uparrow}^{h\uparrow} - D_{q\downarrow}^{h\uparrow}$$

- Collins function



$$\Longrightarrow \quad \vec{P}_q \cdot \vec{q} \times \vec{k}$$

$$\Delta^N D_{h/q\uparrow} = D_{h/q\uparrow}(z, \vec{k}_\perp) - D_{h/q\downarrow}(z, \vec{k}_\perp) \quad (\sim H_1^\perp)$$

$$\sim \mathrm{Im} \sum_{\lambda_h} \sum\!\!\!\!\!\!\int_{X,\lambda_X} \mathcal{D}_{\lambda_h \lambda_X;+} \, \mathcal{D}^*_{\lambda_h \lambda_X;-}$$

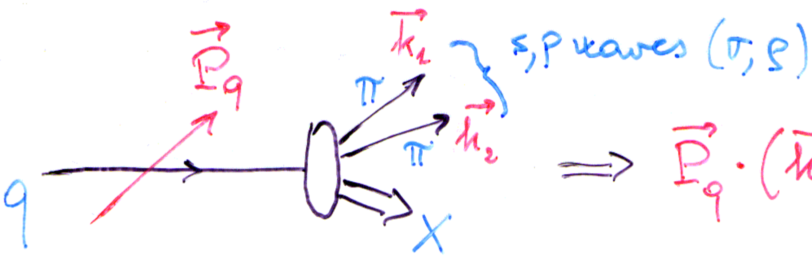
(needs interferences between frag. amplitudes)

$$D_{h/q}(z, k_\perp) = \frac{1}{2} \sum_{\lambda_q \lambda_h} \sum\!\!\!\!\!\!\int_{X,\lambda_X} \left| \mathcal{D}_{\lambda_h \lambda_X;\lambda_q} \right|^2$$

[$H_1^\perp$, Boccchetta, Kundu, Metz, Mulders]

- Interference frag. functions

(Jaffe, Jin, Tang ; Artru, Collins)



$\Longrightarrow \vec{P}_q \cdot (\vec{k}_1 \times \vec{k}_2)$

Int. between s,p $\pi\pi$ states $\Rightarrow$ new f.f.

$\delta\hat{q}_I$ [for a model see Radici, Jakob, Bianconi]

- For production of spin 1 (V) particles [M.A., Boglione, Hansson, Murgia]

$$D^{+,-}_{1,0} \equiv \sum_{X,\lambda_X} \mathcal{D}_{\lambda_X 1,+}\, \mathcal{D}^{*}_{\lambda_X 0,-}$$

contributes to $\rho_{10}(V)$ of vector particles produced in SIDIS

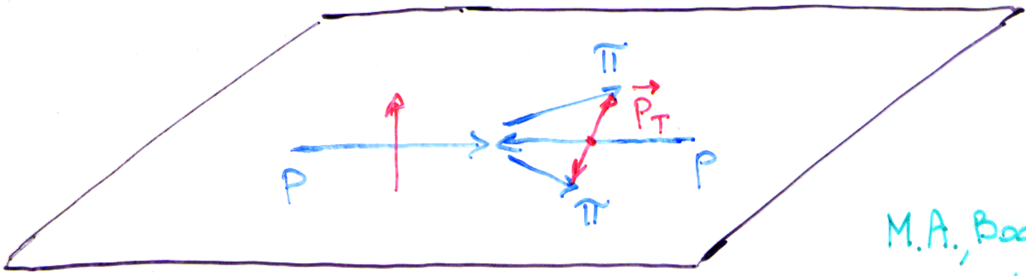
[See also Bacchetta, Mulders]

- Transversal handedness

[Efremov et al.]

Which processes?

- A_N in $p^\uparrow p \to \pi X = \dfrac{d\sigma^\uparrow - d\sigma^\downarrow}{d\sigma^\uparrow + d\sigma^\downarrow}$



M.A. Boglione, Leader, Murgia

left-right asymmetry

$$d\sigma^\uparrow - d\sigma^\downarrow \sim \sum_{abc} \underbrace{h_{1a}}_{\text{transv.}} \otimes f_{b/p} \otimes \Delta\hat{\sigma} \otimes \underbrace{\Delta^N D_{\pi/c^\uparrow}}_{\text{Collins f.}}$$

- P_T^Λ in $p p^\uparrow \to \Lambda^\uparrow X = \dfrac{d\sigma^{\Lambda\uparrow} - d\sigma^{\Lambda\downarrow}}{d\sigma^{\Lambda\uparrow} + d\sigma^{\Lambda\downarrow}}$

[Λ in current fragm. region]

$$P_T^\Lambda \sim \sum_{abc} f_{a/p} \otimes \underbrace{h_{1b}}_{\text{transv.}} \otimes \Delta\hat{\sigma} \otimes \underbrace{\Delta_T D_{\Lambda/c}}_{\text{transverse fragmentation}}$$

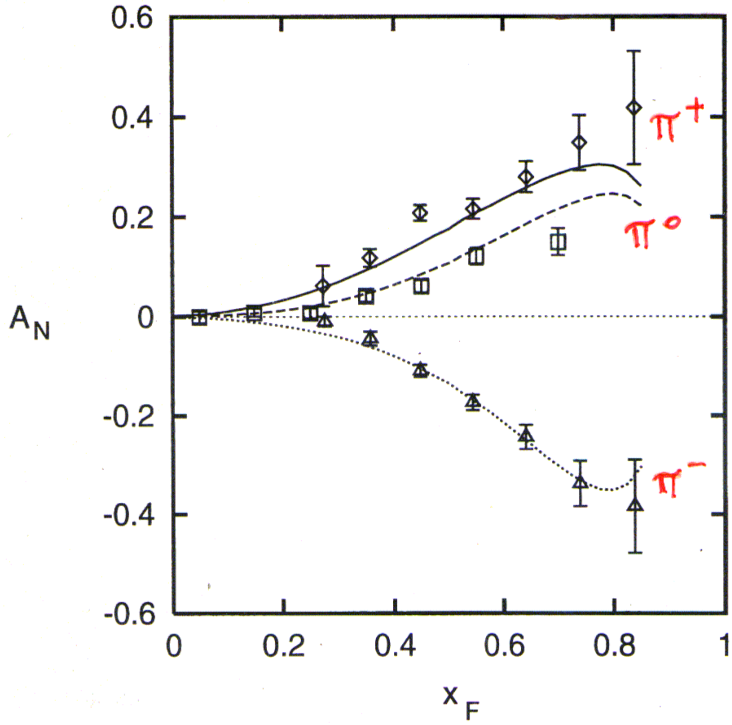


Figure 2: Single spin asymmetry for pion production, $p^\uparrow p \to \pi X$. The data points are the E704 experimental single spin asymmetry for π^+ (diamonds), π^0 (squares) and π^- (triangles) [3]. The solid line is our best fit for π^+, the dashed line for π^0 and the dotted line for π^-, obtained under the assumption of Collins effect only.

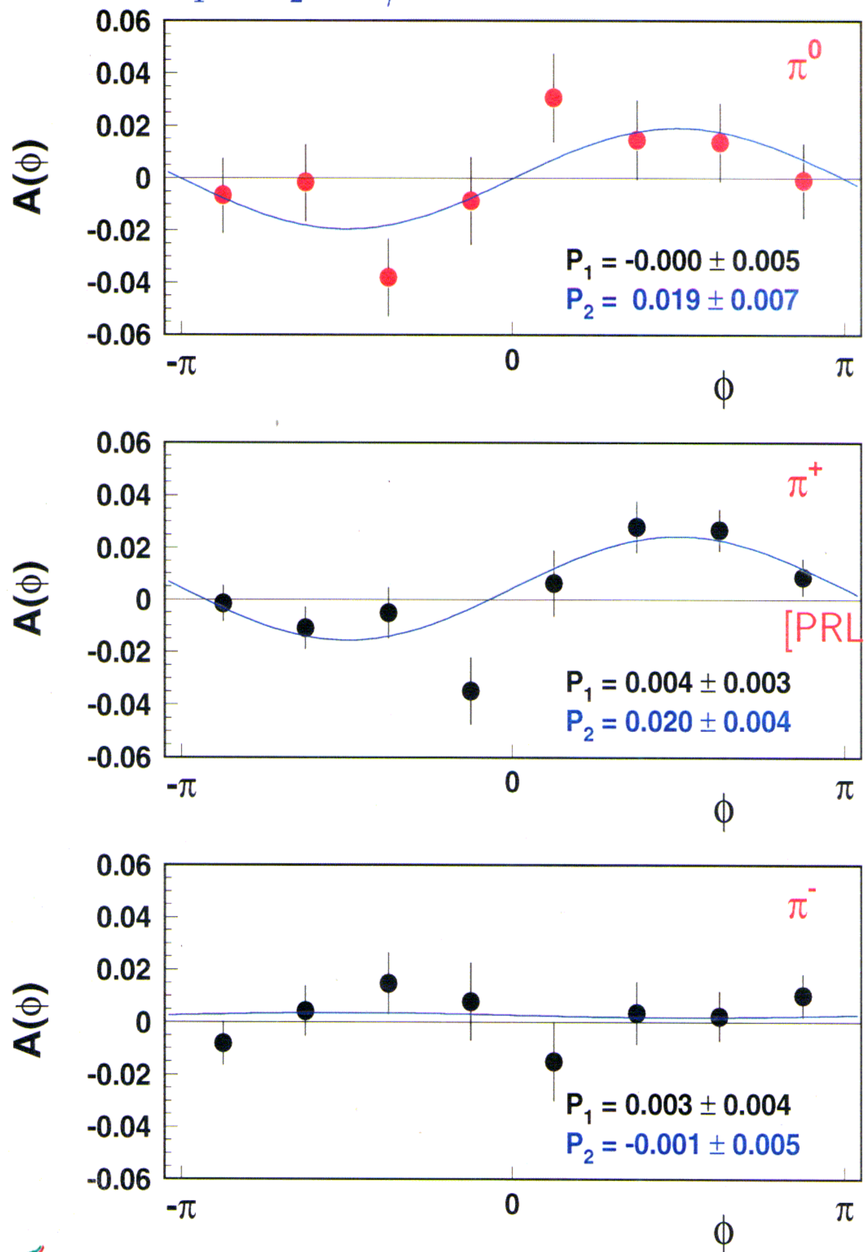
$\Delta^N D_{\pi/q^\uparrow} \neq 0$

$\ell p^{\uparrow} \to \ell \pi X$

single target-spin azimuthal asymmetry

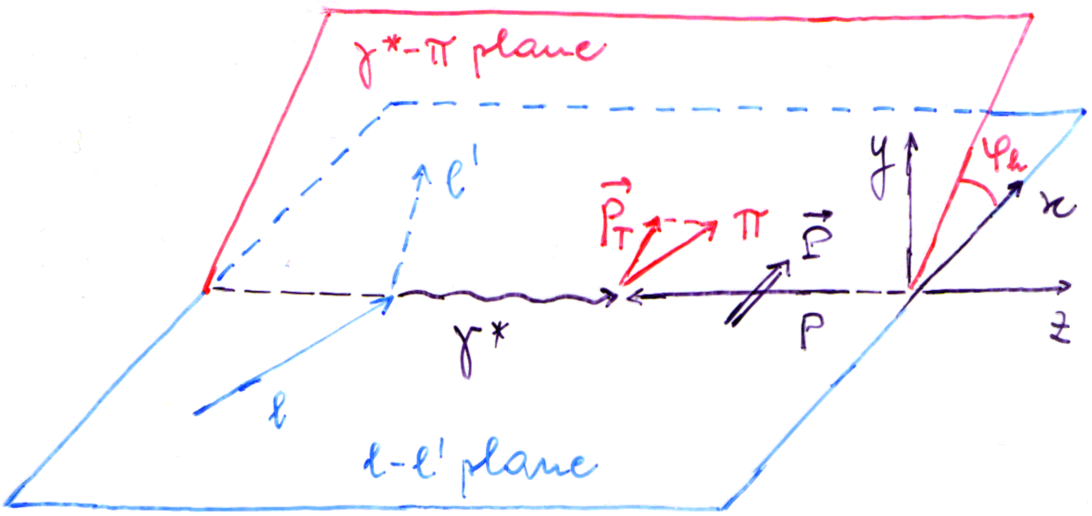
$$A(\phi) = \frac{1}{\langle P_t \rangle} \cdot \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)}$$

$P_1 + P_2 \sin\phi$

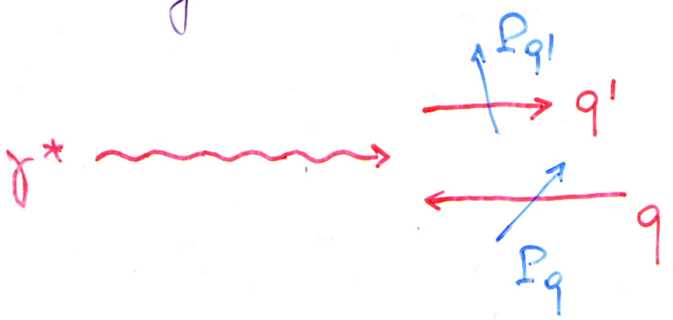


[PRL 84, 2000]

$\ell p^{\uparrow} \to \ell \pi X$ cross-section in γ^*-p c.m.



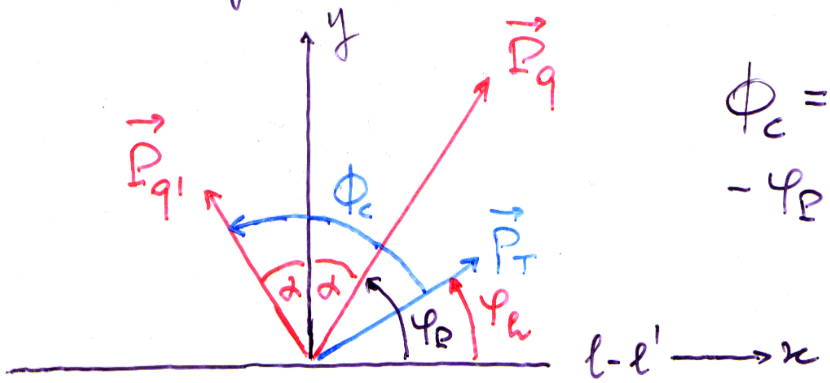
Elementary interaction:



$$\vec{P}_T \equiv \vec{k}_\perp$$

$$y = \frac{Q^2}{x\,s}$$

$$\begin{cases} (P_{q'})_x = -D_{NN}\,(P_q)_x \\ (P_{q'})_y = D_{NN}\,(P_q)_y \end{cases} \qquad D_{NN} = \frac{2(1-y)}{1+(1-y)^2}$$



$$\phi_c = \pi + -\varphi_P - \varphi_h$$

$$\ell p^\uparrow \to \ell \pi X \qquad A_N = \frac{d\sigma^\uparrow - d\sigma^\downarrow}{d\sigma^\uparrow + d\sigma^\downarrow}$$

At leading twist:

$$A_N^h = \frac{\sum_q e_q^2\, h_{1q}\, \Delta^N D_{h/q^\uparrow}}{\sum_q e_q^2\, q \quad 2 D_{h/q}} \frac{2(1-y)}{1+(1-y)^2} P \sin\phi_c$$

Using isospin and charge conjugation invariance ($D_{\pi^+/u} = D_{\pi^-/d}$ etc.) and neglecting non valence contributions ($D_{\pi^+/d} \simeq 0 \ldots$)

$\Rightarrow$

$$A_N^{\pi^i} = \frac{h_i(x)}{f_i(x)} \frac{\Delta^N D_{\pi/q^\uparrow}(z, P_T)}{2 D_{\pi/q}(z, P_T)} \frac{2(1-y)}{1+(1-y)^2} P \sin\phi_c$$

$i = + \quad h_+ = 4 h_{1u} \qquad f_+ = 4u + \bar{d}$

$i = - \quad h_- = h_{1d} \qquad f_- = d + 4\bar{u}$

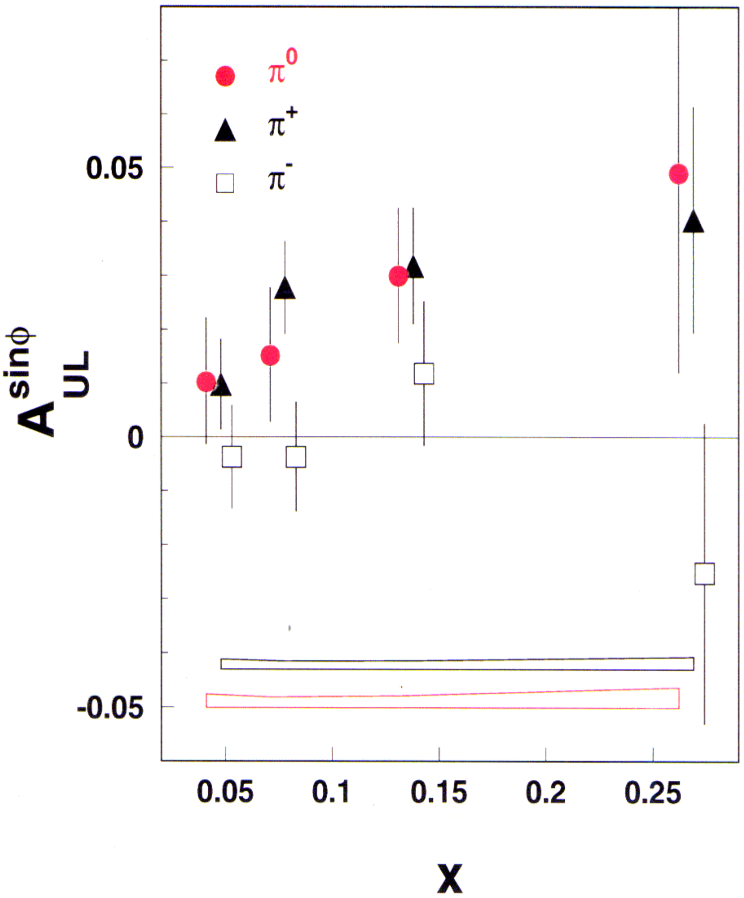
$i = 0 \quad h_0 = 4 h_{1u} + h_{1d} \qquad f_0 = 4u + d + 4\bar{u} + \bar{d}$

One expects:

$A_N^{\pi^+} \simeq A_N^{\pi^0}$ at large x

$A_N^{\pi^i}$ increases with x and P_T

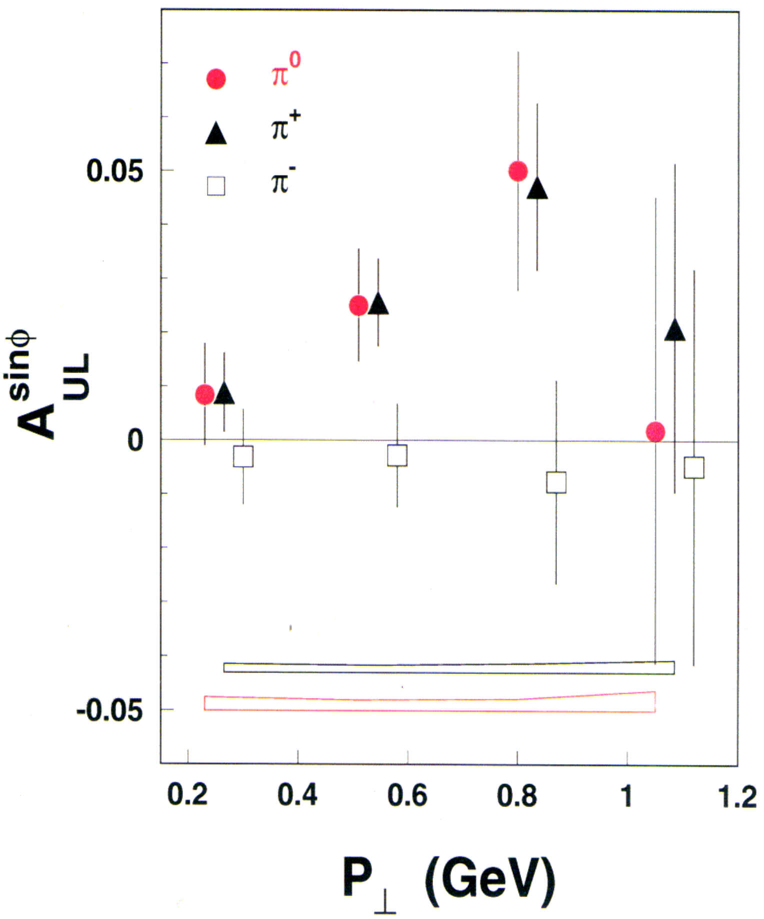
SSA $A_{UL}^{\sin\phi}$: x dependence



similar behaviour of π^0 and π^+

behaviour consistent with increase suggests that single-spin asymmetries are associated with valence quark contributions

SSA $A_{UL}^{\sin\phi}$: $P_\perp$ dependence



related to the dominant kinematic role of the intrinsic transverse momentum of the quark, if $P_\perp$ remains below the typical hadronic mass of ~ 1 GeV

Compare

$$A_N^{\pi^+} = \frac{4\, h_{1u}}{4u + \bar{d}} \; \frac{\Delta^N D_{\pi^+/q^\uparrow}}{2\, D_{\pi^+/q}} \; \frac{2(1-y)}{1+(1-y)^2} \sin\phi_c$$

with SMC data (not suppressed by $\frac{1}{Q}$ factors)

$$A_N^{\pi^+} \simeq -(0.10 \pm 0.06) \sin\phi_c$$

Use Soffer's bound on h_1

$$|h_{1q}| \leq \frac{1}{2}(q + \Delta q)$$

q and Δq are known

$\Rightarrow$ obtain lower bound on $\frac{|\Delta^N D|}{D}$:

$$\frac{|\Delta^N D_{\pi/q}|}{D_{\pi/q}} \geqslant 0.24 \pm 0.15 \qquad \text{large!}$$

Similar results from HERMES data
(but higher twist might be important)
[M.A., F. Murgia]

- A_N in $\ell p^\uparrow \to \ell \pi\pi X$ (or $pp^\uparrow \to \pi\pi X$)

$$d\sigma^\uparrow - d\sigma^\downarrow \sim \sin(\delta_0 - \delta_1) \sum_q e_q^2\, h_{1q}(x)\, \delta\hat{q}_I(z)$$

- $\rho_{10}(V)$ in $\ell p^\uparrow \to \ell V X$

$$\mathrm{Re}\,\rho_{10}(V)\, d\sigma \sim \sum_q h_{1q}(x)\, \underbrace{\hat{M}\hat{M}^*(y)}_{\sim \text{elem. int.}}\, \mathrm{Im}\, D_{1,0}^{+,-}$$

simple model:

$$\mathrm{Im}\, D_{1,0}^{+,-} \simeq \left[D_{V_1/q_+} D_{V_0/q_-} \right]^{\frac{1}{2}}$$

$$\simeq \frac{\sqrt{2}}{3} D_{V/q}$$

- P_T^Λ in $\ell p^\uparrow \to \ell \Lambda^\uparrow X$

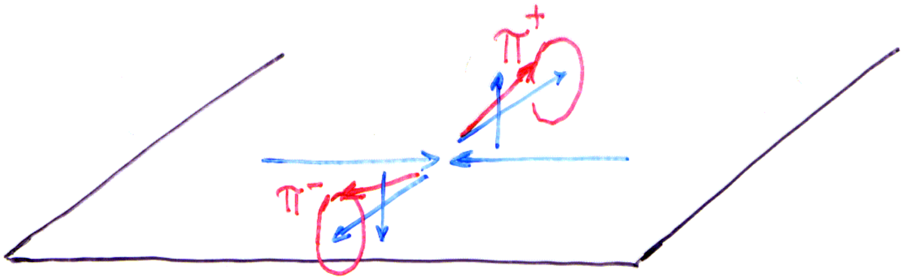
$$P_T^\Lambda = \frac{\sum_q e_q^2\, h_{1q}(x)\, \Delta_T D_{\Lambda/q}(z)}{\sum_q e_q^2\, q(x)\, D_{\Lambda/q}(z)} \; \frac{2(1-y)}{1+(1-y)^2}$$

$\sim$ separate x, y, z dependences

Λ's in <u>current</u> frag. region

Direct access to new f.f. ?

- $e^+e^- \longrightarrow \pi^+\pi^- X$



$\Rightarrow$ Dependence on angle ϕ between the two planes $(e^+e^-\pi^+)$ and $(e^+e^-\pi^-)$

$$d\sigma^{\pi^+\pi^-} \sim (1+\cos 2\phi)\, \Delta^N D_{\pi^+/q^\uparrow}\, \Delta^N D_{\pi^-/\bar{q}^\downarrow}$$

Boer, Jakob, Mulders (BELLE-KEK)

- $e^+e^- \longrightarrow (\pi\pi)(\pi\pi) X$

$\Rightarrow$ ang. correlation $\sim \delta\hat{q}_I\, \delta\hat{\bar{q}}_I$

- $e^+e^- \longrightarrow \Lambda^\uparrow \bar{\Lambda}^\uparrow X$

$\Rightarrow$ information on $\Delta_T D_{\Lambda/q}\, \Delta_T D_{\bar{\Lambda}/\bar{q}}$

Conclusions

- $\Delta_T q$ has same status and rights as q and Δq
- Much harder to measure, as it is chiral-odd
- Couple $\Delta_T q$ with another chiral-odd function $\Longrightarrow$

$$\Delta_T q \otimes \Delta_T q, \quad \Delta_T q \otimes \Delta^N D,$$
$$\Delta_T q \otimes \Delta_T D, \quad \Delta_T q \otimes \delta \hat{q}_I, \ldots$$

- Look for separate variable dependences, separate information on new functions, combined experimental information, models for new functions, ...

[Review paper by Barone, Drago, Ratcliffe]