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(in collab. with K.Goeke and P. Schweitzer)
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COLLINS ANALYZING POWER AND SPIN ASYMMETRIES

Content

1. Azimuthal asymmetries
2. Measurement of $H_1^\perp$ from $e^+e^- \to 2$-jets.
3. Approximations and model.
4. Results for proton target.
5. Predictions for deuteron.
6. Distribution $e(x)$ from A_{LU}.
7. Conclusions.

Azimuthal asymmetries

Airapetian et al., *PRL***84***(00)4047* HERMES data (longitudinally polarized SDIS): $\pi^{\pm}$

Avakian *NP***B79***(99)*

$$A_L^W = \frac{\int d\phi dy\, W\,(d\sigma^+/S^+ dy d\phi - d\sigma^-/S^- dy d\phi)}{\frac{1}{2}\int d\phi dy\,(d\sigma^+/dy d\phi + d\sigma^-/dy d\phi)}$$

Airapetian et al., *PR***D64***(01)097101* π^0

$W = \sin\phi$ or $\sin 2\phi$

$S_H^{\pm}$ is nucleon polarization.

*Mulders, Tangerman, NP***B461***(97)* With twist-2 and twist-3 contributions

$$A_{UL}^{\sin 2\phi} \propto \frac{\Sigma_a e_a^2 h_{1L}^{\perp(1)a}(x)\langle H_1^{\perp a/\pi}(z)\rangle}{\Sigma_a e_a^2 f_1^a(x)\langle D_1^{a/\pi}(z)\rangle},$$

$$A_{UL}^{\sin\phi} \propto \frac{8M}{Q}\times$$

$$\frac{\Sigma_a e_a^2 (x h_L^a(x)\langle H_1^{\perp a/\pi}(z)/z\rangle - h_{1L}^{\perp(1)a}(x)\langle \cancel{\tilde{H}^{a/\pi}(z)/z}\rangle)}{\Sigma_a e_a^2 f_1^a(x)\langle D_1^{a/\pi}(z)\rangle}.$$

$\frac{d}{dz}(zH_1^{\perp}(z))$

*Boglione, Mulders, PL***B478***(00)* *(with opposite to HERMES z-direction!)* Transversal part (with respect to virtual photon momentum)

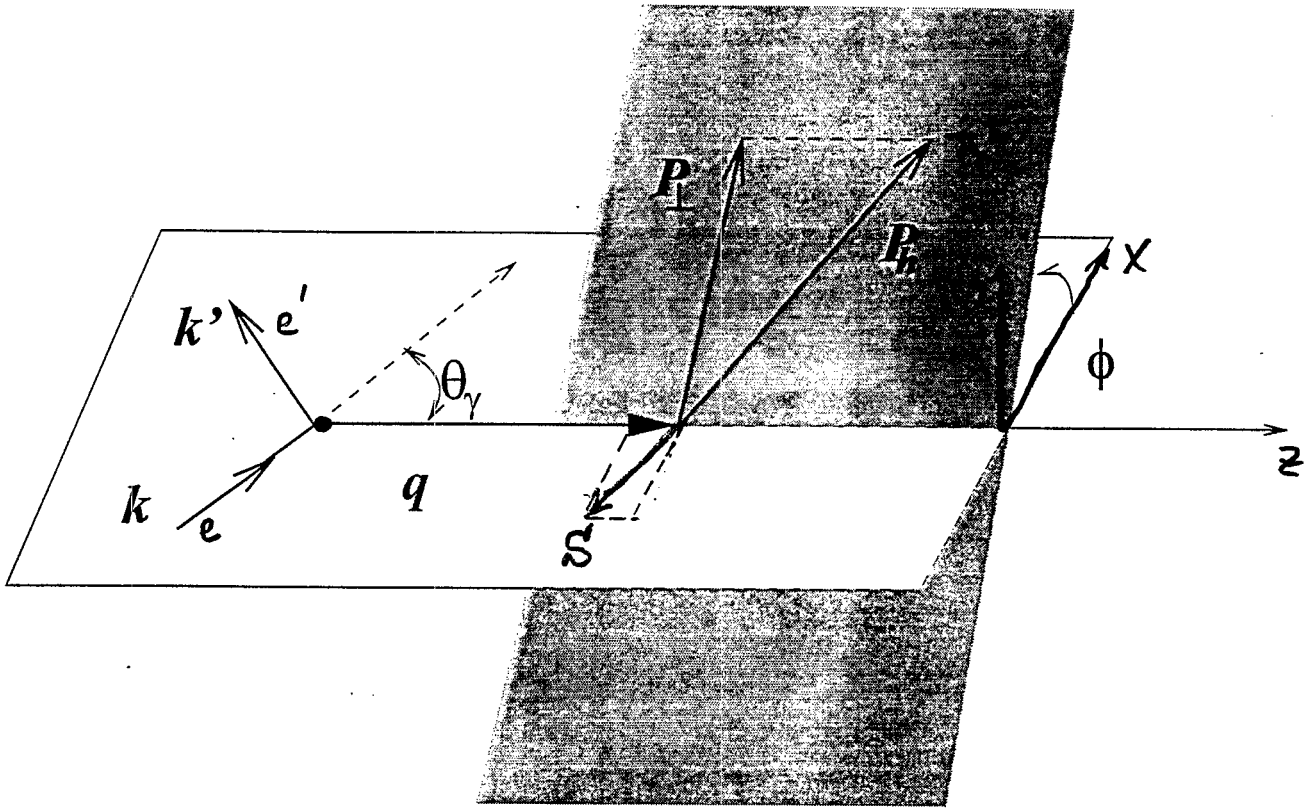
$$A_{UT}^{\sin\phi} \propto \underline{(-1)} \sin\theta_\gamma \frac{\Sigma_a e_a^2 h_1^a(x)\langle H_1^{\perp a/\pi}(z)\rangle}{\Sigma_a e_a^2 f_1^a(x)\langle D_1^{a/\pi}(z)\rangle}$$

with $\sin\theta_\gamma \approx \sqrt{\frac{4M_N^2 x(1-y)}{sy}} \approx \frac{2M_N x}{Q}\sqrt{1-y}$

$$\boxed{A_L^{\sin\phi} = A_{UL}^{\sin\phi} + A_{UT}^{\sin\phi}}$$

H. Avakian (DIS-99)
HERMES

SIDIS Kinematics



Variables are defined as:

$x = Q^2/2P \cdot q,$

$y = P \cdot q/P \cdot k,$

$z = P \cdot P_h/P \cdot q$

$P_\perp$ (hadron transverse momentum)

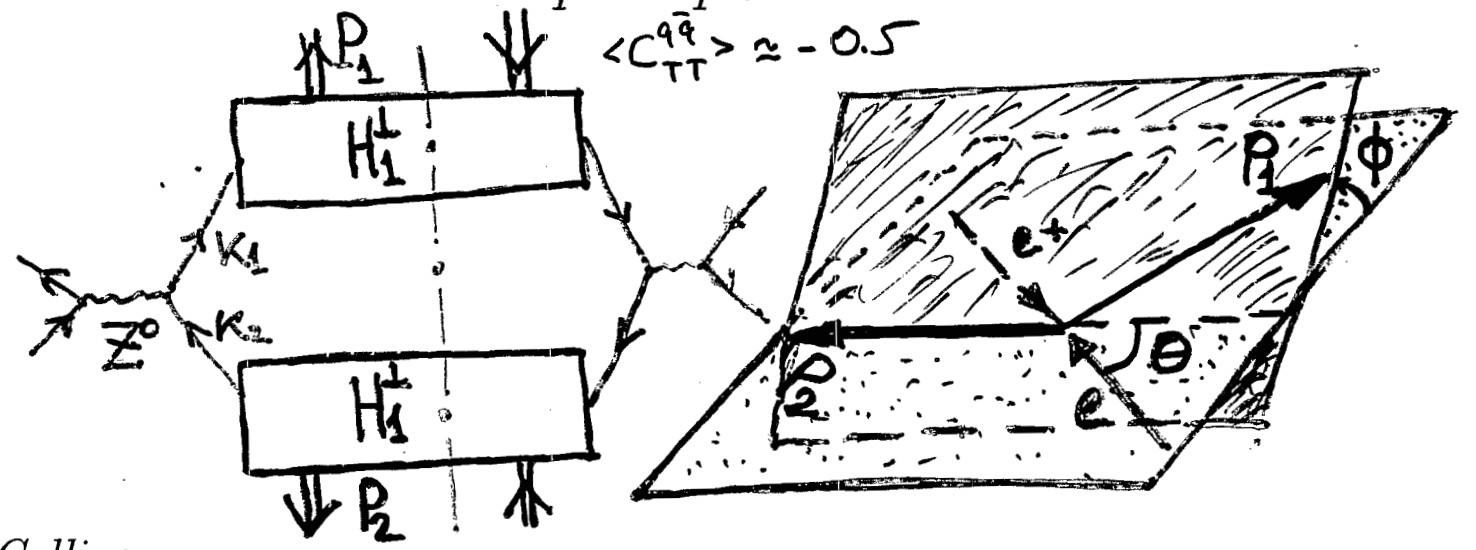
ϕ (azimuthal angle).

$W^2 = 2M\nu + M^2 - Q^2$

$H_1^\perp$ from $e^+e^- \to$ 2-jets

DELPHI (and other LEP experiments) allows to measure $H_1^\perp(z)$. Non zero transversal spin correlation

$$C_{TT}^{q\bar{q}} = \frac{v_q^2 - a_q^2}{v_q^2 + a_q^2} \begin{cases} -0.74 & \text{for up quarks} \\ -0.35 & \text{for down quarks} \end{cases}$$



Collins *NPB396(93);* *Kotzinian* *NPB441(95);* *Artru, Collins* *ZPC69(96);* *Mulders, Boer, Jakob,* *PLB424(98).*

Azimuthal correlation of two opposite jet hadrons ("Collins asymmetry")

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta_2 \mathrm{d}\phi_1} \propto (1+\cos^2\theta) \cdot \left(1 + \frac{6}{\pi}\left[\frac{H_1^{\perp q}}{D_1^q}\right]^2 C_{TT}^{q\bar{q}} \frac{\sin^2\theta}{1+\cos^2\theta}\cos(2\phi)\right)$$

$H_1^\perp$ for 91–95 DELPHI-data

1. Select two-jets hadronic events ($\approx 3.5\,Mev$) (JADE, $y = 0.01$ to 0.08, $T \geq 0.95$)
2. Leading charged particles in each jet,

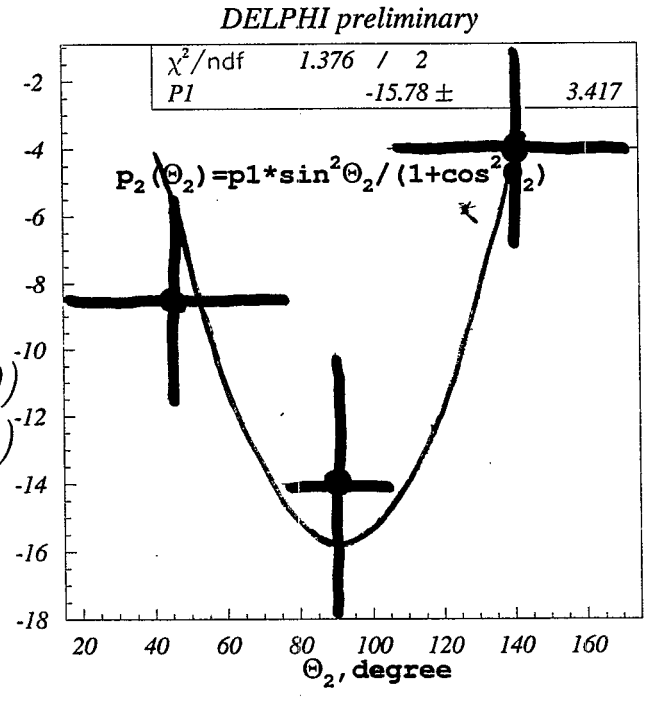
$$15^\circ < \theta < 165^\circ$$

3. Correction factor $f_{corr} = \frac{\sigma_{\rm JETSET}}{\sigma_{\rm MC}}(\theta, \phi)$
4. Fit corrected ϕ-histograms by Expr.

$$P_1(1 + P_2 \cos 2\phi + P_3 \cos \phi)$$

($\cos\phi$ is due to trivial p_T-dependence of usual fragmentation)

*A.E., Smirnova, Tkatchev NP**74,79**(99) (Proc.Suppl.)*



"Optimistic" value

$$\boxed{\left\langle \left| \frac{H_1^\perp}{D_1} \right| \right\rangle = 12.5 \pm 1.4\%}$$

More reliable value

(in the interval

$45^\circ > \theta > 135^\circ$)

$\left\langle \left| \frac{H_1^\perp}{D_1} \right| \right\rangle = 6.3 \pm 1.9\%$

Approximations and model

Disregarding interaction dependent twist-3 corrections $\widetilde{H}$ or $\widetilde{h}_L$ (WW-type approximation)

$$\int d^2p_T \left(\frac{p_T^2}{2M^2}\right) h_{1L}^{\perp}(x,p_T) \equiv h_{1L}^{\perp(1)}(x) =$$

$$= -(x/2)h_L(x) = -x^2 \int_x^1 d\xi h_1(\xi)/\xi^2$$

Assume favored PFF contributions, i.e.

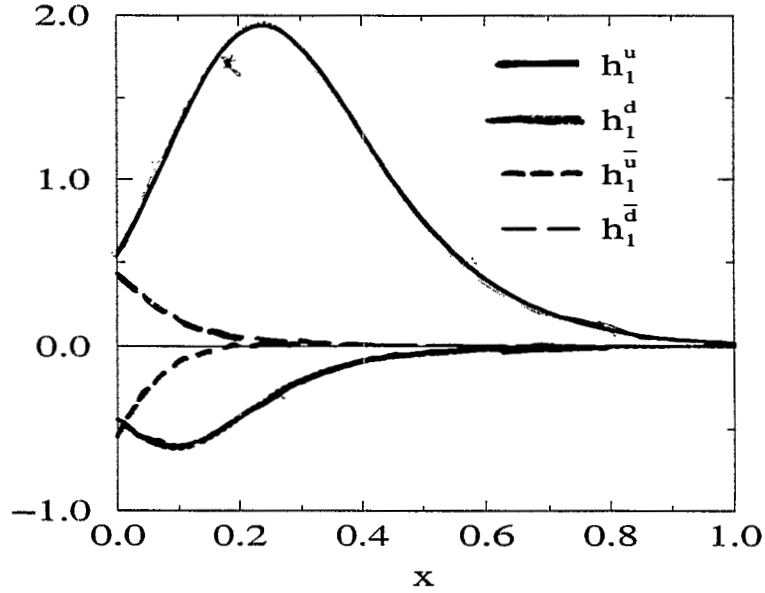
$$D_1^{u/\pi^+}(z) = D_1^{\bar{d}/\pi^+}(z) = D_1^{d/\pi^-}(z) = D_1^{\bar{u}/\pi^-}(z) \equiv D_1(z)$$

one could extract $[4h_1^u + h_1^{\bar{d}}](x)$ for π^+
or $[4(h_1^u + h_1^{\bar{u}}) + h_1^{\bar{d}} + h_1^{\bar{d}}](x)$ for π^0
to compare with a model.

Instead, we use chiral soliton model prediction for $h_1^a(x)$ and GRV parameterization for $f_1^a(x)$

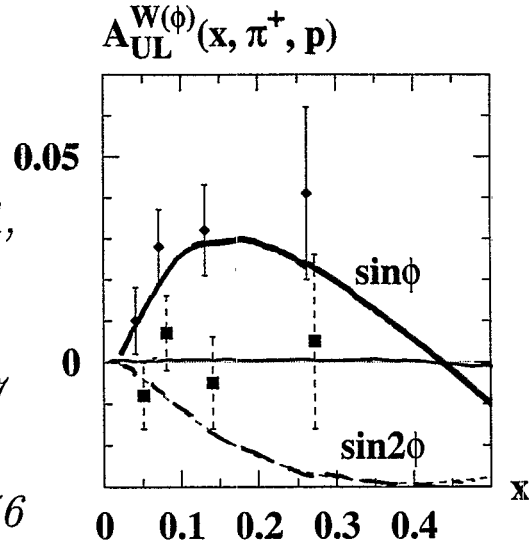
(Good ($\approx 20\%$) describes non-polarized and longitudinal spin PDF's. Satisfies all general QCD requirements.)

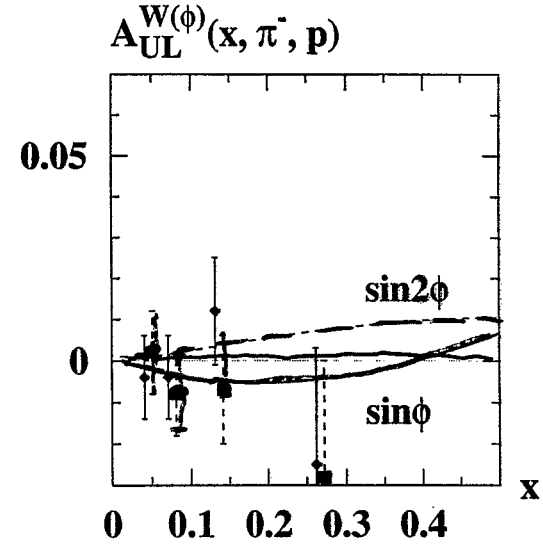
Pobylitsa, Polyakov at al, PLB389(96); Schweitzer at al. PRD64(01)



Results for proton target

A.E. at al.
PLB478(00)94,
A.E., Goeke, Schweitzer
PLB522(01)37
Erratum
hep/ph/0204056





With correct sign!

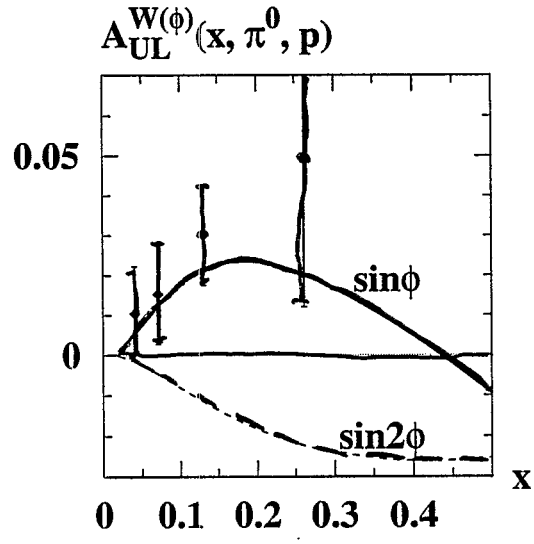
- Agreement with no fit parameters,
- Analyzing power $\frac{\langle H_1^\perp \rangle}{\langle D_1 \rangle}$ is positive,
- "Optimistic" value more preferable,
- The proton tensor charge at $Q^2 = 4\,GeV^2$

$$g_T \equiv \sum_a \int_0^1 dx (h_1^a(x) - h_1^{\bar{a}}(x)) = g_T = 0.6$$

(compare with recent experimental value of axial charge $a_0 = 0.28 \pm 0.05$).

! • $A_{UL}^{\sin\phi}$ should cross zero and change sign at $x \approx 0.4 - 0.5$. (Depends on Beam energy and acceptance)

COMPASS ?



Interesting to reverse the problem and determine $\frac{\langle H_1^\perp \rangle}{\langle D_1 \rangle}$ from π^+ and π^0, using the model h_1^q:

$$A_{UL}^{\sin\phi}(\pi^+) = 0.022 \pm 0.006 \rightarrow \frac{\langle H_1^\perp \rangle}{\langle D_1 \rangle} = (11.7 \pm 3.1)\%$$

$$A_{UL}^{\sin\phi}(\pi^0) = 0.019 \pm 0.008 \rightarrow \frac{\langle H_1^\perp \rangle}{\langle D_1 \rangle} = (14.3 \pm 5.5)\%$$

- Agrees with DELPHI, especially in view of $\approx 20\%$ model error.

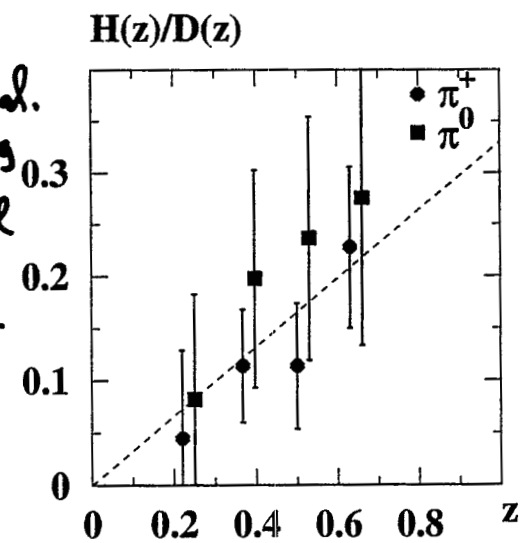
A.Bravar *NPB79(98)521*

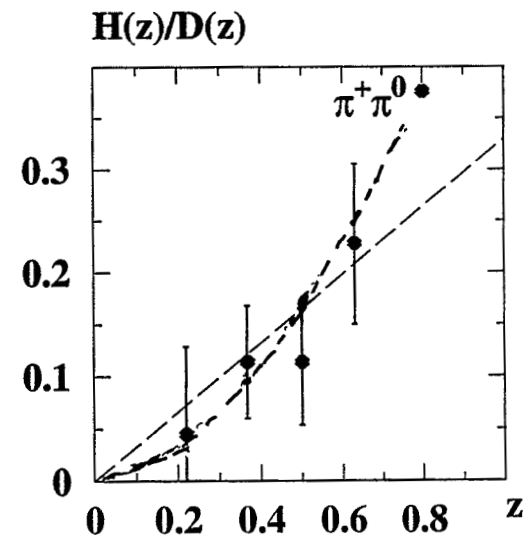
- SMC data gives $\frac{\langle H_1^\perp \rangle}{\langle D_1 \rangle} = -(10 \pm 5)\%$.
- A week scale dependence of the ratio is certified.

(!) More interesting is z-behaviour of $\frac{H_1^\perp(z)}{D_1(z)}$ from z-behaviour of experimental asymmetries

Bacchetta et al. hep-ph/0206309 chiral model

$\frac{H}{D} \simeq 0.63 z^2 + \cdots$

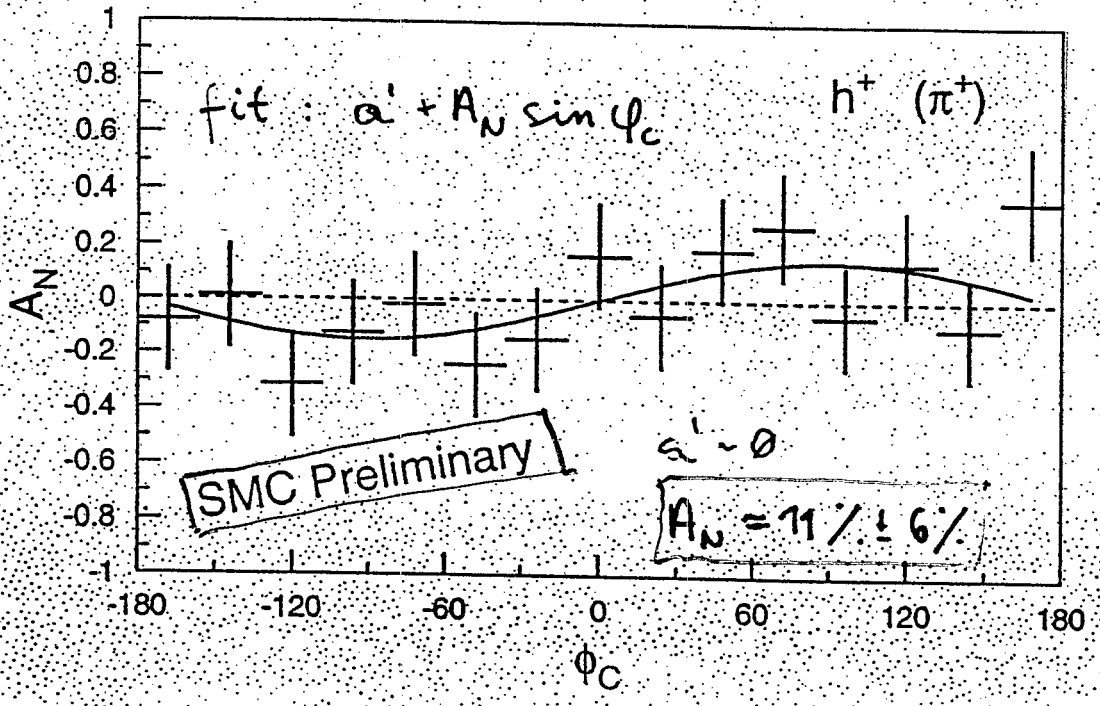


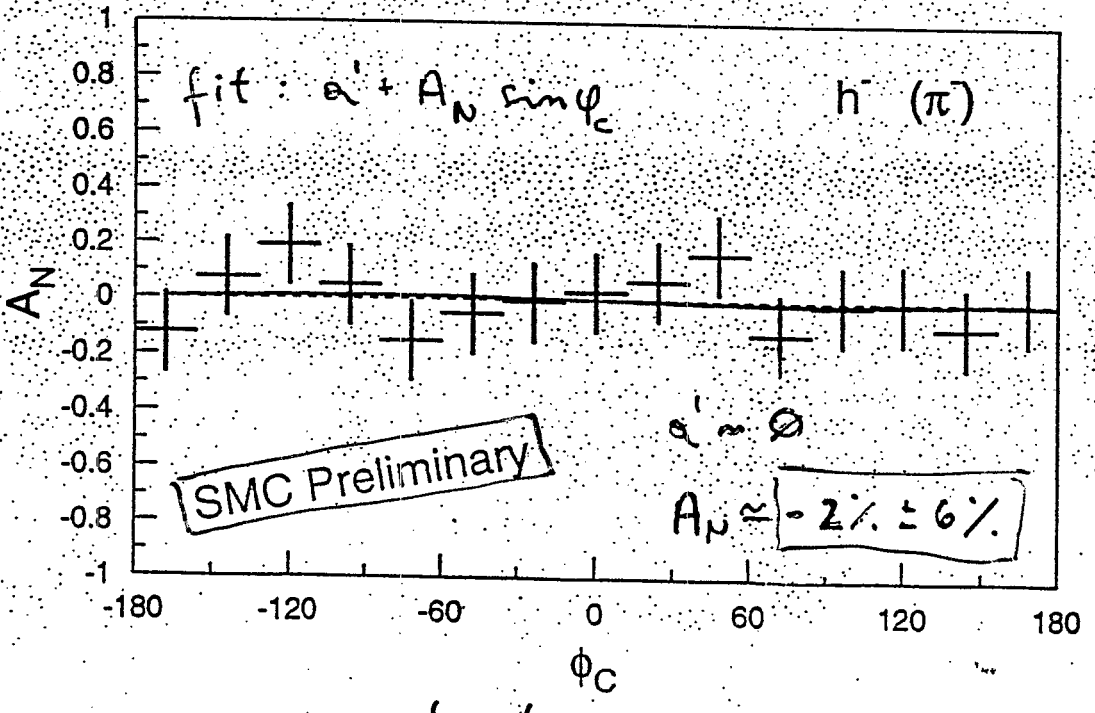


Best fit: $H_1^\perp(z) = (0.33 \pm 0.06) z\, D_1(z)$

SMC
S. Bravar
DIS-99

Azimuthal Hadron Distributions on $p \Uparrow$



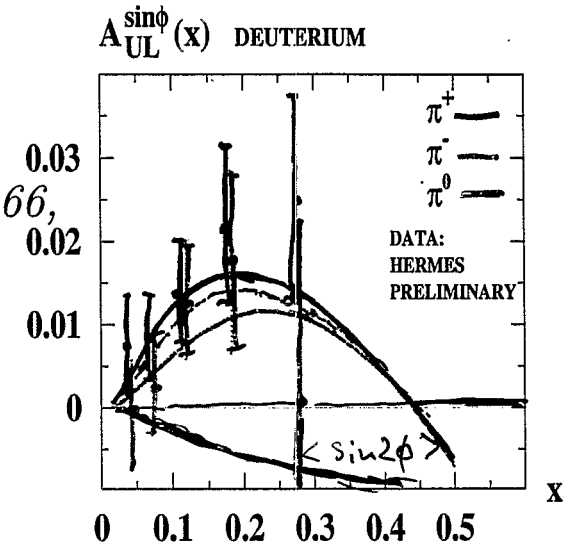


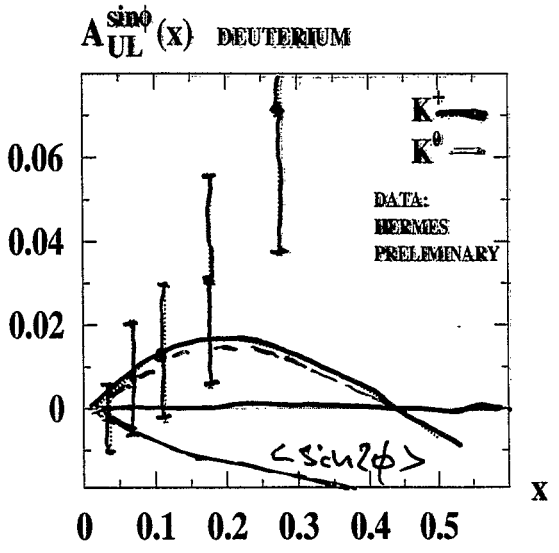
$$\phi_c = \phi_h + \phi_s - \pi$$

Predictions

for longitudinally polarized deuterium target

A.E., Goeke, Schweitzer, hep/ph/0112166, EPJ(2002)





- Almost same for all pion signs and roughly half of the proton's ones.
- "Data points" correspond to a preliminary data of HERMES for π^+, π^- and K^+.
- $\frac{\langle H_1^{\perp K}\rangle}{\langle D_1^K\rangle} \simeq \frac{\langle H_1^{\perp \pi}\rangle}{\langle D_1^\pi\rangle}$ is assumed;
- Close to zero for K^- and $\bar{K}^0$.
- $A_{UL}^{\sin\phi}$ should cross zero and change sign at $x \approx 0.4 \div 0.5$.

$e(x)$ from $A_{LU}^{\sin\phi}$ of CLAS

$$\vec{e} + P \to e' + \pi^+ + X$$

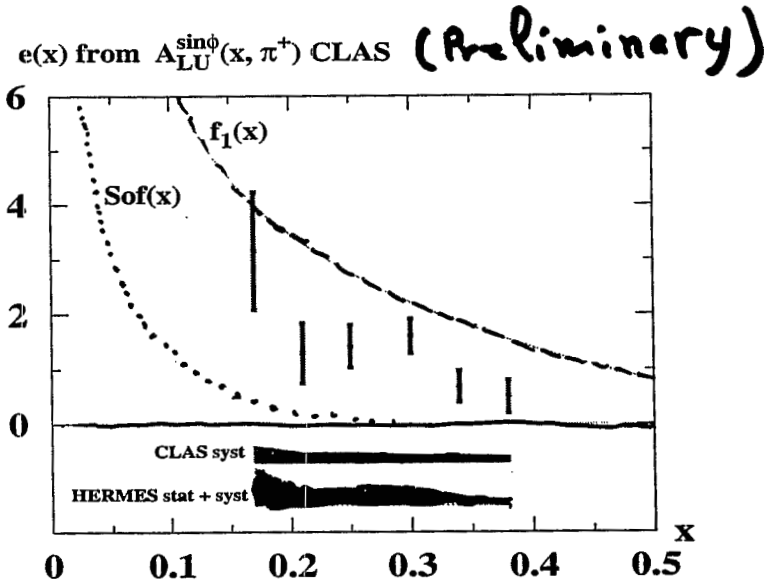
Avakian, JLab semin., Baryon2002

$$A_{LU}^{\sin\phi} \propto \frac{4M}{Q}\frac{y\sqrt{1-y}}{1+(1-y)^2} \cdot \frac{\Sigma_a e_a^2 e^a(x)\langle H_1^{\perp a/\pi}(z)\rangle}{\Sigma_a e_a^2 f_1^a(x)\langle D_1^{a/\pi}(z)\rangle}$$

Disregard unfavored fragmentations and antiquark contributions.

$$\frac{e^u(x)}{u(x)} \cdot \frac{\langle H_1^{\perp}(z)\rangle}{\langle D_1(z)\rangle}$$

Allow to extract $e^u(x)$



Soffer lower bound: $e^a(x) \geq 2|g_T^a(x)| - h_L^a(x)$

Compare with σ-term

$$\int_0^1 dx \sum_a e^a(x) = \frac{2\sigma}{m_u + m_d} \approx 10.$$

Burkardt, Koike, hep/ph/0111343.

Sharp rise at $x \to 0$ or/and $\delta(x)$-term?

Conclusions

1. Definite indications to T-odd PFF and proton transversity are now obtained.
2. The Collins analysing power $\frac{\langle H_1^\perp \rangle}{\langle D_1 \rangle} \approx 10\%$ and grows with z.
3. The proton transversity is order of nonpolarized valence PDF.
4. The proton transversity could be measured **simultaneously** with $\Delta G(x)$.
5. Further measurement of Collins asymmetry and nucleon transversity is necessary and planned (HERMES, COMPASS, RHIC).