Transversity distributions from difference asymmetries in semi-inclusive DIS

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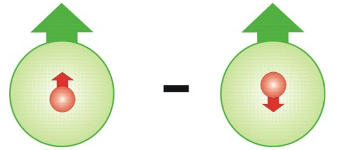
INFN Trieste

Transversity PDF h_1, $\Delta_T q$



- **correlation between the transverse spin of the nucleon and the transverse spin of quarks**
- **together with the number density f_1 and the helicity g_1 the three distributions fully describe the quark structure of the nucleon at LO in the collinear case**
- **proposed in '77** (Ralston & Soper)

- **different properties than helicity**
  - chiral-odd, cannot be measured in inclusive DIS
  - no contribution from the gluons
  - first moment: tensor charge (computed on the lattice)

- **first ideas on possible measurements in the 90s** (Collins, …)

- **first measurements in 2005** **(HERMES, COMPASS)**

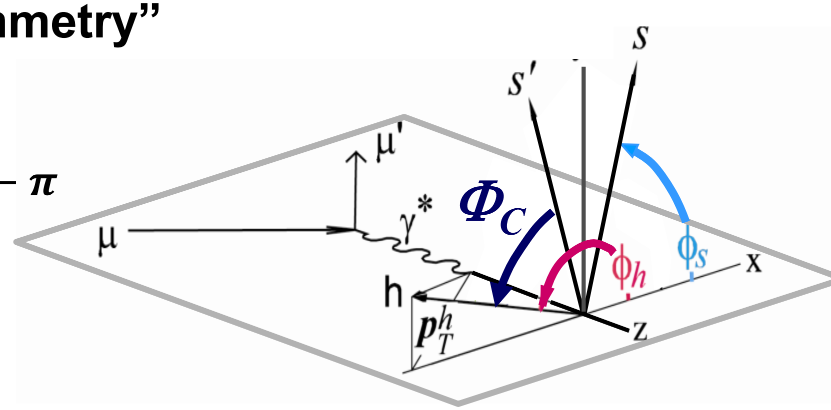
how has Transversity been measured

in SIDIS it shows up as the "Collins asymmetry"

amplitude of the $\sin\Phi_C$ modulation

in the azimuthal distribution
of the final state hadrons

$$\Phi_C = \phi_h + \phi_S - \pi$$



$$A_{Coll} \approx \frac{\sum_q e_q^2 \; h_1^q \otimes H_{1q}^{\perp}}{\sum_q e_q^2 \; f_1^q \otimes D_q}$$

the best way to access transversity

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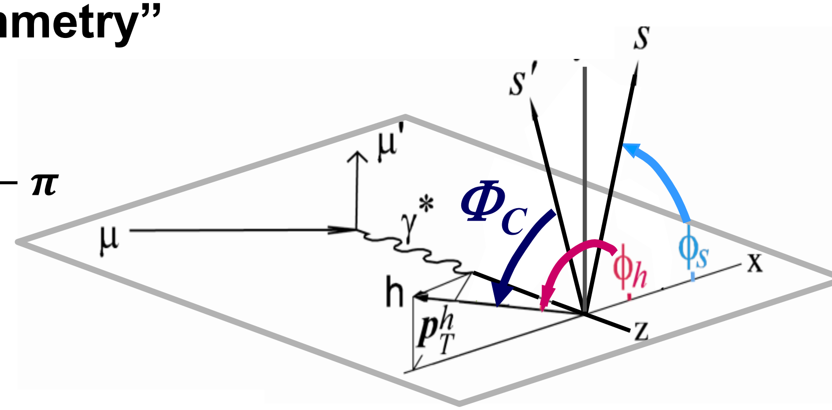


transversity

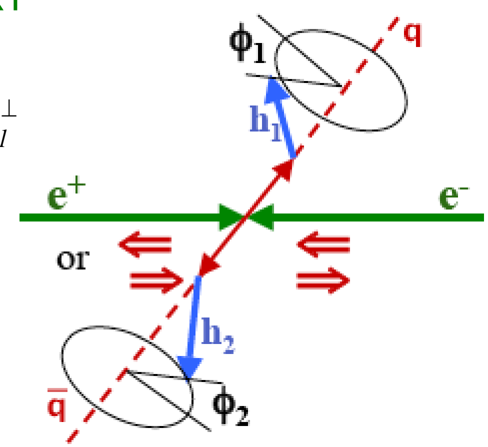
Collins FF, chiral odd

$$A_{Coll} \approx \frac{\sum_q e_q^2 \; h_1^q \otimes H_{1q}^{\perp}}{\sum_q e_q^2 \; f_1^q \otimes D_q}$$

left-right asymmetry of the hadrons in the hadronization
process of a transversely polarized quark
→ QUARK POLARIMETRY

assessed in
e^+e^- annihilation $\approx H_1^{\perp} \otimes H_1^{\perp}$

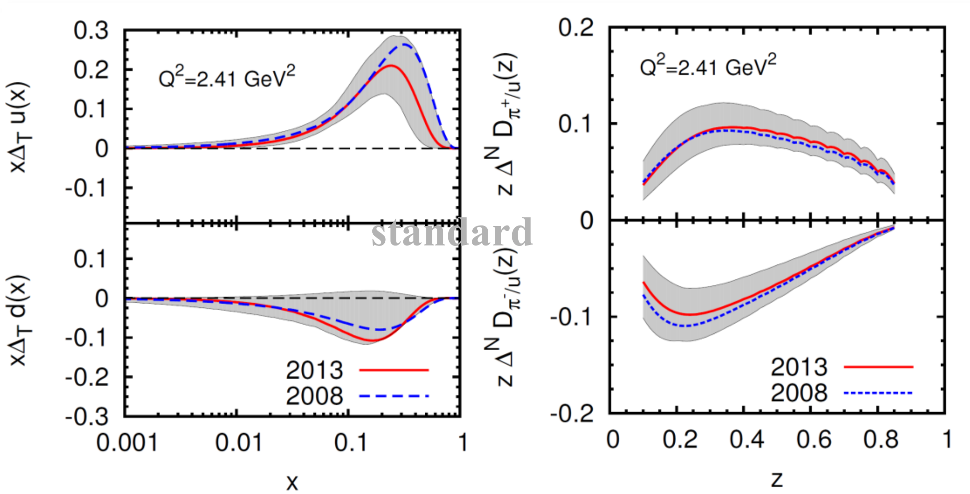
DATA from
Belle, BaBar, BESIII



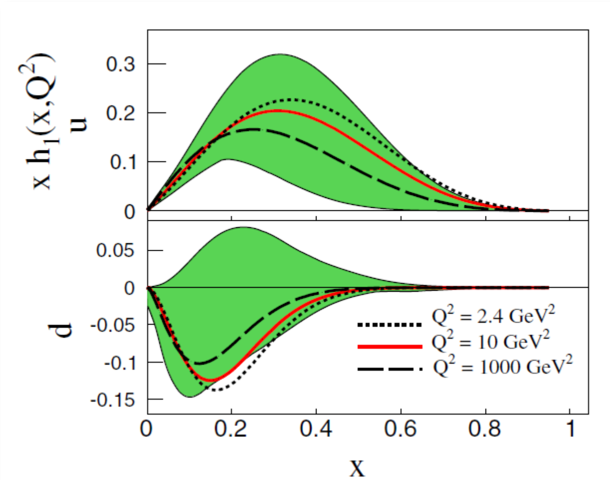
the best way to access transversity

Transversity from SIDIS Collins asymmetry

simultaneous fit of HERMES p, COMPASS p & d, and Belle data



Anselmino et al., PRD87 2013



Kang et al, PRD93 2016

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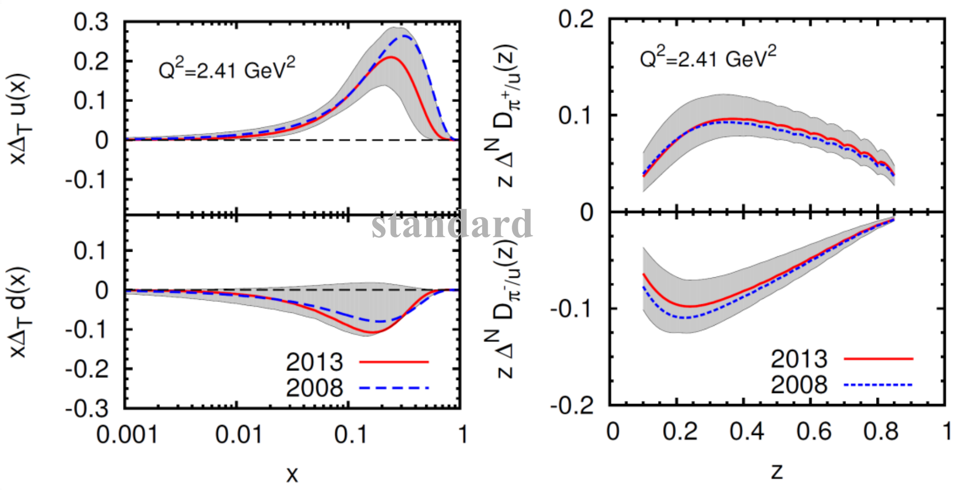

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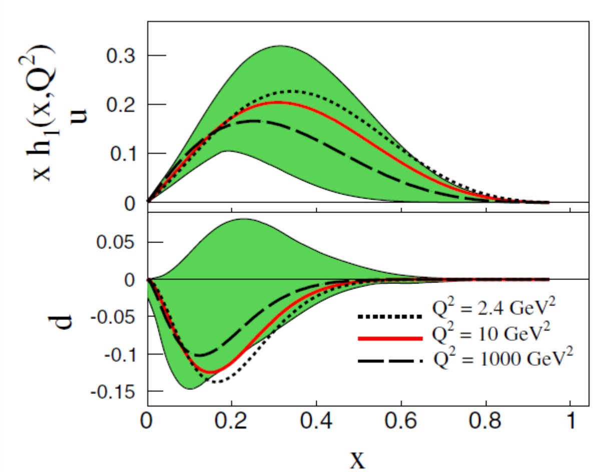
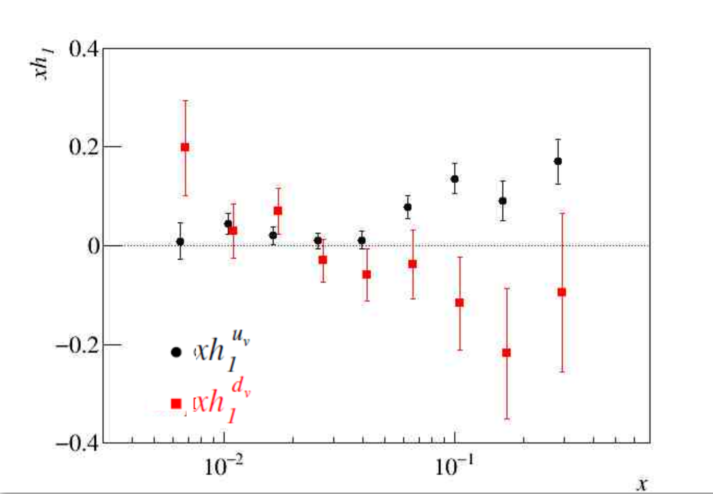


Kang et al, PRD93 2016

point by point extraction from COMPASS p & d, and Belle data

A. Martin, F.B., V. Barone PRD91 2015

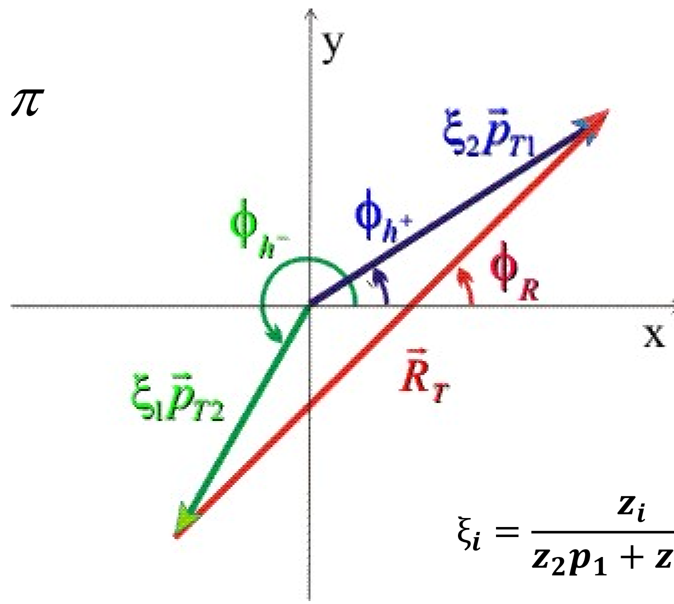


di-hadron asymmetry

an other way to access transversity
in SIDIS off transversely polarised nucleons

azimuthal asymmetry in $\Phi_{RS} = \phi_R + \phi_S - \pi$

$$N^{\pm}(\Phi_{RS}) = N^0 \cdot \{1 \pm P_T D \cdot A_{RS} \cdot \sin\Phi_{RS}\}$$



$$\xi_i = \frac{z_i}{z_2 p_1 + z_1 p_2}$$

"Interference / Di-hadron FF"

Belle Babar

$$A_{RS} \approx \frac{\sum_q e_q^2 \; h_1^q \cdot H_q^{\angle}}{\sum_q e_q^2 \; f_1^q \cdot D_q^{2h}}$$

"spin independent di-hadron FF"
being measured ...

collinear

used to extract transversity (Pavia group),
recently together with pp data

difference asymmetries

namely
the asymmetries in the difference of opposite charge hadrons distributions, have been proposed a long time ago

L.L. Frankfurt et al., PLB 230 141 (1989) 141
E. Christova and E. Leader, NPB 607 (2001) 369
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- they are in the COMPASS Proposal (1996), for SIDIS off longitudinally and transversely polarised protons and deuterons
- they have been measured in SIDIS off longitudinally polarised deuterons

M. Alekseev et al [COMAPSS Coll] PLB 660 (2008) 458

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first extraction from the COMPASS measurement of the Collins asymmetries in SIDIS off transversely polarised protons and deuterons

V. Barone, F. B., A. Bressan, A. Kerbizi, A. Martin, A. Moretti, J. Matousek and G. Sbrizzai,
``Transversity distributions from difference asymmetries in semi-inclusive DIS,''
arXiv:1902.08445 [hep-ph]

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main advantage:

they allow to avoid the use of FFs in the extraction of the PDFs

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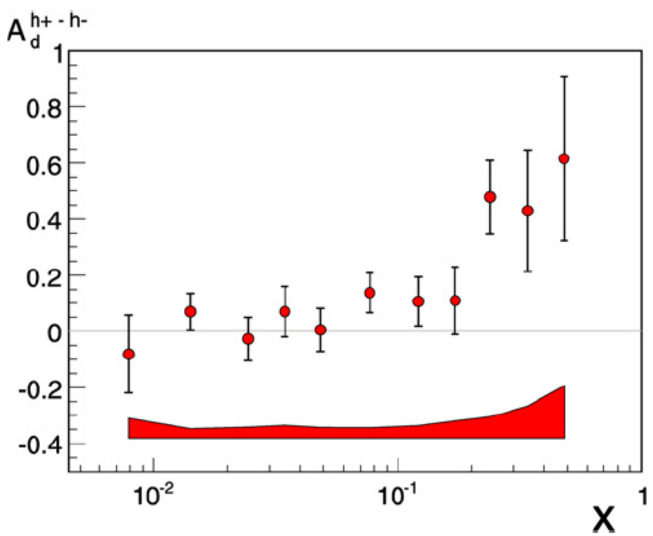
f.i., helicity from double longitudinal spin asymmetries on deuteron

$$A^h(x,z,Q^2) = \frac{\sum_q e_q^2 \Delta q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)}$$

$$A^{h^+-h^-} = \frac{(\sigma_{\uparrow\downarrow}^{h+} - \sigma_{\uparrow\downarrow}^{h-}) - (\sigma_{\uparrow\uparrow}^{h+} - \sigma_{\uparrow\uparrow}^{h-})}{(\sigma_{\uparrow\downarrow}^{h+} - \sigma_{\uparrow\downarrow}^{h-}) + (\sigma_{\uparrow\uparrow}^{h+} - \sigma_{\uparrow\uparrow}^{h-})} \approx \frac{\Delta u_v + \Delta d_v}{u_v + d_v}$$

COMAPSS PLB 660 (2008) 458



not so simple for transversity, still worthwhile

Collins asymmetries and difference asymmetries

notation:

cross-sections for hadrons (pions) of opposite charge
transversely polarised nucleons

$$\sigma_t^{\pm}(\Phi_C) = \sigma_{0,t}^{\pm} + f\, P_T\, D_{NN}\;\; \sigma_{C,t}^{\pm} \sin\Phi_C + \cdots$$

$$t = p, d$$

- Collins asymmetries $\quad A_{C,t}^{\pm} = \dfrac{\sigma_{C,t}^{\pm}}{\sigma_{0,t}^{\pm}}$

- difference asymmetries
  (two slightly different definitions) $\quad \boxed{A_{D,t} = \dfrac{\sigma_{C,t}^{+} - \sigma_{C,t}^{-}}{\sigma_{0,t}^{+} + \sigma_{0,t}^{-}}} \quad \boxed{A'_{D,t} = \dfrac{\sigma_{C,t}^{+} - \sigma_{C,t}^{-}}{\sigma_{0,t}^{+} - \sigma_{0,t}^{-}}}$

difference asymmetries

$$A_{D,t} = \frac{\sigma^{+}_{C,t} - \sigma^{-}_{C,t}}{\sigma^{+}_{0,t} + \sigma^{-}_{0,t}}$$

$$A'_{D,t} = \frac{\sigma^{+}_{C,t} - \sigma^{-}_{C,t}}{\sigma^{+}_{0,t} - \sigma^{-}_{0,t}}$$

Gaussian Ansatz

in terms of PDFs and FFs one has:

$$\sigma^{\pm}_{0,t} \sim \Sigma_{q\bar{q}}\ e_q^2\ x f_1^q\ D^{\pm}_{1,q} \qquad \sigma^{\pm}_{C,t} \sim \Sigma_{q\bar{q}}\ e_q^2 x h_1^q\ H^{\pm}_{1,q}$$

$$H^{\pm}_{1,q} = H^{\perp\,(1/2)\pm}_{1,q}(z, Q^2) \stackrel{\text{def}}{=} \int d^2\vec{p}_T \frac{p_T}{zM_h} H^{\perp\pm}_{1,q}(z, Q^2)$$

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introducing the favored and unfavored unpolarised FFs $D_{1,F}$ and $D_{1,U}$, and $D_{1,s} = D^{\pm}_{1,s} = D^{\pm}_{1,\bar{s}}$

$$\sigma^+_{0,p} \sim\ x\,\{\left(4f_1^u + f_1^{\bar{d}}\right)D_{1,F} + \left(4f_1^{\bar{u}} + f_1^d\right)D_{1,U} + \left(f_1^s + f_1^{\bar{s}}\right)D_{1,s}\}$$
$$\sigma^-_{0,p} \sim\ x\,\{\left(4f_1^u + f_1^{\bar{d}}\right)D_{1,U} + \left(4f_1^{\bar{u}} + f_1^d\right)D_{1,F} + \left(f_1^s + f_1^{\bar{s}}\right)D_{1,s}\}$$

$$\sigma^+_{0,p} - \sigma^-_{0,p} \sim\ x\left(4f_1^{u_v} - f_1^{d_v}\right)\left(D_{1,F} - D_{1,U}\right)$$

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$$\sigma^+_{0,d} - \sigma^-_{0,d} \sim\; 3\,x\left(f_1^{u_v} + f_1^{d_v}\right)\left(D_{1,F} - D_{1,U}\right)$$

and the favored and unfavored Collins FFs $H_{1,F}$ and $H_{1,U}$, and assuming $H_{1,s} = H_{1,s} = 0$

$$\sigma^+_{C,p} - \sigma^-_{C,p} \sim\; x\left(4h_1^{u_v} - h_1^{d_v}\right)\left(H_{1,F} - H_{1,U}\right)$$

$$\sigma^+_{0,d} - \sigma^-_{0,d} \sim\; 3\,x\left(h_1^{u_v} + h_1^{d_v}\right)\left(H_{1,F} - H_{1,U}\right)$$

$$A_{D,p} = \frac{1}{9}\frac{x\left(4h_1^{u_v} - h_1^{d_v}\right)\left(H_{1,F} - H_{1,U}\right)}{\sigma^+_{0,p} + \sigma^-_{0,p}}$$

$$A'_{D,p} = \frac{\left(4h_1^{u_v} - h_1^{d_v}\right)\left(H_{1,F} - H_{1,U}\right)}{\left(4f_1^{u_v} - f_1^{d_v}\right)\left(D_{1,F} - D_{1,U}\right)}$$

$$A_{D,d} = \frac{1}{3}\frac{x\left(h_1^{u_v} + h_1^{d_v}\right)\left(H_{1,F} - H_{1,U}\right)}{\sigma^+_{0,d} + \sigma^-_{0,d}}$$

$$A'_{D,d} = \frac{\left(h_1^{u_v} + h_1^{d_v}\right)\left(H_{1,F} - H_{1,U}\right)}{\left(f_1^{u_v} + f_1^{d_v}\right)\left(D_{1,F} - D_{1,U}\right)}$$

ratio of difference asymmetries

$$A_{D,p} = \frac{1}{9}\frac{x\left(4h_1^{u_v} - h_1^{d_v}\right)\left(H_{1,F} - H_{1,U}\right)}{\sigma_{0,p}^{+} + \sigma_{0,p}^{-}}$$

$$A'_{D,p} = \frac{\left(4h_1^{u_v} - h_1^{d_v}\right)\left(H_{1,F} - H_{1,U}\right)}{\left(4f_1^{u_v} - f_1^{d_v}\right)\left(D_{1,F} - D_{1,U}\right)}$$

$$A_{D,d} = \frac{1}{3}\frac{x\left(h_1^{u_v} + h_1^{d_v}\right)\left(H_{1,F} - H_{1,U}\right)}{\sigma_{0,d}^{+} + \sigma_{0,d}^{-}}$$

$$A'_{D,d} = \frac{\left(h_1^{u_v} + h_1^{d_v}\right)\left(H_{1,F} - H_{1,U}\right)}{\left(f_1^{u_v} + f_1^{d_v}\right)\left(D_{1,F} - D_{1,U}\right)}$$

ratio of difference asymmetries

$$A_{D,p} = \frac{1}{9}\frac{x\left(4h_1^{u_v} - h_1^{d_v}\right)\left(H_{1,F} - H_{1,U}\right)}{\sigma_{0,p}^{+} + \sigma_{0,p}^{-}}$$

$$A'_{D,p} = \frac{\left(4h_1^{u_v} - h_1^{d_v}\right)\left(H_{1,F} - H_{1,U}\right)}{\left(4f_1^{u_v} - f_1^{d_v}\right)\left(D_{1,F} - D_{1,U}\right)}$$

$$A_{D,d} = \frac{1}{3}\frac{x\left(h_1^{u_v} + h_1^{d_v}\right)\left(H_{1,F} - H_{1,U}\right)}{\sigma_{0,d}^{+} + \sigma_{0,d}^{-}}$$

$$A'_{D,d} = \frac{\left(h_1^{u_v} + h_1^{d_v}\right)\left(H_{1,F} - H_{1,U}\right)}{\left(f_1^{u_v} + f_1^{d_v}\right)\left(D_{1,F} - D_{1,U}\right)}$$

$$\boxed{\frac{A_{D,d}}{A_{D,p}} = 3\,\frac{\sigma_{0,p}^{+} + \sigma_{0,p}^{-}}{\sigma_{0,d}^{+} + \sigma_{0,d}^{-}}\,\frac{h_1^{u_v} + h_1^{d_v}}{4h_1^{u_v} - h_1^{d_v}}}$$

$$\boxed{\frac{A'_{D,d}}{A'_{D,p}} = \frac{4f_1^{u_v} - f_1^{d_v}}{f_1^{u_v} + f_1^{d_v}}\,\frac{h_1^{u_v} + h_1^{d_v}}{4h_1^{u_v} - h_1^{d_v}}}$$

from standard PDFs
and FFs parametrisations

CTEQ Collaboration, EPJC 2000
de Florian, Sassot Stratmann, PRD 2007

allow to extract $\frac{xh_1^{d_v}}{xh_1^{u_v}}$ **without knowing** H_1

difference asymmetries – how to measure them

$$\boldsymbol{A'_{D,t} = \frac{\sigma^+_{C,t} - \sigma^-_{C,t}}{\sigma^+_{0,t} - \sigma^-_{0,t}}}$$

in principle, one should measure them starting from

$$\sigma^D_t(\Phi_C) = (\sigma^+_{0,t} - \sigma^-_{0,t}) + f\ P_T\ D_{NN}\ (\sigma^+_{C,t} - \sigma^-_{C,t})\ sin\,\Phi_C \qquad t = p, d$$

if the acceptances for positively and negatively charged particles are not the same, one should correct the number of events for the acceptance before taking the differences, and treat carefully the statistical errors

if the $\boldsymbol{\Phi_C}$ acceptances for positively and negatively charged particles is the same, **the difference asymmetries can be extracted from the measured Collins asymmetries** in a simple way

we verified by Monte Carlo simulations that this is the case for the COMPASS data

thanks to the COMPASS Collaboration for allowing us to use the Monte Carlo simulation results

difference asymmetries – how to measure them

in fact, if the acceptances are the same, one can write

$$A_{D,t} = \frac{\sigma^+_{C,t} - \sigma^-_{C,t}}{\sigma^+_{0,t} + \sigma^-_{0,t}} = \frac{\sigma^+_{0,t}}{\sigma^+_{0,t} + \sigma^-_{0,t}} A^+_{C,t} - \frac{\sigma^-_{0,t}}{\sigma^+_{0,t} + \sigma^-_{0,t}} A^-_{C,t}$$

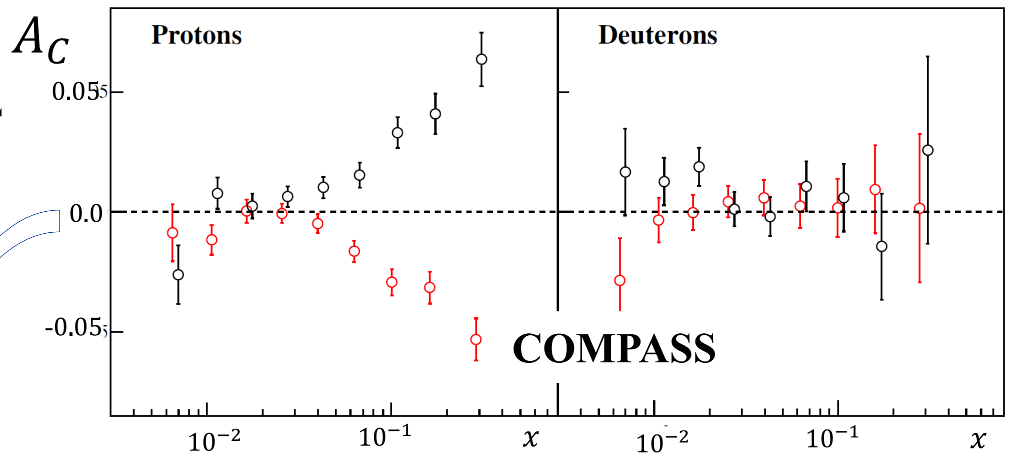
where $\sigma^{+}_{0,t} \sim N^{\pm}_{t} \sim 1/\mathrm{var}(A^{\pm}_{C,t})$

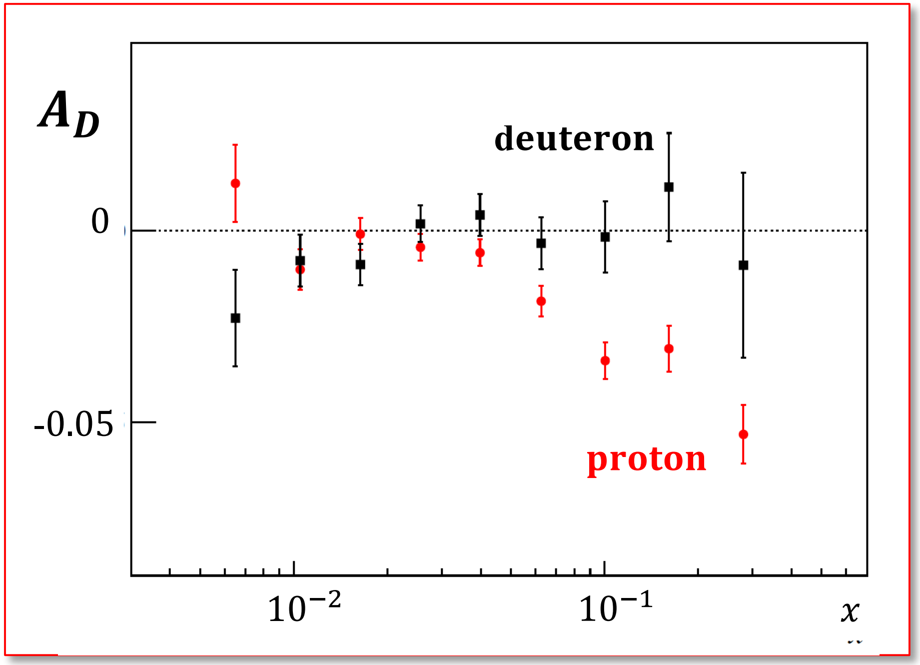
and

$$A_{D,t} = \frac{\mathrm{var}(A^-_{C,t})}{\mathrm{var}(A^+_{C,t}) + \mathrm{var}(A^+_{C,t})} A^+_{C,t} - \frac{\mathrm{var}(A^+_{C,t})}{\mathrm{var}(A^+_{C,t}) + \mathrm{var}(A^+_{C,t})} A^-_{C,t}$$

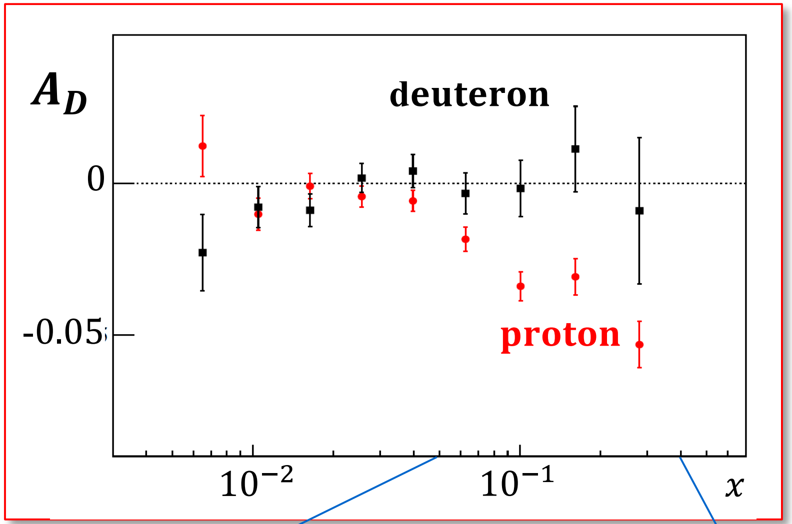
using only the published results

difference asymmetries – results

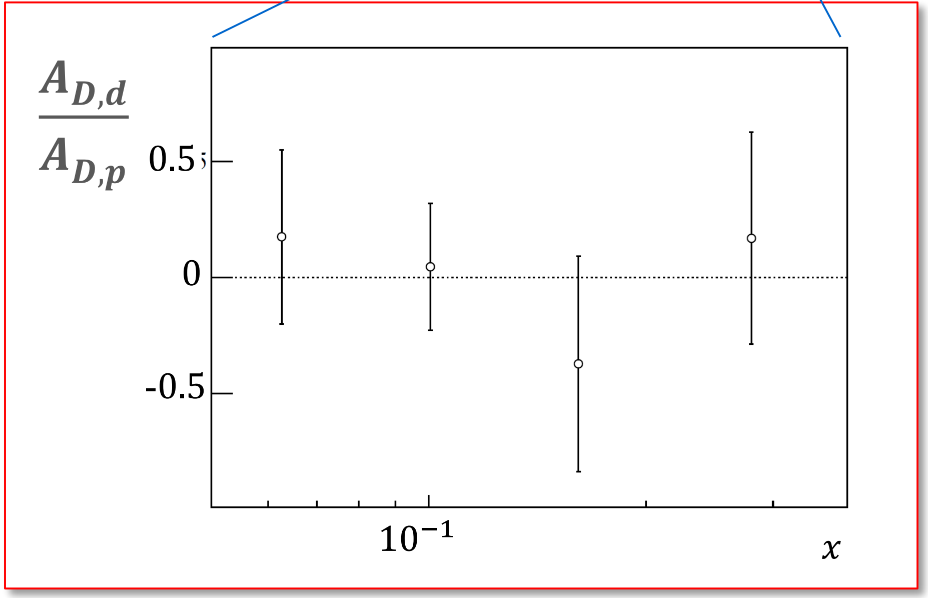




difference asymmetries – results



four highest x bins



same procedure for A'_D

difference asymmetries – results

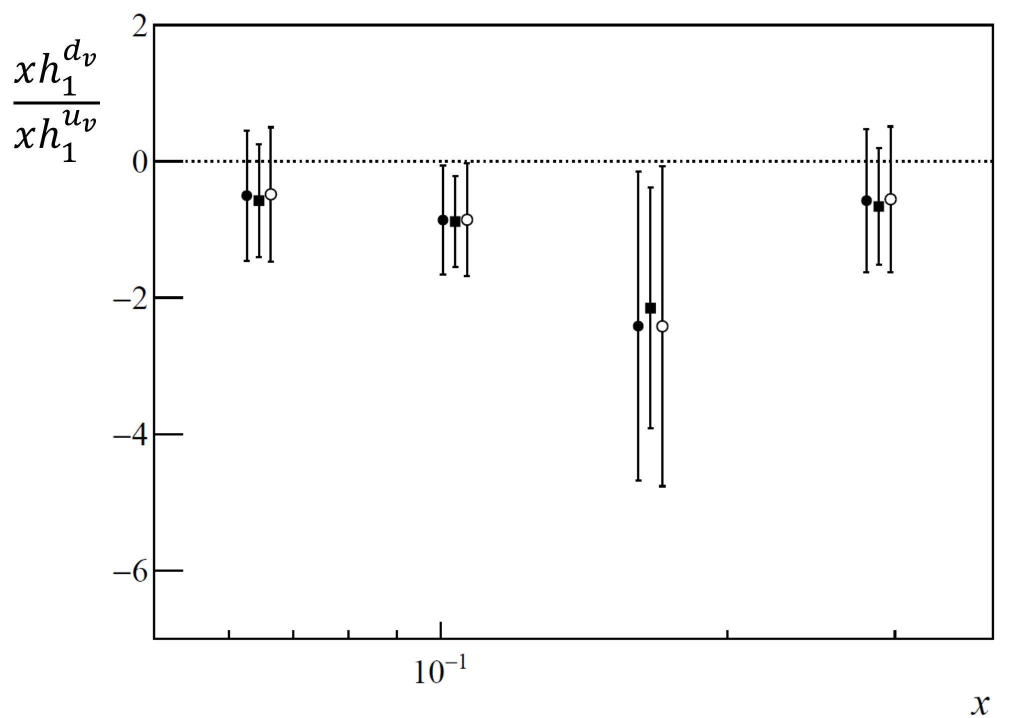
$$\frac{A_{D,d}}{A_{D,p}} = 3\,\frac{\sigma_{0,p}^{+} + \sigma_{0,p}^{-}}{\sigma_{0,d}^{+} + \sigma_{0,d}^{-}}\,\frac{h_1^{u_v} + h_1^{d_v}}{4h_1^{u_v} - h_1^{d_v}}$$

$$\frac{A'_{D,d}}{A'_{D,p}} = \frac{4f_1^{u_v} - f_1^{d_v}}{f_1^{u_v} + f_1^{d_v}}\,\frac{h_1^{u_v} + h_1^{d_v}}{4h_1^{u_v} - h_1^{d_v}}$$

$\rightarrow$ $\boxed{\frac{h_1^{d_v}}{h_1^{u_v}}}$

- ● from A_D
- ■ from A'_D
- ○ from $xh_1^{d_v}$ and $xh_1^{u_v}$

A. Martin, F.B., V. Barone
PRD91 2015



difference asymmetries

conclusions

the method we applied is interesting and simple, and does not require any knowledge of the Collins fragmentation functions

A_D and A'_D give $h_1^{d_v}$/ $h_1^{u_v}$ ratios essentially identical with ratios obtained from standard transversity extractions using SIDIS and e^+e^- data

ratios obtained from A'_D have slightly smaller errors

nice cross-check

everything is consistent