Transversity and Sivers function extraction from SIDIS COMPASS p and d data

Anna Martin

Trieste University and INFN

in collaboration with **V. Barone, F. Bradamante**

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INT Program 17-3 Workshop

“Hadron imaging at Jefferson Lab and at a future EIC”

Seattle, September 25 - 29, 2017

- the COMPASS experiment
- nucleon structure and TMDs
- extraction of transversity
- extraction of the Sivers function
- conclusions

COMPASS fixed target experiment at the CERN SPS

physics programme:

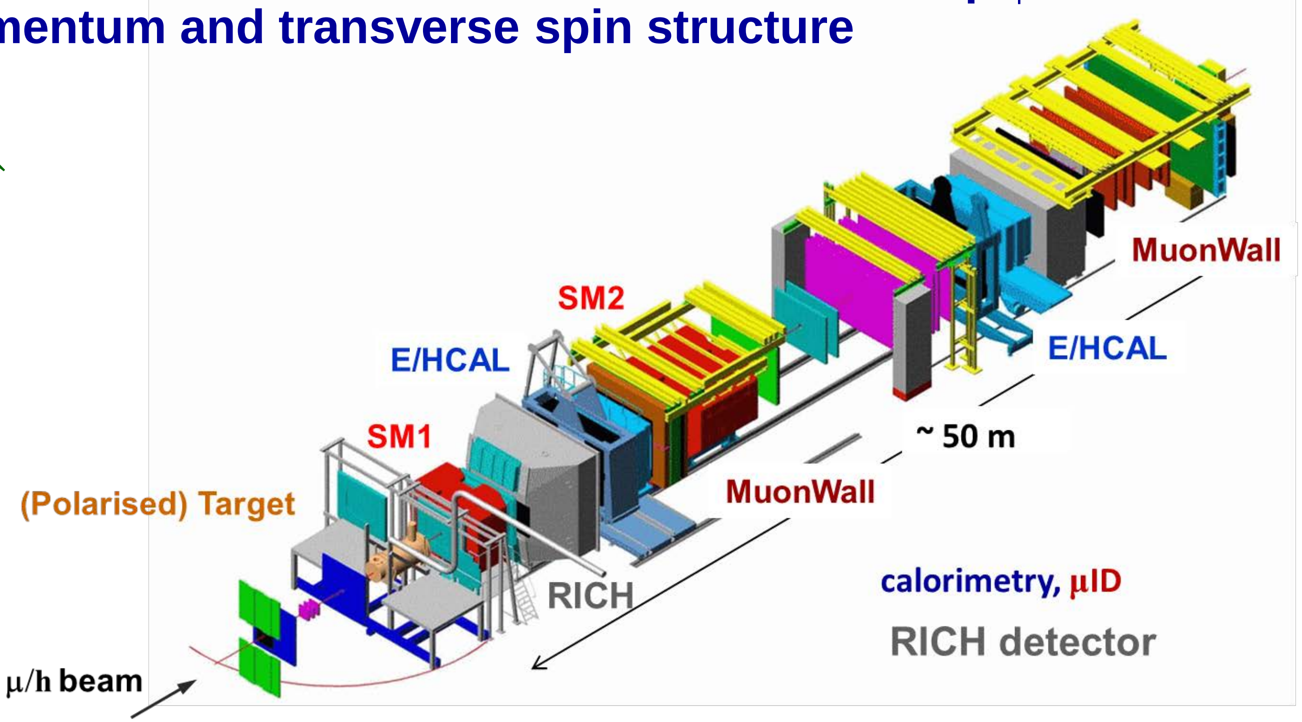
hadron spectroscopy (p, π, K)

- light mesons, glue-balls, exotic mesons
- polarisability of pion and kaon

nucleon structure (μ)

- longitudinal spin structure
- **transverse momentum and transverse spin structure**
- DVCS $\mu\, p$
- Drell-Yan $\pi^{-} p \uparrow$

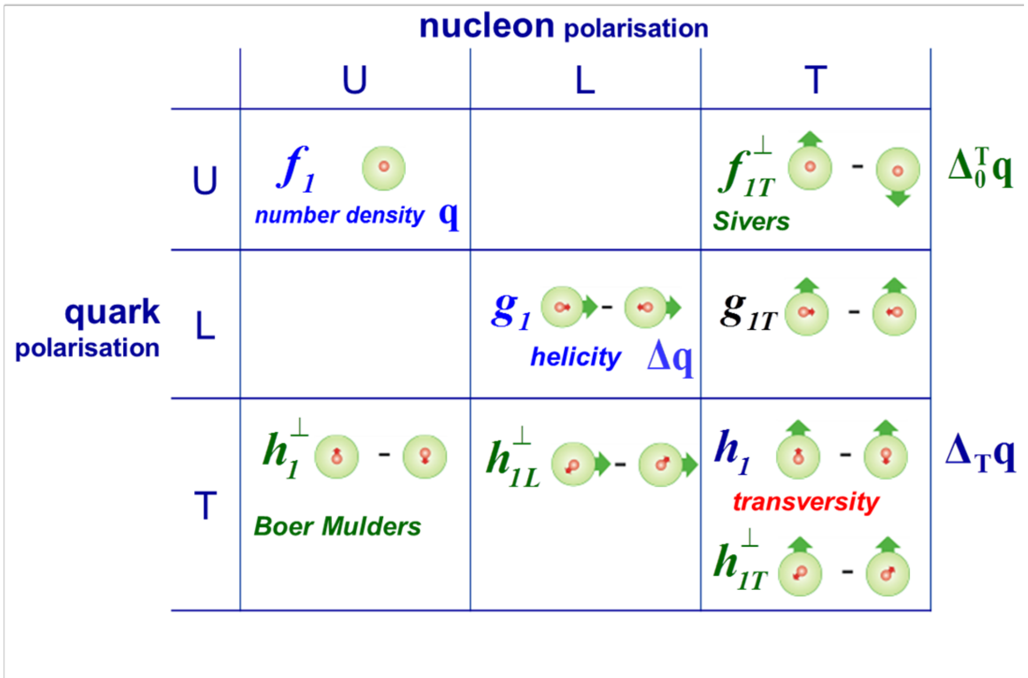
SIDIS off d & p ↑→



the structure of the nucleon

at leading order, 3 parton distribution functions (PDFs) are needed

in the **collinear case**



number density f_1^q

q, well known

helicity g_1^q

Δq, known

transversity h_1^q

$\Delta_T q$, new

as important as the previous ones

give access to the tensor charge

first experimental information in 2005

the structure of the nucleon

taking into account the quark **intrinsic transverse momentum** k_T

at leading order other new 5 TMD PDFs are needed for a full description of the nucleon structure

quark polarisation \ nucleon polarisation	U	L	T	
U	f_1 *number density* q		$f_{1T}^{\perp}$ *Sivers*	$\Delta_0^T q$
L		g_1 *helicity* Δq	g_{1T}	
T	$h_1^{\perp}$ *Boer Mulders*	$h_{1L}^{\perp}$	h_1 *transversity*; $h_{1T}^{\perp}$	$\Delta_T q$

all interesting

correlations among spins and transverse quark momentum

Sivers function $f_{1T}^{\perp q}$

correlation between nucleon transverse spin and quark transverse momentum

SIDIS gives access to all of them

by measuring the azimuthal asymmetries, i.e. the amplitudes of the different modulations in the azimuthal distributions of the final state hadrons

the use of different targets (proton and deuteron/neutron) and the identification of the final state hadrons allow for flavor separation

the structure of the nucleon

in SIDIS off transversely polarised nucleons the

transversity PDF h_1^q

Sivers function $f_{1T}^{\perp q}$

are responsible for the

Collins asymmetry

$$A_{Coll}^{h} = \frac{\sum_{q,\bar{q}} e_q^2 x \boldsymbol{h_1^q} \otimes H_{1q}^{\perp h}}{\sum_{q,\bar{q}} e_q^2 x f_1^q \otimes D_{1q}^{h}}$$

Sivers asymmetry

$$A_{Siv}^{h} = \frac{\sum_{q,\bar{q}} e_q^2 x \boldsymbol{f_{1T}^{\perp q}} \otimes D_{1q}^{h}}{\sum_{q,\bar{q}} e_q^2 x f_1^q \otimes D_{1q}^{h}}$$

di-hadron asymmetry

$$A^{hh} = \frac{\sum_{q,\bar{q}} e_q^2 x \boldsymbol{h_1^q} H_{1q}^{\angle}}{\sum_{q,\bar{q}} e_q^2 x f_1^q D_{1q}^{hh}}$$

the use of different targets (proton and deuteron/neutron) and the identification of the final state hadrons allow for flavor separation

transverse target spin effects at COMPASS

studied measuring SIDIS with

- **160 GeV muon beam**
- **a transversely polarised deuteron** $({}^6LiD)$ **target**
  (2002, 2003 and 2004, ~20% of running time)
- **a transversely polarised proton** (NH_3) **target**
  (2007, ~50%, and 2010, 100%, larger geometrical acceptance)

the spin asymmetries have been extracted using the same x, z, P_T^h binning

→ the mean values of x, Q^2 are almost the same for p and d in each x bin

results:

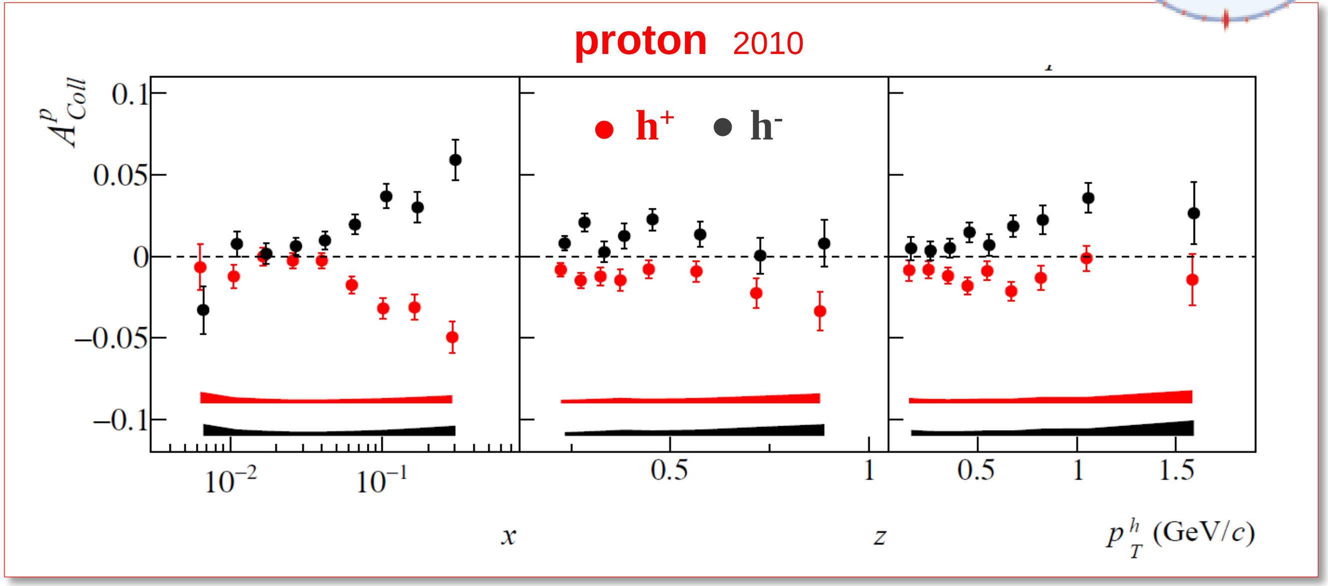
the Collins, the di-hadron asymmetries and the Sivers asymmetries are

- **different from zero on proton**, as seen by HERMES
- **compatible with zero on deuteron** within the large statistical errors

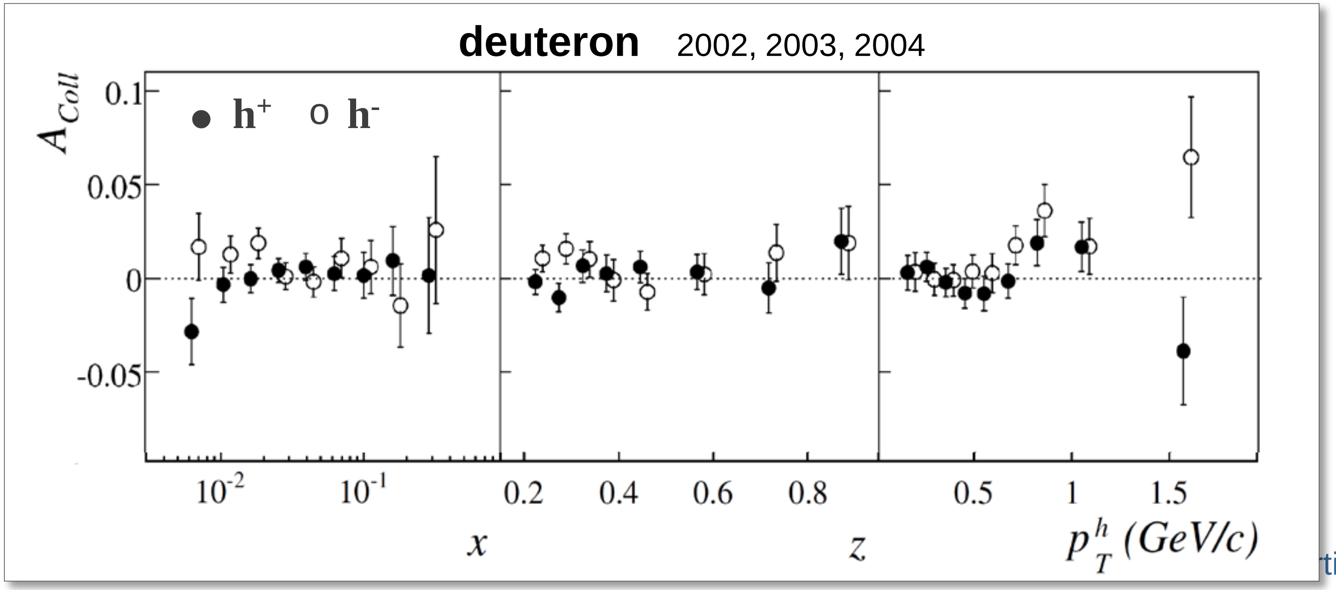
Collins asymmetry

$$A_{Coll}^{h} = \frac{\sum_{q,\bar{q}} e_q^2 x h_1^q \otimes H_{1q}^{\perp h}}{\sum_{q,\bar{q}} e_q^2 x f_1^q \otimes D_{1q}^{h}}$$

Phys. Lett. B 717 (2012) 376



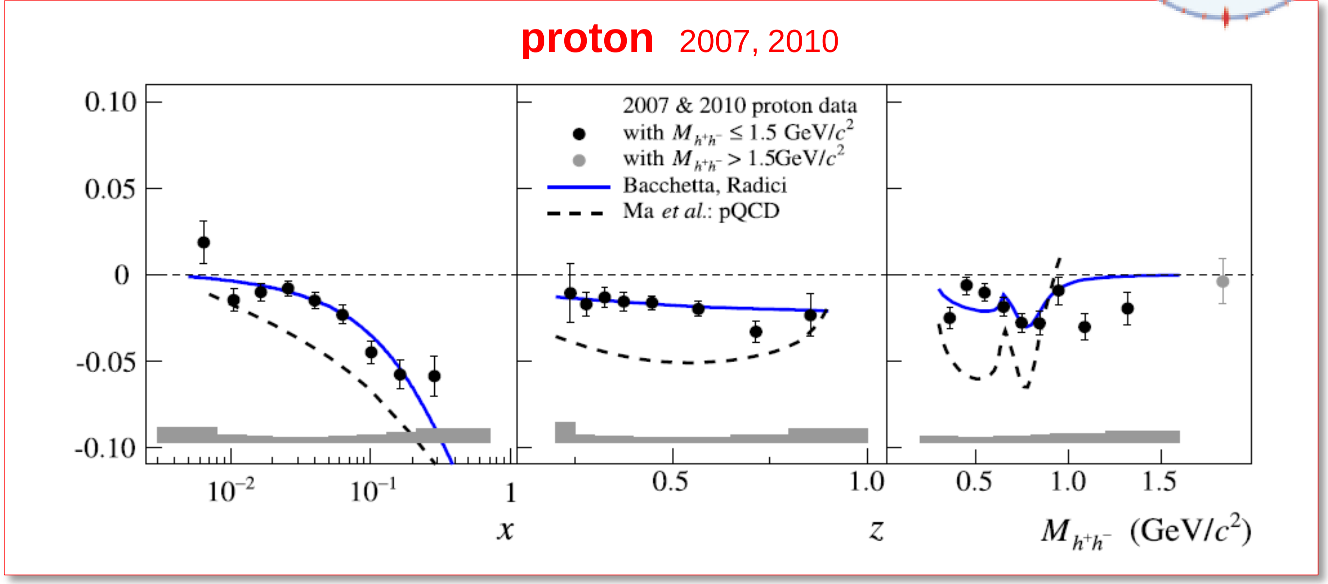
Nucl. Phys. B765 (2007) 31



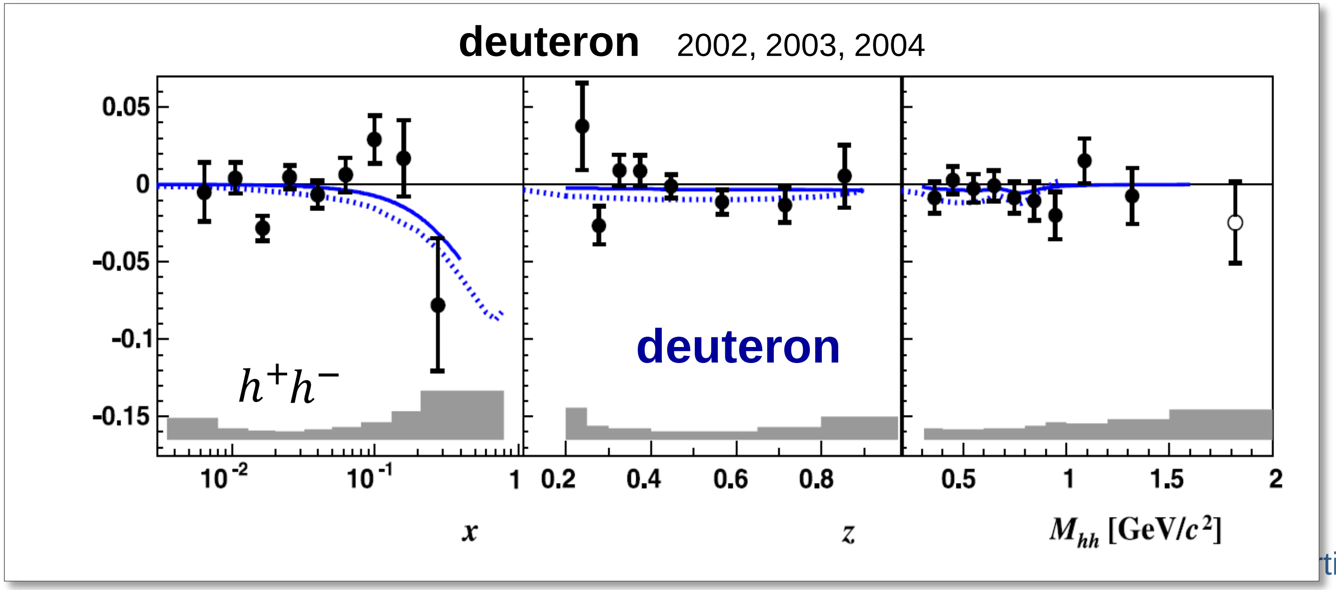
di-hadron asymmetry

$$A^{hh} = \frac{\sum_{q,\bar{q}} e_q^2 x h_1^q H_{1q}^{\angle}}{\sum_{q,\bar{q}} e_q^2 x f_1^q D_{1q}^{hh}}$$

Phys. Lett. B 736 (2014) 124



Phys. Lett. B 713 (2012) 10

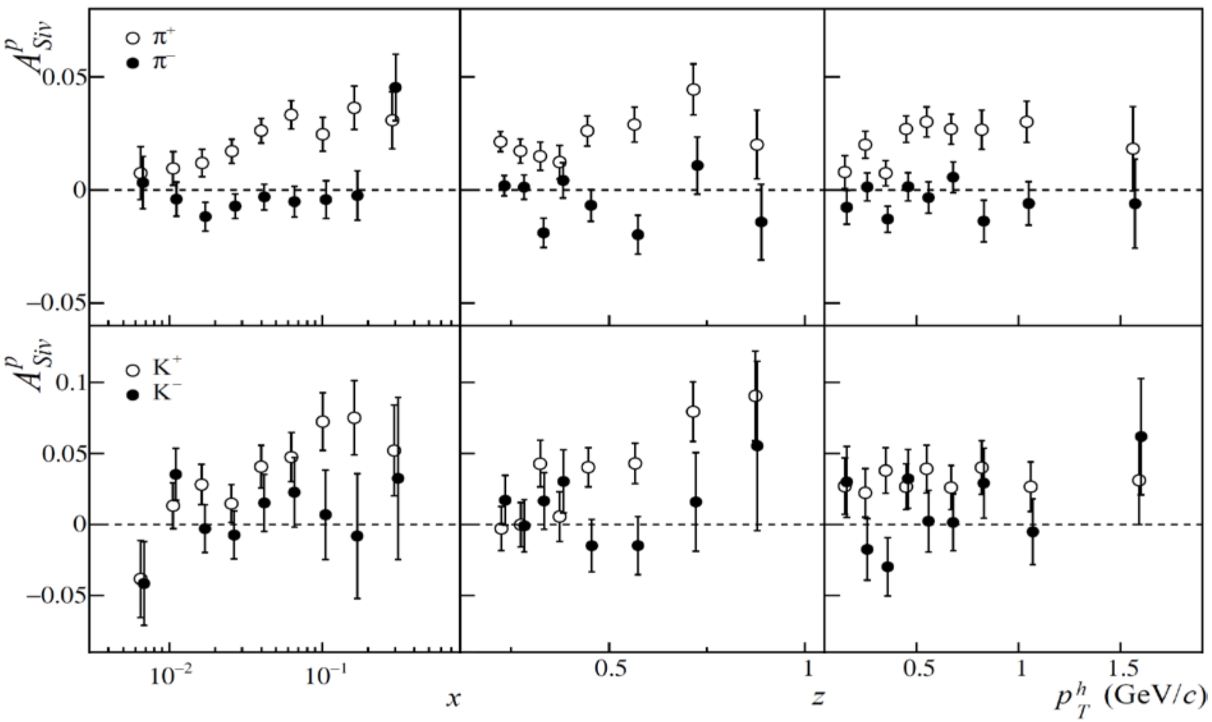


Sivers asymmetry

$$A^h_{Siv} = \frac{\sum_{q,\bar{q}} e_q^2 x f_{1T}^{\perp q} \otimes D_{1q}^h}{\sum_{q,\bar{q}} e_q^2 x f_1^q \otimes D_{1q}^h}$$

COMPASS

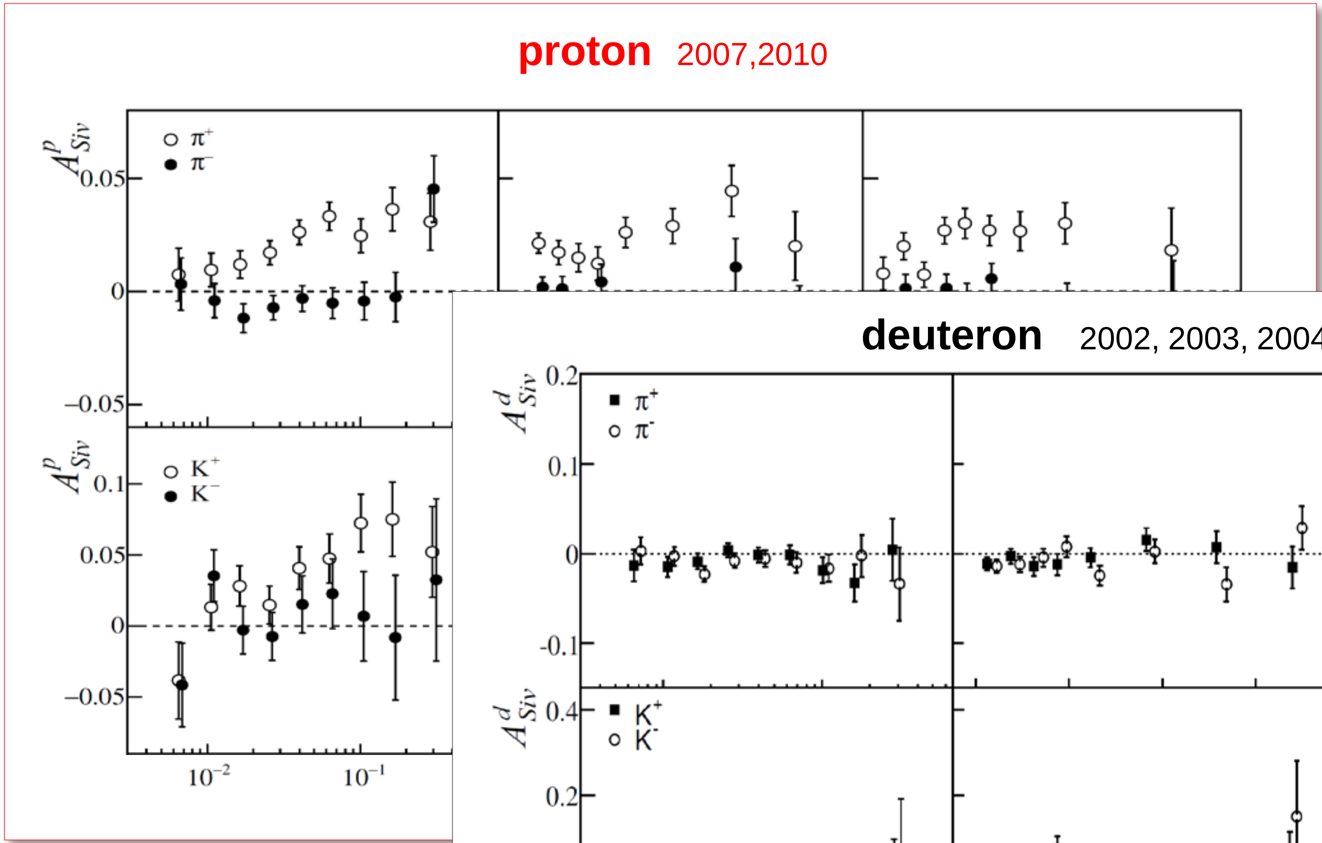
proton 2007,2010



Phys. Lett. B 744 (2015) 250

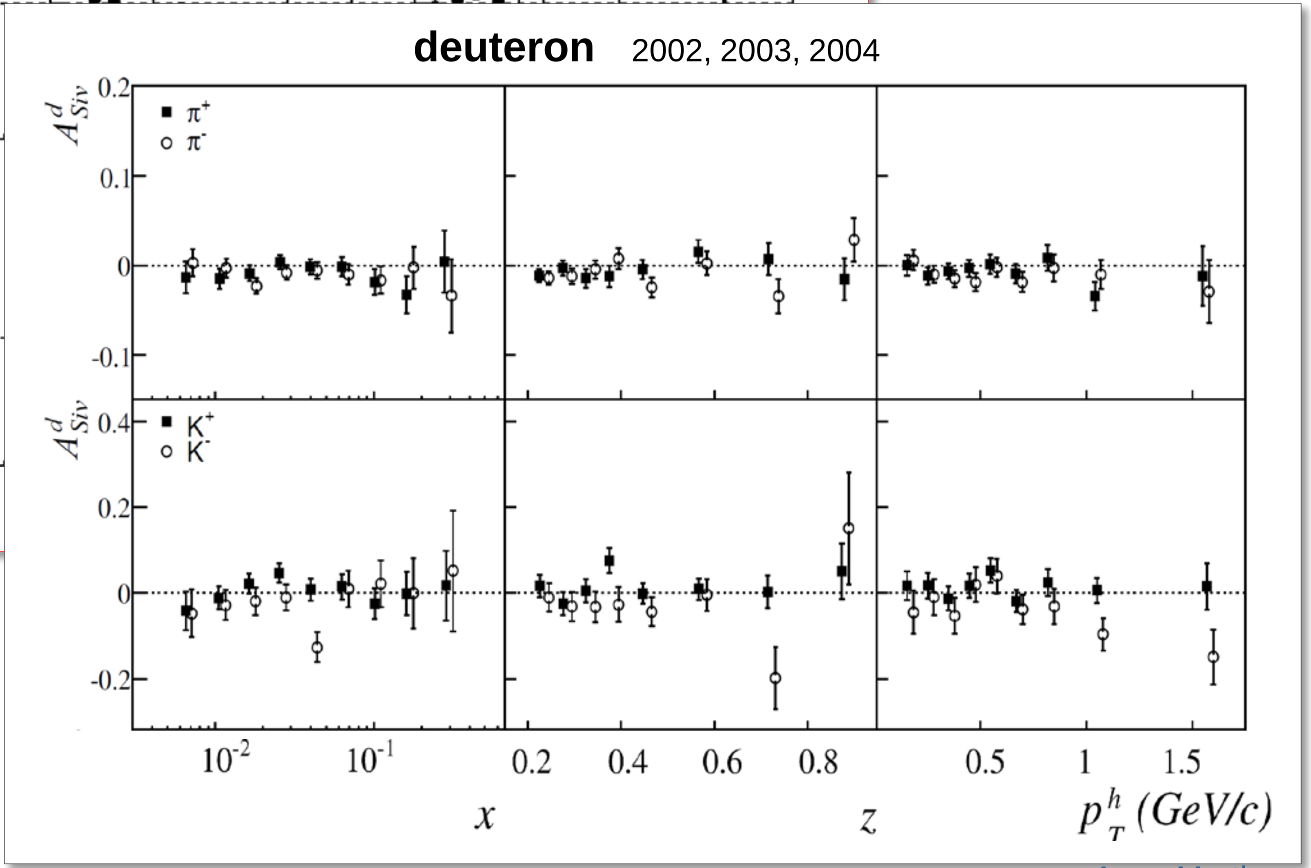
Sivers asymmetry

$$A_{Siv}^{h} = \frac{\sum_{q,\bar{q}} e_q^2 x f_{1T}^{\perp q} \otimes D_{1q}^{h}}{\sum_{q,\bar{q}} e_q^2 x f_1^{q} \otimes D_{1q}^{h}}$$



Phys. Lett. B 744 (2015) 250

Phys. Lett. B 673 (2009) 127



extraction of the Transversity and Sivers functions

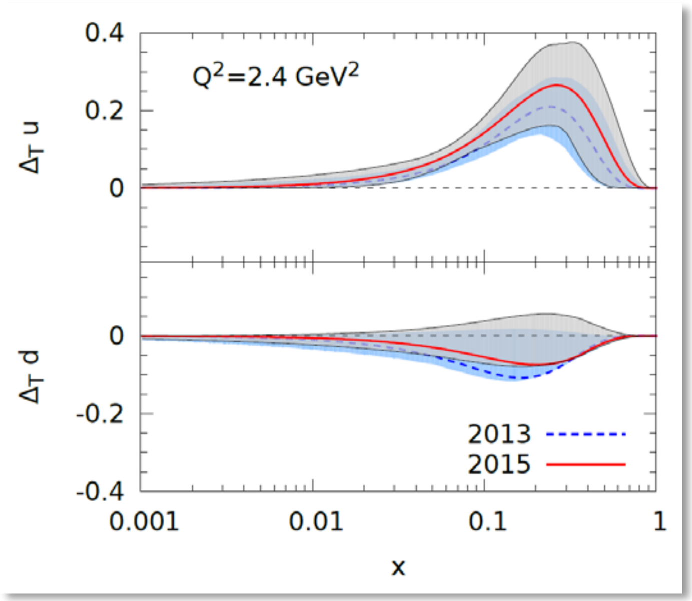
the COMPASS results already used to extract these PDFs

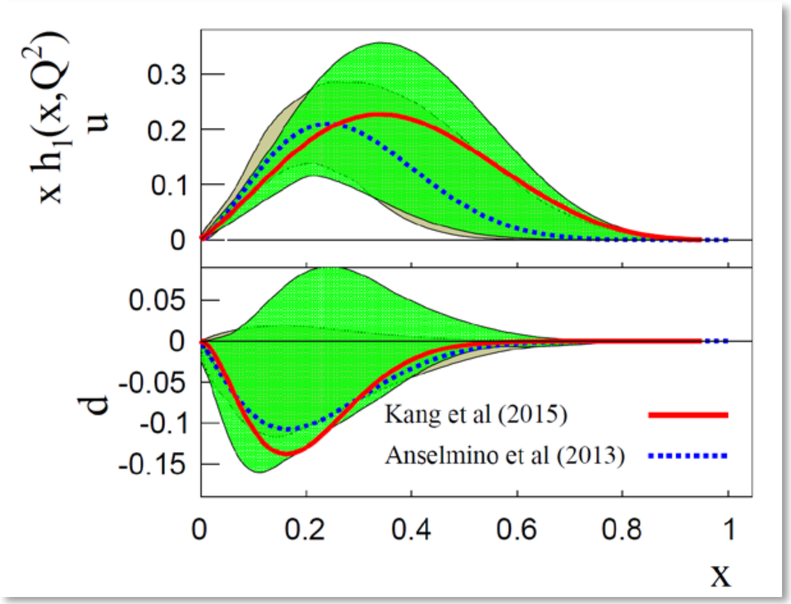
Transversity:

- **Collins asymmetries**

HERMES p, COMPASS p and d, Belle/Babar $e^+e^- \rightarrow hadrons$ data

Anselmino et al. 2013, 2015, Kang et al. 2015, …





using parametrisations for transverity and spin-dependent fragmentation functions

extraction of the Transversity and Sivers functions

the COMPASS results already used to extract these PDFs

Transversity:

- **Collins asymmetries**

HERMES p, COMPASS p and d, Belle/Babar $e^+e^- \rightarrow hadrons$ data

Anselmino et al. 2013, 2015, Kang et al. 2015, …

- **di-hadron asymmetries**

HERMES p, COMPASS p and d, Belle/Babar $e^+e^- \rightarrow hadrons$ data

Bacchetta et al. 2013, Radici et al. 2015, …

using parametrisations for transverity and spin-dependent fragmentation functions (x, z)

Sivers function:

- **Sivers asymmetries**

HERMES p, COMPASS p and d

Anselmino et al. 2012, Echevarria et al. 2014, …

using parametrisations for the Sivers functions (x)

extraction of the Transversity and Sivers functions

this work:

use the COMPASS proton and deuteron measurements at the same x, Q^2 values to perform a direct point-by-point extraction of the transversity and Sivers PDFs

Phys. Rev. D 91 (2015) 014034

- COMPASS results for
  - p and d Collins asymmetry vs x (integrated over z, p_T)
    h^+ and h^- assuming that all hadrons are pions
  - p and d di-hadron asymmetries vs x (integrated over z, M)
- Belle results for the corresponding pion and pion-pair asymmetries
  PRL 107(2011)072004, PRD78(2008)032011 / 86(2012)0399
- unpolarised PDFs and FFs parametrizations
  PDFs: CTEQ5D FFs: DSS LO

→ transversity

$h_1^{u_v}, h_1^{d_v}, h_1^{\bar{u}}, h_1^{\bar{d}}$

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- COMPASS results for
  - p and d Sivers asymmetries vs x (integrated over z, M)
    $\pi^\pm$ and $K^\pm$
- unpolarised PDFs and FFs parametrizations
  PDFs: CTEQ5D FFs: DSS LO

→ Sivers function

$f_{1T}^{\perp(1)\,u_v}, f_{1T}^{\perp(1)\,d_v}, f_{1T}^{\perp(1)\,\bar{u}} - f_{1T}^{\perp(1)\,\bar{d}}$

Transversity

Collins asymmetry – SIDIS

$$A^h(x,z) = \frac{\sum_{q,\bar{q}} e_q^2 x h_1^q(x) \otimes H_{1q}^{\perp h}(z)}{\sum_{q,\bar{q}} e_q^2 x f_1^q(x) \otimes D_{1q}^h(z)}$$

"gaussian ansatz":

$$A^h(x,z) = C_G \frac{\sum_{q\bar{q}} e_q^2 x h_1^q(x) H_{1q}^h(z)}{\sum_{q\bar{q}} e_q^2 x f_1^q(x) D_{1q}^h(z)}$$

Efremov et al., 2006

$$C_G = \frac{1}{\sqrt{1 + z^2 < k_{\perp h_1}^2 > / < p_{\perp H_1}^2 >}}$$

$$H_{1q}^h \equiv H_{1q}^{\perp(1/2)\,h} = \frac{\sqrt{\pi < p_T^2 >}}{2zM_h} H_{1q}^{\perp h}$$

we have assumed

- $C_G = 1$ most of the statistics at low z
- $H_{1u}^+ = H_{1d}^- = H_{1\bar{d}}^+ = H_{1\bar{u}}^- = H_{1\,fav}$ and $H_{1u}^- = H_{1d}^+ = H_{1\bar{d}}^- = H_{1\bar{u}}^+ = H_{1\,unf}$
- $H_{1s}^\pm = H_{1\bar{s}}^\pm = 0$ and c quark contributions to be negligible
- $D_{1u}^+ = D_{1d}^- = D_{1\bar{d}}^+ = D_{1\bar{u}}^- = D_{1\,fav}$ and

$$D_{1u}^- = D_{1d}^+ = D_{1\bar{d}}^- = D_{1\bar{u}}^+ = D_{1s}^\pm = D_{1\bar{s}}^\pm = D_{1\,unf}$$

Collins asymmetry – SIDIS p and d

in each x bin the measured asymmetries can be written as

$$A^h(x) = \frac{\sum_{q\bar{q}} e_q^2 x h_1^q(x)\, \widetilde{H}_{1q}^h}{\sum_{q\bar{q}} e_q^2 x f_1^q(x)\, \widetilde{D}_{1q}^h}$$

$$\widetilde{D}_{1q}^h = \int dz\, D_{1q}^h(z)$$

$$\widetilde{H}_{1q}^h = \int dz\, H_{1q}^h(z)$$

i.e.

$$A_p^+ = \tilde{a}_P^h \frac{4\left(h_1^u + \tilde{\alpha} h_1^{\bar{u}}\right) + \left(\tilde{\alpha} h_1^d + h_1^{\bar{d}}\right)}{f_p^+}$$

$$A_p^- = \tilde{a}_P^h \frac{4\left(\tilde{\alpha} h_1^u + h_1^{\bar{u}}\right) + \left(h_1^d + \tilde{\alpha} h_1^{\bar{d}}\right)}{f_p^-}$$

$$\tilde{a}_P^h = \frac{\widetilde{H}_{1\,fav}}{\widetilde{D}_{1\,fav}}$$ from e^+e^- Belle data

$$A_d^+ = \tilde{a}_P^h \frac{(4+\tilde{\alpha})\left(h_1^u + h_1^d\right) + (1+4\tilde{\alpha})\left(h_1^{\bar{u}} + h_1^{\bar{d}}\right)}{f_d^+}$$

$$\tilde{\alpha} = \frac{\widetilde{H}_{1\,unf}}{\widetilde{H}_{1\,fav}}$$

$$A_d^- = \tilde{a}_P^h \frac{(1+4\tilde{\alpha})\left(h_1^u + h_1^d\right) + (4+\tilde{\alpha})\left(h_1^{\bar{u}} + h_1^{\bar{d}}\right)}{f_d^-}$$

$$x\left[4(f_1^u + \widetilde{\beta} f_1^{\bar{u}}) + (\widetilde{\beta} f_1^d + f_1^{\bar{d}}) + \widetilde{\beta}(f_1^s + f_1^{\bar{s}})\right] \widetilde{D}_{1,\mathrm{fav}} \equiv x f_p^+\, \widetilde{D}_{1,\mathrm{fav}}$$

f_p^+ → known

$$\widetilde{\beta} = \frac{\widetilde{D}_{1\,unf}}{\widetilde{D}_{1\,fav}}$$

Collins asymmetry – SIDIS p and d

in each x bin it is

$$xh_1^{u_v} = \frac{1}{5}\frac{1}{\widetilde{a}_P^h(1-\widetilde{\alpha})}\left[(xf_p^+A_p^+ - xf_p^-A_p^-) + \frac{1}{3}(xf_d^+A_d^+ - xf_d^-A_d^-)\right]$$

$$xh_1^{d_v} = \frac{1}{5}\frac{1}{\widetilde{a}_P^h(1-\widetilde{\alpha})}\left[\frac{4}{3}(xf_d^+A_d^+ - xf_d^-A_d^-) - (xf_p^+A_p^+ - xf_p^-A_p^-)\right]$$

$$\widetilde{a}_P^h = \frac{\widetilde{H}_{1\,fav}}{\widetilde{D}_{1\,fav}}$$

from e^+e^- Belle data

$$\widetilde{\alpha} = \frac{\widetilde{H}_{1\,unf}}{\widetilde{H}_{1\,fav}} = \begin{cases} -1 & \textbf{a1} \\ -\dfrac{\widetilde{D}_{1\,unf}}{\widetilde{D}_{1\,fav}} = -\widetilde{\beta} & \textbf{a2} \end{cases}$$

both reasonable and in agreement with the considerations on the “interplay between the Collins and the di-hadron FFs”

Collins asymmetry – SIDIS p and d

in each x bin it is

$$xh_1^{u_v} = \frac{1}{5}\frac{1}{\tilde{a}_P^h(1-\tilde{\alpha})}\left[(xf_p^+A_p^+ - xf_p^-A_p^-) + \frac{1}{3}(xf_d^+A_d^+ - xf_d^-A_d^-)\right]$$

$$xh_1^{d_v} = \frac{1}{5}\frac{1}{\tilde{a}_P^h(1-\tilde{\alpha})}\left[\frac{4}{3}(xf_d^+A_d^+ - xf_d^-A_d^-) - (xf_p^+A_p^+ - xf_p^-A_p^-)\right]$$

$$\tilde{a}_P^h = \frac{\tilde{H}_{1\,fav}}{\tilde{D}_{1\,fav}}$$

from e^+e^- Belle data

$$\tilde{\alpha} = \frac{\tilde{H}_{1\,unf}}{\tilde{H}_{1\,fav}} = \begin{cases} -1 & \mathbf{a1} \\ -\frac{\tilde{D}_{1\,unf}}{\tilde{D}_{1\,fav}} = -\tilde{\beta} & \mathbf{a2} \end{cases}$$

$$xh_1^{\bar{u}} = \frac{1}{15}\frac{1}{\tilde{a}_P^h(1-\tilde{\alpha}^2)}\left[(1-4\tilde{\alpha})\,xf_p^+A_p^+ + (4-\tilde{\alpha})\,xf_p^-A_p^- - xf_d^+A_d^+ + \tilde{\alpha}\,xf_d^-A_d^-\right],$$

$$xh_1^{\bar{d}} = \frac{1}{15}\frac{1}{\tilde{a}_P^h(1-\tilde{\alpha}^2)}\left[(4\tilde{\alpha}-1)\,xf_p^+A_p^+ - (4-\tilde{\alpha})\,xf_p^-A_p^- - 4\tilde{\alpha}\,xf_d^+A_d^+ + 4\,xf_d^-A_d^-\right]$$

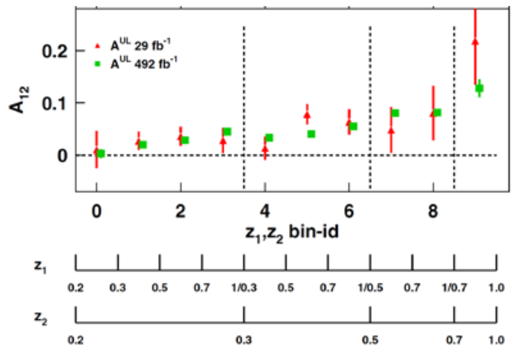
Collins asymmetry – e^+e^- Belle data

we have used the asymmetries (corrected for charm contribution)

$$A^{UL}_{e^+e^-}(z_1, z_2) = \frac{\langle \sin^2\theta \rangle}{\langle 1+\cos^2\theta \rangle}\left[A_U(z_1,z_2) - A_L(z_1,z_2)\right]$$

integrated over M_1, M_2

Phys. Rev D 78, 032011 (2008)



with $z_1 = z_2 = z$

with the previous assumptions on the FFs one obtains

$$\left|a_P^h(z)\right| = \left|\frac{H_{1fav}(z)}{D_{1fav}(z)}\right| = \left[\frac{1}{B(z)}\frac{\langle 1+\cos^2\theta \rangle}{\langle \sin^2\theta \rangle} A^{UL}_{e^+e^-}(z)\right]^{\frac{1}{2}}$$

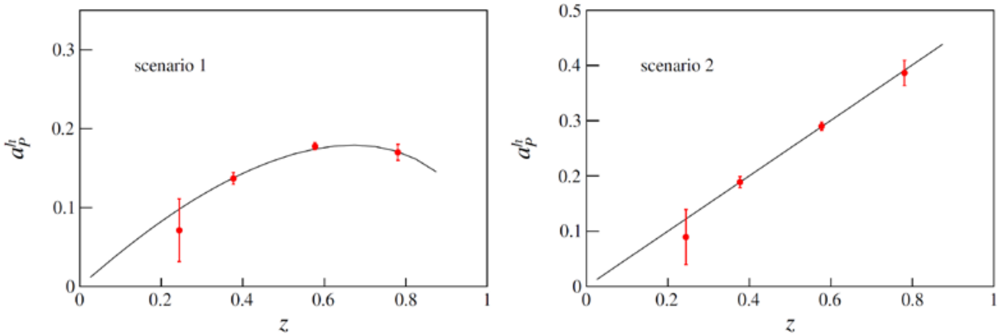
where $$B = \frac{5+5\,\alpha^2}{5+7\,\beta^2} - \frac{5\alpha}{5\beta+\beta^2}$$

$$\boldsymbol{\alpha}(z) = \frac{H_{1\,unf}(z)}{H_{1\,fav}(z)} = \begin{cases} -1 & \boldsymbol{a1} \\ -\dfrac{D_{1\,unf}(z)}{D_{1\,fav}(z)} = -\beta & \boldsymbol{a2} \end{cases}$$

Collins asymmetry – e^+e^- Belle data

the values of the analysing power $\left|a_P^h(z)\right|$ have been calculated in the four z bins with both the assumptions

$$\alpha(z) = \frac{H_{1\,unf}(z)}{H_{1\,fav}(z)} = \begin{cases} -1 & \mathbf{a1} \\ -\frac{D_{1\,unf}(z)}{D_{1\,fav}(z)} = -\beta & \mathbf{a2} \end{cases}$$



and then fitted with two different functions of z

results: $\mathbf{a1}$ $\quad \left|\tilde{a}_P^h\right| = 0.12$

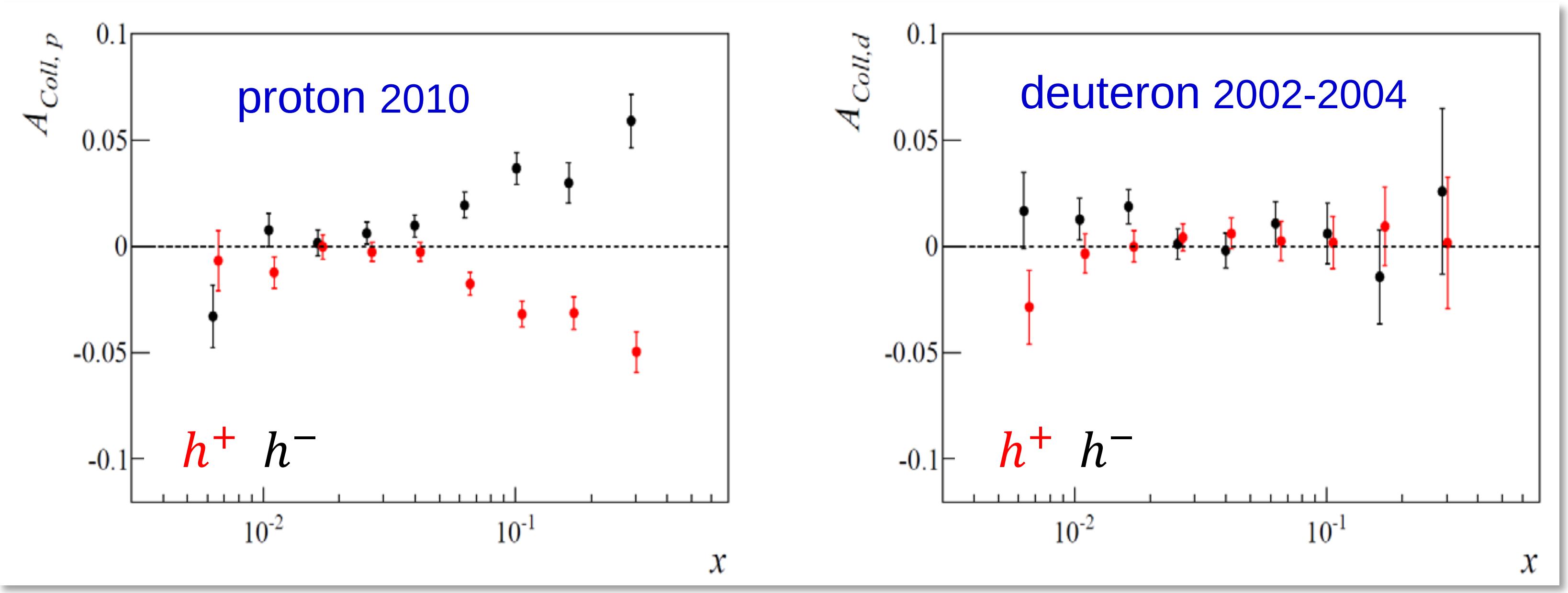
$\mathbf{a2}$ $\quad \left|\tilde{a}_P^h\right| = 0.17$

→ same values for the transversity functions!
compensated by α

we have assumed $\left|a_P^h(z)\right|$ constant in Q^2 i.e. same evolution for H_{1fav} and D_{1fav}

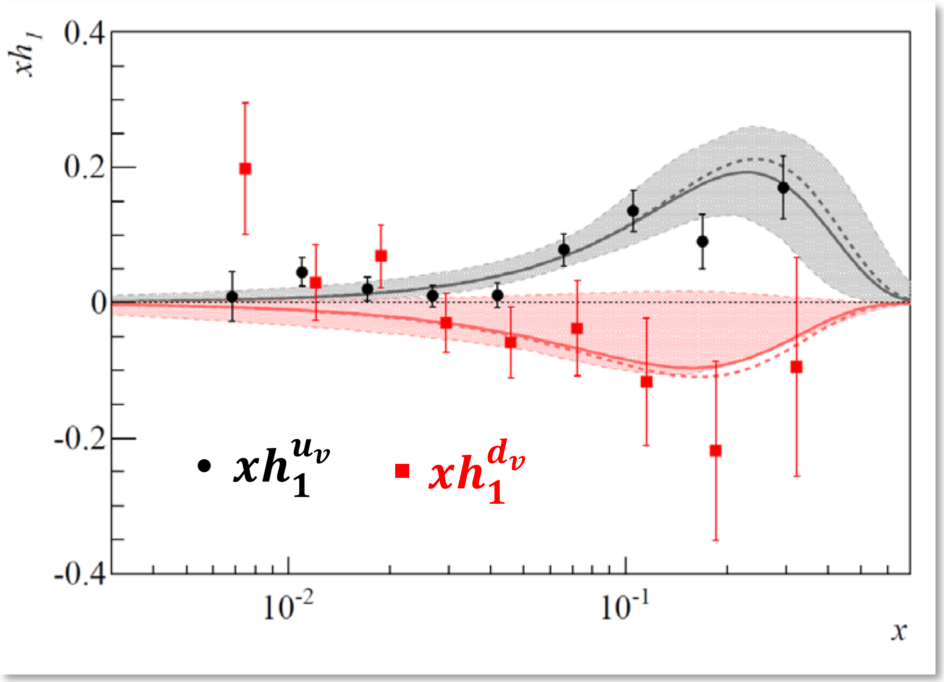
if the evolution of H_{1fav} is negligible, the analysing power at COMPASS Q^2 decreases by ~ 10%

Collins asymmetry – COMPASS data



charged hadrons ~ charged pions

Transversity from the Collins asymmetry



error bars: 1σ stat. only

$xh_1^{u_v}$ clearly different from zero

$xh_1^{d_v}$ opposite sign

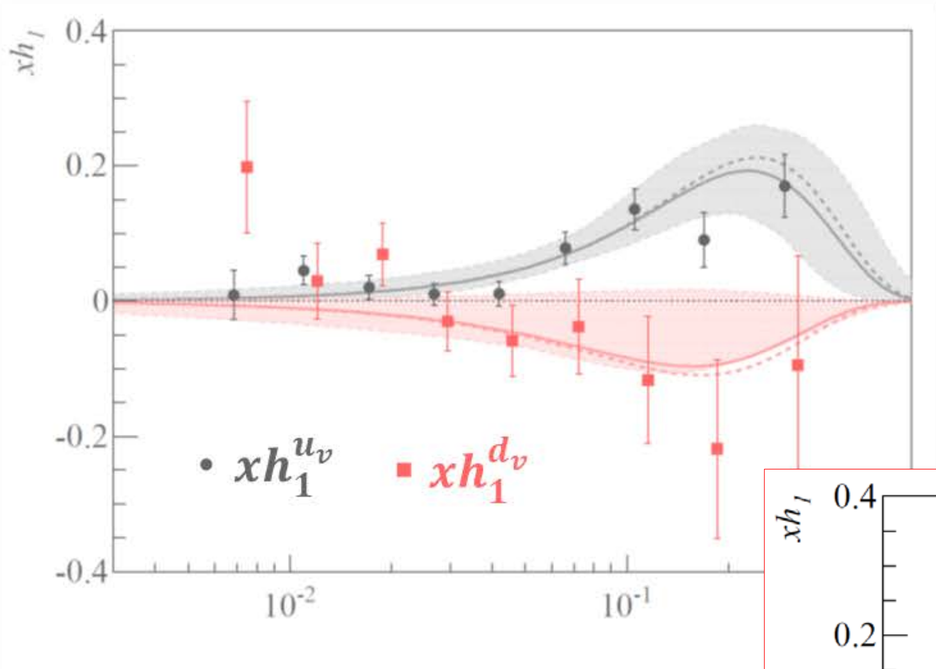
larger errors because of the low statistcs of the d data

curves:

Anselmino et al., 2013

Soffer bound

Transversity from the Collins asymmetry



errors: 1σ stat. only

$xh_1^{u_v}$ clearly different from zero

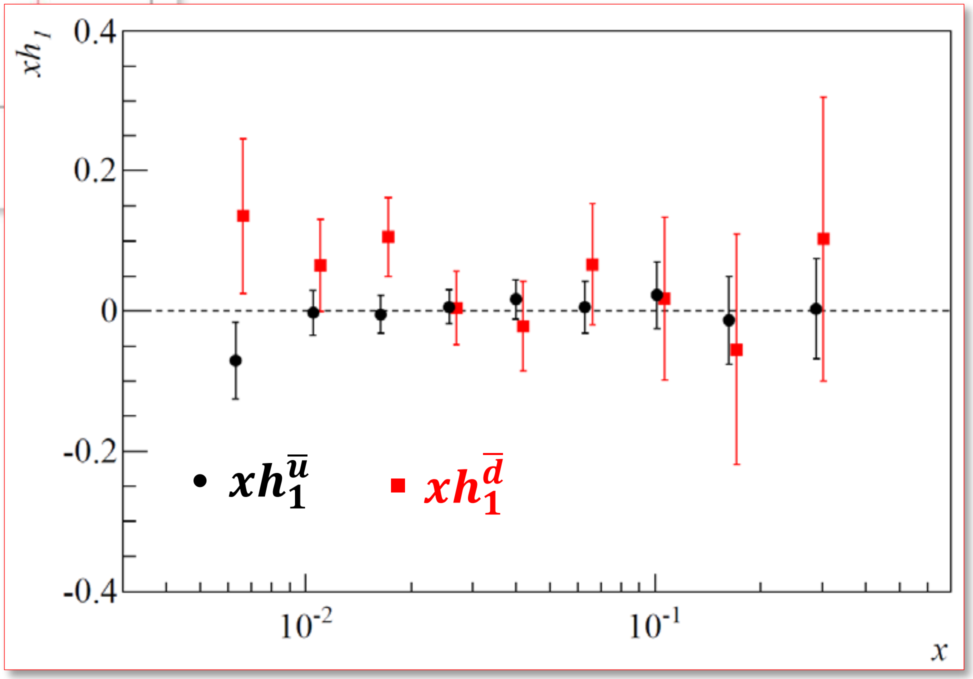
$xh_1^{d_v}$ opposite sign

larger errors because of the low statistics of the d data

$xh_1^{\bar{u}}$, $xh_1^{\bar{d}}$

compatible with zero

same errors as for valence quarks



Transversity from the di-hadron asymmetry

SIDIS $$A^{hh}(x) = \frac{\sum_{q,\bar{q}} e_q^2 x h_1^q(x)\, \widetilde{H}_{1q}^{\angle}}{\sum_{q,\bar{q}} e_q^2 x f_1^q(x)\, \widetilde{D}_{1q}^{hh}}$$

assuming $\widetilde{D}_{1u}^{hh} = \widetilde{D}_{1d}^{hh} = \widetilde{D}_{1\bar{u}}^{hh} = \widetilde{D}_{1\bar{d}}^{hh}$ $\quad \widetilde{D}_{1s}^{hh} = \widetilde{D}_{1\bar{s}}^{hh} = \lambda\, \widetilde{D}_{1u}^{hh}$ $\quad \lambda = 0.5$ $\quad (\widetilde{D}_{1c}^{hh} = \widetilde{D}_{1\bar{c}}^{hh})$

$\widetilde{H}_{1u}^{\angle} = -\widetilde{H}_{1d}^{\angle} = -\widetilde{H}_{1\bar{u}}^{\angle} = \widetilde{H}_{1\bar{d}}^{\angle}$ $\quad \widetilde{H}_{1s}^{\angle} = -\widetilde{H}_{1\bar{s}}^{\angle} = 0$ $\quad (\widetilde{H}_{1c}^{\angle} = -\widetilde{H}_{1\bar{c}}^{\angle} = 0)$

Bacchetta, Courtoy, Radici 2011 Courtoy, Bacchetta, Radici, Bianconi 2012

$$x h_1^{u_v} = \frac{1}{15} \frac{1}{\tilde{a}_P^{hh}} \left[3\left(4\, x\, f_1^{u+\bar{u}} + x\, f_1^{d+\bar{d}} + 0.5\, x f_1^{s+\bar{s}}\right) A_p^{hh} + \left(5\, x\, f_1^{u+\bar{u}} + 5x\, f_1^{d+\bar{d}} + x f_1^{s+\bar{s}}\right) A_d^{hh} \right]$$

$$f_1^{q+\bar{q}} = f_1^q + f_1^{\bar{q}}$$

$$x h_1^{d_v} = \frac{1}{15} \frac{1}{\tilde{a}_P^{hh}} \left[-3\left(4\, x\, f_1^{u+\bar{u}} + x\, f_1^{d+\bar{d}} + 0.5\, x f_1^{s+\bar{s}}\right) A_p^{hh} + 4\left(5\, x\, f_1^{u+\bar{u}} + 5x\, f_1^{d+\bar{d}} + x f_1^{s+\bar{s}}\right) A_d^{hh} \right]$$

$$\tilde{a}_P^{hh} = \frac{\widetilde{H}_{1u}^{\angle}}{\widetilde{D}_{1u}^{hh}}$$ from e^+e^- Belle data

Transversity from the di-hadron asymmetry

$$\tilde{a}_P^{hh} = \frac{\widetilde{H}_{1u}^{\angle}}{\widetilde{D}_{1u}^{hh}}$$ from e^+e^- Belle data

Phys. Rev. Lett. 107, 072004 (2011)

$$\left|\tilde{a}_P^{hh}\right| = \left|\frac{\widetilde{H}_{1u}^{\angle}}{\widetilde{D}_{1u}^{hh}}\right| = \left[-\frac{1}{5}(1+\mu^2)(5+\lambda^2)\frac{\langle 1+\cos^2\theta\rangle}{\langle \sin^2\theta\rangle} A_{e^+e^-}^{hh}\right]^{\frac{1}{2}}$$

$\mu^2 = 0.5$ charm yield ~ one half the uds

$$e_c^2\, \widetilde{D}_{1c}^{hh}\, \widetilde{D}_{1\bar{c}}^{hh} = \mu^2 \left(e_u^2\, \widetilde{D}_{1u}^{hh}\, \widetilde{D}_{1\bar{u}}^{hh} + e_d^2\, \widetilde{D}_{1d}^{hh}\, \widetilde{D}_{1\bar{d}}^{hh} + e_s^2\, \widetilde{D}_{1s}^{hh}\, \widetilde{D}_{1\bar{s}}^{hh}\right)$$

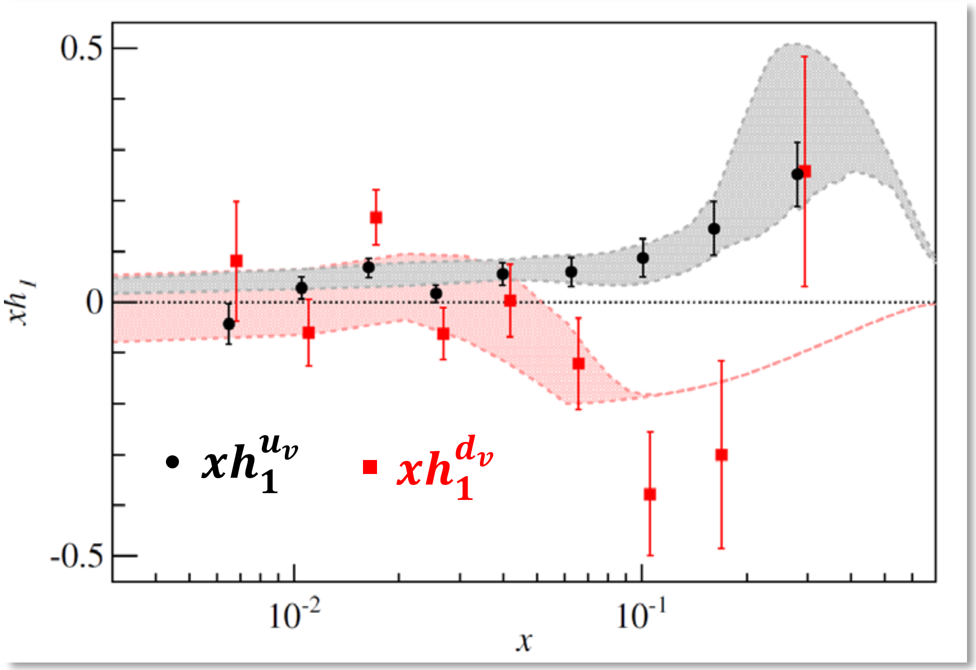
$$A_{e^+e^-}^{hh} = -0.196$$

↓

$\left|\tilde{a}_P^{hh}\right| = 0.201$ at $Q_B^2 \cong 110\ \mathrm{GeV}^2/c^2$

assumed constant in Q^2

Transversity from the di-hadron asymmetries



error bars: 1σ stat. only

$xh_1^{u_v}$ clearly different from zero

$xh_1^{d_v}$ opposite sign

larger errors because of the low statistcs of the d data

curves:
Bacchetta et al, 2013
Soffer bound

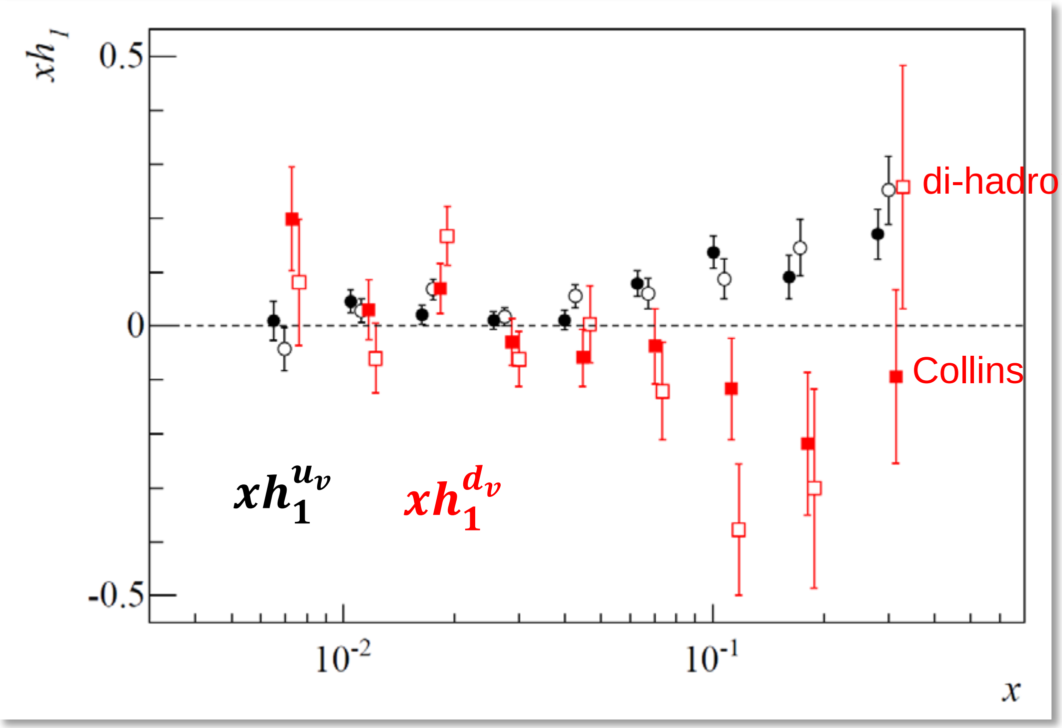
Transversity

from the **Collins** and from the **di-hadron** asymmetries

closed points
Guassian ansatz
evolution not known

open points
collinear
known evolution

different assumptions



Sivers function

Sivers functions from the SIDIS Sivers asymmetries

a similar method has been used to extract the Sivers function
from the COMPASS p and d Sivers asymmetries for charged pions and kaons

$$A^h_{Siv}(x,z) = \frac{\sum_{q,\bar{q}} e_q^2 x \boldsymbol{f}_{\boldsymbol{1T}}^{\perp \boldsymbol{q}}(x) \otimes D^h_{1q}(z)}{\sum_{q,\bar{q}} e_q^2 x f_1^q(x) \otimes D^h_{1q}(z)}$$

“gaussian ansatz”:

$$A^h_{Siv}(x,z) = G\, z\, \frac{\sum_{q,\bar{q}} e_q^2 x \boldsymbol{f}_{\boldsymbol{1T}}^{\perp(\boldsymbol{1})\boldsymbol{q}}(x) D^h_{1q}(z)}{\sum_{q,\bar{q}} e_q^2 x f_1^q(x) D^h_{1q}(z)}$$

$$\boldsymbol{f}_{\boldsymbol{1T}}^{\perp(\boldsymbol{1})\boldsymbol{q}} = \int d^2\vec{k}_T \frac{k_T^2}{2M^2} f_{1T}^{\perp q}(k_T^2)$$

assuming $G = \frac{\sqrt{\pi} M}{\left[z^2 \langle k_T^2 \rangle_S + \langle p_T^2 \rangle\right]^{1/2}} \simeq \frac{\pi M}{2\langle P_T \rangle}$ *known* and integrating over z

$$A^h_{Siv}(x) = G \frac{\sum_q e_q^2 \cdot x f_{1T}^{\perp(1)q}(x) \cdot \widetilde{D}^{(1)h}_{1q}}{\sum_q e_q^2 \cdot x f_1^q(x) \cdot \widetilde{D}^h_{1q}}$$

$$\widetilde{D}^h_{1q} = \int dz\, D^h_{1q}(z,) \qquad \widetilde{D}^{(1)h}_{1q} = \int dz\, z\, D^h_{1q}(z)$$

Sivers functions from the SIDIS Sivers asymmetries

writing explicitly the Sivers asymmetries one finds, for **pions**

$$xf_{1T}^{\perp(1)u_v} = \frac{1}{5G\rho_\pi(1-\beta_\pi^{(1)})}\left[(xf_p^{\pi^+}A_p^{\pi^+} - xf_p^{\pi^-}A_p^{\pi^-}) + \frac{1}{3}(xf_d^{\pi^+}A_d^{\pi^+} - xf_d^{\pi^-}A_d^{\pi^-})\right]$$

$$xf_{1T}^{\perp(1)d_v} = \frac{1}{5G\rho_\pi(1-\beta_\pi^{(1)})}\left[\frac{4}{3}(xf_d^{\pi^+}A_d^{\pi^+} - xf_d^{\pi^-}A_d^{\pi^-}) - (xf_p^{\pi^+}A_p^{\pi^+} - xf_p^{\pi^-}A_p^{\pi^-})\right]$$

$$x\left[4(f_1^u + \beta_\pi f_1^{\bar{u}}) + (\beta_\pi f_1^d + f_1^{\bar{d}}) + N\beta_\pi(f_1^s + f_1^{\bar{s}})\right]\widetilde{D}_{1,\mathrm{fav}}^\pi \equiv xf_p^{\pi^+}\widetilde{D}_{1,\mathrm{fav}}^\pi$$

$$\beta_\pi = \frac{\widetilde{D}_{1,unf}^\pi}{\widetilde{D}_{1,fav}^\pi} \qquad \beta_\pi^{(1)} = \frac{\widetilde{D}_{1,unf}^{(1)\pi}}{\widetilde{D}_{1,fav}^{(1)\pi}} \qquad \rho_\pi = \frac{\widetilde{D}_{1,fav}^{(1)\pi}}{\widetilde{D}_{1,fav}^\pi} \qquad \widetilde{D}_1^\pi = \int dz\, D_1^\pi(z) \qquad \widetilde{D}_1^{(1)\pi} = \int dz\, z\, D_1^\pi(z)$$

$$xf_{1T}^{\perp(1)\bar{u}} - xf_{1T}^{\perp(1)\bar{d}} = \frac{1}{15G\rho_\pi\left(1-\beta_\pi^{(1)2}\right)}\Big[2(1-4\beta_\pi^{(1)})xf_p^{\pi^+}A_p^{\pi^+} + 2(4-\beta_\pi^{(1)})xf_p^{\pi^-}A_p^{\pi^-}$$
$$- (1-4\beta_\pi^{(1)})xf_d^{\pi^+}A_d^{\pi^+} - (4-\beta_\pi^{(1)})xf_d^{\pi^-}A_d^{\pi^-}\Big] .$$

can be obtained directly from the p and d measured asymmetries in each x bin, at the corresponding $\langle Q^2 \rangle$

Sivers functions from the SIDIS Sivers asymmetries

writing explicitly the Sivers asymmetries one finds, for **kaons**

$$xf_{1T}^{\perp(1)u_v} = \frac{1}{4G\rho_K(1-\beta_K^{(1)})}\left[xf_p^{K^+}A_p^{K^+} - xf_p^{K^-}A_p^{K^-}\right]$$

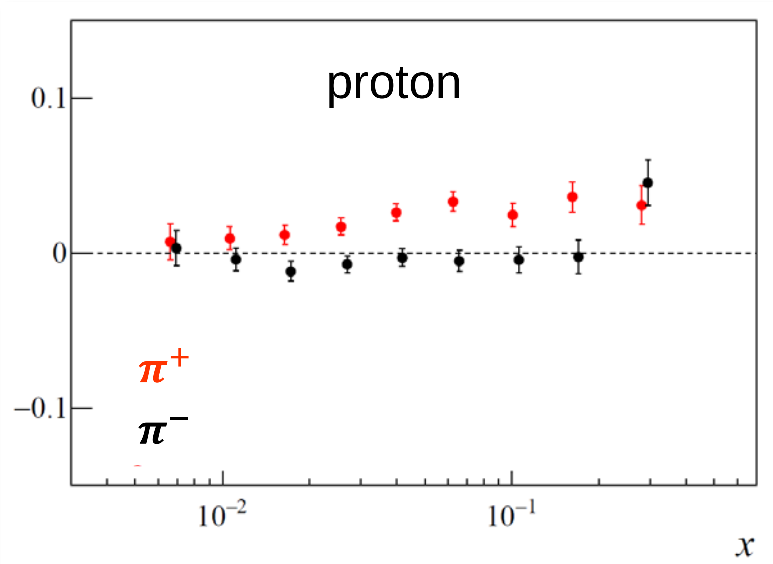
assuming $f_{1T}^{\perp(1)s} = f_{1T}^{\perp(1)\bar{s}}$

$$xf_{1T}^{\perp(1)d_v} = -\frac{1}{4G\rho_K(1-\beta_K^{(1)})}\left[xf_p^{K^+}A_p^{K^+} - xf_p^{K^-}A_p^{K^-} - (xf_d^{K^+}A_d^{K^+} - xf_d^{K^-}A_d^{K^-})\right]$$

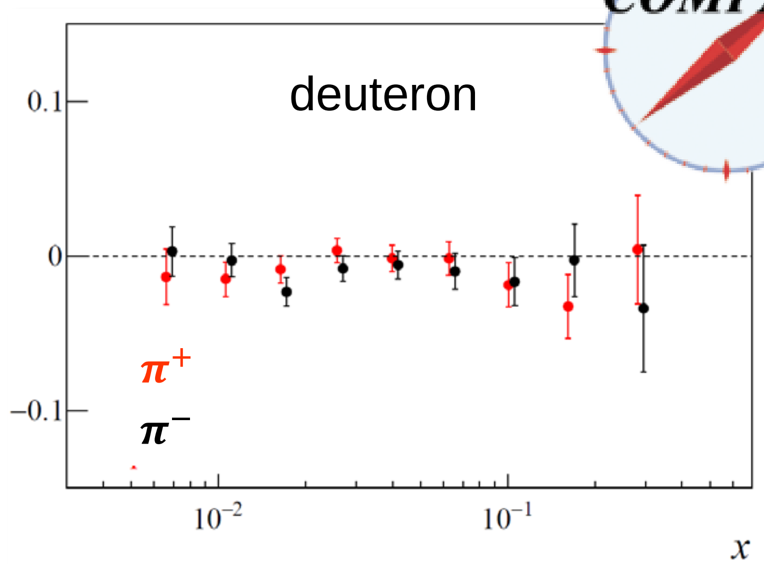
no linear combination give access to $f_{1T}^{\perp(1)s,\bar{s}}$

Sivers functions from the SIDIS Sivers asymmetries

A_{Siv}

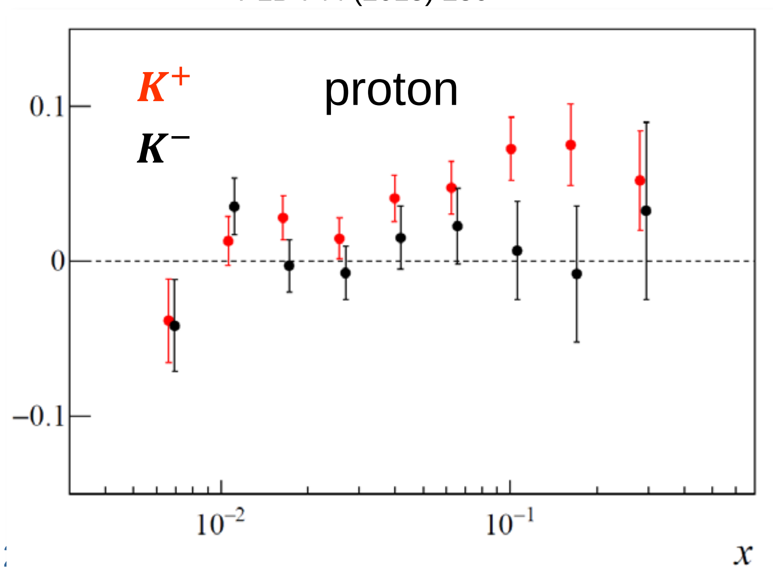


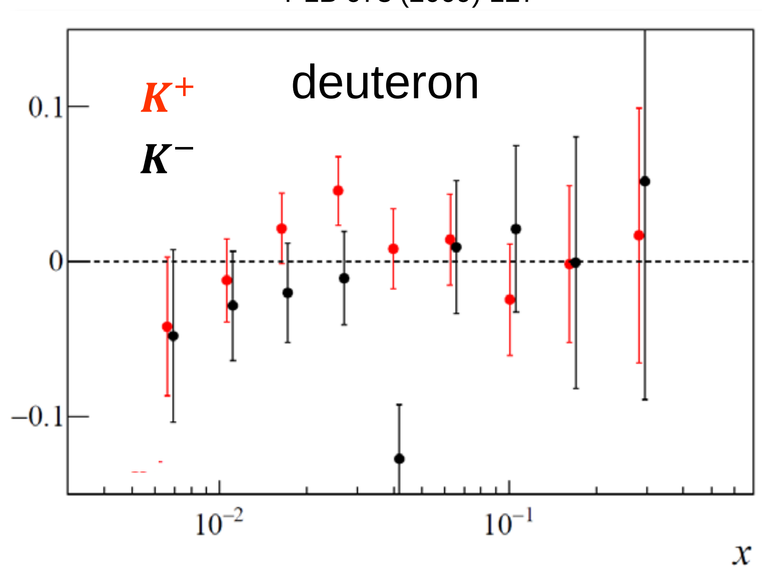
PLB 744 (2015) 250



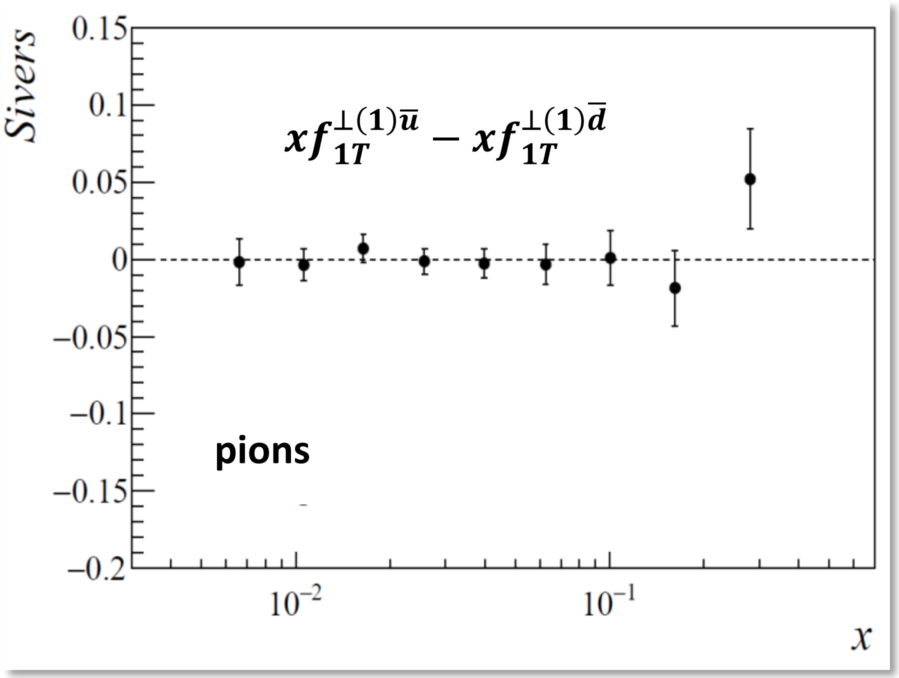
PLB 673 (2009) 127

A_{Siv}





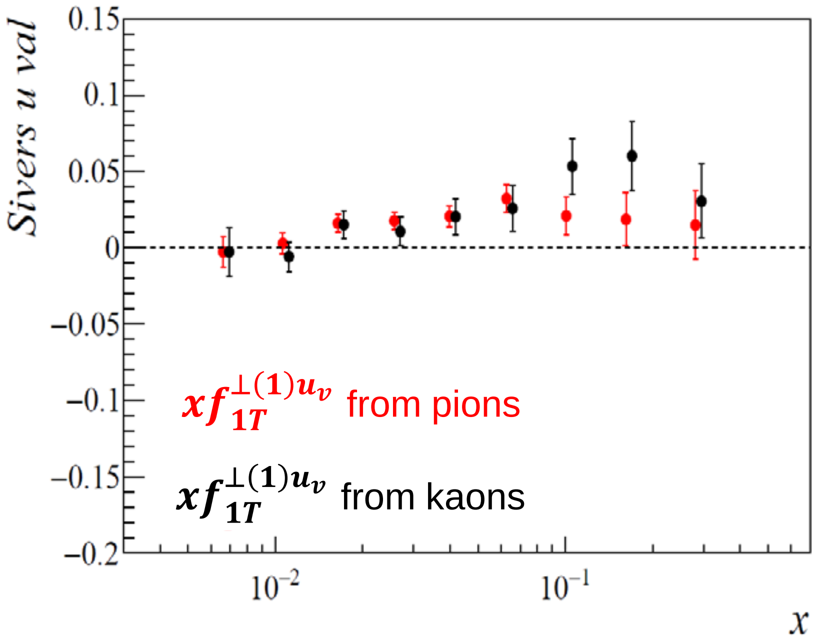
Sivers functions from the SIDIS Sivers asymmetries

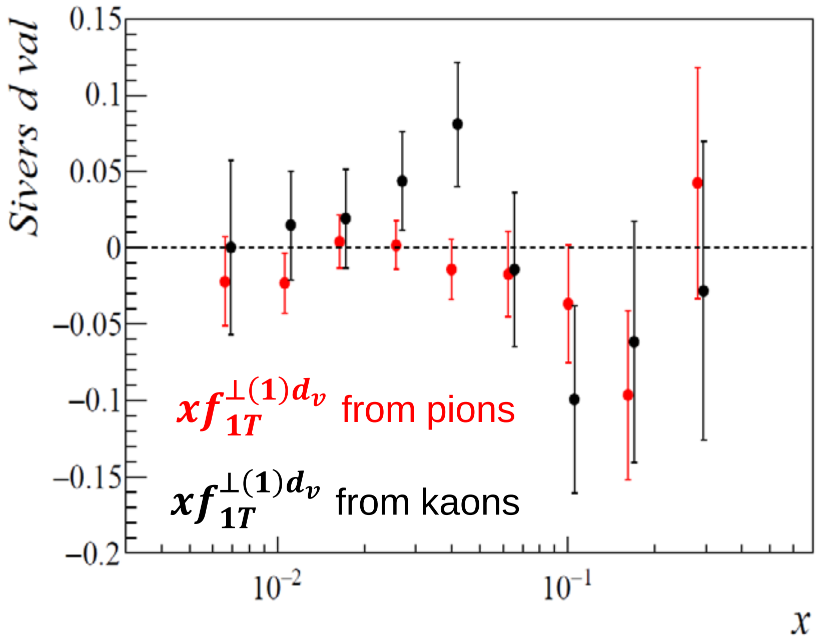


compatible with zero
→ $xf_{1T}^{\perp(1)\bar{u}}$ and $xf_{1T}^{\perp(1)\bar{d}}$ small

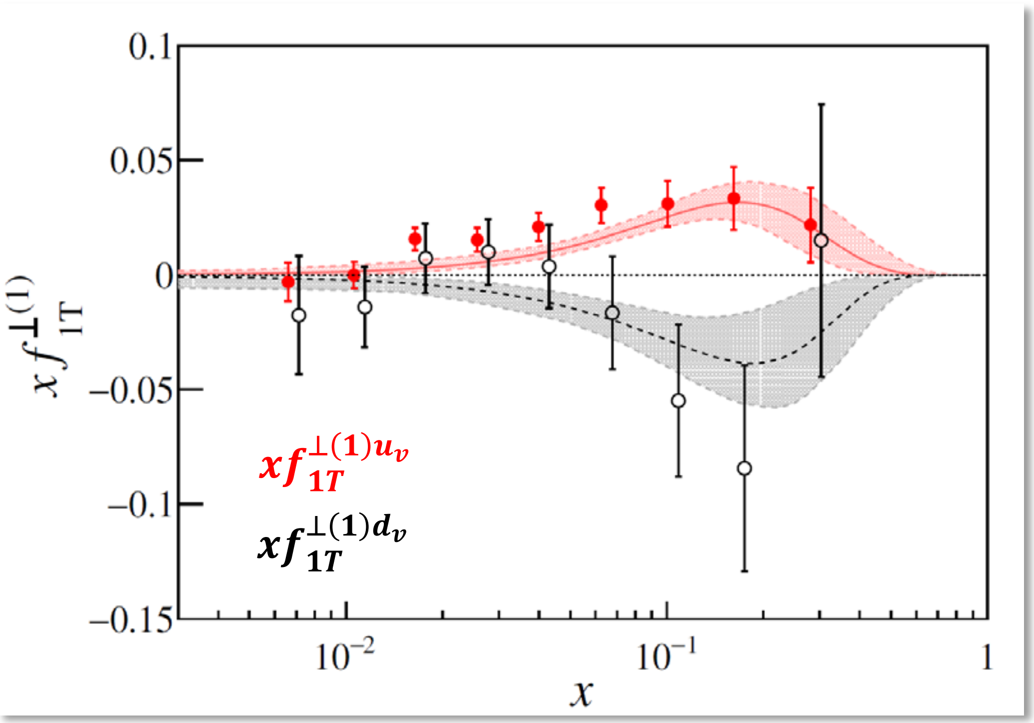
In the large Nc limit, the isotriplet $(\bar{u} - \bar{d})$ Sivers combination is expected to dominate over the isosinglet one $(\bar{u} + \bar{d})$

Sivers functions from the SIDIS Sivers asymmetries





Sivers functions from the SIDIS Sivers asymmetries



curves:
Anselmino Boglione Melis, 2012, $Q^2 = 4\ \mathrm{GeV}^2$

Summary

the point-by-point extraction of PDFs looks promising

- interesting results for the transversity and the Sivers functions
- no parametrisation of the unknown PDFs and FFs is needed
- can be used also for the weighted asymmetries, …

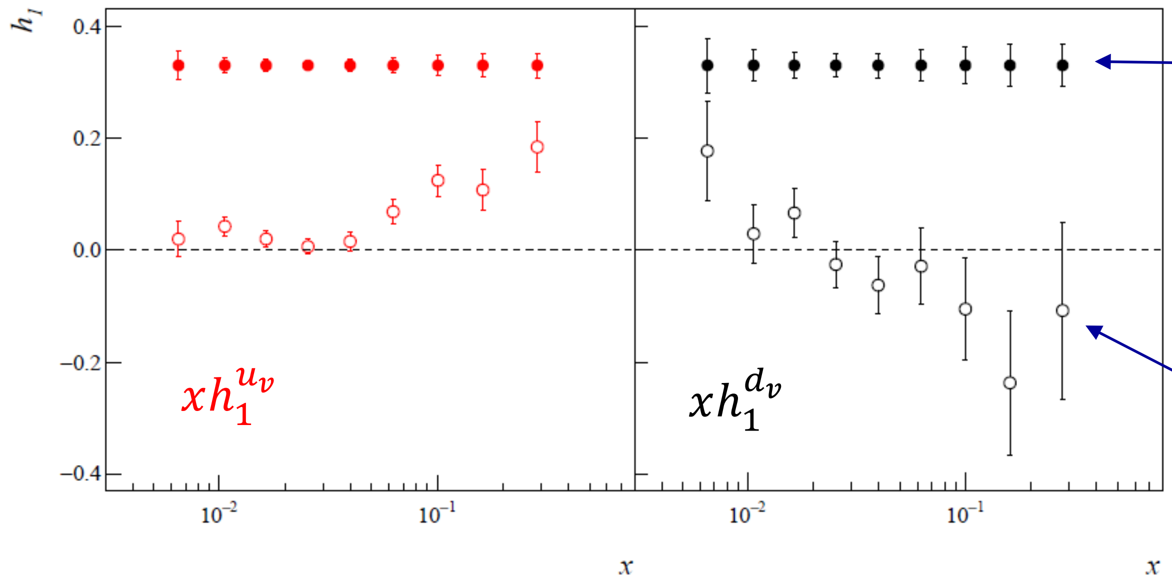
- needs proton and deuteron/neutron data at the same $\langle x \rangle$, $\langle Q^2 \rangle$ values

to be kept in mind in planning future experiments

presently, large uncertainties for the d quark due to the
low statistics deuteron data

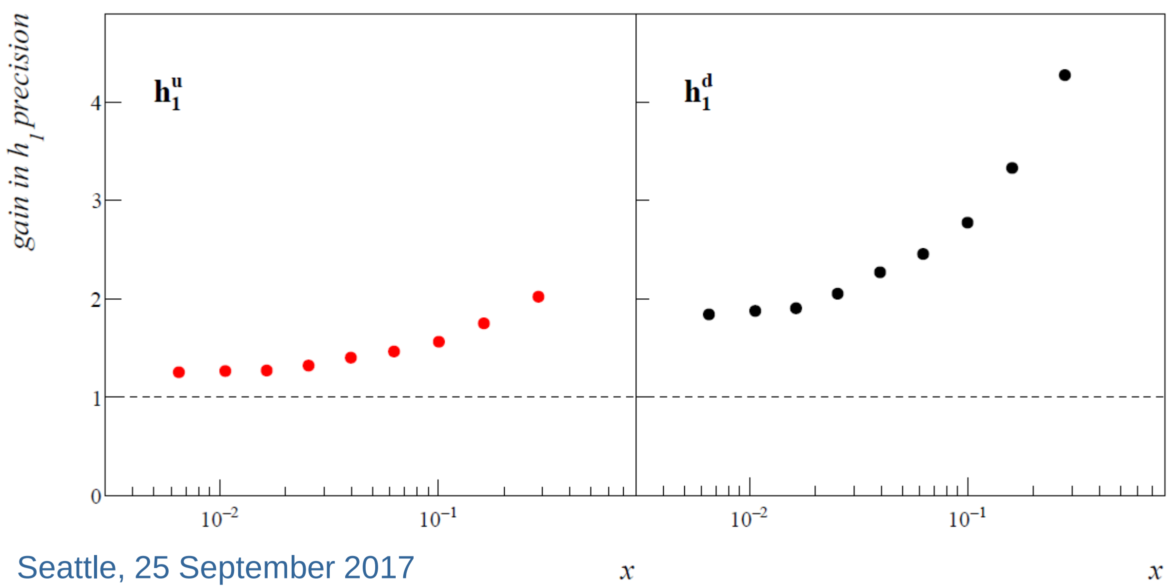
we have repeated the extraction of transversity assuming one full year
of data taking in COMPASS with the transversely polarised d target
in the same conditions of the 2010 proton run

Transversity



statistical errors with one year of data taking with the ^{6}LiD transversely polarized target at COMPASS

present results



ratios of the statistical errors

present / present+one year d

F. Bradamante
EICUG meeting
Trieste, July 2017

Summary

the point-by-point extraction of PDFs looks promising

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→ remarkable improvement

unique opportunity to improve our knowledge at “small” x and “large” Q^2, in a range complementary to the JLab12 measurements

COMPASS can produce other relevant results, useful for EIC thank you