COMPASS results on weighted Sivers asymmetry in SIDIS

Anna Martin

Trieste University and INFN

on behalf of the COMPASS Collaboration

content of the talk

- reminder
  - the COMPASS experiment
  - SIDIS measurements and some target transverse spin results

- the Sivers asymmetry

- the transverse momentum weighted Sivers asymmetry

- extraction of the Sivers function

***CO**mmon*
***M**uon and*
***P**roton*
***A**pparatus for*
***S**tructure and*
***S**pectroscopy*

fixed target experiment at the CERN SPS

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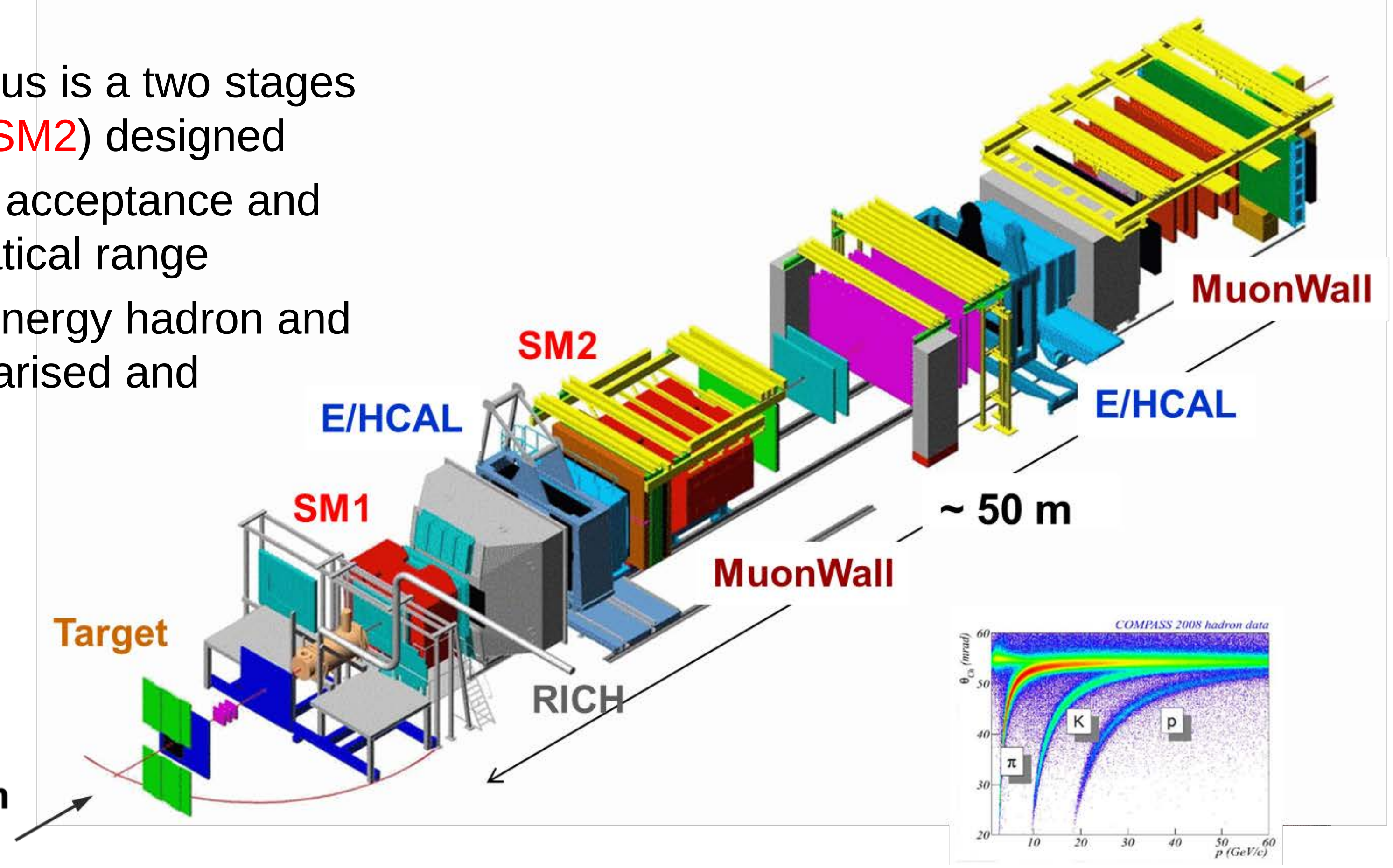
***S**tructure and*
***S**pectroscopy*

fixed target experiment at the CERN SPS

the experimental apparatus is a two stages spectrometer (SM1 and SM2) designed

- to have large angular acceptance and cover a broad kinematical range
- to operate with high energy hadron and muon beams and polarised and unpolarised targets



***CO**mmon*
***M**uon and*
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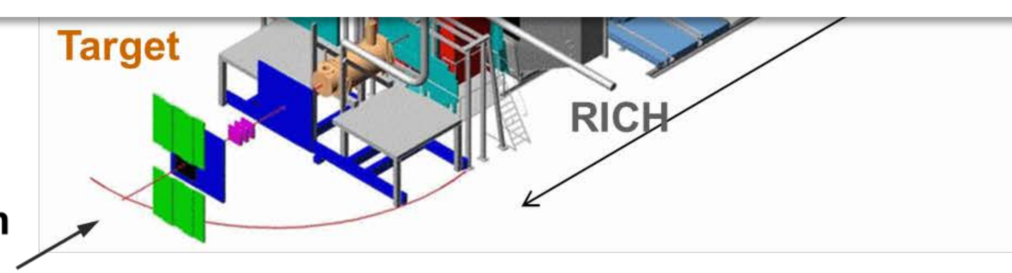
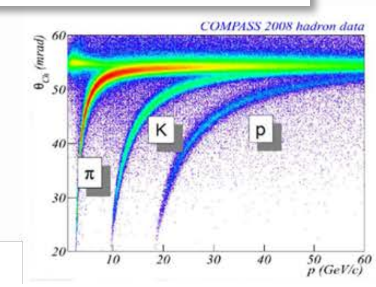
fixed target experiment at the CERN SPS

wide 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





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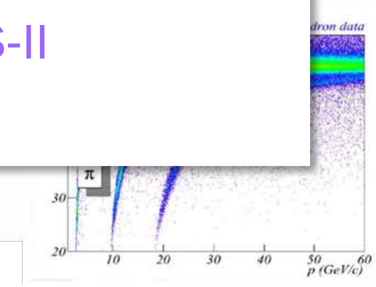
- Drell-Yan (π)
- Deeply Virtual Compton Scattering (μ)

COMPASS-II



beam

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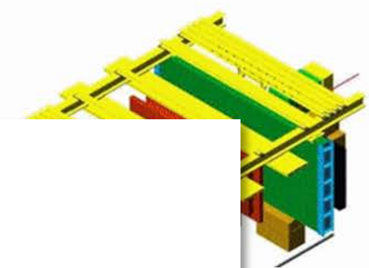

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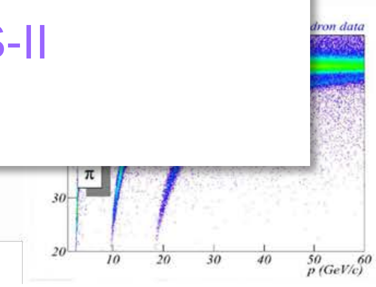
Semi-Inclusive Deep Inelastic Scattering

- longitudinal spin structure
- transverse momentum and transverse spin structure
- Drell-Yan (π)
- Deeply Virtual Compton Scattering (μ)

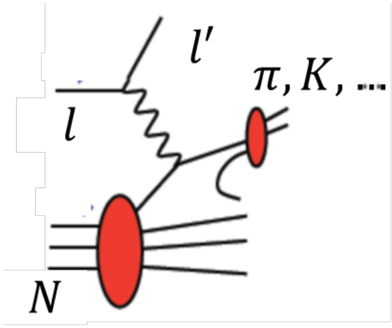
COMPASS-II



beam

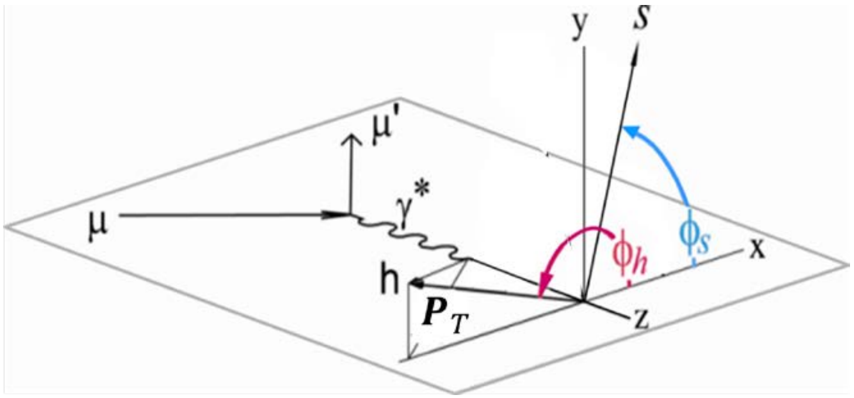
Semi-Inclusive Deep Inelastic Scattering

hard interaction of a lepton with a nucleon via virtual photon exchange



$$x = \frac{Q^2}{2P \cdot q} \qquad y = \frac{P \cdot q}{P \cdot \ell} =_{LAB} \frac{E - E'}{E} \qquad z = \frac{P \cdot P_h}{P \cdot q} =_{LAB} \frac{E_h}{E - E'}$$

$$Q^2 = -q^2 \qquad W^2 = (P + q)^2 \qquad P_T \,,\ \phi_h$$



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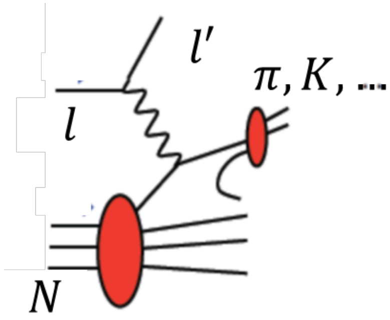

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cross-section

one photon exchange approximation

- unpolarised targets
- longitudinally polarised targets
- transversely polarised targets

with unpolarised and longitudinally polarised lepton beam

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{\underbrace{F_{UU,T}}_{f_1} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1+\varepsilon)}\cos\phi_h\, F_{UU}^{\cos\phi_h}$$

$$+\,\varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h}\ [h_1^\perp H_1^\perp] + \lambda_e\sqrt{2\varepsilon(1-\varepsilon)}\sin\phi_h\,F_{LU}^{\sin\phi_h}$$

$$+\,S_\parallel\Big[\sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_h\,F_{UL}^{\sin\phi_h} + \varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\ [h_{1L}^\perp H_1^\perp]\Big] + S_\parallel\lambda_e\Big[\sqrt{1-\varepsilon^2}\,F_{LL}\ [g_1] + \sqrt{2\varepsilon(1-\varepsilon)}\cos\phi_h\,F_{LL}^{\cos\phi_h}\Big]$$

$$+\,|\boldsymbol{S}_\perp|\Big[\sin(\phi_h-\phi_S)\Big(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \varepsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\Big)\ [f_{1T}^\perp D_1]$$

$$+\,\varepsilon\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}\ [h_1 H_1^\perp] + \varepsilon\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)}\ [h_{1T}^\perp H_1^\perp]$$

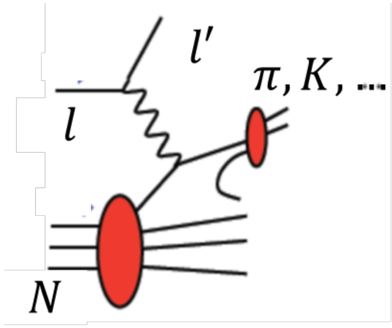
$$+\,\sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_S\,F_{UT}^{\sin\phi_S} + \sqrt{2\varepsilon(1+\varepsilon)}\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Big]$$

$$+\,|\boldsymbol{S}_\perp|\lambda_e\Big[\sqrt{1-\varepsilon^2}\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}\ [g_{1T}D_1] + \sqrt{2\varepsilon(1-\varepsilon)}\cos\phi_S\,F_{LT}^{\cos\phi_S}$$

$$+\,\sqrt{2\varepsilon(1-\varepsilon)}\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\},$$

Semi-Inclusive Deep Inelastic Scattering

hard interaction of a lepton with a nucleon via virtual photon exchange



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$$Q^2 = -q^2 \qquad W^2 = (P + q)^2 \qquad P_T\ , \ \phi_h$$

cross-section
one photon exchange approximation

$$\frac{d\sigma}{dx\, dy\, d\psi\, dz\, d\phi_h\, dP_{h\perp}^2} =$$

- unpolarised targets (f_1, $h_1^\perp H_1^\perp$)

$$\frac{\alpha^2}{xyQ^2} \frac{y^2}{2(1-\varepsilon)} \left(1 + \frac{\gamma^2}{2x}\right) \Big\{ F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1+\varepsilon)} \cos\phi_h F_{UU}^{\cos\phi_h} + \varepsilon \cos(2\phi_h) F_{UU}^{\cos 2\phi_h} + \lambda_e \sqrt{2\varepsilon(1-\varepsilon)} \sin\phi_h F_{LU}^{\sin\phi_h}$$

- longitudinally polarised targets ($h_{1L}^\perp H_1^\perp$, g_1)

$$+ S_\parallel \left[\sqrt{2\varepsilon(1+\varepsilon)} \sin\phi_h F_{UL}^{\sin\phi_h} + \varepsilon \sin(2\phi_h) F_{UL}^{\sin 2\phi_h} \right] + S_\parallel \lambda_e \left[\sqrt{1-\varepsilon^2} F_{LL} + \sqrt{2\varepsilon(1-\varepsilon)} \cos\phi_h F_{LL}^{\cos\phi_h} \right]$$

- transversely polarised targets ($f_{1T}^\perp D_1$, $h_{1T}^\perp H_1^\perp$, $h_1 H_1^\perp$, $g_{1T} D_1$)

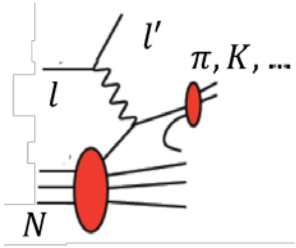
$$+ |S_\perp| \Big[\sin(\phi_h - \phi_S) \left(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \varepsilon F_{UT,L}^{\sin(\phi_h-\phi_S)} \right) + \varepsilon \sin(\phi_h + \phi_S) F_{UT}^{\sin(\phi_h+\phi_S)} + \varepsilon \sin(3\phi_h - \phi_S) F_{UT}^{\sin(3\phi_h-\phi_S)}$$
$$+ \sqrt{2\varepsilon(1+\varepsilon)} \sin\phi_S F_{UT}^{\sin\phi_S} + \sqrt{2\varepsilon(1+\varepsilon)} \sin(2\phi_h - \phi_S) F_{UT}^{\sin(2\phi_h-\phi_S)} \Big]$$
$$+ |S_\perp| \lambda_e \Big[\sqrt{1-\varepsilon^2} \cos(\phi_h - \phi_S) F_{LT}^{\cos(\phi_h-\phi_S)} + \sqrt{2\varepsilon(1-\varepsilon)} \cos\phi_S F_{LT}^{\cos\phi_S}$$
$$+ \sqrt{2\varepsilon(1-\varepsilon)} \cos(2\phi_h - \phi_S) F_{LT}^{\cos(2\phi_h-\phi_S)} \Big] \Big\},$$

with unpolarised and longitudinally polarised lepton beam

high statistics

COMPASS, hermes, Jefferson Lab

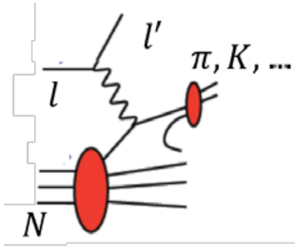
Semi-Inclusive Deep Inelastic Scattering



at COMPASS

μ^+ muon beam, 160 (190) **GeV/c**, -80% longitudinal polarisation

Semi-Inclusive Deep Inelastic Scattering



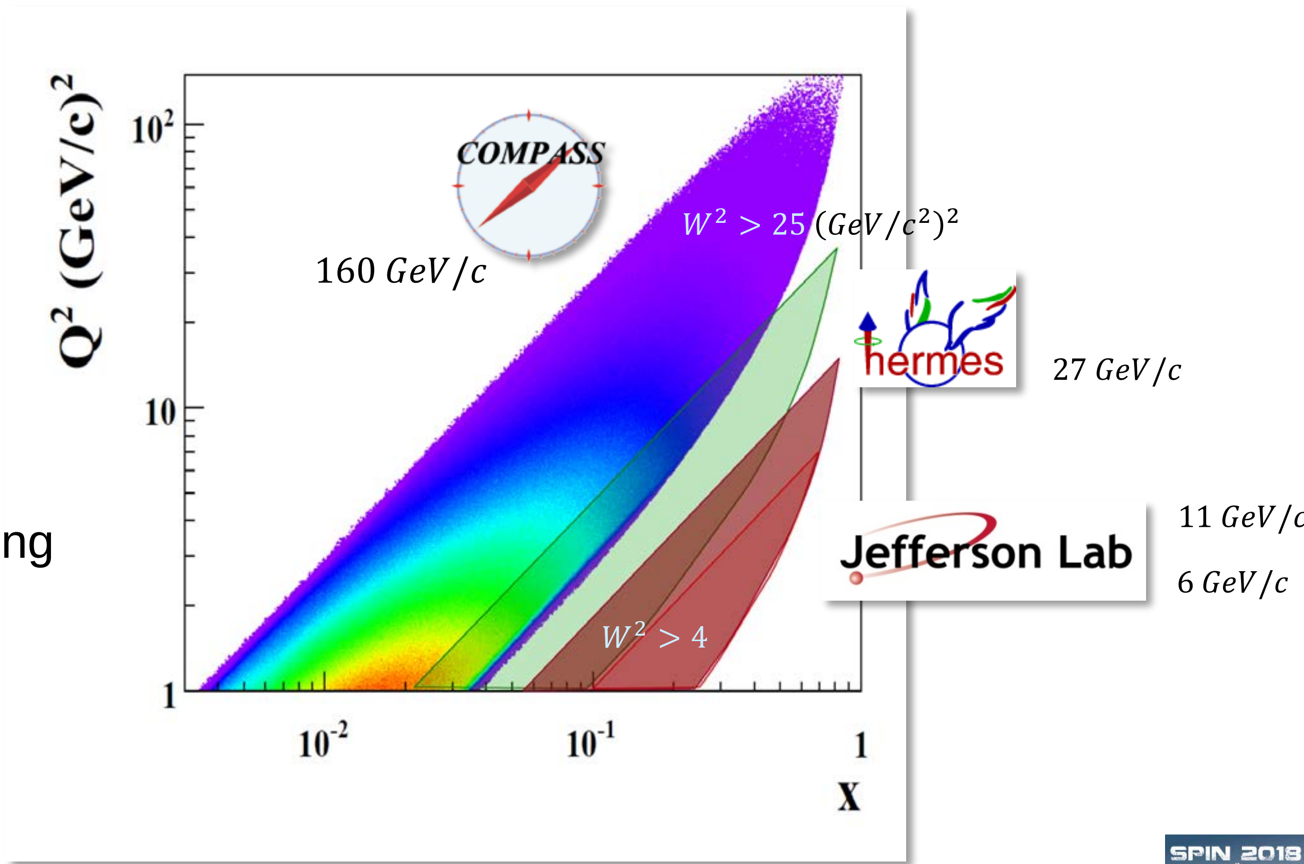
at COMPASS

μ^+ **muon beam, 160** (190) **GeV/c**, -80% longitudinal polarisation

wide $x - Q^2$ range

complementary to
that of the HERMES
experiment
and JLab12
experiments

not competitive concerning
luminosity,
still a unique facility
while EIC is not running



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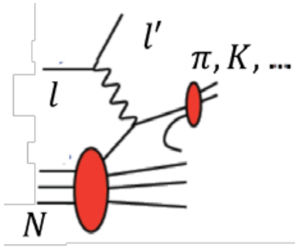

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μ^+ **muon beam, 160** (190) **GeV/c**, -80% longitudinal polarisation

polarised deuteron target

2002, 2003, 2004
20% **transverse**, 80% **longitudinal**

2006 100% **longitudinal**

unpolarised deuteron

polarised proton target

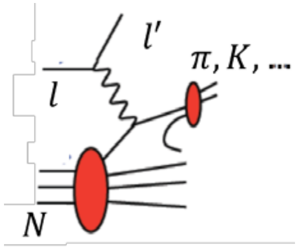
2007
50% **transverse**, 50% **longitudinal**

2010 100% **transverse**, 2011 100% **longitudinal**

unpolarised proton

2016, 2017
in parallel with DVCS

Semi-Inclusive Deep Inelastic Scattering



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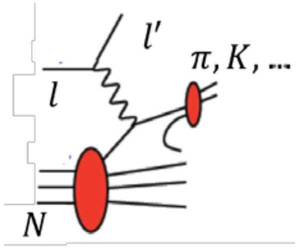
a full year of running with the
transversely polarised deuteron target in **2021** (after the LS2)
to complete the transverse spin program has been approved by CERN

Semi-Inclusive Deep Inelastic Scattering



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2016, 2017 in parallel with DVCS

Y. Bedfer 13 Sep, 16:40
Nucleon helicity structure

A. Moretti 12 Sep 14:30
A. Kerbizi 12 Sep 14:55
this session
F. Kunne 13 Sep 14:50
Nucleon helicity structure

F. Bradamante 11 Sep 14:55
this session

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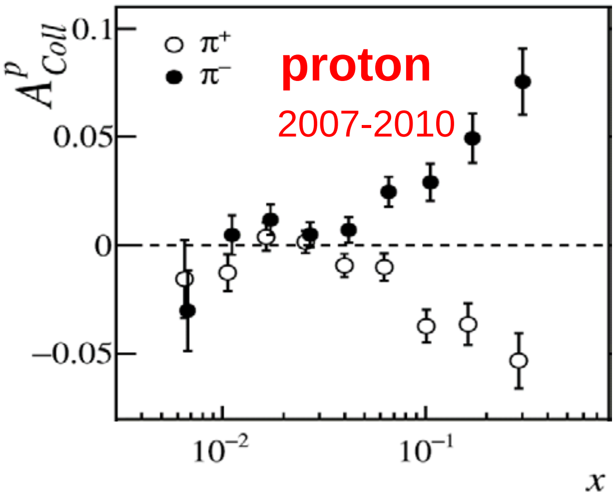
SIDIS off transversely polarised targets
some results

SIDIS off transversely polarised targets

some results

$l\, N^{\uparrow} \rightarrow l'\, h\, X$

Collins asymmetry amplitude of the modulation $\sin(\phi_h + \phi_s - \pi)$ $\sim h_1 \otimes H_1^{\perp}$



PLB693 2010
PLB717 2012
PLB744 2015

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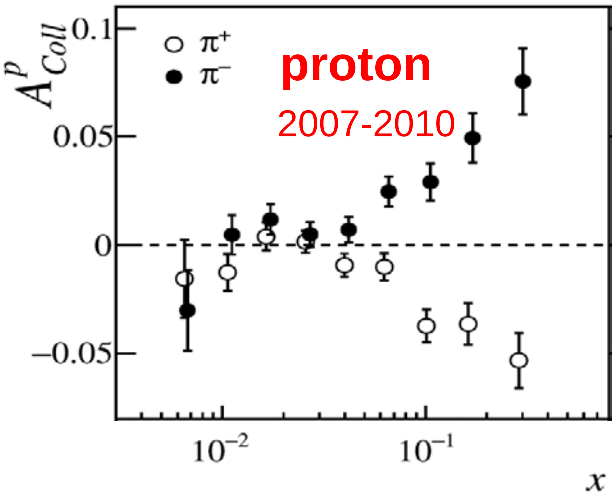
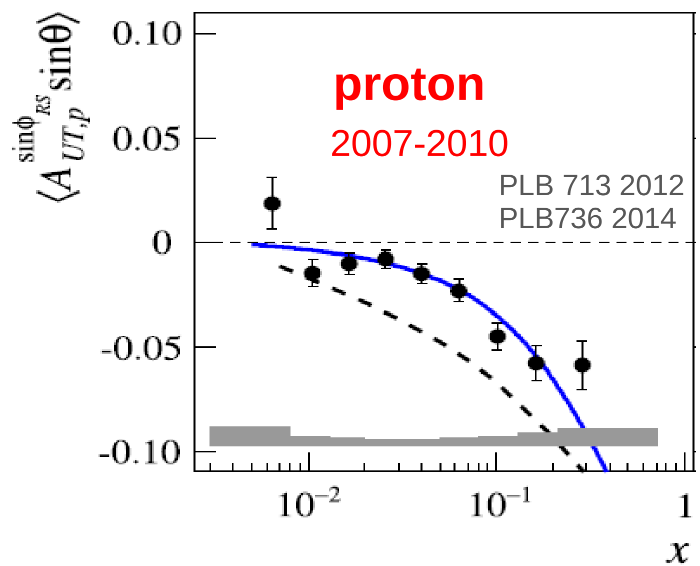


PLB693 2010
PLB717 2012
PLB744 2015

with d, HERMES p, and Belle/BaBar data
→ **transverisy PDF**

$l\, N^{\uparrow} \rightarrow l'\, h_1 h_2\, X$

dihadron asymmetry $\sim h_1\, H_1^{\measuredangle}$



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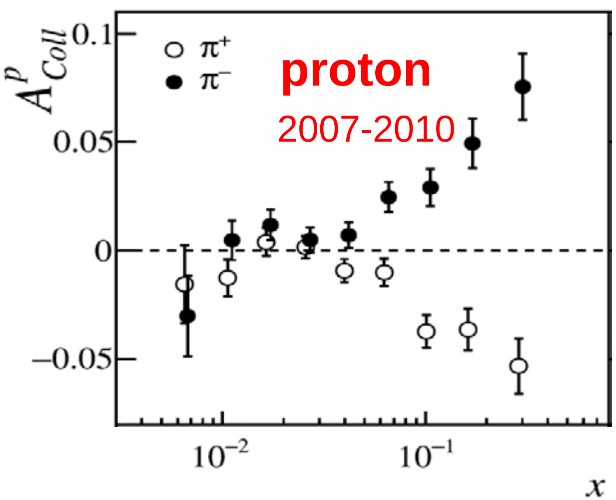

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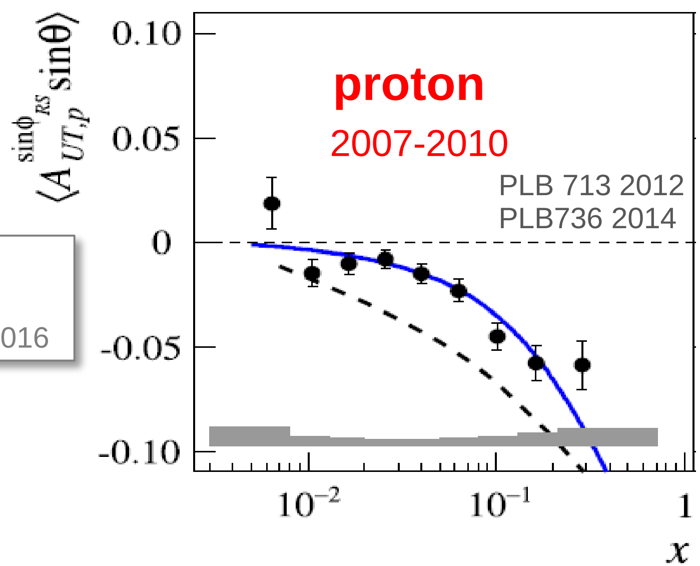
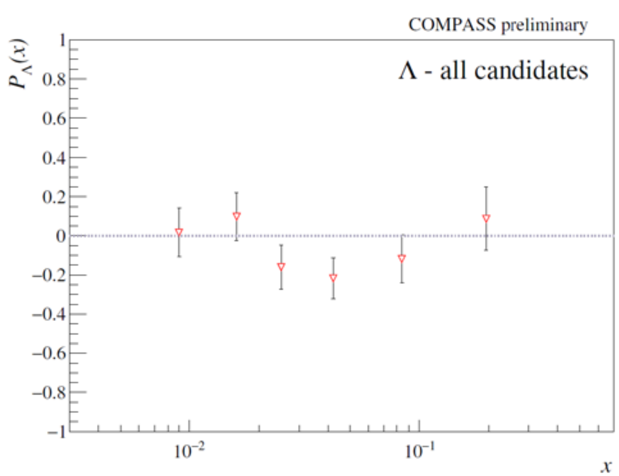


their interplay
PLB753 2016

$l\,N^{\uparrow} \rightarrow l'\,\Lambda(\bar{\Lambda})\,X$

Λ ($\bar{\Lambda}$) polarisation



A. Moretti
13 Sep 17:20
Nucleon helicity structure

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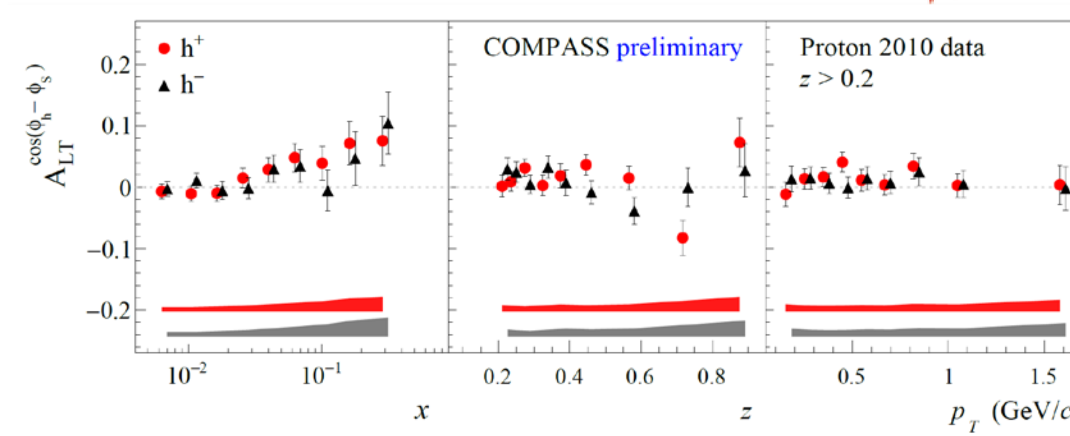
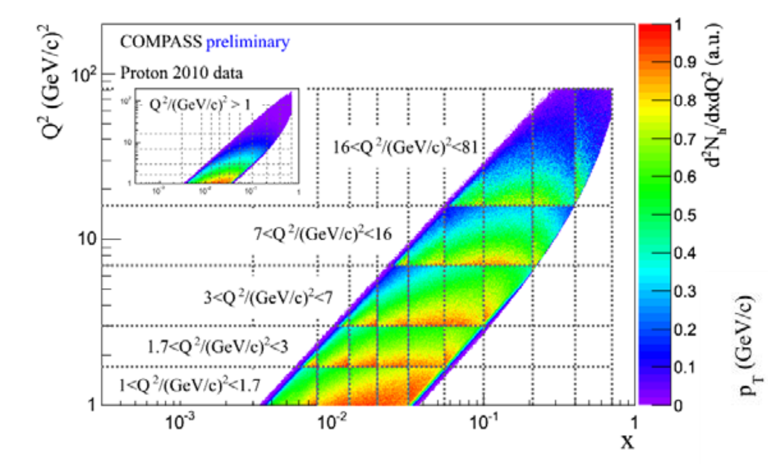
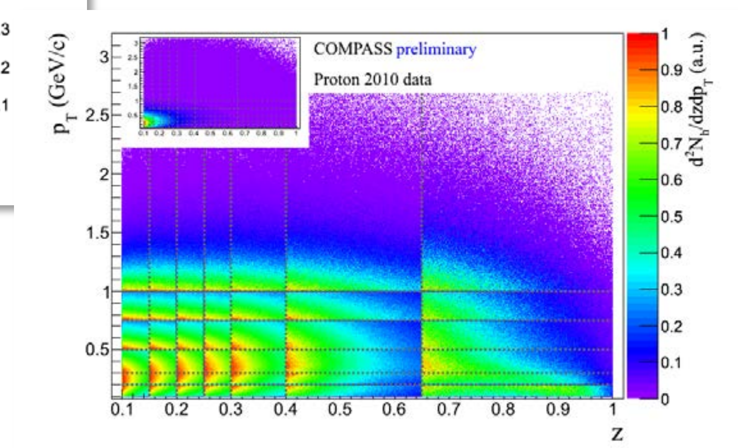


- other Transverse Spin Asymmetries beyond Collins and Sivers

- multidimensional analysis of all the proton TSAs





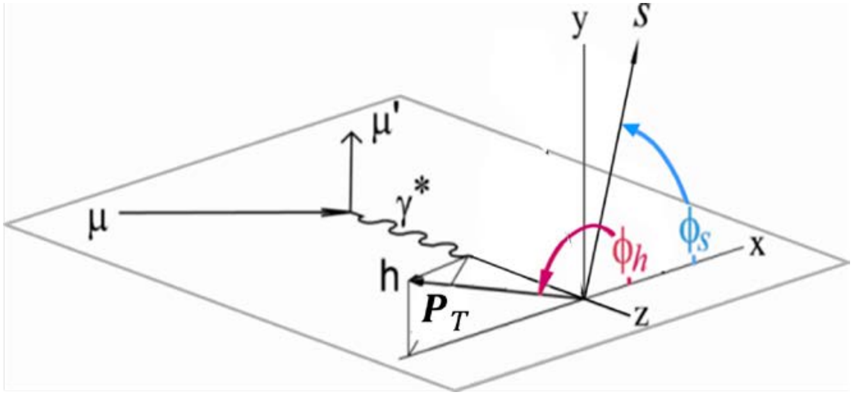
the Sivers asymmetry

the Sivers asymmetry

$l\,N^{\uparrow} \rightarrow l'\,h\,X$

Sivers asymmetry amplitude of the $\sin\Phi_{Siv} \equiv \sin(\phi_h - \phi_S)$ modulation

$\sim f_{1T}^{\perp} \otimes D_1$



the Sivers function $f_{1T}^{\perp}$ is the most famous of the Transverse Momentum Dependent parton distribution functions

it gives the correlation between the parton transverse momentumand the nucleon transverse polarisation

it requires final/initial-state interactions

should change sign from SIDIS to Drell-Yan (important test !!)

see next talk (J. Matousek)

the Sivers asymmetry
some results

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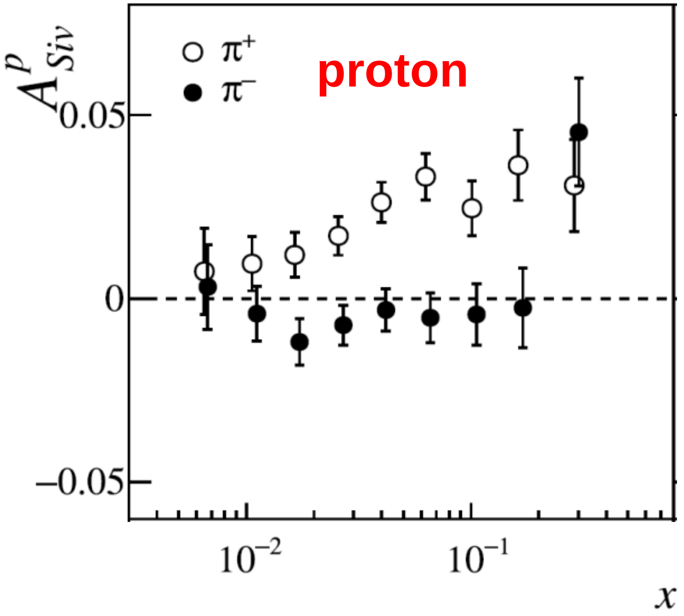

PLB693 2010
PLB717 2012
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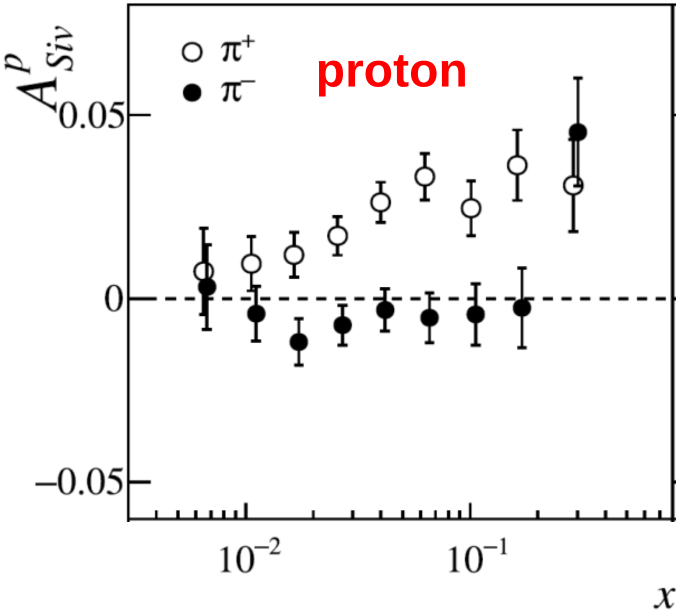
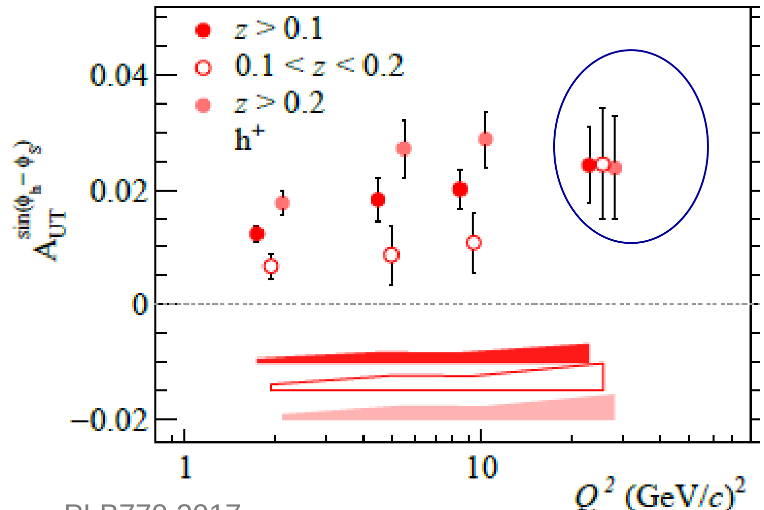


PLB693 2010
PLB717 2012
PLB744 2015

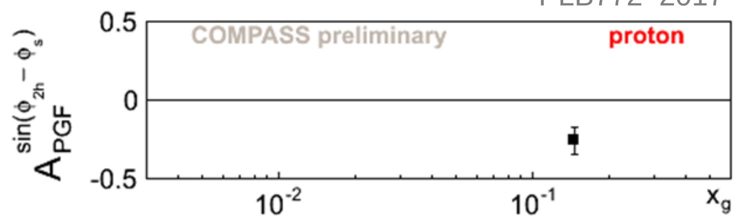
measured on p also at high Q^2 for direct comparison with Drell-Yan

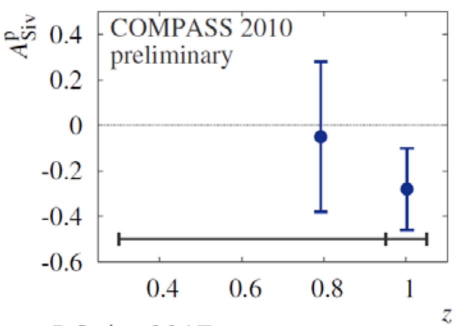


PLB770 2017

gluon Sivers related TSAs:
high P_T hadron pairs and
J/Ψ production

PLB772 2017





DSpin 2017

the Sivers asymmetry
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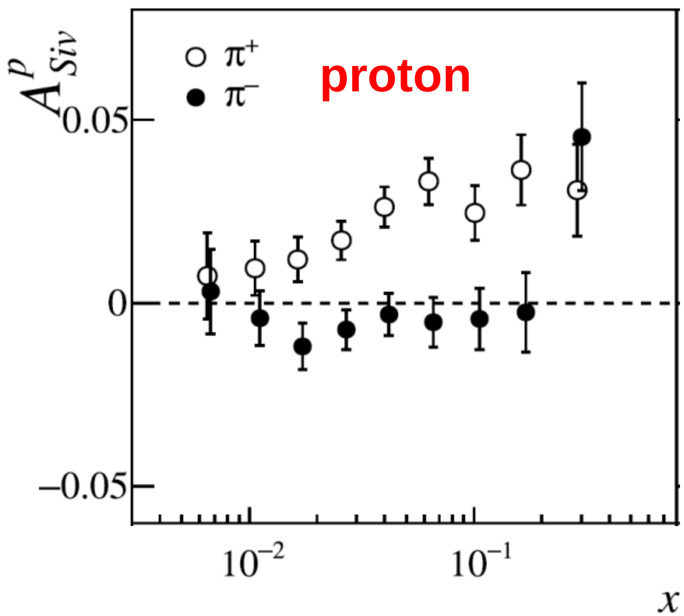

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PLB717 2012
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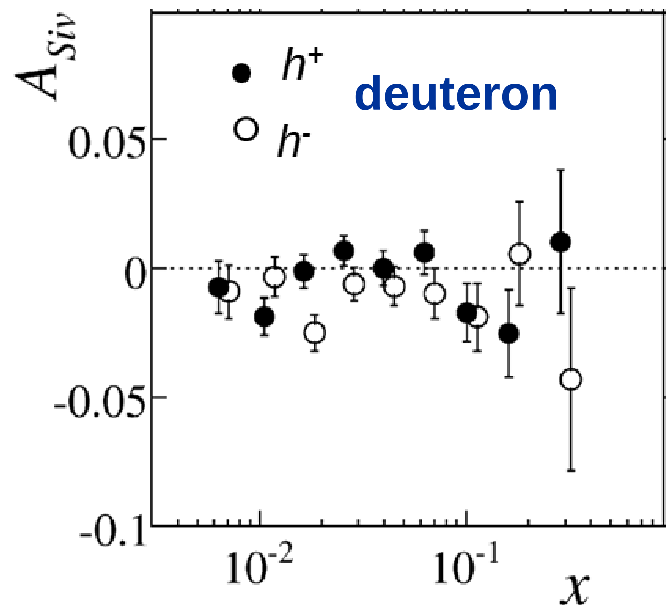


PRL94 2005
NPB765 2007
PLB673 2009

→ **Sivers PDF**

usually using also the HERMES proton data

the Sivers asymmetry

is associated to the amplitude σ_S of the $\sin\Phi_{Siv} \equiv \sin(\phi_h - \phi_S)$ modulation

$$A_{Siv} = \frac{\sigma_S}{\sigma_U}$$

the Sivers asymmetry

is associated to the amplitude σ_S of the $\sin\Phi_{Siv} \equiv \sin(\phi_h - \phi_S)$ modulation

$$A_{Siv} = \frac{\sigma_S}{\sigma_U}$$

at leading twist and leading order in QCD it is

$$A_{Siv}(x,z,P_T) = \frac{\sum_q e_q^2 x C\left[\frac{\boldsymbol{P_T}\cdot\boldsymbol{k}_T}{MP_T} f_{1T}^{\perp q}(x,k_T^2)\, D_1^q(z,p_T^2)\right]}{\sum_q e_q^2 x C\left[f_1^q\,(x,k_T^2)\, D_1^q(z,p_T^2)\right]}$$

transverse momentum of the hadron

transverse momentum of the q with respect to the nucleon direction

transverse momentum of the hadron with respect to the direction of the fragmenting quark

transverse momentum convolutions

$$C\left[f_1^q\, D_1^q\right] = \int d^2\boldsymbol{k}_T \int d^2\boldsymbol{p}_T\, \delta^2(z\boldsymbol{k}_T + \boldsymbol{p}_T - \boldsymbol{P}_T)\, f_1^q(x,k_T^2)\, D_1^q(z,p_T^2)$$

$$C\left[\frac{\boldsymbol{P_T}\cdot\boldsymbol{k}_T}{MP_T} f_{1T}^{\perp(1)q}\, D_1^q\right] = \int d^2\boldsymbol{k}_T \int d^2\boldsymbol{p}_T\, \delta^2(z\boldsymbol{k}_T + \boldsymbol{p}_T - \boldsymbol{P}_T)\,\frac{\boldsymbol{P_T}\cdot\boldsymbol{k}_T}{MP_T} f_{1T}^{\perp q}(x,k_T^2)\, D_1^q(z,p_T^2)$$

the Sivers asymmetry

is associated to the amplitude σ_S of the $\sin\Phi_{Siv} \equiv \sin(\phi_h - \phi_S)$ modulation

$$A_{Siv} = \frac{\sigma_S}{\sigma_U}$$

at leading twist and leading order in QCD it is

$$A_{Siv}(x,z,P_T) = \frac{\sum_q e_q^2 x C\left[\frac{\boldsymbol{P_T}\cdot\boldsymbol{k}_T}{MP_T} f_{1T}^{\perp q}(x,k_T^2)\, D_1^q(z,p_T^2)\right]}{\sum_q e_q^2 x C\left[f_1^q(x,k_T^2)\, D_1^q(z,p_T^2)\right]}$$

when integrating over $\boldsymbol{P_T}$:

$$A_{Siv}(x,z) = \frac{\sum_q e_q^2 x \int d^2\boldsymbol{P_T} C\left[\frac{\boldsymbol{P_T}\cdot\boldsymbol{k}_T}{MP_T} f_{1T}^{\perp q}(x,k_T^2)\, D_1^q(z,p_T^2)\right]}{\sum_q e_q^2\, x f_1^q(x)\, D_1^q(z)}$$

cannot be analytically evaluated in the general case:

to disentangle $f_{1T}^{\perp}$ and D_1 , and **extract the Sivers function** assumptions for the transverse-momentum dependence of the distribution and fragmentation functions are needed

assuming a Gaussian dependence ...

the Sivers asymmetry

assuming a Gaussian dependence

$$A_{Siv,G}(x,z) = \frac{a_G \sum_q e_q^2 \, x f_{1T}^{\perp(1)q}(x) \, z D_1^q(z)}{\sum_q e_q^2 \, x f_1^q(x) \, D_1^q(z)}$$

$$a_G = \frac{\sqrt{\pi} M}{\sqrt{\langle p_T^2 \rangle + z^2 \langle k_T^2 \rangle_S}} \simeq \frac{\pi M}{2\langle P_T \rangle}$$

($a_G \cong 1$ for the Collins asymmetry)

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

the Sivers asymmetry

assuming a Gaussian dependence

$$A_{Siv,G}(x,z) = \frac{a_G \sum_q e_q^2 \, x f_{1T}^{\perp(1)q}(x) \, z D_1^q(z)}{\sum_q e_q^2 \, x f_1^q(x) \, D_1^q(z)} \qquad a_G = \frac{\sqrt{\pi} M}{\sqrt{\langle p_T^2 \rangle + z^2 \langle k_T^2 \rangle_S}} \simeq \frac{\pi M}{2\langle P_T \rangle}$$

($a_G \cong 1$ for the Collins asymmetry)

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

but the assumption introduces a bias into the extraction of the Sivers function

this problem can be avoided measuring the P_T weighted asymmetries:

$$w = P_T / zM \qquad A_{Siv}^{w}(x,z) = \frac{\sum_q e_q^2 x \int d^2\boldsymbol{P_T} \frac{P_T}{zM} \, C\left[\frac{\boldsymbol{P_T}\cdot\boldsymbol{k}_T}{M P_T} f_{1T}^{\perp q}(x,k_T^2) \, D_1^q(z,p_T^2)\right]}{\sum_q e_q^2 \, x f_1^q(x) \, D_1^q(z)}$$

$$= 2 \frac{\sum_q e_q^2 \, x f_{1T}^{\perp(1)q}(x) \, D_1^q(z)}{\sum_q e_q^2 \, x f_1^q(x) \, D_1^q(z)}$$

$$w' = P_T / M \qquad A_{Siv}^{w'}(x,z) = 2 \frac{\sum_q e_q^2 \, x f_{1T}^{\perp(1)q}(x) \, z D_1^q(z)}{\sum_q e_q^2 \, x f_1^q(x) \, D_1^q(z)} \qquad \frac{A_{Siv}^{w'}(x,z)}{A_{Siv,G}(x,z)} = \frac{4\langle P_T \rangle}{\pi M}$$

the weighted Sivers asymmetry

we have measured
the weighted Sivers asymmetries on transversely polarised protons vs x and z
using as weights both $w = P_T/zM$ and $w' = P_T/M$

paper submitted

the weighted Sivers asymmetry

COMPASS

we have measured
the weighted Sivers asymmetries on transversely polarised protons vs x and z
using as weights both $w = P_T/zM$ and $w' = P_T/M$

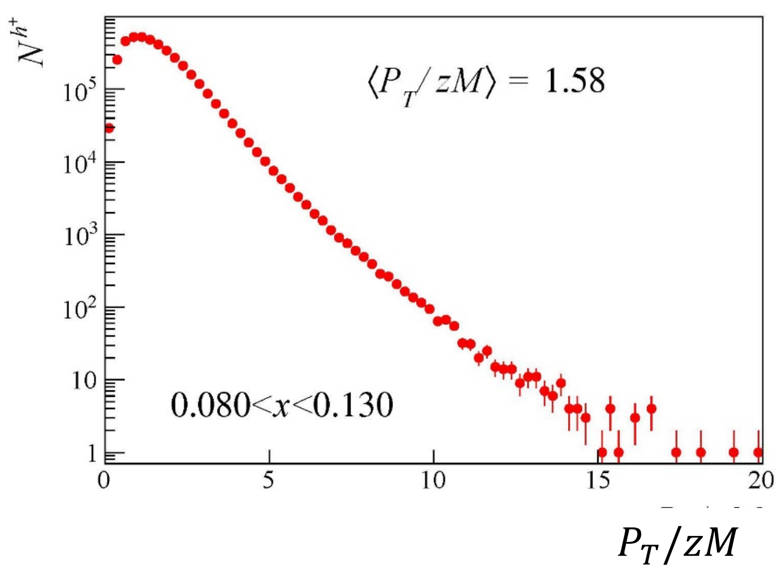
paper submitted

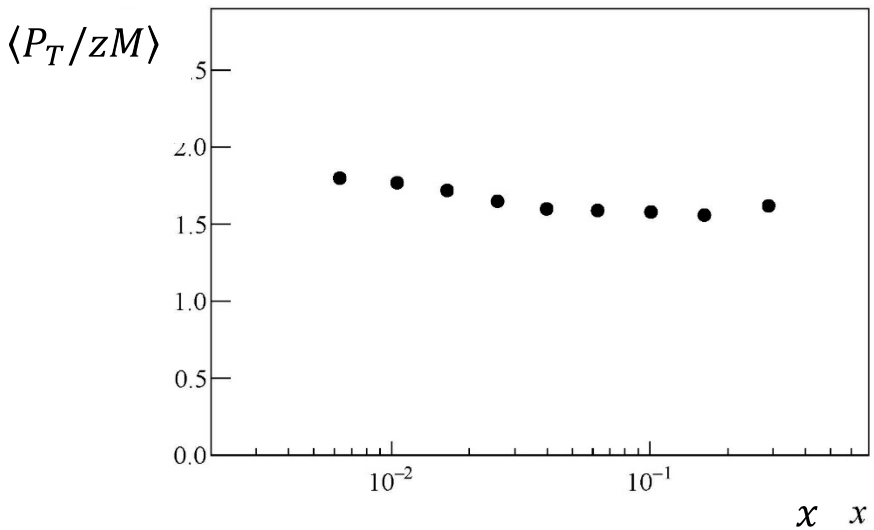
we have used the 2010 data, already used for the standard analyses
with the same standard cuts to select DIS events

$$Q^2 > 1\ \mathrm{GeV}^2,\quad 0.1 < y < 0.9,\ W > 5\ \mathrm{GeV/c}^2$$

and charged final state hadrons

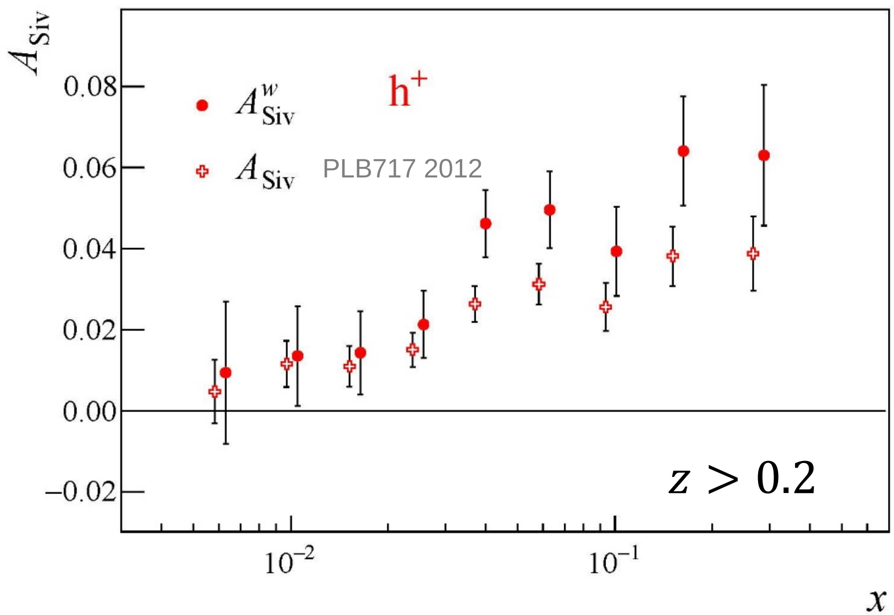
$$P_T > 0.1\ \mathrm{GeV/c},\ z > 0.2 \text{ and } 0.1 < z < 0.2$$

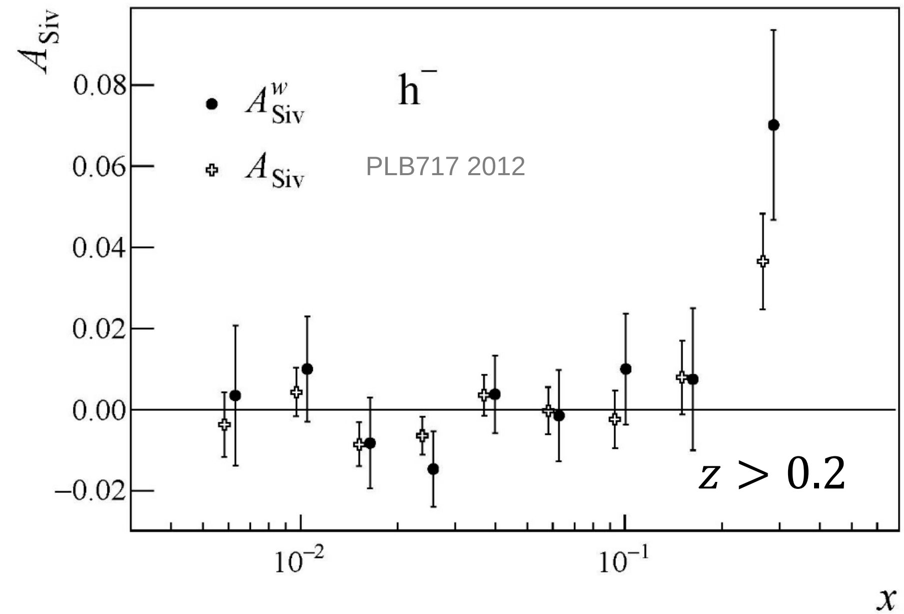




the P_T/zM weighted Sivers asymmetry
a few results

$$A^{w}_{Siv}(x) = 2\frac{\sum_q e_q^2 x f_{1T}^{\perp(1)q}(x)\widetilde{D}_1^q}{\sum_q e_q^2 x f_1^q(x)\widetilde{D}_1^q} \qquad \widetilde{D}_1^q = \int_{z_{min}}^{z_{max}} dz D_1^q(z)$$

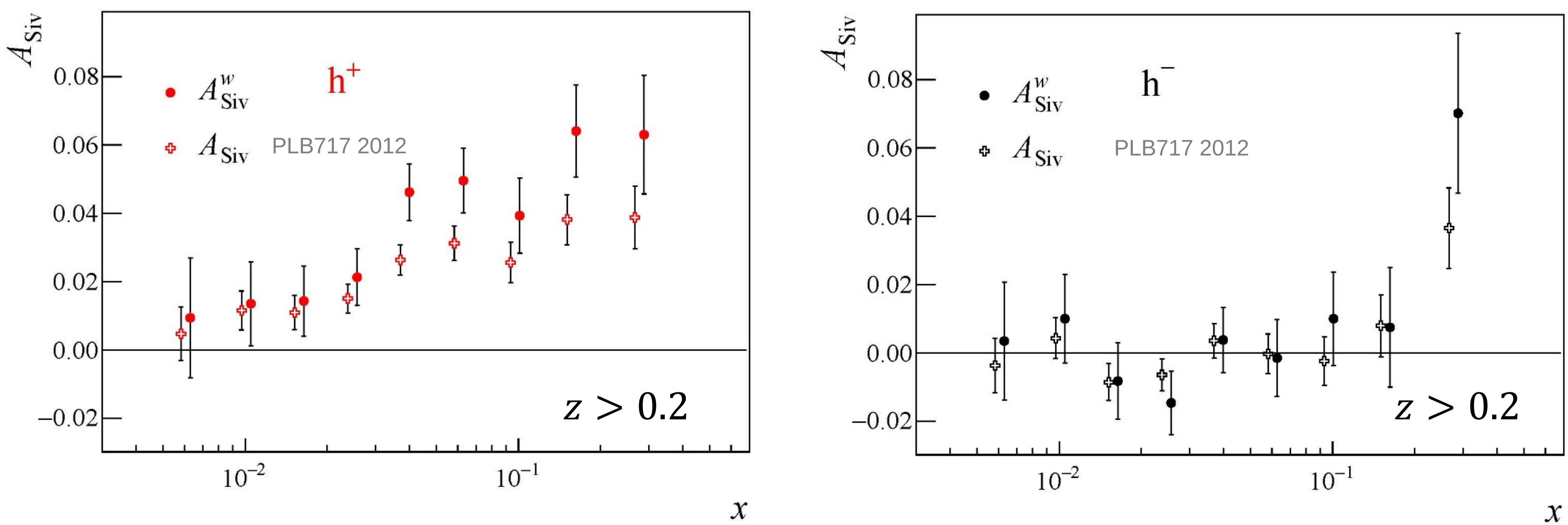




the trends of the weighted and unweighted asymmetries are similar
both for positive and negative hadrons

the P_T/zM weighted Sivers asymmetry
a few results

$$A^w_{Siv}(x) = 2\frac{\sum_q e_q^2 x f_{1T}^{\perp(1)q}(x)\widetilde{D}_1^q}{\sum_q e_q^2 x f_1^q(x)\widetilde{D}_1^q} \qquad \widetilde{D}_1^q = \int_{z_{min}}^{z_{max}} dz D_1^q(z)$$



the trends of the weighted and unweighted asymmetries are similar
both for positive and negative hadrons

positive hadrons: asymmetry clearly different from zero, in particular at large x

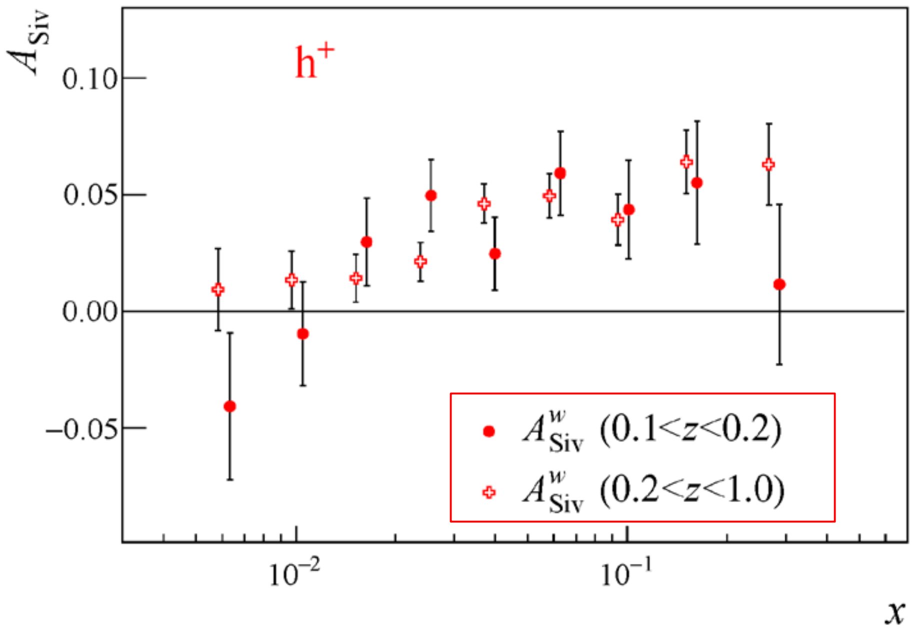
ratio $\sim\langle P_T/zM\rangle$

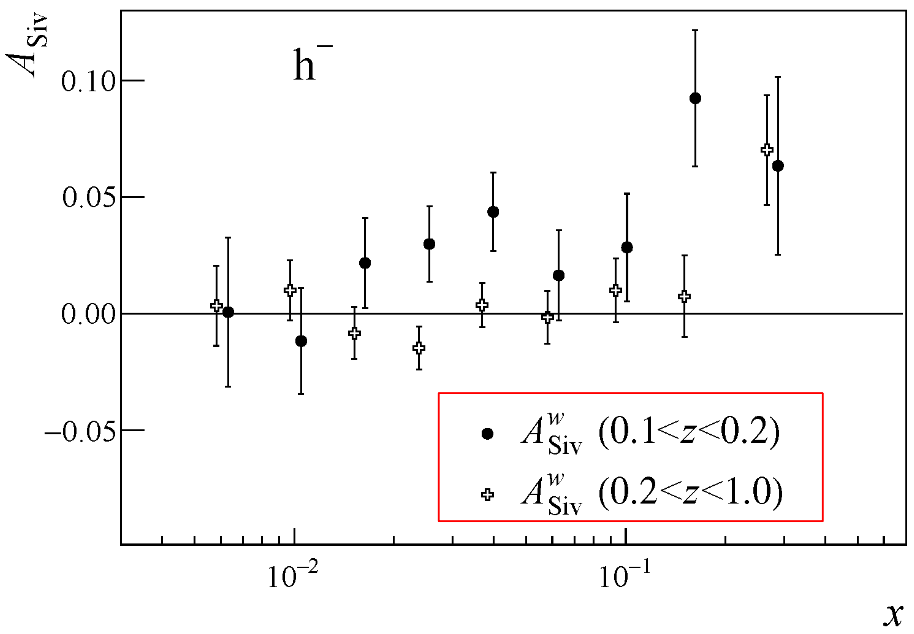
assuming u-dominance, $A^{w,+}_{Siv}(x) \simeq 2\, f_{1T}^{\perp(1)u}(x)/f_1^u(x)$

and our result represents the first direct measurement of $f_{1T}^{\perp(1)u}(x)$

the P_T/zM weighted Sivers asymmetry
a few results

$$A^w_{Siv}(x) = 2\frac{\sum_q e_q^2 x f_{1T}^{\perp(1)q}(x)\widetilde{D}_1^q}{\sum_q e_q^2 x f_1^q(x)\widetilde{D}_1^q} \qquad \widetilde{D}_1^q = \int_{z_{min}}^{z_{max}} dz D_1^q(z)$$





positive hadrons: similar asymmetries at low and higher z

u-quark dominance

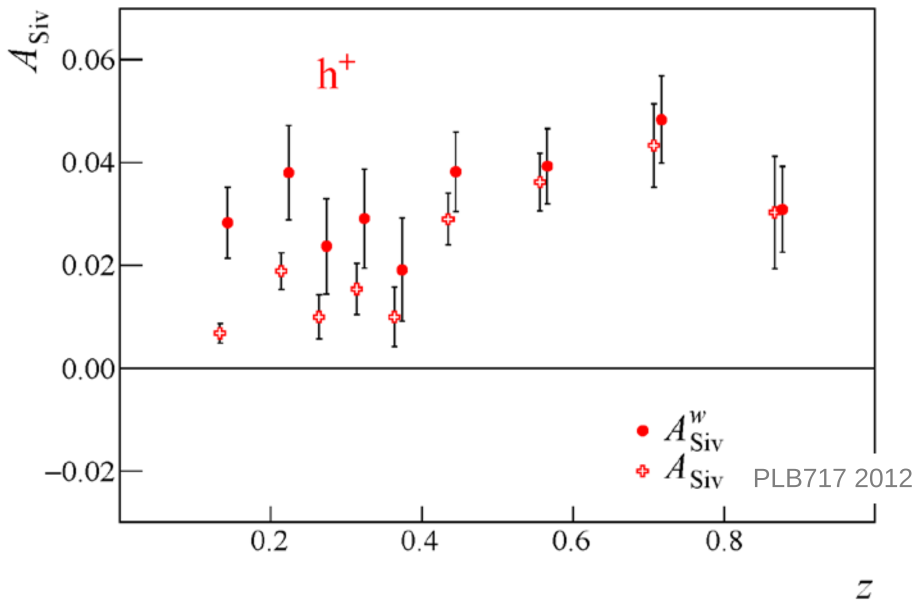
supports the idea that factorisation works at small z too, in our kinematic range

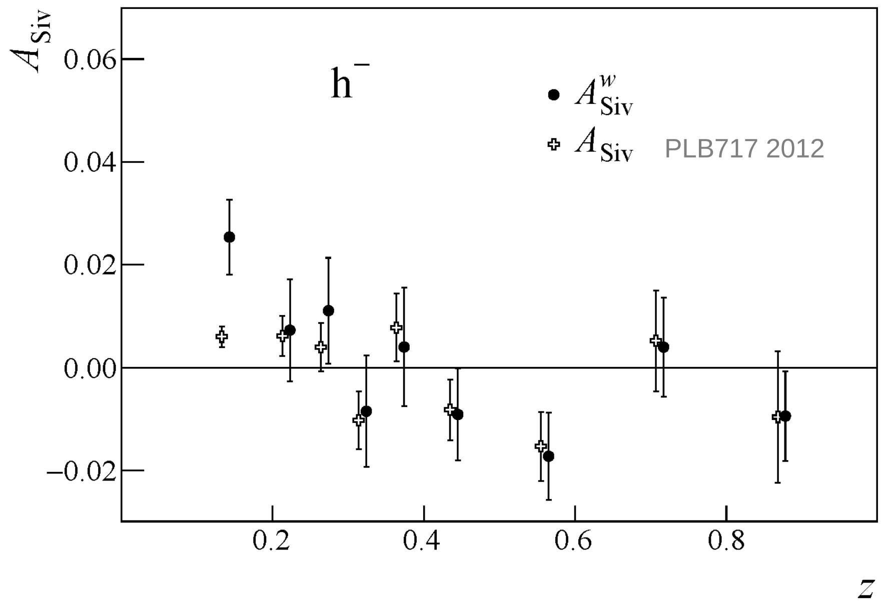
negative hadrons: at small z the asymmetry increase, as expected

similar favored and unfavored FFs, the u-quark contribution increases

the P_T/zM weighted Sivers asymmetry
a few results

$$A^w_{Siv}(z)$$





positive hadrons: almost constant values vs z -- u-quark dominance
supports the idea that factorisation works at small z in our kinematic range

negative hadrons: at small z the asymmetry increases, as already seen

the weighted Sivers asymmetry
results

summary:

- the results confirm the naïve expectations
- no indication that we are nor in the current fragmentation region or that factorisation does not work in our kinematic range

having the P_T/z weighted asymmetries, it is straightforward to extract the first transverse moment of the Sivers function

new

extraction of $f_{1T}^{\perp(1)}(x)$

P_T/zM weighted asymmetries for positive e negative hadrons:

$$A_{Siv}^{w,\pm}(x) = 2\frac{\sum_q e_q^2 x f_{1T}^{\perp(1)q}(x)\widetilde{D}_1^{q,\pm}}{\sum_q e_q^2 x f_1^q(x)\widetilde{D}_1^{q,\pm}}$$

$$\widetilde{D}_1^{q,\pm} = \int_{z_{min}}^{z_{max}} dz D_1^{q,\pm}(z)$$

$f_1^q, \widetilde{D}_1^{q,\pm}$ from parametrisations

extraction of $f_{1T}^{\perp(1)}(x)$

P_T/zM weighted asymmetries for positive e negative hadrons:

$$A_{Siv}^{w,\pm}(x) = 2\frac{\sum_q e_q^2 x f_{1T}^{\perp(1)q}(x)\widetilde{D}_1^{q,\pm}}{\sum_q e_q^2 x f_1^q(x)\widetilde{D}_1^{q,\pm}} \qquad \widetilde{D}_1^{q,\pm} = \int_{z_{min}}^{z_{max}} dz D_1^{q,\pm}(z)$$

$f_1^q, \widetilde{D}_1^{q,\pm}$ from parametrisations (CTEQ5D and DSS)

neglecting the sea-quark Sivers distributions, it is

$$A_{Siv}^{w,\pm} = 2\frac{4xf_{1T}^{\perp(1)u_v}\widetilde{D}_1^{u,\pm} + xf_{1T}^{\perp(1)d_v}\widetilde{D}_1^{d,\pm}}{\delta^{\pm}} \qquad \delta^{\pm} = 9\,\Sigma_q e_q^2 x f_1^q \widetilde{D}_1^q$$

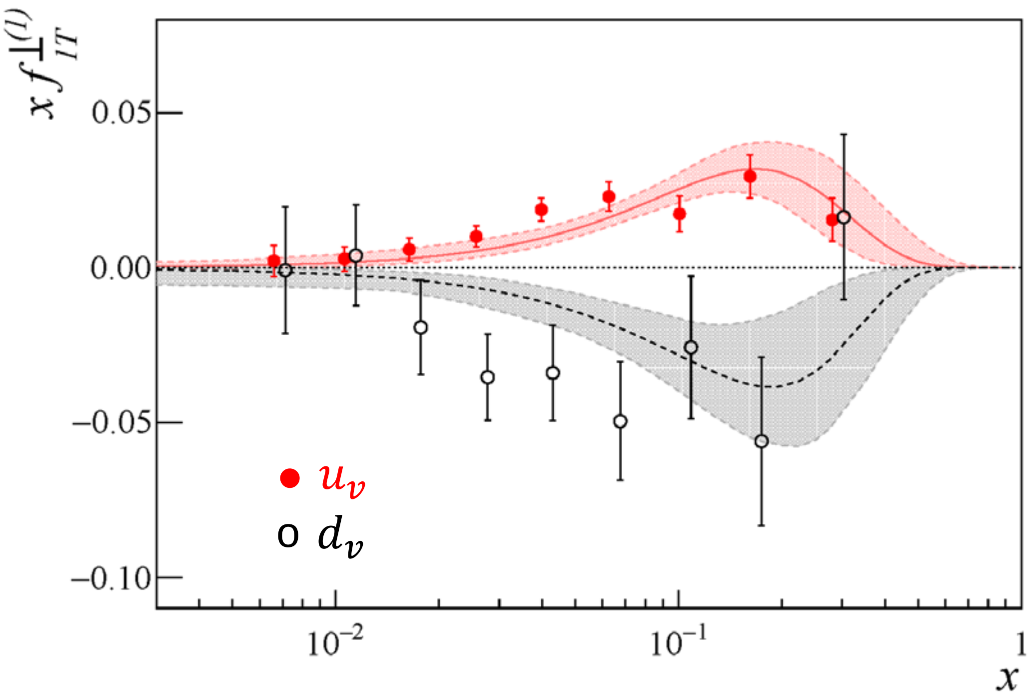
and

$$xf_{1T}^{\perp(1)u_v} = \frac{1}{8}\frac{\delta^+ A_{Siv}^{w,+}\widetilde{D}_1^{d,-} - \delta^- A_{Siv}^{w,-}\widetilde{D}_1^{d,+}}{\widetilde{D}_1^{u,+}\widetilde{D}_1^{d,-} - \widetilde{D}_1^{d,+}\widetilde{D}_1^{u,-}}$$

$$xf_{1T}^{\perp(1)d_v} = \frac{1}{2}\frac{\delta^- A_{Siv}^{w,-}\widetilde{D}_1^{u,+} - \delta^+ A_{Siv}^{w,+}\widetilde{D}_1^{u,-}}{\widetilde{D}_1^{u,+}\widetilde{D}_1^{d,-} - \widetilde{D}_1^{d,+}\widetilde{D}_1^{u,-}}$$

extraction of $f_{1T}^{\perp(1)}(x)$

results



bars: statistical uncertainties only

at the Q^2 of the measurement (1.24 to $25.6\ \mathrm{GeV}^2$)

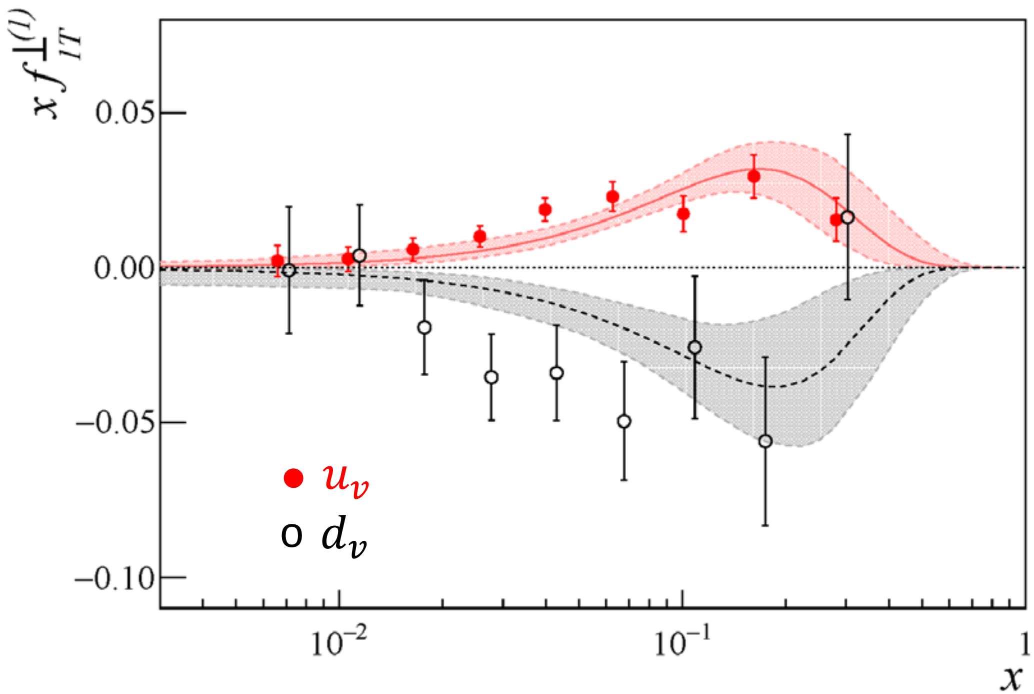
- values clearly different from zero
- much larger uncertainties on $f_{1T}^{\perp(1)d_v}$ than on $f_{1T}^{\perp(1)u_v}$ because of the lack of corresponding deuteron data

$$x f_{1T}^{\perp(1)u_v} = \frac{1}{8}\,\frac{\delta^{+} A_{Siv}^{w,+}\tilde{D}_1^{d,-} - \delta^{-} A_{Siv}^{w,-}\tilde{D}_1^{d,+}}{\tilde{D}_1^{u,+}\tilde{D}_1^{d,-} - \tilde{D}_1^{d,+}\tilde{D}_1^{u,-}}$$

$$x f_{1T}^{\perp(1)d_v} = \frac{1}{2}\,\frac{\delta^{-} A_{Siv}^{w,-}\tilde{D}_1^{u,+} - \delta^{+} A_{Siv}^{w,+}\tilde{D}_1^{u,-}}{\tilde{D}_1^{u,+}\tilde{D}_1^{d,-} - \tilde{D}_1^{d,+}\tilde{D}_1^{u,-}}$$

extraction of $f_{1T}^{\perp(1)}(x)$

results



bars: statistical uncertainties only

curves and bands:
fit to the HERMES p and COMPASS p and d data by the Torino group
$Q^2 = 4\ \mathrm{GeV}^2$
PRD 86, 2012

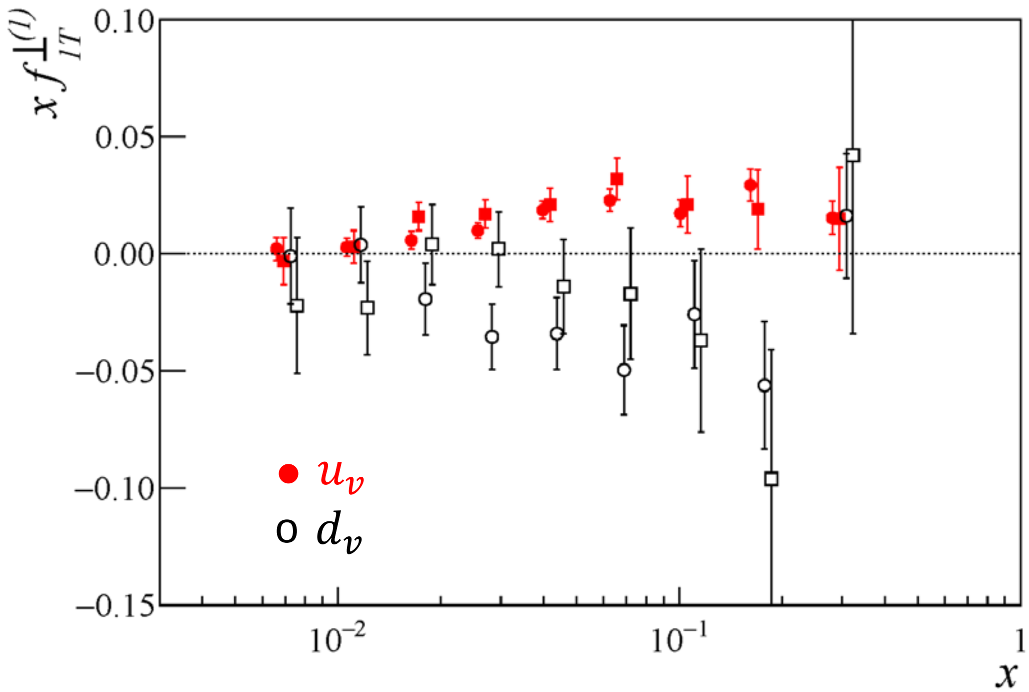
at the Q^2 of the measurement
(1.24 to $25.6\ \mathrm{GeV}^2$)

- values clearly different from zero
- much larger uncertainties on $f_{1T}^{\perp(1)d_v}$ than on $f_{1T}^{\perp(1)u_v}$ because of the lack of corresponding deuteron data

- substantial agreement with the fit to the HERMES p and the COMPASS p and d data by the Torino group (DGLAP evolution and Gaussian ansatz), with a slightly different trend for $f_{1T}^{\perp(1)d_v}$

extraction of $f_{1T}^{\perp(1)}(x)$

results

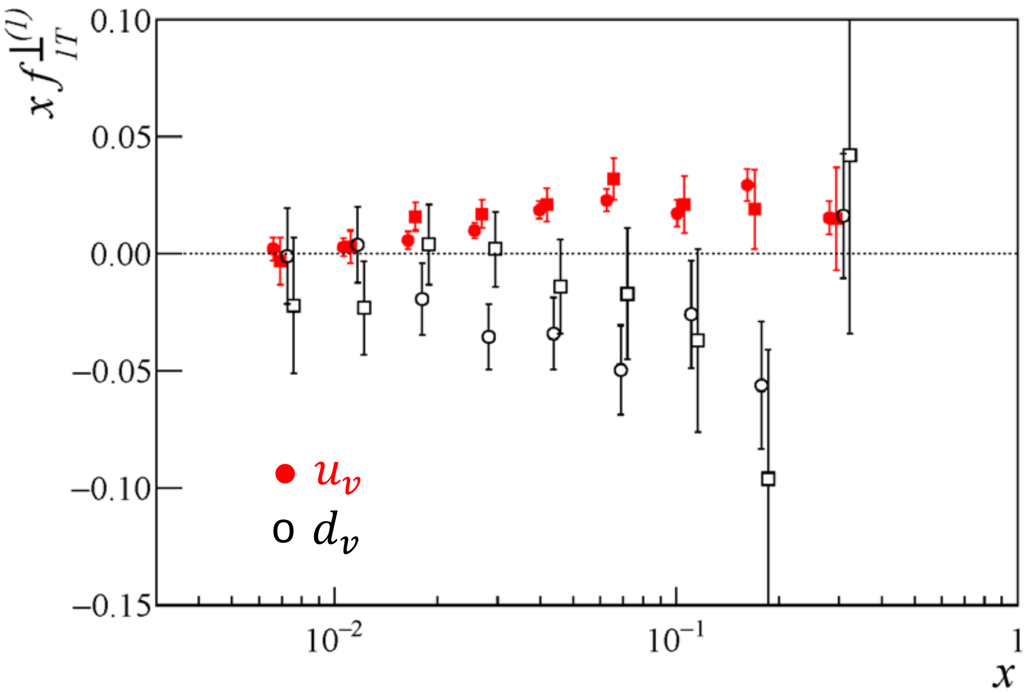


- ❑ previous point-by-point extraction [A.M., F.Bradamante, V.Barone, PRD95, 2017]
  using pion Sivers asymmetries from the COMPASS p and d data,
  no assumptions on the Sivers function of the sea quarks, Gaussian ansatz

  slightly different trend for $f_{1T}^{\perp(1)d_v}$, uncertainties on average larger by a factor ~1.5

extraction of $f_{1T}^{\perp(1)}(x)$

results



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  slightly different trend for $f_{1T}^{\perp(1)d_v}$, uncertainties on average larger by a factor ~1.5

we checked that using the p data only and imposing the sea-quark Sivers functions to be zero, both the central values and the uncertainties become very similar to the present ones

→ the differences are not due to the use of unweighted asymmetries

conclusions

- COMPASS has measured the P_T/zM and the P_T/M weighted Sivers asymmetries in SIDIS off transversely polarised protons for positive and negative hadrons
- the z dependence for positive hadrons agrees with the expectation in the case of u-quark dominance for a measurement performed in the current-fragmentation region
- we have extracted the first moments of the Sivers functions for u_v and d_v quarks without assumptions on the transverse momentum dependence of the partonic and fragmentation functions
    - the results compare well with previous extractions based on the Gaussian ansatz, hinting at its validity in our kinematic domain
    - as in previous works, the d-quark Sivers function is poorly determined because of the lack of data with a transversely polarised deuteron

Thank you