COMPASS results on the Collins and Sivers asymmetries

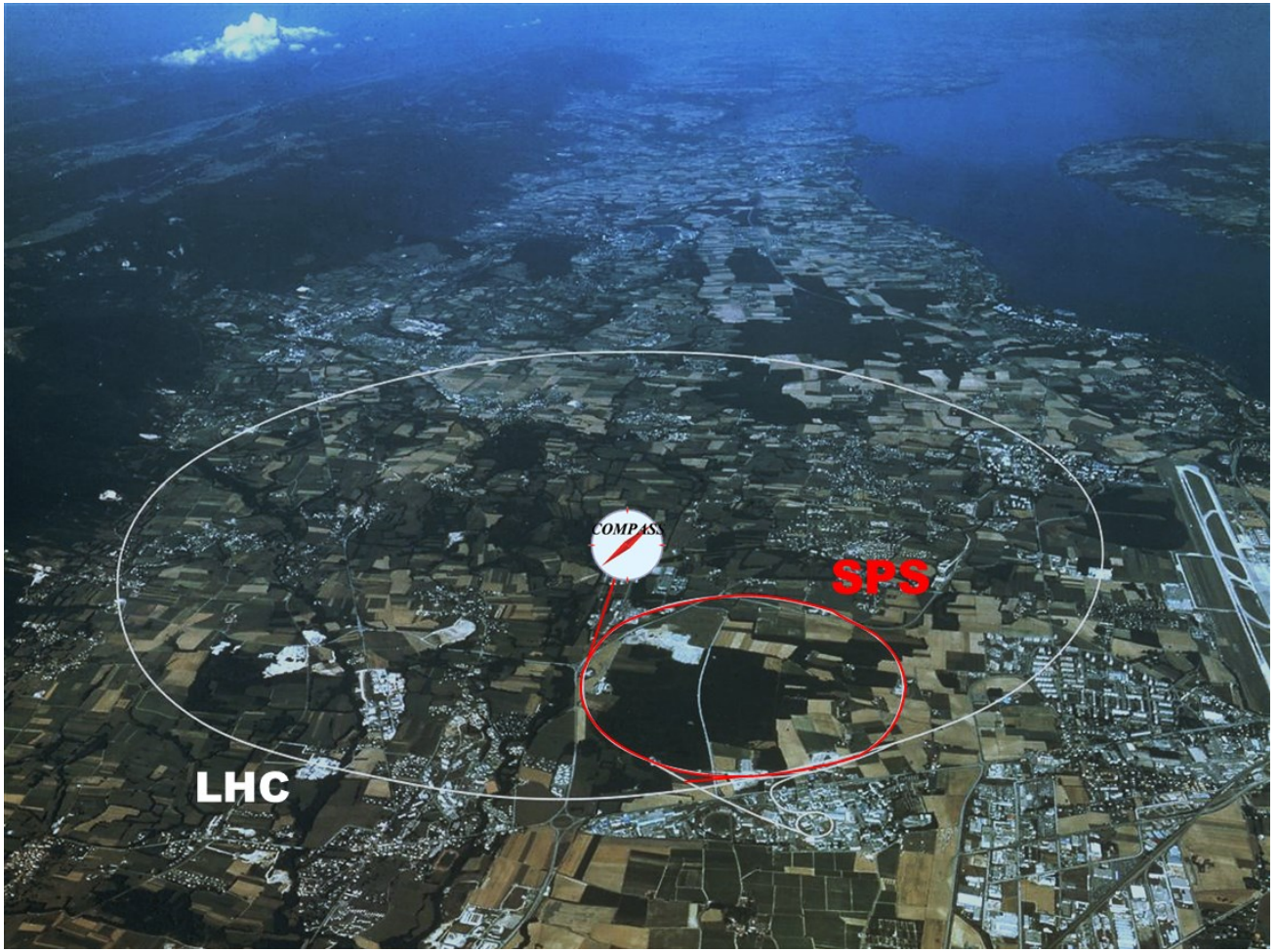
Anna Martin
Trieste University & INFN
on behalf of the
COMPASS Collaboration

COmmon
Muon and
Proton
Apparatus for
Structure and
Spectroscopy

Collaboration
~ 250 physicists
from 25 Institutions
of 11 Countries

fixed target
experiment
at the CERN SPS

data taking: since 2002



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hadron spectroscopy (p, π, K beams)

nucleon structure (with μ beam)

- longitudinal spin structure
- transverse momentum and transverse spin structure

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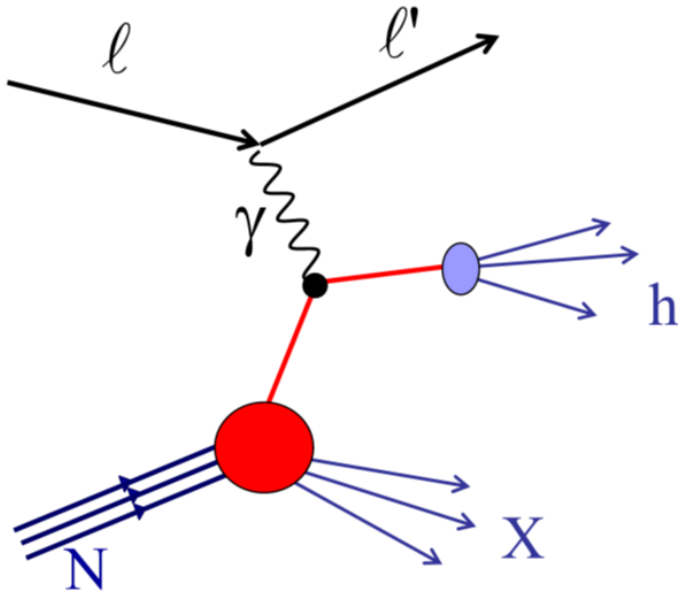
- longitudinal spin structure
- **transverse momentum and transverse spin structure**
  - **results on the Collins and Sivers transverse spin asymmetries in SIDIS**

Semi-Inclusive Deep Inelastic Scattering



$$x = \frac{Q^2}{2P \cdot q}$$

$$Q^2 = -q^2$$

$$y = \frac{P \cdot q}{P \cdot \ell} =_{LAB} \frac{E - E'}{E}$$

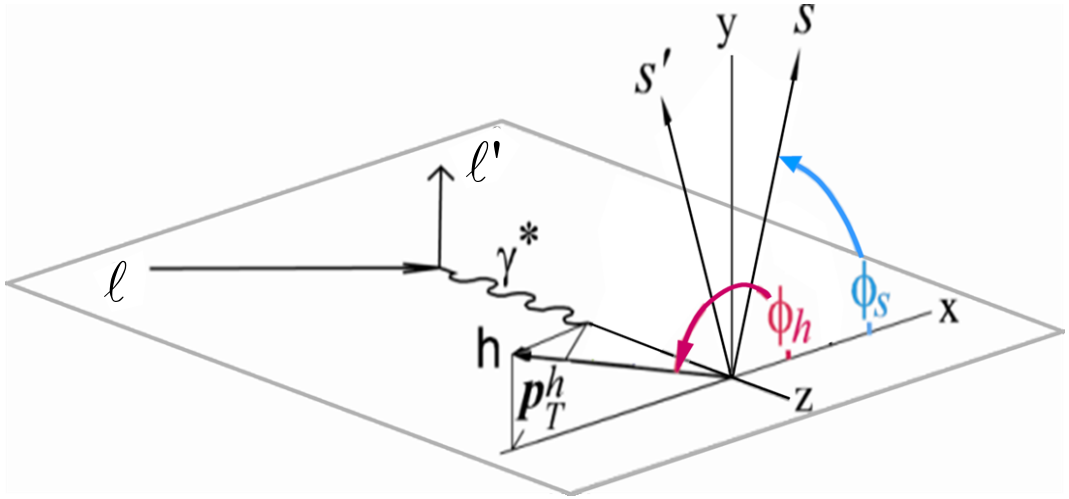
$$W^2 = (P + q)^2$$

$$z = \frac{P \cdot P_h}{P \cdot q} =_{LAB} \frac{E_h}{E - E'}$$

$\boldsymbol{p_T^h}$

$\boldsymbol{\Phi_h}$

$\boldsymbol{\Phi_S}$



Semi-Inclusive Deep Inelastic Scattering

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

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

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

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

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

$$+\varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)}$$

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

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

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

18 structure functions

14 independent azimuthal modulations

all the 14 amplitudes are been measured in COMPASS

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Sivers asymmetry

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

$$+\varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)}$$

Collins asymmetry

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

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

18 structure functions

14 independent azimuthal modulations

all the 14 amplitudes are been measured in COMPASS

SIDIS off transversely polarised nucleons

azimuthal distribution of the inclusively produced hadrons

$$N_h^{\pm}(\phi_h,\phi_S) = N_h^0(\phi_h)\left[1 \pm P_T D_{NN} A_{Coll} \sin(\phi_h+\phi_S+\pi) \pm P_T A_{Siv} \sin(\phi_h-\phi_S) \pm \ldots\right]$$

polarisation direction

nucleon transverse polarisation

spin transfer coefficient

Collins angle

Sivers angle

A_{Coll} and A_{Siv} and the other 6 transverse spin asymmetries are measured by fitting the (ϕ_h,ϕ_S) distributions in the different x, z, p_T^h bins

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$$N_h^{\pm}(\phi_h,\phi_S) = N_h^0(\phi_h)\left[1 \pm P_T D_{NN} A_{Coll} \sin(\phi_h+\phi_S+\pi) \pm P_T A_{Siv} \sin(\phi_h-\phi_S) \pm \ldots\right]$$

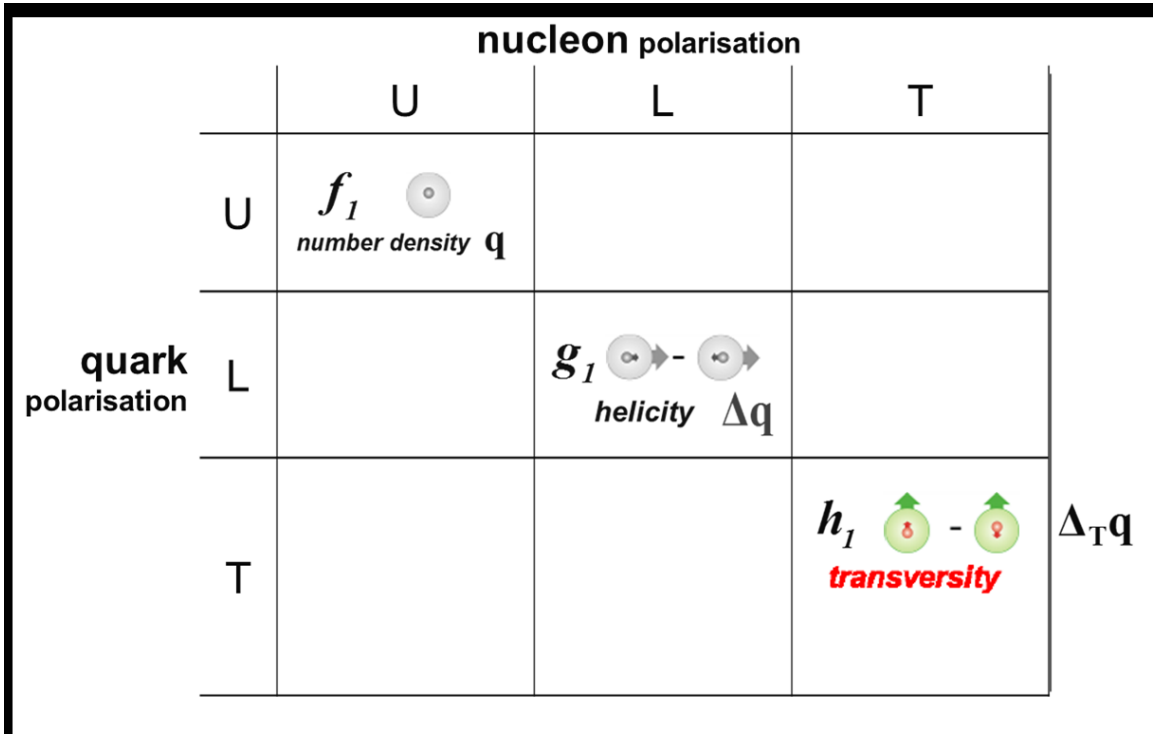
$$A_{Coll} \approx \frac{\sum_q e_q^2 \, h_1^q \otimes H_{1q}^{\perp h}}{\sum_q e_q^2 \, f_1^q \otimes D_{1q}^h}$$

Collins FF BELLE, BaBar

transversity PDF

correlation between the **transverse polarisation** of the nucleon and the transverse polarisation of the quark

quark structure of the nucleon in the collinear case



it is chiral odd

it can not be measured in inclusive DIS, and it is still poorly know

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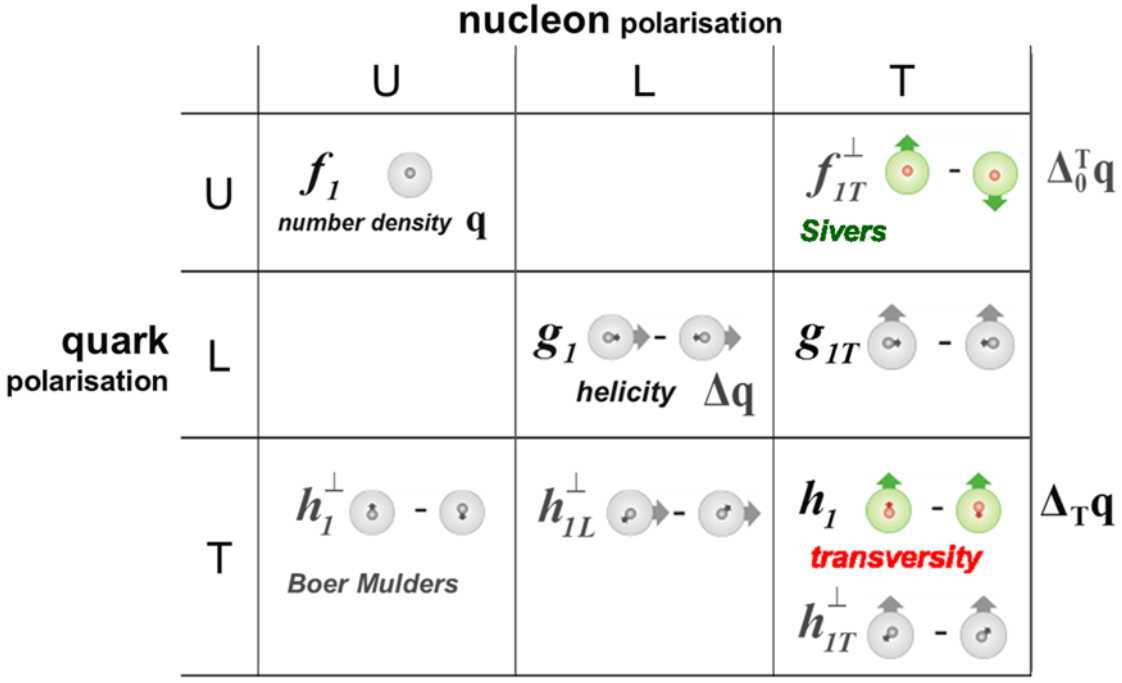
$$N_h^{\pm}(\phi_h,\phi_S) = N_h^0(\phi_h)\left[1 \pm P_T D_{NN} A_{Coll} \sin(\phi_h+\phi_S+\pi) \pm P_T A_{Siv} \sin(\phi_h-\phi_S) \pm \ldots\right]$$

$$A_{Siv} \approx \frac{\sum_q e_q^2 \left(f_{1T}^{\perp q}\right) \otimes D_{1q}^h}{\sum_q e_q^2 f_1^q \otimes D_{1q}^h}$$

Sivers PDF

correlation between the **transverse spin of the nucleon** and the **transverse momentum of the quark** ***sensitive to orbital angular momentum***

the quark structure of the nucleon
at LO with quark intrinsic transverse momentum k_T



T-odd, poorly known

SIDIS off transversely polarised nucleons

azimuthal distribution of the inclusively produced hadrons

$$N_h^{\pm}(\phi_h,\phi_S) = N_h^0(\phi_h)\left[1 \pm P_T D_{NN} A_{Coll} \sin(\phi_h+\phi_S+\pi) \pm P_T A_{Siv} \sin(\phi_h-\phi_S) \pm \ldots\right]$$

transversity PDF

$$A_{Coll} \approx \frac{\sum_q e_q^2 \, h_1^q \otimes H_{1q}^{\perp h}}{\sum_q e_q^2 \, f_1^q \otimes D_{1q}^h}$$

and 2h transverse spin asymmetry

Sivers PDF

$$A_{Siv} \approx \frac{\sum_q e_q^2 \, f_{1T}^{\perp q} \otimes D_{1q}^h}{\sum_q e_q^2 \, f_1^q \otimes D_{1q}^h}$$

the most promising way to access the transversity PDFs and the Sivers PDFs

different targets and PID → flavor separation

the COMPASS spectrometer

designed to

- use high energy beams
- have large angular acceptance
- cover a broad kinematical range

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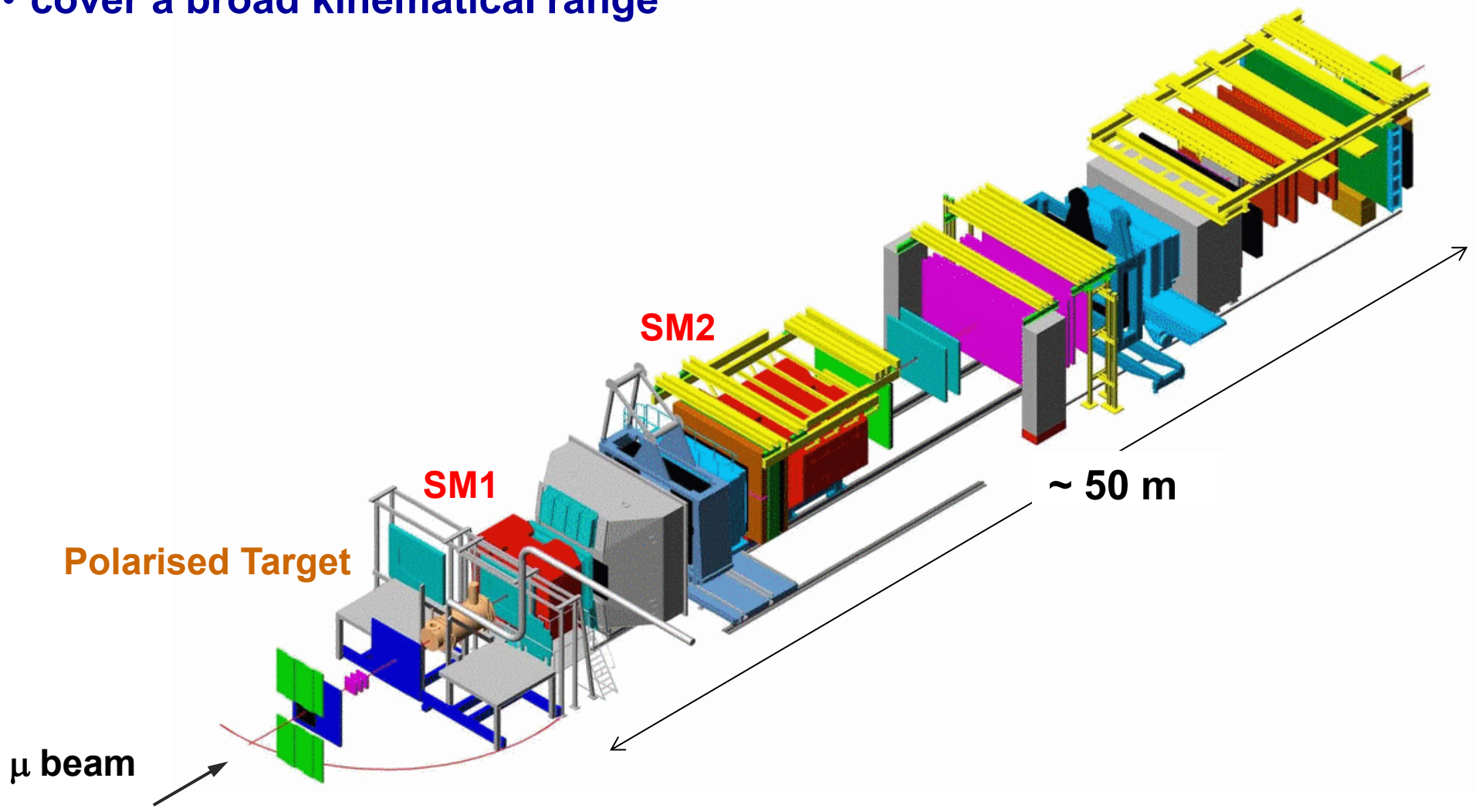
two stages spectrometer
- Large Angle Spectrometer (SM1)
- Small Angle Spectrometer (SM2)



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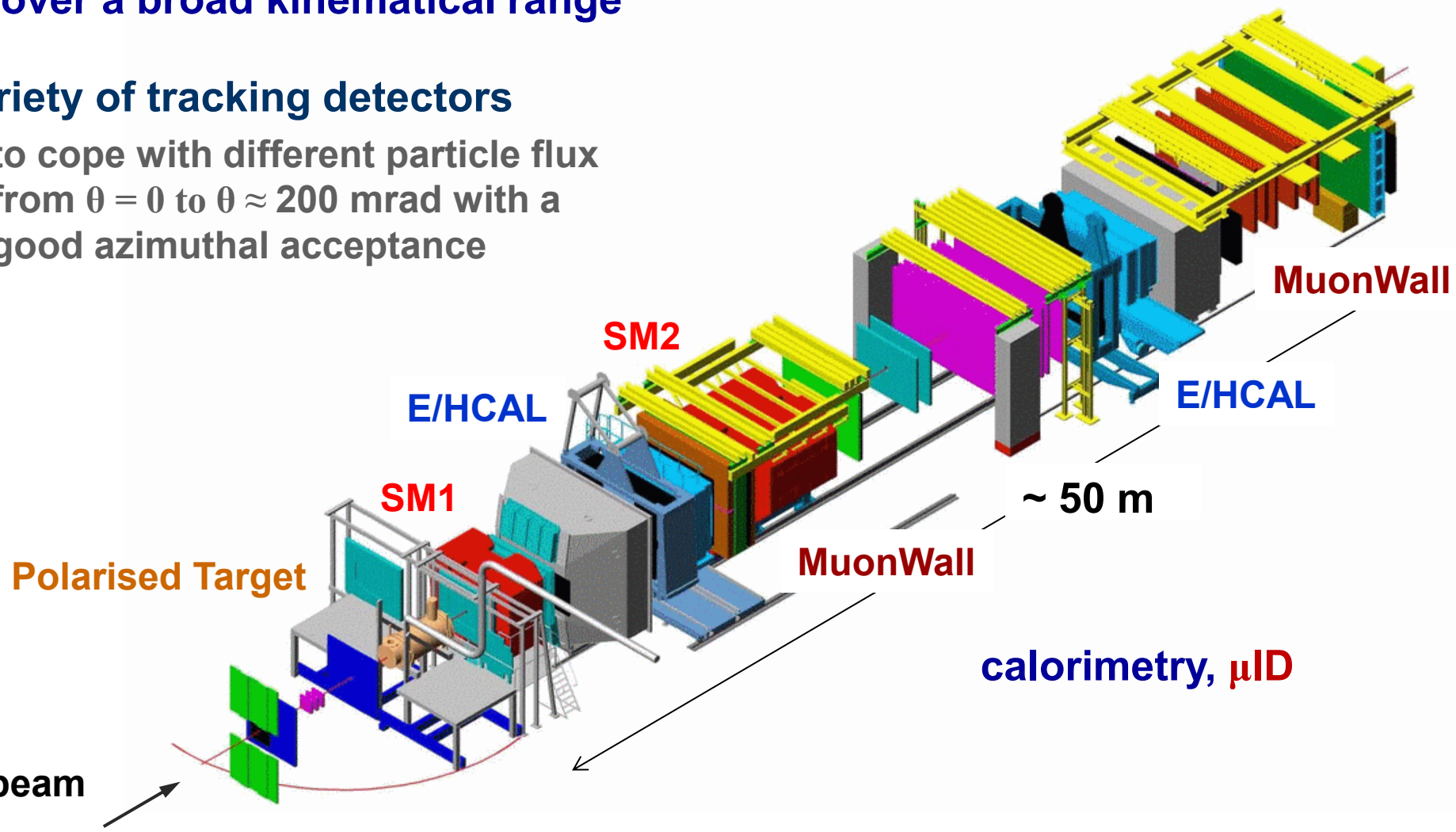
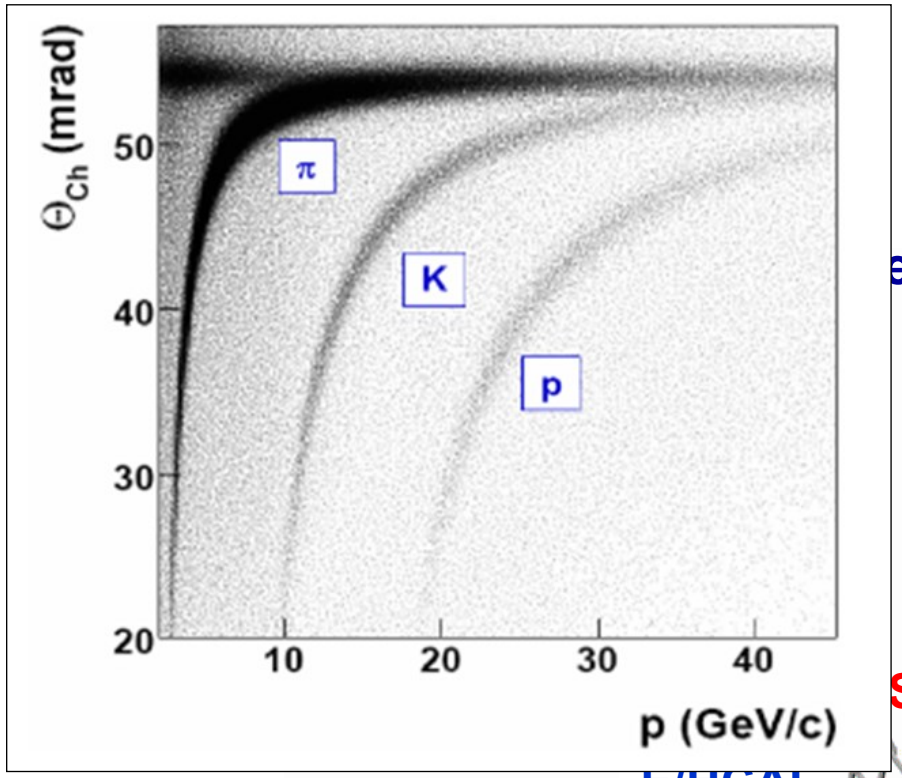
variety of tracking detectors

to cope with different particle flux from $\theta = 0$ to $\theta \approx 200$ mrad with a good azimuthal acceptance



the COMPASS spectrometer



two stages spectrometer

- Large Angle Spectrometer (SM1)
- Small Angle Spectrometer (SM2)

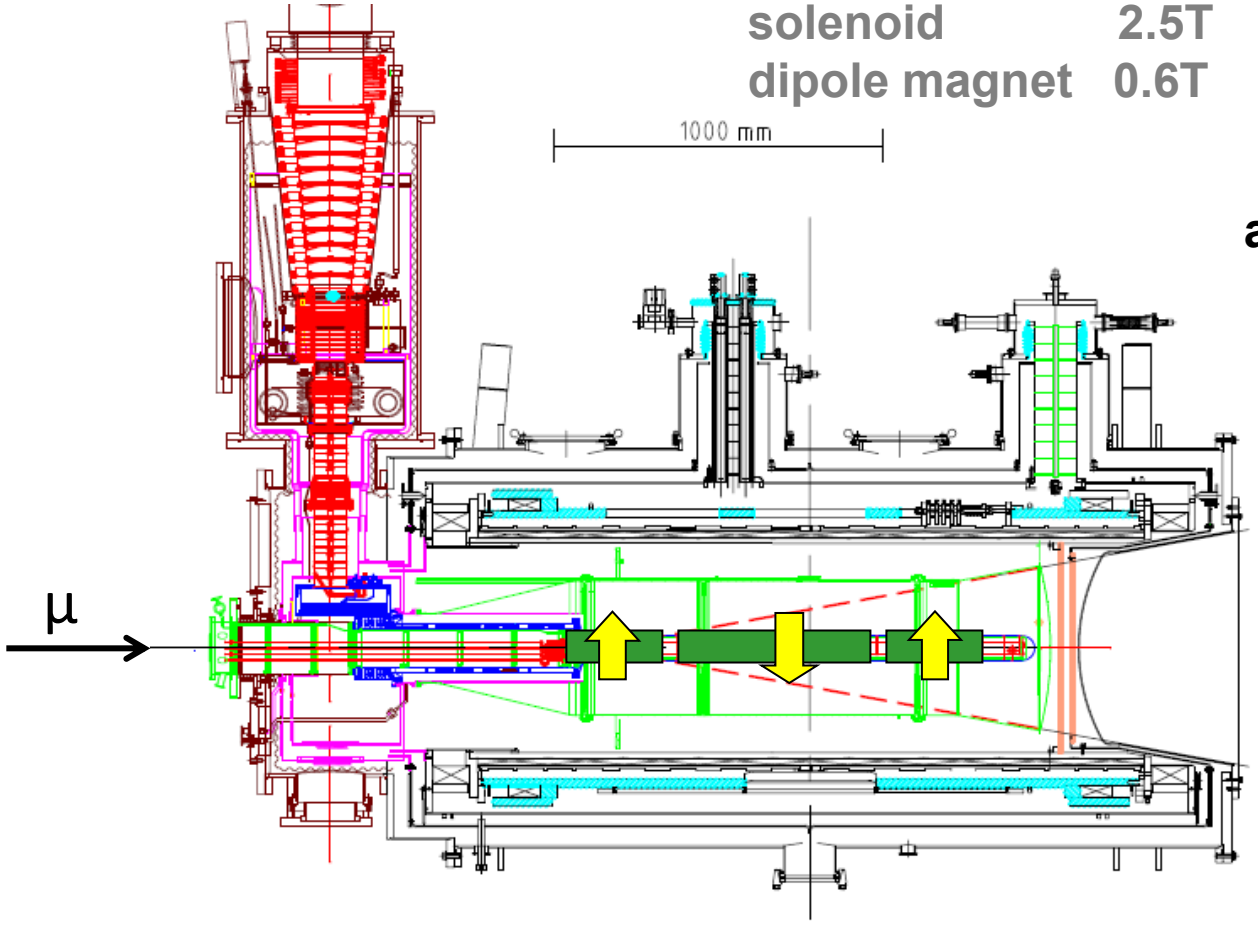
calorimetry, μID

RICH detector

the polarized target system (>2005)

^{3}He – ^{4}He dilution refrigerator (T~50mK)

solenoid 2.5T
dipole magnet 0.6T



acceptance > ± 180 mrad

3 target cells
30, 60, and 30 cm long

opposite polarisation

	d (^{6}LiD)	p (NH_3)
polarization	50%	90%
dilution factor	40%	16%

no evidence for relevant nuclear effects *(160 GeV)*

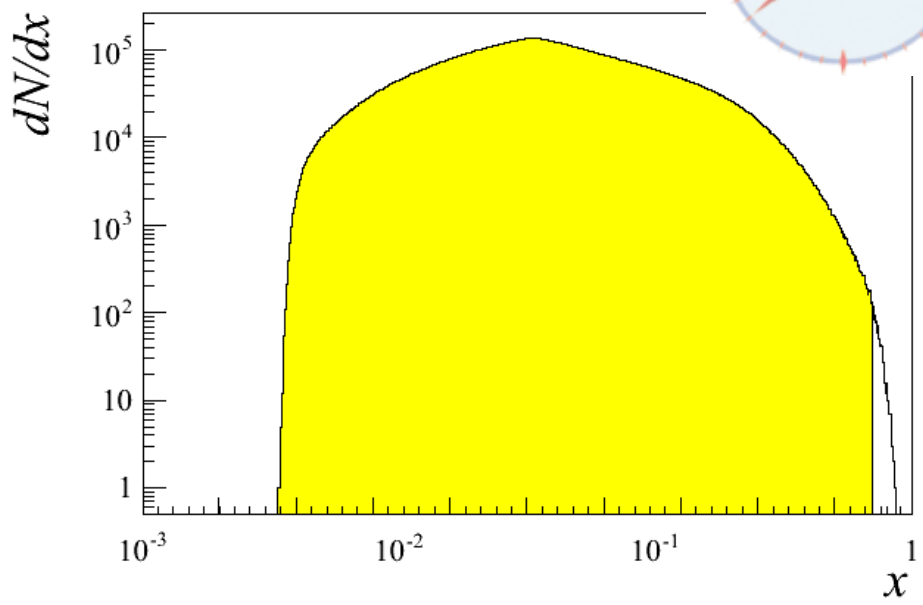
SIDIS event and hadron selection

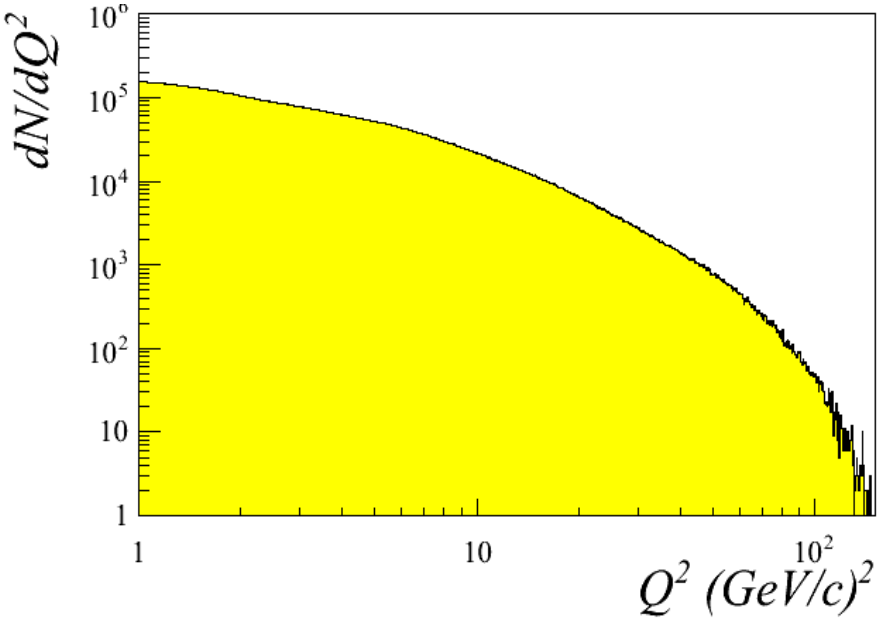
SIDIS event selection

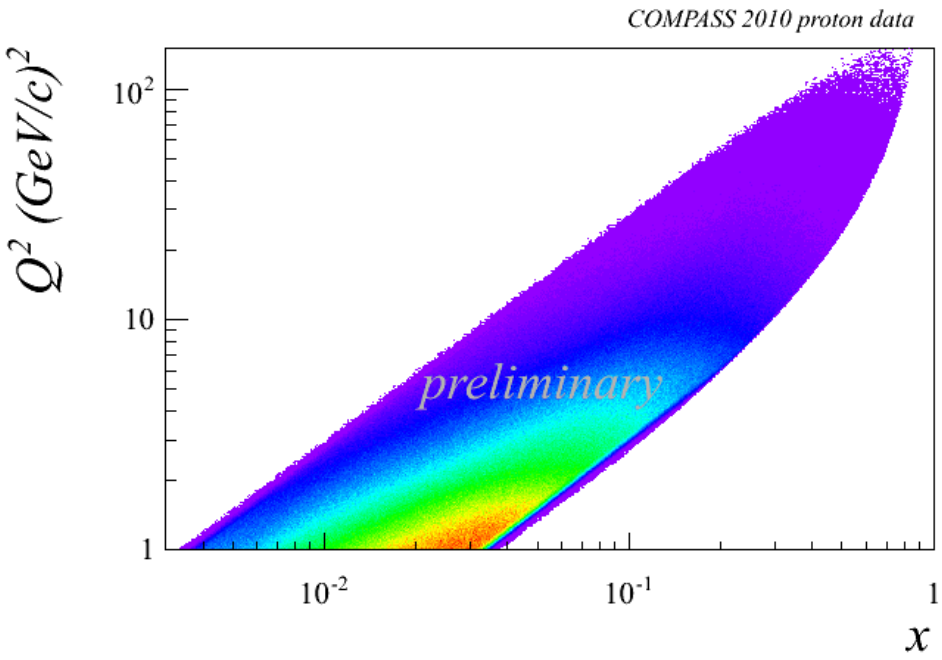
p_μ = 160 GeV/c

DIS cuts: $Q^2 > 1$ (GeV/c)^2
$0.1 < y < 0.9$
$W > 5$ GeV/c^2

h$^\pm$ selection: $p_t^h > 0.1$ GeV/c
$z > 0.2$







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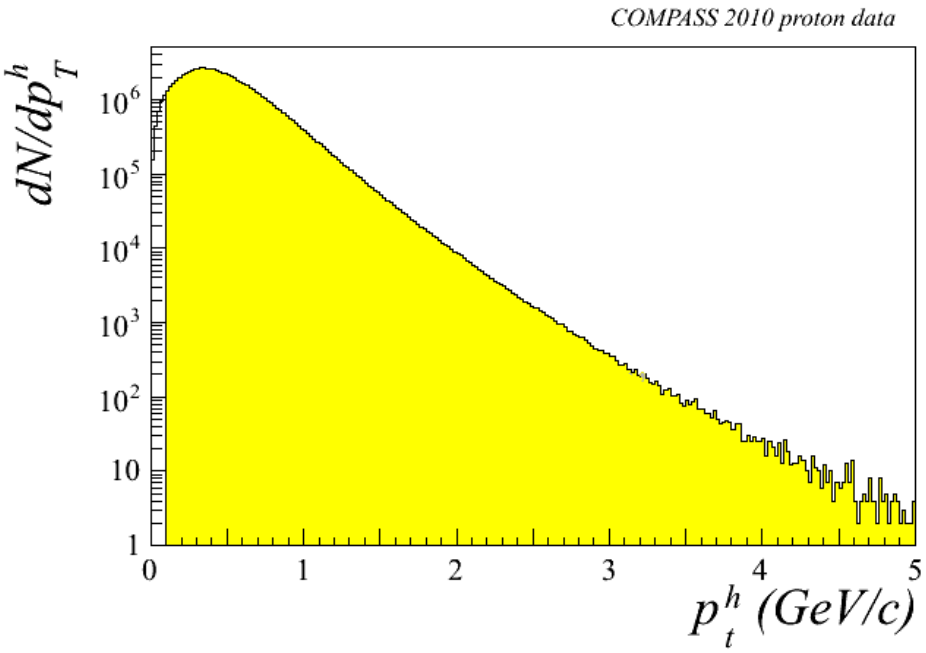

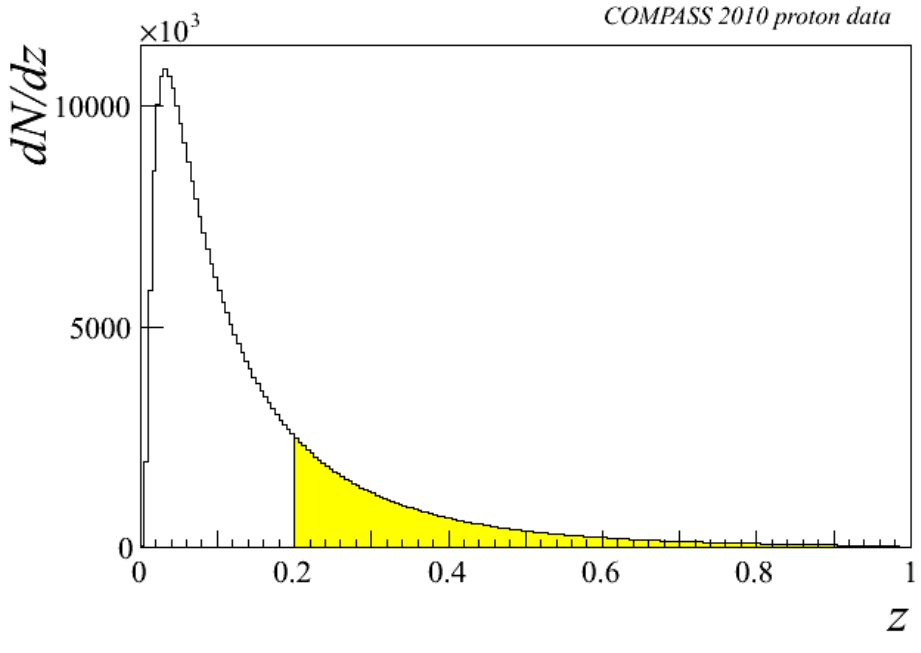

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PID: $\pi^\pm$ $1.5 < p^\pi < 50$ GeV/c
$K^\pm$ $9.5 < p^K < 50$ GeV/c

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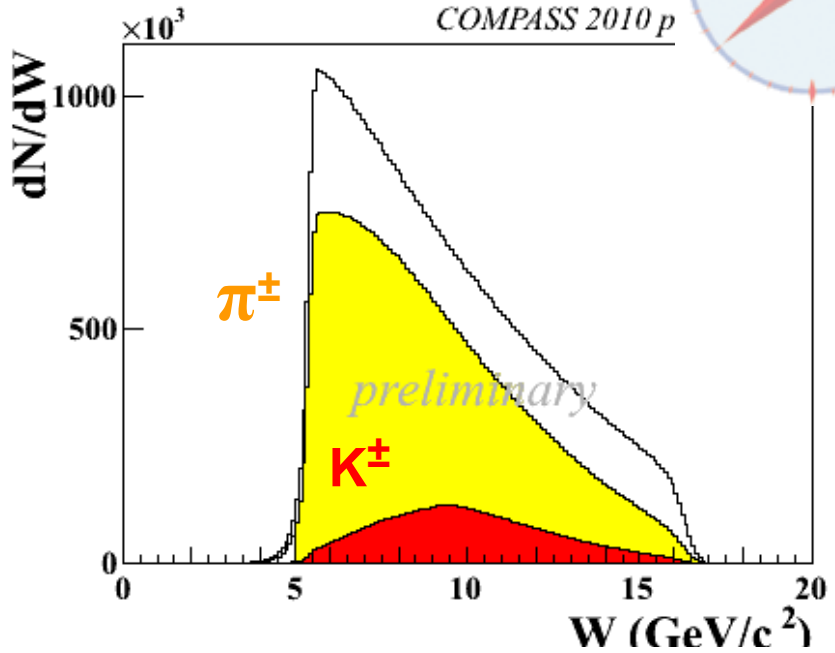

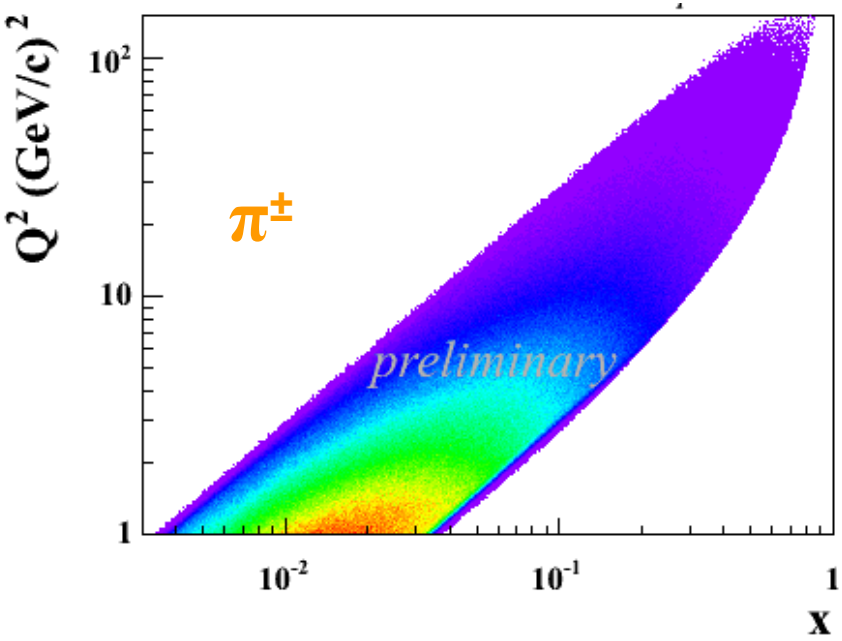

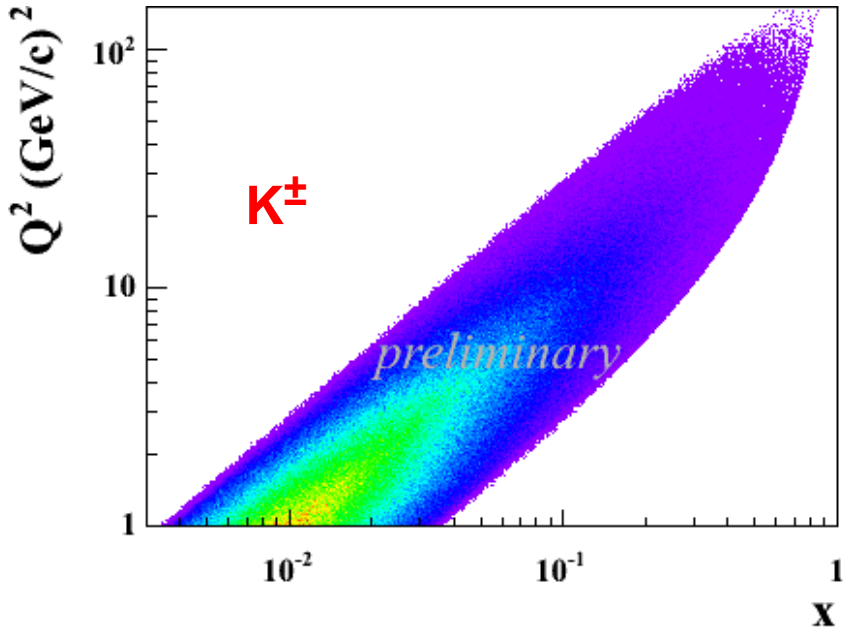

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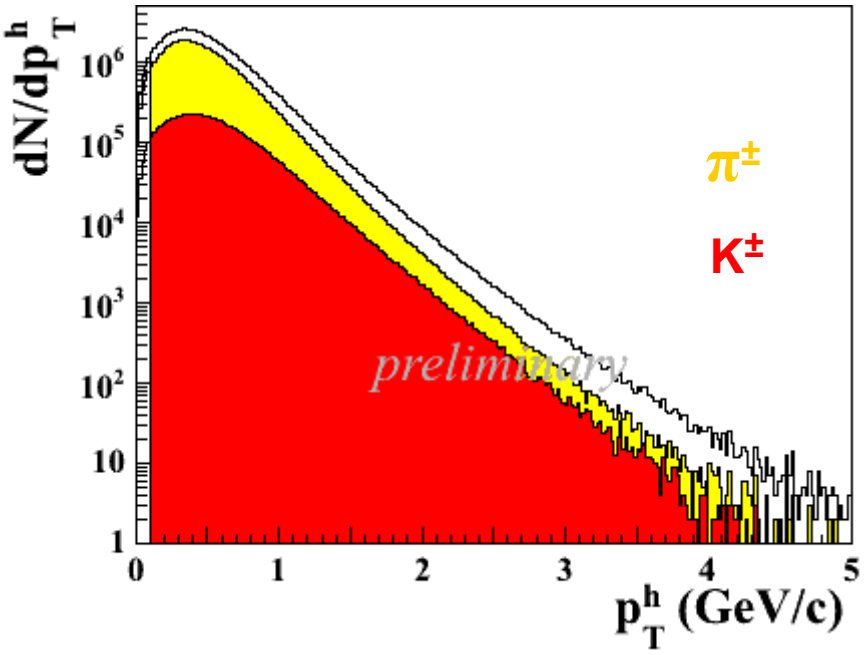
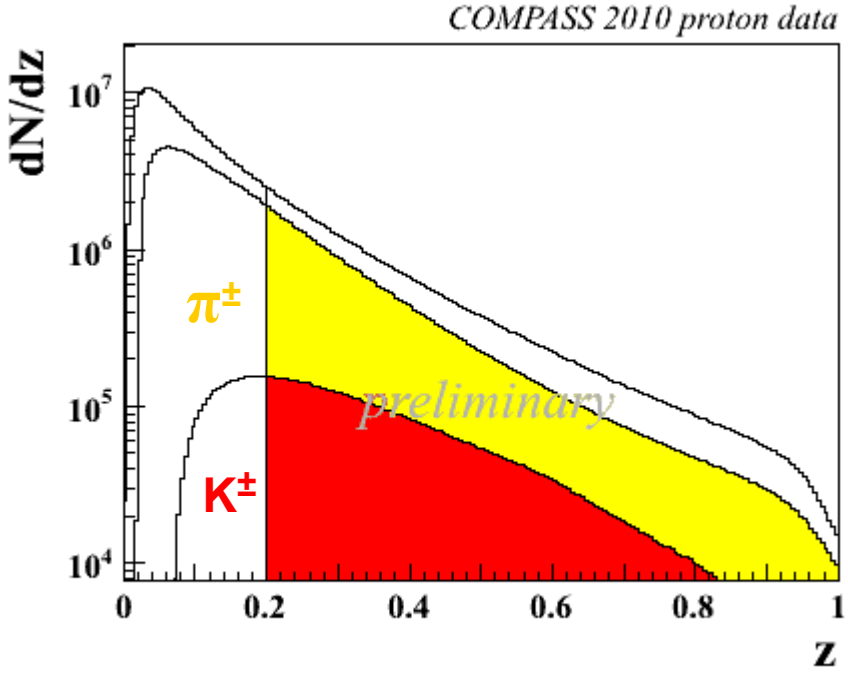




results

Collins asymmetry

Collins asymmetry

data taken with transversely polarised targets

deuteron (^{6}LiD) **target, 160 GeV μ beam**

2002, 2003, 2004

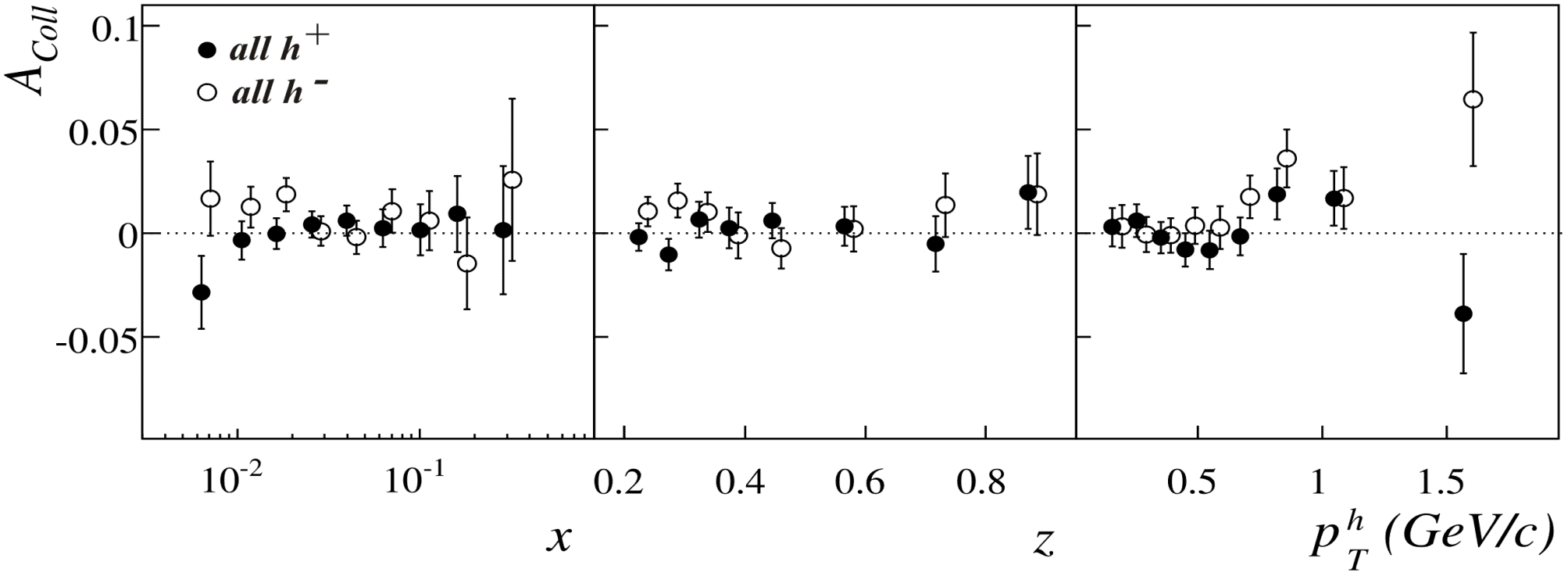
proton (NH_3) **target, 160 GeV μ beam**

2007, 2010

Collins asymmetry on deuteron

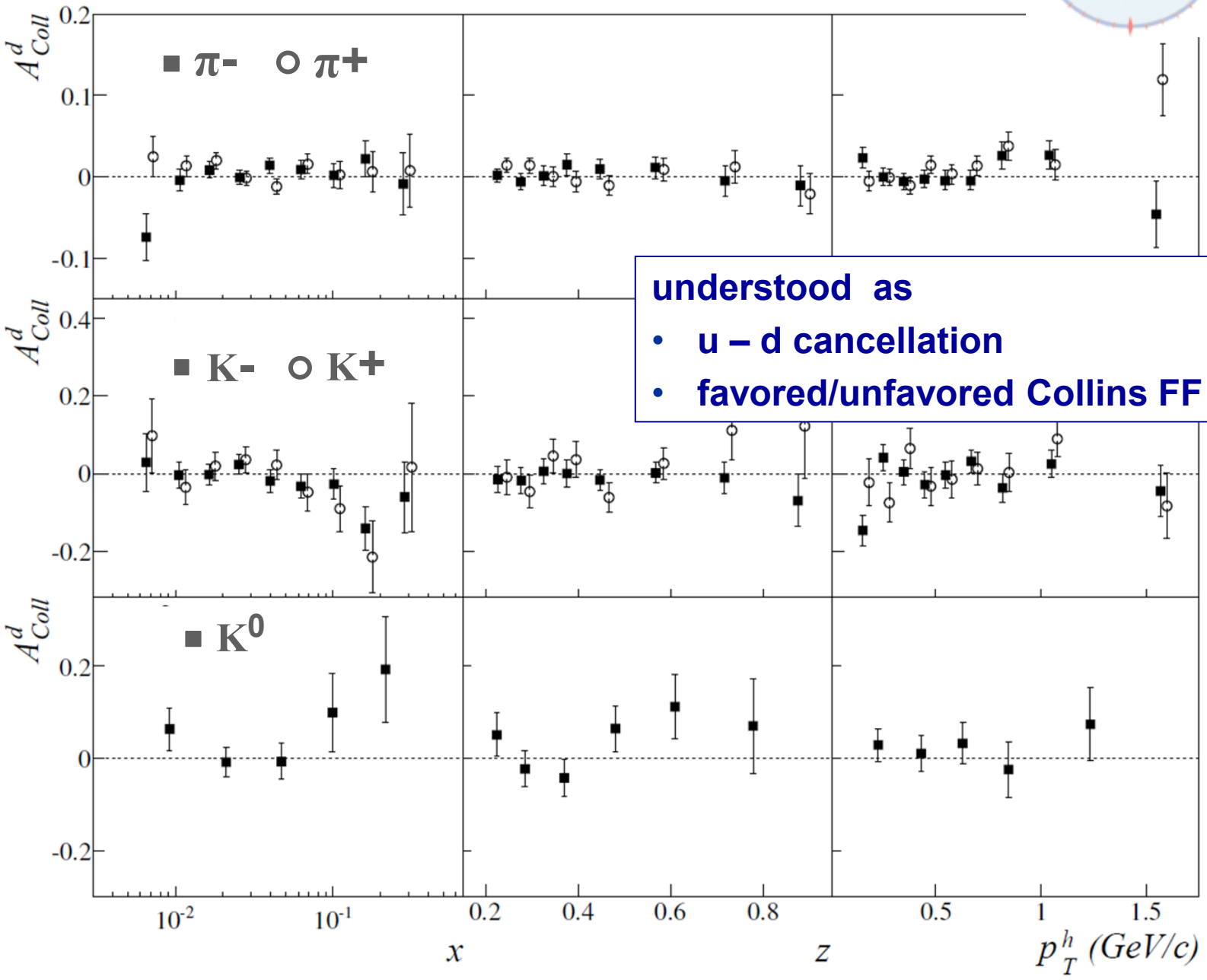
final results 2002-2004 data

PRL 94 (2005) 202002, NPB 765 (2007) 31, PLB 673 (2009) 127



Collins asymmetry on deuteron

final results **2003-2004 data** *PLB 673 (2009) 127*



understood as

- **u – d cancellation**
- **favored/unfavored Collins FF**

Collins asymmetry on proton

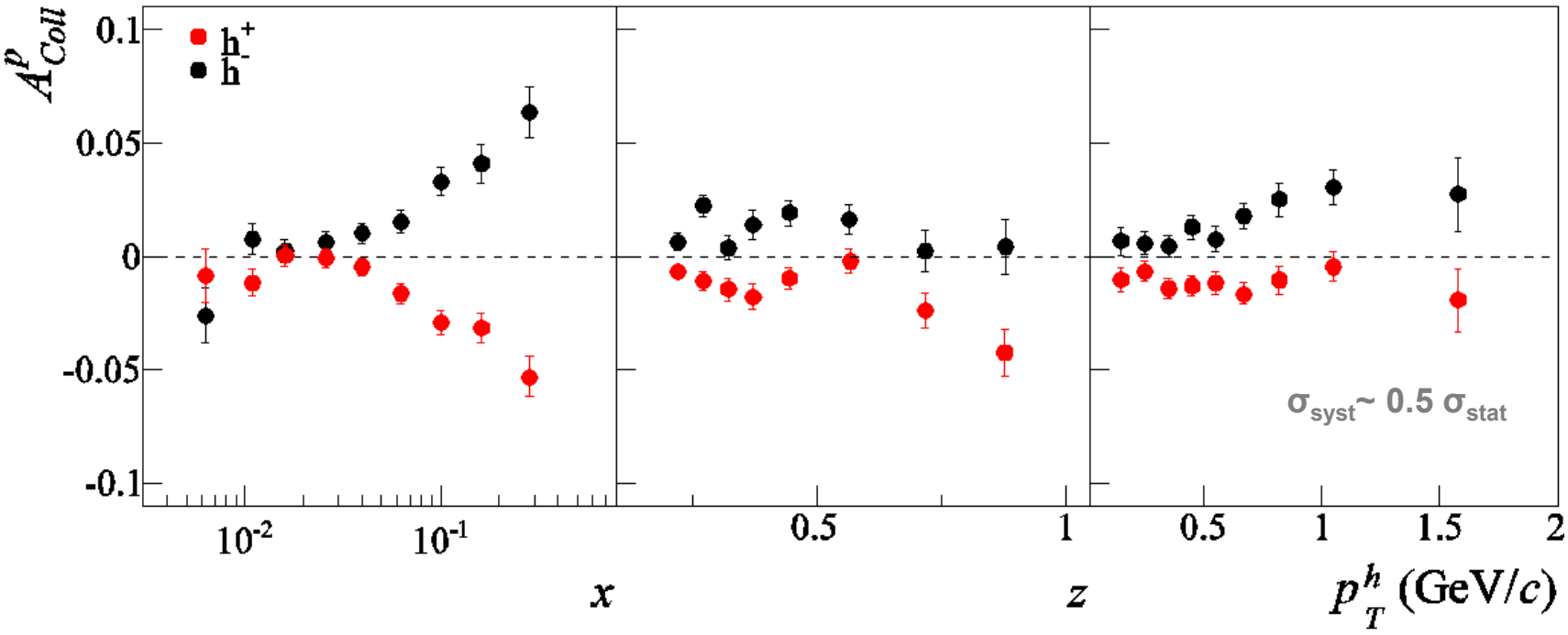
Collins asymmetry on proton

charged hadrons - published 2007 & 2010 data results

PLB 692 (2010) 240 *PLB 717 (2012) 376*

very good agreement between the two independent data sets

combined 2007 – 2010 results



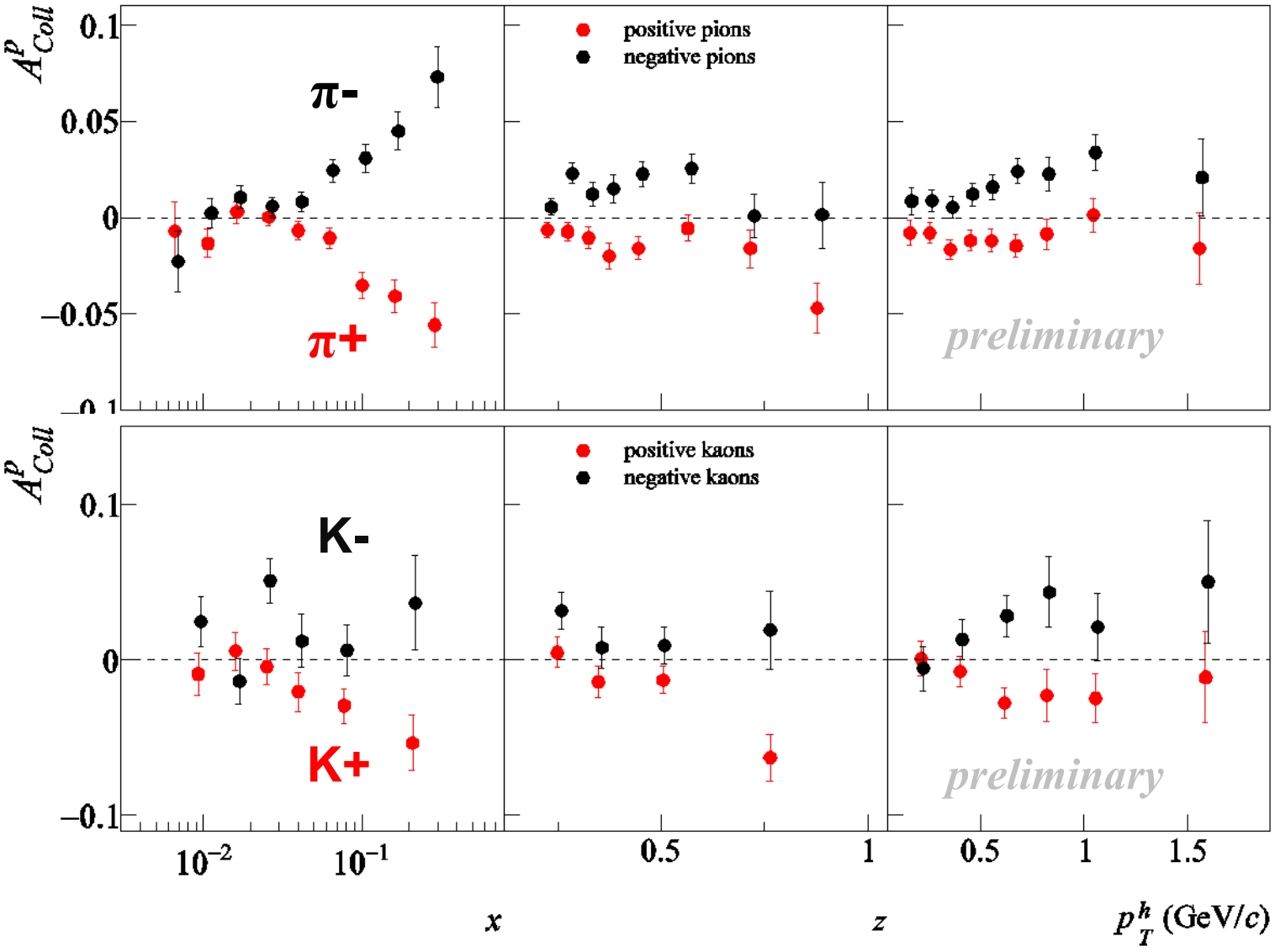
- **precise measurements**
- **clear signal at x > 0.3, with opposite sign for h+ and h-**

Collins asymmetry on proton

charged pions and kaons
results from 2007 *(SPIN2010)* and 2010 *(SPIN2012)* data

~ h+ / h-

compatible with π+ / π-

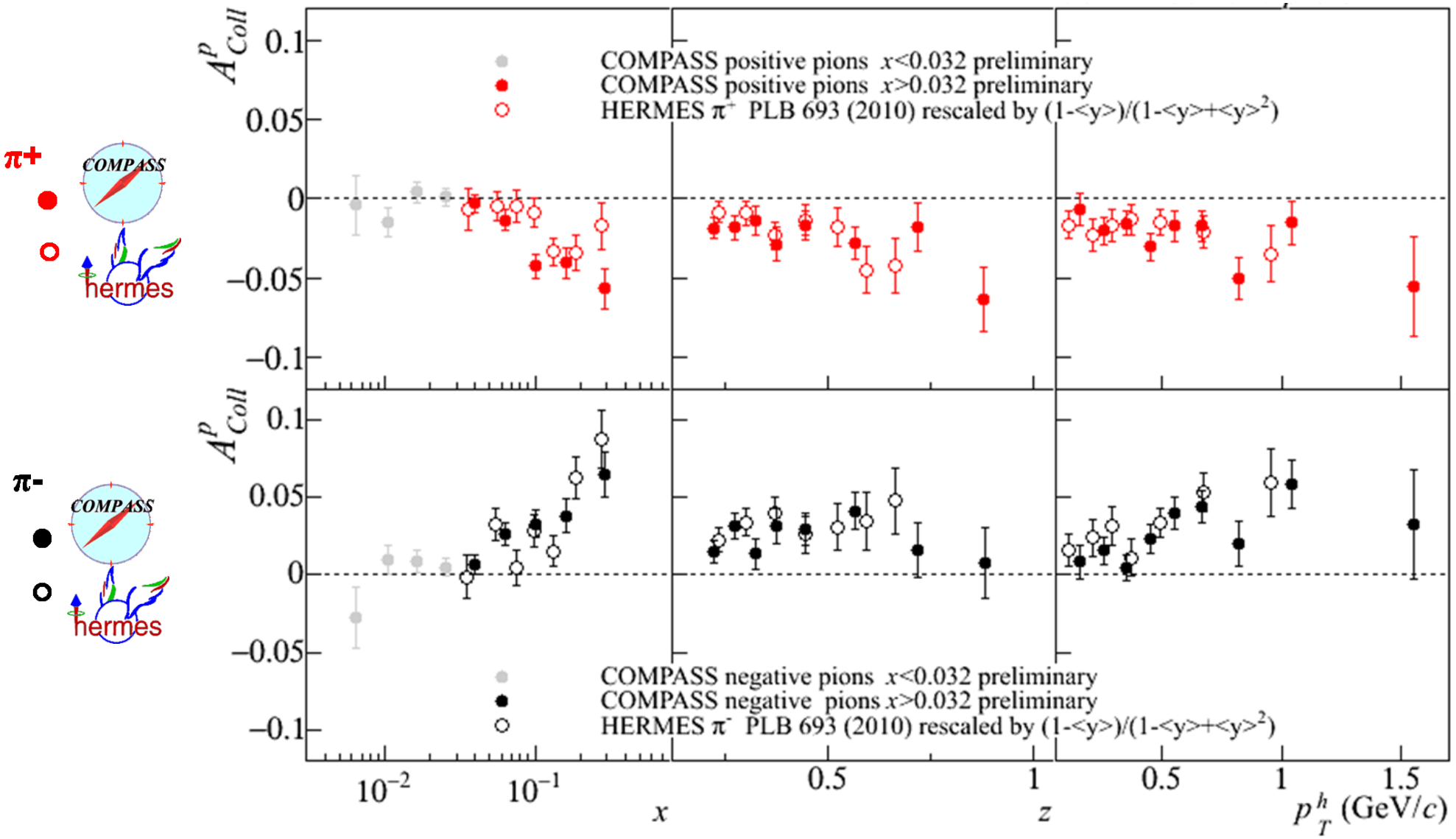


Collins asymmetry on proton

x > 0.032 region

charged pions (and kaons), 2010 data

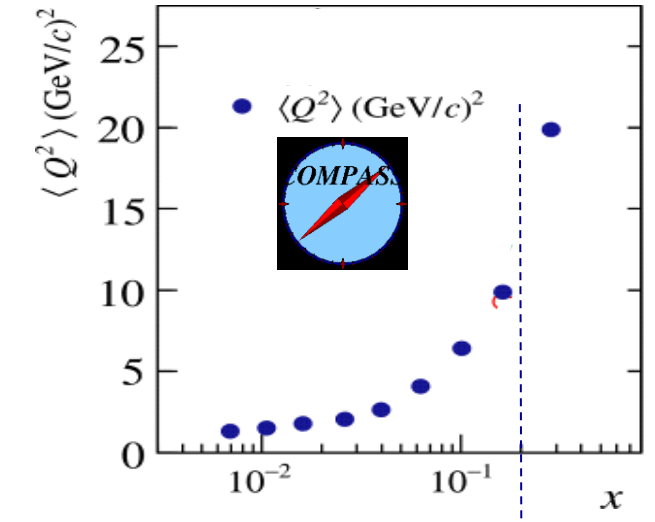
comparison with HERMES results



Collins asymmetry on proton

x > 0.032 region

same strength:
a very important, not obvious result!



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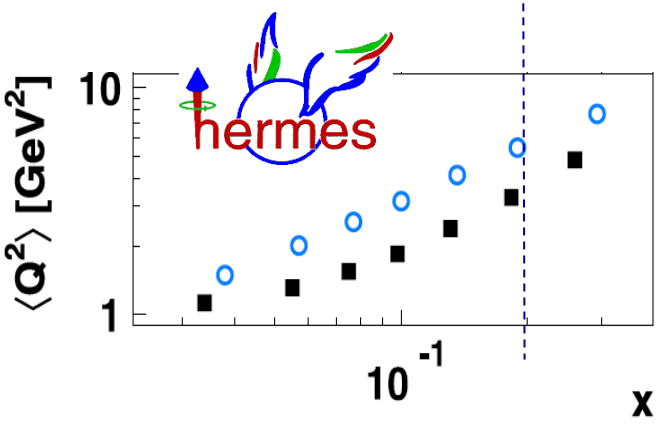


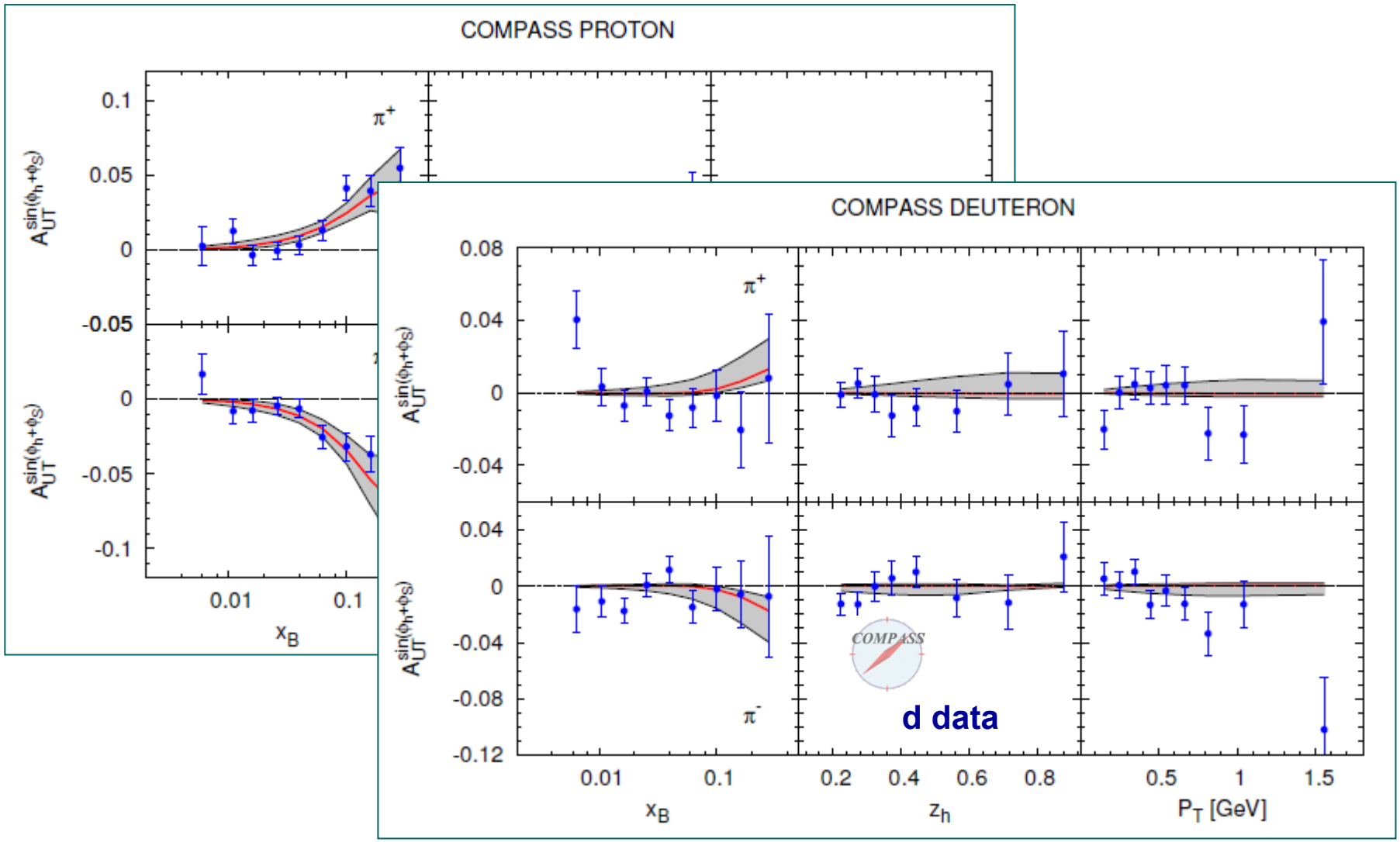
~ 4

no strong Q^2 dependence

Collins asymmetry on proton

M. Anselmino et al., arXiv:1303.3822

fit to HERMES p, COMPASS p and d, Belle e+e- data



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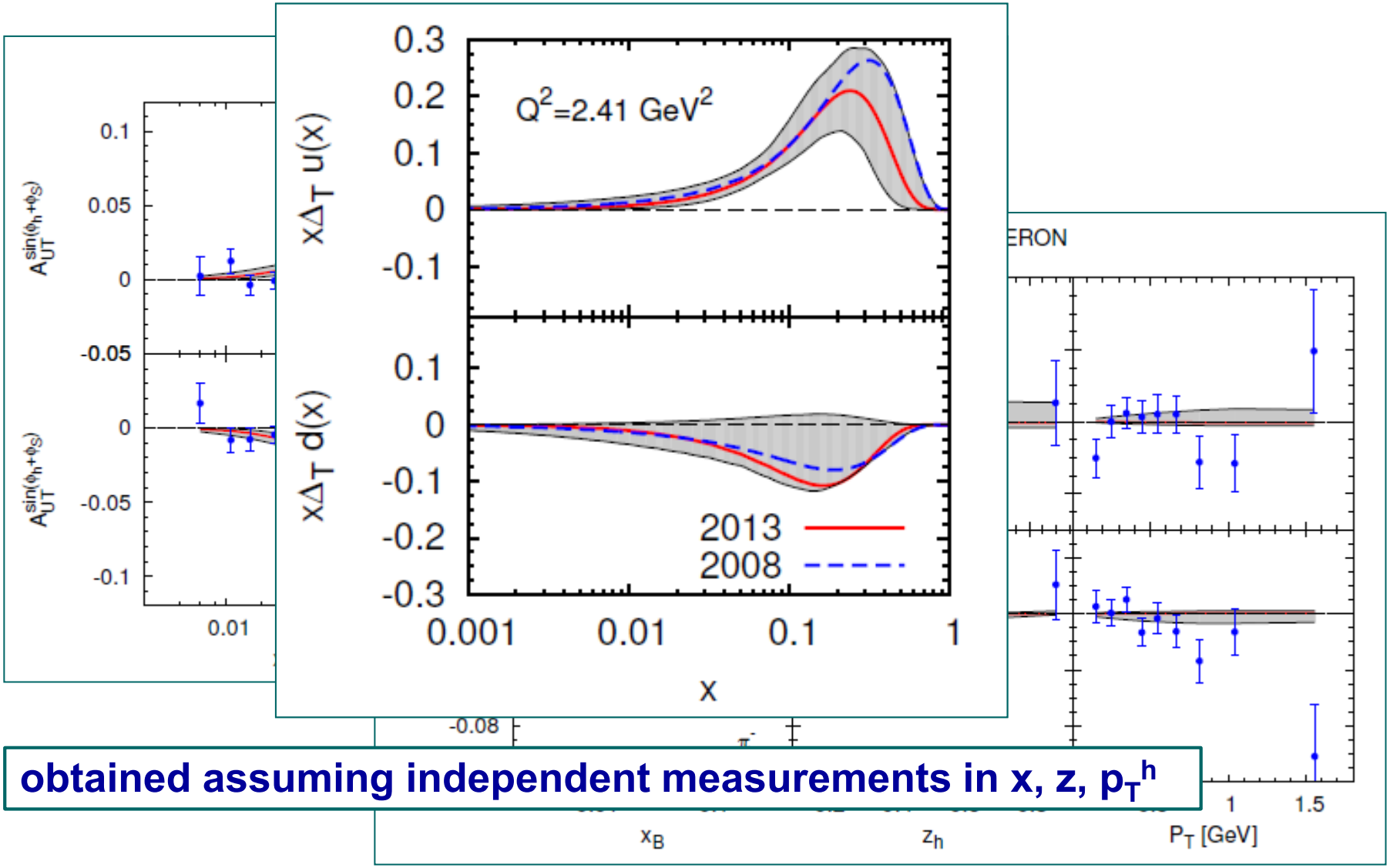

obtained assuming independent measurements in x, z, p_T^h

statistical correlations 2010 data

Collins (Sivers, …) asymmetries measured vs x, z, p_T^h

statistical correlations 2010 data

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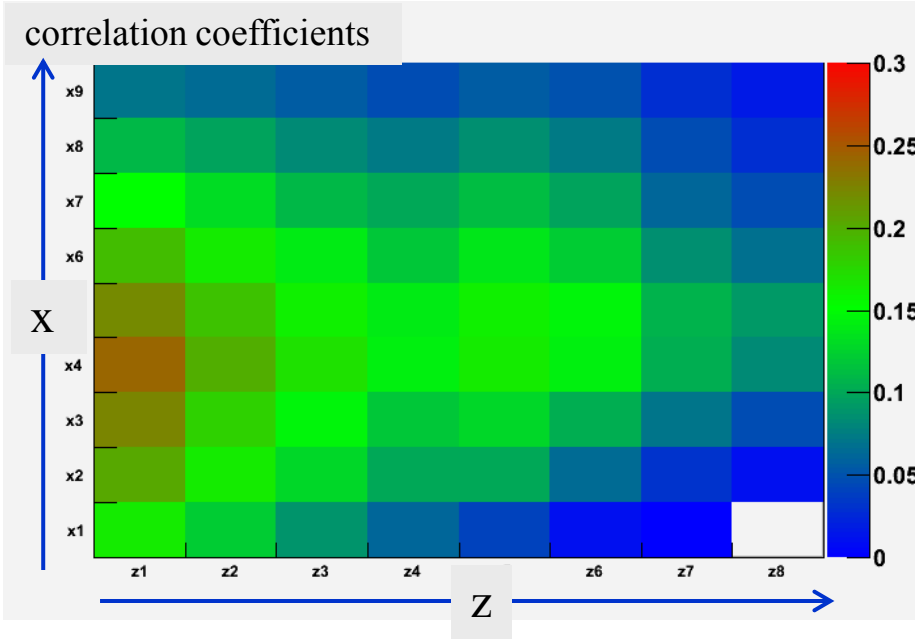
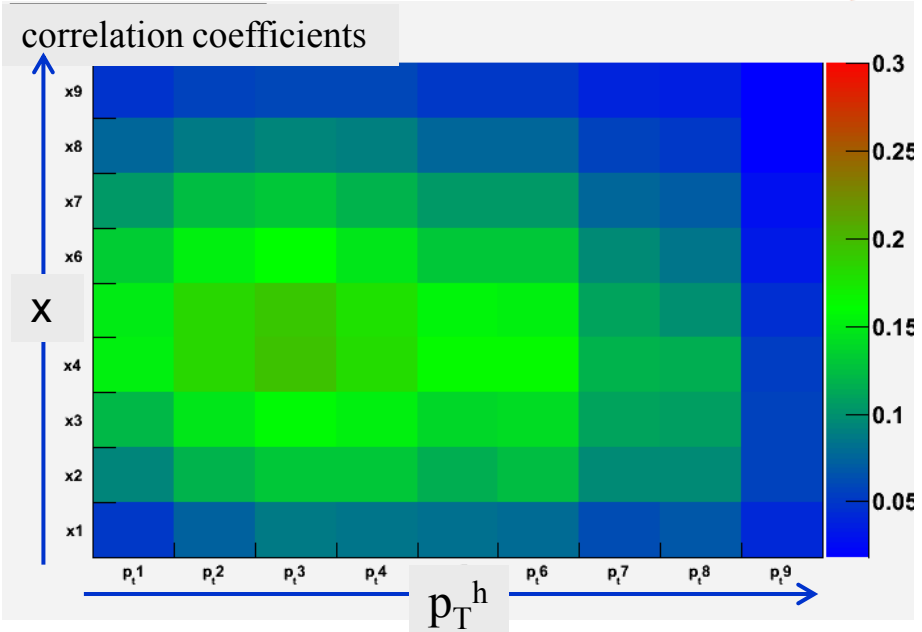
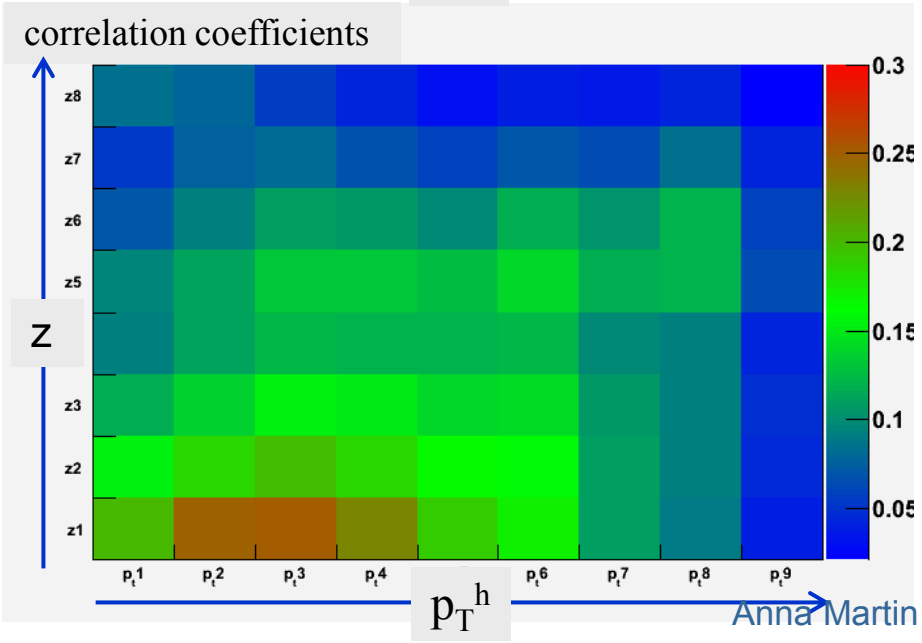






charged pions *new*

also available for

charged hadrons (HEPDATA)

charged kaons *new*

for all data selection

have to be taken into account

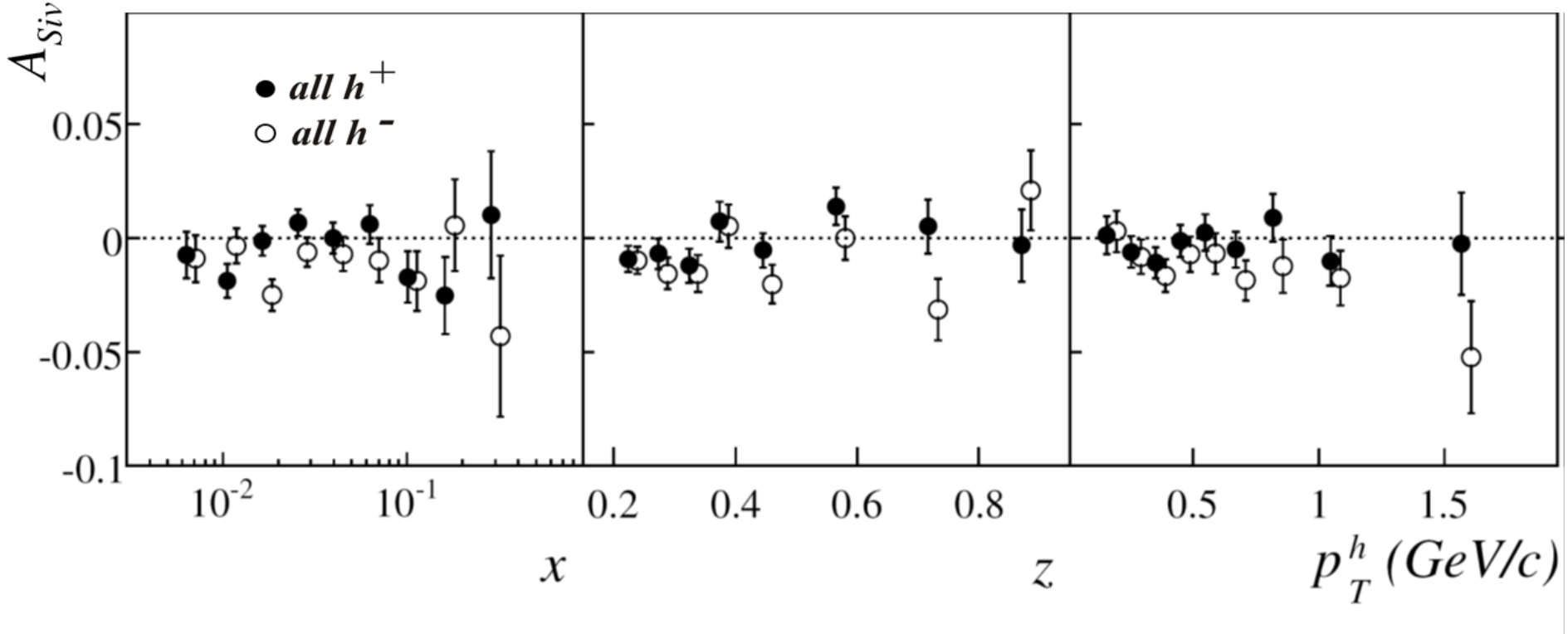
results

Sivers asymmetry

Sivers asymmetry on deuteron

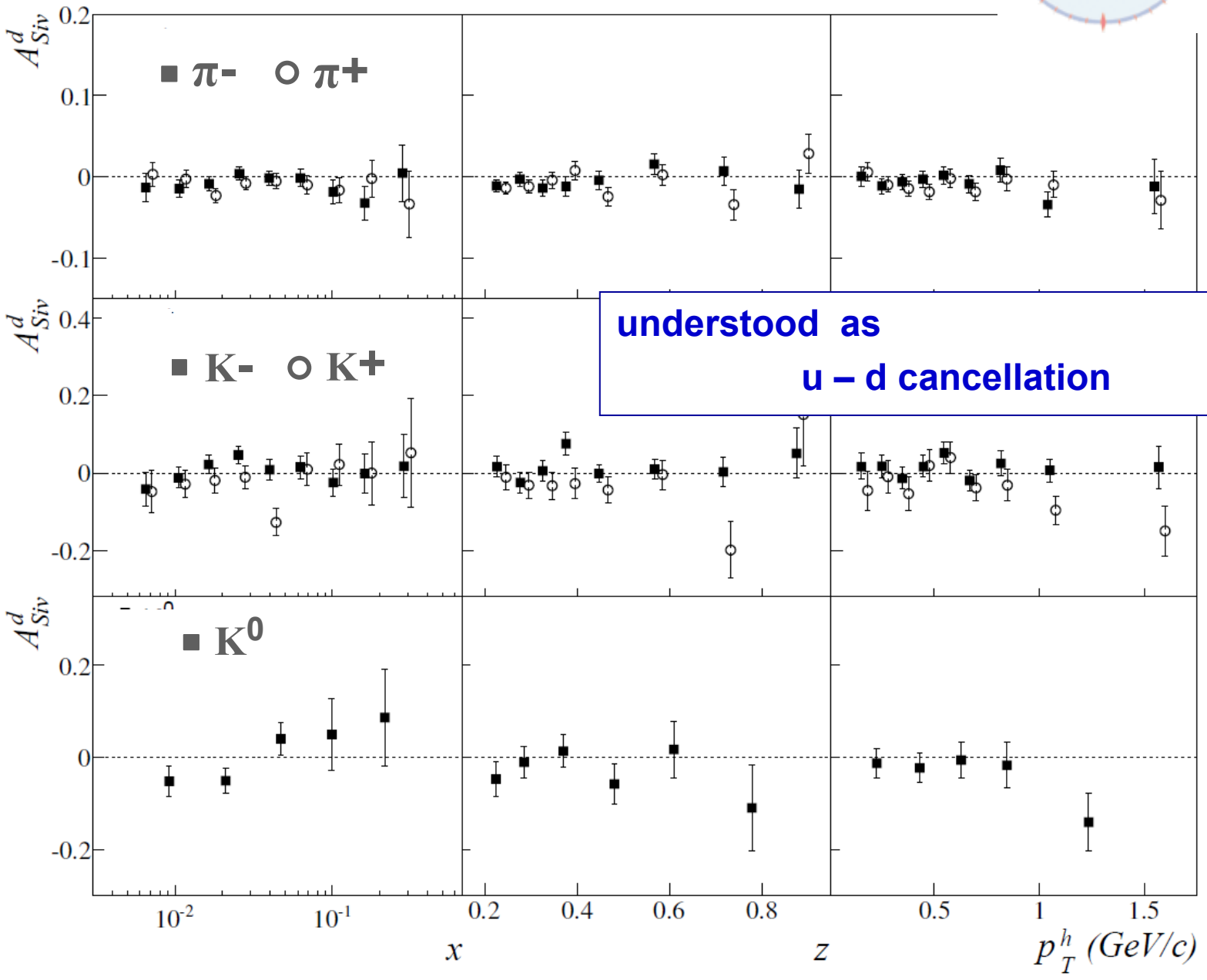
final results 2002-2004 data

PRL 94 (2005) 202002, NPB 765 (2007) 31, PLB 673 (2009) 127



Sivers asymmetry on deuteron

final results **2003-2004 data** *PLB 673 (2009) 127*



Sivers asymmetry on proton

Sivers asymmetry on proton

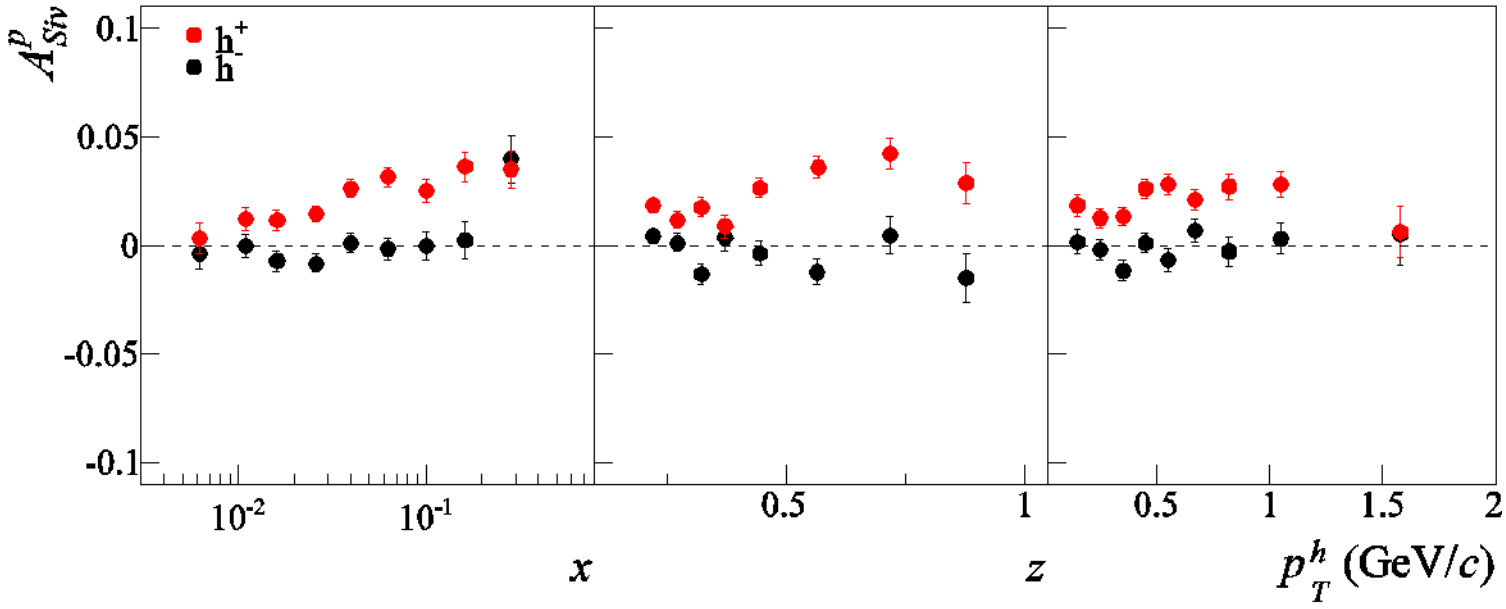
charged hadrons - published 2007 & 2010 data results

PLB 692 (2010) 240 *PLB 717 (2012) 383*

good agreement between the two independent data sets !

combined results in HEPDATA

combined 2007 – 2010 results:



h+ : clear signal down to low x, in the previously unmeasured region

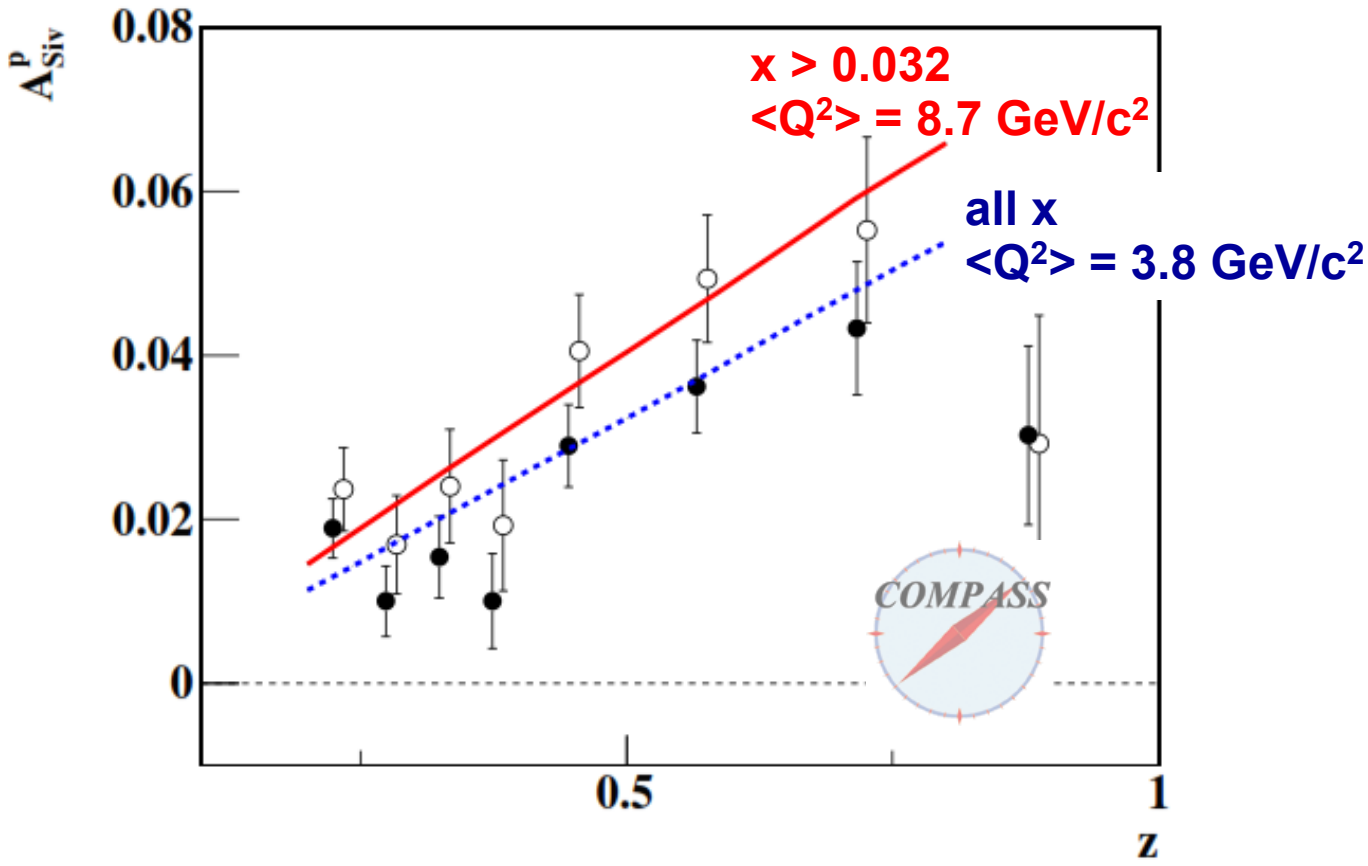
in the overlap x range, agreement with HERMES, but clear indication that the strength decreases

Sivers asymmetry on proton

charged hadrons, 2010 data - Q^2 evolution

comparison with

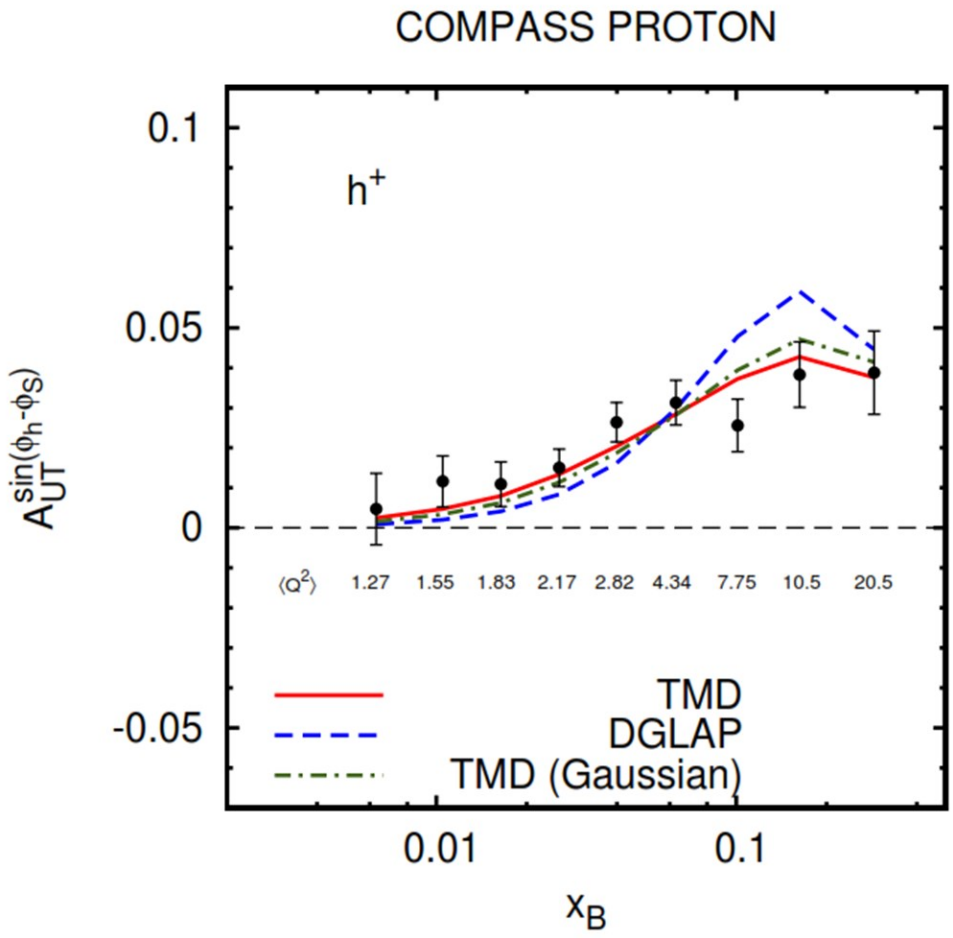
S. M. Aybat, A. Prokudin and T. C. Rogers calculations PRL 108 (2012) 242003



Sivers asymmetry on proton

charged hadrons, 2010 data - Q^2 evolution

M. Anselmino, M. Boglione, S. Melis arXiv:1204.1239



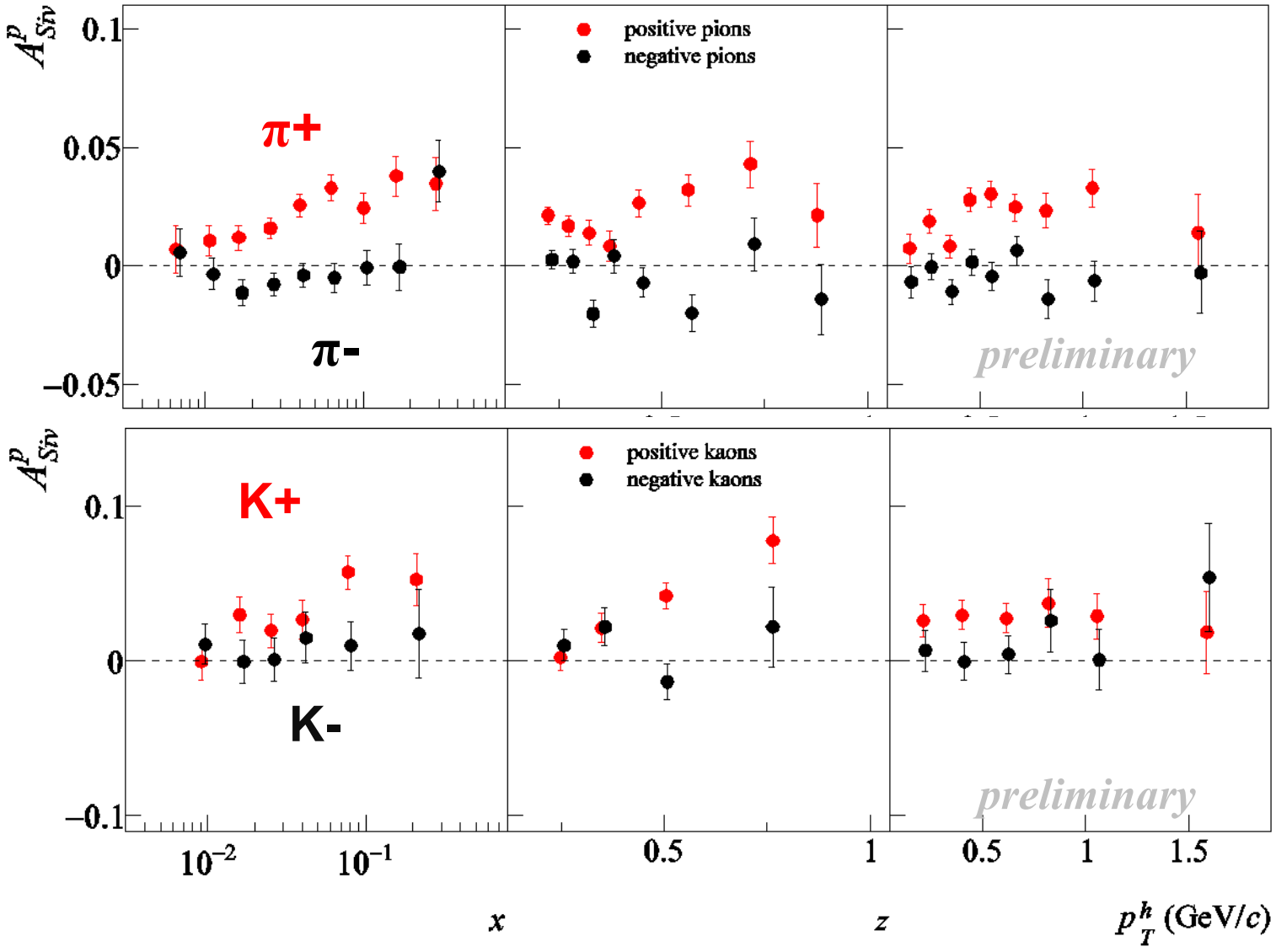
Sivers asymmetry on proton

charged pions and kaons
results from 2007 *(SPIN2010)* and 2010 *(SPIN2012)* data

combined 2007 – 2010 results

~ h+ / h-

larger than for π+

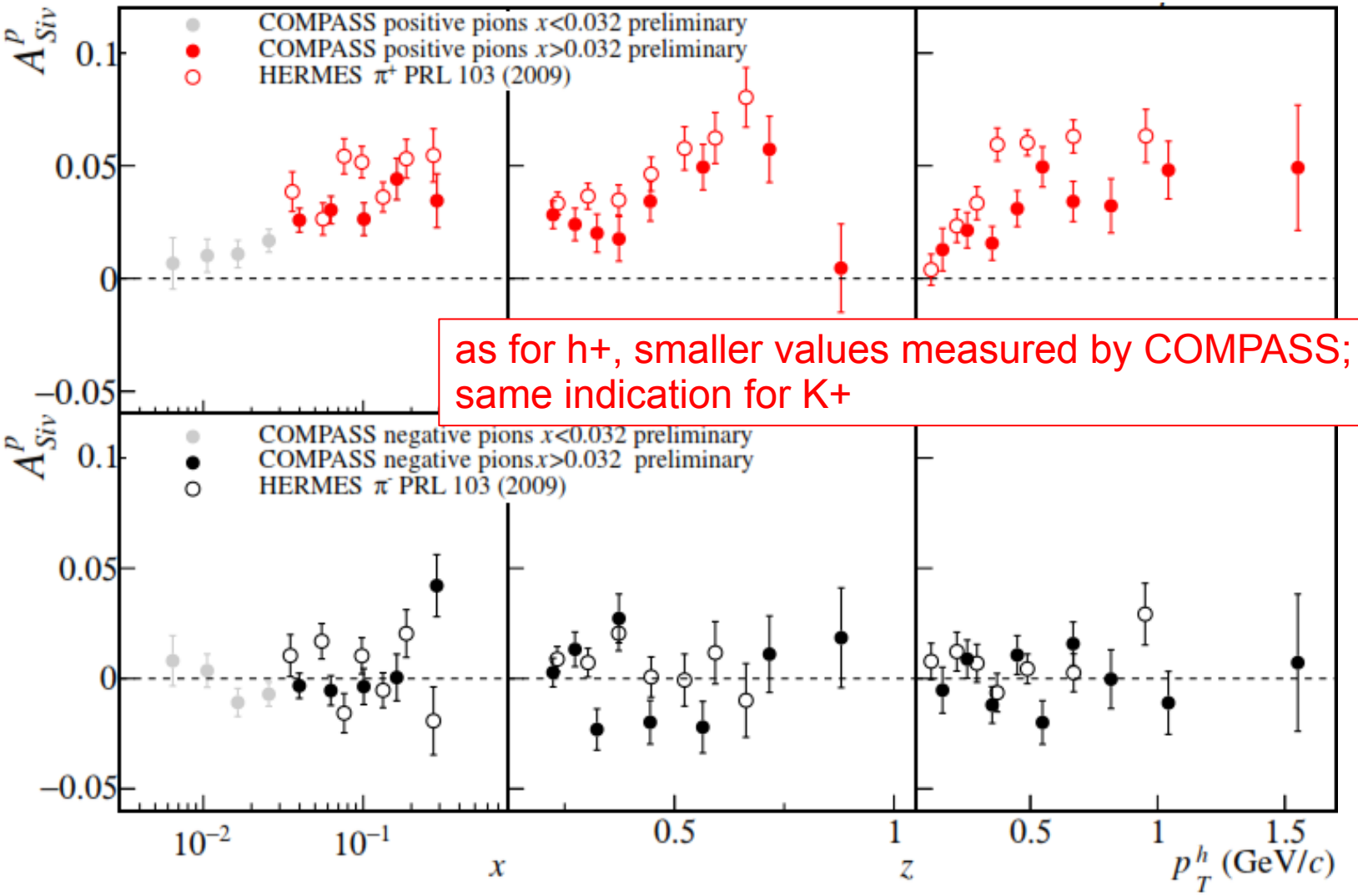


Sivers asymmetry on proton

x > 0.032

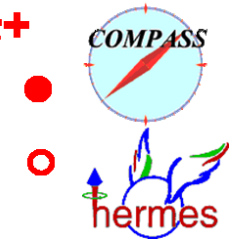
charged pions (and kaons), 2010 data

comparison with HERMES results

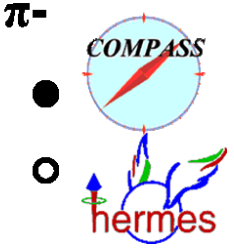


as for h+, smaller values measured by COMPASS; same indication for K+

π+



π-



more on Collins and Sivers asymmetries

thanks to the high beam momentum,
we have enlarged the usual COMPASS phase space
still remaining in the DIS CF region

- **low z** → **(0.1,0.2)** (0.2,0.3) (0.3,1.0)
- **low y** → **(0.05,0.1)** (0.1,0.2) (0.2,0.9)

for charged and identified hadrons

more on Collins and Sivers asymmetries

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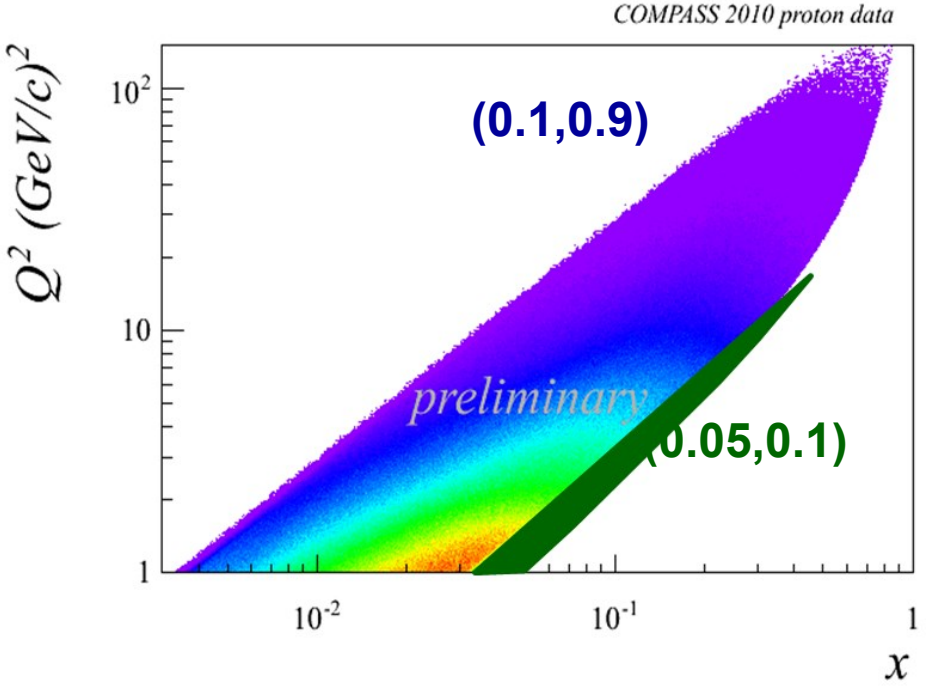
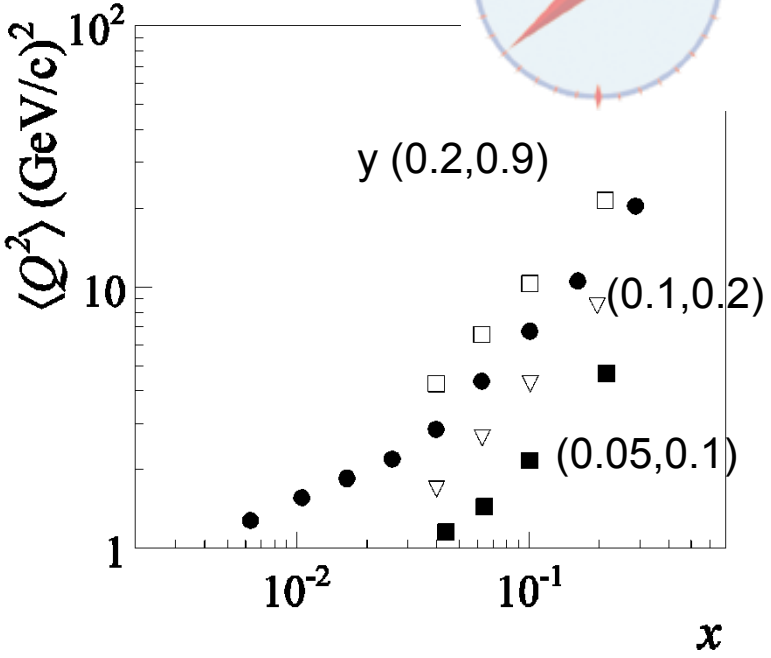
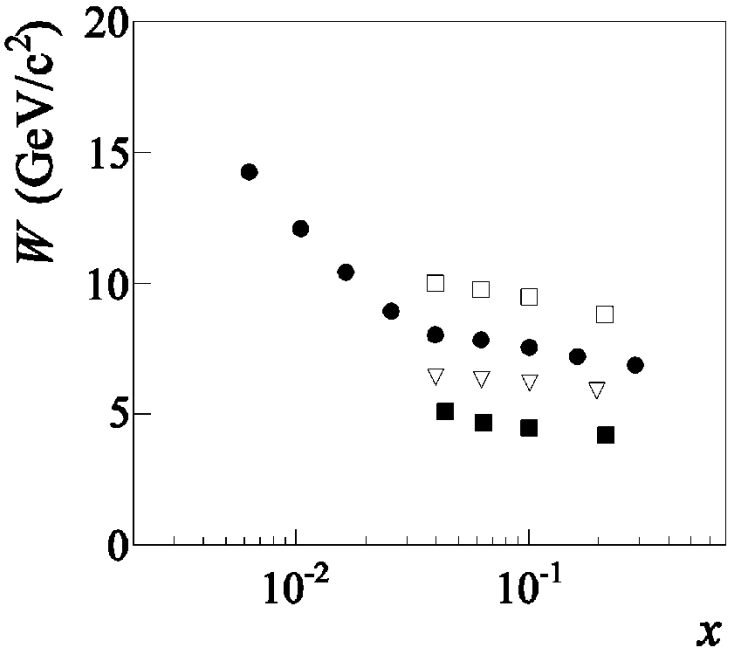
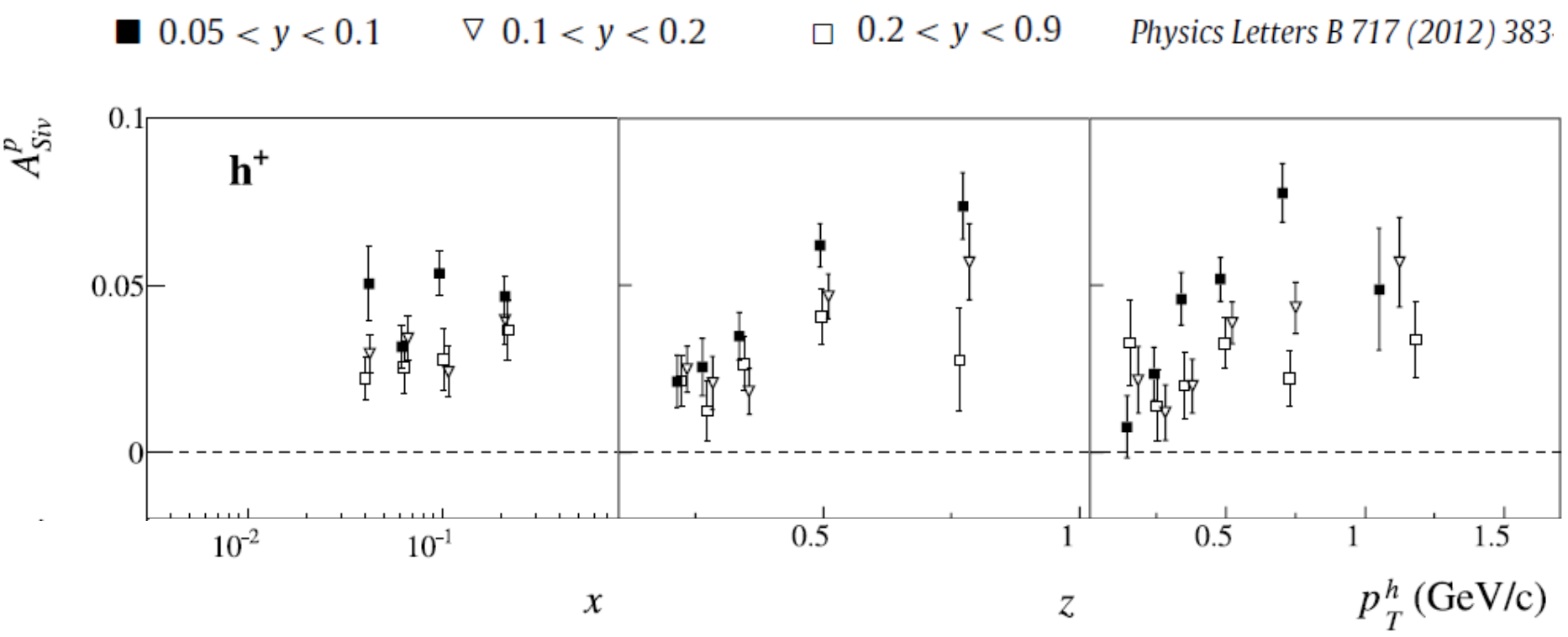






more on Collins and Sivers asymmetries

charged hadrons, proton data



complete multidimensional analysis: starting

conclusions

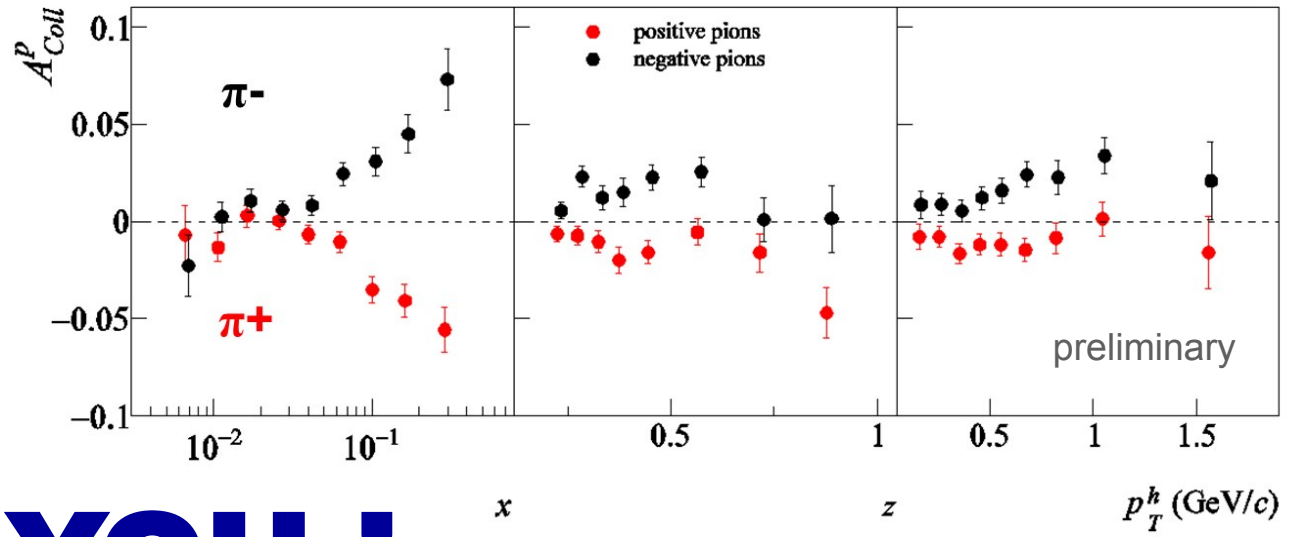
COMPASS
has measured the Collins and Sivers asymmetries
on d and on p using a 160 GeV muon beam
for charged and identified hadrons

clear signals on p have been measured,
with interesting kinematical dependences

***to be done soon*:**
multidimensional analysis (x, Q^2, z, p_t) of the p data

on a longer time scale: possible measurements with
- **transversely polarised p** and **100 GeV** muon beam
- **transversely polarised d** and **160 GeV** muon beam

combined 2007 and 2010 p data



THANK YOU !