

***RECENT COMPASS RESULTS
ON
TRANSVERSE SPIN ASYMMETRIES
IN
SIDIS***

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OUTLINE

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 - *Nucleon PDFs*
- ***Transversity***
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 - *Sivers Asymmetry on proton*
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- ***Conclusion***

COMPASS at CERN



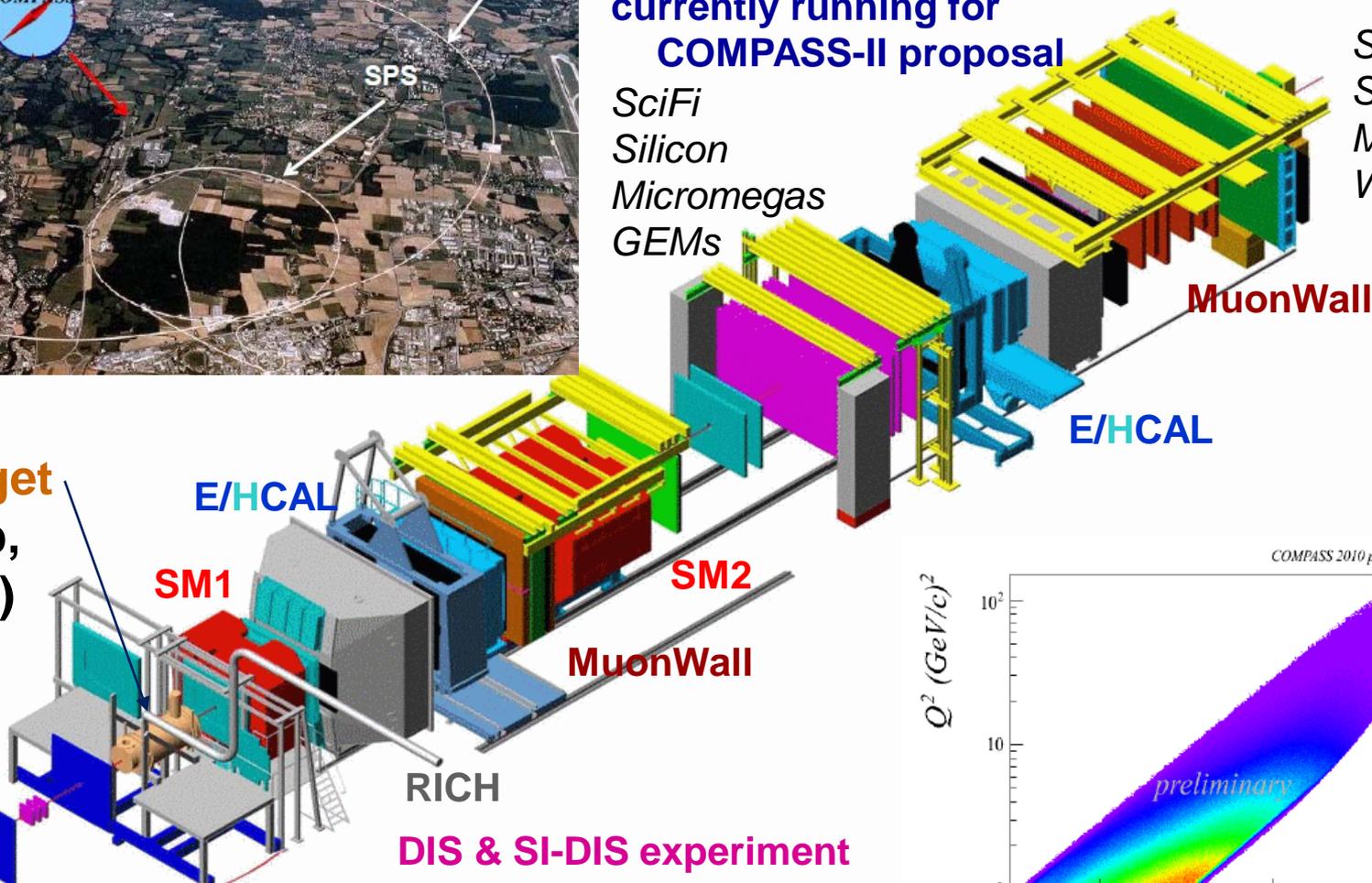
data taking: 2002-2012,
currently running for
COMPASS-II proposal

SciFi
Silicon
Micromegas
GEMs

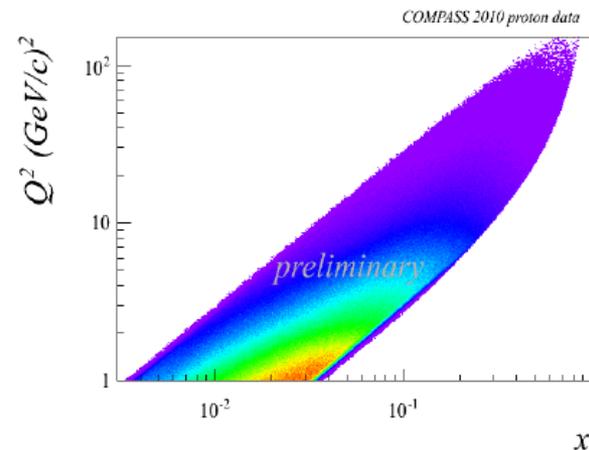
Straws
SDC
MWPC
W45

**Polarised
solid Target
(NH₃ for p,
⁶LiD for d)**

Pol.
 μ beam
from SPS
160-200 GeV,
pol. = 80%



DIS & SI-DIS experiment
two stage spectrometer
tracking, calorimetry, PID



Nucleon PDFs

at twist-2, taking account of transverse momentum(k_T) of the quarks

Nucleon

unpol.

long. pol.

trans. pol.

unpol.

long. pol.

trans. pol.

$q(= f_1)$ **number density**

Nucleon
Parton

f_{1T}^\perp **Sivers**

T-odd

$\Delta q(= g_{1L})$ **helicity**

g_{1T} **worm-gear-1**

h_1^\perp **Boer-Mulders**

T-odd

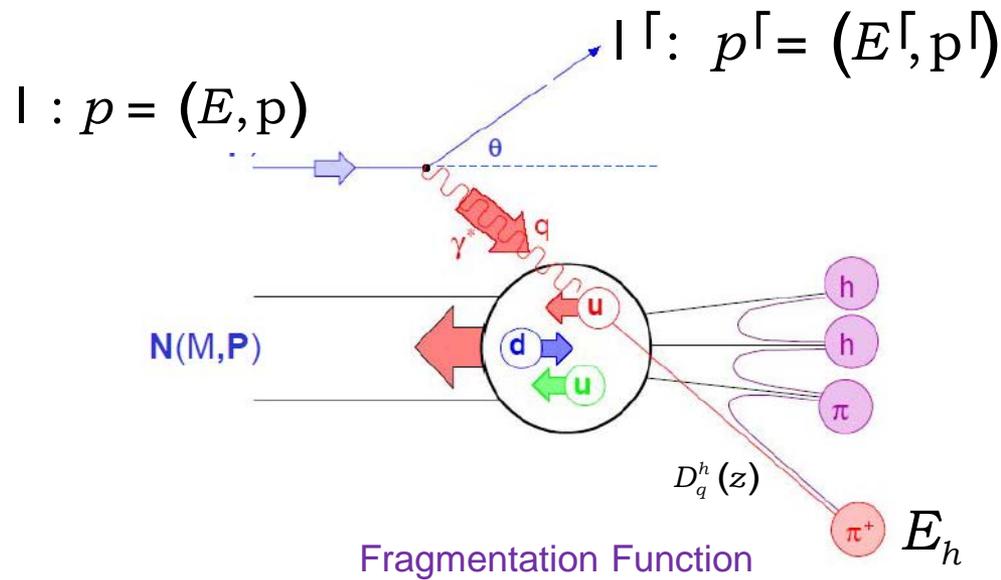
$\Delta_T q(= h_1)$ **transversity**

h_{1L}^\perp **worm-gear-2**

h_{1T}^\perp **pretzelosity**

Quark

SIDIS



$$Q^2 = -(p - p')^2$$

$$n = E - E'$$

$$x = \frac{Q^2}{2Mn} \text{ (Lab.)}$$

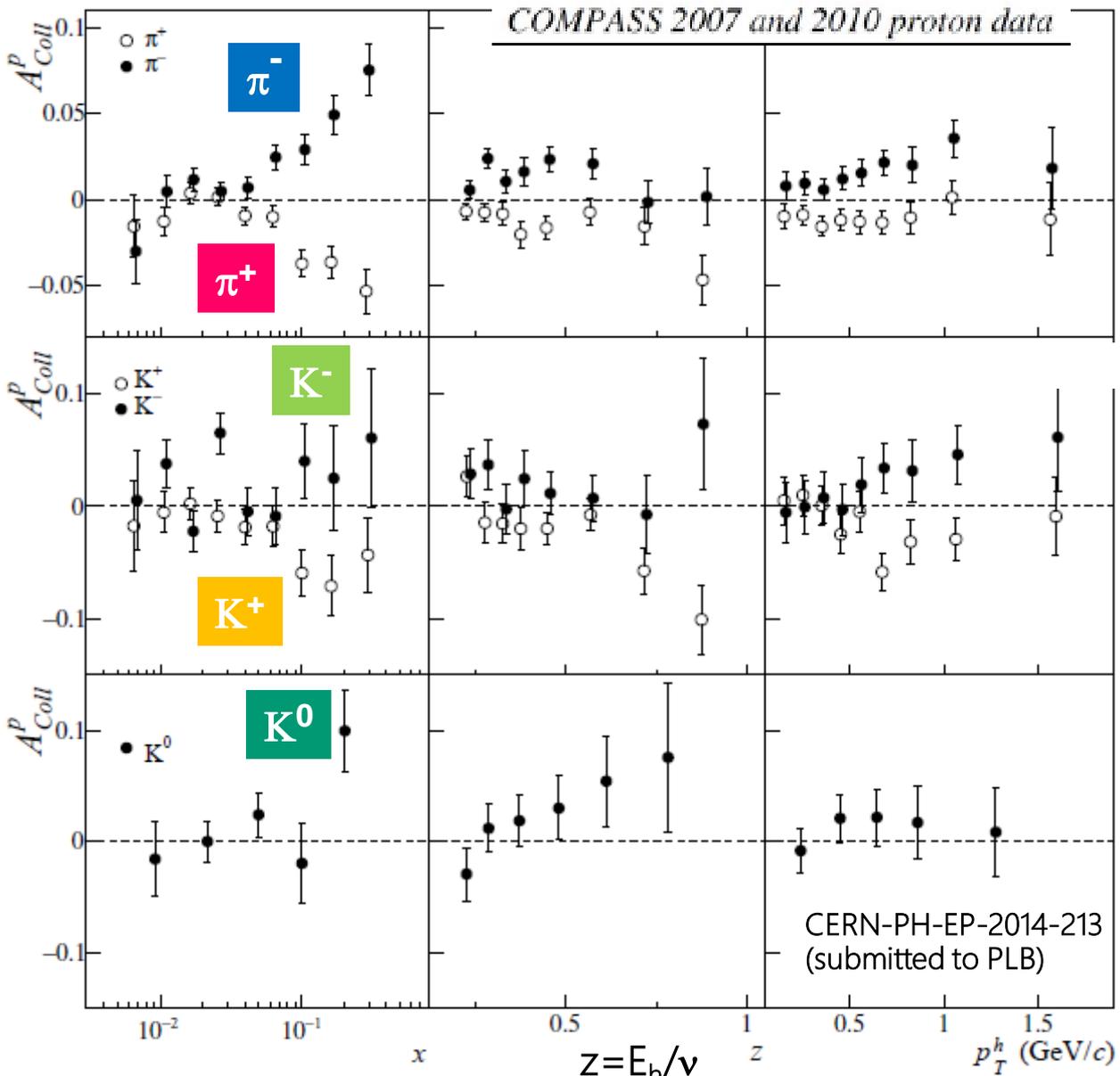
$$y = n/E$$

$$z = E_h/n$$

Energy fraction of the hadron

Collins Asymmetry on Proton

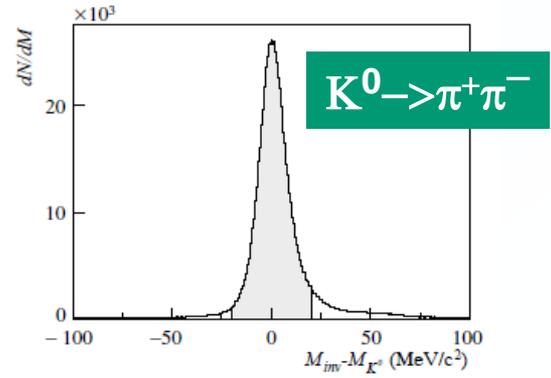
Event Selection
 $Q^2 > 1 \text{ (GeV/c)}^2$
 $W > 5 \text{ GeV/c}^2$
 $0.05 < y < 0.9$
 $z > 0.1$
 $|P_T^h| > 0.07 \text{ GeV/c}$



PID is by RICH

Clearly non-zero in valence region, negative for π^+ , positive for π^-

Similar trend for K , negative for K^+ , positive for K^-

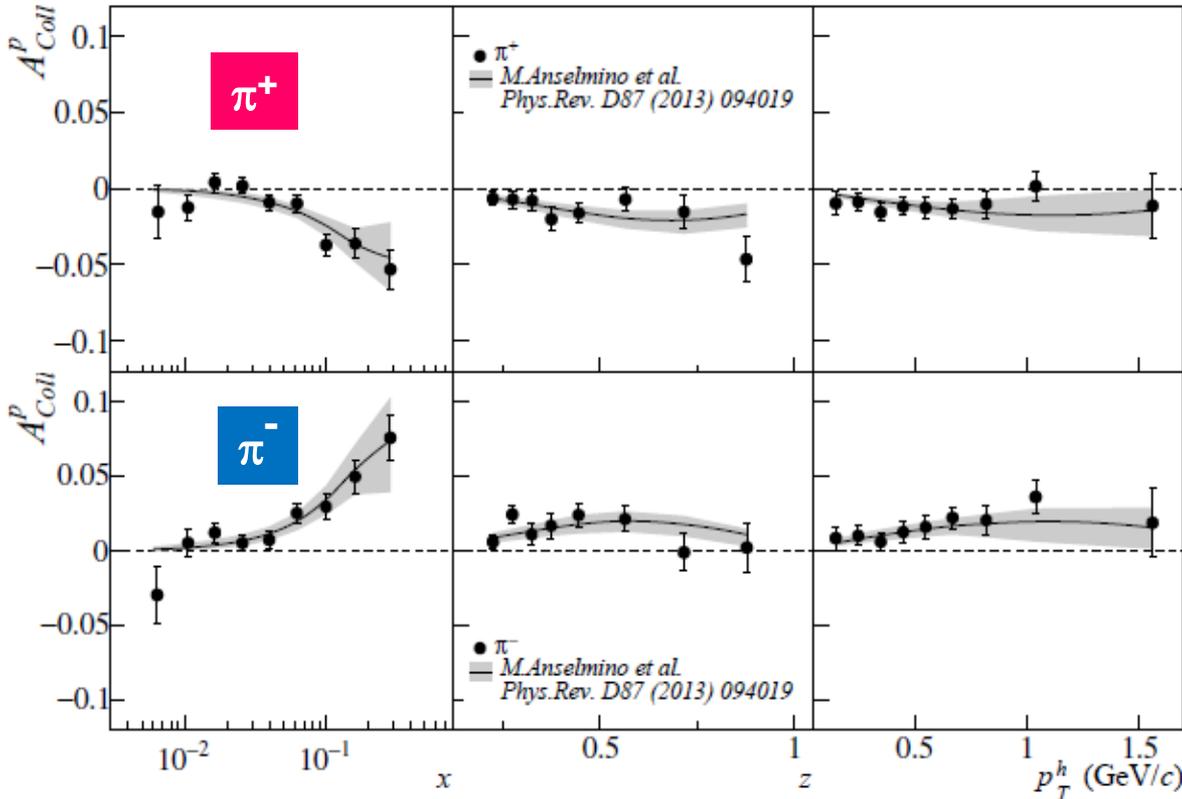


Deuteron data already published Phys. Lett. B673 (2009) 127 compatible with zero.

Collins Asymmetry compared with a Fit



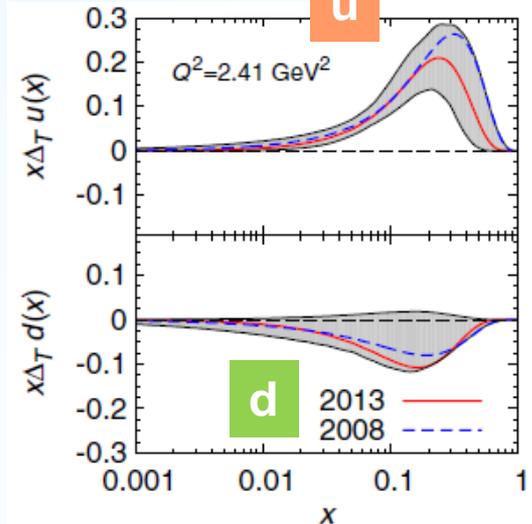
COMPASS 2007 and 2010 proton data



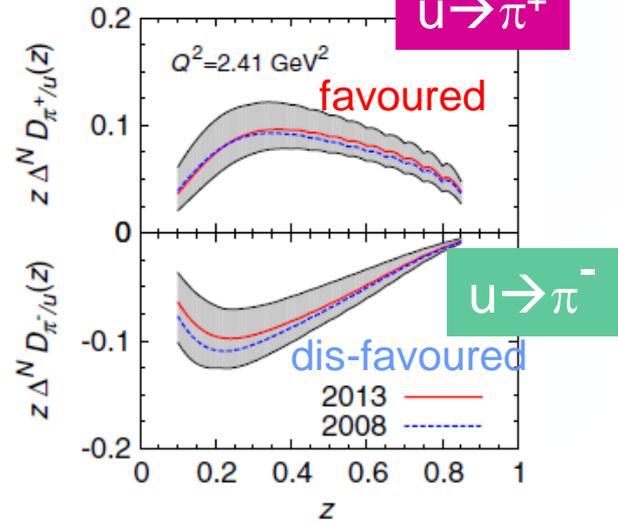
The fit reproduces the COMPASS data well

fit with HERMES, COMPASS, Belle data [PRD87(2013) 094019]

Transversity



Collins F.F.



Di-hadron Asymmetry & Transversity

$$lN^\uparrow \rightarrow l'h^+h^-X$$

Transversity PDF

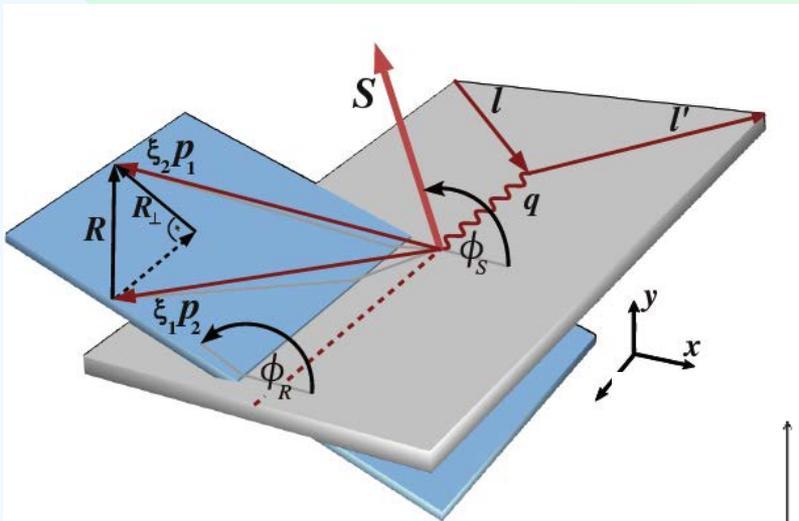
“Di-hadron FF”

$$A_{UT}^{\sin\phi_{RS}} \approx \frac{\sum_q e_q^2 \cdot \Delta_T q \cdot H_q^\perp}{\sum_q e_q^2 \cdot f_q^q \cdot D_q^{2h}}$$

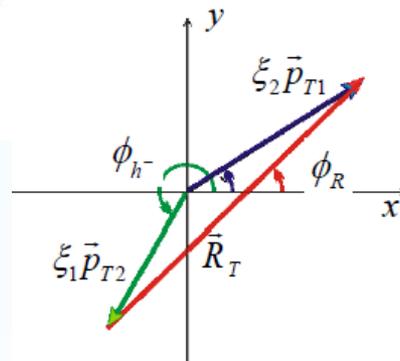
Modulation according to

$$\phi_{RS} = \phi_R - \phi_{S'} = \phi_R + \phi_S - \pi$$

ϕ_R : azimuthal angle of \mathbf{R} (Relative hadron momentum vector)



the γ^* -nucleon system



$$\mathbf{R} = \frac{z_2 \mathbf{p}_1 - z_1 \mathbf{p}_2}{z_1 + z_2} =: \xi_2 \mathbf{p}_1 - \xi_1 \mathbf{p}_2$$

$$\phi_R = \frac{(\mathbf{q} \times \mathbf{l}) \cdot \mathbf{R}}{|(\mathbf{q} \times \mathbf{l}) \cdot \mathbf{R}|} \arccos \left(\frac{(\mathbf{q} \times \mathbf{l}) \cdot (\mathbf{q} \times \mathbf{R})}{|\mathbf{q} \times \mathbf{l}| |\mathbf{q} \times \mathbf{R}|} \right)$$

ϕ_S : azimuthal angle of struck quark spin

ϕ_S : azimuthal angle of initial quark spin

$$N_{h+h^-}(x, y, z, M_{h+h^-}^2, \cos\theta, \phi_{RS})$$

$$\propto \sigma_{UU}(1 + f(x, y)P_T D_m(y)A_{UT}^{\sin\phi_{RS}} \sin\theta \sin\phi_{RS}),$$

Di-hadron Asymmetry on Proton



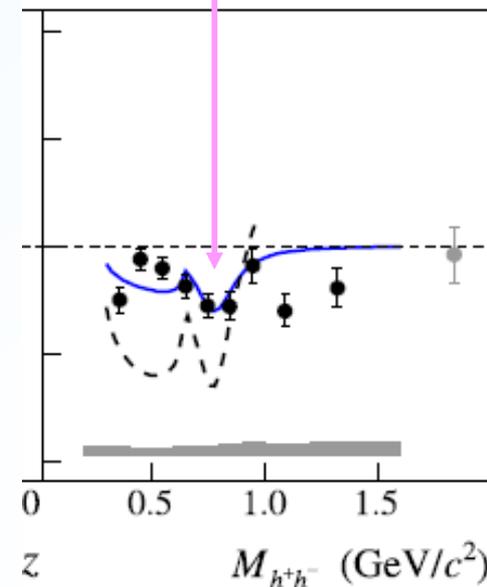
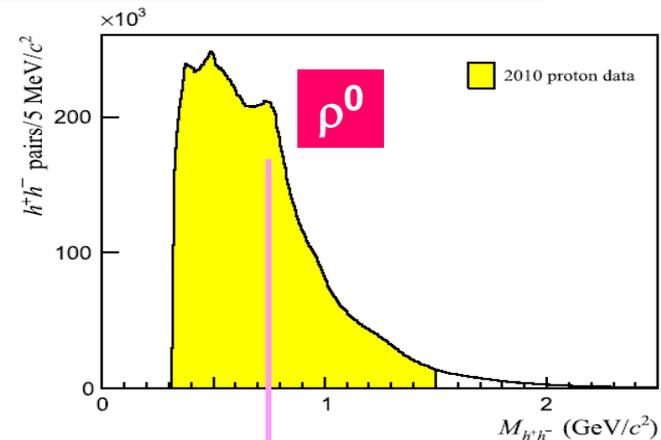
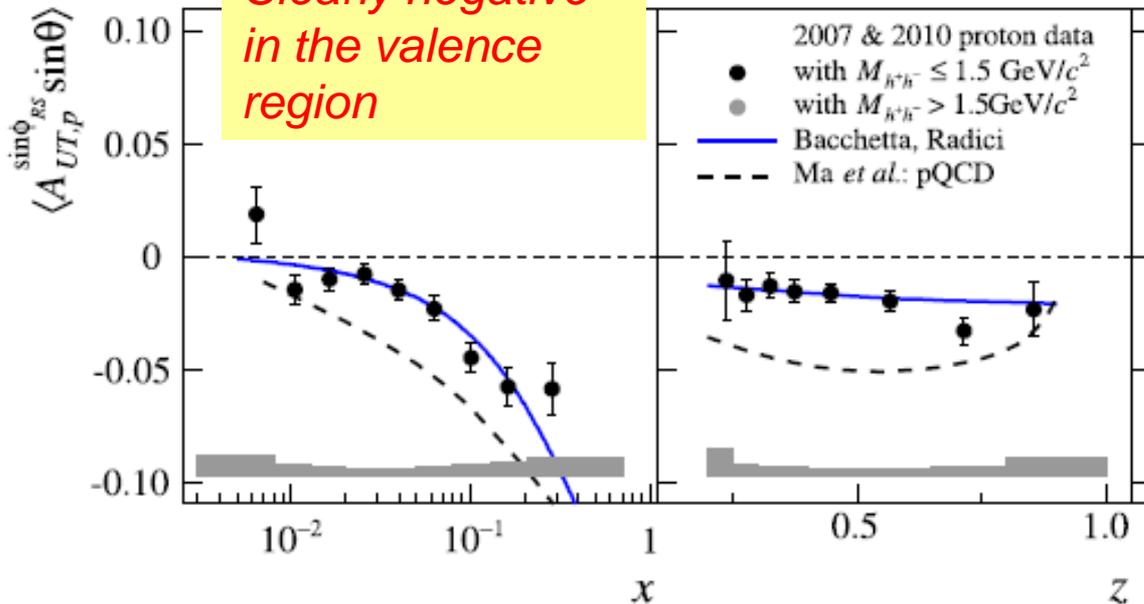
COMPASS 2007/2010 proton

$N_{\text{pair}} = 3.5 \times 10^7$
after the cuts

Event Selection

$Q^2 > 1 \text{ (GeV/c}^2\text{)}$
 $W > 5 \text{ GeV/c}^2$
 $0.1 < y < 0.9$
 $z > 0.1$
 $|R_T| > 0.07 \text{ GeV/c}$

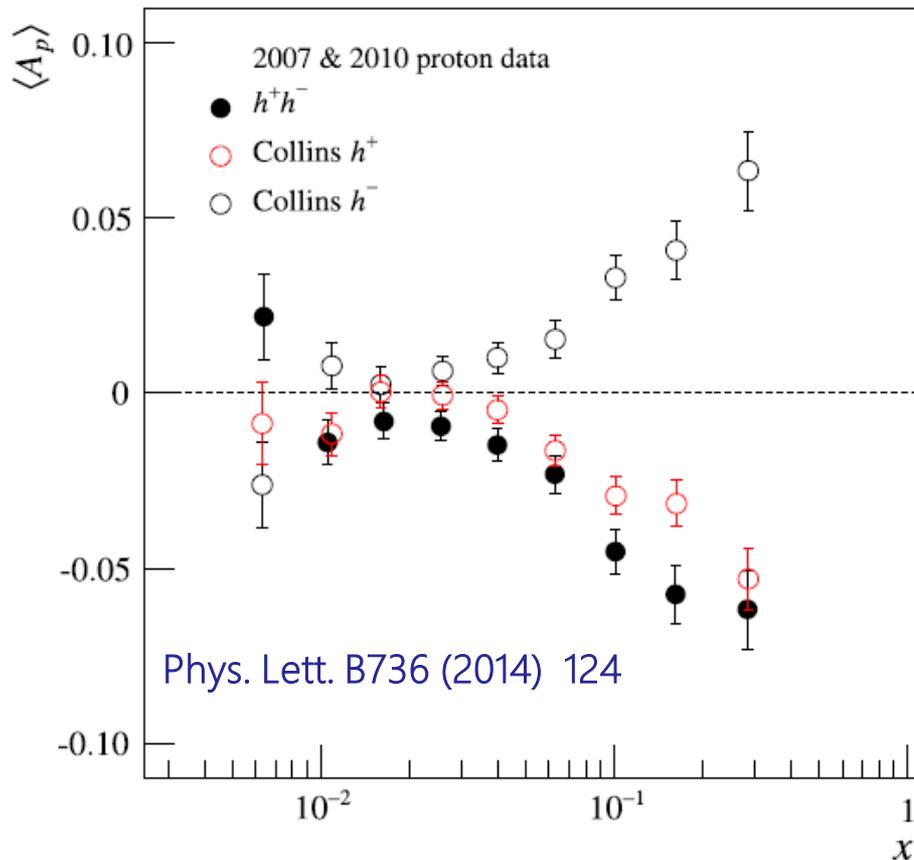
Clearly negative
in the valence
region



Deuteron data also published
 Phys. Lett. B713 (2012) 10
 The asymmetry is compatible with zero!

Phys. Lett. B736 (2014) 124

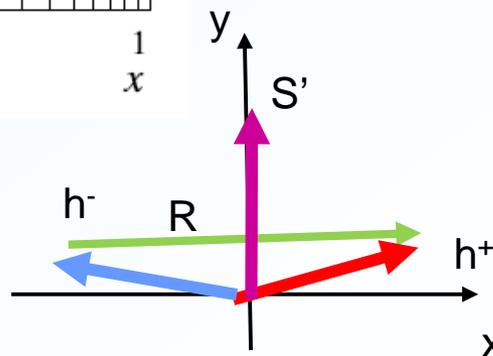
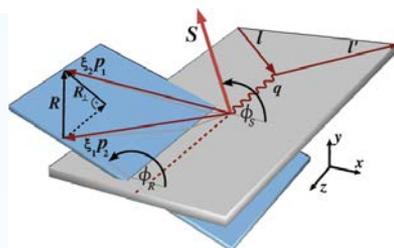
Interplay; Di-hadron & Collins Asymmetries



[1] Mirror symmetry
between Collins h^+ and h^-

[2] Di-hadron asymmetry
similar to the Collins h^+

➔ Hint of common
physical origin
between Di-hadron FF
and Collins mechanism



Collins asymmetries
for di-hadron events
to be studied

Sivers Asymmetry on Proton



Event Selection

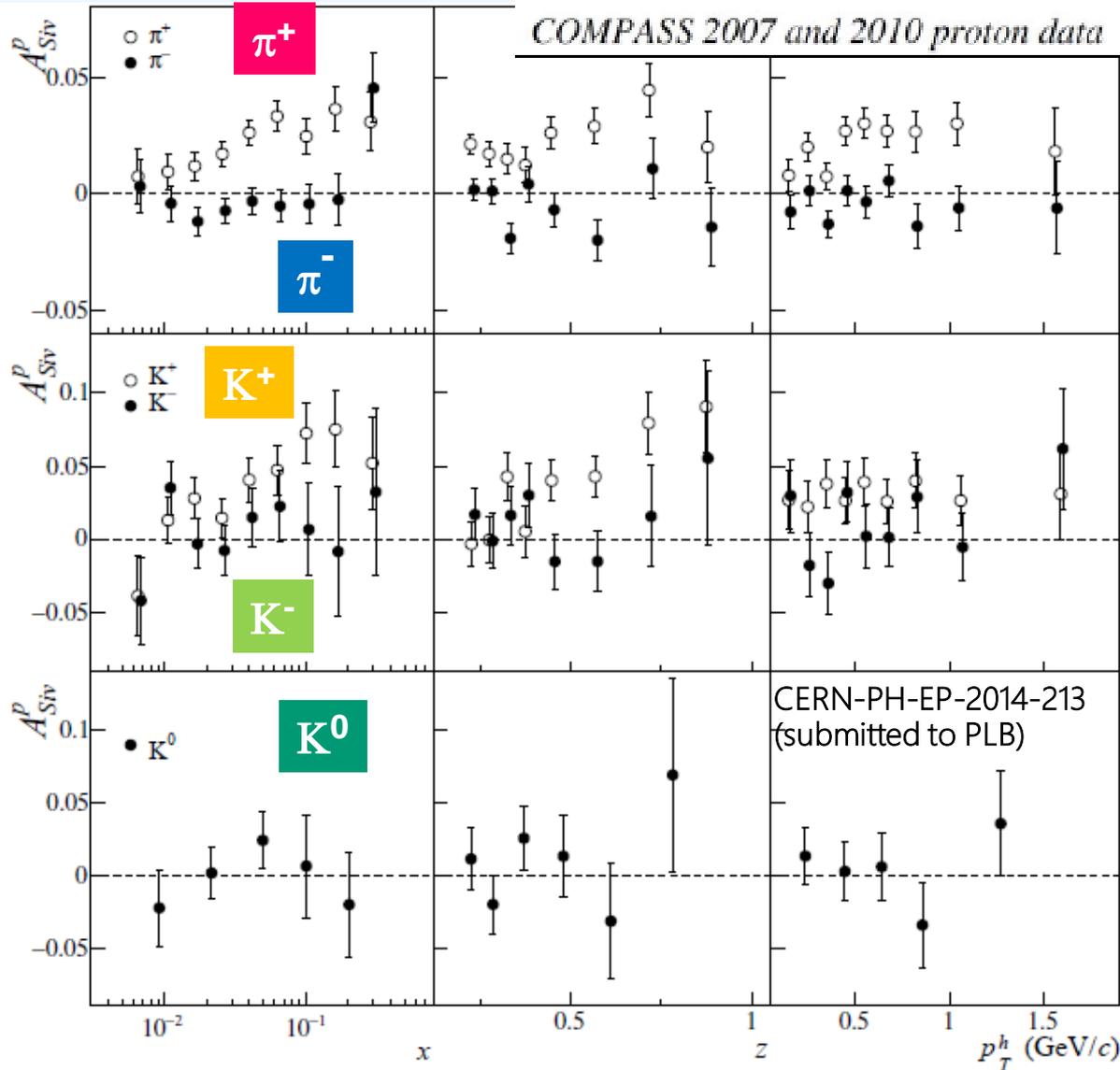
$Q^2 > 1 \text{ (GeV/c)}^2$

$W > 5 \text{ GeV/c}^2$

$0.05 < y < 0.9$

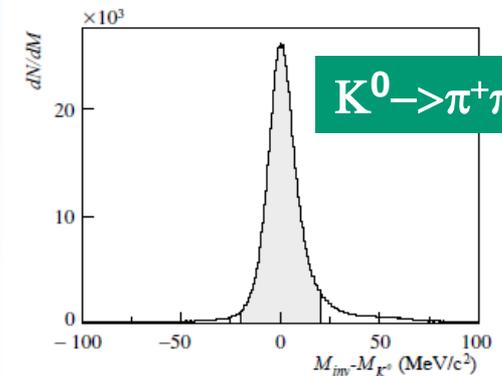
$z > 0.1$

$|\text{Ph}_T| > 0.07 \text{ GeV/c}$



Significantly large signal for π^+ and K^+

Compatible with zero for π^- , K^- and K^0

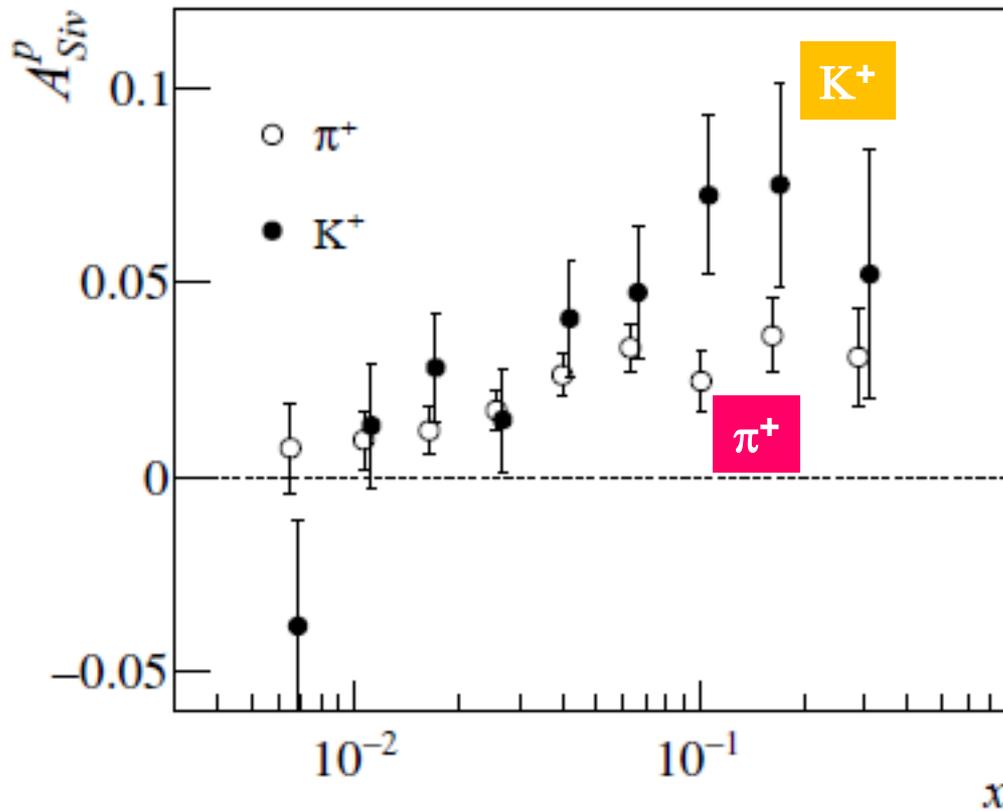


Deuteron data already published
Phys. Lett. B673 (2009) 127

Sivers Asymmetry on Proton; π^+ & K^+



COMPASS 2007 and 2010 proton data



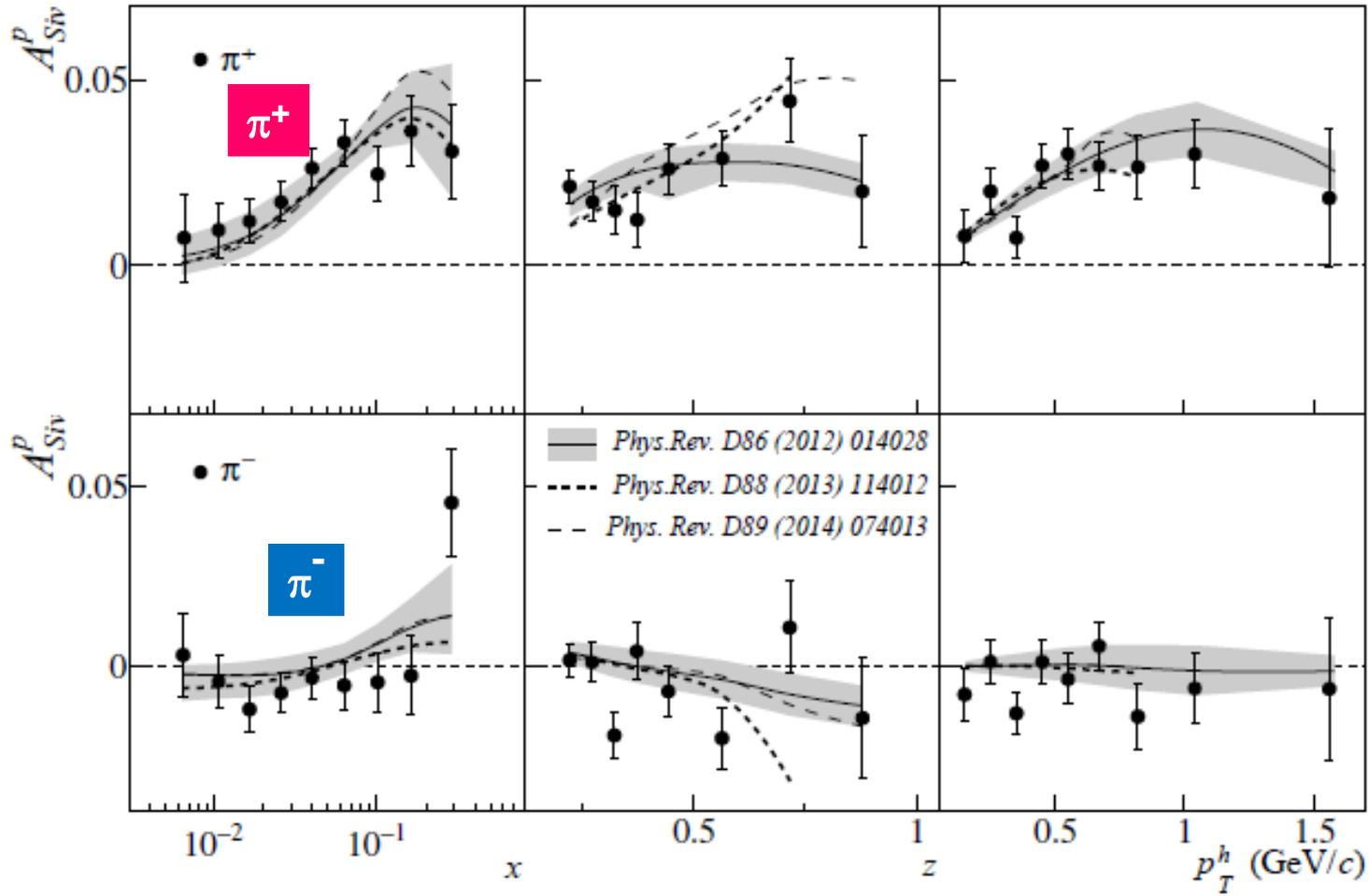
K^+ signal is even larger than that of π^+

→ possible contribution from sea quarks

Sivers Asymmetry compared with Global Fits



COMPASS 2007 and 2010 proton data



The fits reproduce the COMPASS data reasonably well.

COMPASS results for unidentified hadrons on proton is included in the global fits

Conclusions

- COMPASS is a DIS and SI-DIS experiment at CERN to study the nucleon spin structure using a polarized muon beam and a polarized target.
- Collins and Sivers asymmetries have been measured on proton target for identified hadrons.
- The Collins asymmetries for charged pions show non-zero signals in the valence region. The signals for the different charged pions give opposite signs to each other.
- The Sivers asymmetries have been measured on proton target for identified hadrons. Those for positive charged pions and kaons show positive values.
- The di-hadron asymmetries have been measured on proton. They are clearly negative in the valence region. A dip structure has been observed around the rho meson mass as expected.
- The di-hadron asymmetry and the Collins asymmetry for positive hadron show a similar behavior.