COMPASS results on

Collins and Sivers asymmetries

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on behalf of the COMPASS Collaboration

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TRANSVERSITY 2011
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TRANSVERSE POLARIZATION PHENOMENA IN HARD SCATTERING
29 August - 2 September 2011
Veli Lošinj, Croatia

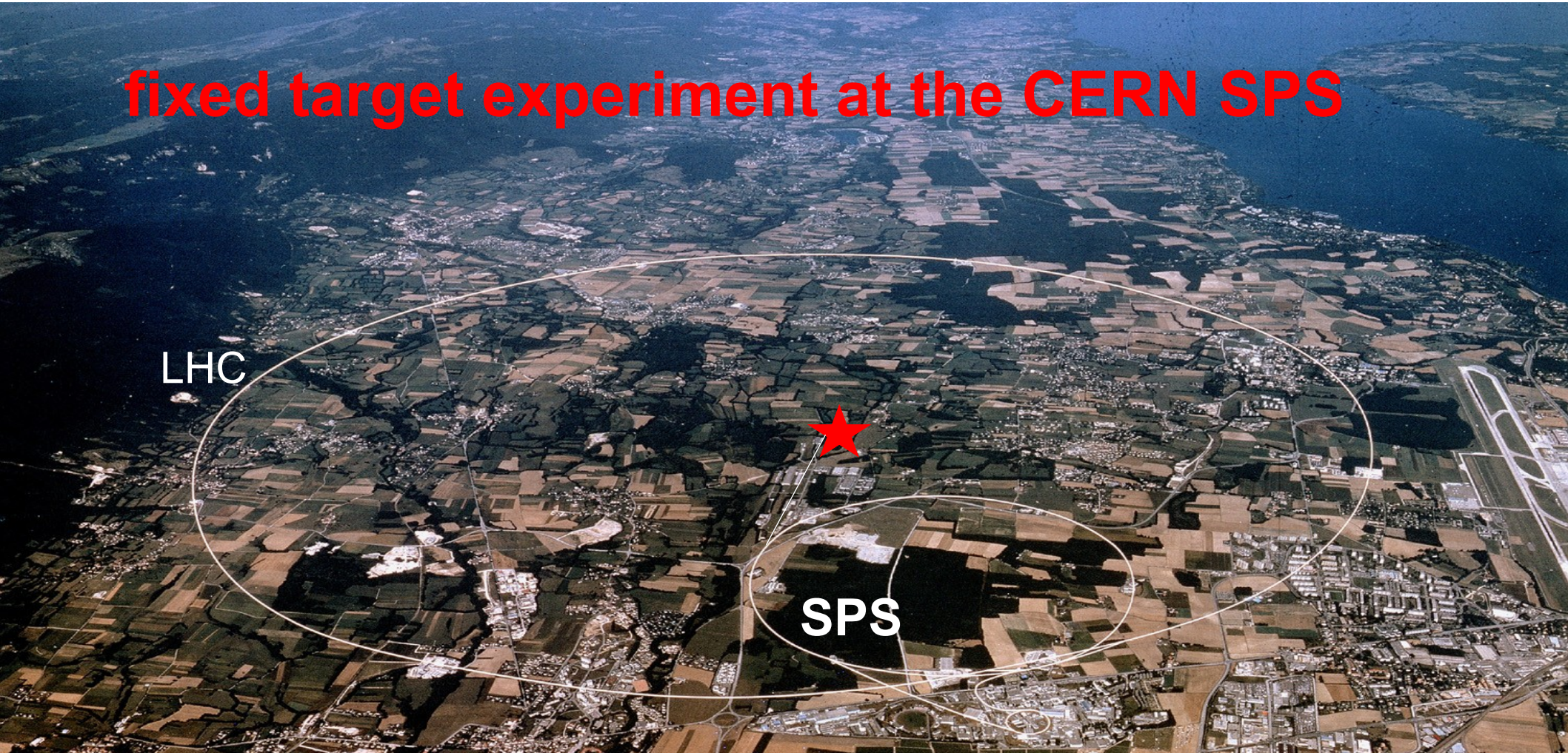
ECSAC
European Centre for Science Arts and Culture

OUTLINE

- the COMPASS experiment
- COMPASS results on
  Collins and Sivers asymmetries from 2010 run
- comparison with previous measurements
- outlook

COMPASS

COmmon
Muon and
Proton
Apparatus for
Structure and
Spectroscopy



COmmon
Muon and
Proton
Apparatus for
Structure and
Spectroscopy

proposed 1996, approved 1998, data taking since 2002

goals

- **meson and baryon spectroscopy**
  π polarizability

with **high energy hadron beams**

- **nucleon spin structure** with a **high energy muon beam** and **longitudinally polarised targets**
  - **gluon polarisation**
  - **helicity PDFs**

  and **transversely polarised targets**
  - **transversity PDFs**
  - **Sivers function (add-on)**

COMPASS data taking

2002
2003 } **polarised deuteron target** — **L, T** (25% of the time)
2004

2005 *CERN shutdown*

2006 **polarised deuteron target** — **L only**

ΔG

published results
→ *F. Sozzi*

2007 **polarised proton target** — **L, T** (50% of the time)

2008 / 2009 spectroscopy

2010 **polarised proton target** — **T only** ***first results***

2011 ***polarised proton target*** — ***L only***

MOTIVATION for a PROTON RUN in 2010

- in 2007 in half a year run clear signal for
  Collins asymmetry (h^+, h^-)
  Sivers asymmetry (h^+) *smaller than that measured at HERMES*
  on NH_3 target and 160 GeV μ

  but, for Sivers
  - some systematics not fully understood
  - glimpse for a possible dependence on W

- in 2010 full year of run on transversely polarised NH_3
  - to reduce the errors
  - to investigate the z, p_T, Q^2 dependence
  - to assess the relevance of the other TMD's
  - to provide data for a global analysis

COMPASS spectrometer

- high energy beams
- large angular acceptance
- broad kinematical range

two stages spectrometer

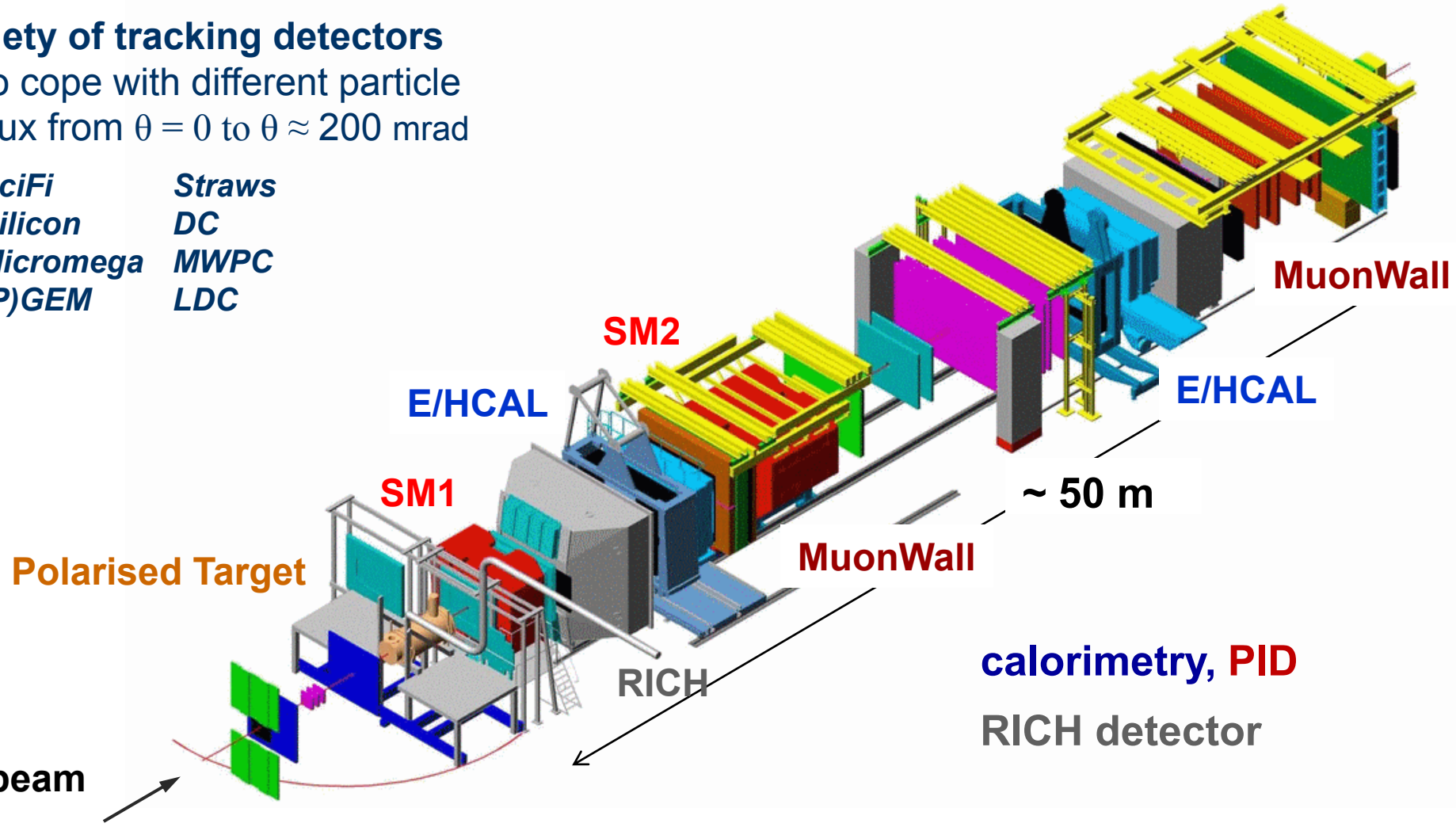
Large Angle Spectrometer (SM1)

Small Angle Spectrometer (SM2)

variety of tracking detectors

to cope with different particle flux from $\theta = 0$ to $\theta \approx 200$ mrad

SciFi	*Straws*
Silicon	*DC*
Micromega	*MWPC*
(P)GEM	*LDC*



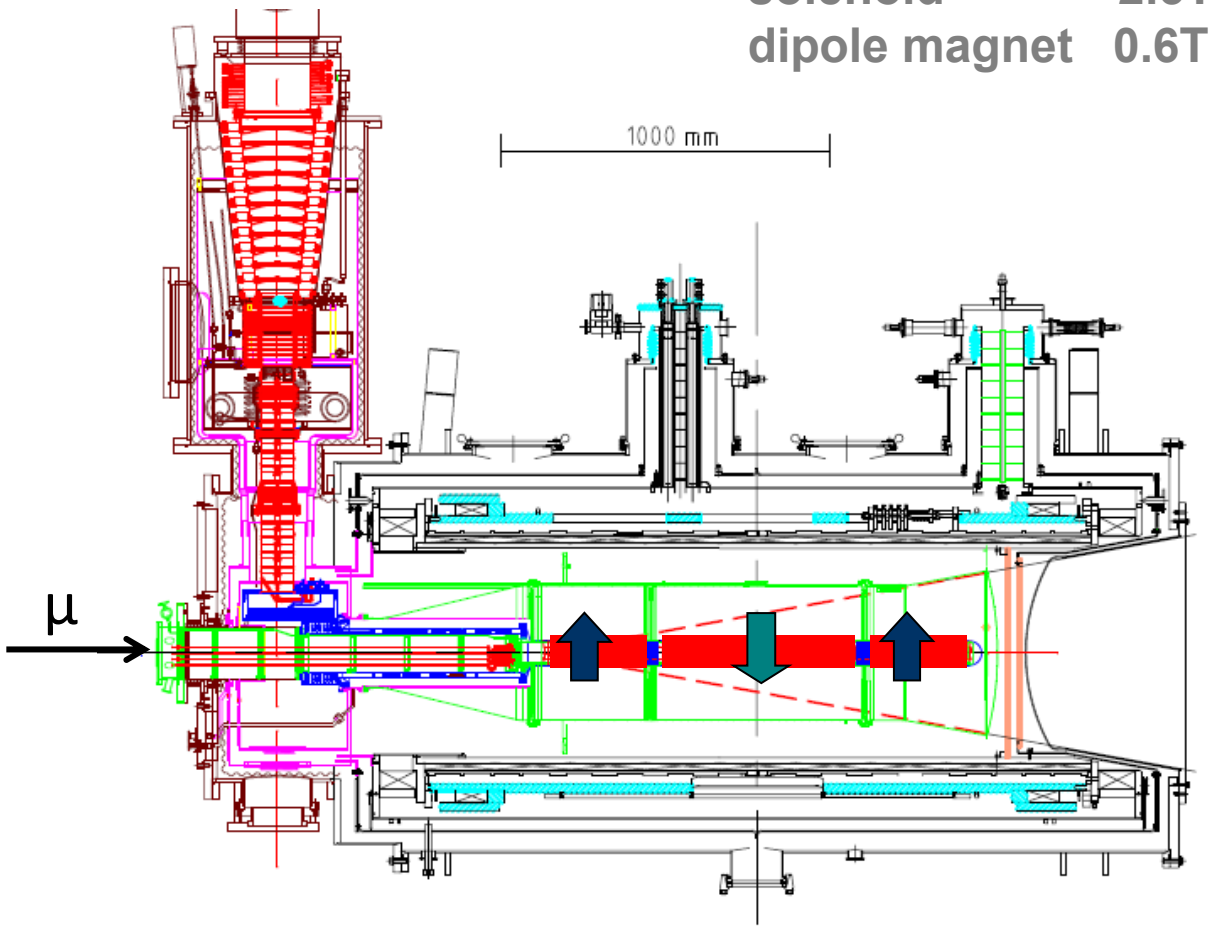
calorimetry, PID

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%

COMPASS spectrometer in 2010

as in 2007 plus

- more EM Calorimetry (not used yet)
- **a new Large Angle Spectrometer Trigger (LAST)**

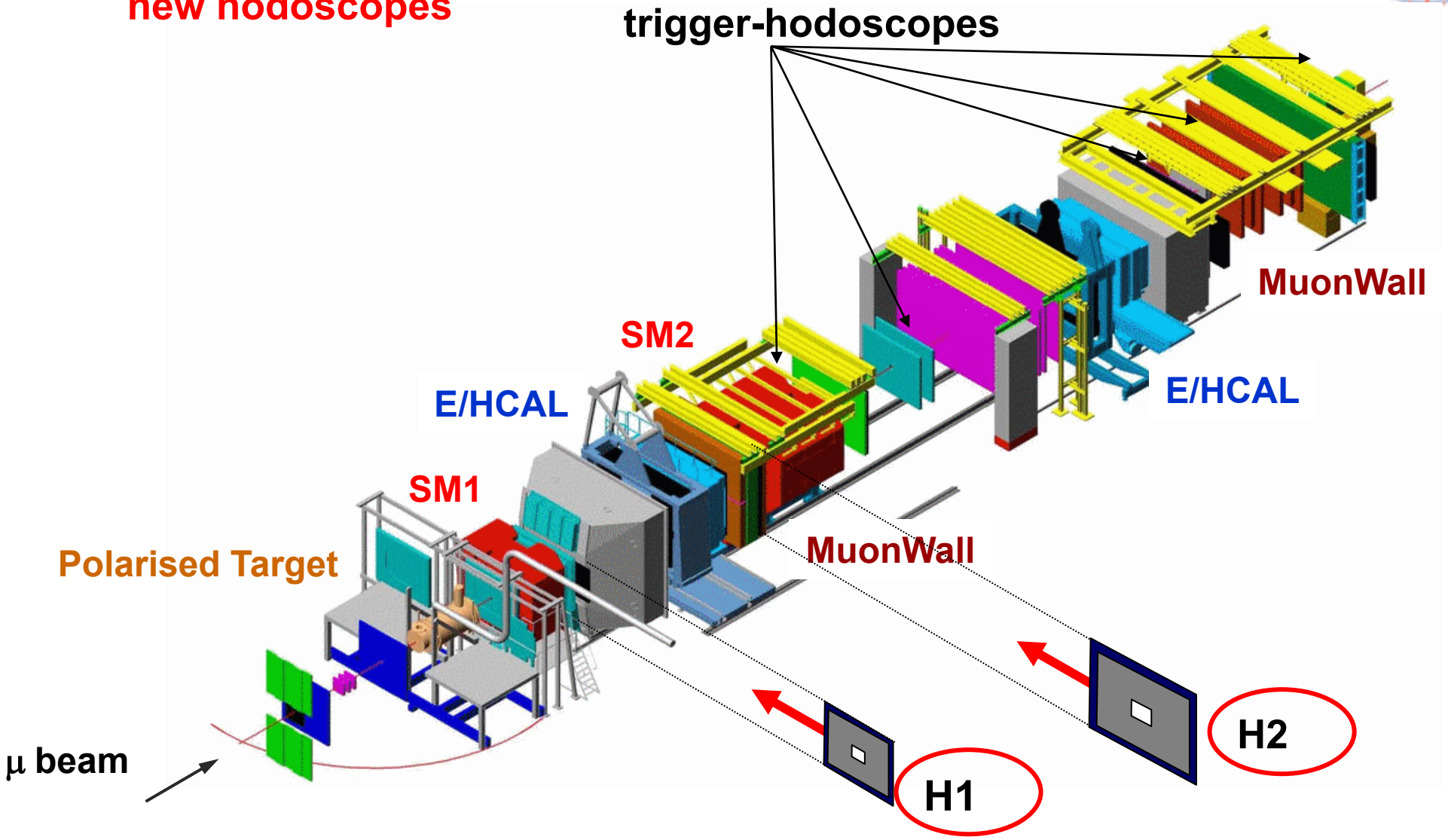
  triggering on the scattered muon
  horizontal bars for target pointing in vertical plane

  to

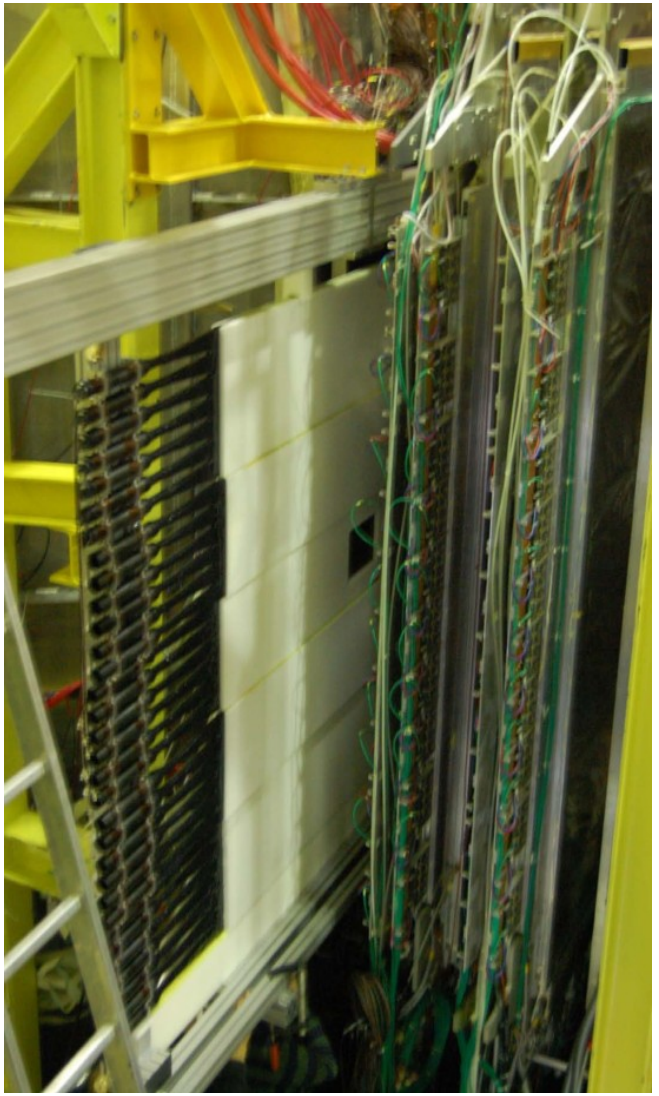
  - **increase the acceptance at large x**
  - **avoid triggering with the calorimeters**

Large Angle Spectrometer Trigger

two
new hodoscopes

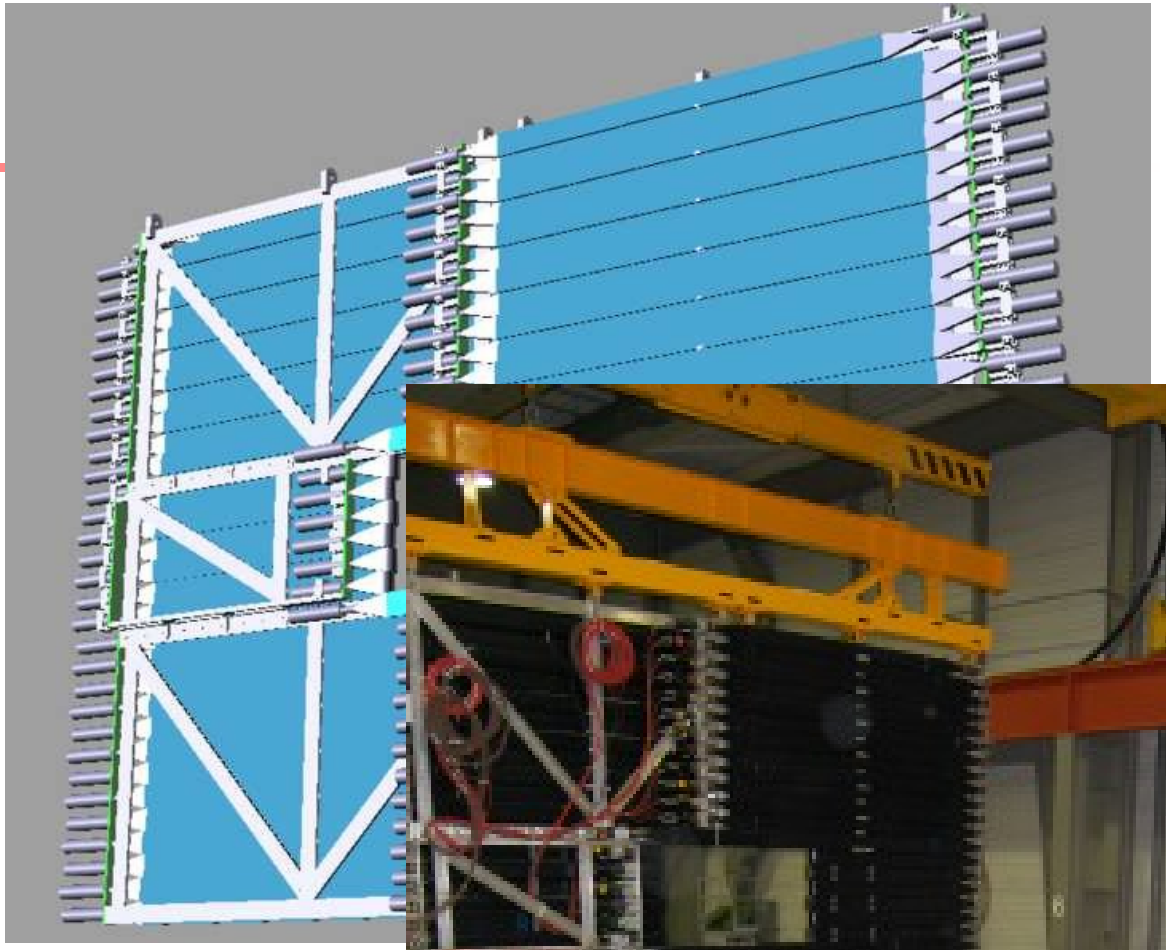


H1 and H2



H1

1.8 x 2.2 m^2, 64 channels



H2

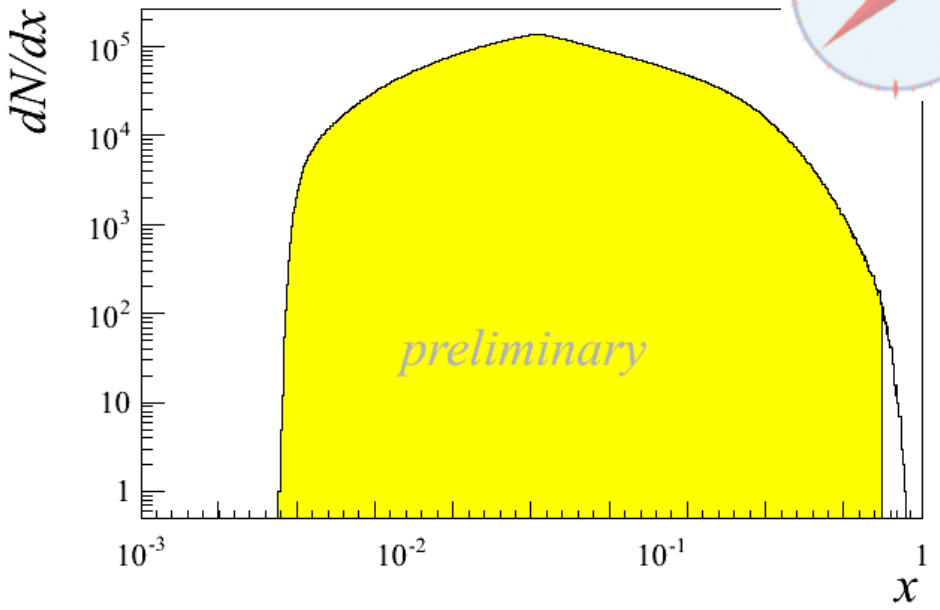
large size
4.0 x 5.2 m^2
128 channels

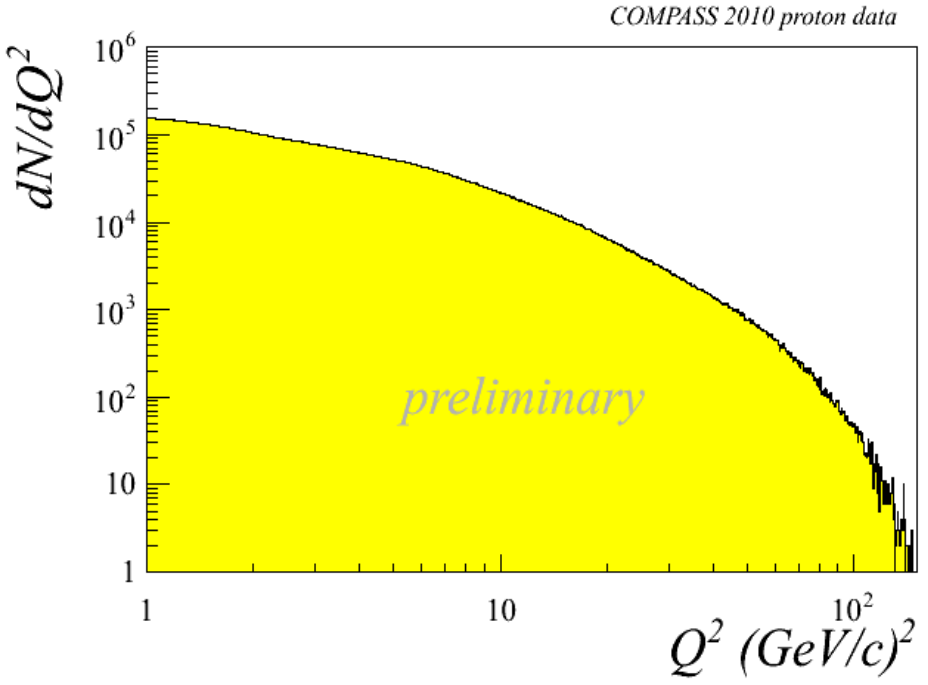
SIDIS event selection

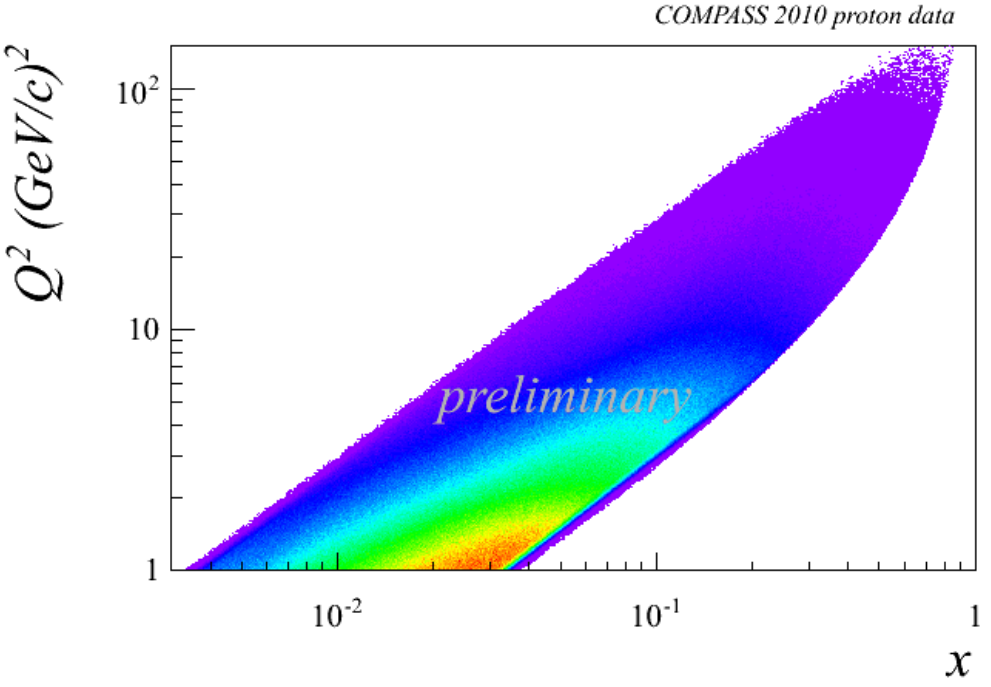
DIS cuts: $Q^2 > 1\ (GeV/c)^2$

$0.1 < y < 0.9$

$W > 5\ GeV/c^2$



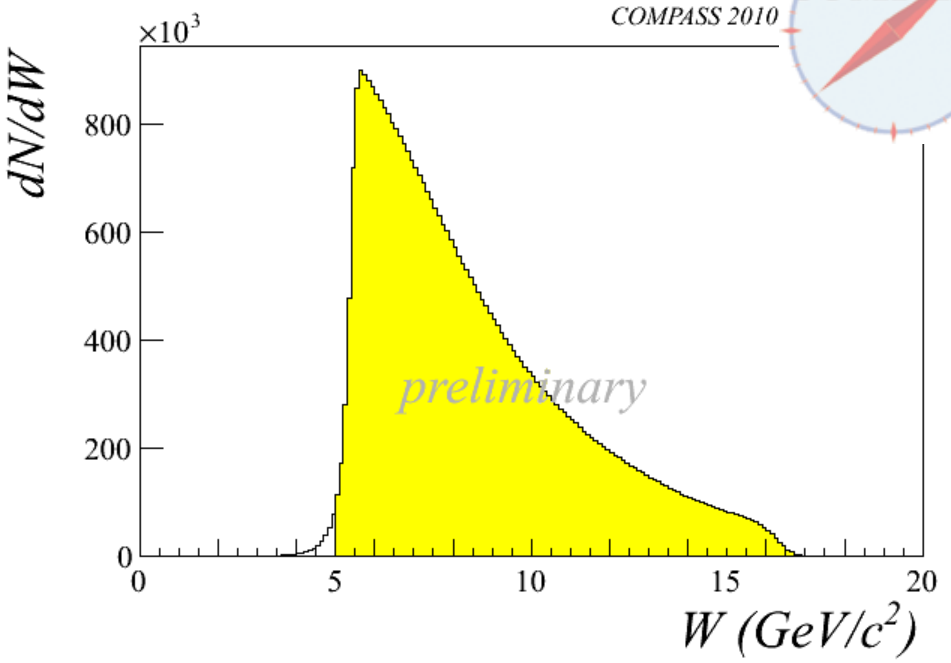


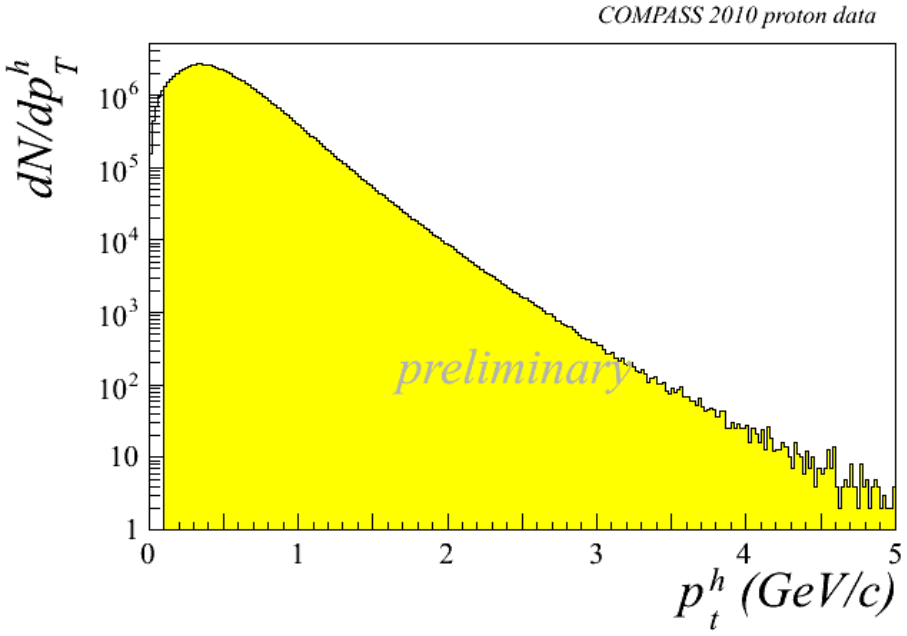


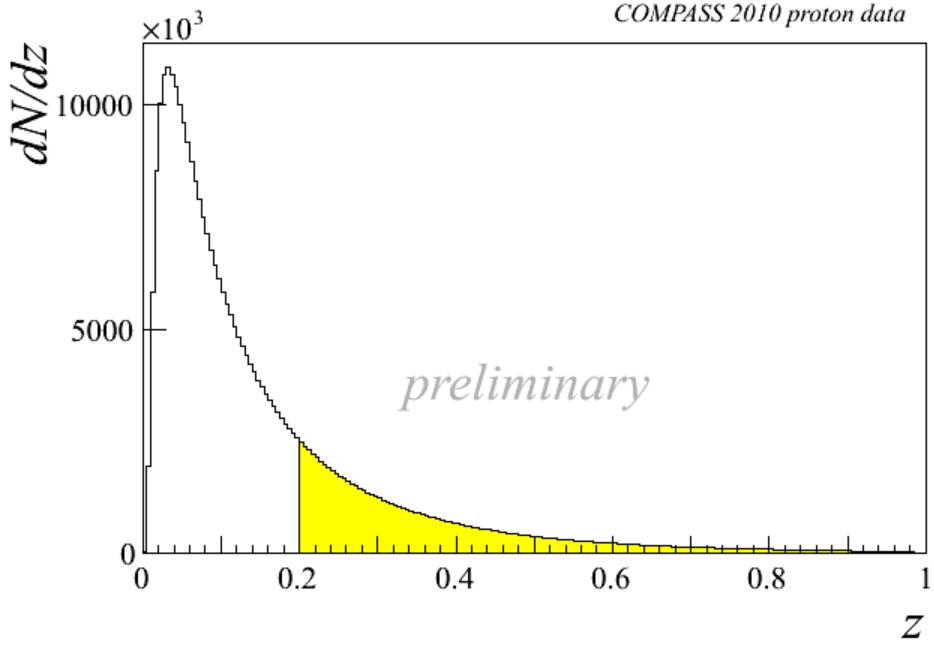
SIDIS event selection

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

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





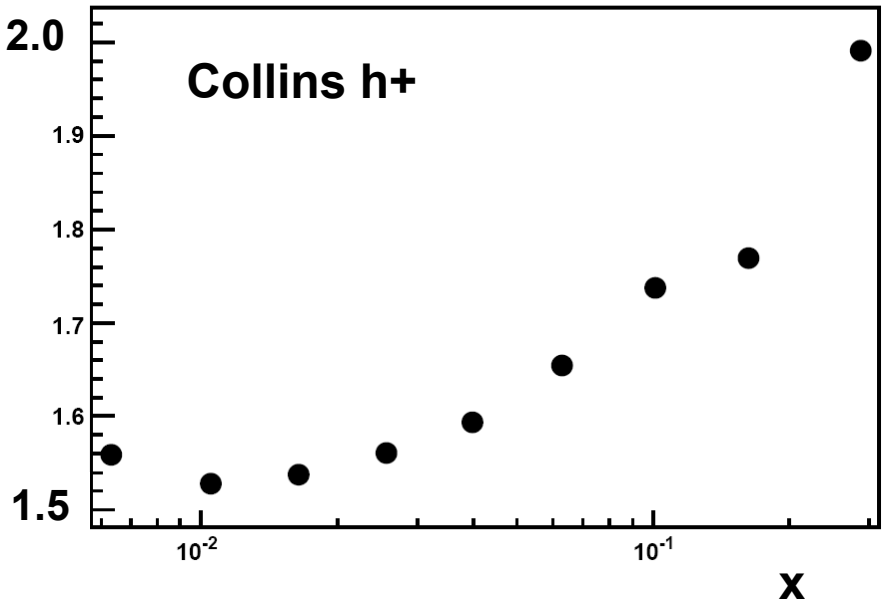


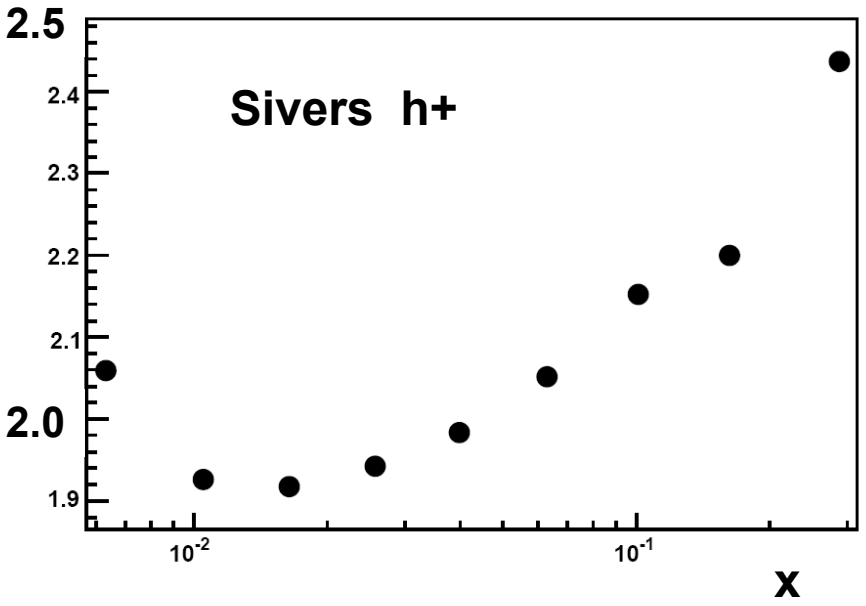
2010 statistics

events on tape	37×10^9
DIS events after all cuts	1.6×10^8
hadrons after all cuts	0.8×10^8

final statistics: 43×10^6 h+ 34×10^6 h-

ratio of statistical errors: 2007 / 2010





Collins asymmetry

in SIDIS off transversity polarised nucleons

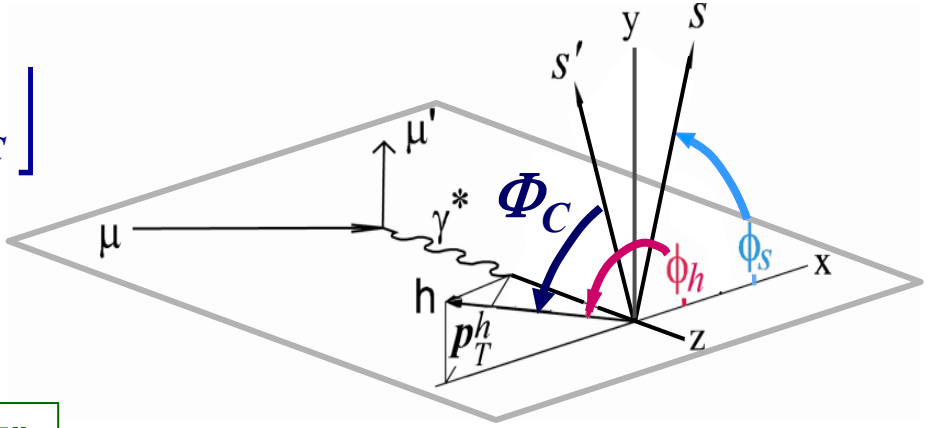
amplitude of the $\sin\Phi_C$ modulation in the azimuthal distribution of the final state hadrons

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

ϕ_h azimuthal angle of the hadron,

ϕ_S azimuhtal angle of the nucleon spin

$$N_h^{\pm}(\Phi_C) = N_h^0 \cdot \left[1 \pm P_T \cdot D_{NN} \cdot A_{Coll} \cdot \sin\Phi_C\right]$$



transversity

"Collins FF"

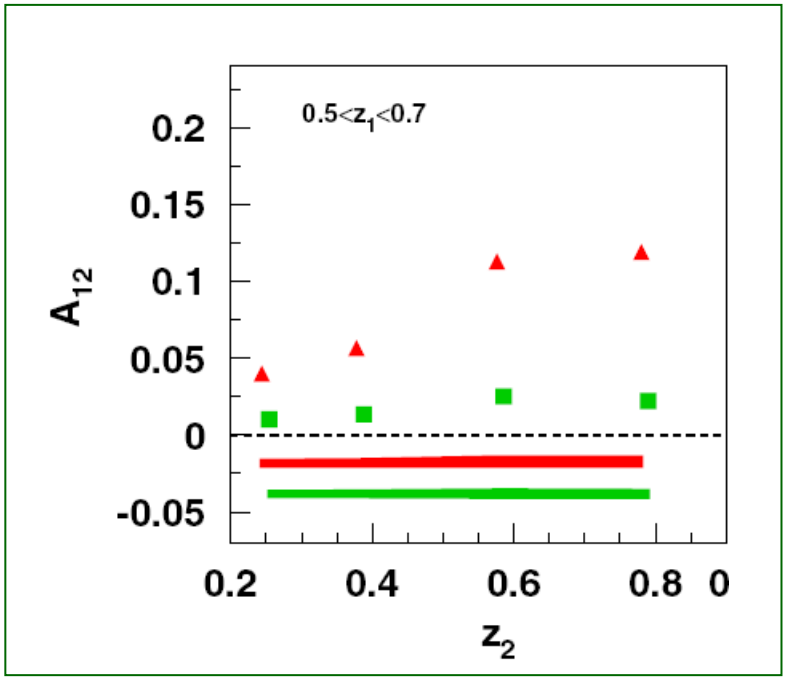
$$A_{Coll} \approx \frac{\sum_q e_q^2 \, \Delta_T q \otimes \Delta_T^0 D_q^h}{\sum_q e_q^2 \, q \otimes D_q^h}$$

today the most promising way to access transversity

Collins asymmetry

in SIDIS off transversity polarised nucleons

Collins FF: gives a LR asymmetry in the hadronisation of transversely polarised quarks



products of Collins FFs can be measured in

$$e^+e^- \rightarrow \pi^+\pi^- X$$

first low statistics results from LEP data

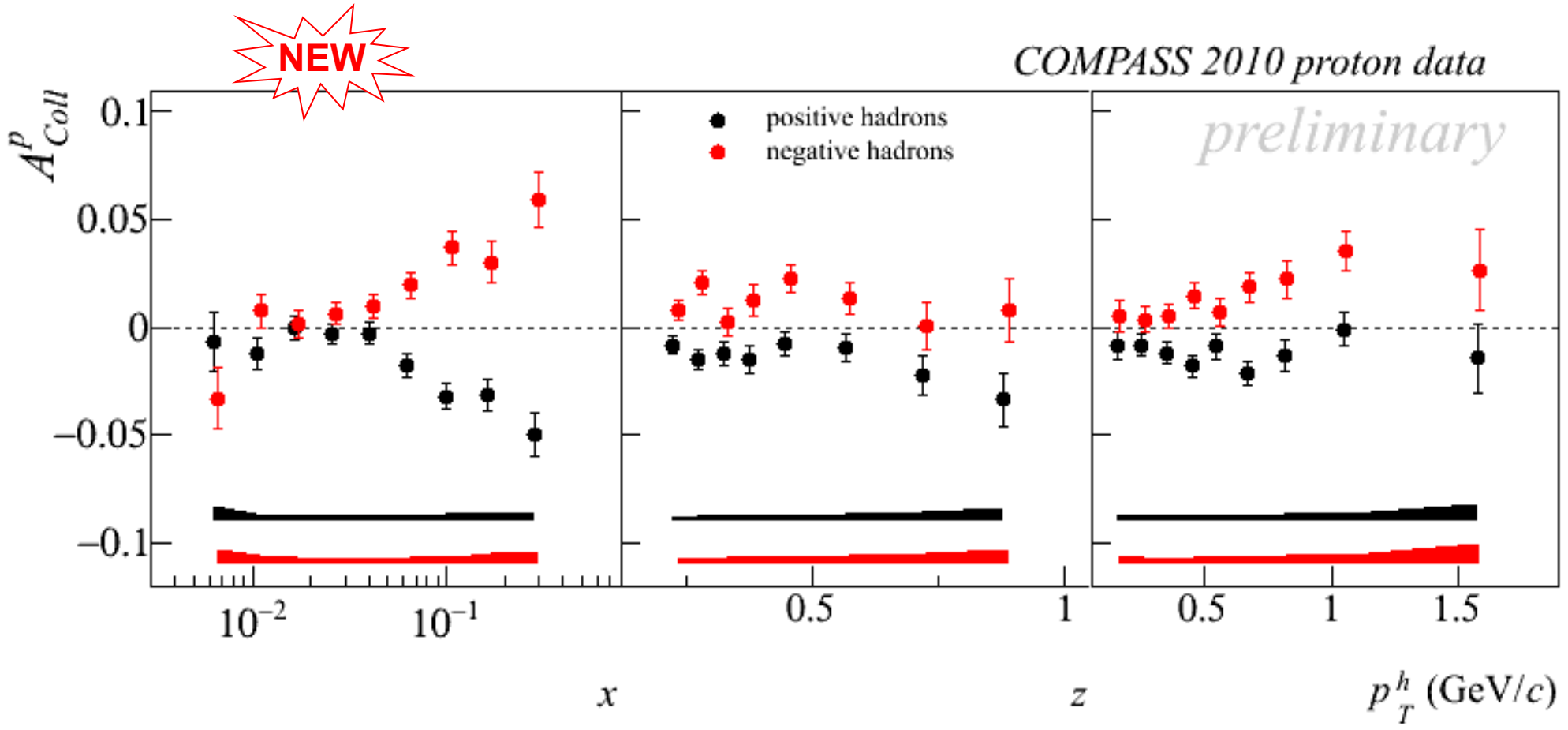
2005 first data from BELLE

"Collins FF"

$$A_{Coll} \approx \frac{\sum_q e_q^2 \, \Delta_T q \otimes \Delta_T^0 D_q^h}{\sum_q e_q^2 \, q \otimes D_q^h}$$

today the most promising way to access transversity

Collins asymmetry 2010 data

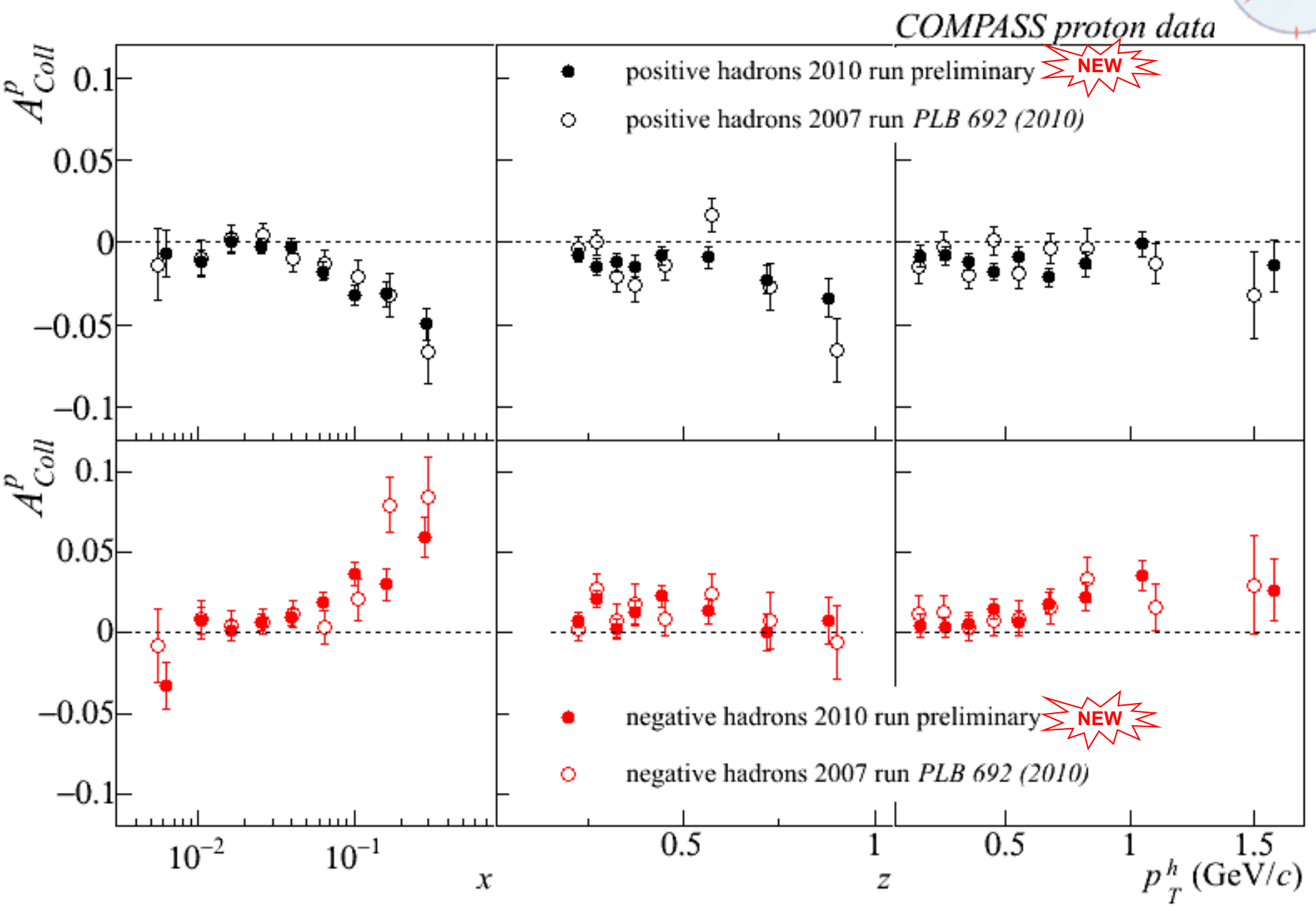


nice confirmation of the 2007 results,

with better statistics

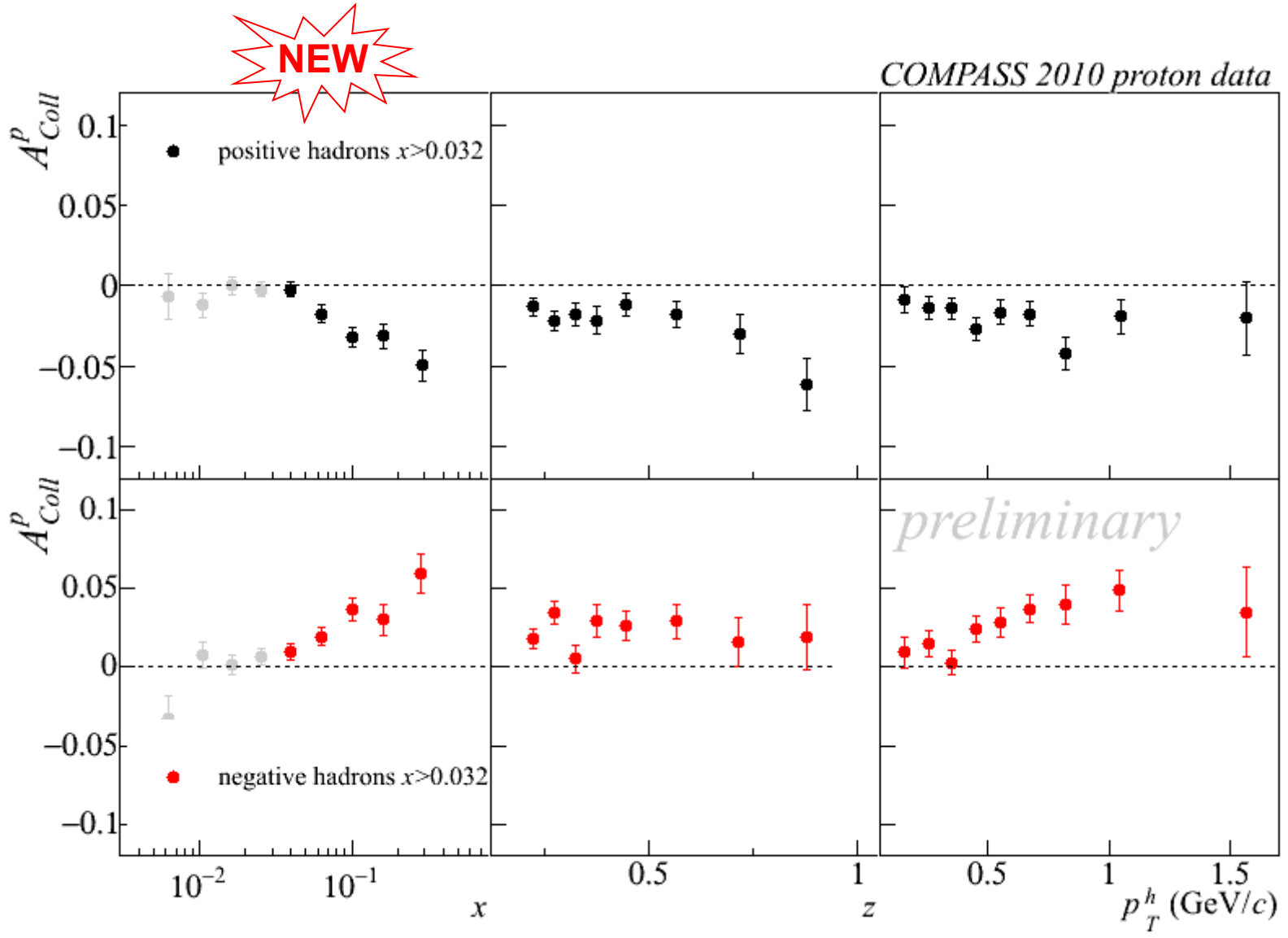
$\sigma_{syst} \sim 0.5\ \sigma_{stat}$

Collins asymmetry 2010 vs 2007 data



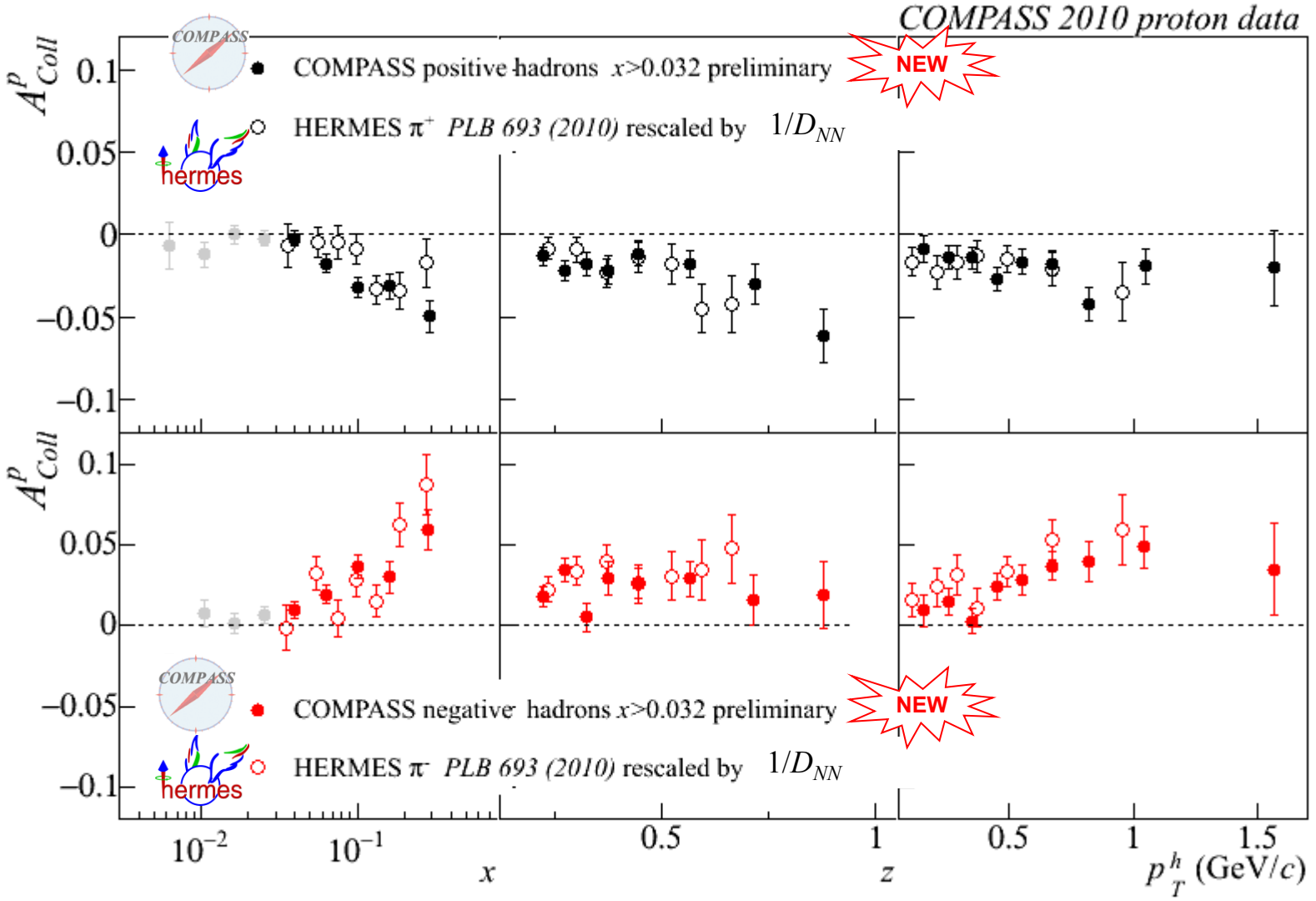
Collins asymmetry 2010 data

x > 0.032 region



Collins asymmetry 2010 data

x > 0.032 region - comparison with HERMES results



nice agreement

the Sivers function

a long debate

1992 introduced by D. Sivers

1993 J. Collins demonstrate that it must vanish

2002 S. Brodsky et al.: it can be ≠ 0 because of FSI

2002 J. Collins: process dependent, change of sign SIDIS ↔ DY

....

2005 first measurements of the Sivers asymmetry in SIDIS

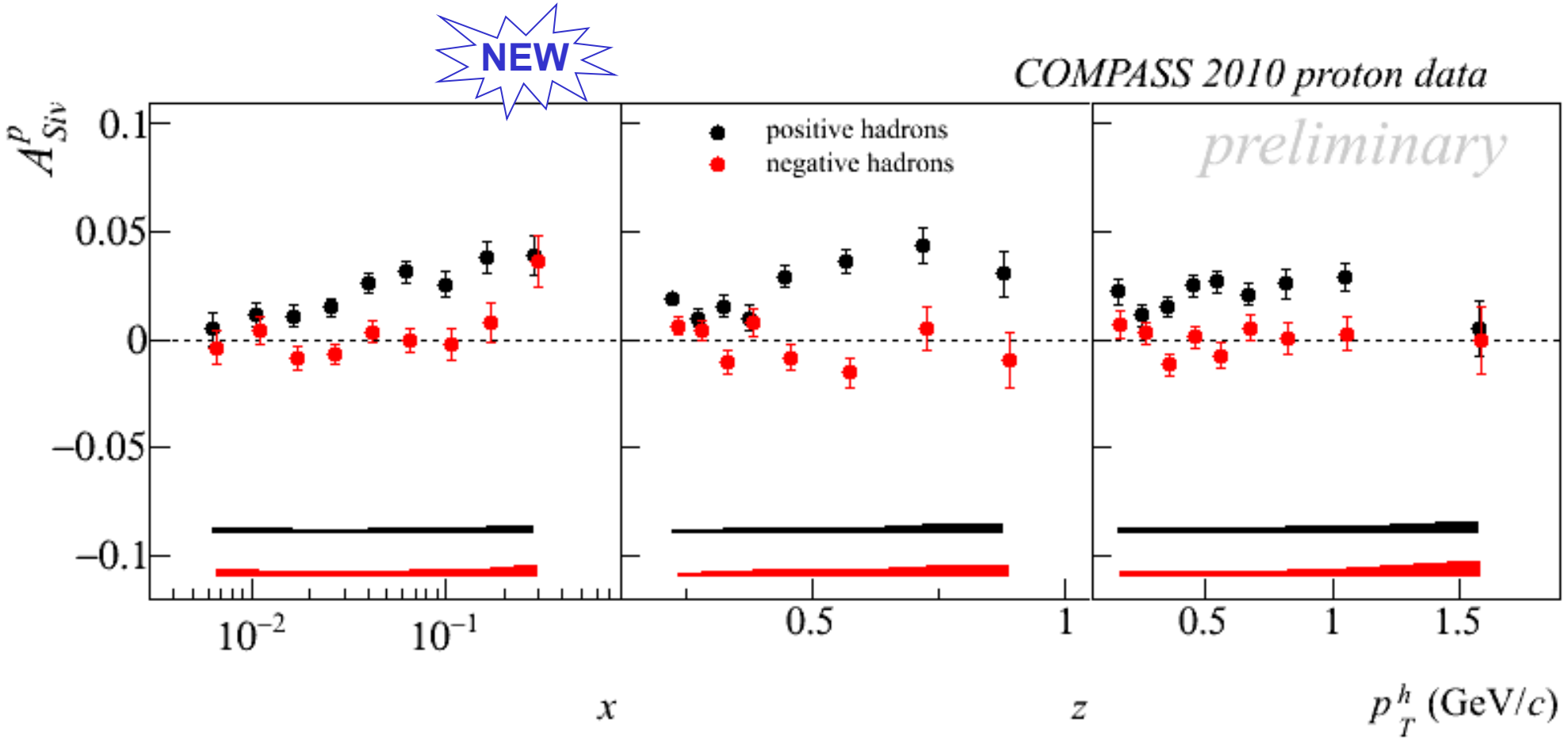
$$A_{Siv} = \frac{\sum_q e_q^2 \, f_{1T}^{\perp q} \otimes D_1^q}{\sum_q e_q^2 \, f_1 \otimes D_1^q} \qquad \frac{F_{UT}^{\sin(\phi_h - \phi_S)}}{F_{UU}}$$

strong signal seen by HERMES for π^+ on protons

no signal seen by COMPASS for h^+ and h^- on deuterons

a signal seen also by COMPASS for h^+ on protons (2007 run)

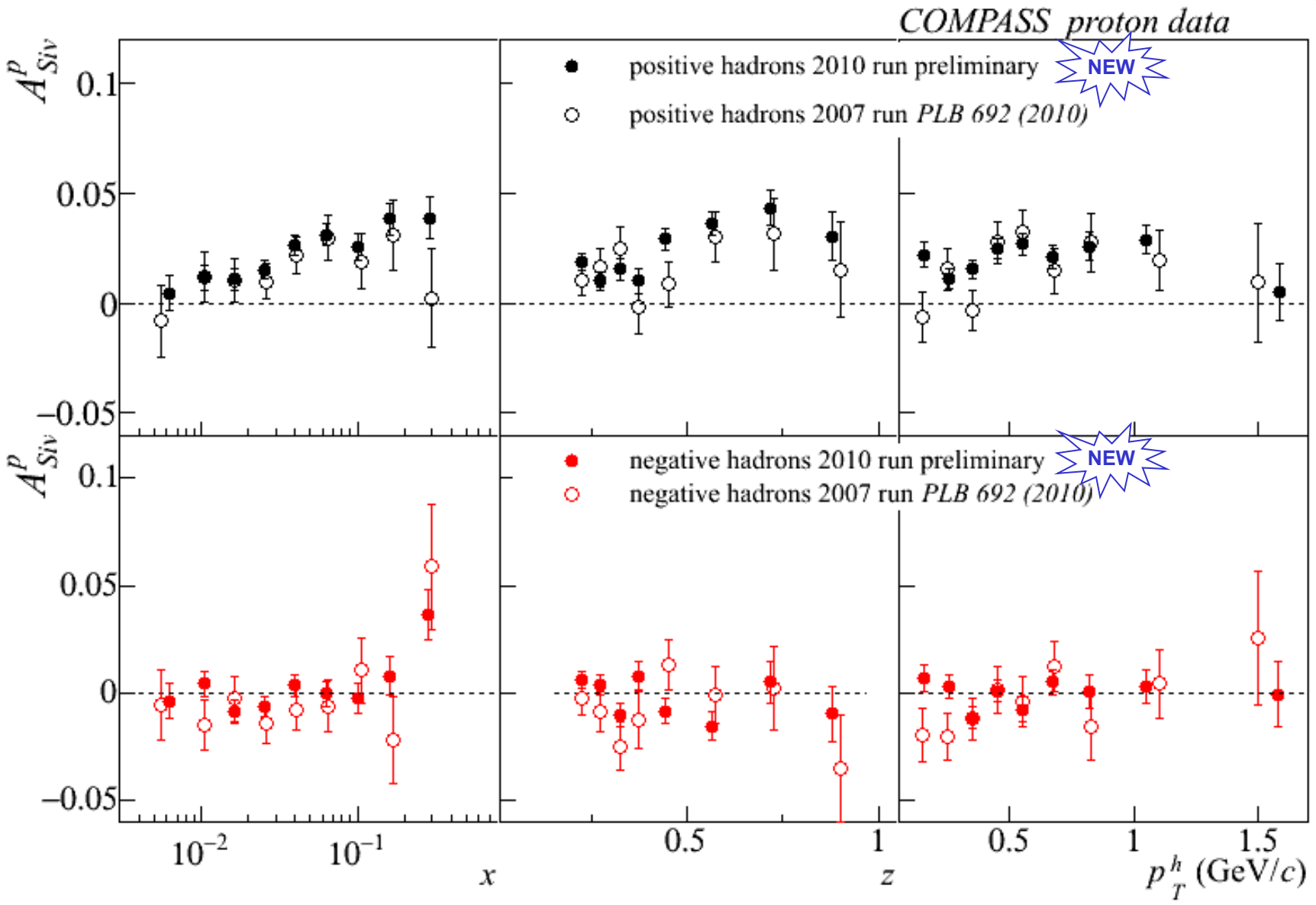
the Sivers asymmetry 2010 data



again, nice confirmation of the 2007 published results, with smaller errors

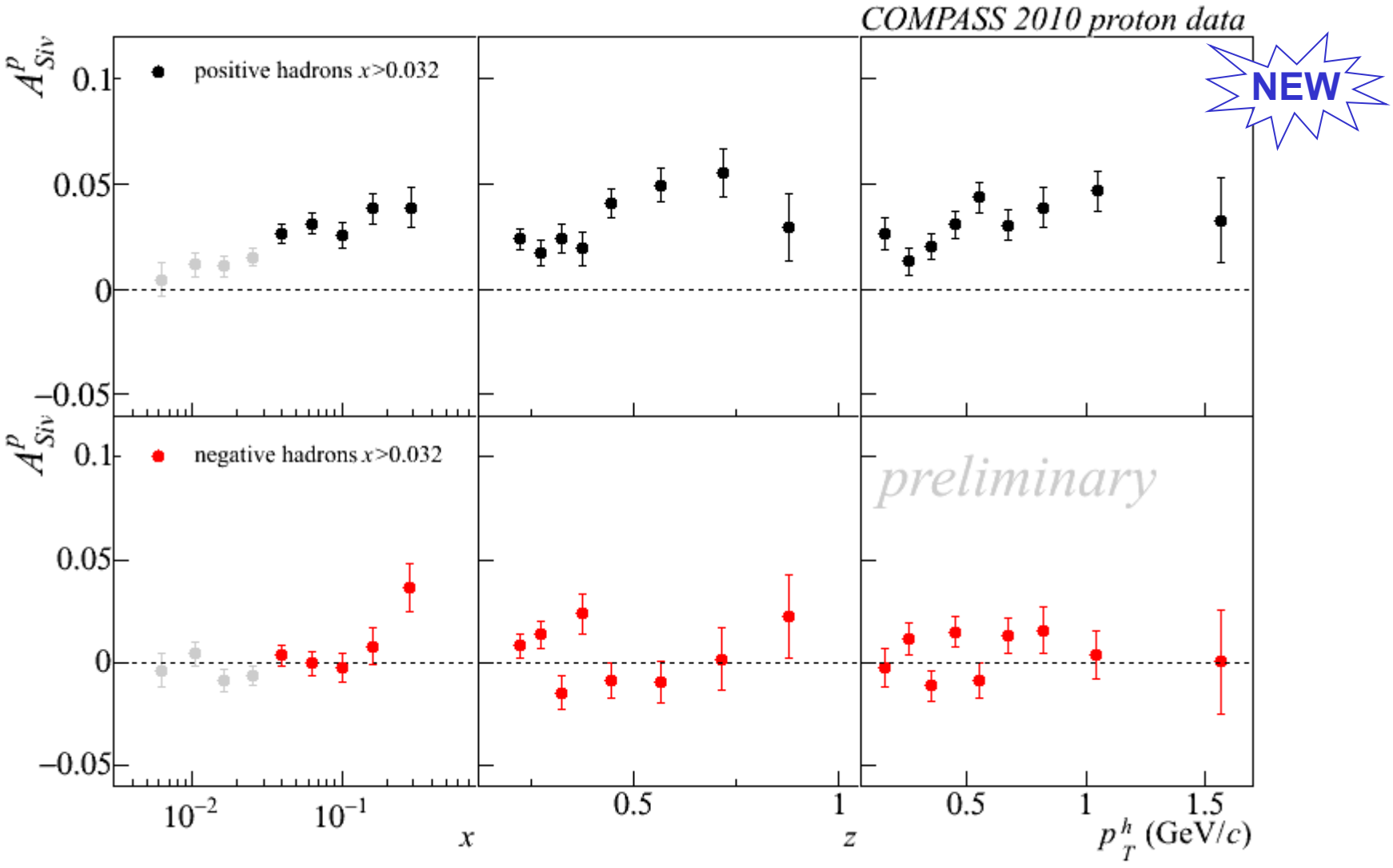
2010: $\sigma_{syst} \sim 0.5\ \sigma_{stat}$

the Sivers asymmetry 2010 vs 2007 data



the Sivers asymmetry 2010 data

x > 0.032 region



the Sivers asymmetry 2010 data

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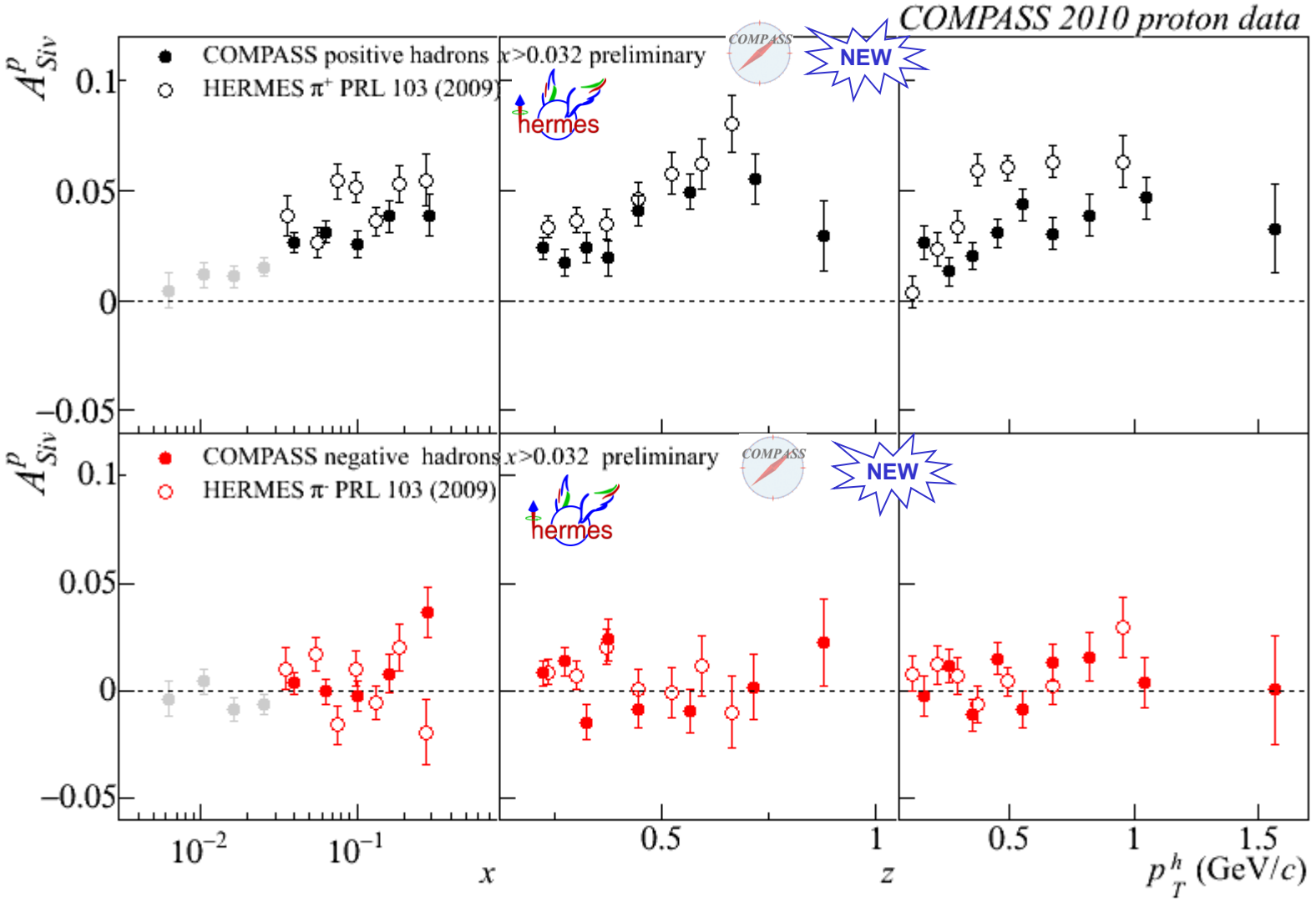
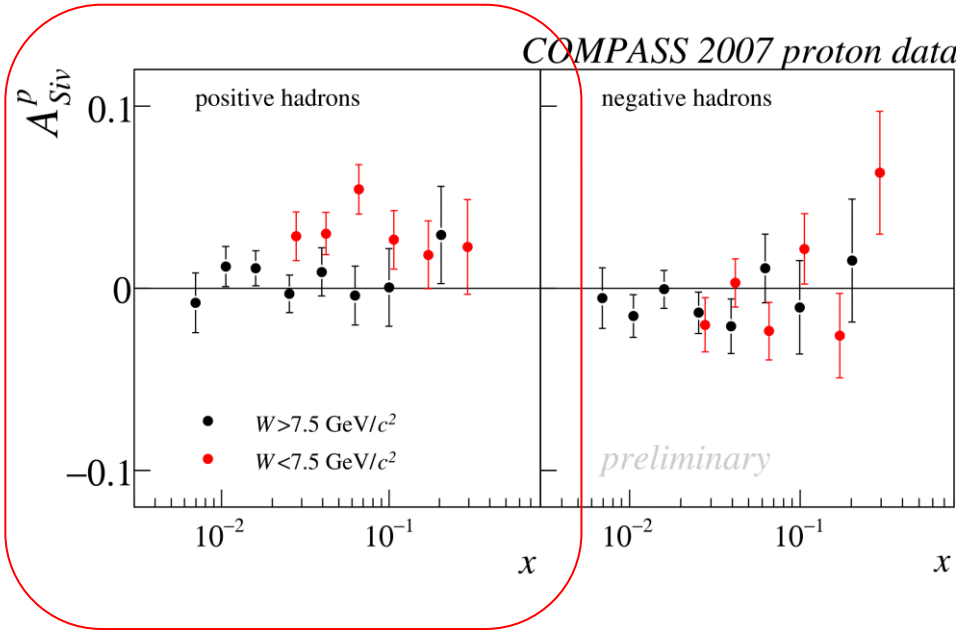
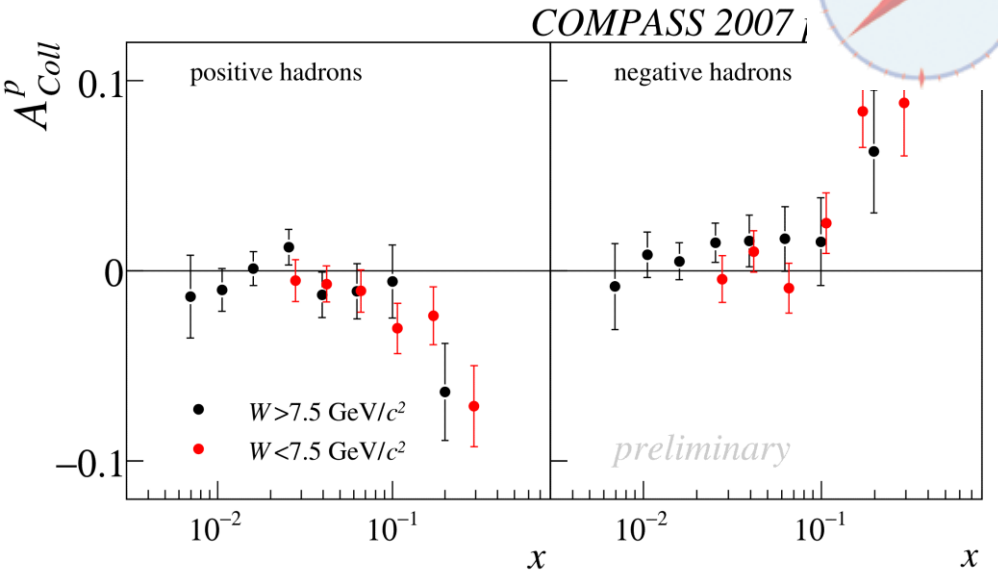


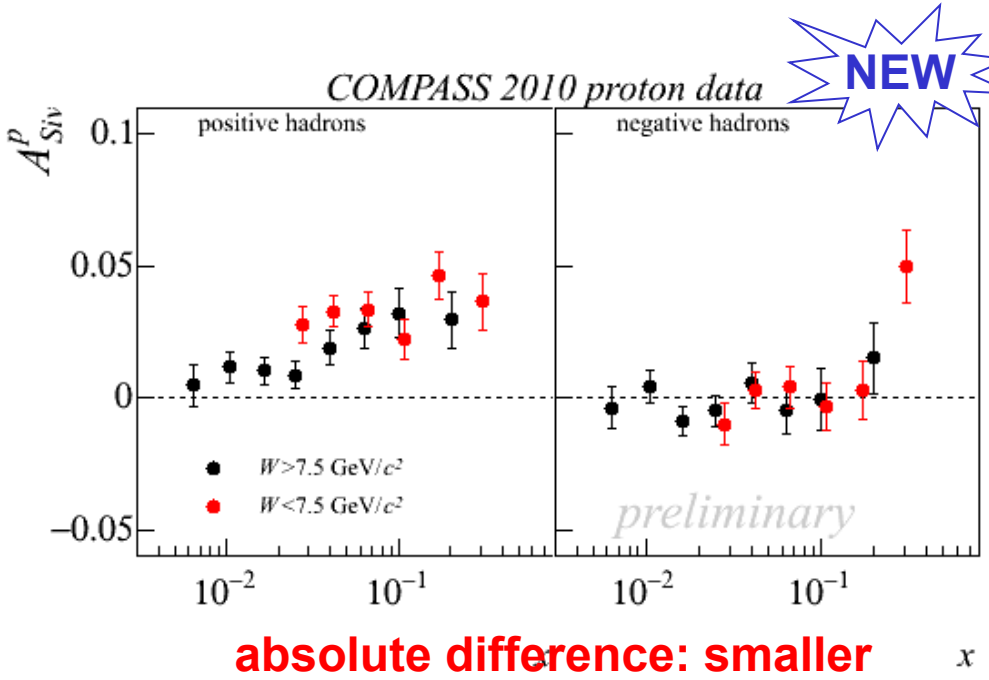
W dependence

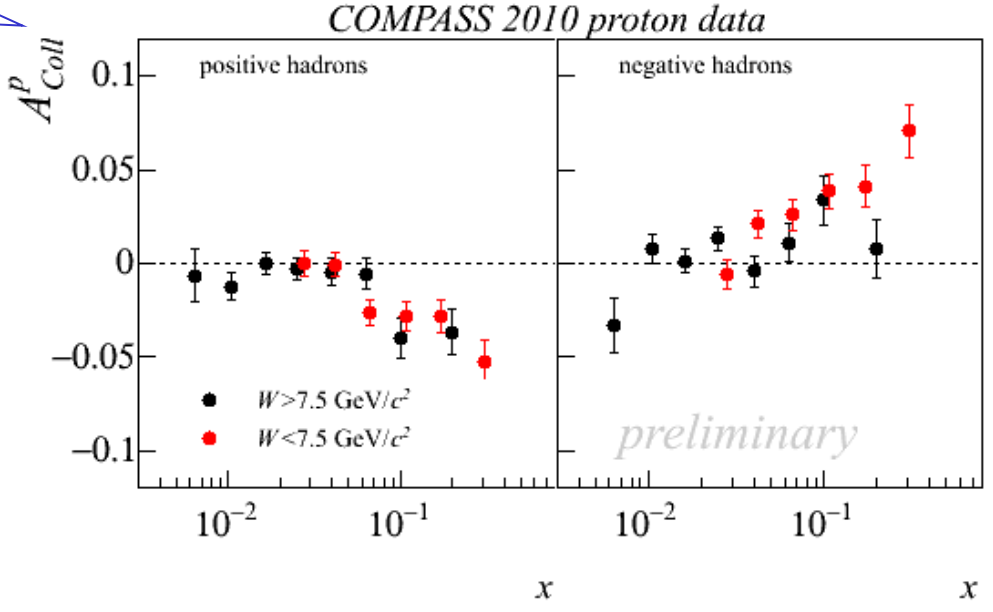
2007 results: hints for a W-dependence of the Sivers asymmetry for positive hadrons

"more statistics needed"









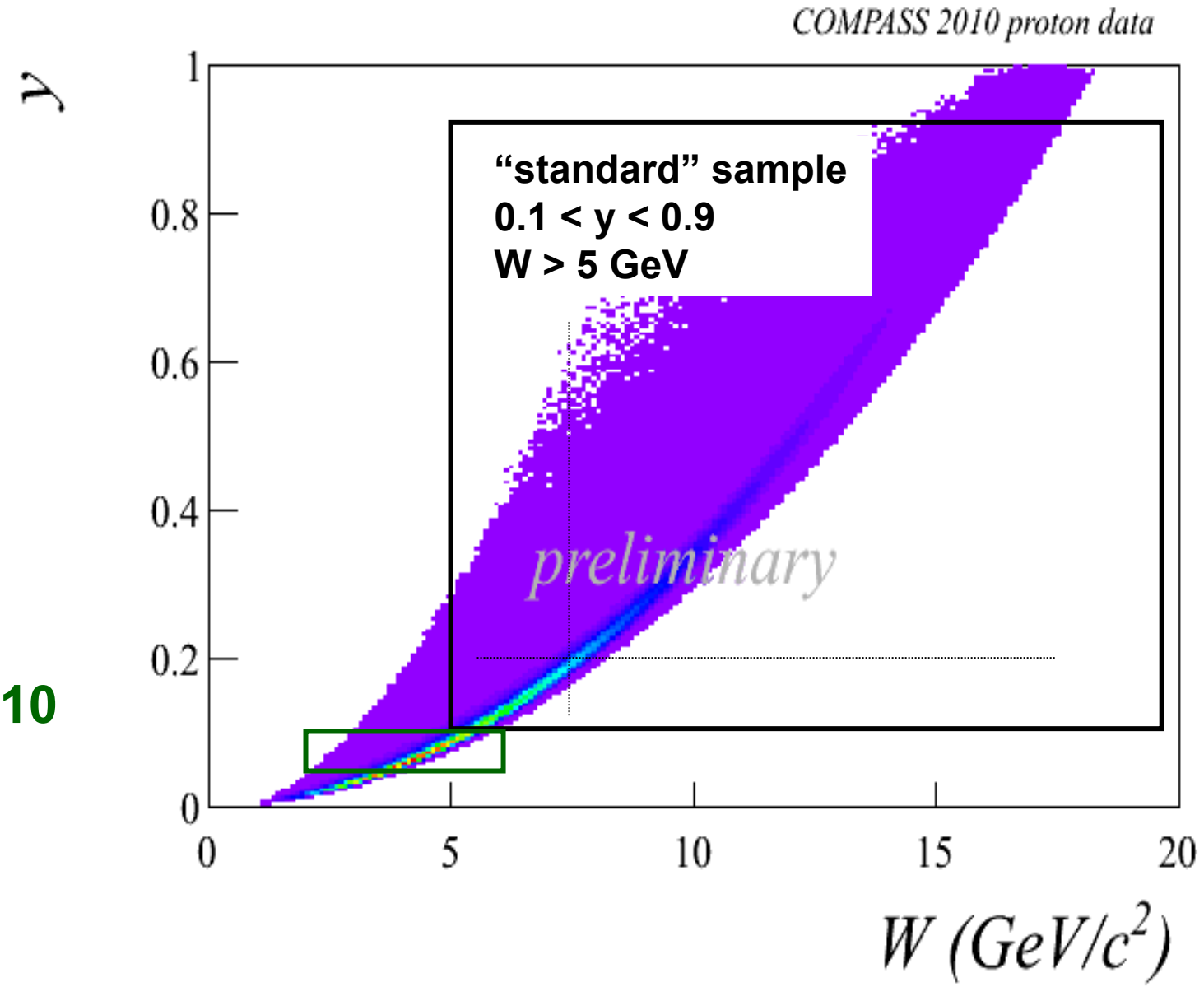
absolute difference: smaller

thanks to the high beam momentum,
we can enlarge the kinematical region
still remaining in the DIS regime

first look:

- **low y**
- **low z**

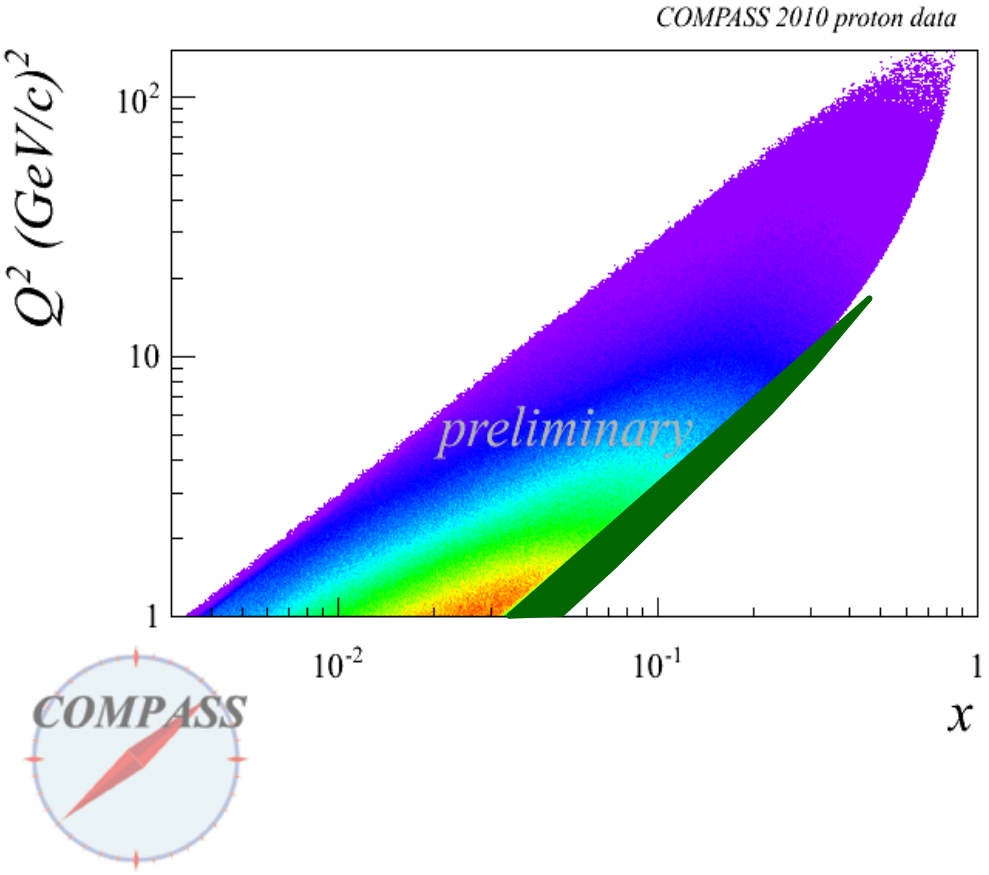
low y

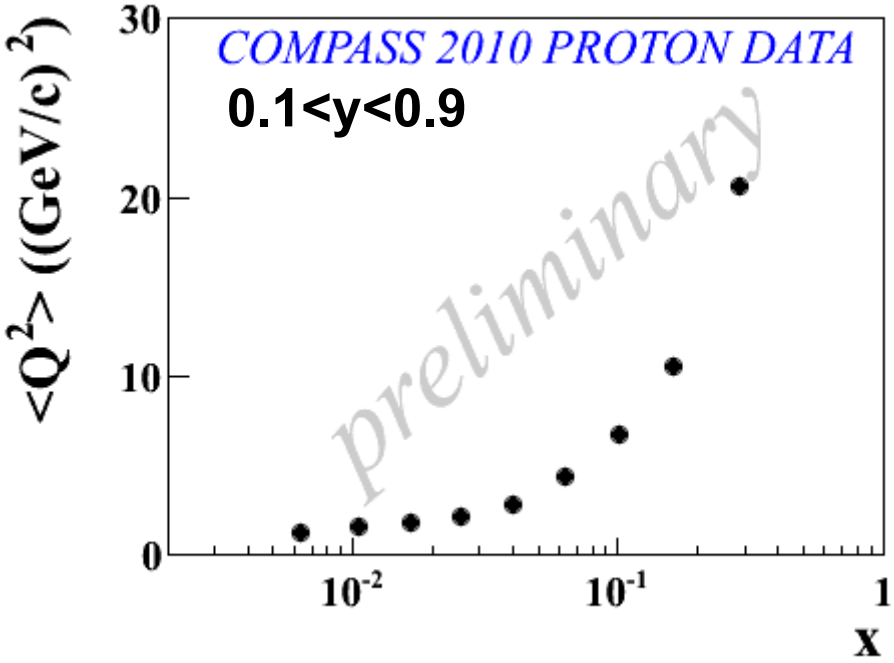


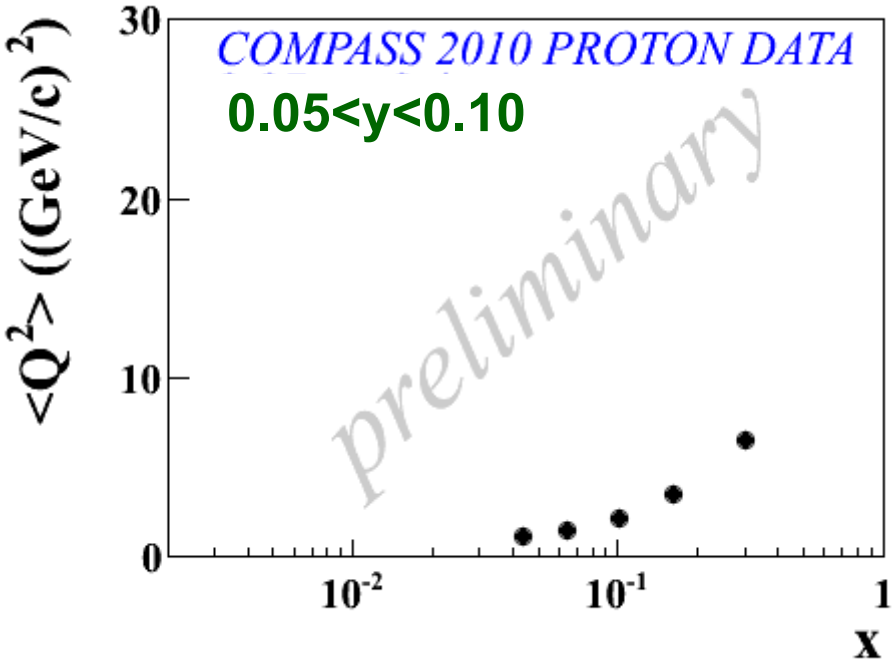
0.05 < y < 0.10 sample

low y

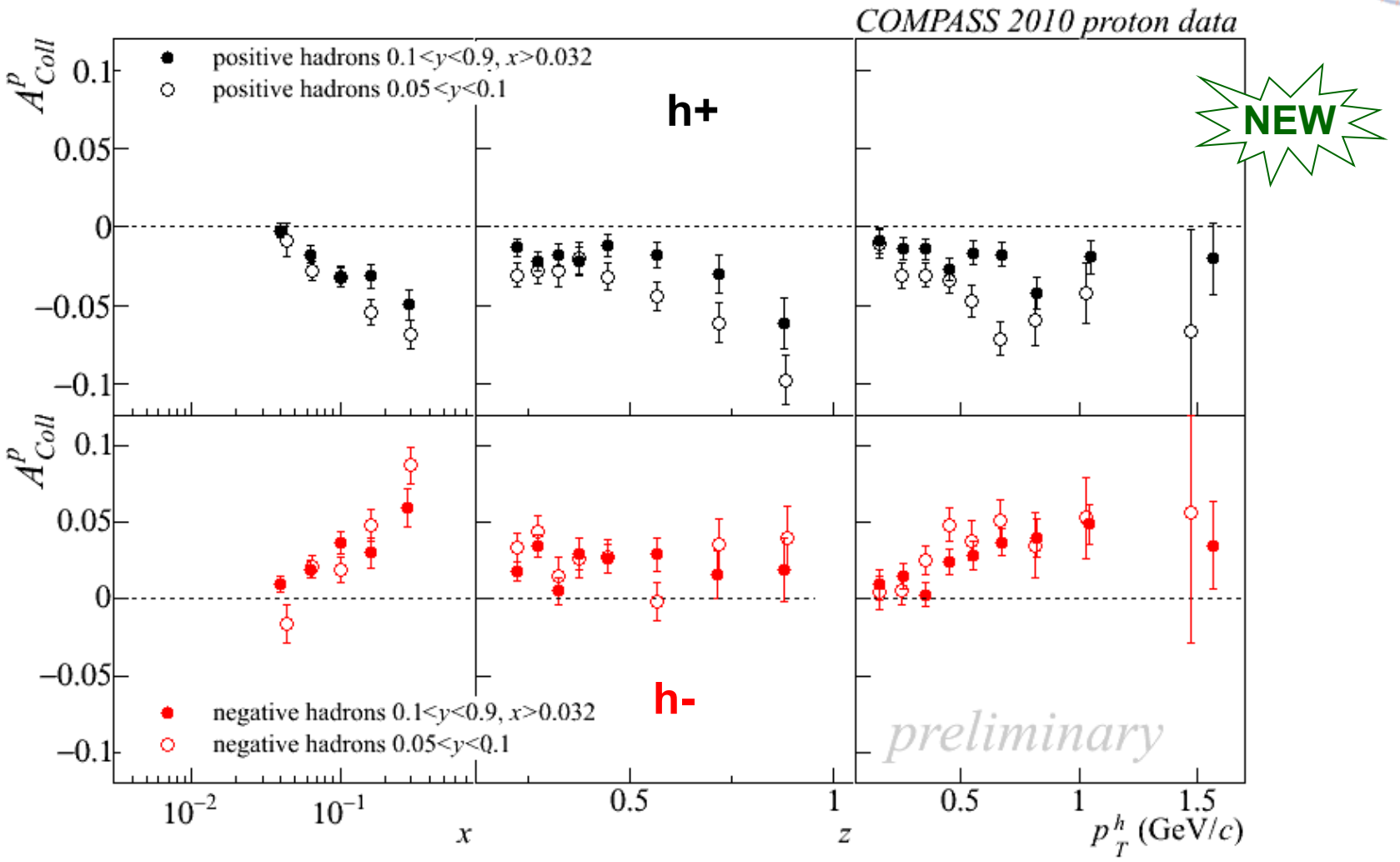
0.05 < y < 0.10 sample







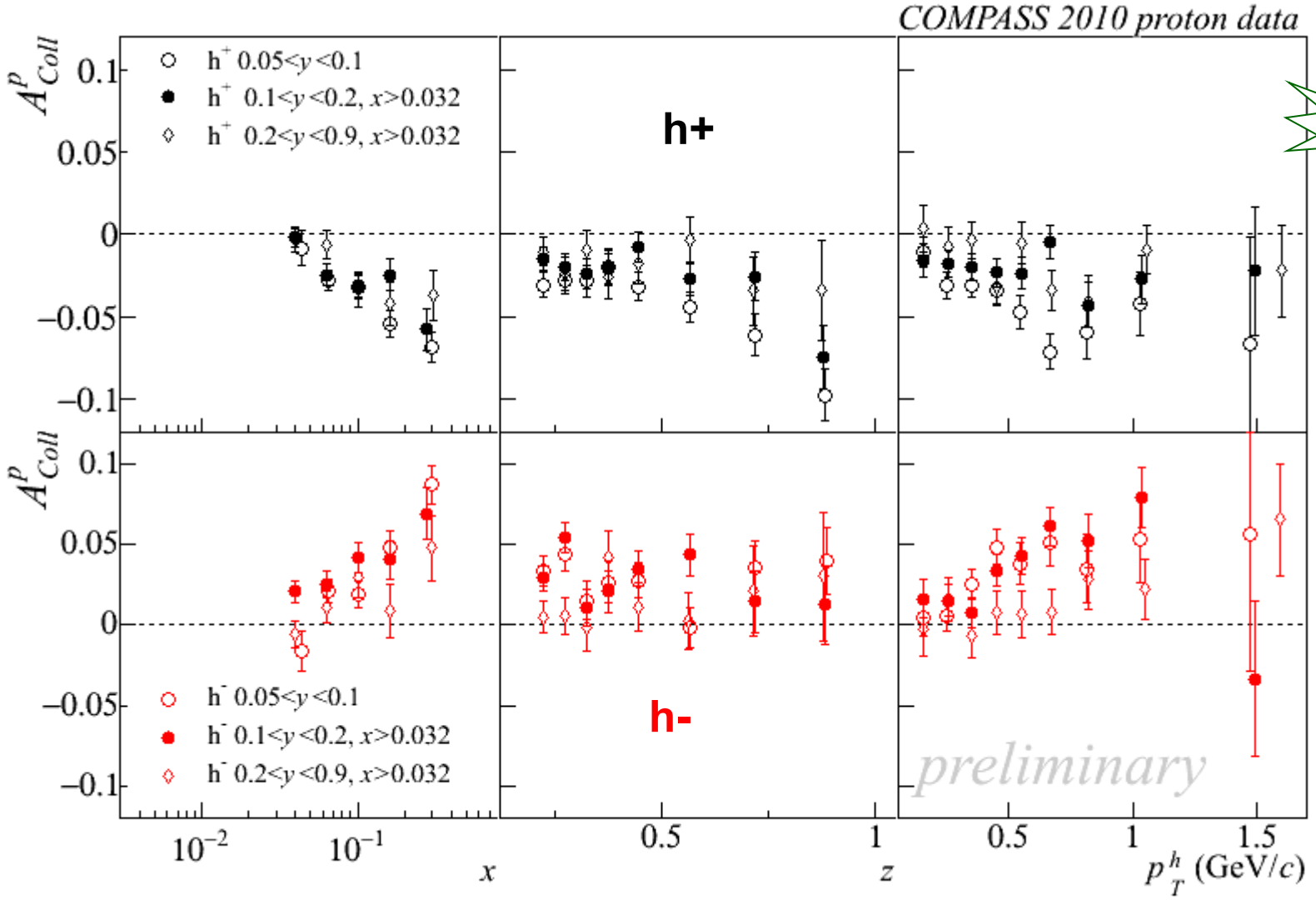
0.05 < y < 0.10 - Collins asymmetry



a small effect is visible for h+

no effect splitting the "standard" sample in two bins (0.1 < y< 0.2; 0.2 < y < 0.9)

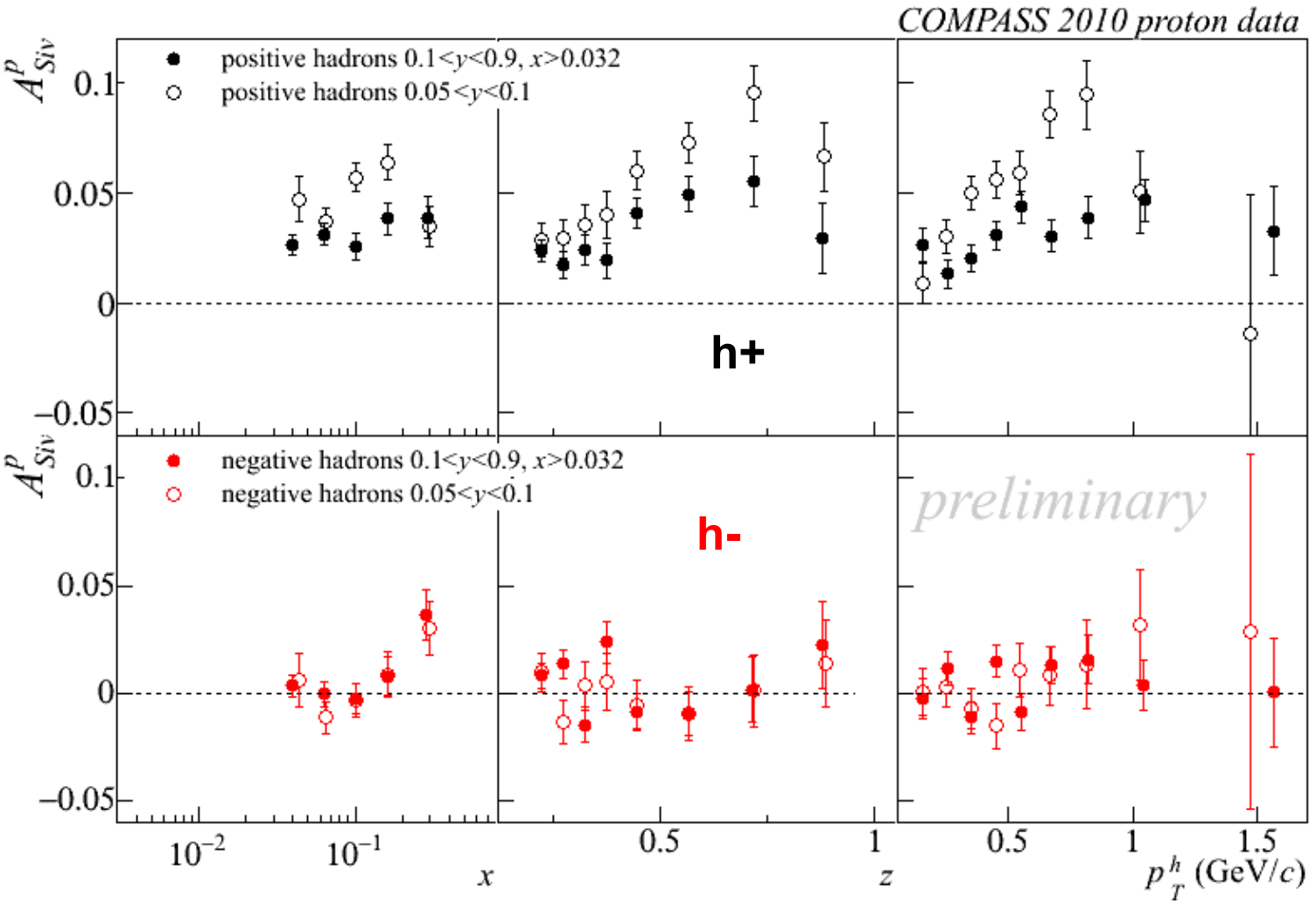
3 y-bins - Collins asymmetry



a small (x) **effect is visible for h+ at low y**

no effect splitting the "standard" sample in two bins (0.1 < y< 0.2; 0.2 < y < 0.9)

0.05 < y < 0.10 - Sivers asymmetry



NEW

a clear enhancement of the asymmetry for h+ is obvserbed

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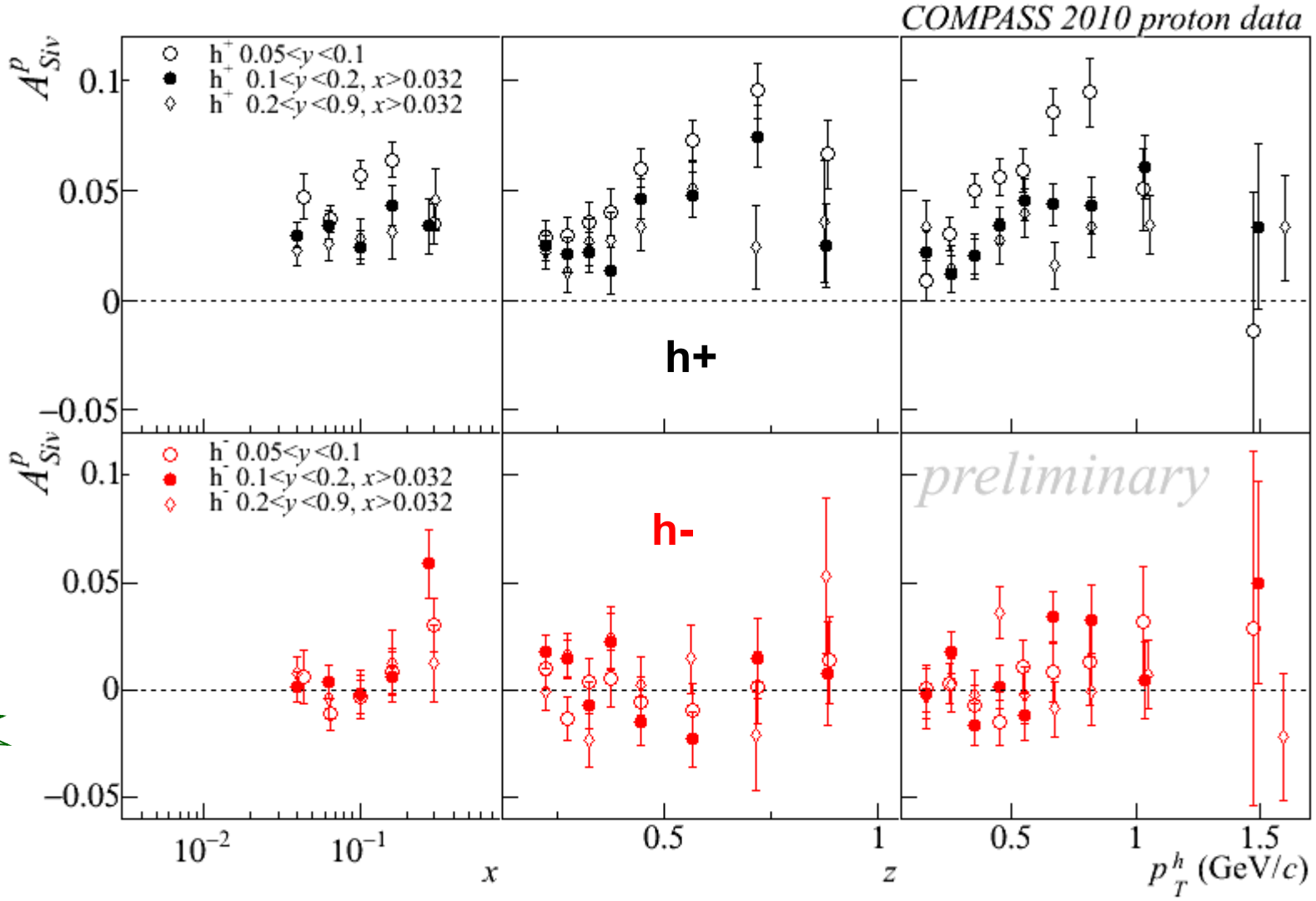
3 y-bins - Sivers asymmetry



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no clear effect splitting the “standard” sample in two bins (0.1 < y< 0.2; 0.2 < y < 0.9)

thanks to the high beam momentum,
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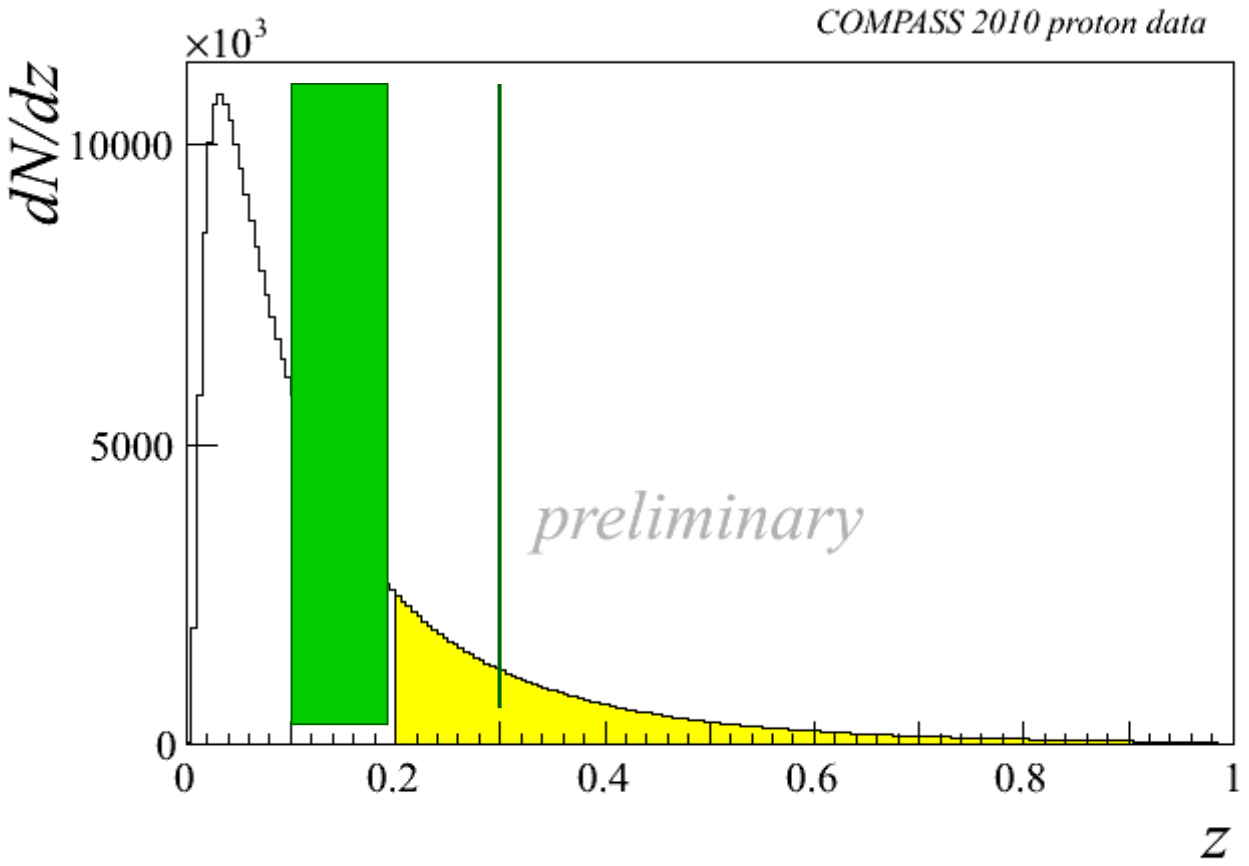
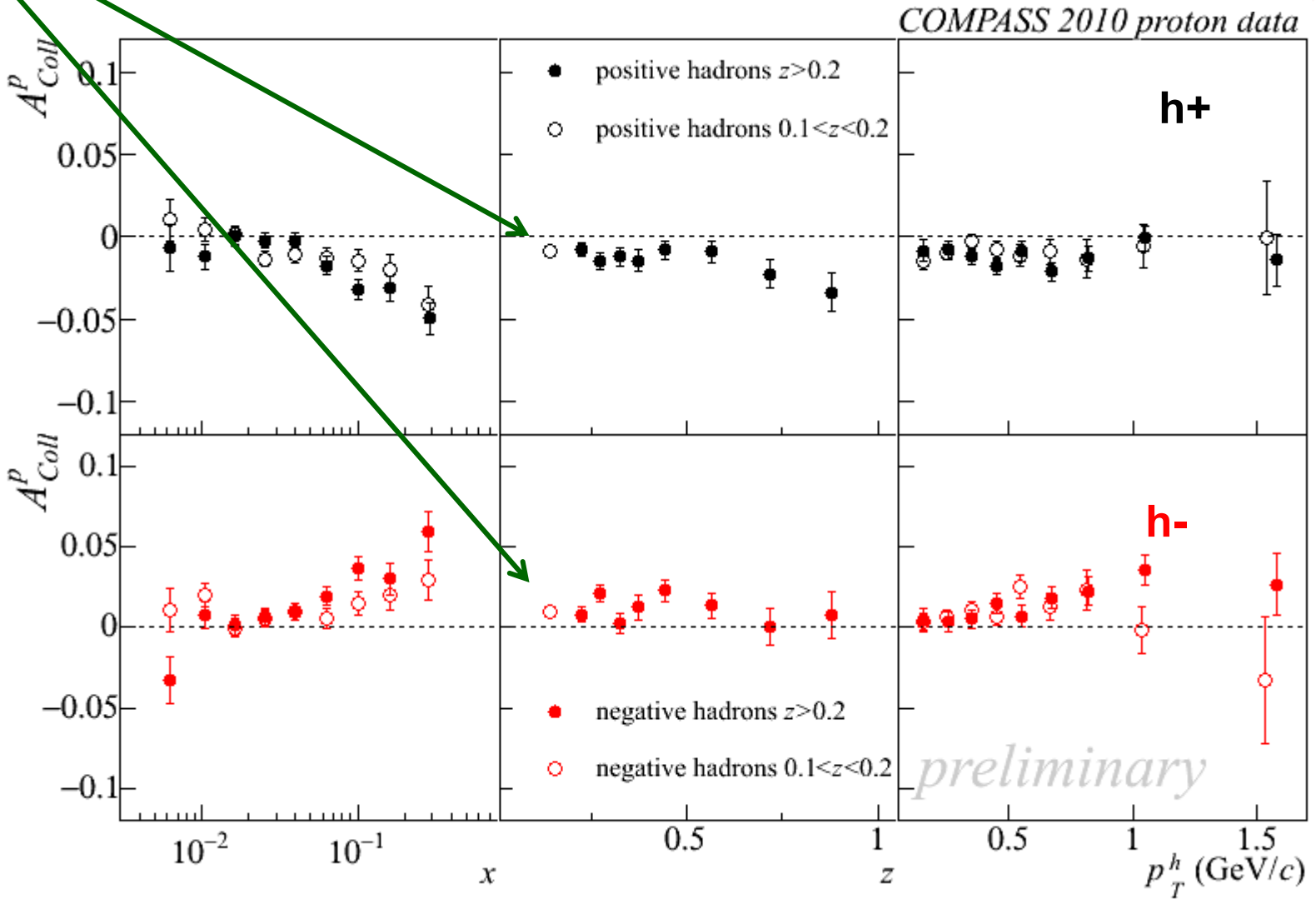
first look:

- low y
- **low z**



0.1 < z < 0.2 - Collins asymmetry

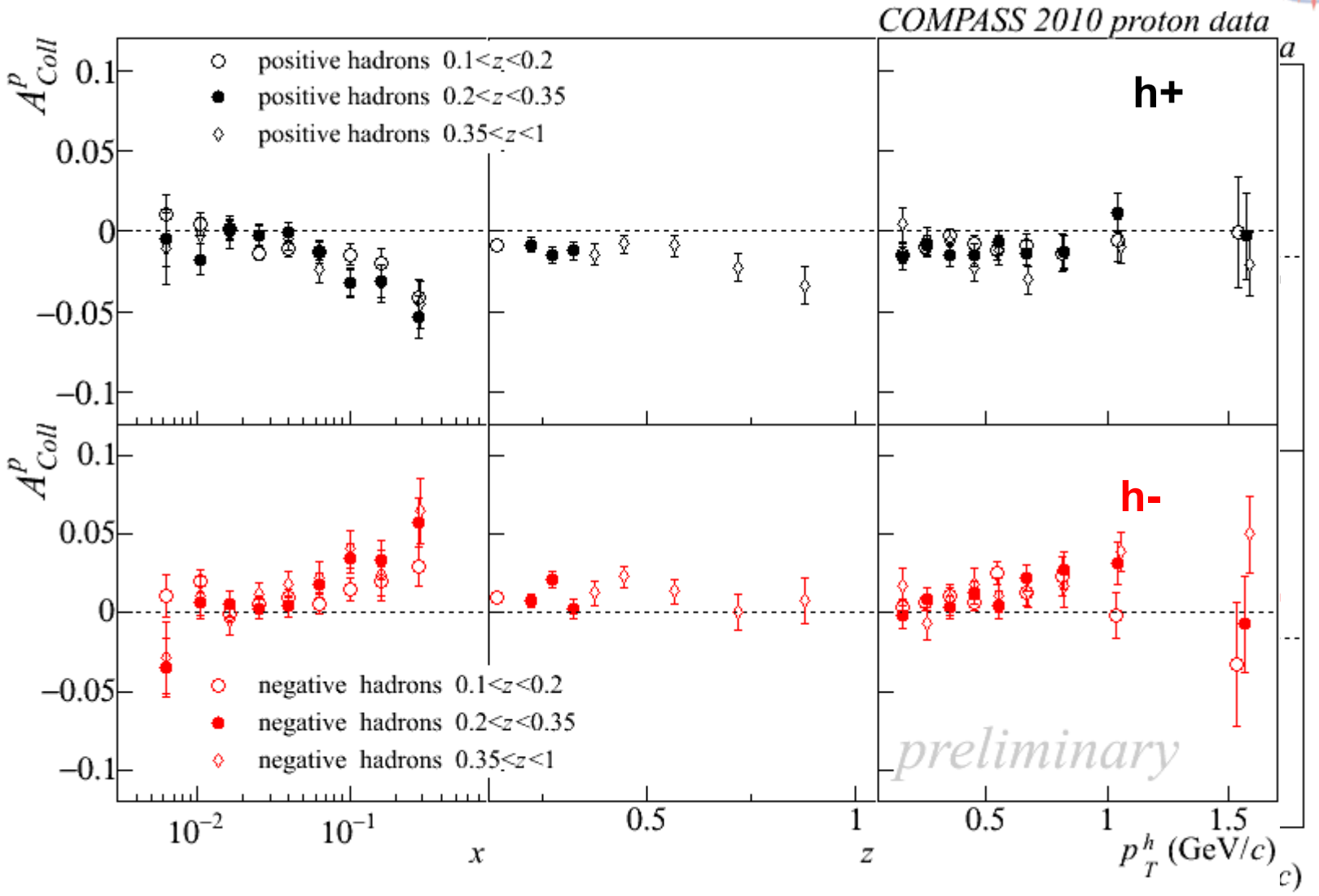


NEW

asymmetries somewhat smaller for 0.1<z<0.2 sample

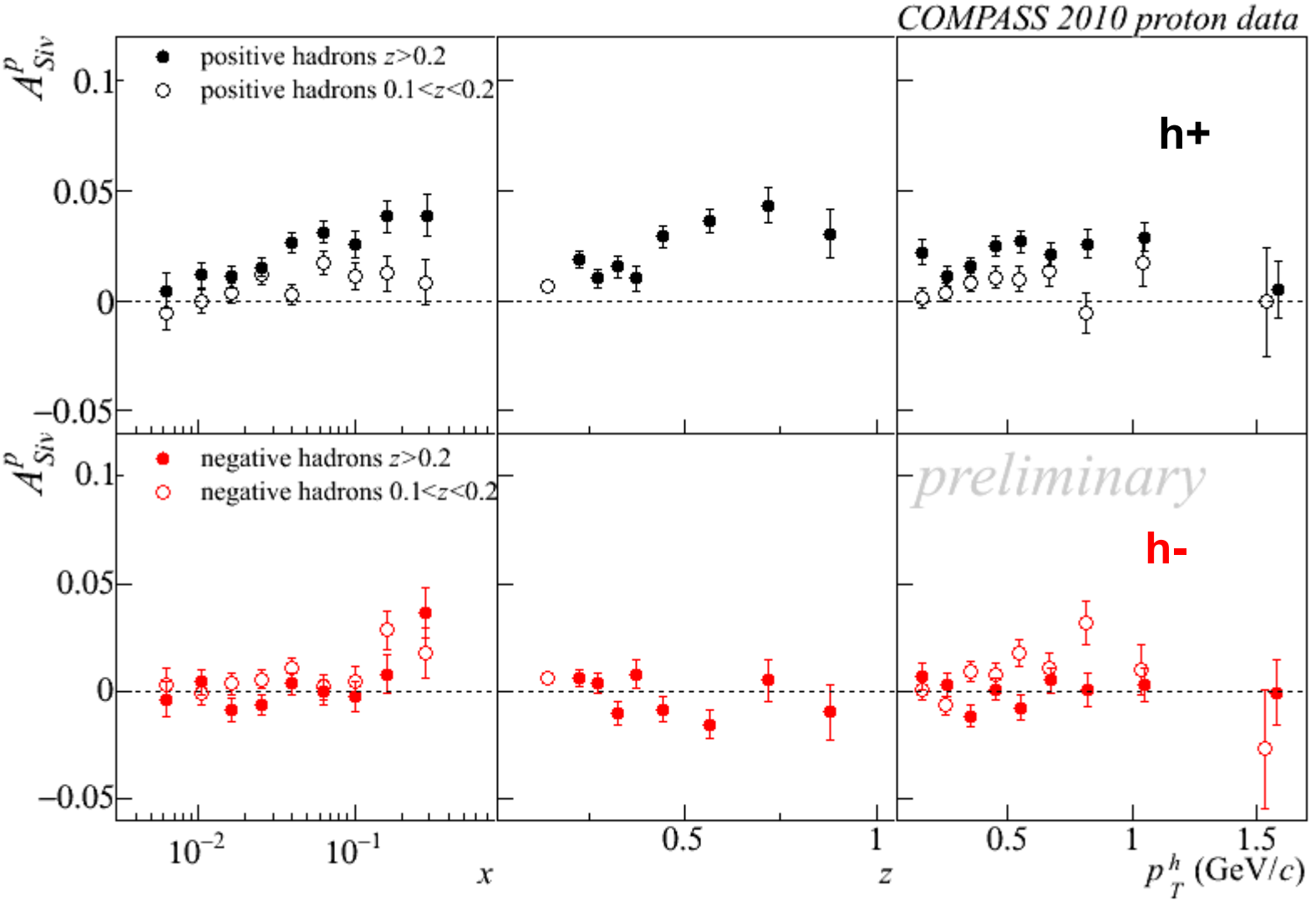
3 z-bins - Collins asymmetry

NEW



asymmetries somewhat smaller for 0.1<z<0.2 sample

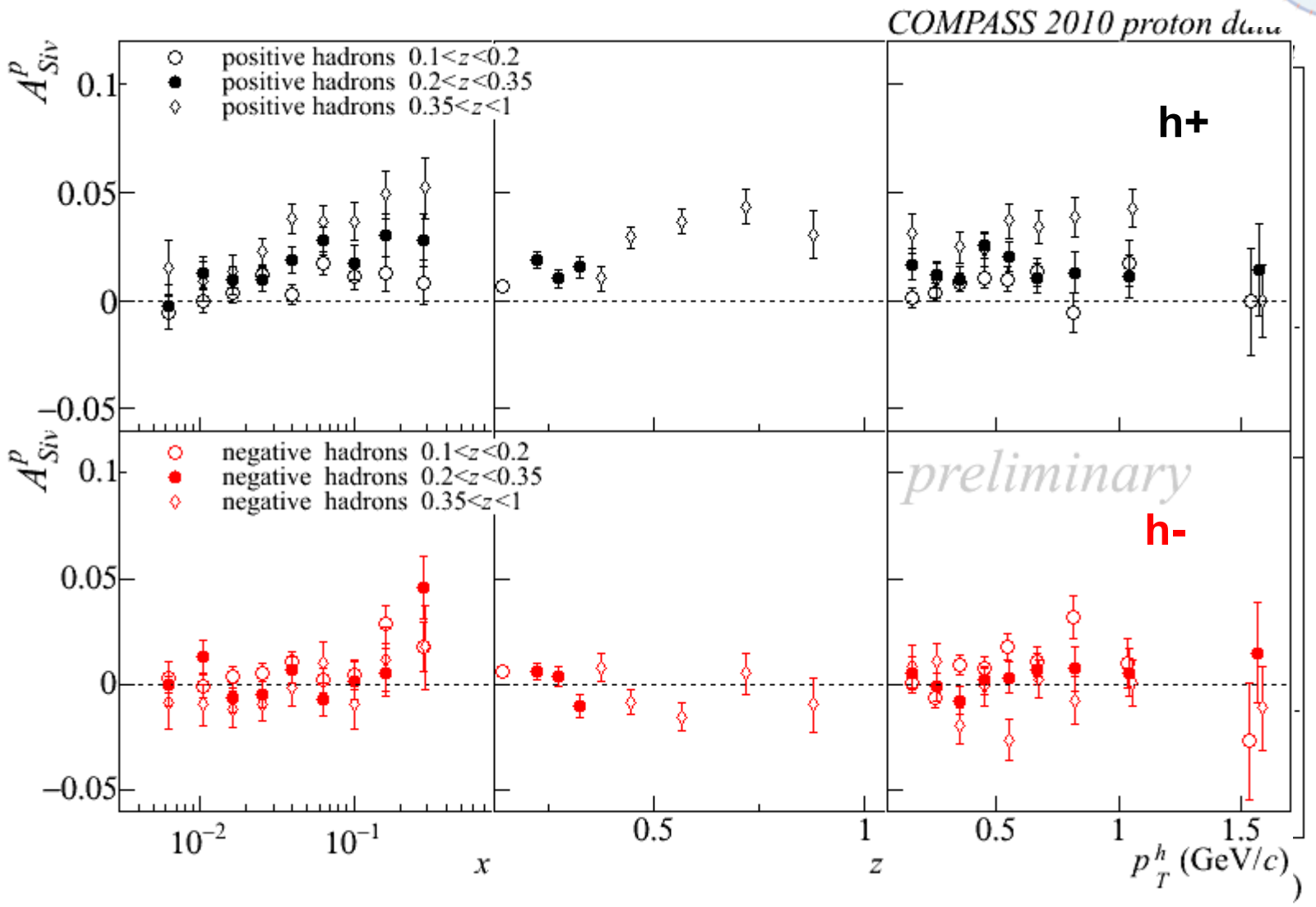
0.1 < z < 0.2 - Sivers asymmetry



NEW

clear decrease of the asymmetries for the 0.1<z<0.2 sample

3 z-bins - Sivers asymmetry



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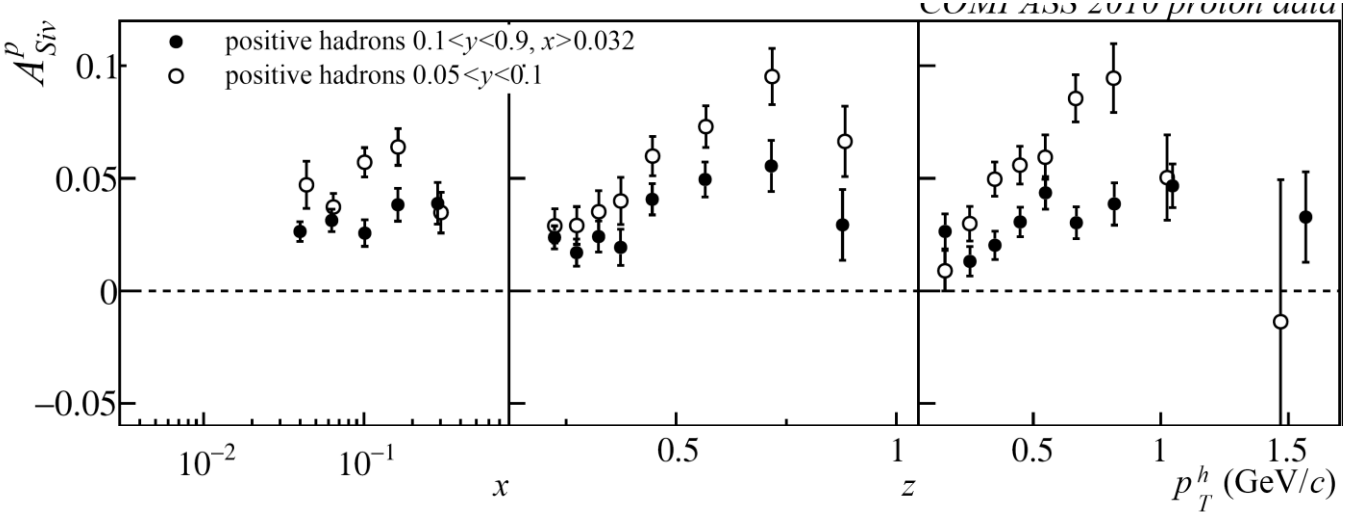


first look:

- **low y**
- **low z**

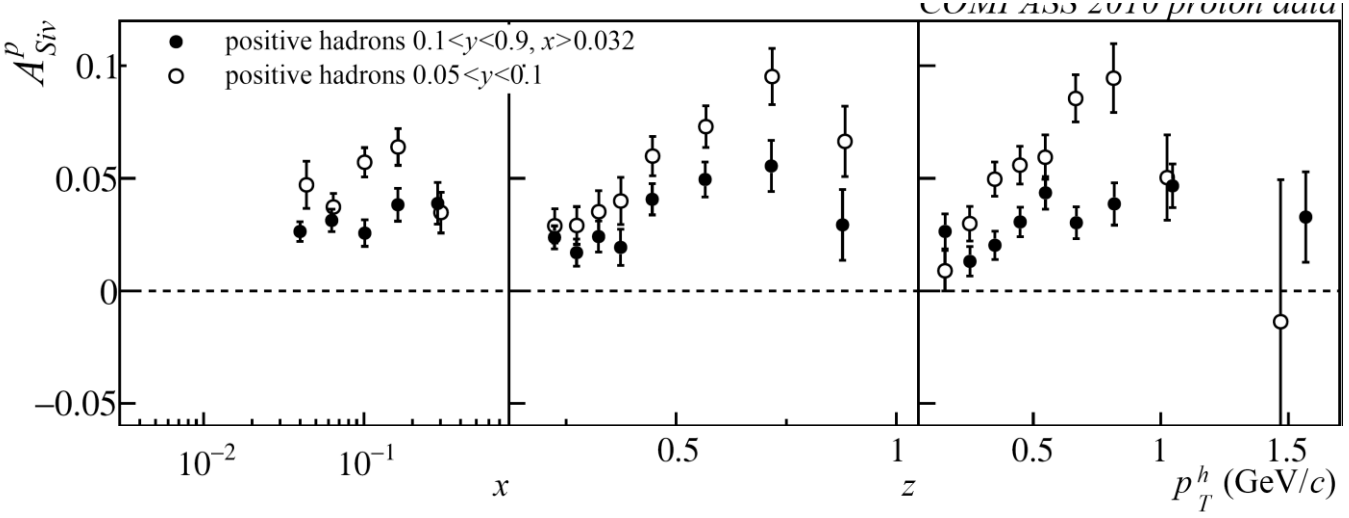
summary:

Sivers asymmetry h+

- **larger at small y**

first look:

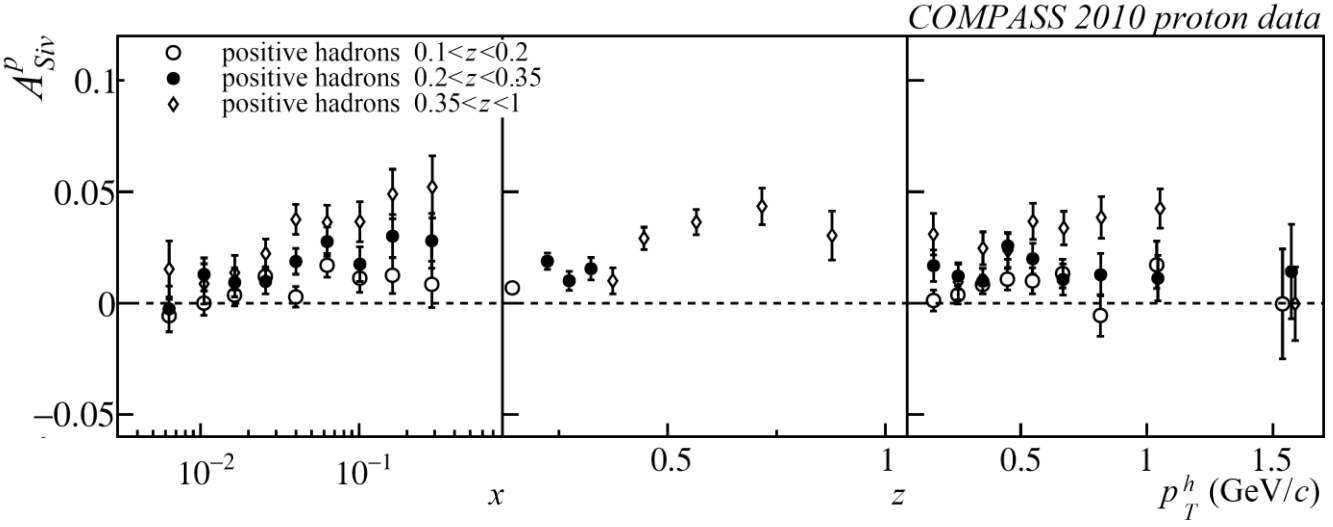
- **low y**
- **low z**



summary:

Sivers asymmetry h+

- **larger at small y**
- **smaller at small z**



summary and outlook

a lot of SIDIS results on TMDs have been produced since 2005
very interesting, with some surprises

- **solid evidence for: transversity PDF to be different from zero**
  Sivers function to be different from zero

- **intersting results from the first look at z and y dependence**

- **to come from single hadron 2010 transverse spin data**
  more investigation on kinematical dependence
  other 6 asymmetries
  PID

- **the ball is on the theory side!**

NO EXCUSE FOR NOT PERFORMINING
GLOBAL ANALYSIS OF ALL THESE BEAUTIFUL DATA

The Structure of the Nucleon

three distribution functions are necessary to describe the quark structure of the nucleon at LO in the collinear case

Jaffe and Ji, '91

transversity PDF $\Delta_T q$ or h_1 : correlation between the transverse spin of the nucleon and the transverse spin of the quark

nucleon polarisation

quark polarisation	**U**	**L**	**T**
U	f_1  q *number density*		
L		g_1  *helicity* Δq	
T			h_1  *transversity*

$\Delta_T q$

tensor charge

$$\int dx \left[\Delta_T q(x) - \Delta_T \bar{q}(x)\right]$$

chiral odd

can be measured in SIDIS off transversely polarised nucleons

Collins effect: LR asymmetry in the hadronisation of transversely polarised quarks

The Structure of the Nucleon

three distribution functions are necessary to describe the quark structure of the nucleon at LO in the collinear case

taking into account the quark intrinsic transverse momentum k_T,

at leading order 8 PDFs are needed for a full description of the nucleon structure

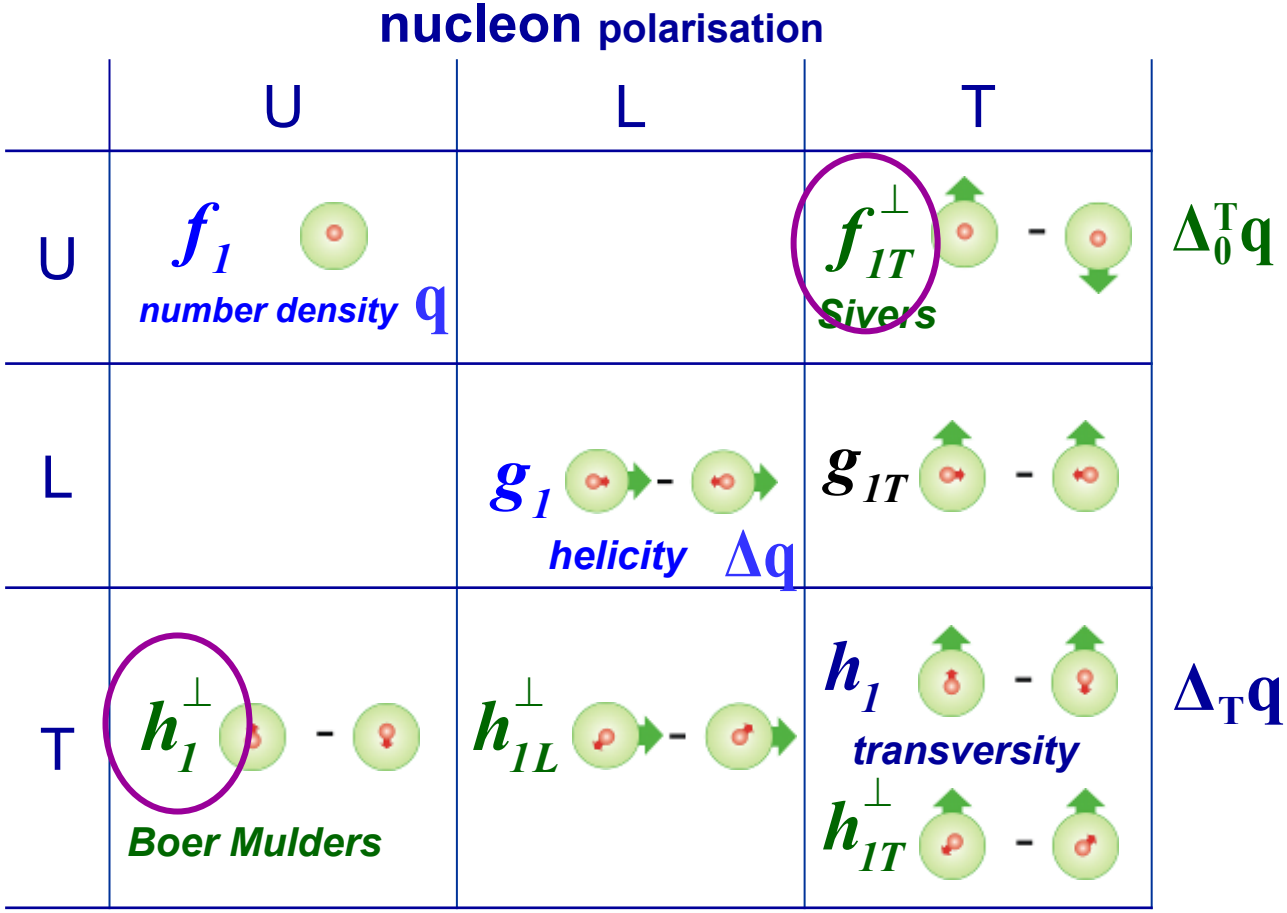
"TMDs"

Sivers function
correlation between the transverse spin of the nucleon and the transverse momentum of the quark

sensitive to orbital angular momentum

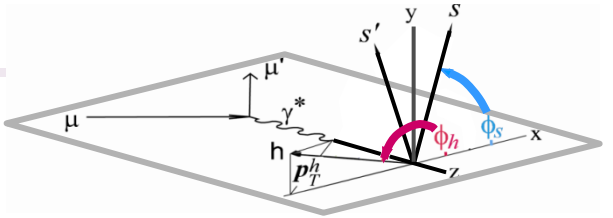
Boer-Mulders function
correlation between the transverse spin and the transverse momentum of the quark in unpol nucleons

T-odd



SIDIS give access to all of them

SIDIS cross-section



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

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

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

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

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

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

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

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

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

Sivers

Collins

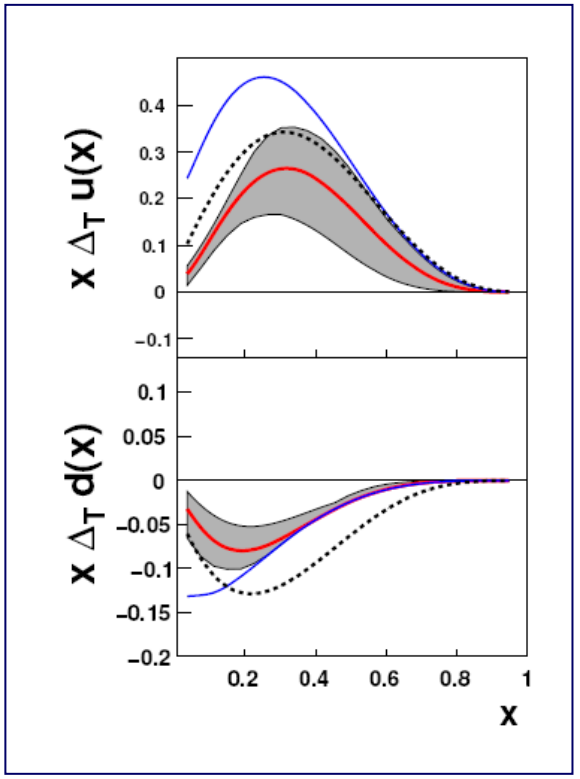
18 structure functions
14 azimuthal modulations

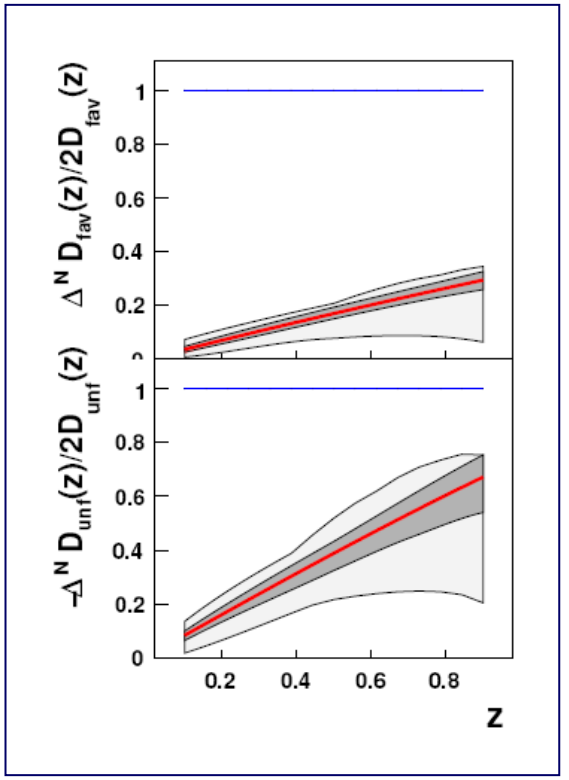
A Bacchetta et al., 2006

Collins asymmetry

the COMPASS d, HERMES p, and BELLE data are well described in global fits

→ *first extractions of the Collins FFs and the transversity PDFs, and tensor charge*





M. Anselmino et al., Nucl.Phys.Proc.Suppl.191 (2009) 98

Q^2 dependence?

→ COMPASS p data