COMPASS RESULTS ON COLLINS AND SIVERS ASYMMETRIES

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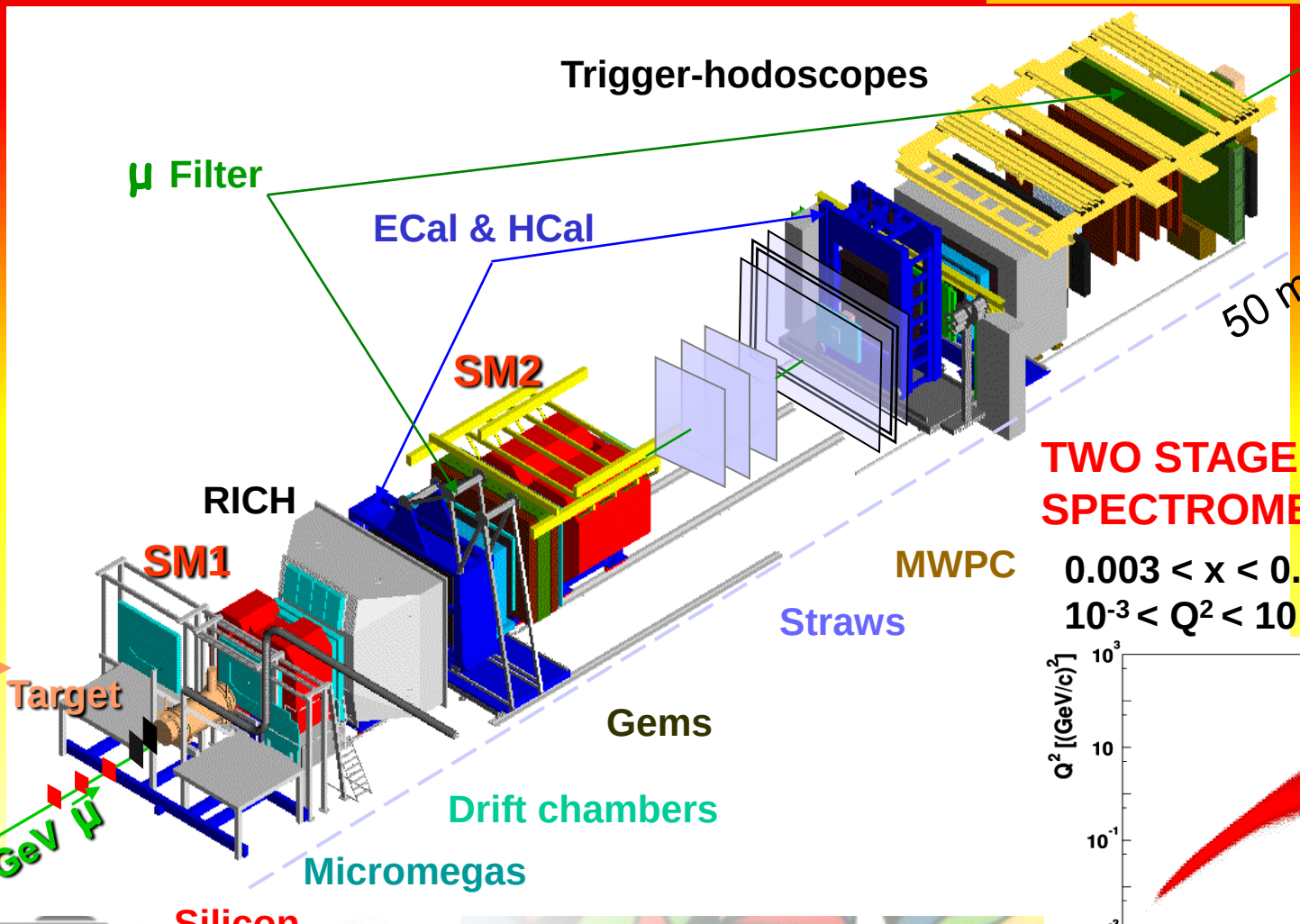
On behalf the COMPASS collaboration

The Spectrometer for the Muon Programme



TWO STAGE SPECTROMETER:

$0.003 < x < 0.5$

$10^{-3} < Q^2 < 10$ (GeV/c

A summary

	^{6}LiD (2002-4) 20%		NH_3 (2007) 50%	
	unID	ID	unID	ID
Collins	**X**	**X**	X	
Sivers	**X**	**X**	X	
Other SSA	X			
2hadrons	X	X	X	
Lambda		X		X
Unpolarized	X			

SIDIS azimuthal asymmetries

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Bigg\{ \ldots$$

All possible 8 azimuthal asymmetries extracted at once.

From **A. Bacchetta** et al., **JHEP 0702:093,2007**. e-Print: **hep-ph/0611265**

Sivers

Collins

6 further modulations

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

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

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

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

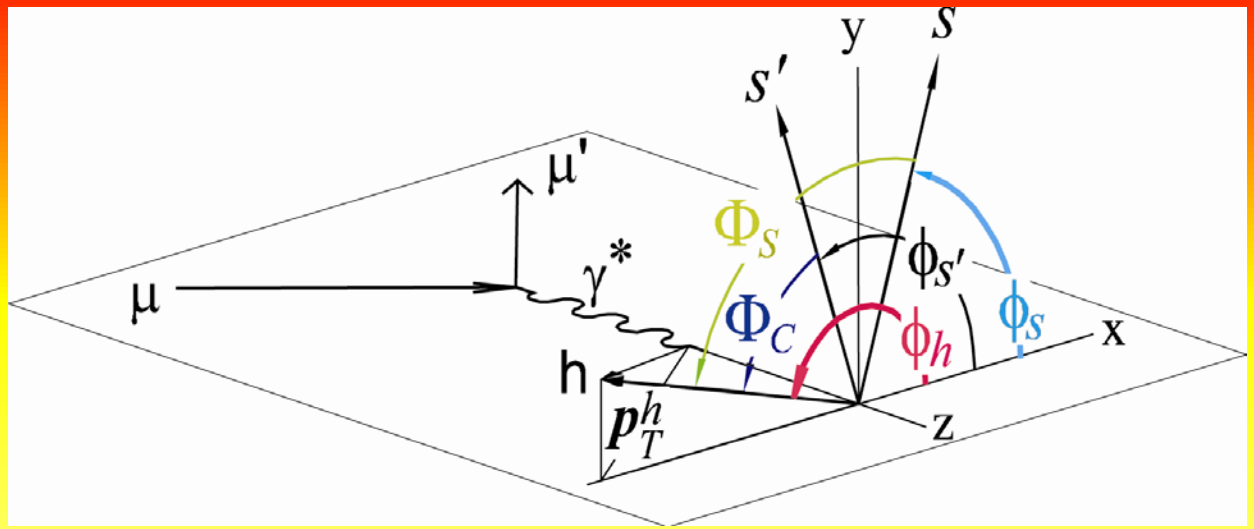
$$+ \sqrt{2\varepsilon(1-\varepsilon)} \cos(2\phi_h - \phi_S) F_{LT}^{\cos(2\phi_h-\phi_S)} \Big] \Big\},$$

Azimuthal modulations

Collins and Sivers angles

$\Phi_C = \phi_h - \phi_{S'}$

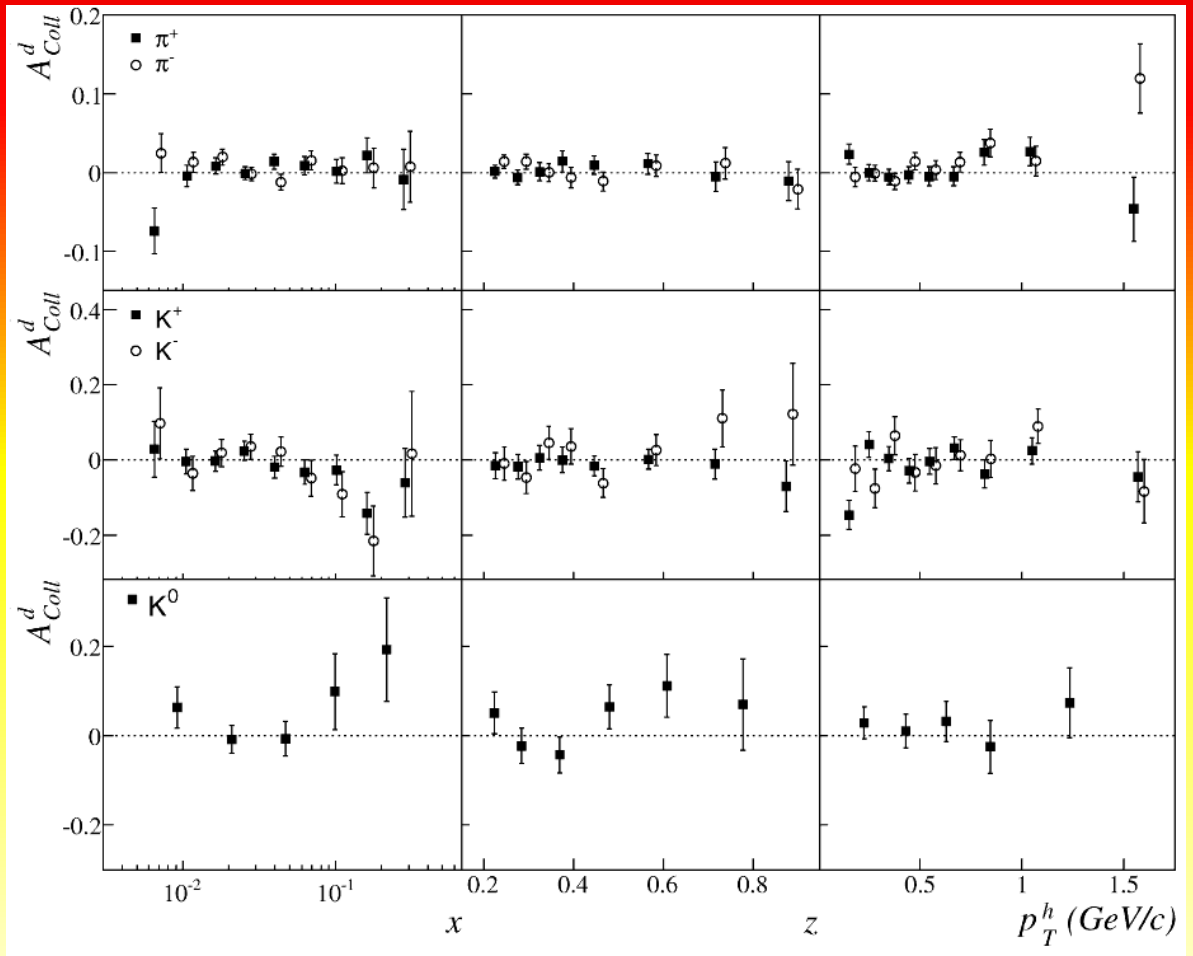
$\Phi_S = \phi_h - \phi_S$



ϕ_S , azimuthal angle of spin vector of fragmenting quark ($\phi_{S'} = \pi - \phi_S$)

ϕ_h azimuthal angle of hadron momentum

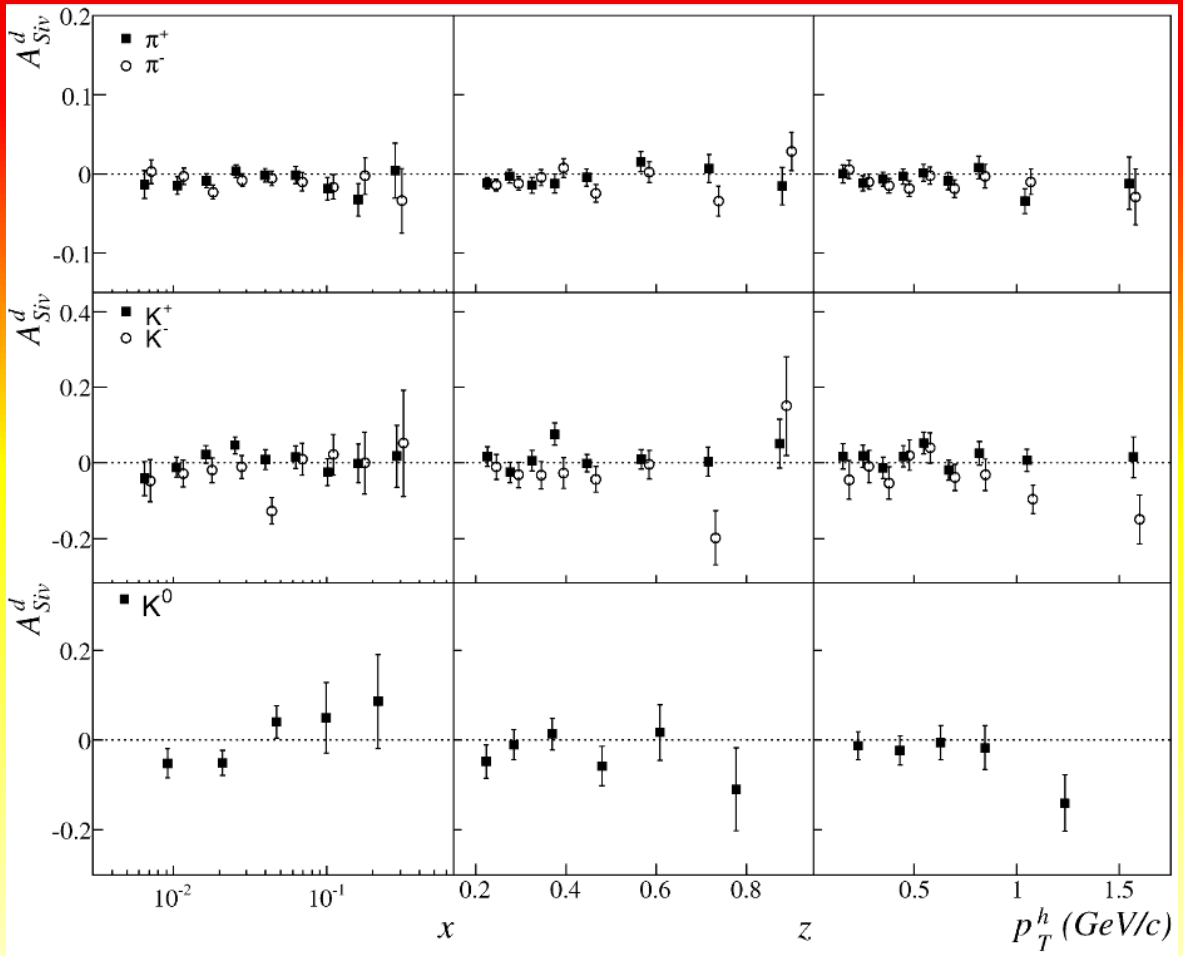
Collins Final on Deuteron



COMPASS Collaboration Physics Letters B 673 (2009) 127–135

Systematic error well below 30% of the statistical one

Sivers Final on Deuteron



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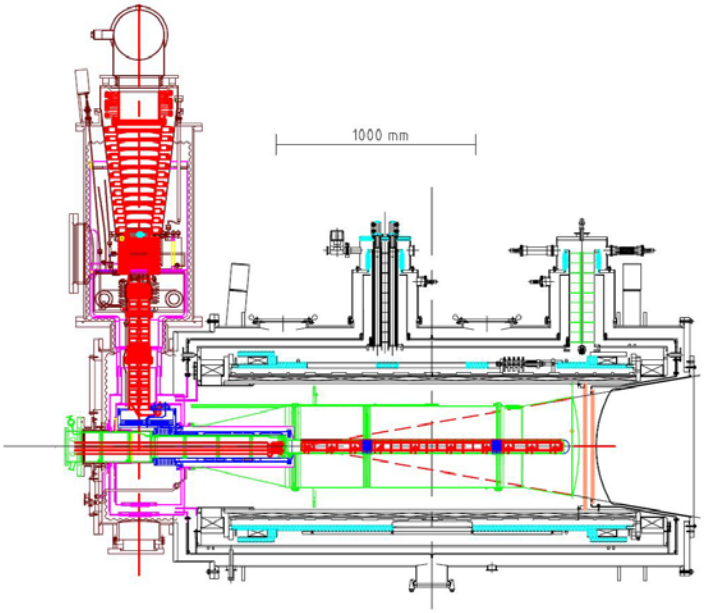
Systematic error well below 30% of the statistical one

Polarized Target



New COMPASS target magnet:

→180 mrad geometrical acceptance

→excellent field homogeneity

To match larger acceptance:

→new microwave cavity

→3 target cells: reduction of false asymmetries

Target material:

→NH_3

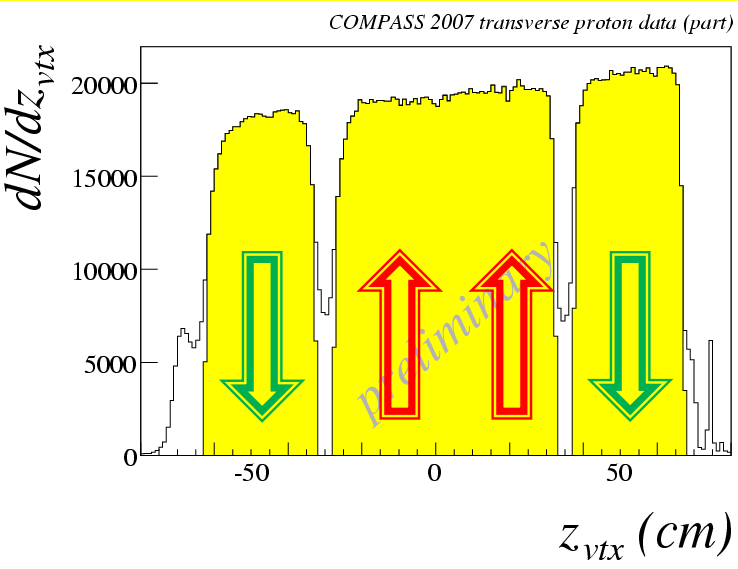
→high polarisation

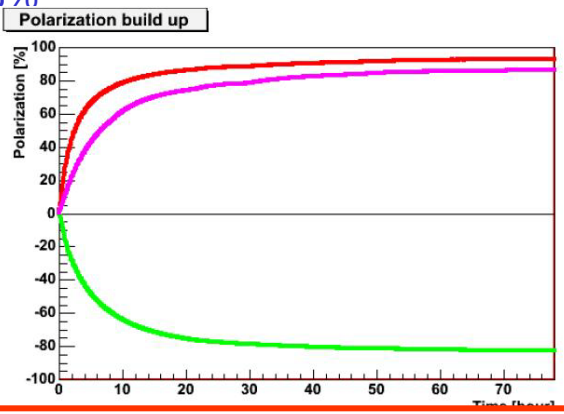
→very long relaxation time (~ 4000 h)

→magnetic field rotation without polarisation loss

→ Polarisation of NH_3 in 2007:

-92%, +88%, -83%

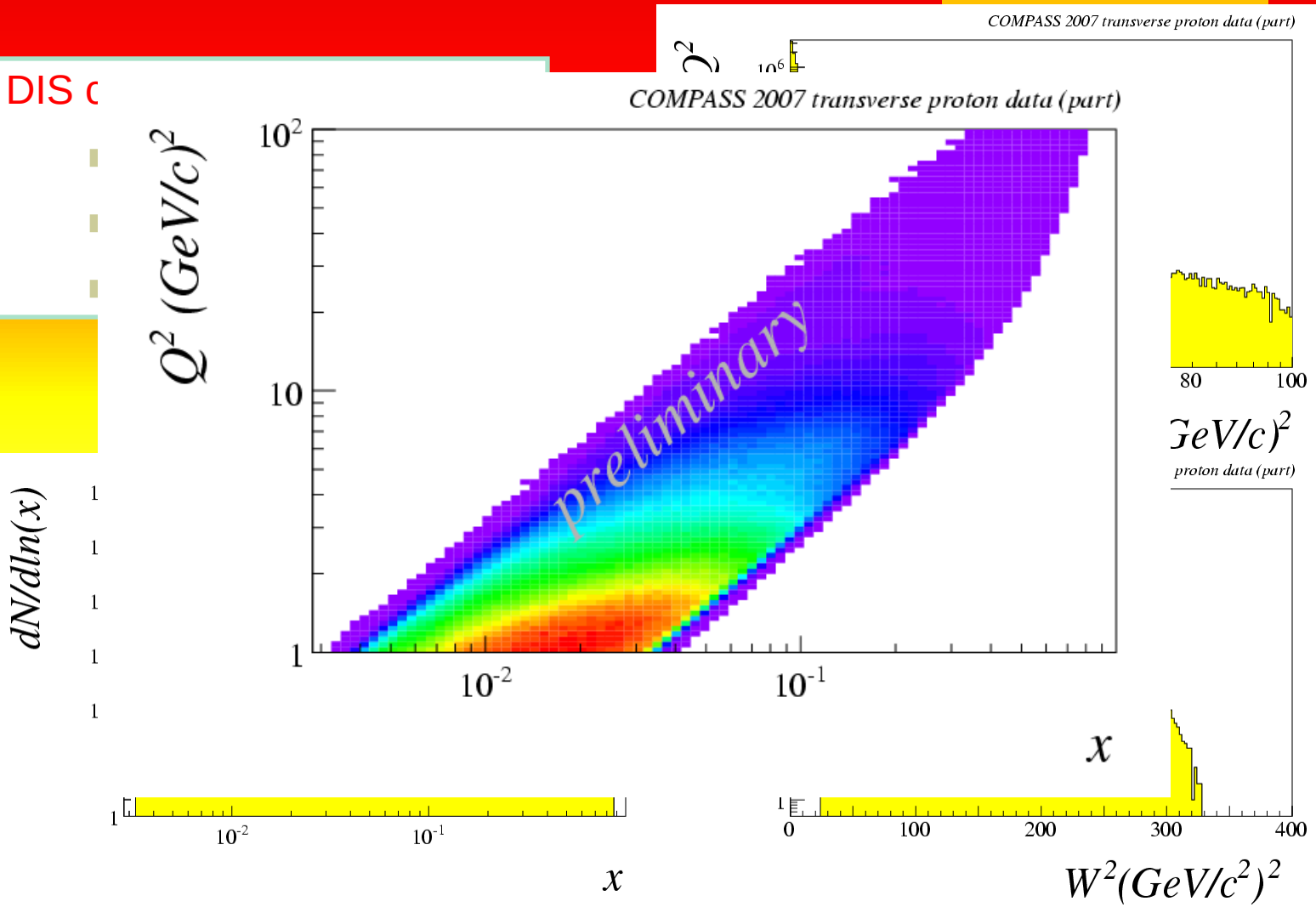




arget Polarization reversed every week

DIS Event Selection

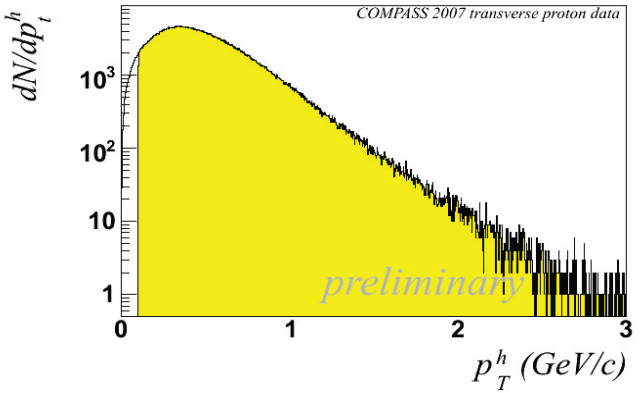
DIS c

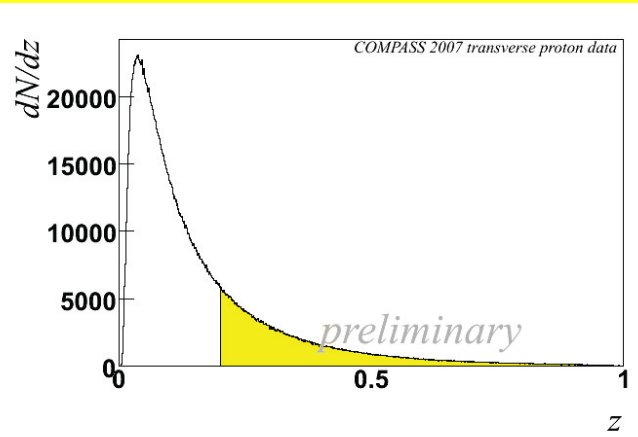


Hadron Selection

All hadrons

- Energy Deposit in HCALs>Thr. (4 GeV HCal1 and 5 GeV Hcal2)
- Only 1 HCAL fired
- p_T>0.1 GeV/c
- z>0.2





	+ hadrons	- hadrons
Total statistics entering the analysis	5.7×10^6 h	4.5×10^6 h

2007 Transverse data taking statistics

- 2007 Compass Data taking

  Begin of run: 18 May 2007

  End of run: 11 November 2007

- Split between transverse and longitudinal target polarization:

  - μ on tape for transverse (40.0×10^{12})

  - μ on tape for longitudinal (41.5×10^{12})

- First results on about 20% of the collected statistics shown at Transversity 2008 in Ferrara

Data quality checks

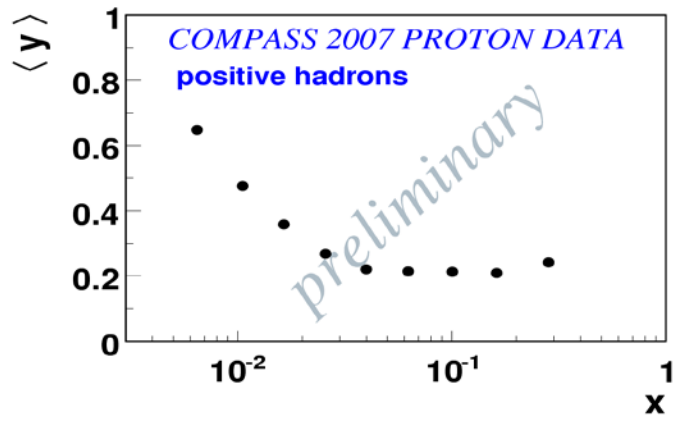
- Data taking stability is needed:

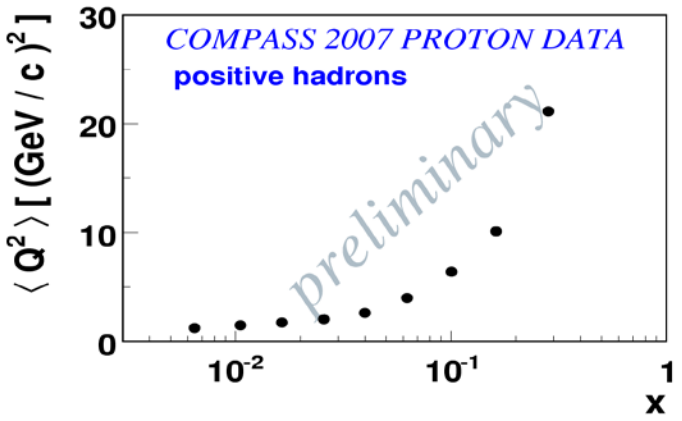
  A set of quality checks have been developed and applied to fulfil this condition

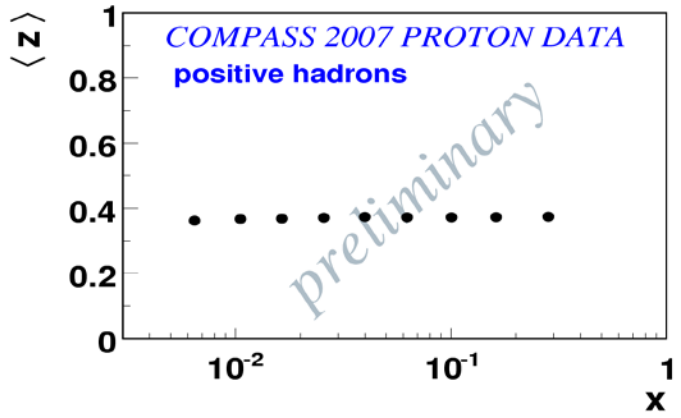
- **the detector profiles stability**
- ***the number of primary vertices per event***
- ***the number of tracks per primary vertex***
- ***beam particles per primary vertex***
- ***the number of K^0 per primary vertex***
- ***the reconstructed mass of the K^0 meson***
- ***stability of many kinematical variables:***

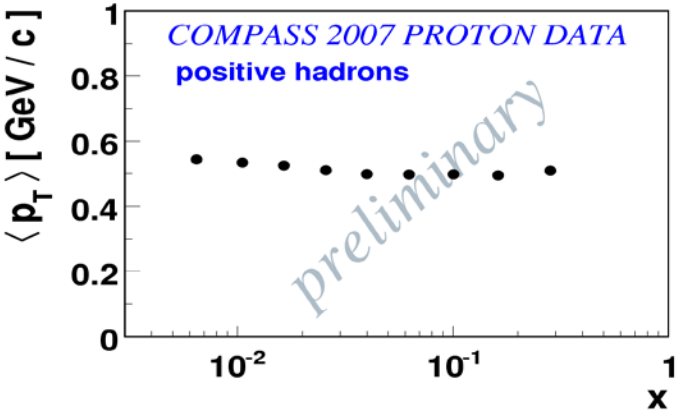
  (z_{vtx}, $E_{\mu'}$, $\phi_{\mu'}$, x_{Bj} Q^2,y, W, E_{had}, $\phi_{had_{Lab}}$, $\theta_{had_{Lab}}$, $\phi_{had_{GNS}}$, $\theta_{had_{GNS}}$, p_T)

Mean of kinematical quantities





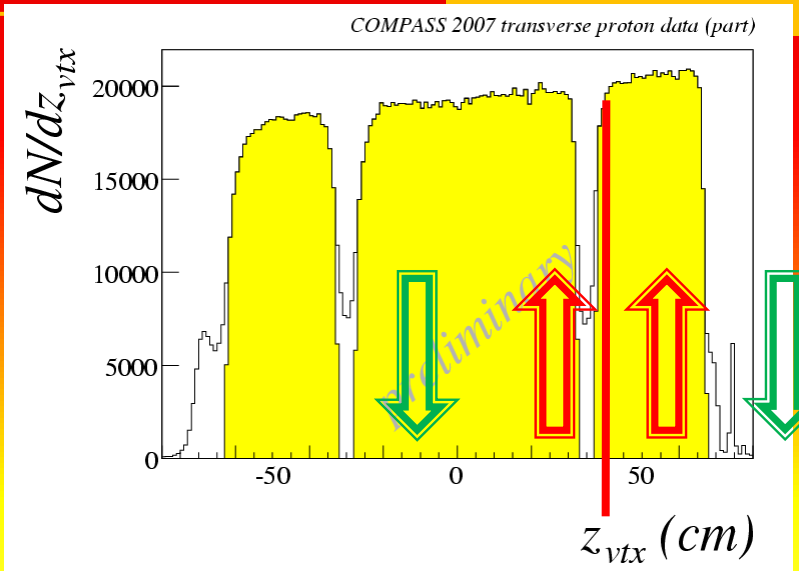




Asymmetry Extraction

Splitting middle cell into two parts

- two couples of cells with opposite polarization
- two independent values for the asymmetries per period



Extraction: 2D Binned Maximum Log-Likelihood Fit:

eight by eight grid in ϕ_h and ϕ_S;
in each bin of the matrix one expects N_j counts :

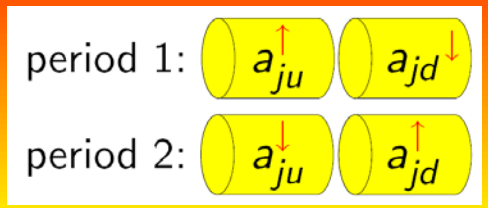
$$N_j^{\uparrow\downarrow} = a_j \, \Delta_j^{\uparrow\downarrow}(\vec{A}) \quad \text{with :} \begin{cases} \uparrow\downarrow & = \text{orientation of the target polarization} \\ a_j & = \text{acceptance in bin j} \\ \Delta_j^{\uparrow\downarrow}(\vec{A}) & = \text{all 8 spin dependent modulations in bin j} \end{cases}$$

Asymmetry Extraction - II

Separation of acceptance and spin dependent modulations:

Coupling of two cells (u,d) with opposite polarization (↑↓)

and two periods (p_1,p_2) with opposite target polarization:



Reasonable assumption: $\frac{a_{ju}^{\uparrow}}{a_{ju}^{\downarrow}} = C\frac{a_{jd}^{\downarrow}}{a_{jd}^{\uparrow}}$

$4 \cdot 64 = 256$ nonlinear equations $\left(\vec{f}(\vec{a})\right)$

$1 + 8 + 3 \cdot 64 = 201$ fit parameter, $(\vec{a})$

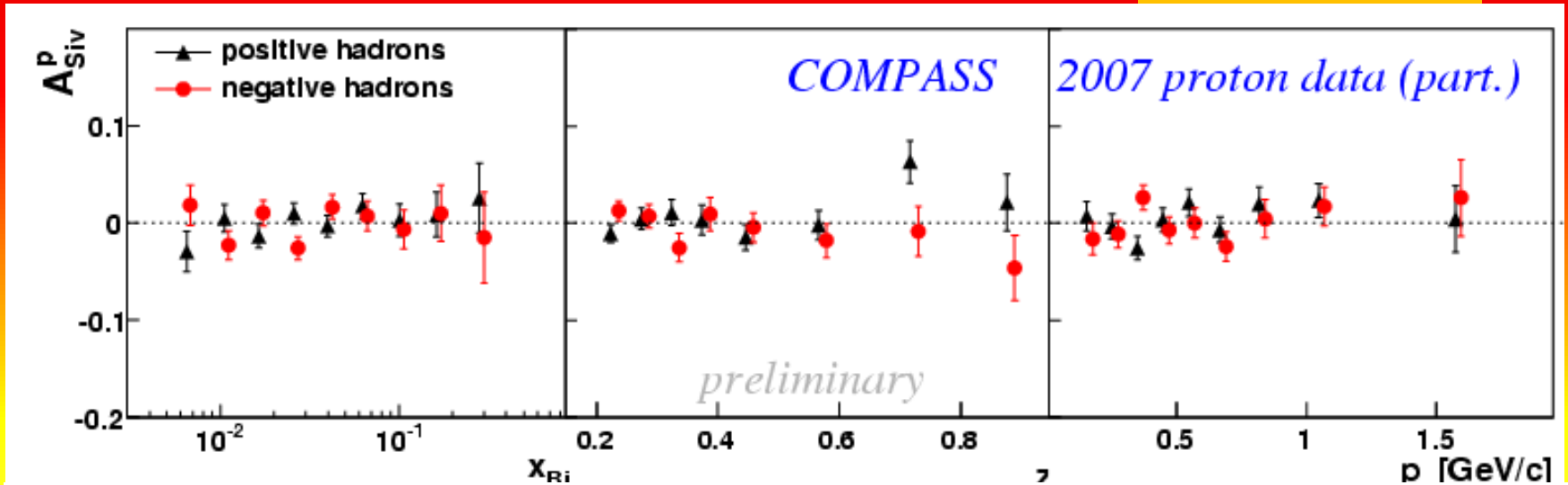
Poisson distribution to account for low statistics: $P_j(\vec{a}) = \frac{f_j(\vec{a})^{N_j}\, e^{-f_j(\vec{a})}}{N_j!}$

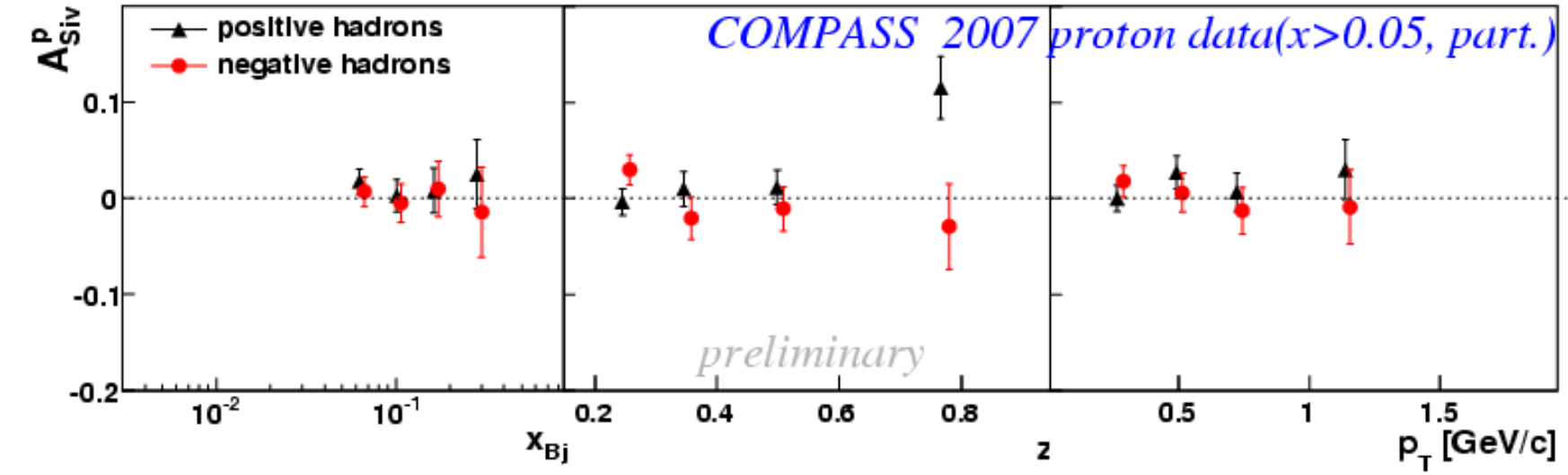
Tests for systematic errors:

- For false asymmetries: combination of cells with same polarization
- Comparison of 5 estimators for asymmetry extraction included the one used in previous analysis (deuteron data)

For this analysis: overall systematic error is 30% and 50% of the statistical error for Collins and Sivers respectively

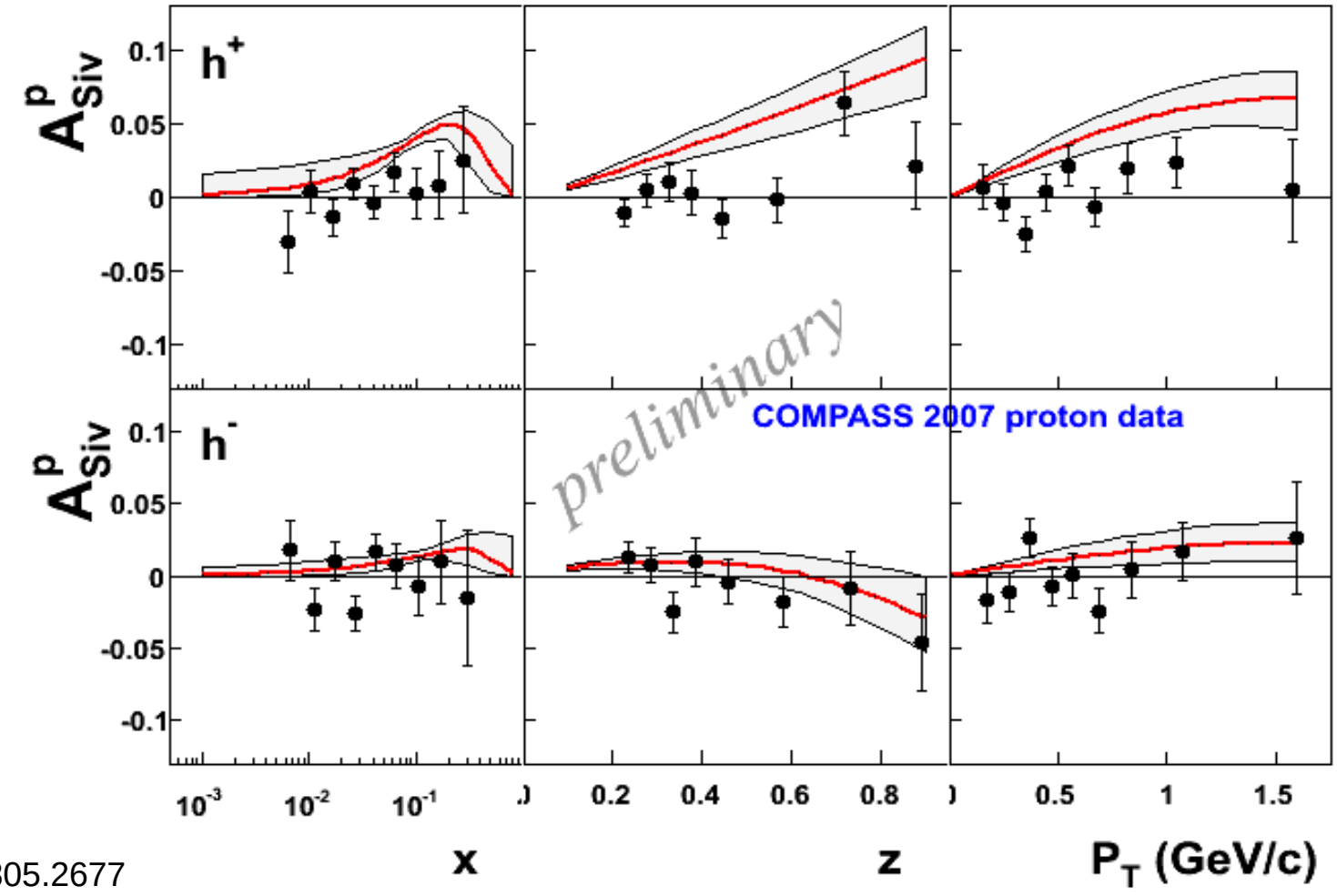
Sivers – proton data





Sivers asymmetry– proton data

comparison with the most recent predictions from M. Anselmino et al.

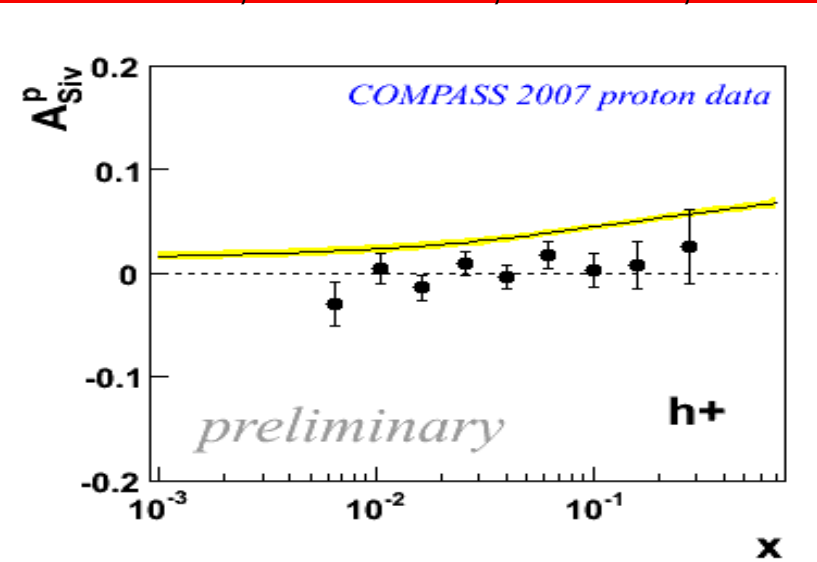


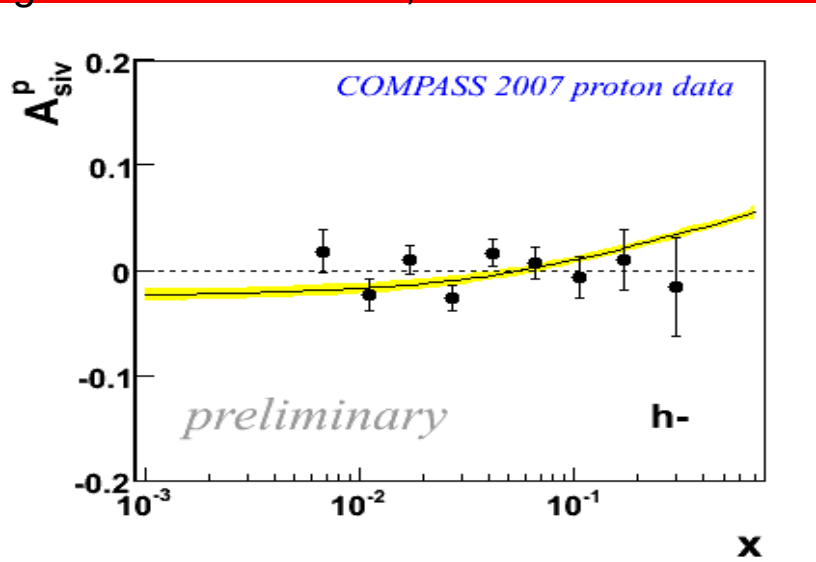
arXiv:0805.2677

Results: Sivers asymmetry

comparison with predictions from

S.Arnold, A.V.Efremov, K.Goeke, M.Schlegel and P.Schweitzer, arXiv:0805.2137

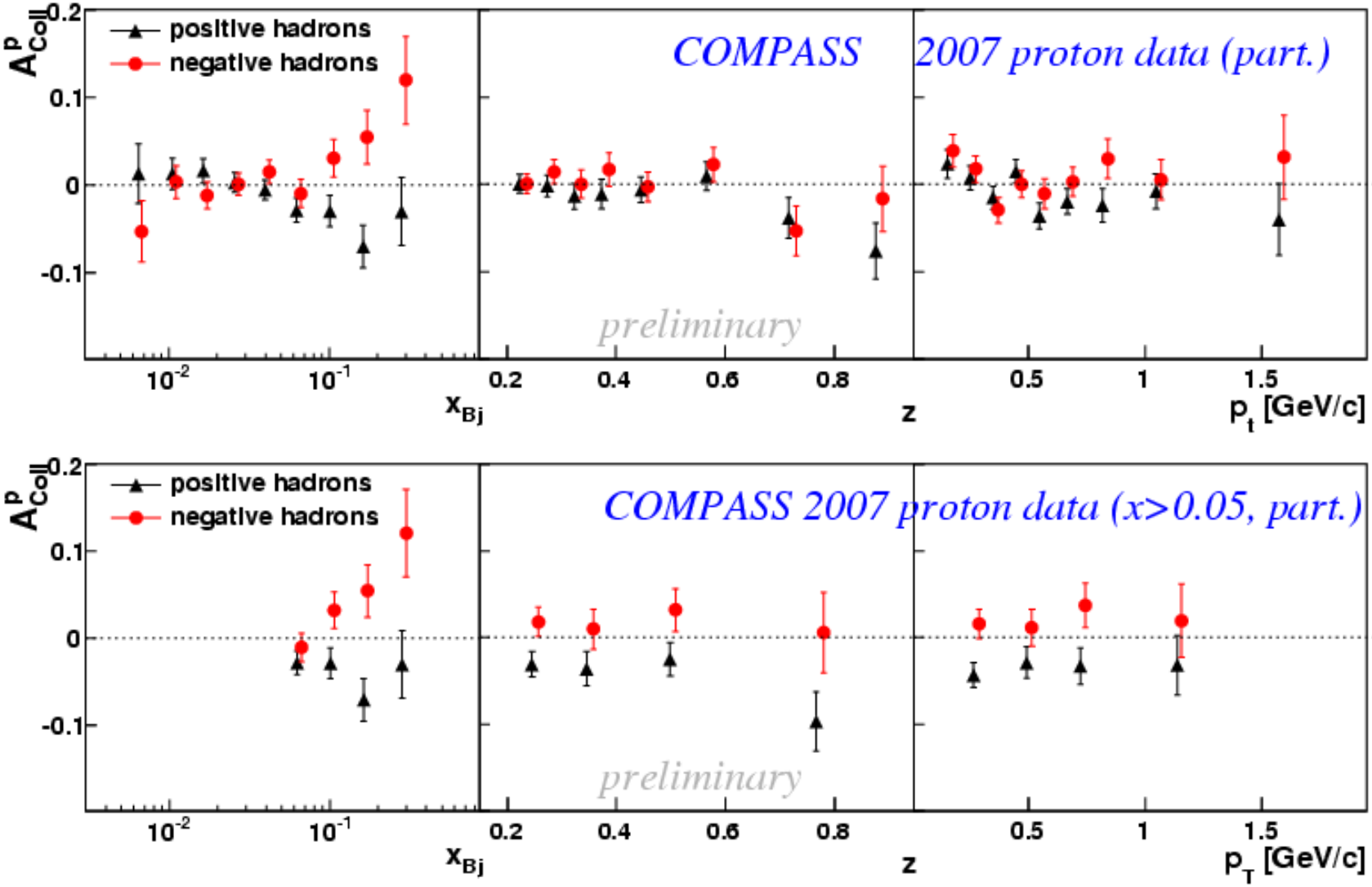




$$A_{UT\,\text{measured}}^{\sin(\phi-\phi_S)} = \left\{\text{'twist-2 Sivers effect' in Eqs. (11, 15)}\right\} + C(Q)\frac{M_N^2}{Q^2}$$

Maybe such corrections are irrelevant for $Q^2 > 1\,\text{GeV}^2$ which is typically used as DIS-cut. In any case, a careful comparison of all (present and future) data from COMPASS, HERMES and JLab will shed light on the possible size of power corrections.

Collins asymmetry



Collins over the full 2007

1 year have been spend to further analyse the data collected in the first part of the 2007 run to

- reproduce the data with improved quality
- Improve quality checks
- Increase systematic checks

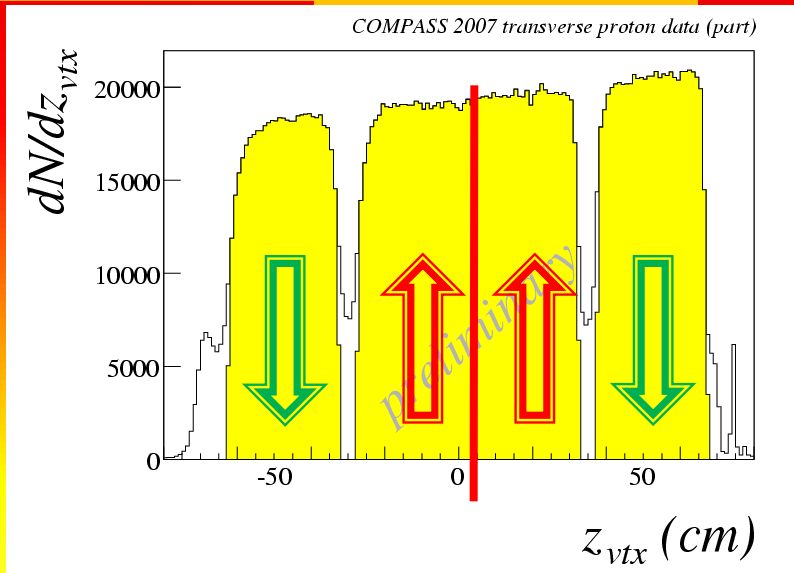
resulting in an increase of usable statistics for the Collins asymmetries by ~ a factor 3, while previous results for Sivers have been confirmed

	COLLINS	SIVERS
Total statistics entering the analysis	29×10^6 h	11×10^6 h

Asymmetry Extraction

Splitting middle cell into two parts

- two couples of cells with opposite polarization
- two independent values for the asymmetries per period



Extraction: Extended Unbinned Maximum Likelihood Fit

$$L = e^{-N_e} \prod_{i=1}^{N} p(\phi_S^i, \phi_h^i; a_1 \cdots a_m)$$

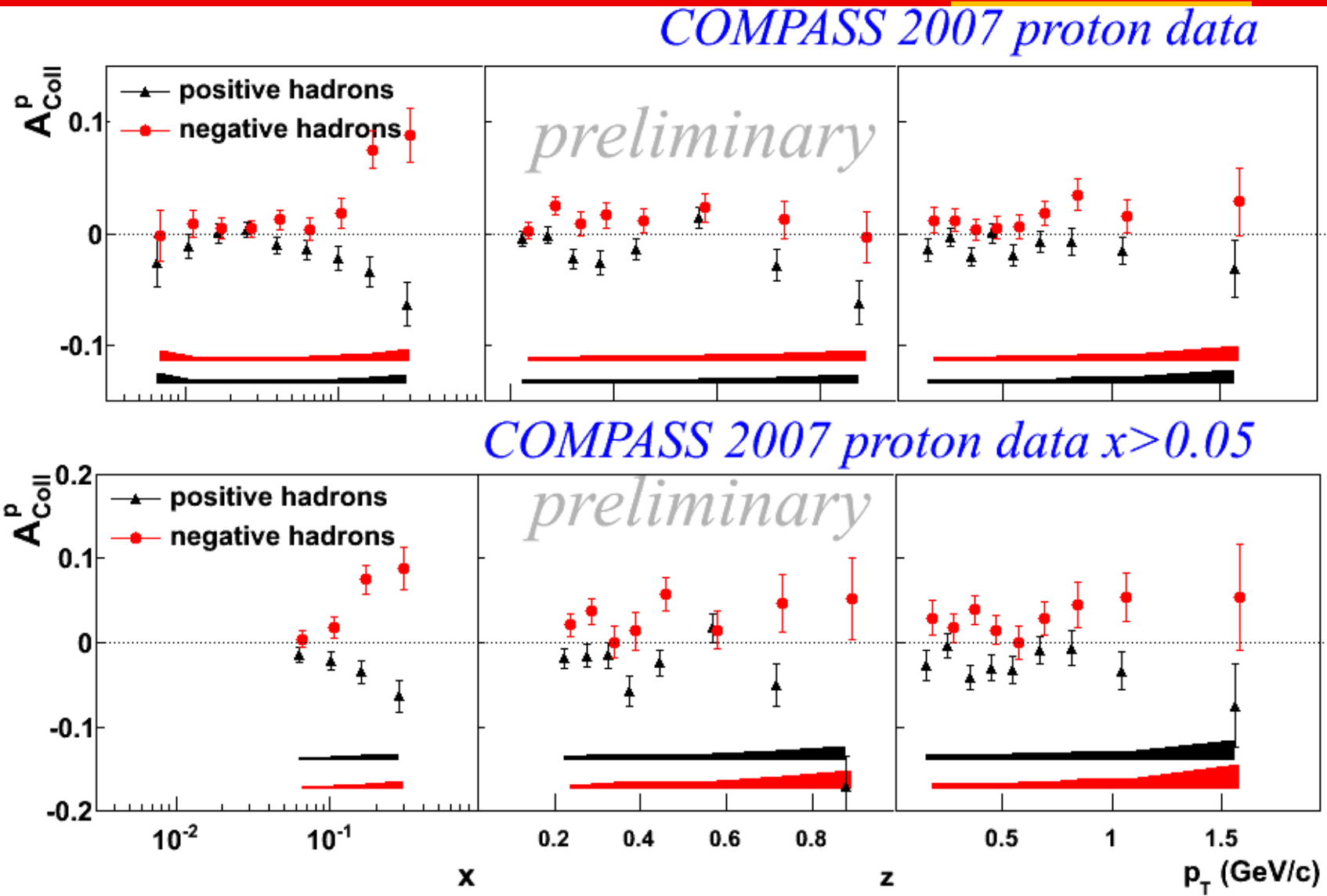
Where N is the number of hadrons, N_e is the expected n.of.h, $\{a_1 \ldots a_m\}$ are the unknown parameters and p describes the probability density of the sampling variables ϕ_S and ϕ_h

$$\int\int p(\phi_S \phi_h; a_1 \cdots a_m) d\phi_S d\phi_h = N_e(a_1 \cdots a_m)$$

i.e. p describes also the size of the distribution, not only the shape

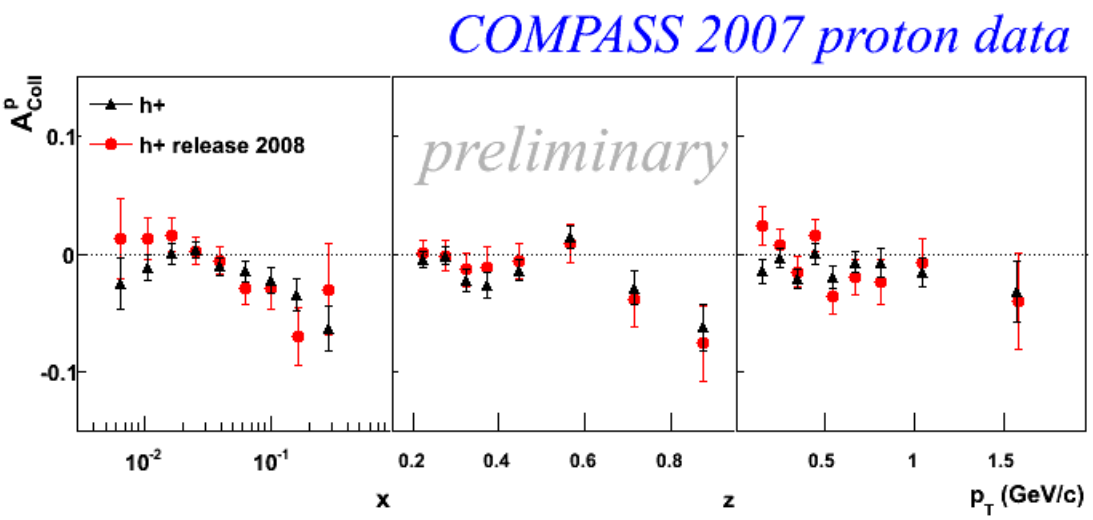
p parameterization contains the single hadron cross-section

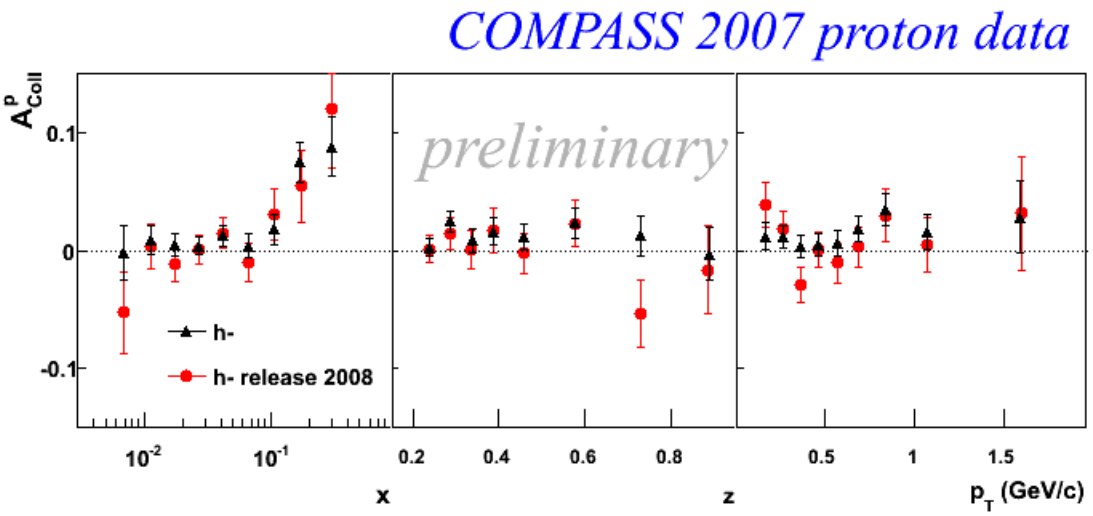
Collins asymmetry



Compass proton data

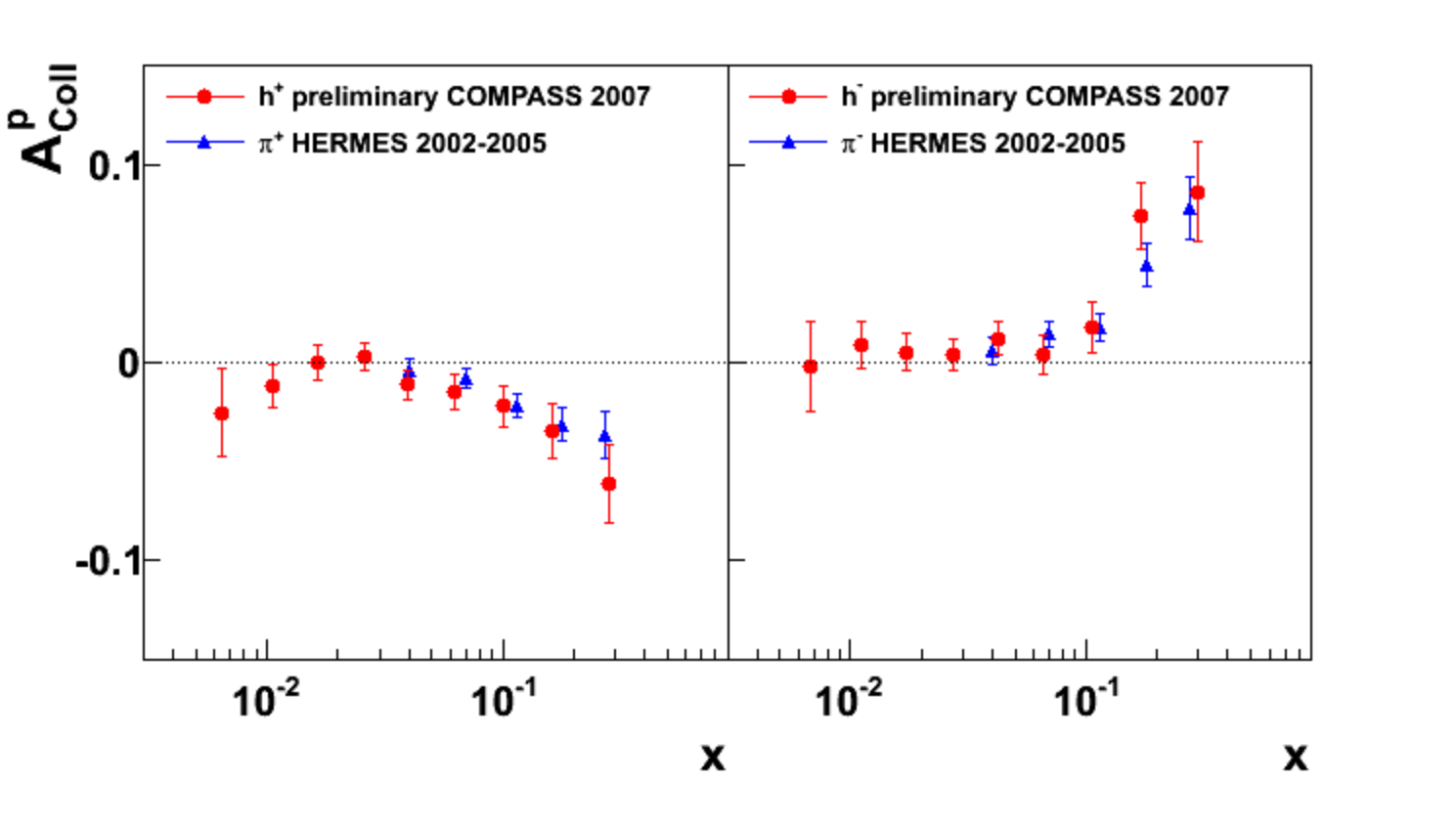
comparison previous results





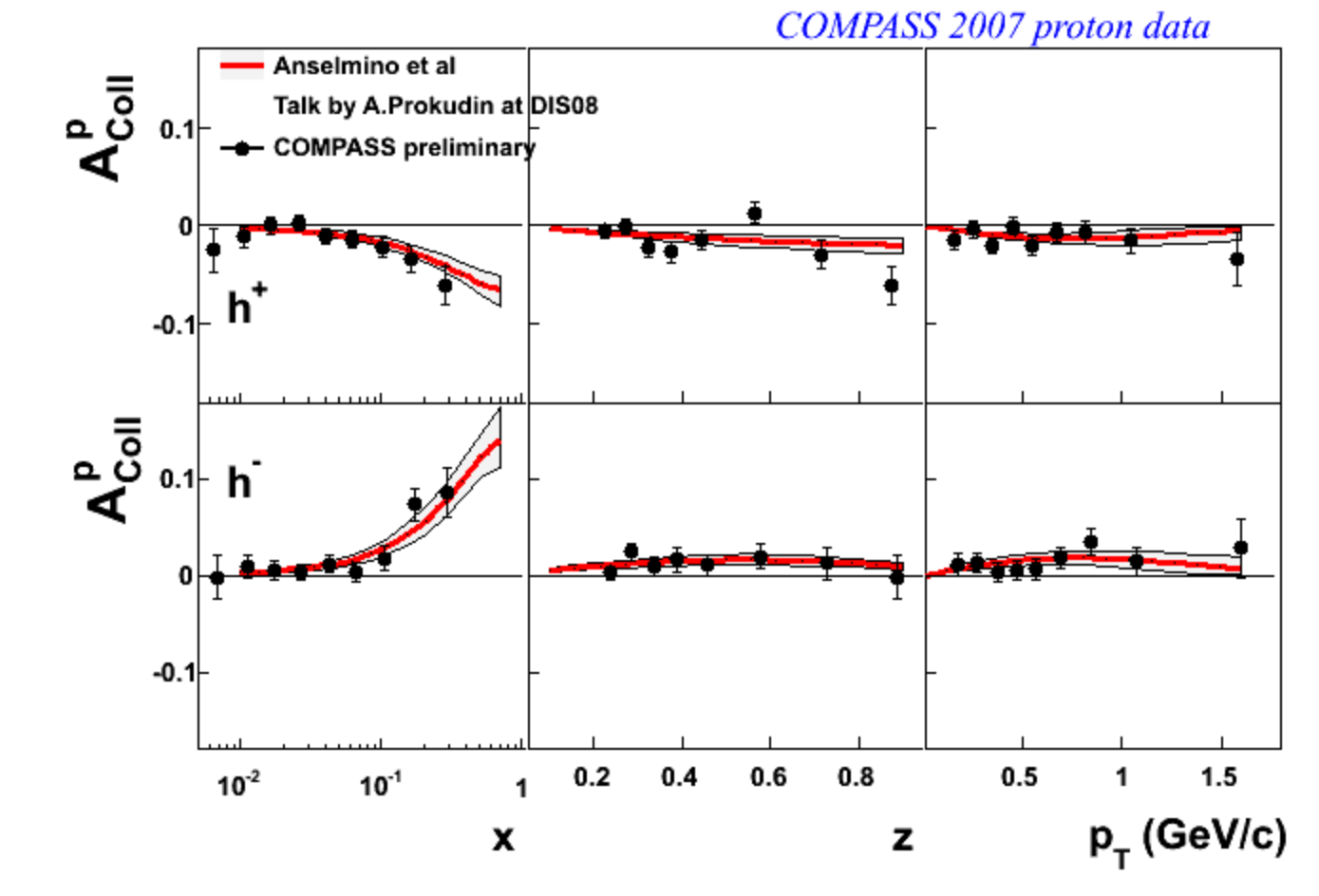
Compass proton data

comparison with HERMES



Compass proton data

comparison with M. Anselmino et al. predictions

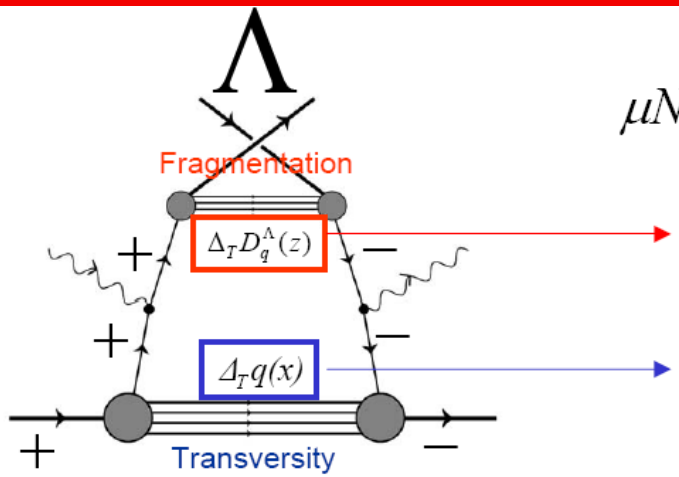


Summary

- Collins Asymmetry:
  - different from zero, comparable to HERMES
  - agreement with predictions of Anselmino et al
  - factor ~3 in statistics gained
- Sivers Asymmetry:
  - small and compatible with zero within the statistical errors

Extraction of the Sivers asymmetry on the full 2007 run looks difficult due to instabilities of the spectrometer in the first part of the run

Transverse Λ polarization



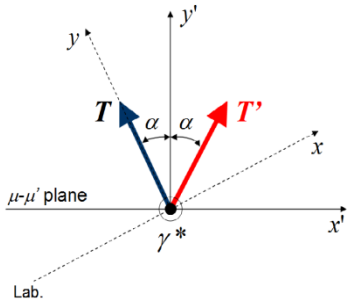
$$\mu N^{\Uparrow} \rightarrow \mu' \Lambda^{\Uparrow} X \quad @ \text{ SIDIS } (Q^2 > 1 \text{ (GeV/c)}^2)$$

Differentiate between terms $\Delta_T D(z)$ and $\Delta_T q(x)$ due to factorization in x and z?

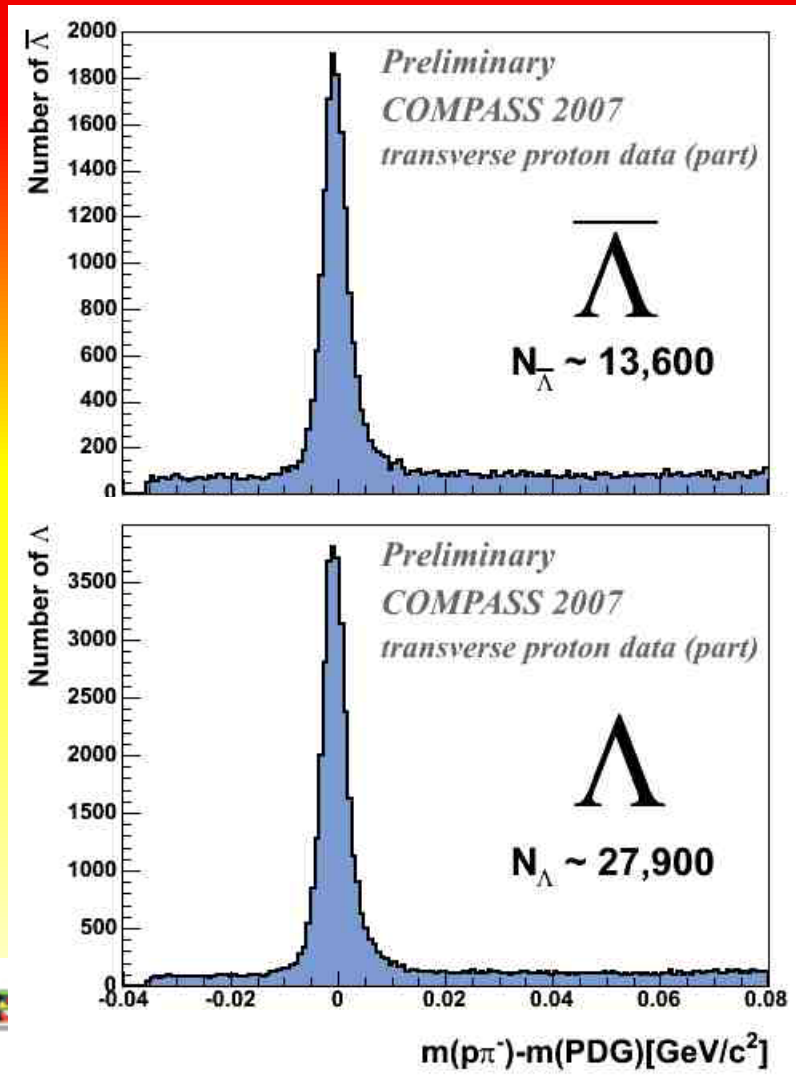
Transverse Λ polarization in a transversely polarized target

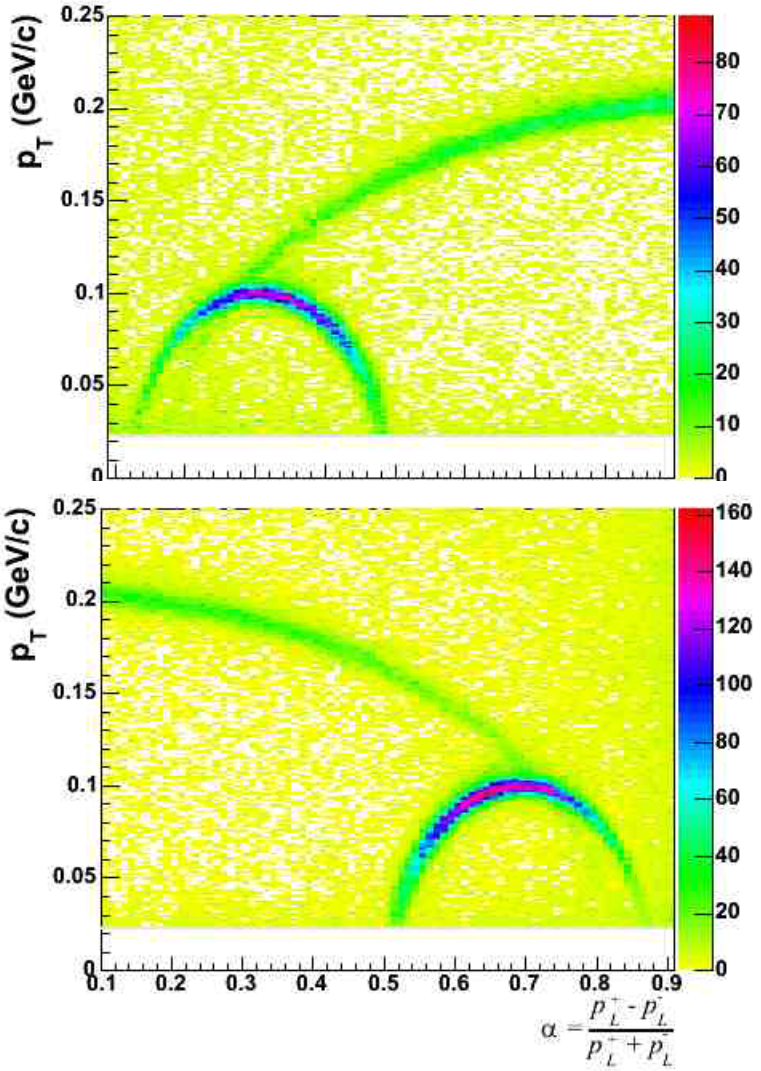
$$P^\Lambda \propto \frac{\sum_q e_q^2 \Delta_T q(x) \Delta_T D_q^\Lambda(z)}{\sum_q e_q^2 q(x) D_q^\Lambda(z)}$$

$\Delta_T q(x)$ = transversely polarized quark distribution
$q(x)$ = unpolarized quark distribution function
$\Delta_T D_q(z)$ = transversely polarized fragmentation
$D_q(z)$ = unpolarized fragmentation function

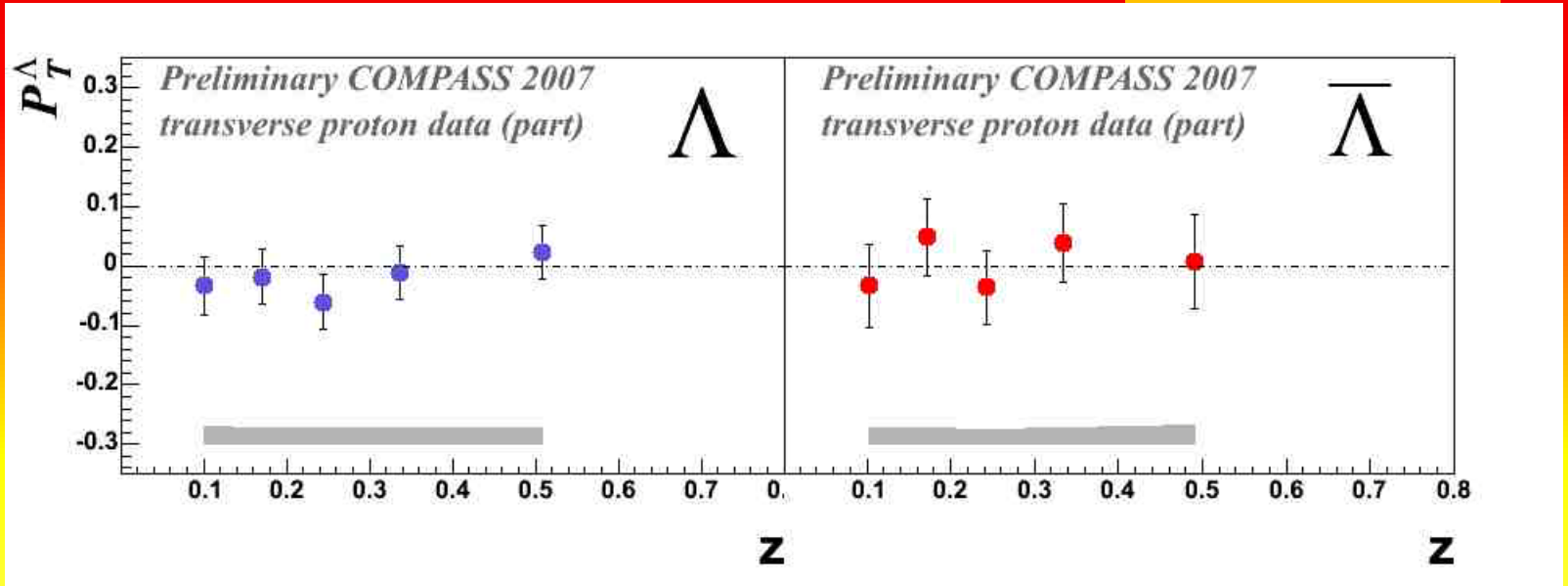


Data Selection





Results with proton target



- ~60% higher statistics with respect deuteron data (after)
- Systematic errors have been estimated to be smaller than statistical errors from false polarization.
- No dependence on *x*.

Thank You