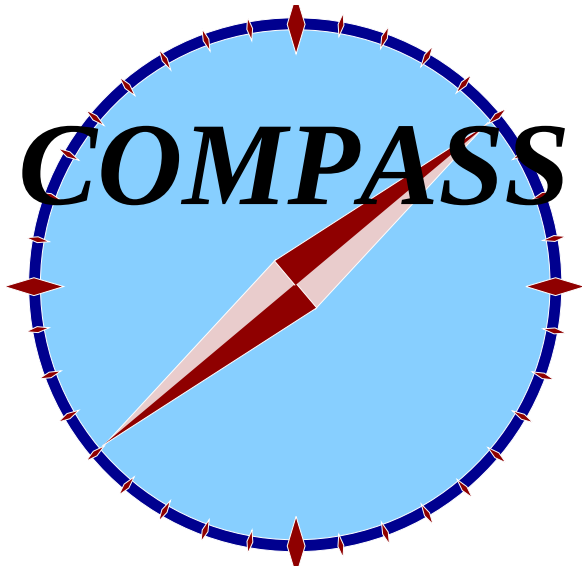
Transverse spin effects at *COMPASS*



Heiner Wollny
University of Freiburg
on behalf of COMPASS

Outline:

- COMPASS experiment
- Collins and Sivers Asymmetry
- Results of 2007 Proton run

COMPASS Spectrometer

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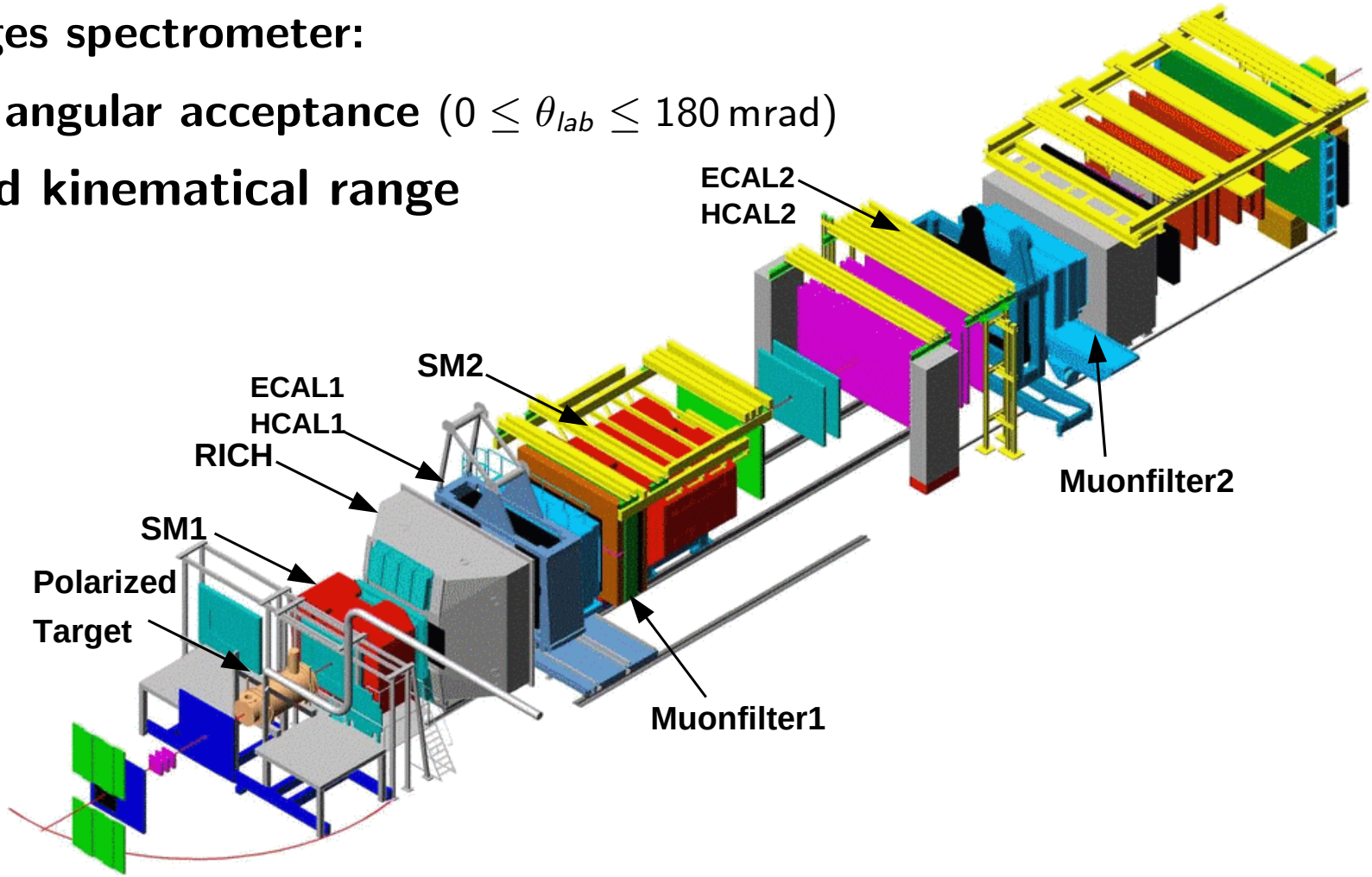
- **high energy muon beam (160 GeV)**
- **high intensity beam** ($2 \cdot 10^8 \mu^+ / spill$)
- **two stages spectrometer:**

  $\rightsquigarrow$ **large angular acceptance** ($0 \leq \theta_{lab} \leq 180\,\mathrm{mrad}$)

  $\rightsquigarrow$ **broad kinematical range**



COMPASS Polarized Target

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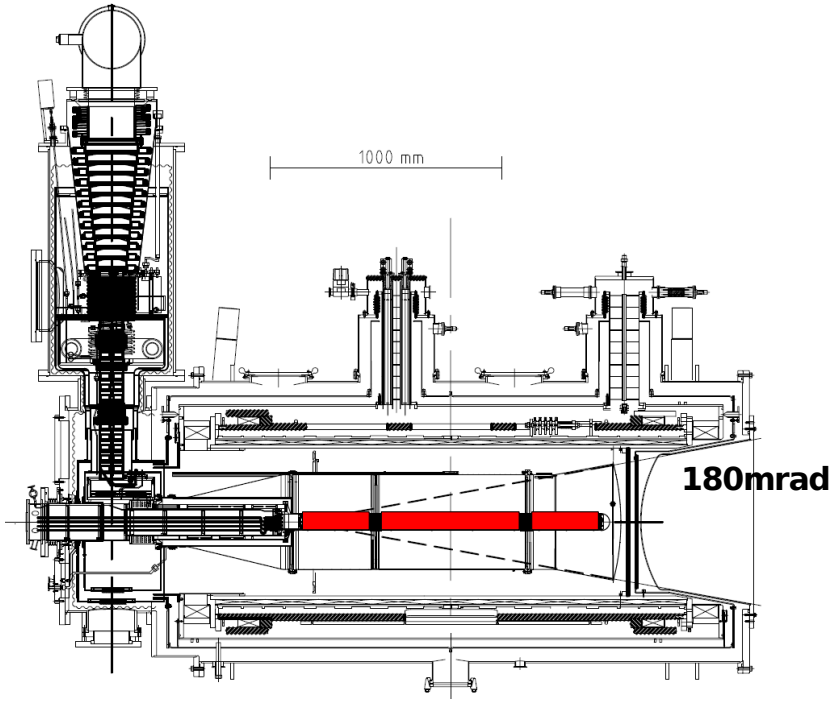
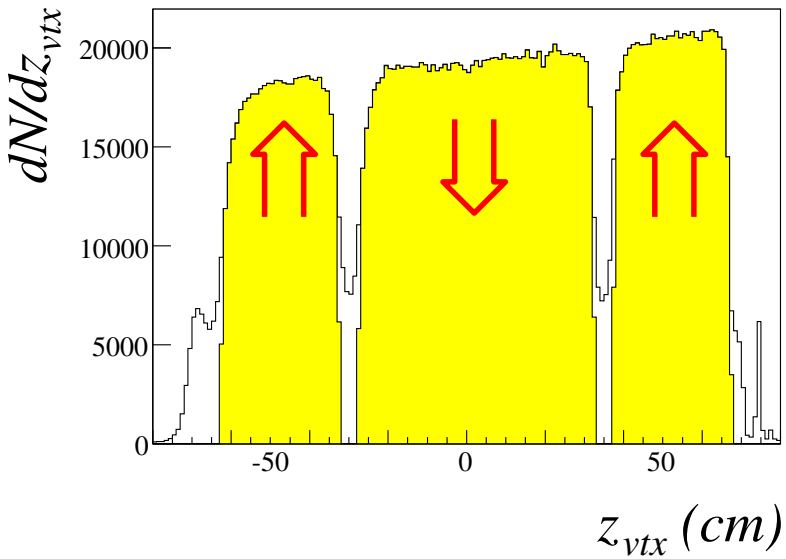




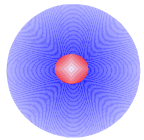
COMPASS target ($\geq$ 2006):

- 3 target cells
- acceptance: 180 mrad
- target material: NH_3
- dilution factor: $f \simeq 15\,\%$
- polarization: $P_T \sim 90\,\%$
- reversal of polarization every 4-5 days

Transverse Spin Physics

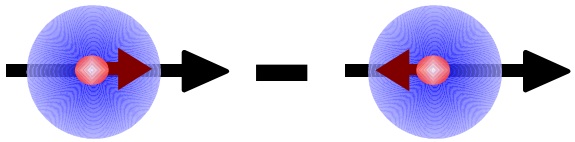
In leading order three parton distributions are needed to describe the structure of the nucleon:

$\mathbf{q}(x)$



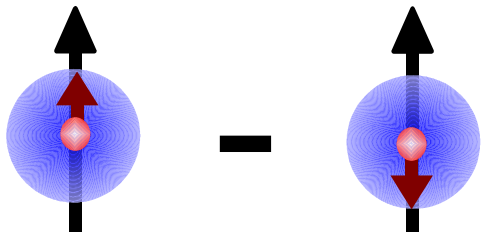
mometum distribution
in unpolarized DIS
$\ell P \to \ell' X$

$\Delta\mathbf{q}(x)$



helicity distribution
in polarized DIS
$\vec{\ell}\vec{P} \to \ell' X$

$\Delta_T\mathbf{q}(x) = \mathbf{q}^{\uparrow\uparrow}(x) - \mathbf{q}^{\uparrow\downarrow}(x)$



transversity distribution
in polarized SIDIS
$\ell P^{\uparrow} \to \ell' h X$

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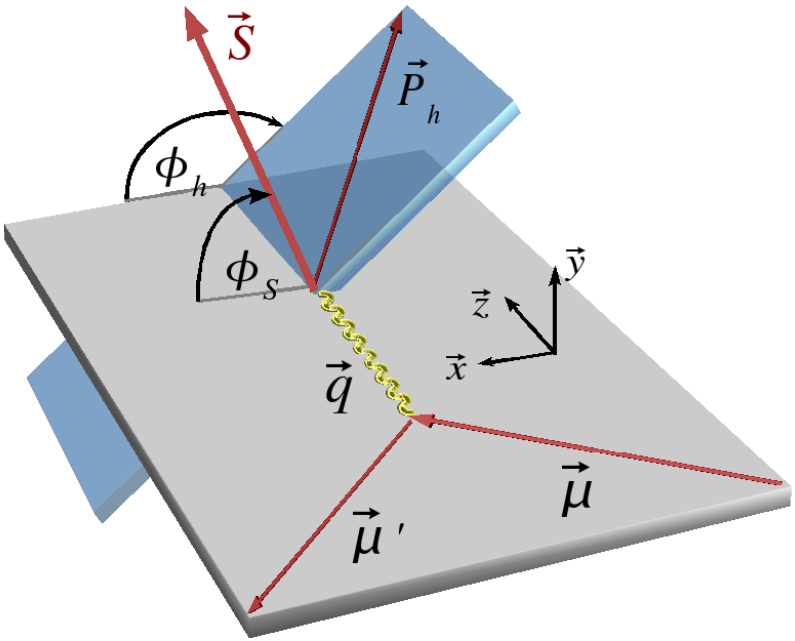
Measuring transversity with Collins-FF $\Delta_T^0 D_q^h$:

fragmentation of a transversely polarized quark into an unpolarized hadron



$\rightsquigarrow$ azimuthal asymmetry:

$$N_h^{\uparrow\downarrow}(\Phi_{Coll}) \propto 1 \pm A_C^h \cdot \sin \Phi_{Coll}$$

$$\Phi_{Coll} = \phi_h + \phi_S - \pi$$

ϕ_h azimuthal angle of hadron

ϕ_S azimuthal angle of spin of the initial quark

Collins Asymmetry

Measured asymmetry A_C^h is a convolution of transversity $\Delta_T q(x)$ and Collins-FF $\Delta_T^0 D_q^h$:

$$A_{Coll} = \frac{A_C^h}{f\, P_T\, D_{nn}} = \frac{\sum_q e_q^2 \cdot \Delta_T q(x) \cdot \Delta_T^0 D_q^h}{\sum_q e_q^2 \cdot q(x) \cdot D_q^h}$$

f target dilution factor

P_T target polarization

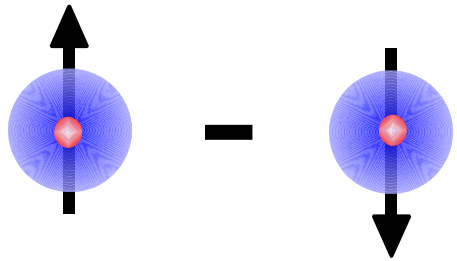
$D_{nn} = \frac{1-y}{1-y+y^2/2}$ depolarization factor

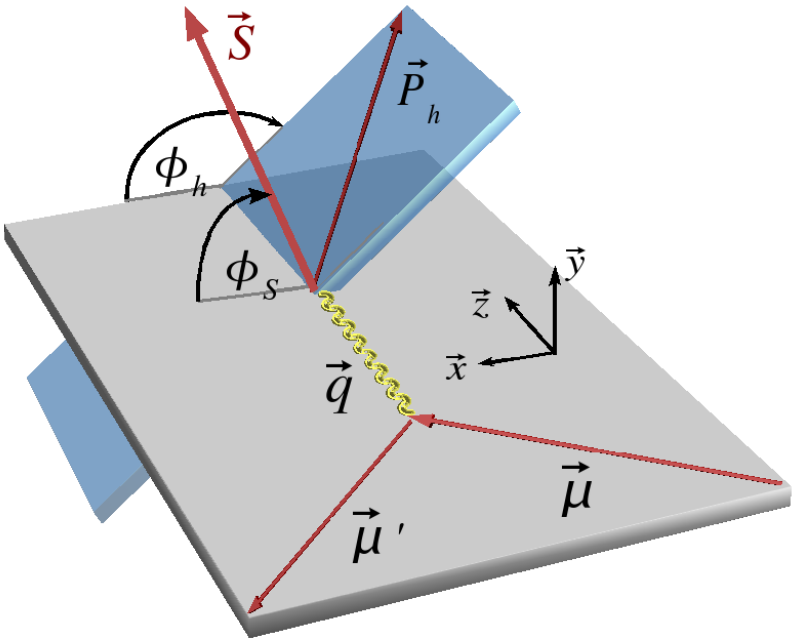
Sivers Asymmetry

Intrinsic transverse momentum of quarks $\rightsquigarrow$ several further distributions

Sivers-Function $\Delta_0^T q(x)$:

distribution of unpolarized quarks with transverse momentum k_T in a transversely polarized nucleon





$\rightsquigarrow$ azimuthal asymmetry:

$$N_h^{\uparrow\downarrow}(\Phi_{Siv}) \propto 1 \pm A_S^h \cdot \sin \Phi_{Siv}$$

$$\Phi_{Siv} = \phi_h - \phi_S$$

ϕ_h azimuthal angle of hadron

ϕ_S azimuthal angle of spin of the initial quark

Sivers Asymmetry

Measured asymmetry A_S^h is a convolution

of Sivers-function $\Delta_0^T q(x)$ and unpolarized-FF D_q^h:

$$A_{Siv} = \frac{A_S^h}{f\, P_T} = \frac{\sum_q e_q^2 \cdot \Delta_0^T q(x) \cdot D_q^h}{\sum_q e_q^2 \cdot q(x) \cdot D_q^h}$$

f target dilution factor

P_T target polarization

SIDIS Cross-Section

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

$$\frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{\ \ldots$$

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

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

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

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

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

Sivers

Collins

6 further modulations

A.Bacchetta et al

JHEP 0702:093,2007

E-print number: hep-ph/0611265

2007 Proton Run: Statistics

Data taking in 2007: May to November

$81.5 \cdot 10^{12}$ **muons on tape**

equally shared between transverse and longitudinal target polarization

Total statistics for this analysis (after all cuts):

pos hadrons	neg hadrons
$5.7 \cdot 10^6$	$4.5 \cdot 10^6$

Not the whole statistics 2007! $\rightsquigarrow$

For this analysis $\sim 20\%$ **of the collected data has been prepared**

2007 Proton Run: Data Quality Checks

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Data quality checks:

- detector profiles
- event reconstruction
- K^0-reconstruction (invariant mass)
- distributions of kinematical variables

$(x_{bj}, Q^2, y, W, p_{\mu'}, \phi_{\mu'_{Lab}}, \theta_{\mu'_{Lab}}, p_{had}, p_{T_{had}}, z, \phi_{had_{Lab}}, \theta_{had_{Lab}}, \phi_h, \phi_S, Z_{vertex})$

SIDIS Event Selection

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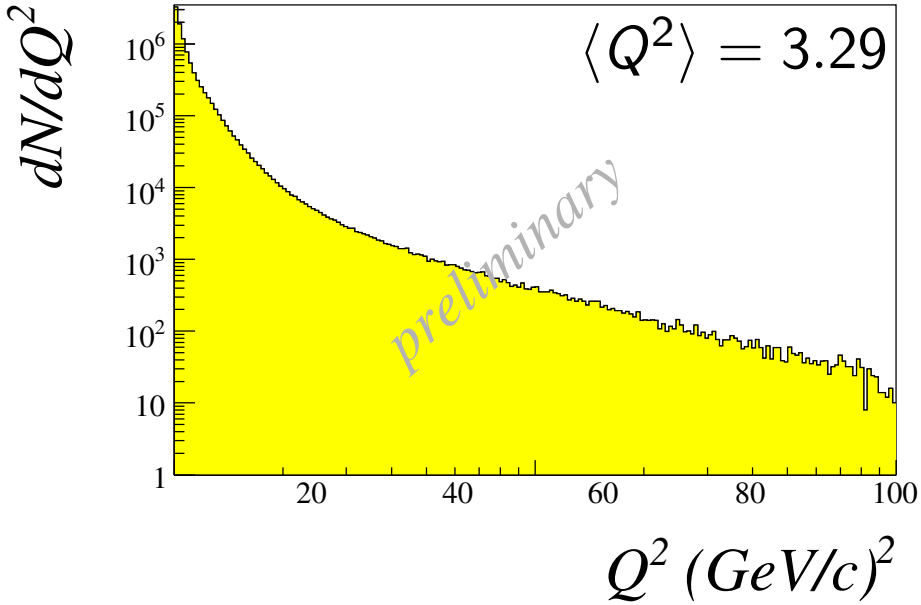
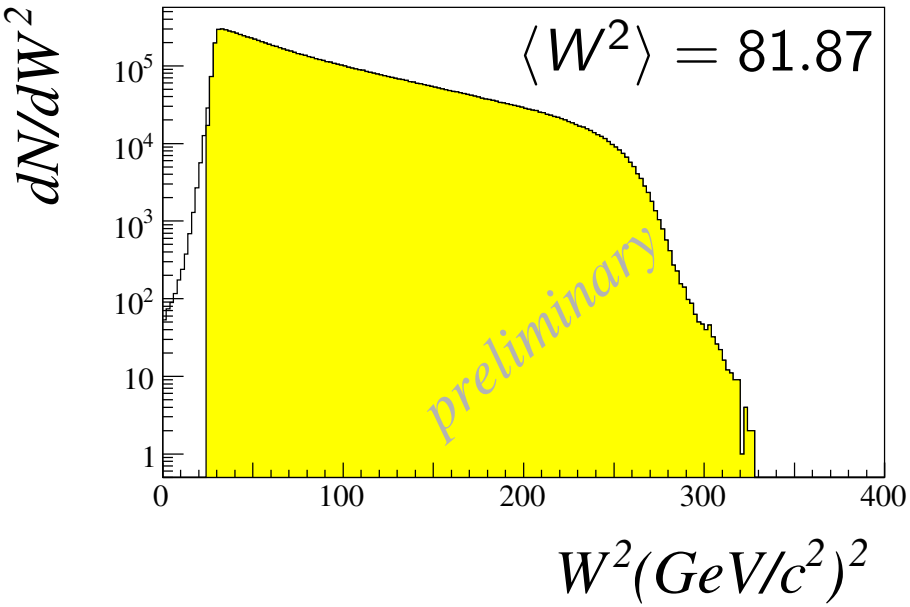
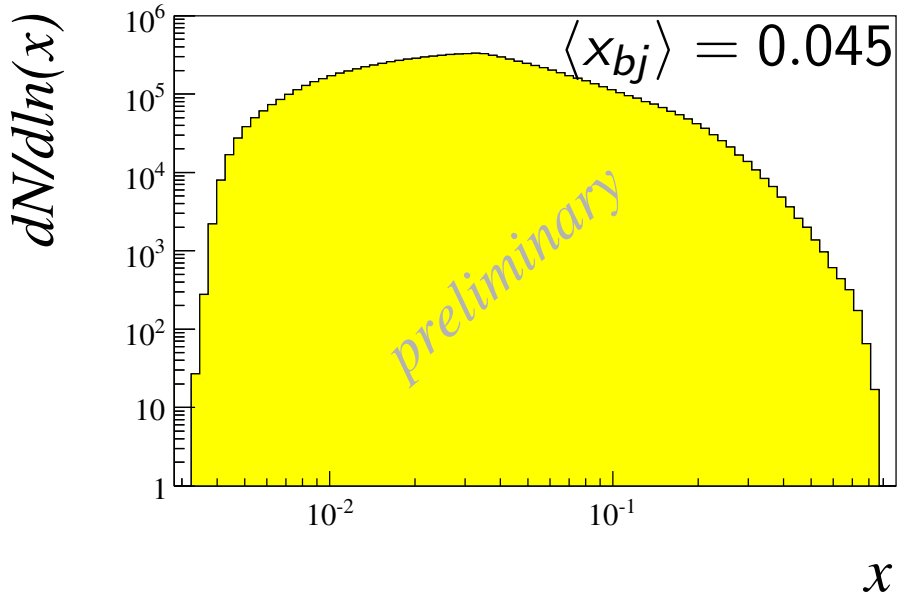
DIS cuts:

- $Q^2 > 1\,(\mathrm{GeV}/c)^2$
- $0.1 < y < 0.9$
- $W^2 > 25\,\mathrm{GeV}^2/c^4$







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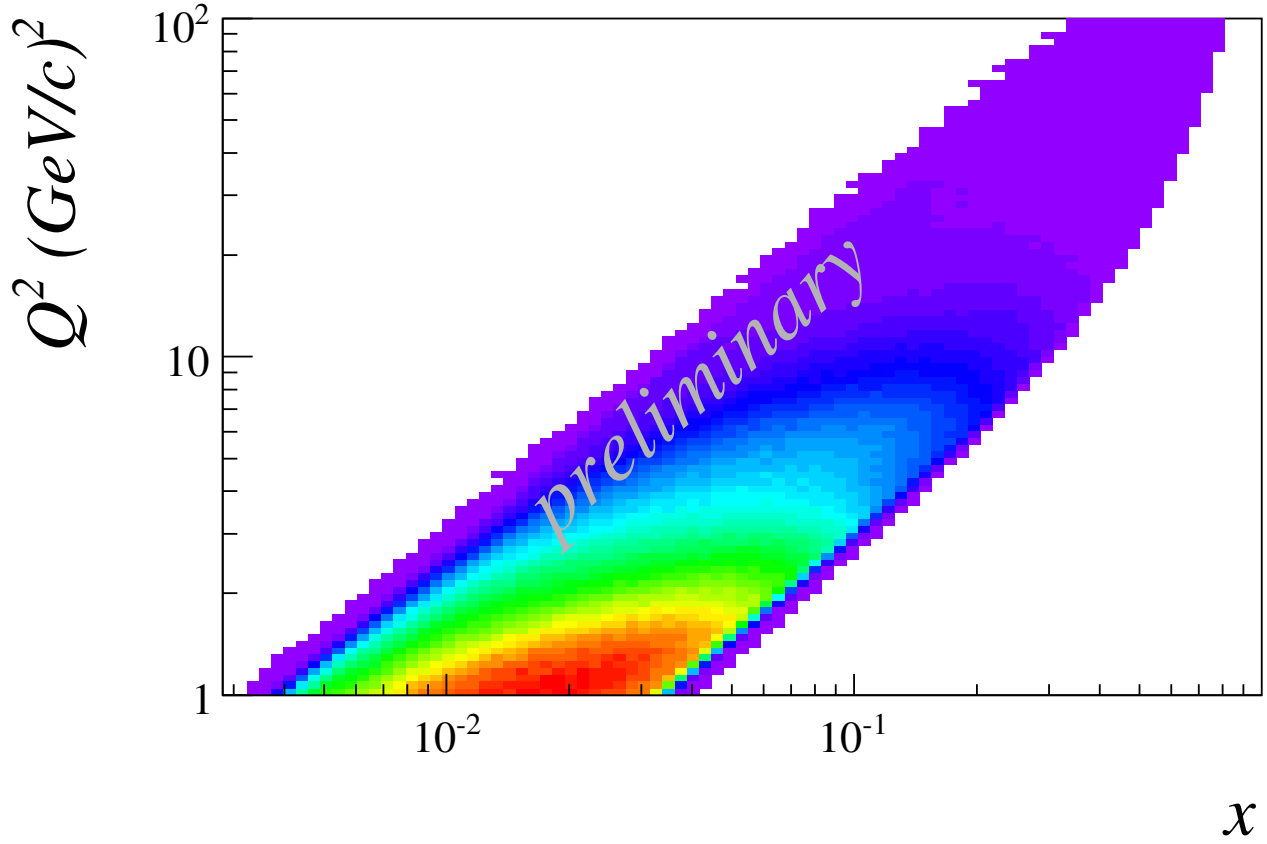

SIDIS Event Selection

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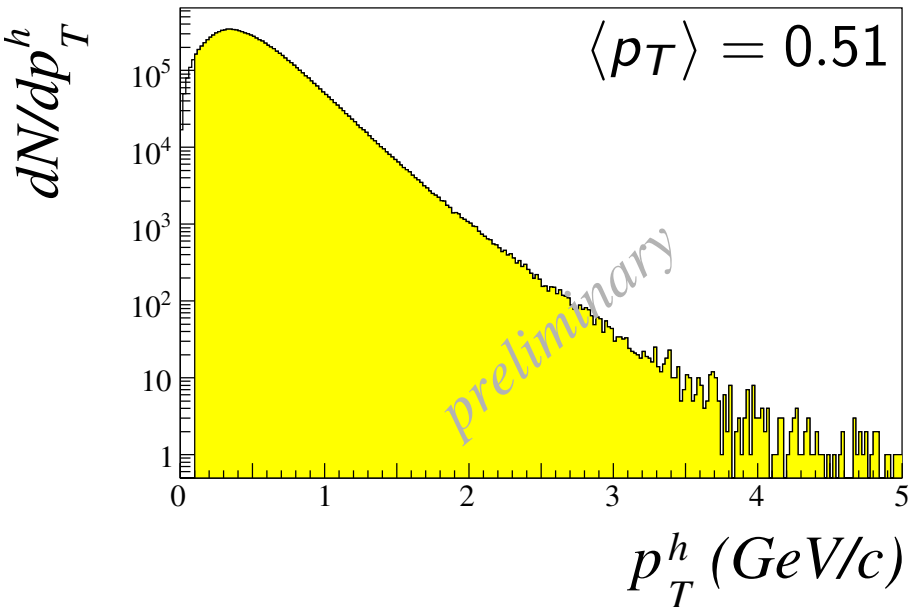
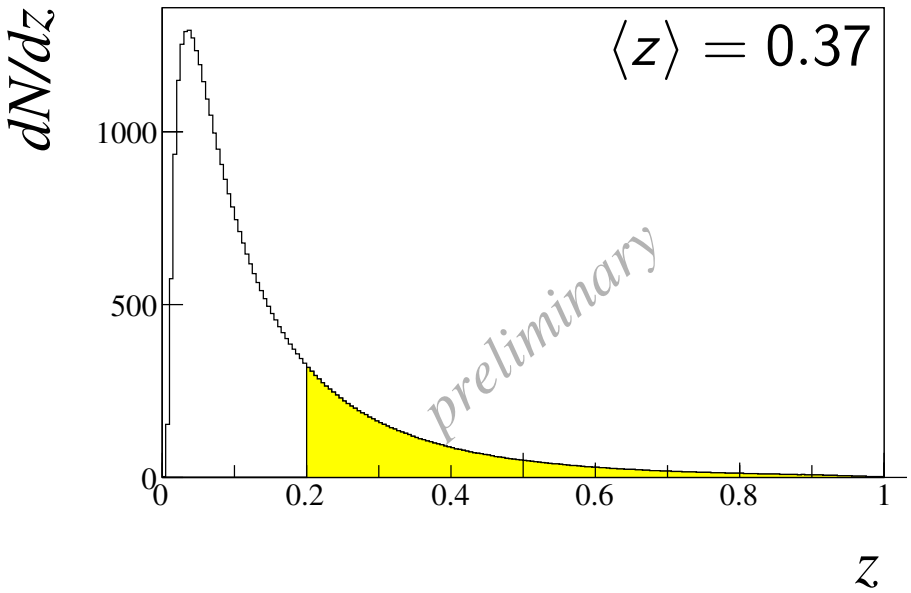
hadron cuts:

- $p_T > 0.1\,\mathrm{GeV}/c$
- $z > 0.2$
- μ rejection with HCALs:
  E deposit $>$ Thr. ($\sim 5\,$GeV)





Mean Kinematics - Proton Data 2007

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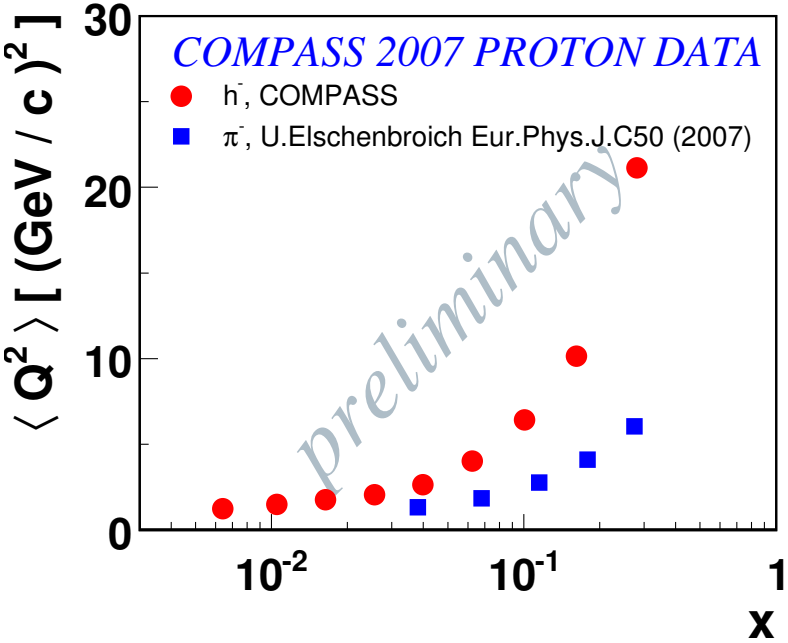

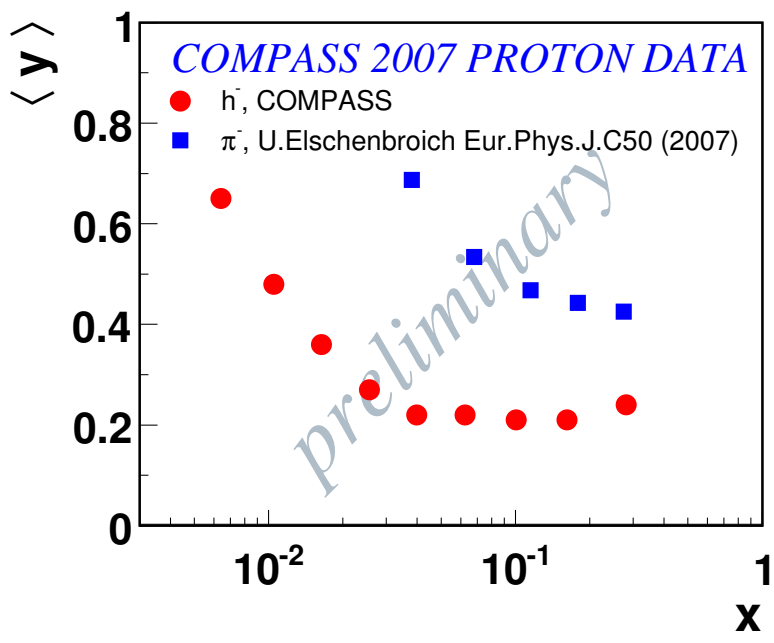

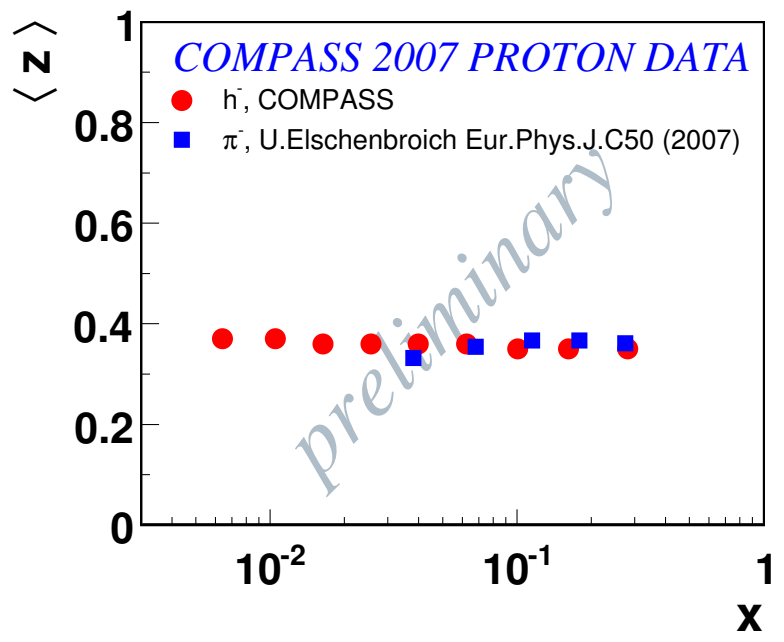

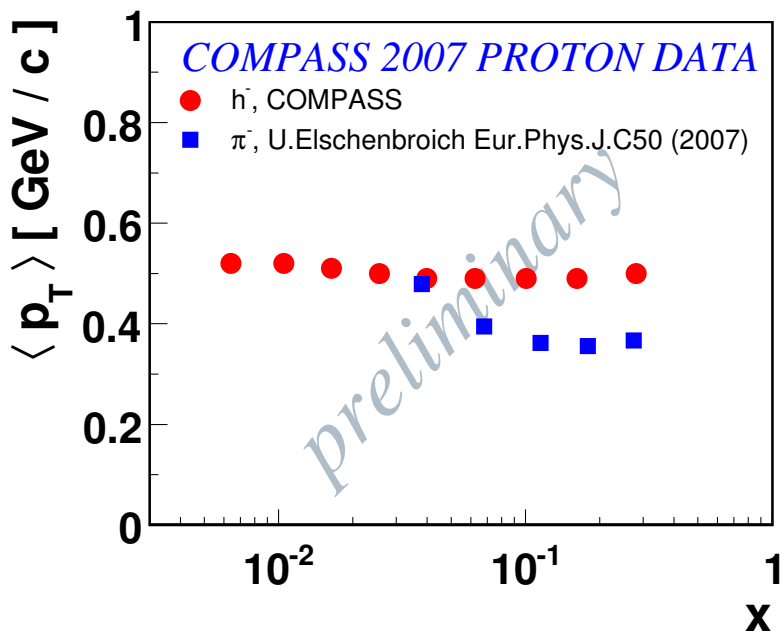

Mean Kinematics - Proton Data 2007

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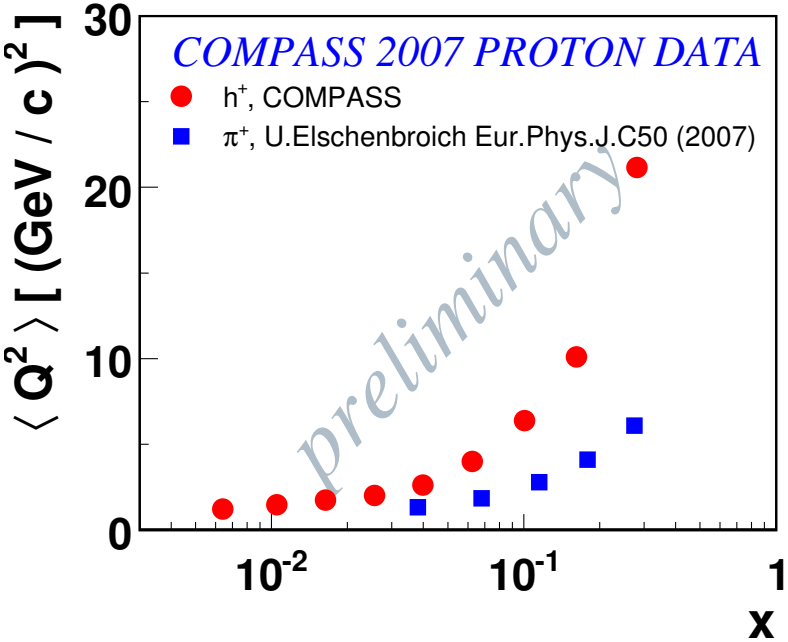

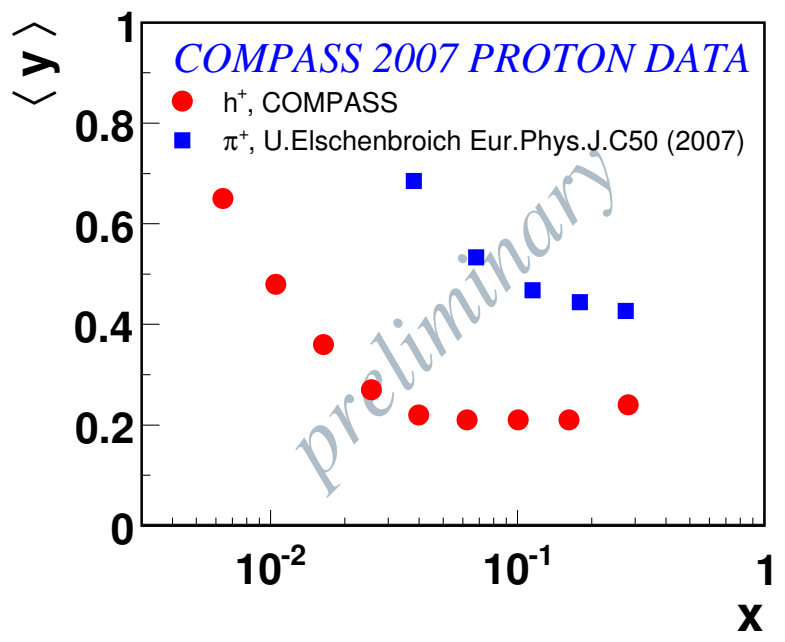

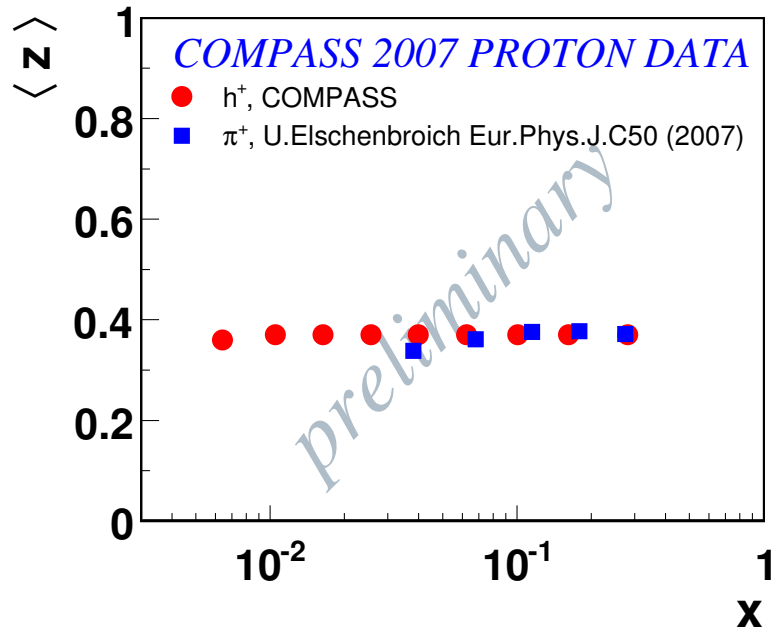

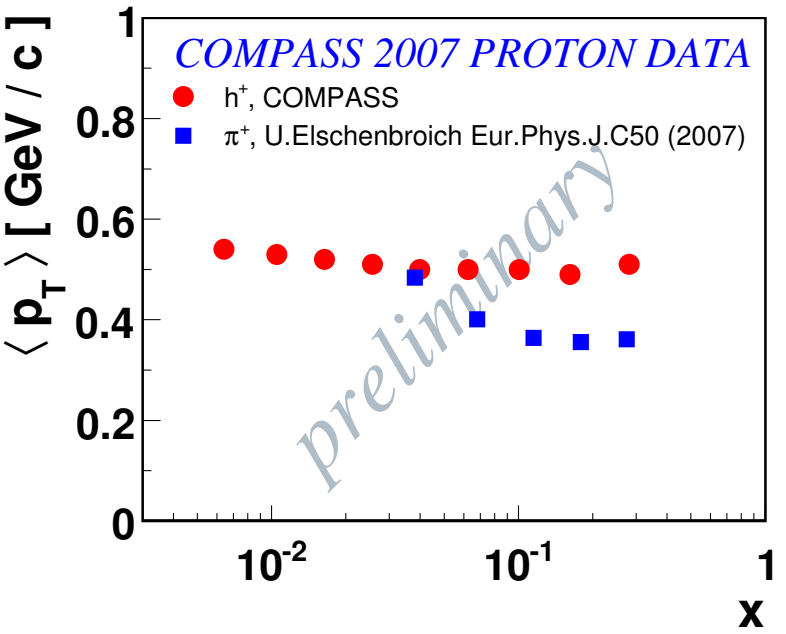

Asymmetry Extraction: Method

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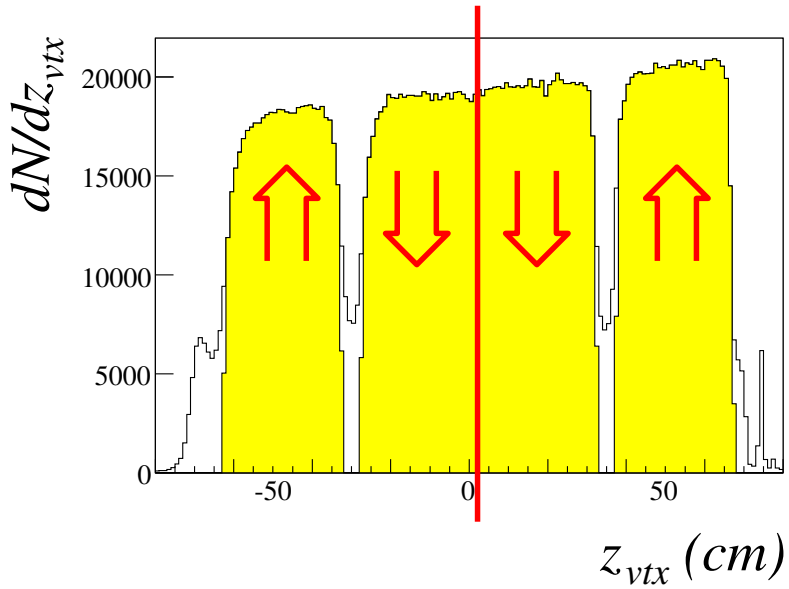
Splitting middle cell into two parts

$\rightsquigarrow$ two couples of cells with opposite polarization

$\rightsquigarrow$ 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 $j = \{1, 2, ..64\}$ one expects number of counts N_j:

$$N_j^{\uparrow\downarrow} = a_j g_j^{\uparrow\downarrow}(\vec{A}),$$

$^{\uparrow\downarrow}$ = sign of target polarization

a_j = acceptance in bin j

$g_j^{\uparrow\downarrow}(\vec{A})$ = all 8 spin dependent modulations of cross-section in bin j

Asymmetry Extraction: Method

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Separation of acceptance and spin dependent modulations:

Coupling of two cells (u,d) with opposite polarization $\uparrow\downarrow$ and two periods (p1,p2) with opposite target polarization:

period 1: $a_{ju}^{\uparrow}$ $a_{jd}^{\downarrow}$

period 2: $a_{ju}^{\downarrow}$ $a_{jd}^{\uparrow}$

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

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

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

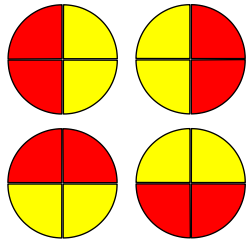
Poisson distribution to account for low statistics: $P_j(\vec{a}) = \frac{e^{-f_j(\vec{a})} f_j(\vec{a})^{N_j}}{N_j!}$

$\rightsquigarrow$ Solution $= \max\left(\prod_{j=1}^{256} P_j(\vec{a})\right)$

Systematic Tests

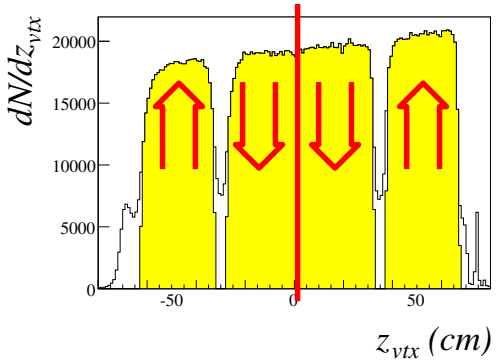
Tests for systematic errors:

- Splitting target volume into sectors:
  - Left / Right
  - Top / Bottom



- Splitting middle cell:

  two asymmetries per double period



- Check for false asymmetries:

  Combination of cells with same polarization

- Comparison of 5 estimators for asymmetry extraction

  1D double ratio (dr), new 1D dr, 2D dr, binned LH, unbinned LH

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

Collins Asymmetry - Proton Data 2007

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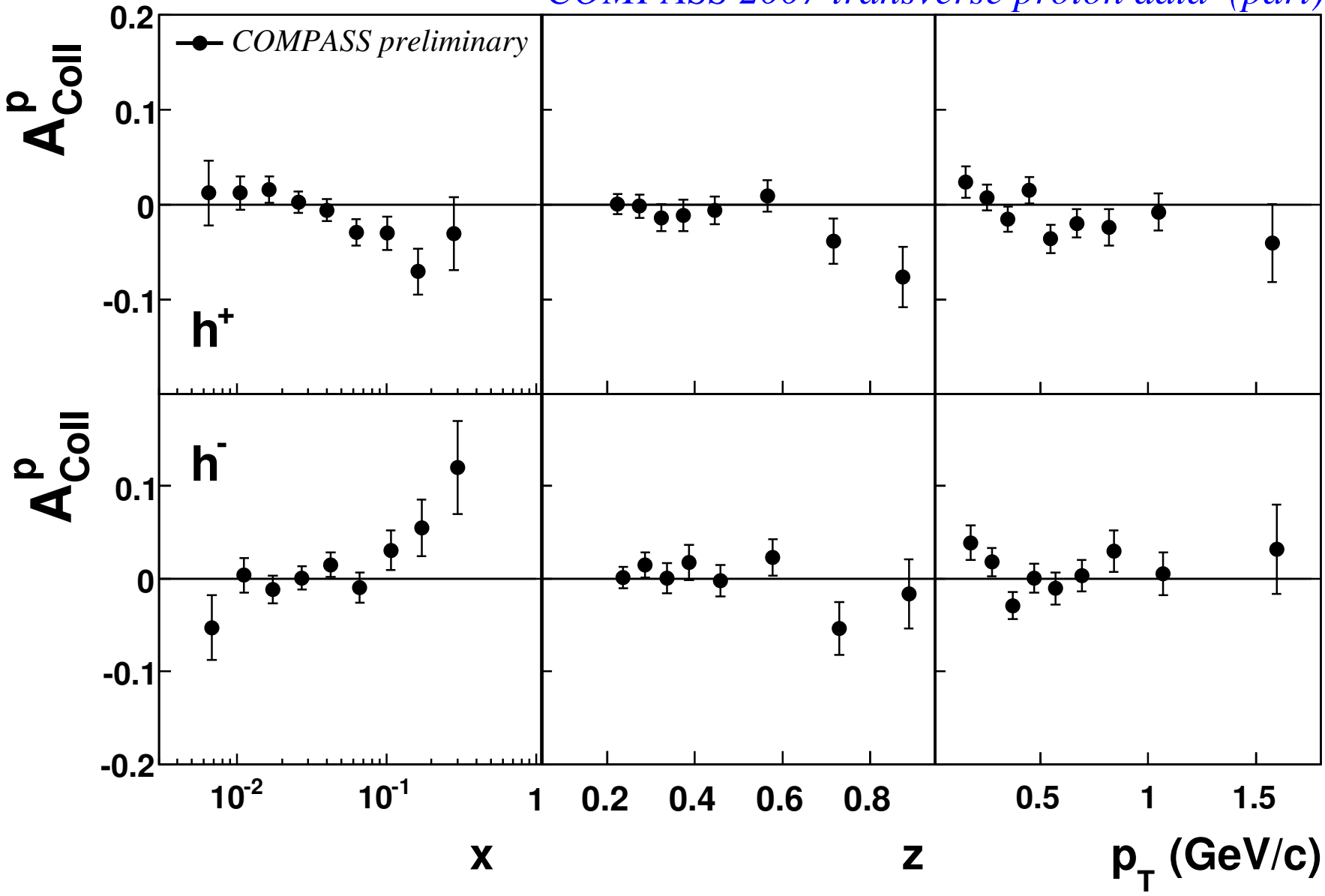
COMPASS 2007 transverse proton data (part)



Collins Asymmetry - Proton Data 2007

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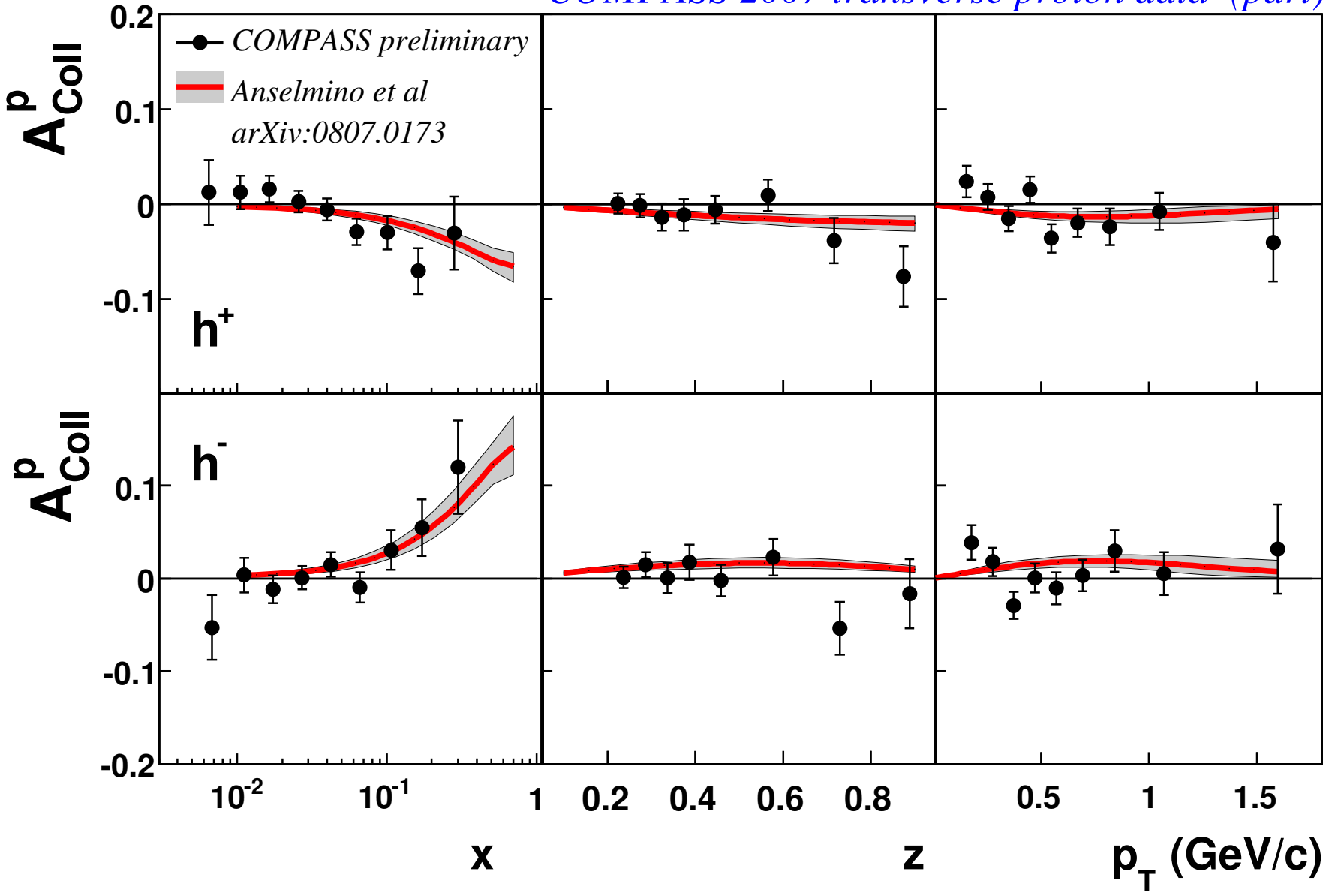

Collins Asymmetrie: $x_{bj} > 0.05$

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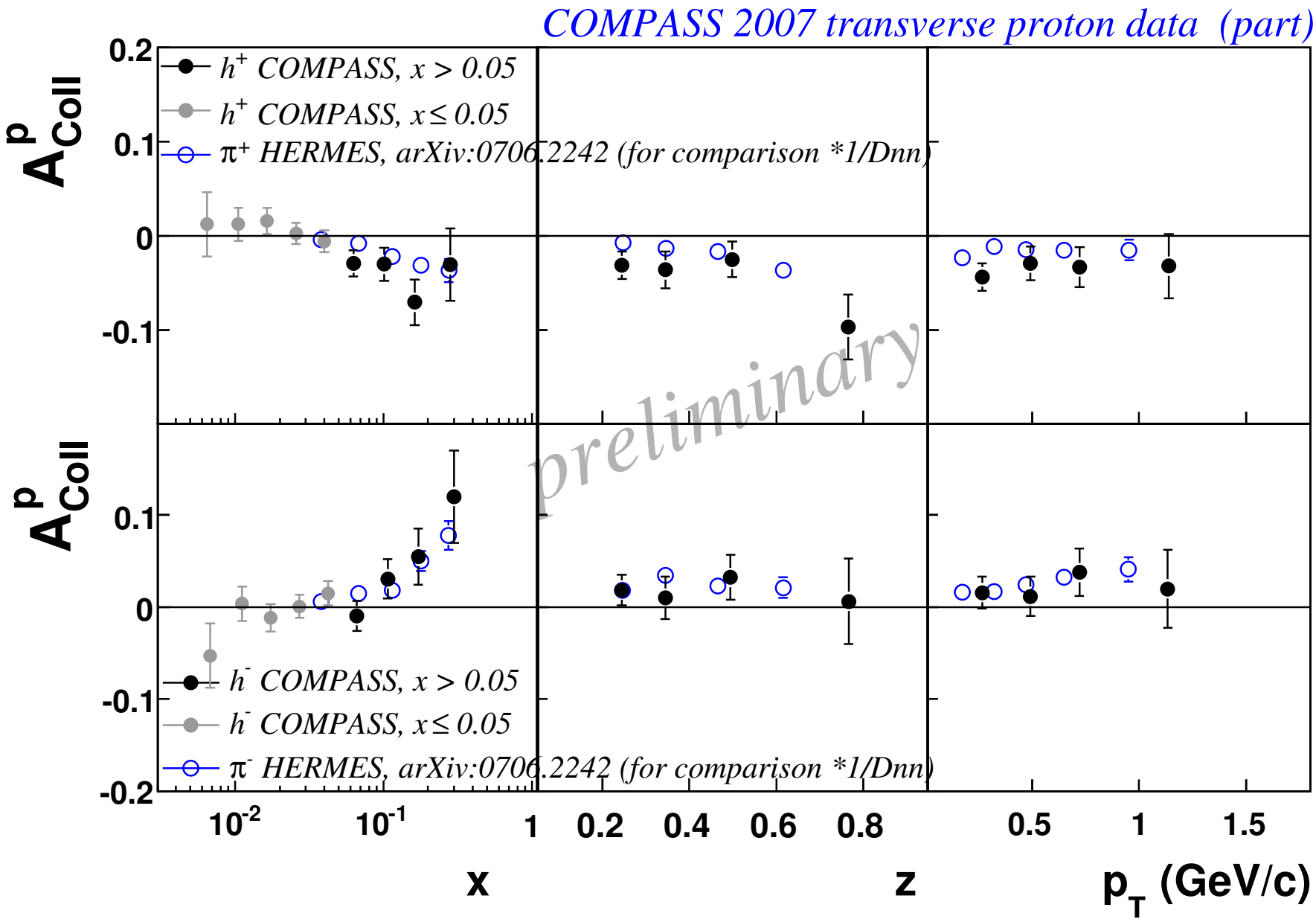

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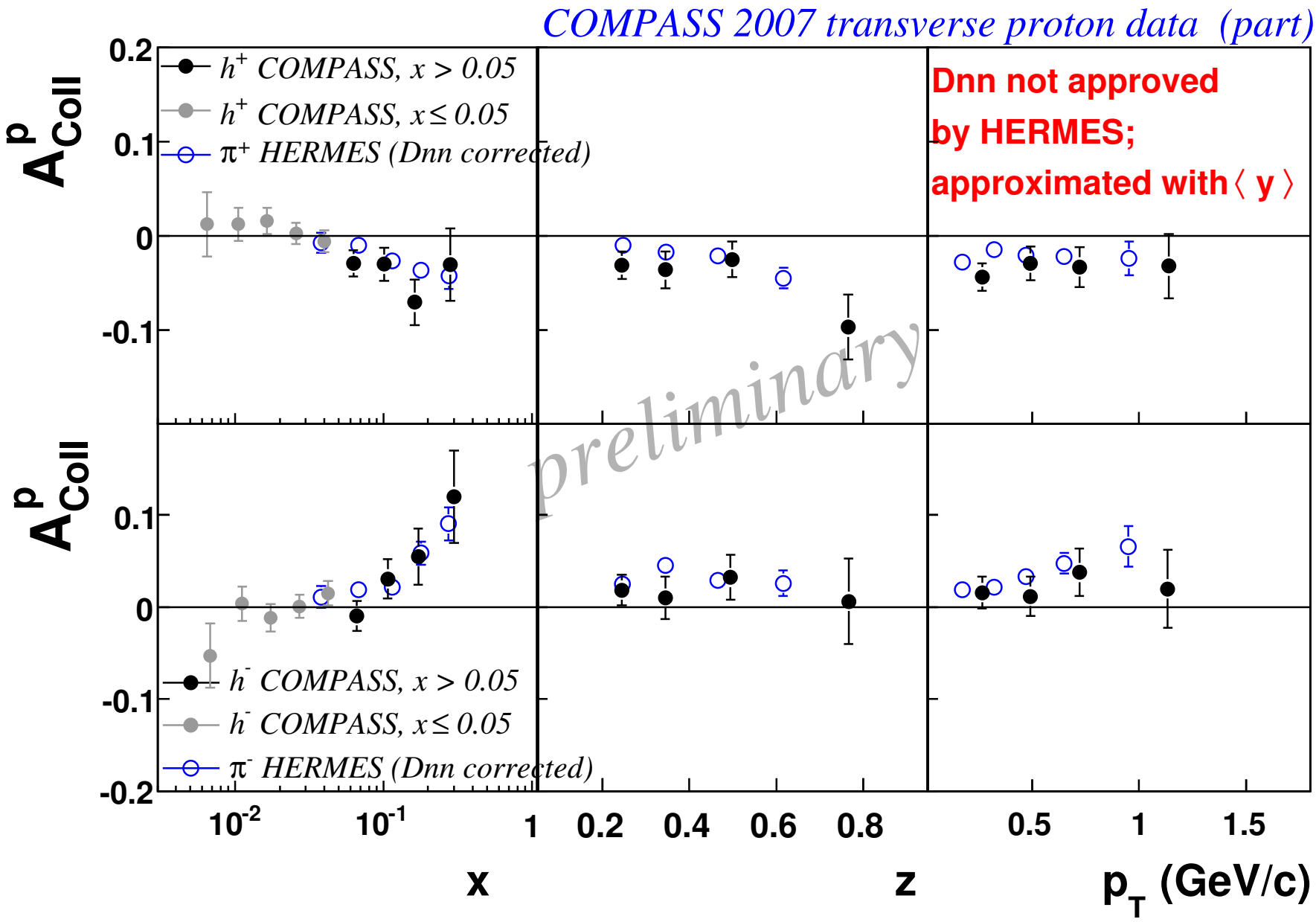

Sivers Asymmetry - Proton Data 2007

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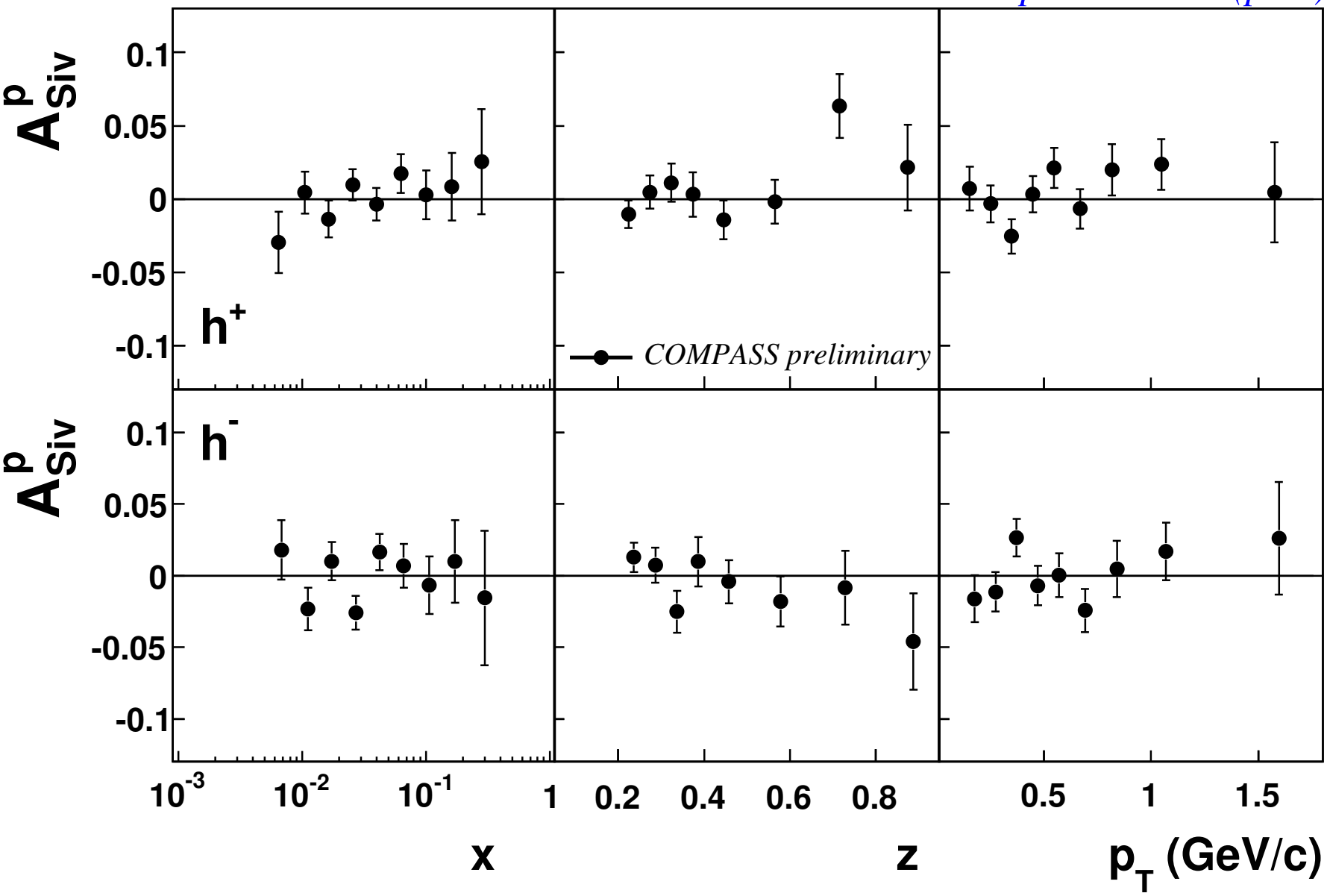
COMPASS 2007 transverse proton data (part)



Sivers Asymmetry - Proton Data 2007

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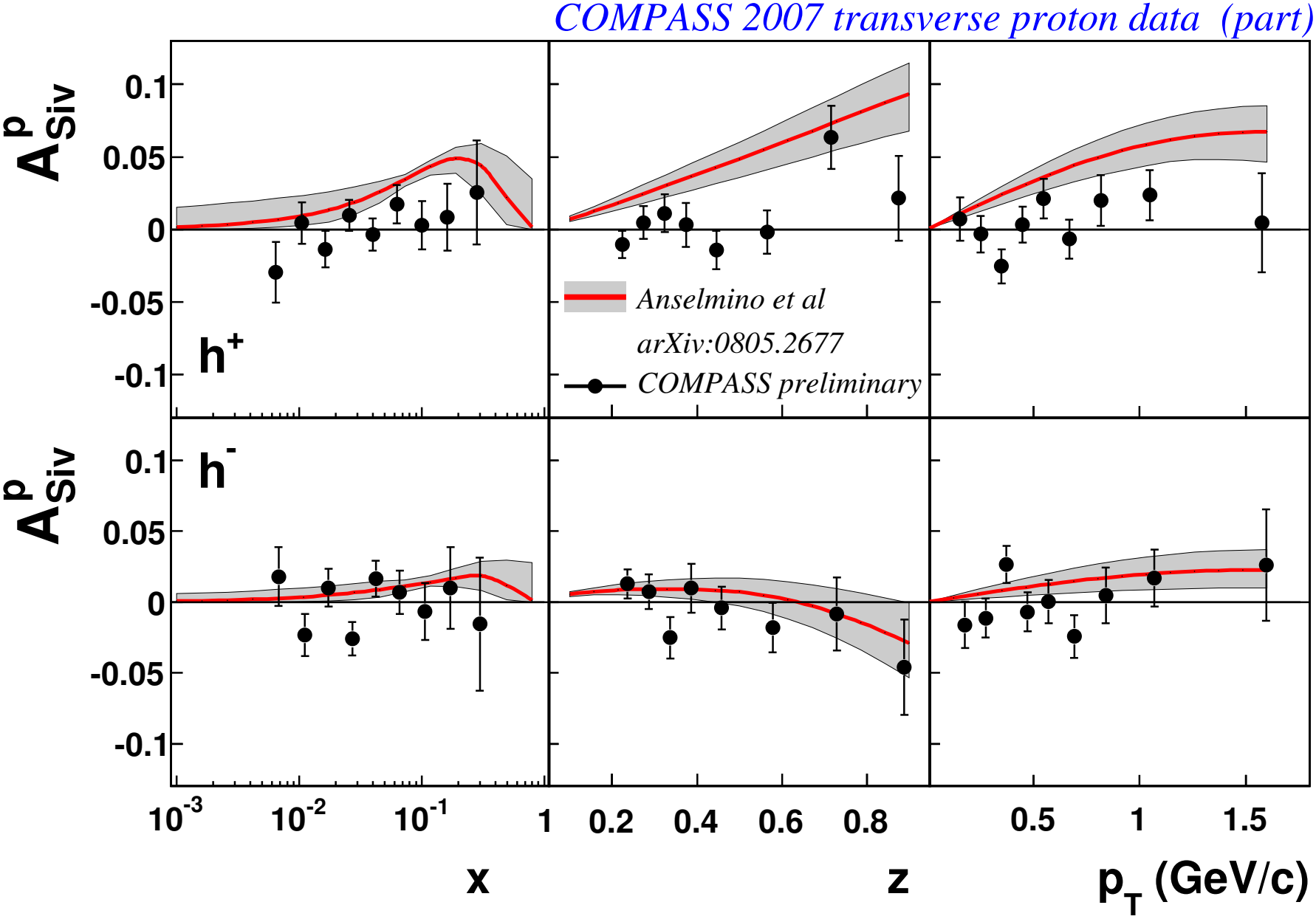

Sivers Asymmetry - Proton Data 2007

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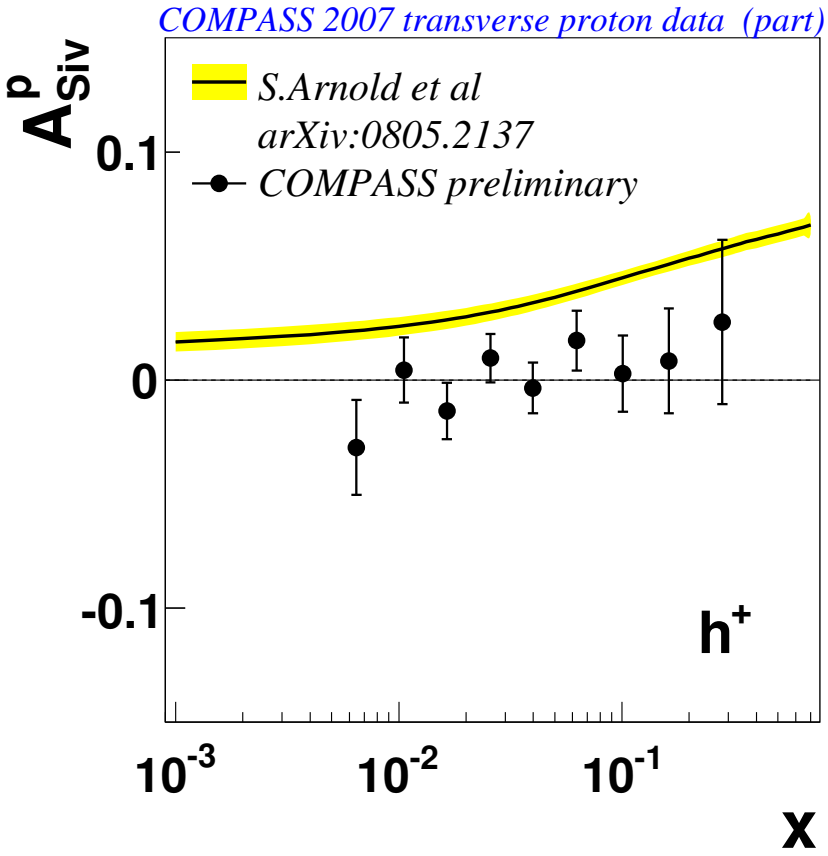

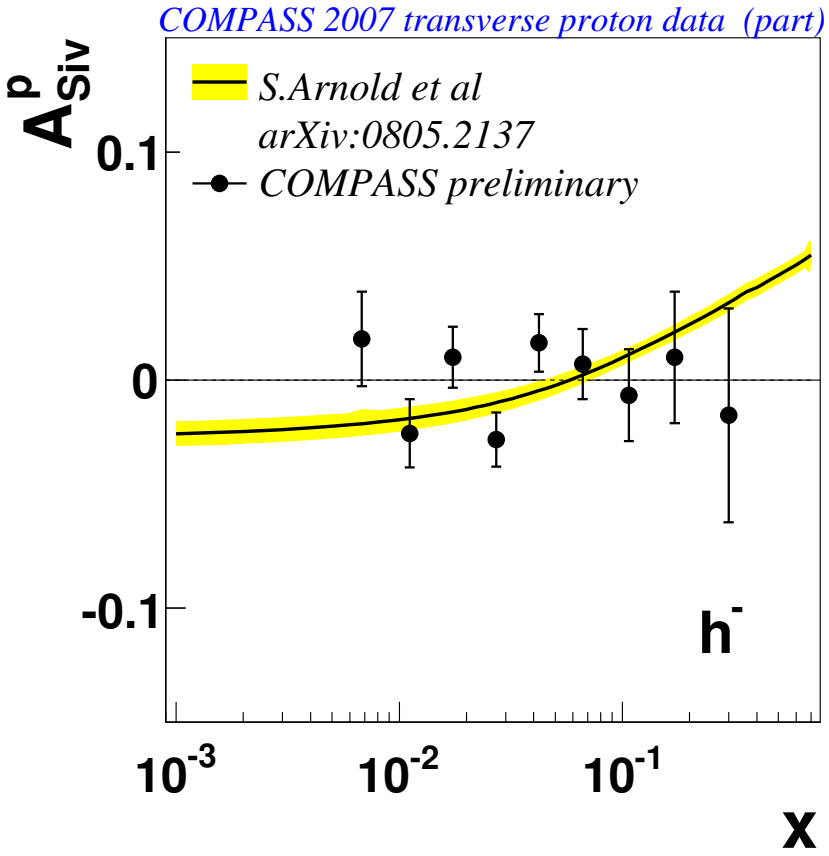

Sivers Asymmetrie: $x_{bj} > 0.05$

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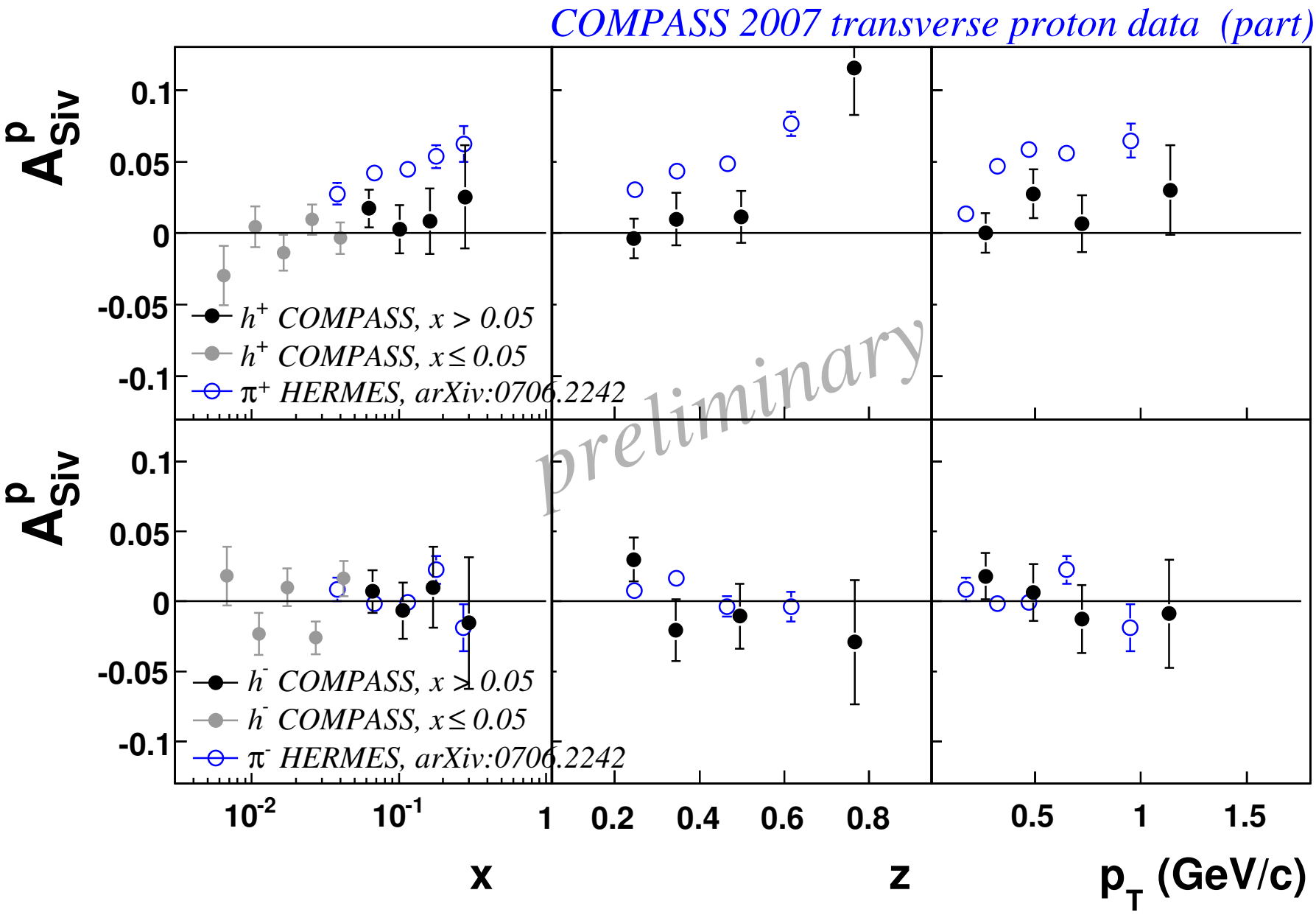

Summary

First preliminary results of COMPASS 2007 proton transverse run:

- **Collins Asymmetry:**
  - different from zero, comparable to HERMES
  - agreement with predictions of Anselmino et al
- **Sivers Asymmetry:**
  - small and compatible with zero within present statistical errors
- **Outlook:**
  - **Analysis of whole data sample**
  - **Identified hadrons**
  - **Hadron pairs**

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Thank You

email: heiner.wollny@cern.ch

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Back Up

Kinematics - Proton Data 2007

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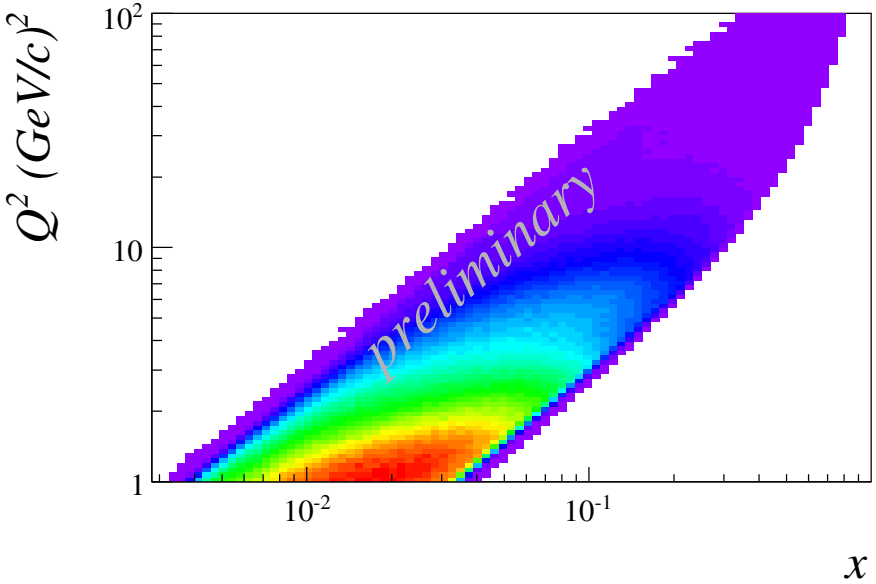

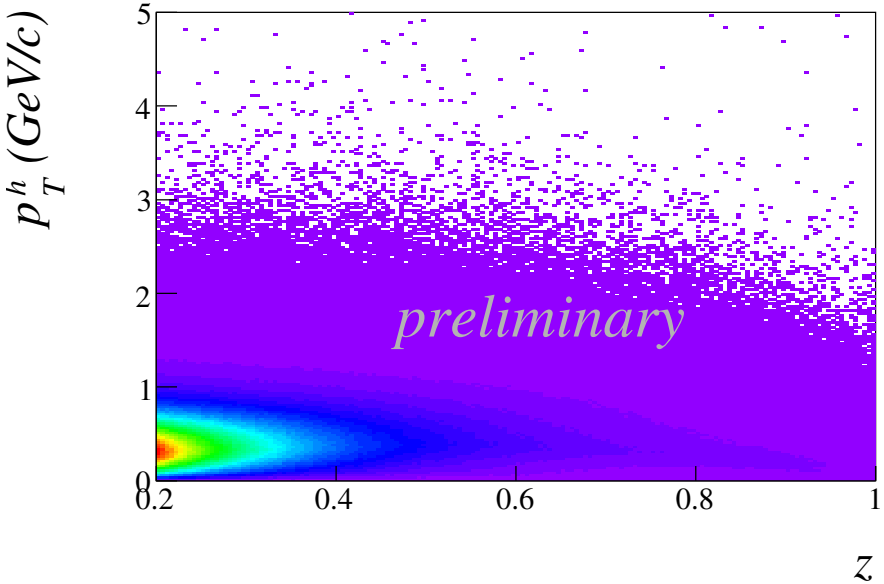

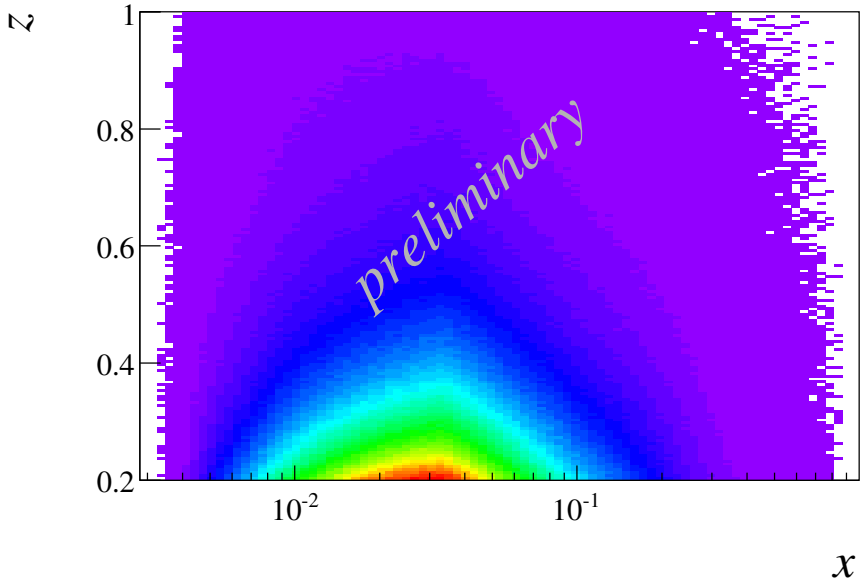

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