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The
COMPASS
spectrometer

The Collins
modulation

The Sivers
modulation

Conclusions

Single Spin asymmetries for identified hadrons at COMPASS

Giulia Pesaro

Trieste University and INFN

on behalf of the **COMPASS Collaboration**

- 1 The COMPASS spectrometer
- 2 The Collins modulation
Charged hadrons
Identified hadrons
- 3 The Sivers modulation
Charged hadrons
Identified hadrons
- 4 Conclusions



The COMPASS spectrometer in 2007



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The COMPASS spectrometer in 2007



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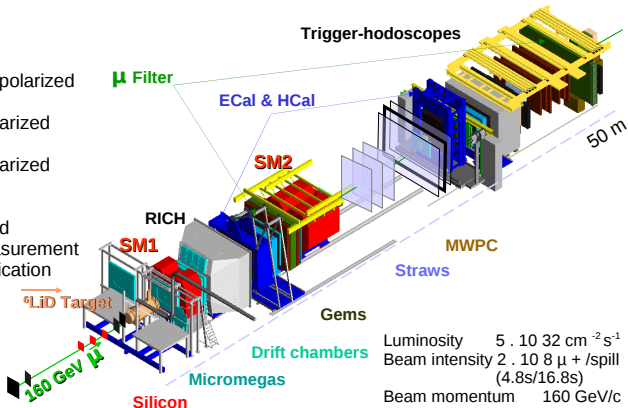
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Conclusions

- Longitudinally polarized muon beam
- 2002-2004 polarized deuteron target
- 2006-2007 polarized ammonia target
- Two stages
- Momentum and calorimetry measurement
- Particle identification (RICH)



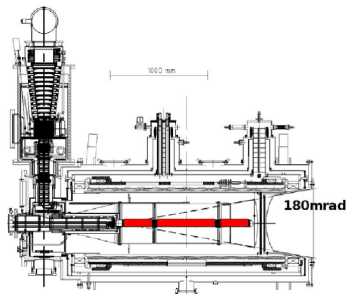
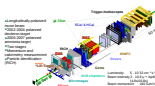
Luminosity	$5 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$
Beam intensity	$2 \cdot 10^8 \mu + / \text{spill}$ (4.8s/16.8s)
Beam momentum	160 GeV/c



The COMPASS spectrometer in 2007



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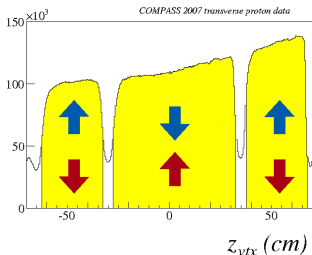


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- 180 mrad geometrical acceptance
- 2007 material NH_3 , polarization: $\sim 90\%$, dilution factor $f \sim 0.15$
- 2002-2004 6LiD , $P \sim 48\%$, $f \sim 0.38$
- very long relaxation time
- target polarization reversed every week

Data selection- DIS cut



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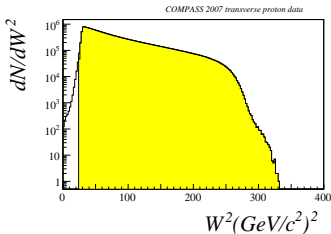
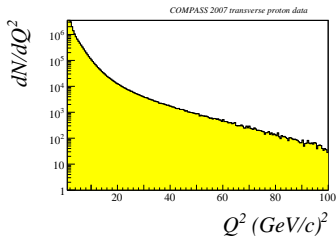
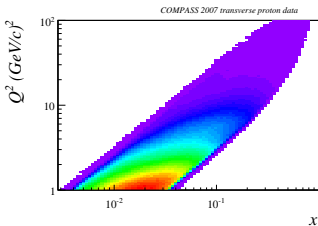


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- $Q^2 > 1$ (GeV/c)²
- $0.1 < y < 0.9$
- $W > 5$ GeV/c²



Data selection- Hadron sample



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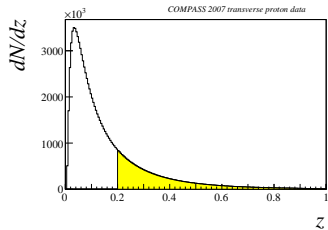
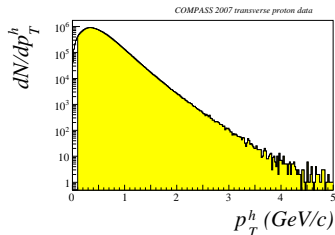
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- $p_T > 0.1 \text{ GeV}/c$
- $z > 0.2$





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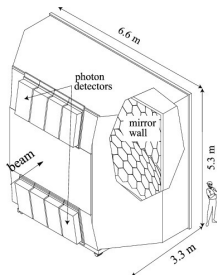
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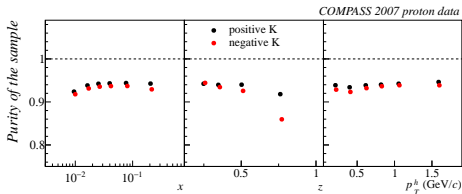
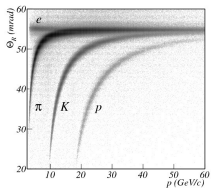
The Sivers
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Hadron identification



- Upgraded in 2005
- likelihood-based algorithm
- $p_{thr}^{\pi} \sim 3 \text{ GeV}/c$
- $p_{thr}^K \sim 9 \text{ GeV}/c$
- $p_{thr}^p \sim 17 \text{ GeV}/c$
- $p_{max}^{2007} = 50 \text{ GeV}/c$
- purity of π sample $> 99\%$





Identified hadrons distributions



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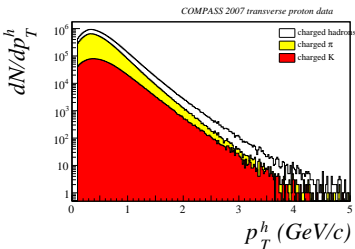
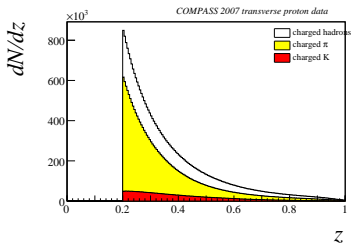
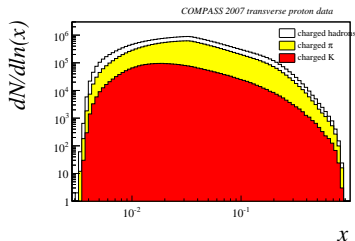
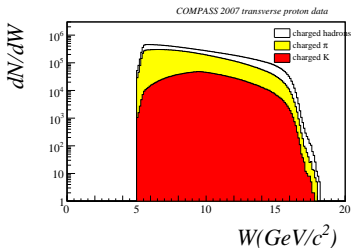


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Deuteron statistics
(2002-2004):

charged hadrons

h^+	8.5M
h^-	7.0M

identified hadrons

π^+	5.2M
π^-	4.5M
K^+	0.9M
K^-	0.6M

Proton statistics
(2007):

charged hadrons

	Collins	Sivers
h^+	15.1M	10.2M
h^-	12.0M	8.1M

identified hadrons

	Collins	Sivers
π^+	9.6M	6.6M
π^-	8.4M	5.8M
K^+	1.7M	1.2M
K^-	1.1M	0.7M



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The structure of the nucleon



At L.O. in the collinear approximation, the nucleon structure can be described by 3 pdf:

		quark		
		U	L	T
nucleon	U	$f_1(x)$ 		
	L		$g_1(x)$ 	
	T			$h_1(x)$

$$h_1(x) = \Delta T_q(x)$$



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Transversity



Transversity DF is chirally odd:

not observable in DIS

observable in SIDIS (via “quark polarimetry”)

In COMPASS following SIDIS channels are measured:

- $\ell N^\uparrow \rightarrow \ell' h X$ (Collins asymmetry): transversity DF is coupled with Collins Fragmentation Function
- $\ell N^\uparrow \rightarrow \ell' h h X$ (pair production): transversity DF is coupled with interference fragmentation function
- $\ell N^\uparrow \rightarrow \ell' \Lambda X$ (Λ polarization): transversity DF is coupled with fragmentation function $q^\uparrow \rightarrow \Lambda$

Results are available both for the deuteron target and for the proton target.



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Results are available both for the deuteron target and for the proton target.

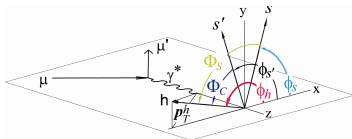
Collins Modulation



Azimuthal distribution of the produced hadrons:

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

\pm refers to the opposite orientation of the spin of the nucleon, P_T is the target polarization and D_{NN} is the spin transfer coefficient from the initial to the struck quark



$$\Phi_C = \phi_h - \phi_{s'} = \phi_h + \phi_s - \pi$$

$$A_{Coll} = \frac{\sum_q e_q^2 h_{1Tq} \Delta_T^0 D_q^h}{\sum_q e_q^2 f_{1q} D_q^h}$$



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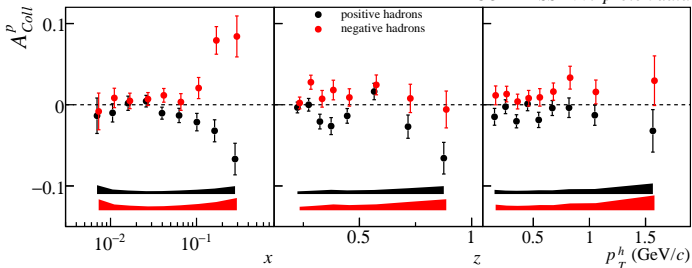
Conclusions

The Collins modulation



PLB 692 (2010)

COMPASS 2007 proton data



$$\sigma_{\text{sys}} \sim 0.5 \sigma_{\text{stat}}$$

Large asymmetry in the valence region



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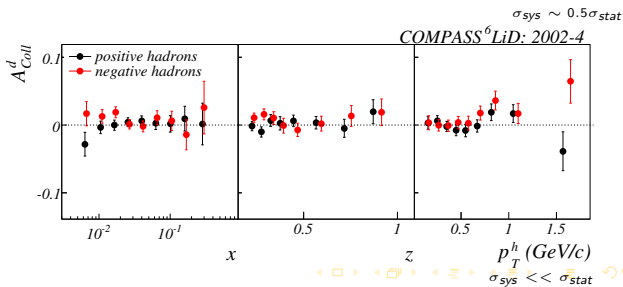
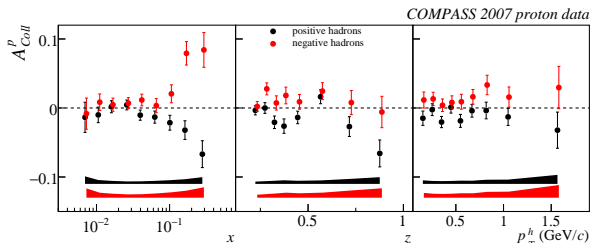
The Collins modulation



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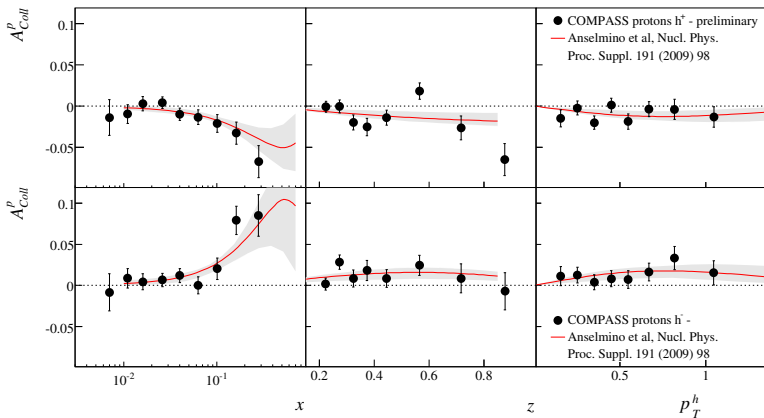
Conclusions

NPB 765
(2007)

The Collins modulation



Comparison with the predictions from the fit to the COMPASS deuteron, HERMES proton SIDIS data and BELLE e^+e^- data:



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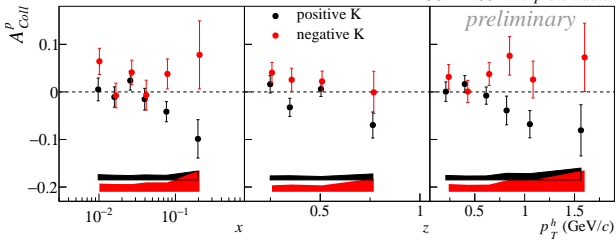
The Sivers
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The Collins modulation, identified π and K

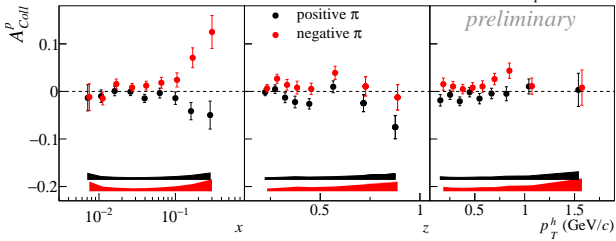


COMPASS 2007 proton data



$K^+, \pi^+ \sim 0.5\sigma_{stat}$, $K^-, \pi^- \sim 0.7\sigma_{stat}$

COMPASS 2007 proton data



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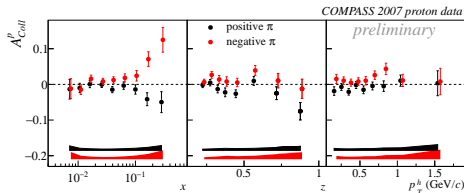
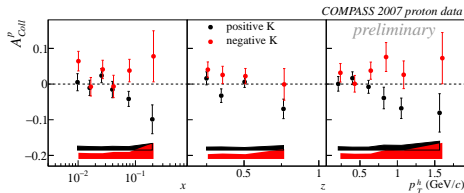
The Sivers
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Conclusions

The Collins modulation, identified π and K



- π strong signal in the valence region
- K^+ negative trend in the valence region
- K^- positive in average
- The K^+ shows some trend to increase as p_T increases.



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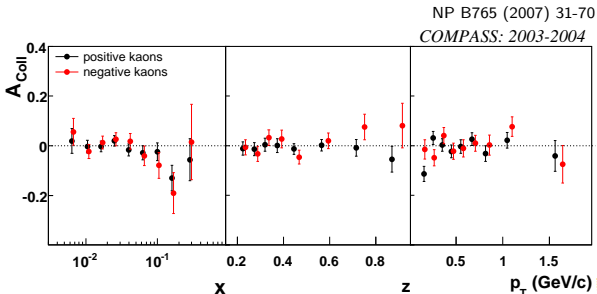
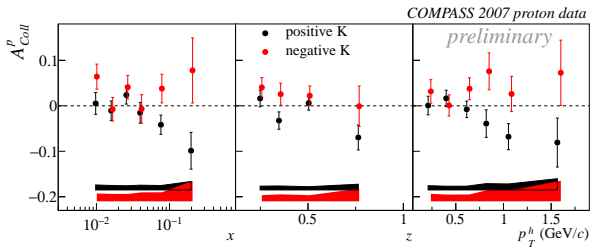
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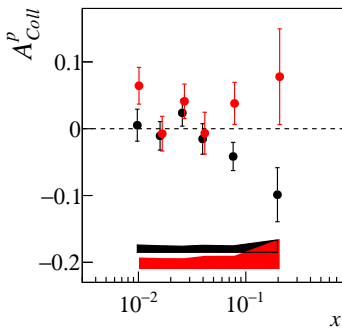
The Collins modulation, identified K



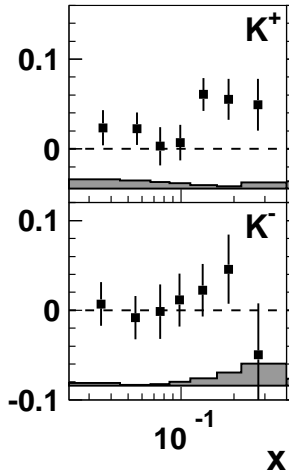
HERMES P.L.B 693 (2010)



- positive K
- negative K



$2 \langle \sin(\phi + \phi_s) \rangle_{UT}^K$



- Opposite sign convention
- Hermes data not D_{nn} corrected



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The structure of the nucleon



Including k_T , 8 functions are needed:

		quark		
		U	L	T
nucleon	U	$f_1(x, k_T)$		$h_1^\perp(x, k_T)$ Boer-Mulders
	L		$g_1(x, k_T)$	$h_{1L}(x, k_T)$ Worm-gear 1
	T	$f_{1T}^\perp(x, k_T)$ Sivers	$g_{1T}(x, k_T)$ Worm-gear 2	$h_{1T}(x, k_T)$ Transversity $h_{1T}^\perp(x, k_T)$ Pretzelosity

all measurable in SIDIS

See also G.Sbrizzai and B.Parsamyan and A. Efremov talks!

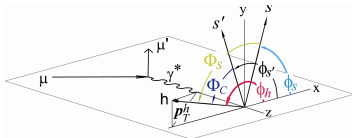
Sivers Modulation



Azimuthal distribution of the produced hadrons:

$$N_h^\pm(\Phi_S) = N_h^0 \left(1 \pm P_T A_{Sivers} \sin(\Phi_S) \right)$$

\pm refers to the opposite orientation of the spin of the nucleon, P_T is the target polarization



$$\Phi_S = \phi_h - \phi_s$$

$$A_{Sivers} = \frac{\sum_q e_q^2 f_{1Tq}^\perp D_q^h}{\sum_q e_q^2 f_{1q} D_q^h}$$

f_{1Tq}^\perp = **Sivers Distribution Function**: correlation between the intrinsic transverse momentum of unpolarized quarks and the spin in a transversely polarized nucleon.



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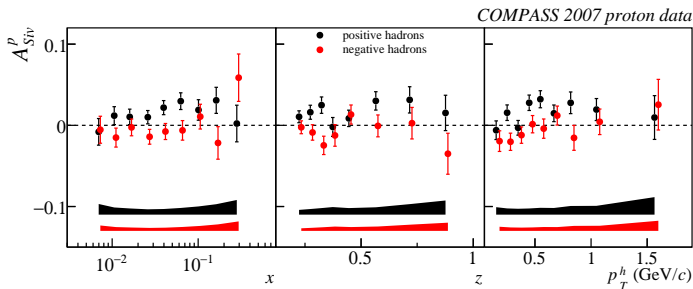
Charged hadrons
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Conclusions

The Sivers modulation



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$$h^- \sigma_{sys} \sim 0.5 \sigma_{stat}, h^+ \sigma_{sys} \sim 0.8 \sigma_{stat}, h^+ \text{ scale uncertainty } \pm 0.01 \text{ (abs.)}$$

- positive signal for h^+
- h^- asymmetry compatible with zero



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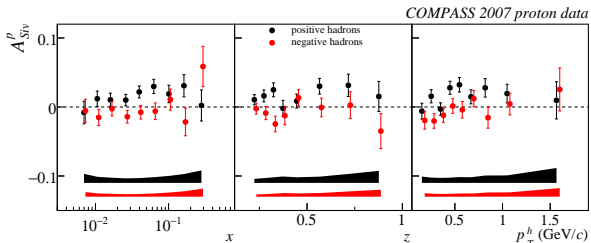
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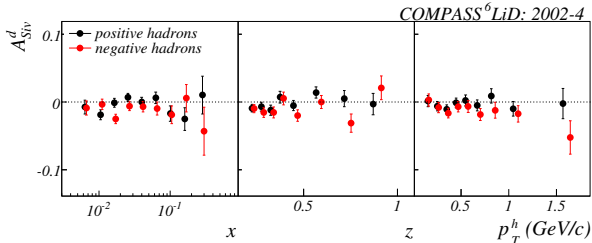
Conclusions

The Siverts modulation



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$$h^- \sigma_{sys} \sim 0.5 \sigma_{stat}, h^+ \sigma_{sys} \sim 0.8 \sigma_{stat}, h^+ \text{ scale uncertainty } \pm 0.01 \text{ (abs.)}$$



NP B765
(2007)



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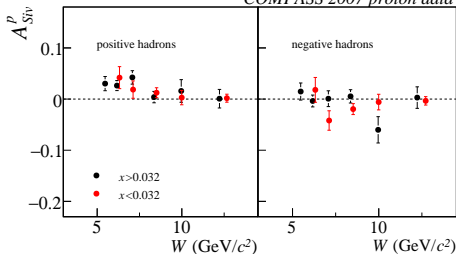


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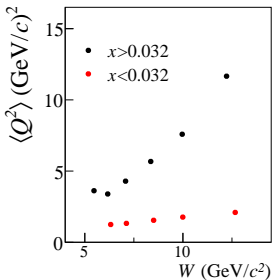
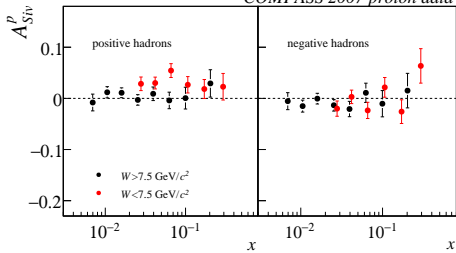


- h^+ asymmetry concentrated at small W

COMPASS 2007 proton data



COMPASS 2007 proton data



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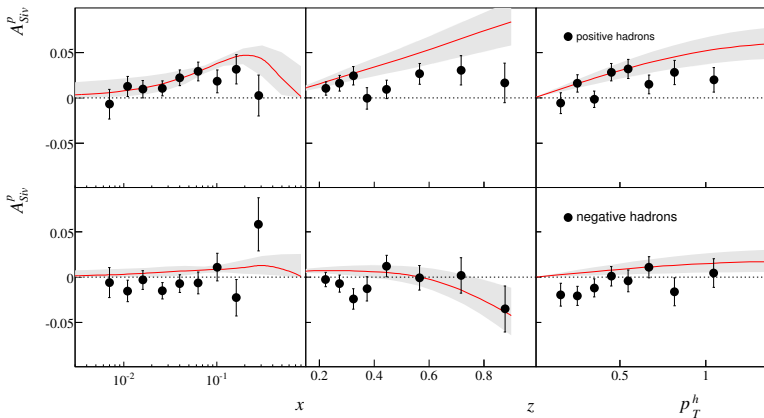
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Comparison with the predictions from the fit to the COMPASS deuteron, HERMES proton SIDIS data:



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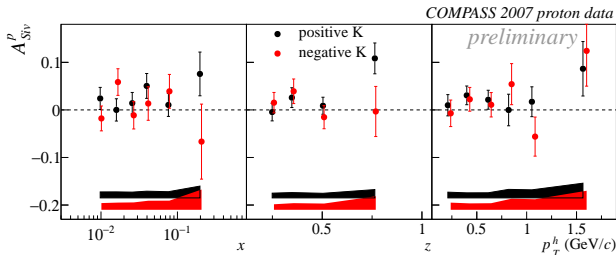
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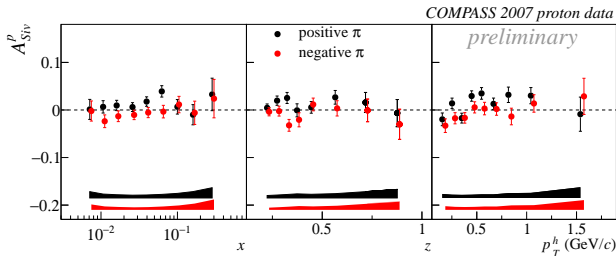
Charged hadrons
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Conclusions

The Siverts modulation, identified π and K



$K^+, K^-, \pi^- \sim 0.5\sigma_{stat}$, $\pi^+ \sim 0.6\sigma_{stat}$, π^+ scale uncertainty ± 0.012 (abs.)



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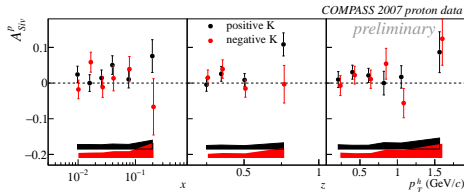
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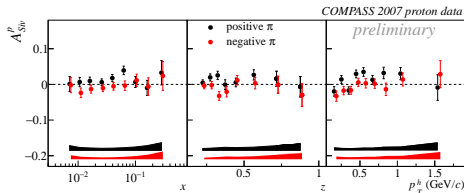
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- K^+ positive in average
- K^- asymmetry is compatible with 0



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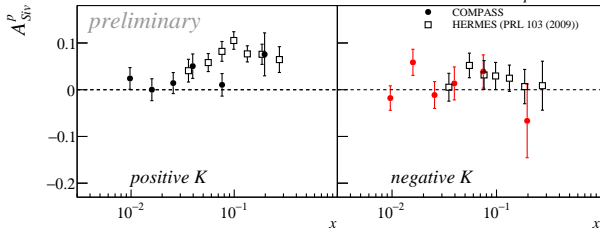
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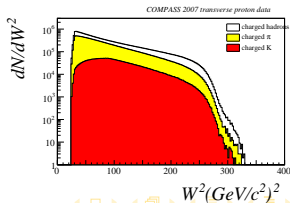
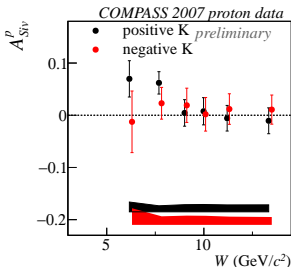
The Siverts modulation, identified K



COMPASS 2007 proton data



The Siverts asymmetry shows a clear signal at small values of W for K^+



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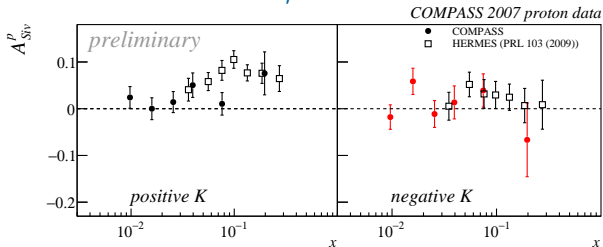
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The Siverts modulation, identified K



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The
COMPASS
spectrometer

The Collins
modulation

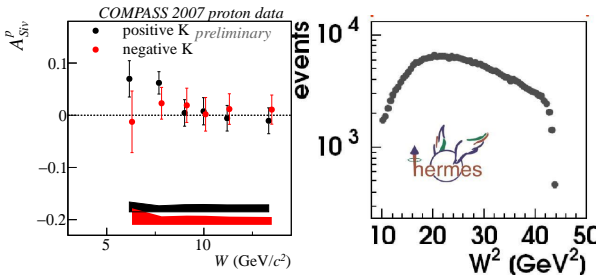
The Siverts
modulation

Charged hadrons
Identified
hadrons

Conclusions



The Siverts asymmetry shows a clear signal at small values of W for K^+





The Siverts modulation, identified K



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Comparison with the predictions from the fit to the COMPASS
deuteron, HERMES proton SIDIS data:



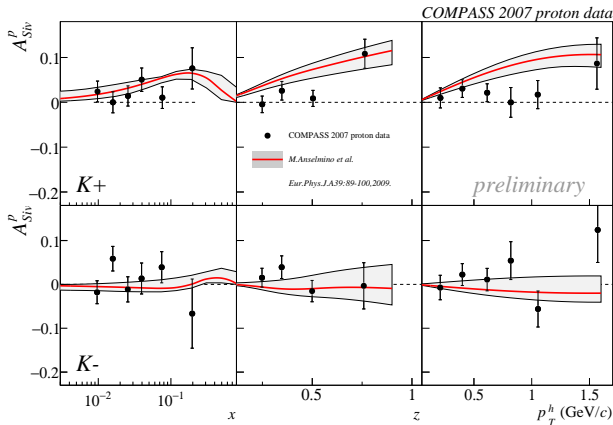
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Conclusions



2007 transverse data analysis is finalized:

- Large Collins asymmetry
- Sivers asymmetry different from zero
- Sivers asymmetry concentrated at small W

- possible dependence of K^+ Collins asymmetry on p_T
- Sivers asymmetry for K^+ larger than for h^+
- Sivers asymmetry or K^+ concentrated at small W

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(2010)



2010 transverse data taking is ongoing!



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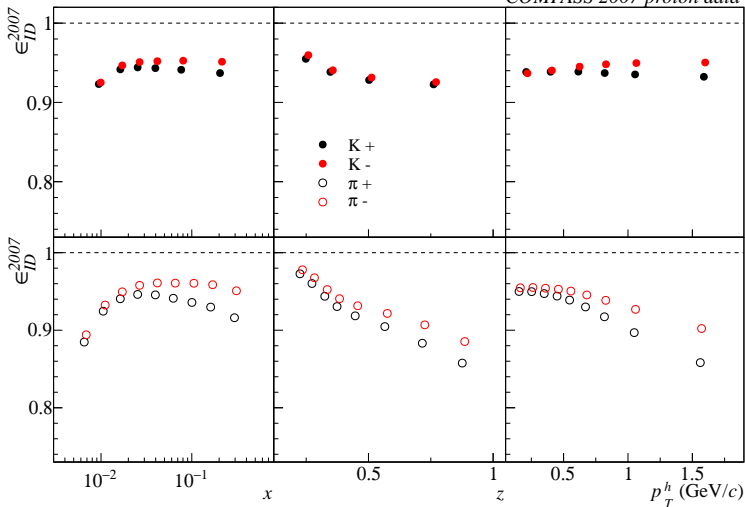
Conclusions

Backup

RICH efficiency 2007



COMPASS 2007 proton data



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Purity correction



$$N_{ID} = N_K^T + N_\pi^T$$
$$A_K = \frac{a_K N_K^T + a_\pi N_\pi^T}{N_{ID}} = a_K P_K + a_\pi (1 - P_K)$$
$$A_\pi = \frac{a_\pi N_\pi^T + a_K N_K^T}{N_{ID}} = a_\pi P_\pi + a_K (1 - P_\pi)$$

$$P_K > 0.9, P_\pi \sim 1:$$
$$a_K = \frac{1}{0.9} [A_K - 0.1 A_\pi]$$



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$$a_K = \frac{1}{0.9} [A_K - 0.1A_\pi]$$

● positive K

● negative K

● positive π

● negative π

