Recent results on transverse spin effects at COMPASS

Giulia Pesaro
Trieste University and INFN
on behalf of the COMPASS Collaboration

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Transversity

Three distribution functions are necessary to describe the spin structure of the nucleon at twist two level:

q(x) 

momentum distribution $q(x)$ or $f_1(x)$: probability of finding a quark with a fraction x of nucleon momentum.

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Transversity

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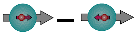
Δq(x) 

helicity distribution $\Delta q(x)$ or $g_1(x)$: probability of finding a quark with spin parallel to nucleon spin in a longitudinally polarized nucleon.

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Transversity

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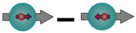
Δq(x)



helicity distribution $\Delta q(x)$ or $g_1(x)$: probability of finding a quark with spin parallel to nucleon spin in a longitudinally polarized nucleon.

Δ_Tq(x)

transversity distribution $\Delta_T q(x)$ or $h_1(x)$: probability of finding a quark with spin parallel to nucleon spin in a transversely polarized nucleon.

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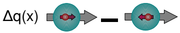
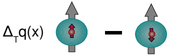
Transversity

Three distribution functions are necessary to describe the spin structure of the nucleon at twist two level:

momentum distribution $q(x)$ or $f_1(x)$: probability of finding a quark with a fraction x of nucleon momentum.



helicity distribution $\Delta q(x)$ or $g_1(x)$: probability of finding a quark with spin parallel to nucleon spin in a longitudinally polarized nucleon.



transversity distribution $\Delta_T q(x)$ or $h_1(x)$: probability of finding a quark with spin parallel to nucleon spin in a transversely polarized nucleon.

Transversity

Transversity DF is chirally odd:

not observable in inclusive 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 on deuteron and proton data measured at COMPASS are available for all channels.

SIDIS cross section

$$\frac{d\sigma}{dx\,dy\,dz\,d\phi_h\,dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{ F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} + \epsilon\cos(2\phi_h)F_{UU}^{\cos 2\phi_h} + P_{\mathrm{beam}}\sqrt{2\epsilon(1-\epsilon)}\sin\phi_h F_{LU}^{\sin\phi_h} + P_L\left[\sqrt{2\epsilon(1+\epsilon)}\sin\phi_h F_{UL}^{\sin\phi_h} + \epsilon\sin(2\phi_h)F_{UL}^{\sin(2\phi_h}\right] + P_L P_{\mathrm{beam}}\left[\sqrt{1-\epsilon^2}F_{LL} + \sqrt{2\epsilon(1-\epsilon)}\cos\phi_h F_{LL}^{\cos\phi_h}\right] + |P_T|\Big[\sin(\phi_h-\phi_S)\big(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\big) + \epsilon\sin(\phi_h+\phi_S)F_{UT}^{\sin(\phi_h+\phi_S)} + \epsilon\sin(3\phi_h-\phi_S)F_{UT}^{\sin(3\phi_h-\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\sin\phi_S F_{UT}^{\sin\phi_S} + \sqrt{2\epsilon(1+\epsilon)}\sin(2\phi_h-\phi_S)F_{UT}^{\sin(2\phi_h-\phi_S)}\Big] + |P_T|P_{\mathrm{beam}}\Big[\sqrt{1-\epsilon^2}\cos(\phi_h-\phi_S)F_{LT}^{\cos(\phi_h-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos\phi_S F_{LT}^{\cos\phi_S} + \sqrt{2\epsilon(1-\epsilon)}\cos(2\phi_h-\phi_S)F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\}$$

JHEP 0702:093,2007

Complete SIDIS cross section contains several modulations:

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SIDIS cross section

$$
\begin{aligned}
\frac{d\sigma}{dx\,dy\,dz\,d\phi_h\,dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{ & F_{UU,T}+\epsilon F_{UU,L} \\
& +\sqrt{2\epsilon(1+\epsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} \\
& +\epsilon\cos(2\phi_h)F_{UU}^{\cos 2\phi_h} + P_{\rm beam}\sqrt{2\epsilon(1-\epsilon)}\sin\phi_h F_{LU}^{\sin\phi_h} \\
& +P_L\left[\sqrt{2\epsilon(1+\epsilon)}\sin\phi_h F_{UL}^{\sin\phi_h}+\epsilon\sin(2\phi_h)F_{UL}^{\sin(2\phi_h}\right] \\
& +P_L P_{\rm beam}\left[\sqrt{1-\epsilon^2}F_{LL}+\sqrt{2\epsilon(1-\epsilon)}\cos\phi_h F_{LL}^{\cos\phi_h}\right] \\
& +|P_T|\Big[\sin(\phi_h-\phi_S)\big(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\epsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\big) \\
& +\epsilon\sin(\phi_h+\phi_S)F_{UT}^{\sin(\phi_h+\phi_S)}+\epsilon\sin(3\phi_h-\phi_S)F_{UT}^{\sin(3\phi_h-\phi_S)} \\
& +\sqrt{2\epsilon(1+\epsilon)}\sin\phi_S F_{UT}^{\sin\phi_S} \\
& +\sqrt{2\epsilon(1+\epsilon)}\sin(2\phi_h-\phi_S)F_{UT}^{\sin(2\phi_h-\phi_S)}\Big] \\
& +|P_T|P_{\rm beam}\Big[\sqrt{1-\epsilon^2}\cos(\phi_h-\phi_S)F_{LT}^{\cos(\phi_h-\phi_S)} \\
& +\sqrt{2\epsilon(1-\epsilon)}\cos\phi_S F_{LT}^{\cos\phi_S} \\
& +\sqrt{2\epsilon(1-\epsilon)}\cos(2\phi_h-\phi_S)F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\}
\end{aligned}
$$

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Complete SIDIS cross section contains several modulations:

- 3 unpolarized modulations

SIDIS cross section

$$
\begin{aligned}
\frac{d\sigma}{dx\,dy\,dz\,d\phi_h\,dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{ & \\
& F_{UU,T} + \epsilon F_{UU,L} \\
& + \sqrt{2\epsilon(1+\epsilon)}\,\cos\phi_h F_{UU}^{\cos\phi_h} \\
+ \epsilon\cos(2\phi_h) F_{UU}^{\cos 2\phi_h} + P_{\rm beam}\sqrt{2\epsilon(1-\epsilon)}\,\sin\phi_h F_{LU}^{\sin\phi_h} & \\
+ P_L\left[\sqrt{2\epsilon(1+\epsilon)}\,\sin\phi_h F_{UL}^{\sin\phi_h} + \epsilon\sin(2\phi_h) F_{UL}^{\sin(2\phi_h}\right] & \\
+ P_L P_{\rm beam}\left[\sqrt{1-\epsilon^2}\,F_{LL} + \sqrt{2\epsilon(1-\epsilon)}\,\cos\phi_h F_{LL}^{\cos\phi_h}\right] & \\
+ |P_T|\Big[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\right) & \\
+ \epsilon\sin(\phi_h+\phi_S) F_{UT}^{\sin(\phi_h+\phi_S)} + \epsilon\sin(3\phi_h-\phi_S) F_{UT}^{\sin(3\phi_h-\phi_S)} & \\
& + \sqrt{2\epsilon(1+\epsilon)}\,\sin\phi_S F_{UT}^{\sin\phi_S} \\
& + \sqrt{2\epsilon(1+\epsilon)}\,\sin(2\phi_h-\phi_S) F_{UT}^{\sin(2\phi_h-\phi_S)}\Big] \\
+ |P_T| P_{\rm beam}\Big[\sqrt{1-\epsilon^2}\,\cos(\phi_h-\phi_S) F_{LT}^{\cos(\phi_h-\phi_S)} & \\
& + \sqrt{2\epsilon(1-\epsilon)}\,\cos\phi_S F_{LT}^{\cos\phi_S} \\
& + \sqrt{2\epsilon(1-\epsilon)}\,\cos(2\phi_h-\phi_S) F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\}
\end{aligned}
$$

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Complete SIDIS cross section contains several modulations:

- 3 unpolarized modulations
- 8 target transverse spin dependent modulations.

SIDIS cross section

$$
\begin{aligned}
\frac{d\sigma}{dx\,dy\,dz\,d\phi_h\,dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{ & \\
& F_{UU,T} + \epsilon F_{UU,L} \\
& + \sqrt{2\epsilon(1+\epsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} \\
& + \epsilon\cos(2\phi_h) F_{UU}^{\cos 2\phi_h} + P_{\text{beam}}\sqrt{2\epsilon(1-\epsilon)}\sin\phi_h F_{LU}^{\sin\phi_h} \\
& + P_L\left[\sqrt{2\epsilon(1+\epsilon)}\sin\phi_h F_{UL}^{\sin\phi_h} + \epsilon\sin(2\phi_h) F_{UL}^{\sin(2\phi_h}\right] \\
& + P_L P_{\text{beam}}\left[\sqrt{1-\epsilon^2}F_{LL} + \sqrt{2\epsilon(1-\epsilon)}\cos\phi_h F_{LL}^{\cos\phi_h}\right] \\
& + |P_T|\Big[\sin(\phi_h-\phi_S)\big(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\big) \\
& + \epsilon\sin(\phi_h+\phi_S) F_{UT}^{\sin(\phi_h+\phi_S)} + \epsilon\sin(3\phi_h-\phi_S) F_{UT}^{\sin(3\phi_h-\phi_S)} \\
& + \sqrt{2\epsilon(1+\epsilon)}\sin\phi_S F_{UT}^{\sin\phi_S} \\
& + \sqrt{2\epsilon(1+\epsilon)}\sin(2\phi_h-\phi_S) F_{UT}^{\sin(2\phi_h-\phi_S)}\Big] \\
& + |P_T| P_{\text{beam}}\Big[\sqrt{1-\epsilon^2}\cos(\phi_h-\phi_S) F_{LT}^{\cos(\phi_h-\phi_S)} \\
& + \sqrt{2\epsilon(1-\epsilon)}\cos\phi_S F_{LT}^{\cos\phi_S} \\
& + \sqrt{2\epsilon(1-\epsilon)}\cos(2\phi_h-\phi_S) F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\}
\end{aligned}
$$

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Complete SIDIS cross section contains several modulations:

- 3 unpolarized modulations
- 8 target transverse spin dependent modulations.
- all measured at COMPASS on deuterium

The COMPASS spectrometer in 2007

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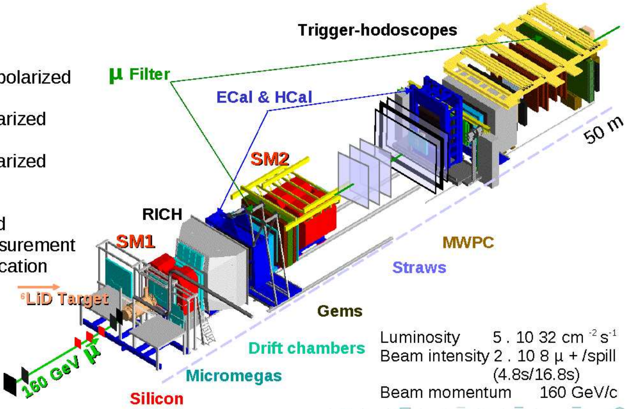
The COMPASS spectrometer in 2007

- 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 . 10 32 cm $^{-2}$ s^{-1}
Beam intensity 2 . 10 8 μ + /spill (4.8s/16.8s)
Beam momentum 160 GeV/c

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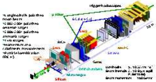
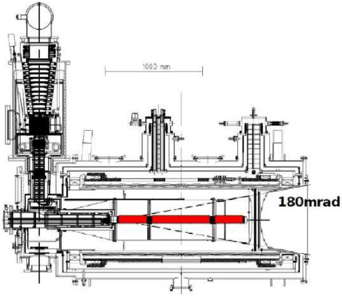
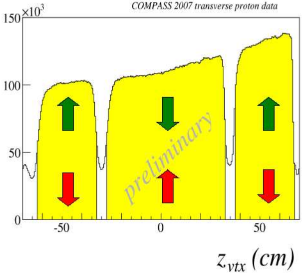
The COMPASS spectrometer in 2007







- 180 *mrad* geometrical acceptance
- material NH_3
- high polarization: $\sim 90\%$
- dilution factor $f \sim 0.15$
- very long relaxation time
- target polarization reversed every week

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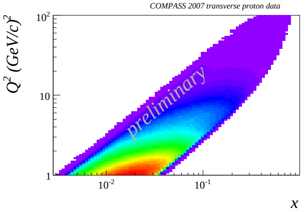
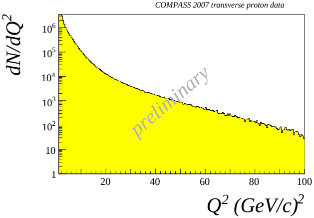
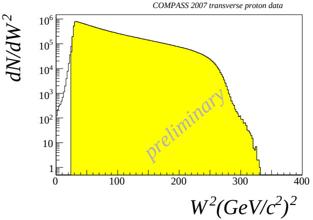
Data selection



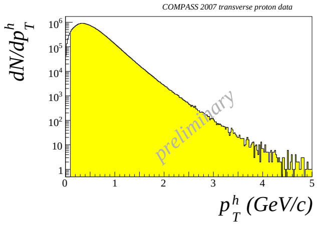


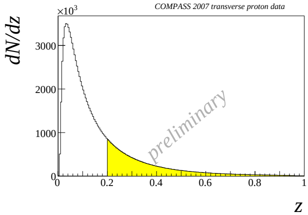


- $Q^2 > 1\ (GeV/c)^2$
- $0.1 < y < 0.9$
- $W > 5\ GeV/c^2$

Data selection- single hadron asymmetries

- $p_T > 0.1\ GeV/c$
- $z > 0.2$





SIDIS cross section-Collins asymmetry

$$\frac{d\sigma}{dx\,dy\,dz\,d\phi_h\,dP^2_{h\perp}} = \frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{$$

$$F_{UU,T} + \epsilon F_{UU,L}$$

$$+\sqrt{2\epsilon(1+\epsilon)}\cos\phi_h F_{UU}^{\cos\phi_h}$$

$$+\epsilon\cos(2\phi_h)F_{UU}^{\cos 2\phi_h} + P_{\text{beam}}\sqrt{2\epsilon(1-\epsilon)}\sin\phi_h F_{LU}^{\sin\phi_h}$$

$$+P_L\left[\sqrt{2\epsilon(1+\epsilon)}\sin\phi_h F_{UL}^{\sin\phi_h} + \epsilon\sin(2\phi_h)F_{UL}^{\sin(2\phi_h)}\right]$$

$$+P_L P_{\text{beam}}\left[\sqrt{1-\epsilon^2}F_{LL} + \sqrt{2\epsilon(1-\epsilon)}\cos\phi_h F_{LL}^{\cos\phi_h}\right]$$

$$+|P_T|\Big[\sin(\phi_h-\phi_S)\big(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\big)$$

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

$$+\sqrt{2\epsilon(1+\epsilon)}\sin\phi_S F_{UT}^{\sin\phi_S}$$

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

$$+|P_T|P_{\text{beam}}\Big[\sqrt{1-\epsilon^2}\cos(\phi_h-\phi_S)F_{LT}^{\cos(\phi_h-\phi_S)}$$

$$+\sqrt{2\epsilon(1-\epsilon)}\cos\phi_S F_{LT}^{\cos\phi_S}$$

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

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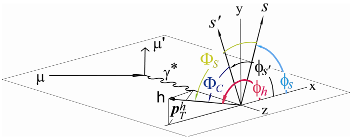
Collins Asymmetry

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 nucleon polarization and D_{NN} is the spin transfer coefficient from the initial to the stuck quark



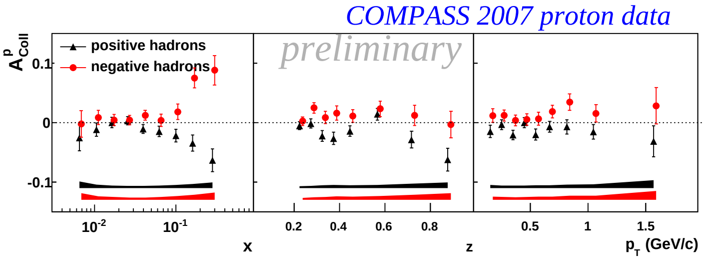
$$\Phi_C = \phi_h - \phi_{s'} = \phi_h + \phi_s - \pi$$

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

Collins asymmetry - proton data

New! Full 2007 statistics.

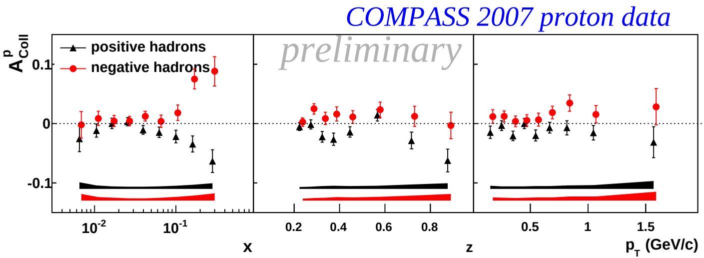
First shown at Transversity 2008 .(Ferrara- May 28-31,2008)

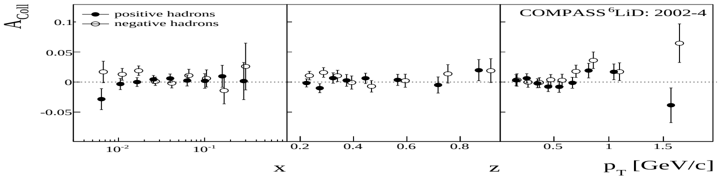


- at small x the asymmetries are compatible with zero
- in the valence region the asymmetries are different from zero

  of opposite sign for positive and negative hadrons
  of the same strength and sign of Hermes

Collins asymmetry - proton data





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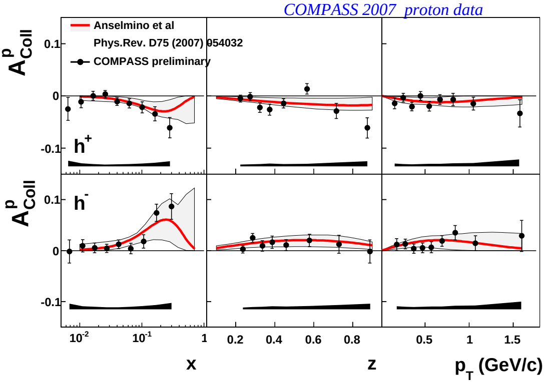
Collins effect - predictions

COMPASS proton data are compared with last prediction of Anselmino et al.



Prediction from : COMPASS deuteron data, most recent HERMES proton and BELLE $e^+e^- \to$ hadrons data.
Good agreement between data and prediction.
COMPASS proton data can be included in next global fits.

SIDIS cross section-Sivers asymmetry

$$\frac{d\sigma}{dx\,dy\,dz\,d\phi_h\,dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Bigg\{ F_{UU,T} + \epsilon F_{UU,L}$$
$$+\sqrt{2\epsilon(1+\epsilon)}\cos\phi_h F_{UU}^{\cos\phi_h}$$
$$+\epsilon\cos(2\phi_h) F_{UU}^{\cos 2\phi_h} + P_{\rm beam}\sqrt{2\epsilon(1-\epsilon)}\sin\phi_h F_{LU}^{\sin\phi_h}$$
$$+P_L\left[\sqrt{2\epsilon(1+\epsilon)}\sin\phi_h F_{UL}^{\sin\phi_h} + \epsilon\sin(2\phi_h) F_{UL}^{\sin(2\phi_h}\right]$$
$$+P_L P_{\rm beam}\left[\sqrt{1-\epsilon^2}F_{LL} + \sqrt{2\epsilon(1-\epsilon)}\cos\phi_h F_{LL}^{\cos\phi_h}\right]$$
$$+|P_T|\Big[\sin(\phi_h-\phi_S)\big(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\big)$$
$$+\epsilon\sin(\phi_h+\phi_S) F_{UT}^{\sin(\phi_h+\phi_S)} + \epsilon\sin(3\phi_h-\phi_S) F_{UT}^{\sin(3\phi_h-\phi_S)}$$
$$+\sqrt{2\epsilon(1+\epsilon)}\sin\phi_S F_{UT}^{\sin\phi_S}$$
$$+\sqrt{2\epsilon(1+\epsilon)}\sin(2\phi_h-\phi_S) F_{UT}^{\sin(2\phi_h-\phi_S)}\Big]$$
$$+|P_T|P_{\rm beam}\Big[\sqrt{1-\epsilon^2}\cos(\phi_h-\phi_S) F_{LT}^{\cos(\phi_h-\phi_S)}$$
$$+\sqrt{2\epsilon(1-\epsilon)}\cos\phi_S F_{LT}^{\cos\phi_S}$$
$$+\sqrt{2\epsilon(1-\epsilon)}\cos(2\phi_h-\phi_S) F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Bigg\}$$

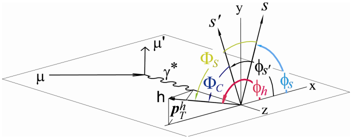
JHEP 0702:093,2007

Sivers Asymmetry

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 nucleon polarization



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

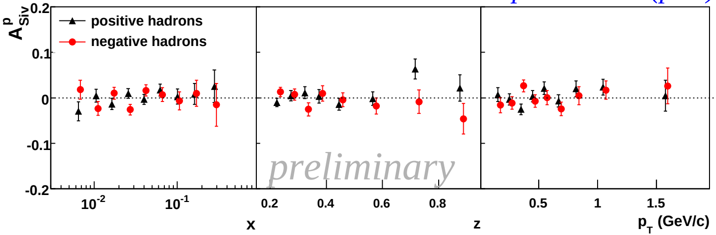
$$A_{Sivers} = \frac{\sum_q e_q^2\, \Delta_T^0 q\, D_q^h}{\sum_q e_q^2 q D_q^h}$$

$\Delta_T^0 q$=Sivers Distribution Function: correlation between the intrinsic transverse momentum of quarks and the spin of the nucleon in a transversely polarized nucleon.

Sivers asymmetry-proton data

First shown at Transversity 2008 .(Ferrara- May 28-31,2008)

COMPASS 2007 proton data (part)



The measured asymmetries are small, compatible with zero within the statistical error.

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Sivers asymmetry-proton data

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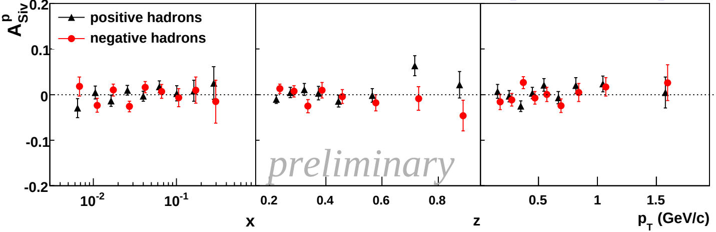
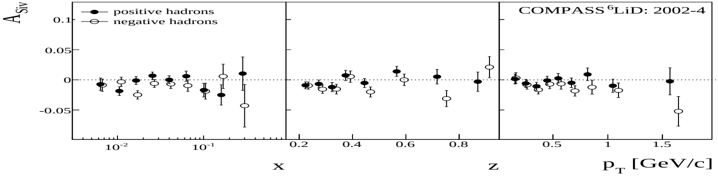
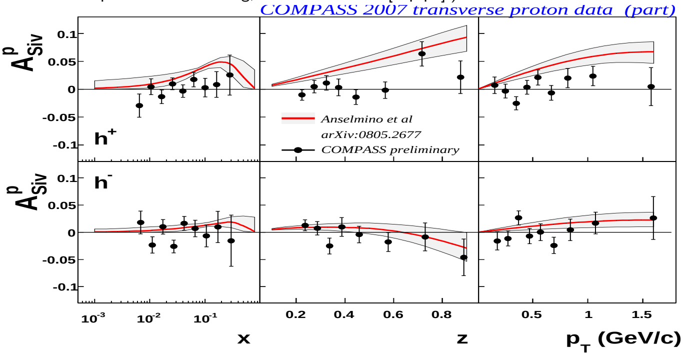
COMPASS 2007 proton data (part)





Sivers asymmetry - predictions

COMPASS proton data are compared with prediction of Anselmino et al. (M. Anselmino et al. "Sivers Effect for Pion and Kaon Production in Semi-Inclusive Deep Inelastic Scattering," arXiv:0805.2677 [hep-ph].).



Prediction from: COMPASS deuteron data and HERMES proton data.

Marginal agreement between data and prediction for positive hadrons. Better agreement for negative

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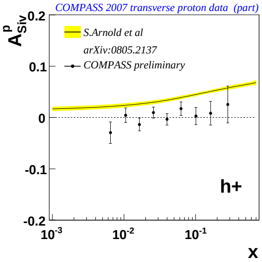
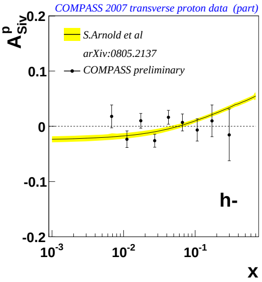
Sivers asymmetry - predictions

COMPASS proton data are compared with last prediction of S.Arnold et Al.(arXiv:0805.2137)



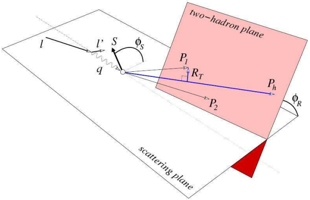


Marginal agreement between data and prediction.

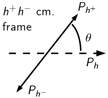
Two hadrons Asymmetry

$$N^{\pm}(\Phi_{RS}) = N^0 \left(1 \pm P_T\, D_{NN}\, A_{RS} \sin(\Phi_{RS}) \sin(\theta)\right)$$

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



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

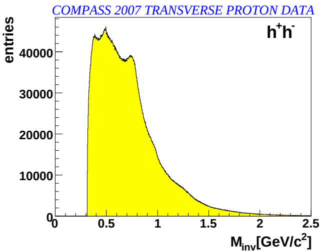


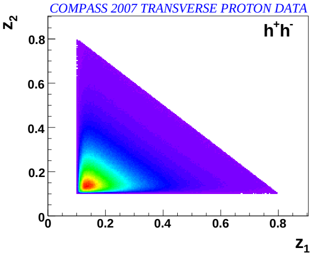
$$R_T = \frac{z_2\, P_{1T} - z_1\, P_{1T}}{z_1 + z_2}$$
$$z = z_1 + z_2$$

$$A_{RS} = \frac{\sum_q e_q^2\, \Delta_T q(x)\, H_q^{\angle}(z, M_h^2)}{\sum_q e_q^2 q(x) D_1(z, M_h^2)}$$

Data selection for 2hadrons asymmetry

- $R_T > 0.07\ GeV/c$
- $z < 0.9$
- $z_i > 0.1$
- $x_F > 0.1$





COMPASS

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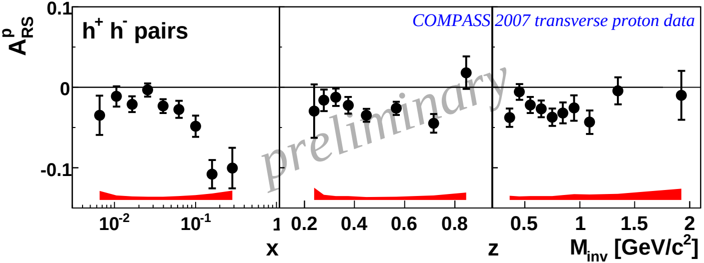
Transversity
The COMPASS spectrometer
1h asymmetries
Two hadrons asymmetry
Λ polarization
1h unpolarized azimuthal asymmetries
Conclusions

2 hadrons - proton data

New results! First shown at DIS 2009.(Madrid- Apr 26-30,2009)



- at small x the asymmetries are compatible with zero
- in the valence region the asymmetries are different from zero
- signal is larger than the Collins asymmetry
- signal larger than measured by Hermes

2 hadrons - proton data

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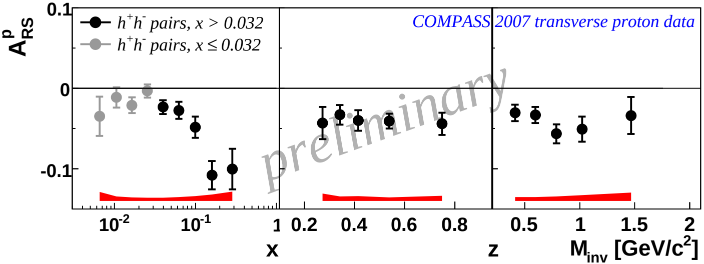

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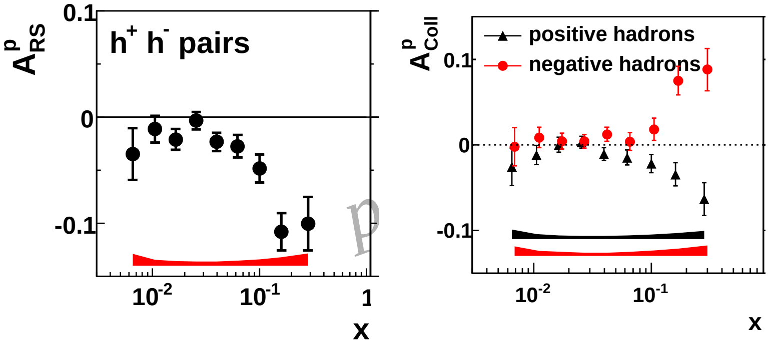

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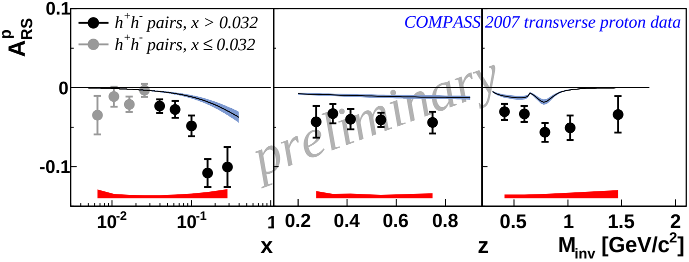
2 hadrons - predictions

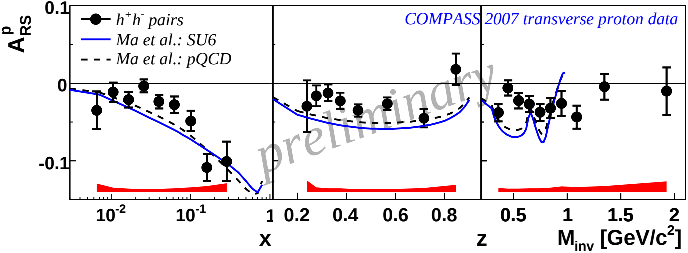
COMPASS proton data are compared with prediction of Bacchetta et Al. (private communication).



Predictions are rescaled to HERMES asymmetry. Data overshoot predictions.

2 hadrons - predictions

COMPASS proton data are compared with prediction of Ma et Al. (private communication).



Predictions are in better agreement with data.

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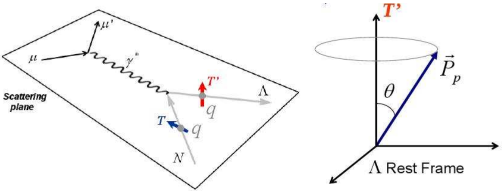
Λ polarization

$$N(\theta) \propto 1 + \alpha\, P_T^{\Lambda} \cos(\theta)$$

$\alpha = \pm 0.643$ is the asymmetry parameter of Λ and $\bar{\Lambda}$



$$P^{\Lambda}_{T,exp} = P_T\, D_{NN} \frac{\sum_q e_q^2\, \Delta_T q(x)\, \Delta_T D_q^{\Lambda}(z)}{\sum_q e_q^2 q(x) D_q^{\Lambda}(z)}$$

P_T is the nucleon polarization and D_{NN} is the spin transfer coefficient from the initial to the stuck quark

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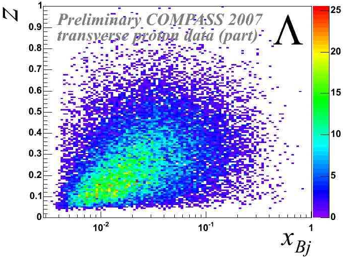
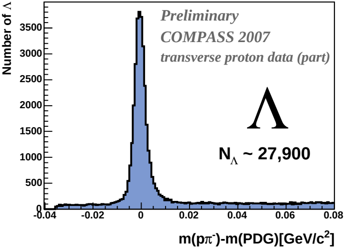
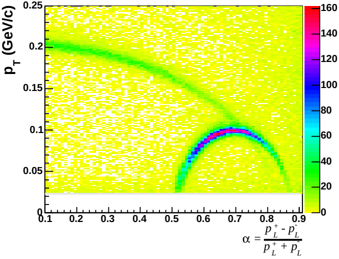
Data selection for Λ polarization

- $p_T > 23\ MeV/c$ to exclude e^+e pairs
- Proton and pion momenta $> 1\ GeV/c$
- $Q2 > 1\ (GeV/c)^2$
- $0.1 < y < 0.9$
- Use of RICH (2007 data)
- Λ decay distance $D_\Lambda > 7\sigma_D$
- Collinearity $< 10\ mrad$







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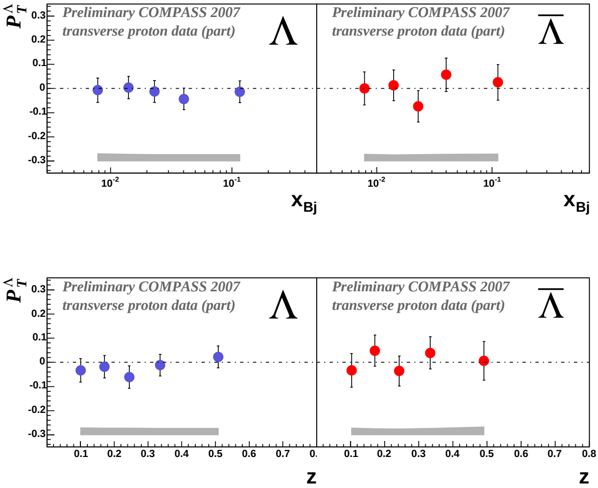
Λ polarization, proton data



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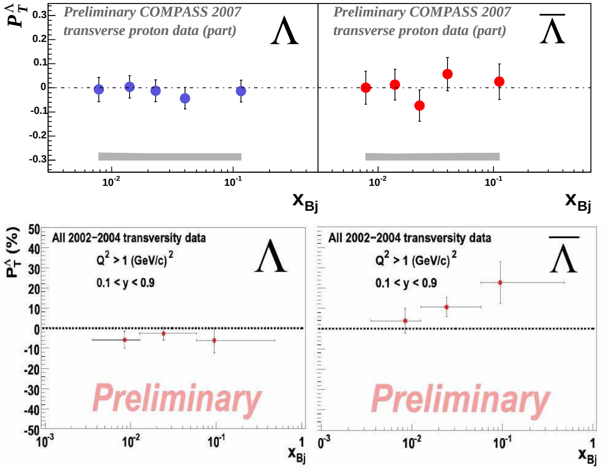

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SIDIS cross section- unpolarized azimuthal asymmetries

$$
\begin{aligned}
\frac{d\sigma}{dx\,dy\,dz\,d\phi_h\,dP^2_{h\perp}} = \frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{ & \\
& F_{UU,T} + \epsilon F_{UU,L} \\
& + \sqrt{2\epsilon(1+\epsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} \\
& + \epsilon\cos(2\phi_h) F_{UU}^{\cos 2\phi_h} + P_{\mathrm{beam}}\sqrt{2\epsilon(1-\epsilon)}\sin\phi_h F_{LU}^{\sin\phi_h} \\
& + P_L\left[\sqrt{2\epsilon(1+\epsilon)}\sin\phi_h F_{UL}^{\sin\phi_h} + \epsilon\sin(2\phi_h) F_{UL}^{\sin(2\phi_h)}\right] \\
& + P_L P_{\mathrm{beam}}\left[\sqrt{1-\epsilon^2} F_{LL} + \sqrt{2\epsilon(1-\epsilon)}\cos\phi_h F_{LL}^{\cos\phi_h}\right] \\
& + |P_T|\Big[\sin(\phi_h-\phi_S)\big(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\big) \\
& + \epsilon\sin(\phi_h+\phi_S) F_{UT}^{\sin(\phi_h+\phi_S)} + \epsilon\sin(3\phi_h-\phi_S) F_{UT}^{\sin(3\phi_h-\phi_S)} \\
& + \sqrt{2\epsilon(1+\epsilon)}\sin\phi_S F_{UT}^{\sin\phi_S} \\
& + \sqrt{2\epsilon(1+\epsilon)}\sin(2\phi_h-\phi_S) F_{UT}^{\sin(2\phi_h-\phi_S)}\Big] \\
& + |P_T| P_{\mathrm{beam}}\Big[\sqrt{1-\epsilon^2}\cos(\phi_h-\phi_S) F_{LT}^{\cos(\phi_h-\phi_S)} \\
& + \sqrt{2\epsilon(1-\epsilon)}\cos\phi_S F_{LT}^{\cos\phi_S} \\
& + \sqrt{2\epsilon(1-\epsilon)}\cos(2\phi_h-\phi_S) F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\}
\end{aligned}
$$

$\sin\phi$

Kinematic effect due to beam polarization

$\cos\phi$, $\cos 2\phi$

Cahn: kinematic effect due to quark transverse momentum
Boer-Mulders PDF: correlation between quark intrinsic transverse momentum and transverse polarization in an unpolarized nucleon

JHEP 0702:093,2007

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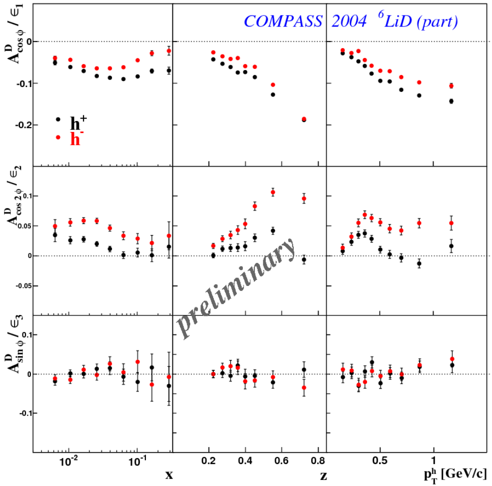
1h unpolarized azimuthal asymmetries, deuteron data

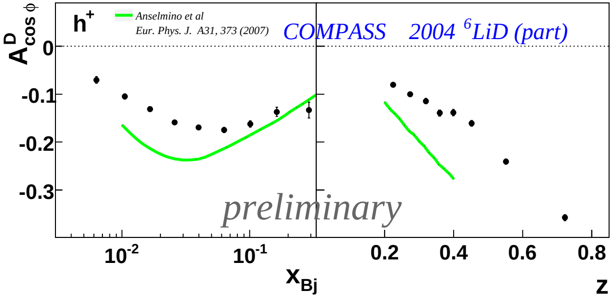
First shown at Transversity 2008 .(Ferrara- May 28-31,2008)



- cos ϕ strongest effect
- cos 2ϕ up to 10%
- sin ϕ is compatible with zero
- good general agreement with predictions
- Differences between asymmetries from positive and negative hadrons (cos ϕ and cos 2ϕ)are a hint of BM pdf

1h unpolarized azimuthal asymmetries, deuteron data

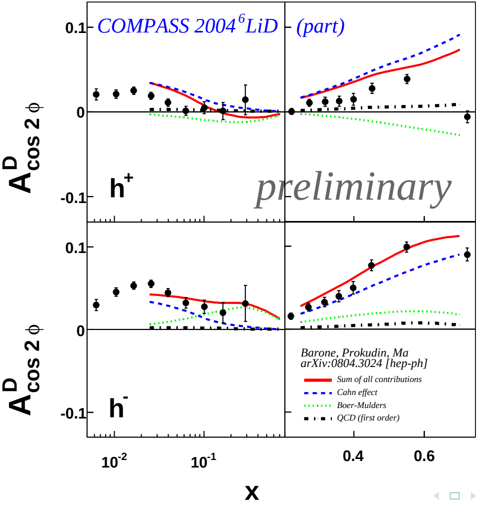
M.Anselmino,M.Boglione, A.Prokudin, C.Turk, Eur.Phys.J.A31,373-381(2007)



The model does not include Boer-Mulders contribution

1h unpolarized azimuthal asymmetries, deuteron data

V.Barone,A.Prokudin,B.Q.Ma arXiv:0804.3024[hepph]



Conclusions

- On deuteron final results are available for:
  - Collins, Sivers and other 6 target transverse spin polarization TMDs
  - two hadron asymmetries
  - Λ polarization
  - unpolarized TMD's structure functions
- On proton new results are available for:
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Thanks