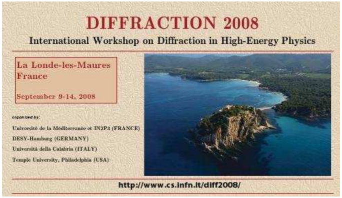
Transverse spin effects at COMPASS

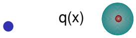
Giulia Pesaro
Trieste University and INFN of Trieste
on behalf of the COMPASS Collaboration



Giulia Pesaro
Trieste University and INFN of Trieste

Transversity

Three distribution functions are necessary to describe the spin structure of the nucleon at leading order:

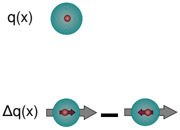


momentum distribution $q(x)$ or $f_1(x)$: probability of finding a quark with a fraction x of nucleon momentum.

Giulia Pesaro
Trieste University and INFN of Trieste

Transversity

Three distribution functions are necessary to describe the spin structure of the nucleon at leading order:

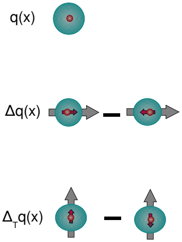


- **momentum distribution** $q(x)$ or $f_1(x)$: probability of finding a quark with a fraction x of nucleon momentum.
- **helicity distribution** $\Delta q(x)$ or $g_1(x)$: probability of finding a quark with spin parallel to nucleon spin in a longitudinally polarized nucleon.

Giulia Pesaro
Trieste University and INFN of Trieste

Transversity

Three distribution functions are necessary to describe the spin structure of the nucleon at leading order:



- **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.

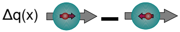
Giulia Pesaro
Trieste University and INFN of Trieste

Transversity

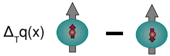
Three distribution functions are necessary to describe the spin structure of the nucleon at leading order:

- 

  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 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 data are available for all channels. New preliminary results on proton data are available for Collins effect and Λ polarization.

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 on deuteron data are available for all channels. New preliminary results on proton data are available for Collins effect and Λ polarization.

Giulia Pesaro
Trieste University and INFN of Trieste

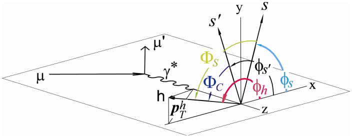
DIFFRACTION 2008

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



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

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

Sivers Asymmetry

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

JHEP 0702:093,2007

Complete SIDIS cross section:

- 8 target transverse spin dependent modulations.
- all independent
- Sivers asymmetry is the most famous among the TMDs DF

Final results on deuteron data are available for all target dependent asymmetries

Giulia Pesaro
Trieste University
and INFN of
Trieste

Sivers Asymmetry

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

JHEP 0702:093,2007

Complete SIDIS cross section:

- 8 target transverse spin dependent modulations.
- all independent
- Sivers asymmetry is the most famous among the TMDs DF

Final results on deuteron data are available for all target dependent asymmetries

Sivers Asymmetry

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

JHEP 0702:093,2007

Complete SIDIS cross section:

- 8 target transverse spin dependent modulations.
- all independent
- Sivers asymmetry is the most famous among the TMDs DF

Final results on deuteron data are available for all target dependent asymmetries

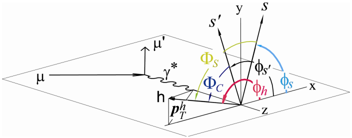
Giulia Pesaro
Trieste University and INFN of Trieste

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 target 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 unpolarized quarks and the spin in a transversely polarized nucleon.

Giulia Pesaro
Trieste University and INFN of Trieste

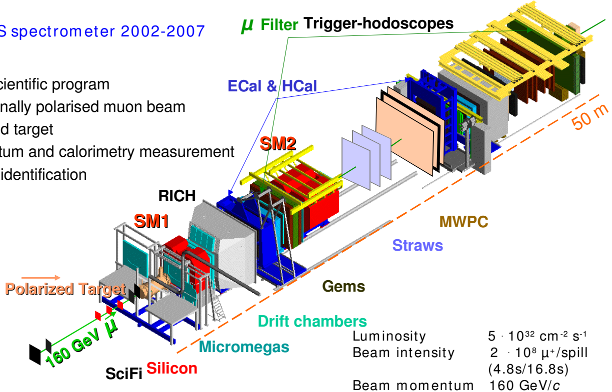
DIFFRACTION 2008

The COMPASS spectrometer

See Barbara Badelek Talk

Giulia Pesaro
Trieste University and INFN of Trieste

The COMPASS spectrometer

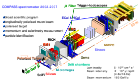


- Broad scientific program
- longitudinally polarised muon beam
- polarised target
- momentum and calorimetry measurement
- particle identification

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

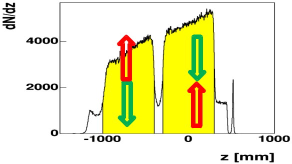
Giulia Pesaro
Trieste University and INFN of Trieste

The COMPASS spectrometer

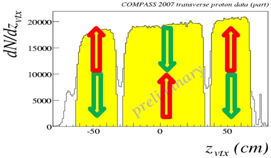


Polarized Target:
- Operated in frozen spin mode
- During transverse data taking polarization is reversed every ~ **4-5 days**
- Data are taken at the same time with 2 opposite polarizations

2002-2004: **^{6}LiD (polarized deuteron)**
- Two cells with opposite polarization
- Dilution factor f= 0.38
- Polarization P_T = 50%
- Full statistics analyzed



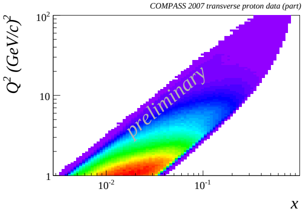
2007: **NH_3 (polarized protons)**
- Three cells with opposite polarization
- Dilution factor f= 0.14
- Polarization P_T = 90%
- 25% statistics analyzed

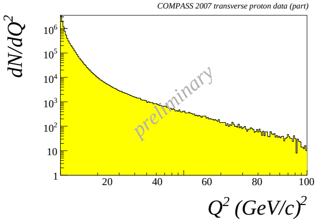


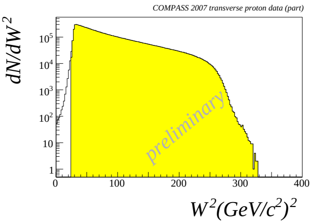
Giulia Pesaro
Trieste University and INFN of Trieste

DIFFRACTION 2008

Data selection- DIS cut



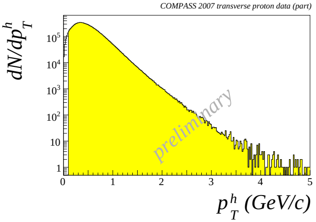


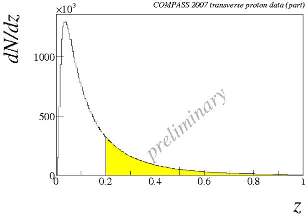


- $Q^2 > 1\ (GeV/c)^2$
- $0.1 < y < 0.9$
- $W > 5\ GeV/c^2$

Data selection- Hadron sample

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

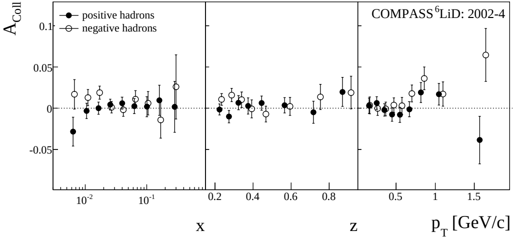




	positive	negative
2002-2004 deuteron	8.5 M	7.0 M
2007 part proton	5.7 M	4.5 M

Collins asymmetry - deuteron data

Final results, all deuteron data: NP B765 (2007) 31-70



Only statistical errors are shown. Systematic errors are considerably smaller.

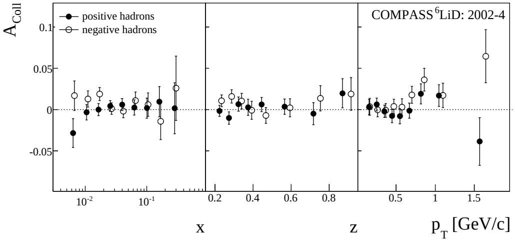
Asymmetries are small, compatible with 0.

Final results on $\pi^{\pm}$,$K^{\pm}$ and K^0 are available: CERN-PH-EP/2008-002
All Collins asymmetries are small, compatible with 0. Results well comparable with 2 hadrons analysis and Λ polarization analysis on deuteron data.

Giulia Pesaro
Trieste University and INFN of Trieste

Collins asymmetry - deuteron data

Final results, all deuteron data: NP B765 (2007) 31-70



Only statistical errors are shown. Systematic errors are considerably smaller.

Asymmetries are small, compatible with 0.

Naïve interpretation (parton model, valence region):

assuming all are pions

$$A_{Coll}^{d,\pi^+} \simeq \frac{\Delta_T u_v + \Delta_T d_v}{u_v + d_v} \, \frac{4\Delta_T^0 D_1 + \Delta_T^0 D_2}{4D_1 + D_2}$$

$$A_{Coll}^{d,\pi^-} \simeq \frac{\Delta_T u_v + \Delta_T d_v}{u_v + d_v} \, \frac{\Delta_T^0 D_1 + 4\Delta_T^0 D_2}{D_1 + 4D_2}$$

HERMES proton data and BELLE data:
$\Delta_T^0 D_2 \approx -\Delta_T^0 D_1$

$$\Rightarrow \Delta_T u(x) + \Delta_T d(x) \sim 0$$

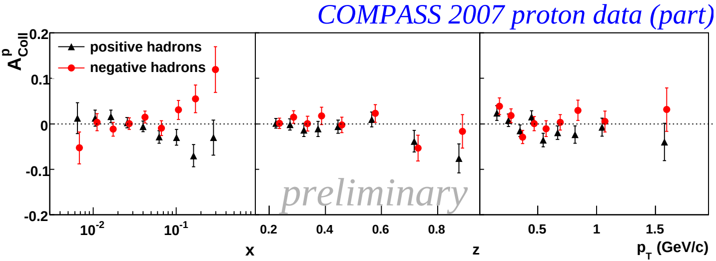
Global fits ongoing.

Giulia Pesaro
Trieste University and INFN of Trieste

DIFFRACTION 2008

Collins asymmetry - proton data

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



Only statistical errors are shown. Systematic errors $\sim$ 0.3 σ_{stat}.

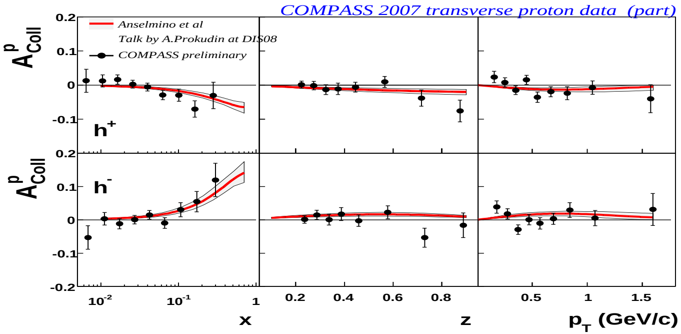
- at small x the asymmetries are compatible with zero
- in the valence region the asymmetries are different from zero

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

Giulia Pesaro
Trieste University and INFN of Trieste

Collins effect - predictions

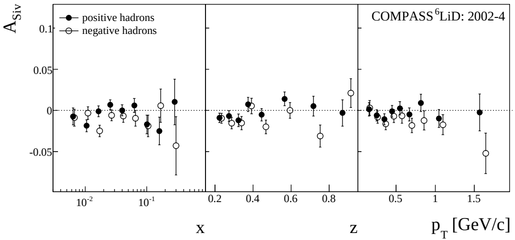
COMPASS proton data are compared with last prediction of Anselmino et al.



Prediction from : COMPASS deuteron data, most recent HERMES proton and BELLE $e^+e^- \rightarrow$ hadrons data.
Good agreement between data and prediction.

Sivers asymmetry - deuteron data

Final results, all deuteron data: NP B765 (2007) 31-70



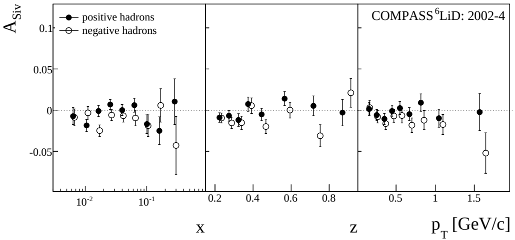
Only statistical errors are shown. Systematic errors are considerably smaller.

Asymmetries are small, compatible with 0.

Final results on $\pi^{\pm}$,$K^{\pm}$ and K^0 are available: CERN-PH-EP/2008-002
All Sivers asymmetries are small compatible with 0.

Sivers asymmetry - deuteron data

Final results, all deuteron data: NP B765 (2007) 31-70



Only statistical errors are shown. Systematic errors are considerably smaller.

Asymmetries are small, compatible with 0.

Naïve interpretation (parton model, valence region):

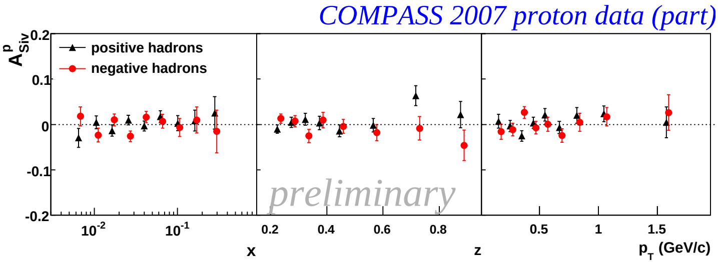
assuming all are pions

$$A_{Siv}^{d,\pi^+} \simeq A_{Siv}^{d,\pi^-} \simeq \frac{\Delta_0^T u_v + \Delta_0^T d_v}{u_v + d_v} \Rightarrow \Delta_0^T u_v \simeq -\Delta_0^T d_v$$

Giulia Pesaro
Trieste University and INFN of Trieste

Sivers asymmetry-proton data

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

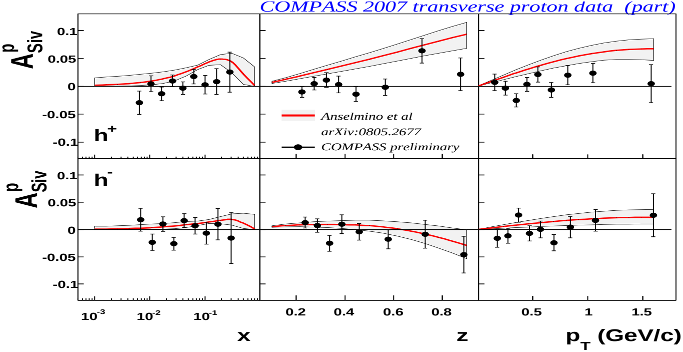


Only statistical errors are shown. Systematic errors $\sim$ 0.5 σ_{stat}.

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

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 most recent HERMES proton data.

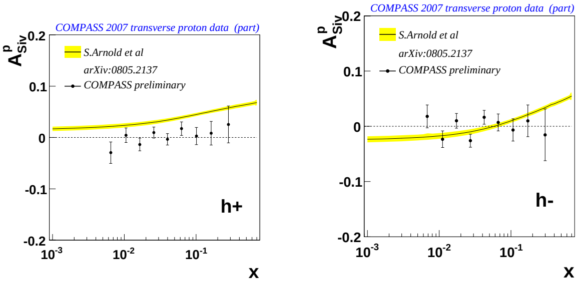
Marginal agreement between data and prediction.

Giulia Pesaro
Trieste University and INFN of Trieste

DIFFRACTION 2008

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.

A flash on unpolarized azimuthal asymmetries

$$\frac{d\sigma}{dx\, dy\, dz\, d\phi_h\, dP^2_{h\perp}} = \frac{\alpha^2}{xyQ^2}\, \frac{y^2}{2(1-\epsilon)} \left(1+\frac{\gamma^2}{2x}\right) \Big\{ F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)} \cos\phi_h F_{UU}^{\cos\phi_h} + \epsilon \cos(2\phi_h) F_{UU}^{\cos 2\phi_h} + P_{\text{beam}} \sqrt{2\epsilon(1-\epsilon)} \sin\phi_h F_{LU}^{\sin\phi_h} + \ldots$$

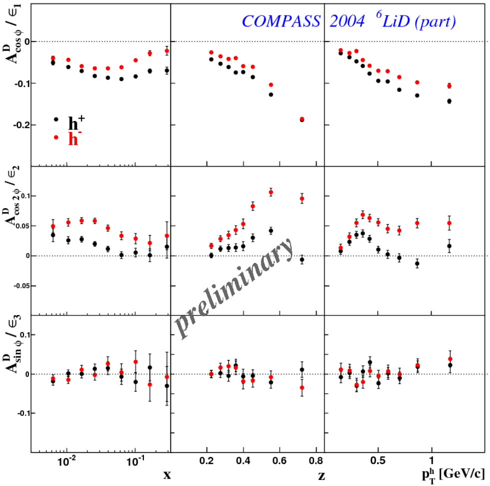
In the complete SIDIS cross section there are also:

- 3 polarization independent modulations

All measured on deuteron data.

Polarization independent modulations are due to kinematical effects (Cahn effect), Boer Mulders PDF, and QCD effects or to Beam polarization.

A flash on unpolarized azimuthal asymmetries



- $\cos\phi$ strongest effect
- $\cos 2\phi$ up to 10%
- $\sin\phi$ is compatible with zero
- good general agreement with predictions
- Differences between asymmetries from positive and negative hadrons ($\cos\phi$ and $\cos 2\phi$)are a hint of BM pdf
- Of great interest for theoreticians (M.Anselmino,M.Boglione, A.Prokudin, C.Turk, Eur.Phys.J.A31,373-381(2007); V.Barone,A.Prokudin,B.Q.Ma arXiv:0804.3024[hepph])

Conclusions

- on deuteron data (2002-2004)

  → analysis is finalized
  → new results for unpolarized asymmetries

- new preliminary results on proton target data

  →Collins asymmetry is different from zero: the effect is there at COMPASS energies
  →Sivers asymmetry is small, compatible with zero: has to be understood

- in the near future:

  →analysis of the full proton sample
  →identified hadrons asymmetries

- long term projects (2010):

  → high precision SIDIS measurements for flavor separation

Giulia Pesaro
Trieste University and INFN of Trieste

DIFFRACTION 2008

Conclusions

- on deuteron data (2002-2004)

  → analysis is finalized
  → new results for unpolarized asymmetries

- new preliminary results on proton target data

  →Collins asymmetry is different from zero: the effect is there at COMPASS energies
  →Sivers asymmetry is small, compatible with zero: has to be understood

- in the near future:

  →analysis of the full proton sample
  →identified hadrons asymmetries

- long term projects (2010):

  → high precision SIDIS measurements for flavor separation

Thanks

Giulia Pesaro
Trieste University and INFN of Trieste

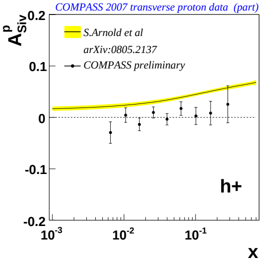
Giulia Pesaro
Trieste University and INFN of Trieste

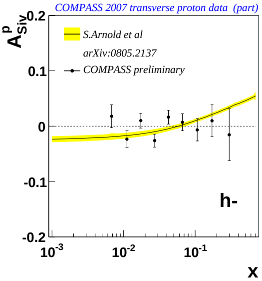
Giulia Pesaro
Trieste University and INFN of Trieste

DIFFRACTION 2008

Sivers asymmetry - predictions

COMPASS proton data are compared with last prediction of S.Arnold et Al.(S.Arnold, A.V.Efremov, K.Goeke, M.Schlegel and P.Schweitzer, arXiv:0805.2137)





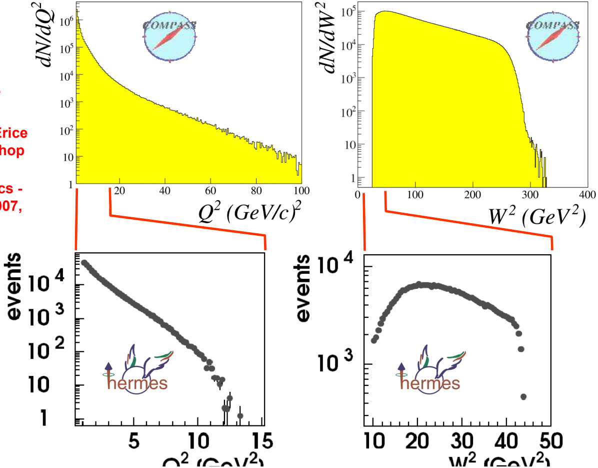
$$A_{UT\,\text{measured}}^{\sin(\phi-\phi_S)} = \Big\{\text{'twist-2 Sivers effect' in Eqs. (11, 15)}\Big\} + C(Q)\,\frac{M_N^2}{Q^2}$$

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.

COMPASS-HERMES kinematics

F. Bradamante

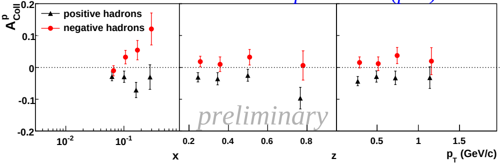
International Erice School/Workshop on Nuclear Physics - Sept. 16-24, 2007, Erice, Italy

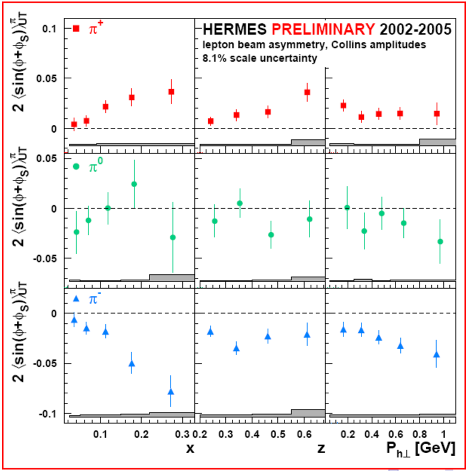


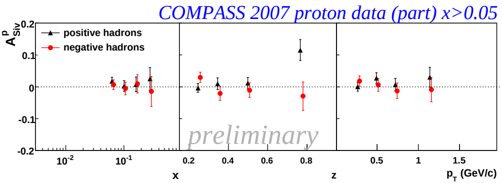
Giulia Pesaro
Trieste University and INFN of Trieste

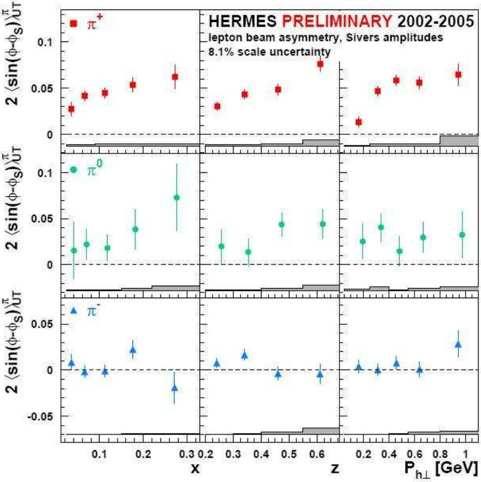
DIFFRACTION 2008

COMPASS 2007 proton data (part) x>0.05

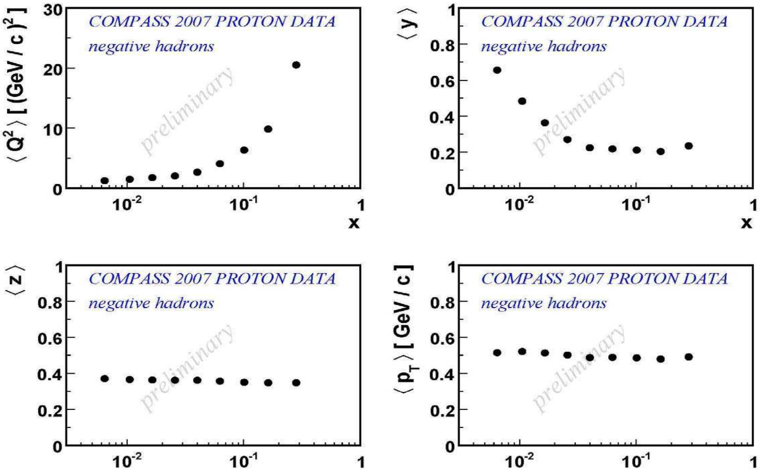




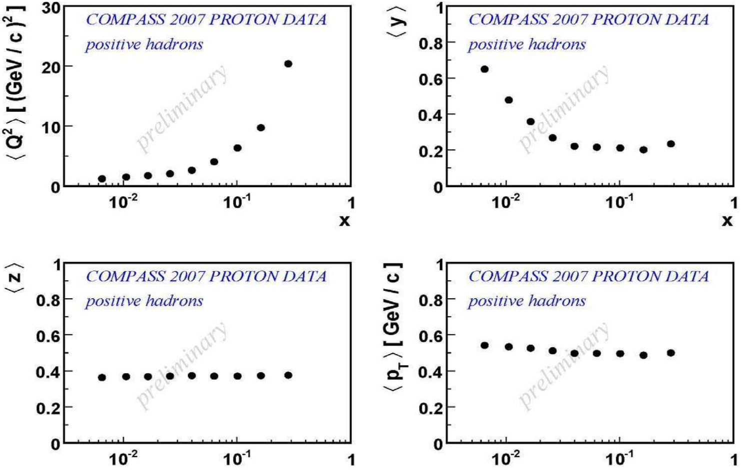

COMPASS 2007 proton data (part) x>0.05
positive hadrons
negative hadrons
preliminary
x
z
p_T (GeV/c)


HERMES PRELIMINARY 2002-2005
lepton beam asymmetry, Sivers amplitudes
8.1% scale uncertainty
π^+
π^0
π^-
$2\,\langle \sin(\phi-\phi_S)\rangle^{\pi}_{UT}$
x
z
$P_{h\perp}$ [GeV]

mean values, negative hadrons



mean values, positive hadrons



Quality checks

- Data taking stability is a required necessary condition:
  A dedicated set of quality checks have been developed and applied to fulfill this condition

Different and independent estimators have been taken into account:

1. ***the detector profiles stability***
2. ***the number of primary vertexes per event***
3. ***the number of tracks per primary vertex***
4. ***beam particles per primary vertex***
5. ***the K_0 number per primary vertex***
6. ***the reconstructed mass of the K_0 meson***
7. ***stability of many kinematical variables:***

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

Giulia Pesaro
Trieste University and INFN of Trieste

systematics

Several systematics tests have been performed:

Splitting of the target into sectors:

1. Left right
2. Up down

False asymmetries test:

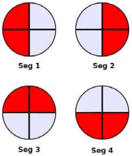
1. Combining cells with the same polarization

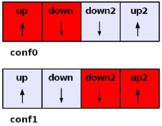
Target split: different target sectors

1. Combining half upstream target cells (conf 0)
2. Combining half downstream target cells (conf 1)

Different methods for asymmetry extraction

1. 5 different methods





Giulia Pesaro
Trieste University and INFN of Trieste

Fit procedure

eight by eight binning in ϕ_h and ϕ_S;

in each bin $j = \{1, 2, ..64\}$ we expect number of counts:

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

$\uparrow\downarrow$ = sign of target polarization

$a_j^{\uparrow\downarrow}$ = acceptance in bin j

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

For extracting asymmetries $\vec{A}$ we need an assumption for the acceptances $a_j^{\uparrow\downarrow}$

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

Giulia Pesaro
Trieste University and INFN of Trieste

DIFFRACTION 2008

Fit procedure

Coupling of two cells with opposite target polarization:
$u^{\uparrow}$, $d^{\downarrow}$ and $u^{\downarrow}$, $d^{\uparrow}$

$$N_{ju}^{\uparrow} = C\frac{a_{jd}^{\downarrow}a_{ju}^{\downarrow}}{a_{jd}^{\uparrow}}g_j^{\uparrow}(\vec{A}) \qquad N_{jd}^{\downarrow} = a_{jd}^{\downarrow}g_j^{\downarrow}(\vec{A})$$
$$N_{ju}^{\downarrow} = a_{ju}^{\downarrow}g_j^{\downarrow}(\vec{A}) \qquad N_{jd}^{\uparrow} = a_{jd}^{\uparrow}g_j^{\uparrow}(\vec{A}) \tag{1}$$

$$C = \frac{a_{ju}^{\uparrow}a_{jd}^{\uparrow}}{a_{ju}^{\downarrow}a_{jd}^{\downarrow}}, \quad \text{reasonable assumption} \tag{2}$$

$j = \{1, 2, ..64\}$ (eight by eight binning in ϕ_h and ϕ_S)

$\rightsquigarrow$ $4 \cdot 64 = 256$ nonlinear equations

$\rightsquigarrow$ $1 + 8 + 3 \cdot 64 = 201$ fit parameter

Fit procedure

Nonlinear system of equation solved with:

gsl_multifit_fdfsolver_lmsder (gsl function)

$\rightsquigarrow$ gsl function minimizes: $\|\vec{F}(\vec{a})\|^2$

target function $\vec{F}(\vec{a})$ was derived with Poisson statistic:

$$P_j(\vec{a}) = \frac{e^{-f_j(\vec{a})} f_j(\vec{a})^{N_j}}{N_j!} \rightsquigarrow \text{maximize} \ \log\left(\prod_{j=1}^{256} P_j(\vec{a})\right)$$

$f_j(\vec{a})$ = fit function in bin j

N_j = measured number of counts in bin j

$\rightsquigarrow$ binned maximum likelihood fit

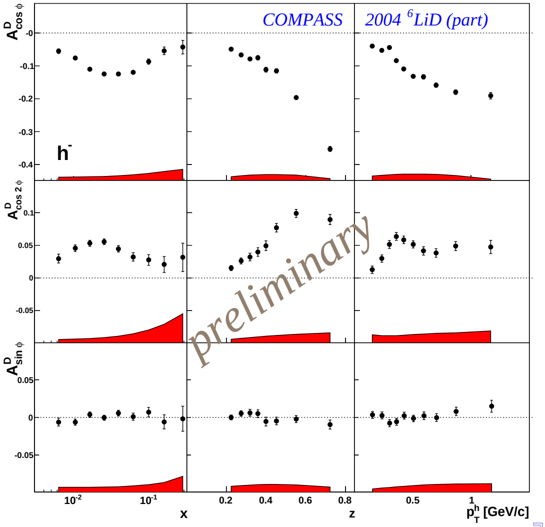
$\rightsquigarrow$ minimization of:

$$F_j(\vec{a}) = \sqrt{2}\sqrt{f_j(\vec{a}) - N_j + N_j \ln(N_j/f_j(\vec{a}))}$$

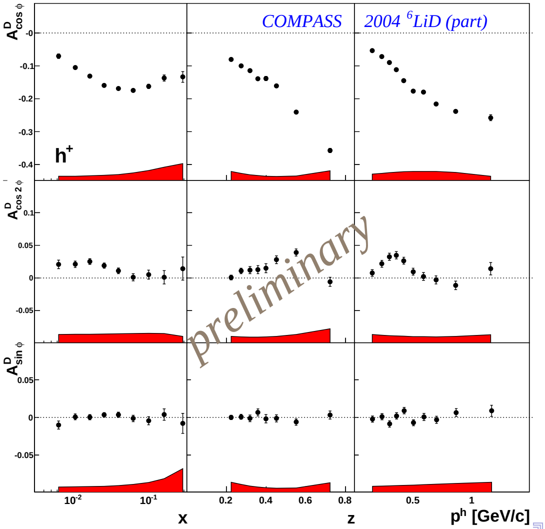
Giulia Pesaro
Trieste University and INFN of Trieste

DIFFRACTION 2008

Unpolarized asymmetries, negative hadrons



Unpolarized asymmetries, positive hadrons

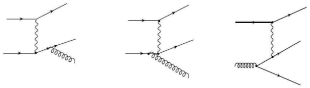


Giulia Pesaro
Trieste University and INFN of Trieste

DIFFRACTION 2008

The origin of the azimuthal asymmetries

- *First measurements were proposed as test for perturbative QCD azimuthal asymmetry due to gluon radiation (Georgi-Politzer, 1978)*
  - **pQCD contributions expected to be important at p_T > 1 GeV/c**



$O(\alpha_s^1)$:
H. Georgi and H. D. Politzer. PRL 40 (1978) 3-6
A. Mendez. NP B145 (1978) 199-220.

$O(\alpha_s^2)$:
A. Daleo, D. de Florian, and R. Sassot. PR D71 (2005) 034013.

The origin of the azimuthal asymmetries

- *First measurements were proposed as test for perturbative QCD azimuthal asymmetry due to gluon radiation (Georgi-Politzer, 1978)*

- *Alternative hypothesis*
  azimuthal asymmetry due to **quark intrinsic transverse momentum** *inside nucleon, kinematical effect (Cahn 1978)*

Giulia Pesaro
Trieste University and INFN of Trieste

Cahn effect

- **Kinematical effect**
- Leading order QED with non null quark transverse momentum (quark-lepton scattering)

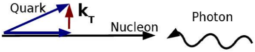
QPM

$$d\sigma^{l\,h \to l'\,h\,X} \propto \sum_i f_i \cdot d\sigma^{q_i\,l \to q_i'\,l'} \cdot D_i^h$$

$$d\sigma^{q\,l \to q'\,l'} \propto \hat{s}^2 + \hat{u}^2 \qquad \hat{s} = (l + k)^2 \qquad \hat{u} = (l - k')^2$$

- $\vec{k}_t = 0$

- $\vec{k}_t \neq 0$



→ **Additional physics**

(modulations in the azimuthal distributions of the hadrons)

$$\cos(\phi) \;;\; \cos(2\phi)$$

Giulia Pesaro
Trieste University and INFN of Trieste

The origin of the azimuthal asymmetries

- *First measurements were proposed as test for perturbative QCD azimuthal asymmetry due to gluon radiation (Georgi-Politzer, 1978)*

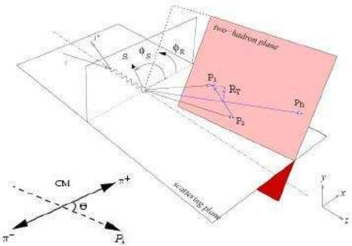
- *Alternative hypothesis*
  azimuthal asymmetry due to **quark intrinsic transverse momentum**
  inside nucleon, kinematical effect (Cahn 1978)

- *Recently, interest is renewed because they can give further informations on Boer-Mulders TMD PDF (Boer-Mulders 1998)*
  - leading order PDF
  - correlation between quark intrinsic transverse momentum and transverse polarization in an unpolarized nucleon

Giulia Pesaro
Trieste University and INFN of Trieste

DIFFRACTION 2008

Hadron pairs



in inclusive production of hadron pairs, one can define the angle $\phi_{R\perp}$ and measure an **azimuthal asymmetry** from the **modulation of the number of events in $\phi_{RS} = \phi_{R\perp} - \phi_{s}$**.

$$N^{\pm}(\Phi_{RS}) = N^{0}\cdot\{1 \pm A\cdot\sin\Phi_{RS}\}$$

$$A_{RS} = \frac{1}{f\cdot P_T\cdot D}\cdot A = \frac{\sum_q e_q^2\cdot\Delta_T q(x)\cdot H_q^{\angle}(z,M_h^2)}{\sum_q e_q^2\cdot q(x)\cdot D_q^h(z,M_h^2)}$$

Transversity distribution function

Interference fragmentation functic presently unknown, being measured at **BELLE**

A. Bacchetta, M. Radici, hep-ph/0407345
X. Artru, hep-ph/0207309

DIS08 Federica Sozzi

Giulia Pesaro
Trieste University and INFN of Trieste

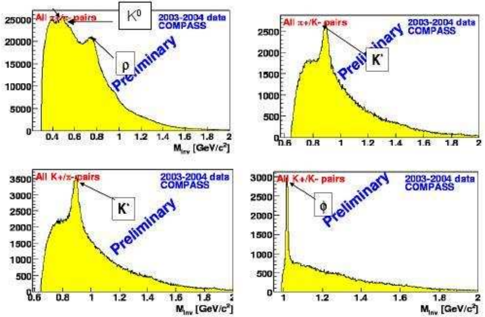
Transversity
Sivers asymmetry
The COMPASS spectrometer
Results
Unpolarized azimuthal asymmetries
Conclusions

Hadron pairs

2 different analysis:

1) **hadron pairs ordered with charge**:

	without PID	π+ π-	π+ K-	K+ π-	K+ K-
total	$5.3*10^6$	$3.7*10^6$	$2.4*10^5$	$3.0*10^5$	$8.7*10^4$



Different hadron combination → different invariant mass spectra

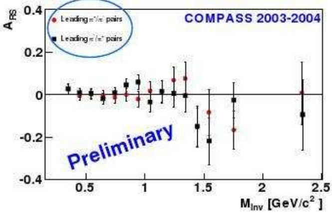
Hadron pairs

2) **z-ordered pairs**: select in the event the two hadrons with the highest relative energy z:

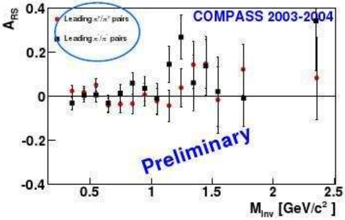
for leading hadron pairs the signal enhancement is predicted,
hadrons with higher energy carry more information
about the fragmenting quark polarization

16 combinations, 4 particle combinations times 4 charge combinations

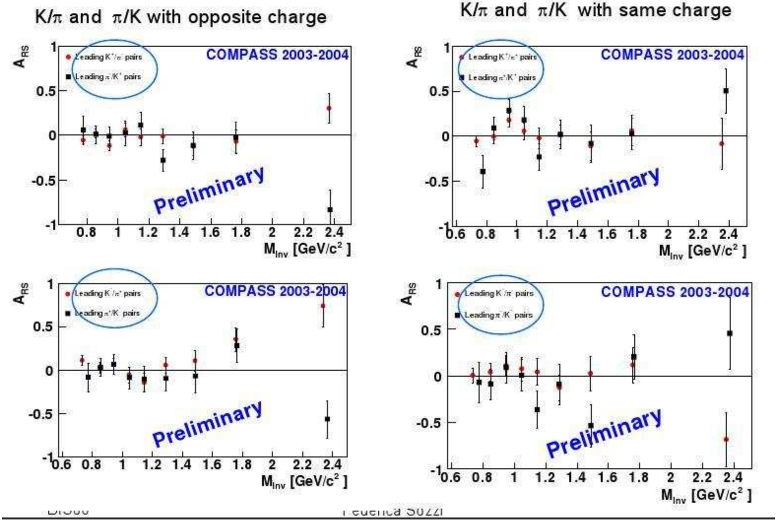
π with opposite charge



π with same charge



Hadron pairs



Giulia Pesaro
Trieste University and INFN of Trieste

Λ polarization

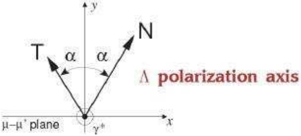
Information on $\Delta_T q$ can be accessed in the processes:

$$\mu N^{\uparrow} \rightarrow \mu' \Lambda X$$

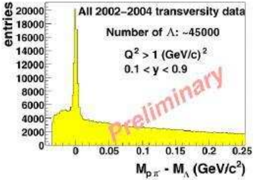
$$\mu N^{\uparrow} \rightarrow \mu' \overline{\Lambda} X$$

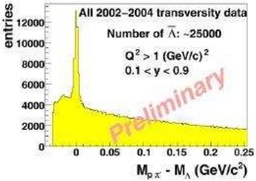
$$P^{\Lambda}_{T,exp} = \frac{d\sigma^{\mu N^{\uparrow} \rightarrow \mu' \Lambda^{\uparrow} X} - d\sigma^{\mu N^{\downarrow} \rightarrow \mu' \Lambda^{\uparrow} X}}{d\sigma^{\mu N^{\uparrow} \rightarrow \mu' \Lambda^{\uparrow} X} + d\sigma^{\mu N^{\downarrow} \rightarrow \mu' \Lambda^{\uparrow} X}}$$

$$= f P_N D(y) \frac{\sum_q e_q^2 \Delta_T q(x) \Delta_T D_{\Lambda/q}(z)}{\sum_q e_q^2 q(x) D_{\Lambda/q}(z)}$$



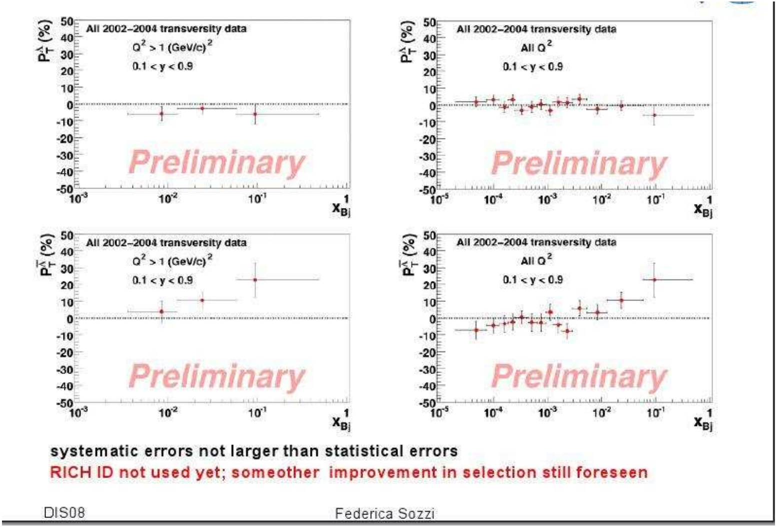
Federica Sozzi



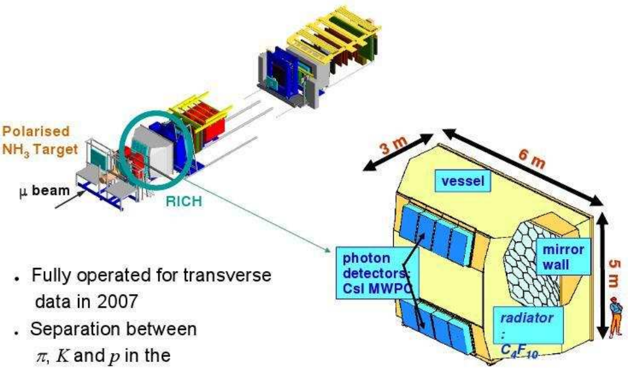


Giulia Pesaro
Trieste University and INFN of Trieste

Λ polarization

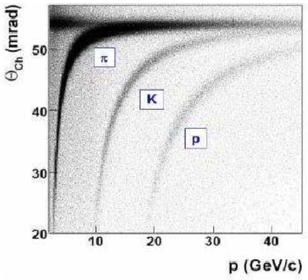


Λ polarization



- Fully operated for transverse data in 2007
- Separation between π, K and p in the momentum range 3-50 GeV/c

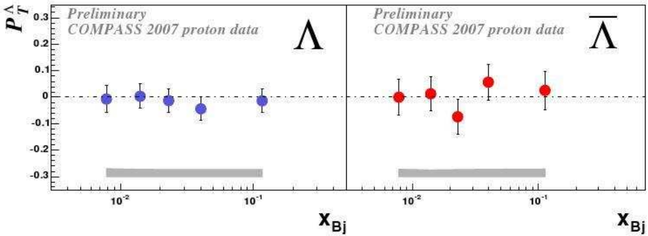
Λ polarization



- Hadron masses calculated from the measured cherenkov angle θ_{ch}
- Threshold momenta:
  - $P_\pi \sim$ 2 GeV/c
  - $p_K \sim$ 9 GeV/c
  - $p_P \sim$ 17 GeV/c
- Likelihood methods are used to reject pion and kaon for proton candidate in the decay of Λ ($\Lambda \rightarrow p\pi^-$) and $\overline{\Lambda}$ ($\overline{\Lambda} \rightarrow \overline{p}\pi^+$)

Λ polarization

- With ~60% higher statistics than 2002-2004 and RICH identification, 5 x_{Bj} and z bins are possible for 2007 data (instead of 3 for 2002-2004).
- Systematic errors have been estimated to be smaller than statistical errors from false polarization.
- No dependence on x_{Bj} with proton target.



Giulia Pesaro
Trieste University and INFN of Trieste

DIFFRACTION 2008

Λ polarization

- With ~60% higher statistics than 2002-2004 and RICH identification, 5 x_{Bj} and z bins are possible for 2007 data (instead of 3 for 2002-2004).
- Systematic errors have been estimated to be smaller than statistical errors from false polarization.
- No dependence on z with proton target.