MEASUREMENT OF TRANSVERSITY AT COMPASS

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on behalf of the COMPASS Collaboration

• The COMPASS spectrometer
• Transversity at COMPASS
• The 2002 data
• First results
• The future

Paris, March 1, 2004
The Spectrometer

- Polarized Target
- SPS 160 GeV μ beam
- Scifi, Silicon
- E/HCAL1
- SM1
- RICH1
- SM2
- E/HCAL2
- Hodoscopes
- Muon Wall 1
- Muon Wall 2, MWPC
- MWPC, Gems, Scifi, W45 (not shown)
- Straws, Gems
- Micromegas, SDC, Scifi

Designed to cover a forward acceptance up to 200 mrad

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The Target System in 2002 and 2003

SMC PT magnet

- Two 60 cm long target cells with opposite polarisation
- Superconducting solenoid (2.5 T)
- $^3$He – $^4$He dilution refrigerator (T~50mK)
- $^6$LiD: $P_T$ ~ 50% $f$ ~ 50%
- (NH$_3$, $P_T$ ~90%, $f$ ~17%)

+ Dipole magnet (0.5T)

Reduced acceptance for $x_{Bj}$ > 0.1

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Operation of the polarized target

Operation in longitudinal mode

- Polarization reversal with respect to m.f. (24h needed, once every ~2 weeks)
- Data taking
- Field rotation (20’ every ~8 hours)
- Data taking

Operation in transverse mode

- In principle, transverse polarization data can be taken at each field rotation → change of sign every 8 hours
- In practice, some beam magnets and beam detectors have to be displaced (dipole field)
- Data taken in blocks of ~1 week, with polarization reversal in between

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## Collected statistics

### 2002 run
- 1 period ~ 12 days ~ $1.1 \times 10^9$ events
  
  (July 31- Aug. 6; Aug. 8- Aug. 12)
- 1 period ~ 7 days ~ $0.7 \times 10^9$ events
  
  (Sept. 11- Sept. 13; Sept. 15- Sept. 18)

50 TB of raw data

### 2003 run
- 1 period ~ 14 days ~ $1.4 \times 10^9$ events
  
  (Aug. 20 - Aug. 26; Aug. 28 - Sept. 3/9)

44 TB of raw data

~ as in 2002 but with a more efficient high $Q^2$ trigger

### 2004 run
- We expect to collect ~ the same statistics of 2002+2003

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Transversity signals in COMPASS

Several channels have been proposed for looking at transversity signals

stronger effects expected with a transversely polarised target:

- Collins effect for leading pions
- Collins effect for all current fragmentation mesons
- Relative Collins effect between leading and subleading mesons
- Λ polarimetry
- ...

with longitudinally polarized target

- single spin asymmetries
Transversity at CERN

HELP CERN/LEPC 93 -14 LEPC/ P7 September 29, 1993, a proposal for an internal jet-target experiment at LEP
L. Dick, A. Penzo, B. Vauridel, ….

the case for transversity
X. Artru, J. Collins, A. Kotzinian, …
Workshop in Geneva organised by R. Hess (March ’93)

taken up in 1994 by HMC
LoI CERN/SPSLC 95 -27 SPSC/I204 March 28, 1995

and then by COMPASS

presently being investigated by HERMES

an important part of the RHIC programme

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Collins effect for leading pions

spelled out in our Proposal

the fragmentation function of a quark of flavor $a$ in an hadron $h$ can be written as

$$D_a^h(z, \vec{p}_T^h) = D_a^h(z, p_T^h) + \Delta D_a^h(z, p_T^h) \cdot \sin \Phi_c$$

where

- $\vec{p}_T^h$ is the final leading hadron* transverse momentum with respect to the quark direction (the virtual photon direction)
- $z = E_h/(E_\mu - E_{\mu'})$
- $\Phi_c = \Phi_h - \Phi_{s'}$ is the “Collins angle”

for sub-leading particle opposite sign

* experimentally, the leading hadron is the most energetic hadron produced in the event

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Collins angle \( \Phi_C = \Phi_h - \Phi_s' \)

Breit frame:
ref. system with z axis defined by \( \gamma \) direction and x-z plane defined by the scattering plane

- \( \Phi_h \): final leading hadron azimuthal angle around the final quark direction
- \( \Phi_s' \): azimuthal angle of the final quark transverse spin around the quark direction
- \( \Phi_s' = \pi - \Phi_s \)

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Collins effect for leading pions (cont.)

$\Delta_T q_a(x) = q_a^{uu}(x) - q_a^{dd}(x)$  \quad $q_a(x) = q_a^{uu}(x) + q_a^{dd}(x)$

+ and – indicate target polarization direction in the lab system “up” and “down”

calculating $\Phi_C$ as if the target polarization “up”

$$N_{h,a}^\pm \propto q_a^{uu} (D_a^h \pm \Delta D_a^h \cdot \sin \Phi_C) + q_a^{dd} (D_a^h \mp \Delta D_a^h \cdot \sin \Phi_C)$$

$$\propto q_a \cdot D_a^h \pm \Delta_T q_a \cdot \Delta D_a^h \cdot \sin \Phi_C$$

Summing on quark flavors and introducing
\begin{align*}
  f & = \text{polarized target dilution factor}, \\
  P_T & = \text{target nucleon polarization}, \\
  D & = (1-y)/(1-y-y^2/2)
\end{align*}

we measure

$$N_{h}^\pm (\Phi_C) = N_{h}^0 \cdot [1 \pm A_1 \cdot \sin \Phi_C]$$

and thus

$$A_1 = f \cdot P_T \cdot D \cdot A_{Coll} = f \cdot P_T \cdot D \cdot \frac{\sum_a e_a^2 \cdot \Delta_T q_a \cdot \Delta D_a^h}{\sum_a e_a^2 \cdot q_a \cdot D_a^h}$$
Collins effect for leading pions (cont.)

For $\pi^\pm$, assuming $D_1 = D_{u}^{\pi^+} = D_{d}^{\pi^-} = D_{u}^{\pi^-} = D_{d}^{\pi^+}$ and $D_2 = D_{u}^{\pi^-} = D_{d}^{\pi^+} = D_{u}^{\pi^+} = D_{d}^{\pi^-}$,

1. With a proton polarized target, combining $\pi^+$ and $\pi^-$ we can measure

$$A_{i}^{p1} = f_{p} \cdot P_{T}^{p} \cdot D \cdot \frac{4\Delta_{T}u + \Delta_{T}d}{4u + d + 4\bar{u} + d} \cdot \frac{4\Delta_{T}\bar{u} + \Delta_{T}d}{4\bar{u} + d + 4u + d} \cdot \frac{\Delta D_{1} + \Delta D_{2}}{D_{1} + D_{2}}$$

2. With a deuteron target

$$A_{i}^{d1} = f_{d} \cdot P_{T}^{d} \cdot D \cdot \frac{\Delta_{T}u + \Delta_{T}d + \Delta_{T}\bar{u} + \Delta_{T}d}{u + d + \bar{u} + d} \cdot \frac{\Delta D_{1} + \Delta D_{2}}{D_{1} + D_{2}}$$

$$A_{i}^{d2} = f_{d} \cdot P_{T}^{d} \cdot D \cdot \frac{3(\Delta_{T}u + \Delta_{T}d)}{5(u + d + \bar{u} + d)} \cdot \frac{\Delta D_{1} - \Delta D_{2}}{D_{1} + D_{2}}$$

a smaller signal is expected

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Analysis of 2002 data

• Data selection

• Event selection

• Preliminary results

• Monte Carlo studies

• Systematics
Data selection

Many tests to check the stability of the apparatus during data taking:

after a first filtering of the data on logbook basis,

- profiles on the tracker planes
- track reconstruction and vertex reconstruction
- angular distributions and kinematical variable distributions
dividing the data taking periods in blocks of ~ 10 h

13 runs / 470 runs rejected (~3% of the events)

separate analysis for the 2 periods of data taking
Event selection

Requirements:
- primary vertex with identified $\mu, \mu'$
- $Q^2 > 1 \text{(GeV/c)}^2$
- $0.1 < y < 0.9$
- $W > 5 \text{ GeV/c}^2$
- incident muon inside the two target cells and primary vertex inside the target cells
Event selection

Requirements (cont.):

- **Leading hadron (l.h.):**
  - at least 1 charged hadron from primary vertex with less than 10 radiation lengths
  - energy deposit in HCALs > 5 or 8 GeV (if signal)
  - $p_T > 0.1$ GeV/c
  - if $z < 1 - z_{\text{tot}}$, no cluster in HCALs corresponding to particles with no associated track and energy larger than the candidate leading hadron
  - $z > 0.25$
    - to eliminate events with real leading hadron not detected: neutral leading hadron, leading hadron not in acceptance, …
Final sample

Some distributions
Final sample

final statistics:

<table>
<thead>
<tr>
<th></th>
<th>1st period</th>
<th>2nd period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st orientation</td>
<td>2nd orientation</td>
</tr>
<tr>
<td>Cell 1</td>
<td>187k</td>
<td>203 k</td>
</tr>
<tr>
<td>Cell 2</td>
<td>257 k</td>
<td>278 k</td>
</tr>
</tbody>
</table>

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Asymmetry calculation

The asymmetry has been calculated separately for the events with positive and negative charge leading hadrons.

The data have been divided in 5 $x_{Bj}$ bins.

For each data taking period and each cell, the distributions

\[ \frac{N^+(\Phi_c) - R \cdot N^-(\Phi_c)}{N^+(\Phi_c) + R \cdot N^-(\Phi_c)} \]  \quad ( R = \frac{N^{+}_{tot}}{N^{-}_{tot}} )

have been fitted with the function

\[ c \cdot (1 + A_1 \cdot \sin \Phi_c) \]

all the 4 values the $A_1$ are in good agreement.

Finally, the "Collins" asymmetries

\[ A_{Coll} = \frac{1}{f \cdot D \cdot P_T} \cdot A_1 \]

have been evaluated and their values have been averaged.

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Results from 2002 data

positive leading hadrons

negative leading hadrons

preliminary
MonteCarlo studies

- to estimate the resolution in measured quantities
- to estimate the "contamination" of non leading hadrons in the final sample of reconstructed leading hadrons

MC events

- generated with Lepto 6.5.1 and the last version of COMGeant (trigger geometry and mean efficiency of trackers included)
- reconstructed using the same CORAL version used for DST production
- standard analysis but:
  - $\mu'$ selection: only $\mu'$ in SAS
  - leading hadron selection:
    - no $z_{tot}$ cut
    - HCALs not used

comparison with a small sample of real data

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Comparison MC - data

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MC studies: resolution in measured quantities

- resolution in the different quantities as requested from the measurements
- no signal dilution due to the resolution in the Collins angle and in \( z_{vtx} \)
MC studies: 
"contamination" of non leading hadrons

non leading hadrons in the final sample (wrongly reconstructed l.h.)
due to acceptance, neutral leading hadrons
[Collins effect for subleading hadrons]

--- all rec. l.h.
--- correctly rec. l.h.
--- correctly rec. l.h., but l.h. not a $\pi$

$z > 0.25$
still events with wrongly rec. l.h. at $z<0.45$

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MC studies:
"contamination" of non leading hadrons

wrongly reconstructed l.h.: ~ 20% of the final sample
SMALLER IN THE DATA: $z_{\text{tot}}$ and HCAL cuts not applied to Monte Carlo events

correctly rec. l.h., but l.h. not a $\pi$: ~ 20% of the final sample
mainly K (and p): RICH1 not yet used in the analysis

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Systematics

Several test have been performed to check the consistency of the result:

- it is free from acceptance effects only if the ratio of the acceptances and efficiencies in $\Phi_C$ for the two cells does not change from one orientation to the other

In particular

- Combining differently the cells
- Splitting of the cells in two parts
- Splitting the data in high and low hadron momenta
- Changing the $\Phi_C$ binning
- Use of a different estimator for $A_1$
- Check of possible variations of acceptance and efficiency
- ....
Variations of efficiency and acceptance

expected distributions in $\Phi_C$ for each $x_{Bj}$ bin

$$N_{1B}(\Phi_C) = c_{1B} \cdot a_{1B}(\Phi_C) \cdot [1 - A_1 \cdot \sin \Phi_C]$$
$$N_{2B}(\Phi_C) = c_{2B} \cdot a_{2B}(\Phi_C) \cdot [1 + A_1 \cdot \sin \Phi_C]$$
$$N_{1C}(\Phi_C) = c_{1C} \cdot a_{1C}(\Phi_C) \cdot [1 + A_1 \cdot \sin \Phi_C]$$
$$N_{2C}(\Phi_C) = c_{2C} \cdot a_{2C}(\Phi_C) \cdot [1 - A_1 \cdot \sin \Phi_C]$$

acceptance, efficiency

assuming

$$\frac{a_{2B}(\Phi_C)}{a_{1B}(\Phi_C)} = \frac{a_{2C}(\Phi_C)}{a_{1C}(\Phi_C)} = \alpha(\Phi_C)$$

it is

$$R(\Phi_C) = \frac{N_{1C}(\Phi_C) \cdot N_{2C}(\Phi_C)}{N_{1B}(\Phi_C) \cdot N_{2B}(\Phi_C)} = \frac{c_{1C} \cdot c_{2C}}{c_{1B} \cdot c_{2B}} \cdot \left[ \frac{a_{1C}(\Phi_C)}{a_{1B}(\Phi_C)} \right]^2$$

if $R$ does not depend on $\Phi_C$, the hypothesis done in the standard analysis is correct

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Variations of efficiency and acceptance (cont.)

Test on the dependence of $R$ on $\Phi_C$:

done for l.h.$^+$ and l.h.$^-$, for the two data taking periods

$R$ does not depend on $\Phi_C$ inside statistical errors

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Systematics: conclusion

All the tests we made are consistent with the fact that, systematic effects, if present, are smaller than statistical errors.
Conclusions and outlook

• COMPASS is in business !!!

• Within the statistics of the 2002 run, the measured Collins asymmetries for the leading hadron are compatible with zero.

• Combining the data of 2002, 2003, and 2004, the sensitivity should improve by at least a factor of 2.

• Systematic investigations of Collins (and Sivers) asymmetries for subleading hadrons still to be done.

  many results from deuteron target in the next future!

• Measurements with the polarized proton target from 2006.

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