New Measurements of $\Delta G/G$ at COMPASS

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on behalf of the COMPASS collaboration

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– Polarised DIS
– COMPASS experiment
– Longitudinal spin structure
– Gluon polarisation
– Summary and outlook
The spin of the nucleon

Naive parton model:

\[ \Delta \Sigma = \Delta u_v + \Delta d_v = 1 \]

E155

\[ \Delta \Sigma = 0.23 \pm 0.07 \pm 0.19 \]

Gluons important in unpolarized case

\[ \Delta G? \]

Complete description: orbital angular momenta

\[ S_N = \frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + L_q + L_g \]
Polarised DIS
Deep inelastic scattering

\[ Q^2 = -q^2 \quad x = Q^2 / 2M \nu \]
\[ \nu = E - E' \quad y = \nu / E \]
\[ z = E_h / \nu \]
\[ p_T : \text{hadron transverse momentum} \]
\[ D^h_q(x) : \text{fragmentation function} \]
\[ (\text{from quark } q \text{ into hadron } h) \]

- **Inclusive cross section**

\[
\frac{d^2\sigma}{d\Omega dE'} \sim \left( c_1 F_1(x, Q^2) + c_2 F_2(x, Q^2) + c_3 g_1(x, Q^2) + c_4 g_2(x, Q^2) \right)
\]

\[ F_1, F_2, g_1, g_2 \quad \text{structure functions} \]
Polarised deep inelastic scattering

- absorption of polarised photons (QPM)

\[ q(x) = q(x)^+ + q(x)^- \]
\[ \Delta q(x) = q(x)^+ - q(x)^- \]

+ quark \( \uparrow \uparrow \) nucleon
- quark \( \downarrow \uparrow \) nucleon

- photon nucleon asymmetry

\[ A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \approx \frac{\sum q e_q^2 (q(x)^+ - q(x)^-)}{\sum q e_q^2 (q(x)^+ + q(x)^-)} = \frac{g_1(x)}{F_1(x)} \]

- spin structure function

\[ g_1 = \frac{1}{2} \sum q e_q^2 \Delta q(x) = A_1 \cdot \frac{F_2}{2x(1 + R)} \approx \frac{A_\parallel}{D} \cdot \frac{F_2}{2x(1 + R)} \]
COMPASS at CERN
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Bielefeld, Bochum, Bonn, Burdwan/Calcutta, CERN, Dubna, Erlangen, Freiburg, Lissabon, Mainz, Moscow, Munic, Nagoya, Prague, Protvino, Saclay, Tel Aviv, Turino, Trieste, Warsaw

(28 institutes, 240 physicists)
Muon beam

160 GeV/c
2 \cdot 10^8 \mu/16.8 s
78% polarisation

Spectrometer

- Two stages: SM1 1Tm, SM2 4.5Tm
- Tracking: SciFi, Silicon, MicroMega, GEM, MWPC, Drift, Straws, Driftubes
- PID: RICH, ECAL, HCAL, muon filter
The polarised target

- Reconstructed interaction vertices

- target material: $^6$LiD
- polarisation: > 50%
- dilution factor: ~ 0.4
- Dynamic Nuclear Polarization
- solenoid field: 2.5 T
- $^3$He/$^4$He: $T_{\text{min}} \approx 50$ mK
- two 60 cm long target cells with opposite polarisation
- 2006 new solenoid with 180 mrad acceptance
- regular polarisation reversal by field rotation
Method

• to be measured:

\[ A_{\parallel} = \frac{\sigma_{\uparrow\downarrow} - \sigma_{\uparrow\uparrow}}{\sigma_{\uparrow\downarrow} + \sigma_{\uparrow\uparrow}} \]

• flux normalization:

\[ A_{\text{exp}} = \frac{N_u - N_d}{N_u + N_d} \]

• acceptance difference:

Polarisation rotation

• take average asymmetry:

\[ \Rightarrow A_{\text{exp}} = \frac{A + A'}{2} = \frac{1}{2} \left( \frac{N_u - N_d}{N_u + N_d} + \frac{N_d' - N_u'}{N_u' + N_d'} \right) \]

\[ \Rightarrow \ \text{minimization of bias} \]

• experimental asymmetry

\[ A_{\text{exp}} = p_\mu \ p_T \ f \ A_{\parallel} \]

\[ \frac{p_\mu, \ p_T}{f} \ \text{beam and target polarisation dilution factor} \]
New results on

- inclusive asymmetries
- open charm production
- high $p_T$ hadrons pairs
- $\Lambda$ polarisation
- exclusive $\rho$ production

<table>
<thead>
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<th>2002</th>
<th>2003</th>
<th>2004</th>
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<tr>
<td>Beam Time</td>
<td>106d</td>
<td>90d</td>
<td>110d</td>
</tr>
<tr>
<td>Preparation</td>
<td>30d</td>
<td>7d</td>
<td>3d</td>
</tr>
<tr>
<td>Integrated luminosity / fb$^{-1}$</td>
<td>1</td>
<td>1.2</td>
<td>$\sim$ 2.4</td>
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<td>(20% for transverse target polarisation)</td>
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Longitudinal spin structure
Inclusive asymmetries for $Q^2 > 1 \text{ GeV}^2$

- high statistics $A_1$ at low $x$, factor 2–3 improvement (PLB 612(2005) 154)
- $xg_1$ points at measured $Q^2$
- NLO QCD fit ($\overline{\text{MS}}$) to world data ($Q^2 = 3 \text{ GeV}^2$)

$$\Delta \Sigma = 0.25 \pm 0.02(\text{stat.}) \pm ?$$
$$\Delta G = 0.4 \pm 0.2(\text{stat.}) \pm ?$$

(error 0.03 without COMPASS data)
Inclusive asymmetries for $Q^2 < 1 \text{ GeV}^2$

- 2002 – 2003 data, COMPASS error 10 times smaller than previous measurement
- $A_1^d$ is compatible with 0 at small $x$
- more data for $Q^2 < 1 \text{ GeV}^2$ and $Q^2 > 1 \text{ GeV}^2$, semi-inclusive asymmetries
Longitudinal $\Lambda$ and $\bar{\Lambda}$ polarisation

- $\Lambda$ polarisation related to spin transfer from struck quark → sensitivity to $\Delta s$?
- 2003 data: $31000 \Lambda$, $18000 \bar{\Lambda}$ for $Q^2 > 1$ GeV$^2$
- more data from 2004
Hard exclusive $\rho^0$ production

- large statistics of diffractive $\rho$, $\Phi$, $J/\Psi$
- 2.4 M events with $\rho^0$ from 2002 and 2003
- large range in $Q^2$ and $x$
- $A_1$ for $\rho^0$ compatible with zero, more data from 2004
- measurement of spin density matrix elements
Gluon polarisation
**ΔG/G measurement in DIS**

- **Photon gluon fusion**

\[ \gamma^* q \rightarrow \mu \mu' G \]

\[ A_{\gamma N}^{PGF} = \frac{\int d\hat{s} \Delta \sigma_{PGF} \Delta G(x_g, \hat{s})}{\int d\hat{s} \sigma_{PGF} G(x_g, \hat{s})} \approx \langle a_{LL}^{PGF} \rangle \frac{\Delta G}{G} \]

\[ \langle a_{LL}^{PGF} \rangle \text{ analysing power} \]

- **Methods**

  - **Open charm production**
    \[ \gamma g \rightarrow c\bar{c} \rightarrow D^0 \rightarrow \pi K \quad \text{BR: 4%} \]
    hard scale: \( m_c^2 \)
    clean channel, limited statistics

  - **High \( p_T \) hadron pairs**
    \[ \gamma g \rightarrow q\bar{q} \rightarrow 2 \text{ jets or } H^+H^- \]
    hard scale: \( Q^2 \) or \( \Sigma p_T^2 \)
    oppositely charged hadrons pairs with large \( p_T \) und \( \Delta \Phi \approx \pi \)
Untagged: $D^0 \rightarrow K\pi$

Tagged: $D^* \rightarrow D^0 \pi_{\text{slow}} \rightarrow (K\pi)\pi_{\text{slow}}$

- no decay vertex reconstruction
- Kaon identification by RICH essential
- cut on $D^0$ kinematics ($z_{D^0}, \cos(\theta)$)
- effective signal: $S_{\text{eff}} = \frac{S}{1 + S/B}$
- weighting method used ($p_{\mu} p_{\text{T}} f a_{\text{LL}} \frac{S}{S+B} \frac{\Delta G}{G}$)

- cut on mass difference $M_{K\pi\pi} - M_{K\pi} - M_{\pi}$
- 3900 $D^0$ from $D^*$
- experimental asymmetry $A_{\text{exp}} = p_{\mu} p_{\text{T}} f a_{\text{LL}} \frac{S}{S+B} \frac{\Delta G}{G}$
Extraction of $\Delta G/G$

- $\langle a_{LL}^{PGF} \rangle$ not exactly calculable from data
- MC with AROMA generator
- good description of data distributions by MC
- parametrisation determined with neural net
- preliminary result
  at $\langle x_g \rangle = 0.15$ (RMS: 0.08)
  from 2002–2004

$\Delta G/G = -0.57 \pm 0.41$ (stat)

- systematic error under study
e.g false asymmetries, background asymmetries
High $p_T$ hadron pairs ($Q^2 > 1$ GeV$^2$)

- contributions to experimental asymmetry

\[ \frac{A_{||}}{D} = R_{PGF} \left\langle \frac{A_{PLG}^{PGF}}{D} \right\rangle \frac{\Delta G}{G} + \left( R_{QCDC} \left\langle A_{QL}^{QCD} \right\rangle + R_{LO} \left\langle A_{QL}^{LO} \right\rangle \right) A_1^d \]

- Monte Carlo for $R$, $\left\langle A_{LL} \right\rangle$

- data selection

  Current fragmentation: $x_F > 0.1$ and $z > 0.1$

  Radiative corrections/ photon polarisation: $0.1 < y < 0.9$

  High $p_T$: $p_{T,1}, p_{T,2} > 0.7$ GeV and $p_{T,1}^2 + p_{T,2}^2 > 2.5$ GeV$^2$
**ΔG/G for Q^2 > 1 GeV^2**

- 2002/03 data (prelim.)
  
  \[ A_{||}/D = -0.015 \pm 0.080 \text{(stat.)} \pm 0.013 \text{(syst.)} \]

- Monte Carlo sample generated with LEPTO reasonable agreement with data

- additional x cut ⇒ \( A_{d}^{1} \) small, LO and QCDC neglected

- preliminary result:
  
  \[ \langle \frac{A_{LL}^{PGF}}{D} \rangle = -0.75 \pm 0.05 \]
  
  \[ R_{PGF} = 0.33 \pm 0.07, \langle x_g \rangle = 0.13 \text{ (RMS=0.08)} \]

\[ \Delta G/G = 0.06 \pm 0.31 \text{ (stat.)} \pm 0.06 \text{ (syst.)} \]

- main contribution to systematic error: false asymmetries

- only 10% of statistics at \( Q^2 > 1 \text{ GeV}^2 \)

- expectation 2002–2004: \( δ(ΔG/G) = 0.22 \)

- improvement by neural net selection studied

- single hadron analysis started
\( \Delta G/G \) for \( Q^2 < 1 \) GeV\(^2\)

- much more statistics (500k events from 2002–2004) but additional background from resolved photon processes
- data selection similar to large \( Q^2 \) but \( 0.35 < y < 0.9 \)
- preliminary result with \( \langle D \rangle = 0.64 \)

\[
A_{\parallel}/D = 0.004 \pm 0.013 \text{ (stat.)} \pm 0.003 \text{ (exp.syst.)}
\]

- MC simulation with PYTHIA compared to data (blue points)
Contributions to asymmetry

- LO, low $p_T$ neglected
Estimate of resolved photon contribution

- polarised PDFs in deuteron and photon needed
- polarised photon PDFs are sum of non perturbative and perturbative part
- estimate non perturbative contribution from unpolarised photon PDFs:

\[-q_{\text{VMD}}^\gamma < \Delta q_{\text{VMD}}^\gamma < q_{\text{VMD}}^\gamma\]

- use as contribution to systematic error

Preliminary result

- determination of $R_{\text{PGF}}$ and $a_{\text{LL}}$ from Monte Carlo
- most sensitive parameters in PYTHIA: $k_N^T$ and $k_N^\gamma$

$$\frac{\Delta G}{G}(x_g = 0.085^{+0.07}_{-0.035}, \mu^2 = 3 \text{ GeV}^2) = 0.016 \pm 0.058(\text{stat.}) \pm 0.055(\text{syst.})$$

- systematic error includes exp. syst.(0.014) (mainly false asymmetries), MC syst.(0.052) and estimate of photon contribution (0.013)
\[ \Delta G/G \text{ measurements in DIS} \]

\[ \int G(x) dx = 2.5 \]

\[ \Delta G/G \text{ is small or has a node around } x_g \approx 0.1 \]

HERMES, all \( Q^2 \)

SMC \( Q^2 > 1 \text{ (GeV/c)}^2 \)

COMPASS, \( Q^2 > 1 \text{ (GeV/c)}^2 \) (02-03, prelim)

COMPASS, \( Q^2 < 1 \text{ (GeV/c)}^2 \) (02-04, prelim)

COMPASS, open charm (02-04, prelim)
Summary and outlook

- New results from COMPASS from 2002 – 2004 data
- Gluon polarisation measured with several methods
- New precise data for the longitudinal spin structure function at small $x$
- Results on $\rho$ meson production, $\Lambda$ polarisation

Plans:

- data taking continues in 2006, $^6$LiD for longitudinal polarisation, NH$_3$ for transverse polarisation
- new target solenoid $\Rightarrow$ larger hadron acceptance
- improvement of RICH (electronics, photon detection)
- many other detector upgrades

$\Rightarrow$ we hope to double the statistics for most channels