$A_1^p$ and $g_1^p$ at low $x$ and low $Q^2$ from COMPASS

Ana Sofia Nunes (LIP-Lisbon)
on behalf of the COMPASS Collaboration

DSPIN-2013, Dubna, Russia
October 8th, 2013
Outline

1 Motivation
2 Definitions
3 The COMPASS experiment
4 Previous COMPASS results
5 Data sample for the extraction of $A_1^p$ and $g_1^p$
6 Double spin longitudinal asymmetry $A_1^p$
7 Spin dependent structure function $g_1^p$
8 Summary and outlook
Motivation
Motivation

- Low $x \Leftrightarrow$ high parton densities

- Fixed target experiments $\Leftrightarrow$ strong correlation between $x$ and $Q^2$: low $x$ $\Rightarrow$ low $Q^2$, where pQCD isn’t expected to work

- Some models, to be confronted with data, allow a smooth extrapolation to the low-$Q^2$ and high-$Q^2$ regions (resummation, VDM)

- Structure function $g_{1}^{NS} = g_{1}^{p} - g_{1}^{n}$:
  - decouples from gluons
  - predicted by models
  - can be measured with improved precision by COMPASS

- The results will be presented also as functions of $\nu$, as requested by theoreticians
Definitions
Spin independent and spin dependent DIS cross sections

For a longitu[di]nally/transversely polarised proton target (with spin $\Rightarrow$ and $\Leftarrow$ / $\uparrow$ and $\downarrow$) and a longitudinally polarised lepton beam (with spin $\rightarrow$):

**Unpolarised differential cross-section**

\[
\left( \frac{d^2\sigma \Rightarrow}{d\Omega dE'} + \frac{d^2\sigma \Leftarrow}{d\Omega dE'} \right) = \frac{\alpha^2}{4E^2 \sin^4 \frac{\theta}{2}} \left[ 2\sin^2 \frac{\theta}{2} F_1(x, Q^2) + \frac{M}{\nu} \cos^2 \frac{\theta}{2} F_2(x, Q^2) \right]
\]

**Longitudinal differential cross-section asymmetry**

\[
\left( \frac{d^2\sigma \Rightarrow}{d\Omega dE'} - \frac{d^2\sigma \Leftarrow}{d\Omega dE'} \right) = \frac{4\alpha^2}{\nu Q^2 E} \frac{E'^2}{M\nu} \left[ (E + E' \cos \theta) g_1(x, Q^2) - 2xM g_2(x, Q^2) \right]
\]

**Transverse differential cross-section asymmetry**

\[
\left( \frac{d^2\sigma \uparrow}{d\Omega dE'} - \frac{d^2\sigma \downarrow}{d\Omega dE'} \right) = \frac{4\alpha^2}{\nu Q^2 E} \sin \theta \left[ g_1(x, Q^2) + \frac{2E}{\nu} g_2(x, Q^2) \right]
\]

g_2 term suppressed relative to g_1 term $\Rightarrow$ At COMPASS, a longitudinally polarised muon beam and a longitudinally polarised target with protons allow the measurement of $g_1(x, Q^2)$

$A_1^p$ and $g_1^p$ at low $x$ and $Q^2$ (COMPASS)
Spin dependent observables

**Experimental asymmetry**

\[ A_{\text{exp}} = \frac{N \leftrightarrow - N \Rightarrow}{N \leftrightarrow + N \Rightarrow} = P_{\text{beam}} P_{\text{target}} f A_{\parallel} \]

\( f \): dilution factor (of the target)

**Lepton-nucleon asymmetry**

\[ A_{\parallel} = \frac{d\sigma \leftrightarrow - d\sigma \Rightarrow}{d\sigma \leftrightarrow + d\sigma \Rightarrow} = D (A_1 + \eta A_2) \]

\( D \): (virtual photon) depolarisation factor

\( \eta \) - kinematic variable. COMPASS case: \( \eta \sim 0 \rightarrow A_1 \sim A_{\parallel}/D \)

**Virtual photon-nucleon asymmetry**

\[ A_1 = A_1^{\gamma^* N} = \frac{\sigma_1/2 - \sigma_3/2}{\sigma_1/2 + \sigma_3/2} = \frac{g_1 - \gamma^2 g_2}{F_1} \sim \frac{g_1}{F_1} \]

\[ A_2 = \gamma \frac{g_1 + g_2}{F_1} \sim 0 \]

\( \gamma \) - kinematic variable (small at COMPASS)

**Spin dependent structure function \( g_1 \)**

\[ g_1(x, Q^2) = \frac{F_2(x, Q^2)}{2x(1 + R(x, Q^2))} A_1(x, Q^2), \quad \text{with} \quad R \equiv \sigma_L/\sigma_T \]
The COMPASS experiment
Fixed target experiment at the SPS using a tertiary muon beam or a secondary hadron beam

Collaboration of around 220 members from 13 countries and 24 institutions
COMPASS spectrometer

- 160/200 GeV $\mu^+$ (or $\mu^-$) naturally polarised beams or 190 GeV hadron beams (positive or negative)
- $^6\text{LiD}$ or $\text{NH}_3$, 1.2 m long, polarised target

- large acceptance, two staged spectrometer
- tracking
- calorimetry
- RICH
Polarised target

$^6\text{LiD} (2002-2006): f \sim 40\%, P_{\text{target}} \sim 50\%$

$\text{NH}_3 (2007-2011): f \sim 16\%, P_{\text{target}} \sim 85\%$

$N \leftrightarrow = a_φ n \bar{\sigma} (1 \pm P_{\text{beam}} P_{\text{target}} f_{\text{DA}})$

Cancellation of $a_φ n \bar{\sigma}$ via:

- **flux cancellation**
  - beam or extrapolation must cross all the target cells

- **acceptance cancellation**
  - 3 target cells
  - polarisation rotation every 24 hours
  - grouping of runs in $\sim 48$ h long configurations
  - reversal of “microwave setting” at least once per year
Previous COMPASS results
COMPASS published $A_{1}^{p,d}$ data

<table>
<thead>
<tr>
<th></th>
<th>$Q^2 &lt; 1 ,(\text{GeV/c})^2$</th>
<th>$Q^2 &gt; 1 ,(\text{GeV/c})^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{1}^{d}$</td>
<td>![Graph](COMPASS, PLB 647 (2007) 330)</td>
<td>![Graph](COMPASS, PLB 647 (2007) 8)</td>
</tr>
<tr>
<td>$A_{1}^{p}$</td>
<td>![Graph](COMPASS, PLB 690 (2010) 466)</td>
<td>![Graph](COMPASS, PLB 690 (2010) 466)</td>
</tr>
</tbody>
</table>

$A_{1}^{p}$ and $g_{1}^{p}$ at low $x$ and $Q^2$ (COMPASS)

→ more in A. Ivanov’s talk

Ana S. Nunes (LIP-Lisbon)
COMPASS published $g_{1}^{p,d}$ data

<table>
<thead>
<tr>
<th>$Q^2 &lt; 1 \ (GeV/c)^2$</th>
<th>$Q^2 &gt; 1 \ (GeV/c)^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$g_{1}^{d}$</td>
<td>$x_{g}^{d}(x)$</td>
</tr>
<tr>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
</tr>
</tbody>
</table>

[COMPASS, PLB 647 (2007) 330]  
[COMPASS, PLB 647 (2007) 8]  

$g_{1}^{p}$

![Graph](image3.png)

[COMPASS, PLB 690 (2010) 466]  
$\leftrightarrow$ more in A. Ivanov’s talk
Data sample for the extraction of $A_1^p$ and $g_1^p$
Data sample for the extraction of $A_1^p$ and $g_1^p$

- Longitudinally polarised target ($\text{NH}_3$): $676 \times 10^6$ events
  (447 $\times 10^6$ with 160 GeV beam in 2007, 229 $\times 10^6$ with 200 GeV beam in 2011)

- Before, SMC low $x$, low $Q^2$ proton data: $4.5 \times 10^6$ events
  $\Rightarrow$ The COMPASS data set has $150 \times$ more events than SMC

Main selection criteria:

- at least one additional track (besides the scattered muon) in the interaction vertex
  (“hadron method”)

- not a $\mu e$ elastic scattering event

- $Q^2 < 1$ (GeV/$c$)$^2$

- $x \geq 4 \times 10^{-5}$

- $0.1 < y < 0.9$
Removal of $\mu e$ elastic scattering events for 2007 data

$q^\theta*$: charge $\times$ angle of the track with respect to the virtual photon direction

The cut effectively eliminates the $\mu e$ events from the sample.
Kinematic variables of the final samples

\[ x \quad Q^2 \text{(GeV/c)}^2 \]

- 160 GeV beam (2007)
- 200 GeV beam (2011)

\( \nu \) (GeV)
\( W \) (GeV)

COMPASS Preliminary

Ana S. Nunes (LIP-Lisbon)
Features of the final samples

\[ \langle Q^2 \rangle \ (\text{GeV}/c)^2 \text{ vs } \langle x \rangle \]

\[ \langle x \rangle \text{ vs } \langle \nu \rangle \ (\text{GeV}) \]

- \[ \langle Q^2 \rangle \ (\text{GeV}/c)^2 \text{ vs } \langle x \rangle \]
- \[ \langle x \rangle \text{ vs } \langle \nu \rangle \ (\text{GeV}) \]

\[ \langle f \rangle \text{ vs } x \]

\[ \langle D \rangle \text{ vs } x \]
Double spin longitudinal asymmetry $A_1^p$
Double spin longitudinal asymmetry $A_1^p$

- Obtained giving each event a weight $\omega = fD|P_b|$ (→ details in A. Ivanov’s talk)

- Unpolarised radiative corrections (RC), included in the dilution factor, from TERAD

- Polarised radiative corrections ($A^{RC} \leq 0.25 \delta A_{1\text{stat}}$) from POLRAD

- Corrected for polarisable $^{14}\text{N}$ ($A^{^{14}\text{N}} \leq 0.01 \delta A_{1\text{stat}}$)

- Thorough checks on possible sources of false asymmetries (which dominate the systematic error) ⇒ systematic errors are smaller than the statistical errors
New results for $A_1^p$ as a function of $x$

The results for the two beam energies are compatible within errors. The systematic errors are smaller than the statistical errors. The asymmetries are mostly incompatible with zero and positive.
The results for the two beam energies are compatible within errors. The systematic errors are smaller than the statistical errors. The asymmetries are mostly **incompatible with zero and positive**. No special dependence with \( \nu \) is observed.
Spin dependent structure function $g_1^p$
Spin dependent structure function $g_1^p$

- The structure function is obtained in bins of $x$ or $\nu$ according to:

$$g_1^p = \frac{F_2^p (\langle x \rangle, \langle Q^2 \rangle)}{2x \left[ 1 + R (\langle x \rangle, \langle Q^2 \rangle) \right]} A_1^p$$

- $F_2^p (\langle x \rangle, \langle Q^2 \rangle)$ from the SMC fit on data or from a model (for low $x$ and $Q^2$)

- $R (\langle x \rangle, \langle Q^2 \rangle)$ from data or from a parameterisation (for low $x$)
  [COMPASS, PLB 647 (2007) 330]
New results for $g_1^p$ as a function of $x$

The results for the two beam energies are compatible within errors.
The systematic errors are smaller than the statistical errors.
$g_1^p$ is mostly incompatible with zero and positive.
New results for $g_1^p$ as a function of $\nu$

The results for the two beam energies are compatible within errors. The systematic errors are smaller than the statistical errors. $g_1^p$ is mostly **incompatible with zero and positive**. No special dependence with $\nu$ is observed.
Summary and outlook
Summary and outlook

Done

- $A_1^p$ and $g_1^p$ measured for $0.001 < Q^2 < 1 \text{ (GeV/c)^2}$, $4 \times 10^{-5} < x < 4 \times 10^{-2}$, and $14 < \nu < 194 \text{ GeV}$, in bins of $x$ or in bins of $\nu$

- Total statistics 150 times larger than SMC

- Results from data at 160 GeV and 200 GeV are compatible

- Results of $A_1^p$ and $g_1^p$ are incompatible with zero and positive

Next

- Obtain $g_1^{NS}$ from $g_1^p$ and $g_1^d$. Fit data to models.

- Extract asymmetries and $g_1^p$ in 2D bins, e.g. $(x, Q^2)$. Extract $A_1^d$ and $g_1^d$ from the full COMPASS deuteron data (2002-2006) in bins of $\nu$.  

$A_1^p$ and $g_1^p$ at low $x$ and $Q^2$ (COMPASS)

Ana S. Nunes (LIP-Lisbon)

October 8th, 2013 29 / 34
BACKUP
Target polarisation in 2011

![Graph of target polarization over runs](image)

**COMPASS 2011**

Preliminary

$A_{1}^{D}$ and $g_{1}^{D}$ at low $x$ and $Q^2$ (COMPASS)
$Z$ position of the primary vertices (DIS sample)

(The cut on $Z_{PV}$ is missing.)
Removal of $\mu e$ elastic scattering events for 2011 data

$q\theta^*: \text{charge} \times \text{angle of the track with respect to the virtual photon direction}$

The cut effectively eliminates the $\mu e$ events from the sample.
Polar angle of the scattered muon in the laboratory frame

\[ \theta_0 \]

Graph showing the polar angle of the scattered muon in the laboratory frame, with two datasets for 160 GeV beam (2007) and 200 GeV beam (2011) and their respective counts in thousands.