Results on $A_1^p$ and $g_1^p$ from 2011 COMPASS data

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Outline

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2. Asymmetry extraction

3. Results

4. Outlook and Summary
Motivation

Spin Contribution:

\[ S = \frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + L \]
\[ \Delta \Sigma = \Delta u + \Delta d + \Delta s \]

- Quarks spin contributes only 30% to the nucleon spin
- Gluon contribution known only for a limited x range
- Hardly any experimental information on orbital angular momentum
Deep Inelastic Scattering

- 4-momentum of the virtual photon: \( q = k - k' \)
- Energy of the virtual photon:
  \[ \nu = \frac{Pq}{M} \approx E - E' \]
- \( Q^2 = -q^2 \approx 4EE' \sin^2 \frac{\theta}{2} \)
- Bjorken scaling variable:
  \[ x_{\text{lab}} = \frac{Q^2}{2M\nu} \]
- \( y_{\text{lab}} = \frac{\nu}{E} \)

Inclusive cross section:

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

\[ \text{spin independent} \]

\[ \text{spin dependent} \]
Polarised Deep Inelastic Scattering

- Absorption of polarised photons
  \[ \sigma_{1/2} \sim q^+ \]
  \[ \sigma_{3/2} \sim q^- \]
- \( q(x) = q(x)^+ + q(x)^- \)
  \( \Delta q(x) = q(x)^+ - q(x)^- \)

Photon nucleon asymmetry

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

Spin structure function

\[ g_1(x, Q^2) = \frac{1}{2} \sum_q e_q^2 \Delta q(x) = A_1(x, Q^2) \cdot F_1(x, Q^2) \]
Bjorken Sum Rule

\[ \int_0^1 g_{1NS}^{NS}(x, Q^2) \, dx = \int_0^1 (g_{1}^{p}(x, Q^2) - g_{1}^{n}(x, Q^2)) \, dx = \frac{1}{6} \left| \frac{g_A}{g_V} \right| C_{1NS}(Q^2) \]

Previous results
- \( g_{1NS}^{NS} \) determined only from COMPASS data @ \( Q^2 = 3 \) (GeV/c)^2
- \( \left| \frac{g_A}{g_V} \right| = 1.2694 \pm 0.0028 \) obtained from neutron \( \beta \)-decay.
- COMPASS result: \( \left| \frac{g_A}{g_V} \right| = 1.28 \pm 0.07 \pm 0.10 \)
- Verification of the Bjorken sum rule
Bjorken Sum Rule

\[
\int_0^1 g_{1NS}^N(x, Q^2) dx = \int_0^1 \left( g_{1}^p(x, Q^2) - g_{1}^n(x, Q^2) \right) dx = \frac{1}{6} \left| \frac{g_A}{g_V} \right| C_{1NS}^N(Q^2)
\]

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Verification of the Bjorken sum rule
Polarised PDFs from LO fit

\[ A_1^h(x, z) = \frac{\sum_q e_q^2 (\Delta q(x)D^h_q(z) + \Delta \bar{q}(x)D^h_{\bar{q}}(z))}{\sum_q e_q^2 (q(x)D^h_q(z) + \bar{q}(x)D^h_{\bar{q}}(z))} \]

Previous results

- **Input:**
  - Unpolarised PDF \( q(x), \bar{q}(x) \)
  - Fragmentation function \( D^h_q, D^h_{\bar{q}} \) describing \( q \rightarrow h \)

- **Measured:**
  - \( A_{1p}, A_{1p}^{\pi^+}, A_{1p}^{\pi^-}, A_{1p}^{K^+}, A_{1p}^{K^-}, \)
  - \( A_{1d}, A_{1d}^{\pi^+}, A_{1d}^{\pi^-}, A_{1d}^{K^+}, A_{1d}^{K^-} \)

- **Flavor asymmetry of the sea**
Flavor asymmetry of the sea

- Compatible with zero
- Indication: Slightly positive
- Data compatible with all shown models $\rightarrow$ new data needed
- Data favour models with $\Delta \bar{u} - \Delta \bar{d} \approx \bar{d} - \bar{u}$

$$\int_{0.004}^{0.3} (\Delta \bar{u} - \Delta \bar{d}) \, dx = 0.06 \pm 0.04 \pm 0.02$$
**NLO pQCD analyses**

- **DGLAP equations**

\[
\frac{d}{d \ln Q^2} \Delta q_{NS} = \frac{\alpha_s(Q^2)}{2\pi} \Delta P_{qq}^{NS} \otimes \Delta q_{NS}
\]

\[
\frac{d}{d \ln Q^2} \left( \begin{array}{c} \Delta q_{Si} \\ \Delta g \end{array} \right) = \frac{\alpha_s(Q^2)}{2\pi} \left( \begin{array}{cc} \Delta P_{qq}^S & 2n_f \Delta P_{qg} \\ \Delta P_{gq} & \Delta P_{gg} \end{array} \right) \otimes \left( \begin{array}{c} \Delta q_{Si} \\ \Delta g \end{array} \right)
\]

- **Input parameterization** \( F \) of \( \Delta q_{Si}, \Delta q_3, \Delta q_8, \Delta g \) at \( Q_0^2 \)

\[
F = \eta \frac{x^\alpha(1-x)^\beta(1+\gamma x)}{\int_0^1 x^\alpha(1-x)^\beta(1+\gamma x)dx}
\]

with \( \Delta q_{Si} = \Delta u + \Delta d + \Delta s, \Delta q_3 = \Delta u - \Delta d, \Delta q_8 = \Delta u + 2\Delta d - \Delta s \)

- using only inclusive asymmetries quarks and antiquarks cannot be disentangled e.g. determination of \( \Delta u + \Delta \bar{u}, \Delta d + \Delta \bar{d}, \Delta s + \Delta \bar{s} \) and \( \Delta g \)

- many analyses from different groups ( theor. and exp.)
  e.g. COMPASS, LSS, GRSV, BB, AAC, DSSV......
Polarised parton distributions

**COMPASS QCD fit, $\overline{M}\bar{S}$, $Q^2=3$(GeV/c)$^2$, $\Delta G>0$**

- $x (\Delta u+\Delta \bar{u})$
- $x (\Delta d+\Delta \bar{d})$
- $x (\Delta s+\Delta \bar{s})$
- $x \Delta G$

**COMPASS QCD fit, $\overline{M}\bar{S}$, $Q^2=3$(GeV/c)$^2$, $\Delta G<0$**

- $x (\Delta u+\Delta \bar{u})$
- $x (\Delta d+\Delta \bar{d})$
- $x (\Delta s+\Delta \bar{s})$
- $x \Delta G$

- Small sensitivity to light sea and gluon polarisation
- Quark polarisation $\Delta \Sigma = \int \Delta q_S(x) dx$
- $\Delta \Sigma = 0.30 \pm 0.01$ (stat) $\pm 0.02$ (evol)
- Gluon polarisation $\Delta G = \int \Delta g(x) dx \quad |\Delta G| < 0.5$
- Strange quark polarisation $\Delta s + \Delta \bar{s} = -0.08 \pm 0.01$ (stat) $\pm 0.02$ (syst)
• SPS proton beam: 400 GeV
• Secondary hadron beams ($p, K, \pi$) 150 – 270 GeV
• Tertiary muon beam 160 – 200 GeV
COMPASS @ CERN

- M2 beamline
- Polarised $\mu$ beam ($\sim 80\%$)
  160 GeV/c, 200 GeV/c
- Solid state polarised target (1.2m)

Spectrometer

- Two magnets
- Tracking ($p > 0.5$ GeV/c)
  SciFi, Silicon MicroMega, Gem
  MWPC, Drift, Straws, Driftubes
- PID: RICH($\pi$, $K$, $p$)
  ECAL, HCAL, muon filters
Polarised target

- Upgrade of the target system in 2005
- Three target cells, oppositely polarised
- 180 mrad geometrical acceptance
- Regular polarisation reversals by field rotation
- 2.5 T solenoid field
- Low temperature 50 mK
- NH$_3$ (Longitudinal proton polarisation: $\sim 90\%$)
Method

- **Aim:**
  \[ A = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} \]

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

- **Needed:**
  - Flux cancellation
  - Acceptance cancellation
    \[ \rightarrow \text{polarisation rotation} \]
    \[ \rightarrow 3 \text{ target cells} \]
  - \[ A_{\text{exp}} = A \cdot P_B \cdot P_T \cdot f \]

- **Averaging:**
  \[ A_{\text{exp}} = \frac{A + A'}{2} = \frac{1}{2} \left( \frac{N_u - N_d}{N_u + N_d} + \frac{N'_u - N'_d}{N'_u + N'_d} \right) \]
2011 Data

2007 and 2011 data taking
- Target: NH$_3$
- Increased beam energy
  160 GeV → 200 GeV
- Higher $Q^2$
- Smaller $x$

Improve results on
- Bjorken sum rule (systematic error)
- QCD fit
- Flavor asymmetry

Event selection
- Kinematic cuts:
  - $Q^2 > 1$ (GeV/c)$^2$
  - $0.1 < y < 0.9$ remove radiative events
  - $0.0025(0.0040) < x < 0.7$
- Extrapolated beam track crosses all target cells
  → Flux cancellation
Systematic studies

- Determination of the exact target position
- Checking the data quality
  → e.g. Influence of small detector movements, detector problems,…
- Most important contribution to the systematic error
  → False asymmetries
    - Fake configuration (same spin orientation)
Microwave reversal

- Simultaneous data taking for both spin configurations
Microwave reversal

- Simultaneous data taking for both spin configurations
- Rotating the solenoid field every 24 h

Solenoid field reversal
Microwave reversal

- Simultaneous data taking for both spin configurations
- Rotating the solenoid field every 24 h
- Changing the microwave settings in the middle of 2011
- Reducing the systematic uncertainty due to acceptance / field differences
- Comparing results on $A_1$ for both microwave settings gives hint on false asymmetries \(\Rightarrow\) Negligible effect
Input for $A_1^p$

- **Target polarization in %**
  - COMPASS 2011 Preliminary
  - Upstream cell
  - Center cell
  - Downstream cell

- **Q^2 (GeV^2/c^2)**
  - COMPASS 200 GeV preliminary
  - COMPASS 160 GeV

- **Run**
  - 92000, 92500, 93000, 93500, 94000, 94500, 95000, 95500, 96000

- **Dilution factor**
  - Inclusive Triggers
  - Hadron Triggers
  - COMPASS 2011 Preliminary

- **78 \cdot 10^6 Events**

- **Dilution factor includes radiative corrections**

- **Higher $Q^2$ / Smaller $x$ in 2011**

- **Reach $x \sim 10^{-3}$ in polarised DIS**
Results for $A_1^p$ in bins of $x$

- Good agreement between COMPASS 2011/07 and SMC
- Combined statistical uncertainty (2011 + 2007) smaller than SMC
- $g_1^p(x, Q^2) = A_1^p \cdot F_1^p$
$Q^2$ dependence of $A_{1p}$

- No $Q^2$ dependence visible
- New data point at very small $x$
Results in bins of $x$ and $Q^2$

- COMPASS 2011 (200 GeV)
- COMPASS 2007 (160 GeV)
- LSS’05 fit at NLO
- New data point at very low $x$
- New input for global QCD fit
- Indirect $\Delta G$ extraction
Summary and Outlook

- New measurement at 200 GeV/c
- Measurement of $A_1^p$ and $g_1^p$
  - New value at small $x$
  - 2011 data improve the precision of the COMPASS results
- Outlook
  - Improve the results on the test of the Bjorken sum rule
  - Identified hadron asymmetry
  - LO extraction of polarised PDFs
  - Include our results in a NLO pQCD fit