COMPASS Results on the Strange Quark Polarisation

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on behalf of the COMPASS Collaboration

- The $g_1$ structure function
- Longitudinal spin structure functions
- The strange quark polarisation

XVII International Workshop on Deep-Inelastic Scattering and Related Subjects
Polarised Deep Inelastic Scattering

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

\[ + \text{ quark } \uparrow \downarrow \text{ nucleon} \]
\[ - \text{ quark } \uparrow \uparrow \text{ nucleon} \]

Inclusive asymmetry
\[
A_1(x, Q^2) = \frac{\sigma_{\uparrow \downarrow} - \sigma_{\uparrow \uparrow}}{\sigma_{\uparrow \downarrow} + \sigma_{\uparrow \uparrow}} \approx \frac{\sum_q e_q^2 \Delta q(x, Q^2)}{\sum_q e_q^2 q(x, Q^2)} = \frac{g_1(x, Q^2)}{F_1(x, Q^2)}
\]

Semi-inclusive asymmetry
\[
A_1^h(x, z, Q^2) = \frac{\sigma_{h}^{\uparrow \downarrow} - \sigma_{h}^{\uparrow \uparrow}}{\sigma_{h}^{\uparrow \downarrow} + \sigma_{h}^{\uparrow \uparrow}} \approx \frac{\sum_q e_q^2 \Delta q(x, Q^2)D_q^h(z, Q^2)}{\sum_q e_q^2 q(x, Q^2)D_q^h(z, Q^2)}
\]
The COMPASS Experiment

- Trackers
- Magnets SM1 and SM2
- RICH
- Electromagnetic Calorimeters
- Hadronic Calorimeters
- Absorbers
- Target

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**μ⁺ beam:**
- Polarisation $P_B \sim 80$
- $2.10^8 \mu$/spill (4.8/16.8 s)

**$^6$LiD target:**
- Polarisation $P_T \sim 50$
- Dilution factor $f \sim 40$

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Spectrometer Upgrade

Performed during SPS shutdown in 2005

POLARISED TARGET

• Larger acceptance: 70 → 180 mrad
• 2 → 3 target cells for false asymmetries reduction

RICH DETECTOR

• Central part replaced by MAPMTs → Increase number of detected photons
• New readout system in the peripheral region

Improved resolution → \(\pi/K\) separation at 2.5\(\sigma\) up to 50 GeV/c

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• $Q^{t \rightarrow i}$ is the probability of a hadron, identified as type $i$, to be truly of type $t$

• Unfolding method is applied in bins of momentum and polar angle → effect on asymmetries is small
Inclusive DIS Asymmetry

3 years of deuteron data taking, 2002 - 2004: 89x10^6 events


- $A_1$ compatible with 0 for $x < 0.05$
- Large asymmetry at large $x$
- Systematic errors: Multiplicative $\rightarrow \delta \approx 0.10A$ ($\delta P_B$, $\delta P_T$, $\delta f$ and $\delta D$)
  
  Additive $\rightarrow$ rad. corrections $\approx 10^{-4} - 10^{-3}$; $A_{false} < 0.4\delta A_{stat}$

Q^2 > 1 (GeV/c)^2
0.1 < y < 0.9
0.004 < x < 0.7

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The $g_1^d(x)$ Structure Function

$$g_1(x) = A_1(x) \frac{F_2(x)}{2x(1+R)}$$

$$R(x,Q^2) = \frac{\sigma_L}{\sigma_T}$$
First Moment of $g_1$

(COMPASS data only)

\[
\Gamma_1^N(Q_0^2 = 3\text{GeV}/c^2) = \int_0^1 g_1^N(x)\,dx = 0.0502 \pm 0.0028\text{(stat)} \pm 0.0020\text{(evol)} \pm 0.0051\text{(syst)}
\]

- in literature (S.A. Larin et al., PLB404 (1997) 153):

\[
\Gamma_1^N(Q^2) = \frac{1}{9} \left(1 - \frac{\alpha_s(Q^2)}{\pi} + O(\alpha_s^2)\right) \left(a_0(Q^2) + \frac{1}{4} a_8\right)
\]

(from Y. Goto et al., PRD62 (2000) 034017:
\[a_8 = 0.585 \pm 0.025\])

\[
a_0(Q_0^2 = 3\text{GeV}/c^2) = 0.35 \pm 0.03\text{(stat)} \pm 0.05\text{(syst)}
\]

extrapolating to $Q^2 \rightarrow \infty$

\[
\hat{a}_0(Q^2 \rightarrow \infty) = 0.33 \pm 0.03\text{(stat)} \pm 0.05\text{(syst)}
\]

\[
(\Delta s + \Delta \bar{s}) = \frac{1}{3} (\hat{a}_0 - a_8) = -0.08 \pm 0.01\text{(stat)} \pm 0.02\text{(syst)}
\]
Semi-inclusive asymmetries


- Phase space: $Q^2 > 1 \text{(GeV/c)}^2$, $0.004 < x < 0.3$, $10 < p < 50 \text{ GeV/c}$, $0.2 < z < 0.85$

- Statistics: $\pi^+ = 23 \times 10^6$, $\pi^- = 21 \times 10^6$, $K^+ = 4.8 \times 10^6$, $K^- = 3.3 \times 10^6$

- Systematics errors: $\delta \cong 0.08 A$ ($\delta P_B$, $\delta P_T$, $\delta f$ and $\delta D$); $\sigma_{\text{false asym}} < 0.4 \sigma_{\text{stat}}$

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SIDIS Predictions

Curves are NLO predictions from DSSV Group (D. De Florian, R. Sassot, M. Stratmann and W. Vogelsang)

COMPASS preliminary, full deuteron statistics
Polarised PDFs

LO evaluation of $\Delta u_\gamma + \Delta d_\gamma$, $\Delta u + \Delta d$ and $\Delta s$:

- Asymmetries assumed to be independent on $Q^2$ \( \Rightarrow A_i^h(x,z) = \frac{\sum q e_q^2 \Delta q(x)D_q^h(z)}{\sum q e_q^2 q(x)D_q^h(z)} \)
- $\Delta s \equiv \Delta \bar{s}$ assumed
- Unpolarised PDFs: MRST04
- Fragmentation functions:
  - DSS (global analysis of $e^-e^+$, SIDIS and $p+p$ collisions)
  - From EMC $D_u^{\pi^+,\pi^-}$ and $D_u^{K^+,K^-}$ measurements. (For comparison only. $D_s^{K^+} = D_u^{\pi^+}$ assumed, in addition to charge conjugation and isospin symmetry. All unfavored FFs assumed to be equal.)

Least square fit in each x bin
Polarised PDFs (cont.)

\[ \Delta u_v + \Delta d_v: \]
small sensitivity to different FFs; good agreement with DNS curve

\[ \Delta \bar{u} + \Delta \bar{d}: \]
compatible with 0; little effect from different FFs

\[ \Delta s: \]
statistical errors 2–3 times larger with EMC FFs

LO DNS analysis, based on KKP param. of FFs, includes all DIS \( g_1 \) prior to COMPASS 2004 data and all SIDIS data from SMC and HERMES

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First Moments

Full deuteron data: 2002 – 2006

<table>
<thead>
<tr>
<th></th>
<th>FF’s from DSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta u_v + \Delta d_v$</td>
<td>$0.28 \pm 0.06 \pm 0.03$</td>
</tr>
<tr>
<td>$\Delta \bar{u} + \Delta \bar{d}$</td>
<td>$-0.03 \pm 0.03 \pm 0.01$</td>
</tr>
<tr>
<td>$\Delta s \equiv \Delta \bar{s}$</td>
<td>$-0.01 \pm 0.01 \pm 0.01$</td>
</tr>
</tbody>
</table>

• Truncated to measured range (0.004 < x < 0.3), at $Q^2 = 3$ (GeV/c)$^2$

• $\int_{0.3}^{1} \Delta s(x)dx \leq 0.002$ (positivity condition)

From COMPASS 2002-2004 results:

• $\Delta u_v + \Delta d_v = 0.26 \pm 0.07 \pm 0.04$, from $A_1^{h^+-h^-}$ approach (at $Q^2 = 10$ (GeV/c)$^2$)

• $\Delta \bar{u} + \Delta \bar{d} = 0.0 \pm 0.04 \pm 0.03$, (0 < x < 1) Phys. Lett. B 660 (2008) 458

• $\Delta s = -0.045 \pm 0.005 \pm 0.010$, from $\Gamma_1 (0 < x < 1)$ – LO evaluation Phys. Lett. B 647 (2007) 8
**Δs from charged kaon asymmetry**

\[
\frac{\Delta s}{s} = A_1^d + \left( A_1^{K^+K^-} - A_1^d \right) \frac{Q/s + \alpha}{\alpha - 4/5}
\]

\[
\alpha = \frac{2R_{UF} + 2R_{SF}}{3R_{UF} + 2}
\]

\[
Q = u + \bar{u} + d + \bar{d}
\]

\[
R_{UF} = \frac{\int D_d^{K^+}(z)dz}{\int D_u^{K^+}(z)dz}
\quad R_{SF} = \frac{\int D_s^{K^+}(z)dz}{\int D_u^{K^+}(z)dz}
\]

- If \(A_1^d = A_1^{K^+K^-} \Rightarrow \Delta s \geq 0\), insensitive to FFs
- If \(A_1^{K^+K^-} < 0\) (at low x) \(\Rightarrow \Delta s < 0\)

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$\Delta s$ as a function of $R_{SF}$

- $R_{UF}$ fixed at 0.14 from the DSS fragmentation functions
- Large statistical uncertainty due to $R_{SF}$; slight dependence on $R_{UF}$
- If $R_{SF} \geq 5$: $\Delta S(SIDIS) > \Delta S(DIS) \Rightarrow \Delta S(x) < 0$ for $x < 0.004$ (unmeasured), but $2\sigma$ difference only
- If $R_{SF} \leq 4$: $A^{K^+K^-}$ becomes insensitive to $\Delta s$ (small $D_s^{K^+}$)
Conclusions

From the first moment of $g_1^d$ and semi-inclusive asymmetries, we extract the $\Delta s$ contribution to the nucleon spin:

$$\Delta s \text{ (inclusive)} = -0.045 \pm 0.005 \pm 0.010$$

$$\Delta s \text{ (SIDIS)} = -0.01 \pm 0.01 \pm 0.01$$

Strange quark polarisation strongly dependent on $R_{SF}$. Comparison between first moments of $\Delta s$ from DIS and SIDIS limited by statistics

New evaluation of valence quark polarisations

Sea polarisation is consistent with 0 over the measured range

Prospects:

Analysis of COMPASS proton data for flavour separation

Extraction of RUF and RSF from COMPASS data on $\sigma_{K^-}/\sigma_{K^+}$

Next-to-Leading Order analysis
Spares
• (Invariant mass)$^2$ of the virtual photon: $Q^2 > 1$ GeV$^2$
• Fraction of the energy carried by the virtual photon: $0.1 < y < 0.9$
• Bjorken scaling variable: $0.004 < x < 0.7$
Asymmetry correlation matrices, before and after unfolding
PDFs before and after unfolding

LO analysis of deuteron data of COMPASS, $Q^2=3$ GeV$^2$

- **PRELIMINARY results for**
  - Identifed hadrons
  - True hadrons
  - MRST04

$x(\Delta u + \Delta d)$

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

$x \Delta s$

$x$

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