Results on longitudinal spin physics at COMPASS

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on behalf of the COMPASS collaboration

9th September 2015

POETIC 6

- COMPASS
- Structure functions
- Quark & gluon polarisation

bmb+f - Förderschwerpunkt COMPASS
Großgeräte der physikalischen Grundlagenforschung

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

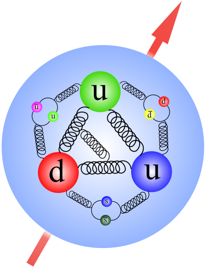
Symmetry Breaking

Motivation

Spin contributions of the nucleon:

$$S = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$

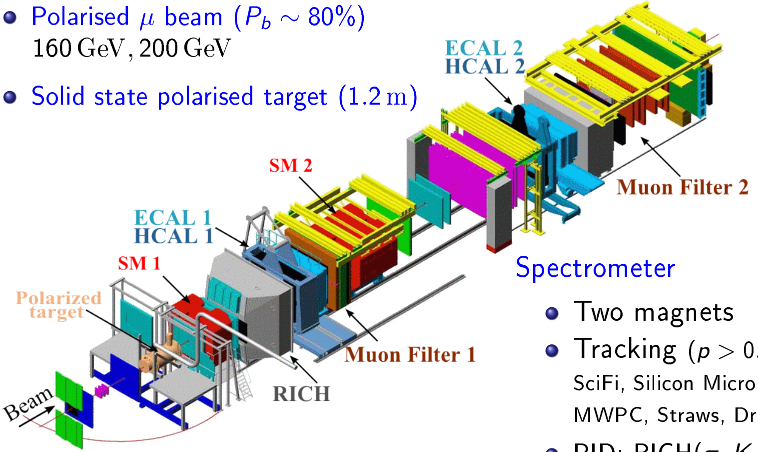
$$\Delta\Sigma = \Delta u + \Delta d + \Delta s$$



- Measured in DIS
- Quark spin contributes only about 30% to the nucleon spin
- Gluon contribution constrained only for a limited x range
- Hardly any experimental information on orbital angular momentum

COMPASS @ CERN

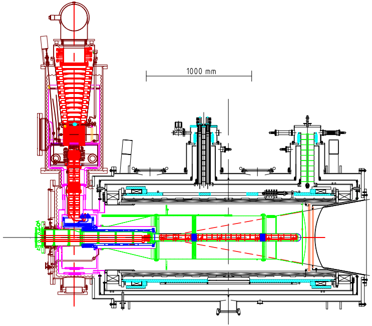
- M2 beamline
- Polarised μ beam ($P_b \sim 80\%$)
  $160\,\mathrm{GeV}, 200\,\mathrm{GeV}$
- Solid state polarised target ($1.2\,\mathrm{m}$)



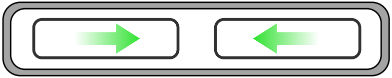
Spectrometer

- Two magnets
- Tracking ($p > 0.5\,\mathrm{GeV}/c$)
  SciFi, Silicon MicroMega, Gem, MWPC, Straws, Drift tubes
- PID: RICH(π, K, p)
  ECAL, HCAL, muon filters

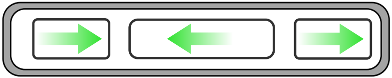
Polarised target



2002 - 2004



2006 - 2011



- Two/Three target cells, oppositely polarised
- 180 mrad geometrical acceptance
- Regular polarisation reversals by field rotation
- ^{6}LiD (Longitudinal deuteron polarisation: $\sim 50\%$)
- NH_3 (Longitudinal proton polarisation: $\sim 90\%$)
- 2.5 T solenoid field
- Low temperature 50 mK

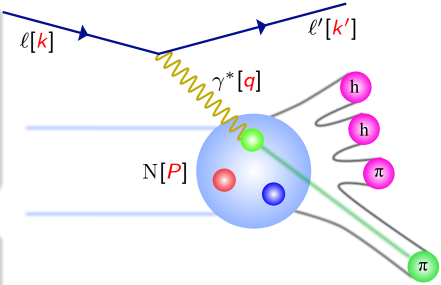
- DIS: $\ell + N \longrightarrow \ell' + X$
- SIDIS: $\ell + N \longrightarrow \ell' + h + X$

DIS variables

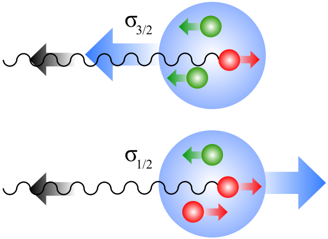
- Photon virtuality: $\mathbf{Q^2 = -q^2}$
- Bjorken scaling variable: $\mathbf{x = \frac{Q^2}{2 \cdot P \cdot q}}$
- Relative photon energy: $\mathbf{y = \frac{E - E'}{E}}$

Hadron variables

- Hadron energy fraction: $\mathbf{z = \frac{E_h}{E - E'}}$
- Transverse momentum: $\mathbf{p_T}$
- Longitudinal momentum: $\mathbf{p_L}$



Polarised Deep Inelastic Scattering



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

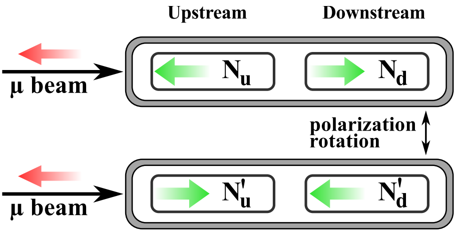
- Photon nucleon asymmetry

$$A_1(x, Q^2) = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \overset{\mathrm{LO}}{\approx} \frac{\sum_q e_q^2 (q(x)^{+} - q(x)^{-})}{\sum_q e_q^2 (q(x)^{+} + q(x)^{-})}$$

- Spin structure function

$$g_1(x, Q^2) = A_1(x, Q^2) \cdot F_1(x, Q^2) \overset{\mathrm{LO}}{=} \frac{1}{2} \sum_q e_q^2 \Delta q(x)$$

Method (idea)

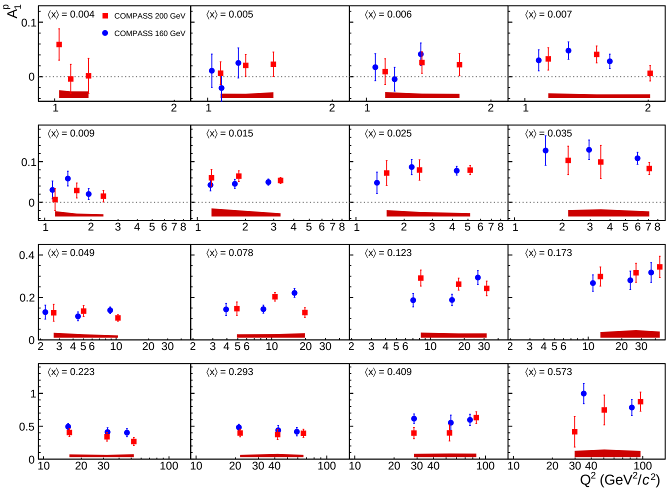


- Aim:
  $A = \frac{\sigma^{\Uparrow\downarrow} - \sigma^{\Uparrow\uparrow}}{\sigma^{\Uparrow\downarrow} + \sigma^{\Uparrow\uparrow}}$
- Measured:
  $A_{exp} = \frac{N_u - N_d}{N_u + N_d}$
- Needed:
  - Flux cancellation
  - Acceptance cancellation
    → polarisation rotation
    → 3 target cells
- $A_{exp} = A \cdot P_B \cdot P_T \cdot f$
  $A = A_1 \cdot D$
  f: Dilution factor
  D: Depolarisation factor

- Averaging:

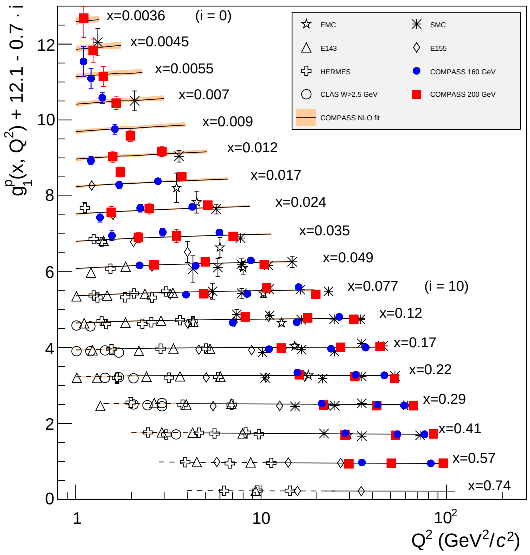
$$A_{exp} = \frac{A + A'}{2} = \frac{1}{2}\left(\frac{N_u - N_d}{N_u + N_d} + \frac{N'_u - N'_d}{N'_u + N'_d}\right)$$

A_1^p in bins of x and Q^2



- ^{14}N correction and pol. rad. corrections included
- New data points at very small x
- Good agreement between COMPASS results at 160/200 GeV

Result compared to the world data



- COMPASS 2011 (200 GeV)
- COMPASS 2007 (160 GeV)
- COMPASS fit at NLO
- New data point at very low x
- Input for global QCD fit
- Indirect ΔG extraction

NLO QCD analyses

- DGLAP equations

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

$$\frac{\mathrm{d}}{\mathrm{d}\ln Q^2}\begin{pmatrix}\Delta q_{Si}\\ \Delta g\end{pmatrix} = \frac{\alpha_s(Q^2)}{2\pi}\begin{pmatrix}\Delta P_{qq}^{Si} & 2n_f\Delta P_{qg}\\ \Delta P_{gq} & \Delta P_{gg}\end{pmatrix}\otimes\begin{pmatrix}\Delta q_{Si}\\ \Delta g\end{pmatrix}$$

- Structure function:

$$g_1 = \frac{1}{2}\langle e^2\rangle\left(C^{Si}(\alpha_s)\otimes\Delta q_{Si} + C^{NS}(\alpha_s)\otimes\Delta q_{NS} + C^{g}(\alpha_s)\otimes\Delta g\right)$$

- Input parametrisation f of $\Delta q_{Si}, \Delta q_3, \Delta q_8, \Delta g$ at $Q_0^2 = 1\,(\mathrm{GeV}/c)^2$ needed

$$f = \eta\frac{x^\alpha(1-x)^\beta(1+\gamma x)}{\int_0^1 x^\alpha(1-x)^\beta(1+\gamma x)\mathrm{d}x}$$

- Using only inclusive asymmetries quarks and anti-quarks cannot be disentangled *e.g.* determination of $\Delta(u+\bar{u})$, $\Delta(d+\bar{d})$, $\Delta(s+\bar{s})$ and Δg

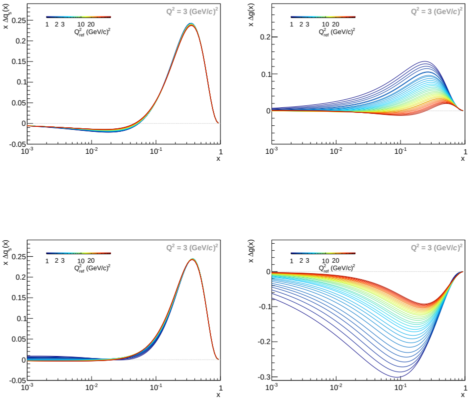
$$\Delta q_{Si} = \Delta U + \Delta D + \Delta S,\ \Delta q_3 = \Delta U - \Delta D,\ \Delta q_8 = \Delta U + 2\Delta D - \Delta S$$

Systematic studies

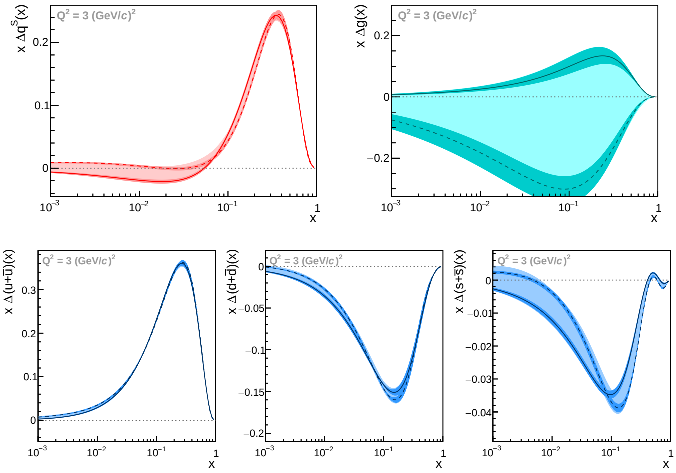
- Remarks on the previously published fit:
  - No systematic uncertainties
- Study impact of:
  - Different parametrisations
  - Reference scale Q_0^2
- χ^2 very stable

$\rightarrow$ Systematic uncertainty larger than statistical

Singlet   Gluon



Polarised parton distributions



- Quark polarisation $0.26 < \Delta\Sigma < 0.36$
- Gluon polarisation $\Delta G = \int \Delta g(x) \mathrm{d}x$ Not well constrained
  $\rightarrow$ Direct measurement

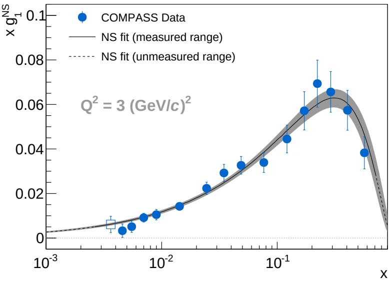
Bjorken sum rule from COMPASS measurement

$$\int_0^1 g_1^{NS}(x, Q^2)dx = \int_0^1 \left(g_1^p(x, Q^2) - g_1^n(x, Q^2)\right) dx = \frac{1}{6}\left|\frac{g_A}{g_V}\right| C_1^{NS}(Q^2)$$

- Non-singlet spin structure function
  $g_1^{NS} = g_1^p - g_1^n = 2\left[g_1^p - \frac{g_1^d}{1-3/2\omega_D}\right]$, $\omega_D = 0.05$
- g_1^{NS} determined from COMPASS data only
  - 2007 & 2011 proton data
  - 2002 - 2004 deuteron data
- $\left|\frac{g_A}{g_V}\right| = 1.2701 \pm 0.0020$ obtained from neutron β-decay.
- Aim: Verification of the Bjorken sum rule

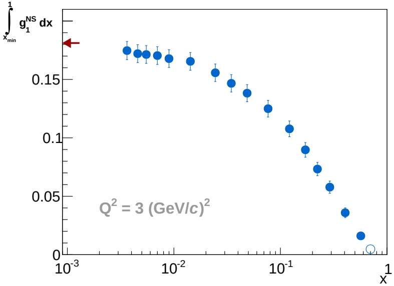
Non-singlet structure function

- Calculate g_1^{NS}
- Perform NLO QCD fit
  - Fit only Δq_3
  - 3 parameters needed
- Evolve g_1^{NS} to $Q^2 = 3\,(\mathrm{GeV}/c)^2$



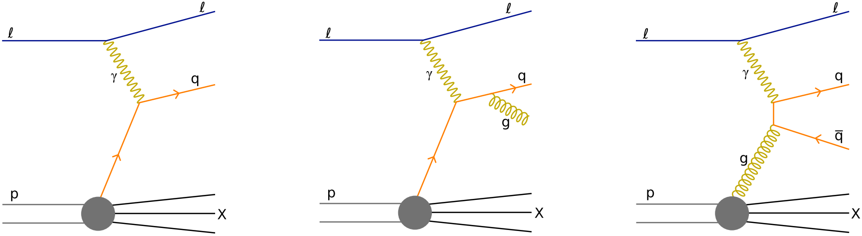
- Extrapolation used for unmeasured region ($x \to 0, 1$)
- 94% in measured range
- Verification of the Bjorken sum rule:

$$\left|\frac{g_A}{g_V}\right|_{NLO} = 1.22 \pm 0.05_{(\mathrm{stat.})} \pm 0.10_{(\mathrm{syst.})}$$



Access to the gluon polarisation

- Contribution from three processes to the cross section



LP QCDC PGF

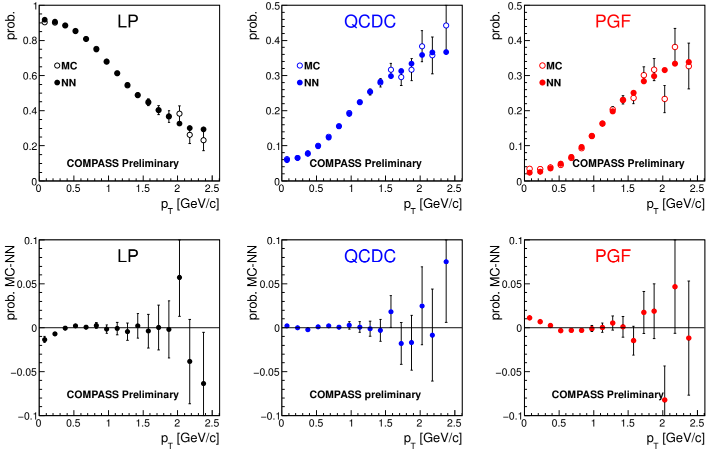
- $A_{LL}^{h} = \frac{\sigma^{\Uparrow\downarrow} - \sigma^{\Uparrow\uparrow}}{\sigma^{\Uparrow\downarrow} + \sigma^{\Uparrow\uparrow}} = \alpha \cdot A_1^{LO}(x_{Bj}) + \beta \cdot A_1^{LO}(x_C) + \gamma \cdot \Delta g/g(x_g)$
- $A_1^{LO} = \frac{\sum_i e_i^2 \Delta q_i}{\sum_i e_i^2 q_i}$
  - From model
  - Simultaneous extraction

Method

- Reanalysis with new method (PLB 718 (2013) 922)
- Treat all processes in the same footing
- Factors α, β, γ depend on: a^i_{LL}, R_i
- Use Neural Network to disentangle the processes
  $\rightarrow$ Events are counted 3 times
- Compare expected and observed number of events
  $\rightarrow$ Minimise the χ^2
- Expected Number of events depends on:
  $a^i_{LL}, R_i, A_1^{LO}, \Delta g/g$, acceptance, unpol. cross section, flux

Neural Network

- NN is trained on MC to parametrise R_i, a^i_{LL}, x_c, x_g
- Input parameters: x_{Bj}, Q^2, p_T, p_L
- High p_T: Clean source of PGF/QCDC
- Low p_T: Clean source of LP



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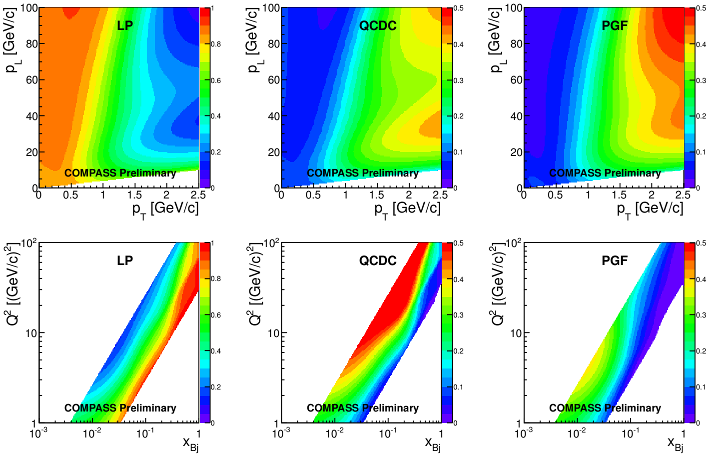
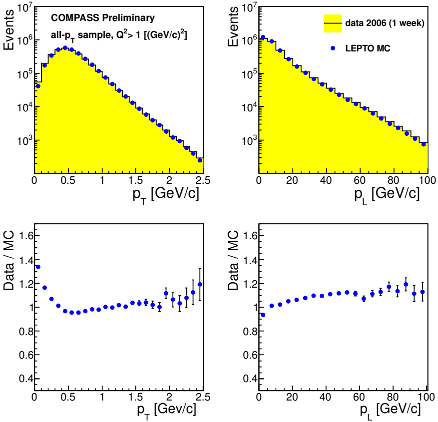


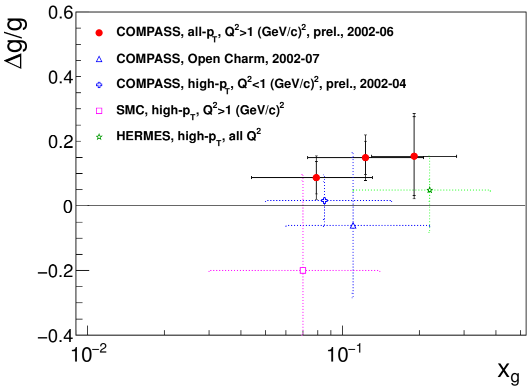
Monte Carlo

- Important variables estimate by MC:
  R_i, a^i_{LL}, x_c, x_g
- Good MC description important
- Reasonable description of the data
- Some improvements possible
- COMPASS high p_T tuning
- Systematic uncertainty from different tunings, PDF, ...



Results

- Assuming $A_1^{QCDC}(x_c) = A_1^{LP}(x_{Bj})$ for $x_c = x_{Bj}$
- Preliminary result: $\Delta g/g = 0.113 \pm 0.038 \pm 0.035$
  - $\langle Q^2 \rangle \approx 3\,(\mathrm{GeV}/c)^2$, $\langle x_g \rangle \approx 0.10$
- Best combined uncertainty
- Good statistic $\rightarrow$ 3 x_g bins
- First direct measurement of a positive $\Delta g/g$



Summary

- New measurement of A_1^p and g_1^p at $200\,\mathrm{GeV}$
  - NLO QCD fit of world data
  - Update on the Bjorken sum rule from COMPASS data only
  - Verification of the Bjorken sum rule
- Extraction of ΔG in LO
  - Reanalysis of COMPASS deuteron data
  - New method to extract $\Delta g/g$
  - Reduction of statistical and systematic uncertainties
  - Positive value of $\Delta g/g$ measured

Further COMPASS results on A_{LL} and ΔG
$\rightarrow$ Talk from Maxime Levillain on Friday