Final results on the spin dependent structure function g_1^d from COMPASS

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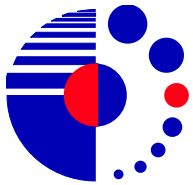


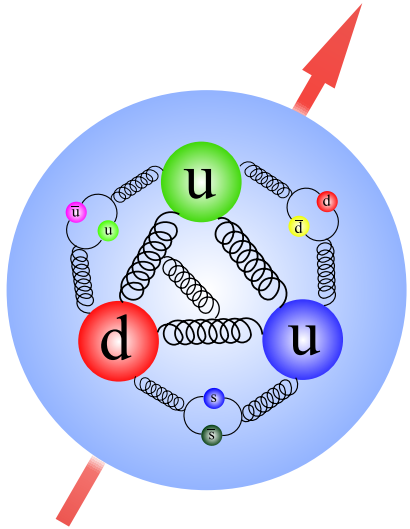
bmb+f - Förderschwerpunkt
COMPASS
Großgeräte der physikalischen Grundlagenforschung

Motivation

Longitudinal spin composition of the nucleon:

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

$$\Delta\Sigma = \Delta U + \Delta D + \Delta S$$

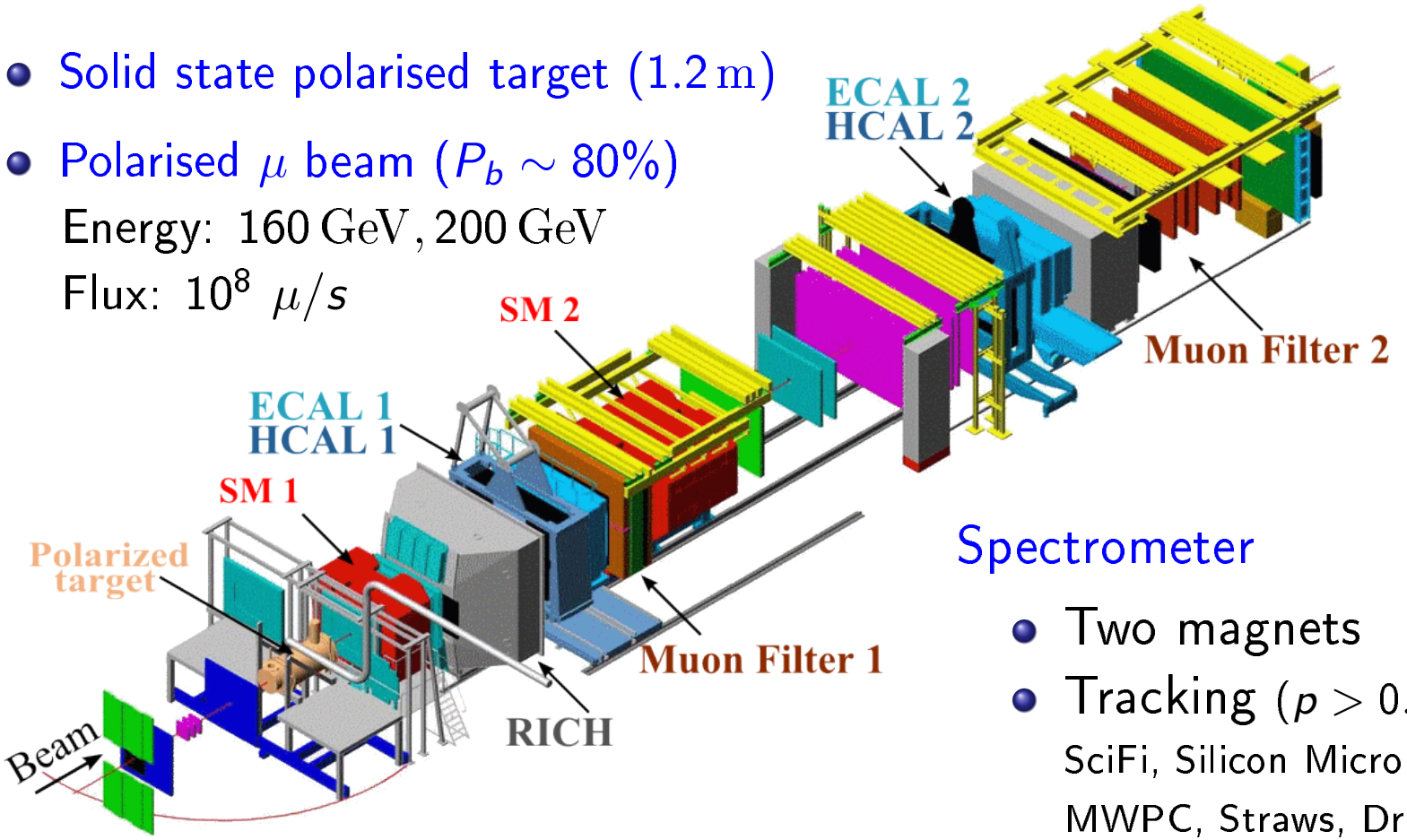


- Quark spin $\Delta\Sigma$ contributes only about 30% to the nucleon spin
- Gluon contribution ΔG some experimental constrains available
- Hardly any experimental information on orbital angular momentum L

COMPASS @ CERN

COmmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy

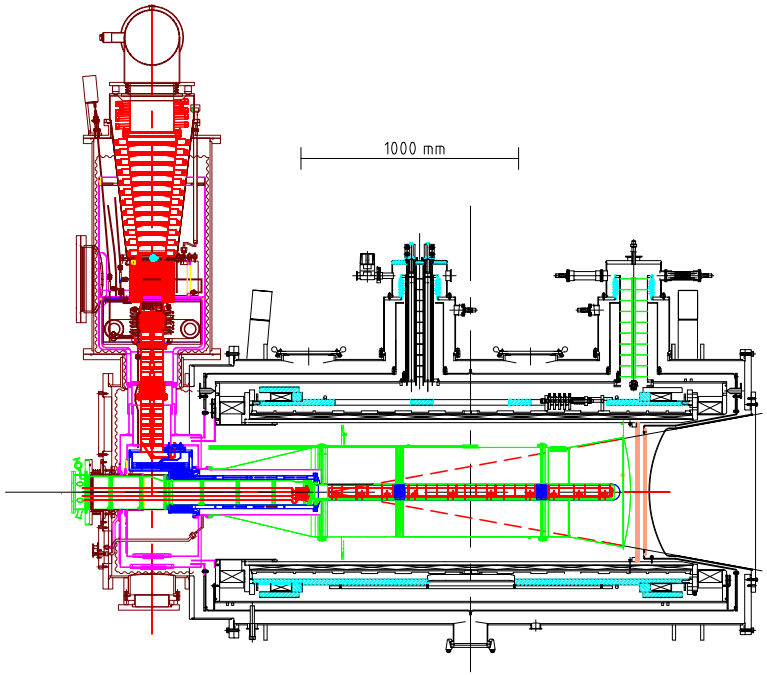
- M2 beamline
- Solid state polarised target (1.2 m)
- Polarised μ beam ($P_b \sim 80\%$)
  Energy: 160 GeV, 200 GeV
  Flux: 10^8 μ/s

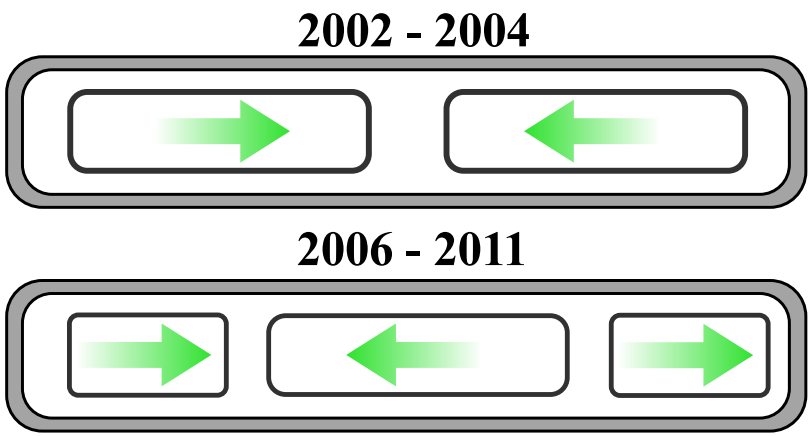


Spectrometer

- 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





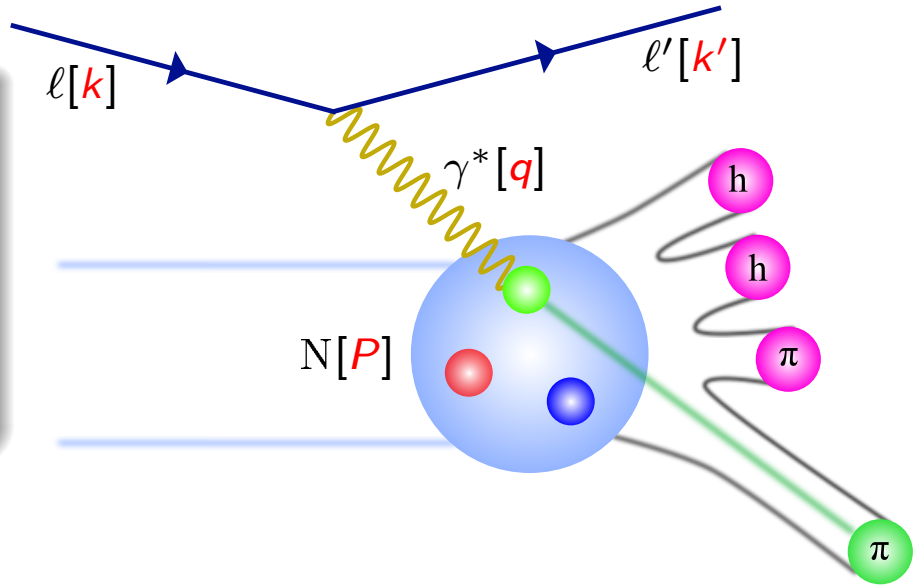
- Two/Three target cells, oppositely polarised
- 180 mrad geometrical acceptance
- 2.5 T solenoid field
- Low temperature 50 mK
- Regular polarisation reversals by field rotation
- ^{6}LiD (Longitudinal deuteron polarisation: $\sim 50\%$)
- NH_3 (Longitudinal proton polarisation: $\sim 90\%$)

Deep Inelastic Scattering

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

DIS variables

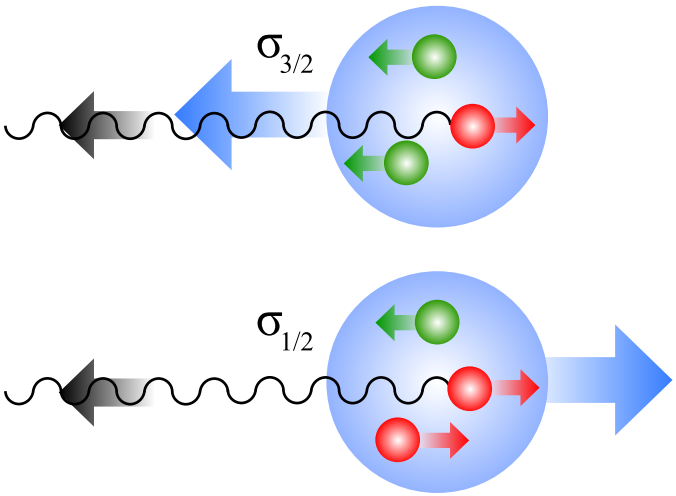
- Photon virtuality: $Q^2 = -q^2$
- Bjorken scaling variable: $x = \frac{Q^2}{2 \cdot P \cdot q}$
- Relative photon energy: $y = \frac{E - E'}{E}$



- At a given Energy:

$$\frac{d^2\sigma}{dx dQ^2} \sim \underbrace{c_1 F_1(x, Q^2) + c_2 F_2(x, Q^2)}_{\text{spin independent}} + \underbrace{c_3 g_1(x, Q^2) + c_4 g_2(x, Q^2)}_{\text{spin dependent}}$$

Polarised Deep Inelastic Scattering



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

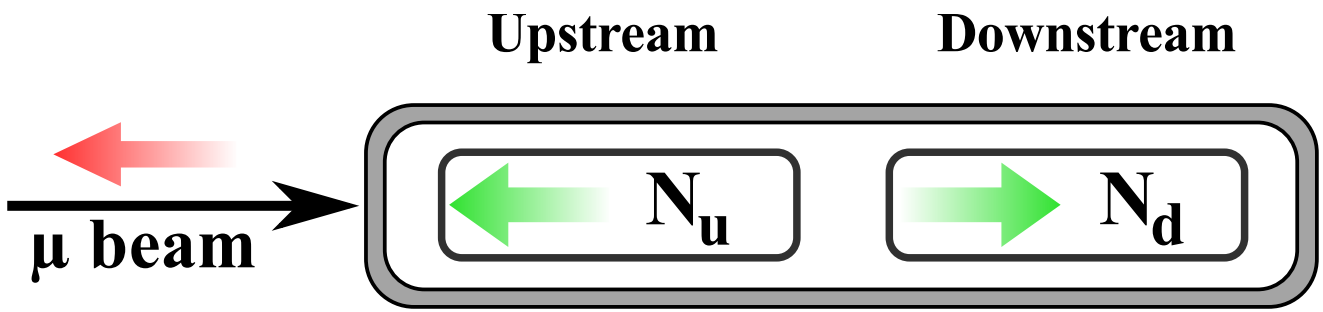
- Photon nucleon asymmetry

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

- Spin structure function

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

Method (idea)



- Aim: $A = \frac{\sigma^{\Uparrow\downarrow} - \sigma^{\Uparrow\uparrow}}{\sigma^{\Uparrow\downarrow} + \sigma^{\Uparrow\uparrow}}$
- Measured: $A_{exp} = \frac{N_u - N_d}{N_u + N_d}$
- $A_{exp} = A \cdot P_B \cdot P_T \cdot f$

  $A \approx A_1 \cdot D$

  f: Dilution factor

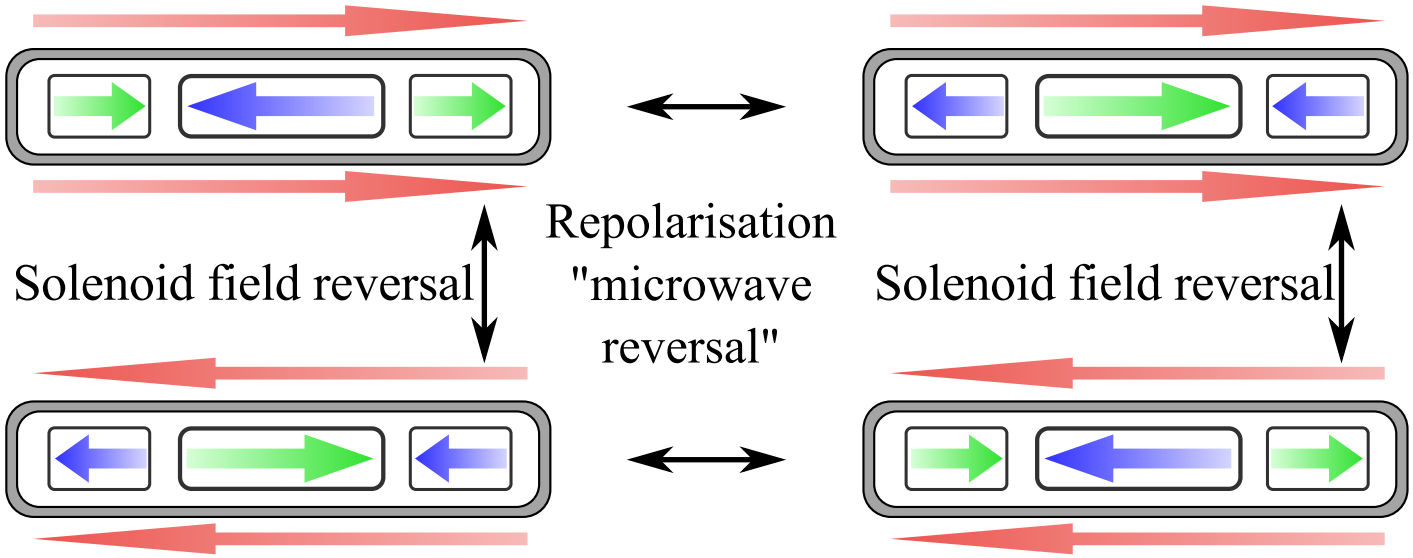
  D: Depolarisation factor

- Needed:
  - Flux cancellation
  - Acceptance cancellation

    $\rightarrow$ polarisation rotation

    $\rightarrow$ 2/3 target cells

Acceptance cancellation

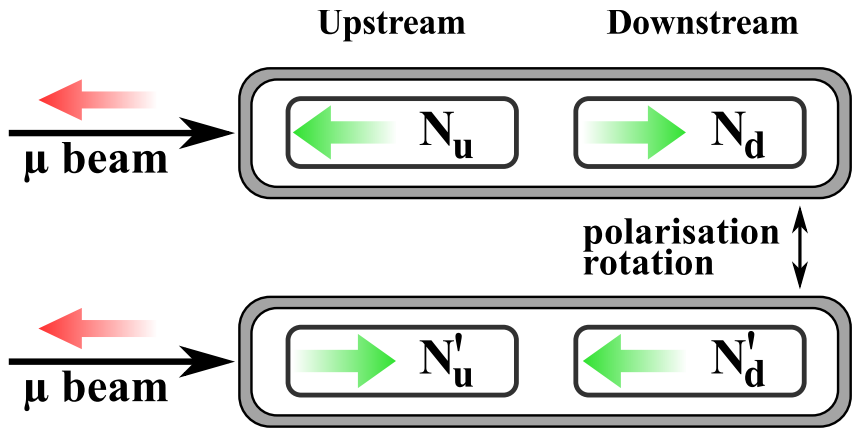


- Acceptance changes with position of interaction point
- Two/Three target cells, oppositely polarised
- Measuring simultaneously all cell polarisations
- Regular polarisation reversals by field rotation
- Once by repolarisation

Asymmetry calculation

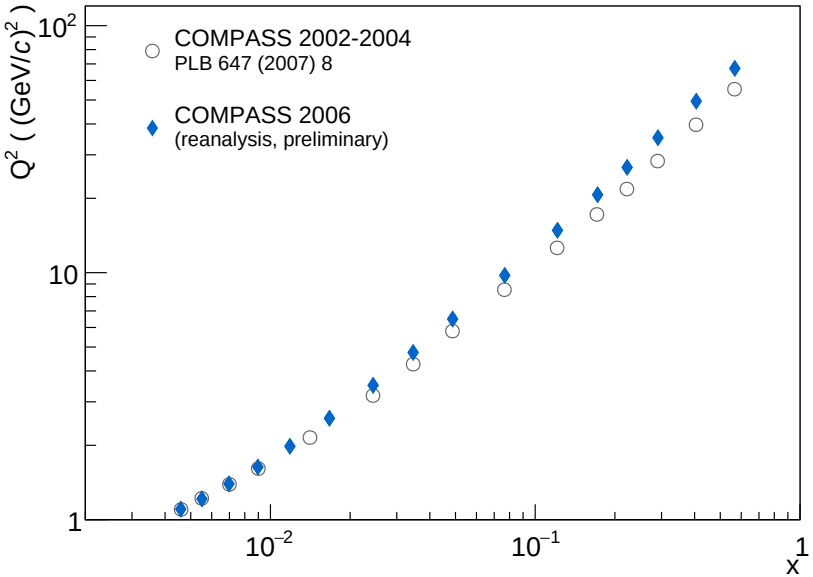
- Number of interactions in each cell: $N_i = a_i \phi_i n_i \overline{\sigma}(1 + fDP_B P_T A_1)$
  - Acceptance: a_i
  - Incoming flux: ϕ_i
  - Number of target nuclei: n_i
  - Spin independent cross section: $\overline{\sigma}$
- Choose weight: $w = fDP_B$
- Calculate $P_i = \sum_{\text{data}} w_i$
- Calculate A_1 from $\delta = \frac{P_{u+d} P'_c}{P'_{u+d} P_c}$

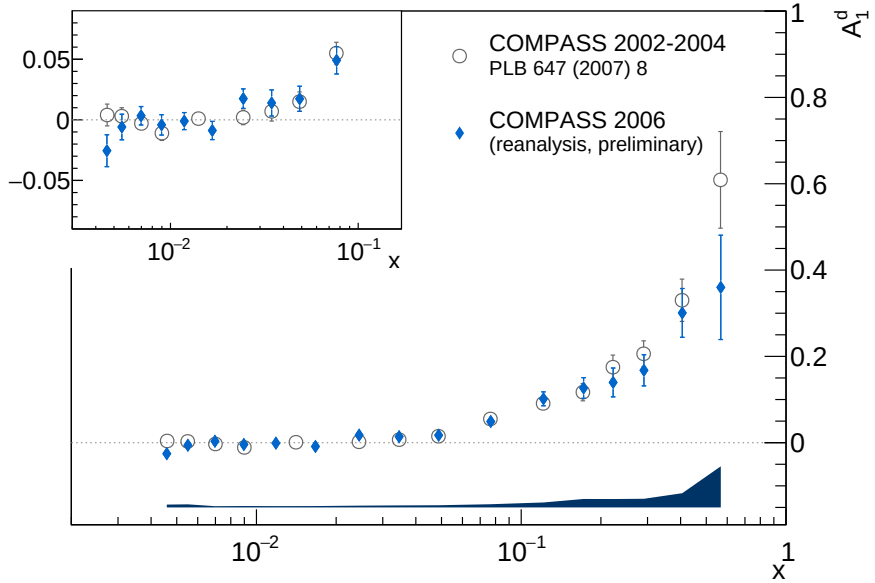
  $\rightarrow a{A_1}^2 + bA_1 + c = 0$
- P_T not included in weight:
  - Change in time
  - Source of false asymmetries
- Mean values: $\frac{\sum w \cdot w \cdot x}{\sum w \cdot w}$



Results from the 2006 run

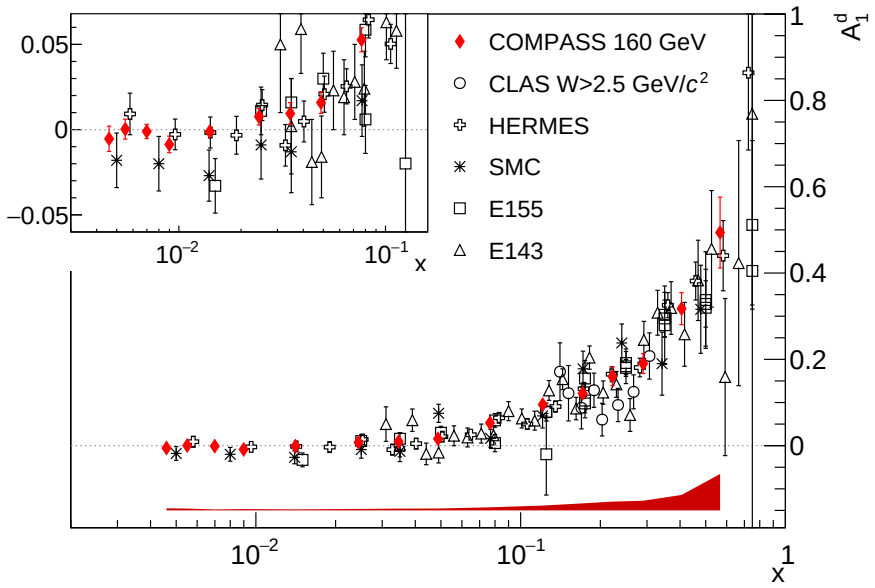
- 2002-2004 results already published **PLB 647 (2007) 8**
- Reanalysis of the 2006 data
- Increase in statistics ($\sim 2\times$ more)
- Unpol. rad. correction "TERAD" included in dilution factor
- Pol. rad. correction from POLRAD
- ^{7}Li correction applied
- Good agreement

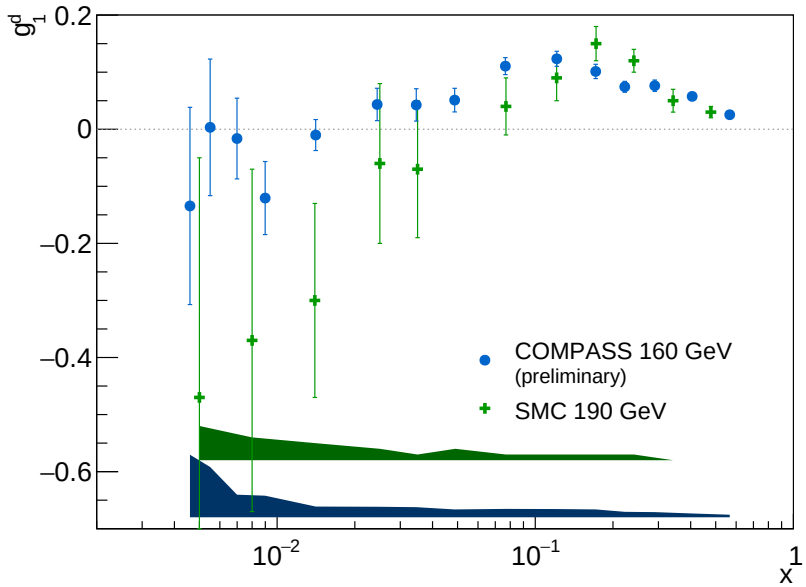




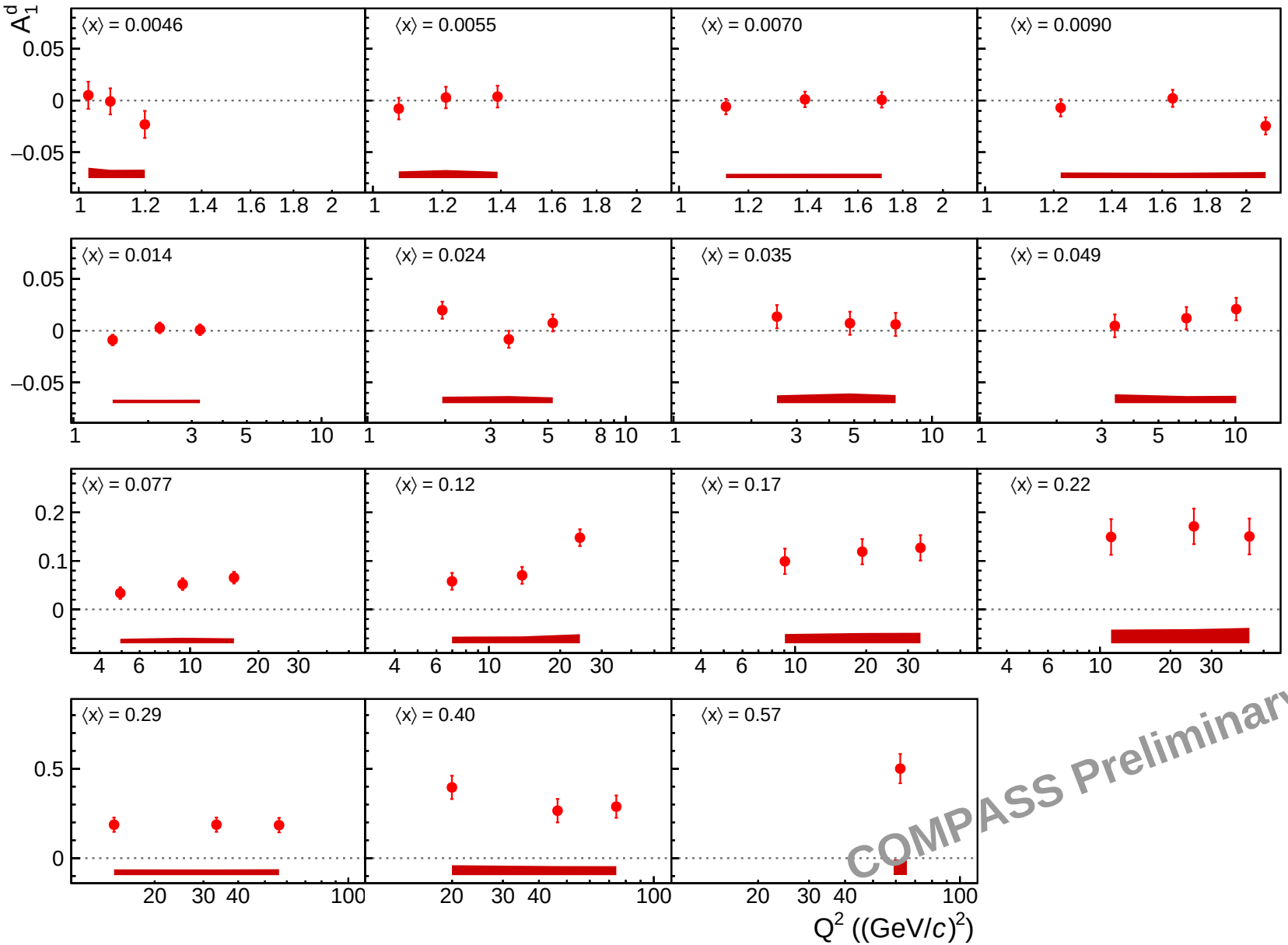
Results in bins of x

- Combined COMPASS results
- Good agreement with world data
- Small statistical uncertainty at low x
- Compatible with zero at low x
- $g_1^{\mathrm{d}}(x, Q^2) = \frac{F_2^{\mathrm{d}}(x,Q^2)}{2x(1+R(x,Q^2))} A_1^{\mathrm{d}}(x, Q^2)$
- F_2 from SMC **PRD 58 (1998) 11201**
- R1998 used **PLB 452 (1999) 194**





A_1^d in bins of x and Q^2

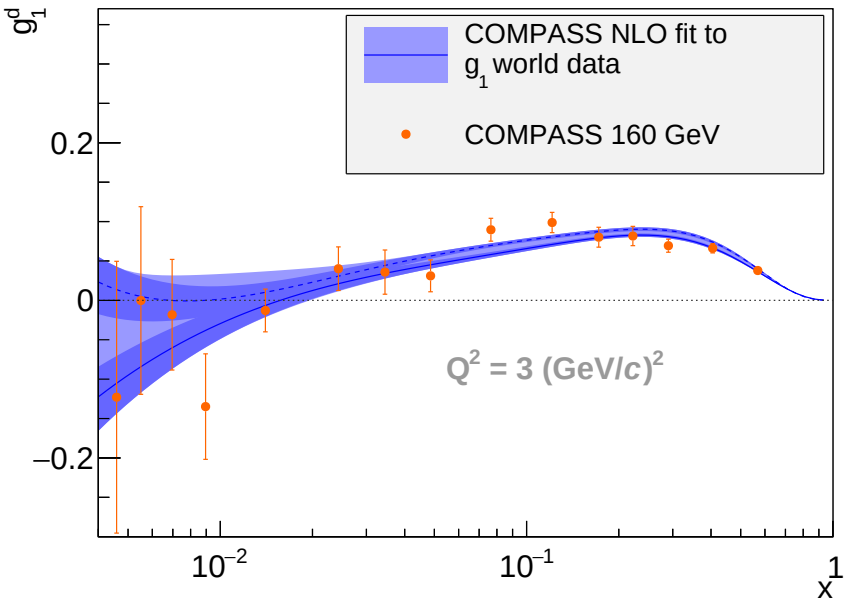


First moment from COMPASS data

$$\Gamma_1^{\mathrm{N}}(Q^2) = \int_0^1 \frac{1}{1-1.5\omega_D} g_1^{\mathrm{d}}(x, Q^2)dx = \frac{1}{36}\left[a_8 C^{\mathrm{NS}}(Q^2) + 4a_0 C^{\mathrm{S}}(Q^2)\right]$$

- Evolve g_1 to $Q^2 = 3\,(\mathrm{GeV}/c)^2$
- Use results from QCD fit

  PLB 753 (2016) 18
- Calculate contributions from unmeasured region ($x \to 0, 1$)
- 97% in measured range



$$\Gamma_1^{\mathrm{N}} = 0.047 \pm 0.002_{\mathrm{stat}} \pm 0.004_{\mathrm{syst}} \pm 0.004_{\mathrm{evo}}$$

- Previous result **(PLB 647 (2007) 8)**:

  $\Gamma_1^{\mathrm{N}} = 0.050 \pm 0.003_{\mathrm{stat}} \pm 0.005_{\mathrm{syst}} \pm 0.003_{\mathrm{evol}}$

Flavour-singlet axial charge

$$a_0 = \frac{1}{C^{\mathrm{S}}(Q^2)} \left(9\Gamma_1^{\mathrm{N}}(Q^2) - \frac{1}{4} a_8 C^{\mathrm{NS}}(Q^2) \right)$$

- Using our first moment and the axial charge a_8 **PRD 87 (2013) 016002**
- a_0 connected to the quark contribution to the nucleon spin
- $\overline{\mathrm{MS}}$: $a_0 = \Delta\Sigma = \Delta U + \Delta D + \Delta S$
- Preliminary result:

$$a_0(Q^2 = 3\,(\mathrm{GeV}/c)^2) = 0.32 \pm 0.02_{\mathrm{stat}} \pm 0.04_{\mathrm{syst}} \pm 0.04_{\mathrm{evol}}$$

- Previous result **(PLB 647 (2007) 8)**:

$$a_0(Q^2 = 3\,(\mathrm{GeV}/c)^2) = 0.33 \pm 0.03_{\mathrm{stat}} \pm 0.05_{\mathrm{syst}}$$

Contributions to the nucleon spin

$$\Delta(u+\overline{u}) = \tfrac{1}{6}\left(2a_0 + a_8 + 3a_3\right) \qquad \Delta(d+\overline{d}) = \tfrac{1}{6}\left(2a_0 + a_8 - 3a_3\right)$$
$$\Delta(s+\overline{s}) = \tfrac{1}{3}\left(a_0 - a_8\right)$$

- Using also the axial charge a_3 PRD 87 (2013) 016002
- Separation for different flavour possible
- Preliminary results for $Q^2 = 3\,(\mathrm{GeV}/c)^2$:

$$\begin{aligned}
\Delta(u+\overline{u}) &= 0.840 \pm 0.007_{\mathrm{stat}} \pm 0.012_{\mathrm{syst}} \pm 0.015_{\mathrm{evol}} \\
\Delta(d+\overline{d}) &= -0.429 \pm 0.007_{\mathrm{stat}} \pm 0.012_{\mathrm{syst}} \pm 0.015_{\mathrm{evol}} \\
\Delta(s+\overline{s}) &= -0.088 \pm 0.007_{\mathrm{stat}} \pm 0.012_{\mathrm{syst}} \pm 0.015_{\mathrm{evol}}
\end{aligned}$$

- Statistical uncertainty reduced compared to published results

PLB 647 (2007) 8

Summary

- Final results on A_1^d and g_1^d from the 2002-2006 COMPASS data
  - Including the 2006 data ($\sim 2\times$ more data)
  - 2006 data improve the precision of the COMPASS results
  - Updated results on Γ_1^{d}
  - Contribution from quarks to the nucleon spin
  - Also for each flavour