Spin structure functions and QCD fits at COMPASS

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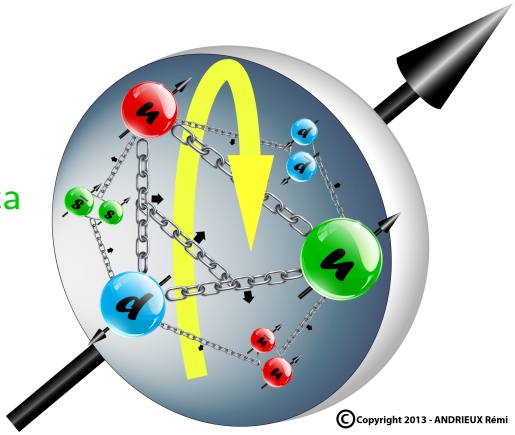
Outline

What is the nucleon spin made up of?

$$\text{Nucleon spin } \frac{1}{2} = \frac{1}{2}\underbrace{\Delta\Sigma}_{\text{quarks}} + \underbrace{\Delta G}_{\text{gluon}} + \underbrace{L_g + L_q}_{\text{orbital momenta}}$$

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



Historically: From relativistic quarks in QM: $\Delta\Sigma \sim 0.6$
In 1988, EMC measured $\Delta\Sigma \sim 0.15 \rightarrow$ "Spin crisis"

- $\Delta\Sigma$ unexpectedly small $\rightarrow \Delta G$ surprisingly large ?
- $\Delta\Sigma \approx 0.58 + 3\Delta s \rightarrow \Delta s$ is negative and large

} New era of spin physics

Covered in this talk:

$\rightarrow$ Measurements of spin structure functions

$\rightarrow$ Extraction of $\Delta\Sigma$ and ΔG via QCD fits

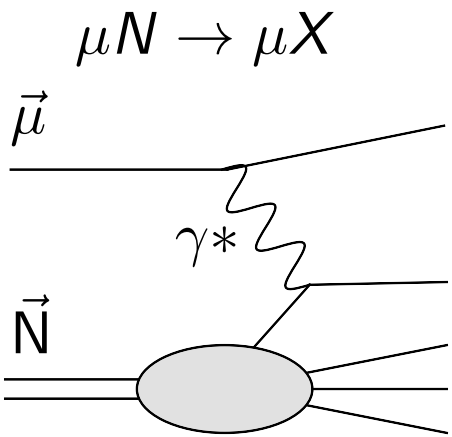
COMPASS Spectrometer

- **Polarised μ^+ beam** from CERN SPS
  200 GeV/160 GeV
  P_μ=80%

- RICH :
  - Hadron identification ($K^\pm$,$\pi^\pm$, ...)

- **Polarised target** of 1.2 m long in a superconducting solenoid
  - Proton
  - Deuteron

DIS and spin structure functions



Q^2: photon virtuality (hard scale)

x: fraction of nucleon mometum carried by the struck quark

DIS cross-section:

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

Spin structure function

$$g_1^p(x,Q^2) \underset{LO}{=} \frac{1}{2}\sum_q e_q^2 \Delta q(x)$$

Δq: quark polarisation u, $\bar{u}$, d, $\bar{d}$, s, $\bar{s}$

Extraction of g_1

- Longitudinal spin asymmetry:

$$A_{LL} = \frac{d\sigma^{\rightleftarrows} - d\sigma^{\rightrightarrows}}{d\sigma^{\rightleftarrows} + d\sigma^{\rightrightarrows}} \simeq D\, A_1$$

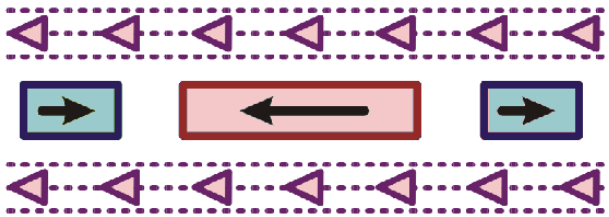
D: Transfert of polarisation from the beam to the photon

- Photon nucleon asymmetry:

$$A_1 \simeq \frac{g_1}{F_1}$$

F_1: Unpolarised structure fonction

- Experimentaly:



COMPASS target with 3 cells

$$A_{LL} = \frac{1}{|P_B\, P_T|\, f} \left(\frac{N^{\rightleftarrows} - N^{\rightrightarrows}}{N^{\rightleftarrows} + N^{\rightrightarrows}} \right)$$

P_B, P_T: Beam, target polarisations

f dilution factor

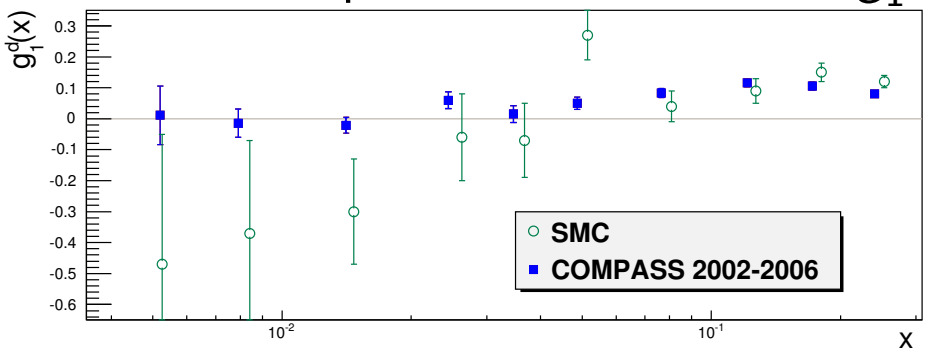
Regular reversals of the cell spin states

$\Rightarrow$ Reduction of acceptance differences

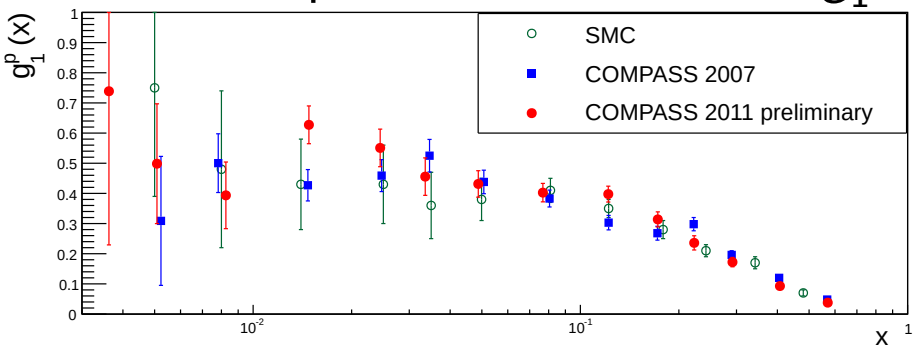
Results on g_1

COMPASS legacy including latest 200 GeV (2011) data

Deuteron spin structure function g_1^d



Proton spin structure function g_1^p

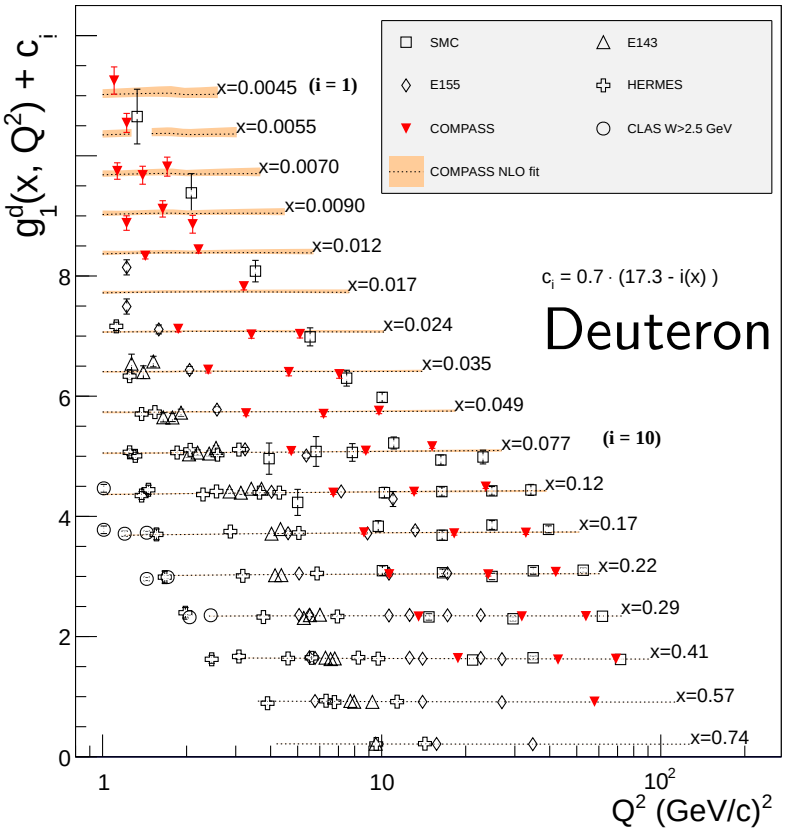


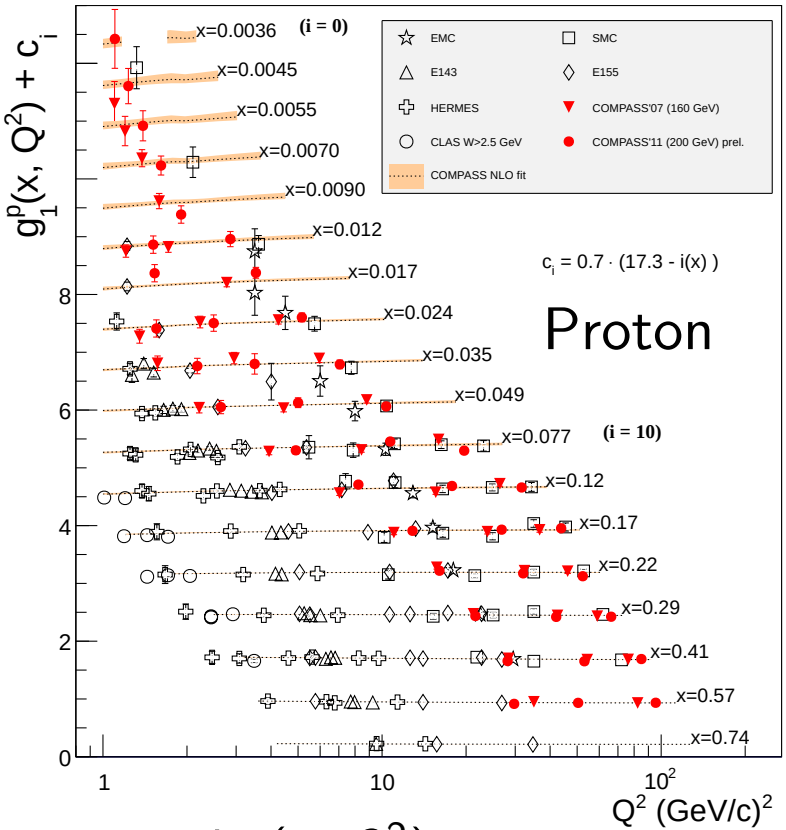
Compared to the previous experiment SMC:

- Compatible within the same kinematic domain
- COMPASS extends the domain down in x for the proton
- **Statistical precision improved by about a factor of 3**

World data on spin structure functions g_1

COMPASS data extends high Q^2 and low x coverage





Input for NLO QCD fit of polarised world data: $\frac{dg_1(x, Q^2)}{dlog(Q^2)} \propto \Delta g(x, Q^2)$

NLO QCD fit of g_1^p, g_1^n and g_1^d world data

$$g_1 \underset{NLO}{=} \frac{1}{2}\langle e^2 \rangle \Big(\underbrace{C_S \otimes \Delta q_S}_{\substack{\text{singlet} \\ \Delta u+\Delta d+\Delta s}} + \underbrace{C_{NS} \otimes \Delta q_{NS}}_{\substack{\text{2 non-singlets} \\ \Delta u-\Delta d \text{ \& } \Delta u+\Delta d-2\Delta s}} + \underbrace{C_g \otimes \Delta g}_{\text{gluon}} \Big)$$

$$\Delta q \equiv \Delta(q + \bar{q})$$

Assumptions:

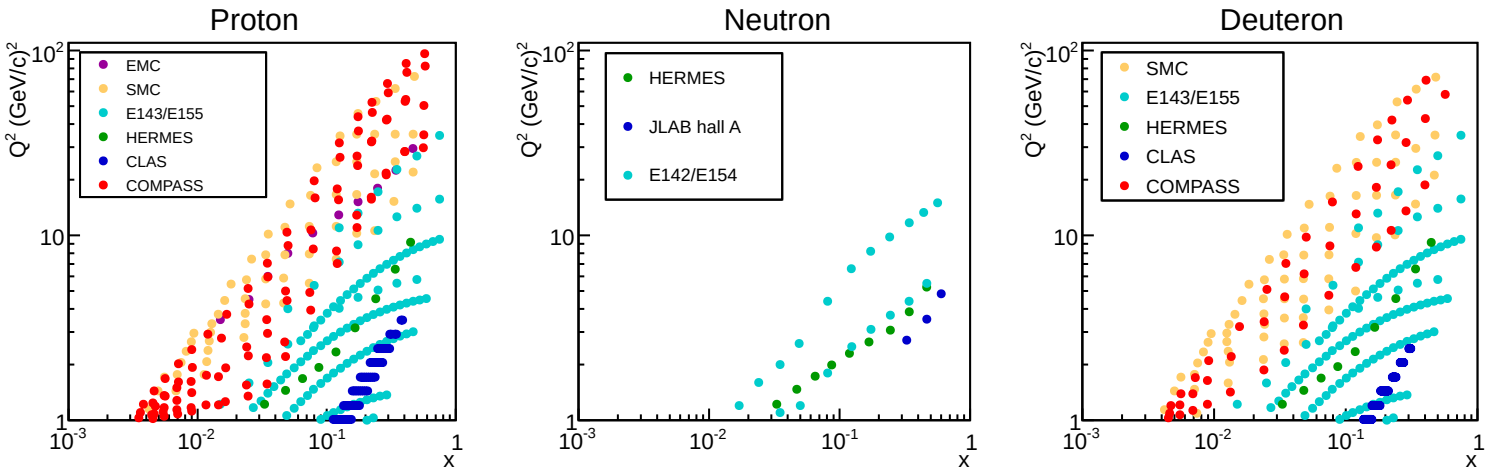
- Functional forms at a Q_0^2 reference scale for: $\Delta q_S(x)$, $\Delta g(x)$ and $\Delta q_{NS}(x)$
- $SU(3)_f$ to fix the non-singlet distribution first moments:
  $\int_0^1 \Delta u - \Delta d \, dx = F + D$
  $\int_0^1 \Delta u + \Delta d - 2\Delta s \, dx = 3F - D$

with F and D the parameters describing the weak axial-vector/vector coupling constants

NLO QCD fit of g_1^p, g_1^n and g_1^d world data

DGLAP equations:

Provide the evolution of the polarised PDFs to the Q^2 of the data points (680 data points with 140 from COMPASS)



Fit to the data:

Minimisation of

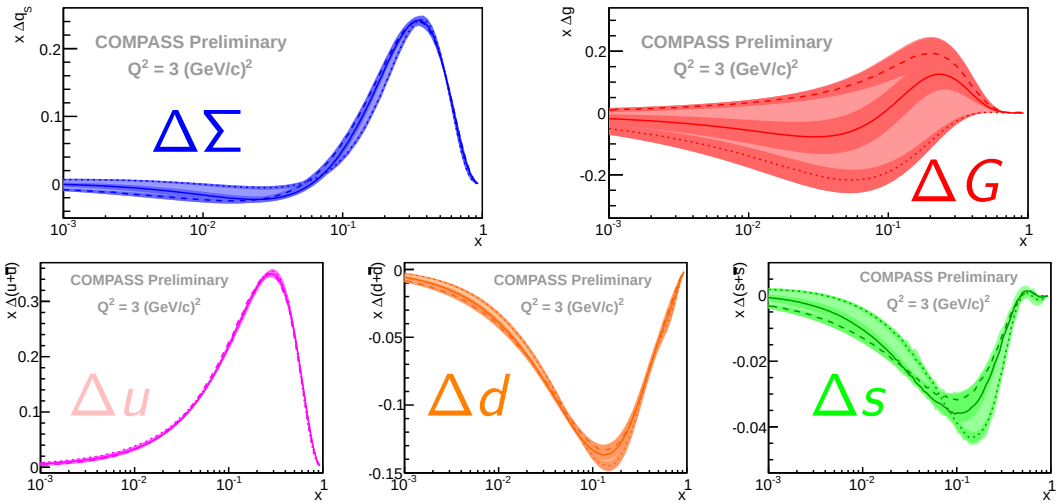
$$\chi^2 = \sum_{exp} \left[\sum_{data} \left(\frac{g_1^{fit}(x_{data}, Q^2_{data}) - \mathcal{N}_{exp} \cdot g_1^{data}}{\mathcal{N}_{exp} \cdot \sigma^{stat}_{data}} \right)^2 + \left(\frac{1 - \mathcal{N}_{exp}}{\delta \mathcal{N}_{exp}} \right)^2 \right]$$

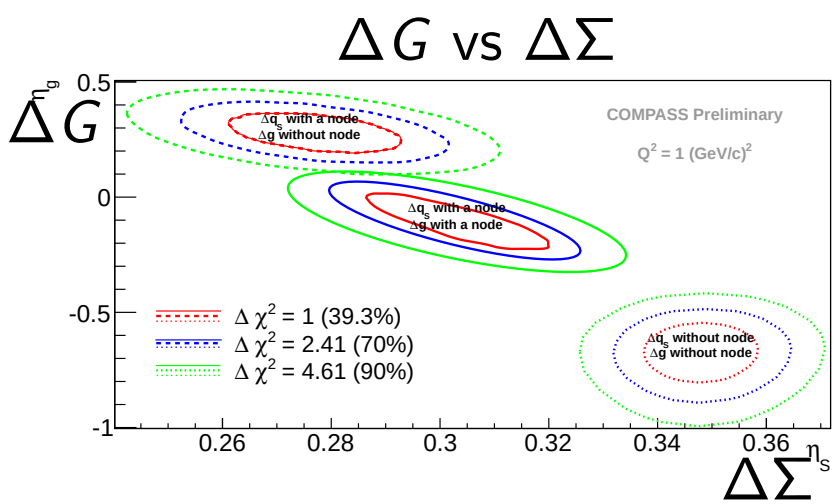
$\mathcal{N}_{exp}$ normalisations

Overall: $\sim$ 28 free parameters

Polarised parton distribution functions

Depending upon assumed fonctional forms, 3 categories of solutions:
$\Delta G > 0$, $\Delta G \sim 0$ and $\Delta G < 0$





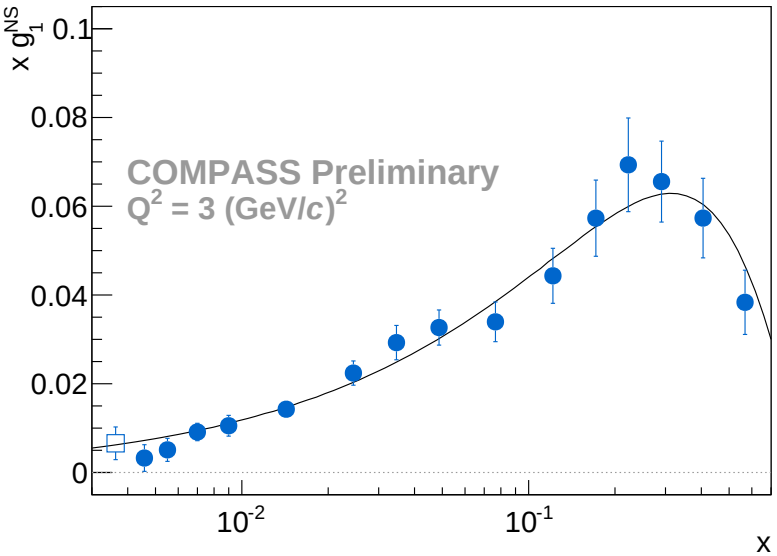
- $0.26 < \Delta\Sigma < 0.34$ at $Q^2 = 3$ (GeV/c)^2 ($\overline{\text{MS}}$)
  - → Largest uncertainty coming from the choice of functional forms
- ΔG not much constrained by DIS data alone
  - → Dedicated measurements needed (RHIC spin, COMPASS)

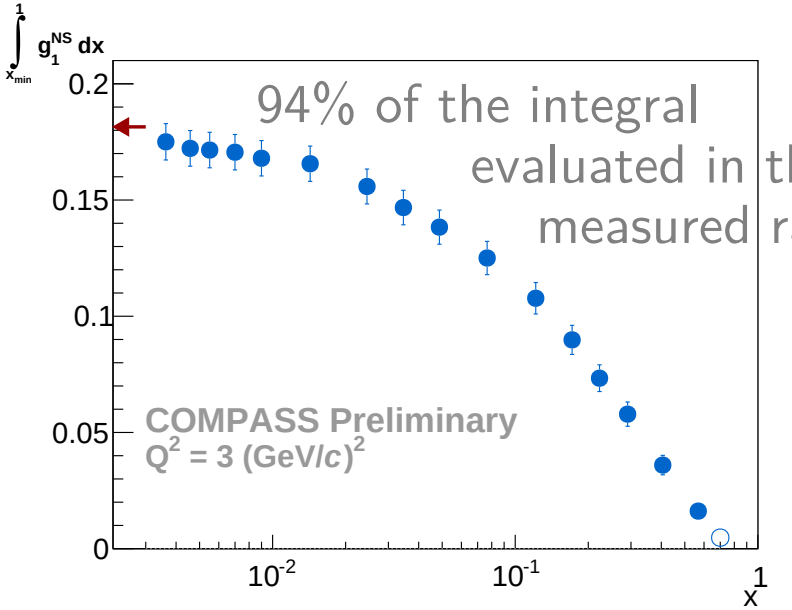
Bjorken sum rule

Fundamental QCD prediction relating p and n:

$$\int_0^1 g_1^p - g_1^n dx = \frac{1}{6} C^{NS}(\alpha_s) \frac{g_A}{g_V}$$

- Test of SU(2)$_{flavour}$
- Decorrelated from ΔG





From COMPASS data alone:

$g_A/g_V|_{NLO}$ = 1.220 ± 0.052 ± 0.095 (prel.) $g_A/g_V|_{NNLO}$=1.251

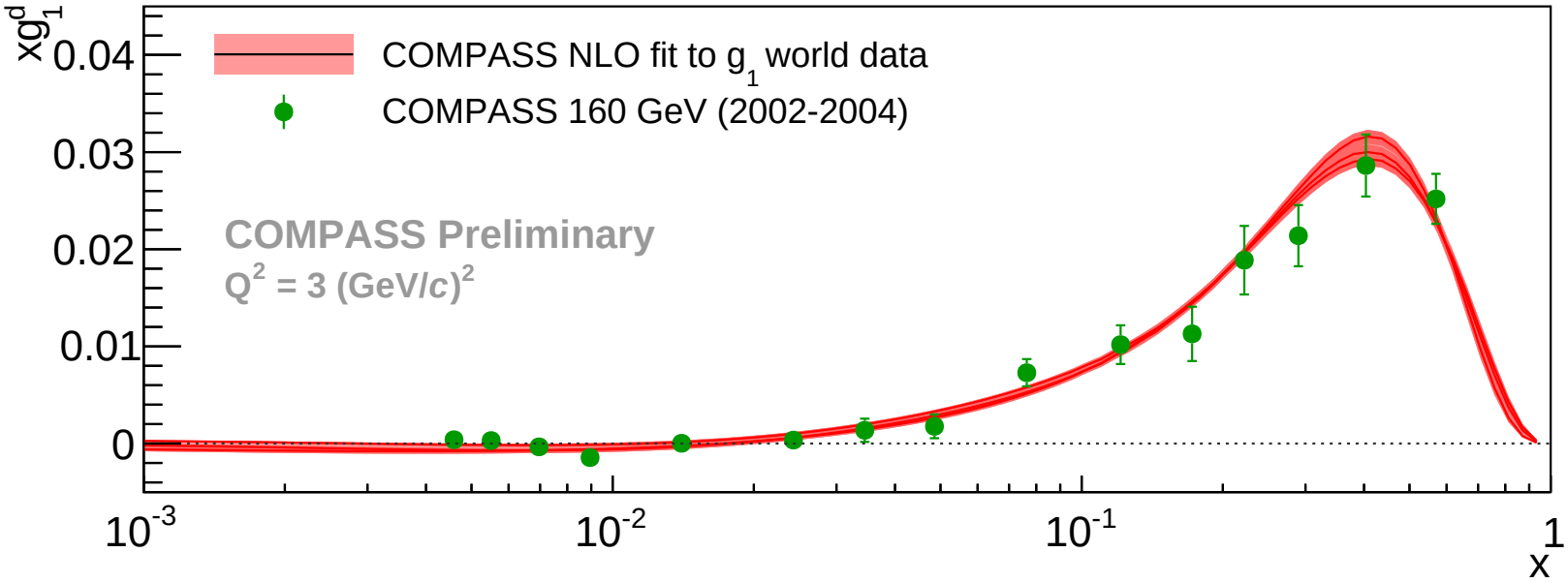
PDG: $g_A/g_V|_\beta = 1.2701 \pm 0.0025$

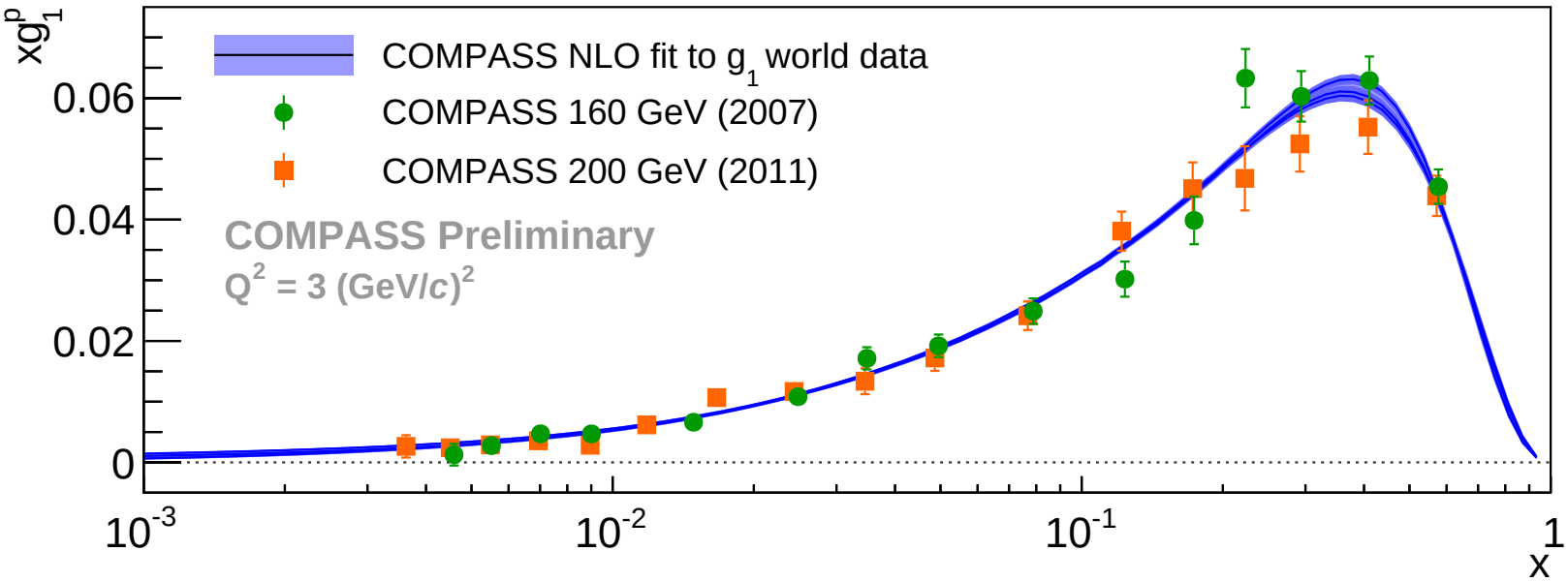
Better statistics and systematics compared to previous COMPASS determination

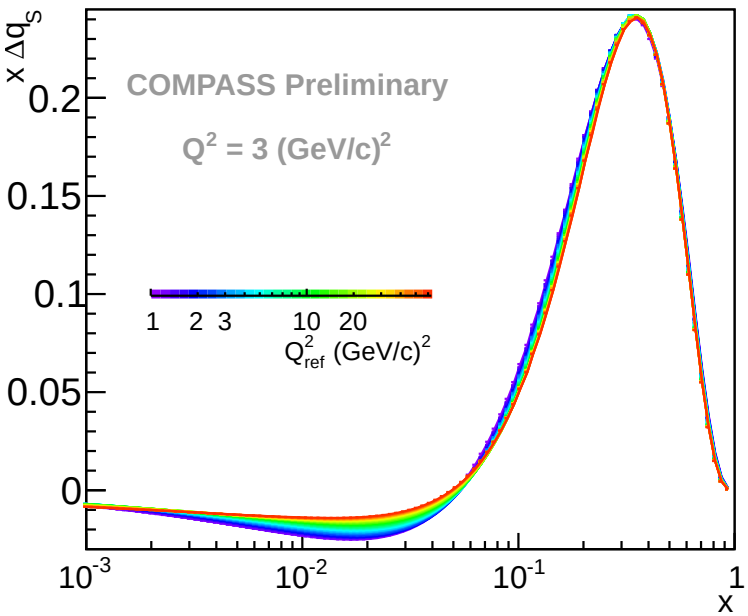
Conclusion and Outlook

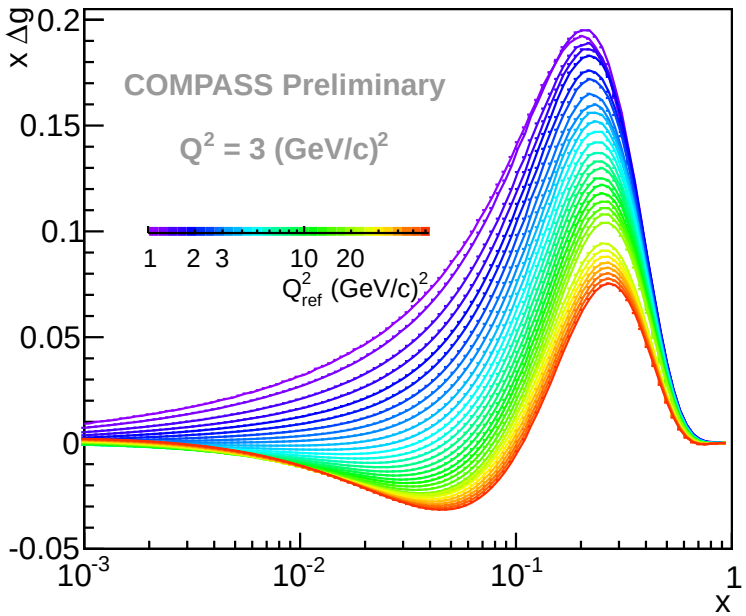
- Improved precision on g_1^p and g_1^d
  a factor of $\sim$3 compared to the previous experiment SMC
- $\Delta\Sigma$ from NLO QCD fits ~ 0.3
  uncertainties dominated by the choice of functional forms
- ΔG not well constrained by DIS data alone
  DSSV and NNPDFpol compatible with >0 and ~ 0 solutions
- Verification of the Bjorken sum rule at 4%
  better uncertainties compared to previous COMPASS publications

BACKUP


xg_1^d
COMPASS NLO fit to g_1 world data
COMPASS 160 GeV (2002-2004)
COMPASS Preliminary
Q^2 = 3 (GeV/c)^2
0.04
0.03
0.02
0.01
0
10^{-3}
10^{-2}
10^{-1}
1
x


xg_1^p
COMPASS NLO fit to g_1 world data
COMPASS 160 GeV (2007)
COMPASS 200 GeV (2011)
COMPASS Preliminary
Q^2 = 3 (GeV/c)^2
0.06
0.04
0.02
0
10^{-3}
10^{-2}
10^{-1}
1
x


x Δq_S
COMPASS Preliminary
Q² = 3 (GeV/c)²
1 2 3 10 20
Q²_ref (GeV/c)²
0.2
0.15
0.1
0.05
0
10⁻³
10⁻²
10⁻¹
1
x


x Δg
COMPASS Preliminary
Q² = 3 (GeV/c)²
1 2 3 10 20
Q²_ref (GeV/c)²
0.2
0.15
0.1
0.05
0
-0.05
10⁻³
10⁻²
10⁻¹
1
x

$\Delta\Sigma$ from COMPASS NLO QCD fits

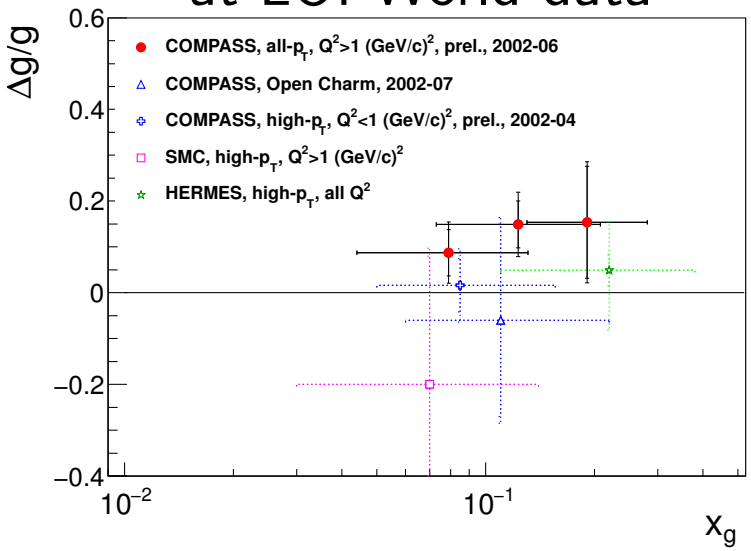
$$\Delta\Sigma \in [0.264,\ 0.356] \text{ at } Q^2 = 1\ (GeV/c)^2$$
$$\Delta\Sigma \in [0.256,\ 0.335] \text{ at } Q^2 = 3\ (GeV/c)^2$$
$$\Delta\Sigma \in [0.258,\ 0.299] \text{ at } Q^2 = 10\ (GeV/c)^2$$

Δg at LO from high-p_T hadron production in DIS

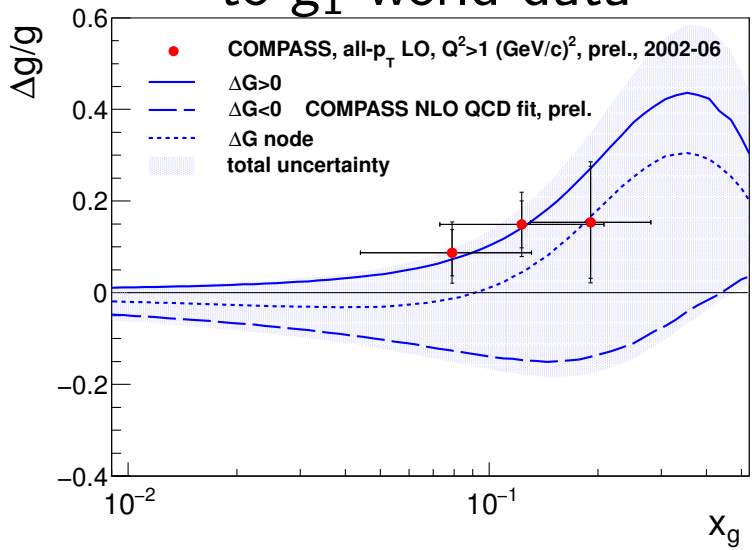
DIS 2014, M. Stolarsky

- COMPASS high-p_T hadron production compared to:

Direct extractions of $\Delta g/g$ at LO: World data



COMPASS NLO QCD fit to g_1 world data

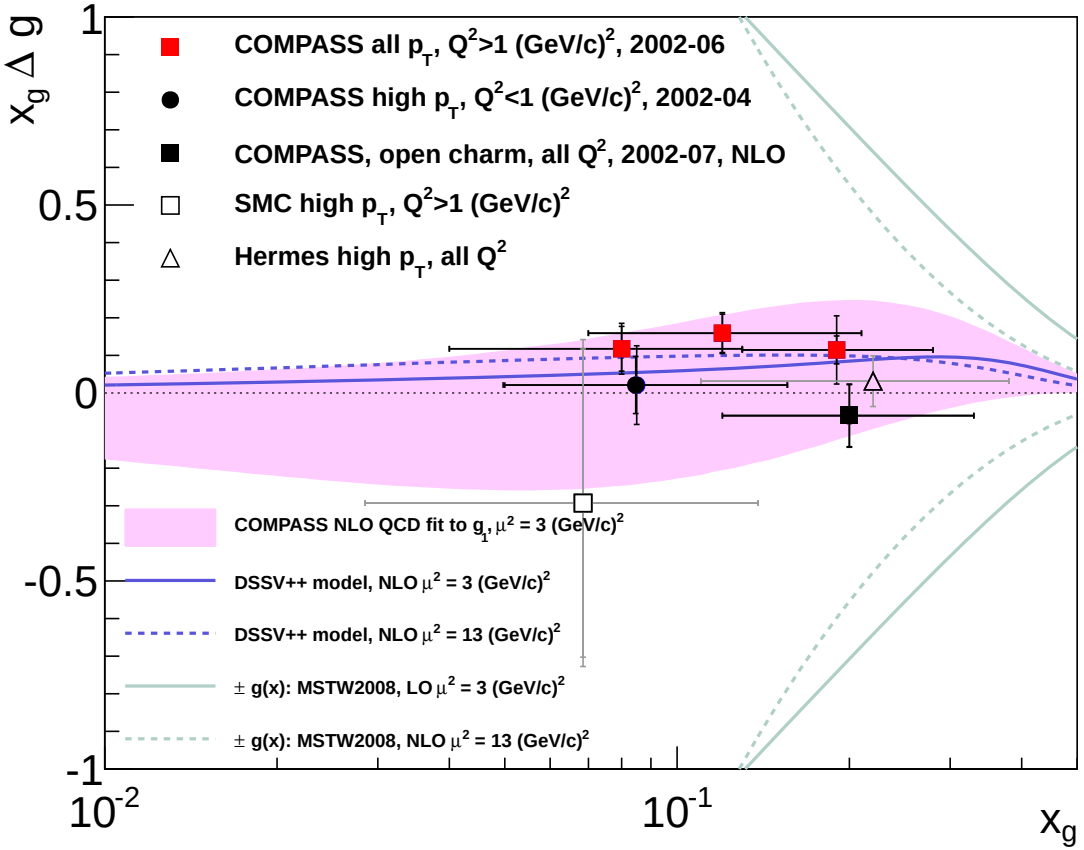


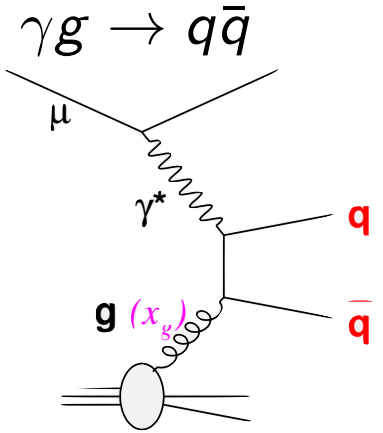
$\Delta G > 0$
$\Delta G \sim 0$
$\Delta G < 0$

$\langle \Delta g/g \rangle = 0.113 \pm 0.035 \pm 0.035$ (Prel.) for $x_g \in [0.04, 0.28]$

- The smallest stat.+syst. uncertainty among LO direct extractions
- In agreement with COMPASS NLO QCD fit and DSSV arχiv:1404:4293
- Favours $\Delta G > 0$ or ~ 0
- Δg is small in the measured range

Direct ΔG extraction from Photon-Gluon-Fusion (PGF)





Two channels:

- High-p_T pairs (LO)
  Leading high-p_T (LO)
- Open Charm (NLO)

DSSV++: De Florian *et al.* arχiv 1404.4293 (2014)

Global fit results from NNPDFpol and DSSV++ also compatible