Spin structure functions of deuteron from COMPASS

A.Korzenev[a], Mainz University

On behalf of the COMPASS collaboration

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \langle L_z \rangle$$

$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$

QCD 06, Montpellier

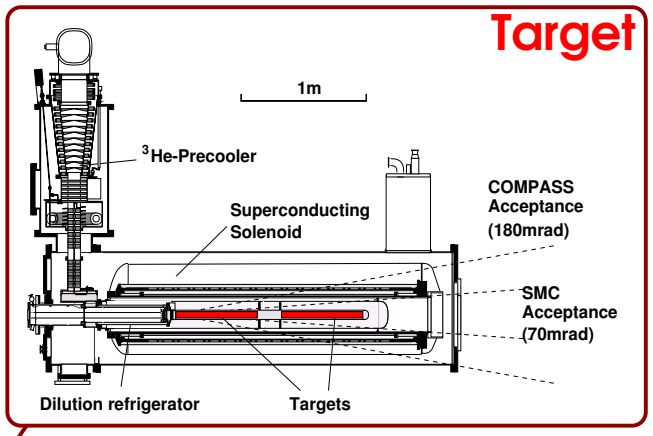
July 3-7, 2006

[a] on leave from JINR, Dubna

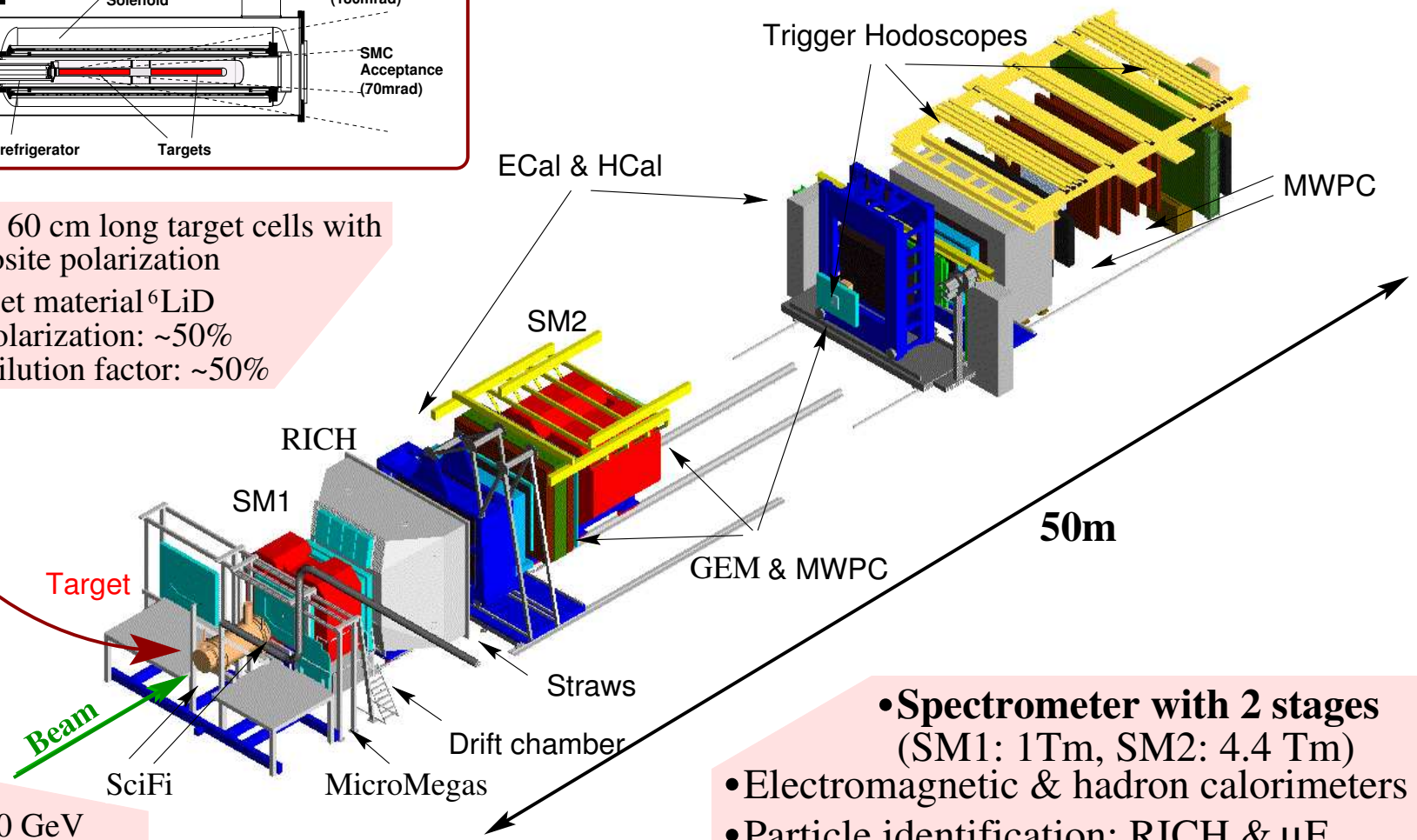
Overview

- COMPASS experiment
- Inclusive asymmetry A_1^d and structure function g_1^d
- QCD analysis of world data with new COMPASS measurements
- Summary and outlook

Spectrometer



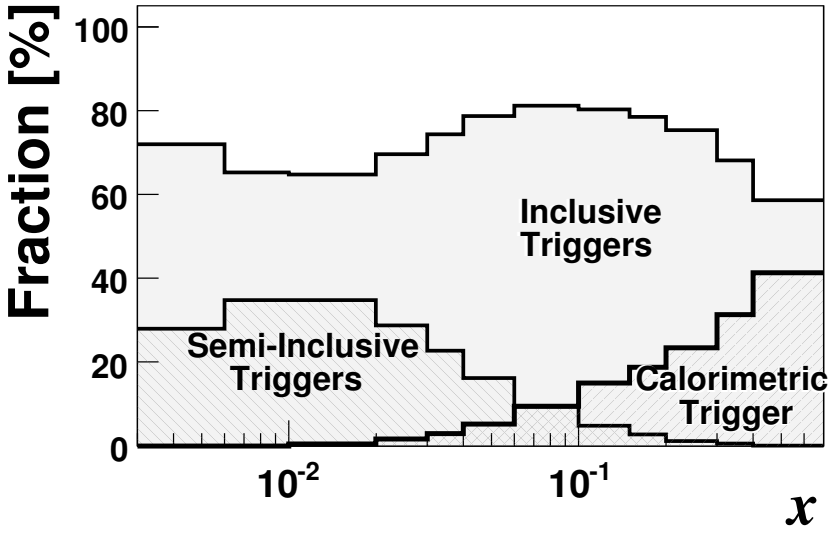
- Two 60 cm long target cells with opposite polarization
- Target material ^{6}LiD
  - Polarization: ~50%
  - Dilution factor: ~50%

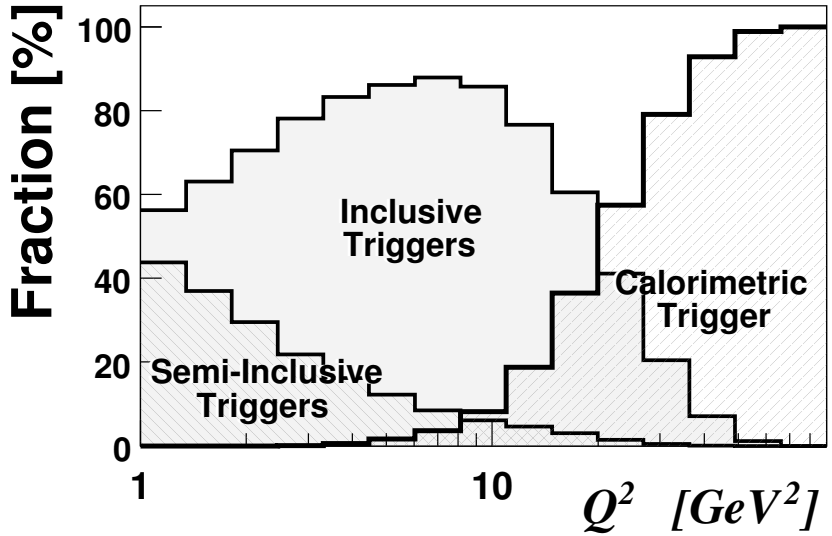


- μ–beam
  - Energy: 160 GeV
  - Intensity: $2 \cdot 10^8$ μ/spill
  - Polarization: −76%

- **Spectrometer with 2 stages** (SM1: 1Tm, SM2: 4.4 Tm)
- Electromagnetic & hadron calorimeters
- Particle identification: RICH & μF

Triggers

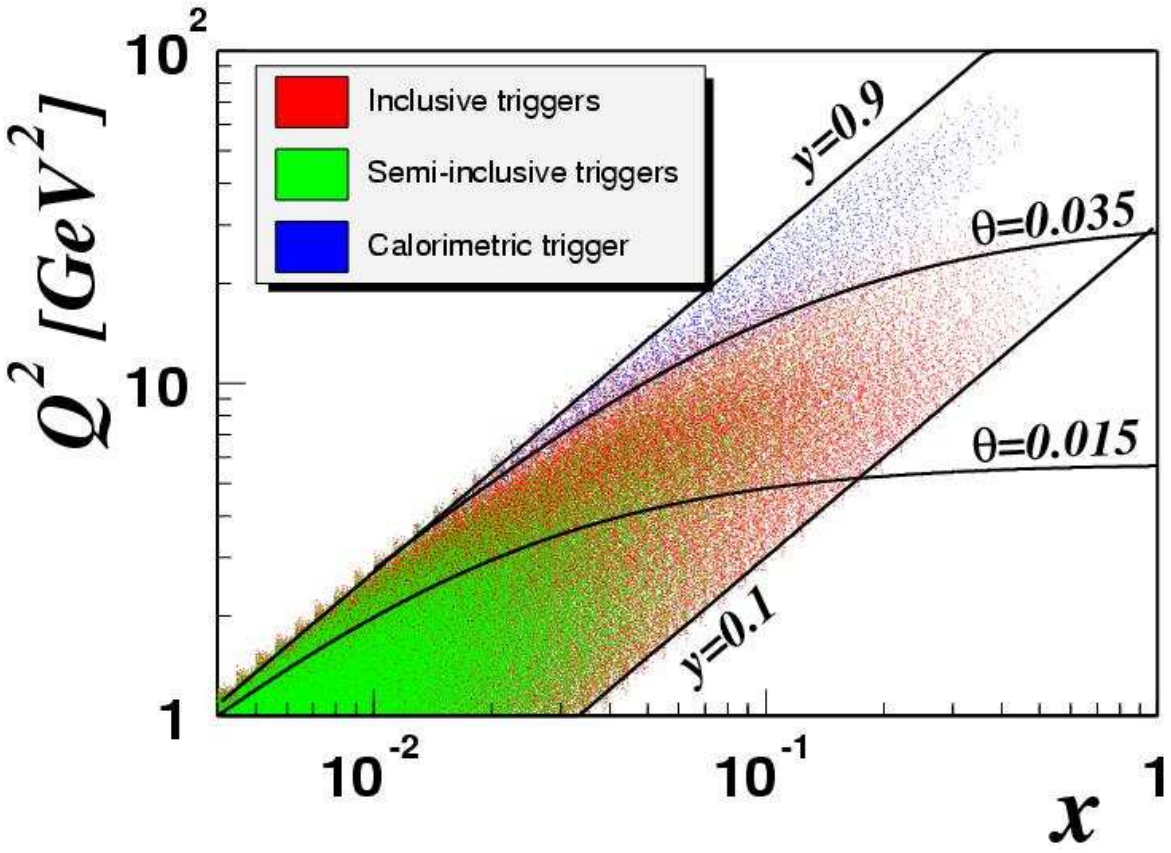




- Inclusive triggers (μ')
- Hadronic triggers
  - Semi-Inclusive triggers (μ'+2MIP)
  - Calorimetric trigger (9MIP)

- Parallel analysis for inclusive and hadronic events
- Hadronic triggers are checked with MC for possible bias

Kinematic region



$$Q^2 > 1\,\mathrm{GeV}^2$$

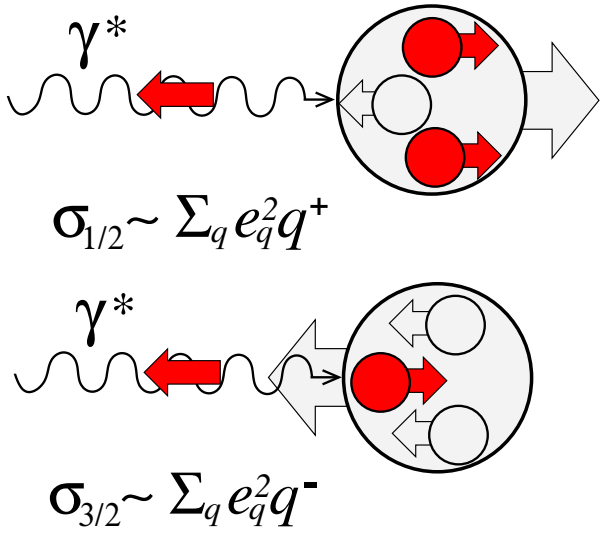
$$0.004 < x < 0.7$$

$$0.1 < y < 0.9$$

- Data of 2002, 2003 & 2004
- $88 \cdot 10^6$ DIS events

Virtual photon-nucleon asymmetry

$$A^{\gamma N} \equiv A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \approx \frac{\sum_q e_q^2 \left(q^+ - q^-\right)}{\sum_q e_q^2 \left(q^+ + q^-\right)}$$



- Structure functions in QPM

$$F_1(x) = \frac{1}{2} \sum_q e_q^2 \left(q^+ + q^-\right)$$

$$g_1(x) = \frac{1}{2} \sum_q e_q^2 \left(q^+ - q^-\right)$$

- Measurement of A_1 gives access to structure functions

$$g_1^d = \frac{g_1^p + g_1^n}{2}(1 - \frac{3}{2}\omega_D) \simeq A_1^d \cdot F_1^d$$

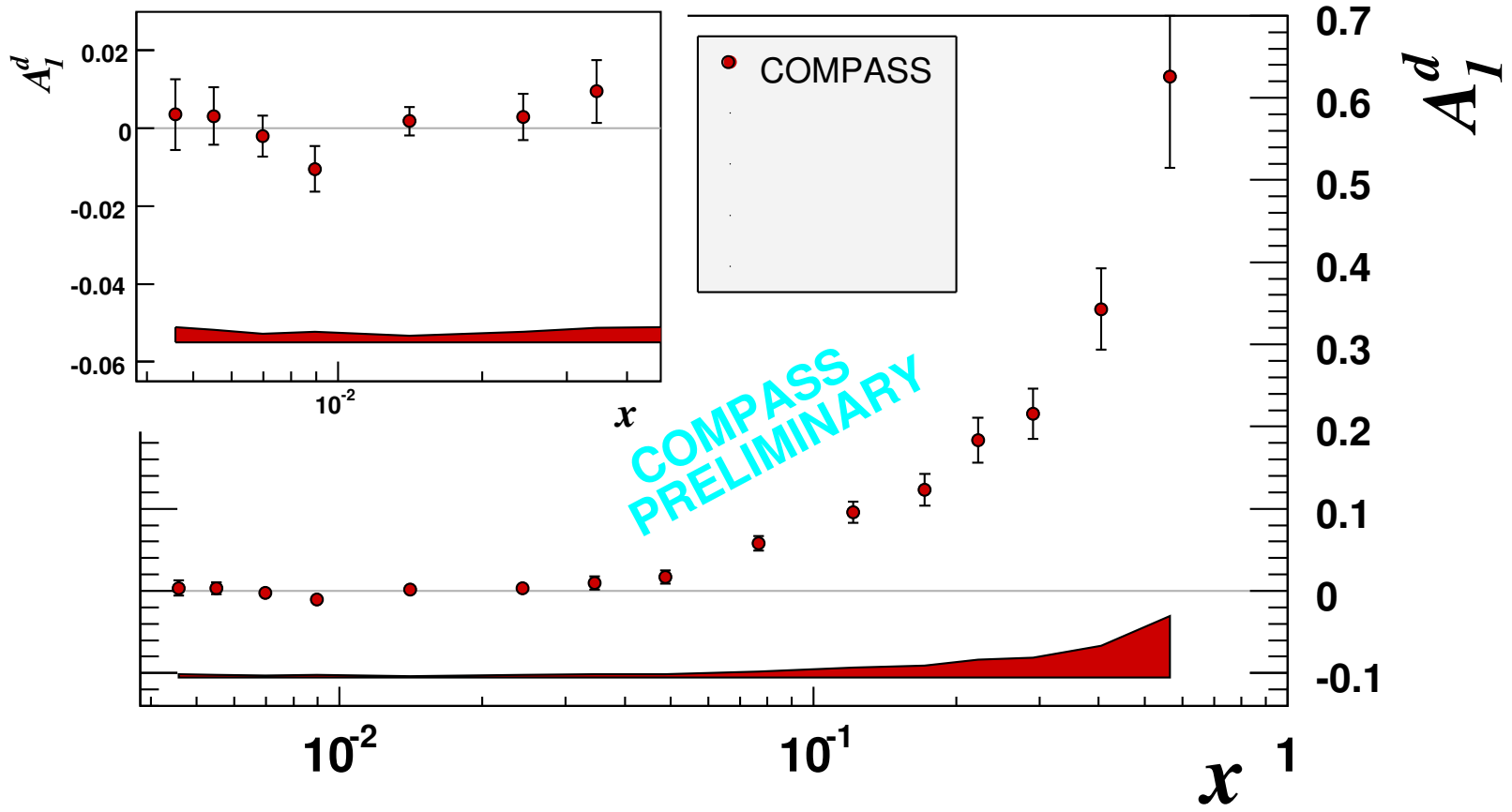
- μ-deuteron asymmetry is measured in experiment

$$A^{\mu d} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} = D\left(A_1 + \eta A_2\right)$$

- $|\eta A_2| \ll |A_1|$

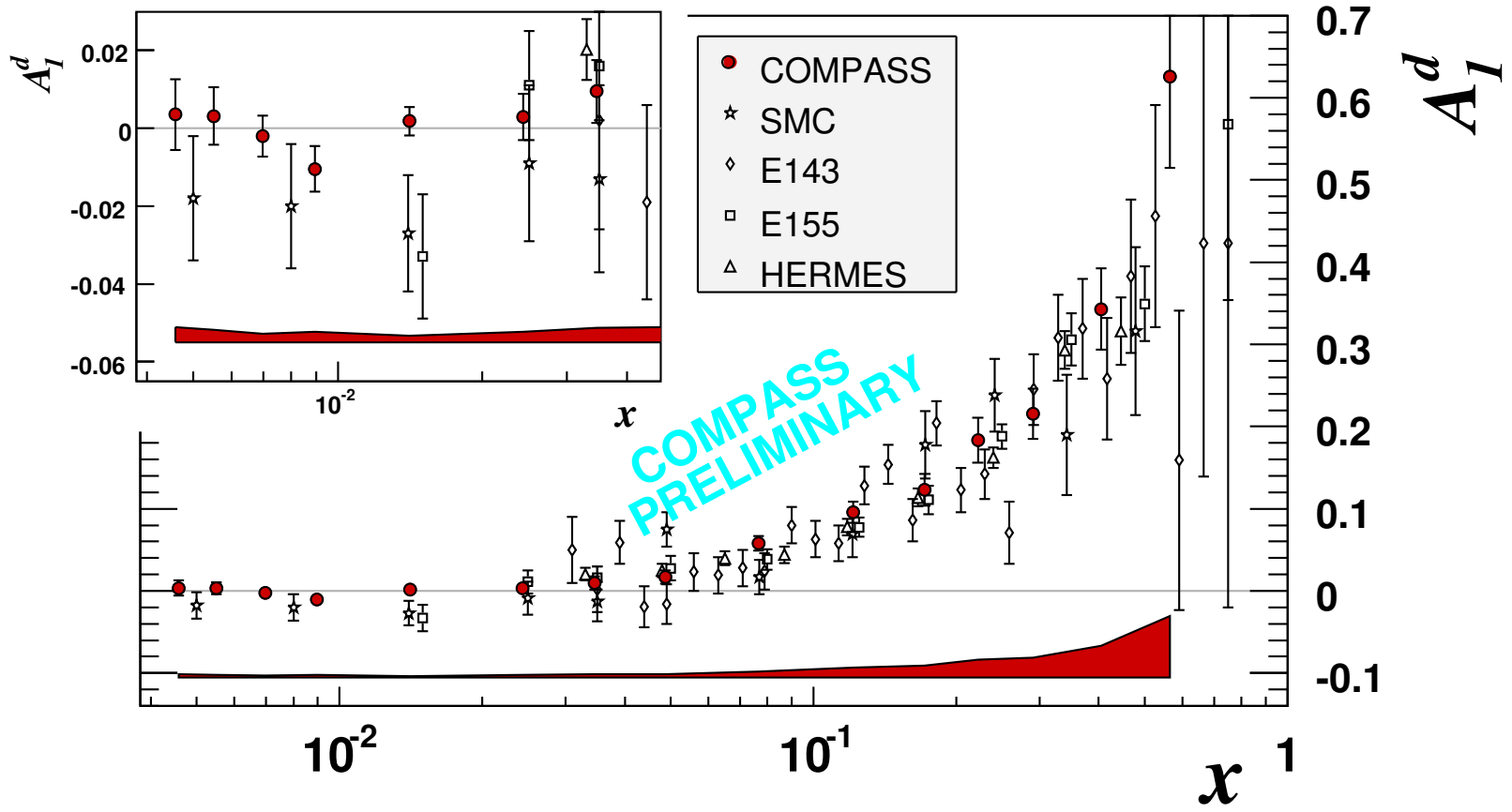
$$A_1 \simeq \frac{A^{\mu d}}{D}$$

Results on Inclusive Asymmetry A_1^d



- Good agreement in the region $x > 0.03$
- For $x < 0.03$ statistical error is reduced by factor 4
- Results show no tendency toward negative values at $x < 0.03$

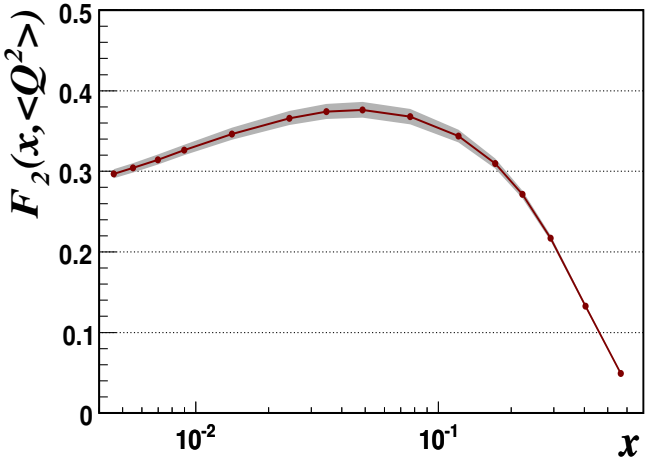
Results on Inclusive Asymmetry A_1^d

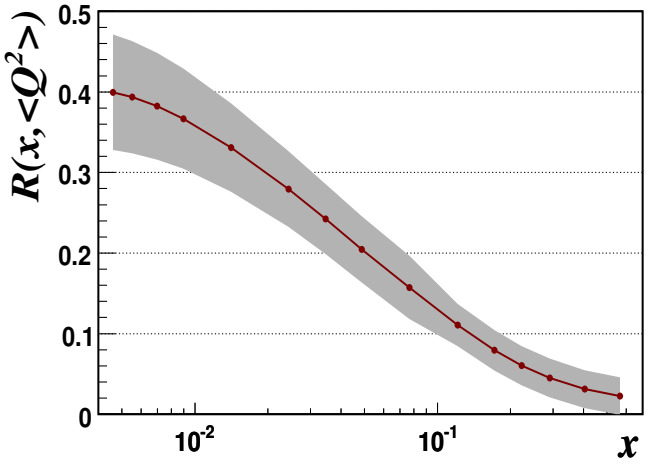


- Good agreement in the region $x > 0.03$
- For $x < 0.03$ statistical error is reduced by factor 4
- Results show no tendency toward negative values at $x < 0.03$

Results on Structure Function g_1^d

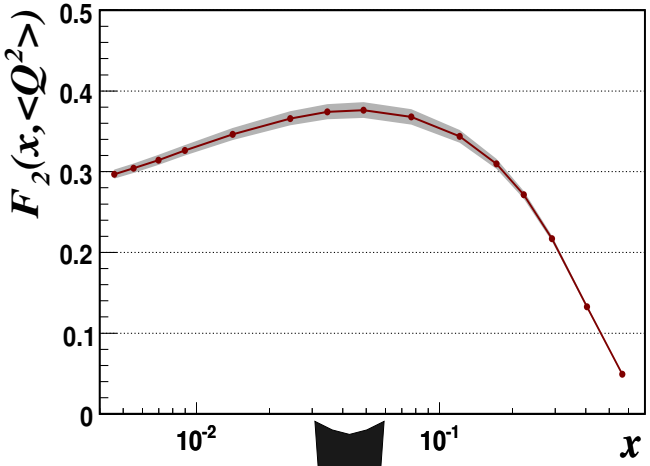
$$g_1^d = g_1^N \cdot (1 - \tfrac{3}{2}\omega_D) = \frac{F_2^d}{2x(1+R)} A_1^d$$

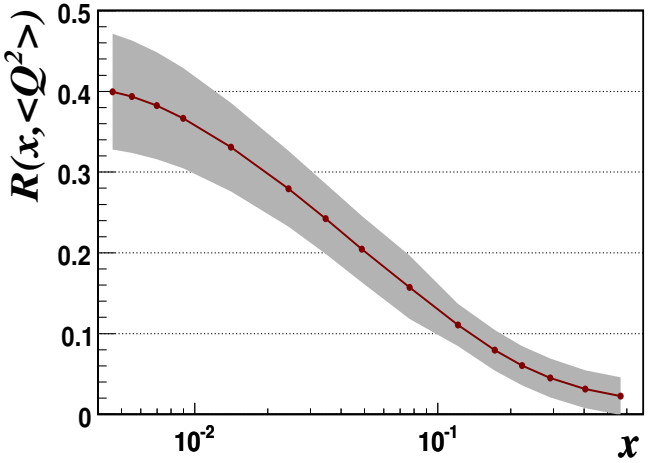


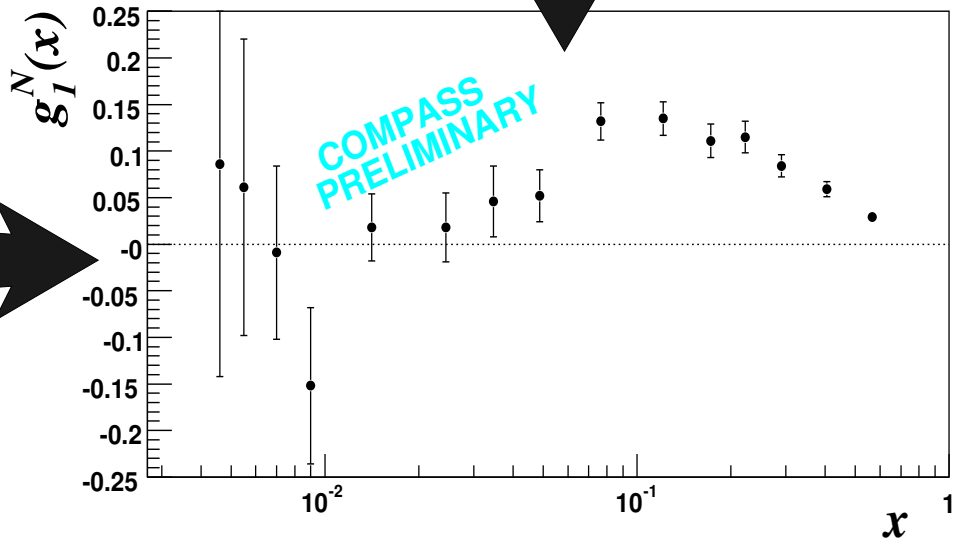


Results on Structure Function g_1^d

$$g_1^d = g_1^N \cdot (1 - \tfrac{3}{2}\omega_D)$$
$$= \frac{F_2^d}{2x(1+R)} A_1^d$$







QCD analysis

- Measured structure functions $g_1^{p,d,n}$ (different x, Q^2)

$$g_1(x,Q^2) = \frac{1}{2}\langle e^2\rangle \left[C_q^S \otimes \Delta\Sigma + C_q^{NS} \otimes \Delta q^{NS} + 2n_f\, C_G \otimes \Delta G\right]$$

- DGLAP equations (Q^2-dependence)

$$\frac{d}{dt}\Delta q^{NS} = \frac{\alpha_s(t)}{2\pi} P_{qq}^{NS} \otimes \Delta q^{NS}$$

$$\frac{d}{dt}\begin{pmatrix}\Delta\Sigma\\ \Delta G\end{pmatrix} = \frac{\alpha_s(t)}{2\pi}\begin{pmatrix}P_{qq}^S & 2n_f P_{qG}^S\\ P_{Gq}^S & P_{GG}^S\end{pmatrix} \otimes \begin{pmatrix}\Delta\Sigma\\ \Delta G\end{pmatrix}, \quad t = \log\left(\frac{Q^2}{\Lambda^2}\right)$$

- Initial parametrization (x-dependence at fixed Q^2)

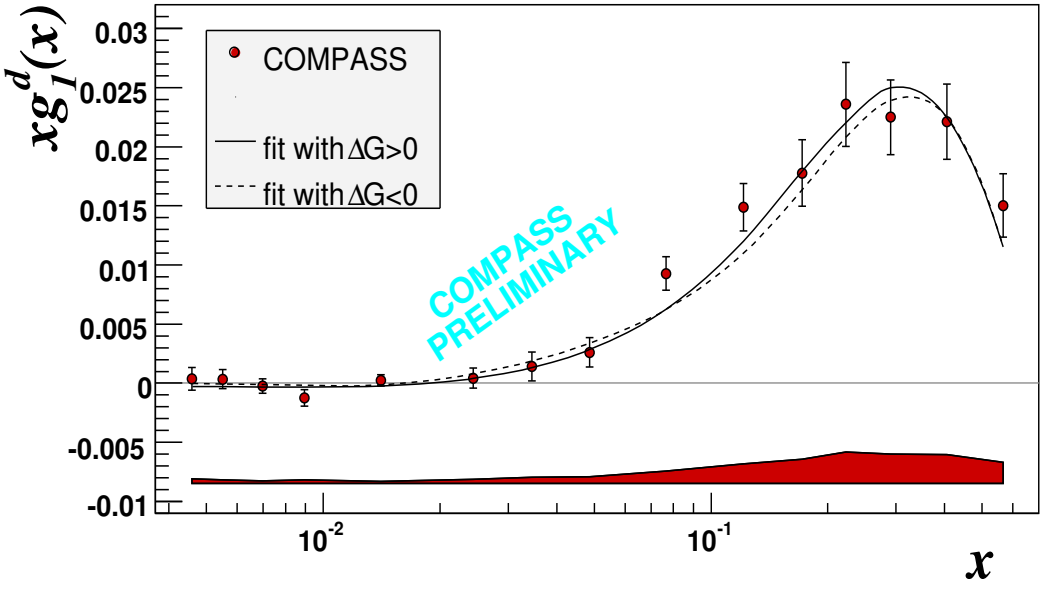
$$(\Delta\Sigma, \Delta q_3, \Delta q_8, \Delta G) = \eta\, \frac{x^\alpha (1-x)^\beta (1+\gamma x)}{\int_0^1 x^\alpha (1-x)^\beta (1+\gamma x) dx}$$

- Minimization routine

$$\chi^2 = \sum_{i=1}^{N} \frac{\left[g_1^{\rm calc}(x,Q^2) - g_1^{\rm exp}(x,Q^2)\right]^2}{\left[\sigma_{\rm stat}^{\rm exp}(x,Q^2)\right]^2}$$

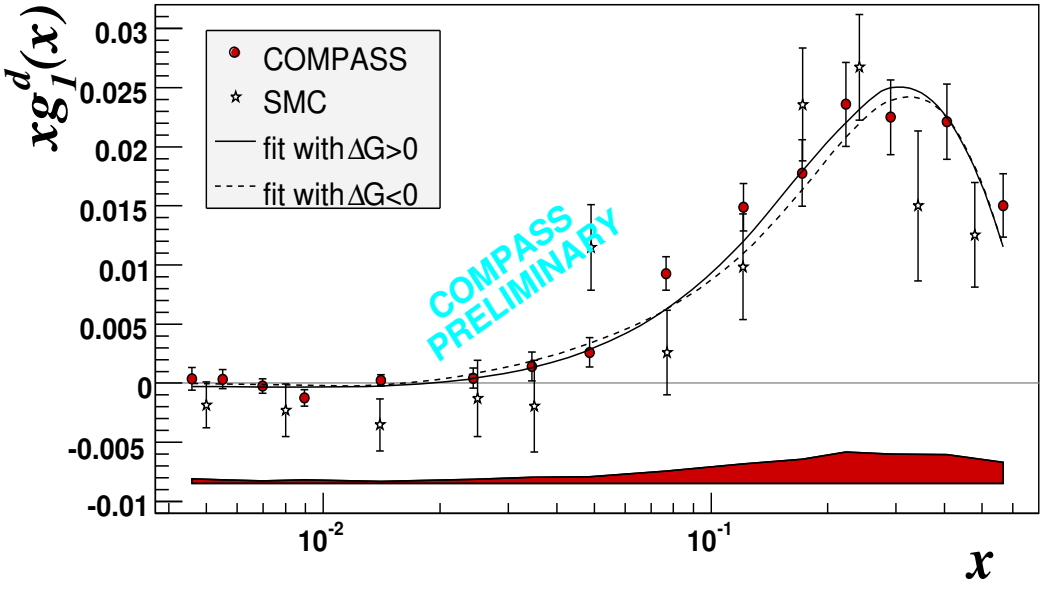
QCD analysis

- Two programs have been used:
  1. Numerical integration in (x, Q^2) space (Phys.Rev.D58(1998)112002)
  2. Solution of DGLAP in space of moments (Phys.Rev.D70(2004)074032)
- NLO calculation in $\overline{MS}$ scheme
- World data fit: 9 experiments, 230 experimental points
- 2 solution were found which describe data equally well and correspond to $\Delta G > 0$ and $\Delta G < 0$

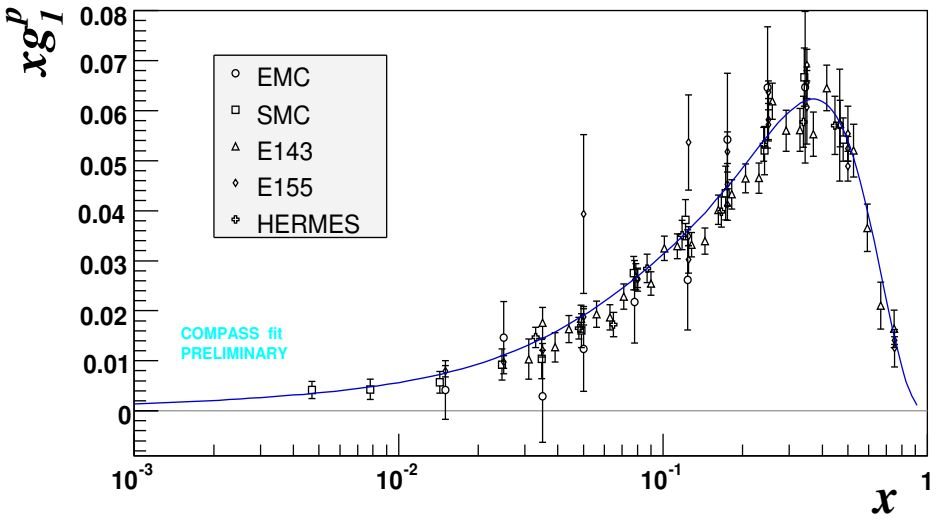


QCD analysis

- Two programs have been used:
  1. Numerical integration in (x, Q^2) space (Phys.Rev.D58(1998)112002)
  2. Solution of DGLAP in space of moments (Phys.Rev.D70(2004)074032)
- NLO calculation in $\overline{MS}$ scheme
- World data fit: 9 experiments, 230 experimental points
- 2 solution were found which describe data equally well and correspond to $\Delta G > 0$ and $\Delta G < 0$



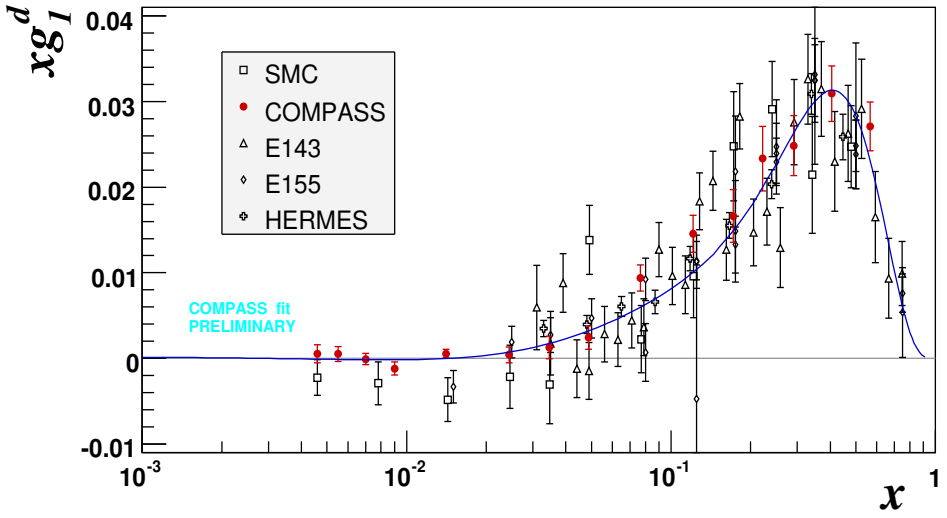
Results (structure functions)

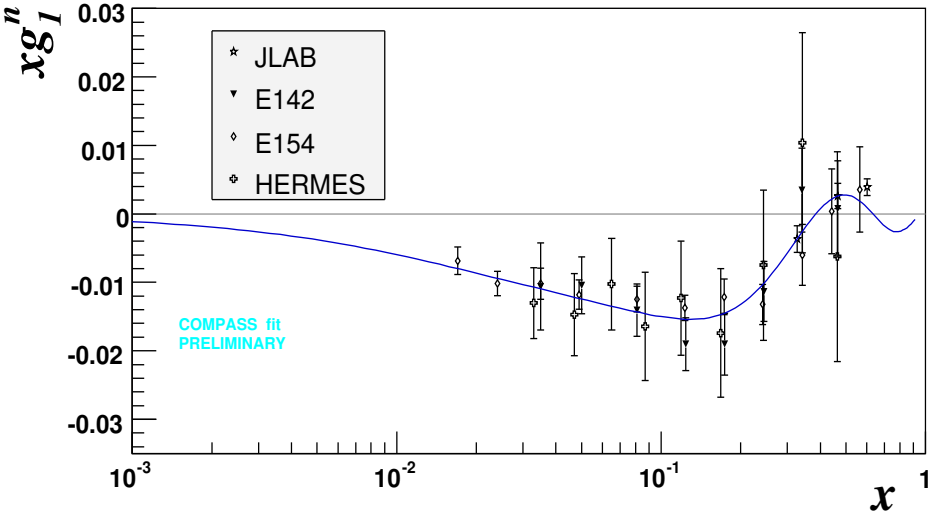


- World data and QCD fit at $Q^2 = 3\,\mathrm{GeV}^2$:

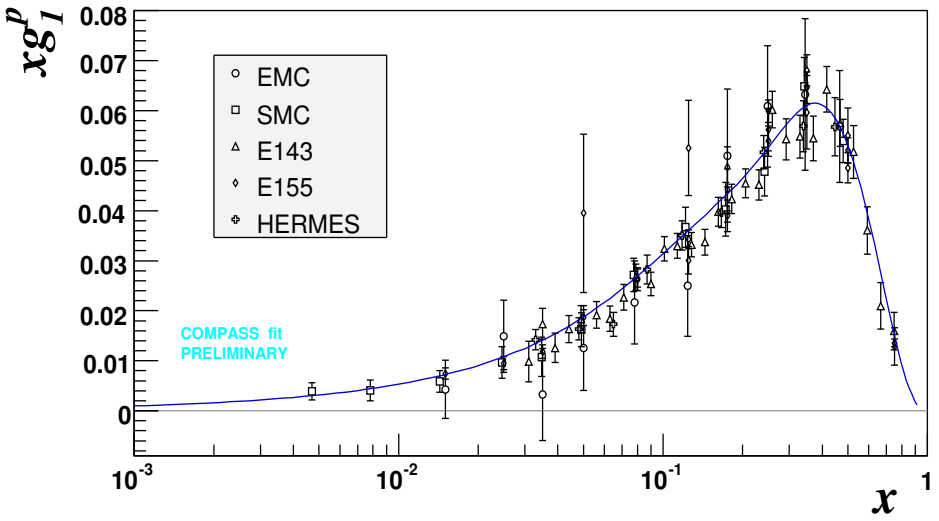
  $g_1(x, Q_0^2) = g_1(x, Q_i^2) + \left[g_1^{fit}(x, Q_0^2) - g_1^{fit}(x, Q_i^2)\right]$

- Curve corresponds to the solution with $\Delta G < 0$





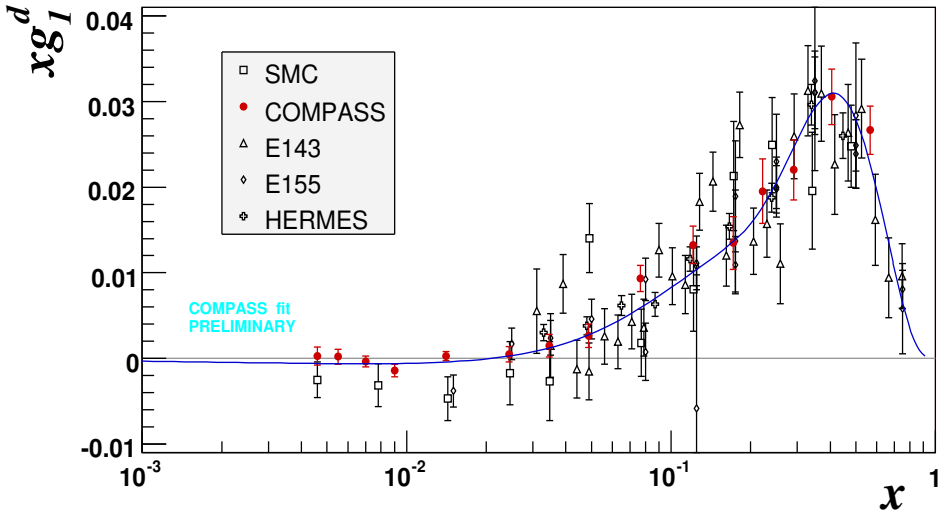
Results (structure functions)

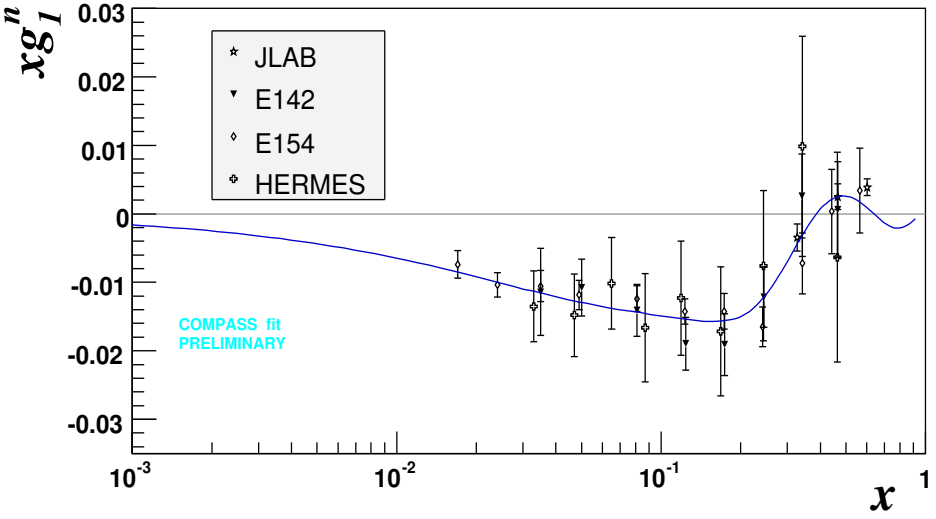


- World data and QCD fit at $Q^2 = 3\,\mathrm{GeV}^2$:

  $g_1(x, Q_0^2) = g_1(x, Q_i^2) + \left[g_1^{fit}(x, Q_0^2) - g_1^{fit}(x, Q_i^2)\right]$

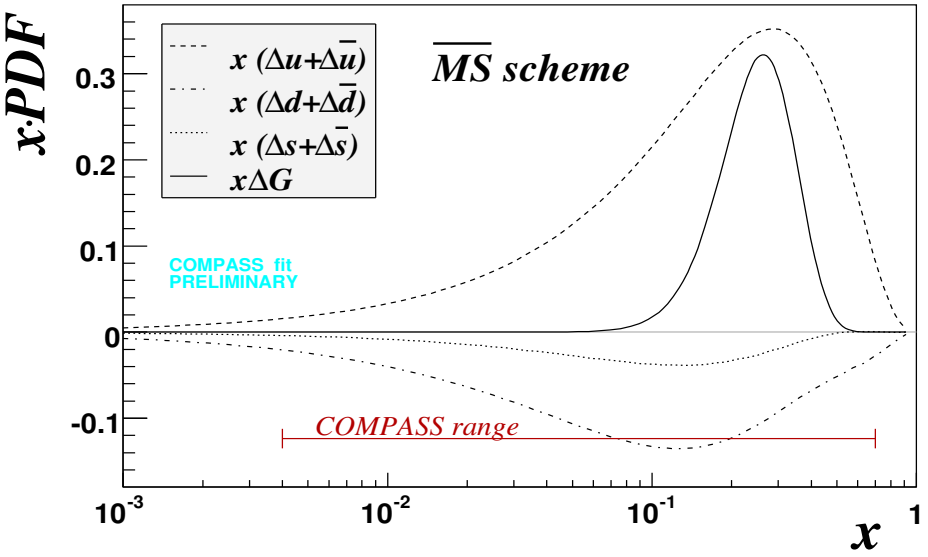
- Curve corresponds to the solution with $\Delta G > 0$

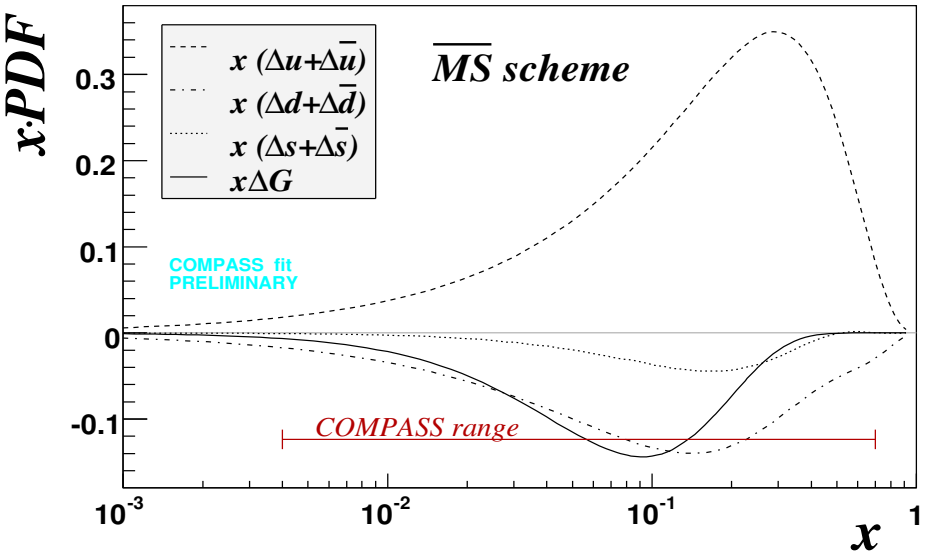


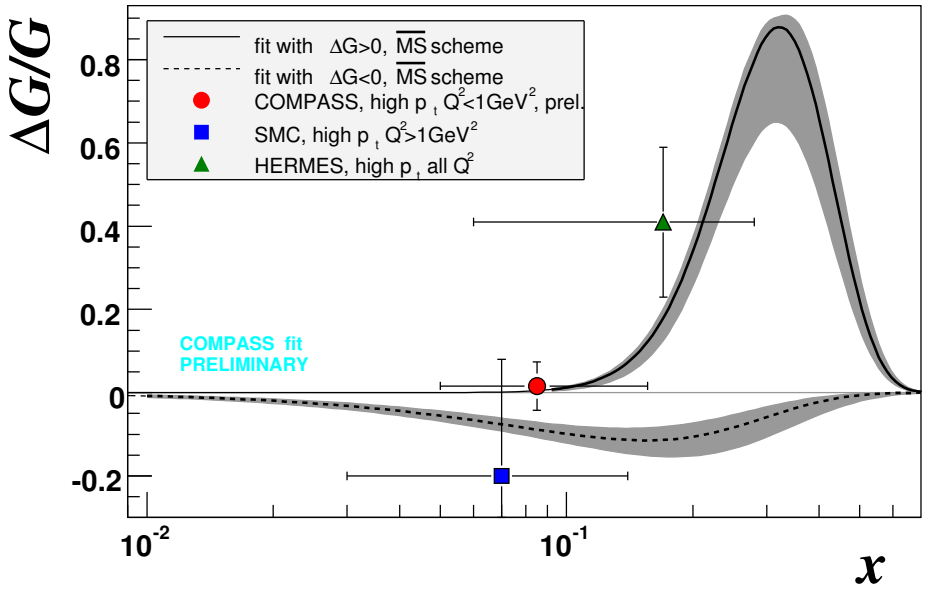


Results (PDF's)

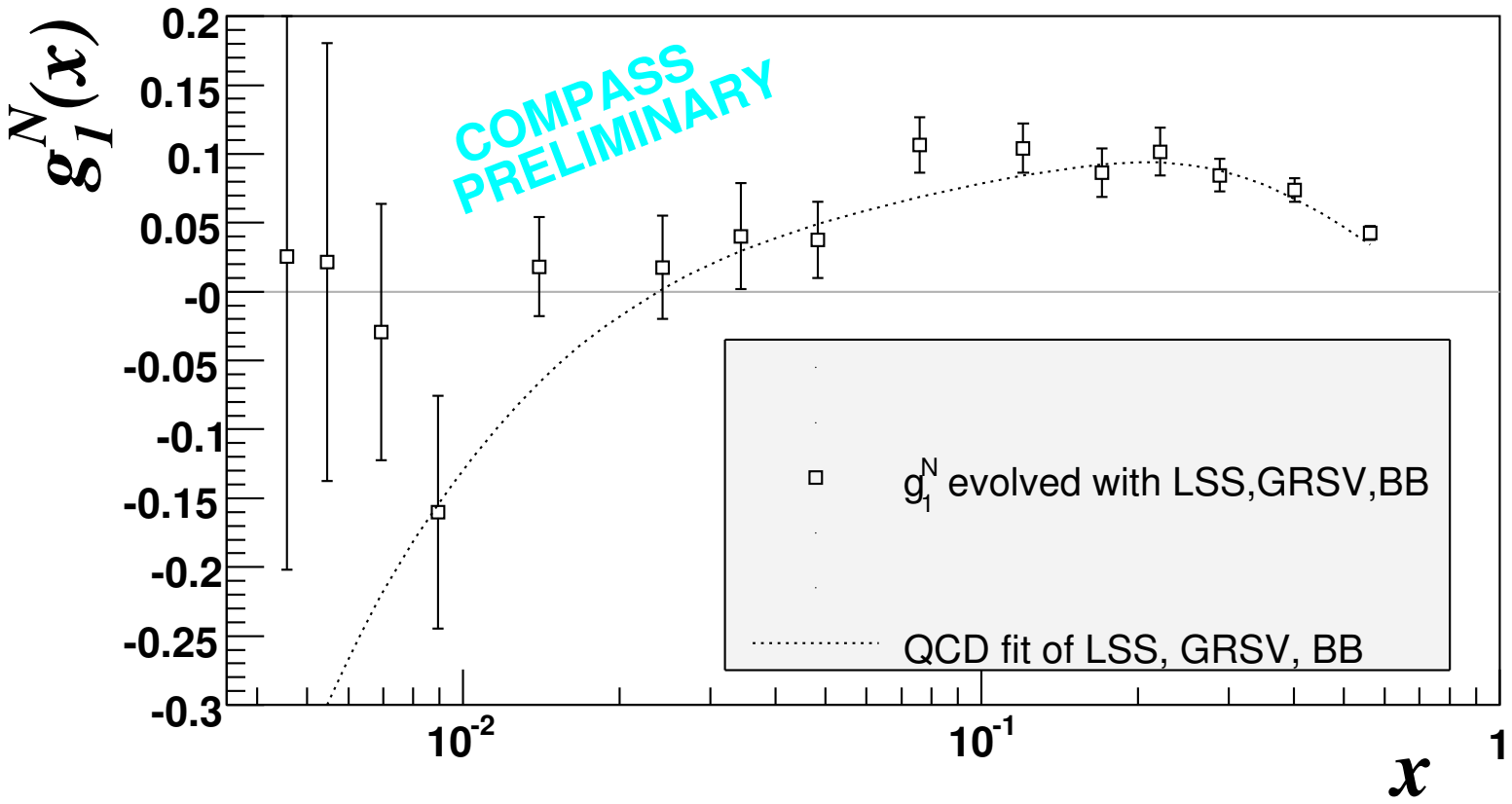
- Individual parton distributions at $Q^2 = 3\,\mathrm{GeV}^2$
- Gluon polarization $\Delta G/G$
  - Unpolarized $G(x)$ from MRST
  - Bands correspond stat. error of ΔG





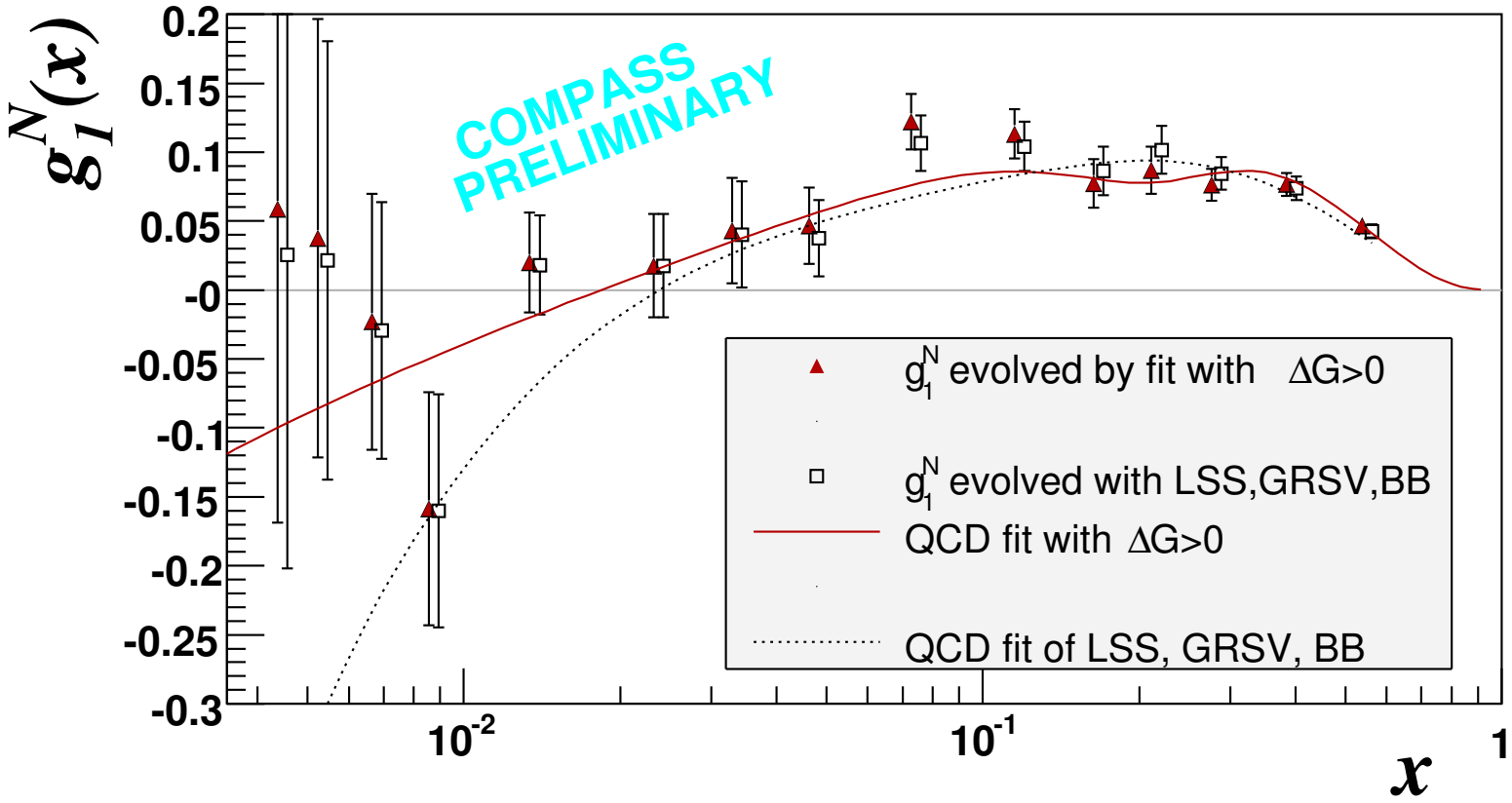


Comparison with published fits ($Q^2 = 3\,\mathrm{GeV}^2$)



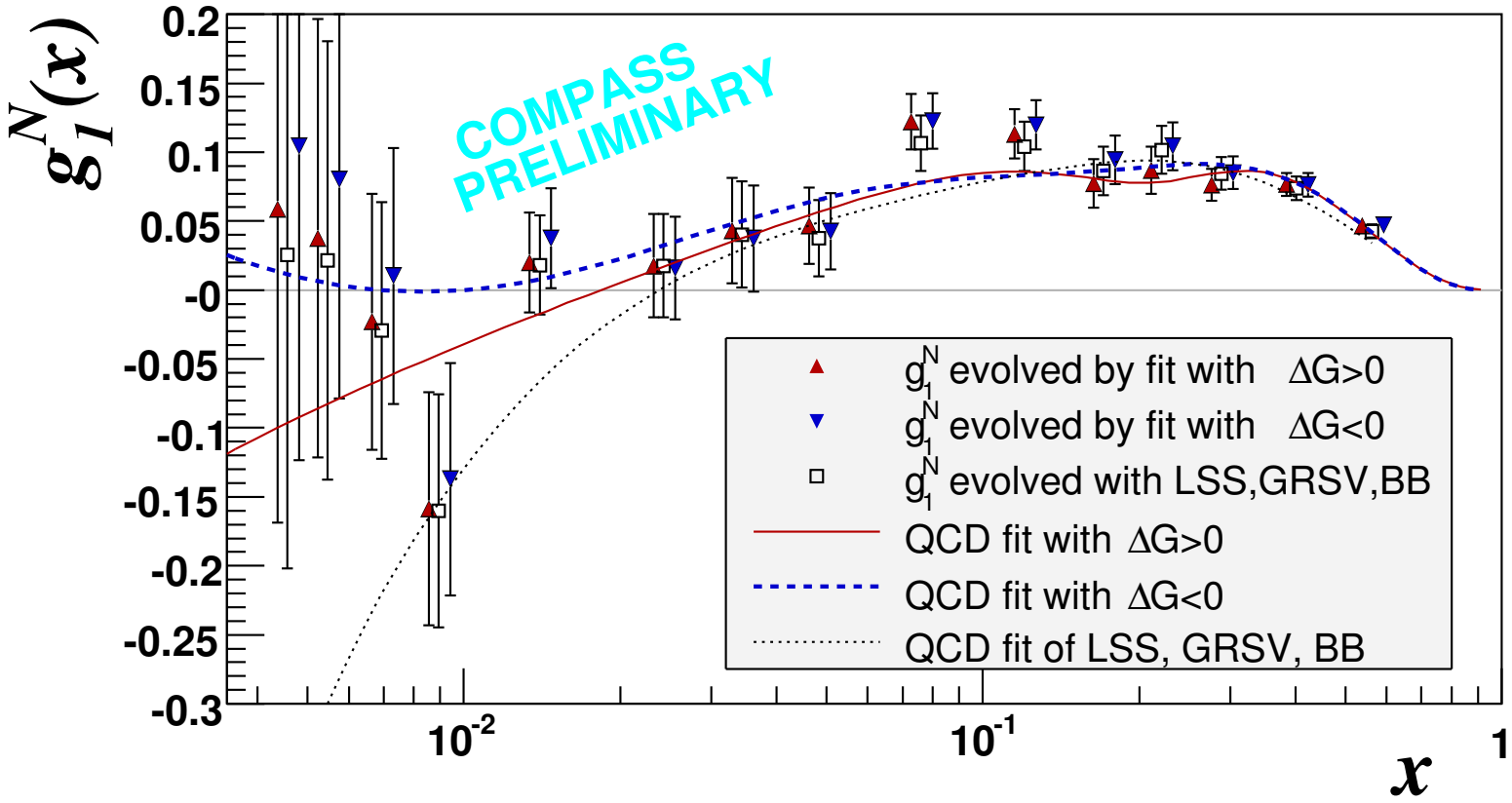
- Disagreement of data with previous QCD fits (Blumlein and Bottcher, GRSV and LSS05) at low x

Comparison with published fits ($Q^2 = 3\,\mathrm{GeV}^2$)



- Disagreement of data with previous QCD fits (Blumlein and Bottcher, GRSV and LSS05) at low x

Comparison with published fits ($Q^2=3\,\mathrm{GeV}^2$)



- Disagreement of data with previous QCD fits (Blumlein and Bottcher, GRSV and LSS05) at low x

Quark polarization η_Σ

- Well determined by data (proportional to the $\int_0^1 g_1^d(x,Q^2)dx$)
- No difference between results of two QCD-fit programs and the difference for two solutions ($\eta_G > 0$ and < 0) is also very small

	$\eta_G > 0$	$\eta_G < 0$
η_Σ	0.28 ± 0.01	0.32 ± 0.01

$\Rightarrow$ $\eta_\Sigma = 0.30 \pm 0.01(stat) \pm 0.02(evol)$

Gluon polarization η_G

- Indirect determination (via evolution questions)
- Solutions with $\eta_G > 0$: $\eta_G^{prog\,1} = 0.26\ ^{+\ 0.04}_{-\ 0.06}$, $\eta_G^{prog\,2} = 0.19\ ^{+\ 0.01}_{-\ 0.10}$
- Solutions with $\eta_G < 0$: $\eta_G^{prog\,1} = -0.31\ ^{+\ 0.1}_{-\ 0.1}$, $\eta_G^{prog\,2} = -0.18\ ^{+\ 0.04}_{-\ 0.03}$

$|\eta_G| \simeq 0.2 - 0.3$

Quark polarization with COMPASS data only

- The first moment of g_1^d at $Q^2{=}3\,\mathrm{GeV}^2$:

$$\Gamma_1^N \;=\; \int_0^1 g_1^N(x,Q^2)dx \;=\; 0.0502 \pm 0.0028(stat) \pm 0.0020(evol) \pm 0.0051(syst)$$

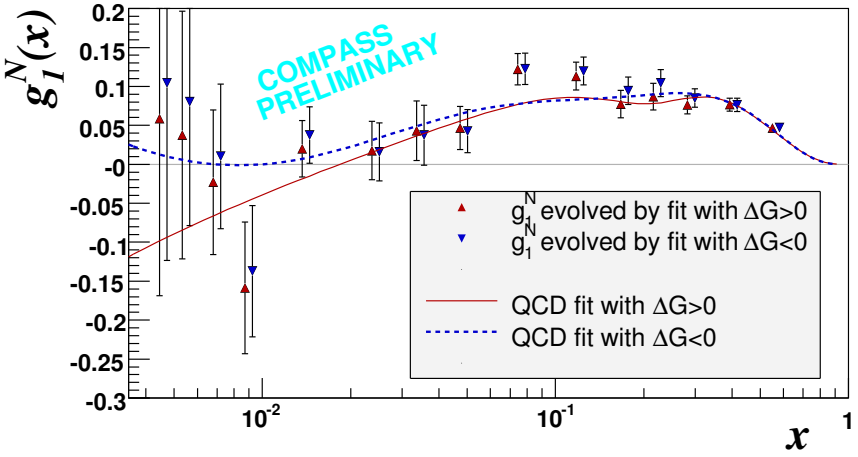
- a_0 can be extracted from the first moment of g_1^N

$$\Gamma_1^N(Q^2)\Big|_{NLO} = \frac{1}{9}\left(1 - \frac{\alpha_s(Q^2)}{\pi} + \mathcal{O}(\alpha_s^2)\right) \times \left(a_0(Q^2) + \frac{1}{4}a_8\right)$$

- From hyperon β decays assuming $SU(3)_f$:

$$a_8 = 0.585 \pm 0.025$$

- Contribution from unmeasured x-range is $\approx$4%



- Quark polarization at $Q^2{=}3\,\mathrm{GeV}^2$:

$$a_0 \;=\; 0.35 \pm 0.03(stat) \pm 0.05(syst)$$

$$\eta_\Sigma \;=\; 0.30 \pm 0.01(stat) \pm 0.02(evol)$$

Summary

- Analysis of COMPASS data 2002, 2003 and 2004
- New measurement of A_1^d and g_1^d in DIS region (Q^2>1 GeV^2, 0.004<x<0.7)
  - ◇ Good agreement with results of previous experiments (middle & high x)
  - ◇ Improvement in statistical precision factor 4 in region $x < 0.03$
  - ◇ No tendency toward negative values at $x < 0.03$
- Existing QCD parameterizations need to be revised

Outlook

- Further increase in statistics with 2006 data
- Hadron asymmetries $A_1^{\pi\pm}$, $A_1^{K\pm}$, $A_1^{K_S^0}$ are coming