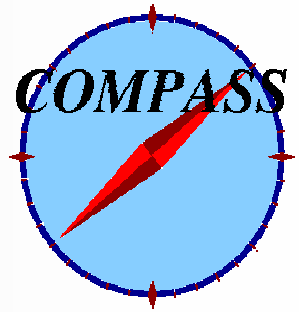
Measurements of the Spin-dependent Structure Function $g_1^d(x,Q^2)$ at COMPASS



Helena Santos

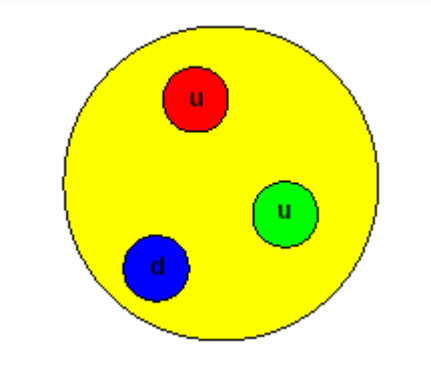
LIP - Lisboa

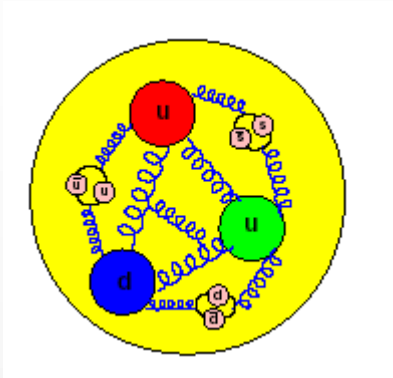
On Behalf of the COMPASS Collaboration

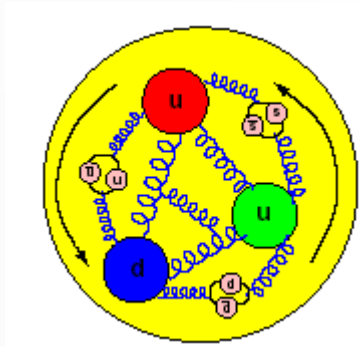
- The nucleon spin
- The COMPASS experiment
- Inclusive asymmetries
- The g_1 structure function

XXI Rencontres de Physique de La Vallée d'Aoste

The Nucleon Spin







naïve parton model:

$\Delta\Sigma = \Delta u + \Delta d = 1$

EMC (1988):

$\Delta\Sigma = 0.12 \pm 0.09 \pm 0.14$

$\Delta s + \Delta\bar{s} = -0.14 \pm 0.03$

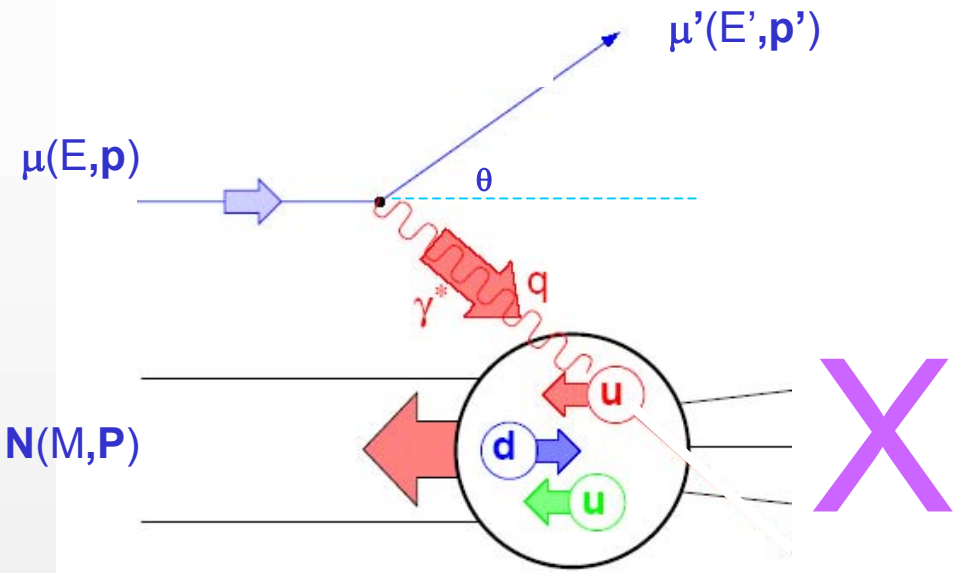
Gluons, sea and *c* quarks are important

complete description: orbital angular momenta

$$S_N = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g \qquad (\hbar=1)$$

H. Santos (helena@lip.pt)

Deep Inelastic Scattering



$Q^2 = -q^2 = (p - p')^2$

$\nu = E - E'$

$x = Q^2/2M\nu$

$y = \nu/E$

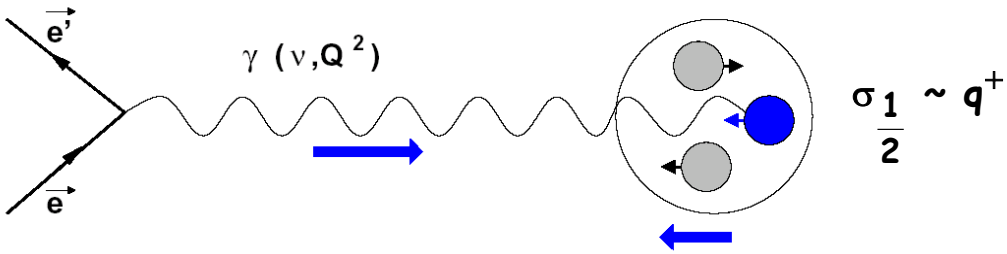
$$\frac{d^2\sigma}{d\Omega dE'} = \underbrace{c_1F_1\left(x,Q^2\right) + c_2F_2\left(x,Q^2\right)}_{\text{spin independent}} + \underbrace{c_3g_1\left(x,Q^2\right) + c_4g_2\left(x,Q^2\right)}_{\text{spin dependent}}$$

H. Santos (helena@lip.pt)

Polarised Deep Inelastic Scattering

photon-nucleon asymmetry

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \approx \frac{\sum_q e_q^2 \, \Delta q(x)}{\sum_q e_q^2 \, q(x)} = \frac{g_1(x)}{F_1(x)}$$



$$\Delta q(x) = q(x)^{+} - q(x)^{-}$$

$$q(x) = q(x)^{+} + q(x)^{-}$$

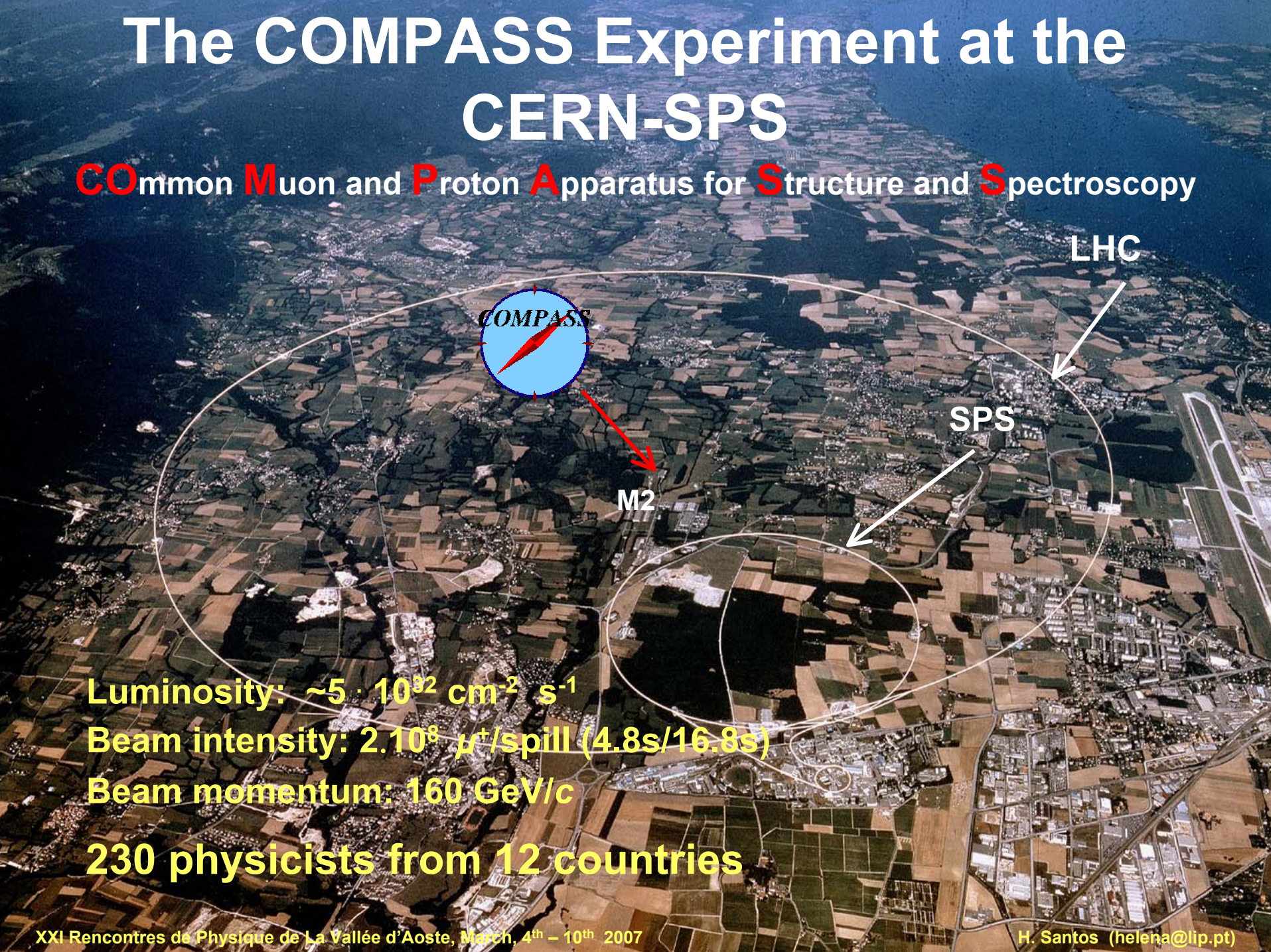
+: quark ↑↑ nucleon

–: quark ↑↓ nucleon

H. Santos (helena@lip.pt)

The COMPASS Experiment at the CERN-SPS

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



Luminosity: $\sim 5 \cdot 10^{32}$ cm^{-2} s^{-1}

Beam intensity: $2 \cdot 10^{8}$ μ^{+}/spill (4.8s/16.8s)

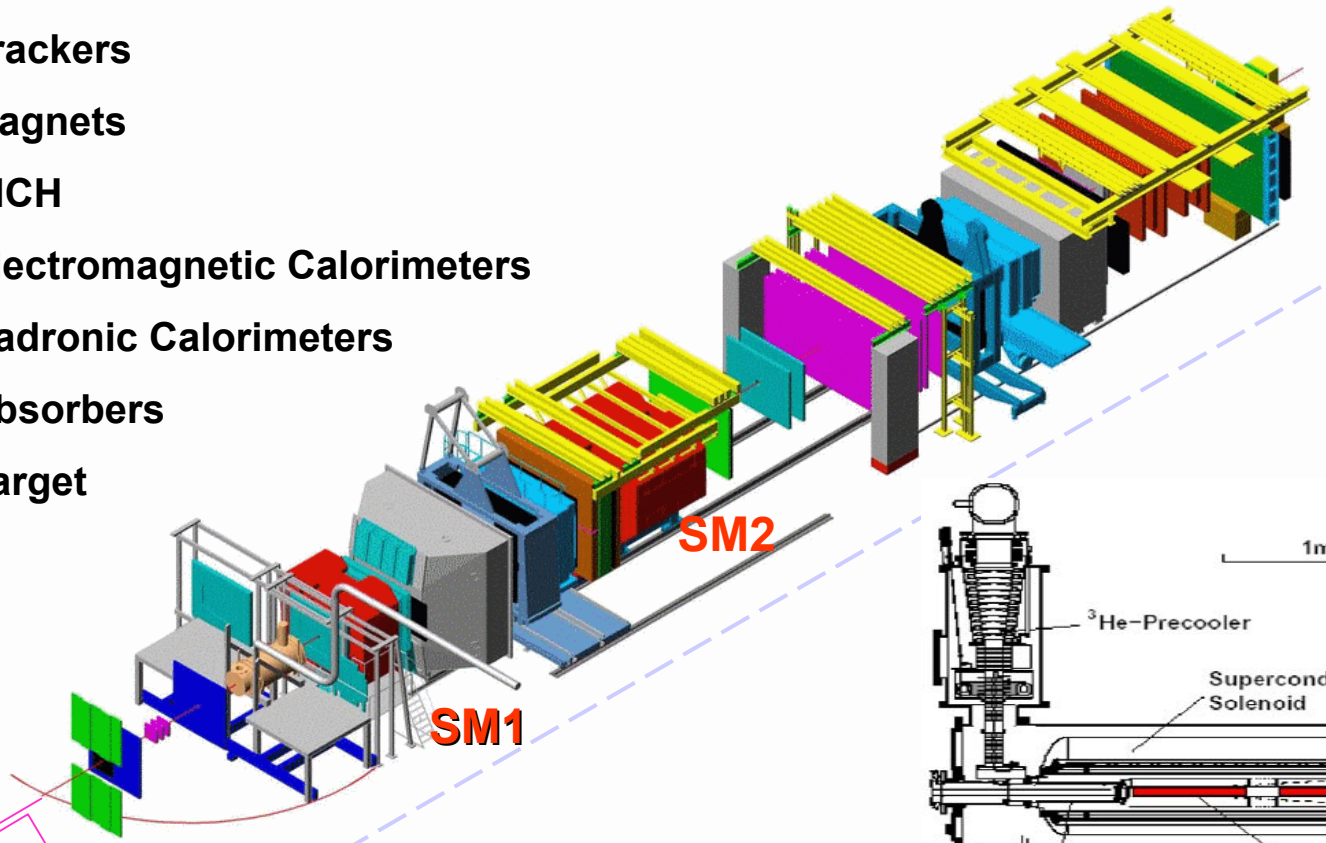
Beam momentum: 160 GeV/*c*

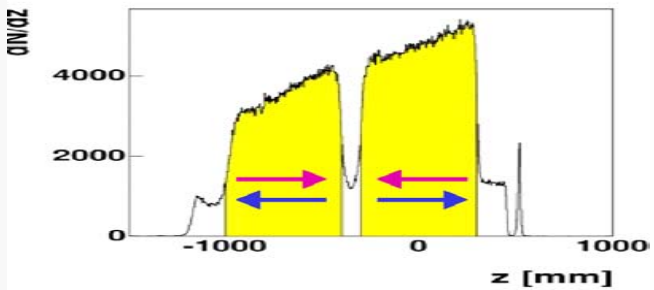
230 physicists from 12 countries

H. Santos (helena@lip.pt)

The COMPASS Spectrometer

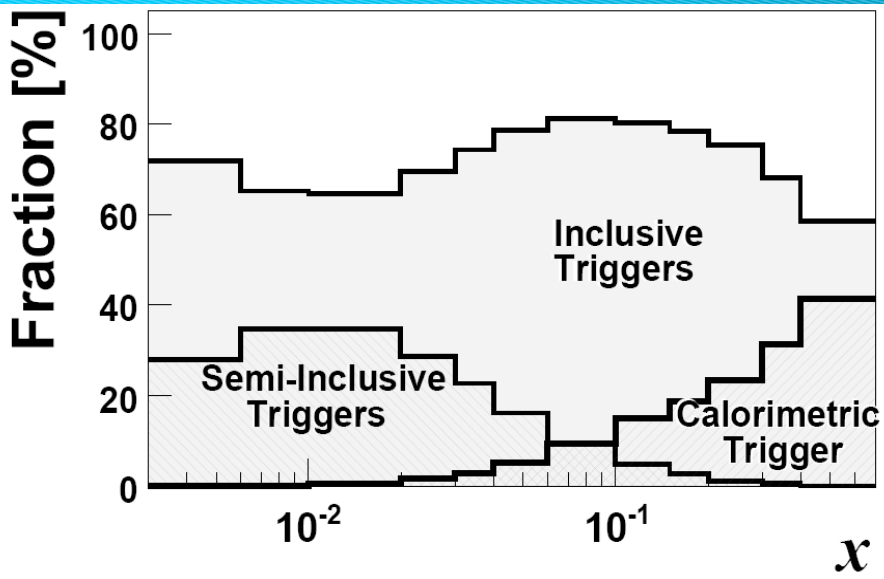
- Trackers
- Magnets
- RICH
- Electromagnetic Calorimeters
- Hadronic Calorimeters
- Absorbers
- Target

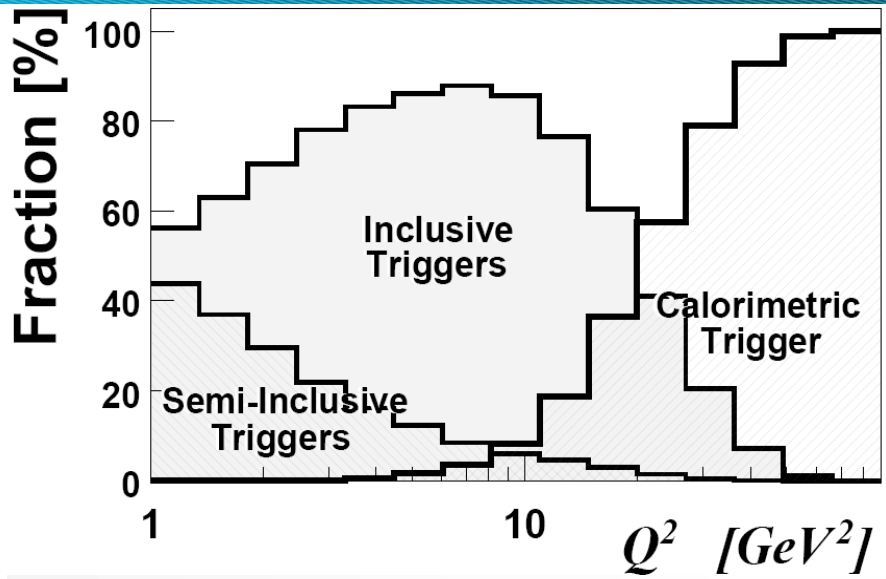


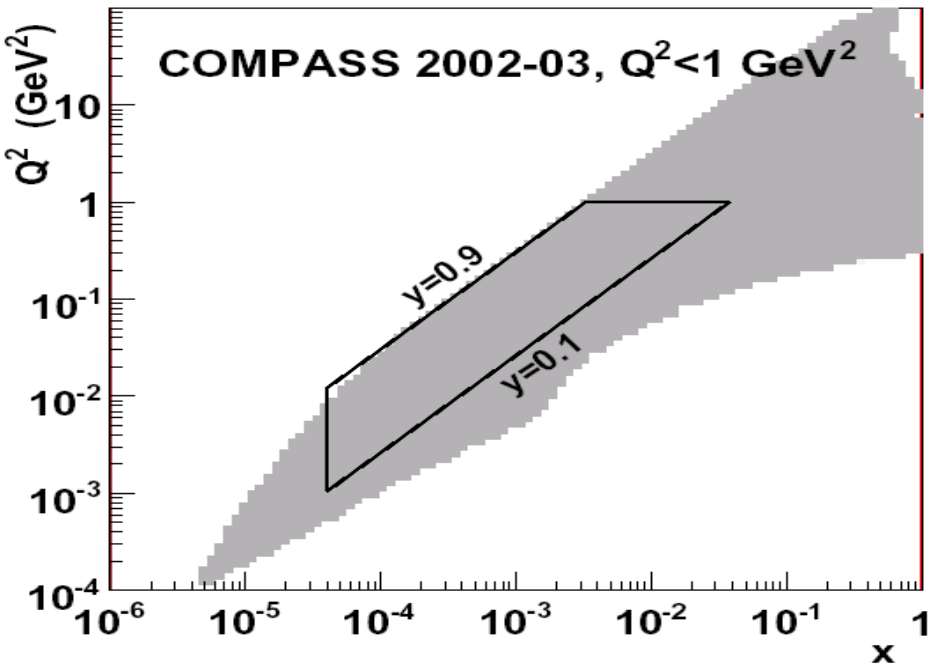


polarised beam and target
-80% ≥50%

Kinematic Domain







60—75% of inclusive triggers over the full COMPASS x range

Semi-inclusive triggers dominant at low x and low Q^2

Calorimetric triggers dominant for $Q^2 > 30$ GeV^2

H. Santos (helena@lip.pt)

The Longitudinal Photon-Deuteron Asymmetry

$$A^d = D(A_1^d + \eta A_2^d), \qquad A_2^d = \sigma_{TL}/\sigma_T \qquad (d \equiv \text{deuteron})$$

$$\eta = \frac{2(1-y)}{y(2-y)}\sqrt{Q^2}/E',$$

η is small in the COMPASS kinematic range, as well as A_2

$$A_1^d \cong A^d/D$$

$$A_1^d = \frac{1}{D}\boxed{\frac{1}{P_B P_T f}\frac{1}{2}\left(\frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}} + \frac{N'^{\uparrow\downarrow} - N'^{\uparrow\uparrow}}{N'^{\uparrow\downarrow} + N'^{\uparrow\uparrow}}\right)}$$

$N \equiv$ Number of detected events

$P_B \equiv$ Beam polarisation

$P_T \equiv$ Target polarisation

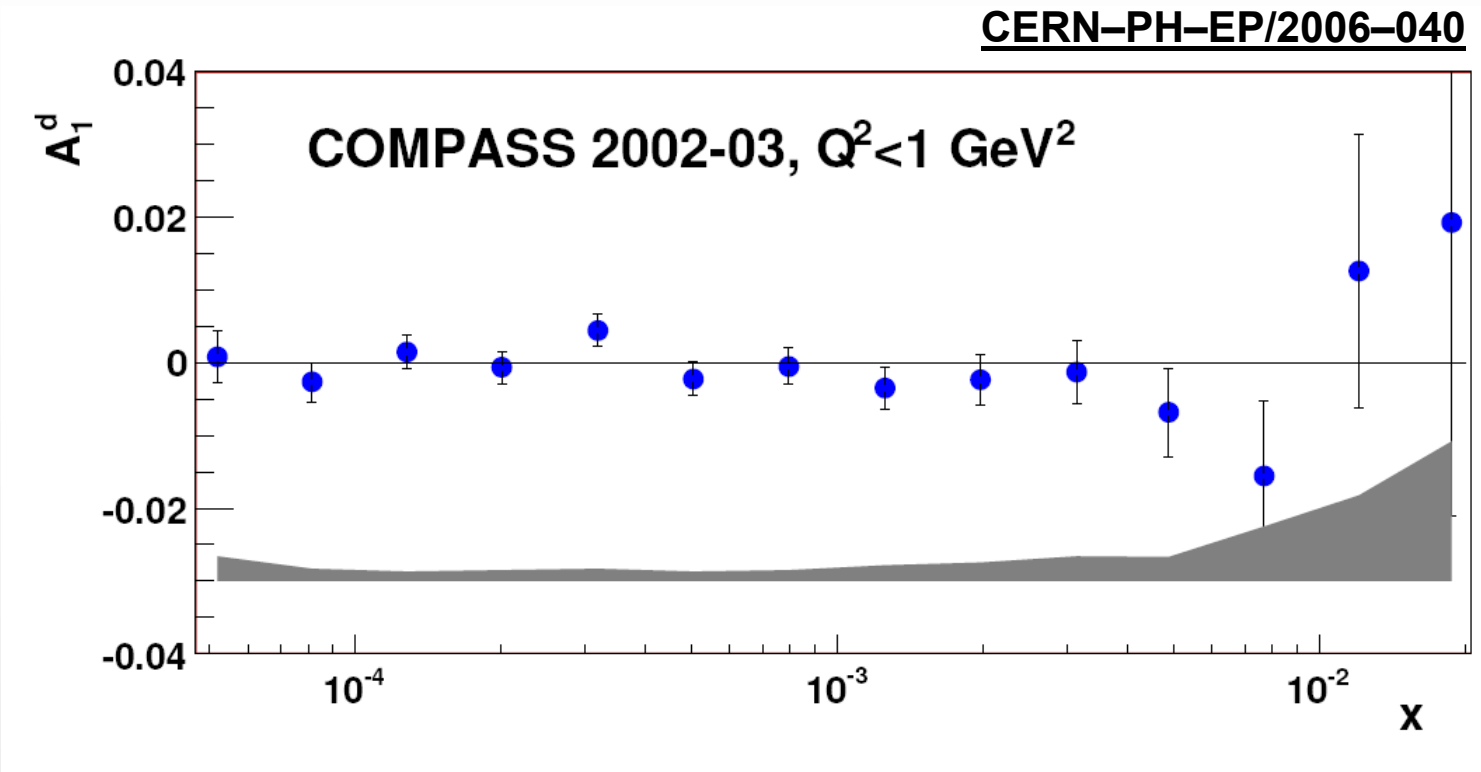
$f \equiv$ Dilution factor

$D \equiv$ Depolarisation factor

$\uparrow\downarrow \equiv 1^{st}$ cell (polarised anti-paralell to beam), $\uparrow\uparrow \equiv$ 2nd cell (polarised parallel to beam)

H. Santos (helena@lip.pt)

Inclusive Asymmetry, $Q^2 < 1$ GeV^2

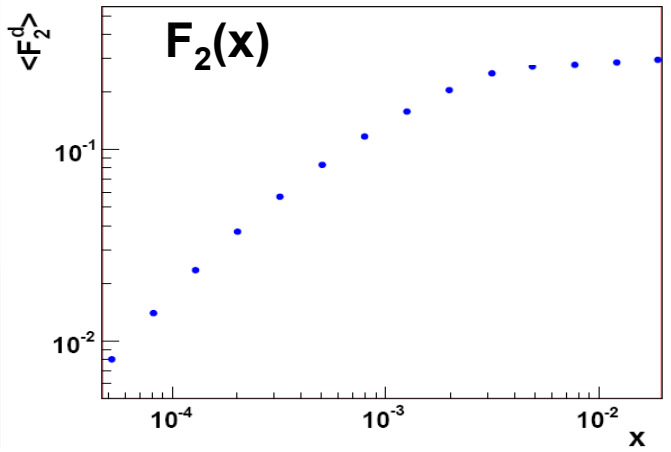


- A_1^d asymmetry compatible with 0 at low x range (0.0005<x<0.02)
- At low x A_1^d has been measured only by COMPASS and SMC
- Systematic errors are mainly due to false asymmetries

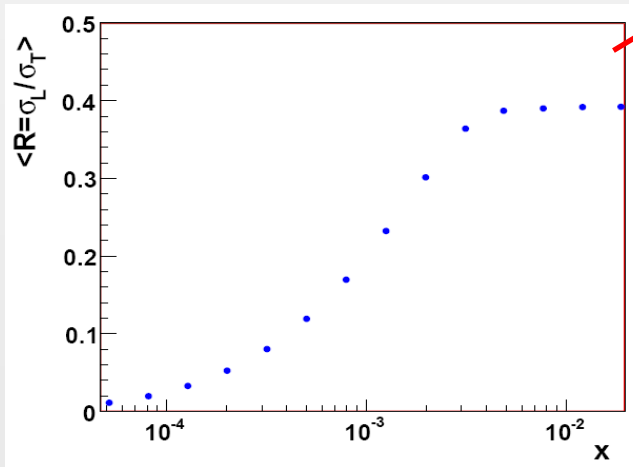
H. Santos (helena@lip.pt)

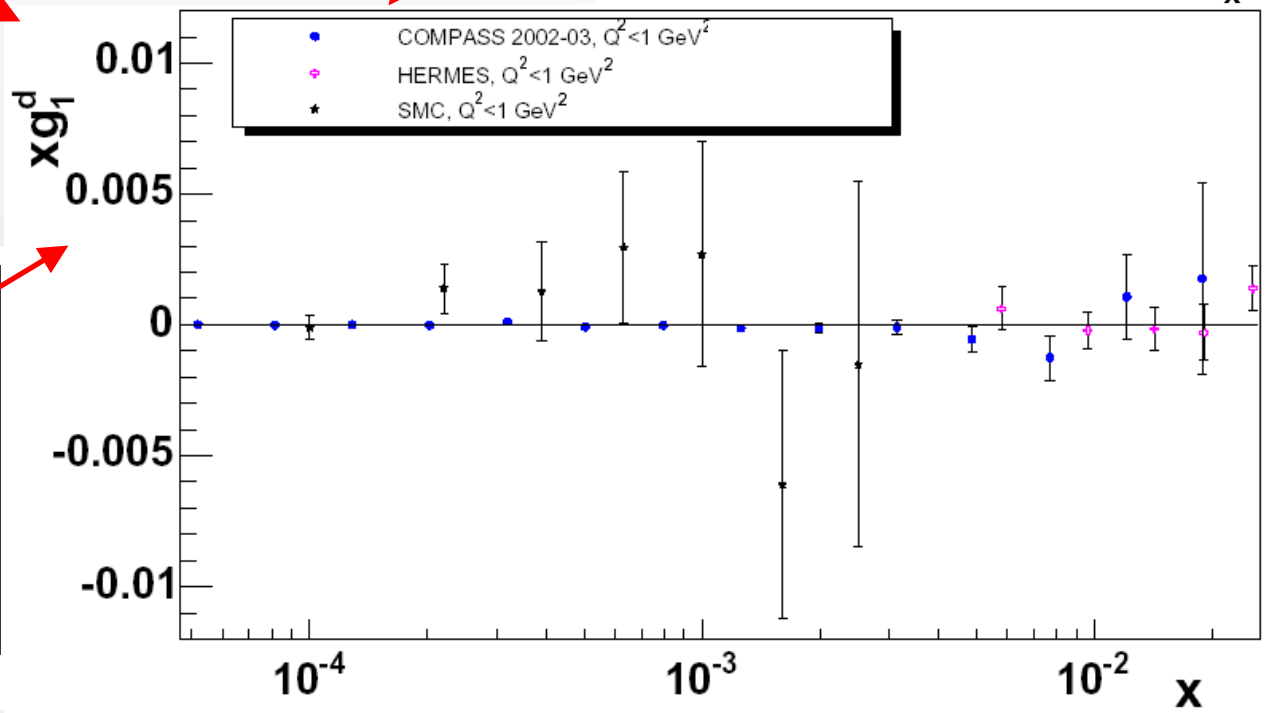
The $g_1(x)$ Structure Function

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



$$R(x,Q^2) = \sigma_L / \sigma_T$$

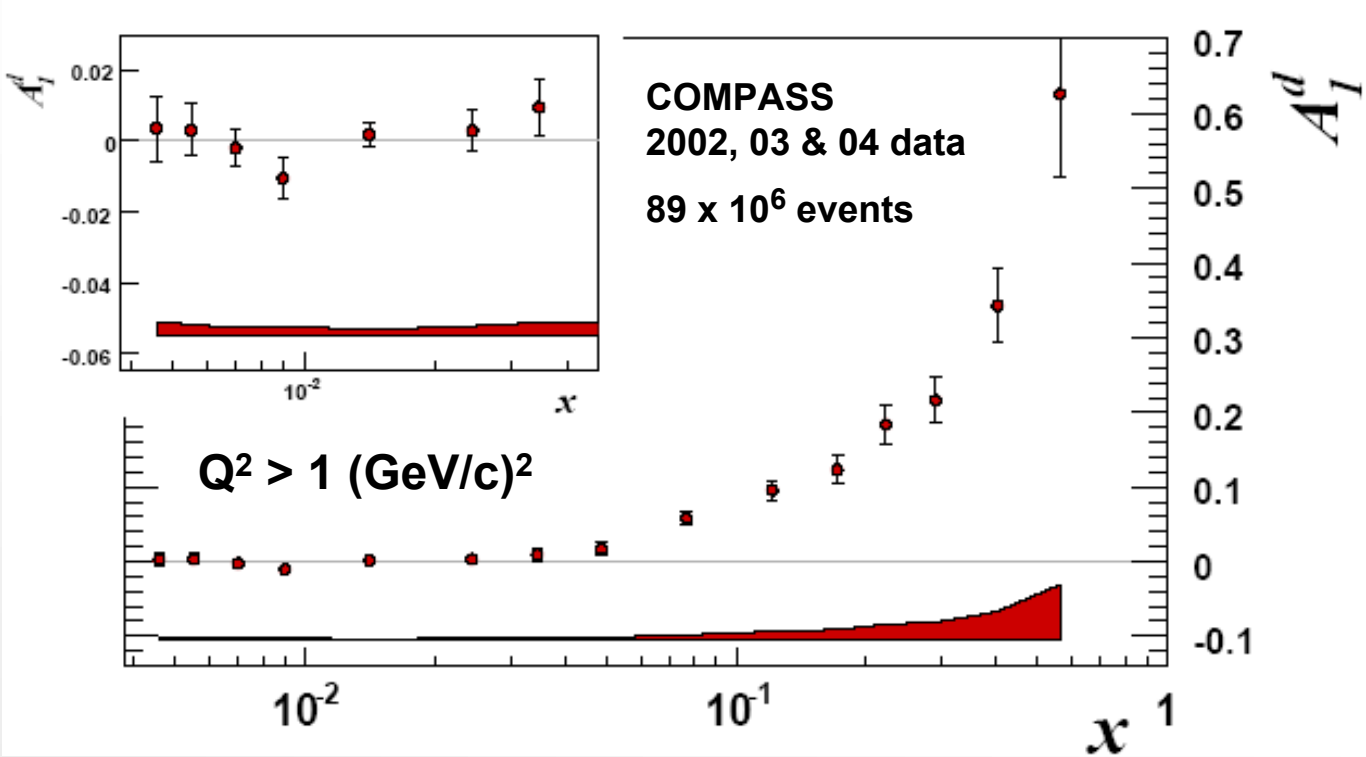




H. Santos (helena@lip.pt)

Inclusive DIS Asymmetry

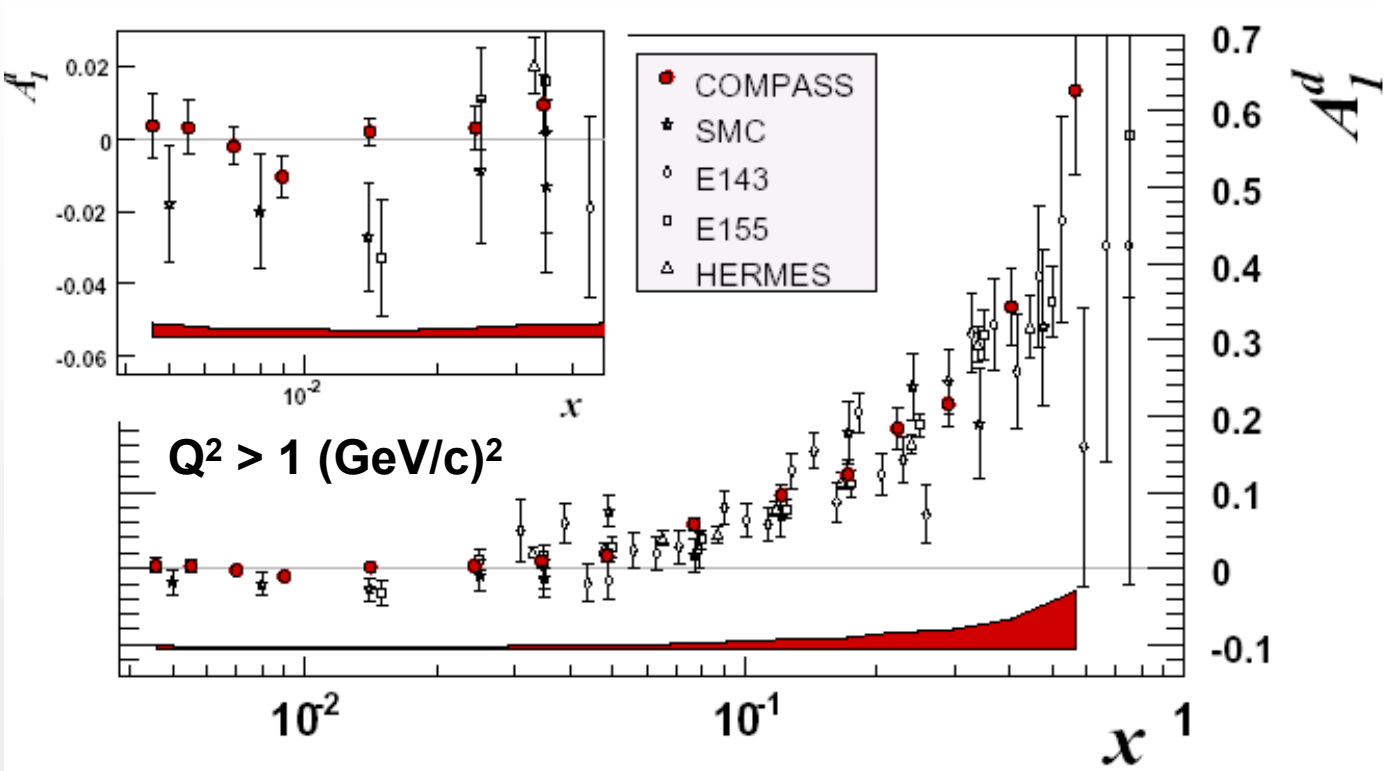
CERN–PH–EP/2006–29



- A_1^d compatible with 0 for x < 0.05
- Large asymmetry at large x

H. Santos (helena@lip.pt)

Inclusive DIS Asymmetry

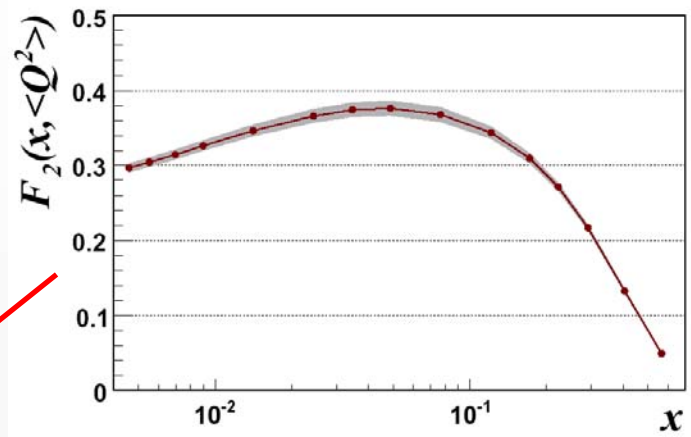


- Good agreement with previous experiments
- Improved significantly statistics at low x
- No tendency towards negative values at x < 0.03

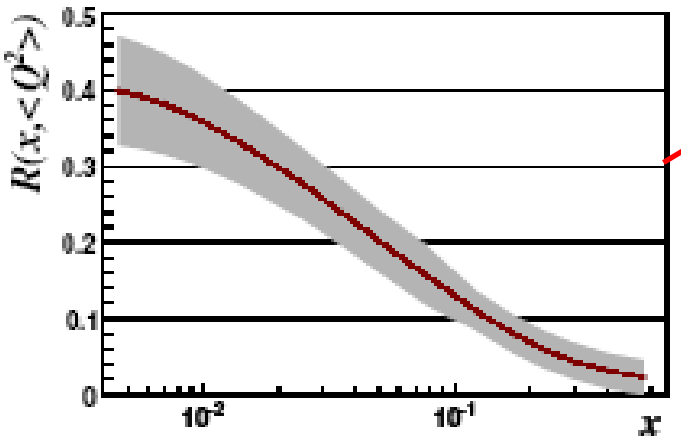
H. Santos (helena@lip.pt)

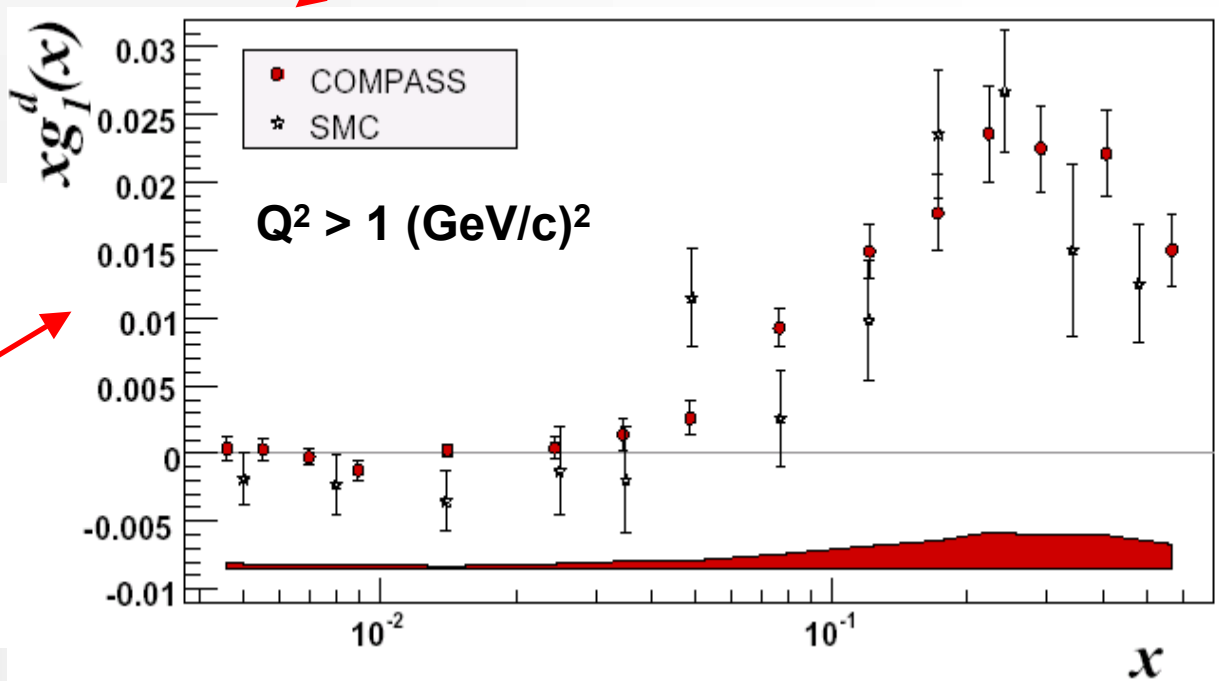
The $g_1^N(x)$ Structure F

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



$$R(x,Q^2) = \sigma_L / \sigma_T$$





H. Santos (helena@lip.pt)

QCD Analyses

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

$\Delta\Sigma = \Delta u + \Delta d + \Delta s$, $\quad \Delta q_3 = \Delta u - \Delta d$, $\quad \Delta q_8 = \Delta u + \Delta d - 2\Delta s$

DGLAP equations:

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

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

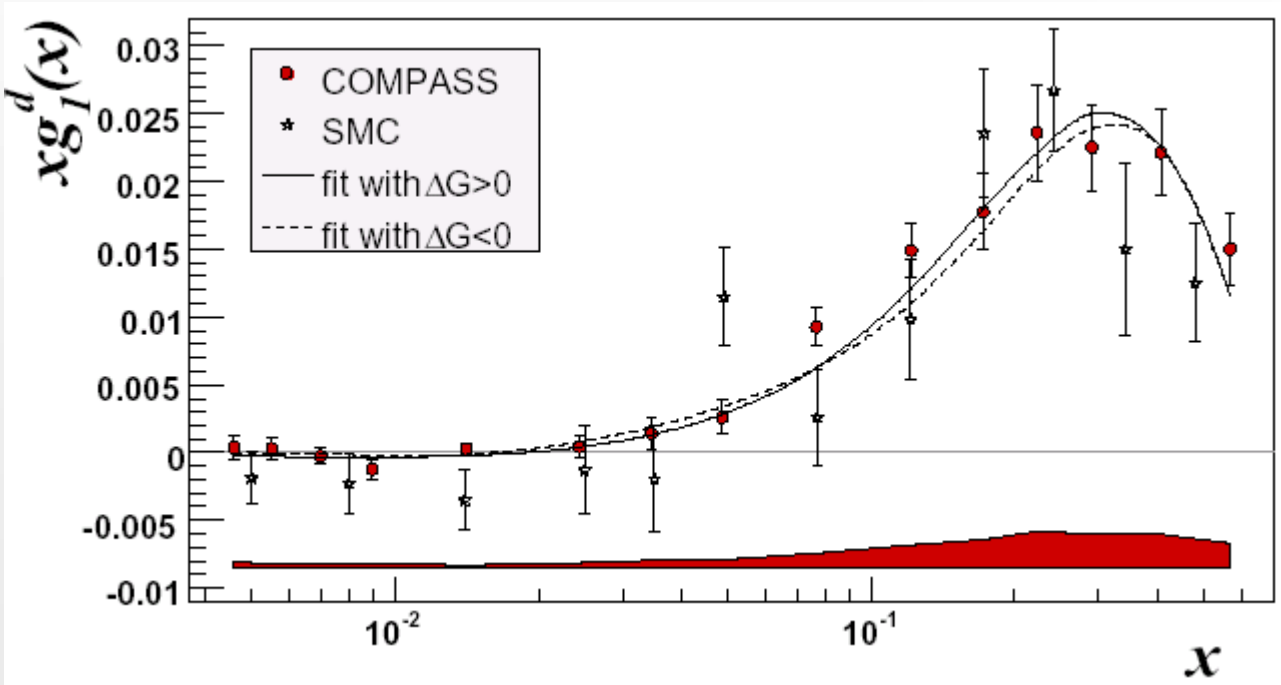
Input parameterisations (x–dependence at a fixed Q_0^2):

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

H. Santos (helena@lip.pt)

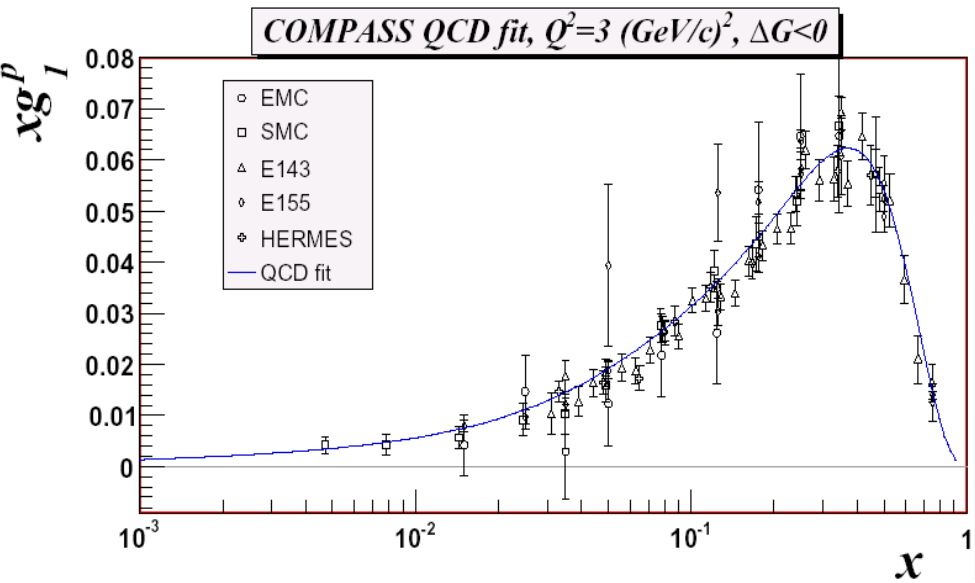
QCD Fits

- **Two different approaches have been used:**
  - **1 - Numerical integration in (x,Q^2) space (PRD58(1998) 112002)**
  - **2 - Solution of DGLAP in space of moments (PRD70(2004) 074032)**
- **Fits to world data → 230 world data points, 43 from COMPASS**
- **NLO analysis ($\overline{\text{MS}}$ scheme)**



Data well described by two solutions: $\Delta G > 0$ and $\Delta G < 0$

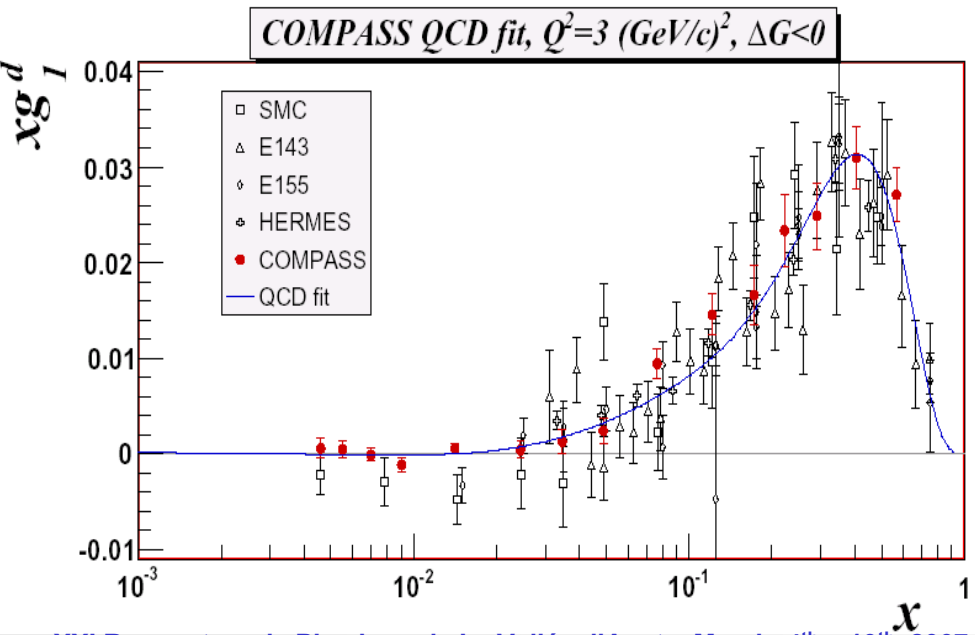
Towards Structure Functions

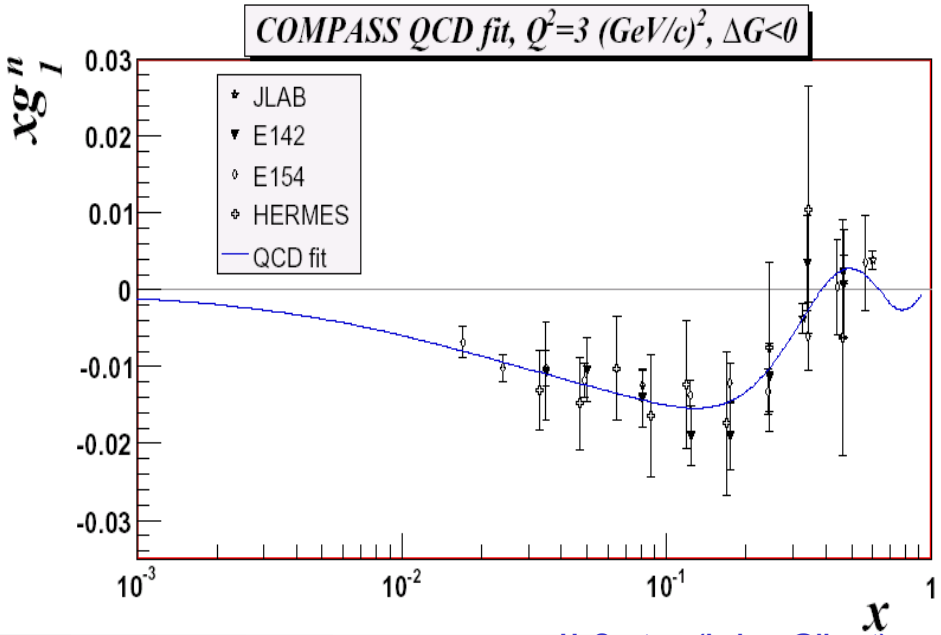


World data and QCD fits at Q_0^2 = 3 GeV^2

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

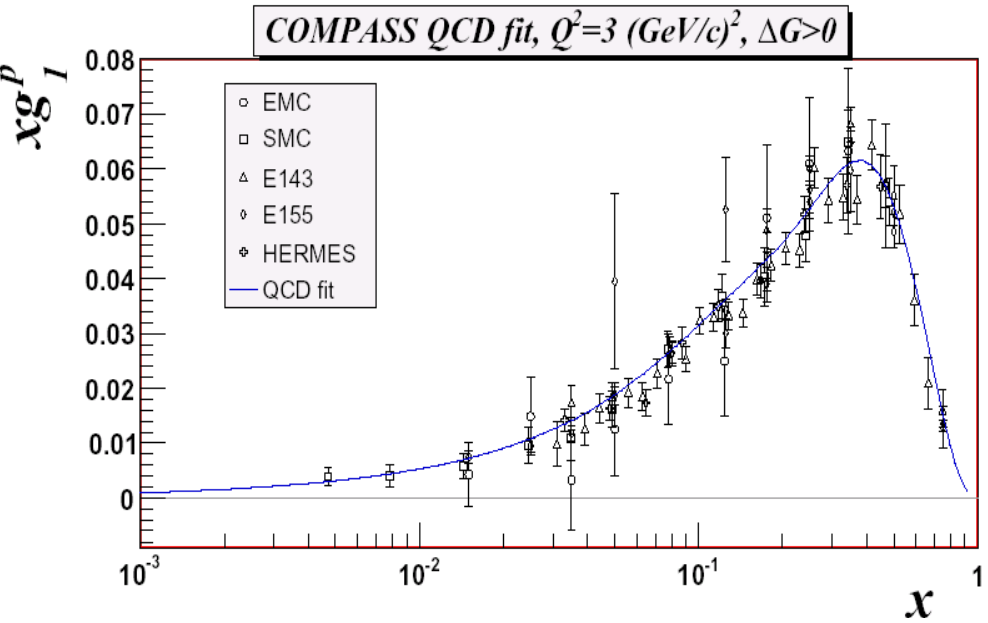
Solutions with ΔG < 0





H. Santos (helena@lip.pt)

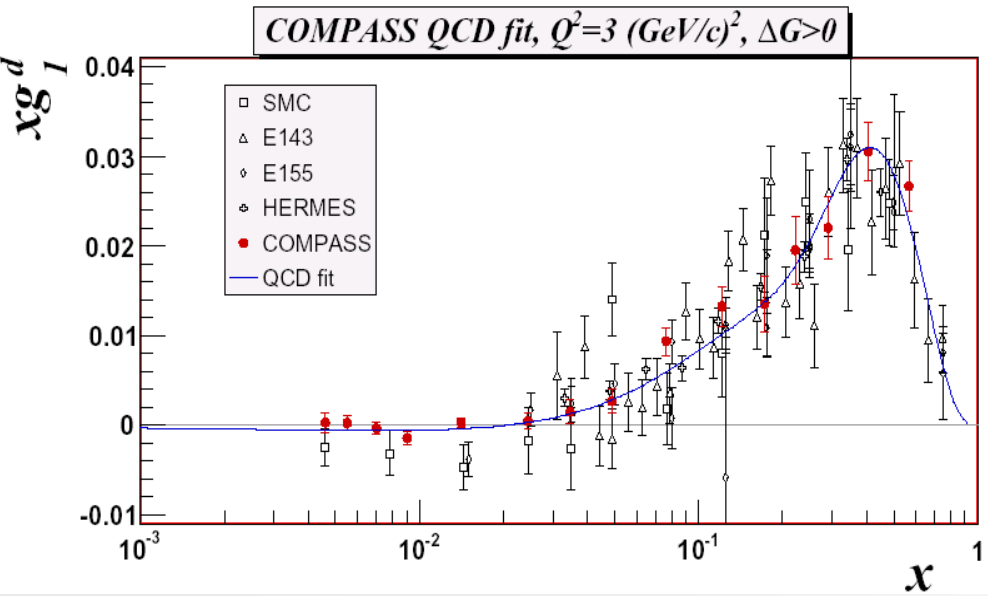
Towards Structure Functions

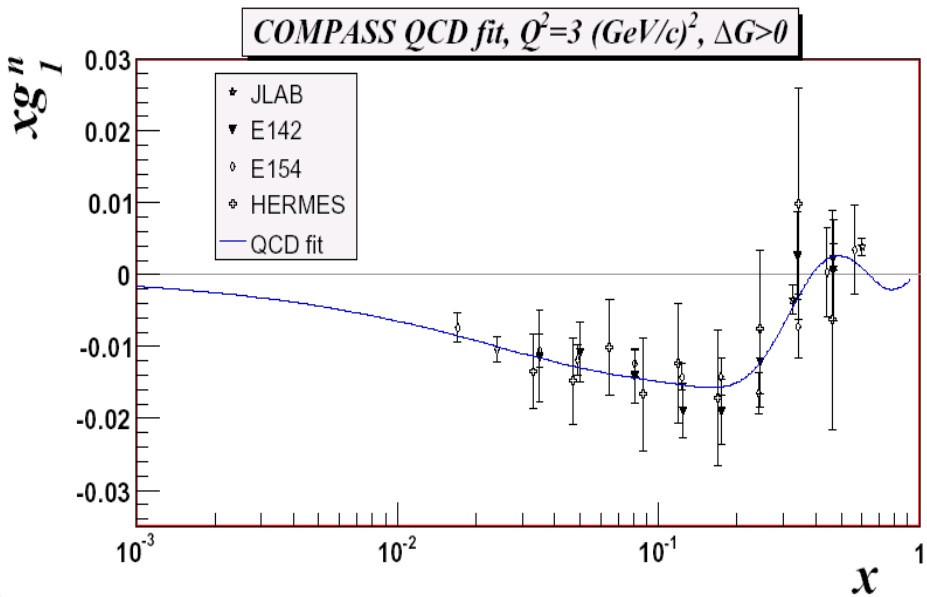


World data and QCD fits at Q_0^2 = 3 GeV^2

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

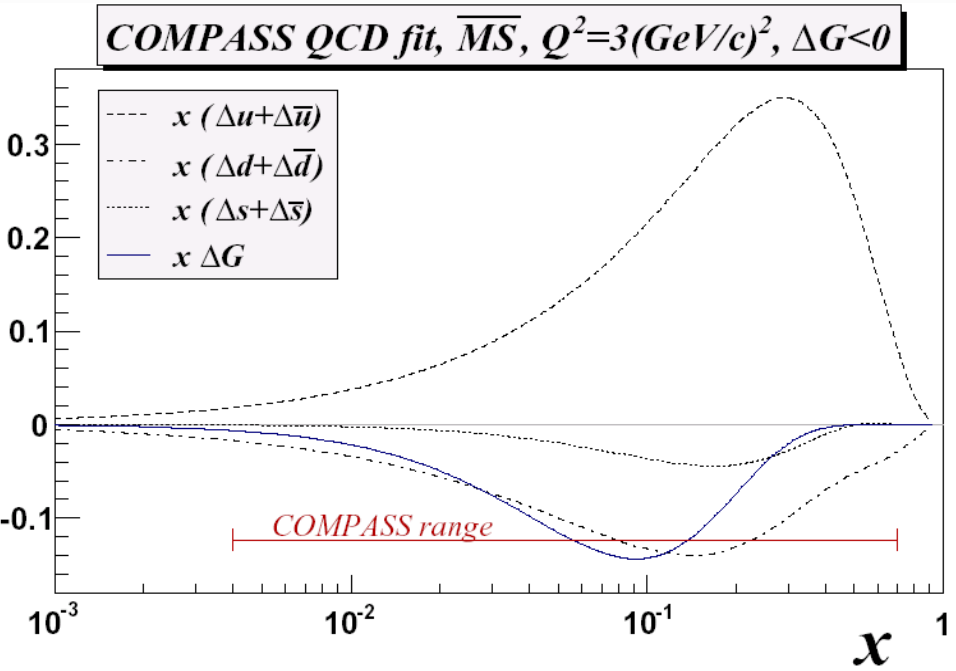
Solutions with ΔG > 0

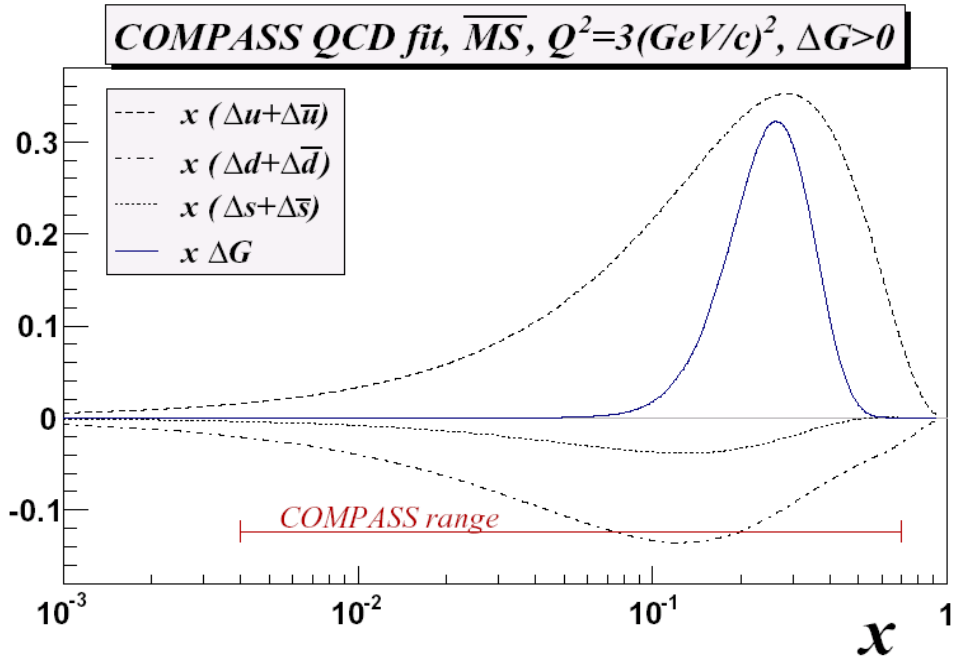




H. Santos (helena@lip.pt)

Polarised Parton Distributions





✓ **Very small sensitivity of $x(\Delta q+\Delta\bar{q})$ to $x\Delta G$**

H. Santos (helena@lip.pt)

QCD Fits Results

(world data)

CERN–PH–EP/2006–29

Quark polarisation:

	$\eta G > 0$	$\eta G < 0$
$\eta\Sigma$	0.27 ± 0.01	0.32 ± 0.01

$$\left(\eta_K = \int_0^1 \Delta k \, dx\right) \longrightarrow \eta_\Sigma = \mathbf{0.30 \pm 0.01(stat) \pm 0.02(evol)}$$

(error ≈ factor 2 larger without COMPASS data)

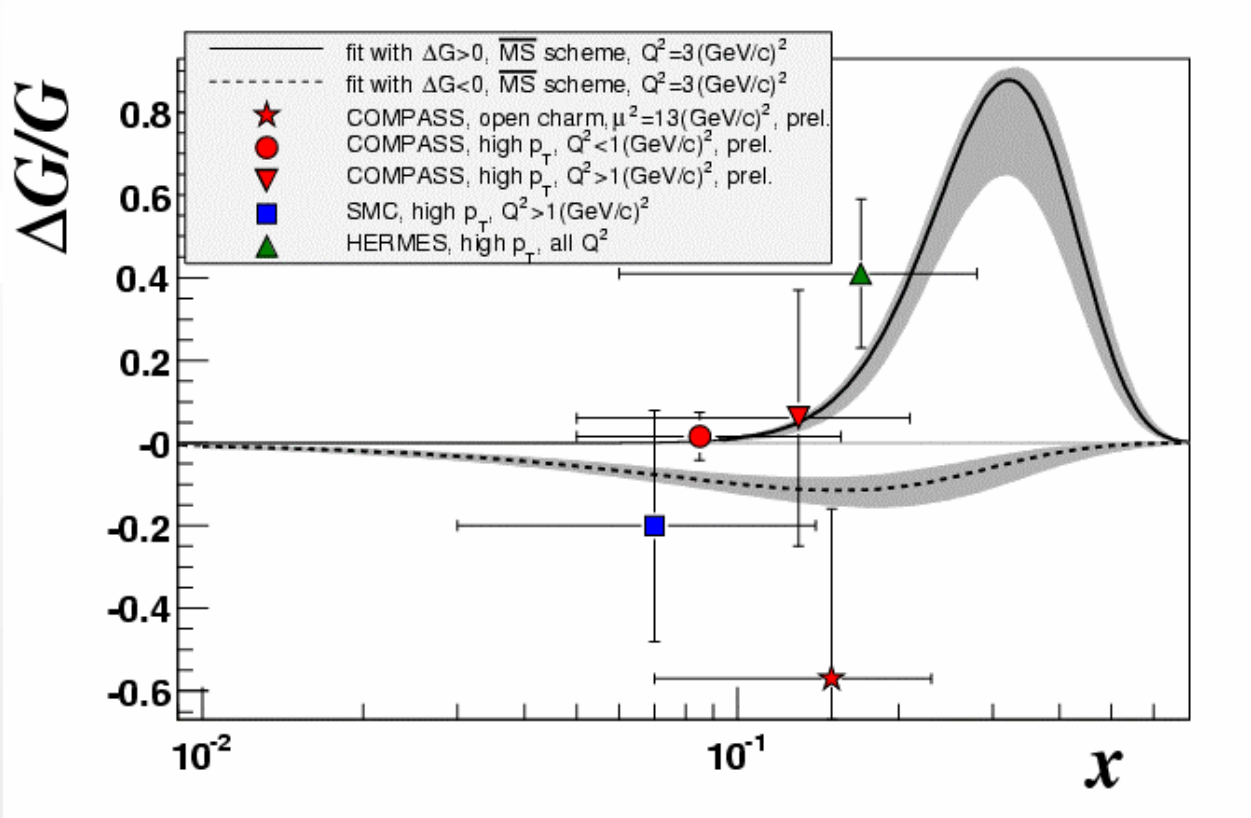
Gluon polarisation (indirect determination via DGLAP):

- Solutions with $\eta_G > 0$: $\eta_G^{prog1} = 0.34^{+0.05}_{-0.07}$, $\eta_G^{prog2} = 0.23^{+0.04}_{-0.05}$
- Solutions with $\eta_G < 0$: $\eta_G^{prog1} = -0.31^{+0.10}_{-0.14}$, $\eta_G^{prog2} = -0.19^{+0.06}_{-0.11}$

$$|\eta_G| \approx \mathbf{0.2 - 0.3}$$

H. Santos (helena@lip.pt)

Gluon Polarisation $\Delta G/G$



Direct measurement of gluon polarisation with NLO QCD fits to g_1

- **Unpolarised $G(x)$ from MRST**
- **Bands correspond to statistical errors of ΔG**

H. Santos (helena@lip.pt)

First Moment of g_1

(COMPASS data only)

CERN–PH–EP/2006–29

$$\Gamma_1^N\left(Q_0^2 = 3GeV^2\right) = \int_0^1 g_1^N(x)dx = 0.050 \pm 0.003(stat) \pm 0.003(evol) \pm 0.005(syst)$$

- **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: $a_8 = 0.585 \pm 0.025$)

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

- **extrapolating to $Q^2 \to \infty$**

$$\mathbf{\hat{a}_{0\left(Q^2 \to \infty\right)} = 0.33 \pm 0.03(stat) \pm 0.05(syst)}$$

$\hat{a}_0$ is interpreted as the fraction of the nucleon spin carried by the quarks, $\Delta\Sigma = \Delta u + \Delta d + \Delta s$

$$\mathbf{(\Delta s + \Delta\bar{s}) = \frac{1}{3}(\hat{a}_0 - a_8) = -0.08 \pm 0.01(stat) \pm 0.02(syst)}$$

H. Santos (helena@lip.pt)

Conclusions & Outlook

✓ Longitudinal A_1 inclusive asymmetries measured using 2002, 2003 & 2004 COMPASS data

✓ From the first moment of g_1^d, we extract the quark contribution to the nucleon spin (COMPASS data only):

$$\hat{a}_0 = 0.33 \pm 0.03(stat) \pm 0.05(syst)$$

✓ QCD fits to world data give for quark and gluon polarisation:

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

$$|\eta_G| \approx 0.2 - 0.3$$

Semi-inclusive analysis towards flavour spin distributions is *in progress*

H. Santos (helena@lip.pt)