New COMPASS results on the spin structure function g_1^p, and QCD fit

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bmb+f - Förderschwerpunkt
COMPASS
Großgeräte der physikalischen Grundlagenforschung

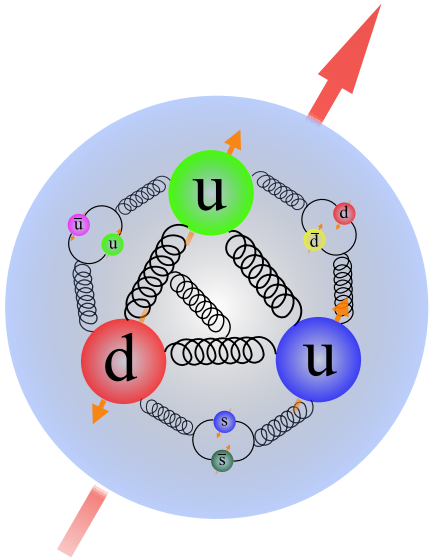
Outline

Motivation

Spin Contribution:

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

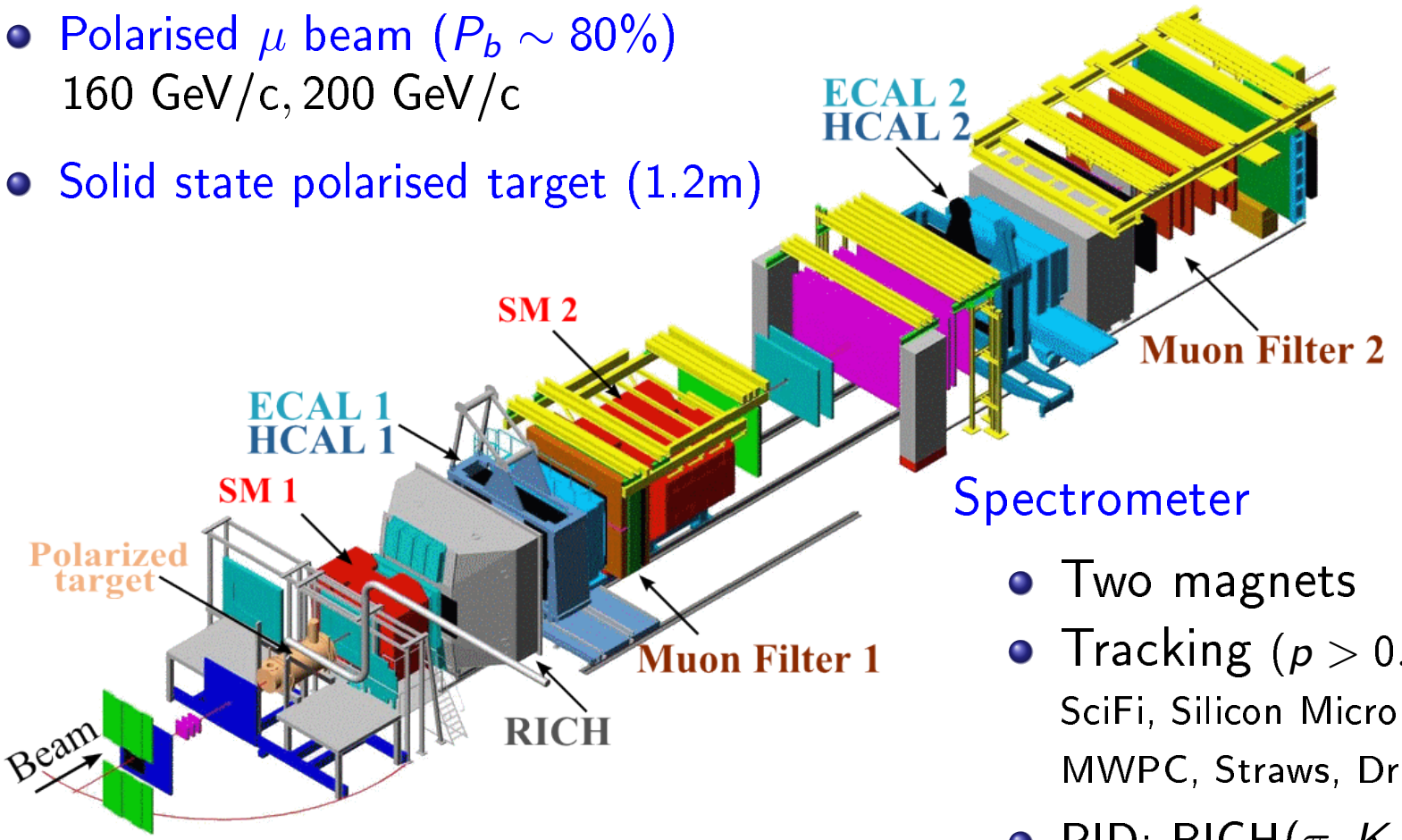
$$\Delta\Sigma = \Delta u + \Delta d + \Delta s$$



- 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

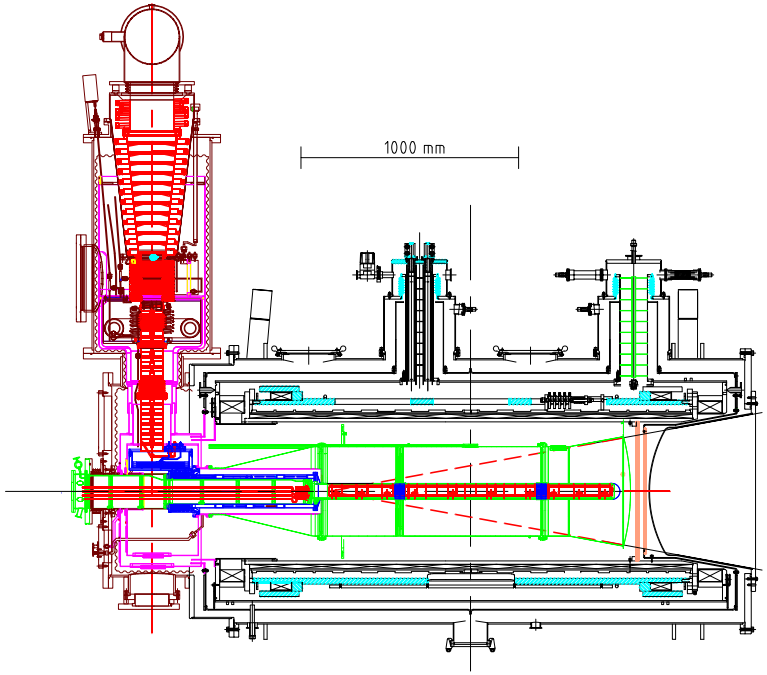
- M2 beamline
- Polarised μ beam ($P_b \sim 80\%$)
  160 GeV/c, 200 GeV/c
- Solid state polarised target (1.2m)

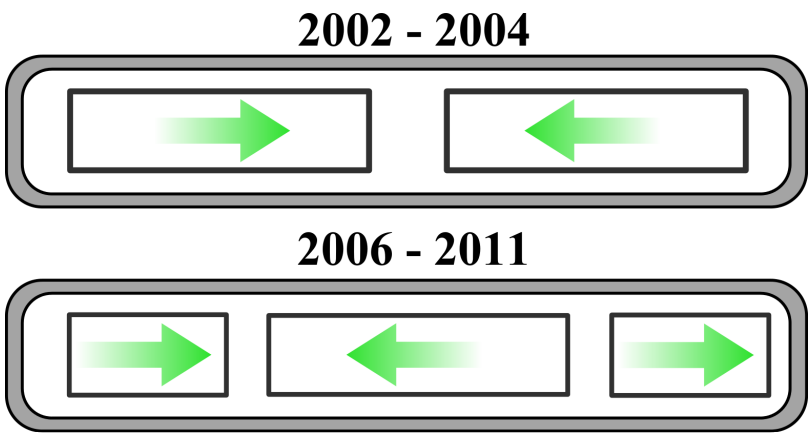


Spectrometer

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

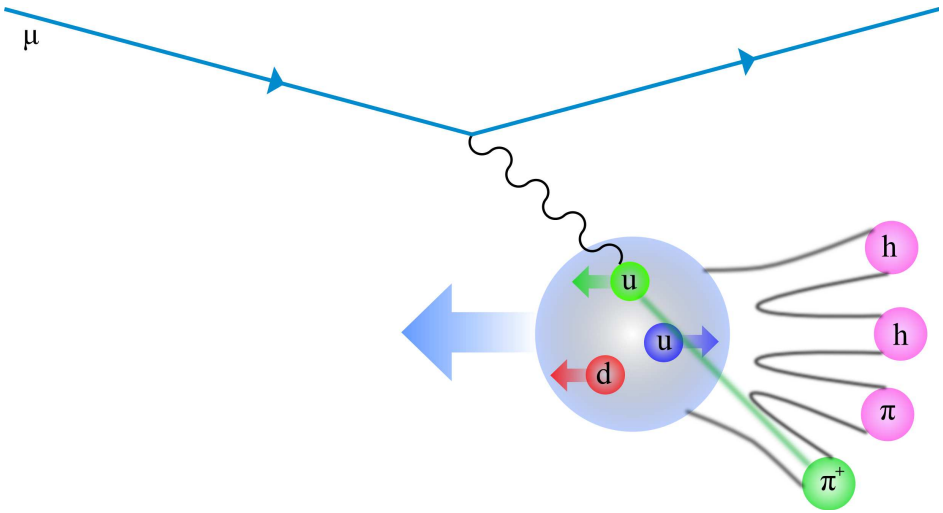
Polarised target





- Upgrade of the target system in 2005
- Three target cells, oppositely polarised
- 180 mrad geometrical acceptance
- Regular polarisation reversals by field rotation
- 2.5 T solenoid field
- Low temperature 50 mK
- NH_3 (Longitudinal proton polarisation: $\sim 90\%$)

Deep Inelastic Scattering

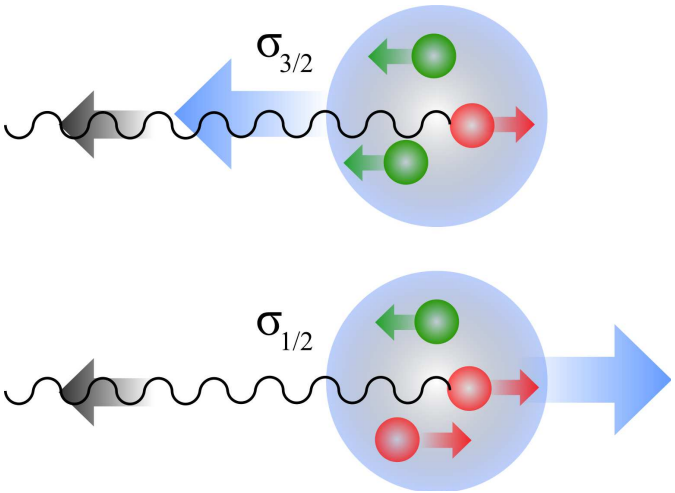


- 4-momentum of the virtual photon: $q = k - k'$
- $Q^2 = -q^2 \overset{\text{lab}}{\approx} 4EE' \sin^2 \frac{\theta}{2}$
- Bjorken scaling variable: $x \overset{\text{lab}}{=} \frac{Q^2}{2M\nu}$

Inclusive cross section:

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

Polarised Deep Inelastic Scattering



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

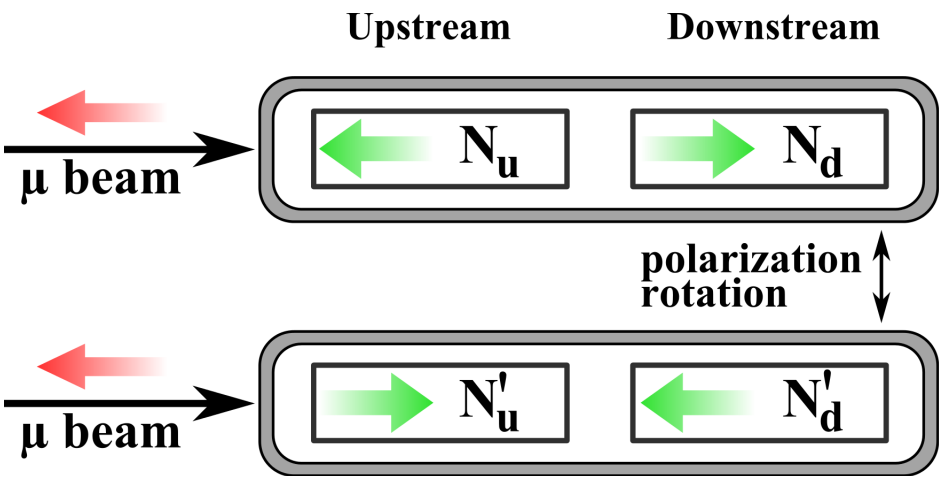
- Photon nucleon asymmetry

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

- Spin structure function

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

Method

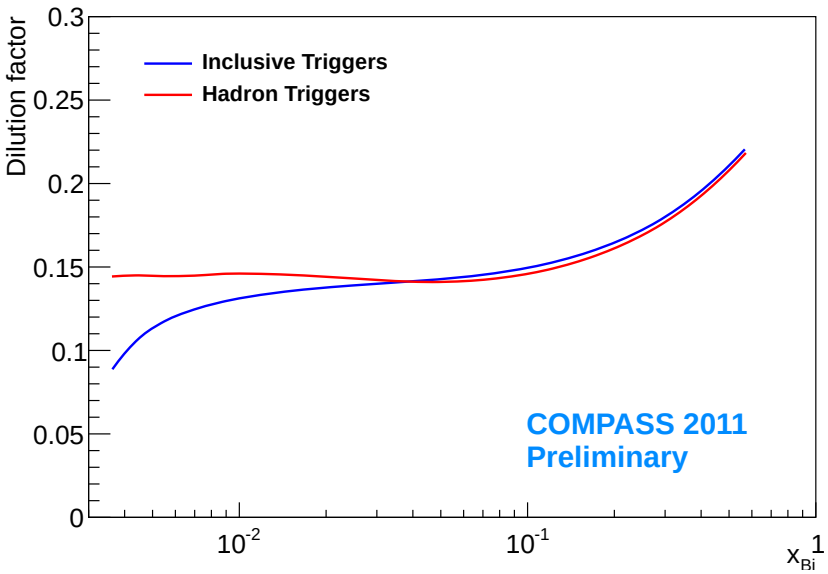


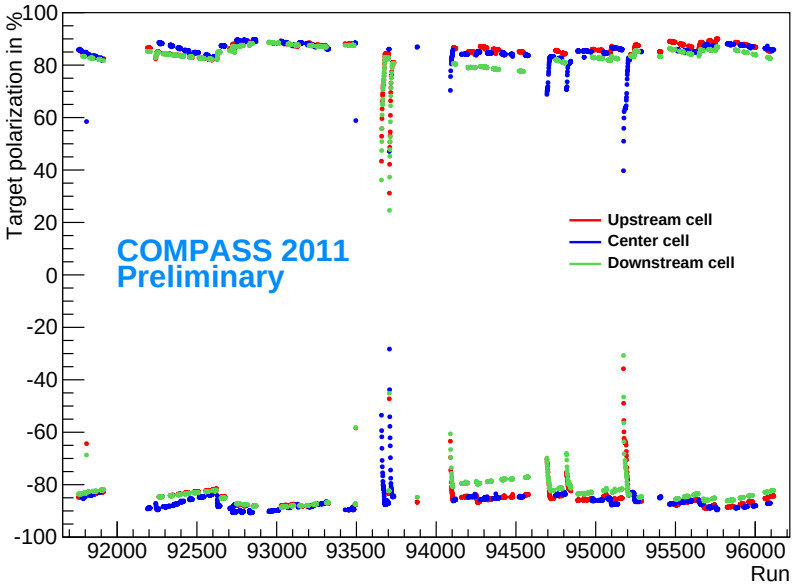
- Aim:
  $A = \frac{\sigma^{\Uparrow\downarrow} - \sigma^{\Uparrow\uparrow}}{\sigma^{\Uparrow\downarrow} + \sigma^{\Uparrow\uparrow}}$
- Measured:
  $A_{exp} = \frac{N_u - N_d}{N_u + N_d}$
- Needed:
  - Flux cancellation
  - Acceptance cancellation
    $\rightarrow$ polarisation rotation
    $\rightarrow$ 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

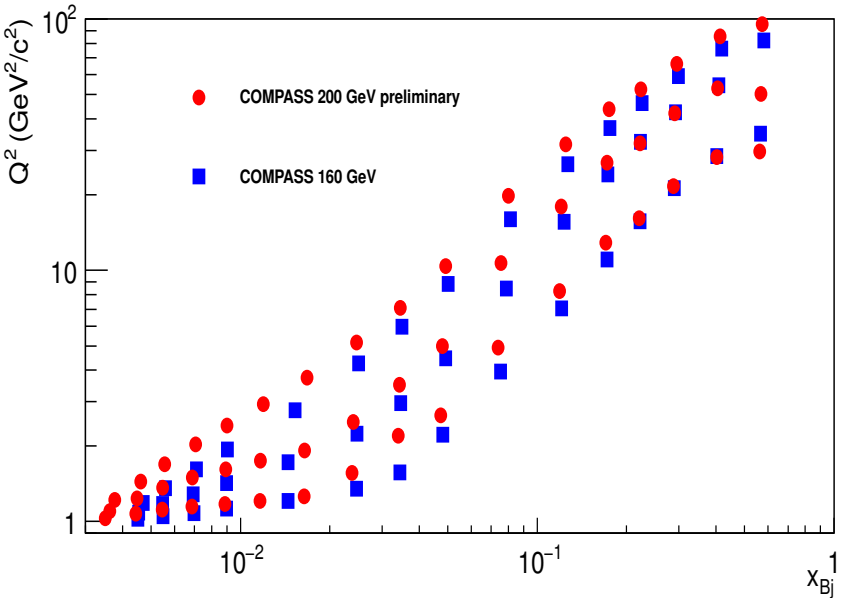
- Averaging:

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

Input for A_1^p

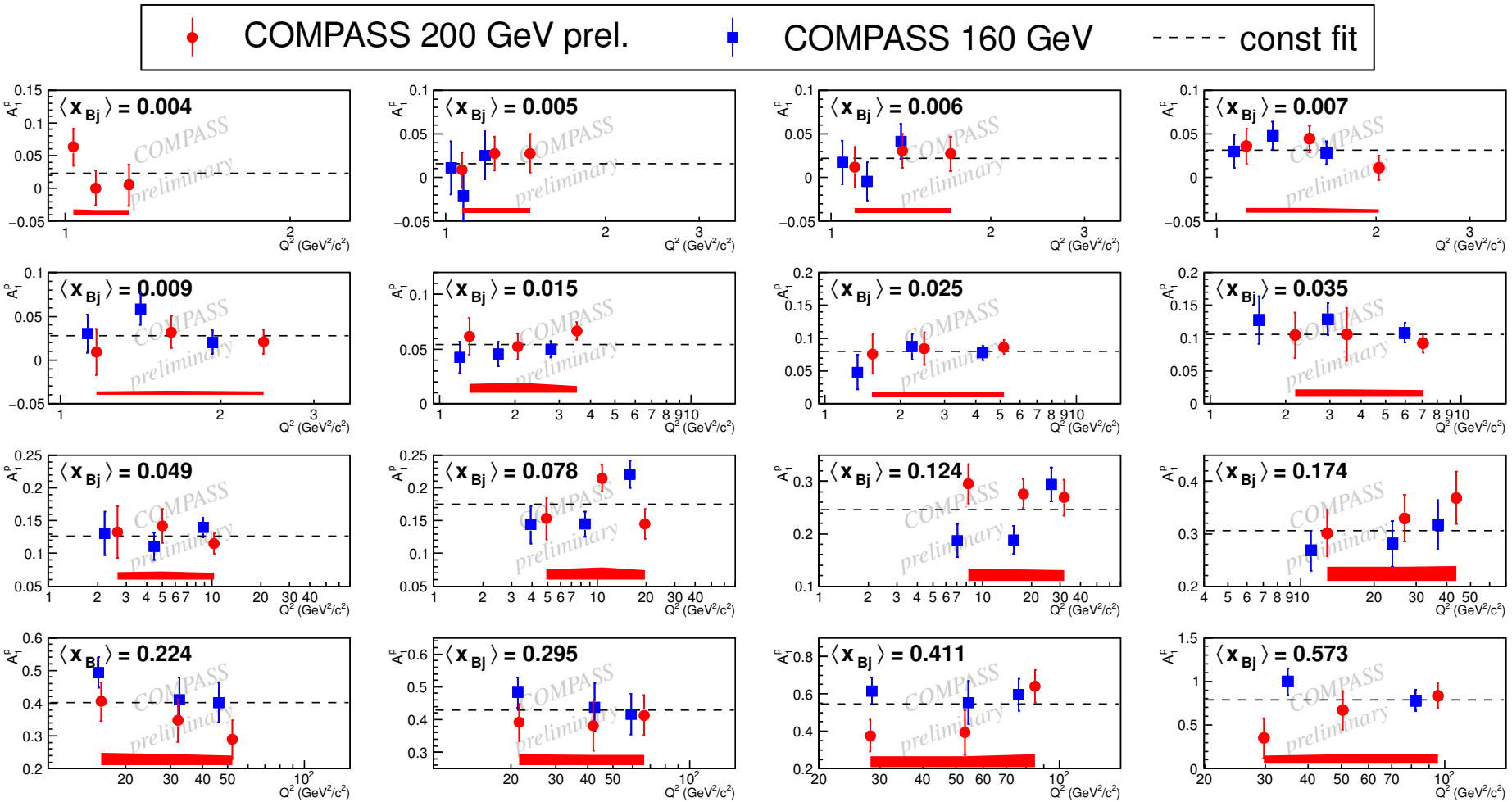






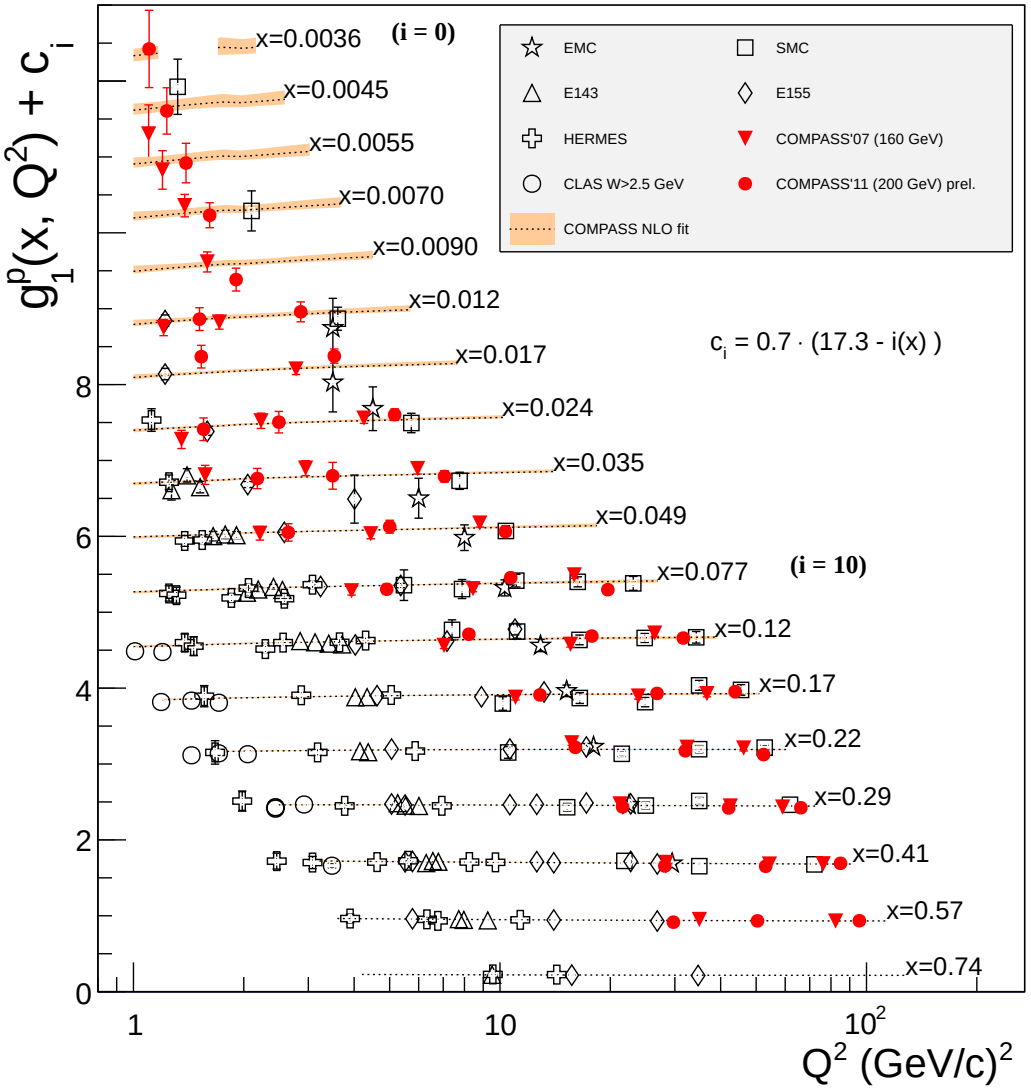
- $78 \cdot 10^6$ Events
- Dilution factor includes radiative corrections
- Higher Q^2, smaller x in 2011
- Reach $x \sim 10^{-3}$ in polarised DIS

A_1^p in bins of x and Q^2



- ^{14}N correction and pol. rad. corrections included
- New data point at very small x
- Good agreement between COMPASS 2011/07

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
- New 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:

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

- Input parametrisation f of $\Delta q_{Si}, \Delta q_3, \Delta q_8, \Delta g$ at Q_0^2 needed

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

- Using only inclusive asymmetries quarks and anti-quarks cannot be disentangled *e.g.* determination of $\Delta u + \Delta\bar{u}$, $\Delta d + \Delta\bar{d}$, $\Delta s + \Delta\bar{s}$ and Δg
- Many analyses from different groups (theor. and exp.)
  e.g. COMPASS, LSS, GRSV, BB, AAC, DSSV.....

Input parametrisation

- Reference scale $Q_0^2 = 1\ (\mathrm{GeV}/c)^2$
- Functional form are given at the reference scale Q_0^2

  $\Delta q_{Si}(x|Q_0^2) = \eta_s x^{\alpha_s}(1-x)^{\beta_s}(1+\gamma_s x)/N_s$

  $\Delta g(x|Q_0^2) = \eta_g x^{\alpha_g}(1-x)^{\beta_g}(1+\gamma_g x)/N_g$

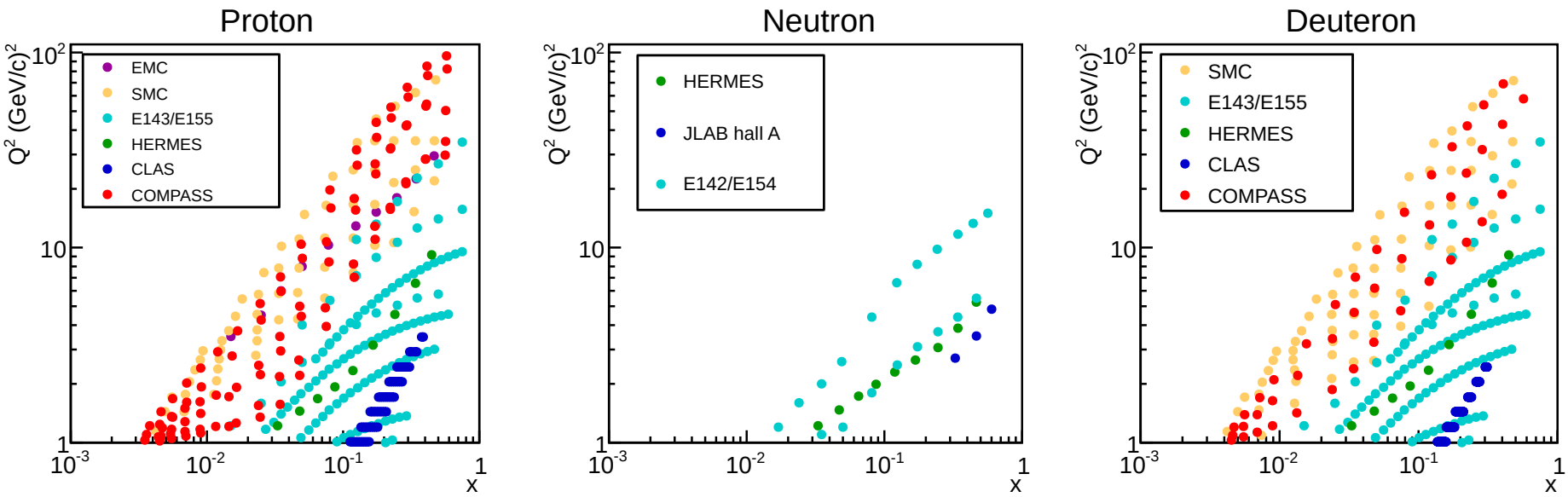
  $\Delta q_3(x|Q_0^2) = \eta_3 x^{\alpha_3}(1-x)^{\beta_3}/N_3$

  $\Delta q_8(x|Q_0^2) = \eta_8 x^{\alpha_8}(1-x)^{\beta_8}/N_8$
- $\eta_3 = F + D = g_A/g_V$

  $\eta_8 = 3F - D$

  β_g is fixed
- Using the DGLAP equations:
- Obtain $\Delta q_{Si}(x, Q^2), \Delta g(x, Q^2), \Delta q_3(x, Q^2), \Delta q_8(x, Q^2)$ at any scale Q^2

Input and constrains

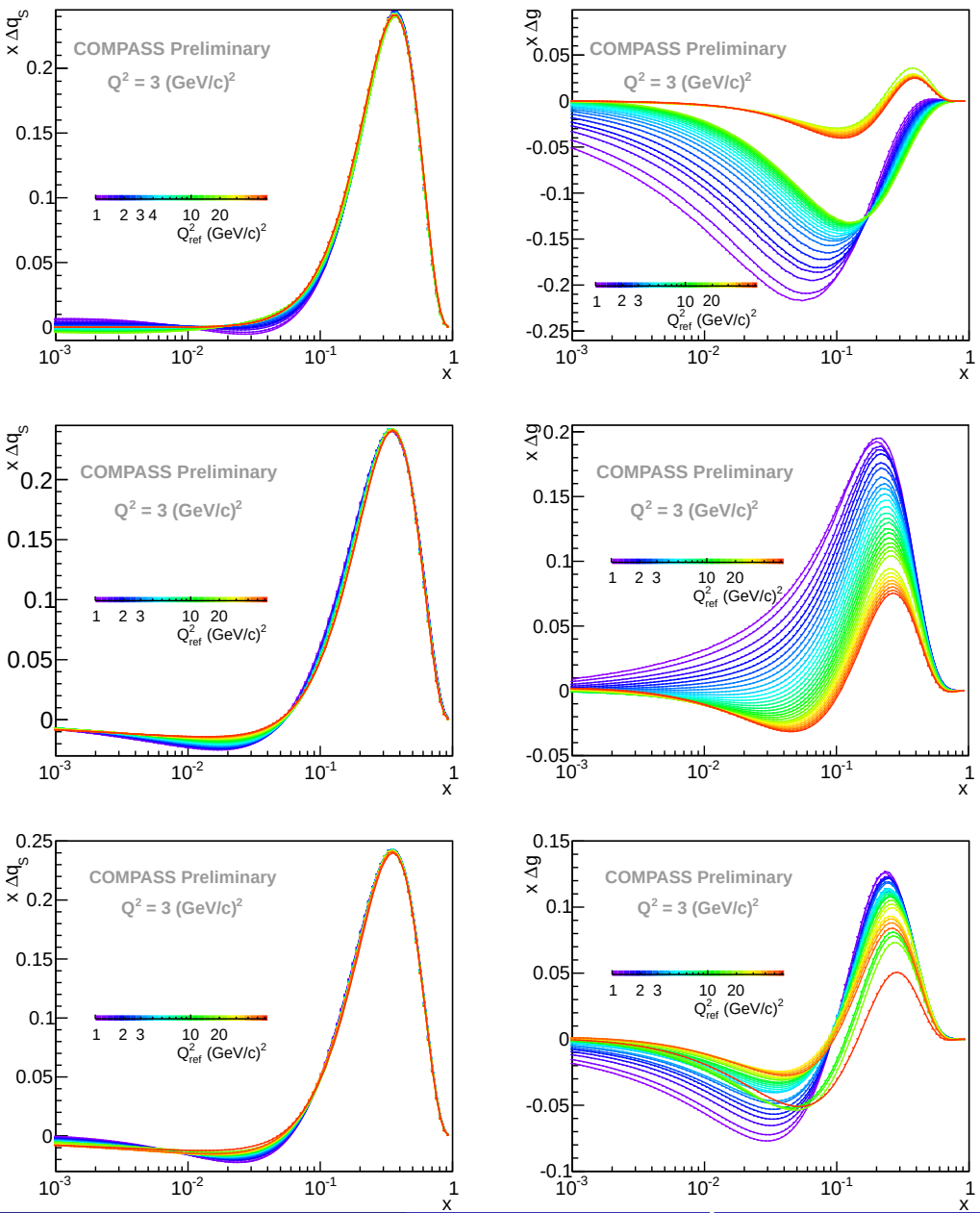


- $\chi^2 = \sum_{n=1}^{N_{exp}} \left[\sum_{i=1}^{N_n^{data}} \left(\frac{g_1^{fit} - \mathcal{N}_n g_{1,i}^{data}}{\mathcal{N}_n \sigma_i} \right)^2 + \left(\frac{1-\mathcal{N}_n}{\delta \mathcal{N}_n} \right)^2 \right] + \chi^2_{positivity}$
- Positivity: $|\Delta g(x)| < |g(x)|$ and $|\Delta(s(x) + \bar{s}(x))| < |s(x) + \bar{s}(x)|$
- Input: g_1^p, g_1^n, g_1^d and our $\Delta g/g$ measurement (Open Charm @ NLO)
- MSTW2008
- Overall: 28 free parameters and 679 data points

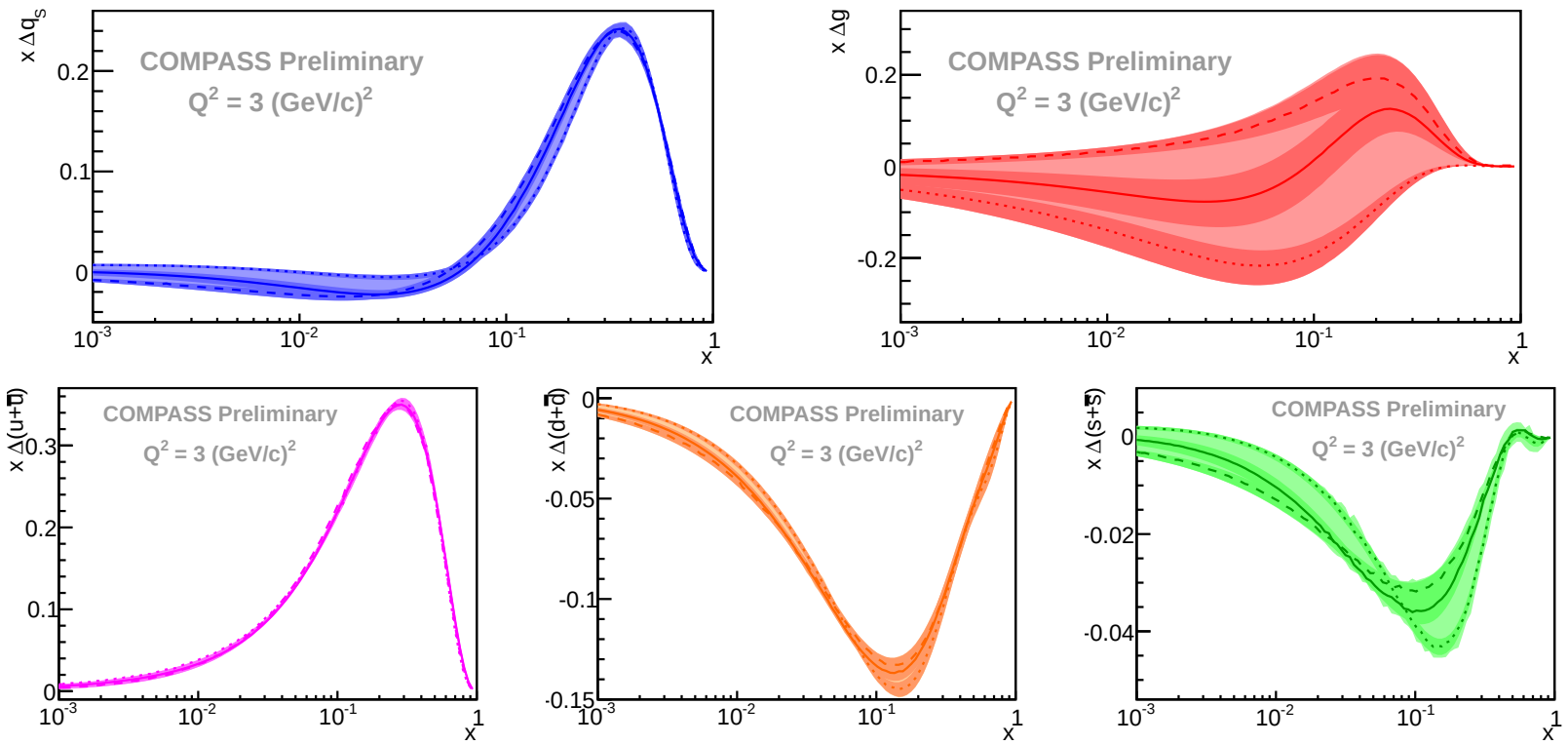
Systematic studies

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

$\rightarrow$ Larger uncertainty compared to statistical one



Polarised parton distributions



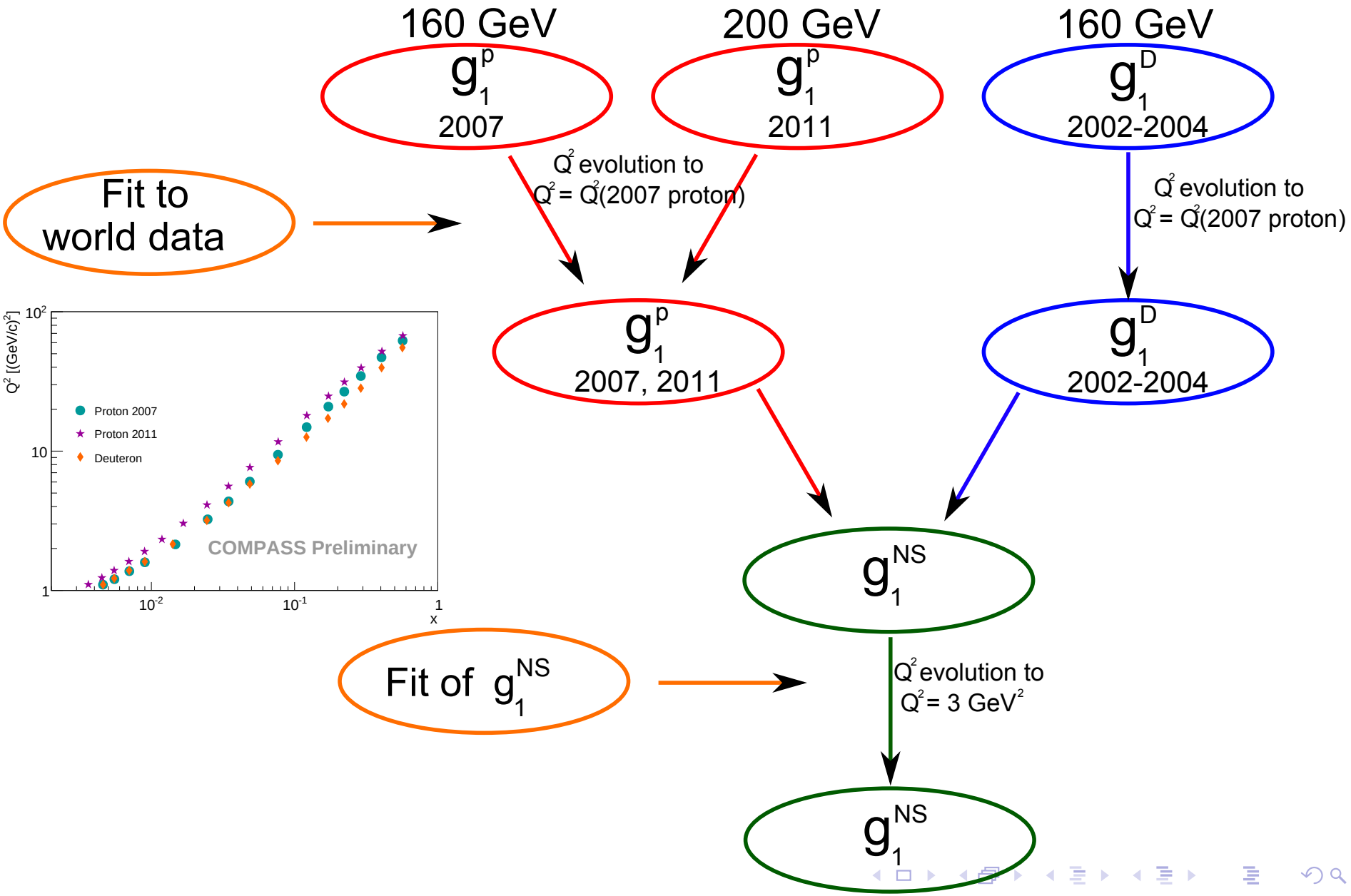
- Small sensitivity to light sea and gluon polarisation
- Quark polarisation $\Delta\Sigma = \int \Delta q_{Si}(x)\mathrm{d}x \sim 0.3$
- Gluon polarisation $\Delta G = \int \Delta g(x)\mathrm{d}x$ Not well constrained

Bjorken sum rule

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

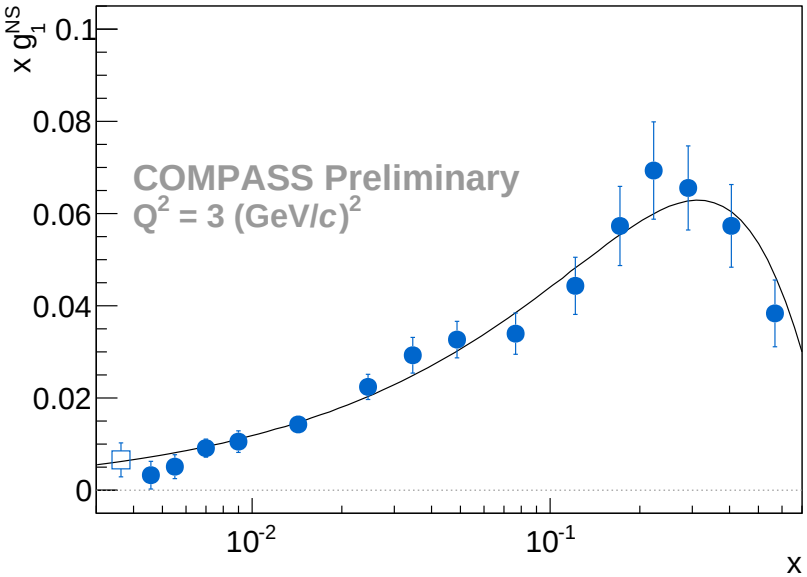
- Non-singlet spin structure function
  $g_1^{NS} = g_1^p - g_1^n = 2\left[g_1^p - \frac{g_1^d}{1-3/2\omega_D}\right]$, $\omega_D = 0.05$
- g_1^{NS} determined only from COMPASS data
  - 2007 & 2011 proton data
  - 2002 - 2004 deuteron data
- $\left|\frac{g_A}{g_V}\right| = 1.2701 \pm 0.0020$ obtained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

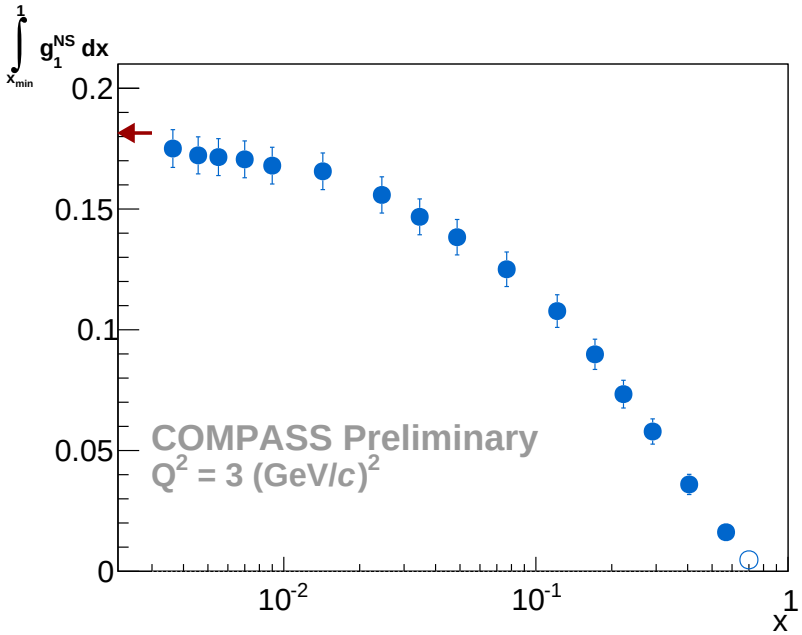
Method


160 GeV
g_1^p 2007
200 GeV
g_1^p 2011
160 GeV
g_1^D 2002-2004
Q^2 evolution to $Q^2 = Q^2$(2007 proton)
Q^2 evolution to $Q^2 = Q^2$(2007 proton)
Fit to world data
g_1^p 2007, 2011
g_1^D 2002-2004
g_1^{NS}
Q^2 evolution to $Q^2 = 3$ GeV^2
Fit of g_1^{NS}
g_1^{NS}
Q^2 [(GeV/c)^2]
Proton 2007
Proton 2011
Deuteron
COMPASS Preliminary
x

Non-singlet structure function

- Calculate g_1^{NS}
- Perform NLO QCD fit
  - Fit only Δq_3
  - 3 parameters needed
- Evolve g_1^{NS} to $Q^2 = 3\ (\mathrm{GeV}/c)^2$
- Missing contributions from unmeasured region ($x \to 0, 1$)
- 94% in measured range





Calculate g_A/g_V

$$\int_0^1 g_1^{NS}(x, Q^2)dx = \frac{1}{6} \mid \frac{g_A}{g_V} \mid C_1^{NS}(Q^2)$$

$$C_1^{NS}(Q^2) = \underbrace{1}_{LO} - \underbrace{\left(\frac{\alpha_s}{\pi}\right)}_{NLO} - \underbrace{p_1 \cdot \left(\frac{\alpha_s}{\pi}\right)^2}_{NNLO} - \underbrace{p_2 \cdot \left(\frac{\alpha_s}{\pi}\right)^3}_{NNNLO}$$

- Value from the neutron β decay: $|\frac{g_A}{g_V}| = 1.2701 \pm 0.0020$
- Mean Q^2 of the COMPASS data $Q^2 \approx 3\ (\mathrm{GeV}/c)^2$
- $g_A/g_V = 1.220 \pm 0.053\ (\mathrm{stat.}) \pm 0.095\ (\mathrm{syst.})$
- Verification of the Bjorken sum rule
- Estimate size and direction of NNLO correction
- Use C_1^{NS} in NNLO: $g_A/g_V = 1.256$

Summary and Outlook

- New measurement of A_1^p and g_1^p at 200 GeV/c
  - New value at small x
  - 2011 data improve the precision of the COMPASS results
  - NLO QCD fit
  - Update on the Bjorken sum rule
- Outlook
  - Identified hadron asymmetries ($A_{1,p}^{\pi^\pm}$ and $A_{1,p}^{K^\pm}$)
  - Extraction of polarised PDFs for each flavour