COMPASS

spin dependent longitudinal asymmetries on deuteron target

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on behalf of the COMPASS collaboration

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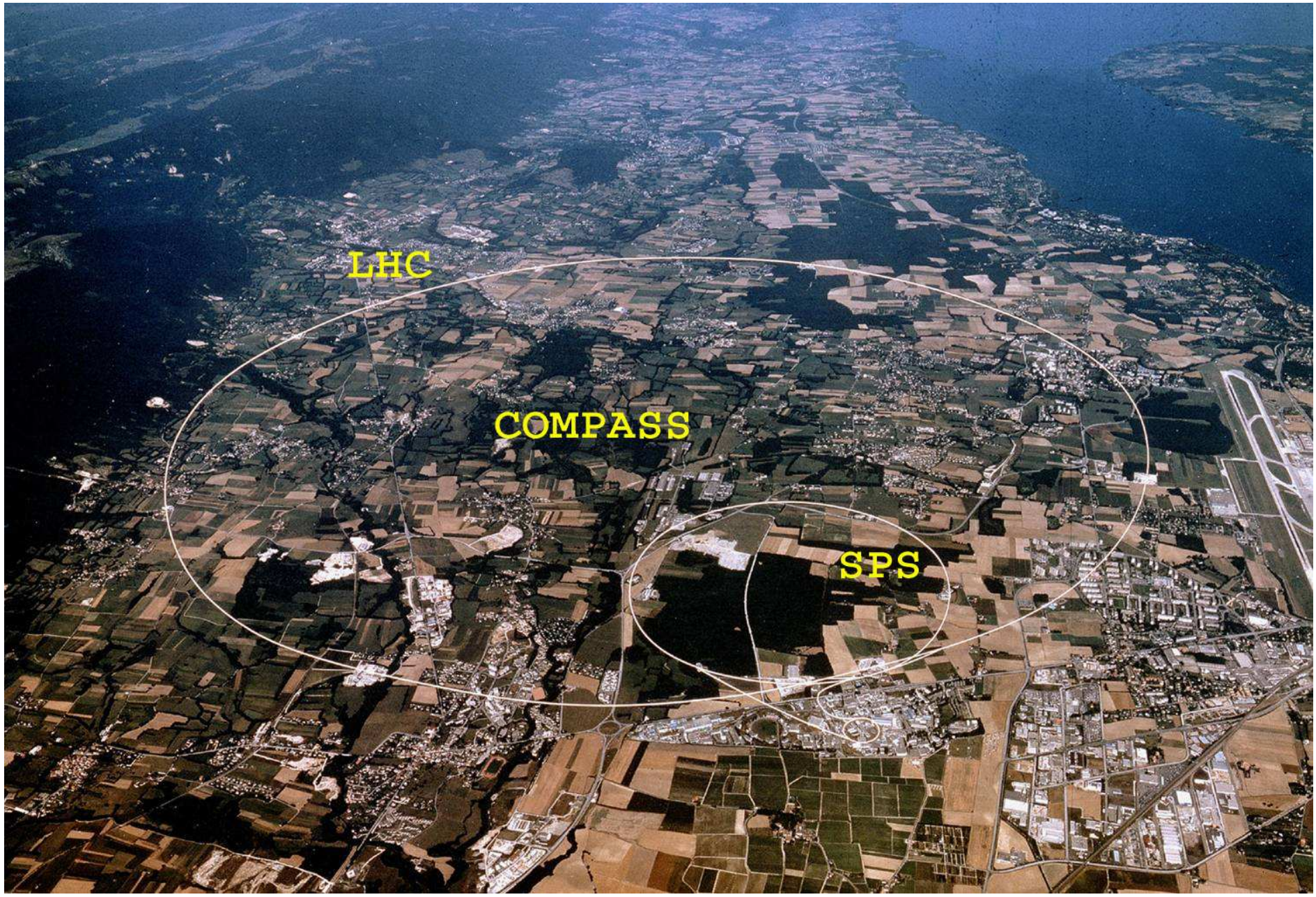
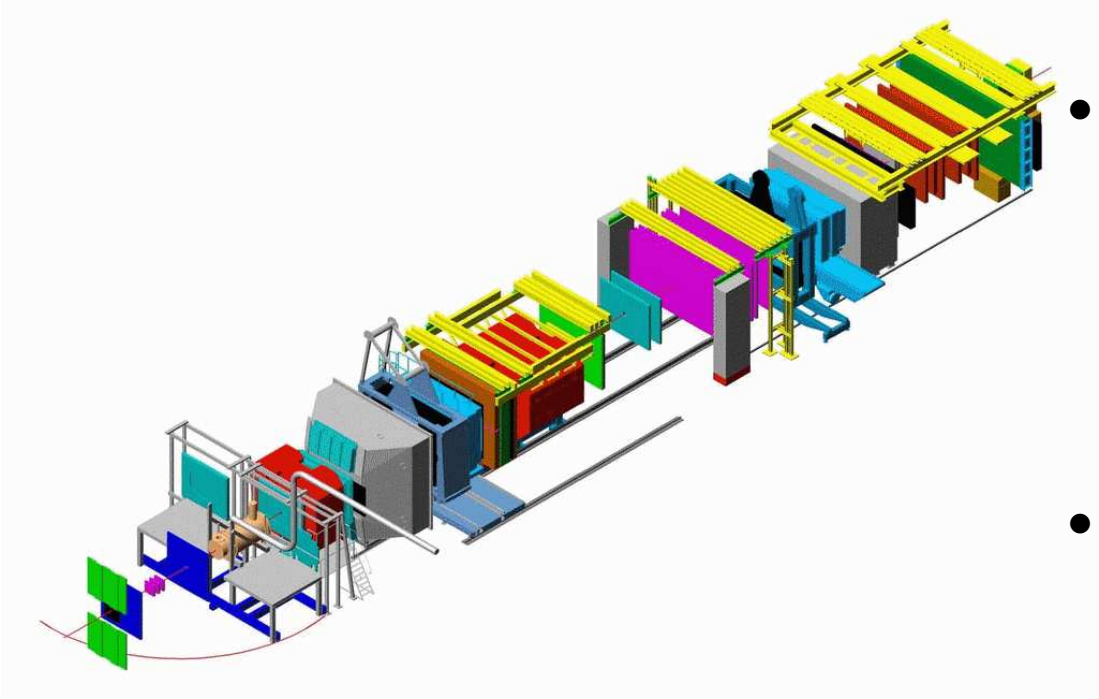
- COMPASS
- results for A_1^d and g_1^d for $Q^2 < 1$ (GeV/c)^2
- results for A_1^d and g_1^d for $Q^2 > 1$ (GeV/c)^2
- QCD analysis of g_1
- valence quarks polarization

COMPASS

COMPASS @ CERN





- COLLABORATION
  - about 240 physicists
  - 29 institutes
- DETECTOR
  - 60 m length
  - 2 (3) magnets
  - about 350 detector planes

- POLARIZED TARGET
  - ^{6}LiD target
  - 2 cells (60 cm long each)
  - $\pm$ 50% polarization
  - polarization reversal every 8h
- POLARIZED BEAM
  - positive muons at 160 GeV/c
  - polarization –80 %
- FEATURES
  - acceptance: 70 mrad
  - track reconstruction: $p > 0.5$ GeV
  - identification: π, K, p (RICH) above 2, 9, 18 GeV respectively

COMPASS scientific program

- muon program
  - gluon polarization
  - spin dependent structure function
  - polarized quark distributions
  - transversity
  - Lambda polarization
  - vector meson production
- hadron program
  - Primakoff reaction
  - hadron spectroscopy
  - exotics searches (glueballs)
  - central production

GENERAL REMARKS

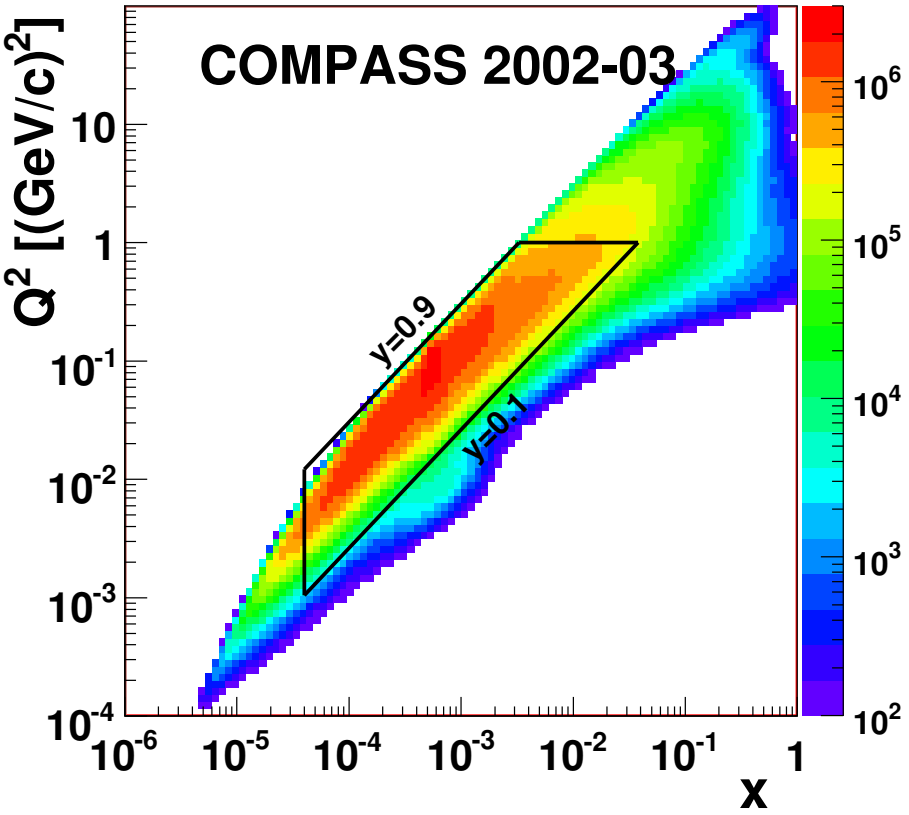
Definitions

- spin dependent longitudinal asymmetry A_1^d
  - we count events collected for different relative orientations of the beam and target particle spins
  - experimental asymmetry: $A_{meas} \approx \frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}}$
  - $\frac{1}{f P_b P_t} A_{meas} = A^{\mu d} = A_{||} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} \approx D A_1^d$
  - P_b, P_t - beam target polarization, respectively
  - D - photon depolarization factor
  - f dilution factor ($\sim$ fraction of polarizable nucleons in the target to all)
- spin dependent longitudinal structure function g_1^d
  - in QPM $g_1^d \approx \sum_{i=0}^{N} e_{q_i}^2 (q_i^{\uparrow\uparrow} - q_i^{\uparrow\downarrow})$
  - $g_1^d = g_1^N (1 - \frac{3}{2}\omega_d) \approx A_1^d F_1^d = A_1^d \frac{F_2^d}{2x(1+R)}$

Motivation

- A_1^d **and** g_1^d $Q^2 < 1$ **(GeV/c)^2:** small x physics, parton saturation non-perturbative models (Regge, VMD), poorly known (only SMC data)
- A_1^d **and** g_1^d **for** $Q^2 > 1$ **(GeV/c)^2:** QCD analysis possible: determination of the helicity distributions of all partons, *e.g.* ΔG

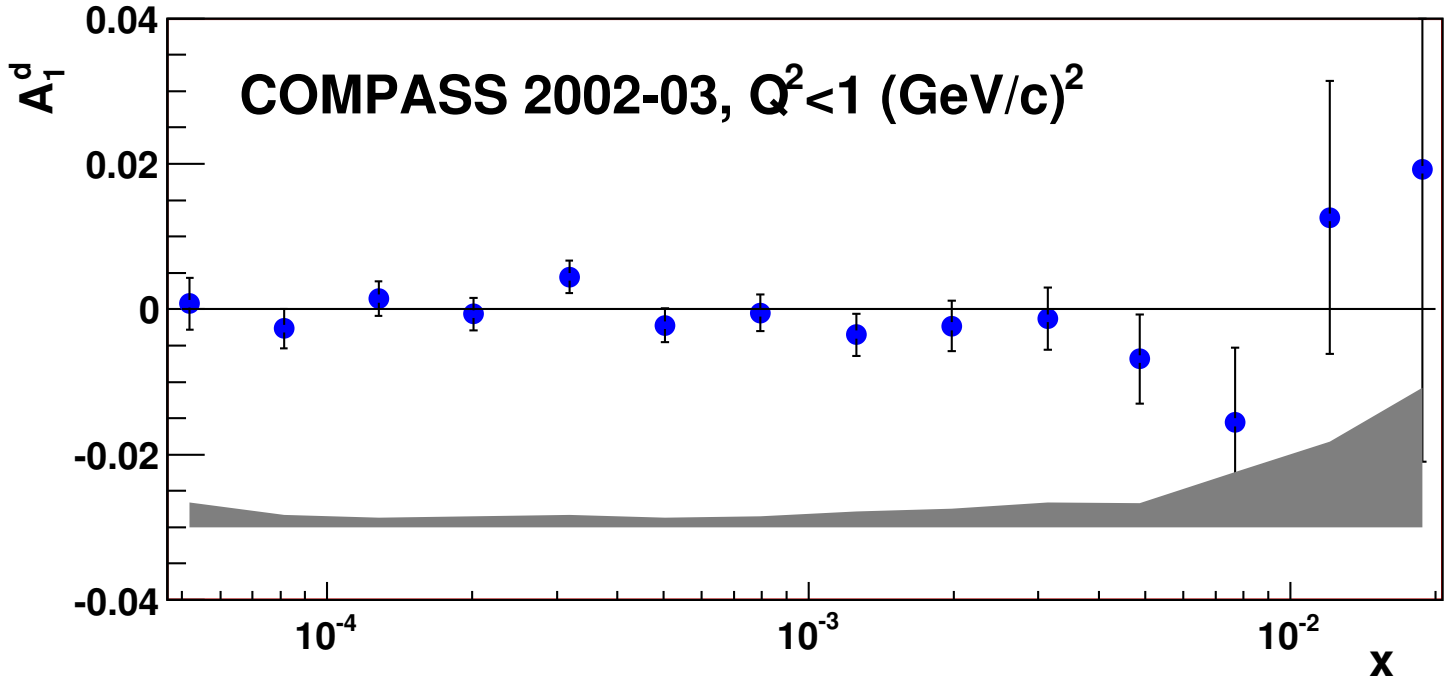
COMPASS acceptance



- example of acceptance for A_1^d analysis $Q^2 < 1$ (GeV/c)^2
- fixed target experiment - high correlation of x and Q^2
- further limitation by too low depolarization factor (y cut)

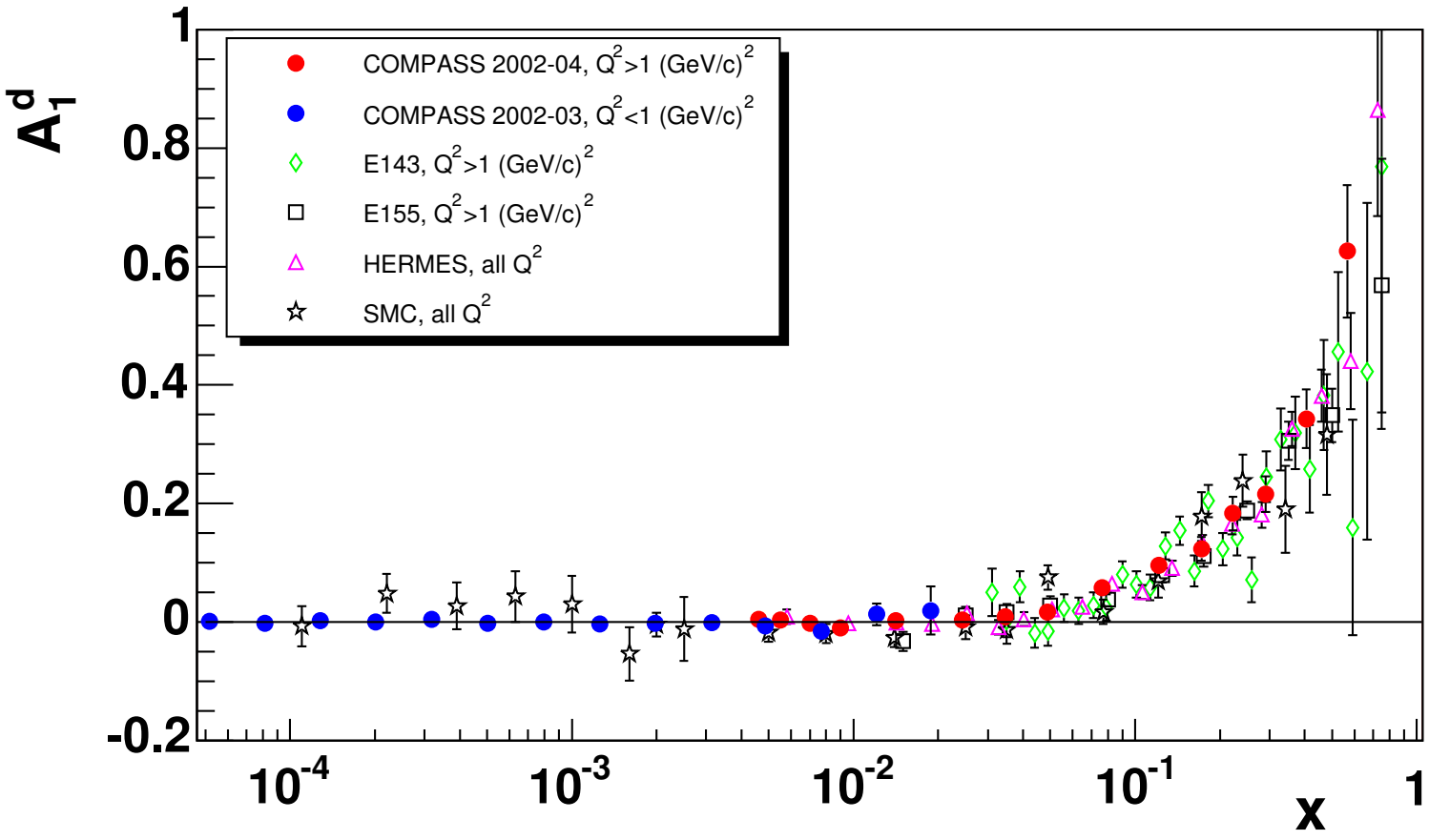
A_1^d AND g_1^d ANALYSIS FOR $Q^2 < 1$ (GeV/c)^2 2002-2003 data

COMPASS A_1^d, $Q^2 < 1$ $(\mathbf{GeV/c})^2$



- results from 2002-03 published: PLB 647 (2007) 330-340
- $300 \cdot 10^6$ events
- compatible with 0 in the whole measured x range

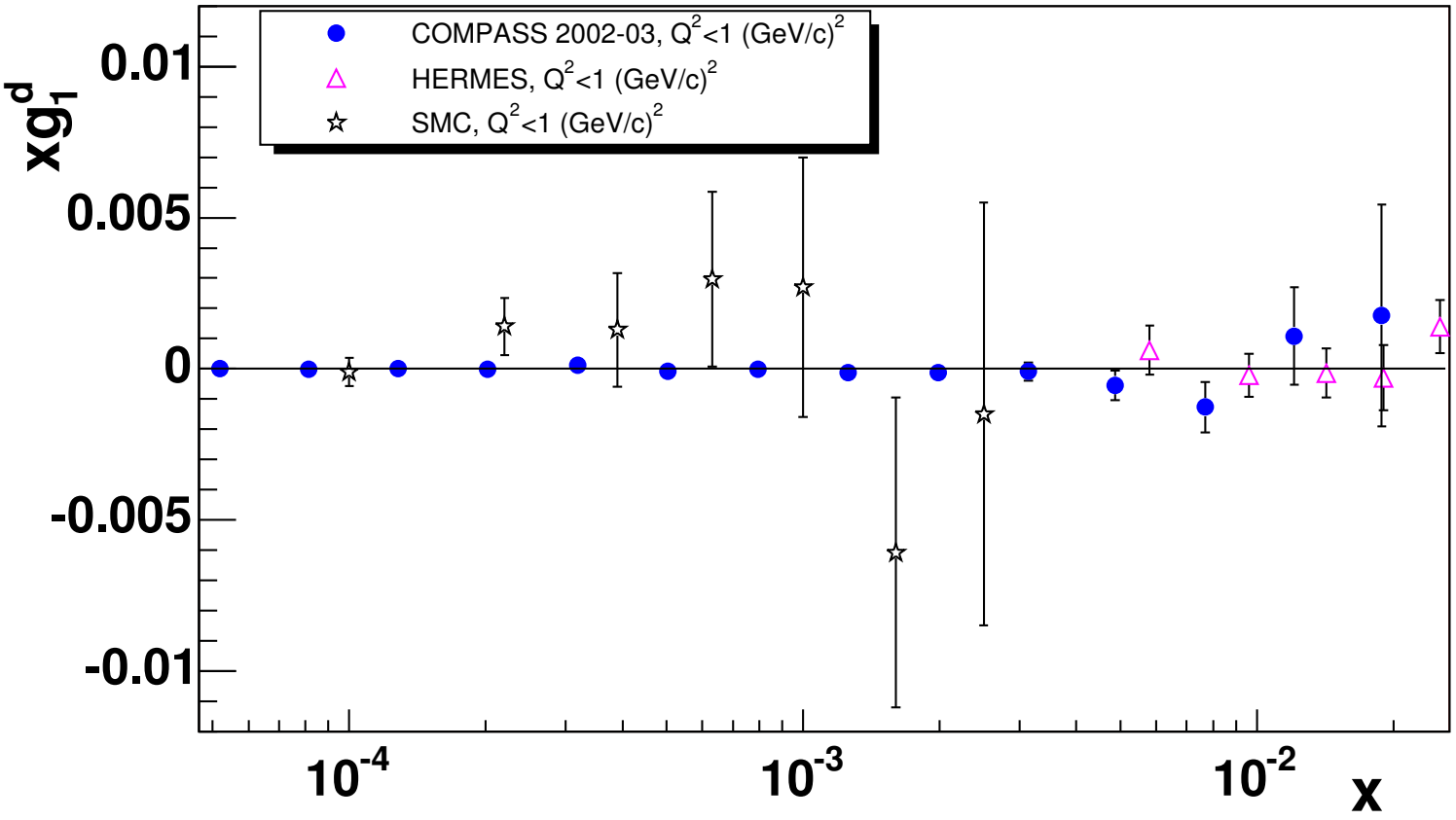
Comparison with other experiments



- very good agreement with SMC (the only experiment in the low x range)
- 10-20 improvement of statistical errors compared to SMC

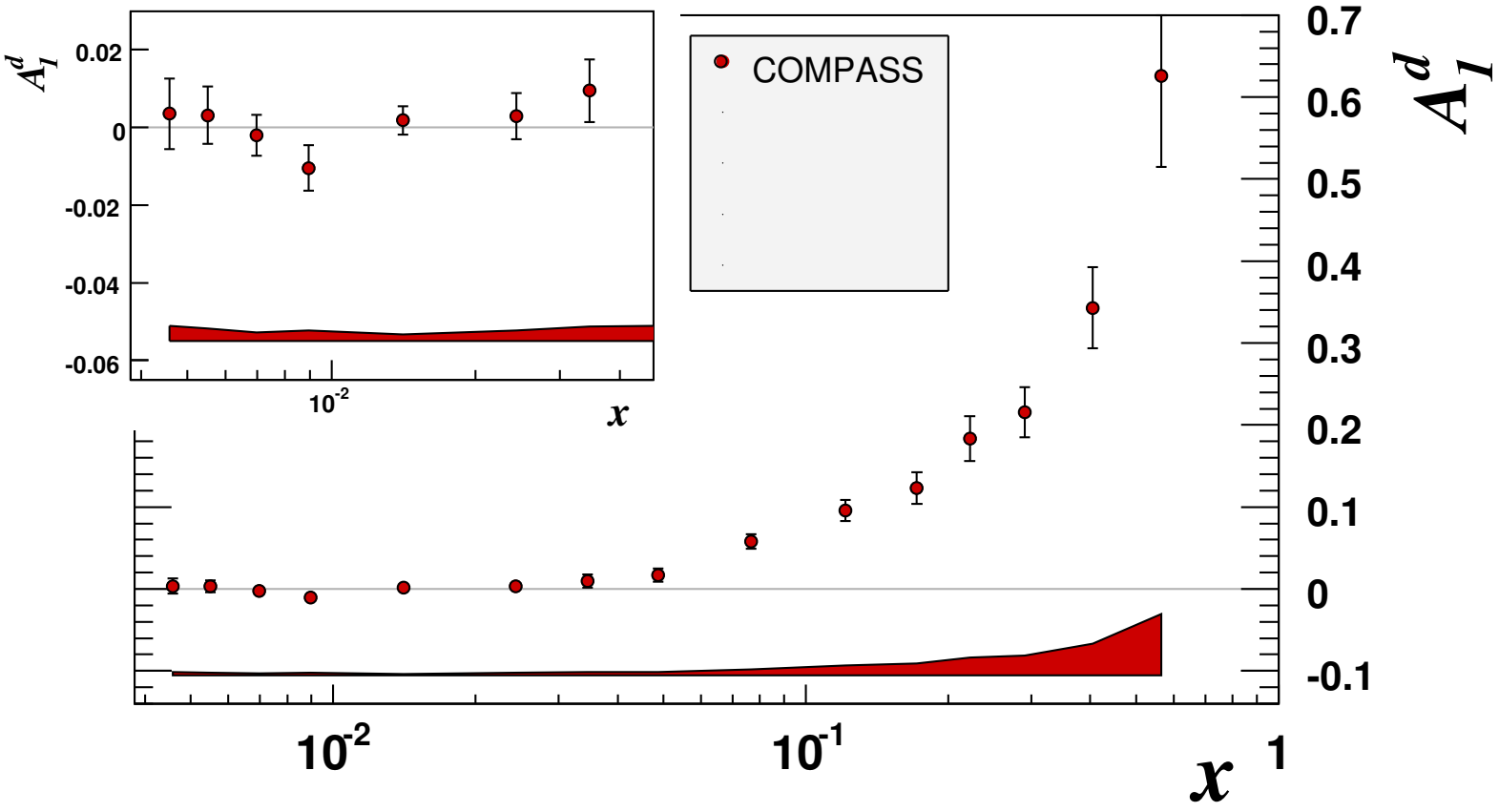
COMPASS g_1^d, $Q^2 < 1$ $(\mathbf{GeV/c})^2$

- $g_1^d = A_1^d \frac{F_2^d}{2x(1+R)}$
- F_2, R *c.f.* PLB 647 (2007) 330-340
- points at measured Q^2



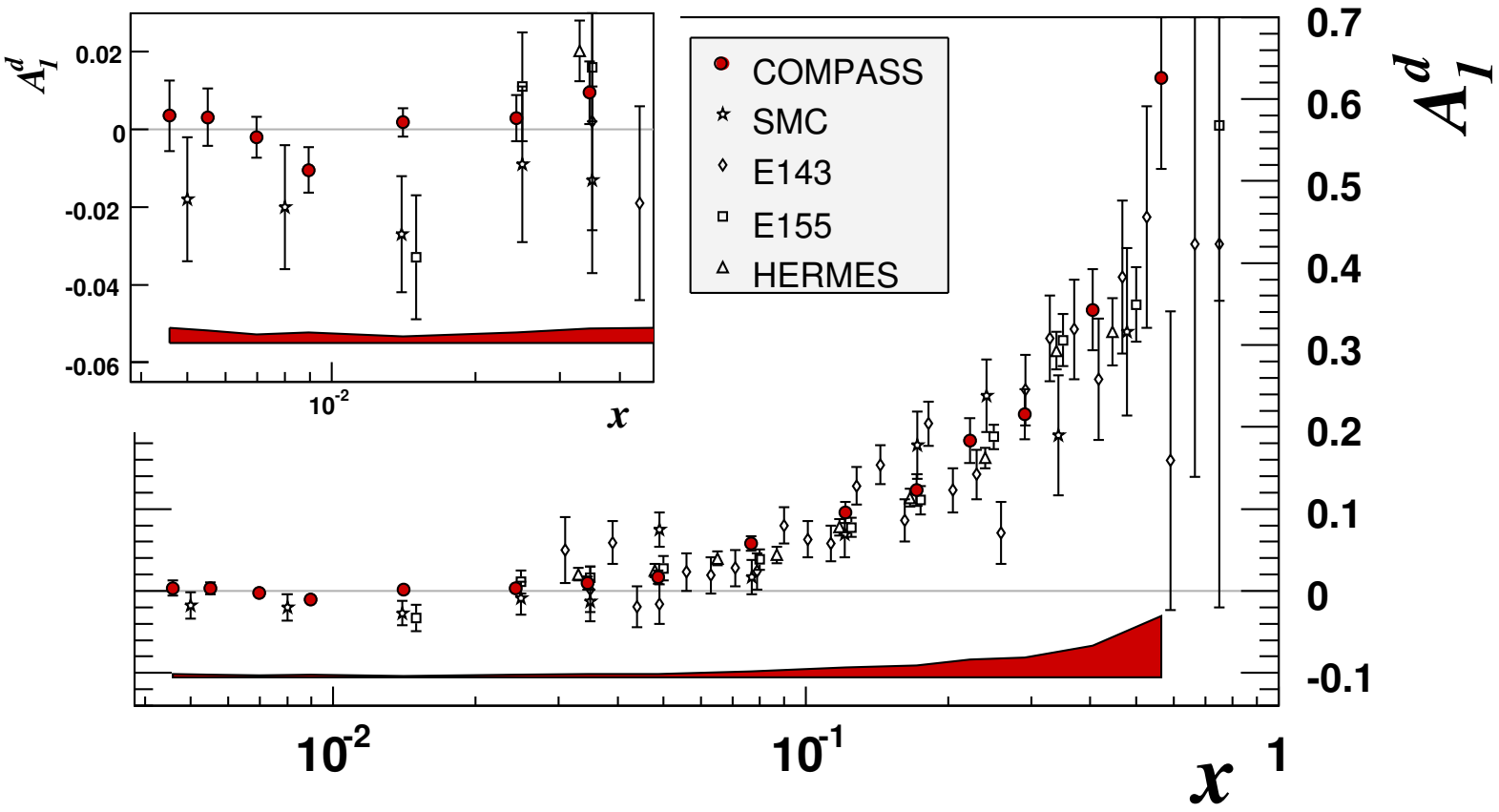
A_1^d AND g_1^d ANALYSIS FOR $Q^2 > 1$ (GeV/c)^2 2002-2004 data

COMPASS A_1^d, $Q^2 > 1$ $(\mathbf{GeV/c})^2$



- results from 2002-04 published: PLB 647 (2007) 8-17
- $89 \cdot 10^6$ events
- compatible with 0 for $x < 0.03$

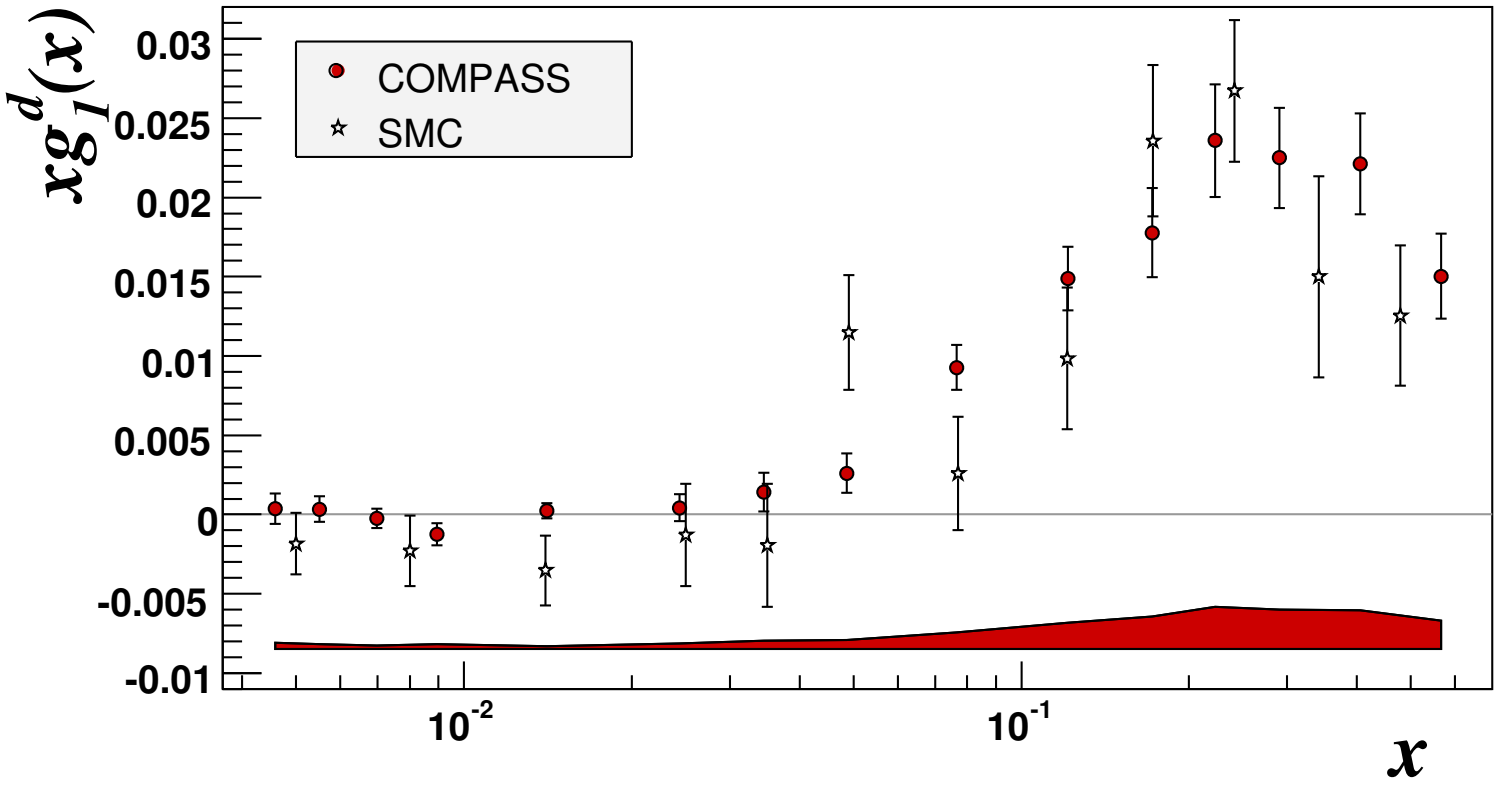
Comparison with other experiments



- good agreement with other experiments
- negative tendency at low x seen in SMC data not confirmed
- large improvement of statistical errors in low x region

COMPASS g_1^d, $Q^2 > 1$ $(\mathbf{GeV/c})^2$

- $g_1^d = g_1^N(1 - \frac{3}{2}\omega_d) = \frac{F_2^d}{2x(1+R)} A_1^d$
- F_2^d from PRD 58 (1998) 112001, R from PLB 452 (1999) 194
- points at measured Q^2

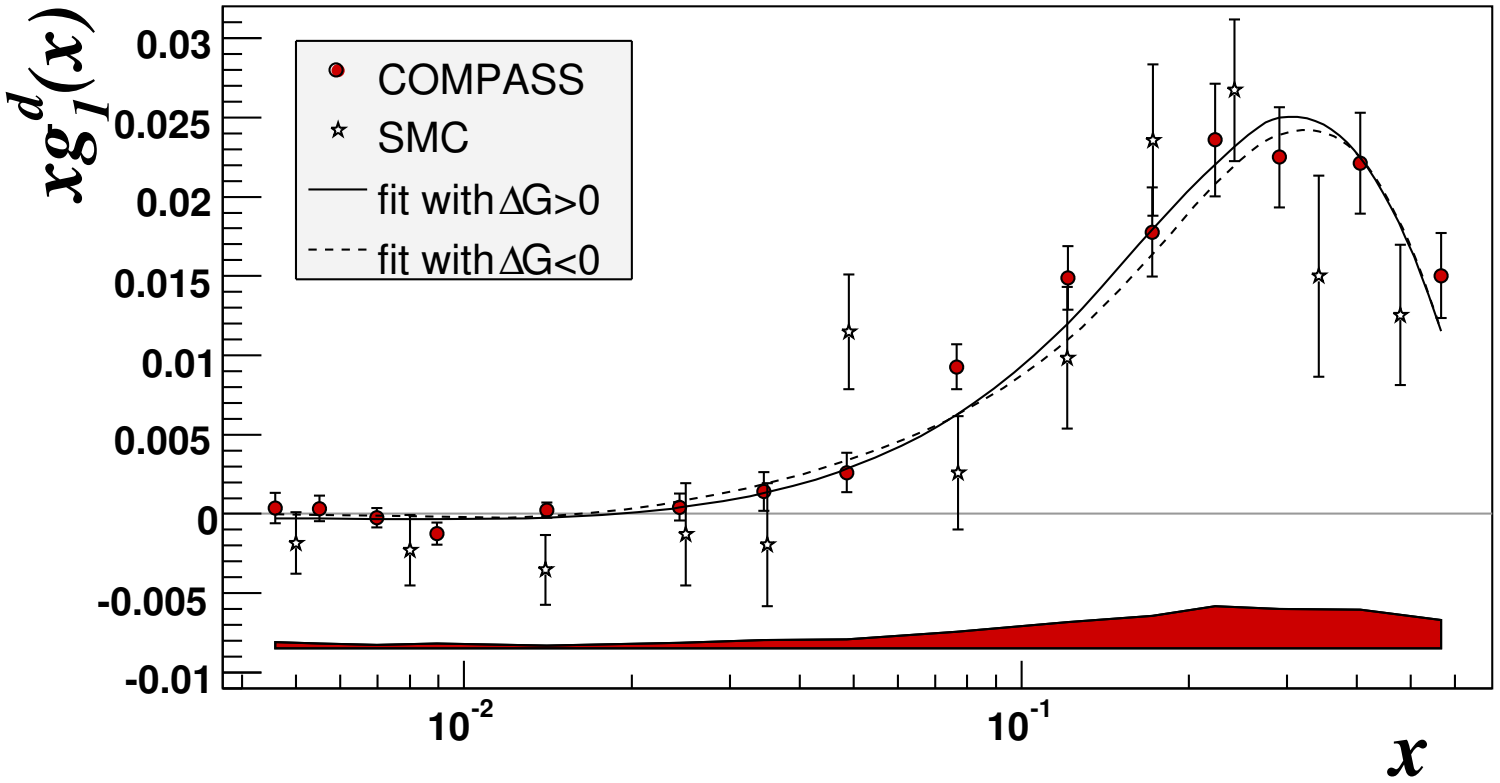


QCD analysis of the world on g_1

QCD analysis of the world on g_1

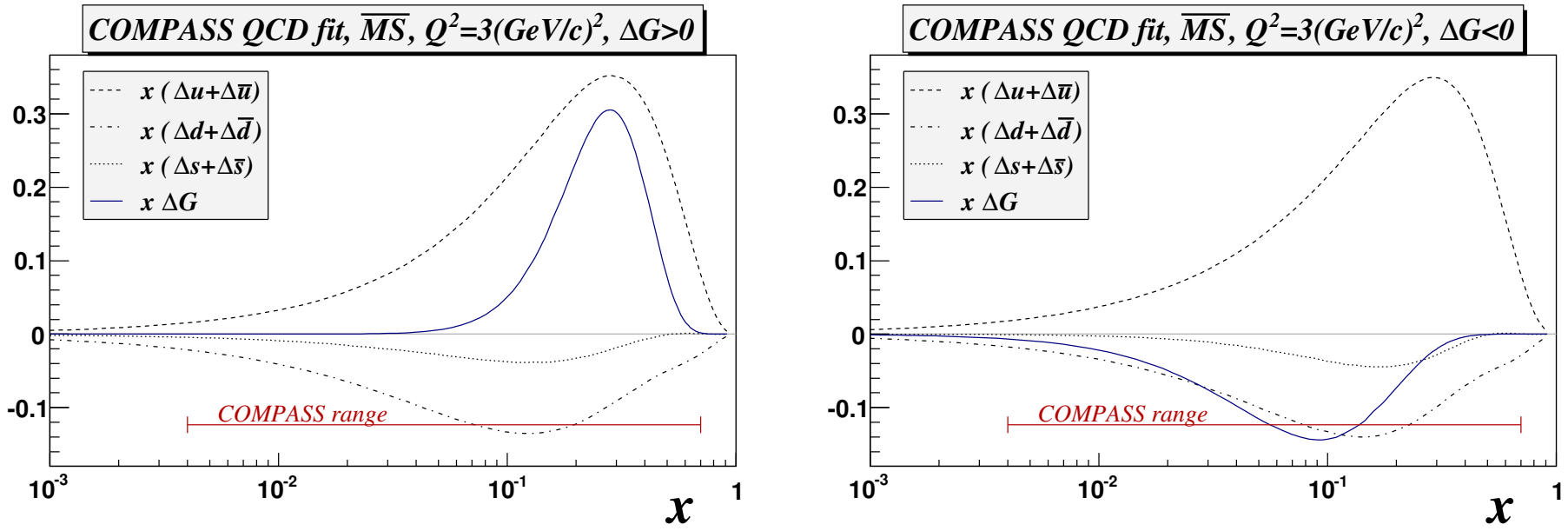
- 240 data points used (COMPASS, EMC, E142, E143, E154, E155, JLAB, HERMES)
- 43 point from COMPASS
- two different approaches in NLO $\overline{MS}$ used:
  - grid in (x, Q^2) space; PRD 58 (1998) 112002
  - Mellin transform + moments space; PRD 70 (2004) 074032
- Initial parametrization:$\Delta\Sigma, \Delta q_3, \Delta q_8, \Delta G = \eta \frac{x^\alpha (1-x)^\beta (1+\gamma x)}{\int_0^1 x^\alpha (1-x)^\beta (1+\gamma x) dx}$
- $\eta_k = \int_0^1 \Delta k \, dx$
- $\chi^2 = \sum_{i=0}^{N} \frac{[g1^{calc}(x,Q^2) - g1^{exp}(x,Q^2)]^2}{[\sigma^{exp}_{stat}(x,Q^2)]^2}$

QCD analysis of the world on g_1



- found two solutions $\Delta G > 0$ and $\Delta G < 0$
- both solutions describe data equally well

QCD analysis
polarized parton distributions



- almost no sensitivity of $x(\Delta q + \bar{\Delta} q)$ to $x\Delta G$

QCD analysis results

- quark polarization:
  - $\eta_\Sigma = 0.30 \pm 0.01(stat) \pm 0.02(evol)$
  - error on η_Σ reduced by factor 2 due to COMPASS data
- gluon polarization:
  - $\eta_G > 0 : \eta_G^{app1} = 0.34^{+0.05}_{-0.07},\ \eta_G^{app2} = 0.23^{+0.04}_{-0.05}$
  - $\eta_G < 0 : \eta_G^{app1} = -0.31^{+0.10}_{-0.14},\ \eta_G^{app2} = -0.19^{+0.06}_{-0.11}$
  - $\mathbf{|\eta_G| = 0.2 - 0.3}$

First moment of g_1^d in NLO

- only COMPASS points used
- $\Gamma_1^N(Q_0^2 = 3\mathrm{GeV}^2) = \int_0^1 g_1^N(x)dx = 0.050 \pm 0.003(stat) \pm 0.003(evol) \pm 0.005(syst)$
- $\Gamma_1^d(Q^2) = \frac{1}{9}C_1^S a_{0|Q^2\to\mathrm{inf}} + \frac{1}{36}C_1^{NS}(Q^2)a_8$
  - $a_8 = 0.585 \pm 0.025$, PRD 62 (2000) 034017
  - C_1^i calculable in QCD, PLB 404 (1997) 153
- $a_{0|Q^2\to\mathrm{inf}} = 0.33 \pm 0.03(stat) \pm 0.05(syst)$
- $(\Delta s + \Delta\bar{s}) = \frac{1}{3}(a_{0|Q^2\to\mathrm{inf}} - a_8) = -0.08 \pm 0.01(stat) \pm 0.02(syst)$
- result points to a significant negative strange quark polarization
- direct measurements of $(\Delta s + \Delta\bar{s})$ possible in semi-inclusive analysis (K^+, K^-, K^0)

Semi-Inclusive analysis $Q^2 > 1$ (GeV/c)^2, 2002-2004 data

Definitions

Semi-inclusive asymmetries

$$A^{\pm} = \frac{\sigma^{h\pm}_{\uparrow\downarrow} - \sigma^{h\pm}_{\uparrow\uparrow}}{\sigma^{h\pm}_{\uparrow\downarrow} + \sigma^{h\pm}_{\uparrow\uparrow}}$$

$$A_1^h(x) = \frac{\sum_q e_q^2 (\Delta q(x) D_q^h + \Delta\bar{q}(x) D_{\bar{q}}^h)}{\sum_q e_q^2 (q(x) D_q^h + \bar{q}(x) D_{\bar{q}}^h)}$$

difference asymmetry

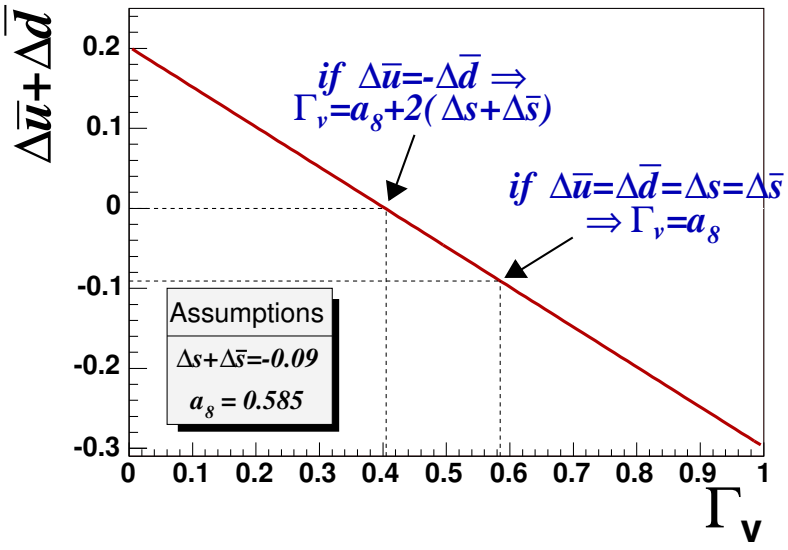
$$A^{+-} = \frac{(\sigma^{h+}_{\uparrow\downarrow} - \sigma^{h-}_{\uparrow\downarrow}) - (\sigma^{h+}_{\uparrow\uparrow} - \sigma^{h-}_{\uparrow\uparrow})}{(\sigma^{h+}_{\uparrow\downarrow} - \sigma^{h-}_{\uparrow\downarrow}) + (\sigma^{h+}_{\uparrow\uparrow} - \sigma^{h-}_{\uparrow\uparrow})}$$

$$A_d^{\pi^+ - \pi^-}(x) = A_d^{K^+ - K^-}(x) = \frac{\Delta u_v(x) + \Delta d_v(x)}{u_v(x) + d_v(x)}$$

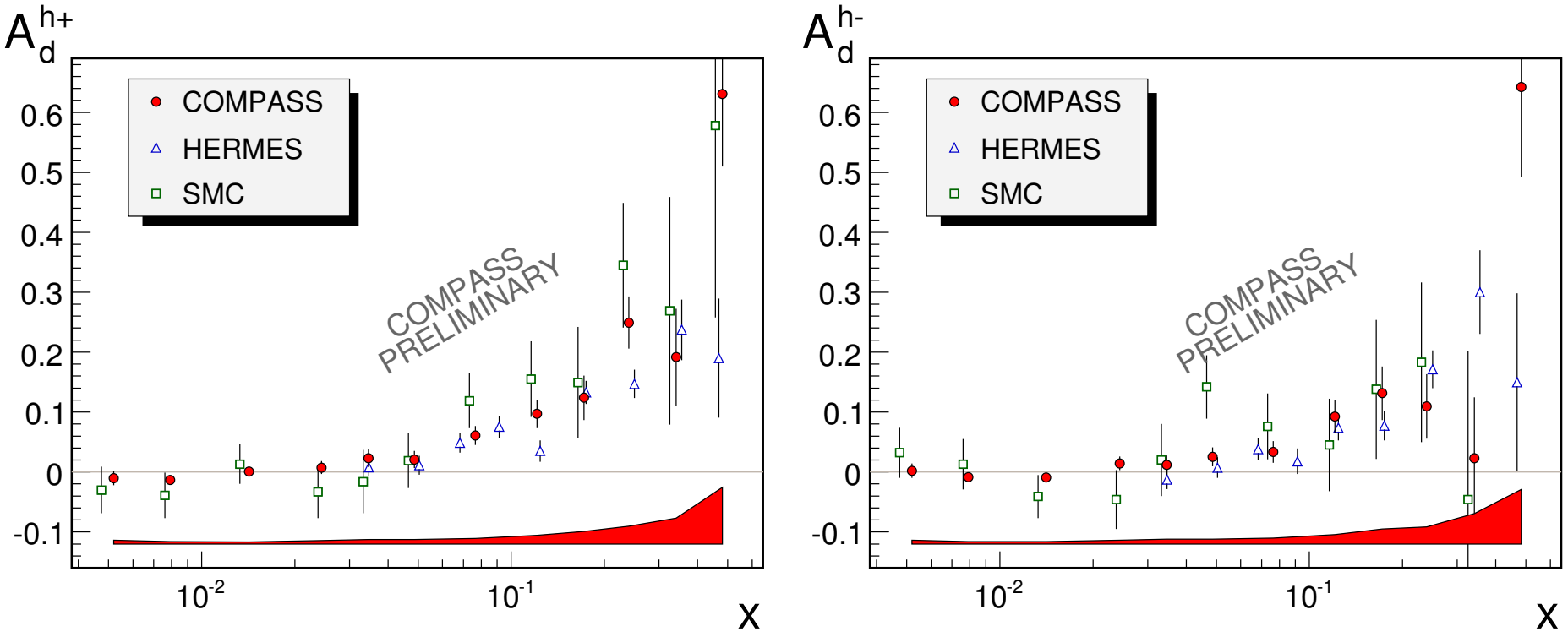
- fragmentation functions $D_q^h = \int_0^1 D_q^g(z) dz$ are poorly known
- they canceled out in LO QCD for difference asymmetry, A^{+-}
- difference asymmetry :
  - proposed in PLB 230 (1989) 141
  - significant reduction of systematic error (due to f.f. cancelation)
  - first used in SMC PLB 369 (1996) 93
  - can be obtained combining A^+ and A^- asymmetries
  - no hadron identification required on deuteron target

Motivation

- study of proprieties of the polarized sea quarks
- possibility to distinguish between "symmetric sea" $(\Delta\bar{u} = \Delta\bar{d} = \Delta s = \Delta\bar{s})$ and "non symmetric sea" $(\Delta\bar{u} = -\Delta\bar{d})$
  - $\Gamma_1^N(Q_0^2 = 3\mathrm{GeV}^2) \ = 0.050 \pm 0.003(stat) \pm 0.003(evol) \pm 0.005(syst)$
  - $\Gamma_1^v \equiv \int_0^1((\Delta u_v(x) + \Delta d_v(x))dx$
  - $\Delta\bar{u} + \Delta\bar{d} = 3\Gamma_1^N - \frac{1}{2}\Gamma_v + \frac{1}{12}a_8 = \Delta s + \Delta\bar{s} + \frac{1}{2}(a_8 - \Gamma_v)$



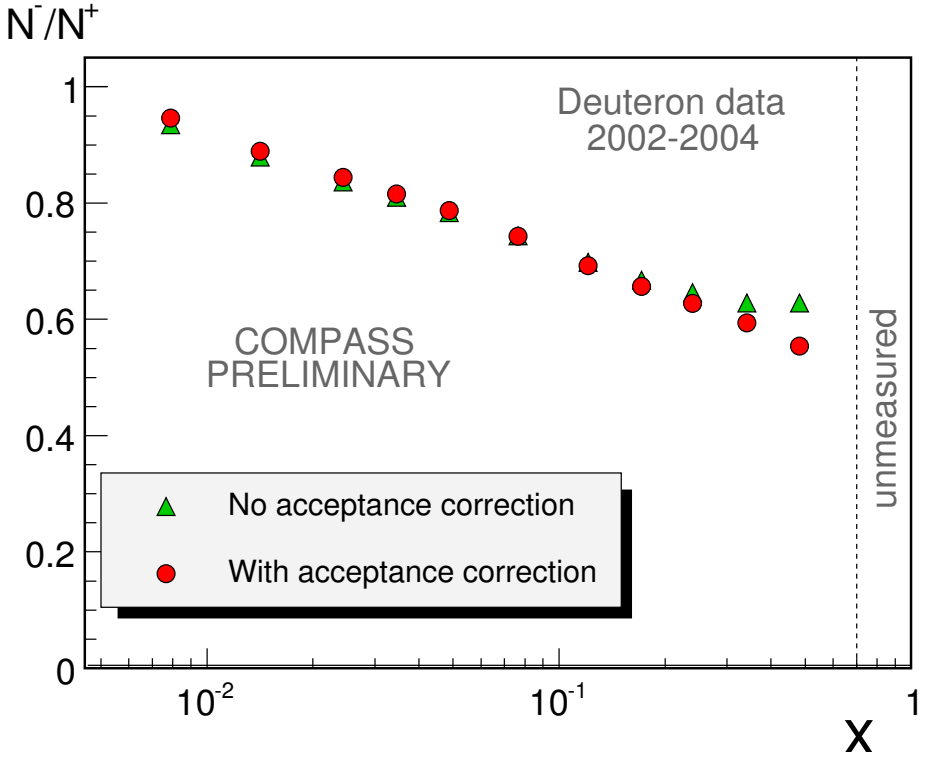
A^+ and A^-



- $Q^2 > 1(\mathrm{GeV/c})^2$, $0.1 < y < 0.9$, $0.2 < z_h < 0.85$
- Final statistics: $N^+ = 30 \cdot 10^6$, $N^- = 25 \cdot 10^6$, $corr(N^+, N^-) \approx 20\%$

Difference Asymmetry

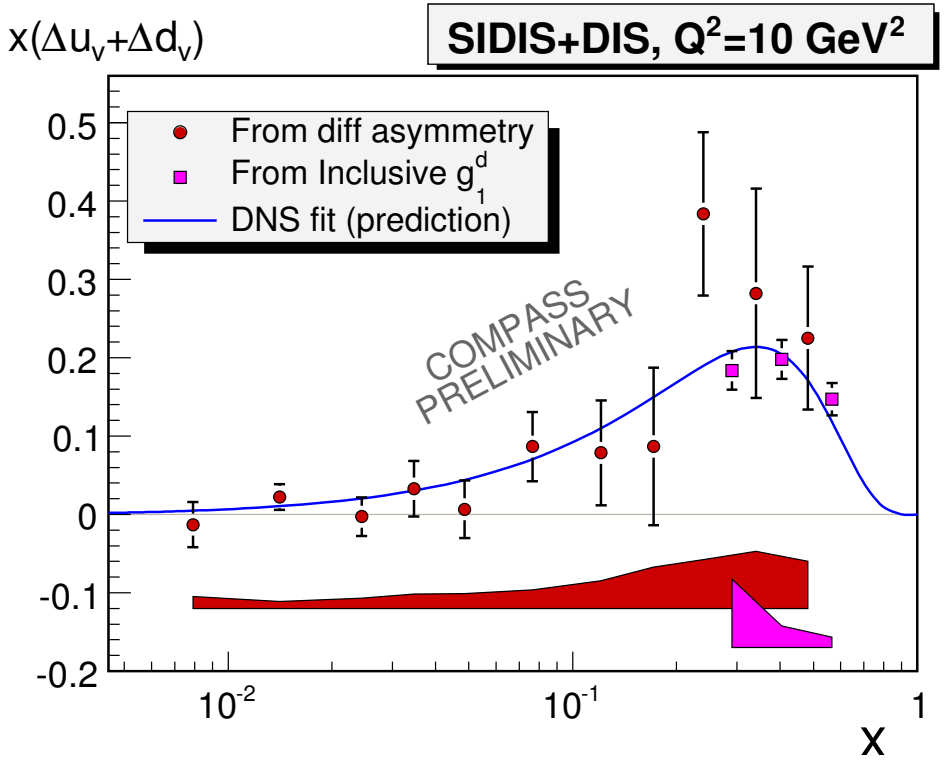
- $\mathbf{A^{+-} = \frac{1}{1-r}(A^{+} - rA^{-})}$
- where $r = \frac{\sigma^{h-}_{\uparrow\downarrow} + \sigma^{h-}_{\uparrow\uparrow}}{\sigma^{h+}_{\uparrow\downarrow} + \sigma^{h+}_{\uparrow\uparrow}} = \frac{\sigma^{h-}}{\sigma^{h+}}$
- r taken from ratio $N^{-}/N+$ corrected by the ratio of acceptances (MC)
- $\delta A^{+-} \sim \frac{\sqrt{N^{+}+N^{-}}}{N^{+}-N^{-}}$



Toward polarized valence quark distribution

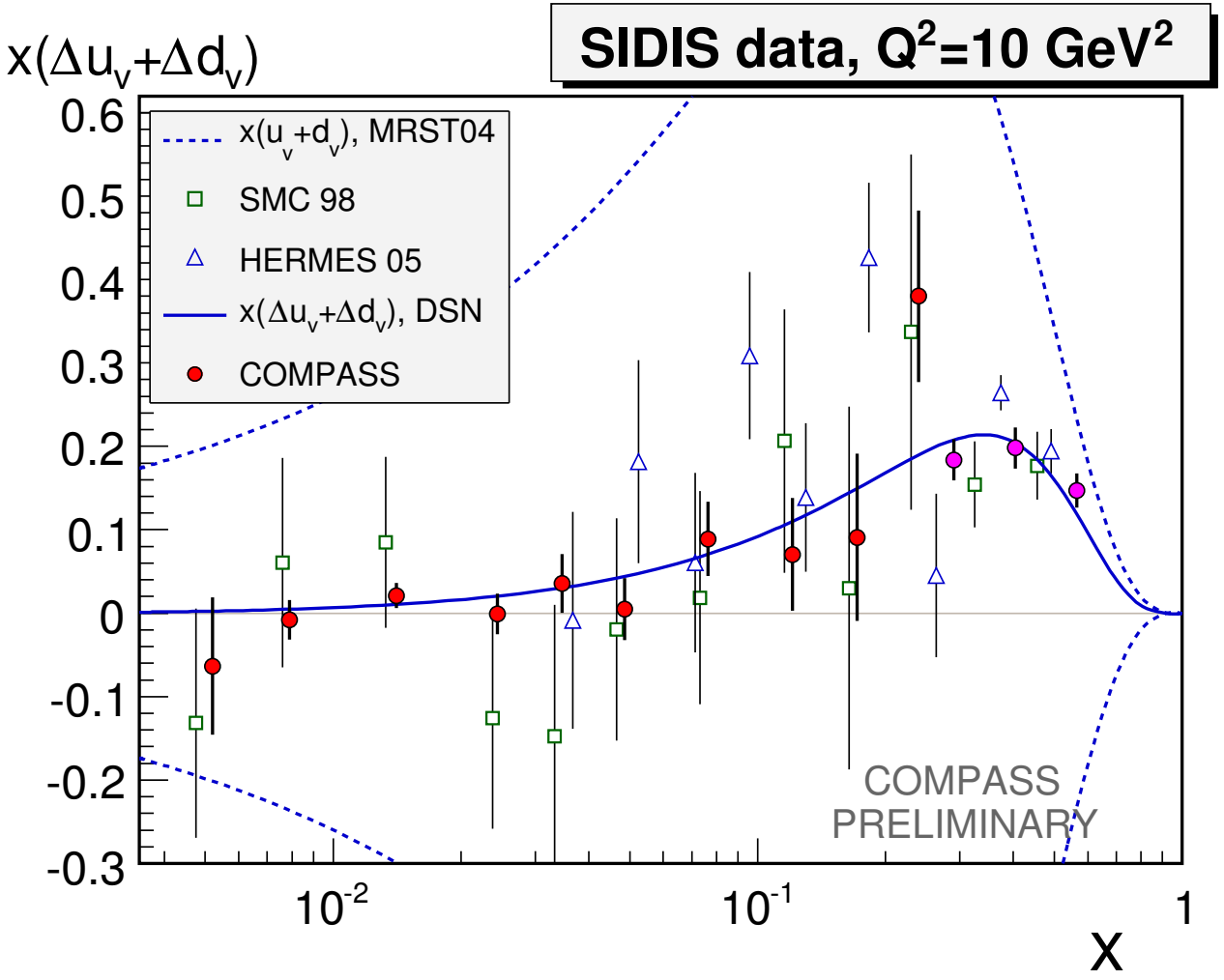
- measured A^{+-} evolved to the same $Q_0^2 = 10$ (GeV/c)^2
- DNS parametrization used (LO) PRD71 (2005) 094018 (D.de Florian, G.A. Navarro and R. Sassot, include SI data)
- $\Delta u_v + \Delta d_v = A^{+-}(u_v + d_v)$
- parametrization of $q(x), \bar{q}(x)$ taken from MRST04 (LO)
- unpolarized sea contribution to F_2 vanishes at high x
- instead of A^{+-} A_1^d can be used ($x > 0.3$)
  - $\Delta u_v + \Delta d_v = \frac{36}{5}\frac{g_1^d(x,Q^2)}{1-1.5\omega_d} - [2(\Delta\bar{u} + \Delta\bar{d} + \frac{2}{5}(\Delta s + \Delta\bar{s})]$
  - reduced (factor ~ 6) statistical error
  - positivity conditions $|\Delta q| < q$, $|\Delta\bar{q}| < \bar{q}$, used to estimate additional systematic error due do neglecting of see contribution at high x

Polarized valence quark distribution



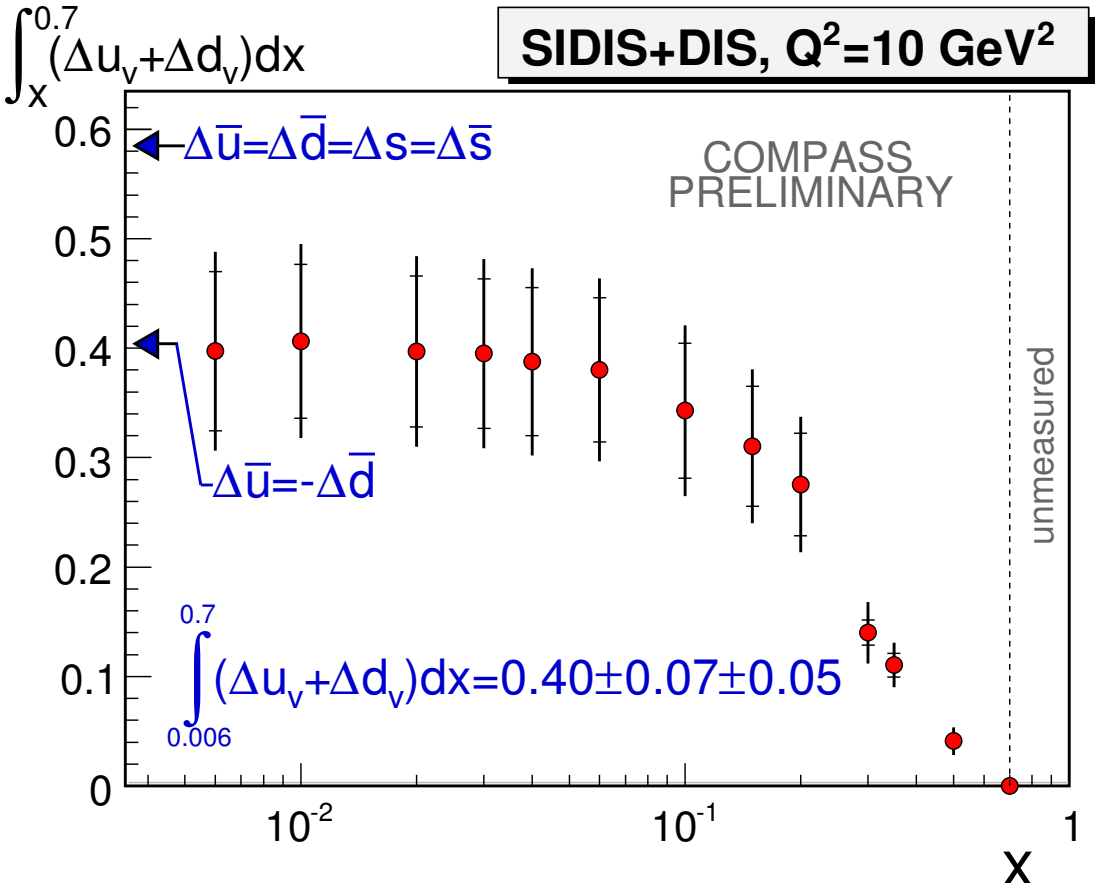
- results in agreement with DNS predictions
- main contribution to systematic error
  - beam, target polarization, dilution, depolarization factor: total $0.08 \cdot A$
  - upper limit for false asymmetries below $0.5 \cdot \delta A$
  - neglected sea contribution (for incl. data)

Comparison with other experiments



- results are in agreement
- largely reduced error at low x region

Calculation of Γ_v



- contribution from unmeasured range x (0.7-1.0) negligible (0.004)
- Γ_v is more than 2σ away from the results expected for the flavor symmetric sea scenario
- non symmetric sea scenario is preferred

SUMMARY

- measurements of A_1^d and g_1^d have been presented
- results from QCD fits were also shown
  - two possible scenarios for $\Delta G(x) > 0$ and $\Delta G(x) < 0$ equally well describe data
  - $|n_g| \approx 0.2 - 0.3$
  - polarized strange quark distribution was indirectly measured and found to be negative
- evaluation of the polarized valence quark distribution have been presented
  - symmetric sea scenario is disfavored ($\Delta\bar{u} = \Delta\bar{d} = \Delta s = \Delta\bar{s}$)

OUTLOOK

- 2006 data are being analyzed (more data in deuteron)
- direct measurement of strange sea polarization (K^+, K^-, K^0)
- presently data on proton target are taken $\rightarrow$ flavor separation