COMPASS results on the spin structure function g_1^d

On behalf of the COMPASS collaboration

Dubna-Spin05

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COMPASS at CERN

- Approuved 1997
- Data taking started in 2002
- One of the few fixed target exp. running at CERN
- Extended muon and hadron program

Spin physics with μ beam and polarised target

- Transverse P_T
- Longitudinal P_T
  - Main topic: ΔG
  - Exclusive channels
  - Semi-inclusive channels
  - Inclusive μ interactions: A_1^d, g_1^d ⟸ This talk

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Reference:

COMPASS, E.S. Ageev et al., Phys. Lett. B **612** (2005) 154-164

- Experimental layout
- DIS data
- Extraction of A_1^d, systematic errors
- A_1^d at low x, COMPASS vs. SMC
- g_1^d from COMPASS
- QCD analysis of world g_1 data

The COMPASS spectrometer

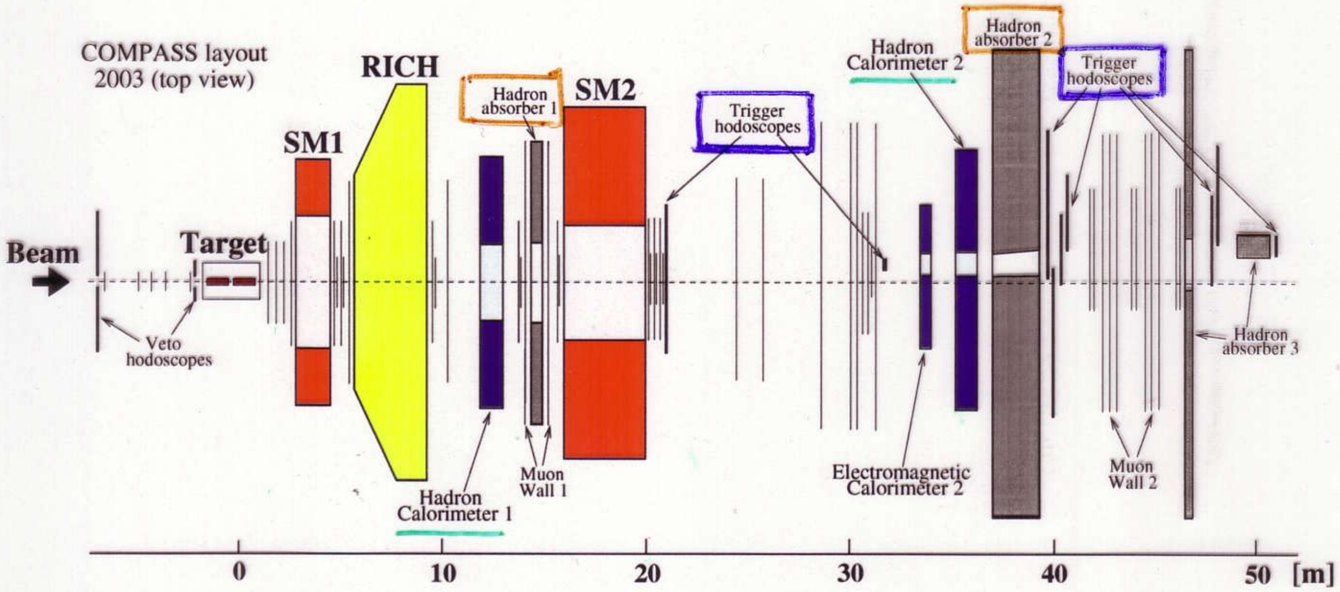


Figure 1: The COMPASS spectrometer.

Beam: μ^+ $E = 160$ GeV $\langle P_b \rangle = -0.76$

$I = 2.10^8$ μ/spill (4 spills/min.)

Polarised target: ^{6}LiD $|P_T| \approx 0.50$

2 cells : $\ell = 60$ cm $\varnothing = 3$ cm

Spectrometer: 2 stages

2 dipole magnets: SM1 $\left\{ \begin{array}{l} \int B.d\ell = 1 \text{ Tm} \\ P > 0.4 \text{ GeV/c} \end{array} \right.$

SM2 $\left\{ \begin{array}{l} \int B.d\ell = 4.4 \text{ Tm} \\ P > 4 \text{ GeV/c} \end{array} \right.$

μID : 2 hadron absorbers

Hadron detection : 2 calorimeters

Large variety of trackers (adapted to part. rate)

The COMPASS trigger system

* 3 types of triggers :

- Inclusive triggers: direction of scattered μ behind SM2 (from coincidence signals in hodoscopes)

- Semi-inclusive triggers:

  μ energy loss (from trigger hodoscopes)
  +
  hadron signal in HCAL

- Calorimeter trigger: (Not ~~used~~ installed in 2002)

  Hadron signal in calorimeter
  (No condition on scattered μ)

* Software requirements :

- in all cases : beam μ + scattered μ + interaction point inside target cells

- for semi-incl. and calor$^{\underline{n}}$ triggers : in addition, at least one hadron at interaction point

** Setup mainly for quasi-real photon interactions

Only a small fraction of triggers for DIS

DIS data 2002 + 2003

$$\left.\begin{array}{l} Q^2 > 1\ \text{GeV}^2 \\ 0.1 < y < 0.9 \\ 140 < P_\mu < 180\ \text{GeV}/c \end{array}\right\} \boxed{34.\ 10^6\ \text{events}}$$

(2/3 from 2003)

2004 data Not analysed yet for DIS events

Expect ≈ same statistics as (2002 + 2003)

Fraction of various trigger types in DIS sample vs. x and Q^2

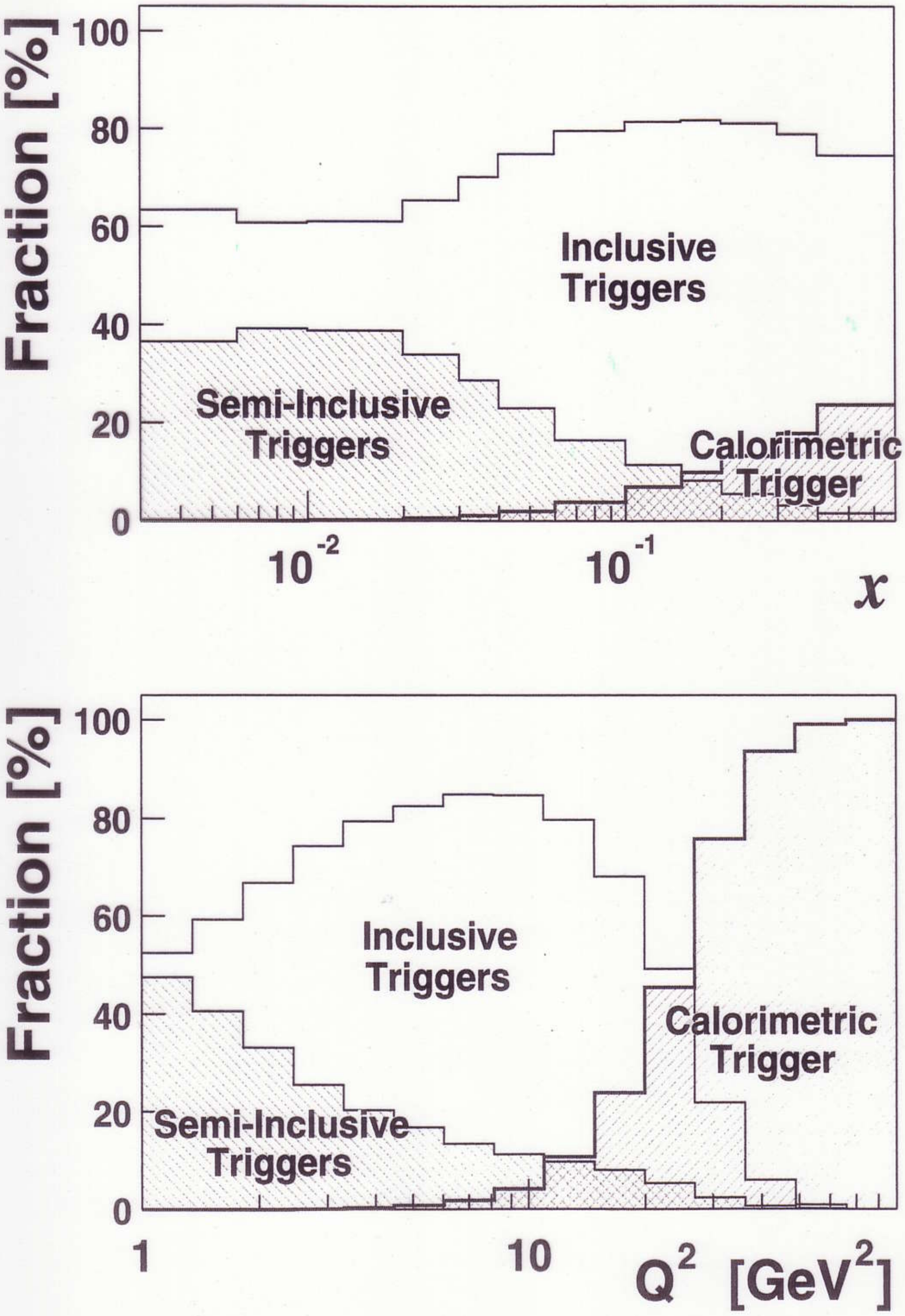


Figure 1: Fraction of inclusive, semi-inclusive and calorimetric triggers in the final data sample (2002–2003) as a function of x and Q^2. Events are counted with the weight they carry in the asymmetry calculation.

Asymmetries and spin-structure function

* Cross-section asymmetry

$$A^d = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}}$$

* Longitudinal γ^*-deuteron asymmetry

$$A_1^d = \frac{\sigma_0^T - \sigma_2^T}{2\,\sigma^T}$$

$\sigma_J^T =$ { transverse cross-section
{ total spin proj^{n} on γ dir^{n} $= J$

with $\sigma^T = \frac{1}{3}\left(\sigma_0^T + \sigma_1^T + \sigma_2^T\right)$

* A_1^d vs. A^d

$$A^d = D\left(A_1^d + \eta\, A_2^d\right)$$

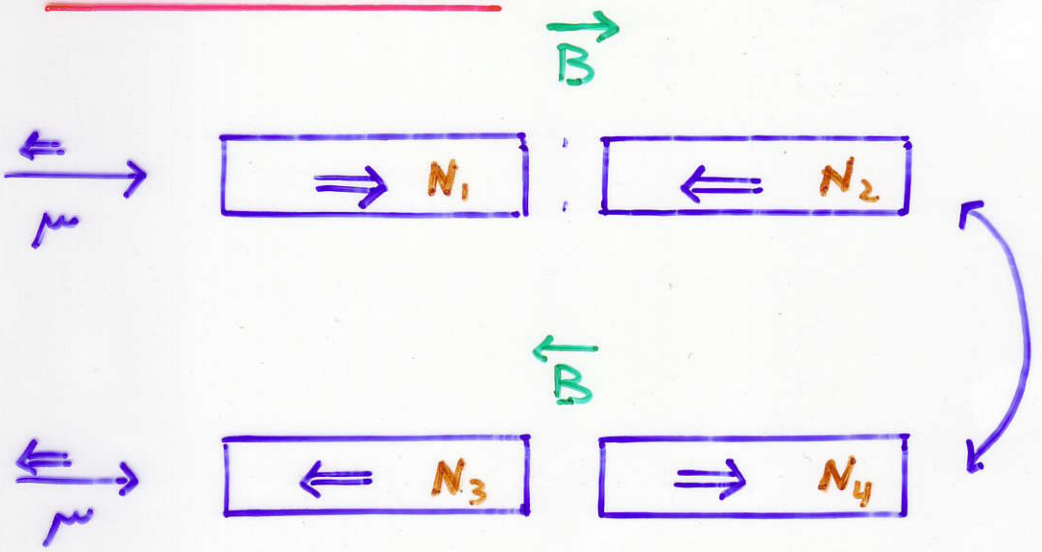
η, D → event kinematics
(+ $R = \sigma_L/\sigma_T$ for D)

Compass kinematics: η, A_2^d small

$$\Longrightarrow \boxed{\begin{aligned} A_1^d &\simeq A^d/D \\ g_1^d &= \frac{F_2^d}{2x(1+R)}\,A_1^d \end{aligned}}$$

A_1^d derived separately for incl./hadronic events
$\Longrightarrow$ compared and merged

Evaluation of A_1^d



Spin reversal by field rotation

$$\boxed{N_i = a_i \varphi_i n_i \bar{\sigma} (1 + P_B P_T f D A_1^d)}$$

a_i = acceptance
φ_i = muon flux
n_i = Nr. target nucleons/surf.
f = target dilution factor

* Same flux for the 2 cells : $\varphi_1 = \varphi_2$ and $\varphi_3 = \varphi_4$

* $\dfrac{N_1 N_4}{N_2 N_3}$ = 2^{d} order eq. in A_1^d

System. errors ⇓

Acceptances cancel out if $\left({}^{a_1}/_{a_2}\right) = \left({}^{a_3}/_{a_4}\right)$

* Statistical error minimized by using weighted events :

$$N_i \longrightarrow \sum_i w_i \quad \text{with} \quad \boxed{w = f P_B D}$$

The polarised target dilution factor

$^6\text{Li} \simeq {}^4\text{He} + \text{D}$

Naïve expectation $f(^6\text{LiD}) \simeq 0.5$

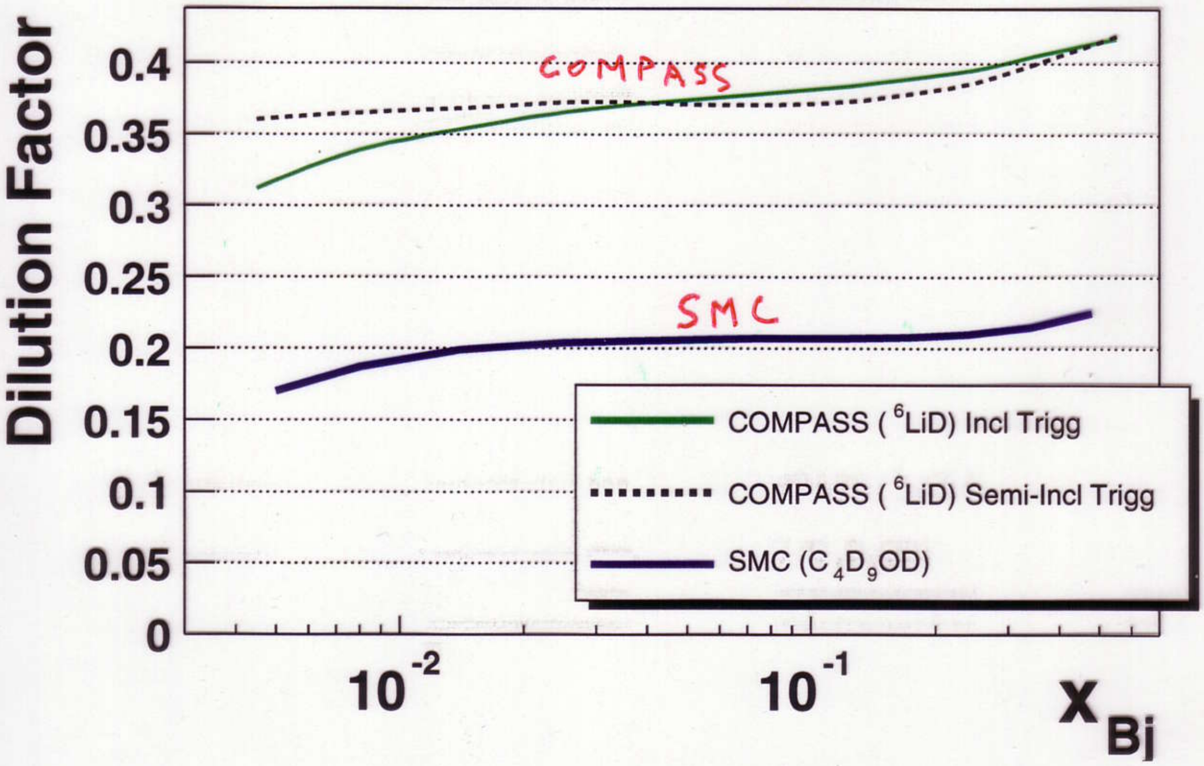


Figure 1: The dilution factor (including radiative effects on the deuteron) as a function of x.

* Ratio of σ's on nucleons bound in nuclei

* correction for polarisation of D bound in ^{6}Li

* correction for radiative effects in deuteron

$$A_1 = \frac{\Delta\sigma^{(1\gamma)}}{\bar{\sigma}^{(1\gamma)}} = \frac{\Delta\sigma^{(t.t)}}{\bar{\sigma}^{(t.t)} \underbrace{\left(\bar{\sigma}^{1\gamma}/\bar{\sigma}^{(t.t)}\right)}_{\text{unpol. RC}}} + \underbrace{\frac{\Delta\sigma^{(1\gamma)} - \Delta\sigma^{(t.t)}}{\bar{\sigma}^{(1\gamma)}}}_{\text{Pol. RC}}$$

{ included in f
different incl./semi-incl.

Systematic errors on A_1^d, g_1^d

1- A_1 from incl./semi-incl. triggers → No effect

Also tested by MC $\Longrightarrow \left\{ \begin{array}{l} \text{deuteron target} \\ \text{OK within exp. conditions} \end{array} \right.$

2- External sources:

$$\left\{ \begin{array}{lll} P_B,\ P_T & \rightarrow & 6.5\%\ \text{scale error} \\ f & \rightarrow & 6\% \\ R & \rightarrow & 4\text{-}5\% \\ F_2^d & \rightarrow & (\text{in } g_1^d) \\ \vdots\ (A_2,\ \underset{(\text{Pol.})}{RC} & \rightarrow & \text{smaller effects}) \end{array} \right.$$

3- False asymmetries due to time variation of (a_u/a_d)

- Divide data into 100 subsamples taken within ~ 16 hours $\frac{\times 2}{200}$
- Distributions of $(A_i - \bar{A})/\sigma_i$ in every x bin $\Longrightarrow \boxed{N(0,1)}$

$\sigma(\hat{\sigma}) = \frac{1}{\sqrt{400}} = 0.05$

$\Longrightarrow$ **No indication for broadening due to time dependent effects**

$\sqrt{\sigma_{stat}^2 + \sigma_{syst}^2} \leq 1.10\, \sigma_{stat}$

$\Downarrow$

$$\boxed{\sigma_{syst.} < 0.5\, \sigma_{stat.}}$$

(conservative limit)

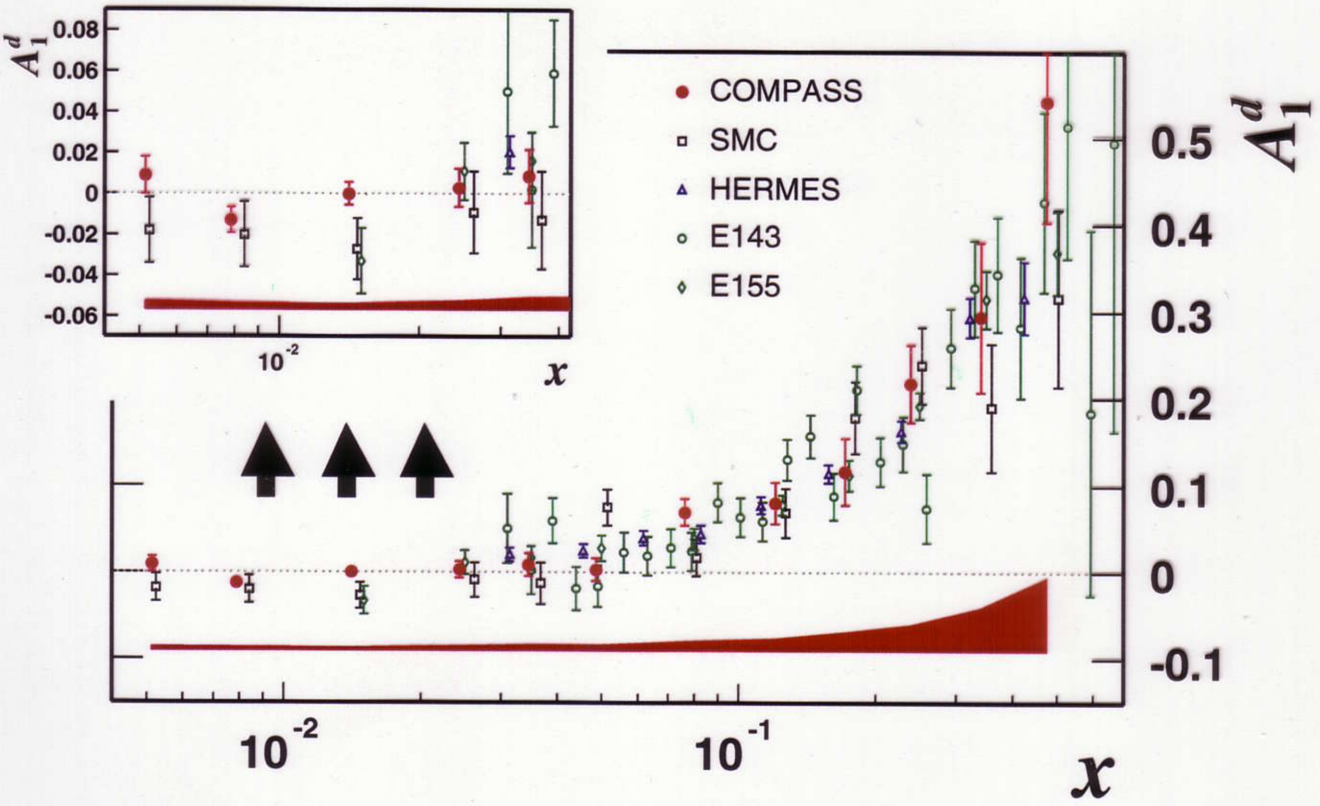


Figure 1: The asymmetry $A_1^d(x)$ as measured in COMPASS and previous results from SMC, HERMES, SLAC E143 and E155 at $Q^2 > 1$ GeV^2.

$A_1^d(x, Q^2)$ almost independent of Q^2

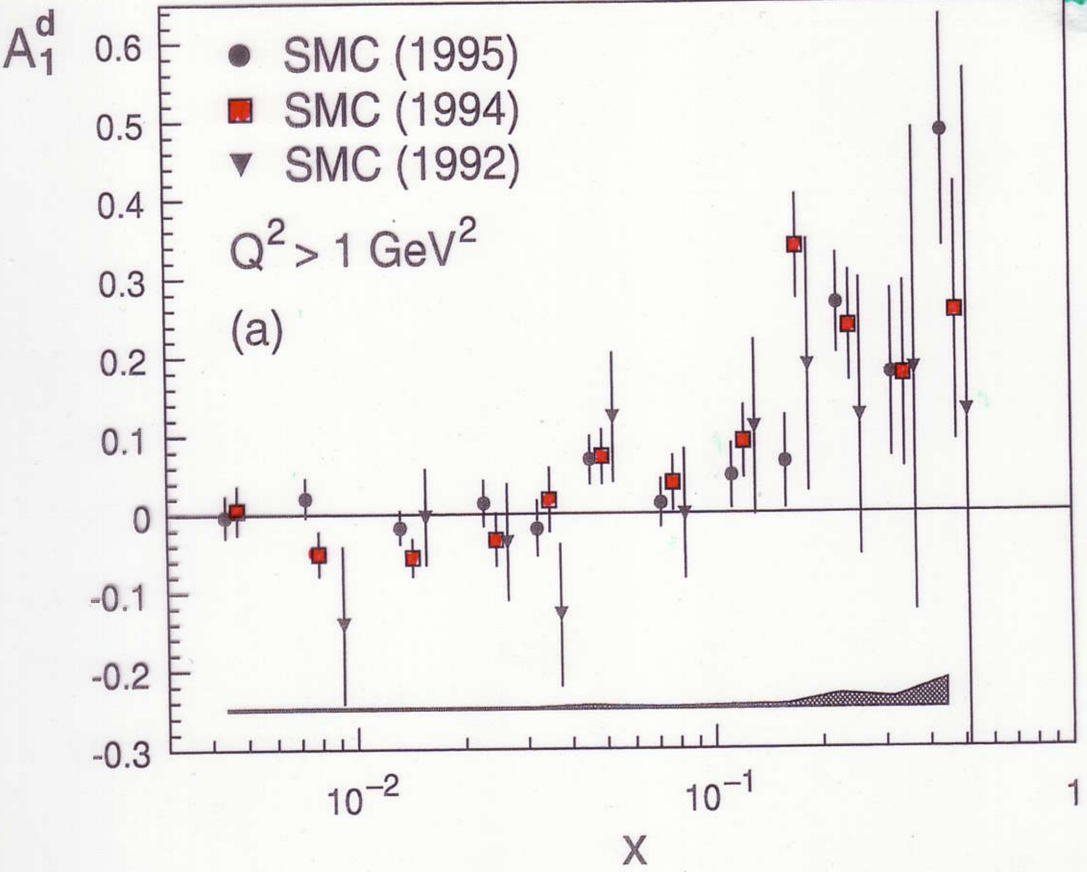
$\Downarrow$

Data at same x $\simeq$ equal for all experiments

A_1^d at low x – Historical aspects

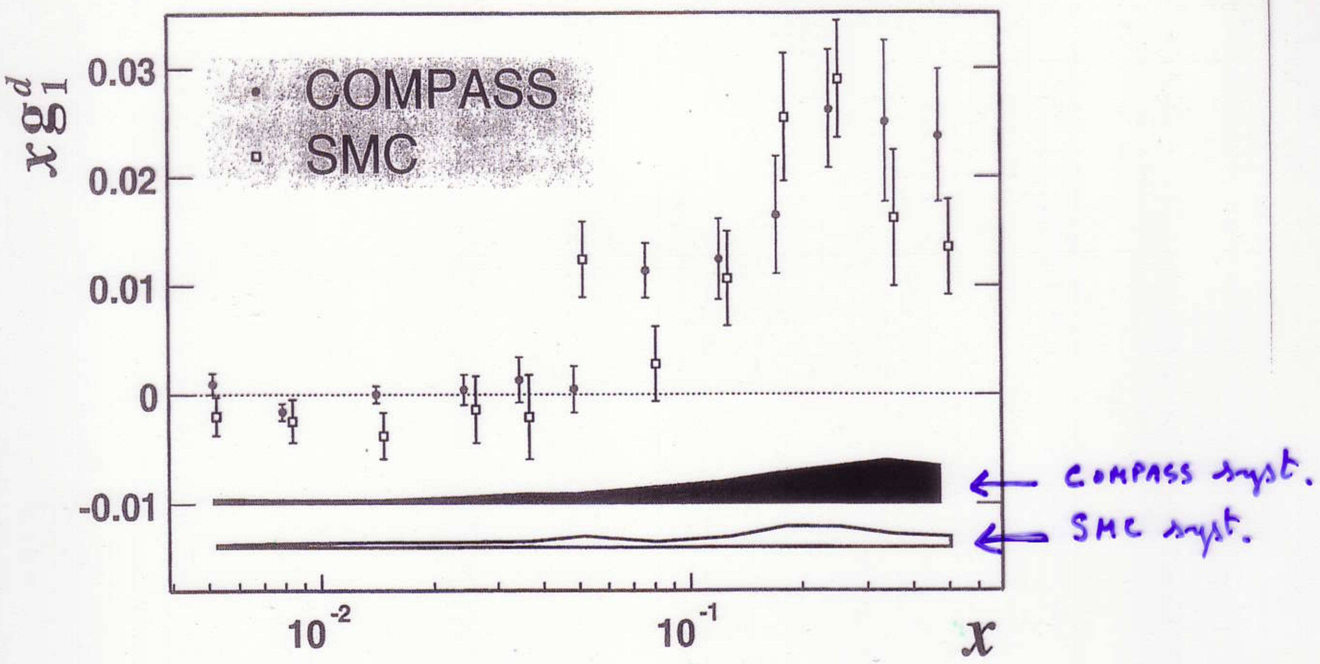
(x < 0.04)

Ph. Lett. B 396 (1997) 338



SMC	1992	2 points < 0	Large errors, E = 100 GeV
	1994	3 points < 0	2.5 σ
	1995 This plot →	{ Reanalysed 94 data	~ 2.5 σ } Merged
		New data	No effect }
		- Combined	~ 1.5 σ ←
	1998	Final analysis	~ 2 σ ($A_1^d < 0$ Not discussed)
Compass	2002-2003	This analysis	No effect

Compass vs. SMC (at Q^2 of COMPASS points)



* $\sigma_{stat.}$(COMPASS) $\lesssim \sigma_{stat}$(SMC)$/2$ for $\boxed{x < 0.06}$

Precision improved at low x

* For $x \geq 0.2$ $\sigma_{stat.}$(COMPASS) $\gtrsim \sigma_{stat.}$(SMC)

(due to incomplete trigger system in 2002)

Γ_1^d (?)

SMC : $\int_{0.003}^{0.7} g_1^d(x, Q_0^2)\,dx \rightarrow \sigma_{stat.} = 0.006$

COMPASS (last bin) : $(0.4 \rightarrow 0.7)$ $\rightarrow \sigma \simeq 0.004$

SUM RULES $\Rightarrow$ $\boxed{\text{Needs 2004 data}}$

QCD fits of world data of $g_1^{p,d,n}$

(with and without COMPASS data)

* **Data sets:** all g_1 data at $Q^2 > 1\ \mathrm{GeV}^2$

$$\left.\begin{array}{ll} \text{SLAC:} & \text{E142 - E143 - E154 - E155} \\ \text{DESY:} & \text{HERMES} \\ \text{JLAB:} & \text{Hall A} \\ \text{CERN:} & \text{EMC - SMC - COMPASS} \end{array}\right\} \underline{\text{200 data points}}$$

* **Fitting program:**

$$\text{(SMC program)}\left\{\begin{array}{l} \underline{\text{NLO}}\ \text{fit} \quad \underline{\overline{\text{MS}}\ \text{scheme}} \\ (x, Q^2)\ \text{space} \end{array}\right.$$

* **PDF's parametrisations:** at $Q_0^2 = 3\ \mathrm{GeV}^2$

$$\left\{\begin{array}{l} \Delta\Sigma = \eta_s N_\Sigma^{-1}(\alpha,\beta,\gamma)\, x^\alpha (1-x)^\beta (1+\gamma x) \\ \Delta G = \eta_g N_g^{-1}(\alpha,\beta)\, x^\alpha (1-x)^\beta \\ \Delta q_{3,8} = \underbrace{K_{3,8}}_{\text{fixed (F, D)}} N_{3,8}^{-1}\, x^\alpha (1-x)^\beta \end{array}\right.$$

Nr. parameters: $4 + 3 + 2 + 2 = \underline{11}$

($\underline{+1}$ floating normalisation for one data set)

* Require $\boxed{|\Delta s(x, Q_0^2)| \le s(x, Q_0^2)}$ Positivity limit

$\uparrow$ $\frac{1}{3}(\Delta\Sigma - \Delta q_8)$

$x \cdot g_1^d(x)$ COMPASS-SMC data vs. fit

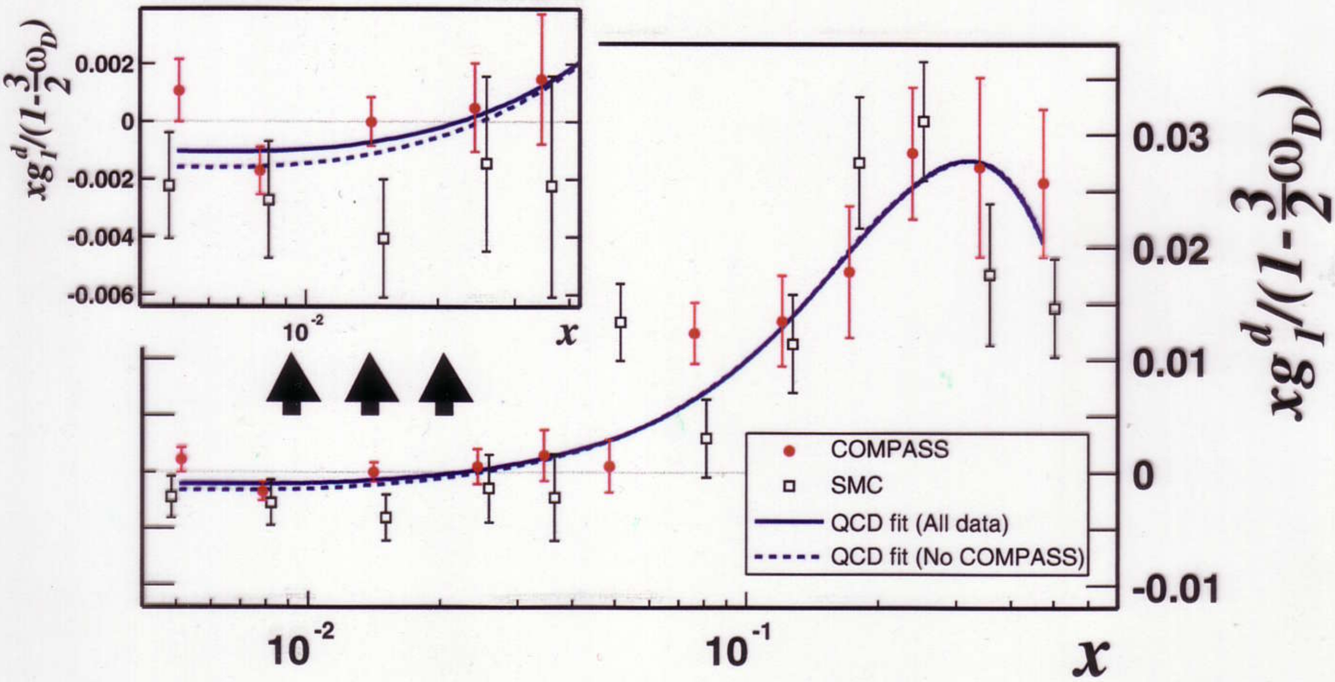


Figure 1: Values of $x \cdot g_1^d(x)$ measured by COMPASS and SMC with the result of fits to world data. The data points are corrected for the deuteron D-wave probability.

$$\int_{0.004}^{0.03} g_1^d(x)\,dx = \begin{cases} (-0.3 \pm 1.0)\ 10^{-3} & \text{COMPASS} \\ (-5.3 \pm 2.3)\ 10^{-3} & \text{SMC} \end{cases}$$

Diff. $\Longrightarrow$ $\boxed{0.0050 \pm 0.0025}$

$$g_1^d \overset{\text{QPM}}{\simeq} 1/9 \left(\Delta\Sigma + \frac{1}{4} \underbrace{\Delta q_8}_{\int \Delta q_8 \text{ fixed}} \right)$$

$\Longrightarrow$ Expect change in $\Delta\Sigma$ w/wo COMPASS $(\simeq 0.045)$

Fit results ($Q^2 = 3$ GeV^2)

①

* $\Delta\Sigma\ (\overline{MS}) = 0.25 \pm 0.02$ (stat.)

  (all g_1 data, including g_1^d from COMPASS)

* $\Delta\Sigma\ (\overline{MS}) = 0.22 \pm 0.03$ (stat.)

  (all g_1 data, except COMPASS)

COMPASS data:
- increase $\Delta\Sigma$ (as expected from g_1^d)
- slight reduction of stat. error

- Statistical errors: Errors on parameters in present fit (1σ)

- Not quoted: systematic effects due to change in parametrisation, ref. Q^2, Nr. parameters ...

- General assumption:

  Parametrisations valid over the range of the data remain valid over the full range of x

  $\Longrightarrow \boxed{\text{MOMENTS}}$

② ΔG at $Q^2 = 3\ \mathrm{GeV}^2$ from NLO fit in $\overline{MS}$ scheme

$$\Delta G = 0.4 \pm 0.2\ (\text{stat.}) \pm ?\ (\text{syst.})$$

- Statistical error = 1σ from present fit
  (3 param. in ΔG(x))
- Systematic error (under study)
  - parametrisation, ref^ce Q^2
  - different fitting programs (moments, (x, Q^2))
  - $\overline{MS}$ vs. other schemes
  - ⋮

Validity of parametrisation outside range of data?

Another approach: direct measurement from high-pt events

NEXT TALK

(by Yann Bedfer)

COMPASS hi-pt

$$\Delta G / G = 0.024 \pm \underline{0.089}\ (\text{stat.}) \pm 0.057\ (\text{syst.})$$

$(0.065 \leq x_g \leq 0.175,\ Q^2 \simeq 3\ \mathrm{GeV}^2)$

↑

(G ≈ 12-13)

2 complementary approaches to ΔG

QCD fits	**High-pt events**
World data on g_1 (200 points, 12 from COMPASS	COMPASS Hadron events
DIS	$Q^2 < 1$ GeV^2
Needs input param^{ns} of Polarised p.d.f's	Large contribution of resolved γ's
Indirect access to ΔG through Q^2 evolution of g_1	Direct access to ΔG in PGF events
NLO analysis	LO analysis
More sensitive to $\int \Delta G$ than to detailed shape	Access to ΔG in limited range of x
Needs control of systematics	Needs precision

$\Downarrow$ $\Downarrow$

2 results on
$\Delta G(0.095, Q^2 \approx 3)$

Very good agreement