Spin structure functions of deuteron from COMPASS

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

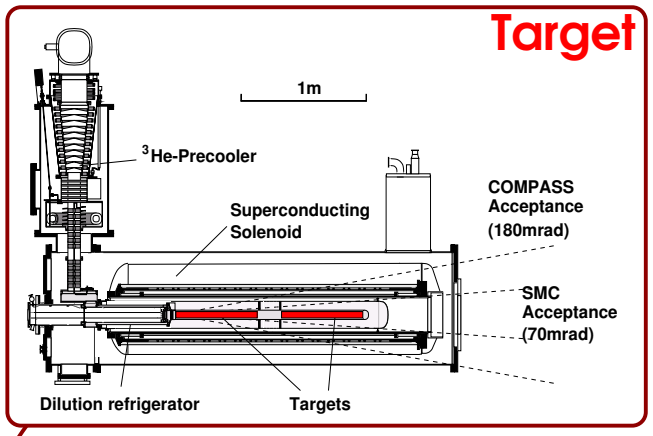
$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$

[a] on leave from JINR, Dubna

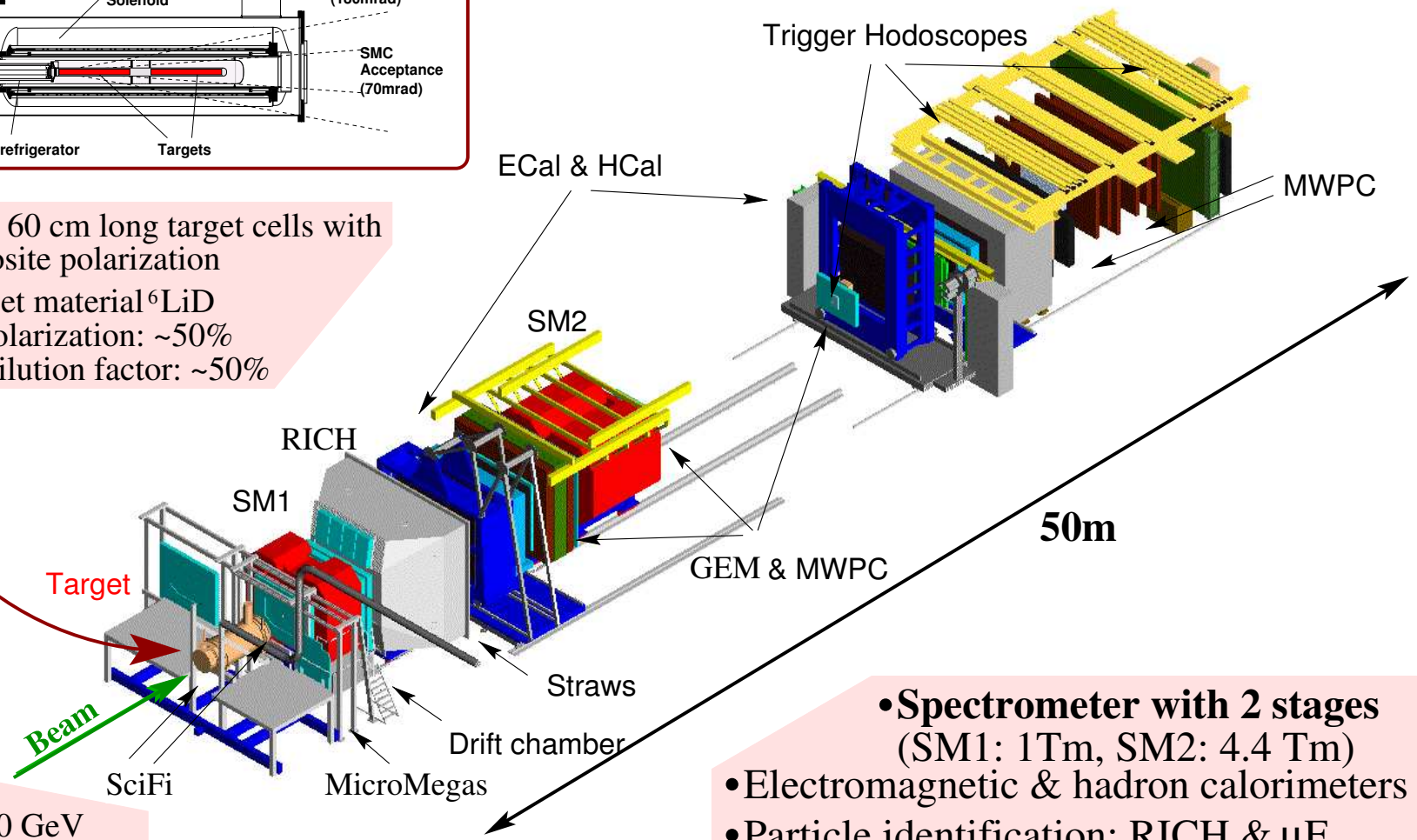
Overview

- COMPASS experiment
- Inclusive asymmetry A_1^d and structure function g_1^d
- Asymmetry extraction procedure & results
- QCD analysis to world data
- Summary and outlook

Spectrometer



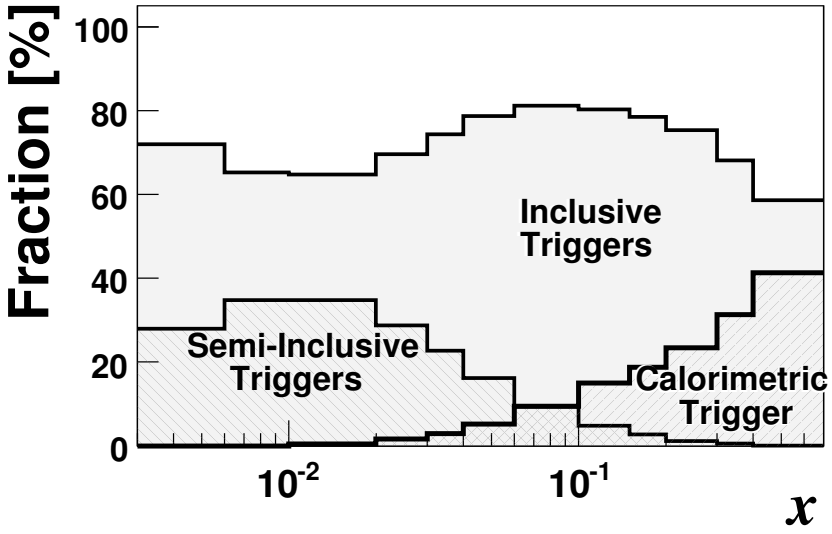
- Two 60 cm long target cells with opposite polarization
- Target material ^{6}LiD
  - Polarization: ~50%
  - Dilution factor: ~50%

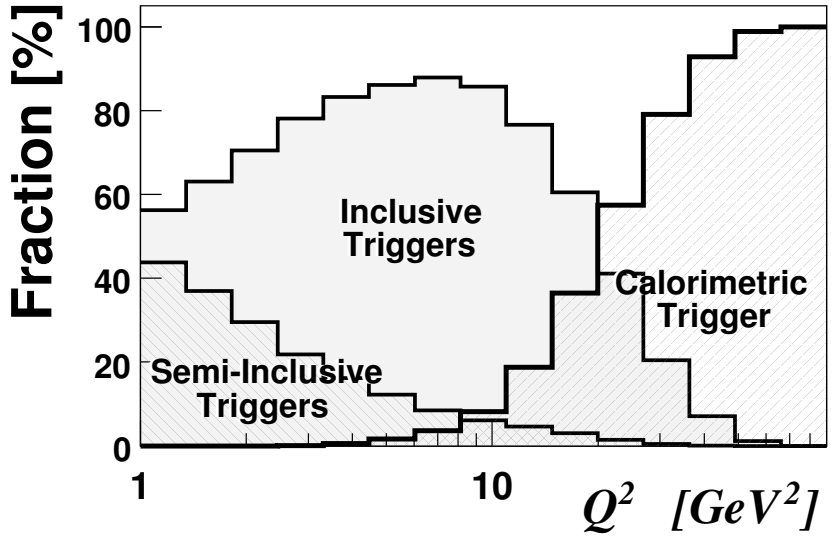


- μ–beam
  - Energy: 160 GeV
  - Intensity: $2 \cdot 10^8$ μ/spill
  - Polarization: −76%

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

Triggers



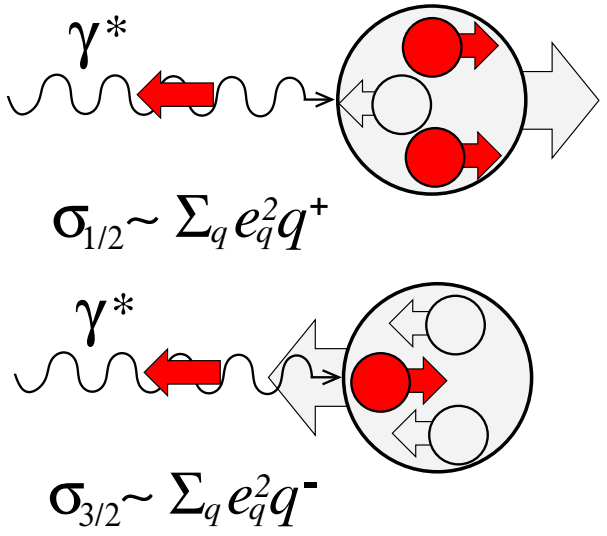


- Inclusive triggers (μ')
- Hadronic triggers
  - Semi-Inclusive triggers (μ'+2MIP)
  - Calorimetric trigger (9MIP)

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

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

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

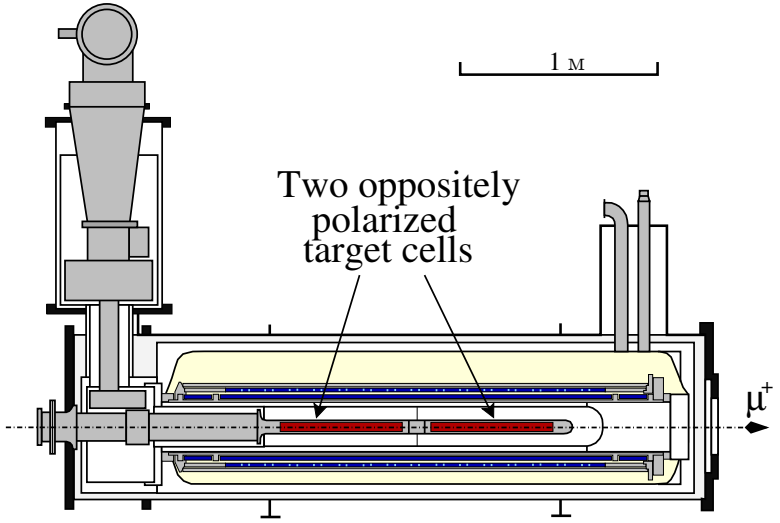
- $|\eta A_2| \ll |A_1|$

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

Data Analysis

- Statistics: $88 \cdot 10^6$ events (2002+03+04)
- Kinematic region:

$$Q^2 > 1\,\mathrm{GeV}^2$$
$$0.004 < x < 0.7$$
$$0.1 < y < 0.9$$

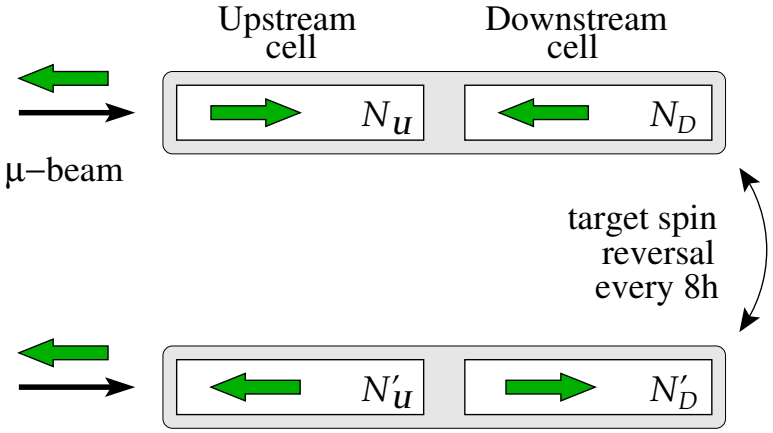


- Extraction of virtual-photon deuteron asymmetry

$$A_1^{1\gamma} = \frac{1}{fDP_bP_t}A^{raw} - \left(\frac{\eta A_2}{\rho} + A_1^{RC}\right)$$

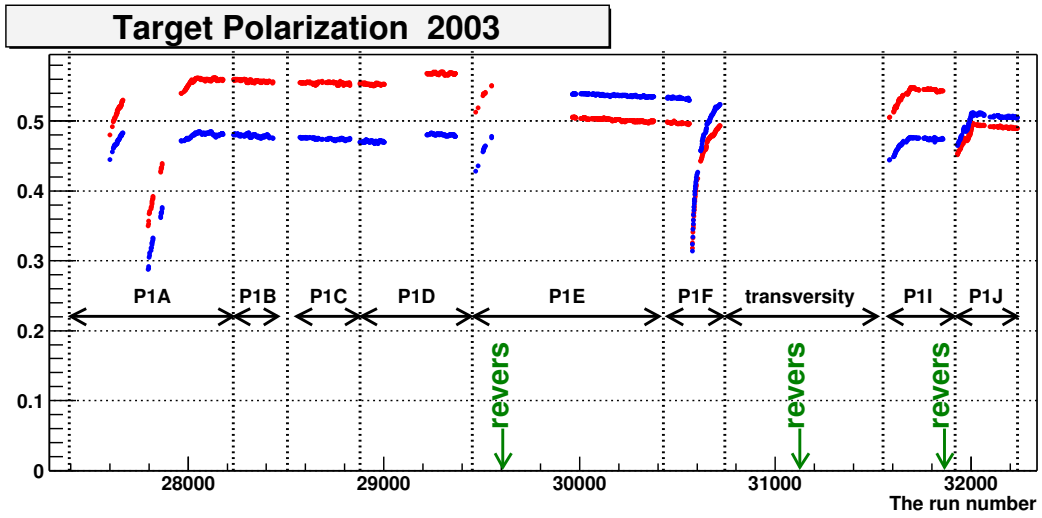
- Raw counting-rate asymmetry:

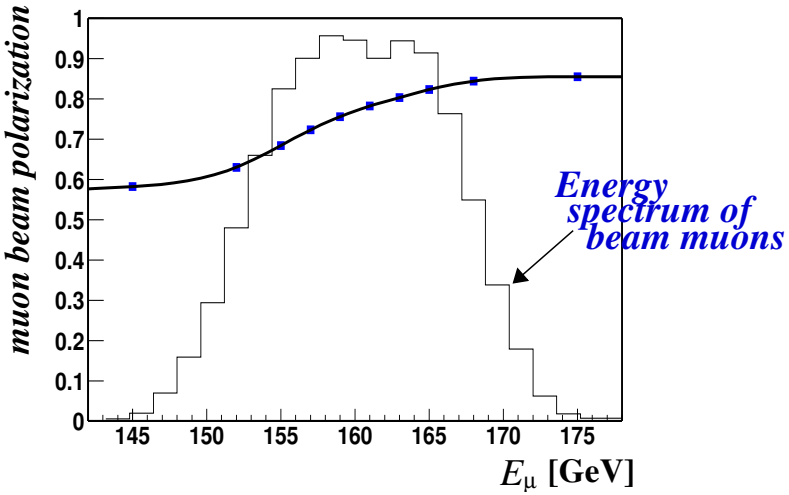
$$A^{raw} = \frac{N_u - N_d}{N_u + N_d}$$



Target polarization

- After 5 days of build-up time: $+0.53$ and -0.50
- Average polarization over 2 years is 0.5
- Measurement by NMR coils with relative precision of 5%





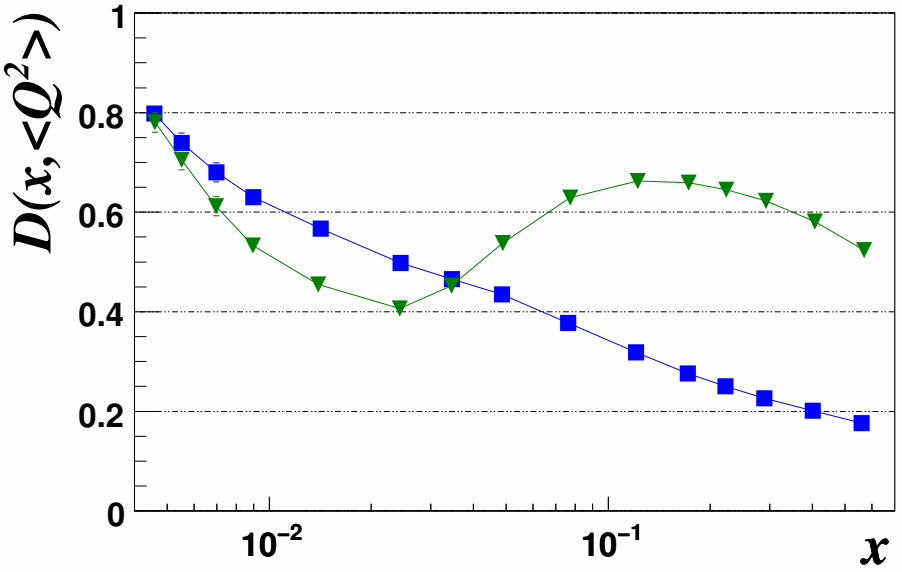
Beam polarization

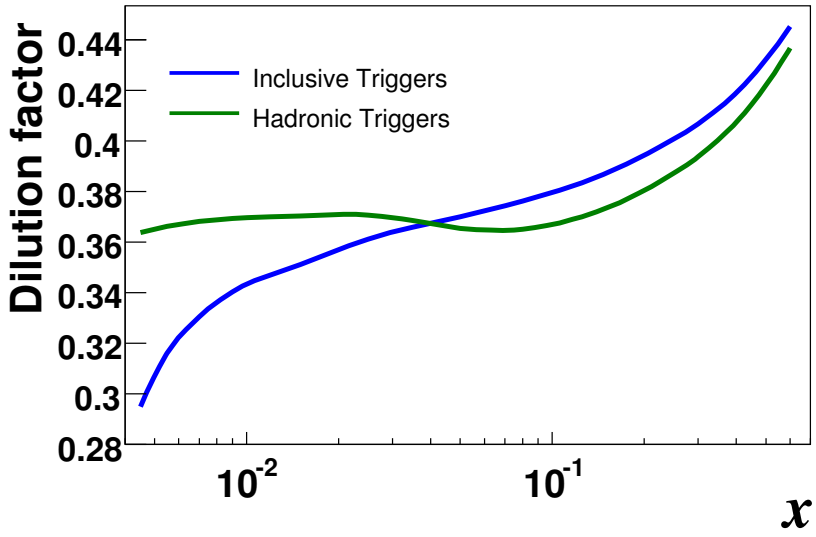
- MC simulation of the beam line
- Energy range: $[140, 180]$ GeV
- Systematic uncertainty is 0.04
- Average polarization is 0.8

Depolarization Factor

- it accounts for polarization transfer from μ to virtual photon

$$D \simeq \frac{y(2-y)}{y^2 + 2(1+R)(1-y)}$$





Dilution Factor

$$f = \frac{n_D \bar{\sigma}_D}{n_D \bar{\sigma}_D + \sum_A (n_A \bar{\sigma}_A)} \cdot \frac{\bar{\sigma}^{1\gamma}}{\bar{\sigma}}$$

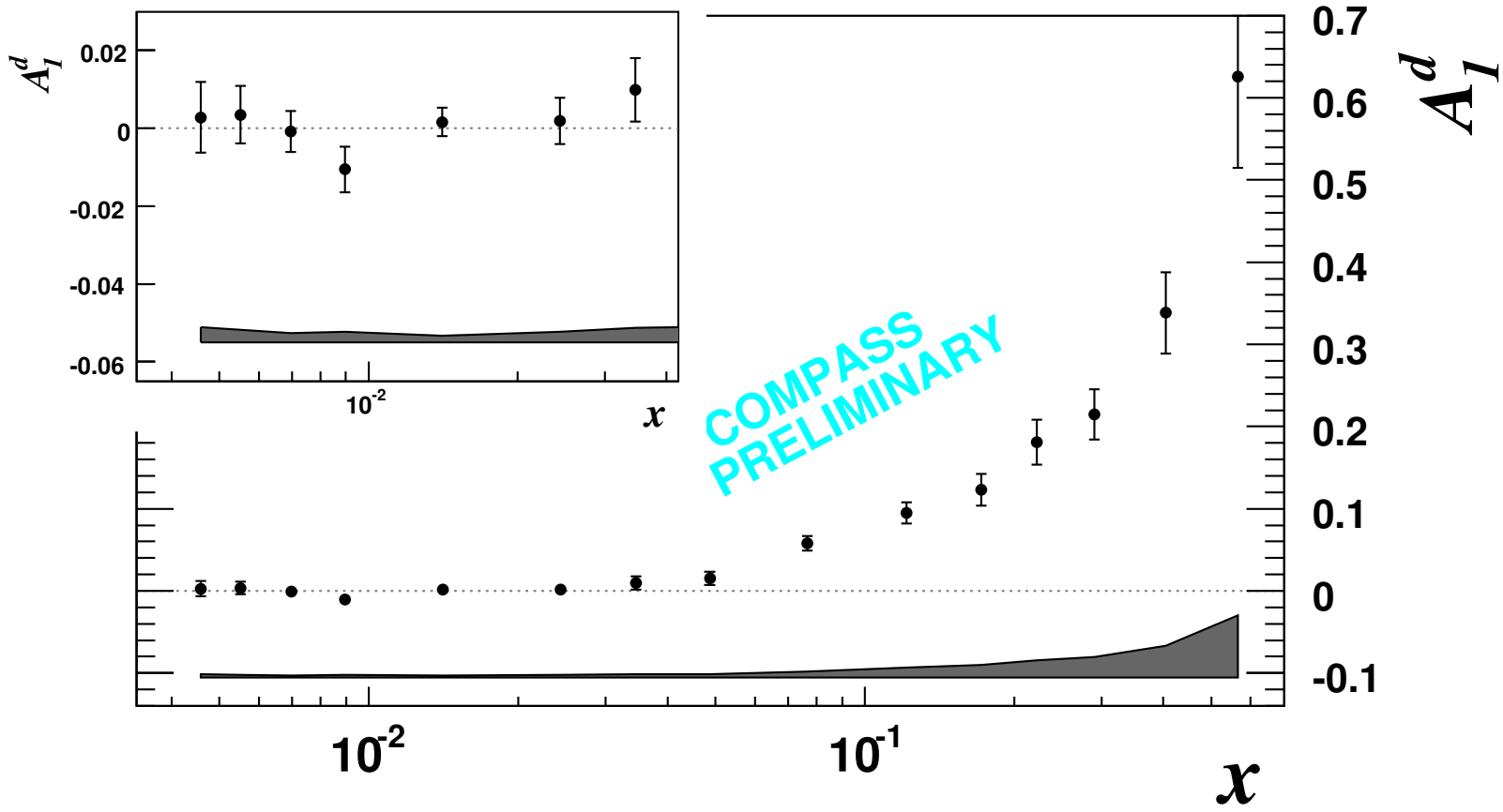
- Fraction of polarized material
- Radiative corrections

Systematic error

$$A_1^{1\gamma} = \frac{1}{fDP_bP_t}A^{raw} - \left(\frac{\eta A_2}{\rho} + A_1^{RC} + A_{false}\right)$$

Multiplicative variables error, ΔA_1^{mult}	Beam polarization	dP_b/P_b	$0.04/0.8 = 5.0\%$
	Target polarization	dP_t/P_t	5%
	Depolariz. factor	dD/D	$2.0 - 3.0$ %
	Dilution factor	df/f	$5.7 - 6.0$ %
	Total		$\Delta A_1^{mult} \simeq 0.1 A_1$
Additive variables error, ΔA_1^{add}	Transverse asymm.	$\eta/\rho \cdot \Delta A_2$	$10^{-4} - 5 \cdot 10^{-3}$
	Rad. corrections	ΔA_1^{RC}	$0.1 \cdot \lvert A_1^{RC}\rvert = 10^{-4} - 10^{-3}$
	False asymmetry	A_{false}	$< 0.42 \cdot \Delta A_1^{stat}$
	x-smearing		$< 0.8 \cdot 10^{-3}$
	Hadron ev. bias		$< 0.5 \cdot 10^{-3}$

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 3.5
- Results show no tendency toward negative values at $x < 0.03$

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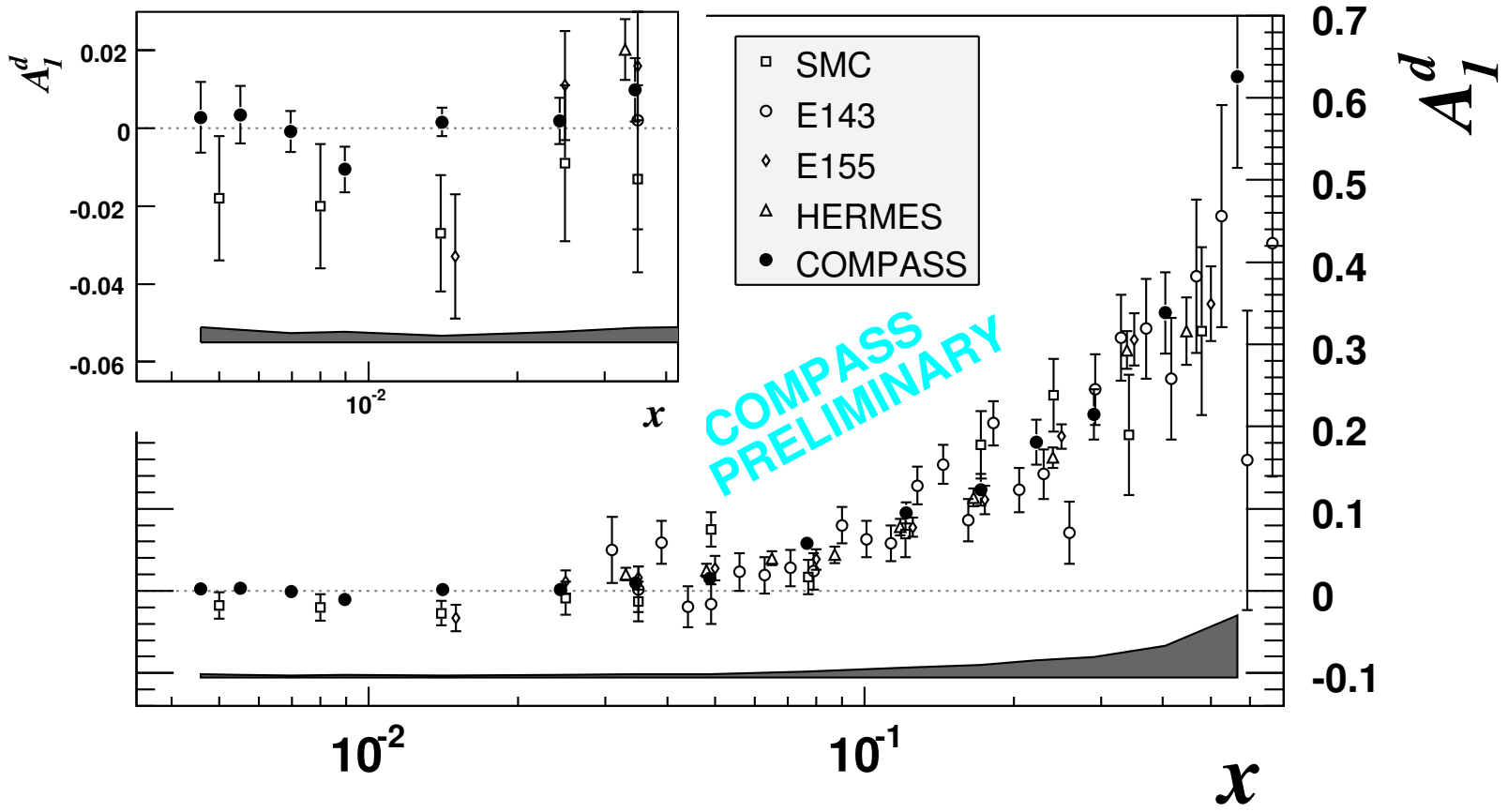

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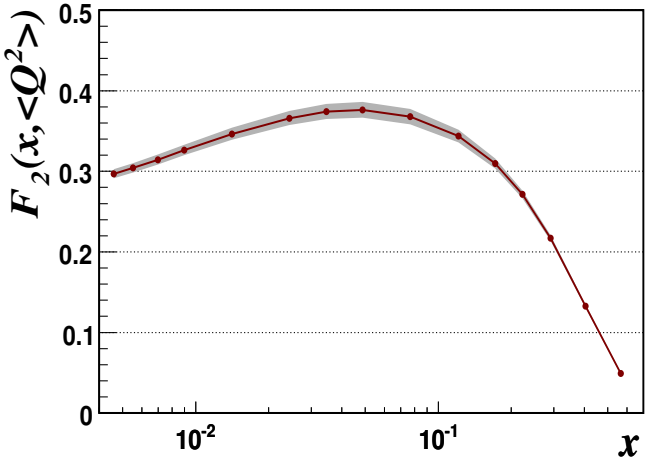
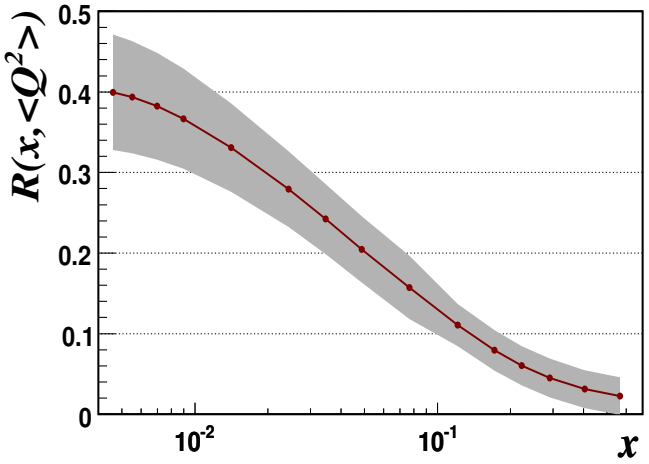
Results on Structure Function g_1^d

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





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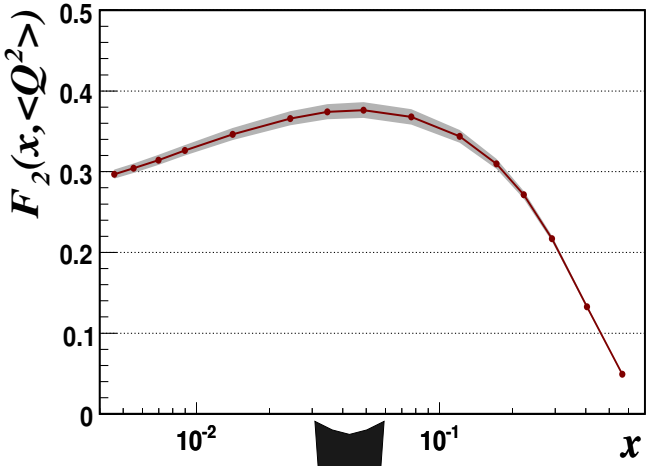
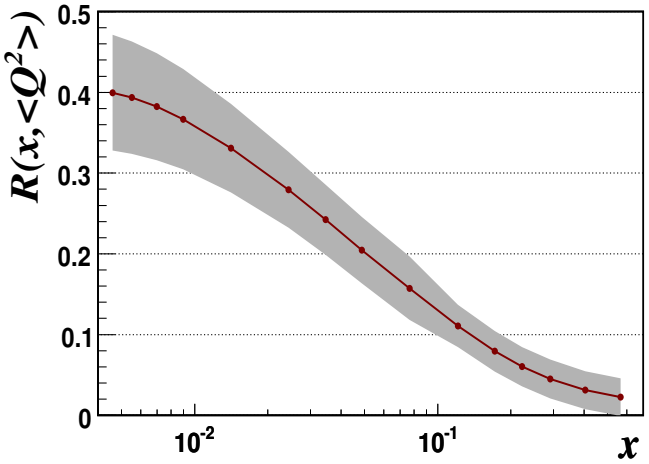
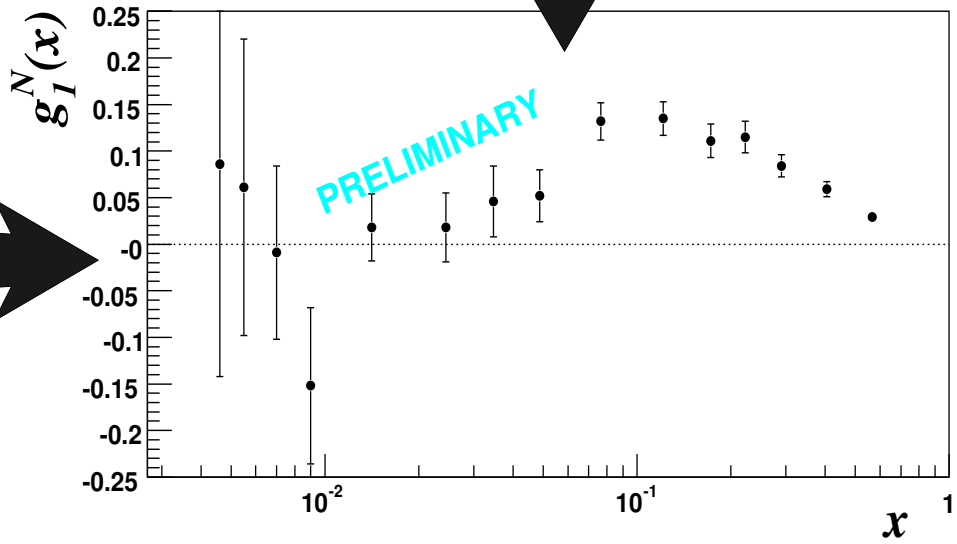
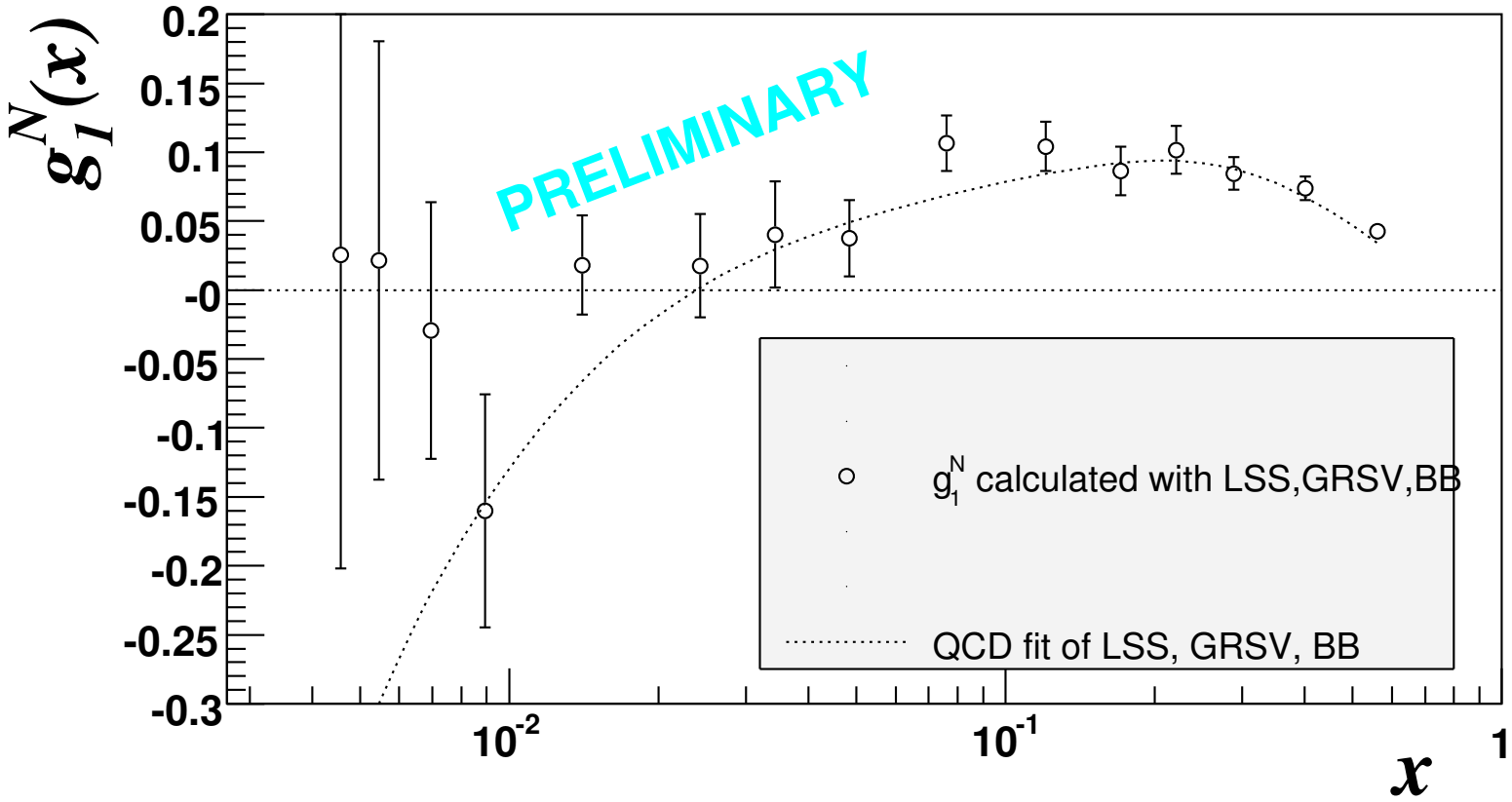




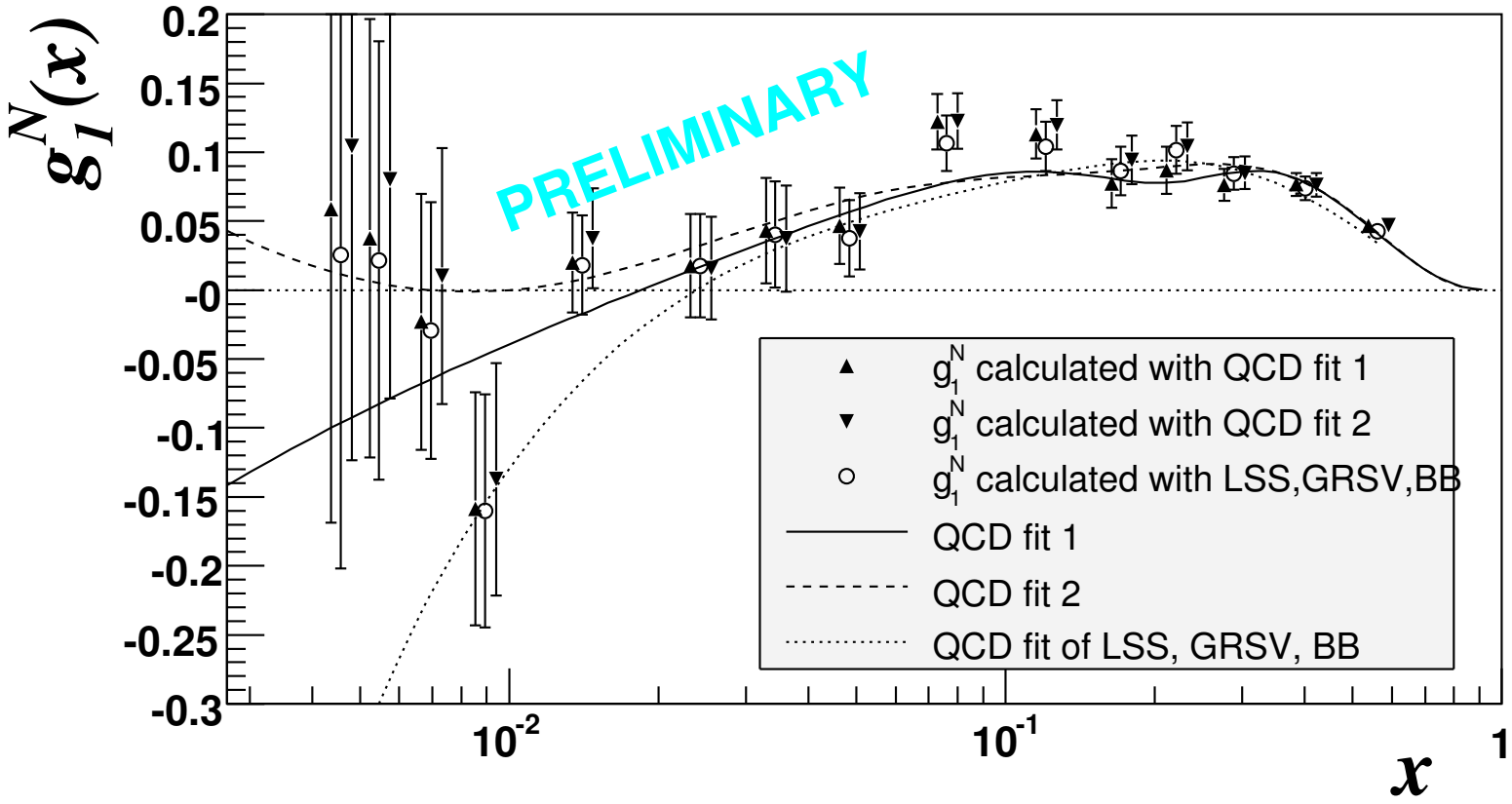


QCD analysis of g_1^d



- QCD fit allows to evolve g_1^d to a fixed Q^2 ($Q^2 = 3\,\mathrm{GeV}^2$)
- Parameterizations of the polarized pdf's (Blumlein and Bottcher, GRSV and LSS05) are in disagreement with data at low x

QCD analysis of g_1^d



- Program "2" in SMC notation (B. Adeva *et al.*, Phys. Rev. D **58** (1998) 112002)
- Numerical calculation in NLO ($\overline{MS}$ scheme)
- World data fit

- The first moment of g_1^d

$$\Gamma_1^N(Q^2{=}3\mathrm{GeV}^2) \;=\; 0.0502 \pm 0.0028(stat) \pm 0.0020(evol) \pm 0.0051(syst)$$

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

$$\Gamma_1^N(Q^2) \;=\; \frac{1}{9}\, C_1^S(Q^2)\; a_0 \;+\; \frac{1}{36}\, C_1^{NS}(Q^2)\; a_8$$

- Coefficient functions (S.A.Larin *et all*, Phys.Lett.B404 (1997) 153):

$$C_1^S(Q^2) = 1 - 0.33333\left(\frac{\alpha_s}{\pi}\right) - 0.54959\left(\frac{\alpha_s}{\pi}\right)^2 - 4.44725\left(\frac{\alpha_s}{\pi}\right)^3$$

$$C_1^{NS}(Q^2) = 1 - \left(\frac{\alpha_s}{\pi}\right) - 0.35833\left(\frac{\alpha_s}{\pi}\right)^2 - 20.2153\left(\frac{\alpha_s}{\pi}\right)^3$$

- Can be found in literature:

$$a_8 = 0.585 \pm 0.025 \qquad \left.\frac{\alpha_s}{\pi}\right|_{Q^2=3\,\mathrm{GeV}^2} = 0.084,$$

- With the $\Gamma_1^N(Q^2{=}3\mathrm{GeV}^2)$ we can get the quark polatization $\Delta\Sigma$:

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

Summary

- Analysis of COMPASS data 2002, 2003 and 2004
- New measurement of A_1^d and g_1^d in DIS region ($Q^2{>}1\,\mathrm{GeV}^2$, $0.004{<}x{<}0.7$)
  - ◇ Good agreement with results of previous experiments (middle x)
  - ◇ Improvement in statistical precision factor 3.5 in region $x < 0.03$
  - ◇ No tendency toward negative values at $x < 0.03$
- QCD analyzes need to be revised

Outlook

- Further increase in statistics with 2006 data
- Hadron asymmetries $A_1^{\pi\pm}$, $A_1^{K\pm}$, $A_1^{K^0_S}$ are coming
- A_1^d at low x and low Q^2