Helicity quark distributions from DIS and SIDIS measured in COMPASS

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On behalf of the COMPASS collaboration

XVI International Workshop on Deep-Inelastic Scattering and Related Subjects

London, April 7-11, 2008

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

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

[a] on leave from JINR, Dubna

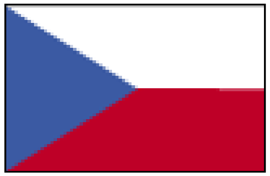
Overview

- COMPASS experiment
- Inclusive asymmetry A_1^d and structure function g_1^d

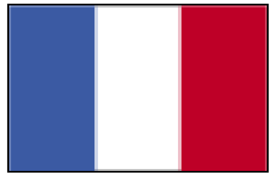
  `V.Yu.Alexakhin et al., PLB 647 (2007) 8-17; PLB 647 (2007) 330-340.`
- Valence quark distributions from hadron asymmetry $A_d^{h^+-h^-}$

  `M.Alekseev et al., PLB 660 (2008) 458-465.`
- Projection of the statistical precision for the data collected on ^{6}LiD target in 2006 and on NH_3 target in 2007
- Summary and outlook

More than 240 physicists from 29 institutes



Prague(CU,CUT, TUL)

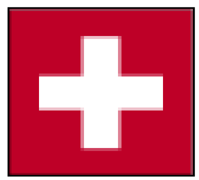


Saclay

Bielefeld
Bochum
Bonn(ISKP&PI)
Erlangen
Freiburg
Heidelberg
Mainz
Munchen(LMU,TU

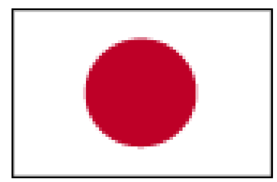
Burdwan
Calcutta

TelAviv



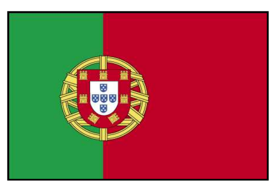
CERN

Torino
(University & INFN)
Trieste
(University & INFN)



Yamagata

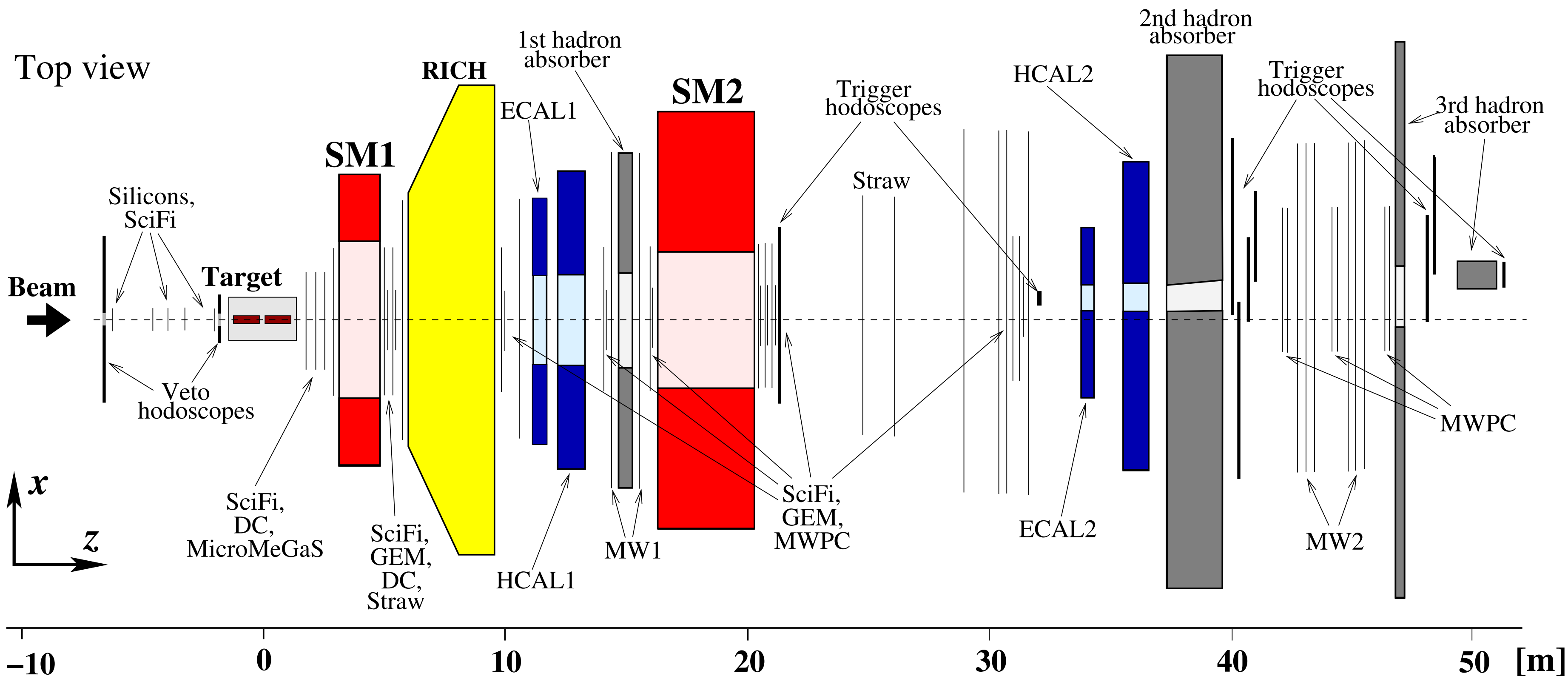
Warsaw
(SINS, TU,
& WU)



Lisbon

Dubna
Moscow(INR,LPI,
State University)
Protvino

Experimental setup



- Polarized beam μ^+ (-80%), E_b=160 GeV
- 2/3 cells polarized target ^{6}LiD (50%) and NH_3 (90%)
- Two stages spectrometer
- Tracking detectors of different types
- Identification: HCALs, ECALs, RICH, muon walls

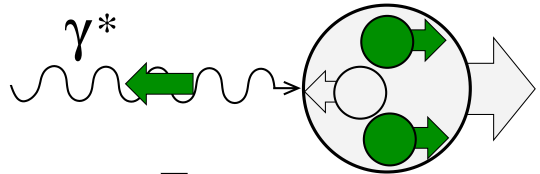
Inclusive asymmetry A_1^d

& structure function g_1^d

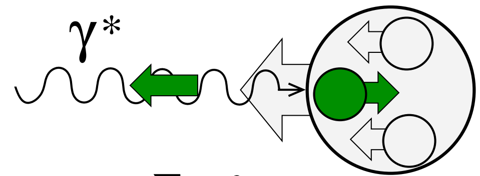
Deep-inelastic scattering

- Quark densities in QPM:

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



$\sigma_{1/2} \sim \Sigma_q e_q^2 q^+$



$\sigma_{3/2} \sim \Sigma_q e_q^2 q^-$

- Longitudinal double-spin asymmetry: $A^{\gamma N} \equiv A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{\sum_q e_q^2 \Delta q}{\sum_q e_q^2 q}$

- Spin (in)dependent cross-sections:

$$\sigma = \bar{\sigma} \pm \Delta\sigma$$

- Structure functions $F_{1,2}$ and $g_{1,2}$

$$\bar{\sigma}(x, Q^2) = aF_1(x, Q^2) + bF_2(x, Q^2)$$
$$\Delta\sigma(x, Q^2) = \alpha g_1(x, Q^2) + \beta g_2(x, Q^2)$$

- Longitudinal spin asymmetry μN:

$$A^{\mu N} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} = \frac{\Delta\sigma}{\bar{\sigma}} \simeq DA_1$$

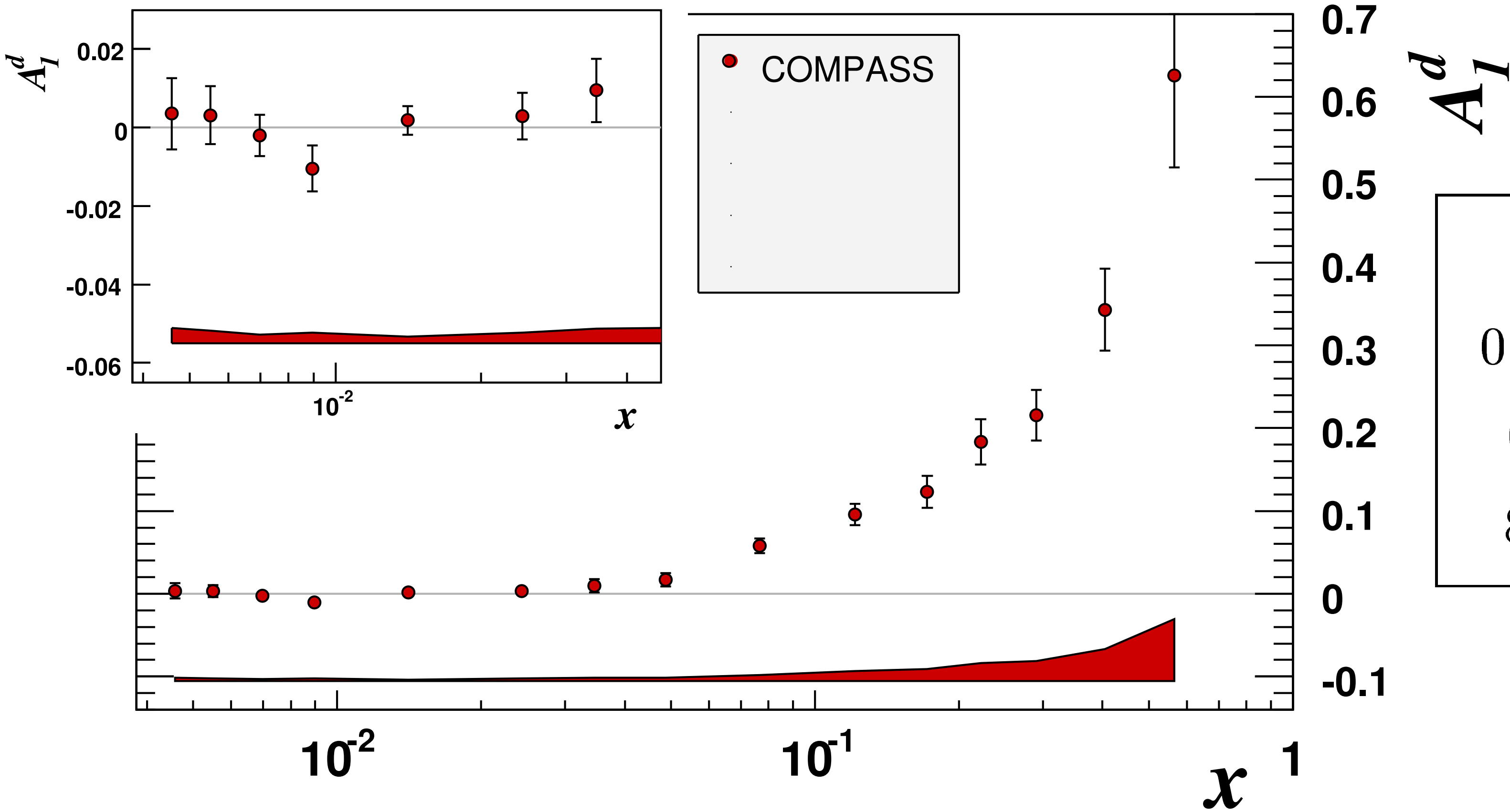
D – depolarization factor of γ

- Structure functions & quark distributions:

$$F_1 = \frac{1}{2}\sum_q e_q^2\,(q + \bar{q}), \quad g_1 = \frac{1}{2}\sum_q e_q^2\,(\Delta q + \Delta\bar{q})$$

- Asymmetry A_1 gives access to g_1: $g_1 \simeq A_1 \cdot F_1$

Results on Inclusive Asymmetry A_1^d



$Q^2 > 1\,\mathrm{GeV}^2$

$0.004 < x < 0.7$

$0.1 < y < 0.9$

$88 \cdot 10^6$events

- Good agreement in the region $x > 0.03$
- For $x < 0.03$ statistical error is reduced by factor 4
- Results show no tendency toward negative values at $x < 0.03$

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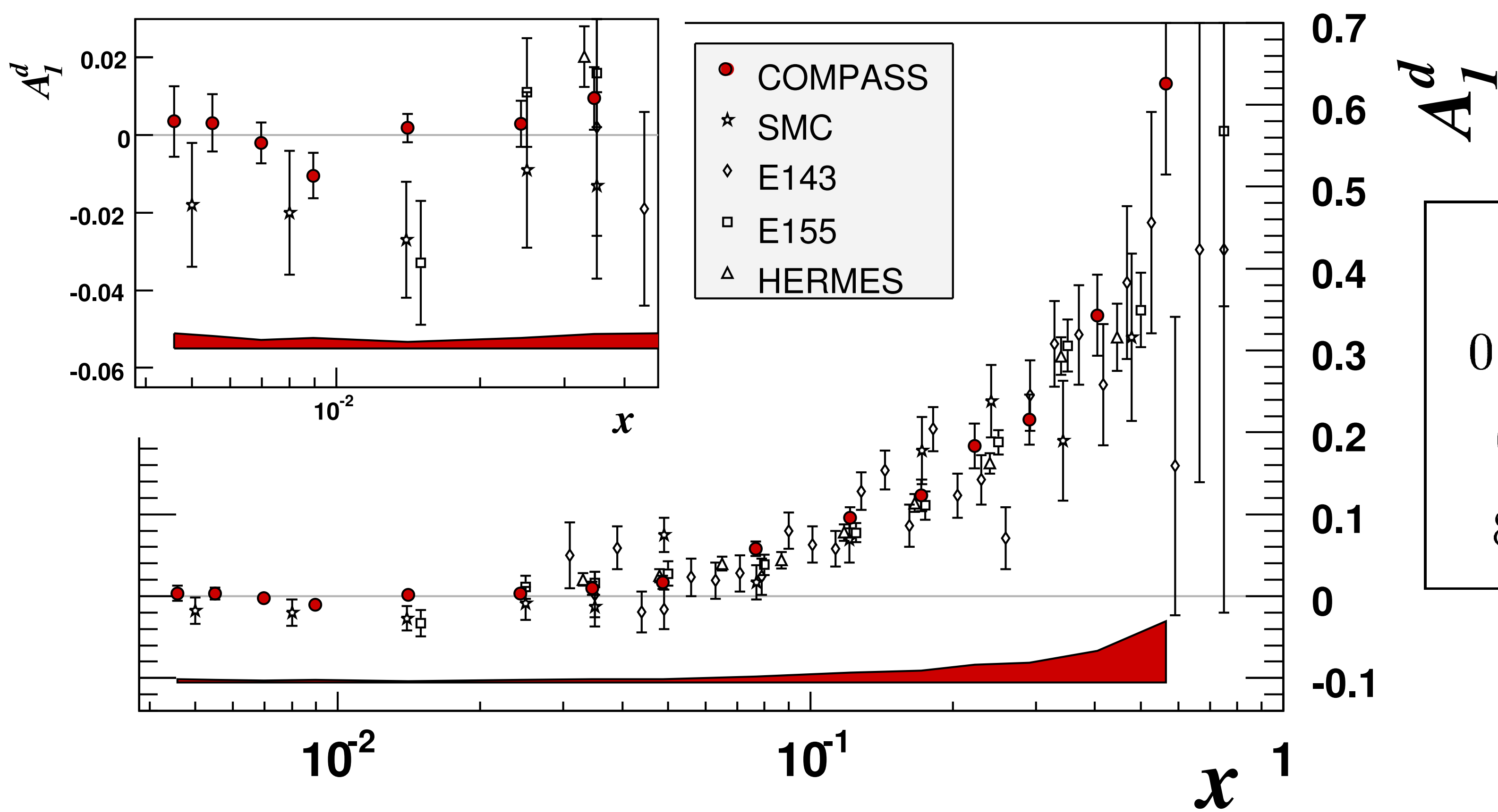

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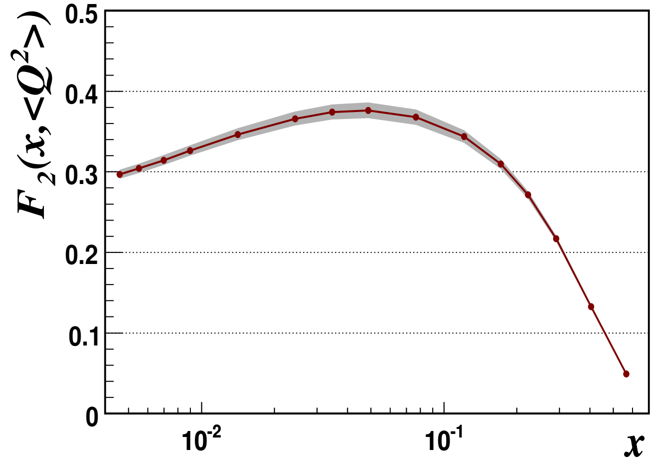
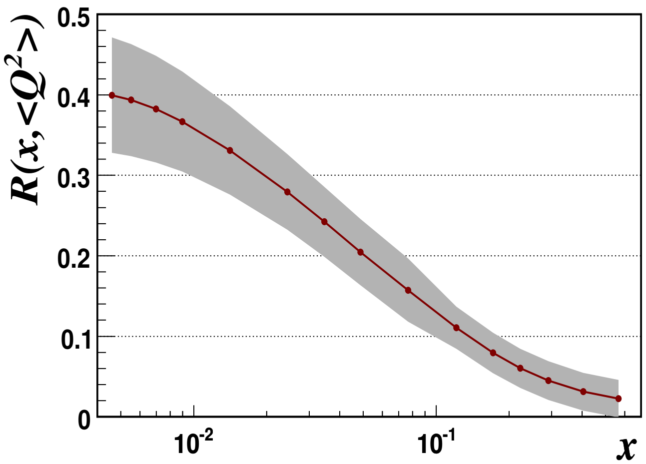
Results on Structure Function g_1^d

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





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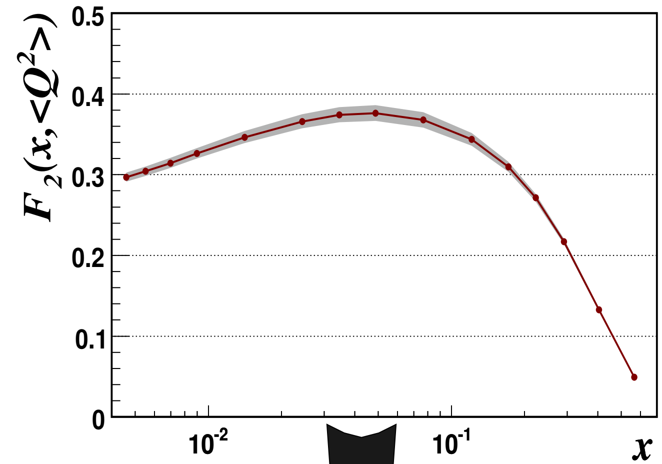
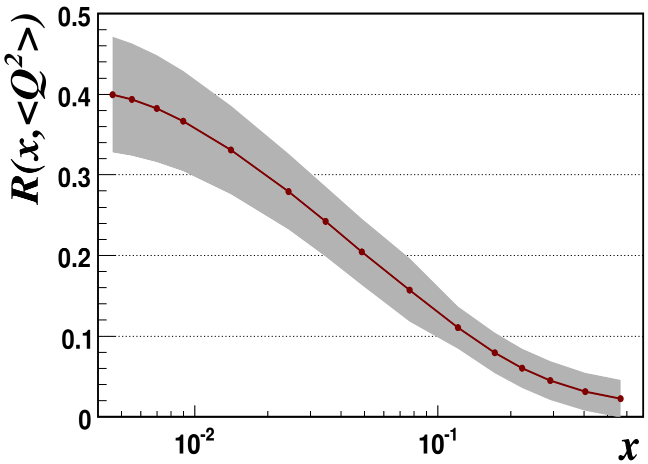
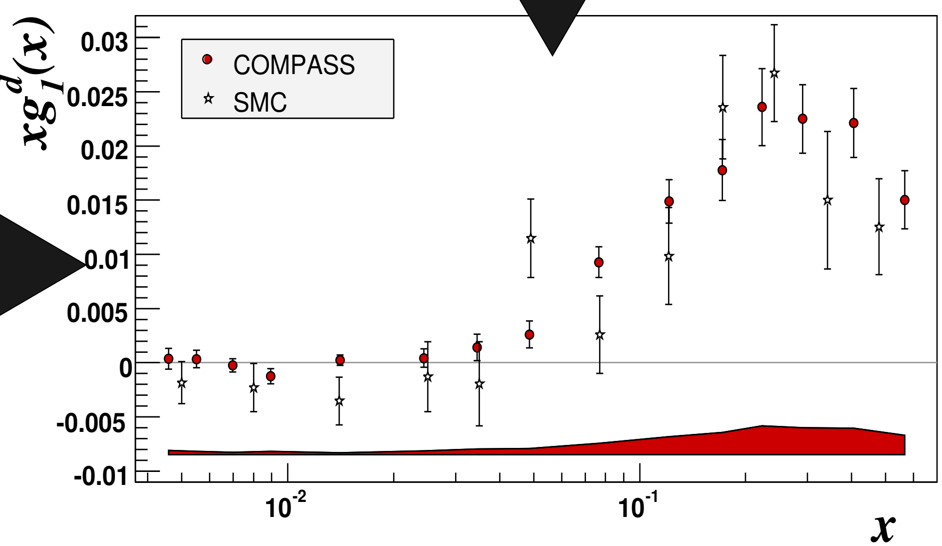






NLO QCD analysis

- Measured structure functions $g_1^{p,d,n}$ (different x, Q^2)

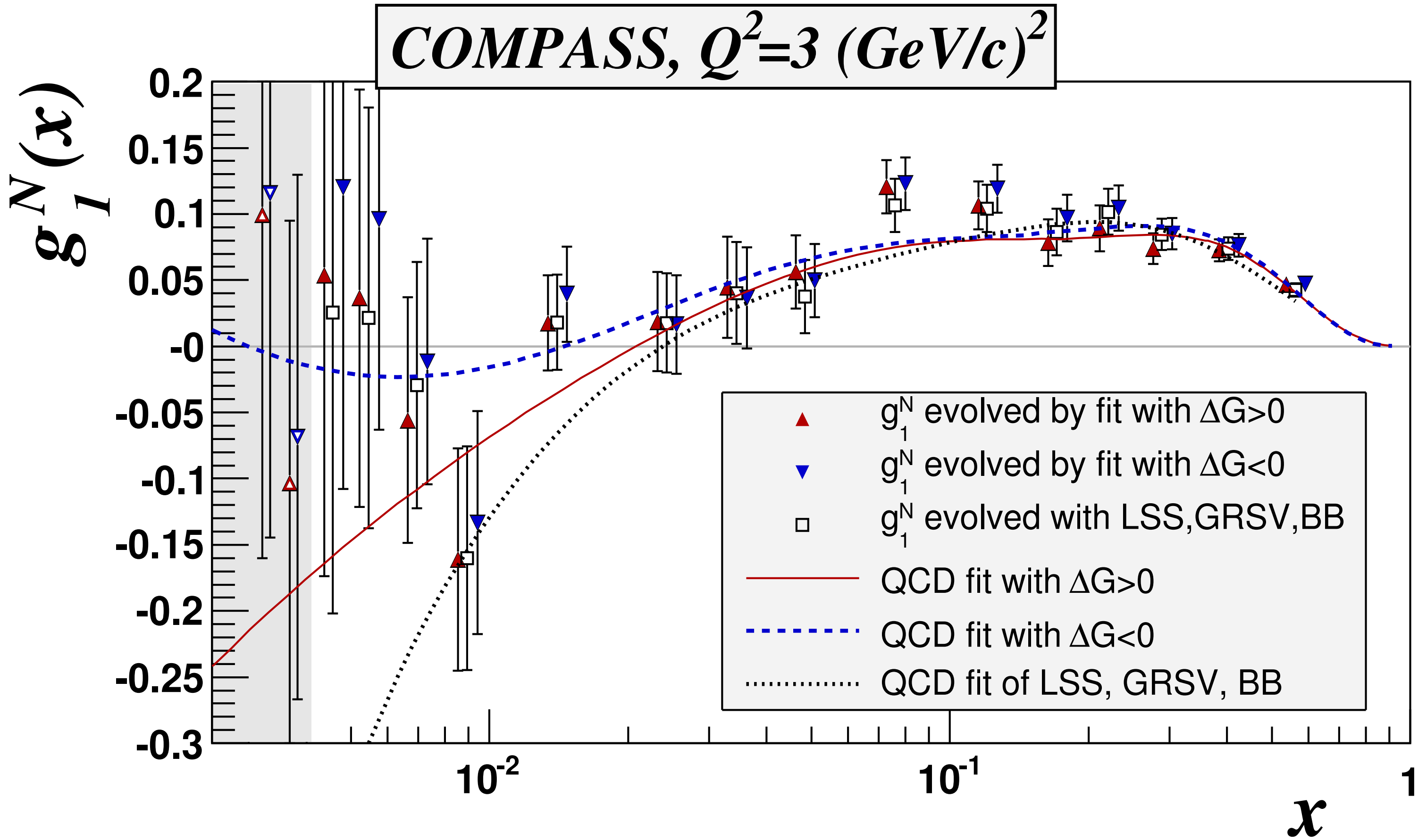
$$g_1(x,Q^2) = \frac{1}{2}\langle e^2\rangle \left[C_q^S \otimes \Delta\Sigma + C_q^{NS} \otimes \Delta q^{NS} + 2n_f\, C_G \otimes \Delta G\right]$$

- Two programs have been used:
  1. Numerical integration in (x, Q^2) space (Phys.Rev.D58(1998)112002)
  2. Solution of DGLAP in space of moments (Phys.Rev.D70(2004)074032)
- NLO calculation in $\overline{MS}$ scheme
- Initial parametrization (x-dependence at fixed Q^2)

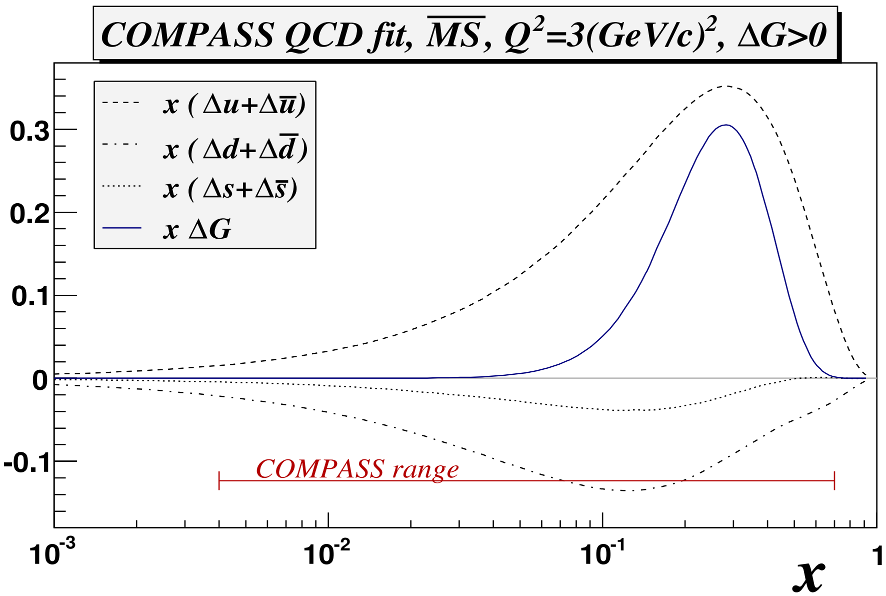
$$\Delta\Sigma = \eta\,\frac{x^\alpha(1-x)^\beta(1+\gamma x)}{\int_0^1 x^\alpha(1-x)^\beta(1+\gamma x)dx}, \qquad (\Delta q_3, \Delta q_8, \Delta G) = \eta\,\frac{x^\alpha(1-x)^\beta}{\int_0^1 x^\alpha(1-x)^\beta dx}$$

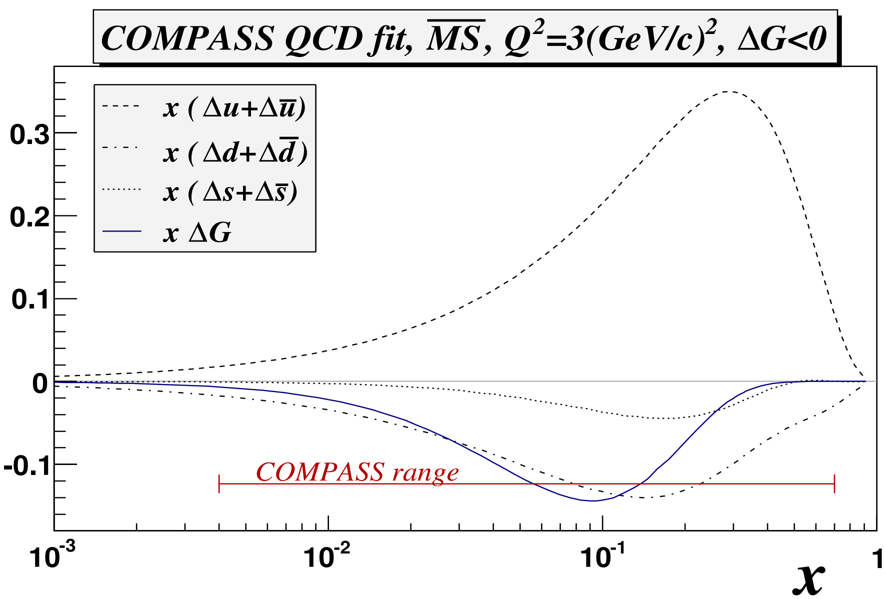
- World data fit: 9 experiments, 230 experimental points
- 2 solutions have been found which describe data equally well and correspond to $\Delta G > 0$ and $\Delta G < 0$

Comparison with published fits ($Q^2 = 3\,\mathrm{GeV}^2$)



- Disagreement of data with previous QCD fits (BB, GRSV, LSS05) at low x
- Updated fits after COMPASS publication: LSS07, DSSV08





- Quark distributions are quite similar for two solutions
- No significant difference between results of two QCD-fit programs and the difference for two solutions ($\eta_G >$ 0 and < 0) is also very small

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

- Indirect determination the gluon function (via evolution equations)
- Solutions with $\eta_G > 0$: $\eta_G^{prog\,1} = 0.26 \begin{smallmatrix} +\ 0.04 \\ -\ 0.06 \end{smallmatrix}$, $\eta_G^{prog\,2} = 0.19 \begin{smallmatrix} +\ 0.01 \\ -\ 0.10 \end{smallmatrix}$
- Solutions with $\eta_G < 0$: $\eta_G^{prog\,1} = -0.31 \begin{smallmatrix} +\ 0.1 \\ -\ 0.1 \end{smallmatrix}$, $\eta_G^{prog\,2} = -0.18 \begin{smallmatrix} +\ 0.04 \\ -\ 0.03 \end{smallmatrix}$

$$|\eta_G| \simeq 0.2 - 0.3$$

Quark polarization with COMPASS data only

- The first moment of g_1^d at $Q^2 = 3\,\mathrm{GeV}^2$:

$$\Gamma_1^N = \int_0^1 g_1^N(x, Q^2)dx = 0.0502 \pm 0.0028(stat) \pm 0.0020(evol) \pm 0.0051(syst)$$

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

$$\Gamma_1^N(Q^2)\Big|_{NLO} = \frac{1}{9}\left(1 - \frac{\alpha_s(Q^2)}{\pi} + \mathcal{O}(\alpha_s^2)\right) \times \left(a_0(Q^2) + \frac{1}{4}a_8\right)$$

- From hyperon β decays assuming $SU(3)_f$:

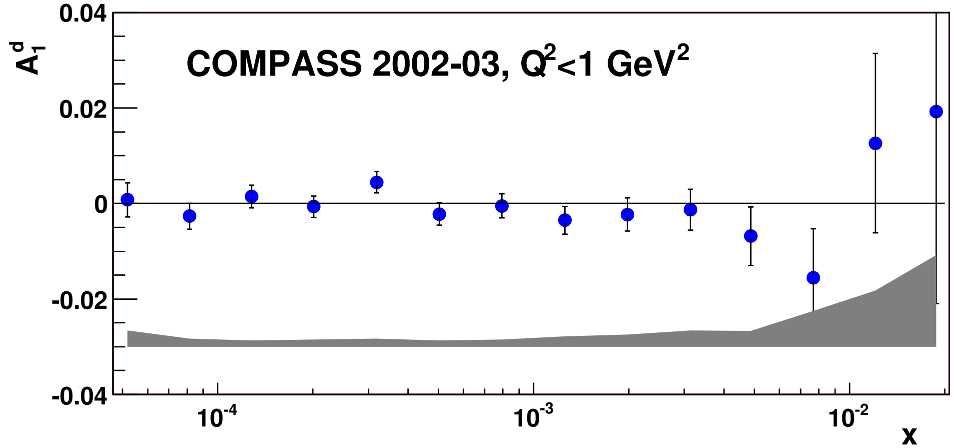
$$a_8 = 0.585 \pm 0.025$$

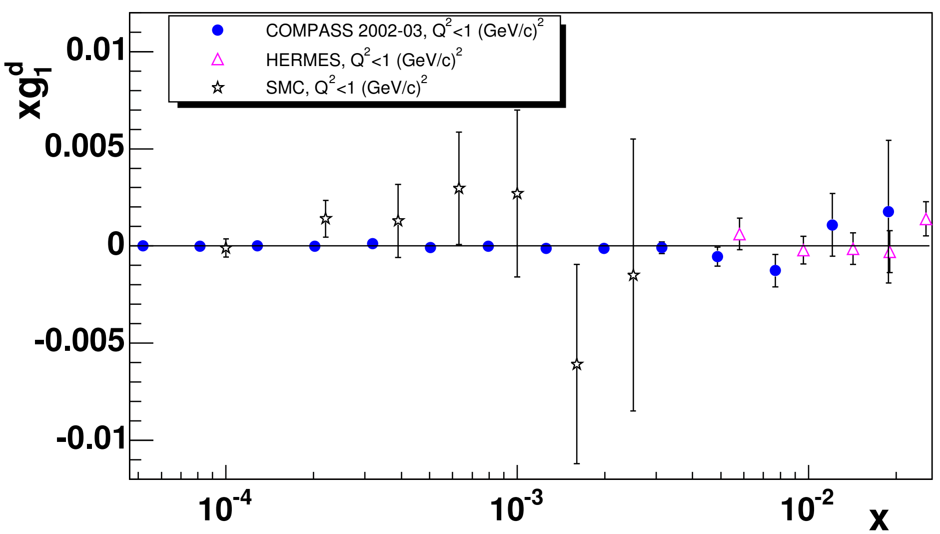
- Contribution to Γ_1^N from unmeasured x-range is $\approx 4\%$
- Quark polarization at $Q^2 = 3\,\mathrm{GeV}^2$:

$$a_0 = 0.35 \pm 0.03(stat) \pm 0.05(syst)$$
$$\eta_\Sigma = 0.30 \pm 0.01(stat) \pm 0.02(evol)$$

g_1^d at low x and $Q^2 < 1\,\mathrm{GeV}^2$

- Results from 2002-2003
- Statistics: $300 \cdot 10^6$ events
- Compatible with 0 in the whole x interval
- Good agreement with results of previous experiments
- Factor 10–20 improvement in statistical precision as compared to SMC
- Parton saturation and non-perturbative models (Regge, VMD)





Hadron asymmetries

Hadron asymmetries

Semi-inclusive asymmetries

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

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

Difference asymmetry

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

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

- Some fragmentation functions $D_q^h = \int D_q^h(z)dz$ are poorly known
- Difference asymmetry originally was proposed in:

  L.Frankfurt *et al.*, Phys. Lett. B230 (1989) 141
- First was used in SMC: B. Adeva *et al.*, Phys. Lett. B369 (1996) 93.
- Meaningful physics results for the deuteron target in LO QCD even without hadron identification

Single hadron asymmetries A^{h+} and A^{h-}

- Deuteron data 2002-2004 are used
- Kinematic cuts (DIS region):

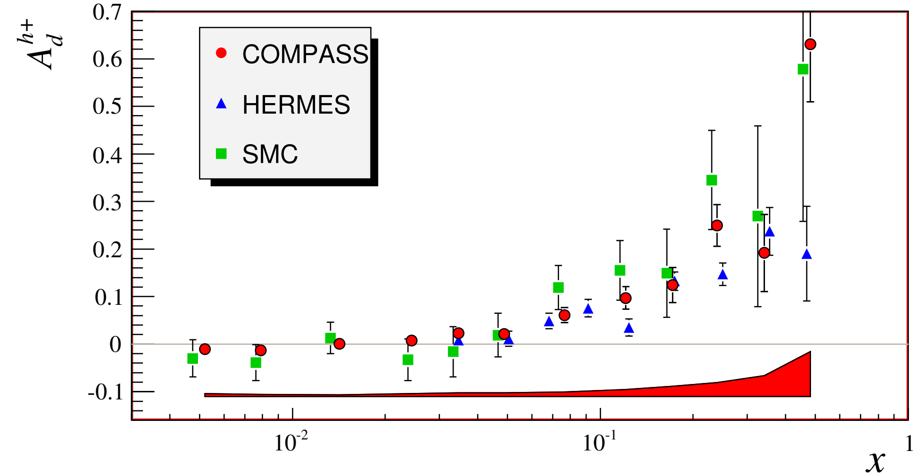
$$Q^2 > 1\,\mathrm{GeV}^2, \qquad 0.1 < y < 0.9$$

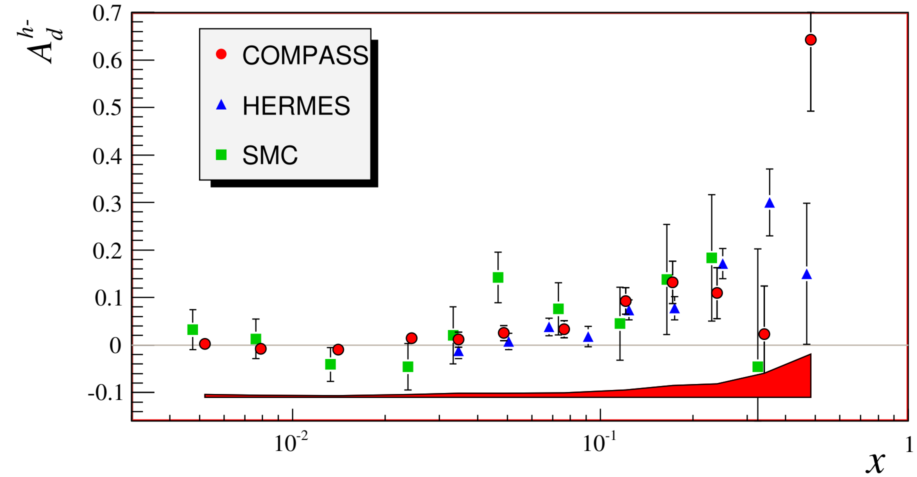
- No hadron identification
- Current fragmentation region: $z > 0.2$
- To avoid ambiguity between secondary μ and the scattered μ, and suppress contribution from diffractive events:

$$z < 0.85$$

- Final statistics:

$$N^+ = 30{\cdot}10^6, \quad N^- = 25{\cdot}10^6, \quad cor(N^+, N^-) \approx 20\%$$





Difference asymmetry

- A^{h+} and A^{h-} are used to obtain $A^{h^+-h^-}$

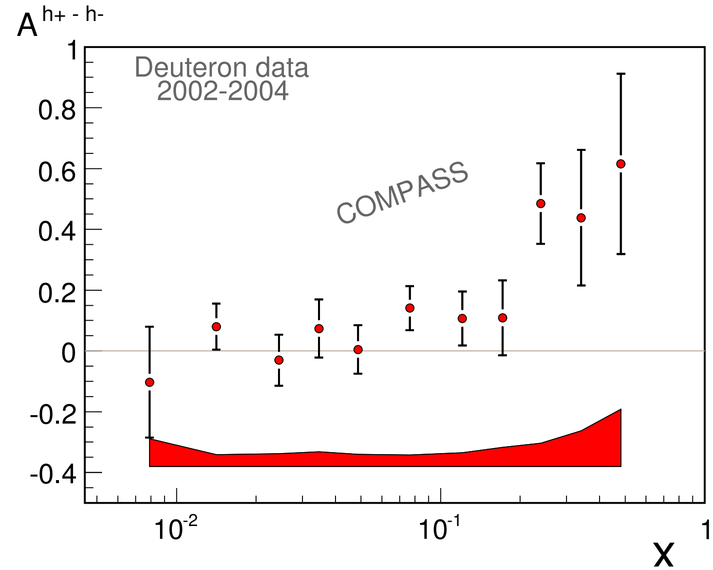
$$A^{h^+-h^-}=\frac{1}{1-r}(A^{h+}-rA^{h-}),\qquad r=\frac{\sigma^{h-}}{\sigma^{h+}}.$$

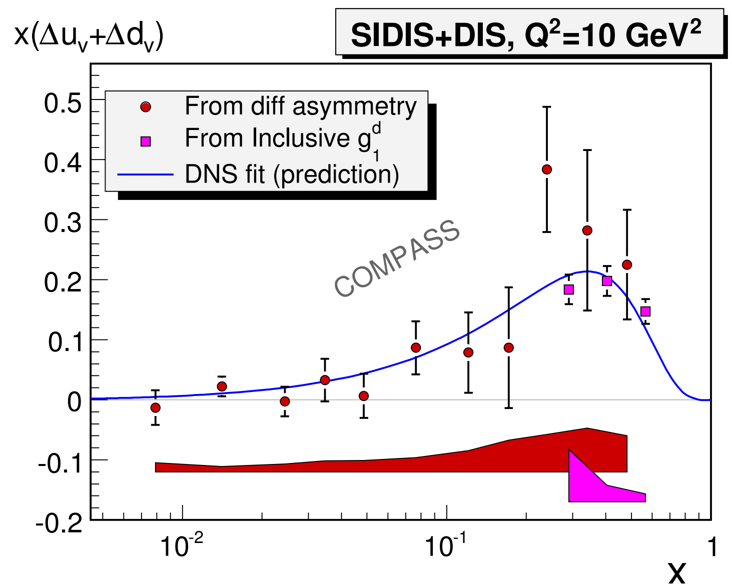
- r is obtained from hadron numbers $N^\pm$ corrected for their acceptances $a^\pm$:

$$r=\frac{\sigma^{h-}}{\sigma^{h+}}=\frac{N^-/a^-}{N^+/a^+}.$$

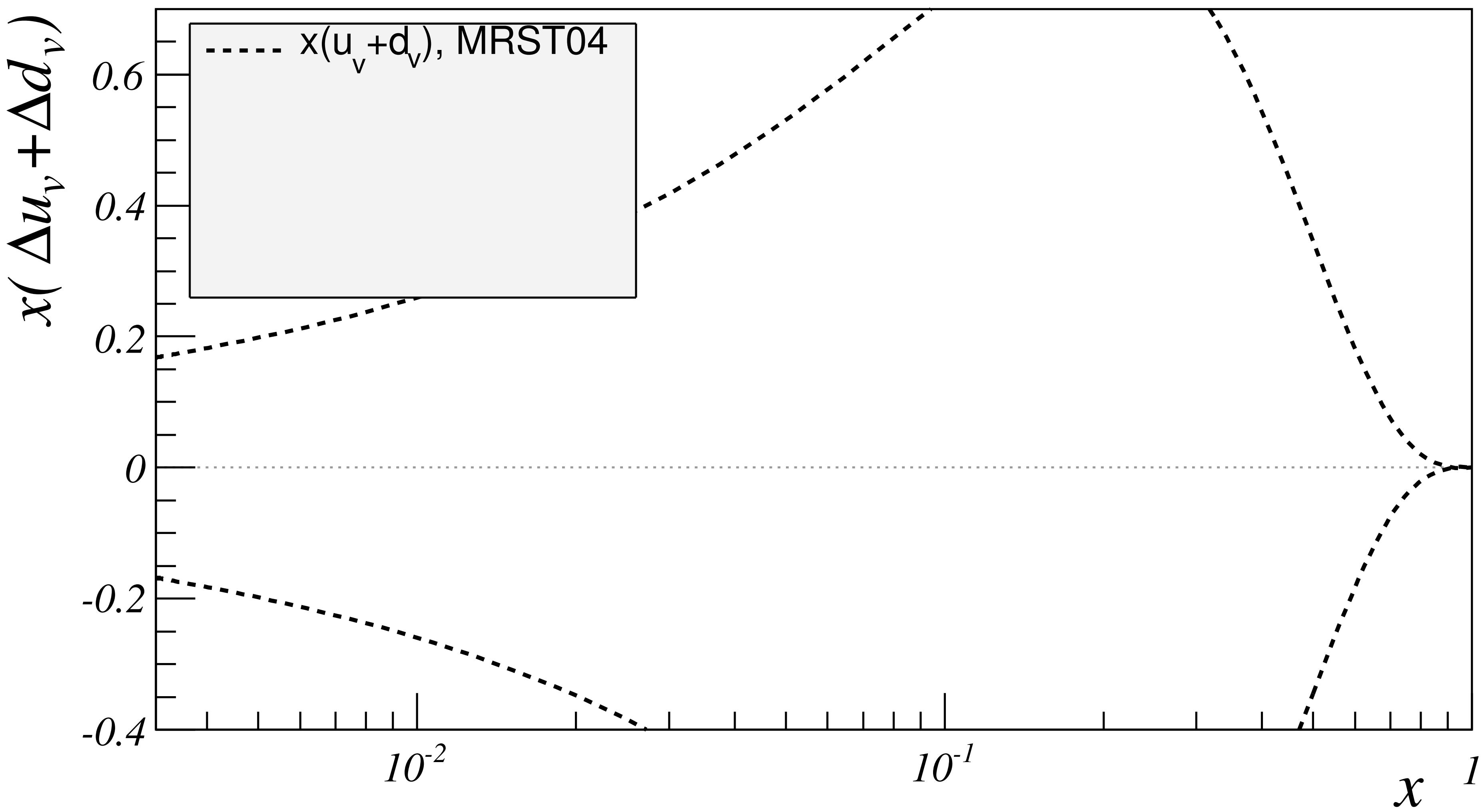
- For unpolarized PDF LO MRST04 was chosen
- Constraint as in SMC & HERMES analyzes: $\Delta\bar{u}=\Delta\bar{d}=\Delta s=0$ at $x>0.3$

$$\Delta u_v+\Delta d_v\simeq\frac{36}{5}\frac{g_1^d(x,Q^2)}{(1-1.5\omega_D)}$$





Comparison with other experiments



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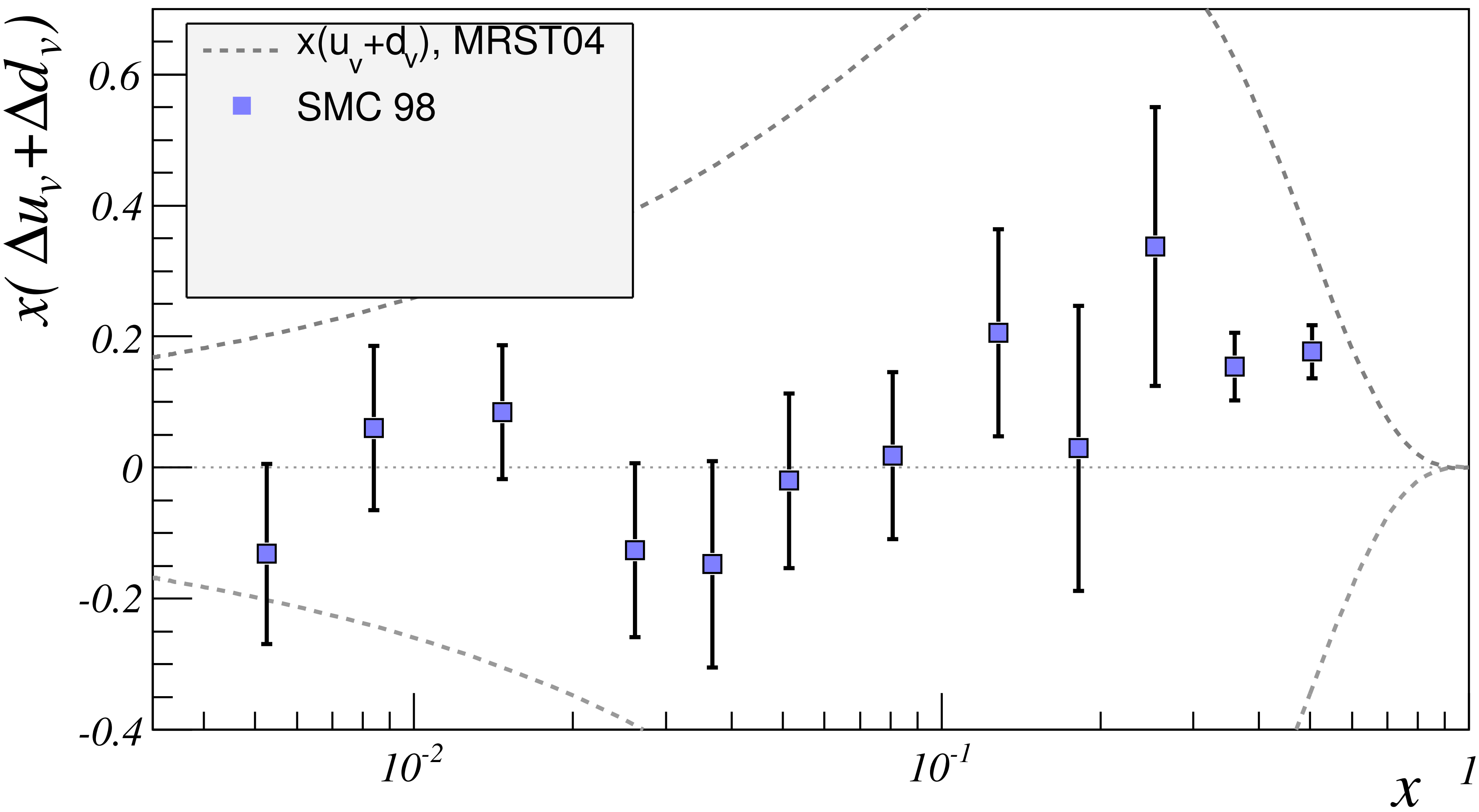

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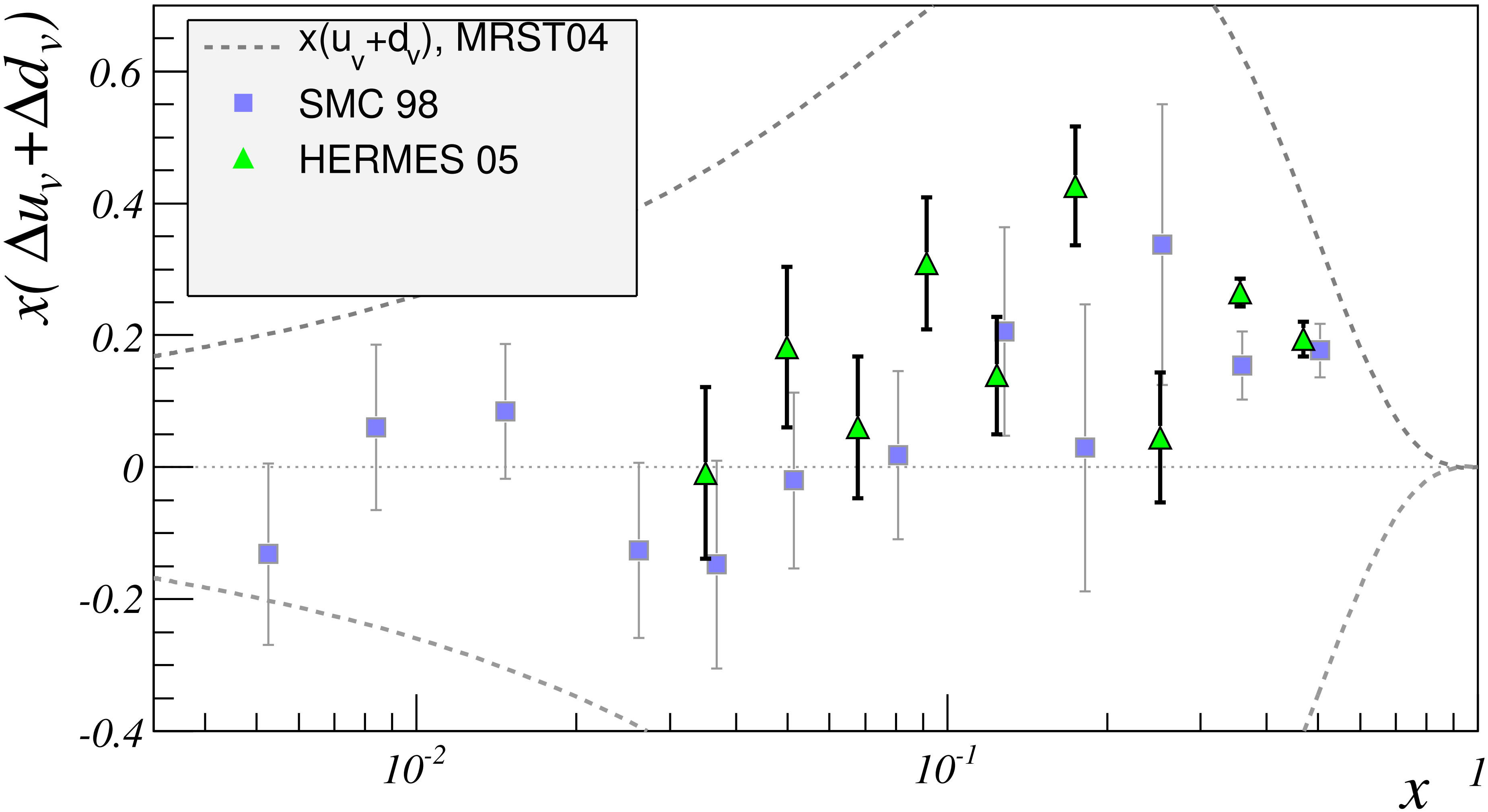

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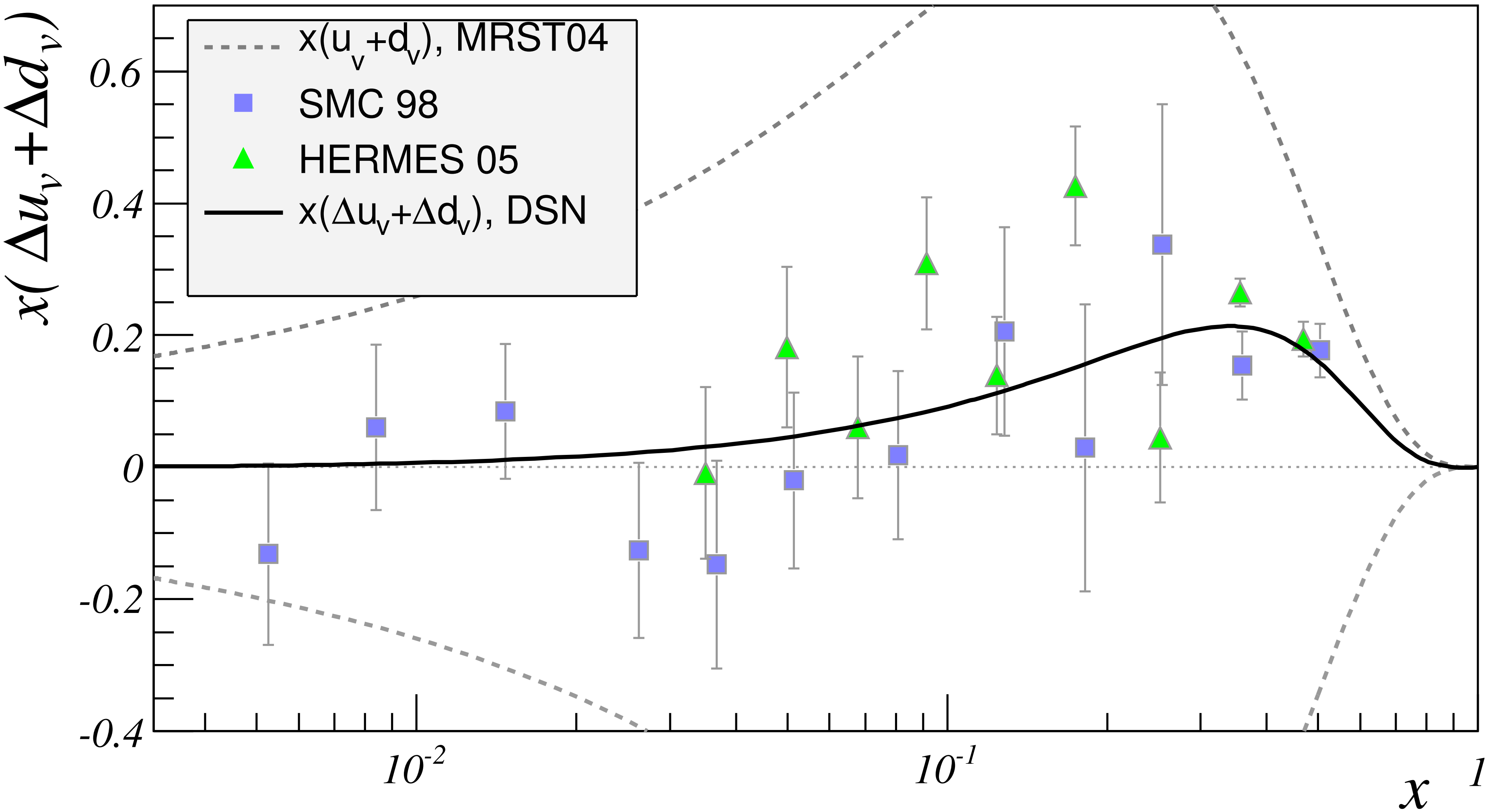

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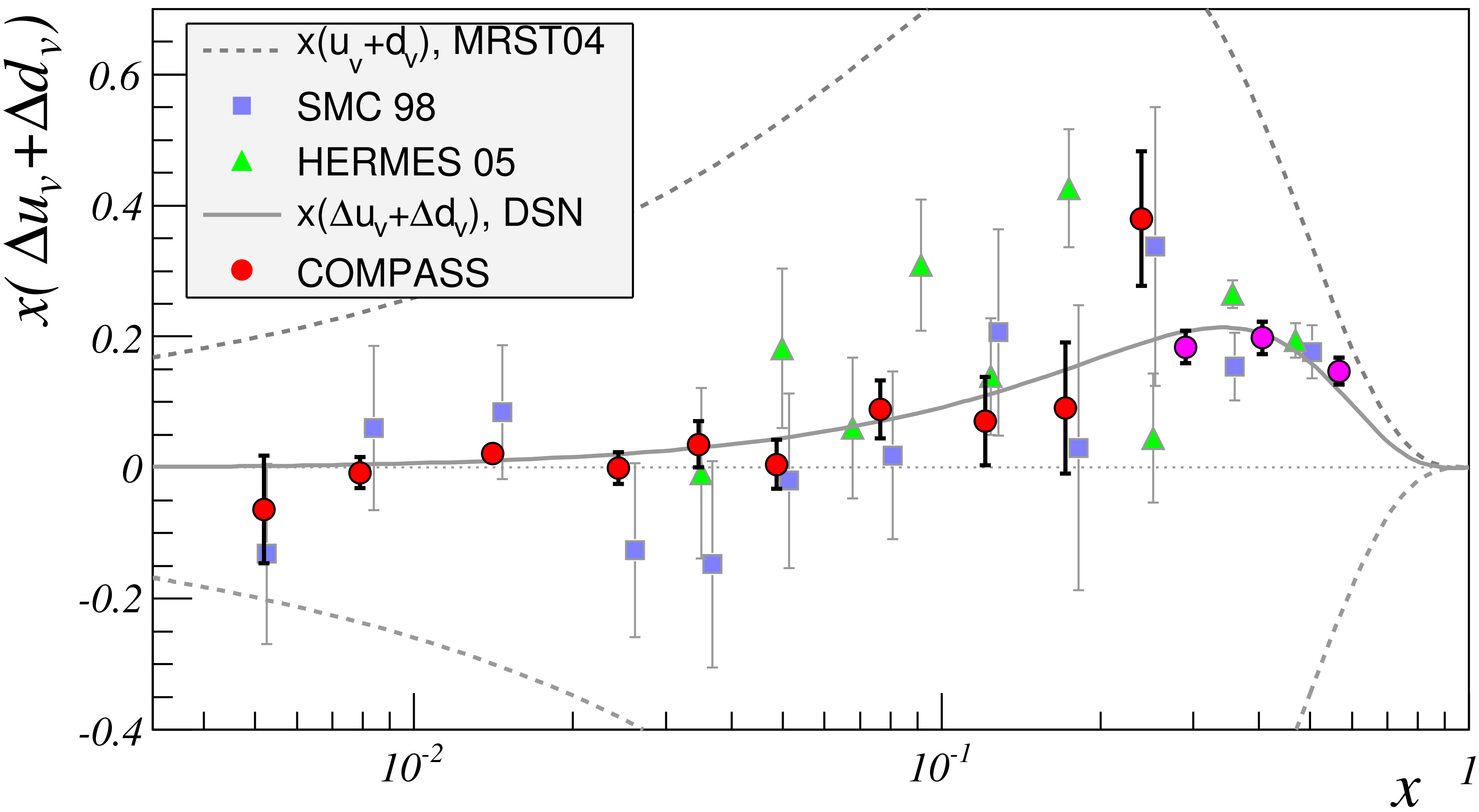
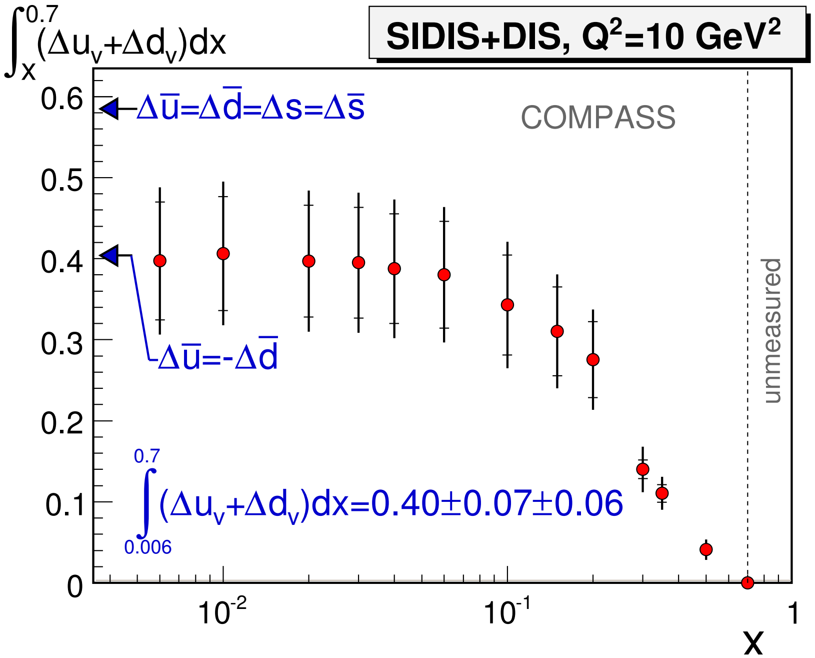


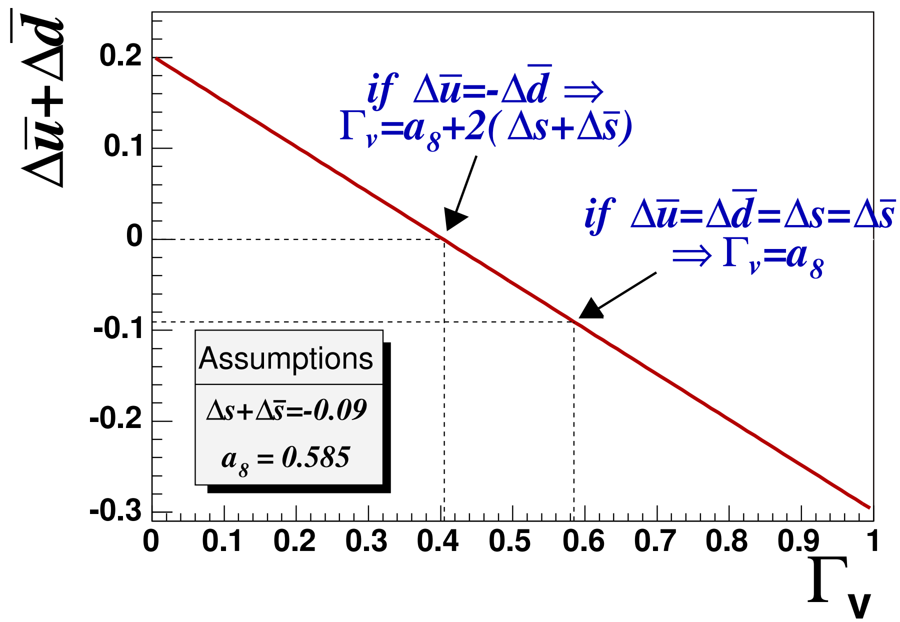
Estimate for the first moments (LO)



$$\Gamma_v \equiv \int_0^1 (\Delta u_v(x) + \Delta d_v(x))dx$$

- Contribution from unmeasured high x region (DNS fit):

$$\int_{0.7}^{1} (\Delta u_v + \Delta d_v)dx = 0.004$$



- Combining with axial charge a_8

$$\Delta\bar{u} + \Delta\bar{d} = (\Delta s + \Delta\bar{s}) + \frac{1}{2}(a_8 - \Gamma_v) = 0.0 \pm 0.04 \pm 0.03$$

- The estimate of Γ_v is 2σ away from the flavor symmetric sea scenario

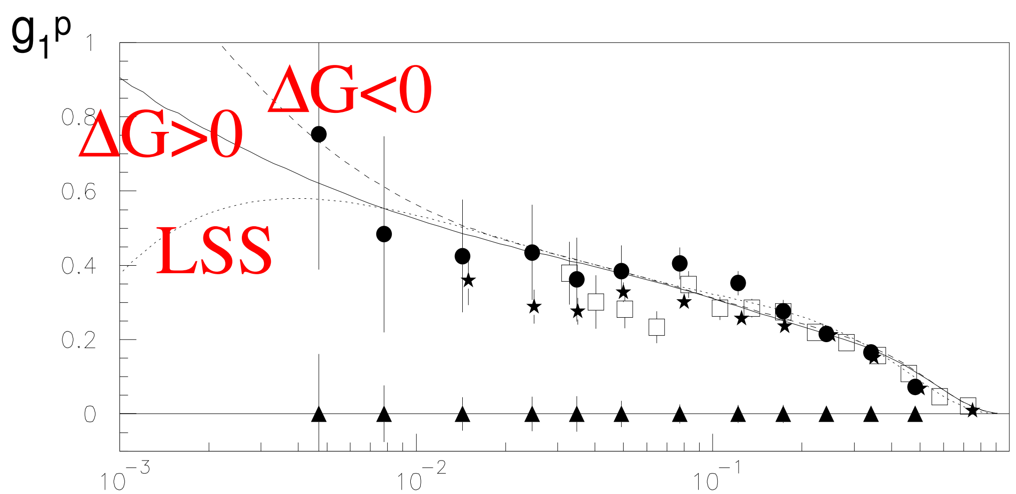
Projection of the stat. precision for data 2006, 2007

Upgrade of setup in 2006/2007

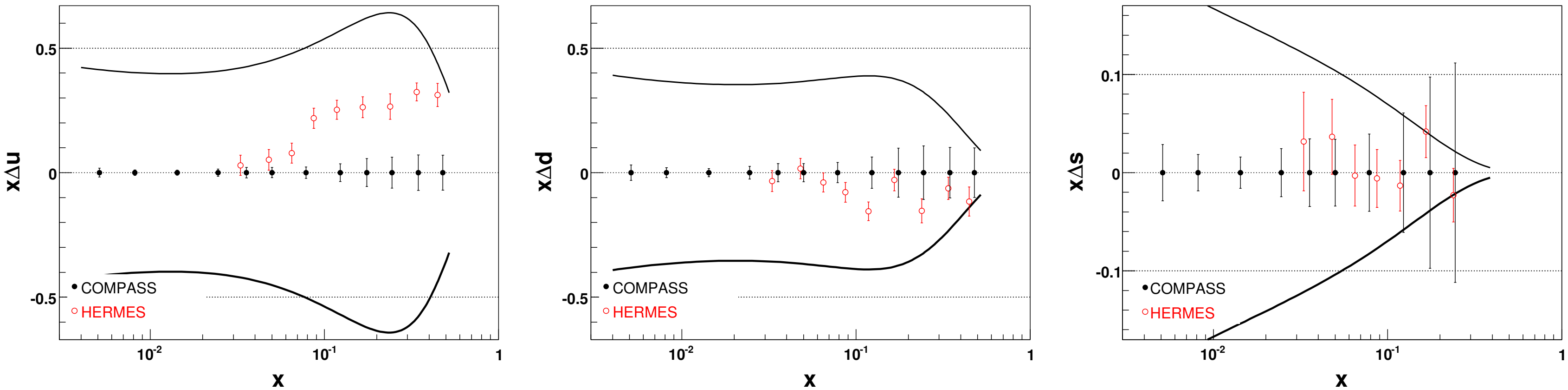
- New target magnet
  - ◇ Angular acceptance is increased by a factor 2 (70 mrad→180 mrad)
  - ◇ 3 cells ⇒ reduction of false asymmetries
- Detectors upgrade (RICH, ECAL, trackers)

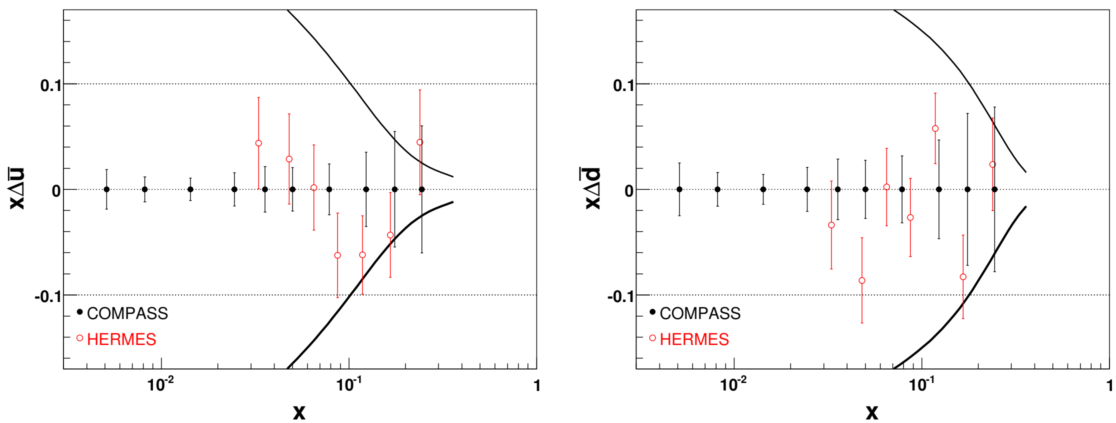
Analysis

- Deuteron data 2006 (^{6}LiD target)
- Proton data 2007 (NH_3 target)
  - ◇ Crosscheck of low x points of g_1^d (so far measured by SMC only)
  - ◇ Full flavor separation



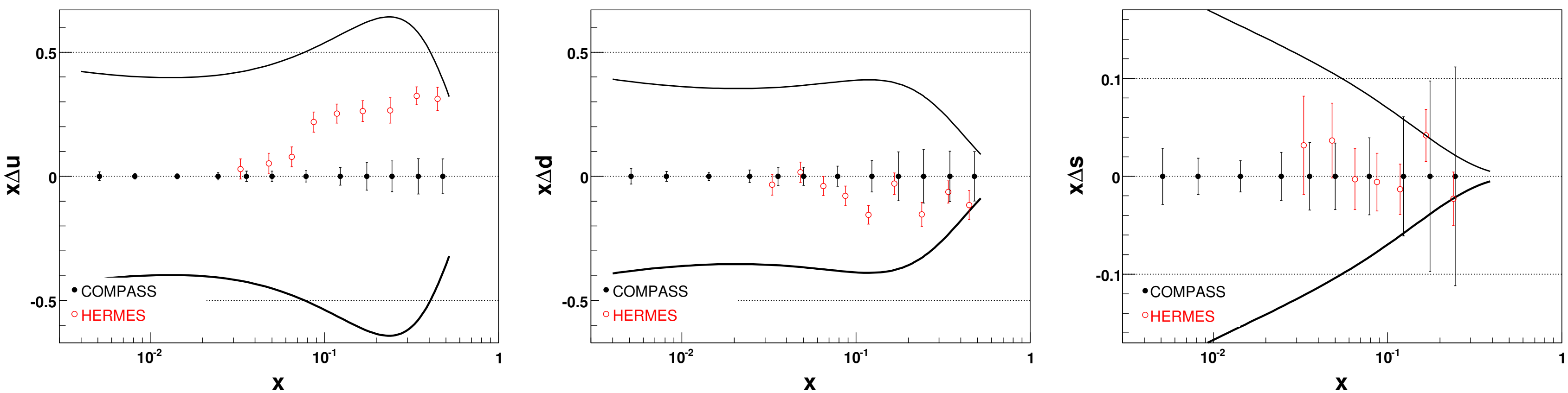
Flavor separation (prediction for stat. error)

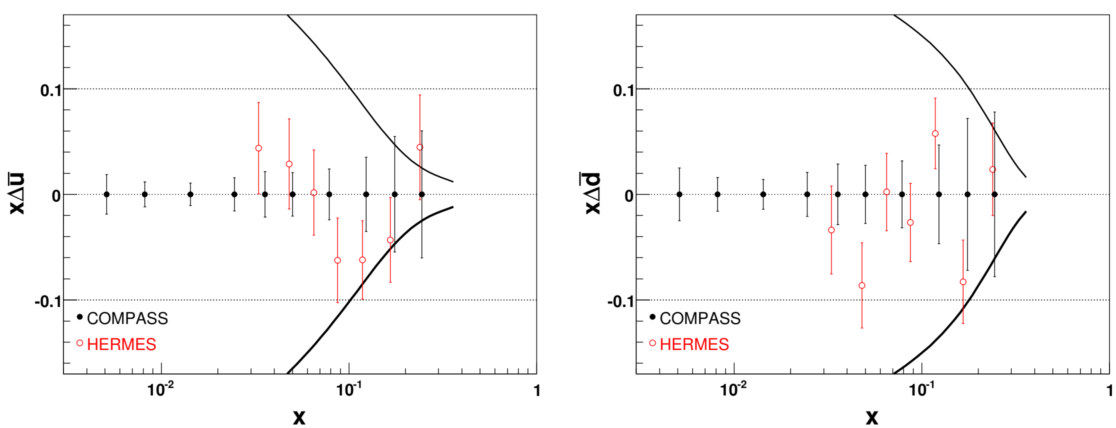




	COMP.	SMC	HERMES
x-int.	0.004-0.7	0.003-0.7	0.023-0.6
$\delta(\Delta u_v)$	0.07	0.11	0.07
$\delta(\Delta d_v)$	0.11	0.30	0.07
$\delta(\Delta \bar{u})$	0.04	0.05	0.04
$\delta(\Delta \bar{d})$	0.05	0.14	0.03
$\delta(\Delta s)$	0.09	-	0.03

Flavor separation (prediction for stat. error)





	COMP.	SMC	HERMES
x-int.	0.004-0.03	0.003-0.7	0.023-0.6
$\delta(\Delta u_v)$	0.020	0.11	0.07
$\delta(\Delta d_v)$	0.036	0.30	0.07
$\delta(\Delta \bar{u})$	0.013	0.05	0.04
$\delta(\Delta \bar{d})$	0.017	0.14	0.03
$\delta(\Delta s)$	0.03	-	0.03

Summary and Outlook

- Analysis of deuteron data 2002 – 2004 have been presented
  - ◇ Inclusive asymmetry A_1^d and structure function g_1^d
  - ◇ Valence quark distributions $\Delta u_v + \Delta d_v$ from hadron asymmetry $A_d^{h^+ - h^-}$
  - ◇ Strong increase in the precision at low x as compared to SMC results
- Data of 2006 have been processed $\Rightarrow$ update on A_1^d, $A_d^{h\pm}$ soon
- Hadron asymmetries $A_d^{\pi\pm}$, $A_d^{K\pm}$ are coming
- Processing of 2007 data (longitudinal polarization) is in progress