Quark helicity distributions in COMPASS experiment at CERN

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SYMMETRIES AND SPIN (SPIN-Praha-2008)
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Outline

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1. COMPASS experiment
   - Spectrometer setup
   - Physics motivation and used methods
2. Inclusive results
   - Inclusive asymmetry A_1^d
   - Structure function g_1^d
   - Quark polarization

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1. COMPASS experiment
   - Spectrometer setup
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2. Inclusive results
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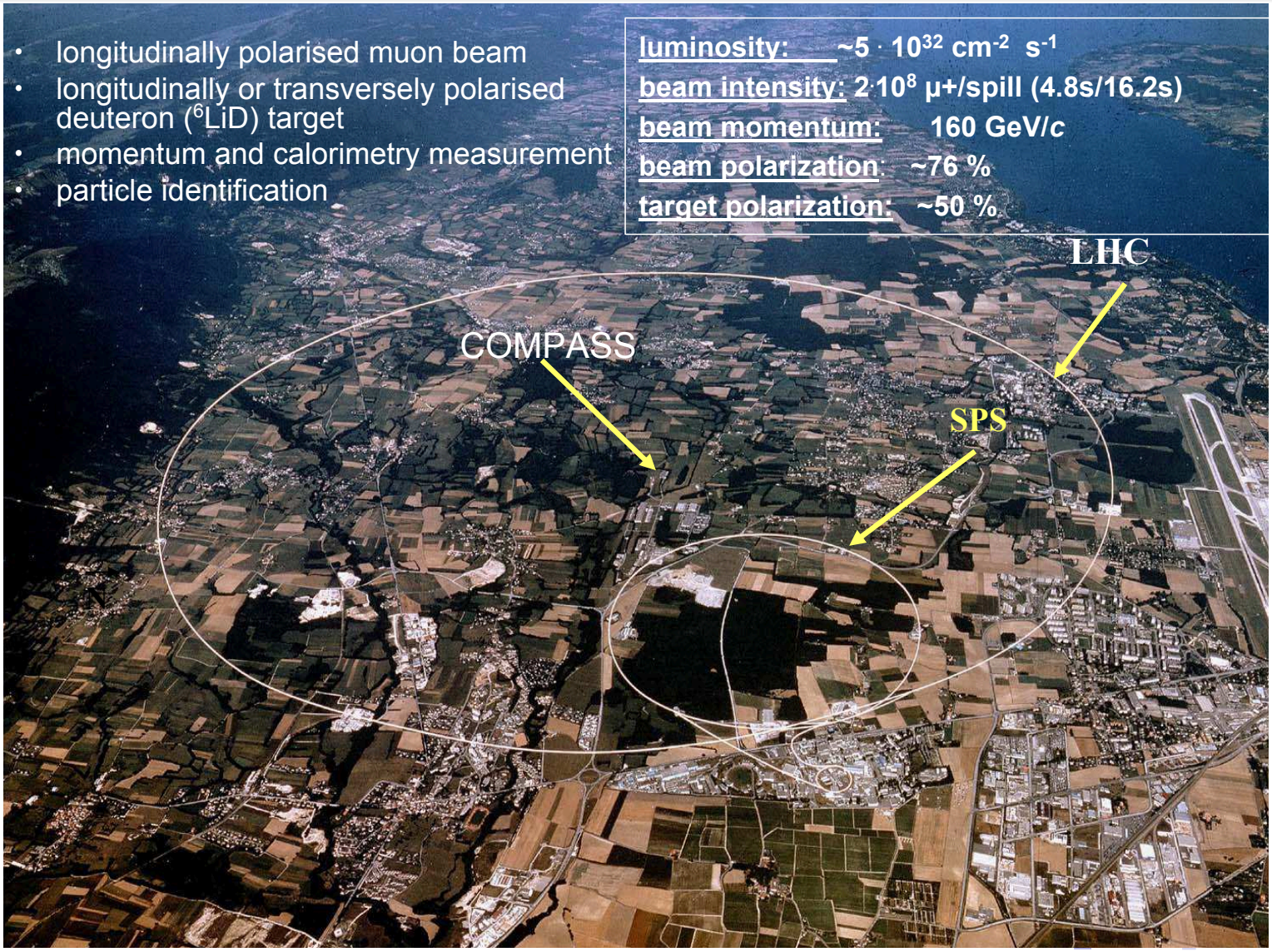
   - Quark polarization
3. Semi-inclusive results
   - Semi-inclusive asymmetries
   - Quark polarization

Outline

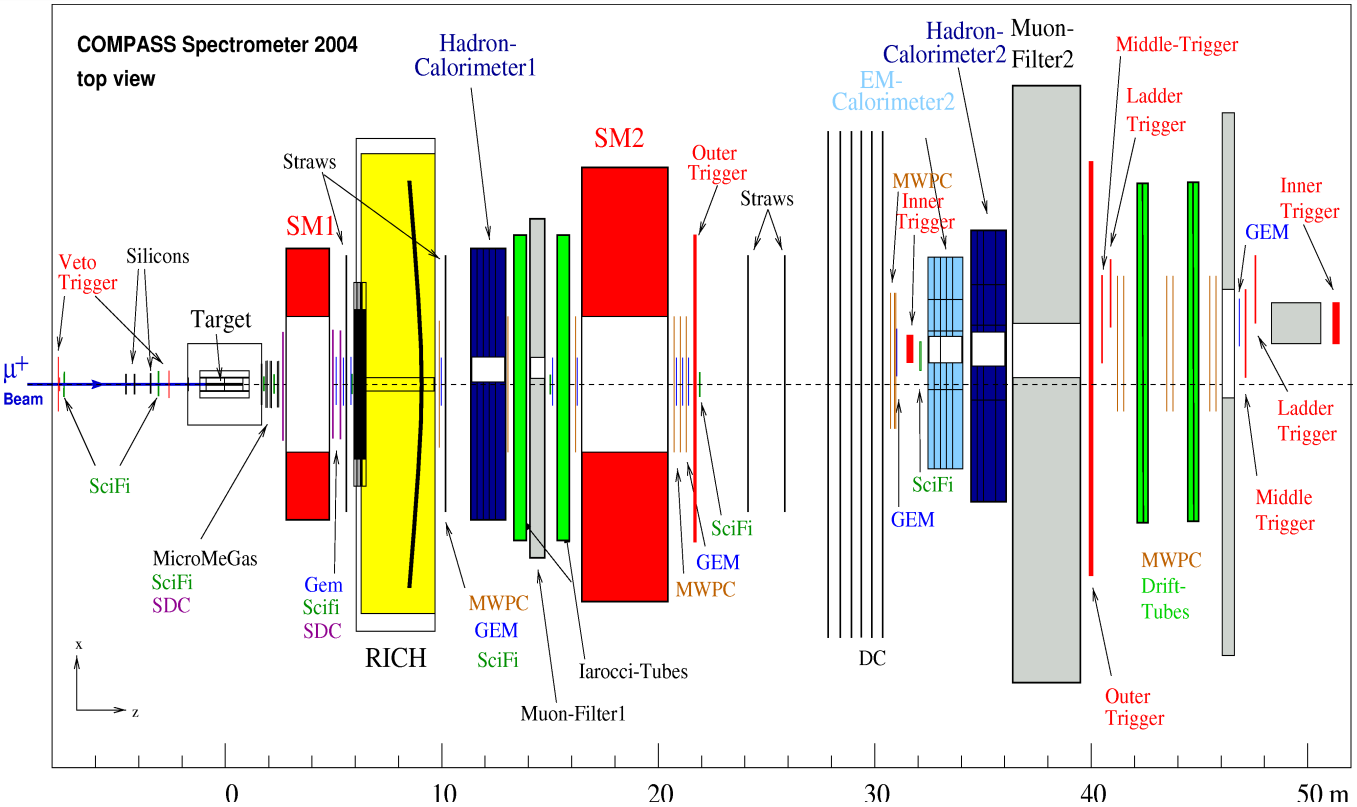
COMPASS experiment at CERN

- longitudinally polarised muon beam
- longitudinally or transversely polarised deuteron (^{6}LiD) target
- momentum and calorimetry measurement
- particle identification

luminosity: ~$5 \cdot 10^{32}$ cm^{-2} s^{-1}
beam intensity: $2 \cdot 10^8$ μ+/spill (4.8s/16.2s)
beam momentum: 160 GeV/c
beam polarization: ~76 %
target polarization: ~50 %

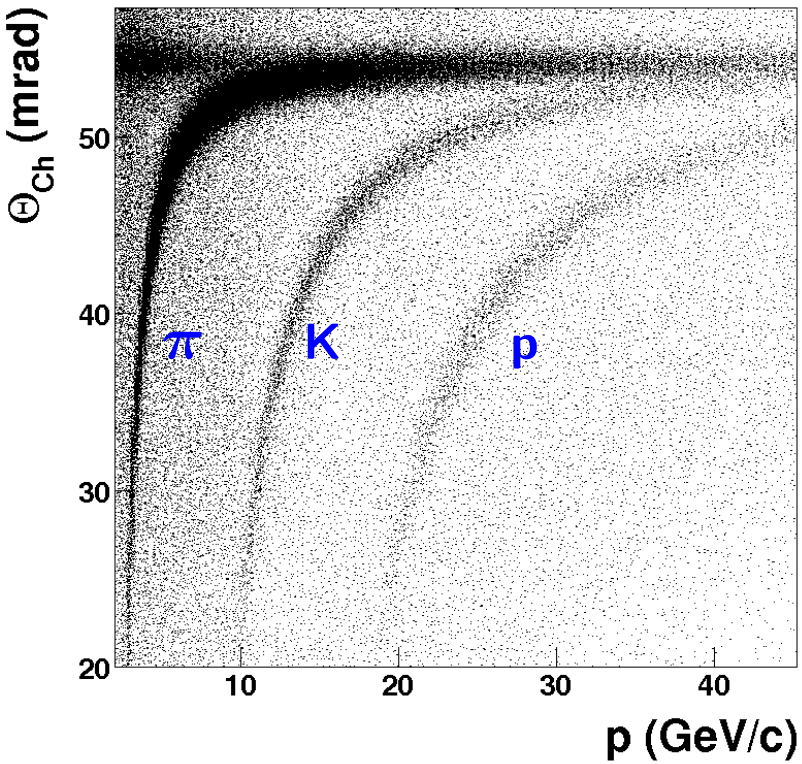


COMPASS spectrometer



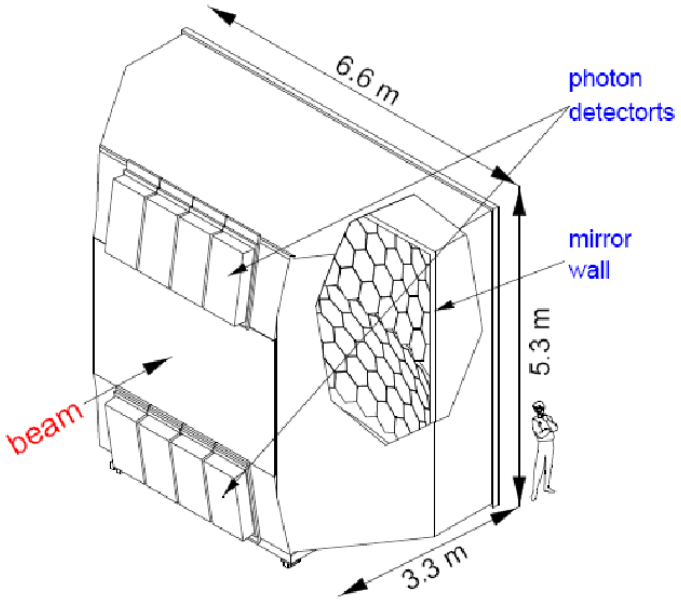
- Two parts of spectrometer (60m length in total)
- About 350 detector planes of different type
- Polarized beam: μ^+ (P_B=80% at 160GeV)
- Polarized target: ^{6}LiD (P_T=50%) and NH_3 (P_T=90%)
- Particle identification by RICH, ECALs, HCALs and μ-filter

Ring Imaging CHerenkov detector

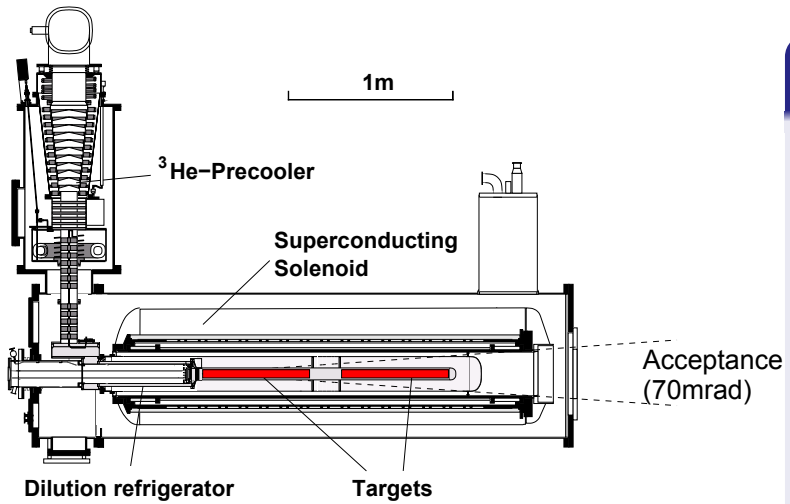


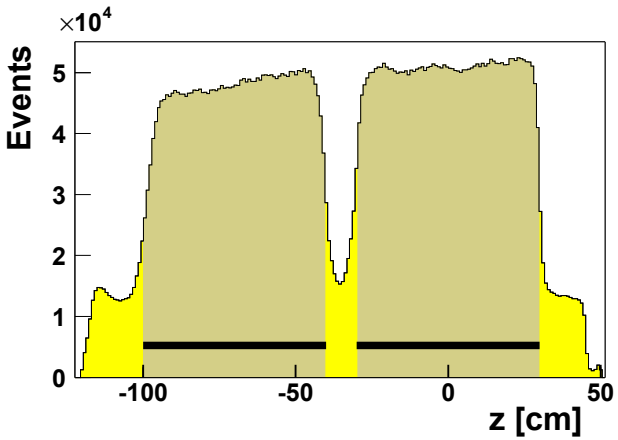
RICH features

- π, K, p separation from 2, 9, 18 GeV up to 50 GeV
- 116 spherical mirrors (21 m^2)
- 80 m^3 C_4F_{10}, n=1.00153
- $< n > = 15$



The polarized target (2002-2004)





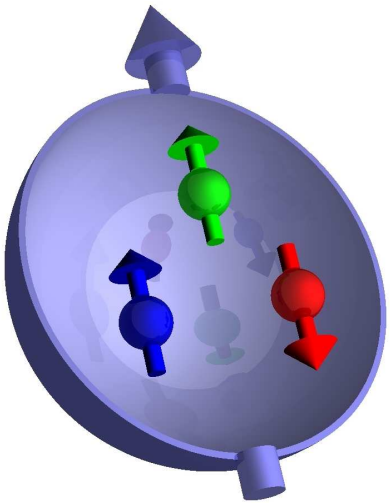
Target features

- target material ^{6}LiD
- Dynamic Nuclear Polarization technique
- polarization about 50%
- acceptance: 70 mrad
- solenoid field: 2.5T
- temperature (^{3}He, ^{4}He): 50mK
- two cells with oposite polarization
- target length: 60 cm each cell
- dilution factor ≈ 0.4

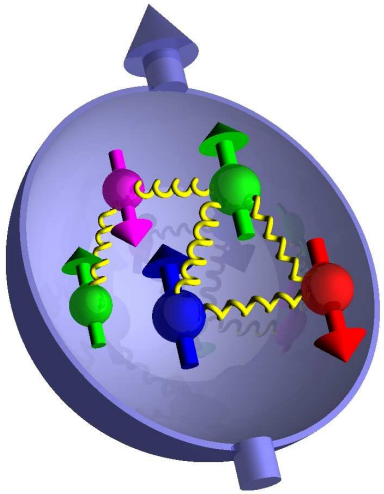
The spin of the nucleon

Angular momentum conservation

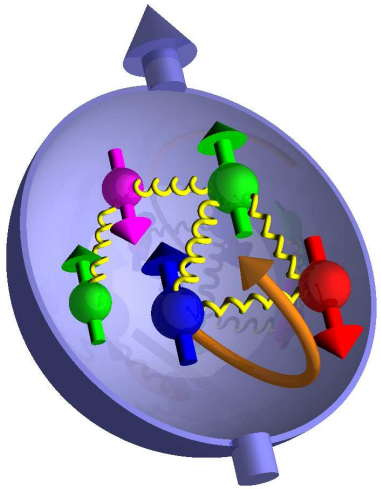
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$



Constituent (naive) parton model:
$\Delta\Sigma = \Delta u_v + \Delta d_v = 1$

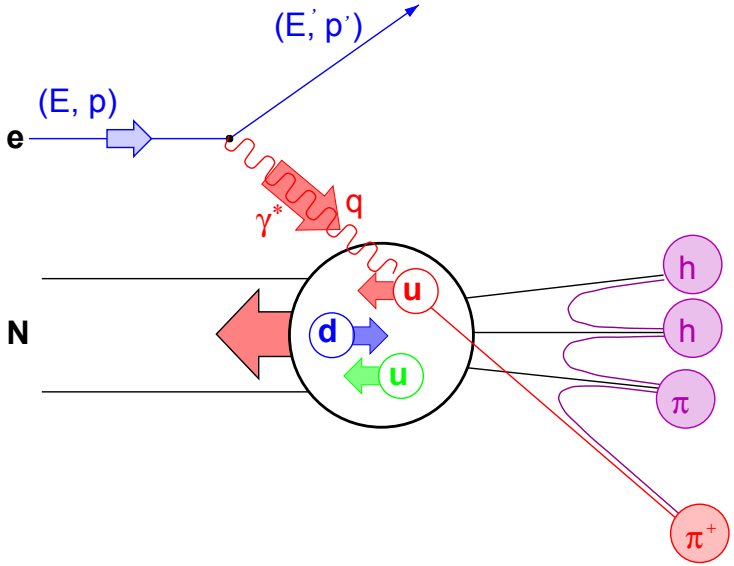


Is contribution from gluons important as in unpolarized case?



Full description should take into account orbital angular momenta

Deep inelastic scattering



Kinematical variables:

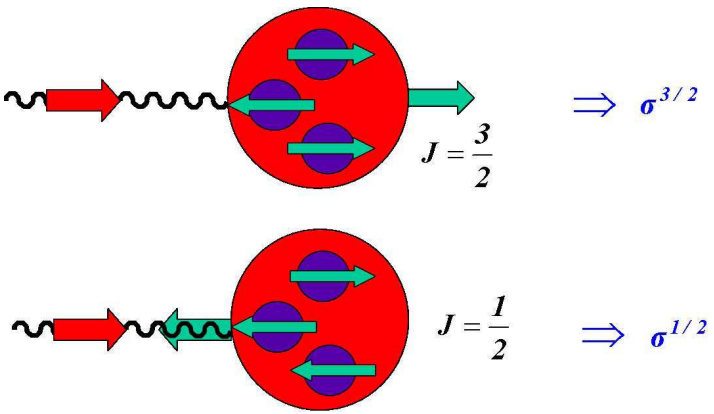
- $Q^2 = -q^2$
- $\nu = E - E'$
- $x = Q^2/2M\nu$
- $y = \nu/E$
- $z = E_h/\nu$

Inclusive cross-section

$$\frac{d^2\sigma}{d\Omega dE'} = c_1 F_1(x, Q^2) + c_2 F_2(x, Q^2) + c_3 g_1(x, Q^2) + c_4 g_2(x, Q^2)$$

where g_1, g_2 and F_1, F_2 are spin dependent and spin independent structure functions.

Polarized deep inelastic scattering



Quark densities in QPM:

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

$q^+(x), q^-(x)$: quarks polarized parallel (antiparallel) to nucleon spin

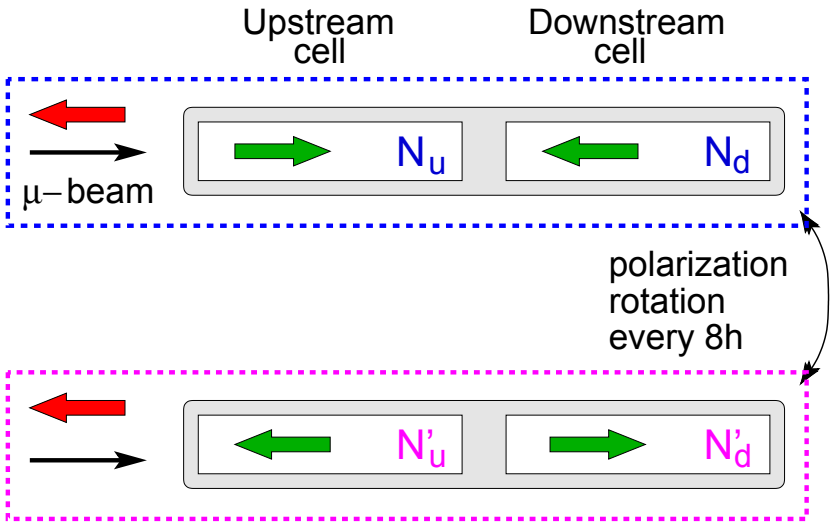
- Photon-nucleon asymmetry:

$$A_1 = \frac{\sigma_{1/2}-\sigma_{3/2}}{\sigma_{1/2}+\sigma_{3/2}} = \frac{\sum_q e_q^2 \Delta q}{\sum_q e_q^2 q} = \frac{g_1}{F_1} = \frac{2x(1+R)}{F_2} g_1, \qquad R=\sigma_L/\sigma_T$$

- Longitudinal asymmetry:

$$A_\parallel = \frac{\sigma^{\uparrow\downarrow}-\sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow}+\sigma^{\uparrow\uparrow}} \approx D A_1 \Longrightarrow g_1 = \frac{A_\parallel}{D} \cdot \frac{F_2}{2x(1+R)}$$

Experimental asymmetry



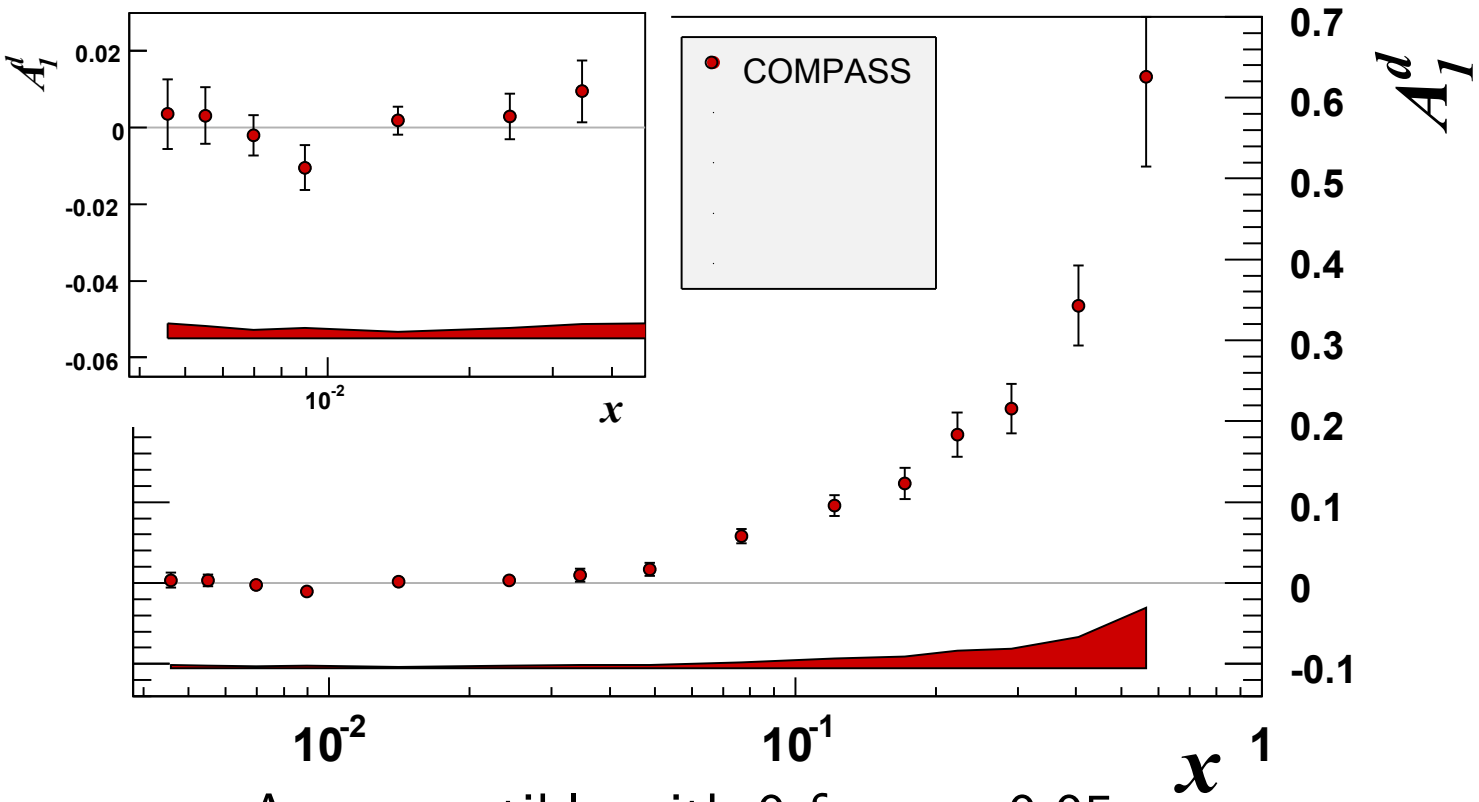
- Target cells polarized in oposite direction
- Acceptance for both cells is not the same
- Polarization reversed every 8 hours

Experimental asymmetry:

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

P_B, P_T - beam and target polarization
f - dilution factor

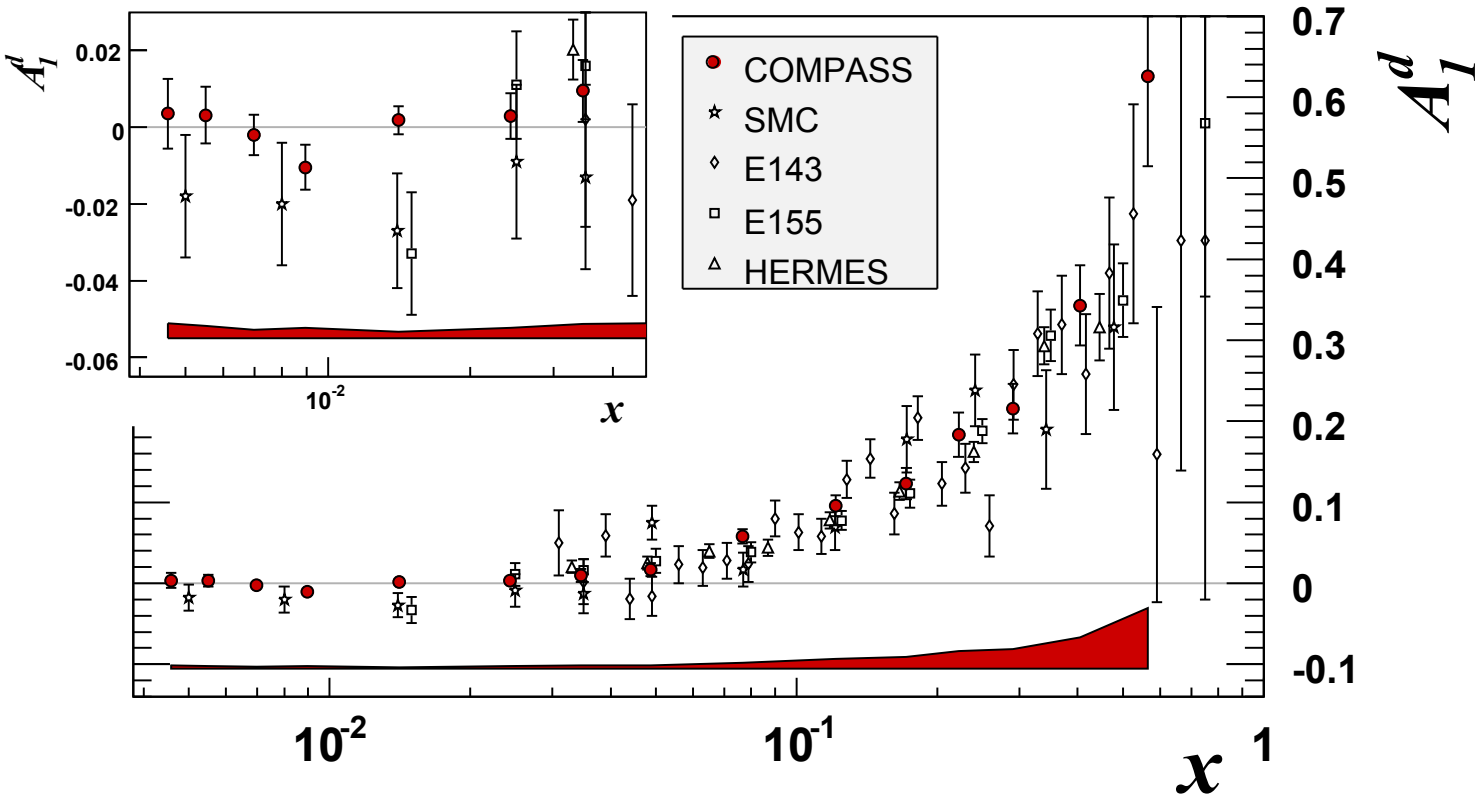
Inclusive asymmetry for $Q^2 > 1 GeV^2$



$Q^2 > 1 \mathrm{GeV}^2$
$0.004 < x < 0.7$
$0.1 < y < 0.9$
$\sim 10^8$ events

- A_1 compatible with 0 for $x < 0.05$
- Large asymmetry at large x
- Sys. errors: $P_B(5\%), P_T(5\%), f(3\%), D(6\%) \Rightarrow \delta A_1 \approx 0.1 A_1$
- Results from 2002-2004, published in PLB 647 (2007) 8

Inclusive asymmetry for $Q^2 > 1 GeV^2$, comparision

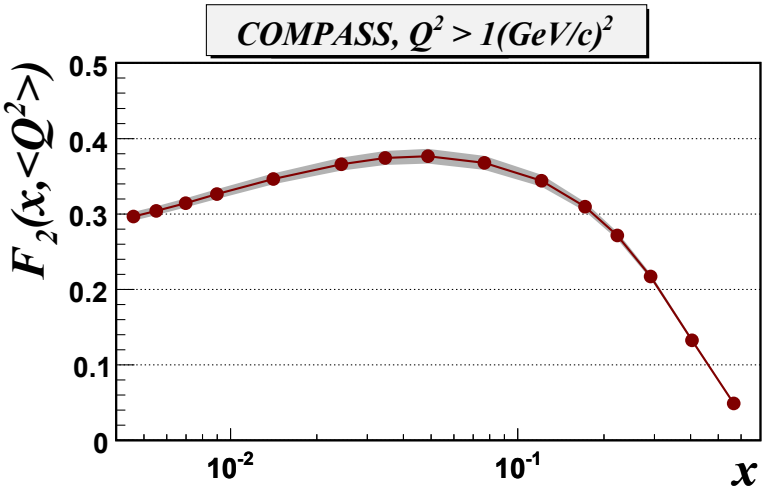


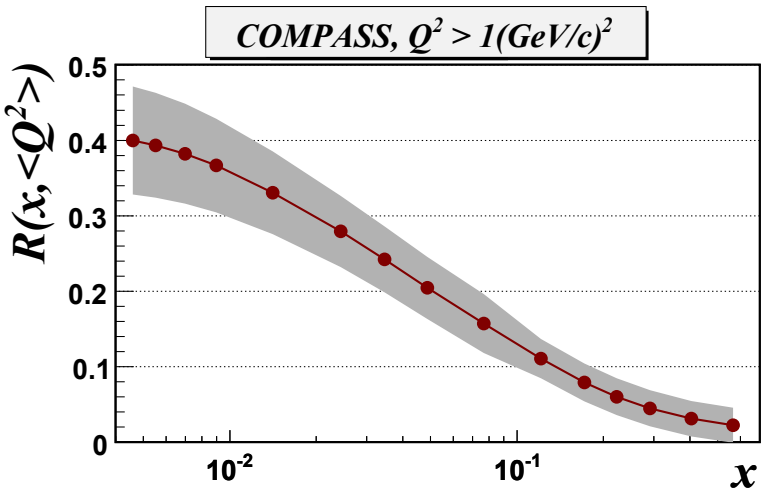
$Q^2 > 1 \mathrm{GeV}^2$
$0.004 < x < 0.7$
$0.1 < y < 0.9$
$\sim 10^8$ events

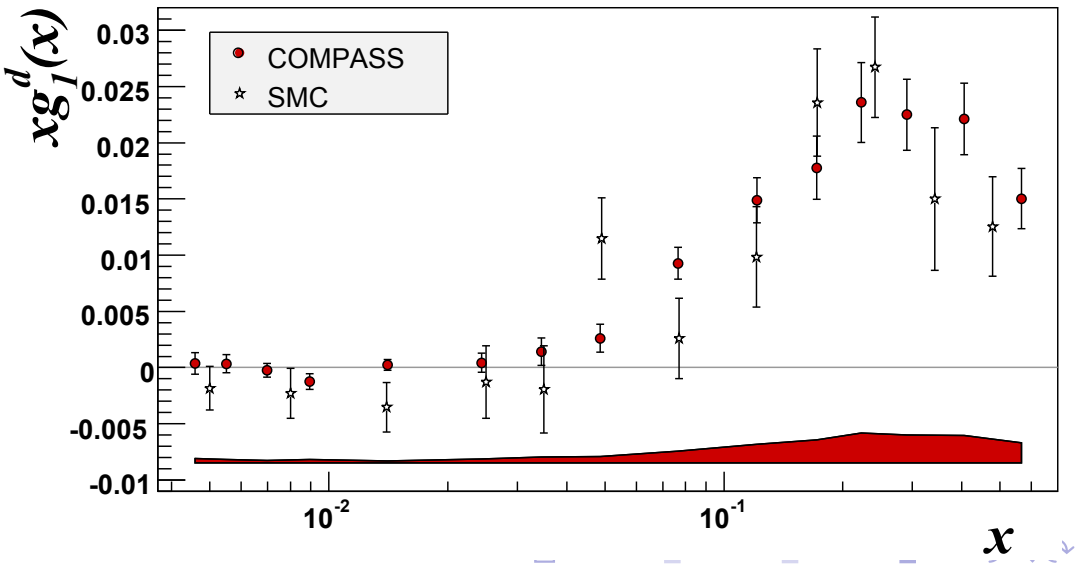
- Good agreement with previous experiments
- Significant impovement at low x region
- No tendency towards negative values at $x < 0.03$

Parametrization of F_2 and R

$$g_1 = \frac{F_2}{2x(1+R)} A_1$$







NLO QCD analysis

$$\Delta\Sigma=\Delta u+\Delta d+\Delta s, \quad \Delta q_3=\Delta u-\Delta d, \quad \Delta q_8=\Delta u+2\Delta d-\Delta s$$

- Spin dependent structure function g_1:

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

- DGLAP equations:

$$\frac{\mathrm{d}}{\mathrm{d}t}\Delta q^{NS} = \frac{\alpha_s(t)}{2\pi}P_{qq}^{NS}\otimes\Delta q^{NS}, \quad t=\log\left(\frac{Q^2}{\Lambda^2}\right)$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\begin{pmatrix}\Delta\Sigma\\ \Delta G\end{pmatrix} = \frac{\alpha_s(t)}{2\pi}\begin{pmatrix}P_{qq}^S & 2n_f P_{qG}^S\\ P_{Gq}^S & P_{GG}^S\end{pmatrix}\otimes\begin{pmatrix}\Delta\Sigma\\ \Delta G\end{pmatrix}$$

- Input parametrization at fixed Q_0^2:

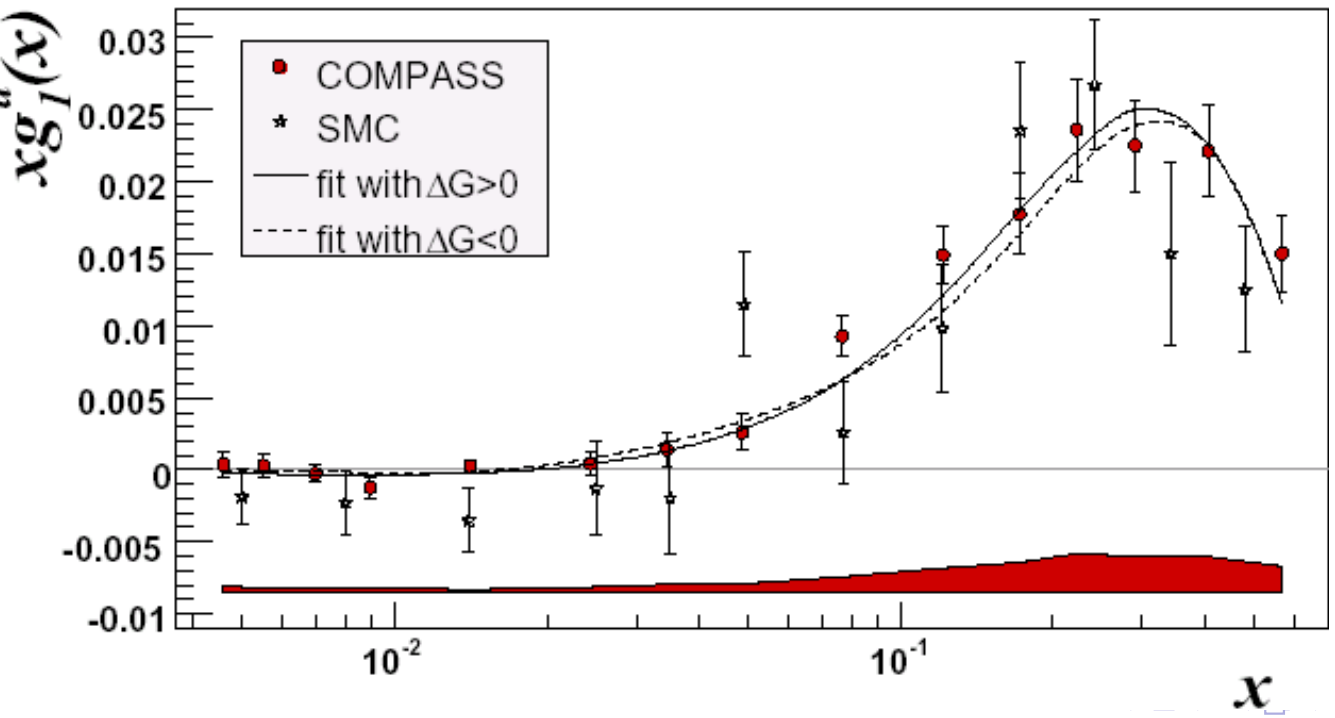
$$(\Delta\Sigma,\Delta q_3,\Delta q_8,\Delta G)=\eta\frac{x^\alpha(1-x)^\beta(1+\gamma x)}{\int_0^1 x^\alpha(1-x)^\beta(1+\gamma x)\mathrm{d}x}$$

- Minimization routine:

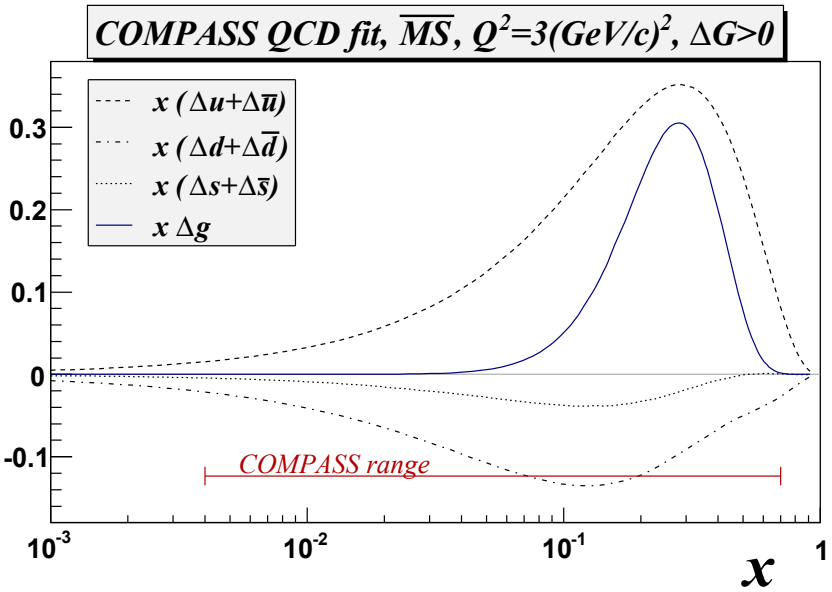
$$\chi^2=\sum_{i=1}^{N}\frac{\left[g_1^{calc}(x,Q^2)-g_1^{exp}(x,Q^2)\right]^2}{\left[\sigma_{stat}^{exp}(x,Q^2)\right]^2}$$

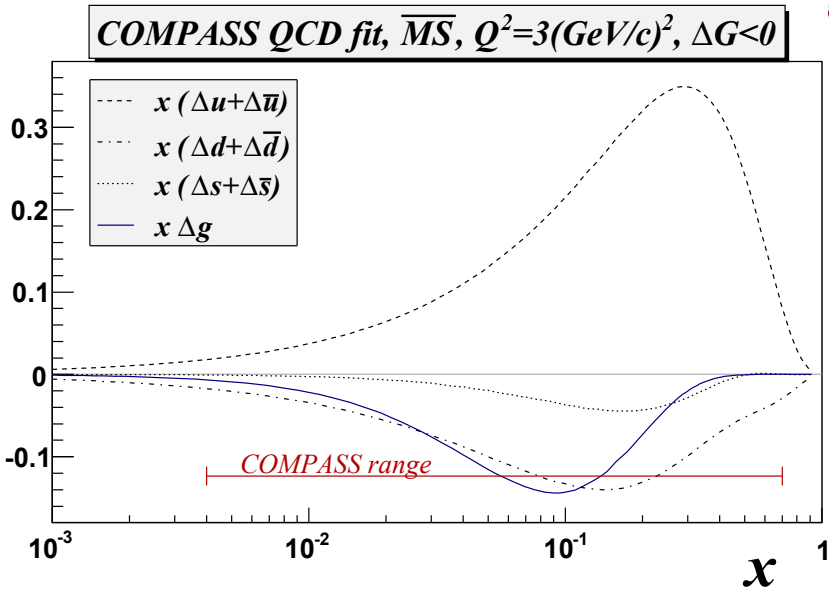
QCD fits

- Two different approaches in NLO $\overline{\text{MS}}$ scheme have been used
  - Numerical integration in (x, Q^2) space (PRD 58 (1998) 112002)
  - Solution of DGLAP in space of moments (PRD 70 (2004) 074032)
- Fit to world data (9 experiments, 230 points in total)
- Two solutions describe data equally well: $\Delta G < 0$ and $\Delta G > 0$



Polarized parton distributions





- Quark distributions are quite similar for two solutions
- Polarization of quarks $\eta_\Sigma = \int \Delta q_{Si}(x)\mathrm{d}x$
  $\eta_\Sigma = 0.30 \pm 0.01(stat) \pm 0.02(evol)$

First moment of g_1

- COMPASS data only
  $\Gamma_1^N(Q^2 = 3GeV^2) = \int_0^1 g_1^N(x)dx =$
  $0.0502 \pm 0.0028(stat) \pm 0.0020(evol) \pm 0.0051(syst)$
- data for $0.004 < x < 0.7$, QCD fit used for extrapolation
- contribution from unmeasured region about 4%
- Extracting a_0 from the first moment of g_1^N (NLO QCD):
  $\Gamma_1^N(Q^2) = \frac{1}{9}\left(1 - \frac{\alpha_s(Q^2)}{\pi} + \mathcal{O}(\alpha_s^2)\right)\left(a_0(Q^2) + \frac{1}{4}a_8\right)$
- From hyperon β decays assuming $SU(3)_f$

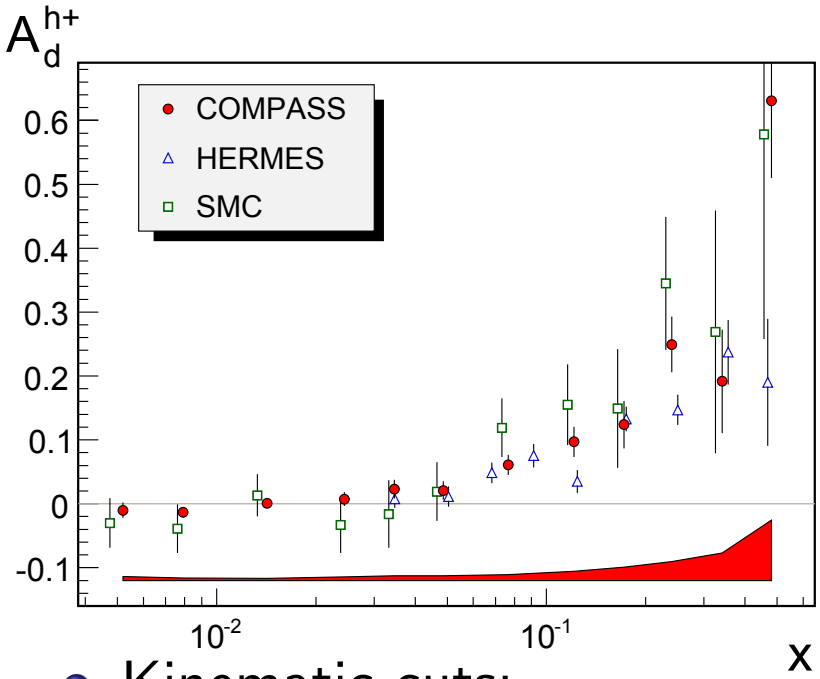
  $a_8 = 0.585 \pm 0.025$ (Y.Goto et. al., PRD62(2000)034017)
- Quark polarization at $Q^2 = 3GeV^2$:

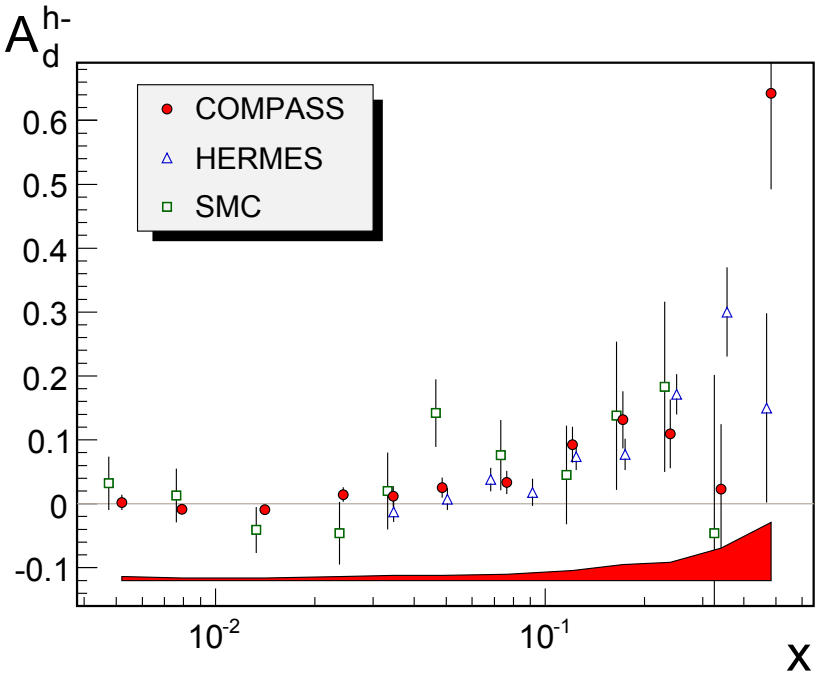
  $a_0 = 0.35 \pm 0.03(stat) \pm 0.05(syst)$

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

Single hadron asymmetries

$$A^h = \frac{\sigma^h_{\uparrow\downarrow} - \sigma^h_{\uparrow\uparrow}}{\sigma^{h+}_{\uparrow\downarrow} + \sigma^h_{\uparrow\uparrow}} \xrightarrow{\text{QPM}} \frac{\sum_q e_q^2 \left(\Delta q(x) D_q^h + \Delta \bar{q}(x) D_{\bar{q}}^h\right)}{\sum_q e_q^2 \left(q(x) D_q^h + \bar{q}(x) D_{\bar{q}}^h\right)}$$

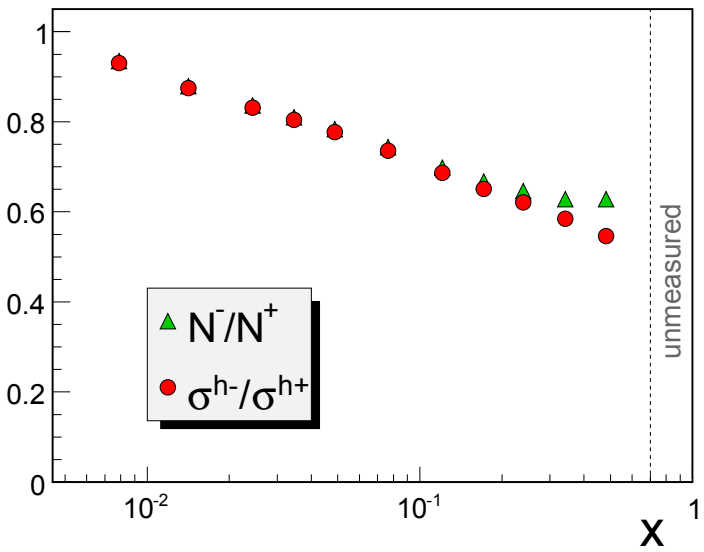


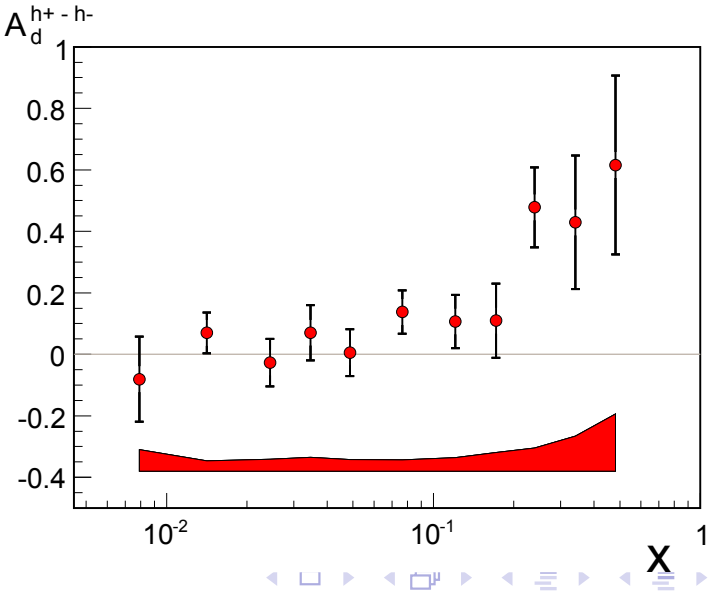


- Kinematic cuts:
  $Q^2 > 1(\mathrm{GeV/c})^2$, $0.1 < y < 0.9$, $0.2 < z < 0.85$
- Final statistics: $N^+ = 30 \cdot 10^6$, $N^- = 25 \cdot 10^6$,
  $corr(N^+, N^-) \approx 20\%$

Difference asymmetry

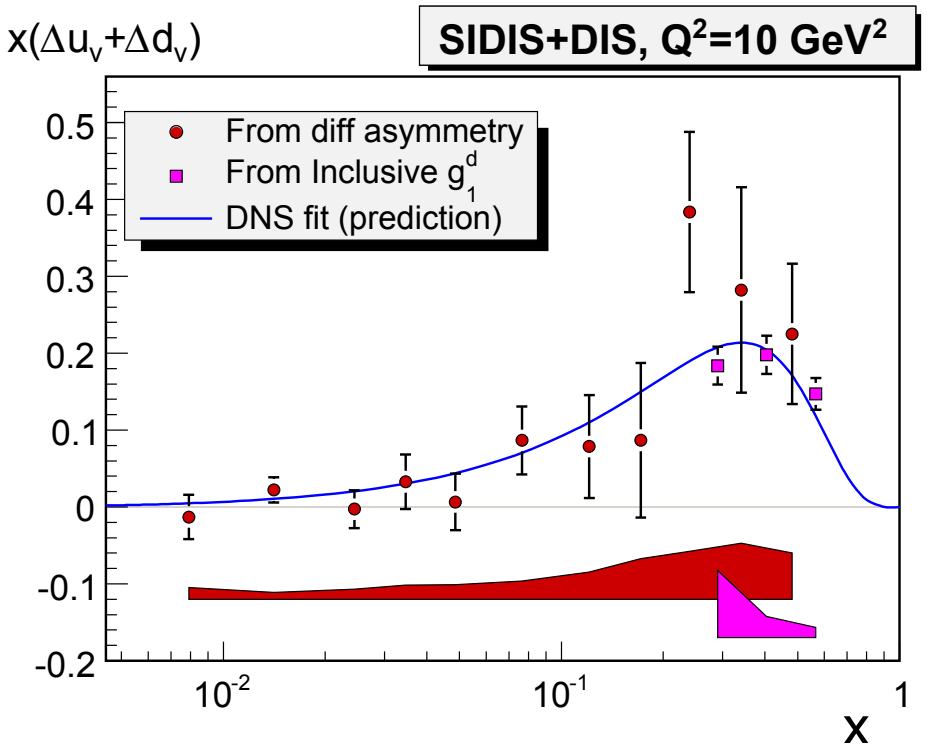
- Definition: $A^{h^+-h^-} = \frac{(\sigma^{h+}_{\uparrow\downarrow} - \sigma^{h-}_{\uparrow\downarrow}) - (\sigma^{h+}_{\uparrow\uparrow} - \sigma^{h-}_{\uparrow\uparrow})}{(\sigma^{h+}_{\uparrow\downarrow} - \sigma^{h-}_{\uparrow\downarrow}) + (\sigma^{h+}_{\uparrow\uparrow} - \sigma^{h-}_{\uparrow\uparrow})}$
- In LO FF cancel out. For a deuteron target:
$$A_d^{\pi^+-\pi^-}(x) = A_d^{K^+-K^-}(x) = \frac{\Delta u_v(x) + \Delta d_v(x)}{u_v(x) + d_v(x)}$$
- $A^{h^+-h^-}$ calculated from A^{h+} and A^{h-}:
$$A^{h^+-h^-} = \frac{1}{1-r}(A^{h+} - rA^{h-}),\ r = \frac{\sigma^{h-}_{\uparrow\downarrow} + \sigma^{h-}_{\uparrow\uparrow}}{\sigma^{h+}_{\uparrow\downarrow} + \sigma^{h+}_{\uparrow\uparrow}} = \frac{\sigma^{h-}}{\sigma^{h+}} = \frac{N^-/a^-}{N^+/a^+}$$





Valence quark distribution

$$x(\Delta x_v(x)+\Delta d_v(x))= \frac{x(u_v(x)+d_v(x))}{(1+R(x))(1-1.5\omega_D)} A^{h^+-h^-}(x), \quad \omega_D=0.05\pm0.01$$

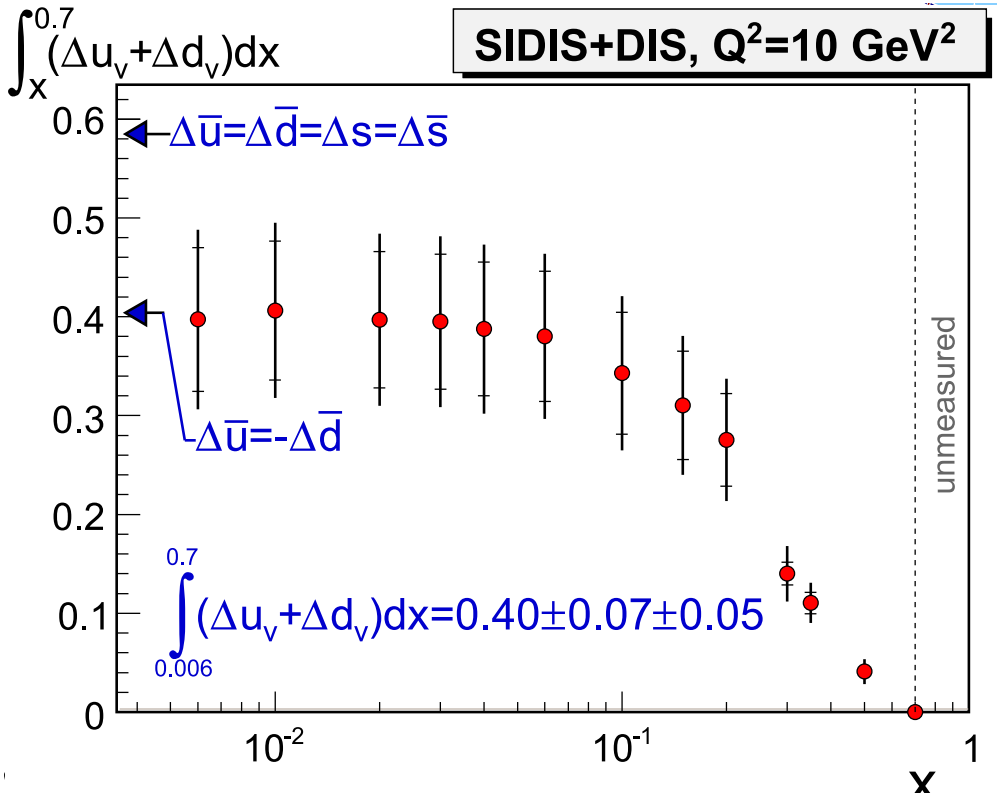


- evolved to $Q^2 = 10$ (GeV/c)^2
- using LO DNS parameterization (PRD 71(2005)094018)
- DNS predicts COMPASS data
- for $u_v + d_v$ MRST04(LO) used

sea very small at large x, with inclusive asymmetry much better precision

$$\Delta u_v + \Delta d_v = \frac{36}{5}\frac{g_1^d(x,Q^2)}{(1-1.5\omega_D)} - \left[2(\Delta\bar{u}+\Delta\bar{d}) + \frac{2}{5}(\Delta\bar{s}+\Delta\bar{s})\right]$$

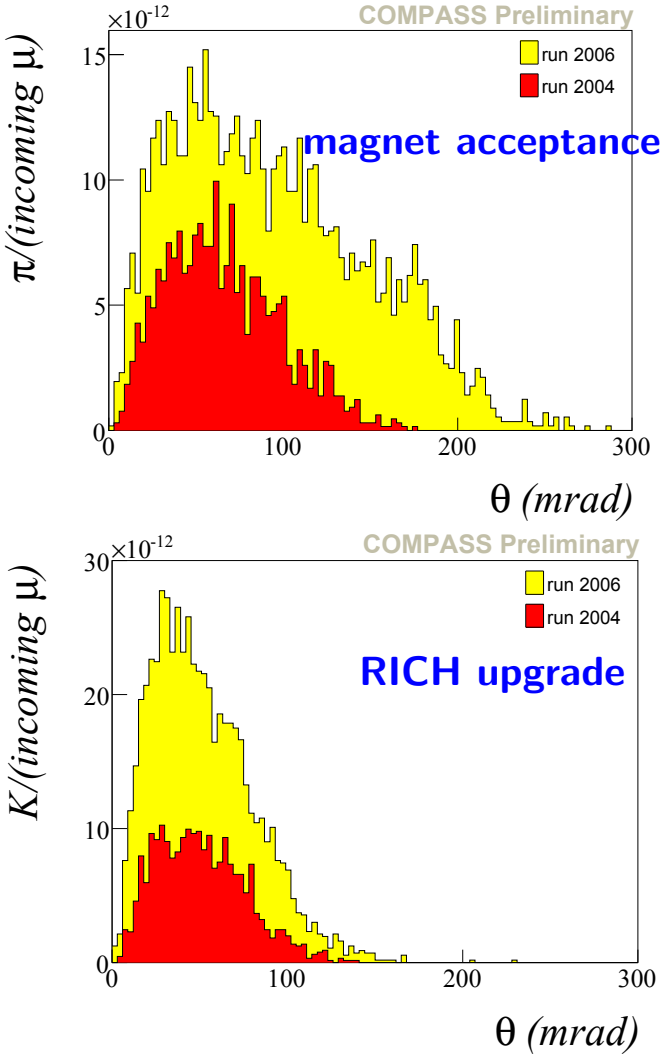
Estimate for the fist moment (LO)



- First moment
  $\Gamma_v = \int_0^1(\Delta u_v(x)+\Delta d_v(x))dx$
- Contribution from $x > 0.7$ about 0.004 (DNS fit)
- Γ_v (DIS+SIDIS) is $2.5\sigma_{stat}$ away from the symetric sea scenario, asymmetric sea favoured

Estimation of the statistical errors with 2006 and 2007 data

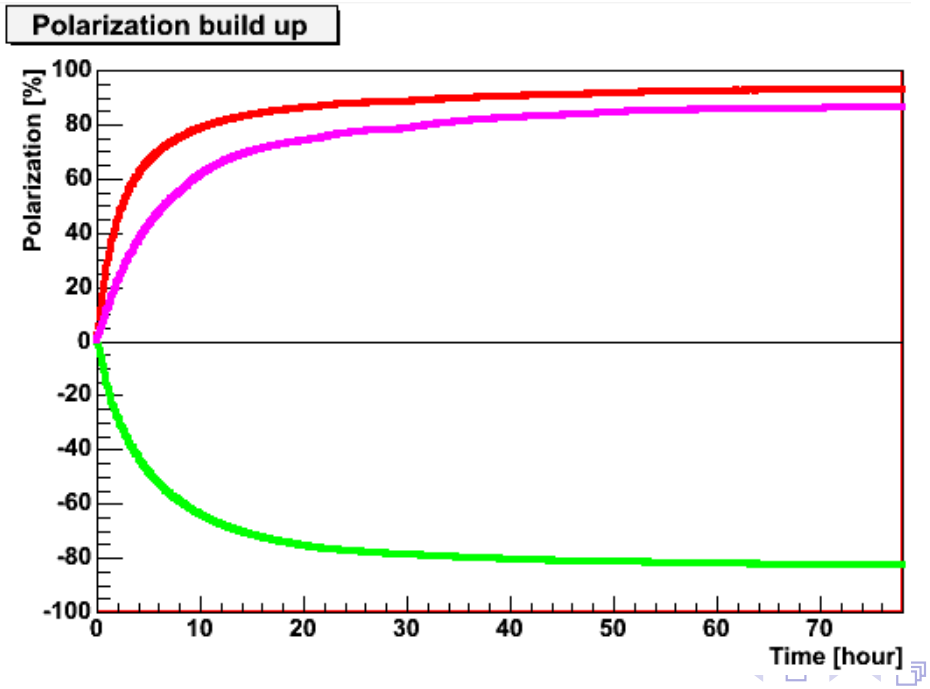
2006 setup



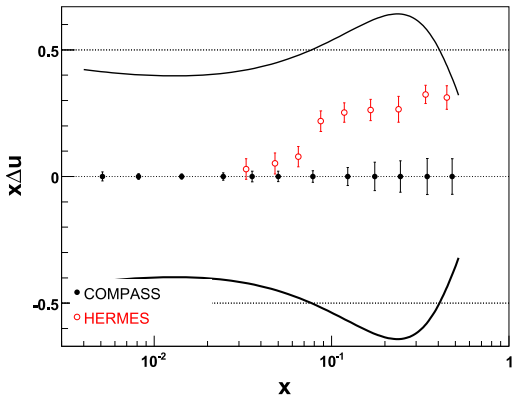
- New target magnet:
  - angular acceptance increased to 180mrad
  - 3 cells used to reduce false asymmetries
- RICH upgrade
- ECAL1 included
- RICH Wall - preshower for ECAL1
- more large angle trackers in first stage
- gain mainly in high x and Q^2

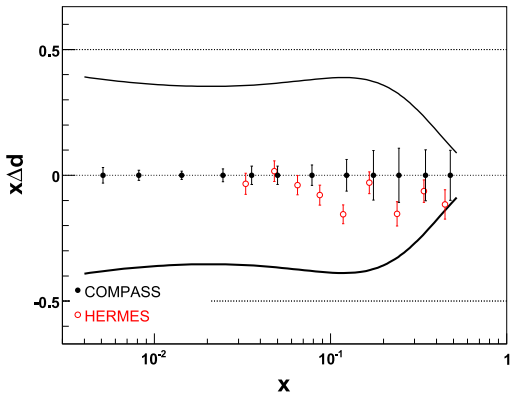
2007 setup

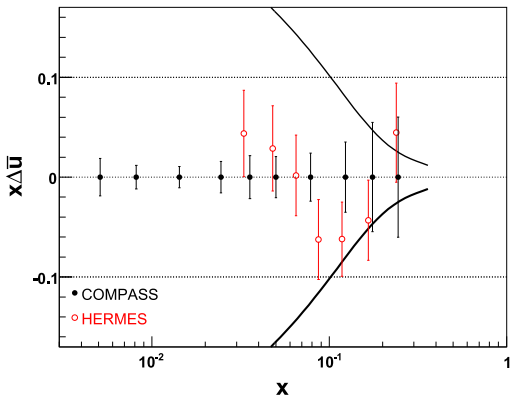
- New target material: NH_3
  - proton data will allow to distinguish u and d polarization
  - very high polarization (90%)
- new trigger using ECAL1
- longitudinal and transverse polarization

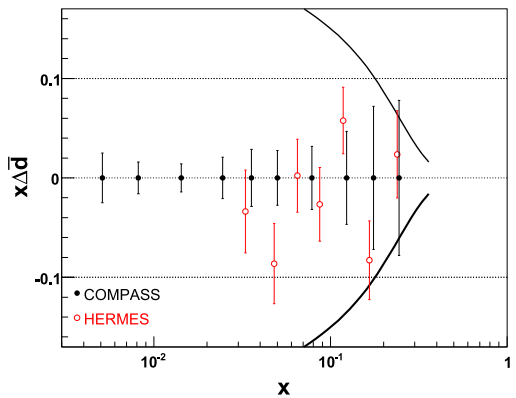


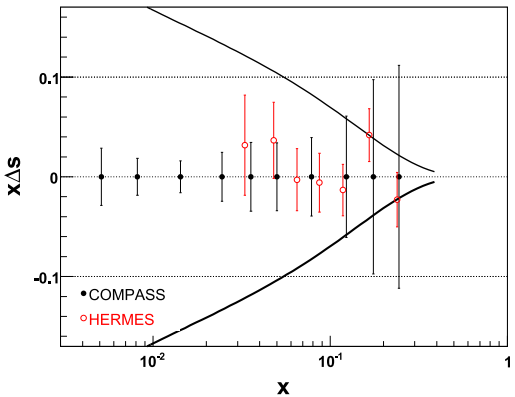
Expectations with 2007 (proton) and 2002-2006 (deuteron) data











	$0.004 - 0.03$	$0.004 - 0.7$
$\delta(\delta u_v)$	0.020	0.07
$\delta(\delta d_v)$	0.036	0.11
$\delta(\delta \bar{u})$	0.013	0.04
$\delta(\delta \bar{d})$	0.017	0.05
$\delta(\delta s)$	0.003	0.09

Summary

- Analysis of 2002-2004 deuteron data has been presented
- QCD fits to world data give for quark and gluon contributions:

$$\eta_\Sigma(Q_0^2 = 3(GeV/c)^2) = 0.30 \pm 0.01(stat) \pm 0.02(evol)$$

- From the first moment of g_1^d we obtained quark contibution to the nucleon spin (at $Q^2 = 3GeV$):

$$\Delta\Sigma = 0.35 \pm 0.03(stat) \pm 0.05(syst)$$

- Δu_v and Δd_v have been extracted from difference asymmetry for $x < 0.3$ and from g_1^d for $x > 0.3$
- $\int_{0.006}^{0.7}(\Delta u_v + \Delta d_v)\mathrm{d}x = 0.4 \pm 0.07(stat) \pm 0.05(syst)$
- Analysis of 2006 and 2007 data is in progress - update of analysis soon