"Inclusive spin-dependent asymmetry A_1 from COMPASS"

D.Peshekhonov

JINR, Dubna

on behalf of the COMPASS collaboration

Hadron Structure and QCD: from low to high energies
Gatchina, Russia, 30 June-4 July 2008

Overview:

- COMPASS experiment
- Spin of the nucleon and deep-inelastic scattering
- Inclusive asymmetry A_1 and structure function g_1
- QCD analysis
- Summary and outlook





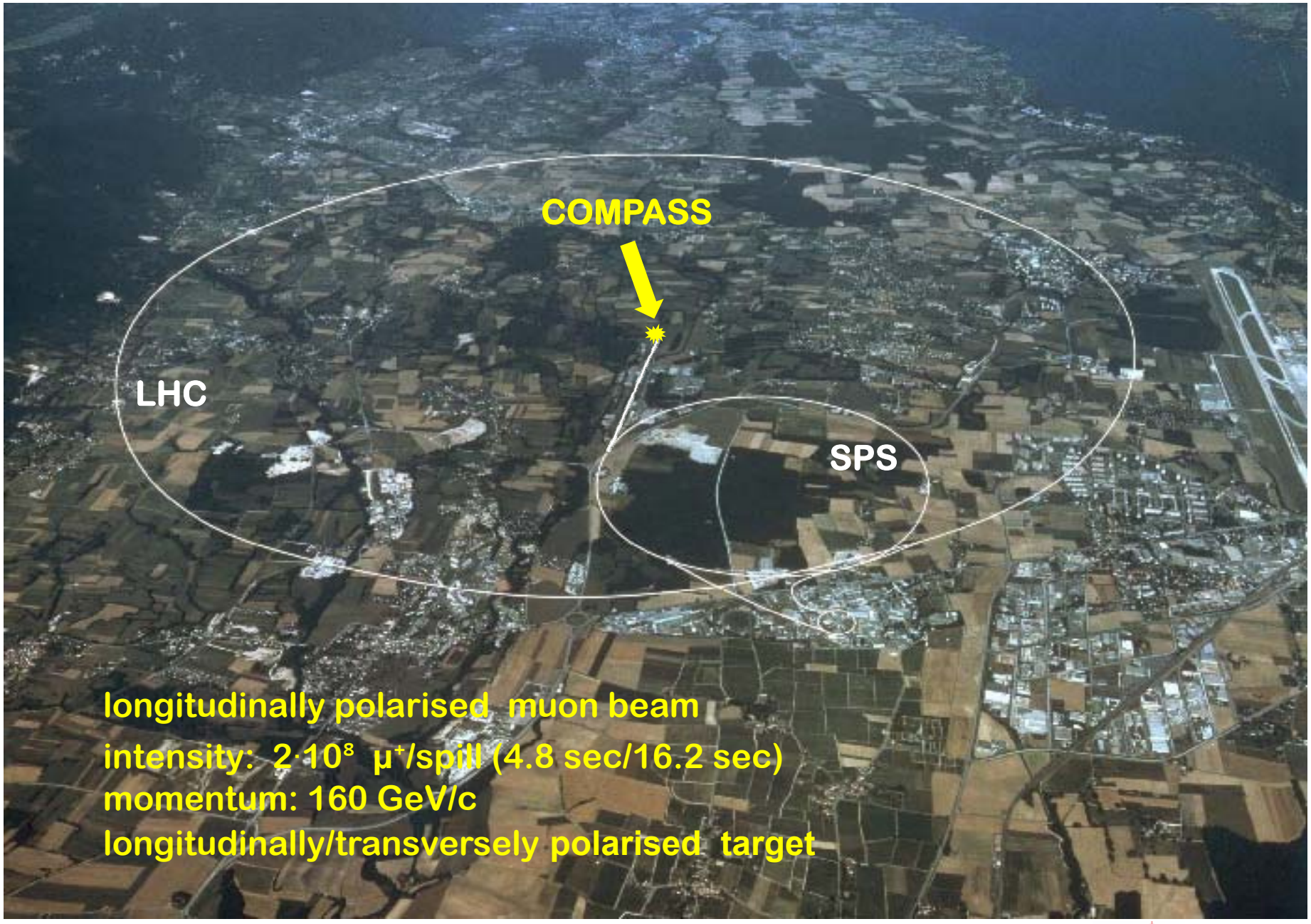





COmmon
Muon and
Proton
Apparatus for
Structure and
Spectroscopy

28 Institutes: ***Bielefeld, Bochum, Bonn, Calcutta, CERN, Dubna, Erlangen, Freiburg, Lisbon, Mainz, Moscow, Munich, Prague, Protvino, Saclay, Tel Aviv, Torino, Trieste, Yamagata, Warsaw***

~ 230 physicists


COMPASS
LHC
SPS
longitudinally polarised muon beam
intensity: $2 \cdot 10^8$ μ^+/spill (4.8 sec/16.2 sec)
momentum: 160 GeV/c
longitudinally/transversely polarised target

Physics program of COMPASS

With μ beam

Spin dependent structure functions

Polarized quark distributions

Gluon polarization

Transversity

Lambda polarization

Vector meson production

With hadron beam

Pion and Kaon polarizabilities

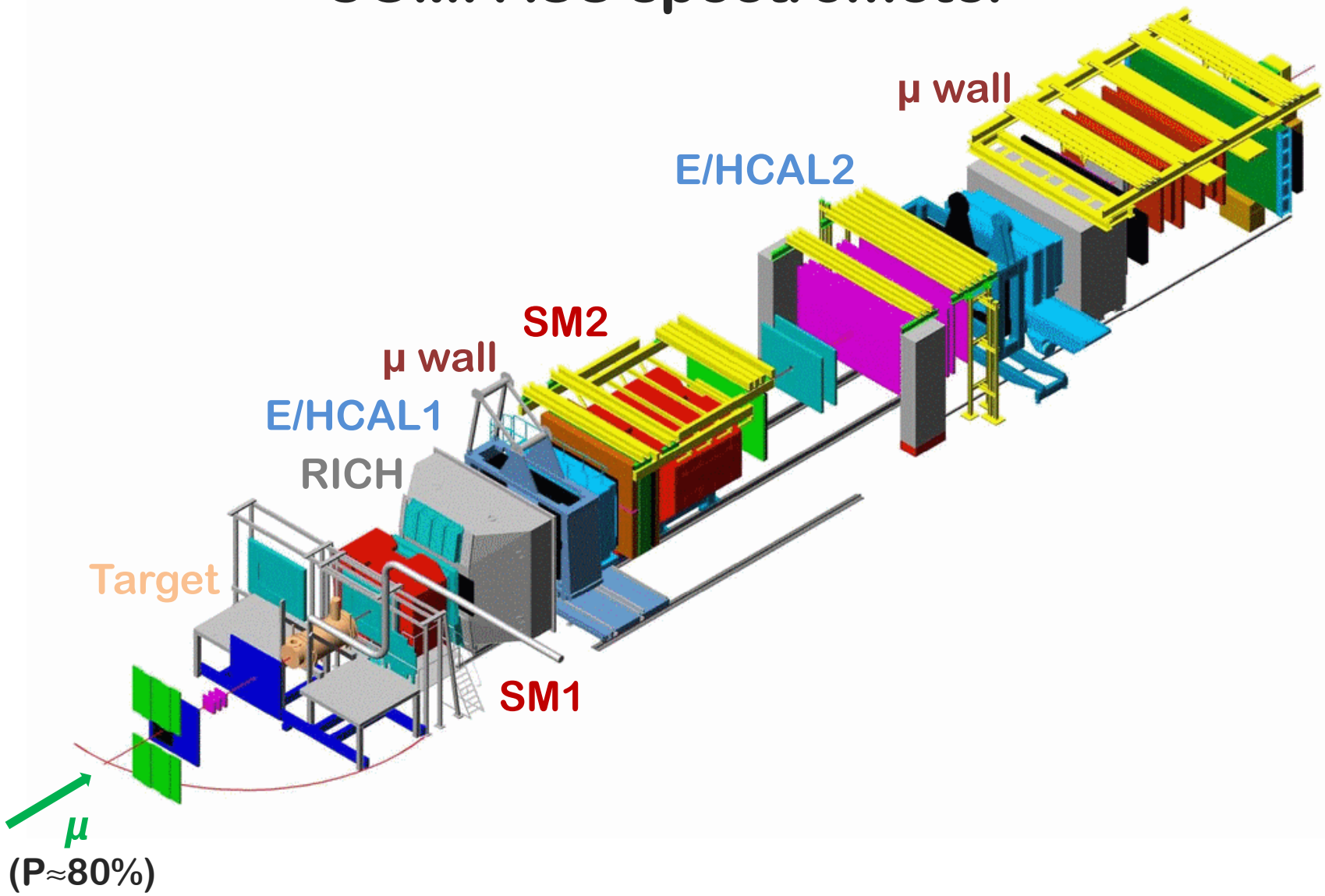
Diffractive production of exotic states

Search for glueball

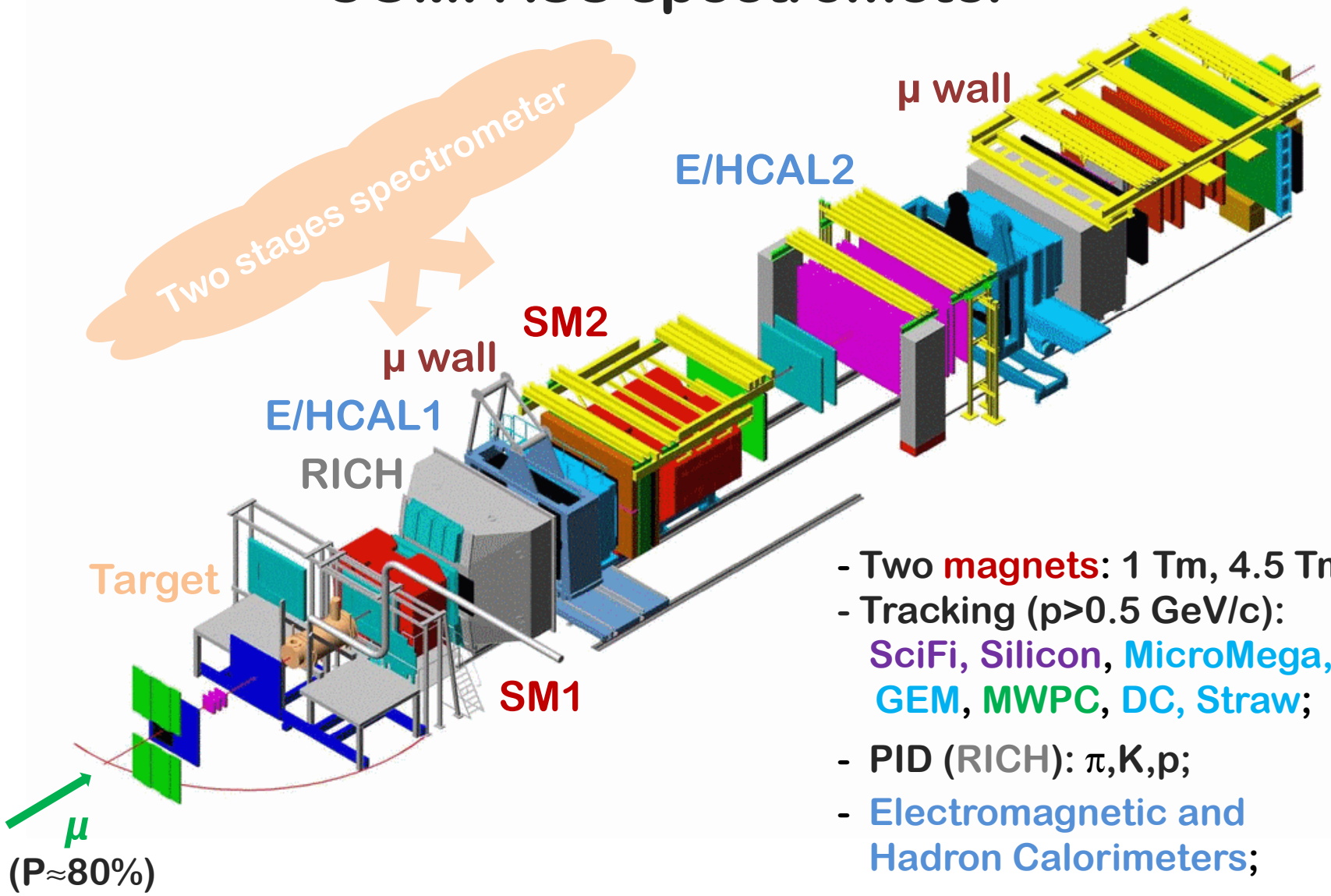
Light meson spectroscopy

Production of double charmed baryons

COMPASS spectrometer

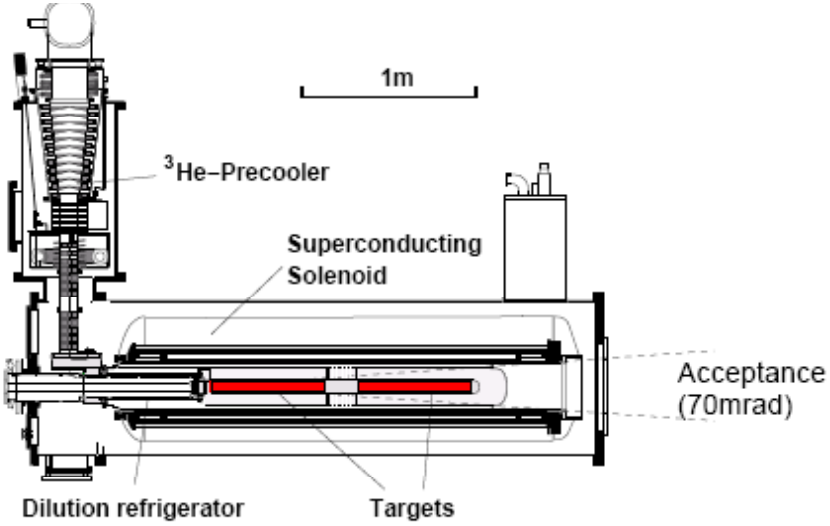


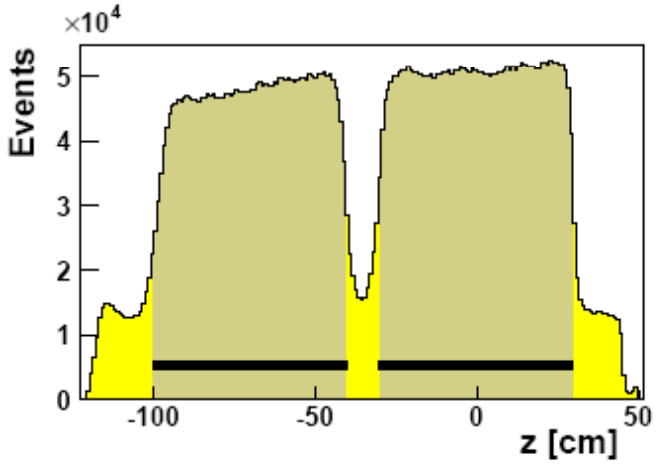
COMPASS spectrometer



- Two magnets: 1 Tm, 4.5 Tm;
- Tracking (p>0.5 GeV/c): SciFi, Silicon, MicroMega, GEM, MWPC, DC, Straw;
- PID (RICH): π,K,p;
- Electromagnetic and Hadron Calorimeters;

COMPASS polarized target 2002-2004



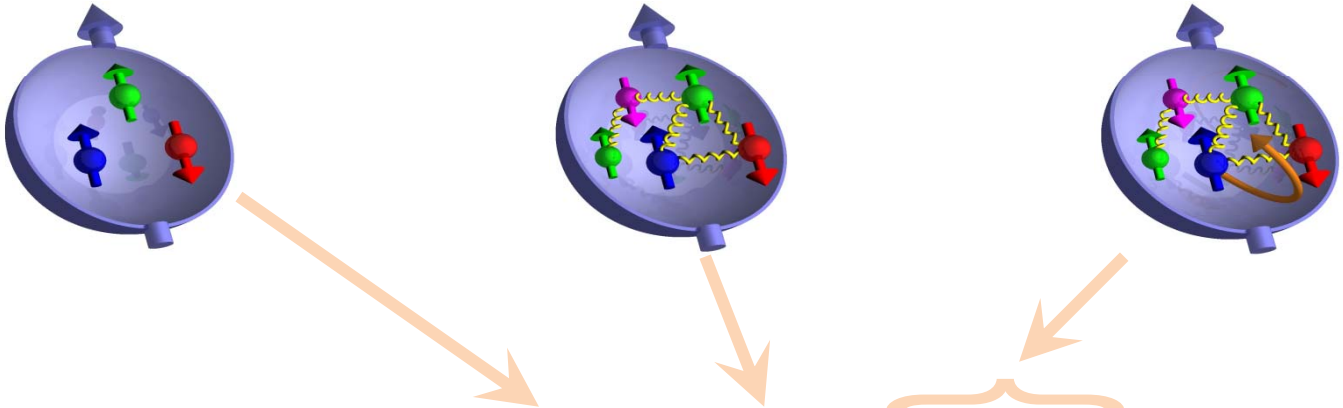


2 cells polarized target ^{6}LiD (50%)

- polarization: P >50%
- dilution factor: ~0.4
- **D**ynamic **N**uclear **P**olarization
- solenoid field: 2.5T
- acceptance: 70mrad
- ^{3}He/ ^{4}He: $t_{min} \approx 50$mK
- two 60cm long target cells with opposite polarization
- regular spin reversal

Spin of the nucleon
&
Deep-inelastic scattering

Spin of the nucleon



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

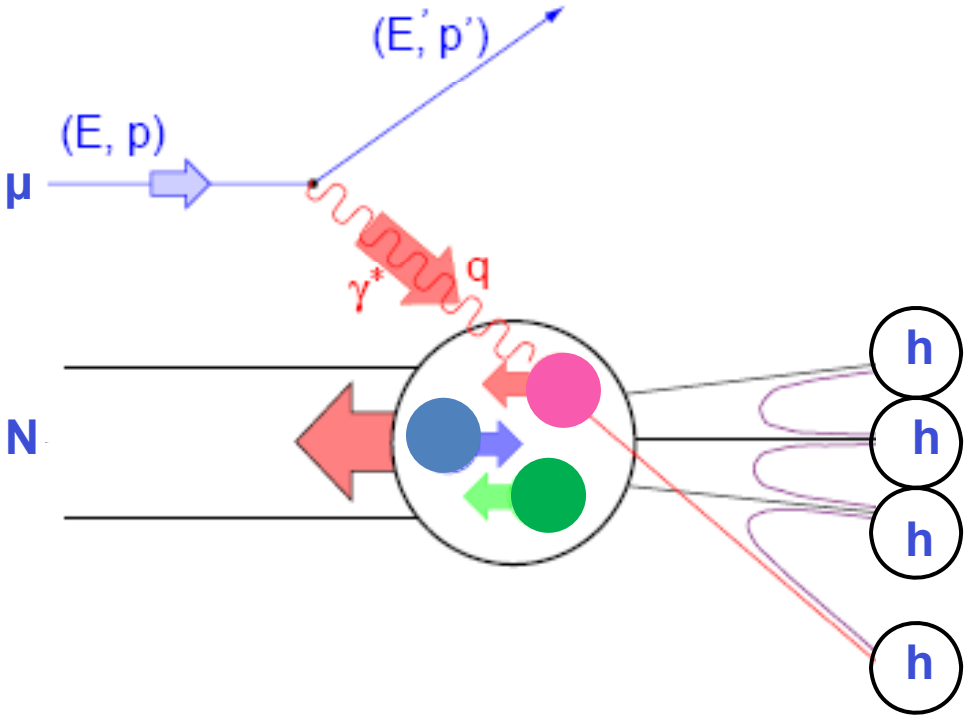
Constituent parton model:

$\Delta\Sigma = \Delta u_v + \Delta d_v = 1$

Complete description :

- $\Delta\Sigma = \Delta u + \Delta d + \Delta s$ (for q and $\bar{q}$)
- ΔG
- orbital angular momenta

Deep inelastic scattering



Kinematical variables:

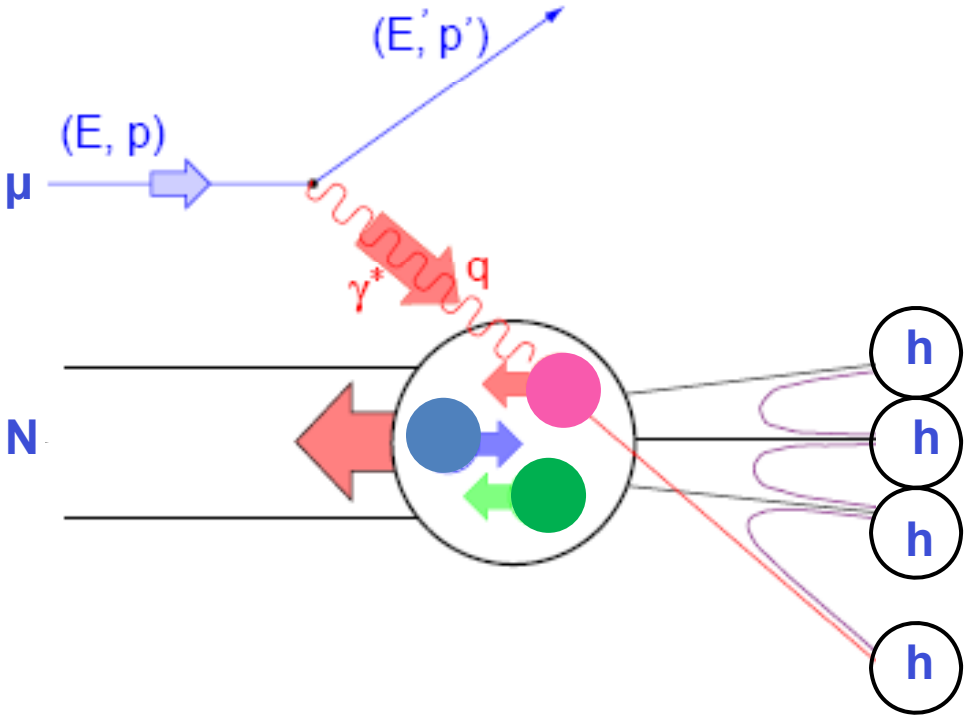
$Q^2 = -q^2$

$x = Q^2/2M\nu$

$\nu = E - E'$

$y = \nu/E$

Deep inelastic scattering



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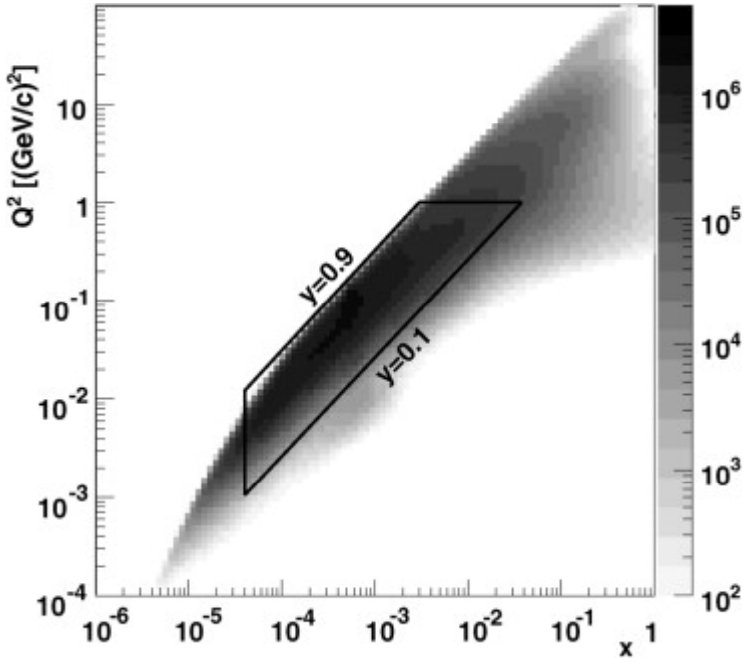
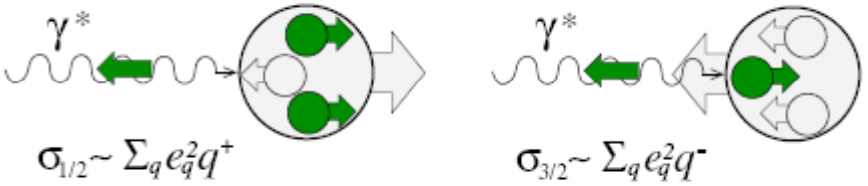


Deep inelastic scattering

- quark densities in QPM:

  $q(x) = q^{+}(x) + q^{-}(x)$

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



- Longitudinal double-spin asymmetry:

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

- Cross-sections

  and

  Structure functions:

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

- Longitudinal spin asymmetry μN:

$$A^{\mu N} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} = \frac{\Delta\sigma}{\bar{\sigma}} \simeq D A_1$$

D – depolarization factor of γ

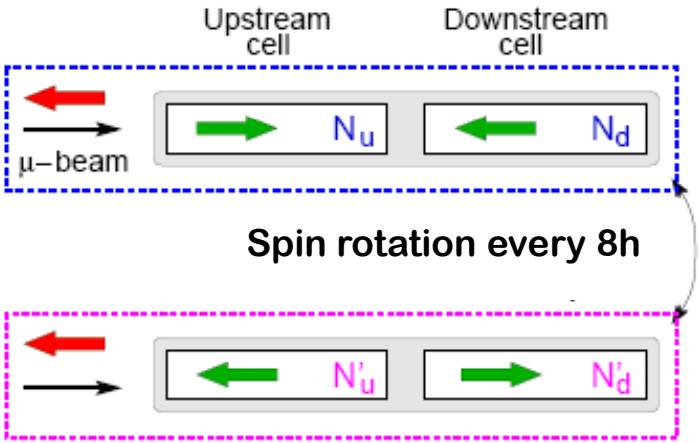
- Structure functions and PDF:

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

- Asymmetry A_1 and structure function g_1: $g_1 \approx A_1 \cdot F_1$

Method

- to be measured: $A_{\parallel} = \frac{\sigma^{\Uparrow\downarrow} - \sigma^{\Uparrow\uparrow}}{\sigma^{\Uparrow\downarrow} + \sigma^{\Uparrow\uparrow}}$
- measured values: $N_u,\ N_d,\ N'_u,\ N'_d$
- flux normalization: $\frac{\Phi_u}{\Phi_d} = 1$
- acceptance: (constant ratio) $\frac{\varepsilon'_d}{\varepsilon'_u} = 1$
- double ratio method: $\delta = \frac{N_u \cdot N'_d}{N'_u \cdot N_d}$



⇒ solve for A_{exp} (2nd order equation)

⇒ minimization of bias

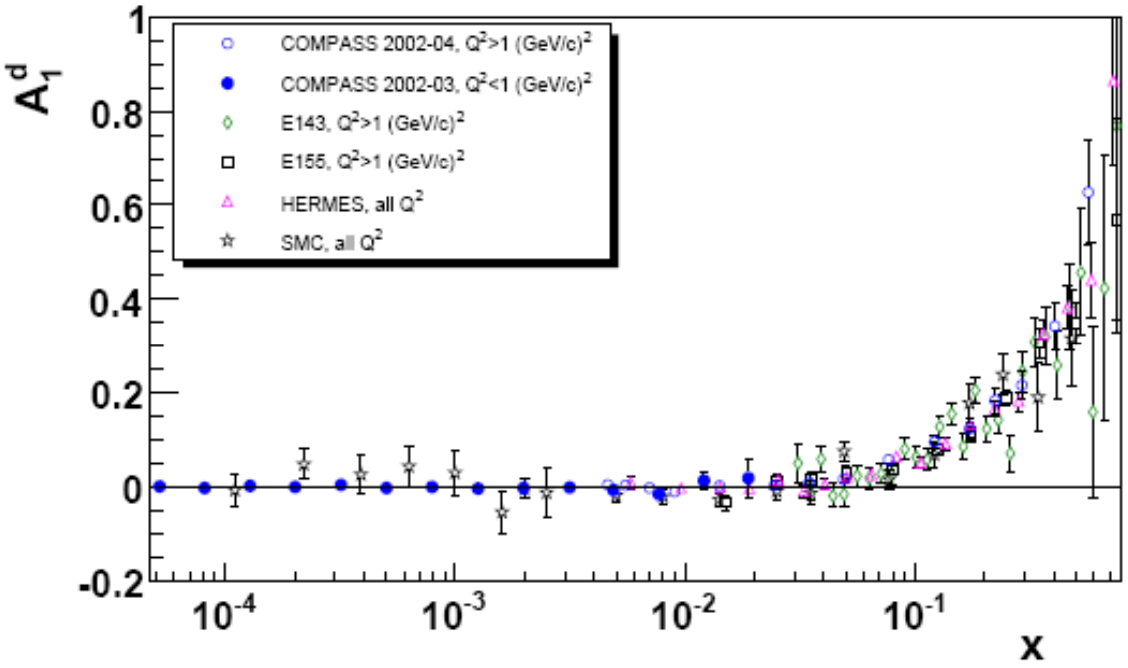
- experimental asymmetry: $A_{exp} = P_\mu\ P_T\ f\ A_{\parallel}$

P_μ ,P_T - beam and target polarization

f - dilution factor

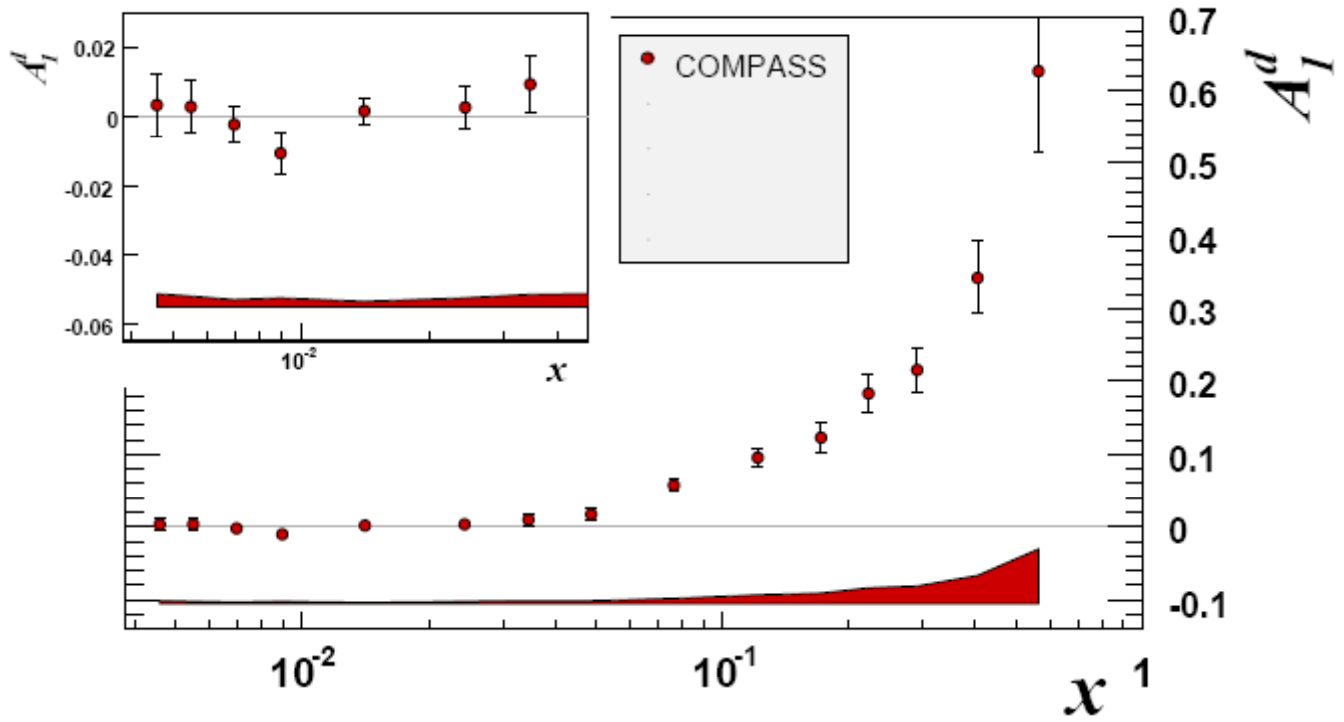
Inclusive asymmetry A_1

Inclusive asymmetry for $Q^2 < 1$ (GeV/c)^2



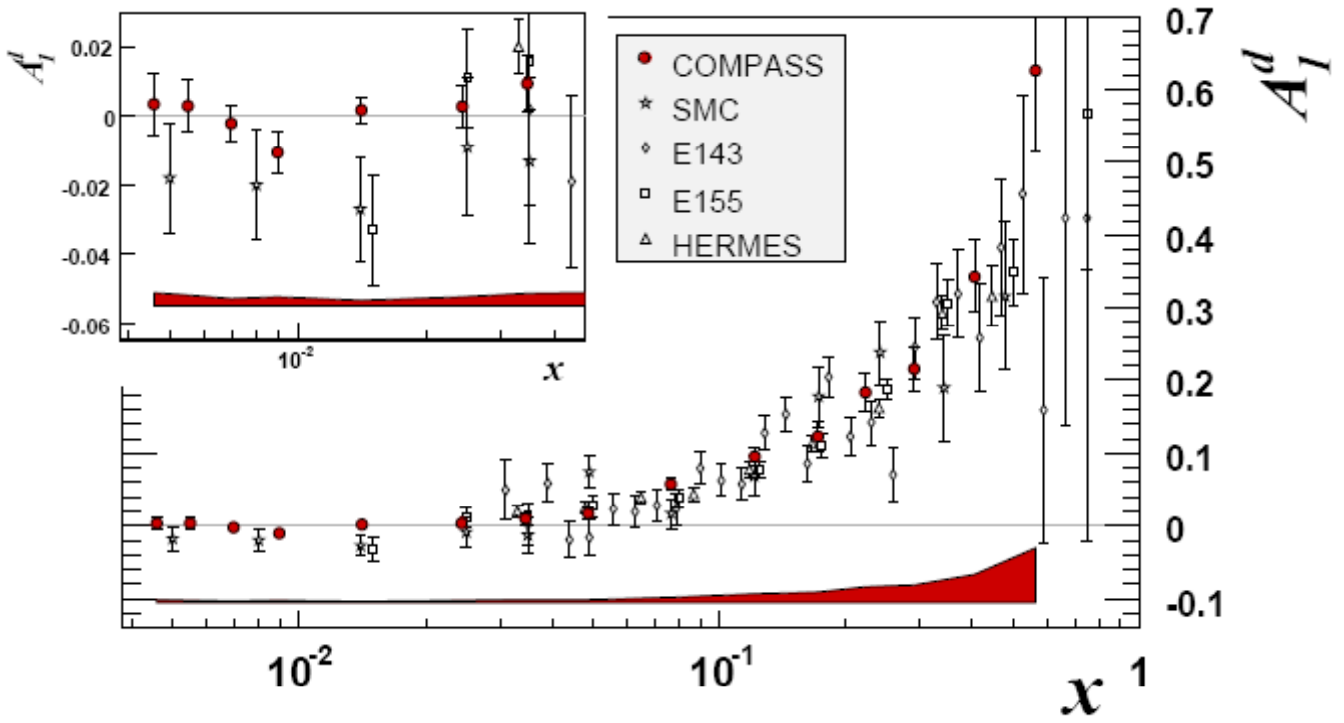
- Results are published in PLB 647(2007)330
- Systematic error mainly due to false asymmetries
- A_1^d is compatible with 0 at small x
- $3 \cdot 10^8$ events: factor 10-20 improvement in statistical errors compared to SMC

Inclusive asymmetry for $Q^2 > 1$ (GeV/c)^2



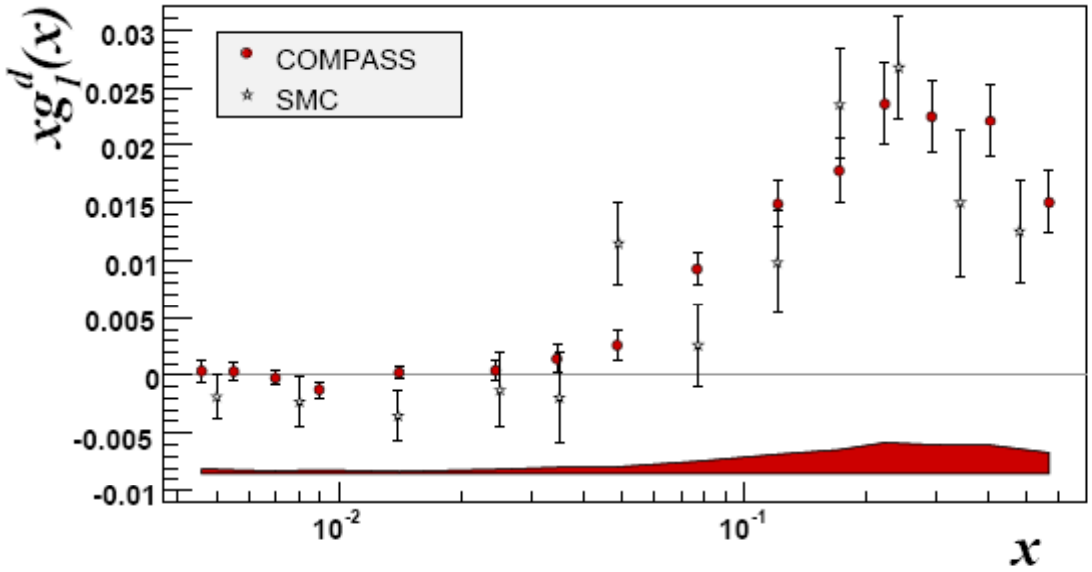
- Results are published in PLB 647(2007) 8
- Systematic errors: p_μ(5%),p_T(5%),f (2÷3%),D (6%) $\rightarrow \delta A_1 \approx 0.1 A_1$
- $88 \cdot 10^6$ events for $0.7 > x > 0.004$, $0.1 < y < 0.9$

Inclusive asymmetry for $Q^2 > 1$ (GeV/c)^2

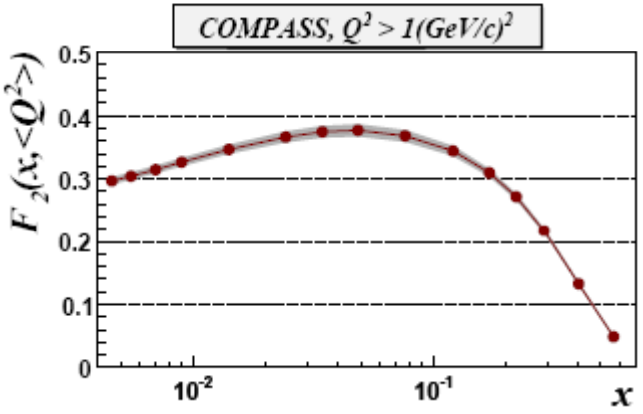


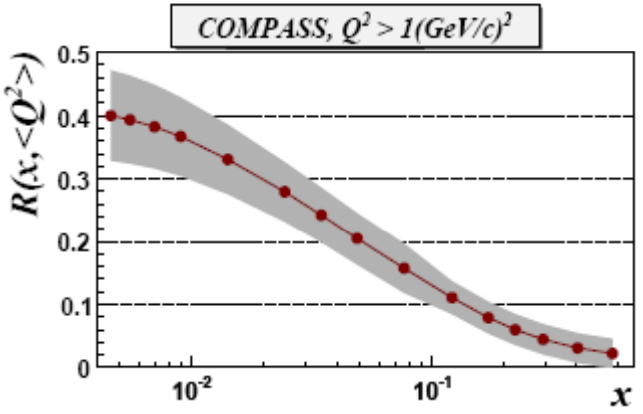
- Results are published in PLB 647(2007) 8
- A_1^d is compatible with 0 for $x < 0.05$
- good agreement with previous experiments

Structure function $g_1(x)$ at measured Q^2



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





First moment of g_1

- COMPASS data only

$$\Gamma_1^{\mathrm{N}}\ (Q^2 = 3(\mathrm{GeV/c})^2) = \int_0^1 g_1^{\mathrm{N}}(x)\,\mathrm{d}x$$

$$= 0.0502 \pm 0.0028(\mathrm{stat}) \pm 0.0020(\mathrm{evol.}) \pm 0.0051(\mathrm{syst.})$$

- data for 0.004<x<0.7, QCD fit used for extrapolation
- contribution of unmeasured region about 3%

- using $\Gamma_1^{\mathrm{N}} = \frac{1}{9}(1 - \frac{\alpha_s(Q^2)}{\pi} + O(\alpha + s^2))(a_0(Q^2) + \frac{1}{4}a_8)$

$$a_0(Q^2 = 3(\mathrm{GeV/c})^2) = 0.35 \pm 0.03(\mathrm{stat}) \pm 0.05(\mathrm{syst})$$

- extrapolation $Q^2 \to \infty$: $\hat{a}_0 = 0.33 \pm 0.03(\mathrm{stat.}) \pm 0.05(\mathrm{syst.}) = \Delta\Sigma$

$$(\Delta s + \Delta\bar{s}) = \tfrac{1}{3}(\hat{a}_0 + a_8) = -0.08 \pm 0.01(\mathrm{stat.}) \pm 0.02(\mathrm{syst.})$$

- negative strange sea polarization

QCD analysis

QCD analysis

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

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

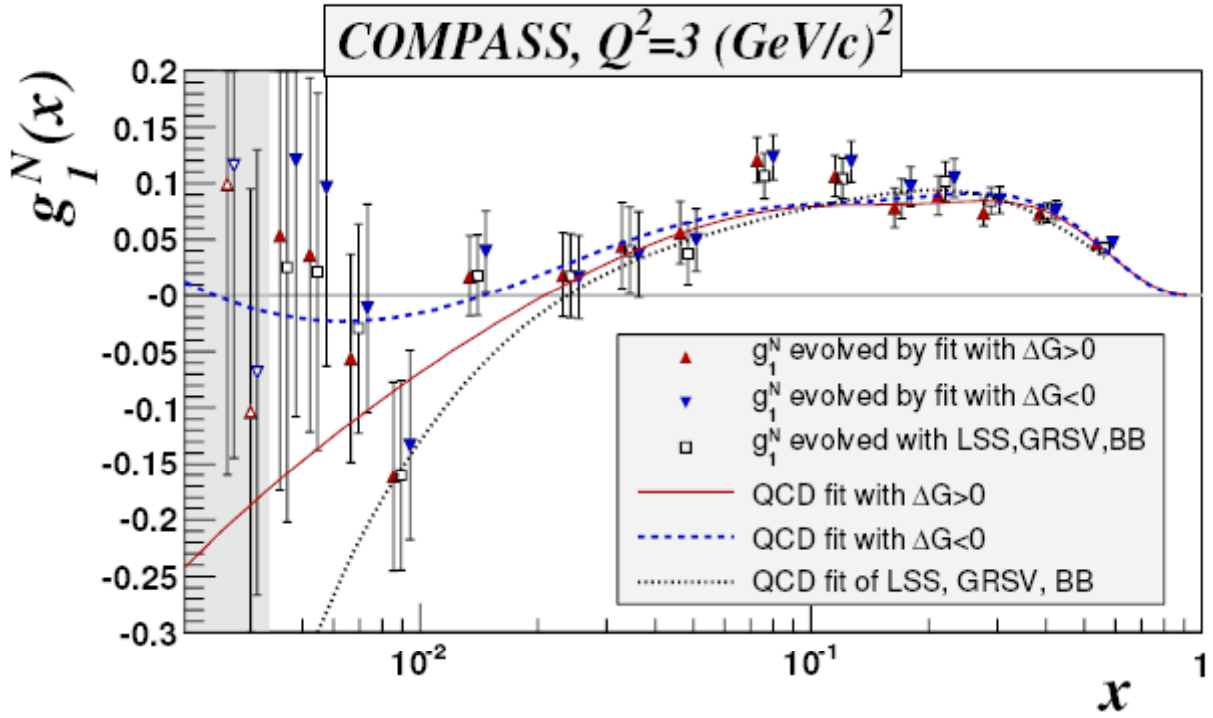
- Two programs have been used:
  1. Numerical integration in x - Q^2 space (Phys.Rev.D58(1998)112002)
  2. Solution of DGLAP in space of moments (Phys.Rev.D70(2004)074032)

- NLO calculation in $\overline{\text{MS}}$ scheme
- Initial parametrization (x-dependence at fixed Q^2)

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

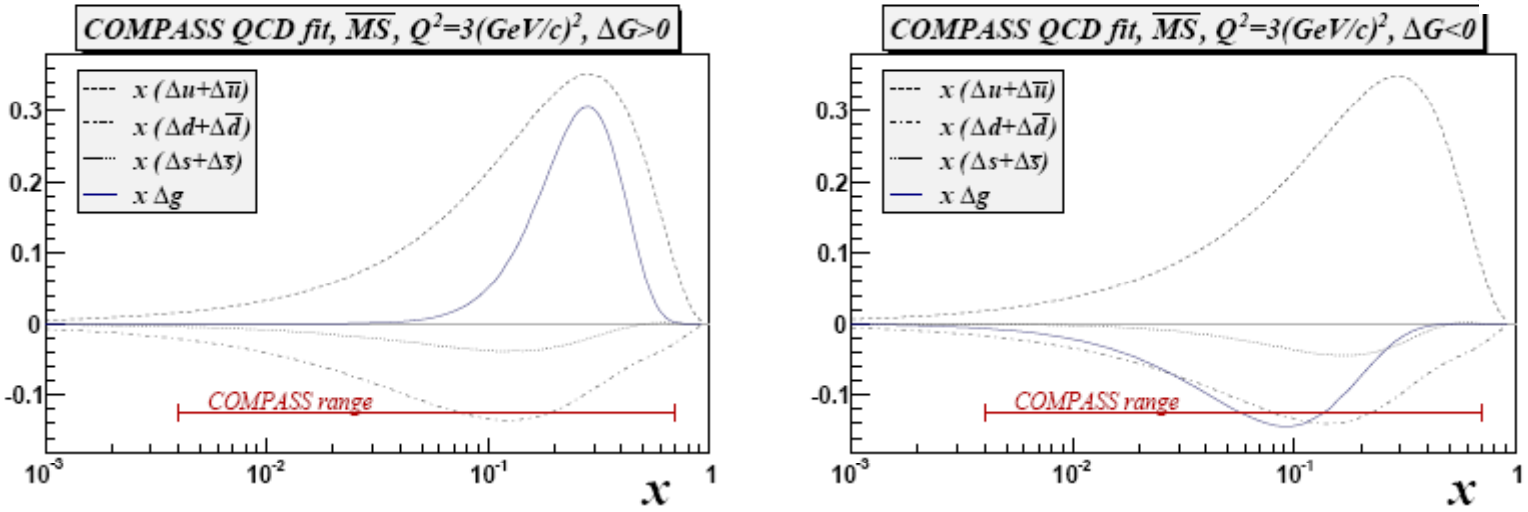
- World data fit: 230 experimental points from 9 experiments
- Two solutions have been found: describe data equally well and correspond to $\Delta G > 0$ and $\Delta G < 0$

QCD analysis



Fit of world data (except final g_1^d from HERMES)

Polarized parton distribution

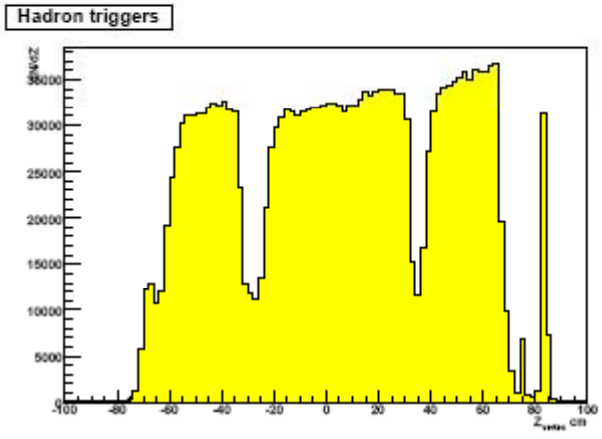


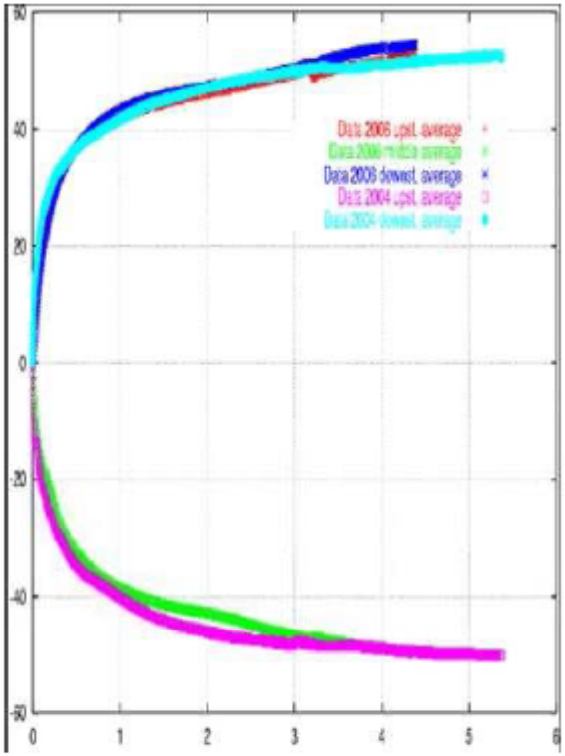
- $\Delta\Sigma = 0.30 \pm 0.01(\text{stat.}) \pm 0.02(\text{evol.})$
- **Small sensitivity to the gluon polarization**
- **Gluon polarization $|\Delta G| \approx 0.2 \div 0.3$**

2006-2007 data

Data taking 2006

- target material: ^{6}LiD
- longitudinal polarization
- increase statistics by about 40%
- larger increase at high x and Q^2 (acceptance)
- reconstruction finished



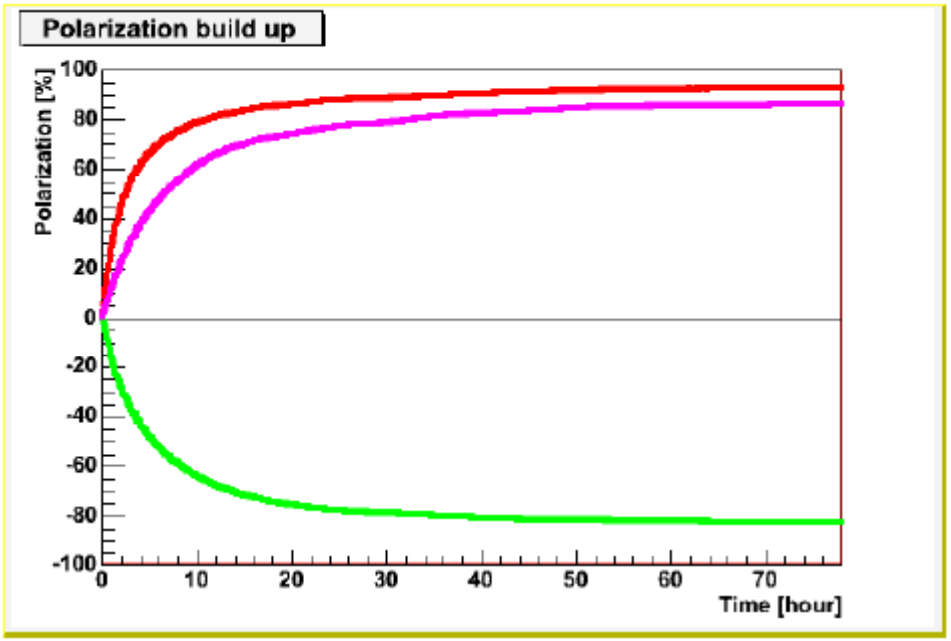


Polarization of ^{6}LiD in 2006:
53.5% -52% 56.2%

Higher and faster than in 2004

Data taking 2007

- longitudinal and transverse polarizations
- new trigger with use of ECAL1
- integrated beam flux about 30% of 2002-2006



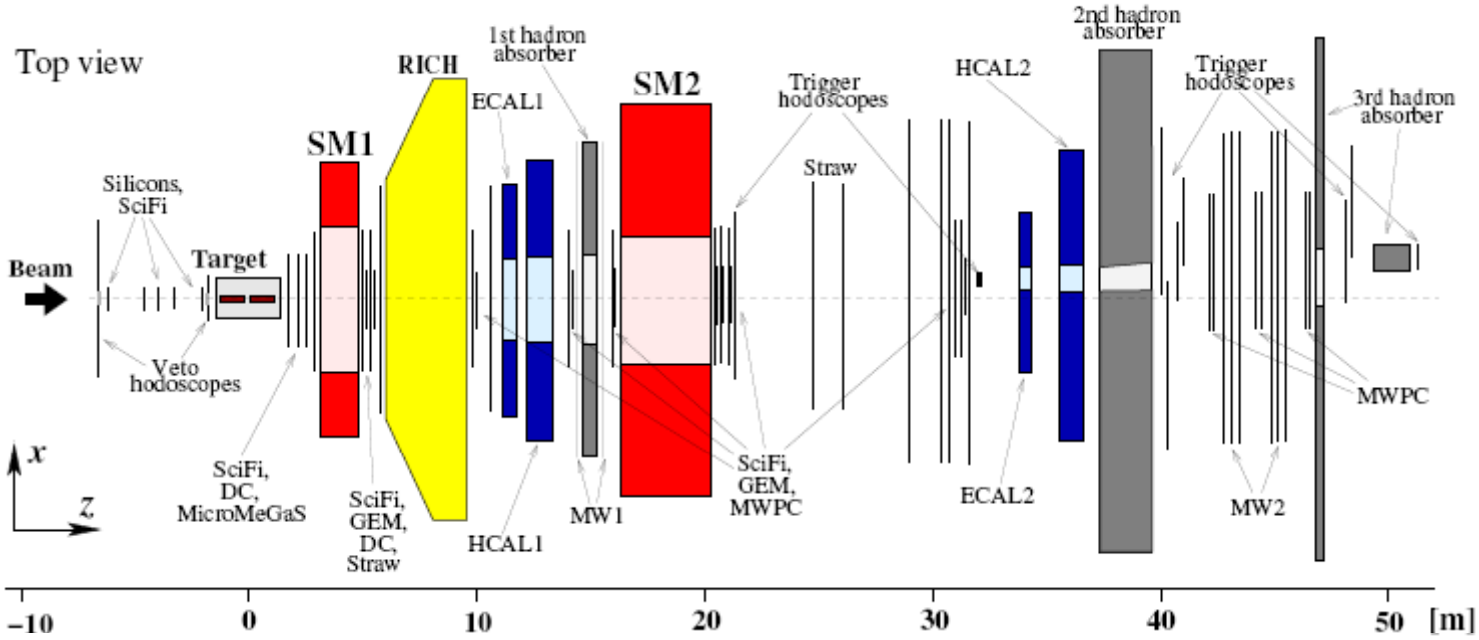
- target material: NH_3
- high polarization
- very good relaxation time (~ 4000h)
- field rotation without loss of polarization

Polarization in 2007:
+92% -83% +88%

Summary

- Analysis of deuteron data 2002-2004 have been presented:
  - Inclusive asymmetry A_1^d and structure function g_1^d
  - First moment of g_1^d and QCD analysis
- Data of 2006 have been processed, update of A_1^d expected to be soon
- Processing of 2007 data (longitudinal polarization) is in progress

Spare slides



- 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

Expectation from 2006-2007

3^6 =

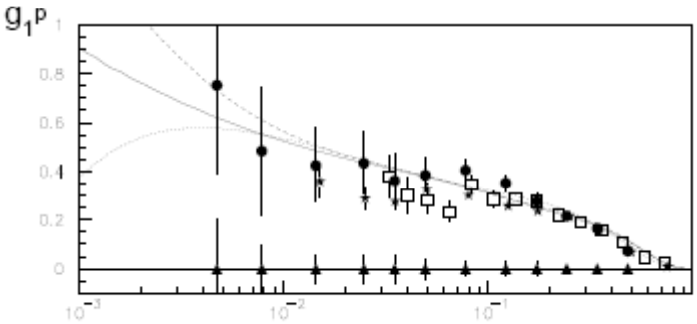
- **longitudinal target polarisation:**

  flavour separation of PDFs

  sign of **strange** sea polarisation at low x

  shape of g_1^p at low x

g_1^p **at low** x

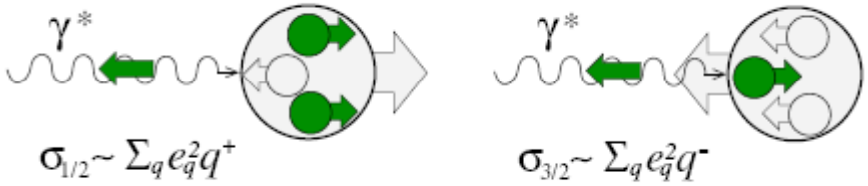


Significant improvement in QCD evolution is possible

Deep inelastic scattering

- Quark densities in QPM:

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



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

- 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:

$$A^{\mu N} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} = \frac{\Delta\sigma}{\bar{\sigma}} \simeq D A_1$$

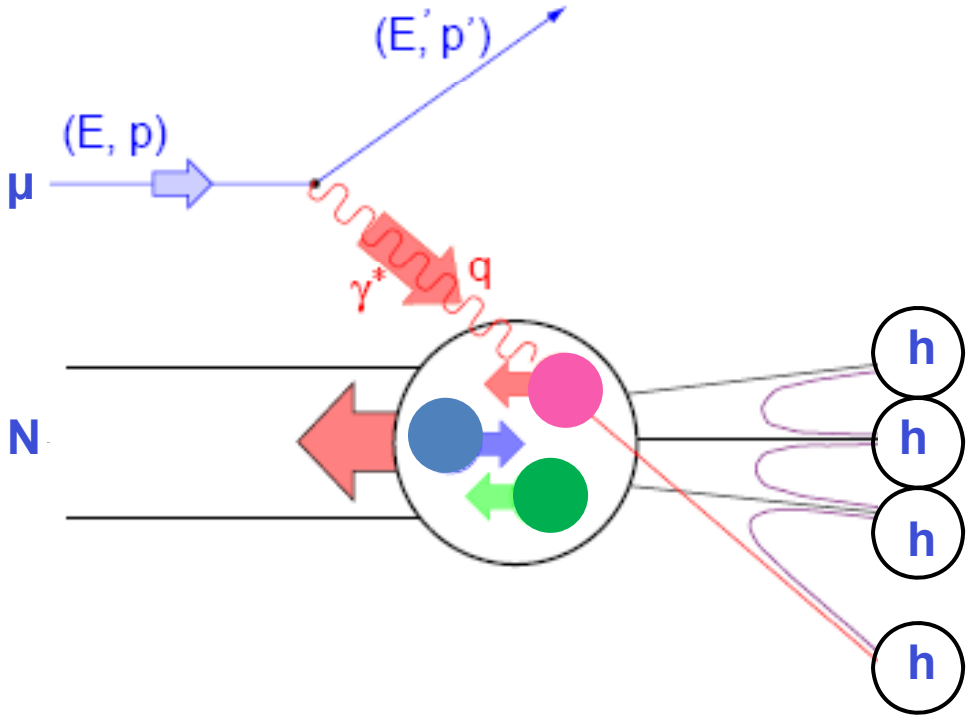
D – depolarization factor of γ

- 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: $g_1 \simeq A_1 \cdot F_1$

Deep inelastic scattering



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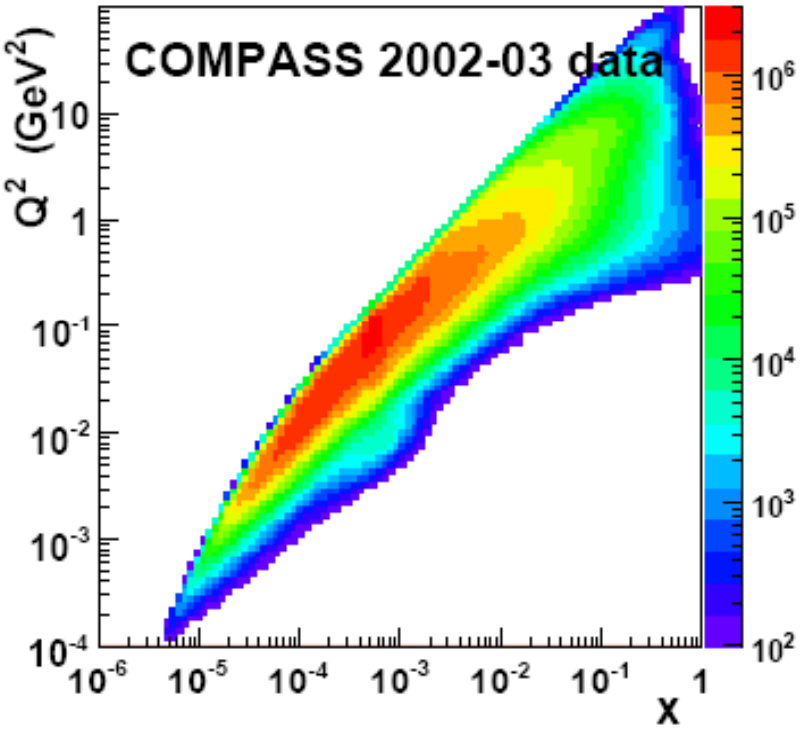

QCD analysis

- 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)
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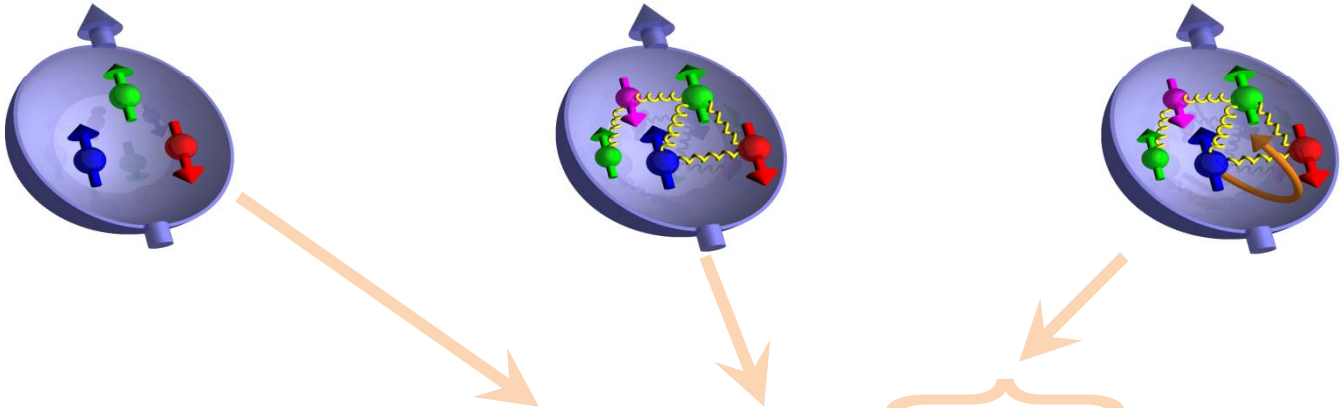
- Initial parametrization (x-dependence at fixed Q^2)

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

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

Spin of the nucleon



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

Naïve parton model:

$\Delta\Sigma = \Delta u_v + \Delta d_v = 1$

$\Delta\Sigma = 0.23 \pm 0.07 \pm 0.19$ (E155)

Complete description :

- $\Delta\Sigma = \Delta u + \Delta d + \Delta s$ (for q and $\bar{q}$)
- ΔG
- orbital angular momenta

Deep inelastic scattering

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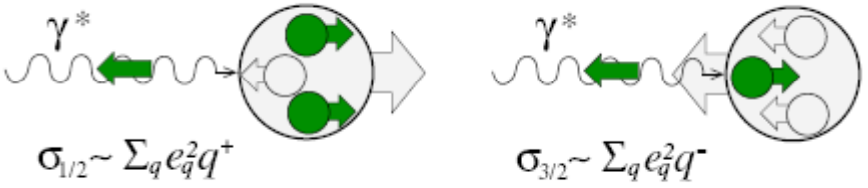

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$$\Delta\sigma(x,Q^2) = \alpha g_1(x,Q^2) + \beta g_2(x,Q^2)$$

- Longitudinal spin asymmetry μN:

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D – depolarization factor of γ

- Structure functions and QDF:

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

- Asymmetry A_1 and structure function g_1: $g_1 \approx A_1 \cdot F_1$