



Longitudinal spin structure of the proton from COMPASS

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DIS-2010
April 19 - 24, 2010

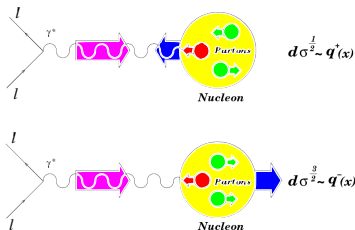


Outline

- 1 COMPASS experiment
- 2 DIS and SIDIS asymmetries with deuteron (2002-06) and proton (2007) data
- 3 Non-singlet spin structure function g_1^{NS} and Bjorken sum rule
- 4 Full flavour separation analysis with LO QCD fit

Polarised Deep Inelastic Scattering

- absorption of polarised photons (QPM)



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

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

+quark $\uparrow\uparrow$ nucleon
-quark $\downarrow\uparrow$ nucleon

- photon-nucleon asymmetry

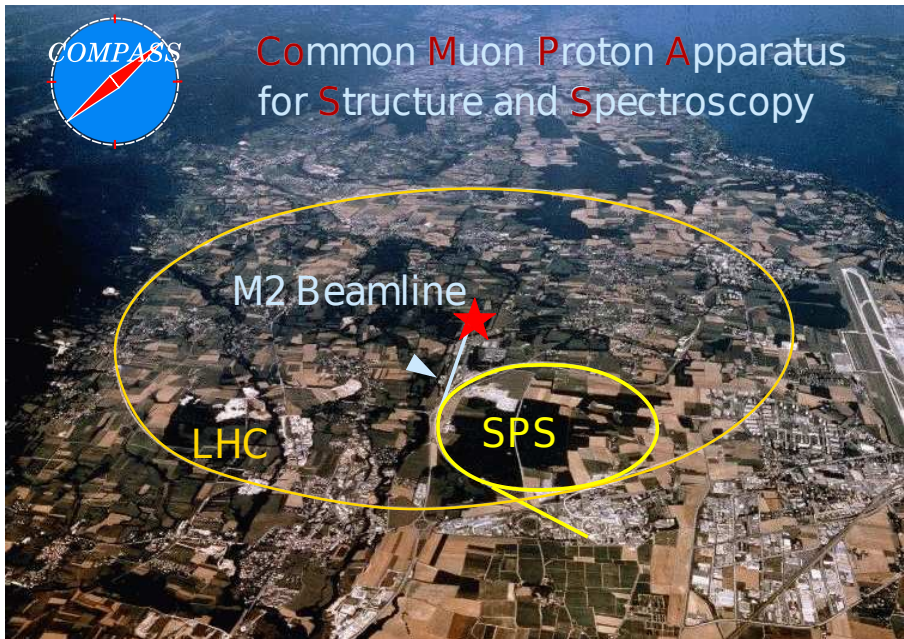
$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \approx \frac{\sum_q e_q^2 \Delta q(x)}{\sum_q e_q^2 q(x)} = \frac{g_1(x)}{F_1(x)}$$

- spin structure function

$$g_1 = \frac{1}{2} \sum_q e_q^2 \Delta q = A_1 \frac{F_2}{2x(1+R)} \approx \frac{A_{||}}{D} \cdot \frac{F_2}{2x(1+R)}$$



Common Muon Proton Apparatus for Structure and Spectroscopy



COMPASS Spectrometer

Muon beam

160 GeV/c

80% polarization

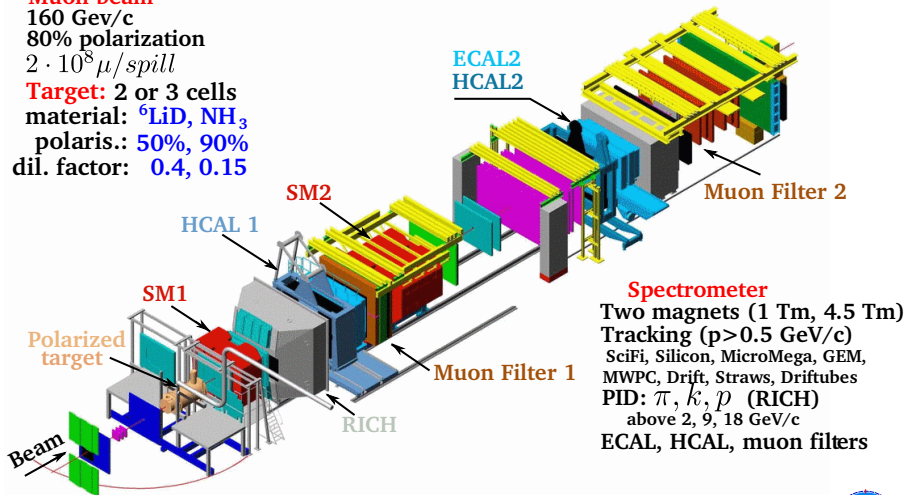
$2 \cdot 10^8 \mu/spill$

Target: 2 or 3 cells

material: ${}^6\text{LiD}$, NH_3

polaris.: 50%, 90%

dil. factor: 0.4, 0.15



Spectrometer

Two magnets (1 Tm, 4.5 Tm)

Tracking ($p > 0.5 \text{ GeV}/c$)

SciFi, Silicon, MicroMega, GEM,

MWPC, Drift, Straws, Driftubes

PID: π , k , p (RICH)

above 2, 9, 18 GeV/c

ECAL, HCAL, muon filters

(NIMA 577 (2007) 455)



Event Selection

- **Kinematic cuts:**

- ✓ $Q^2 > 1$ (GeV/c)²
- ✓ $0.1 < y < 0.9$ – fractional energy, transferred from the incident muon to the virtual photon
- ✓ $0.004 < x < 0.7$
- ✓ $0.2 < z < 0.85$

- **Hadron ID with RICH:**

- ✓ $10 < P_h < 50$ (GeV/c)
- ✓ Purity:
 - on proton: $\pi^\pm - 0.98$; K^+ (K^-)
– from 0.73 to 0.93 (0.91)
 - on deuteron: $\pi^\pm - 0.98$; K^+ (K^-)
– from 0.8 to 0.93

Total sample, [$\times 10^6$ evts]

	target	
	deuteron	proton
incl.	135.1	85.3
π^+	22.8	12.3
π^-	20.5	10.9
K^+	4.8	3.6
K^-	3.3	2.3

Asymmetries calculation

- to be measured:

$$A_{||} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}}$$

- flux cancellation:

$$A_{exp} = \frac{N_u - N_d}{N_u + N_d}$$

- acceptance difference:

Polarisation rotation

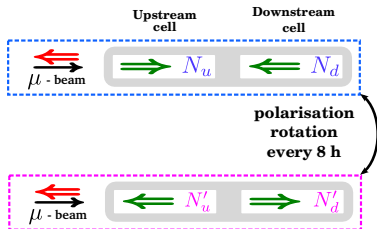
- take average asymmetry:

$$A_{exp} = \frac{A + A'}{2} = \frac{1}{2} \left(\frac{N_u - N_d}{N_u + N_d} + \frac{N'_d - N'_u}{N'_d + N'_u} \right) \Rightarrow \text{minimization of bias}$$

- experimental asymmetry:

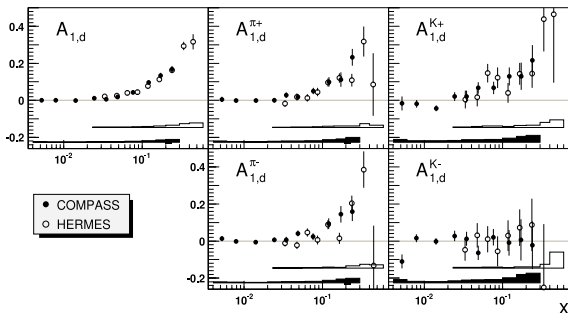
$$A_{exp} = P_B P_T f A_{||}$$

P_B, P_T beam and target polarisation
 f dilution factor



Double spin asymmetries

- **kinematic domain:**
 $Q^2 > 1 \text{ (GeV/c)}^2$
 $0.1 < y < 0.9$
 $0.004 < x < 0.3$

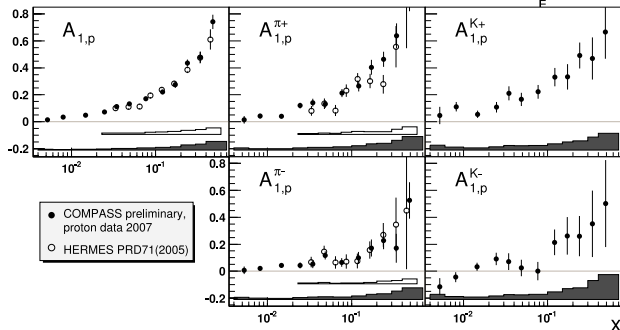
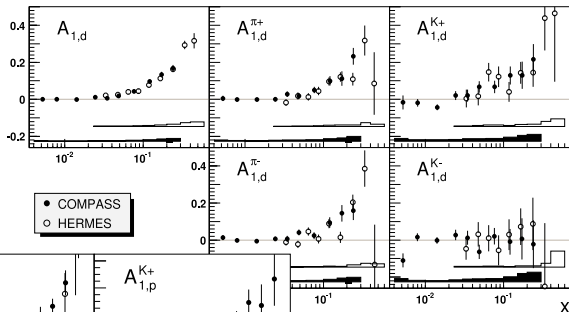


- deuteron data: 2002-2006 (PLB 680 (2009) 217-224)
- inclusive plus identified pion and kaon asymmetries
- A_1^d compatible with 0 for $x < 0.05$
- good agreement with previous experiments



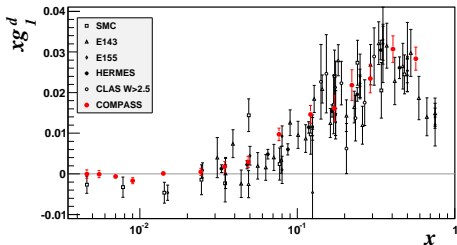
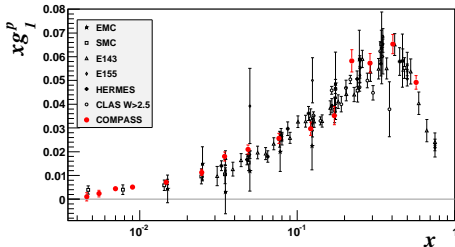
Double spin asymmetries

- **kinematic domain:**
 $Q^2 > 1 \text{ (GeV/c)}^2$
 $0.1 < y < 0.9$
 $0.004 < x < 0.3$



- **Deuteron:** 2002-06
- **Proton:** 2007 (prelim.)
- **Identified hadrons:** COMPASS and HERMES data only



Structure functions g_1^d and g_1^p 

- The non-singlet spin structure function g_1^{NS}

$$g_1^{NS}(x) = g_1^p(x) - g_1^n(x) = 2 \left[g_1^p(x) - \frac{g_1^d(x)}{(1 - 3/2\omega_D)} \right]$$

- The first moments provide a test of the Bjorken sum rule, a fundamental result of QCD derived using current algebra:

$$\int_0^1 g_1^{NS}(x) dx = \frac{1}{6} \left| \frac{g_A}{g_V} \right| C^{NS} \quad \text{or} \quad \Delta u - \Delta d = \left| \frac{g_A}{g_V} \right|$$

Fit of COMPASS data at $Q^2 = 3 \text{ (GeV/c)}^2$

Non-singlet Q^2 dependence is **not dependent from gluon densities**:

$$g_1^{NS}(x, Q^2) = \frac{1}{6} \int_x^1 \frac{dx'}{x'} C^{NS} \left(\frac{x}{x'}, \alpha_s(Q^2) \right) \Delta q_3(x', Q^2)$$

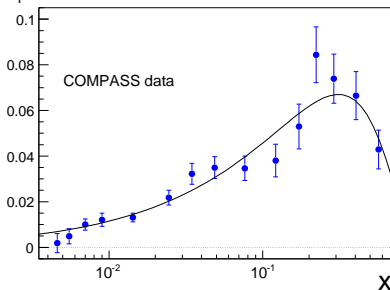
Parametrisation of **the isovector spin density**:

$$\Delta q_3(x) = \eta_3 \frac{x^{\alpha_3} (1-x)^{\beta_3}}{\int_0^1 x^{\alpha_3} (1-x)^{\beta_3} dx}$$

Fit with two different programs:

- * (x, Q^2) space
- * space of moments

Param.	Value
η_3	1.28 ± 0.07
α_3	-0.22 ± 0.07
β_3	$2.2 \pm_{0.4}^{0.5}$
χ^2/NDF	14.4/12
Prob.	0.27

 $xg_1^{NS}(x)$


$$|g_A/g_V| = 1.28 \pm 0.07(\text{stat.}) \pm 0.10(\text{syst.})$$

- dominant systematic error: beam and target polarisation
- PDG value: $g_A/g_V = 1.268 \pm 0.003$

Flavour separation



- **SIDIS**

$$A_1^h = \frac{\sum e_q^2 [\Delta q(x) \int D_q^h(z) dz + \Delta \bar{q}(x) \int D_{\bar{q}}^h(z) dz]}{\sum e_q^2 [q(x) \int D_q^h(z) dz + \bar{q}(x) \int D_{\bar{q}}^h(z) dz]}$$

- $D_q^h \neq D_{\bar{q}}^h$
yields quark and antiquark separation

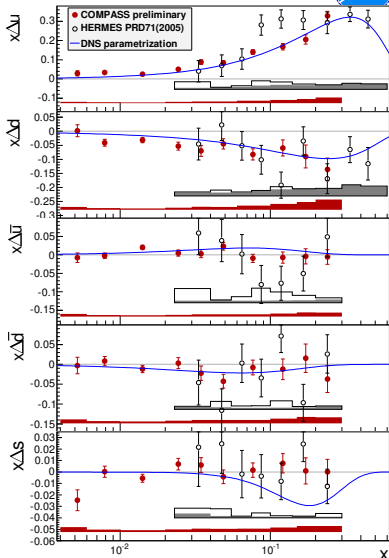
- **measured:**

$$A_1^d, A_{1d}^{K^\pm}, A_{1d}^{\pi^\pm}, A_1^p, A_{1p}^{K^\pm}, A_{1p}^{\pi^\pm}$$

- **determined:** $\Delta u, \Delta \bar{u}, \Delta d, \Delta \bar{d}, \Delta s \equiv \Delta \bar{s}$

- system of linear equations in LO

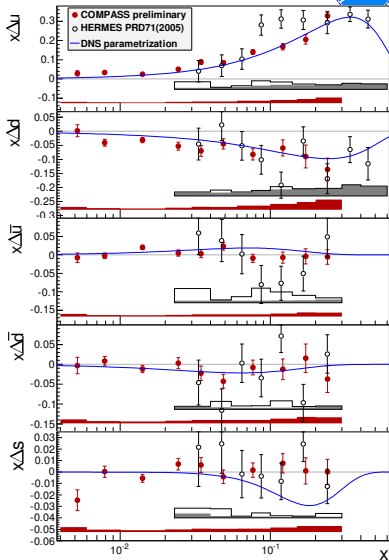
- **input:** MRST04 unpolarised PDFs,
DSS parametrisation of FFs
(e^+e^- , DIS, hadron-hadron)



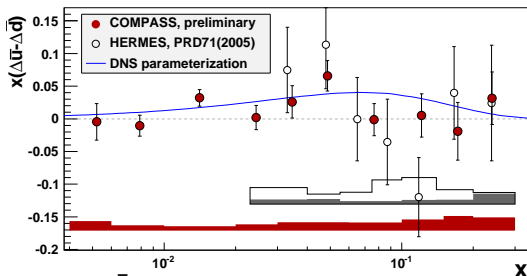
Flavour separation



- **preliminary result** at $Q^2 = 3$ (GeV/c)²
- good agreement with HERMES results
- all sea quark distributions compatible with zero
- good agreement with global fit for $\Delta u, \Delta \bar{u}, \Delta d, \Delta \bar{d}$
- significant discrepancy with ΔS obtained from QCD fits to g_1
- **but** result for ΔS depends on assumptions for FFs



The sea flavour helicity asymmetry



- Presently $\Delta\bar{u} - \Delta\bar{d}$ is accessible only via SIDIS processes

HERMES ($Q^2 = 2.5 \text{ (GeV/c)}^2$):

$$\int_{0.3}^{0.03} (\Delta\bar{u} - \Delta\bar{d}) dx = 0.048 \pm 0.057(\text{stat.}) \pm 0.028(\text{syst.})$$

COMPASS ($Q^2 = 3 \text{ (GeV/c)}^2$):

$$\int_{0.023}^{0.3} (\Delta\bar{u} - \Delta\bar{d}) dx = 0.052 \pm 0.035(\text{stat.}) \pm 0.013(\text{syst.})$$

- Pres. analysis: no estimation of systematics from uncertainties of FF
- Effect is comparable to the one observed in unpolarised case

$$\int_0^1 (\bar{u} - \bar{d}) dx = 0.118 \pm 0.012$$

Conclusion

- ① All COMPASS data with deuteron (2002-2006) and proton (2007) targets have been processed and analysed
- ② Combined analysis of proton and deuteron data

- Non-singlet structure function g_1^{NS} and a test of Bjorken sum rule

$$|g_A/g_V| = 1.28 \pm 0.07(\text{stat.}) \pm 0.10(\text{syst.})$$

- Full flavour separation analysis with LO QCD fit
 - ✓ Good agreement on non-strange PDFs with results of previous QCD fits
 - ✓ Shape of $\Delta s(x)$ disagrees significantly with previous fits
 - ✓ Flavour asymmetry of the light sea quarks have been observed
- $$\Delta \bar{u} \gtrsim \Delta \bar{d}$$

- ③ New longitudinal polarised proton data in 2011 year