“Helicity quark distributions from DIS and SIDIS measured in COMPASS”

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on behalf of the COMPASS collaboration

COmmon
Muon and
Proton
Apparatus for
Structure and
Spectroscopy

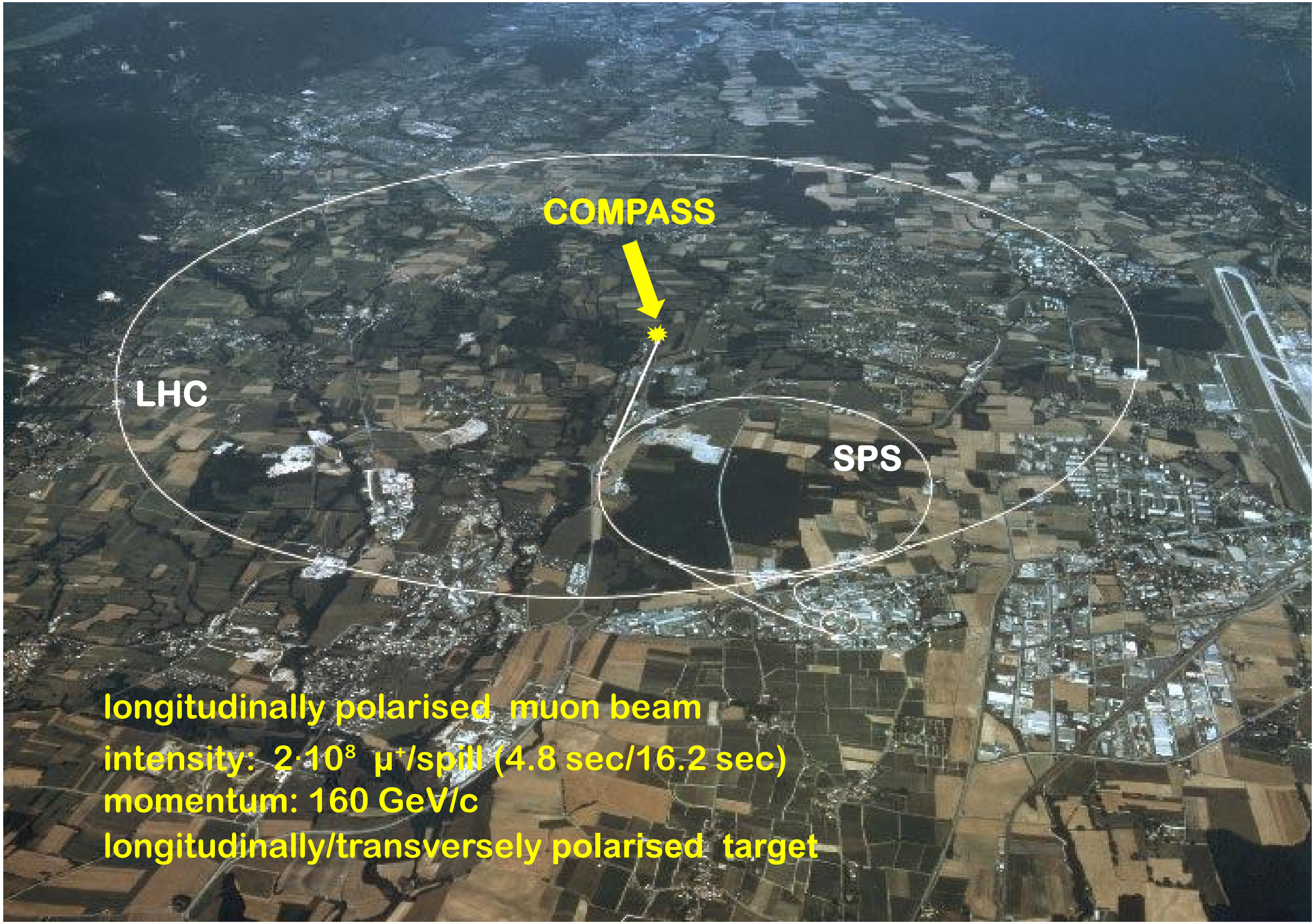
NA58 experiment at CERN

~230 physicists from 11 countries

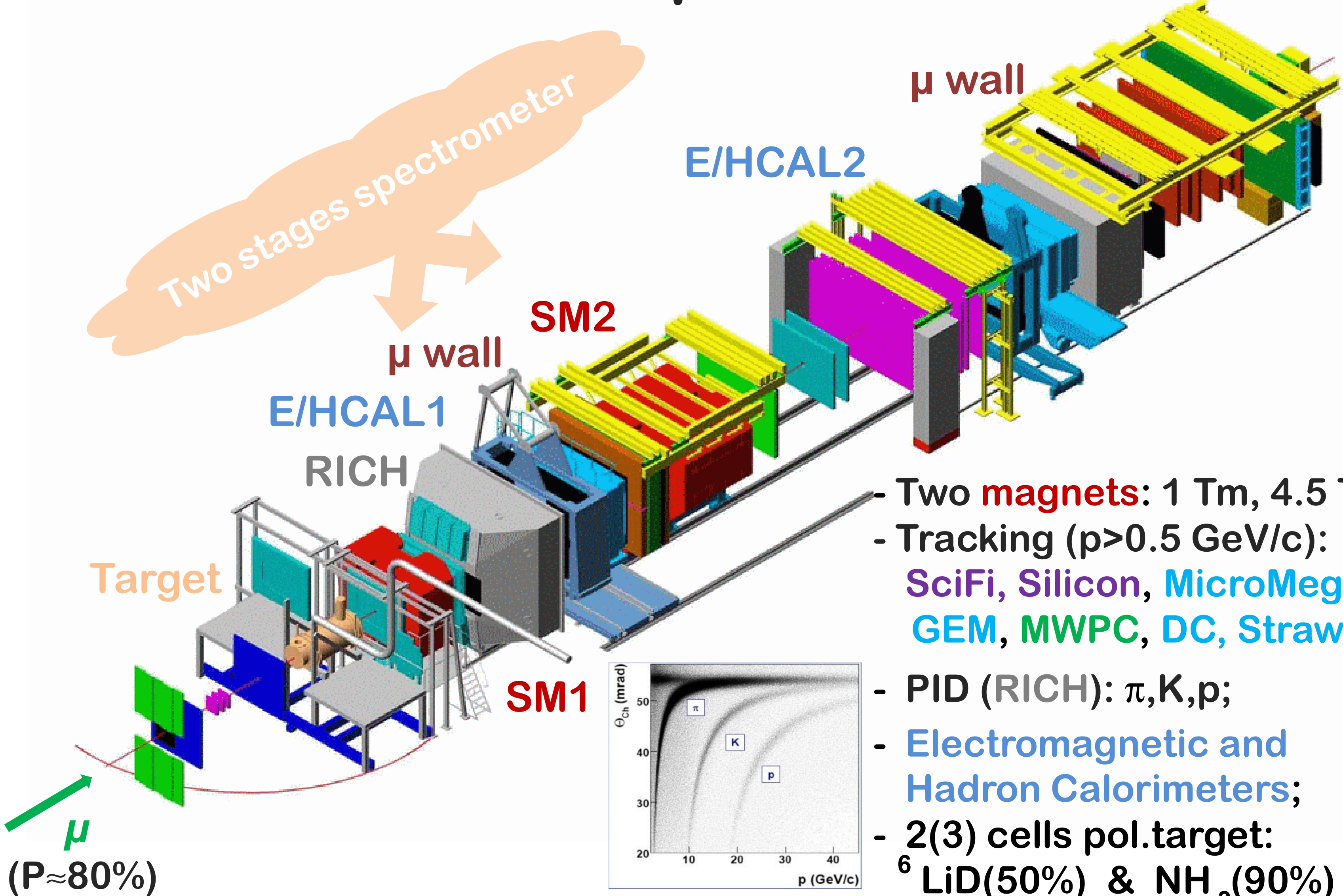
Czech Republic, Finland, France, Germany, India, Israel, Italy, Japan, Poland, Portugal and Russia

- **Muon program (2002-2007)**
  Deep Inelastic Scattering (DIS) of polarized 160 GeV/c muons on polarized deuterons and protons

- **Hadron program (2008-2009)**
  190 GeV/c π, K , p beams search for exotics in diffractive excitation and central production, polarizability of π, K

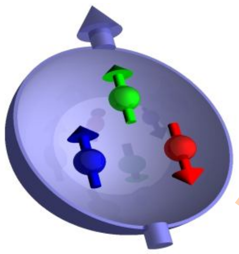
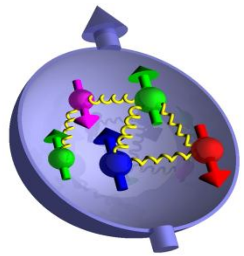
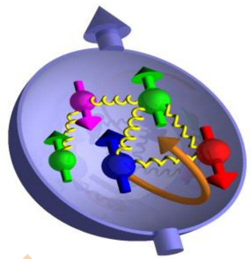

COMPASS
LHC
SPS
longitudinally polarised muon beam
intensity: 2·10⁸ μ⁺/spill (4.8 sec/16.2 sec)
momentum: 160 GeV/c
longitudinally/transversely polarised target

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;
- 2(3) cells pol.target: ^{6}LiD(50%) & NH_3(90%)

Spin of the nucleon

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

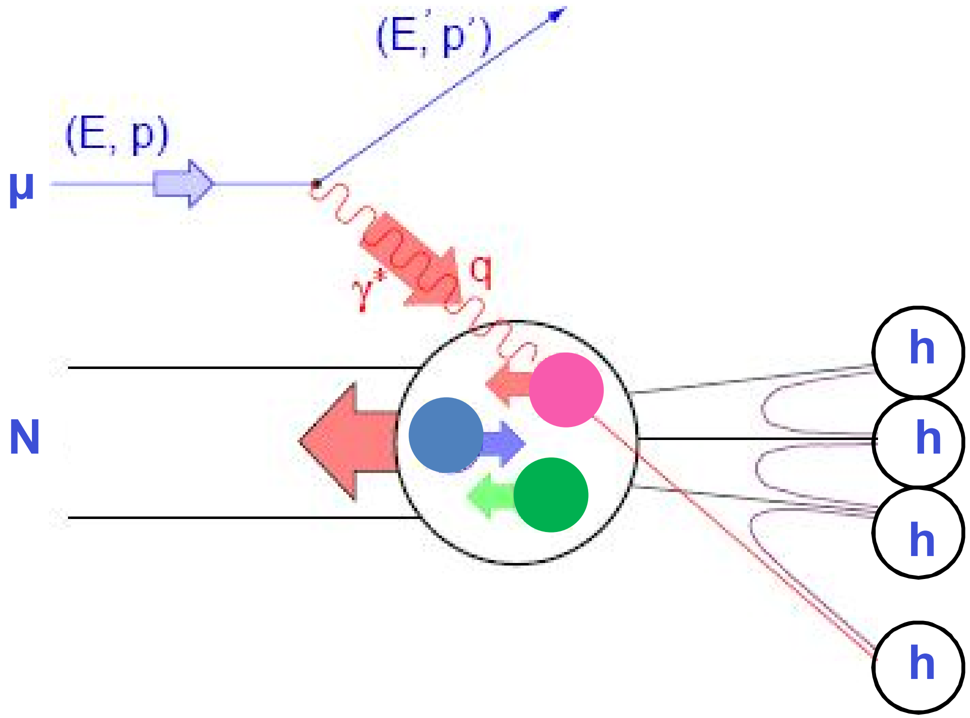
Naive view:

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

Complete description :

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

Deep inelastic scattering



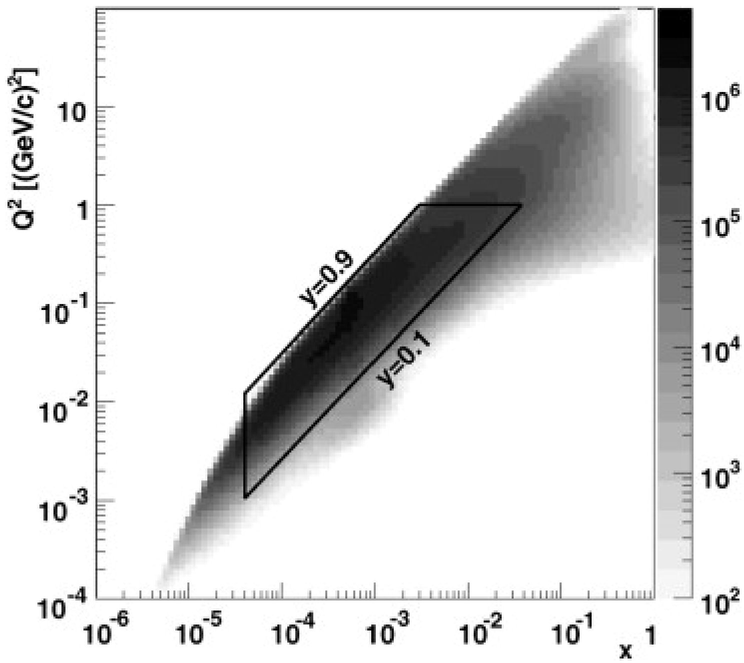
Kinematical variables:

$Q^2 = -q^2$

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

$\nu = E - E'$

$y = \nu/E$

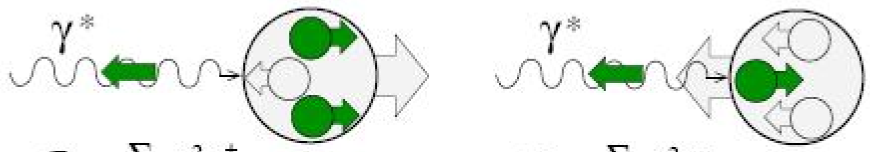


Deep inelastic scattering

- quark densities in QPM:

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

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



$\sigma_{1/2} \sim \sum_q e_q^2 q^{+}$ $\sigma_{3/2} \sim \sum_q e_q^2 q^{-}$

- Longitudinal double-spin asymmetry:

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

- 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

- Cross-sections

  and

  Structure functions:

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

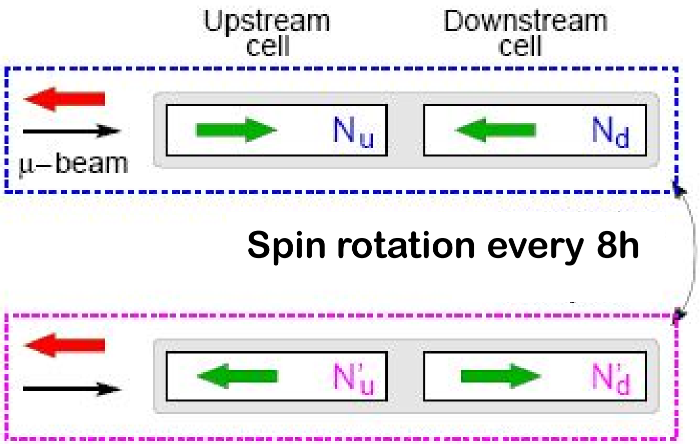
- Structure functions and PDF:

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

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

Asymmetry measurement

- 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: $\frac{a'_d}{a'_u} = 1$
  (constant ratio)



- double ratio method: $\delta = \frac{N_u \cdot N'_d}{N'_u \cdot N_d}$

$\Rightarrow$ solve for A_{exp} (2nd order equation)

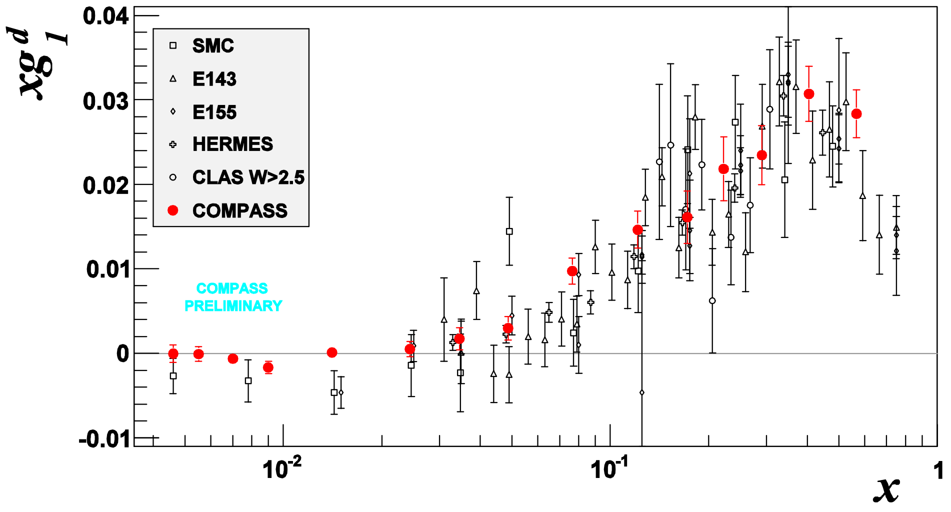
$\Rightarrow$ minimization of bias

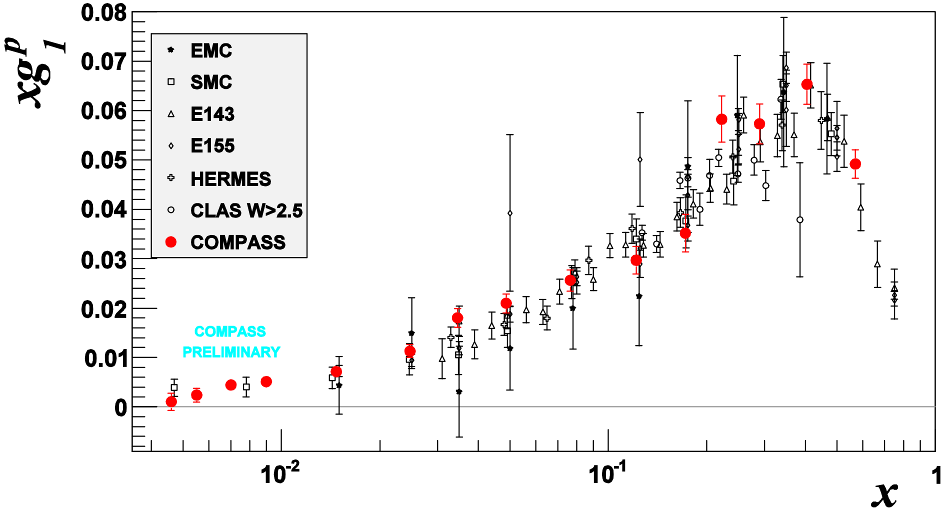
- experimental asymmetry: $A_{exp} = p_{\mu}\ p_T f\ A_{\parallel}$

p_{μ}, p_T - beam and target polarization

f - dilution factor

Structure functions g_1^d and g_1^p





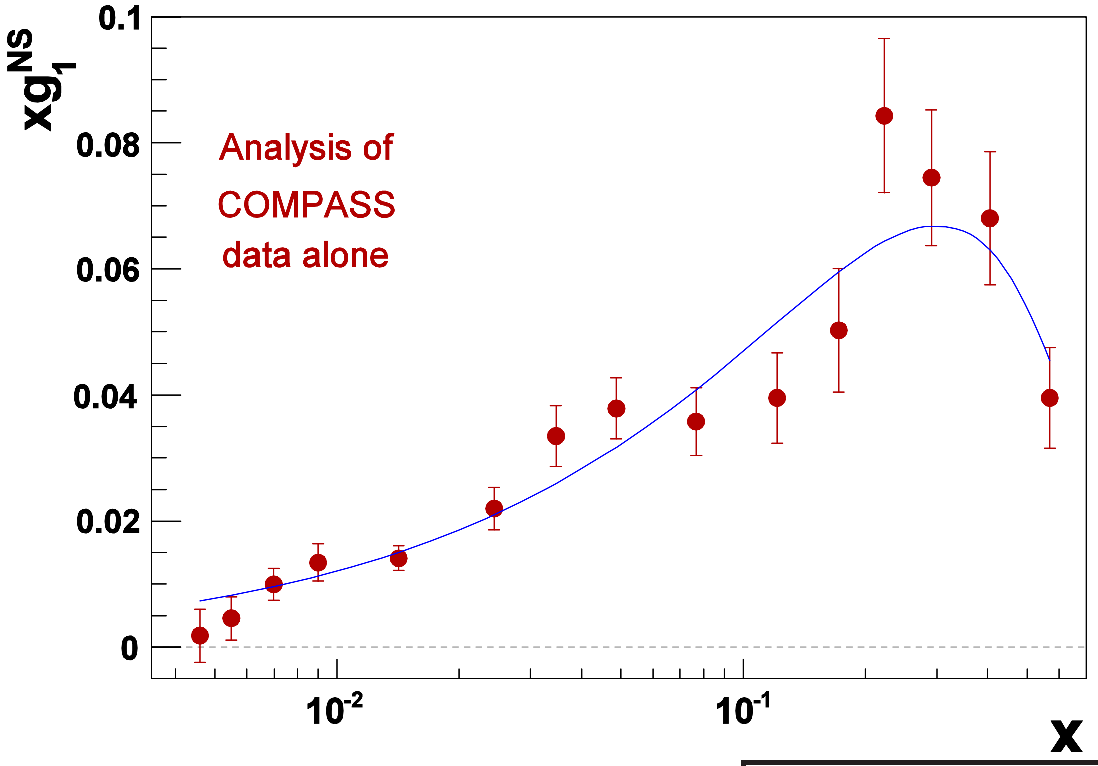
- The non-singlet spin structure function $g_1^{NS}(x)$ can be evaluated

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

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

$$\Gamma_1^{NS} = \Gamma_1^p - \Gamma_1^n = \frac{1}{6}\left|\frac{g_A}{g_V}\right| C^{NS} \qquad \text{or} \qquad \Delta u - \Delta d = \left|\frac{g_A}{g_V}\right|$$

Structure functions g_1^{NS}



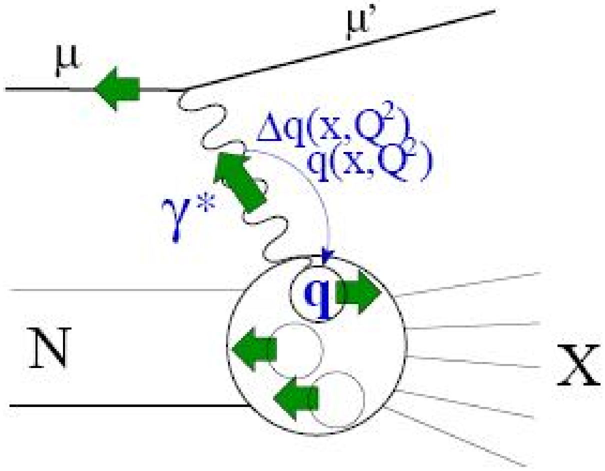
$$g_A/g_V = 1.30 \pm 0.07(stat) \pm 0.10(syst)$$

$$g_A/g_V{}^{PDG} = 1.269 \pm 0.003$$

Systematic error:

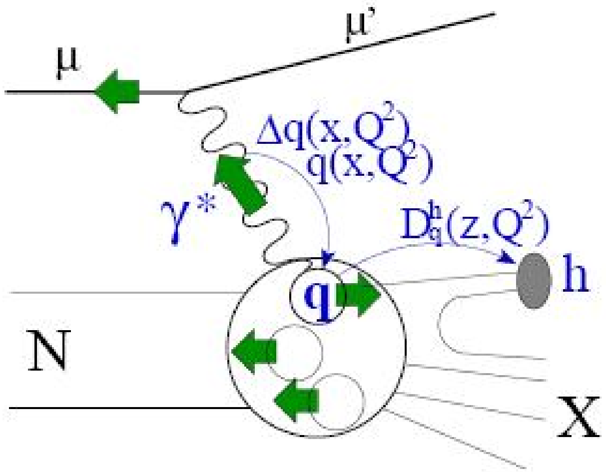
- δ(P_b) is dominant : 5% → ±0.065
- ^{6}LiD: 7% due to *f* and P_t → ±0.041
- NH_3 : 3% due to *f* and P_t →±0.056

Full flavor separation analysis with LO QCD fit



Inclusive DIS

- Detected particle: μ, μ'
- $A_1 = \frac{\sum_q e_q^2(\mathbf{\Delta q(x)+\Delta \bar{q}(x)})}{\sum_q e_q^2(q(x)+\bar{q}(x))}$
- only $\Delta q + \Delta \bar{q}$ can be measured



Semi-Inclusive DIS

- Detected particle: μ, μ', h, ...
- $A_1^h = \frac{\sum_q e_q^2(\mathbf{\Delta q(x)} \int \mathbf{D_q^h dz} + \mathbf{\Delta \bar{q}(x)} \int \mathbf{D_{\bar{q}}^h dz})}{\sum_q e_q^2(q(x) \int D_q^h dz + \bar{q}(x) \int D_{\bar{q}}^h dz)}$
- $D_q^h \neq D_{\bar{q}}^h \Rightarrow$ quarks and anti-quarks separation

- LO QCD analysis (independent quark fragmentation)

$$A_{1,d} = \frac{5(\Delta \mathrm{u}+\Delta \mathrm{d}) + 5(\Delta \bar{\mathrm{u}}+\Delta \bar{\mathrm{d}}) + 4\Delta \mathrm{s}}{5(u+d)+5(\bar{u}+\bar{d})+2(s+\bar{s})}$$

$$A_d^h = \frac{(4D_u^h+D_d^h)(\Delta \mathrm{u}+\Delta \mathrm{d}) + (4D_{\bar{u}}^h+D_{\bar{d}}^h)(\Delta \bar{\mathrm{u}}+\Delta \bar{\mathrm{d}}) + 2(D_s^h+D_{\bar{s}}^h)\Delta \mathrm{s}}{(4D_u^h+D_d^h)(u+d)+(4D_{\bar{u}}^h+D_{\bar{d}}^h)(\bar{u}+\bar{d})+2(D_s^h s+D_{\bar{s}}^h \bar{s})}$$

$$A_{1,p} = \frac{4(\Delta \mathrm{u}+\Delta \bar{\mathrm{u}}) + (\Delta \mathrm{d}+\Delta \bar{\mathrm{d}}) + 2\Delta \mathrm{s}}{4(u+\bar{u})+(d+\bar{d})+(s+\bar{s})}$$

$$A_{1,p}^h = \frac{4(D_u^h\Delta \mathrm{u}+D_{\bar{u}}^h\Delta \bar{\mathrm{u}}) + (D_d^h\Delta \mathrm{d}+D_{\bar{d}}^h\Delta \bar{\mathrm{d}}) + (D_s^h+D_{\bar{s}}^h)\Delta \mathrm{s}}{4(D_u^h u+D_{\bar{u}}^h \bar{u})+(D_d^h d+D_{\bar{d}}^h \bar{d})+(D_s^h s+D_{\bar{s}}^h \bar{s})}$$

- Matrix form. 10 equations with 5 unknowns

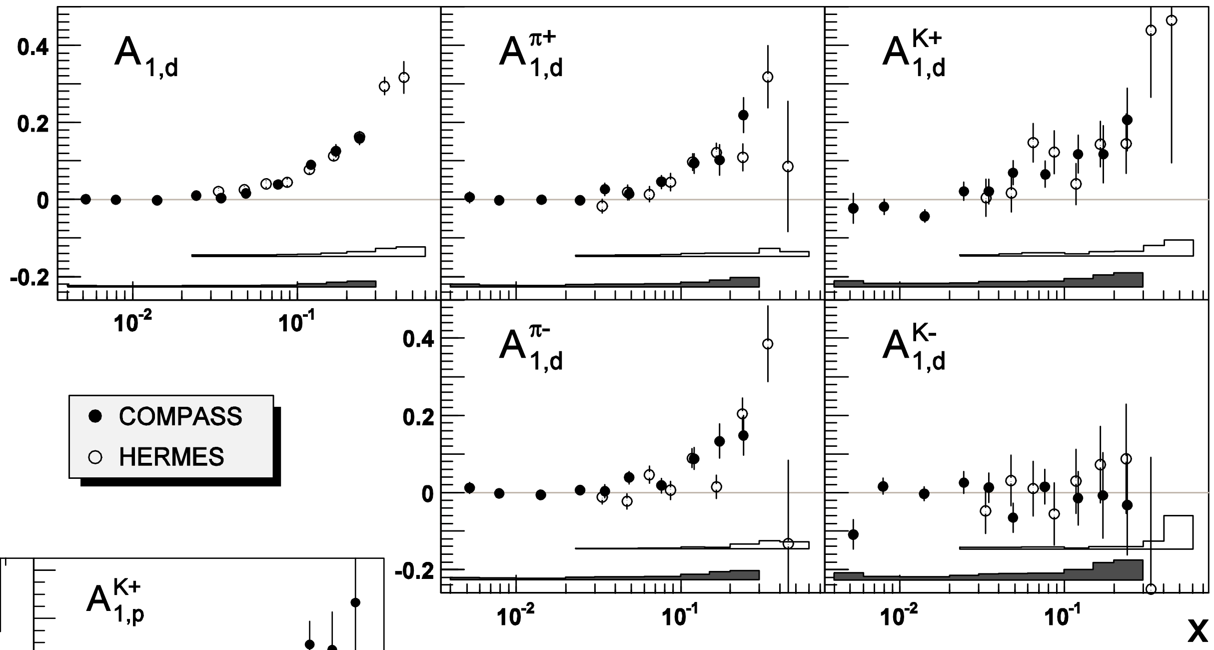
$$\vec{A} = \mathsf{B}\,\Delta\vec{q}, \quad \text{where} \quad \begin{cases} \vec{A} = (A_1^d, A_d^{\pi+}, A_d^{\pi-}, A_d^{K+}, A_d^{K-},\ A_1^p, A_p^{\pi+}, A_p^{\pi-}, A_p^{K+}, A_p^{K-}) \\ \Delta\vec{q} = (\Delta u, \Delta d, \Delta \bar{u}, \Delta \bar{d}, \Delta s) \end{cases}$$

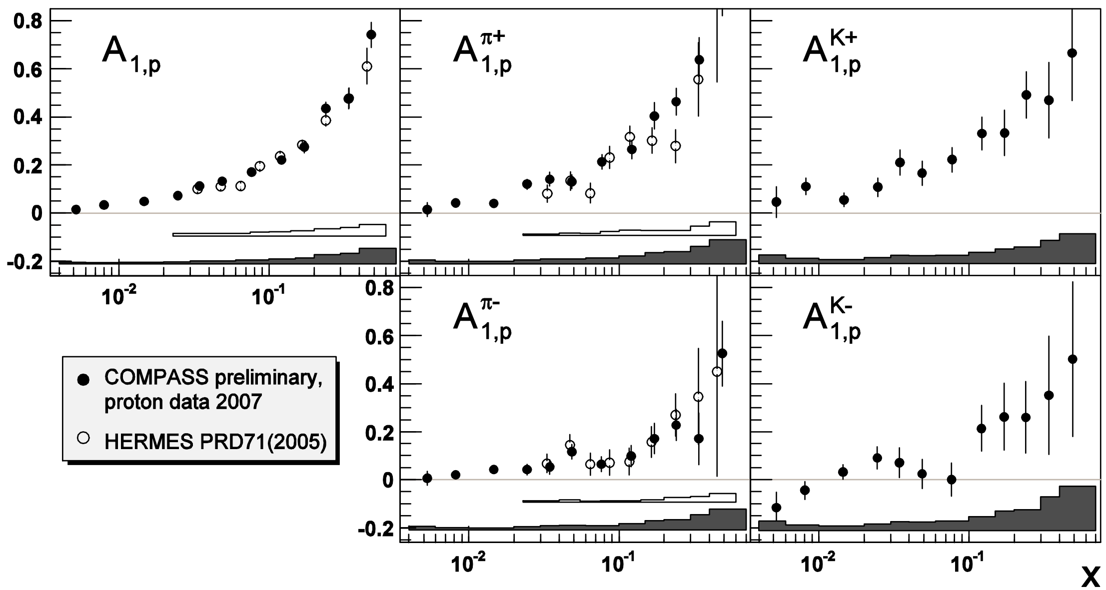
- LS estimation: uniqueness, unbiasedness and minimum variance of the solution

$$\chi^2 = (\vec{A} - \mathsf{B}\Delta\vec{q})^T \,\mathsf{Cov}_A^{-1} (\vec{A} - \mathsf{B}\Delta\vec{q}).$$

Proton and deuteron asymmetries A_1

- **Kinematic**
  $Q^2 > 1\ GeV^2$
  $0.1 < y < 0.9$
  $0.004 < x < 0.7$





- **Asymmetries of identified hadrons were measured only by COMPASS and HERMES**

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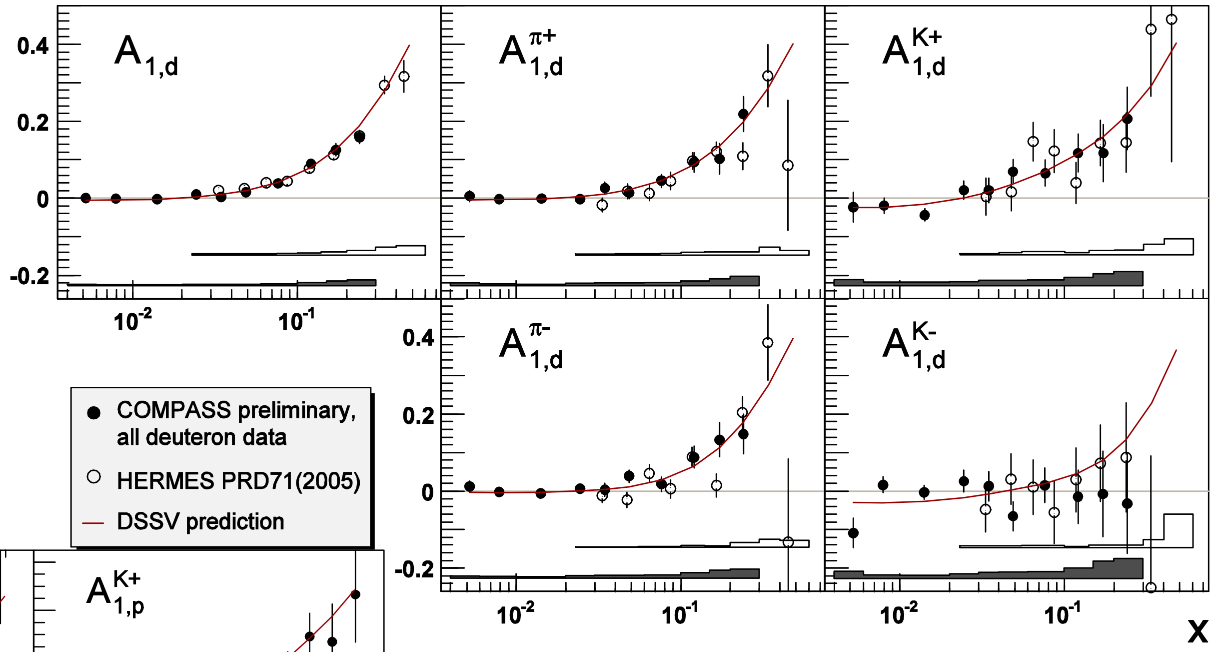

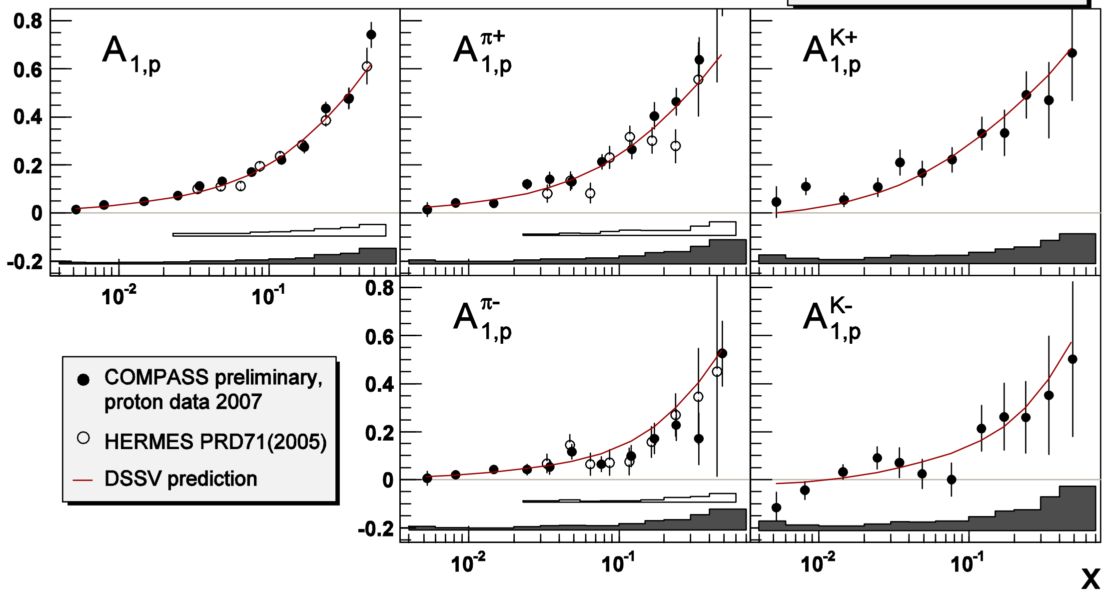

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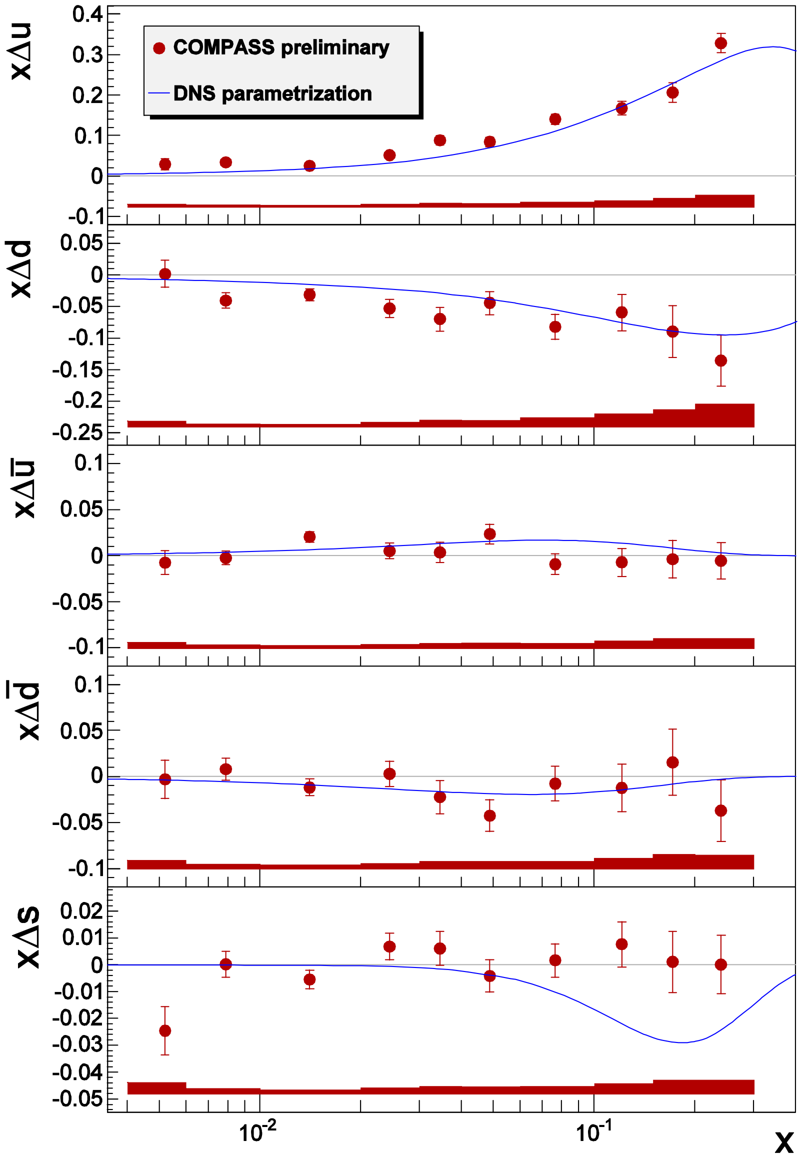


- MRST04 (for unpol.PDFs) and DSS (for FFs);
- Good agreement with global fit exept Δs

Statistic ($\cdot 10^6$)

	Proton	deuteron
Incl	92,5	135,1
π^+	13,3	22,8
π^-	11,8	20,5
K^+	3,9	4,8
K^-	2,6	3,3

- Asymmetry between the unpolarized $\bar{u}$ and $\bar{d}$ distrib. is well established experimental fact

Experiment	$\langle Q^2 \rangle$ [GeV^2]	$\int_0^1 [\bar{u} - \bar{d}] dx$	Reference
NMC/DIS	4	0.147 ± 0.039	M.Arneodo et al., Phys.Rev.D55(1994)R1
HERMES/SIDIS	2.3	0.16 ± 0.03	K.Ackerstaff et al., Phys.Rev.Lett.81(1998)5519
FNAL E866/DY	54	0.118 ± 0.012	R.S.Towell et al., Phys.Rev.D64(2001)052002

- Many non-perturbative models predicts a sizable asymmetry of the helicity densities

	Model	$\int_0^1 [\Delta\bar{u} - \Delta\bar{d}] dx$	Reference
Meson cloud	π-meson	0	A.W.Thomas, Phys.Lett.B126(1983)97
	ρ-meson	$\simeq$ -0.0007 to -0.027	R.J.Fries,A.Schafer, Phys.Lett.B443(1998)40
	π-ρ interf.	$=-6\int_0^1 g^p(x)dx \simeq -0.7$	K.G.Boreskov, A.B.Kaidalov, Eur.Phys.J.C10(1999)143
	ρ and π-ρ interf.	$\simeq$ -0.004 to -0.033	F.G.Cao, A.I.Signal, Eur.Phys.J.C21(2001)105
	ρ-meson	< 0	S.Kumano, M.Miyama, Phys.Rev.D65(2002)034012
	π-σ interf.	$\simeq 0.12$	R.J.Fries,A.Schafer,C.Weiss, hep-ph/0204060
Pauli-blocking	bag model	$\simeq 0.09$	F.G.Cao, A.I.Signal, Eur.Phys.J.C21(2001)105
	ansatz	$\simeq 0.3$	M.Gluck at al., Phys.Rev.D63(2001)094005
		$= \frac{5}{3}\int_0^1 [\bar{d} - \bar{u}] dx \simeq 0.2$	F.M.Steffens, Phys.Lett.B541(2002)346
Chiral-quark soliton		0.31	B.Dressler et al., hep-ph/9809487
		$\simeq \int_0^1 2x^{0.12}[\bar{d} - \bar{u}] dx$	M.Wakamatsu, T.Watabe, Phys.Rev.D62(2000)017506
Instanton		$\frac{5}{3}\int_0^1 [\bar{d} - \bar{u}] dx \simeq 0.2$	Dorokhov, hep-ph/0112332
Statistical		$\simeq \int_0^1 [\bar{d} - \bar{u}] dx \simeq 0.12$	C.Bourrely,J.Soffer,F.Buccella, Eur.Ph.J.C23(2002)487
		$> \int_0^1 [\bar{d} - \bar{u}] dx > 0.12$	R.S.Bhalerao, Phys.Rev.C63(2001)025208

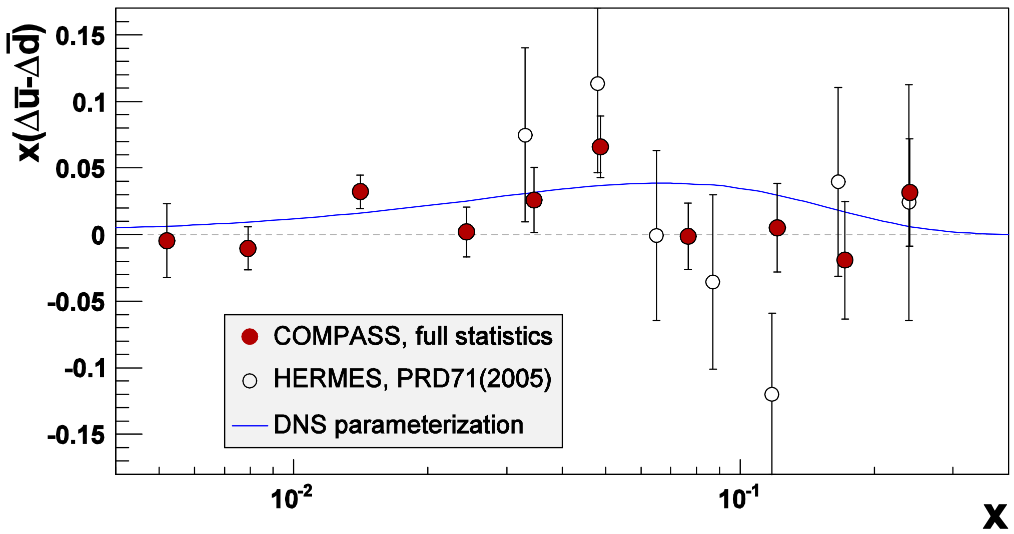
taken from J.C.Peng "Flavor Structure of the nucleon sea", hep-ph/0301053

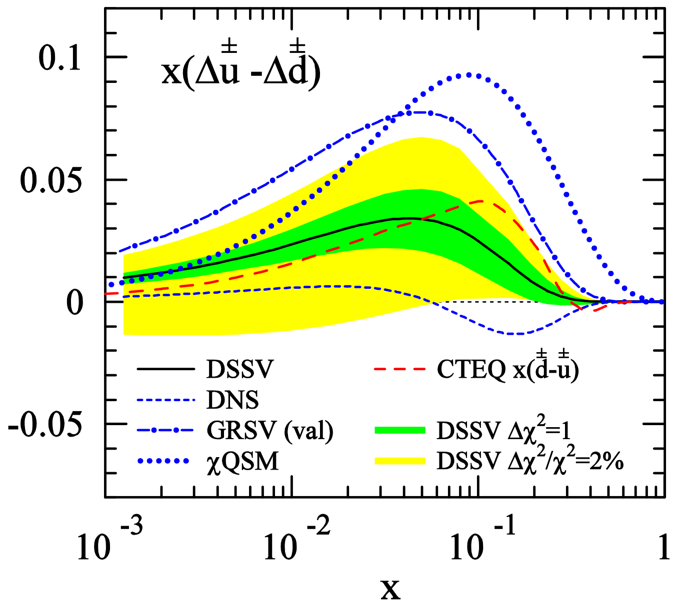
Flavor symmetry breaking of the light sea

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

HERMES : $\int_{0.023}^{0.3}(\Delta\bar{u}-\Delta\bar{d})dx = 0.048 \pm 0.057(stat) \pm 0.028(syst)$

COMPASS : $\int_{0.004}^{0.3}(\Delta\bar{u}-\Delta\bar{d})dx = 0.052 \pm 0.035(stat) \pm 0.013(syst)$





Conclusion

- **All COMPASS data with deuteron(2002-2006) and proton(2007) targets have been processed and analyzed;**
- **g_1^{NS} was obtained from combined analysis of proton and deuteron data**

  $$g_A/g_V = 1.30 \pm 0.07(\mathit{stat}) \pm 0.10(\mathit{syst})$$

  confirm the validity of Bjorken sum rule;
- **Full flavor separation analysis with LO QCD fit was done:**
  - **Good agreement of non-strange PDFs with results of previous QCD fits;**
  - **Shape of $\Delta s(x)$ disagree significantly with previous fits;**
  - **Flavor asymmetry of the light sea quarks is observed.**

Spin budget of the nucleon

- **Contribution of quarks to the nucleon spin $\Delta\Sigma$ is well fixed by inclusive data $\Delta\Sigma = 0.30 \pm 0.01 \pm 0.02$ (Q^2=3 GeV^2);**
- **QCD fit provides indirect way to determine ΔG: $|\Delta G| < 0.2 \div 0.3$**