Overview of the longitudinal spin physics at COMPASS

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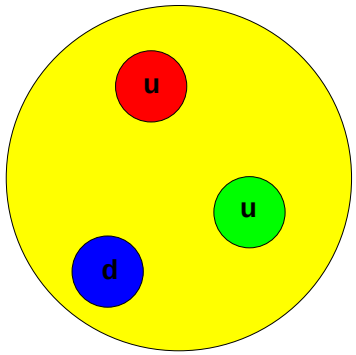
on behalf of the COMPASS collaboration

Electromagnetic interactions with nucleons and nuclei
Milos, 28.9. – 2.10.2009

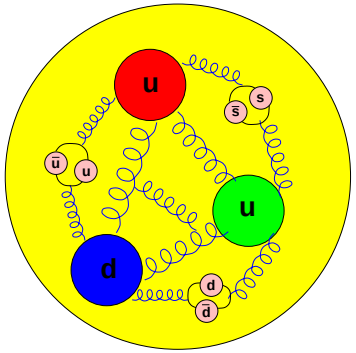
- **COMPASS experiment**
- **Longitudinal asymmetries**
- **Spin structure functions**
- **Bjorken sum rule**
- **Gluon polarisation**
- **Flavourseparation**
- **Status and outlook**

The spin of the nucleon

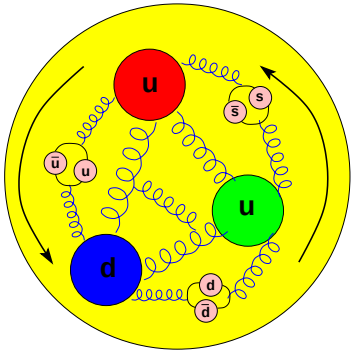


Naive parton model:
$\Rightarrow \Delta\Sigma = \Delta u_v + \Delta d_v = 1$

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



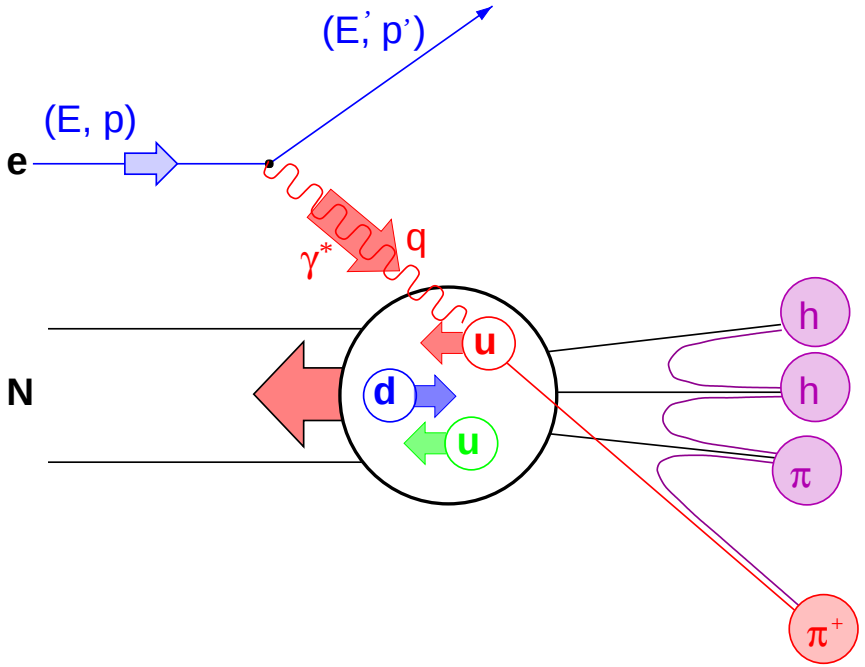
gluons important in unpolarized case
ΔG?



complete description:
orbital angular momenta

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

Deep inelastic scattering



$$Q^2 = -q^2$$

$$\nu = E - E'$$

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

$$y = \nu/E$$

$$z = E_{\mathrm{h}}/\nu$$

p_{T} : hadron transverse momentum

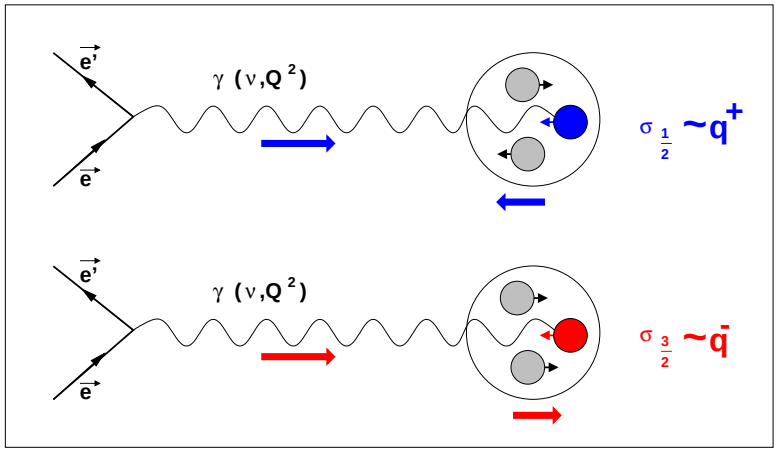
- **Inclusive cross section**

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}\Omega \mathrm{d}E'} \sim \underbrace{c_1 F_1(x,Q^2) + c_2 F_2(x,Q^2)}_{\text{spin independent}} + \underbrace{c_3 g_1(x,Q^2) + c_4 g_2(x,Q^2)}_{\text{spin dependent}}$$

F_1, F_2, g_1, g_2 structure functions

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**

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

- **spin structure function**

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

COMPASS at CERN

Bielefeld, Bochum, Bonn, Burdwan/Calcutta, CERN, Dubna, Erlangen, Freiburg, Lissabon, Mainz, Moscow, Munich, Prague, Protvino, Saclay, Tel Aviv, Turino, Trieste, Warsaw, Yamagata
(30 institutes, 240 physicists)

COMMON MUON AND PROTON APPARATUS FOR STRUCTURE AND SPECTROSCOPY

Muon beam

Spin dependent structure functions

Gluon polarisation

Polarised quark distributions

Transversity

Lambda polarisation

Vector meson production

future plans:
DVCS

Hadron beam

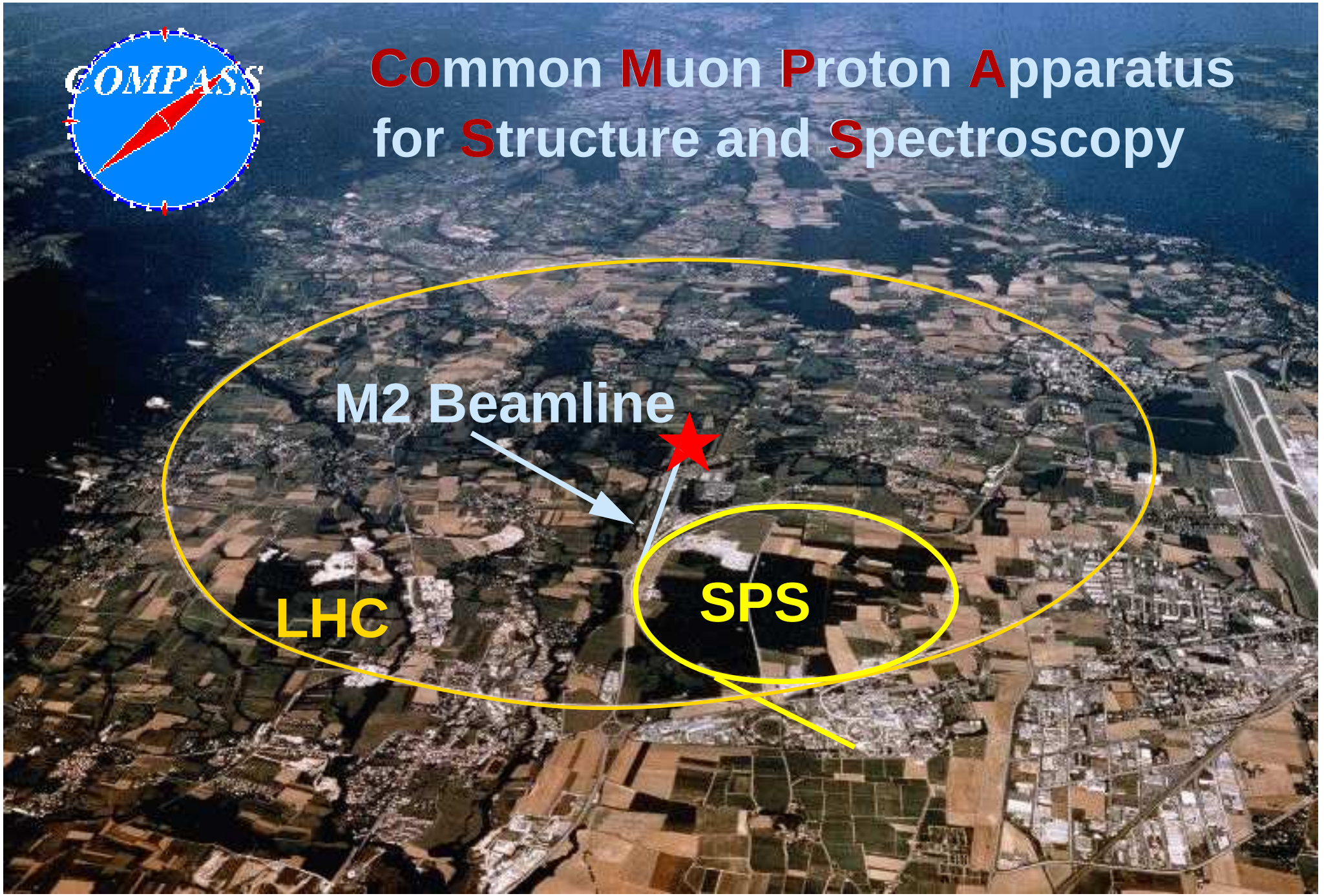
Primakoff scattering

Mesonspectroscopy

- Glueballs
- Hybrids
- Multi-quark states

Charmed baryons

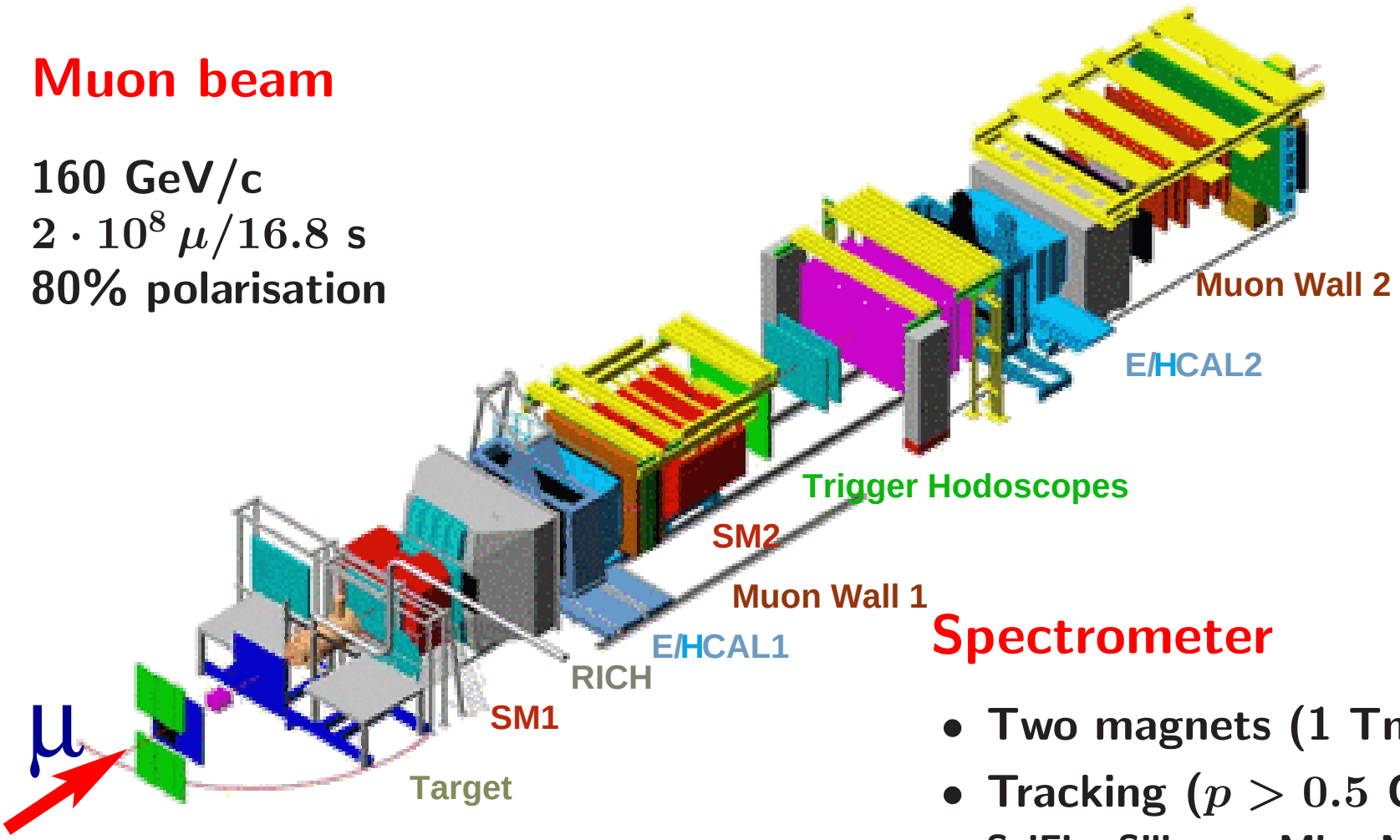
future plans:
Drell Yan measurements


COMPASS
Common Muon Proton Apparatus
for Structure and Spectroscopy
M2 Beamline
LHC
SPS

COMPASS spectrometer

Muon beam

160 GeV/c
$2 \cdot 10^8\ \mu/16.8$ s
80% polarisation



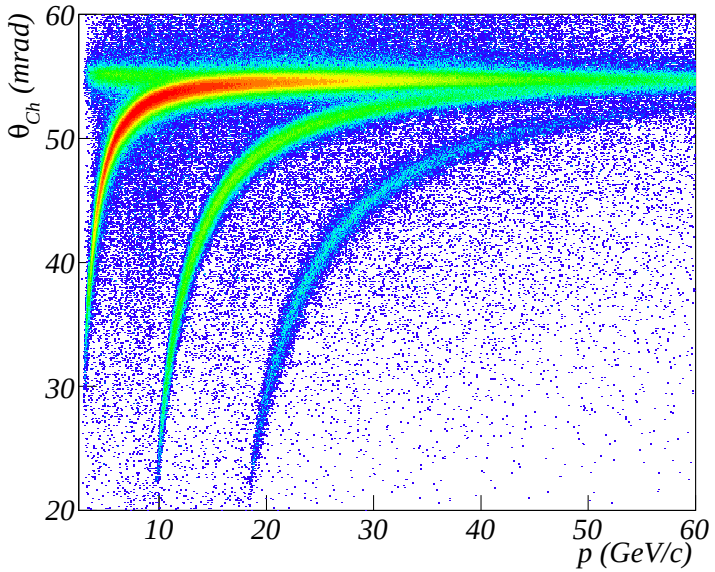
(NIMA 577 (2007) 455)

Spectrometer

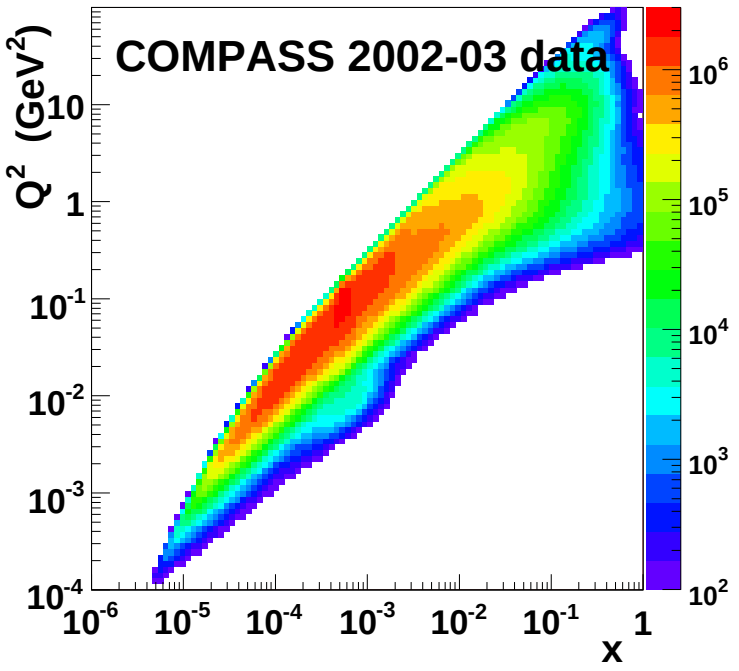
- Two magnets (1 Tm, 4.5 Tm)
- Tracking ($p > 0.5$ GeV/c):
  SciFi, Silicon, MicroMega, GEM, MWPC, Drift, Straws, Driftubes
- PID: π, K, p (RICH)
  above 2, 9, 18 GeV/c
- ECAL, HCAL, muon filter

COMPASS spectrometer

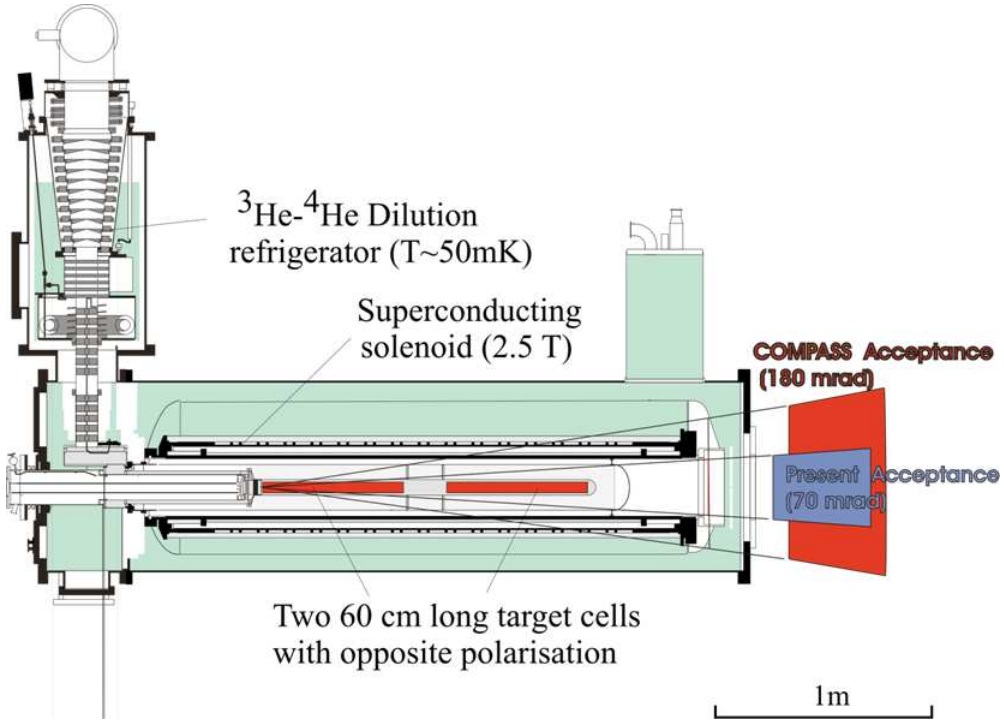
Particle Id.

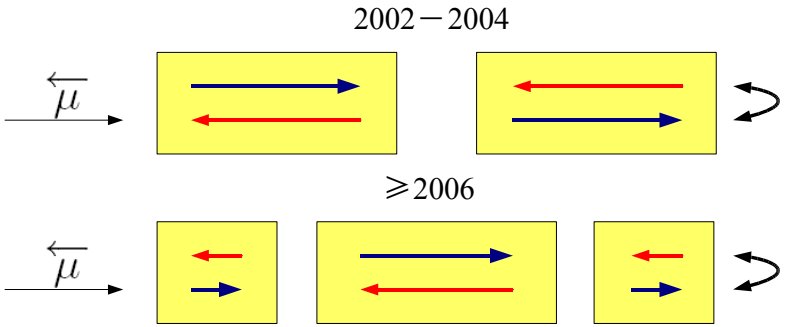


Acceptance:



The polarised target





- target material: ^{6}**LiD, NH_3**
- polarisation: $\mathbf{50\%, 90\%}$
- dilution factor: $\mathbf{0.4, 0.15}$
- Dynamic Nuclear Polarization

- 2006 new solenoid with 180 mrad acceptance
- target cells with opposite polarisation
- regular polarisation reversal by field rotation

Method

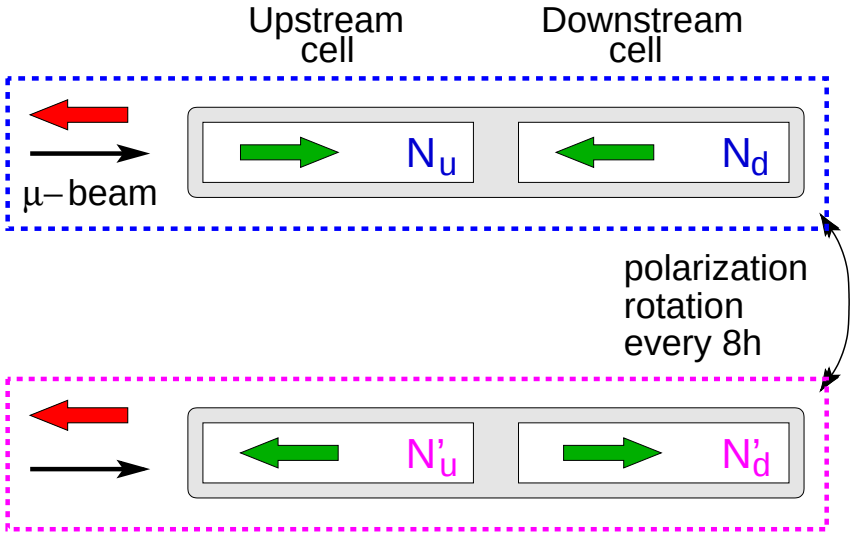
- **to be measured:**

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

- **flux normalization:**

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

- **acceptance difference:**
  Polarisation rotation



- **take average asymmetry:**

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

  $\Rightarrow$ minimization of bias

- **experimental asymmetry**

$$A_{\text{exp}} = p_\mu \; p_{\text{T}} \; f \; A_{\parallel}$$

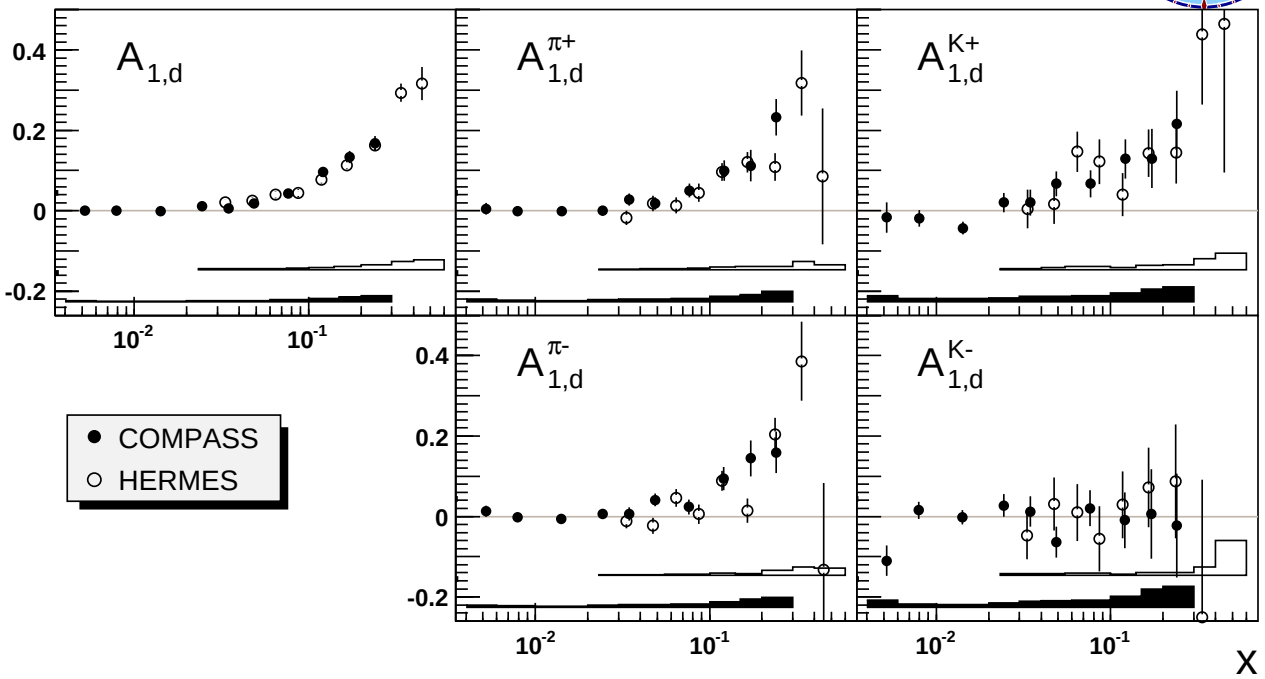
p_μ, p_{T} beam and target polarisation
f dilution factor

Inclusive asymmetries

Deuteron and Proton asymmetries

- **Kinematic domain:**

  $Q^2 > 1\ (\mathrm{GeV}/c)^2$
  $0.1 < y < 0.9$
  $0.004 < x < 0.7$



- deuteron data: 2002 – 2006 (hep-0905.2828)
- inclusive plus identified pion and kaon asymmetries
- A_1^{d} compatible with 0 for $x < 0.05$
- good agreement with previous experiments

Deuteron and Proton asymmetries

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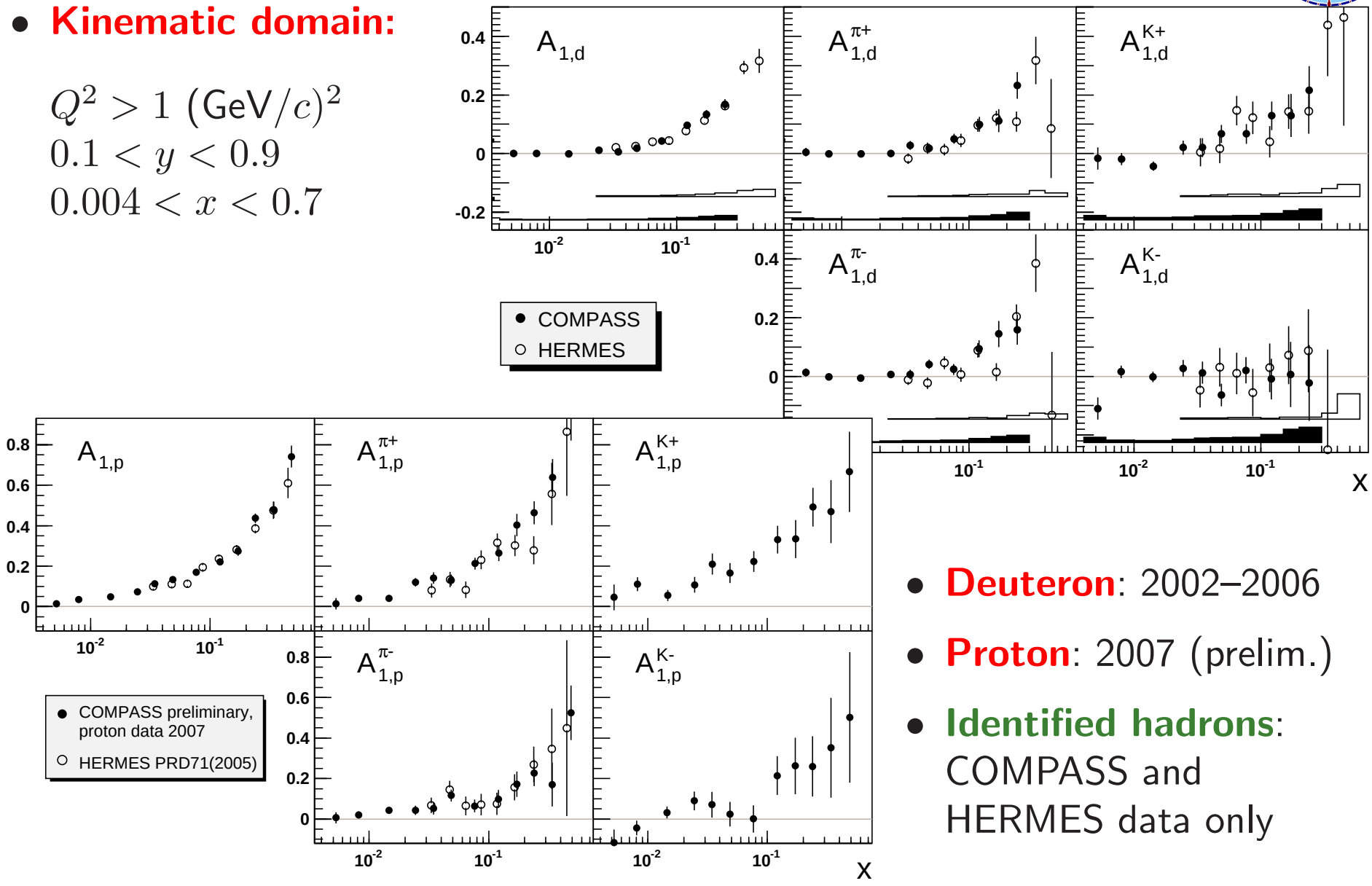
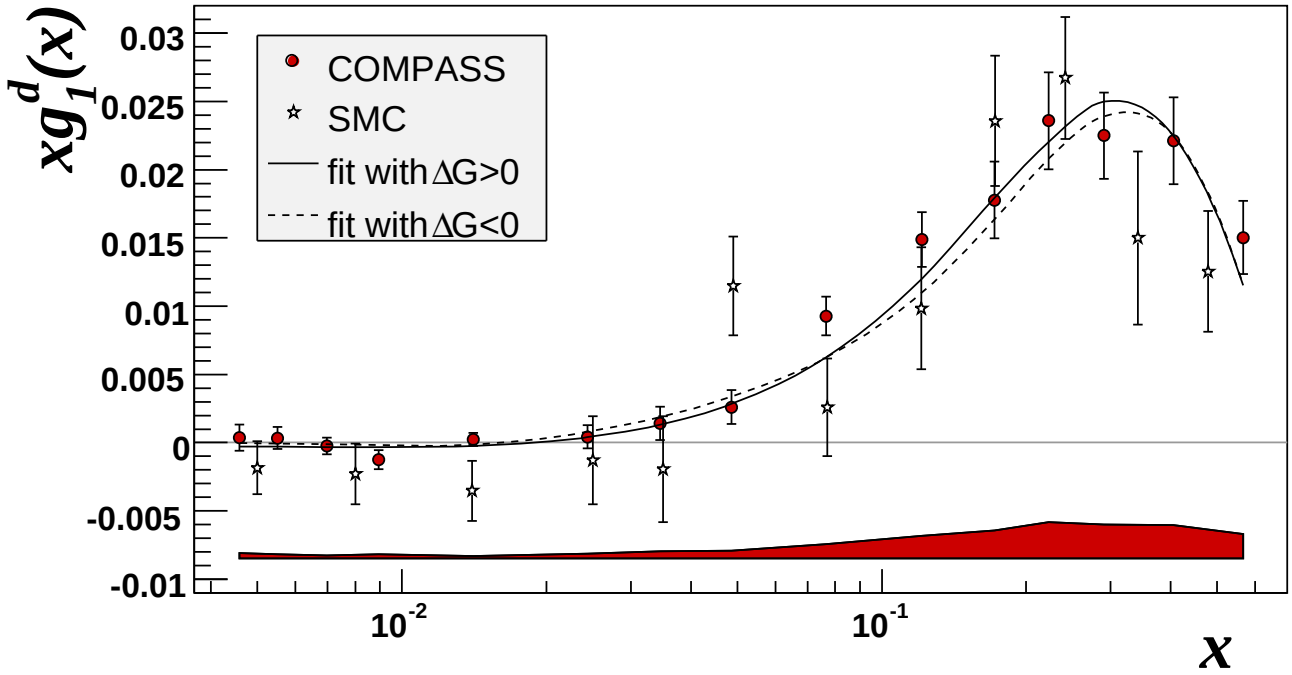
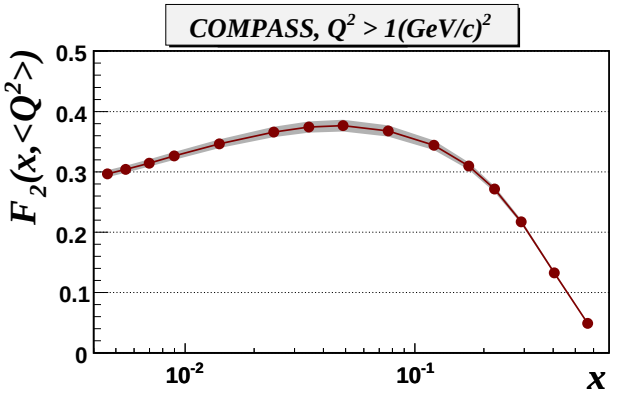
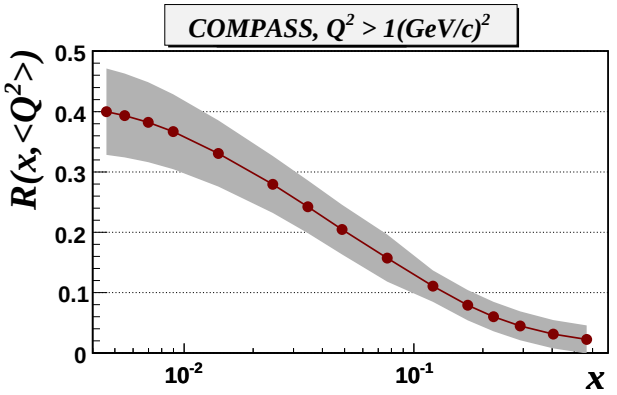


- **Deuteron**: 2002–2006
- **Proton**: 2007 (prelim.)
- **Identified hadrons**: COMPASS and HERMES data only

Spin structure function g_1







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

First moment:

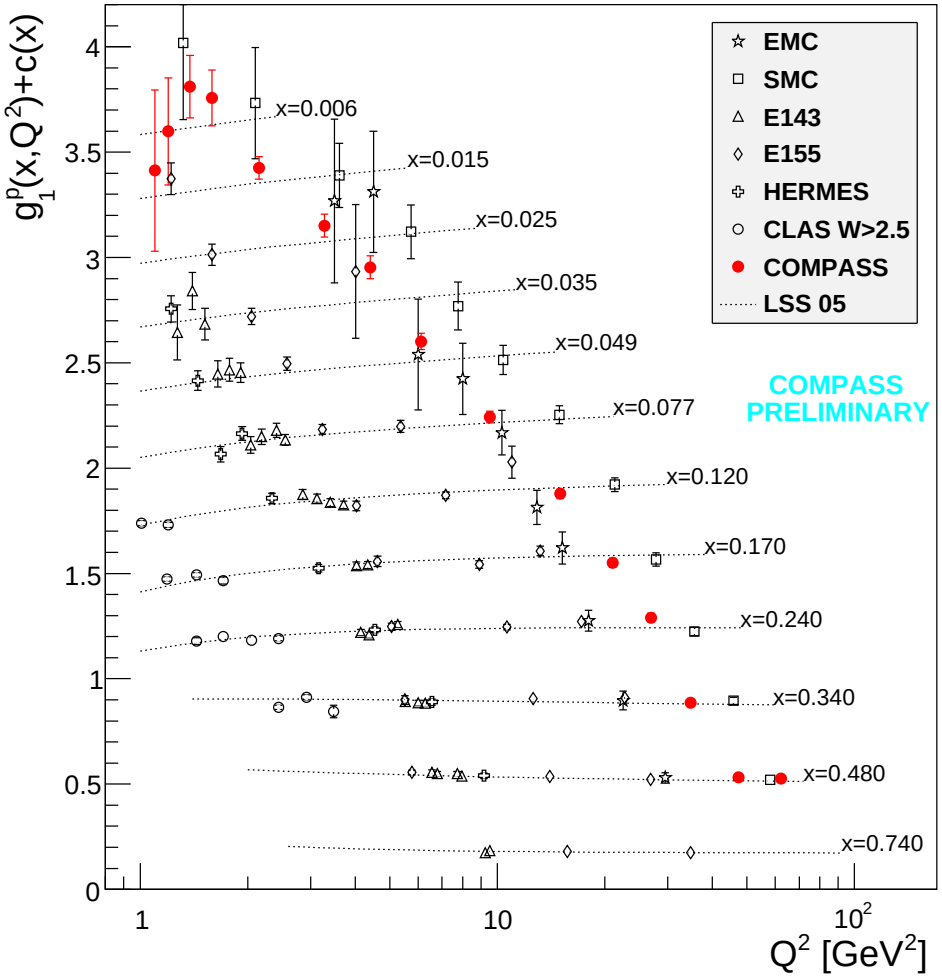
$$g_1^{\mathrm{N}} = g_1^{\mathrm{d}}/(1-1.5\omega_{\mathrm{D}})$$

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

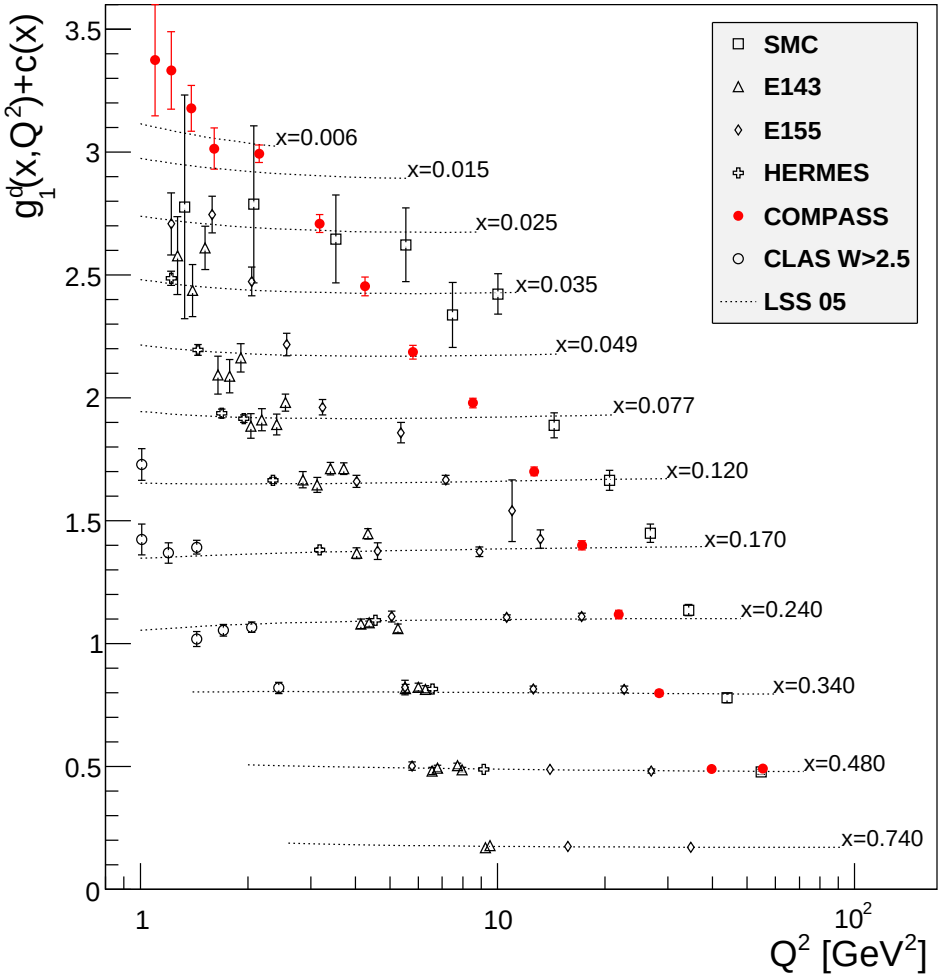
$$= 0.0502 \pm 0.0028(\mathrm{stat}) \pm 0.0020(\mathrm{evol}) \pm 0.0051(\mathrm{syst})$$

World data on g_1 structure function

Proton

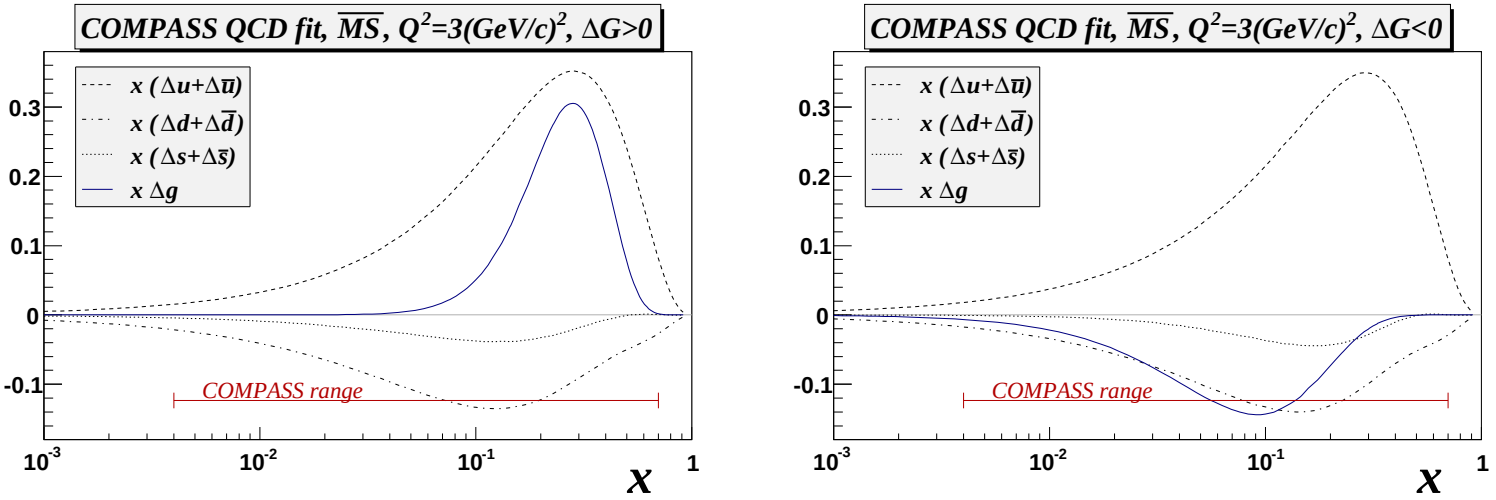


Deuteron



Polarised parton distributions

- **NLO QCD analysis of world data** (PLB 647(2007) 8)
  - numerical integration in (x,Q^2) space (PRD 58 (1998) 112002)
  - solution of DGLAP in space of moments (PRD 70 (2004) 074032)
- **data well described by two solutions with $\Delta G > 0$ and $\Delta G < 0$**



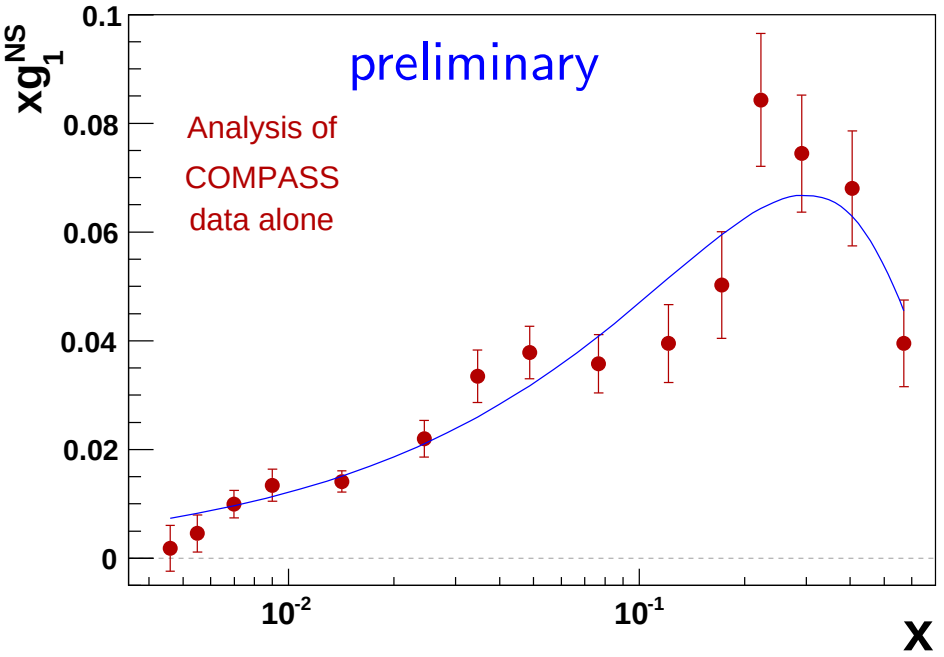
- **small sensitivity to light sea and gluon polarisation**
- **quark polarisation** $\Delta\Sigma = 0.30 \pm 0.01(\text{stat}) \pm 0.02(\text{evol})$

  (stat. error factor 2 larger without COMPASS)
- **gluon polarisation** $|\Delta G| \approx 0.2 - 0.3 \implies$ **direct measurement needed**

Non-singlet structure function

- **non-singlet structure function**

$$g_1^{\mathrm{NS}} = g_1^{\mathrm{p}} - g_1^{\mathrm{n}} = 2\left[g_1^{\mathrm{p}} - \frac{g_1^{\mathrm{d}}}{1 - 1.5\omega_{\mathrm{D}}}\right]$$



- **Bjorken sum rule**

$$\int_0^1 g_1^{\mathrm{NS}} \mathrm{d}x = \left|\frac{g_A}{g_V}\right| C^{\mathrm{NS}}$$

- QCD fit of COMPASS data alone: $\Delta q_{\mathrm{NS}} = \left|\frac{g_A}{g_V}\right| x^{\alpha}(1-x)^{\beta}$

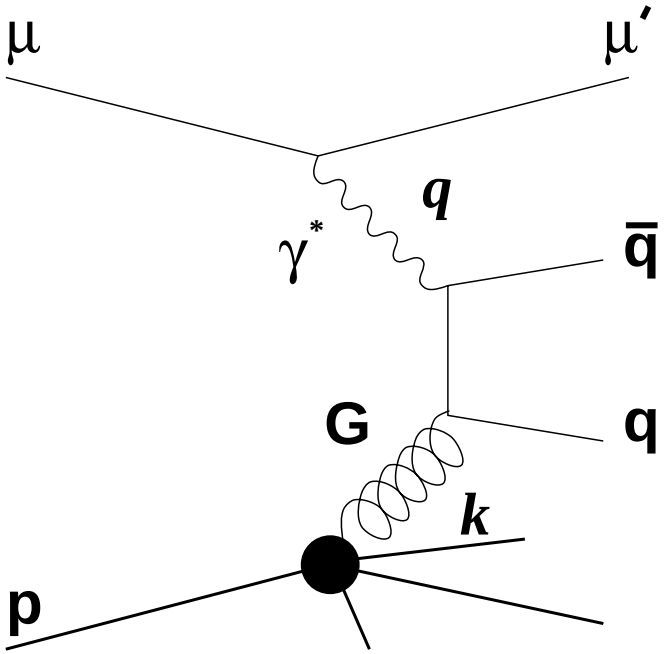
$$\boldsymbol{g_A/g_V = 1.30 \pm 0.07(\mathrm{stat}) \pm 0.10(\mathrm{syst})}$$

- dominant systematic errors: beam and target polarisation
- PDG value: $g_A/g_V = 1.269 \pm 0.003$

Gluon polarisation

$\Delta G/G$ measurements in DIS

Photon gluon fusion



$$A_{\gamma N}^{PGF} = \frac{\int d\hat{s}\, \Delta\sigma^{PGF} \Delta G(x_g, \hat{s})}{\int d\hat{s}\, \sigma^{PGF} G(x_g, \hat{s})} \approx \langle a_{LL}^{PGF} \rangle \frac{\Delta G}{G}$$

$\langle a_{LL}^{PGF} \rangle$ analysing power

Methods

- **Open charm production**

  $\gamma g \to c\bar{c}$

  $\to D^0, D^*$

  hard scale: M_c^2
  theoretically clean channel,
  low staticstics

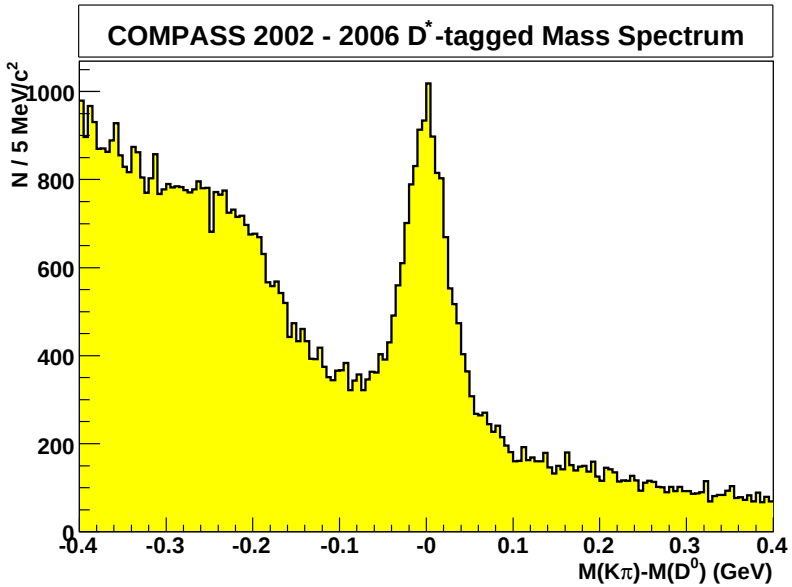
- **High p_T hadron pairs**

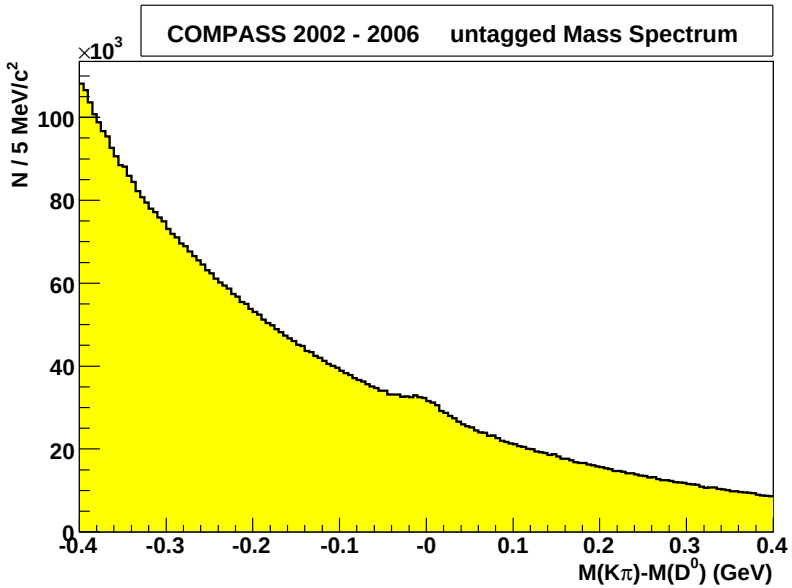
  $\gamma g \to q\bar{q}$

  $\to$ 2 jets or H^+H^-

  hard scale: Q^2 or Σp_T^2
  high statistics
  contributions from background processes

Open charm production





- **channels investigated**

$$D^* \rightarrow D^0\pi_{\rm slow} \rightarrow K\pi\pi_{\rm slow}$$
$$D^* \rightarrow D^0\pi_{\rm slow} \rightarrow K\pi\pi^0\pi_{\rm slow}$$
$$D^0 \rightarrow K\pi$$

- all deuteron data (PLB 676 (2009) 31)
- all Q^2, $a_{\rm LL}$ in LO
- scale $\mu^2 \approx 13\ ({\rm GeV}/c)^2$
- update with additional channels

$$\Delta g/g = -0.39 \pm 0.24({\rm stat}) \pm 0.11({\rm syst})$$

at $x_{\rm g} = 0.11$

- **future**: more channels, proton data, improved analysis method, $a_{\rm LL}$ in NLO

High p_{T} hadron pairs

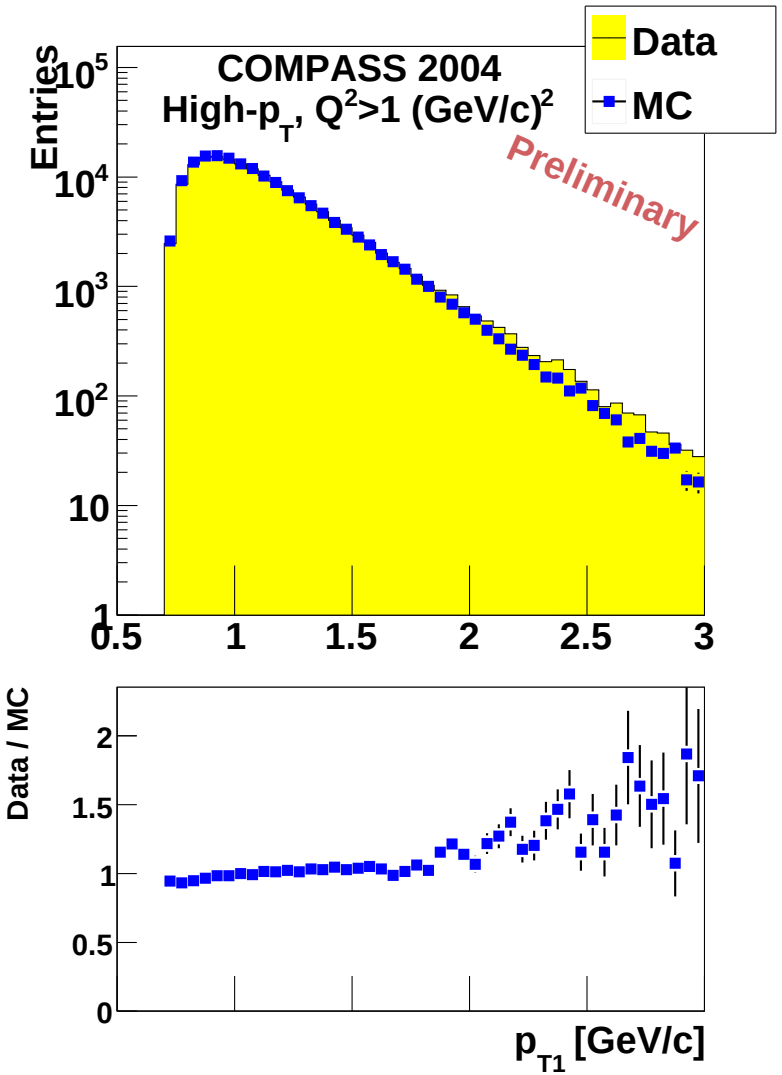
$$\Delta g/g(x_{\mathrm{g}}) = (A_{\mathrm{LL}}^{2h} + A^{\mathrm{corr}})/\beta$$

- **selection**
  $Q^2 > 1$ (GeV/c)^2, $p_{\mathrm{T}}(h_1, h_2) > 0.7$ GeV/c
- **background processes**

  QCD-Compton, leading order
  (plus resolved photons for small Q^2)
- determined from MC (Lepto) plus neural net
- **preliminary result** from 2002-2004 data

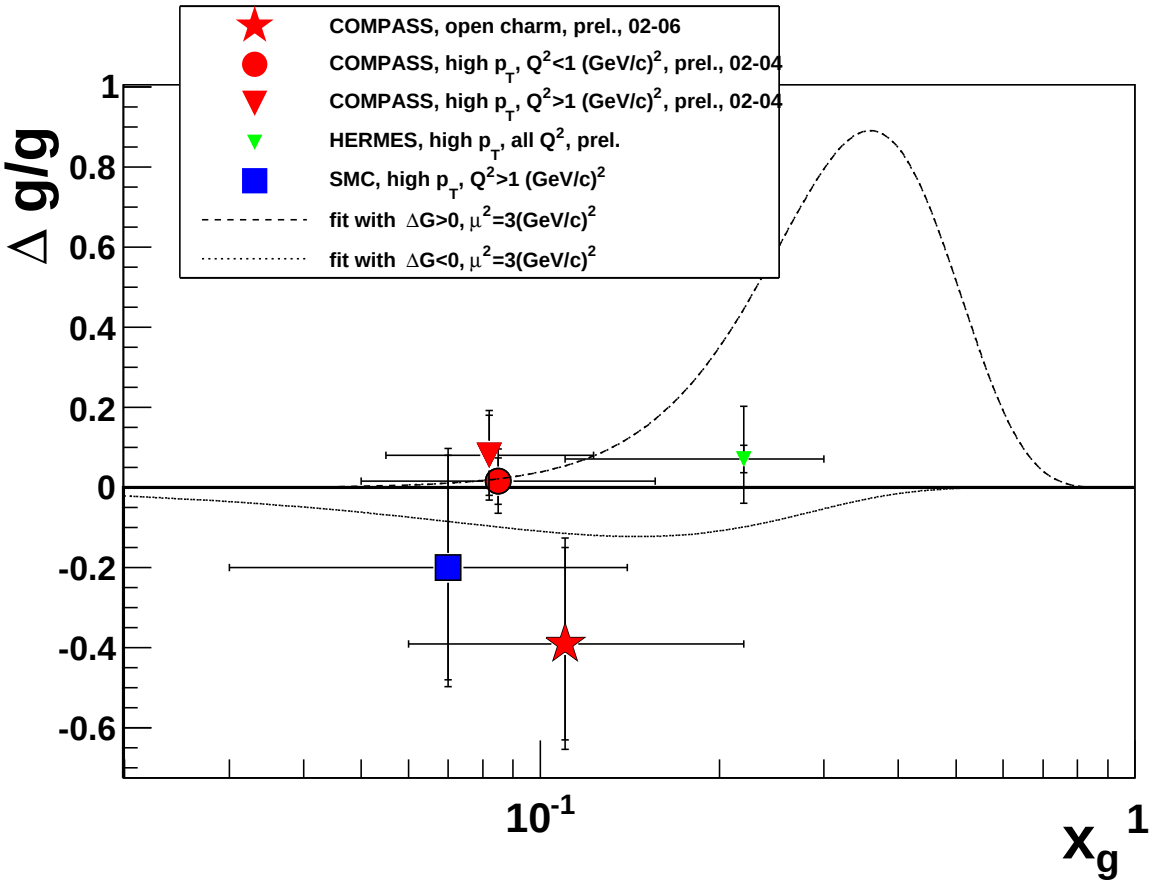
$$\Delta g/g = -0.08 \pm 0.10(\mathrm{stat}) \pm 0.05(\mathrm{syst})$$

- at $x_{\mathrm{g}} = 0.082$ and scale $\mu^2 \approx 3$ (GeV/c)^2
- systematic error dominated by MC error



similar for other variables

Results for $\Delta G/G$



- $\Delta G/G$ is small or has a node around $x_{\mathrm{g}} \approx 0.1$
- supported by recent PHENIX and STAR results from pp-collisions

Semi-inclusive asymmetries

Flavour separation

- **SIDIS**
  $A_1^h = \frac{\Sigma e_q^2 (\Delta q(x) \int D_d^h(z)\mathrm{d}z + \Delta\bar{q} \int D_{\bar{q}}^h(z)\mathrm{d}z)}{\Sigma e_q^2 q(x) \int D_d^h(z)\mathrm{d}z + \bar{q} \int D_{\bar{q}}^h(z)\mathrm{d}z}$

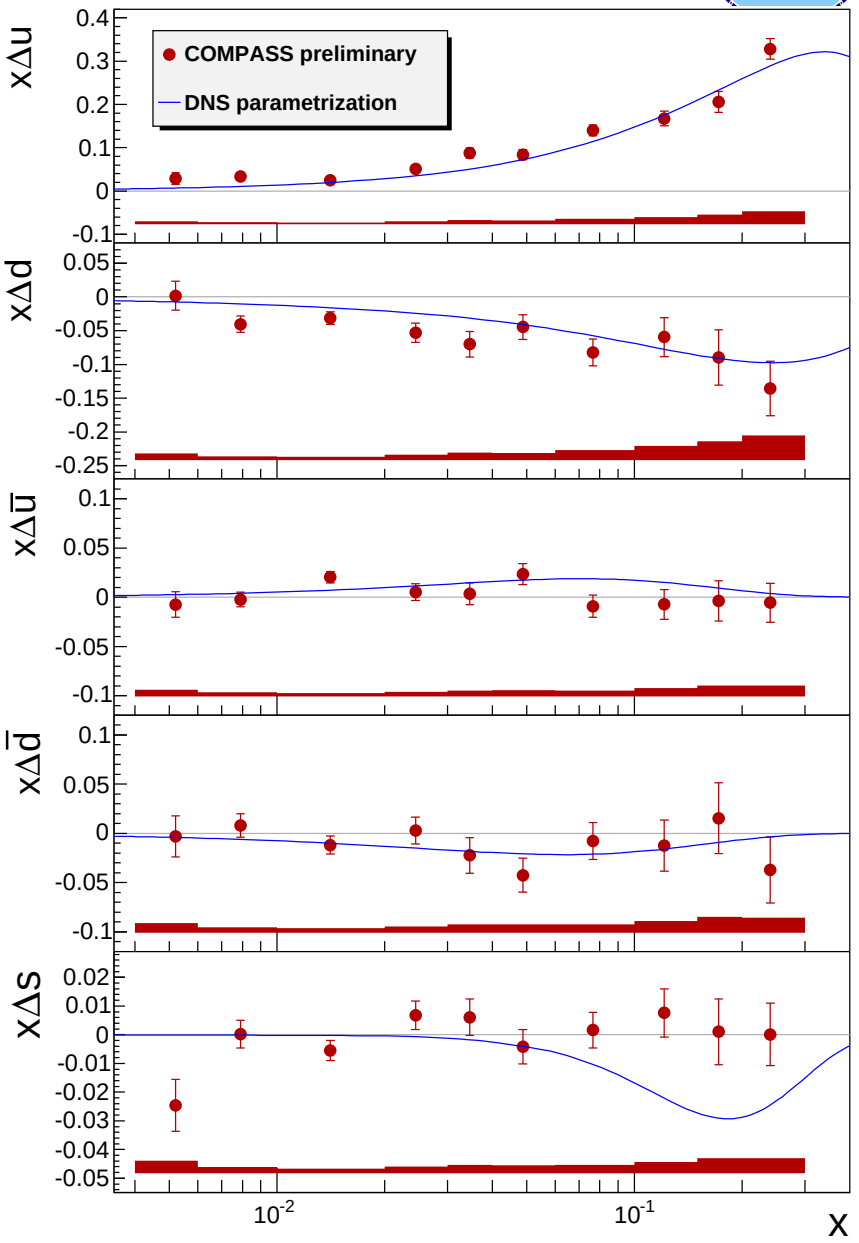
- $D_q^h \neq D_{\bar{q}}^h$
  yields quark and antiquark separation

- **measured**:
  A_1^{d}, $A_{1\mathrm{d}}^{K^\pm}$, $A_{1\mathrm{d}}^{\pi^\pm}$, A_1^{p}, $A_{1\mathrm{p}}^{K^\pm}$, $A_{1\mathrm{p}}^{\pi^\pm}$

- **determined**: Δu, $\Delta\bar{u}$, Δd, $\Delta\bar{d}$, $\Delta s = \Delta\bar{s}$

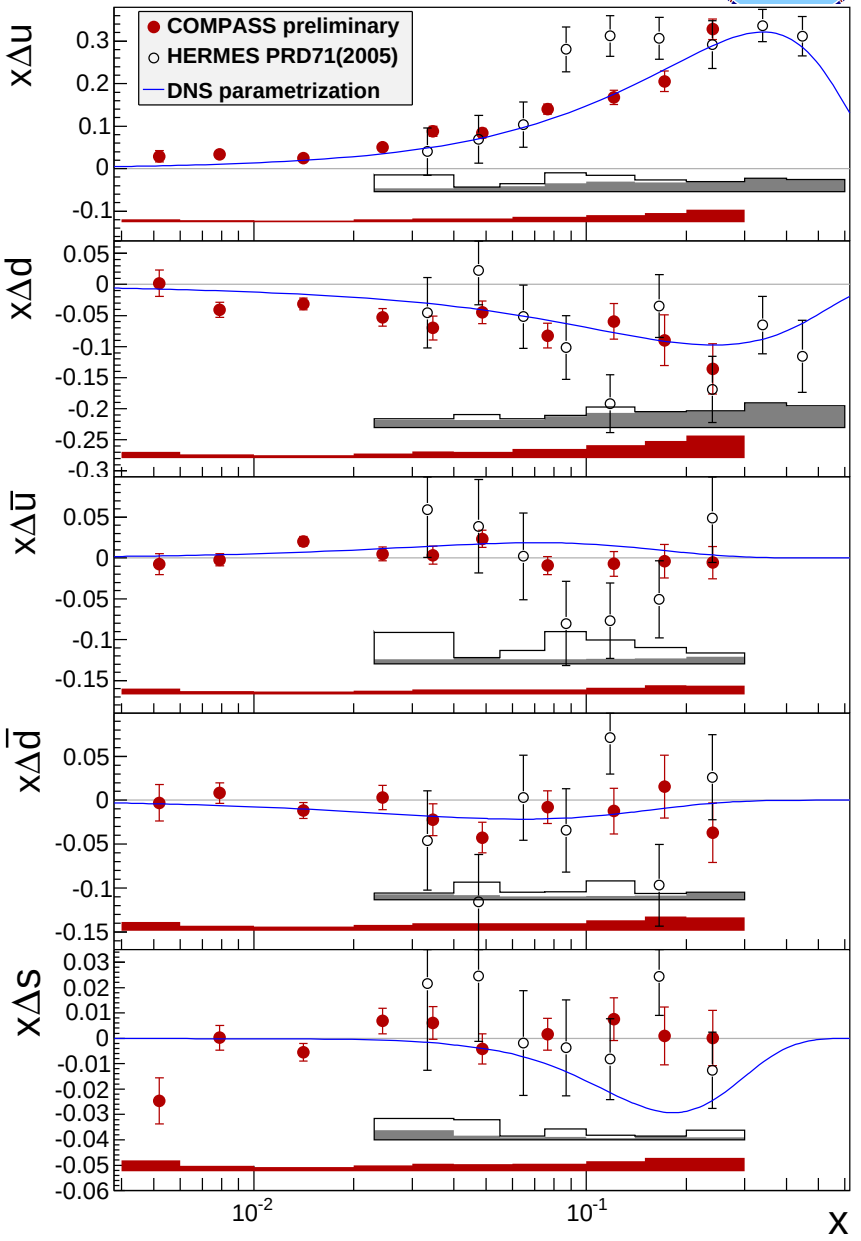
- system of linear equations in LO

- **inputs**: MRST04 unpolarised PDFs, DSS parametr. of FFs (parametrisation of e^+e^-, DIS, hadron-hadron results)



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 Δu, $\Delta\bar{u}$, Δd, $\Delta\bar{d}$
- significant discrepancy with Δs obtained from QCDfits to g_1
- **but** result for Δs depends on assumptions for FFs



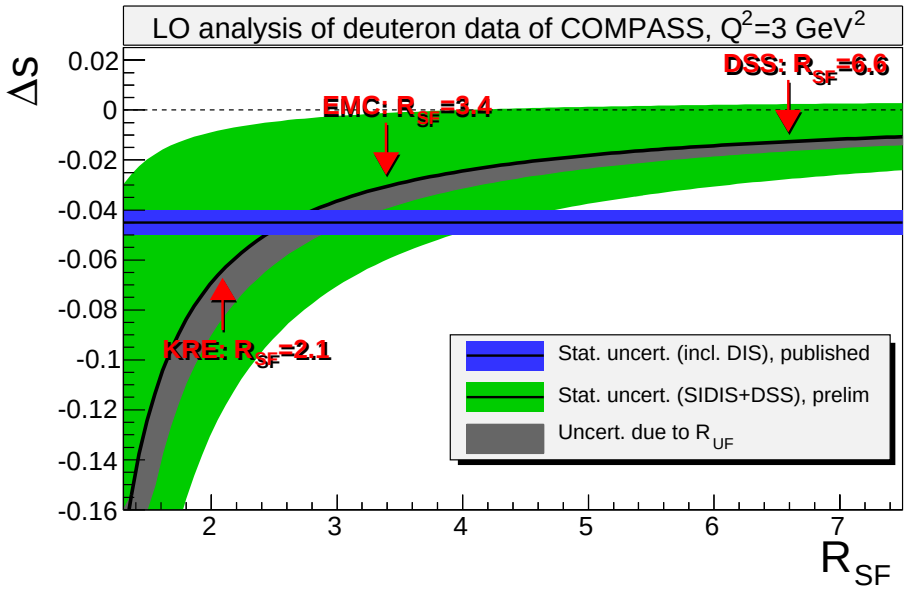
Dependence on FFs

- $K^{\pm}$ asymmetries from deuteron data

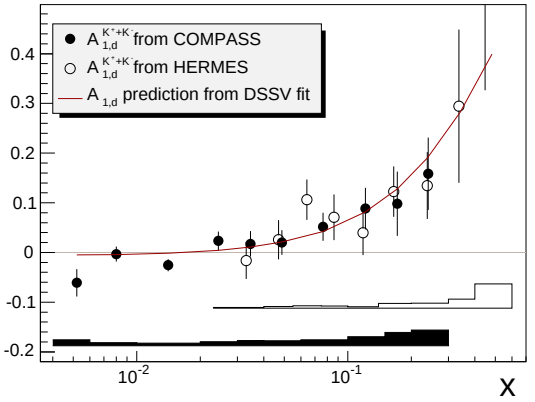
$$\frac{\Delta s}{s} = A_1^{\mathrm{d}} + \left(A_1^{K^+ + K^-} - A_1^{\mathrm{d}}\right) \frac{Q/s + \alpha}{\alpha - 0.8}$$

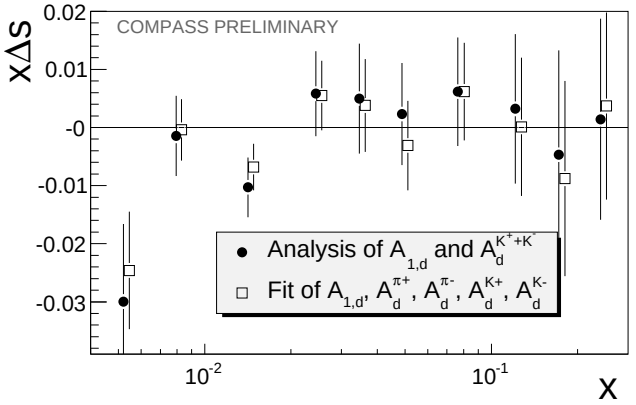
- $Q = u + \bar{u} + d + \bar{d},\ \alpha = \frac{2R_{UF} + 2R_{SF}}{3R_{UF} + 2}$

- $R_{UF} = \frac{\int D_d^{K^+}(z)\mathrm{d}z}{\int D_u^{K^+}(z)\mathrm{d}z},\ R_{SF} = \frac{\int D_{\bar{s}}^{K^+}(z)\mathrm{d}z}{\int D_u^{K^+}(z)\mathrm{d}z}$



(hep-0905.2828)

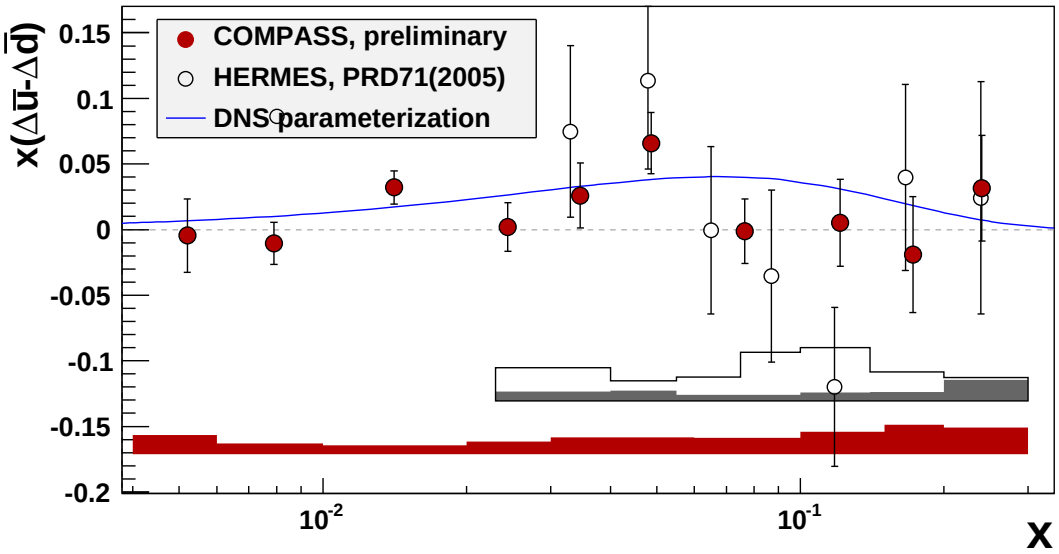


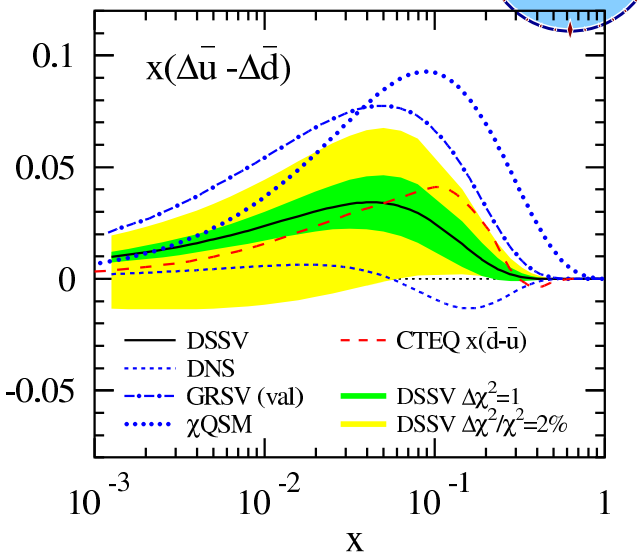


- large dependence on R_{SF}, slight dependence on R_{UF} for Δs

- determination of R_{SF} from data (hadron multiplicities) on the way

Flavour symmetry breaking





- presently only accessible via SIDIS
- uncertainty from FFs not yet estimated
- preliminary result at $Q^2 = 3$ (GeV/c)^2:

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

- compatible with HERMES result
- comparable with effect in unpolarised PDFs ($\int(\bar{u} - \bar{d})\mathrm{d}x = -0.118 \pm 0.012$)

Summary and outlook

Results

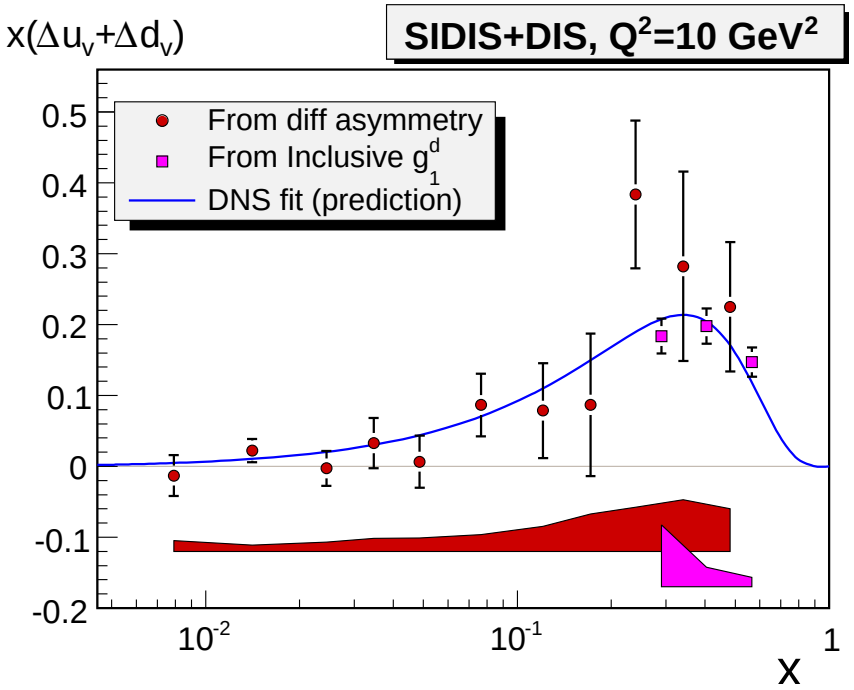
- results from all proton and deuteron data
- new determination of Bjorken sum rule
- full flavour separation from SIDIS data
- update of result for gluon polarisation
- more results on ρ asymmetries, Λ polarisation, azimuthal asymmetries, low Q^2 asymmetries

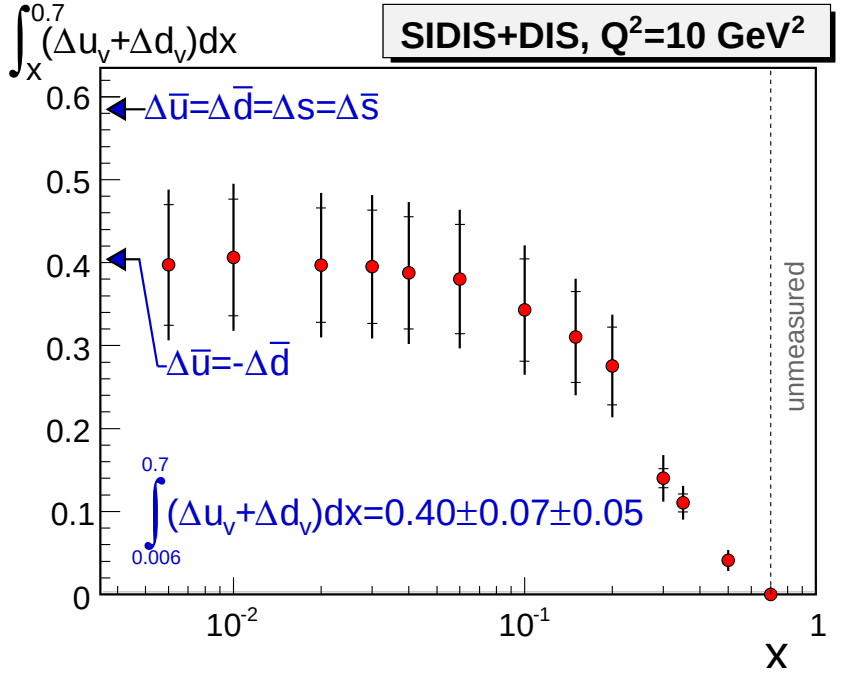
Future

- muon data taking will be resumed in 2010
- with transversely and longitudinally polarised NH_3 target
- quark angular momentum contribution can be accessed via DVCS
- proposal for DVCS and DY measurements in preparation

Towards polarised sea quarks

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





- first moment $\Gamma_v = \int_0^1 (\Delta u_v(x) + \Delta d_v(x))\mathrm{d}x$
- with Γ_1^{N} and a_8: $\Delta\bar{u} + \Delta\bar{d} = 3\,\Gamma_1^{\mathrm{N}} - \frac{1}{2}\Gamma_v + \frac{1}{12}a_8$ a_8 from hyperon decays
- disentangle between flavour **symmetric** ($\Delta\bar{u}{=}\Delta\bar{d}{=}\Delta s{=}\Delta\bar{s}$) and **asymmetric** ($\Delta\bar{u}{=}{-}\Delta\bar{d}$) sea: **asymmetric** sea favoured ($2.5\ \sigma_{\mathrm{stat}}$) (PLB 660 (2008) 458)
- next step: $\mathrm{K}^{\pm}$ asymmetries $\longrightarrow \Delta s$