

Longitudinal spin physics at COMPASS

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on behalf of the COMPASS collaboration

**International school on nuclear physics
33rd Course
From Quarks and Gluons to Hadrons
Erice, 16.9. – 24.9.2011**



bmb+f - Förderschwerpunkt
COMPASS
Großgeräte der physikalischen
Grundlagenforschung

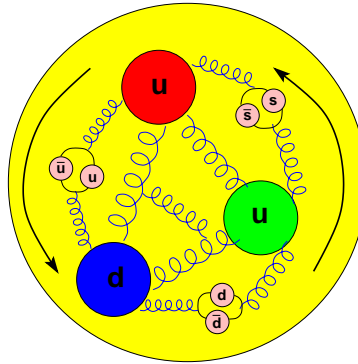


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The spin of the nucleon

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



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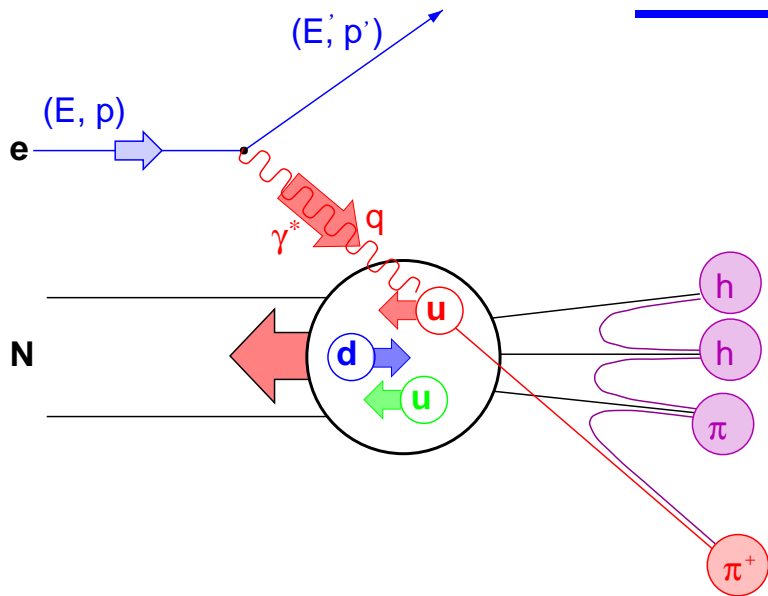
$\Delta\Sigma$, Δs
 Δu , Δd , Δs
 ΔG
 L_q

inclusive DIS
semi-inclusive DIS
PGF in DIS
DVCS

Content

- COMPASS experiment
- Longitudinal asymmetries
- Spin structure functions
- Flavourseparation
- Gluon polarisation

Deep inelastic scattering



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

$$\nu = E - E'$$

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

$$z = E_h / \nu$$

p_T^h : transverse
momentum

$$q(x) = q(x)^+ + q(x)^- \quad + \text{quark } \uparrow\uparrow \text{ nucleon}$$

$$\Delta q(x) = q(x)^+ - q(x)^- \quad - \text{quark } \downarrow\uparrow \text{ nucleon}$$

• photon nucleon asymmetry

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

• spin structure function

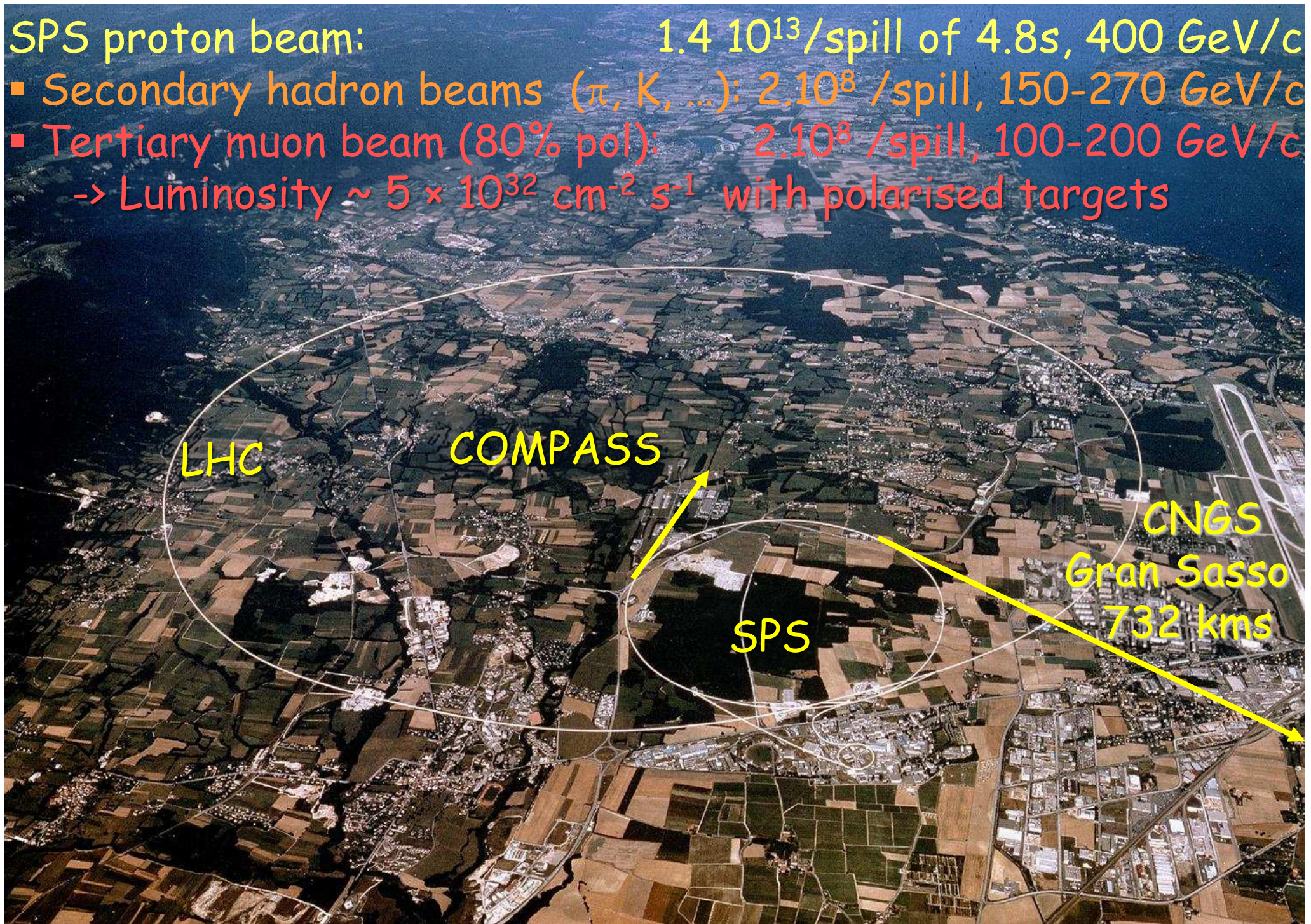
$$g_1 = \frac{1}{2} \sum_q e_q^2 \Delta q(x) = A_1 \cdot \frac{F_2}{2x(1+R)} \approx \frac{A_{\parallel}}{D} \cdot \frac{F_2}{2x(1+R)}$$

COMPASS at CERN

SPS proton beam:

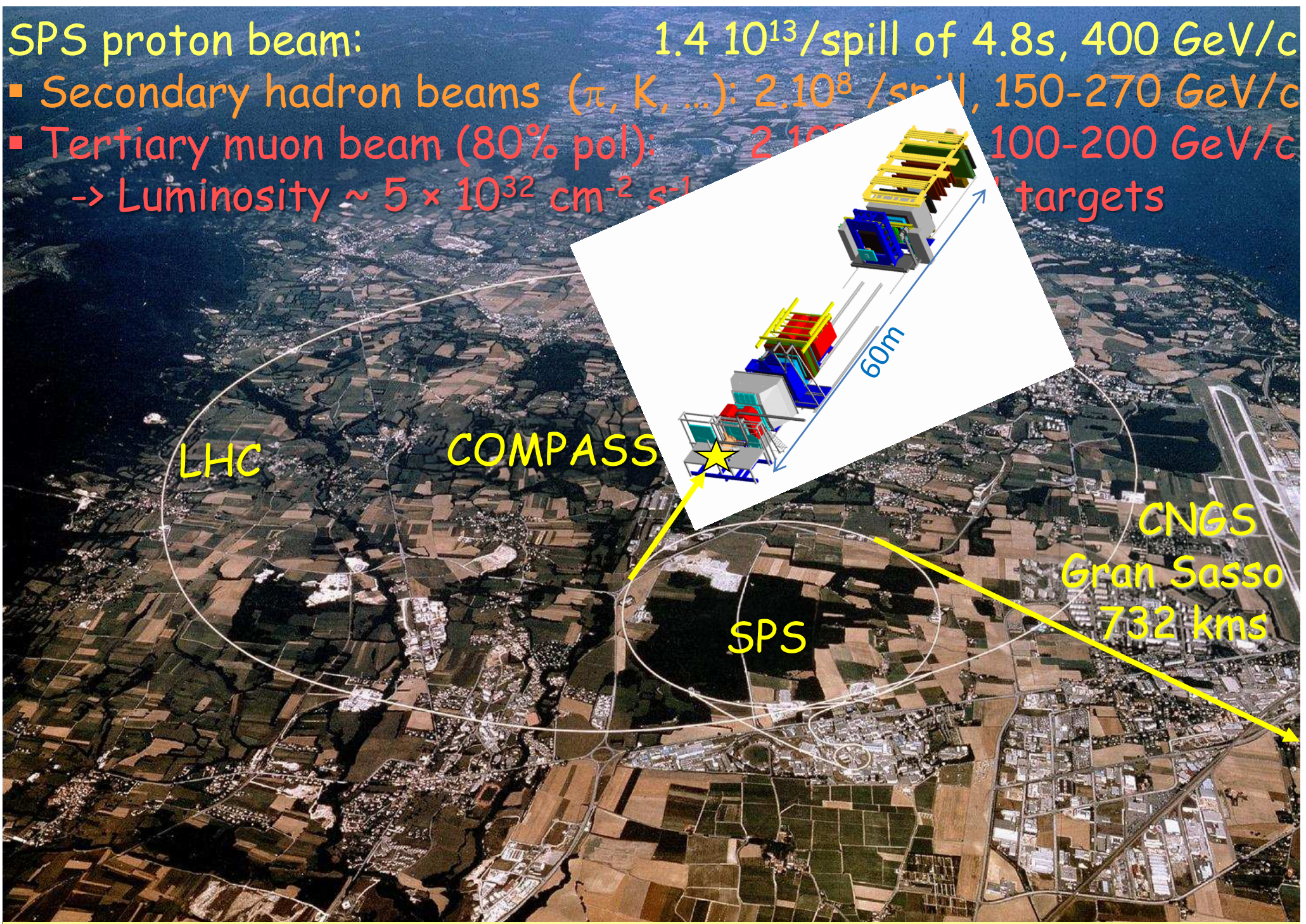
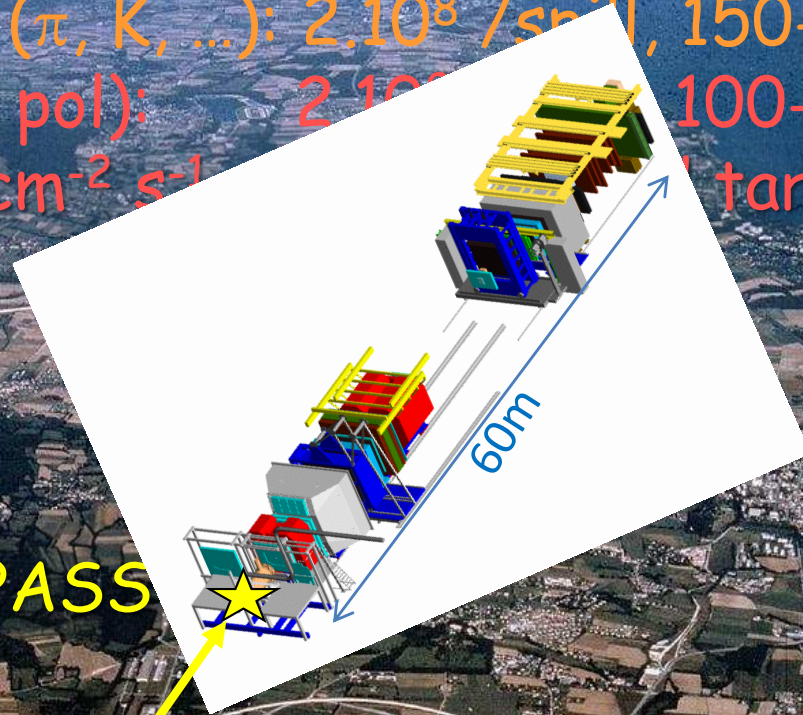
$1.4 \cdot 10^{13}$ /spill of 4.8s, 400 GeV/c

- Secondary hadron beams (π , K, ...): $2 \cdot 10^8$ /spill, 150-270 GeV/c
- Tertiary muon beam (80% pol): $2 \cdot 10^8$ /spill, 100-200 GeV/c
-> Luminosity $\sim 5 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ with polarised targets



SPS proton beam:

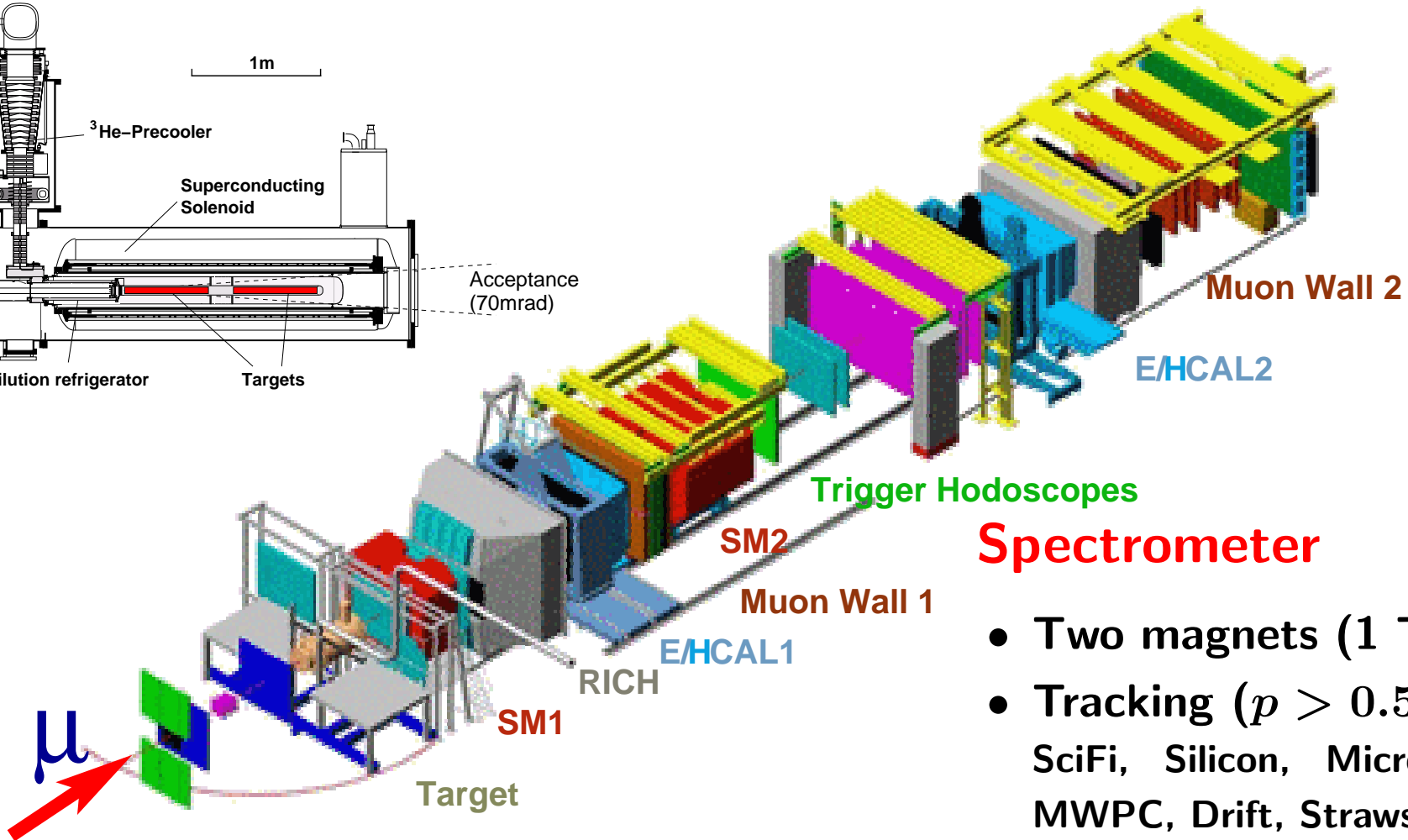
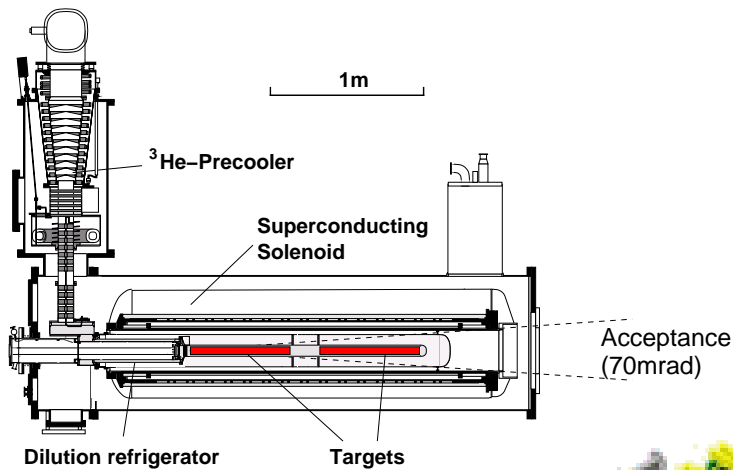
- Secondary hadron beams (π, K, \dots): $2 \cdot 10^8$ /spill, 150-270 GeV/c
- Tertiary muon beam (80% pol): $2 \cdot 10^8$ /spill, 100-200 GeV/c
-> Luminosity $\sim 5 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ targets



COMPASS spectrometer



Polarised target



target material: ^6LiD , NH_3
polarisation: 50%, 90%

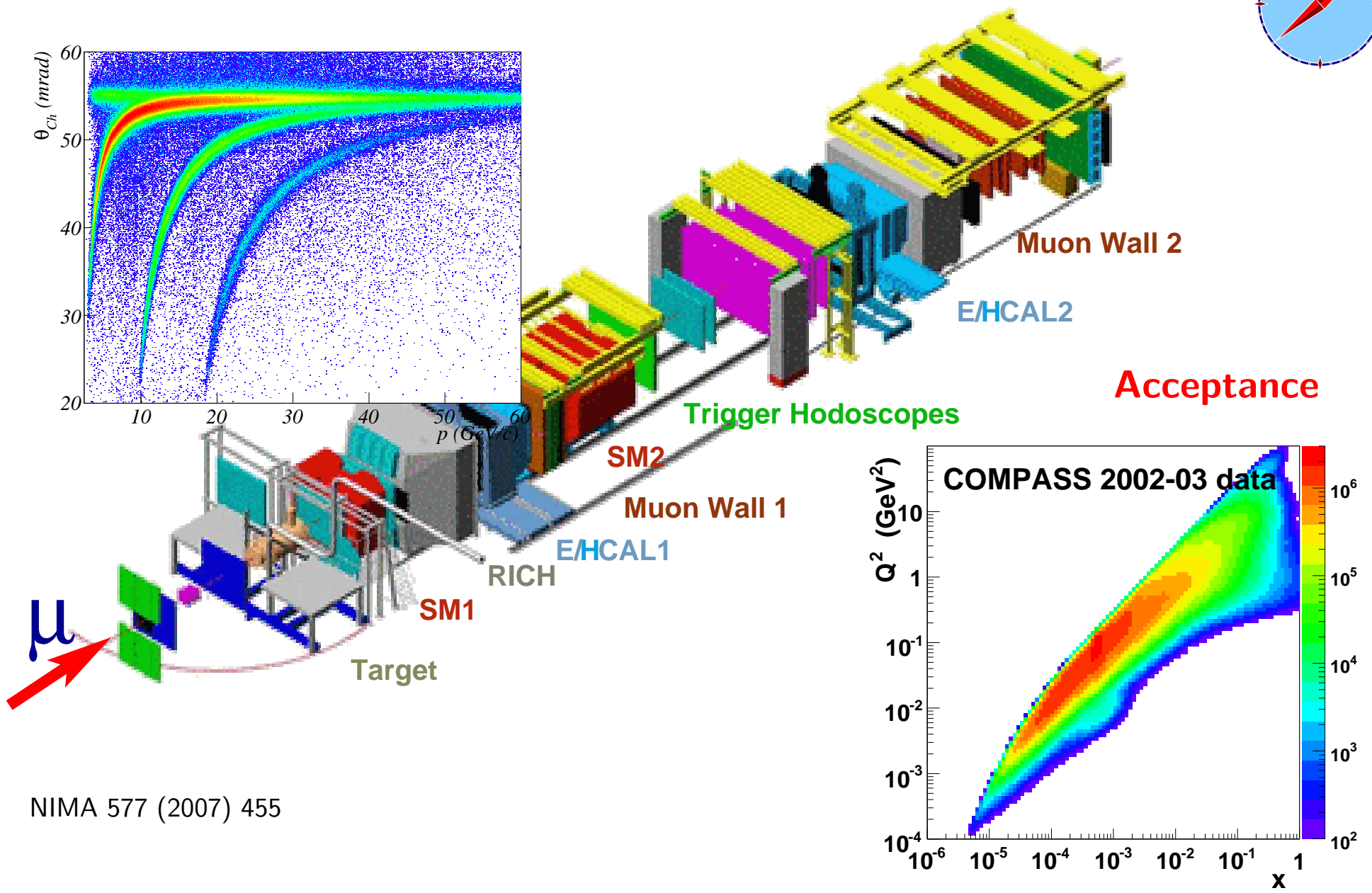
Spectrometer

- 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 filter

COMPASS spectrometer



Particle Id.



NIMA 577 (2007) 455

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:

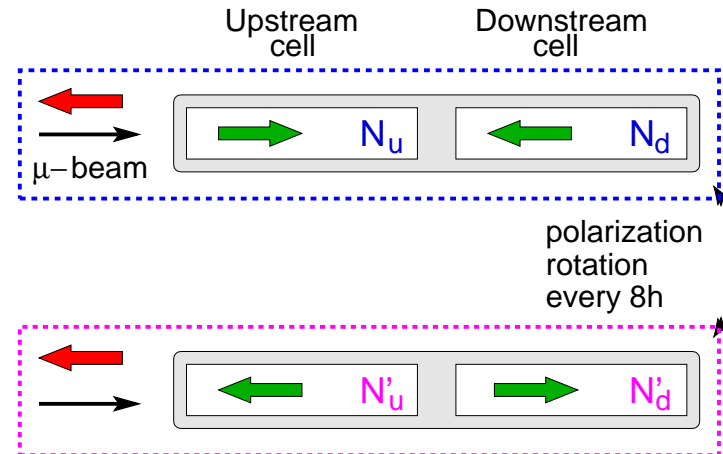
$$\Rightarrow A_{\text{exp}} = \frac{A + A'}{2} = \frac{1}{2} \left(\frac{N_u - N_d}{N_u + N_d} + \frac{N'_d - N'_u}{N'_u + N'_d} \right)$$

\Rightarrow minimization of bias

- experimental asymmetry

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

p_{μ}, p_T beam and target polarisation
 f dilution factor



Asymmetries

Deuteron and Proton asymmetries



- Kinematic domain:**

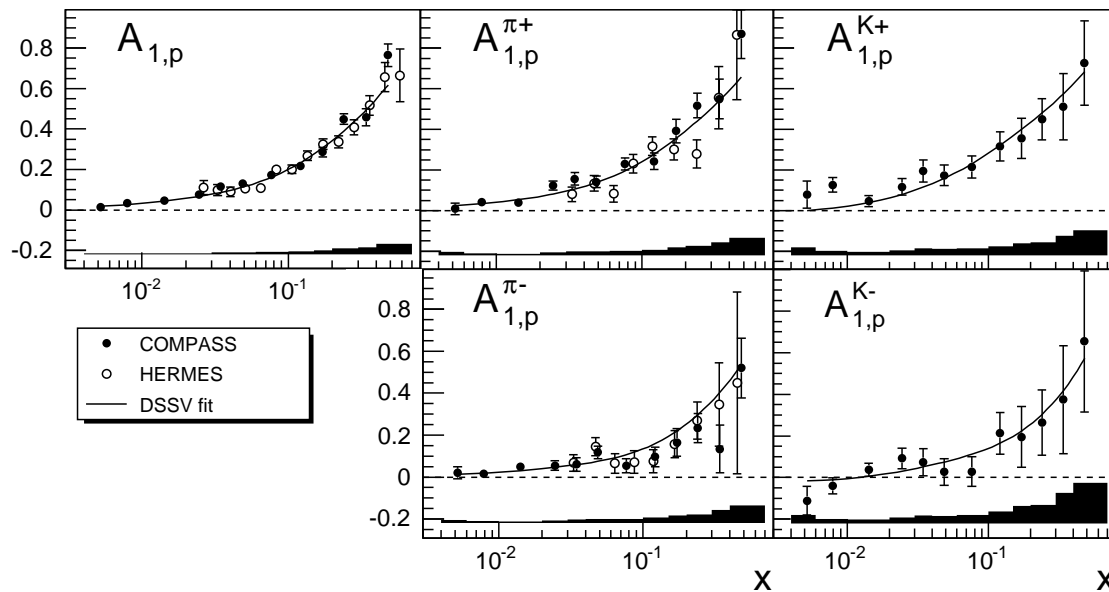
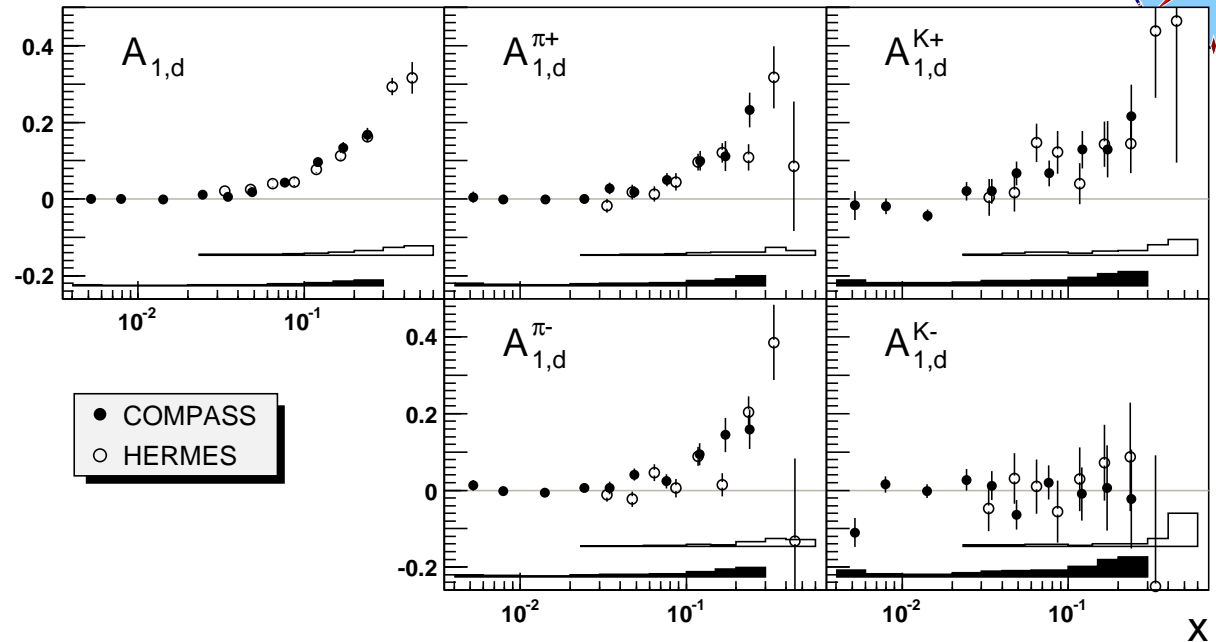
$$Q^2 > 1 \text{ (GeV}/c)^2$$

$$0.1 < y < 0.9$$

$$0.2 < z < 0.85$$

$$0.004 < x < 0.7 \text{ DIS}$$

$$0.004 < x < 0.3 \text{ SIDIS}$$



- Deuteron:** 2002–2006

PLB 647 (2007) 8, 680 (2009) 217

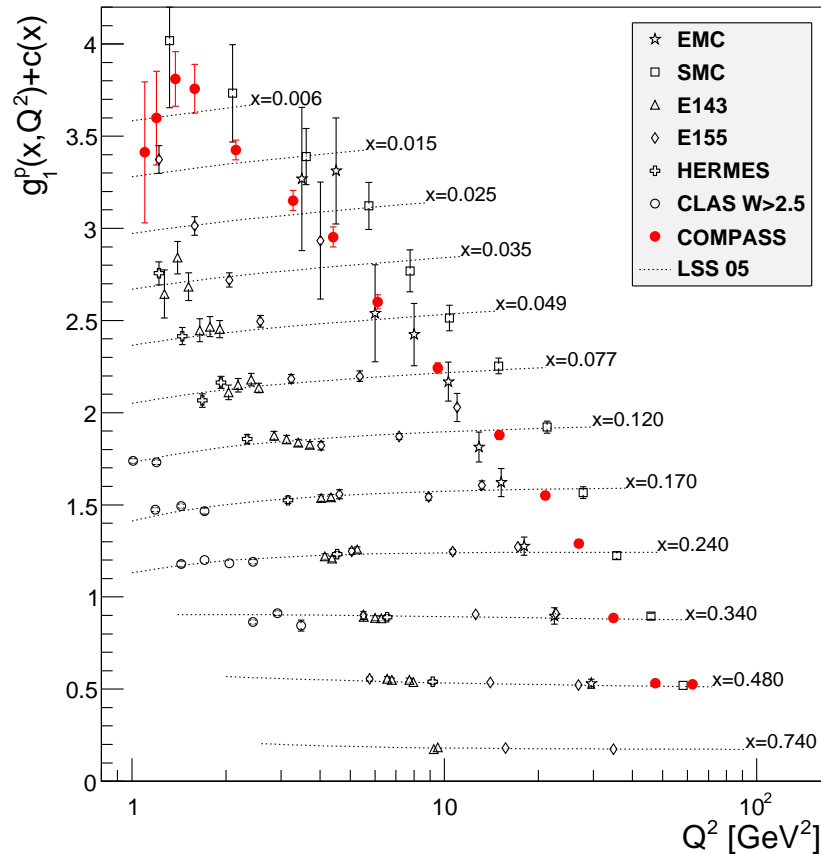
- Proton:** 2007

PLB 690 (2010) 466, 693 (2010) 227

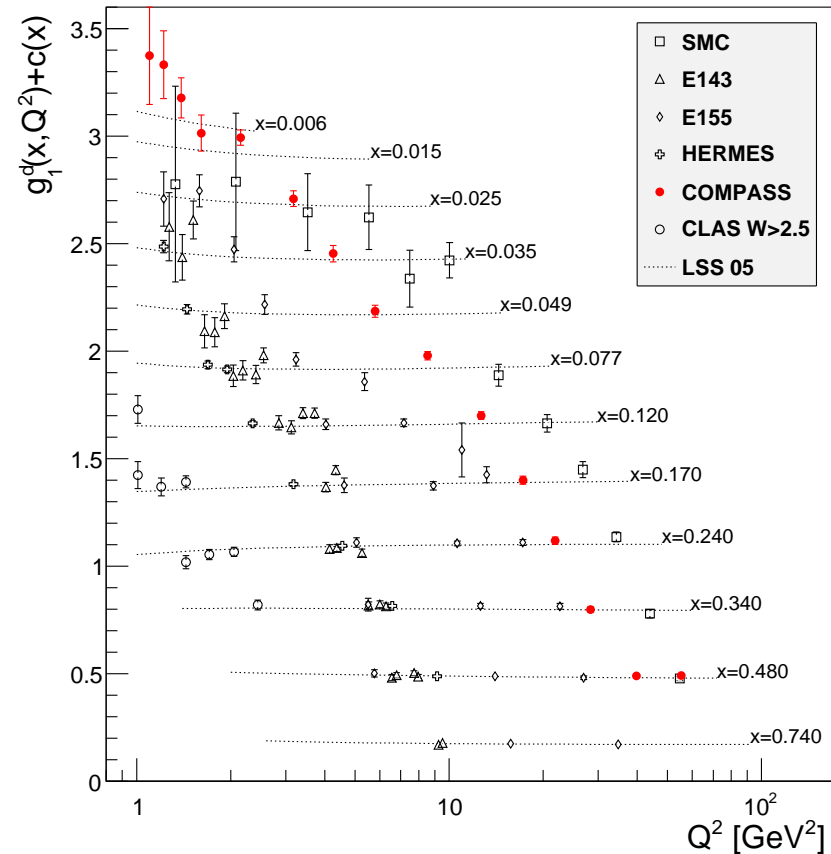
- Identified pions and kaons

World data on $g_1(x, Q^2)$

Proton



Deuteron



pQCD analyses

- $\Delta u + \Delta \bar{u}$ and $\Delta d + \Delta \bar{d}$ well constrained by data (LSS PRD 80 (2009) 054026)
- Δs and Δg need other data in addition to inclusive data
- Δs comes out negative (except for DSSV includes SIDIS data)
- $|\Delta G|$ is small (< 0.5) \implies **direct measurement needed**

First moment of g_1^d



Can one learn something without pQCD fits?

- **First moment of g_1^d** (at $Q^2 = 3(\text{GeV}/c)^2$)

$$\Gamma_1^N = \int_0^1 \frac{g_1^d(x)}{1 - 1.5\omega_D} dx = 0.0502 \pm .0028(\text{stat}) \pm .0020(\text{evol}) \pm .0051(\text{syst})$$

- data used in measured range, QCD fit used for extrapolation
- contribution of unmeasured region few %

- **using:** $a_0^{\overline{\text{MS}}} = \Delta\Sigma$ and $\Gamma_1^N = \frac{1}{9}(a_0\Delta C_S^{\overline{\text{MS}}} + \frac{1}{4}a_8\Delta C_{NS}^{\overline{\text{MS}}})$

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

- **assuming SU(3) symmetry:** $(\Delta s + \Delta\bar{s}) = \frac{1}{3}(\hat{a}_0 + a_8)$

$$(\Delta s + \Delta\bar{s}) = -0.08 \pm 0.01(\text{stat}) \pm 0.02(\text{syst})$$

- negative strange sea polarisation

Is this supported by direct measurements?

Flavour separation

Flavour separation



- **SIDIS**

$$A_1^h = \frac{\sum_q e_q^2 (\Delta q(x) \int D_q^h(z) dz)}{\sum_q e_q^2 q(x) \int D_q^h(z) dz}$$

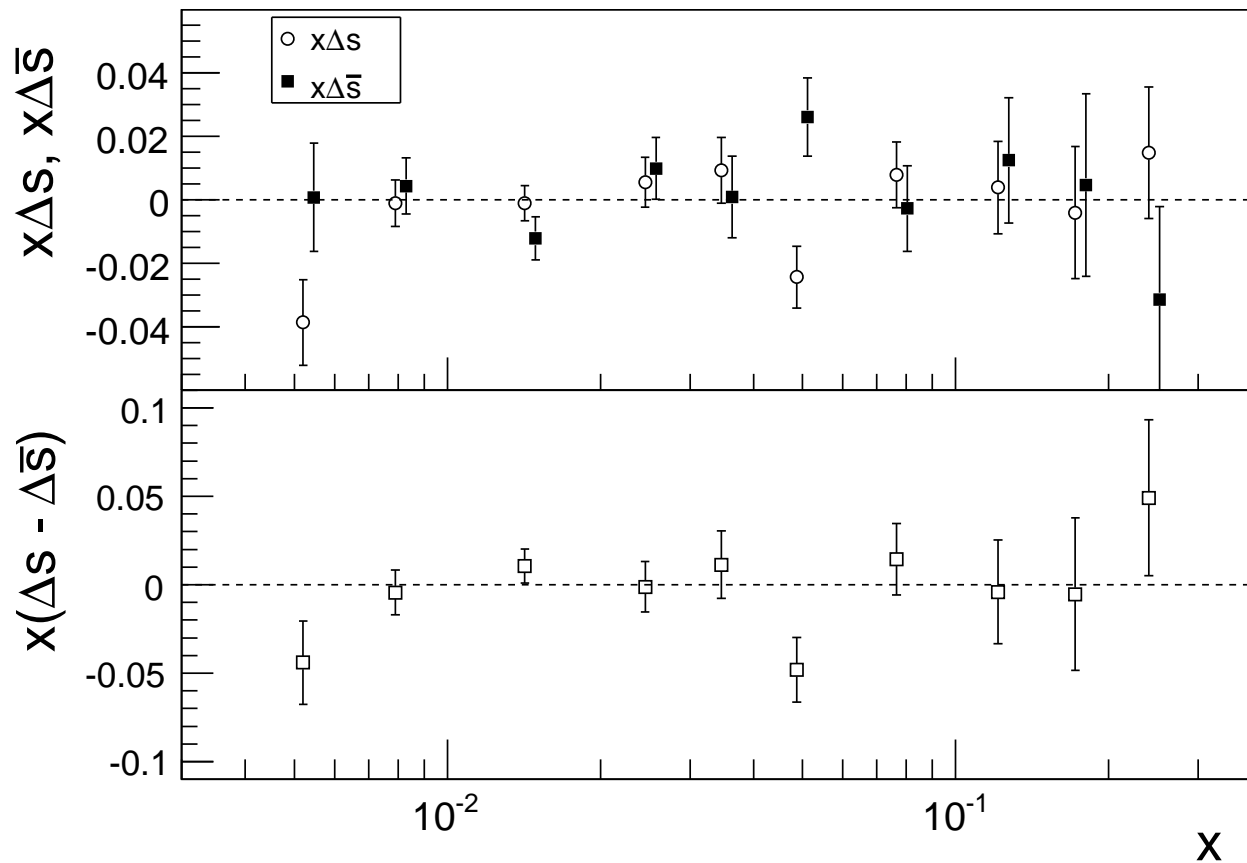
- **measured:**

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

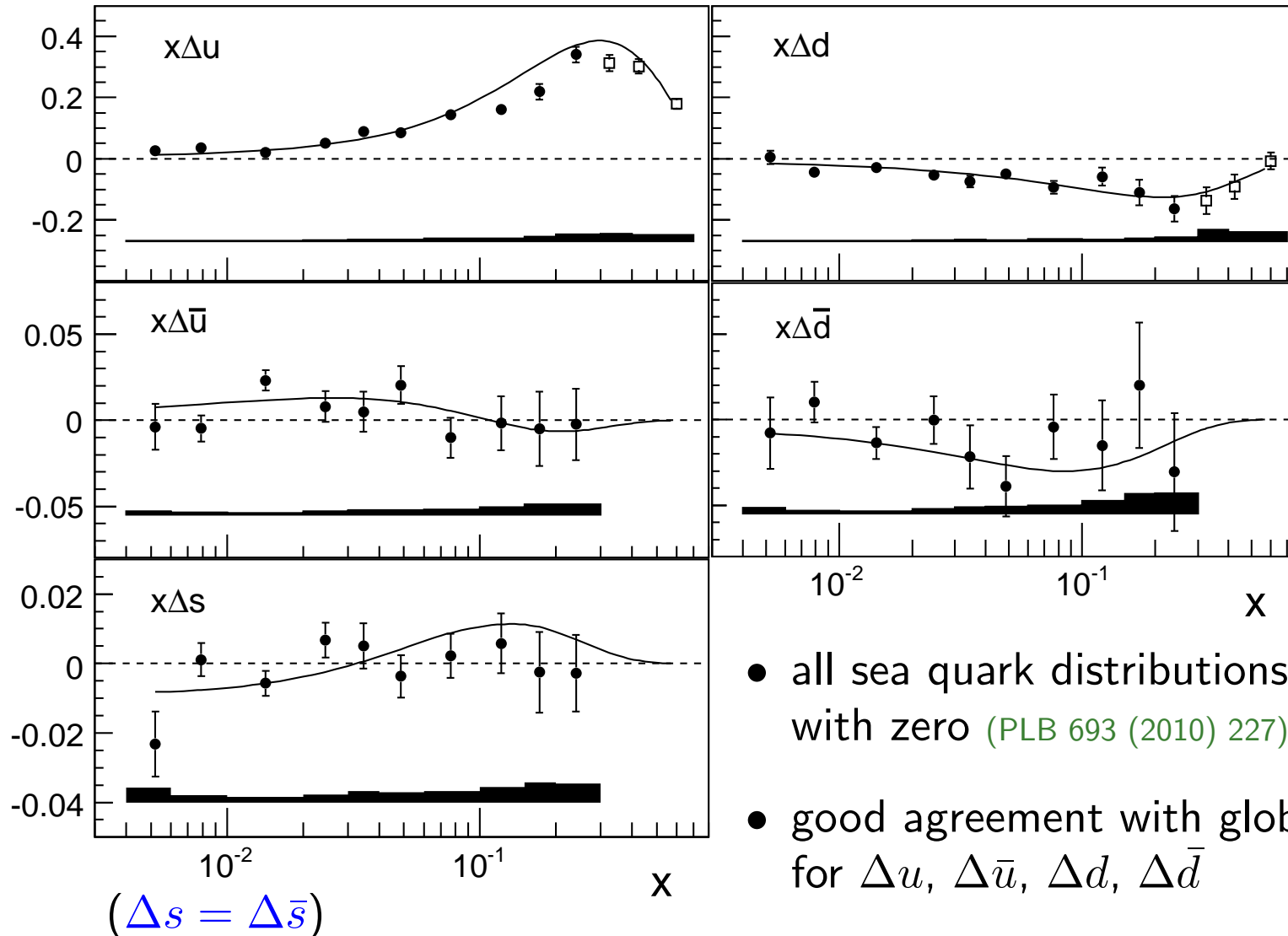
- **inputs:** MRST04 unpolarised LO PDFs, DSS parametr. of FFs

- **determined:**

$$\Delta u, \Delta \bar{u}, \Delta d, \Delta \bar{d}, \Delta s, \Delta \bar{s}$$

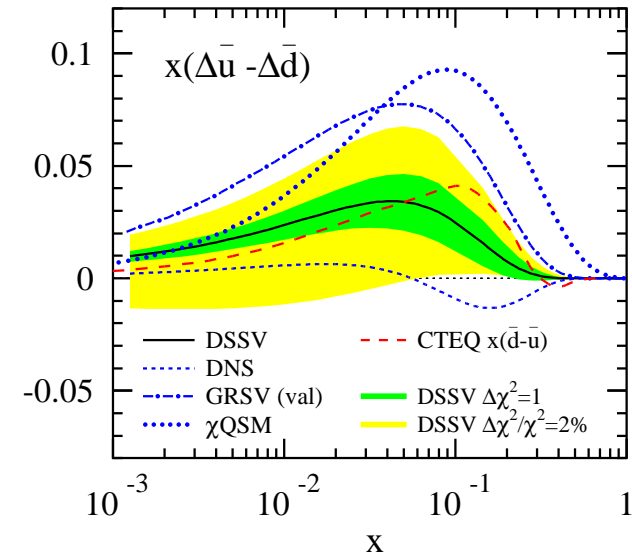
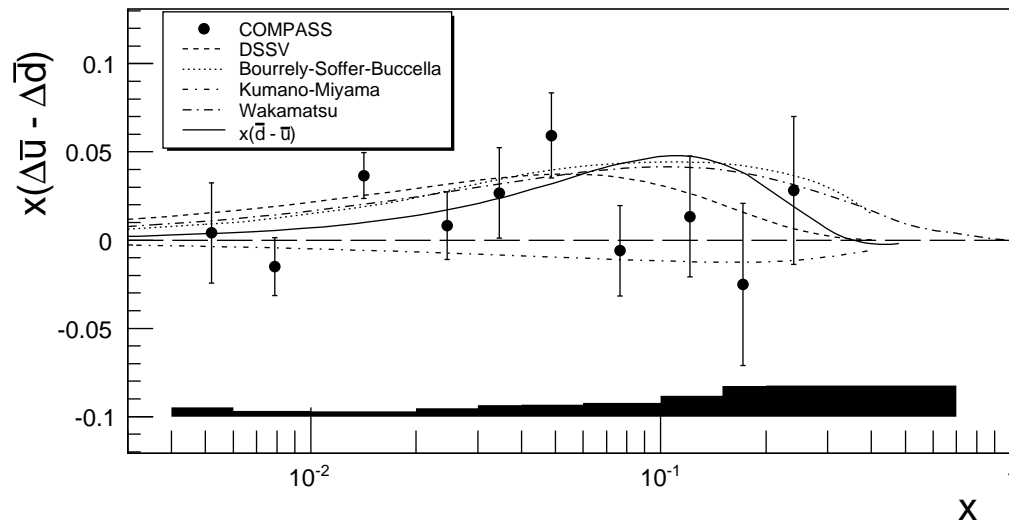


Polarised quark distributions at $Q^2 = 3 \frac{\text{GeV}}{c^2}$



- all sea quark distributions compatible with zero (PLB 693 (2010) 227)
- good agreement with global fit for Δu , $\Delta \bar{u}$, Δd , $\Delta \bar{d}$
- **significant discrepancy** with Δs obtained from QCD fits to g_1

Flavour symmetry breaking



- presently only accessible via SIDIS
- uncertainty from FFs not included
- result at $Q^2 = 3 \text{ (GeV}/c)^2$:

$$\int_{0.004}^{0.3} (\Delta\bar{u} - \Delta\bar{d}) dx = 0.06 \pm 0.04(\text{stat}) \pm 0.02(\text{syst})$$

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

Dependence on fragmentation functions

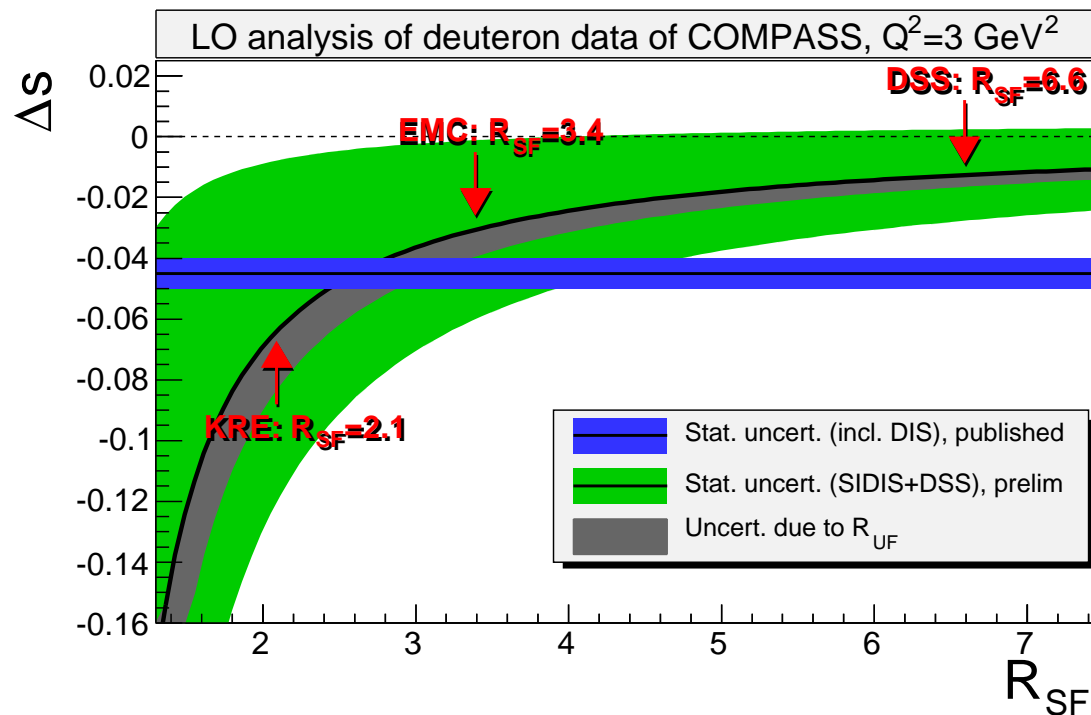


- relation between SIDIS asymmetries and Δ_s depends on

$$R_{UF} = \frac{\int D_d^{K^+}(z)dz}{\int D_u^{K^+}(z)dz}$$

$$R_{SF} = \frac{\int D_s^{K^+}(z)dz}{\int D_u^{K^+}(z)dz}$$

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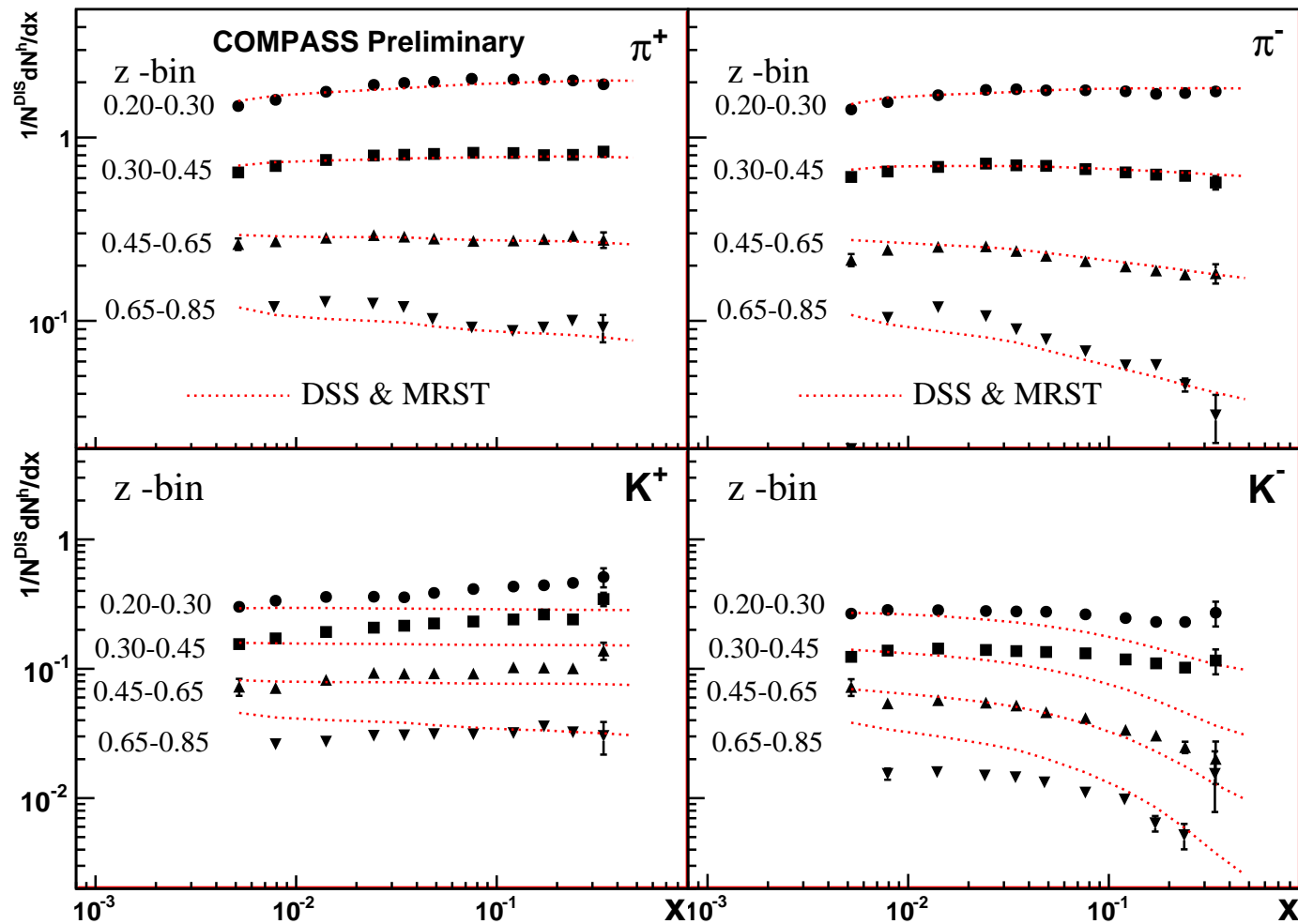


- large dependence on R_{SF} , slight dependence on R_{UF} for Δ_s
- determination of R_{SF} from data needed hadron multiplicities on the way

First look on multiplicities



x dependence of $\frac{1}{N_{\text{DIS}}} \cdot \frac{dN^h}{dzdx}$

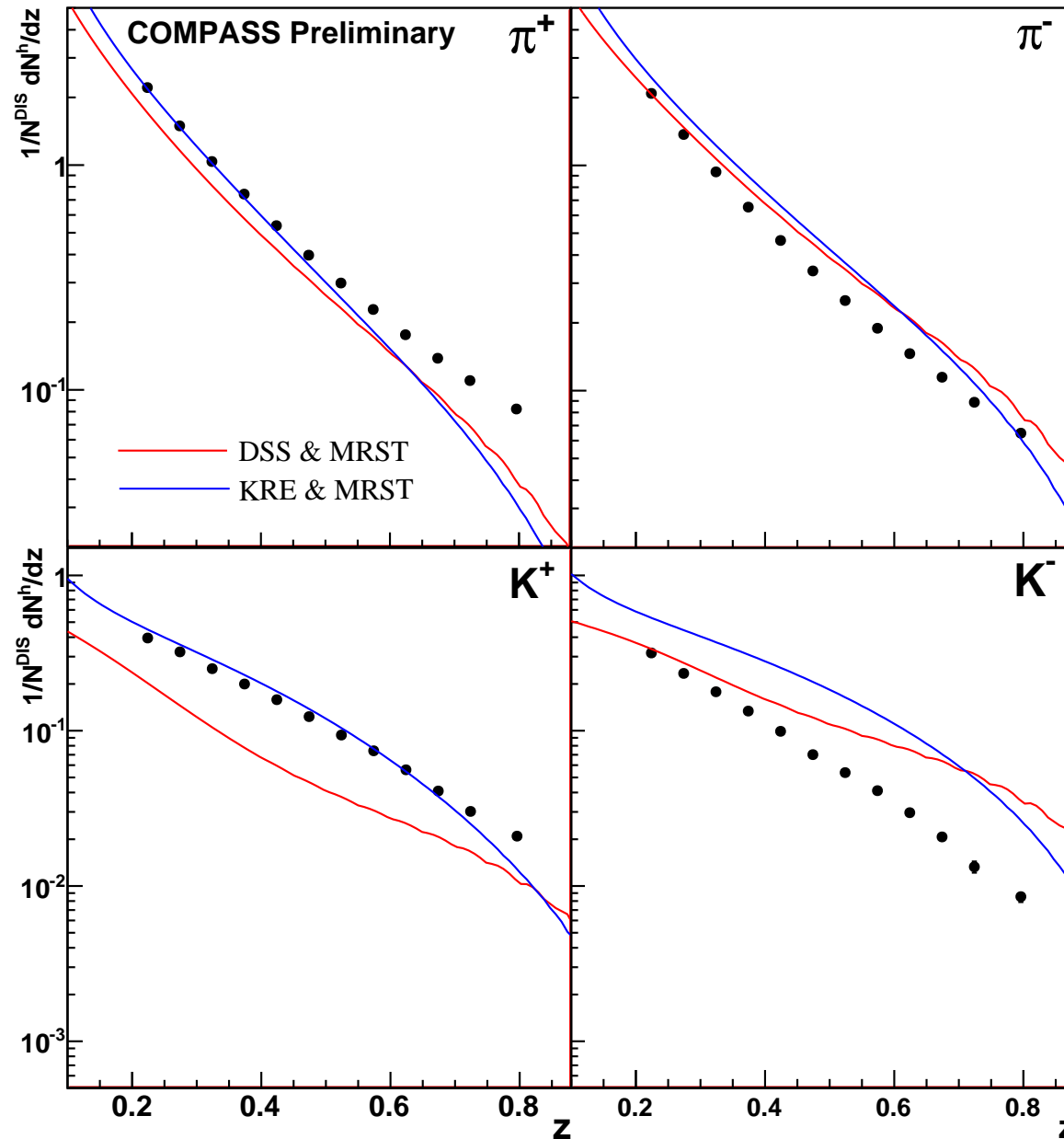


related in LO
to product of PDFs
and FFs

obtained from
small part
of ⁶LiD data

kaons and pions

Comparison to parametrisations



$$\frac{1}{N_{\text{DIS}}} \cdot \frac{dN^h}{dz}$$

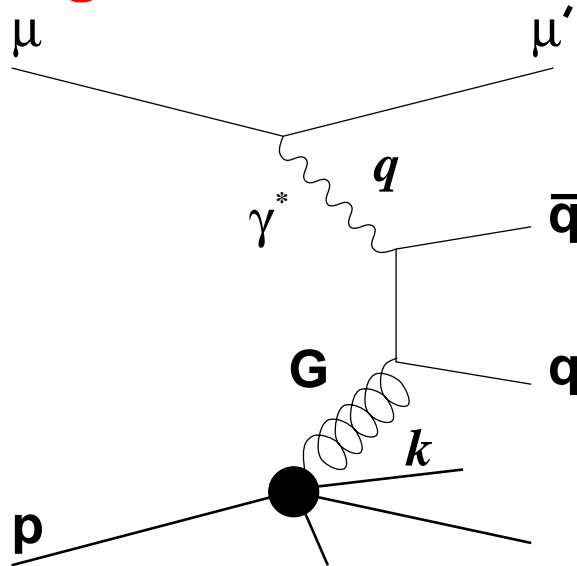
- some discrepancies, especially for kaons
- data can be used for LO extraction of FF and PDF
- will significantly contribute to knowledge on hadronisation process

Gluon polarisation

$\Delta G/G$ measurements in DIS



Photon gluon fusion



$$A_{\gamma N}^{\text{PGF}} = \frac{\int d\hat{s} \Delta\sigma^{\text{PGF}} \Delta G(x_g, \hat{s})}{\int d\hat{s} \sigma^{\text{PGF}} G(x_g, \hat{s})}$$

$$\approx \langle a_{LL}^{\text{PGF}} \rangle \frac{\Delta G}{G}$$

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

Direct methods

- **Open charm production**

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

$$\rightarrow D^0, D^*$$

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

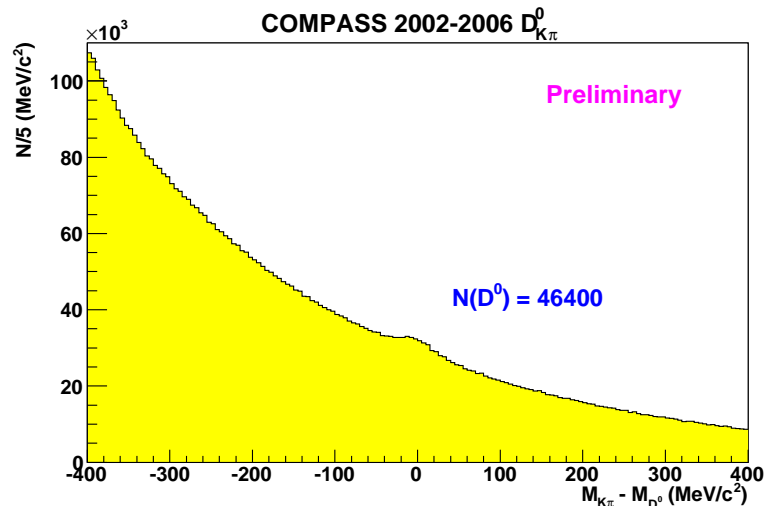
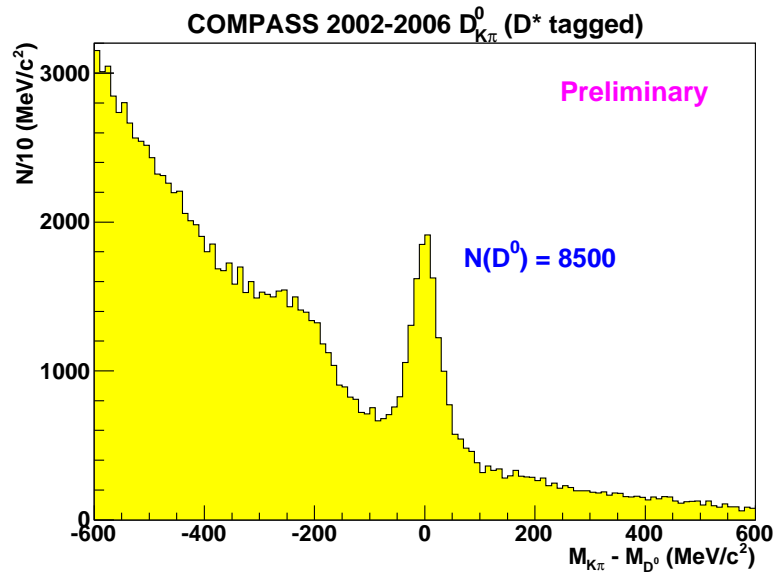
- **High p_T hadron (pairs)**

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

$$\rightarrow H^+H^- \text{ or } H$$

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

Open charm production



- channels investigated

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

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

$$D^0 \rightarrow K \pi$$

- all deuteron data (PLB 676 (2009) 31)
- update with proton data (2007) and more channels (**preliminary**)

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

- improved analysis method
- all Q^2 , a_{LL} in LO or NLO

$$\Delta g/g^{LO} = -0.08 \pm 0.21(\text{stat}) \pm 0.08(\text{syst})$$

at $x_g = 0.11$ and scale $\mu^2 \approx 13 \text{ (GeV/c)}^2$

High p_T hadron pairs



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

- **selection**

$$Q^2 > 1 \text{ (GeV/c)}^2, p_T^{h_1(h_2)} > 0.7(0.4) \text{ GeV/c}$$

- **background processes**

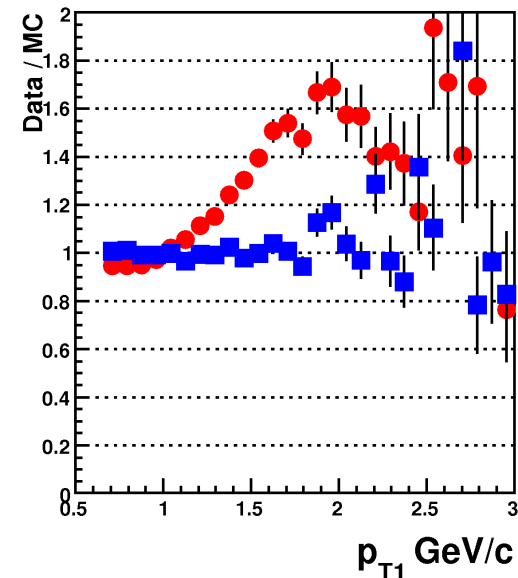
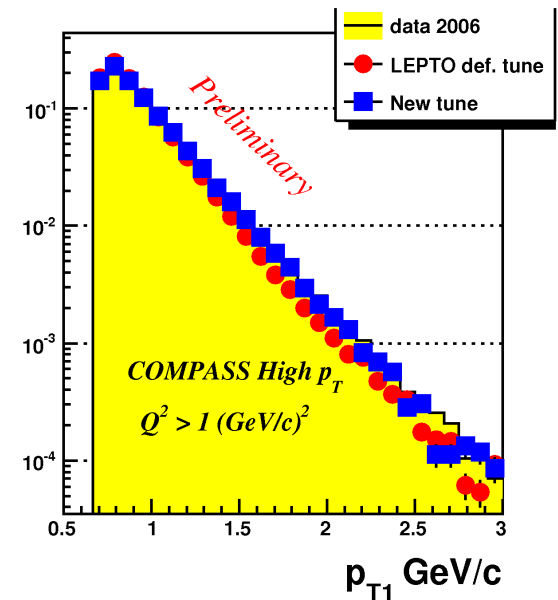
QCD-Compton, leading order
(plus resolved photons for small Q^2)

- improved MC (Lepto) and NN method,
new JETSET tuning

- **new preliminary result** from all deuteron data
(2002–2006), three bins in x_g

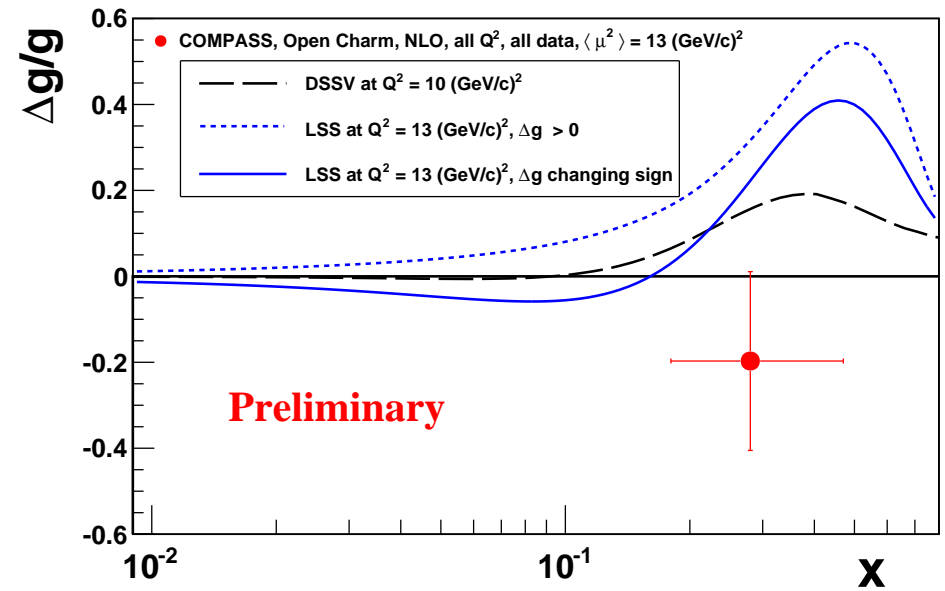
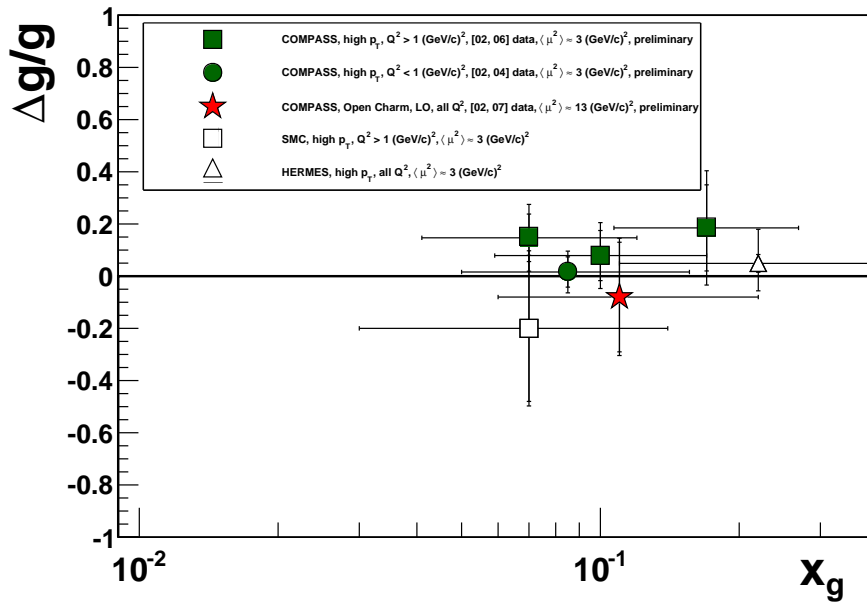
$$\Delta g/g^{LO} = 0.125 \pm 0.06(\text{stat}) \pm 0.064(\text{syst})$$

- at $x_g = 0.09$ and scale $\mu^2 \approx 3.4 \text{ (GeV/c)}^2$



similar for other variables

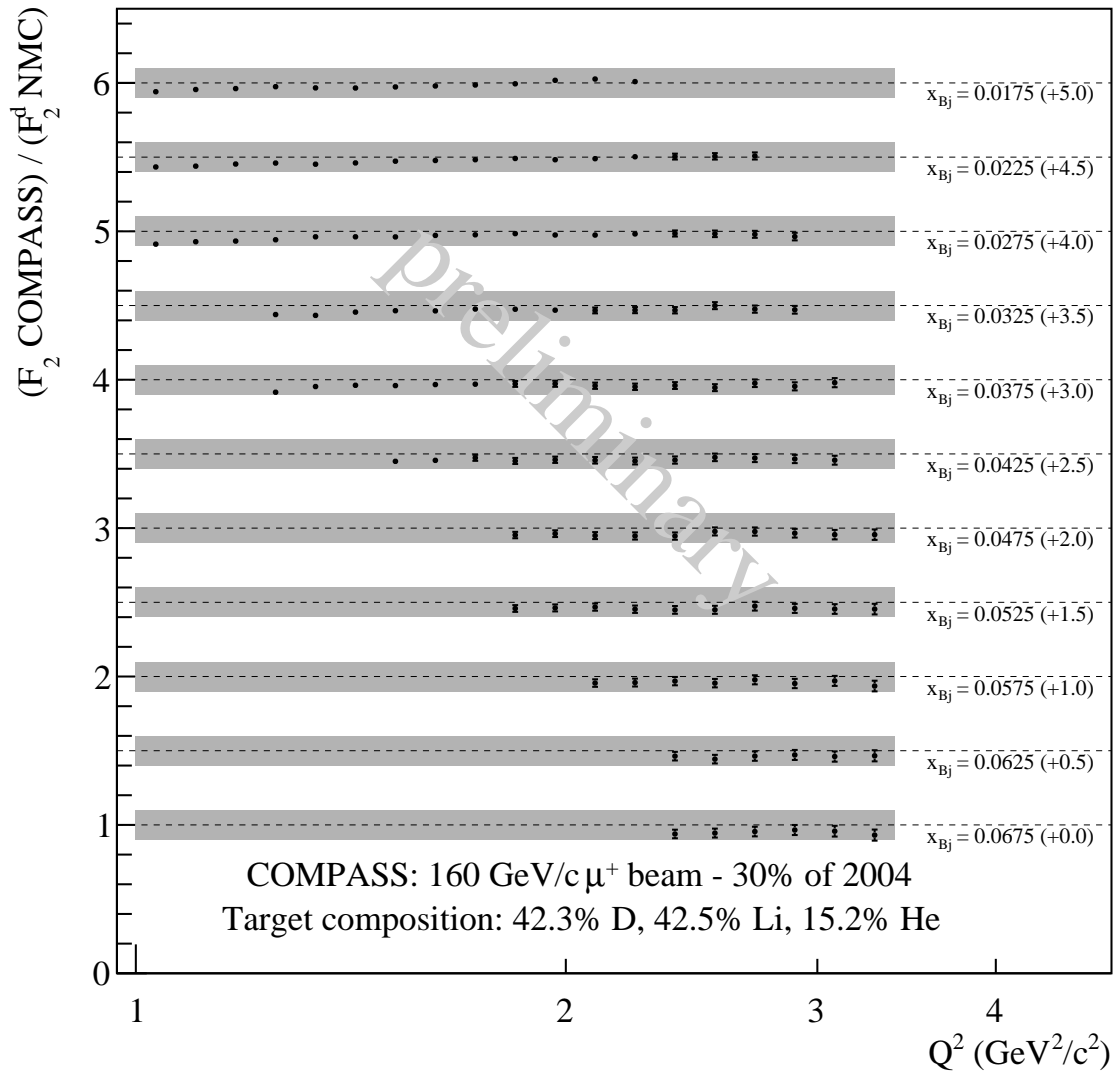
Results for $\Delta G/G$



- LO results from high p_T hadrons (SMC, HERMES, COMPASS) and charm
- NLO result from charm (COMPASS): systematic error still under investigation
- $\Delta G/G$ is small or has a node around $x_g \approx 0.1$

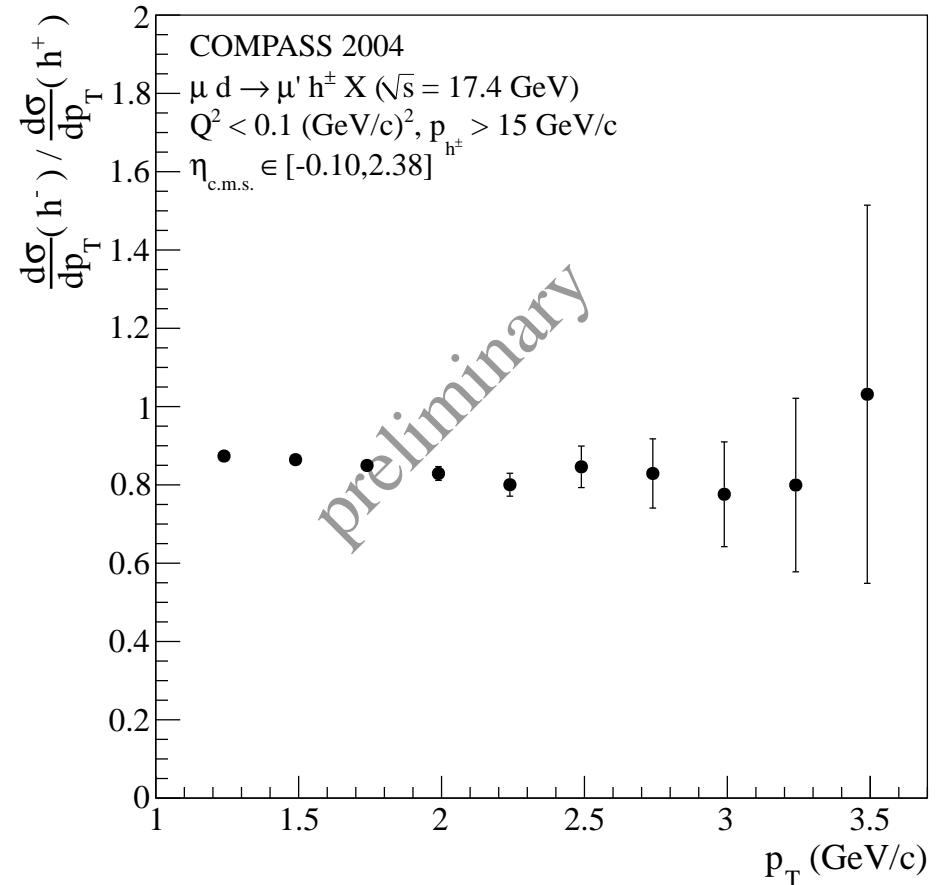
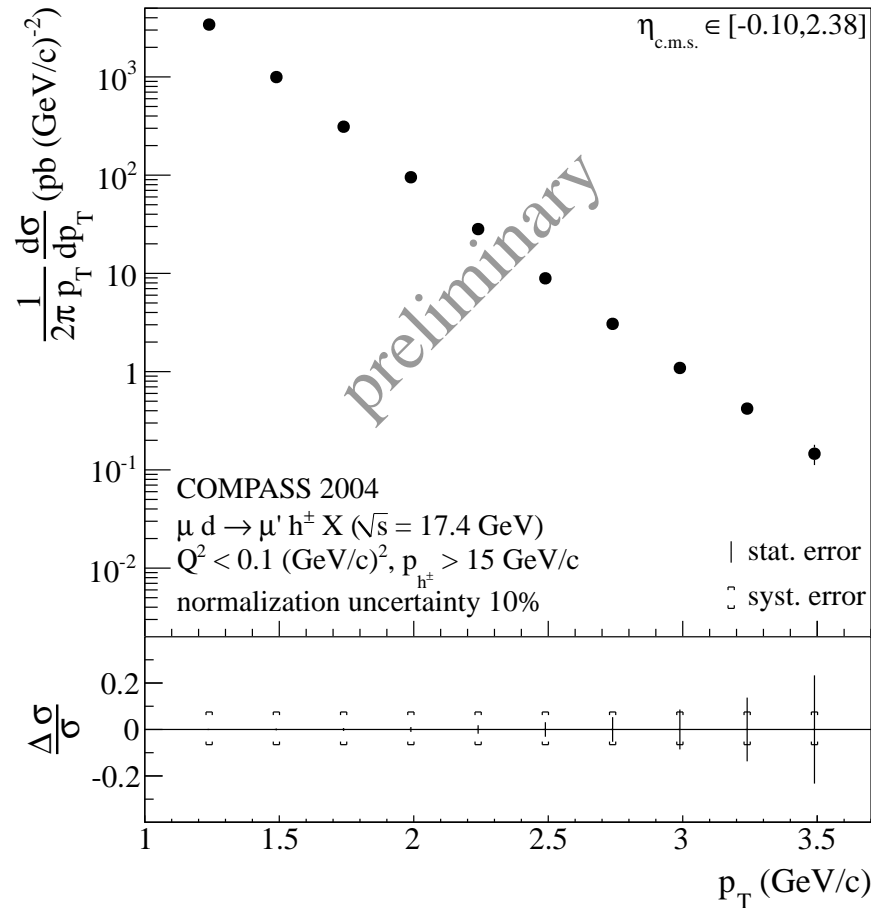
$$\Delta g/g^{\text{NLO}} = -0.20 \pm 0.21(\text{stat})$$

What about cross sections?



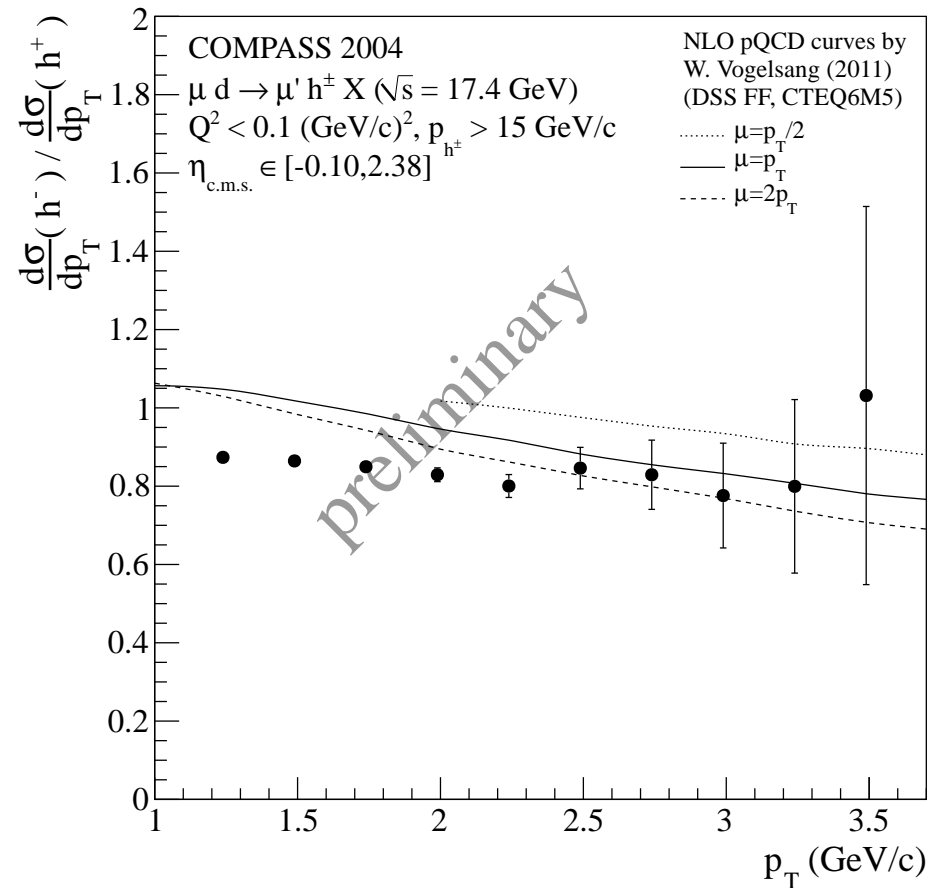
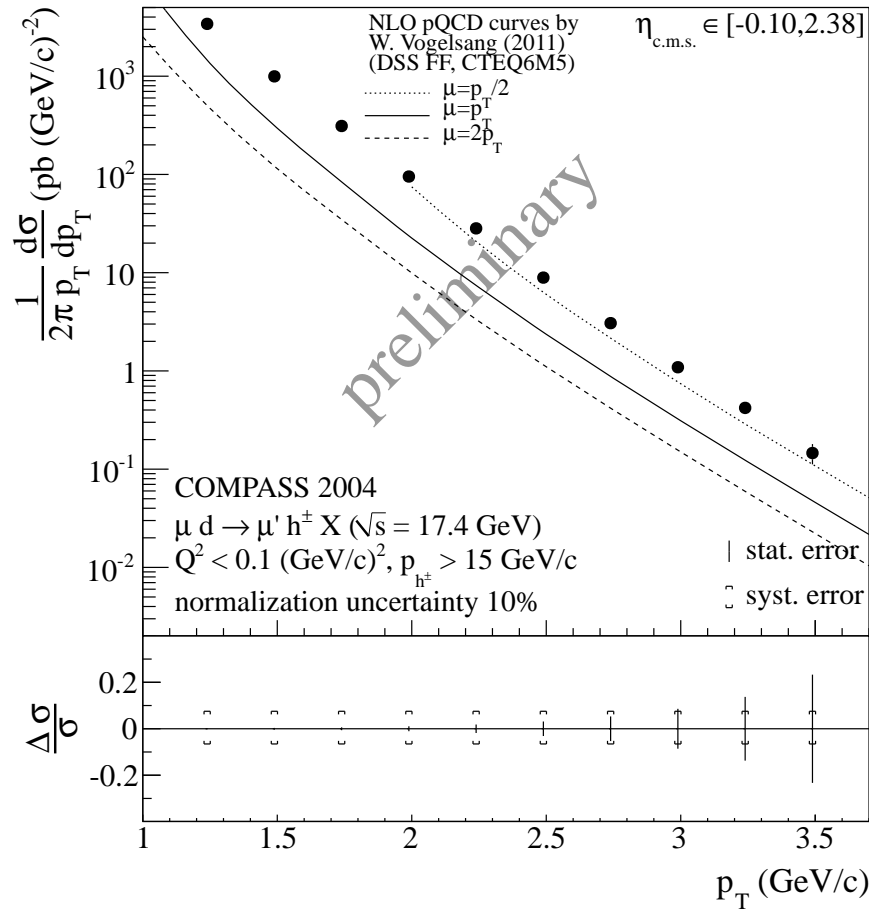
- unpolarised PDFs much better known
- COMPASS optimised for asymmetries
- luminosity from beam flux and target density
- checked with **F2** from ${}^6\text{LiD}$
- Q^2 from 1 to 3 $(\text{GeV}/c)^2$, $0.015 < x < 0.07$
- shaded areas correspond to 10% luminosity error
- comparison to **NMC F_2 parametrisation**

Quasi-real photoproduction of hadrons



- cross section for $H^+ + H^-$ and charge ratio ($Q^2 < 0.1$ (GeV/c) 2)

Comparison to pQCD prediction



some discrepancies observed

- experimental cross section larger than prediction, resummations needed?
- p_T dependence of charge ratio from pQCD not confirmed, fragmentation functions?

Summary and outlook



Results

- results from all proton and deuteron data
- determination of quark contribution to nucleon spin
- full flavour separation from SIDIS data
- update of result for gluon polarisation
- more results on ρ asymmetries, Λ polarisation, azimuthal asymmetries

Still to come

- study of fragmentation functions and strange quark distribution
- gluon polarisation from single hadrons
- more data with longitudinally polarised NH_3 in 2011
- proton g_1 at low x and flavour separation
- future COMPASS II programme: DVCS and DVMP