COMPASS measurements of the longitudinal spin structure of the nucleon

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On behalf of the
COMPASS Collaboration

MENU 2013

Outline

Spin of the nucleon

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

$\Delta\Sigma$ - quarks ΔG - gluons $L_{q,g}$ - orbital angular momentum

- $\Delta\Sigma \approx 0.3$ from direct measurement
- What about gluons?
- How different quark flavours contribute to the nucleon spin?
- How do we access L? (cf. talk by N. D'Hose)

Observables in $\vec{\mu}\vec{N}$ scattering

- Inclusive asymmetry

$$A_{meas} = \frac{1}{fP_T P_B}\left(\frac{N^{\leftrightarrows} - N^{\rightleftarrows}}{N^{\leftrightarrows} + N^{\rightleftarrows}}\right) \approx DA_1$$

$$A_1 = \frac{g_1(x,Q^2)}{F_1(x,Q^2)} = \frac{\sum_q e_q^2 \Delta q(x,Q^2)}{\sum_q e_q^2 q(x,Q^2)}$$

$$\Delta q = q^+ - q^-, \quad q = q^+ + q^-$$

- Semi-inclusive asymmetry (LO)

$$A_1^h(x,z,Q^2) \approx \frac{\sum_q e_q^2 \Delta q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)}$$

$$D_q^h \neq D_{\bar{q}}^h$$

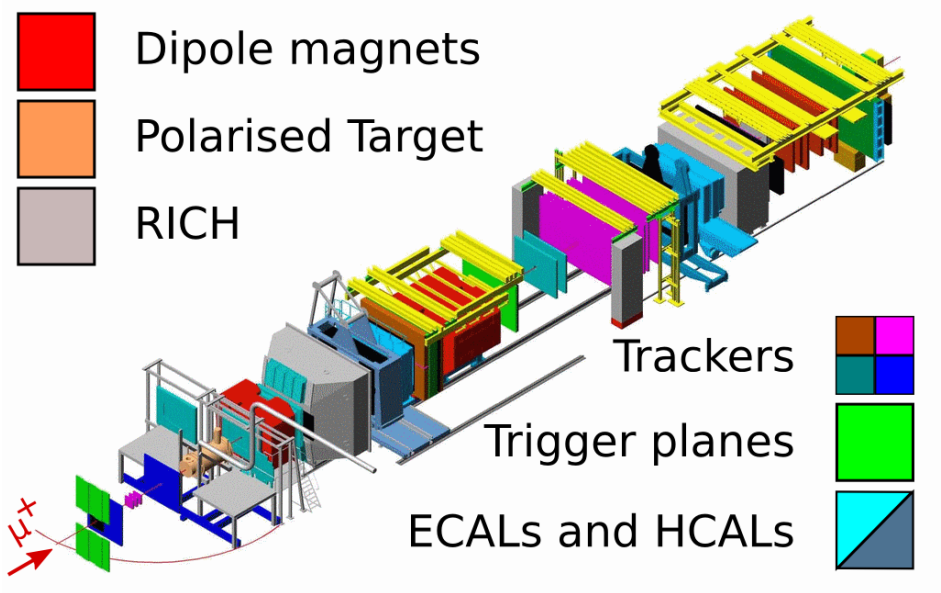
COMPASS: Spectrometer

Muon beam

- Beam: μ^+
- Momentum: 160 GeV (200 GeV)
- Polarisation: $\sim 80\%$
- $2 \cdot 10^8 \mu$ per Spill of $\sim$10s ($1 \cdot 10^8$)

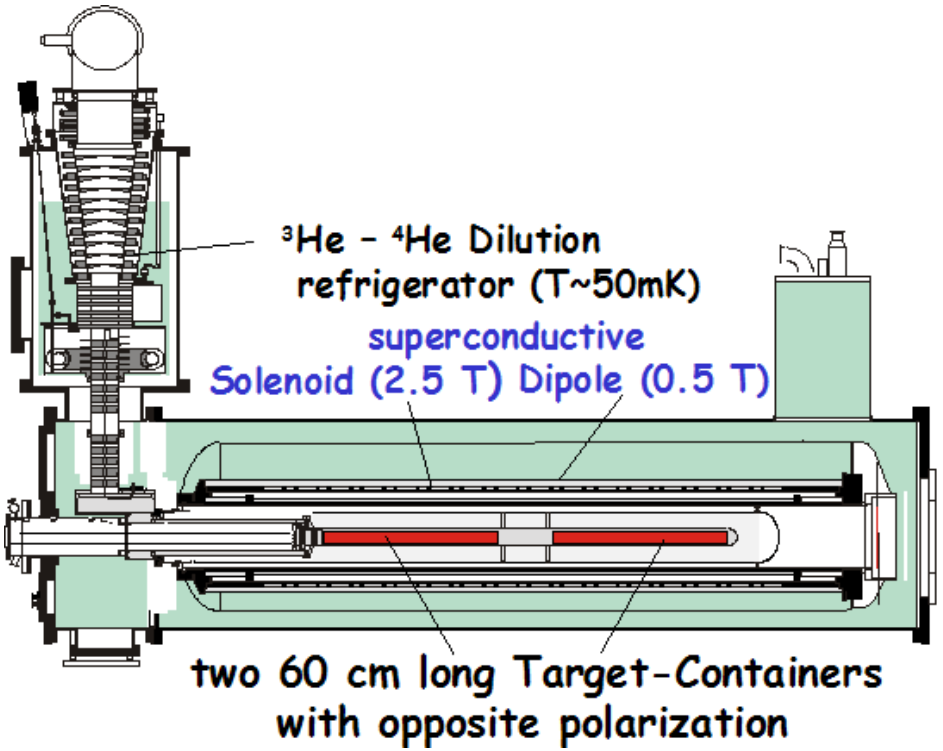
Muon data taking

- 2002-04, 2006: deuteron, 160 GeV
  - $\sim$ 20% in transverse mode
- 2007: proton, 160 GeV
  - $\sim$ 50% in transverse mode
- 2010: proton, 160 GeV
  - 100% in transverse mode
- **2011: proton, 200 GeV**



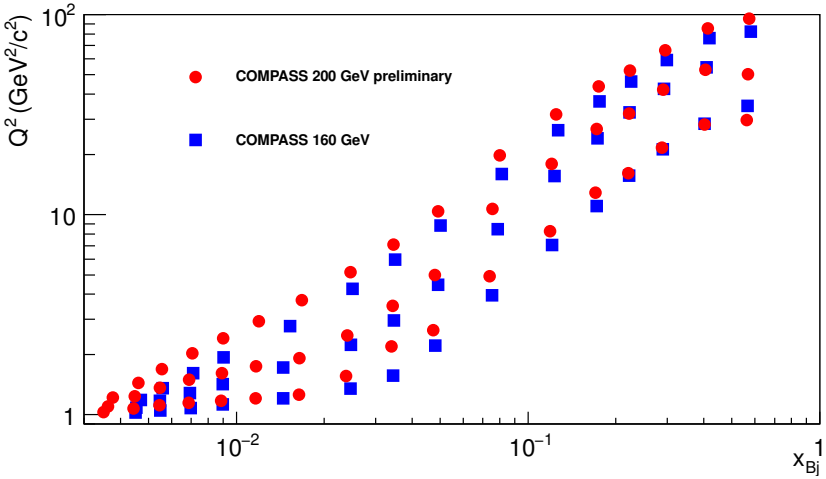
COMPASS: Polarised target

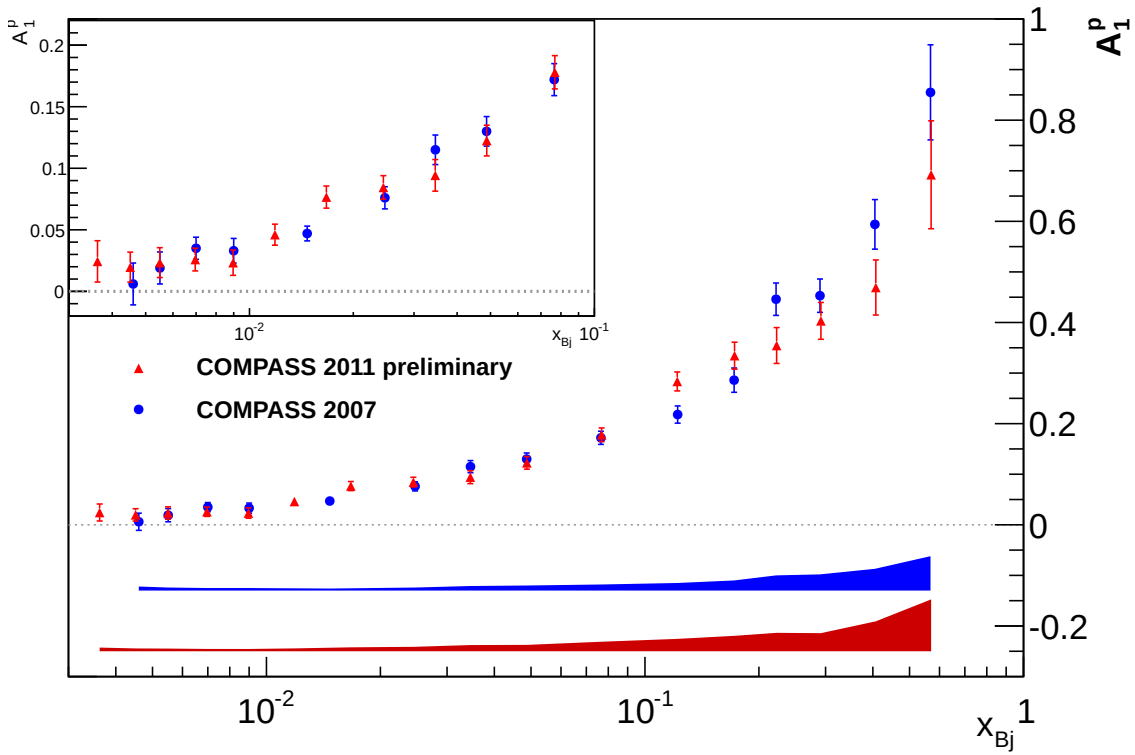
- Two (three) cells, oppositely polarised
- 1.2m long
- ^{6}LiD: $f \simeq 40\%$, $P_T \simeq 50\%$
- NH_3:$f \simeq 16\%$, $P_T \simeq 85\%$
- Acceptance: ~ 70 mrad ($>$2005:~ 180 mrad)



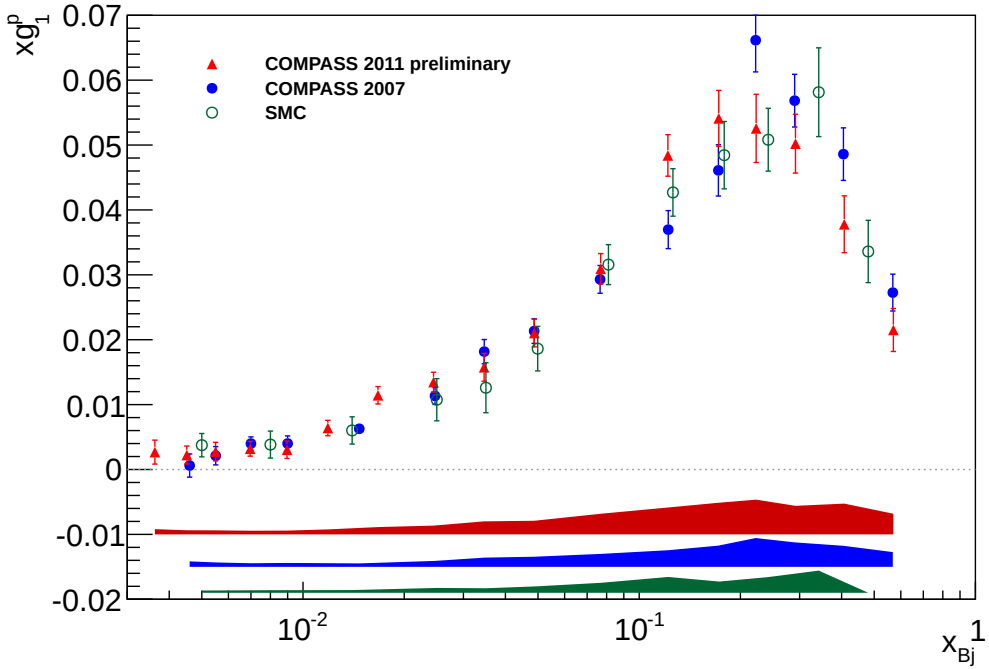
A_1^p - new results at 200 GeV

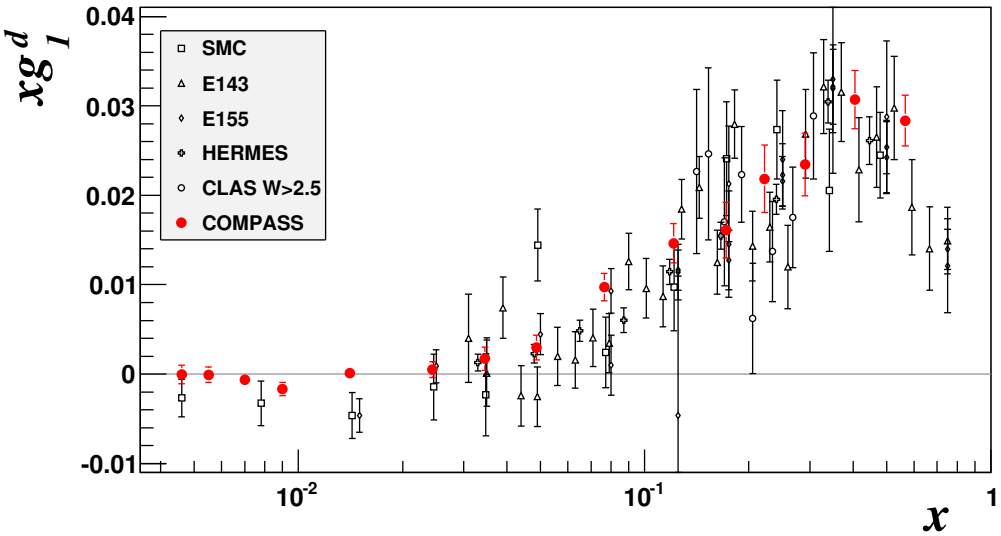
- Extend measured range to lower x
- Provide balance to deuteron data
  - Increase precision of Bjorken sum rule test
  - Better constrain strange quark polarisation Δs





Structure functions g_1^p and g_1^d at low x

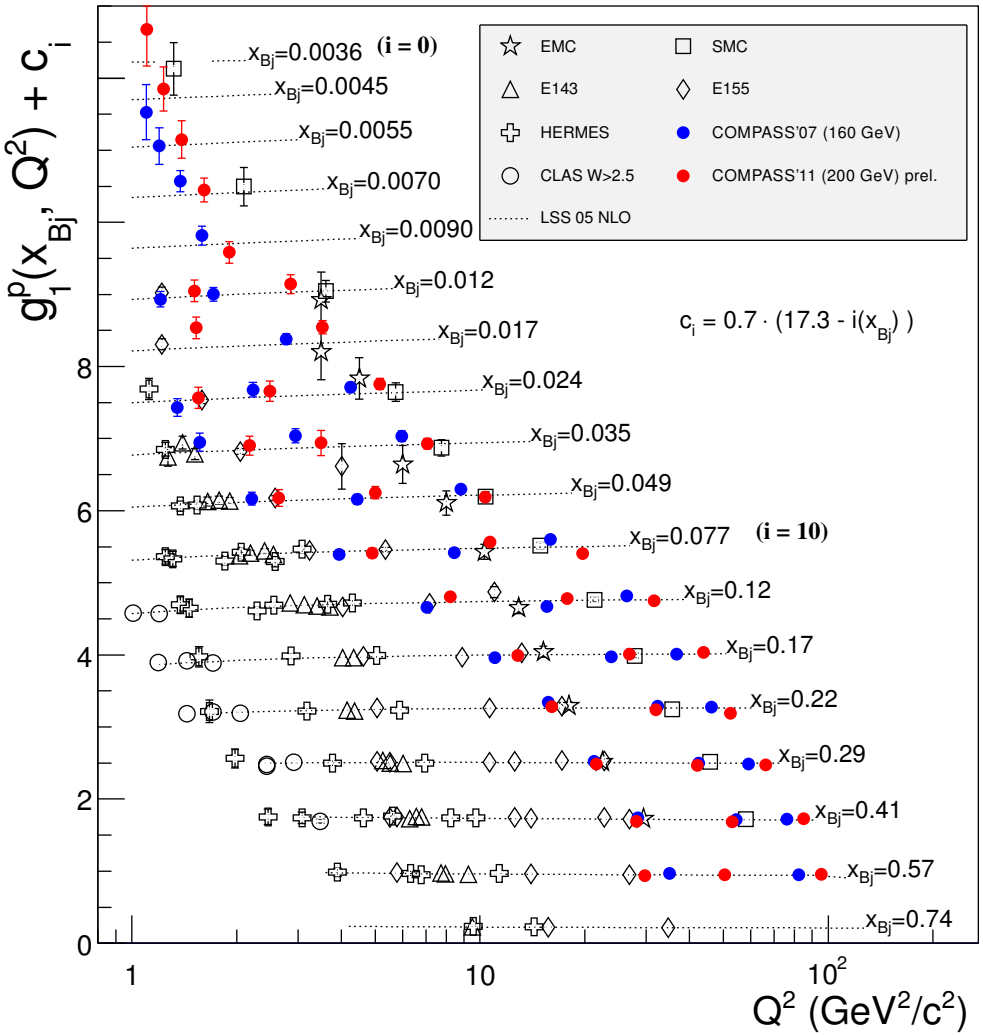


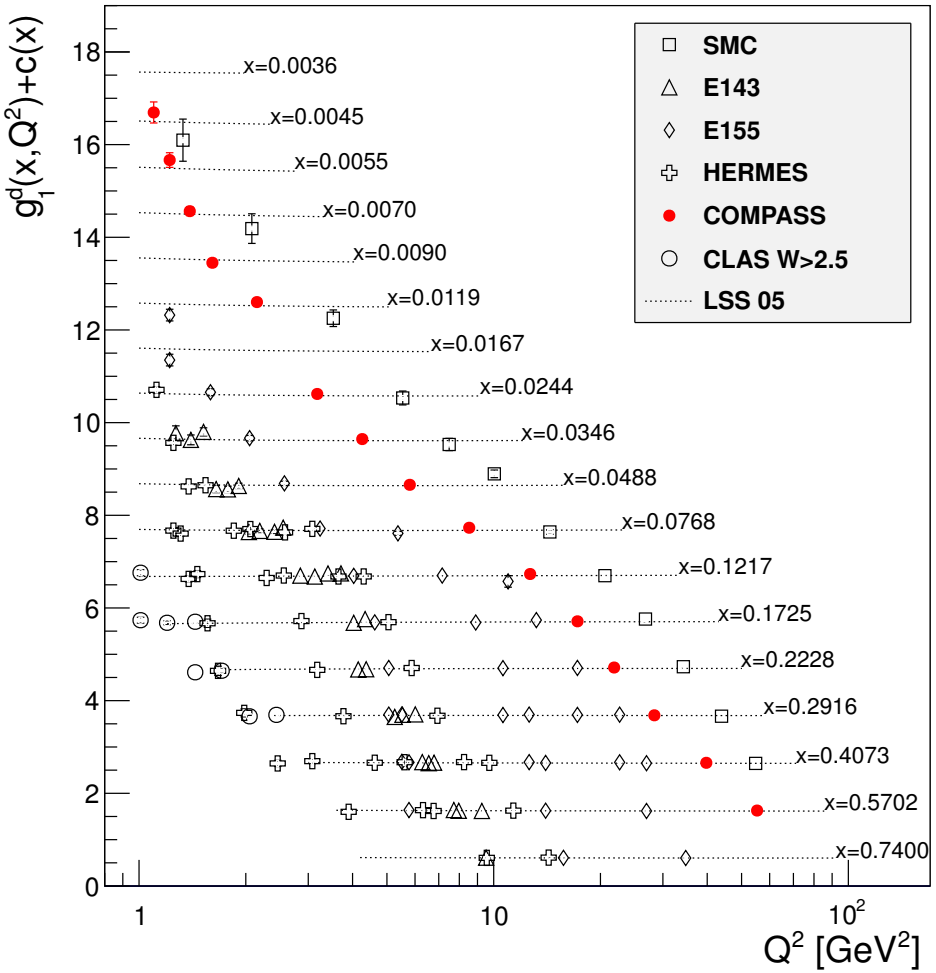


- SMC parametrisation of F_2
  SMC PRD 55 (1998) 112001

- $R = \frac{\sigma^L}{\sigma^T}$
  COMPASS PLB 647 (2007) 330

World data on g_1 structure function





New input to global QCD fits

Bjorken sum rule

$$\Gamma_1^p - \Gamma_1^n = \frac{1}{6}\left|\frac{g_A}{g_V}\right| C_1^{NS}$$

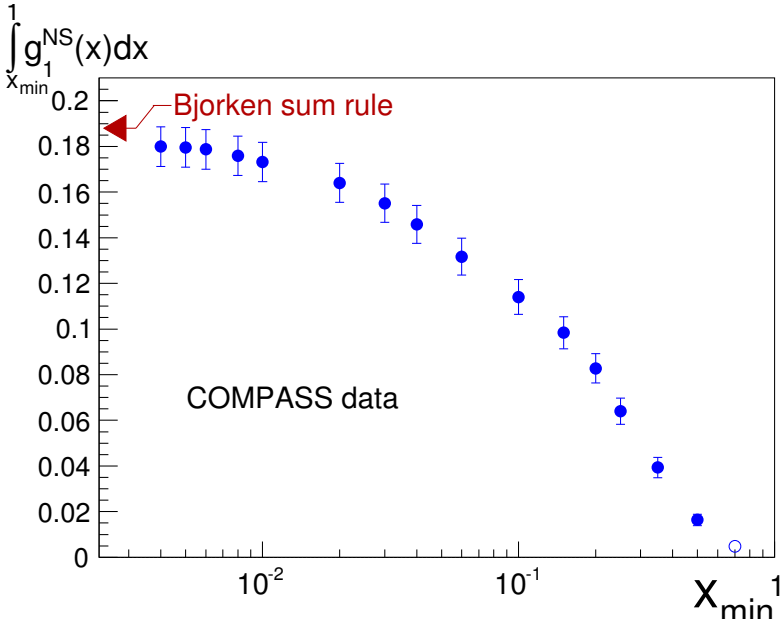
$$\Gamma_1^{NS} \cong \int_{0.004}^{0.7} g_1^{NS}(x)dx$$

$$g_1^{NS} = g_1^p - g_1^n = 2g_1^p - \frac{g_1^d}{1-\frac{3}{2}\omega_D}$$

- $\omega_D = 0.05 \pm 0.1$
- $g_{A,V}$ - measured in weak β decays
- C_1^{NS} - calculable in pQCD

$$\Gamma_1^{NS} = 0.175 \pm 0.009 \pm 0.015$$

$$x\epsilon(0.004,\ 0.7)$$



COMPASS Phys.Lett. B 690 (2010)466

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- C_1^{NS} - calculable in pQCD

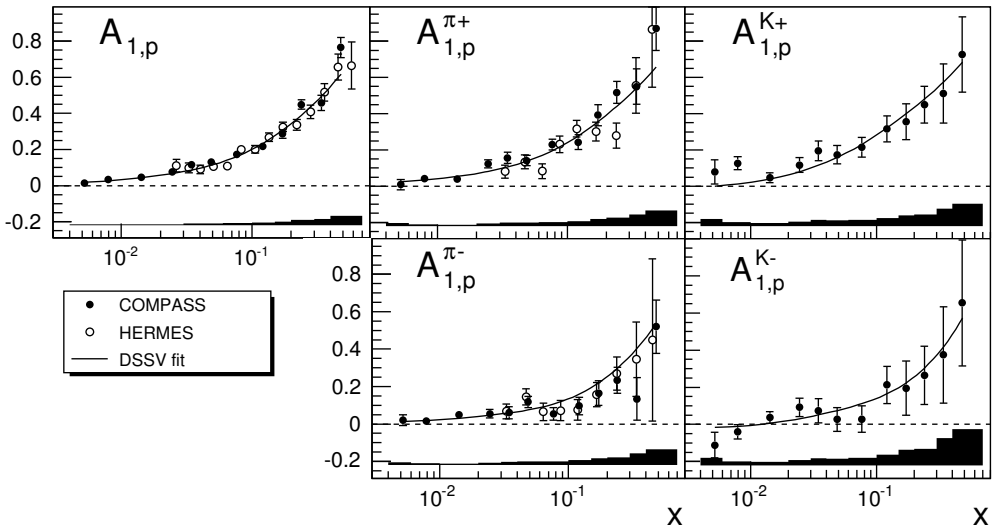
Projected precision (2011)

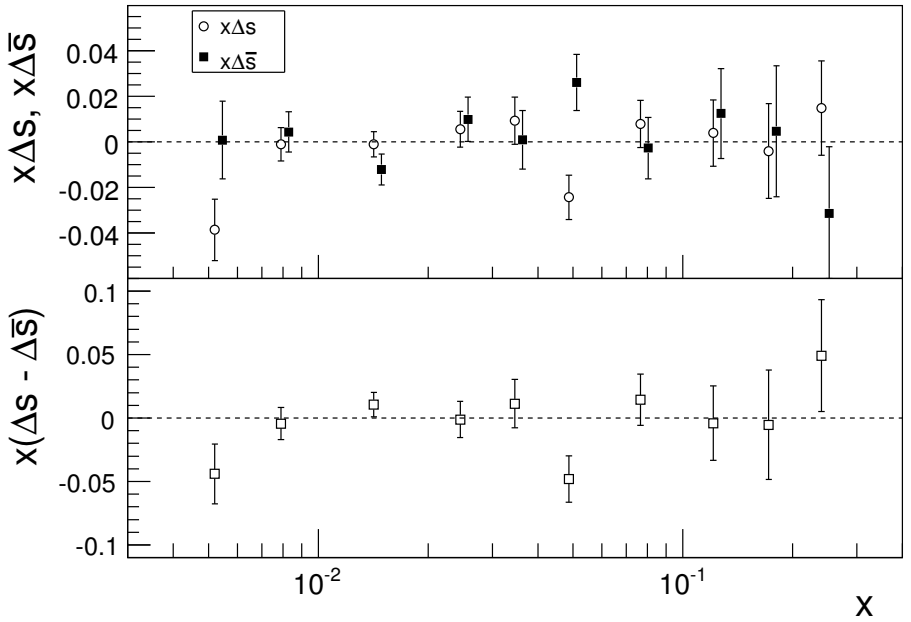
$$\Gamma_1^{NS} = \pm 0.006 \pm 0.011$$

$$x\epsilon(0.003,\ 0.7)$$

Semi-inclusive asymmetries

- Data collected on both p and d targets
- Measured:
  A_1^d, $A_{1d}^{\pi\pm}$, $A_{1d}^{K\pm}$, A_1^p, $A_{1p}^{\pi\pm}$, $A_{1p}^{K\pm}$
- Determined:
  Δu, $\Delta\bar{u}$, Δd, $\Delta\bar{d}$, $\Delta s \equiv \Delta\bar{s}$
- LO approximation

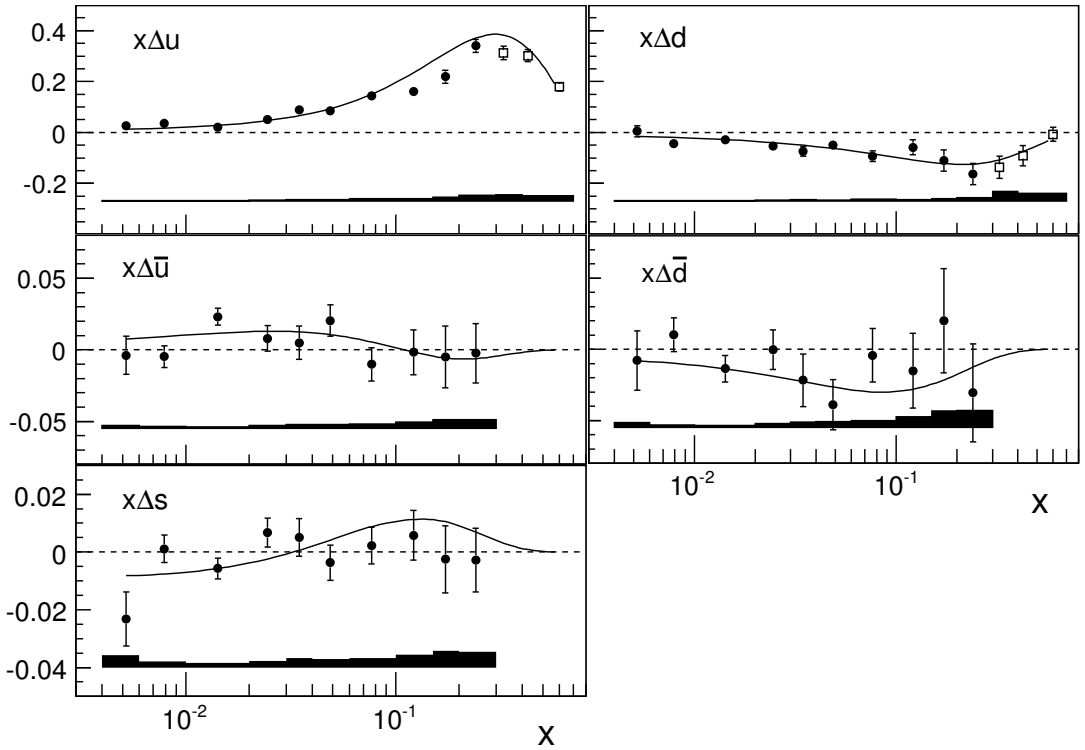


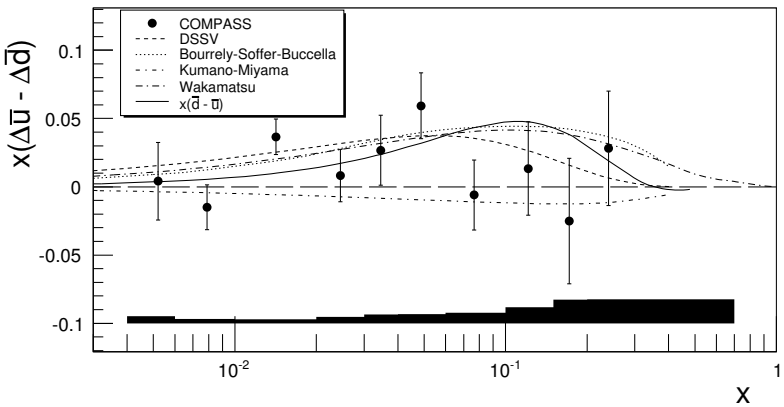


- LO DSS fragmentation functions
- LO unpolarised MRST pdf

COMPASS, Phys. Lett. B 680 (2009) 217
DSSV, Phys. Rev. D 80 (2009) 034030

Flavour separation





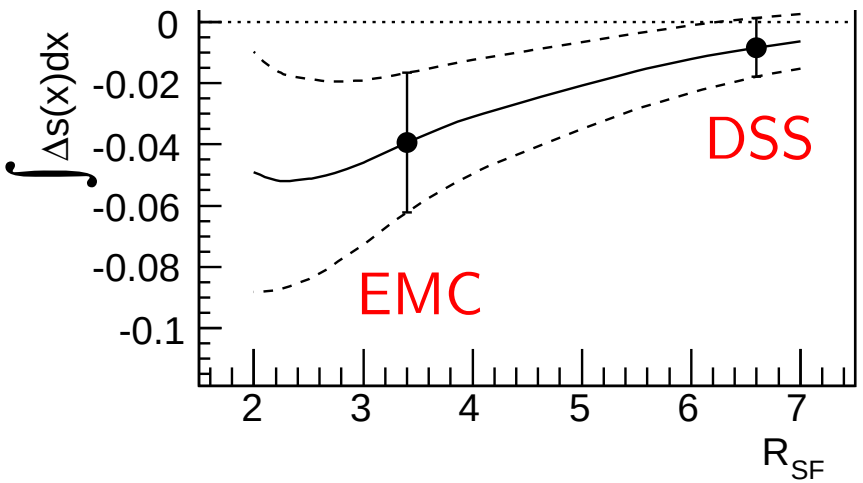
- The sea is not unsymmetric
- Thus the data disfavour models predicting $\Delta\bar{u} - \Delta\bar{d} \gg \bar{d} - \bar{u}$

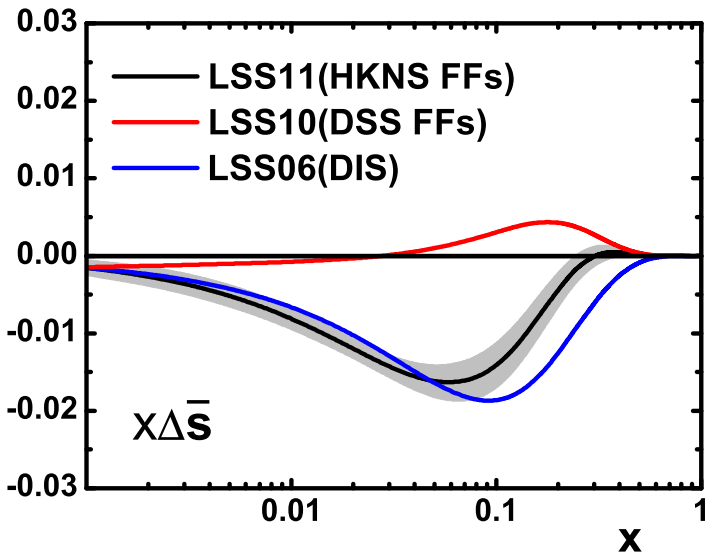
- NLO parametrisation of DSSV describes the data well

$$\int_{0.004}^{0.3} [\Delta\bar{u}(x, Q^2) - \Delta\bar{d}(x, Q^2)]dx = 0.06 \pm 0.04 \pm 0.02 \,@\, Q^2 = 3\,\mathrm{GeV}^2$$

Polarisation of strange sea

- Inclusive measurements:
  $2\Delta S = \int_0^1 (\Delta s(x) + \Delta\bar{s}(x))dx = -0.09 \pm 0.01 \pm 0.02$
- Semi-inclusive measurements compatible with zero
  - ΔS obtained in semi-inclusive analysis strongly depends on the fragmentation functions
  - Most critical: $R_{SF} = \frac{\int D_{\bar{s}}^{K^+}(z)dz}{\int D_u^{K^+}(z)dz}$





Leader, Sidorov, Stamenov: arXiv:1103.5979 [hep-ph]

Fragmentation Functions

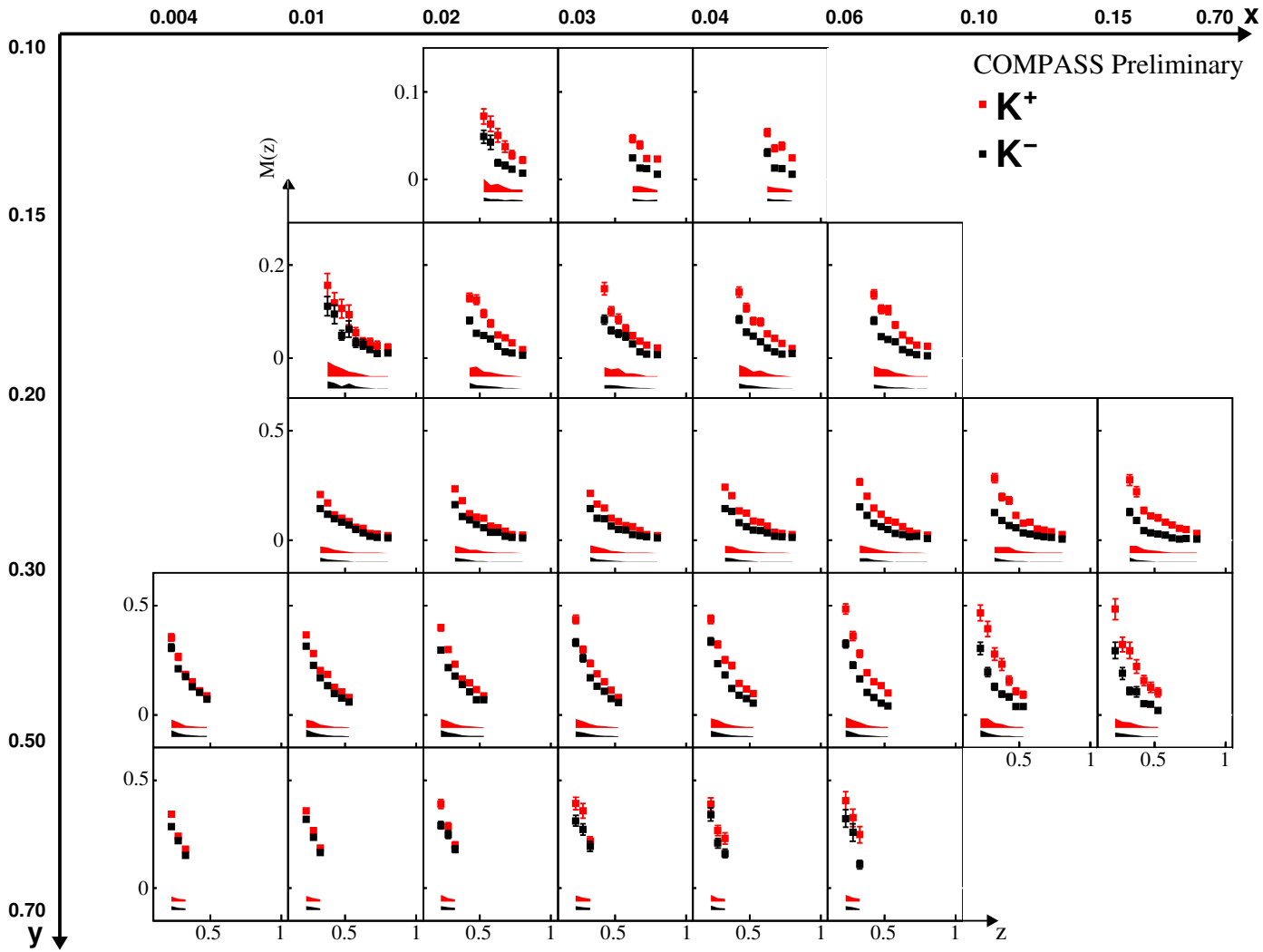
Current knowledge of FFs based on

- High precision data from e^+e^- colliders
  - Fixed energy scales (far from fixed target experiments)
  - No separation of q and $\bar{q}$
- Data from hadron colliders (RHIC)
  - Most sensitive to gluon FFs
- Data from semi-inclusive DIS (new results from HERMES)
  - Sensitive to parton flavour and hadron charge

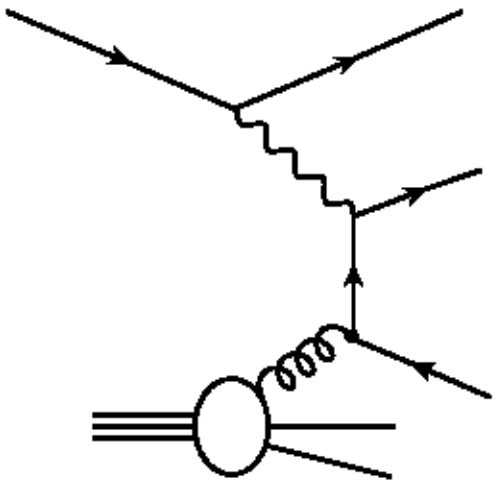
COMPASS contributes with measurement of charged hadron multiplicities with K and π identification

$$M^h(x,z) = \frac{d\sigma^h/dxdz}{d\sigma^{DIS}/dxdz} = \frac{\sum_q e_q^2 \left[q(x)D_q^h(z) + \bar{q}(x)D_{\bar{q}}^h(z)\right]}{\sum_q e_q^2 \left[q(x) + \bar{q}(x)\right]}$$

Charged hadron multiplicities (identified kaons)



Access to gluons



PGF

Photon Gluon Fusion

- **Open Charm**
  - Search for D^0 meson in the final state
  - No charm in the nucleon in COMPASS kinematics
  - Charm is produced only via PGF (LO)
  - Perturbative region ensured by charm mass
  - Weakly depends on MC simulations
  - Low statistics
- **High p_T hadrons**
  - Search for hadrons with high transverse momenta in the final state
  - Large statistics
  - Perturbative region: $Q^2 > 1\,\mathrm{GeV}^2$ or p_T
  - Background processes
  - MC simulations essential

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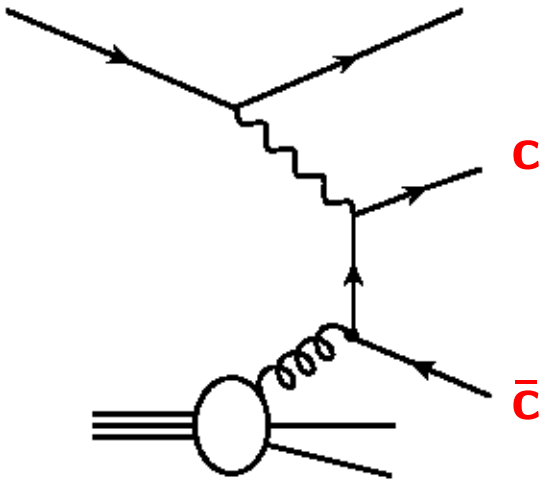

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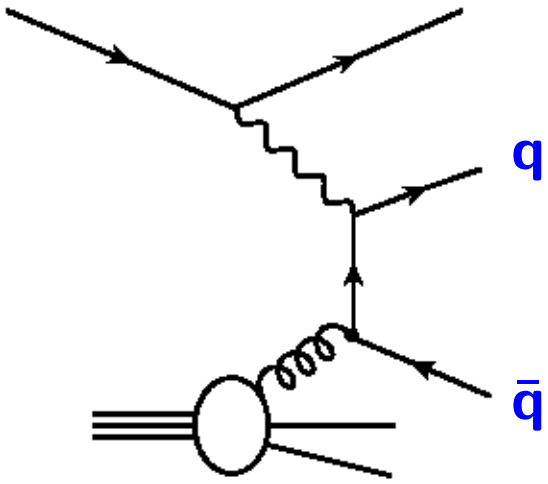

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ΔG: High-p_T pairs ($Q^2 > 1\,\mathrm{GeV}^2$) PLB 718 (2013) 922

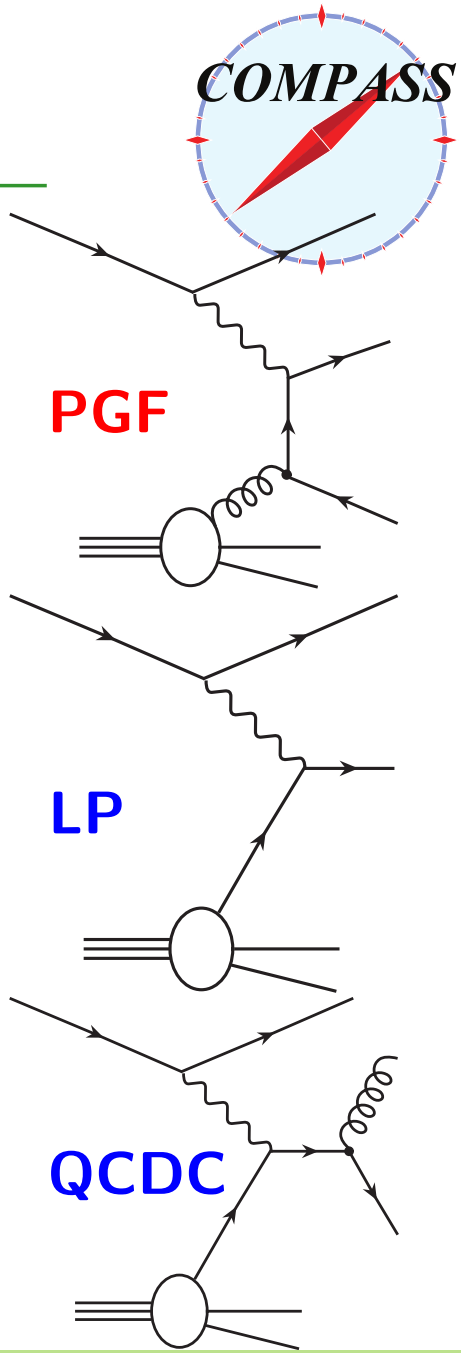
$$A_{LL}^{2h}(x_{Bj}) = \frac{\Delta\sigma}{\sigma} \approx \frac{\Delta G}{G} a_{LL}^{PGF} R_{PGF} + A_1^{LO}(x_C) a_{LL}^{C} R_C + A_1^{LO}(x_{Bj}) D R_{LP}$$

- R_n - process fraction (MC+NN)
- a_{LL}^n - partonic asymmetry (pQCD)
- $A_1^{LO} = \frac{\sum_i e_i^2 \Delta q_i}{\sum_i e_i^2 q_i}$

$$\frac{\Delta G}{G} = 0.125 \pm 0.060(stat) \pm 0.063(syst)$$

$$x_G = 0.09^{+0.08}_{-0.04} \quad @ \quad \mu^2 \approx 3(\mathrm{GeV/c})^2$$

bin	1	2	3
$\Delta G/G$	$0.15 \pm 0.09 \pm 0.09$	$0.08 \pm 0.10 \pm 0.08$	$0.19 \pm 0.17 \pm 0.14$
x_G	$0.07^{+0.05}_{-0.03}$	$0.10^{+0.07}_{-0.04}$	$0.17^{+0.10}_{-0.06}$



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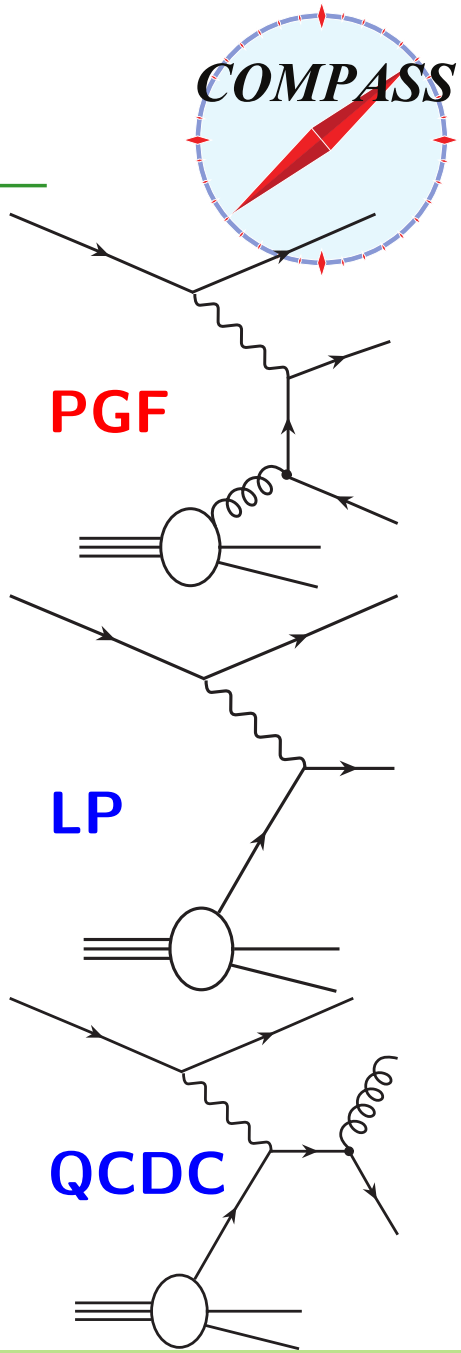

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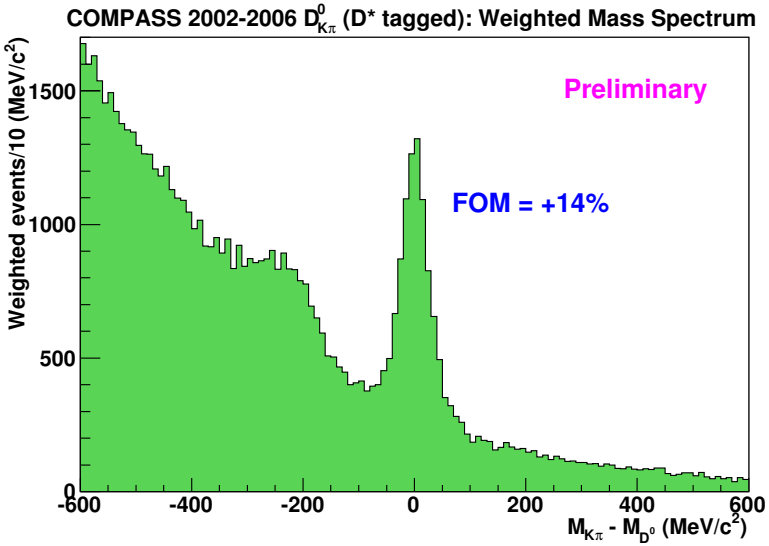
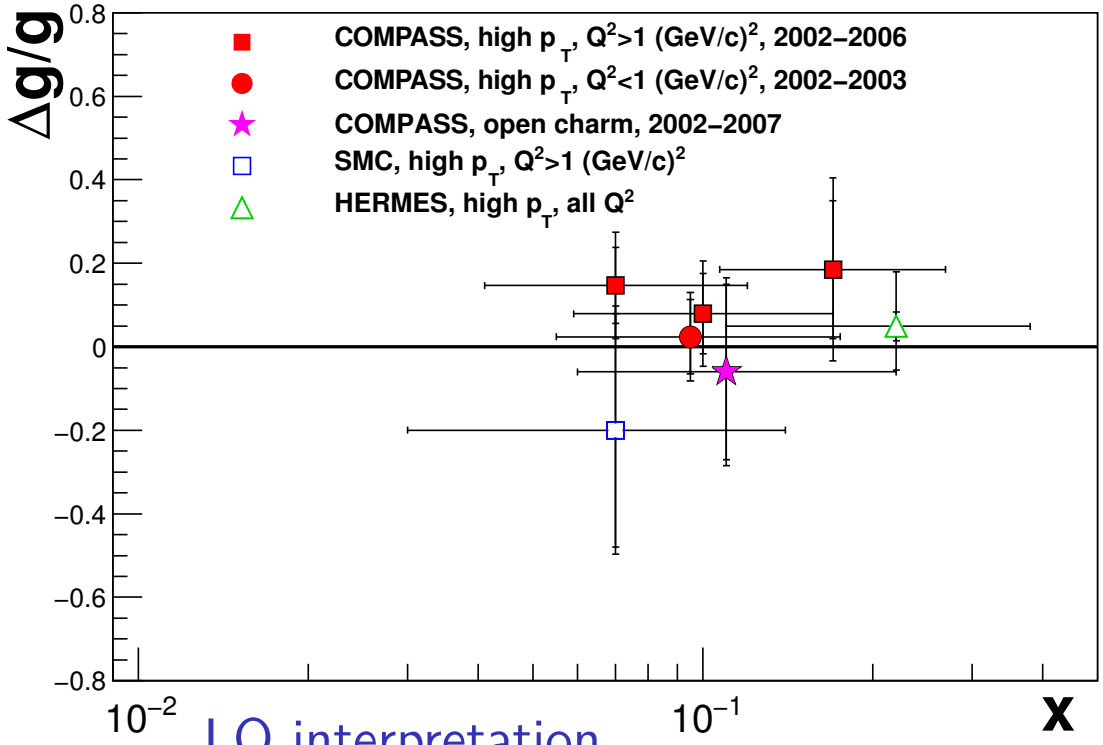
ΔG: Open charm LO PRD 87 (2013) 052018

$$A_{meas} = P_B P_T f a_{LL} \frac{\sigma_{PGF}}{\sigma_{PGF}+\sigma_{BG}} \frac{\Delta g}{g} + A_{BG}$$

Open charm selection

E.g. $D^* \to D^0\pi \to K\pi\pi$





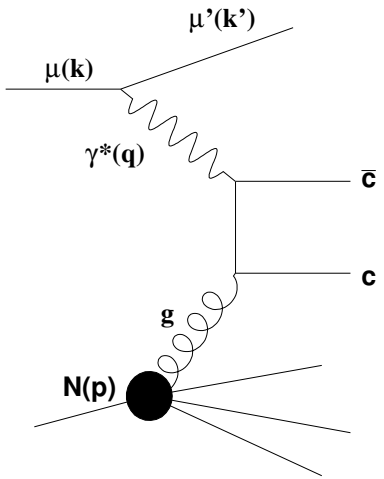
LO interpretation

$$\Delta G/G = -0.08 \pm 0.21 \pm 0.11$$

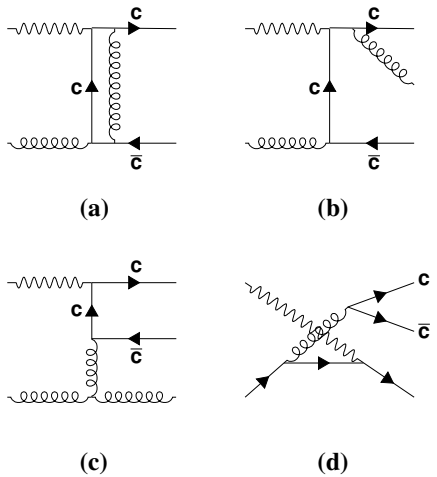
$$x_g = 0.11^{+0.11}_{-0.05}; \quad \mu^2 = 13\,\mathrm{GeV}^2$$

ΔG: Open charm NLO

LO



NLO examples



- AROMA with parton shower used for simulation of phase space for NLO
- NLO calculations by I. Bojak and M. Stratmann, PL B433 (1998) 411; NP B 540 (1999) 345
- a_{LL}^{NLO} calculated event-by-event
- NLO background corrected for (A_{corr})

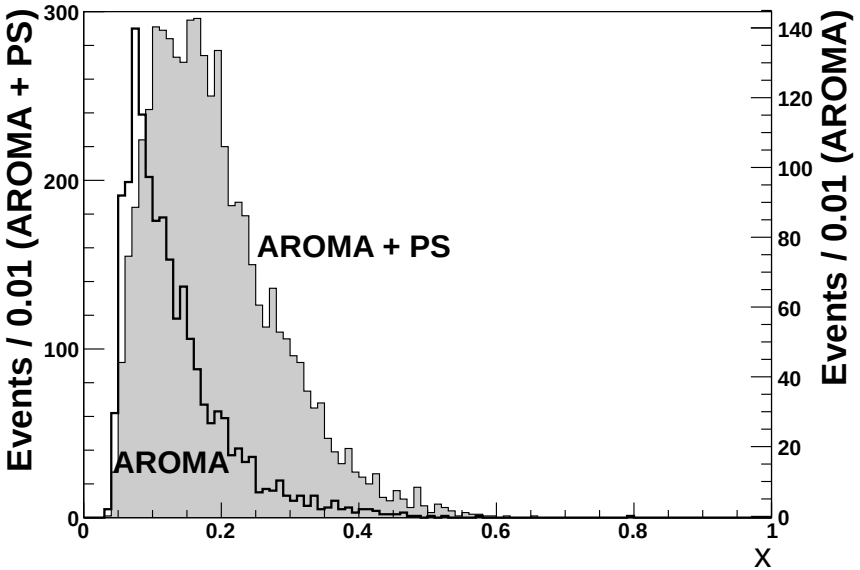
$$A^{\gamma N} = \frac{a_{LL}}{D}\frac{\Delta g}{g} + A_{corr}$$

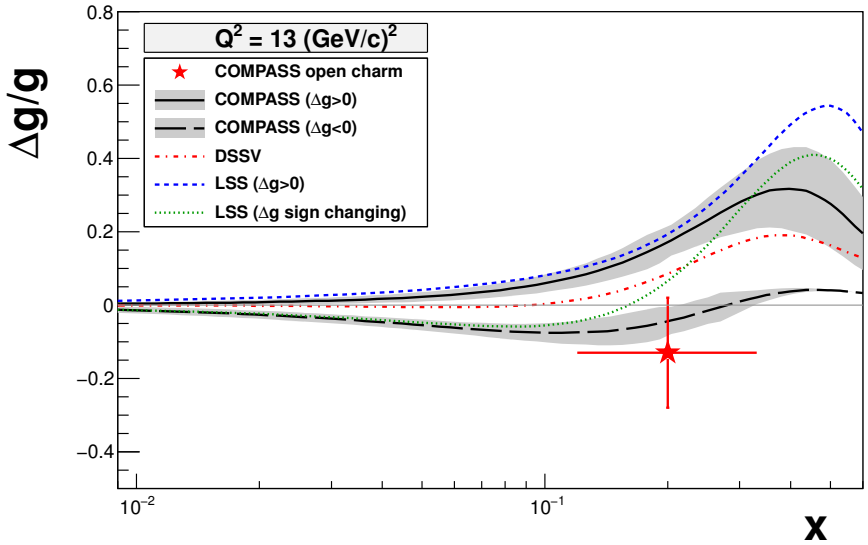
ΔG: Open charm NLO PRD 87 (2013) 052018

- Significant impact on x_g
- NLO QCD result of COMPASS influences $\Delta g(x) > 0$ fit
  $\Delta G = 0.36 \pm 0.07 \;\Rightarrow\; \Delta G = 0.24 \pm 0.09$

$$\Delta G/G = -0.13 \pm 0.15 \pm 0.15$$

$$x_g = 0.20^{+0.13}_{-0.08}; \quad \mu^2 \approx 13\text{GeV}^2$$

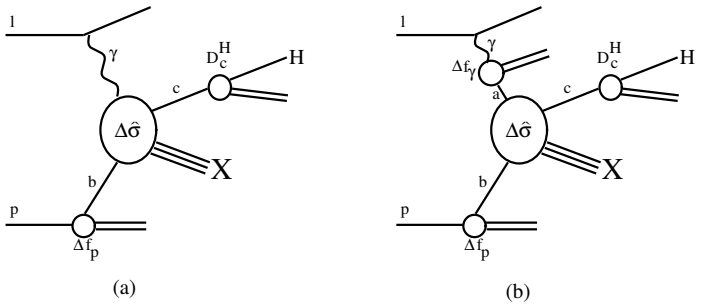


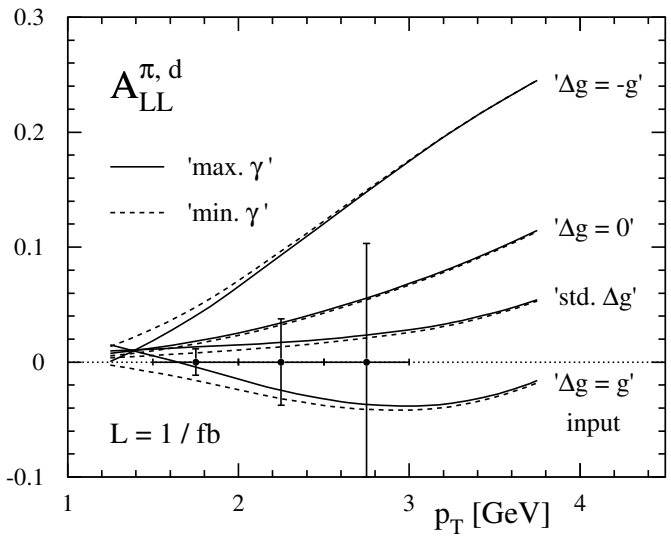


- In addition asymmetries binned along p_T are provided (also in (p_T ,E) bins)

ΔG: High-p_T hadron photoproduction

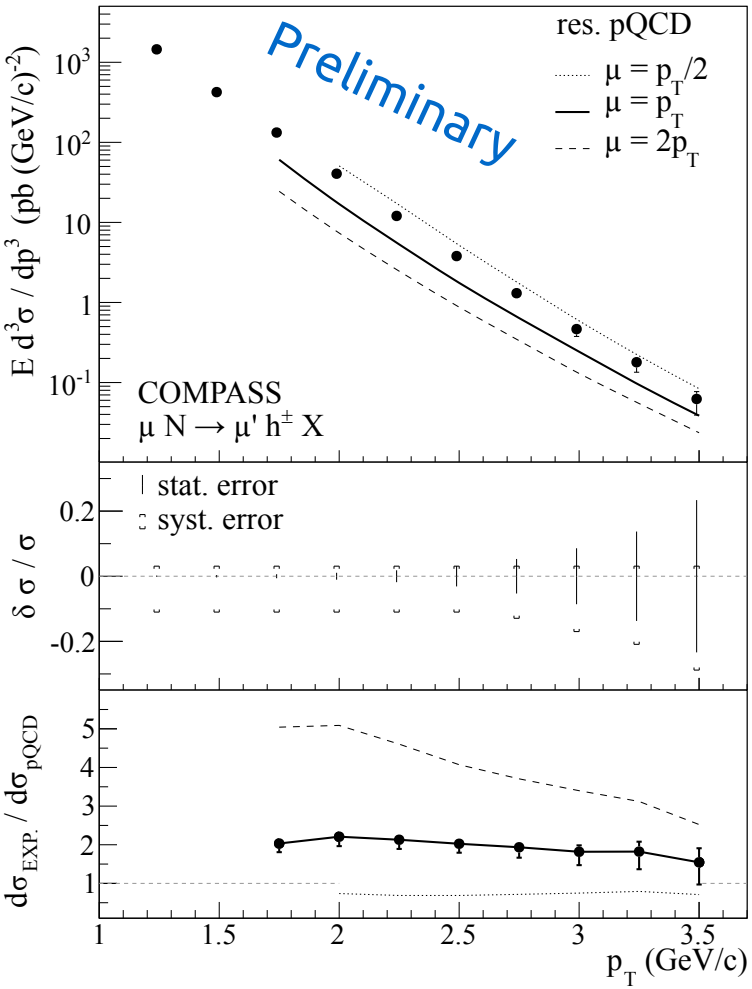
- Measured cross-section: COMPASS hep-ex/1207.2022
  $Q^2 < 0.1\,\mathrm{GeV}^2$, $-0.1 < \eta_{CMS} < 2.4$, $p_T < 3.6\,\mathrm{GeV}$
- NLO pQCD photoproduction of inclusive hadrons
  B. Jäger, M. Stratmann and W. Vogelsang,EPJ C44 (2005) 533
- Projections ($1\ fb^{-1}$) compared to GRSV options
- Goal: constrain the Δg by the QCD calculations of the single high-p_T hadron asymmetries.

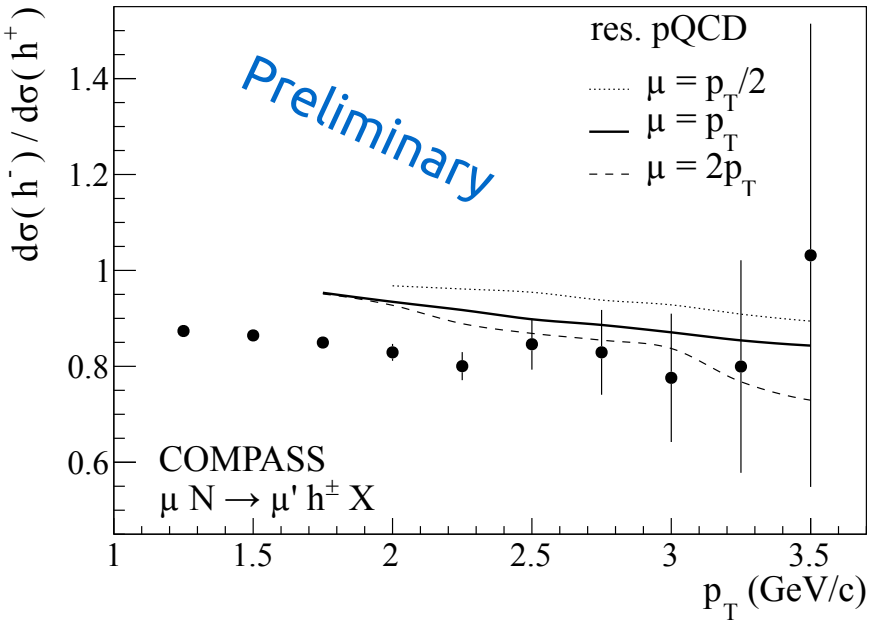




Total COMPASS integrated luminosity: $\sim 4\ fb^{-1}$

ΔG: Hadron photoproduction x-section vs p_T





New calculation w/ "threshold resummation"

de Florian, Pfeuffer, Schäfer, Vogelsang arXiv:1305.6468 [hep-ph]

Summary

- New proton (2011) data extend measurements of g_1^p to low x and will permit a more accurate extraction of polarised pdf
- Extraction of FF ratios from hadron multiplicities on the way
  - Will help to solve the "Δs puzzle"
- Gluon polarisation, Δg updated in LO and (new) NLO suggest a small ΔG at the measured x with all world measurements compatible
- COMPASS II with interesting scientific program awaits restart of SPS (cf. talk by N. D'Hose)