Review of recent direct gluon polarisation measurements

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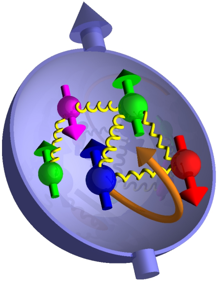
On behalf of the
COMPASS Collaboration

Spin'16

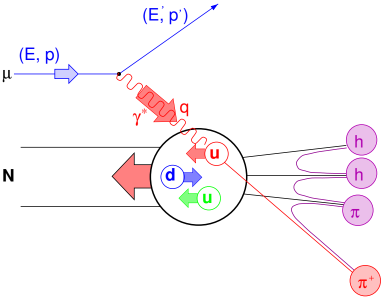
Spin of the nucleon

$$\frac{1}{2} = \frac{1}{2}\underbrace{\Delta\Sigma}_{\text{quarks}} + \underbrace{\Delta G}_{\text{gluons}} + \underbrace{L_q + L_g}_{\text{orbital momenta}}$$



- $\Delta\Sigma \approx 0.3$ from direct measurement
- What about gluons?
- How different quark flavours contribute to the nucleon spin?
- How do we access L?

Deep inelastic scattering



DIS variables

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

$$\nu = E - E'$$

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

Hadron variables

$$z = E_h/\nu$$

p_T^h : transverse momentum

- Inclusive cross section

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

- Measured asymmetry

$$A_{\parallel}(x, Q^2) = \frac{d\sigma^{\uparrow\downarrow} - d\sigma^{\uparrow\uparrow}}{d\sigma^{\uparrow\downarrow} + d\sigma^{\uparrow\uparrow}} = D(A_1 + \eta A_2)$$

$\uparrow$ photon, $\uparrow$ nucleon

D depolarisation factor, A_1 photon-nucleon asymmetry

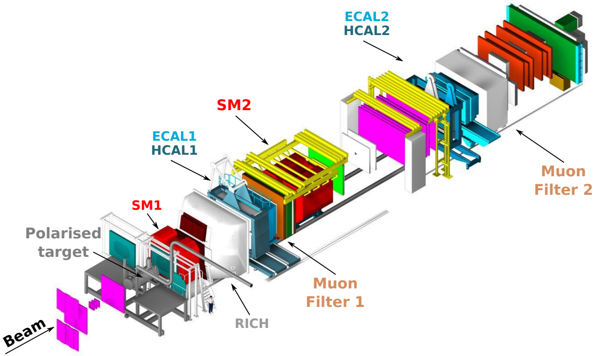
COMPASS: Spectrometer

Muon beam

- Beam: μ^+
- Energy: 160 GeV (200 GeV)
- Polarisation: $\sim 80\%$
- Flux: $10^8 \mu/s$

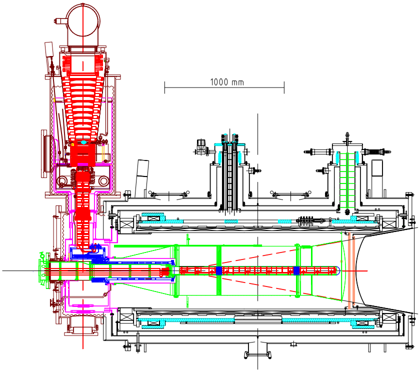
Spectrometer

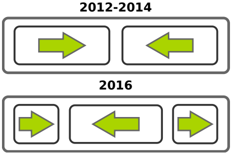
- Two magnets
- Tracking (p$>$0.5 GeV/c)
- PID: RICH(π, K, p), ECAL, HCAL, muon filters



COMPASS: Polarised target

- Two (three) cells, oppositely polarised
- 1.2m long
- 2.5 T solenoid field
- Low temperature 50 mK
- Reversible polarisation
- Acceptance: $\sim$ 70 mrad ($>$2005:$\sim$ 180 mrad)
- ^{6}LiD: $f \simeq 40\%$, $P_T \simeq 50\%$
- NH_3:$f \simeq 16\%$, $P_T \simeq 85\%$





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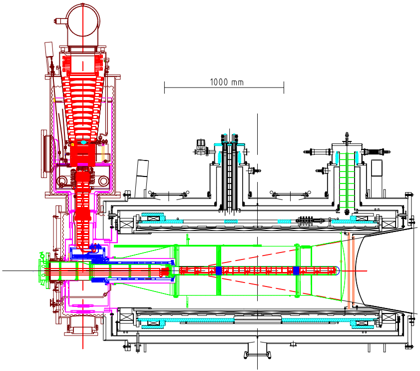
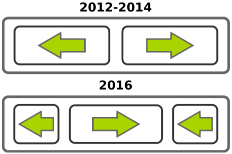
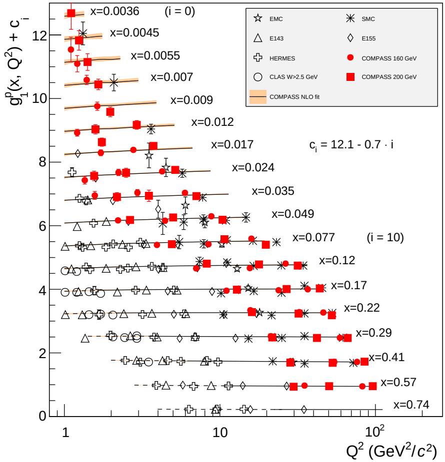




Proton g_1 structure function

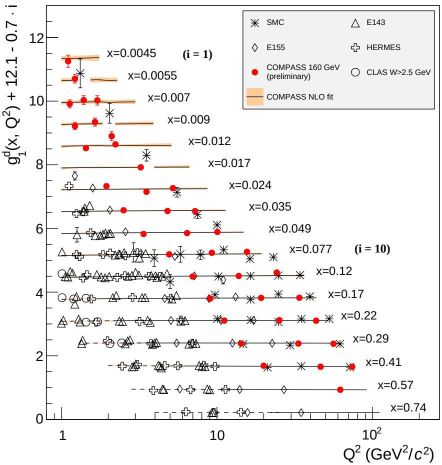
PLB 753 (2016) 18



- Final proton results from COMPASS
- Good agreement with world data
- Measurement at 160 and 200 GeV
- Improvement at low x
- Kinematic domain:
  $Q^2 > 1(\mathrm{GeV}/c)^2$
  $0.1 < y < 0.9$
  $0.0025 < x < 0.7$

cf. talk by M. Wilfert

Deuteron g_1 structure function



- Final deuteron results from COMPASS
- Supersede PLB 647 (2007) 8
- Published results from 2002-2004
- 2006 data added (factor 2)
- g_1^d compatible with zero at low x
- Kinematic domain:

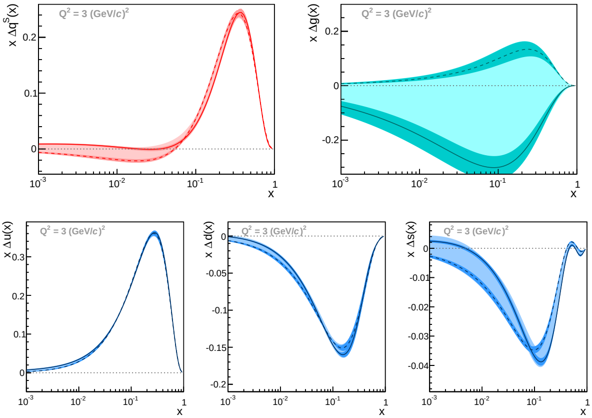
  $Q^2 > 1(\mathrm{GeV}/c)^2$

  $0.1 < y < 0.9$

  $0.004 < x < 0.7$

cf. talk by M. Wilfert

Polarised PDFs at $Q^2 = 3(\mathrm{GeV}/c)^2$ PLB 753 (2016) 18



- NLO pQCD analysis of world data:
  - proton
  - deuteron
  - neutron (^{3}He)
- Detailed study of systematics related to functional form

cf. talk by M. Wilfert

- Quark contribution $0.26 < \Delta\Sigma < 0.36$,
  $\rightarrow$Dominant uncertainty from functional form of Δg
- ΔG not well constrained by DIS data alone
  $\rightarrow$Additional measurements required (semi-inclusive DIS, RHIC spin)

Dedicated measurements for ΔG

Additional Δg measurements for global fits

- pQCD calculation with collinear fragmentation
- Similar approach to used at RHIC
- Channel studied at COMPASS:
  - Photo-production of charged hadrons at high p_T (NLO)

Direct extraction of ΔG

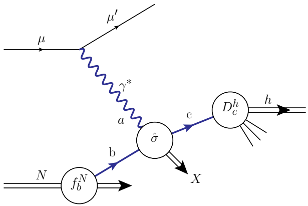
- Based on Monte-Carlo generator with Lund fragmentation
- Channels studied at COMPASS:
  - Production of charged hadron at high p_T (LO)
  - Open charmed meson production (LO & NLO)

High-p_T hadron photo-production PLB 753 (2016) 573

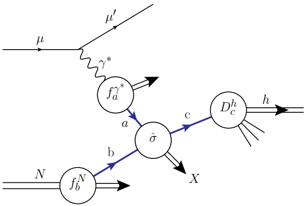
Double spin asymmetry of hadron production cross-section.
NLO interpretation available (B. Jäger et al., EPJC 44 (2005) 533) for:

- single hadron at high p_T
- photo-production regime ($Q^2 < 1(\text{GeV/c})^2$)

direct γ-contribution



resolved γ-contribution



$$\frac{d\Delta\sigma^h}{d\sigma^h}(p_T, \eta_h) = \frac{\sum_{a,b,c} \Delta f_a^\mu \otimes \Delta f_b^N \otimes d\Delta\hat{\sigma}_{a,b\to c,X} \otimes D_c^h}{\sum_{a,b,c} f_a^\mu \otimes f_b^N \otimes d\hat{\sigma}_{a,b\to c,X} \otimes D_c^h} = \frac{d\Delta\sigma_{dir} + d\Delta\sigma_{res}}{d\sigma_{dir} + d\sigma_{res}}$$

Unpolarised cross-section

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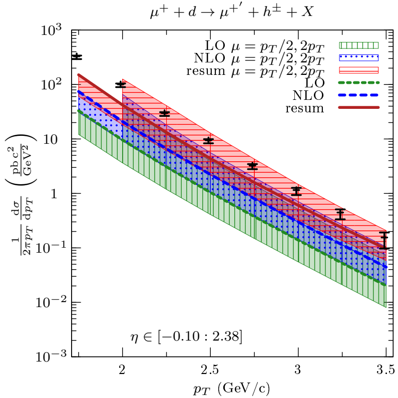
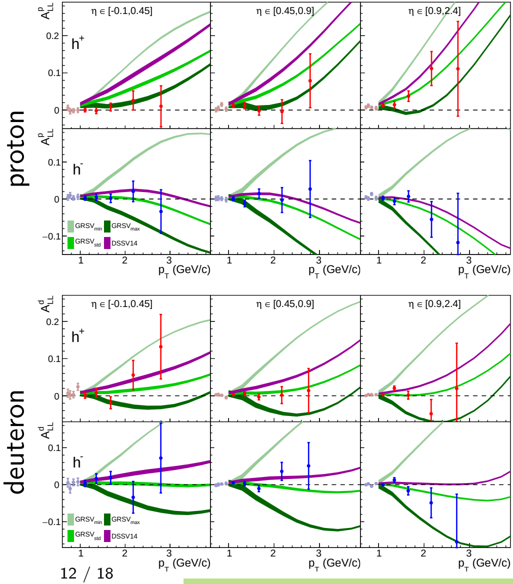


COMPASS, PRD 88 (2013) 091101
D. de Florian et al., PRD 88 (2013) 014024

$$\frac{\sigma_{exp}}{dydp_T} \Big/ \frac{\sigma_{th}}{dydp_T}$$

- Data / Theory in agreement over 4 orders of magnitude
- Requires inclusion of NLL threshold resummation
- Validates applicability of the theory framework for ΔG

Single hadron asymmetry $A_{LL}(p_T)$ PLB 753 (2016) 573 COMPASS



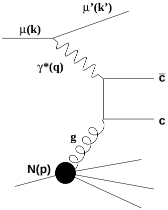
- Measurement performed for 3 bins in η_h to boost the sensitivity to ΔG
- Theoretical asymmetries computed at NLO without gluon resummation
- Data prefer positive gluon polarisation as suggested by recent RHIC data

- Calculations for polarised case with NLL threshold resummation for direct component available (C. Uebler et al., Phys. Rev. D 92 094029)
- Still missing NLL threshold resummation for resolved component of the x-section

cf. talk by F. Ringer

Direct measurements of gluon polarisation

Photon gluon fusion



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

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

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

Direct methods

- Open charm production
  $\gamma g \rightarrow c\bar{c}$
  $\rightarrow D^0, D^*$
  hard scale: M^2
  theoretically clean channel
  low statistics
- High p_T hadrons
  $\gamma g \rightarrow c\bar{c}$
  $\rightarrow$2 jets or H^+H^-
  hard scale: Q^2 or $\sum p_T^2$
  high statistics
  background processes

Open charm production

PRD 87 (2013) 052018

Measured channels

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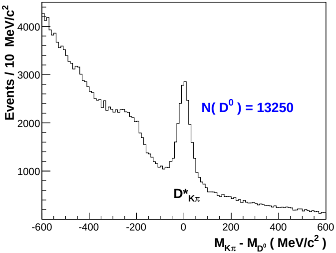
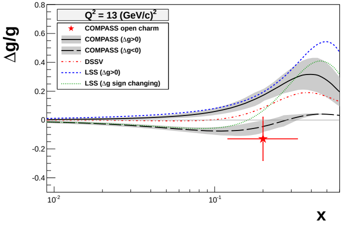
$$D^0 \rightarrow K\pi$$



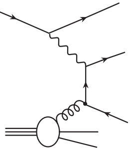


- all deuteron and 2007 proton data
- all Q^2, a_{LL} in NLO
- scale $\mu^2 \approx 13(\mathrm{GeV/c})^2$
- result at $x_g = 0.11$

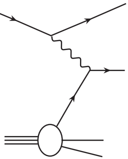
$$\Delta g/g^{NLO} = -0.13 \pm 0.15(stat) \pm 0.15(syst)$$

Hadron production

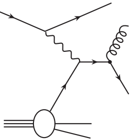
arXiv:1512.05053 COMPASS



PGF



LP



QCDC

In LO three processes contribute to the observed asymmetry

$$A_{LL}^{h}(x) = R_{PGF}\, a_{LL}^{PGF}\, \Delta g/g(x_G) + R_{LP}\, D A_1^{LO}(x) + R_{QCDC}\, a_{LL}^{QCDC}\, A_1^{LO}(x_C)$$

- $A_1^{LO} \equiv \frac{\sum_i e_i^2 \Delta q_i}{\sum_i e_i^2 q_i}$ (in previous analyses from external input)
- R_i - process fraction; a_{LL}^{i} - partonic asymmetry
  obtained from MC based on Neural Network parametrisation

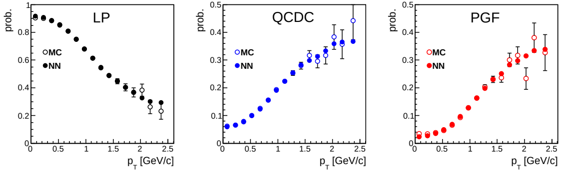
Principle of the method

larger p_T $\rightarrow$ larger PGF $\rightarrow$ larger sensitivity to $\Delta g/g$

Hadron production "All-p_T method" arXiv:1512.05053

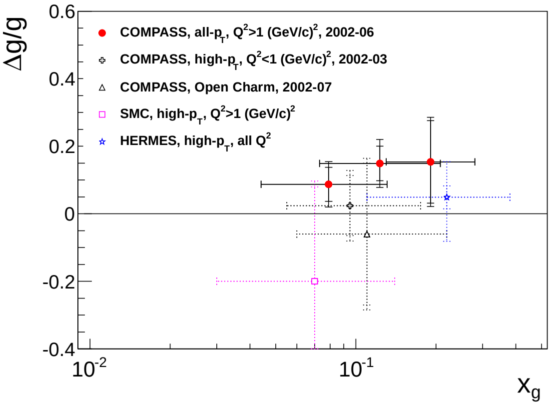
- Kinematic domain:
  $Q^2 > 1(\text{GeV}/c)^2$
  $0.1 < y < 0.9$
  No minimal p_T required
- The processes differ in p_T dependence:
  - high p_T region: PGF and QCDC
  - low p_T region: LO
- Extract simultaneously A_1^{LO} and $\Delta g/g$

- Calculate and minimise:
  $\chi^2 = (N_{exp} - N_{obs}) cov^{-1} (N_{exp} - N_{obs})^T$
- N_{exp} and N_{obs} calculated for each process
- $N_{exp,i}$ depends on a^i_{LL}, R_i, beam flux, acceptance, unpolarised cross-section, A_1^{LO} and $\Delta g/g$



Hadron production results

arXiv:1512.05053



- Most precise direct measurement
- The $\Delta g/g$ extracted in 3 x_G bins

$$\mu^2 = \langle Q^2 \rangle \approx 3(\mathrm{GeV/c})^2$$

$$\langle x_G \rangle \approx 0.10$$

$$\Delta g/g = 0.113 \pm 0.038(stat.) \pm 0.035(syst.)$$

Data suggest positive value of $\Delta g/g$ ($\sim 2\sigma$)

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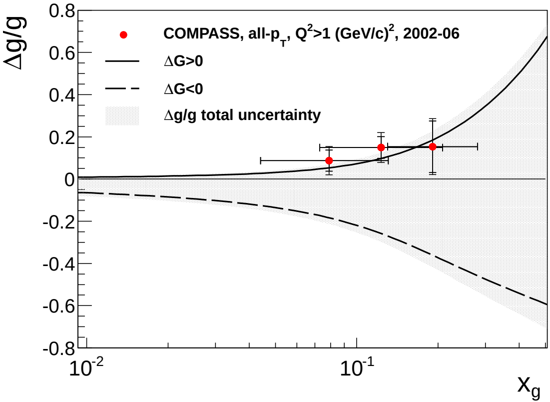

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Conclusions

- Improved precision on g_1^p and g_1^d by at least a factor of ~ 3 (compared to SMC)
  - weak constraint on ΔG from DIS only
- $\langle \Delta g(x) \rangle |_{LO} > 0$ at $\sim 2\sigma$ in hadron "All-p_T" measurement
  - first positive direct measurement
  - measurement in 3 bins of x_G
- $A_{LL}(p_T)$ from photo-production available for global NLO analysis

- Future $\rightarrow$Access orbital angular momentum L via DVCS