An overview of COMPASS Δg results

M. Stolarski LIP

On behalf of the COMPASS Collaboration

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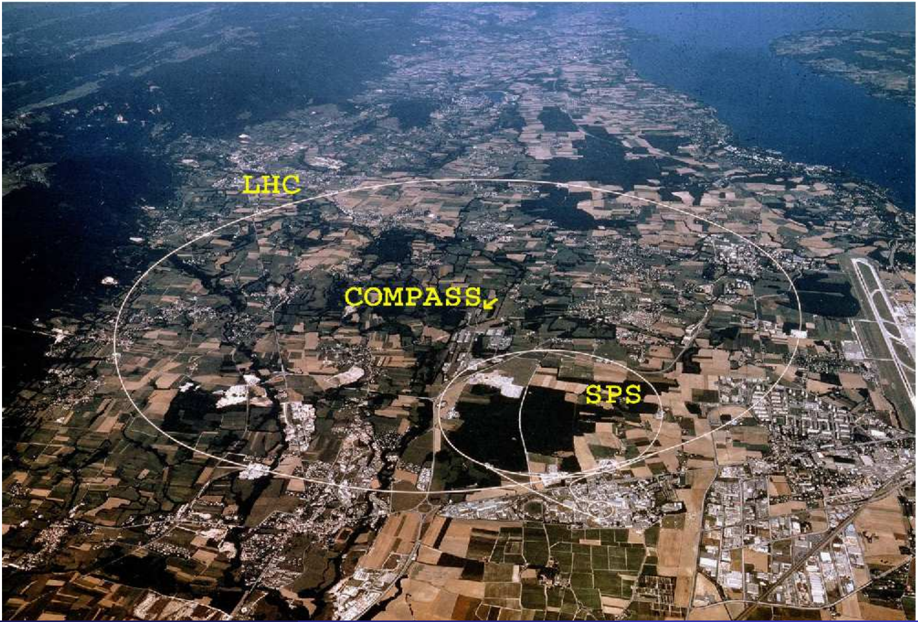
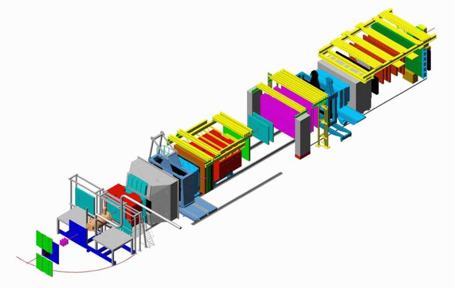
Overview

- COMPASS
- Nucleon spin polarisation puzzle
- COMPASS $\Delta g/(g)$ results from:
  - NLO $g_1^{p,d}$ fit
  - Open charm, (LO and NLO)
  - High-p_T, low Q^2 events (LO and NLO)
  - High-p_T, high Q^2 events (LO)

COMPASS at CERN



COMPASS Spectrometer



- COLLABORATION
  - about 210 physicists
  - 27 institutes
- DETECTOR
  - two stage spectrometer
  - 60 m length
  - about 350 detector planes
- POLARISED TARGET
  - ^{6}LiD, (NH_3) target
  - 2-3 cells (120 cm total length)
  - $\pm$ 50% (85%) polarisation
  - pol. reversal every 8h-24h
- POLARISED BEAM
  - μ^+ at 160 GeV/c
  - polarisation –80 %
- FEATURES
  - angular acceptance: $\pm$70 mrad ($\pm$180 mrad from 2006)
  - track reconstruction: $p > 0.5$ GeV/c
  - identification h, e, μ: calorimeters and muon filters
  - identification: π, K, p (RICH) $p > 3, 9, 18$ GeV/c respectively

Motivation a'la 1990-2014

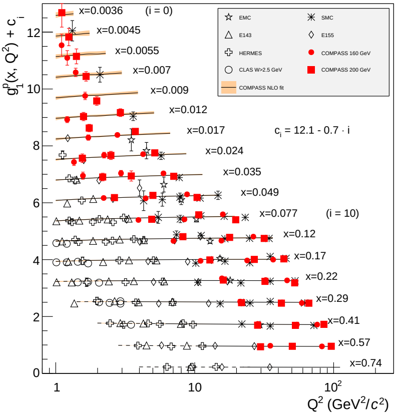
- Spin of the proton ($S_p = 1/2\hbar$) can be decomposed as:
  - $\Delta\Sigma$ - quark contribution to the nucleon spin
  - ΔG - gluon contribution
  - ΔL_q,ΔL_g - orbital momentum of quarks and gluons
- $S_p = 1/2\hbar = 1/2\Delta\Sigma + \Delta G + \Delta L_q + \Delta L_g$
- In the simplest QPM model: $S_p = 1/2\Delta\Sigma$
- The direct measurement: $\Delta\Sigma \approx 0.3$
- How much is then ΔG?
- So far (NLO) QCD fits of DIS data **do not** constrain ΔG
- Possible direct measurement of ΔG in photon-gluon fusion
  - asymmetries in open-charm production
  - asymmetries for events with high transverse momentum hadrons
- Early RHIC results used in QCD fits suggested that ΔG changes sign and in overall was compatible with zero!
- Only later RHIC results suggested that ΔG is positive in the measured x_g range

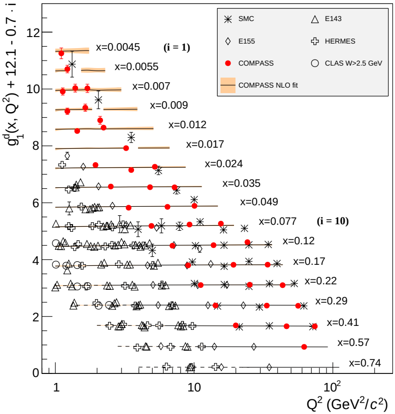
Δg from g_1 Scaling Violations

Δg from g_1 Scaling Violations

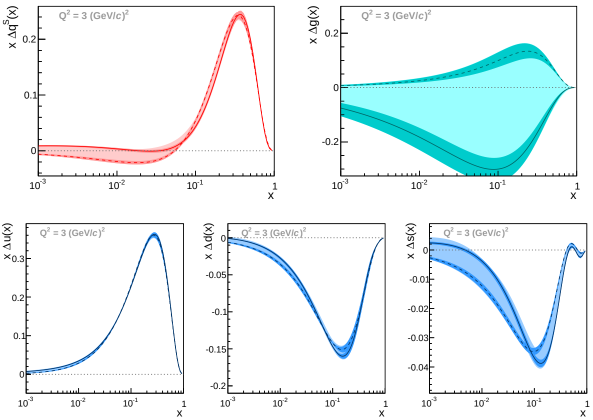
- Study of scaling violation of $g1$ function is the most model independent way to obtain $\Delta g(x)$
- It works extremely well for unpolarised g distribution, due to presence of HERA collider data, $\sqrt{s} = 318$ GeV$/c^2$, data cover up to 5 decades in Q^2
- In case of polarised experiments, we lack of high energy collider data and thus access to high Q^2
- In addition due to factors like ,depolarisation factor, beam and target polarisation, target dilution factor the figure of merit is poor

World Data on g_1^p and g_1^d





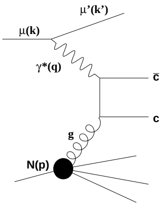
COMPASS NLO Fit to World Data on g_1^p and g_1^d



- PLB **753** (2016) 18
- Dark bands stand for statistical uncertainties, lighter one for systematic ones
- The value of Δg is not constrained
- Unconstrained Δg has significant impact on uncertainty of extracted $\Delta\Sigma$, *i.e.* $\Delta\Sigma \in [0.26, 0.36]$ @ $Q^2 = 3\ (\mathrm{GeV}/c)^2$ in $\overline{MS}$-scheme

Open Charm Analysis

Open Charm Analysis



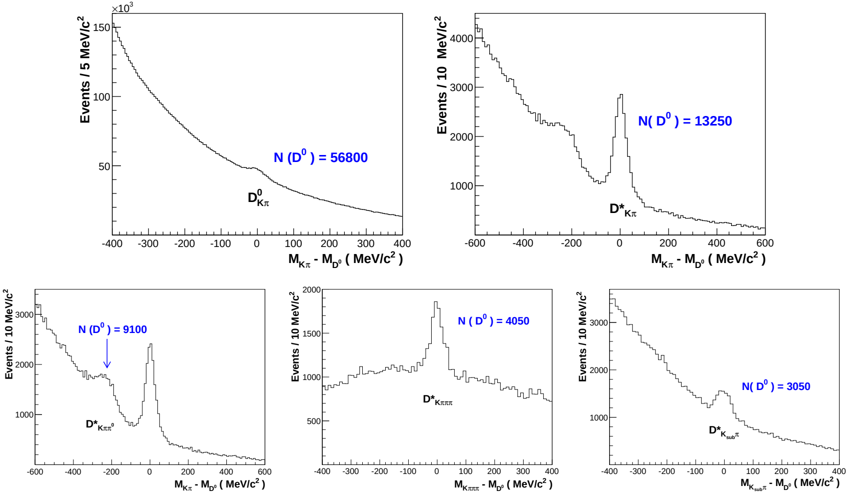
Considerations:

- Formally it is/was considered golden channel to extract $\Delta g/g$ in COMPASS
- Presence of D^0 meson is a smoking gun of PGF process
- At LO there is no background from other processes to D^0 production
- $\Delta g/g = \frac{1}{\langle a_{LL} \rangle} A_{LL}^{D^0}$
- At low x, where COMPASS observes D^0 there is no contamination of intrinsic charm events.
- At low x, Q^2 is below 1 $(\mathrm{GeV}/c)^2$, however the hard scale is given by the mass of heavy quarks, $\mu^2 \approx 4m_c^2$.

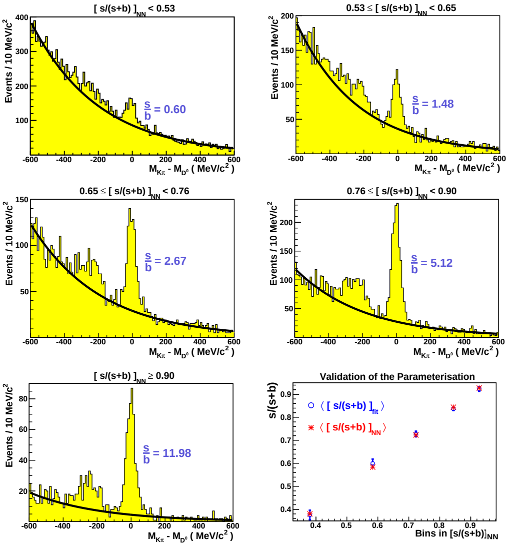
Analysis Method

- Five channels of were studied
  - $D^0 \to K\pi$
  - $D^* \to D^0\pi_s \to K\pi\pi_s$
  - $D^* \to D^0\pi_s \to K3\pi\pi_s$
  - $D^* \to D^0\pi_s \to K_{sub\_threshold}\pi\pi_s$
  - $D^* \to D^0\pi_s \to K\pi\pi^0\pi_s$
- RICH used to identify particles of D^0 decay (usually kaon)
- COMPASS target is dense and long - it is impossible to detect secondary vertex of D^0 decay
- We used Neural Network approach to better select D^0 candidates, wrong charge combinations were used as background
- The partonic cross section a_{LL} was parametrised on the event by event basis by Neural Network
- For LO, event-by-event weighting procedure was used to optimise statistical uncertainties

D^0 Spectra in Various Channels



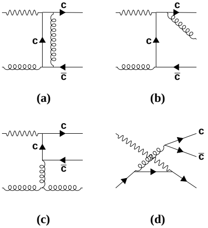
D^0 Spectra for Different NN Responses



NN is able to select phase-space region where purity of the signal is higher than average

NLO $\Delta g/g$ Analysis

- At higher order D^0 can be produced not only in PGF process e.g.



- $\Delta g/g = \frac{D}{\langle a_{LL}^{NLO} \rangle} A_{LL}^{\gamma N} - A_{corr}$
- It turned out that a_{LL}^{NLO} is unexpectedly very different from a_{LL}^{LO}
- The reason is that with COMPASS limited centre of mass energy D^0 production is near the energy threshold
- The difference is only visible when COMPASS acceptance is taken into account!
- Large change in x_g between LO and NLO is also seen

Results - $\Delta g/g$ from Open Charm

- PRD **87** (2013) 052018
- LO analysis:
  - $\Delta g/g = -0.06 \pm 0.21 \pm 0.08$
  - x_g range 0.06–0.22, $\langle x_g \rangle = 0.11$, $\mu^2 \approx 13$ (GeV$/c)^2$
- NLO analysis:
  - $\Delta g/g = -0.13 \pm 0.15 \pm 0.15$
  - x_g range 0.12–0.33, $\langle x_g \rangle = 0.20$, $\mu^2 \approx 13$ (GeV$/c)^2$

p_T of D^0	a_{LL}^{LO}/D	a_{LL}^{NLO}/D
0.0–0.3	$+0.70$	-0.13
0.3–0.7	$+0.51$	-0.24
0.7–1.0	$+0.27$	-0.42
1.0–1.5	$+0.02$	-0.57
>1.5	-0.24	-0.68

- Due to large statistical uncertainties a great variation in a_{LL} values between LO and NLO does not change much $\Delta g/g$ results
- However, if one generates PGF asymmetry according to NLO a_{LL} and repeats analysis in LO one obtains $\Delta g^{extracted} = -0.2\Delta g^{assumed}$!

Δg from Hadron Production at High-p_T, $Q^2 < 1$

Δg from Hadron Production at High-p_T, $Q^2 < 1$

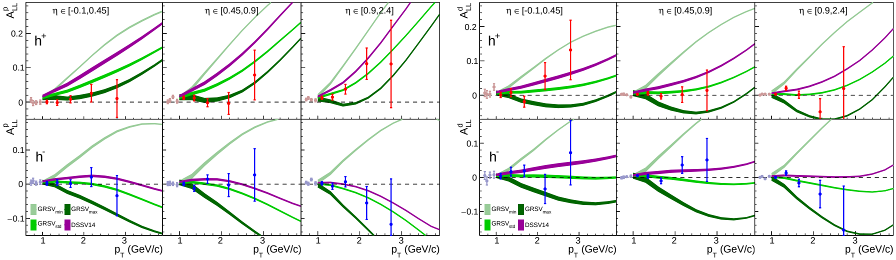
- The p_T of hadrons produced in Leading QCD Process is small
- Higher order processes like PGF and QCDC are characterised by larger p_T
- Selecting hadrons with high p_T one enhances contamination of PGF and QCDC
- However, at low Q^2 one need to deal with the so called resolved photon events,
- COMPASS performed an analysis of such events
  - PLB **633** (2006) 25
  - $A_{LL}^{\gamma N}$ are measured for High p_T events with $Q^2 < 1$ (GeV/c)^2
  - PYTHIA generator is used to estimate fraction of various processes, R_i in the selected sample and analysing power $\langle a_{LL} \rangle$
  - $\Delta g/g = 0.024 \pm 0.089(stat.) \pm 0.057(syst.)$, $\langle x_g \rangle = 0.095$, $\mu^2 = 3$ (GeV/c)^2

$A_{LL}^{\mu N}$ at High p_T and Low Q^2

- It turned out that perturbative calculation can be carried out in NLO for single hadron asymmetry $A_{LL}^{\mu N}$ at high-p_T and low Q^2
- Hard scale of the process is p_T^2
- There are significant calculation problems in case one would like to perform analysis with two hard scales present like p_T^2 and Q^2
- Thus the method can only be used for low Q^2 events
- The theoretical calculations, B. Jager, M. Stratmann and W. Vogelsang, Eur. Phys. J. C **44** (2005) 533. for various input parameters like $\Delta g(x)$ can be then compared with theory predictions (alternatively measured asymmetries can be used in pQCD fits)

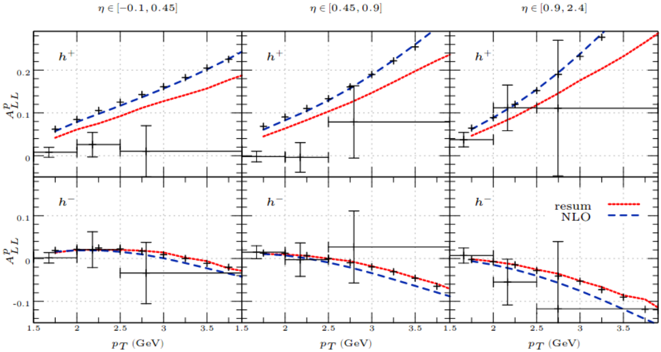
$A_{LL}^{\mu N}$ at High p_T and Low Q^2 cont.

- Results published in PLB **753** (2016) 573
- $A_{LL}^{\mu N}$ for proton and deuteron target, left and right panel, respectively
- At the time of COMPASS publication theoretical results without threshold re-summations were available
- Clear tensions visible in certain kinematic ranges



Impact of Threshold Re-summation

- C. Uebler, A. Schäfer, W. Vogelsang, PRD **96** (2017) 074026
- "To have some confidence that our perturbative methods are valid, we require the hadron p_T to be at least $p_T = 1.75$ GeV/c "
- The polarised PDFs used in calculations correspond to PRL **113**, (2014) 012001
- Better observed agreement, but much of experimental data are not used in analysis



All-p_T analysis, $Q^2 > 1$

The Analysis Method of High-p_T Events in the DIS Region

- Contribution from 3 processes to the observed asymmetry is assumed:

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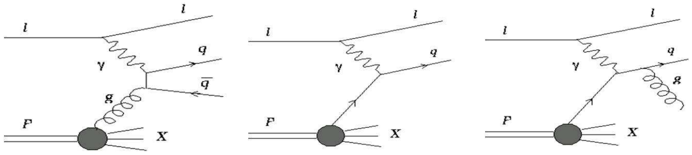


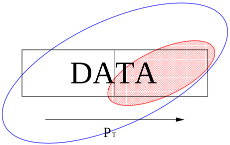
PGF LP QCDC

- $A^h_{LL}(x_{Bj}) = R_{PGF}\, a^{PGF}_{LL}\, \Delta g/g(x_G) + R_{LP}\, D A^{LP}_1(x_{Bj}) + R_{QCDC}\, a^{QCDC}_{LL}\, A^{LP}_1(x_C)$
  where:
  - $A^{LP}_1 \equiv \frac{\sum_i e_i^2 \Delta q_i}{\sum_i e_i^2 q_i}$
  - the fraction of the processes (R_i) and partonic cross-section asymmetries (a^i_{LL}) are obtained from MC and parametrised by NN
- Idea: larger p_T → larger R_{PGF} → larger sensitivity to $\Delta g/g$

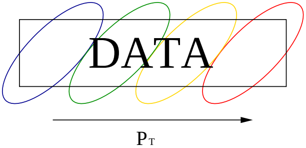
The Analysis Method cont.

- $A^h_{LL}(x_{Bj}) = R_{PGF}\, a^{PGF}_{LL}\, \Delta g/g(x_G) + R_{LP}\, D A^{LP}_1(x_{Bj}) + R_{QCDC}\, a^{QCDC}_{LL}\, A^{LP}_1(x_C)$
- A^{LP}_1 is unknown, an additional information is needed in order to extract $\Delta g/g$
- Several possibilities exists:
  - take existing polarised LO PDF (biased result and error)
  - take existing polarised NLO PDF (depends upon ΔG!, higher order)
  - use inclusive A^d_1 - PLB **718**, (2013) 922
  - extract A^{LP}_1 simultaneously with $\Delta g/g$ - EPJC **77** (2017) 209

PLB **718** (2013) 922:

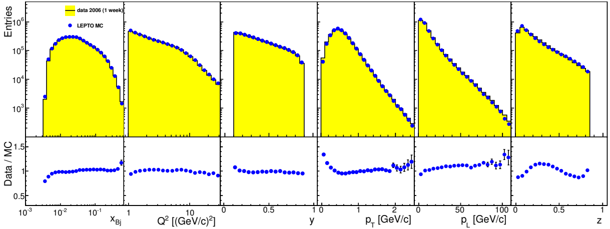


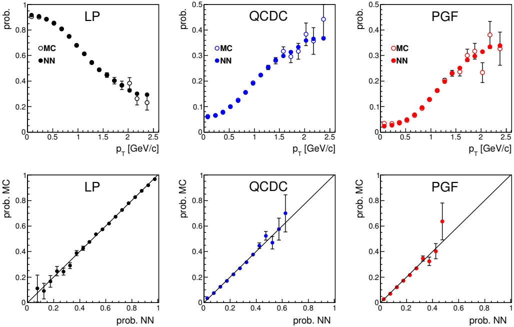
EPJC **77** (2017) 209:



- The 2nd method improves statistical uncertainty by a factor of 1.6
- It allows better treatment of systematic uncertainties
- As R_i and a_{LL} are taken from MC $\rightarrow$ good MC description of data is crucial

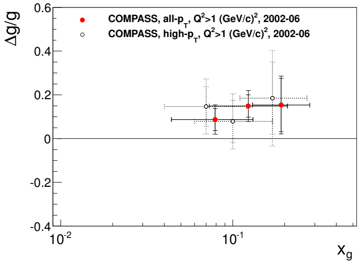
Data/MC and R_i NN Parametrisations

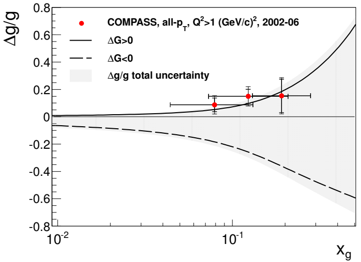




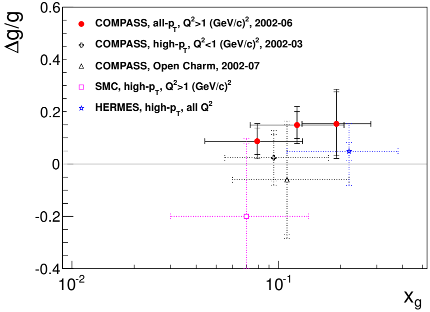
Results

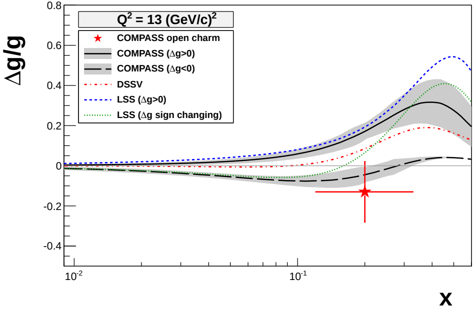
- $\Delta g/g = 0.113 \pm 0.038(stat.) \pm 0.036(syst.)$, $\langle x_g \rangle \approx 0.10$, $\mu^2 = Q^2 = 3\ (\mathrm{GeV}/c)^2$
- Results of $\Delta g/g$ in three x_g bins were also obtained





World Results of Direct $\Delta g/g$ Extraction





Summary

- Several COMPASS results concerning Δg were presented
- COMPASS obtained the world most precise results in direct extraction of $\Delta g/g$
- COMPASS measurements, both direct and indirect, do agree with positive Δg
- On average a bit larger Δg than in DSSV fits would better fit COMPASS data
- Sometimes surprising impact of higher order corrections was found across our analyses
- Suggestion: Work with theory colleagues right from beginning!