COMPASS measurements of the longitudinal spin structure of the nucleon

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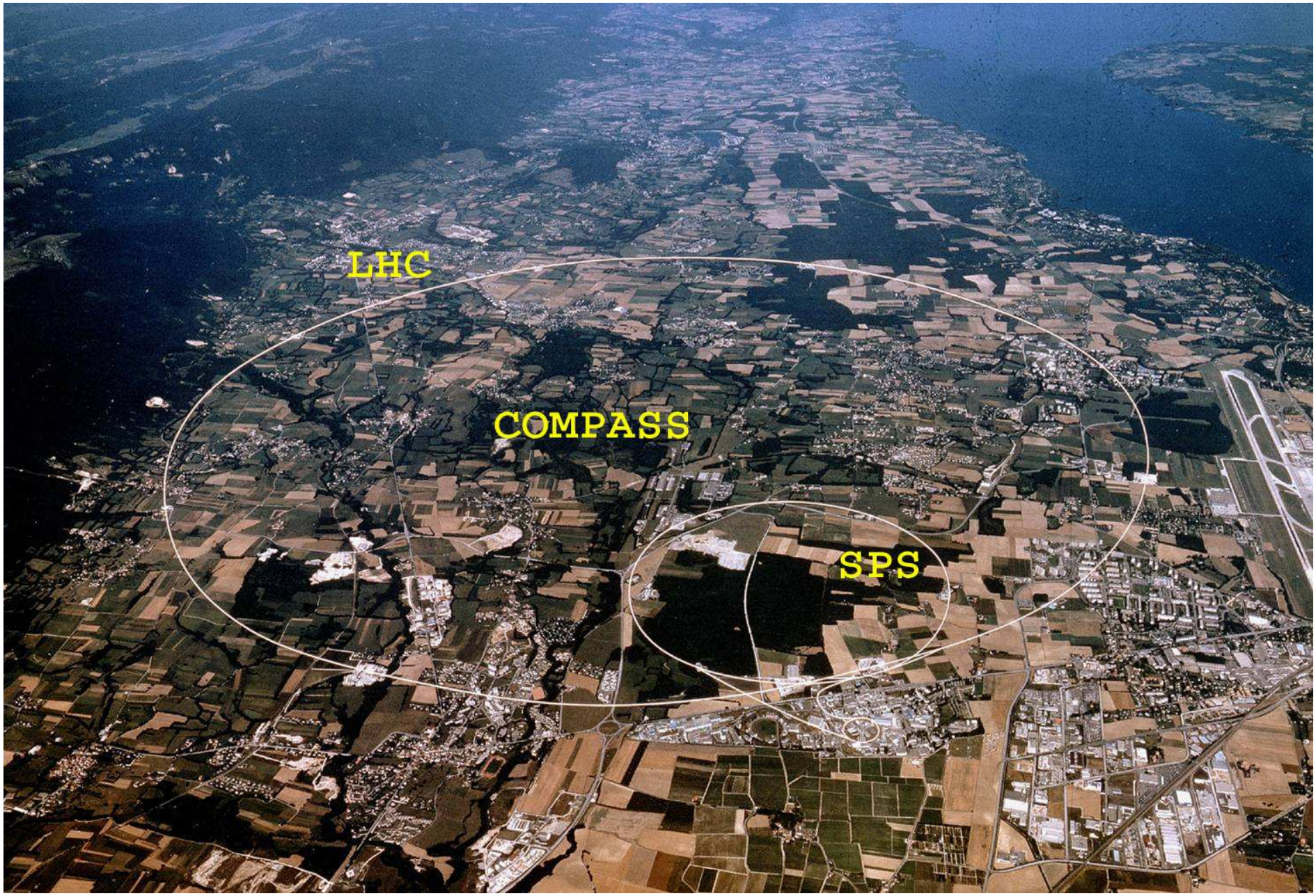
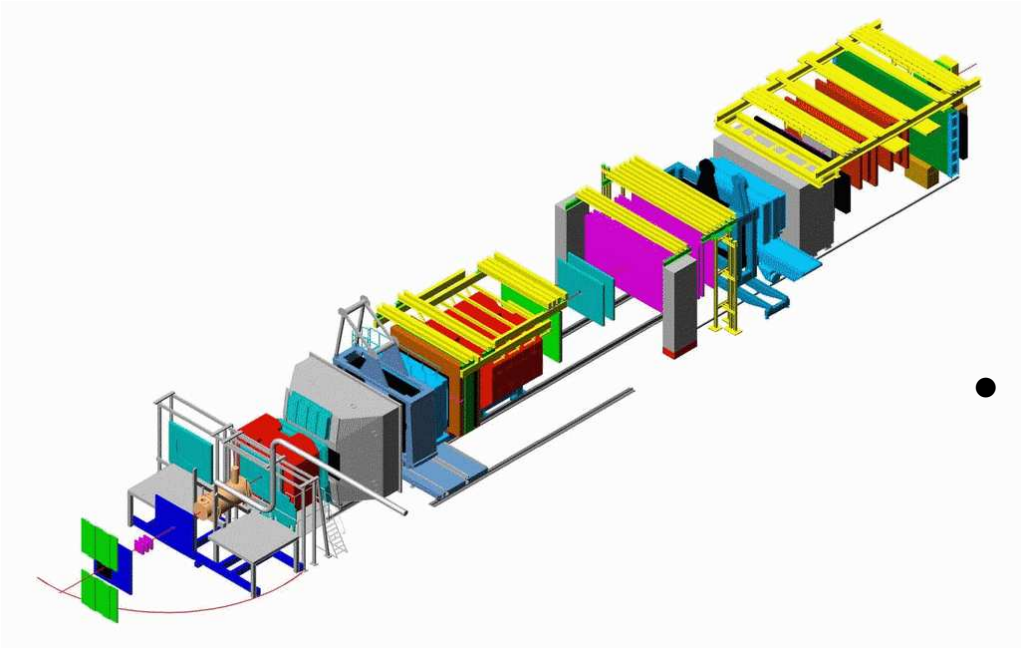
on behalf of the COMPASS collaboration

- inclusive A_1^p and g_1^p from 2011 data
- flavor separation
- $\Delta G/G$ measurements
  - open charm analysis
  - high-p_T 2hadrons, Q^2 >1 $(\mathrm{GeV/c})^2$ analysis

COMPASS @ CERN





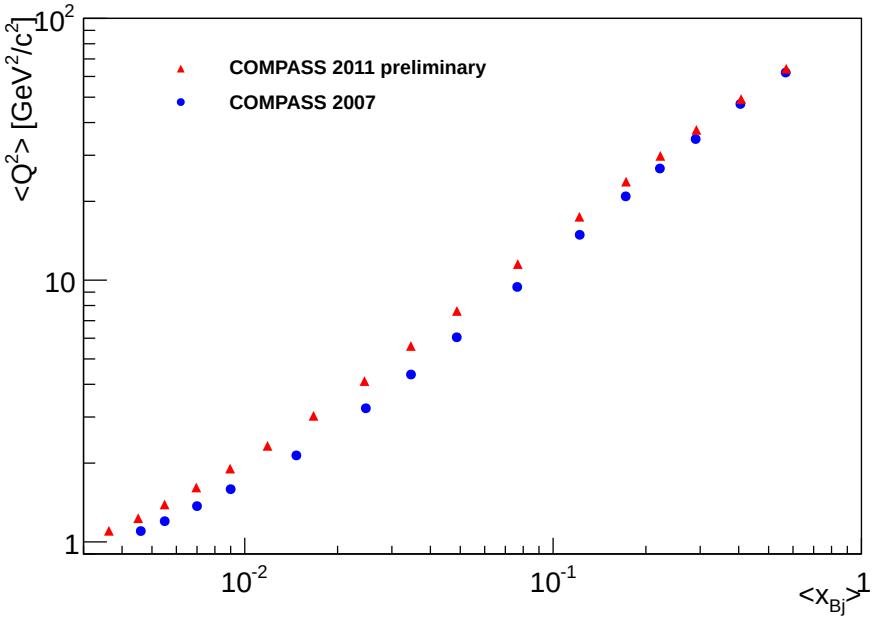
- COLLABORATION
  - about 210 physicists
  - 27 institutes
- DETECTOR
  - 60 m length
  - 2 (3) magnets
  - about 350 detector planes

- POLARISED TARGET
  - ^{6}LiD (NH_3) target
  - 2-3 cells (120 cm total length)
  - $\pm$ 50% (90%) polarization
  - polarisation reversal every 8h-24h
- POLARISED BEAM
  - positive muons at 160/(200) GeV/c (2011)
  - polarisation –80 %
- FEATURES
  - acceptance: 70 (180) mrad (2006)
  - track reconstruction: $p > 0.5$ GeV/c
  - identification h, e, μ: ECAL, HCAL and muon filters
  - identification: π, K, p (RICH) above 2, 9, 18 GeV/c respectively

(Semi)-Inclusive Asymmetries and Flavour Separation

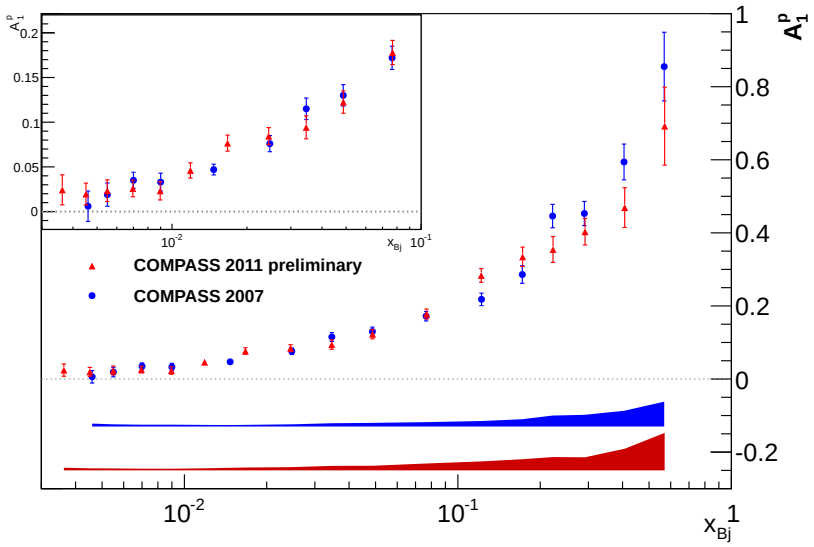
New 2011 data

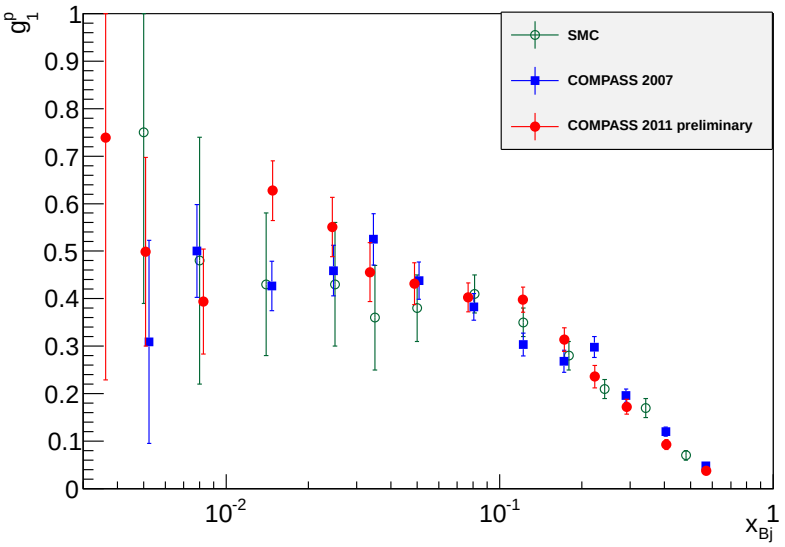
- more data on the NH_3 target was collected
- in order to access lower x region the muon beam of 200 GeV/c was used in 2011 (160 GeV/c in 2007)
- the main physics goal: measure better strange quark polarisation inside the nucleon
- the data are being analysed, so far the inclusive spin dependent A_1^p asymmetry and spin dependent structure function g_1^p were measured



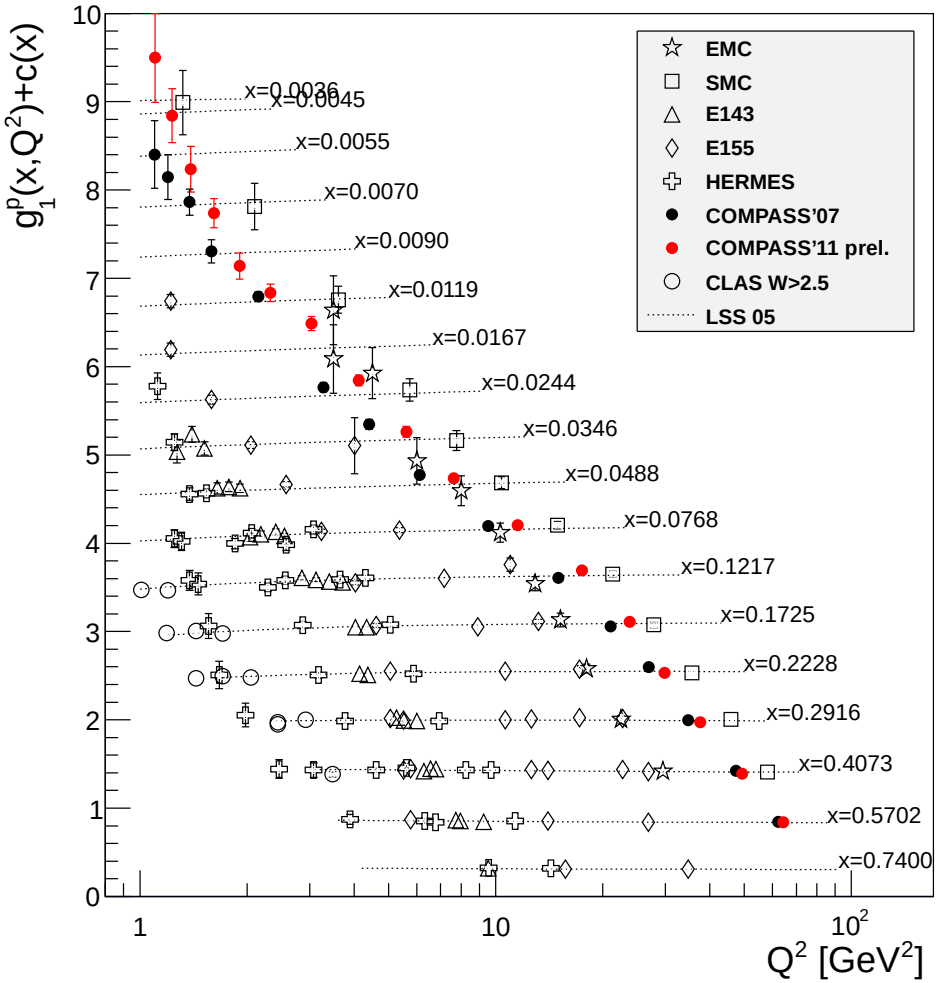
New A_1^p and g_1^p from 2011 data

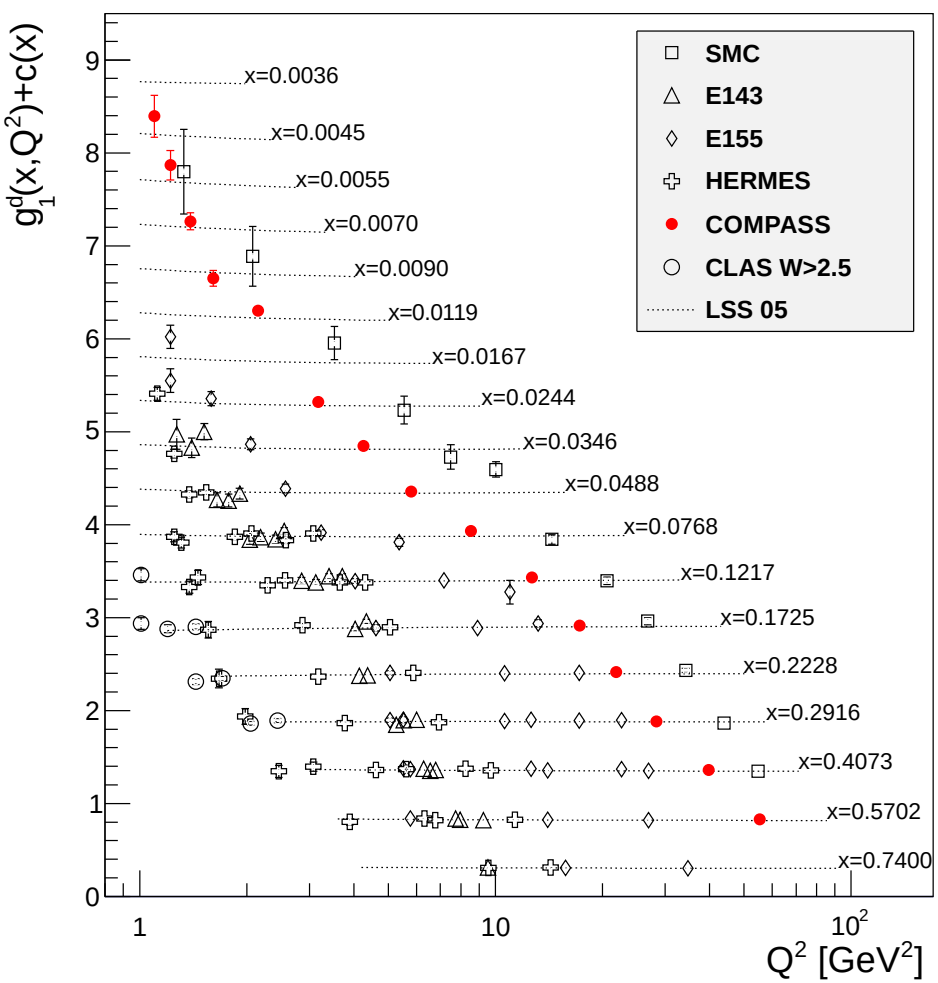
- events with $Q^2 > 1$ (GeV/c)^2, and $0.1 < y < 0.9$ are accepted
- reconstruction of μ and μ' and additional hadron for SI triggers
- $A_{raw} = \frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}}$ $\qquad A_1^p = \frac{1}{fDP_bP_t} A_{raw}$ $\qquad g_1^p = \frac{F_2^p}{2x(1+R)} A_1^p$
  - f- the dilution factor of the target; D - depolarisation factor of the photon
  - P_b, P_t - beam and target polarisations
  - $R = \sigma_L/\sigma_T$
- further precision improvement observed in the low x_{Bj} region





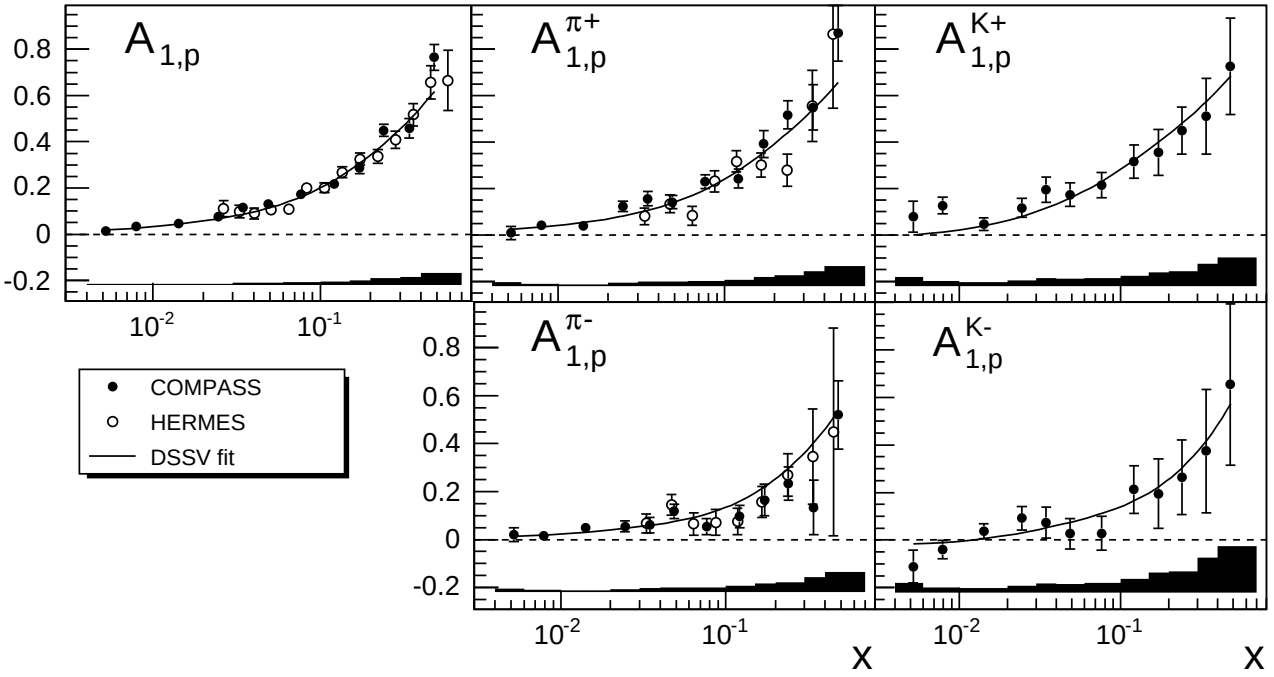
World data on $g_1^{p,d}$





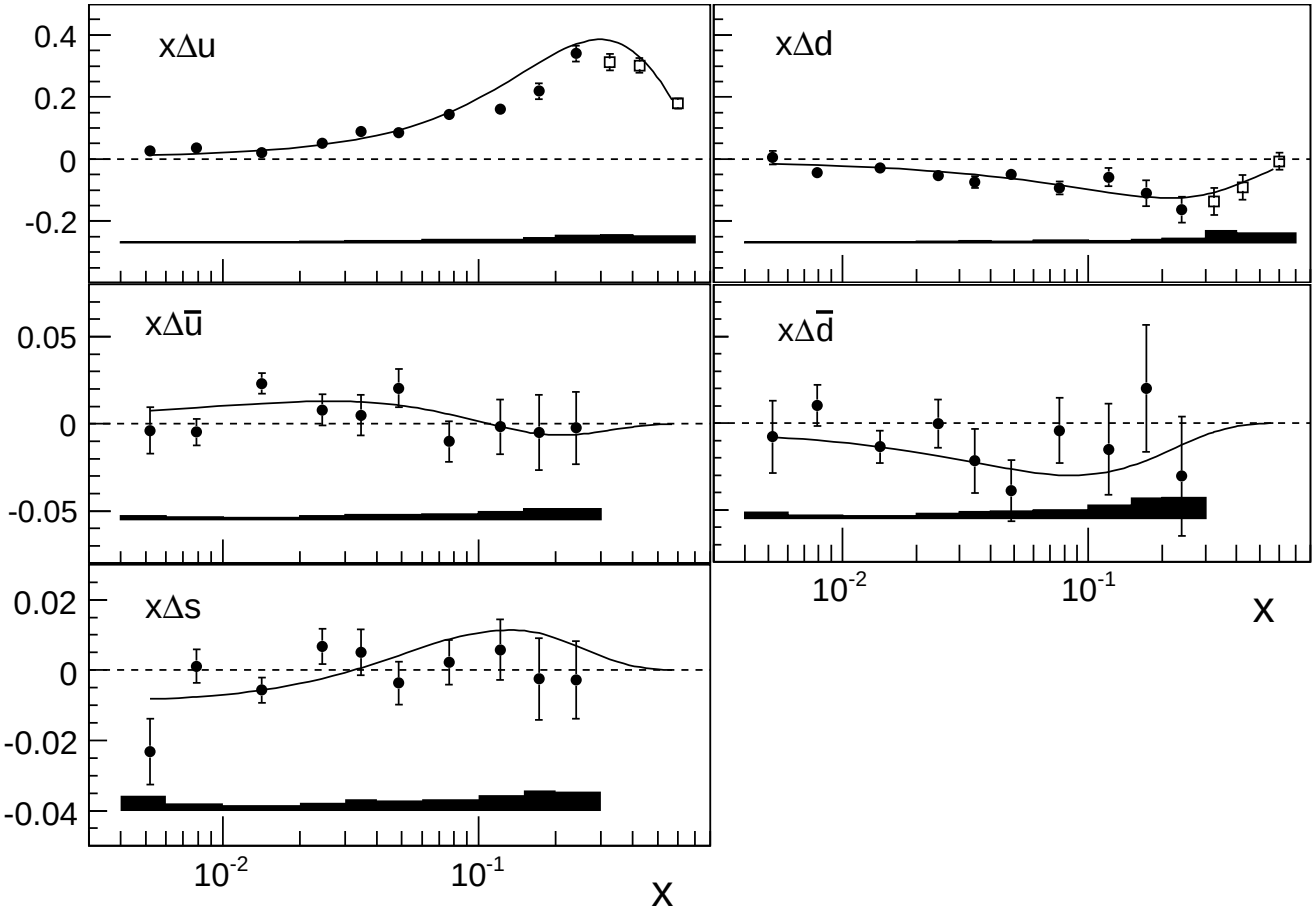
Semi-Inclusive Asymmetries

- semi-inclusive asymmetries were measured on both p and d targets
- for the first time Kaon asymmetries were measured on p target
- in the LO approximation $A_1^h(x,Q^2,z) = \frac{\sum_q e_q^2 \Delta q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)}$
- D_q^h are fragmentation Functions (FF) of quark q into hadron h
- with 10 asymmetries ($A_{1p,d}^{incl}, A_{1p,d}^{\pi\pm}, A_{1p,d}^{K\pm}$) and 5 unknown parameters ($\Delta u, \Delta d, \Delta\bar{u}, \Delta\bar{d}, \Delta s$) a flavor separation is possible



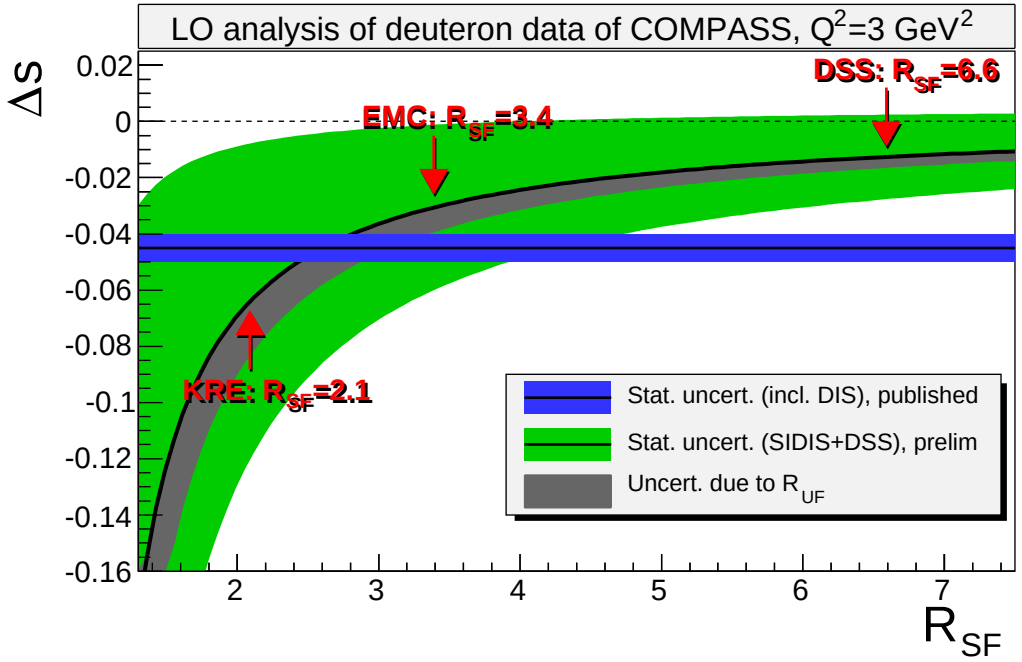
LO Flavour Separation

- results are published in PLB 693 (2010) 227
- curves are DSSV NLO parametrisation Phys. Rev. Lett. 101 (2008) 072001; Phys. Rev. D80 (2009) 034030.
- good agreement between COMPASS data and DSSV parametrisation



Strange Sea Polarisation

- $\int_0^1 \Delta s(x) + \Delta\bar{s}(x)dx = 2\Delta S$ is negative from inclusive asymmetries $2\Delta S = -0.09 \pm 0.01 \pm 0.02$
- ΔS obtained in semi-inclusive analysis strongly depends upon the choice of fragmentation functions used
- ratio $D_s^{K^-}/D_{\bar{u}}^{K^-} = D_{\bar{s}}^{K^+}/D_u^{K^+}$, known as R_{SF} is especially important
- try to extract R_{SF} from COMPASS data alone cf. Nour Makke talk on hadron multiplicities

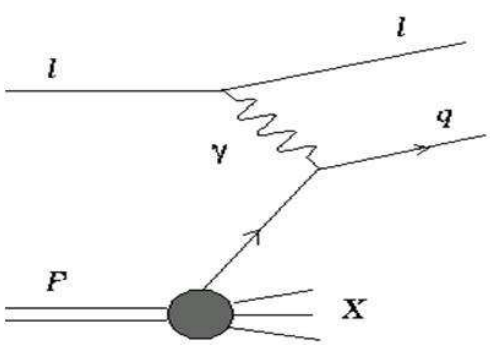


High-p_T Hadron Pairs Analysis
2002-2006 Data

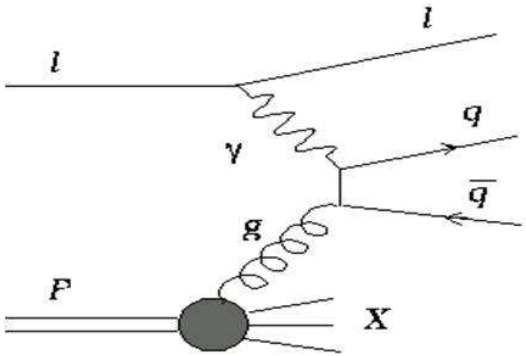
hep-ex/1202.4064, submitted to PLB

High-p_T Hadron Pairs Analysis
2002-2006 Data, $Q^2 > 1$ (GeV/c)^2

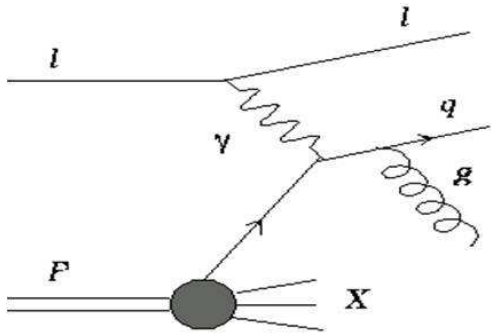
- much larger statistics than in the open charm analysis (*c.a.* 7.3M)
- in LO three processes are contributing: LP, PGF and QCDC
- the fraction of each process has to be estimated from MC
- in general, for higher p_T a larger fraction of PGF is expected
- perturbative scale is defined by $Q^2 > 1$ (GeV^2),
- as the scale is defined by Q^2, the cuts on p_T of hadrons can be kept low: $p_{T1} > 0.7$ (GeV/c) and $p_{T2} > 0.4$ (GeV/c)



LP



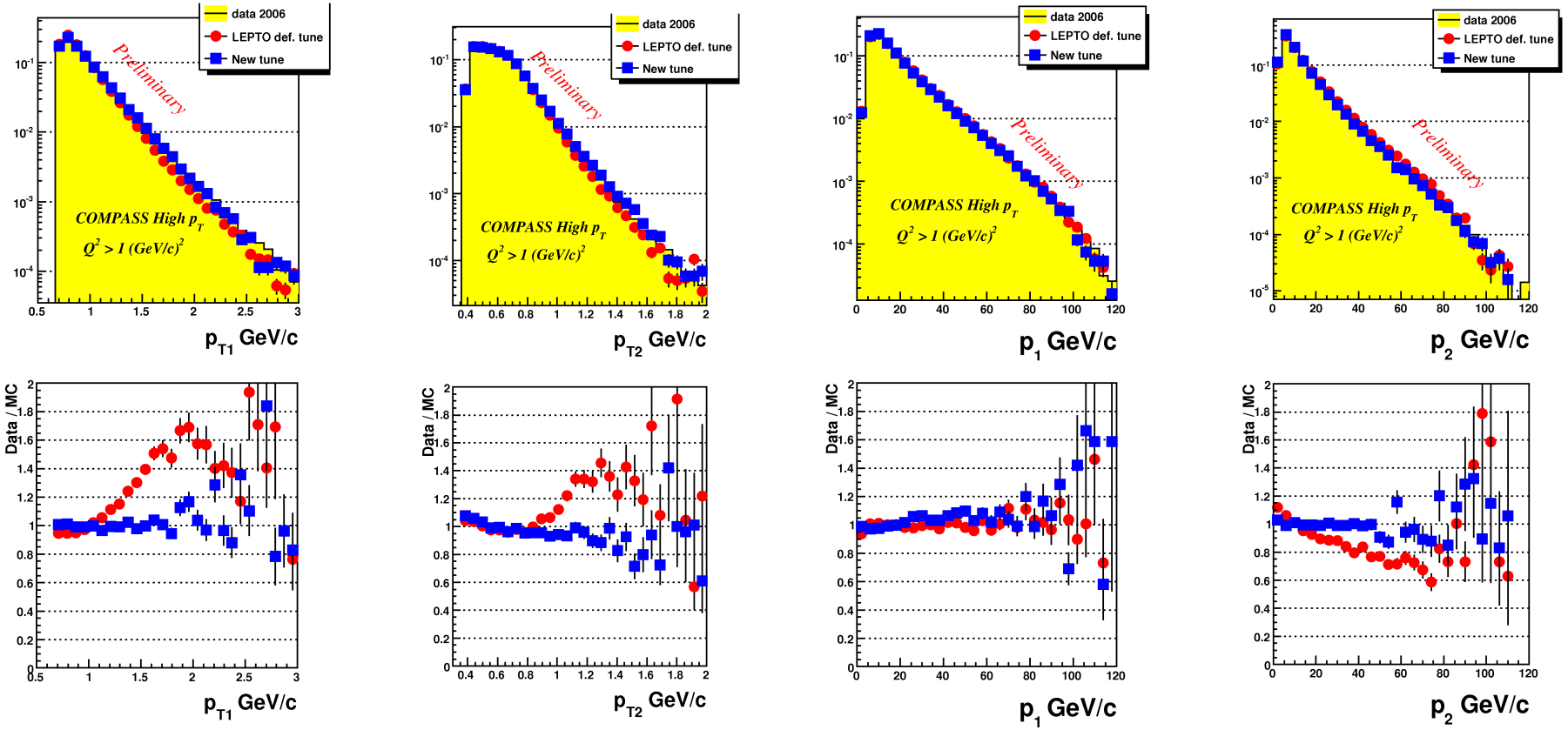
PGF



QCDC

MC and Data Comparison

- LEPTO generator is used in the analysis
- parton Shower is ON, PDF set it MSTW08LO
- to improve data/MC agreement k_T and fragmentation parameters were adjusted, hadron variables affected

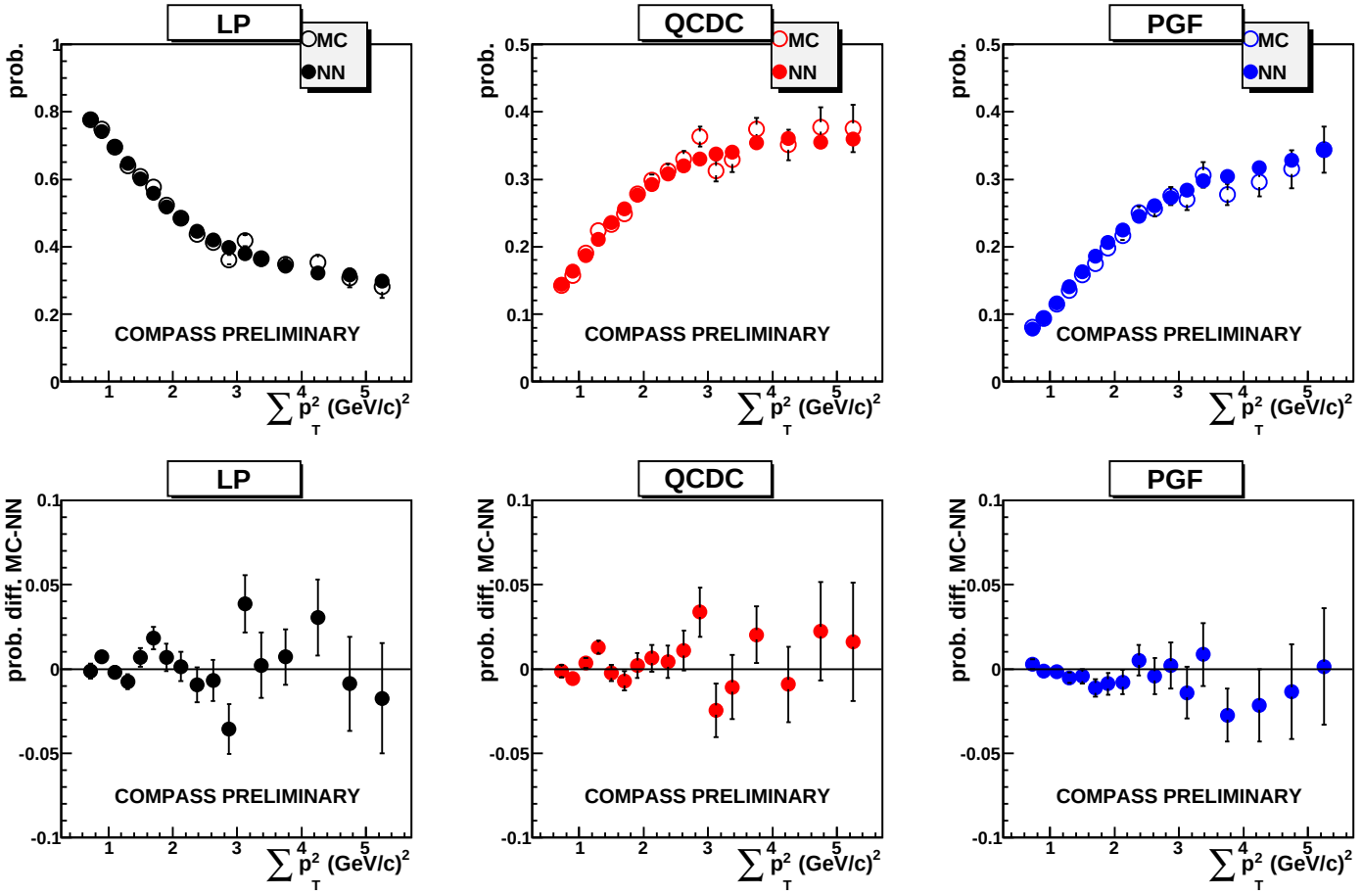


The Extraction of $\Delta G/G$

- observed asymmetry in the 2 hadrons sample is:
- $A_{LL}^{2h}(x_{Bj}) = R_{PGF}\, a_{LL}^{PGF}\, \frac{\Delta G}{G}(x_G) + R_{LP}\, D\, A_1^{LP}(x_{Bj}) + R_{QCDC}\, a_{LL}^{QCDC}\, A_1^{LP}(x_C)$
  - $A_1^{LP} \equiv \frac{\sum_i e_i^2 \Delta q_i}{\sum_i e_i^2 q_i}$
  - Rs - fractions of the sub-processes (LO, PGF, QCDC), taken from MC
  - a_{LL}s - analysing powers for LO,PGF and QCDC, taken from MC
- we have two unknowns A_1^{LP} and $\Delta G/G$, and so far only one equation...
- additional information is provided by the inclusive sample:
  $A_1^d(x_{Bj}) = R_{PGF}^{incl} a_{LL}^{incl,PGF} \frac{\Delta G}{G}(x_G) + R_{LP}^{incl} D A_1^{LP}(x_{Bj}) + R_{QCDC}^{incl} a_{LL}^{incl,QCDC} A_1^{LP}(x_C)$
- $\Delta G/G = \Delta G/G(x_G^{av}) = \frac{A_{LL}^{2h}(x_{Bj}) + A^{corr}}{\beta}$
- $\beta = a_{LL}^{PGF} R_{PGF} - a_{LL}^{PGF,incl} R_{PGF}^{incl} \left(\frac{R_L}{R_L^{incl}} + \frac{R_C}{R_L^{incl}} \frac{a_{LL}^C}{D}\right)$
- A^{corr} is a linear function of $A_1^d(x_{Bj} \sim 0.03)$ and $A_1^d(x_C \sim 0.11)$

The Extraction of $\Delta G/G$ cont.

- to reduce statistical error we use a weighted method for the asymmetry extraction. We must know all Rs and a_{LL}s on the event by event basis
- we use a Neural Network trained on MC to obtain parametrizations which are used on data, *cf.* example below



Results

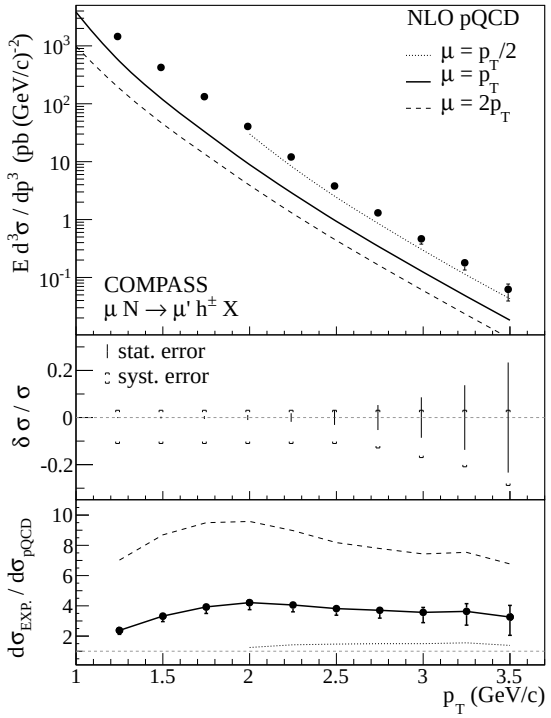
- $\Delta G/G = 0.125 \pm 0.060 \pm 0.063$
- $< x_G >= 0.09, \qquad \mu^2 = 3\ (\mathrm{GeV/c})^2$
- the dominating systematic contribution comes from the MC (0.045)
- COMPASS obtained results in 3 bins of x_G
  - we use a Neural Network to parametrise $x_{G,true}$
  - the correlation between $x_{G,param}$ and $x_{G,true}$ is about 60%

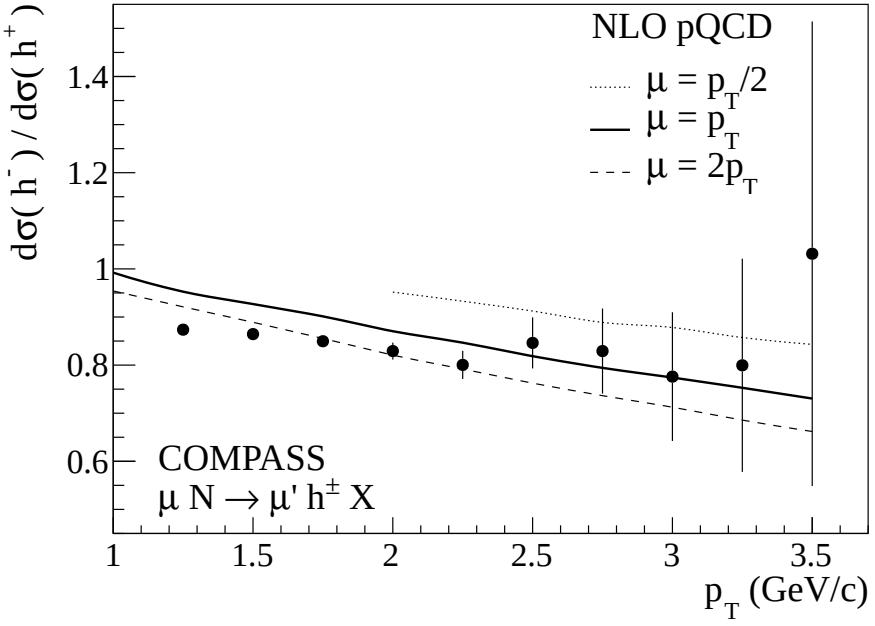
$< x_G >$	$\Delta G/G$
$0.07^{+0.05}_{-0.03}$	$0.147 \pm 0.091 \pm 0.088$
$0.10^{+0.07}_{-0.04}$	$0.079 \pm 0.096 \pm 0.081$
$0.17^{+0.10}_{-0.06}$	$0.185 \pm 0.165 \pm 0.143$

- The paper submitted to PLB will be soon updated with A_{LL}^{2h}/D asymmetries extracted in bins of x_{Bj} and $\sum p_T^2$

NLO $\Delta G/G$ from High$-p_T$ Hadrons for $Q^2 < 0.1$ (GeV/c)^2

- it uses as theoretical input the calculations of B.Jeager, M.Stratmann & W.Vogelsang, Phys. J. C44 (2005) 533-543
- so far hadron cross section is compared with theoretical expectations
- results were send for publication
- spin dependent asymmetries are being evaluated

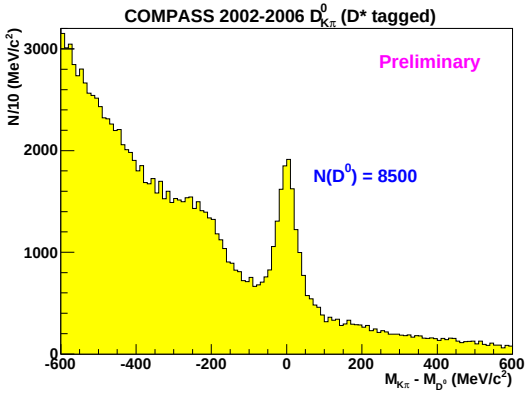


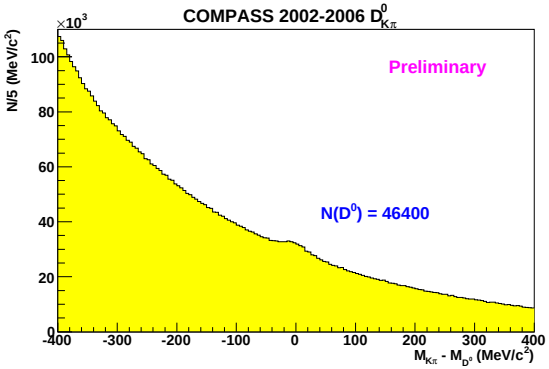


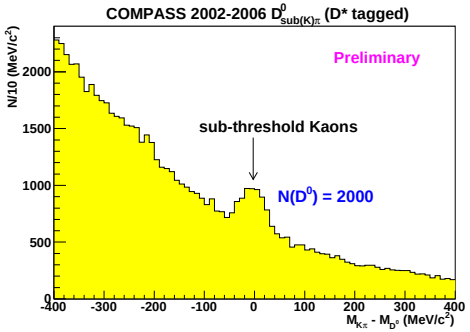
$\Delta G/G$ from Open Charm Analysis 2002-2007 Data

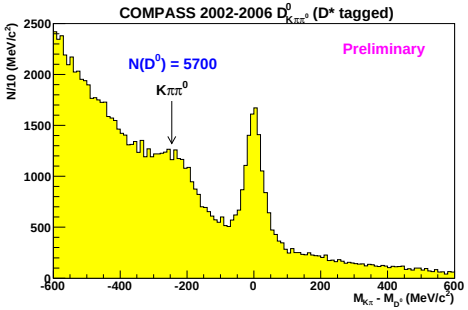
$\Delta G/G$ from Open Charm Analysis

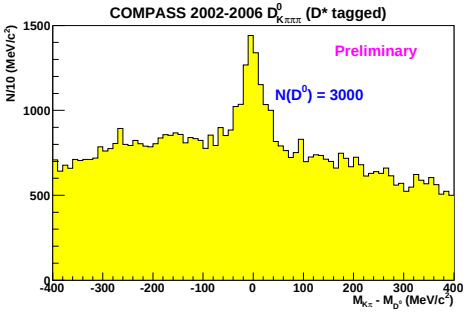
- open-charm - clean source of PGF
- hard scale $\approx 4m_c^2$, even though $Q^2 < 1$ (GeV/c)^2
- low statistics - various decay modes of D mesons analysed











- Number of D^0 events : 65500
- Number of D^* 29000 (13100 in the golden channel, $D^* \to K\pi\pi_{soft}$)

Gluon Polarisation

$$\frac{\Delta G}{G} = \frac{1}{P_t P_b f a_{LL} \frac{S}{S+B}} A_{raw}^{\mu N}$$

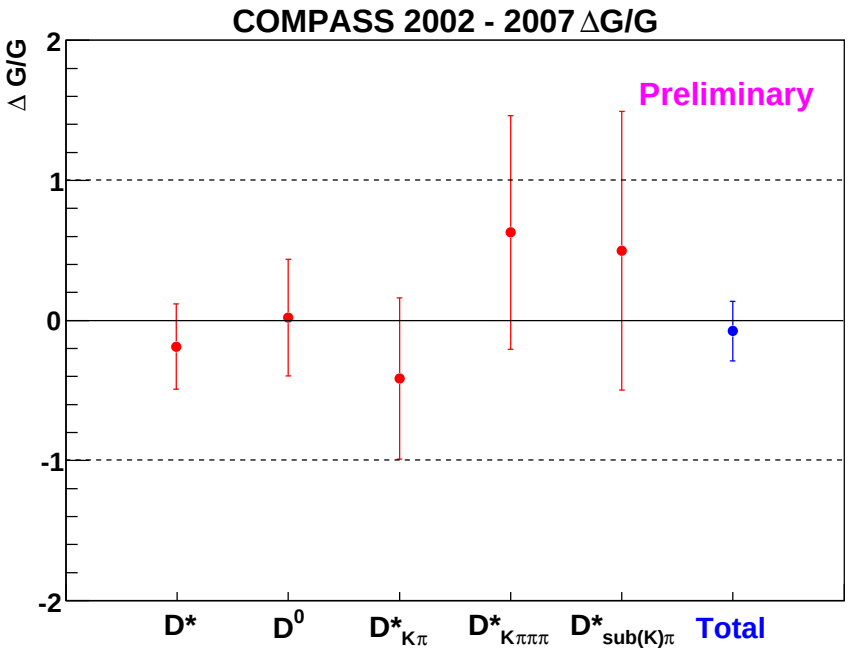
- P_t, P_b, f - target, beam polarisations and dilution factor
- analysing power, a_{LL}, is taken from MC
- $\frac{S}{S+B}$ is parametrised on data using a Neural Network approach
- NOTE: In reality a more complex $\Delta G/G$ extraction method is used:
  - in the analysis we use weight $P_b f a_{LL} \frac{S}{S+B}$ on the event by event basis to improve the statistical accuracy of the measurement.
  - $A_{bgr} = \frac{1}{P_t P_b f D \frac{B}{S+B}} A_{raw}^{\mu N}$ is extracted simultaneously with $\Delta G/G$, *cf.* J. Pretz and J.M. Le Goff Nucl. Instr. Meth. A 602 (2009) 594

The $\Delta G/G$ Results

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

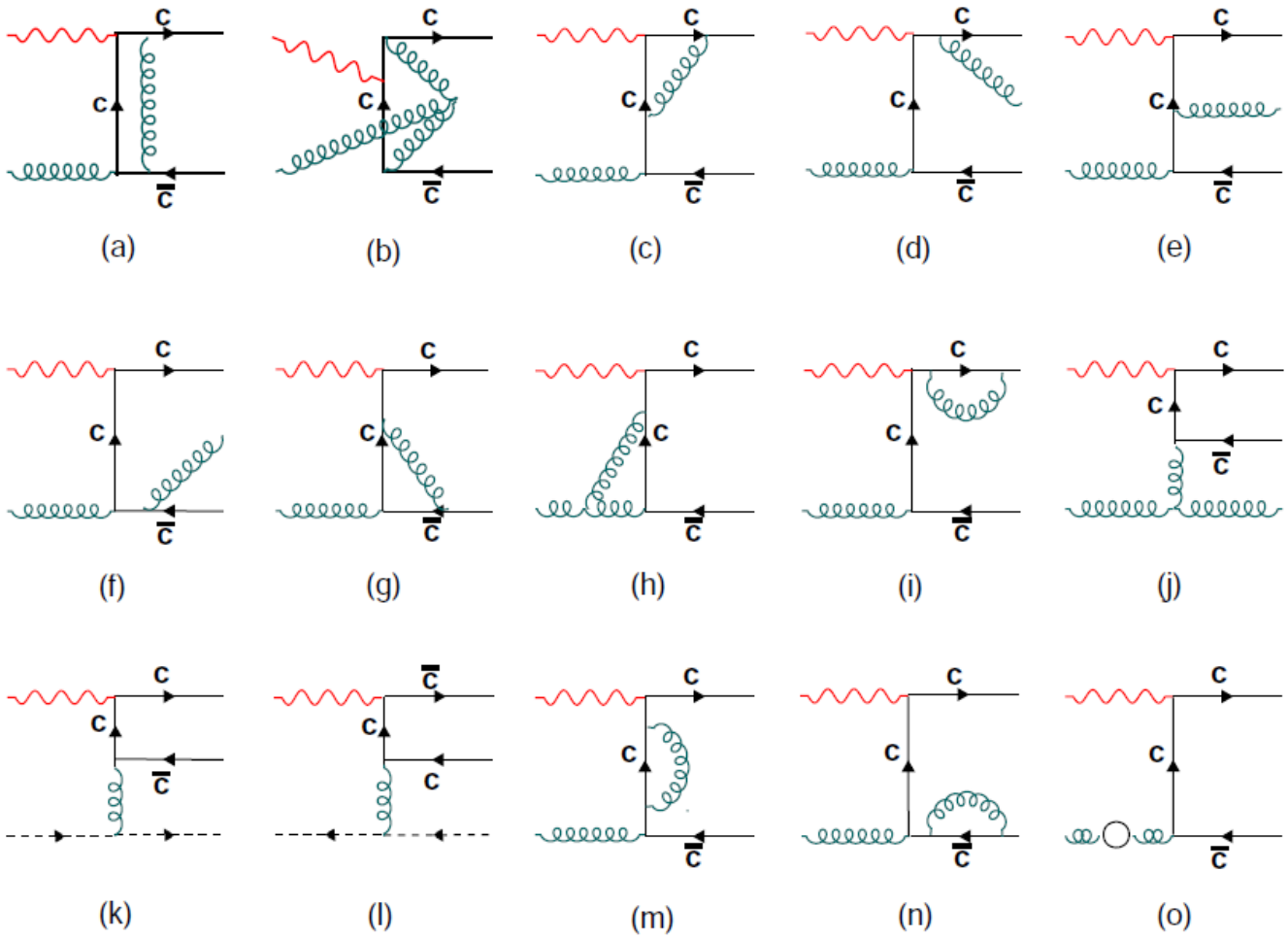
$$< x_G >= 0.11^{+0.11}_{-0.05} \quad < \mu^2 > = 13 \text{ (GeV/c)}^2$$

channel	$\Delta G/G$
$D^* \to K\pi\pi_{slow}$	-0.19 ± 0.30
$D^0 \to K\pi$	0.02 ± 0.42
$D^* \to K\pi\pi^0\pi_{slow}$	-0.41 ± 0.58
$D^* \to K3\pi\pi_{slow}$	0.63 ± 0.83
$D^* \to K_{subth}\pi\pi_{slow}$	0.5 ± 1.0



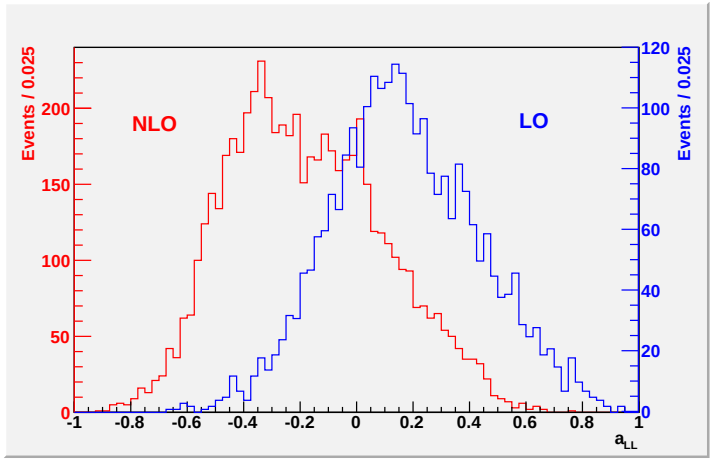
- large part of the systematic error is proportional $\delta\Delta G/G_{stat}$
- key point: $\sigma_{stat} >> \sigma_{sys}$

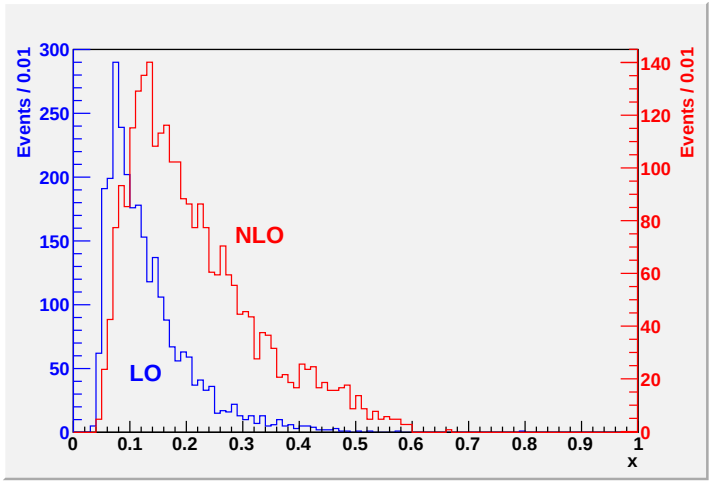
NLO Analysis of Open Charm Events



NLO Analysis of Open Charm Events cont.

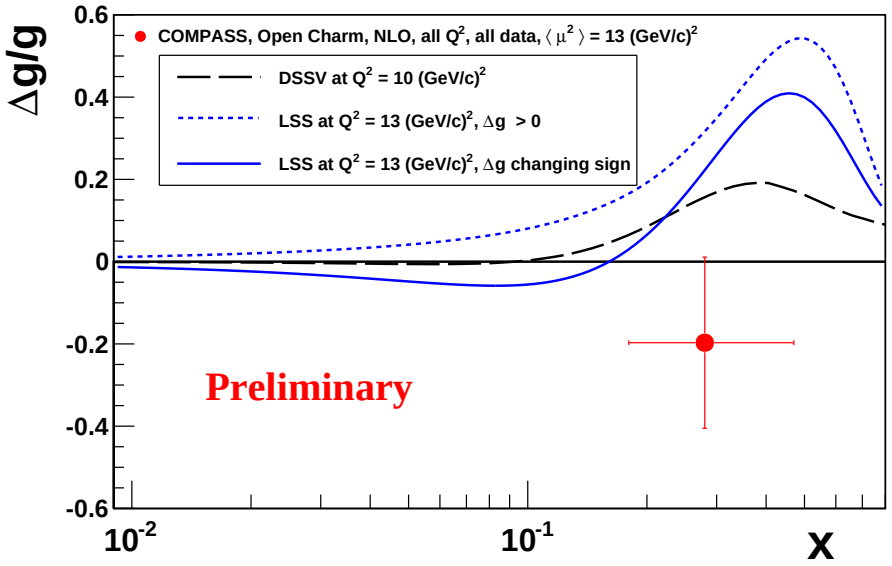
- based on I.Bojak, M.Stratmann, Nucl.Phys.B 540 (1999) 345
- AROMA generator is used with parton showers ON
- on the event by event basis parton shower simulates the phase-space for NLO calculation
- in NLO part of the D^0's are not produced from PGF processes $\rightarrow A_{corr} \sim A_1^{d,p}$ term appears.
- significant differences are observed between a_{LL}^{LO} and a_{LL}^{NLO} as well as between x_G^{LO} and x_G^{NLO}





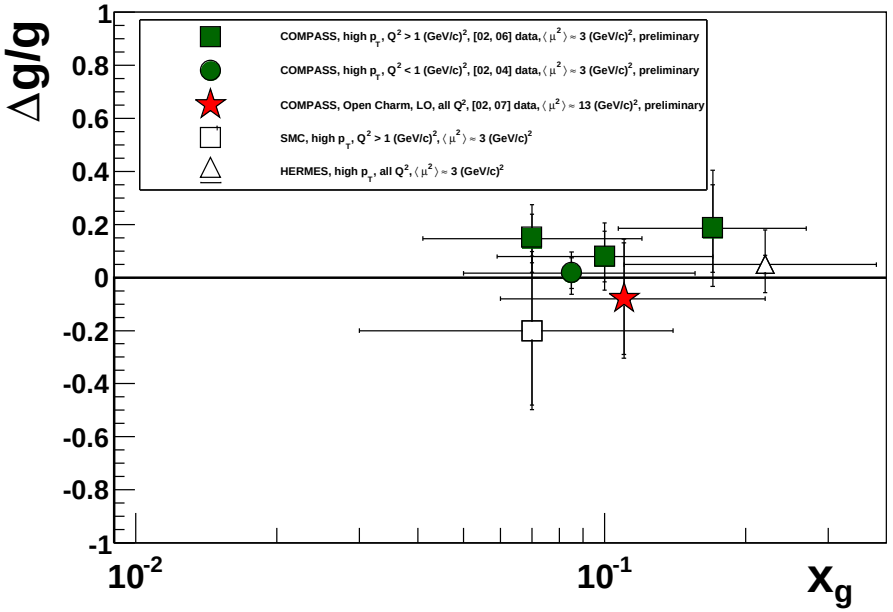
Results of NLO $\Delta G/G$ Extraction

- $\Delta G/G = \frac{A^{\gamma N} - A_{corr}}{<a_{LL}^{NLO}/D>}$
- the preliminary result is $\Delta G/G_{NLO} = -0.20 \pm 0.21 \pm 0.08$
- $\mu^2 = 13$ (GeV/c)^2, $< x_{G,NLO} >= 0.28$
- publication of the $\Delta G/G$ results obtained in LO and NLO is being prepared

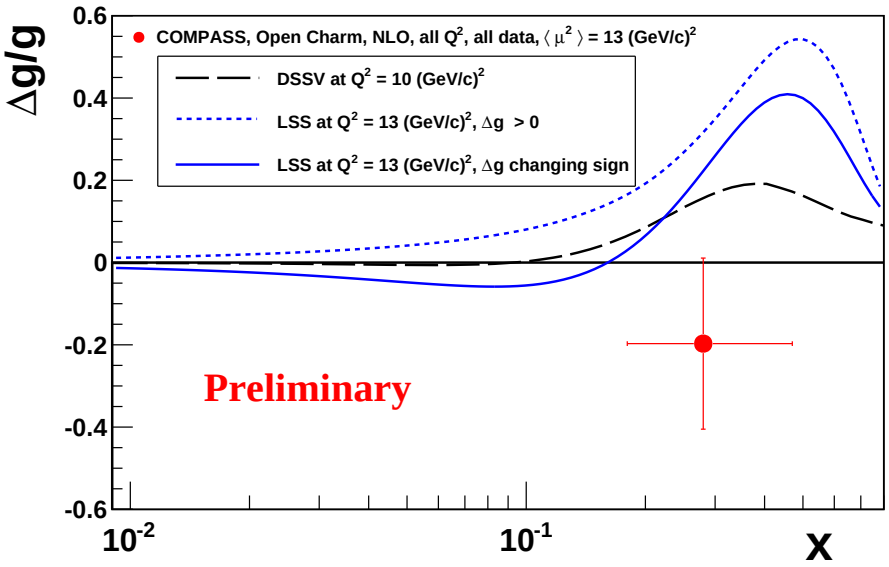


Summary of $\Delta G/G$ from COMPASS

LO



NLO



- all results agree with each other
- the ΔG is small, but the data are not precise enough to determine its sign

Summary

- A_1^p and g_1^d from 2011 data were presented
- LO flavour separation results were shown
  - the results agree with DSSV NLO parametrisation
  - COMPASS is on the way to extract FF ratios, which are needed to understand better ΔS puzzle
  - if R_{SF} is small then inclusive and semi-inclusive results for ΔS agree with each other
- updated results for $\Delta G/G$ obtained in various analyses were presented
  - updated high-p_T hadron pairs, $Q^2 > 1$ (GeV/c)^2 analysis: $\Delta G/G = 0.125 \pm 0.060 \pm 0.063$, subm. to PLB
  - updated LO open charm analysis: $\Delta G/G = -0.08 \pm 0.21 \pm 0.11$
  - new NLO open charm analysis: $\Delta G/G = -0.20 \pm 0.21 \pm 0.08$
  - all world results agree with each other
  - ΔG is small, but the sign of it is still not determined