Overview of Spin Physics and Gluon Polarisation Results in COMPASS

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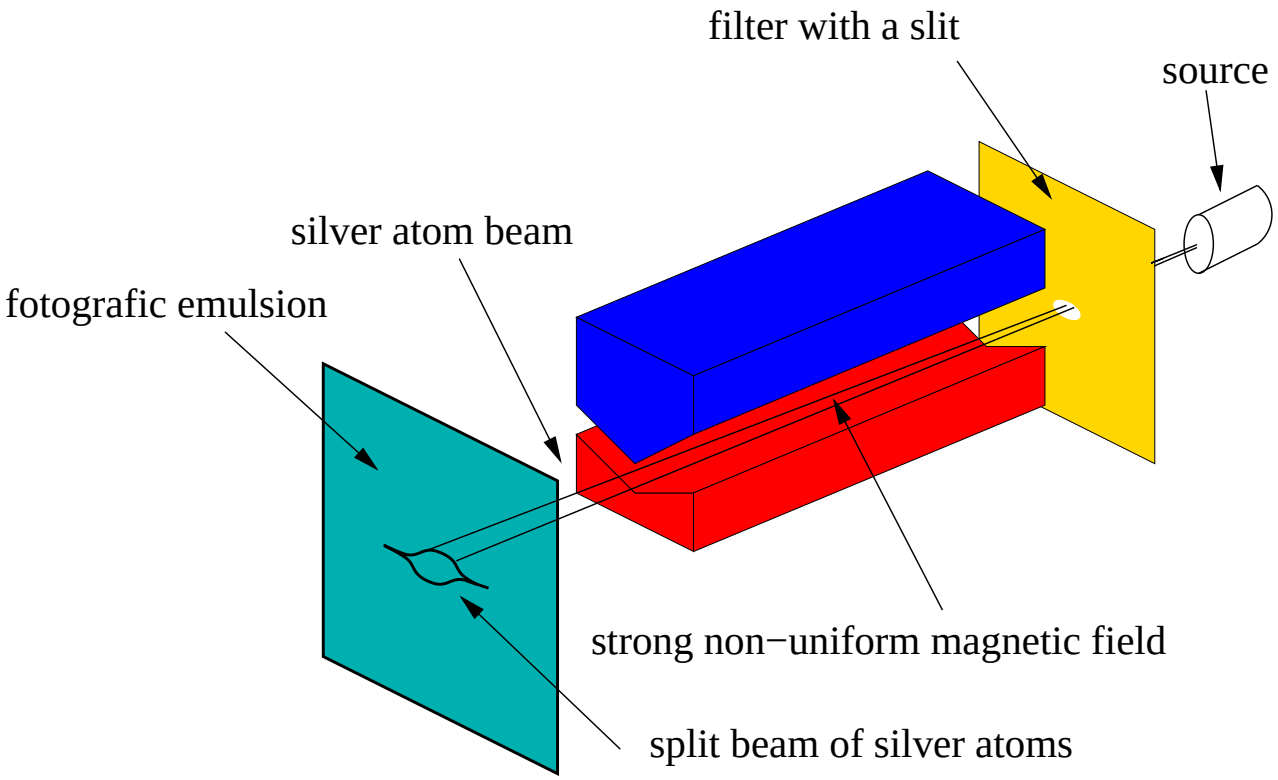
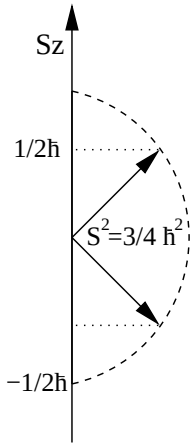
LIP

Stern-Gerlarch Experiment (1922)



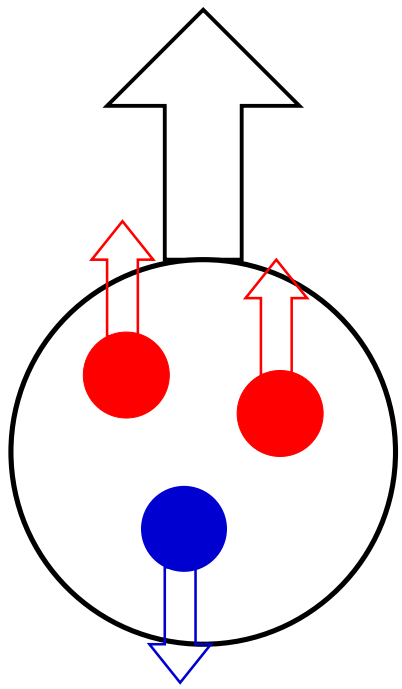


- classical: continuous spread of the beam
- quantum: split on 2L+1 levels; L=**0**, 1, 2...
- Uhlenbeck, Goudsmit (1925) introduced spin concept, as a quantum degree of freedom of particles

Quark Parton Model

- quark parton model describes:
  - masses
  - charges
  - anomalous magnetic moments ($\vec{\mu} = \frac{e_i}{2m_i}\vec{spin}$)

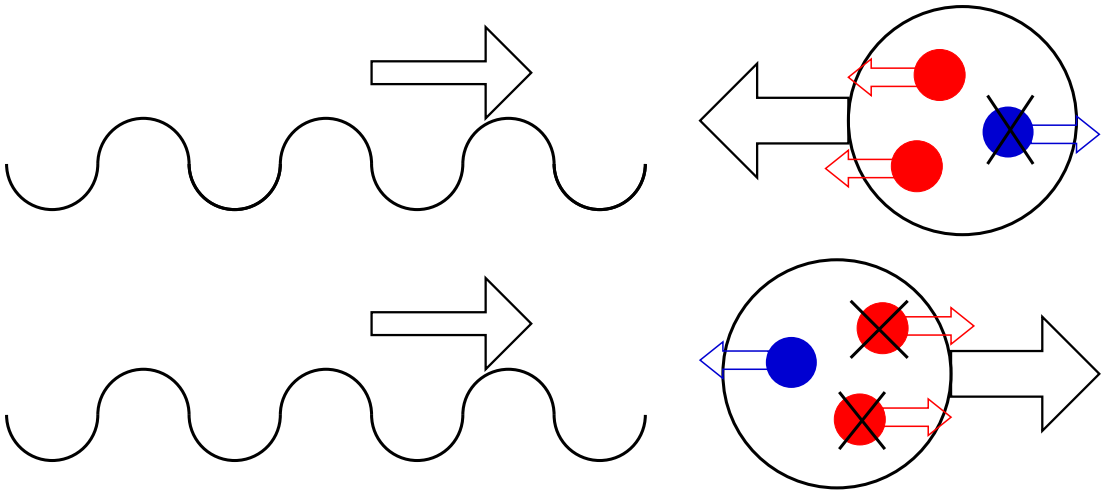
	mag.mom. QPM	mag.mom. mes.
p	+2.79	+2.793
n	-1.86	-1.913
Λ	-0.61	-0.614



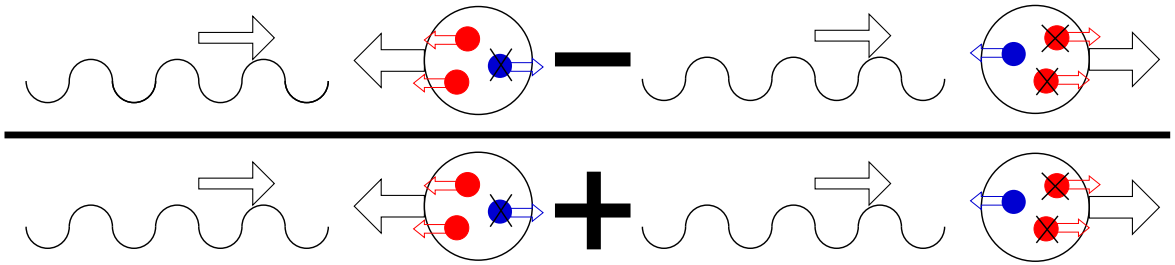
- spin ???
- in QPM: $S_p = 1/2\Delta\Sigma$ $\rightarrow$ quarks build proton spin!

Idea of experiment

- interaction of polarized muons (electrons) with nucleon



- because of angular momentum conservation only quarks with a spin opposite to the spin of the photon can interact with it
- spin effects are small, precise method of extraction is needed like, asymmetry measurements

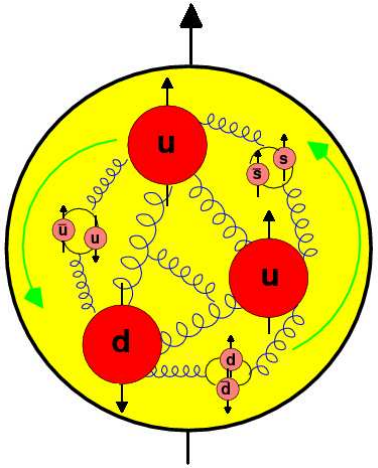


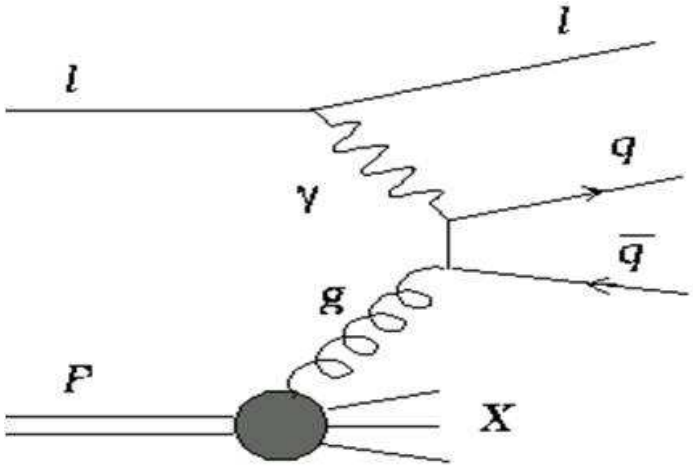
Short Story of Spin Measurements

- first asymmetry measurement in SLAC, USA since 1975, made by Vernon Hughes.
- results with large uncertainties were agreeing with expectations
- unexpected results of EMC (1987) starts the so-called "spin crisis": quarks carry only $10\% \pm 15\%$ of the proton spin
  - **Phys.Lett.B206**(1988),364; cited 1541 times
  - **Nucl.Phys.B328**(1989),1; cited 1315 times
- second generation of experiments to confirm EMC results, at CERN and US (early-mid of 90')
- third generation of experiments trying to solve spin puzzle COMPASS @ CERN, HERMES @ DESY, experiments at US in RHIC and JLab laboratories

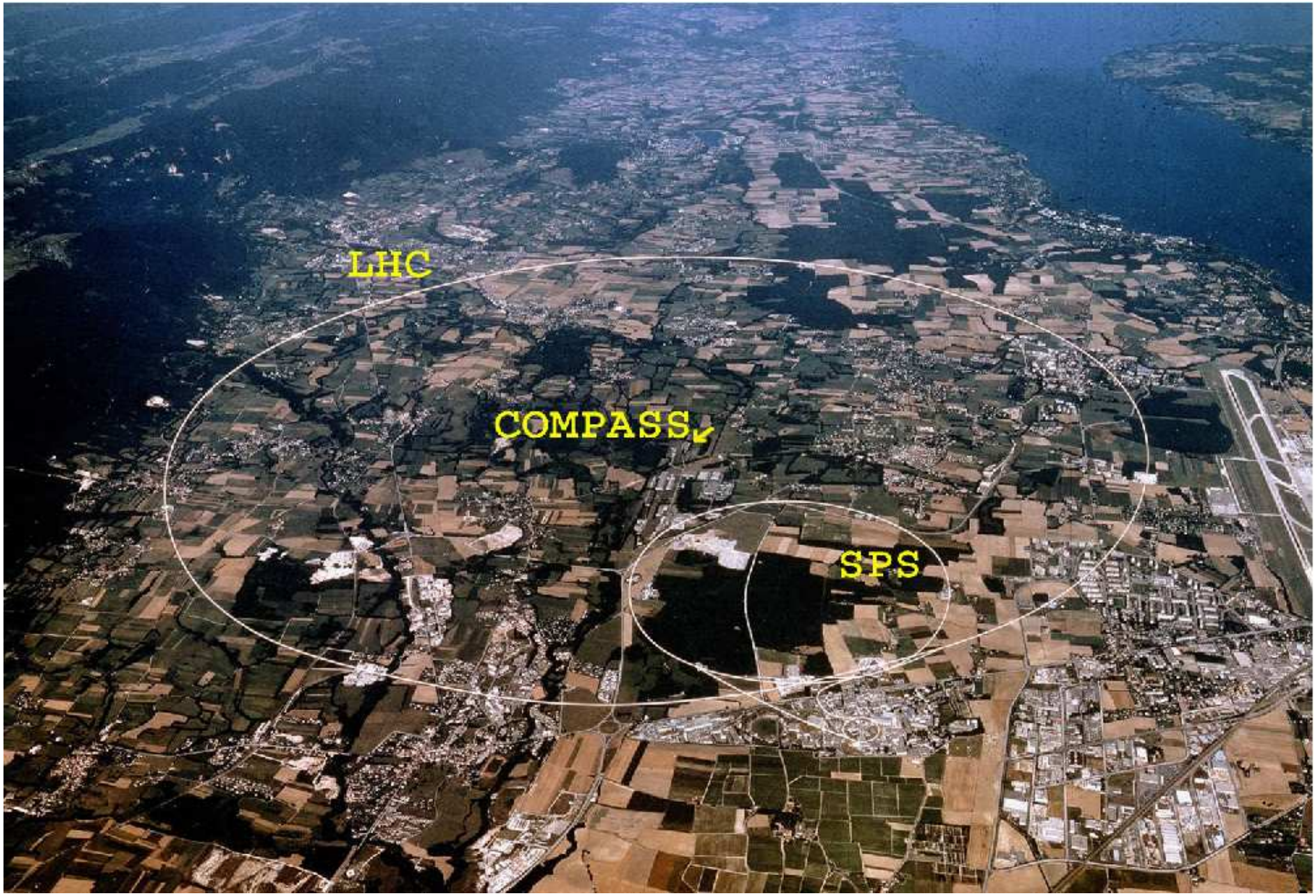
$\Delta G/G$ Measurement

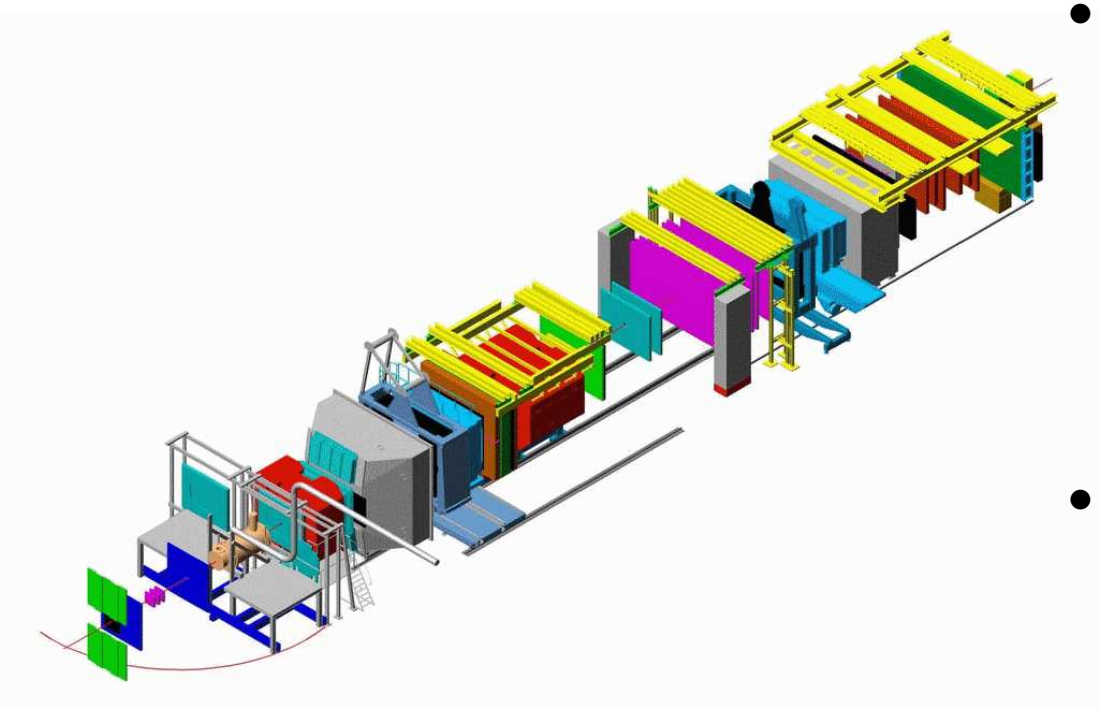
- $S_p = 1/2 = 1/2\Delta\Sigma + \Delta G + L_{q,G}$
- Gluons may carry missing spin of the proton
- problem: photon doesn't directly interact with gluons (q=0)
- to measure $\Delta G/G$ higher order processes in α_s must be studied, namely photon–gluon fusion (PGF) from *e.g.*
  - open-charm events (Celso)
  - high-p_T hadron pairs (Luis and myself)





COMPASS @ CERN



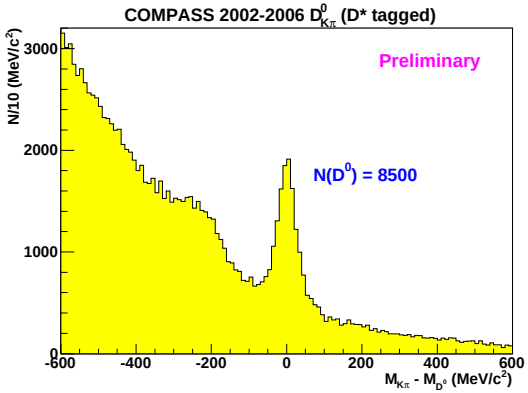


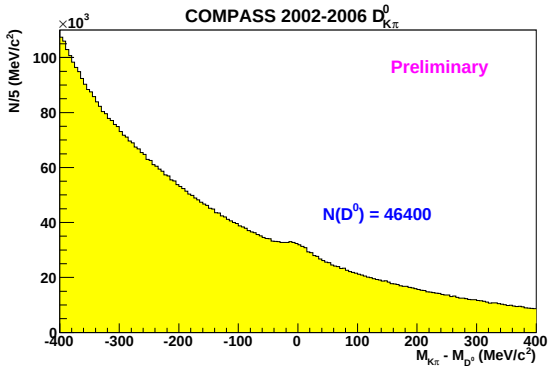
- COLLABORATION
  - about 210 physicists
  - 27 institutes
- DETECTOR
  - 60 m length
  - 2 (3) magnets
  - about 350 detector planes

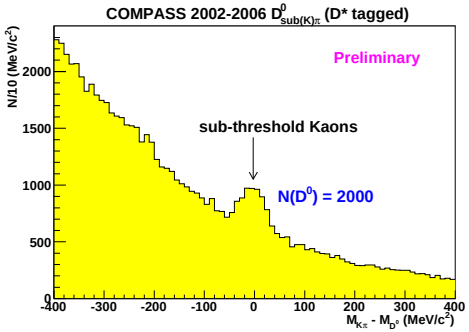
- POLARIZED TARGET
  - ^{6}LiD (NH_3) target
  - 2-3 cells (120 cm total length)
  - $\pm$ 50% (90%) polarization
  - polarization reversal every 8h-24h
- POLARIZED BEAM
  - positive muons at 160 GeV/c
  - polarization –80 %
- FEATURES
  - acceptance: 70 $\rightarrow$ 180 mrad (2006)
  - track reconstruction: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

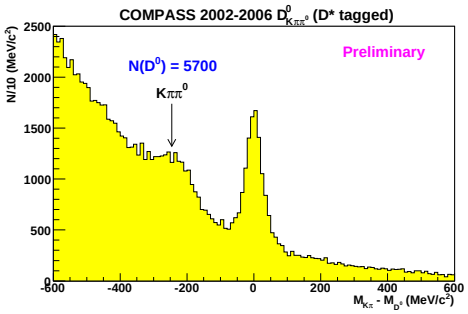
$\Delta G/G$ from Open Charm Analysis

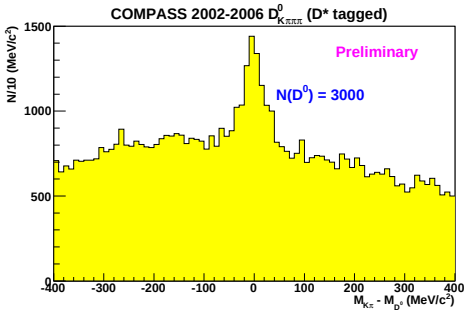
- open-charm - clean source of PGF
- hard scale $\approx 4m_c^2$, even though $Q^2 < 1$ (GeV/c)^2
- low statistics - various decay modes of D mesons analyzed











- Number of D^0 events : 65500
- Number of D^* events : 29000

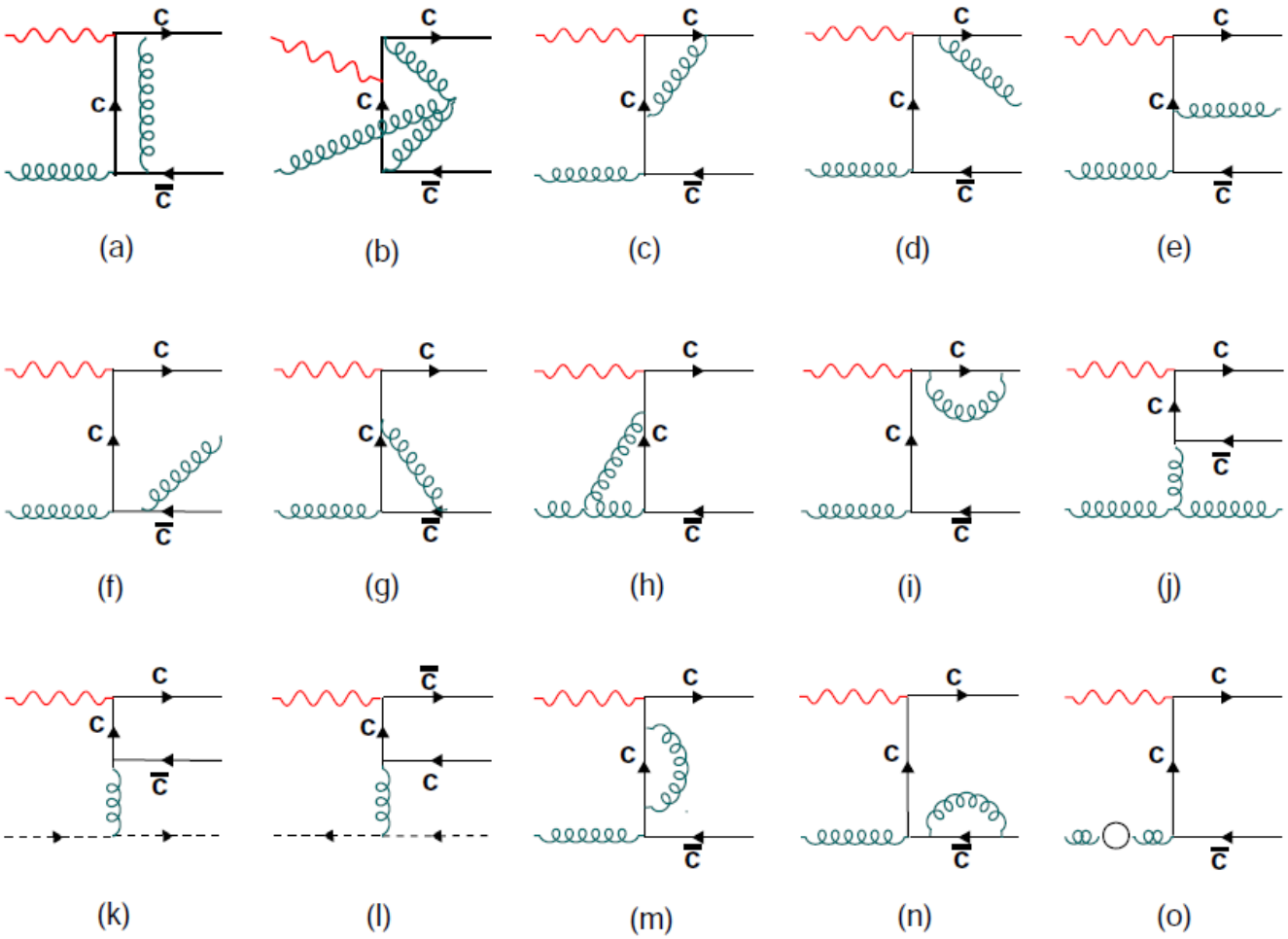
Gluon Polarization LO

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

- P_t, P_b, f - target, beam polarizations and dilution factor
- analyzing power, a_{LL}, is taken from MC
- $\frac{S}{S+B}$ is parametrized on data using a Neural Network approach
- In reality a more complex $\Delta G/G$ extraction method is used: signal and background asymmetries are extracted simultaneously, event weighting is used to improve the statistical accuracy of the measurement.

- RESULT: $\Delta G/G = -0.08 \pm 0.21 \pm 0.11$
  $< x_G >= 0.11^{+0.11}_{-0.05}$ $< \mu^2 > = 13$ (GeV/c)^2

NLO Analysis of Open Charm Events

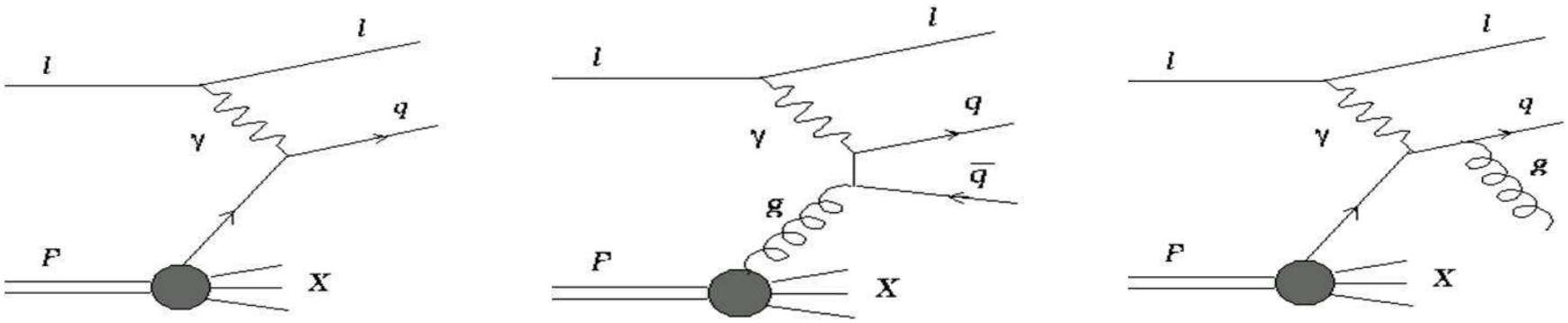


NLO Analysis of Open Charm Events cont.

- 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.
- $\Delta G/G = \frac{A^{\gamma N} - A_{corr}}{<a_{LL}^{NLO}/D>}$
- the preliminary result is $\Delta G/G_{NLO} = -0.20 \pm 0.21 \pm 0.08$
- μ^2= 13 (GeV/c)^2, $< x_{G,NLO} >= 0.28$

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

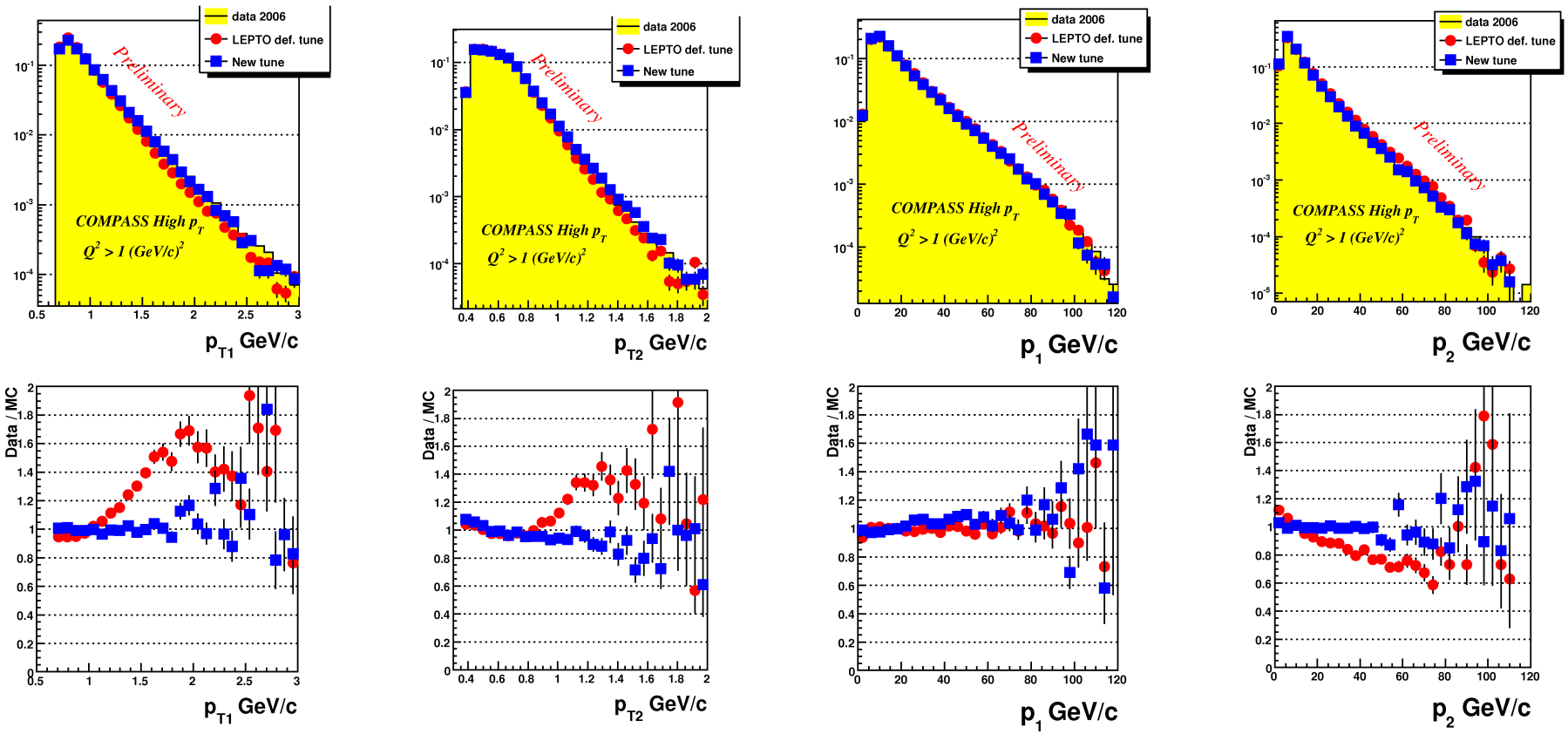
- much larger statistics than in the open charm analysis (*c.a.* 7.3M)
- in LO three processes are contributing: LP, PGF and QCDC
- the fraction of each process has to be estimated from MC
- in general, for higher p_T a larger fraction of PGF is expected
- perturbative scale is defined by $Q^2 > 1$ (GeV^2)
- 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 ON, PDF set: MSTW08LO
- to improve data/MC agreement k_T and fragmentation parameters were adjusted, hadron variables affected

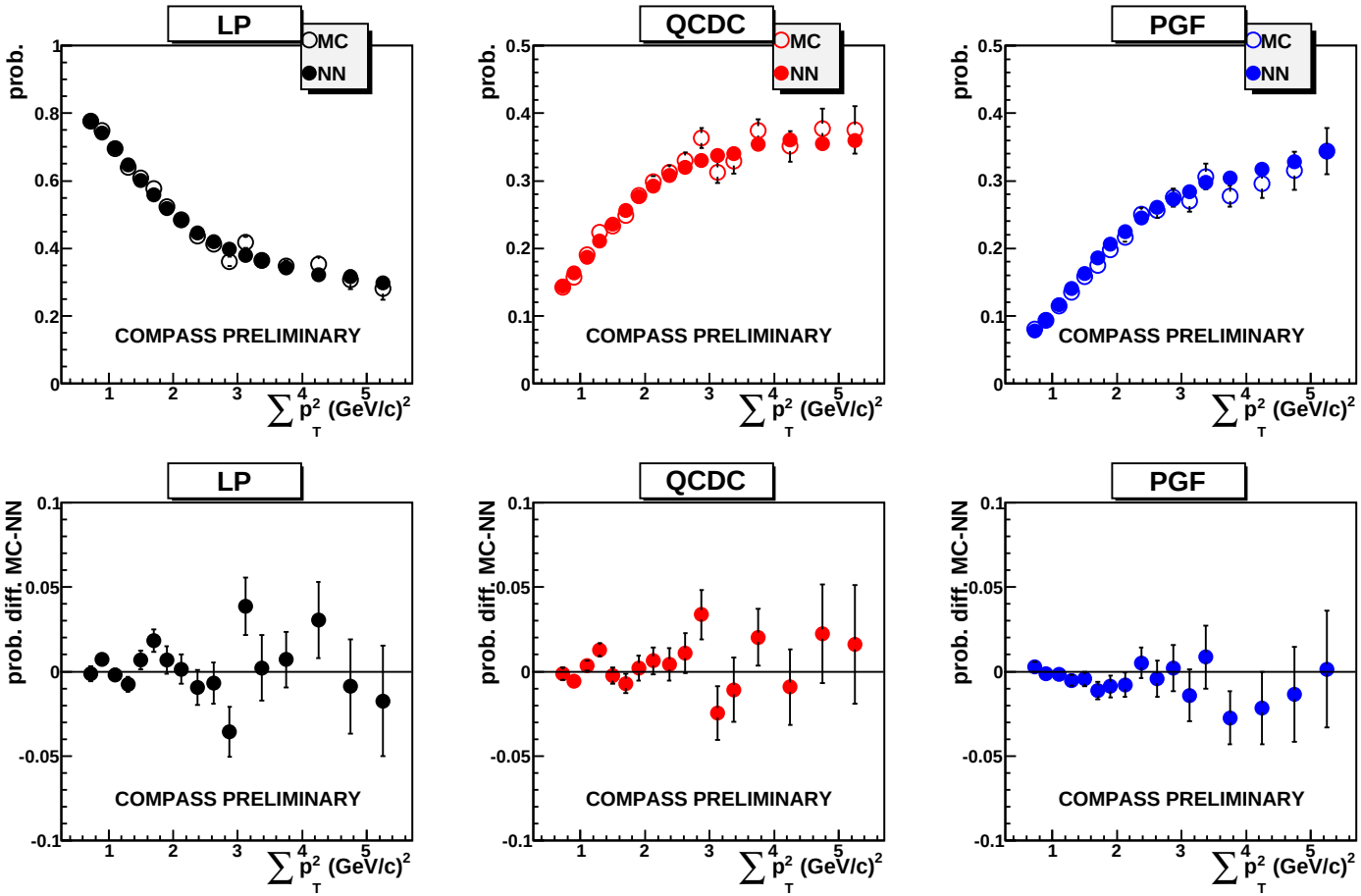


The Extraction of $\Delta G/G$

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



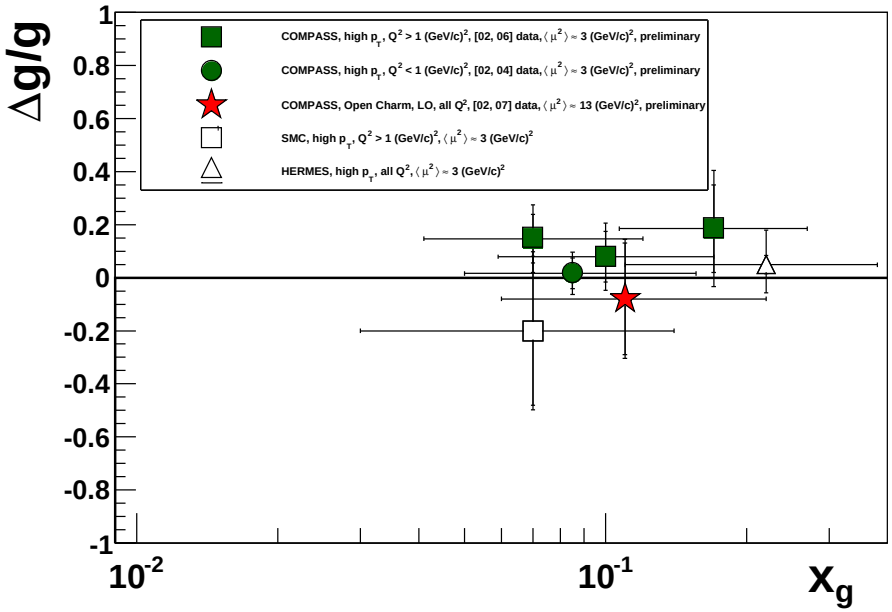
Results

- $\Delta G/G = 0.125 \pm 0.060 \pm 0.063$ (LO)
- $< x_G >= 0.09$, $\mu^2 = 3$ (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 parametrize $x_{G,true}$
  - the correlation between $x_{G,param}$ and $x_{G,true}$ is about 60%

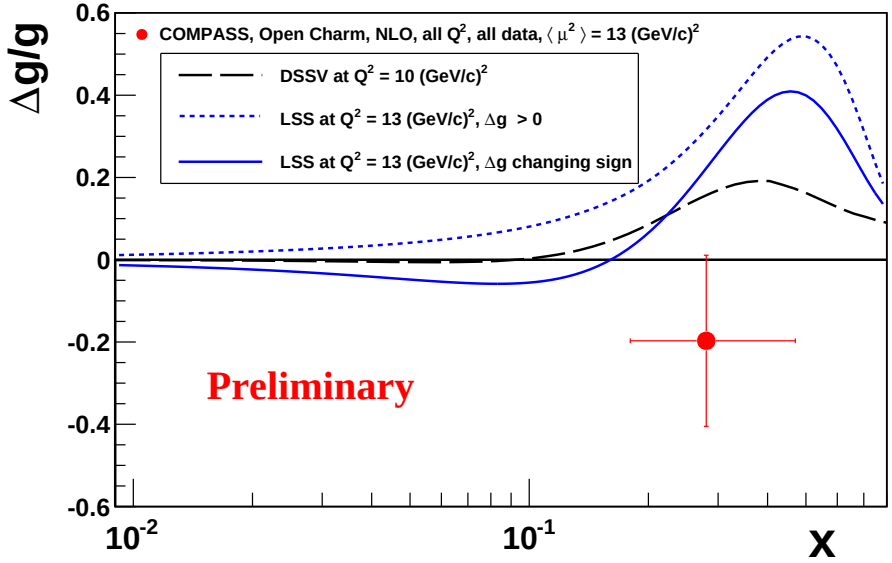
$< x_G >$	$\Delta G/G$
$0.07^{+0.05}_{-0.03}$	$0.147 \pm 0.091 \pm 0.088$
$0.10^{+0.07}_{-0.04}$	$0.079 \pm 0.096 \pm 0.081$
$0.17^{+0.10}_{-0.06}$	$0.185 \pm 0.165 \pm 0.143$

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
- we are working on the method which allows reduction of statistical error by about 40%