Measurement of the Gluon Polarisation in the Nucleon at COMPASS

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Outline:
- COMPASS experiment
- Three methods of ΔG/G measurement:
  - Open charm
  - High p_T pairs (Q^2>1 GeV^2)
  - High p_T pairs (Q^2<1 GeV^2)
- Outlook and conclusions

COmmon Muon and Proton Apparatus for Structure and Spectroscopy

The experiment:
- ~250 physicists
- 28 institutes
- programms with muon and hadron beams
- data taking started in 2002
- continued in 2003/4
- break in 2005
- resumed in 2006

Beam parameters:
- momentum: 160 GeV
- luminosity: $\sim 5 \cdot 10^{32}$ $cm^{-2}s^{-1}$
- intensity: $2 \cdot 10^{8}$ μ^{+}/spill
- spills: 4.8/16.8 s
- longitudinally polarised
- polarisation: ~76% (~81%)

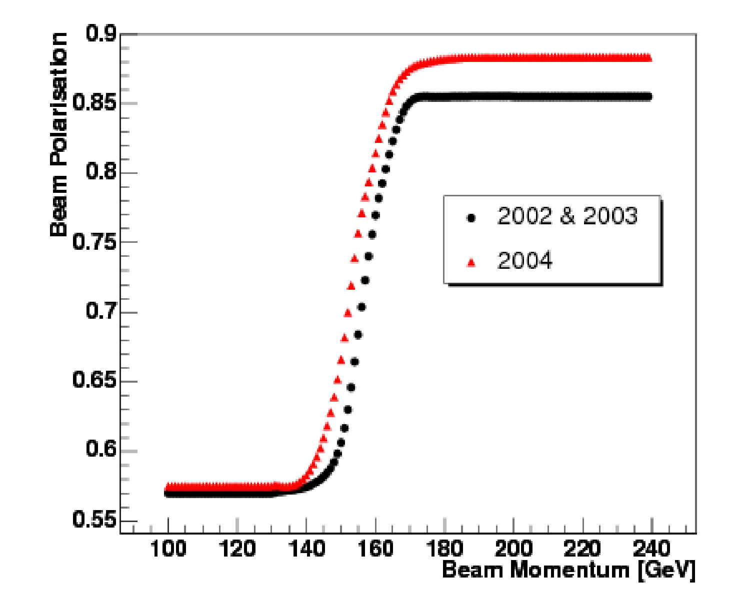
The production of the beam

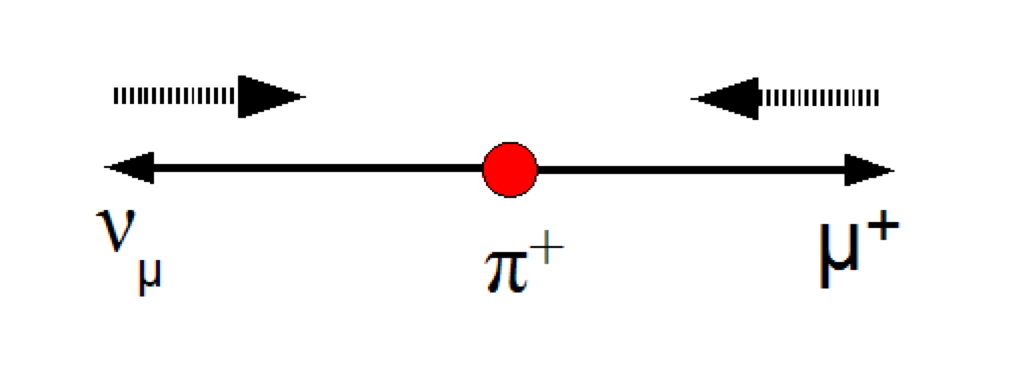
- $\pi \rightarrow \mu\nu$ is a parity violating decay
- μ are 100% polarised in a decaying pion rest frame

In the LAB frame:

$$P_\mu = \frac{m_\pi^2 + (1 - 2\frac{E_\pi}{E_\mu}) m_\mu^2}{m_\pi^2 - m_\mu^2}$$

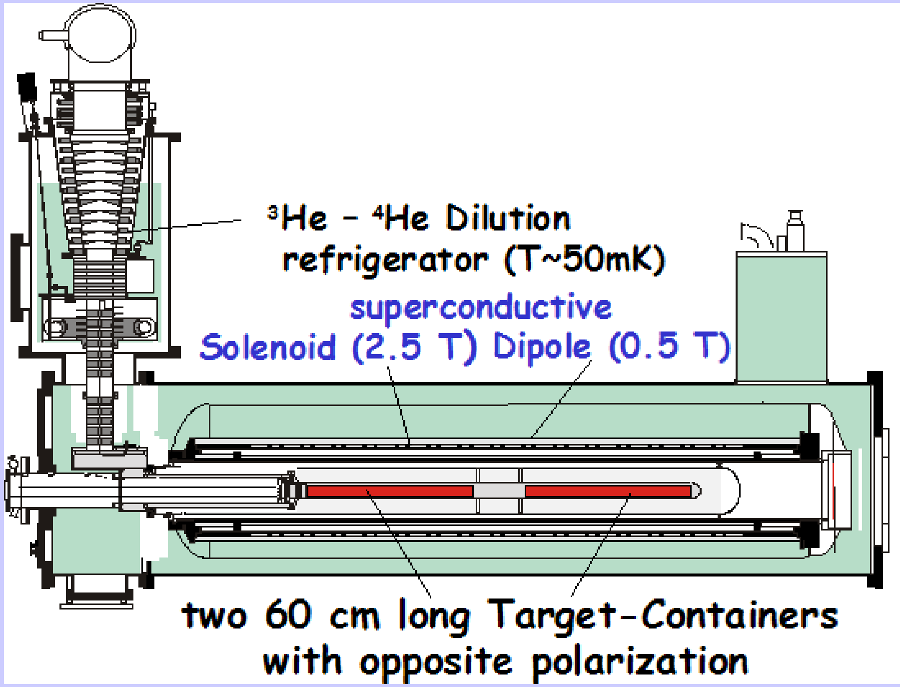
The average polarisation is: -0.76 in 2002-3
-0.81 in 2004





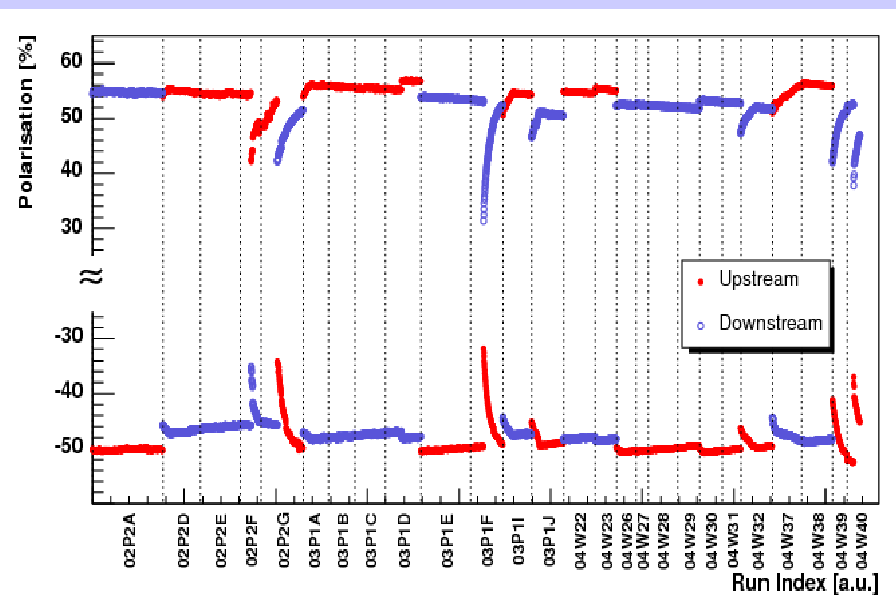
The polarisation: MC and SMC measurments

The target

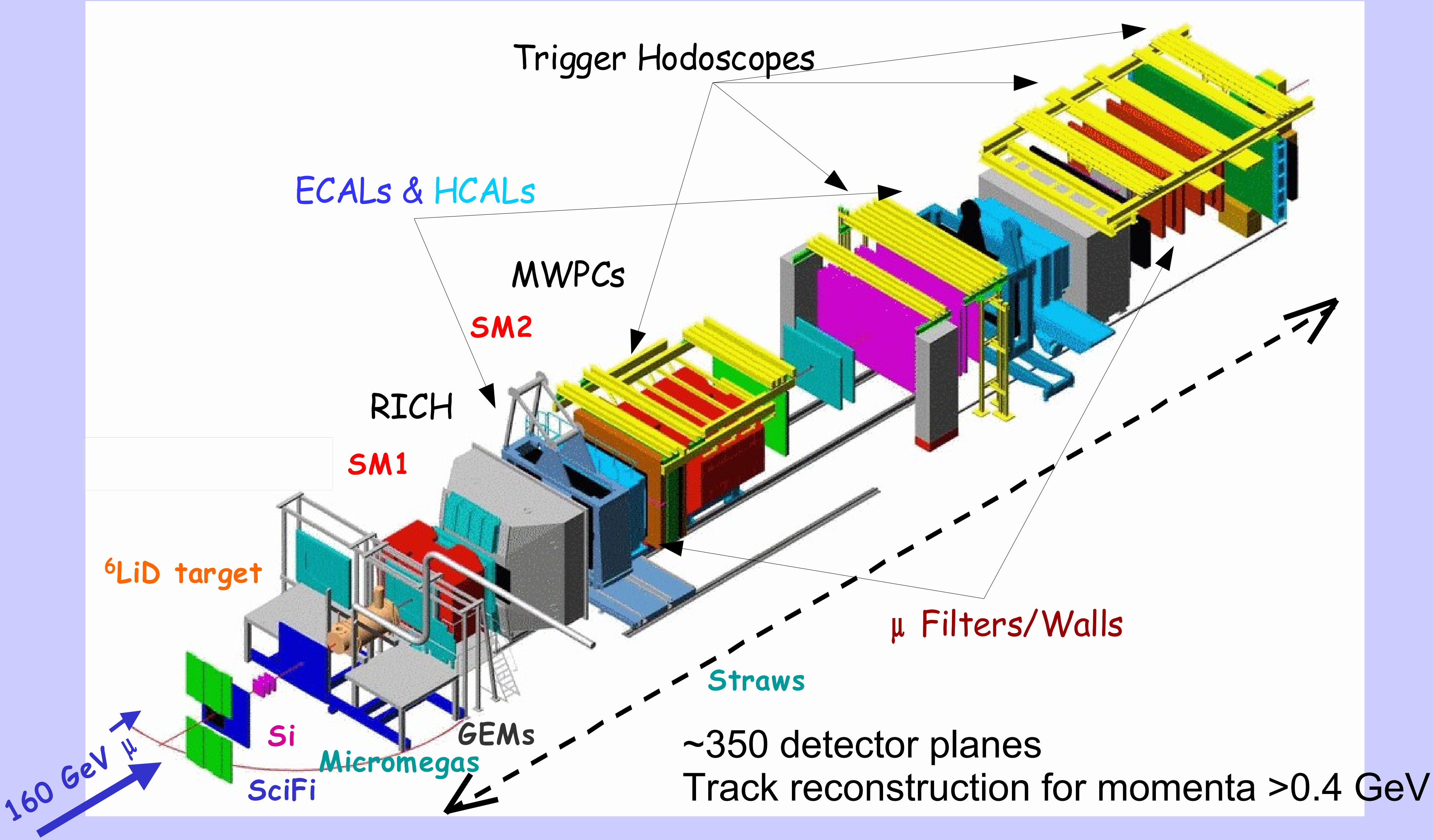


Target:

- two cells – 60 cm long each
- high luminosity
- material: ^{6}LiD
- opposite polarisation: ~50%
- exposed to the same beam flux
- dilution factor: 0.4
- polarisation reversal every 8 hours
- cooling system: 50 mK
- acceptance: ±70 mrad
- in 2006 acceptance: ±180 mrad



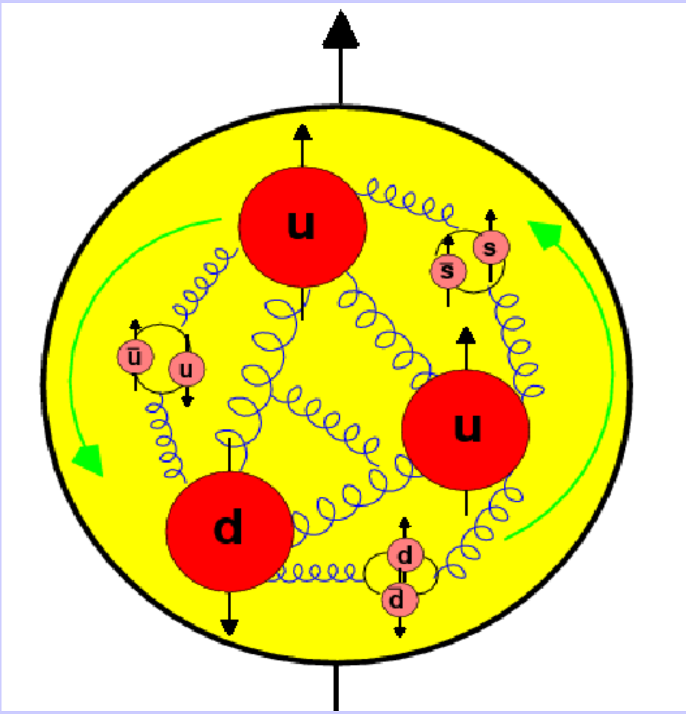
The spectrometer layout



Two-stage forward-spectrometer:
LAS – 1 Tm magnet (±180 mrad)
SAS – 4.5 Tm magnet (±30 mrad)

PID:
RICH, ECAL, HCAL, muon filters

Physics Motivation



Nucleon spin decomposition:

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_{q,g}$$

contribution from quarks and anti-quarks

contribution from gluons

orbital momenta of quarks and gluons

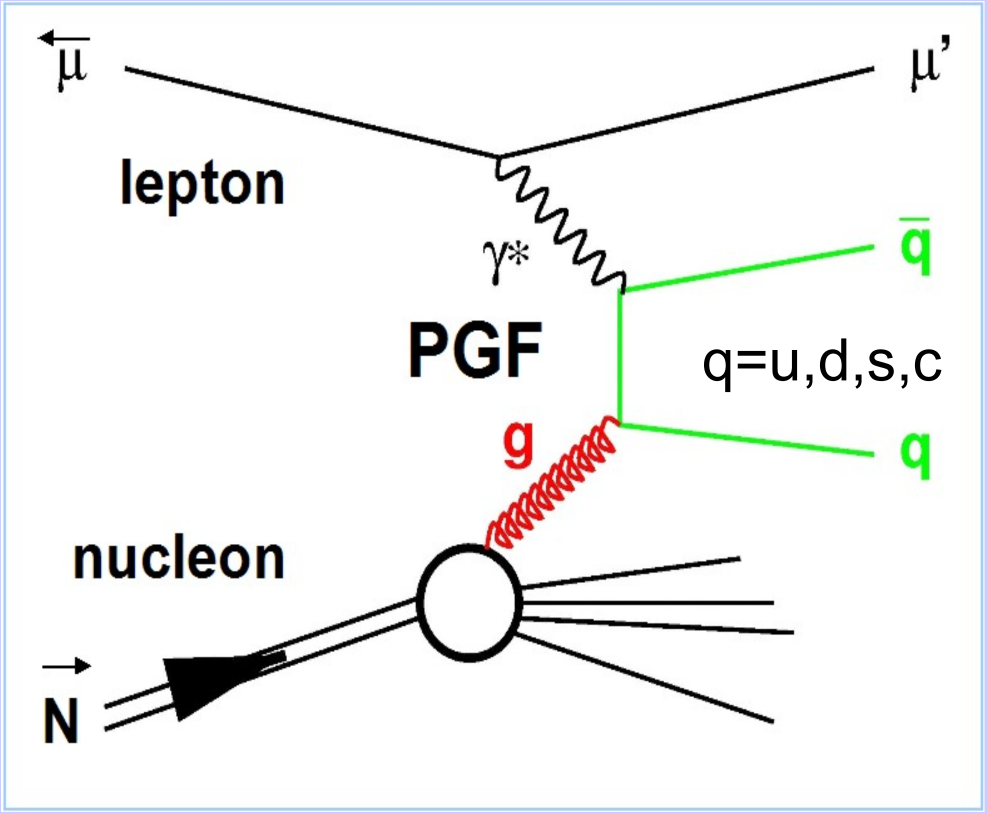
- Only a small fraction of nucleon spin is carried by quarks ~0.3
- Where does the rest of the nucleon spin comes from?
- Gluons helped to solve the missing momentum problem. Will they also be a remedy for the missing spin?

SPIN CRISIS

How to measure ΔG?

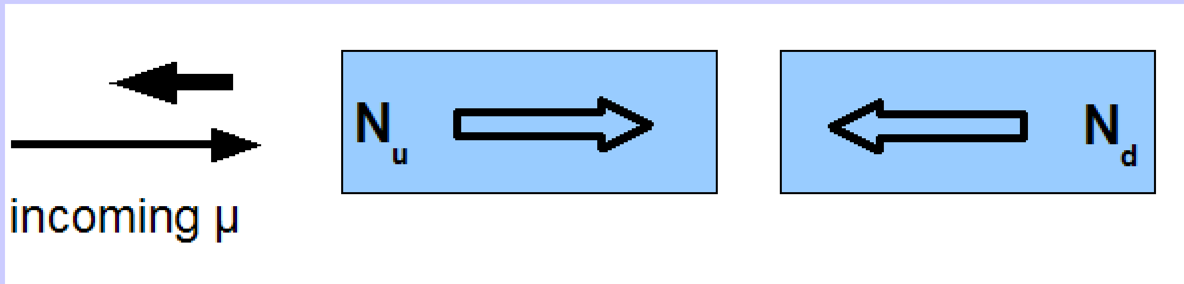
In DIS – through the interaction that probes directly gluons inside the nucleon.

Photon Gluon Fussion (PGF): $\gamma^* g \rightarrow \bar{q}q$



What is measured in the experiment

In the experiment we have:



Asymmetry for the interactions measured in the experiment:

$$A_{\exp} = \frac{N_u - N_d}{N_u + N_d}$$

Asymmetry of the cross sections for PGF process:

$$A = \frac{\sigma^{\overset{\leftarrow}{\Rightarrow}} - \sigma^{\overset{\leftarrow}{\Leftarrow}}}{\sigma^{\overset{\leftarrow}{\Rightarrow}} + \sigma^{\overset{\leftarrow}{\Leftarrow}}}$$

The physics and experimental asymmetries:

$$A_{\exp} = P_T P_B f \; A$$

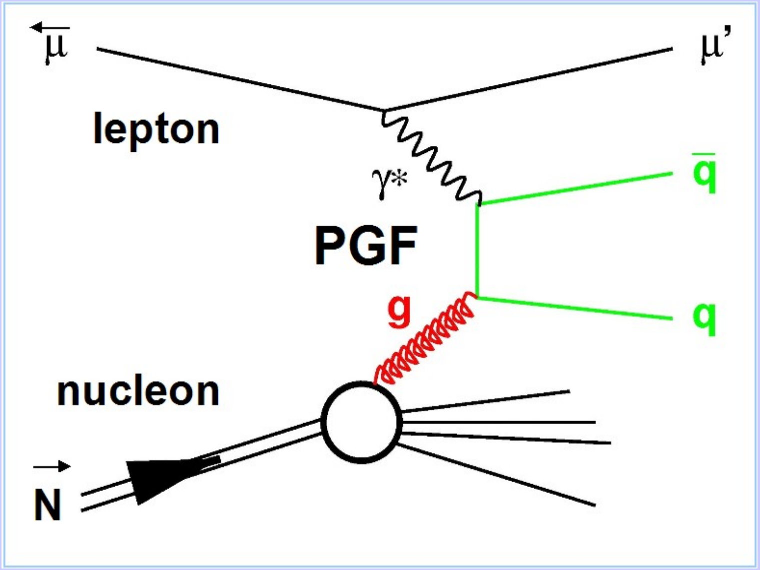
P_T – target polarization (~50%), ± 5%

P_B – beam polarization (~76%, 81%), ± 5%

f – dilution factor (~40%) ± 5%

Methods of the PGF measurement

Photon Gluon Fussion:



Method I – open charm production ("golden channel")

- $c\bar{c}$ production
- 1.2 D^0 per $c\bar{c}$-event
- $D^0 \rightarrow K\pi$ (BR ~4%)
- hard scale set by $4m_c^2$
- no background asymmetry
- only weakly MC dependent
- limited statistics

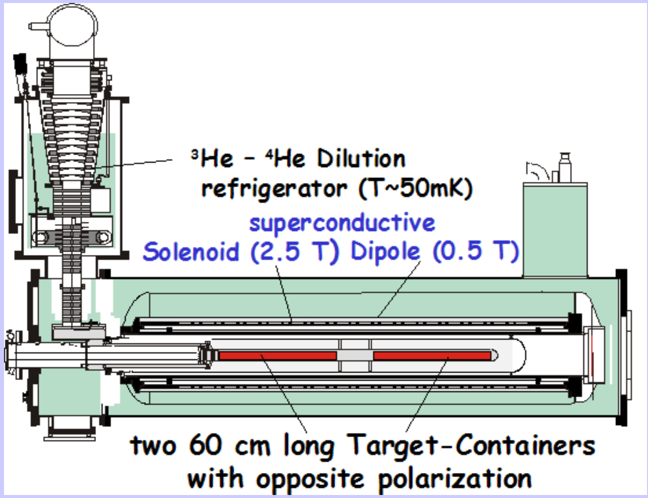
Method II – 2 high p_T hadrons (Q^2>1 GeV^2)

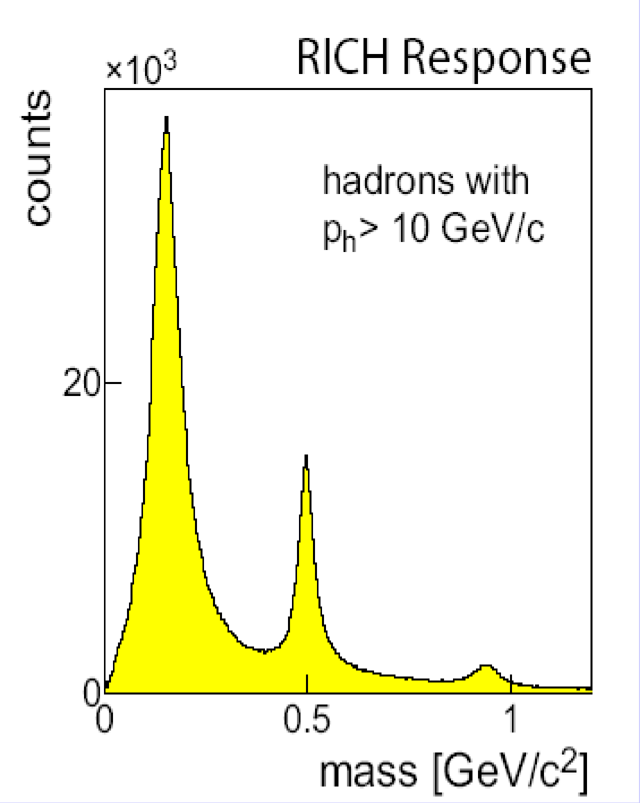
- hard scale set by Q^2
- larger statistics
- resolved photon negligible
- large dilution of other processes
- dependence on MC

Method III – 2 high p_T hadrons (Q^2<1 GeV^2)

- hard scale set by p_T^2
- very large statistics
- resolved photon not negligible
- large dilution of other processes
- strong dependence on MC

Open charm production and decay





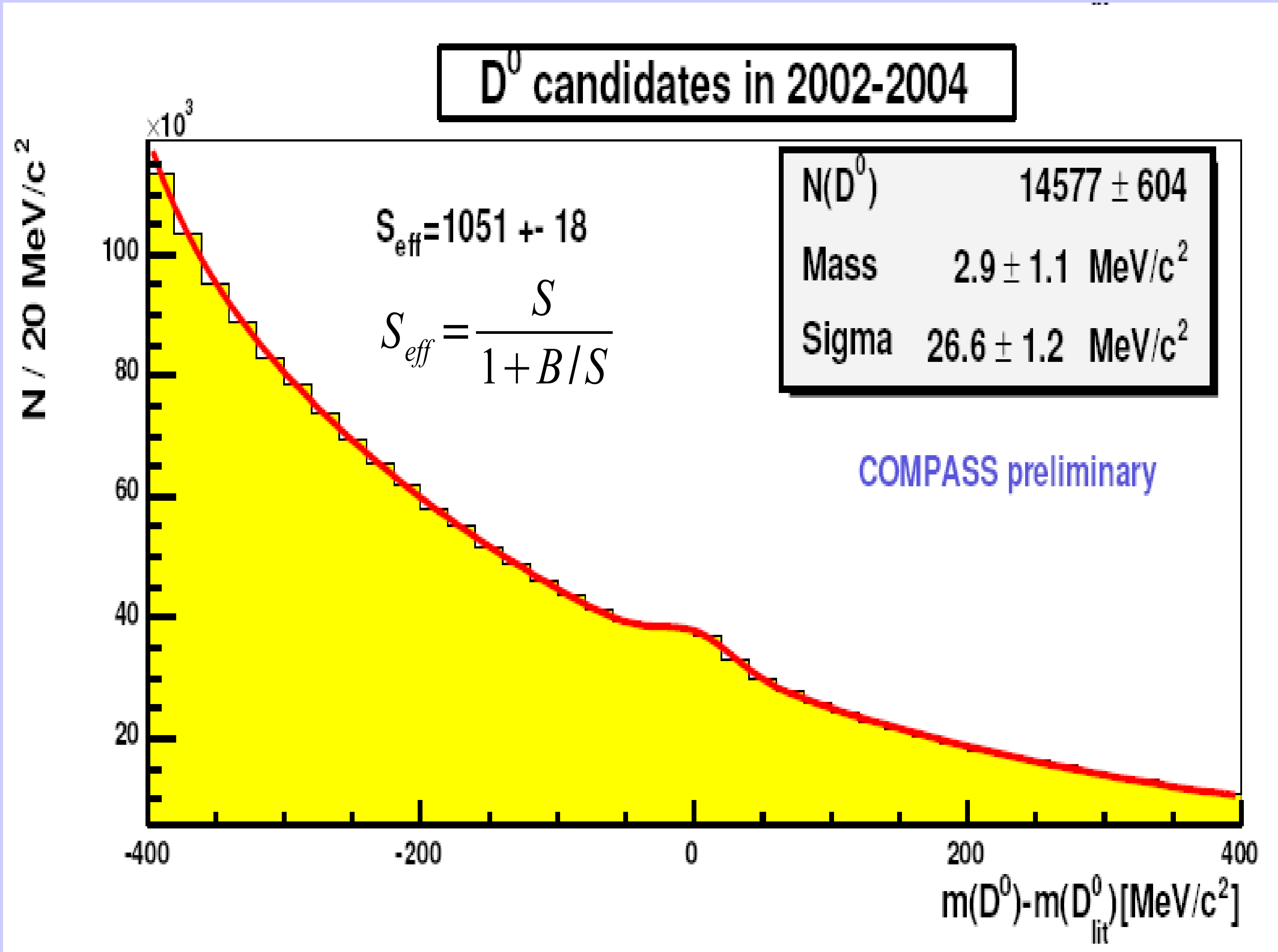
$D^0 \rightarrow K\pi$ (BR ~4%)

- Each of the cells 60 cm long
- Enclosed in the solenoid and cooling system
- No vertex detector
- Very high combinatorial background
- RICH identification of kaons essential

- Kaons identification for momenta > 9 GeV
- π is not identified as K

- Cuts on kinematics:
  - $z(D^0) > 0.25$ where $z(D^0)=E_{D^0}/\nu$
  - $|\cos\theta_K^*| < 0.5$

Open charm signal

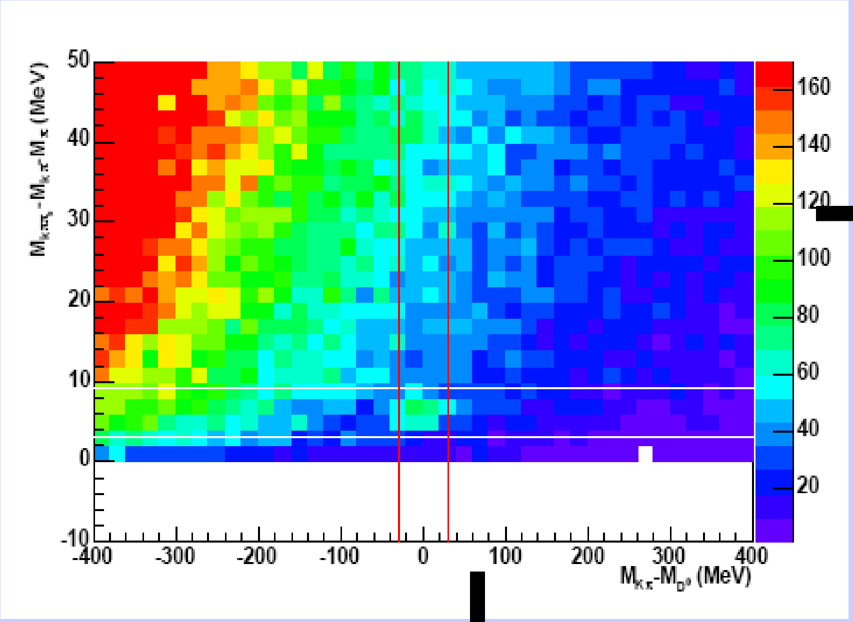


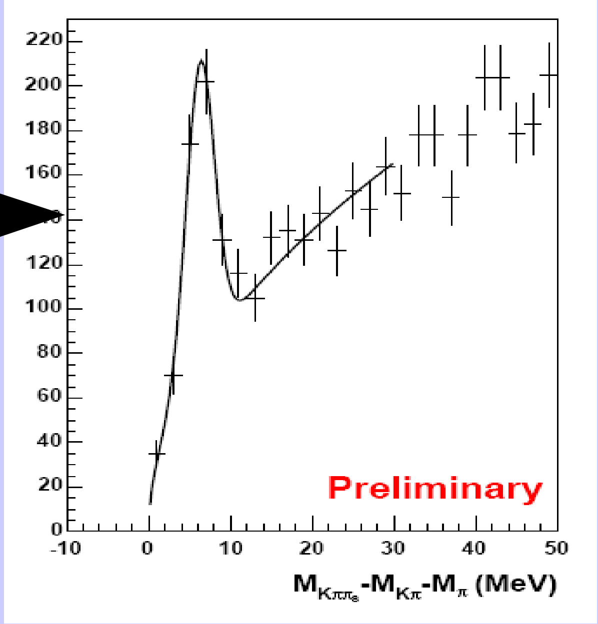
Still high combinatorial background...

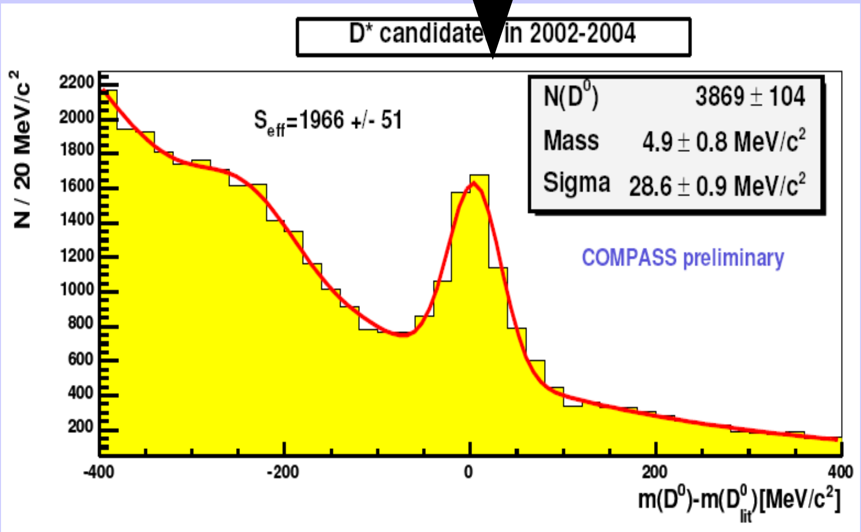
Open charm tagged with D*

~30% D^0 come from D* decays:

$$D^* \rightarrow D^0 \pi_s \rightarrow K \pi \pi_s$$



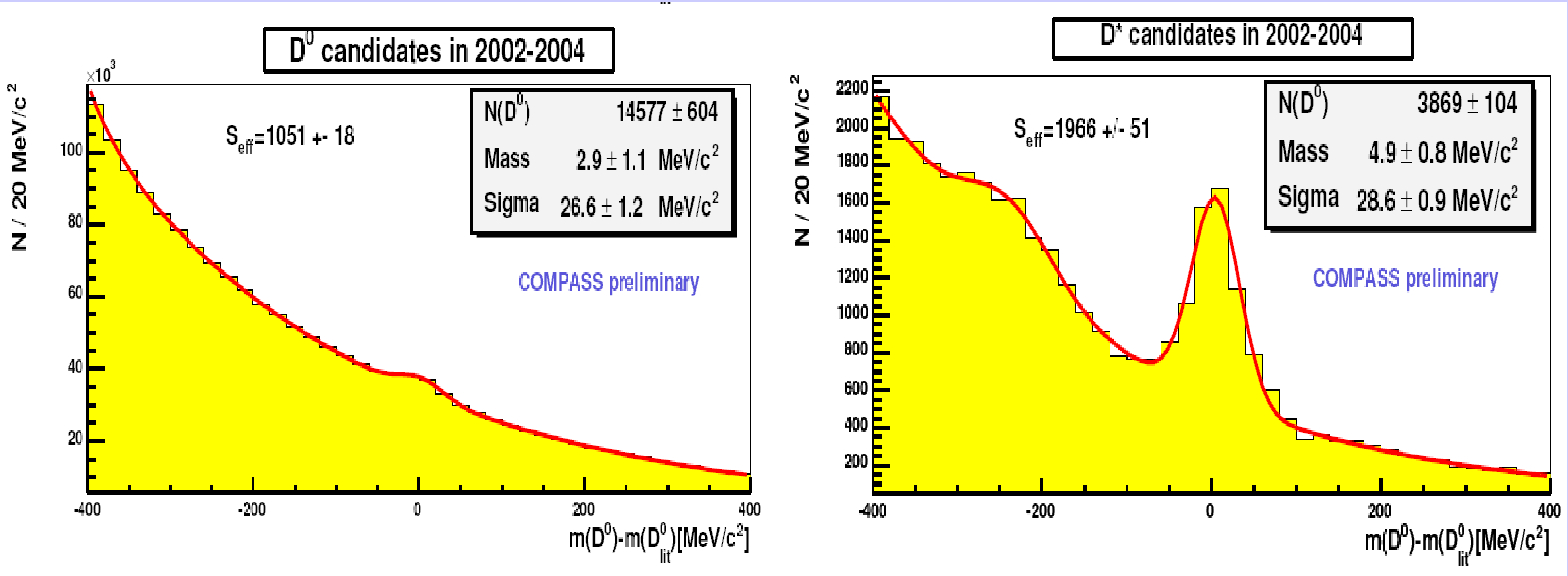




Open charm production and decay

$D^0 \rightarrow K\pi$ (BR ~4%)

~30% D^0 come from D* decays: $D^* \rightarrow D^0 \pi_s \rightarrow K \pi \pi_s$

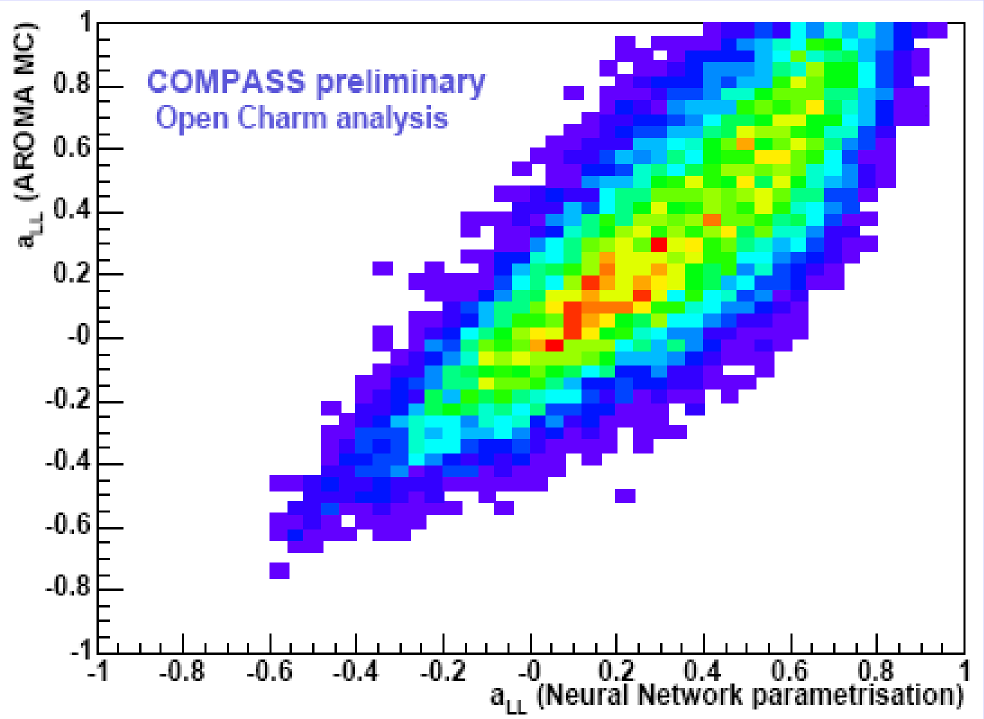


From asymmetry to ΔG/G: $$A^{\gamma N} = \frac{S}{S+B} < a_{LL} > \frac{\Delta G}{G}$$

Where a_{LL} – partonic asymmetry for the $\gamma^* g$ reaction (PGF analyzing power)

NN parametrisation

- a_{LL} for each event cannot be calculated directly – only one charmed meson measured per event
- Parametrisation based on the Aroma Monte Carlo is used
- Parametrisation prepared with Neural Networks
- z_{D^0}, $p_{T_{D^0}}$, (x_{bj}, y, Q^2) variables used for parametrisation

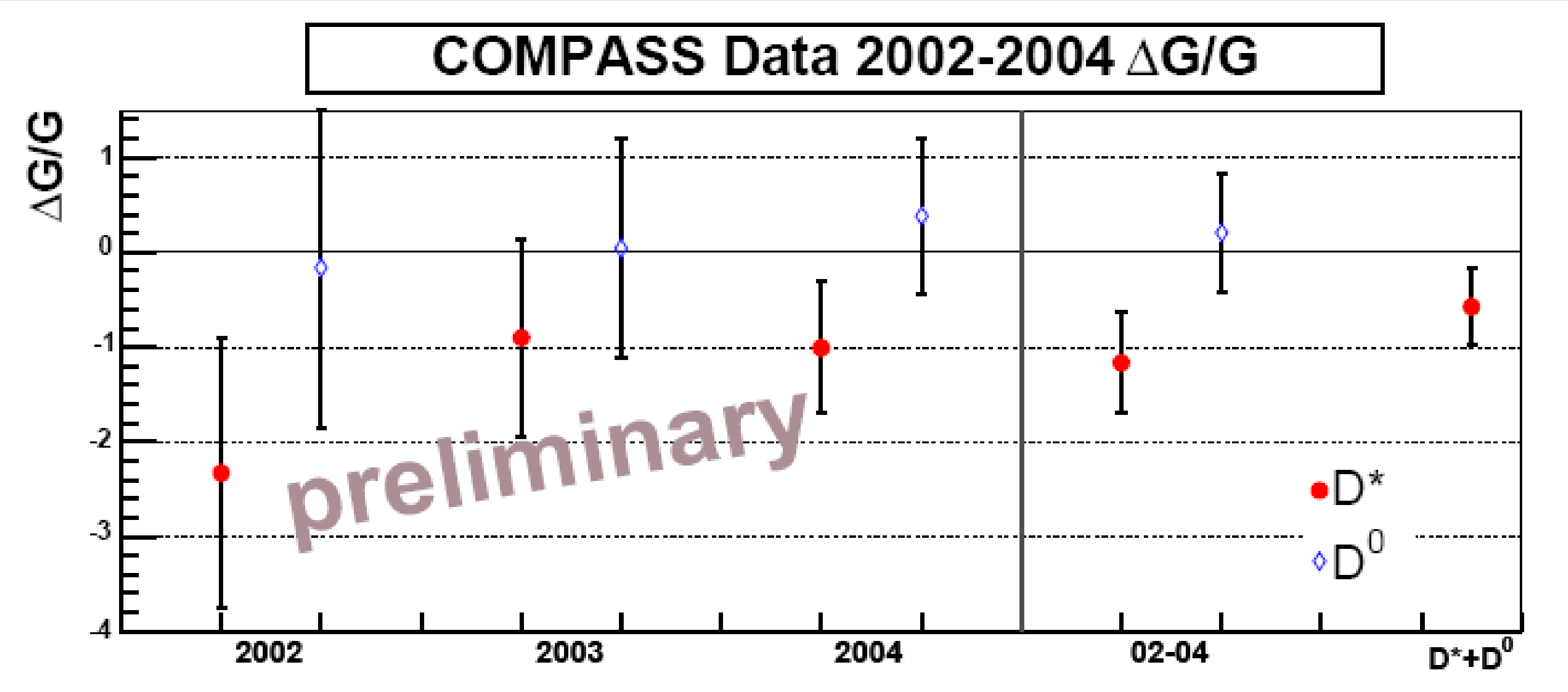


Correlation factor 82%

Preliminary results from open charm channel from 2002/3/4 data

$\Delta G/G = -0.57 \pm 0.41$ (stat.)

$x_g \approx 0.15$ (RMS 0.08)
scale ≈ 13 GeV^2 ($\approx 4m_c^2$)



Systematic error

A number of potential systematic effects studied:

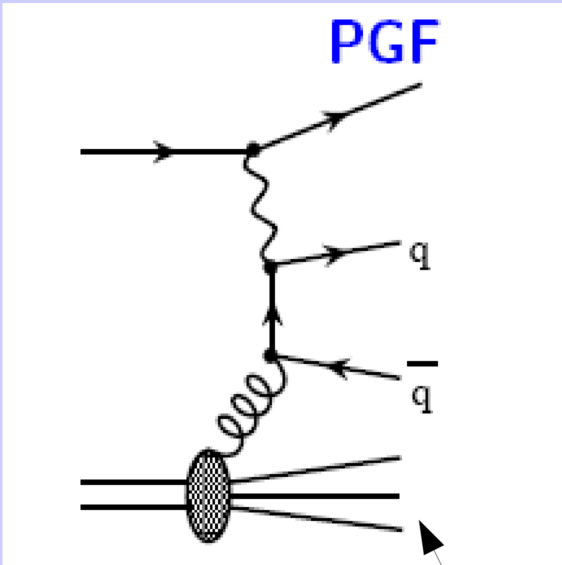
Source of uncertainty	$\delta(\Delta G/G)$
• Background asymmetry	0.07
• Binning procedure	0.04
• False asymmetries (pulls method)	0.10
• Fitting	0.09
• Parameters of Aroma	0.05
• Target polarisation	0.03
• Beam polarisation	0.03
• Dilution factor	0.03

Combined systematic error is: 0.17

$$\Delta G/G = -0.57 \pm 0.41 \text{ (stat.)} \pm 0.17 \text{ (syst.)}$$

2 hadrons with high p_T ($Q^2>1$ GeV^2)

Signal



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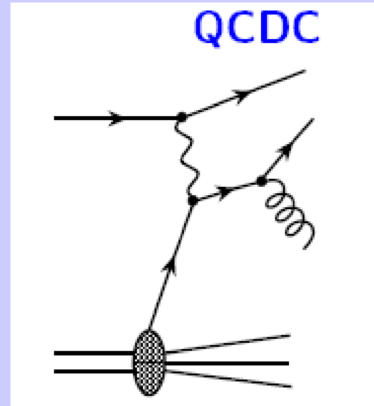
Background



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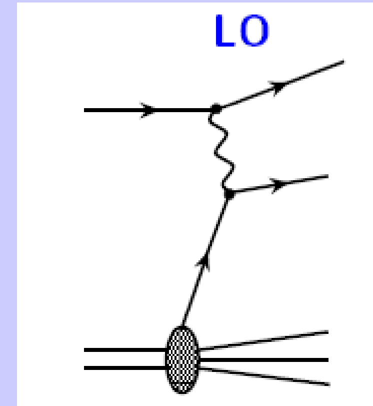
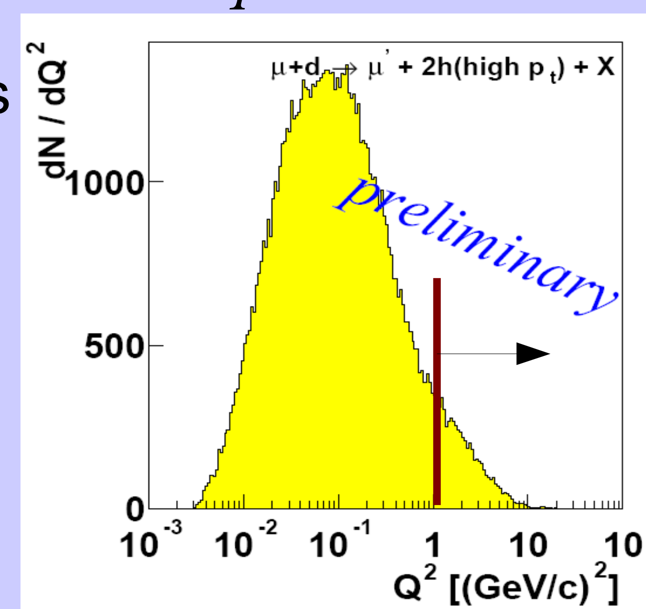


$$A = R_{pgf}\, a_{LL}^{PGF} \frac{\Delta G}{G} + \left(R_{QCDC}\, a_{LL}^{QCDC} + R_{LO}\, a_{LL}^{LO} \right) \frac{\Delta q}{q}$$

where R_{PGF}, R_{QCDC}, R_{LO} are the fractions of processes



- $Q^2>1$GeV^2 sample – 10% of the whole statistics
- MC needed for R_{PGF} fraction and a_{LL}^{PGF}
- LEPTO 6.5.1 generator is used + GEANT
- $x<0.05 \rightarrow A_1^d$ - small, LO and QCDC negligible

2 hadrons with high p_T ($Q^2<1$ GeV^2)

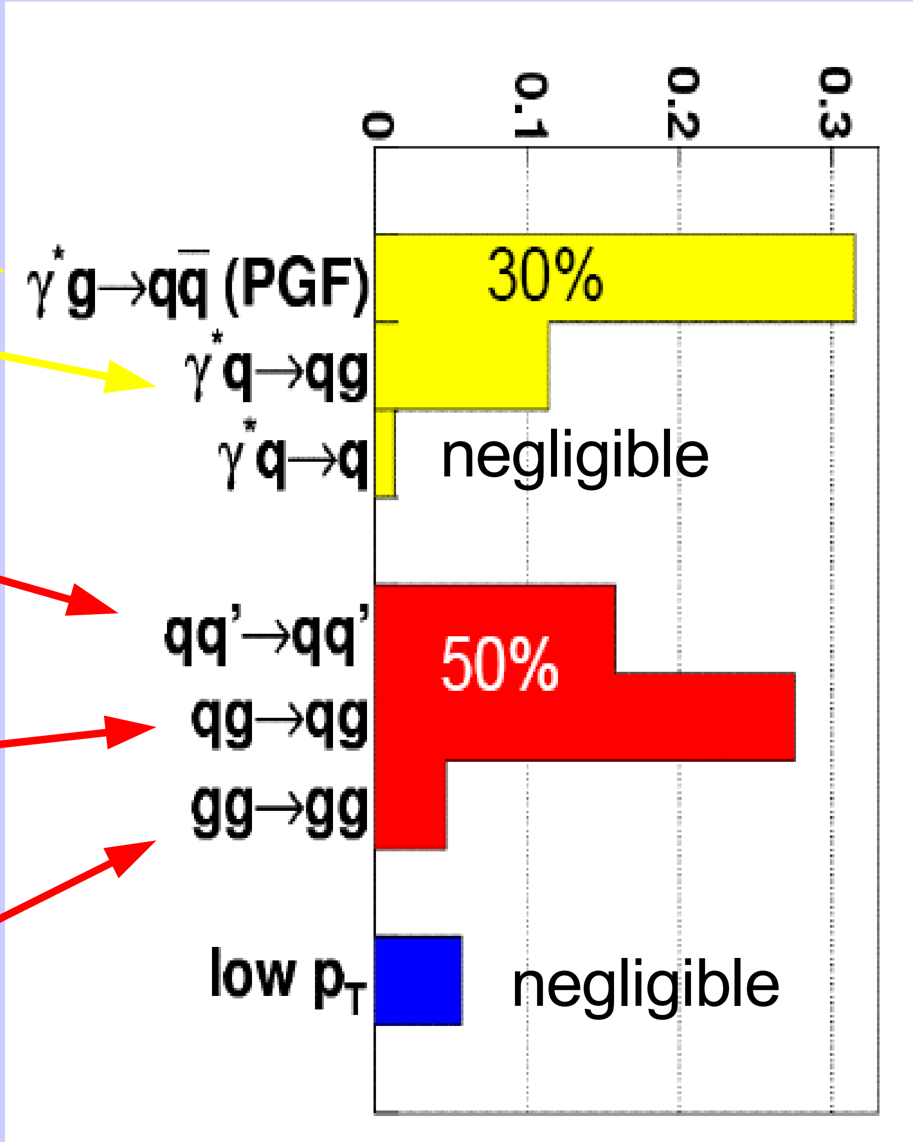
$$A = R_{PGF}\, a_{LL}^{PGF} \frac{\Delta G}{G}$$

$$+ R_{QCDC}\, a_{LL}^{QCDC} \frac{\Delta q}{q}$$

$$+ R_{qq}\, a_{LL}^{qq} \frac{\Delta q}{q} \left(\frac{\Delta q}{q}\right)^{\gamma}$$

$$+ R_{qq}\, a_{LL}^{qg} \frac{\Delta q}{q} \left(\frac{\Delta G}{G}\right)^{\gamma}$$

$$+ R_{gg}\, a_{LL}^{gg} \frac{\Delta G}{G} \left(\frac{\Delta G}{G}\right)^{\gamma}$$



Fractions of each process obtained from PYTHIA 6.2 Monte Carlo.

Preliminary results from 2 hadrons with high p_T ($Q^2>1$ GeV^2) channel for 2002/3 data

- p_{T1}, p_{T2} > 0.7 GeV
- $p_{T1}^2 + p_{T2}^2 > 2.5$ GeV^2

For $Q^2>1$ GeV^2

$$\Delta G/G = 0.06 \pm 0.31 \text{ (stat.)} \pm 0.06 \text{ (syst.)}$$

$R_{PGF} = 0.34 \pm 0.07$

$x_g = 0.13$ (RMS 0.08)

scale: 3 GeV^2

For $Q^2<1$ GeV^2

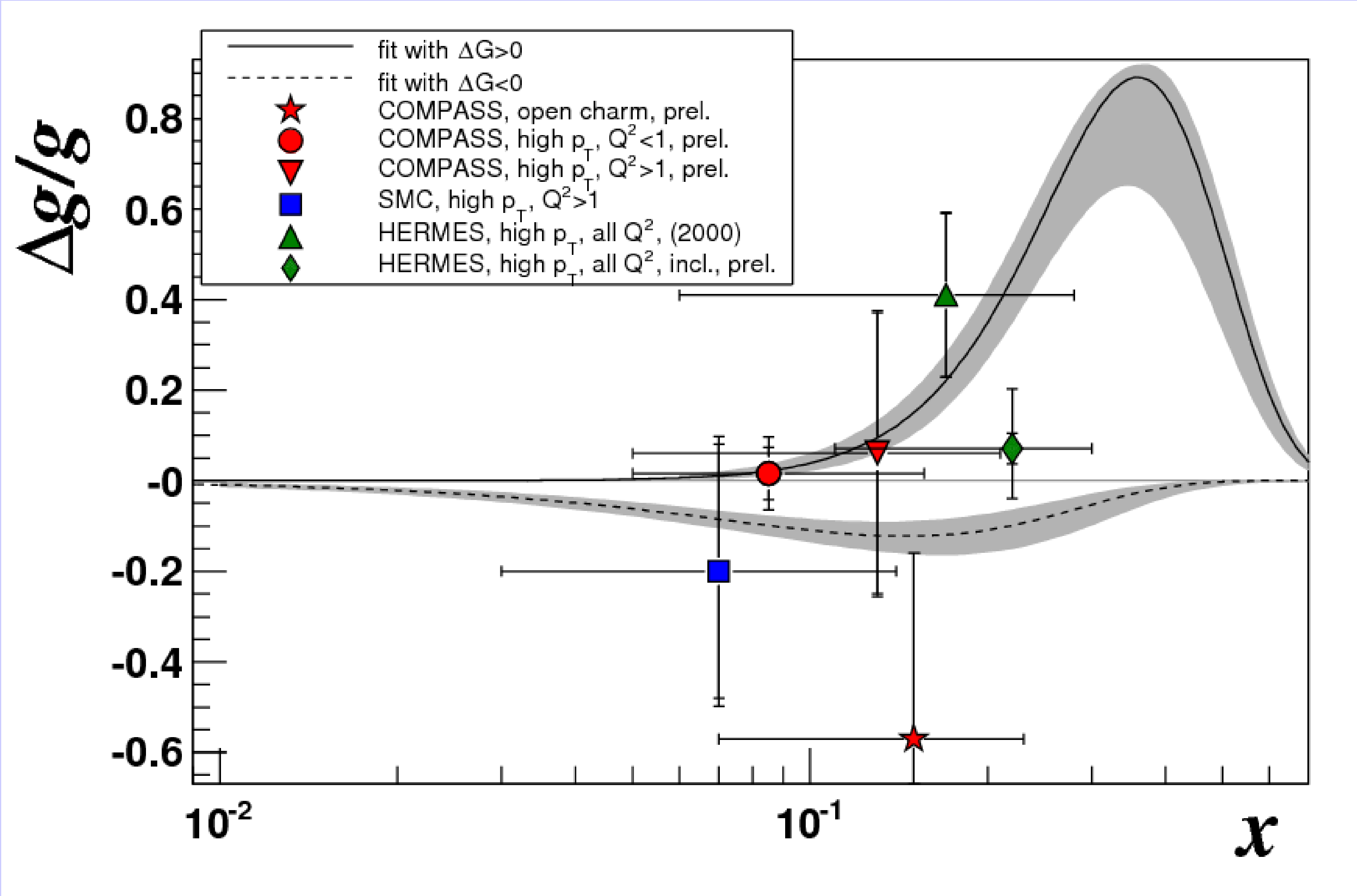
$$\Delta G/G = 0.016 \pm 0.058 \text{ (stat.)} \pm 0.055 \text{ (syst.)}$$

$R_{PGF} = 0.30$

$x_g = 0.095^{+0.08}_{-0.04}$

scale: 3 GeV^2

Results from COMPASS



Lines obtained from NLO QCD fits including a new COMPASS deuteron results on g_1^d (hep-ex/0701014 and PLB 647 (2007)). Two equally good solutions for ΔG/G were found. For both |ΔG| = 0.2 - 0.3.

Summary

- Results of $\Delta G/G$ measurements were presented
- 3 channels were studied:
  - ➔ Open charm (2002-4):

$$\Delta G/G = -0.57 \pm 0.41 \text{ (stat.)} \pm 0.17 \text{ (syst.)}$$

  - ➔ High p_T ($Q^2>1$) (2002-3):

$$\Delta G/G = 0.06 \pm 0.31 \text{ (stat.)} \pm 0.06 \text{ (syst.)}$$

  - ➔ High p_T ($Q^2<1$) (2002-4):

$$\Delta G/G = 0.016 \pm 0.058 \text{ (stat.)} \pm 0.055 \text{ (syst.)}$$

- Small ΔG are prefered
- But still scenarios with large ΔG (>0.4) not excluded
- The question of $L_{q,g}$ importance still open

Prospects

- Results from 2002-4 high p_T (Q^2>1) analysis available soon
- 2002-4 open charm analysis still ongoing
- For high p_T analysis bining in x_g considered, NN approach under investigation
- Improvements of COMPASS in 2006:
  - New target solenoid – improvement in hadron acceptance (+30%)
  - Improvements in RICH efficiency
  - New tracking detectors