$\Delta G/G$ measurement at COMPASS

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on behalf of the COMPASS collaboration

SYMMETRIES AND SPIN (SPIN-Praha-2006)
Praga, 22.07.2006

Outline:
- COMPASS experiment
- Motivation for $\Delta G/G$ measurement
- Three methods of $\Delta G/G$ 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

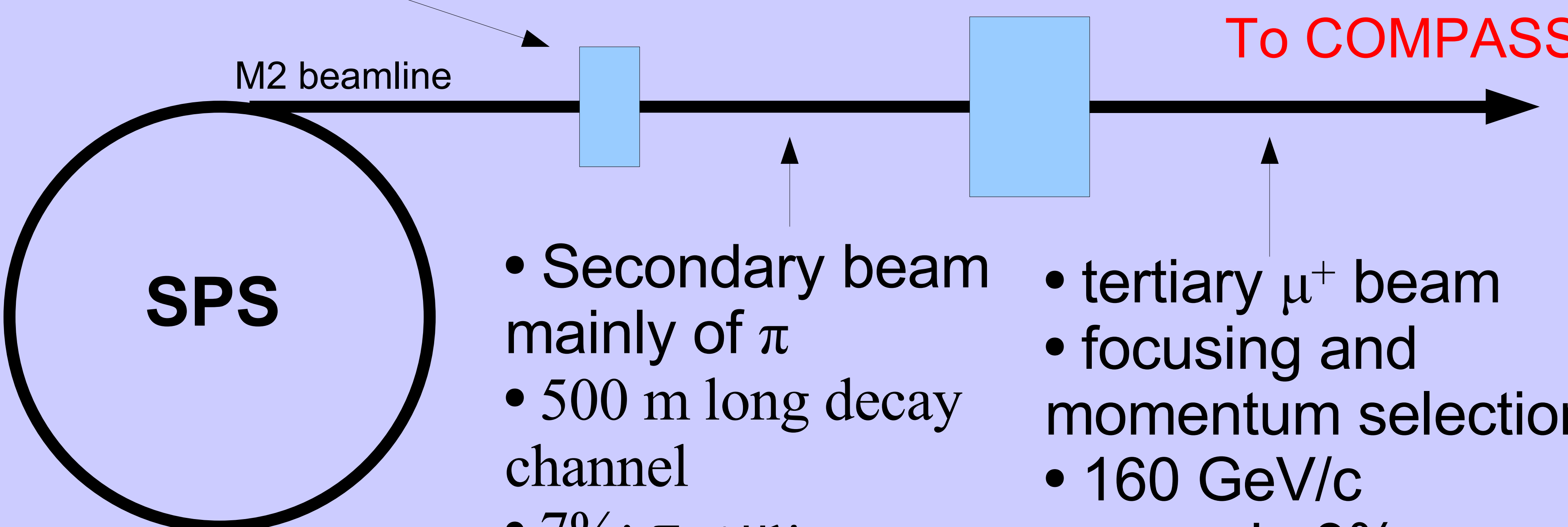
Beam parameters:

- 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

- berylium target
- ~500 mm long
- production of K and π

- heavy absorber
- only μ & ν pass



- Secondary beam mainly of π
- 500 m long decay channel
- 7%: $\pi \rightarrow \mu\nu$

- tertiary μ^+ beam
- focusing and momentum selection
- 160 GeV/c
- spread ~3%
- BMS → momentum measurment

- 400 GeV protons
- ~10^{13} p/spill
- spills 4.8/16.8 s

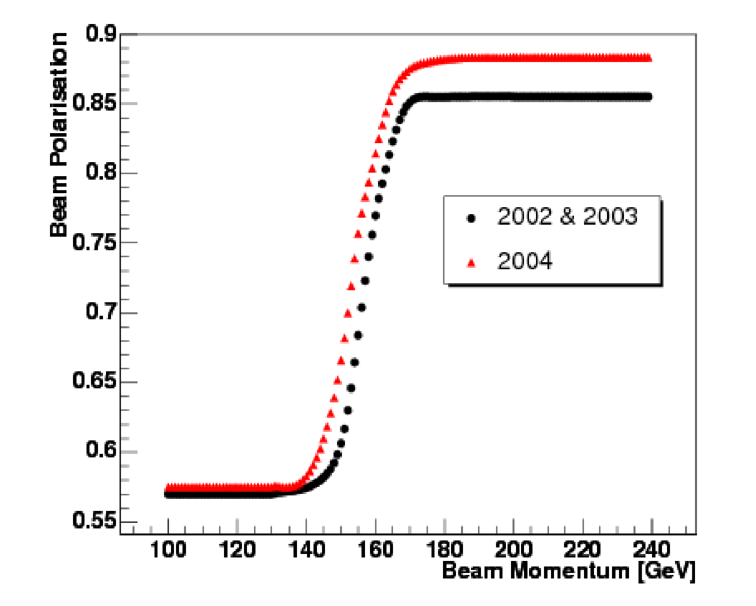
The production of the beam

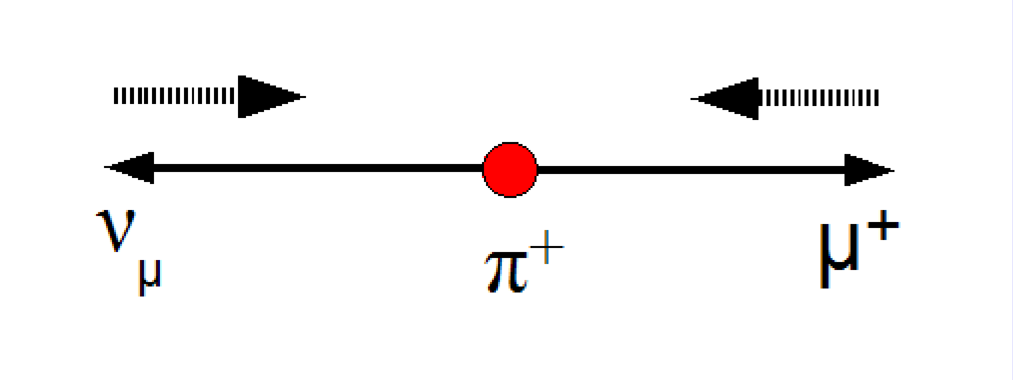
- $\pi \rightarrow \mu\nu$ is a parity violating decay
- μ are 100% polarised in a decaying pion rest frame

In the LAB frame:

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

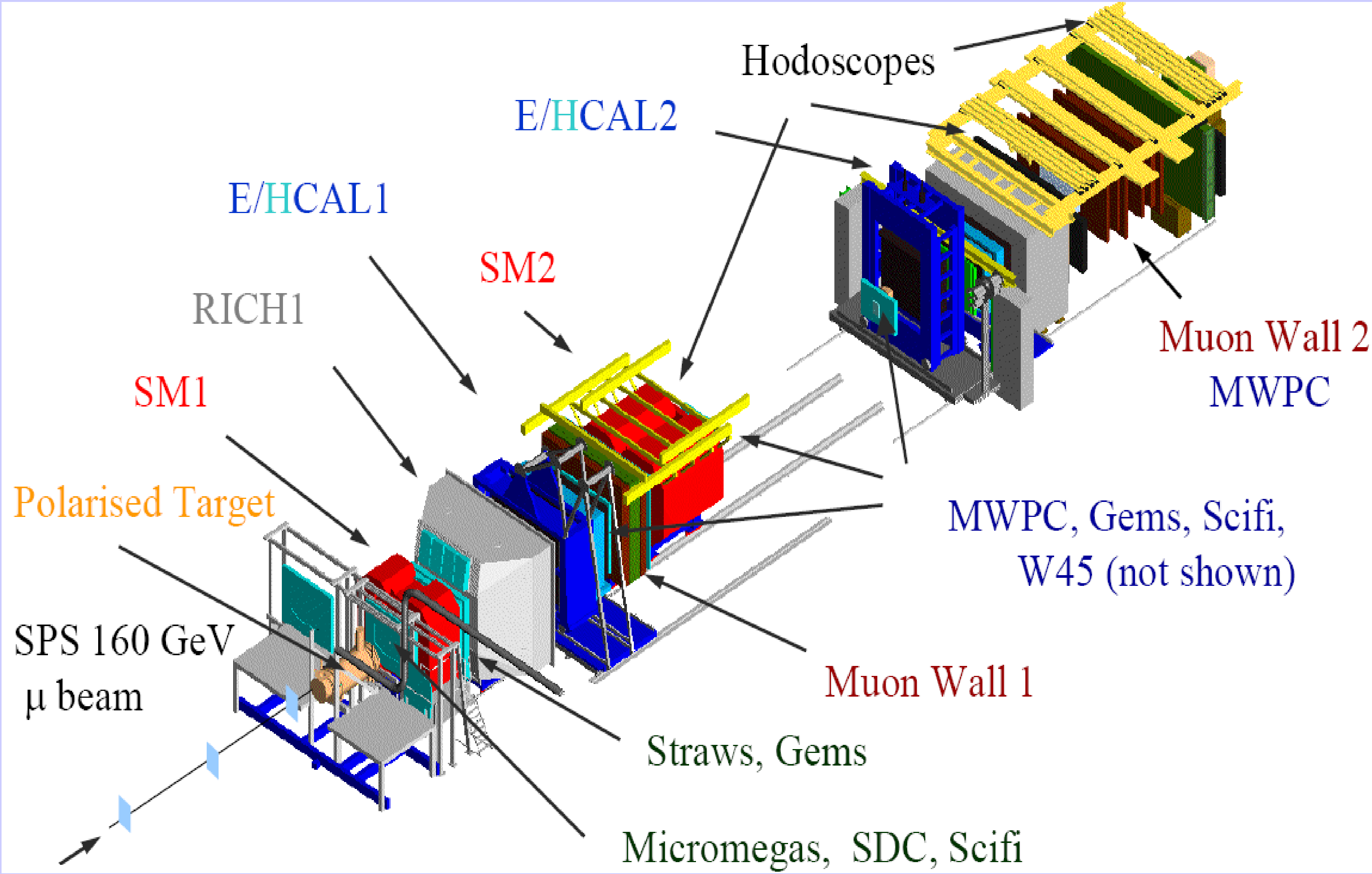
The average polarisation is: -0.76 in 2002-3
-0.81 in 2004





The polarisation: MC and SMC measurments

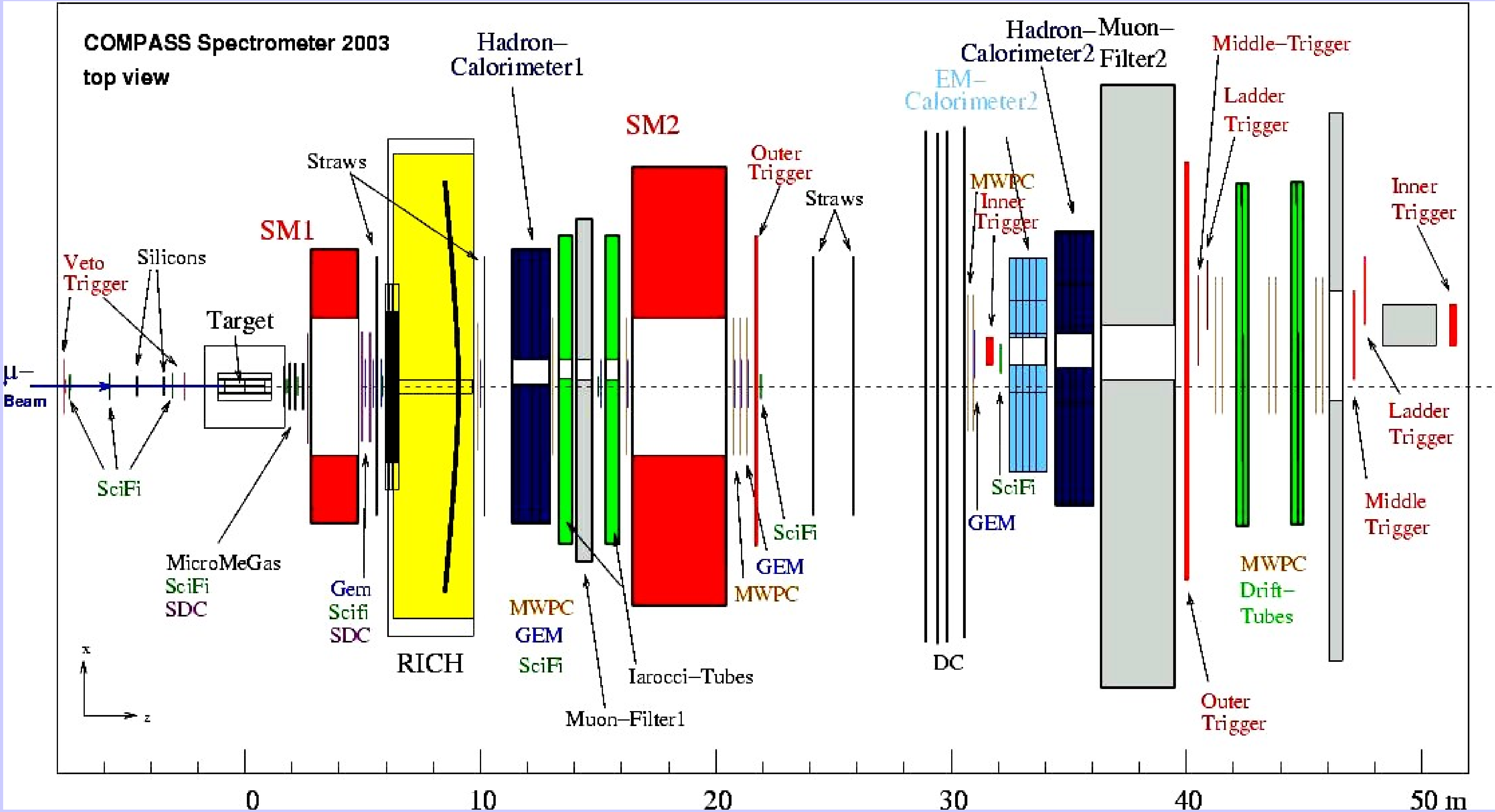
The spectrometer layout



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

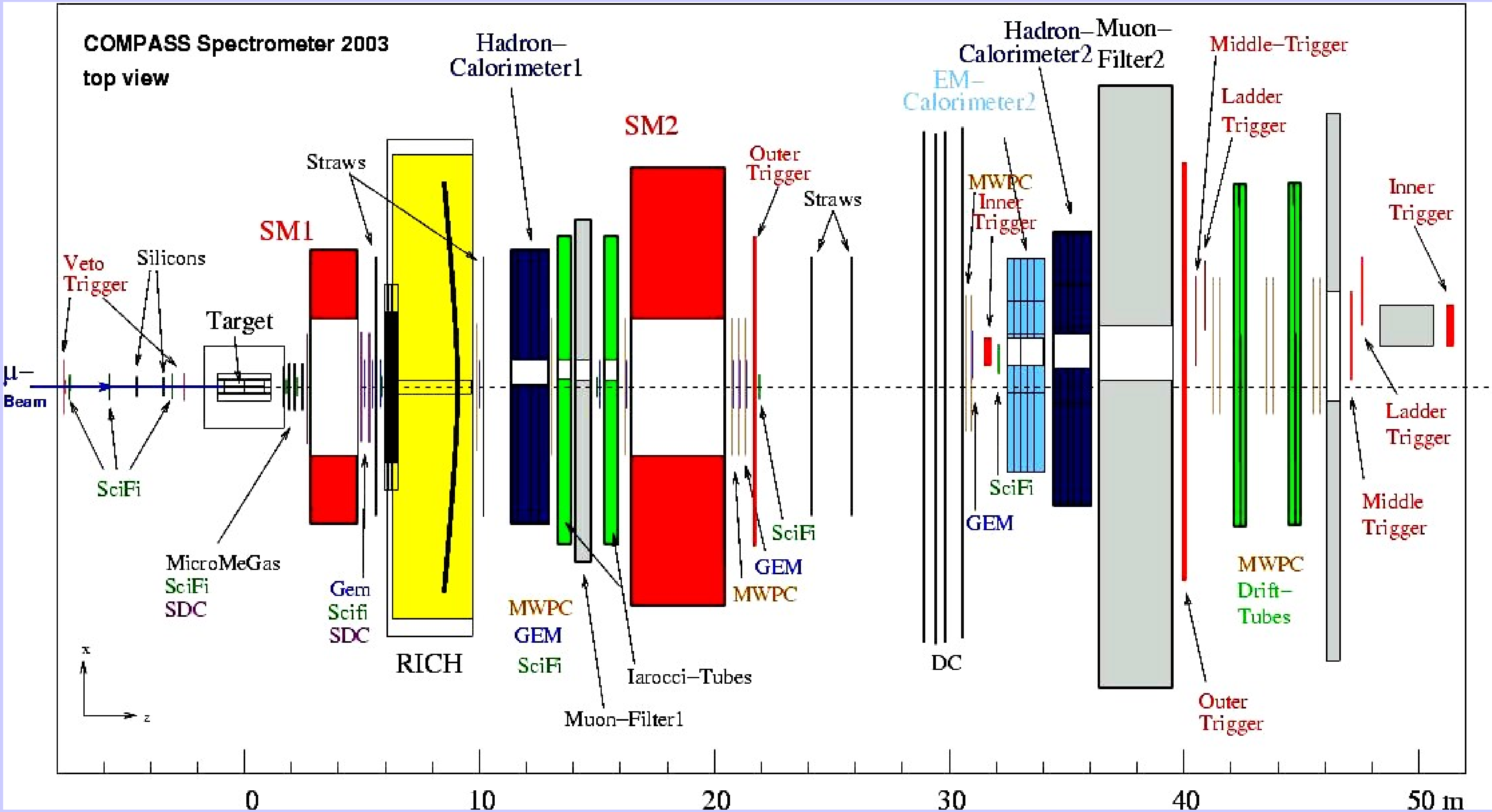
PID:
RICH, ECAL, HCAL, muon filters

The spectrometer layout



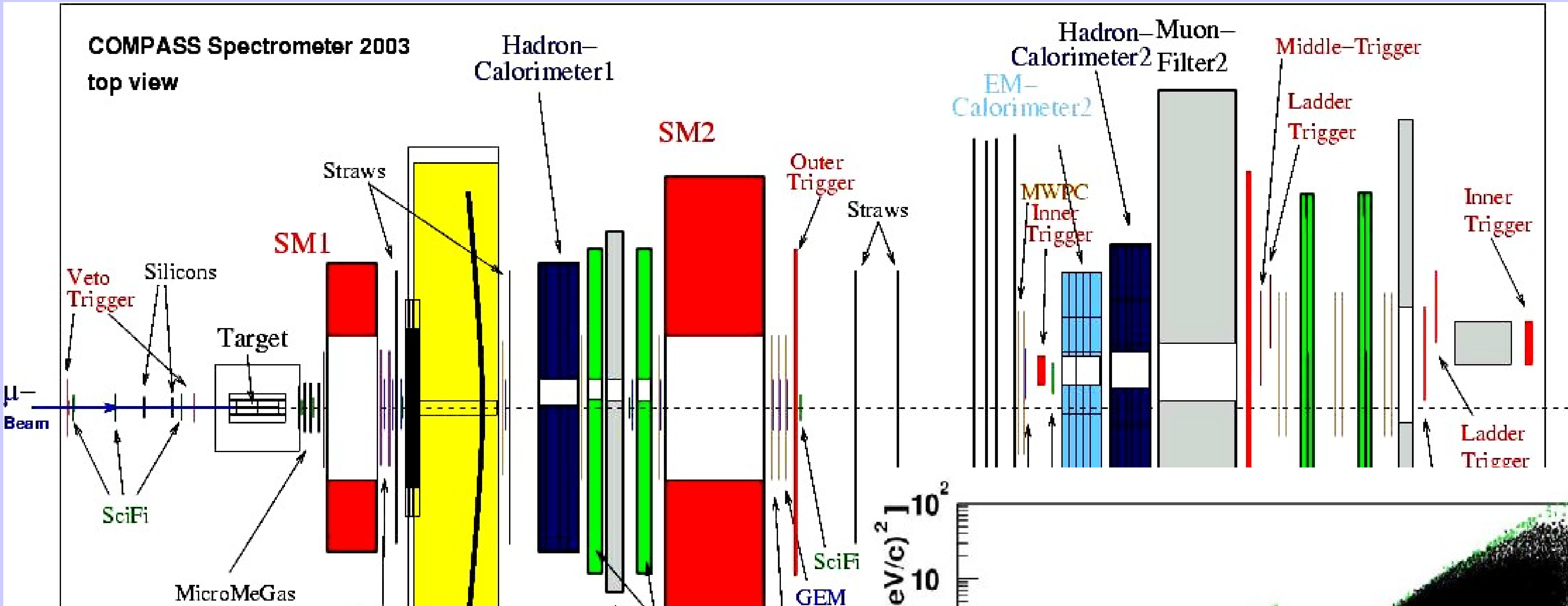
- ~350 detector planes
- Track reconstruction for momenta > 0.5 GeV
- Very small angles: SciFi, Silicon Microstrips
- Small angles: Micromega, GEM
- Large angles: Drift Chamber, Straw Tubes, MWPC

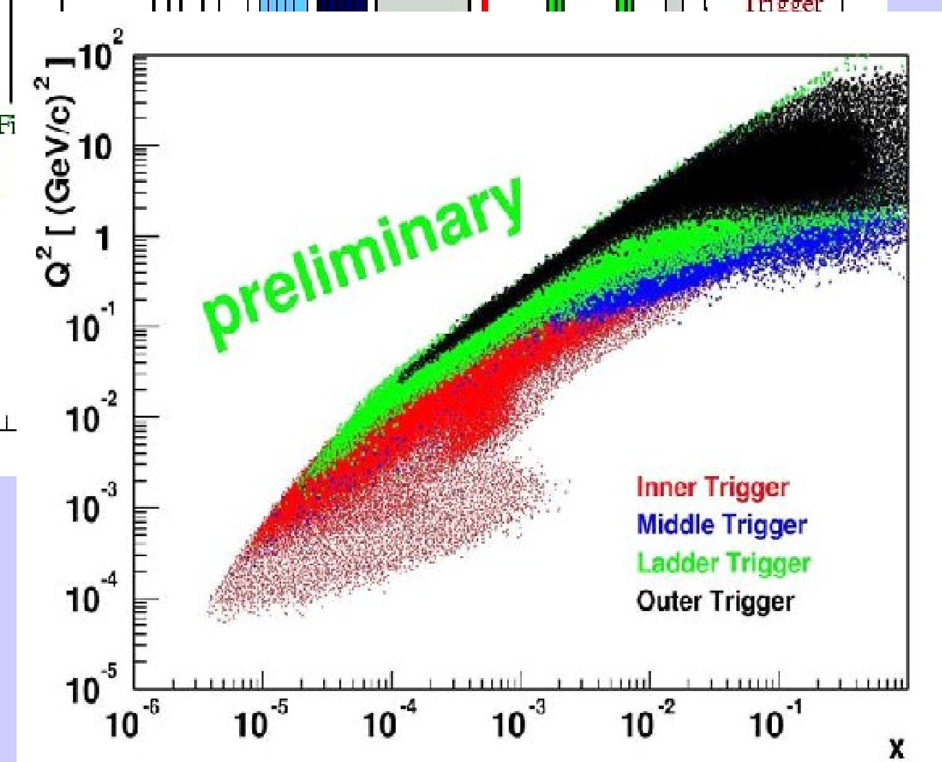
The spectrometer layout



- Triggers: dedicated hodoscopes
- + hadronic calorimeters

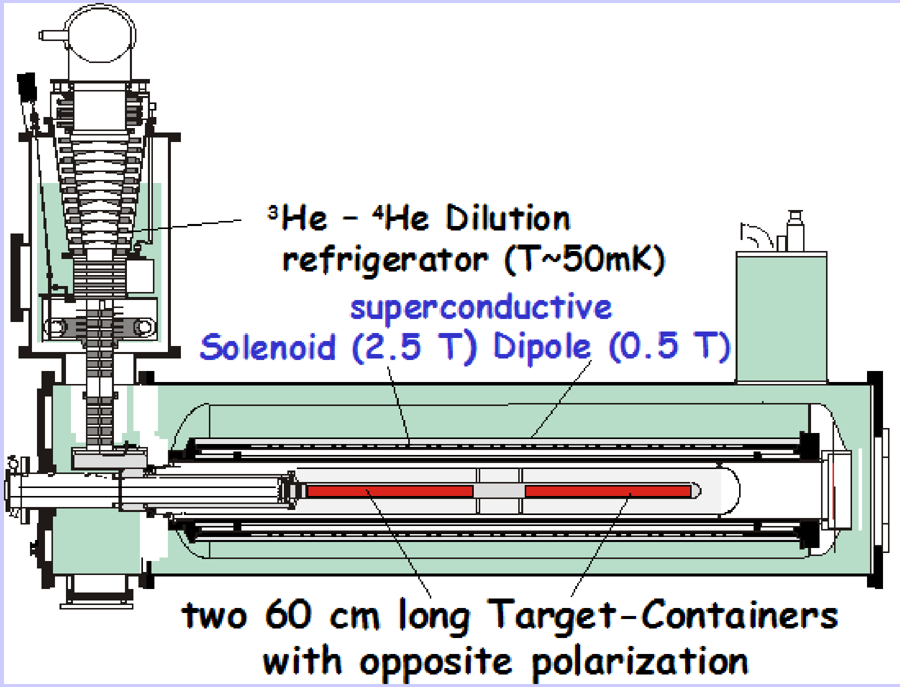
The spectrometer layout





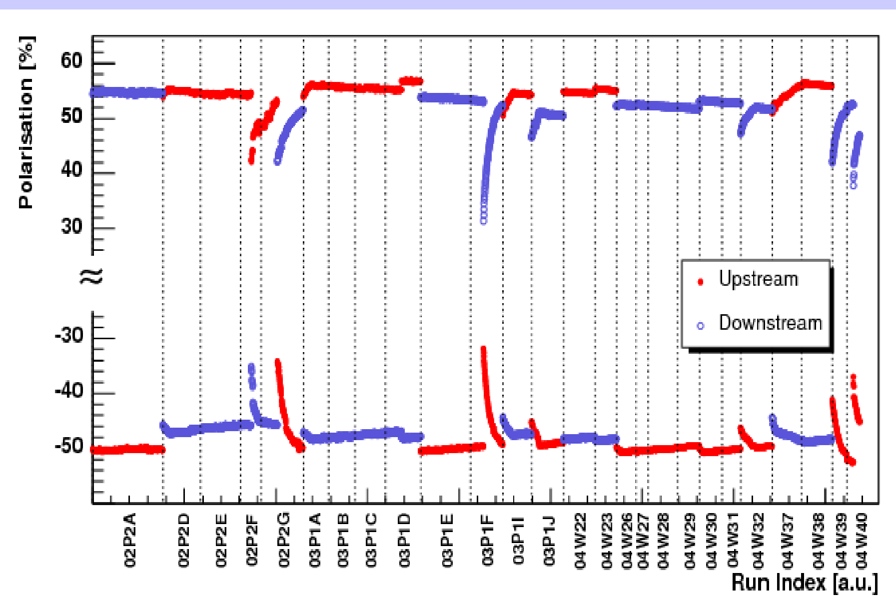
- Triggers: dedicated hodoscopes
- + hadronic calorimeters

The target



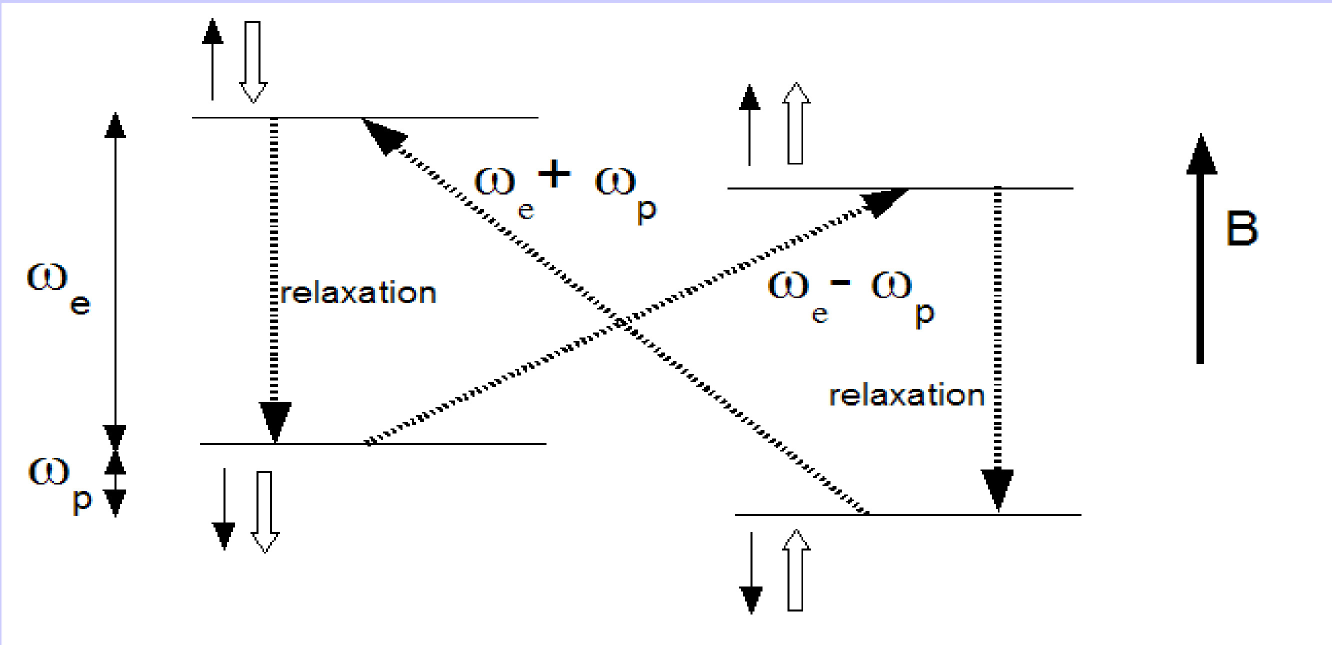
Target:

- 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 Dynamic Nuclear Polarisation (DNP)

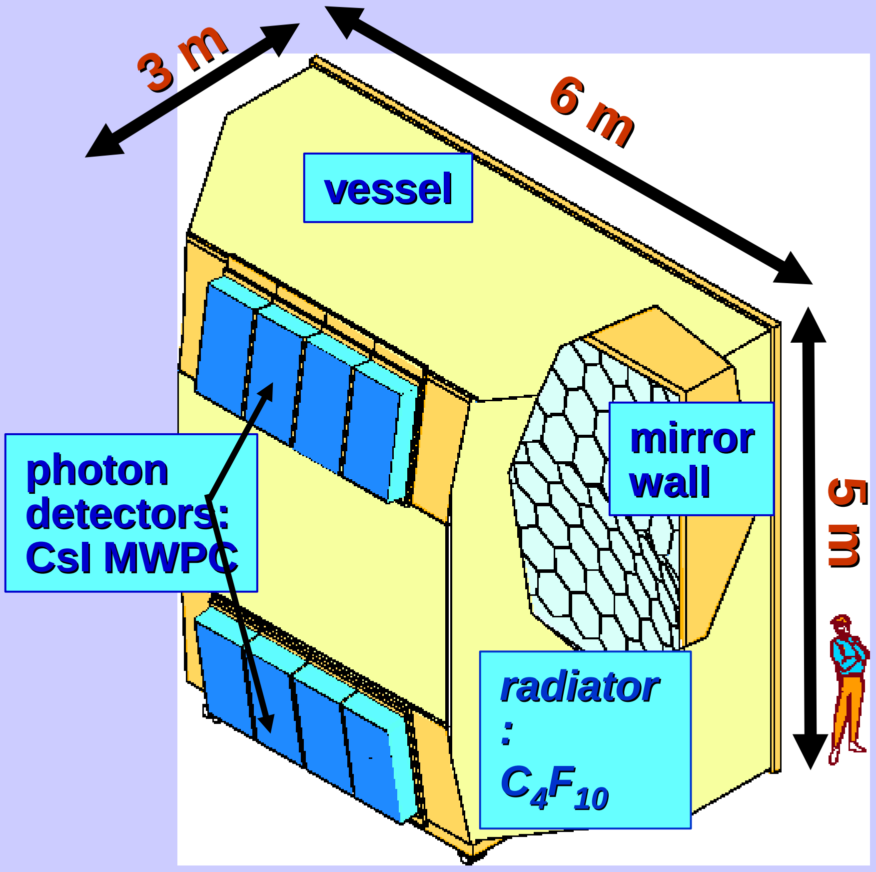
- The target material is kept at a low temperature (0.4 K) + strong magnetic field – very high electron polarisation is achieved.
- Microwave radiation of energy needed for the simultaneous flip of the proton and electron spins.
- This energy depends on the value of the total spin of the electron-proton system.
- After rotation electron relaxates to the lower energy state.
- While proton does not change the spin orientation.
- Separate microwave system for each of the cells.
- In the gap there is a microwave stopper.
- Polarisation is measured by NMR coils



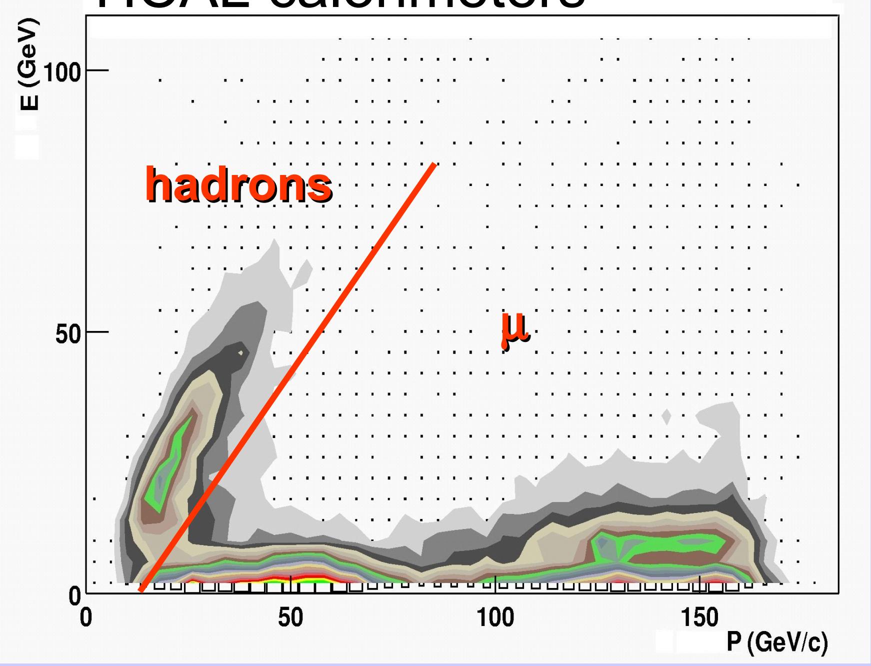
Particles Identification

- >80 m^3 filled with C_4F_{10}
- 116 VUV mirrors
- active area: 5.3 m^2 photodetectors
  82 944 pixels
- >80k channels
- π/K/p identification up to 50 GeV from 2.5/9/17 GeV

80% of K from D^0

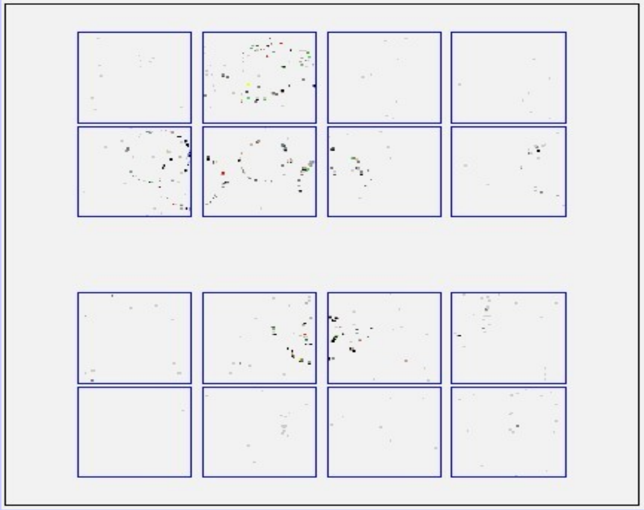


HCAL calorimeters

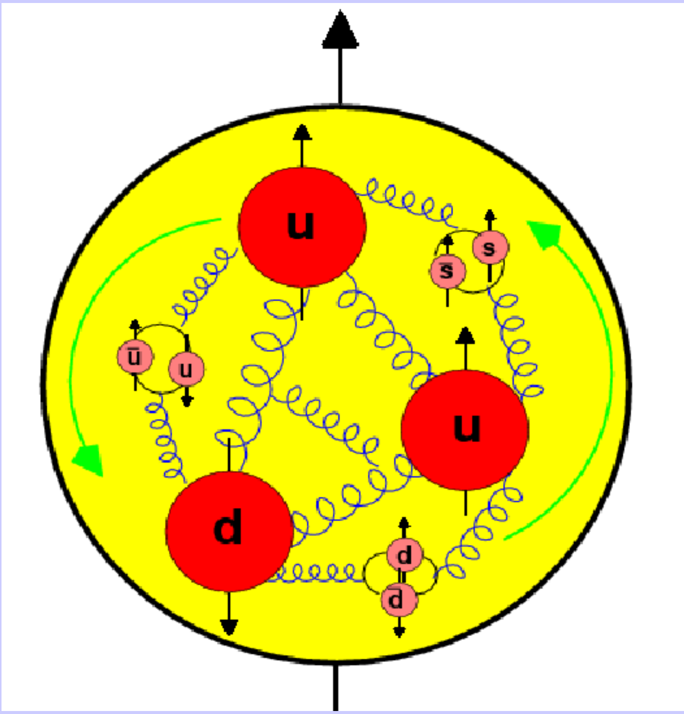


iron – scintilator sandwiche

For muons identification additionally muon filters and calorimeters are used



Motivation



Nucleon spin decomposition:

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

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 ~0.25
- 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?

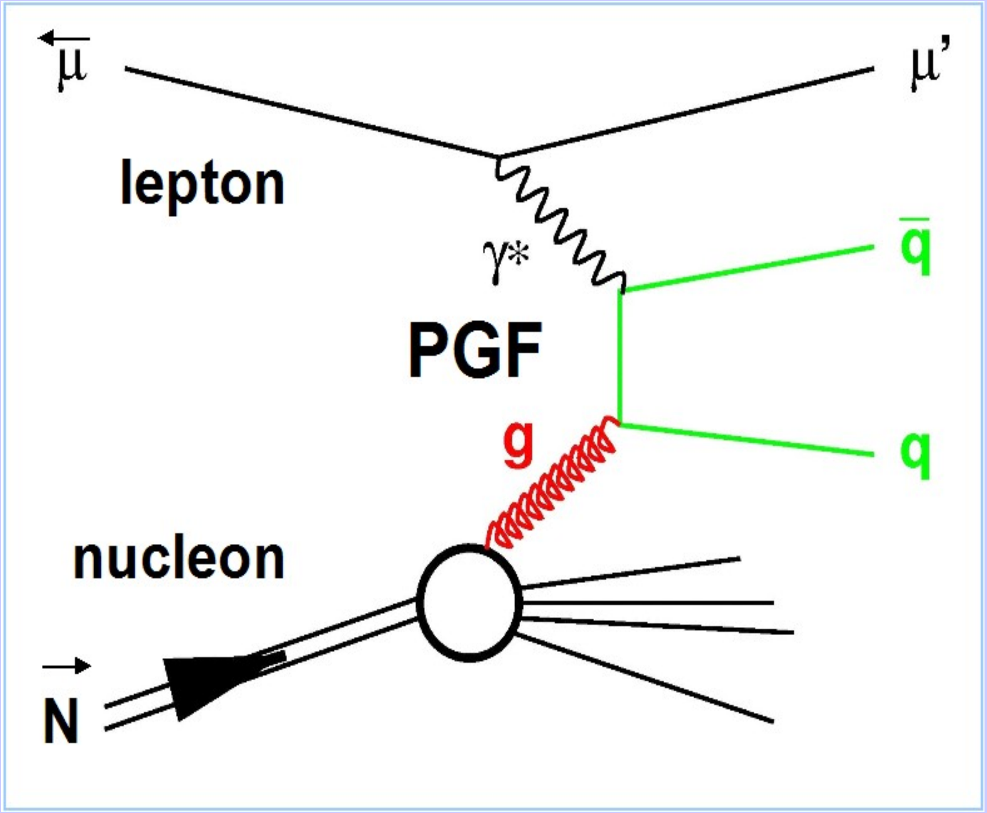
If ΔG=0.4 then $\tfrac{1}{2} \approx \tfrac{1}{2}\, 0.25 + 0.4$

SPIN CRISIS

How to measure ΔG?

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

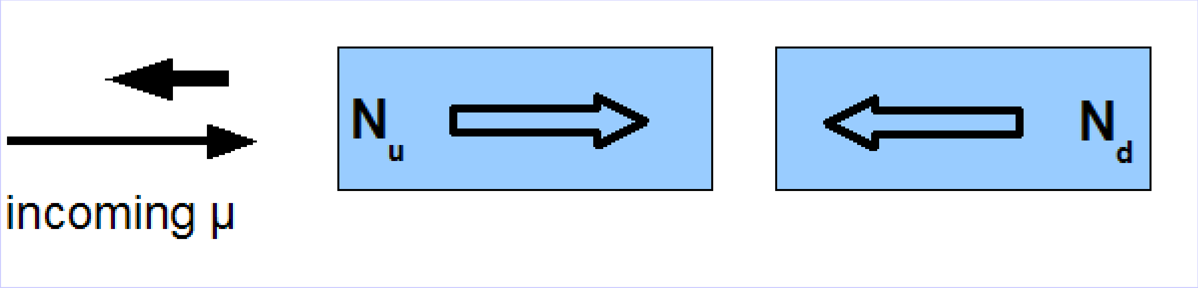
Photon Gluon Fussion (PGF): $\gamma^* g \rightarrow \bar{q}q$



What is measured in the experiment

Asymmetry of the cross sections for PGF process: $$A = \frac{\sigma^{\uparrow\Downarrow} - \sigma^{\uparrow\Uparrow}}{\sigma^{\uparrow\Downarrow} + \sigma^{\uparrow\Uparrow}}$$

In the experiment we have:

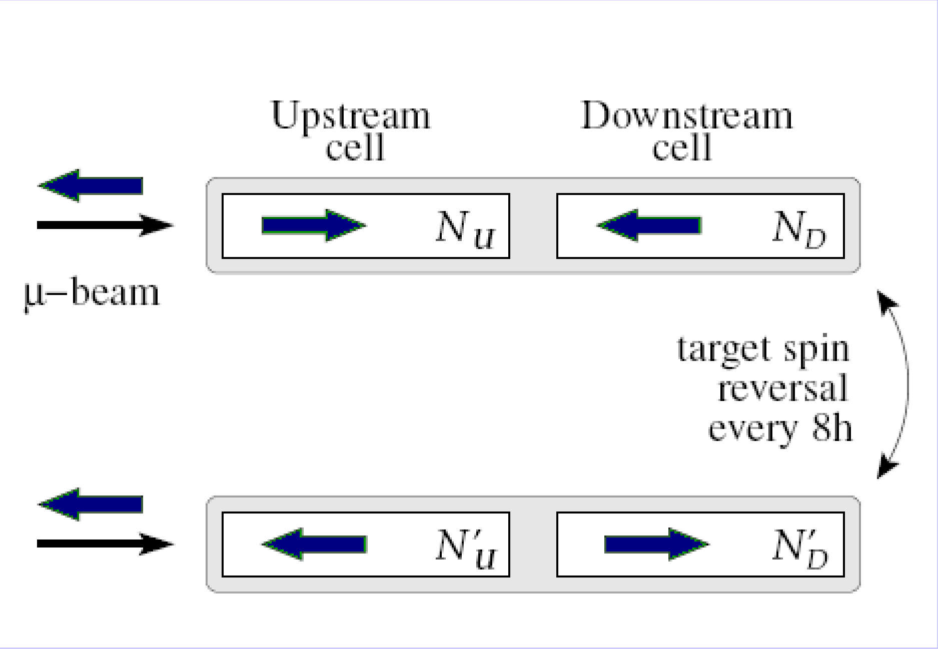


Asymmetry for the interactions measured in the experiment:

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

- Both spin combinations are measured simultaneously.
- Measurment independent on the beam flux
- But the detectors acceptance is different for both target cells.

What is measured in the experiment



Taking into account also asymmetry after pol. rotation:

$$A_{\exp} = 1/2\left(\frac{N_u - N_d}{N_u + N_d} + \frac{N_d' - N_u'}{N_d' + N_u'}\right)$$

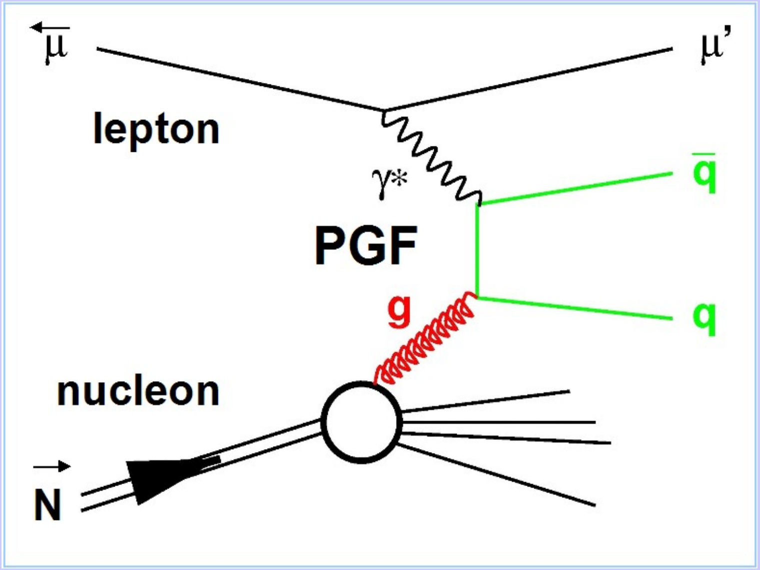
The physical and experimental asymmetries:

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

P_T – target polarization (~50%), ± 5%
P_B – beam polarization (~76%, 81%), ± 5%
f – dillution factor (~40%) ± 5%

Methods of the PGF measurement

Photon Gluon Fussion:



I method – 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
- less MC dependent
- limited statistics

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

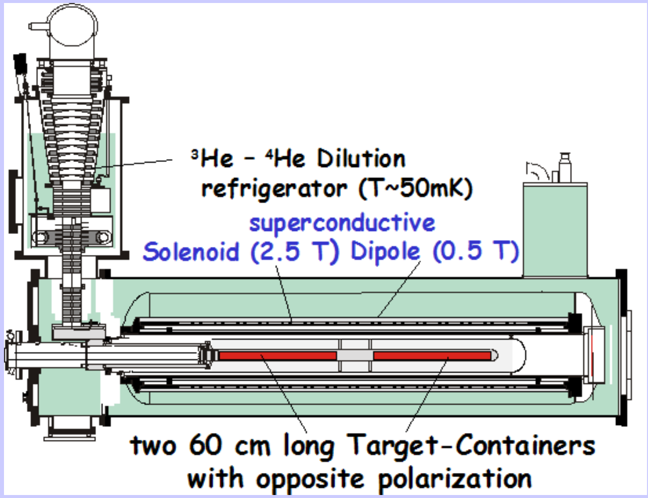
- hard scale set by Q^2
- larger statistics
- resolved photon negligible
- large contamination of other processes
- strong dependence on MC

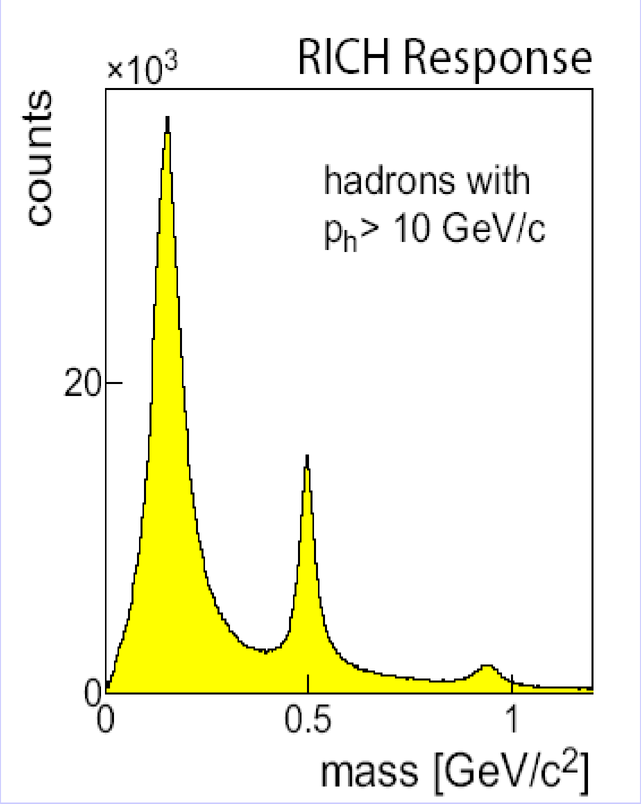
III method – 2 high p_T hadron
(Q^2<1 GeV^2)

- hard scale set by p_T
- very large statistics
- resolved photon not negligible
- large contamination of other processes
- very strong dependence on MC (model dependence)

The open charm method

Open charm method





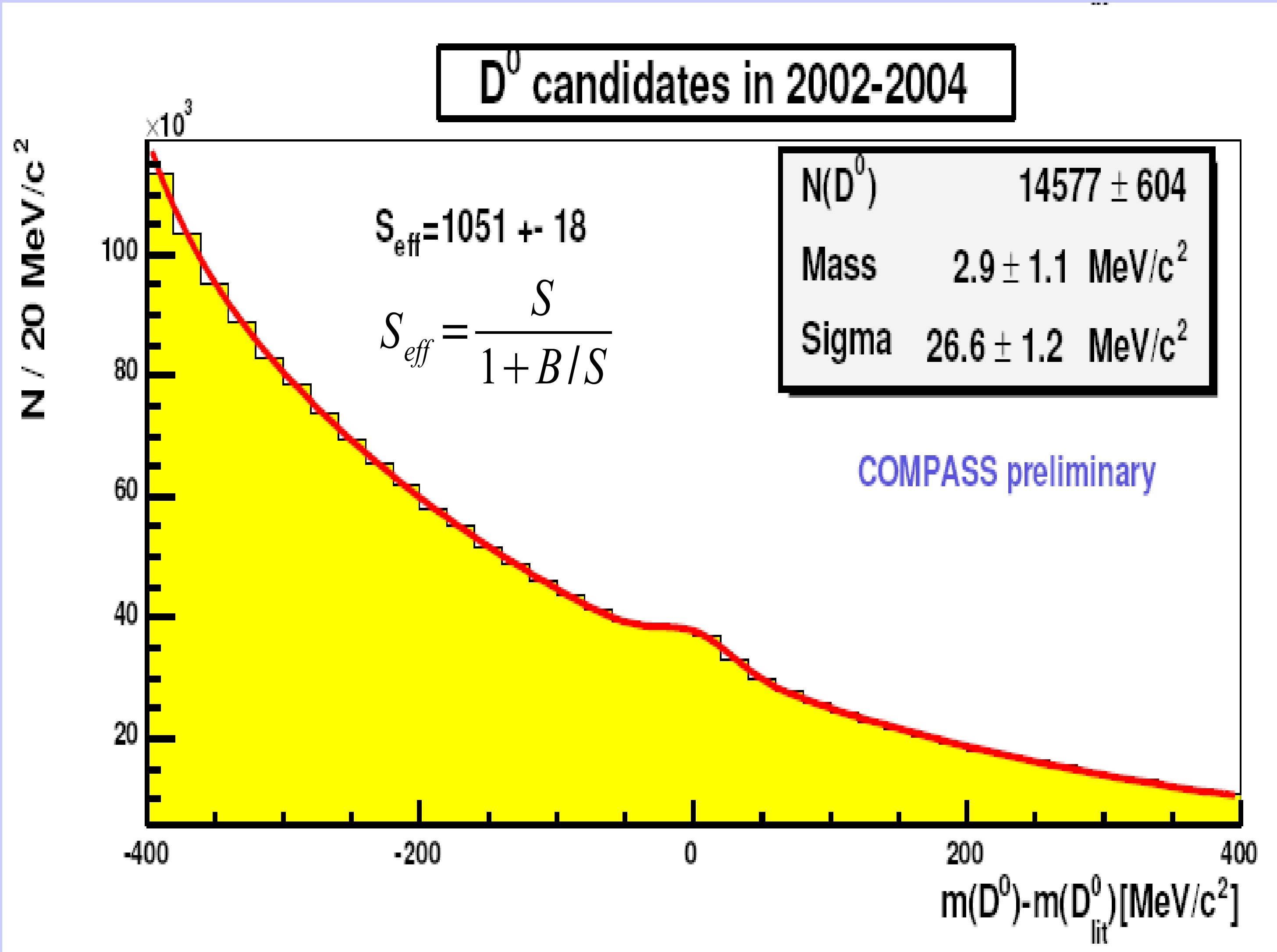
$D^0 \rightarrow K\pi$ (BR ~4%)

- 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
- Two methods of PID:
  - χ^2
  - *Likelihood*
- π is not identified as K

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

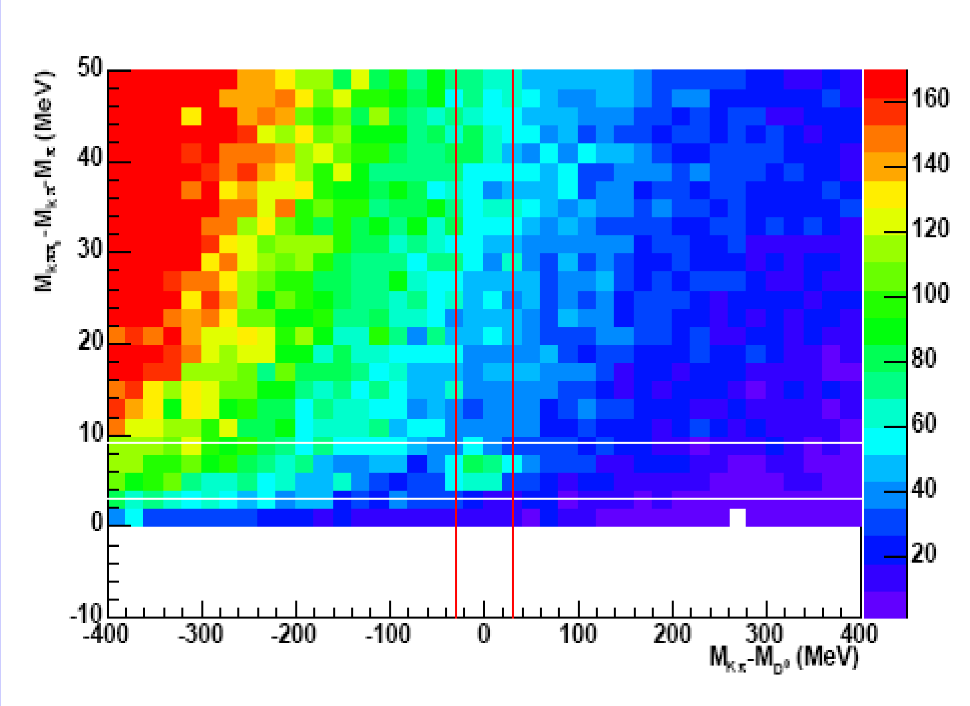
Open charm method



Still high combinatorial background...

Open charm method

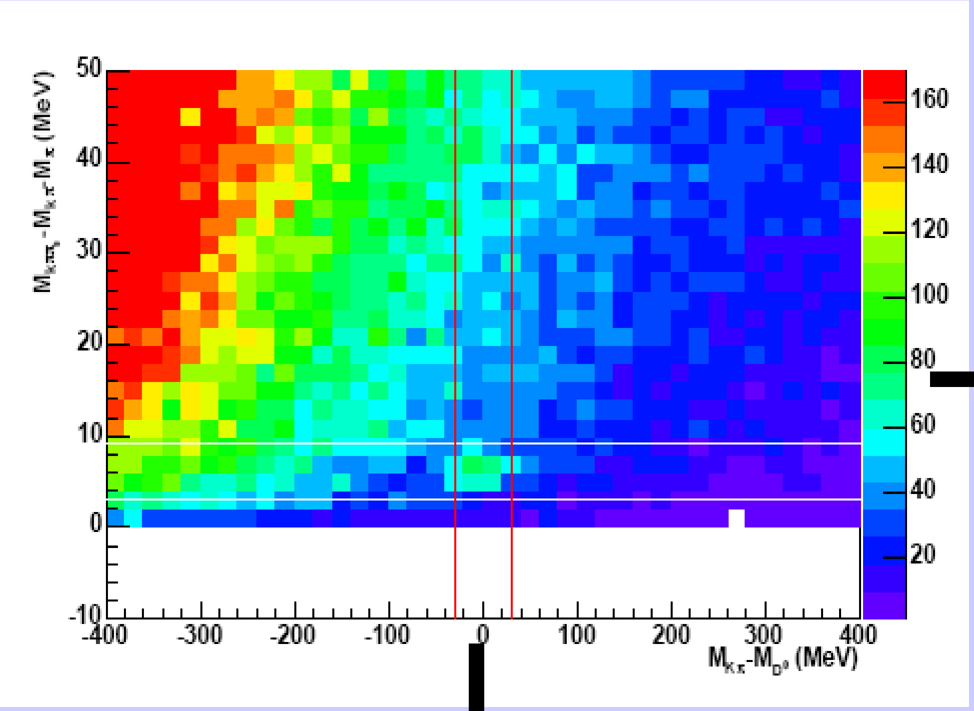
- ~30% D^0 comes from D^* decays:
  $$D^* \rightarrow D^0 \pi_s \rightarrow K \pi \pi_s$$
- Cut on a mass difference:
  $$3.1 \text{ MeV} < M_{K\pi\pi} - M_{K\pi} - M_{\pi} < 9.1 \text{ MeV}$$

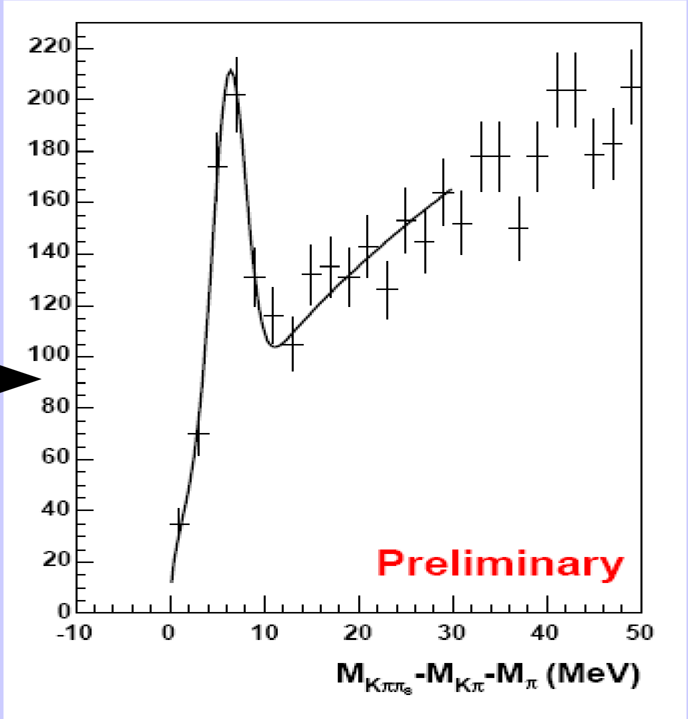


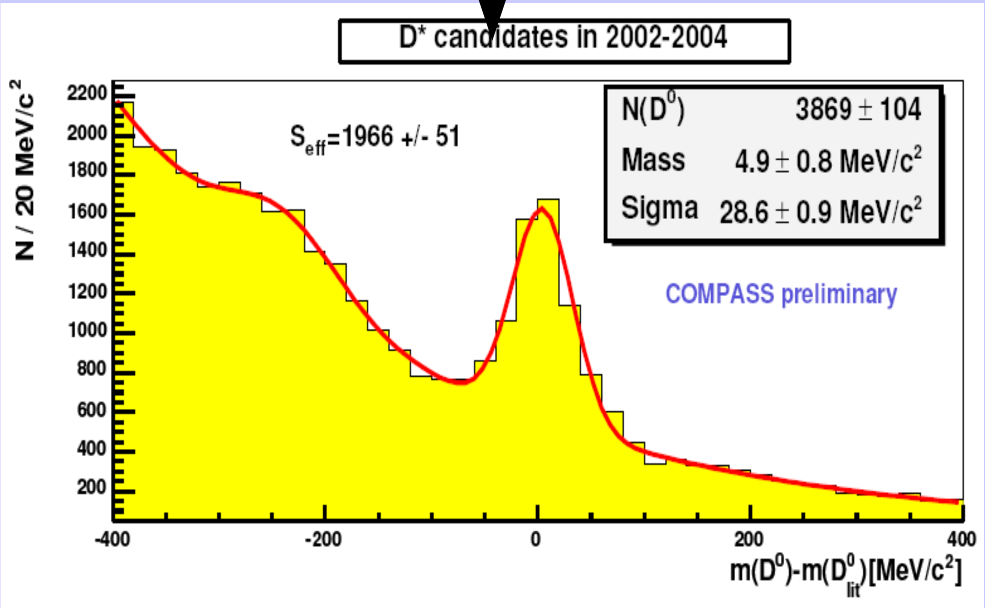
- Cuts on kinematics:
  - $z(D^0) > 0.20$
  - $|\cos\theta_K^*| < 0.85$

(
- $z(D^0) > 0.25$
- $|\cos\theta_K^*| < 0.5$
)

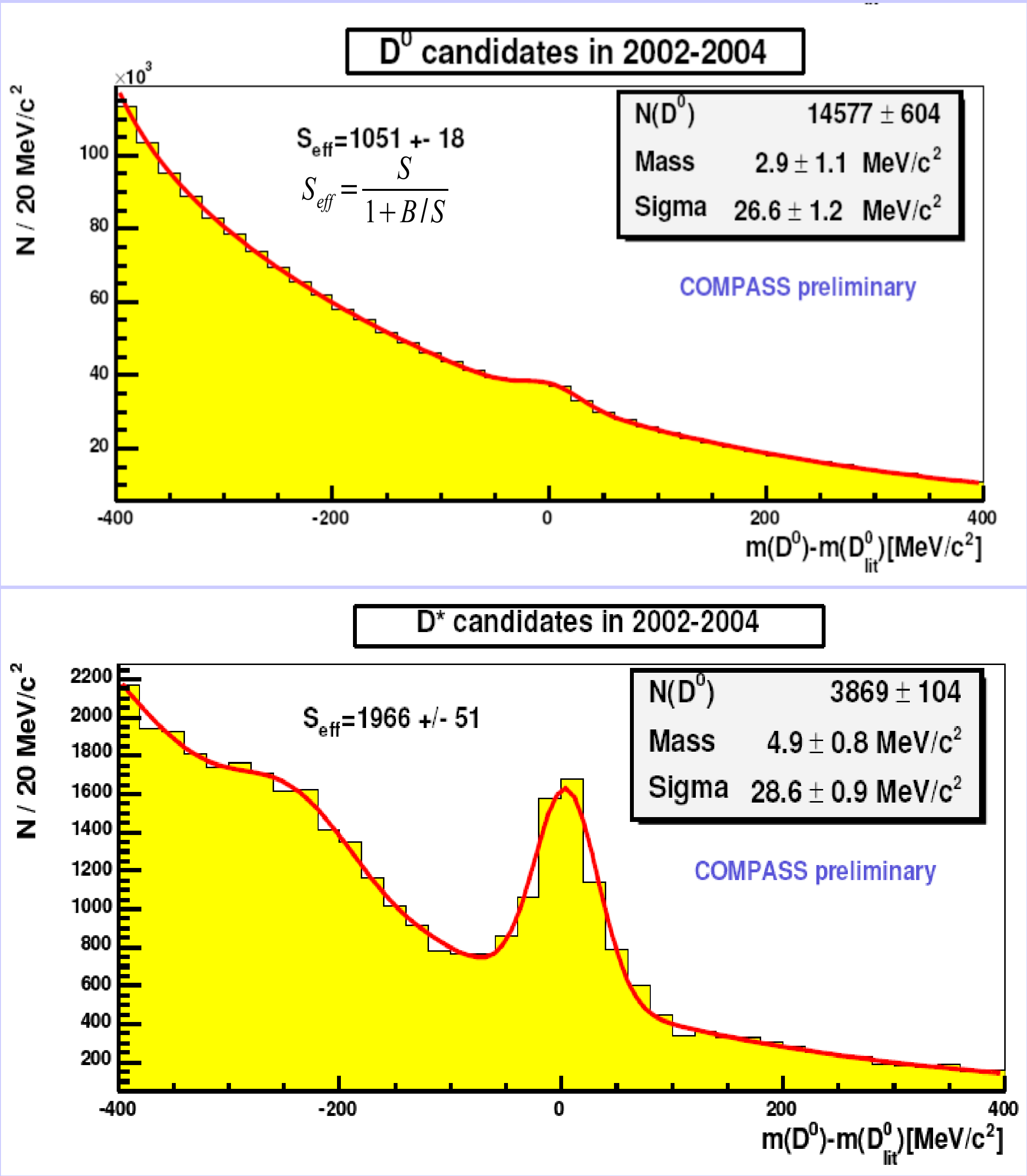
Open charm method







Open charm method



Open charm method

From asymmetry to ΔG/G:

$$A = \frac{S}{S+B} < a_{LL} > \frac{\Delta G}{G}$$

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

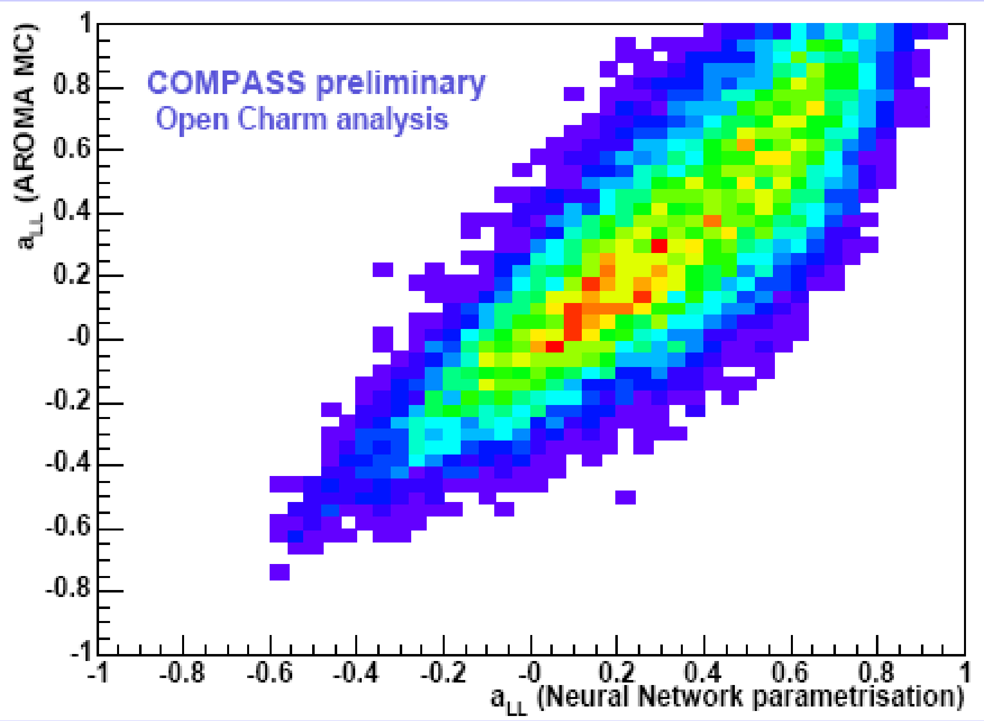
Therefore

$$\frac{\Delta G}{G} = \frac{1}{P_T P_B < a_{LL} > f\, S/(S+B)} 1/2 \left(\frac{N_u - N_d}{N_u + N_d} + \frac{N_d' - N_u'}{N_d' + N_u'} \right)$$

Instead of using average P_B, f, S/(S+B) and a_{LL} a weighted method is introduced – statistical error minimalisation

Open charm method

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



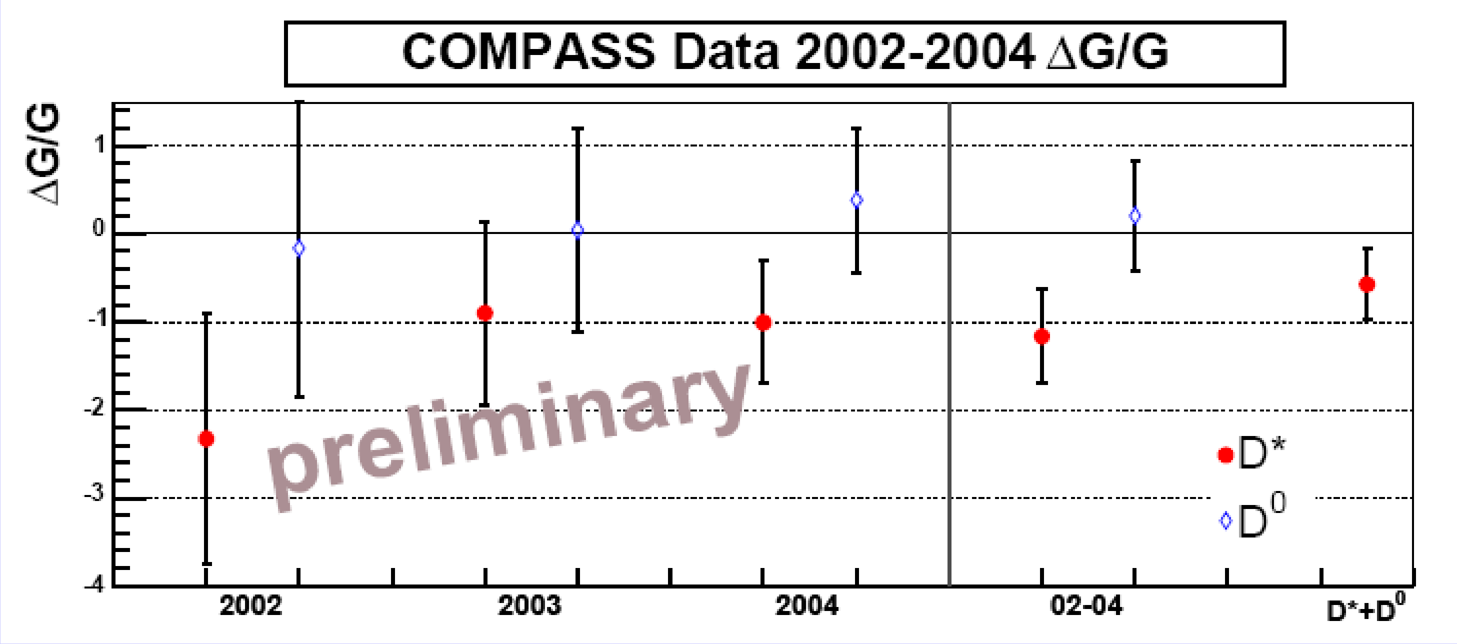
Correlation factor 82%

The preliminary results from open charm channel 2002/3/4

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

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

The studies on the systematical uncertainty ongoing



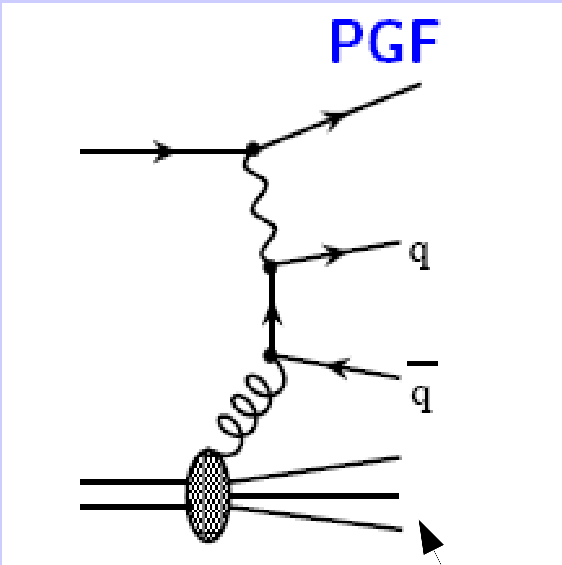
Plans for the future: improve RICH PID, cross section

The high p_T method
(Q^2>1 GeV^2)

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

Signal

Background



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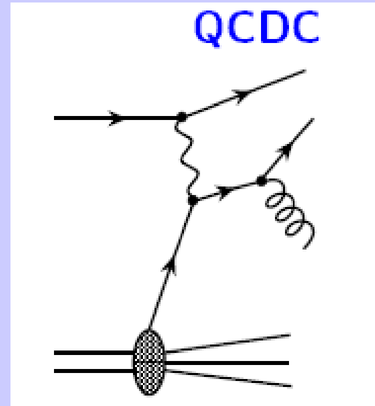

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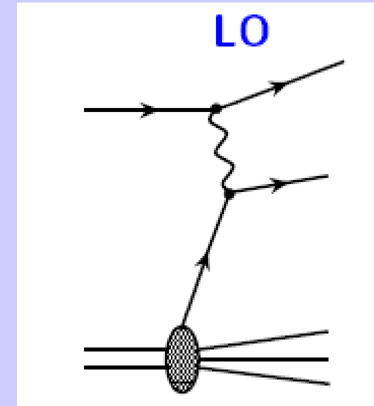
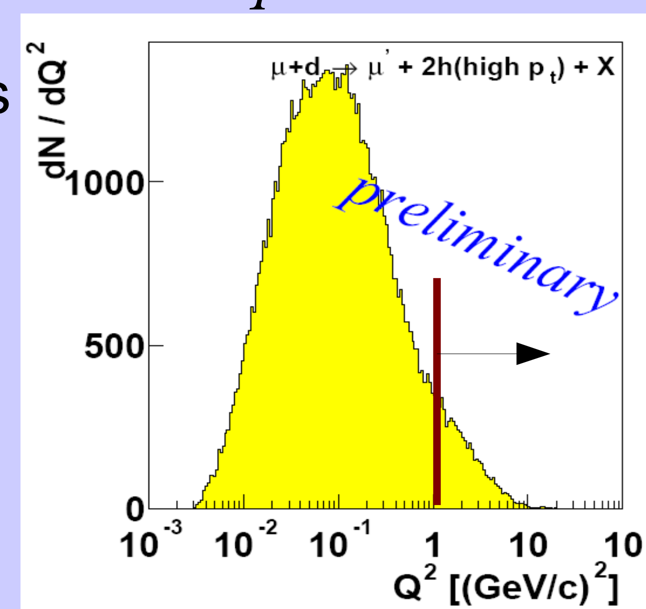


$$\frac{A}{D} = R_{pgf}\, a_{LL}^{PGF} \frac{\Delta G}{G} + \left(R_{QCDC}\, a_{LL}^{QCDC} + R_{LO}\, a_{LL}^{LO}\right) \frac{\Delta q}{q}$$

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



- Q^2>1GeV^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

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

- Cuts used:
  - hadrons detected in the hadronic calorimeters
  - & discarded if detected behind the hadron absorbers
  - current fragmentation region (x_F>0.1 & z>0.1)
  - 0.1<y<0.9 (assure that there is no big influence of radiative corrections),
  - $x<0.05 \rightarrow A_1^d$ - small, LO and QCDC negligible
  - p_{T1}, p_{T2} > 0.7 GeV
  - $p_{T1}^2 + p_{T2}^2 > 2.5\ GeV^2$
  - invariant mass $m_{h_1h_2}$ > 1.5 GeV (avoid the resonance region)

as in SMC

The preliminary results from 2 hadrons with high p_T (Q^2>1 GeV^2) channel 2002/3

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

$R_{PGF} = 0.34 \pm 0.07$

$x_g = 0.13$ (RMS 0.08)

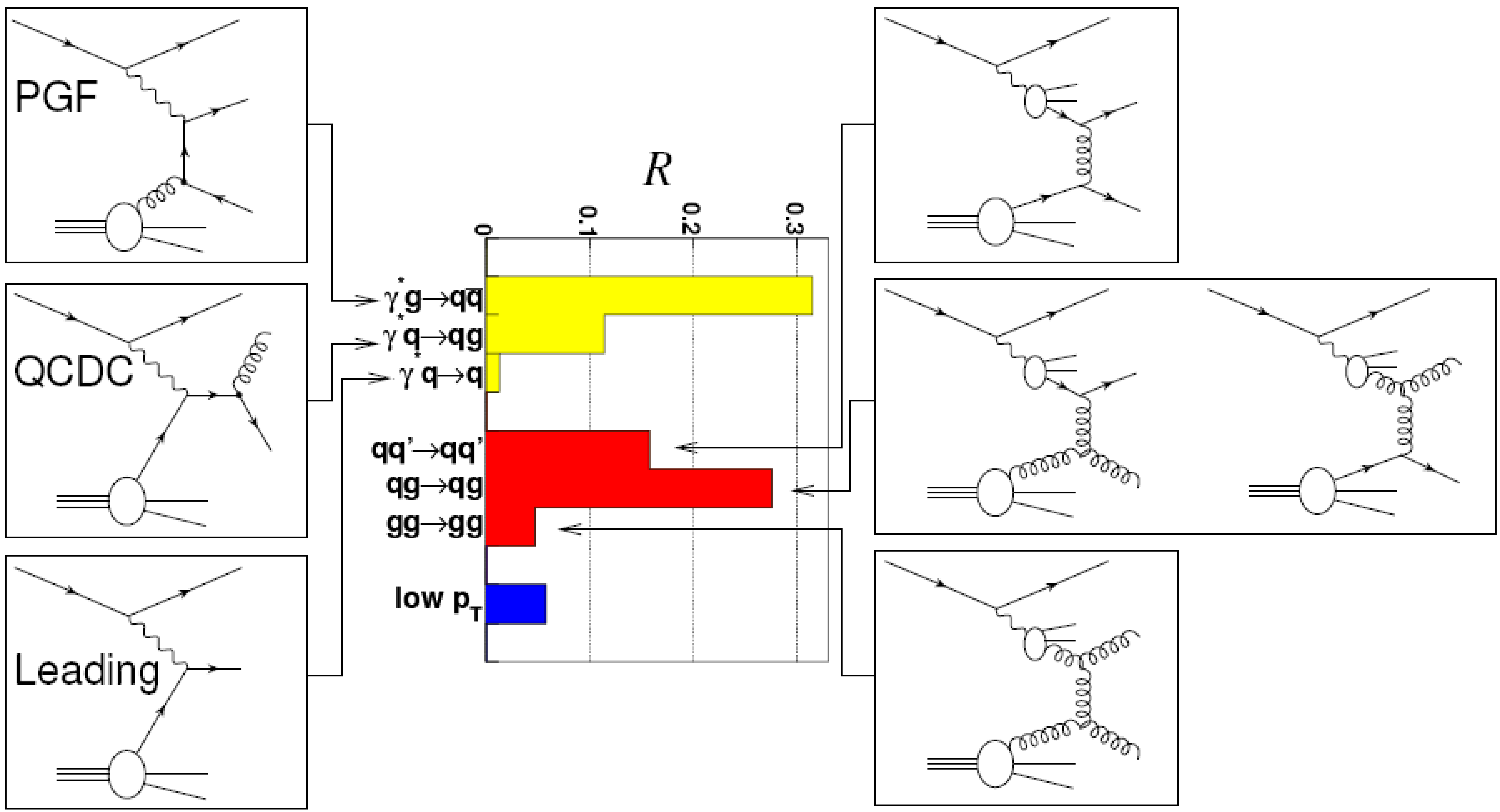
2 hadrons with high p_T (Q^2>1 GeV^2) - prospects

- Scale is set by Q^2 – the cut on Σp_{Ti}^2>2.5 GeV^2 can be tuned
- Optimal cuts can be found with Neural Networks
  - ➔ Higher statistics and lower R_{PGF}
  - ➔ Lower statistics and higher R_{PGF}
- 2004 data under studies
- The analysis is ongoing – results will be presented soon

The high p_T method
(Q^2<1 GeV^2)

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

Direct processes: **Resolved-photon processes:**



$q\bar{q} \to q\bar{q}$ + $q\bar{q} \to gg$ + $gg \to q\bar{q}$ ≈ 0.6%
negligible

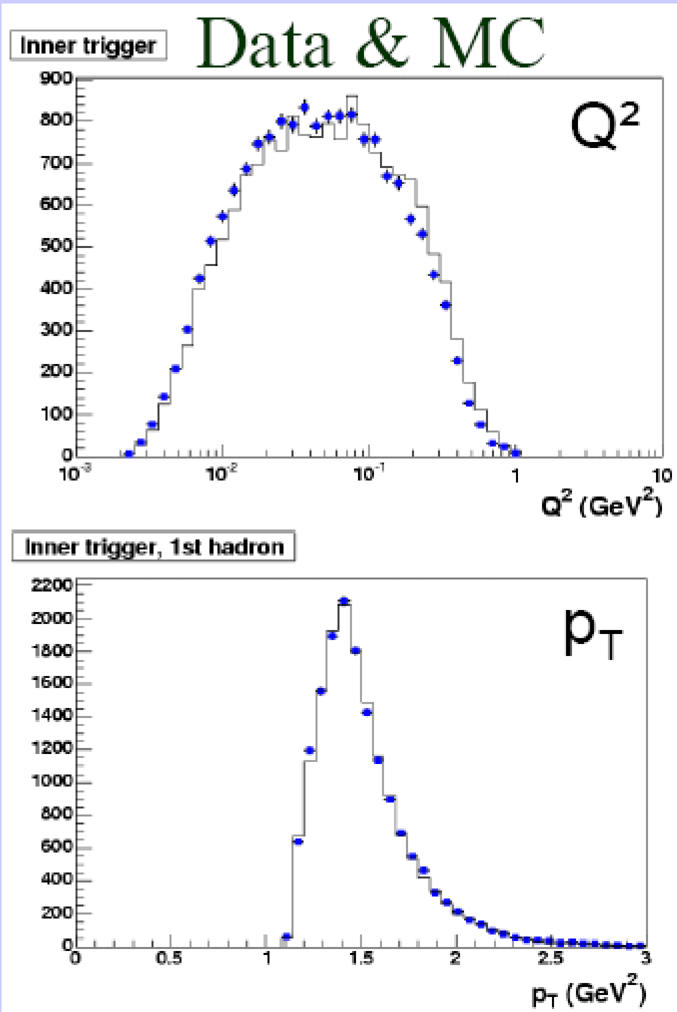
90% of statistics with (Q^2<1) - ~500 k events from 2002-4

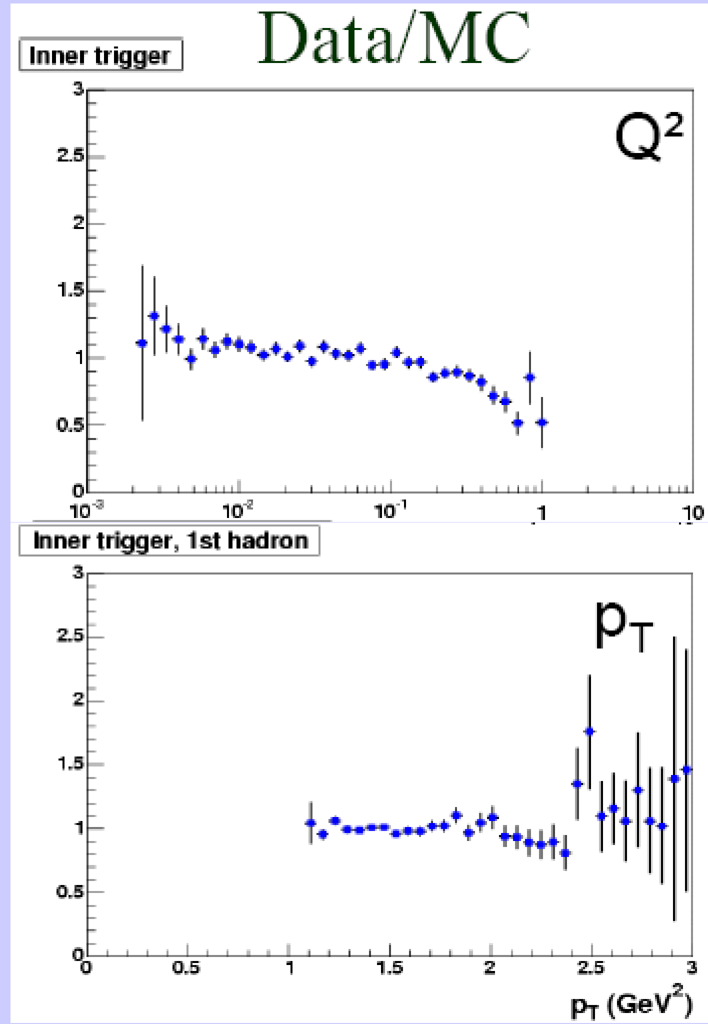
2 hadrons with high p_T (Q^2<1 GeV^2)

The fractions of each process obtained from PYTHIA 6.2 Monte Carlo.

+ GEANT for the detector description

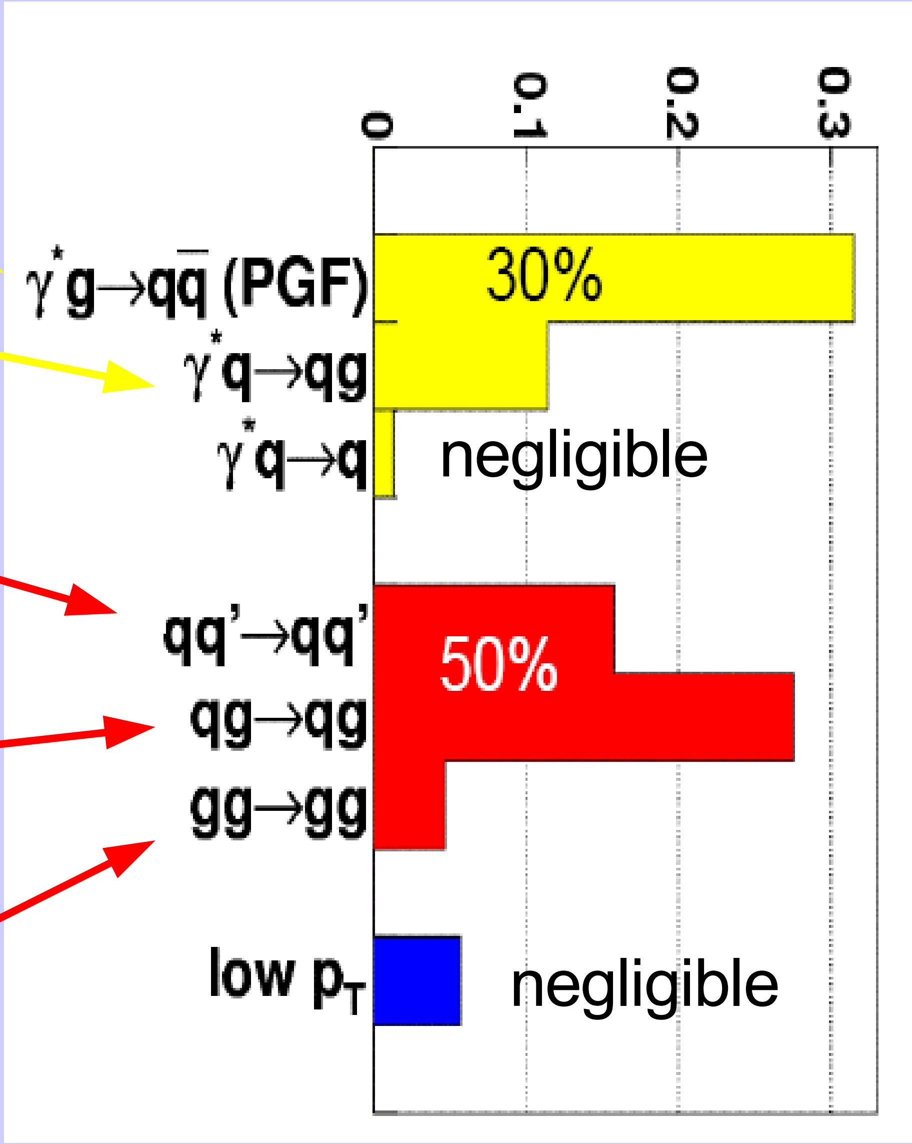
The agreement between Real Data (blue points) and Monte Carlo:





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

$$\frac{A}{D} = R_{PGF}\, a_{LL}^{PGF} \frac{\Delta G}{G} + R_{QCDC}\, a_{LL}^{QCDC} \frac{\Delta q}{q} + R_{qq}\, a_{LL}^{qq} \frac{\Delta q}{q} \left(\frac{\Delta q}{q}\right)^{\gamma} + R_{qq}\, a_{LL}^{qg} \frac{\Delta q}{q} \left(\frac{\Delta G}{G}\right)^{\gamma} + R_{gg}\, a_{LL}^{gg} \frac{\Delta G}{G} \left(\frac{\Delta G}{G}\right)^{\gamma}$$



This process also probes gluon polarization

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

For $\Delta q/q$ GRV98 & GRSV2000 used

The problem:
Photon polarized PDFs are a sum of a perturbative part and a non-perturbative.

- Perturbative part Δq^{γ}_{pert} can be calculated
- Non-perturbative part $\Delta q^{\gamma}_{nonpert}$ has to be measured
- But it is not measured yet!
- An estimation:

$$-q^{\gamma}_{nonpert} < \Delta q^{\gamma}_{nonpert} < q^{\gamma}_{nonpert}$$

- The uncertainty is included in a systematical error

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

- The systematical error can be decomposed:
  - False asymmetries (experimental systematics): 0.014
  - Resolved photon contribution: 0.013
  - Monte Carlo tuning: 0.052
    - The MC parameters were changed in a range where the resonable agreement between the data and MC remains
    - 30% difference in R_{PGF} found

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

The results 2002/3 (**PLB 633 (2006) 25-32**):

$$\Delta G/G = 0.024 \pm 0.089 \text{ (stat.)} \pm 0.057 \text{ (syst.)}$$

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

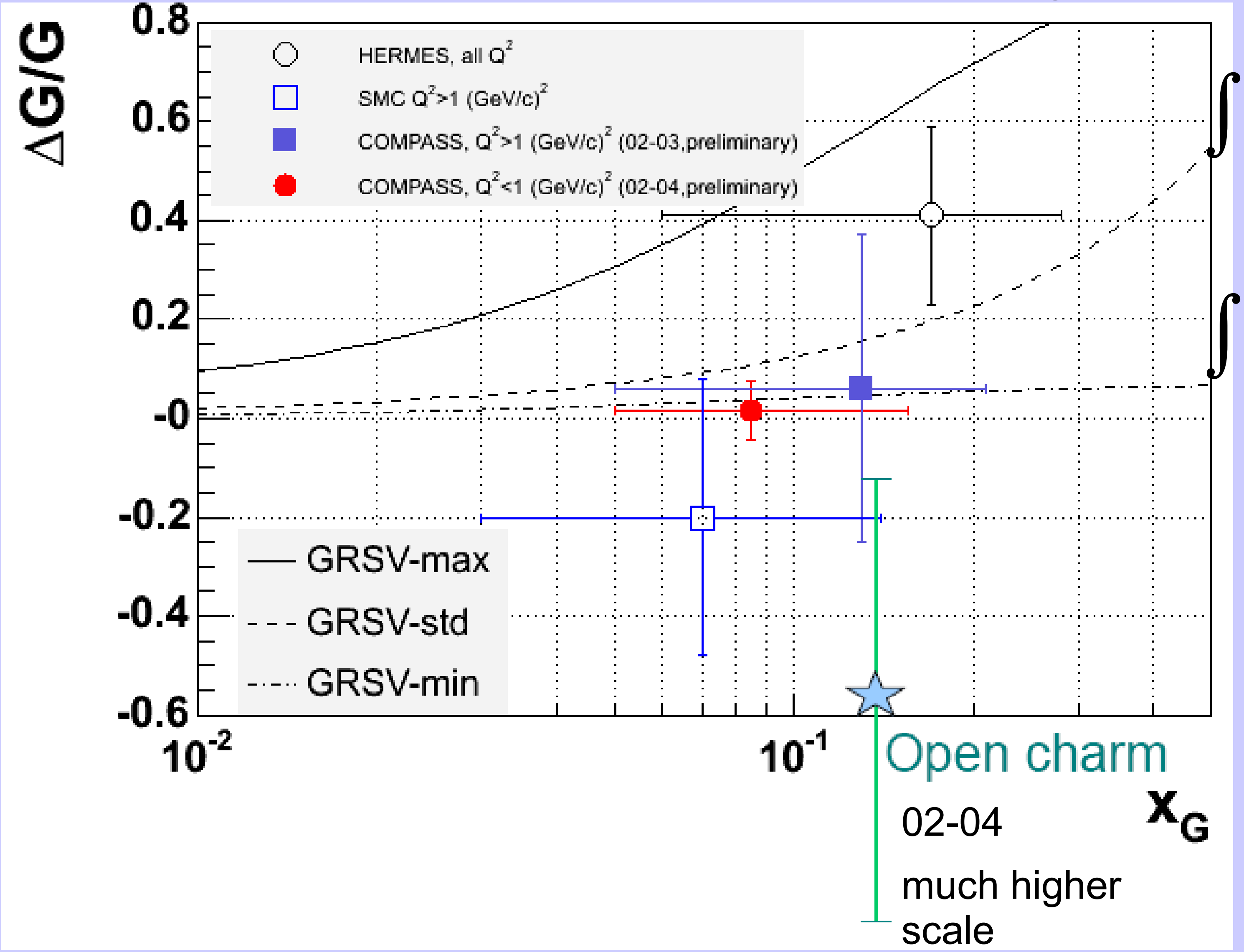
scale: 3 GeV^2

The preliminary results 2002/3/4:

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

The results from COMPASS

$$\int \Delta G\, dx = 2.5$$

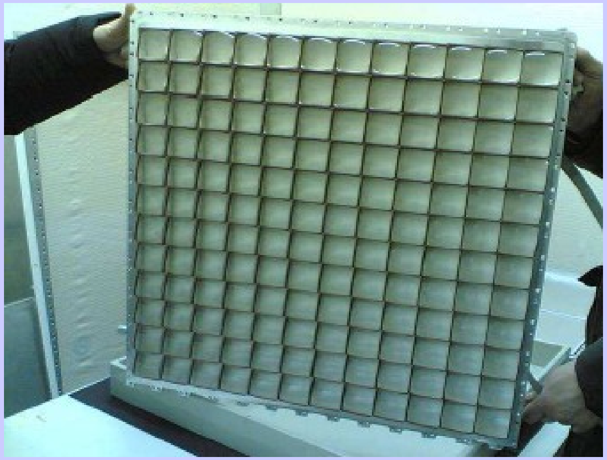


$$\int \Delta G\, dx = 0.62$$

$$\int \Delta G\, dx = 0.16$$

Prospects

- Results from 2002-4 high p_T (Q^2>1) analysis available soon
- 2002-4 open charm analyis still ongoing – reduction on statistical error expected, systematical error
- For high p_T analysis bining in x_g considered, NN under investigation
- Improvements of COMPASS in 2006:
  - New target solenoid – improvement in hadron acceptance (+30%)
  - Improvements in RICH efficiency
  - New tracking detectors
- We hope to double statistics with 2006 data



Summary

- New results of $\Delta G/G$ measurments were presented
- 3 channels were studied:
  - → Open charm (2002-4):

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

  - → High p_T (Q^2>1) (2002-3):

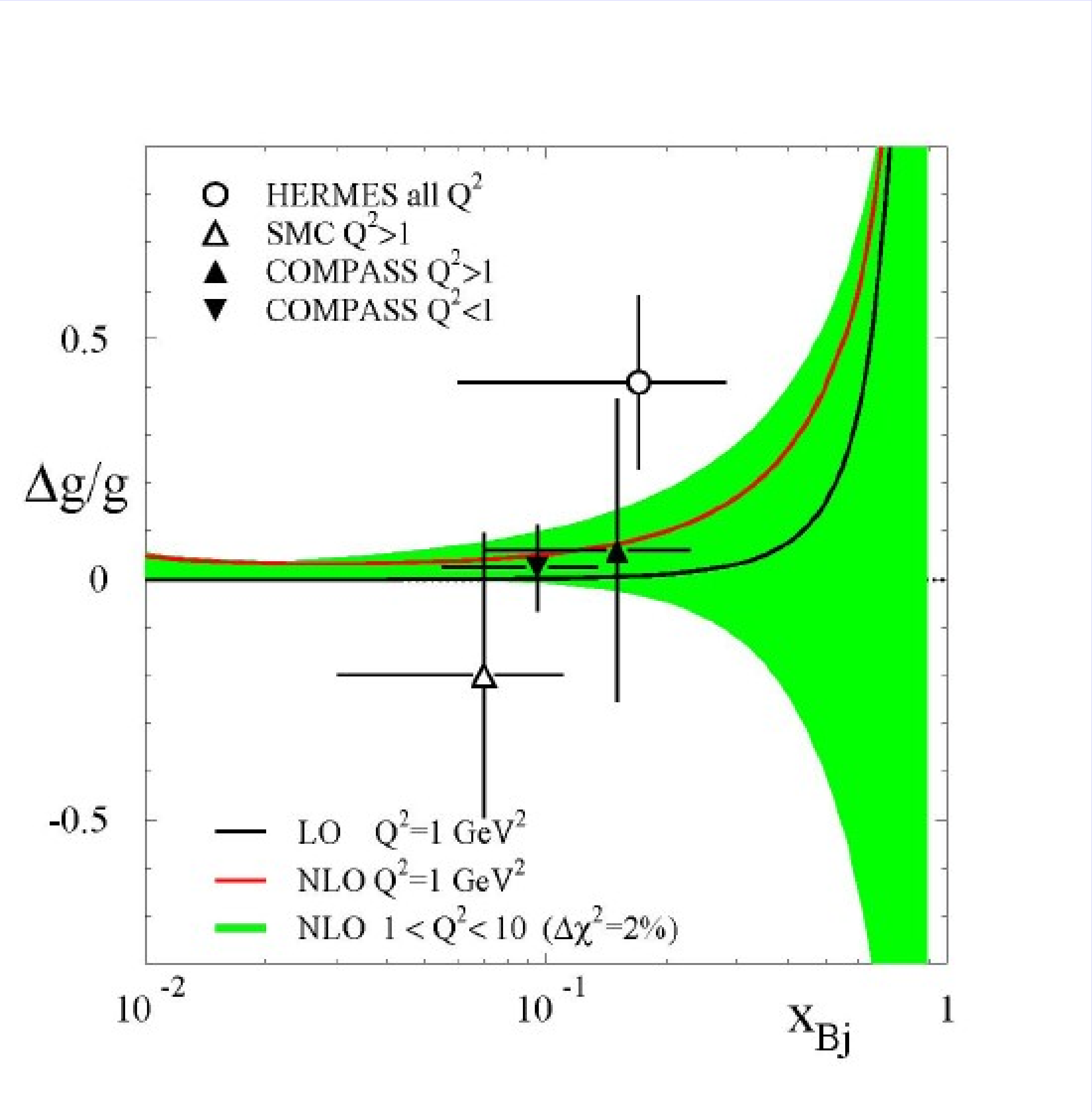
$$\Delta G/G = 0.06 \pm 0.31 \text{ (stat.)} \pm 0.06 \text{ (syst.)}$$

  - → 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

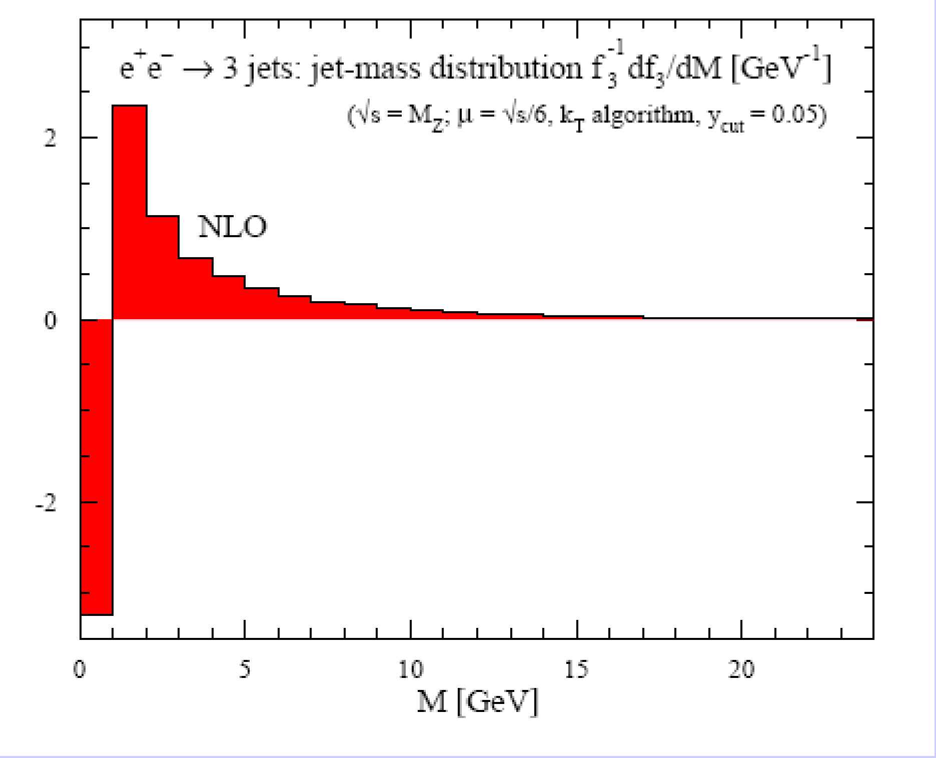
Summary



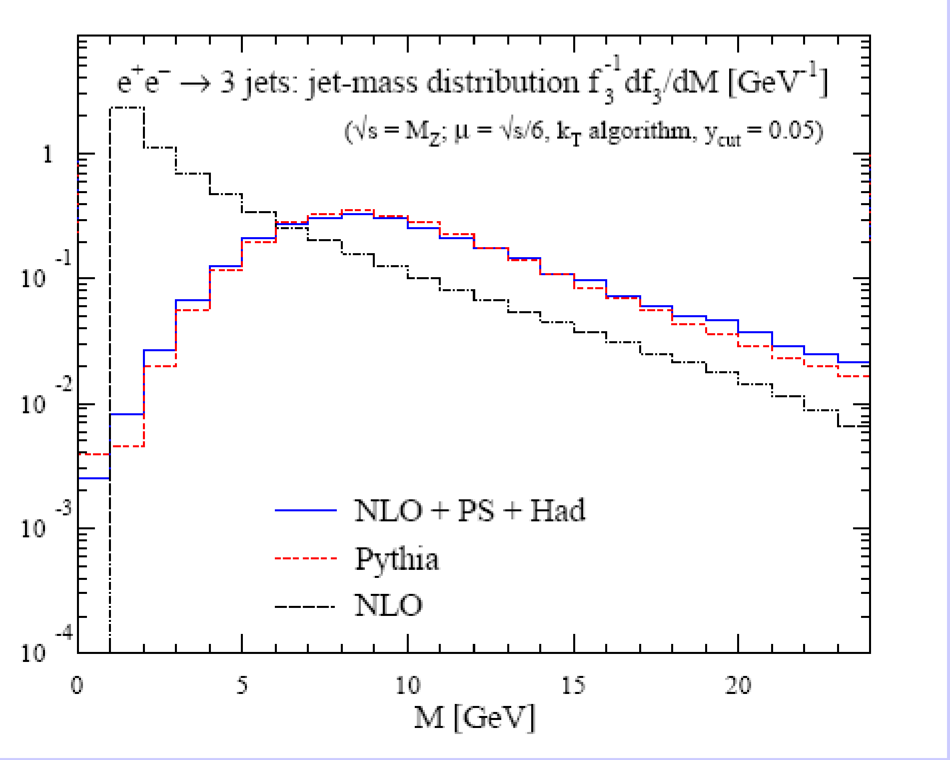
COMPASS, HERMES and SMC points not included in the fit

From presentation of Rodolfo Sassot in DIS06

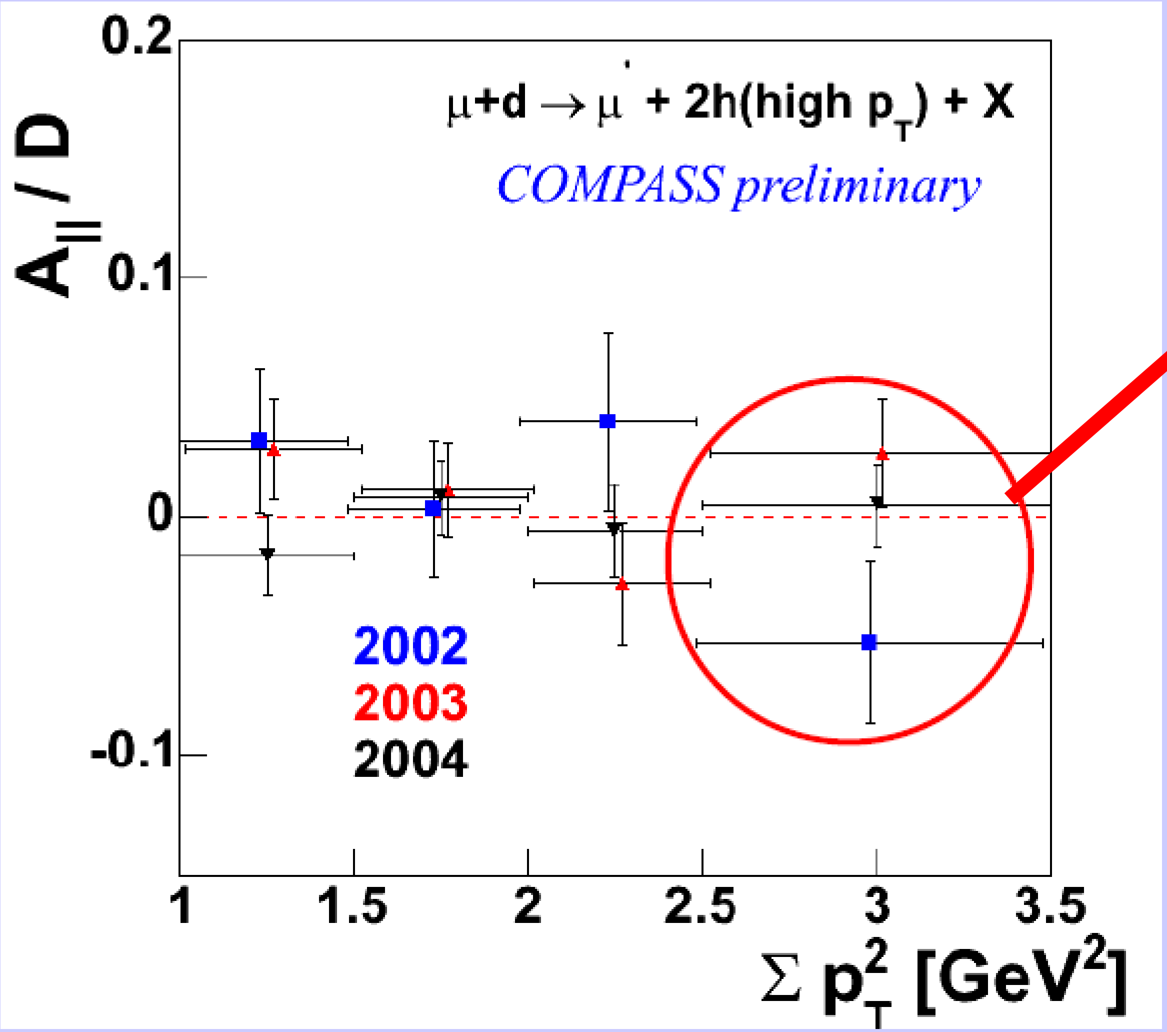
Spares



e+e− → 3 jets: jet-mass distribution f3-1 df3/dM [GeV-1]
(√s = MZ; μ = √s/6, kT algorithm, ycut = 0.05)
NLO
2
0
-2
0
5
10
15
20
M [GeV]

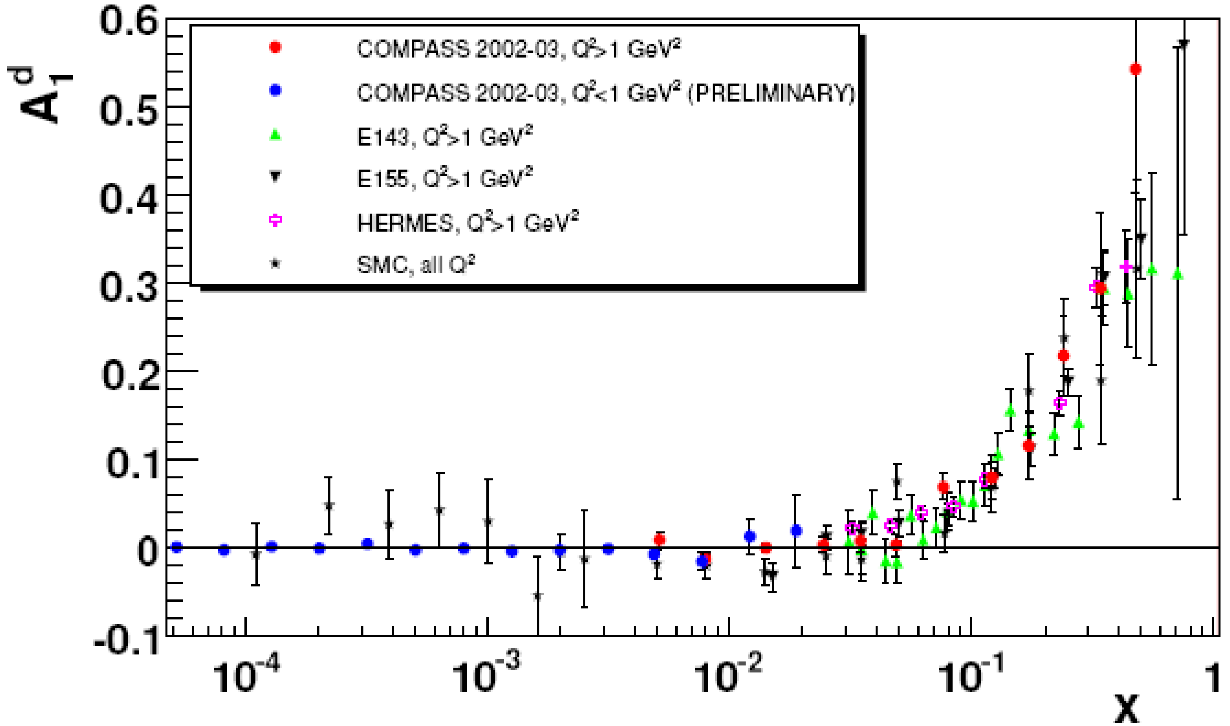


e+e− → 3 jets: jet-mass distribution f3-1 df3/dM [GeV-1]
(√s = MZ; μ = √s/6, kT algorithm, ycut = 0.05)
NLO + PS + Had
Pythia
NLO
1
10-1
10-2
10-3
10-4
0
5
10
15
20
M [GeV]



Values used for extraction of $\Delta G/G$

A_1^d WORLD DATA



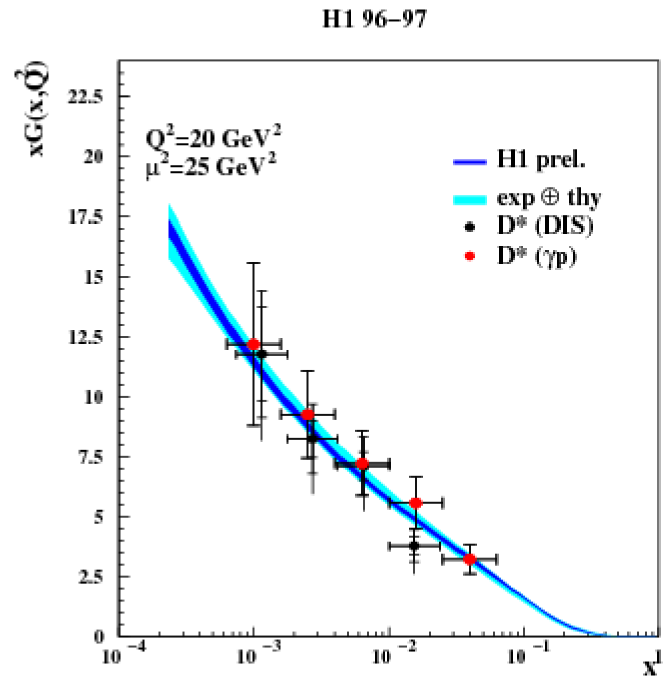


Figure 2.11: The gluon momentum distribution extracted from a QCD analysis compared to the result obtained with an open charm tagging approach. The line ("H1 prel") shows $xG(x)$ as extracted via a QCD fit on NMC and H1 data, error bands taking into account theoretical and experimental uncertainties are indicated. The points are obtained from a $D^\star$ meson cross-section measurement by the H1 collaboration. For the DIS measurement $Q^2 > 2\,(\mathrm{GeV}/c)^2$ was required, whereas for the photoproduction (γp) $Q^2 < 0.01\,(\mathrm{GeV}/c)^2$ was used [50].