$\Delta G/G$ results from the COMPASS experiment for $Q^2>1(GeV/c)^2$ using high p_T hadrons

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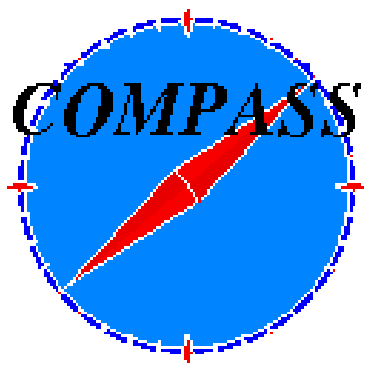
On behalf of the COMPASS Collaboration

1 Oct 2010



Outline

- Motivation
- COMPASS experiment
- Direct measurement of $\Delta G/G$
- High p_T analysis, $Q^2 > 1\ (GeV/c)^2$
- $\Delta G/G$ results
- Summary and Conclusions

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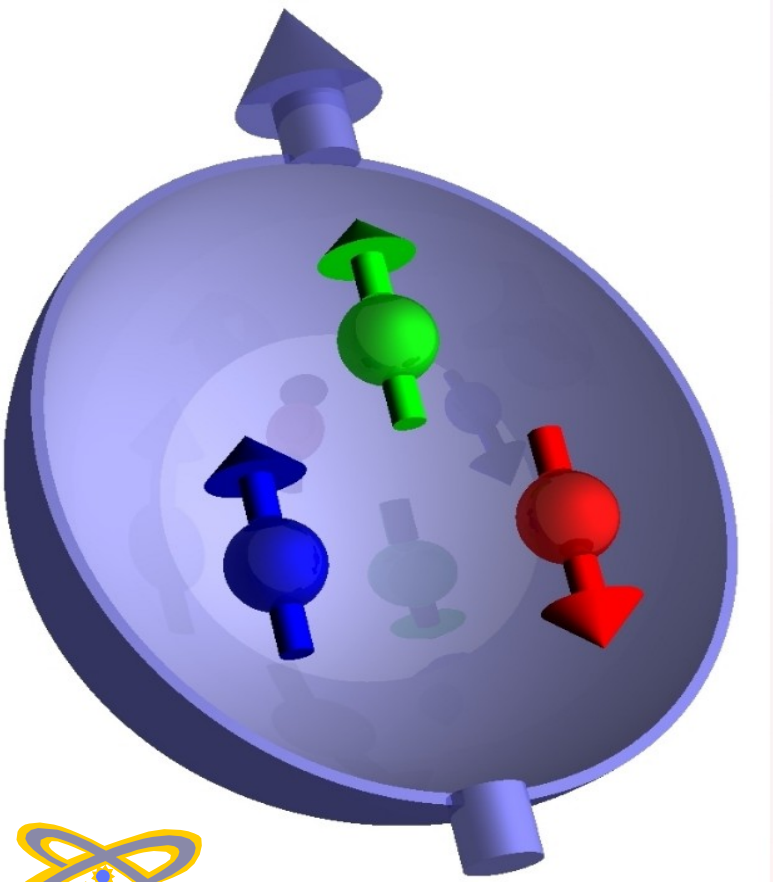
The Nucleon Spin



$S_N = ½ = ½ \Delta\Sigma$

The naïve Quark-Parton Model (QPM) considers only the contribution from quarks

$\Rightarrow \Delta\Sigma = 1$

Using the Ellis-Jaffe Sum rule, Hyperon decays and Relativistic Corrections

$\Rightarrow \Delta\Sigma \approx 0.6$

In 1988 EMC measured

$\Rightarrow \Delta\Sigma = 0.12 \pm 0.17$ (Phys.Lett.B206,364)

Today world data result, including COMPASS, gives:

$\Rightarrow \Delta\Sigma = 0.30 \pm 0.01(\text{stat.}) \pm 0.02(\text{evol.})$

@ $\langle\mu^2\rangle = 3$ (GeV/c)^2

(using QCD NLO fits) Phys.Lett.B647, (2007)8

Spin crisis !

The Nucleon Spin

$$S_N = \frac{1}{2} = \frac{1}{2}\,\Delta\Sigma + \Delta G + L$$

The missing part could be accounted by the following contributions:

ΔG – from gluons

$L = L_g + L_q$ – from orbital angular momenta of quarks and gluons

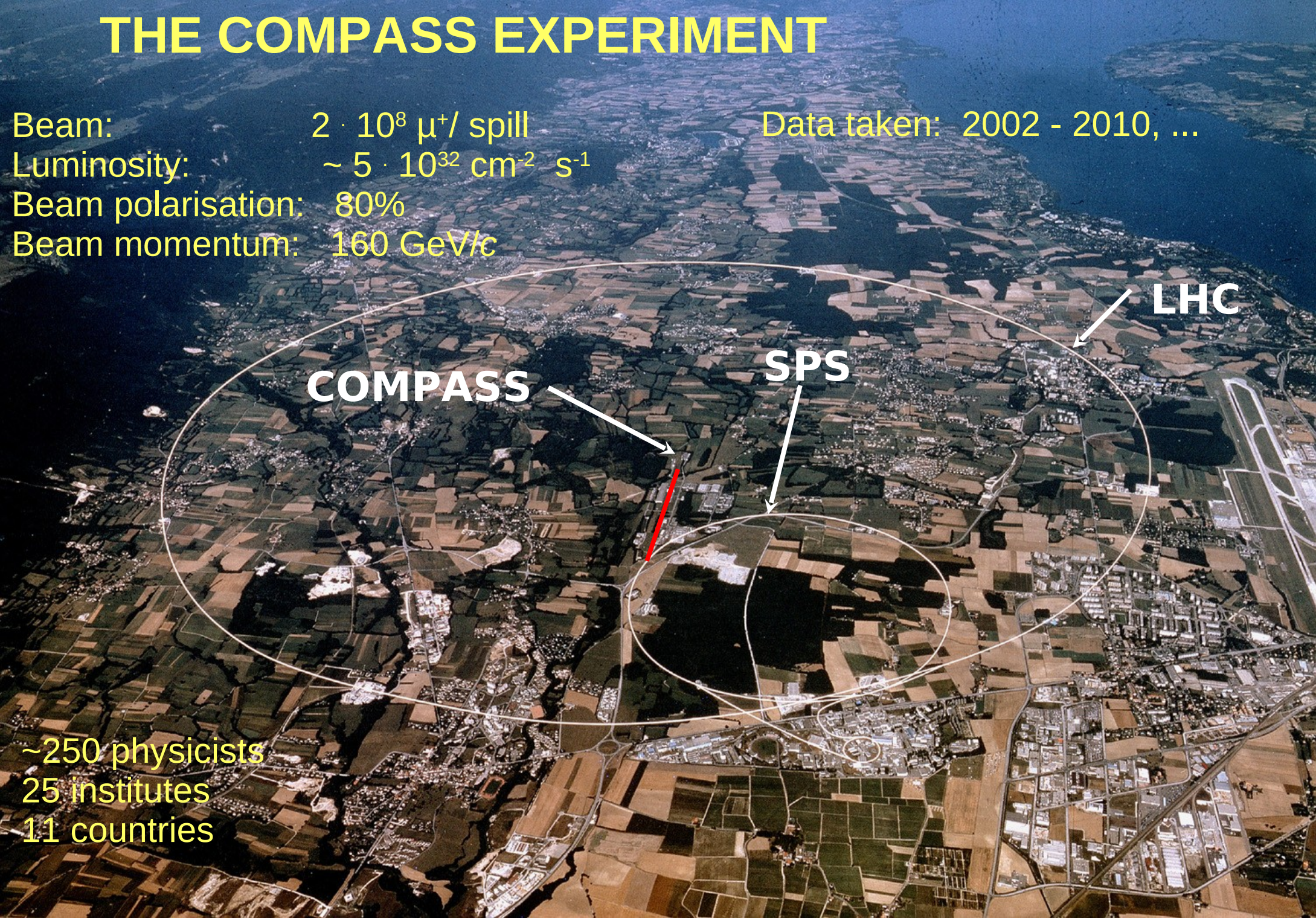
How much is the contribution from gluons and from L?

Spin Puzzle

THE COMPASS EXPERIMENT

Beam: $2 \cdot 10^8$ μ^+/ spill
Luminosity: $\sim 5 \cdot 10^{32}$ cm^{-2} s^{-1}
Beam polarisation: 80%
Beam momentum: 160 GeV/c

Data taken: 2002 - 2010, ...



~250 physicists
25 institutes
11 countries

The COMPASS Spectrometer

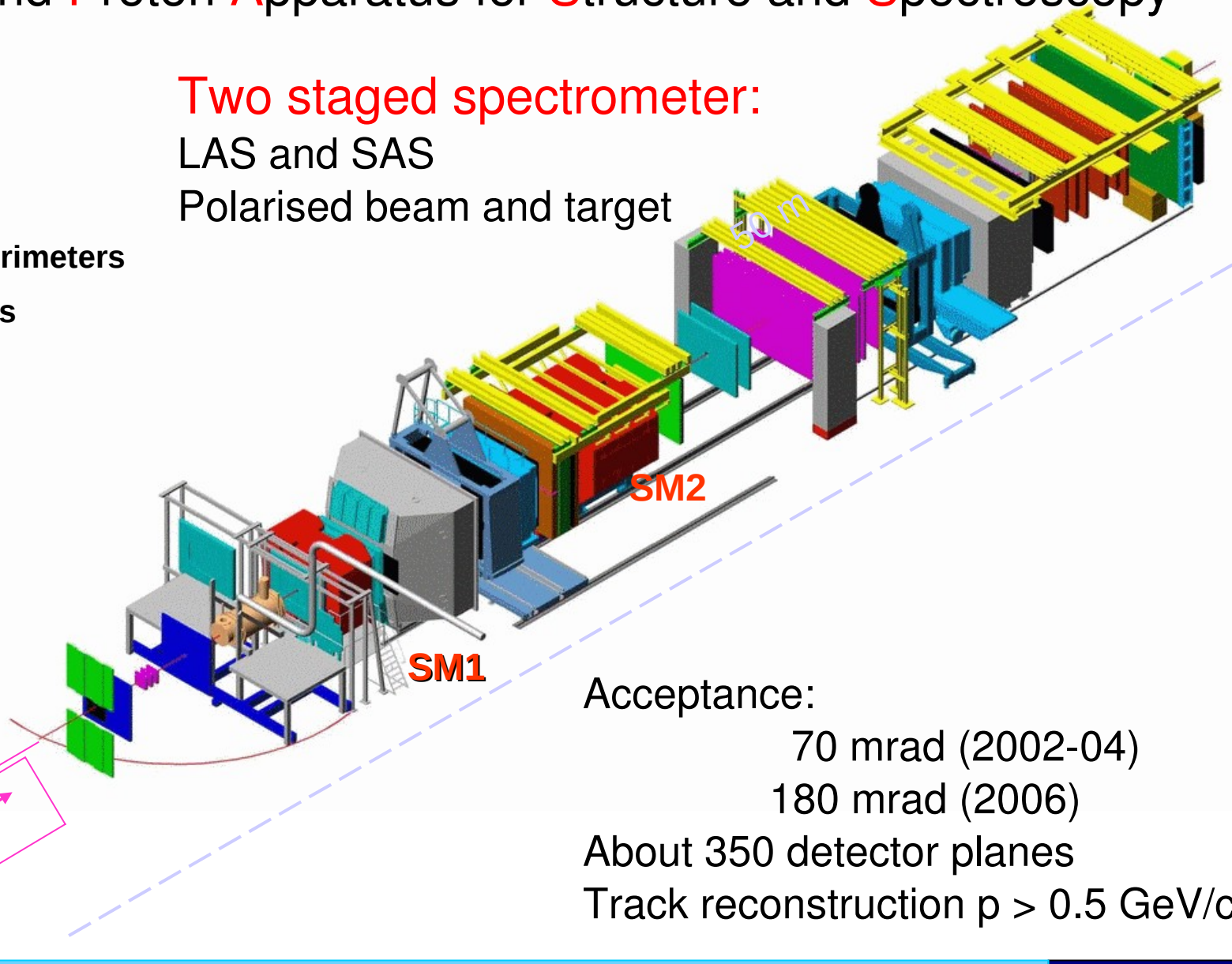
Common Muon and Proton Apparatus for Structure and Spectroscopy

- **Trackers**
- **Magnets**
- **RICH**
- **Electromagnetic Calorimeters**
- **Hadronic Calorimeters**
- **Absorbers**
- **Target**

Two staged spectrometer:

LAS and SAS

Polarised beam and target



NIM A577 (2007) 455

Acceptance:

70 mrad (2002-04)

180 mrad (2006)

About 350 detector planes

Track reconstruction p > 0.5 GeV/c

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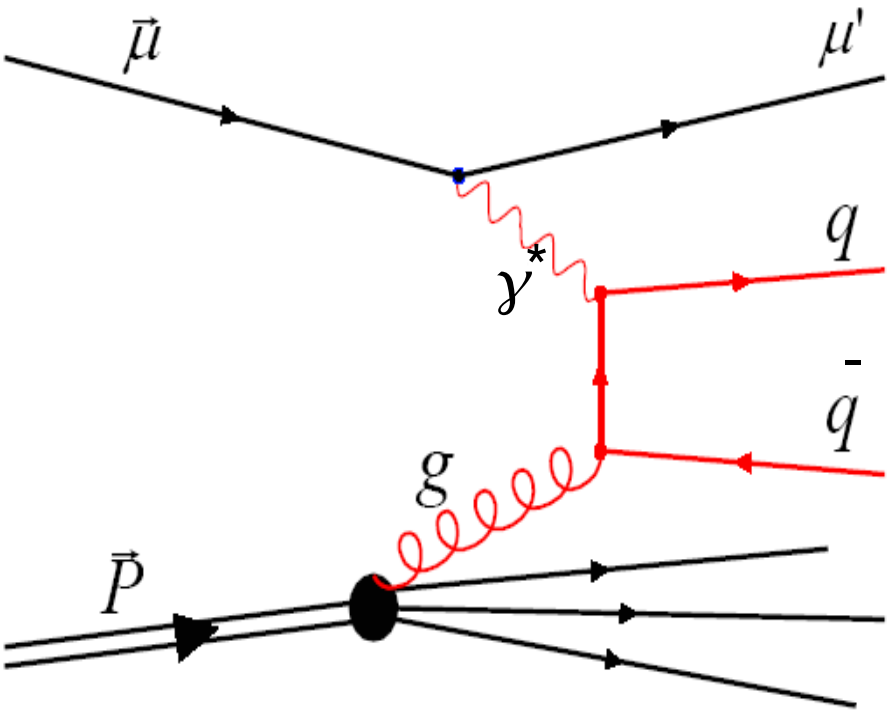
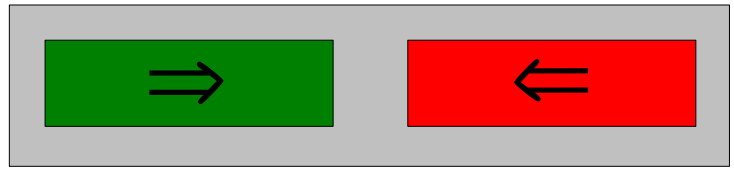
Direct measurement of ΔG/G

$\gamma^* g \rightarrow q \bar{q}$

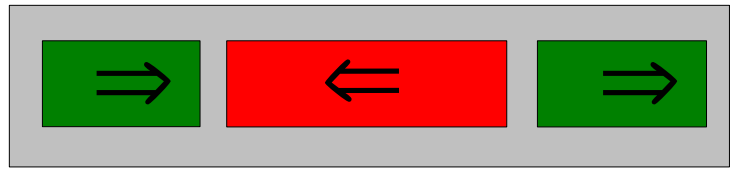


μ-beam

2002-2004



2006



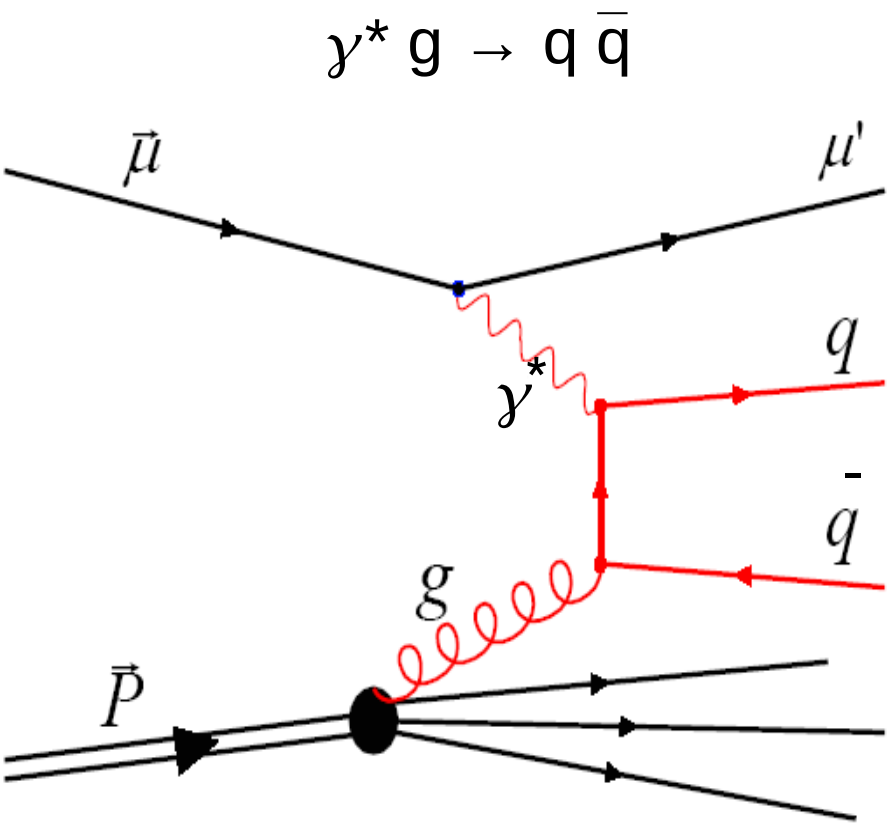
$$A_{PGF} = \frac{N^{\overleftarrow{\Rightarrow}}_{PGF} - N^{\overleftarrow{\Leftarrow}}_{PGF}}{N^{\overleftarrow{\Rightarrow}}_{PGF} + N^{\overleftarrow{\Leftarrow}}_{PGF}}$$

$\Rightarrow$ ΔG/G

Photon-gluon fusion process (PGF)

Experiments with polarised beam and target could be sensitive to gluon helicity

Direct measurement of ΔG/G



Photon-gluon fusion process (PGF)

To tag this process there are two procedures concerning event selection :

- Open-charm meson (cf. K.Kurek talk)
  - ☺ Provides the purest sample of PGF events, almost free from background contamination. Small dependence on MC.
  - ☹ Low statistics.
- High transverse momentum hadrons ($Q^2<1$ and $Q^2>1$ $(GeVc)^2$)
  - ☺ Much more statistics.
  - ☹ Physical background: strongly model dependent, requires a very good agreement between MC and Data.

High p_T Analysis

How is ΔG/G measured?

ΔG/G from PGF process:

Estimated from MC

$$A_{LL}^{PGF} = \frac{\Delta G}{G} a_{LL}^{PGF} \frac{\sigma^{PGF}}{\sigma^{Tot}}$$

The asymmetry for PGF process

Fraction of PGF process, R^i

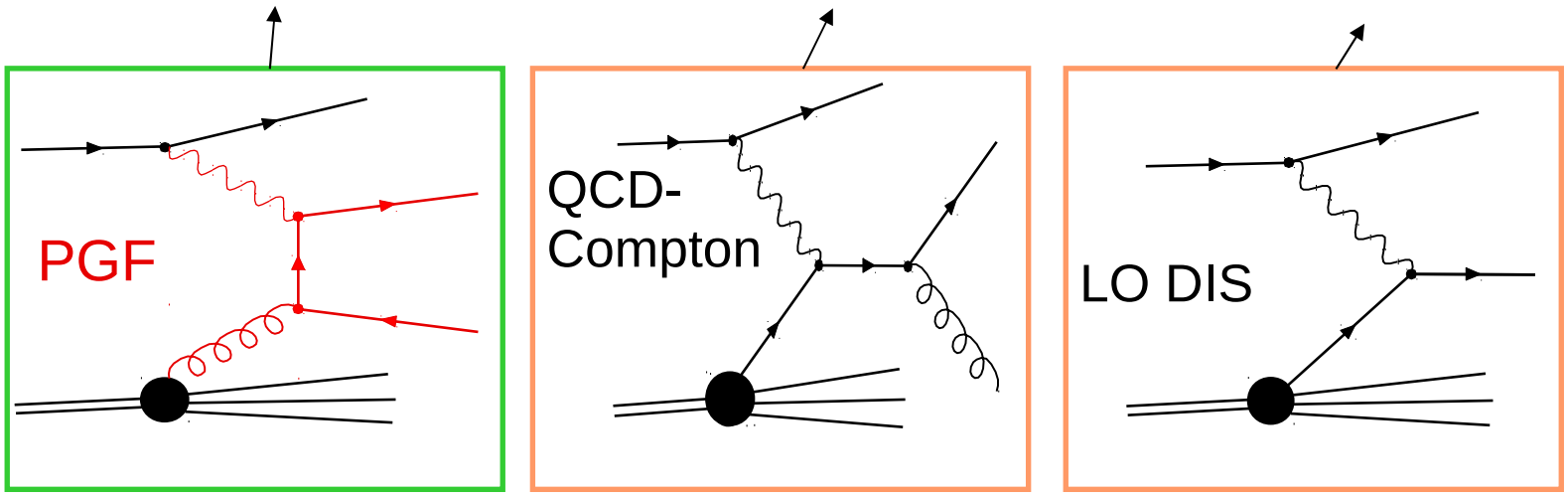
$$a_{LL}^{PGF} = \frac{\Delta\hat{\sigma}^{PGF}}{\hat{\sigma}^{PGF}}$$

What we want to extract

High p_T Analysis

We access A^{PGF} by measuring the helicity asymmetry in a sample of events with two high-p_T hadrons produced at large Q^2. This measurement includes also contributions from other physical processes:

$$A_{LL}^{2h}(x) = \frac{\Delta G}{G}(x_g)\, a_{LL}^{PGF}\, \frac{\sigma^{PGF}}{\sigma^{Tot}} + A_1^{LO}(x_C)\, a_{LL}^{C}\, \frac{\sigma^{C}}{\sigma^{Tot}} + A_1^{LO}(x_{Bj})\, D\, \frac{\sigma^{LO}}{\sigma^{Tot}}$$



A_1^{LO} is estimated by the measured A_1 asymmetry on inclusive sample

D is the fraction of polarisation transferred from the muon to the virtual photon

ΔG/G from High p_T

To extract the gluon polarisation, information from two samples is need: the two high p_T hadrons and the inclusive data samples.

The final formula for the gluon polarisation is the following:

$$\frac{\Delta G}{G}(x_g^{av}) = \frac{1}{\beta}\left[A_{LL}^{2h}(x_{Bj}) + A_{corr} \right]$$

$$\beta = a_{LL}^{PGF} R_{PGF} - a_{LL}^{PGF,incl} R_{PGF}^{incl} \frac{R_{LO}}{R_{LO}^{incl}} - a_{LL}^{PGF,incl} \frac{R_C R_{PGF}^{incl}}{R_{LO}^{incl}} \frac{a_{LL}^{C}}{D}$$

$$A_{corr} = -\left(A_1(x_{Bj}) D \frac{R_{LO}}{R_{LO}^{incl}} - A_1(x_C)\beta_1 + A_1(x_C')\beta_2 \right)$$

- A^{2h}_{LL} is the measured asymmetry in the 2-h sample.
- β_1 and β_2 are factors depending on a^{i}_{LL} and R^{i}
- Where i stands for signal or background processes.

Event selection

- Interaction vertex which contains an incoming and an outgoing muon
- For DIS variables: $Q^2>1$ (GeV/c)^2 and $0.1 < y < 0.9$

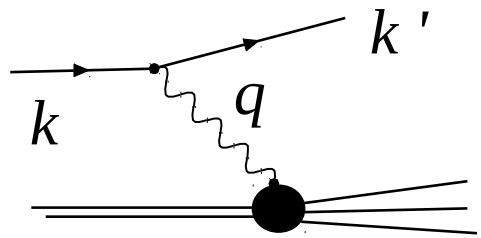
⇒ This selection constitutes the inclusive sample

- Events with at least 2 outgoing hadrons are selected
- The hadrons of the high p_T pair are required to have:

$$p_{T1} > 0.7 \text{ GeV/c} , \quad p_{T2} > 0.4 \text{ GeV/c}$$

$$z_1 + z_2 < 0.95$$

⇒ All this selection produces the high p_T sample



$$Q^2 = -q^2$$
$$q = k - k'$$
$$\nu = E - E'$$
$$y = \frac{\nu}{E}$$
$$x = \frac{Q^2}{2M\nu}$$

Years	2002	2003	2004	2006	all years
Statistics	450 K	1.3 M	2.8 M	2.7 M	7.3 M

Events

Monte Carlo Simulation

This analysis uses information from the MC, thus a strong effort and care to ensure that the MC simulation describes as good as possible the data was undertaken.

Two MC samples were used in the analysis: high p_T and inclusive samples.

- Full chain of MC has been used:

Generator (LEPTO) + Apparatus Simulation (GEANT) + Reconstruction Program.

- PDF: MSTW2008LO.
- High p_T sample:
  - MC with parton shower ON has been used in the analysis.
  - A new tuning was performed to improve the hadron description.

MC Tuning

- The purpose of the MC tuning is to correct the shapes of the hadron variables (momenta) and fragmentation (multiplicity).
- In LEPTO this can be achieved by changing JETSET parameters:

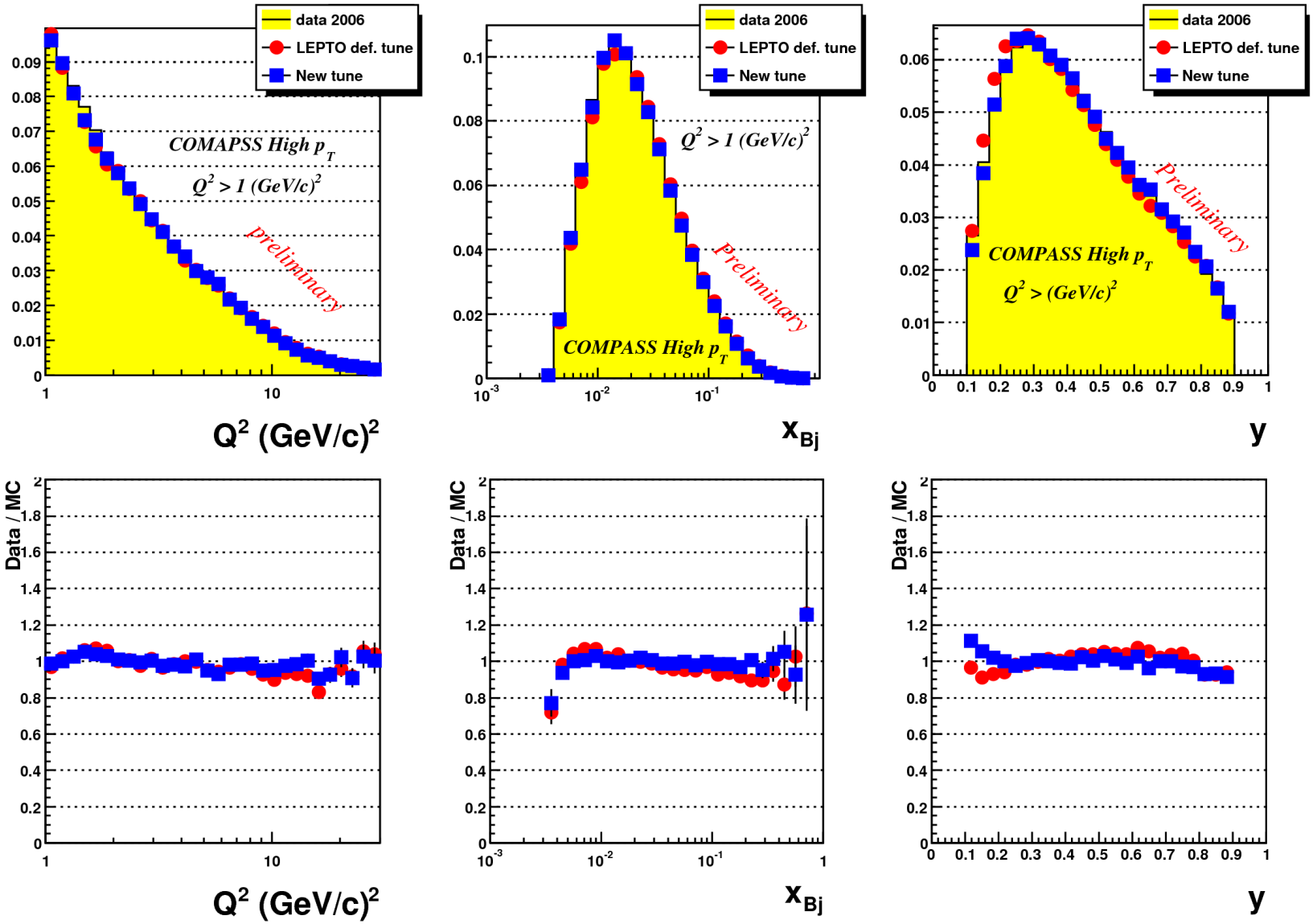
PARJ(21)	PARJ(23)	PARJ(24)	PARJ(41)	PARJ(42)
Transverse momentum of the hadron fragmentation			Fragmentation function	

- These parameters can be divided into two sets regarding the component of the trajectory of the particles: Transverse and longitudinal variable components.
- The sets can be tuned independently.

$\Rightarrow$ The tuning improves substantially the Data-MC agreement.

Data – Monte Carlo comparison

high-p_T sample (Q^2, x and y)



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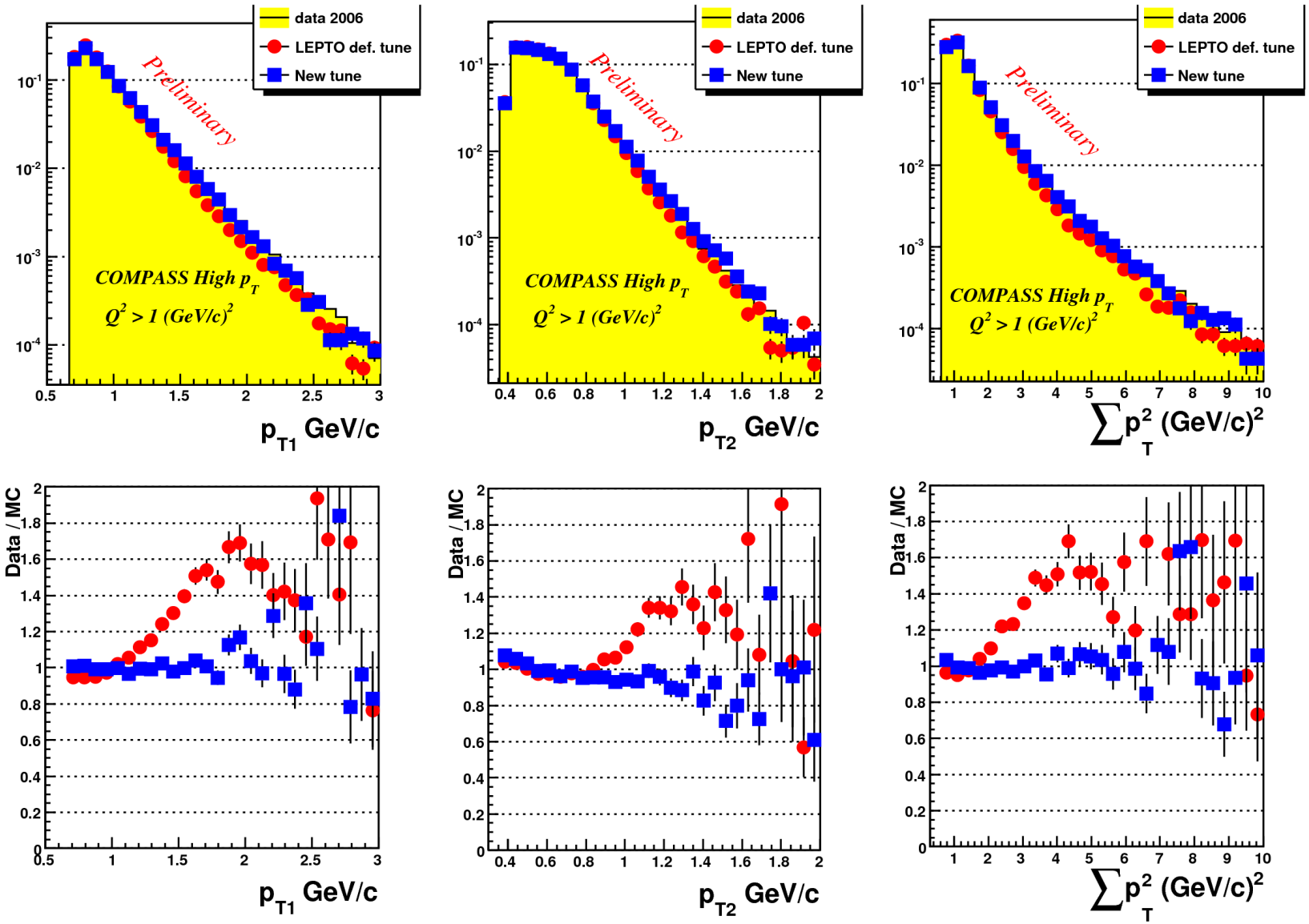
Data – Monte Carlo comparison

high-p_T sample: hadron variables (p_{T1}, p_{T2} and Σp_T^2)



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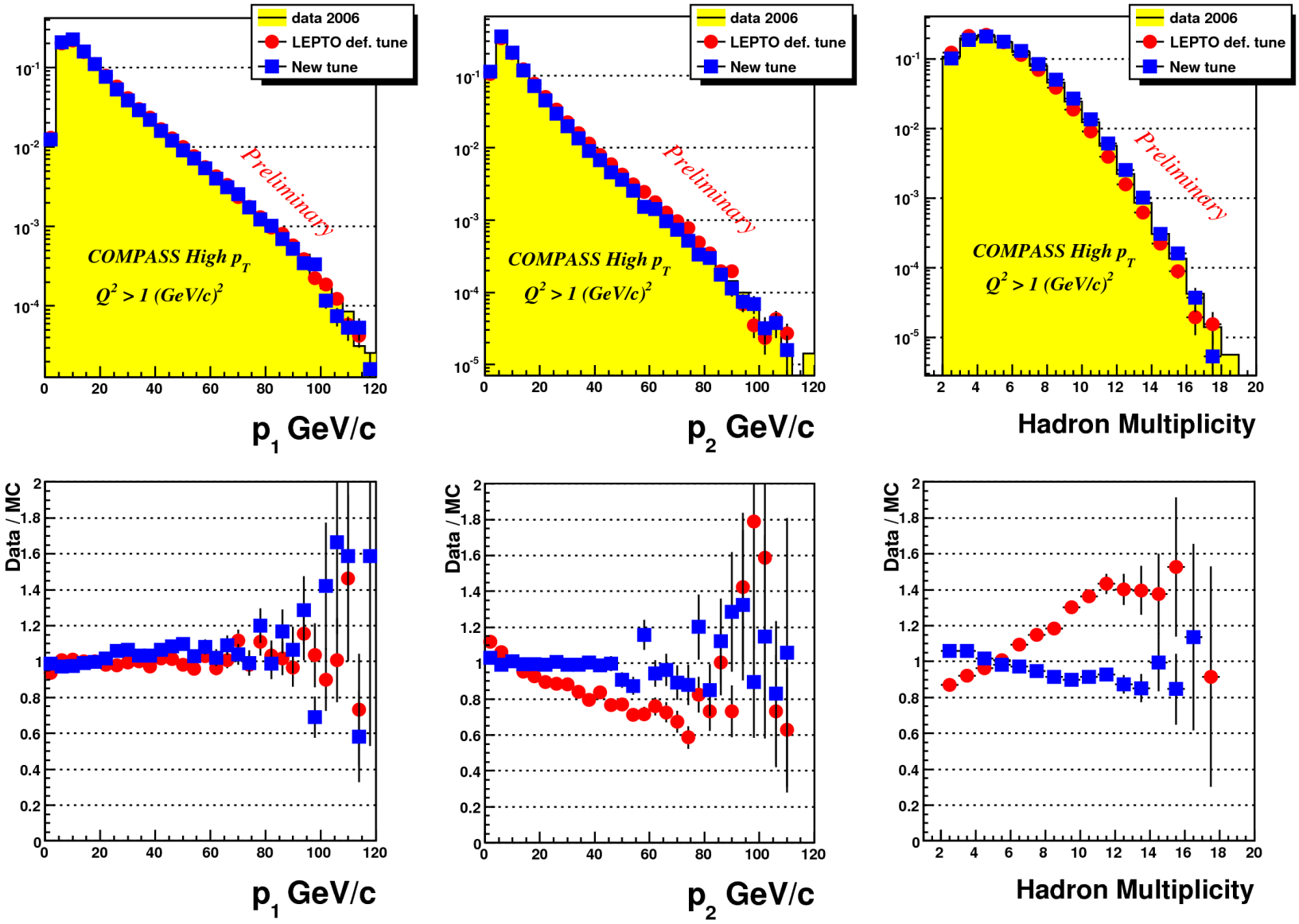
Data – Monte Carlo comparison

high-p_T sample: hadron variables (p_1, p_2 and multiplicity)



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Weighted method

- A weight is applied on event-by-event basis:

$W = fDP_b\beta$, where β is a factor depending on a^{i}_{LL} and R^{i}

- Therefore for every event we have to know:

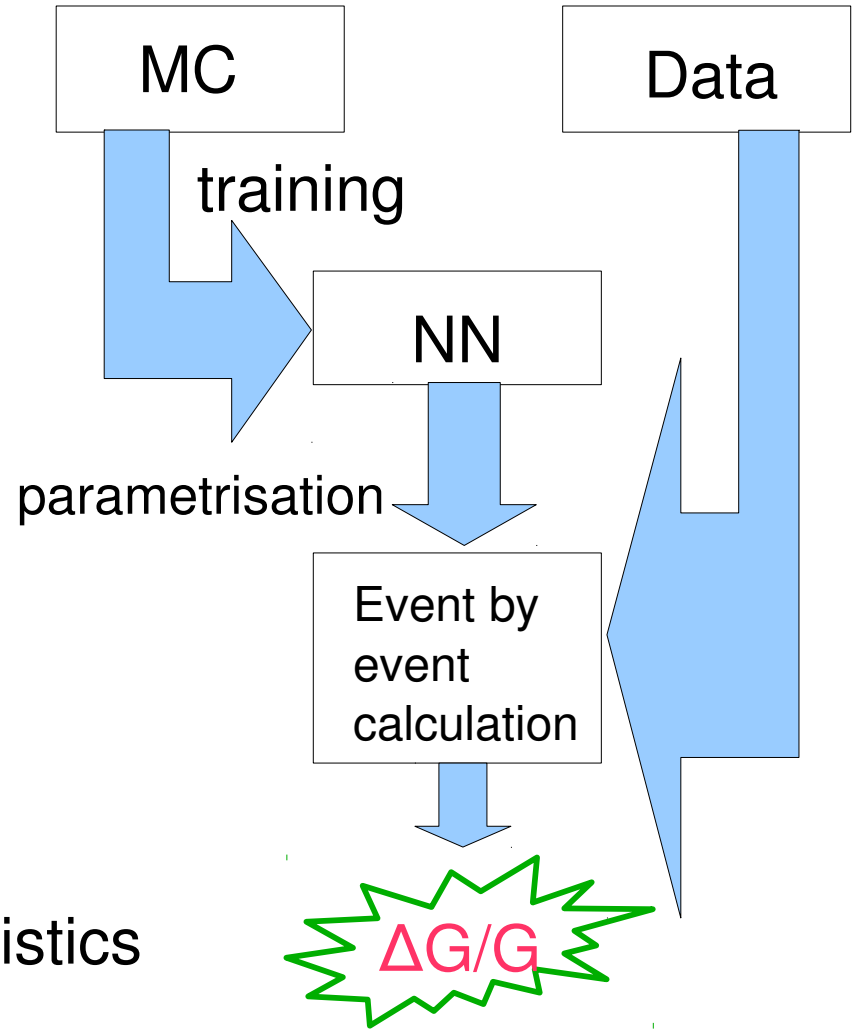
$$R_{PGF}, R_C, R_{LO}, R^{incl}_{PGF}, R^{incl}_C, R^{incl}_{LO},$$
$$a^{PGF}_{LL}, a^{C}_{LL}, a^{PGF,incl}_{LL}, a^{C,incl}_{LL},$$
$$x_C, x_G,$$
$$f, D, P_b$$

f,D,P_b are directly obtained from data.
The all the others variables have to be estimated/parametrised.

Weighted method

A Neural Network is used to assign to each event a probability to be originated from each of the three processes (LO, PGF or Compton).

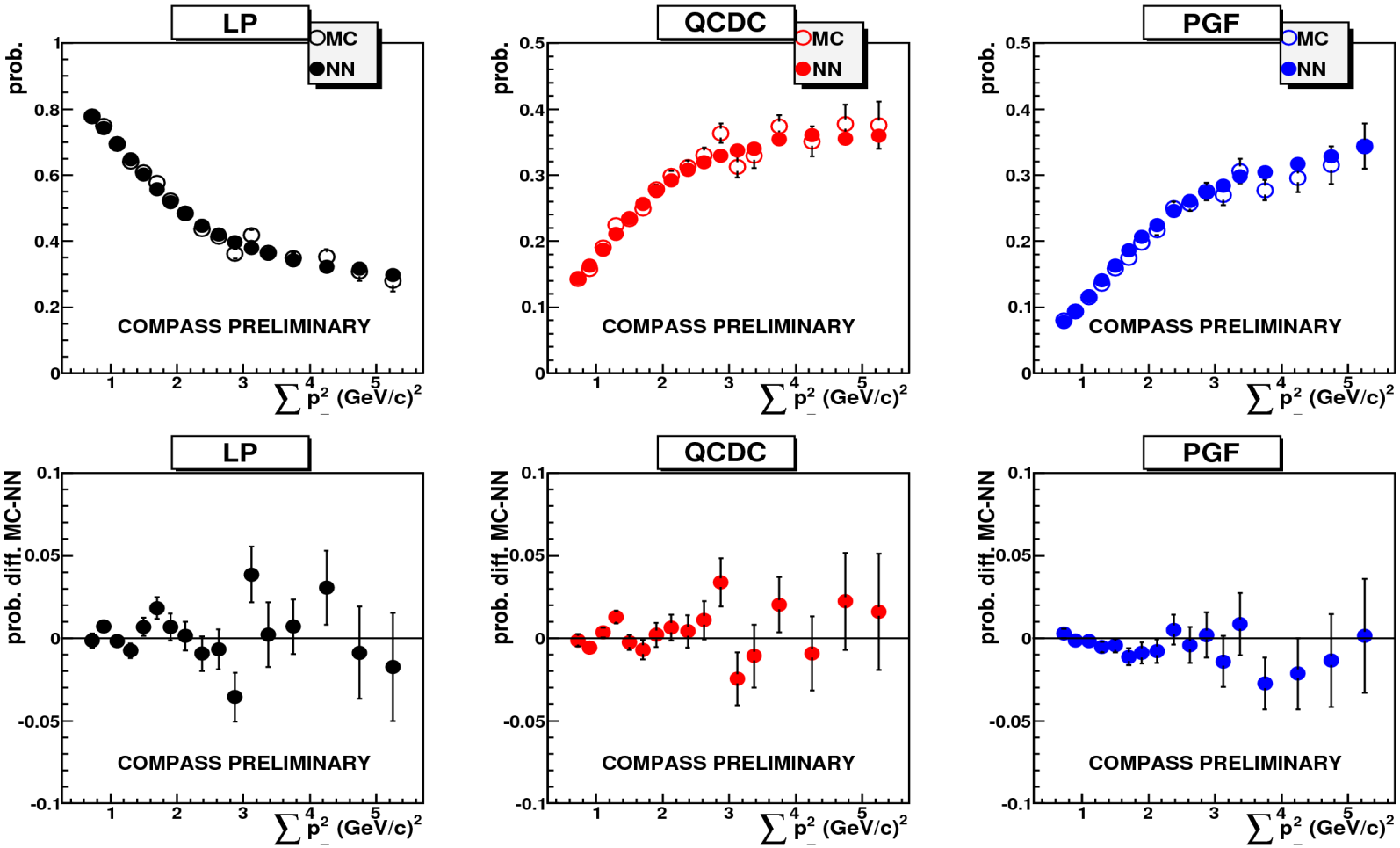
- A MC sample is used to train the Neural Network (NN).
- A parametrisation is constructed for all variables involved in the weight.
- A Data sample is weighted on an event-by-event basis.



Optimal usage of the data sample statistics

Example: Stability plots for NN

We parametrise the R^i fractions as probabilities.



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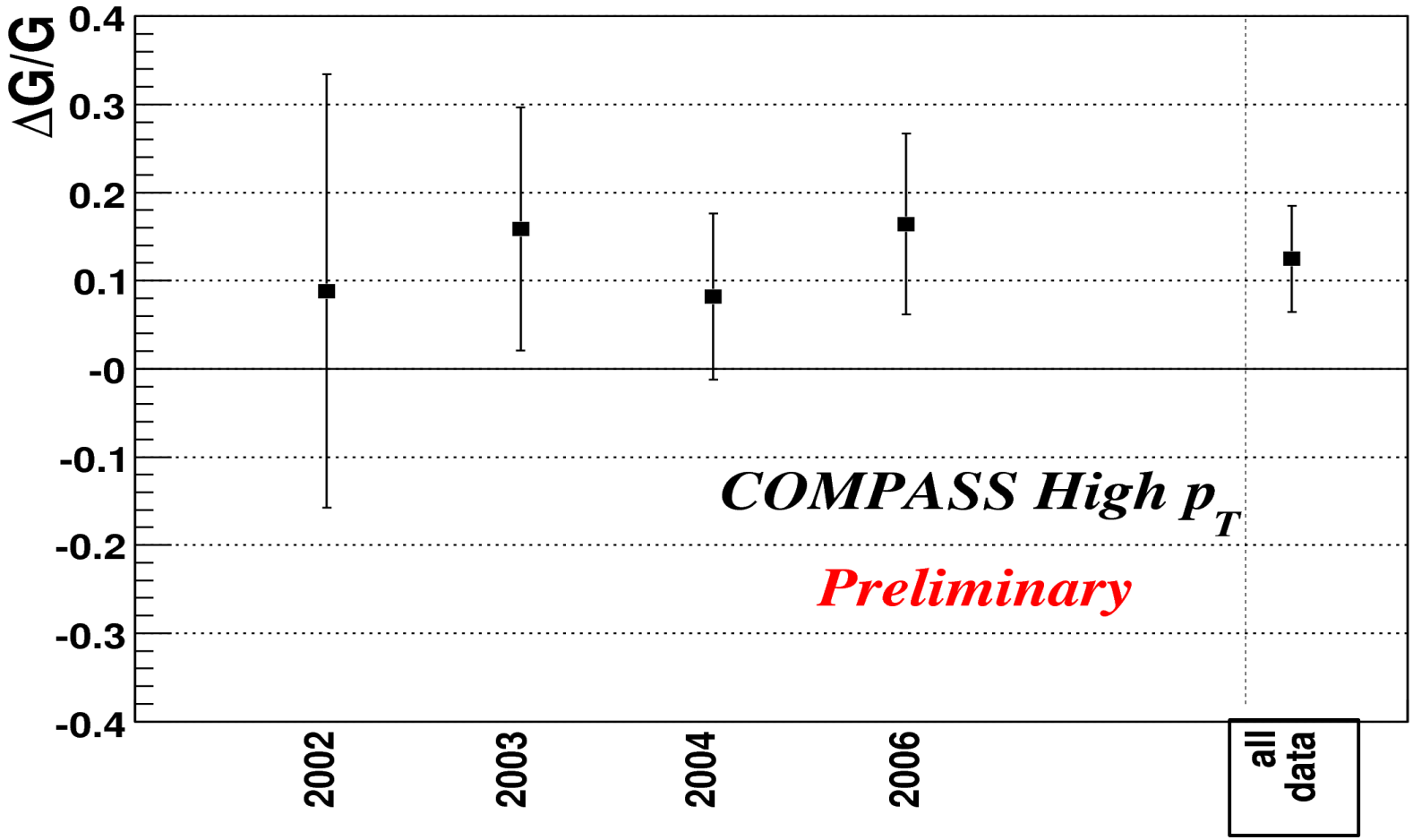
Results

$$\frac{\Delta G}{G} = 0.125 \pm 0.060 \pm 0.063 \qquad x_G = 0.09^{+0.08}_{-0.04} \qquad \langle \mu^2 \rangle = 3.4 \ (\mathrm{GeV/c})^2$$



Results

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- The whole statistics was divided, for the first time, in 3 independent samples, having each one its own x_g distribution.

	1st point	2nd point	3rd point
ΔG/G	0.15 ± 0.09 ± 0.09	0.08 ± 0.10 ± 0.08	0.19 ± 0.17 ± 0.14
$\langle x_g \rangle$	$0.07^{+0.05}_{-0.03}$	$0.10^{+0.07}_{-0.04}$	$0.17^{+0.10}_{-0.06}$

⇒ Within the errors the 3 points show no x_g dependence

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Systematic errors Study

What has been checked?

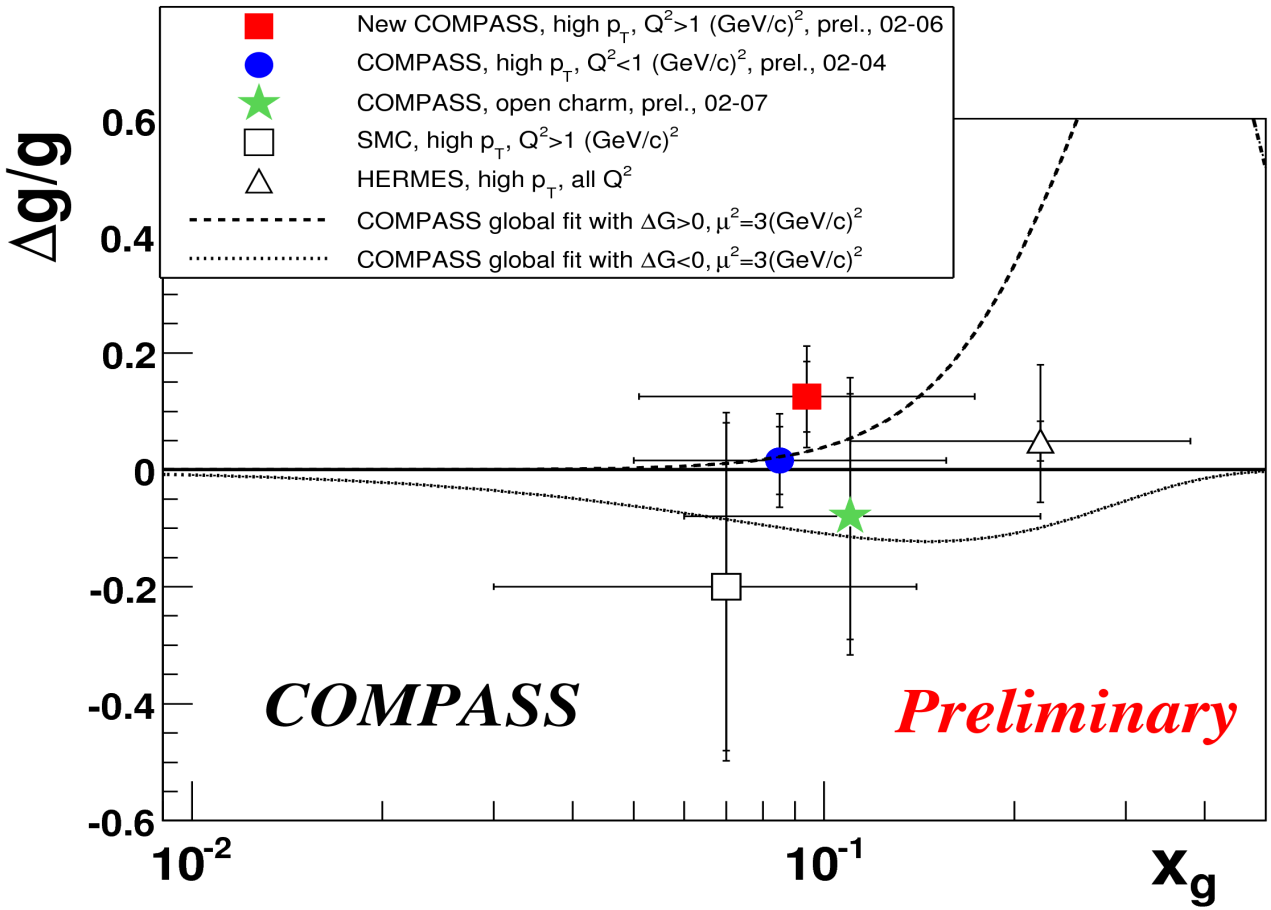
- Neural Network stability
- MC
- False Asymmetries
- δP_b ,δP_t ,δf
- A_1 parametrisation
- Simplification of the Formula for $\Delta G/G$

$\delta(\Delta G/G)_{NN}$	0.010
$\delta(\Delta G/G)_{MC}$	0.045
$\delta(\Delta G/G)_{false}$	0.019
$\delta(\Delta G/G)_{f,Pb,Pt}$	0.004
$\delta(\Delta G/G)_{A1}$	0.015
$\delta(\Delta G/G)_{formula}$	0.035
Total	0.063

ΔG/G Results

$$\frac{\Delta G}{G} = 0.125 \pm 0.060 \pm 0.063 \qquad x_G = 0.09^{+0.08}_{-0.04} \qquad \langle \mu^2 \rangle = 3.4 \text{ (GeV/c)}^2$$

- All points at x_g ~ 0.1 are compatible with each other
- All points are compatible with the COMPASS QCD fits and other predictions.
- At x_g ~ 0.1 ⇒ ΔG/G ~ 0



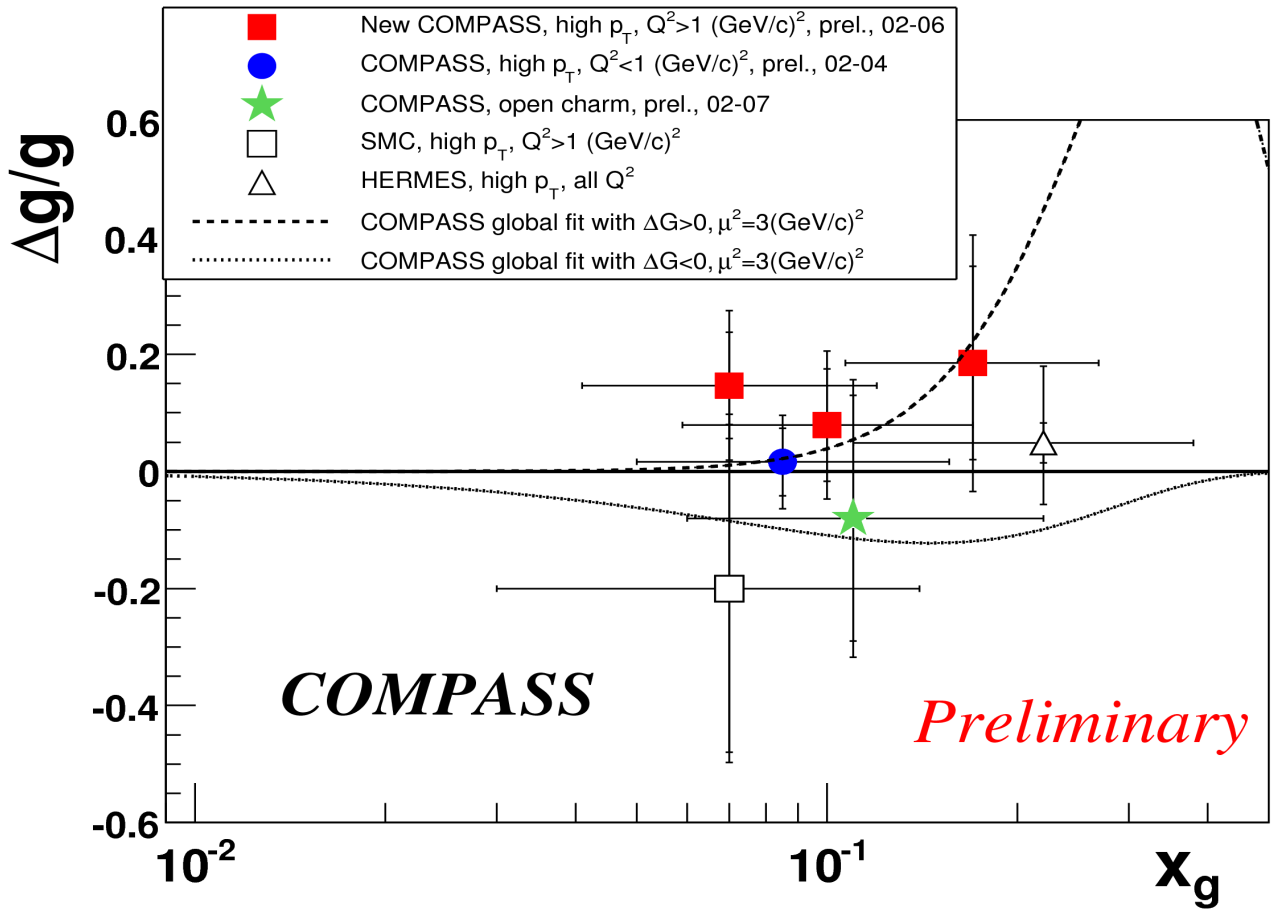
ΔG/G Results

1st point : $0.147 \pm 0.091_{stat} \pm 0.088_{sys}$ @ $x_g = 0.07^{+0.05}_{-0.03}$

2nd point : $0.079 \pm 0.096_{stat} \pm 0.082_{sys}$ @ $x_g = 0.10^{+0.07}_{-0.04}$

3rd point : $0.185 \pm 0.165_{stat} \pm 0.143_{sys}$ @ $x_g = 0.17^{+0.10}_{-0.06}$

First experiment giving a measurement in 3 points in x_g



Spares

ΔG/G for High p_T, Q^2 >1 GeV^2

The final formula for the gluon polarization:

$$\frac{\Delta G}{G}(x_g^{av}) = \frac{A_{LL}^{2h}(x_{Bj})}{\beta} - \frac{A_1(x_{Bj})}{\beta} D \frac{R_{LO}}{R_{LO}^{incl}} - \frac{A_1(x_C)}{\beta}\beta_1 + \frac{A_1(x_C')}{\beta}\beta_2$$

$$\beta = a_{LL}^{PGF} R_{PGF} - a_{LL}^{PGF,incl} R_{PGF}^{incl} \frac{R_{LO}}{R_{LO}^{incl}} - a_{LL}^{PGF,incl} \frac{R_C R_{PGF}^{incl}}{R_{LO}^{incl}} \frac{a_{LL}^C}{D} \qquad R_i = \frac{\sigma^i}{\sigma^{Tot}}$$

$$\beta_1 = \frac{1}{R_{LO}^{incl}}\left(a_{LL}^C R_C - a_{LL}^{C,incl} R_C^{incl} \frac{R_{LO}}{R_{LO}^{incl}}\right) \qquad \beta_2 = a_{LL}^{C,incl} \frac{R_C R_C^{incl}}{(R_{LO}^{incl})^2} \frac{a_{LL}^C}{D}$$

- A^{2h}_{LL} is the measured 2-h asymmetry.
- a_{LL} and R are estimated using MC.
- The A_1 are taken using a parametrisation on inclusive data. (EPJ C52 (2007)255)

ΔG/G for High p_T, Q^2 >1 GeV^2

The final formula for the gluon polarization:

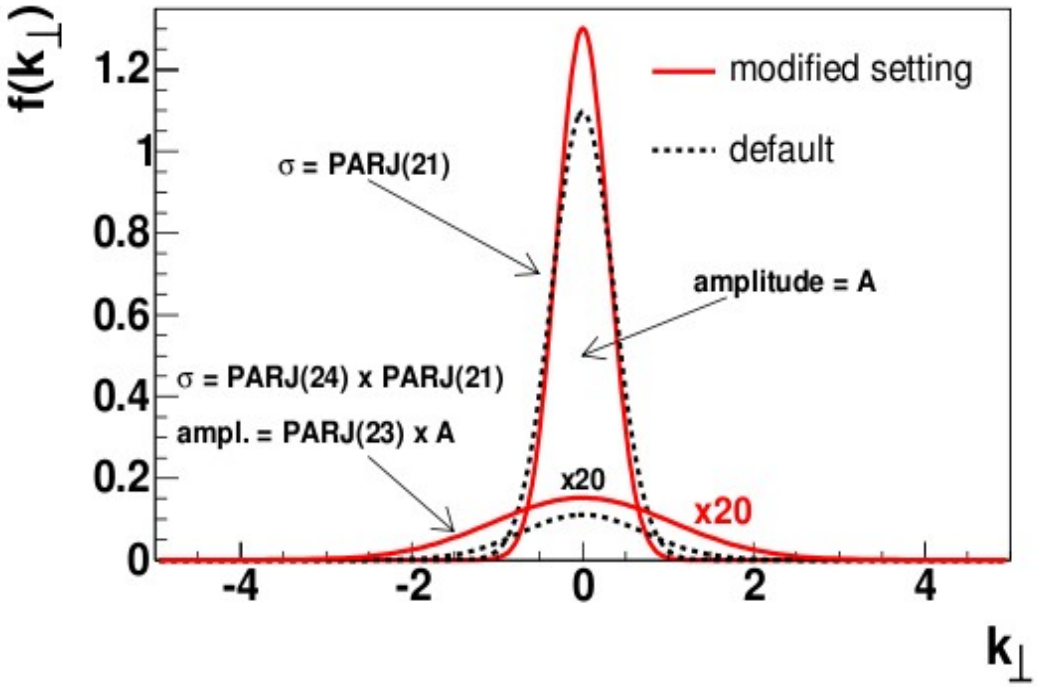
$$\frac{\Delta G}{G}(x_g^{av}) = \frac{1}{\beta}\left[A_{LL}^{2h}(x_{Bj}) + A_{corr}(x_{Bj}) \right]$$

- A^{2h}_{LL} is the measured 2-h asymmetry.
- β is composed by a_{LL} and R. They are estimated using MC.
- A_{corr} is a corrective factor for Compton-QCD and LO processes:
  - a_{LL} and R are estimated using MC.
  - The A_1 are taken using a parametrization on inclusive data.

(EPJ C52 (2007)255)

$$A_{corr} = -\left(A_1(x_{Bj}) D \frac{R_{LO}}{R_{LO^{incl}}} - A_1(x_C)\beta_1 + A_1(x_C')\beta_2 \right)$$

Monte Carlo Simulation



a = PARJ(41)

b = PARJ(42)

$$f(z) \propto \frac{1}{2}(1-z)^{a} \exp\left(-\frac{b\ m_T^2}{z}\right)$$

	PARJ(21)	PARJ(23)	PARJ(24)	PARJ(41)	PARJ(42)
COMPASS new tuning	0.34	0.04	2.8	0.025	0.075
LEPTO default tuning	0.36	0.01	2.0	0.3	0.58
	Transverse momentum of the hadron fragmentation			Fragmentation function	

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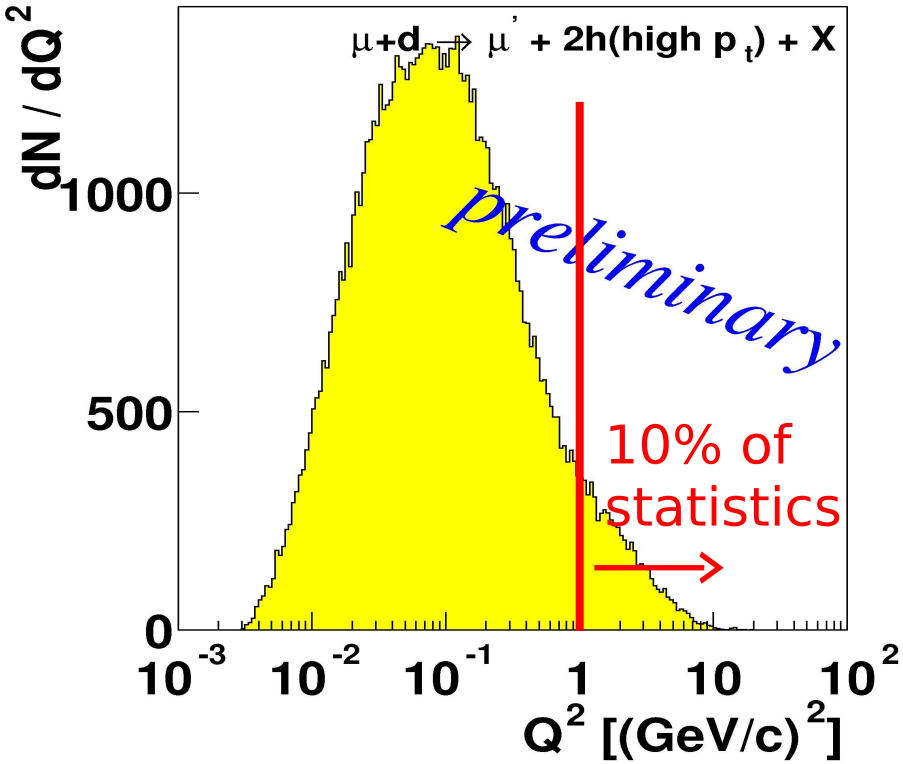
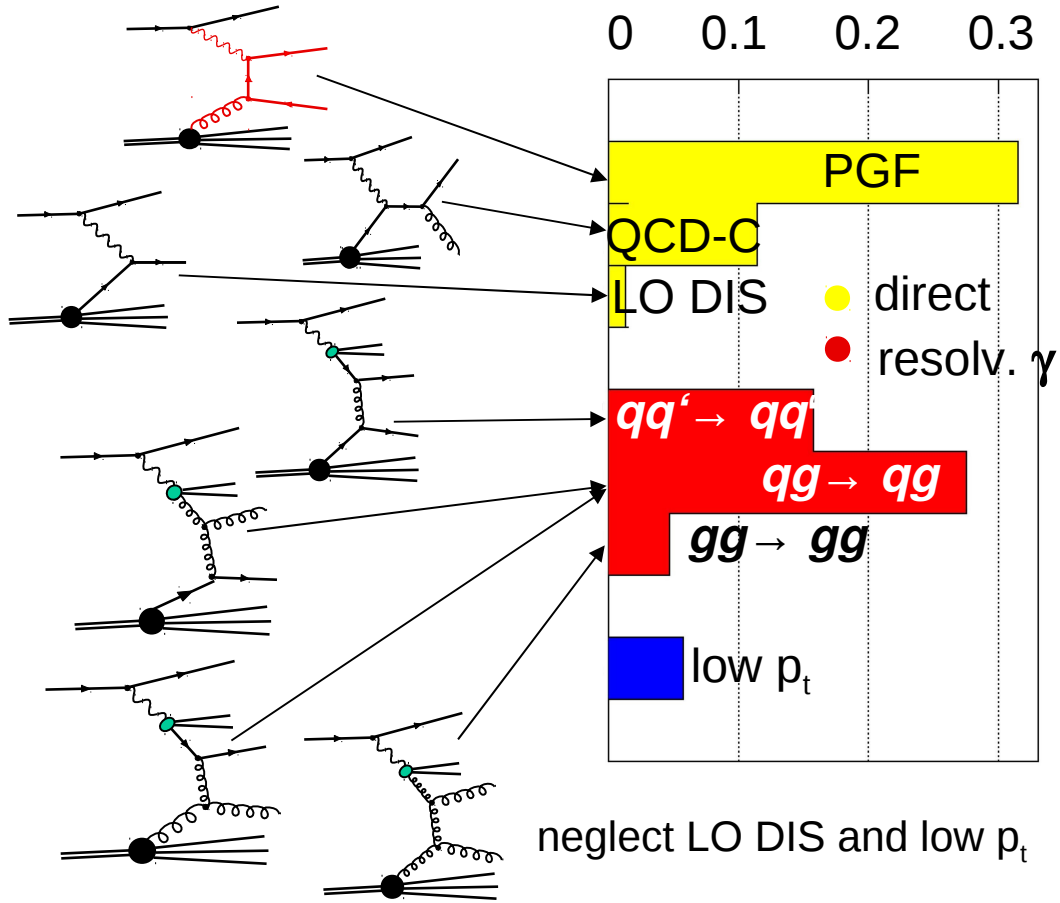
High p_T Analysis, $Q^2 < 1$ (GeV/c)^2

~90 % of our statistics in this sample





neglect LO DIS and low p_t

2002-2004 Preliminary:

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

2002-2003 Published:

$\Delta G/G = 0.024 \pm 0.089(\text{stat}) \pm 0.057(\text{syst})$ *Phys. Lett. B 633 (2006) 25 - 32*