COMPASS results on gluon polarisation from high p_T hadron pairs

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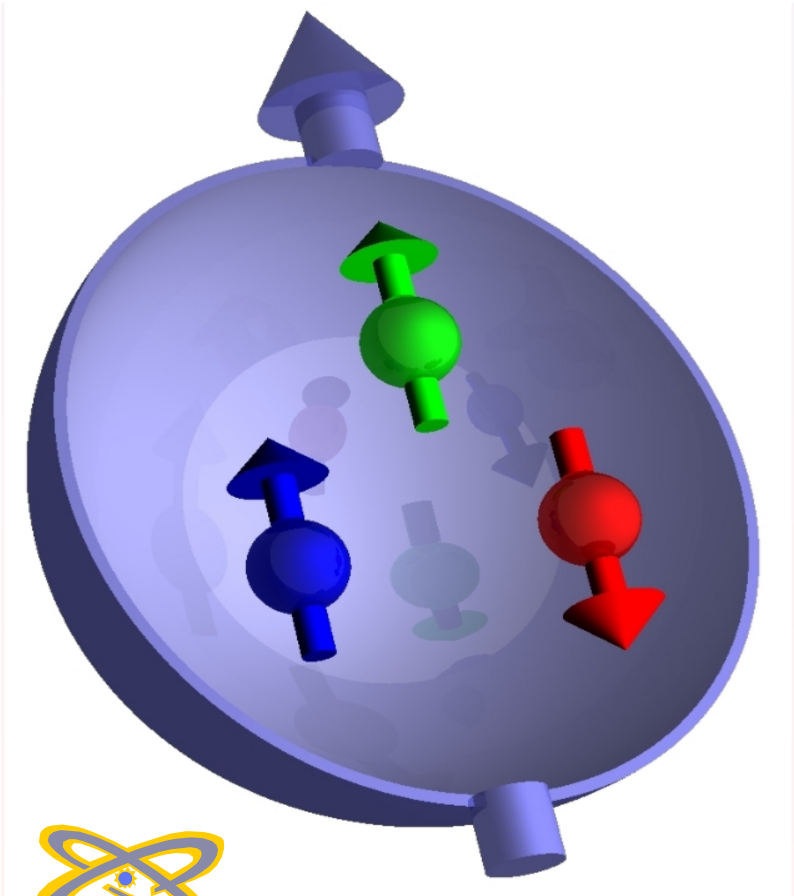
1 Sep 2009

Outline

- Motivation
- COMPASS experiment
- Direct measurement of $\Delta G/G$
- High pT analysis, $Q^2 > 1\ (GeV/c)^2$ and $Q^2 < 1\ (GeV/c)^2$
- $\Delta G/G$ results
- Conclusion and Outlook

The Nucleon Spin

$S_N = \frac{1}{2}\hbar = \frac{1}{2}\Delta\Sigma$



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 results, including COMPASS, gives:

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

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

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

Spin crisis !

The Nucleon Spin

$$S_N = ½\,\hbar = ½\,\Delta\Sigma + \Delta G + L$$

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 Spectrometer

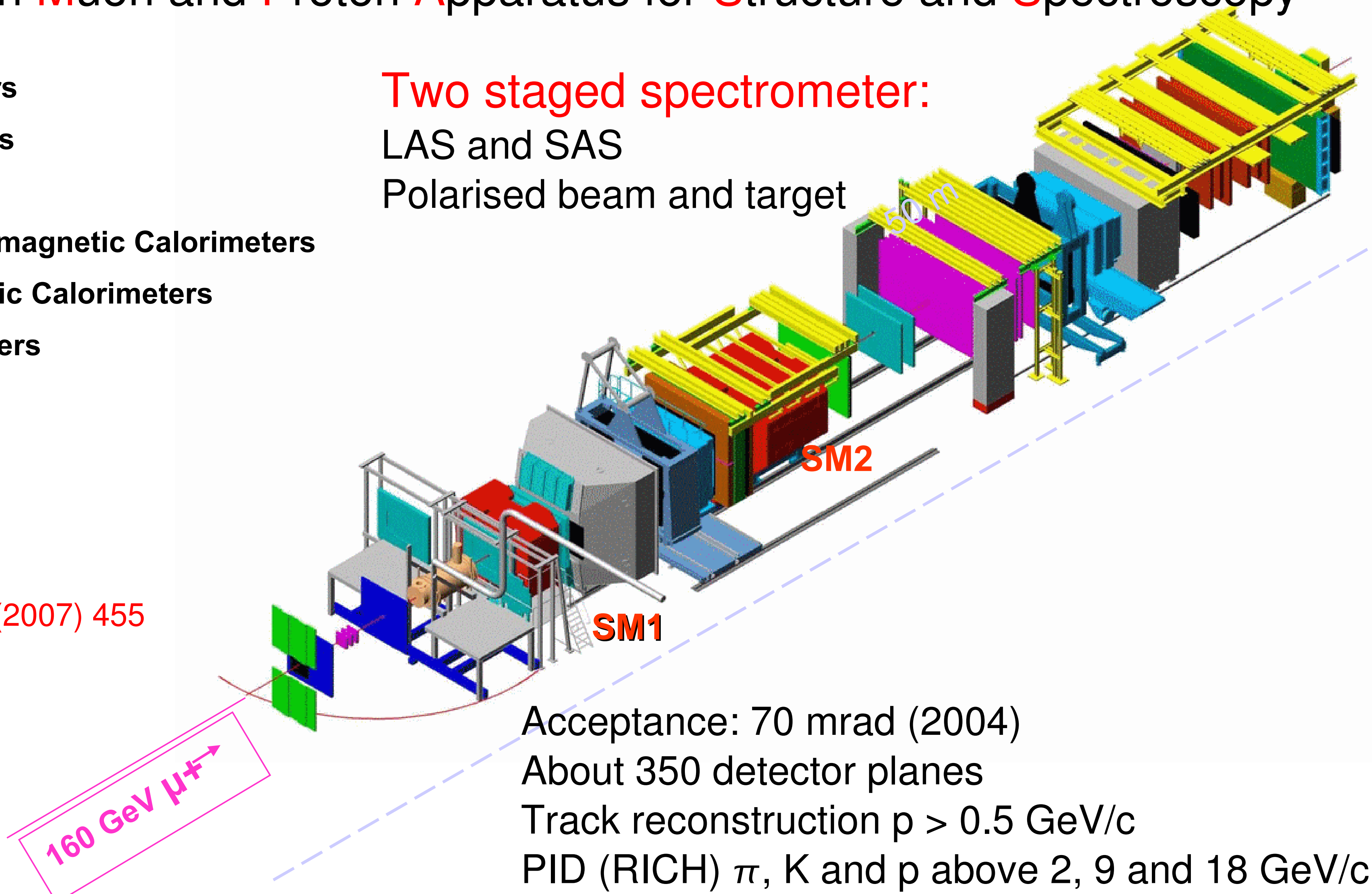
Common Muon and Proton Apparatus for Structure and Spectroscopy

	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 (2004)

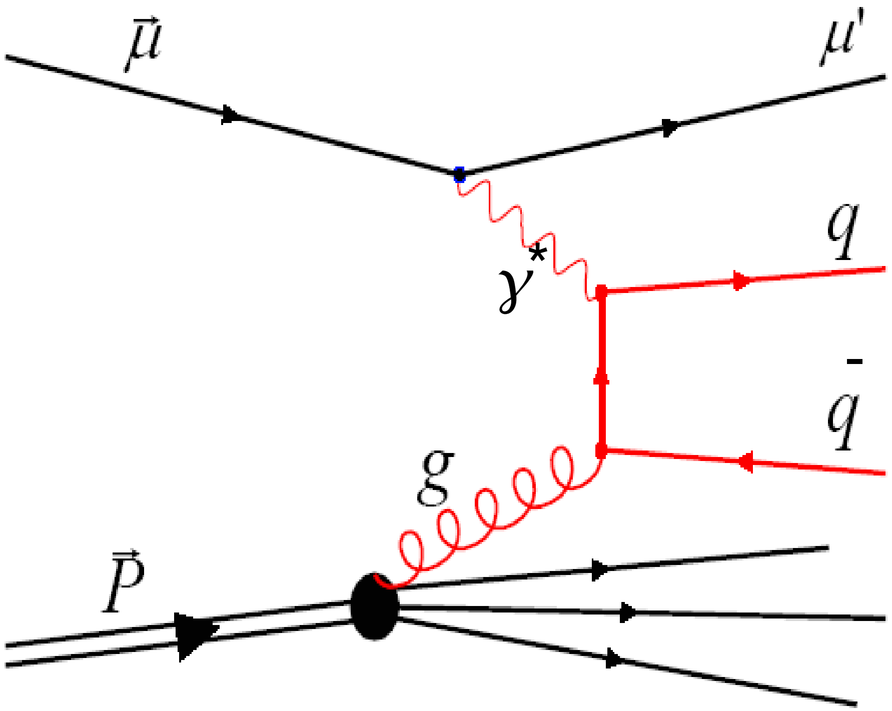
About 350 detector planes

Track reconstruction p > 0.5 GeV/c

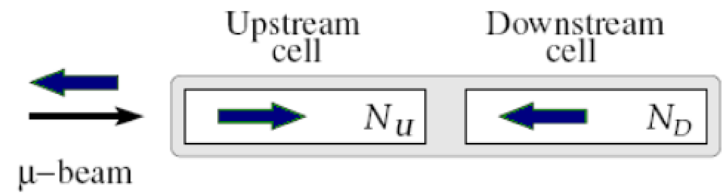
PID (RICH) π, K and p above 2, 9 and 18 GeV/c

Direct measurement of ΔG/G

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



Photon-gluon fusion process (PGF)



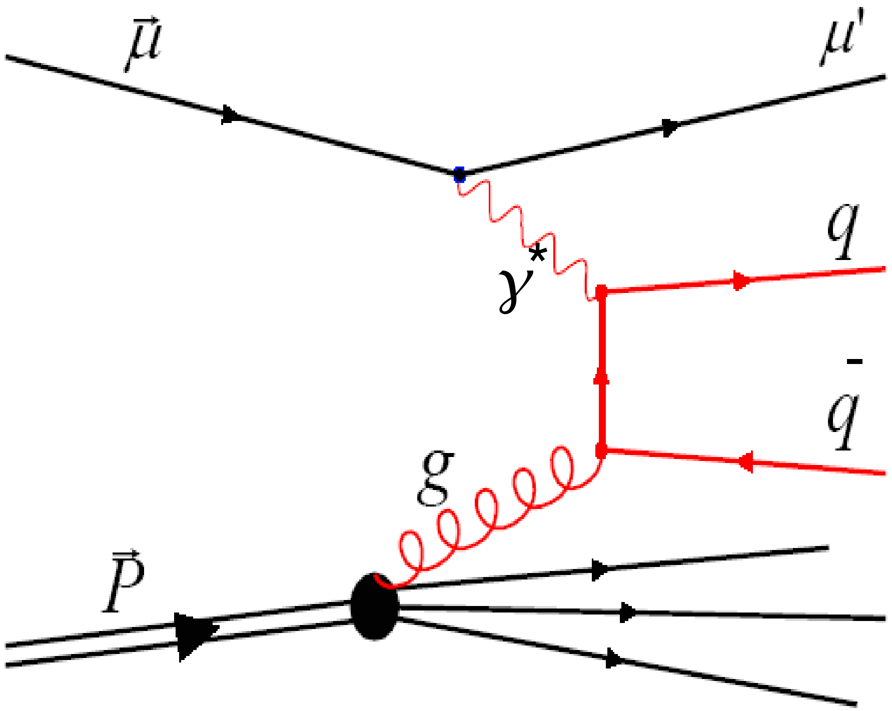
$$A_{PGF} = \frac{N^{\overset{\leftarrow}{\Rightarrow}}_{PGF} - N^{\overset{\leftarrow}{\Leftarrow}}_{PGF}}{N^{\overset{\leftarrow}{\Rightarrow}}_{PGF} + N^{\overset{\leftarrow}{\Leftarrow}}_{PGF}}$$

$\Rightarrow$ 

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

Direct measurement of $\Delta G/G$

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



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 Data and MC.

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

High p_T Analysis, $Q^2 > 1\ GeV^2$

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

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

What we want to extract

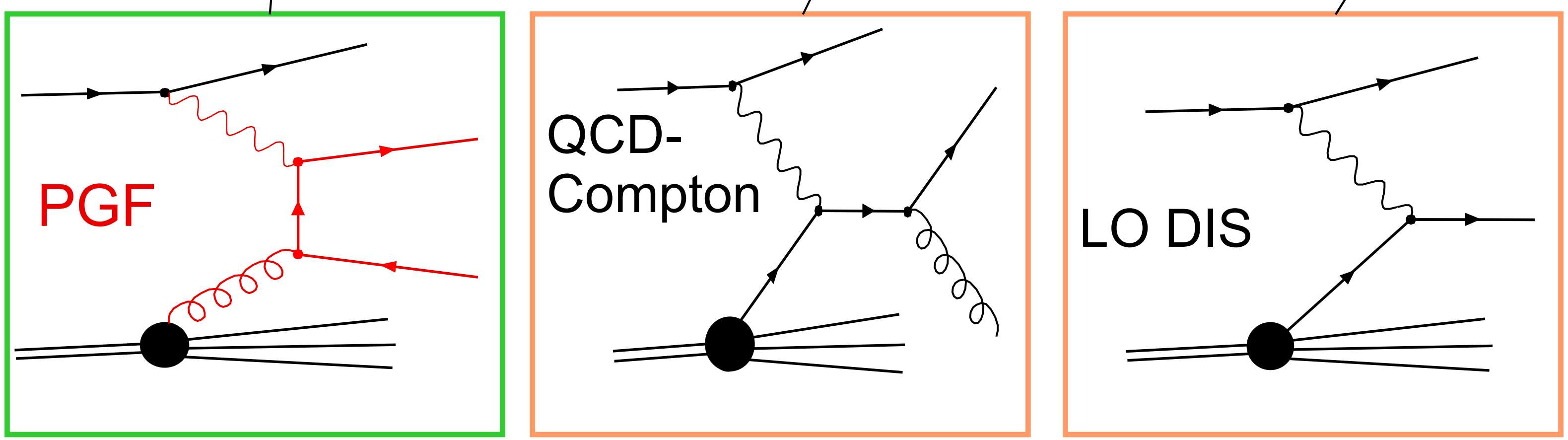
High p_T Analysis, $Q^2 > 1$ GeV^2

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

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

$$A_{LL}^{2h} = A^{PGF} + A^{COM} + A^{LO}$$

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



$$R^i = \frac{\sigma^i}{\sigma^{Tot}}$$

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

$\Delta G/G$ for High p_T, $Q^2 > 1$ GeV^2

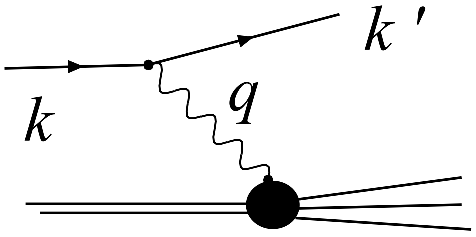
To extract the gluon polarisation information from two samples is need to be taken into account: the two high pT hadrons and the inclusive data samples. The final formula for the gluon polarisation is the following:

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

- A^{2h}_{LL} is the measured asymmetry in the 2-h sample.
- A_{corr} and β are factors depending on a^i_{LL} and R^i taken from High p_T and from inclusive MC samples.
- a^i_{LL} and R^i. Where i stands for signal and background processes.

Event selection

- Interaction vertex which contains an incoming and an outgoing muon and at least 2 outgoing hadrons
- For DIS variables: $Q^2>1$ $(\mathrm{GeV}/c)^2$ and $0.1 < y < 0.9$
- Each hadron is required to have: $p_T > 0.7$ GeV/c
- The pair of hadrons must have an invariant mass $m > 1.5$ GeV/c^2 and $z_1 + z_2 < 0.95$



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

Years	2002	2003	2004	all years
Statistics	49585	170943	286685	507213

⇒ This selection is for the High pT sample

⇒ The inclusive sample is done by using only the DIS cuts

The scale of this analysis is set by the Q^2

Monte Carlo Simulation

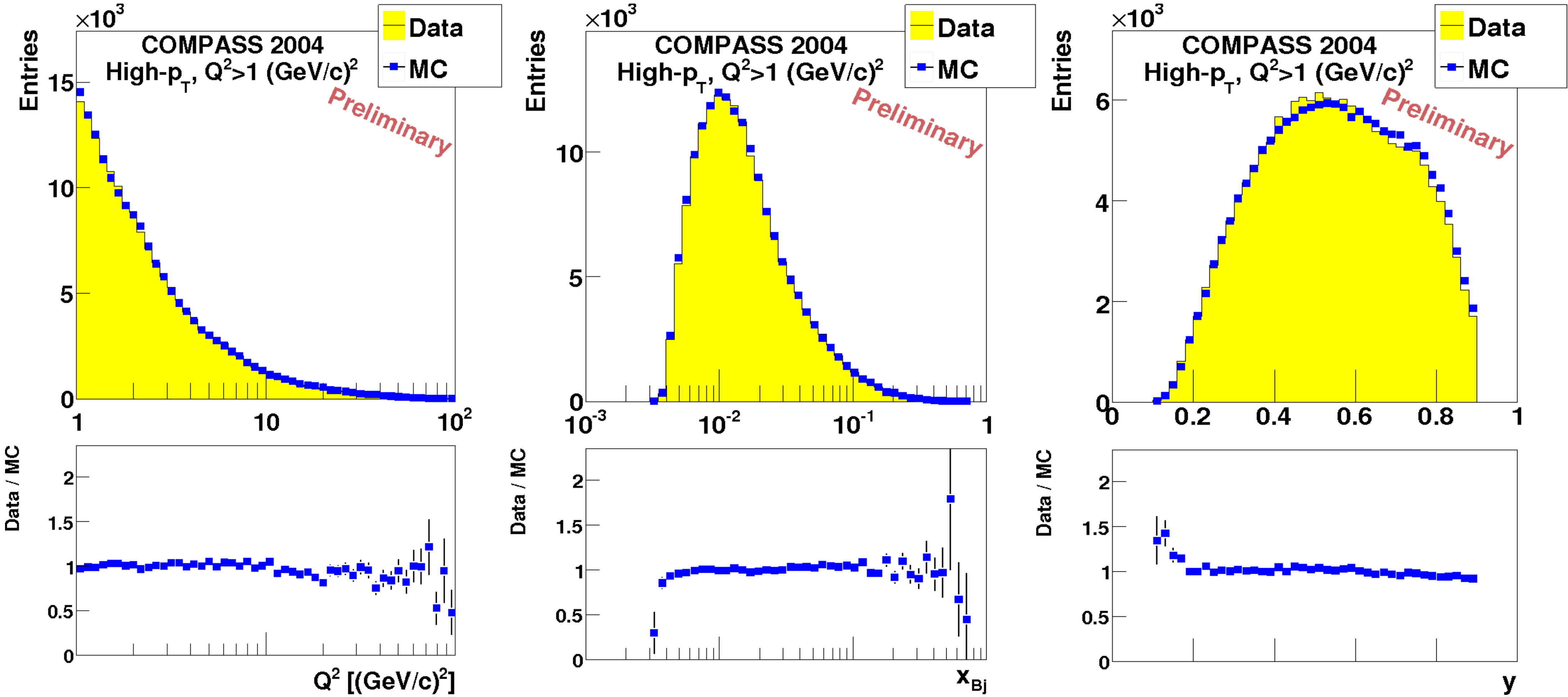
Two MC samples were used in the analysis: high-p_T and inclusive samples.

- Full chain of MC has been used:

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

- PDF: MRST2004LO.
- High p_T sample:
  - MC parton shower on has been used in the analysis.
  - MC parton shower off used to evaluate systematics.
  - Two generator tunings were used: Default and so-called COMPASS tunings.

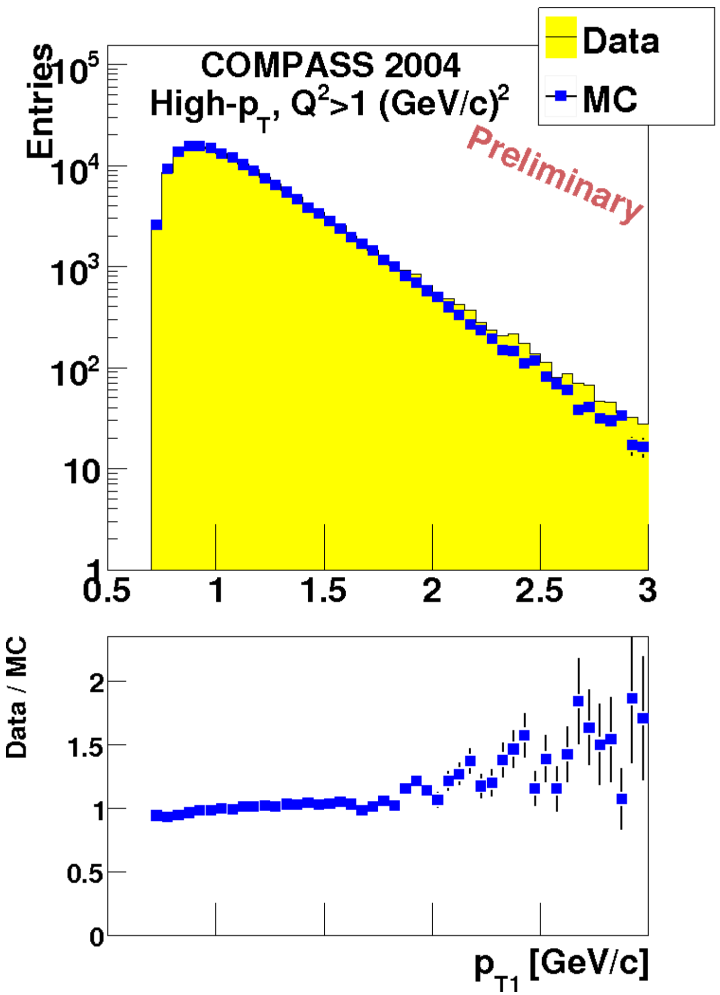
Data – Monte Carlo comparison, $Q^2>1(GeV/c)^2$

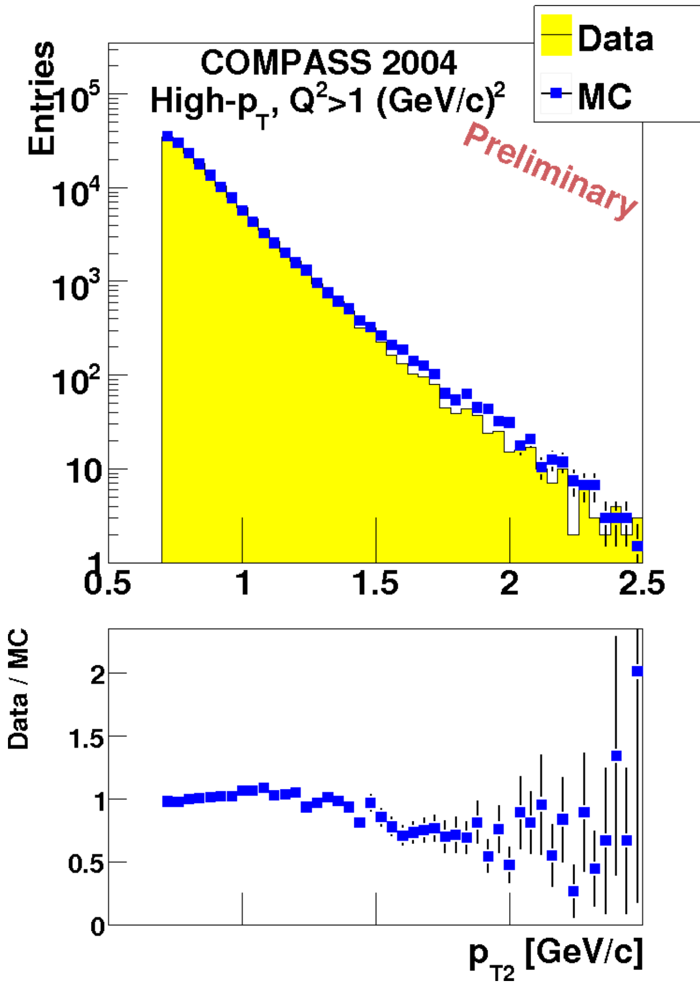


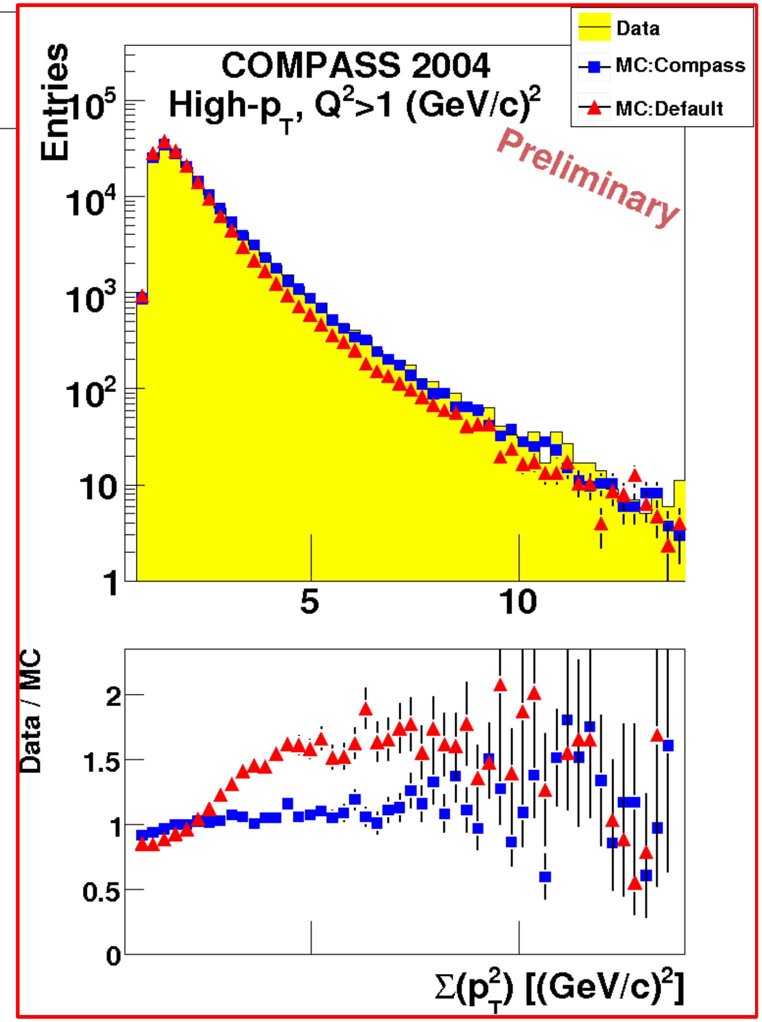
high-p_T sample (Q^2,x and y)

The agreement between data and MC is good

Data – Monte Carlo comparison, $Q^2>1 (GeV/c)^2$







Data/MC

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

Tunning comparison

Weighting method

The idea is to enhance the PGF events sample and to reduce the physical background.

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

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

- Therefore for every event we have to know:

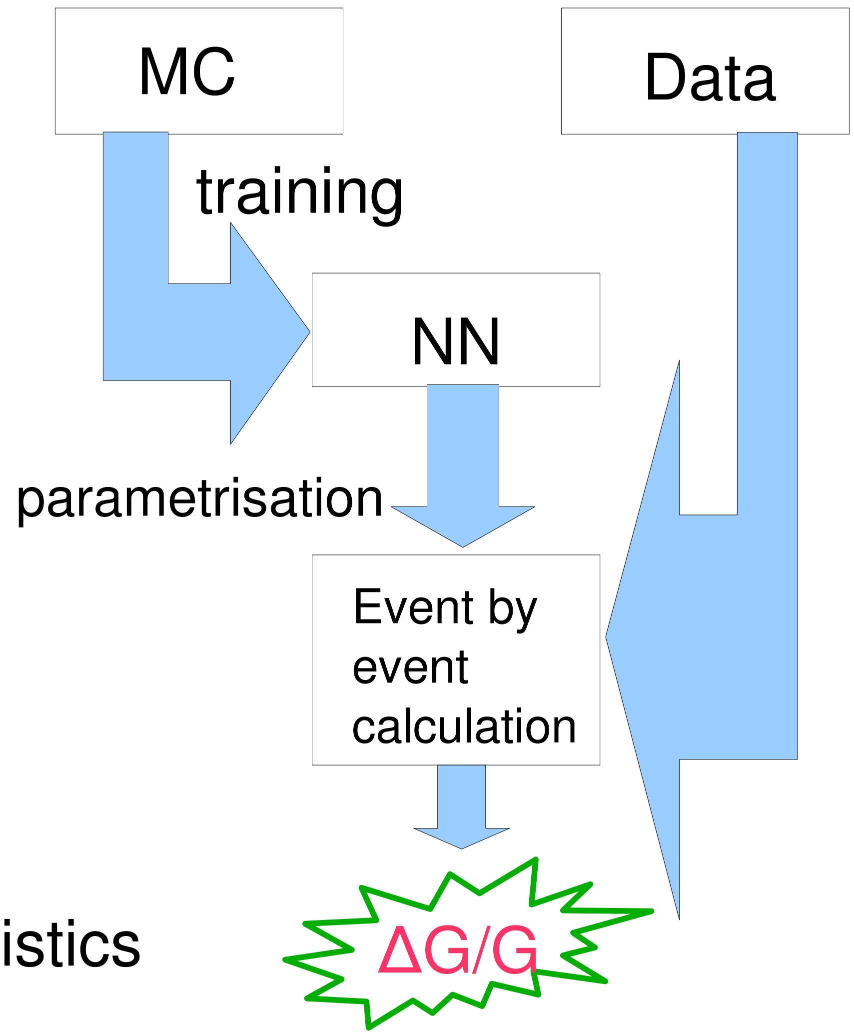
$$R_{PGF}, R_C, R_{LO}, R^{incl}_{PGF}, R^{incl}_{C}, R^{incl}_{LO},$$
$$a^{PGF}_{LL}, a^{C}_{LL}, a^{PGF,incl}_{LL}, a^{C,incl}_{LL},$$
$$x_C, x_G, f, D, P_b$$

f, D, P_b are directly obtained from data; the rest has to be estimated/parametrised.

Weighting 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).

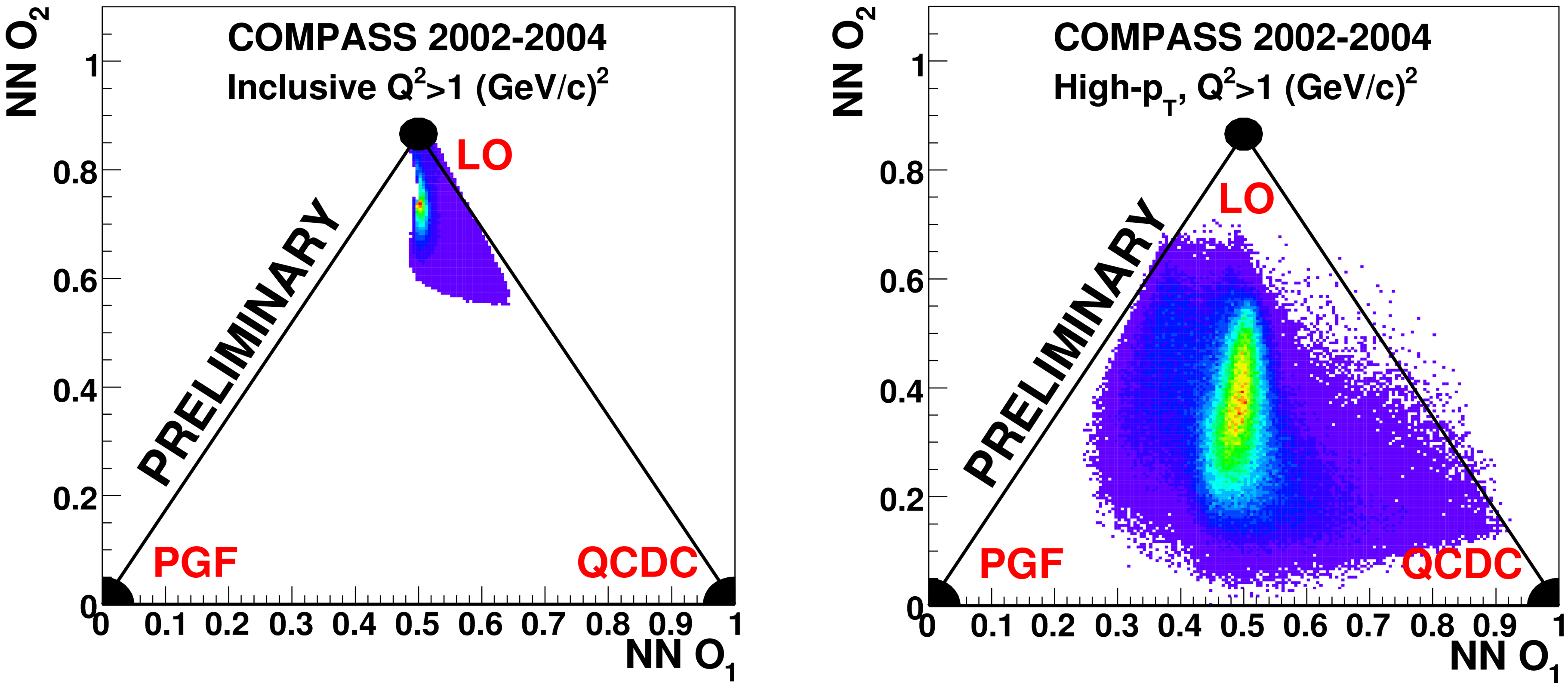
- MC sample is used to train the Neural Network (NN).
- A parametrisation is constructed.
- A weight is built from the parametrisation.
- Data sample is weighted on an event-by-event basis.



Optimal usage of the data sample statistics

Fractions R^i

We parametrise fractions R^i's (probabilities). $R^i = \frac{\sigma^i}{\sigma^{Tot}}$

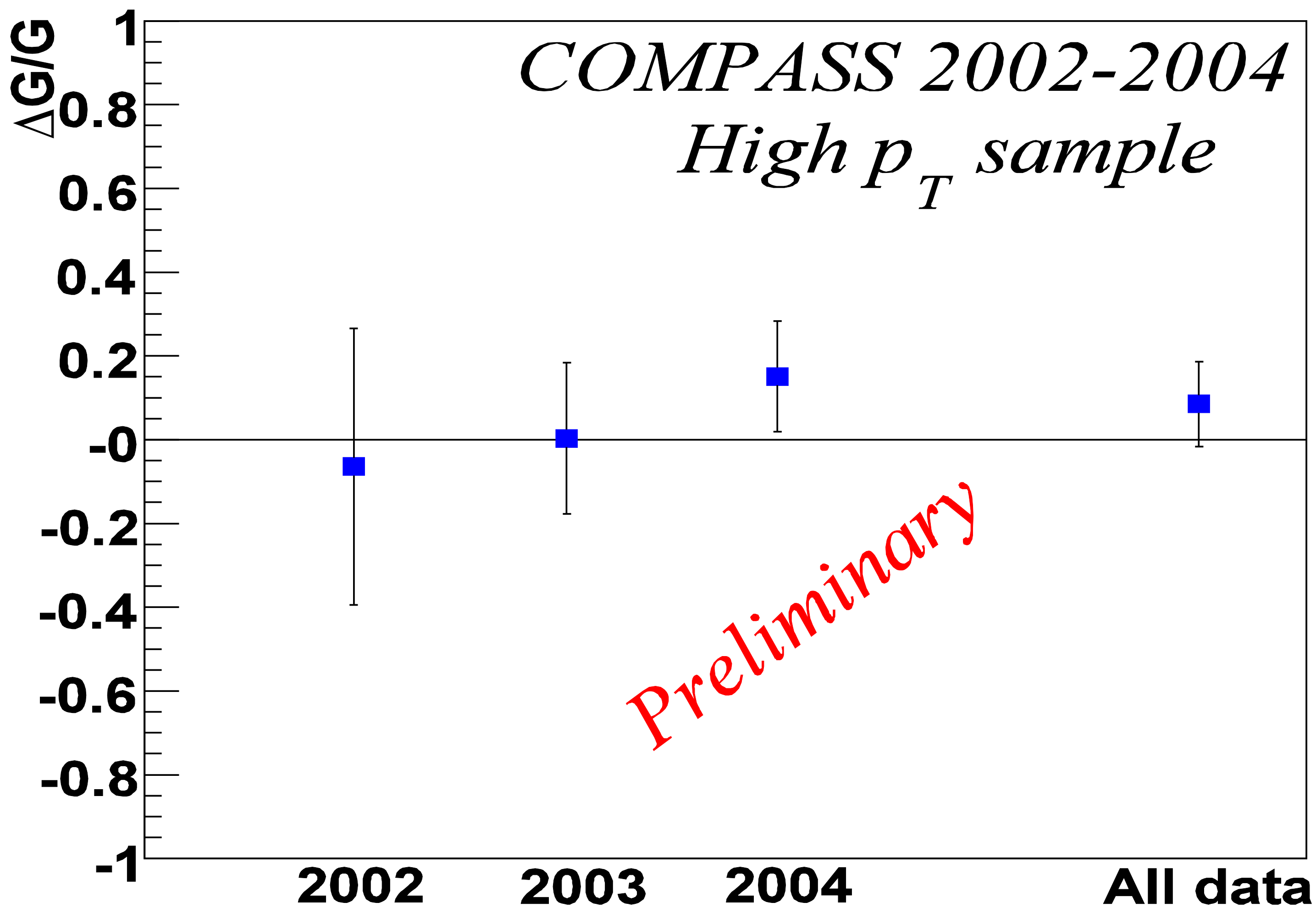


$$R^{PGF} = 1 - O_1 - \frac{1}{\sqrt{3}} O_2 \quad R^{QCDC} = O_1 - \frac{1}{\sqrt{3}} O_2 \quad R^{LO} = \frac{2}{\sqrt{3}} O_2$$

The sum of R^i's must add up to the unity.

Results

$$\frac{\Delta G}{G} = 0.08 \pm 0.10 \pm 0.05 \qquad x_G = 0.08^{+0.04}_{-0.03} \qquad \langle \mu^2 \rangle = 3\ (\mathrm{GeV/c})^2$$



Systematic errors Study

What has been checked?

- False asymmetries.
- Neural Network stability.
- Systematic errors due to MC:
  - Parton shower radiation on/off.
  - Generator tuning.
- δP_b ,δP_t ,δf.
- A_1 parametrisation.

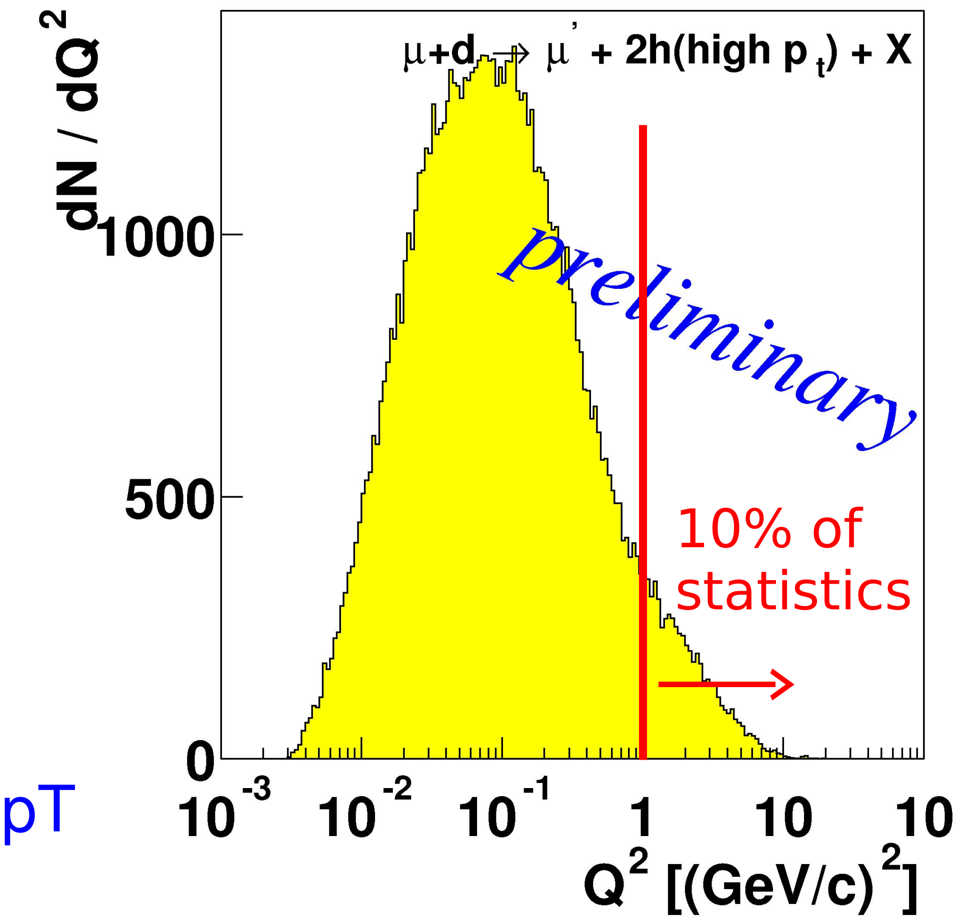
$\delta(\Delta G/G)_{false}$	0.011
$\delta(\Delta G/G)_{NN}$	0.006
$\delta(\Delta G/G)_{MC}$	0.040
$\delta(\Delta G/G)_{f,Pb,Pt}$	0.006
$\delta(\Delta G/G)_{A1}$	0.008
Total	0.045

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

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

For this analysis, the same selection as the $Q^2 > 1\ (GeV/c)^2$ analysis was applied plus a slightly tighter set of cuts :

- $x_F > 0.1$ and $z > 0.1$
- $x_{Bj} < 0.05$
- $\sum p_T^2 > 2.5\ (GeV/c)^2$



The scale of this analysis is given by the pT of the hadrons

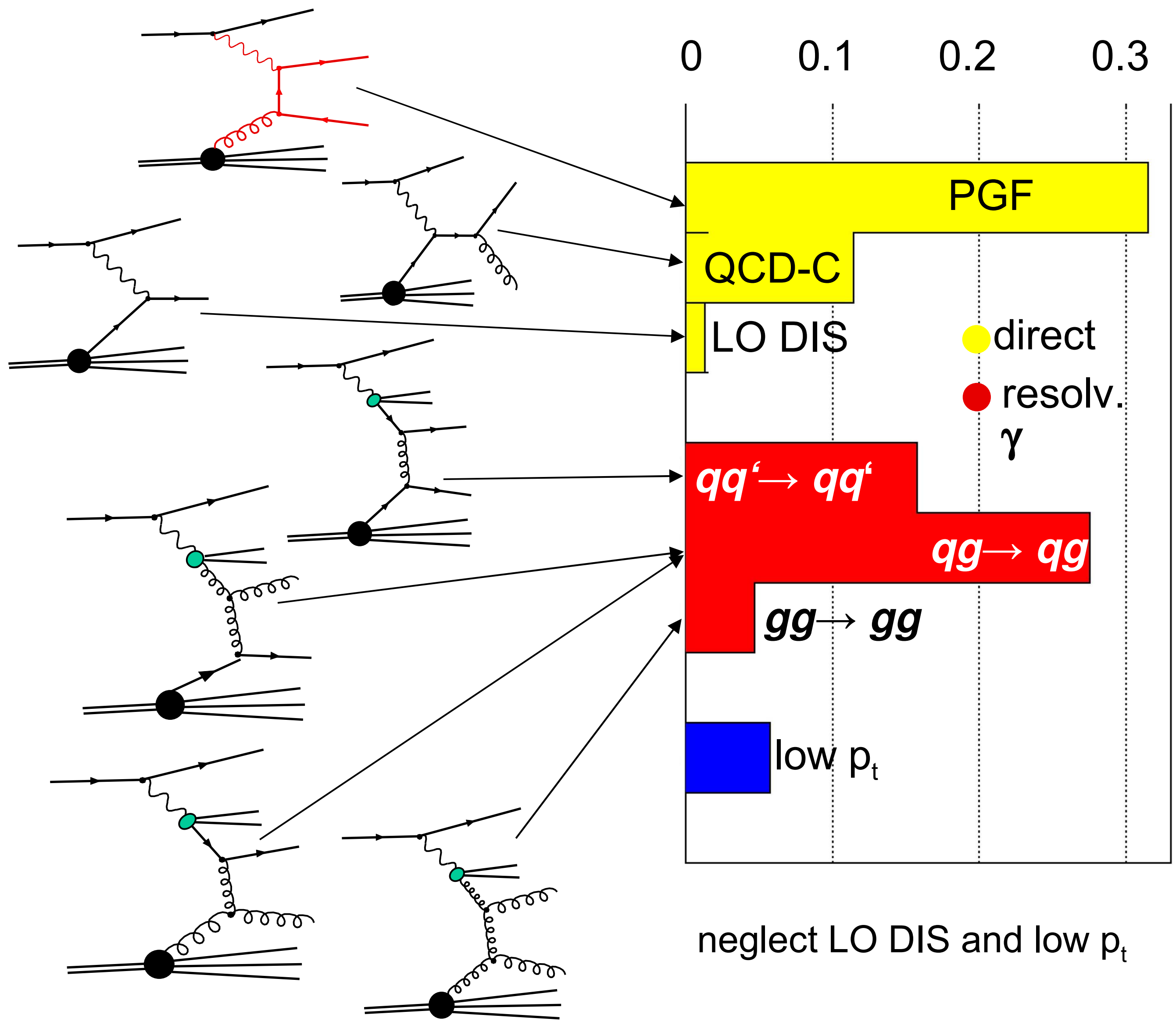
~90 % of our statistics in this sample

PGF and Background events:

MC Generator PYTHIA

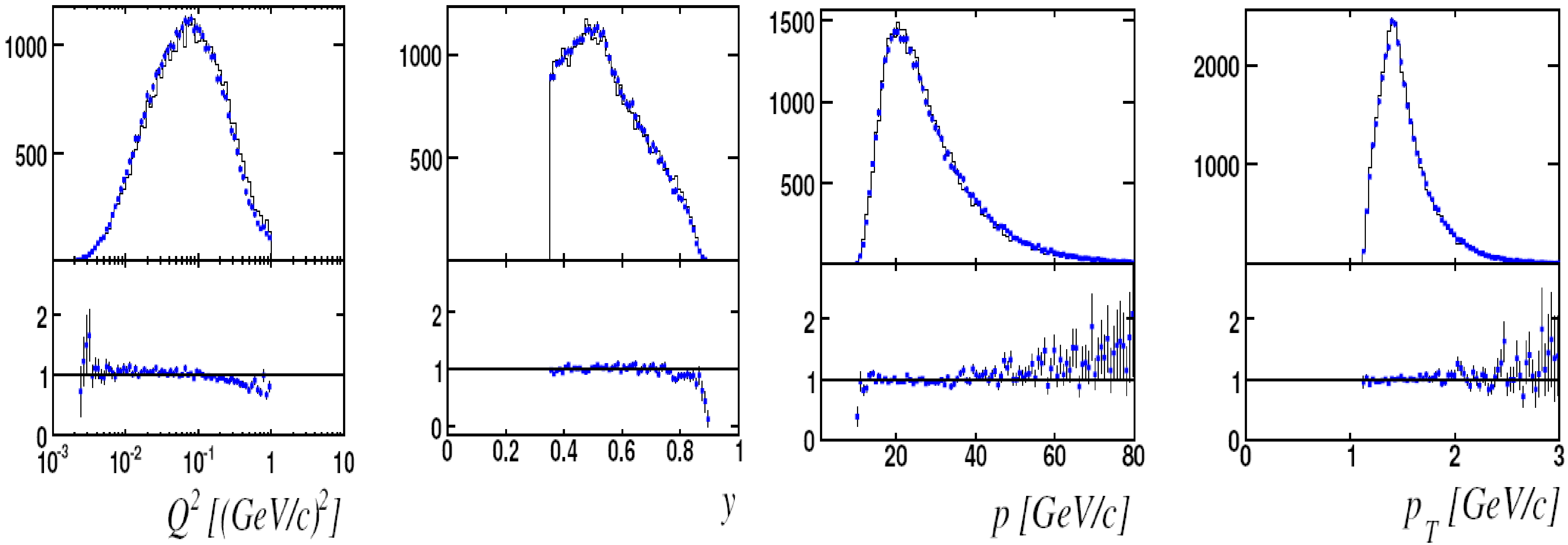
- Same background as $Q^2 > 1\ (GeV/c)^2$ case

- Additional background from resolved photon events



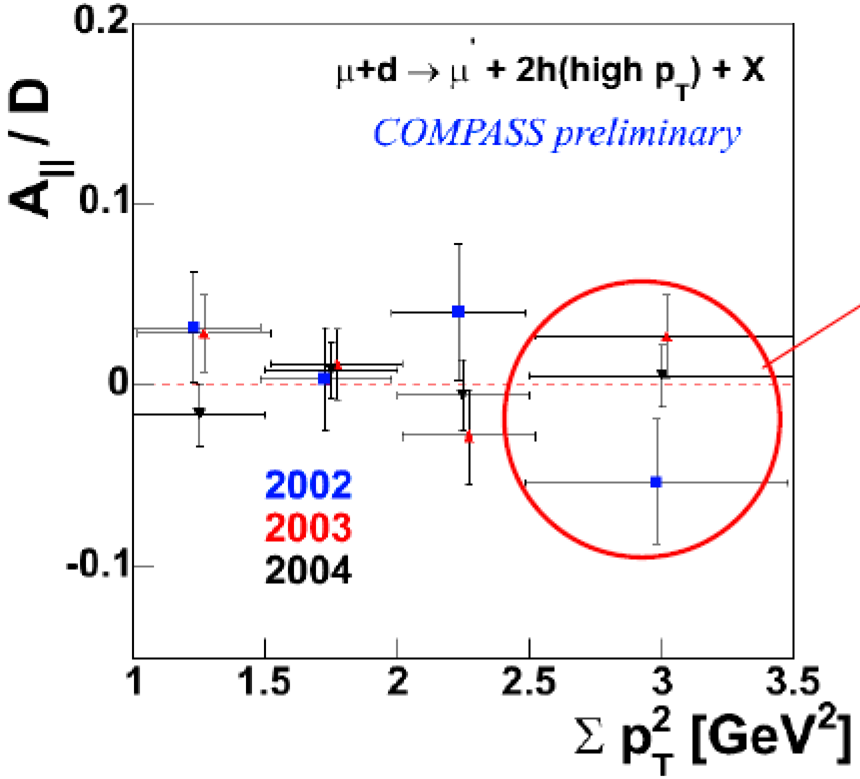
neglect LO DIS and low p_t

Data – Monte Carlo comparison, $Q^2<1\ (GeV/c)^2$



The agreement between MC and data is good

Results, $Q^2 < 1\ (GeV/c)^2$



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

$$@\, x_g = 0.085^{+0.071}_{-0.035}$$

$$<\mu^2> = 3\ (GeV/c)^2$$

2002-2004 Preliminary:

$\Delta G/G$ = 0.016 ± 0.058(stat) ± 0.014(exp syst) ± 0.052(MC syst) ± 0.013(γ)

(0.014(exp syst) ± 0.052(MC syst) ± 0.013(γ) combined: 0.055(syst))

2002-2003 Published:

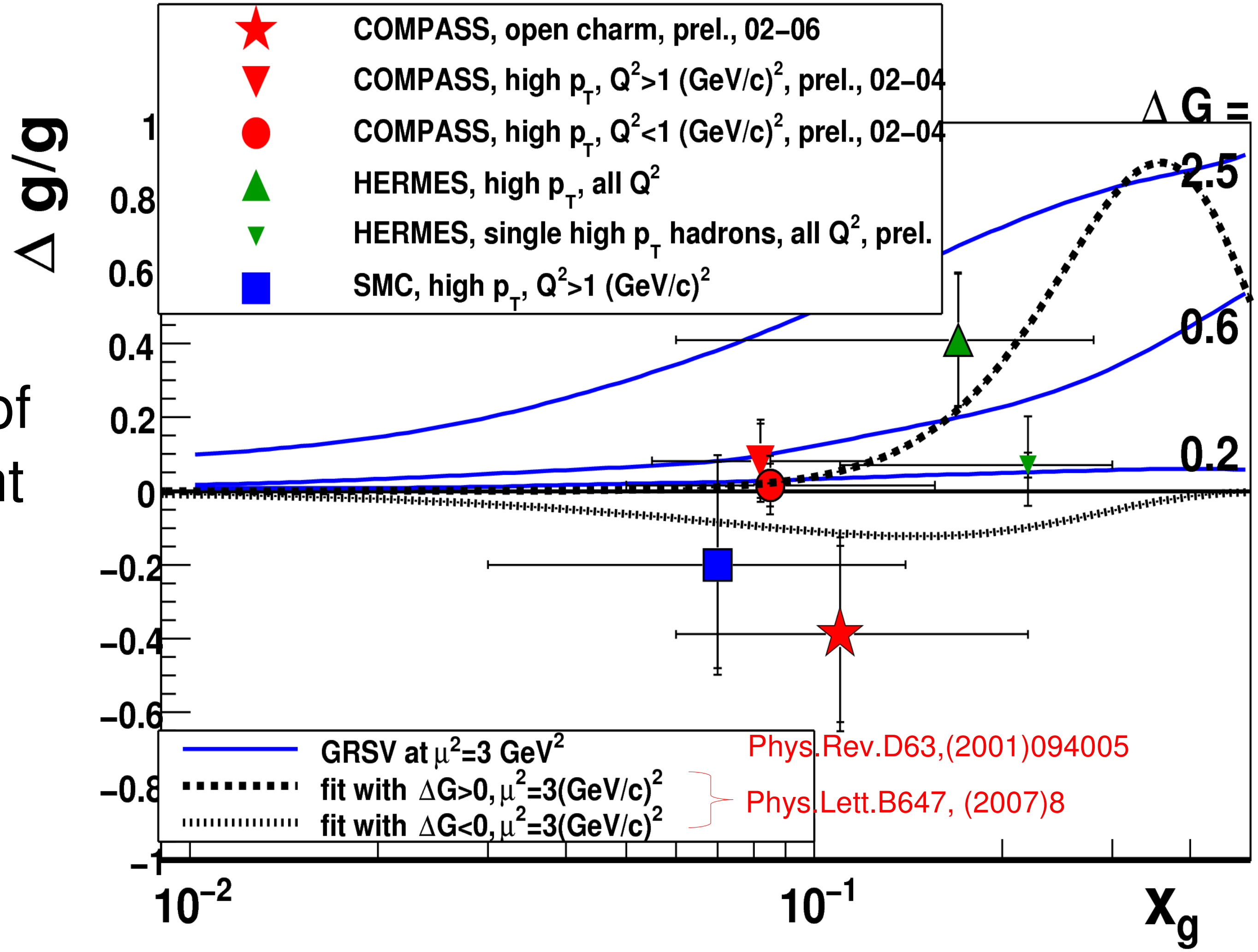
$\Delta G/G$ = 0.024 ± 0.089(stat) ± 0.057(syst) *Phys. Lett. B 633 (2006) 25 - 32*

ΔG/G Results

$Q^2 > 1\ GeV^2$: **$\Delta G/G = 0.08 \pm 0.10_{stat} \pm 0.05_{sys}$** @ $x_g = 0.08^{+0.04}_{-0.03}$

$Q^2 < 1\ GeV^2$: **$\Delta G/G = 0.02 \pm 0.06_{stat} \pm 0.06_{sys}$** @ $x_g = 0.09^{+0.07}_{-0.04}$

2 independent analyses of high p_T with quite different backgrounds lead to compatible results

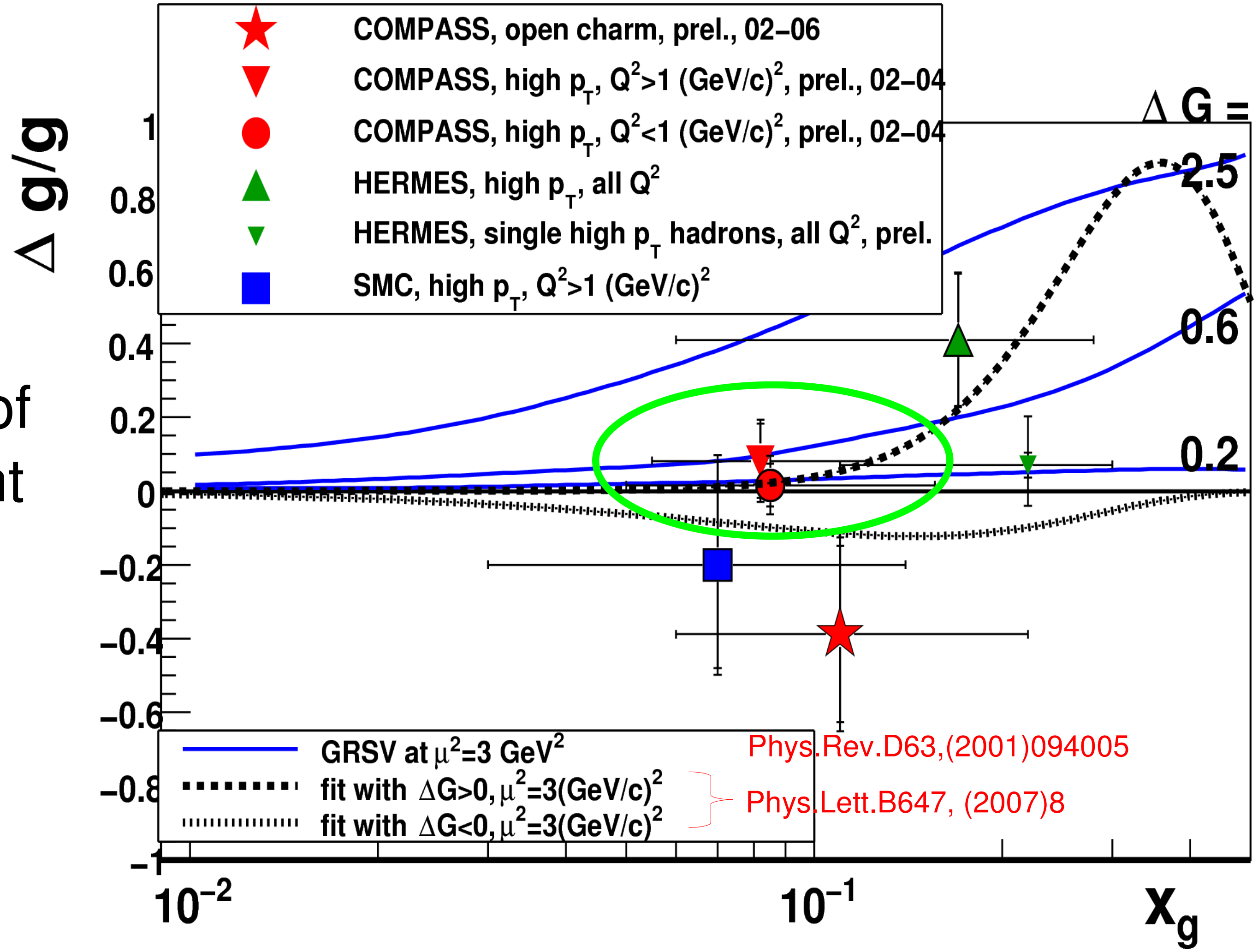


ΔG/G Results

$Q^2 > 1\ GeV^2$: $\mathbf{\Delta G/G = 0.08 \pm 0.10_{stat} \pm 0.05_{sys}}$ @ $\mathbf{x_g = 0.08^{+0.04}_{-0.03}}$

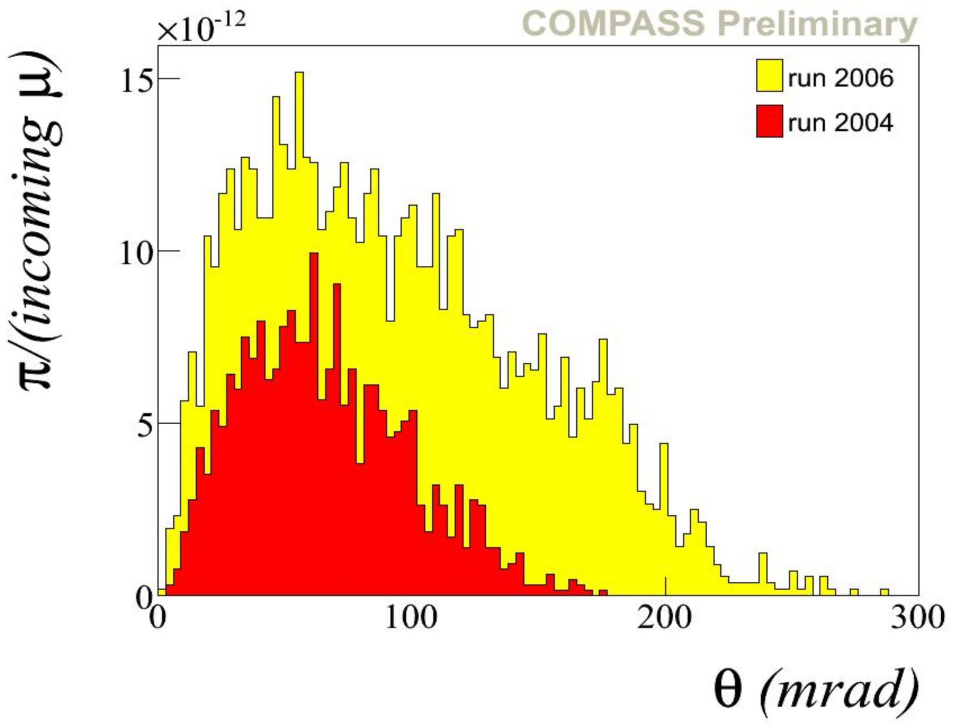
$Q^2 < 1\ GeV^2$: $\mathbf{\Delta G/G = 0.02 \pm 0.06_{stat} \pm 0.06_{sys}}$ @ $\mathbf{x_g = 0.09^{+0.07}_{-0.04}}$

2 independent analyses of high p_T with quite different backgrounds lead to compatible results



2006 and 2007 data

- Increase in acceptance due the 2006 upgrade (70 to 180 mrad on the target aperture).
- Target in 2006 and in 2007. Events are weighted by $f \times P_t$. In 2007 this factor is slightly small than in 2006.
- The analysis is on going ...
- COMPASS will run beyond 2009 (longitudinal and transverse pol.). Positive feed-back from SPSC (CERN)



	2006	2007
Material	6LiD	NH3
Polarisation	~50 %	~85 %
f	0.4	0.15

Outlook and Conclusions

- 2006 and 2007 data to be analysed
- Improvements in the method of analysis, e.g. lowering p_T cut from 0.7 to 0.4 GeV/c
- Analysis with two bins in x_g

- Recent results on $\Delta G/G$ from COMPASS high p_T analysis have been presented
- These measurements are consistent with zero @ $x_g \approx 0.1$

Спасибо!

Spares

Uncertainty for γ, $Q^2 < 1\ GeV^2$

Contribution from resolved photons

- Problem: polarised PDFs of the photon is not measured !

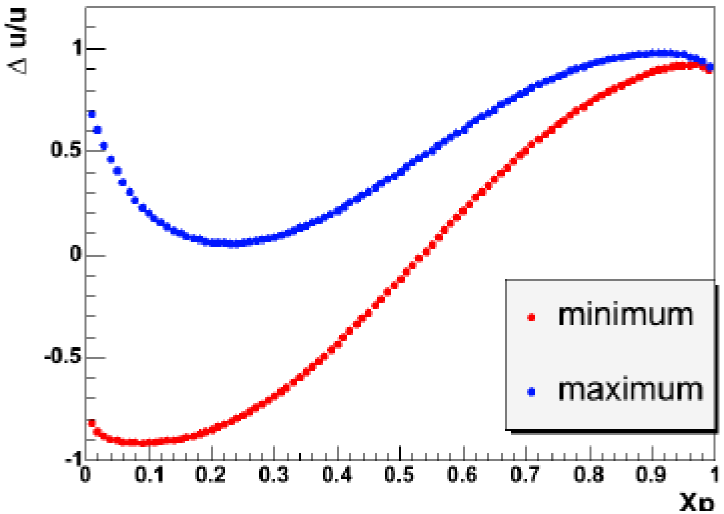
  → use unpolarised PDFs to constrain polarised

$$-q^{\gamma}(x,Q^2) < \Delta q^{\gamma}(x,Q^2) < q^{\gamma}(x,Q^2)$$

⇨ This leads to 2 extreme (max & min) scenarios

additional uncertainty band.

Glück, Reya, Sieg, *Eur. Phys. J. C20* (2001) 271



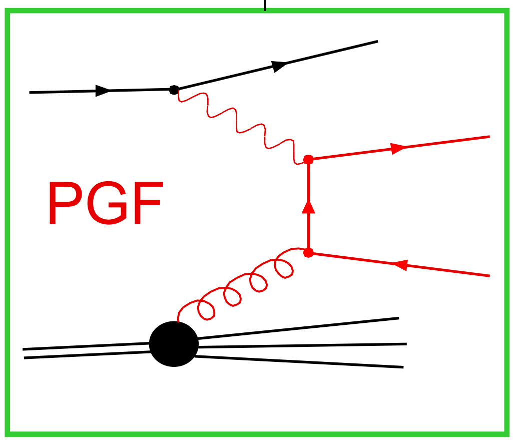
High p_T Analysis, $Q^2 > 1$ GeV^2

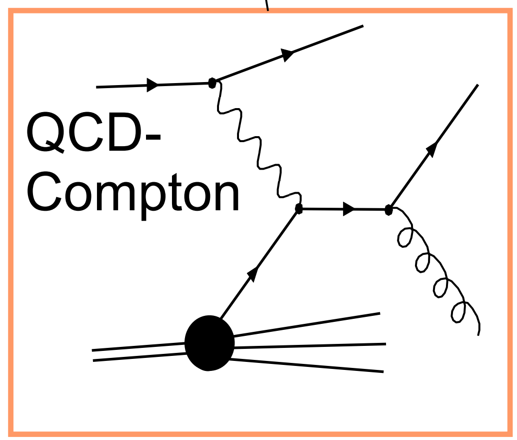
We access A^{PGF} by measuring of the helicity asymmetry of two high-p_T hadrons at large Q^2, this measurement includes also contribution other physical processes:

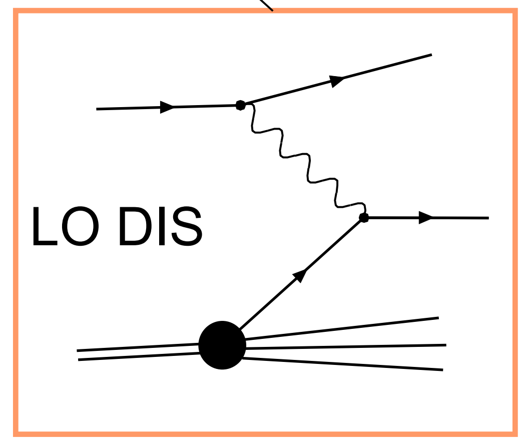
$$A_{LL}^{2h} = A^{PGF} + A^{COM} + A^{LO}$$

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

$$A_1^{LO} \equiv \frac{\sum_i e_i^2 \Delta q_i}{\sum_i e_i^2 q_i}$$







The same decomposition can be done for inclusive asymmetry :

$$A_{LL}^{incl}(x_{Bj}^{incl}) = \frac{\Delta G}{G}(x_g^{incl})\, a_{LL}^{incl,\,PGF} \left(\frac{\sigma^{PGF}}{\sigma^{Tot}}\right)_{incl} + A_1^{LO}(x_C^{incl})\, a_{LL}^{incl,\,C} \left(\frac{\sigma^{C}}{\sigma^{Tot}}\right)_{incl} + A_1^{LO}(x_{Bj}^{incl})\, D \left(\frac{\sigma^{LO}}{\sigma^{Tot}}\right)_{incl}$$

$\Delta G/G$ 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.
- A_1 are taken using a parametrisation on inclusive data. (EPJ C52 (2007)255)

$\Delta G/G$ for High p_T, $Q^2 > 1$ GeV^2

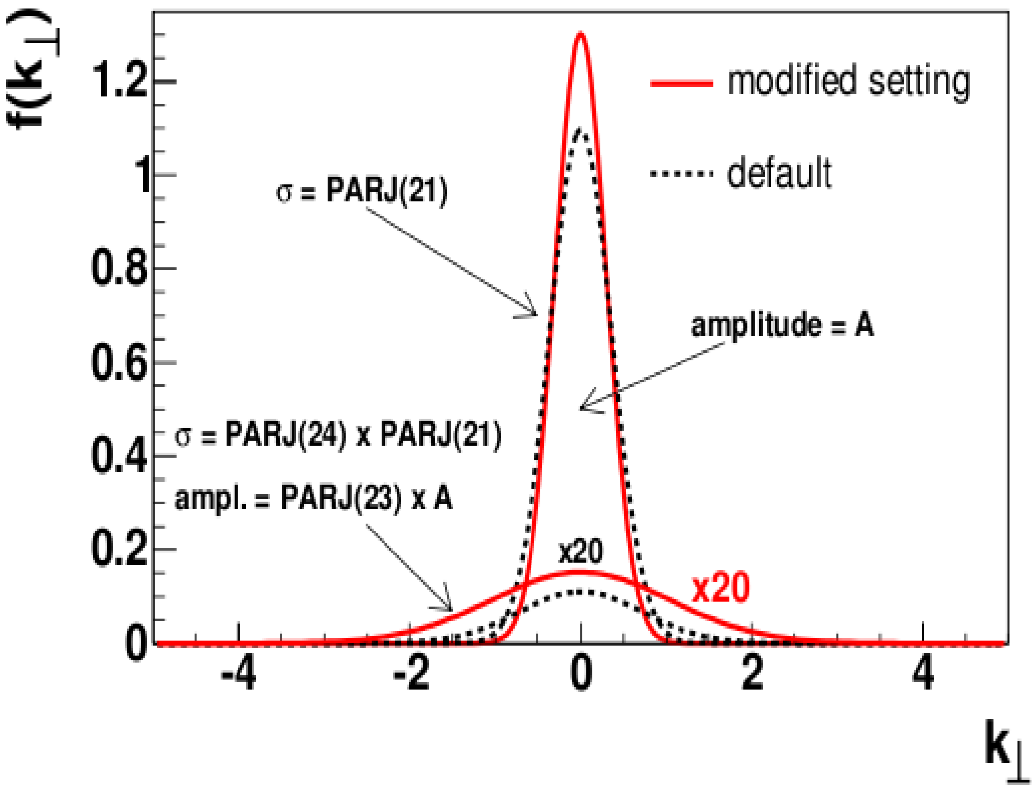
The final formula for the gluon polarization:

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

- A^{2h}_{LL} is the measured 2-h asymmetry.
- β is composed by a_{LL} and R. They are estimated using MC.
- A_{coor} is a corrective factor for Compton-QCD and LO processes:
  - a_{LL} and R are estimated using MC.
  - 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



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

	PARJ(21)	PARJ(23)	PARJ(24)	a	b
Default	0.36	0.01	2.0	0.3	0.58
Compass	0.3	0.02	3.5	0.6	0.1