Gluon polarisation from high transverse momentum hadron pairs production @ COMPASS

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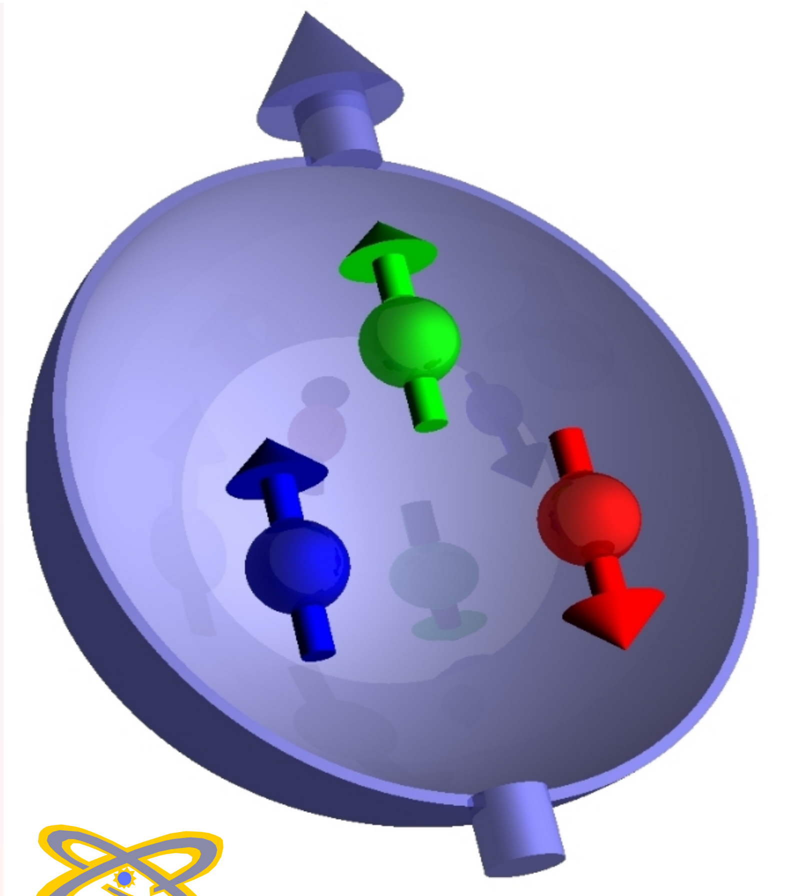
The Nucleon Spin



$S_N = ½ = ½\ \Delta\Sigma$

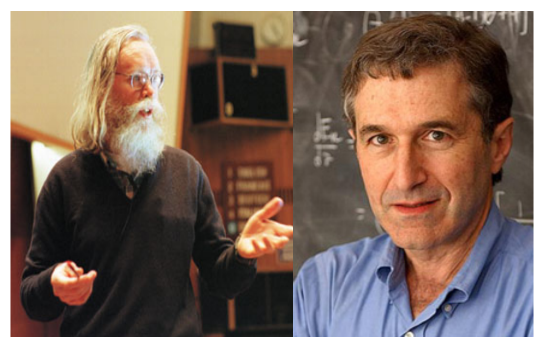
The naïve Quark-Parton Model (QPM) considers only the contribution from quarks

$$\Rightarrow\ \Delta\Sigma = 1$$

Applying Relativistic Corrections

$$\Rightarrow\ \Delta\Sigma \approx 0.75$$

Using the Ellis-Jaffe Sum rule and Hyperon decays $\Rightarrow\ \Delta\Sigma \approx 0.6$

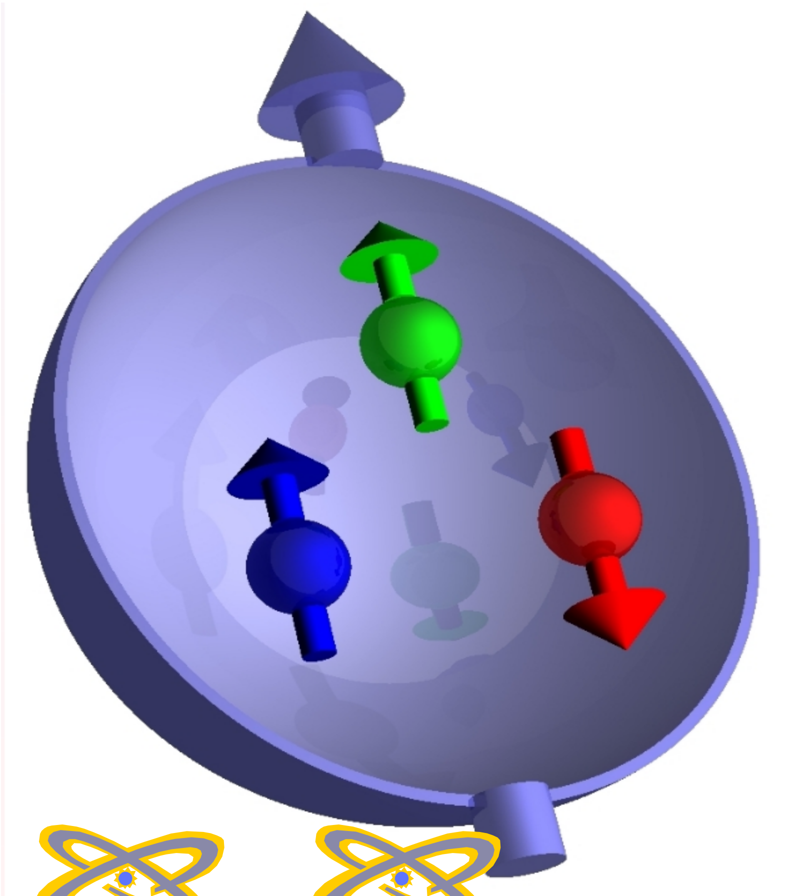


Phys.Rev.D9,(1974)1444

Erratum-ibid.D10,(1974)1669.

(J.Ellis and R.Jaffe)

The Nucleon Spin



$S_N = ½ = ½\ \Delta\Sigma$

In 1988 EMC measured

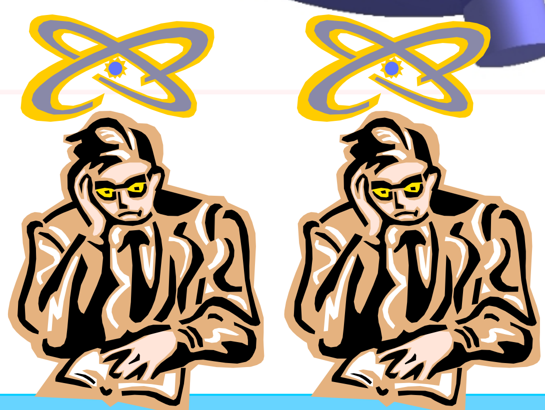
$\Delta\Sigma = 0.12 \pm 0.17$ (Phys.Lett.B206,364)

Today world data results, including COMPASS, gives:

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

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

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



Spin crisis !

Where is the remaining part?

How is the nucleon spin composed?

The Nucleon Spin

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

Adding the following contributions:

ΔG – from gluons

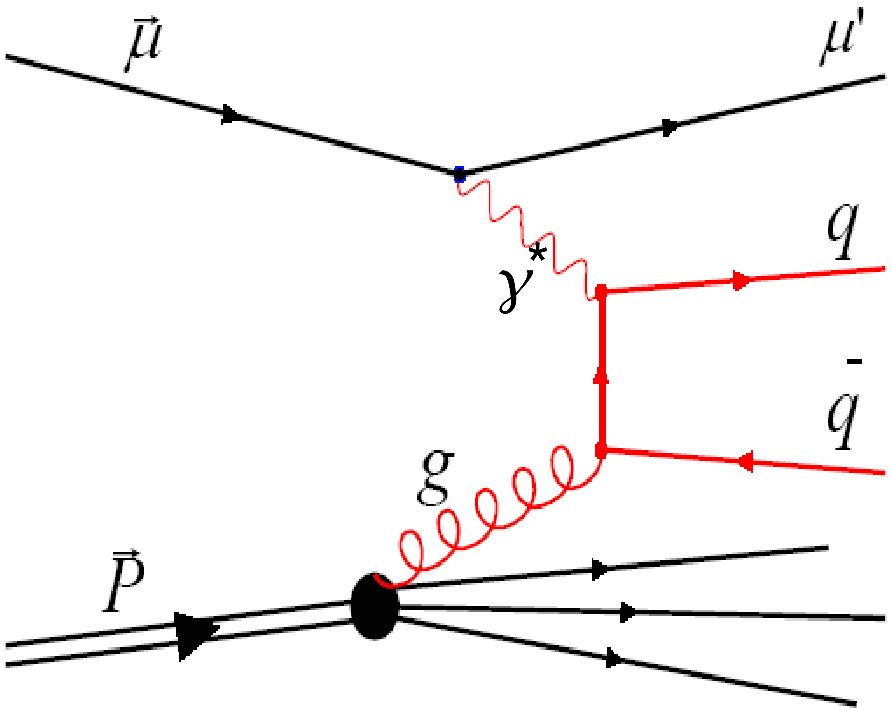
$L = L_g + L_q$ – from orbital angular momenta of quarks and gluons

How much is the contribution from gluons and from L?

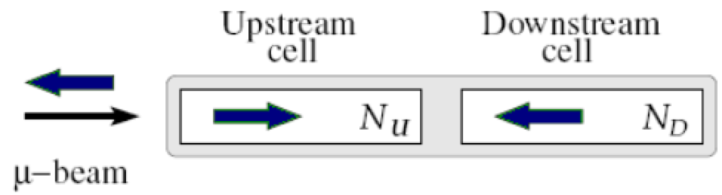
Spin Puzzle

Direct measurement of ΔG/G

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



Photon-gluon fusion process (PGF)



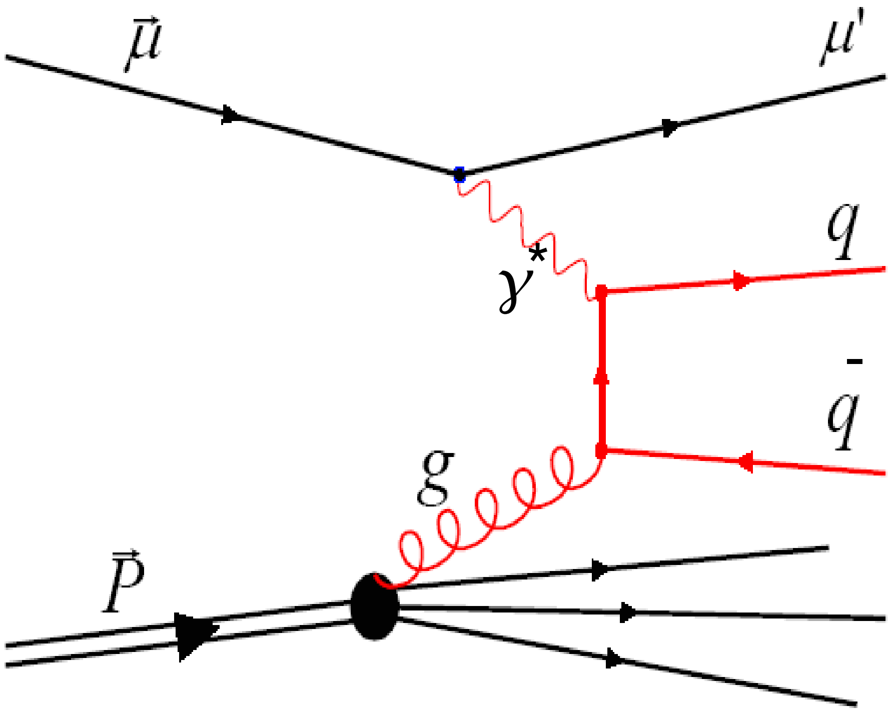
$$A_{PGF} = \frac{N^{\stackrel{\leftarrow}{\Rightarrow}}_{PGF} - N^{\stackrel{\leftarrow}{\Leftarrow}}_{PGF}}{N^{\stackrel{\leftarrow}{\Rightarrow}}_{PGF} + N^{\stackrel{\leftarrow}{\Leftarrow}}_{PGF}}$$

$\Rightarrow$ ΔG/G

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

Direct measurement of ΔG/G

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

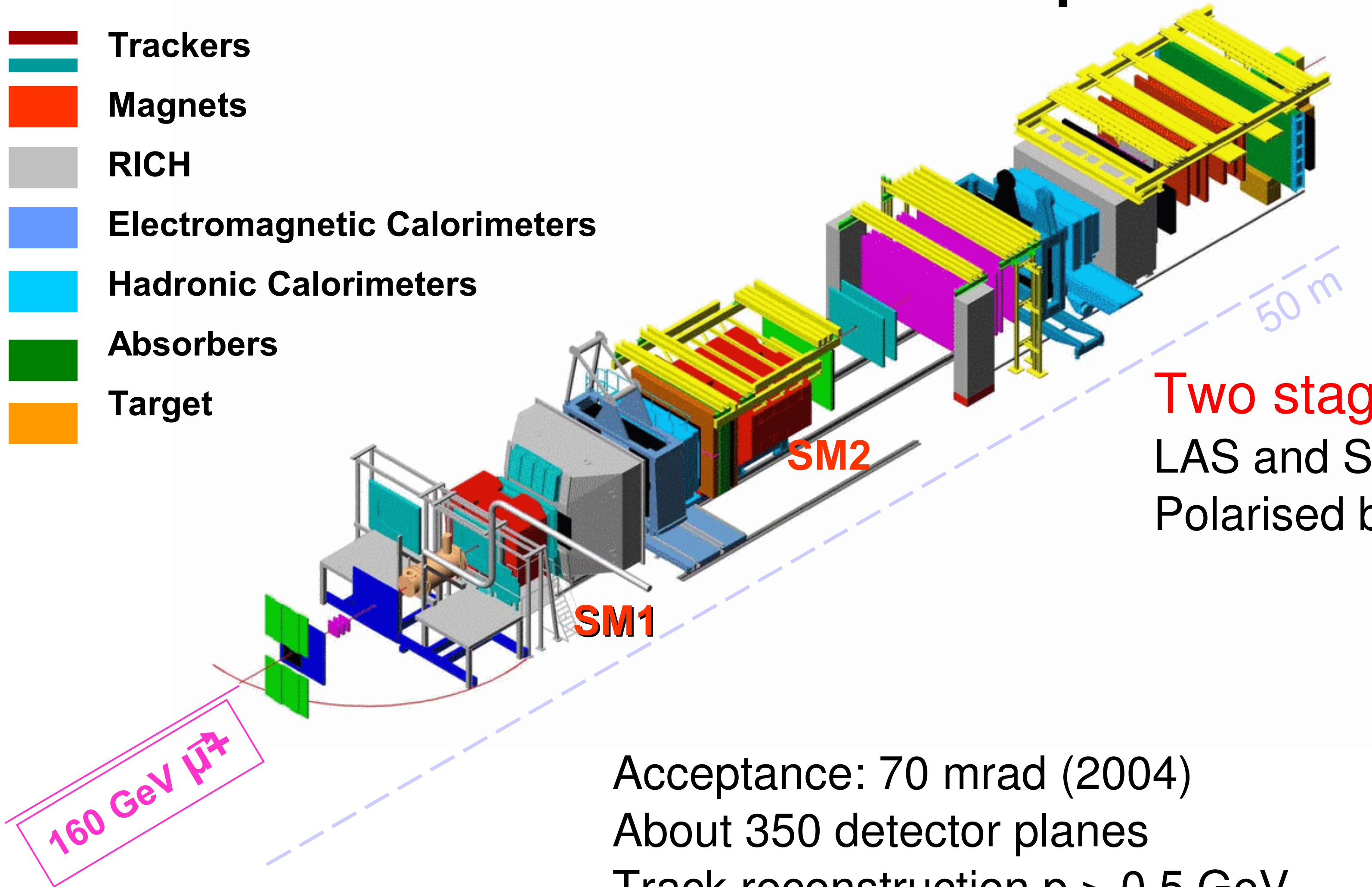


Photon-gluon fusion process (PGF)

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

- Open-charm meson (C.Franco talk)
  - ☺ Provides the purest sample of PGF events, almost free from background contamination. Not much MC dependent.
  - ☹ Low statistics. NLO corrections can be important.
- 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.

The COMPASS Spectrometer



NIM A577 (2007) 455

Two staged spectrometer:

LAS and SAS

Polarised beam and target

Acceptance: 70 mrad (2004)

About 350 detector planes

Track reconstruction p > 0.5 GeV

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

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:

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

The asymmetry for PGF process

What we want to extract

Estimated from MC

Fraction of PGF process

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

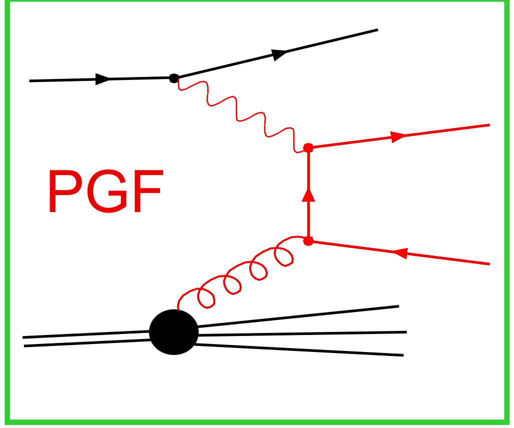
High p_T Analysis, $Q^2 > 1\ GeV^2$

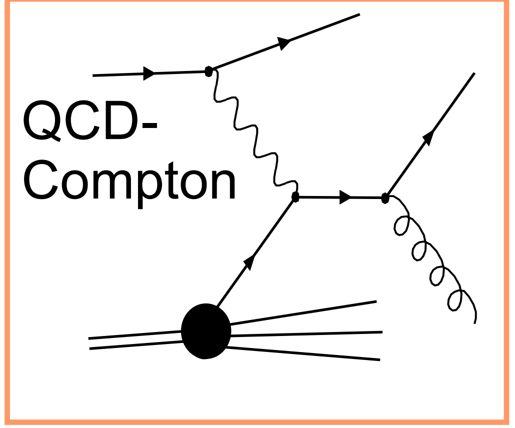
We access A^{PGF} by measuring of the helicity asymmetry of two high-p_T hadrons at large Q^2, this measurement includes also contribution other physical processes:

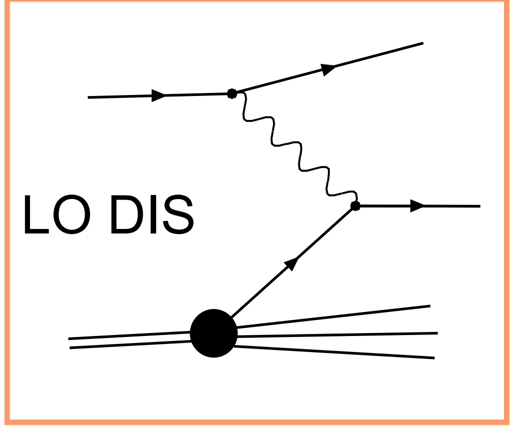
$$A_{LL}^{2h} = A^{PGF} + A^{COM} + A^{LO}$$

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

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







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:

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

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

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

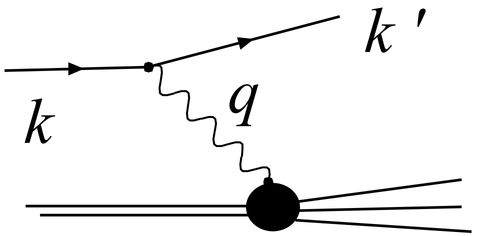
- A^{2h}_{LL} is the measured 2-h asymmetry.
- a_{LL} and R are estimated using MC.
- A_1 are taken using a parametrisation on inclusive data. (EPJ C52 (2007)255)

Event selection

- Interaction vertex which contains an incoming and a scattered muon and at least 2 outgoing hadrons
- For Deep Inelastic Scattering 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
- For the pair of hadrons is required an invariant mass $m > 1.5$ GeV/c^2 and $z_1 + z_2 < 0.95$

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

Years	2002	2003	2004	all years
Statistics	49585	170943	286685	507213



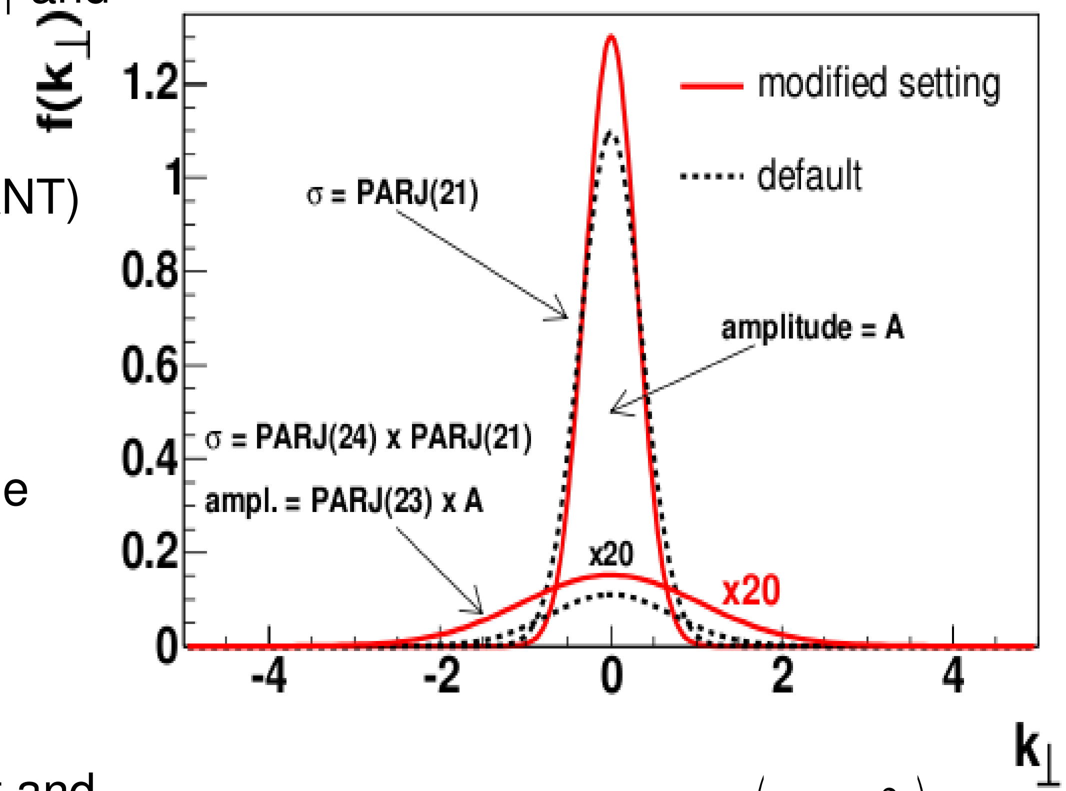
Monte Carlo Simulation

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.

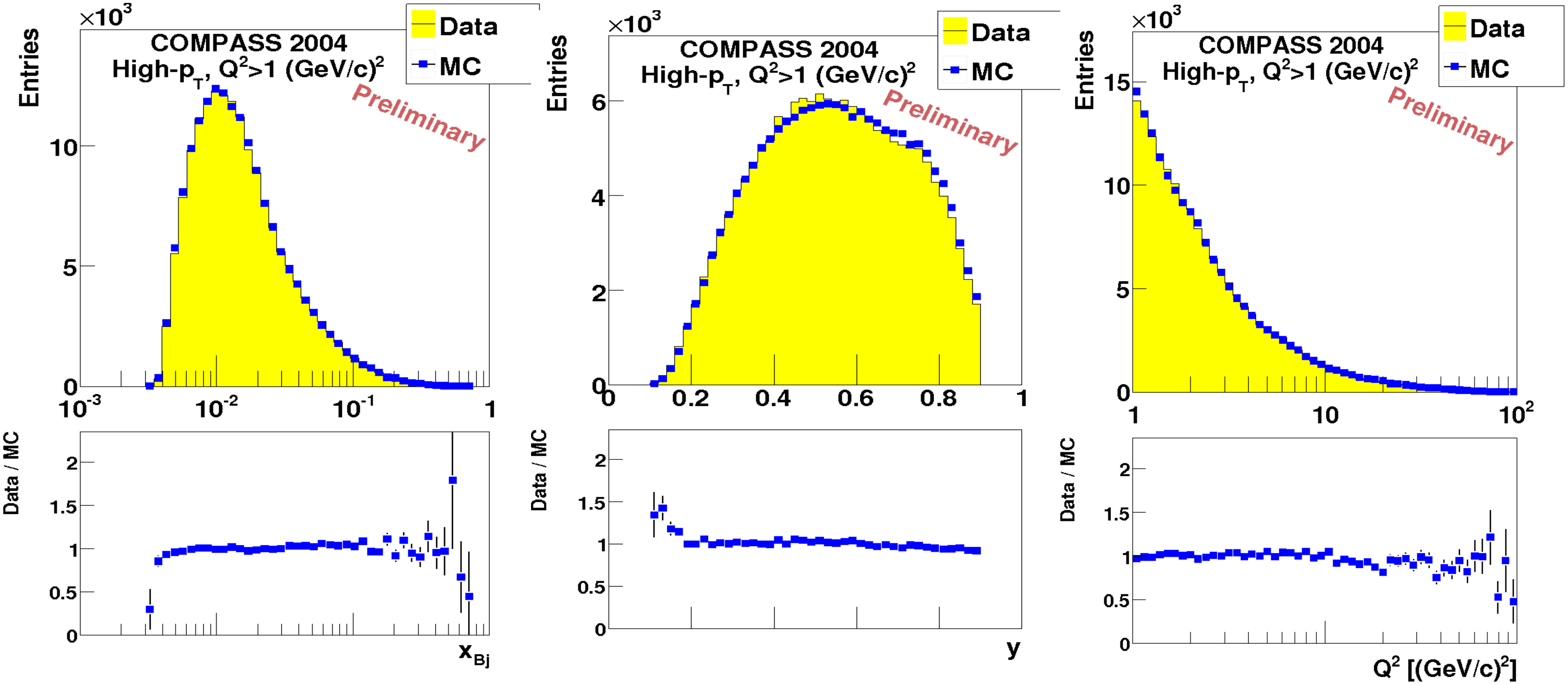
- PDF: MRST2004LO.
- High p_T sample:
  - MC parton shower on has been used in the analysis.
  - MC parton shower off used to evaluate systematics.
  - Two generator tunings were used: Default and so-called COMPASS tunings:



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

	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

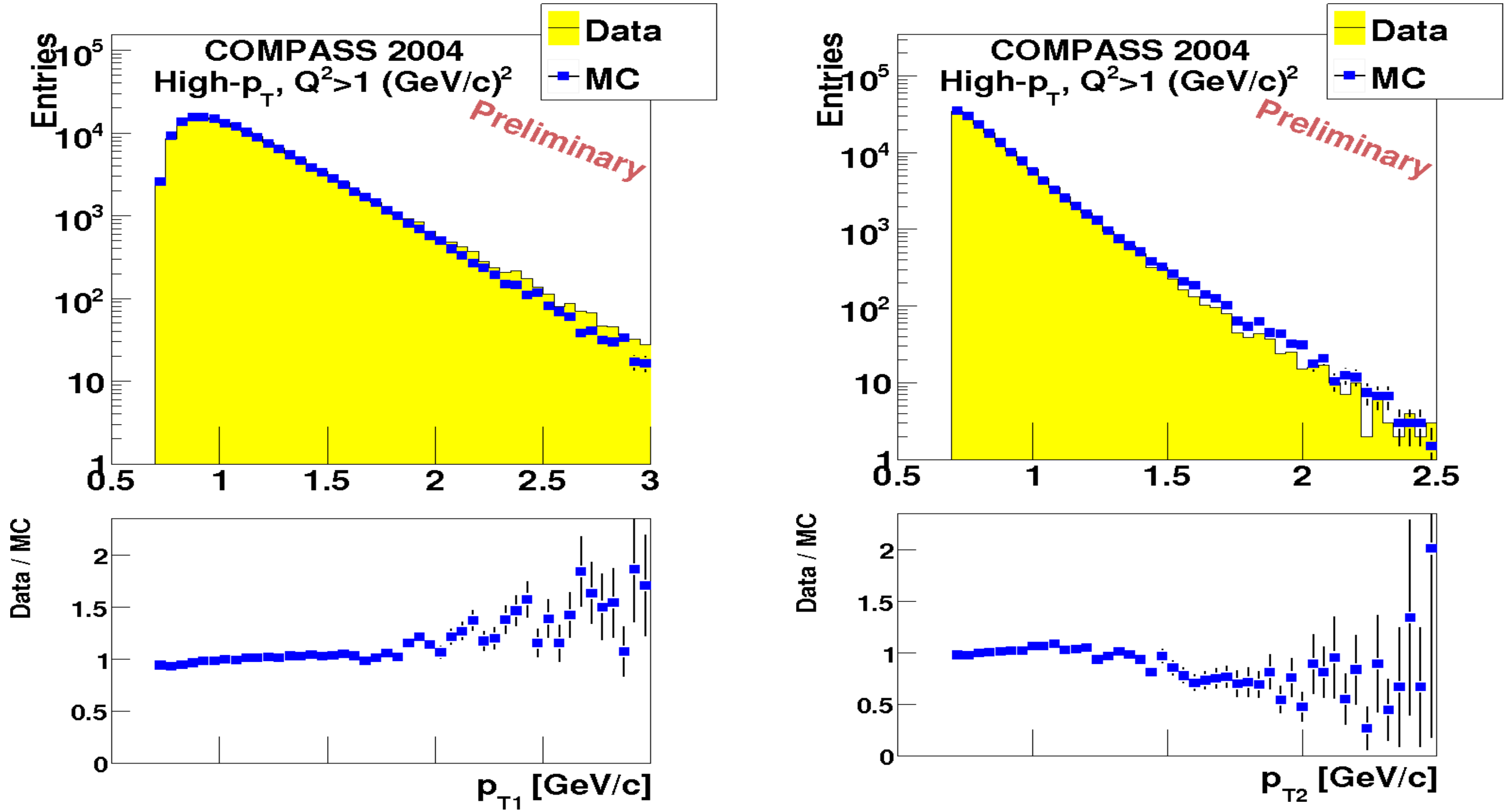
Data – Monte Carlo comparison, $Q^2 > 1 (GeV/c)^2$



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

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}

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:

$$W = fDP_b\beta$$

- Therefore for every event we have to know:

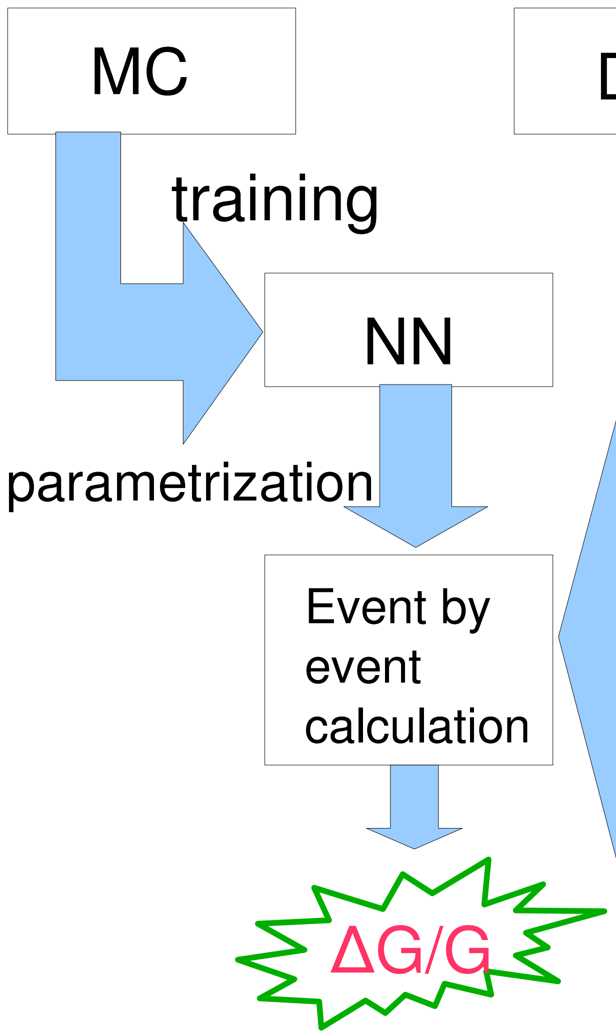
$$R_{PGF}, R_C, R_{LO}, R_{PGF}^{incl}, R_C^{incl}, R_{LO}^{incl},$$
$$a_{LL}^{PGF}, a_{LL}^{PGF,incl}, a_{LL}^{C}, a_{LL}^{C,incl},$$
$$x_C, x_G, f, D, P_b$$

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

Weighting method

Using a Neural Network to assign to each event a probability of originating from each of the three processes (LO, PGF or Compton).

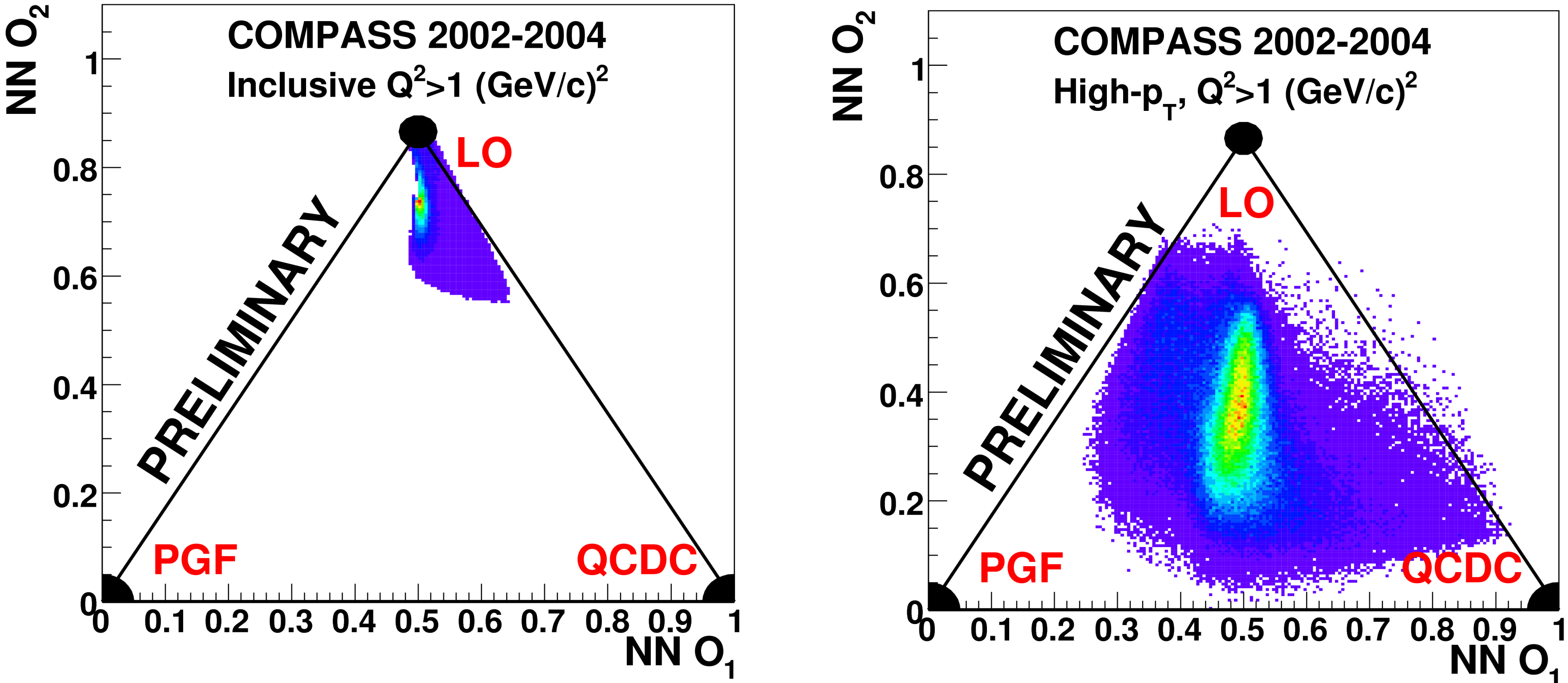
- MC is used to train the Neural Network (NN).
- A parametrization is constructed.
- A weight is built from the parametrization.
- Data is weighted in an event-by-event basis.



Fractions R_i

We parametrise fractions R (probabilities).
Two variables O_1 and O_2 are used (R sum up to 1).

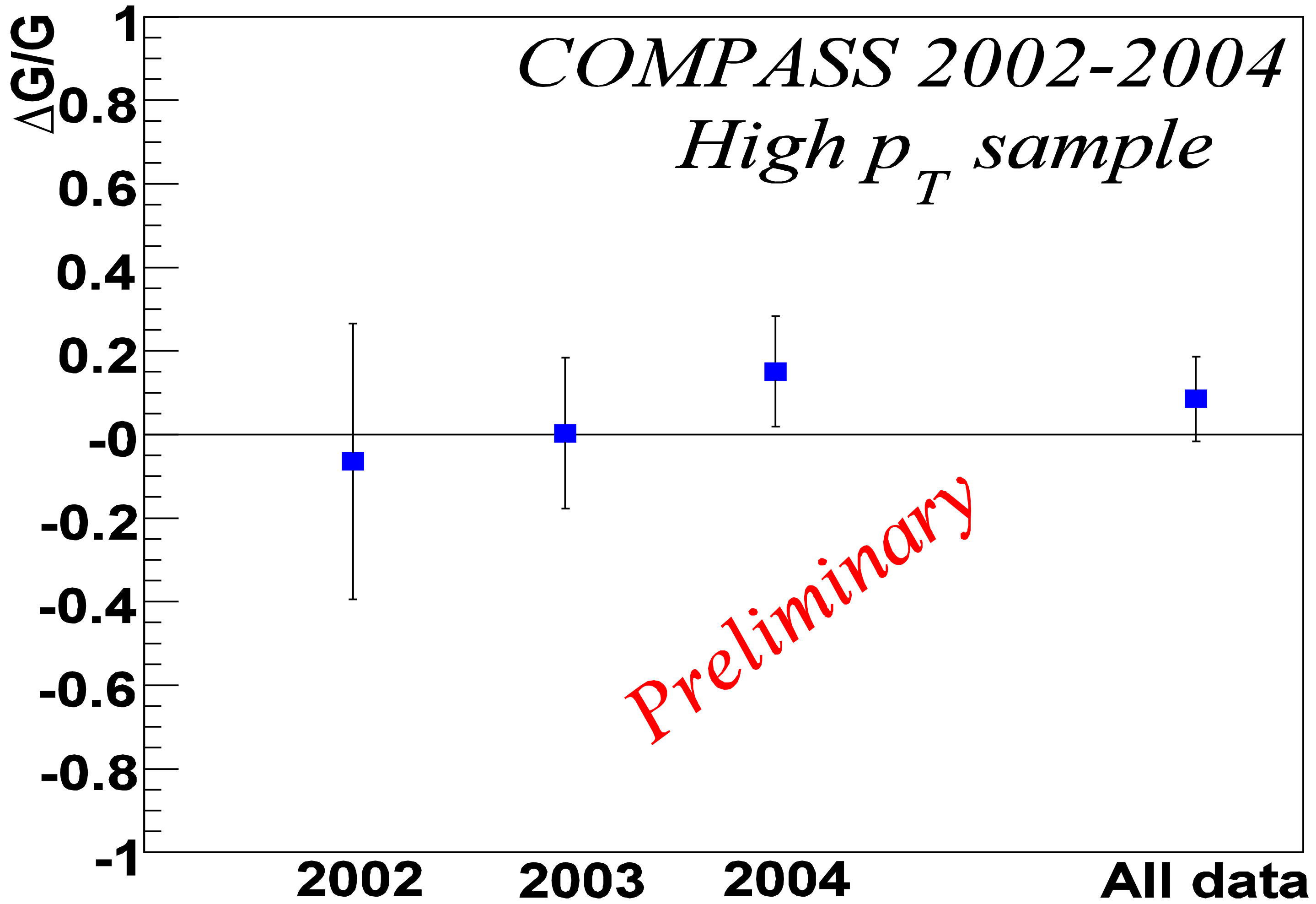
$$R_i = \frac{\sigma^i}{\sigma^{Tot}}$$



$$R_{PGF} = 1 - O_1 - \frac{1}{\sqrt{3}} O_2 \qquad R_{QCDC} = O_1 - \frac{1}{\sqrt{3}} O_2 \qquad R_{LO} = \frac{2}{\sqrt{3}} O_2$$

Results

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



Systematics errors Study

What has been checked?

- False asymmetries:
- Neural Network stability:
  - Several training MC samples
- Systematic errors due to MC:
  - Parton shower radiation on/off and tuning
- $\delta P_b, \delta P_t, \delta f$
- A_1 parametrisation
  - Different parametrisations were used

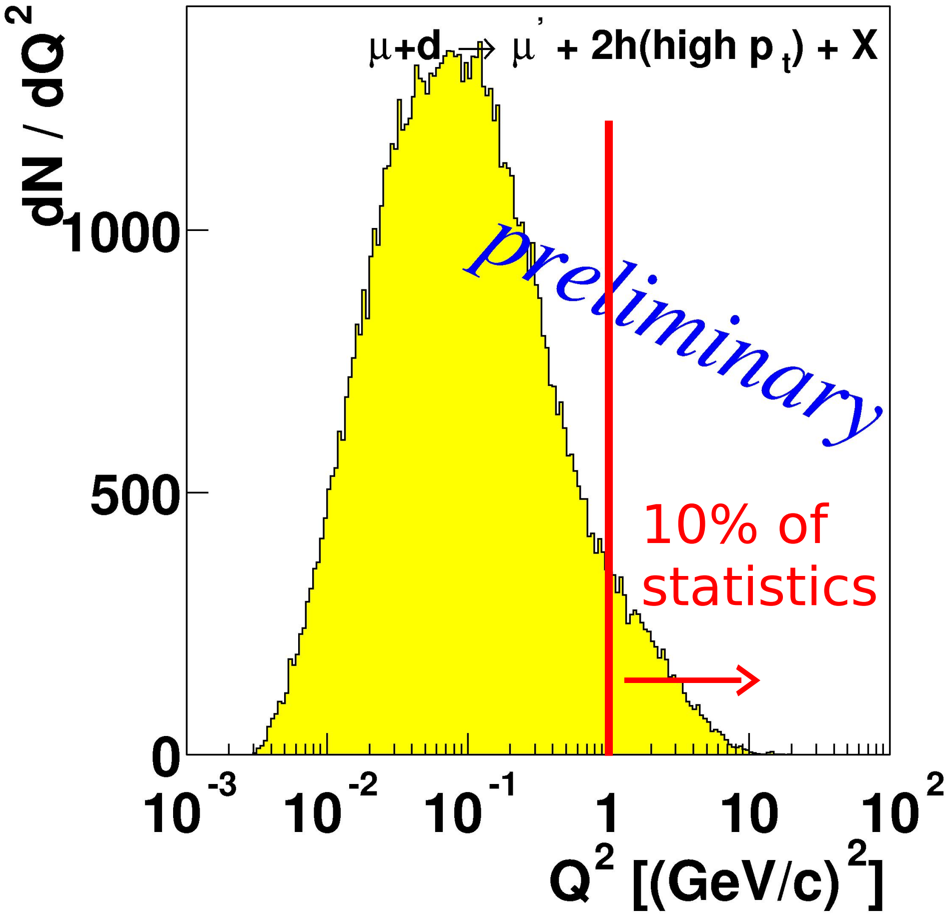
$\delta(\Delta G/G)_{false}$	0.011
$\delta(\Delta G/G)_{NN}$	0.006
$\delta(\Delta G/G)_{MC}$	0.040
$\delta(\Delta G/G)_{f,Pb,Pt}$	0.006
$\delta(\Delta G/G)_{A1}$	0.008
Total	0.045

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 $Q^2 > 1\ (GeV/c)^2$ analysis was applied plus a slightly tighter set of cuts :

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



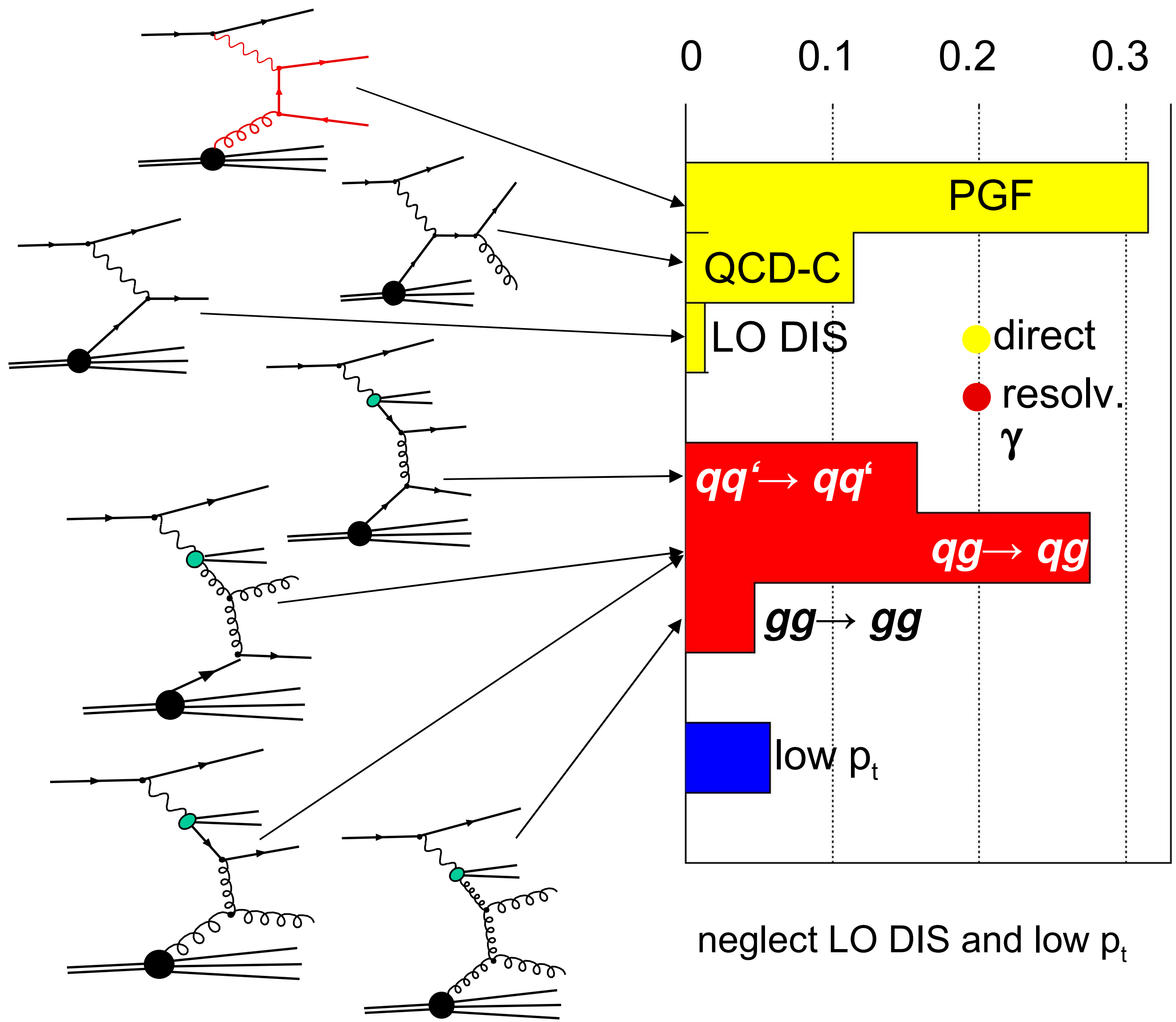
~90 % of our statistics in this sample

Processes Contribution for high p_T, $Q^2<1$ (GeV/c)^2

PGF and Background events:

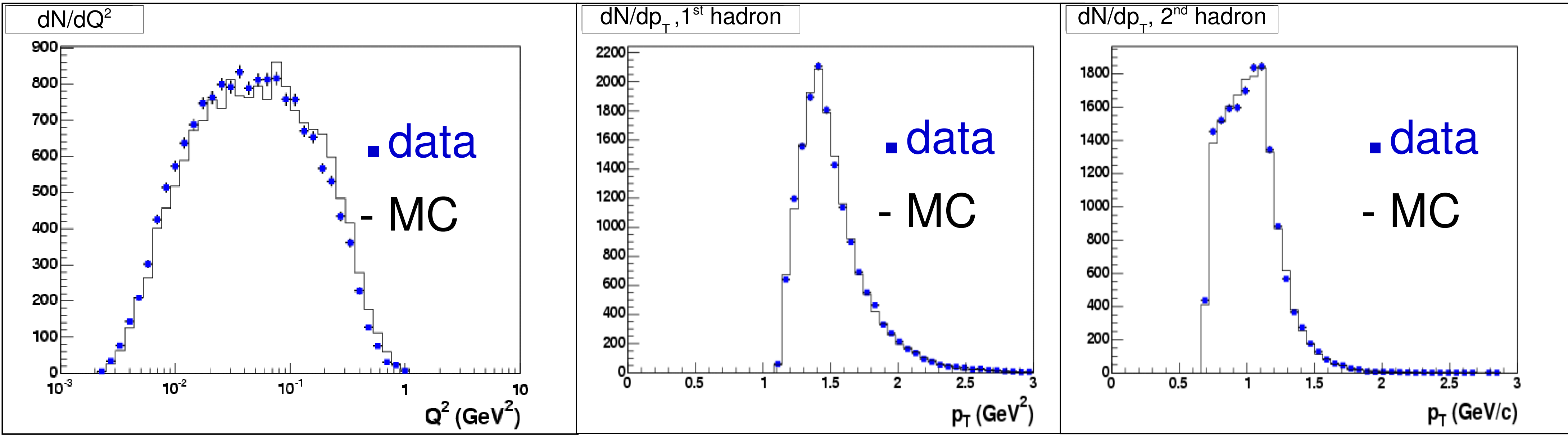
MC Generator PYTHIA

- Same background as $Q^2 > 1$ (GeV/c)^2 case
- Additional background from resolved photon events
- Additional processes sensitive to gluons in the nucleon



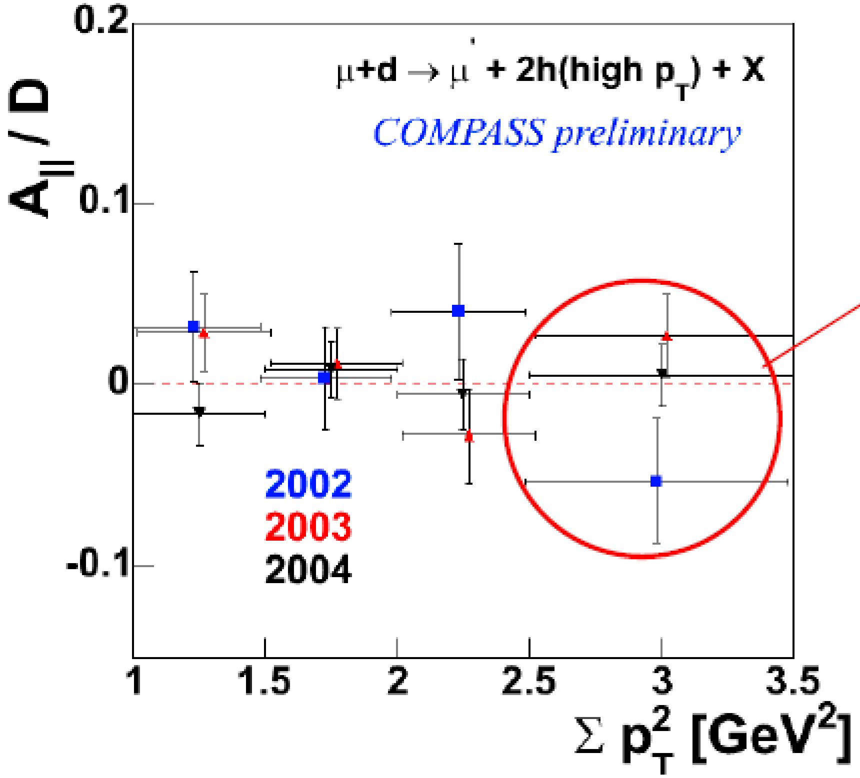
neglect LO DIS and low p_t

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 extraction of ΔG/G

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

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

2002-2004

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

0.055(syst)

2002-2003

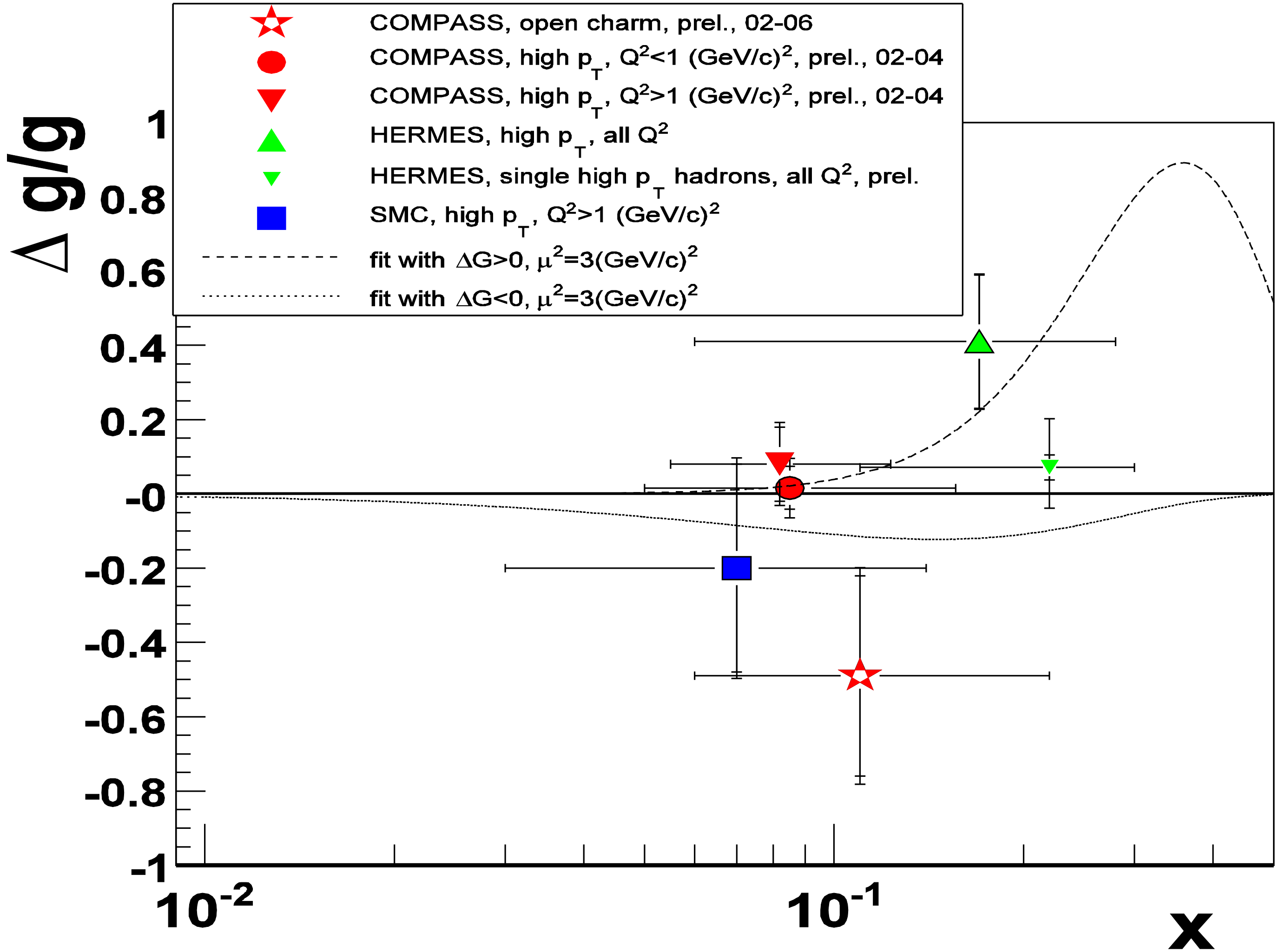
ΔG/G = 0.024 ± 0.089(stat) ± 0.057(syst)

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 : **$\Delta G/G = 0.02 \pm 0.06_{stat} \pm 0.06_{sys}$** **@ $x_g = 0.09^{+0.04}_{-0.03}$**



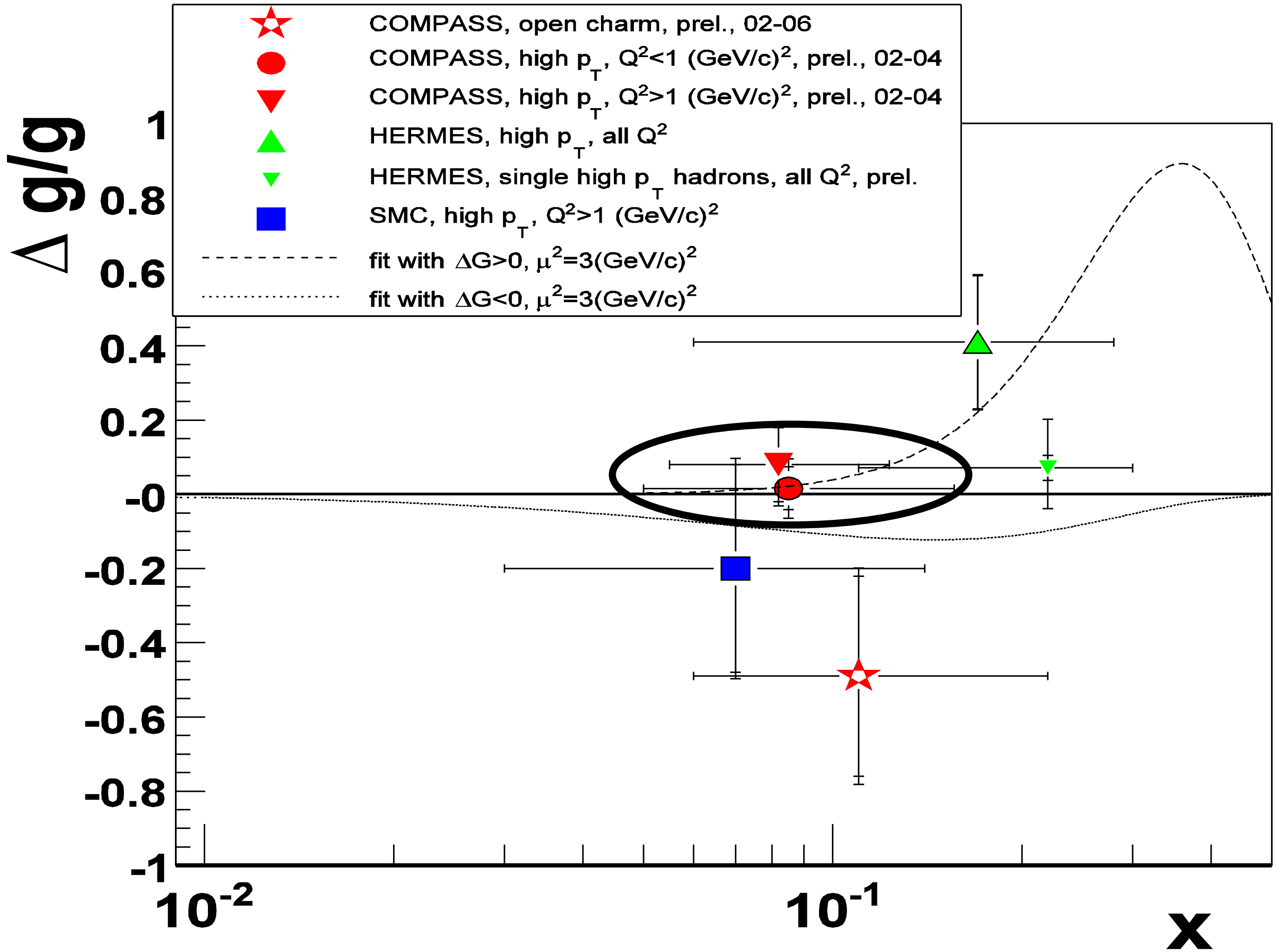
2 independent analyses with quite different backgrounds lead to compatible results

ΔG/G Results

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

$Q^2 < 1\ GeV^2$: $\Delta G/G = 0.02 \pm 0.06_{stat} \pm 0.06_{sys}$ @ $x_g = 0.09^{+0.04}_{-0.03}$

2 independent analyses with quite different backgrounds lead to compatible results



Conclusions and Outlook

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

- 2006 and 2007 data to be analyzed
- Increase statistics for 2006 and 2007 data due to the new COMPASS magnet

Spares

Uncertainty for γ, $Q^2 < 1$ GeV^2

Contribution from resolved photons

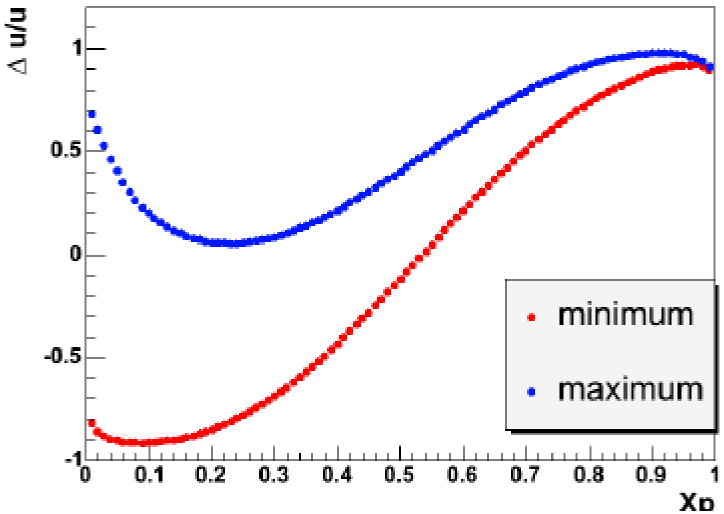
- Problem: polarised PDFs of the photon is not measured !

  → 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