Gluon Polarisation Measurements @ COMPASS

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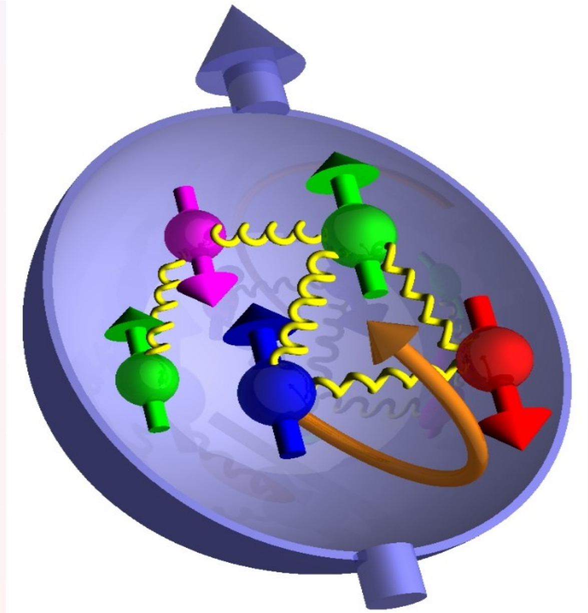
Outline:

- Brief Motivation
- High p_T analysis
- Open Charm (LO and NLO) analyses
- $\Delta G/G$ results
- Summary and Conclusion


On behalf of the COMPASS Collaboration

The Nucleon Spin



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

Quarks

Gluons

Partons Angular Orbital Momenta

Future !

GPDs

Well known !

In 1988 EMC measured

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

A recent result, including COMPASS, gives:

$\Delta\Sigma$ = 0.30 ± 0.01(stat.) ± 0.02(evol.) Phys.Lett.B647,8

Poorly known

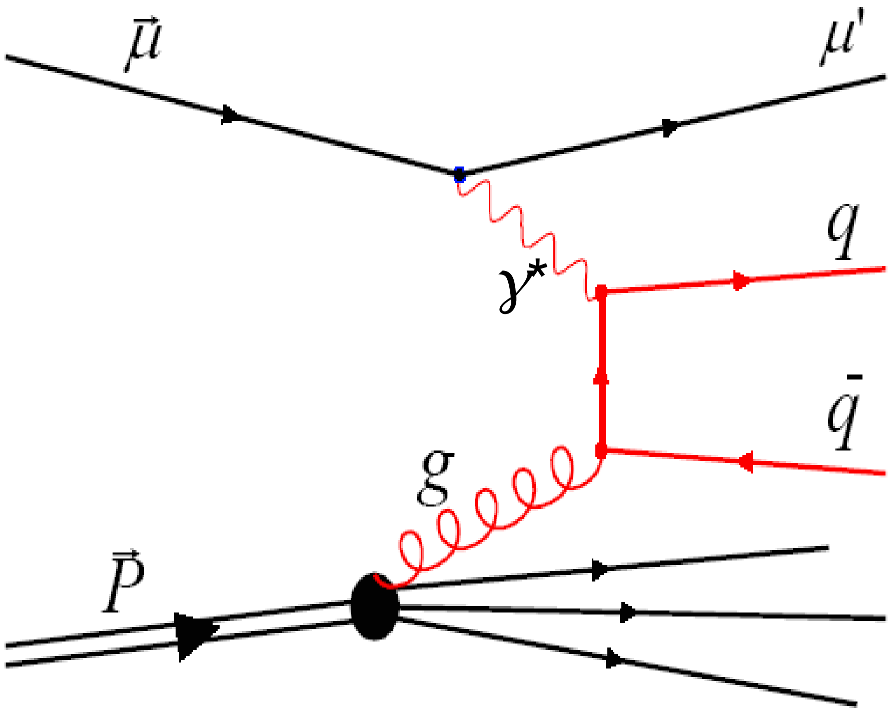
Exploratory and discovery stage.

Some experiments and data might give hints.

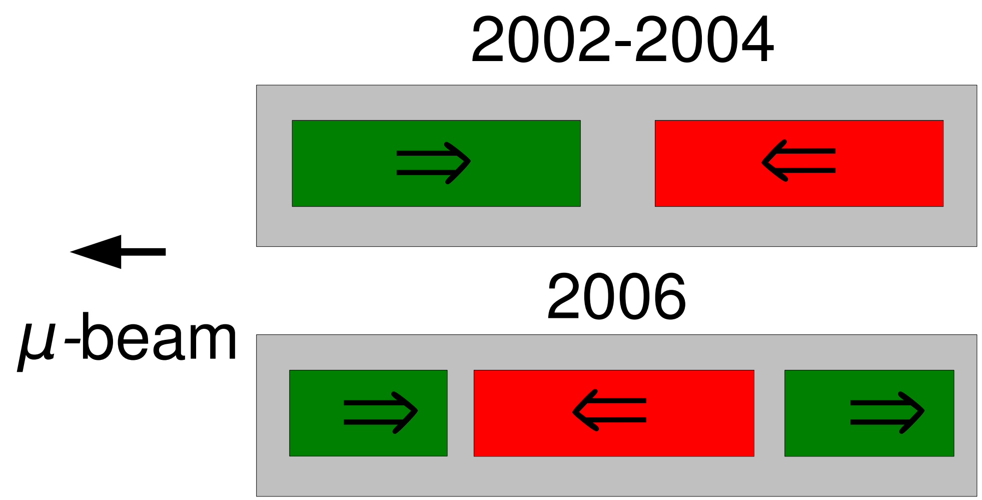
COMPASS, HERMES, CLAS, STAR, PHOENIX

Direct measurement of ΔG/G

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



Photon-gluon fusion process (PGF)



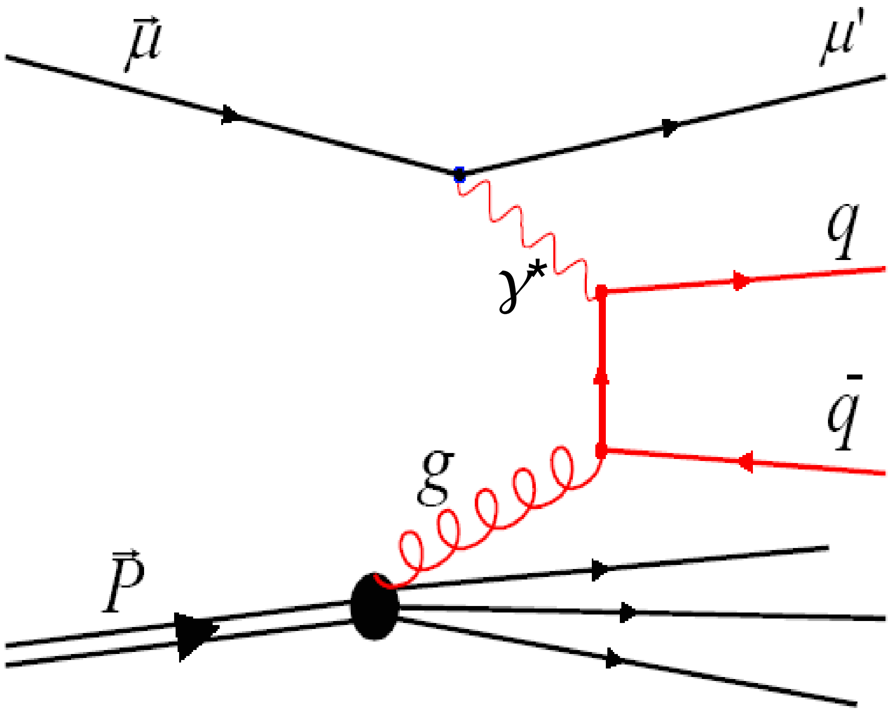
$$A_{PGF} = \frac{N^{\overleftarrow{\Rightarrow}}_{PGF} - N^{\overleftarrow{\Leftarrow}}_{PGF}}{N^{\overleftarrow{\Rightarrow}}_{PGF} + N^{\overleftarrow{\Leftarrow}}_{PGF}}$$

$\Rightarrow$ ΔG/G

Experiments with polarised beam and target are sensitive to gluon helicity

Direct measurement of ΔG/G

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



Photon-gluon fusion process (PGF)

To select this process there are two methods :

- 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.

- Open-charm meson (D mesons)

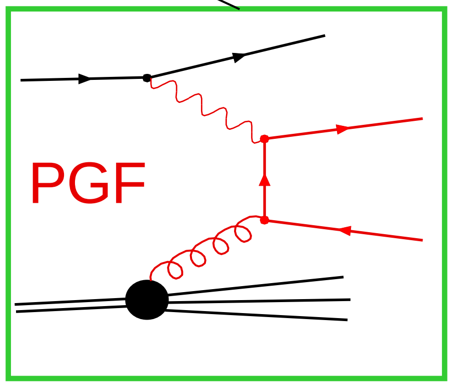
  ☺ Provides the purest sample of PGF events, almost free from background contamination. Small dependence on MC.

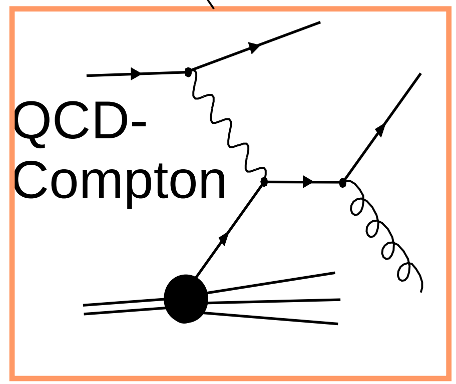
  ☹ Low statistics.

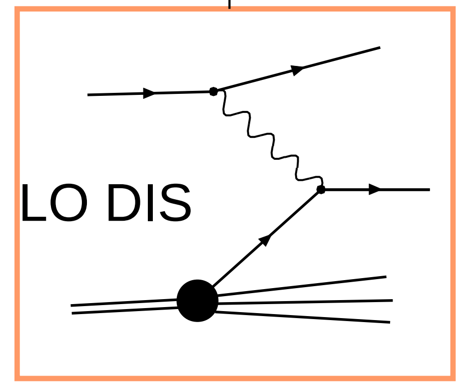
High p_T Analysis

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

A_1^{LO} : estimated by an inclusive sample







Final formula for the gluon polarisation

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

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

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

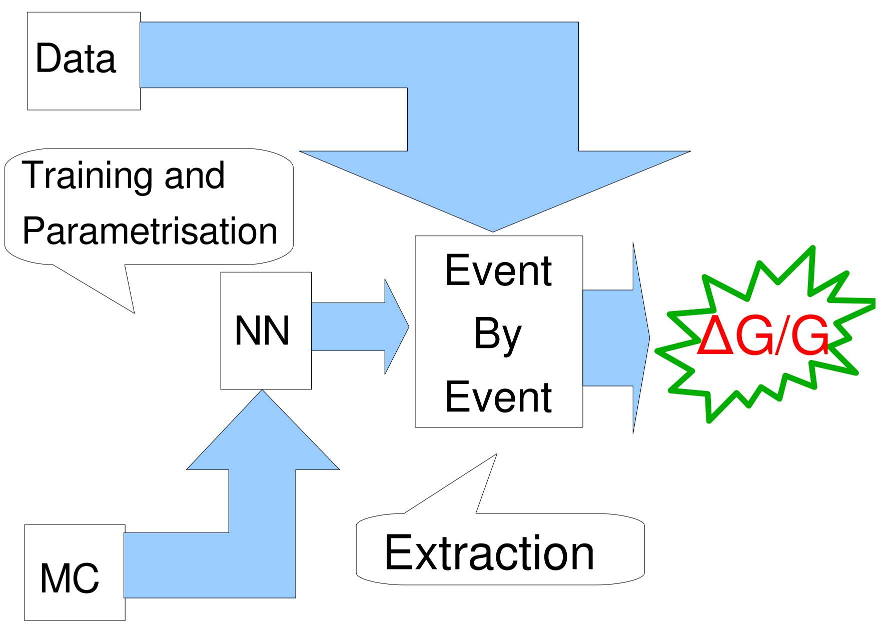
- A^{2h}_{LL} : measured from the two hadron sample.
- a^{i}_{LL} and R_i : estimated from MC and parametrised using a Neural Network.

MC Simulation and Neural Network

- Full chain of MC has been used:

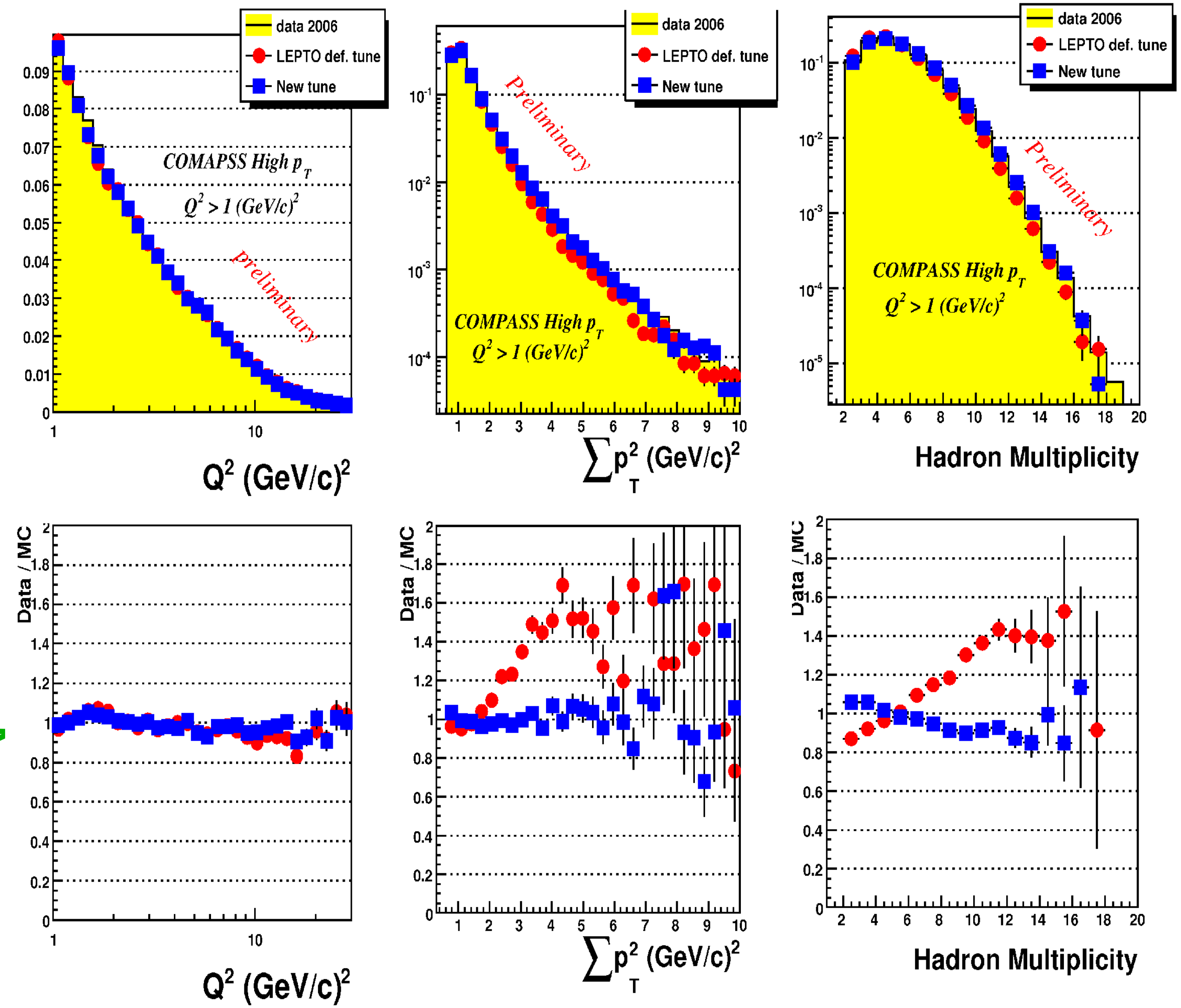
Generator (LEPTO) + Apparatus Simulation (GEANT) + Reconstruction Program.

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



Data-MC comparison:

Q^2, p_T and Hadron Multiplicities.



Results

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

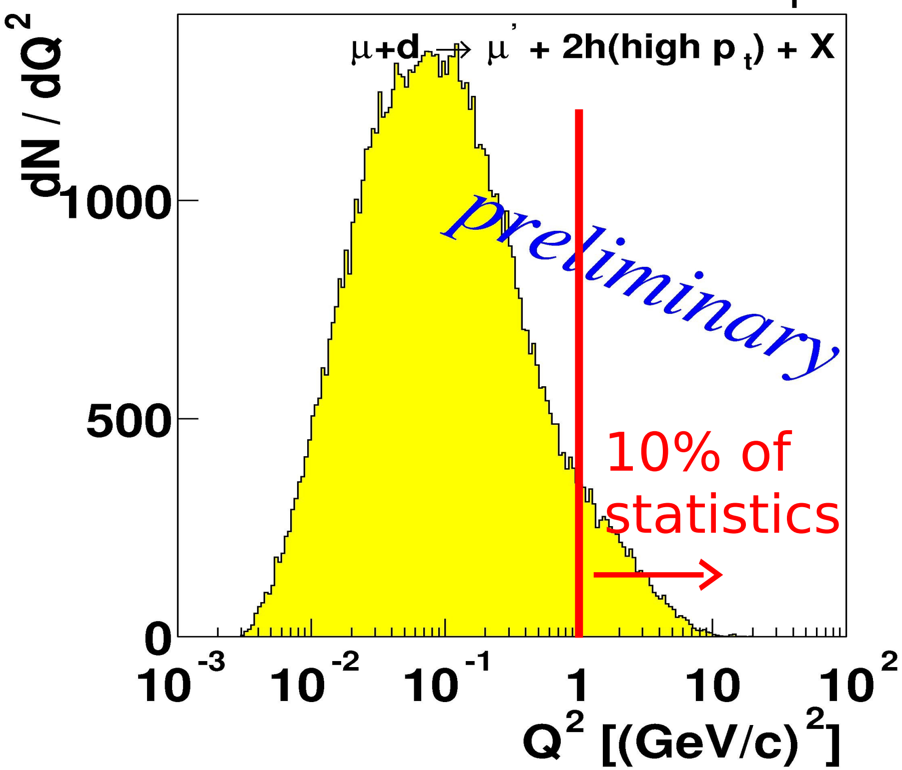
- The whole statistics was divided, for the first time, in 3 independent samples, having each one its own x_g distribution.

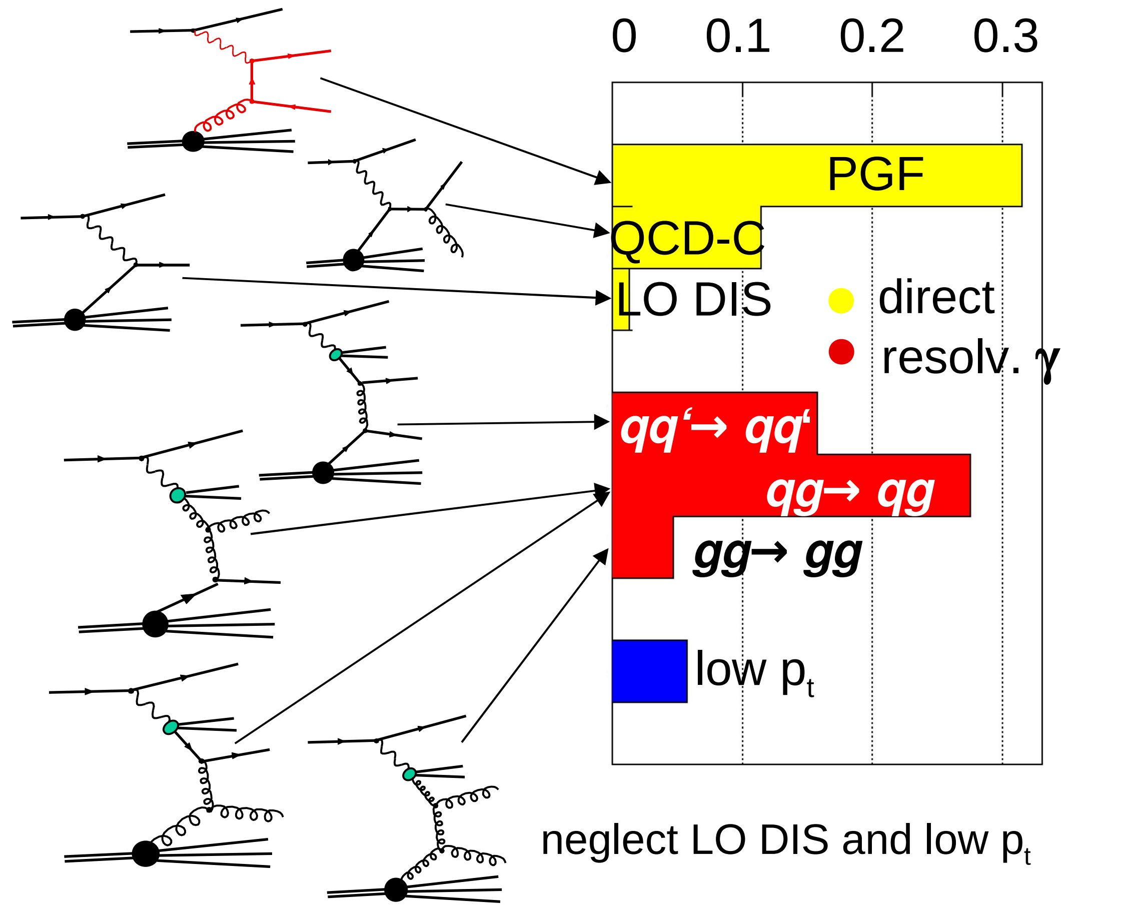
	1st point	2nd point	3rd point
ΔG/G	0.147 ± 0.091 ± 0.088	0.079 ± 0.096 ± 0.082	0.185 ± 0.165 ± 0.143
$\langle x_g \rangle$	$0.07^{+0.05}_{-0.03}$	$0.10^{+0.07}_{-0.04}$	$0.17^{+0.10}_{-0.06}$

⇒ Within the errors the 3 points show no x_g dependence

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:

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

2002-2003 Published:

$\Delta G/G = 0.024 \pm 0.089(stat) \pm 0.057(syst)$ *Phys. Lett. B 633,25*

Open Charm

- The relation between the number of reconstructed D^0 (<u>for each target cell configuration</u>) and ΔG/G is given by:

$$N_t = a\,\phi\,n(S+B)\left(1+f\,P_T P_\mu\left[a_{LL}\frac{S}{S+B}\frac{\Delta G}{G}+D\frac{B}{S+B}A^{bg}\right]\right),\quad t=(u,d,u',d')$$

acceptance, muon flux, number of target nucleons

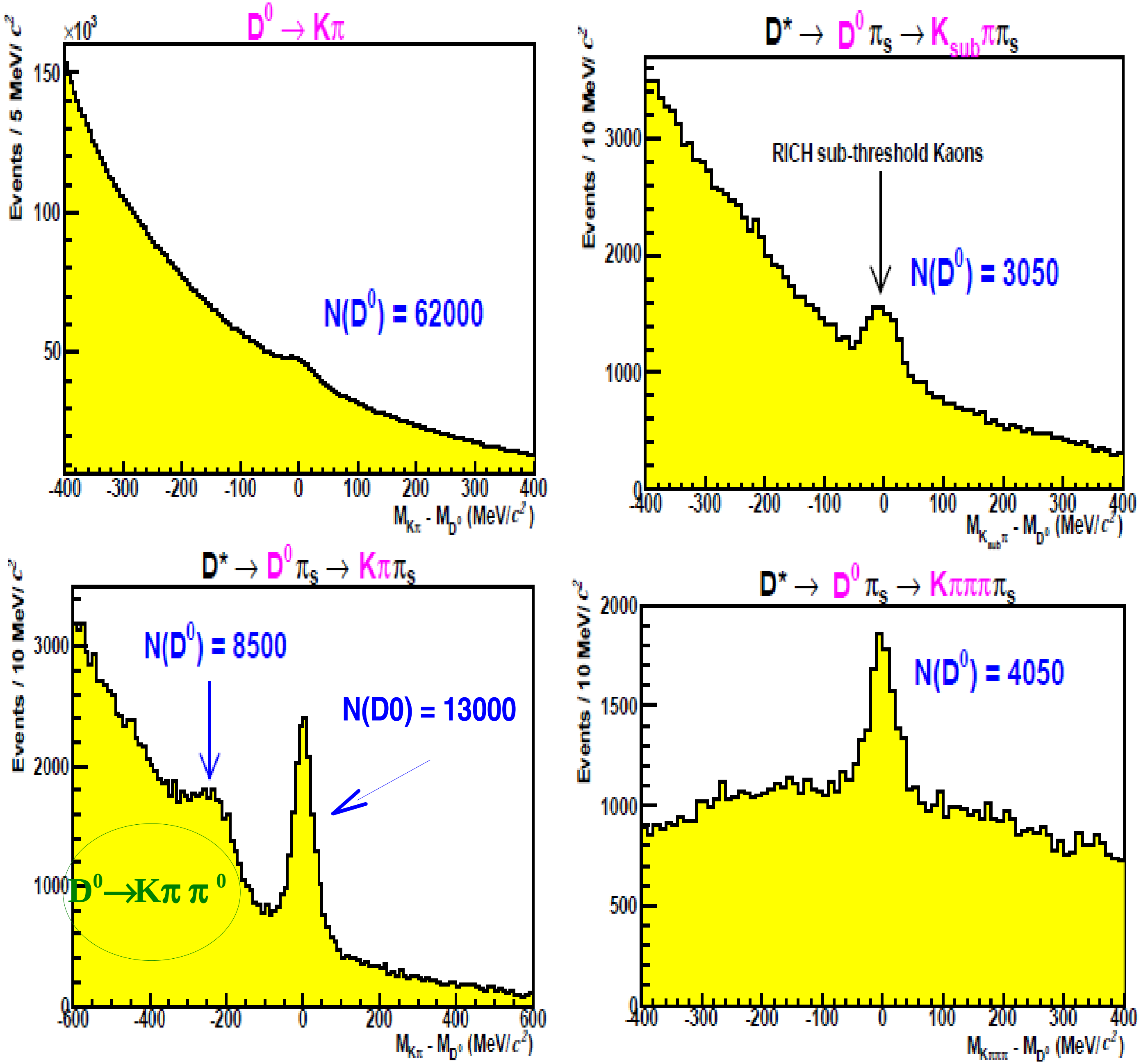
Open Charm event probability

- <u>Each equation is weighted</u> with a signal weight $w_S = f\,P_m\,a_{LL}\,S/(S+B)$ and also with a background weight $w_B = f\,P_m\,D\,B/(S+B)$:

<u>8 equations with 7 unknowns</u>: ΔG/G, A^{bg} + 5 independent $\alpha = (a\phi n)$ factors

The system is solved by a χ^2 minimisation

D^0 invariant mass spectra: 2002-2007 data



D^0 →
- $K\pi$
- $K_{sub}\pi$
- $K\pi\pi^0$
- $K\pi\pi\pi$

Number of D^0:

- Total = 90600
- ^{6}LiD = 65600
- NH_3 = 25000

Neural Network parametrisation

- **Two real data samples** (with the same cuts applied) **are compared by a Neural Network** (<u>using some kinematic variables as a learning vector</u>)**:**
  - **Signal model**

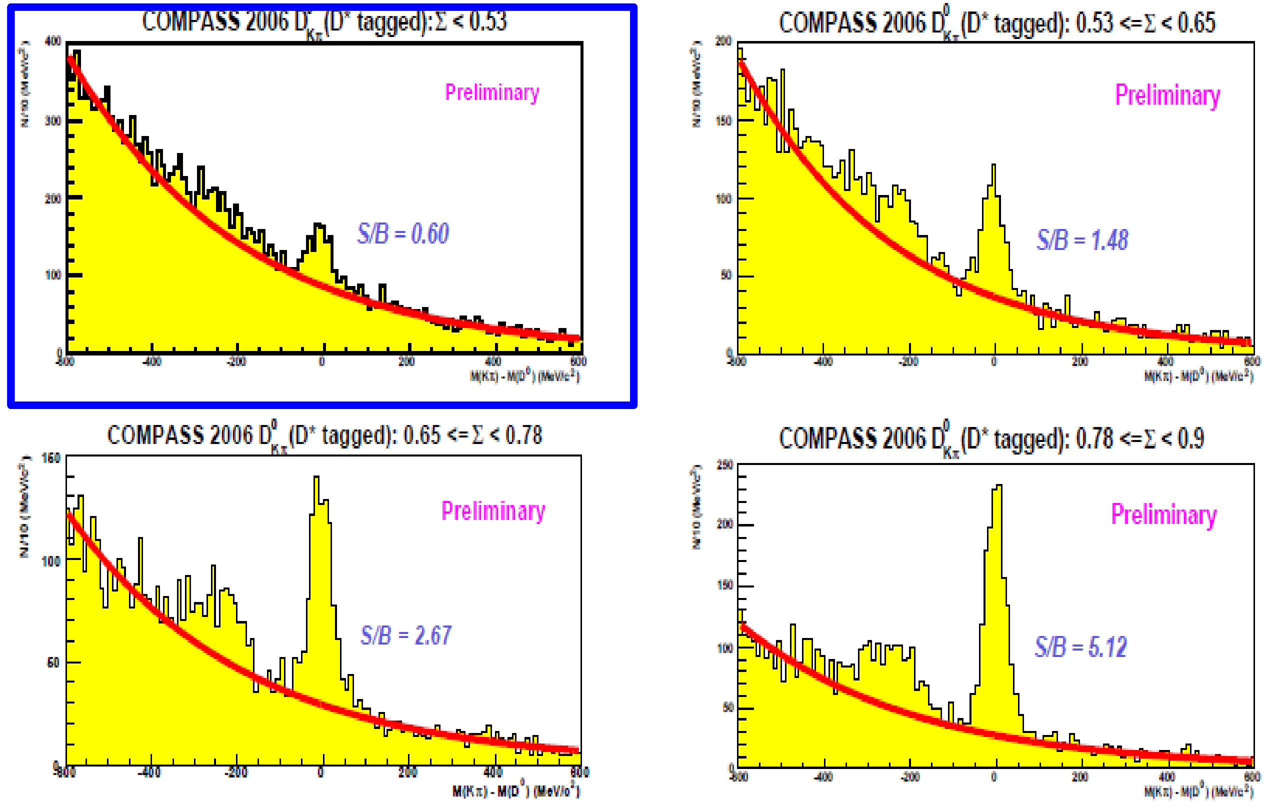
    gcc = $K^{+}\pi^{-}\pi_{s}^{-} + K^{-}\pi^{+}\pi_{s}^{+}$

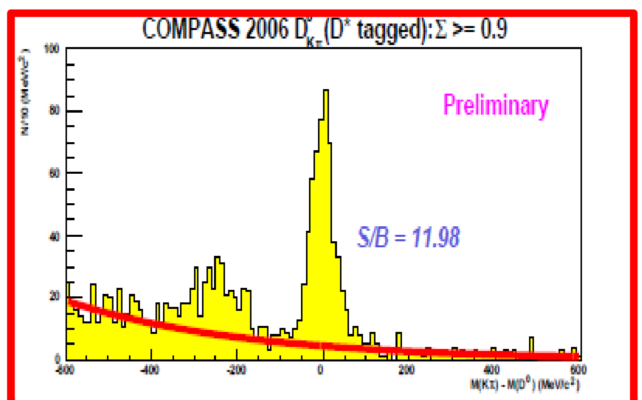
    (D^0 spectrum: signal + background)
  - **Background model**

    wcc = $K^{+}\pi^{+}\pi_{s}^{-} + K^{-}\pi^{-}\pi_{s}^{+}$

    (no D^0 is allowed)
- **If the background model is good enough:** <u>The Neural Network is able to distinguish the signal from the combinatorial background on a event by event basis</u> (inside gcc)

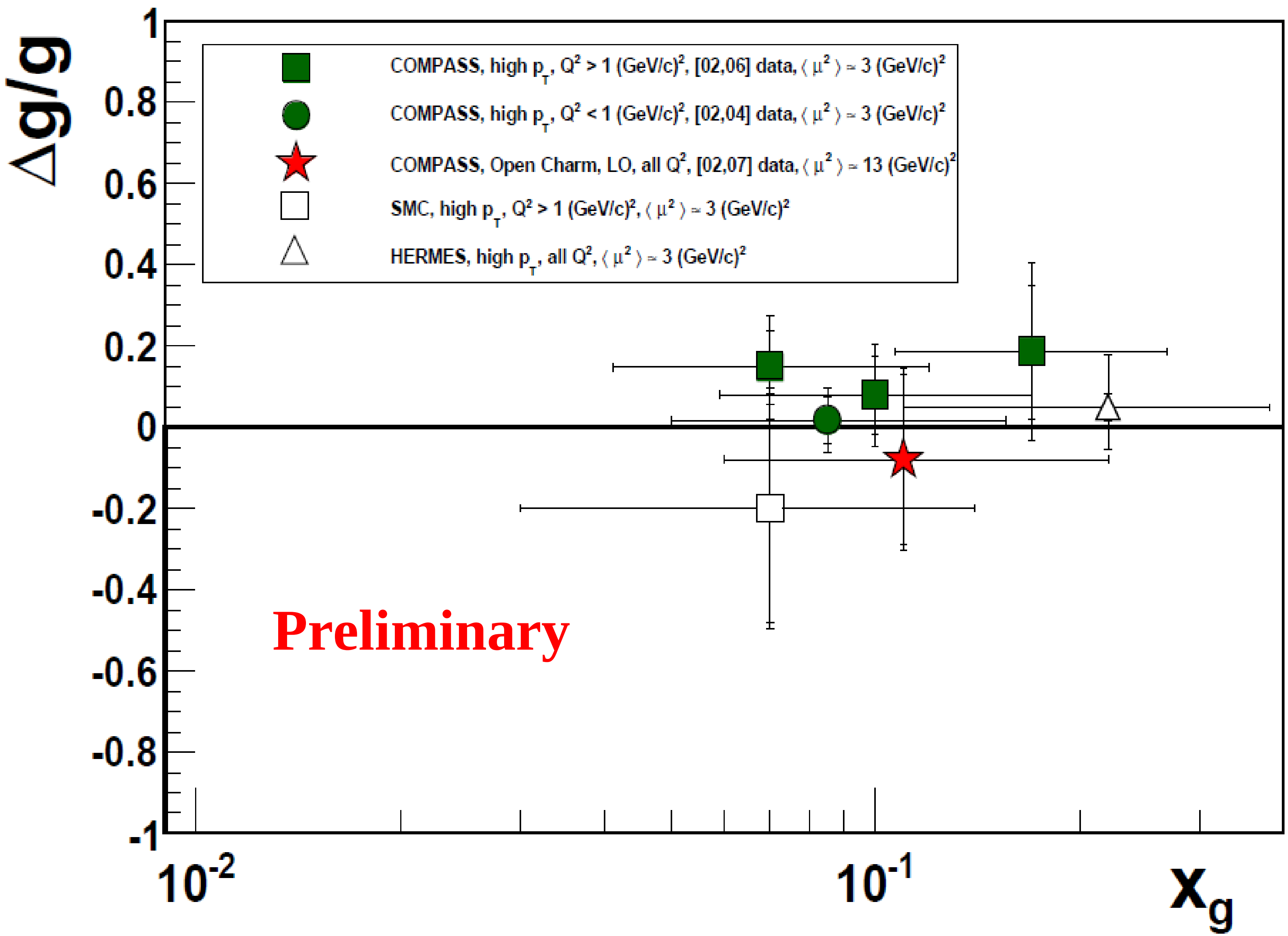
$D^0_{K\pi}$ tagged spectrum in bins of $\sum = S/(S+B)_{NN}$



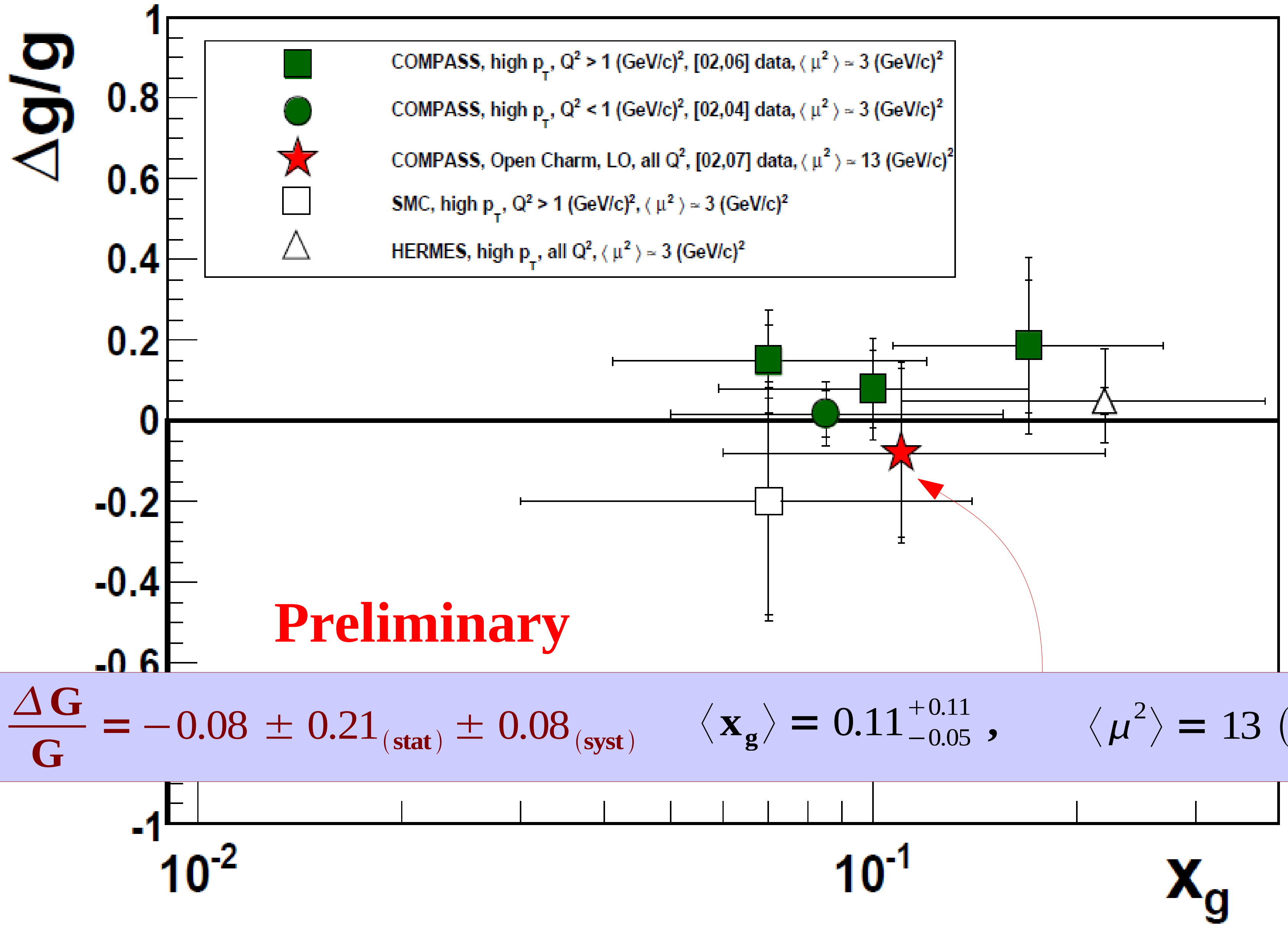


$$\delta\left(\frac{\Delta G}{G}\right) \propto \frac{1}{FOM}$$

ΔG/G Results (LO)



ΔG/G Results (LO)

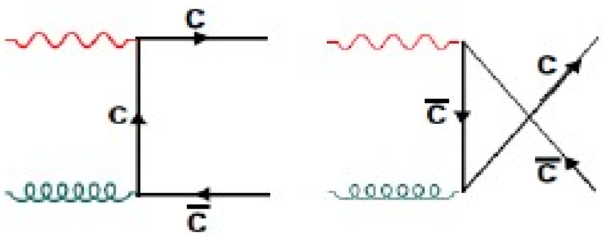


$$\frac{\Delta G}{G} = -0.08 \pm 0.21_{(stat)} \pm 0.08_{(syst)} \qquad \langle x_g \rangle = 0.11^{+0.11}_{-0.05}, \qquad \langle \mu^2 \rangle = 13\ (\mathrm{GeV}/c)^2$$

NLO corrections for Open Charm analysis

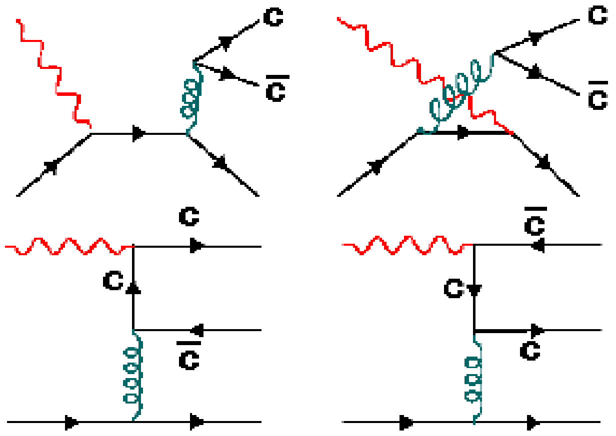
NLO corrections to the analysing power

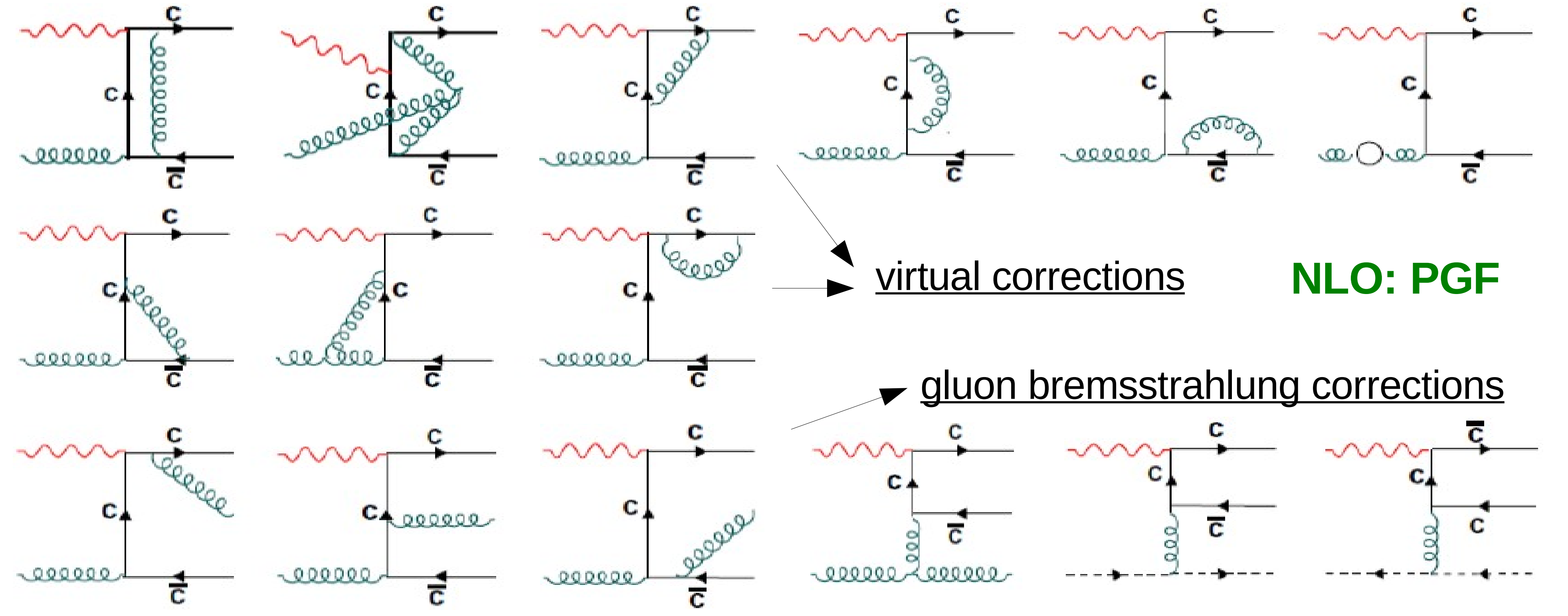
a_{LL}



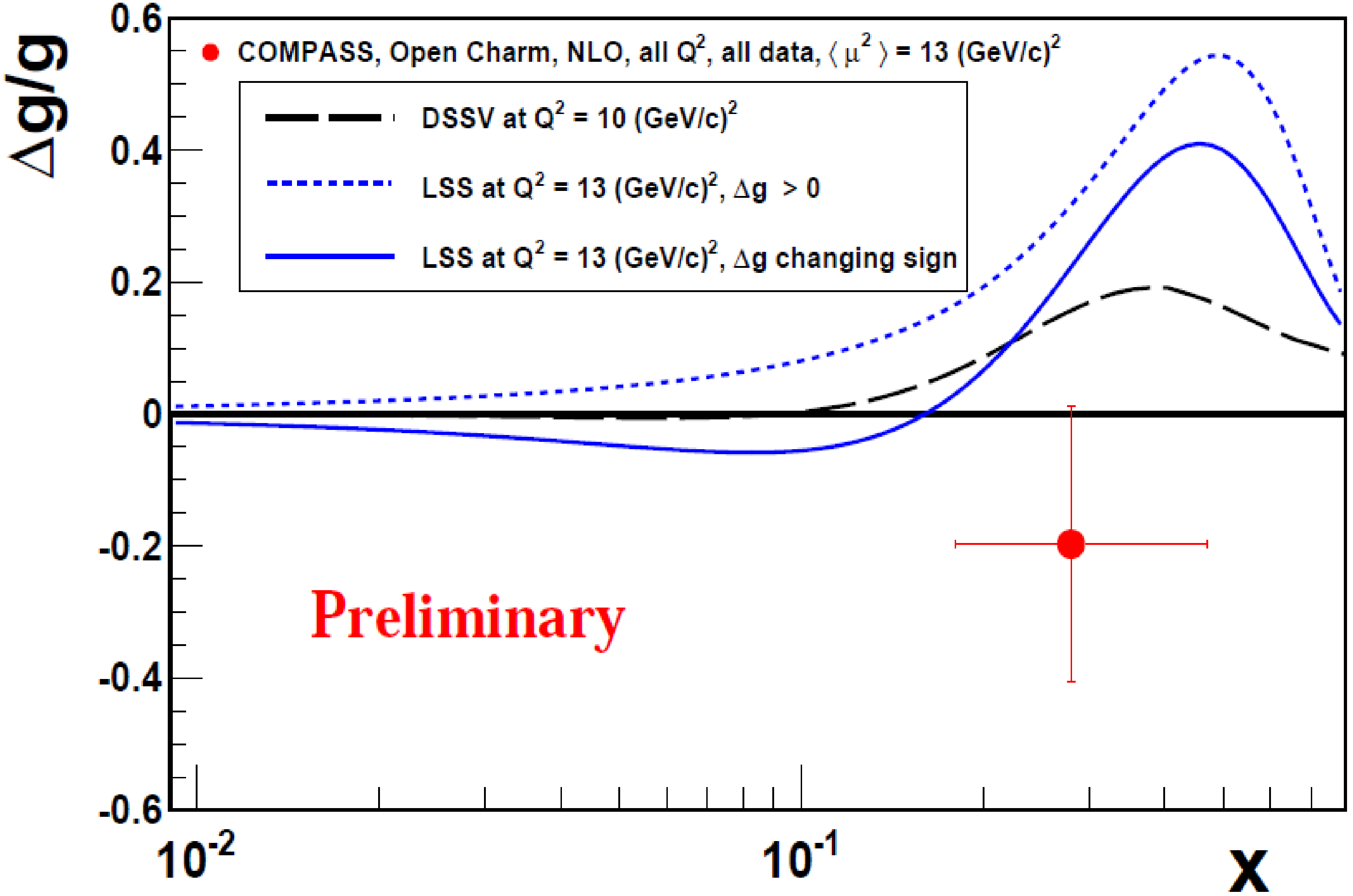
LO: PGF

NLO: bg





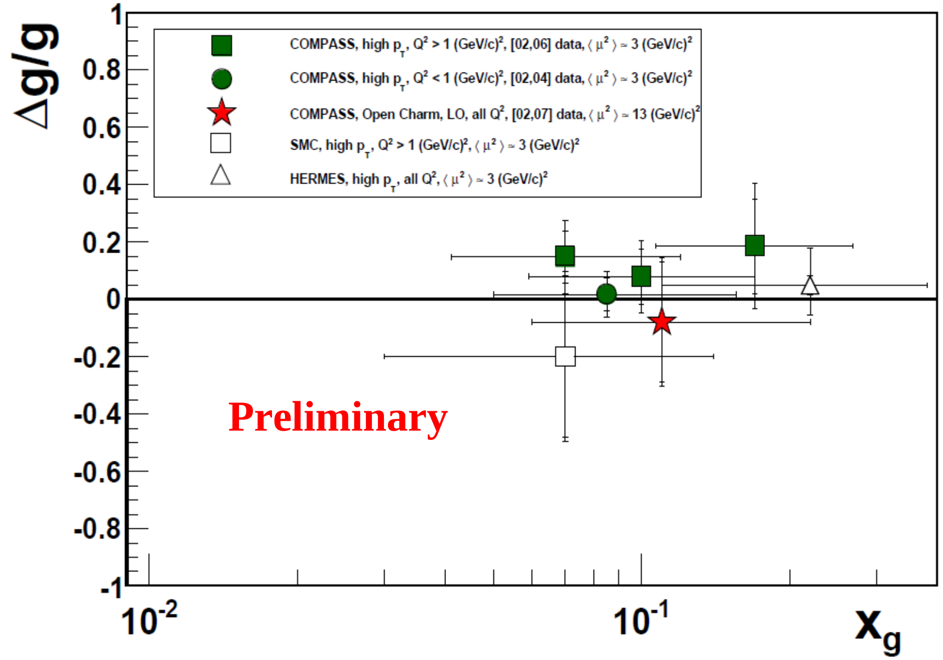
ΔG/G new Result (NLO)

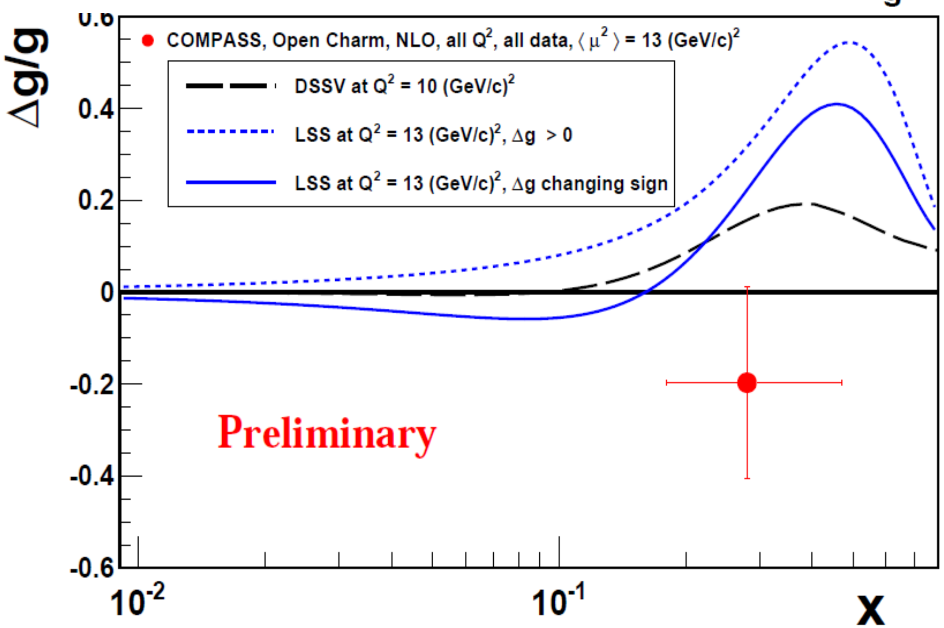


$$\frac{\Delta G}{G} = -0.20 \pm 0.21 \pm 0.08\ (\mathbf{syst}) \qquad @ <x_g> = 0.28^{+0.19}_{-0.10}\ ,\ <\mu^2> = 13\ (\mathbf{GeV/c})^2$$

Preliminary: theoretical uncertainties still under study (a_{LL})

Summary and Conclusion





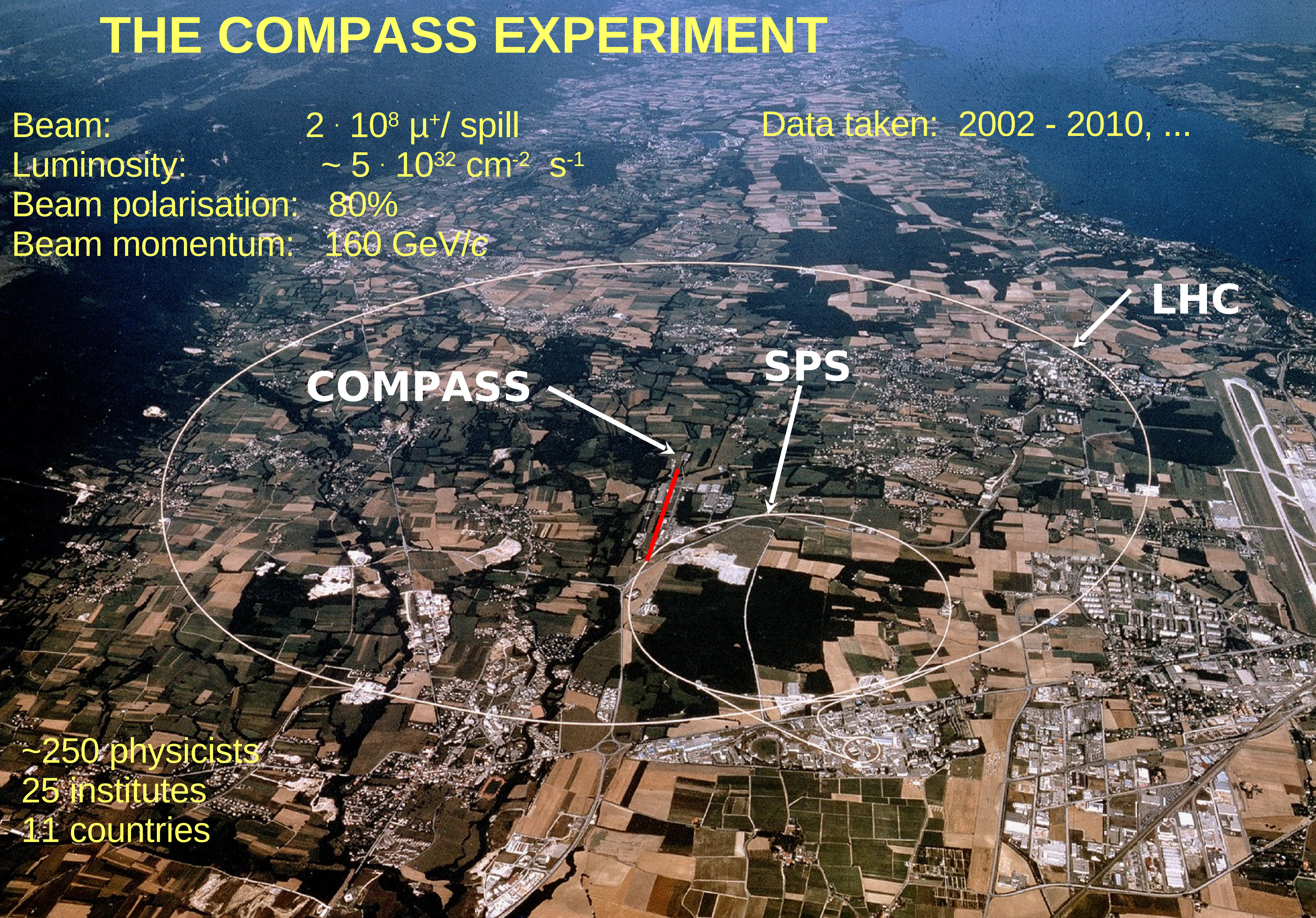
Summary:

- The importance of the gluon polarisation measurement concerning the nucleon spin structure was emphasised.
- The direct measurement methods were explained.
- The gluon polarisations results are presented.

Conclusion:

- All measurements of $\Delta G/G$ are compatible with zero, around $X_g \sim 0.1$
- The ΔG seems to be small contribution.
- The missing contribution could be in $L_{partons}$.
- COMPASS-II program foresees to measure $L_{partons}$ via GPDs.

Spares


THE COMPASS EXPERIMENT
Beam: 2 · 10^8 μ+/ spill
Luminosity: ~ 5 · 10^32 cm^-2 s^-1
Beam polarisation: 80%
Beam momentum: 160 GeV/c
Data taken: 2002 - 2010, ...
LHC
SPS
COMPASS
~250 physicists
25 institutes
11 countries

The COMPASS Spectrometer

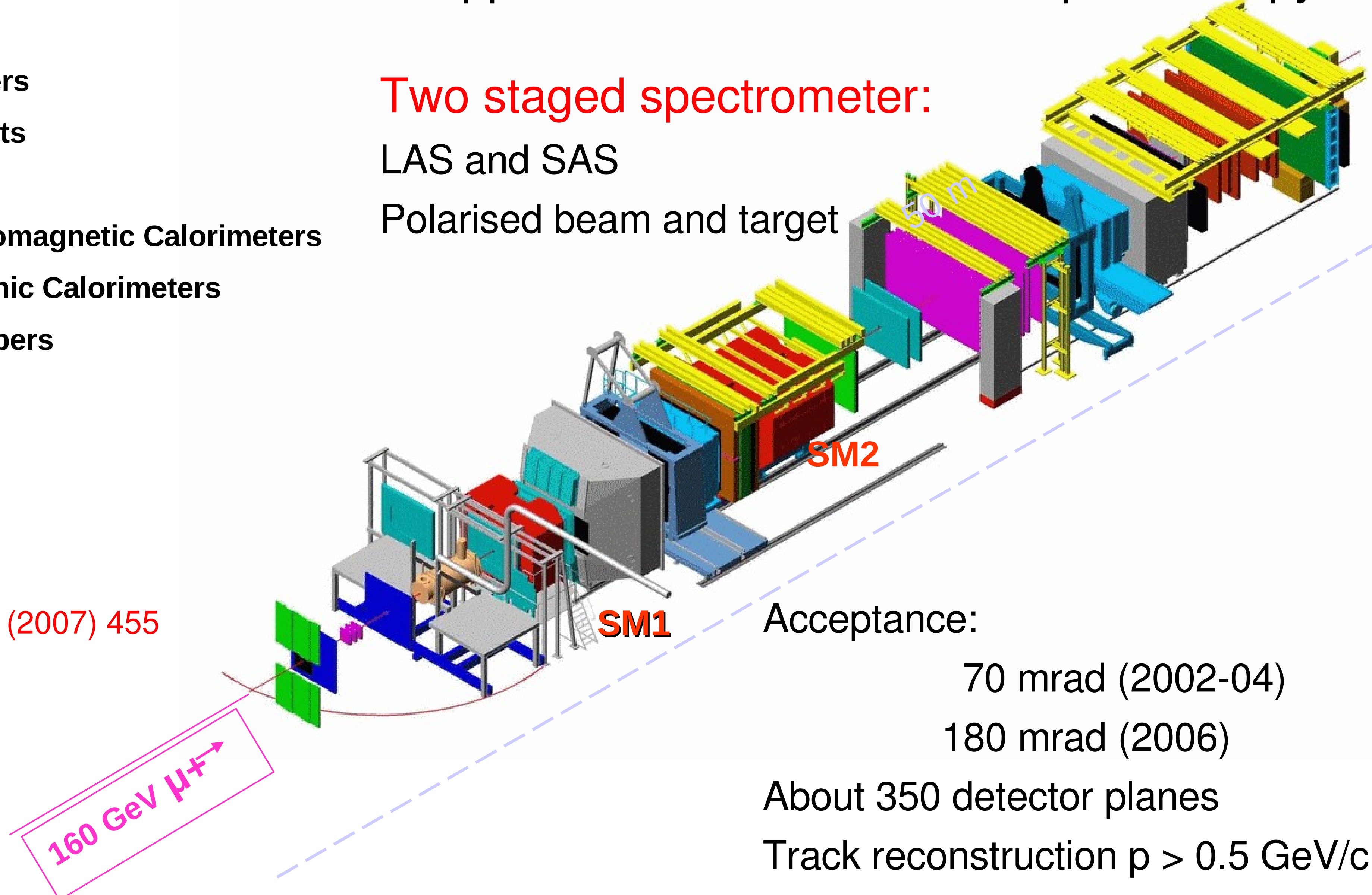
Common Muon and Proton Apparatus for Structure and Spectroscopy

- 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

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

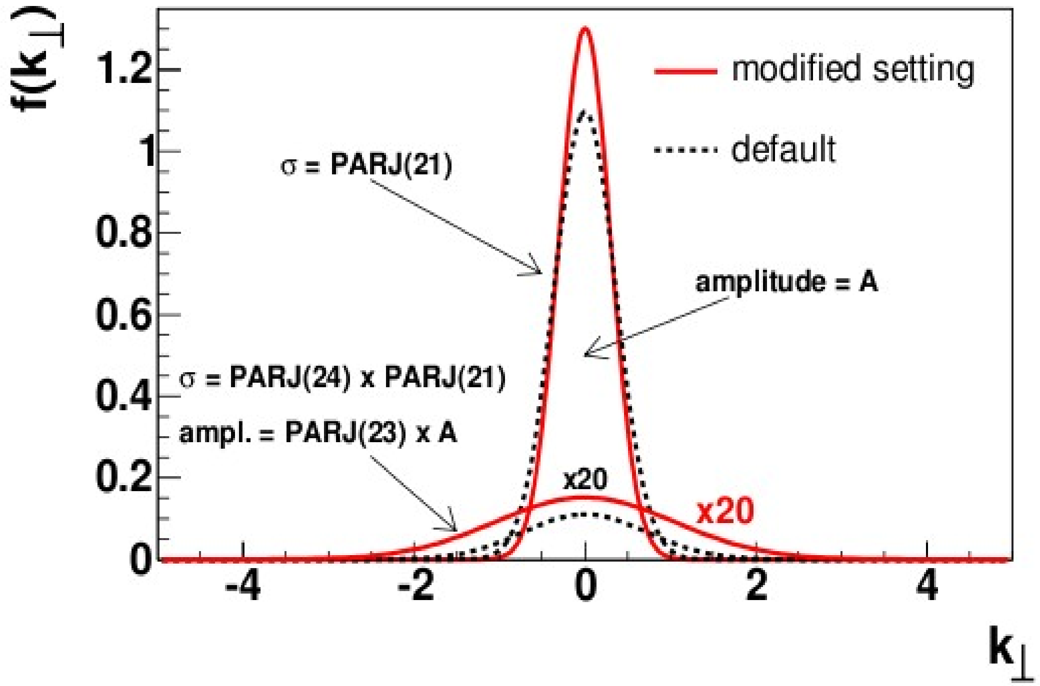
- The purpose of the MC tuning is to correct the shapes of the hadron variables (momenta) and fragmentation (multiplicity).
- In LEPTO this can be achieved by changing JETSET parameters:

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.

⇒ The tuning improves substantially the Data-MC agreement.

Monte Carlo Simulation



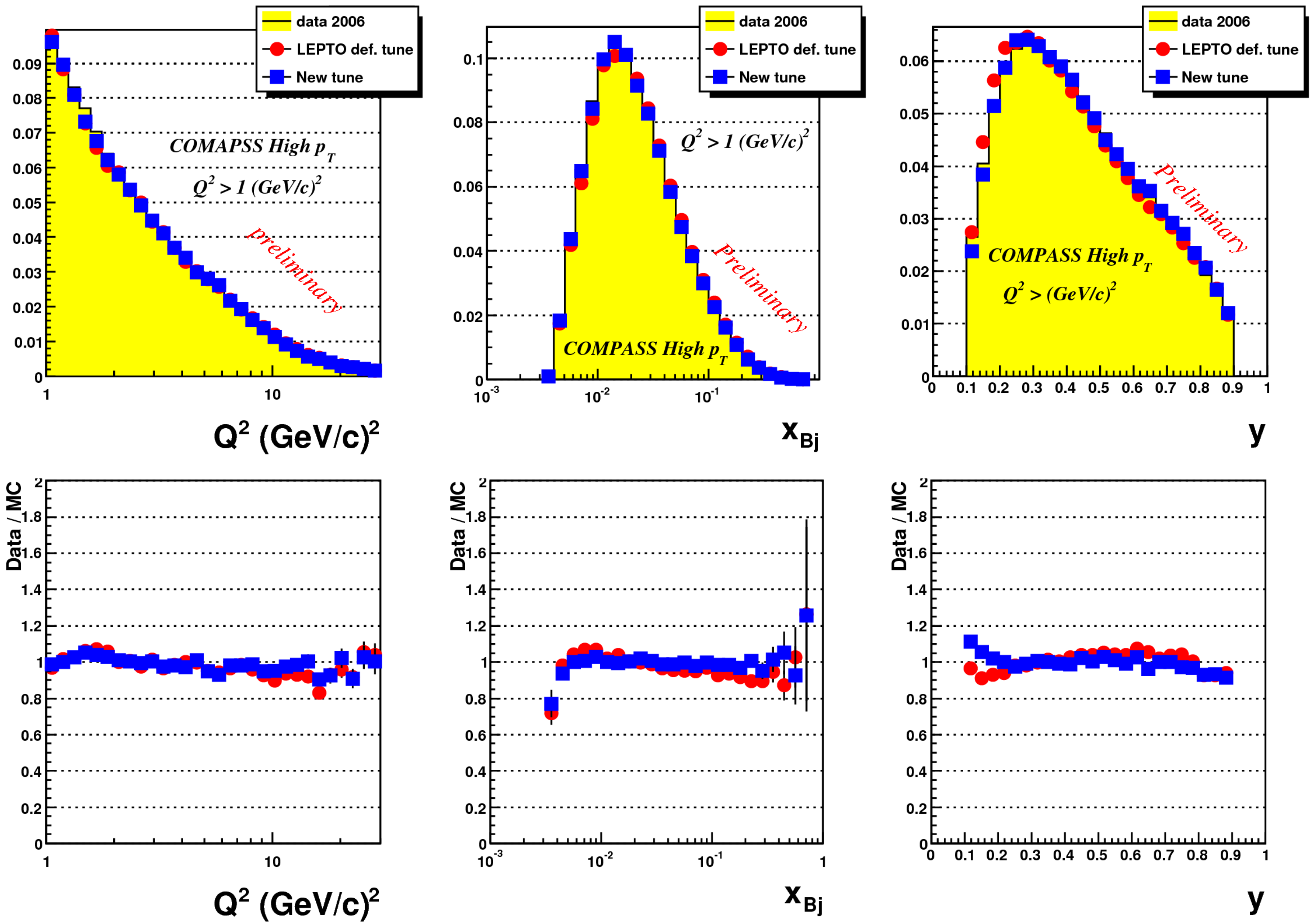
a = PARJ(41)

b = PARJ(42)

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

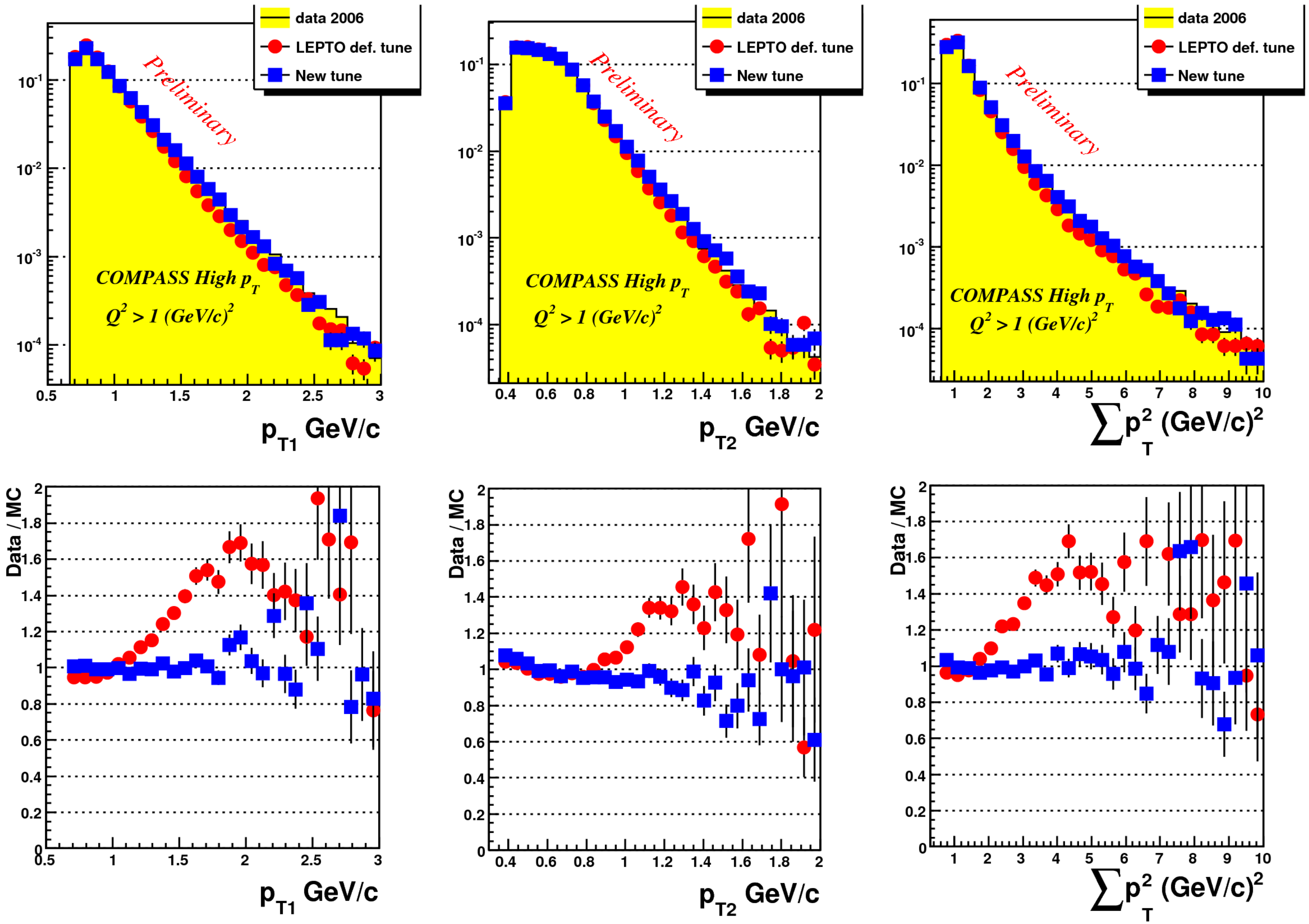
	PARJ(21)	PARJ(23)	PARJ(24)	PARJ(41)	PARJ(42)
COMPASS new tuning	0.34	0.04	2.8	0.025	0.075
LEPTO default tuning	0.36	0.01	2.0	0.3	0.58
	Transverse momentum of the hadron fragmentation			Fragmentation function	

Data – Monte Carlo comparison



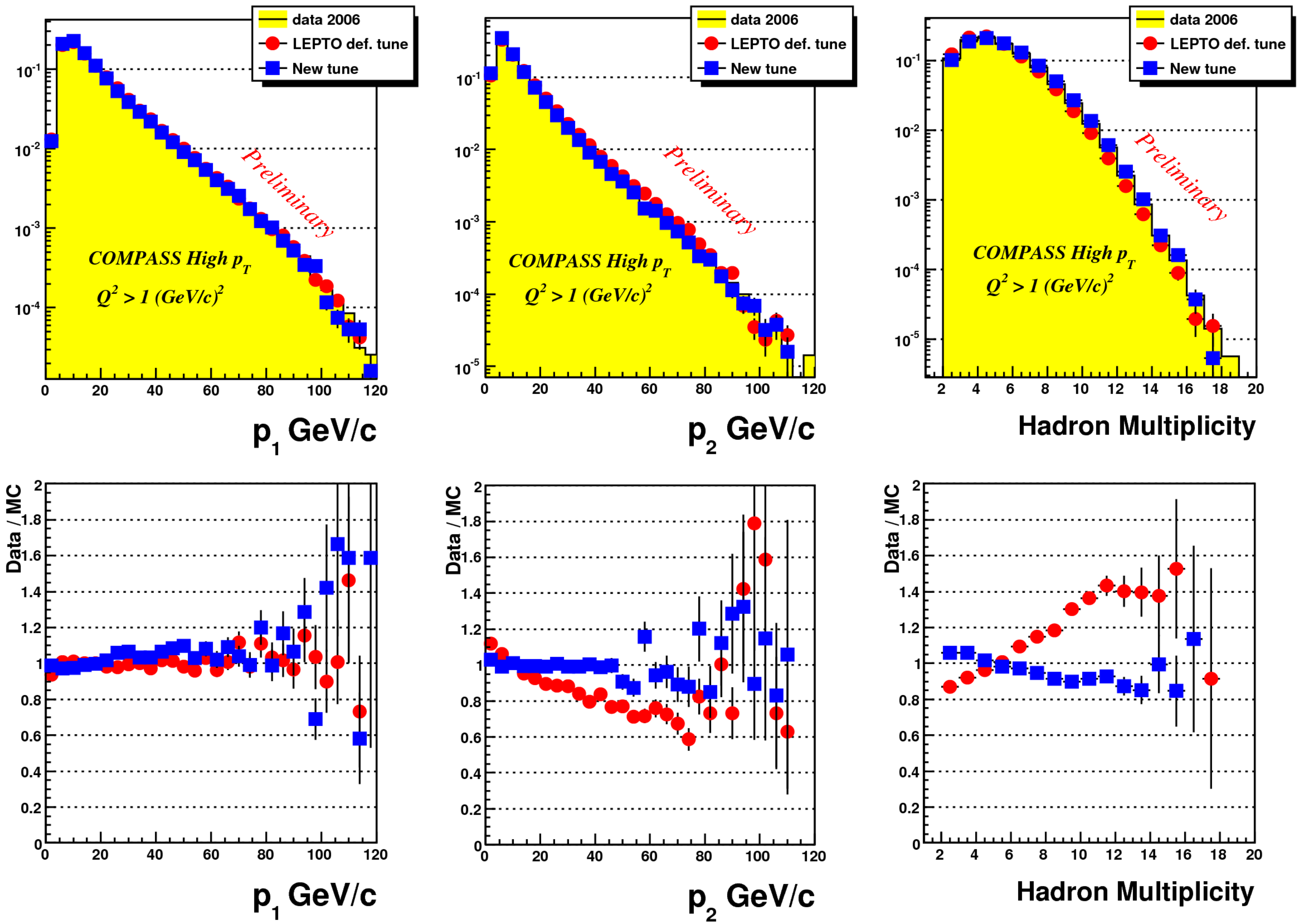
Data – Monte Carlo comparison

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



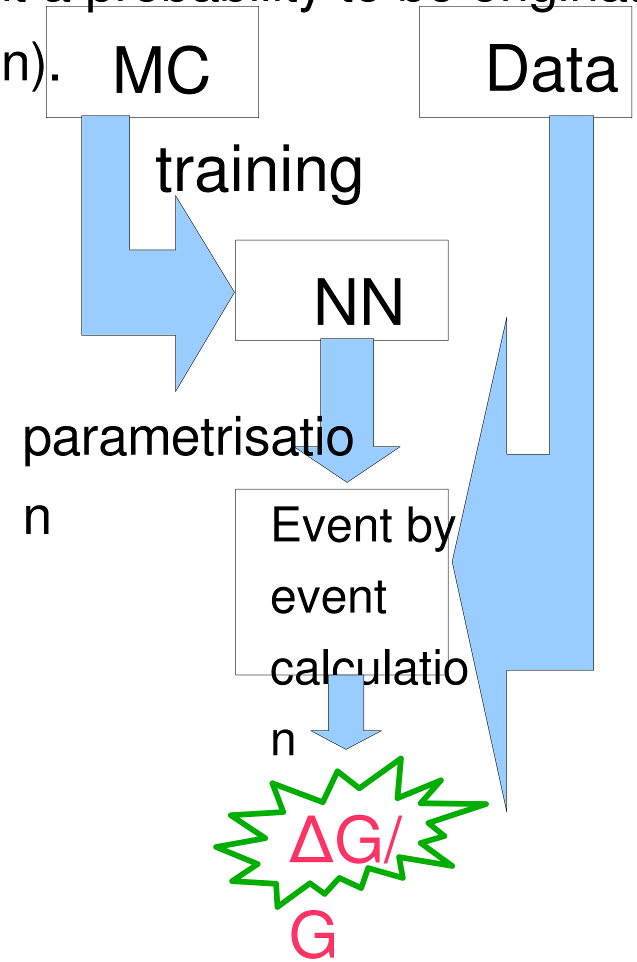
Data – Monte Carlo comparison

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



Weighted method

A Neural Network is used to assign to each event a probability to be originated from one 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

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}

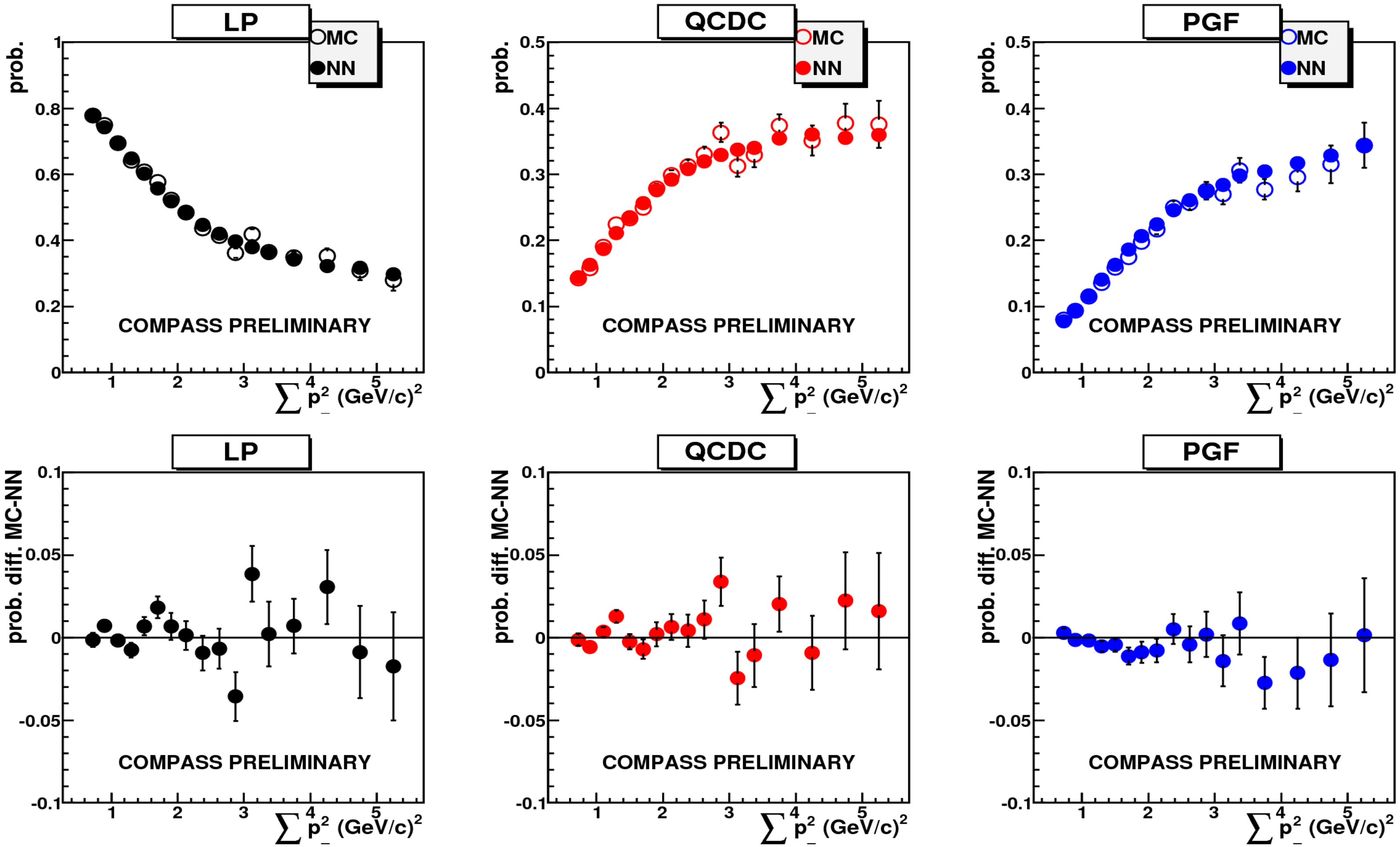
- Therefore for every event we have to know:

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

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

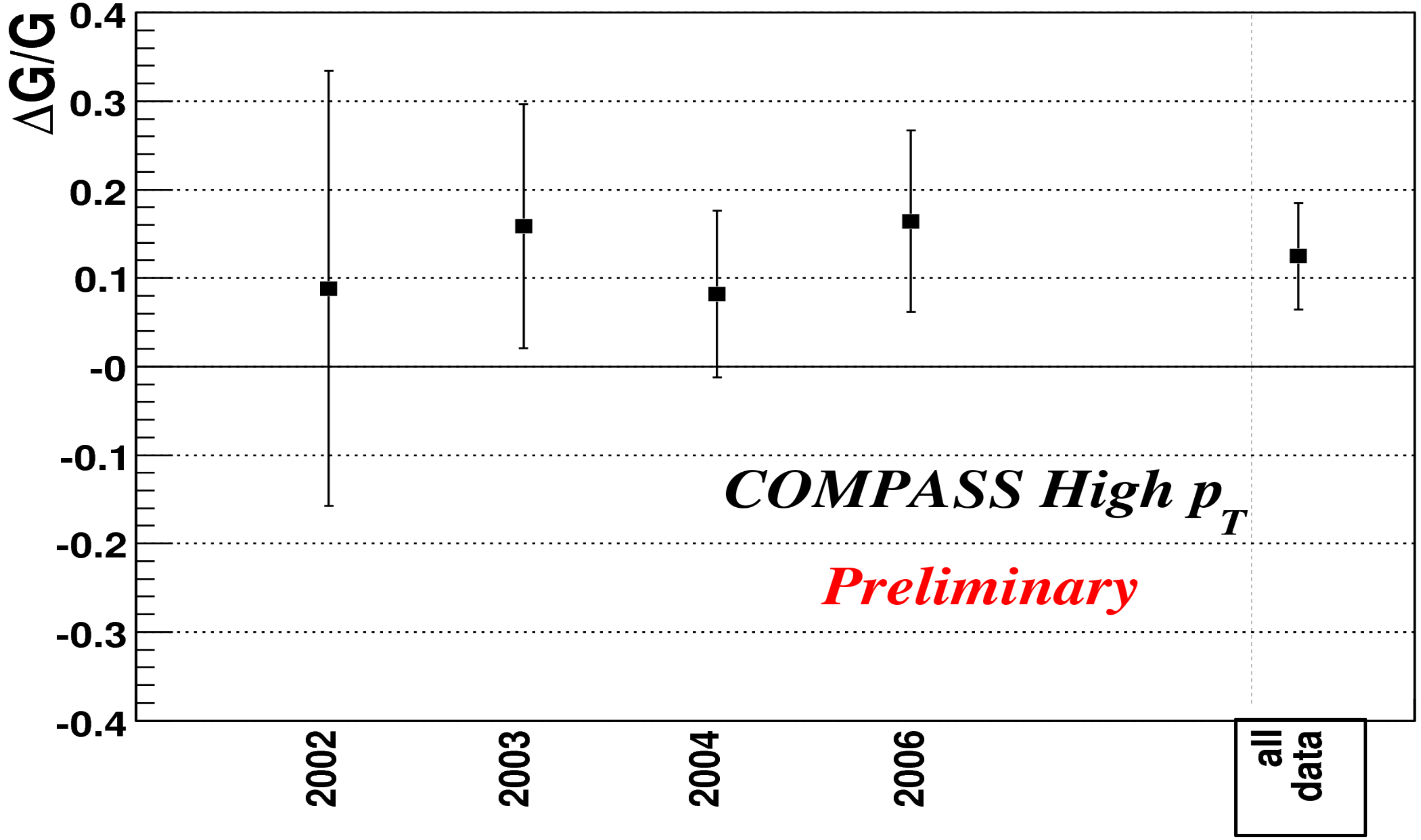
Example: Stability plots for NN

We parametrise the R^i fractions as probabilities.



Results

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



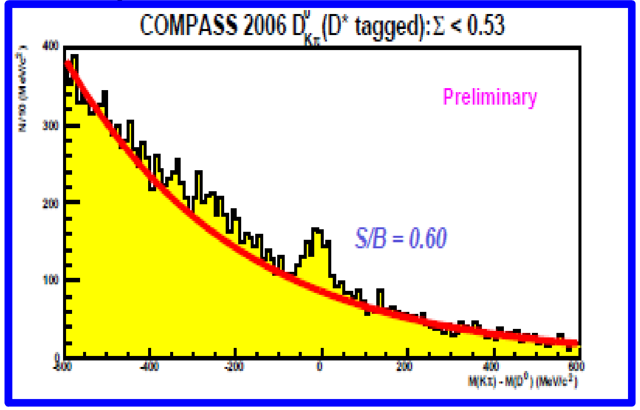
Systematic Uncertainties

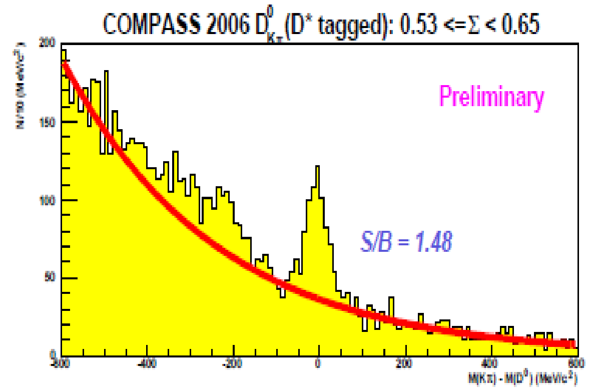
Sources of Systematic Uncertainties	δ(ΔG/G)	
	High pT	Open Charm
MC Simulation	**0.05**	
Formula Simplification	**0.04**	
False Asymmetries	0.02	**0.08**
A_1 Parametrisation	0.02	
NN Parametrisation	0.01	
P_B, P_T, f	0,004	0.01
a_{LL}		0.01
s/(s+b)		0.01
Total	0.06	0.08

S/(S+B): Obtaining final probabilities for a D^0 candidate

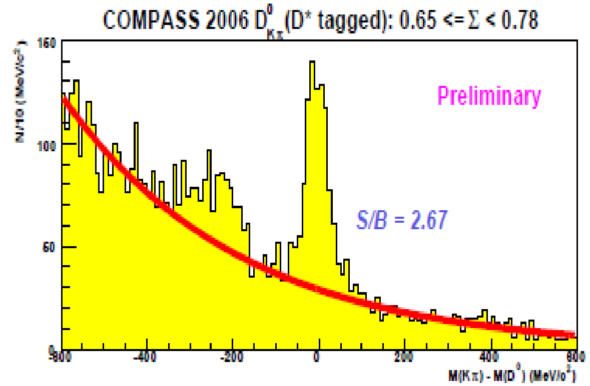
D^0_{Kp} tagged spectrum in bins of $\Sigma = S/(S+B)_{NN}$

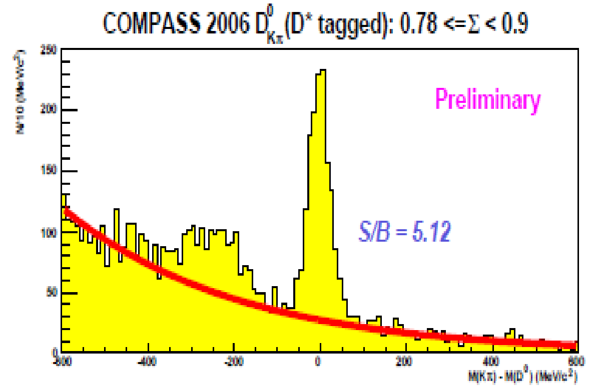
- **Events with small $S/(S+B)_{NN}$**
  - Mostly combinatorial background is selected



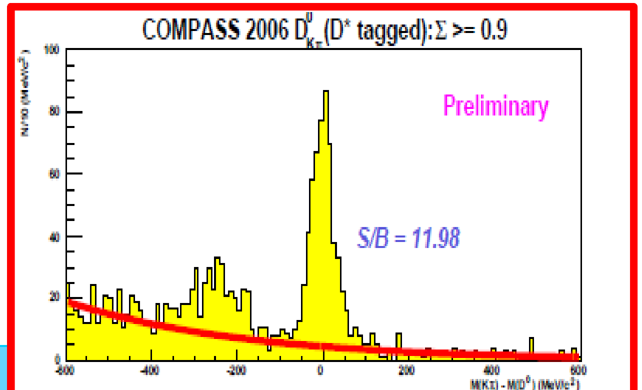


<u>**S/(S+B)** is obtained from a fit inside this bins</u> *(correcting with the NN parameterisation)*





- **Events with large $S/(S+B)_{NN}$**
  - Mostly Open Charm are selected

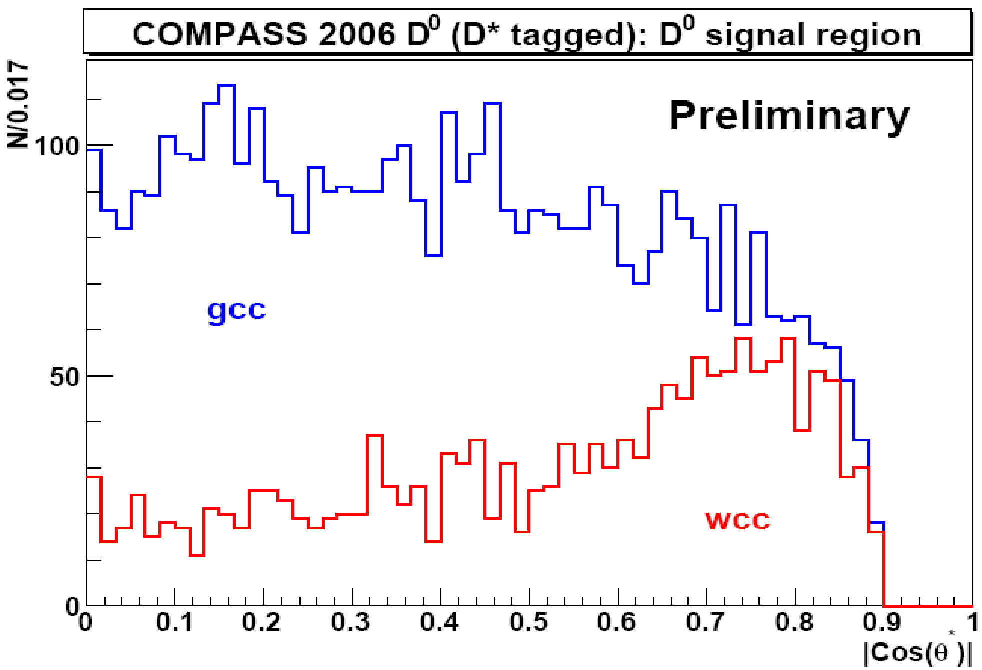


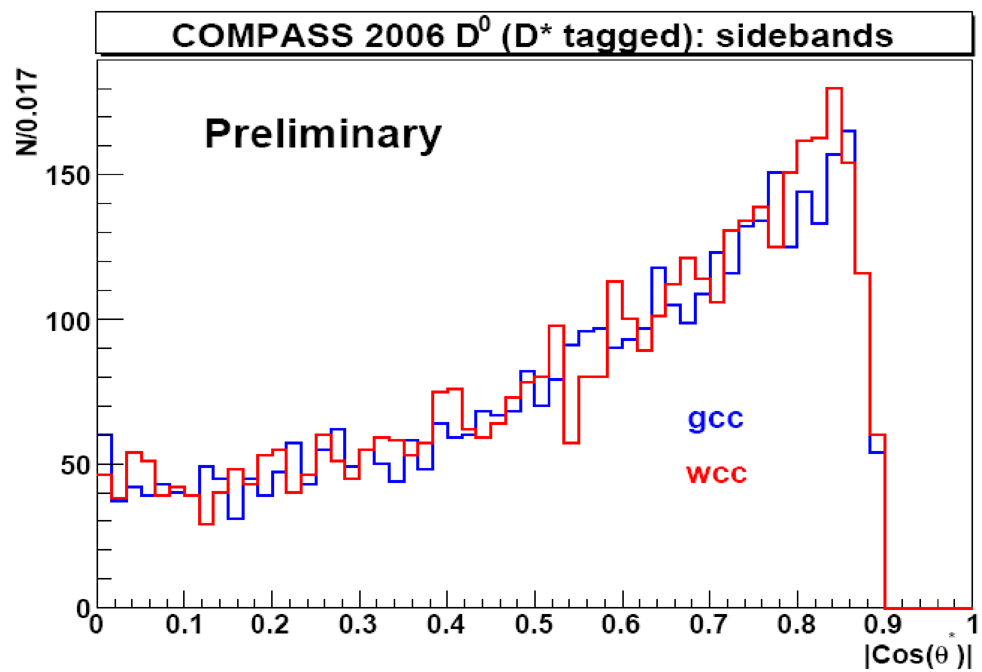
$$\delta\left(\frac{\Delta G}{G}\right) \propto \frac{1}{FOM}$$

Neural Network qualification of events

- **Two real data samples** (with the same cuts applied) **are compared by a Neural Network** (using some kinematic variables as a learning vector)**:**
  - **Signal model** → **gcc** = $K^+\pi^-\pi_s^-$ + $K^-\pi^+\pi_s^+$ (*D^0 spectrum: signal + background*)
  - **Background model** → **wcc** = $K^+\pi^+\pi_s^-$ + $K^-\pi^-\pi_s^+$ (*no D^0 is allowed*)
- **If the background model is good enough:** The Neural Network is able to distinguish the signal from the combinatorial background on a event by event basis (inside gcc)

Example of a good learning variable





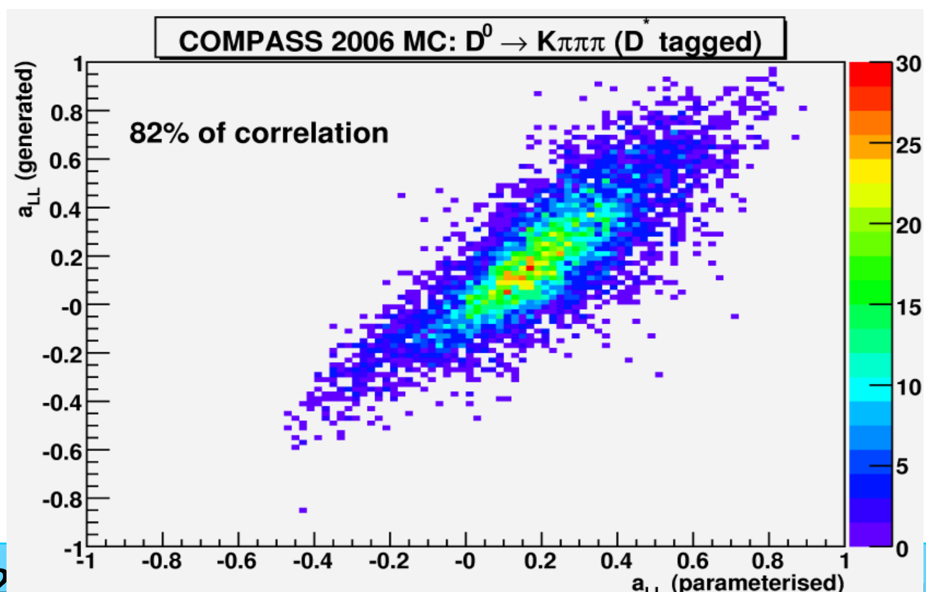
Analysing power (muon-gluon asymmetry a_{LL})

- a_{LL} is dependent on the full knowledge of the partonic kinematics:

$$a_{LL} = \frac{\Delta\sigma^{PGF}}{\sigma_{PGF}}(y, Q^2, x_g, z_C, \phi)$$

Can't be experimentally obtained: only one charmed meson is reconstructed

- a_{LL} is obtained from Monte-Carlo (in LO), to serve as input for a Neural Network parameterisation on some reconstructed kinematical variables: y, x_{Bj}, Q^2, z_D and p_T



Parameterised a_{LL}, shows a strong correlation with the generated one *(using AROMA)*

Comparison of a_{LL}(LO) with a_{LL}(NLO)

- **The AROMA generator is used to simulate the fase space for the NLO (PS on) / LO (PS off) calculations of a_{LL}**. The resulting D^0 mesons are reconstructed in the COMPASS spectrometer like real events. The respective a_{LL} distributions are: