

COMPASS results on gluon polarisation

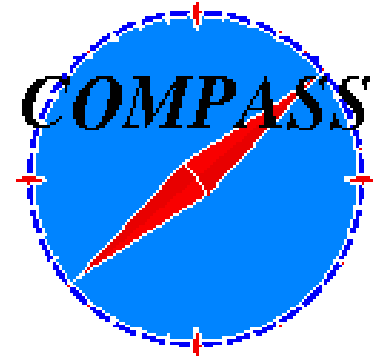


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On behalf of the COMPASS Collaboration

Outline:

- Brief Motivation
- High p_T and Open Charm analyses
- $\Delta G/G$ results
- Summary and Conclusion



THE COMPASS EXPERIMENT








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

Data taken: 2002 - 2011, ...



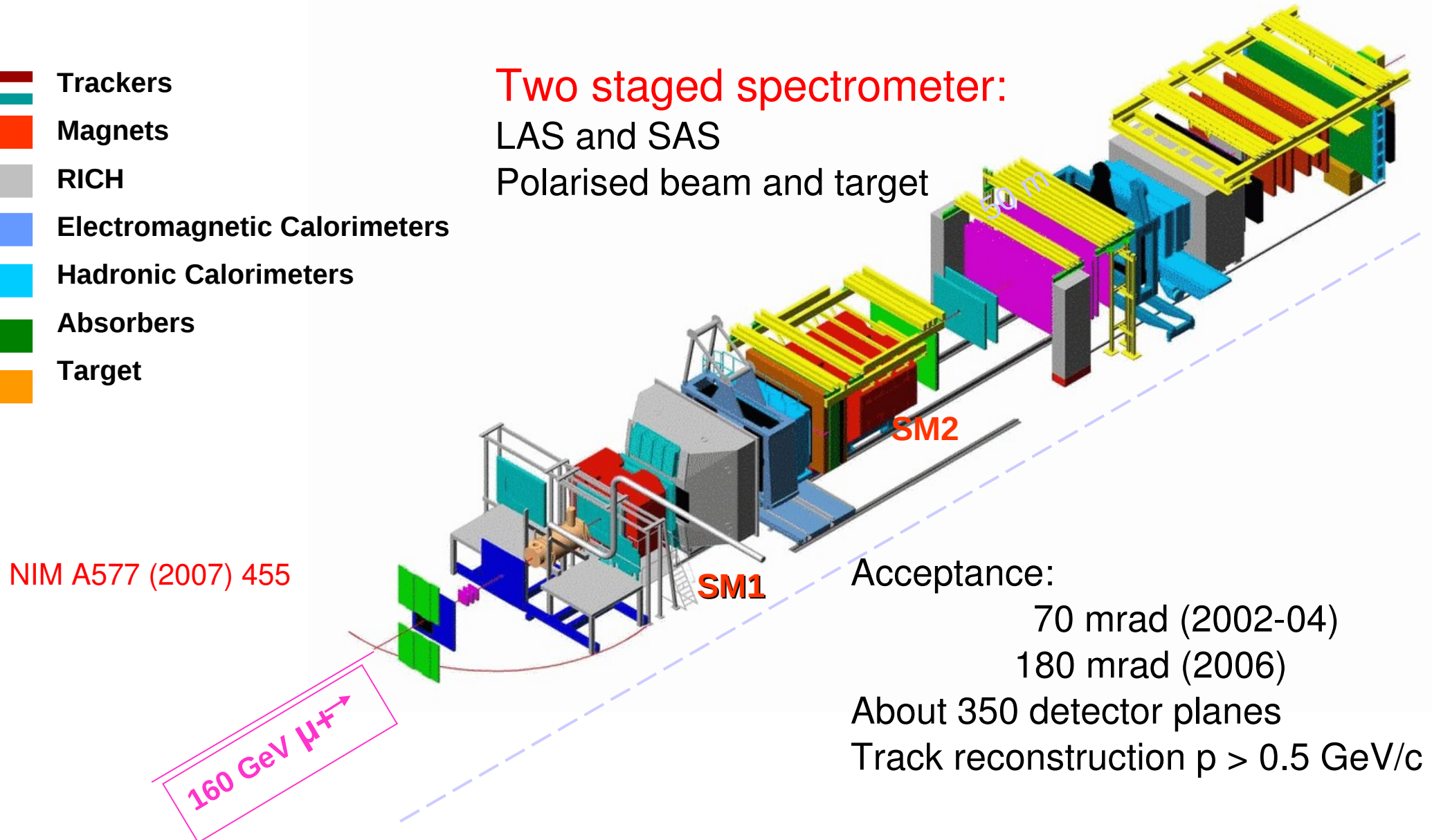
~250 physicists
25 institutes
11 countries

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



Acceptance:

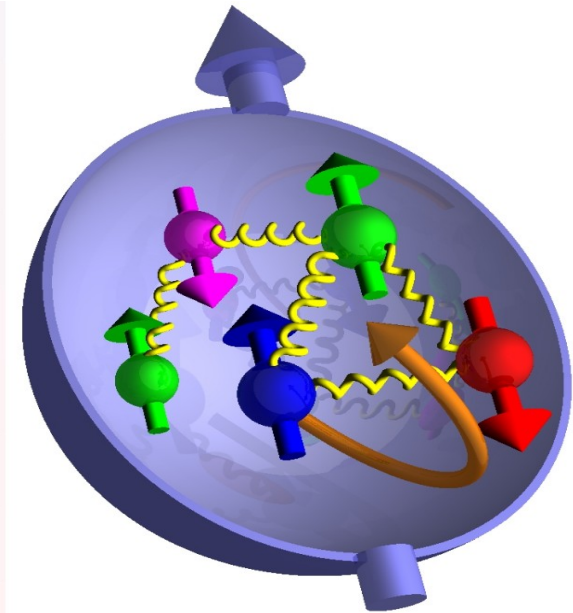
70 mrad (2002-04)

180 mrad (2006)

About 350 detector planes

Track reconstruction $p > 0.5 \text{ GeV}/c$

The Nucleon Spin



$$S_N = 1/2 = 1/2 \Delta\Sigma + \Delta G + L$$

Partons
Orbital Angular
Momenta

Quarks

Gluons

Future !
GPDs

Well known !

In 1988 EMC measured

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

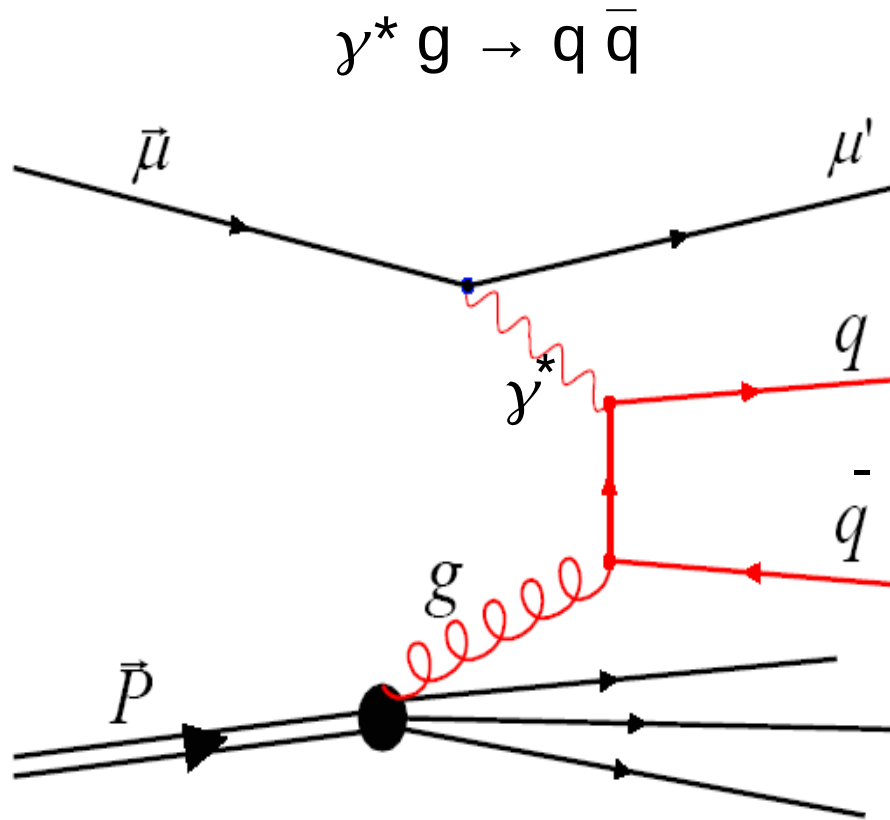
A recent result, including COMPASS, gives:

$$\Delta\Sigma = 0.30 \pm 0.01(\text{stat.}) \pm 0.02(\text{evol.}) \text{ Phys.Lett.B647,8}$$

Poorly known

Exploratory and discovery stage.
Some experiments and data
might give hints.

COMPASS, HERMES, CLAS,
STAR, PHOENIX



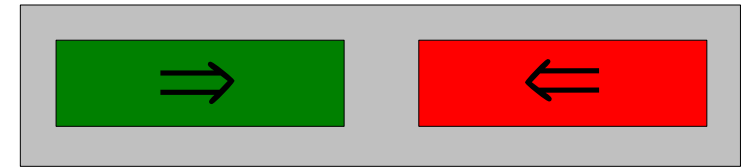
To select this process there are two methods :

- **High transverse momentum hadrons** ($Q^2 < 1$ and $Q^2 > 1$ (GeVc)²)
 - ☺ High 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.

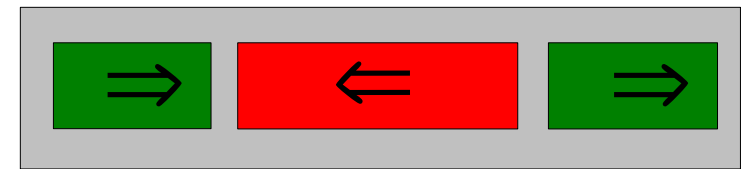
Photon-gluon fusion process (PGF)

Direct measurement of $\Delta G/G$

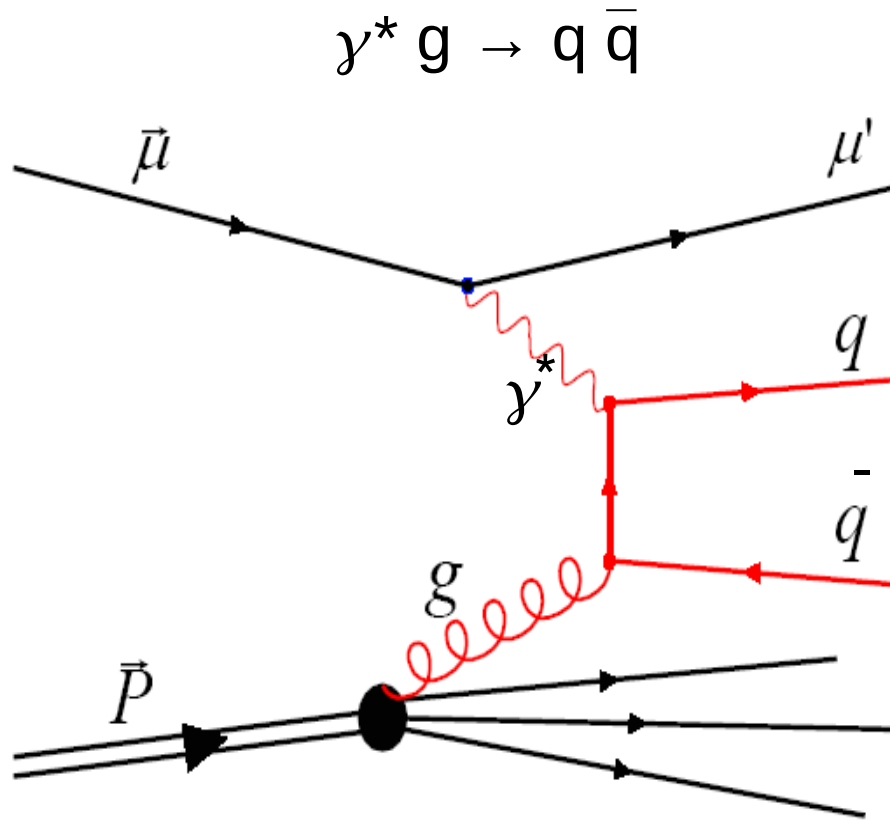
2002-2004



2006



μ -beam \leftarrow



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

$$A_{PGF} = \frac{N_{PGF}^{\rightarrow\leftarrow} - N_{PGF}^{\leftarrow\leftarrow}}{N_{PGF}^{\rightarrow\leftarrow} + N_{PGF}^{\leftarrow\leftarrow}}$$

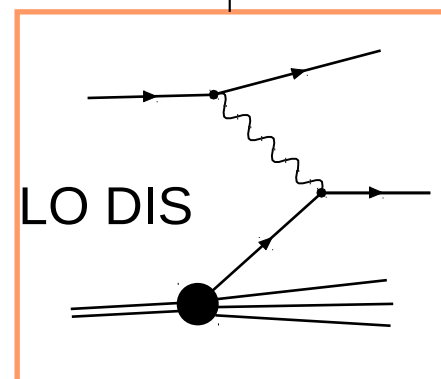
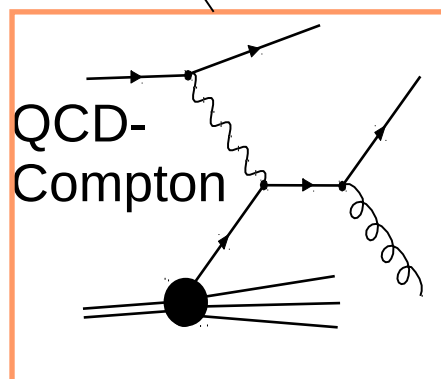
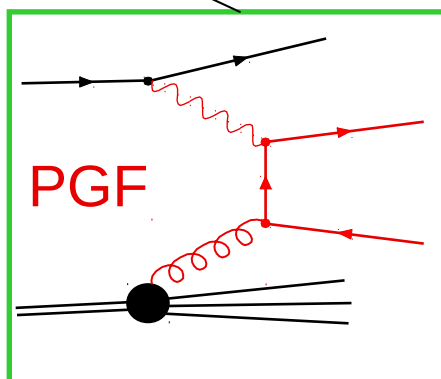
$$\Rightarrow \Delta G/G$$

Photon-gluon fusion process (PGF)

Experiments with polarised beam and target are sensitive to gluon helicity

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

A_1^{LO} : estimated by an
inclusive sample



Final formula for
the gluon
polarisation

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

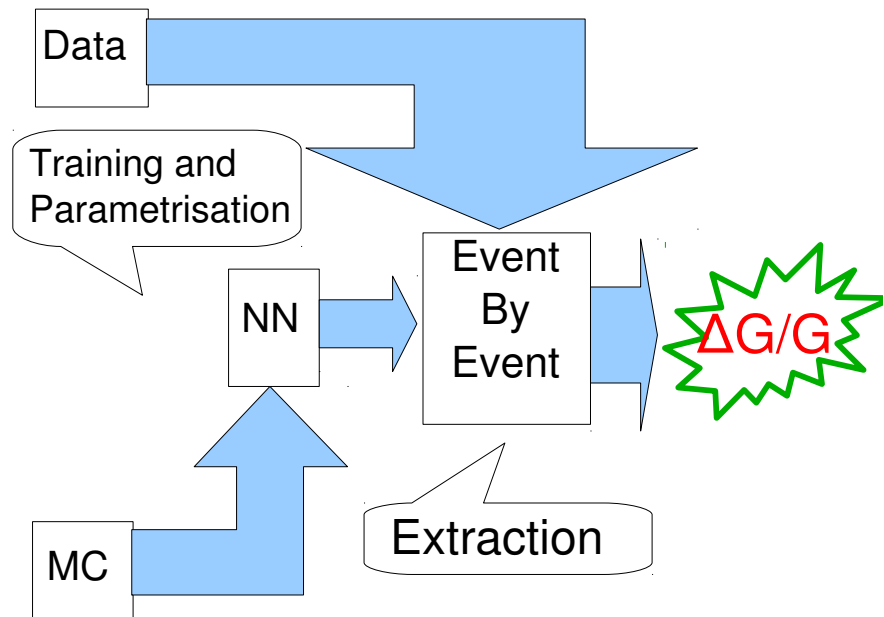
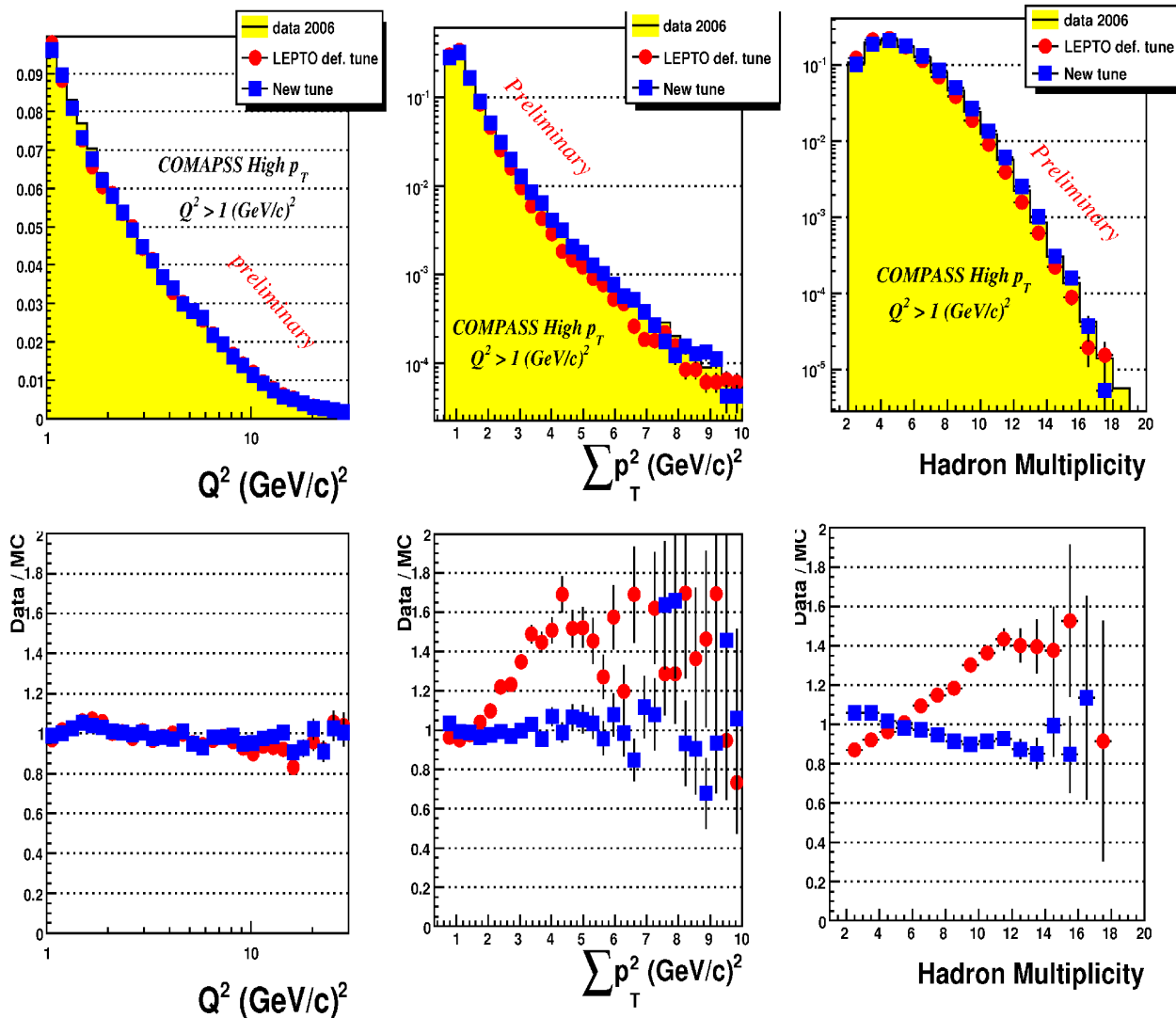
$$\beta = a_{LL}^{PGF} R_{PGF} - a_{LL}^{PGF, incl} R_{PGF}^{incl} \frac{R_{LO}}{R_{LO}^{incl}} - a_{LL}^{PGF, incl} \frac{R_C R_{PGF}^{incl}}{R_{LO}^{incl}} \frac{a_{LL}^C}{D}$$

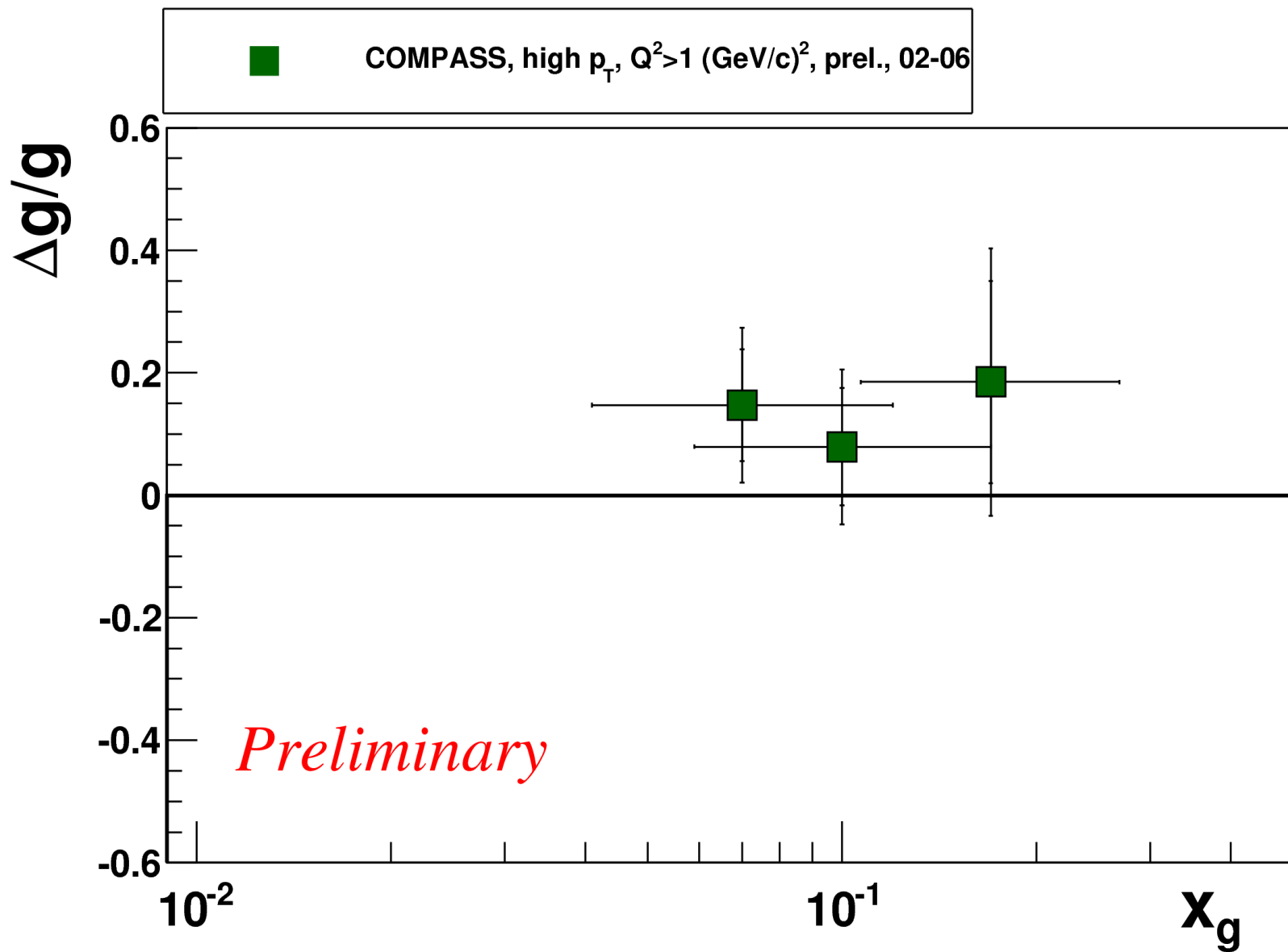
$$A_{corr} = - \left(A_1(x_{Bj}) D \frac{R_{LO}}{R_{LO}^{incl}} - A_1(x_C) \beta_1 + A_1(x_C') \beta_2 \right)$$

- A_{LL}^{2h} : measured from the two hadron sample.
- a_{LL}^i and R_i : estimated from MC and parametrised using a 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.

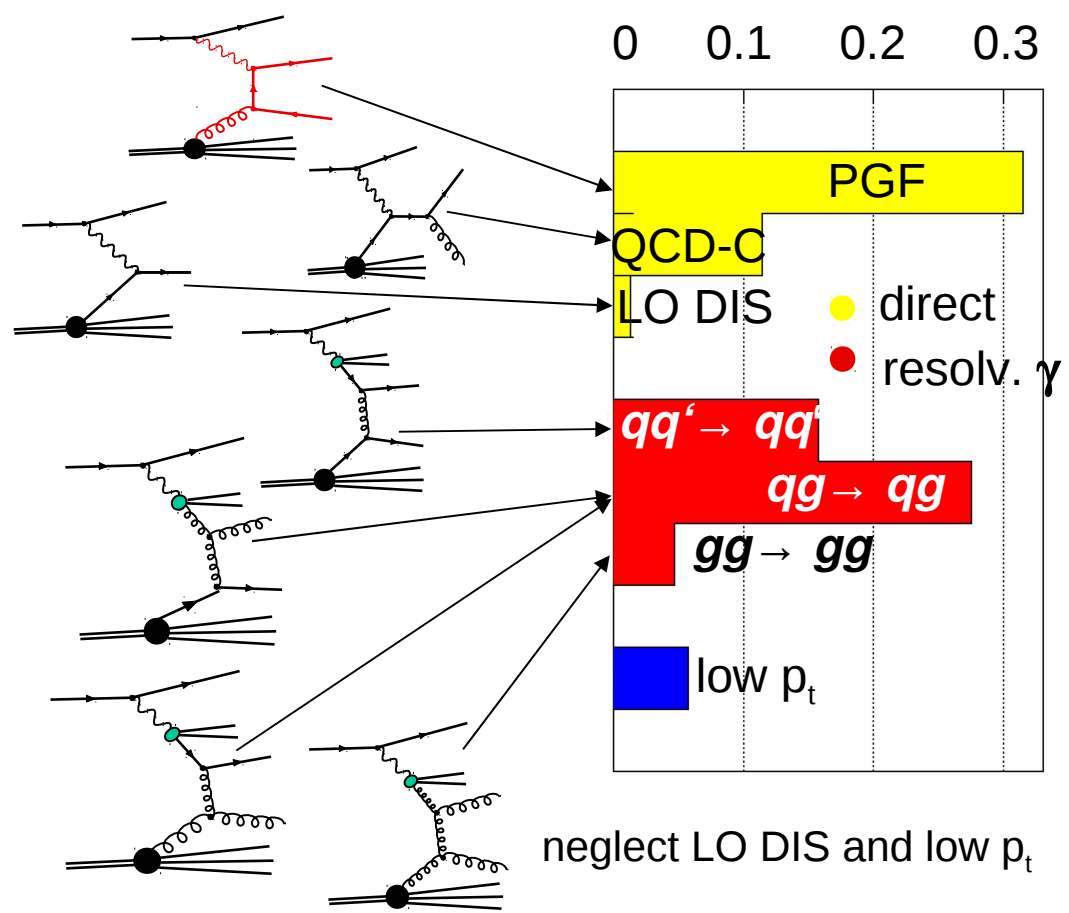
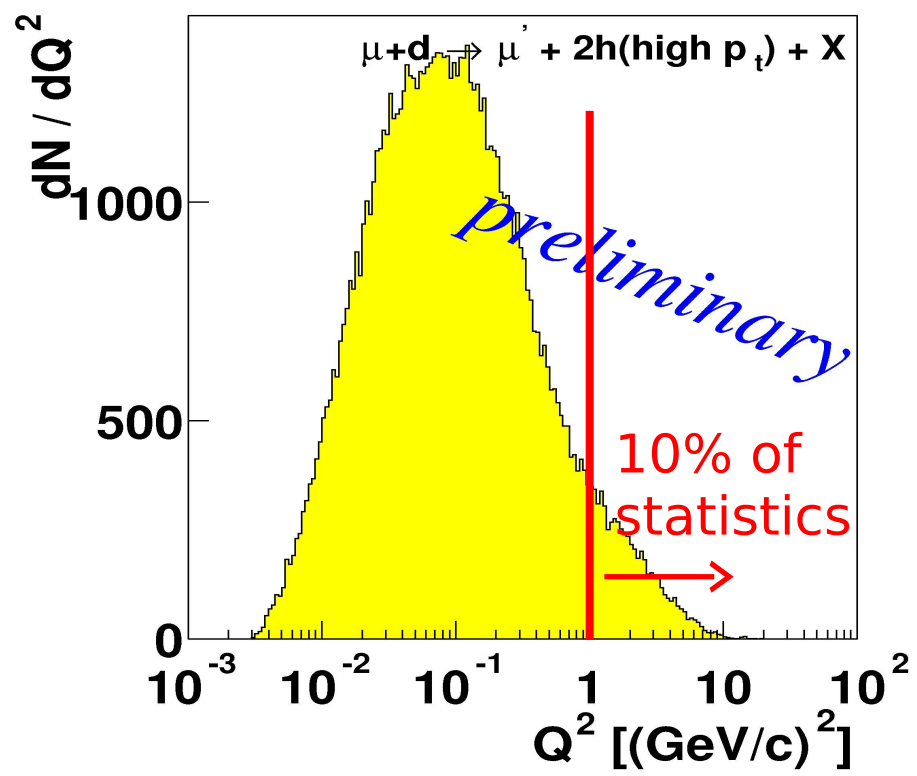
Data-MC comparison:
 Q^2 , p_T and Hadron Multiplicities.





The whole statistics was divided, for the first time, resulting in 3 independent measurements, for $Q^2 > 1 \text{ GeV/c}$.

~ 90 % of our statistics in this sample



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 633,25

- The relation between the number of reconstructed D^0 (for each target cell configuration) and $\Delta G/G$ 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

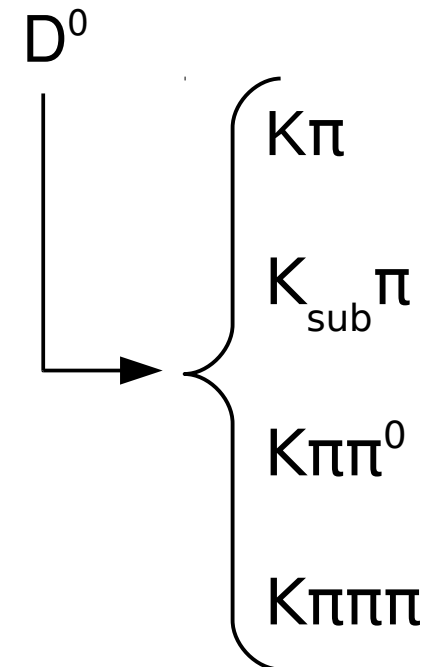
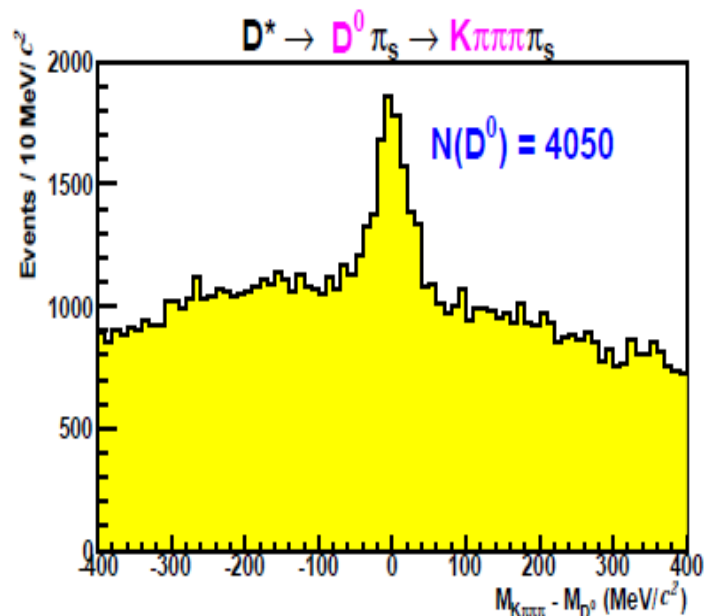
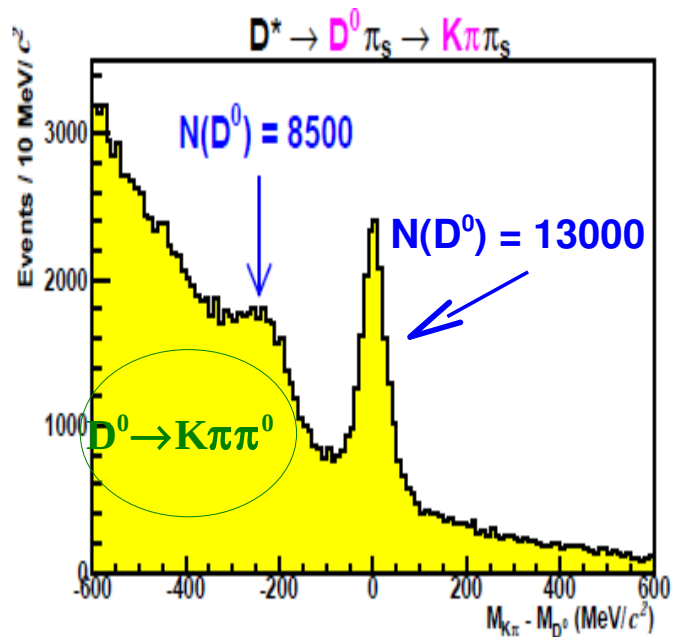
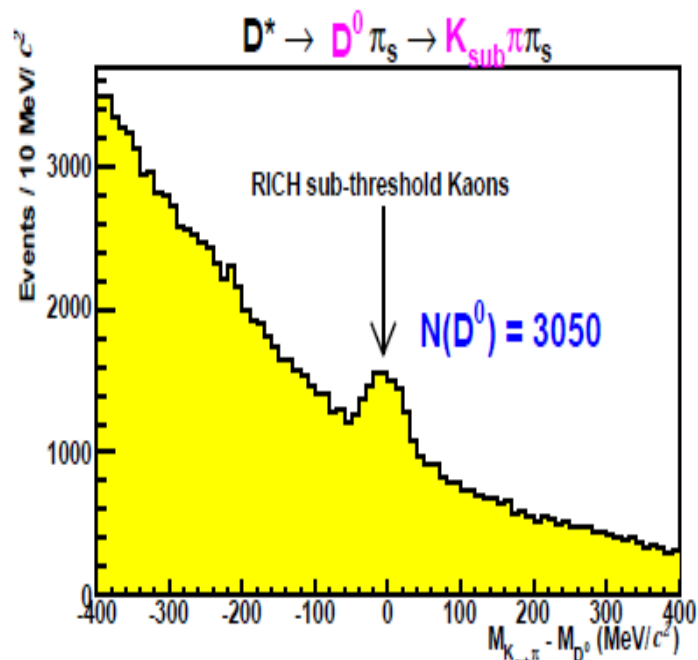
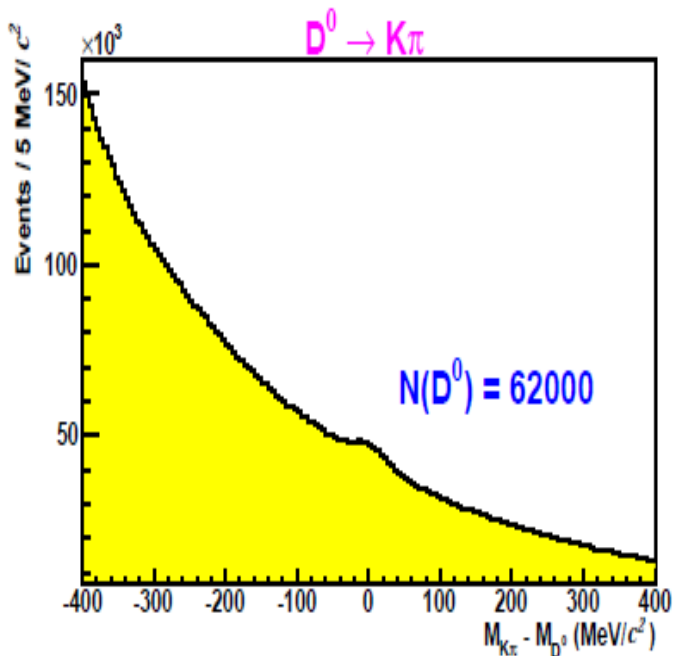
- Each equation is weighted with a signal weight $w_S = f P_m a_{LL} S/(S+B)$ and also with a background weight $w_B = f P_m D B/(S+B)$:

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

The system is solved by a χ^2 minimisation



D⁰ invariant mass spectra: 2002-2007 data



Number of D^0 :

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

- 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)

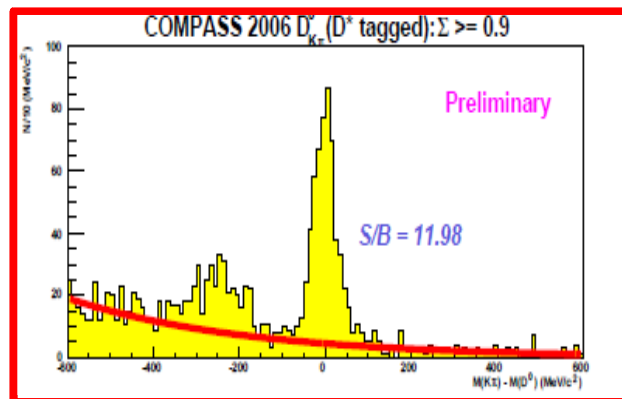
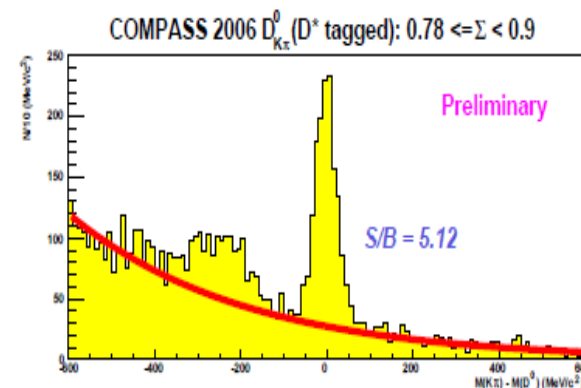
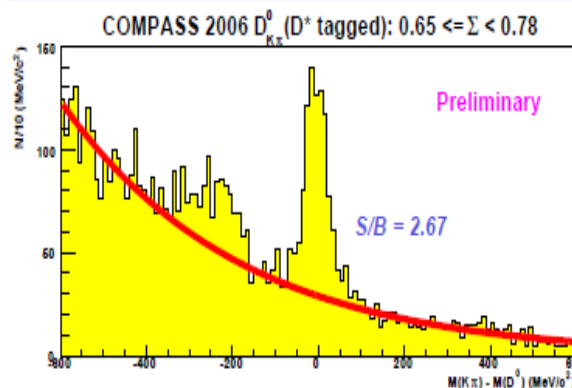
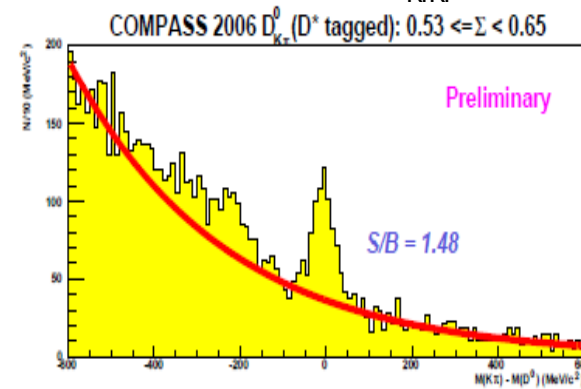
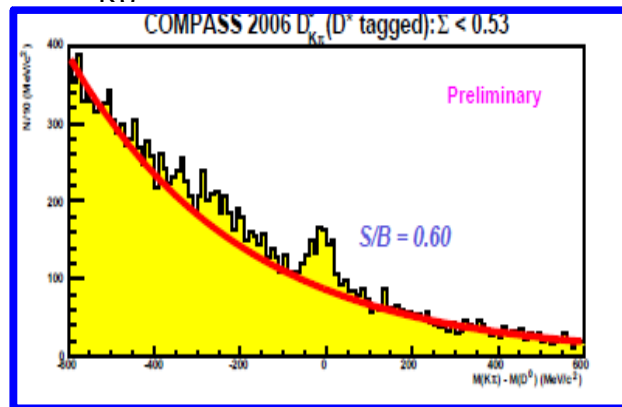
- **Background model**

$$wcc = K^+ \pi^+ \pi_s^- + K^- \pi^- \pi_s^+$$

(no D^0 is allowed)

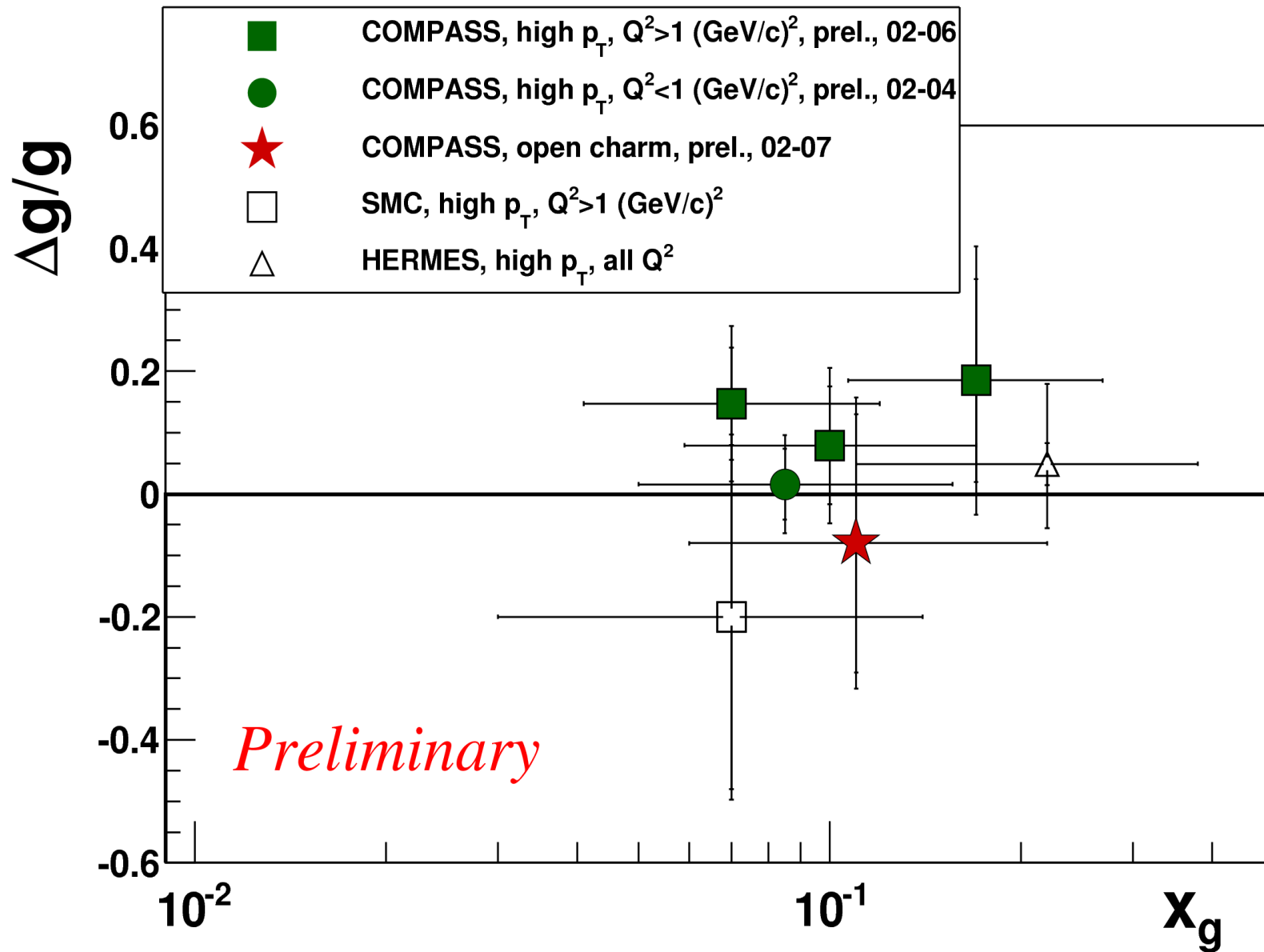
- If the background model is good enough: The Neural Network is able to distinguish the signal from the combinatorial background on a event by event basis (inside gcc)

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

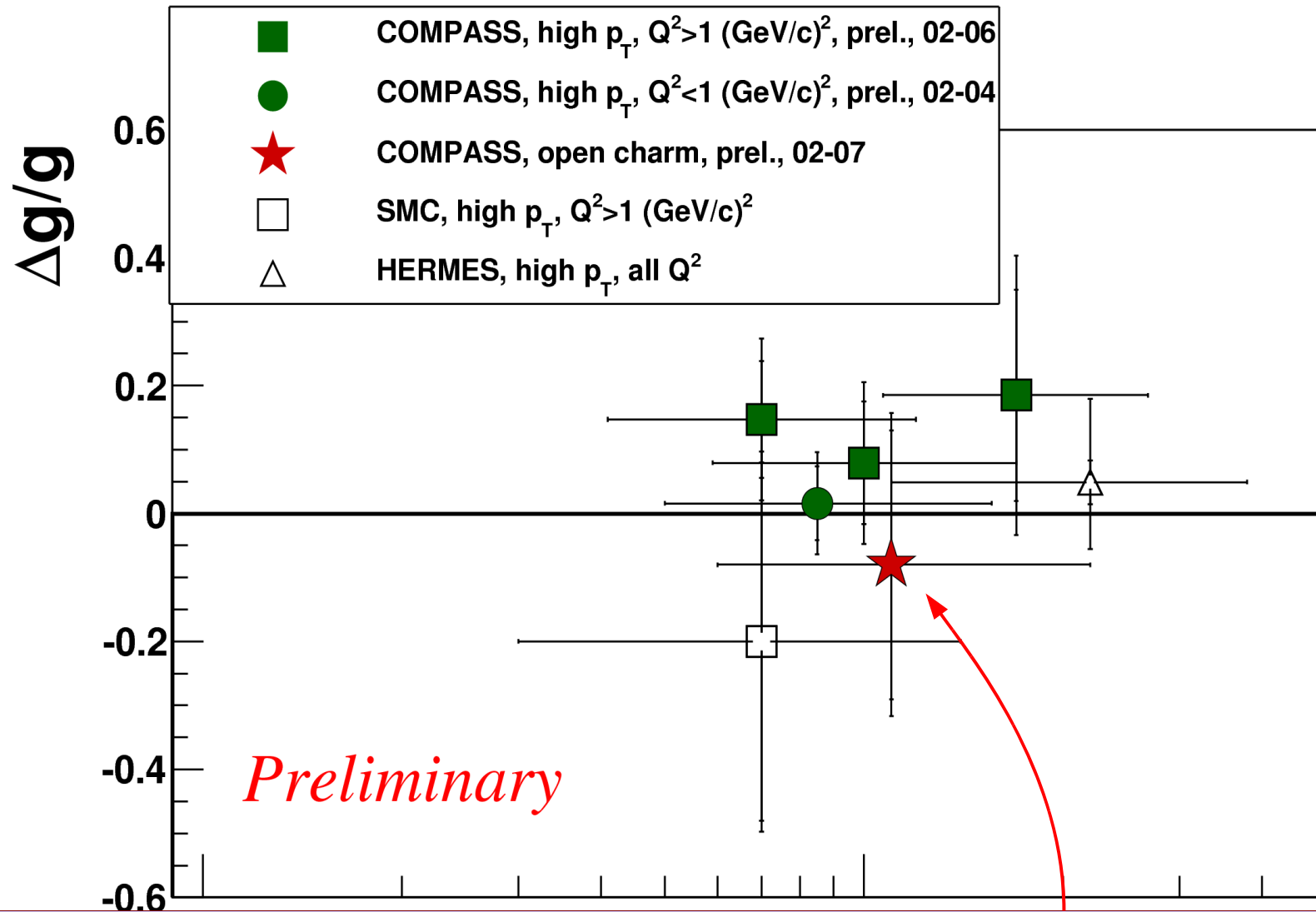


$$\delta \left(\frac{\Delta G}{G} \right) \propto \frac{1}{\text{FOM}}$$

$\Delta G/G$ Results (LO)

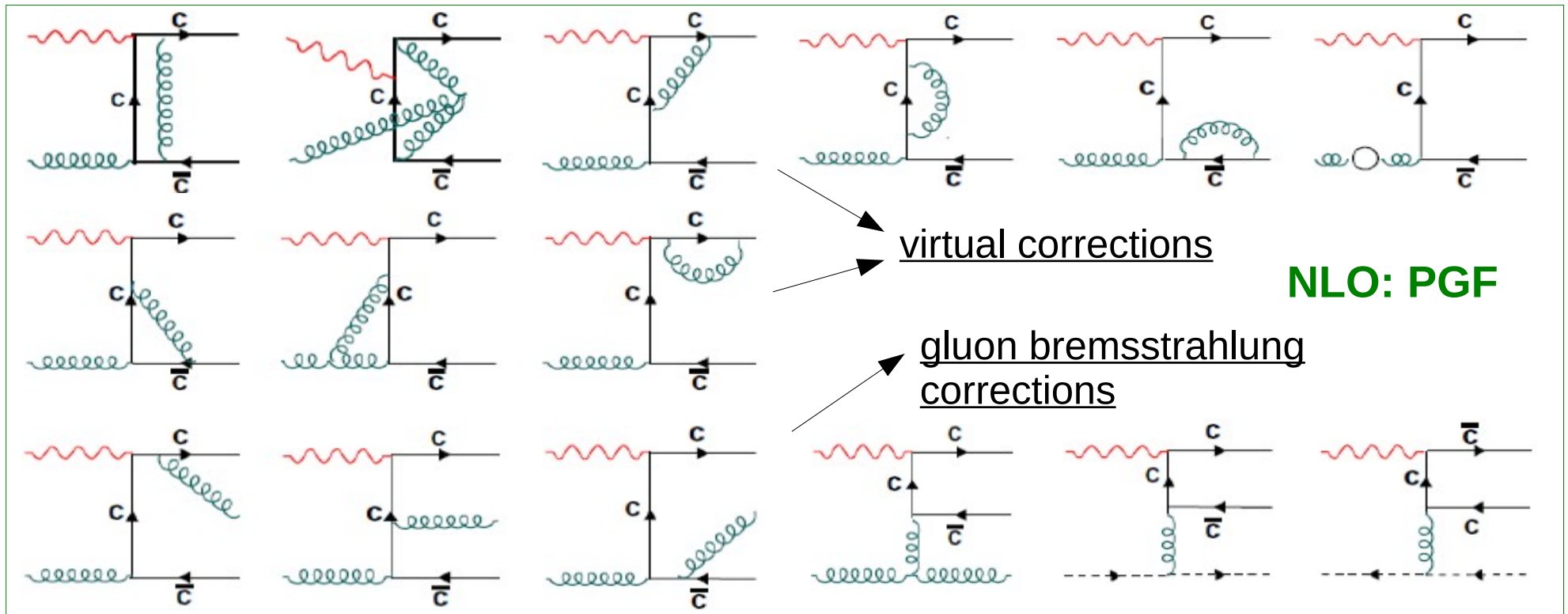
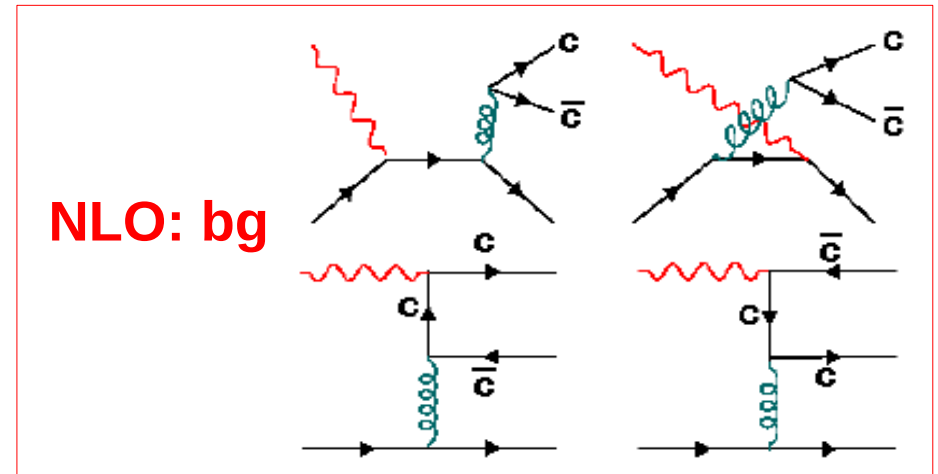
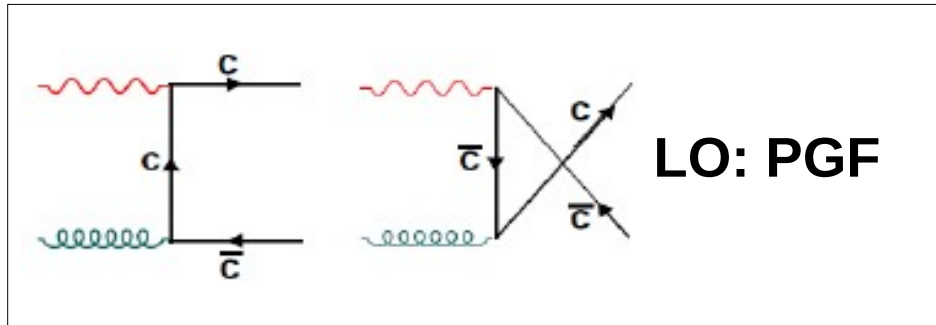


$\Delta G/G$ Results (LO)

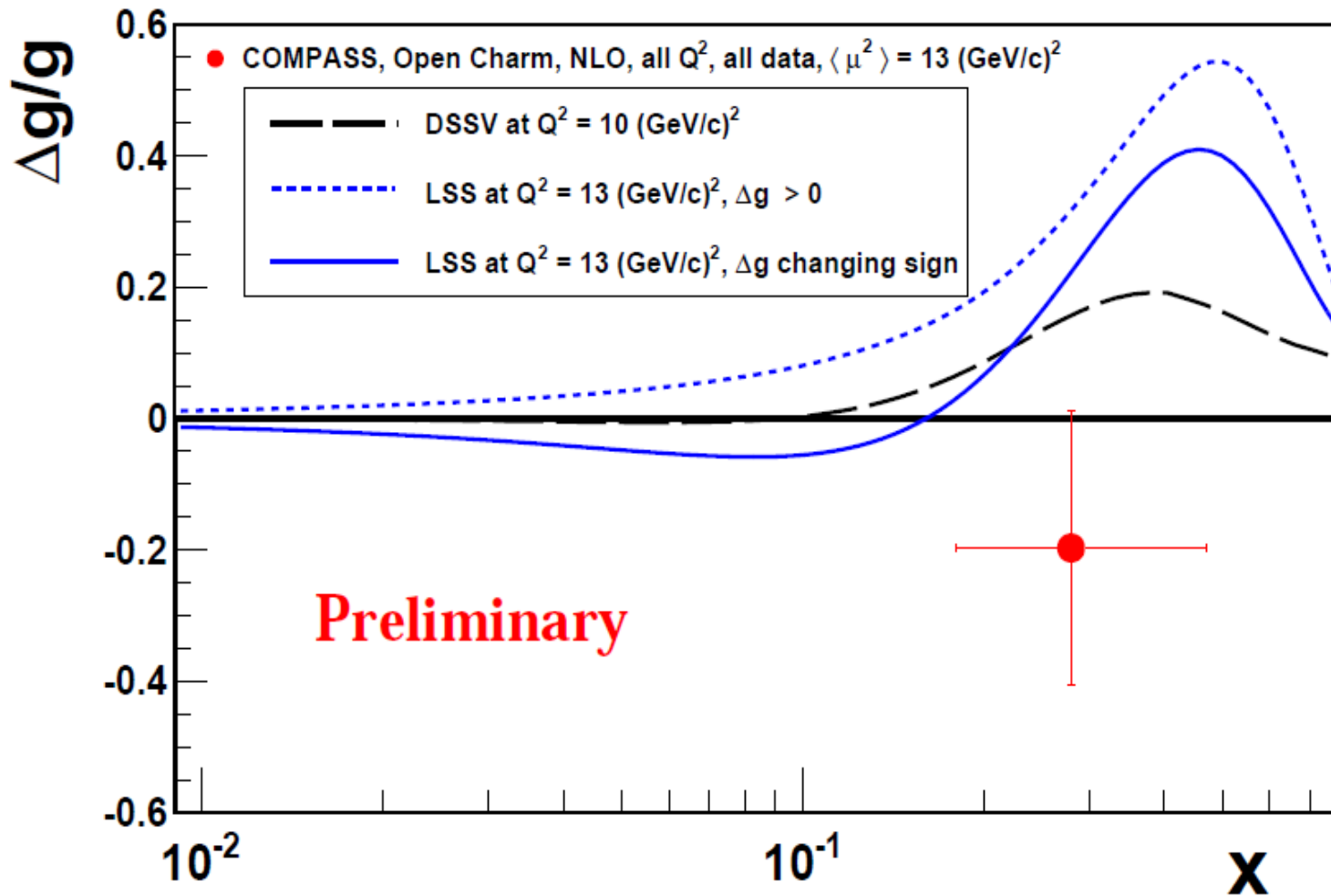


$$\frac{\Delta G}{G} = -0.08 \pm 0.21_{(\text{stat})} \pm 0.08_{(\text{syst})} \quad \langle x_g \rangle = 0.11^{+0.11}_{-0.05}, \quad \langle \mu^2 \rangle = 13 \text{ (GeV/c)}^2$$

NLO corrections to the analysing power a_{LL}

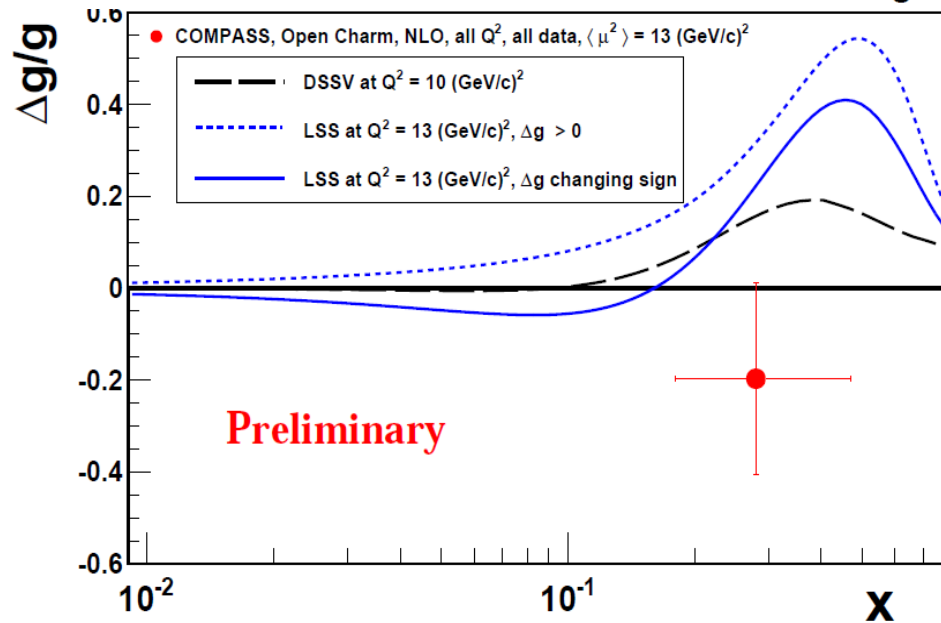
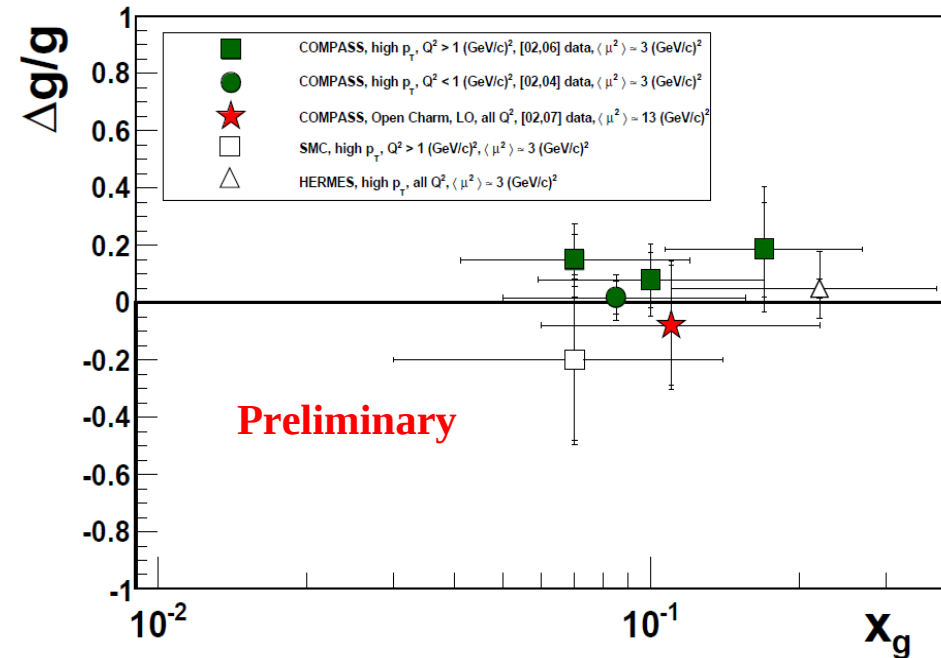


$\Delta G/G$ new Result (NLO)



$$\frac{\Delta G}{G} = -0.20 \pm 0.21 \pm 0.08 \text{ (syst)} \quad \langle x_g \rangle = 0.28_{-0.10}^{+0.19}, \quad \langle \mu^2 \rangle = 13 \text{ (GeV/c)}^2$$

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



Summary:

- The direct measurement methods used in COMPASS experiment were explained.
- Several gluon polarisations results presented are in full agreement among themselves.

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

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:

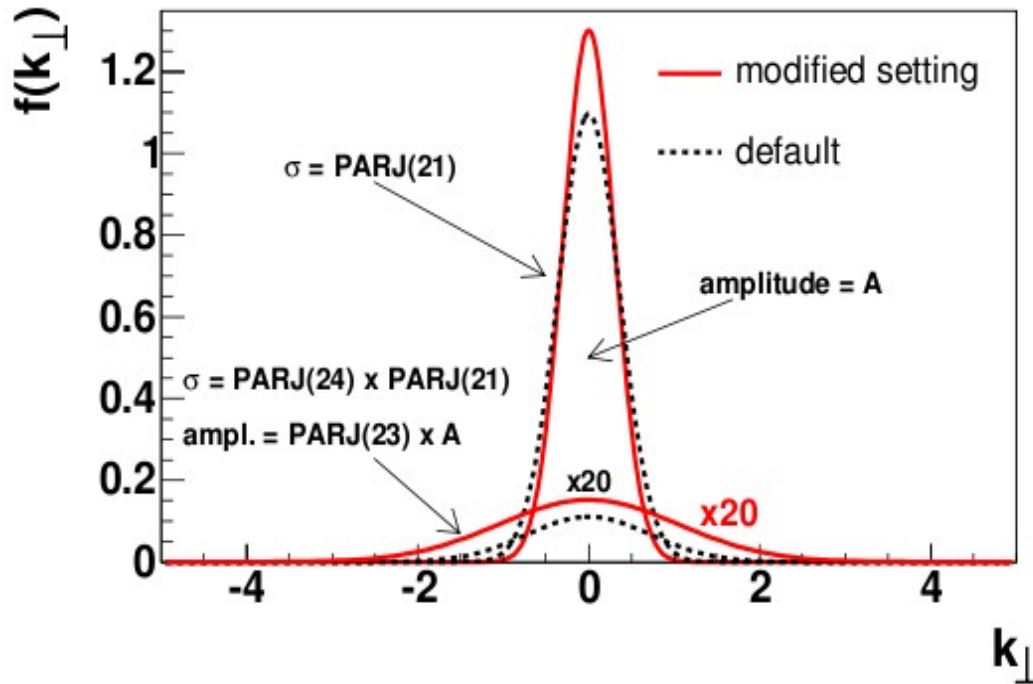
Generator (LEPTO) + Apparatus Simulation (GEANT) +
Reconstruction Program.

- 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.

- 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.

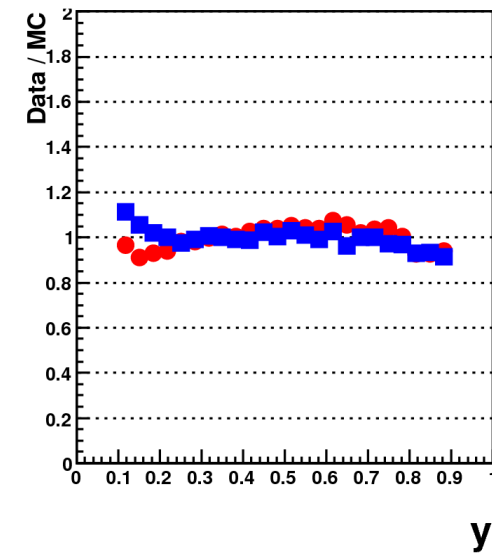
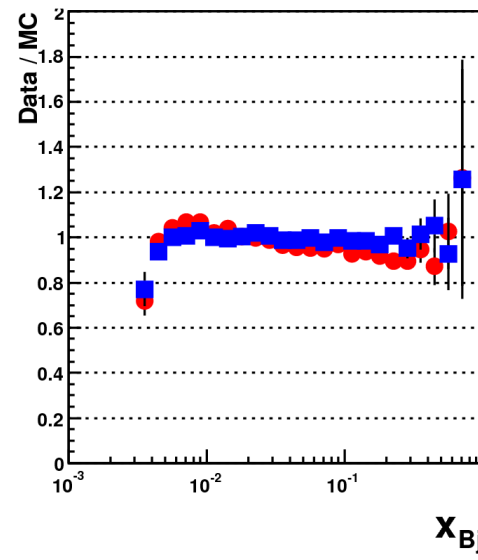
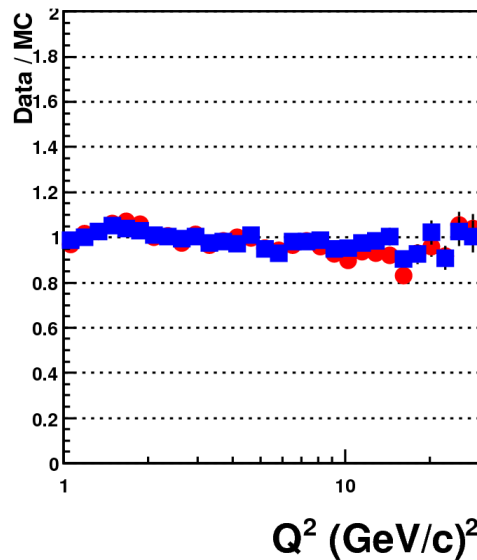
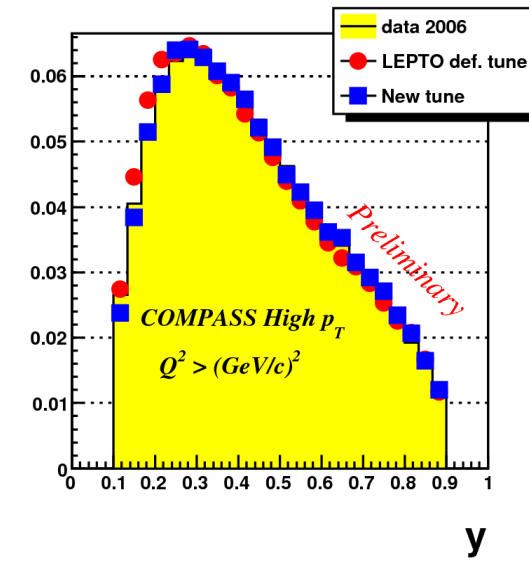
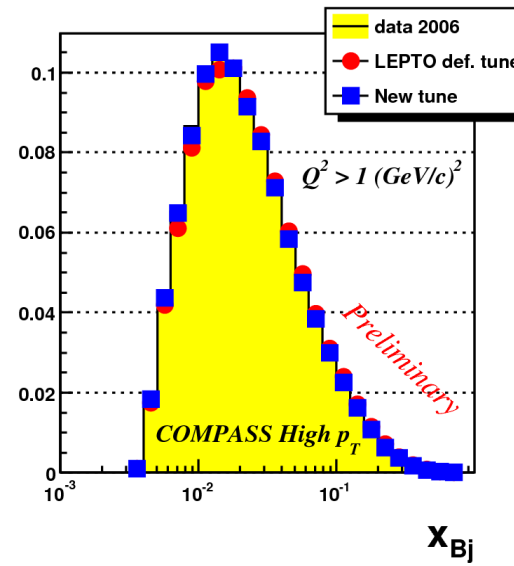
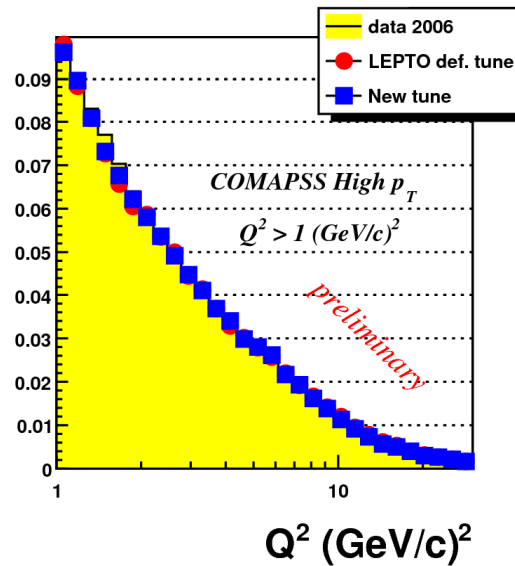


$a = \text{PARJ}(41)$
 $b = \text{PARJ}(42)$

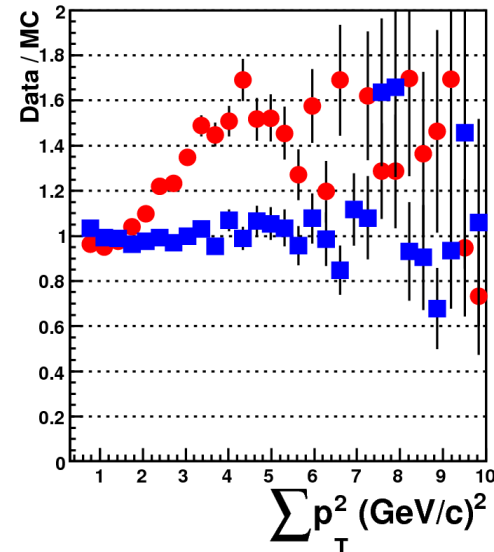
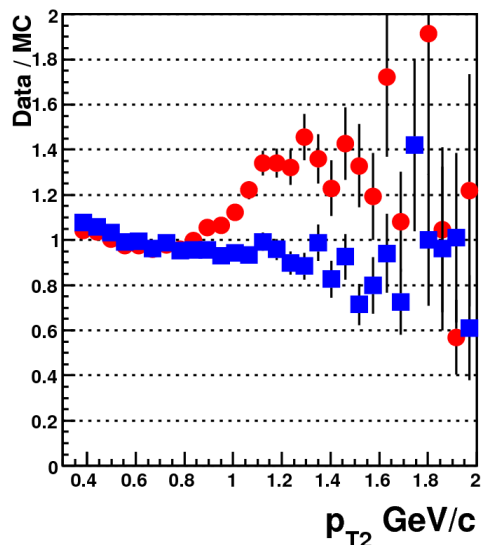
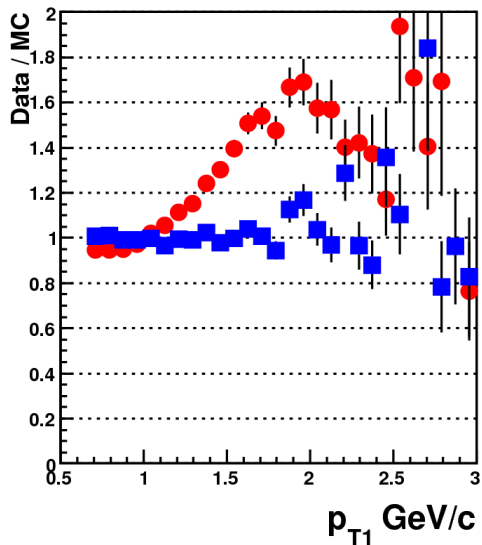
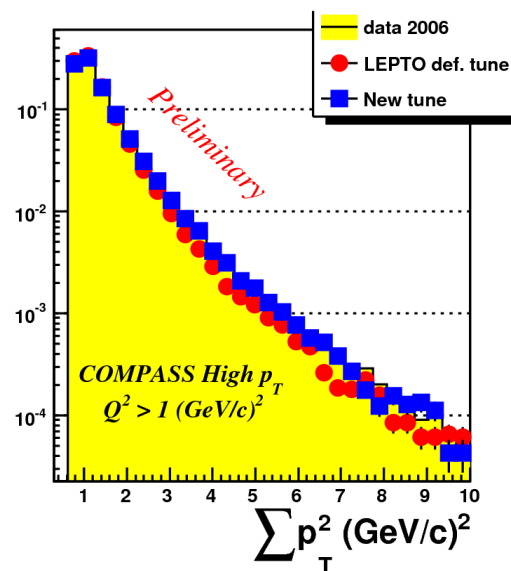
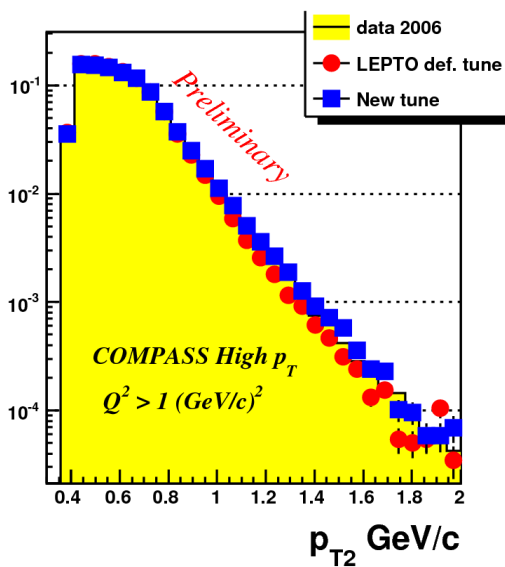
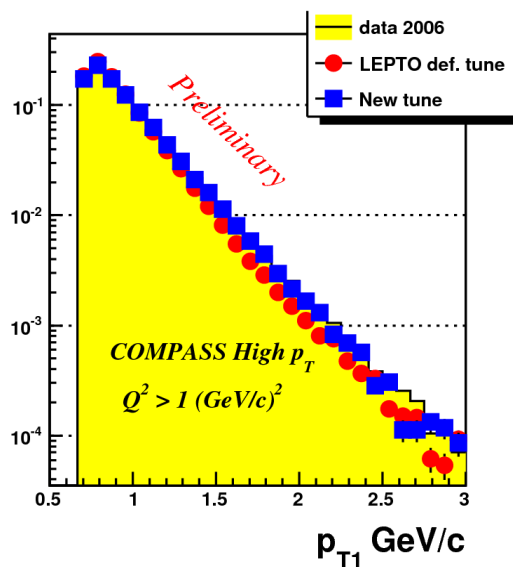
$$f(z) \propto \frac{1}{2} (1-z)^a \exp\left(-\frac{b m_T^2}{z}\right)$$

COMPASS new tuning
LEPTO default tuning

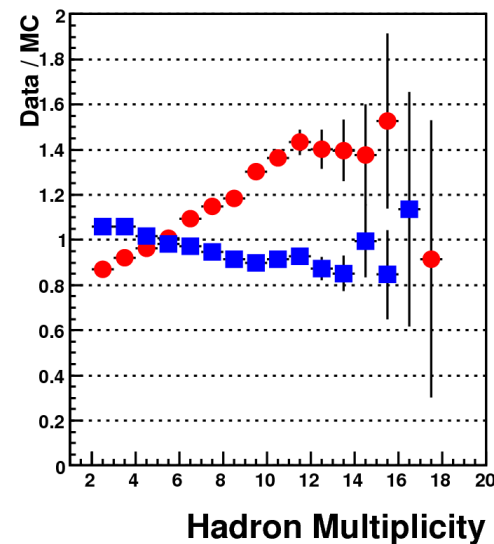
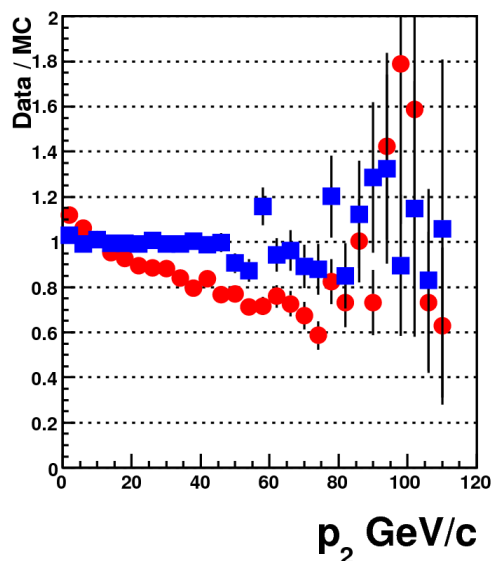
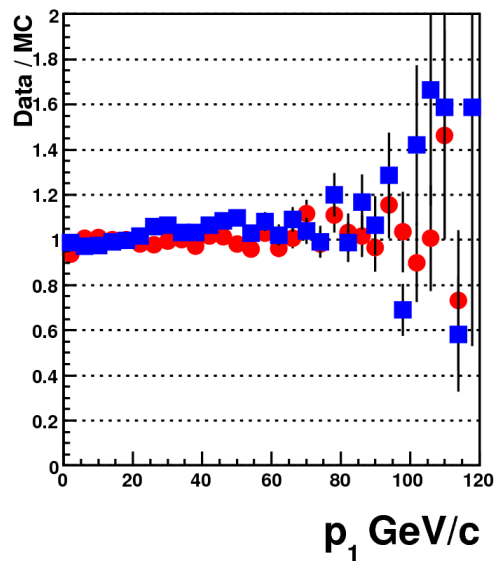
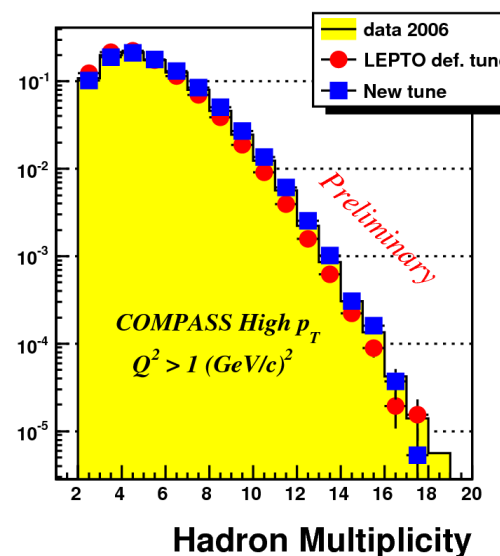
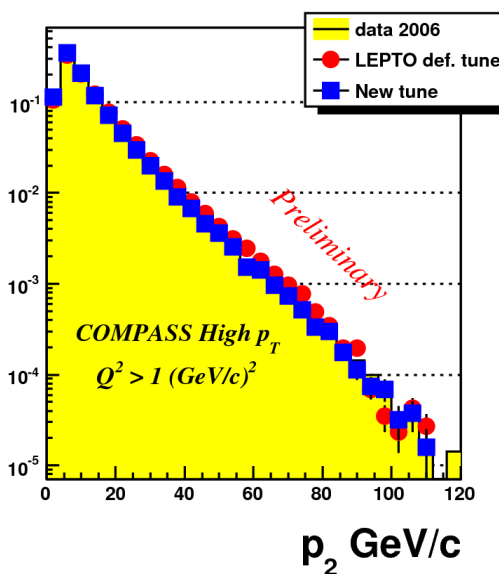
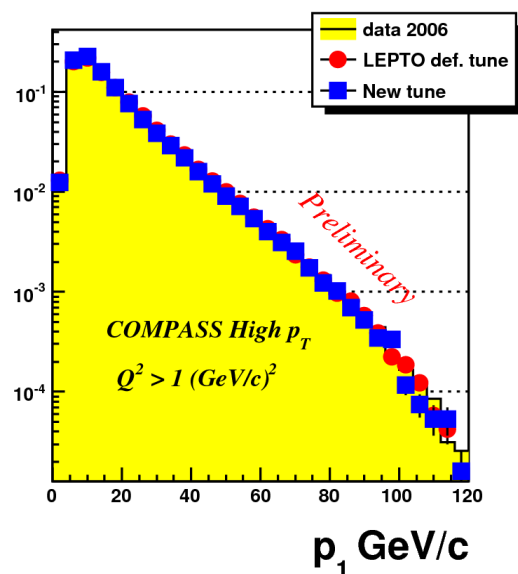
PARJ(21)	PARJ(23)	PARJ(24)	PARJ(41)	PARJ(42)
0.34	0.04	2.8	0.025	0.075
0.36	0.01	2.0	0.3	0.58
Transverse momentum of the hadron fragmentation			Fragmentation function	



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

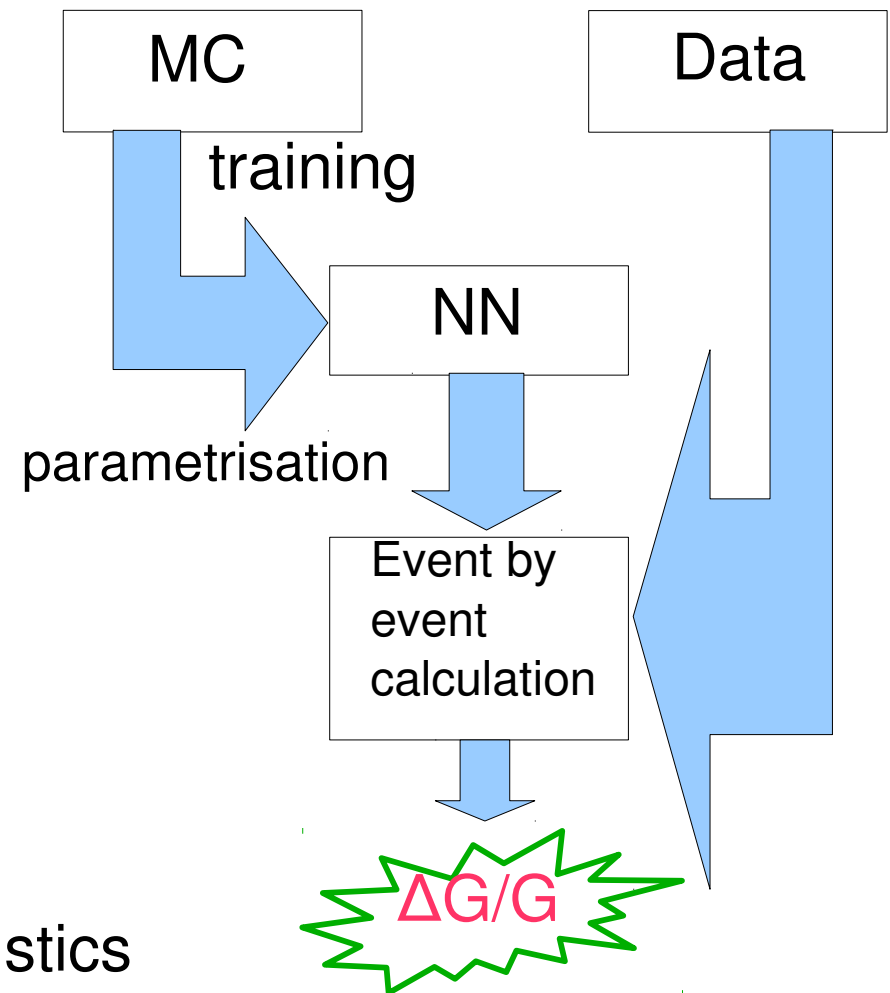


high- p_T sample: hadron variables (p_1 , p_2 and multiplicity)



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

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

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

- Therefore for every event we have to know:

$$R_{PGF}, R_C, R_{LO}, R_{PGF}^{incl}, R_C^{incl}, R_{LO}^{incl},$$

$$a_{LL}^{PGF}, a_{LL}^C, a_{LL}^{PGF, incl}, a_{LL}^{C, incl},$$

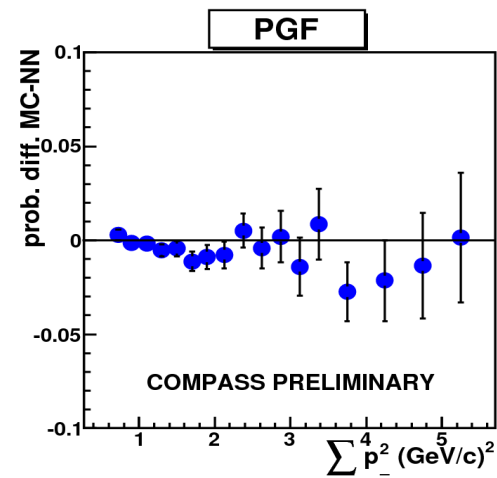
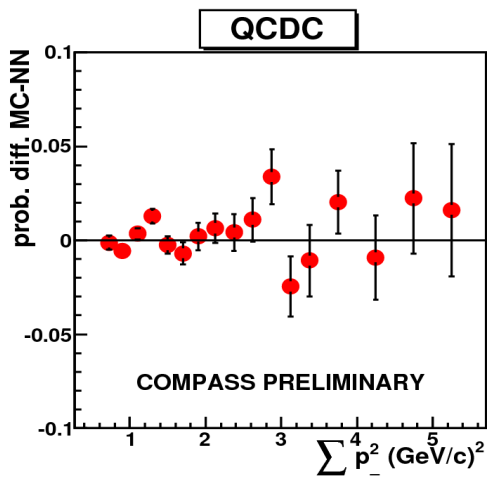
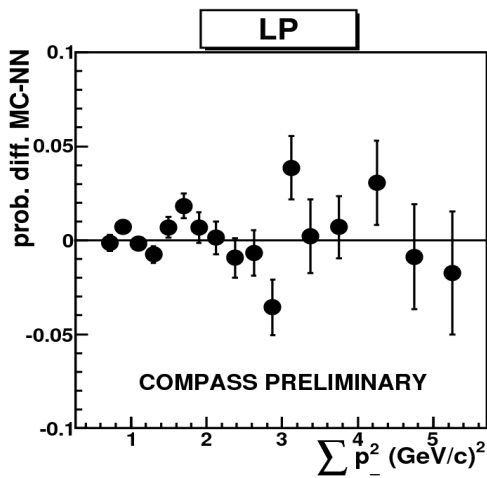
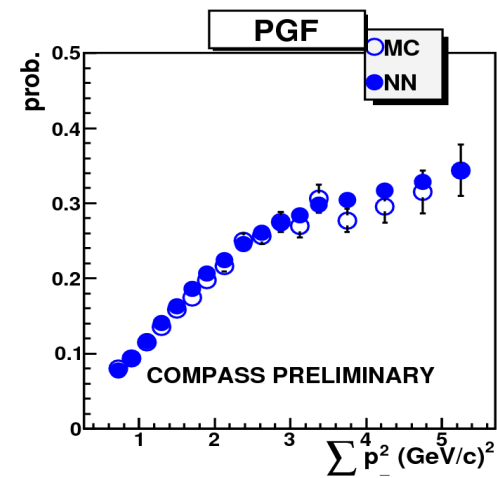
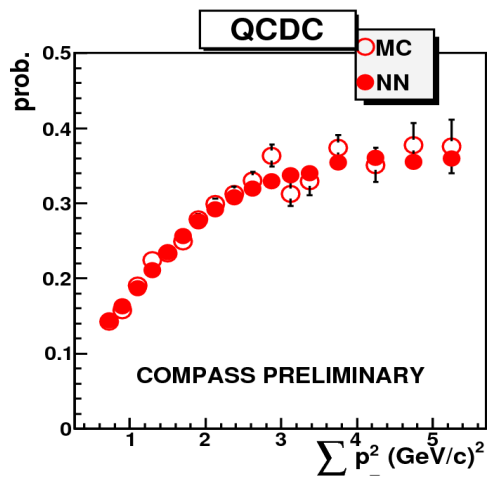
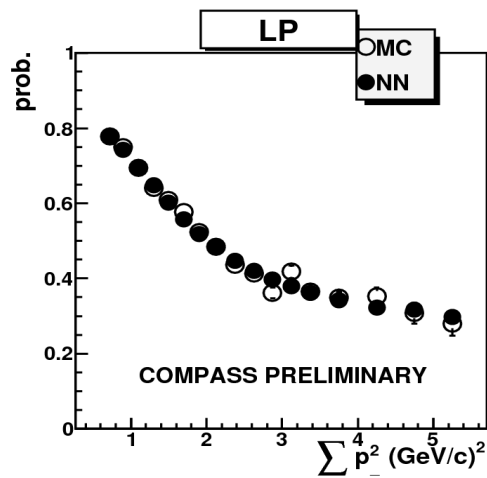
$$X_C, X_G,$$

$$f, D, P_b$$

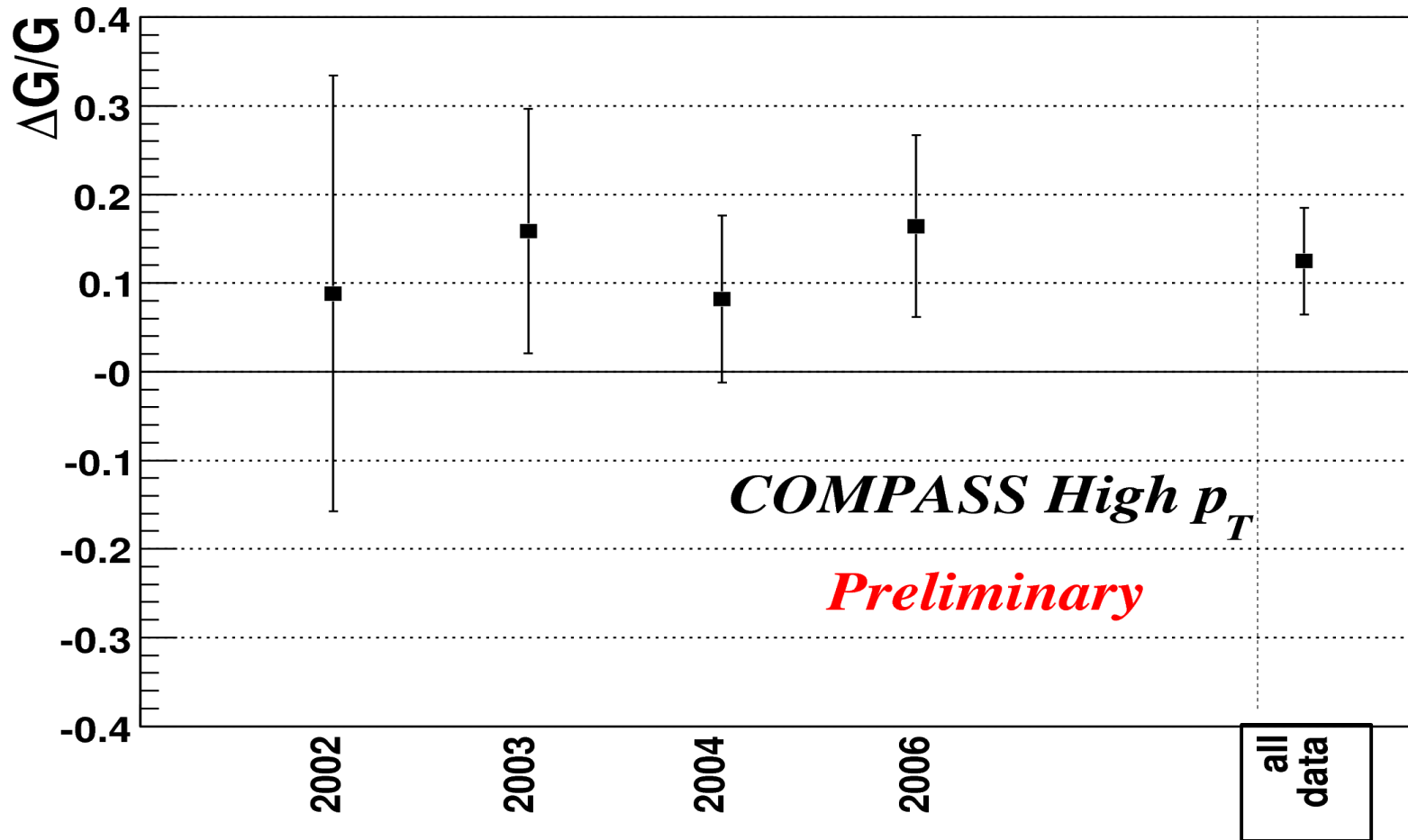
f, D, P_b are directly obtained from data.

The all the others variables have to be estimated/parametrised.

We parametrise the R^i fractions as probabilities.



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



Sources of Systematic Uncertainties	$\delta(\Delta G/G)$	
	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

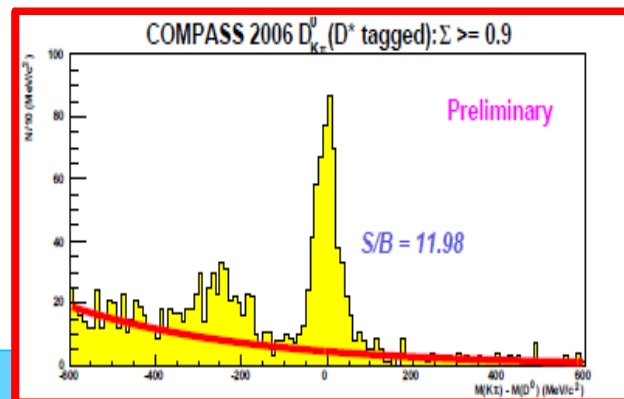
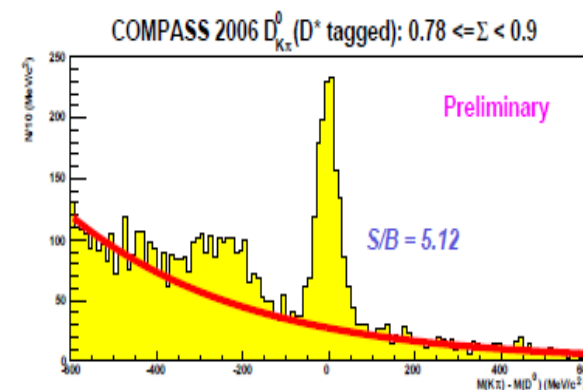
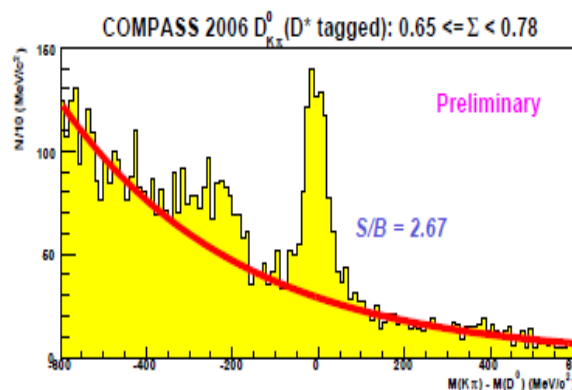
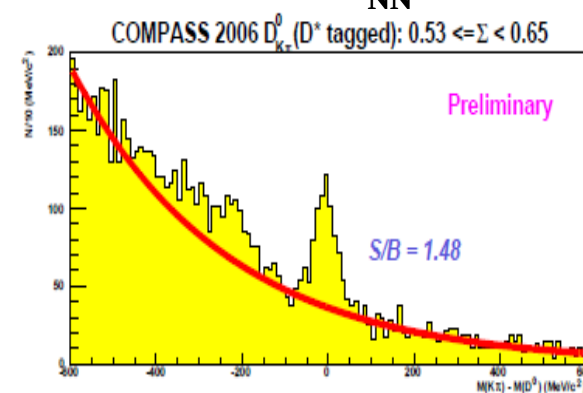
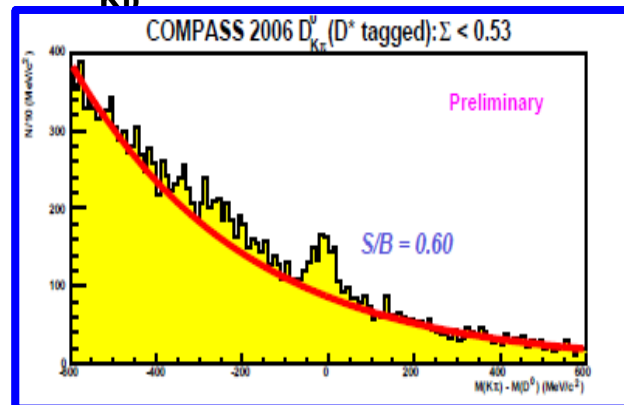
S/(S+B): Obtaining final probabilities for a D⁰ candidate

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

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

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

D⁰_{Kπ} tagged spectrum in bins of $\Sigma = S/(S+B)_{NN}$

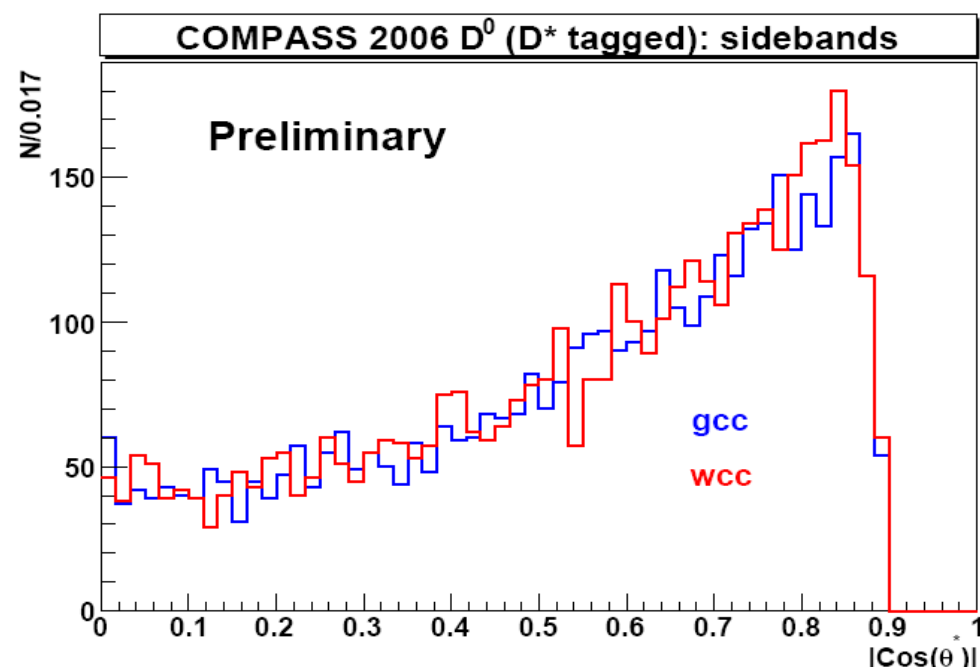
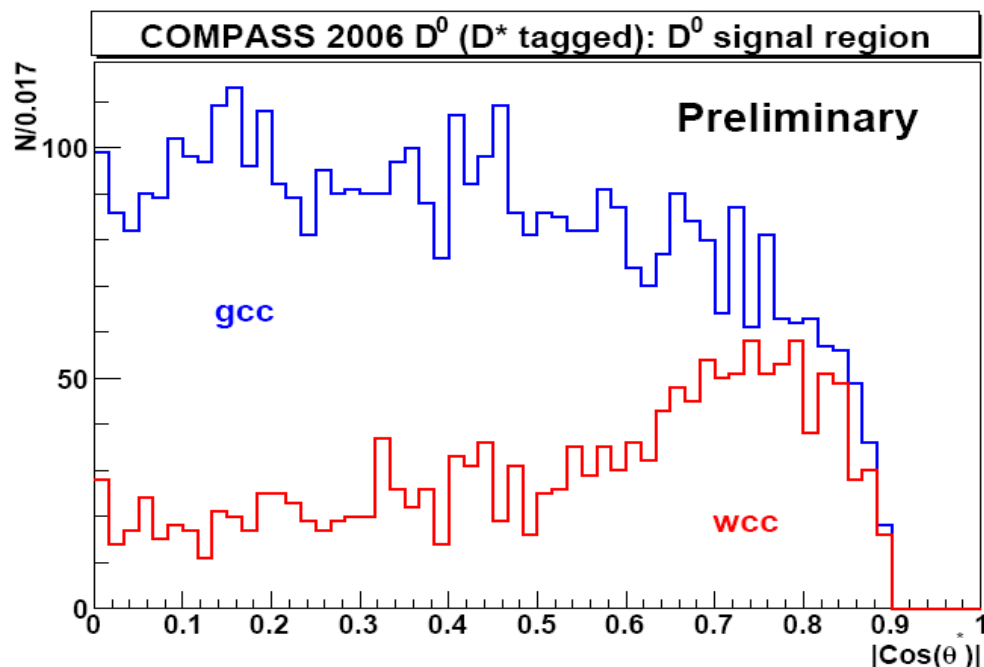


$$\delta \left(\frac{\Delta G}{G} \right) \propto \frac{1}{\text{FOM}}$$

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** \rightarrow $gcc = \mathbf{K}^+ \pi^- \pi_s^- + \mathbf{K}^- \pi^+ \pi_s^+$ (D^0 spectrum: signal + background)
 - **Background model** \rightarrow $wcc = \mathbf{K}^+ \pi^+ \pi_s^- + \mathbf{K}^- \pi^- \pi_s^+$ (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})

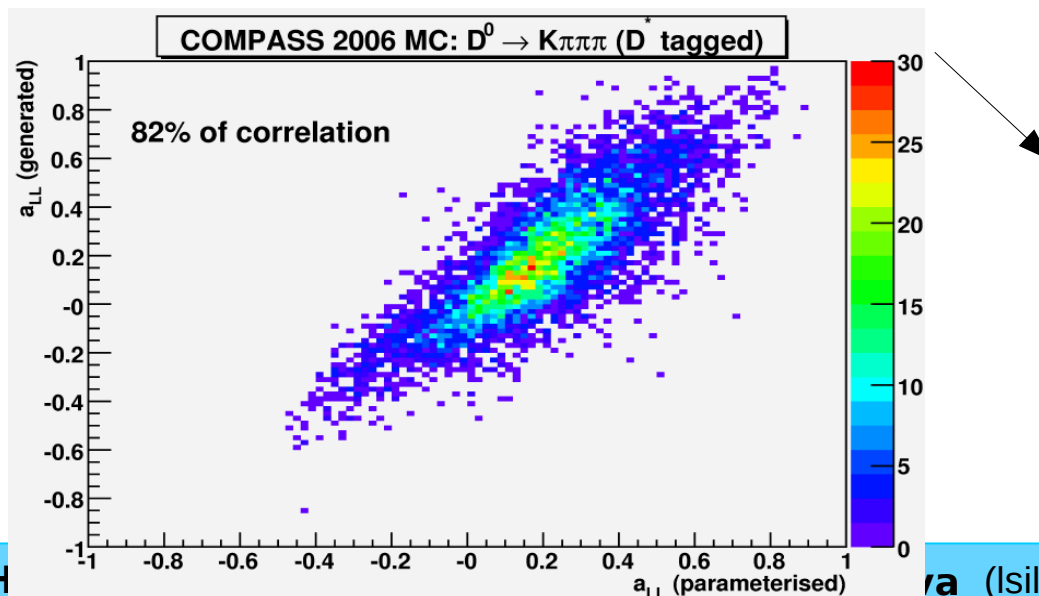
- a_{LL} is dependent on the full knowledge of the partonic kinematics:

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



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)

- The AROMA generator is used to simulate the phase 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:

