Open-Charm results on gluon polarisation from COMPASS

DIS 2009 - MADRID

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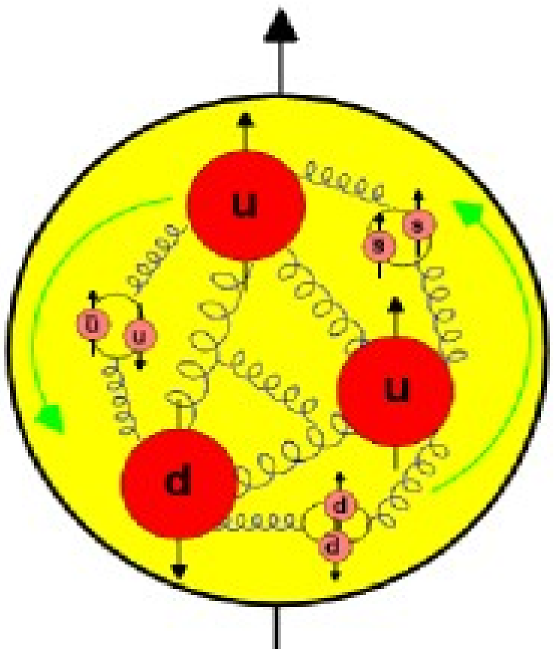
on behalf of the COMPASS collaboration

Nucleon spin structure

- **Nucleon spin** $\rightarrow$ $\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$

quarks gluons orbital angular momentum *(quarks/gluons)*



- **Assuming the static quark model wave function:**

$$|p\uparrow\rangle = \frac{1}{\sqrt{18}}\Big\{2|u\uparrow u\uparrow d\downarrow\rangle - |u\uparrow u\downarrow d\uparrow\rangle - |u\downarrow u\uparrow d\uparrow\rangle + (u \leftrightarrow d)\Big\}$$

$$\Delta u = \langle p\uparrow|N_{u\uparrow} - N_{u\downarrow}|p\uparrow\rangle = \tfrac{3}{18}(10-2) = \tfrac{4}{3}$$

$$\Delta d = \langle p\uparrow|N_{d\uparrow} - N_{d\downarrow}|p\uparrow\rangle = \tfrac{3}{18}(\ 2-4) = -\tfrac{1}{3}$$

- $\Delta\Sigma = \Delta u + \Delta d = 1$

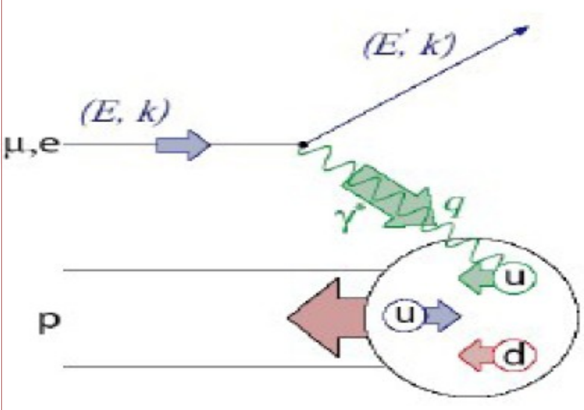
$\Rightarrow$ Up and down quarks carry all the nucleon spin

Spin crisis

- **However, applying relativistic corrections** *(and assuming SU(3) symmetry)*:
  - $\Delta\Sigma \sim 0.60$

- **Where is the remaining part of the nucleon spin?** *(ΔG ? $L_{q(G)}$?)*
  - Gluons solved the nucleon missing momentum problem:
    - Will they be the solution too for this missing spin ? $\Rightarrow$ Measure ΔG

- **Experimental $\Delta\Sigma$** *(from polarised DIS)*:



$Q^2 = -q^2$

$\nu = E - E'$

$x = Q^2 / 2M\nu$

$y = \nu / E$

Phys. Lett. B447, (2007) 8

$\Delta\Sigma = 0.30 \pm 0.01 \pm 0.02$ ***(world data)***
@ $Q^2 = 3\ (GeV/c)^2$

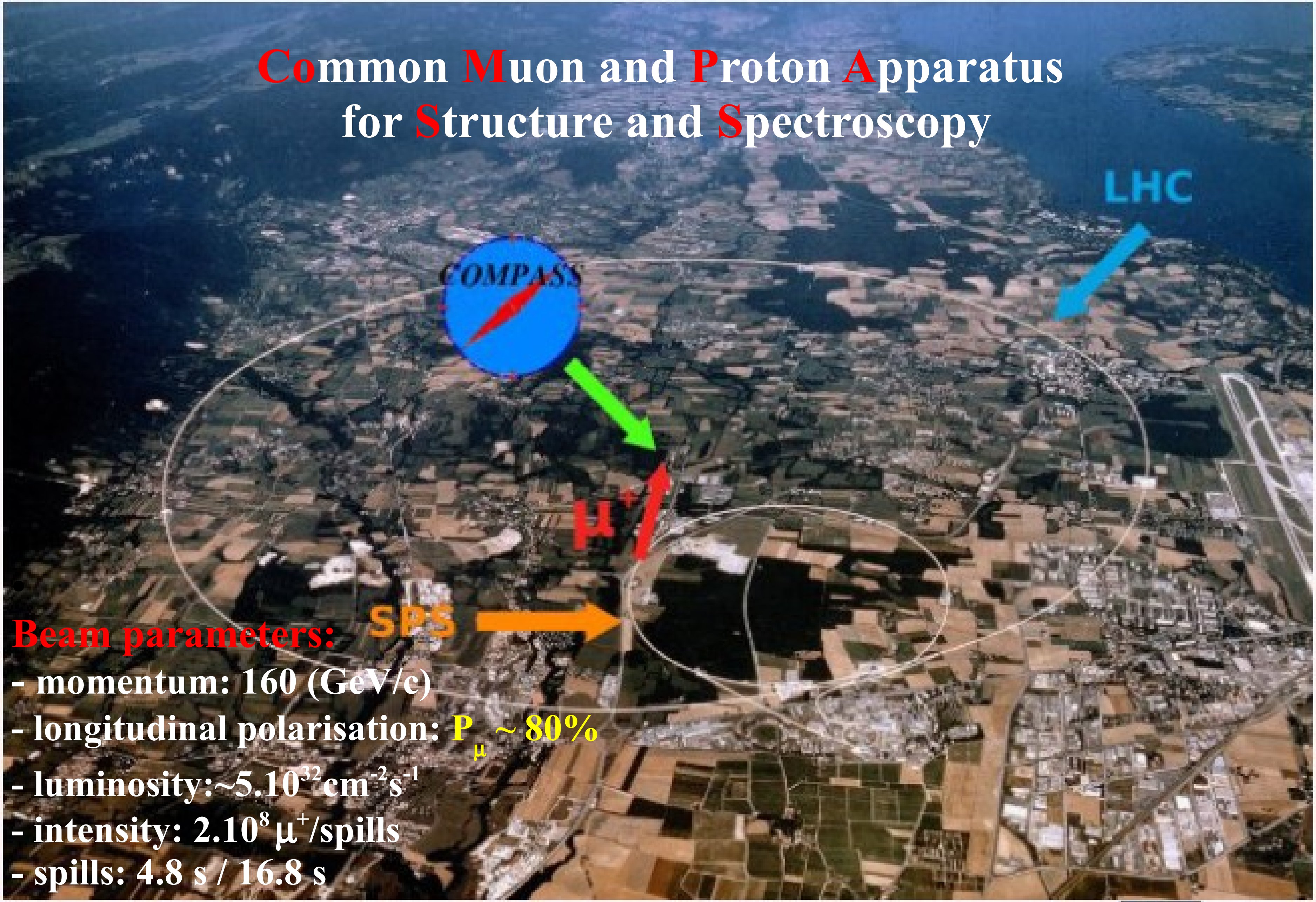
Much smaller than expected...

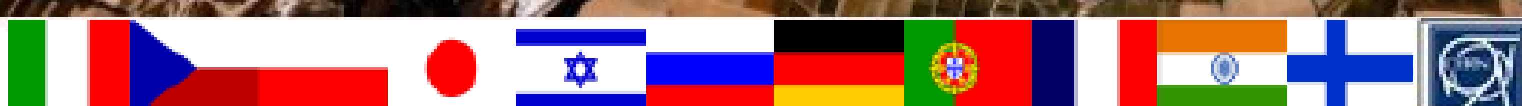
$\Downarrow$

SPIN CRISIS!!!

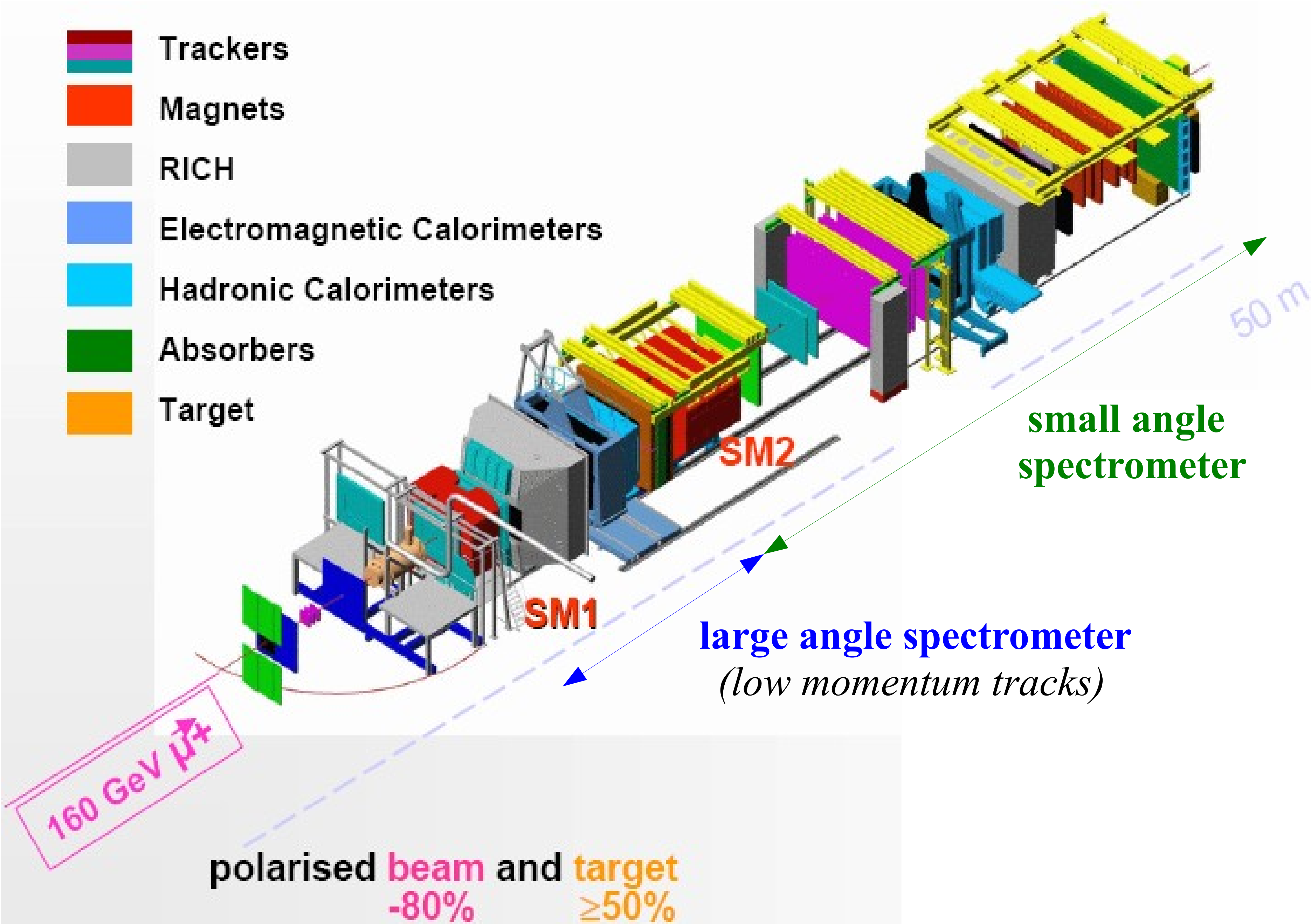
- **Another reason for measuring the gluon spin contribution:**
  - Due to the gluon axial anomaly, if ΔG is large *(~2.5)*, it could explain why $\Delta\Sigma$ was found so small

The COMPASS experiment at CERN



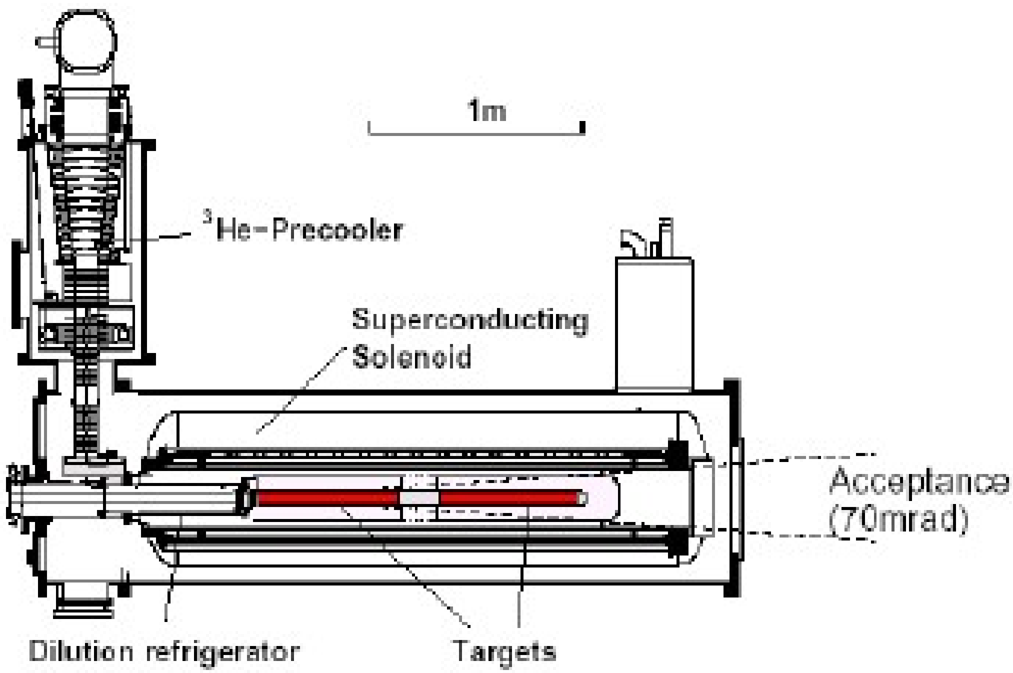


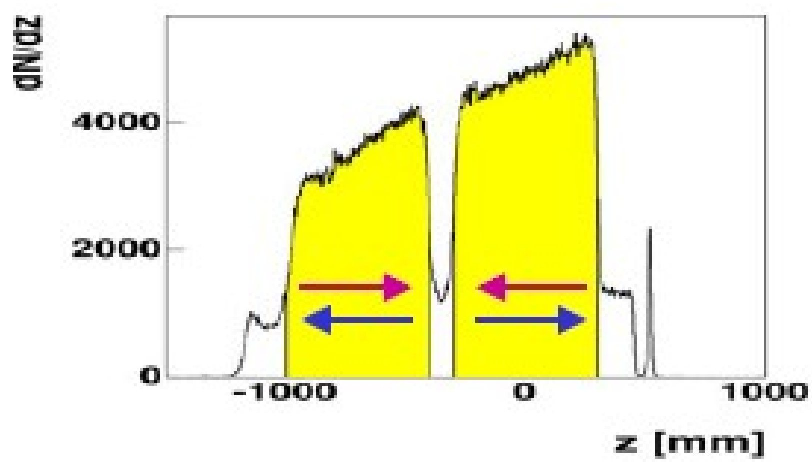
The COMPASS spectrometer



Polarised target *(2002-2004)*

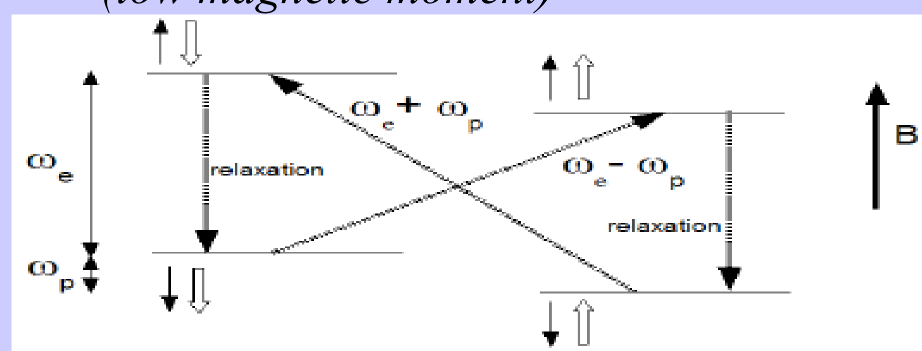
- **Target material: ^{6}LiD**
- **Polarisation: $P_T > 50\%$**
- **Solenoid field: 2.5 T**
- **^{3}He/^{4}He: $T_{min} \sim 50$ mK**
- **Dilution factor: f ~ 0.4**





Dynamic nuclear polarisation:

- High electron polarisation
  (high magnetic moment)
- Microwave irradiation of material, for simultaneous flip of electron and nucleon spin
- After spin flip, electron relaxates to lower energy state
- Nucleon has long relaxation time
  (low magnetic moment)

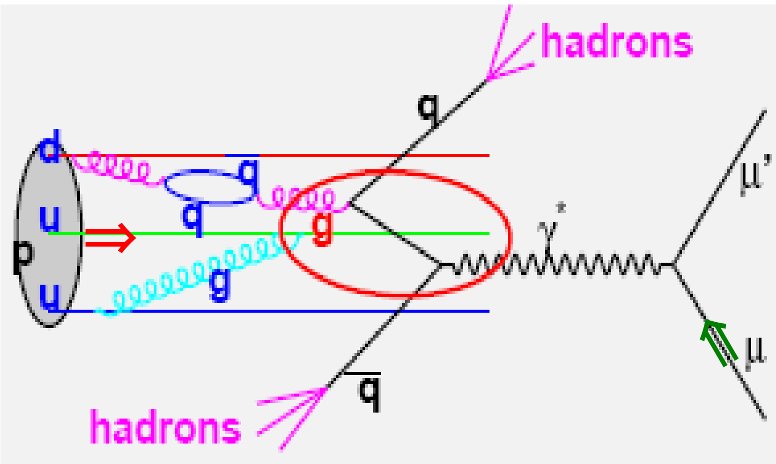


→ **3 target cells were used in 2006!**

Open-Charm DIS production
The photon-gluon fusion process
(PGF)

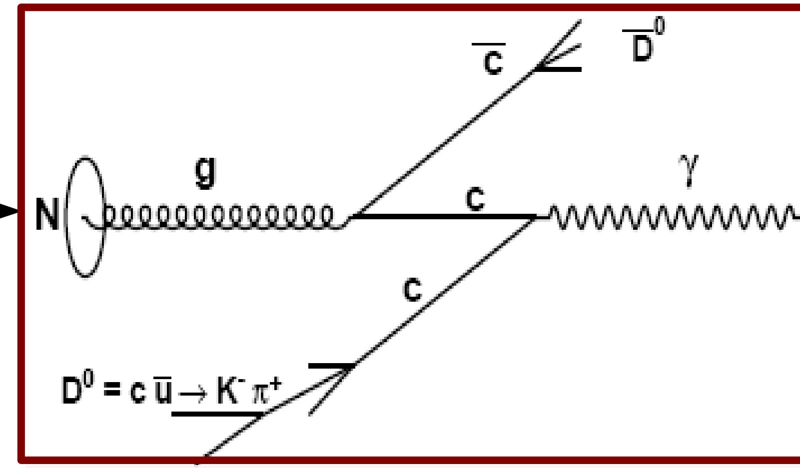
How to measure ΔG?

- **Polarised collision in DIS** *(probing gluons through photon-gluon fusion)*:



tag $\gamma^* g \to q\bar{q}$

via Open-Charm production



- **After reconstructing the invariant mass for charmed mesons** *(gluon tag)*:
  - Measure raw asymmetries for gluon spin information!

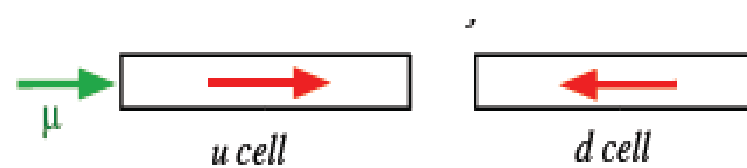
$$A^{exp} = \frac{N^u - N^d}{N^u + N^d} = f \cdot P_\mu \cdot P_T \cdot A^{\mu,T} + A^{bg}$$

Number of events

Depolarization from lepton to virtual photon

$$A^{\mu,T} = D \cdot A_1 = D \cdot \frac{\sigma_{\gamma,T}^{\rightleftarrows} - \sigma_{\gamma,T}^{\rightrightarrows}}{\sigma_{\gamma,T}^{\rightleftarrows} + \sigma_{\gamma,T}^{\rightrightarrows}}$$

Photon-target asymmetry



Why asymmetries for ΔG ?

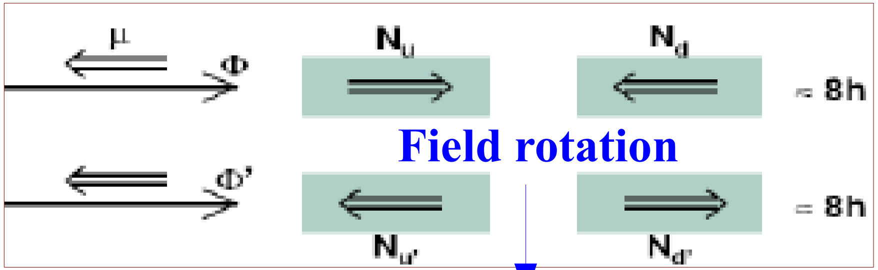
Gluon polarisation from Open-Charm channel

- **Using** → $A_1^{LO} = \langle a_{LL} \rangle \langle \frac{\Delta G}{G} \rangle$ with $a_{LL} = \frac{\Delta\sigma^{PGF}}{\sigma^{PGF}}$

$\Downarrow$ Asymmetries are less sensitive to experimental changes than cross section differences

Considering $A_B = 0$

$$\frac{\Delta G}{G} = \frac{1}{2P_T P_\mu f a_{LL} \frac{S}{S+B}} \times \left(\frac{N^u - N^d}{N^u + N^d} + \frac{N^{d'} - N^{u'}}{N^{u'} + N^{d'}} \right)$$



equal acceptance for both cells

ω = event weight

partonic asymmetry

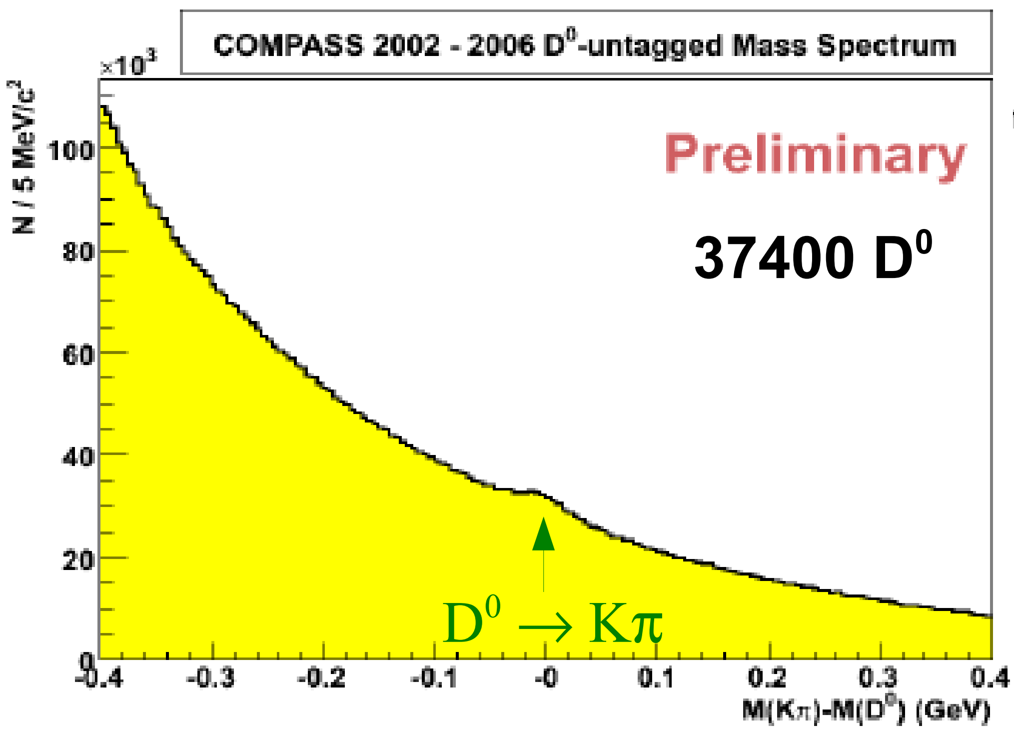
signal strength of Open-Charm events

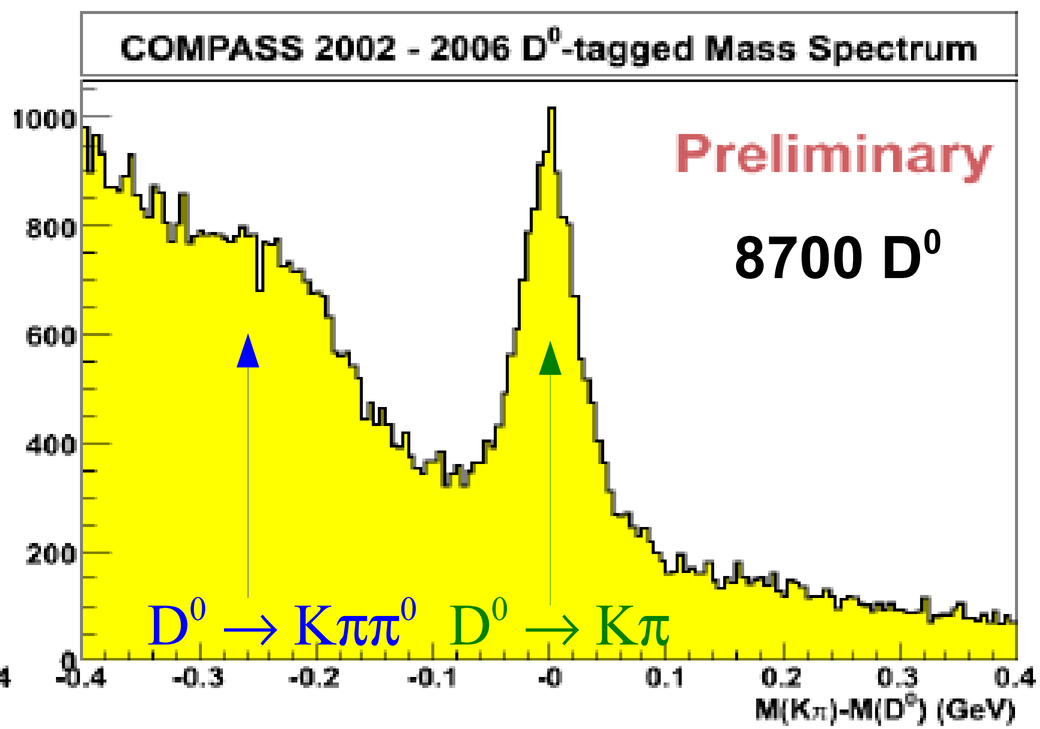
- **Events with small factors** *($P_\mu \cdot P_T \cdot f \cdot a_{LL} \cdot S/(S+B)$)* **contain less information about the asymmetry:**
  - Weighting the events *(with ω)* minimizes de statistical error !

$$\frac{\Delta G}{G} = \frac{1}{2P_T} \times \left(\frac{\omega_u - \omega_d}{\omega_u^2 + \omega_d^2} + \frac{\omega_{u'} - \omega_{d'}}{\omega_{u'}^2 + \omega_{d'}^2} \right) \text{ with a statistical gain: } \frac{\langle \omega^2 \rangle}{\langle \omega \rangle^2}$$

Open-Charm mesons reconstruction

- **Events considered** *(resulting from the c quarks fragmentation)*:
  - $D^0 \rightarrow K\pi$ *(BR: 4%)*
  - $D^* \rightarrow D^0\pi_s \rightarrow K\pi\pi_s$ *(30% D^0 <u>tagged with</u> D^*)*
- **Selection to reduce the combinatorial background**:
  - Kinematical cuts: Z_D, D^0 decay angle, K and π momentum
  - RICH identification: <u>K and π ID</u> + electrons rejected from the π_s sample

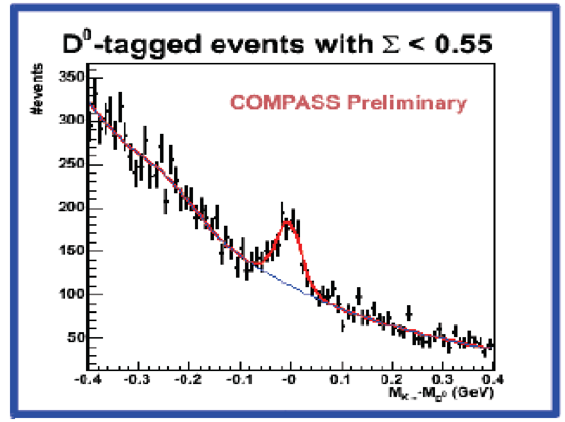


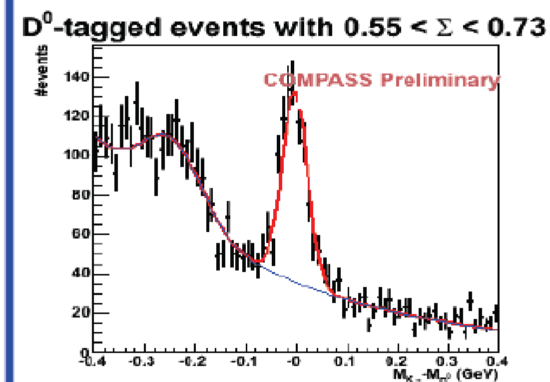


Σ $(=S/(S+B))$ as an Open-Charm event probability

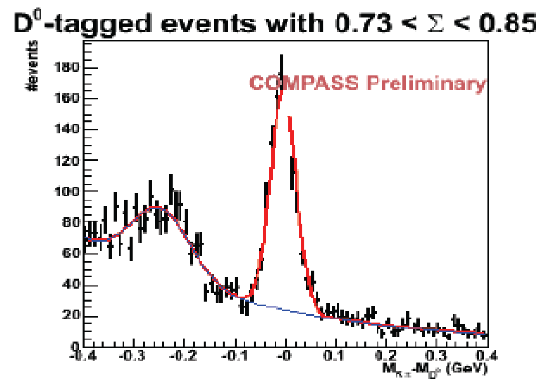
Why is better to have S/(S+B) for every event?

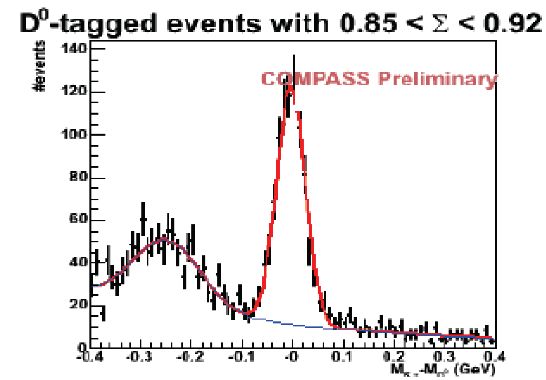
- **Events with small $\Sigma \Rightarrow$ low weight**
  - Mostly combinatorial background selected



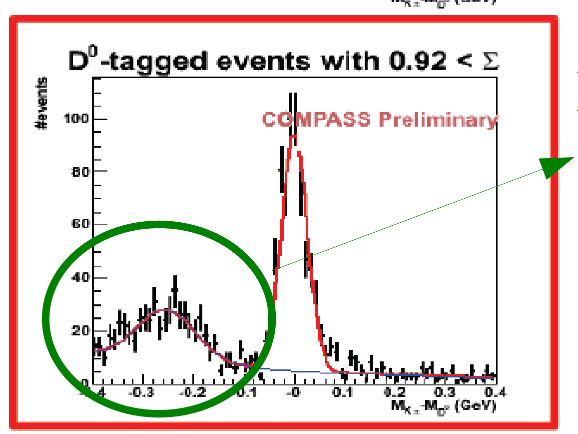


- **With Σ in the weight, the kinematical cuts can be loose:**
  - More background events
  - Preserve signal events





- **Events with large $\Sigma \Rightarrow$ high weight**
  - Mostly Open-Charm events selected



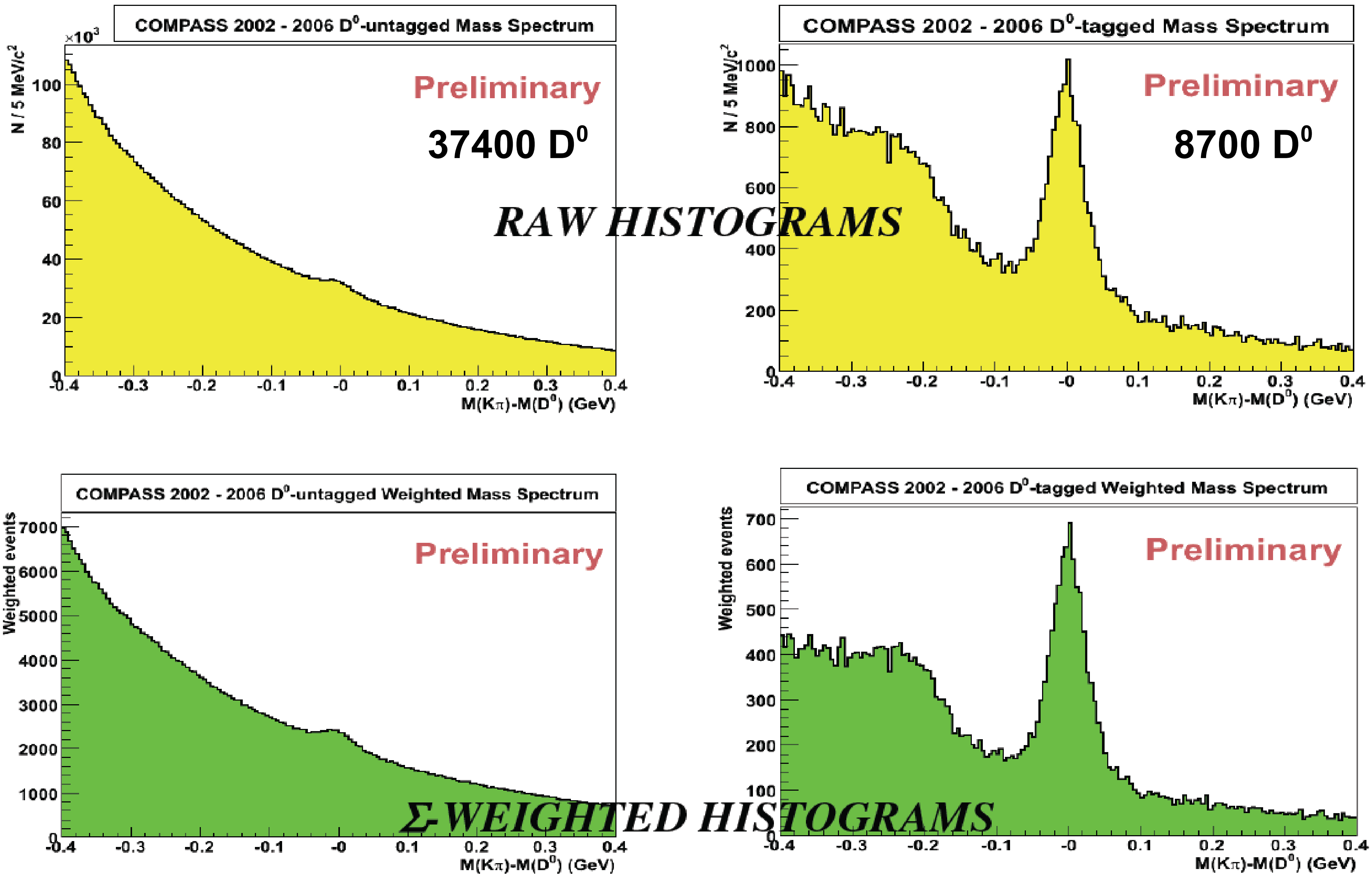
Possibility to include a new Open-Charm channel in the analysis for statistical error improvement

How to parameterize Σ ?

- **A function to build Σ_p = S/B is defined, and parameterized for every event:**
  - Σ_p is built *(iteratively)* over some kinematic variables and RICH response:
    - $(\Sigma_p)_{initial} = 1$
    - Mass spectra is divided in bins of each variable *(binning needed for statistical gain)*
    - Fit all D^0 and D^* mass spectra <u>inside each bin of each variable</u>
    - Σ_p is ajusted *(for every event inside each bin)* to $(S/B)_{fit}$
  - After convergence, parameterization is checked:
    - <u>No artificial peak produced in wrong charge mass spectra</u>
  - <u>Mass dependence</u> $\Rightarrow$ Included in Σ after convergence of Σ_p *(in bins of Σ)*

- $\Sigma = \Sigma_p / (\Sigma_p + 1)$ in the weight → **probability for a given event to be Open-Charm**

Σ parameterization: S/B improvement

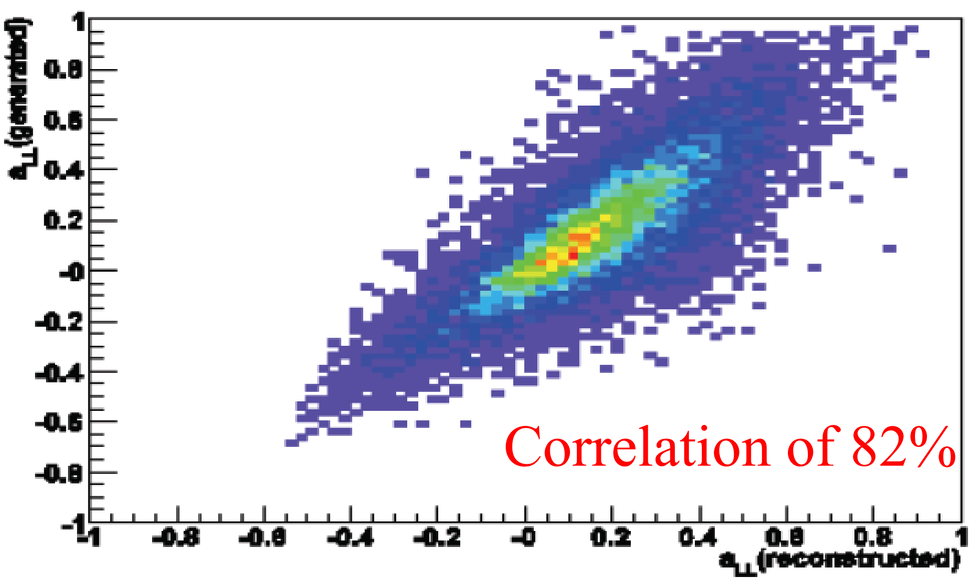


Partonic *(muon-gluon)* asymmetry a_{LL}

- **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! ⇒ <u>Only one charmed meson is reconstructed</u>

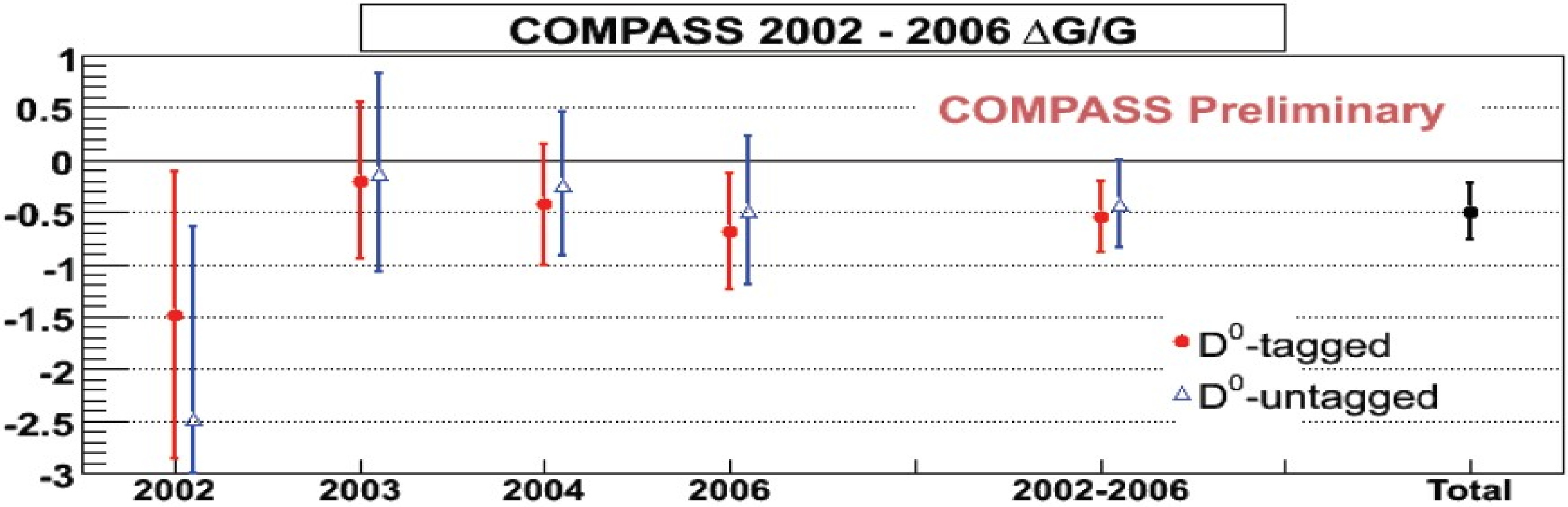
- a_{LL} is obtained from Monte-Carlo *(in LO)*, to serve as input for a Neural Network parameterization on reconstructed kinematical variables: y, x_{Bj}, Q^2, z_D and $p_{T,D}$

- **With the help of parameterised a_{LL}** *(real data)*, **<u>ΔG/G can be estimated in LO</u>!**

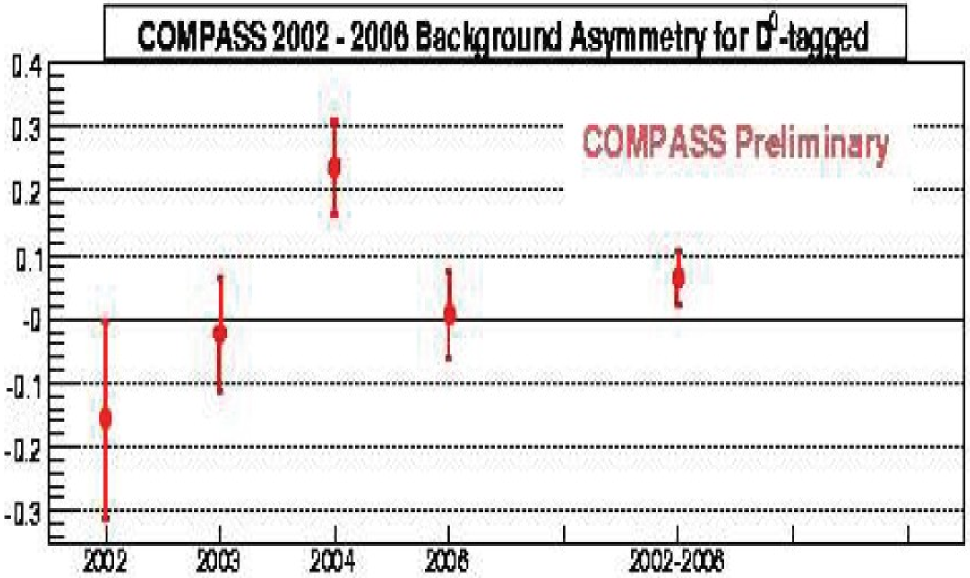


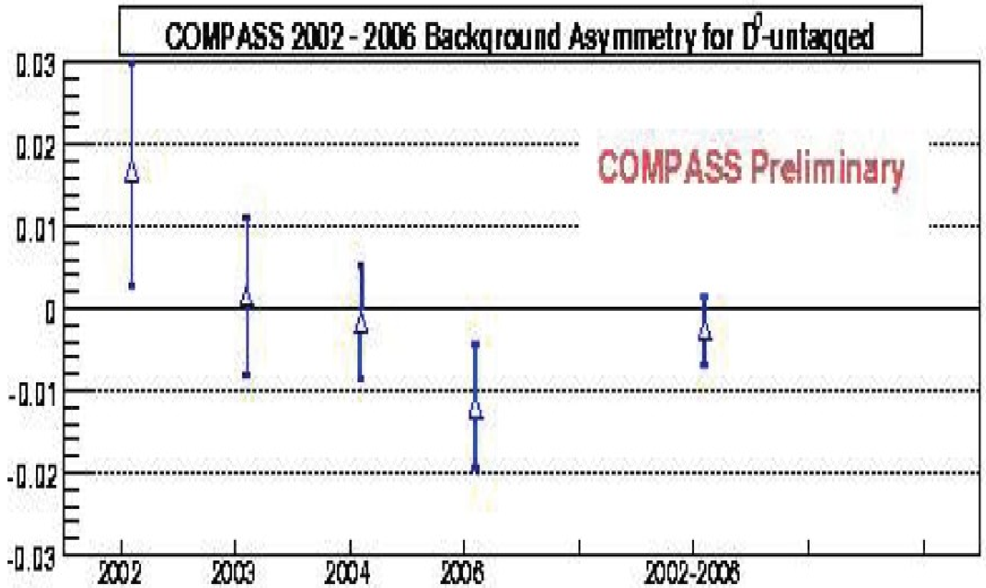
Parameterized a_{LL} *(by NN)*, shows a strong correlation with the generated one *(comparison with generated a_{LL} using AROMA)*

Preliminary results *(2002-2006)*: PLB – in press



$$\frac{\Delta G}{G} = -0.49 \pm 0.27(stat) \pm 0.11(sys) \rightarrow @ <x_g> = 0.11, <\mu^2> = 13\ \mathrm{GeV}^2$$





More contributions from the D^* channel → NEW

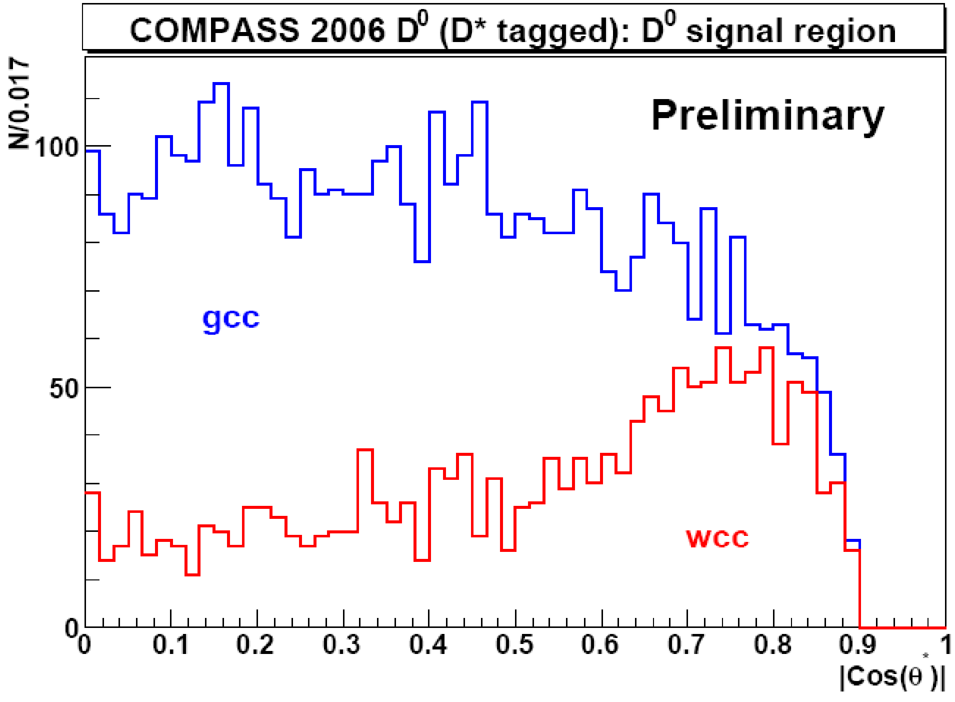
- **<u>Because the channel is very clean from background contamination</u>** *(due to a 3-body mass cut)*, **the following contributions can be added:**
  - **π^0 reflection "bump": $D^0 \to K\pi\pi^0$**
  - **RICH sub-threshold Kaons events**: <u>Candidates with p < 9 GeV/c</u> *(no RICH ID for Kaon mass)* → Recover D^0 if there is no positive pion or electron ID *(for the Kaon candidate)*

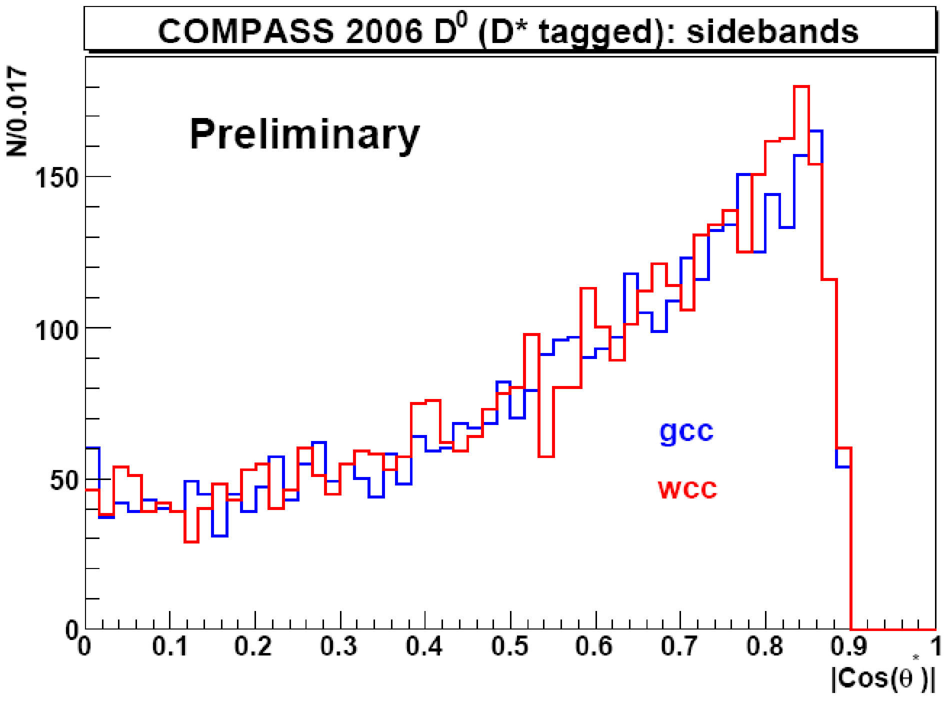
- **Signal strength parameterization** *(<u>Σ = S/(S+B)</u>)*:
  - **Problem**:
    - <u>Low purity samples with low statistics</u> ⇒ Very difficult to build Σ in several bins of several variables
  - **Solution**:
    - Multi-dimentional parameterization using a Neural Network *(all kinematic and RICH dependences are taken into account at same time)*

Neural Network qualification of events

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

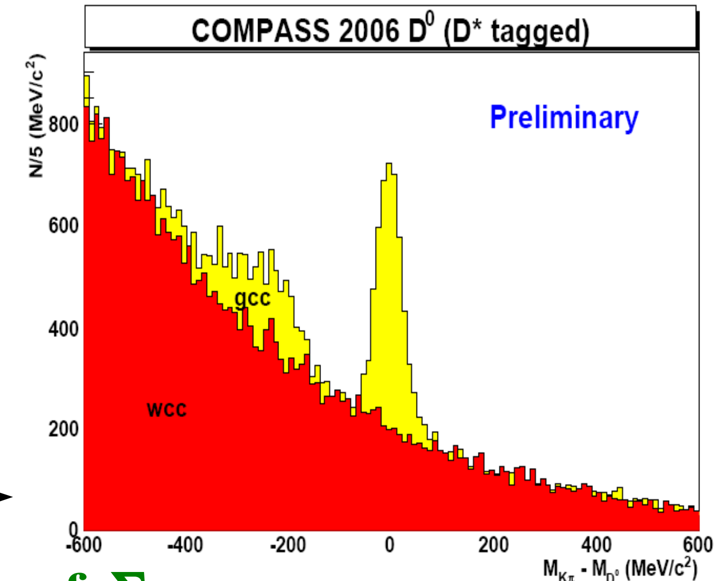
Example of a good learning variable



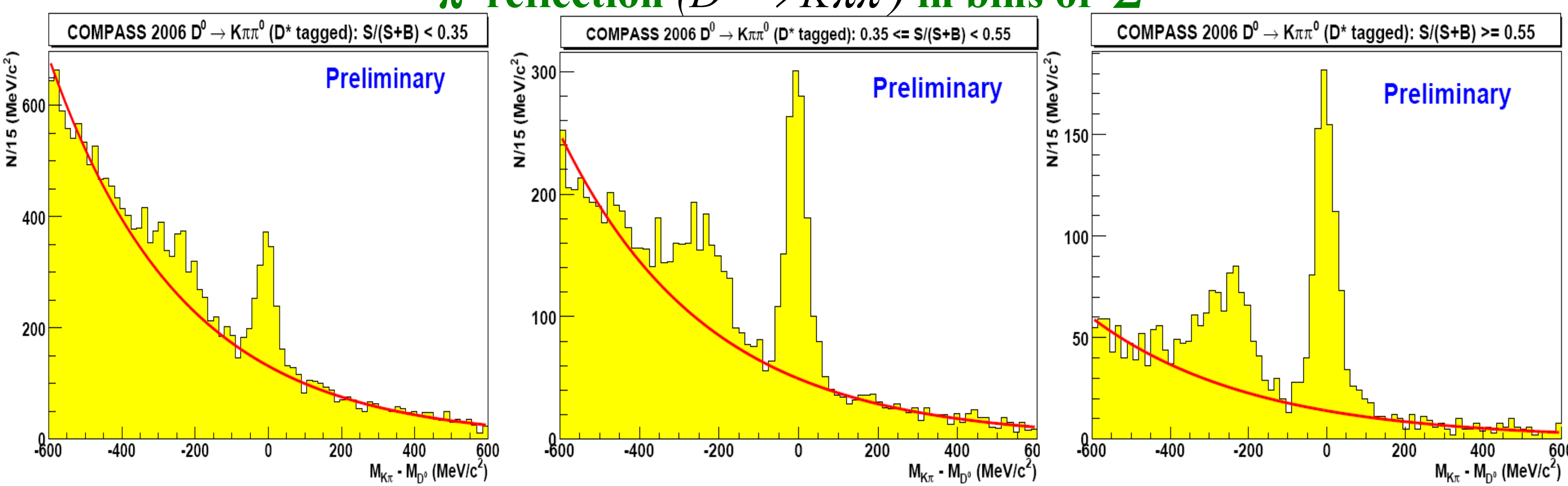


π^0 reflection "bump": Probability behaviour

- Σ is built in the same way as for main channels, **BUT**:
  - Only 1variable is used: Neural Network output
    - Sorts the events according to similar kinematic dependences *(thus improving our statistical precision)*
    - Results from 2 real data samples comparison, in a mass window around the meson mass

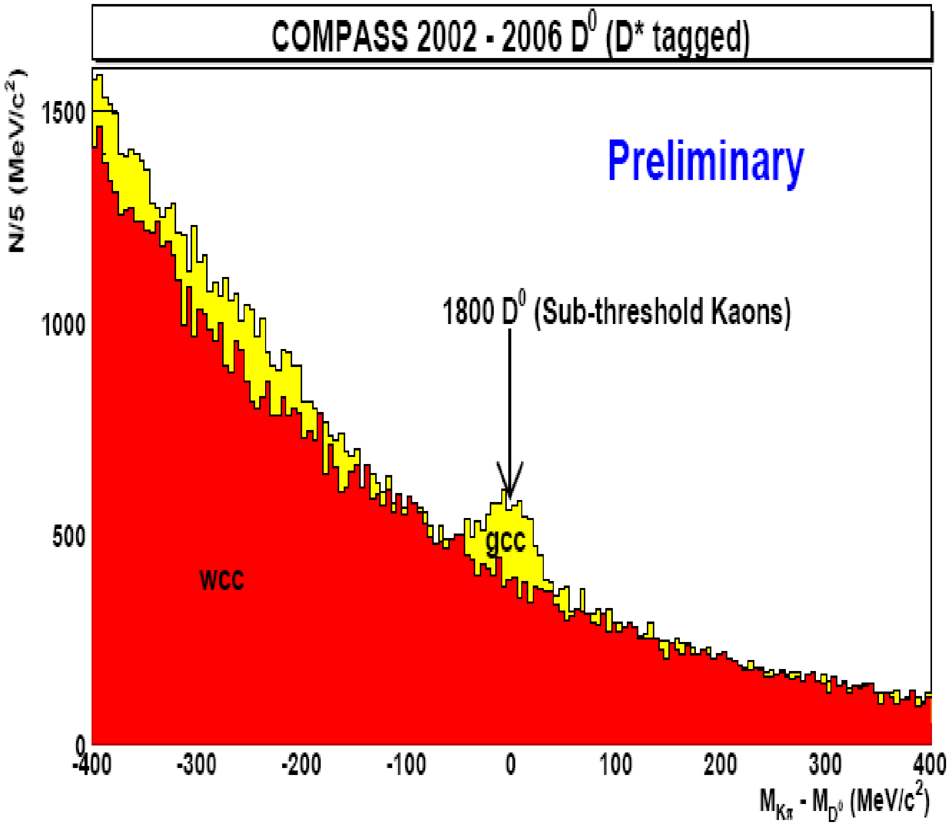


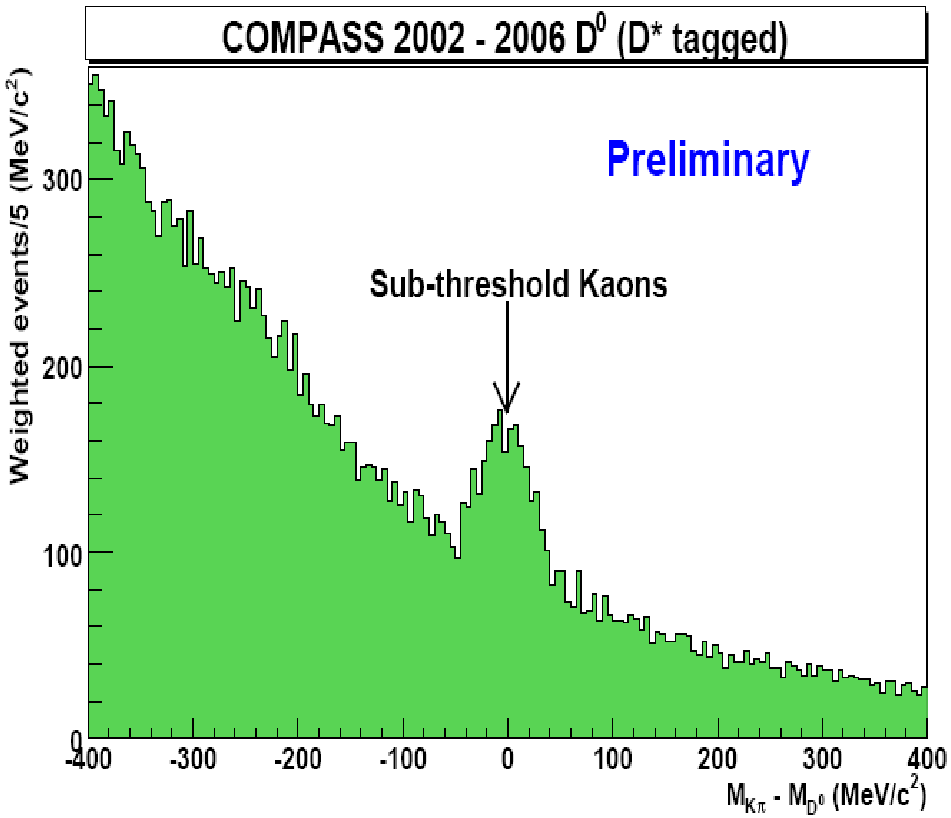
π^0 reflection $(D^0 \rightarrow K\pi\pi^0)$ in bins of Σ



Sub-threshold Kaons: S/B improvement

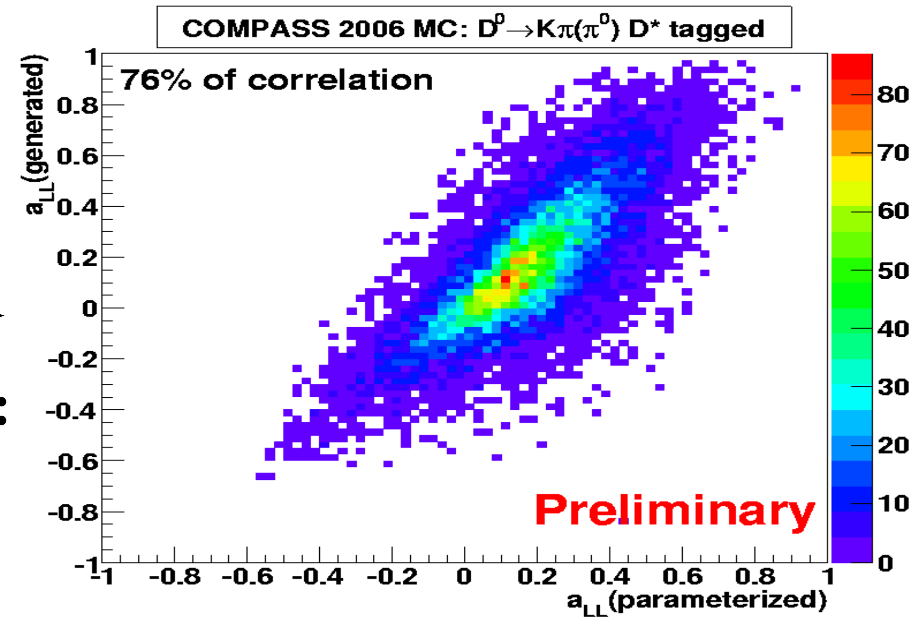
- **Events considered: $D^0 \rightarrow K\pi$ with <u>$p(K) < 9$ GeV/c</u>**
- **Σ is built in the same way as for the π^0 reflection channel:**
  - The gain introduced by this parameterization can clearly be seen *(green spectrum)*





Preliminary results including all channels

- **For the π^0 reflection channel, a specific parameterization for the partonic asymmetry (a_{LL}) was used**



- **New channels contributions to ΔG/G:**

ΔG/G: -0.15 ± 0.63 **Bg. Asymmetry: 0.02 ± 0.03**

→ 2002–2006 data: **π^0 reflection "bump"**

ΔG/G: 0.57 ± 1.02 **Bg. Asymmetry: -0.04 ± 0.05**

→ 2002–2006 data: **Sub-threshold Kaons**

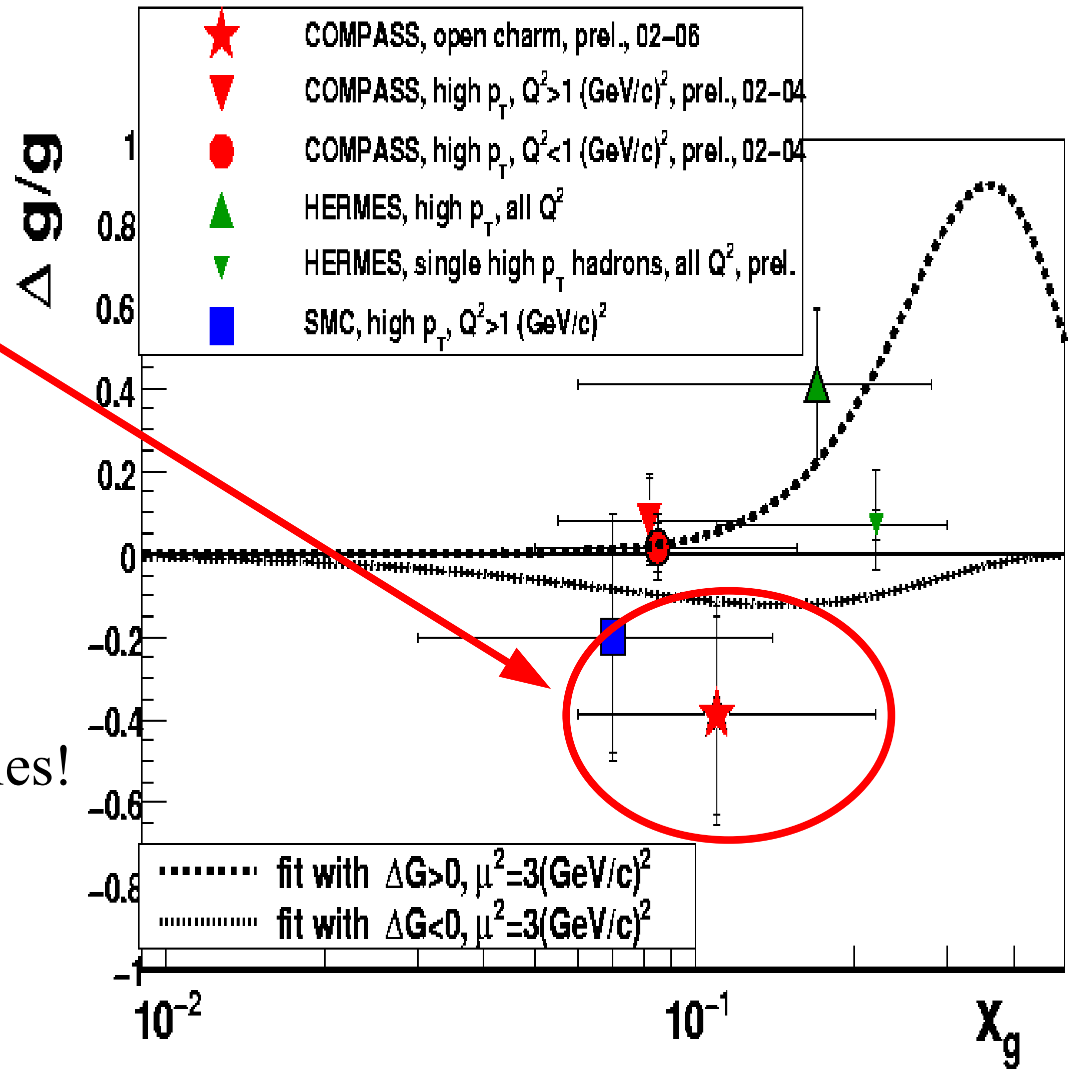
- **Final result** (*including also the main channels: D^0 and D^0 tagged with a D^**):

$$\frac{\Delta G}{G} = -0.39 \pm 0.24(stat) \pm 0.11(sys) \rightarrow @ \langle x_g \rangle = 0.11, \langle \mu^2 \rangle = 13\ \mathrm{GeV}^2$$

10 % improvement in our statistical significancy

Conclusions and prospects

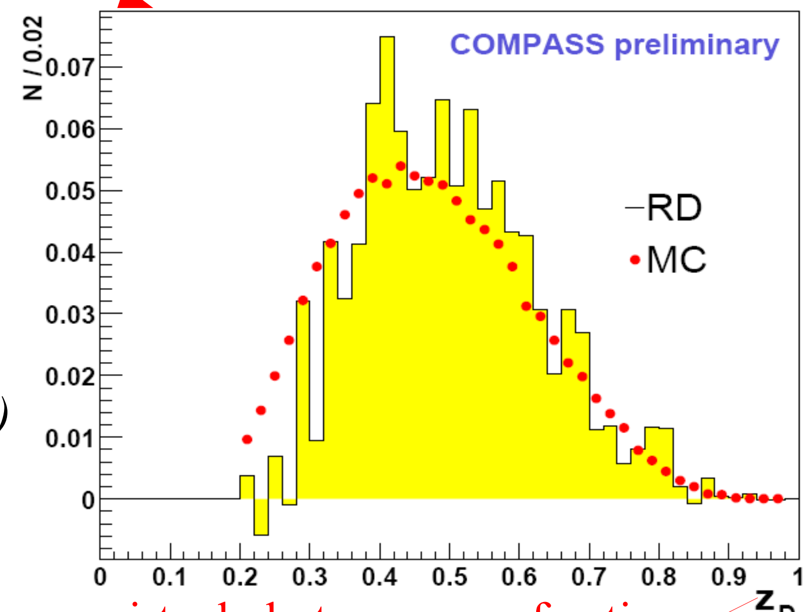
- **Gluon polarisation was obtained directly from the data, in LO, and in a model independent way**
- **Small values of ΔG are preferred:**
  - Gluon polarisation compatible with zero within 2σ
- **Under study:**
  - 2007 data
  - Extended Neural Network approach to all channels, <u>in a fit independent way</u>:
    - Low systematic uncertainties!
  - **NLO analysis is ongoing**:
    - <u>First results expected soon</u>



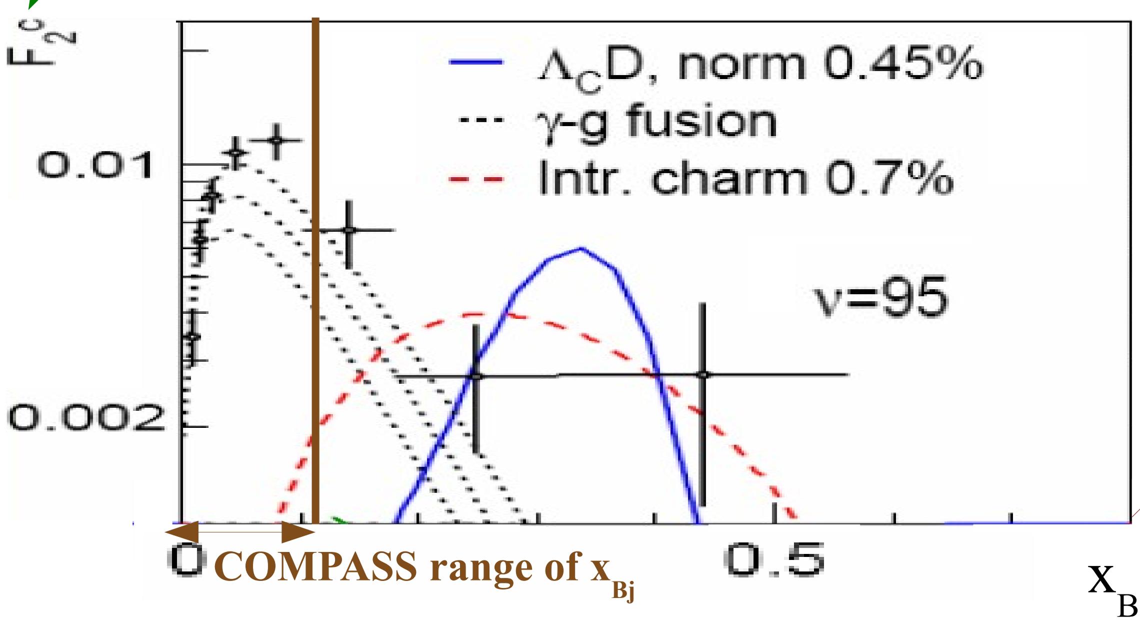
SPARES

Why measure gluon spin from Open-Charm?

- **$c\bar{c}$ production is dominated by the PGF process** *(in LO)*, **and is <u>free from physical background</u>** *(ideal for probing gluon polarisation)*:
  - In our center of mass energy, the contribution from intrinsic charm *(c quarks not coming from hard gluons)* in the nucleon is negligible
  - Perturbative scale set by charm mass: $\mathbf{4m_c^2}$
  - Nonperturbative sea models predict at most 0.7% for intrinsic charm contribution
    - Expected at high x_{Bj} *(compass $x_{Bj} < 0.1$)*
  - $c\bar{c}$ supressed during fragmentation *(at our energies)*



virtual photon energy fraction carried by the D^0 meson



COMPASS range of x_{Bj}

x_{Bj}

Ref. Hep-ph/0508126 and hep-ph/9508403
Phys. Lett. B93 (1980) 451
Data from EMC:Nucl.Phys.B213, 31(1983)

Systematic errors: D^0 and D^* channels

- **Possible errors of experimental systematics** *(false asymmetries)*, **Σ and a_{LL} in weights definitions:**
  - Results in an error which is proportional to ΔG/G

- **Σ was obtained in different mass windows** *(around the peak)*, **different fit functions were used, different order for the variables on which the parameterization is applied, and different number of iterations**

- **a_{LL} was estimated with different values for the charm quark mass and different pdf**
  - For a nominal analysis with weight w^0, and uncertainty in the weight w^i, the spread in ΔG/G is given by the spread of: $< w^0 w^i > / < (w^0)^2 >$

All systematic contributions for ΔG/G →

Source	D^0	D^*
Beam polarisation	0.025	0.025
Target polarisation	0.025	0.025
Dilution factor	0.025	0.025
False asymmetry	0.05	0.05
Σ	0.07	0.01
a_{LL}	0.05	0.03
Total	**0.11**	0.07

Method for $\Delta G/G$ and polarised A_B extraction

- **The number of events comes from the asymmetries in the following way:**

$$N_{u,d} = a\,\phi\,n\,(S+B)\left(1+P_T P_\mu f\left(a_{LL}\frac{S}{S+B}\frac{\Delta G}{G}+a_{LL}^{B}\frac{B}{S+B}A_B\right)\right)$$

a = acceptance, ϕ = muon flux, n = number of target nucleons

- **We have 4 cell configurations** *(2 cells oppositely polarised + field reversal for acceptance normalization)***:**
  - Weight the 4 $N_{u,d}$ equations by ω_s and by $\omega_B = P_\mu \cdot f \cdot D(y) \cdot (B/S+B)$:

$$<\sum_{k=1}^{N_{cell}} \omega_i^k> = \hat{a}_{cell,i}\left(1+(<\beta_{cell,S}>\omega_i)A_S+(<\beta_{cell,B}>\omega_i)A_B\right)=f_{cell,i}$$

(cell = u , d , u' , d') **($\Delta G/G$)** **(i = S , B)**

$$\hat{a} = a\,\phi\,n\,\sigma = a\,\phi\,n(\sigma_{PGF}+\sigma_B) = a\,\phi\,n(S+B)$$

$$\beta_S = P_B P_T f\, a_{LL}\frac{S}{S+B} \qquad \beta_S = P_B P_T f\, D\frac{B}{S+B}$$

8 eq. with 10 unknowns

How to solve the equations for simultaneous $\Delta G/G$ and A_B extraction?

- **Possible acceptance changes with time are the same for both cells** *(also the muon flux is the same for both cells)*:

  10 $\Rightarrow$ 8 unknowns: 6 $\hat{a}$, A_S and A_B $\longrightarrow$ $\frac{\hat{a}_{u,S}\hat{a}_{d',S}}{\hat{a}_{u',S}\hat{a}_{d,S}}=1$, $\frac{\hat{a}_{u,B}\hat{a}_{d',B}}{\hat{a}_{u',B}\hat{a}_{d,B}}=1$

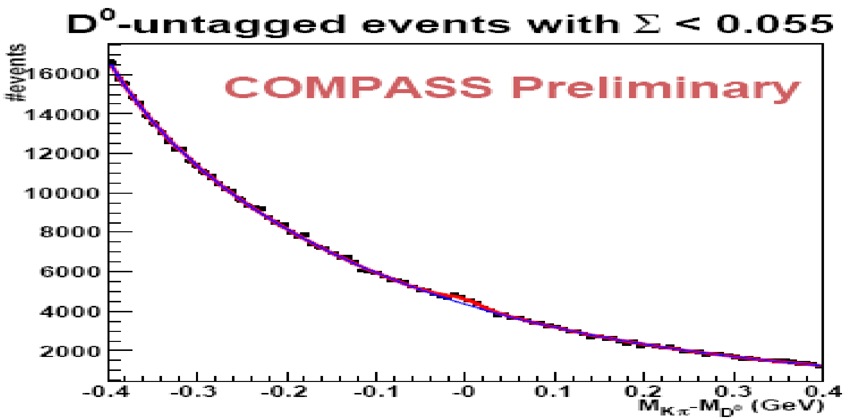
- **Signal and background events are affected in the same way before and after a field reversal:**

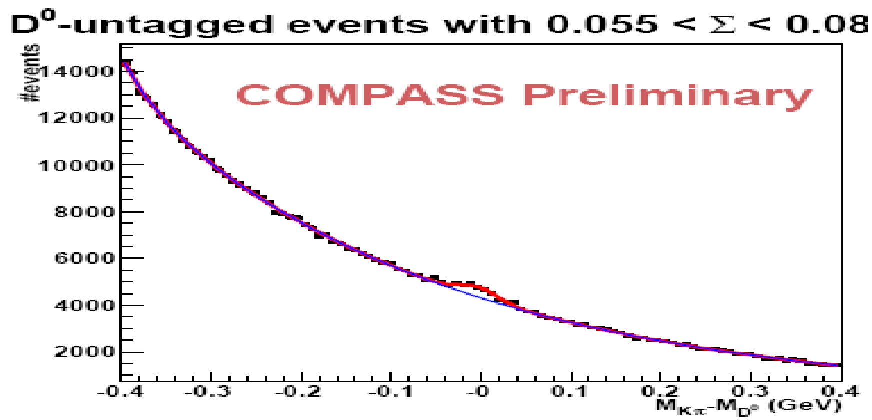
  8 $\Rightarrow$ 7 unknowns: 5 $\hat{a}$, A_S and A_B $\longrightarrow$ $\frac{\hat{a}_{u,S}}{\hat{a}_{u,B}}=\frac{\hat{a}_{u',S}}{\hat{a}_{u',B}}$, $\frac{\hat{a}_{d,S}}{\hat{a}_{d,B}}=\frac{\hat{a}_{d',S}}{\hat{a}_{d',B}}$

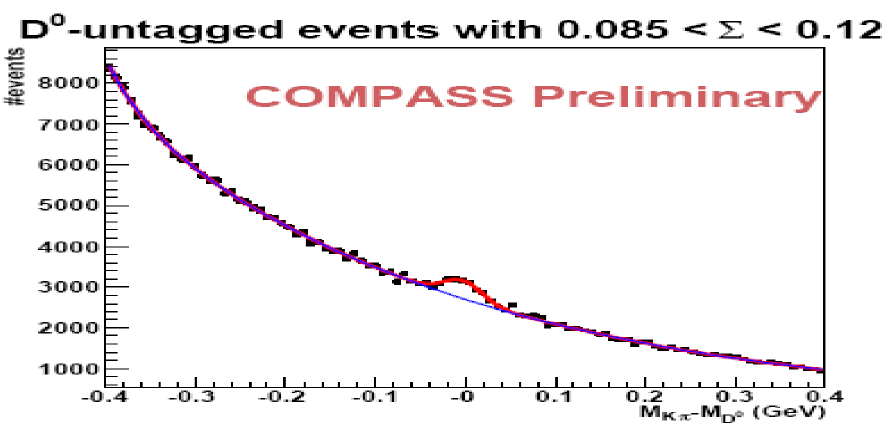
- **Unknowns are obtained by a χ^2 minimization:**

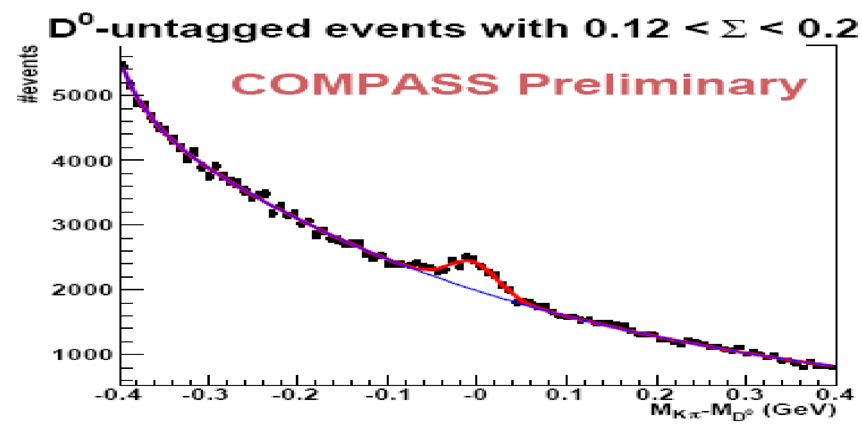
$$\chi^2=(\vec{N}-\vec{f})^T \mathrm{Cov}^{-1}(\vec{N}-\vec{f})$$

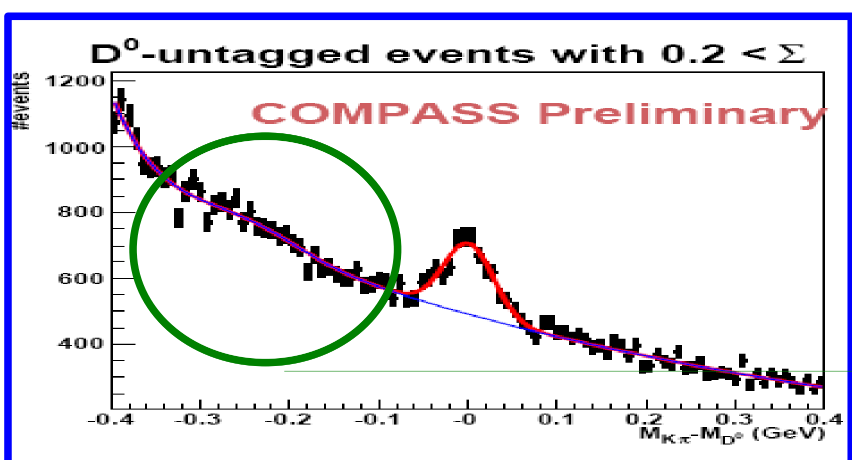
Σ $(=S/(S+B))$ effect in D^0 mass spectra











- **Improved S/B for D^0 not tagged**
  - For high Σ events, the combinatorial background is reduced significatively
    - π^0 reflection is seen for high Σ

Validation of parameterization *(2006 example)*