$\Delta G/G$ at COMPASS

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Physics Motivation

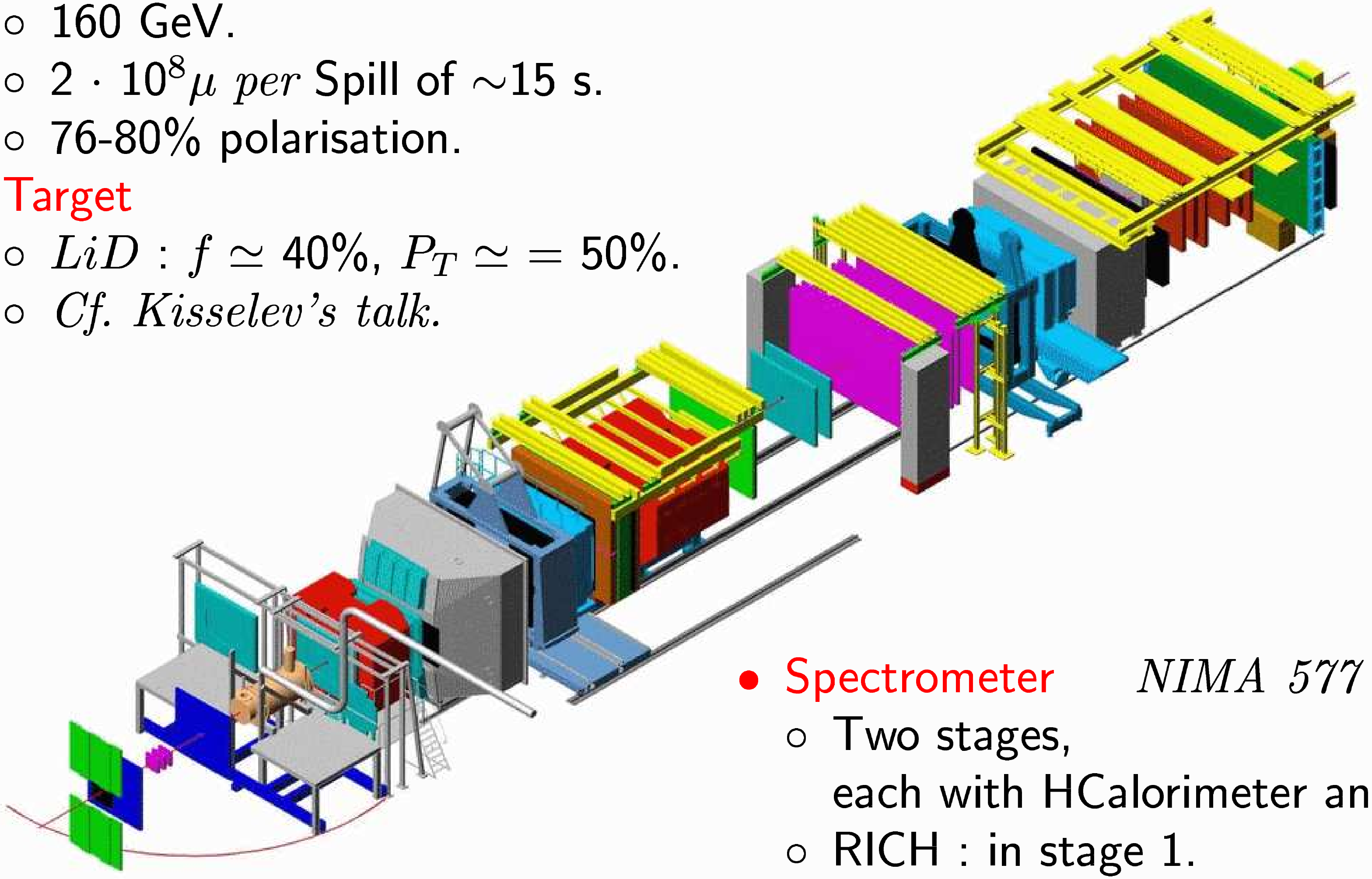
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

- $\Delta\Sigma$ @ SMC, SLAC, HERMES, JLab :
  - Ellis-Jaffe sum rule violated.
  - $\Delta\Sigma$ contributes little to nucleon spin.
  - Where is the nucleon spin ?

- ΔG :
  - Next candidate contributor.
  - Large ΔG, ~2-3 at SMC Q^2 would mask quark spin via axial anomaly
    Efremov, Teryaev, JINR Report E2-88-287 (1988).
    Altarelli, Ross, Phys.Lett. B212, 391 (1988).

COMPASS Spectrometer

- Muon Beam
  - 160 GeV.
  - $2 \cdot 10^8 \mu$ *per* Spill of ∼15 s.
  - 76-80% polarisation.
- Target
  - LiD : $f \simeq$ 40%, $P_T \simeq =$ 50%.
  - *Cf. Kisselev's talk.*



- Spectrometer *NIMA 577 (2007) 455*
  - Two stages,
    each with HCalorimeter and μ-filter.
  - RICH : in stage 1.
  - ECalorimeter : 2(*since mid-2004*), 1 (*in 2006*).

Asymmetry Measurement

- Two oppositely polarized target cells : *upstream*, *downstream*
- Polarization reversal by field rotation every 8 hours :

$$\frac{A^{\|}}{D} = \frac{1}{|P_T P_\mu| f D} \frac{1}{2} \left(\frac{N_u^{\Uparrow\downarrow} - N_d^{\Uparrow\uparrow}}{N_u^{\Uparrow\downarrow} + N_d^{\Uparrow\uparrow}} + \frac{N_d^{\Uparrow\downarrow} - N_u^{\Uparrow\uparrow}}{N_d^{\Uparrow\downarrow} + N_u^{\Uparrow\uparrow}} \right) \qquad D = Depolarization factor$$

$$P_T \times P_\mu \times f \times D \simeq 50\% \times 80\% \times 40\% \times 60\% \simeq 10\%$$

- Weighted asymmetry

$$\frac{A^{\|}}{D} = \frac{1}{P_T} \frac{1}{2} \left(\frac{\sum_u^{\Uparrow\downarrow} w - \sum_d^{\Uparrow\uparrow} w}{\sum_u^{\Uparrow\downarrow} w^2 + \sum_d^{\Uparrow\uparrow} w^2} + \frac{\sum_d^{\Uparrow\downarrow} w - \sum_u^{\Uparrow\uparrow} w}{\sum_d^{\Uparrow\downarrow} w^2 + \sum_u^{\Uparrow\uparrow} w^2} \right) \qquad w_i = \langle P_\mu f D \rangle_i$$

$\Rightarrow$ Gain in precision $= \sqrt{\langle w^2 \rangle / \langle w \rangle^2}$

- Microwave reversal (once *per* ~month) cancels acceptance *vs.* target field correlation.
- 2006 : 3-cell target $\Rightarrow$ Even better false asymmetry suppression. Rotation once *per* day.

Data Taking

- Luminosity in the longitudinal mode :

	2002	2003	2004	2006
Integrated Luminosity (fb^{-1})	0.43	0.58	0.92	0.85

- 2006 upgrade :
  - Larger acceptance : 70 mrd $\rightarrow$ 180 mrd.
  - Better RICH PID
  - Electromagnetic calorimetry.

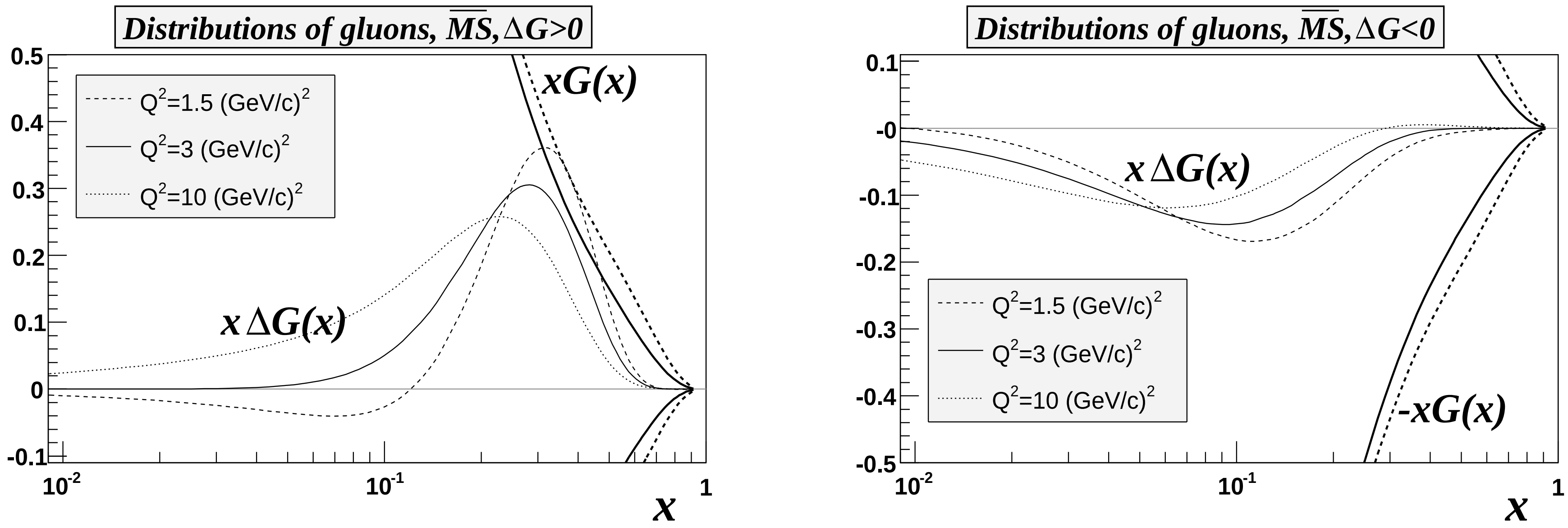
- Only partially analyzed : 2002 $\leftrightarrow$ 2004 ($most\ of\ the\ time$)

- COMPASS resumed data taking in 2007,
  w/ a polarized proton (NH_3) target.

ΔG *via* scaling violation in g_1

- COMPASS QCD fit :
  - *Cf.* talk of Helena Santos.

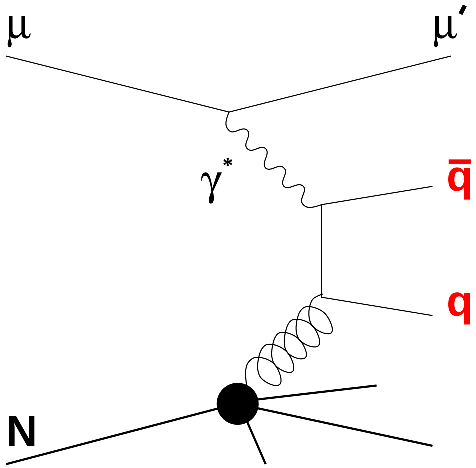
  ⇒ World data described well by two solutions, with $\Delta G > 0$ and $\Delta G < 0$, *resp.* :



⇒ Small sensitivity to ΔG ⇒ Need direct measurement

⇒ *Sensitivity to assumed functional shape.*

$\Delta G/G$ direct measurement : Photon Gluon Fusion



q = c : Open Charm production

- Triggered by PGF at LO (neglecting Intrinsic Charm)

⇒ Theory Golden Channel

- Experimentally difficult

- pQCD scale set by $\hat{s} > 4m_c^2$

q = u,d,s,c : High p_T Hadrons

- Competing LO-DIS, QCD-Compton and resolved photon processes.

⇒ Theoretical uncertainties.

- Higher statistics

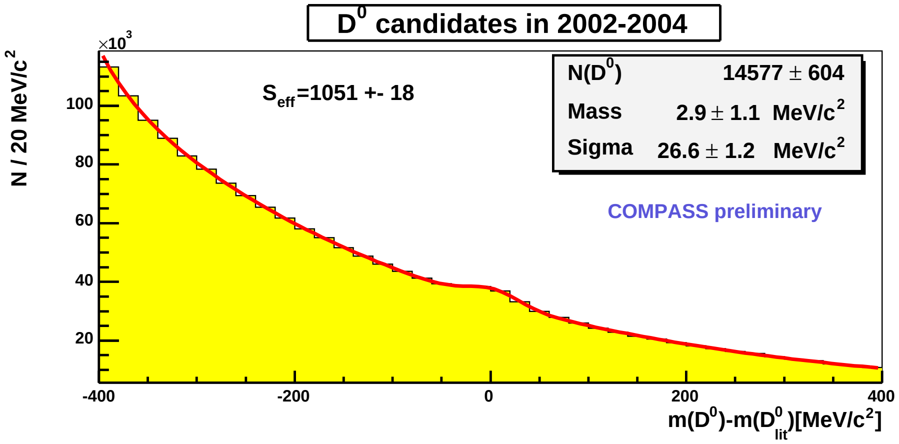
- pQCD scale can be set by p_T

⇒ Explore all Q^2

Open charm : D^o meson reconstruction

- $D^o \to K\pi$
  - Thick target
    $\Rightarrow$ No Charm decay vertex reconstruction
  - RICH PID
  + Kinematical cuts
    - Momentum fraction z_{D^o}
    - D^o decay angle

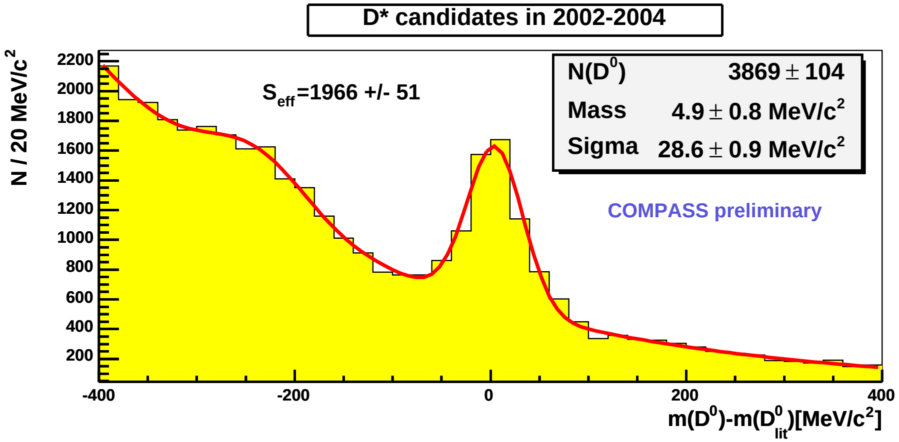
$\Longrightarrow$



$\mathrm{S_{eff}} = \textit{effective Signal} = \mathrm{S}^2/(\mathrm{S}+\mathrm{B})$
where S *and* B *Signal and Background counts.*

- Favorable case : D^o from $D^* \to D^o\pi \to K\pi\pi$
  - $1/3$ of D^o's
  - D^* tagging by cut on 3-body invariant mass
  - Bump $= D^o \to K\pi\pi^o$ missing π^o

$\Longrightarrow$



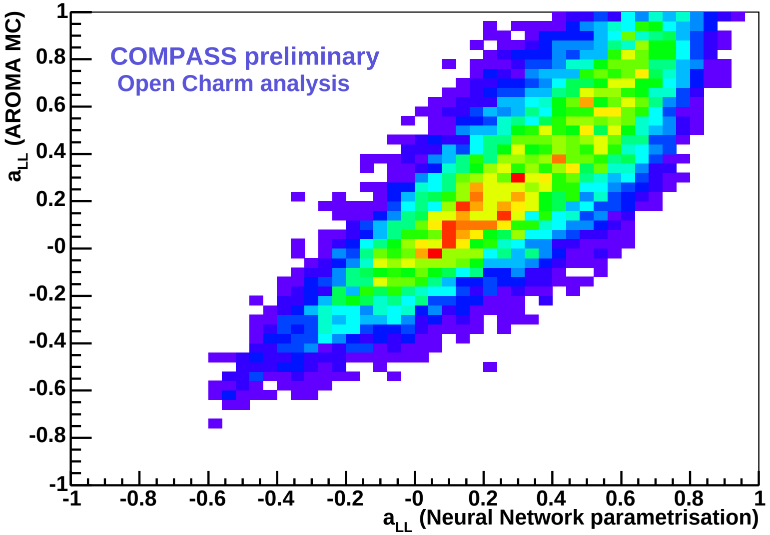
Open charm : Extraction of $\Delta G/G$

$$\frac{N^{\Uparrow\downarrow} - N^{\Uparrow\uparrow}}{N^{\Uparrow\downarrow} + N^{\Uparrow\uparrow}} = P_T\, P_\mu\, f\, a_{LL}\, \frac{S}{S+B}\, \frac{\Delta G}{G} + A_B$$

- A_B determined to be negligible on side bands.
- In order to minimize statistical error use event weighting
  $w = P_\mu\, f\, a_{LL}\, S/(S+B)$
- Needed inputs :
  - Signal purity $S/(S+B)$: derived from fit.
  - a_{LL} from a parameterization derived from MC simulation.

Open charm : Analyzing power a_{LL}

$$\langle a_{LL} \rangle \frac{\Delta G}{G} \simeq \frac{\int \Delta\sigma^{PGF}(\hat{s})\, \Delta G(x_g, \hat{s})\, d\hat{s}}{\int \sigma^{PGF}(\hat{s})\;\; G(x_g, \hat{s})\;\; d\hat{s}}$$

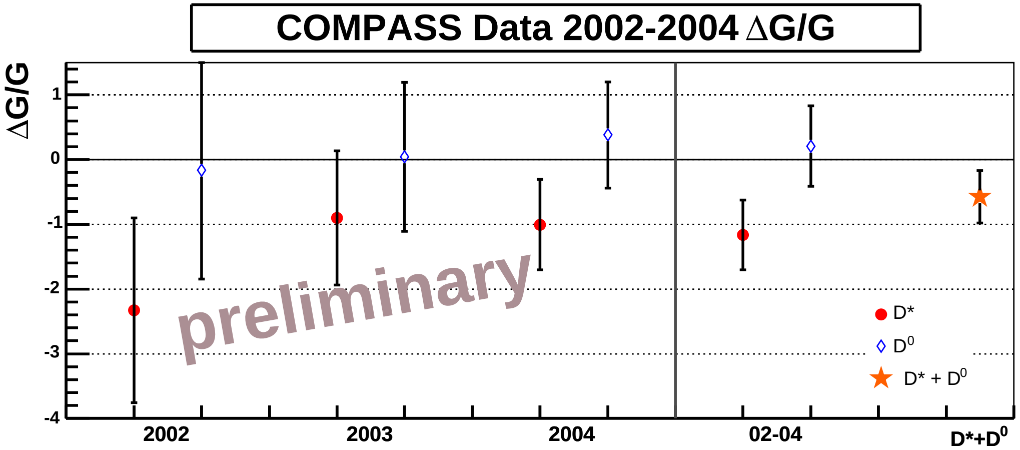


Correlation factor $\simeq$ 82%

- Hard scattering kinematics
  - Needs MC information
  - MC = AROMA. Checked *vs.* data.
- Parametrization with : $y, Q^2, z_{D^o}, p^{\gamma}_{T D^o}$
- Using neural network

$\Rightarrow$ LO extraction of $\Delta G/G$.

Open charm : Result



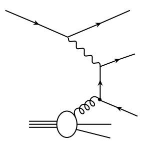
- Preliminary result from COMPASS 2002-2004 data

  Systematics include :
  - False asymmetry : Upper bound from high statistics including background.
  - Background asymmetry.
  - Fitting procedure.
  - MC : charm mass and PDFs.

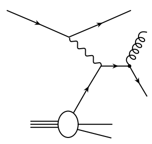
$$\Delta G/G = -0.57 \pm 0.41(stat.) \pm 0.17(syst.)$$
$$\langle x_g \rangle = 0.15$$
$$\mu^2 \simeq 13\, GeV^2$$

High p_T hadrons

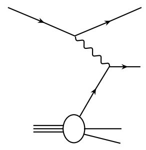
- Competing processes :



PGF

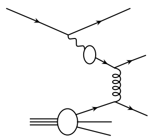


QCDC

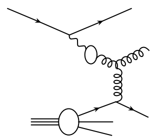


LO (p_T via hadronization)

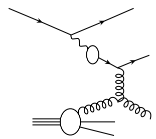
$+$ Resolved photons :



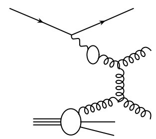
$qq \to qq$



$qg \to qg$



$qg \to qg$



$gg \to gg$

(*Introduce a dependence upon the poorly known polarized structure of the photon.*)

- Factorization granted by hard scale.
- 2 different methods :

I) At LO : $A_{||} \simeq \left(R_{PGF} \langle a_{LL}^{PGF} \rangle + \sum R_i \langle a_{LL}^{i} \Delta q/q \rangle \right) \Delta G/G + A_{Background}$

Determine R, $\langle a_{LL} \rangle$ and $A_{Background}$ from MC simulation.

II) Asymmetry *vs.* p_T compared to theoretical prediction based on ΔG parametrization. Can be NLO.

High p_T measurement *via* MC generator

- $Q^2 < 1$ GeV^2
  - PYTHIA used :
    pQCD + resolved photon + model dependent low scale processes.
  - Hard scale defined by p_T
  - Highest statistics.

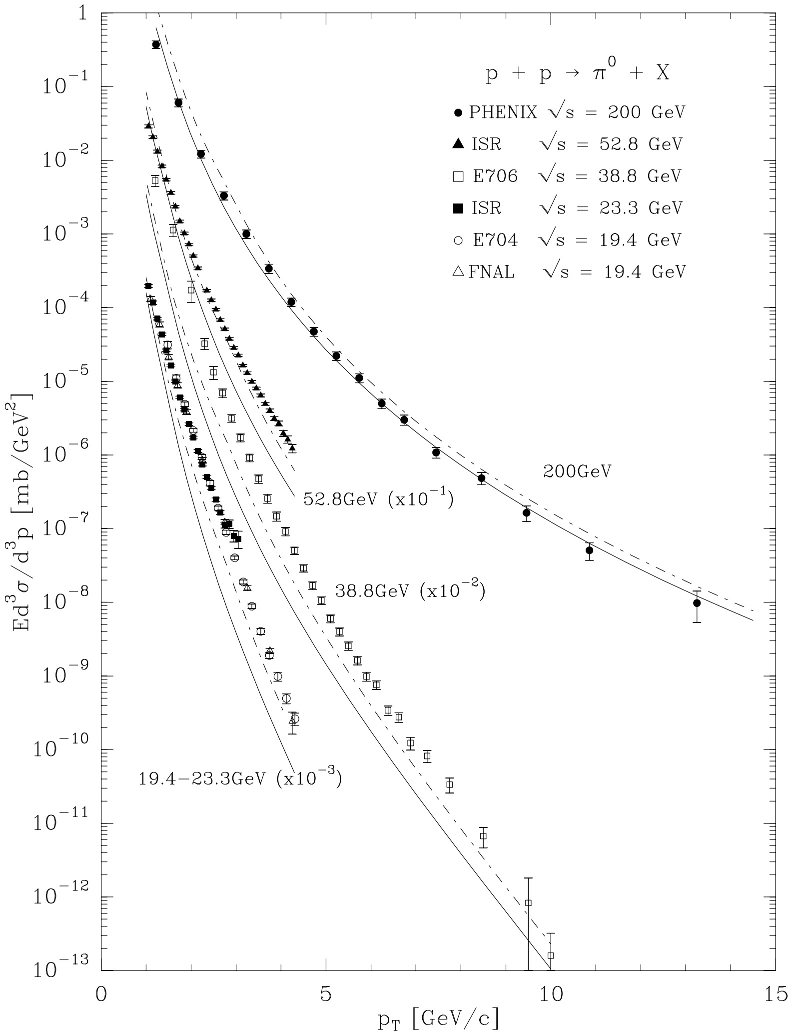
- $Q^2 > 1$ GeV^2
  - LEPTO used :
    pQCD alone ⇒ better controlled.
  - Hard scale defined by Q^2
  - Lower statistics.
  - Resolved photons assumed negligible.

- *Cf.* presentation by K. Klimaszewski

NLO calculation : high p_T photoproduction

- Calculations by group of *BNL/Regensburg*.
  - Single high p_T hadron
    Jäger, Stratmann, Vogelsang, Eur.Phys.J. C44 (2005) 533-543.
  - Pair of high p_T hadrons
    Hendlmeier, Stratmann, Schäfer, arXiv :0706.3766 [hep-ph]
- Photoproduction : $Q^2 < 0.5$ GeV^2
- ΔG independent of MC model.
- Dependent upon functional shape $\Delta g(x)$
- Need to validate calculation on unpolarized cross section

General Trend in NLO Calculations at low $\sqrt{s}$

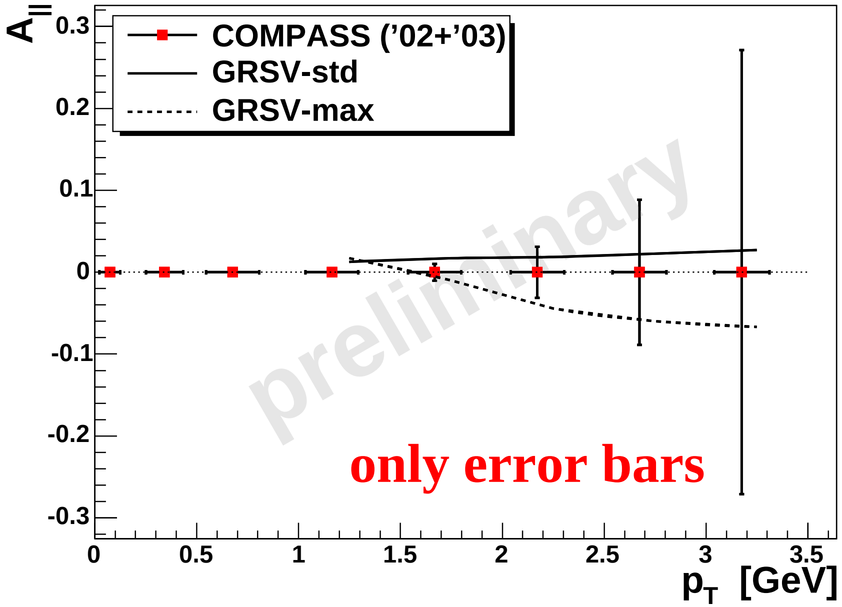


Eur.Phys.J. C36 (2004) 371-374

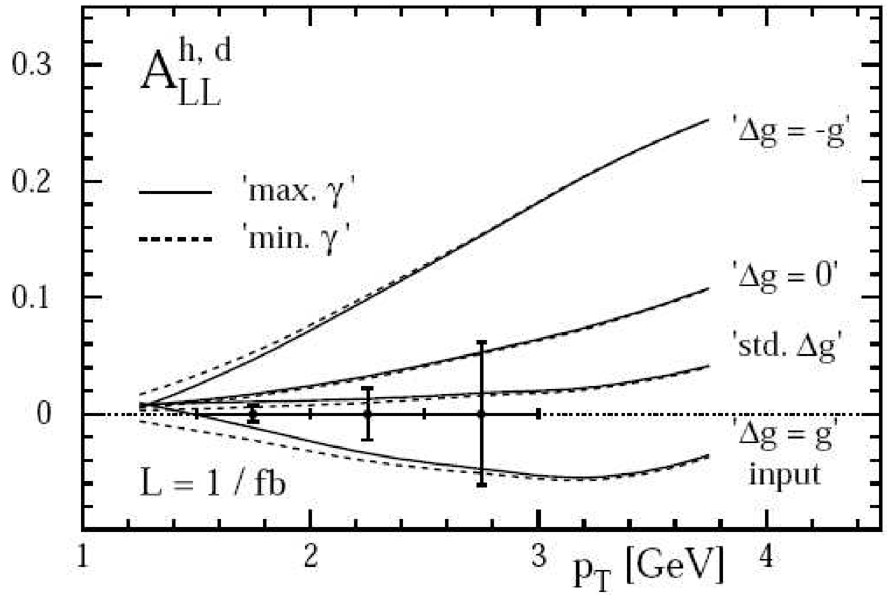
- Everything is fine at $\sqrt{s} = 200$ GeV.
- Discrepancy grows at lower $\sqrt{s}$.
- All-order resummations of large logarithms greatly bridge the gap *Phys. Rev. D71 (2005) 114004*.
- Resummations not yet done in COMPASS case, $\sqrt{s} = 17.3$ GeV.
  For the time being, assume they do not impact on the asymmetries.

High p_T photoproduction : Projections

- Measurement not released yet.
- Projections (*compared to GRSV scenarios*) :

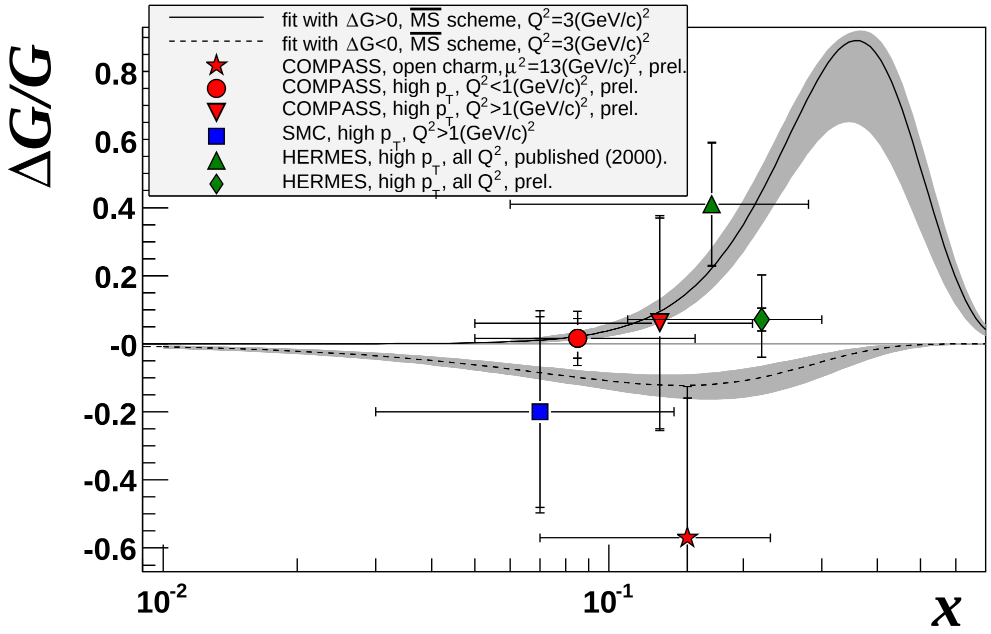


Single hadron : Data analysis of ∼1/3 of recorded data.



Hadrons pair : Hendlmeier et al., arXiv :0706.3766 [hep-ph]

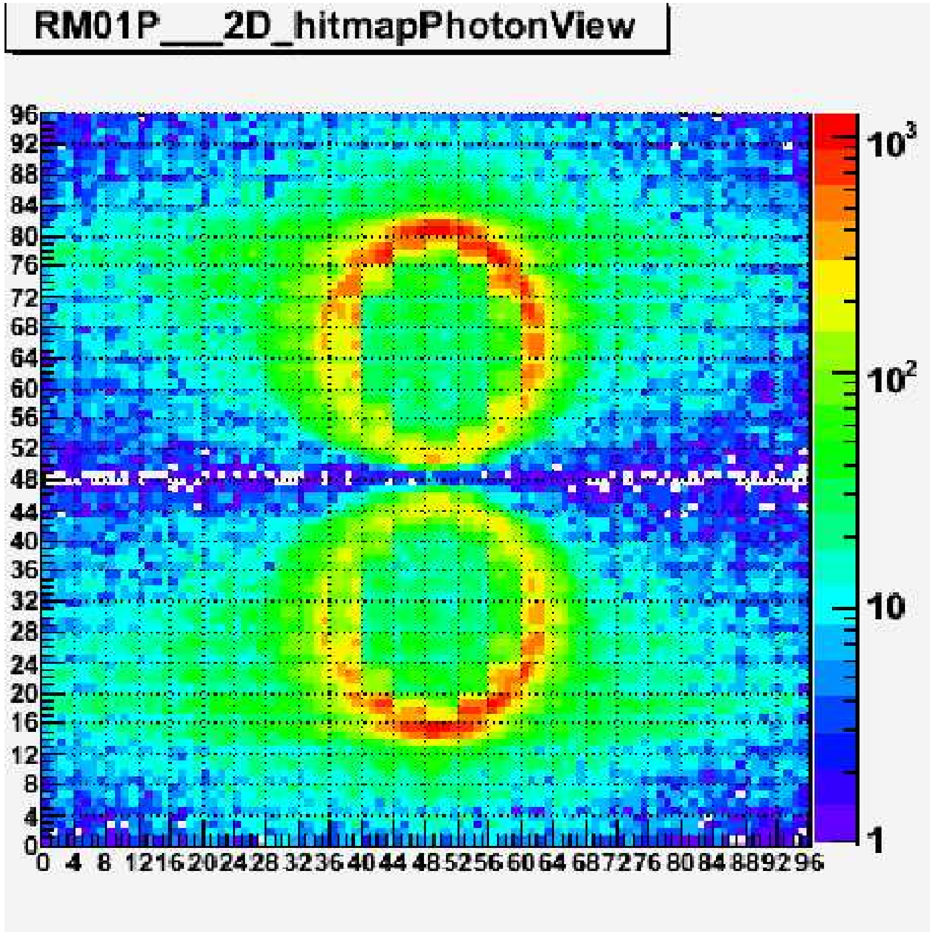
$\Delta G/G$: Summary of results

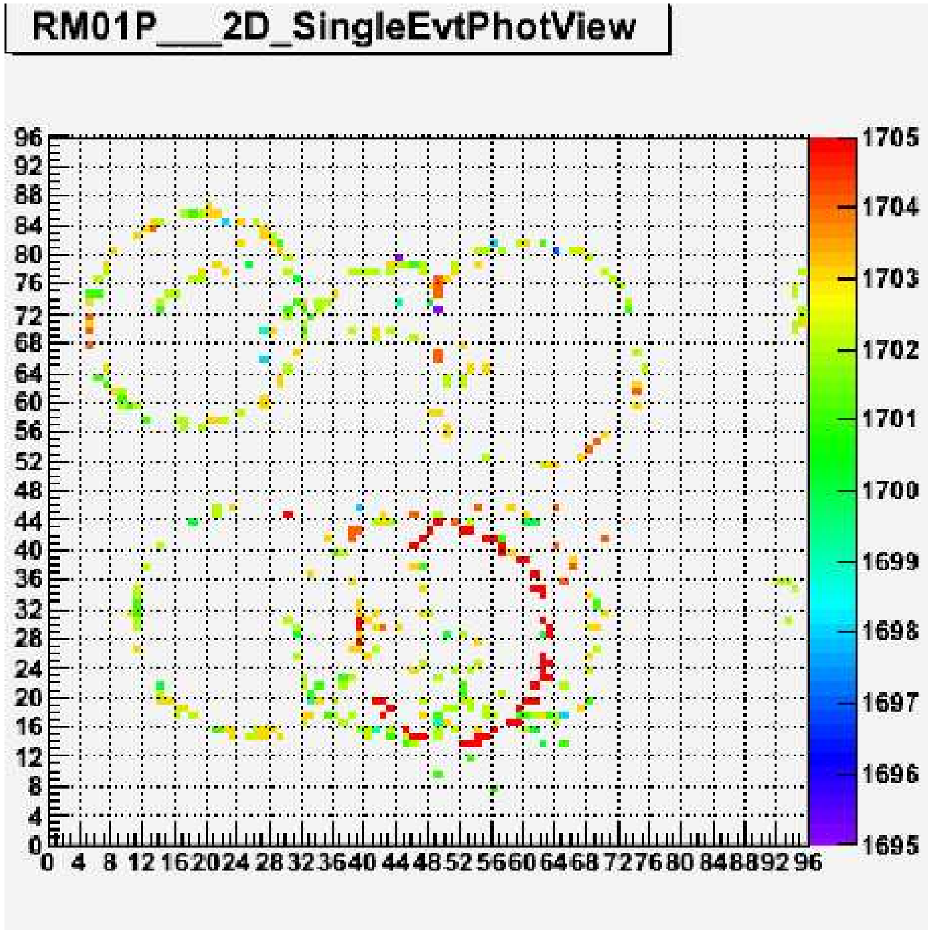


- COMPASS disfavors the large values needed for ΔG to account for the g_1 results via the axial anomaly.
- But compatible with $|\Delta G/G| \simeq 0.2 : 0.3$

2006 Upgrade : RICH

- Central part : CsI+MWPC photodetectors → MAPMTs
- Outer part : Faster electronics.

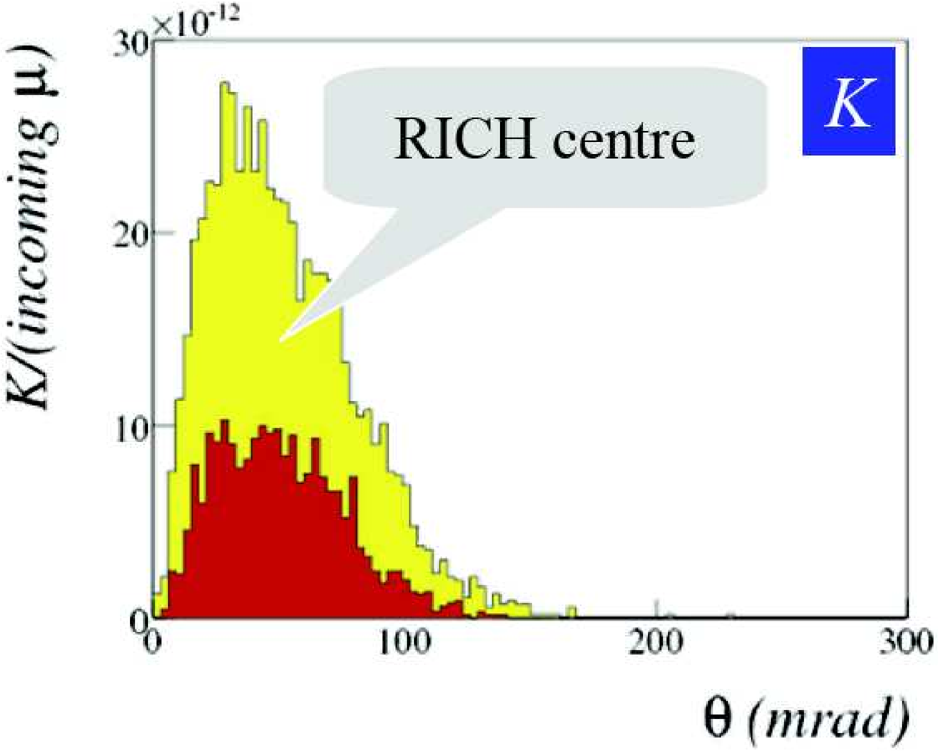


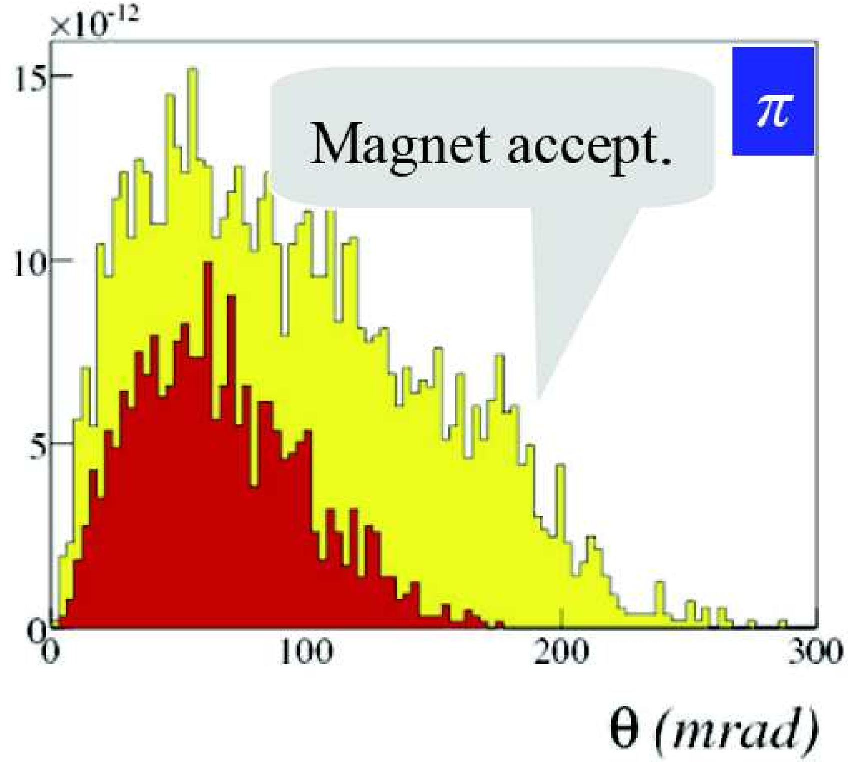


μs range : Event dominated by halo muons. *ns time resolution.*

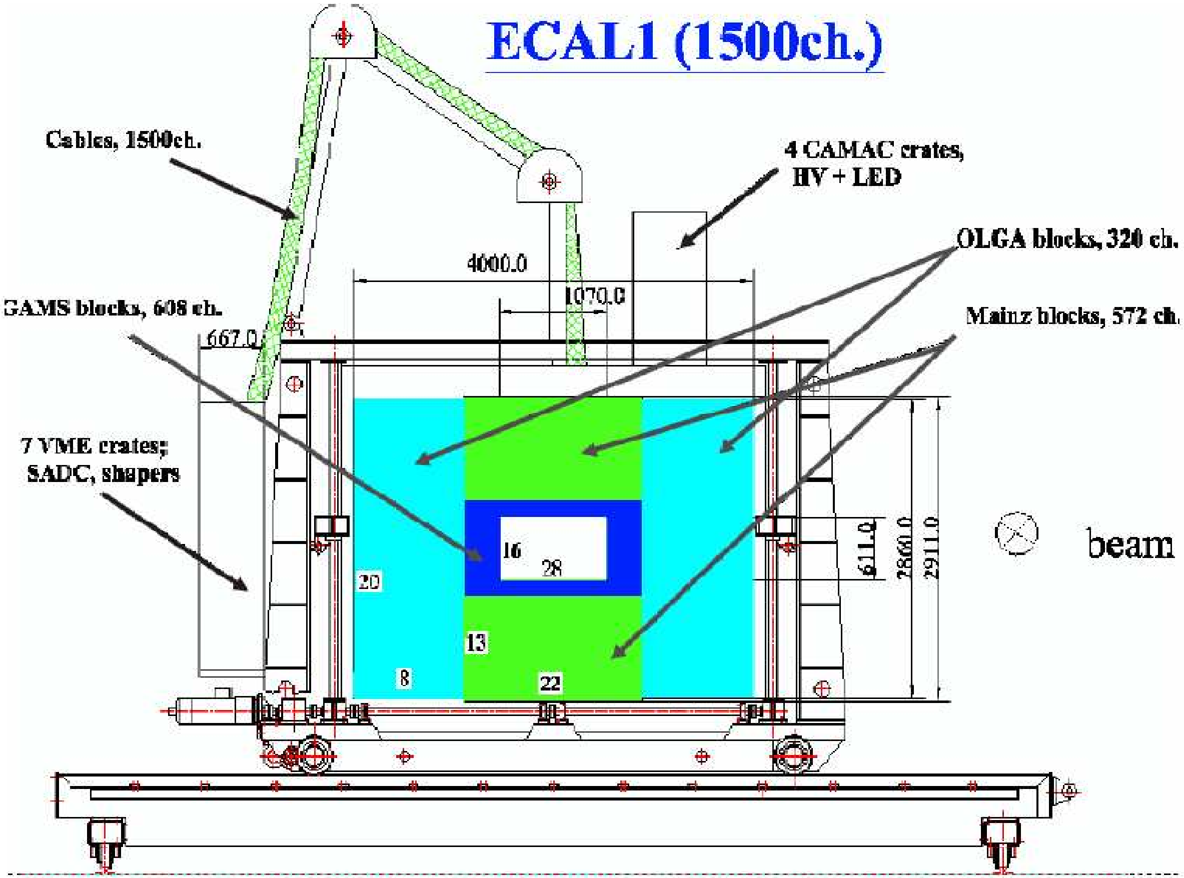
2006 Upgrade : RICH + Acceptance

- Combined effect on tracking of :
  - ∘ RICH improvements
  - \+ Enlarged acceptance : 70 mrd → 180 mrd





2006 Upgrade : ECalorimetry



- Electromagnetic calorimeter in first stage : 1500 lead glass blocks.
  - Installed in 2006. Included into trigger system in 2007.
  - 2006 data being analyzed.

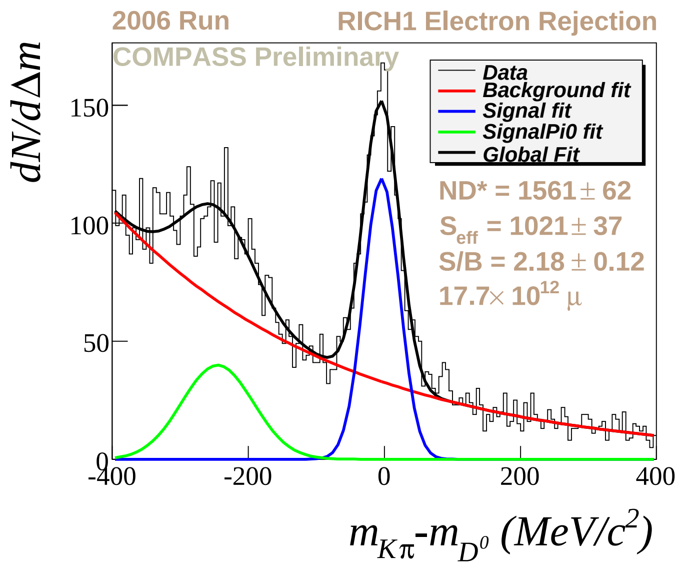
2006 Upgrade : Impact on $\Delta G/G$ channels

- Gain in $\mathcal{F}o\mathcal{M}$ *per* incident muon.

($Caveat$: - $\mathcal{F}o\mathcal{M}(\propto \delta\Delta G/G^{-2})$ *evaluated on effective #events, ignoring event weighting.*)

- Open charm D^* : $\times$ 2.25 $\Longrightarrow$

(*Extra gain from RICH PID below K threshold.*)



$D*$'s in 1/2 of 2006 data.

- High p_T $Q^2 > 1$: $\times$ 1.8

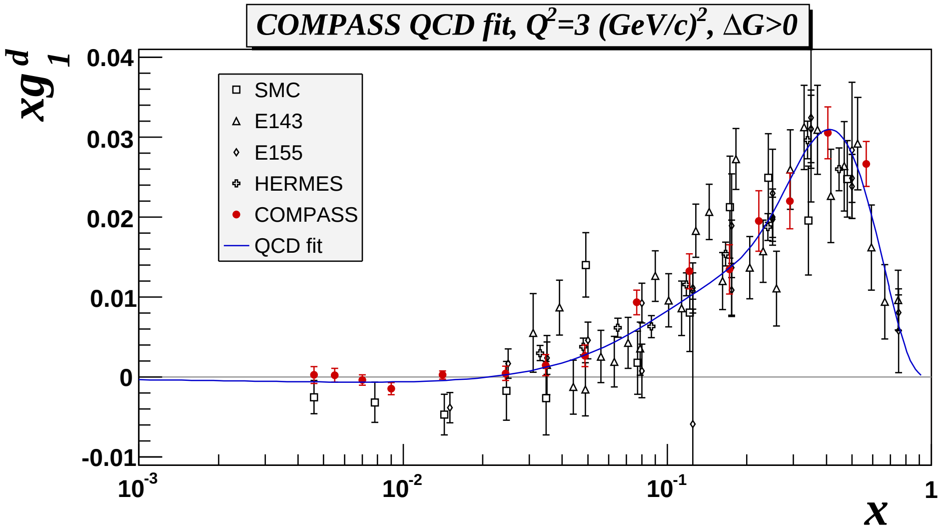
Conclusion

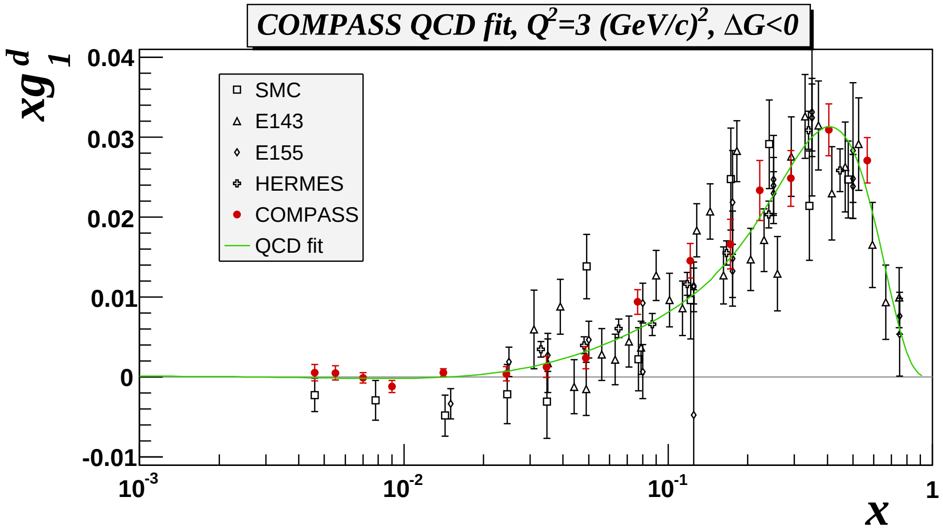
- Open charm
  $\Delta G/G = -0.57 \pm 0.41(stat.) \pm 0.17(syst.) \quad x_g \simeq 0.15 \quad \mu^2 \simeq 13\,GeV^2$
- High p_T $Q^2 < 1$ (*2002-2003 data*)
  $\Delta G/G = \ 0.06 \pm 0.31(stat.) \ \pm 0.06(syst.) \quad x_g \simeq 0.13$
- High p_T $Q^2 > 1$ (*PLB 633 (2006) 25-32*)
  $\Delta G/G = 0.016 \pm 0.058(stat.) \pm 0.055(syst.) \ x_g \simeq 0.085 \ \mu^2 \simeq 3\,GeV^2$
- Favors low value of ΔG
- NLO extraction from high p_T photoproduction to be released.
- 2006 :
  - 1/2 more statistics.
  - Larger impact on $\mathcal{F}o\mathcal{M}$ due to upgrade.
- 2007 : Polarized proton target.
  (*Not optimum for* ΔG *since* $f P_T$ *reduced.*)
- 2008 : Hadron beam.

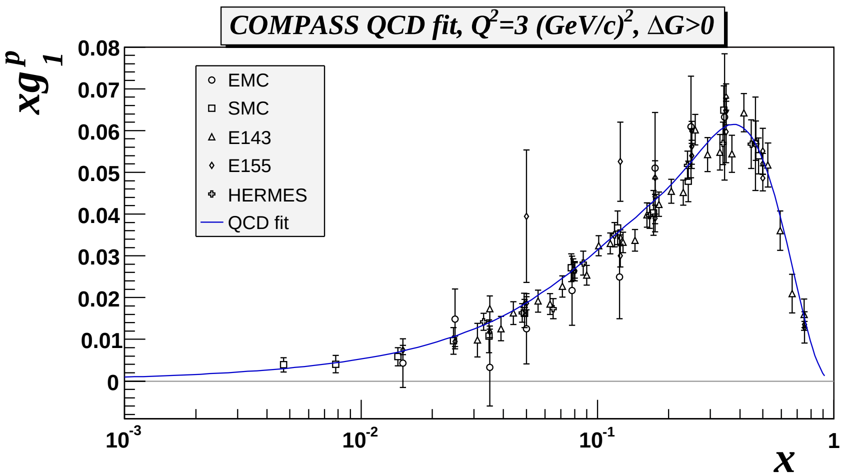
SPARES

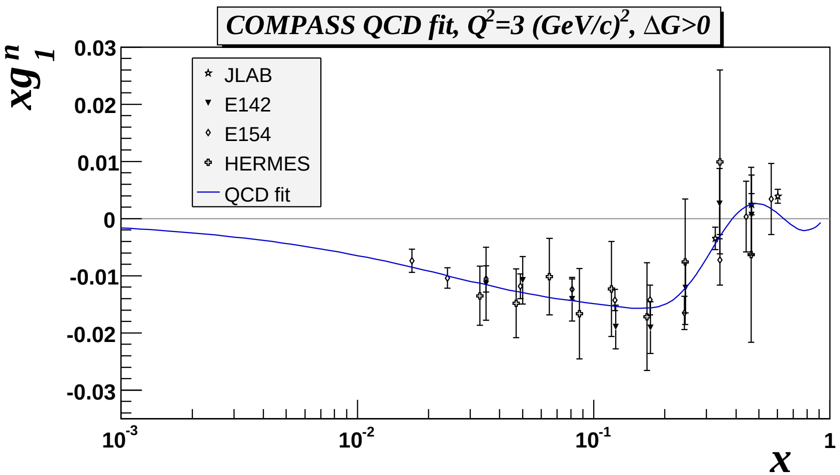
COMPASS QCD fit : Results for p, n and d

- World data at $Q^2 = 3GeV^2$. p, n and d with $\Delta G > 0$, and d with $\Delta G < 0$
  $\Delta G < 0$ preferred at low x.









Open charm : Extraction of $\Delta G/G$

$$N_i = a\Phi(\sigma_S + \sigma_B)(1 + P_T P_\mu f(a_{LL}\frac{\Delta G}{G}\frac{\sigma_S}{\sigma_S + \sigma_B} + A_B\frac{\sigma_B}{\sigma_S + \sigma_B})$$

for each of $i = (u, d) \times (\Uparrow\uparrow, \Uparrow\downarrow)$

- Look at double ratio $\frac{u^{\Uparrow\downarrow}d^{\Uparrow\uparrow}}{u^{\Uparrow\uparrow}d^{\Uparrow\downarrow}}$
  - Φ same for u and d $\Rightarrow$ cancels out.
  - Assume stable acceptance u/d ratio =¿ a cancels out.
- Determine $A_B = 0$ from side bands.
- Solve for $\Delta G/G$
- Needed inputs : a_{LL} and purity.

2006 Upgrade : RICH + Acceptance