GLUON POLARIZATION MEASUREMENTS AT COMPASS

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on behalf of the COMPASS Collaboration

RIKEN Workshop on Gluon Polarization **December 3, 2005**

COmmon
Muon and
Proton
Apparatus for
Structure and
Spectroscopy

NA58

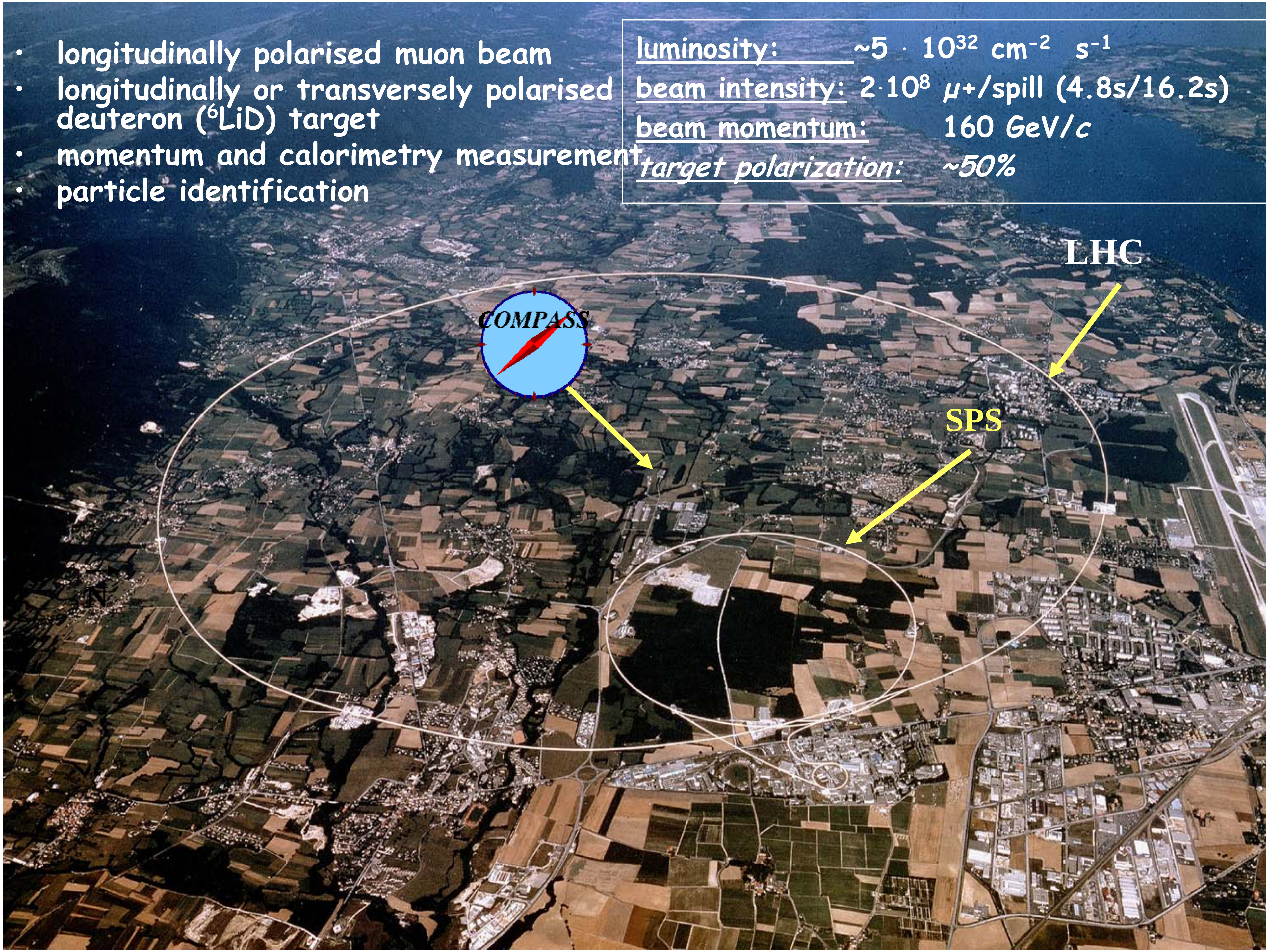
Czech Republic, Finland, France, Germany, India, Israel, Italy, Japan, Poland, Portugal, Russia

Bielefeld, Bochum, Bonn, Burdwan, Calcutta, CERN, Dubna, Erlangen, Freiburg, Heidelberg, Helsinki, Lisbon, Mainz, Miyazaky, Moscow, Munich, Nagoya, Prague, Protvino, Saclay, Tel Aviv, Torino, Trieste, Warsaw

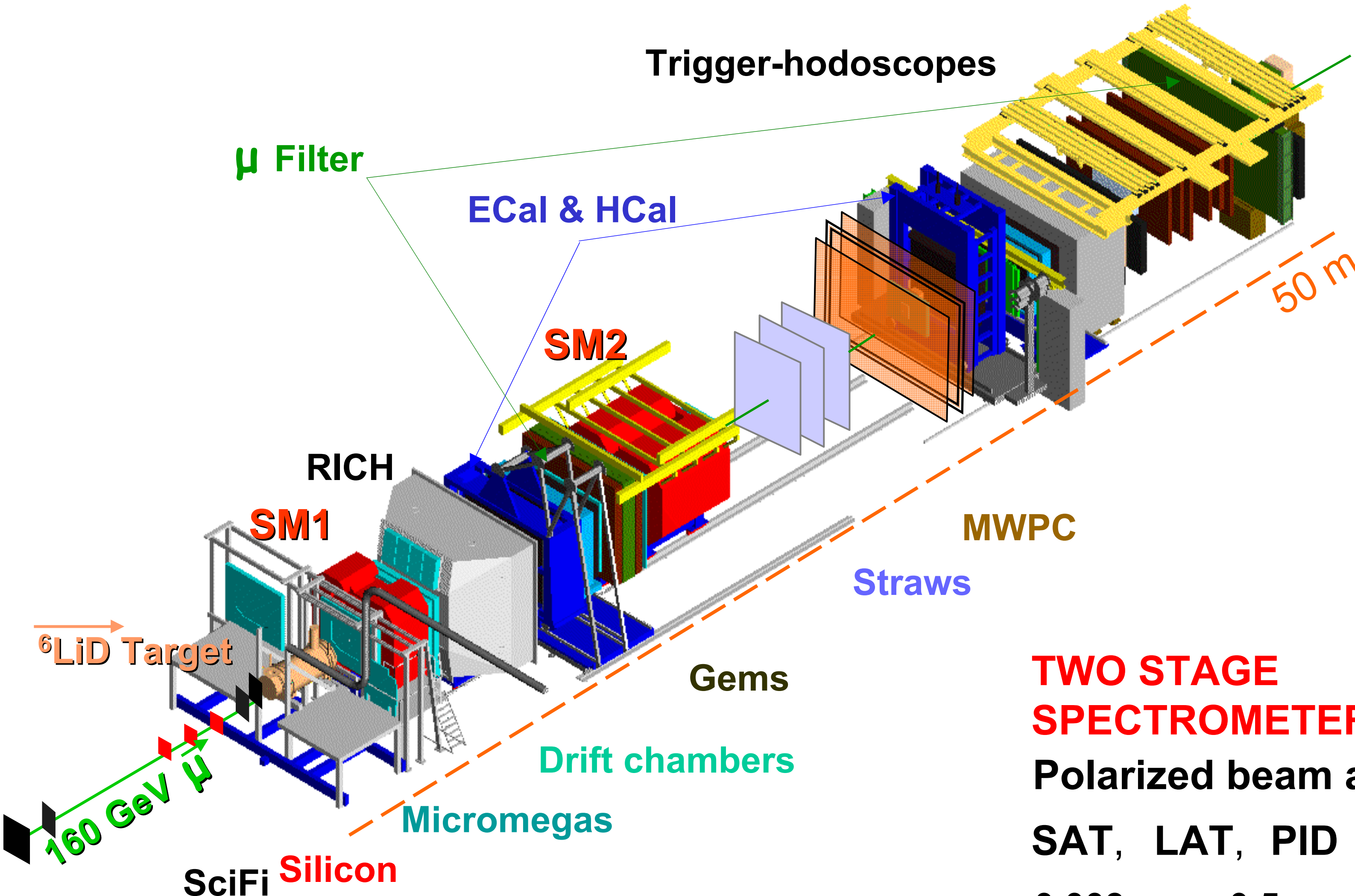
28 Institutes, ~230 physicists

- longitudinally polarised muon beam
- longitudinally or transversely polarised deuteron (^{6}LiD) target
- momentum and calorimetry measurement
- particle identification

luminosity:	~5 · 10^{32} cm^{-2} s^{-1}
beam intensity:	$2\cdot10^8$ μ+/spill (4.8s/16.2s)
beam momentum:	160 GeV/c
target polarization:	*~50%*



The COMPASS Spectrometer



TWO STAGE SPECTROMETER:

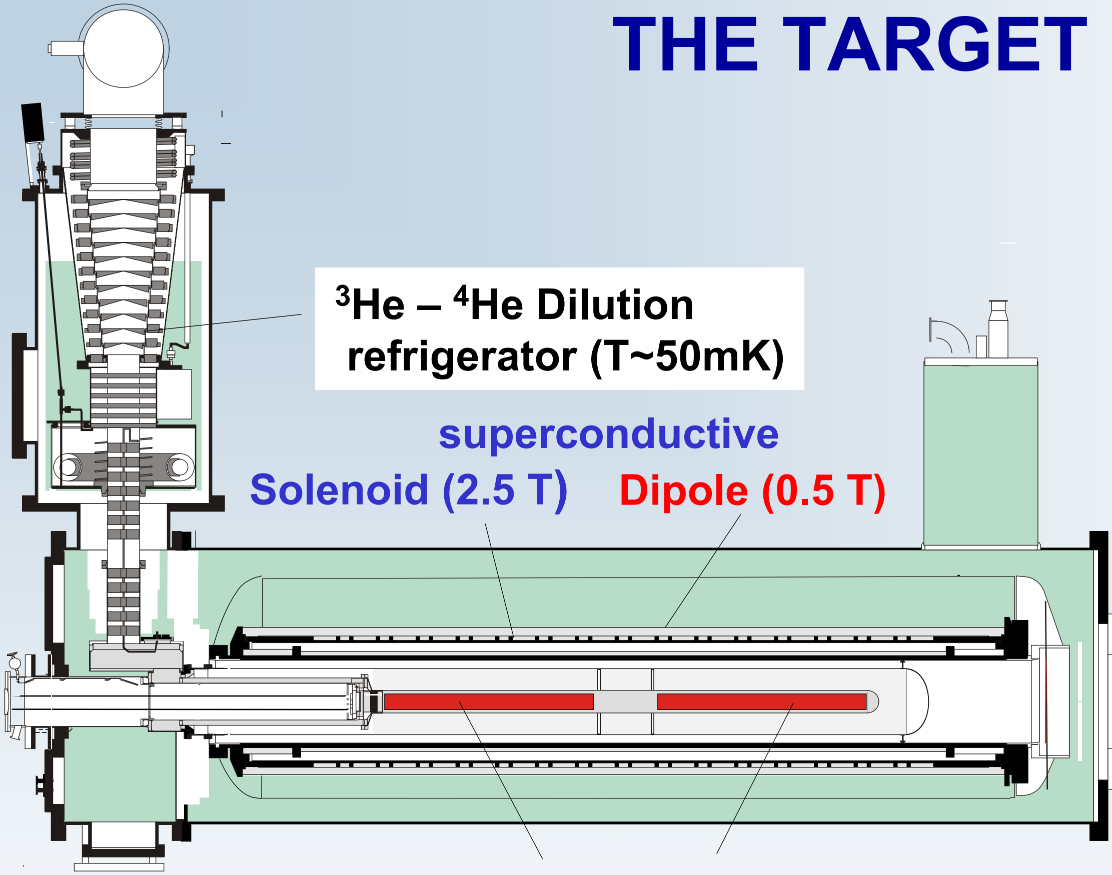
Polarized beam and target

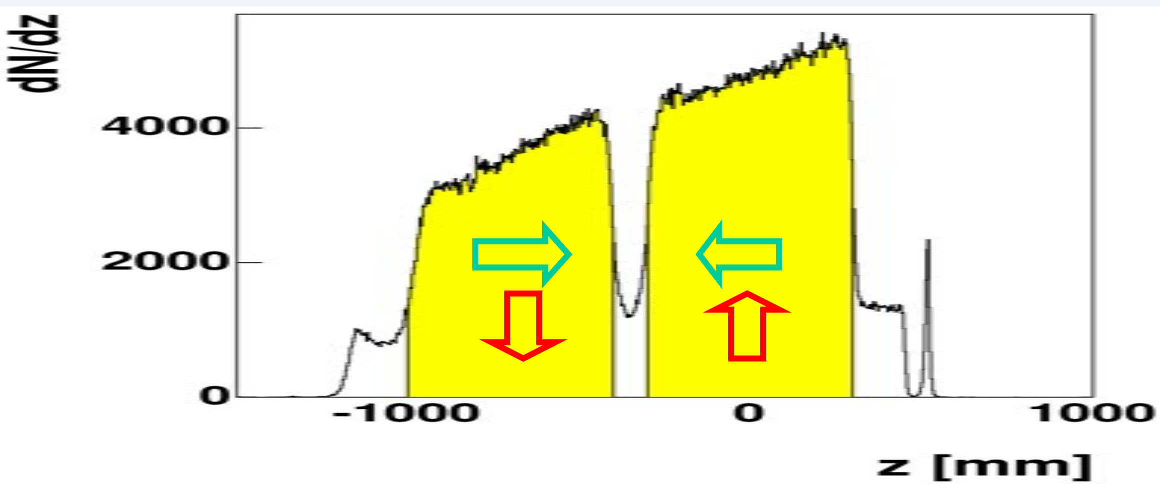
SAT, LAT, PID

$0.003 < x < 0.5$

$10^{-3} < Q^2 < 10$ GeV^2

THE TARGET SYSTEM



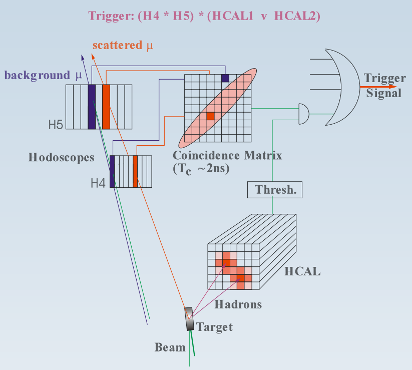


two 60 cm long cells with opposite polarization

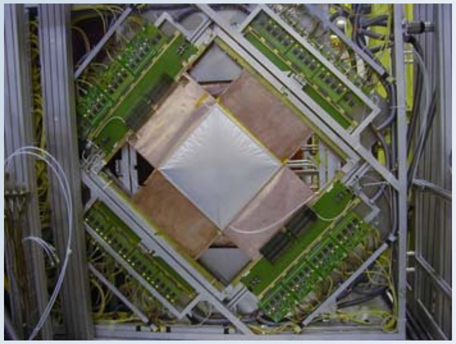
^{6}LiD:
Polarization 50%
Dilution factor 0.38

NEW TECHNOLOGIES

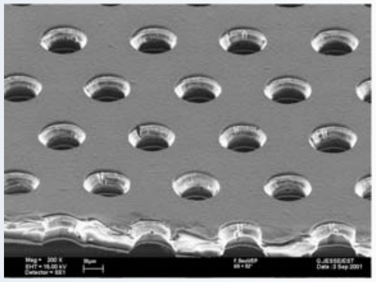
DAQ, off-line system



Trigger-System

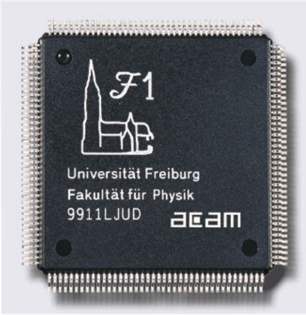


MicroMegas

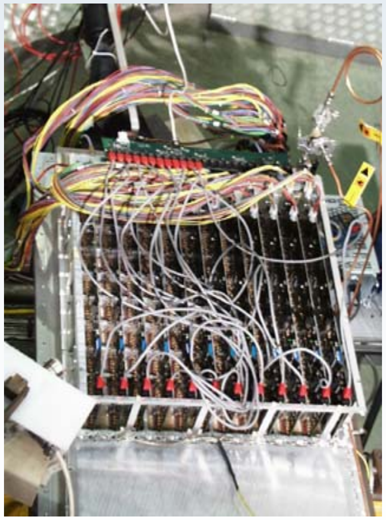


GEM

Straws



Readout electronics



RICH1 readout

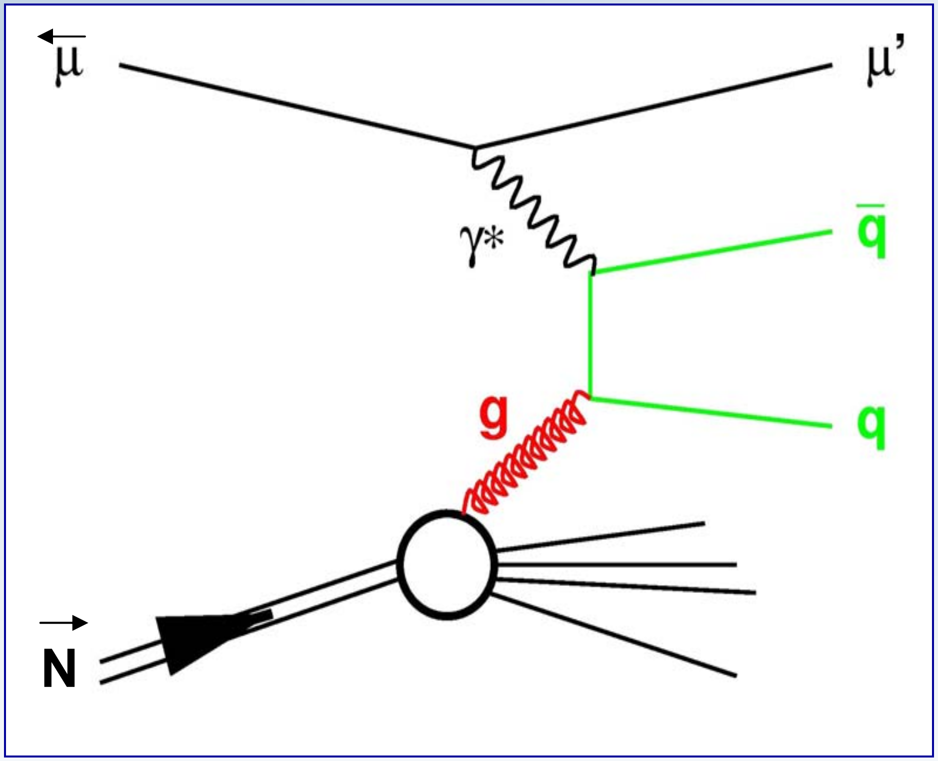
Scintillating fiber trackers

MEASUREMENTS OF GLUON POLARIZATION

FOUR LINES OF ATTACK:

1. Double spin asymmetry of the OPEN CHARM cross-section in high energy μD scattering
2. Double spin asymmetry of the HIGH-p_t HADRON PAIRS in high energy μD DIS ($Q^2 > 1$ GeV^2)
3. Double spin asymmetry of the high-p_t hadron pairs in high energy μD scattering ($Q^2 < 1$ GeV^2)
4. Measurement of g_1 of the deuteron and QCD fit of all the world data

Photon-Gluon fusion



q = c

"OPEN CHARM"
cross section difference
in charmed meson production
→ *theory well understood*
→ *experiment challenging*

q = u,d,s

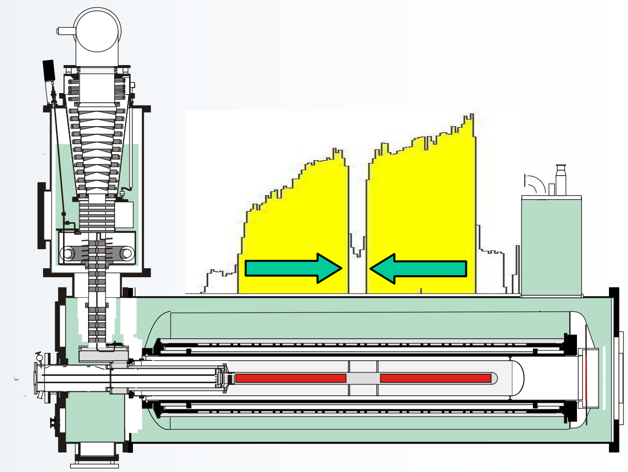
"HIGH p_T HADRON PAIRS"
cross section difference in 2+1
jet production in COMPASS:
events with 2 hadrons with
high p_T
→ *experiment "easy"*
→ *theory more difficult*

ΔG/G and counting rate asymmetry

- **Asymmetry**

$$\frac{A_{LL}^{\mu N}}{D} = \frac{1}{P_T\, f\, P_b D} \frac{N^{\leftrightarrows} - N^{\leftleftarrows}}{N^{\leftrightarrows} + N^{\leftleftarrows}}$$

target polarisation $P_T \approx$ 0.50
dilution factor $f \approx$ 0.40
beam polarisation $P_b \approx$ 0.76
depolarisation factor D



- **ΔG/G**

$$\frac{A_{LL}^{\mu N}}{D} = \frac{a_{LL}^{PGF}}{D} \frac{\Delta G}{G} \frac{\sigma^{PGF}}{\sigma^{tot}} + \frac{A_{LL}^{Background}}{D}$$

$$a_{LL} = \frac{\Delta\sigma^{\mu g}}{\sigma^{\mu g}}$$

- **Different background contributions for the different channels**

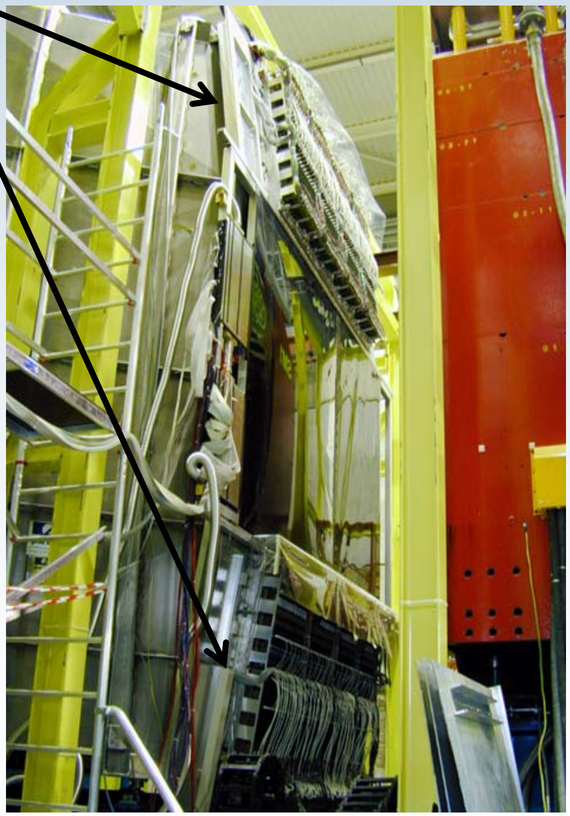
COMPASS

$\Delta G/G$ from
OPEN CHARM

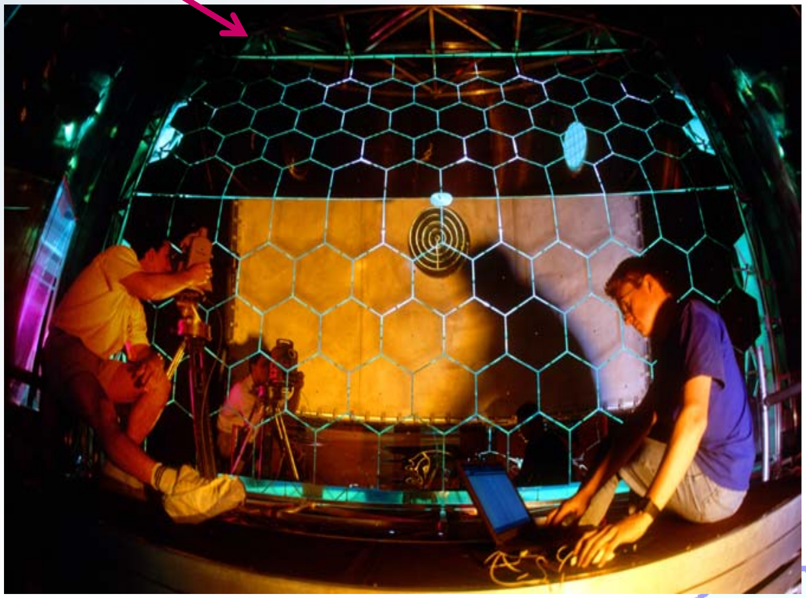
PID crucial

RICH1

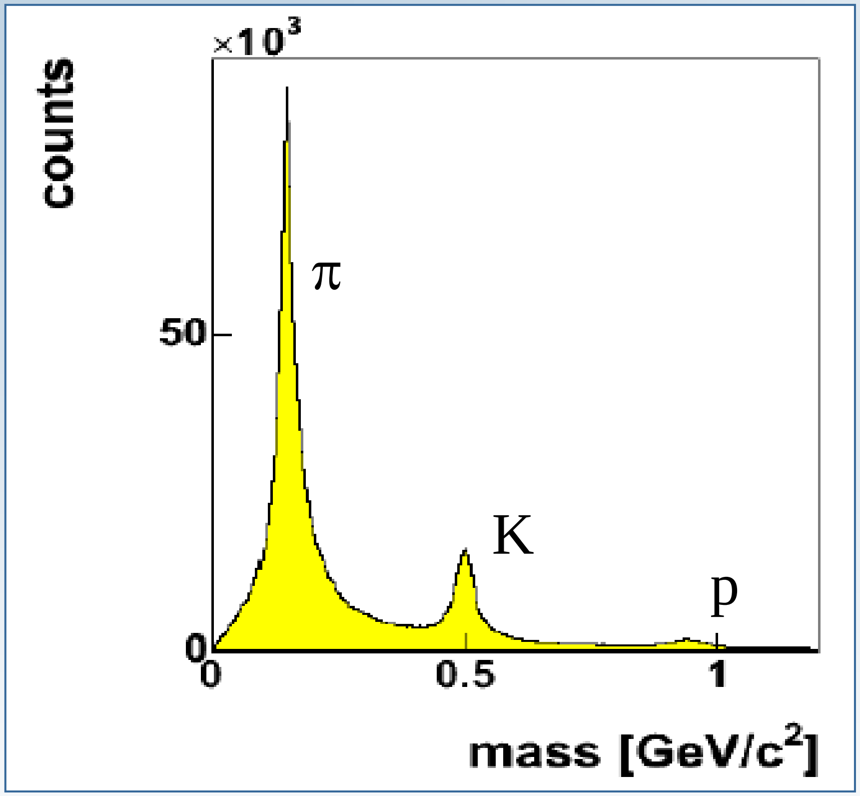
Photon detectors (PD) : 5.3 m^2 of CsI MWPCs,
84,000 analogic read-out channels



VUV mirror wall, 20 m^2,
116 mirror pieces

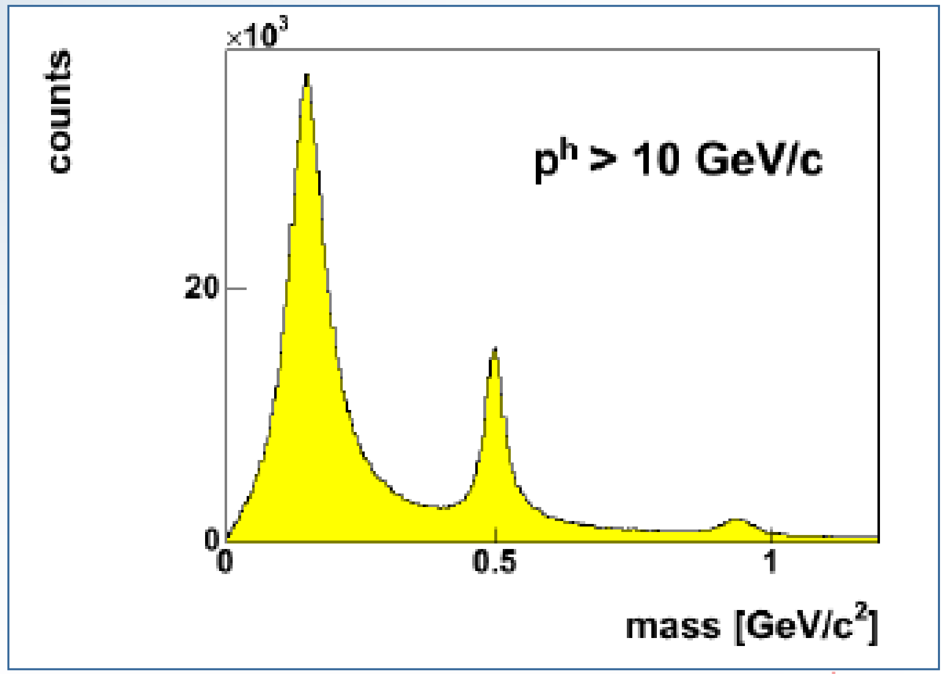


RICH response for DIS events



Threshold momenta:

- P_π = 2 GeV/c
- p_K = 9 GeV/c
- p_P =17 GeV/c



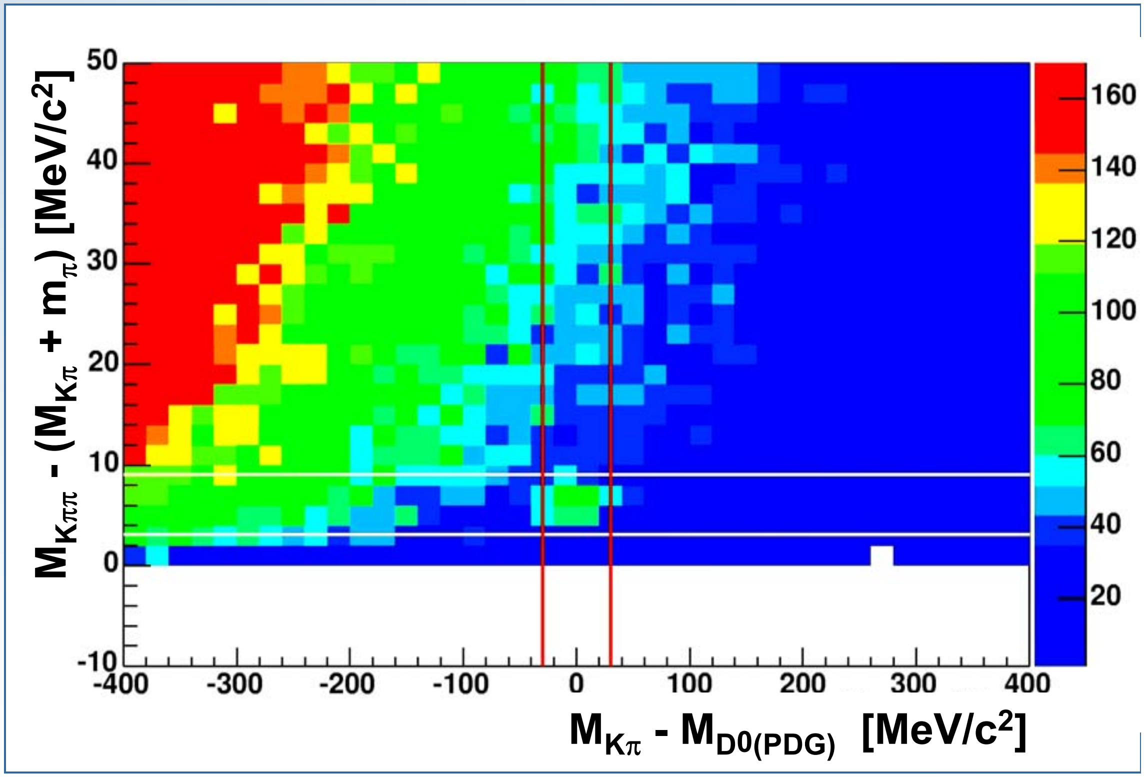
Hadron masses calculated from the measured Cherenkov angle

Open Charm Selection

$$D^{*+} \to D^0 \pi^+_{soft} \qquad D^0 \to K^- \pi^+$$

BR ≈ 68%   BR ≈ 4%

- z_D > 0.2 (0.25 for D^0)
  |cosθ*| < 0.85 (0.5 for D^0)
- RICH identification for $K^{\pm}$
  9 GeV/c < p ($K^{\pm}$) < 50 GeV/c



- 3.1 MeV/c² < $M_{K\pi\pi} - (M_{K\pi} + m_\pi)$ < 9.1 MeV/c²

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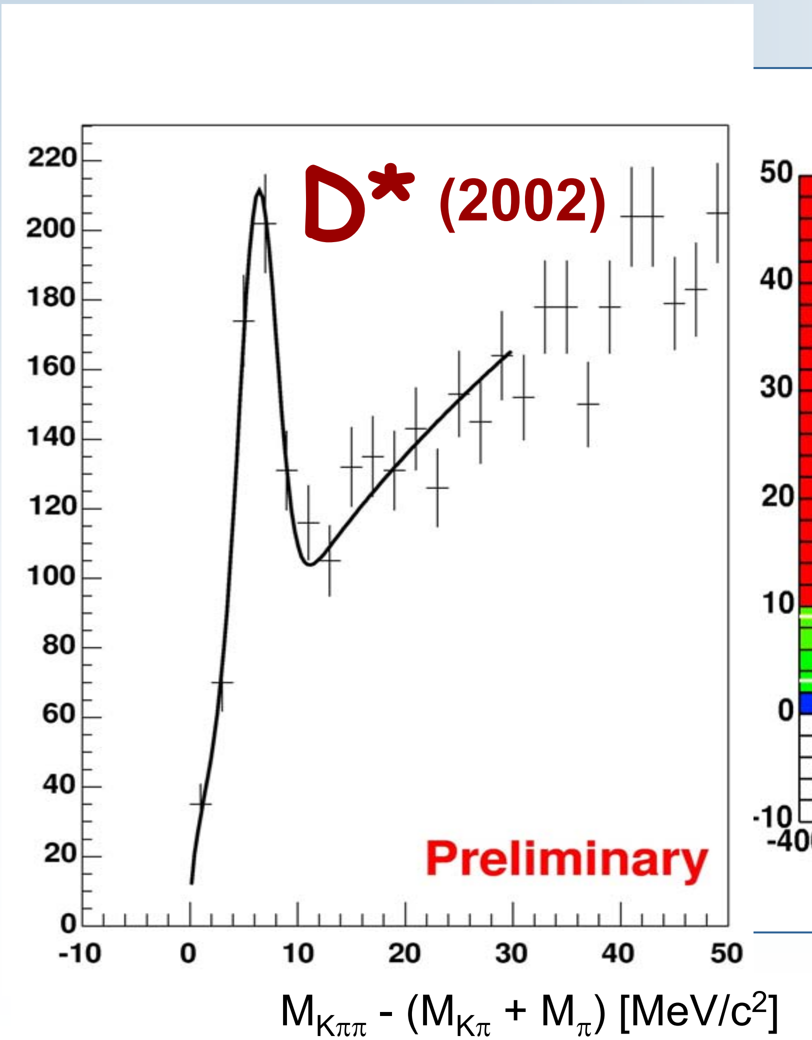
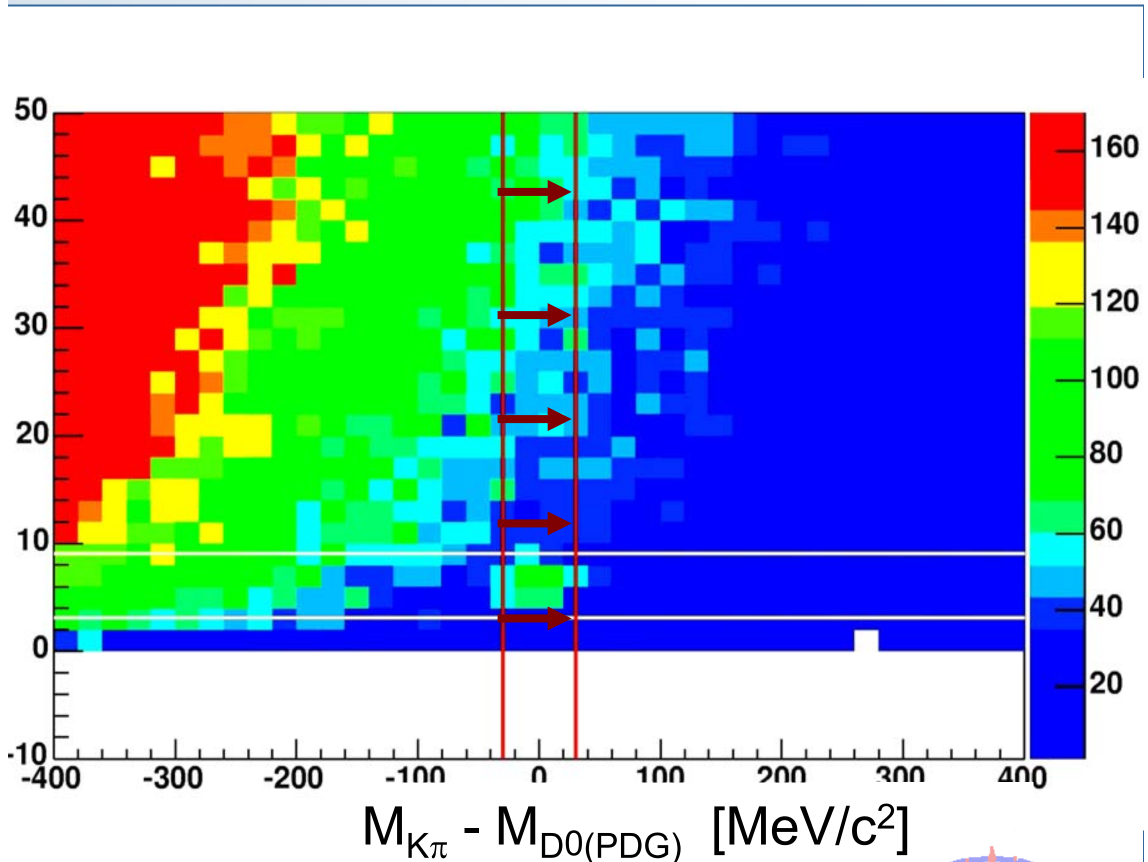
ΔG/G from Open Charm

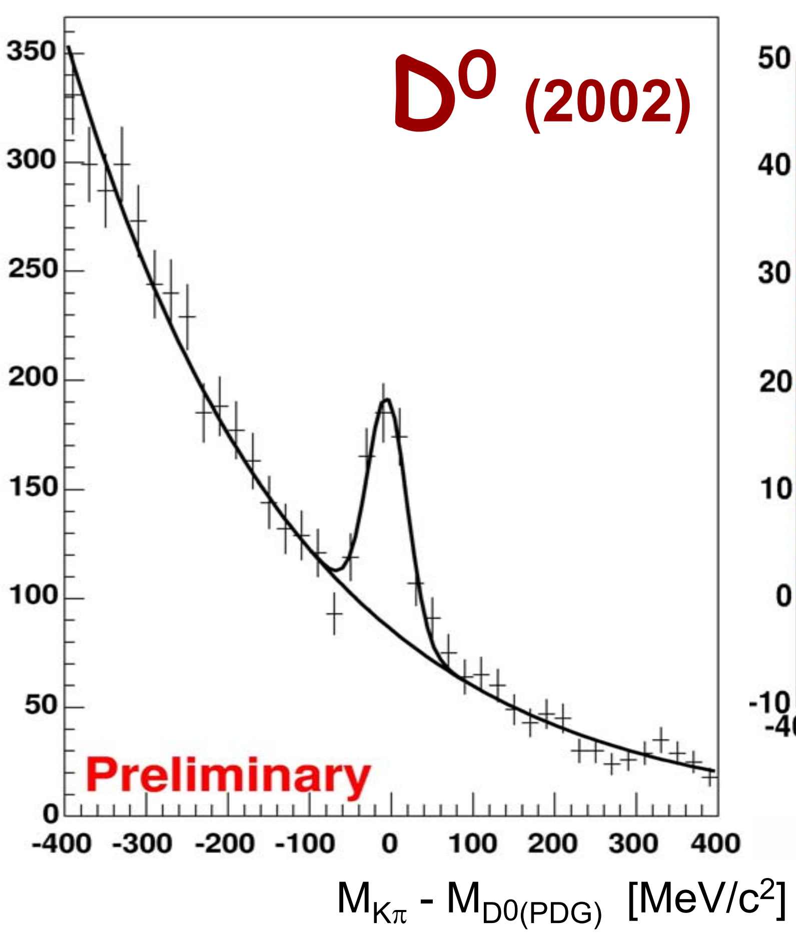
$$D^{*+} \rightarrow D^0 \pi^+_{soft} \qquad D^0 \rightarrow K^- \pi^+$$

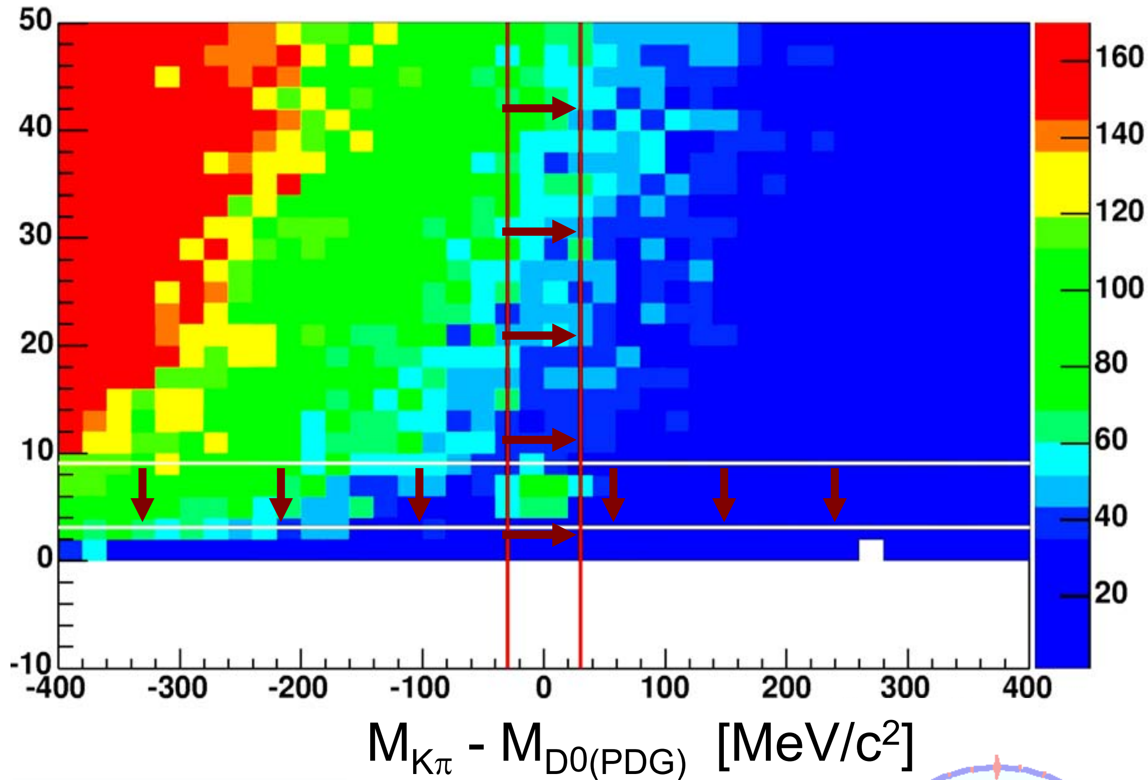




ΔG/G from Open Charm

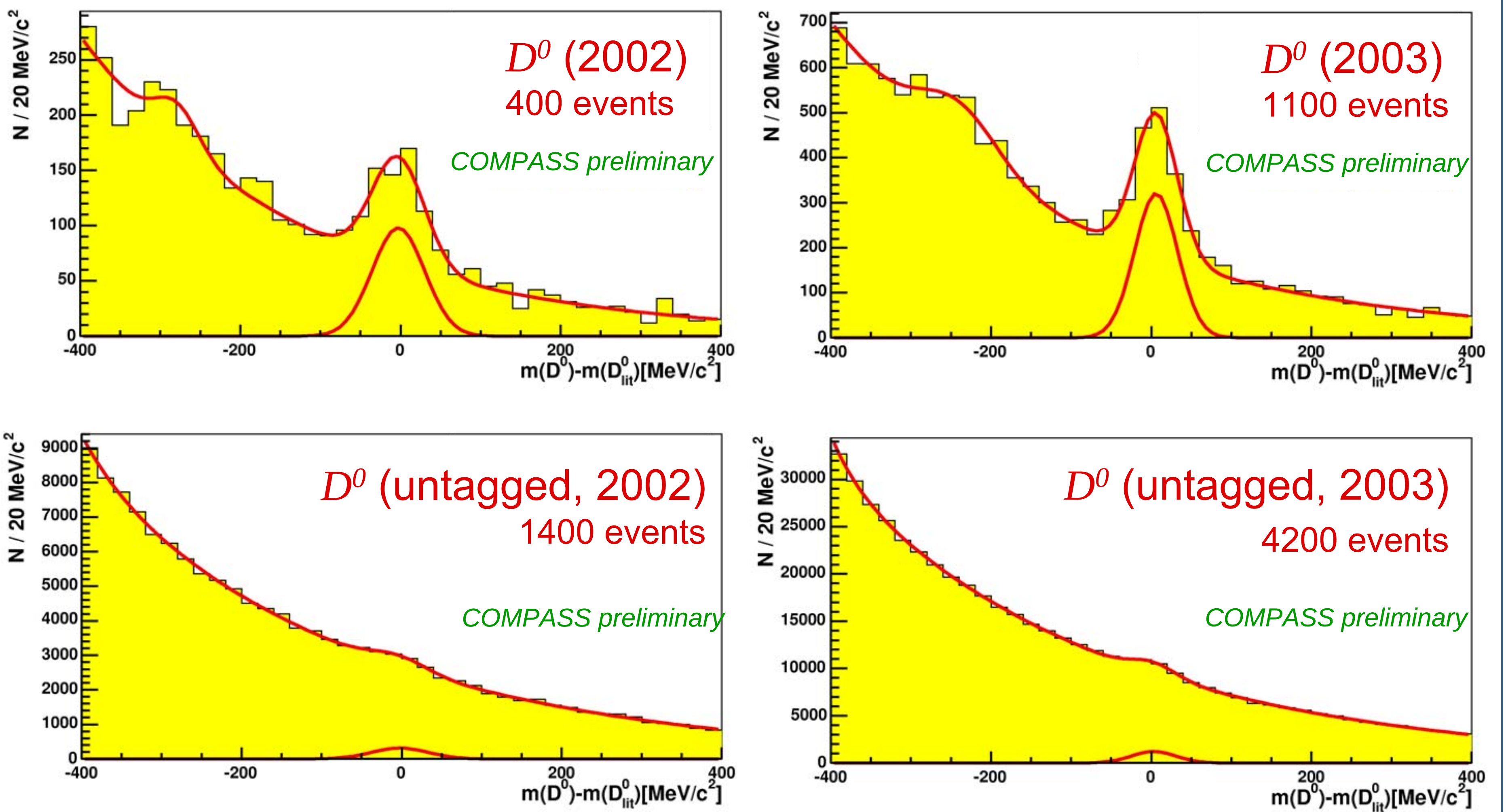
$$D^{*+} \rightarrow D^0 \pi^+_{soft} \qquad D^0 \rightarrow K^- \pi^+$$





COMPASS

ΔG/G from Open Charm



ΔG/G from Open Charm

- **no asymmetry contribution from background**

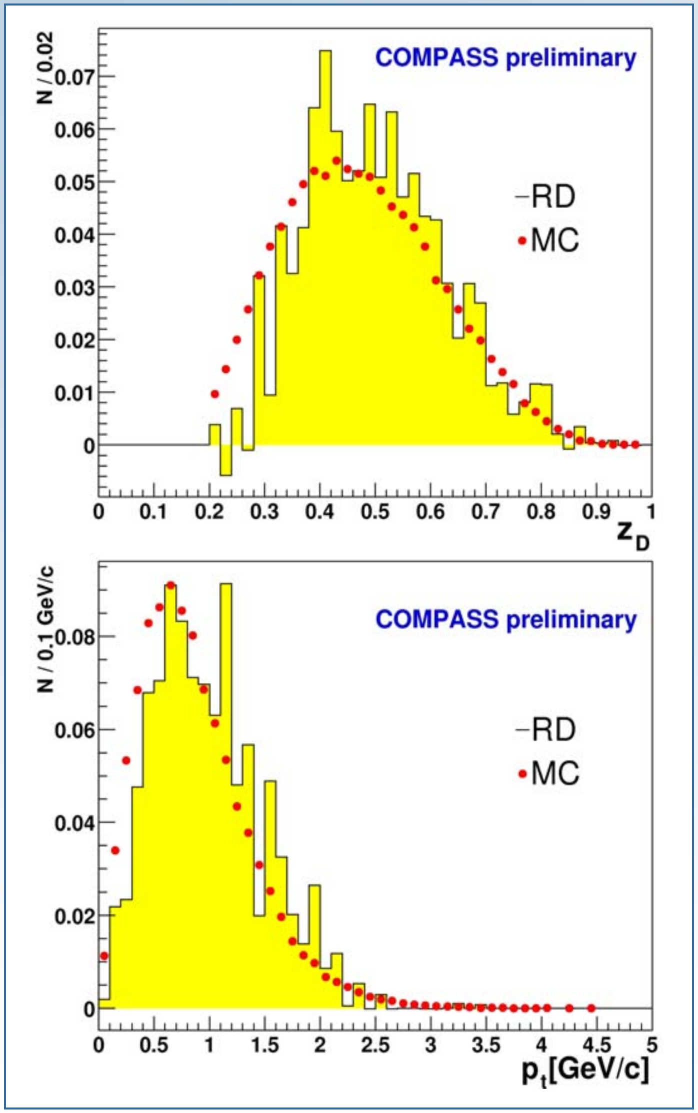
$$\frac{\Delta G}{G} = \frac{1}{a_{LL}\, f P_b P_T \, \sigma^{PGF} / \sigma^{tot}} \frac{N^{\overleftarrow{\Rightarrow}} - N^{\overleftarrow{\Leftarrow}}}{N^{\overleftarrow{\Rightarrow}} + N^{\overleftarrow{\Leftarrow}}}$$

- **$\sigma^{PGF}/\sigma^{tot}$ = S/(S+B) determined from the fit**

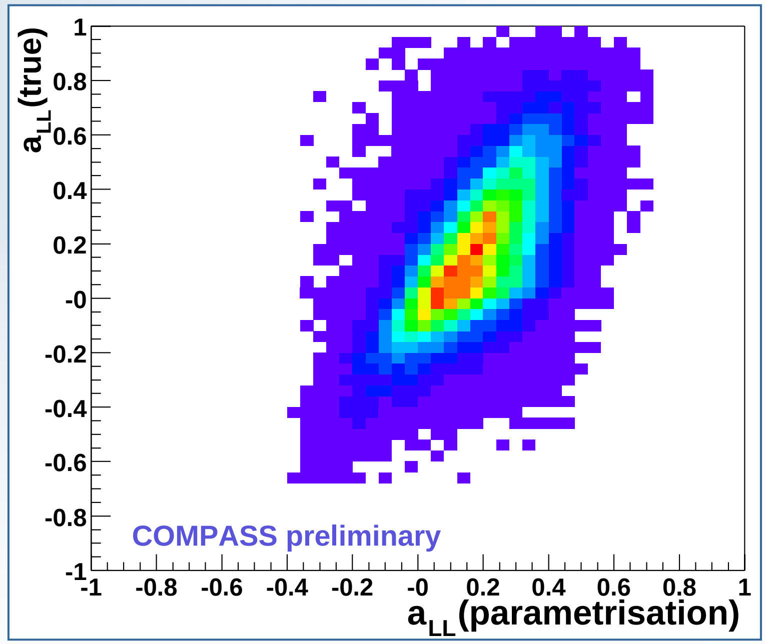
- **a_{LL} (m (gγ), y, Q^2,…) parametrised for data by p_t, z_D, y with Monte Carlo (AROMA with POLDIS)**

POLDIS: A.Bravar et al., *Comput. Phys. Commun. 105* (1997) 42

ΔG/G from Open Charm

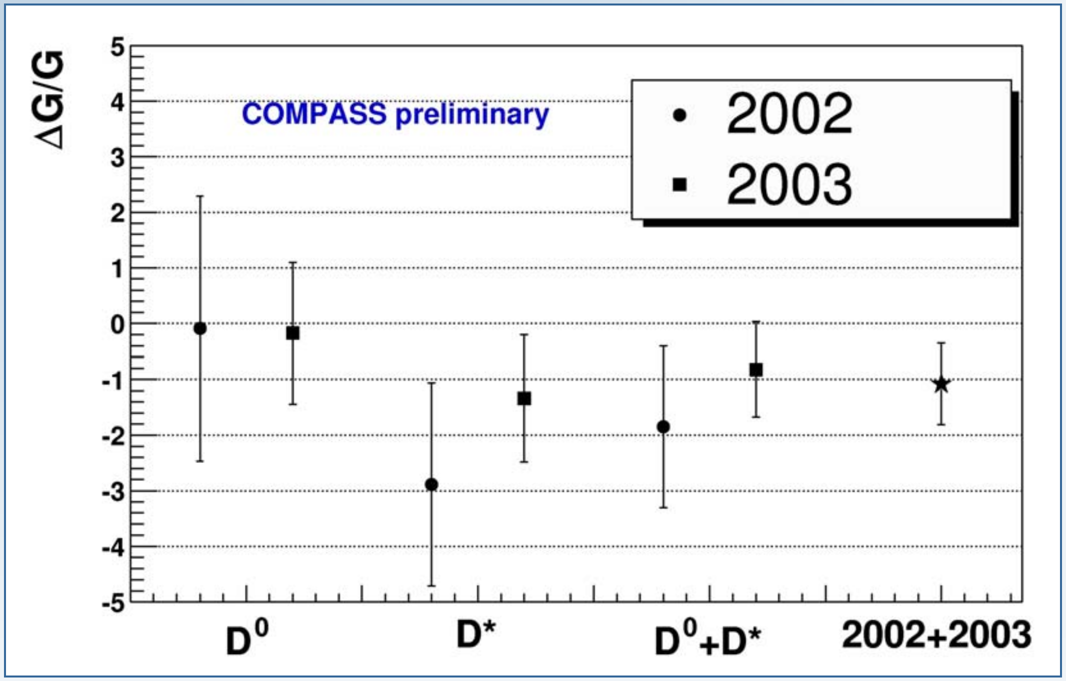


a_{LL} parametrised by p_t, z_D, y



comparison of background-subtracted data and AROMA Monte Carlo

ΔG/G from Open Charm



First measurement of ΔG/G with Open Charm tagging

$$\frac{\Delta G}{G} = -1.08 \pm 0.73 \qquad @ \left\langle x_g \right\rangle = 0.15 \pm 0.08$$

with 2004 data: 0.73 → 0.43

$\Delta G/G$ from HIGH p_t HADRON PAIRS

$Q^2 > 1$ GeV^2

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RIKEN, Dec 3 2005

High-p_t Hadron Pairs

- **enrich photon-gluon fusion events with high-p_t cuts**

  $p_t > 0.7$ GeV/c

  $p_{t1}^2 + p_{t2}^2 > 2.5$ (GeV/c)^2

  x_F, $z > 0.1$

  $m(h_1,h_2) > 1.5$ GeV/c^2

- **asymmetry contributions from background events**

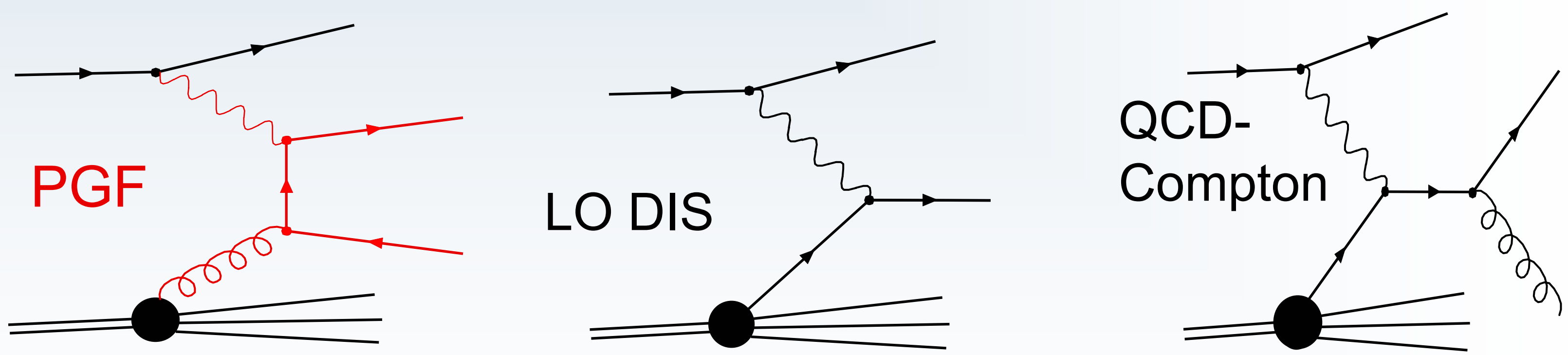
$$\frac{A_{LL}^{\mu N}}{D} = \frac{a_{LL}^{PGF}}{D} \frac{\Delta G}{G} \frac{\sigma^{PGF}}{\sigma^{tot}} + \frac{A_{LL}^{Background}}{D}$$

a_{LL} and σ^i/σ^{tot} from Monte Carlo

High-p_t Hadrons, $Q^2 > 1$ (GeV/c)^2

PGF and background

$$\frac{A_{LL}}{D} \approx \frac{a_{LL}^{PGF}}{D}\frac{\Delta G}{G}\frac{\sigma^{PGF}}{\sigma^{tot}} + A_1\frac{a_{LL}^{LO}}{D}\frac{\sigma^{LO}}{\sigma^{tot}} + A_1\frac{a_{LL}^{QCD-C}}{D}\frac{\sigma^{QCD-C}}{\sigma^{tot}}$$



High-p_t Hadrons, $Q^2 > 1$ $(GeV/c)^2$

PGF and background

$$\frac{A_{LL}}{D} \approx \frac{a_{LL}^{PGF}}{D}\frac{\Delta G}{G}\frac{\sigma^{PGF}}{\sigma^{tot}} + A_1\frac{a_{LL}^{LO}}{D}\frac{\sigma^{LO}}{\sigma^{tot}} + A_1\frac{a_{LL}^{QCD-C}}{D}\frac{\sigma^{QCD-C}}{\sigma^{tot}}$$

$x_B < 0.05$

→ in this region $A_1 \approx 0$ and LO DIS & QCD-Compton contributions can be neglected

COMPASS

High-p_t Hadrons, $Q^2 > 1$ $(GeV/c)^2$

PGF and background

$$\frac{A_{LL}}{D} \approx \frac{a_{LL}^{PGF}}{D}\frac{\Delta G}{G}\frac{\sigma^{PGF}}{\sigma^{tot}} + \underbrace{A_1 \frac{a_{LL}^{LO}}{D}\frac{\sigma^{LO}}{\sigma^{tot}} + A_1 \frac{a_{LL}^{QCD-C}}{D}\frac{\sigma^{QCD-C}}{\sigma^{tot}}}_{\sim 0}$$

$x_B < 0.05$

→ in this region $A_1 \approx 0$ and LO DIS & QCD-Compton contributions can be neglected

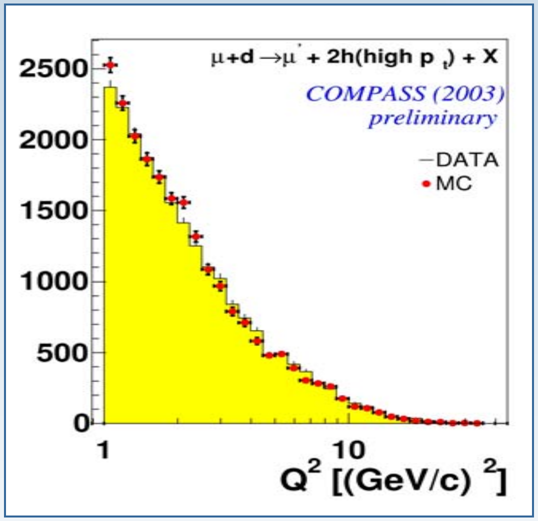
Asymmetry

$A_{LL}/D = -0.015 \pm 0.080_{\,stat.} \pm 0.013_{\,syst.}$ (2002 + 2003)

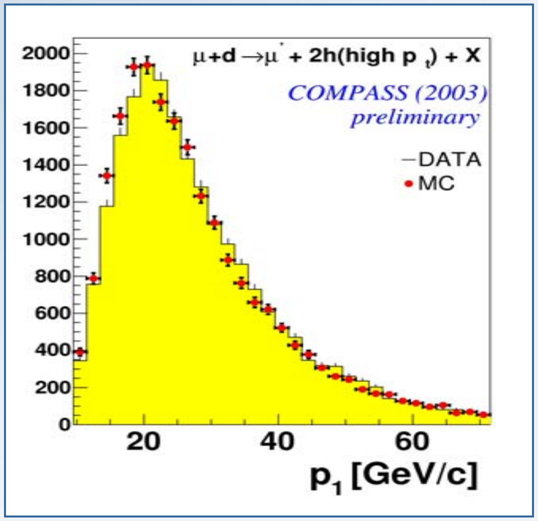
COMPASS

High-p_t Hadrons, $Q^2 > 1$ $(GeV/c)^2$

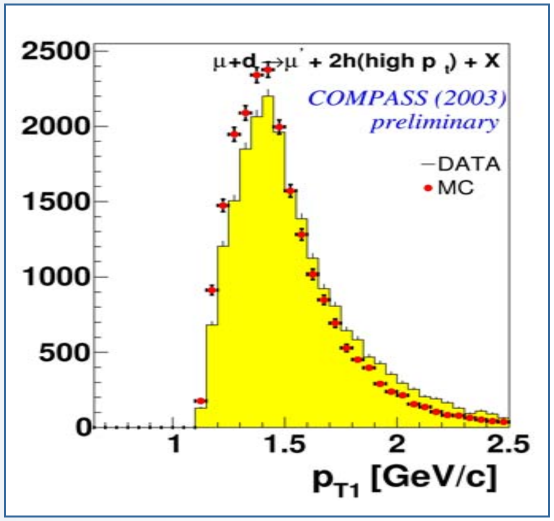
Data – Monte Carlo (LEPTO) comparison



Q^2



leading hadron: p



leading hadron: p_t

High-p_t Hadrons, $Q^2 > 1$ (GeV/c)^2

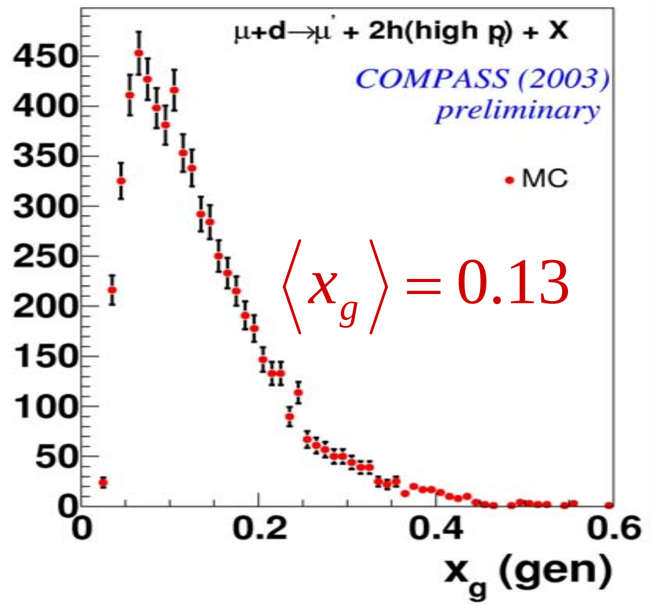
Results from Monte Carlo:

Ratio of PGF events $$\frac{\sigma^{PGF}}{\sigma^{tot}} = 0.34 \pm 0.07$$

$$a_{LL}^{PGF} / D = -0.75 \pm 0.05$$

Gluon polarisation

$$\frac{\Delta G}{G} = +0.06 \pm 0.31_{\text{stat.}} \pm 0.06_{\text{syst.}}$$



with 2004 data: 0.31 → 0.22

COMPASS

$\Delta G/G$ from HIGH p_T HADRON PAIRS

$Q^2 < 1$ GeV^2

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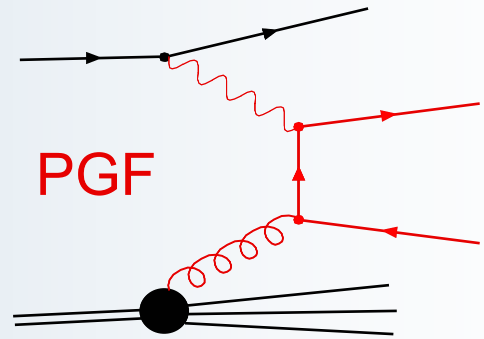
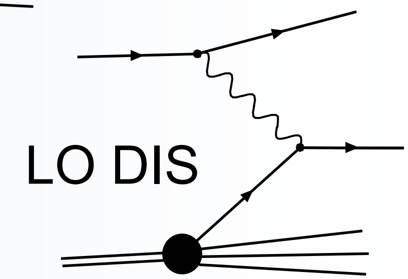
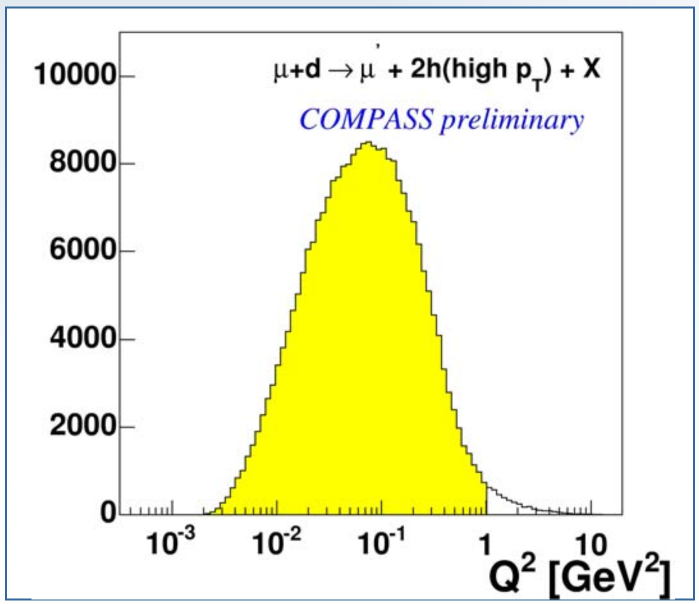
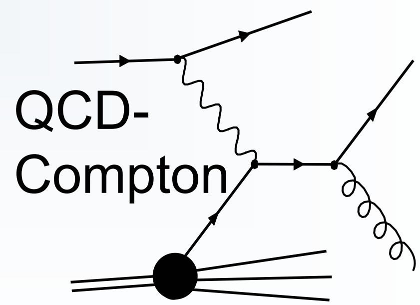
High-p_t Hadrons, $Q^2 > 1$ $(GeV/c)^2$



all Q^2

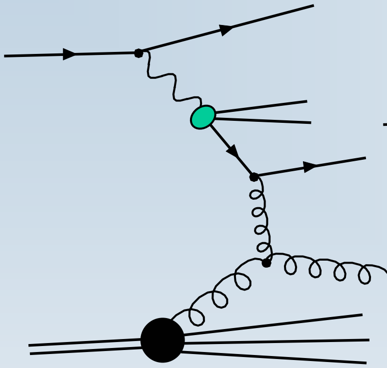


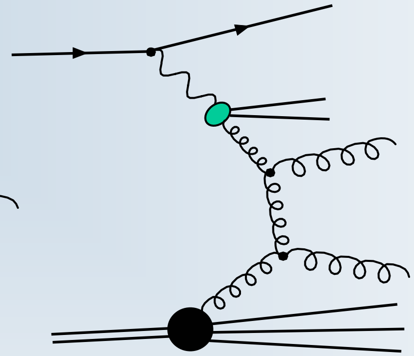


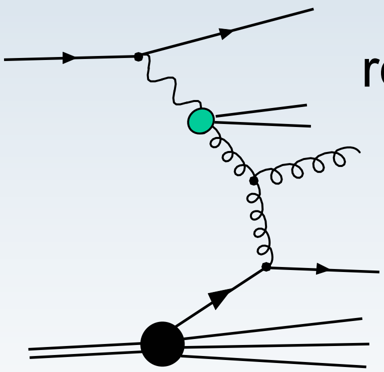


High-p_t Hadrons, $Q^2 < 1$ $(GeV/c)^2$

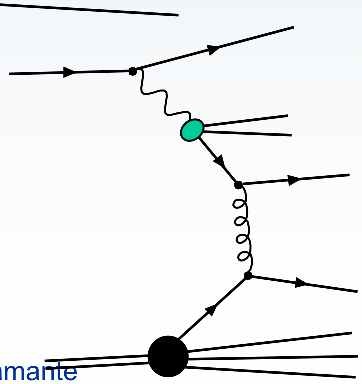
low Q^2



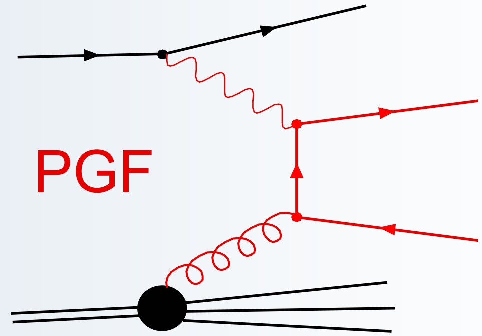




resolved photon

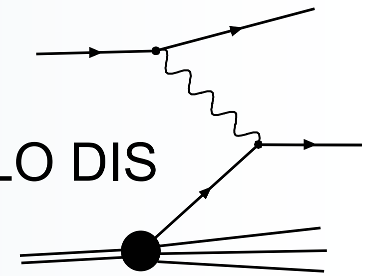


PGF

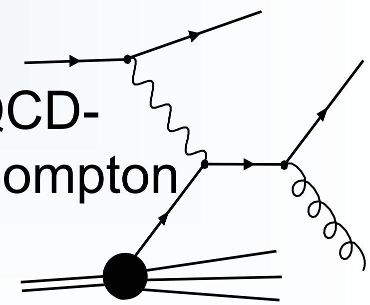


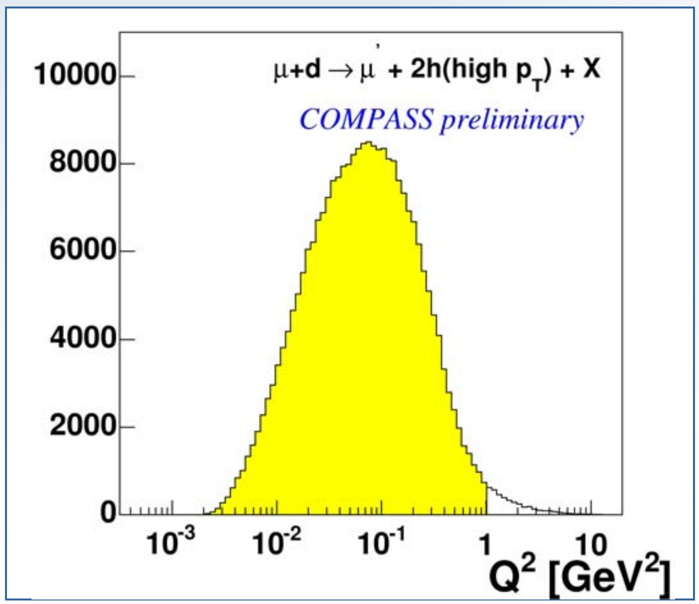
all Q^2

LO DIS



QCD-Compton

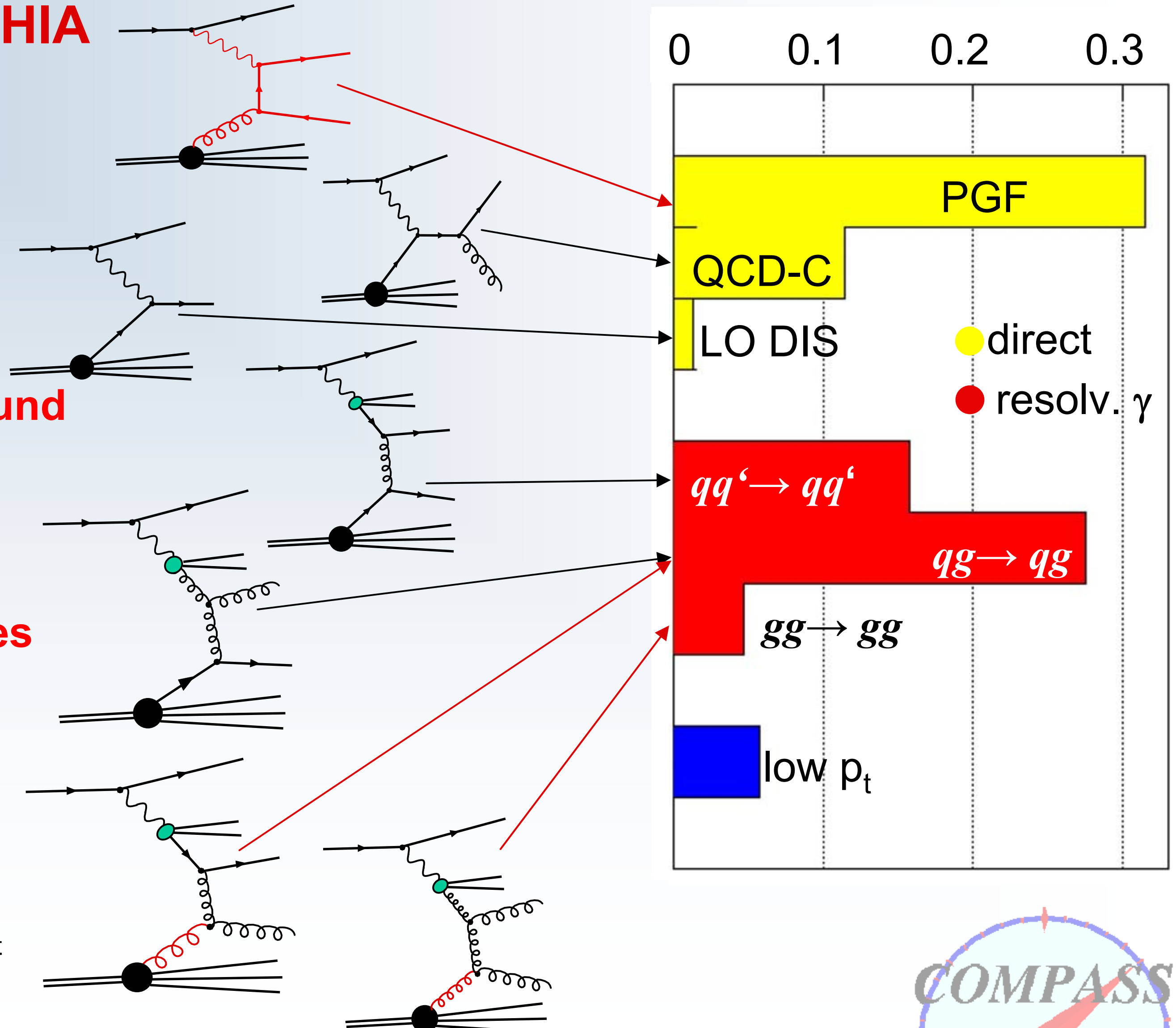




COMPASS

High-p_t Hadrons, $Q^2 < 1$ (GeV/c)^2

Results from PYTHIA



Background

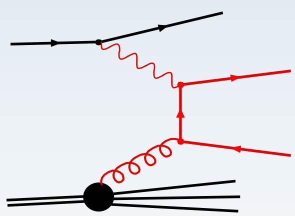
- as for $Q^2 > 1$ (GeV/c)^2
- additional background from resolved photon events
- additional processes sensitive to gluons in the nucleon

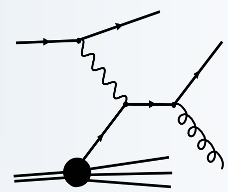
neglect LO DIS and low p_t

High-p_t Hadrons, $Q^2 < 1$ (GeV/c)^2

Determination of ΔG/G

$$\frac{A_{LL}^{\mu N}}{D} = R^{PGF} \; a_{LL}^{PGF}/D \; \frac{\Delta G}{G} + R^{QCD-C} \; a_{LL}^{QCD-C}/D \; A_1$$



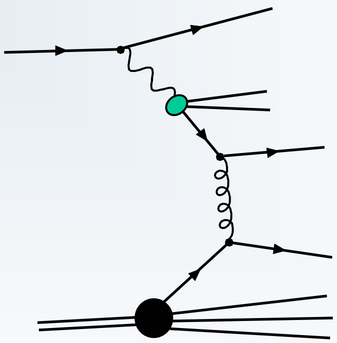


$$R^i = \frac{\sigma^i}{\sigma^{tot}}$$

COMPASS

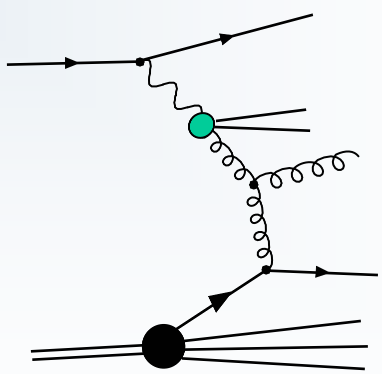
High-p$_t$ Hadrons, $Q^2 < 1$ (GeV/c)^2

$$A_{LL}^{\mu N} / D = R^{PGF} \; a_{LL}^{PGF} / D \; \Delta G / G + R^{QCD-C} \; a_{LL}^{QCD-C} / D \; A_1$$
$$+ R^{qq'} \; a_{LL}^{qq'} / D \; A_1 \; A_1^{\gamma}$$



High-p_t Hadrons, $Q^2 < 1$ $(GeV/c)^2$

$$A_{LL}^{\mu N}\Big/D = R^{PGF}\ a_{LL}^{PGF}/D\ \ \Delta G\Big/G + R^{QCD-C}\ a_{LL}^{QCD-C}/D\ A_1 + R^{qq'}\ a_{LL}^{qq'}/D\ A_1\ A_1^{\gamma} + R^{qg}\ a_{LL}^{qg}/D\ A_1\left(\Delta G\Big/G\right)^{\gamma}$$



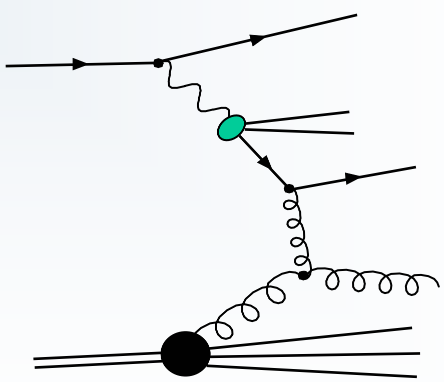
High-p_t Hadrons, $Q^2 < 1$ $(GeV/c)^2$

$$
A_{LL}^{\mu N}\Big/D = R^{PGF}\; a_{LL}^{PGF}/D\; \Delta G\big/G + R^{QCD-C}\; a_{LL}^{QCD-C}/D\; A_1
$$

$$
+ R^{qq'}\; a_{LL}^{qq'}/D\; A_1\; A_1^{\gamma}
$$

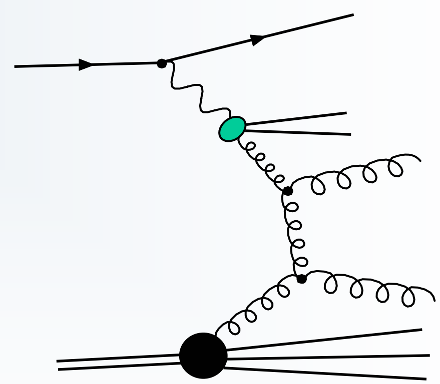
$$
+ R^{qg}\; a_{LL}^{qg}/D\; A_1\; \left(\Delta G\big/G\right)^{\gamma}
$$

$$
+ R^{qg}\; a_{LL}^{qg}/D\; \Delta G\big/G\; A_1^{\gamma}
$$



High-p_t Hadrons, $Q^2 < 1$ $(GeV/c)^2$

$$A_{LL}^{\mu N}/D = R^{PGF}\, a_{LL}^{PGF}/D\, \Delta G/G + R^{QCD-C}\, a_{LL}^{QCD-C}/D\, A_1$$
$$+ R^{qq'}\, a_{LL}^{qq'}/D\, A_1\, A_1^{\gamma}$$
$$+ R^{qg}\, a_{LL}^{qg}/D\, A_1 \left(\Delta G/G\right)^{\gamma}$$
$$+ R^{qg}\, a_{LL}^{qg}/D\, \Delta G/G\, A_1^{\gamma}$$
$$+ R^{qg}\, a_{LL}^{qg}/D \left(\Delta G/G\right)\left(\Delta G/G\right)^{\gamma}$$



COMPASS

High-p_t Hadrons, $Q^2 < 1$ (GeV/c)^2

Contribution from resolved photons

- **unknown:** polarised PDFs of the photon
- **known:** unpolarised PDFs of the photon

→ **use unpolarised PDFs to constrain polarised PDFs**

$$-q^{\gamma}(x,Q^2) < \Delta q^{\gamma}(x,Q^2) < q^{\gamma}(x,Q^2)$$

→ **additional theoretical uncertainty**

Glück, Reya, Sieg, *Eur. Phys. J. C20* (2001) 271

High-p_t Hadrons, $Q^2 < 1$ (GeV/c)^2

Determination of ΔG/G

2002 + 2003: **$A_{LL}/D = 0.002 \pm 0.019_{stat.} \pm 0.003_{syst}$**

$$\frac{\Delta G}{G} = +0.024 \pm 0.089_{\text{stat.}} \pm 0.014_{\text{exp. syst.}} \pm 0.052_{\text{MC syst.}} \pm 0.018_{\text{photon}}$$

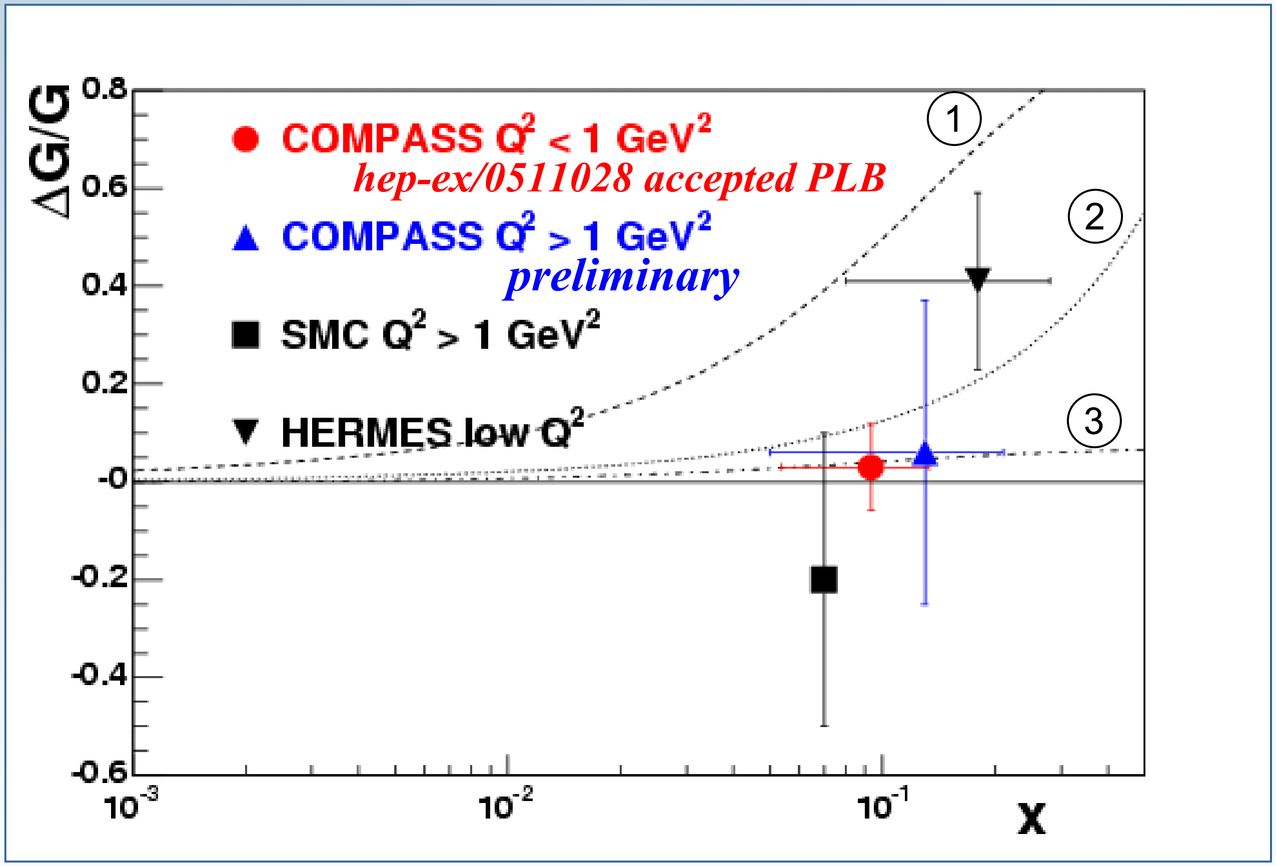
$$\boxed{\frac{\Delta G}{G} = +0.024 \pm 0.089_{\text{stat.}} \pm 0.057_{\text{syst.}}} \qquad \langle x_g \rangle = 0.095$$

hep-ex/0511028, CERN-PH-EP/2005-049, Phys. Lett. B

with 2004 data: 0.089 → 0.06

COMPASS

High-p_t Hadrons - 2002-2003 data



GRSV2000 with

① ΔG = 2.5

② ΔG = 0.6

③ ΔG = 0.2

Glück et al., *Phys. Rev. D63* (2001) 094005

results favour small ΔG or

ΔG crosses 0 around $x_g \approx 0.1$

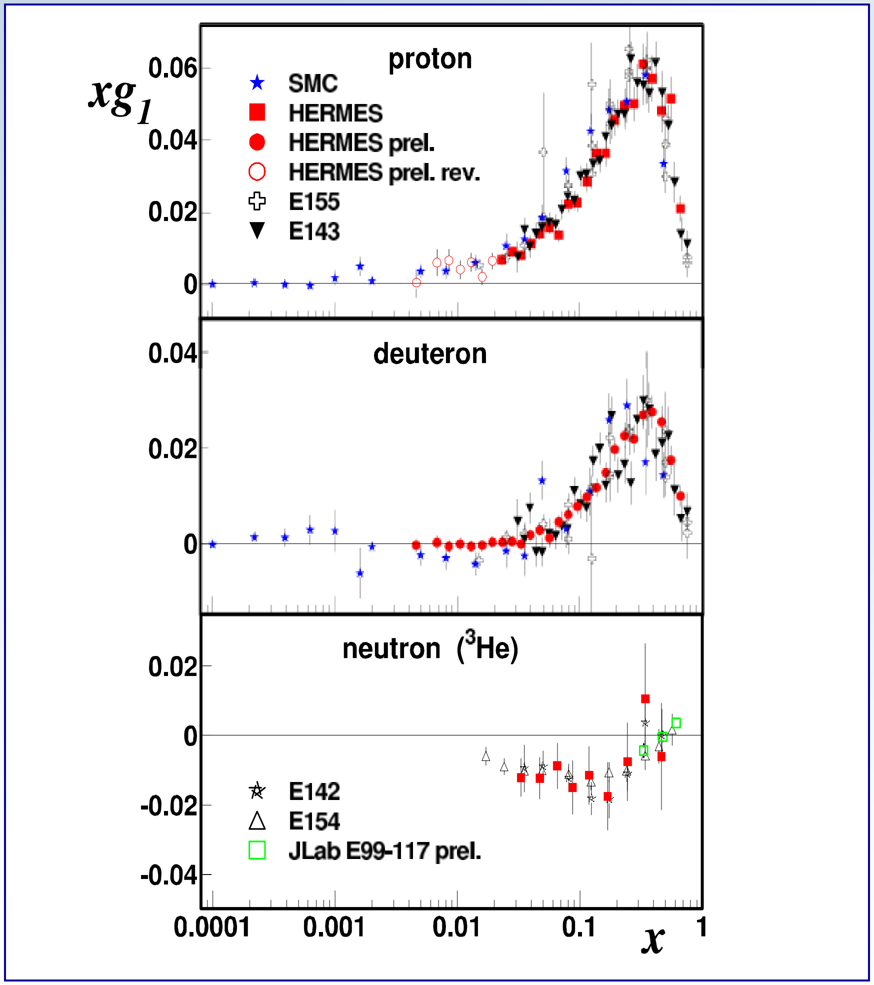
$\Delta G/G$ from QCD EVOLUTION

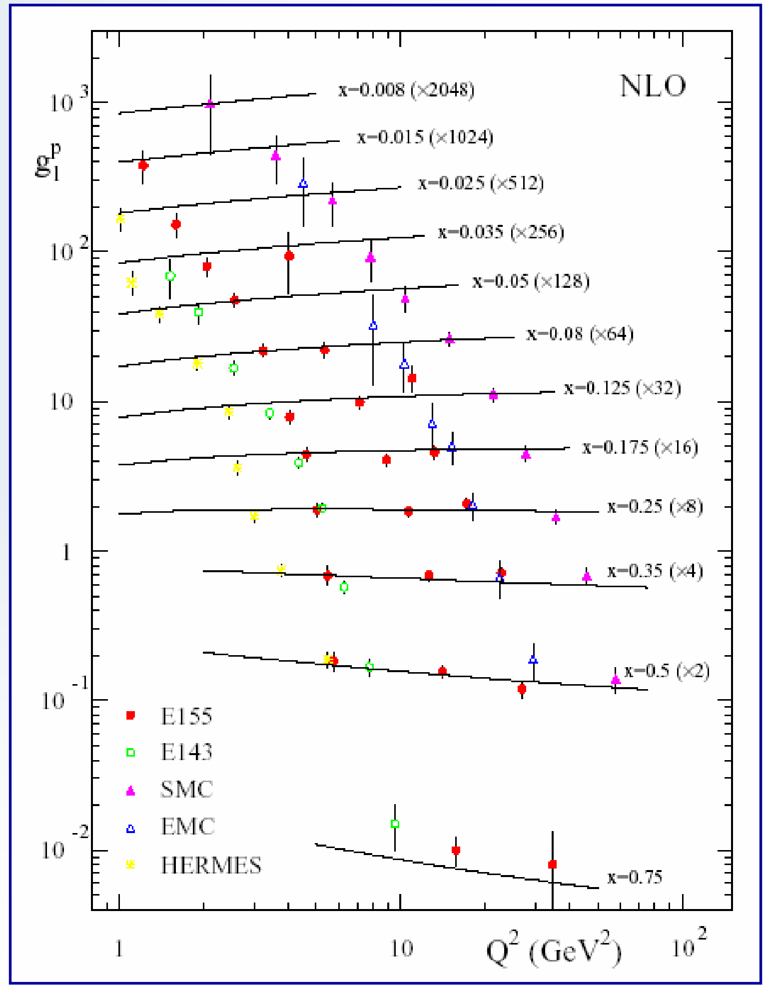
F. Bradamante
RIKEN, Dec 3 2005

Polarized DIS

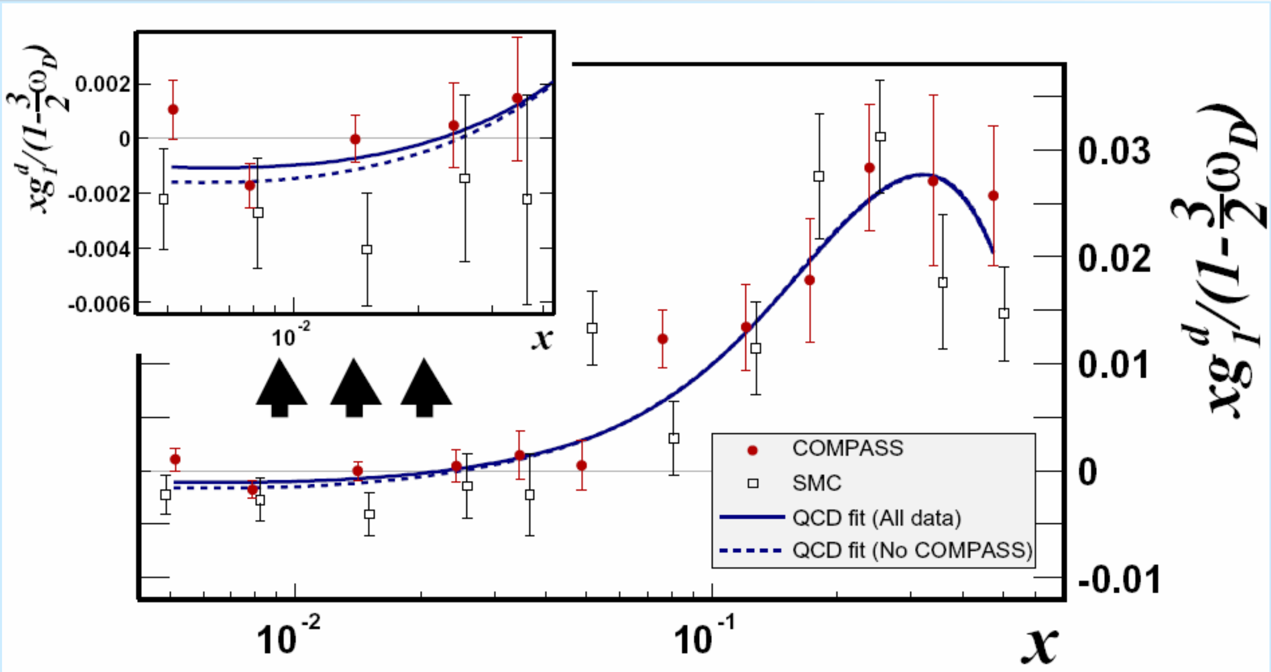
Parton Model

$$\rightarrow \quad g_1 = \tfrac{1}{2} \sum e_i^2 \, [\Delta q_i(x,Q^2) + \Delta \bar{q}_i(x,Q^2)]$$





New measurement of g_1 of the deuteron



COMPASS
2002-2003 data
PLB 612 (2005) 154

- **most precise measurement for $0.004 < x < 0.03$**
- **new NLO QCD fit, precision of a_0 improves factor 2 ($Q^2 = 4$ GeV^2)**

$$a_0 = \Delta\Sigma = 0.237^{+0.024}_{-0.029}$$

($\overline{MS}$ *scheme*)

$\Delta G = 0.4 \pm 0.2$ (stat) ± ?? (syst) ***[COMPASS SPIN2005]***

Results from QCD anaysis of g_1 data

Stamenov – SPIN05

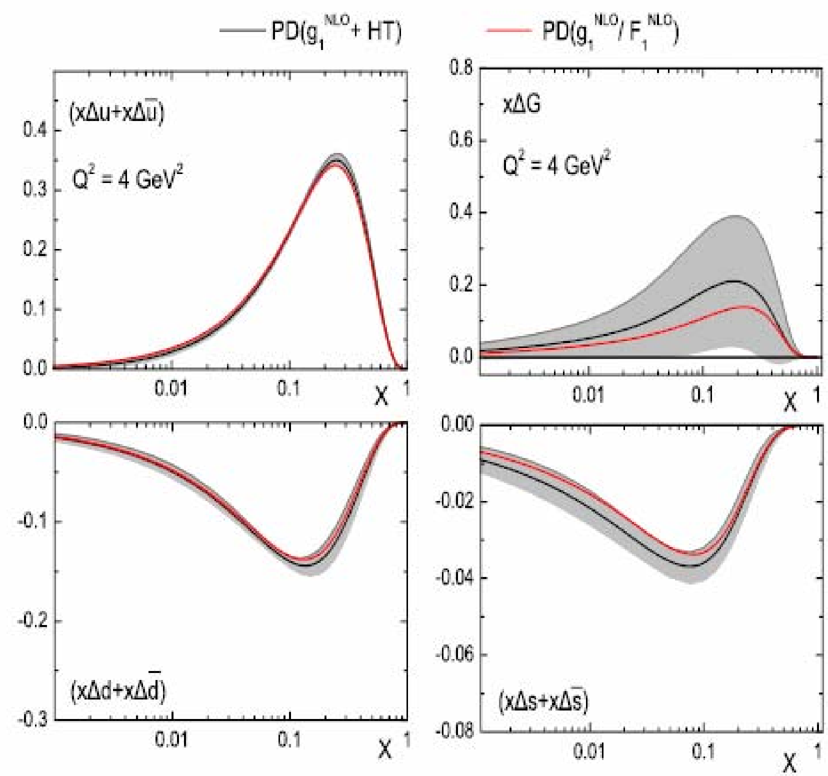
- $(\Delta u + \Delta\bar{u}), (\Delta d + \Delta\bar{d})$ well determined
- $(\Delta s + \Delta\bar{s})$ reasonably well determined and negative if accept for a_8 its SU(3) symmetric value a_8 = 3F-D = 0.58
- ΔG not well constrained

$$PD(g_1^{NLO} + HT) \Leftrightarrow PD(g_1^{NLO} / F_1^{NLO})$$

$$\chi^2_{DF,NLO} = 0.872 \Leftrightarrow \chi^2_{DF,NLO} = 0.874$$

In g_1 data fit HT corrections are important !

NLO($\overline{MS}$)

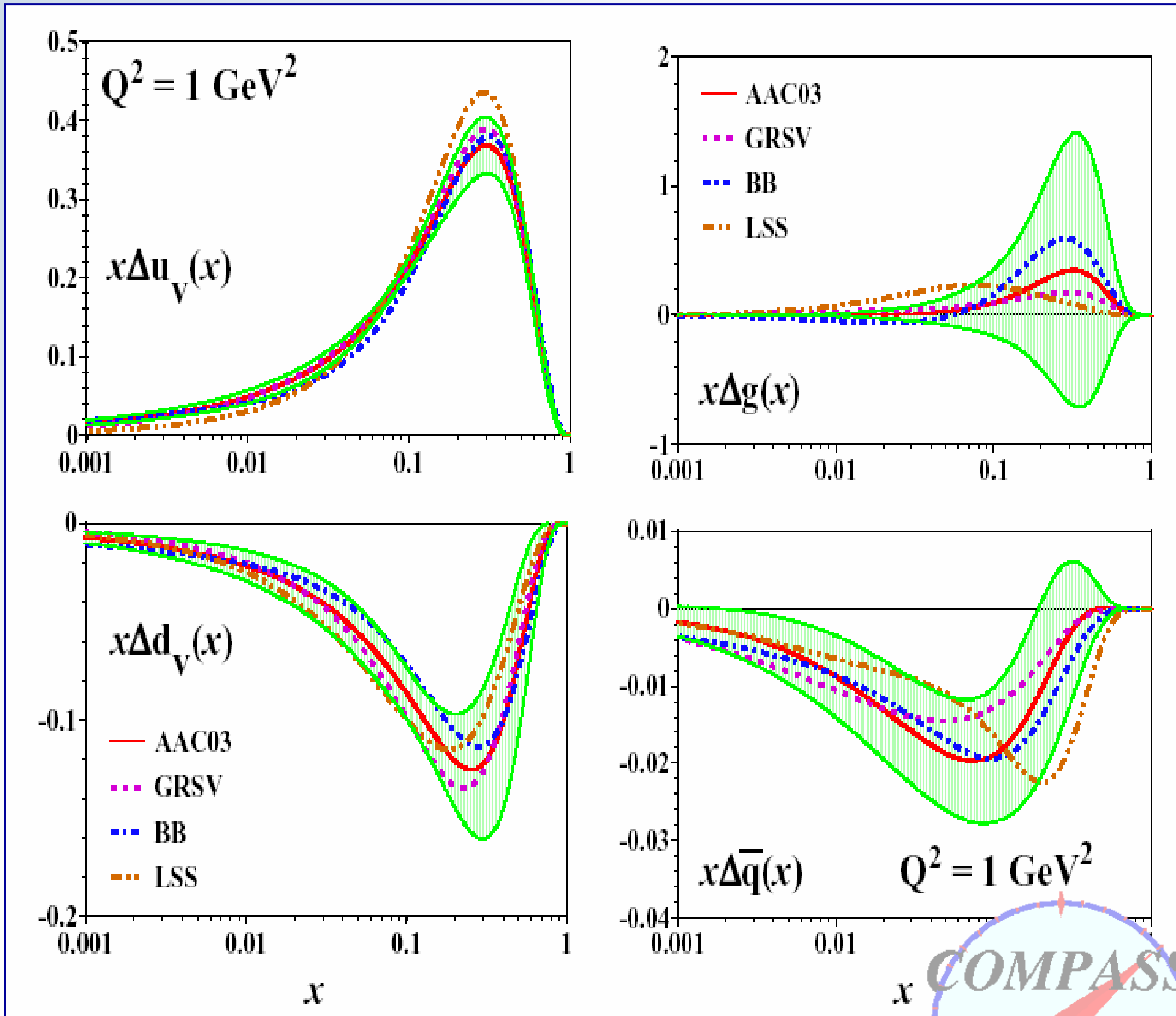


Fit	$\Delta\Sigma(Q^2)_{\overline{MS}}$	$\Delta G(Q^2)_{JET}$	$\Delta\Sigma_{JET}$
LSS01	0.21 ± 0.10	0.68 ± 0.32	0.37 ± 0.07
LSS05	0.19 ± 0.06	0.29 ± 0.32	0.29 ± 0.08

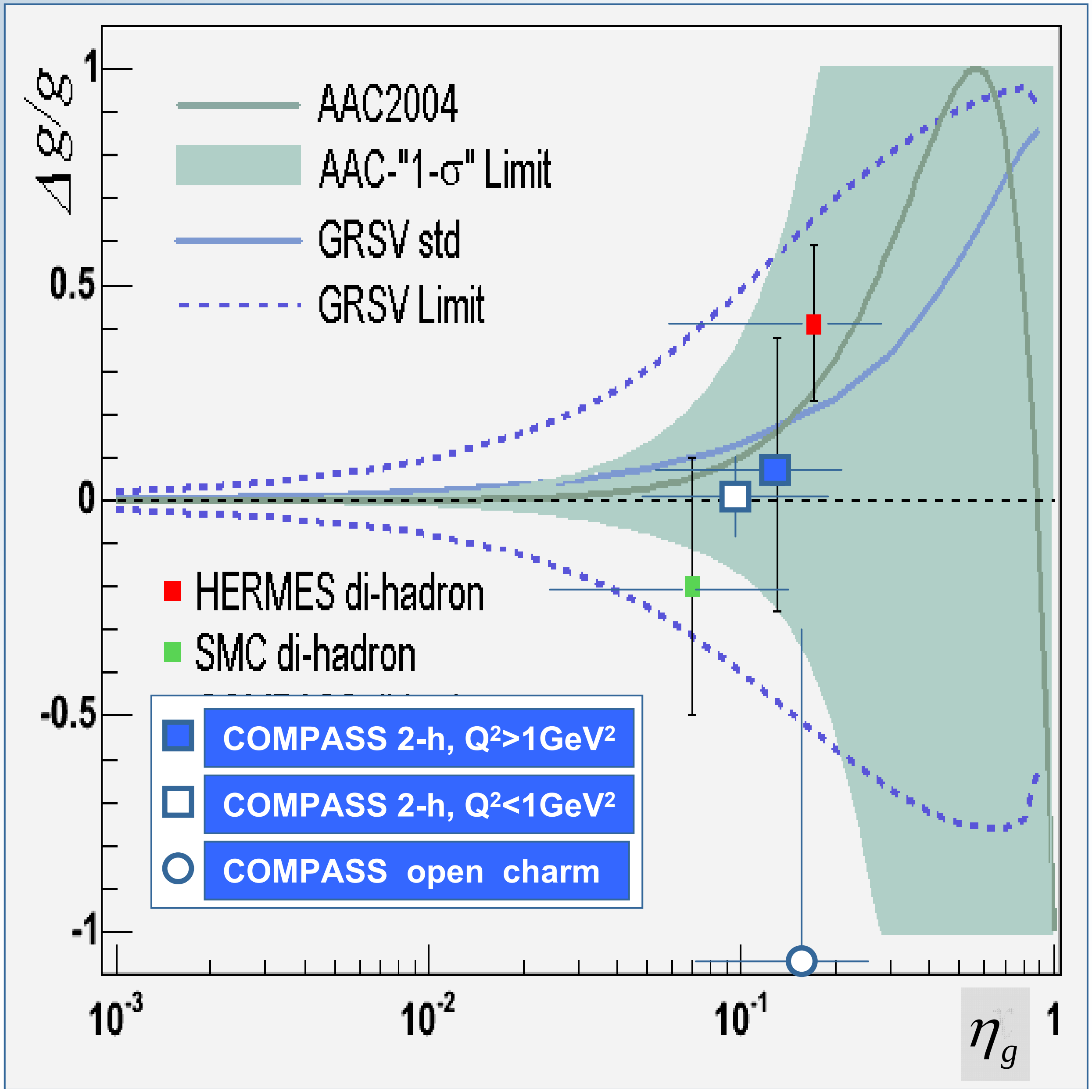
Results from QCD anaysis of g_1 data

Asymmetry **A**nalysis **C**ollaboration, **M. Hirai, S. Kumano and N. Saito, PRD (2004)**

- **Valence Dist's are determined well**
- **Sea Dist' is poorly constrained**
- **Gluon can be either >0, =0, <0**



Results on ΔG



PERSPECTIVES for ΔG

from collected COMPASS data

	2002+2003	+2004 (proj.)
$Q^2 < 1\ \mathrm{GeV}^2$	$\frac{\Delta G}{G} = 0.024 \pm \underline{0.089} \pm 0.057$	$\pm\underline{0.065}$
$Q^2 > 1\ \mathrm{GeV}^2$	$\frac{\Delta G}{G} = 0.06 \pm \underline{0.31} \pm 0.06$	$\pm\underline{0.22}$
charm	$\frac{\Delta G}{G} = -1.08 \pm \underline{0.73}$	$\pm\underline{0.43}$

- only one point cannot a priori rule out large values of ΔG
- looking at QCD fits of g_1 data, our results favor $\Delta G < 0.5$

COMPASS

NEAR FUTURE (2006-2010)

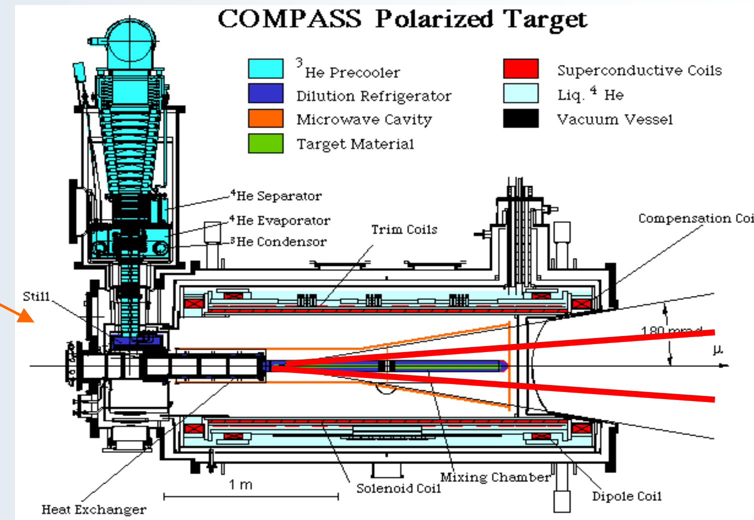
Workshop on Future Physics @ COMPASS
Yellow Report CERN-2004-011, 22 Nov. 2004

- **IMPORTANT UPGRADE of the SPECTROMETER ONGOING**
  - RICH
  - TRACKING
  - E.M. CALORIMETERS
  - O. D. P.T. MAGNET
  - Veto System
- **2006 MUON RUNNING**
  - 100 days 6LiD Longitudinal Polarization
  - 30 days NH3 Transverse Polarization
- **2007 HADRON RUNNING**
  - CENTRAL PRODUCTION
  - with 300 GeV hadron beam and LH2 target
- **2008- 2010 COMPLETE THE APPROVED MUON and HADRON PROGRAMME**

COMPASS upgrades for 2006

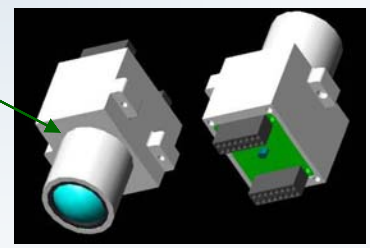
New solenoid magnet

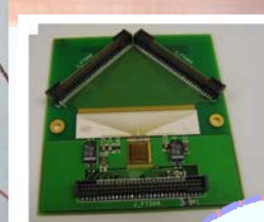
- 70 mrad → 180 mrad



RICH upgrade

- Central region: MAPMT system
  - More photons
  - Improved S/N
- Outer region: New faster electronics
  - Improved S/N





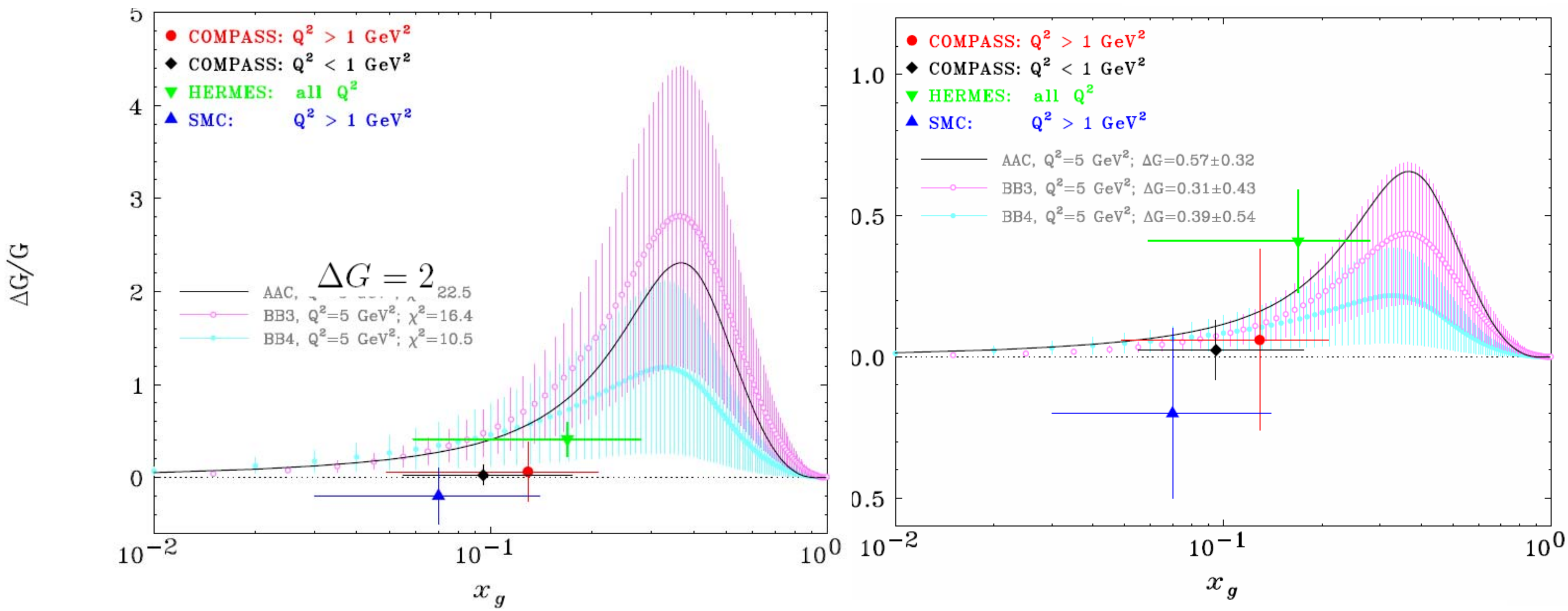
Other important upgrades:

- Large Drift Chamber
- RICHWall
- Full ECAL coverage
- trigger

Direct Estimate of the Gluon Polarization in the Nucleon

John Ellis Marek Karliner

CERN-PH-TH/2005-001
TAUP–2792-05
Cavendish-HEP-05/02



There are good prospects for a significant improvement soon in the accuracy with which ΔG is known, thanks to new data from COMPASS and RHIC. The present data are insufficient to exclude strongly the hypothesis that all the apparent negative value of Δs might be induced by gluons via renormalization in one particular scheme. The forthcoming data should be able to resolve this issue. However, they might not be able to determine whether gluons carry a large part of the nucleon spin, $\Delta G \sim 1/2$, or whether their contribution is as small as that due to the quarks, as expected qualitatively in chiral soliton models [3]. There are surely still many interesting twists and turns still to come in our understanding of the nucleon spin, but direct determinations of the gluon spin now seem poised to make an important step forward.