Results from COMPASS

F.Kunne – CEA Saclay, France
on behalf of the COMPASS collaboration

- Nucleon spin
- COMPASS experiment at CERN
- Physics results: Quark and gluon polarizations, transversity,...
- Spectrometer upgrades and future running

Nucleon Spin

$$\tfrac{1}{2} = \tfrac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$
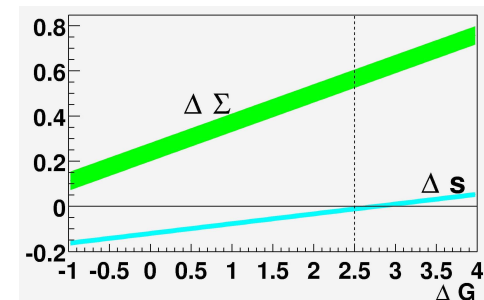
quark   gluon   orbital momenta

Predictions:
- Naive quark parton model + relativistic corr. $\Delta\Sigma \sim 0.75$
- QCD ; Ellis- Jaffe   assuming $\Delta s = 0$, $\Delta\Sigma \sim 0.60$

Measurements: Polarized DIS $\vec{\ell}\,\vec{N}$ spin aymmetry $A_1 = \dfrac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \dfrac{g_1}{F_1}$

$$\int_0^1 g_1\, dx$$ + neutron and hyperon decay measurements
Gives small $a_0 \sim 0.2 - 0.3$

- In QPM, $a_0 = \Delta\Sigma$
- In QCD (AB scheme) $a_0 = \Delta\Sigma - n_f\,(\alpha_s/2\pi)\,\Delta G$

For $a_0 = 0.3$, need large $\Delta G \sim 2.5$ (and $L_z \sim -2.3$) to restore $\Delta\Sigma \sim 0.6$

$\rightarrow$ motivated direct measurements of ΔG

F.Kunne, Saclay

Longitudinally polarized muons   160 GeV/c
        2.10^8 μ/ spill (4.8s / 16.2s)
        P_B= -80%
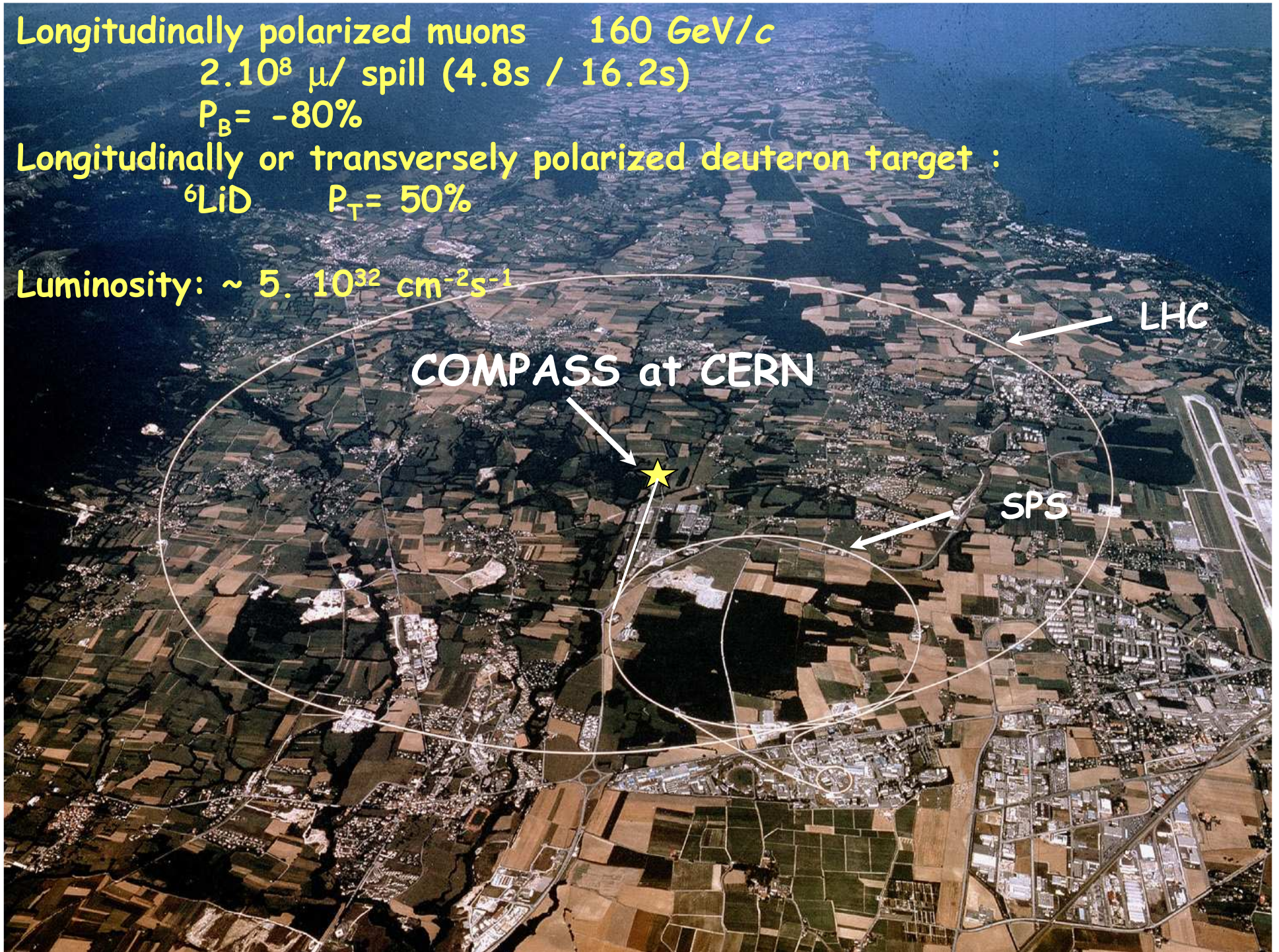Longitudinally or transversely polarized deuteron target :
        ^{6}LiD P_T= 50%

Luminosity: ~ 5. 10^{32} cm^{-2}s^{-1}

LHC

COMPASS at CERN

SPS

COMPASS Collaboration at CERN

Common **M**uon and **P**roton **A**pparatus

for **S**tructure and **S**pectroscopy

Czech Rep., France, Germany, India, Israel, Italy, Japan, Poland, Portugal, Russia and CERN

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

240 physicists, 28 institutes

F.Kunne, Saclay

COMPASS Physics Program

Muon beam

Longitudinally or transversely polarized target

- Gluon contribution to nucleon spin

 + quark polarization (g_1, $\Delta\Sigma$, Δq flavor decomposition)

- Transversity

Others: ρ, ϕ, J/ψ, Λ, ... production

Hadron beams π,K,p

- Primakoff reactions: π, K polarisabilities
- Spectroscopy: glueballs, hybrids, charm

H_2 target

- Generalized parton distributions (project ~2010)

F.Kunne, Saclay

COMPASS two stage spectrometer

SM1

SM2

^{6}LiD Target

160 GeV μ

50 m

Polarized beam and target

F.Kunne, Saclay

COMPASS two stage spectrometer

SM2

SM1

50 m

^{6}LiD Target

Gems

160 GeV μ

Micromegas

SciFi Silicon

Polarized beam and target

Small Area Trackers,

F.Kunne, Saclay

COMPASS two stage spectrometer

SM2

SM1

SM1

SM2

50 m

MWPC

Straws

Polarized beam and target

^{6}LiD Target

Gems

Small Area Trackers,

160 GeV μ

Drift chambers

Large area trackers,

Micromegas

SciFi Silicon

F.Kunne, Saclay

COMPASS two stage spectrometer

μ Filter

ECal & HCal

SM2

50 m

RICH

SM1

MWPC

Straws

⁶LiD Target

Micromega

160 GeV μ

SciFi Silicon

Polarized beam and target

Small Area Trackers,

Large area trackers,   PID

RICH Response

counts

×10³

hadrons with
p_h> 10 GeV/c

π K p

20

0

0   0.5   1

mass [GeV/c²]

• Runs in 2002, 2003, 2004
• Resume in 2006, ...

F.Kunne, Saclay

COMPASS polarized target
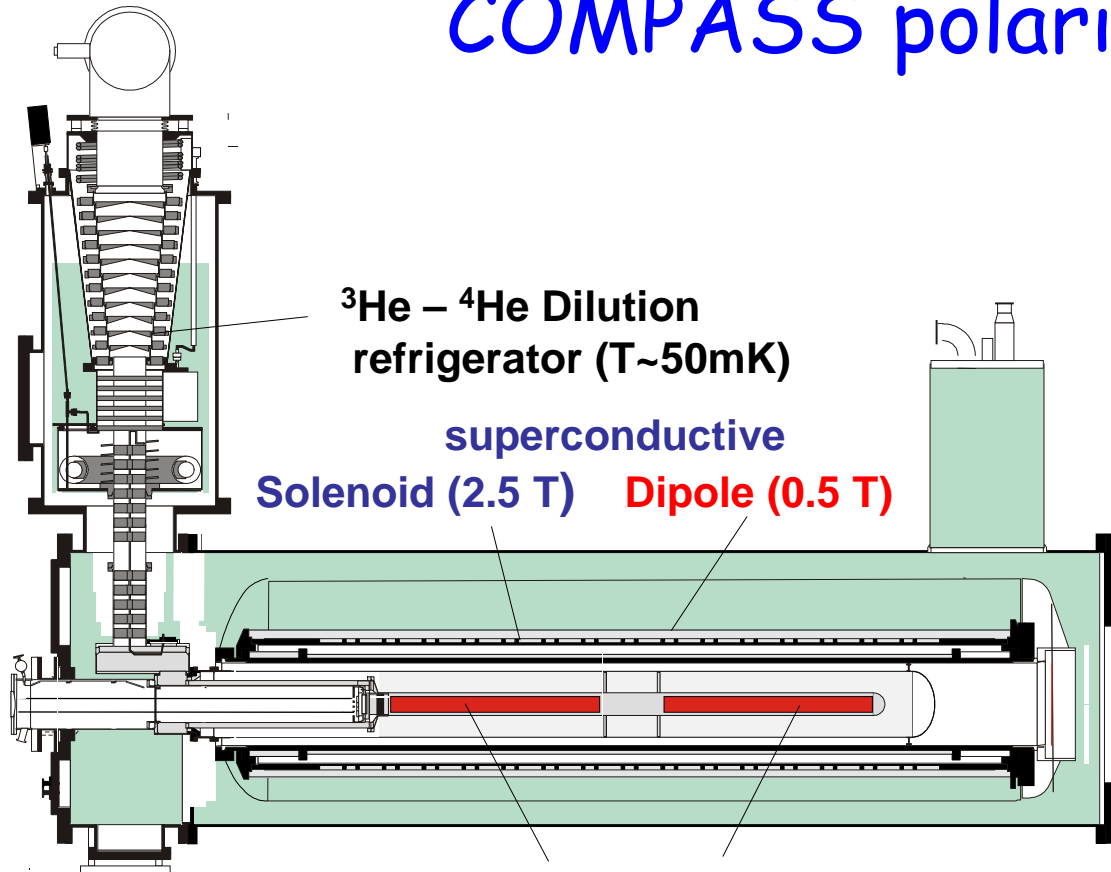
^{3}He – ^{4}He Dilution refrigerator (T~50mK)

superconductive
Solenoid (2.5 T)   Dipole (0.5 T)

^{6}LiD:
Polarization 50%
Dilution factor 0.4

two 60 cm cells
with opposite polarization
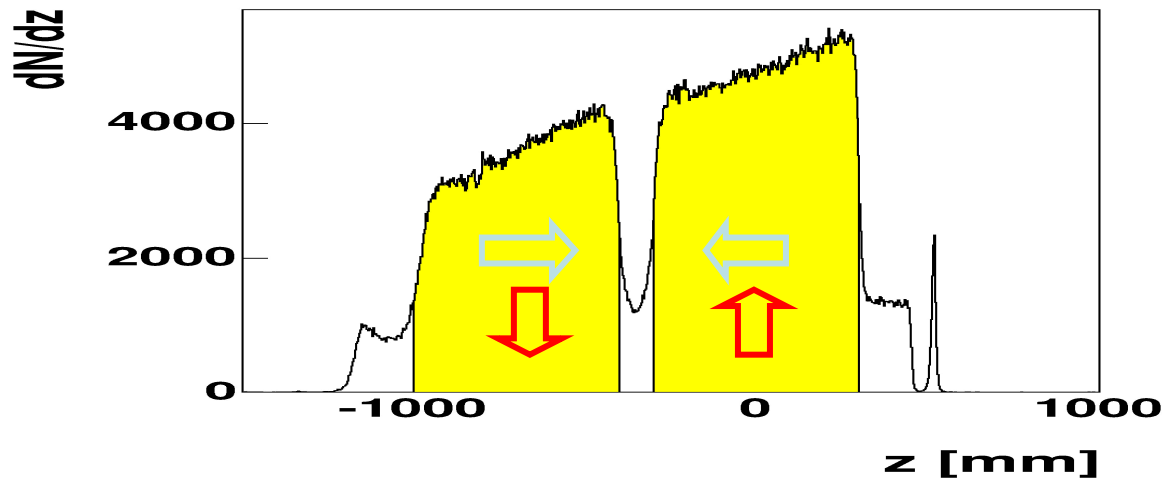
Polarizations reversed:
- every 8 hours in longitudinal
- once a week in transverse

dN/dz

4000

2000

0

-1000   0   1000

z [mm]

How to extract ΔG ?

- QCD evolution of g_1

- Spin asymmetry in Photon Gluon Fusion events

- Polarized pp collisions

F.Kunne, Saclay

New COMPASS NLO QCD fit

- Uses world data on g_1

- Includes COMPASS
  2002+2003 g_1^d data
  PLB 612 (2005) 154

-most precise measurement at
0.004 < x < 0.03

-important for low x extrapolation

-2004 data to come very soon with
better statistics at high x
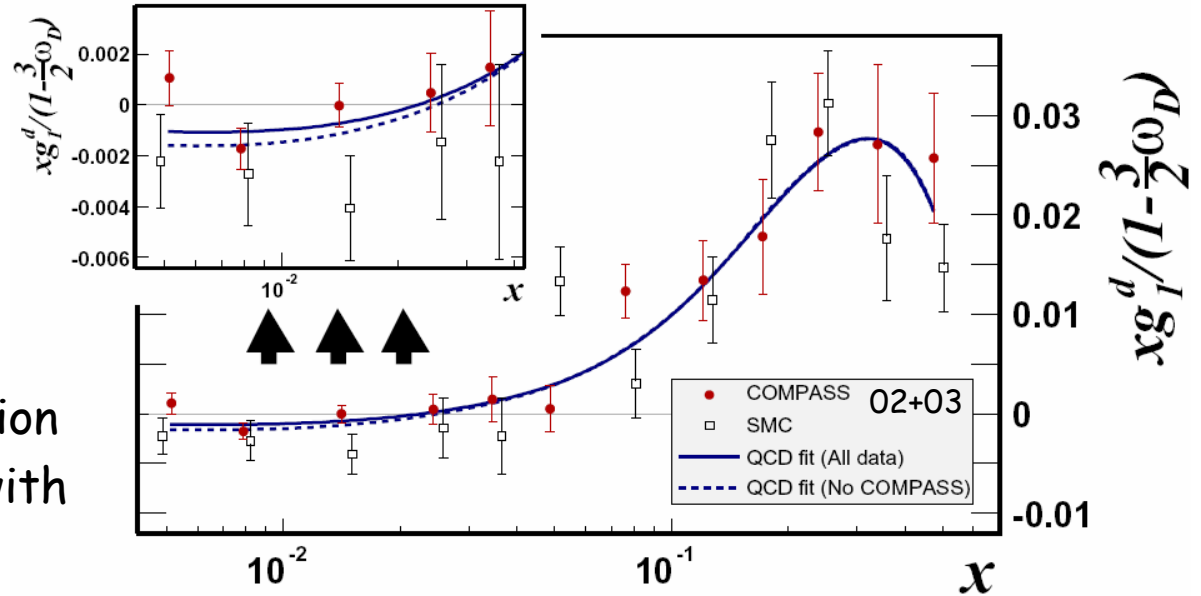
Prelim. results from COMPASS NLO QCD fit $Q^2 = 3$ GeV^2

$$\Delta\Sigma = 0.25 \pm 0.02 \pm ?$$

Uncertainty on $\Delta\Sigma$ reduced
(0.03 without COMPASS data)

$$\Delta G = 0.4 \pm 0.2 \pm ?$$

Hint on ΔG value, but for a
given parametrisation

F.Kunne, Saclay

COMPASS new result on A^d_1

Inclusive asymmetry   (high Q^2 data published).   New results at low Q^2:

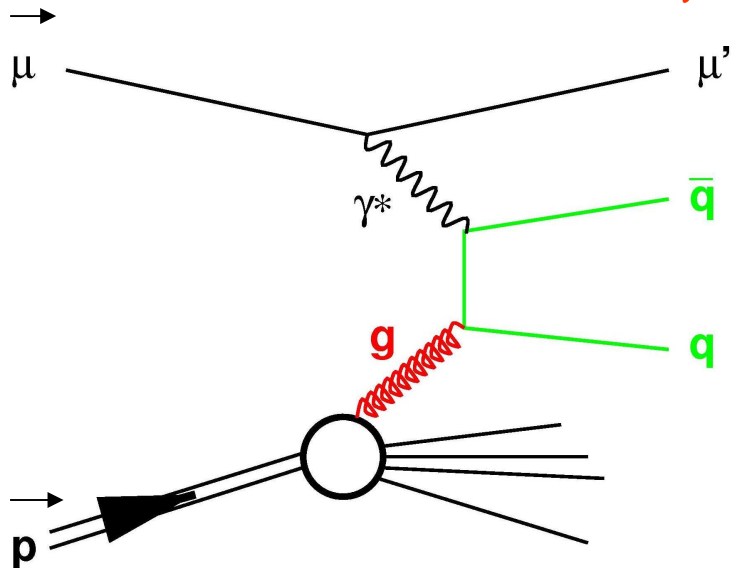See talk by Marcin Stolarski

2002-2003 data.
Still more data to come
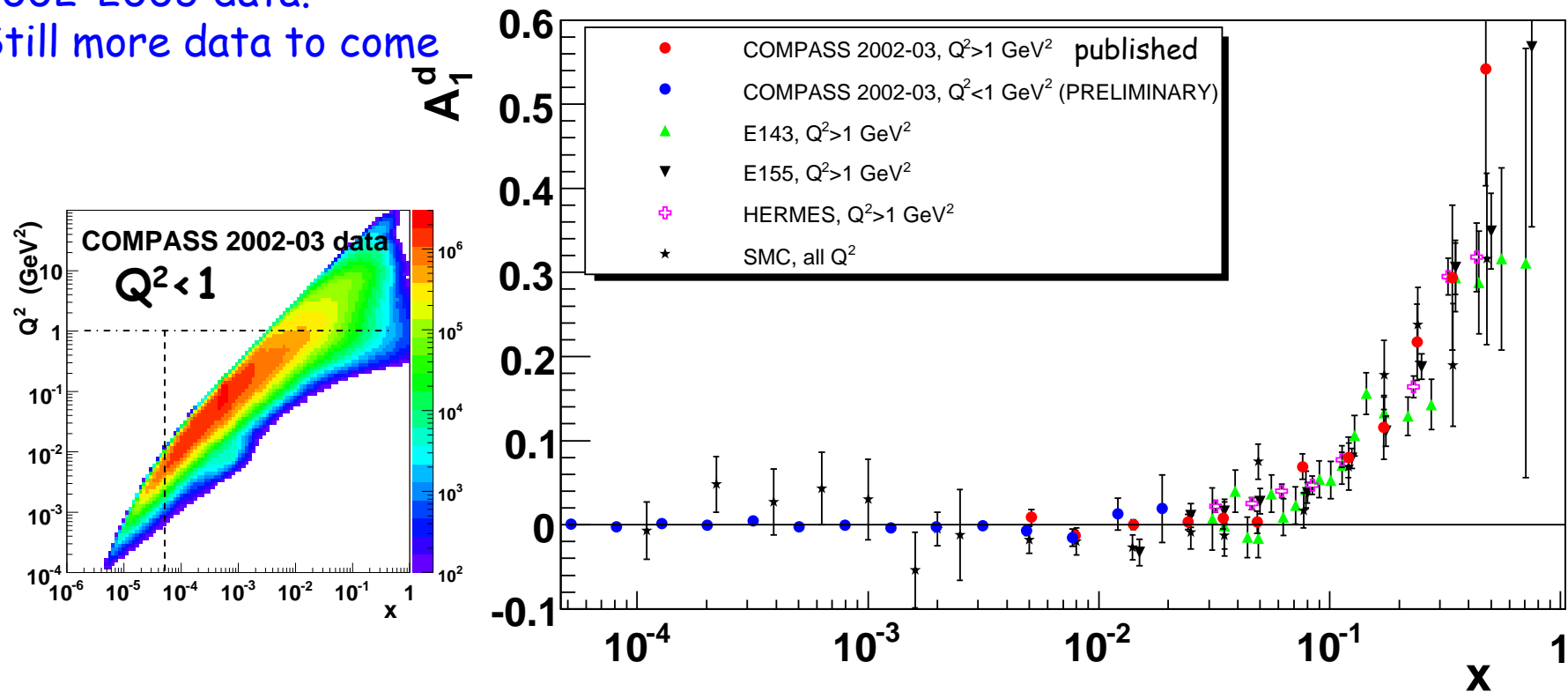
COMPASS explores x values 10 times smaller than SMC
Errors 10 times smaller

F.Kunne, Saclay

ΔG/G from Photon Gluon Fusion events

F.Kunne, Saclay

ΔG/G measurement

Photon gluon fusion $\gamma g \rightarrow q\bar{q}$

- charm $c \rightarrow D^0 \rightarrow K\pi$

scale $\mu^2 = 4\, m_c^2$

theory understood, but:

combinatorial background & limited stat:

$\sigma = 100\,nb,\ BR = 4\%,$ kaon identification

challenging experiment

F.Kunne, Saclay

ΔG/G measurement

Photon gluon fusion $\gamma g \rightarrow q\bar{q}$
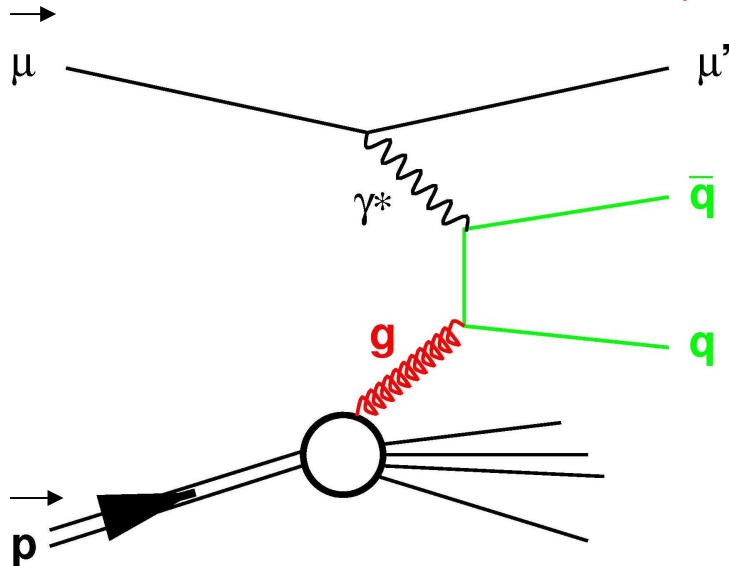
- charm $c \rightarrow D^0 \rightarrow K\pi$

scale $\mu^2 = 4 m_c^2$

theory understood, but:

combinatorial background & limited stat:

$\sigma = 100nb$, $BR = 4\%$, kaon identification

challenging experiment

- high p_T hadron pair $q\ \bar{q} \rightarrow h\ h$

- scale $\mu^2 = Q^2$ or Σp_T^2
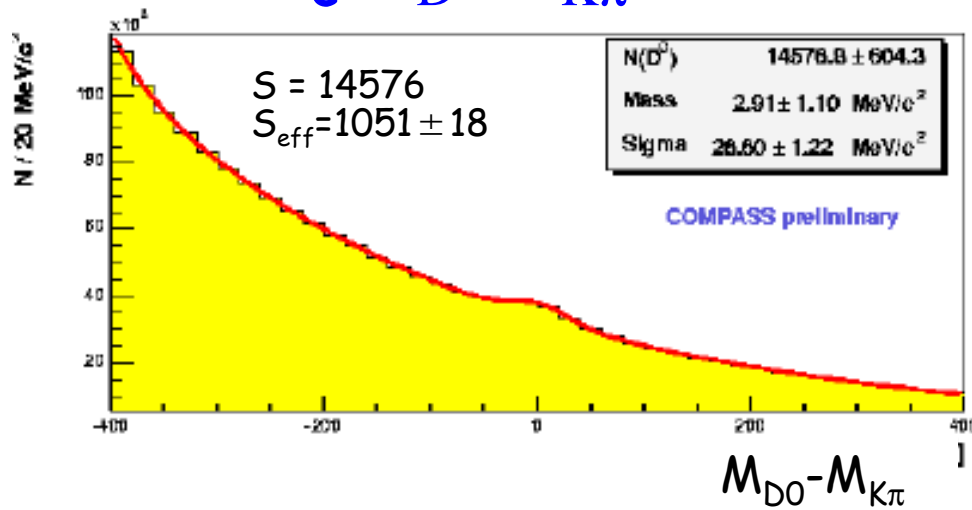
large statistics

but physical background

2 cases: $Q^2 > 1$ GeV/c²

$Q^2 < 1$ GeV/c²

F.Kunne, Saclay

Open charm 2002-2004 data

D⁰

$$c \to D^0 \to K\pi$$

S = 14576
S_{eff} = 1051 ± 18

N(D⁰)	14576.9 ± 604.3	
Mass	2.91 ± 1.10	MeV/c²
Sigma	26.60 ± 1.22	MeV/c²

COMPASS preliminary

$M_{D0} - M_{K\pi}$

D⁰ tagged by D*

$$c \to \quad D^* \to D^0 \, \pi_s \to K\pi\pi_s$$

S = 3869
S_{eff} = 1966 ± 51

N(D⁰)	3868.9 ± 104.4	
Mass	4.86 ± 0.76	MeV/c²
Sigma	28.58 ± 0.87	MeV/c²

COMPASS preliminary

$M_{D0} - M_{K\pi}$ [MeV/c²]

$$< A_{LL} / D > = \frac{S}{S+B} < a_{LL} / D > \frac{\Delta G}{G}(x_g)$$

F.Kunne, Saclay

$\Delta G/G$ from charm - result

COMPASS Data 2002-2004 $\Delta G/G$
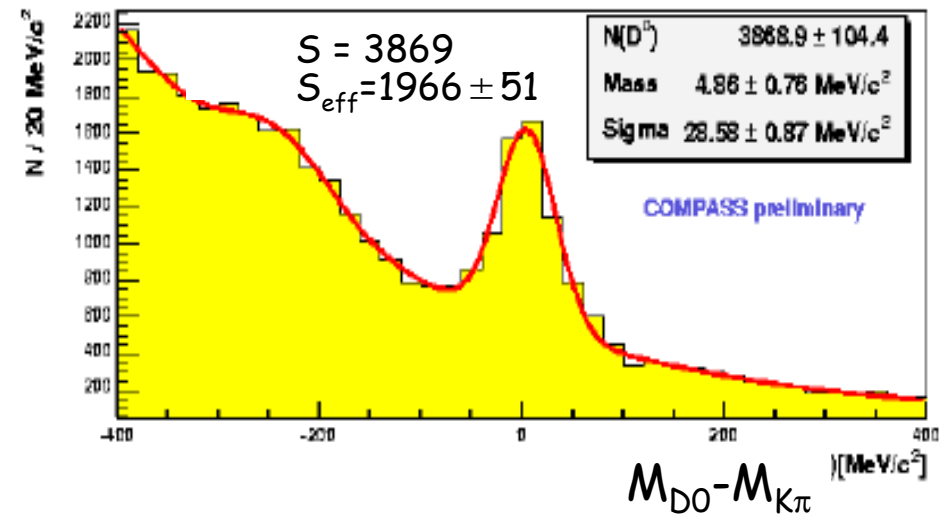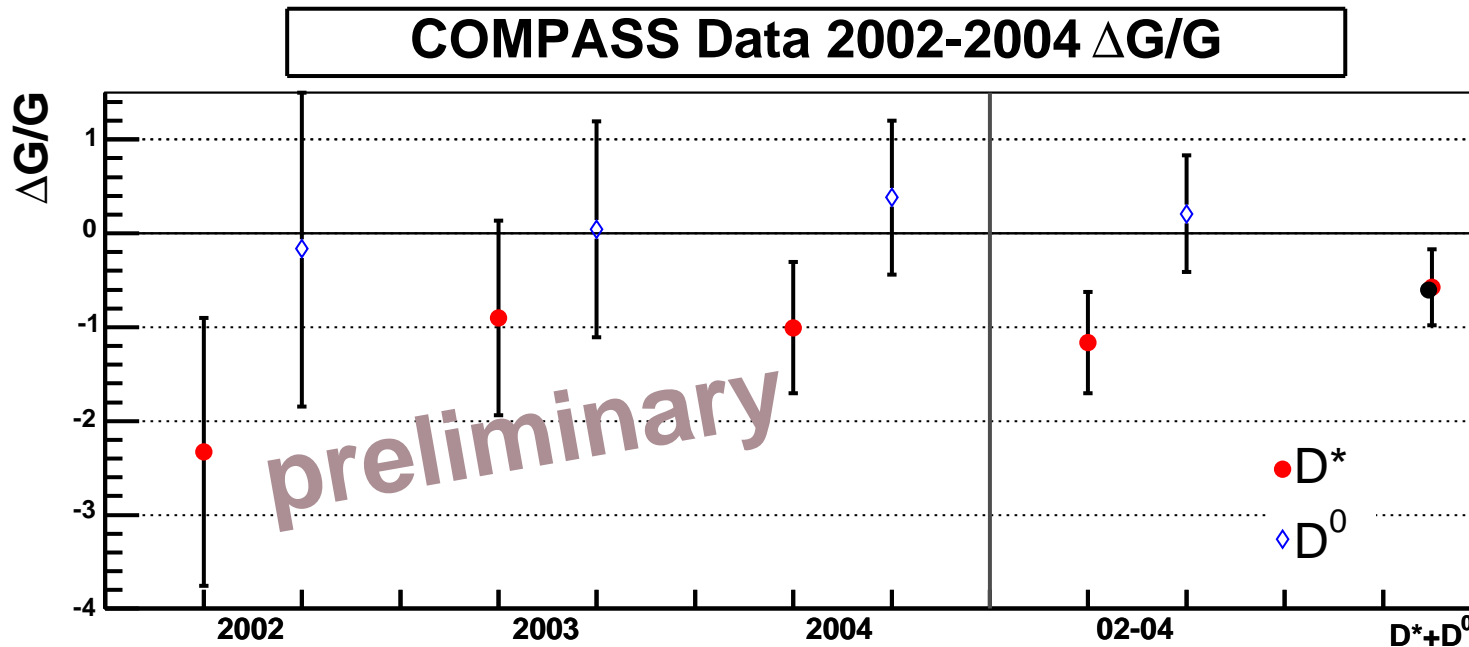
$$\Delta G/G = -0.57 \pm 0.41$$

$x_g = 0.15$ scale $\mu^2 = 13$ GeV^2

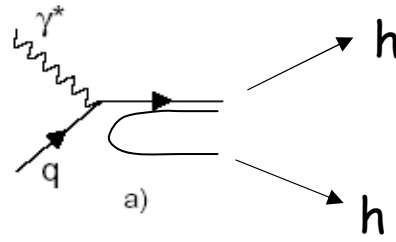D^0 and D^* results within 1.7 σ

Much progress in charm analysis; no systematic effect larger than statistics oberved yet. Study ongoing.

F.Kunne, Saclay
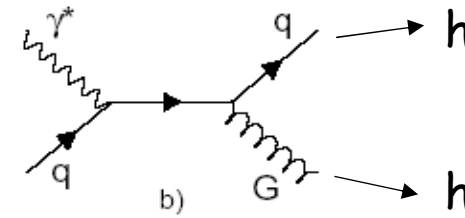
$\Delta G/G$ from high p_T hadron pairs

$Q^2 > 1 \; GeV/c^2$
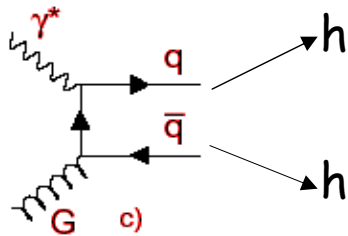
Photon Gluon Fusion (PGF)   Leading process   Gluon radiation

PGF ~ 33 % (Lepto MC, preliminary)

$$\frac{A_{\parallel}}{D} = R_{pgf} \left\langle \frac{\hat{a}_{pgf}}{D} \right\rangle \left(\frac{\Delta G}{G} \right)^d + \; \dots$$

$\begin{cases} \Sigma p_T^2 > 2.5 \; GeV^2 \;\; \text{(LO suppr)} \\ x_{Bj} < 0.01 \quad\quad\quad \text{(A_1 small)} \end{cases}$

Preliminary result 2002-2003 data:

$\Delta G/G = 0.06 \pm 0.31$ (stat) ± 0.06 (syst) $\langle x_g \rangle \sim 0.13$

Value compatible with 0. Systematics small

F.Kunne, Saclay

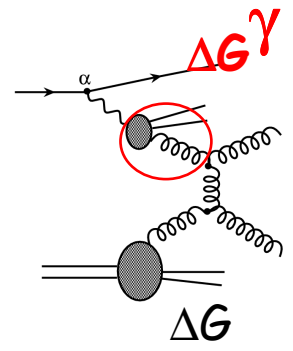# $\Delta G/G$ from high p_T hadron pairs $\boxed{Q^2 < 1 \; GeV/c^2}$
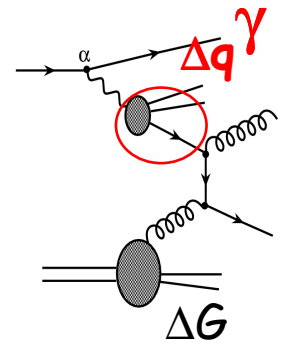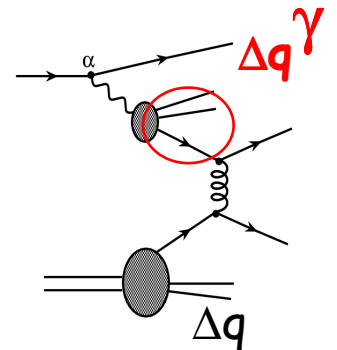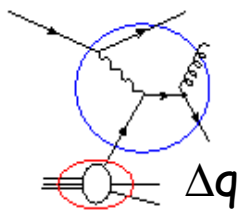
$Q^2 < 1$ **10 times more data**, but additional background: **resolved photon** processes

PGF ~30%

QCDC

Δq

Resolved
photons

~50%

Δq^γ Δq^γ ΔG^γ

Δq ΔG ΔG

MC simul
PYTHIA

F.Kunne, Saclay

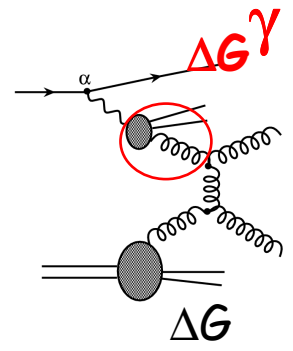# $\Delta G/G$ from high p_T hadron pairs $\quad$ $Q^2 < 1$ GeV/c^2

$Q^2 < 1$ $\quad$ 10 times more data, but additional background: resolved photon processes

MC simul
PYTHIA
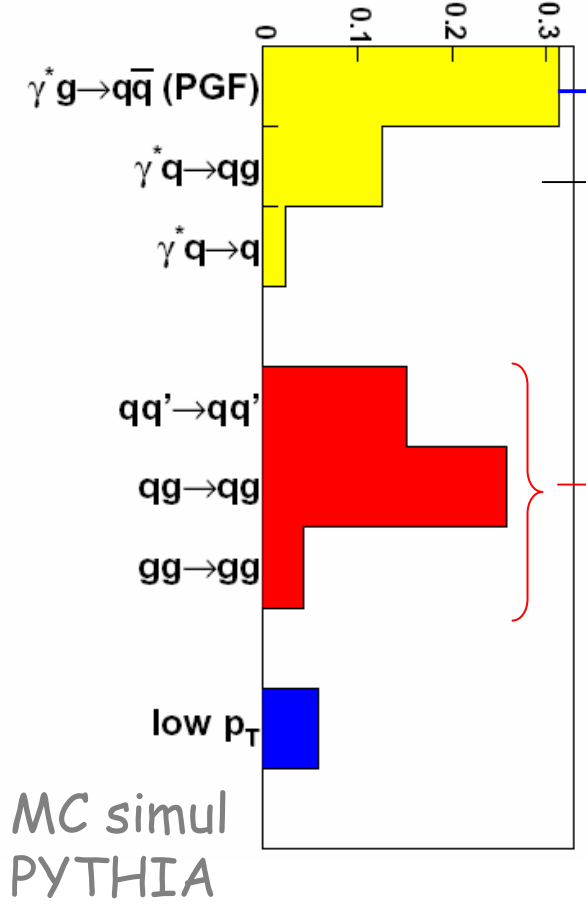
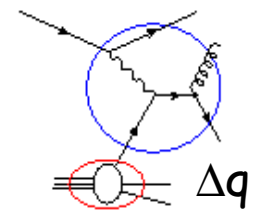PGF ~30%

QCDC

Resolved
photons

~50%

Δq

Δq^γ $\quad$ Δq^γ $\quad$ ΔG^γ

Δq $\quad\quad$ ΔG $\quad\quad$ ΔG
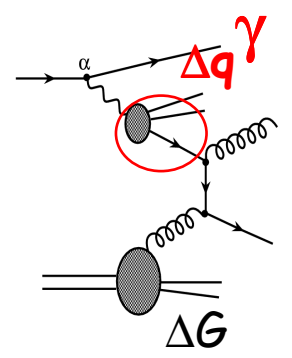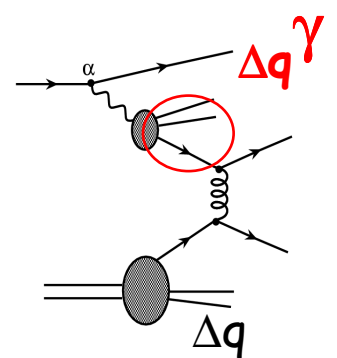
→ Need polarized parton distribution in the photon:
- perturbative part calculable
- non pert. part of Δq^γ bounded by $\pm q^\gamma$

→ Estimation of the limited theoretical uncertainty for ΔG

F.Kunne, Saclay

$\Delta G/G$ from high p_T pairs, result $Q^2 < 1$ GeV/c² data

- 2002-2003 data published *PLB 633 (2006) 25*

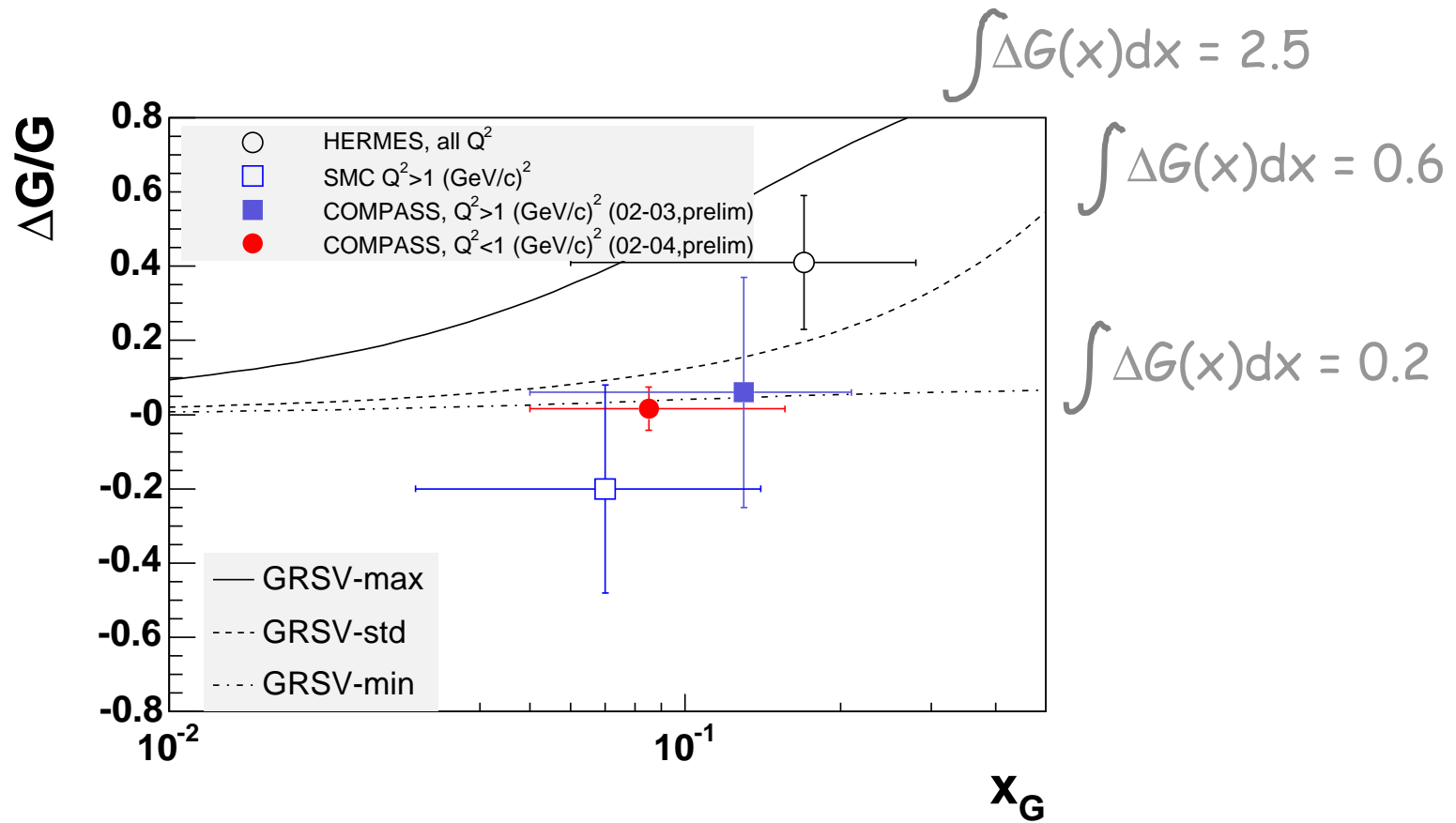- New result from 2004 data (consistent with previous)

Preliminary, 2002-2004 data: x_g=0.085, μ^2=3GeV/c²

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

Statistics and systematics small

→ Two independent results at Q^2<1 and Q^2>1, consistent with zero

F.Kunne, Saclay

New COMPASS 2002-2004 data, $Q^2 < 1$

$\int \Delta G(x)dx = 2.5$

$\int \Delta G(x)dx = 0.6$

$\int \Delta G(x)dx = 0.2$

Legend:
- ○ HERMES, all Q^2
- □ SMC $Q^2 > 1$ $(GeV/c)^2$
- ■ COMPASS, $Q^2 > 1$ $(GeV/c)^2$ (02-03,prelim)
- ● COMPASS, $Q^2 < 1$ $(GeV/c)^2$ (02-04,prelim)

— GRSV-max
--- GRSV-std
-·- GRSV-min

$\int \Delta G(x)dx$ small, or $\Delta G(x)$ has a node at $x \sim 0.1$

Consistent also with RHIC A_{LL} (π^0 channel) measurements

F.Kunne, Saclay

New COMPASS 2002-2004 data, $Q^2 < 1$

$\int \Delta G(x)dx = 2.5$

$\int \Delta G(x)dx = 0.6$

$\int \Delta G(x)dx = 0.2$

Legend:
- ○ HERMES, all Q^2
- □ SMC $Q^2 > 1$ (GeV/c)^2
- ■ COMPASS, $Q^2 > 1$ (GeV/c)^2 (02-03, prelim)
- ● COMPASS, $Q^2 < 1$ (GeV/c)^2 (02-04, prelim)
- ▲ COMPASS, open charm (02-04, prelim)

— GRSV-max
--- GRSV-std
-·- GRSV-min

Y-axis: $\Delta G/G$, X-axis: x_G

$\int \Delta G(x)dx$ small, or $\Delta G(x)$ has a node at $x \sim 0.1$

Consistent also with RHIC A_{LL} (π^0 channel) measurements

F.Kunne, Saclay
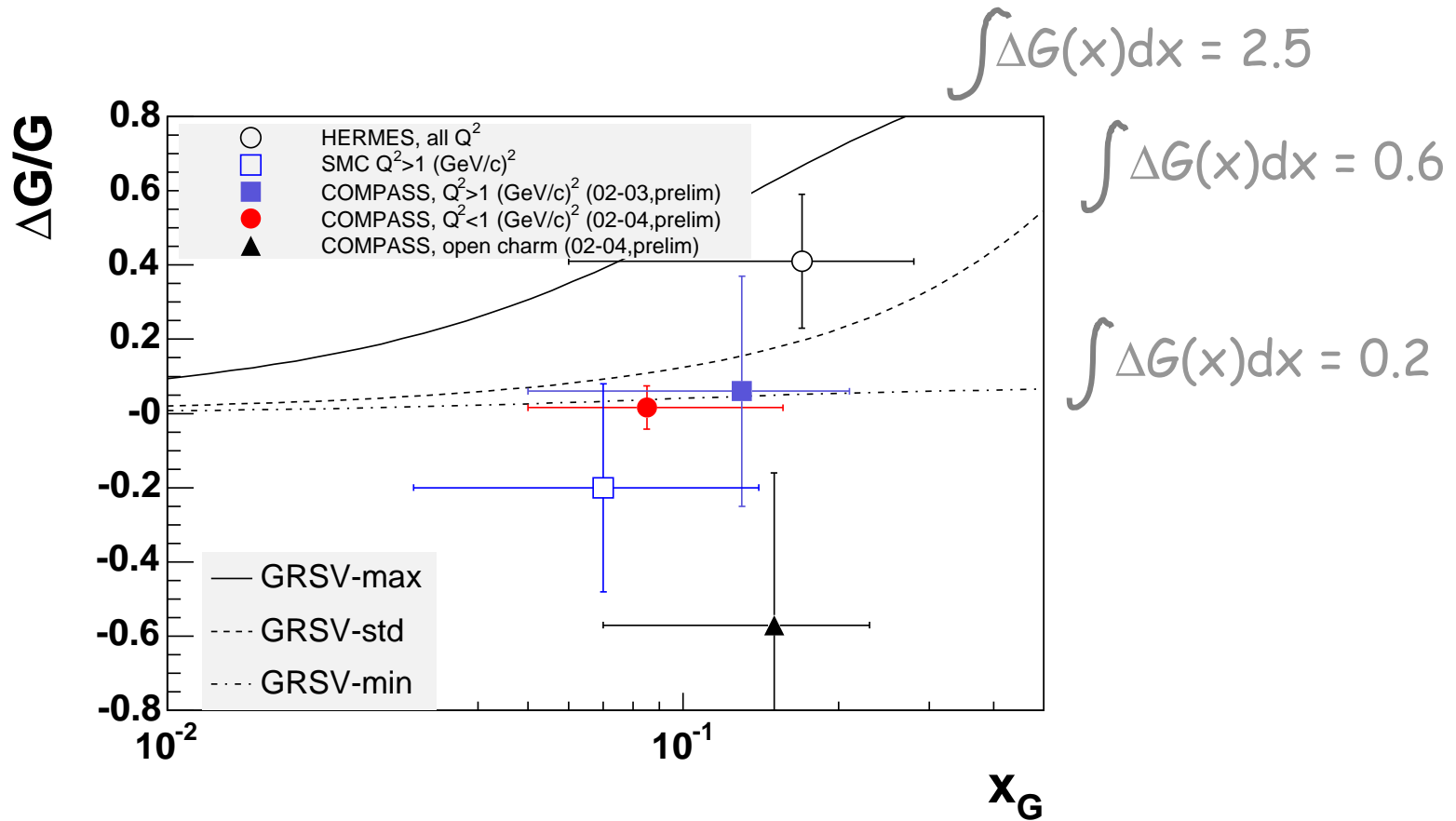
$\int \Delta G(x)dx$ and nucleon spin

$$\int \Delta G(x)dx = \Delta G$$
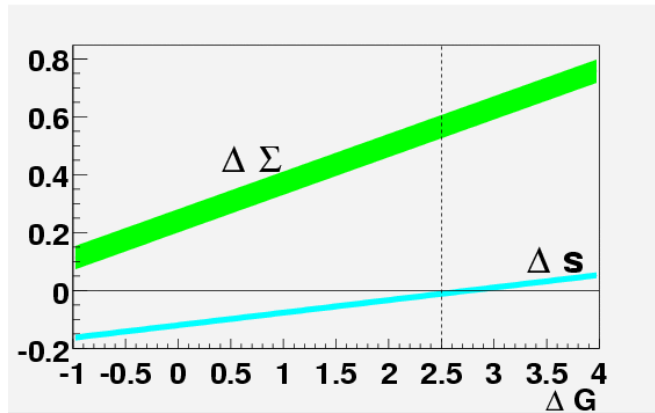
$\rightarrow \Delta G$ not large $\Rightarrow \Delta\Sigma$ small ($\neq$ predictions)

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

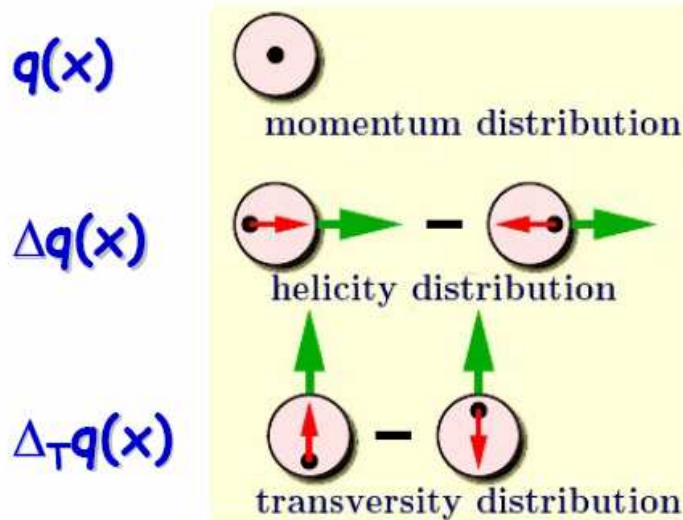possible scenarios:
$$\frac{1}{2}0.2 + 0.4 + 0.0$$
$$\frac{1}{2}0.2 + 0.0 + 0.4$$
...

F.Kunne, Saclay

Transversity

F.Kunne, Saclay

Transversity

3 structure functions at LO, all of equal importance

$q(x)$

$F_2(x)$

momentum distribution

$\Delta q(x)$

$g_1(x)$

helicity distribution

$\Delta_T q(x)$

$h_1(x)$

transversity distribution
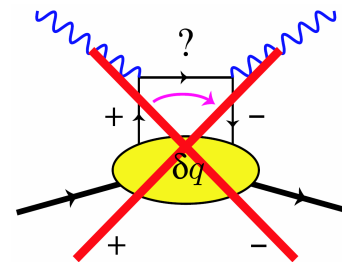
helicity flip : not measurable in DIS

Need e.g. fragmentation function

3 methods used in COMPASS :

See talk by Horst Fischer

- Azimuthal distribution of single hadron: "Collins" asymmetry

- Azimuthal dependence of "two hadron" plane

- transverse polarization of Λ

F.Kunne, Saclay

Transversity – Collins

Deuteron target transversely polarized ~25% of the total running time

Measure simultaneously two azimuthal asymmetries:

Collins: Correlation between direction of outgoing hadron & <u>transverse spin of q</u>

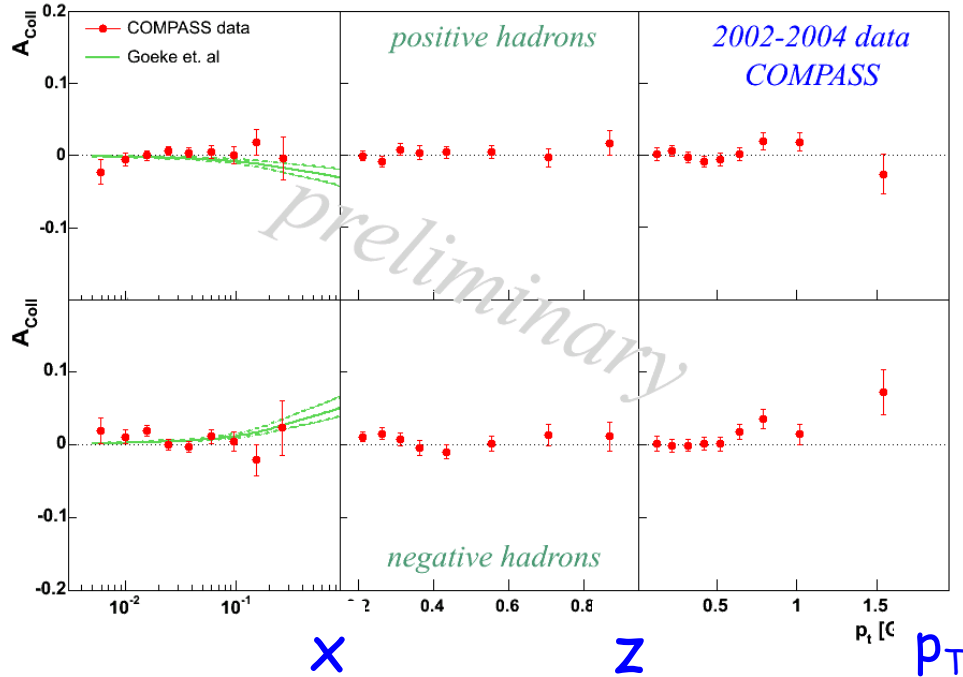Sivers: Correlation between nucleon spin & transverse momentum of q

10^6 events

2002   2003   2004

PRL94(2005) 202002

New!
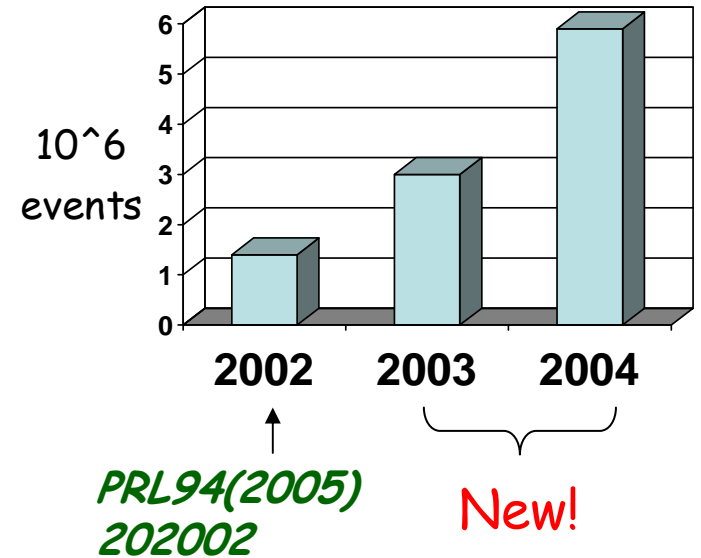
Collins

transverse distributions

$$A_{Coll} = \frac{\Sigma_q e_q^2 \cdot \Delta_T q \cdot \Delta D_q^h}{\Sigma_q e_q^2 \cdot q \cdot D_q^h}$$

fragmentation function

Sivers

$$A_{Siv} = \frac{\Sigma_q e_q^2 \cdot f_{1Tq}^\perp \cdot D_q^h}{\Sigma_q e_q^2 \cdot q \cdot D_q^h}$$

F.Kunne, Saclay
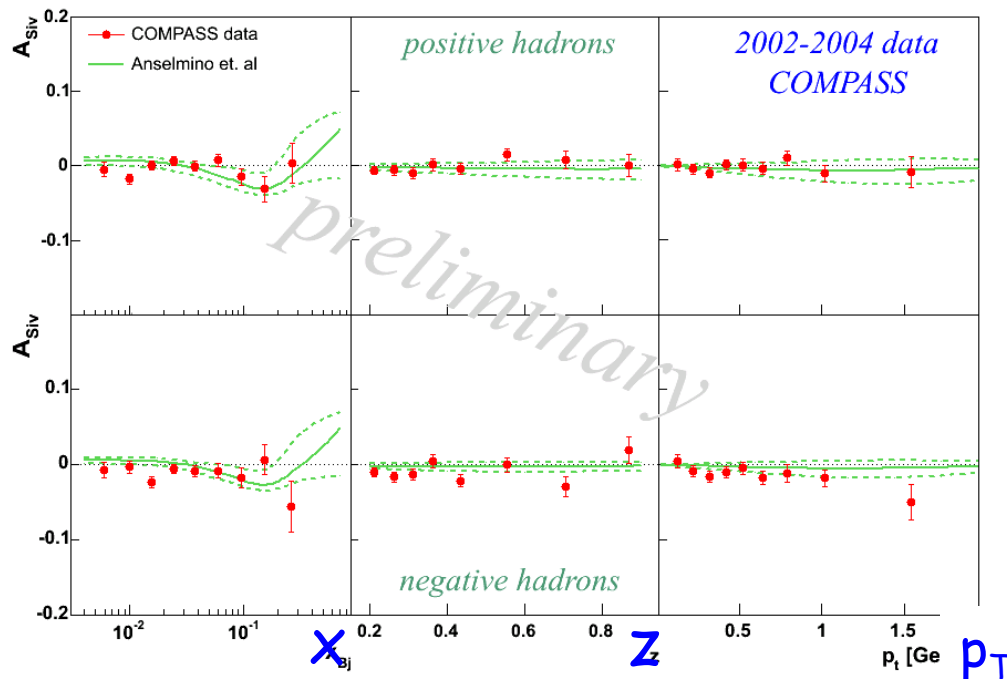
New:2002-2004 data on d

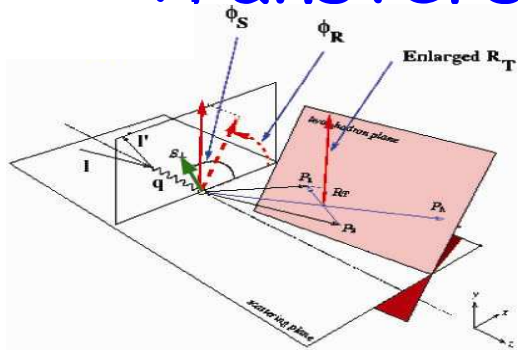A-Collins

Results consistent with 0

Models describing Hermes p data
and using fragmentation function
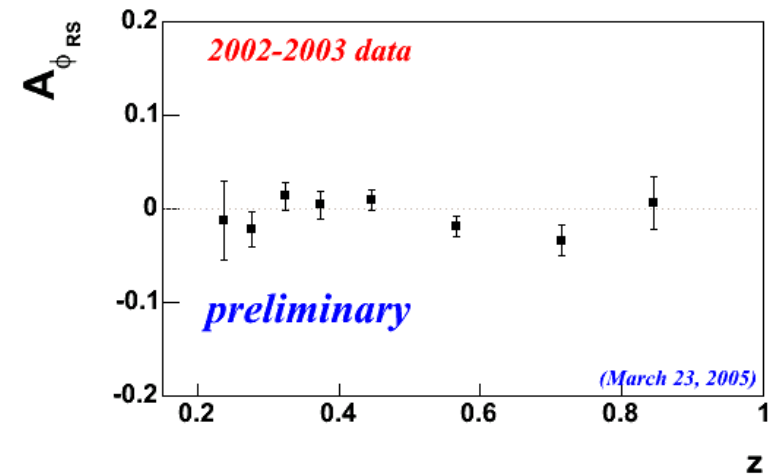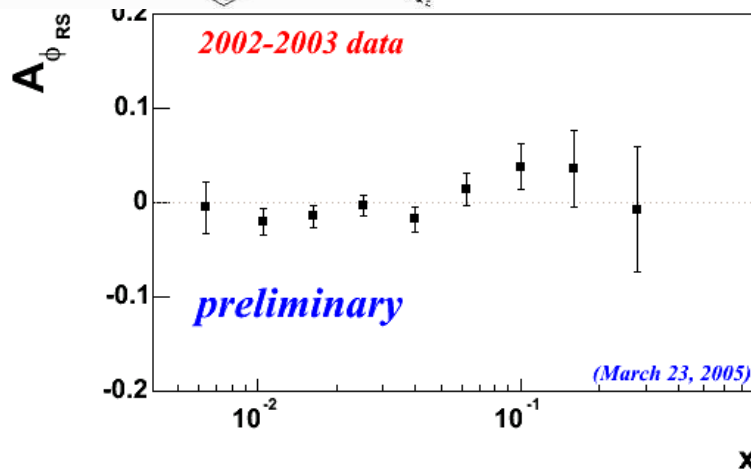from Belle describe also
COMPASS results

A-Sivers

Cancellation between
proton and neutron?

Transversity –"Two hadron" asymmetries

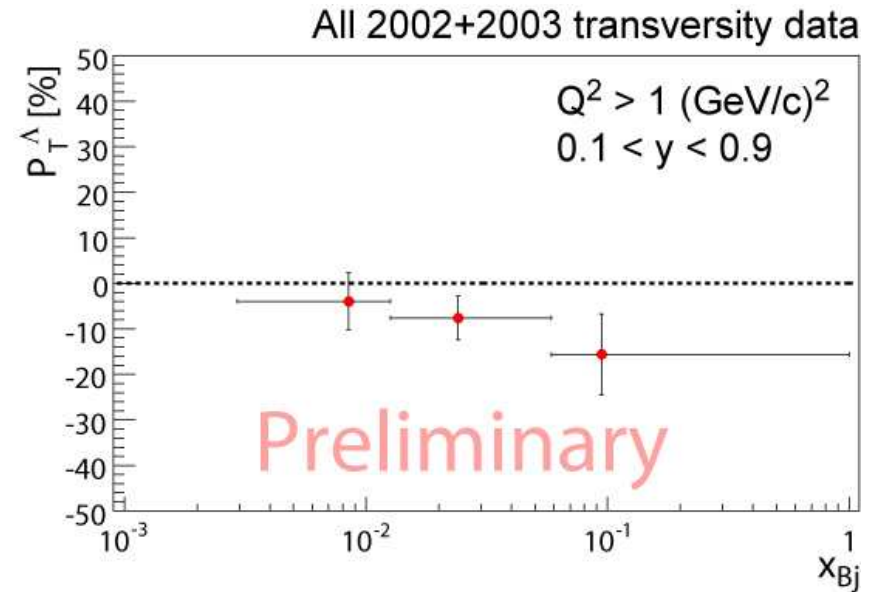Independent access to $\Delta_T q$ from azimuth of plane of 2 hadrons
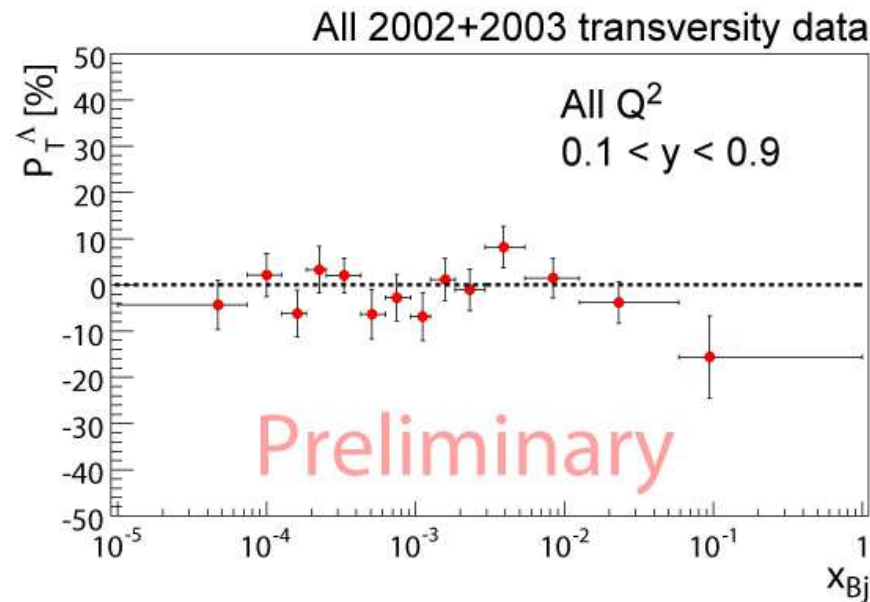

Precise measurement of few %
Systematics seems well under control
More data to come soon (2004 data) !

Also compatible with zero

F.Kunne, Saclay

Transversity - Λ polarization

$$P_T^\Lambda = f \, P_T \, D \frac{\sum_q e_q^2 \left(\Delta_T q \cdot \Delta D_q^\Lambda \right)}{\sum_q e_q^2 \cdot q \cdot D_q^\Lambda}$$
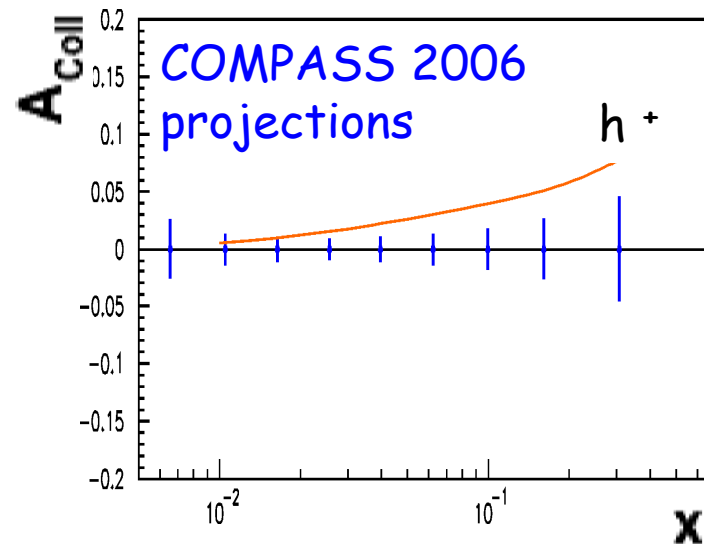

Negative trend for Q² >1, but
deviation from zero not significant

Statistics will double with 2004 data

F.Kunne, Saclay

Collins asymmetry on proton – 2006 proj.

Interesting to see proton in 2006!

COMPASS 2006 projections

h^+

NH_3 **target**

A. Efremov et al., Eur.Phys. J.C32:337-346,2003

+ new target magnet: larger acceptance
→ higher statistics at large x

F.Kunne, Saclay

Other physics at COMPASS

- Diffractive physics →   See talk by Nicole d'Hose

- Lambda →   See talk by Boris Grube

- Semi-inclusive spin asymmetries

- Primakoff reactions: polarisabilities of π and K

- …

F.Kunne, Saclay

Hard exclusive ρ^0 meson production

Large statistics on diffractive production of ρ, ϕ, J/ψ

Large x, Q^2 range

Measure spin density matrix elements & double spin asymmetry
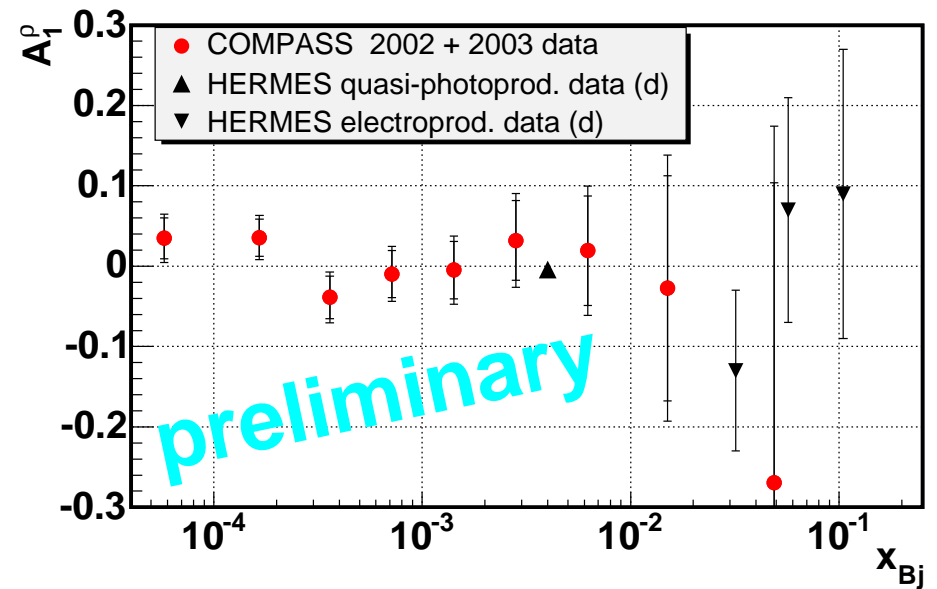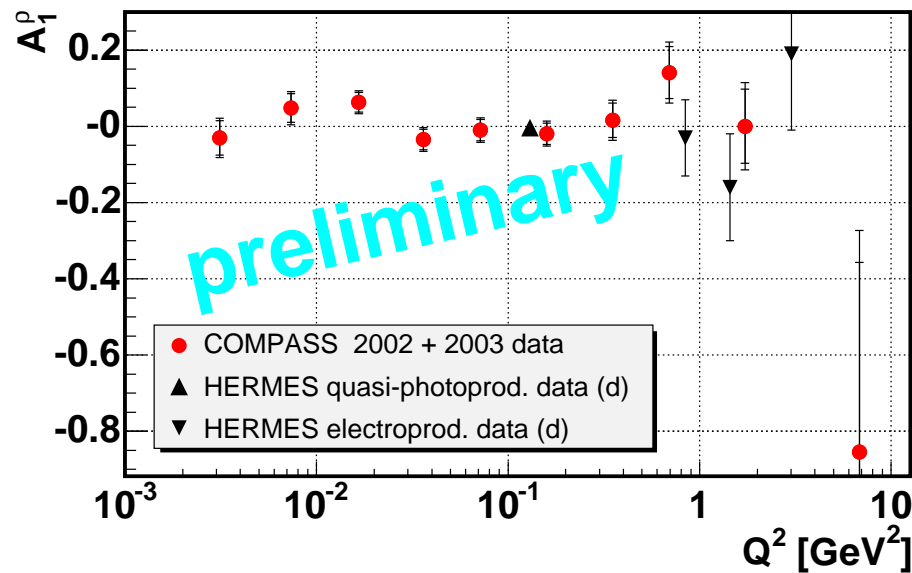
ρ^0 asymmetry compatible with zero

F.Kunne, Saclay

Spectrometer upgrades

- Need excellent figure of merit for ΔG :

    charm channel &   high p_T high Q^2 data

- Need large acceptance for:

    - transversity large x_{Bj}

    - ΔG : x_g coverage and x_g binning from high p_T low Q^2 data
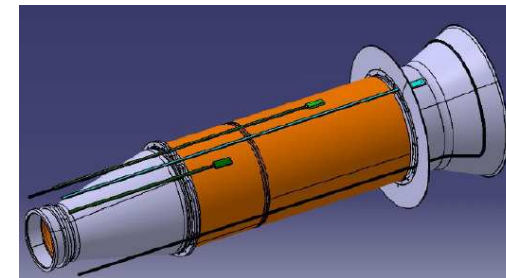
F.Kunne, Saclay

COMPASS 2006 upgrades (1)

New target magnet
70 mrad $\rightarrow$ 180 mrad

Gain in statistics ~ 30%

New 3 cell- cavity
Reduce systematic effects

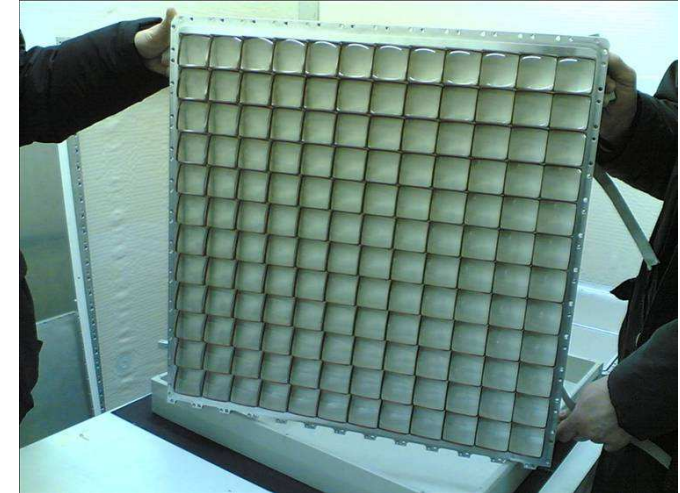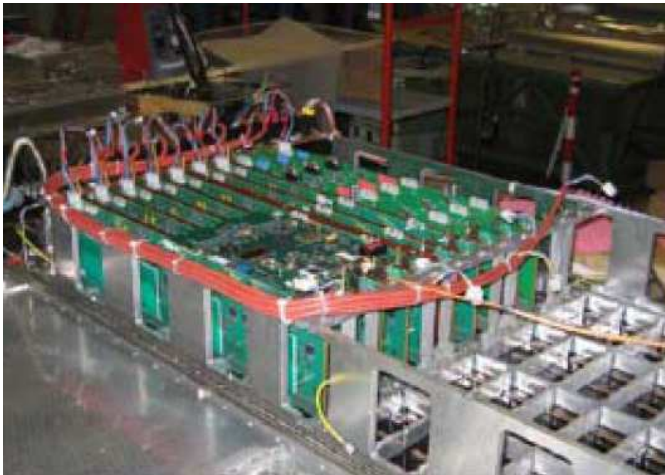| +	–	–	+

F.Kunne, Saclay
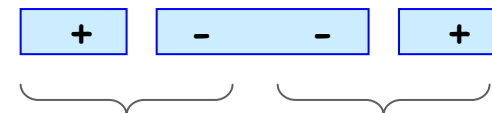
COMPASS 2006 upgrades (2)

RICH upgrade
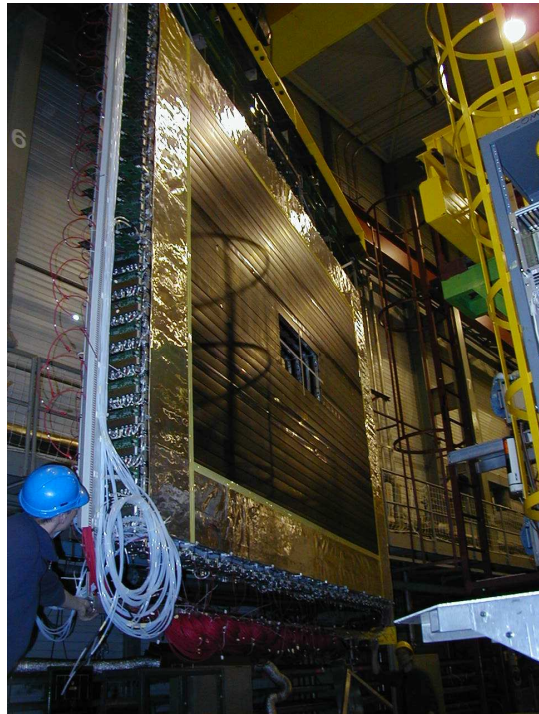
Central region: Multi Anode PMTs
more photons and improved S/N
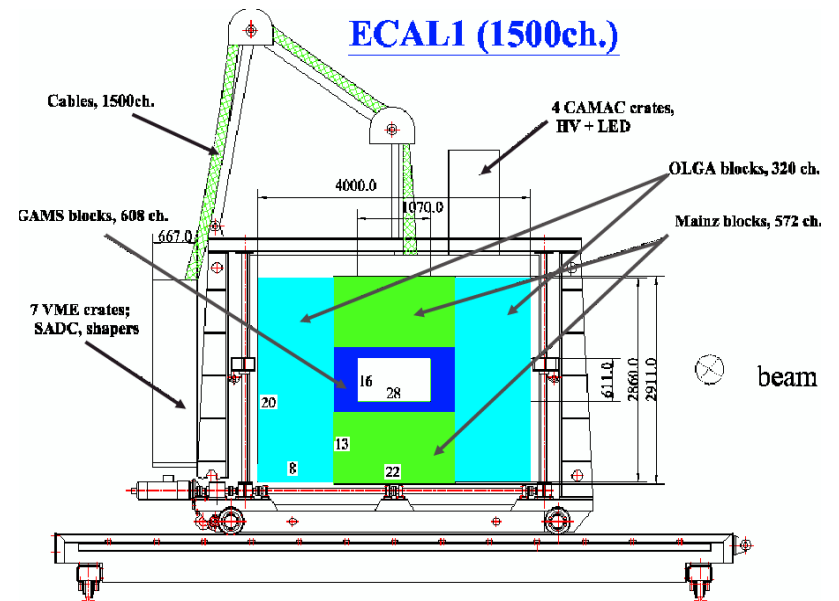
Outer region: New faster electronics
improved S/N

Gain in statistics ~ 50%

F.Kunne, Saclay

COMPASS 2006 upgrades (3)

ECAL1 (1500ch.)

Cables, 1500ch.

4 CAMAC crates, HV + LED

OLGA blocks, 320 ch.

GAMS blocks, 608 ch.

Mainz blocks, 572 ch.

4000.0

1070.0

667.0

7 VME crates; SADC, shapers

16 28

20

13

8 22

611.0

2860.0

2911.0

beam

Full ECAL coverage

Gain in statistics ~ 20%

RICHWall
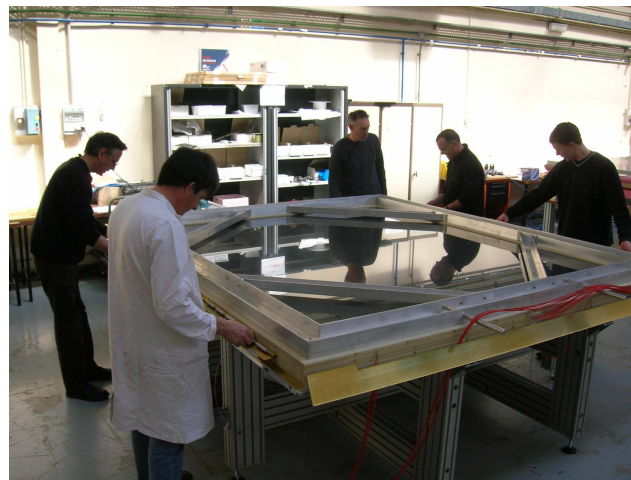
Large Drift Chamber

F.Kunne, Saclay

COMPASS - Summary

- More precise measurement of $\Delta G/G$ from high p_T
  confirms our surprising result:
  ΔG small, or $\Delta G(x_g)$ has a node at $x_g \sim 0.1$

- Independent result from high Q^2 data, where physics background small

- Progress in D^0 channel

- Inclusive DIS : precise $g_1^d \to$ improves QCD fits for $\Delta\Sigma$ and ΔG

- Transversity: very precise asymmetries for deuteron
  $\to$ compatible with zero

F.Kunne, Saclay

Outlook

- 2006 Important upgrade of the spectrometer, FoM x 2:
  - significant improvement on $\Delta G / G$ from D^0 channel
  - possible x_g binning from high p_T channel

  Transverse spin: take data with proton target

- Future : 2007 hadron run : central production, 300 GeV + LH_2 target

  2008-2010 complete the approved muon and hadron programmes

  beyond : high potential for GPD measurements

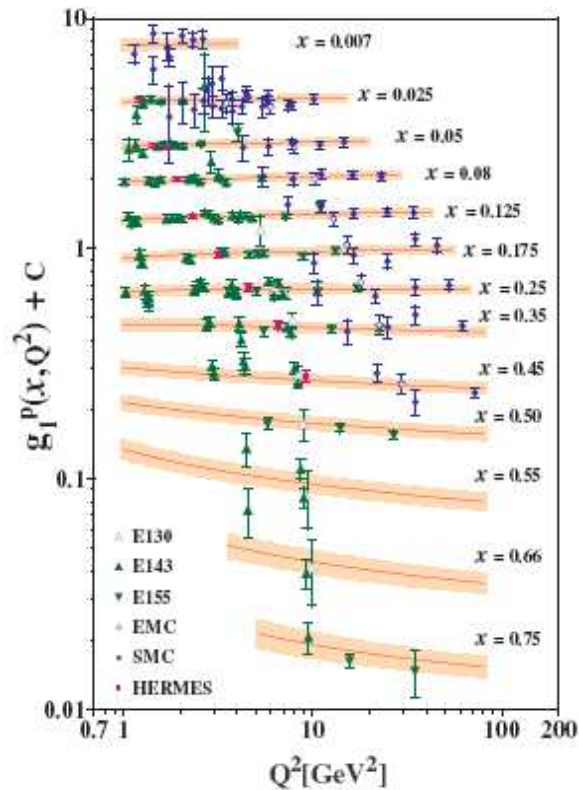 See talk by Fritz-Herbert Heinsius

Broad future for COMPASS!

F.Kunne, Saclay

Spares

F.Kunne, Saclay

Progress on QCD fits of g_1

Various NLO pQCD global analyses of world data on $g_1{}^{p,\,d,\,n}$ with different parameterizations

Δu Δd well constrained, but ΔG shape unknown

Recent progress when including new data:

e.g. AAC new analysis including g_1 new data from HERMES, COMPASS and JLAB + PHENIX A_{LL} π^0
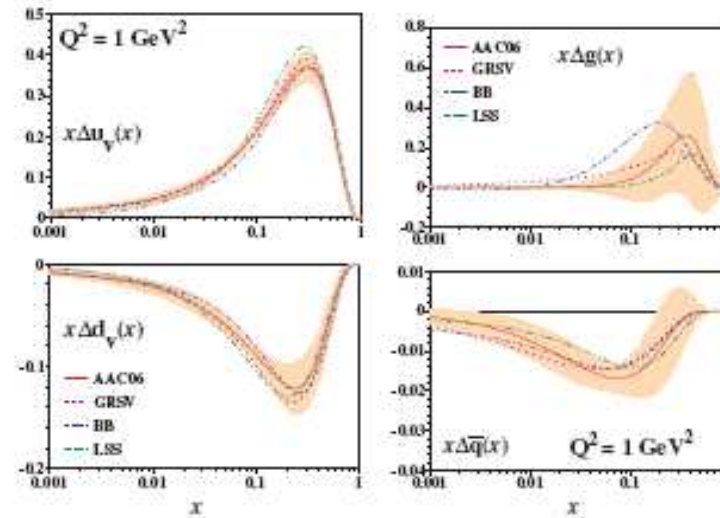

AAC -hep-ph/0603213

F.Kunne, Saclay
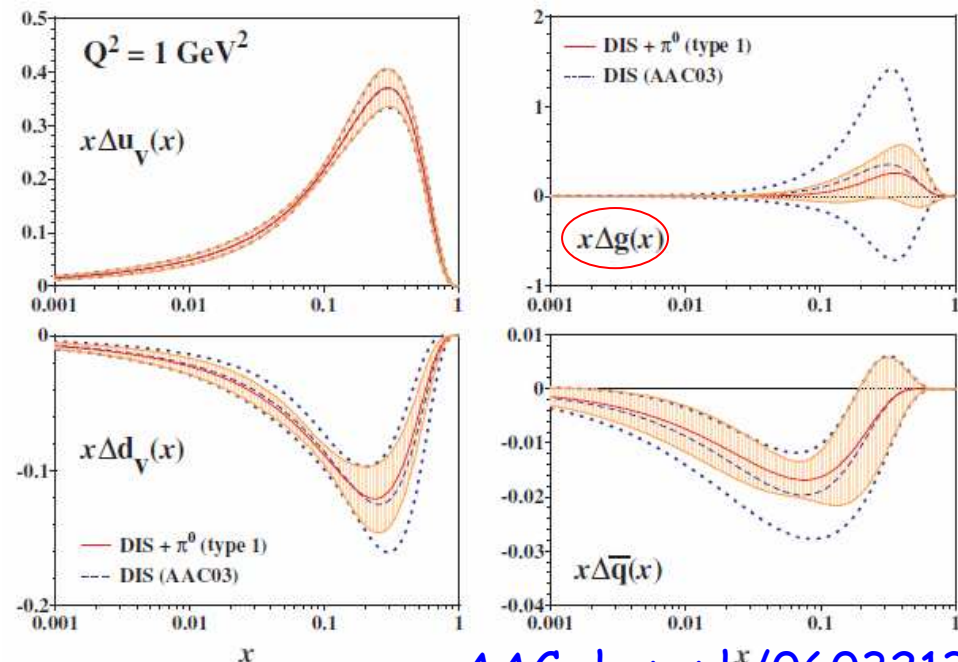
NLO fits

FIG. 5: (Color online) Comparison with other polarized PDFs at $Q^2=1$ GeV^2. The type 1 distributions and their uncertainties are shown by the solid curves and bands. The others are the GRSV, BB, and LSS parametrizations.
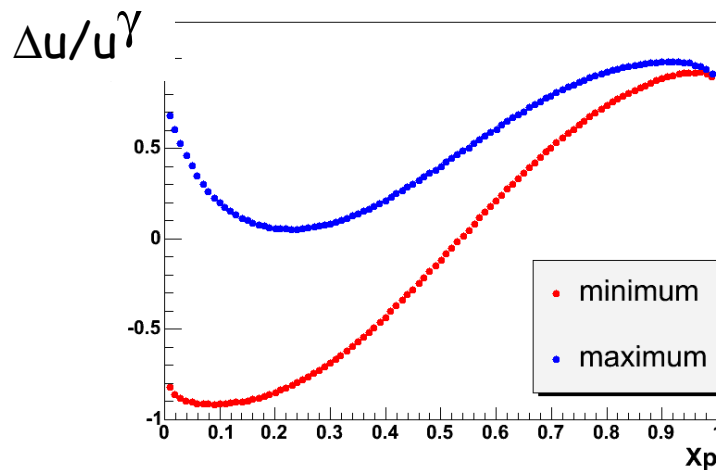
LO $\quad\int\Delta G$

$\begin{cases}
\text{BB02} & 1.19 \\
\text{AAC00} & 1.15 \\
\text{LSS01} & 1.0 \\
\text{GRSV00} & 0.6
\end{cases}$

F.Kunne, Saclay

Polarized parton distributions in the photon

- Perturbative part calculable

- Non perturbative part unknown, but: $\quad -q^{\gamma}(x,\mu_0{}^2) < \Delta q^{\gamma}(x,\mu_0{}^2) < q^{\gamma}(x,\mu_0{}^2)$

measured

Try two extreme scenarios and evaluate effect on $\Delta G/G$ value

gives a range for $(\Delta q/q)^{\gamma}$ and $(\Delta G/G)^{\gamma}$

• First estimation of the resolved photon polarized PDFs!

• Estimation of the <u>limited</u> theoretical uncertainty for ΔG

F.Kunne, Saclay

$\Delta G/G$ from high p_T pairs, result $Q^2 < 1$ GeV/c^2 data

$p_T > 0.7$ GeV, $\Sigma p_T{}^2 > 2.5$ GeV² :

- 2002-2003 data published *PLB 633 (2006) 25*

- New result from 2004 data (consistent with previous)

Systematics for $\Delta G/G$ ± 0.014 (exp.syst)
± 0.052 (MC.syst) $\Big\}$ 0.055
± 0.013 (photon)

All data: $x_g = 0.085$, $\mu^2 = 3$GeV/c^2

$$\Delta G/G = 0.016 \pm 0.058 \text{ (stat)} \pm 0.055 \text{ (syst)}$$
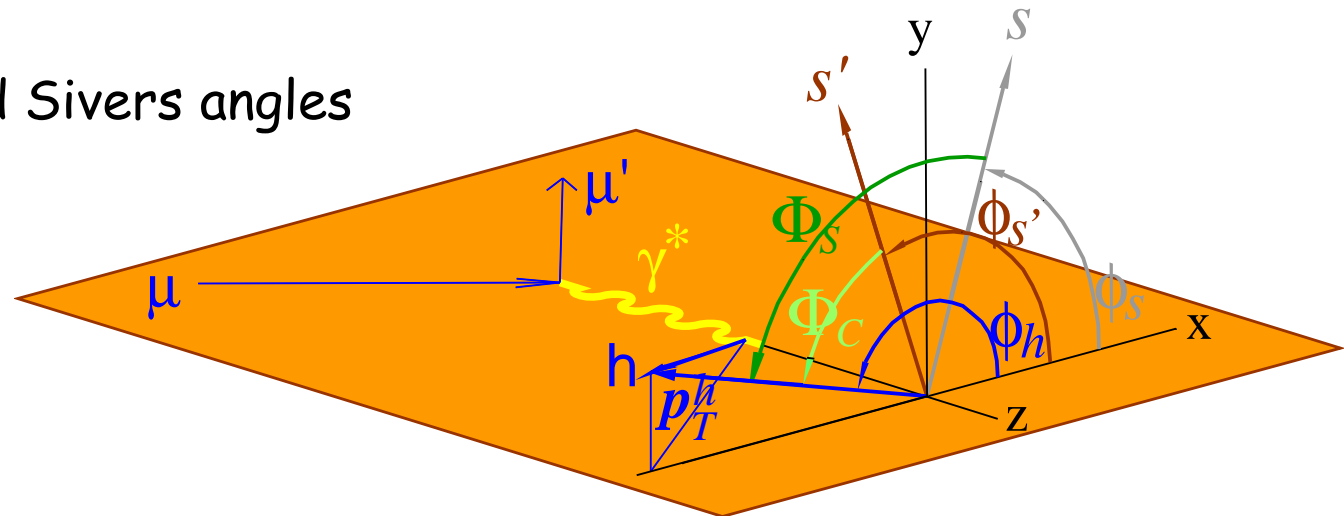
$\Delta G/G$ compatible with 0. Statistics and systematics small

$\rightarrow$ 2 independent results ($Q^2<1$ and $Q^2>1$) consistent with zero

Collins and Sivers asymmetries

Deuteron target
transverse polarization ~25% of the
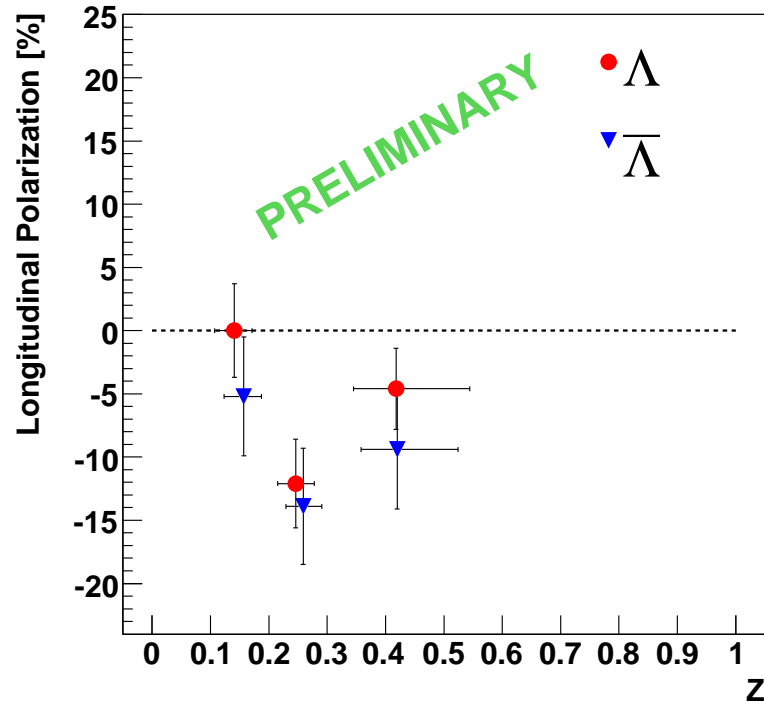total running time

Define Collins and Sivers angles

$\Phi_{Col} = \Phi_h + \Phi_S - \pi$

$N^{\pm}_h = N^0_h (1 \pm A_1 \sin\Phi_C)$

$A_1 = f.PT.D.A_{Coll}$ Single spin asymmetry

F.Kunne, Saclay

Λ longit polarization

F.Kunne, Saclay