

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

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

quark
gluon
orbital momenta

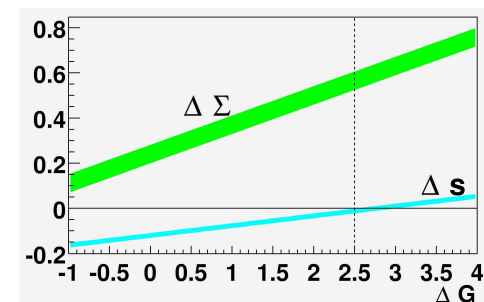
- Predictions:
- Naive quark parton model + relativistic corr. $\Delta\Sigma \sim 0.75$
 - QCD ; Ellis- Jaffe assuming $\Delta s = 0$, $\Delta\Sigma \sim 0.60$

Measurements: Polarized DIS $\vec{\ell} \vec{N}$ spin asymmetry

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{g_1}{F_1}$$

$\int_0^1 g_1 dx$ + 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 $\Delta\Sigma \sim 0.6$

→ motivated direct measurements of ΔG

Longitudinally polarized muons $160 \text{ GeV}/c$

$2 \cdot 10^8 \mu / \text{spill}$ (4.8s / 16.2s)

$P_B = -80\%$

Longitudinally or transversely polarized deuteron target :

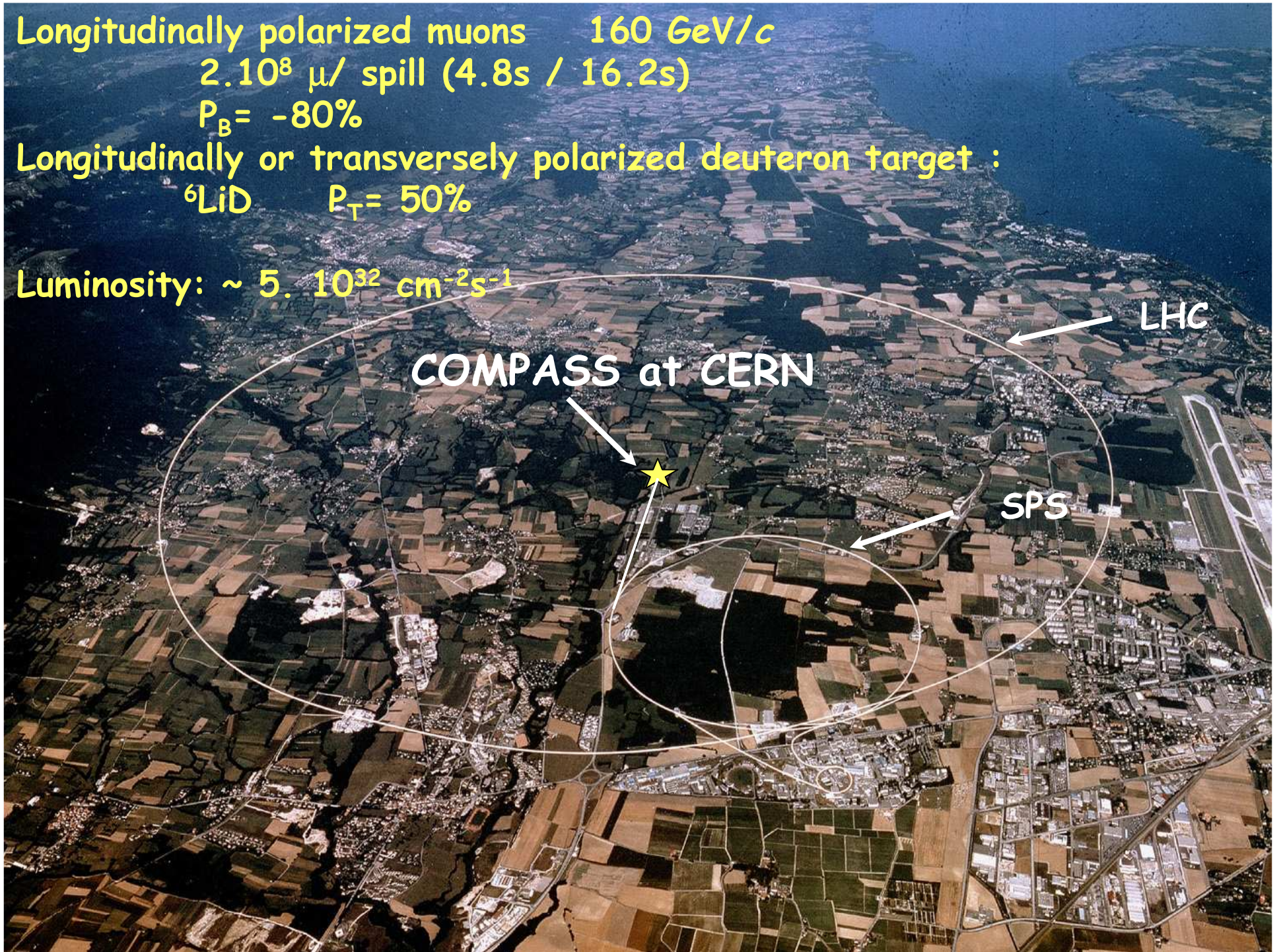
${}^6\text{LiD}$ $P_T = 50\%$

Luminosity: $\sim 5 \cdot 10^{32} \text{ cm}^{-2}\text{s}^{-1}$

COMPASS at CERN

LHC

SPS



COMPASS Collaboration at CERN

Common Muon and Proton Apparatus

for Structure and Spectroscopy

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

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

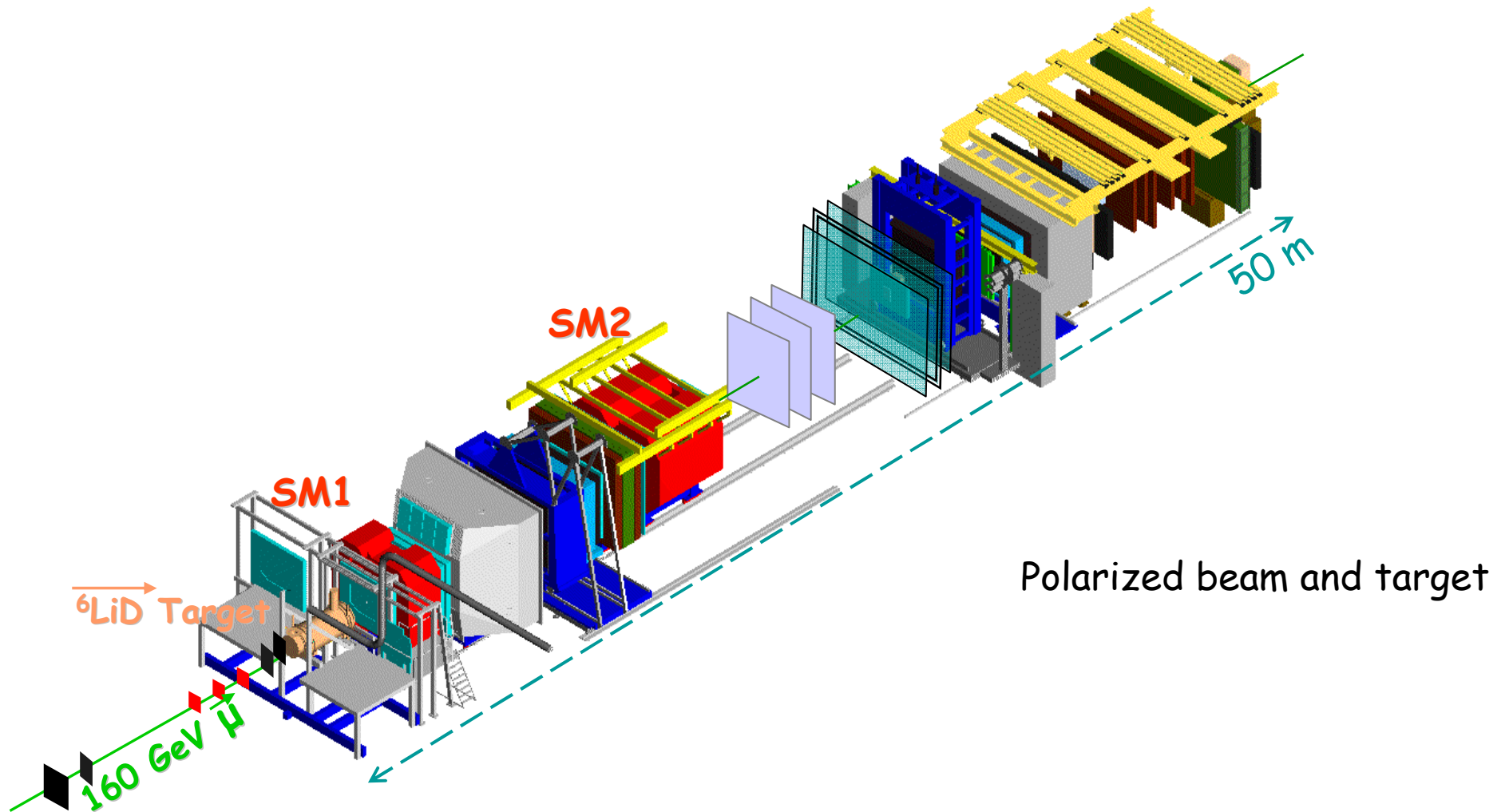
H_2 target

- Generalized parton distributions (project ~2010)

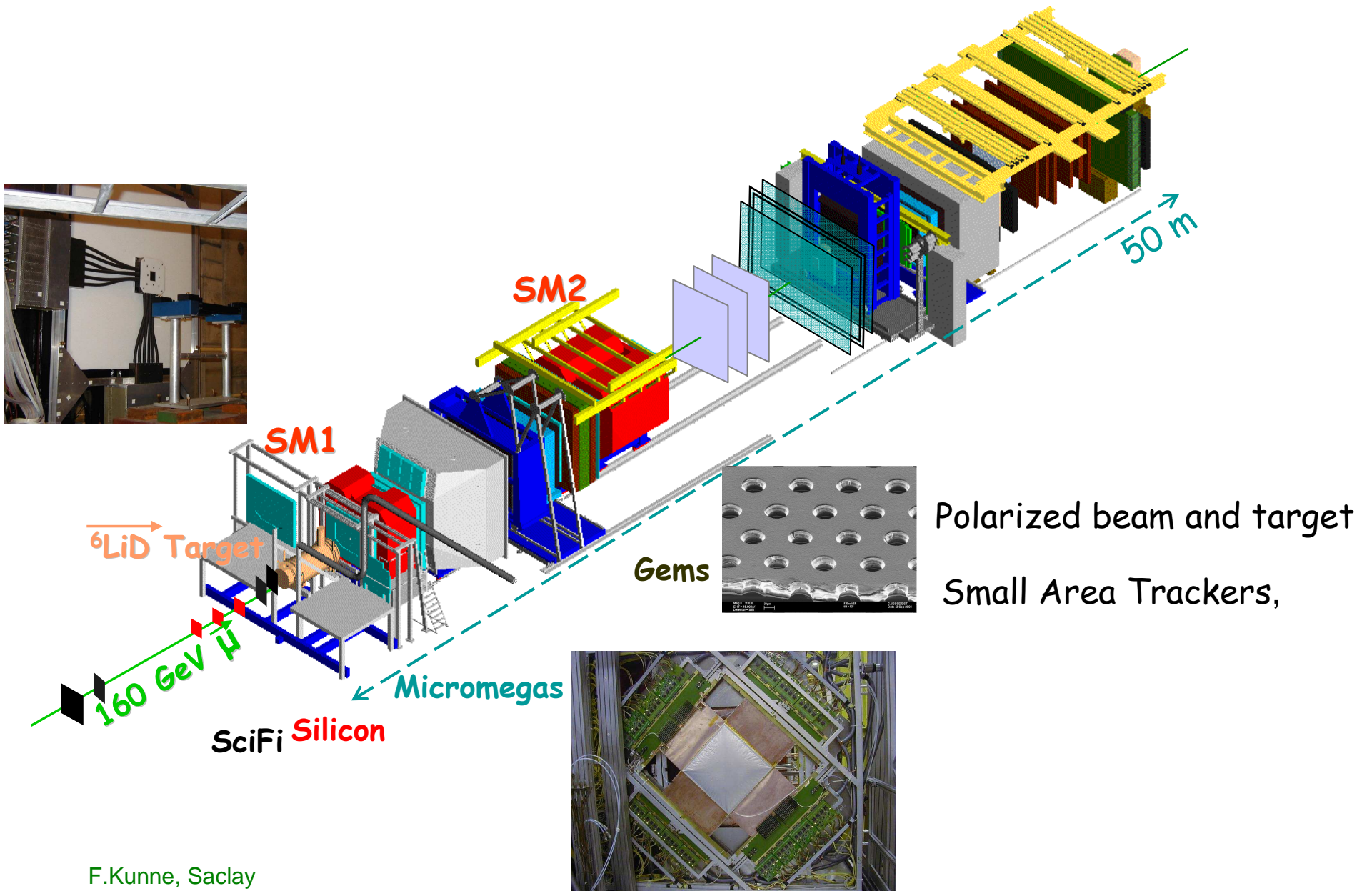
Hadron beams π, K, p

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

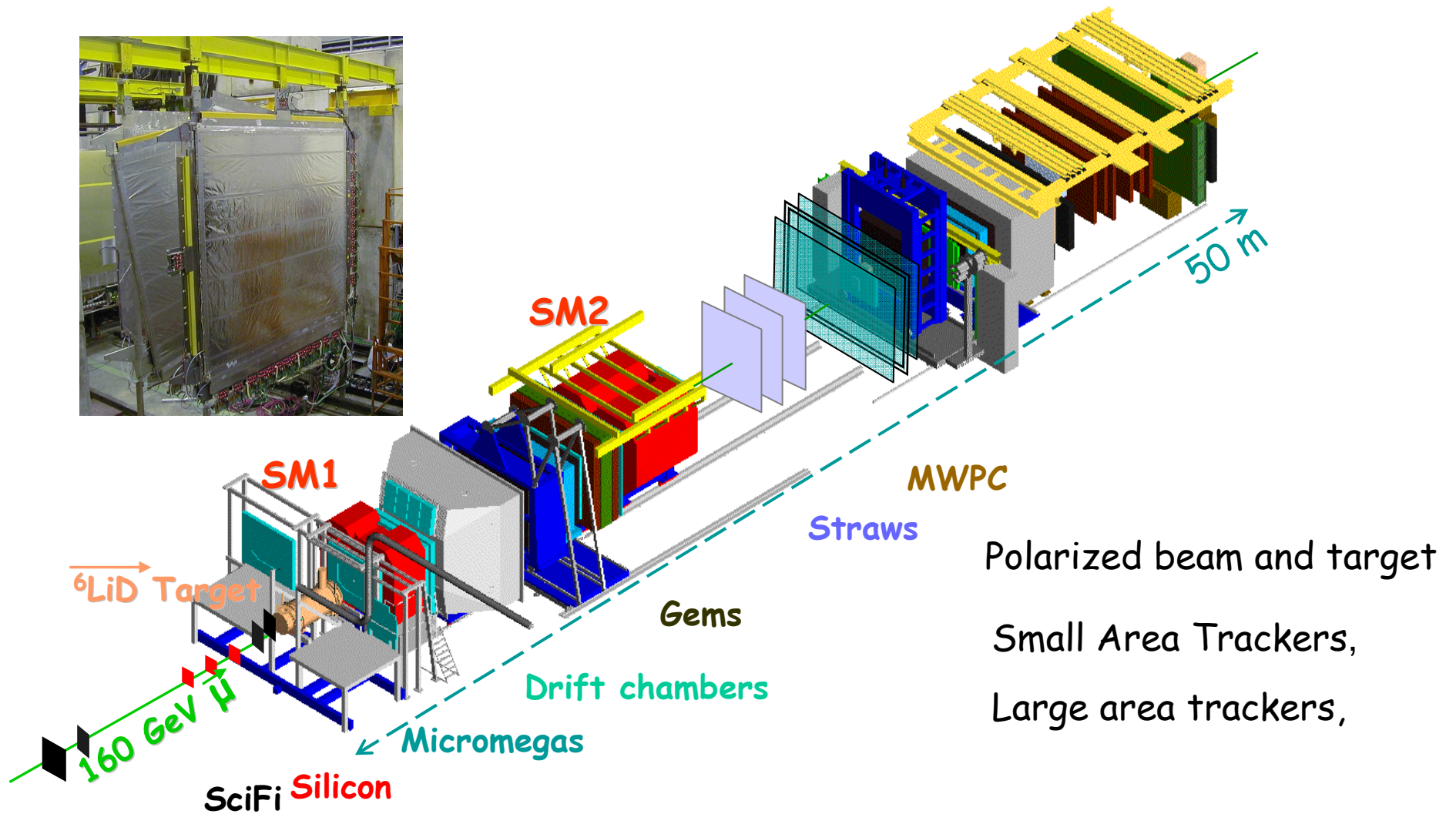
COMPASS two stage spectrometer



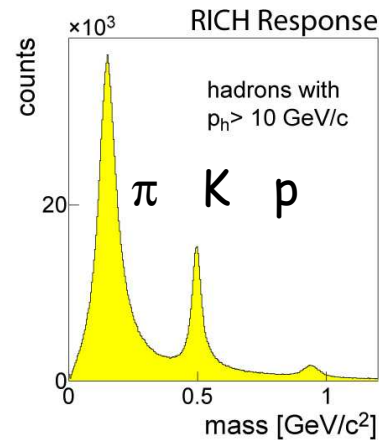
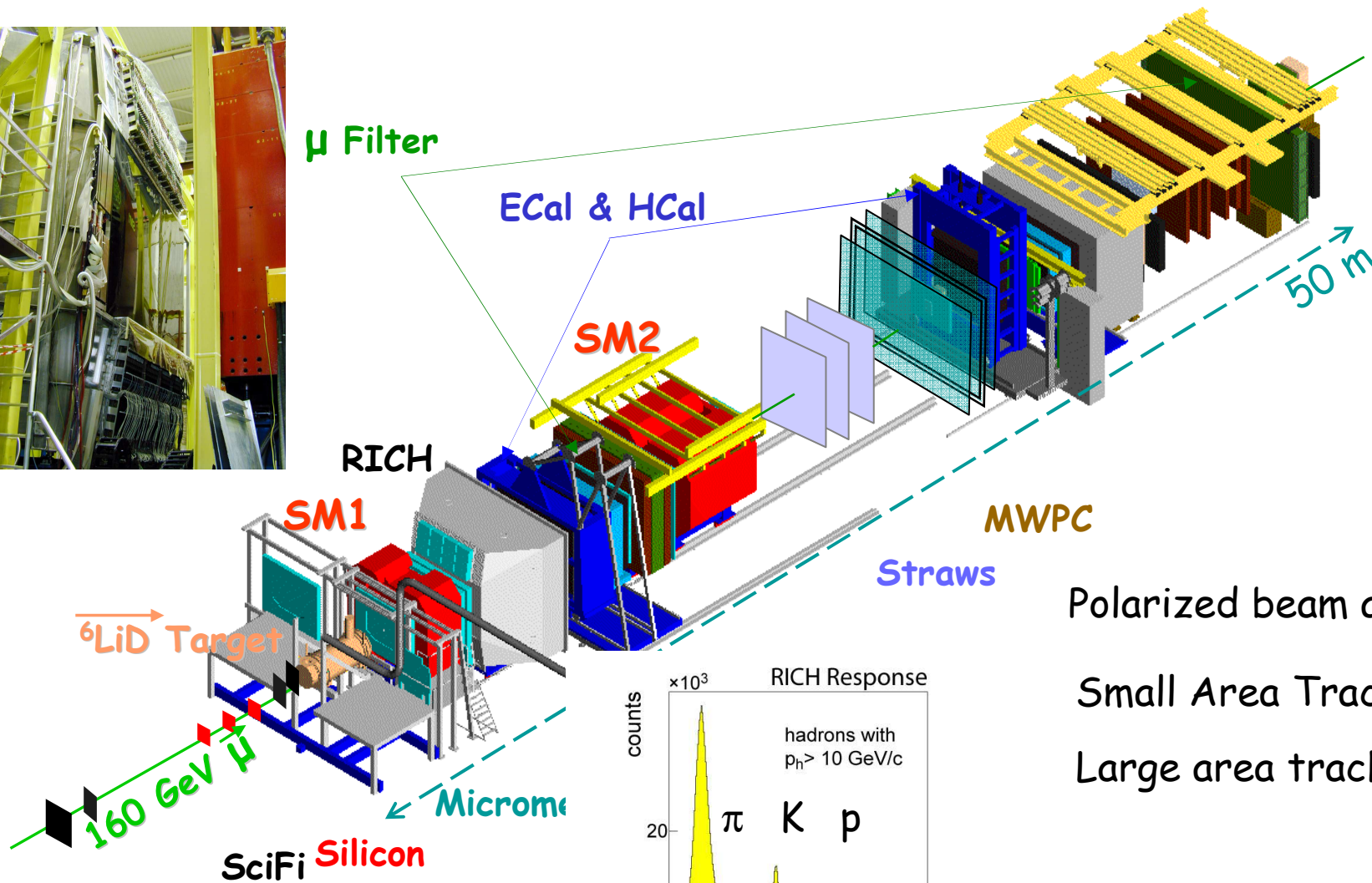
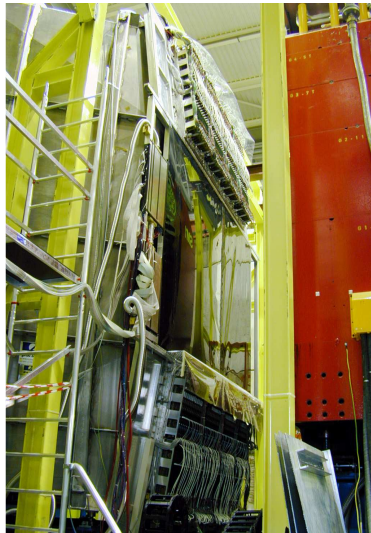
COMPASS two stage spectrometer



COMPASS two stage spectrometer



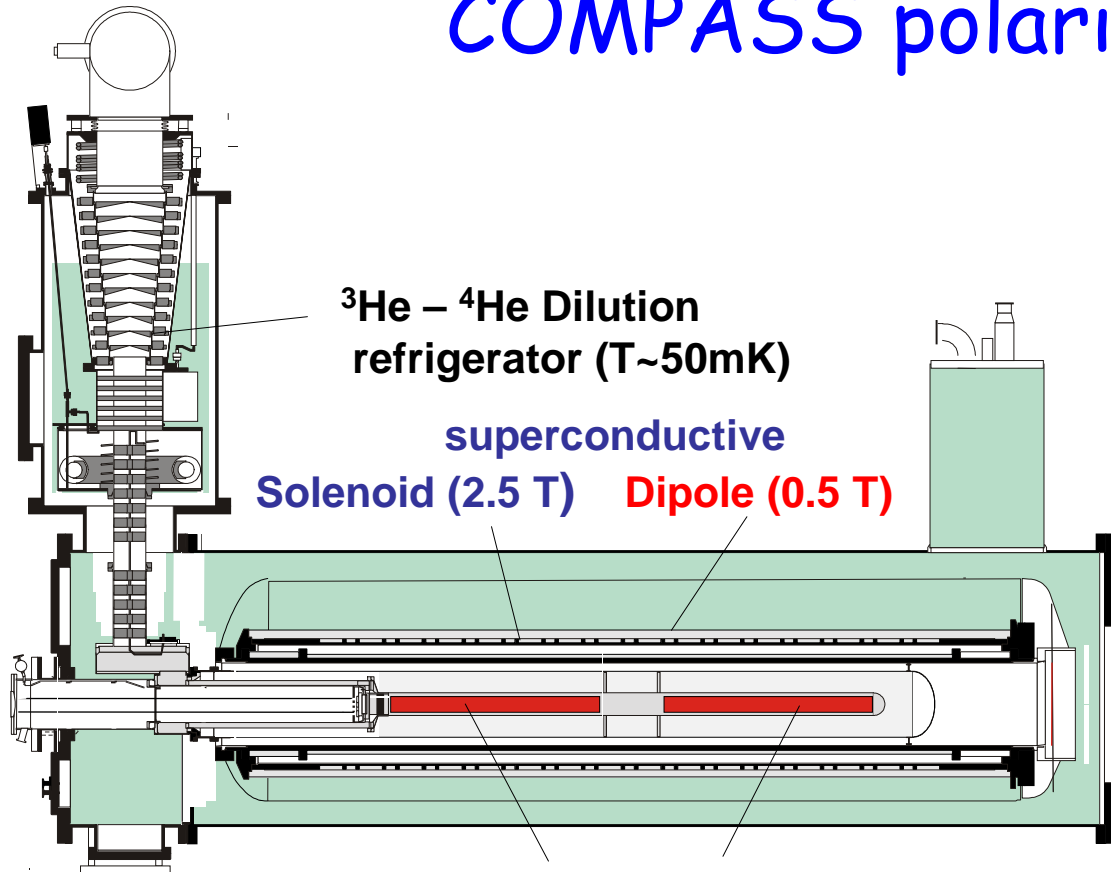
COMPASS two stage spectrometer



Polarized beam and target
 Small Area Trackers,
 Large area trackers, PID

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

COMPASS polarized target

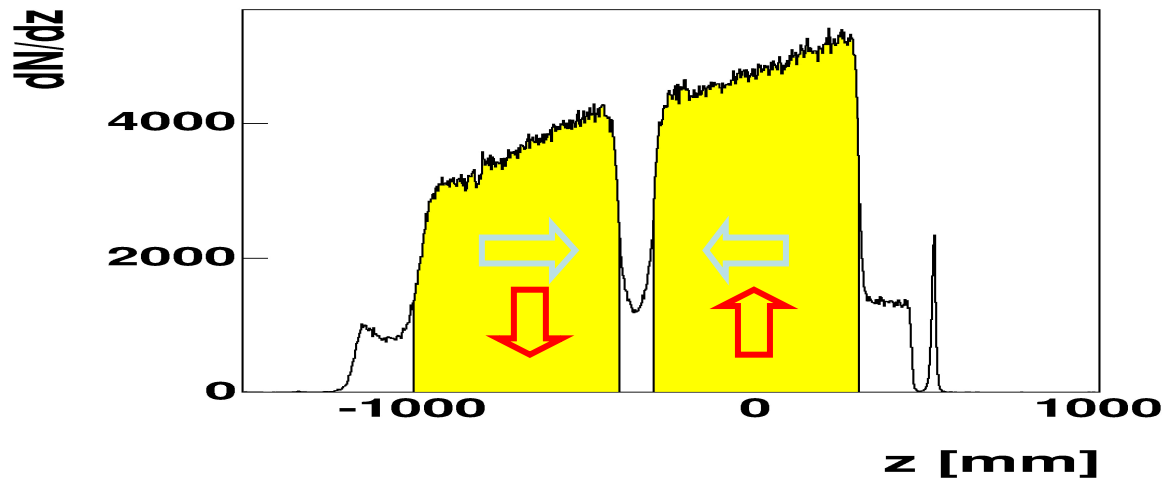


$^3\text{He} - ^4\text{He}$ Dilution refrigerator ($T \sim 50\text{mK}$)

superconductive Solenoid (2.5 T) Dipole (0.5 T)

^6LiD :
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

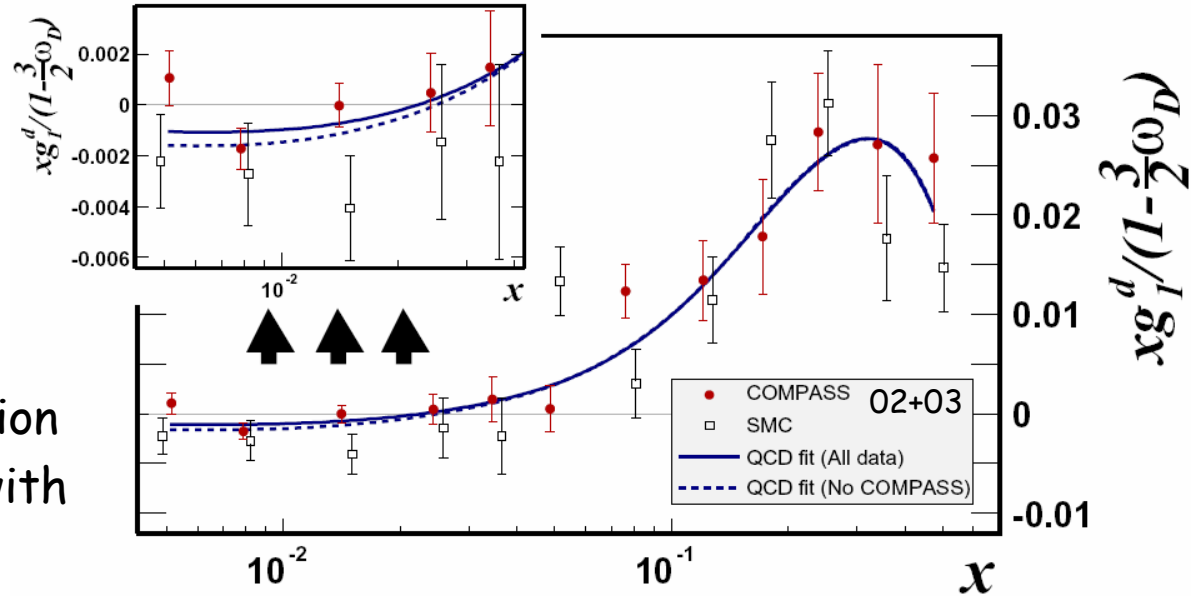
How to extract ΔG ?

- QCD evolution of g_1
- Spin asymmetry in Photon Gluon Fusion events
- Polarized pp collisions

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 $Q^2 = 3 \text{ GeV}^2$

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

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

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

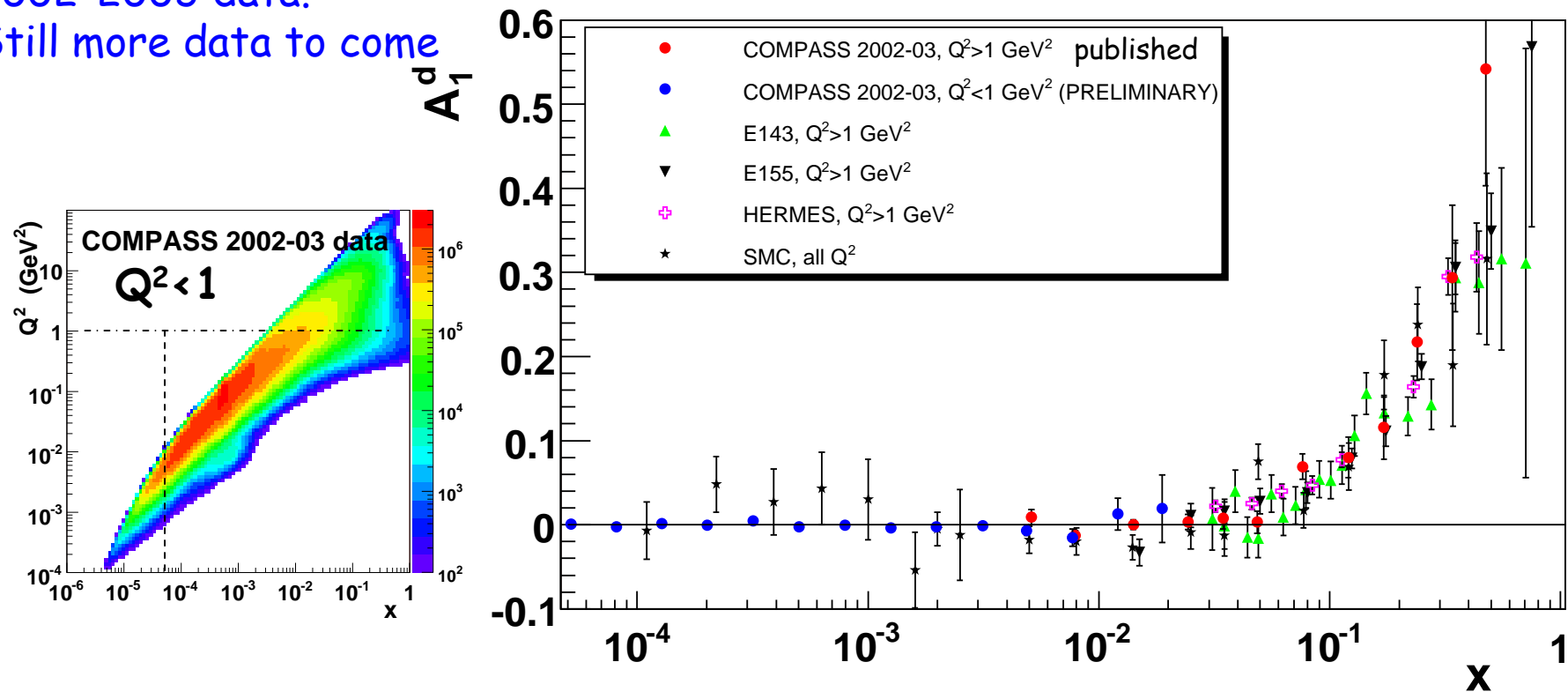
Hint on ΔG value, but for a
given parametrisation

COMPASS new result on A_1^d

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



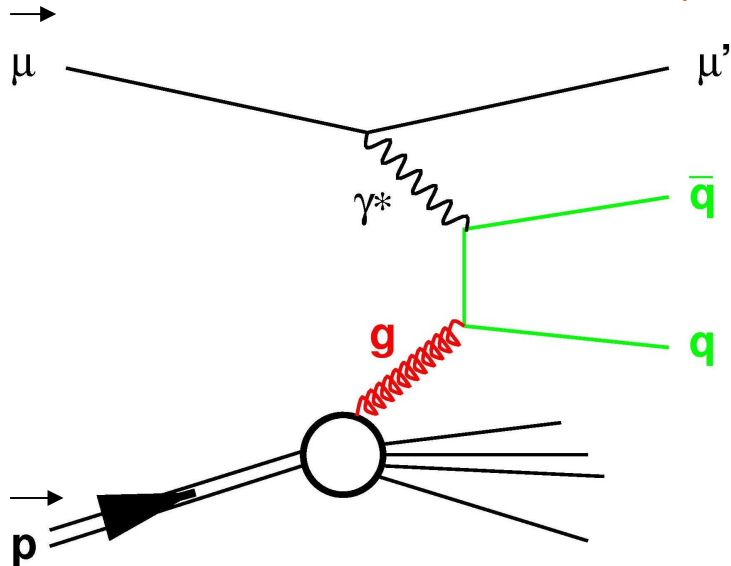
COMPASS explores x values 10 times smaller than SMC
Errors 10 times smaller

$\Delta G/G$ from Photon Gluon Fusion events

$\Delta G/G$ measurement

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

See talk by Krzysztof Kurek



• charm

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

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

theory understood, but:

combinatorial background & limited stat:

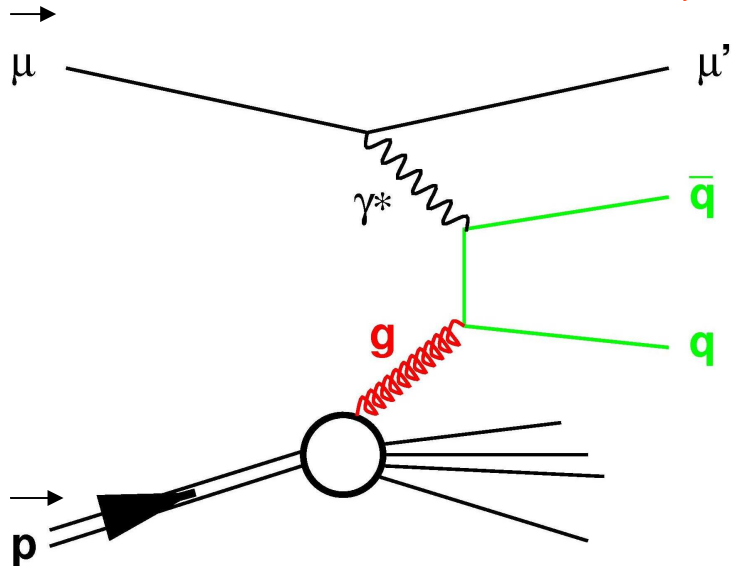
$\sigma = 100 \text{ nb}$, $\text{BR} = 4\%$, kaon identification

challenging experiment

$\Delta G/G$ measurement

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

See talk by Krzysztof Kurek



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

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combinatorial background & limited stat:

$\sigma = 100 \text{ nb}$, $BR = 4\%$, 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

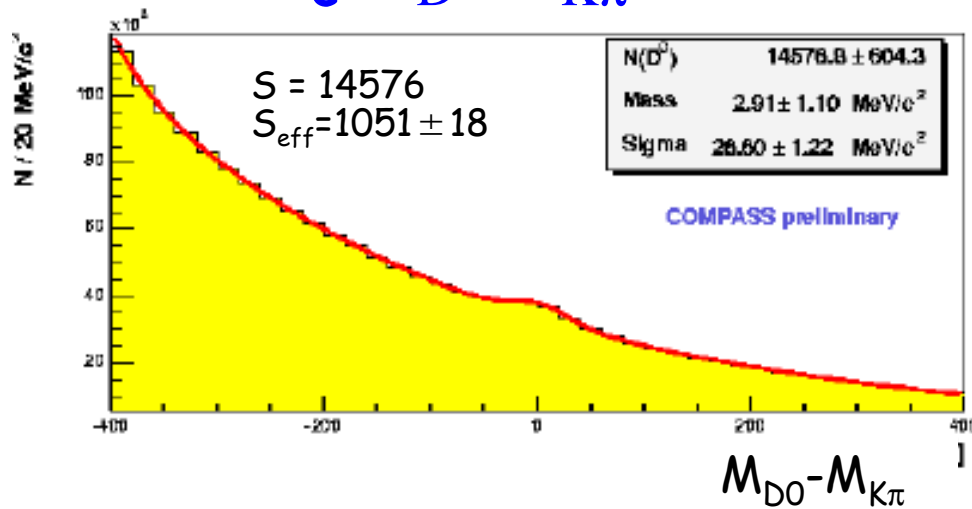
2 cases: $Q^2 > 1 \text{ GeV}/c^2$

$Q^2 < 1 \text{ GeV}/c^2$

Open charm 2002-2004 data

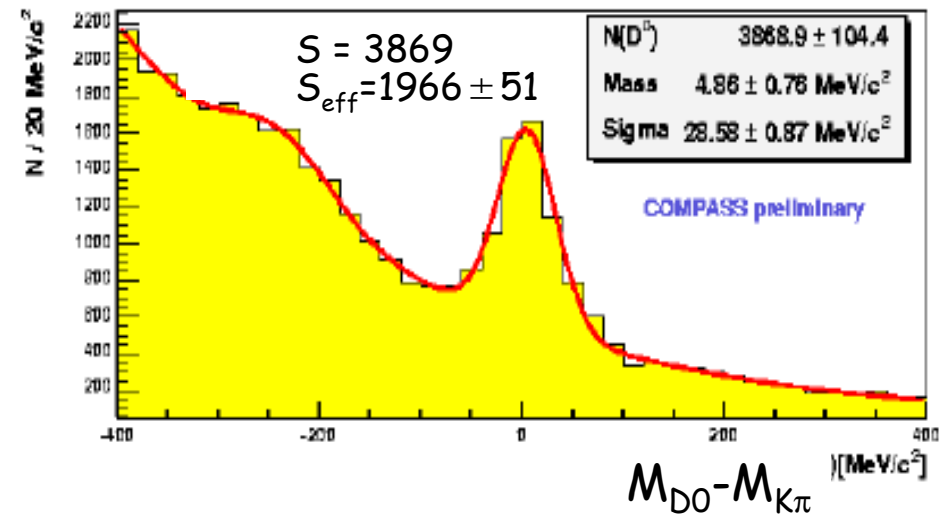
D^0

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



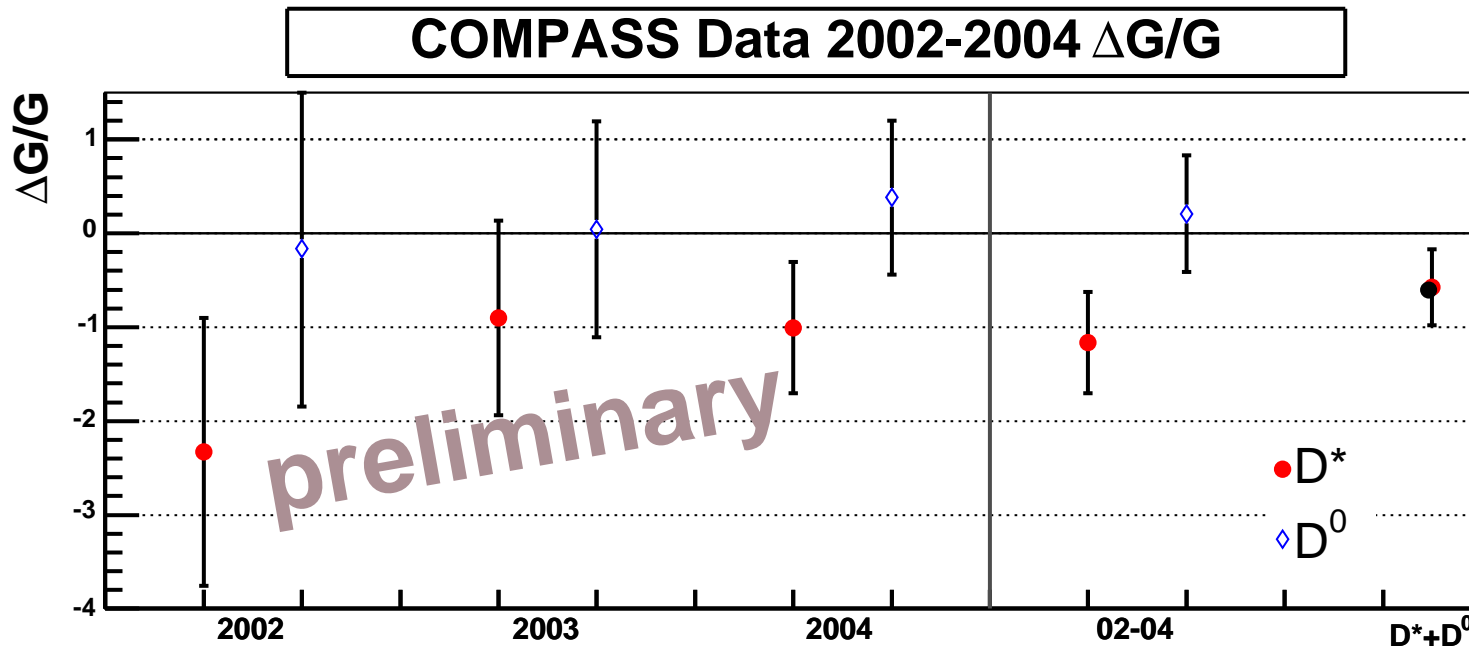
D^0 tagged by D^*

$c \rightarrow D^* \rightarrow D^0 \pi_s \rightarrow K\pi\pi_s$



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

$\Delta G/G$ from charm - result



$$\Delta G/G = -0.57 \pm 0.41$$

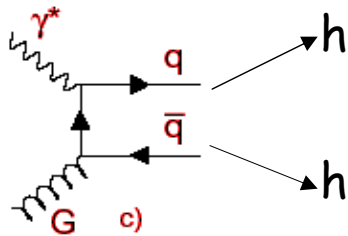
$$x_g = 0.15 \quad \text{scale } \mu^2 = 13 \text{ GeV}^2$$

D^0 and D^* results within 1.7σ

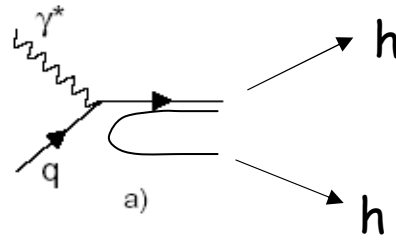
Much progress in charm analysis; no systematic effect larger than statistics observed yet. Study ongoing.

$\Delta G/G$ from high p_T hadron pairs

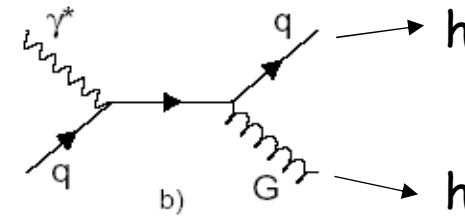
$Q^2 > 1 \text{ GeV}/c^2$



Photon Gluon Fusion (PGF)



Leading process



Gluon radiation

PGF ~ 33 % (Lepto MC, preliminary)

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

$$\begin{cases} \Sigma p_T^2 > 2.5 \text{ GeV}^2 \text{ (LO suppr)} \\ x_{Bj} < 0.01 \text{ (A}_1 \text{ small)} \end{cases}$$

Preliminary result 2002-2003 data:

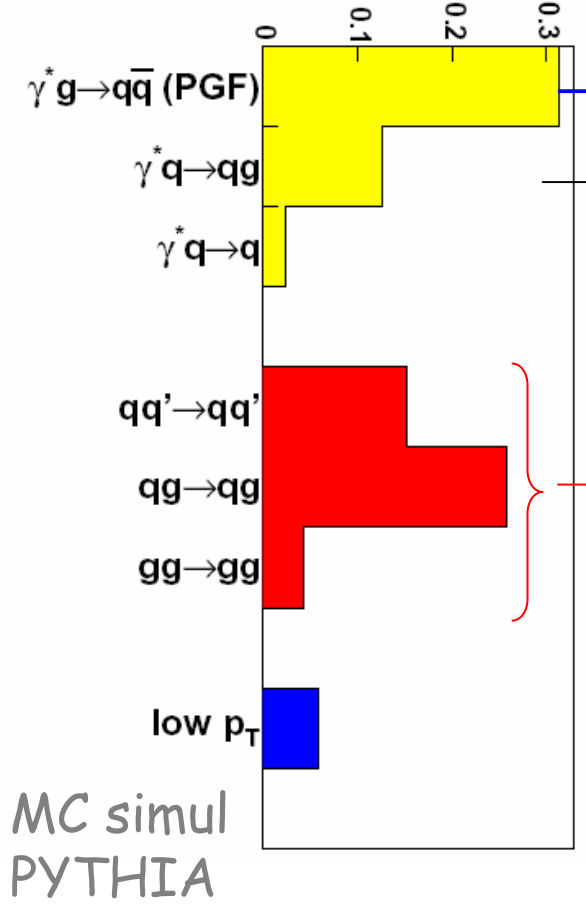
$$\Delta G/G = 0.06 \pm 0.31 \text{ (stat)} \pm 0.06 \text{ (syst)} \quad \langle x_g \rangle \sim 0.13$$

Value compatible with 0. Systematics small

$\Delta G/G$ from high p_T hadron pairs

$Q^2 < 1 \text{ GeV}/c^2$

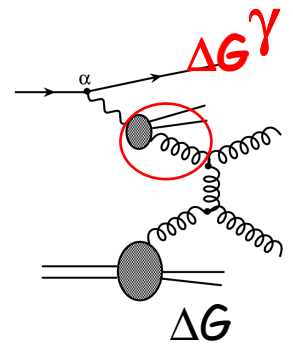
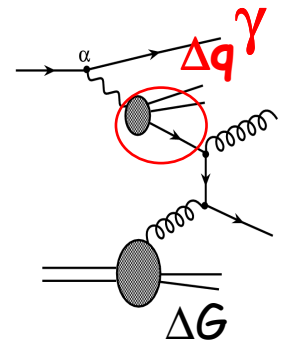
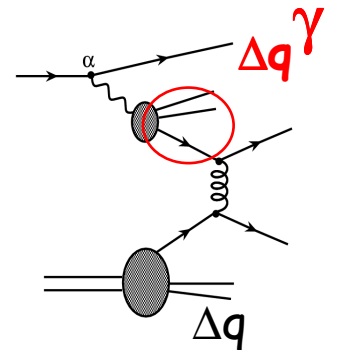
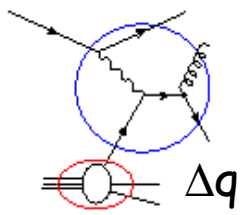
$Q^2 < 1$ 10 times more data, but additional background: resolved photon processes



PGF ~30%

QCDC

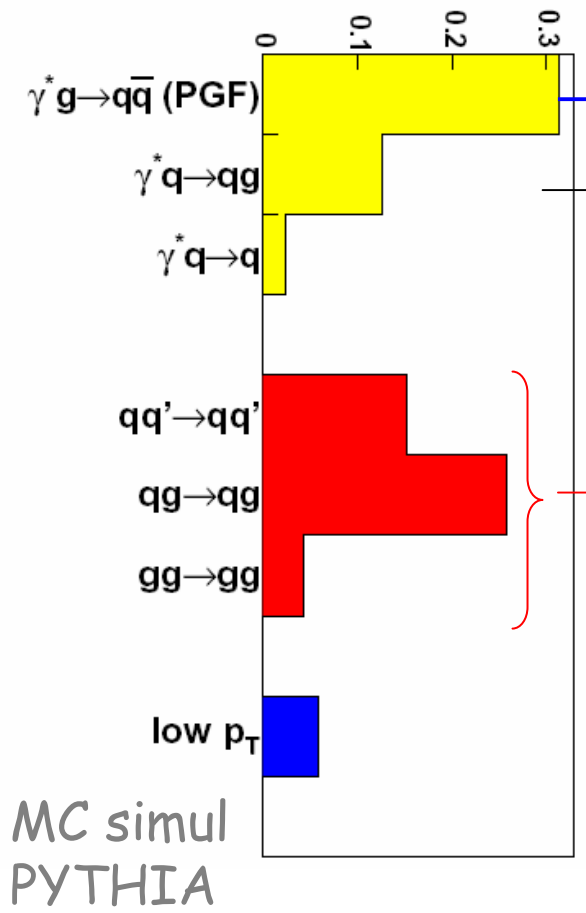
Resolved photons
~50%



$\Delta G/G$ from high p_T hadron pairs

$Q^2 < 1 \text{ GeV}/c^2$

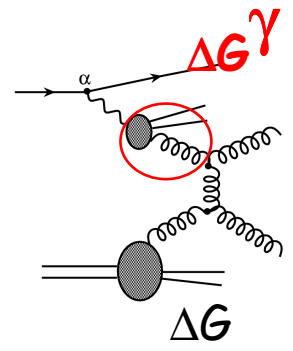
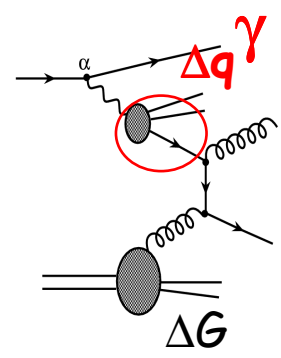
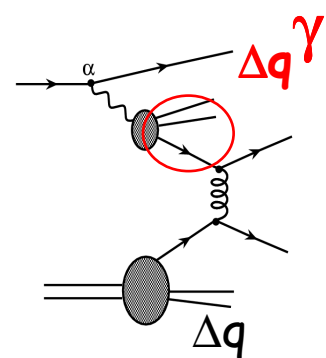
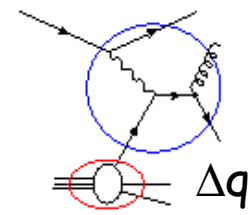
$Q^2 < 1$ 10 times more data, but additional background: resolved photon processes



PGF ~30%

QCDC

Resolved photons
~50%



- 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

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

- 2002-2003 data published *PLB 633 (2006) 25*
- **New result** from 2004 data (consistent with previous)

Preliminary, 2002-2004 data:

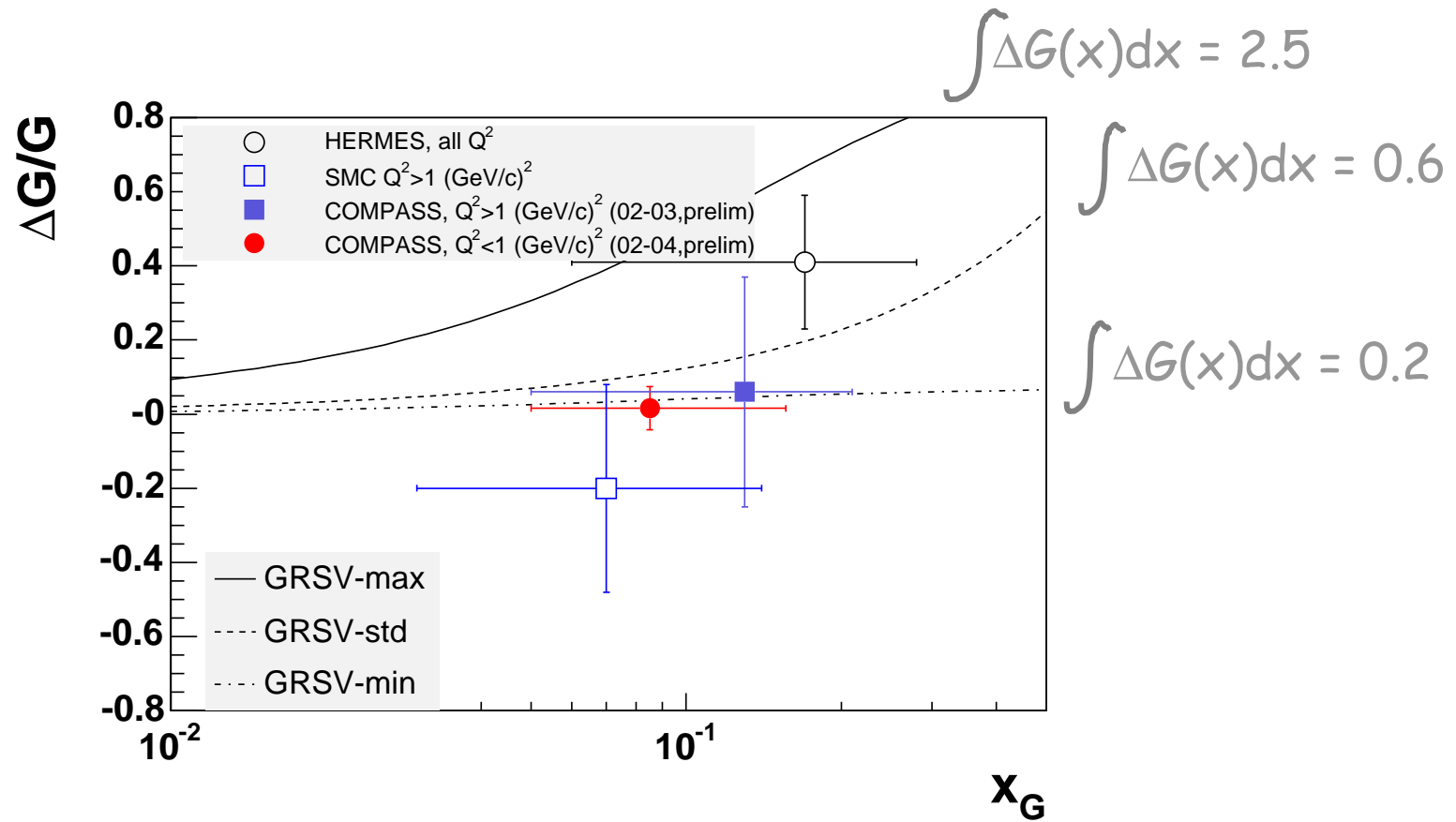
$x_g=0.085, \mu^2=3\text{GeV}/c^2$

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

Statistics and systematics small

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

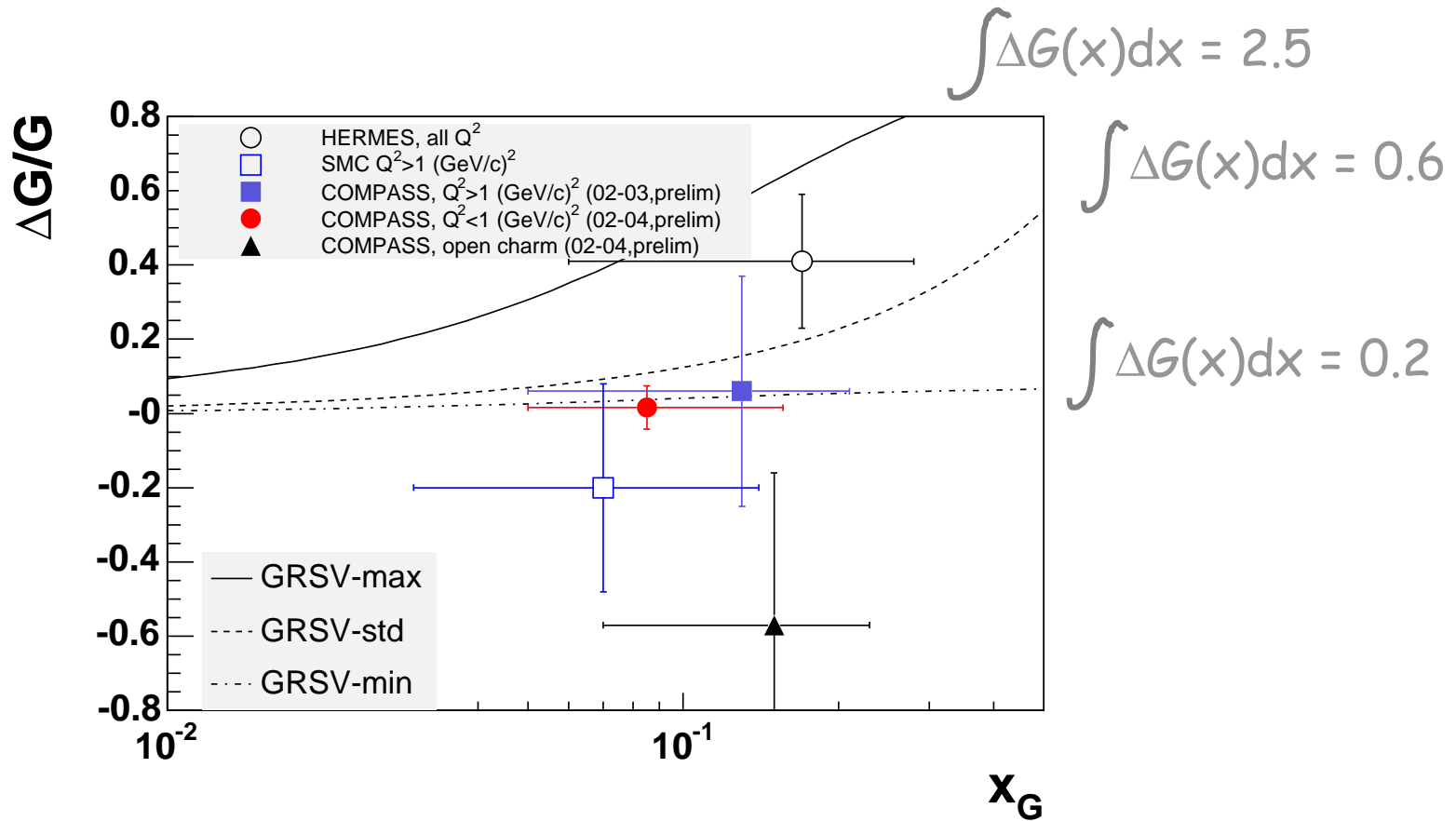
New COMPASS 2002-2004 data, $Q^2 < 1$



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

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

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

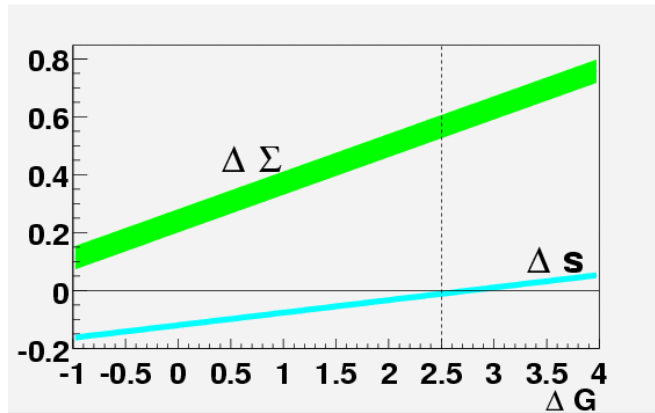


$\int \Delta G(x) dx$ small, or $\Delta G(x)$ has a node at $x \sim 0.1$

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

$\int \Delta G(x) dx$ and nucleon spin

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



$\rightarrow \Delta G$ not large $\Rightarrow \Delta \Sigma$ small (\neq predictions)

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

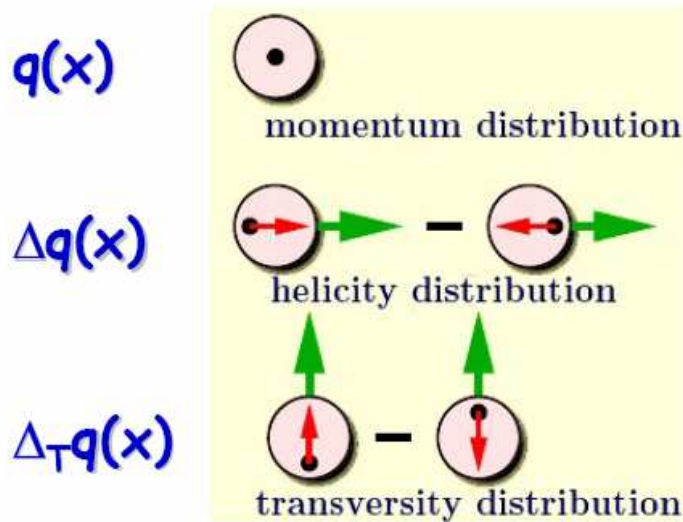
possible scenarios:

$$\left\{ \begin{array}{l} \frac{1}{2} 0.2 + 0.4 + 0.0 \\ \frac{1}{2} 0.2 + 0.0 + 0.4 \\ \dots \end{array} \right.$$

Transversity

Transversity

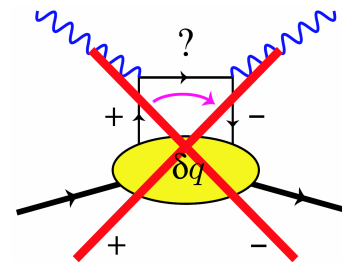
3 structure functions at LO, all of equal importance



$F_2(x)$

$g_1(x)$

$h_1(x)$



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

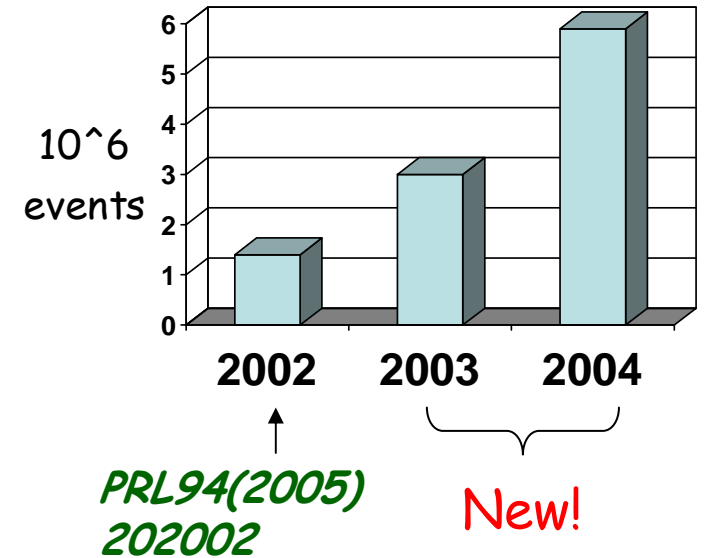
Transversity - Collins

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

Measure simultaneously two azimuthal asymmetries:

Collins: Correlation between direction of outgoing hadron & transverse spin of q

Sivers: Correlation between nucleon spin & transverse momentum of q



Collins

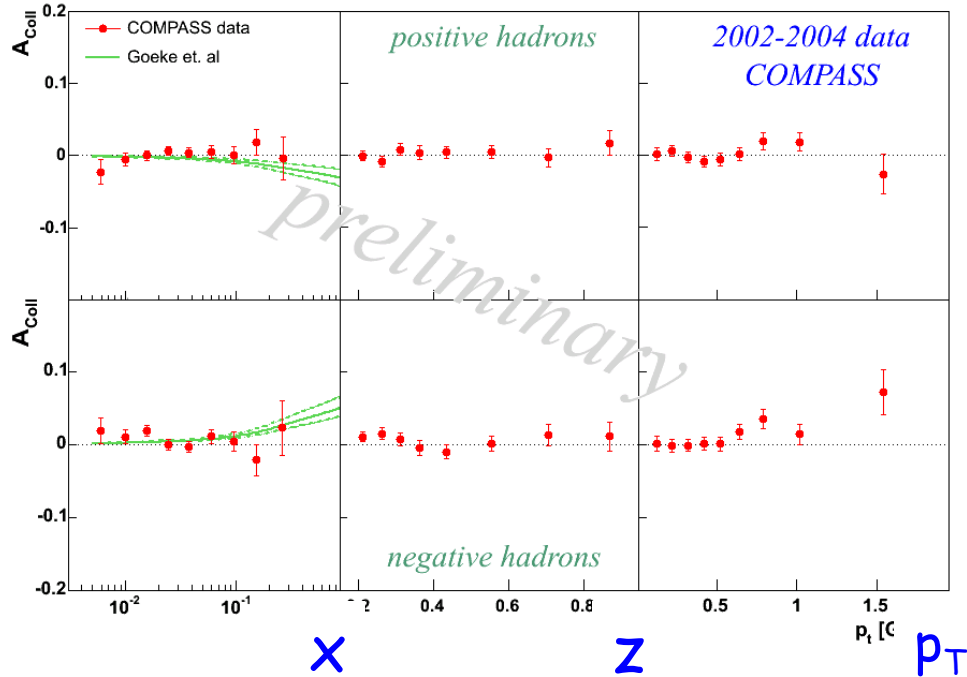
transverse distributions

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

fragmentation function

Sivers

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

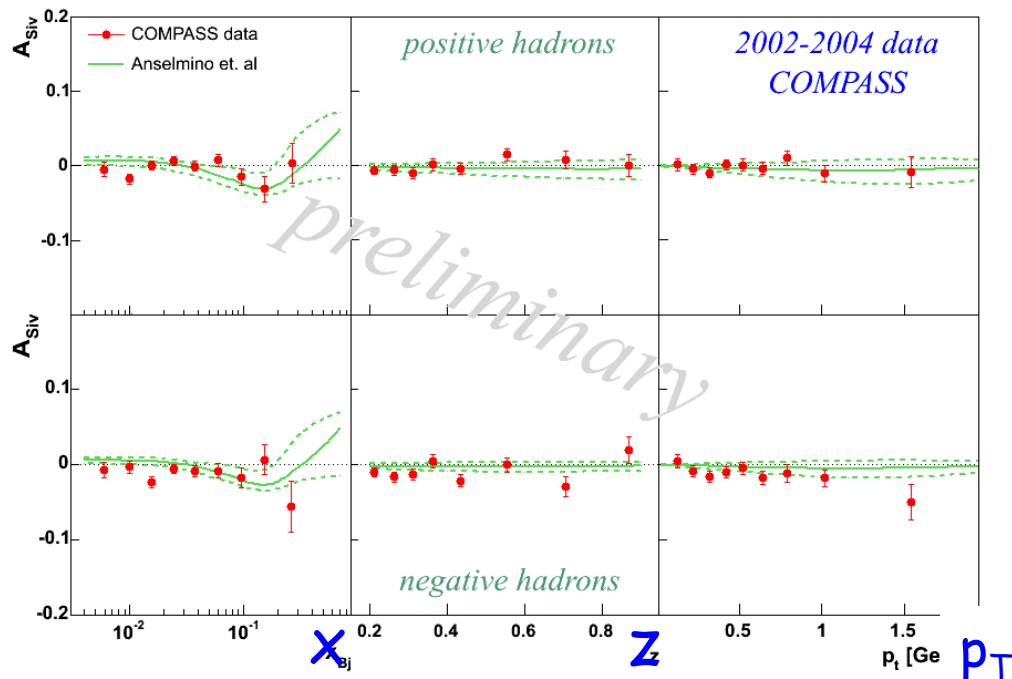


New: 2002-2004 data on d

A-Collins

Results consistent with 0

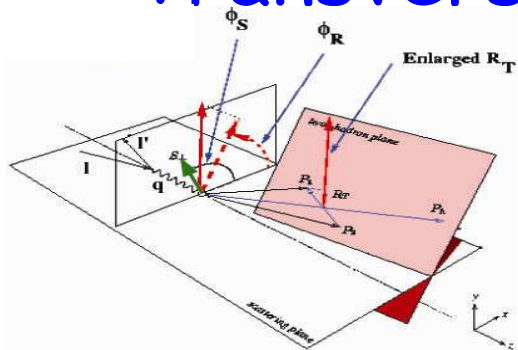
Models describing Hermes p data and using fragmentation function from Belle describe also COMPASS results



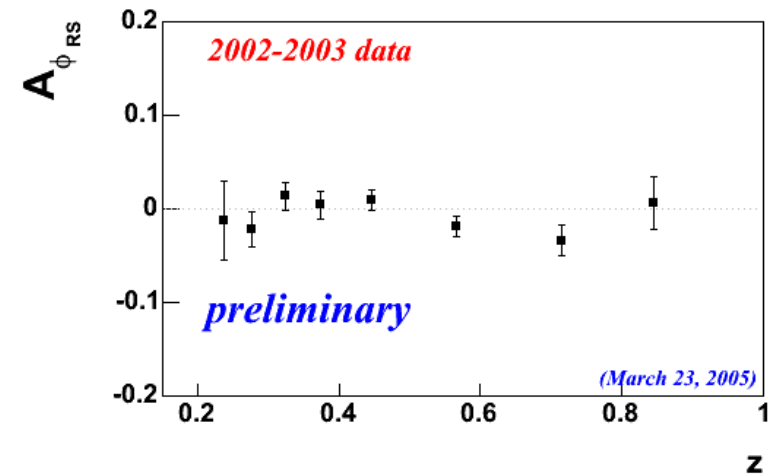
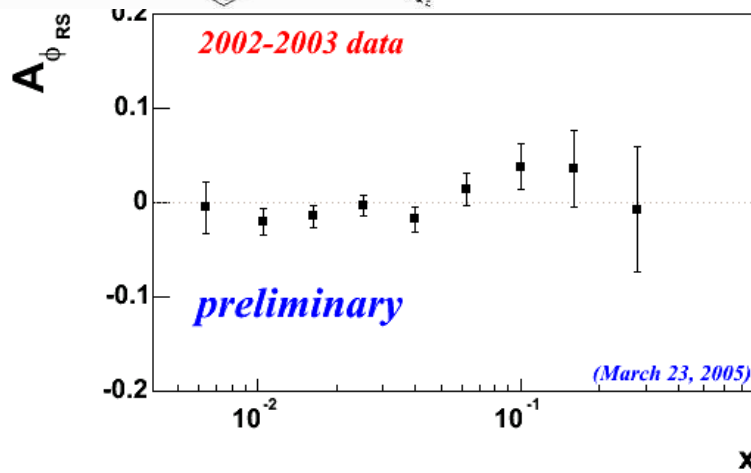
A-Sivers

Cancellation between proton and neutron?

Transversity - "Two hadron" asymmetries



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

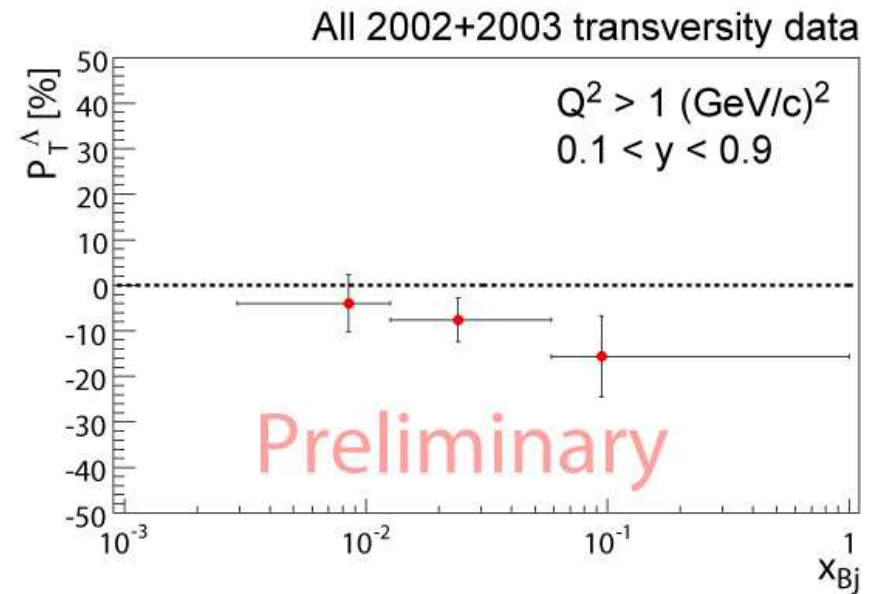
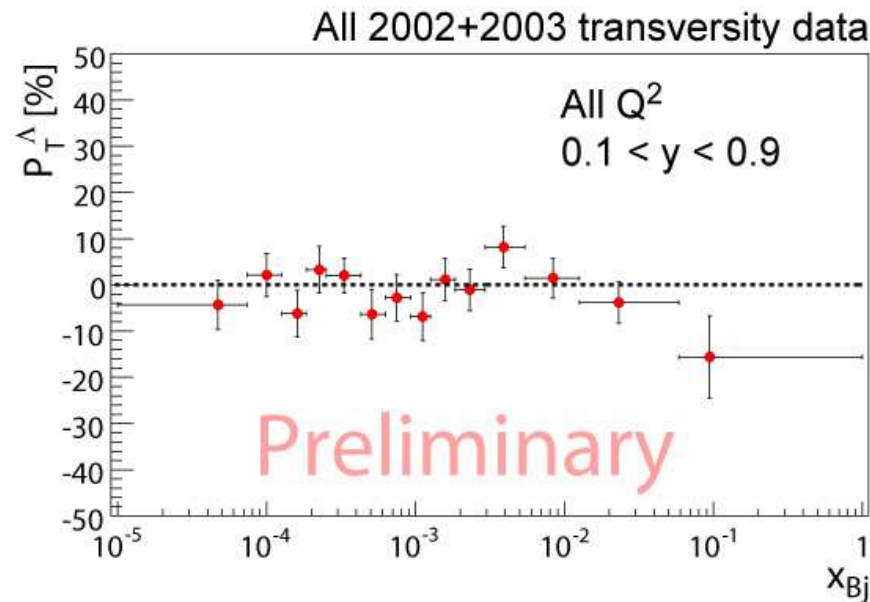


Precise measurement of few %
 Systematics seems well under control
 More data to come soon (2004 data)!

Also compatible with zero

Transversity - Λ polarization

$$P_T^\Lambda = f P_T D \frac{\sum_q e_q^2 \Delta_{Tq} \cdot \Delta D_q^\Lambda}{\sum_q e_q^2 \cdot q \cdot D_q^\Lambda}$$

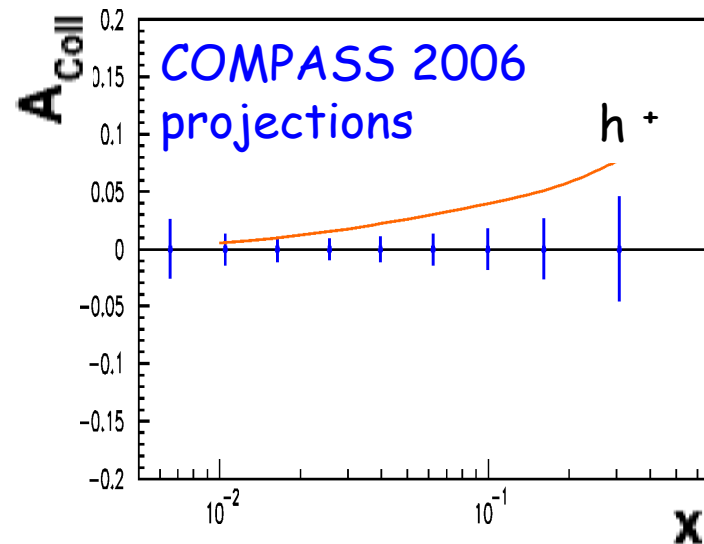


Negative trend for $Q^2 > 1$, but
deviation from zero not significant

Statistics will double with 2004 data

Collins asymmetry on proton - 2006 proj.

Interesting to see proton in 2006!



NH_3 target

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

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

Other physics at COMPASS

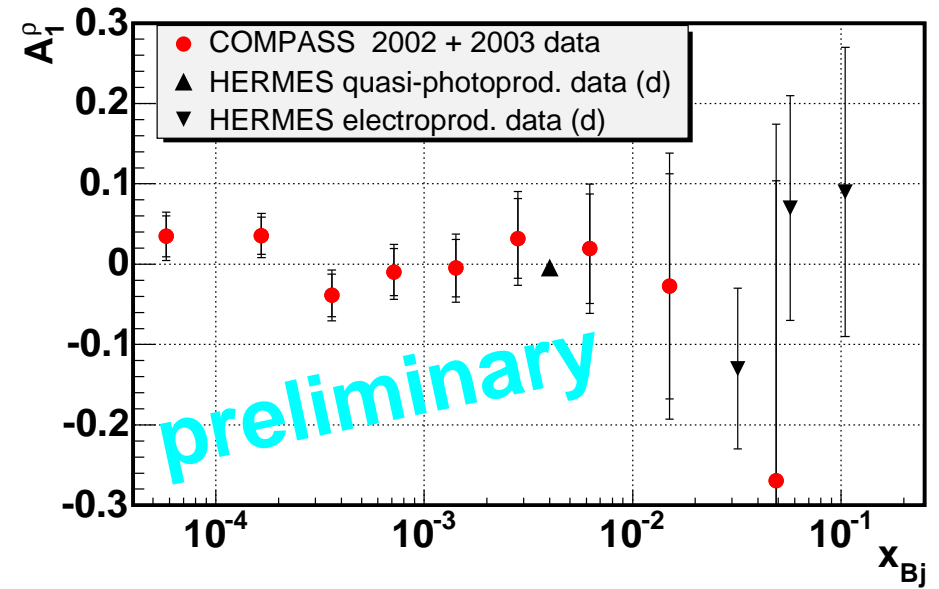
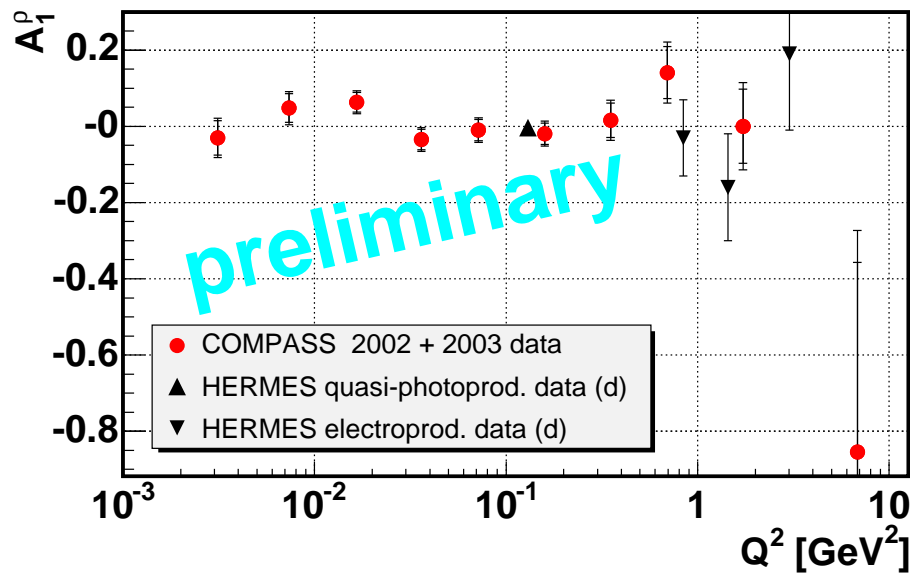
- Diffractive physics → See talk by Nicole d'Hose
- Lambda → See talk by Boris Grube
- Semi-inclusive spin asymmetries
- Primakoff reactions: polarisabilities of π and K
- ...

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

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

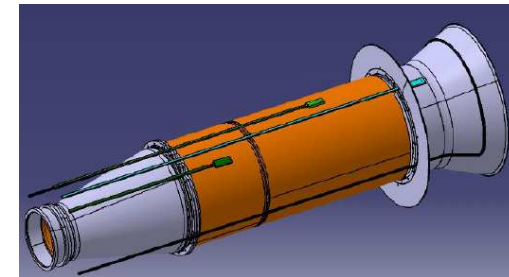
COMPASS 2006 upgrades (1)



New target magnet

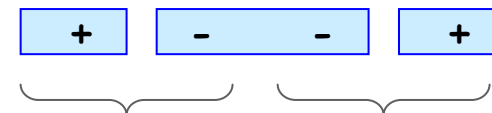
70 mrad \rightarrow 180 mrad

Gain in statistics \sim 30%



New 3 cell- cavity

Reduce systematic effects

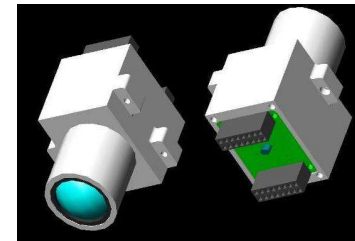
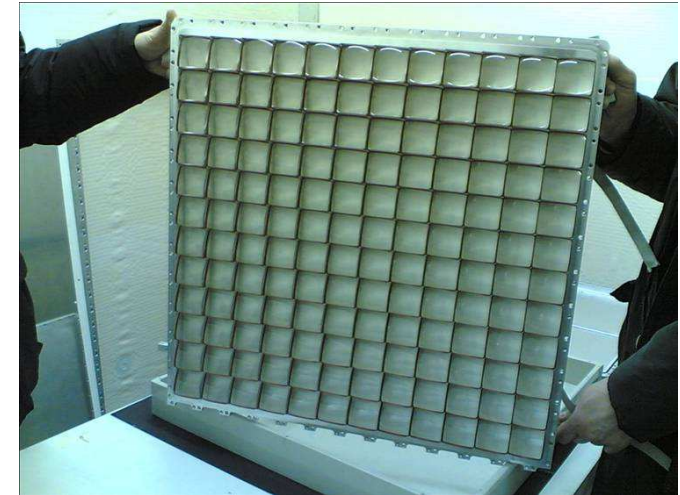
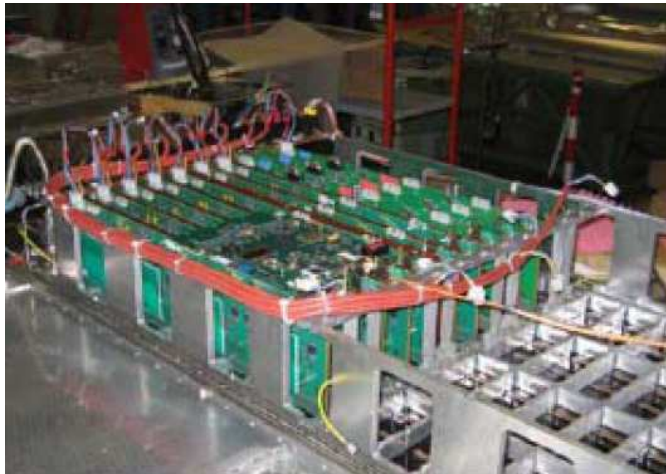


COMPASS 2006 upgrades (2)

RICH upgrade

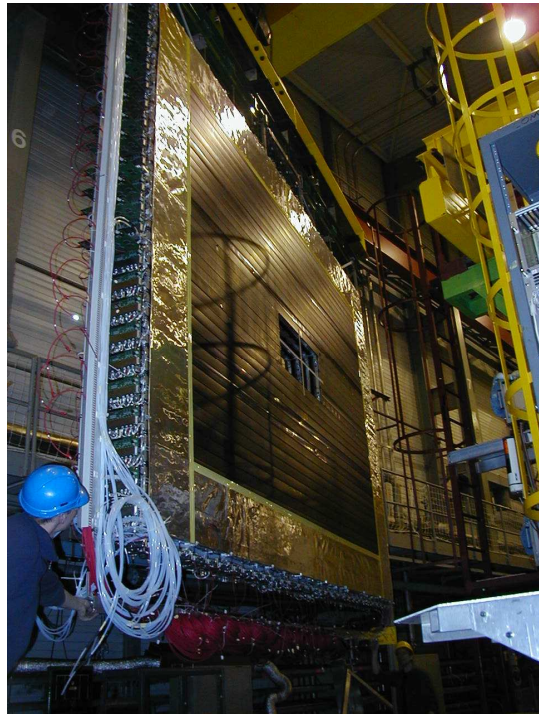
Central region: Multi Anode PMTs
more photons and improved S/N

Outer region: New faster electronics
improved S/N

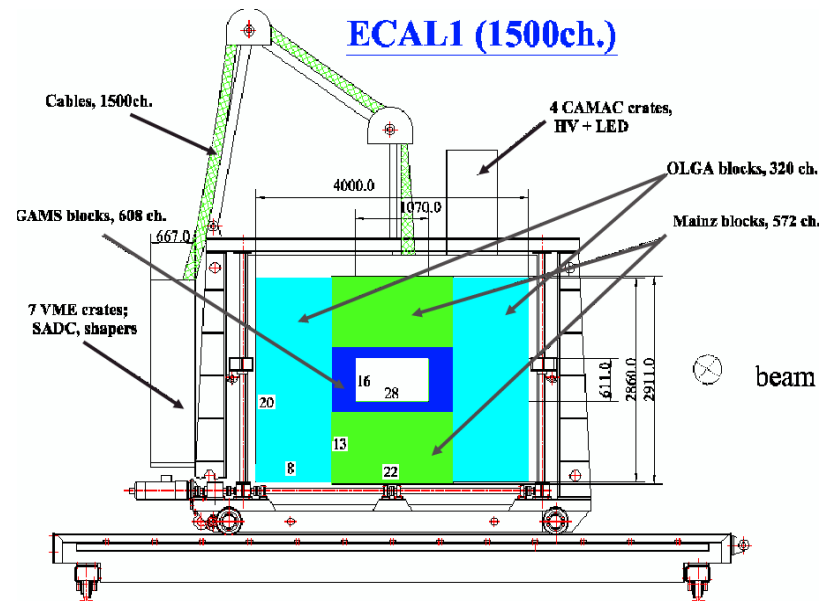


Gain in statistics ~ 50%

COMPASS 2006 upgrades (3)

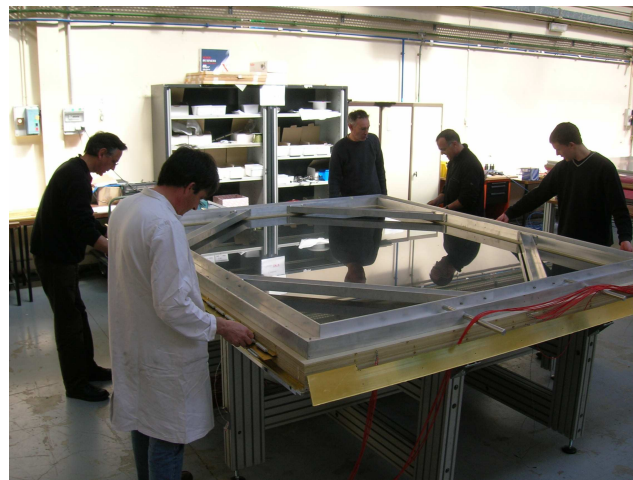


RICHWall



Full ECAL coverage

Gain in statistics ~ 20%



Large Drift Chamber

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 $g_1^d \rightarrow$ improves QCD fits for $\Delta\Sigma$ and ΔG
- Transversity: very precise **asymmetries** for deuteron
 \rightarrow compatible with zero

Outlook

- 2006 Important **upgrade of the spectrometer** will more than double the figure of merit of experiment, with
 - 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 + LH₂ 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!

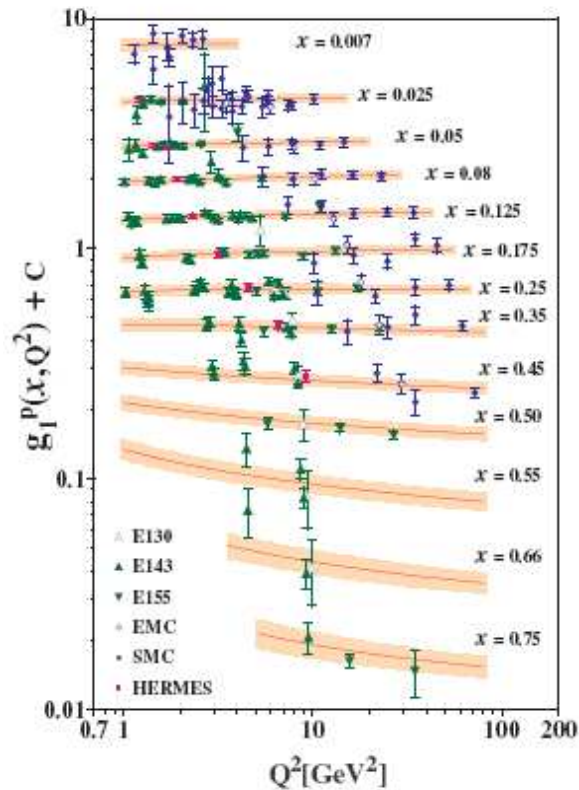
Spares

Progress on QCD fits of g_1

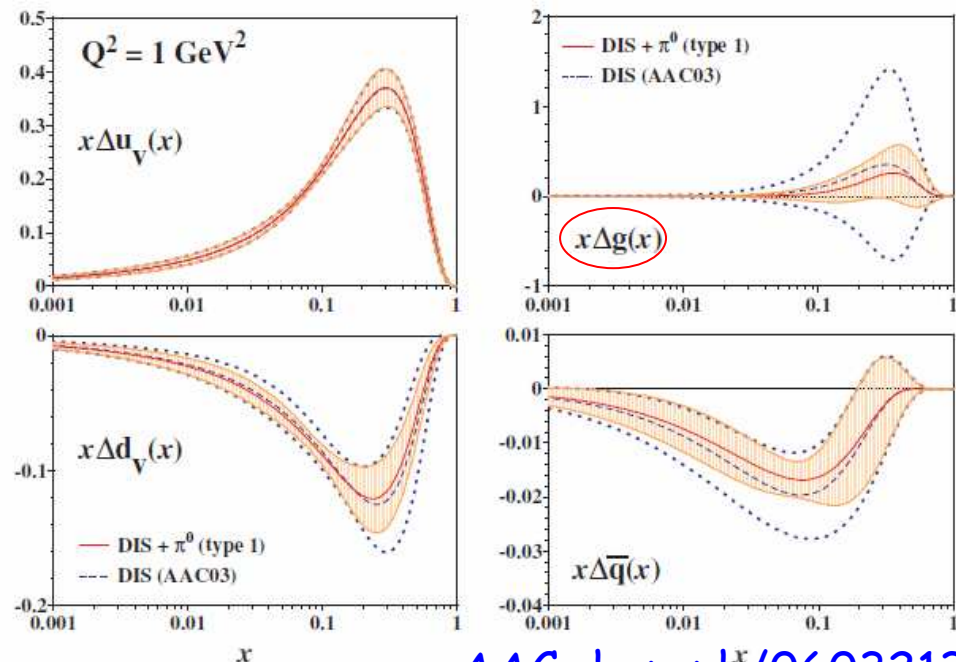
Various NLO pQCD global analyses of world data on $g_1^{p,d,n}$ with different parameterizations

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 $A_{LL} \pi^0$



AAC -hep-ph/0603213

NLO fits

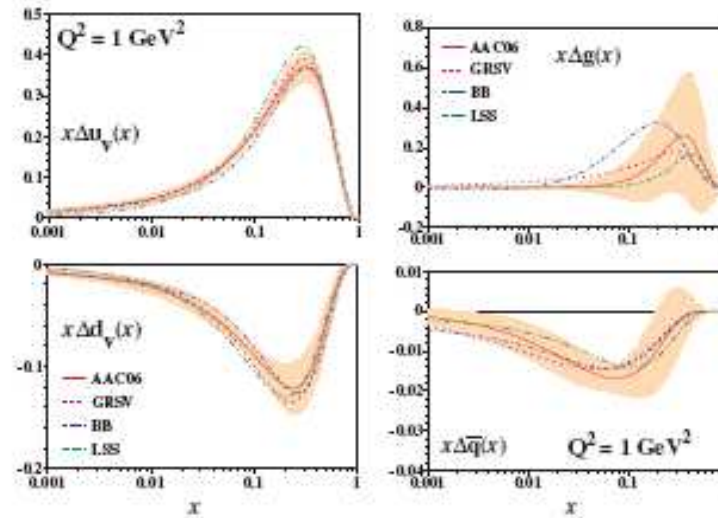


FIG. 5: (Color online) Comparison with other polarized PDFs at $Q^2=1 \text{ GeV}^2$. The type 1 distributions and their uncertainties are shown by the solid curves and bands. The others are the GRSV, BB, and LSS parametrizations.

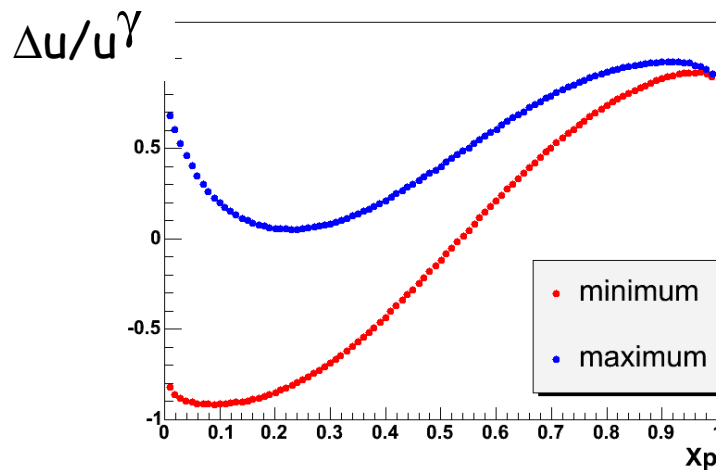
LO

{	BB02	$\int \Delta G$	1.19
	AAC00		1.15
	LSS01		1.0
	GRSV00		0.6

Polarized parton distributions in the photon

- Perturbative part calculable
- Non perturbative part unknown, but: $-q^\gamma(x, \mu_0^2) < \Delta q^\gamma(x, \mu_0^2) < q^\gamma(x, \mu_0^2)$
↑
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 limited theoretical uncertainty for ΔG

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

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

- 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)
 ± 0.013 (photon) } 0.055

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

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

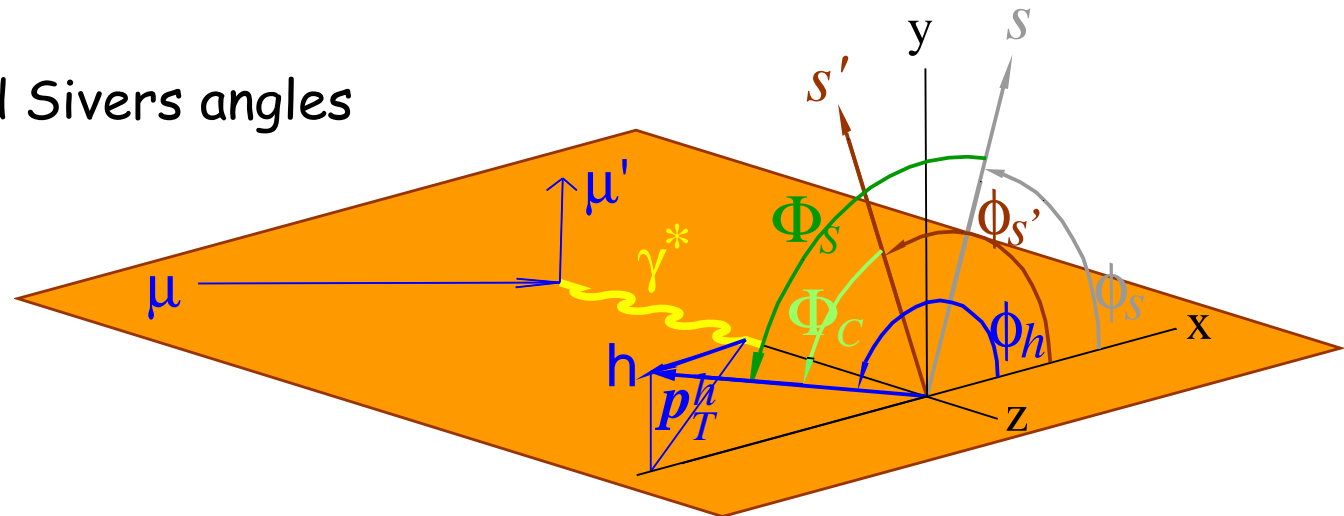
$\Delta G/G$ compatible with 0. Statistics and systematics small

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

Collins and Sivers asymmetries

Deuteron target
transverse polarization $\sim 25\%$ of the
total running time

Define Collins and Sivers angles



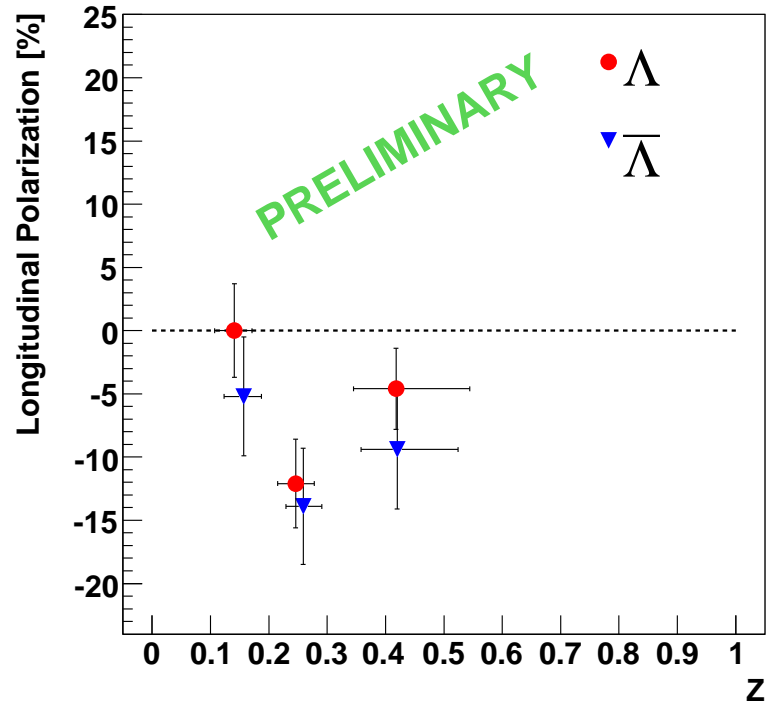
$$\Phi_{\text{Col}} = \Phi_h + \Phi_S - \pi$$

$$N_h^\pm = N_h^0 (1 \pm A_1 \sin \Phi_C)$$

$$A_1 = f.P.T.D.A_{\text{Coll}} \quad \text{Single spin asymmetry}$$

Λ longit polarization

COMPASS 2003



COMPASS 2003

