Measuring the gluon polarization at COMPASS

F.Kunne - CEA Saclay, France

- The nucleon spin : quark and gluon contributions
- The COMPASS experiment at CERN
- Gluon polarization measurement
  - from charm events
  - from high p_T hadron pairs
- Summary and outlook

6th Circum-Pan-Pacific Symposium on
High Energy Spin Physics
Tokyo, July 5-8. 2005

The Nucleon Spin

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

quark contribution

gluon contribution

orbital angular momentum

Naive quark parton model + relativistic corr. $\Delta\Sigma \sim 0.75$

QCD ; Ellis- Jaffe assuming $\Delta s = 0$, $\Delta\Sigma \sim 0.60$

→ Quark contribution to spin expected to be large

The Nucleon Spin

$$\tfrac{1}{2} = \tfrac{1}{2}\Delta\Sigma + \Delta G + \langle L_z \rangle$$

$\Delta\Sigma$ (quarks) | ΔG (gluons) | $\langle L_z \rangle$ (Orbital momentum)

$\Delta\Sigma = \Delta u + \Delta d + \Delta s$

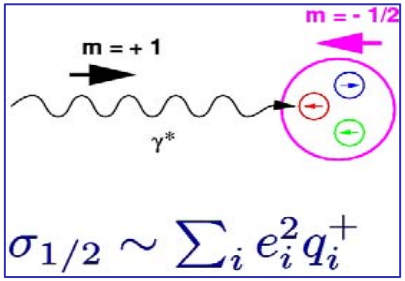
EMC, SMC, SLAC, HERMES…

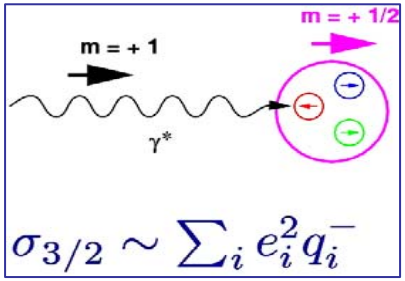
HERMES, COMPASS, RHIC

$\Delta q(x) = q^{+}(x) - q^{-}(x) + \bar{q}^{+}(x) - \bar{q}^{-}(x)$

$$\Delta q = \int \Delta q(x)\,\mathrm{d}x$$

How to measure $\Delta\Sigma$? Polarized Deep Inelastic





Photon absorbed by quark of opposite helicity

$$A_1 \approx \frac{1}{P_b P_t f D} A_{meas} = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \approx \frac{\sum_i e_i^2 \left(q_i^+ - q_i^-\right)}{\sum_i e_i^2 \left(q_i^+ + q_i^-\right)} \text{ (QPM)} = \frac{g_1(x)}{F_1(x)}$$

$g_1(x, Q^2)$ longitudinal spin structure function

Quark contribution $\Delta\Sigma$ and first moment of g_1

$$\Gamma_1^{p,n} = \int_0^1 g_1^{p,n}(x,Q^2)dx$$

$$\Gamma_1^p = \frac{1}{2}\left\{\frac{4}{9}\Delta u + \frac{1}{9}\Delta d + \frac{1}{9}\Delta s\right\}$$

$$= \frac{1}{12}\underbrace{(\Delta u - \Delta d)}_{a_3} + \frac{1}{36}\underbrace{(\Delta u + \Delta d - 2\Delta s)}_{\sqrt{3}a_8} + \frac{1}{9}\underbrace{(\Delta u + \Delta d + \Delta s)}_{a_0}$$

EMC, SMC, SLAC, HERMES

Neutron decay
$a_3 = g_A/g_V$

hyperon decay
a_8 = 3F-D

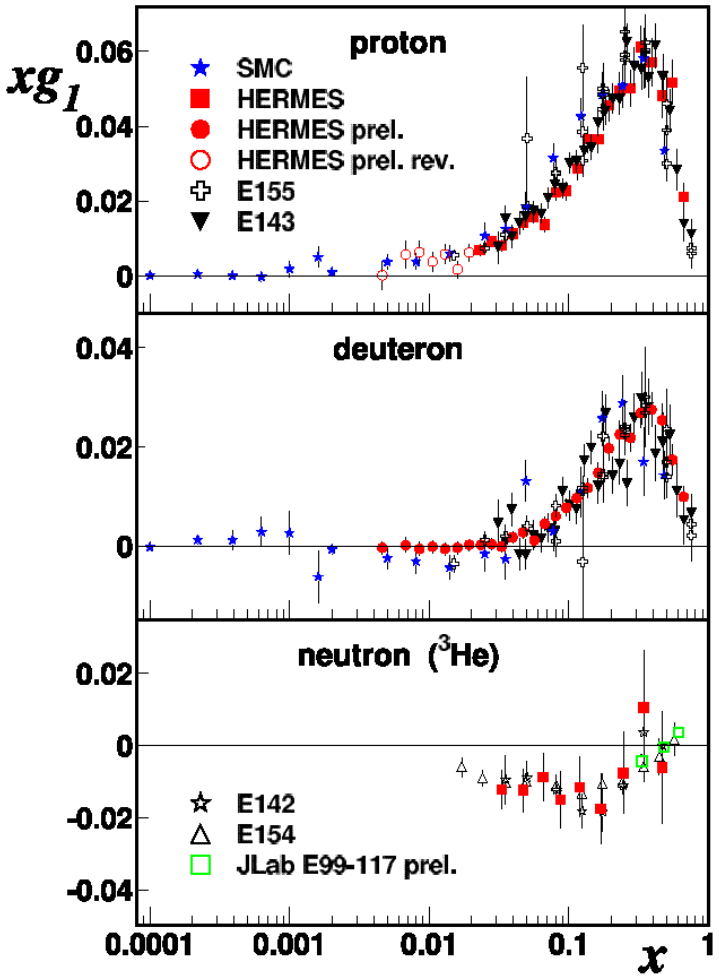
a_0 related to $\Delta\Sigma$

… and COMPASS, at low x

(see talk by Tatsuro Matsuda for COMPASS measurement of $g_1^d(x)$ and precise result on $\Delta\Sigma$)

Polarized spin structure function g_1

SLAC, EMC, SMC and HERMES data



Various pQCD global analyses of world data on g_1 (p, d, n) with different assumptions and parameterizations

$$\rightarrow \int_0^1 g_1^{p,n}(x)dx$$

→ $\mathbf{a_0}$ ~ 0.2 - 0.3

Quark contribution to spin small, very different from QPM expectation 0.6

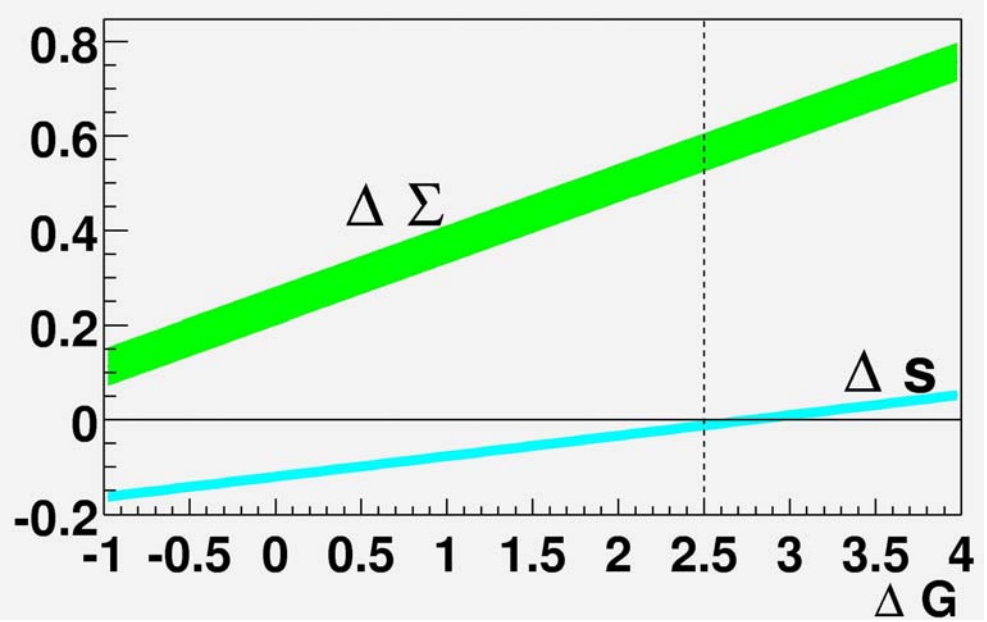
Interpretation

- QPM : $a_0 = \Delta\Sigma$

- QCD (AB scheme) :

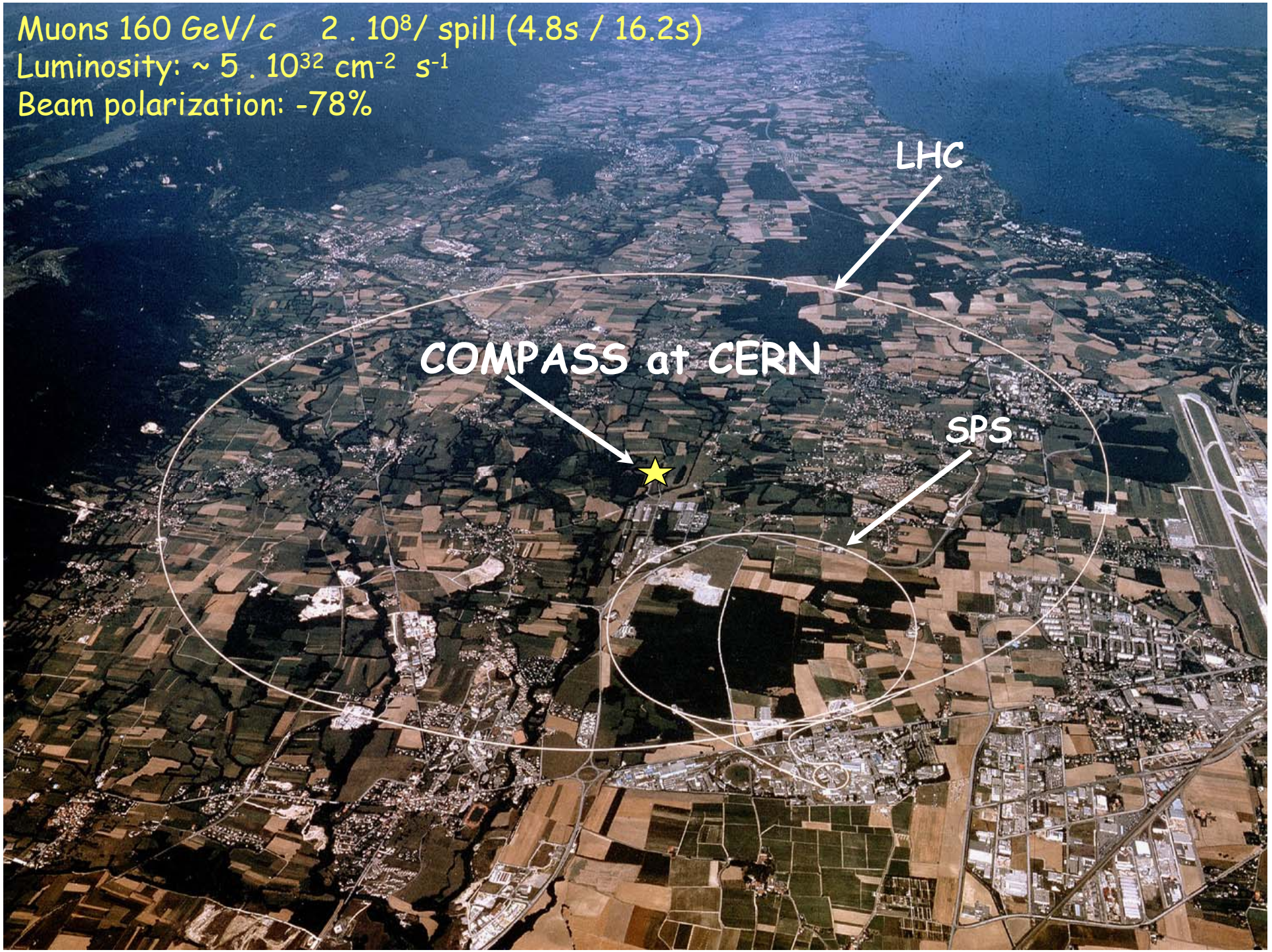
$$a_0 = \Delta\Sigma - n_f\,(\alpha_s/2\pi)\,\Delta G(Q^2)$$

$\Delta\Sigma$ and Δs cannot be accessed directly, they depend on ΔG



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

→ Need independent measurement of ΔG


Muons 160 GeV/c 2 . 10^8/ spill (4.8s / 16.2s)
Luminosity: ~ 5 . 10^32 cm^-2 s^-1
Beam polarization: -78%
LHC
COMPASS at CERN
SPS

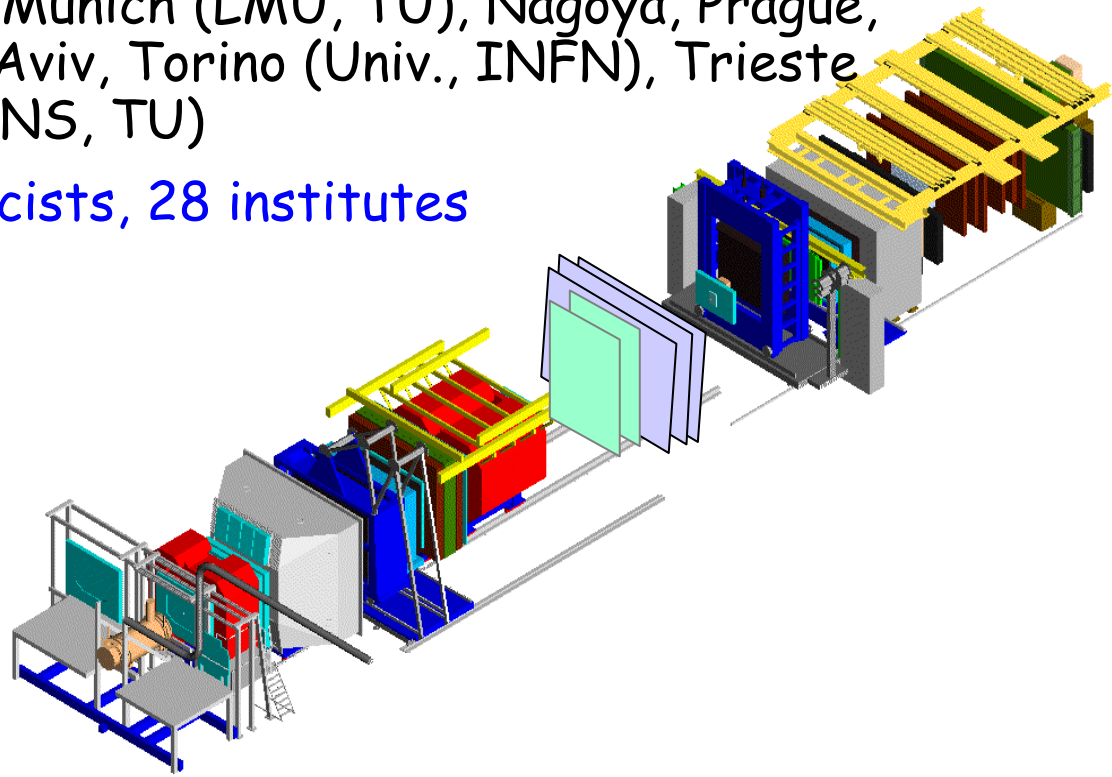
COMPASS Collaboration at CERN

Common Muon and Proton Apparatus

for Structure and Spectroscopy

Bielefeld, Bochum, Bonn (ISKP, PI), Burdwan and Calcutta, CERN, Dubna, Erlangen, Freiburg, Heidelberg, Helsinki, Lisbon, Mainz, Moscow (INR, LPI, MSU), Munich (LMU, TU), Nagoya, Prague, Protvino, CEA Saclay, Tel Aviv, Torino (Univ., INFN), Trieste (Univ.,INFN), Warsaw (SINS, TU)

230 physicists, 28 institutes



COMPASS – Physics program

Muon beam

Polarized target

- Gluon contribution to nucleon spin **L**
  + quark polarization (g_1, $\Delta\Sigma$, Δq flavor decomposition)
- Transversity **T**

Others: ρ, ϕ, J/ψ, Λ, ... production

H_2 target

- Generalized parton distributions (project ~2010)

Hadron beams π,K,p

- X_{PT} tests
- Spectroscopy

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See talk by Pr. Tatsuro Matsuda

Hadron beams π,K,p

- X_{PT} tests
- Spectroscopy

H_2 target

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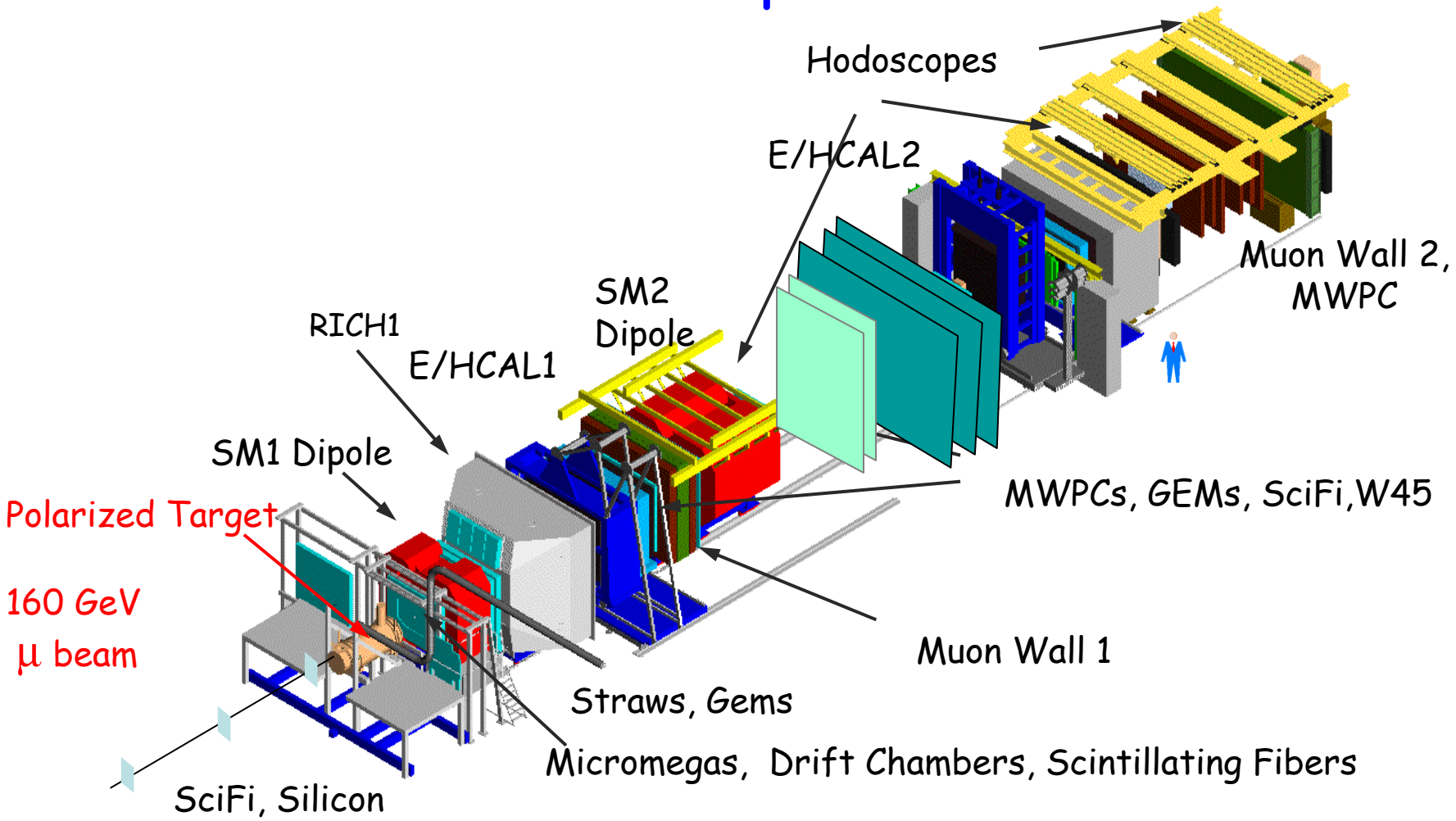
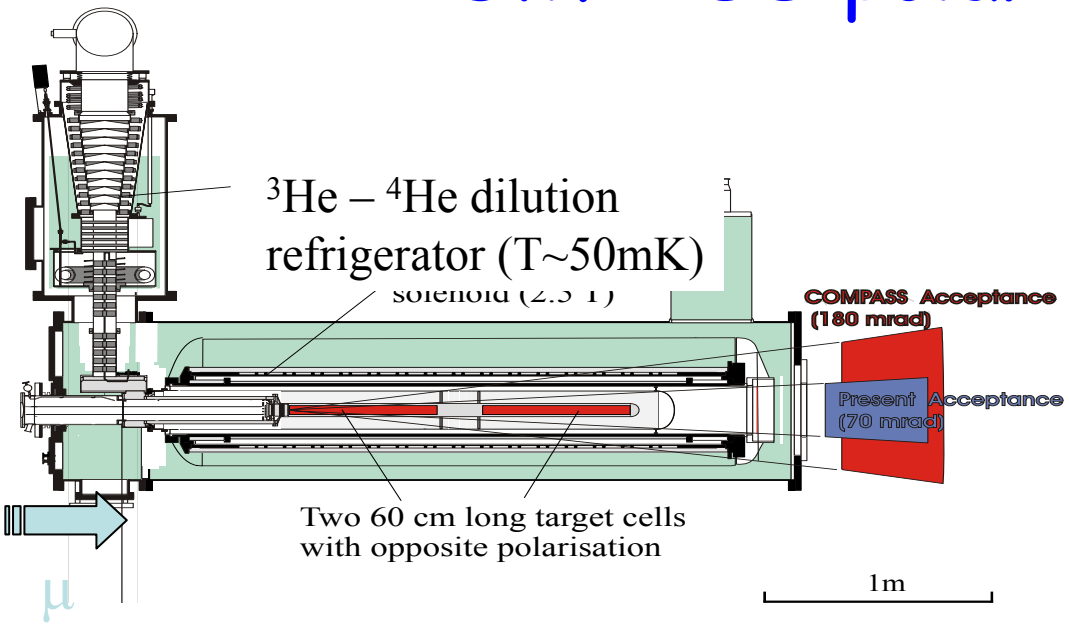
COMPASS spectrometer

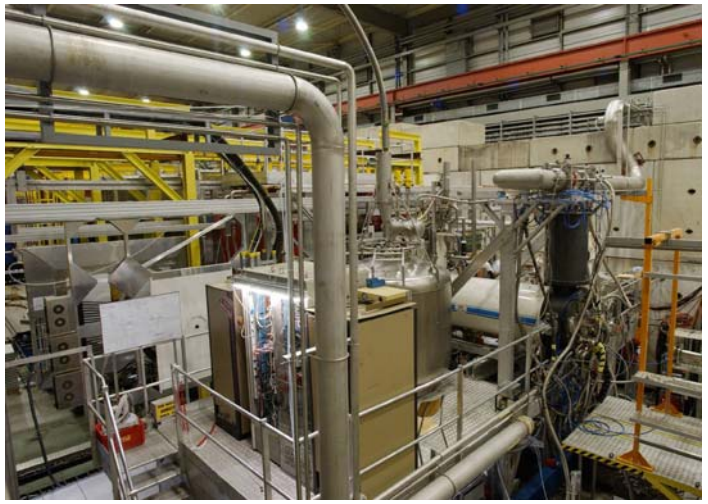


- Runs in 2002, 2003, 2004
- Resume in 2006, …

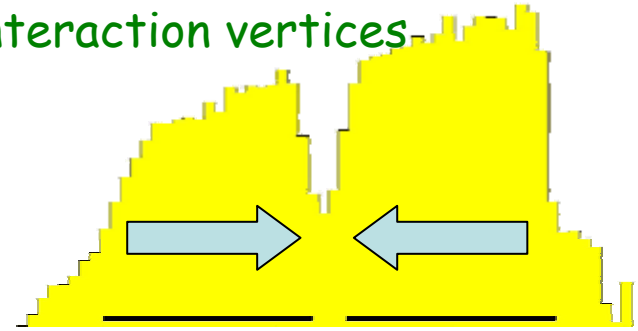
COMPASS polarized target



^{6}LiD Dilution =0.4
Polarization 50%

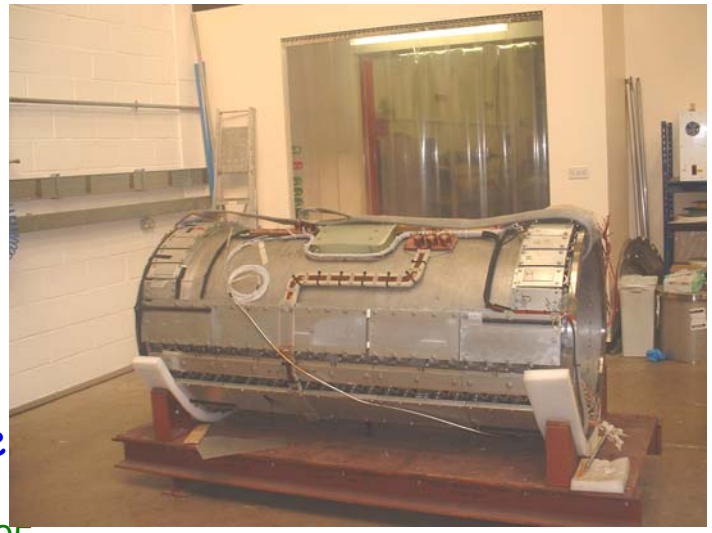


Reconstructed
interaction vertices

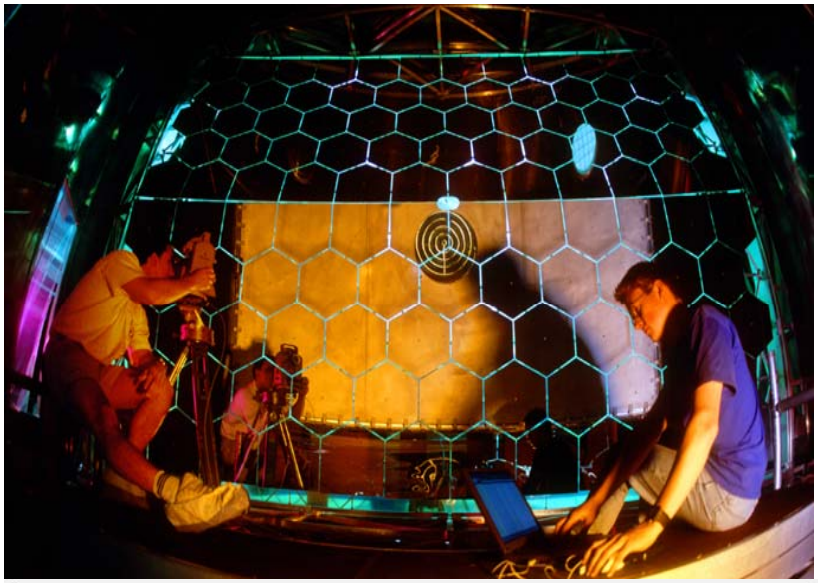


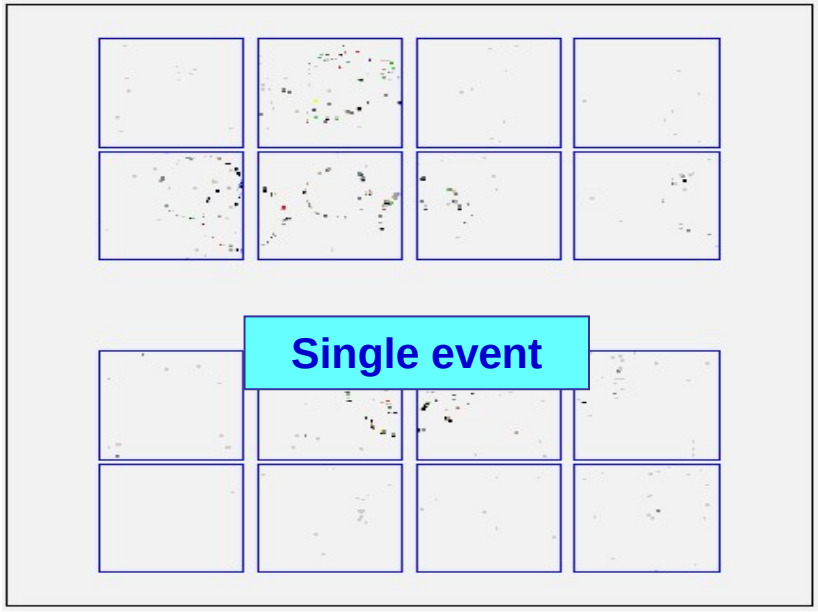
2006:

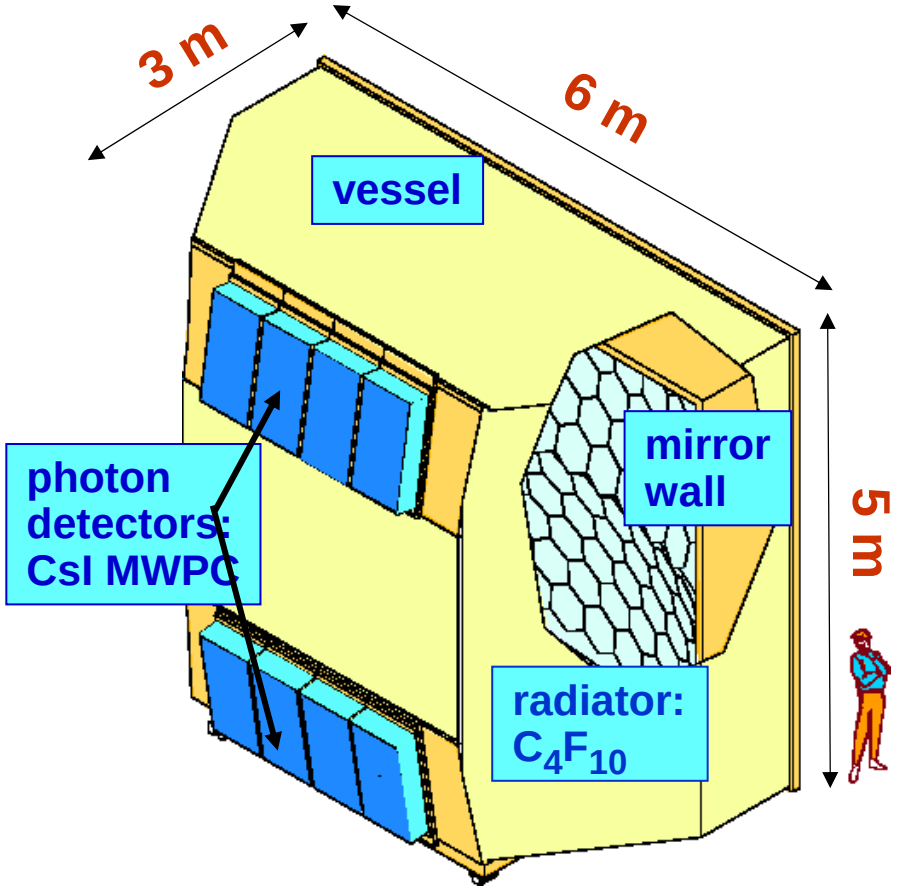
New
solenoid
180 mrad
acceptance



π, p, K separation with RICH



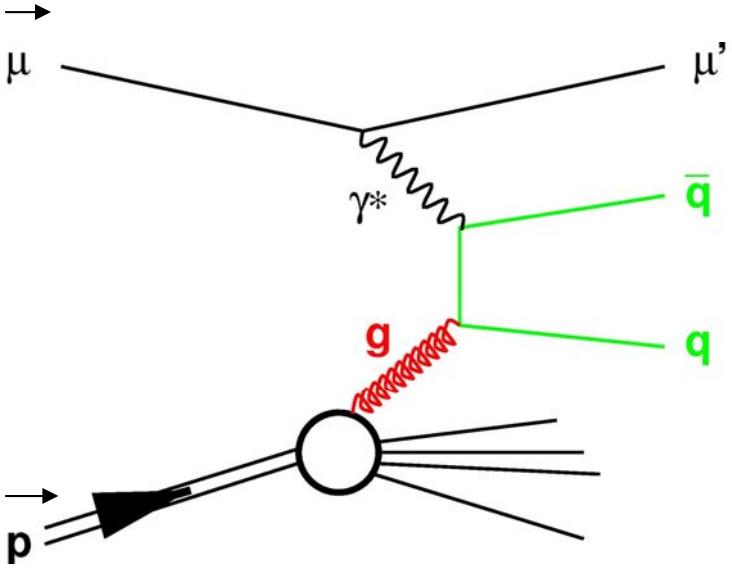




single photon:	σ = 1.2 mrad
ring:	σ = 0.4 mrad
photons/ring	n ~14
3σ π /K sep.	up to 40 GeV/c

ΔG/G measurement

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



•charm **c → D^0 → K π**

scale $\mu^2 = m_c^2$

clean signal from charm

limited statistics:

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

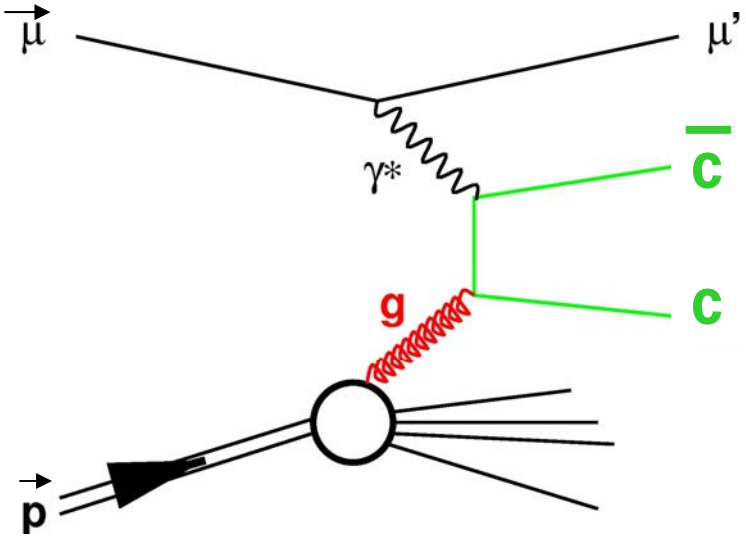
•high p_T hadron pair q $\bar{q}$ → h^+h^-

scale $\mu^2 = Q^2$ or Σp_T^2

large statistics

but… physical background

ΔG from open charm



$D^0 \Rightarrow K^-\pi^+$

$D^{*+} \Rightarrow D^0\pi_s^+$ D* tagging

$\Rightarrow K^-\pi^+\pi_s^+$

define : $M_{D^*} - (M_{D^0} + M_\pi)$

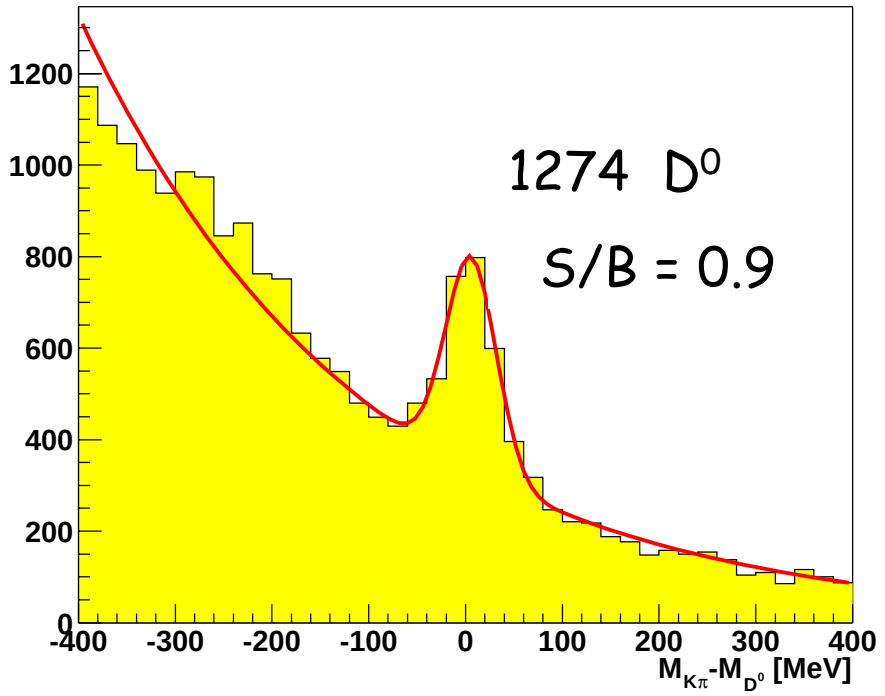
$$\Delta M_{K\pi\pi} = M_{K\pi\pi_s} - (M_{K\pi} + M_{\pi_s})$$

D^0 production

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

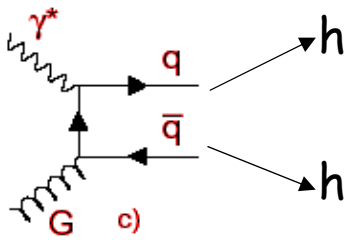
- Detection : $\mu\,\mu'$, $K\,\pi\,\pi$
- Cut on $\Delta M_{K\pi\pi}$
- Invariant $K\,\pi$ mass

$M_{K\pi}-M_{D^0}$ (2002+2003)

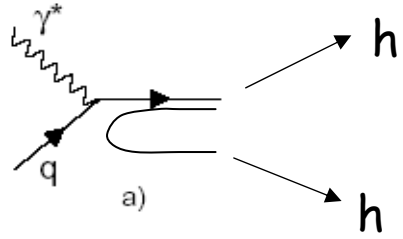


More statistics to come from 2004, then 2006 data

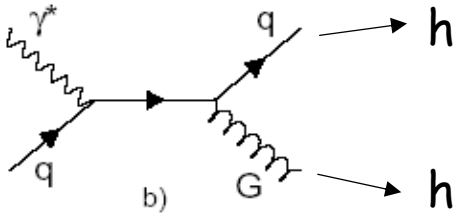
$\Delta G/G$ from high p_T hadron pairs $Q^2 > 1$ GeV/c^2 data



Photon Gluon Fusion (PGF)



Leading process



Gluon radiation

$Q^2 > 1$ GeV/c^2

PGF ~ 33 % (Lepto MC, preliminary)

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

$\Sigma p_T^2 > 2.5$ GeV^2 (LO suppr)

$x_{Bj} < 0.01$ (A_1 small)

Preliminary result 2002-2003:

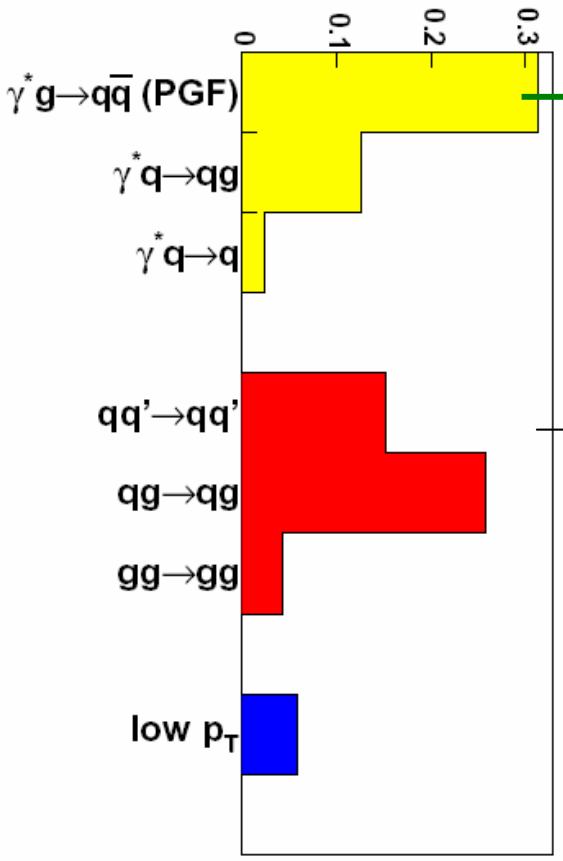
$A = -0.015 \pm 0.080 \pm 0.013$ (syst)

$\langle x_g \rangle \sim 0.13$

$\Delta G/G = 0.06 \pm 0.31$ (stat) ± 0.06 (syst)

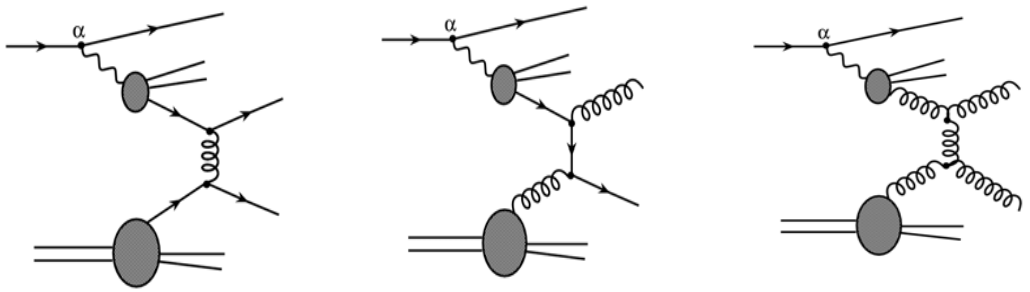
Additional physical background $Q^2 < 1\ GeV/c^2$ data

$Q^2 < 1$ 10 times more data, but additional uncertainty:
spin structure of resolved photon



MC simul PYTHIA

PGF +... +



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

$$+ R_{qq'}\langle \hat{a}_{qq'} \rangle \left(\frac{\Delta q}{q}\right)^{d} \left(\frac{\Delta q'}{q'}\right)^{\gamma} + \ldots$$

Need polarized parton distribution in the deuteron and in the photon ...

$\Delta G/G$ extraction $Q^2 < 1$ GeV/c^2 data

$$A_{LL}/D = \mathbf{R_{pgf}}\ \mathbf{\Delta G/G}\ \mathbf{a_{LL}^{pgf}/D}$$

$$+ R_{qcdc}\ A_1\ a_{LL}^{qcdc}/\mathbf{D}$$

$$+ R_{qq}\ A_1\ a_{LL}^{qq} A_1^{\gamma}$$

$$+ R_{qg}\ \mathbf{\Delta G/G}\ a_{LL}^{qg} A_1^{\gamma}$$

$$+ R_{gq}\ A_1\ a_{LL}^{gq}\ (\Delta G/G)^{\gamma}$$

$$+ R_{gg}\ \mathbf{\Delta G/G}\ a_{LL}^{gg}\ (\Delta G/G)^{\gamma}$$

Inputs:
- Monte Carlo event generation
- A_1 parameterization (world data)
- LO - QCD calculations

Polarized parton distribution in the photon : perturbative part calculable
Non perturbative part unknown, but:

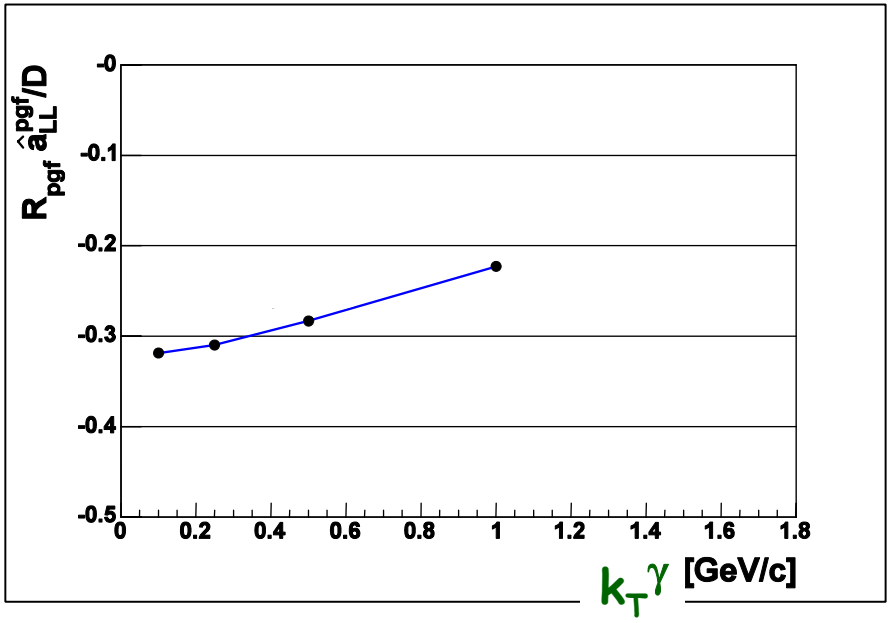
$$-q^{\gamma}(x,\mu^2) < \Delta q^{\gamma}(x,\mu^2) < q^{\gamma}(x,\mu^2)$$

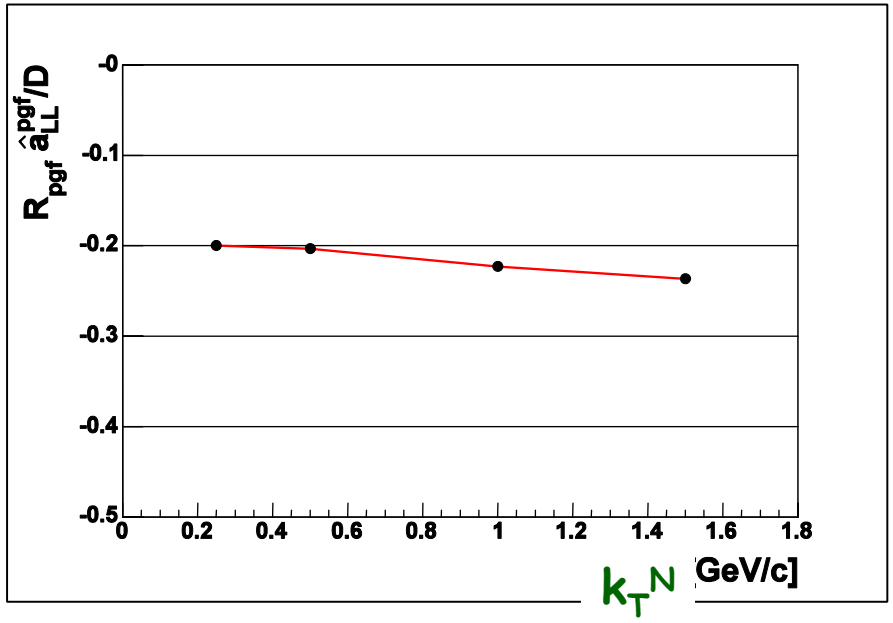
Try two extreme scenarios and evaluate effect on $\Delta G/G$ value
→ additional limited theoretical uncertainty

Systematic errors from MC

$Q^2 < 1\ GeV/c^2$ data

- PYTHIA parameters varied in range where fair data/MC agreement
  - → Effect on R_{PGF}. a_{LL}
- Most sensitive parameter : k_T^{γ}





→ Contribution to systematic error on $\Delta G/G$: 0.052

$\Delta G/G$ result $Q^2 < 1\ GeV/c^2$ data

2002+2003 data $p_T > 0.7\ GeV$, $\Sigma p_T^2 > 2.5\ GeV^2$:

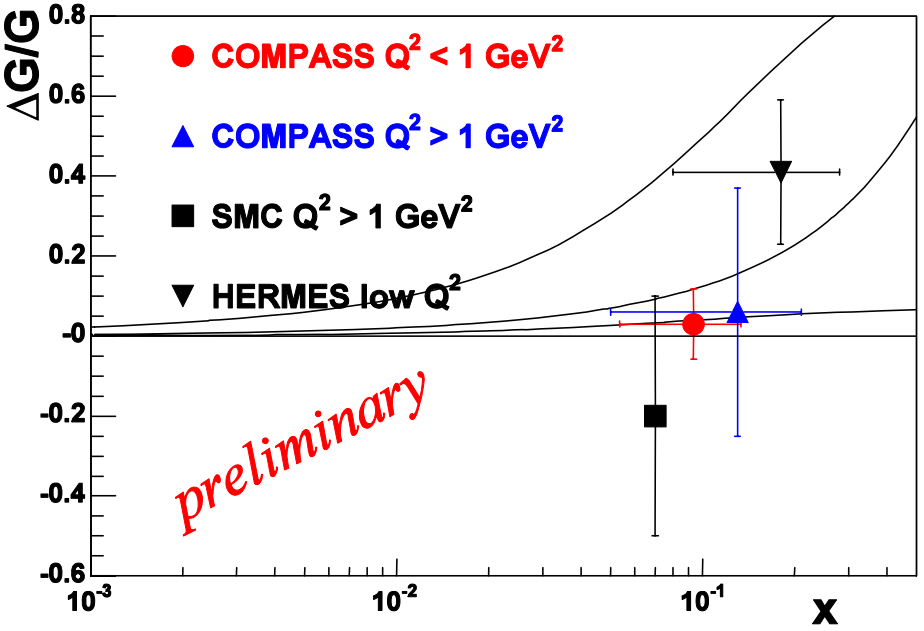
$$A_{LL}/D = 0.002 \pm 0.019(stat) \pm 0.003\ (exp.syst)$$

$\Delta G/G$ $(x_g=0.1, \mu^2=3 GeV/c^2)$ = +0.024 $\pm$ 0.089(stat) $\pm$ 0.014 (exp.syst)
$\pm$ 0.052 (MC.syst)
$\pm$ 0.018 (photon)
} 0.057

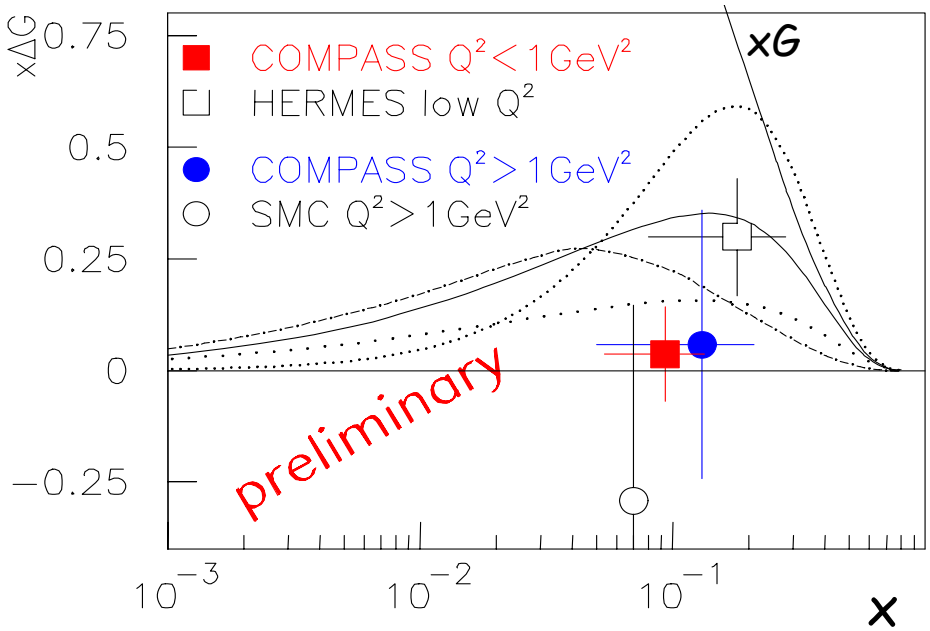
$\Delta G/G$ = 0.024 $\pm$ 0.089 (stat) $\pm$ 0.057 (syst)

COMPASS 2002+2003 data

$\Delta G(x)/G(x)$



$x\Delta G(x)$



Curves: QCD analyses- GRSV00 - NLO

$\int \Delta G$ = 0.16 min.
0.62 std.
2.48 max. scenario

LO

	$\int \Delta G$
BB02 (Bluemlein,B)	1.19
AAC00 (Japan)	1.15
LSS01 (Leader,...)	1.0
GRSV00 (Gluck, Reya)	0.6

ΔG small, or $\Delta G(x_g)$ has a node at $x_g \sim 0.1$

COMPASS - Conclusion and outlook

- First precise result on $\Delta G/G$ from high p_T (x_g= 0.1)

  → ΔG small, or $\Delta G(x_g)$ has a node at $x_g \sim 0.1$

- Inclusive DIS : g_1^d and $\Delta\Sigma$

- Collins and Sievers asymmetries from data on transverse polarized deuteron target (T.Matsuda talk)

- Future: run in 2006

  - add statistics on $\Delta G/G$ from D^0 channel and high p_T ,

  - transverse spin, p target