Longitudinal Spin Structure of The Nucleon

F.Kunne - CEA Saclay, France

- Nucleon spin
- Gluon polarization : direct measurements
  evaluation from QCD g_1 analysis
- Polarized quark distributions

EINN 07

7th Int. European Research Conference on Electromagnetic Interactions with Nucleons and Nuclei

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

quark gluon orbital momenta

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

$\Delta q = \vec{q} - \overleftarrow{q}$

$\Delta\Sigma$ Predictions:

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

$\Delta\Sigma$ Measurements:

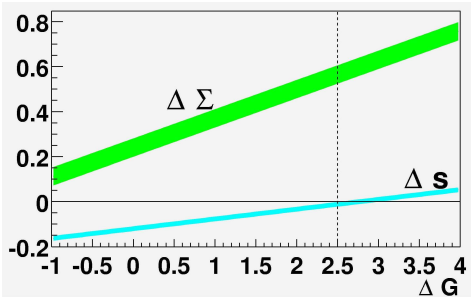
Polarized DIS $\vec{l}\,\vec{N}$ spin aymmetry $A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{g_1}{F_1}$

$\int_0^1 g_1 dx$ + neutron and hyperon decay measurements to determine a_0, singlet axial matrix element, related to $\Delta\Sigma$

Quark contribution to Nucleon Spin

World data on g_1 → $a_0 \sim 0.2 - 0.3$

- Quark Parton Model, $a_0 = \Delta\Sigma$
- 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

How to extract ΔG ?

- Polarized Lepton Nucleon Scattering

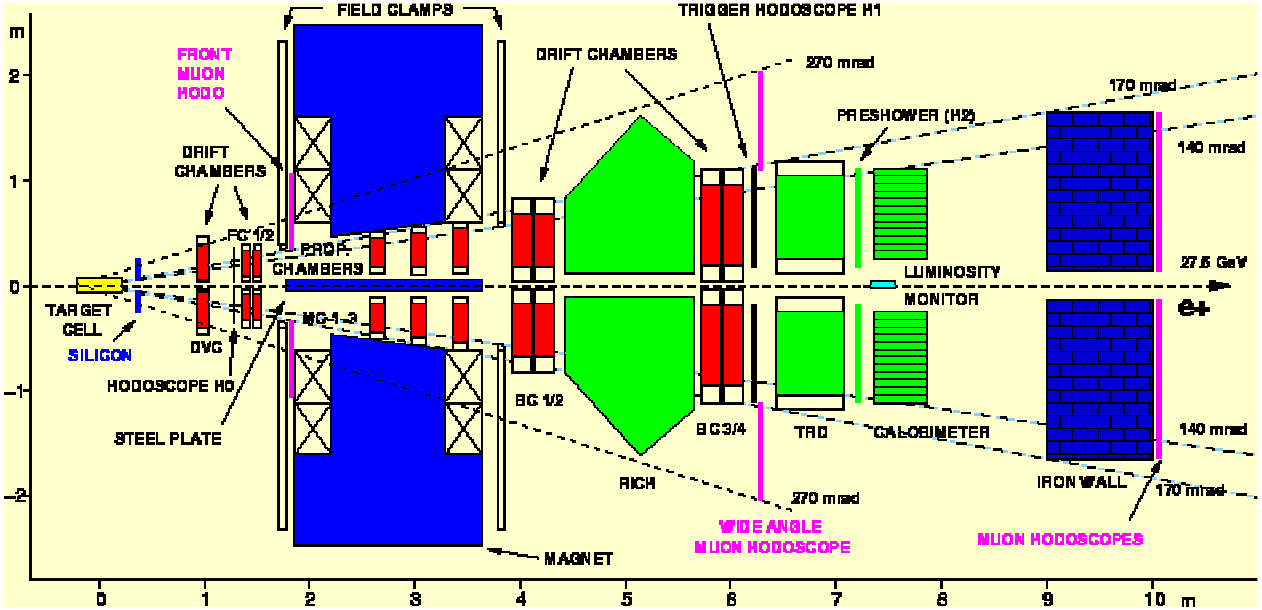
  HERMES, (SMC), COMPASS

- Polarized pp collisions PHENIX, STAR

- QCD fits : Q^2 evolution of g_1

HERMES

Beam: 27.5 GeV $e^{\pm}$; <50>% polarization
Target: (un)-polarized gas targets; <85%> polarization



ΔG, Δq all flavors, transversity, GPDs, …

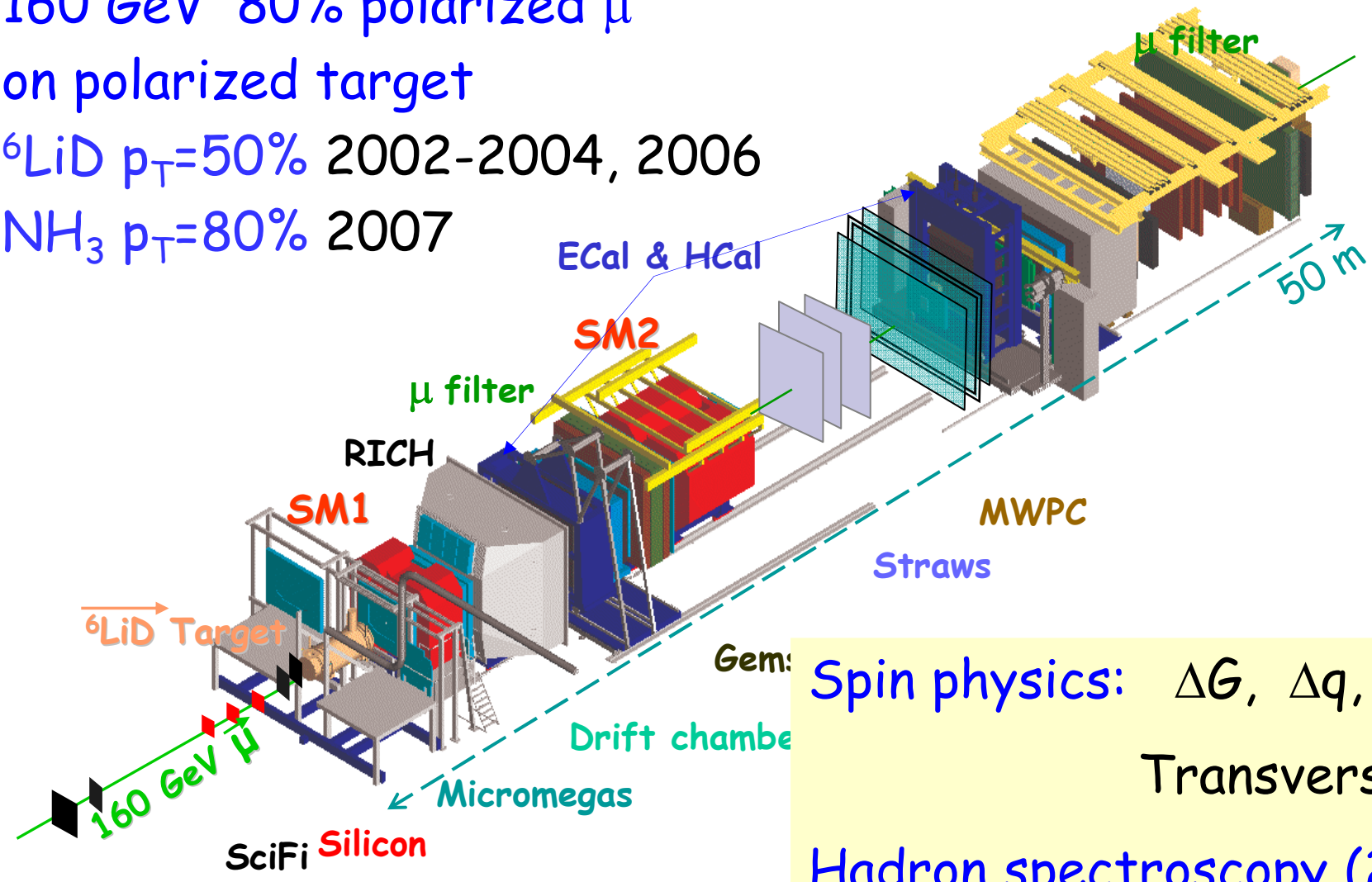
COMPASS

160 GeV 80% polarized μ

on polarized target

^{6}LiD p_T=50% 2002-2004, 2006

NH_3 p_T=80% 2007



Spin physics: ΔG, Δq, g_1, …

Transversity…

Hadron spectroscopy (2008)

GPDs (2010)…

$\Delta G/G$ from Polarized Lepton Nucleon Scattering

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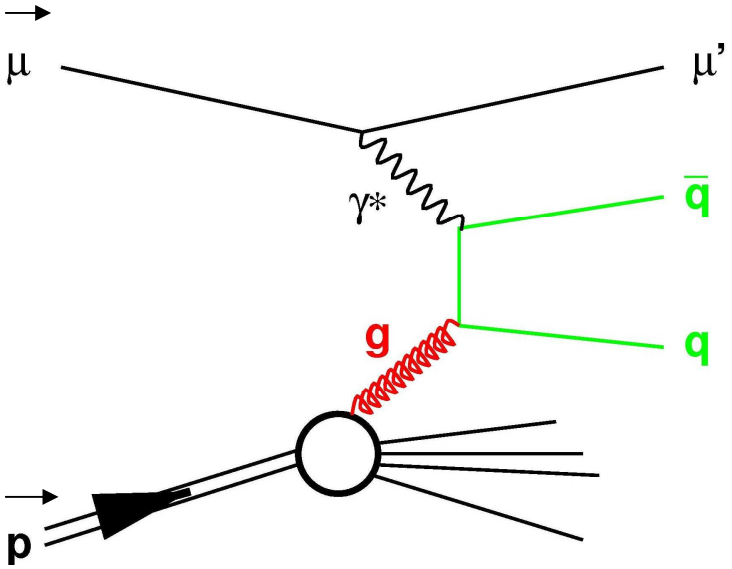
ΔG/G measurement

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



- charm $c \to D^0 \to K\,\pi$

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

theory understood, but:

combinatorial background & limited stat:

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

COMPASS

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

- scale $\mu^2 = Q^2$ or Σp_T^2

large statistics

but physical background

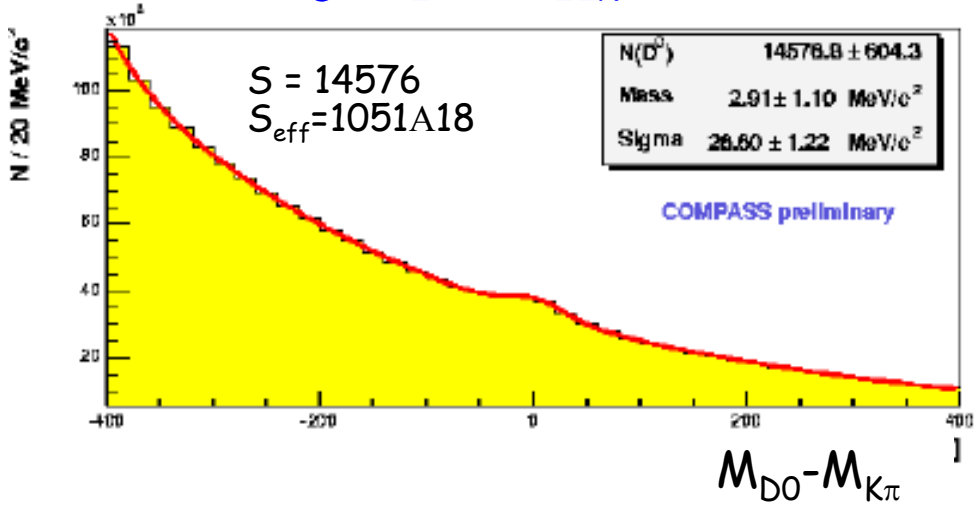
HERMES + COMPASS

COMPASS open charm

See talk by S.Koblitz

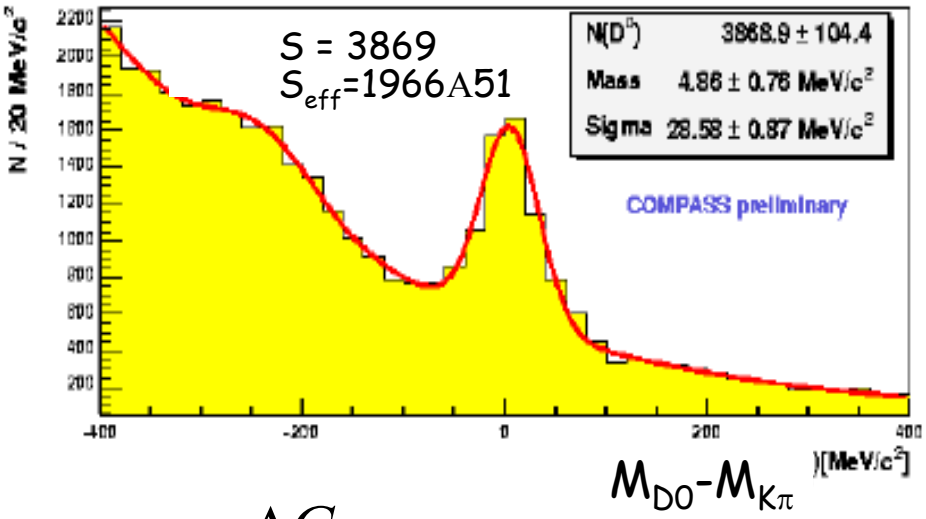
D^0

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



D^0 tagged by D^*

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



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

2002-2004 data, d target

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

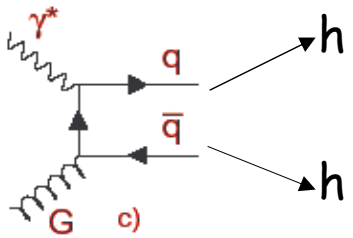
$\langle x_g \rangle = 0.15$ scale μ^2=13 GeV^2

2006 data to come…

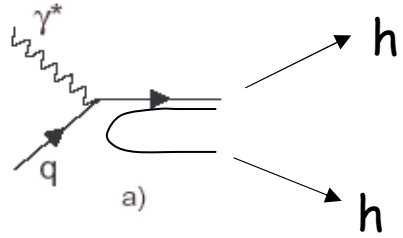
$\Delta G/G$ from high p_T hadron pairs

- $Q^2 > 1$ GeV/c^2 — COMPASS
- $Q^2 < 1$ GeV/c^2 — HERMES + COMPASS
- 1 hadron — HERMES + COMPASS

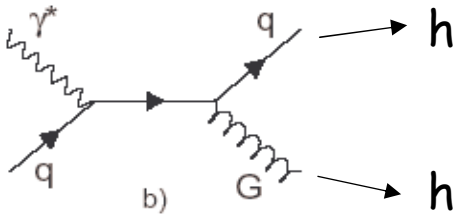
COMPASS $\Delta G/G$, high p_T hadron pairs $Q^2 > 1\ GeV/c^2$



Photon Gluon Fusion (PGF)



Leading process



Gluon radiation

PGF ~ 33 % (Lepto MC)

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

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

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

COMPASS 2002-2003 data:

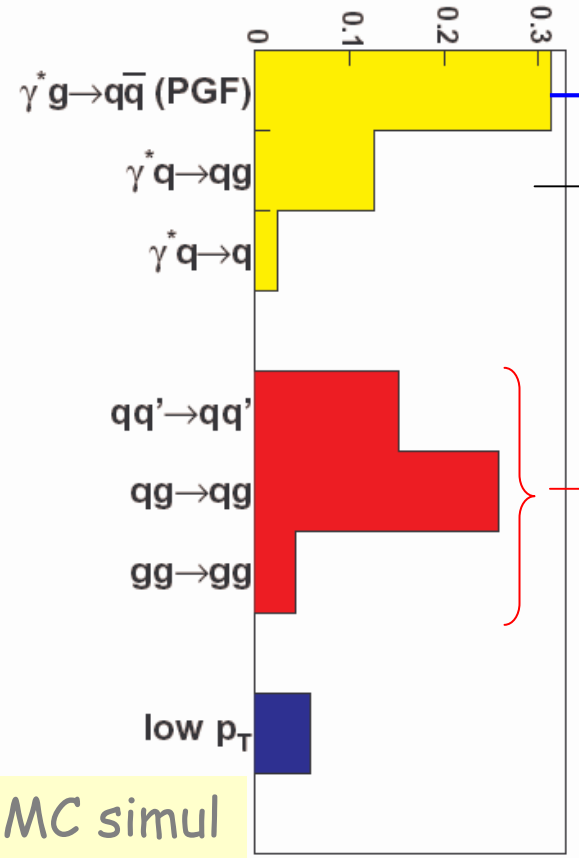
$$\Delta G/G = 0.06 \pm 0.31\ (stat) \pm 0.06\ (syst)$$

$\langle x_g \rangle \sim 0.13$

Value compatible with 0. Systematics small

COMPASS $\Delta G/G$, high p_T hadron pairs $Q^2 < 1\ GeV/c^2$

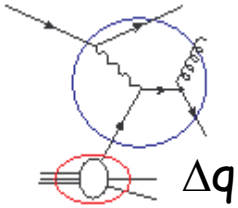
$Q^2 < 1$ 10 times more data, but additional background: resolved photon processes



MC simul
PYTHIA
COMPASS

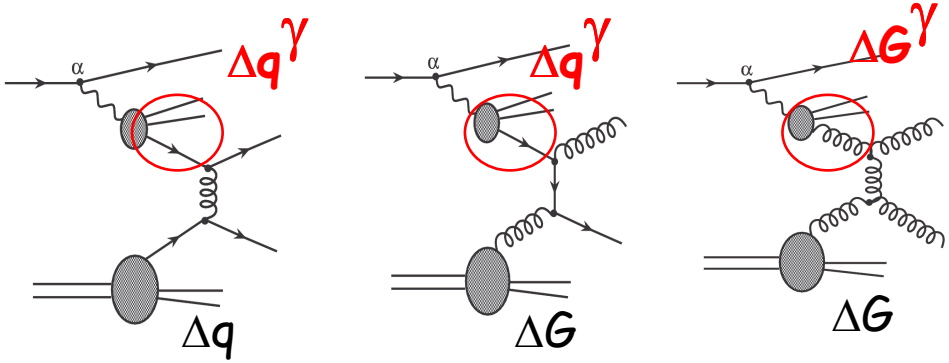
PGF ~30%

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

COMPASS $\Delta G/G$, high p_T hadron pairs

$Q^2 < 1\ GeV/c^2$ $x_g = 0.085$, $\mu^2 = 3 GeV/c^2$ 2002-2004 data

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

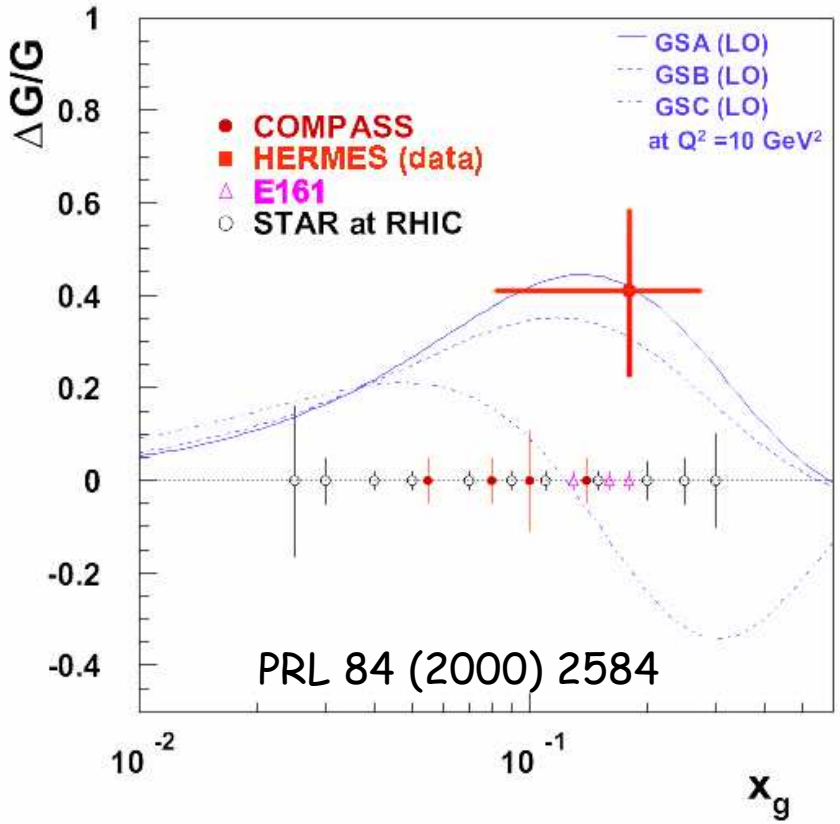
$\Delta G/G$ compatible with 0. Statistics and systematics small

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

HERMES $\Delta G/G$, high p_T hadron pair

all Q^2

2000: 'old' HERMES point shown with 'old' projections



HERMES A_{LL}, high p_T hadrons

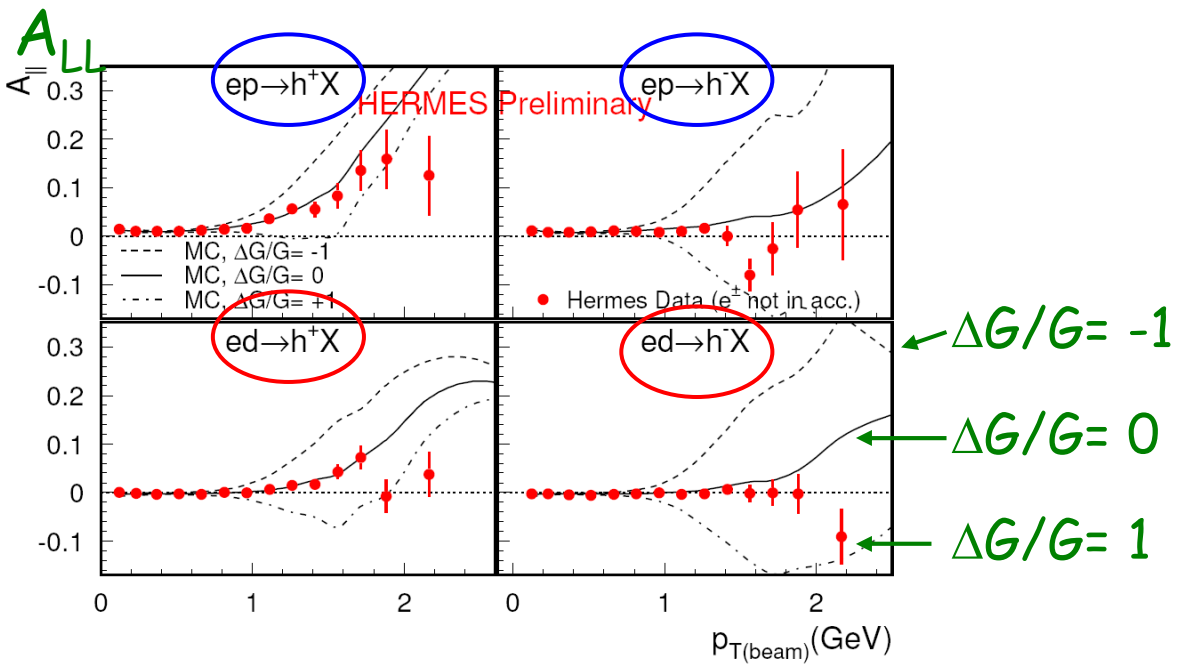
all Q^2

"New point" :

Spin asymmetry for various signatures,

p and d targets

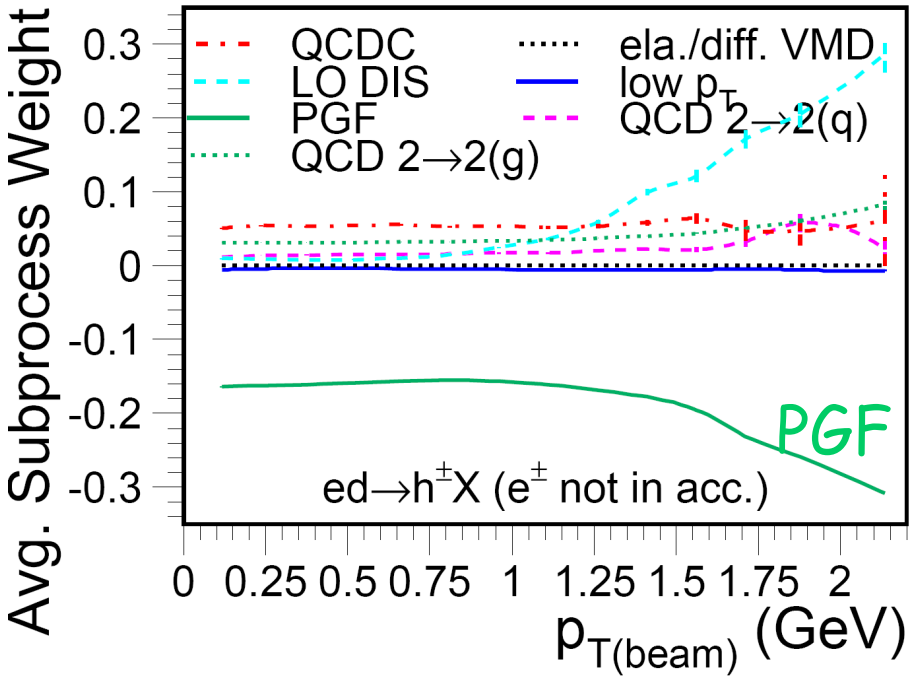
$e\ d \rightarrow\ h^+\ (h^-)\ (e')$



HERMES, new point, high p_T hadrons

all Q^2

Competing subprocesses weight



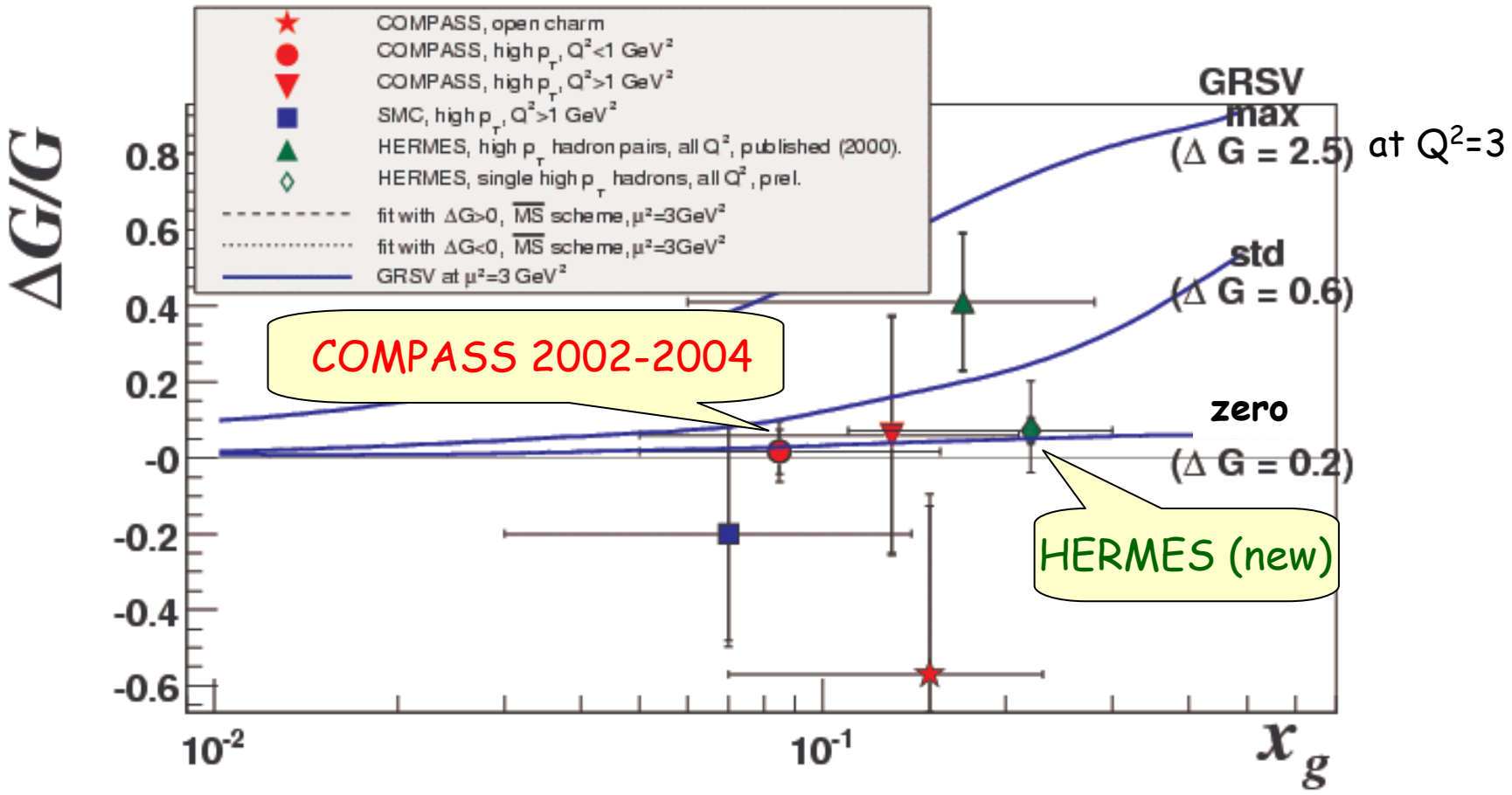
$\langle x_g \rangle = 0.22$, $\mu^2 = 1.35$ GeV/c^2

$$\Delta g/g(x_g,\mu^2) = 0.071 \pm 0.034(\text{stat}) \pm 0.010\ (\text{sys-exp}) \begin{matrix} -0.127 \\ -0.105 \end{matrix} (\text{sys-model})$$

Syst. model uncertainties still dominating (PDFs, PYTHIA model)

HERMES new result: $\Delta G/G$ is likely small

$\Delta G/G$ direct measurements

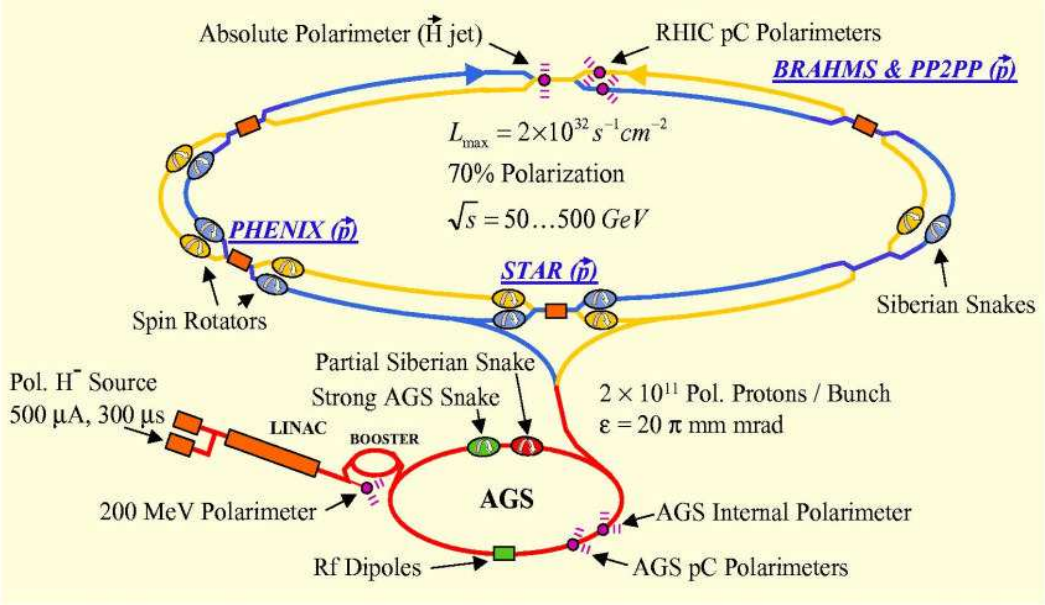


at Q^2=3

GRSV: Gluck, Reya, Stratmann, Vogelsang PRD63 (2002) 094005

Large ΔG strongly disfavoured

$\Delta G/G$ $\vec{p}\vec{p}$ collisions at RHIC

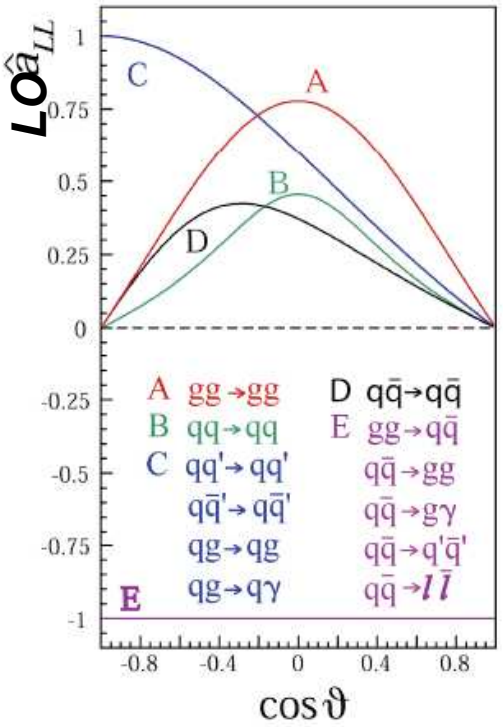


$\Delta G/G$ $\vec{p}\vec{p}$ collisions PHENIX and STAR

Various channels detected, sensitive to gluon at LO:

$pp \rightarrow \gamma X$ $pp \rightarrow$ jet X $pp \rightarrow \pi X$ $pp \rightarrow c\bar{c}X$

$$\frac{\Delta G}{G} \times \frac{\Delta q}{q} \qquad \frac{\Delta G}{G} \times \frac{\Delta G}{G}$$



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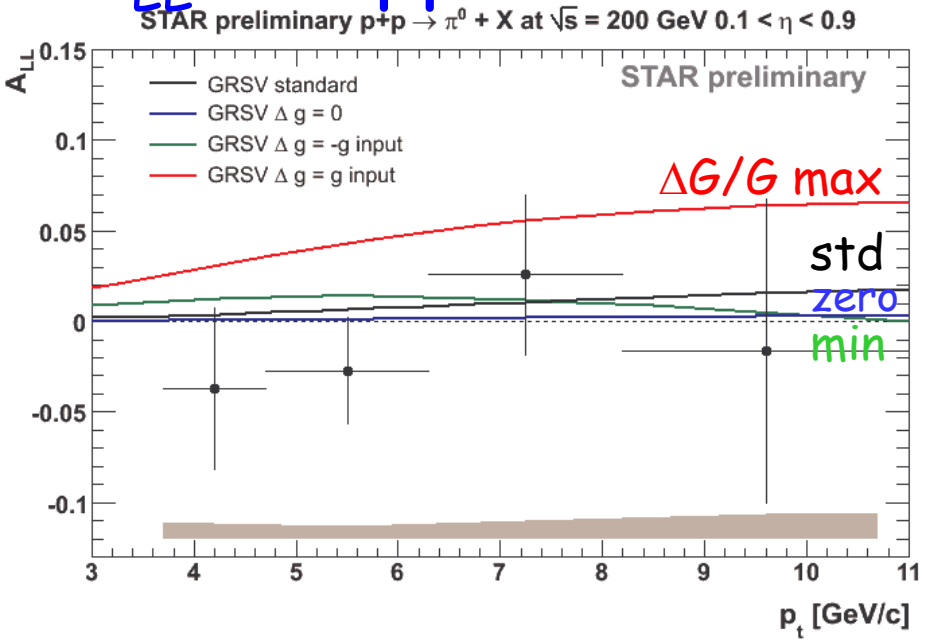
- Different kinematics and systematics
- Beam energies 200 - 500- 64 GeV

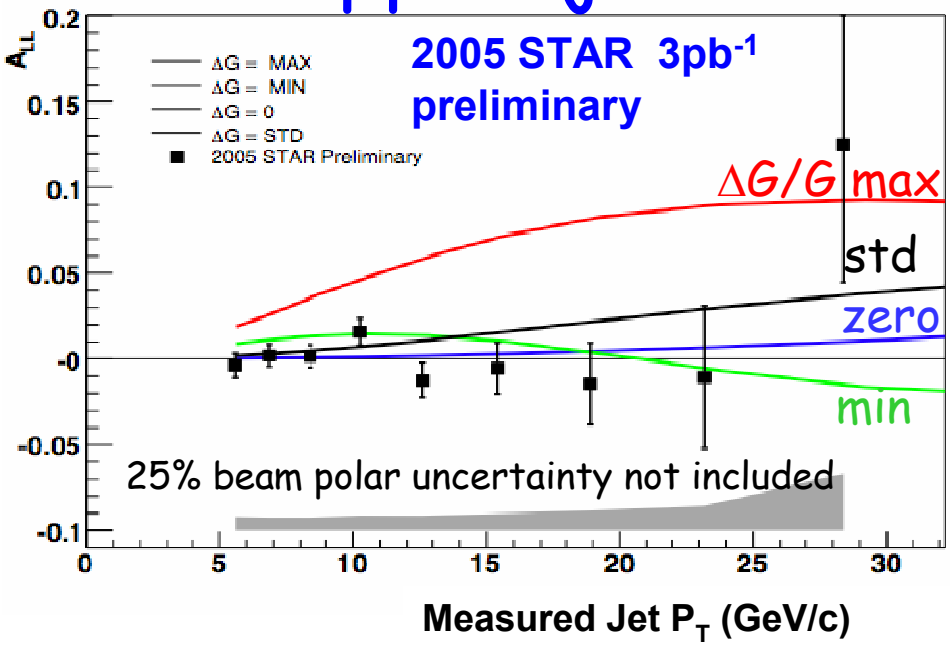
$\rightarrow$ p_T or x_g range

STAR - A_{LL} results

A_{LL} for $pp \rightarrow \pi^0 X$



$pp \rightarrow jet + X$



GRSV scenario for ΔG at $Q_0^2 = 1$ (GeV/c)^2:

max	1.9
min	-1.8
Std	0.4
'zero'	0.1

GRSV max scenario disfavored

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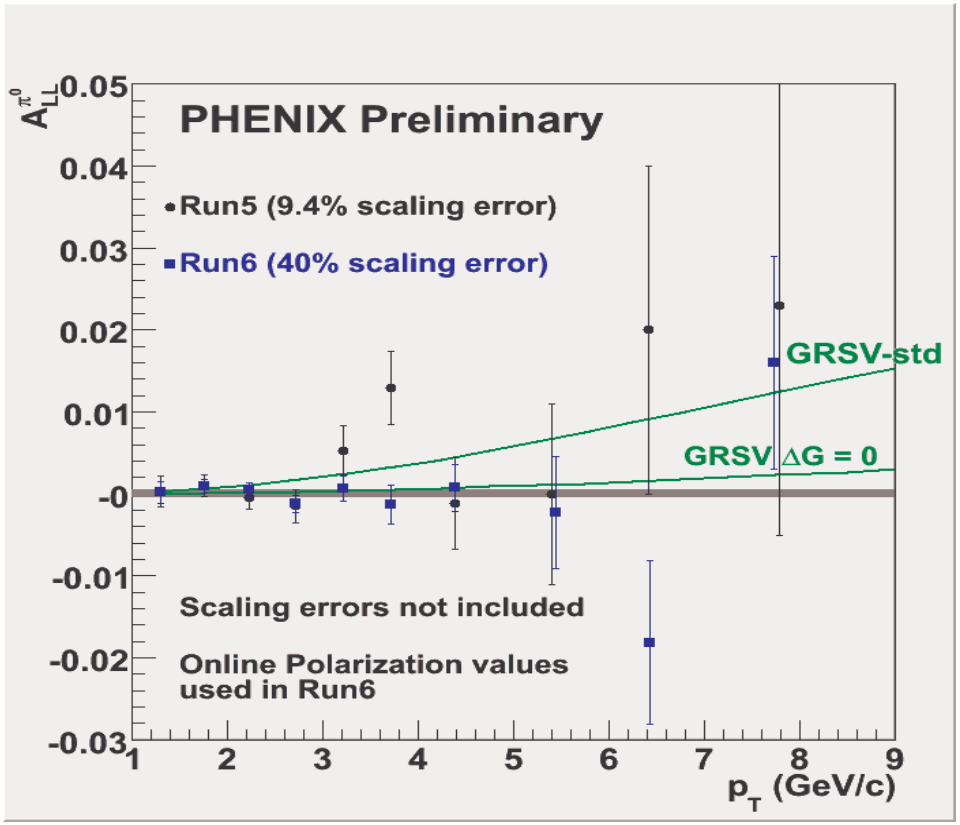
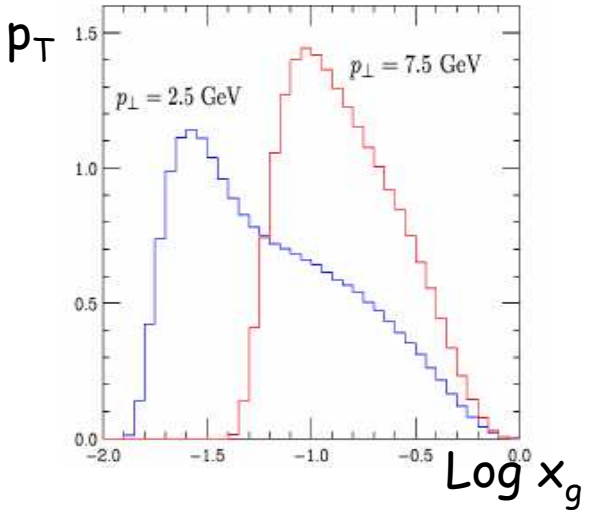
PHENIX - A_{LL} for $pp \rightarrow \pi^0$



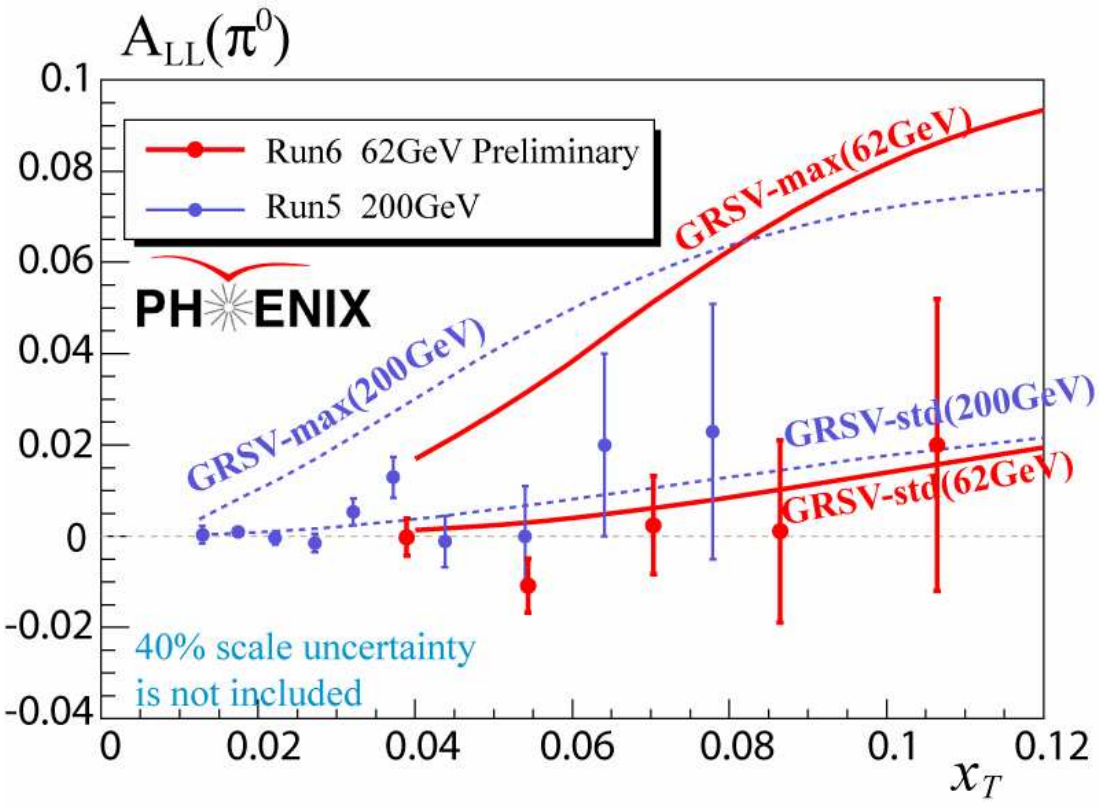
Run3,4,5: PRL 93, 202002; PRD 73, 091102; hep-ex-0704.3599



Overlapping p_T bins cover wide range in x_g: p_T=2–9 GeV/c → x_g=0.02–0.3

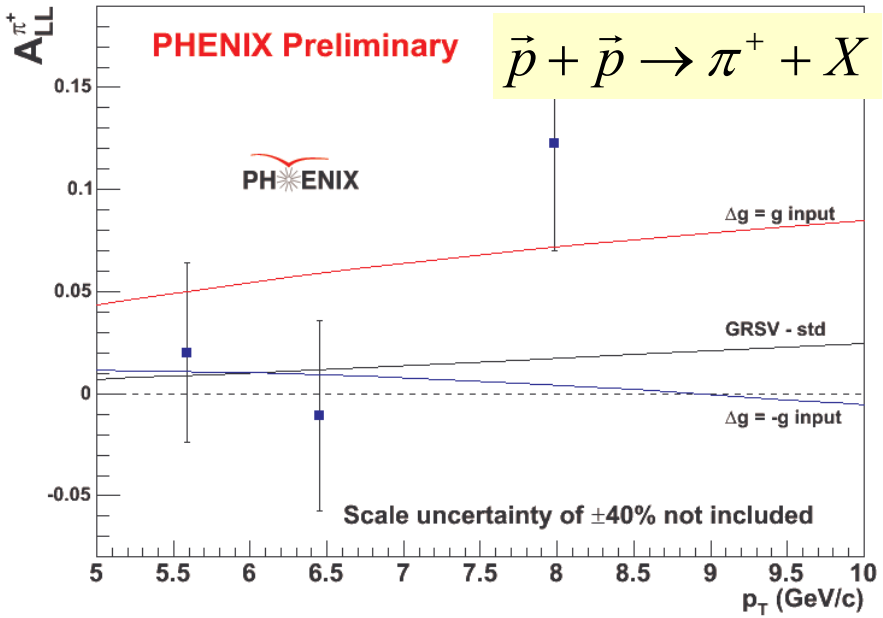
- GRSV model: $\Delta G(x_g=0.02 \rightarrow 0.3) \sim 0.6 \cdot \Delta G(x_g=0 \rightarrow 1)$
- "GRSV-std" excluded by data on >3 sigma level (Vogelsang and Stratmann, stat. only)

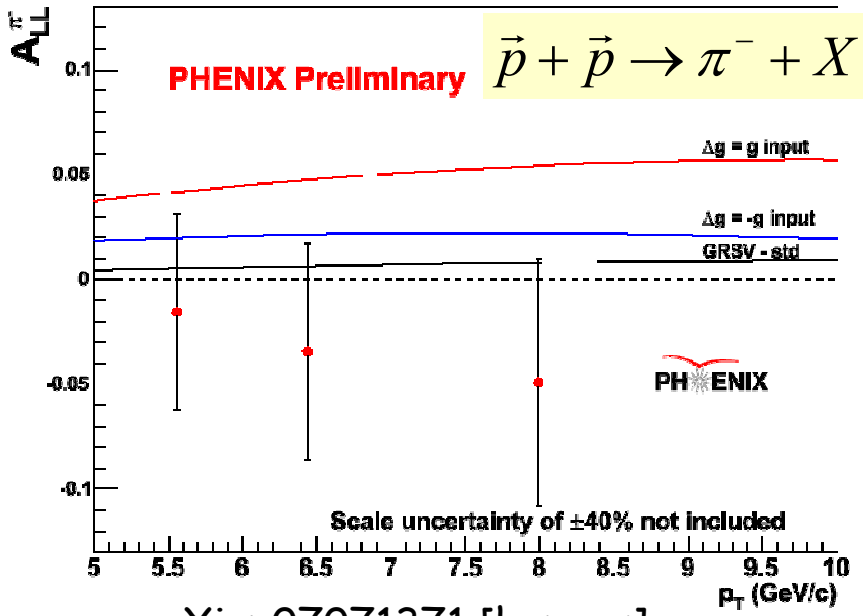
PHENIX 200 & 62 GeV



From Bazileski, PACSPIN07

PHENIX π^+, π^-





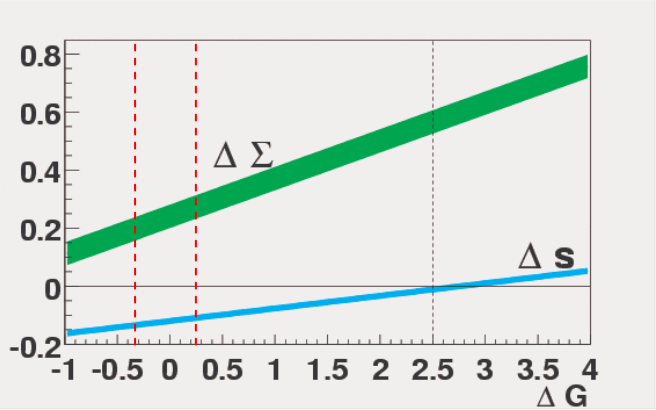
arXiv: 07071371 [hep-ex]

- Different sensitivities of charged pions to Δu and $\Delta d \rightarrow$ more sensitivity to sign of ΔG
- Less background than in π^0
- Statistics run05: no constraint on ΔG yet. (2.7 smaller for run06)
- Problem in fragmentation functions ?

Gluon polarization and nucleon spin
(from direct measurements)

- $\Delta G = \int \Delta G(x)dx$ not large

$\Rightarrow \Delta\Sigma \sim 0.3$ small ($\neq$ predictions)



- Consequence for spin decomposition

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

possible scenarios:

$\tfrac{1}{2}0.3 + 0.35 + 0.0$

$\tfrac{1}{2}0.3 + 0.0 + 0.35$

... or even $\Delta G<0$

$\Delta G/G$ from QCD fits
Global analysis of g_1 world data

Global analysis of g_1 world data

DGLAP evolution equations rule $\partial / \partial \ln Q^2$ dependence of parton distribution functions

Method

- parameterize parton distributions at Q_0^2

e.g. $\Delta q_i \sim x^{\alpha i} (1-x)^{\beta i}(1+\gamma i x)$

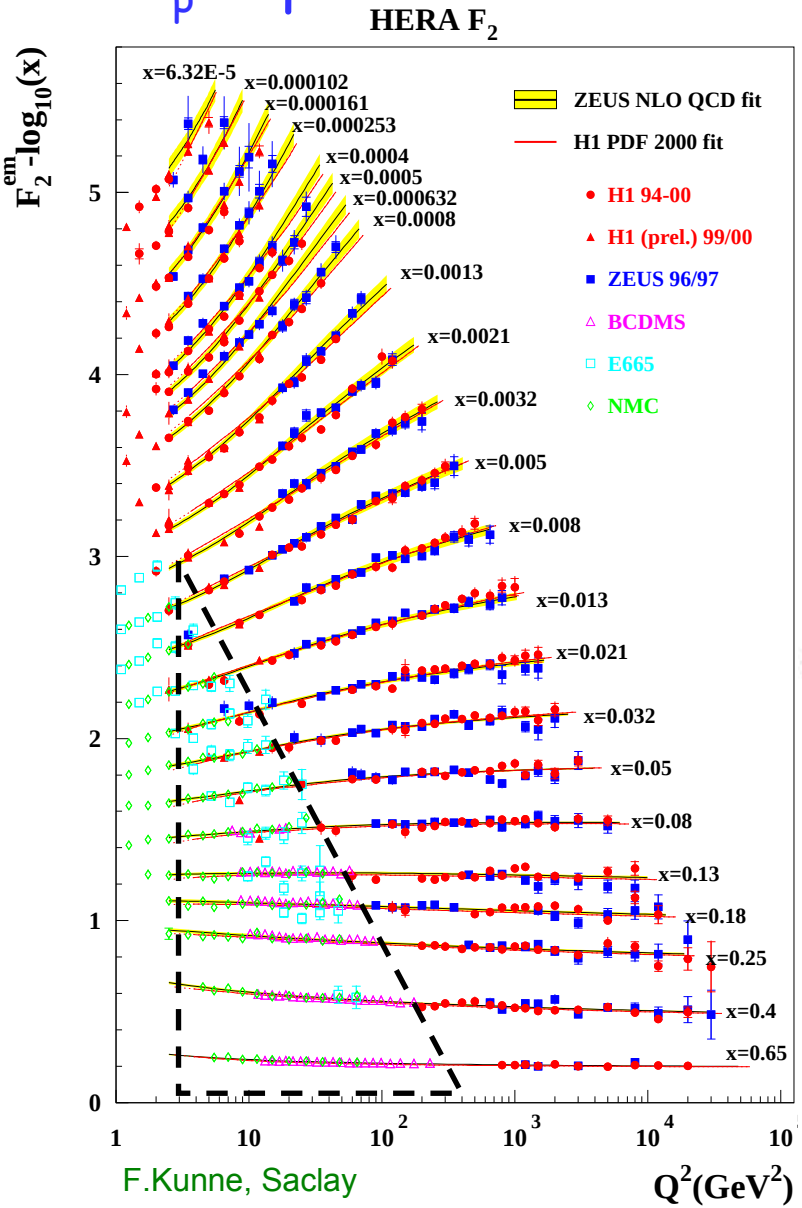
- DGLAP evolution to measured Q^2
- calculate g_1 and fit all g_1 data together

$\Delta\Sigma$ and ΔG coupled in the evolution

$\rightarrow$ Indirect determination of $\Delta G(x)$, assumming an initial parameterization

Fonctions de structure du proton (x,Q^2)

F^2_p unpolarized DIS



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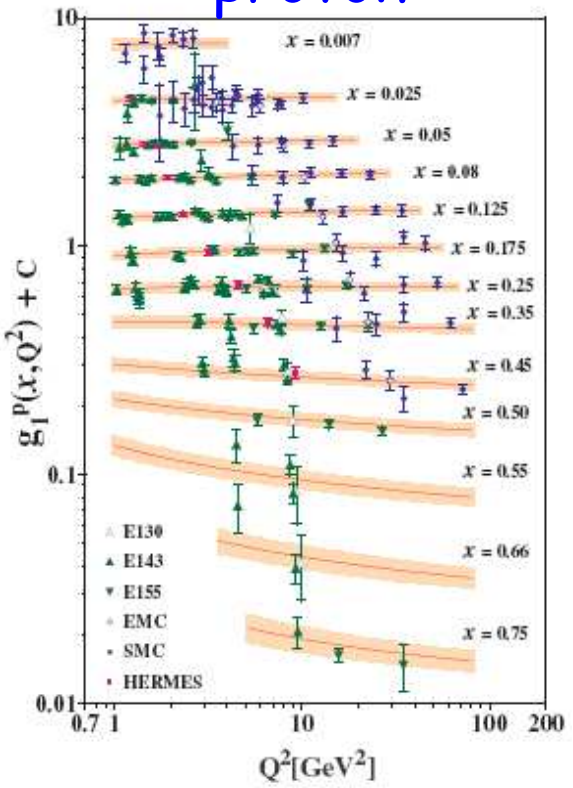
Big lever arm in x and Q^2

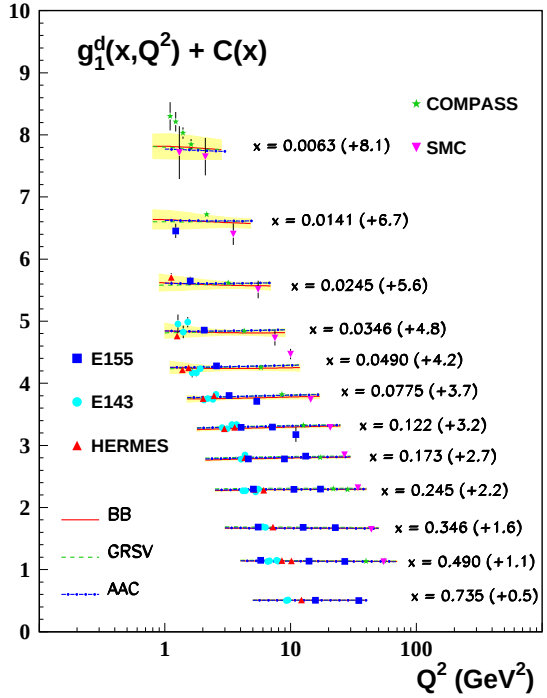
→ High precision for G(x)

g^1 polarized DIS

proton



deuteron



QCD fits of g_1

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

Results : Δu Δd well constrained, but ΔG shape unknown

Progress when including new data, e.g.:

- AAC06 analysis including g_1 new data from HERMES, COMPASS and JLAB + PHENIX A_{LL} π^0

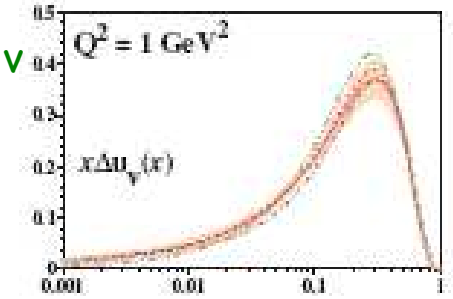
AAC -hep-ph/0603213

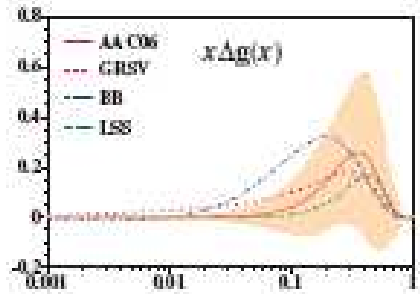
- COMPASS analysis

...

Global QCD analyses: AAC, BB, LSS, GRSV …

$x\Delta u_v$

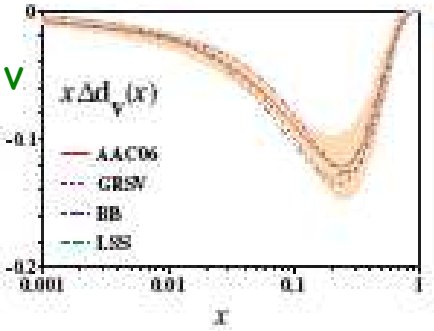


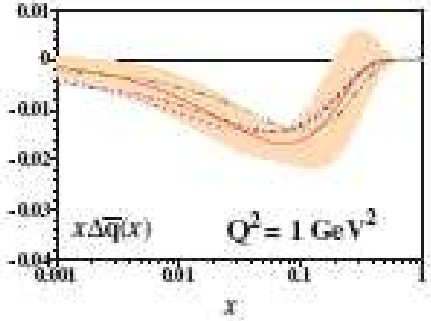


$x\Delta G$

$\Delta G = 0.31 \pm 0.32$ at $Q^2 = 1\ GeV^2$

$x\Delta d_v$





$x\Delta\bar{q}$

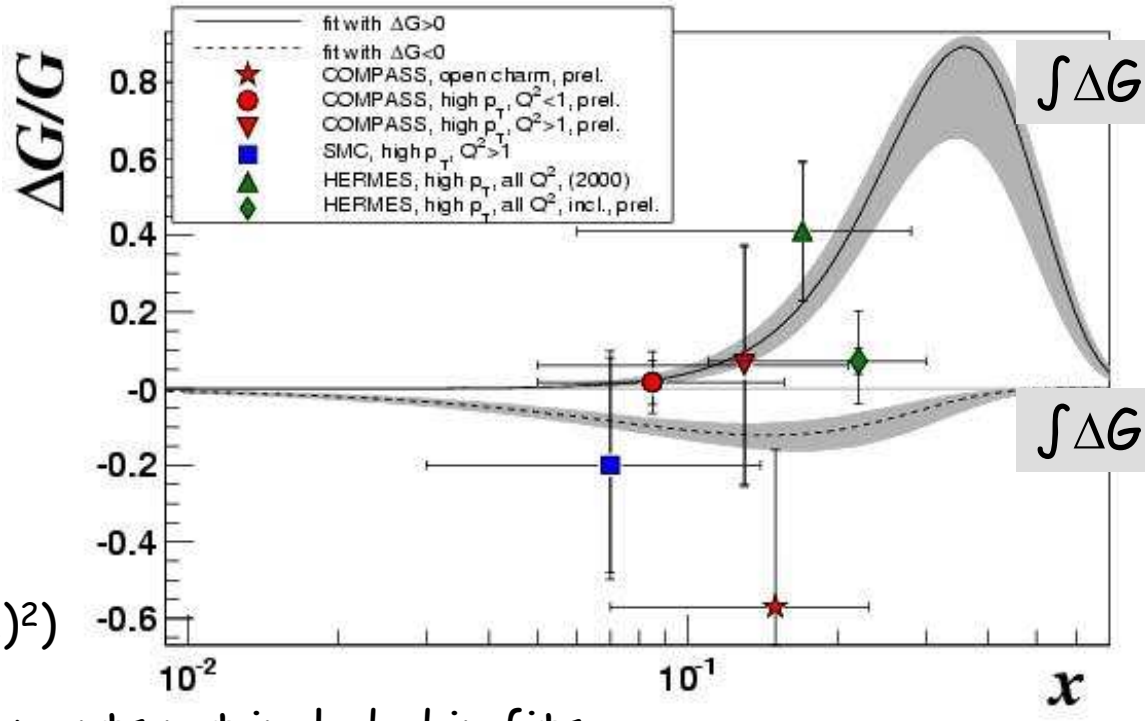
$\Delta\bar{q} = -0.05 \pm 0.01$

AAC – NLO, hep-ph/0603213

Compared to GRSV, BB and LSS

COMPASS – Global QCD NLO g_1 analysis

→ two solutions, one with $\Delta G > 0$, the other with $\Delta G < 0$



$\int \Delta G(x) \sim 0.2 - 0.3$

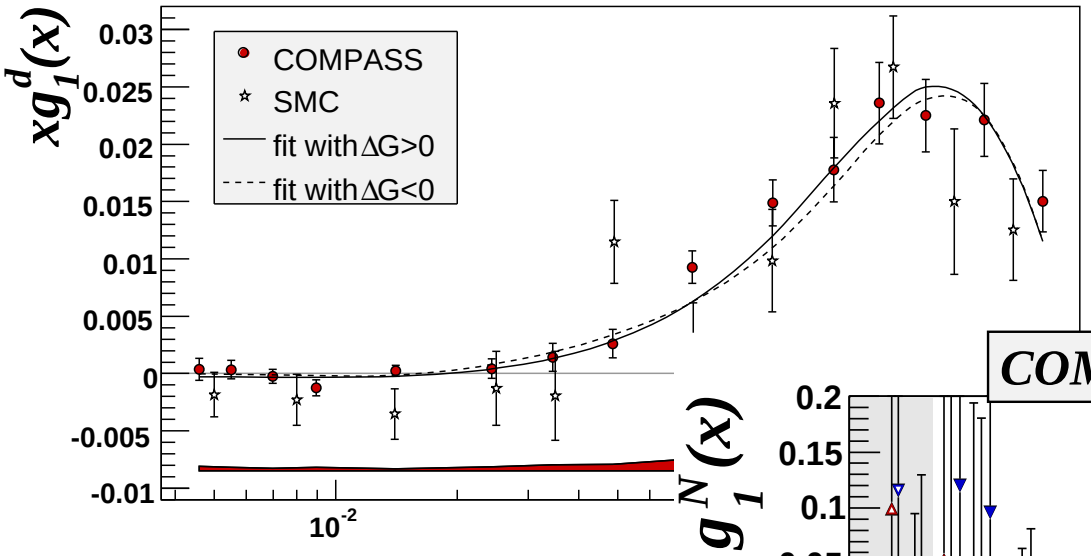
$\int \Delta G(x) \sim -0.3$

($Q^2 = 3 (GeV/c)^2$)

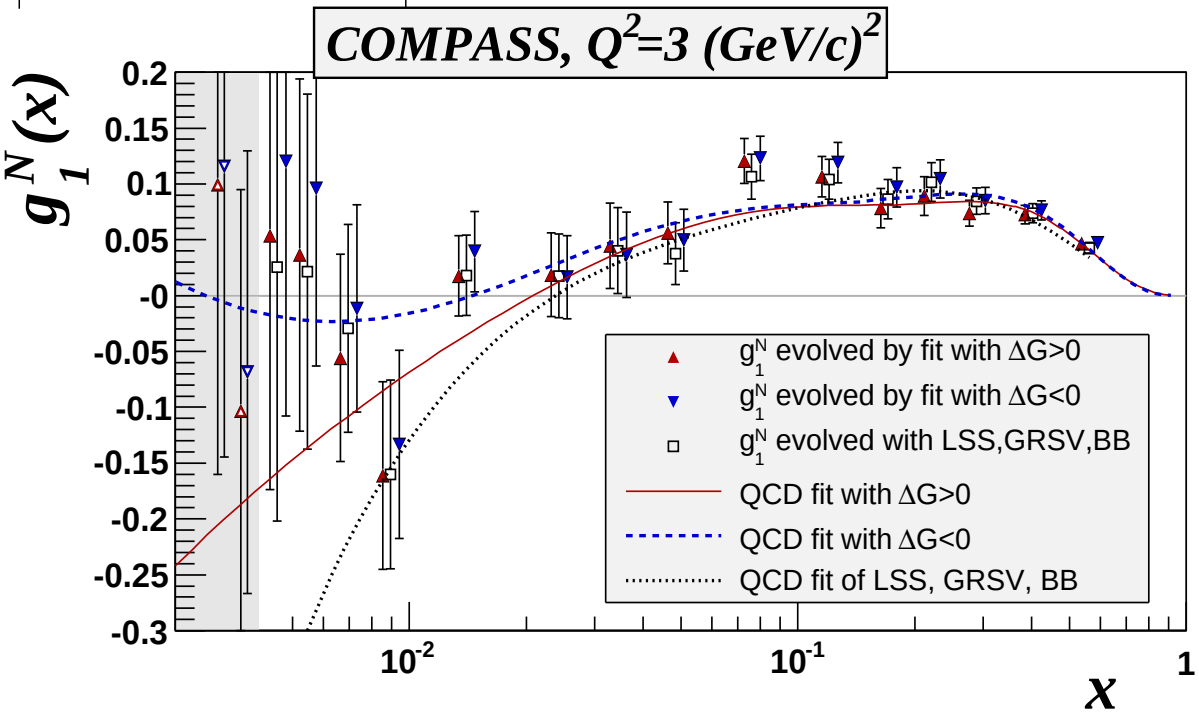
ΔG measurements not included in fits

- For both solutions, small first moment $|\Delta G| \sim 0.2 - 0.3$
- $\Delta\Sigma = 0.30 \pm 0.01$ (stat.) $\pm$ 0.02 (evol.)
- $\Delta s = -0.08 \pm 0.01 \pm 0.02$ (← COMPASS data alone)

Impact of low x data



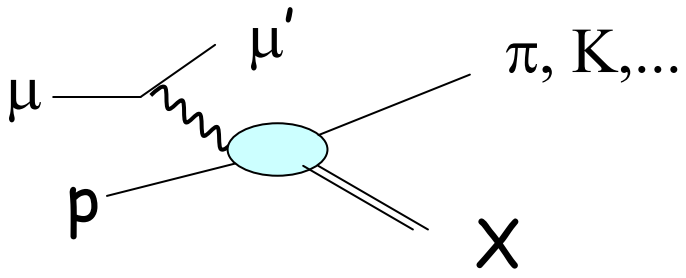
$\Gamma_1 = \int g_1(x)dx$:
only 2% correction from unmeasured low x
(was 50% negative before)



Disagreement of new data with earlier QCD fits

Flavor separation Δu, Δd, $\Delta \bar{q}$, Δs

Semi-inclusive DIS : $\mu\, p \rightarrow \mu'\, h\, X$



Outgoing hadron
→ quark flavor

Fragmentation
function D_q^h

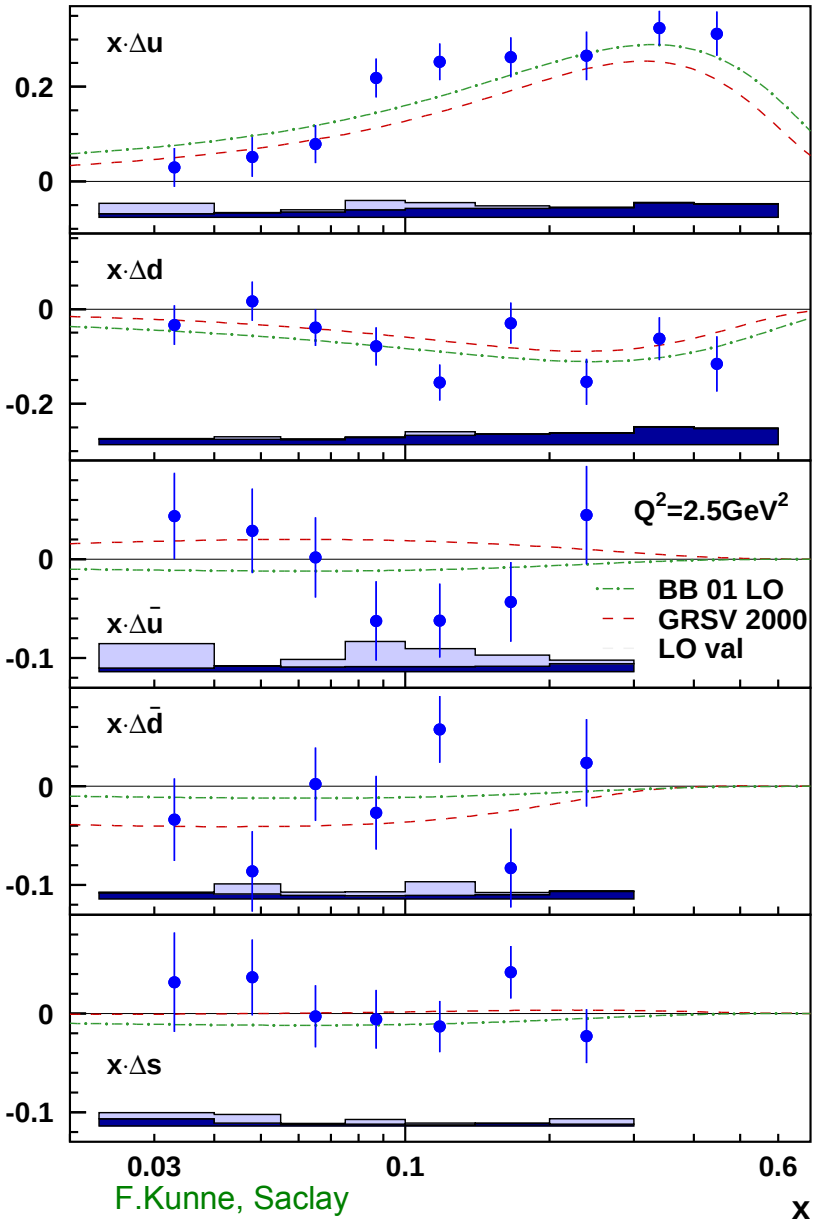
$$A_1^{h(p/d)} = \frac{\sum_q e_q^2 D_q^h \Delta q}{\sum_q e_q^2 D_q^h q}$$

$$D_q^h(z, Q^2)$$

$$z = E_h / \nu$$

deuteron & proton data necessary

HERMES semi inclusive : Δu Δd $\Delta \bar{u}$ $\Delta \bar{d}$ Δs



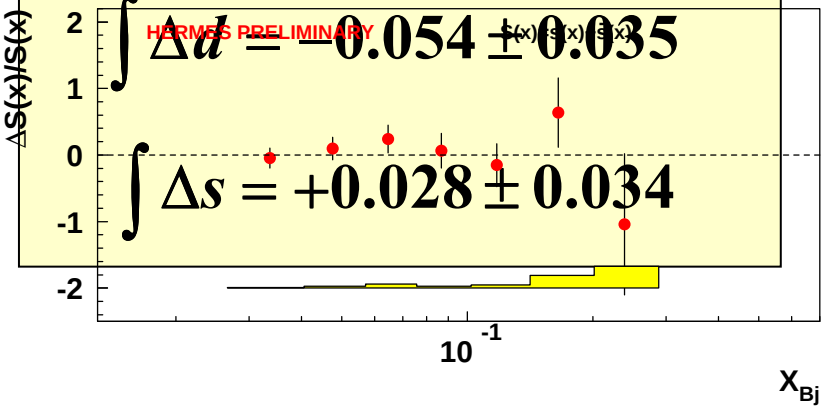
F.Kunne, Saclay

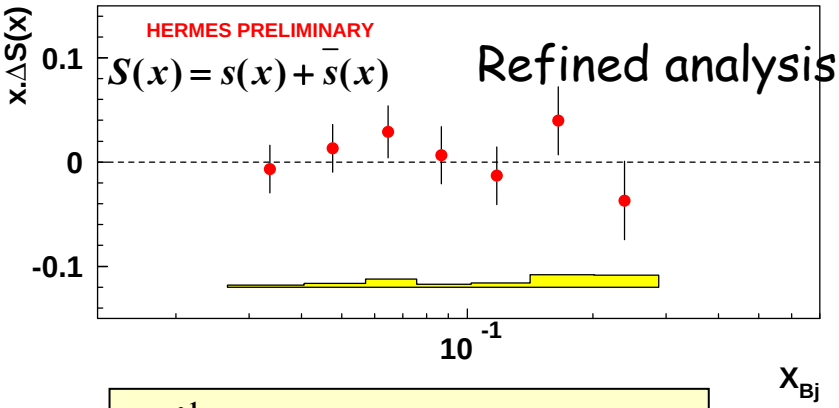
In measured x_{Bj} range (0.023 - 0.6)

$$\int \Delta \bar{u} = -0.002 \pm 0.043$$

$$\int \Delta \bar{d} = -0.054 \pm 0.035$$

$$\int \Delta s = +0.028 \pm 0.034$$

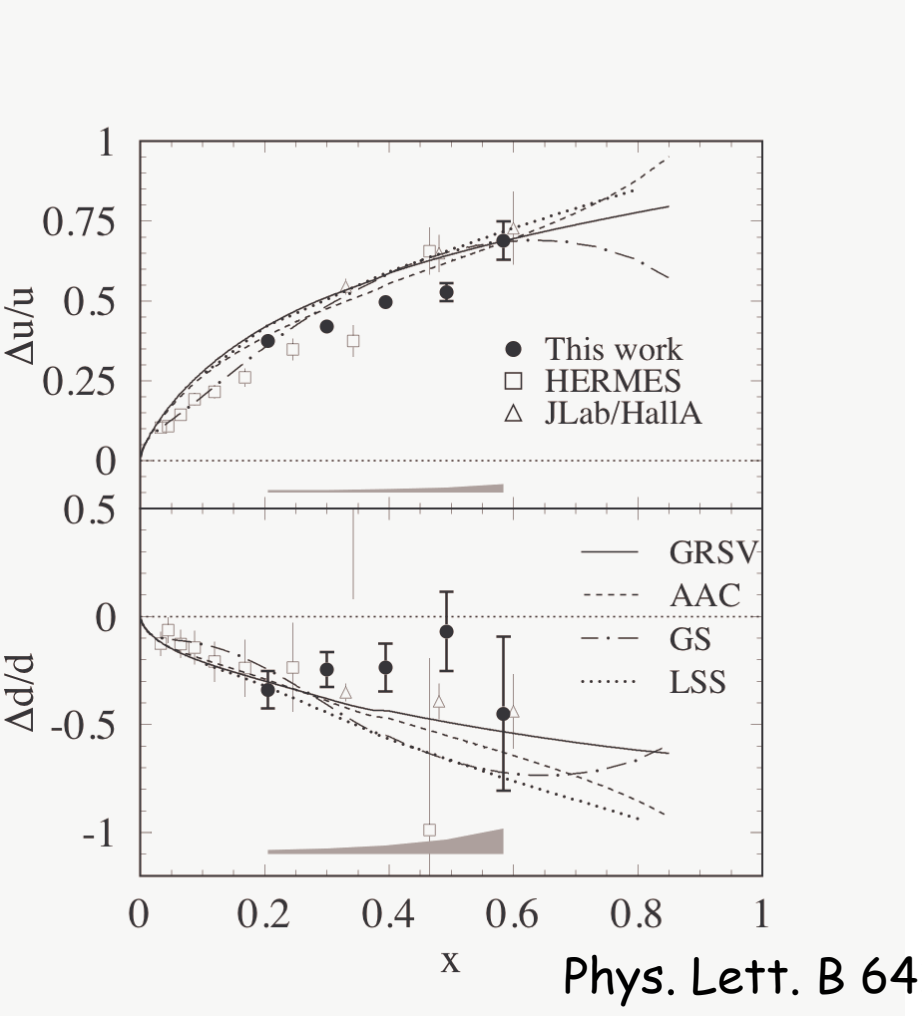




$$\int_{0.02}^{1} \Delta S = 0.006 \pm 0.029 \pm 0.007$$

JLab $\Delta q/q$ high x

EG1 collab.
Hall B



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High x data improve NLO PDF fits

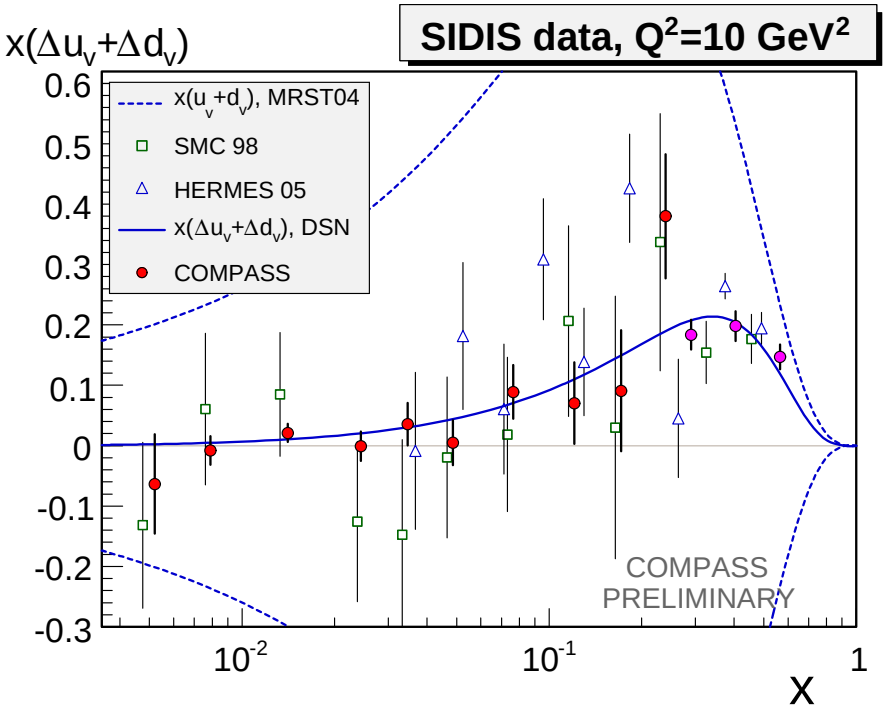
COMPASS Semi inclusive : valence/sea

Only deuteron data $\mu\, d \rightarrow \mu'\, h\, X$ $D_q^h \neq D_{\bar{q}}^h \rightarrow$ separate valence and sea

$$u_v = u - \bar{u}$$

See talk by W.Wislicki

LO: $$A^{h^+ - h^-}(x) = \frac{\Delta u_v(x) + \Delta d_v(x)}{u_v(x) + d_v(x)}$$



Integrals:

- $\Delta u_v + \Delta d_v = 0.41 \pm 0.07 \pm 0.05$
- using $\Delta u_v + \Delta d_v$, Γ_1 and a_8:
  $\Delta\bar{u} + \Delta\bar{d} = 0.00 \pm 0.04 \pm 0.03$

Data favor $\Delta\bar{u} = -\Delta\bar{d}$, in contrast with usual assumption: $\Delta\bar{u} = \Delta\bar{d} = \Delta s = \Delta\bar{s}$, leading to $\Delta u_v + \Delta d_v = a_8 = 0.58$

Summary …

- ΔG likely below 0.4, direct measurements & g_1 QCD fits
- $\Delta\Sigma \sim a_0$ now established (since ΔG small)

  and low x contribution measured
- Total Nucleon Spin: $\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$

Possible scenarios

$\frac{1}{2}0.3 + 0.35 + 0.0$

$\frac{1}{2}0.3 + 0.0 + 0.35$

… or even $\Delta G<0$

… and Outlook:

COMPASS: 2006+2007 stat., larger acceptance + improved RICH + 3-cell target; proton data. $\Delta G/G$, g_1, semi-inclusive → QCD fits

RHIC : More stat on π channels; new channels : γ +jet…; Δu and Δd

JLab : g_1 and semi-inclusive data → QCD fits