Experimental review of ΔG

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Content

- The nucleon spin problem; why measure ΔG ?
- Present knowledge of ΔG
- Ongoing experiments :

  RHIC spin, HERMES, COMPASS
- Summary

Quark & gluon spin

Nucleon spin: $\frac{1}{2} = \frac{1}{2}\,\Delta\Sigma + \Delta G + \langle L_z \rangle$

quark contribution

gluon contribution

Orbital angular momentum

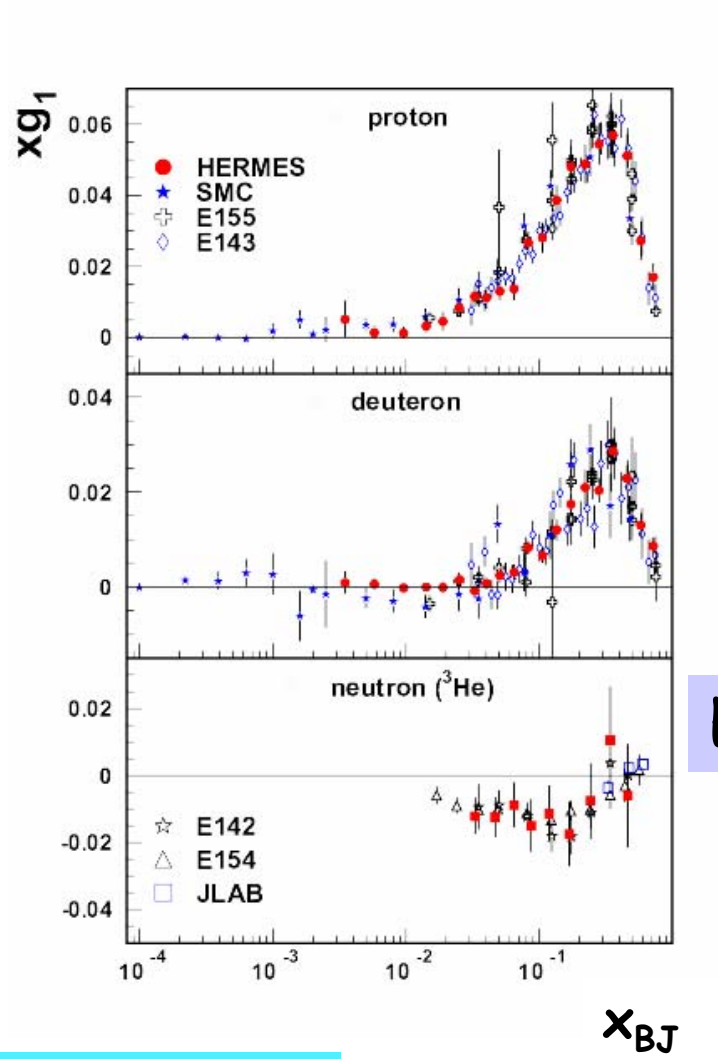
Naive quark parton model + relativistic corrections

$\Delta\Sigma \sim 0.60$

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

$\Delta\Sigma \sim 0.60$

Spin structure function g_1



- Various pQCD global analysis of world data on g_1 (p, d, n) with different assumptions and parametrisations

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

- Need knowledge of F & D meson octet decay constant & assumption of $SU(3)_F$

EMC → "$\Delta\Sigma$" = 0.12 +/- .09 +/- .14

- Quark contribution to spin $\Delta\Sigma$ small, very different from expectations ~0.6

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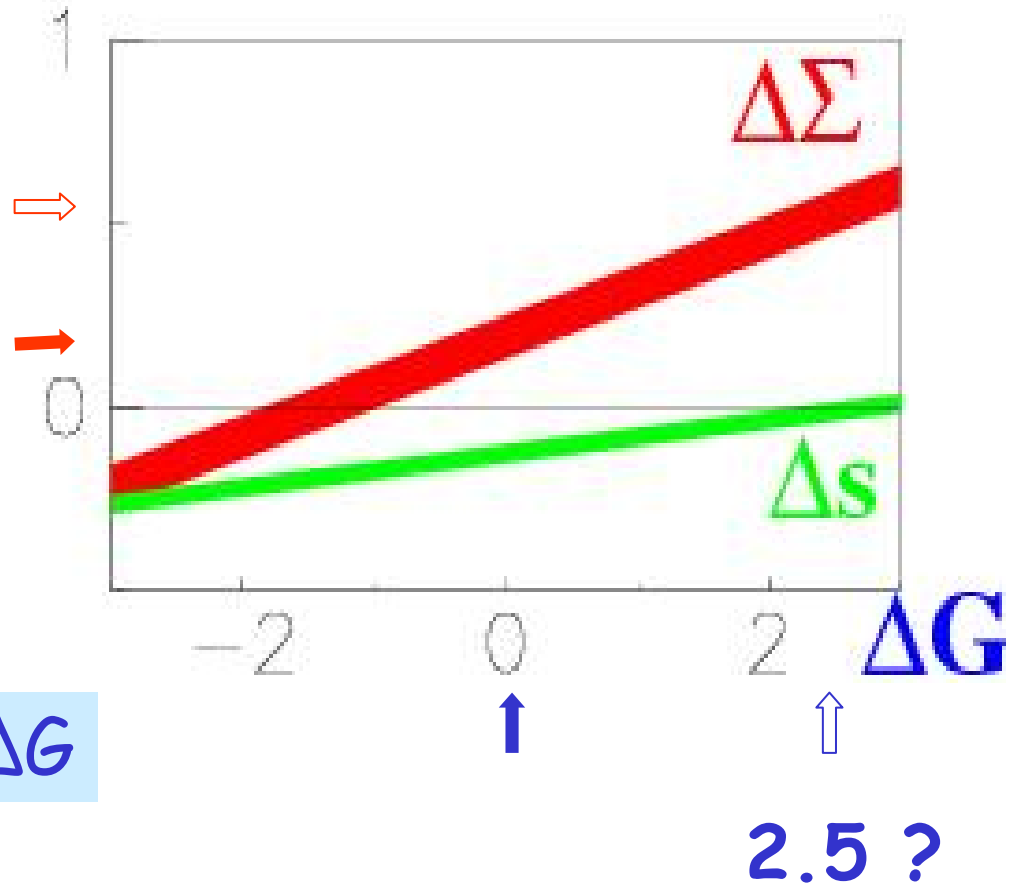
Interpretation

In polarised DIS, one measures flavor singlet axial matrix element

$$a_0 = \Delta\Sigma - (\alpha_s/2\pi) n_f \Delta G^{(*)}$$

All experiments (SLAC,EMC,SMC, SLAC, HERMES) confirm:

$$a_0 \sim 0.2 \div 0.3$$

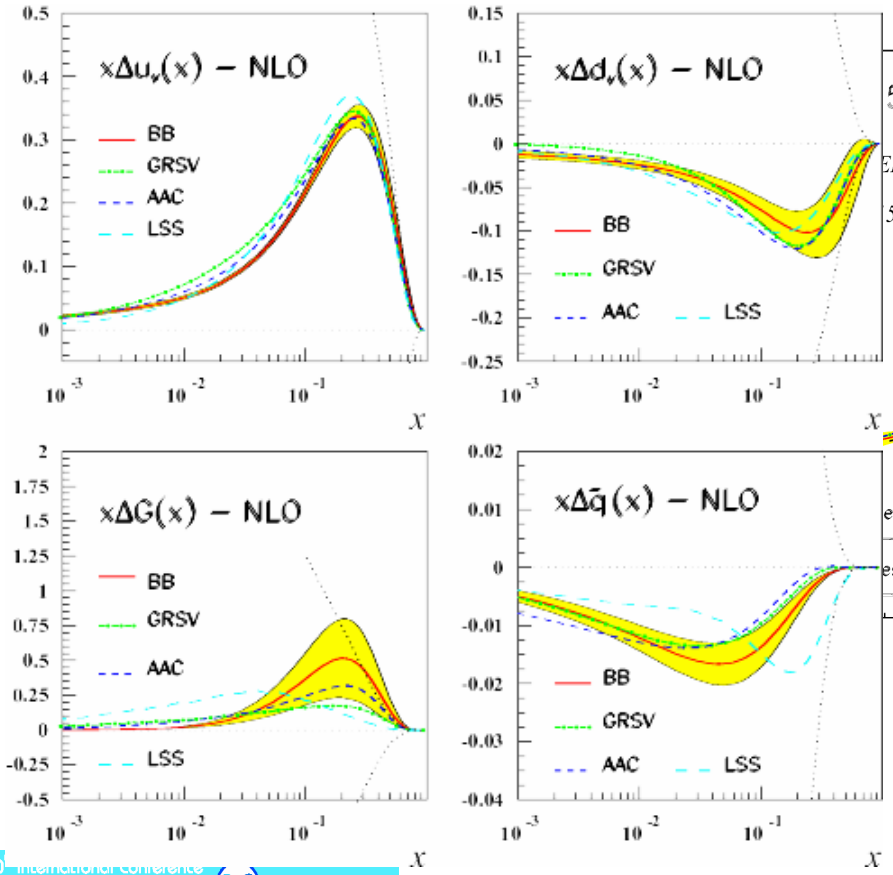


Imperative to measure ΔG

(*)Scheme dependent, Q^2 dep. omitted

Δq (ΔG) from inclusive data

$$g_1^{NLO}(x) = g_1^{LO} + \frac{\alpha_s}{2\pi}\frac{1}{2}\sum_q e_q^2 \left[\Delta q(x,Q^2) \otimes C_q + \Delta G(x,Q^2) \otimes C_g\right]$$

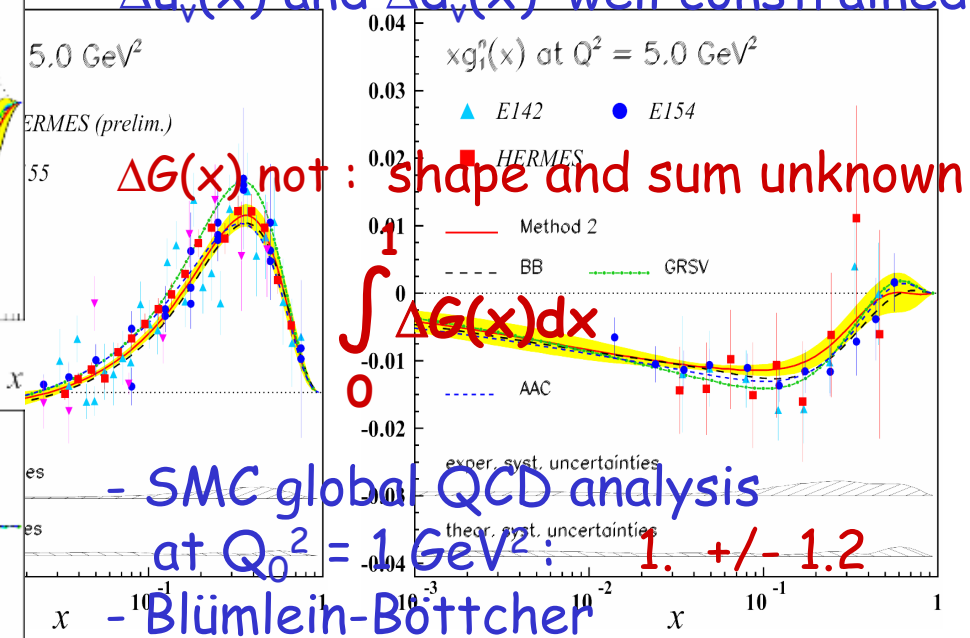


$\Delta u_v(x)$ and $\Delta d_v(x)$ well constrained

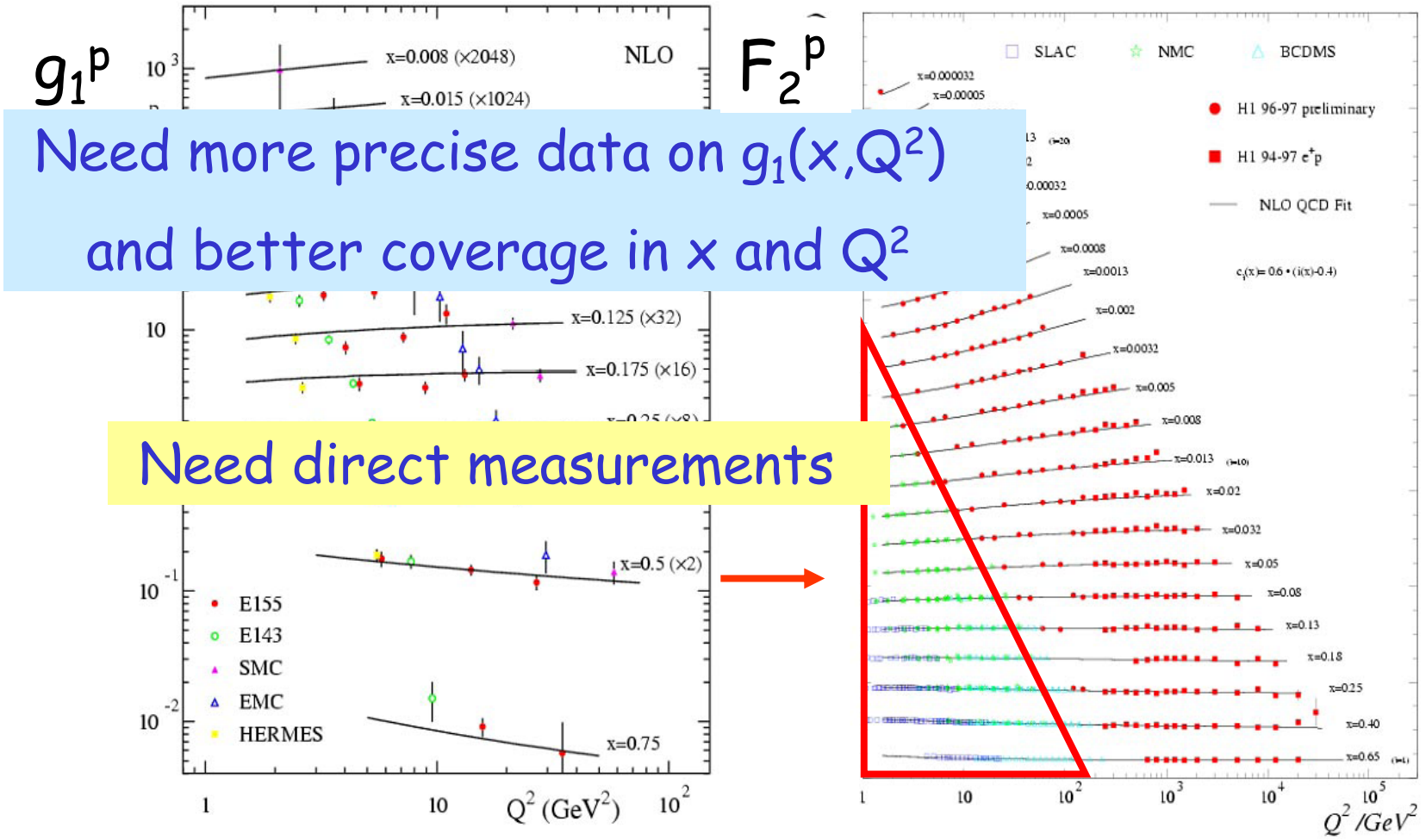
$\Delta G(x)$ not : shape and sum unknown

$$\int_0^1 \Delta G(x)dx$$

- SMC global QCD analysis at $Q_0^2 = 1$ GeV²: 1. +/- 1.2
- Blümlein-Böttcher at $Q_0^2 = 2$ GeV²: 1. +/- 0.6



Δq & ΔG from inclusive data



Need more precise data on $g_1(x,Q^2)$ and better coverage in x and Q^2

Need direct measurements

Direct Measurements

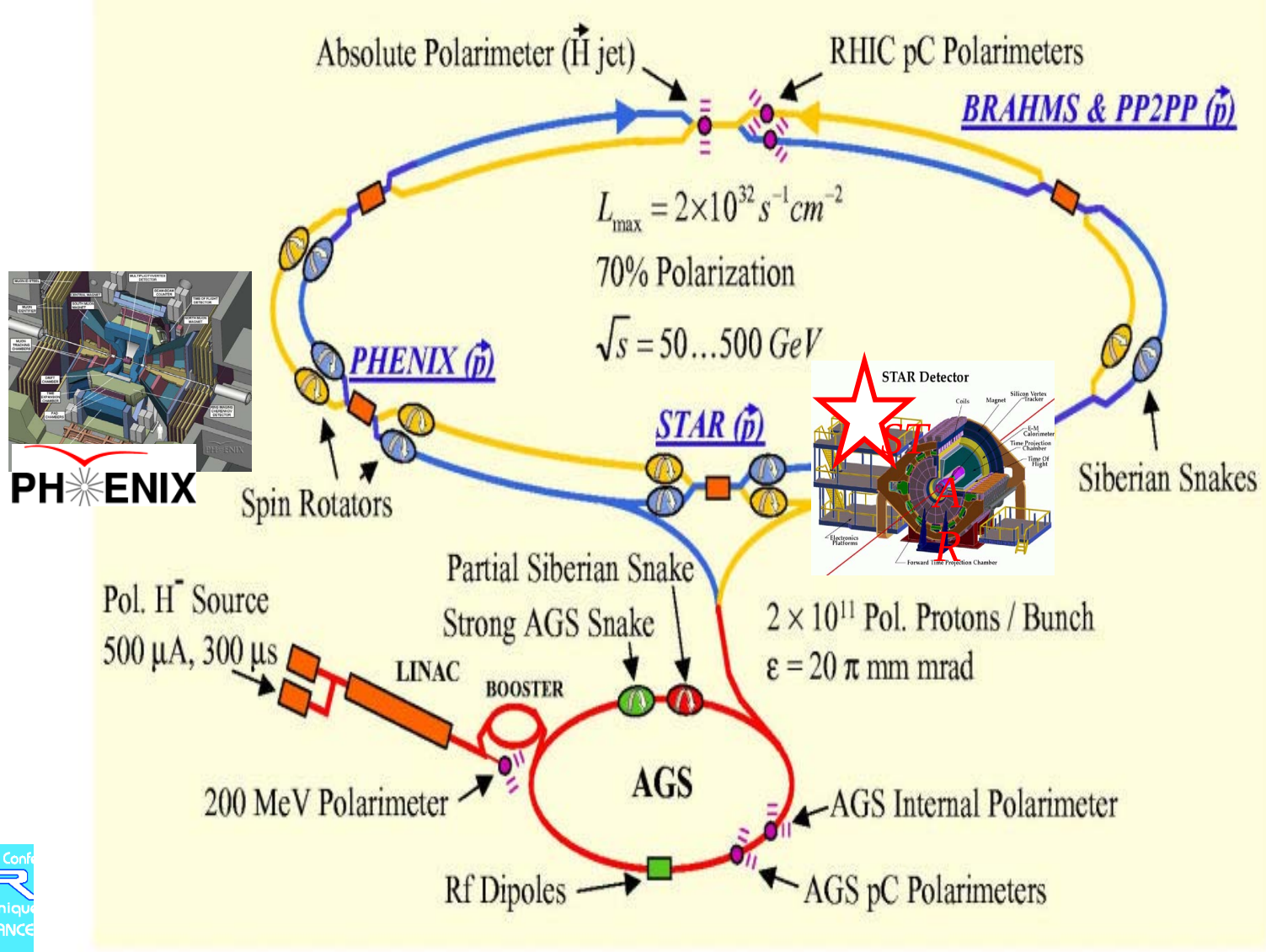
- RHIC (polarized) collider

  $\vec{p} \rightarrow \vec{\vec{p}}$

- HERMES, COMPASS

  $\vec{e}, \vec{\mu} \rightarrow \vec{\overline{N}}$

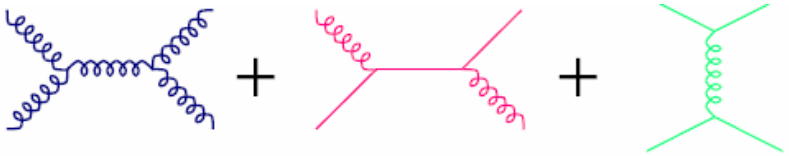
RHIC polarized protons collider



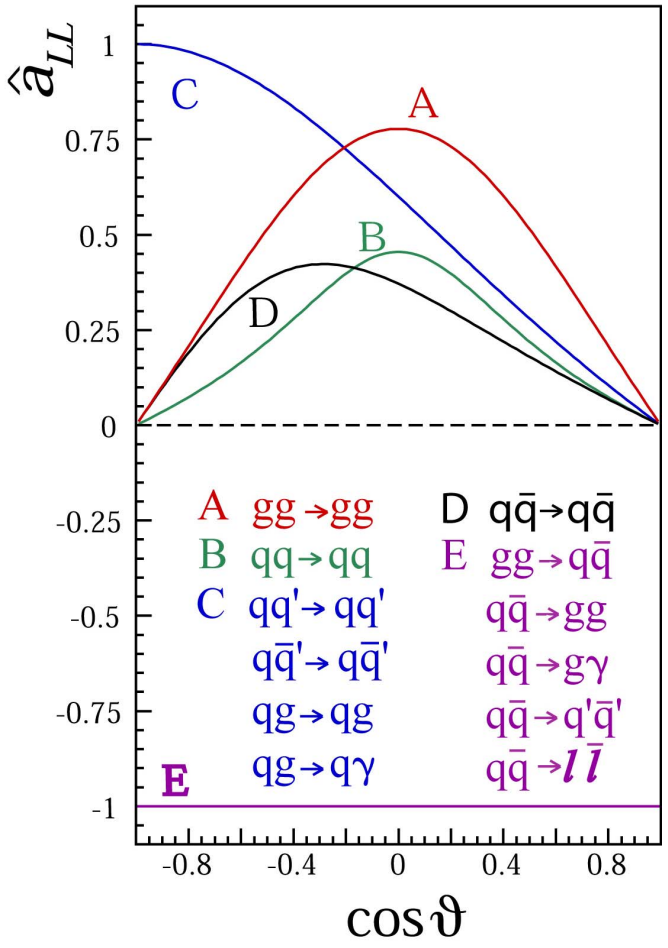
$\Delta G/G$ - RHIC $\vec{p}\,\vec{p}$

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}}$$

$$A_{LL} \simeq \frac{\Delta p_1}{p_1} \times \frac{\Delta p_2}{p_2} \times \hat{a}_{LL}$$



$$\left(\frac{\Delta G}{G}\right)^2 \quad \frac{\Delta G}{G}\frac{\Delta q}{q} \quad \left(\frac{\Delta q}{q}\right)^2$$

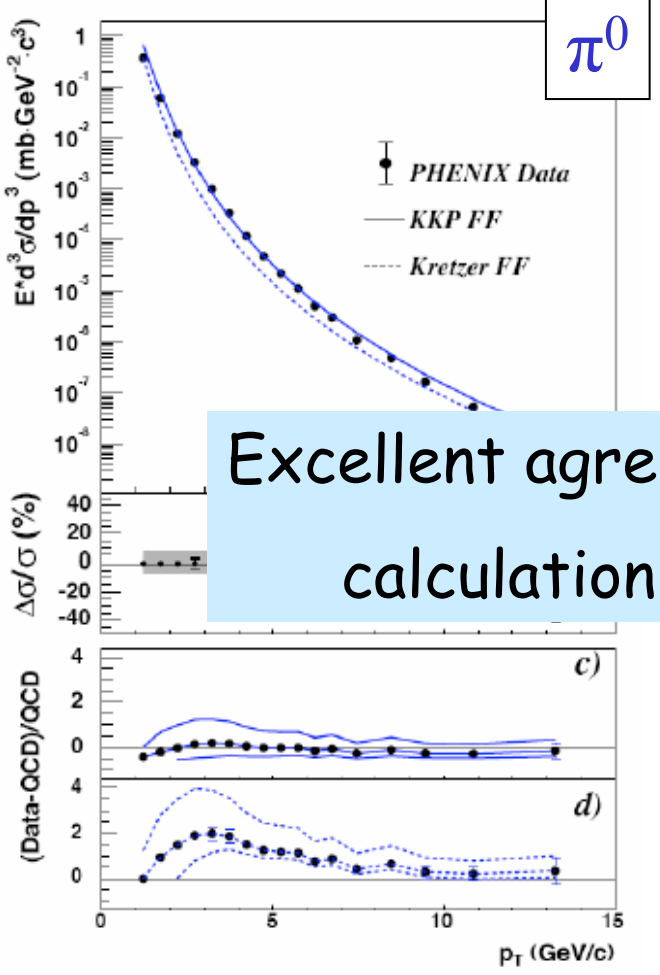


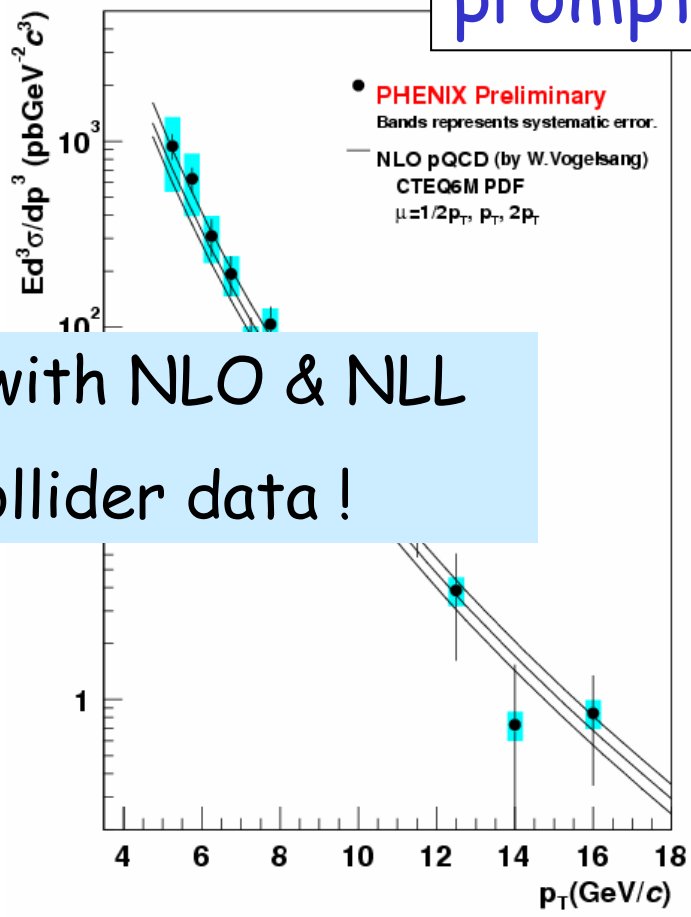
pp –> π^0/prompt γ + X

π^0

PHENIX

prompt γ



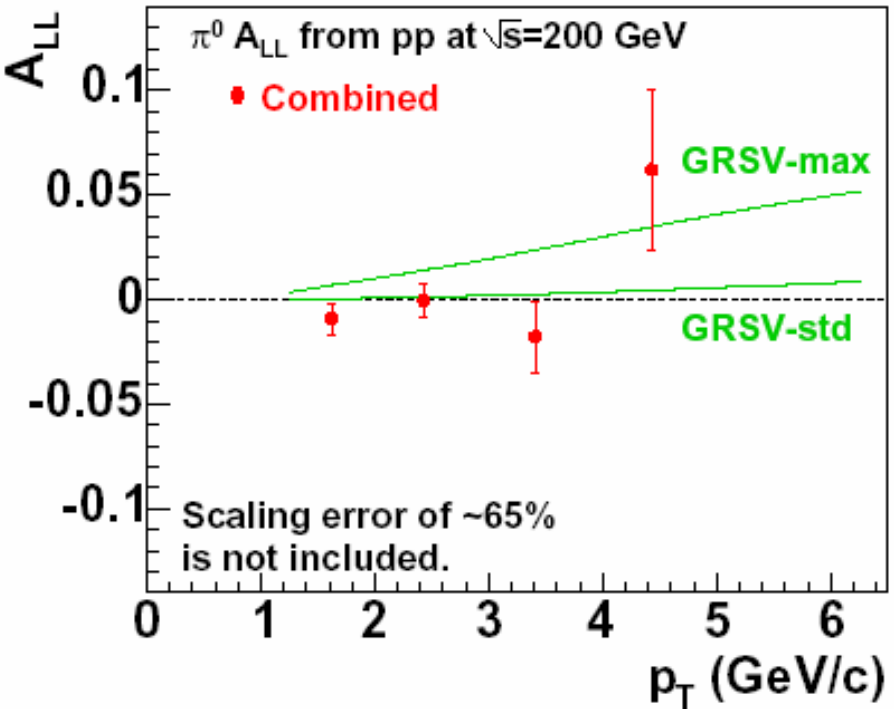


Excellent agreement with NLO & NLL calculation with collider data !

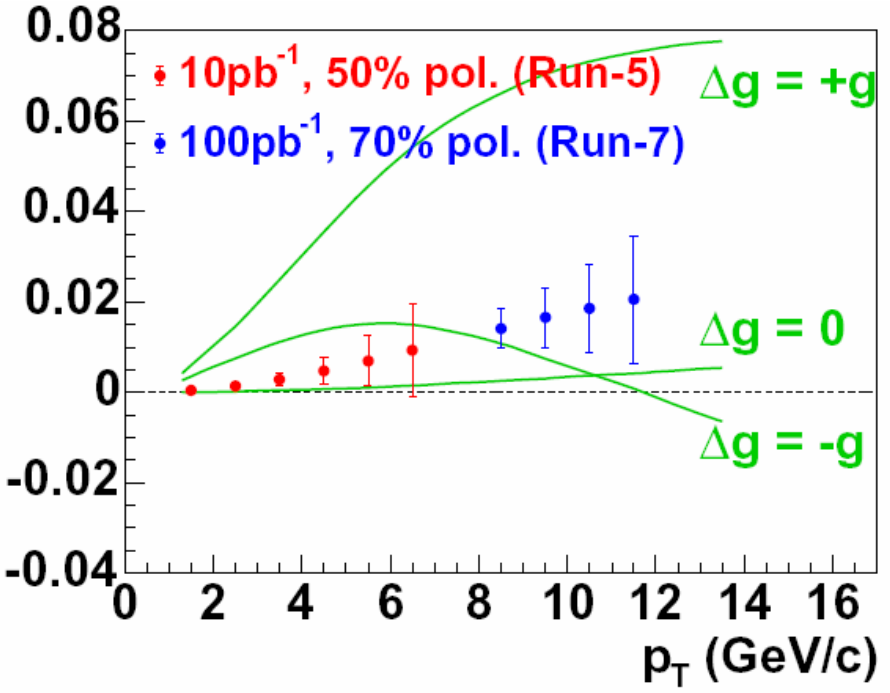
ΔG - Phenix: A_{LL} for π^0

PHENIX

2003/4



Outlook 2005/7



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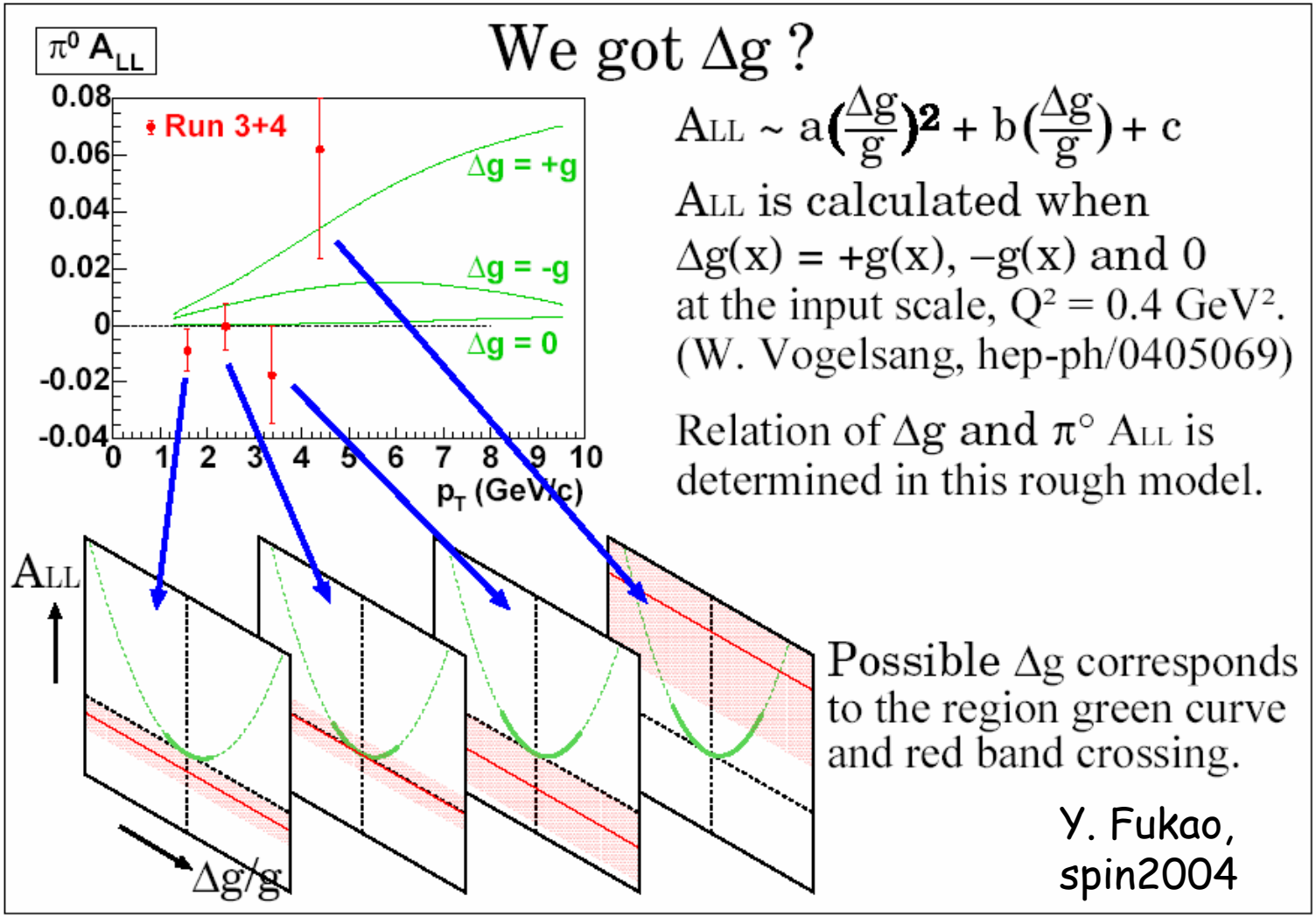
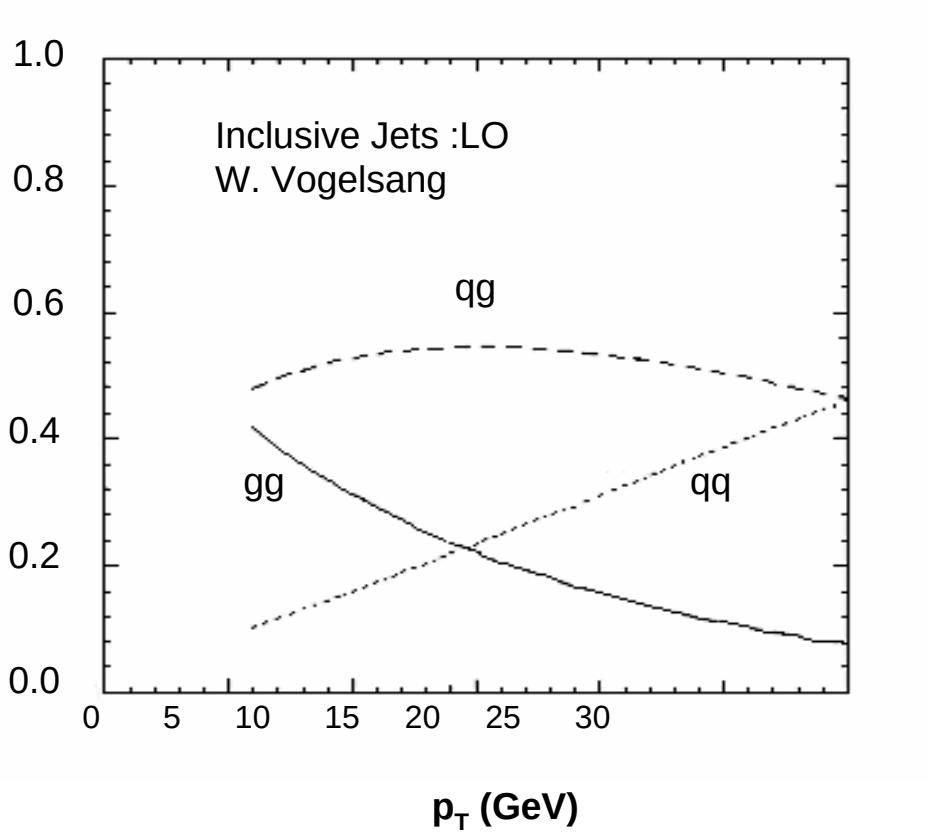
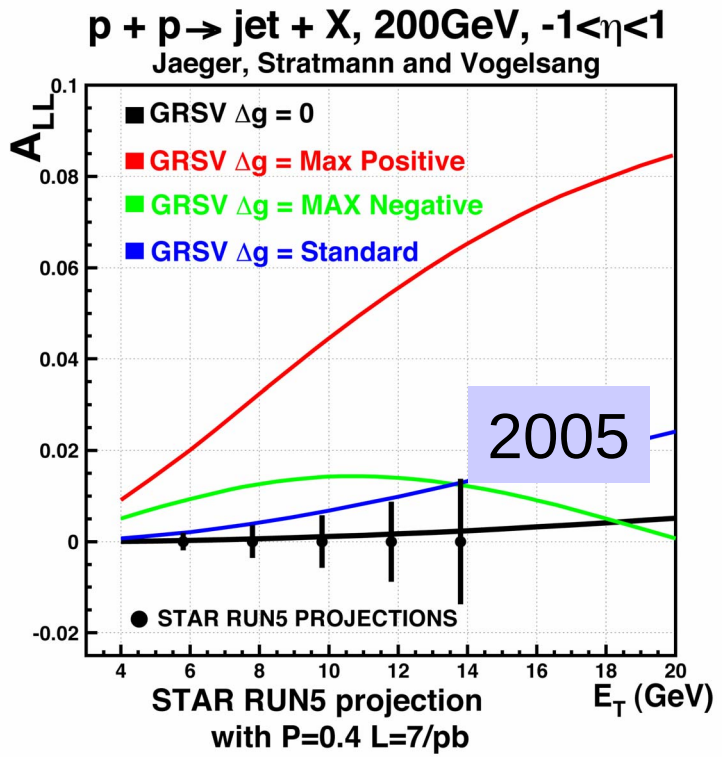
ΔG - Phenix: A_{LL} for π^0



ΔG - Star: A_{LL} for jets (2005)





ΔG at RHIC – summary & outlook

- **Various channels, large coverage in x_g**

  - Jet/leading hadron production :
    First results of A_{LL} $pp \rightarrow \pi^0 + X$ from PHENIX
    Very good perspective for π^{+-} at PHENIX and jets at STAR
  - Direct photon production:
    hard scale 100 GeV ^{2}, x_g reconstructed in STAR
  - Heavy flavours, ...

- **RHIC Spin program on track, major effort to reach performance**

Run	$s^{1/2}$(GeV)	P_{beam}	$\mathcal{L}$(pb^{-1})
3	200	0.27	0.35
4 + 5	200	>0.40	10
>5	200	0.70	320
	500	0.70	800

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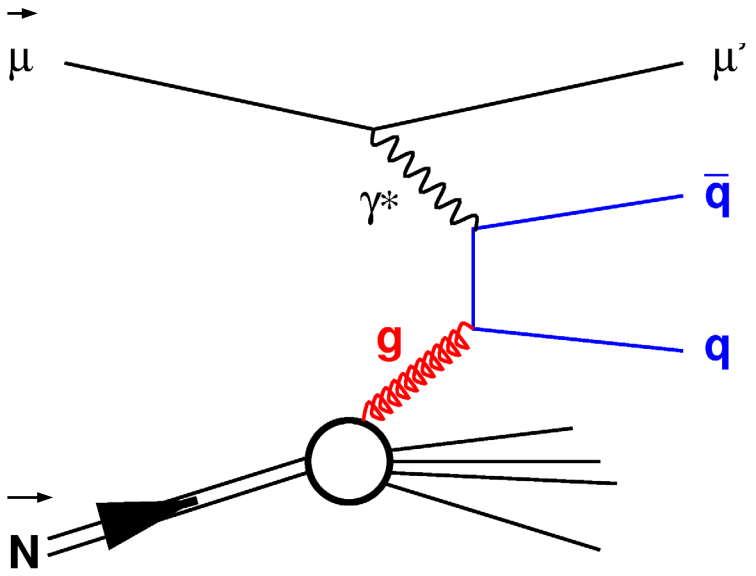
ΔG/G from Photon-Gluon Fusion



Photon-Gluon Fusion

- **Strategies to suppress background:**

1) Open charm production:
   $q = c$ unique, no background
   charm fragmentation, 1.2 D^0 per event

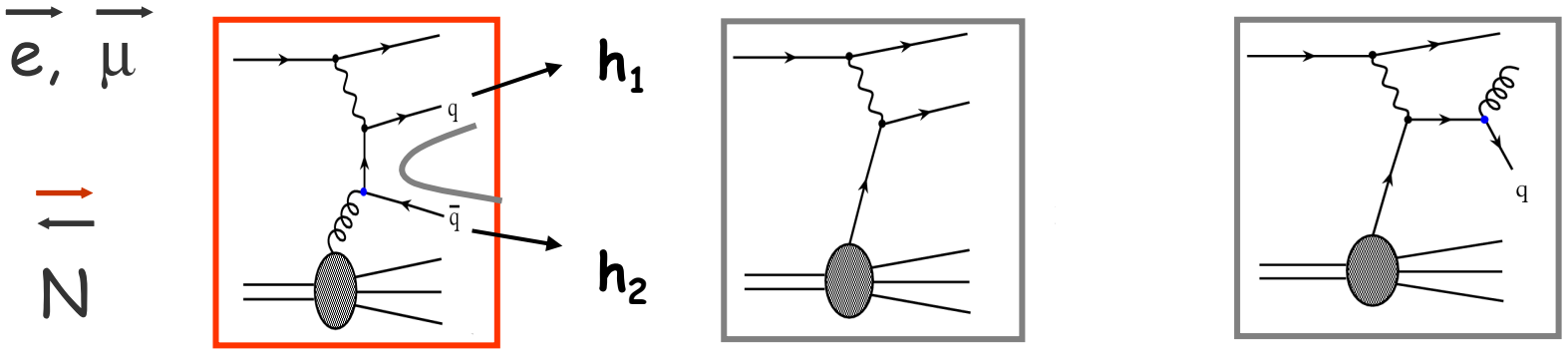
   $D^0 \rightarrow K^- \pi^+$ (BR 4%), D^{*+}(~20%) $\rightarrow D^0 \pi^+$

2) High-P_T hadron pair production:
   q=u,d,s
   σ_{kT}(intr) = 450 MeV/c
   σ_{pT}(frag) = 350 MeV/c

- **pQCD scale set by:**

1) $\hat{s} > 4m_c^2$ or
2) $\hat{s} > (p_{t1}+p_{t2})^2$

$\Delta G/G$ from high-P_T hadron pair production



Photon Gluon Fusion Leading Order Process QCD-Compton

$$A^{\ell h \to \ell h h X} = \frac{\Delta G}{G}\langle \hat{a}_{LL}\rangle^{PGF} R_{PGF} + \frac{\Delta q}{q}\left\{\langle \hat{a}_{LL}\rangle^{LP} R^{LP} + \langle \hat{a}_{LL}\rangle^{QCDC} R^{QCDC}\right\}$$

measured

a_{LL} : calculable partonic asymmetries

R : Monte-Carlo (Lepto/Phytia depending on Q^2)

HERMES & DESY

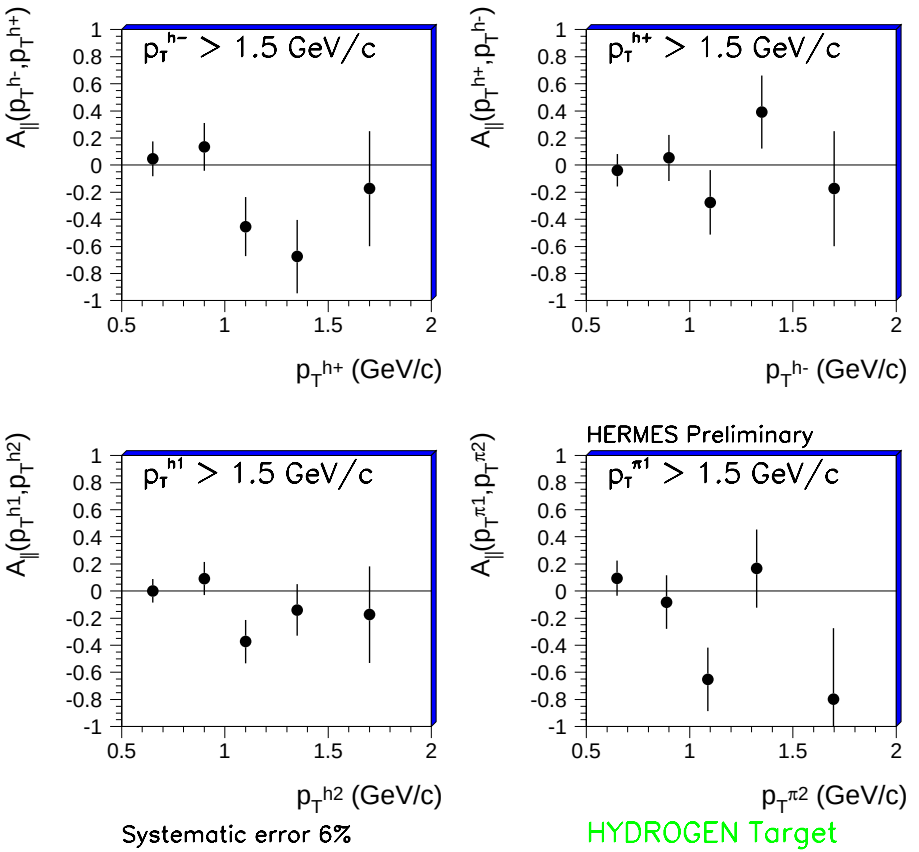
- 27.5 GeV $\vec{e}$
- Pure atomic H or D targets
- Spectrometer with complete hadron identification

HERMES A_{LL} from high P_T hadrons

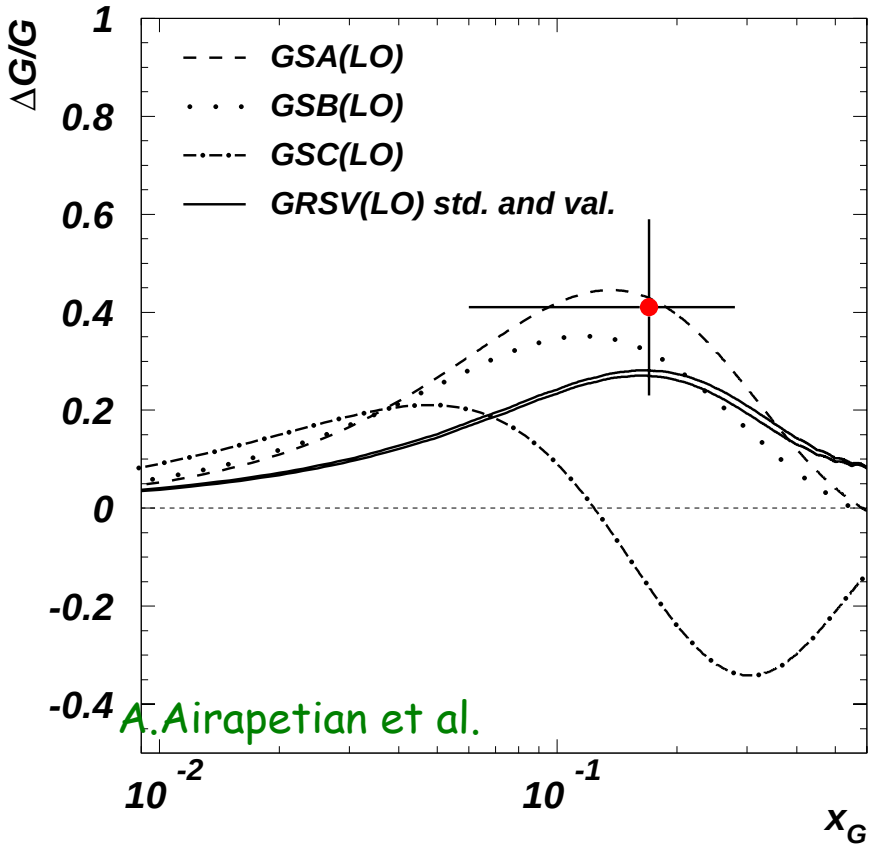
$$A_{LL} = \frac{N_+ - N_-}{N_+ + N_-} = P_e P_T f A^{eN \to ehhX}$$

- Statistics decreases with p_T
- Need good description of background (also polarized)

Proton target



ΔG/G from HERMES



27.5 GeV $\vec{e}$ on $\vec{p}$

$\langle x_g \rangle$ = 0.17

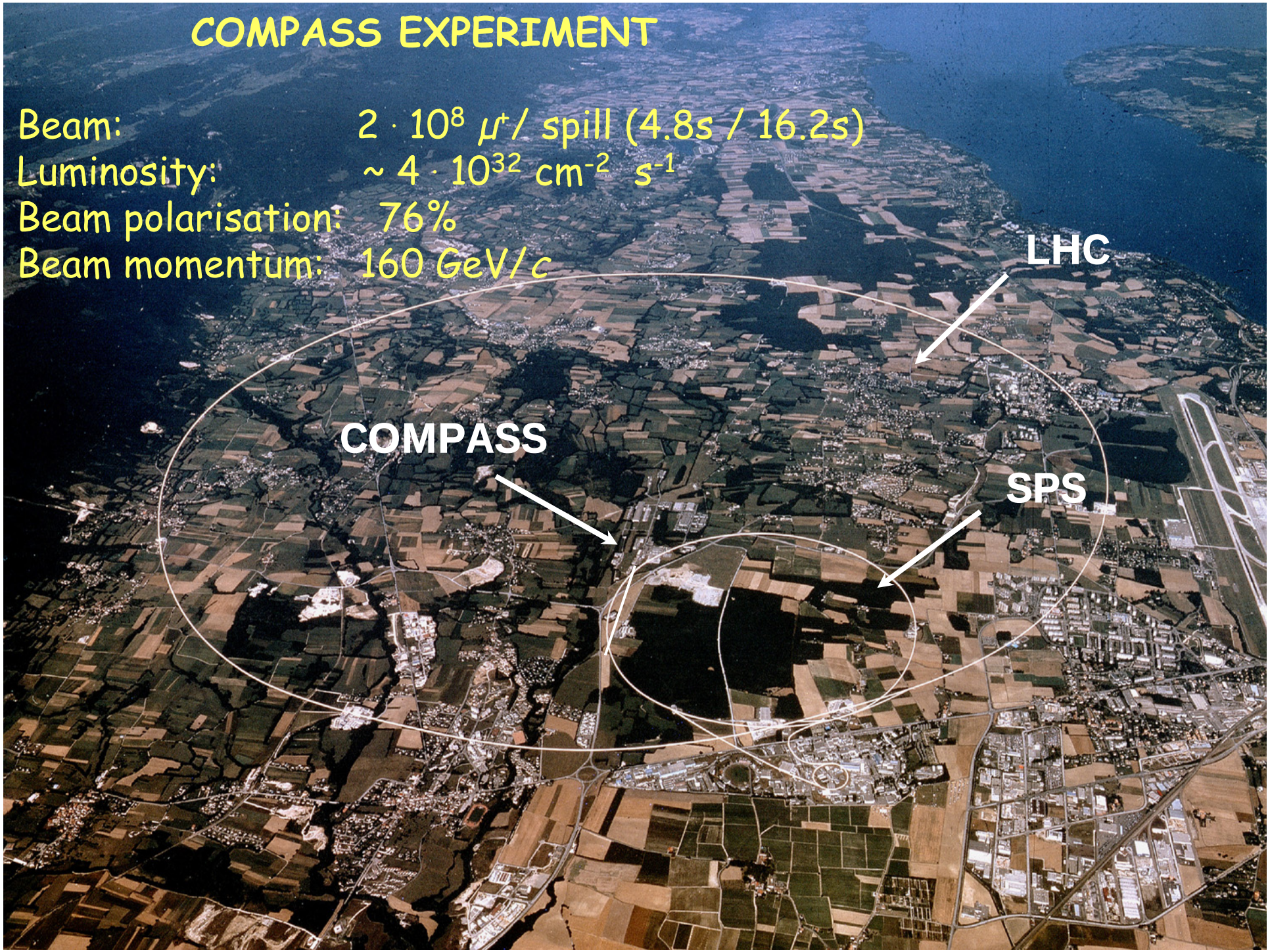
$\langle Q^2 \rangle$ = 0.06 (GeV/c)^2

$\langle p^2_T \rangle$ = 2.1 (GeV/c)^2

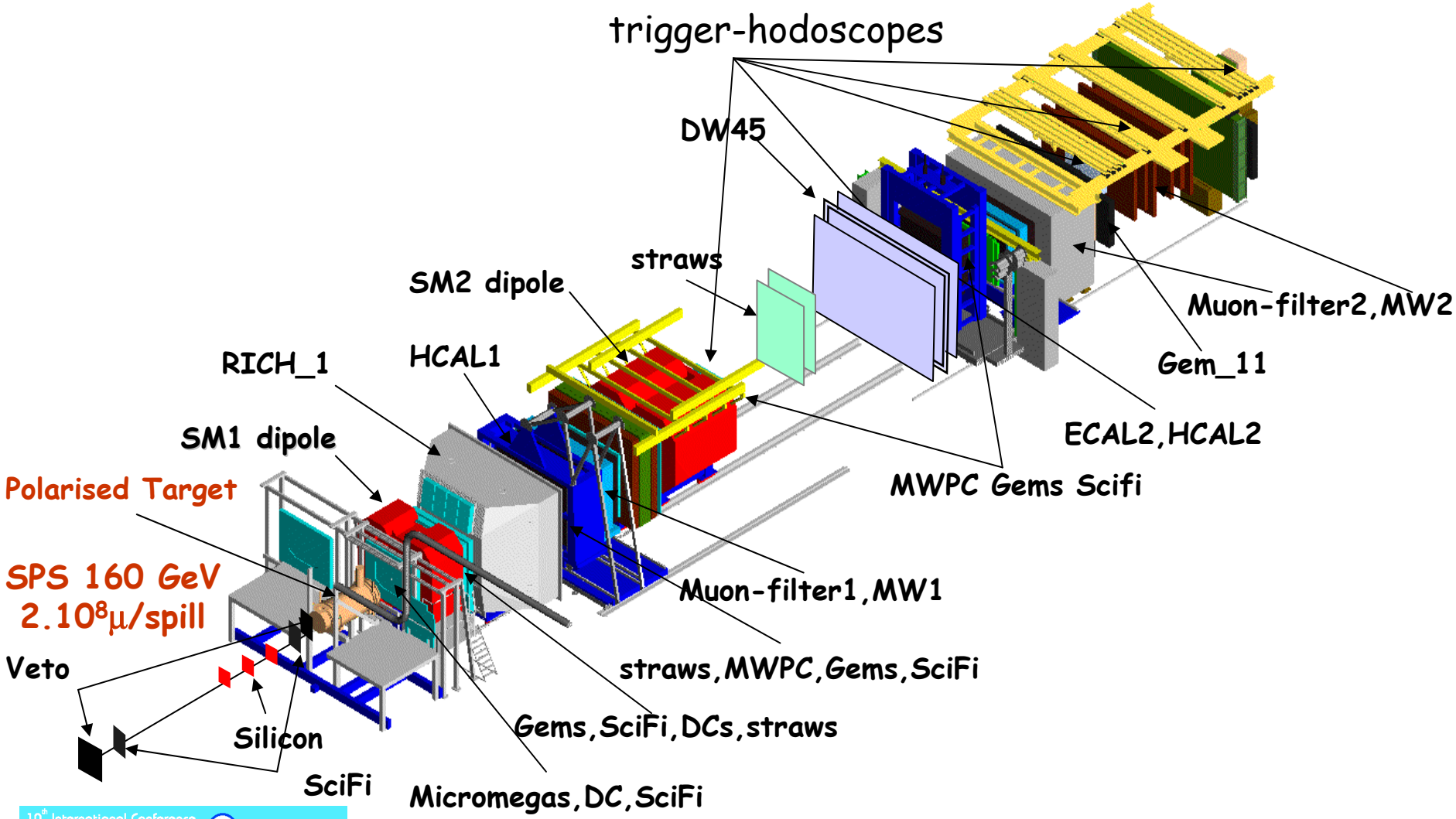
Promising channel, but …

theoretical uncertainty

might be large


COMPASS EXPERIMENT
Beam: $2 \cdot 10^8$ μ^+/ spill (4.8s / 16.2s)
Luminosity: $\sim 4 \cdot 10^{32}$ cm^{-2} s^{-1}
Beam polarisation: 76%
Beam momentum: 160 GeV/c
LHC
COMPASS
SPS

Spectrometer 2002 -> 2004



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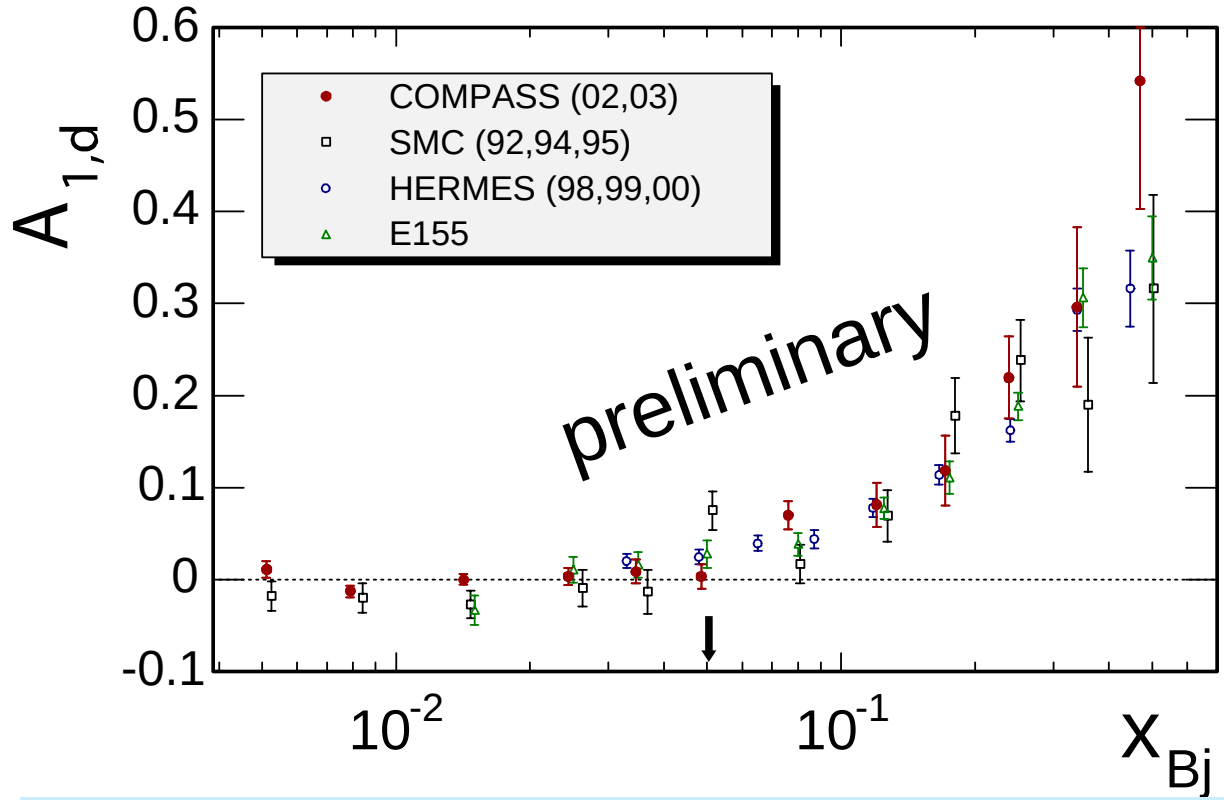
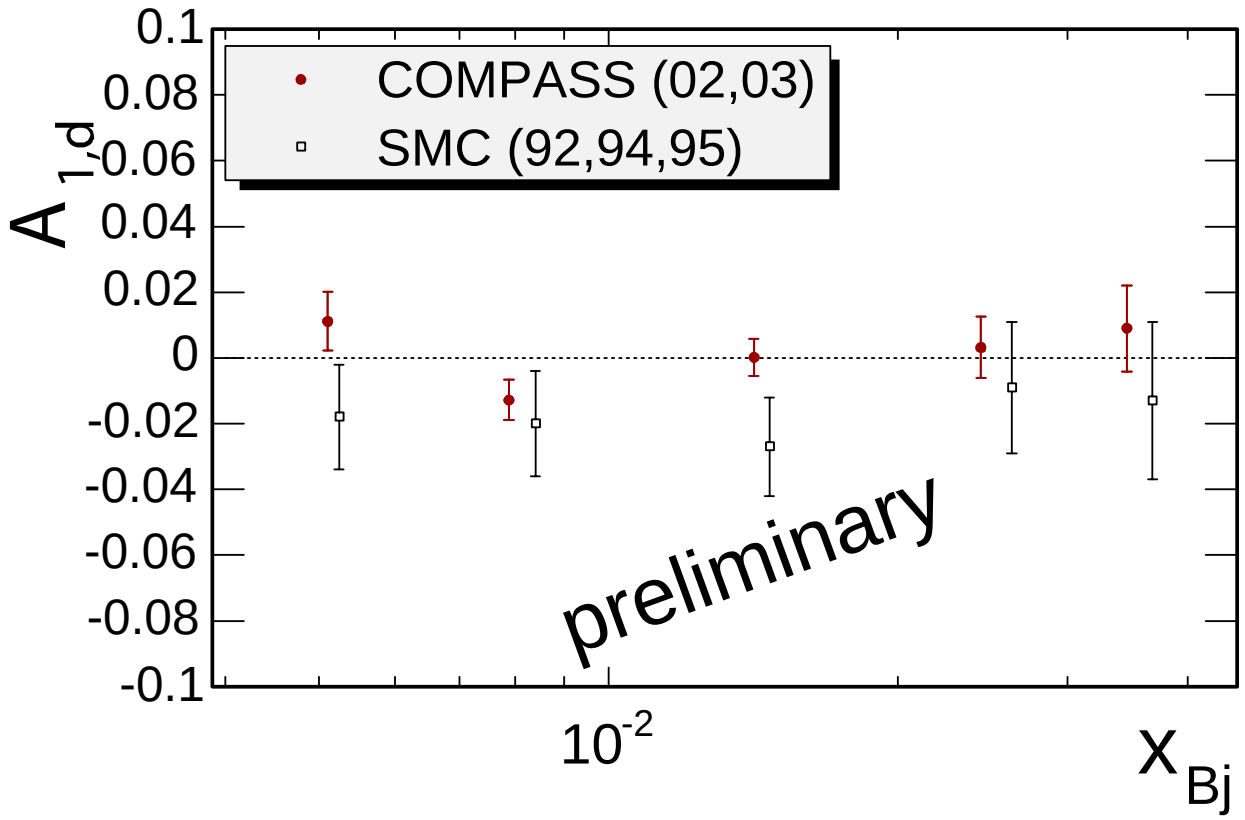
Inclusive longitudinal spin asymetry A_1^d



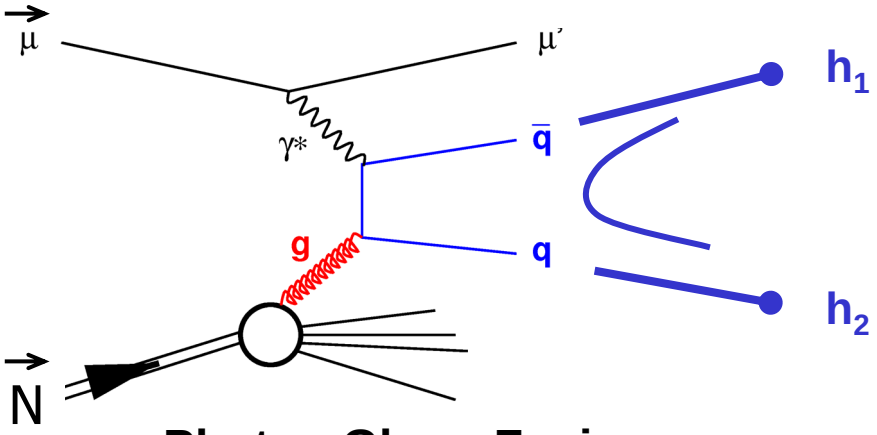
COMPASS has the potential to digest high luminosity and get high precision results

Inclusive longitudinal spin asymetry A_1^d



Low x region important for precision on $\Delta\Sigma$

Pairs of hadrons with high p_T



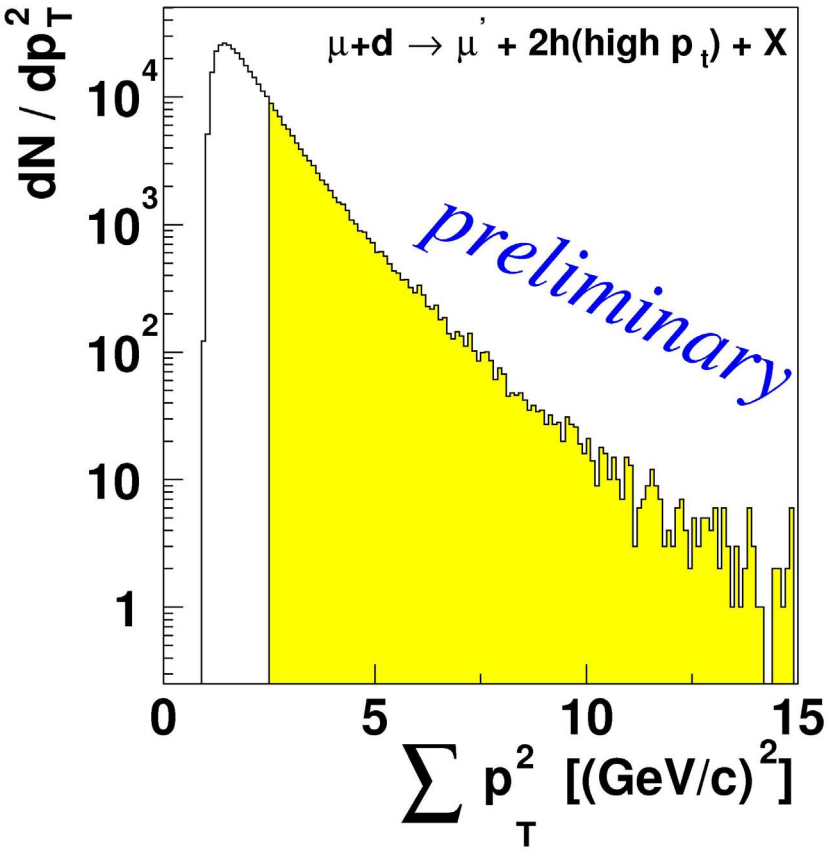
Photon Gluon Fusion

current fragmentation:

$x_F > 0.1$
$z > 0.1$

event cuts:

$Q^2 > 1\ (GeV/c)^2$, $x_{Bj} < 0.05$
$0.1 < y < 0.9$



- 2 high p_t hadrons:

$p_t > 0.7$ GeV/c
$p_{t1}^2+p_{t2}^2 > 2.5\ (GeV/c)^2$
$m(h_1h_2) > 1.5$ GeV/c²

Result for high p_T asymmetry

Asymmetry for high-pt hadron pairs at Q2 > 1 (GeV/c)2:

2002/2003 data

$$A_{\gamma^*}^{d} = -0.015 \pm 0.080\ (\text{stat.}) \pm 0.013\ (\text{syst.})$$

Systematic uncertainty contains contributions from:
- target and beam polarisation measurement (5% resp. 3%)
- upper limit on false asymmetries (0.013)
- determination of depolarisation and dilution factors, D and f (5% each)

Preliminary determination of ΔG/G

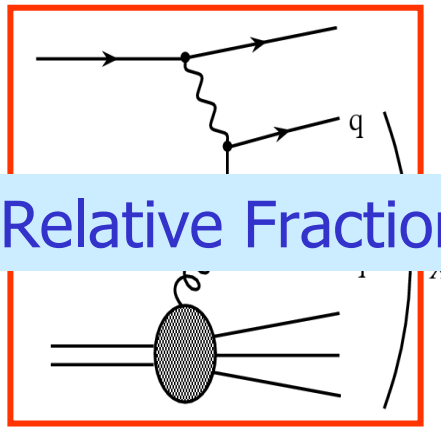
$$A^{\gamma^* d} = \frac{A_{LL}^{\mu N \to hh}}{D} \approx \left\langle \frac{\hat{a}_{LL}^{PGF}}{D} \right\rangle \left\langle \frac{\Delta G}{G} \right\rangle \frac{\sigma^{PGF}}{\sigma^{tot}} + \left\langle \frac{\hat{a}_{LL}^{Com}}{D} \right\rangle \left\langle \frac{\Delta q}{q} \right\rangle \frac{\sigma^{Com}}{\sigma^{tot}} + LO\ DIS$$

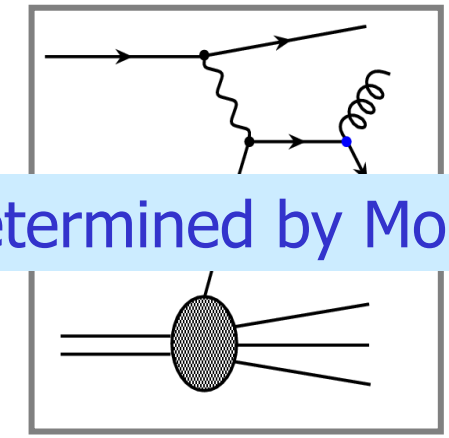
cut on $x_{Bj} < 0.05$:

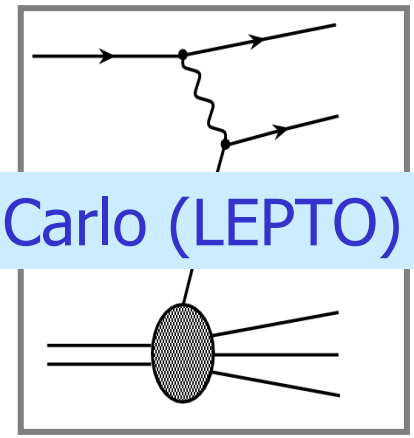
$\left\langle \hat{a}_{LL}^{PGF} / D \right\rangle \approx -0.74 \pm 0.05$

$\left\langle \hat{a}_{LL}^{Com} / D \right\rangle A_1^d \approx 0$

$A_1^d \approx 0$





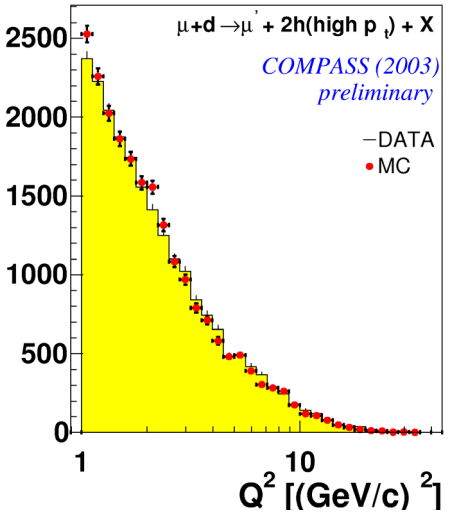


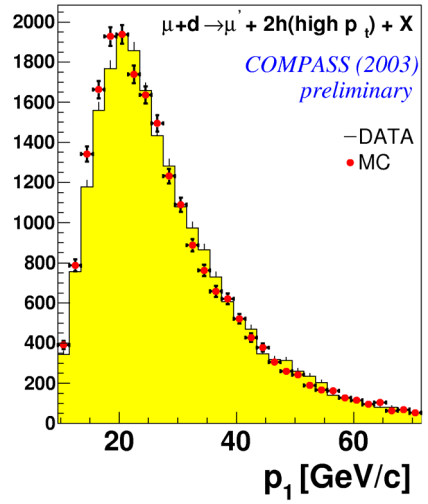
Relative Fractions determined by Monte Carlo (LEPTO)

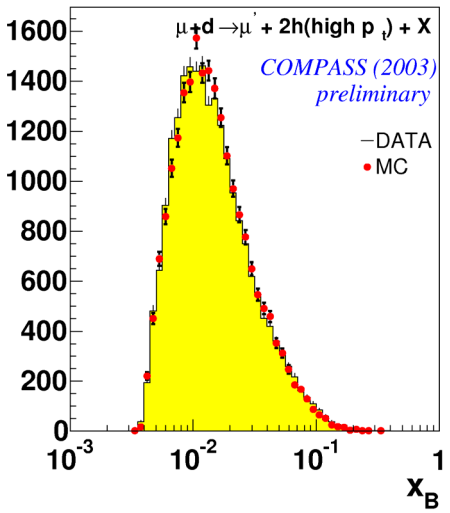
Photon Gluon Fusion | **QCD-Compton** | **Leading Order**

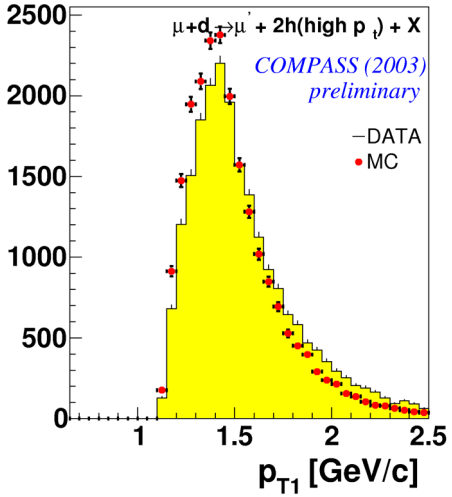
Data Monte Carlo comparison

Use LEPTO Monte Carlo for $Q^2>1$ (GeV/c)^2 including RADGEN









Determination of the fraction of PGF events in LEPTO:

$\sigma^{PGF}/\sigma^{tot} = 0.34 \pm 0.07$ (syst.)

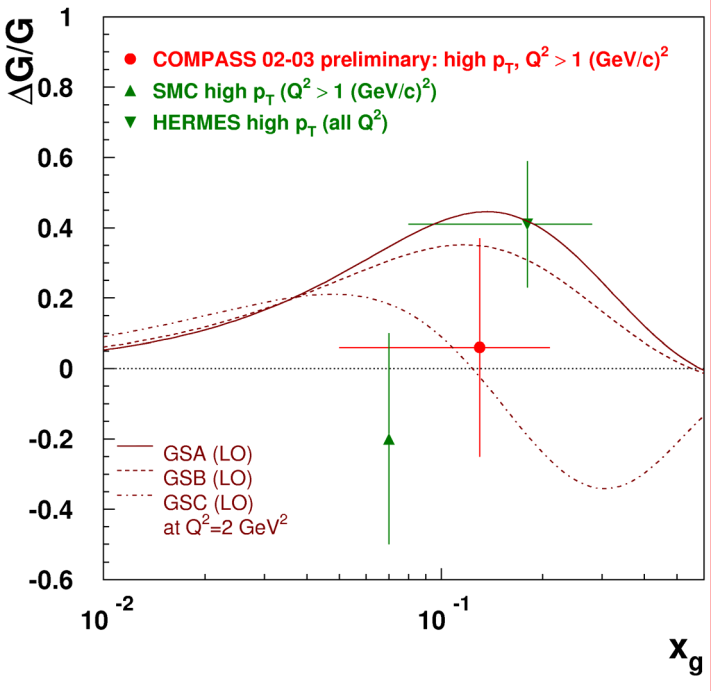
- Variation of the cut on p_t^2
- Standard and modified* set of fragmentation parameters

* SMC, B. Adeva et al., Phys. Rev. D70:012002, 2004

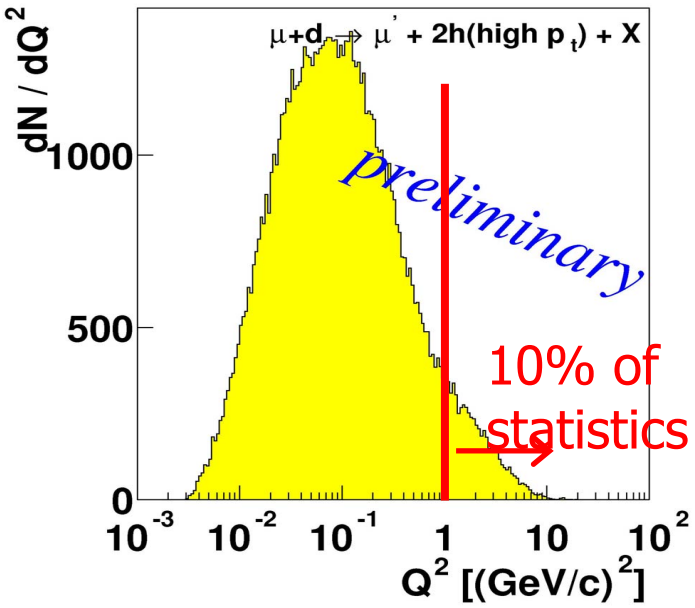
COMPASS result for $\Delta G/G$

$$\Delta G/G = 0.06 \pm 0.31_{stat.} \pm 0.06_{syst.}$$

at $\langle x_g \rangle = 0.13 \pm 0.08$



2002/03 data
$Q^2 > 1$ (GeV/c)^2



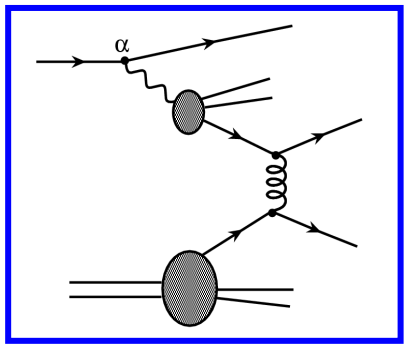
GSA,B,C: T. Gehrmann and W. Sterling, Z. Phys. C65 (1994) 461.

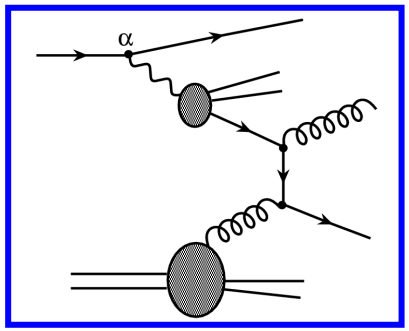
$Q^2 < 1$ GeV/c^2, additional background

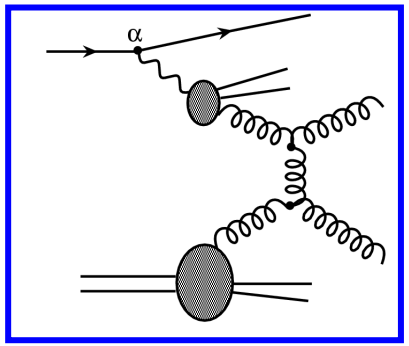
for all Q^2 : 10 times more data

Projection for 2002-2004 data (all Q2):

Statistical error on $\Delta G/G$ of 0.05



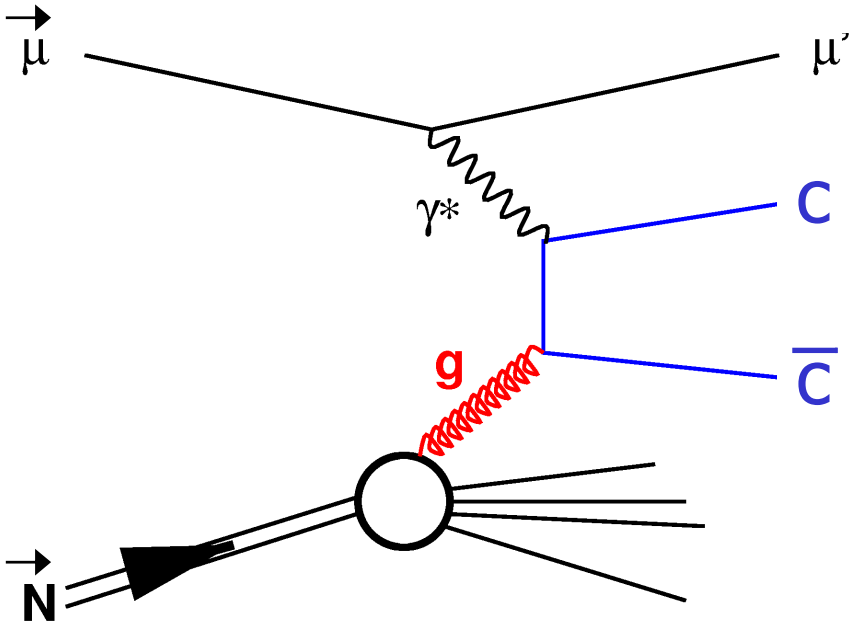




Relevant for Q2< 1 (GeV/c)^2, uncertainty due to unknown spin content of the resolved photon

ΔG/G from open charm

$$A_{\gamma N}^{c\bar{c}} = \frac{\int d\hat{s}\, \Delta\sigma^{PGF}(\hat{s})\, \Delta G(x_G, \hat{s})}{\int d\hat{s}\, \sigma^{PGF}(\hat{s})\, G(x_G, \hat{s})} \approx \langle a_{LL} \rangle \frac{\Delta G}{G}$$



$D^0 \longrightarrow K^- \pi^+$ (BR 4%)

$D^{*+} \longrightarrow D^0 \pi^+ + c.c.$

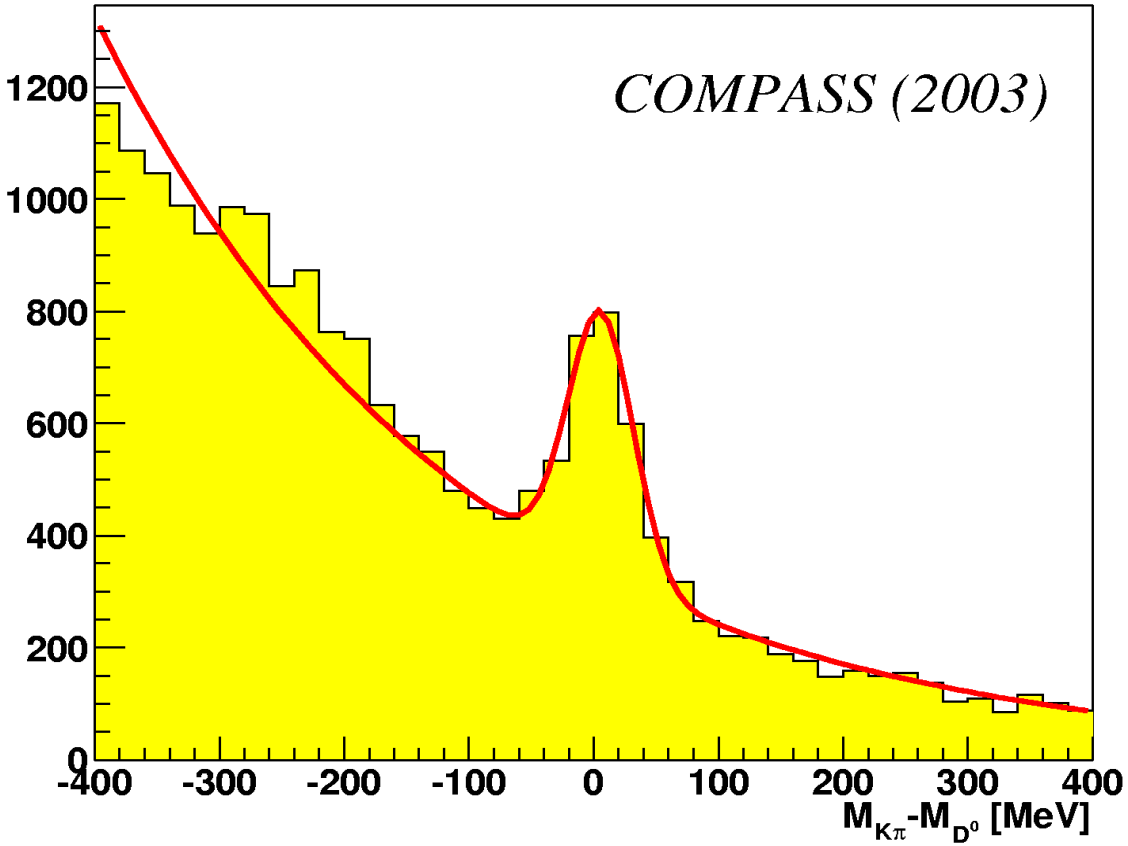
Special trigger: quasi real photoproduction

$\Delta\sigma^{PGF}$ at NLO:
Bojak, Stratmann NPB 540 (1999) 345;
A.P. Contogouris and G. Grispos, Phys. Rev. D 62 (2000).

$\hat{s} = m^2_{cc}$

ΔG/G from open charm

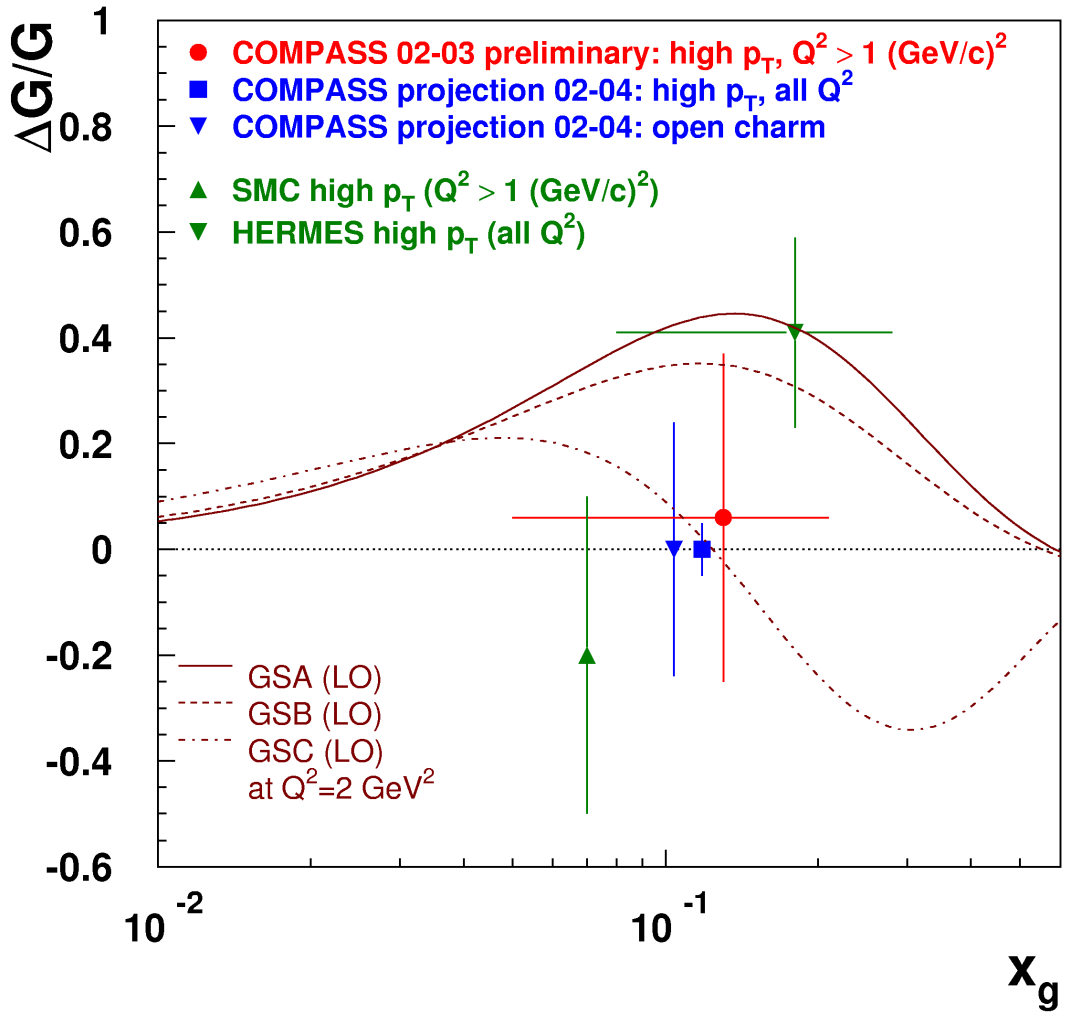
$$D^* \to D^0 \pi_s \to (K\pi)\pi_s$$



Asymmetry determination with full 2002-2004 statistics:

Expected error on ΔG/G from 2002-2004 data: 0.24

Expected errors on ΔG/G



COMPASS Summary

First COMPASS result for high p_t hadron pairs with Q2 > 1 (GeV/c)2

- more data in 2004
- 10 times more data at Q^2<1 (GeV/c)2

Good perspectives for ΔG/G from open charm by D^0 mesons

COMPASS will resume data taking 2006 and continue until ≥ 2010

Future Fixed Target Programme at CERN

Villars meeting, 22-28 Sept.

CERN seminar Villars by John DAINTON

" FT hadron program remains very competitive

…….

COMPASS complete in medium term

- ΔG/G, transversity, polarisability, spectroscopy

- SPSC p.o.t. concern → prioritise

COMPASS longer term

- GPD measurements would be unique"

Conclusions (personal) by Michelangelo MANGANO

" COMPASS μ beam … flagship experiment "

Summary

- Two new facilities are operationnal

RHIC & COMPASS

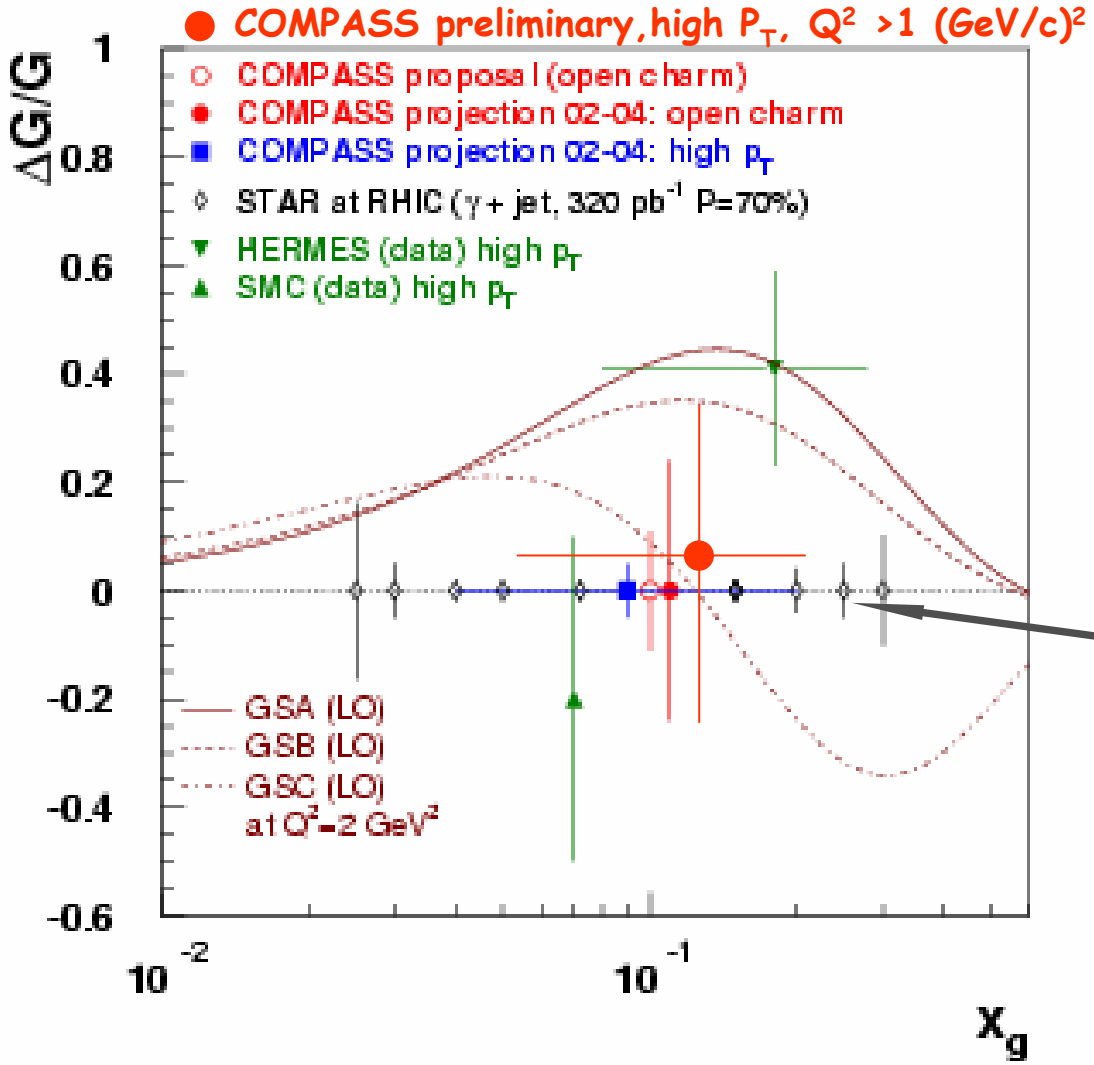
- First COMPASS result for $\Delta G/G$ from high pt hadron pairs with $Q2 > 1\ GeV/c^2$

- Excellent prospects for RHIC and COMPASS

- Very exciting times ahead of us !

Additional slides

Expected errors on $\Delta G/G$



STAR @ RHIC

error & $1/(L3P^4)^{1/2}$

proposal L=320 pb^{-1} P=70%