

# Measurements of $\Delta G$



## Focus on COMPASS data

- $\Delta G$  from scaling violations
- $\Delta G/G$  from hadron production
  - Open charm
  - Hadron pairs
  - Single hadrons
- pp RHIC

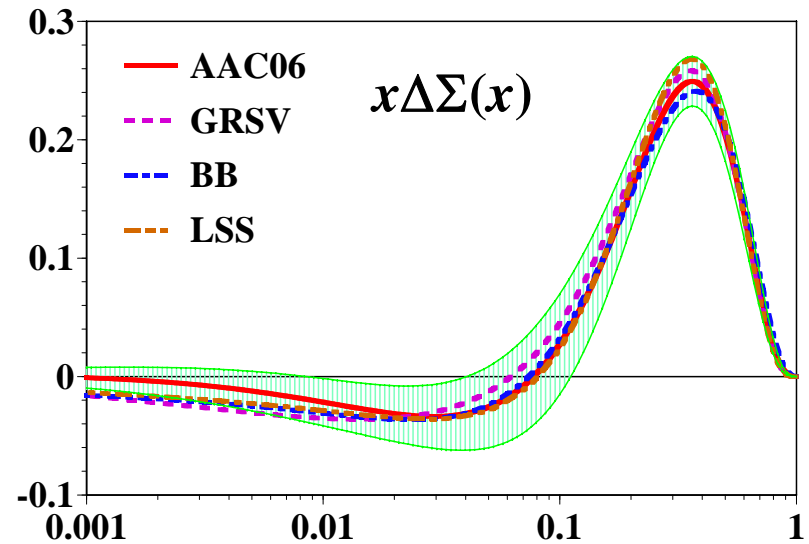
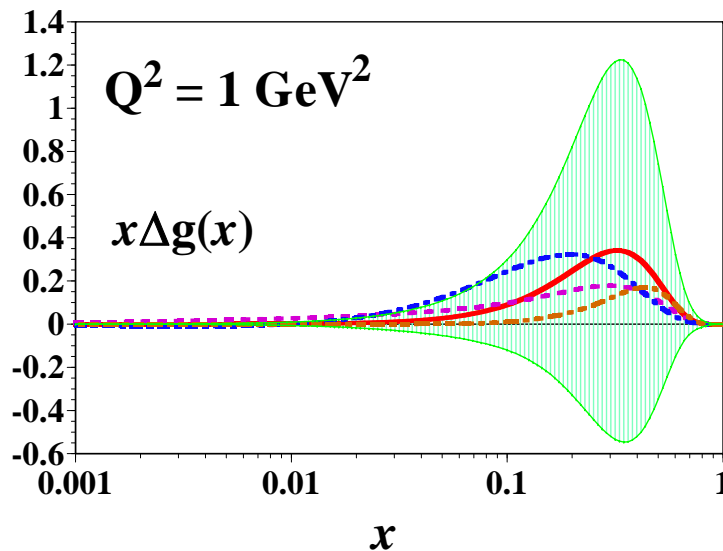
G. Mallot  
CERN/COMPASS

# NLO QCD fits



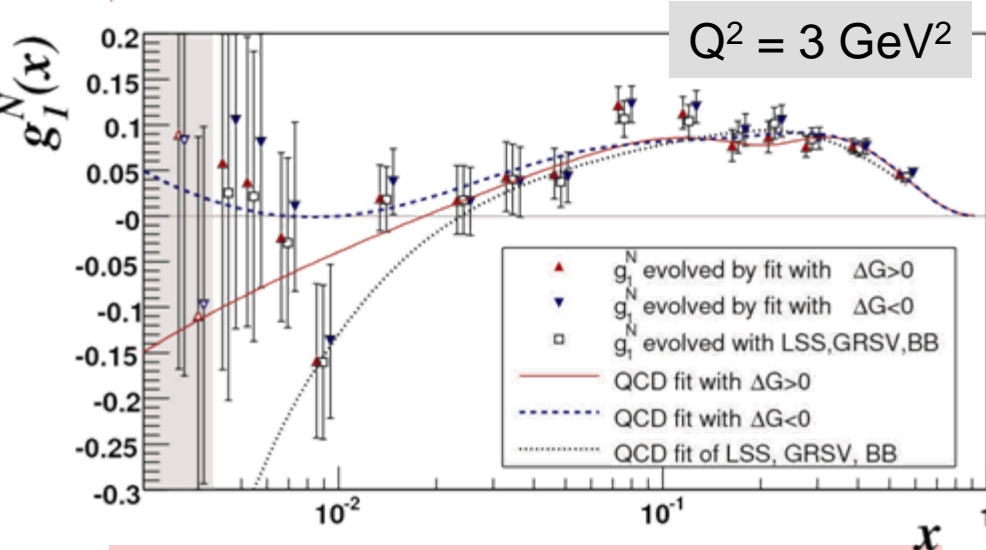
- Several groups performing World Data fits
- Example AAC, new fit 2006
- Still large uncertainty in  $\Delta G$ , even sign not determined
- Extra difficulties in polarized case
  - No positivity condition
  - No momentum sum rule

Hirai, 2a Thu

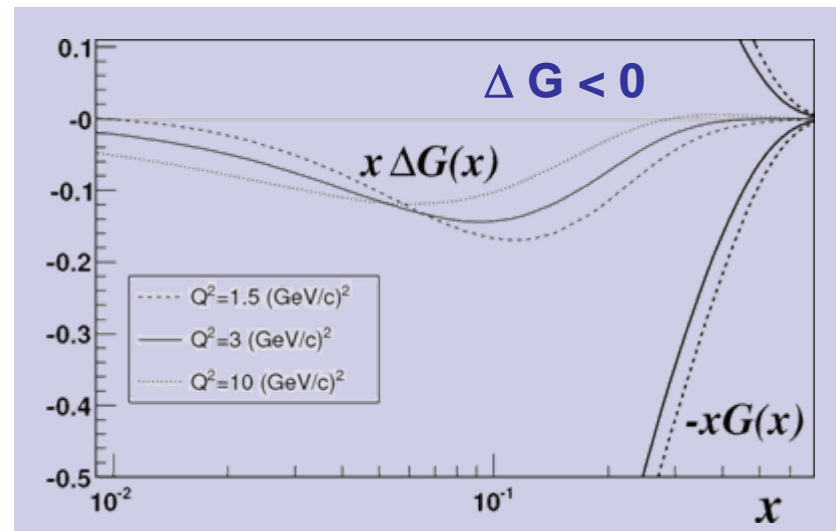
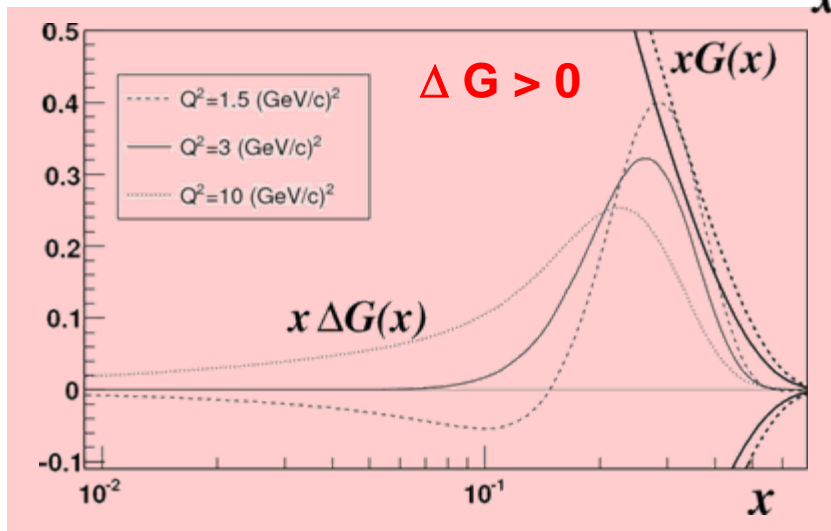




# COMPASS QCD fit

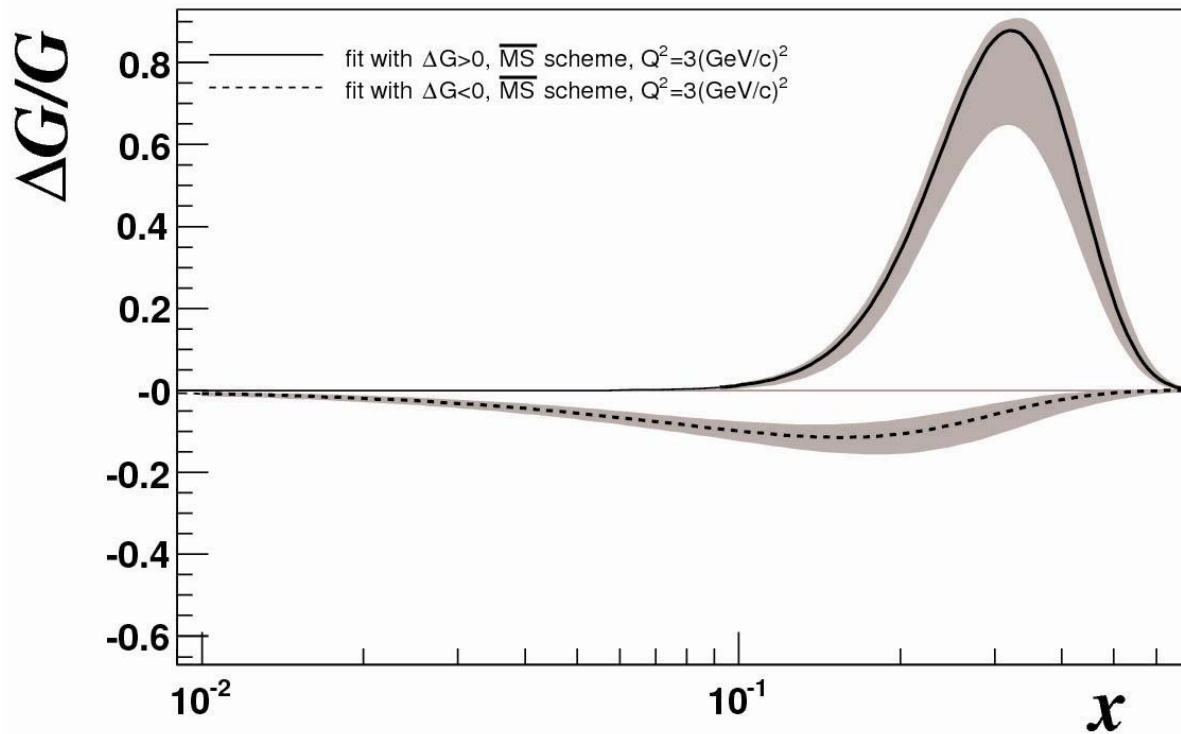


- New  $g_1^d$  data + world data
- $\Delta G > 0$  and  $\Delta G < 0$
- Low- $x$  data prefer  $\Delta G < 0$
- $|\Delta G| \simeq 0.2-0.3$
- $\alpha_0 = 0.33 \pm 0.03 \pm 0.05$
- $\Delta s = -0.08 \pm 0.01 \pm 0.02$



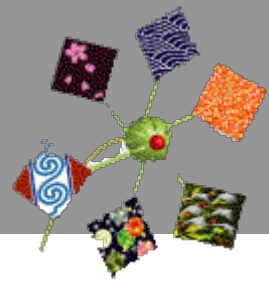


# COMPASS QCD fit

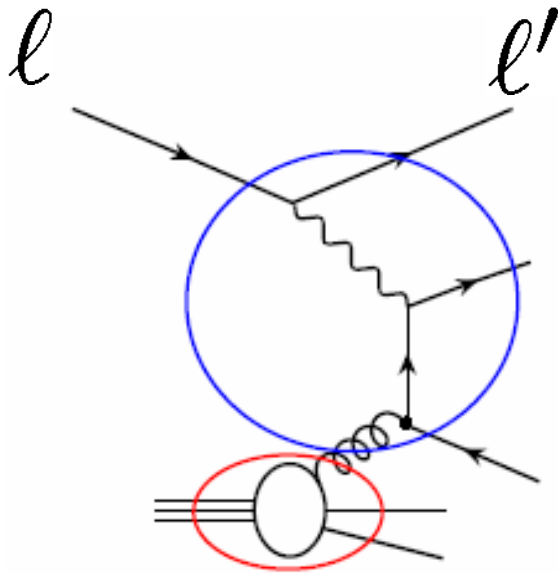


- Not yet included in fits: final Hermes  $g_1^d$   
De Nardo, Thu

# Photon-gluon fusion (PGF)



- Gluon polarisation is measurable in PGF



$$A_{\parallel} = R_{pgf} \langle \hat{a}_{pgf} \rangle \frac{\Delta G}{G}$$

- measure  $A_{\parallel}$
- calculate  $R_{pgf}$  and  $\langle \hat{a}_{pgf} \rangle$

using Monte Carlo

# Hadron production



- LO analysis of hadron-pair asymmetries:

- open charm: single  $D$  meson  
cleanest process wrt physics background
- high- $p_T$  hadron pairs with  $Q^2 > 1 \text{ GeV}^2$
- high- $p_T$  hadron pairs with  $Q^2 < 1 \text{ GeV}^2$

AROMA

LEPTO

PYTHIA

- NLO (photo production)

- open charm
- single incl. high- $p_T$  hadron
- hadron pairs: LO done,
- NLO underway

Bojak, Stratmann

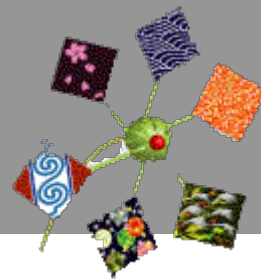
Jaeger, Stratmann, Vogelsang

Hendlmeier, Stratmann, Schäfer

- All analyses up to now in LO (plus parton showers)

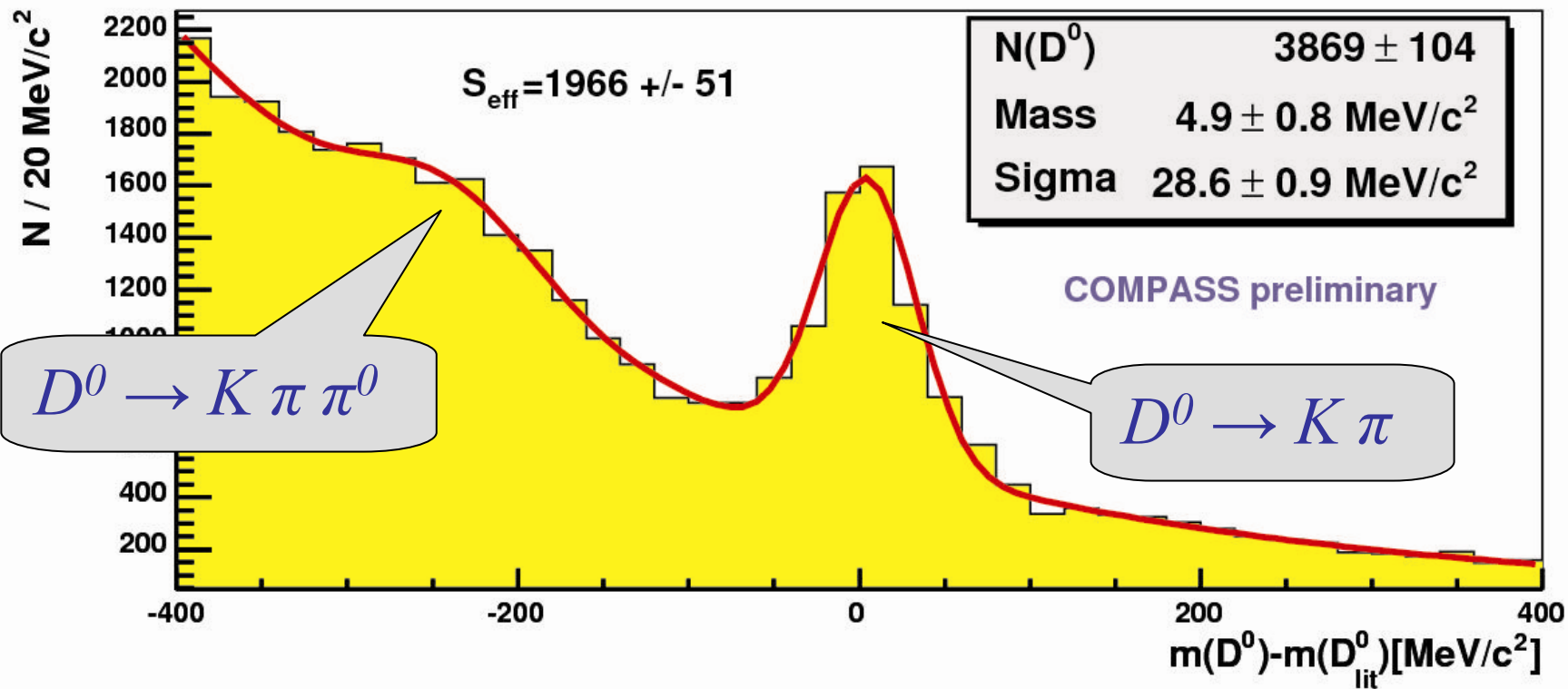


# Open Charm: $D$ 's from $D^*$ 's



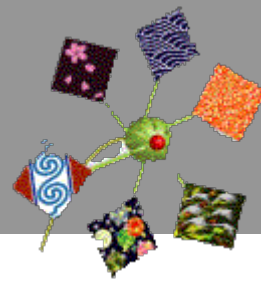
$D^* \rightarrow D \pi_s \rightarrow K \pi \pi_s$  slow pion required

2002–2004

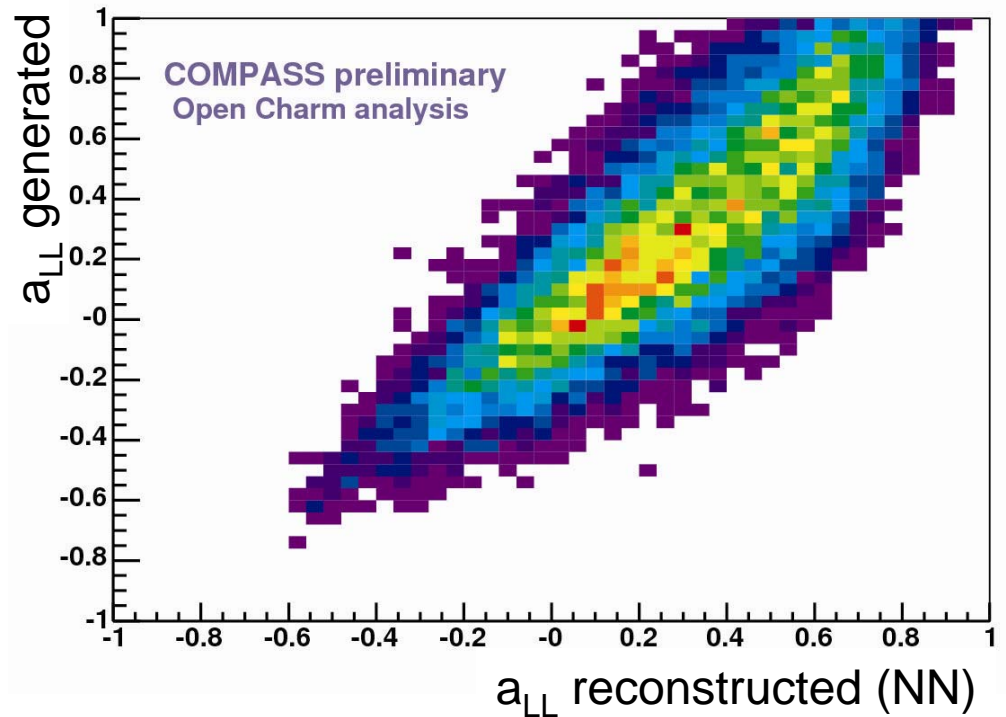




# Open charm: MC



- analysis uses event  $a_{LL}$  weighting,
- $a_{LL}$  estimated with NN from event kinematics
- indispensable due to large variation of  $a_{LL}$
- good correlation of 0.82 between **generated** and **reconstructed**  $a_{LL}$



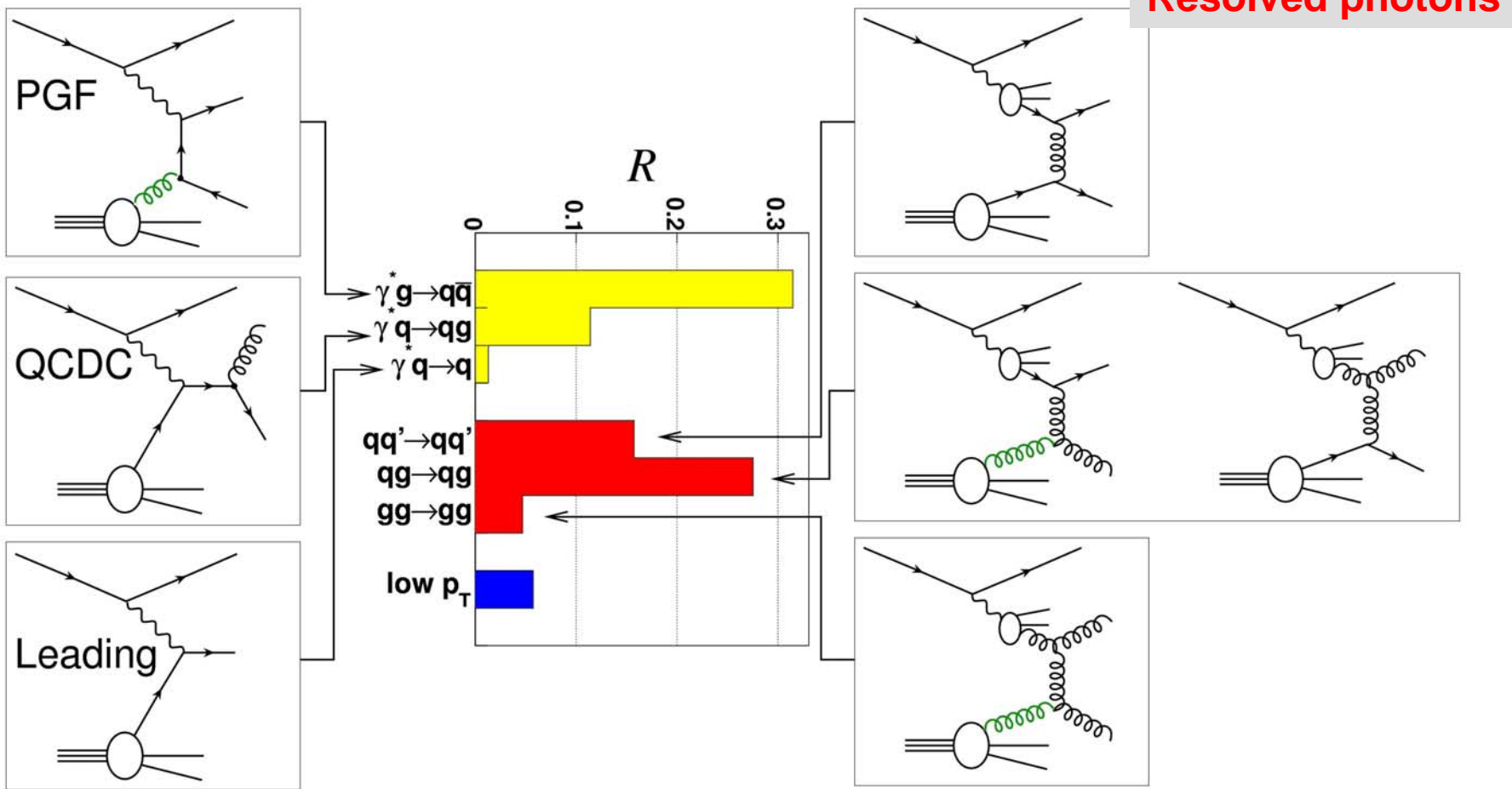




# Hadron production

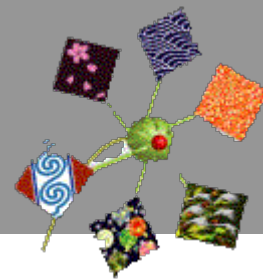


Ratios for processes for  $Q^2 < 1$





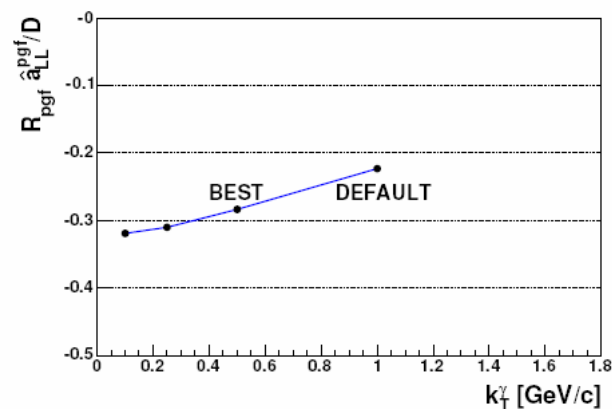
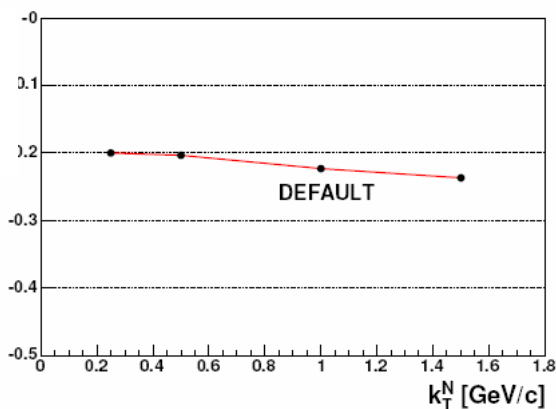
# Example: $k_T$ -tuning



nucleon

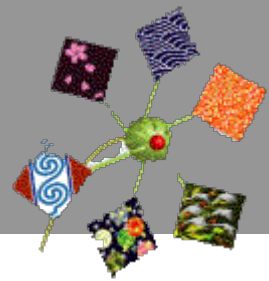
photon

$$R_{pgf} \left\langle \frac{\hat{a}_{pgf}}{D} \right\rangle$$

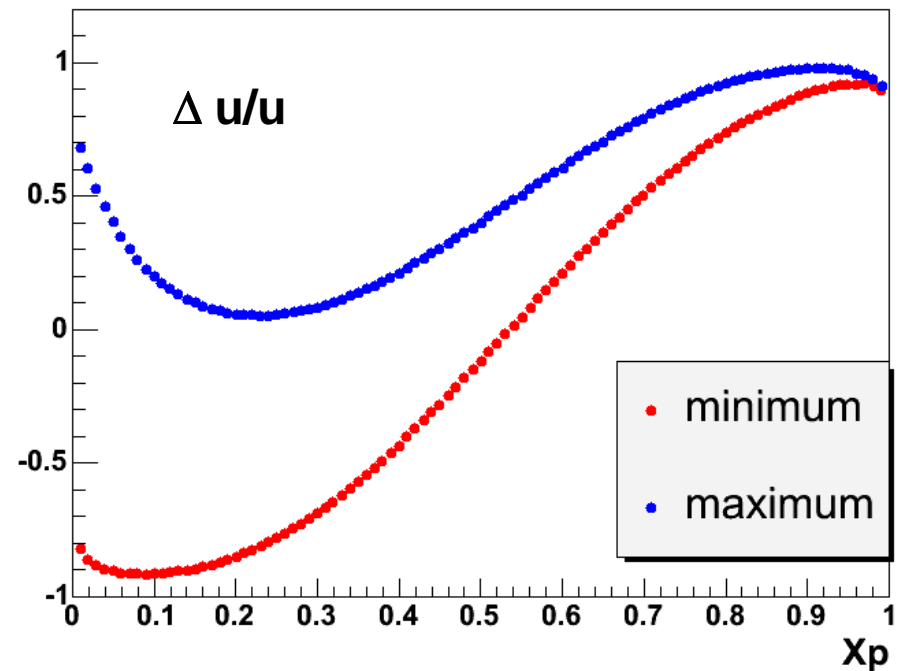


- systematic error:
  - determined using 15 independent MC simulations
  - exploring the parameter space
    - in  $k_T$  of nucleon and photon
    - fragmentation functions
    - parton shower on/off,
    - renormalisation scale

# Resolved photons

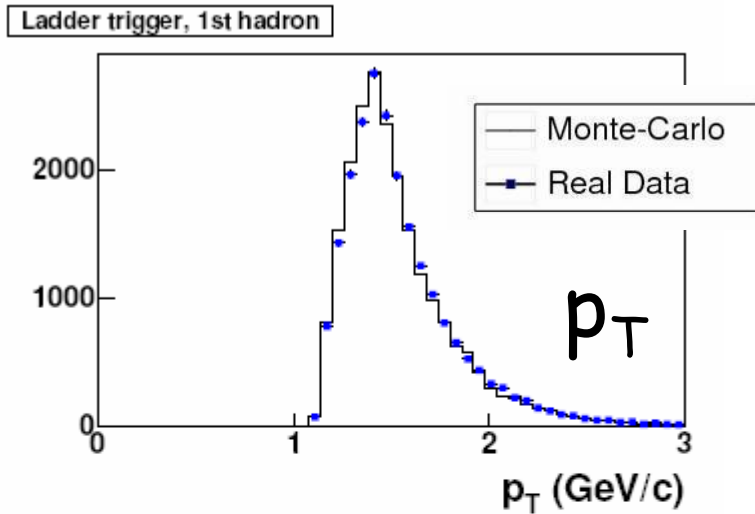
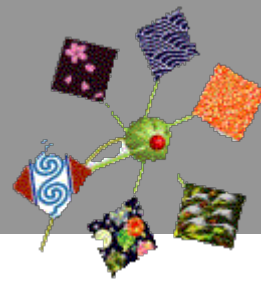


- More than 50%, however assuming a min and max scenario, shows little difference.
- Probing photon at large  $x$ , where photon PDF rather well determined

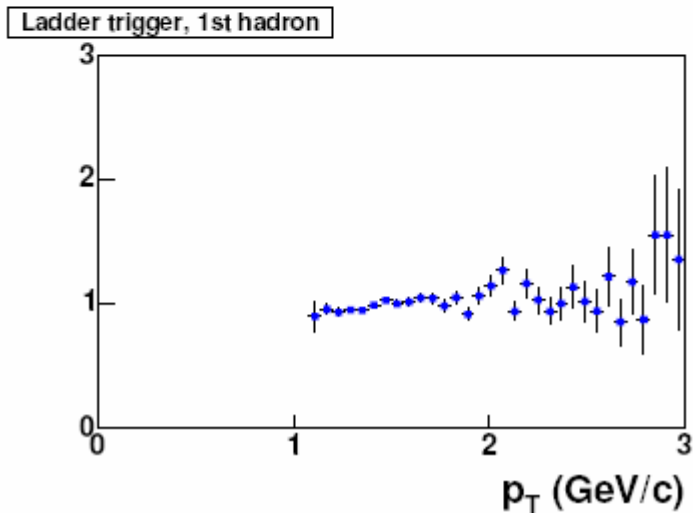


Glück, Reya, Sieg

# Data versus MC



- excellent to good agreement for all kinematics variables





# Gluon polarisation



high-pT pairs;  $Q^2 > 1 \text{ GeV}^2$ :

$$\frac{\Delta G}{G} = 0.06 \pm 0.31(\text{stat.}) \pm 0.06(\text{syst.}) \quad \langle x_g \rangle = 0.13 \quad 2002\text{--}2003$$

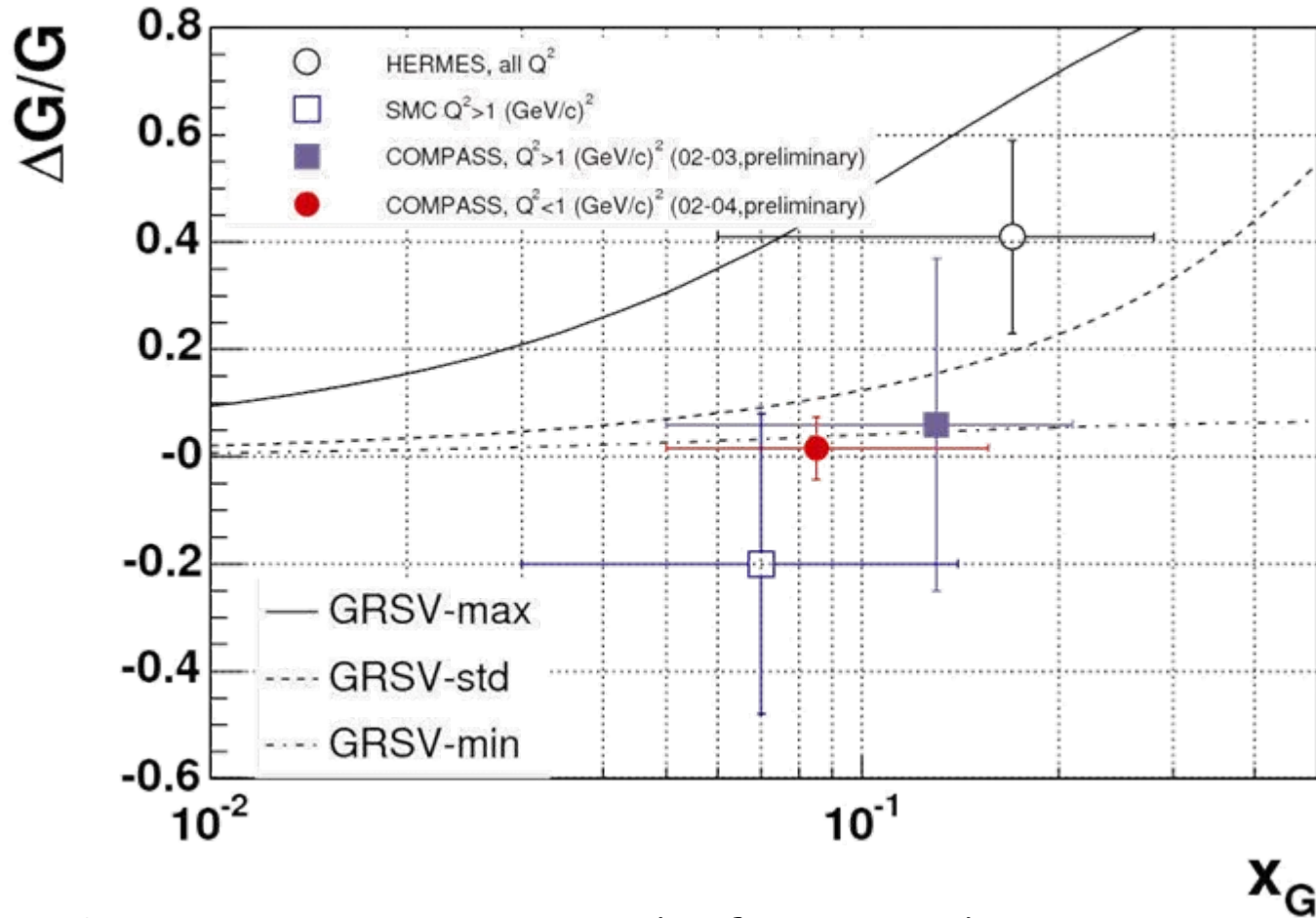
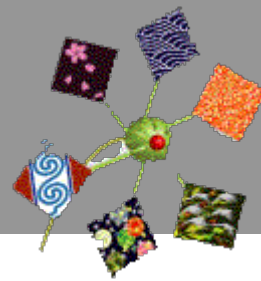
high-pT pairs;  $Q^2 < 1 \text{ GeV}^2$ :

$$\frac{\Delta G}{G} = 0.016 \pm 0.058(\text{stat.}) \pm 0.055(\text{syst.}) \quad 2002\text{--}2004$$
$$\langle x_g \rangle = 0.085 \quad \langle \mu^2 \rangle = 3 \text{ GeV}^2$$

Open charm:

$$\frac{\Delta G}{G} = -0.57 \pm 0.41 \pm 0.058(\text{stat.})$$
$$\langle x_g \rangle = 0.15 \quad \langle \mu^2 \rangle = 13 \text{ GeV}^2$$

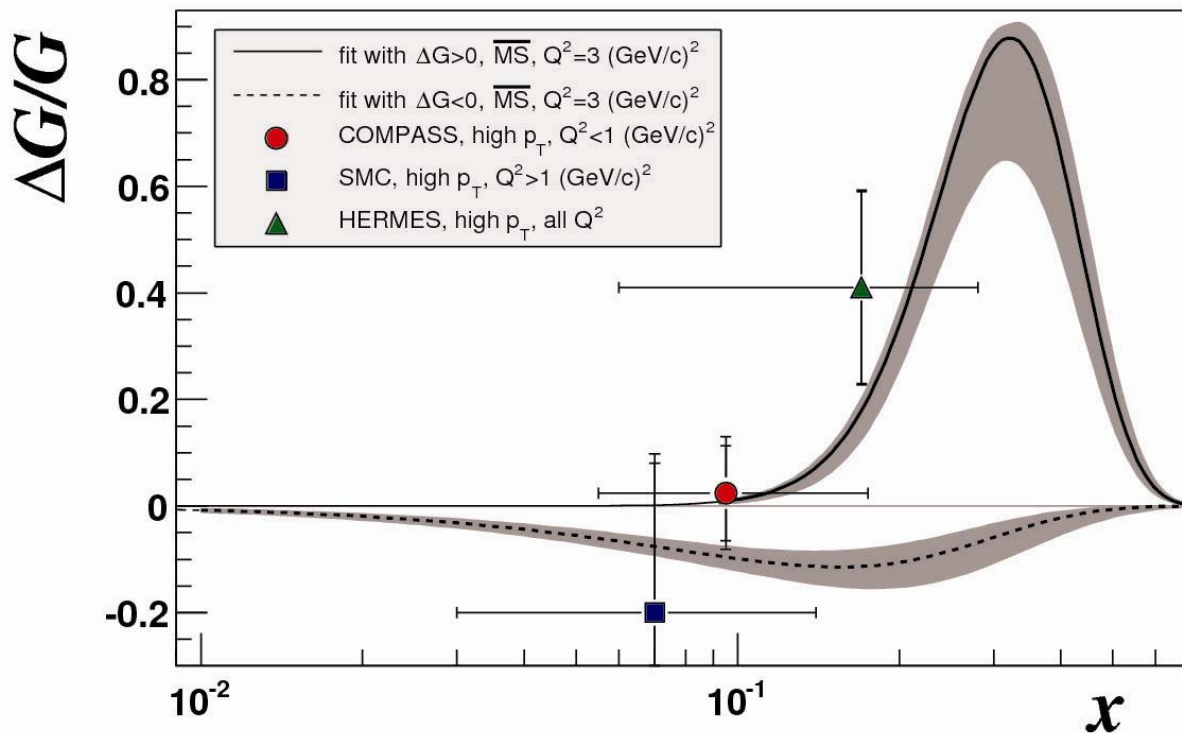
# $\Delta G/G$ from high- $p_T$ pairs



- GRSV-max strongly disfavoured



# COMPASS QCD fit



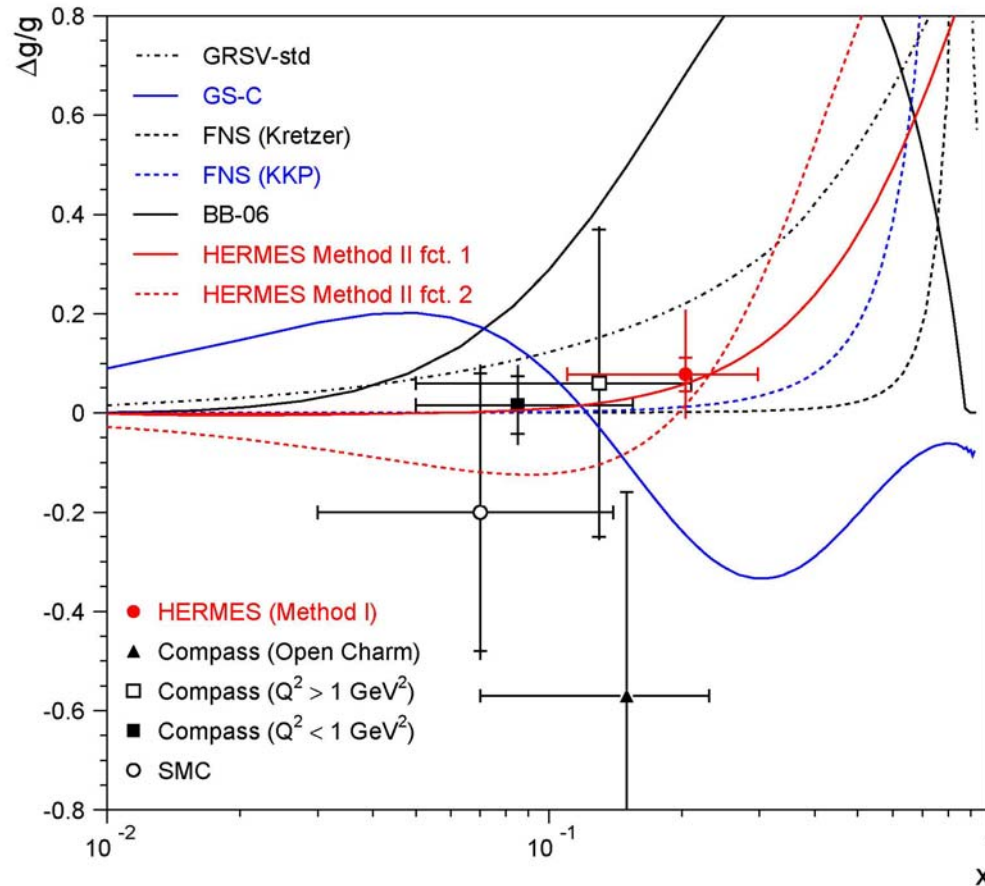
**Note:**  
New Hermes single  
hadron analysis  
analysis to be  
presented at SPIN  
2006

- Note NLO fits, LO data

# New Hermes analysis



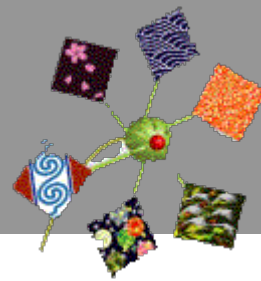
## Single inclusive hadrons



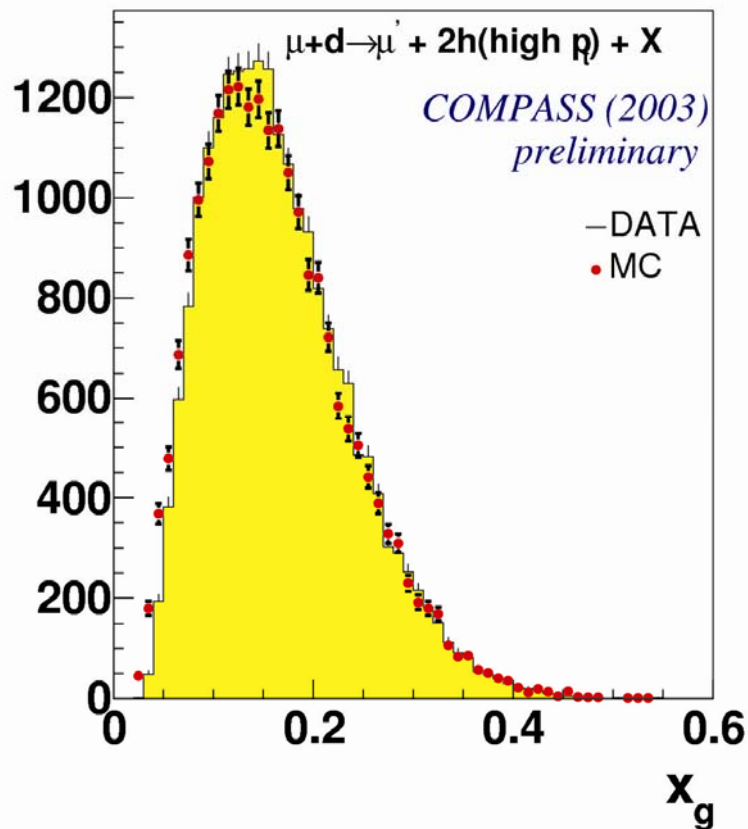
P. Liebing, 2A, Tue



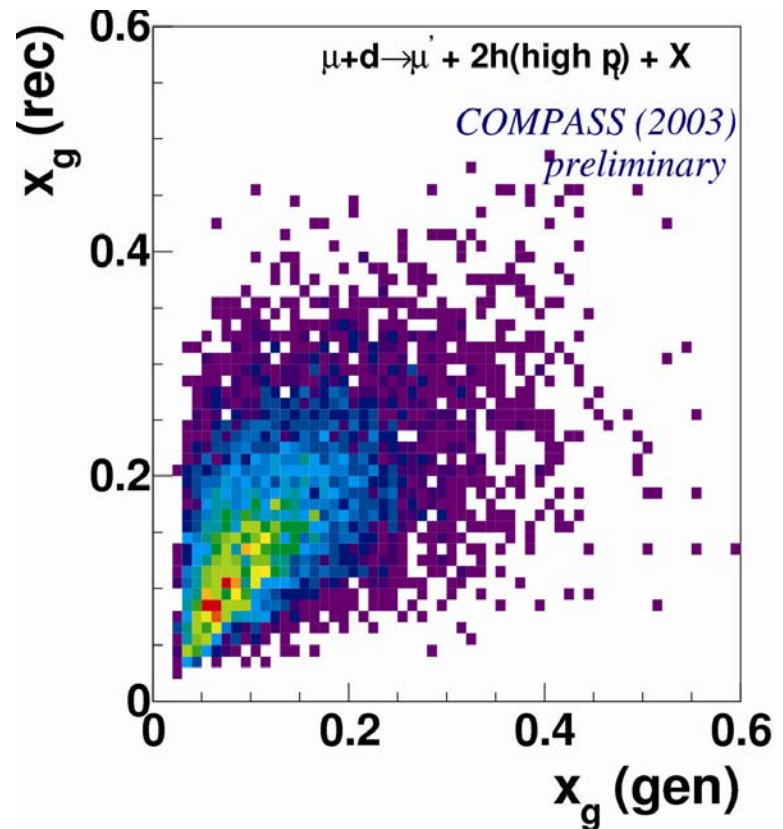
# Can we learn more about $x$ ?



here Lepto and  $Q^2 > 1$

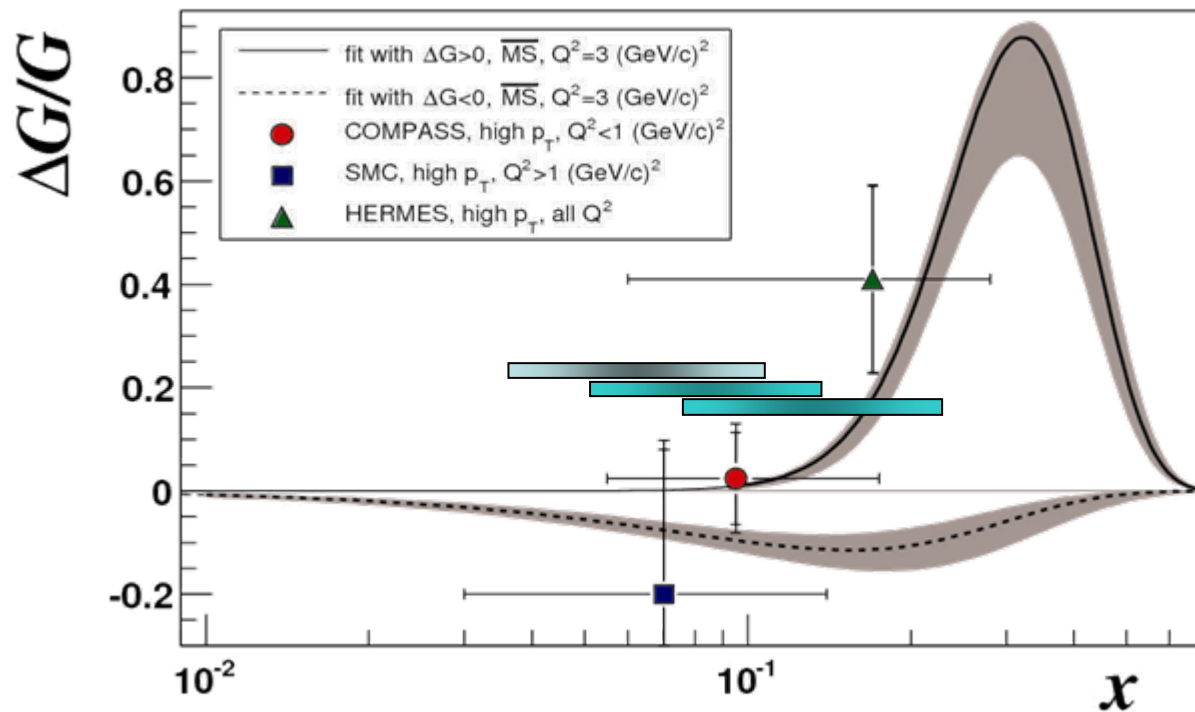


All processes



PGF events (MC)

# Splitting in $x_g$ bins?



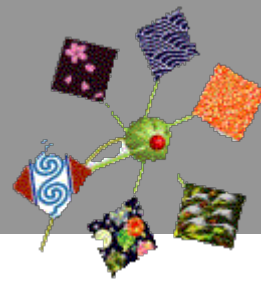
Compass

- Splitting of high- $p_T$ ,  $Q^2 < 1$  data in 3  $x_g$  bins under study
- Optimizing correlation of rec. and 'true'  $x_g$  (NN)
- More significant with 2006 data



- pp at RHIC
- looking forward to many talks in 2a Tue

# pp: NLO Calculations



In much better shape:

Reaction	Dom. partonic process	probes	LO Feynman diagram
$\vec{p}\vec{p} \rightarrow \pi + X$ [61, 62]	$\vec{g}\vec{g} \rightarrow gg$ $\vec{q}\vec{g} \rightarrow qg$	$\Delta g$	
$\vec{p}\vec{p} \rightarrow \text{jet}(s) + X$ [71, 72]	$\vec{g}\vec{g} \rightarrow gg$ $\vec{q}\vec{g} \rightarrow qg$	$\Delta g$	(as above)
$\vec{p}\vec{p} \rightarrow \gamma + X$ $\vec{p}\vec{p} \rightarrow \gamma + \text{jet} + X$ $\vec{p}\vec{p} \rightarrow \gamma\gamma + X$ [67, 73, 74, 75, 76]	$\vec{q}\vec{g} \rightarrow \gamma q$ $\vec{q}\vec{g} \rightarrow \gamma q$ $\vec{q}\vec{q} \rightarrow \gamma\gamma$	$\Delta g$ $\Delta g$ $\Delta q, \Delta \bar{q}$	
$\vec{p}\vec{p} \rightarrow DX, BX$ [77]	$\vec{g}\vec{g} \rightarrow c\bar{c}, b\bar{b}$	$\Delta g$	

Jäger, Schäfer, Stratmann,  
Vogelsang; de Florian

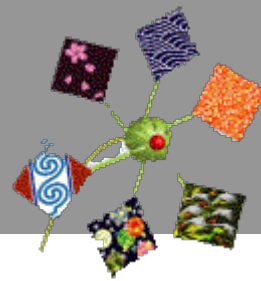
Jäger, Stratmann, Vogelsang,  
Signer et al.

Gordon, Vogelsang;  
Contogouris et al.;  
Gordon, Coriano

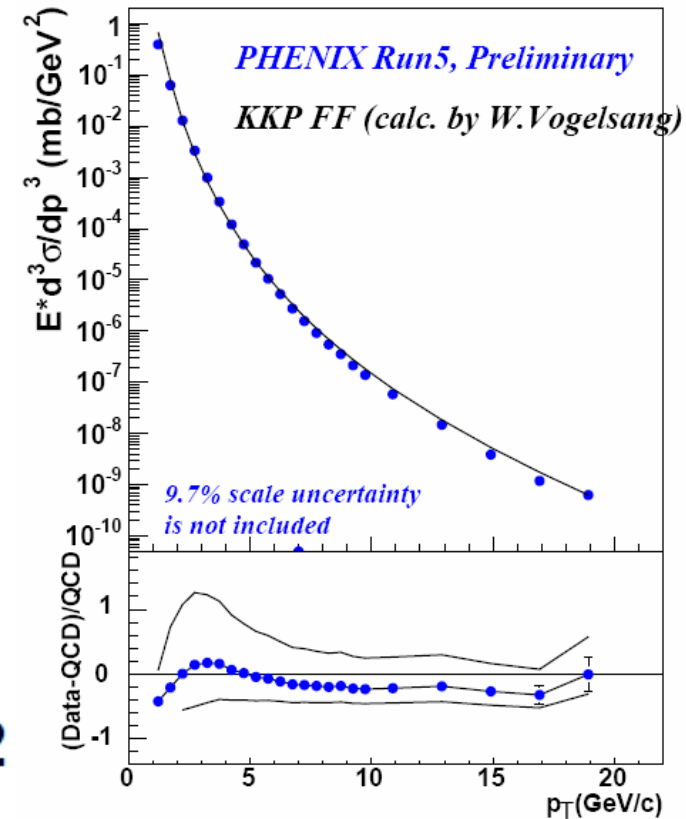
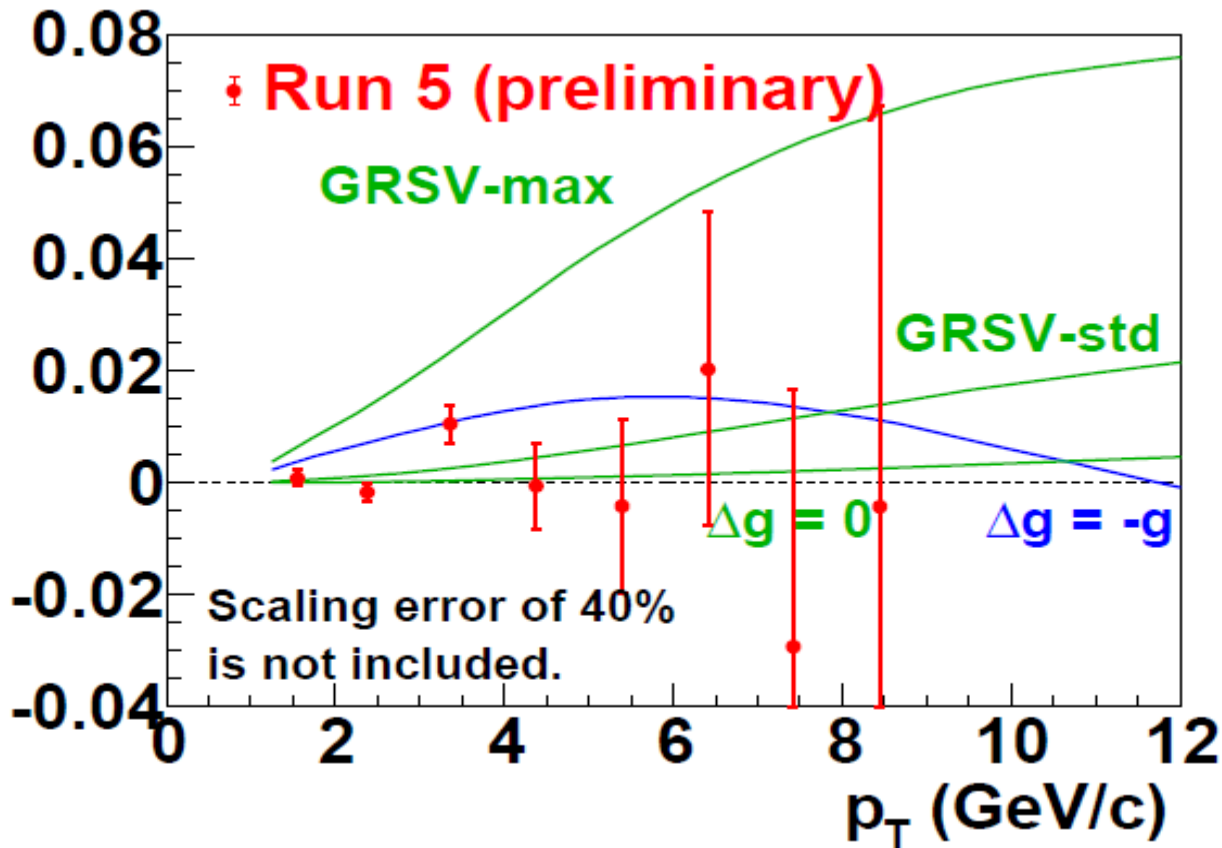
Bojak, Stratmann

Summary by Stratmann, DIS2006

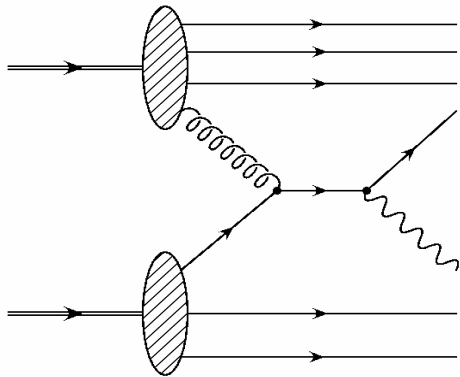
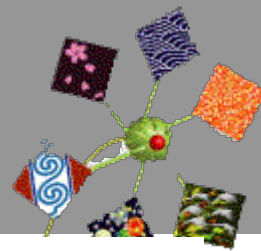
# $\pi^0$ production at RHIC



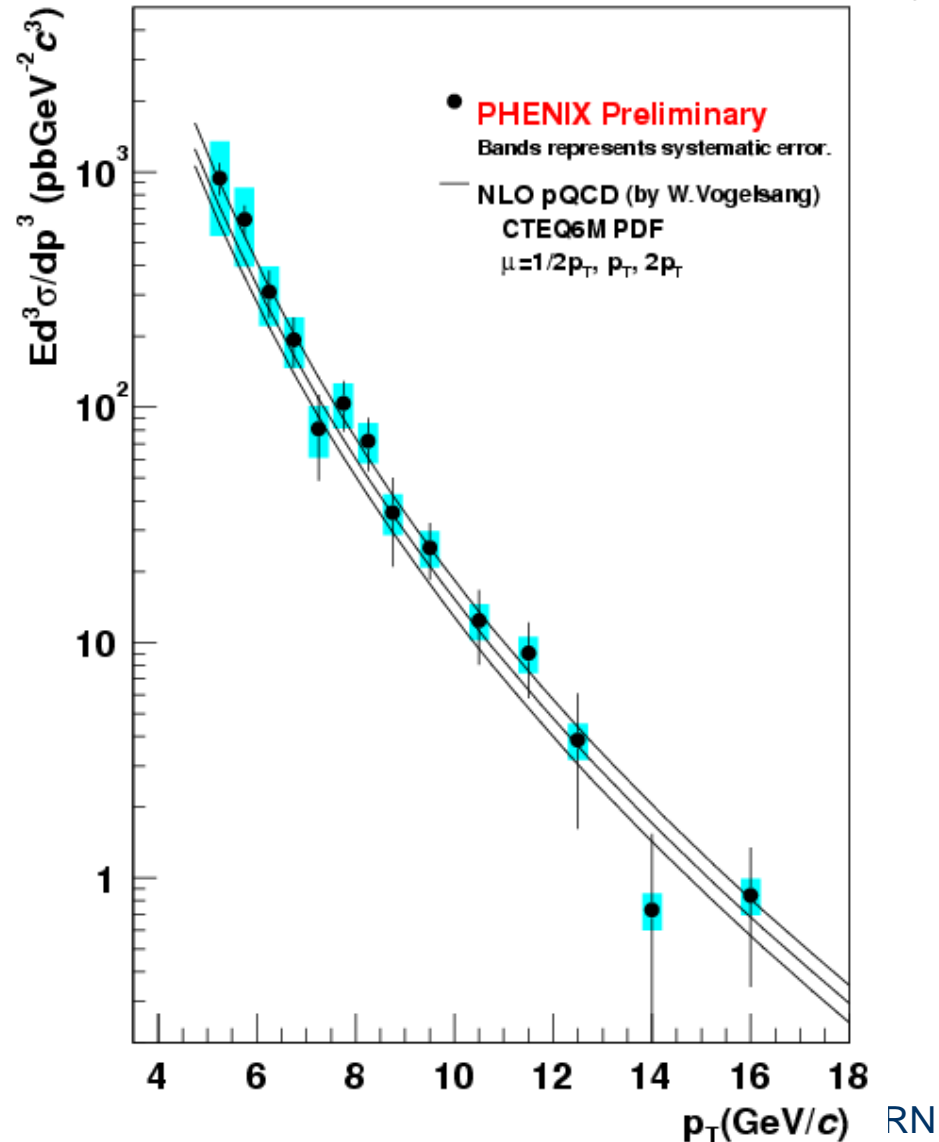
- Phenix



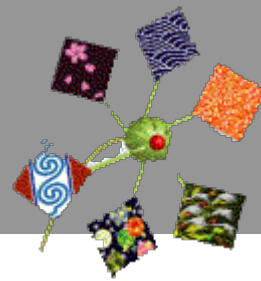
# Direct photons



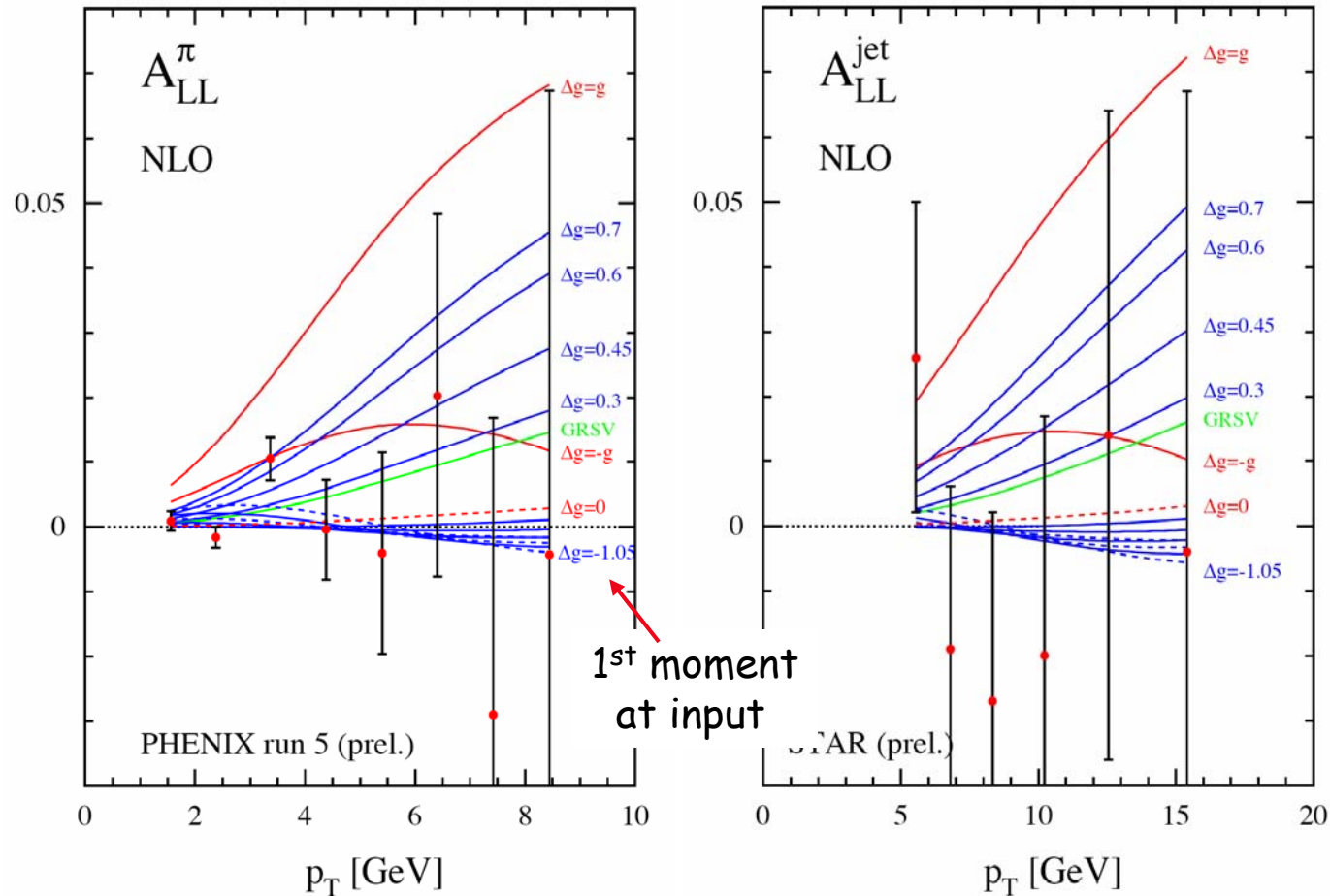
- good agreement of calc. and data at collider energies



# Towards a global analysis



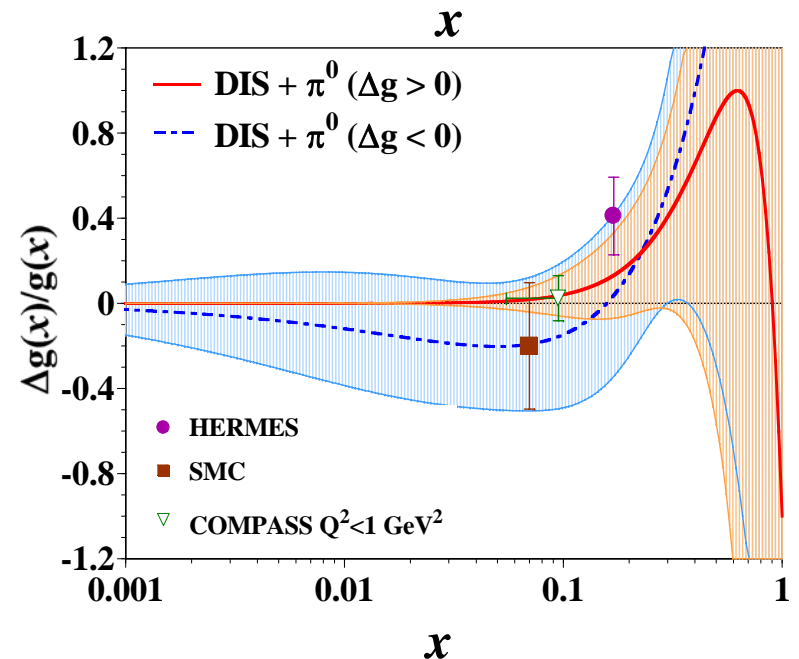
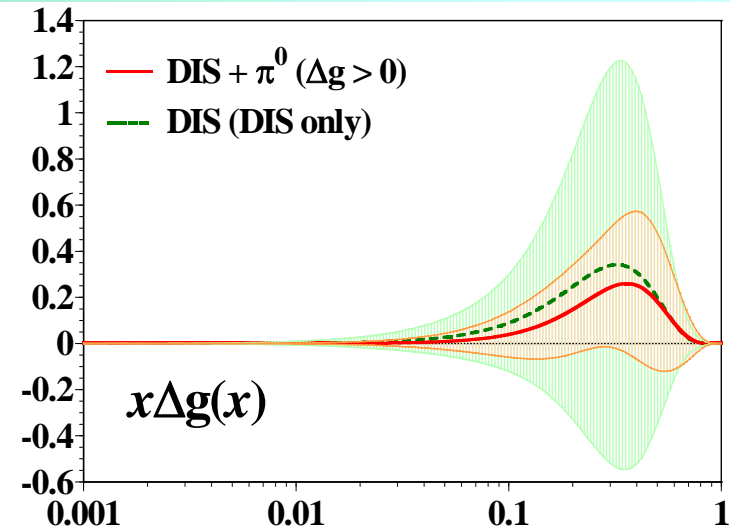
W. Vogelsang, M. Stratmann (DIS2006, work in progress)





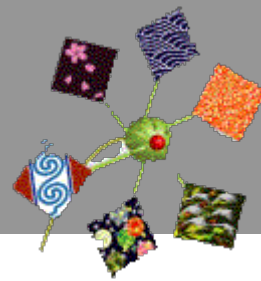
# $\Delta g$ from $\pi^0$ production (RUN05)

- **1<sup>st</sup> moment  $\Delta g$** 
  - $0.31 \pm 0.32$  (DIS+ $\pi^0$ )
  - $0.47 \pm 1.08$  (DIS only)
- **Significant reduction of the  $\Delta g$  uncertainty**
- **Sign problem**
  - **gg process dominates**
    - $\Delta\sigma \propto [\Delta g(x)]^2$
    - **Positive or negative  $\Delta g$ ?**
    - $\chi^2_{\pi^0}$ : 11.18( $\Delta g > 0$ ) vs. 11.05 ( $\Delta g < 0$ )
- **Consistent results** (8 data points)
  - **1<sup>st</sup> moment ( $0.1 < x_{Bj} < 1$ )**
    - $\Delta g > 0$ :  $0.30 \pm 0.30$
    - $\Delta g < 0$ :  $0.32 \pm 0.42$
  - **DIS +  $\pi^0$  data covered**
  - **Large-x is positive**

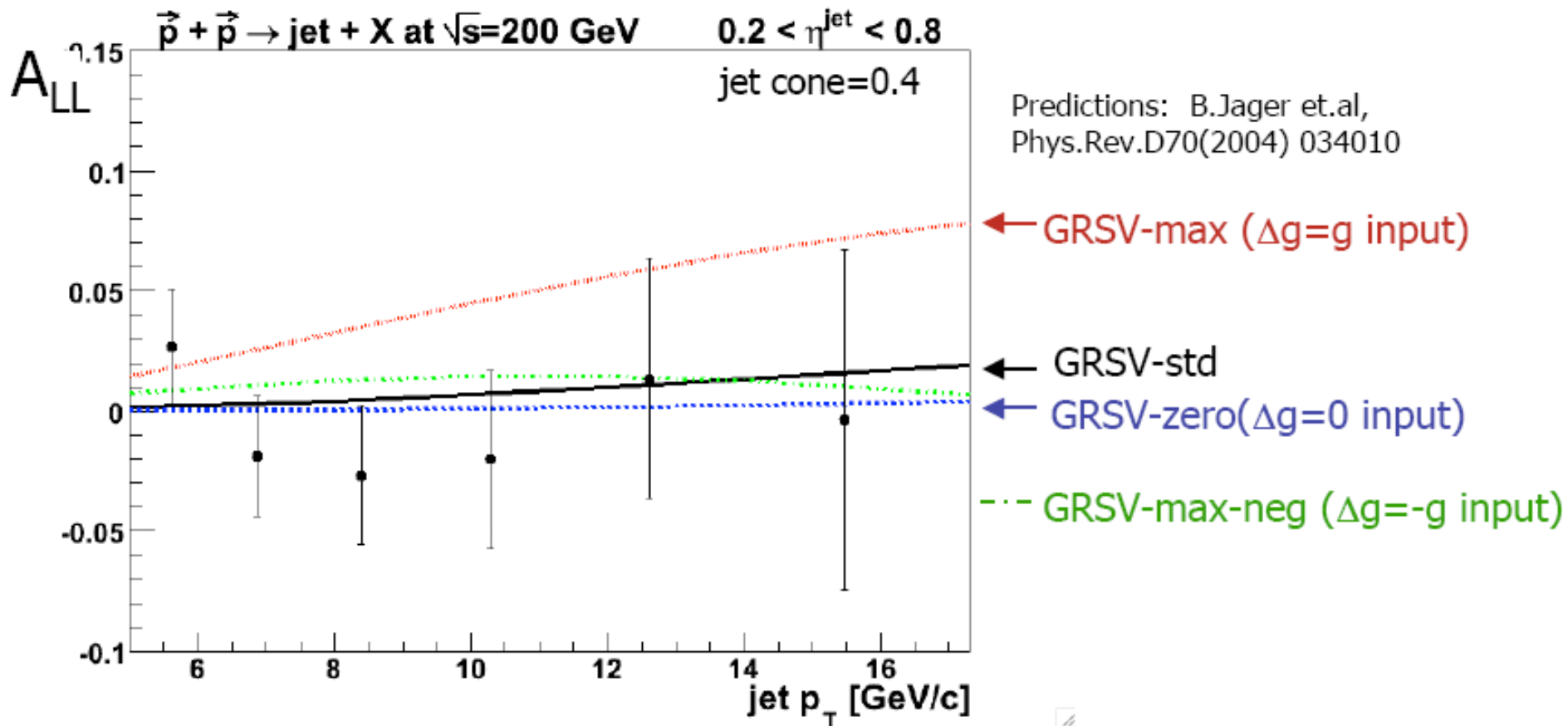




# Inclusive jets at STAR



from Kiryluk, DIS2006



# Summary



- finally data on  $\Delta G$  are coming in!
- all results indicate  $\Delta G$  small compared to some anomaly inspired models
- sign still undefined,  $\Delta G$  still could carry most of the nucleon's spin
- need data on x-dependence to pin down the shape
- need to include COMPASS and HERMES data in starting global analyses (NLO calculations)
- need abs cross sections from COMPASS and HERMES to prove that LO/NLO is applicable
- looking forward to 500 GeV/c at RHIC
- Great and exciting harvest since Trieste 2004



