Overview of the Gluon Polarization Experiments

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Abstract

The chronology of the gluon polarization study is presented. The results of the completed experiments are discussed and the status of the current experiments is outlined. After discovering just 20 years ago the “spin puzzle” phenomena we come to conclusion that this problem is not yet solved - it appears that the gluon contribution to the nucleon spin is small or zero. Only the direct determination of gluon polarization and/or future experiments aiming to reveal the orbital momentum contribution to the nucleon spin and the improved theoretical analyses may bring us closer to the solution of this key problem in spin physics.

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1. **Introduction**
2. **DIS and Δg**

- 1988 -EMC CERN, DIS, "Spin puzzle", ΔG large?
- 2000-HERMES, ΔG large?
- 2004-SMC, ΔG small?
- 2006-HERMES, ΔG small?
- 2006-COMPASS, ΔG small ?

3. **Probing ΔG in pp collisions**

- 1991-E704 FNAL,
  $A_{LL}(\pi^0) \rightarrow \Delta G$ small or zero!
- 1994-E704 FNAL,
  ΔG small or zero!
- 2006-RHIC, ΔG small?

4. **Conclusions**

$$\vec{p}\vec{p} \rightarrow \pi^0 X, \vec{\vec{p}}\vec{p} \rightarrow \pi^0 X.$$

$$\vec{p}\vec{p} \rightarrow [(n\gamma)_L + (m\gamma)_R] + X.$$

1. Introduction

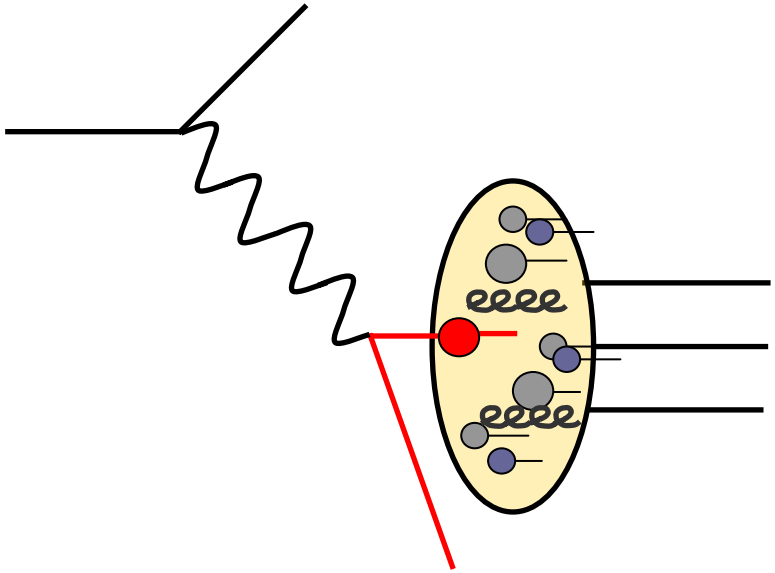
The study of the nucleon spin structure function started in 1978– by SLAC experiment E80 through the deep inelastic polarized electron scattering (DIS) on the polarized proton target [M.J. Alguard et al., Phys. Rev. Lett., 41 (1978) 70]. The search of the gluon polarization was stimulated by the EMC result published in 1988 (J. Ashman et al., Phys. Lett. B 206 (1988) 364). This was the discovery of "spin crisis" problem. **In spite of the tremendous efforts undertaken by physicists following 20 years this problem is not yet solved. Why?**

In 1991 for the first time the polarized proton and antiproton beams of 200 GeV/c + polarized target were used by FNAL E581/E704 Collaboration to approach the gluon polarization problem. Two double spin asymmetries $A_{LL}(\pi^0)$ and A_{LL} (multigamma pair) have been measured.

The conclusion: gluon polarization is small or zero. The recent results from DIS and RHIC are consistent with such conclusion.

2. DIS and Δg

DIS



Comments:

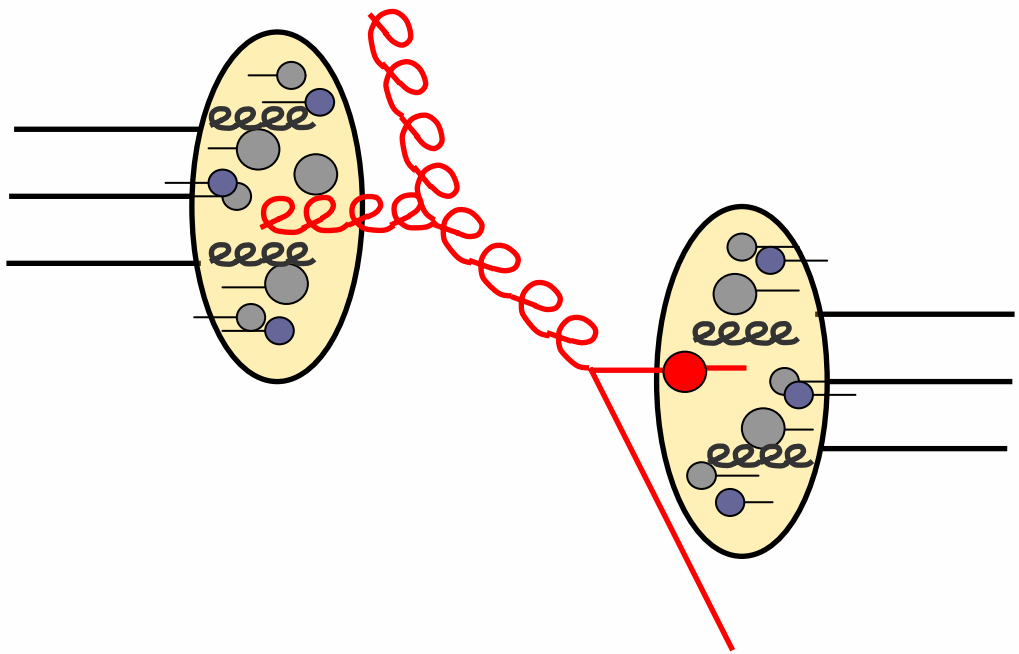
Advantages:

1. Kinematics well defined
2. QED

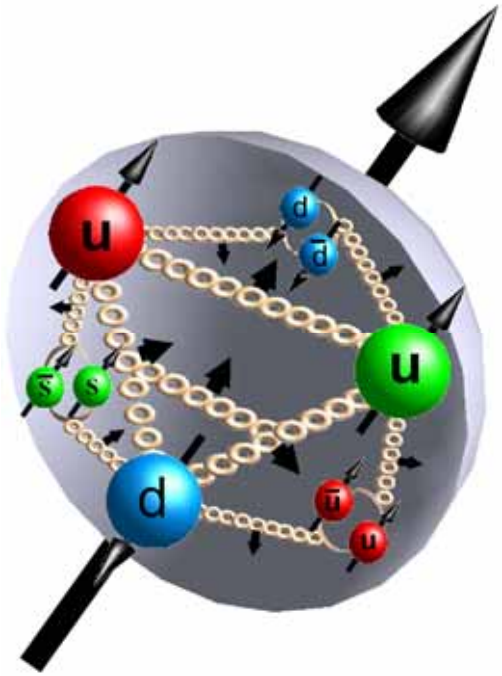
Disadvantages:

1. σ is small
2. No γg interactions, only γq
3. FT experiments (x,Q^2 intervals are small)

pp



- **What else carries the proton spin ? Central question for the field.**



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

Quark spin
≈ 0.1

Gluon spin
contrib.

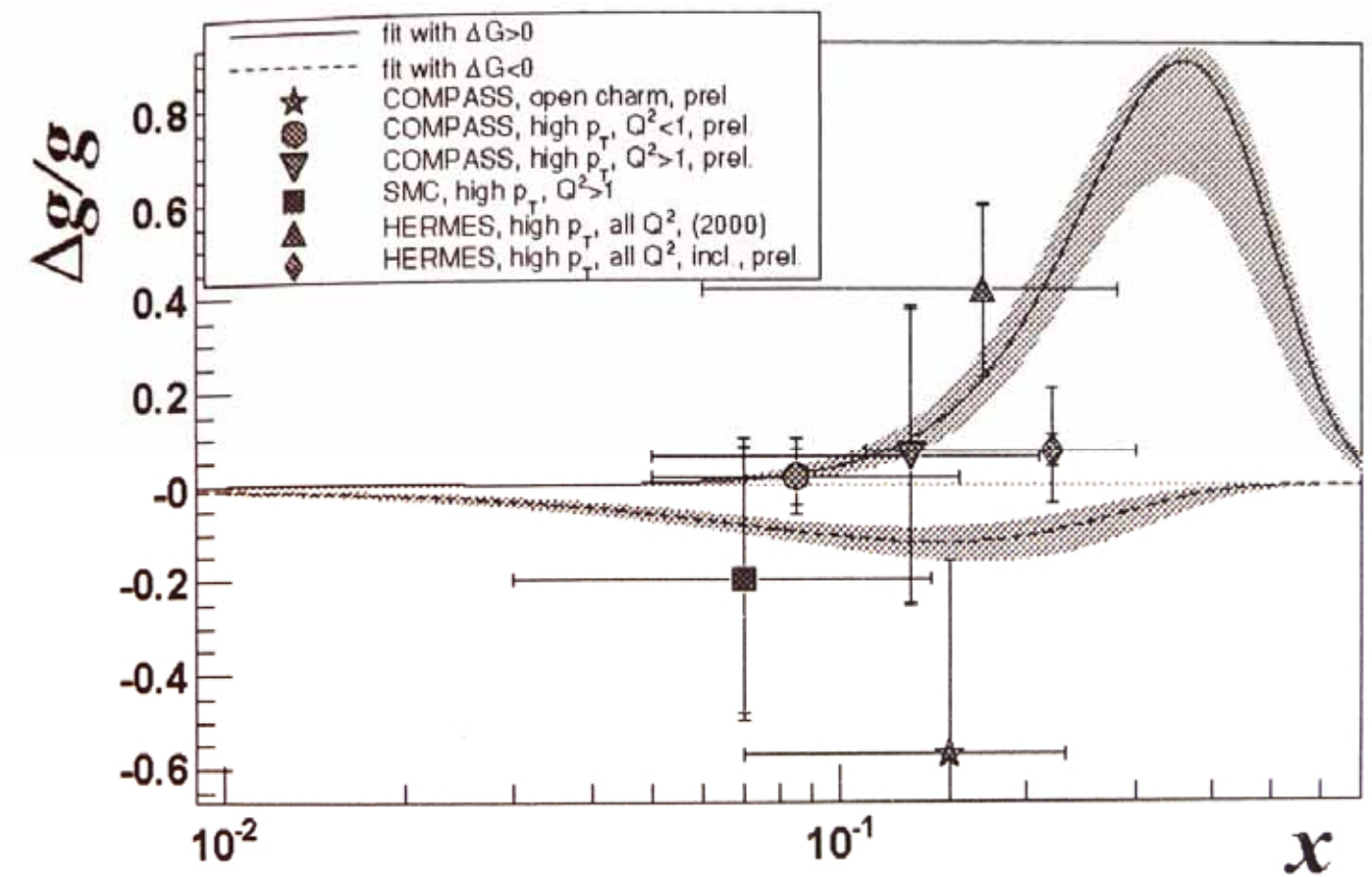
Orbital ang.
momenta

"The QCD analysis of the world data on structure functions $g_1^{p,d,n}$ for proton, deuteron and neutron",
I.A. Savin on the behalf of the COMPASS Collaboration; in Proc. 17-th Intern. Spin Physics Symposium, Kyoto, Japan, 2-7 October 2006, p.399.

- The first moments of the polarized singlet quark, gluon and strange quark distributions found from fits at $Q^2=3$ GeV^2, are equal to: $\eta_\Sigma = 0.30 \pm 0.01(stat) \pm 0.03(syst)$, $|\eta_G| = 0.2\text{-}0.3$, $(\Delta s + \Delta\bar{s}) = -0.10 \pm 0.01(stat) \pm 0.01(stat)$, respectively. $(0.004<x<0.75)$

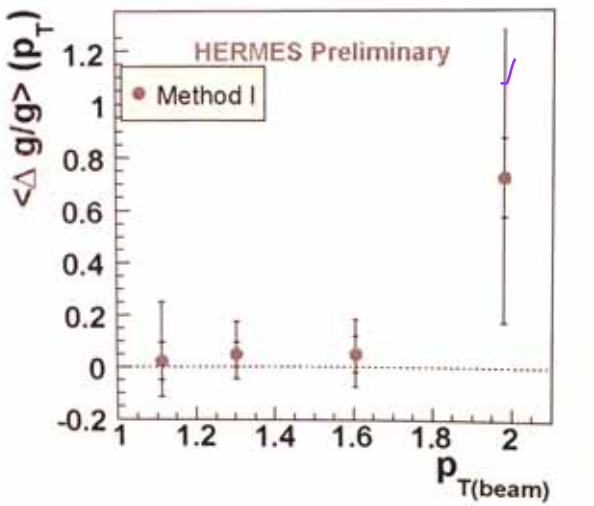
- In conclusion, the new QCD NLO fits on the world data on g_1 have produced consistent results and yielded the two solutions for the PDFs parameters with $\Delta G(x)>0$ and $\Delta G(x)<0$, which equally well describe the present g_1 data. Direct measurements of the gluon polarization could help to choose between them.

I.A. Savin's report (continued)

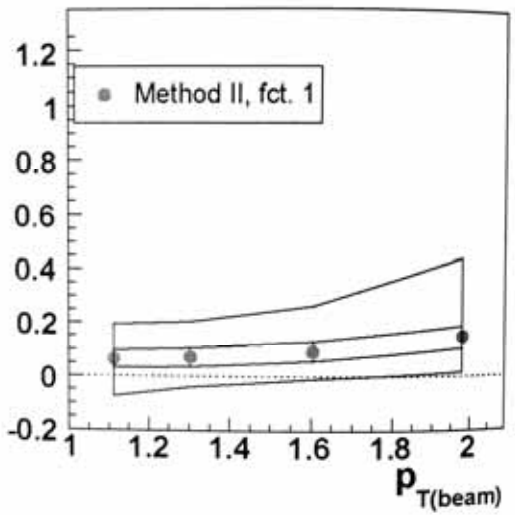


Extraction of Δg/g from Hermes data on inclusive charged hadrons",

P. Liebing, on the behalf of the HERMES Collaboration; in Proc. 17-th Intern. Spin Physics Symposium, Kyoto, Japan, 2-7 October 2006, p.331.

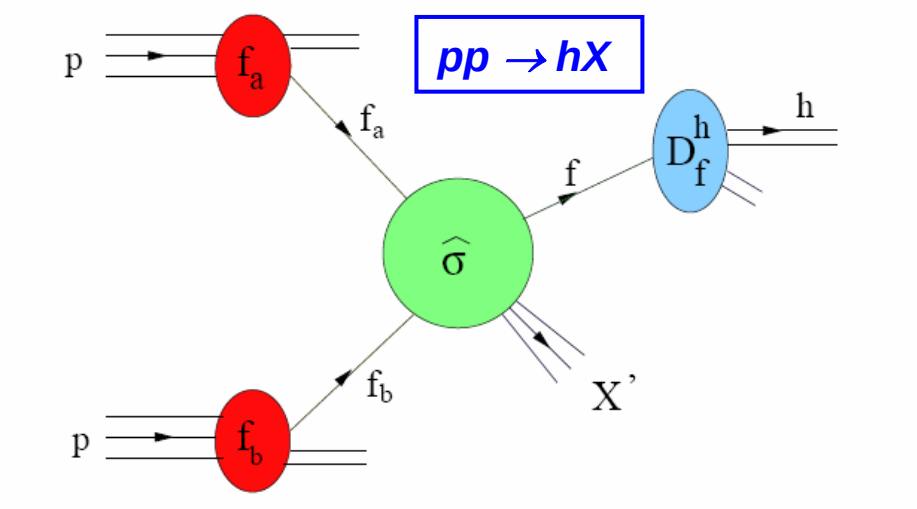


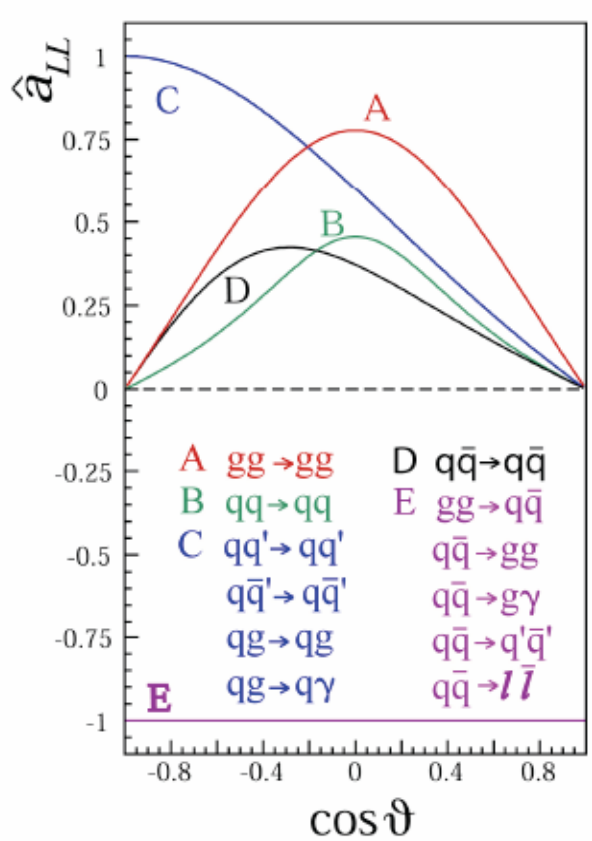
Method I: Δg(x)/g(x) ~ const



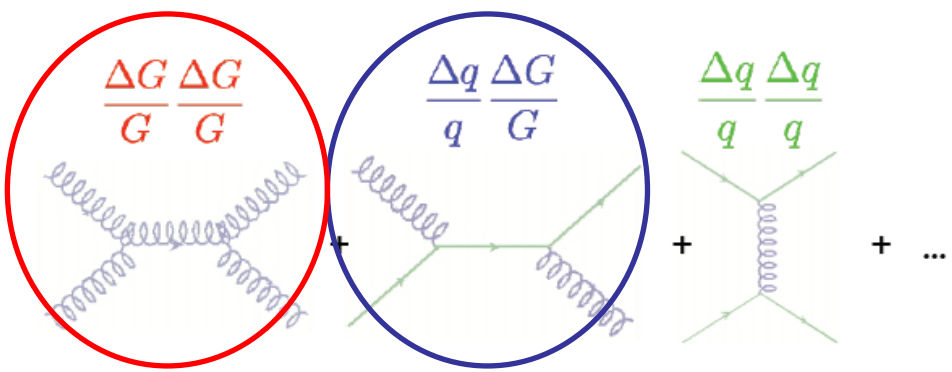
Method II: Δg(x)/g(x) has functional form. Parameters are found by fitting to measured asymmetry at each p_T bin. Method II allows to find **Δg/g=0,071±0,034** (stat)±**0,010**(sys-exp)$_{-0,105}^{+0,127}$(sys-Models)
At <x>=0,22,<μ²>=1,35GeV² integrated over 1.05<p_T<2.5 GeV

Probing ΔG in pp Collisions





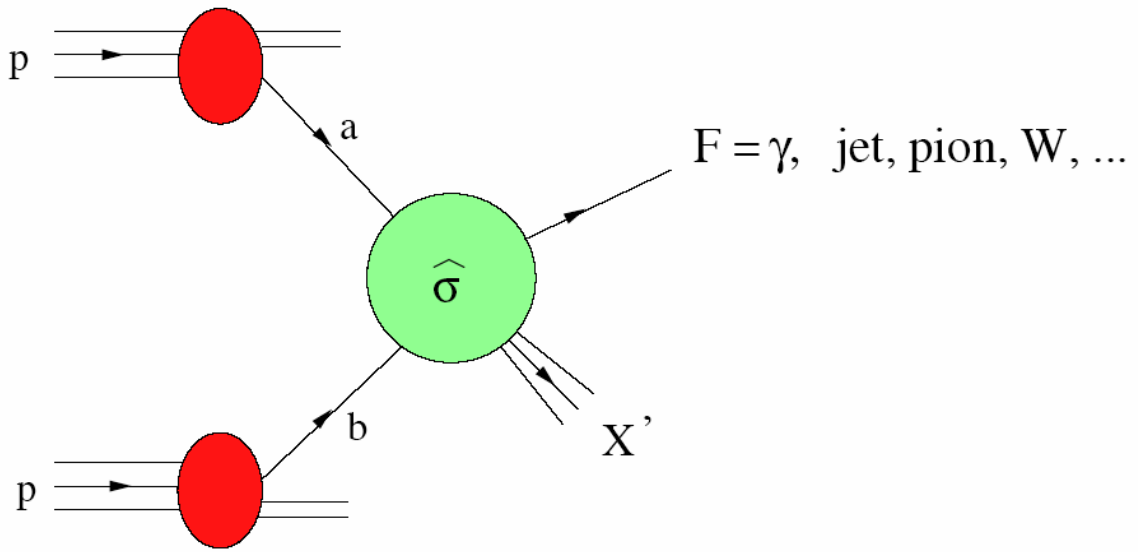
$$A_{LL} = \frac{d\sigma^{++} - d\sigma^{+-}}{d\sigma^{++} + d\sigma^{+-}} = \frac{\sum_{a,b} \Delta f_a \otimes \Delta f_b \otimes d\hat{\sigma}^{f_a f_b \to fX} \cdot \hat{a}_{LL}^{f_a f_b \to fX} \otimes D_f^h}{\sum_{a,b} f_a \otimes f_b \otimes d\hat{\sigma}^{f_a f_b \to fX} \otimes D_f^h}$$



Double longitudinal spin asymmetry A_{LL} is sensitive to ΔG

- perturbative QCD and factorization:

Sterman,Libby; Ellis et al.; Collins,Soper,Sterman



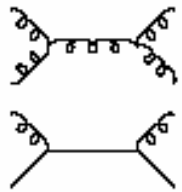
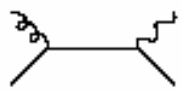
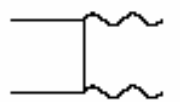
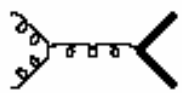
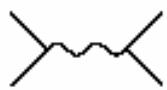
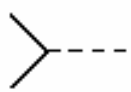
$$\frac{d\sigma}{dp_T d\eta} = \sum_{ab} \int dx_a \int dx_b \, f_a(x_a, p_T) \, f_b(x_b, p_T) \, \frac{d\hat{\sigma}_{ab}}{dp_T d\eta}$$

A_{LL}

universal

parton scatt.
perturbative QCD

Probing the spin structure of the nucleon in polarized pp collisions

Reaction	Dom. partonic process	probes	LO Feynman diagram
$\vec{p}\vec{p} \to \pi + X$	$\vec{g}\vec{g} \to gg$ $\vec{q}\vec{g} \to qg$	Δg	
$\vec{p}\vec{p} \to \text{jet(s)} + X$	$\vec{g}\vec{g} \to gg$ $\vec{q}\vec{g} \to qg$	Δg	(as above)
$\vec{p}\vec{p} \to \gamma + X$ $\vec{p}\vec{p} \to \gamma + \text{jet} + X$	$\vec{q}\vec{g} \to \gamma q$ $\vec{q}\vec{g} \to \gamma q$	Δg Δg	
$\vec{p}\vec{p} \to \gamma\gamma + X$	$\vec{q}\vec{\bar{q}} \to \gamma\gamma$	$\Delta q, \Delta\bar{q}$	
$\vec{p}\vec{p} \to DX, BX$	$\vec{g}\vec{g} \to c\bar{c}, b\bar{b}$	Δg	
$\vec{p}\vec{p} \to \mu^+\mu^- X$ (Drell-Yan)	$\vec{q}\,\vec{\bar{q}} \to \gamma^* \to \mu^+\mu^-$	$\Delta q, \Delta\bar{q}$	
$\vec{p}\vec{p} \to (Z^0, W^\pm)X$ $p\vec{p} \to (Z^0, W^\pm)X$	$\vec{q}\,\vec{\bar{q}} \to Z^0$, $\vec{q}'\vec{\bar{q}} \to W^\pm$ $\vec{q}'\bar{q} \to W^\pm$, $q'\vec{\bar{q}} \to W^\pm$	$\Delta q, \Delta\bar{q}$	

"First results for the two-spin parameter A_{LL} in π^0 production by 200 GeV polarized protons and antiprotons" [FNAL E581/E704 Collaboration, D.L. Adams et al., Phys. Lett. B 261 (1991) 197].

Conclusion:

"We observe good consistency with small or zero values of the spin-weighted gluon distribution, but not with the prediction that assumes very large gluon polarization in longitudinally polarized protons."

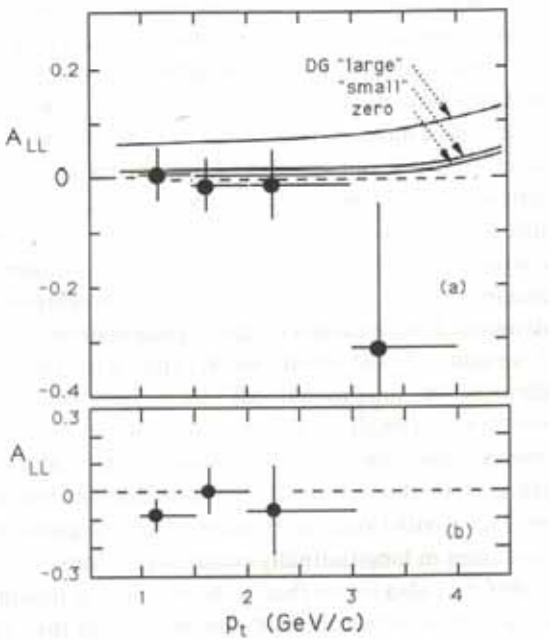


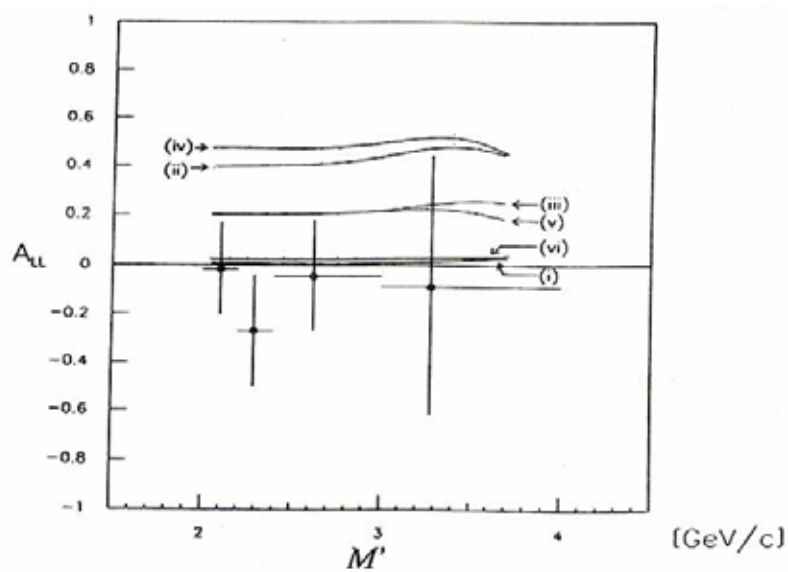
Fig. 2. The two-spin parameter A_{LL} in the reactions (a) $p_\uparrow + p_\uparrow \to \pi^0 + X$ and (b) $\bar{p}_\uparrow + p_\uparrow \to \pi^0 + X$ at 200 GeV, for $-0.1 < x_F < 0.1$. The curves are predictions for different values of the spin-weighted gluon distribution function (see ref. [6]).

$A_{LL}(pp \to \pi^0 X)$

$A_{LL}(\bar{p}p \to \pi^0 X)$

"Measurement of the double-spin asymmetry A_{LL} for inclusive multi-γ pair production with 200 GeV/c polarized proton beam and polarized proton target" [FNAL E581/E704 Collaboration, D.L. Adams et al., Phys. Lett. B 336 (1994) 269].

"The A_{LL} values presented here are the first experimental results which are sensitive to ΔG/G in the proton. Using our results and the LUND Monte Carlo simulation package with the first order partonic asymmetries we conclude that ΔG/G is not so large in the region of 0.05 <x< 0.35."



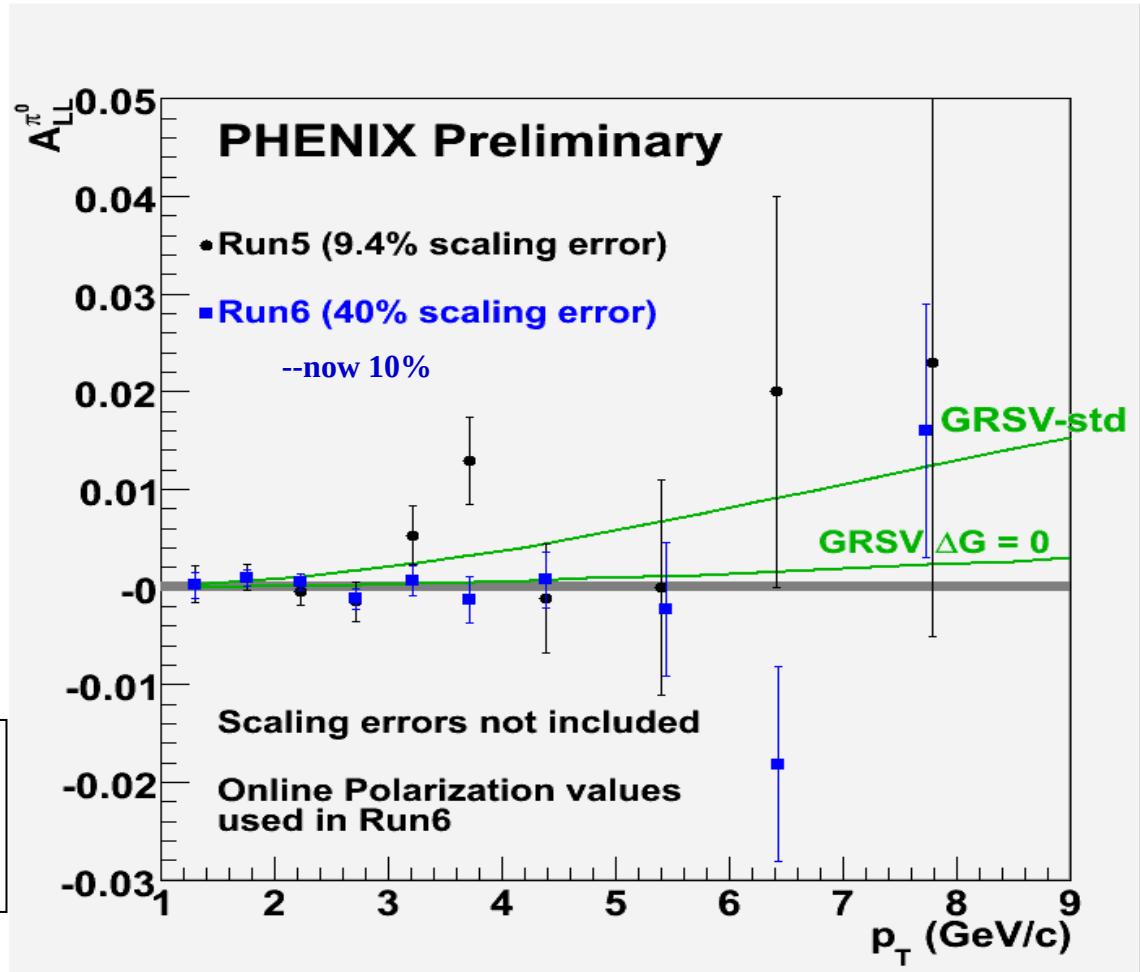
A_{LL} for inclusive multi-γ pair production ($|p_T'| < 1.0$ GeV/c) and several model calculations ((i)–(vi): see Table 2).

Calculate beam spin asymmetry of N(pions) :

$A_{LL} = (N(\pi^0,++) - N(\pi^0,+-))/sum \cdot P^2$

beam spin directions

π^0 A_{LL}



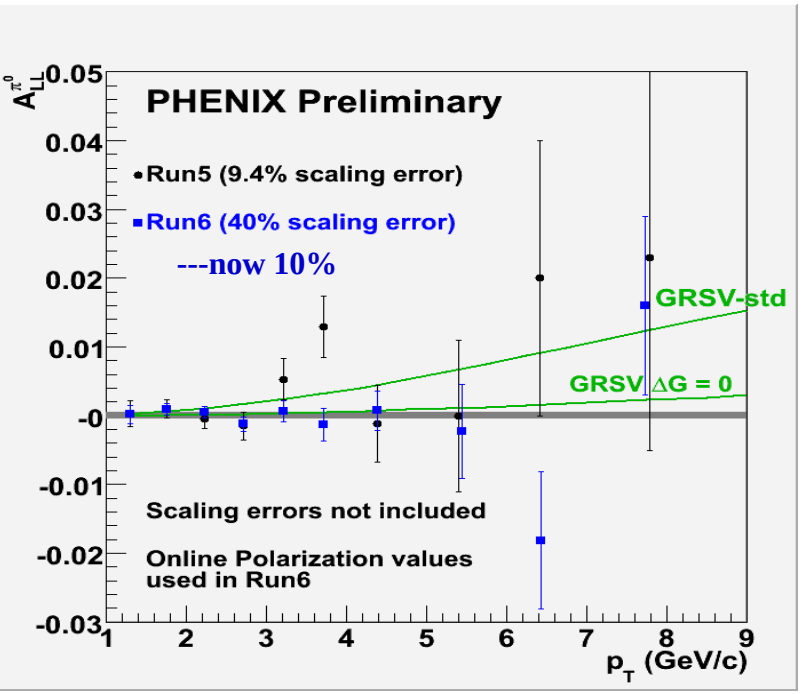
Green:
models of gluon polarization

GRSV model:

"ΔG = 0": $\Delta G(Q^2=1GeV^2)=0.1$

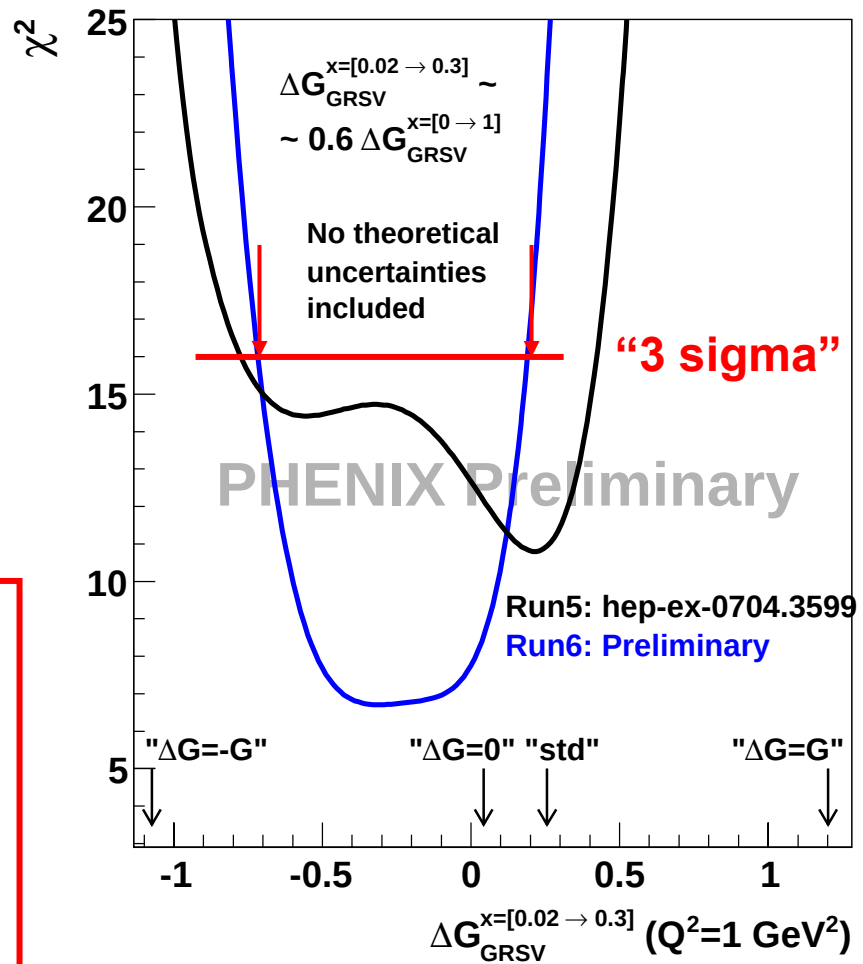
"ΔG = std": $\Delta G(Q^2=1GeV^2)=0.4$

From A_{LL} to ΔG (with GRSV)



⇒

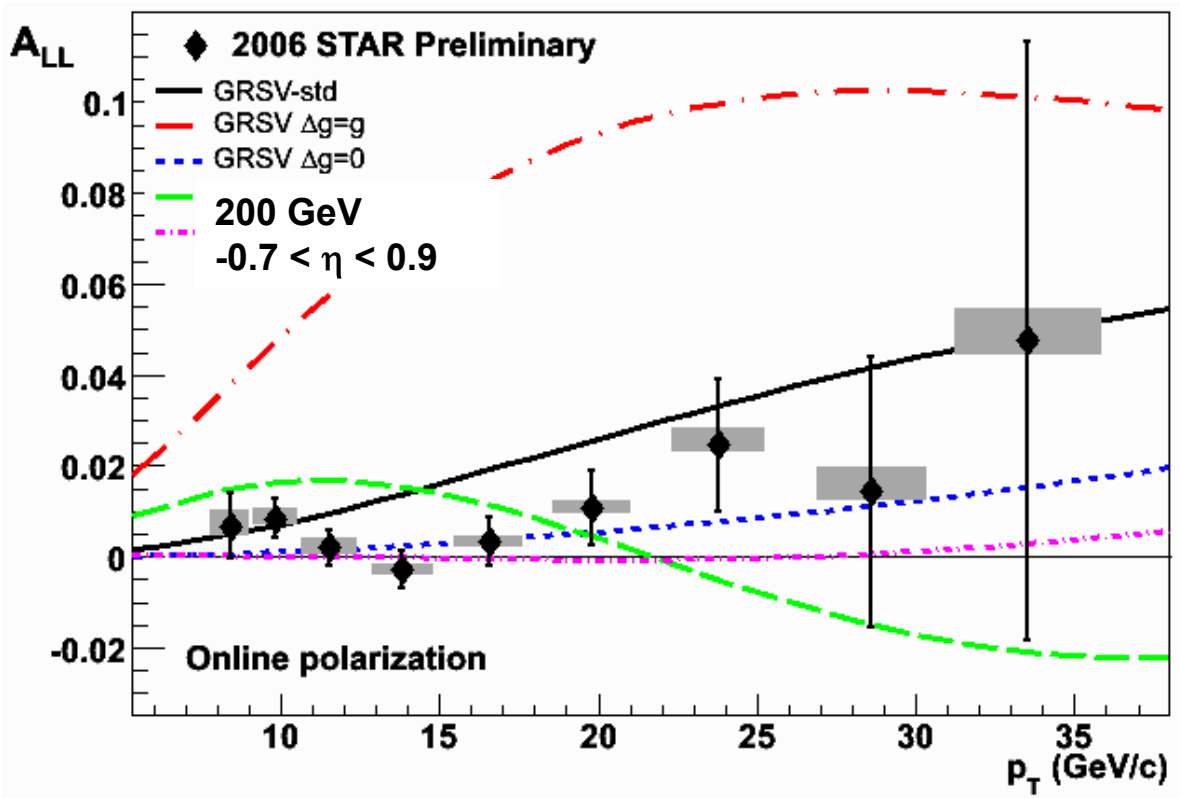
Calc. by W.Vogelsang and M.Stratmann



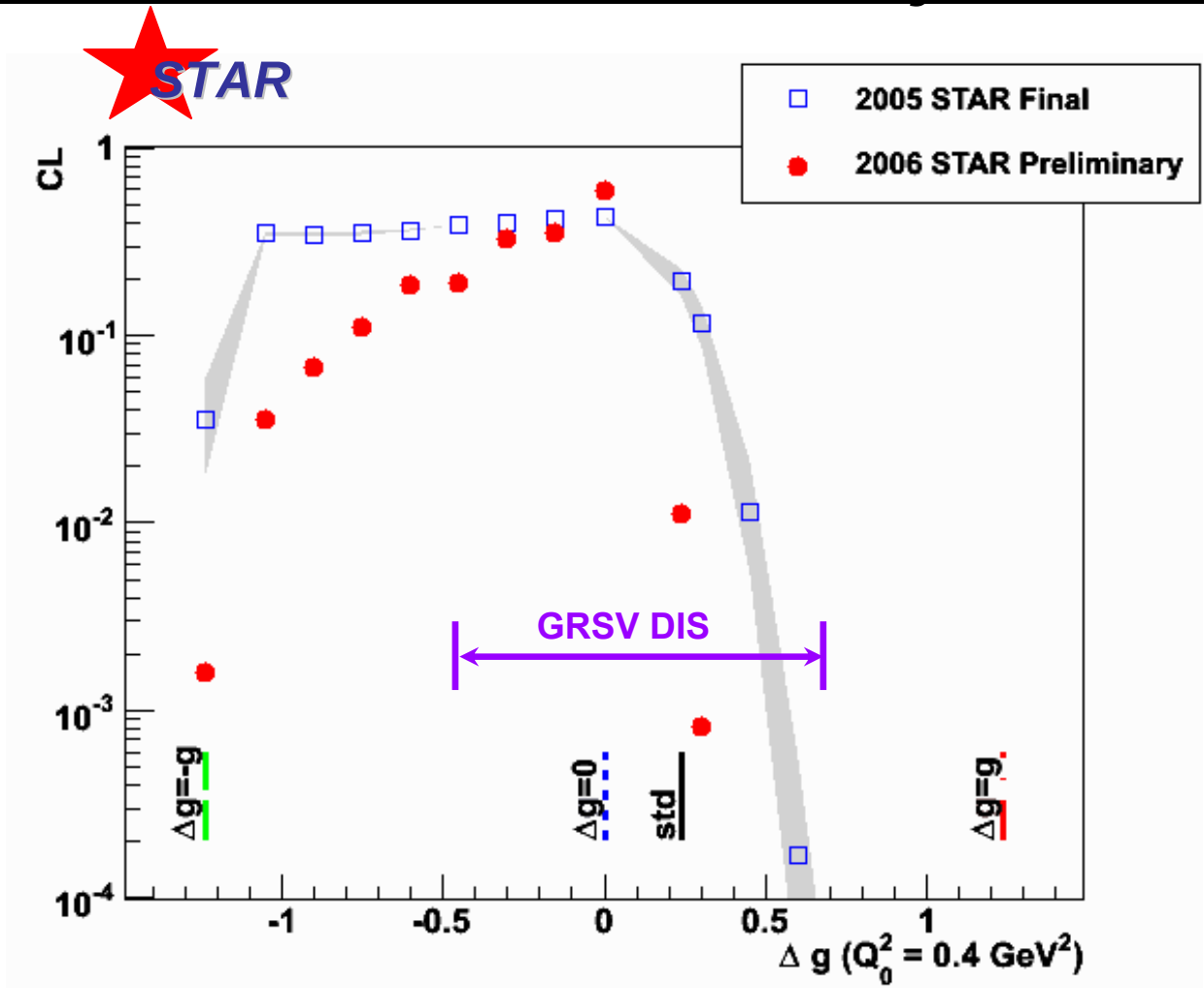
"std" scenario, $\Delta G(Q^2=1GeV^2)=0.4$, is excluded by data on >3 sigma level:
$\chi^2(std)-\chi^2_{min}>9$

- ✓ Only exp. stat. uncertainties are included (the effect of syst. uncertainties is expected to be small in the final results)
- ✓ Theoretical uncertainties are not included

2006 inclusive jets A_{LL}



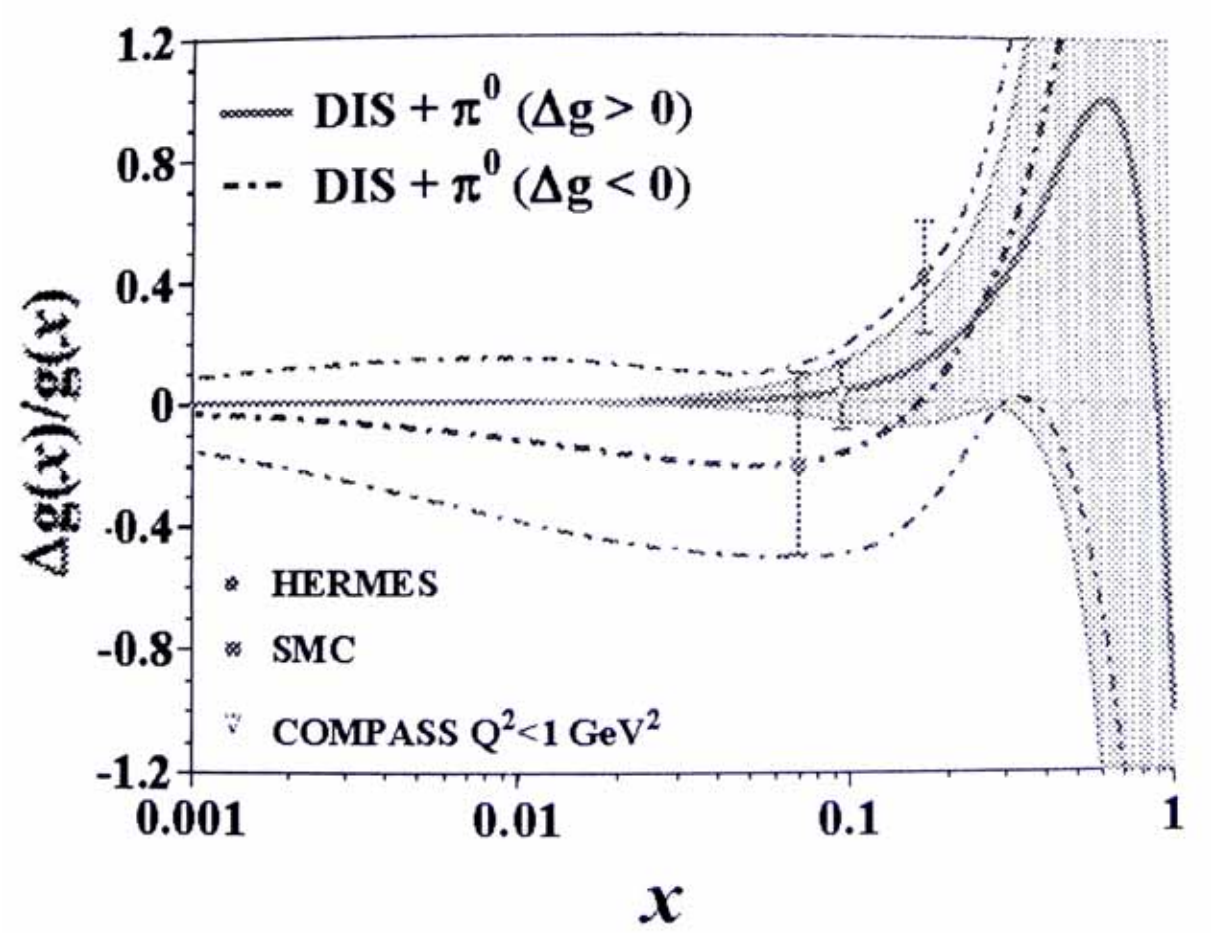
Limits on ΔG from 2006 jet results



- Within the GRSV framework:
  - GRSV-std excluded with 99% CL
  - ΔG < -0.7 excluded with 90% CL

Constraint on $\Delta g(x)$ from π^0 production at RHIC

M. Hirai et al., in Proc. 17-th Intern. Spin Physics Symposium, Kyoto, Japan, 2-7 October 2006, p.412.



M. Hirai's report (continued)

Some of the results:

- "Obtained Δg is 0.47±1.08 for the only DIS data, and 0.31± 0.32 for the DIS + π^0 data. This fact implies that the π^0 data has great impact on the determination of Δg in comparison with the present DIS data" .
- The node at x=0.16 was found for negative solution. The values of Δg is -0.56±2.16 and large uncertainty comes from small x region.
- In the region $0.1<x<1$ $\Delta g = 0.30 \pm 0.32$ (for $\Delta g > 0$) and $\Delta g = 0.32 \pm 0.42$ (for $\Delta g < 0$) .The data at small p_T and $\sqrt{s}$=500 GeV will put constraint at small-x on gluon polarization.

Delta G at RHIC

---present and future

- from π^0 and jets, 2006: **the gluon contribution to the proton spin is not large!***
- more probes: π^+, π^-, π^0 (STAR), η
- more luminosity and P: **π^0**, jets, direct photon; **dijets**, photon + jet

---both experiments requesting long p-p run in 2009 to obtain significant increase in sensitivity to Delta G ($\sqrt{s}$=200 GeV)

*** in range $0.02 < x_{gluon} < 0.3$; using GRSV framework**

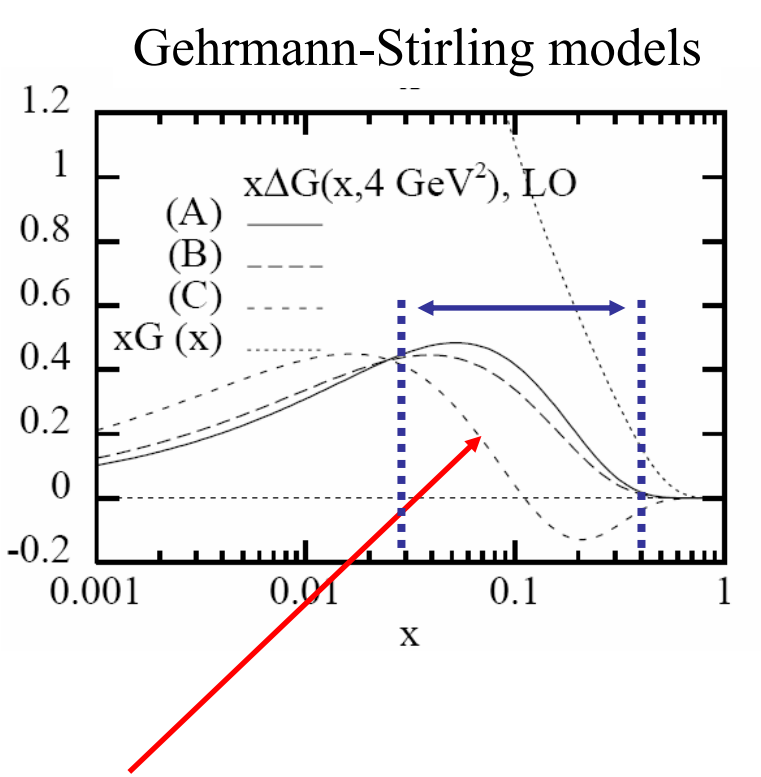
Conclusions

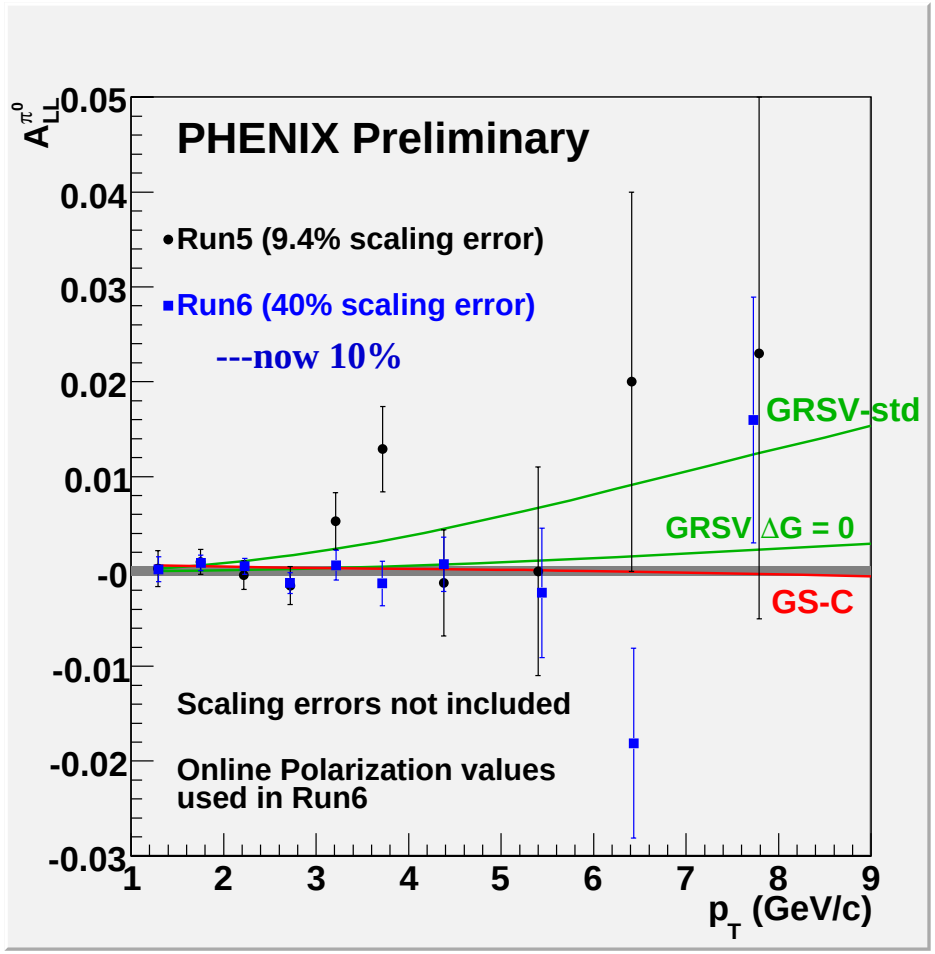
1. DIS experiments reached the very good precisions in measuring the contributions of the quarks to the nucleon spin. But it seems not appropriate for the determination of the gluon contribution to the nucleon spin for the following reasons:
   - Photon does not interact directly with gluon,
   - DIS is up to now the fixed target experiment with limited energy range ($8<\sqrt{s}<20$ GeV)
   - The application of DGLAP equations requires a large kinematical domain and introduces additional systematic error
   - DIS cross section is much smaller than the hadronic cross section

Conclusions

2. Polarized DIS future should be related to the polarized ep-collider
3. Polarized RHIC is a key instrument for determination of the gluon polarization
4. Next goal –the orbital momentum contribution to the nucleon spin.

Also: Extending x range is crucial!





GSC: $\Delta G(x_{gluon} = 0 \rightarrow 1) = 1$

$\Delta G(x_{gluon} = 0.02 \rightarrow 0.3) \sim 0$

GRSV-0: $\Delta G(x_{gluon} = 0 \rightarrow 1) = 0$

$\Delta G(x_{gluon} = 0.02 \rightarrow 0.3) \sim 0$

GRSV-std: $\Delta G(x_{gluon} = 0 \rightarrow 1) = 0.4$

$\Delta G(x_{gluon} = 0.02 \rightarrow 0.3) \sim 0.25$

Current data is sensitive to ΔG for $x_{gluon} = 0.02 \rightarrow 0.3$

RHIC Spin Runs

	P	L(pb^-1)	Results
2002	15%	0.15	first pol. pp collisions!
2003	30%	1.6	pi^0, photon cross section, A_LL(pi^0)
2004	40%	3.0	absolute beam polarization with polarized H jet
2005	50% (P^4 x L = 0.8)	13	large gluon pol. ruled out
2006	60% (P^4 x L = 6)	46	first long spin run
2007			no spin running
2008	50%		(short) run