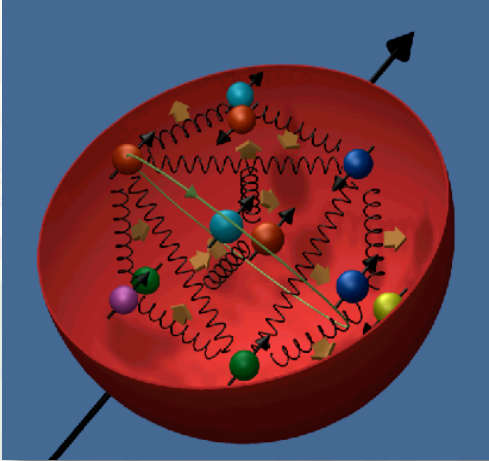


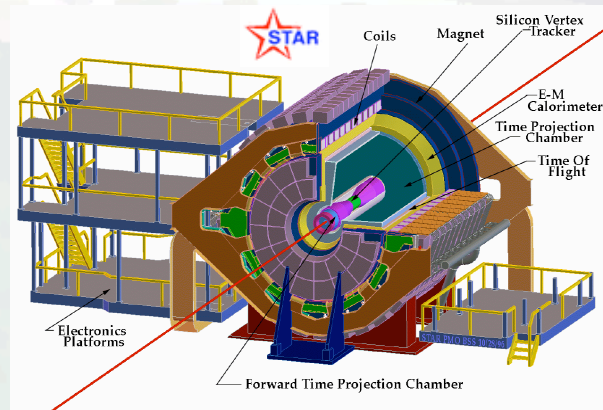


# Recent STAR results constraining the gluon polarization in high-energy polarized p+p collisions at RHIC at $\sqrt{s} = 200\text{GeV}$

Bernd Surrow



# Outline



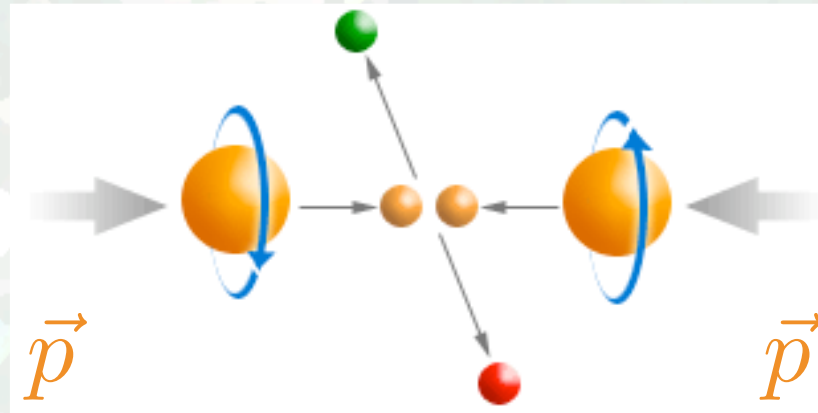
## □ Experiment

## □ Collider

## □ First results:

The quest for spinning glue

## □ Spinning Glue: QCD and Spin



## □ Summary and Outlook

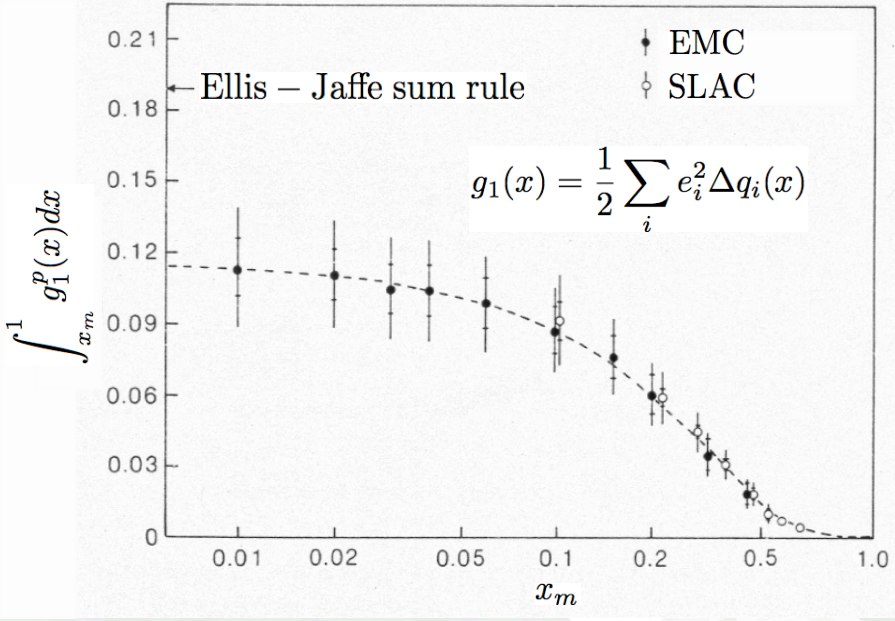
# Spinning Glue: QCD and Spin

- RHIC SPIN program (e.g.  $\Delta G$ )
- Polarized DIS: European Muon Collaboration

- At present:  $\Delta G$  is only poorly constrained from scaling violations in fixed target DIS experiments

$$\Delta G_{(AB)} = 0.99 \begin{matrix} + 1.17 \\ + 0.31 \end{matrix} \text{ at } Q^2 = 1 \text{ GeV}^2$$

B. Adeva et al., SMC Collaboration, Phys. Rev. D58 (1998) 112002.



## RHIC spin program

- EMC/SMC result: Fraction of proton spin carried by quarks is small:

$$\Delta \Sigma_{(AB)} = 0.38 \begin{matrix} + 0.03 \\ + 0.03 \end{matrix} \text{ at } Q^2 = 1 \text{ GeV}^2$$

- Unique multi-year program
- Explore various aspects on the spin structure and dynamics of the proton in a new domain:

- Transverse spin dynamics and transversity
- Gluon polarization
- Quark/anti-quark polarization of different flavors

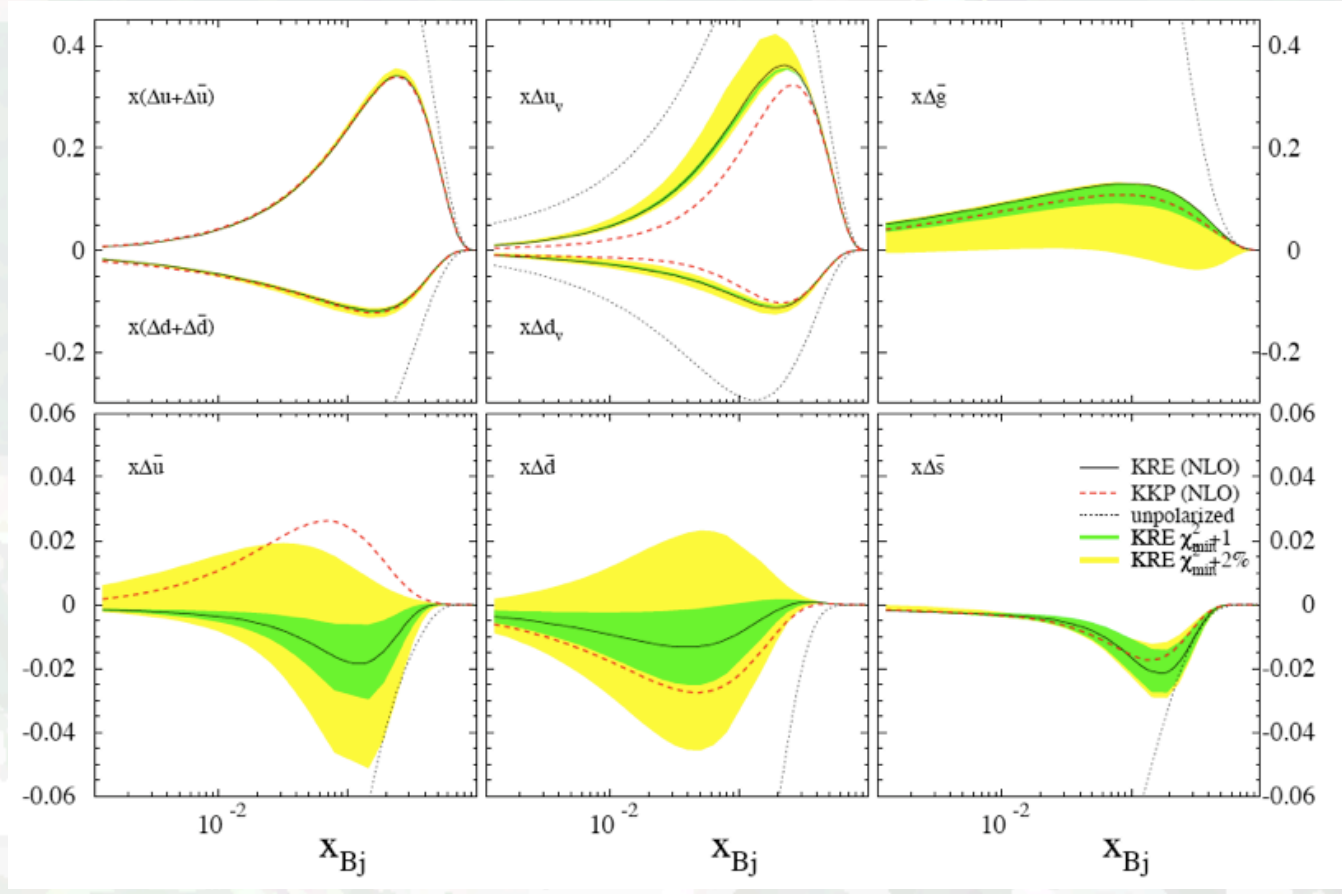
# Spinning Glue: QCD and Spin

□ What do we know about gluons? Spin contribution to proton

○ Spin carried by quarks is very small ( $\Delta\Sigma \sim 0.4$ )!

$$\underbrace{\frac{1}{2}\Delta\Sigma}_{\text{quarks}} = \underbrace{\langle S_q \rangle + \langle S_g \rangle + \langle L_q \rangle + \langle L_g \rangle}_{\Delta G}$$

$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$



D. de Florian et al., Phys. Rev. D71, 094018 (2005).

$$\Delta q_i(Q^2) = \int_0^1 \Delta q_i(x, Q^2) dx$$

$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2) dx$$

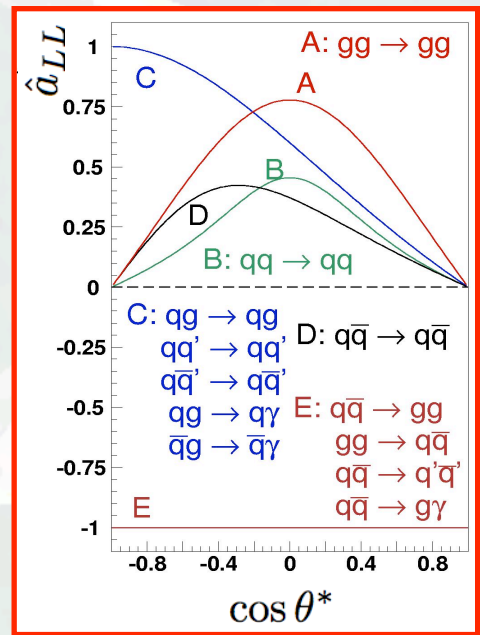
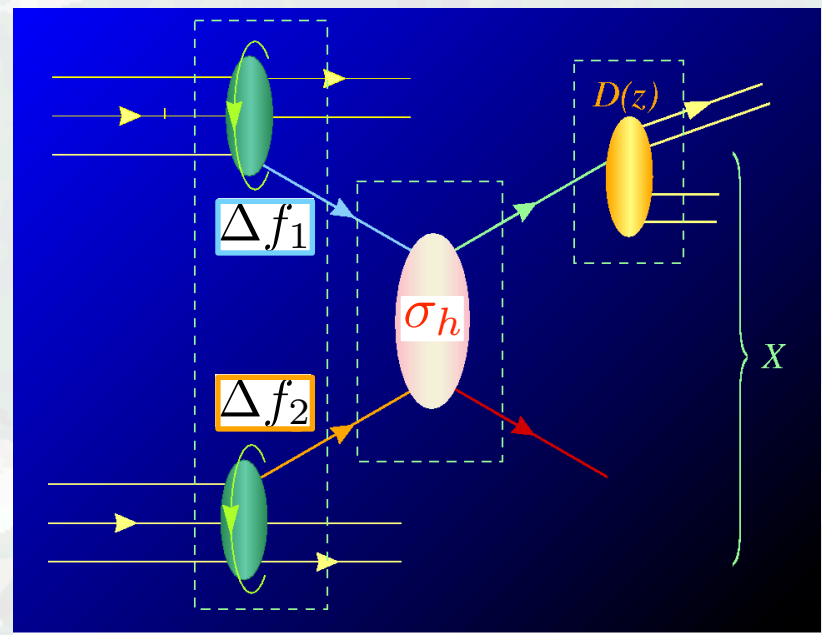
# Spinning Glue: QCD and Spin

□ How do we probe the gluon spin contribution in polarized p+p collisions?

$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2) dx$$



Extract  $\Delta g(x, Q^2)$  through  
Global Fit (Higher Order  
QCD analysis)!



↔ long-range     ↔ short-range     ↔ long-range

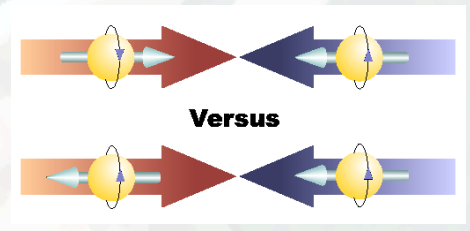
$$A_{LL} = \frac{d\Delta\sigma}{d\sigma}$$

$$\begin{aligned}
 & \left. \begin{aligned} & \Delta f_1 & \Delta f_2 & a_{LL} = \frac{\Delta\sigma_h}{\sigma_h} \end{aligned} \right\} \text{Input} \\
 & \propto \frac{\Delta f_1 \otimes \Delta f_2 \otimes \sigma_h \cdot a_{LL} \otimes D_f^h}{f_1 \otimes f_2 \otimes \sigma_h \otimes D_f^h}
 \end{aligned}$$

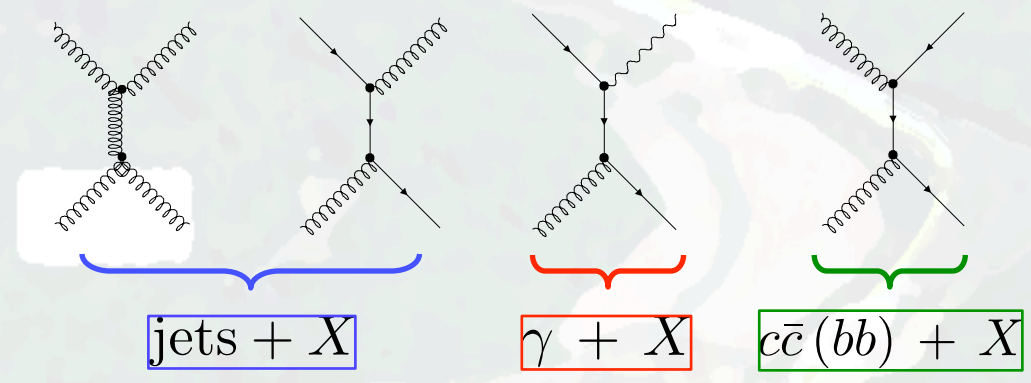
# Spinning Glue: QCD and Spin

□ What is required experimentally to measure the gluon spin contribution?

○ Double longitudinal-spin asymmetry:  $A_{LL}$



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

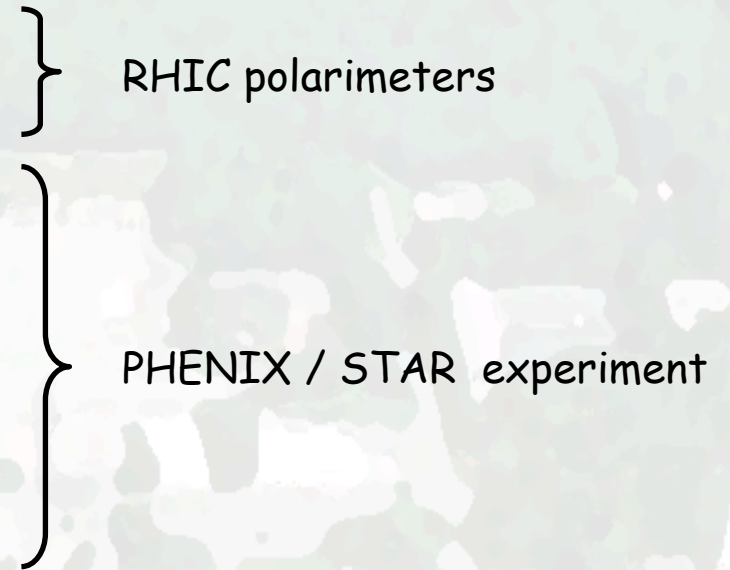


- Study helicity dependent structure functions (*Gluon polarization*)!

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_1 P_2} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}$$

○ Require concurrent measurements:

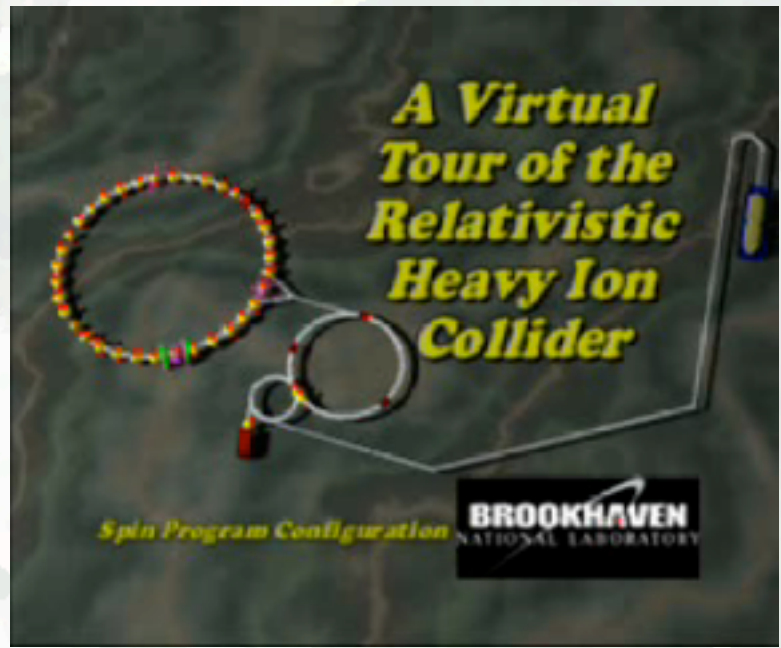
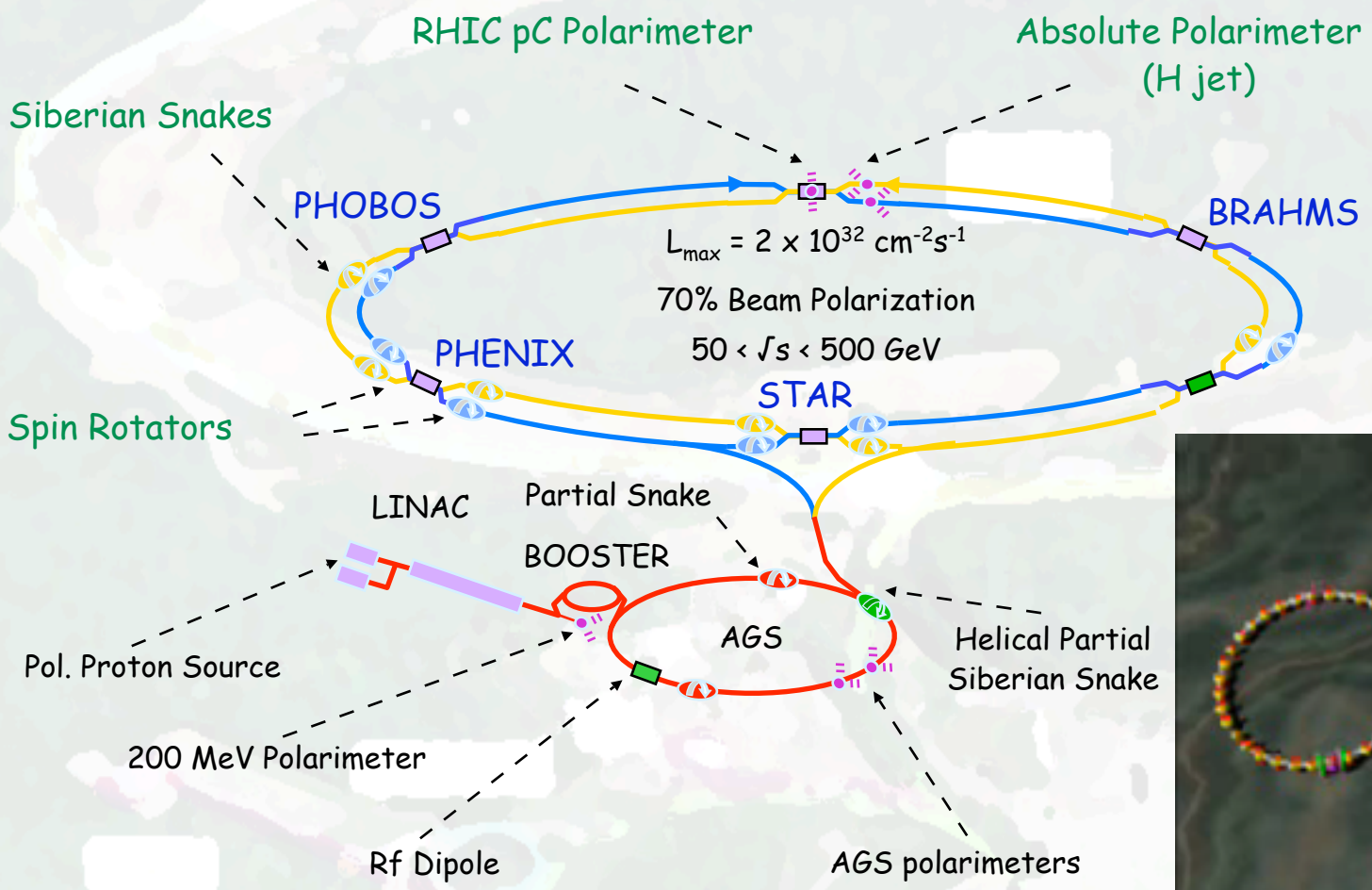
- Magnitude of **beam polarization**,  $P_{1(2)}$
- **Direction of polarization vector**
- **Relative luminosity** of bunch crossings with different spin directions
- **Spin dependent yields** of process of interest  $N_{ij}$





# The polarized proton collider RHIC

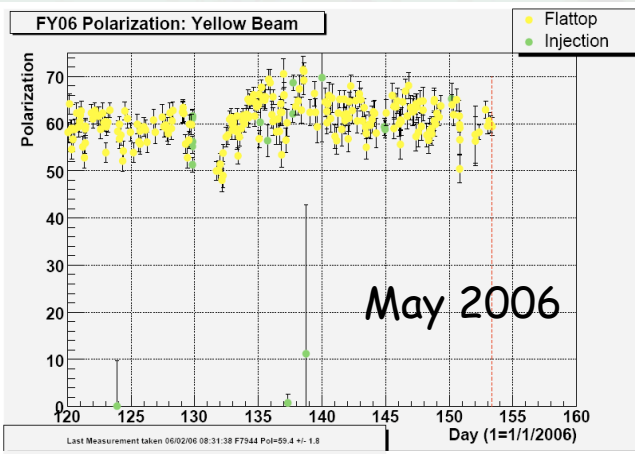
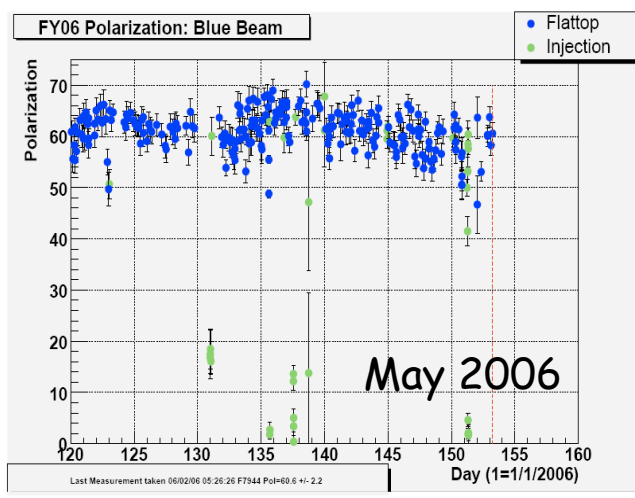
## Overview of RHIC polarized pp collider complex



# The polarized proton collider RHIC

## □ Luminosity (STAR recorded) and polarization performance

RHIC RUN	s [GeV]	$L_{\text{recorded}}$ [ $\text{pb}^{-1}$ ] (transverse)	$L_{\text{recorded}}$ [ $\text{pb}^{-1}$ ] (longitudinal)	Polarization[%]
RUN 2	200	0.15	0.3	15
RUN 3	200	0.25	0.3	30
RUN 4	200	0	0.4	40-45
RUN 5	200	0.4	3.1	45-50
RUN 6	200	3.4/6.8	8.5	60



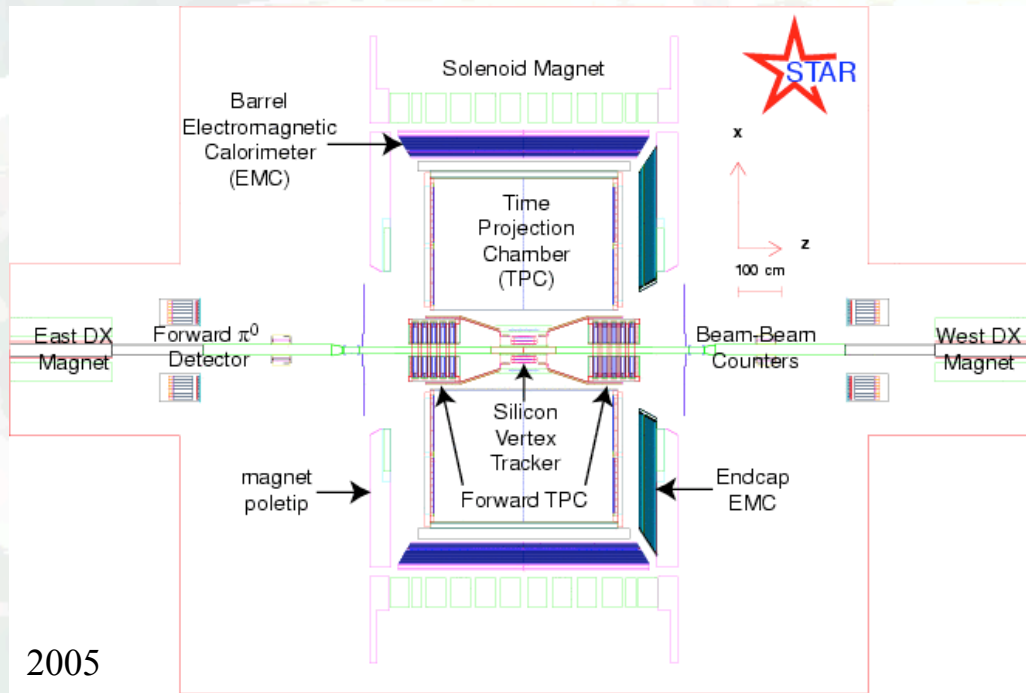
- All RHIC polarized pp accelerator components are in place!
- 2006 performance ( $\sqrt{s}=200\text{GeV}$ ): **~60% polarization** (70% design) and **~1pb<sup>-1</sup>/day** (~3pb<sup>-1</sup>/day design) **delivered**

luminosity



# Experiment: The STAR detector

## Overview



- **Forward-Pion Detector (FPD)** ( $3 < |\eta| < 4$ )
- **FPD++** (Extended coverage for Run 6 with  $3 < \eta < 4$ )
- **FMS** upgrade (Run 7 and beyond with  $2.5 < \eta < 4$ )

- **Beam-Beam Counter (BBC):** ( $3.4 < |\eta| < 5$ )

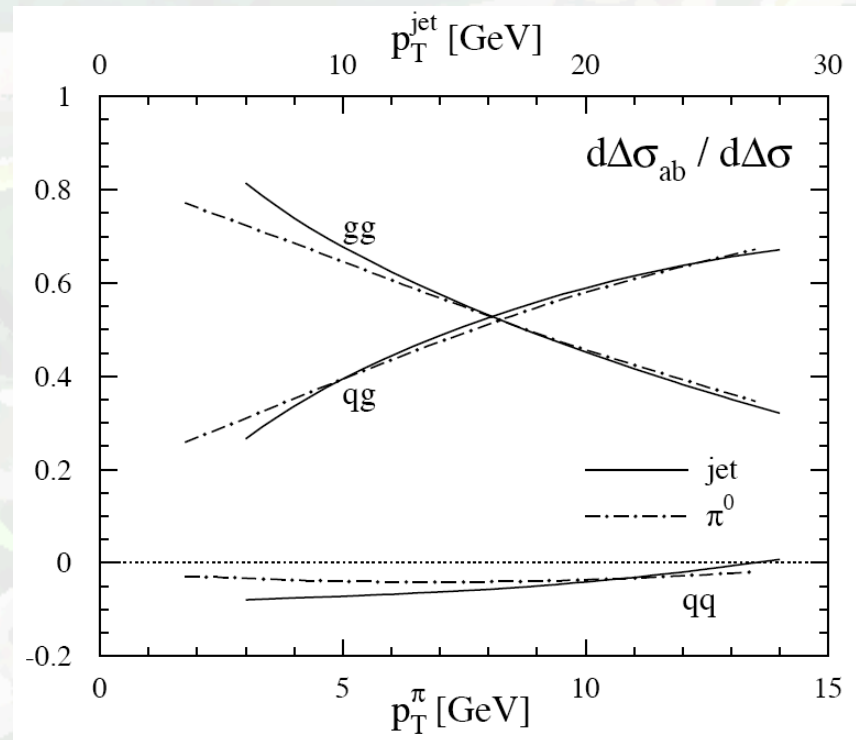
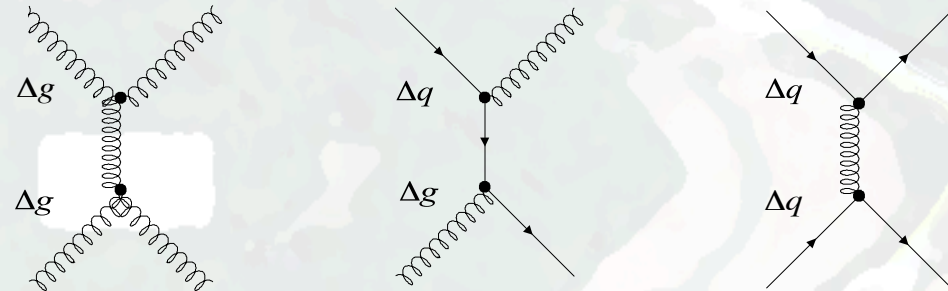
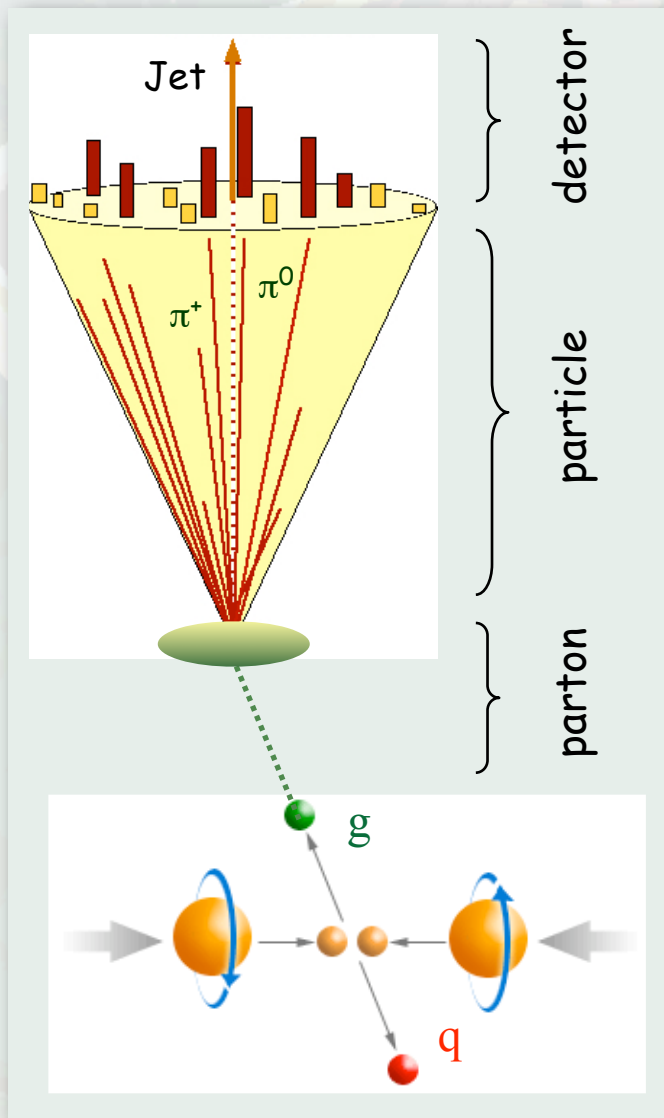
- Relative luminosity measurement
- Absolute luminosity measurement
- Local polarimeter ( $A_N$  for charged particles)

- **EM-Calorimeter:** (**Barrel - BEMC** :  $-1 < \eta < 1$  & **Endcap - EEMC**:  $1.09 < \eta < 2$ )

- Reconstruction of  $\gamma$ ,  $e^\pm$  and  $\pi^0$
- Jet-reconstruction in combination with TPC

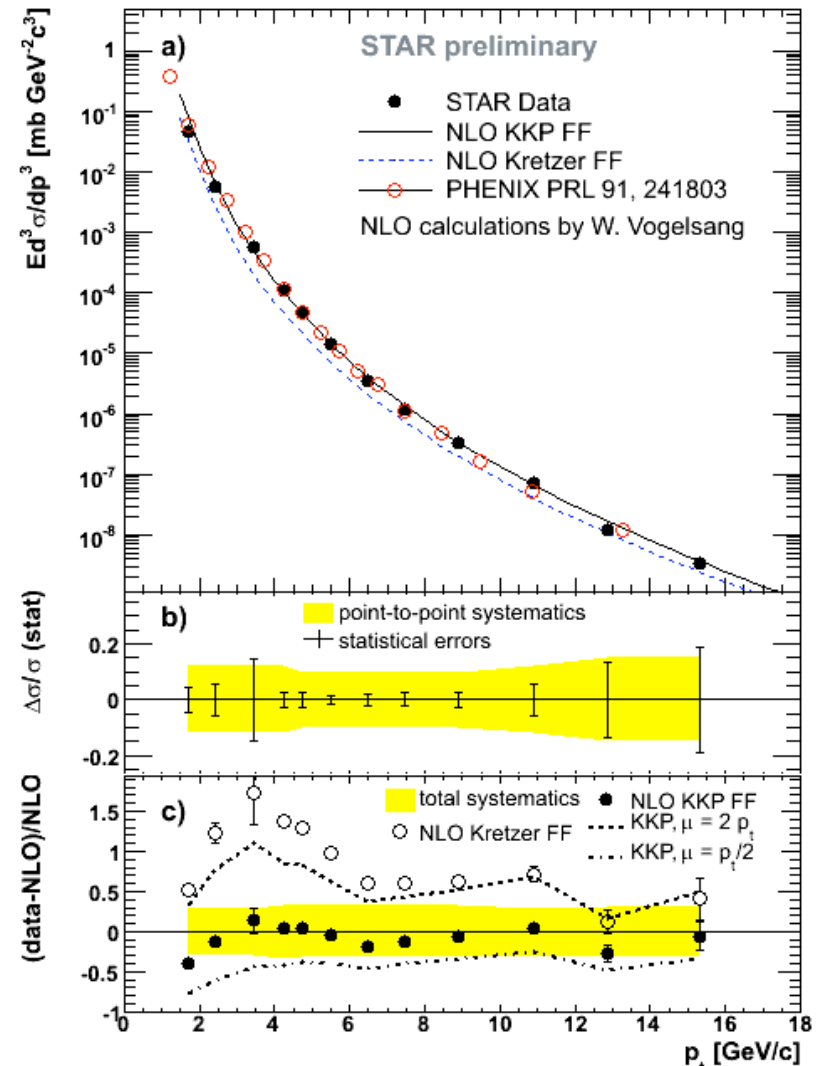
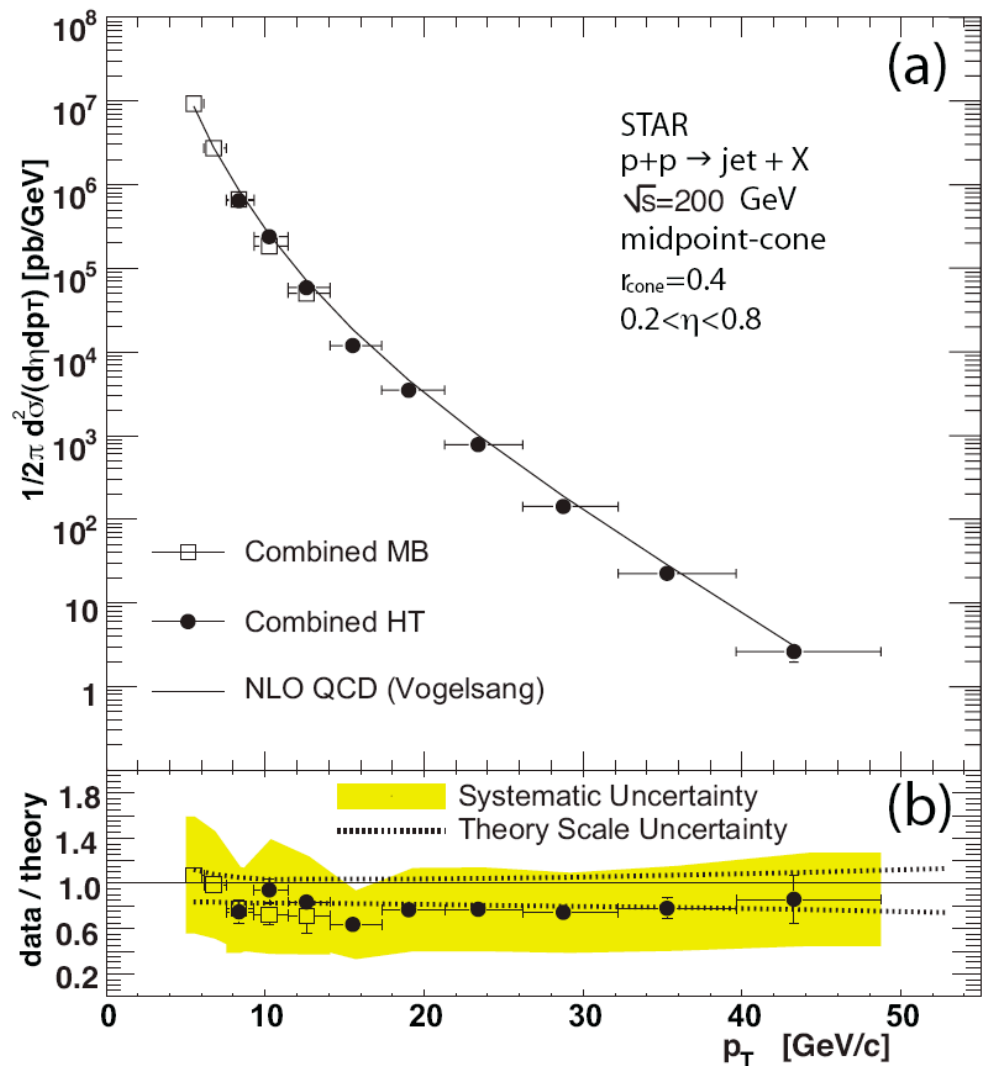
# First results: Gluon Spin contribution

- Inclusive measurements in polarized p+p collisions



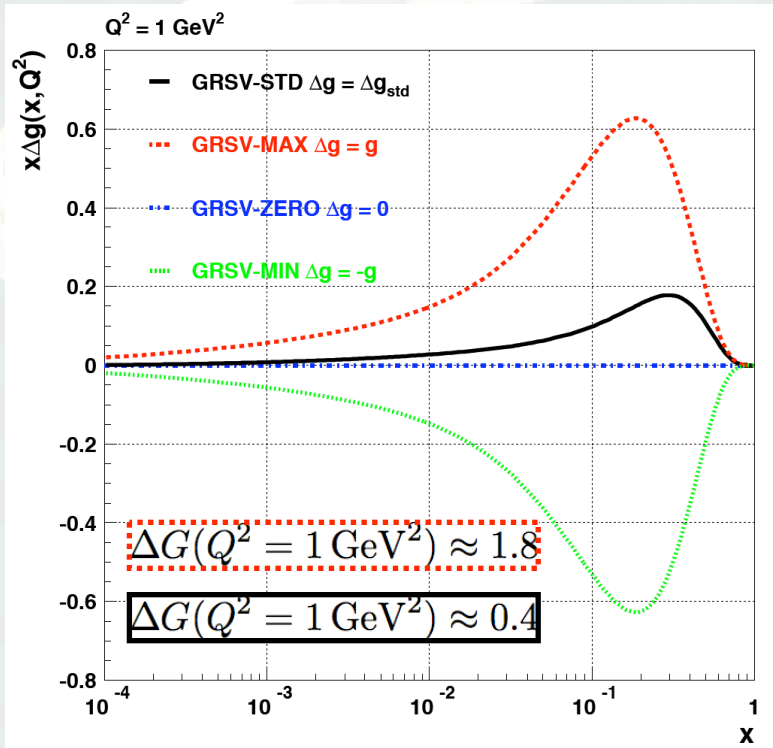
# First results: Gluon Spin contribution

## □ Perturbative QCD at Work: Inclusive cross-section measurements



# First results: Gluon Spin contribution

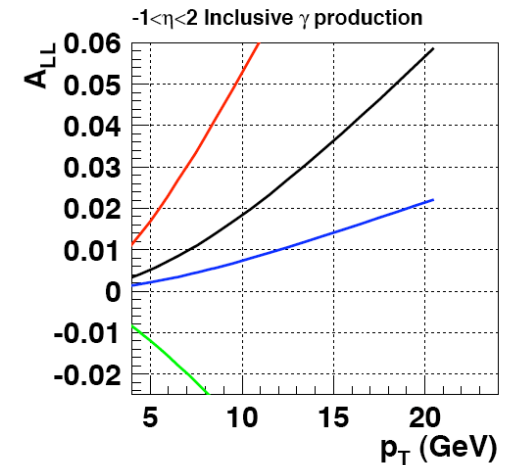
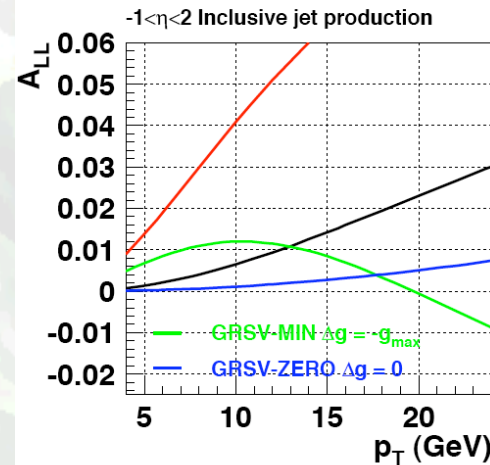
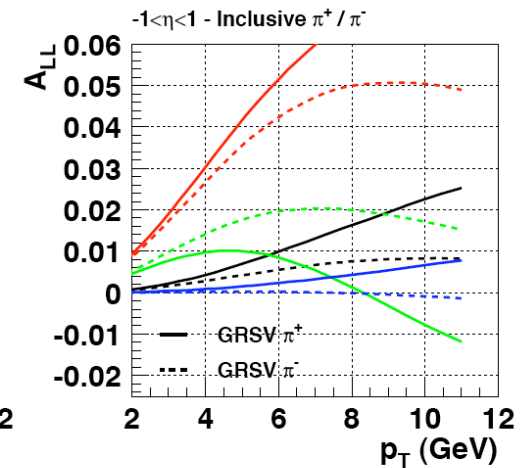
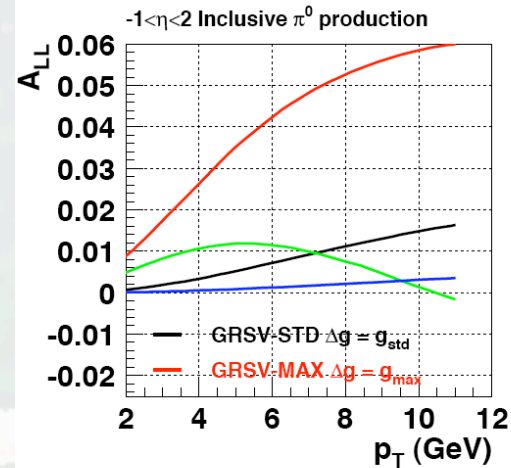
## □ Sensitivity to gluon spin contribution in inclusive processes



- Theoretically allowed range in  $\Delta g$ :  $-g < \Delta g < +g$
- GRSV-STD: Higher order QCD analysis of polarized DIS experiments!

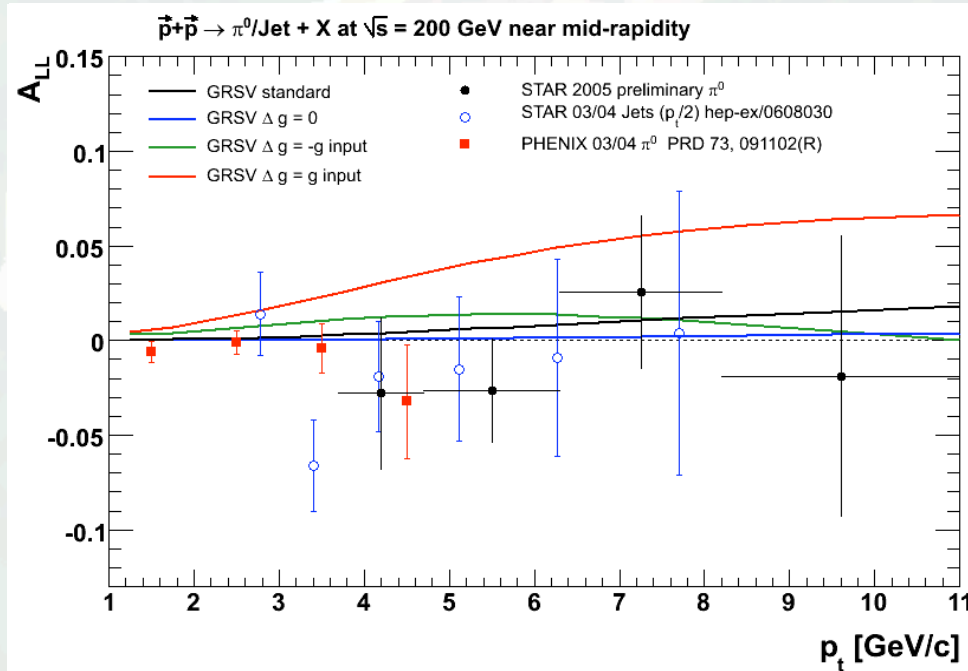
$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2) dx$$

$$x_{\text{parton}} \simeq 2p_T / \sqrt{s}$$



# First results: Gluon Spin contribution

## Neutral pion production: $A_{LL} \Rightarrow$ Gluon spin contribution



$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2) dx$$

$\chi^2$  / ndf to curves: (no sys. errors included)

$$\Delta G(Q^2 = 1\text{GeV}^2) \approx 1.8$$

$$\Delta G(Q^2 = 1\text{GeV}^2) \approx 0.4$$

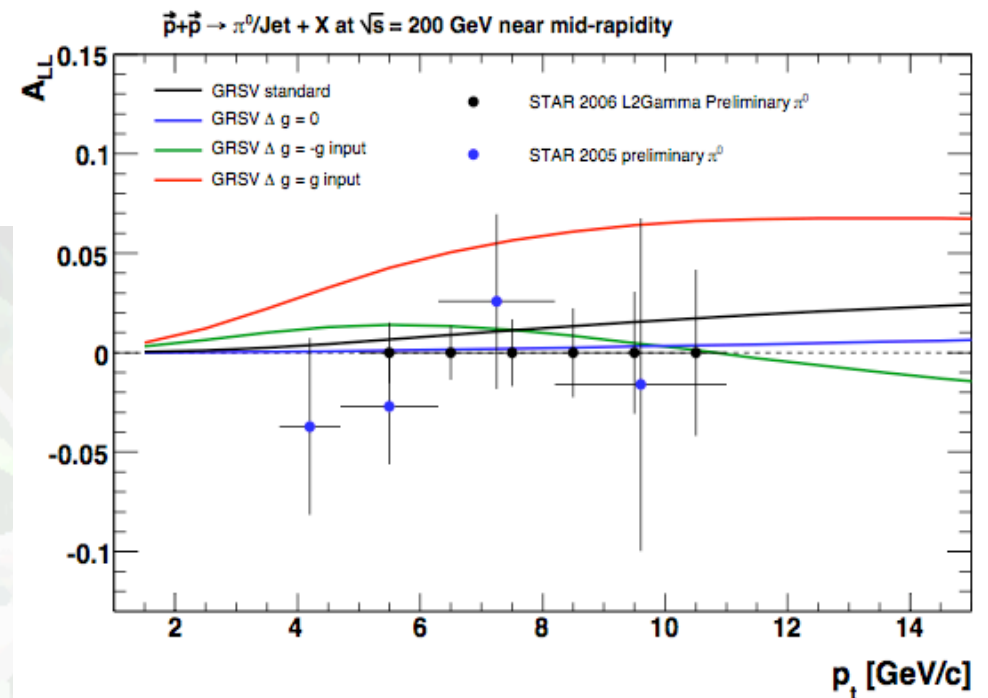
GRSV-STD: 0.8

DG = G: 2.4

DG = 0: 0.8

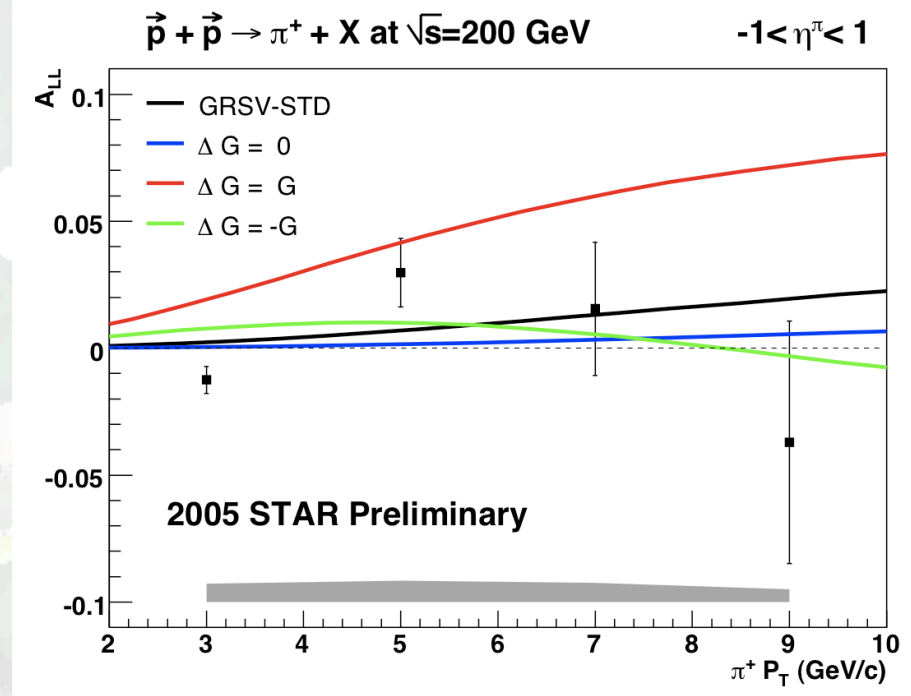
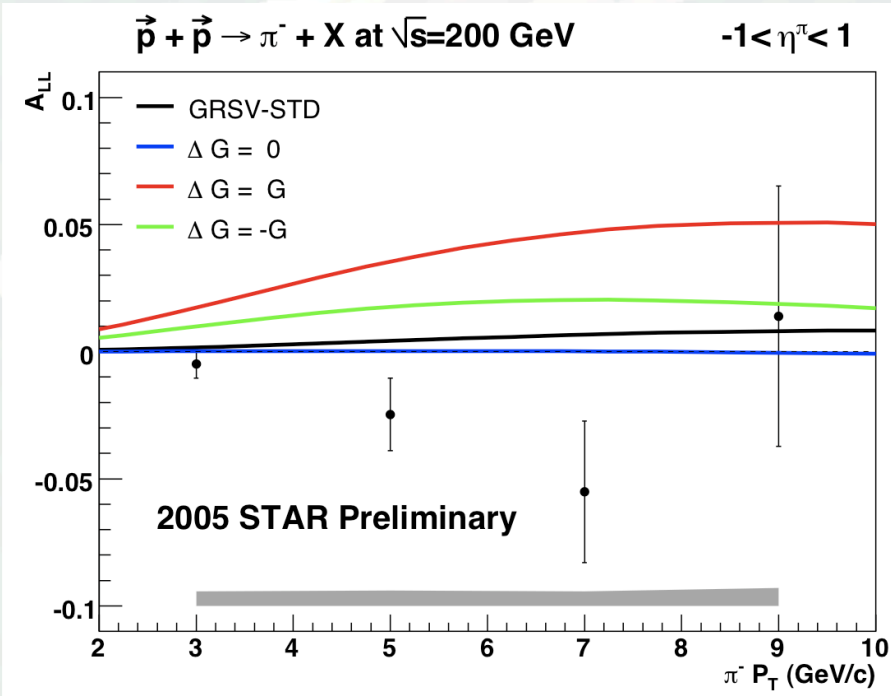
DG = -G: 0.5

- $A_{LL} \pi^0$  result (Run 5) with Run 3/4 jet result and PHENIX  $\pi^0$  result
- Maximum gluon polarization (GRSV-MAX) scenario ruled out
- Improved measurement with Run 6 data



# First results: Gluon Spin contribution

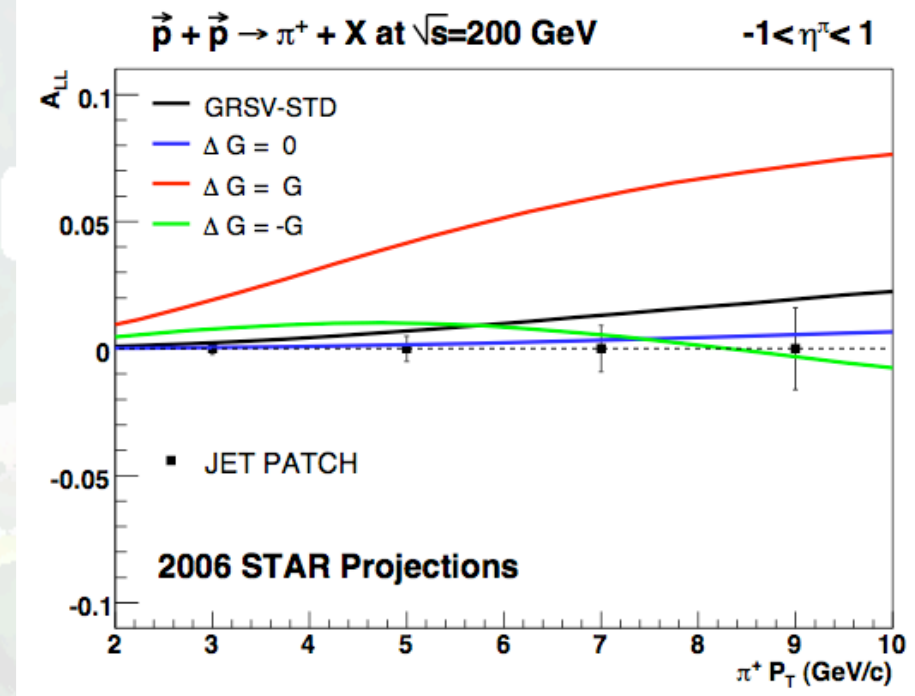
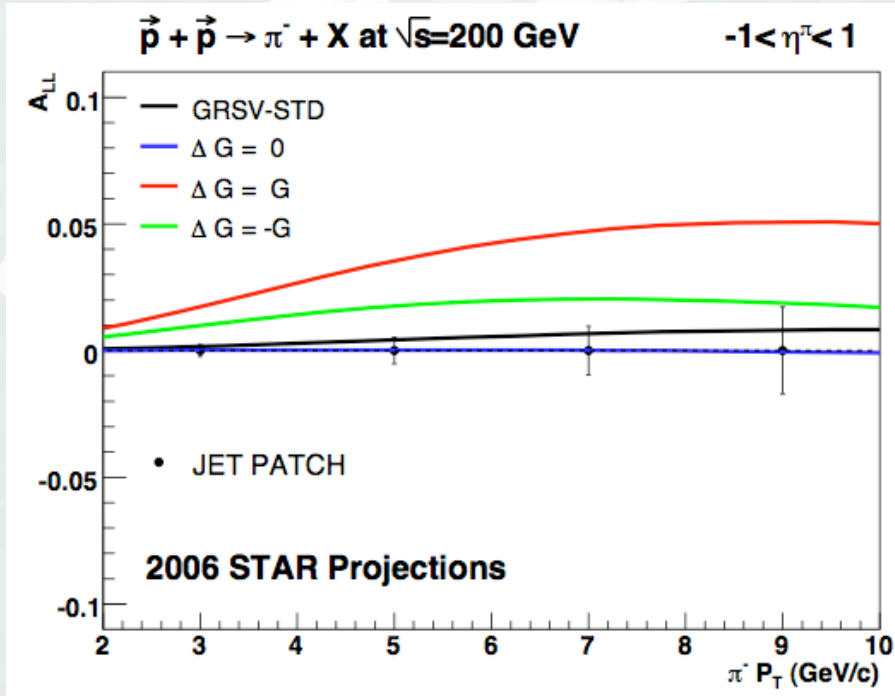
- Charged pion production:  $A_{LL} \Rightarrow$  Gluon spin contribution



- $A_{LL}(\pi^-) / A_{LL}(\pi^+)$  allows to track **sign of  $\Delta G$**  at high  $p_T$  (**qq process dominates**)
- Maximum gluon polarization (GRSV-MAX) scenario disfavored
- Improved precision with Run 6 data

# First results: Gluon Spin contribution

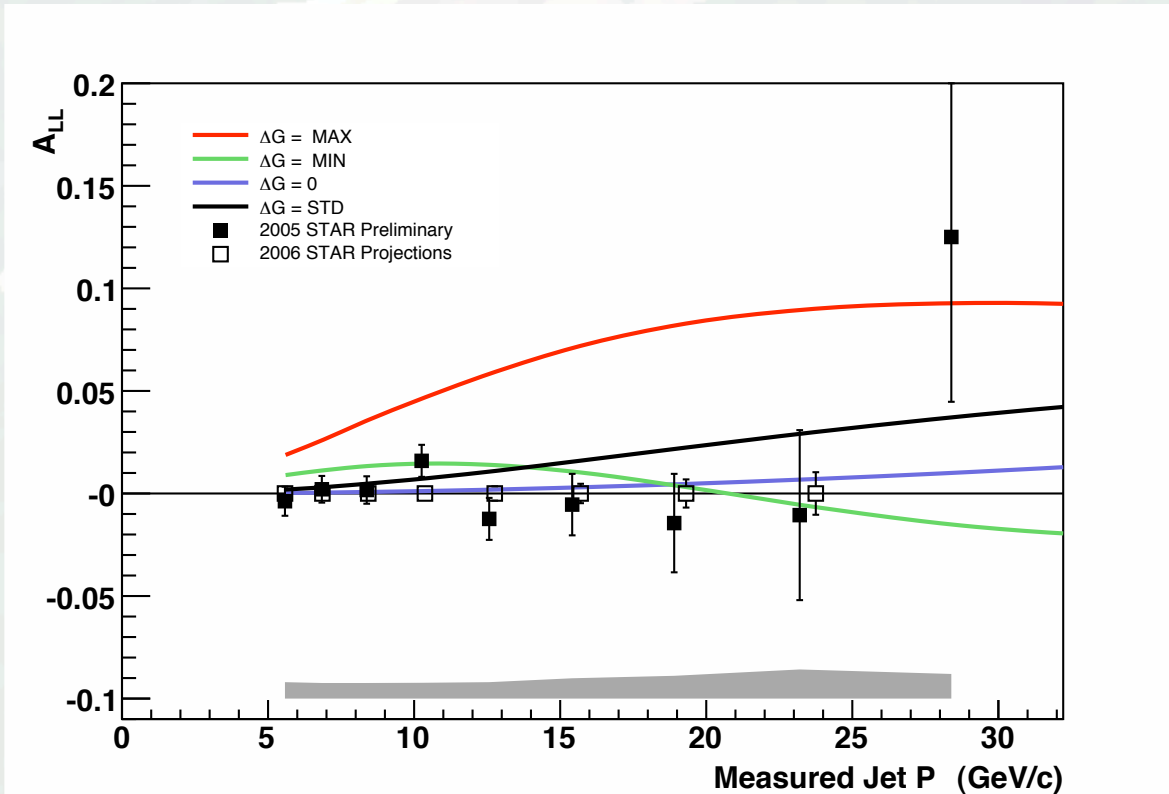
- Charged pion production:  $A_{LL} \Rightarrow$  Gluon spin contribution



- $A_{LL}(\pi^-) / A_{LL}(\pi^+)$  allows to track **sign of  $\Delta G$**  at high  $p_T$  (**qq process dominates**)
- Maximum gluon polarization (GRSV-MAX) scenario disfavored
- Improved precision with Run 6 data

# First results: Gluon Spin contribution

- Inclusive Jet production:  $A_{LL} \Rightarrow$  Gluon spin contribution



$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2) dx$$

$\chi^2$  / ndf to curves:  
(stat.+sys. error in quadrature)

$$\Delta G(Q^2 = 1\text{GeV}^2) \approx 1.8$$

GRSV-STD: 1.1

ΔG = G: 12

$$\Delta G(Q^2 = 1\text{GeV}^2) \approx 0.4$$

ΔG = 0: 0.7

ΔG = -G: 1.4

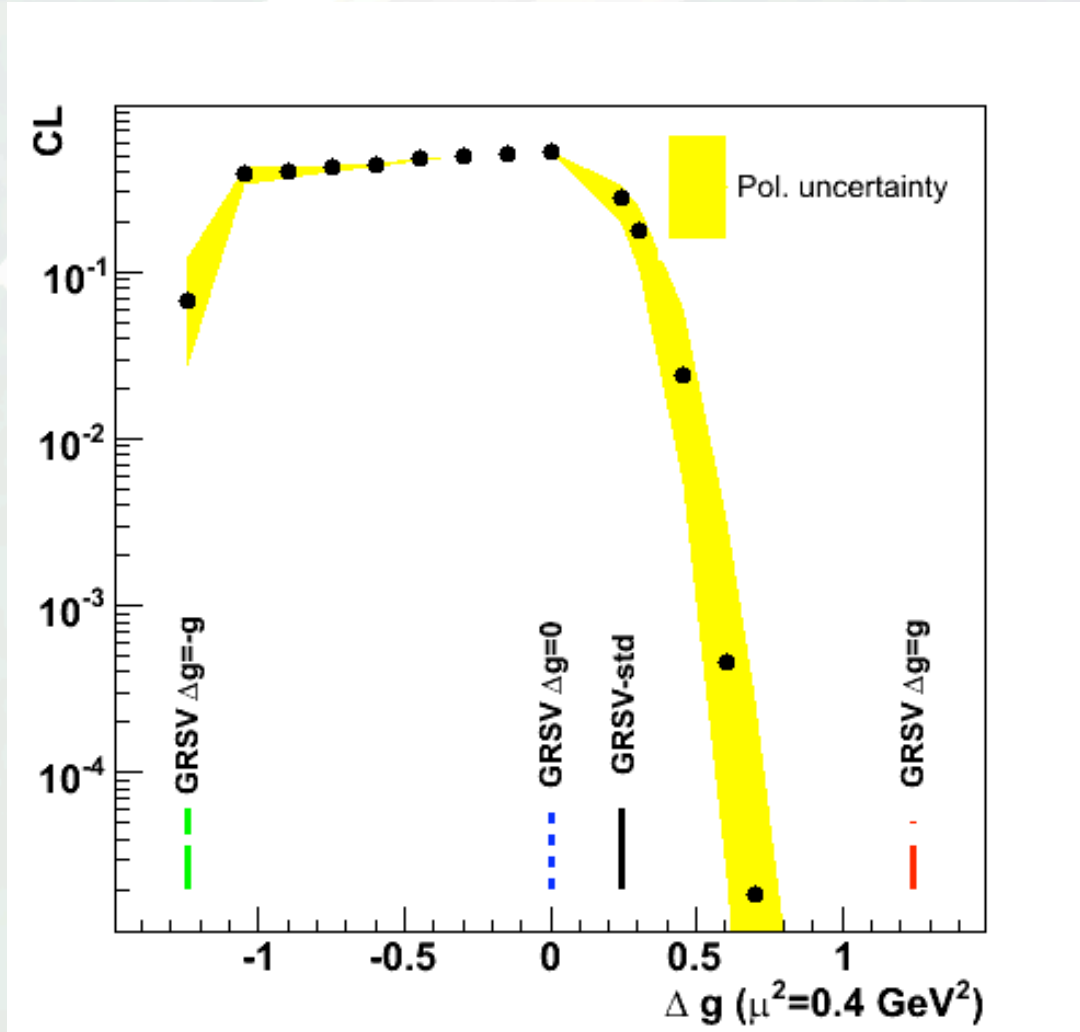
- Maximum gluon polarization scenario (GRSV-MAX) ruled out
- $A_{LL}$  inclusive jet result (Run 5) consistent with previous Run 3/4 result
- Precise measurement of  $A_{LL}$  inclusive jets with Run 6 data

B.I. Abelev et al. (STAR Collaboration),  
Phys. Rev. Lett. 97, 252001 (2006)

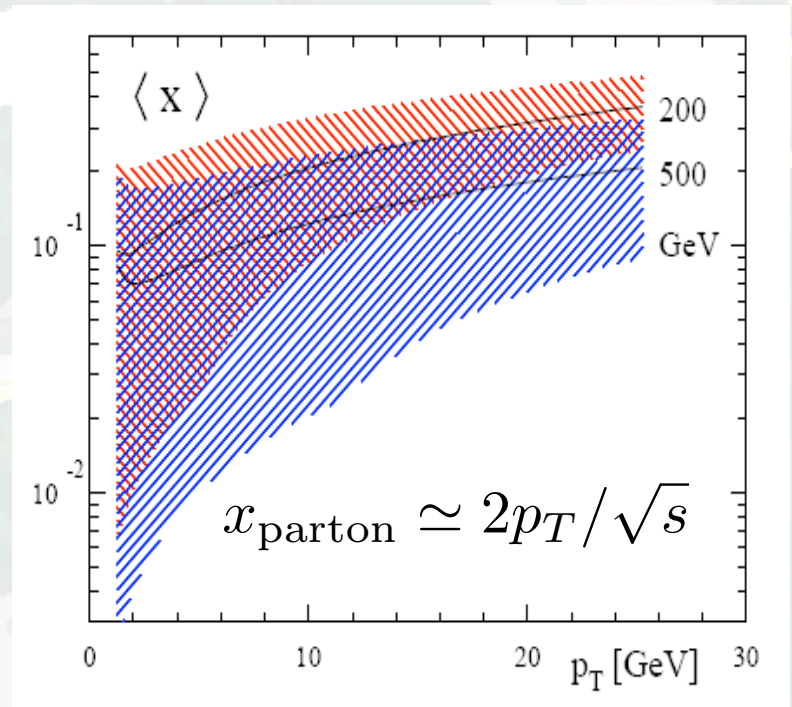


# First results: Gluon Spin contribution

- Quantify GRSV comparison in  $A_{LL}$



- Uncertainties from shape in  $\Delta g$  and pQCD scale not taken into account

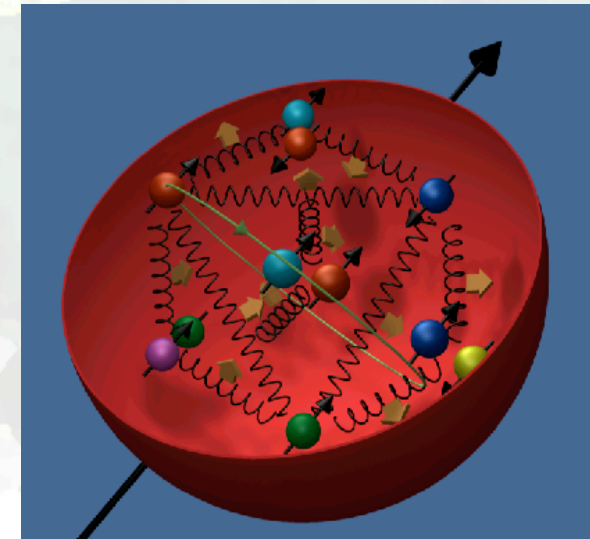
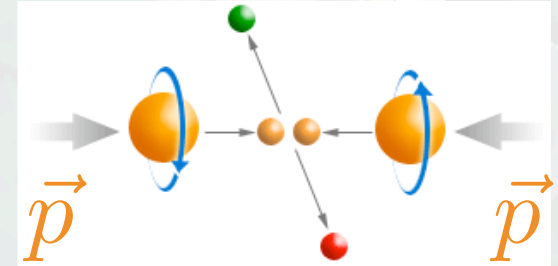


- GRSV polarized DIS best global fit result:  $1\sigma = -0.45$  to  $0.7$

# Summary and Outlook

## □ Summary

- **First successful polarized proton collisions ever** at high energies at RHIC at Brookhaven National Laboratory
- **QCD**: Critical role to interpret measured asymmetries
- Consistent picture emerging to **disfavor large gluon polarization scenario**
- Next critical step:
  - Measurements to constrain shape of  $\Delta g$  (Di-Jet production and Photon-Jet production)
  - QCD analysis to extract  $\Delta g$ !



# Summary and Outlook

## □ Outlook

- Upgrade of STAR Tracking System to study anti-quark polarization in  $W$  production in polarized  $p+p$  collisions
- Long-term: Establish new polarized  $ep/eA$  facility to quark/gluon structure of the proton and nucleus with high precision

