

# Determination of $\Delta g$ from Inclusive $\pi^0$ Measurement at RHIC-PHENIX

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**Inclusive  $\pi^0$  and  $\eta$   $A_{LL}$  measurements by PHENIX**

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## ■ Contents

- Introduction
- PHENIX experiment
- Measurement of  $\pi^0$   $A_{LL}$
- Results from 2005 & 2006 data
- Conclusion

# Introduction

- Proton spin structure  $\frac{1}{2}_{\text{proton}} = \frac{1}{2} \sum_q \Delta q + \Delta g + L_{q,g}$ 
  - proton spin problem (1988 EMC experiment)
  - by many DIS experiments,  $\Sigma \Delta q = 0.330(39)$  [PRD 75, 012007]
  - need determine the gluon polarization  $\Delta g$  first by experiment

- Polarized p+p collisions for  $\Delta g$  measurement

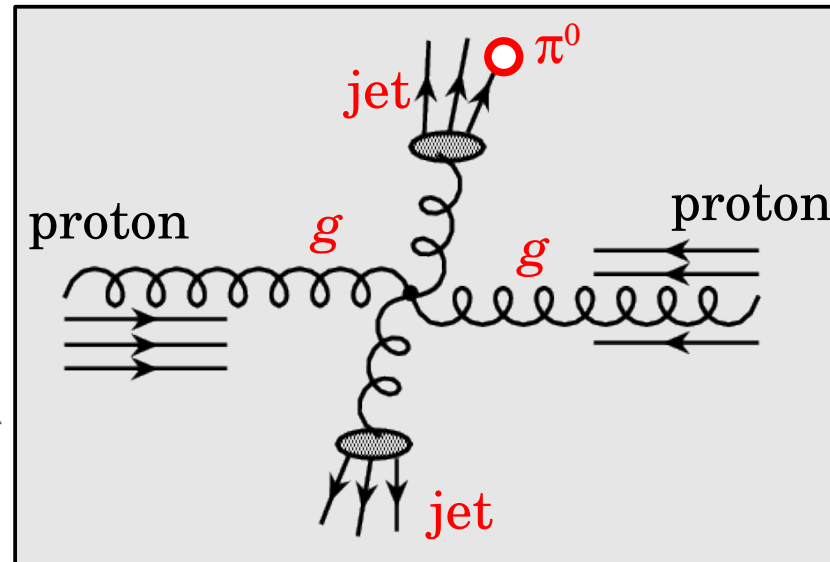
- $\pi^0$ , jet, direct photon productions etc.
- double helicity asymmetry ( $A_{LL}$ )

$$A_{LL} \equiv \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_B P_Y} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}$$

- $g+g$  &  $g+q$  dominate upto  $p_T^{\pi^0} \sim 10 \text{ GeV}/c$

- in case of  $\pi^0$  production via  $g+g$ ,  $A_{LL}^{gg} \sim \int dx_1 dx_2 \frac{\Delta g(x_1)}{g(x_1)} \cdot \frac{\Delta g(x_2)}{g(x_2)} \cdot \hat{a}_{LL}^{gg}$

and similarly  $A_{LL}^{gq} \sim \Delta g / g \cdot \Delta q / q$ ,  $A_{LL}^{qq} \sim \Delta q / q \cdot \Delta q / q$



- Inclusive  $\pi^0$  measurement at mid-rapidity ( $|\eta| < 0.35$ ) is the PHENIX main channel for  $\Delta g$  measurement

# Introduction

- Data accumulation in longitudinally polarized p+p run

Year	$\sqrt{s}$ (GeV)	FoM ( $P^4 L$ ) ( $10^{-3} \text{ pb}^{-1}$ )	Int. Lumi. ( $\text{pb}^{-1}$ )	Pol. (%)
2003	200	1.9	0.35	27%
2004	200	4.5	0.12	44%
2005	200	196	3.4	49%
2006	200	972	7.5	60%
	62.4	5.3	0.1	48%
(2009)	200/500			

- 2005+2006 data has x180 FoM than 2003+2004 data
- low  $\sqrt{s}$  run  $\rightarrow$  better sensitivity to higher  $x$

# Introduction

## ■ PHENIX $\pi^0 A_{LL}$ results

	$\sqrt{s}$ (GeV)	Year of data	Publication/presentation
2006 May	200	2003+2004	PRD73, 091102(R)
2006 Oct.	200	2006, high- $p_T$	<i>preliminary</i> , SPIN2006
	62.4	2006	<i>prel.</i> , SPIN2006
2007 Sep.	200	2005	PRD76, 051106
2007 Jul.	200	2006, low- $p_T$	<i>prel.</i> , RHIC & AGS Users Meeting
(2008 Apr.	global analysis by DSSV used run 2005 & 2006 data)		
2008 Oct.	200	2006	submitted to PRL (arXiv:?.?)
	62.4	2006	submitted to PRD (arXiv:?.?)

- run 2006 data at  $\sqrt{s} = 62.4$  and 200 GeV (combined with run 2005 data) have been submitted recently

# PHENIX Experiment

- Relativistic Heavy Ion Collider (RHIC)
  - the first collider for polarized proton-proton collision
  - $\sqrt{s} = 62.4, 200, (500) \text{ GeV}$

**PHENIX**  
here

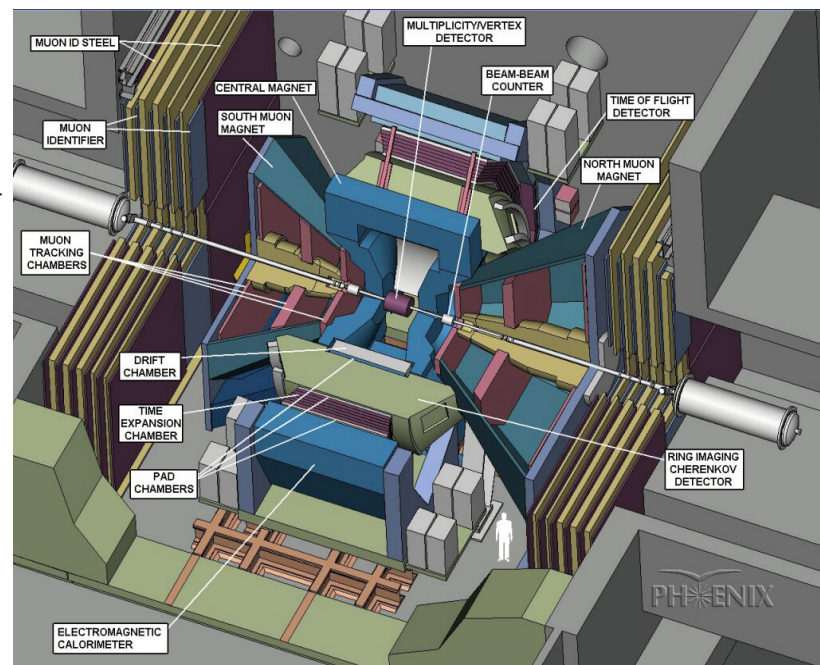


- best to investigate the spin-dependent characteristics of the gluon

# PHENIX Experiment

## Central Arm detectors

- $\Delta\phi = 90^\circ \times 2, |\eta| < 0.35$
- EMCAL (PbSc & PbGl) for photon detection
  - $\sigma_E/E \sim 8\%$  at 1 GeV
  - fine segmentation,  $0.01 \times 0.01$  rad/seg.  $\rightarrow \gamma\gamma$  separation up to  $E^{\pi^0} = 20$  GeV
  - background exclusion by ele.mag. shower shape cut, charged matching and ToF cut

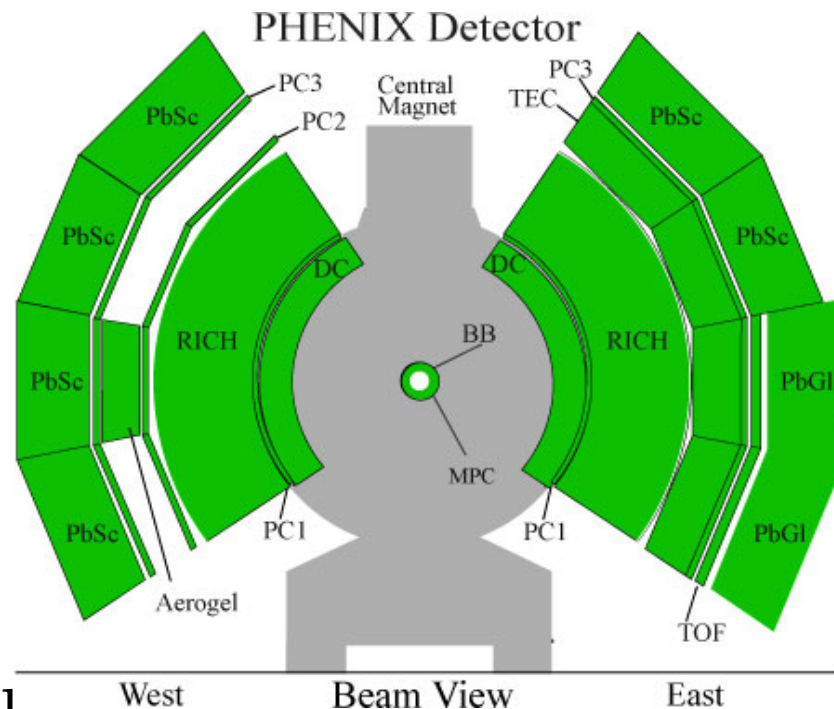


## Forward detectors (near beam pipe)

- Beam-Beam Counter (charged particles at  $3.0 < |\eta| < 3.9$ )
- Zero-Degree Cal. (neutrons at  $\pm 2.8$  mrad)
- absolute & relative luminosity
- beam pol. direction at PHENIX

## Trigger

- Min. Bias trigger by BBC
- high-energy photon ( $> \sim 1.4$  GeV) by EMCAL



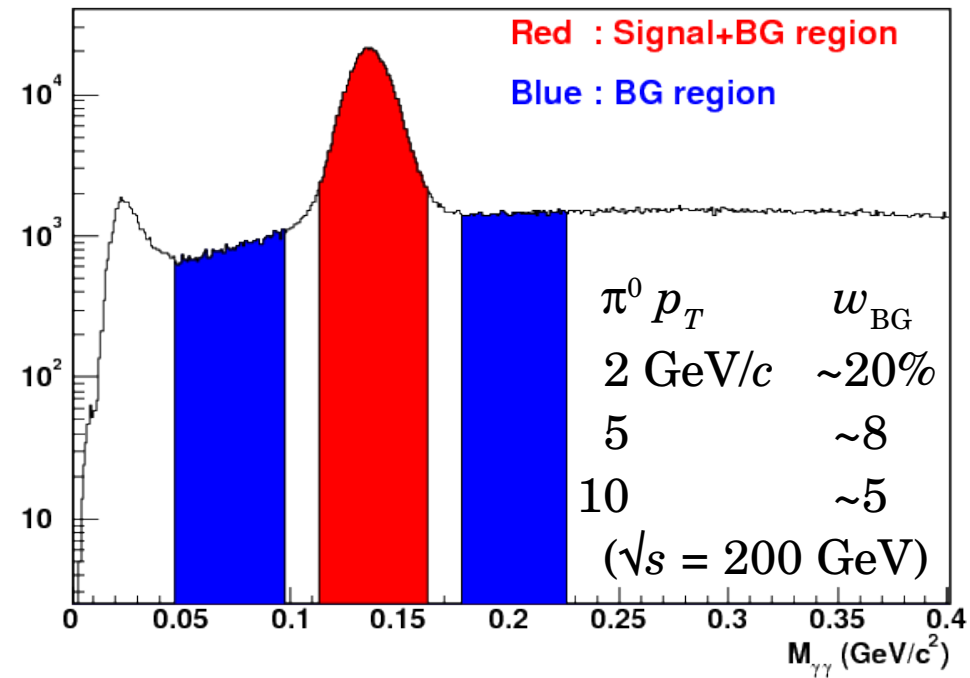
# Measurement of $\pi^0 A_{LL}$

- Well-developed method since 2003
  - detailed syst. error checks done as stat. error decreased

## $\pi^0$ yield measurement

- $\pi^0 \rightarrow \gamma\gamma$ , BR 99%
- combinatorial BG fraction

$$w_{BG} = N_{BG} / N_{all}$$



## $A_{LL}$ measurement

$$A_{LL} \equiv \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_B P_Y} \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}}, \quad R \equiv \frac{L_{++}}{L_{+-}}$$

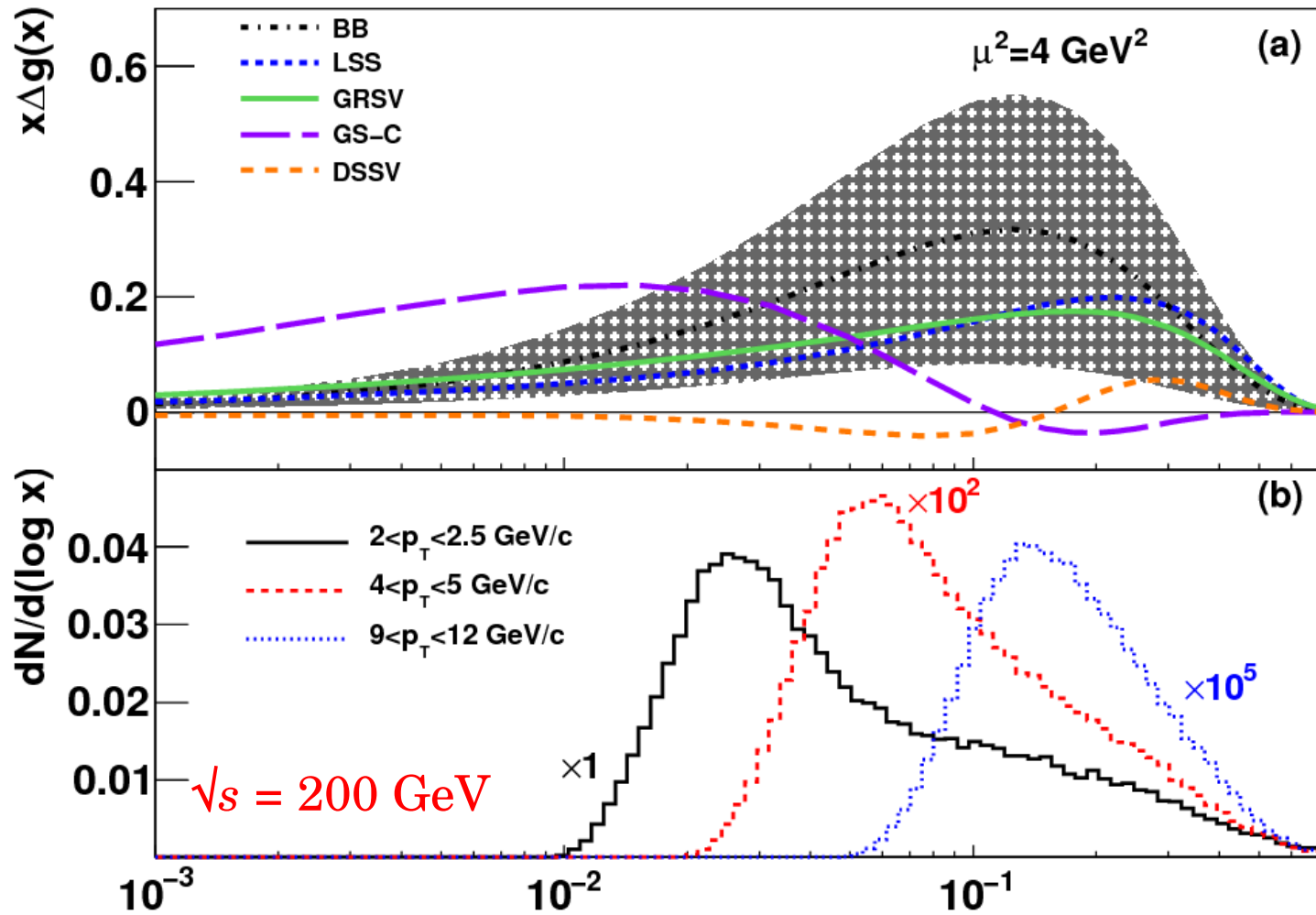
- $P_B, P_Y$  ... beam polarization, ~10% syst. error in  $P_B \cdot P_Y$
- $R$  ... relative luminosity,  $\delta_{ALL} = 2 \times 10^{-4}$  in 2005, =  $7 \times 10^{-4}$  in 2006
- $N_{++} (N_{+-})$  ...  $\pi^0$  yields with same (opposite) helicity of colliding beams
- signal  $A_{LL}$  is corrected for background  $A_{LL}$

$$A_{LL}^{\pi^0} = \frac{A_{LL}^{\pi^0+BG} - w_{BG} A_{LL}^{BG}}{1 - w_{BG}}$$

# Measurement of $\pi^0 A_{LL}$

■  $x_{\text{gluon}}$  coverage by  $\pi^0 A_{LL}$

■ based on a simulation using NLO pQCD as input



■  $0.02 < x_{\text{gluon}} < 0.3$  ( $\sqrt{s} = 200 \text{ GeV}$ ),  $0.06 < x_{\text{gluon}} < 0.4$  ( $62.4 \text{ GeV}$ )

■ larger sensitivity at lower  $x_{\text{gluon}}$  ( $\sim 0.03$  at  $200 \text{ GeV}$ ) within the range above

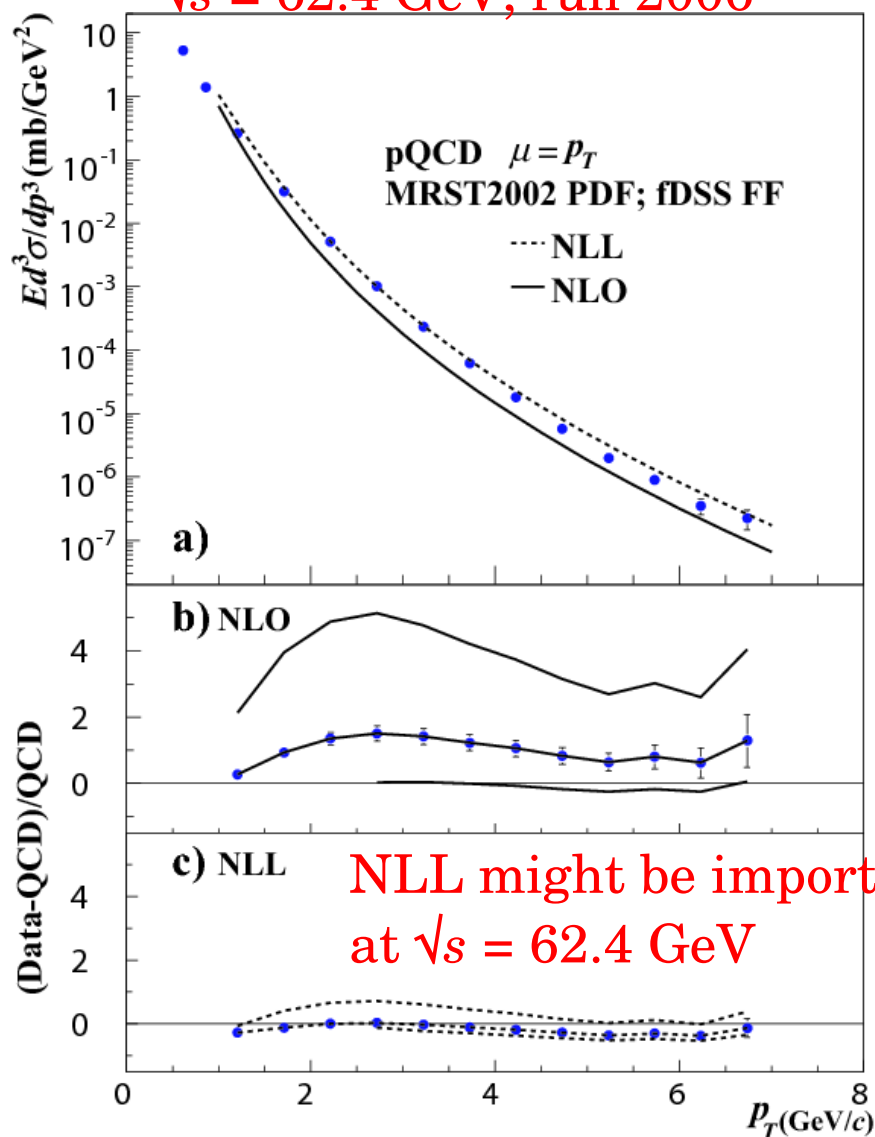


# Results from 2005 & 2006 Data

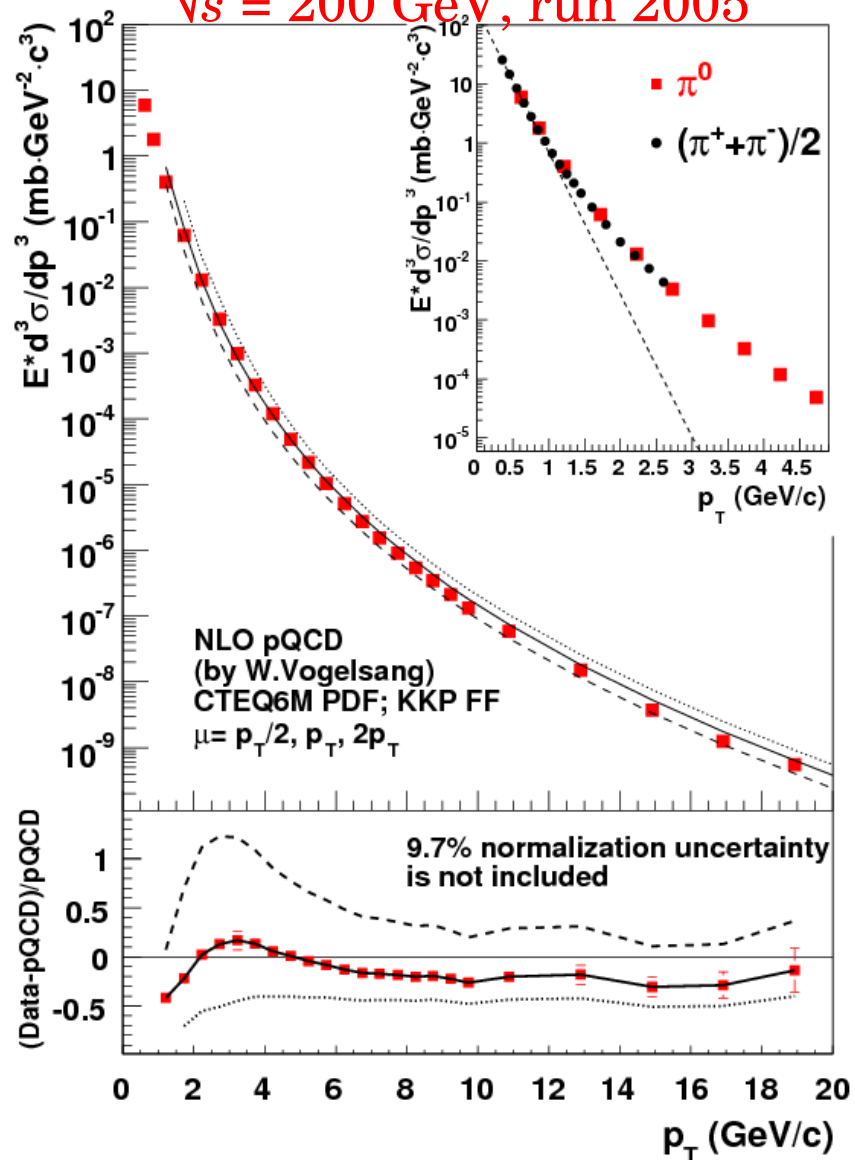
## Cross section

- check the applicability of NLO pQCD → good agreement
- check the contribution of soft-scattering events at low  $p_T$  → OK at  $>2$  GeV/c

$\sqrt{s} = 62.4$  GeV, run 2006



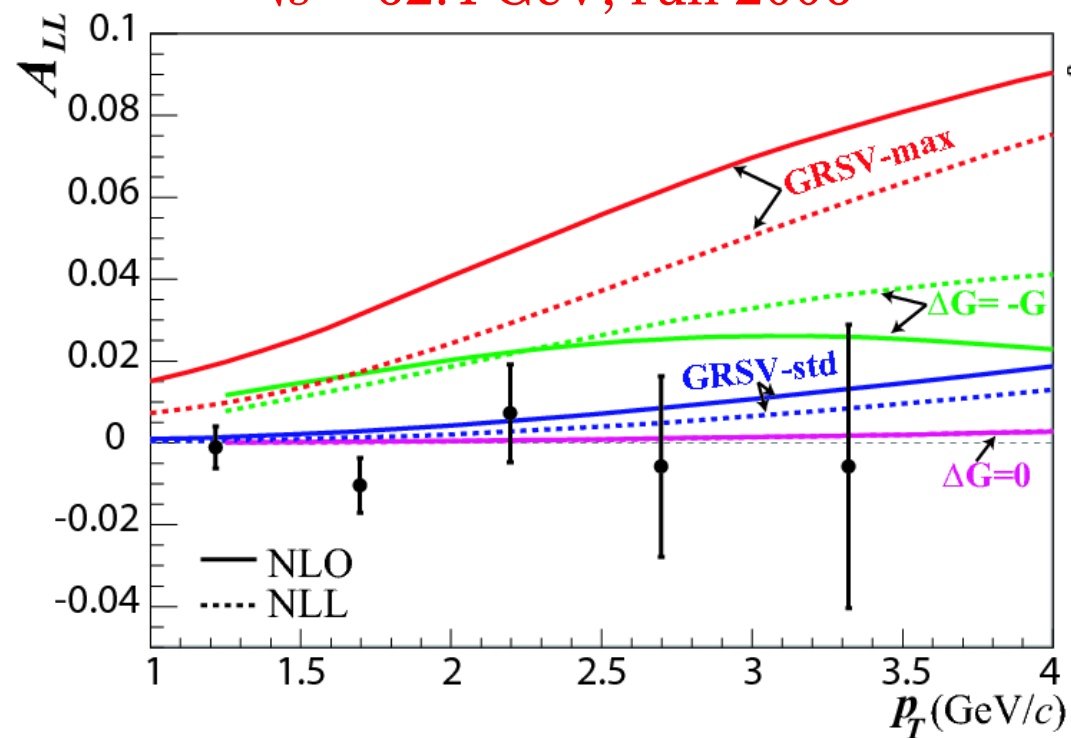
$\sqrt{s} = 200$  GeV, run 2005



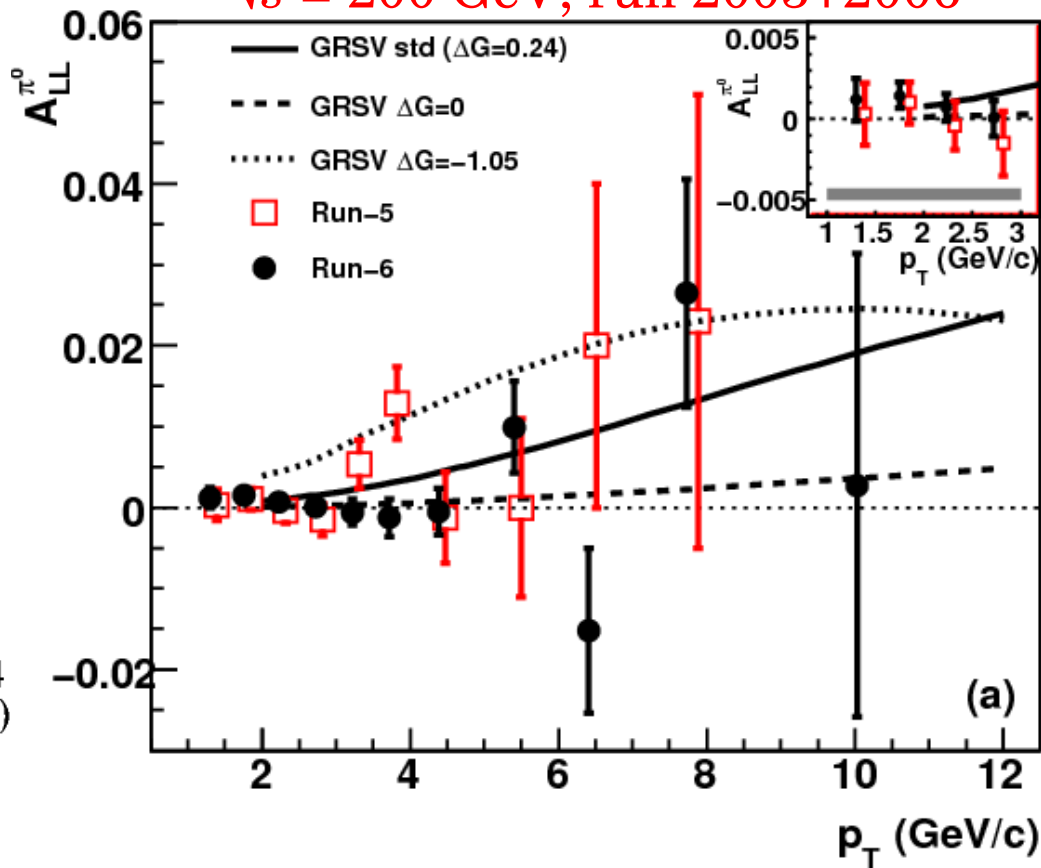
# Results from 2005 & 2006 Data

## Double helicity asymmetry ( $A_{LL}$ )

$\sqrt{s} = 62.4$  GeV, run 2006



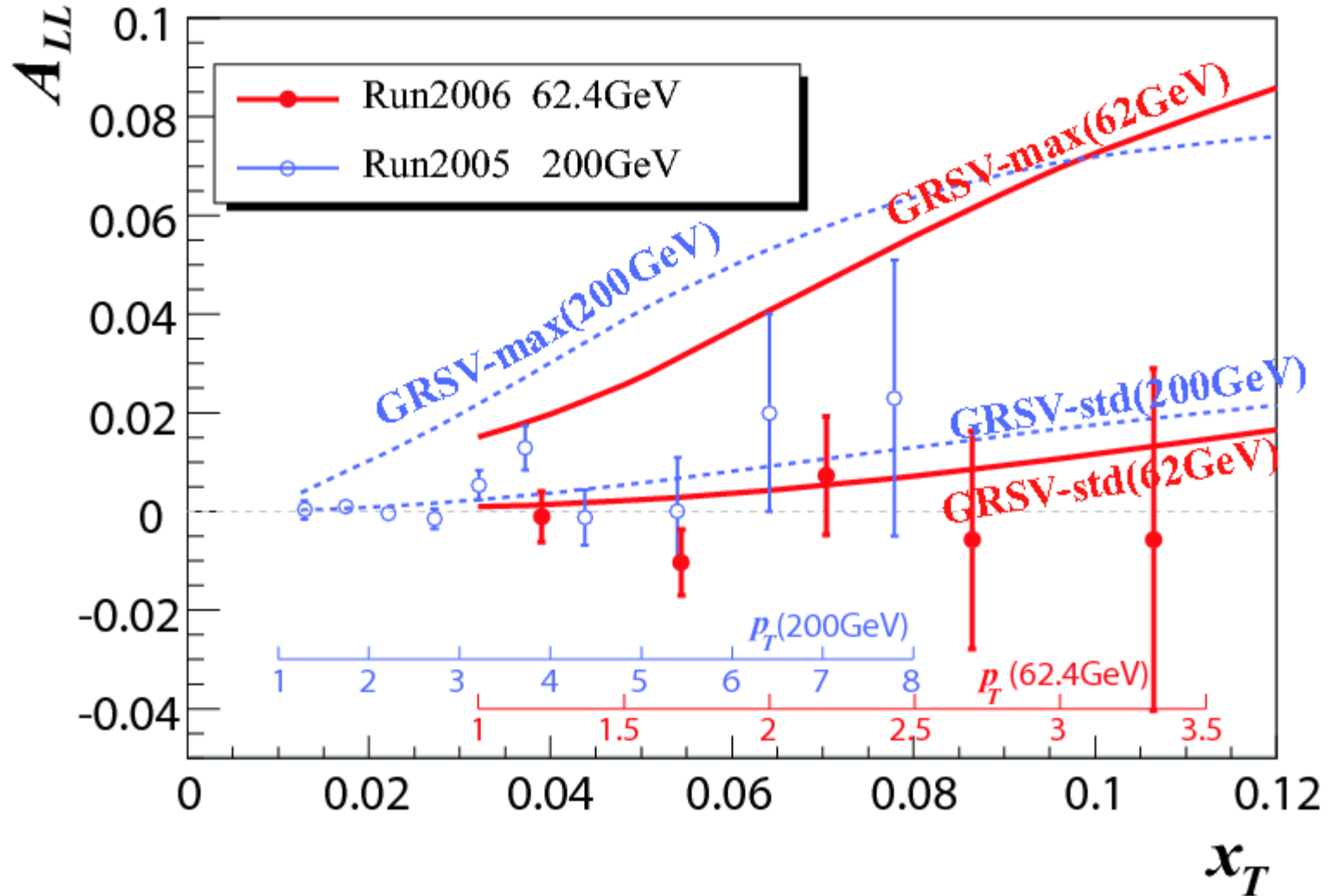
$\sqrt{s} = 200$  GeV, run 2005+2006



■ the size of stat. error approaches to that of relative lumi. error at low  $\pi^0 p_T$

# Results from 2005 & 2006 Data

■  $A_{LL}$  vs  $x_T \dots x$  coverage by  $\pi^0 A_{LL}$



■ 62.4 GeV data probe higher  $x_{\text{gluon}}$  range with better stat. accuracy

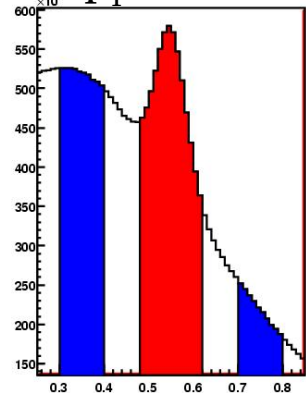
# $\eta$ Measurement

- Can have an enhanced sensitivity to  $\Delta G$  &  $\Delta s$

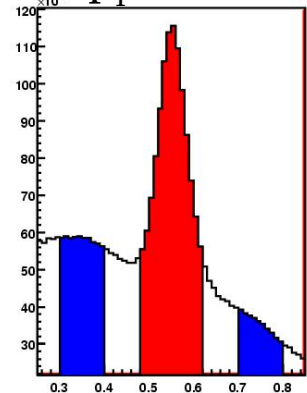
- Measurement method same as  $\pi^0$

- $\eta \rightarrow 2\gamma$ , BR 39%

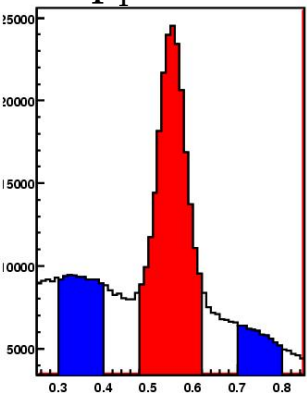
$2 \leq p_T < 3$  GeV/c



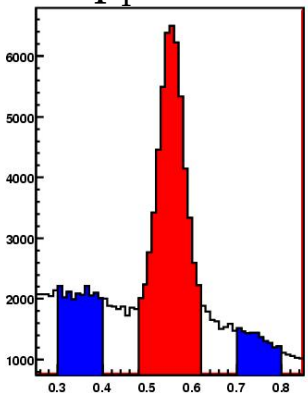
$3 \leq p_T < 4$  GeV/c



$4 < p_T < 5$  GeV/c

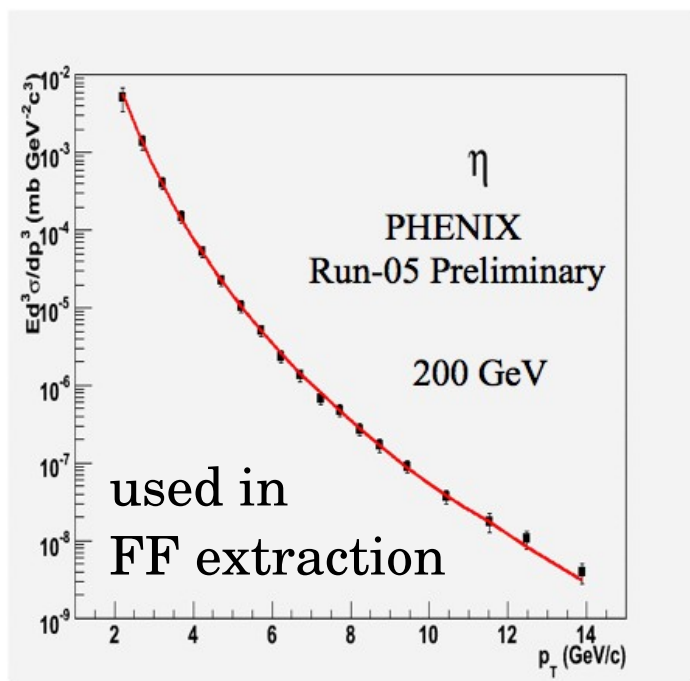


$5 < p_T < 6$  GeV/c

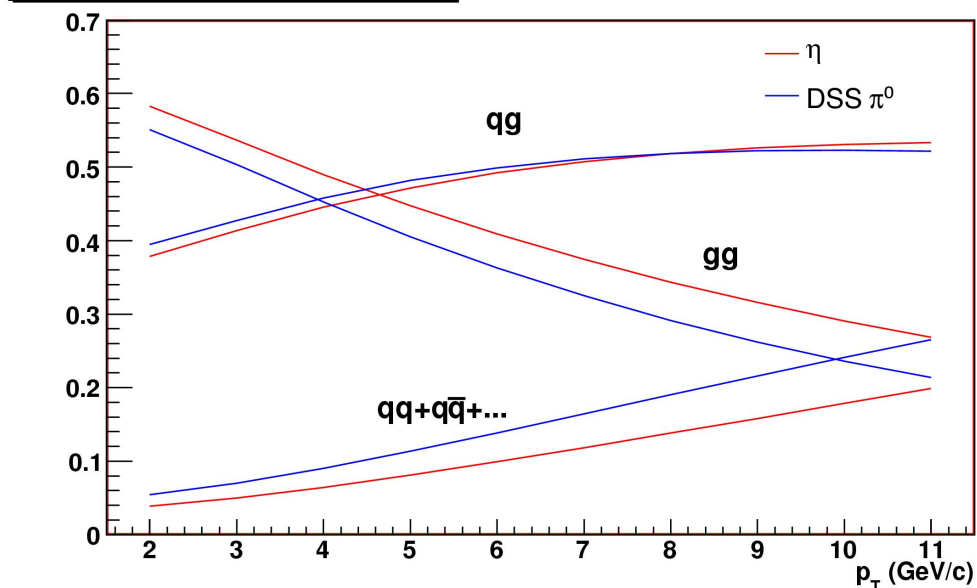


$M_{\gamma\gamma}$  (MeV)

- Fragmentation function evaluated with  $e^+e^-$  & PHENIX data

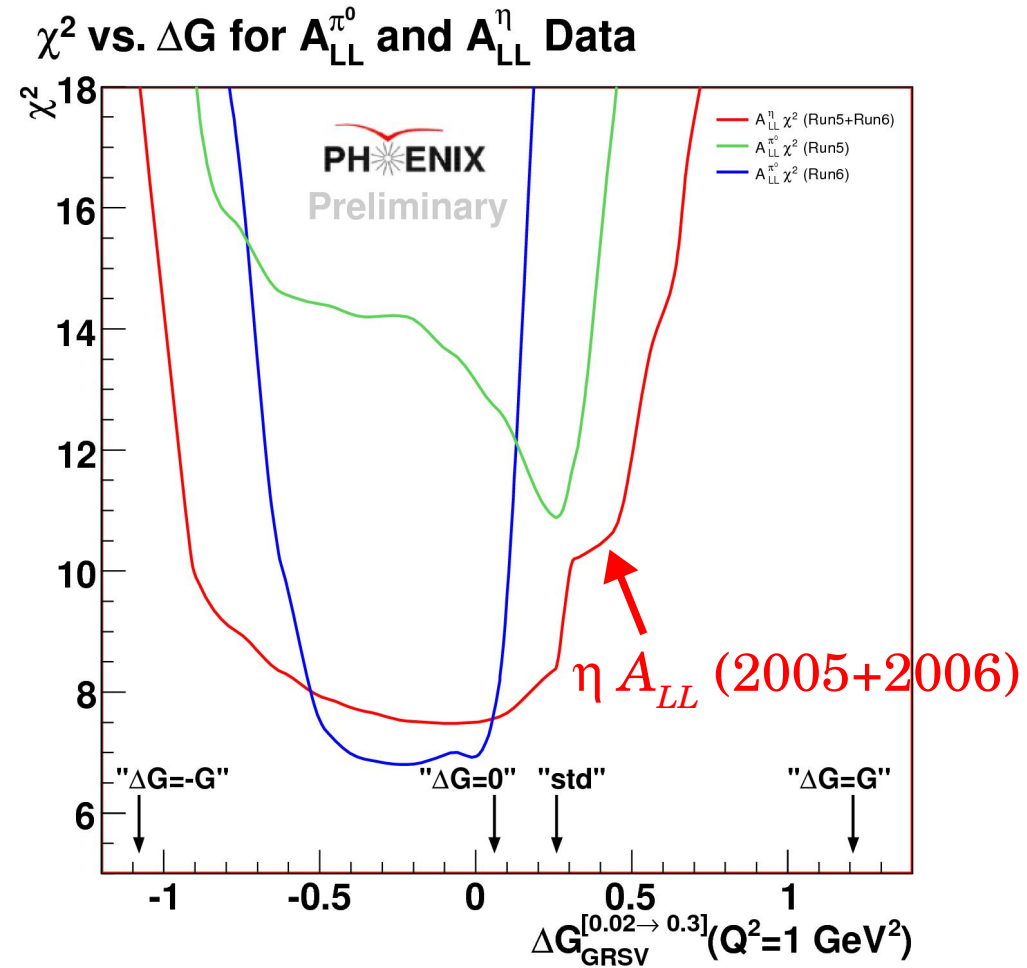
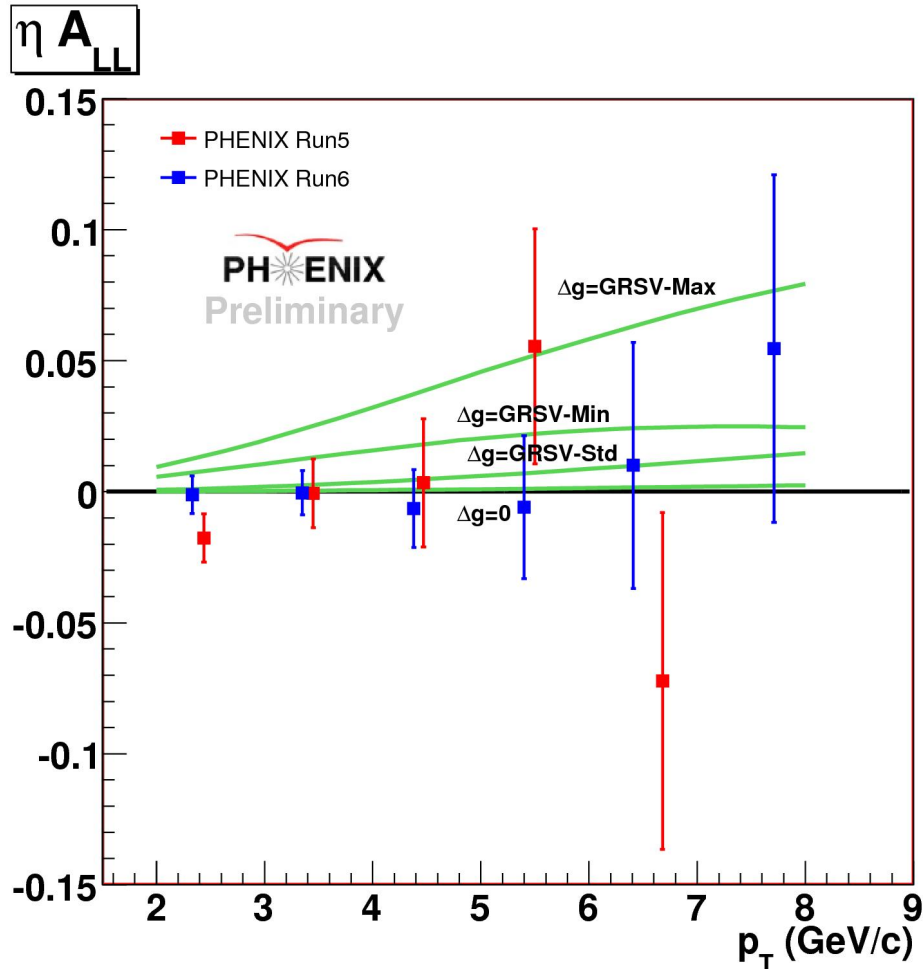


$\eta$  and  $\pi^0$  Subprocess fractions



# $\eta$ Measurement

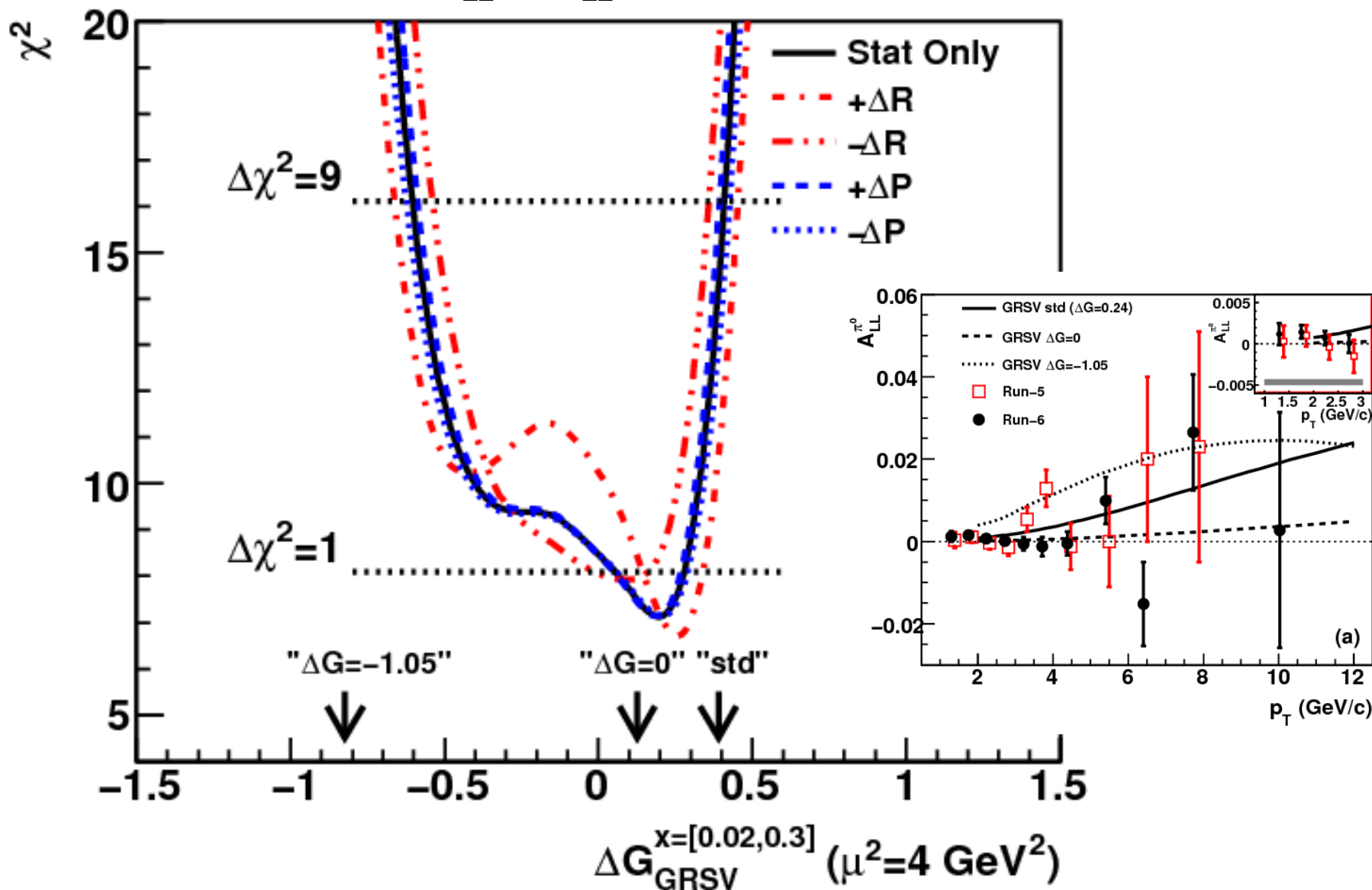
■  $A_{LL}$  result with 2005 & 2006 data



# Results from 2005 & 2006 Data

■ Constraint on  $\Delta g$  with  $\sqrt{s} = 200$  GeV data

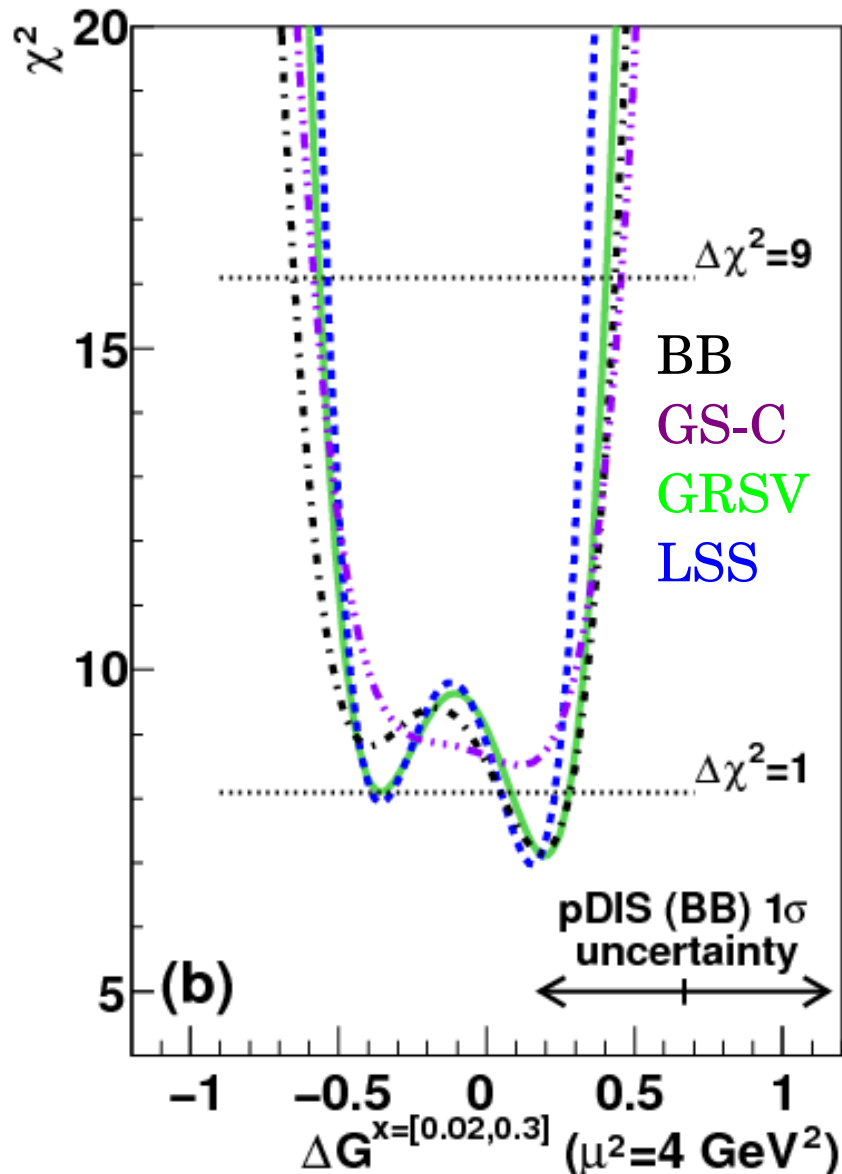
■ compare measured  $A_{LL}^{\pi^0}$  to  $A_{LL}^{\pi^0}$  calculated with various  $\Delta g(x)$  forms



■  $\Delta G_{\text{GRSV}}^{[0.02, 0.3]} = 0.2 \pm 0.1 (1\sigma) = 0.2^{+0.2}_{-0.8} (3\sigma)$  with  $\pm 0.1$  relative lumi. error

## Results from 2005 & 2006 Data

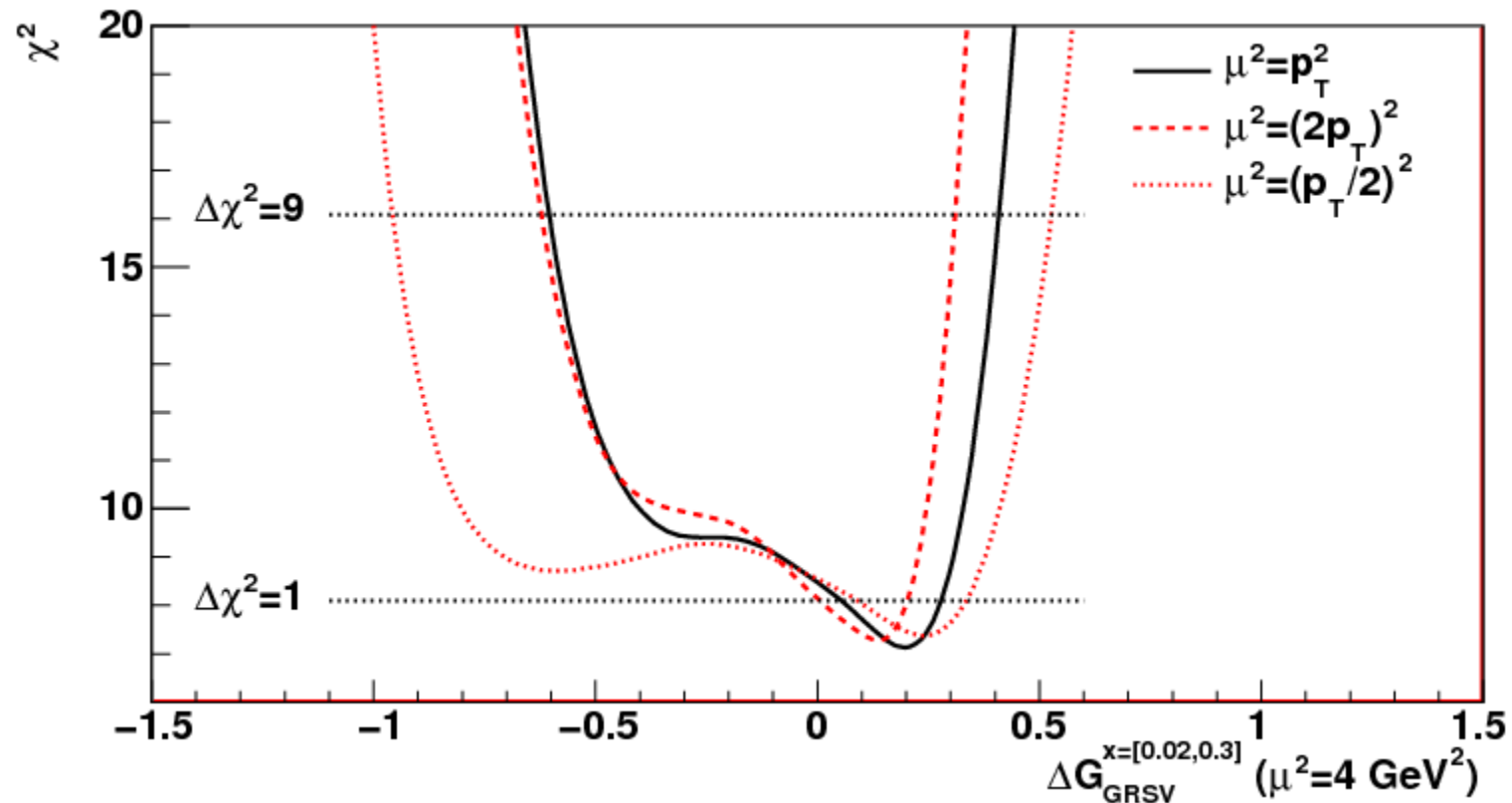
- Systematic uncertainties – pol. PDF functional form
  - for each model, scan  $\Delta G^{[0,1]}$  by varying  $\Delta g$  at the input scale while fixing  $\Delta q(x)$  and the shape of  $\Delta g(x)$ , i.e. no refit to DIS data



- inside of  $x = [0.02, 0.3]$  ...  
 PHENIX  $\pi^0 A_{LL}$  can determine  $\Delta G^{[0.02, 0.3]}$  regardless of  $\Delta g(x)$  shape
- outside ...  
 $\Delta G^{[0, 0.02]} + \Delta G^{[0.3, 1]}$  is not settled and particularly depends on whether  $\Delta g(x)$  has a node

## Results from 2005 & 2006 Data

- Systematic uncertainties – theoretical (factorization & renormalization) scale



- ±0.1 variation at positive  $\Delta G$
- large variation at negative  $\Delta G$ 
  - in case of large negative  $\Delta G$ ,  
(large positive  $g+g A_{LL}$ ) + (large negative  $q+g A_{LL}$ ) = (rather small  $A_{LL}^{\pi^0}$ )
  - this balance can be changed by different gluon evolution



# Conclusion

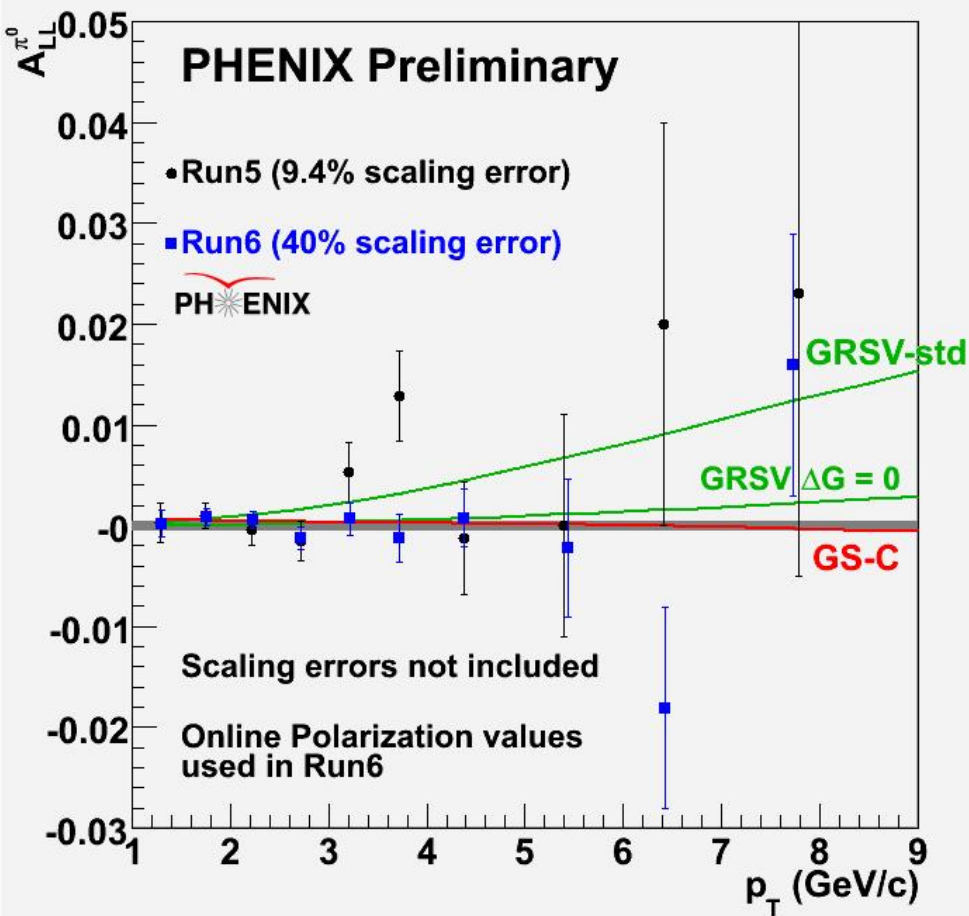
- RHIC-PHENIX is measuring the gluon polarization  $\Delta g$  in proton with longitudinally polarized p+p collisions
  - inclusive  $\pi^0$  measurement at mid-rapidity ( $|\eta| < 0.35$ )
  - new high-stat. data at  $\sqrt{s} = 200$  & 62.4 GeV in 2005 & 2006
- Cross section measurement
  - NLO pQCD is consistent with measurement
  - hard scattering dominates at  $p_T^{\pi^0} > 2$  GeV/c
  - NLL corrections might be important at  $\sqrt{s} = 62.4$  GeV
- $A_{LL}$  measurement
  - 62.4 GeV data ...  $2 < p_T < 4$  GeV/c,  $0.06 < x < 0.4$
  - 200 GeV data ...  $2 < p_T < 12$  GeV/c,  $0.02 < x < 0.3$
  - constraint on  $\Delta g$  with  $\sqrt{s} = 200$  GeV data
    - $\Delta G_{\text{GRSV}}^{[0.02, 0.3]} = 0.2 \pm 0.1$  ( $1\sigma$ ) =  $0.2^{+0.2}_{-0.8}$  ( $3\sigma$ ) with  $\pm 0.1$  relative lumi. error
    - PHENIX  $\pi^0 A_{LL}$  can determine  $\Delta G^{[0.02, 0.3]}$  regardless of  $\Delta g(x)$  shape

# Backup Slides...

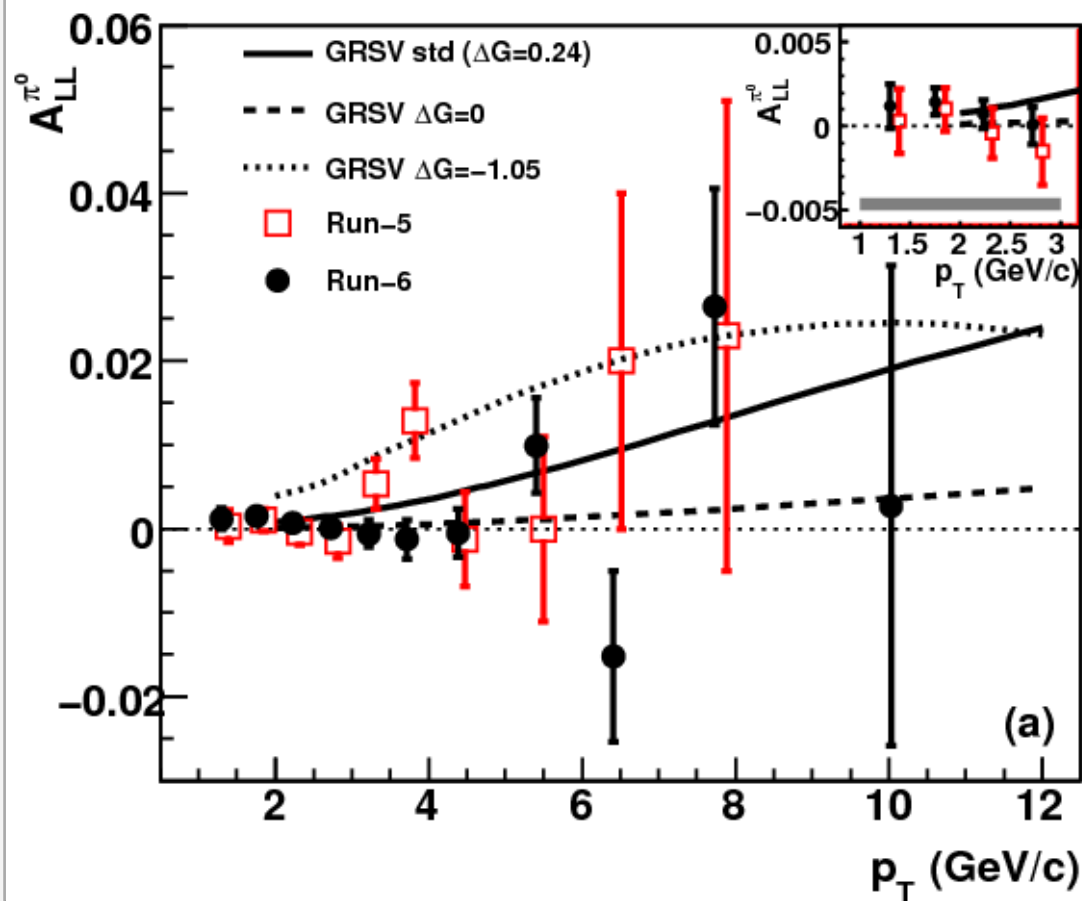
# Results from 2005 & 2006 Data

■ Final vs preliminary ( $\sqrt{s} = 200$  GeV)

Preliminary



Final

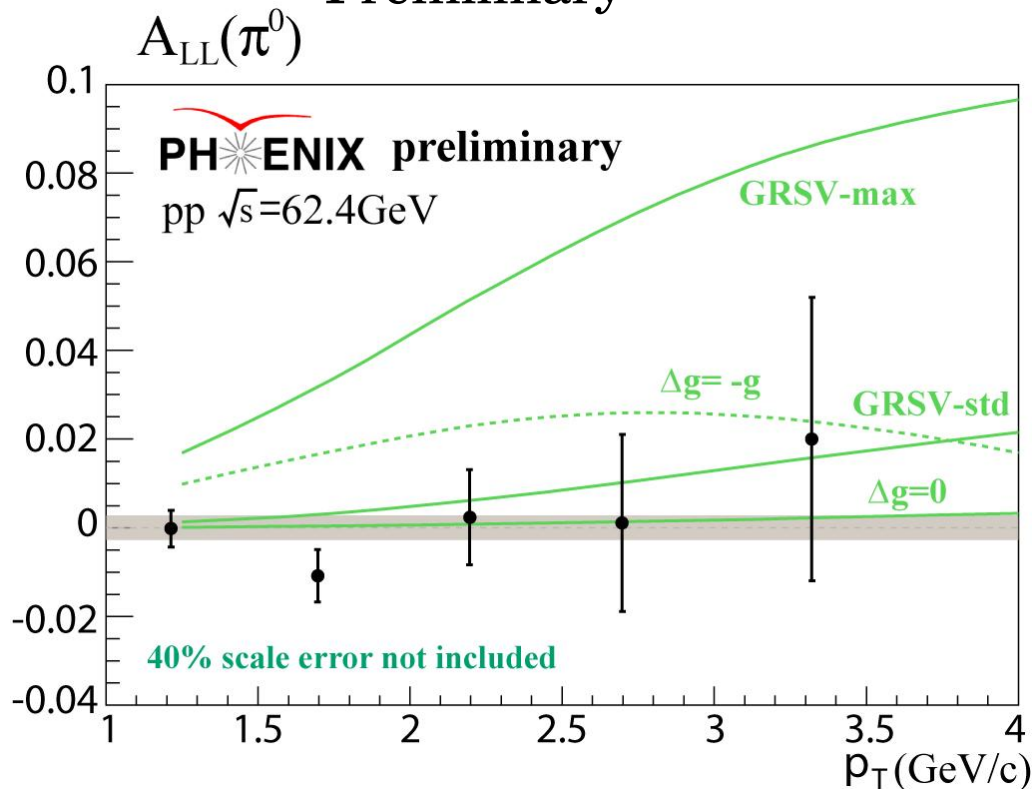


- final beam polarization used
- more data QAs done (EMCal, beam pol., etc.)
- no significant change from preliminary i.e. DSSV analysis

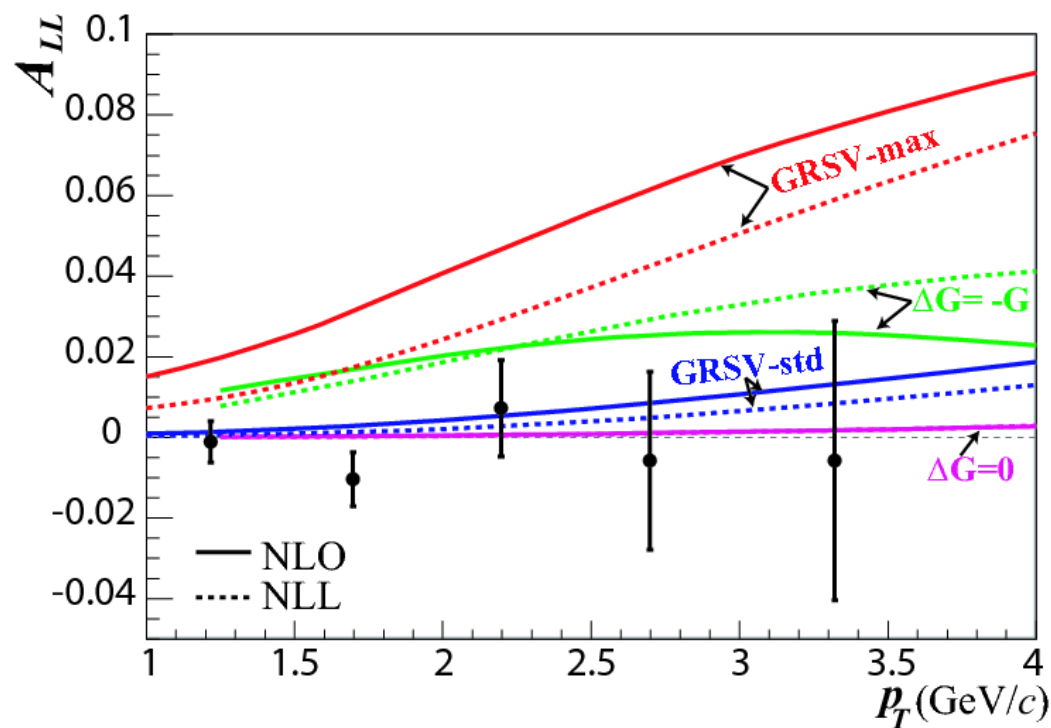
# Results from 2005 & 2006 Data

■ Final vs preliminary ( $\sqrt{s} = 62.4 \text{ GeV}$ )

Preliminary



Final



- final beam polarization used
- more data QAs done (EMCal, beam pol., etc.)
- no significant change from preliminary i.e. DSSV analysis