Determination of Δg from Inclusive π^0 Measurement at RHIC-PHENIX

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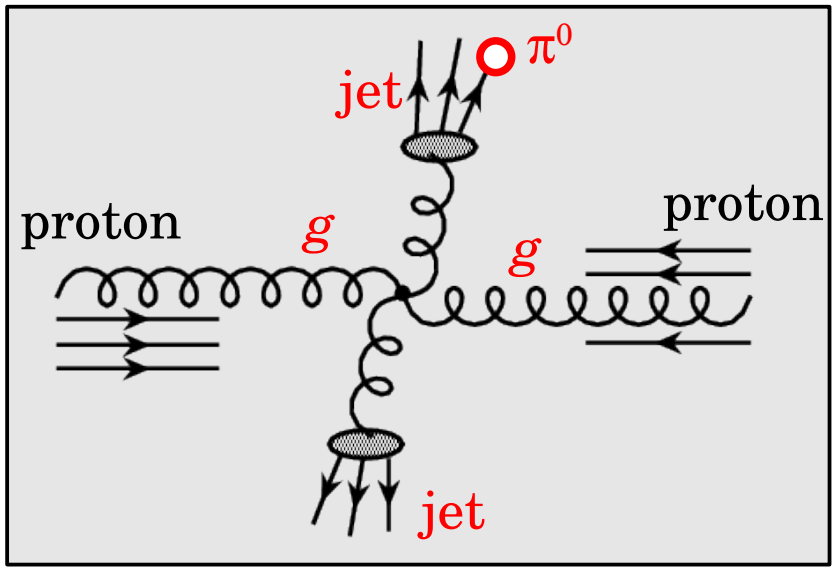
Introduction

- 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 data, $\Sigma\Delta q = 0.330(39)$ at $Q^2 = 5$ GeV^2 [PRD75, 012007]
  - need determine the gluon polarization Δg first by experiment

- Polarized p+p collisions for Δg measurement
  - π^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 $p_T^{\pi 0} \sim 10$ GeV/c
  - in case of π^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 $A_{LL}^{gq} \sim \frac{\Delta g}{g} \cdot \frac{\Delta q}{q}$, $A_{LL}^{qq} \sim \frac{\Delta q}{q} \cdot \frac{\Delta q}{q}$

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

Introduction

- Data accumulation in longitudinally polarized p+p run

Year	$\sqrt{s}$ (GeV)	FoM ($P^4 L$) (10^{-3} pb^{-1})	Int. Lumi. (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 –> better sensitivity to higher x

Introduction

- PHENIX π^0 A_{LL} results

	√s (GeV)	Year of data	Publication/presentation
2006 May	200	2003+2004	PRD73, 091102(R)
2006 Oct.	200	2006, high-p_T	*preliminary*, SPIN2006
	62.4	2006	*prel.*, SPIN2006
2007 Sep.	200	2005	PRD76, 051106
2007 Jul.	200	2006, low-p_T	*prel.*, RHIC & AGS Users Meeting
(2008 Apr.	global analysis by DSSV used run 2005 & 2006 data)		
2008 Oct.	200	2006	submitted to PRL (arXiv:0810.0694)
	62.4	2006	submitted to PRD (arXiv:0810.0701)

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

PHENIX Experiment

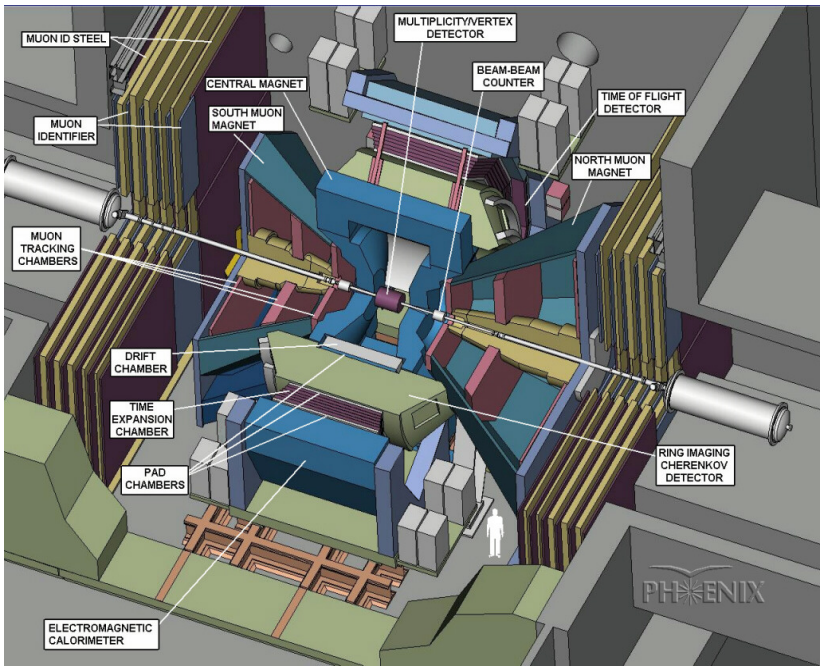
- Relativistic Heavy Ion Collider (RHIC)
  - the first collider for polarized proton-proton collision
  - √s = 62.4, 200, (500) GeV

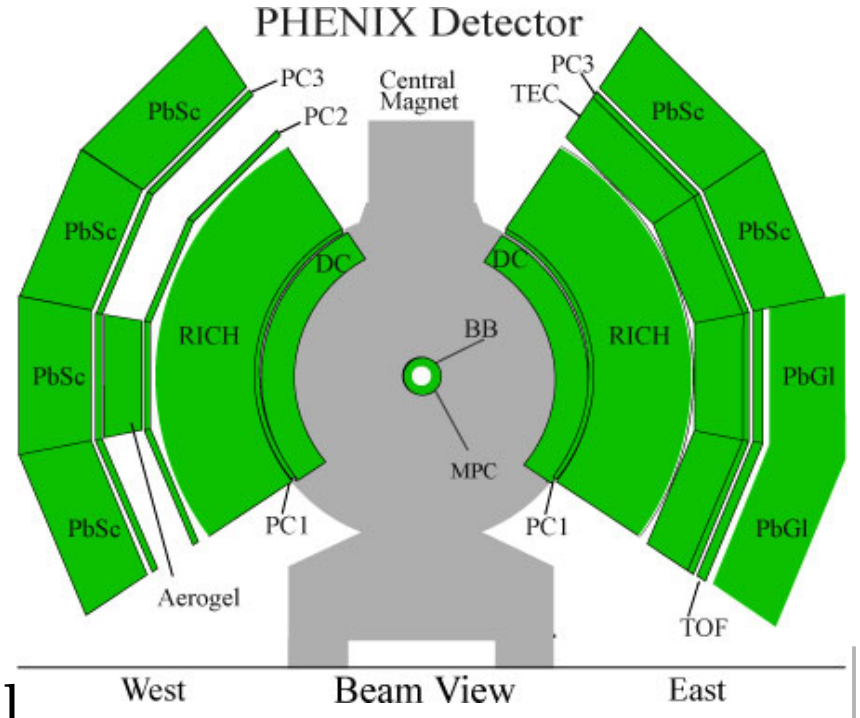
here

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

PHENIX Experiment

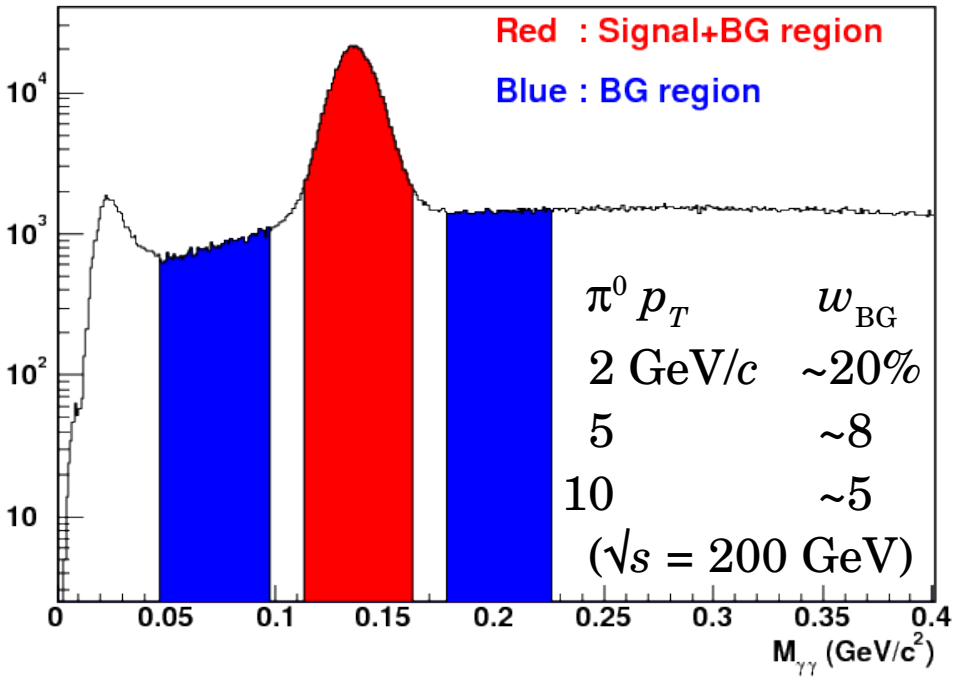
- Central Arm detectors
  - $\Delta\phi$ = 90° x 2, $|\eta| < 0.35$
  - EMCal (PbSc & PbGl) for photon detection
    - σ_E/E ~ 8% at 1 GeV
    - fine segmentation, 0.01x0.01 rad/seg.
      –> $\gamma\gamma$ separation up to $E^{\pi 0}$ = 20 GeV
    - background exclusion by ele.mag. shower shape cut, charged matching and ToF cut
- Forward detectors (near beam pipe)
  - Beam-Beam Counter
    (charged particles at 3.0<|η|<3.9)
  - Zero-Degree Cal. (neutrons at ±2.8 mrad)
  - absolute & relative luminosity
  - beam pol. direction at PHENIX
- Trigger
  - Min. Bias trigger by BBC
  - high-energy photon (>~1.4 GeV) by EMCal





Measurement of π^0 A_{LL}

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



- π^0 yield measurement
  - π^0 –> $\gamma\gamma$, BR 99%
  - combinatorial BG fraction

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

- A_{LL} measurement

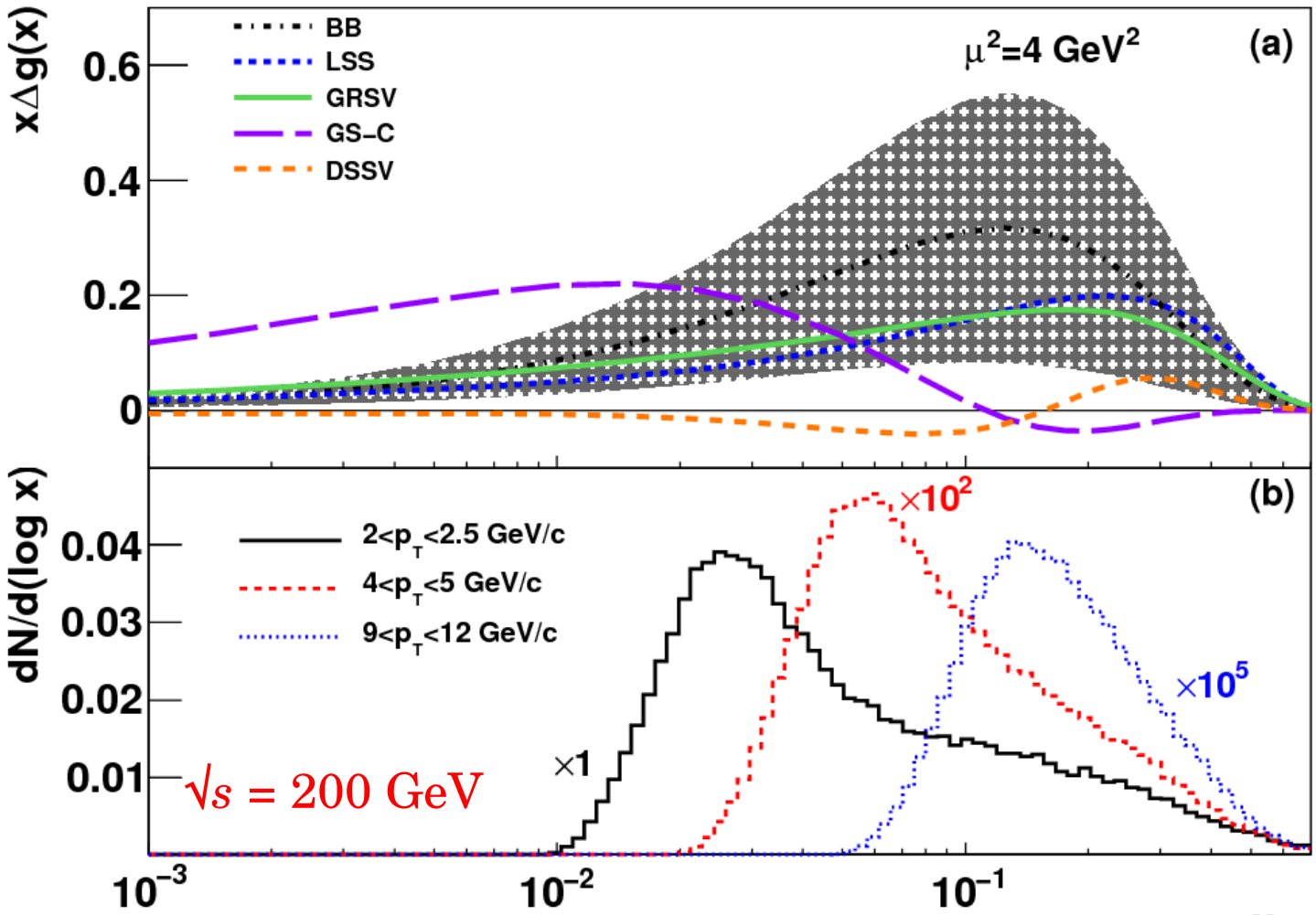
$$A_{LL} \equiv \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_B P_Y} \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}} \quad , \quad R \equiv \frac{L_{++}}{L_{+-}}$$

  - P_B, P_Y ... beam polarization, ~10% syst. error in $P_B \cdot P_Y$
  - R ... relative luminosity, δ_{ALL} = 2x10^{-4} in 2005, = 7x10^{-4} in 2006
  - N_{++} (N_{+-}) ... π^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 π^0 A_{LL}

- x_{gluon} coverage by π^0 A_{LL}
  - based on a simulation using NLO pQCD as input

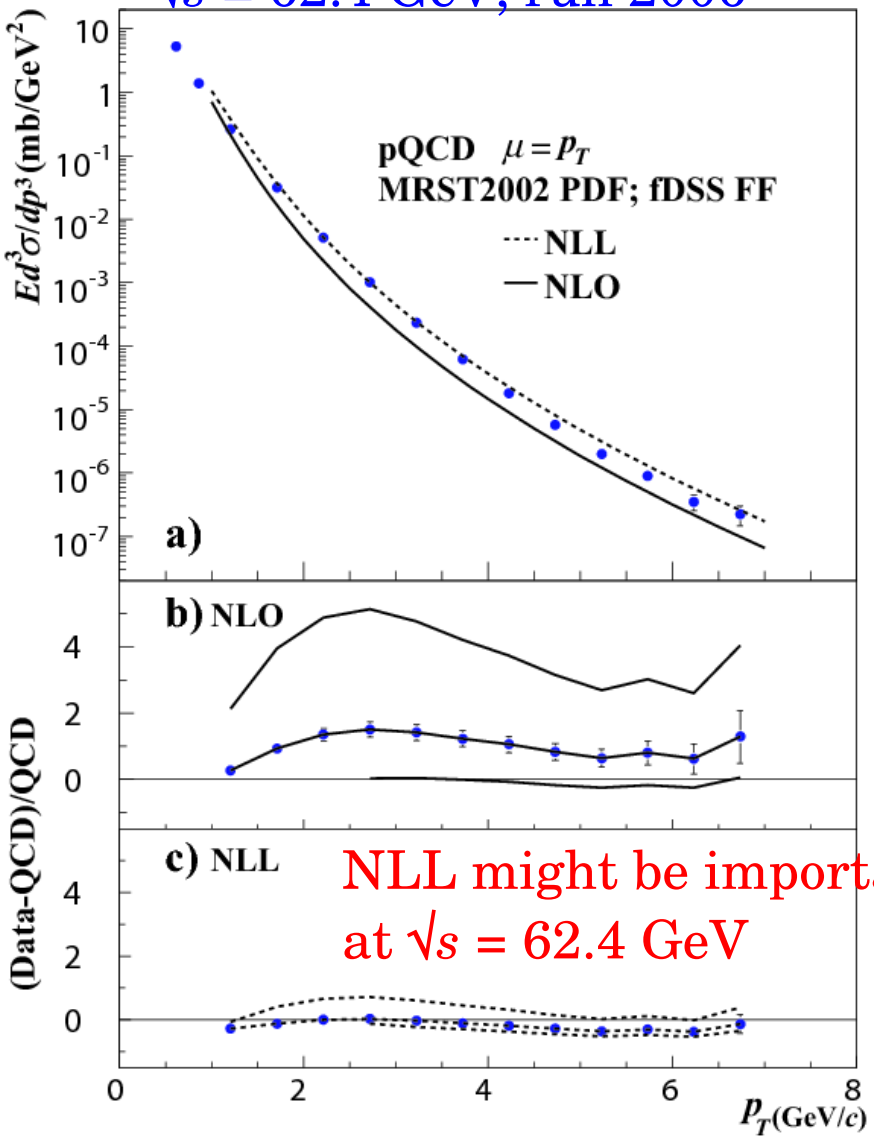


- $0.02 < x_{\text{gluon}} < 0.3$ ($\sqrt{s}$ = 200 GeV), $0.06 < x_{\text{gluon}} < 0.4$ (62.4 GeV)
- larger sensitivity at lower x_{gluon} (~ 0.03 at 200 GeV) within the range above

Results from 2005 & 2006 Data

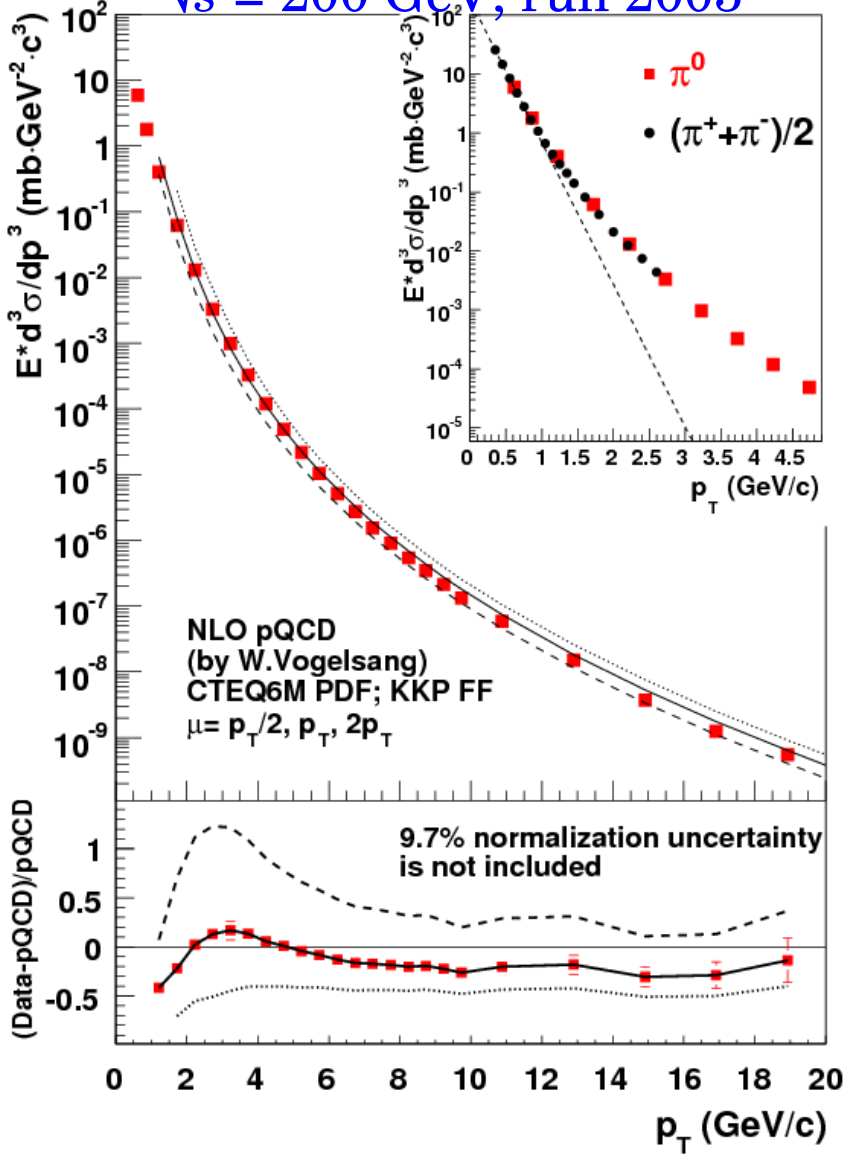
- Cross section
  - check the applicability of NLO pQCD –> good agreement
  - check the contribution of soft-scattering events at low p_T –> OK at >2 GeV/c

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



NLL might be important at $\sqrt{s}$ = 62.4 GeV

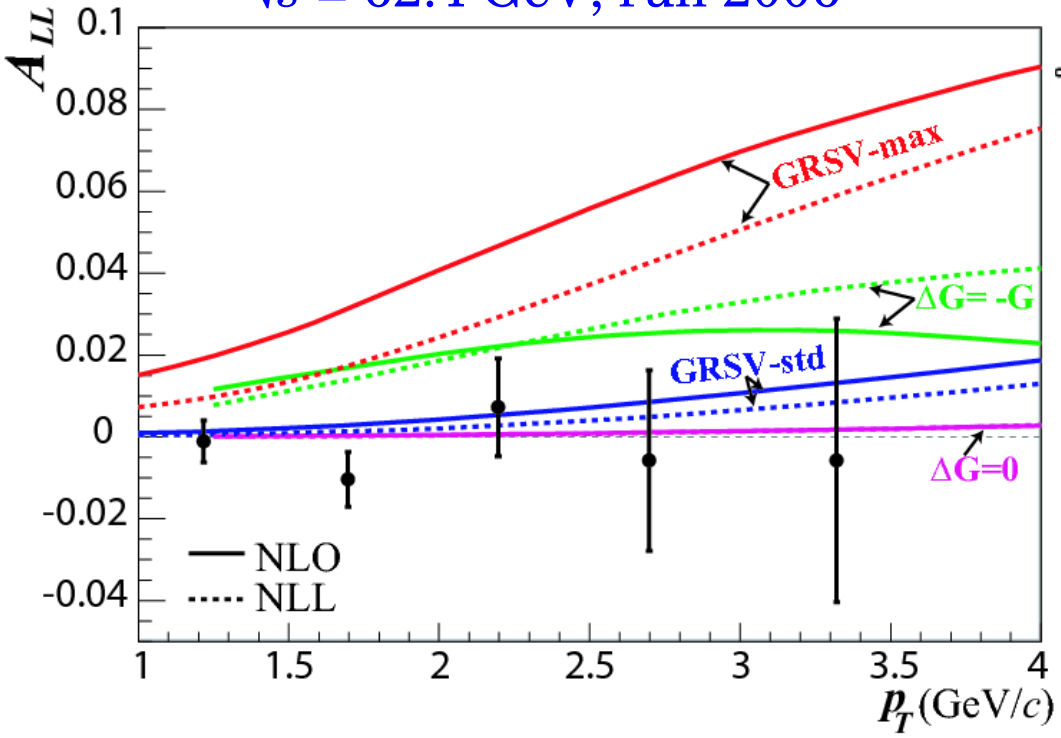
$\sqrt{s}$ = 200 GeV, run 2005



Results from 2005 & 2006 Data

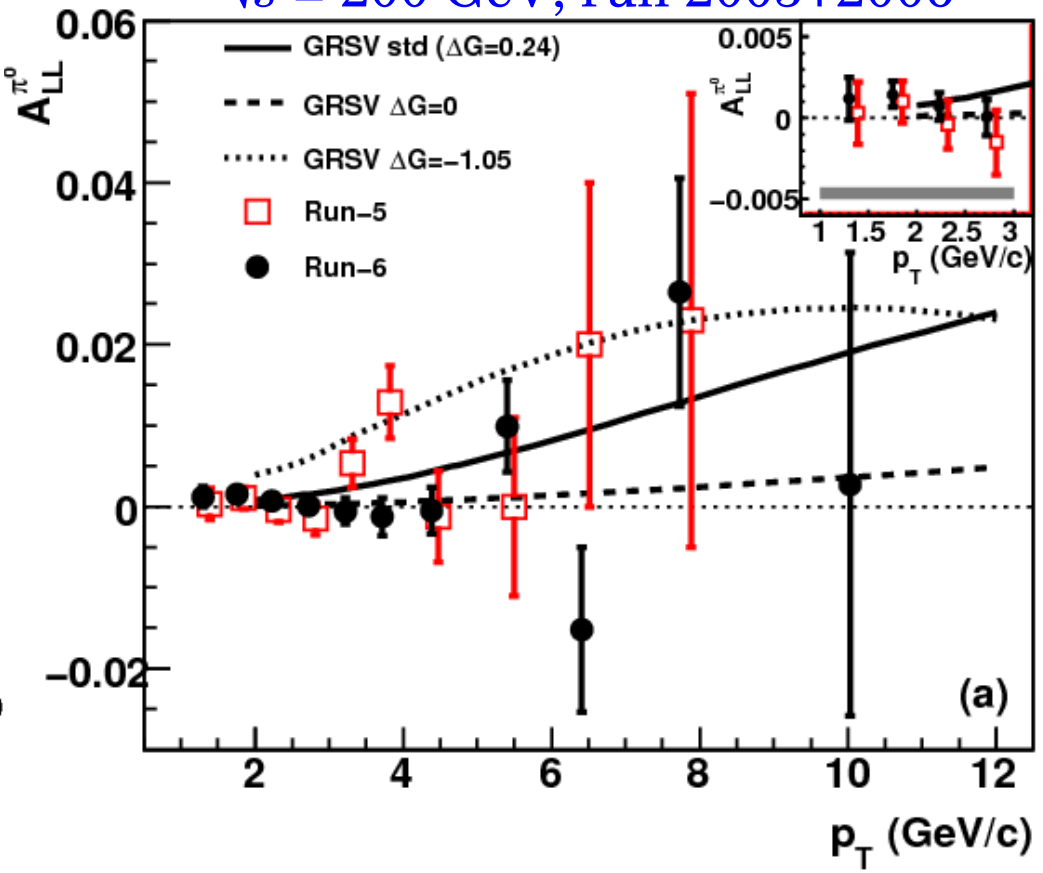
- Double helicity asymmetry (A_{LL})

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



- the difference between NLO and NLL is not pronounced in small-Δg cases

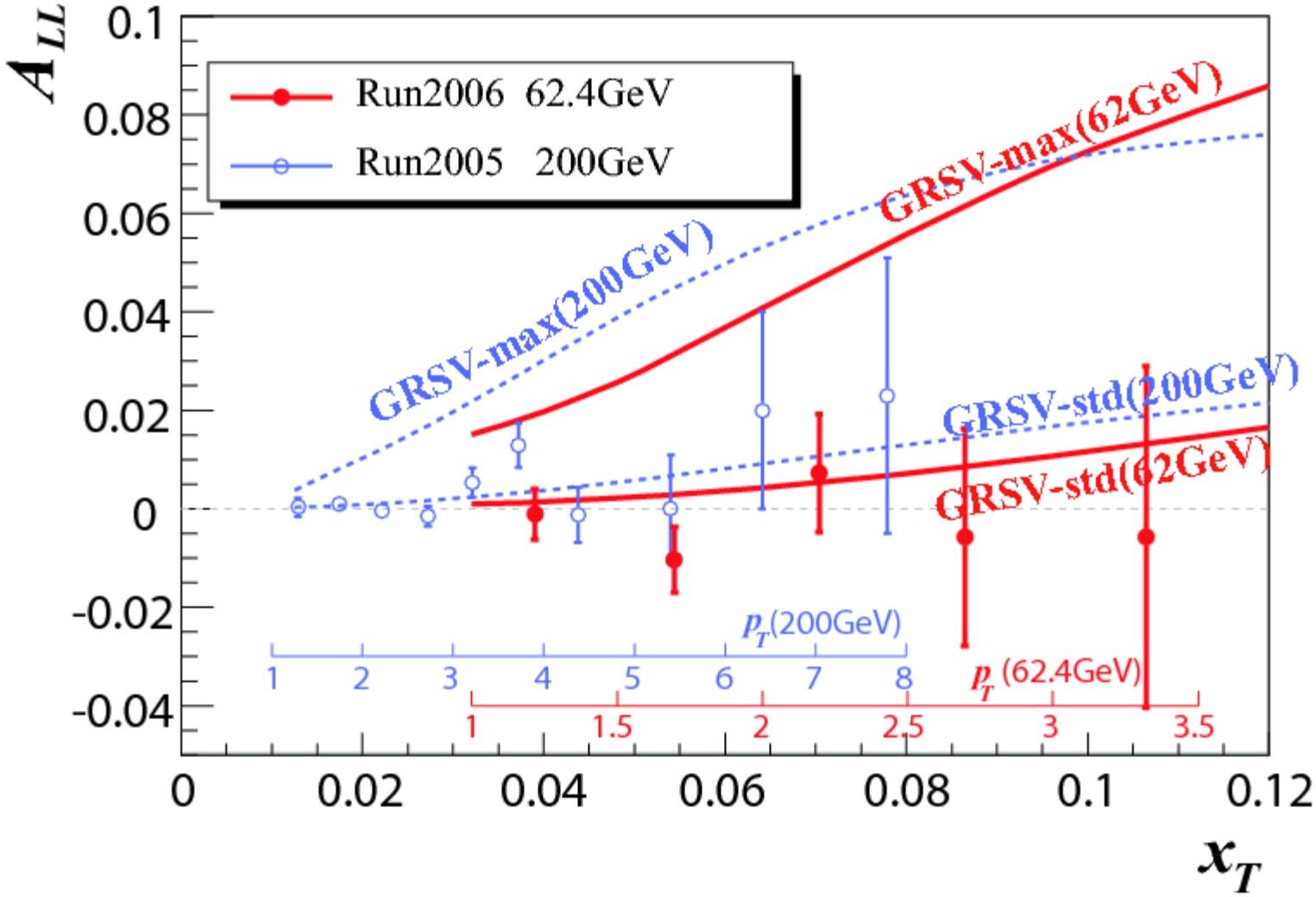
$\sqrt{s}$ = 200 GeV, run 2005+2006



- the size of stat. error approaches to that of relative lumi. error at low π^0 p_T

Results from 2005 & 2006 Data

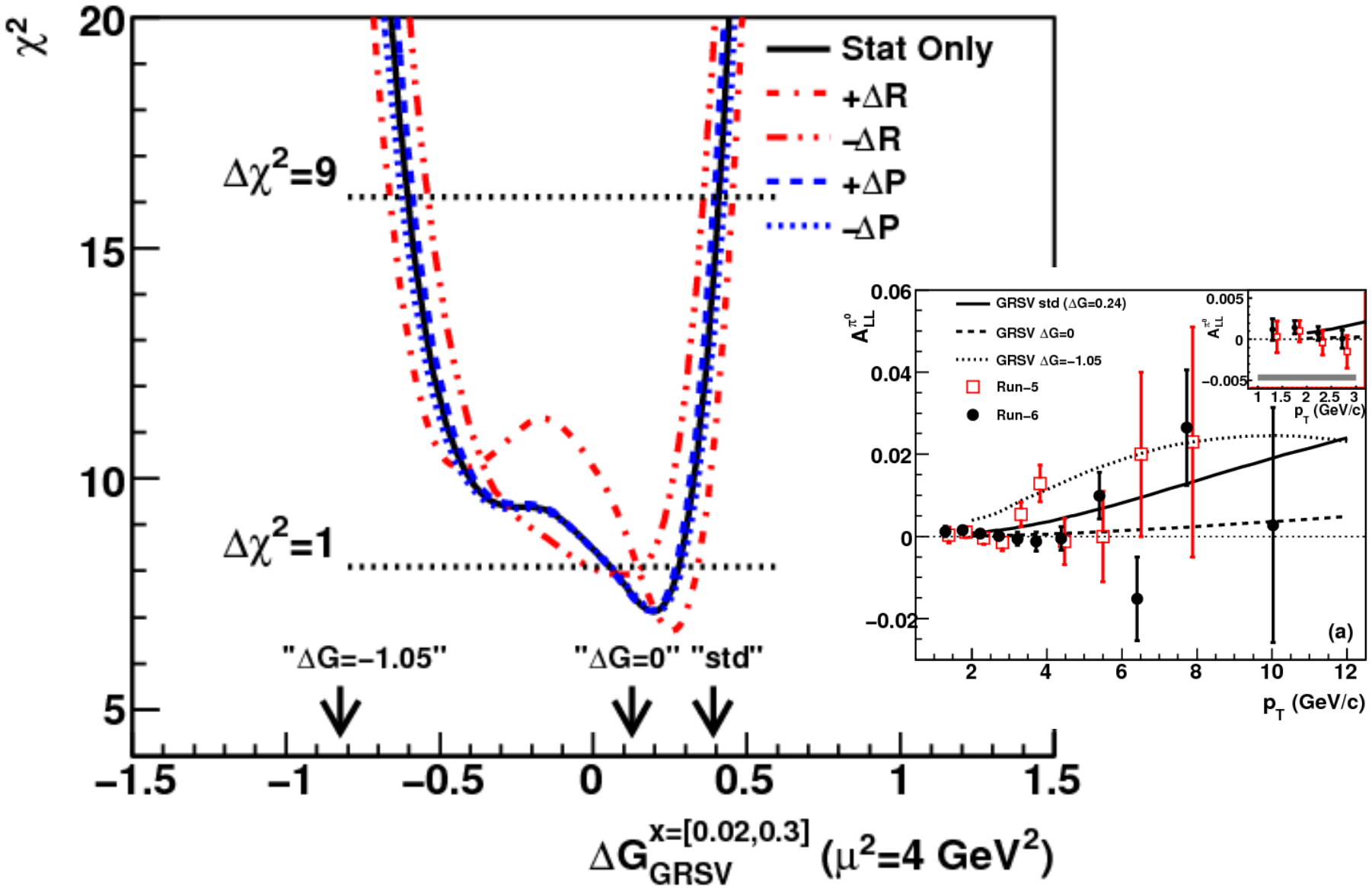
- A_{LL} vs x_T ... x coverage by π^0 A_{LL}



- 62.4 GeV data probe higher x_{gluon} range with better stat. accuracy

Results from 2005 & 2006 Data

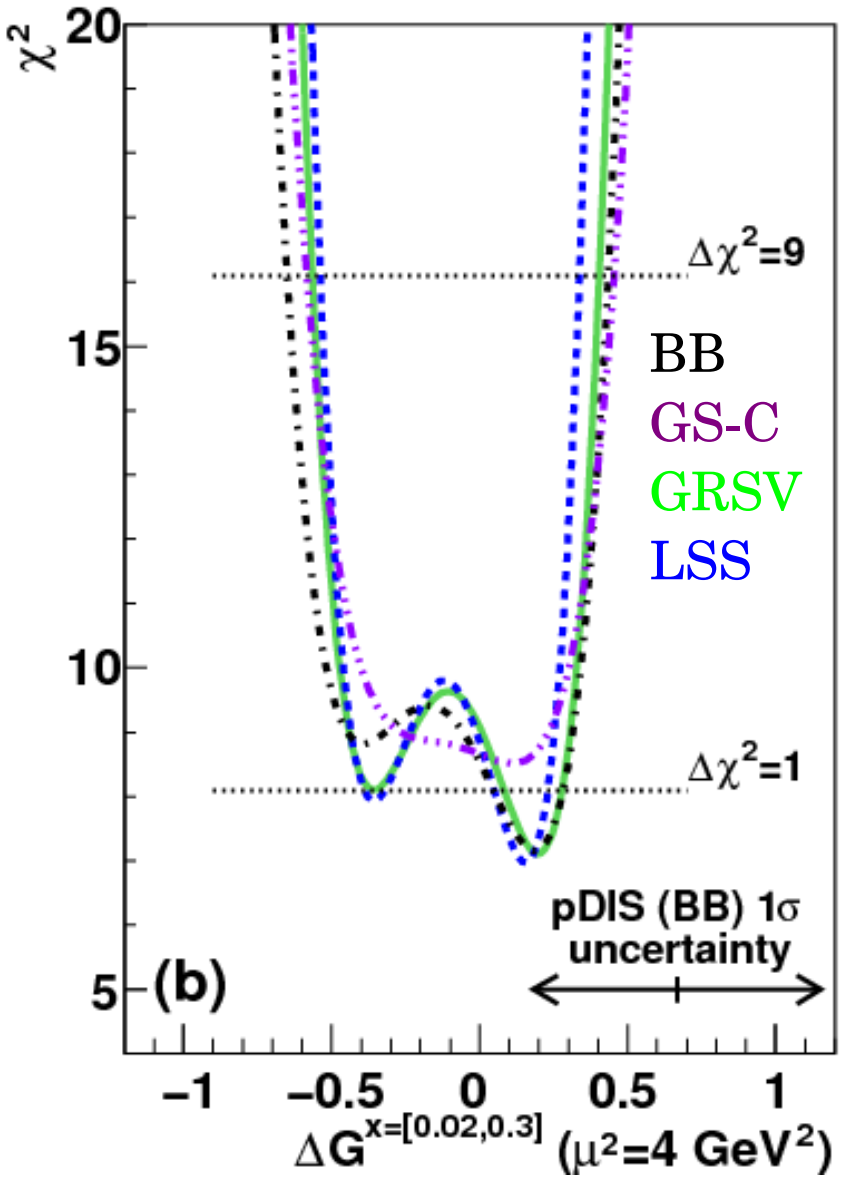
- Constraint on ΔG with $\sqrt{s}$ = 200 GeV data
  - compare measured A_{LL} to A_{LL} calculated with various ΔG sizes



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

Results from 2005 & 2006 Data

- Systematic uncertainties – pol. PDF functional form
  - for each model, scan ΔG by varying ΔG 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 π^0 A_{LL} can determine

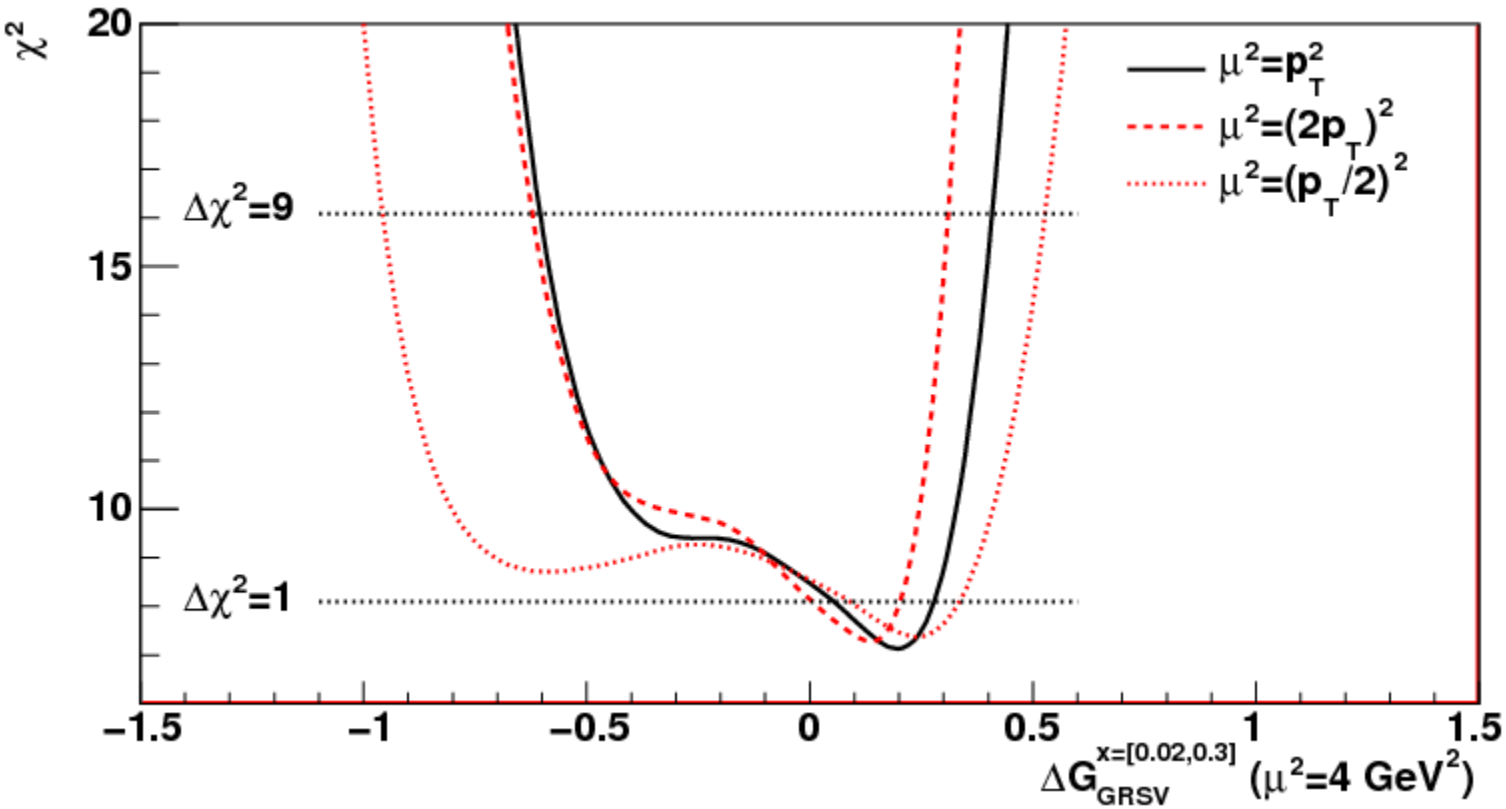
  $\Delta G^{[0.02,\ 0.3]}$ regardless of $\Delta g(x)$ shape

- 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 ΔG
- large variation at negative ΔG
  - in case of large negative ΔG,

    (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 Δg in proton with longitudinally polarized p+p collisions
  - inclusive π^0 measurement at mid-rapidity ($|\eta|<0.35$)
  - new high-stat. data in 2005 & 2006 at $\sqrt{s}$ = 200 GeV (**arXiv:0810.0694**) & 62.4 GeV (**arXiv:0810.0701**)

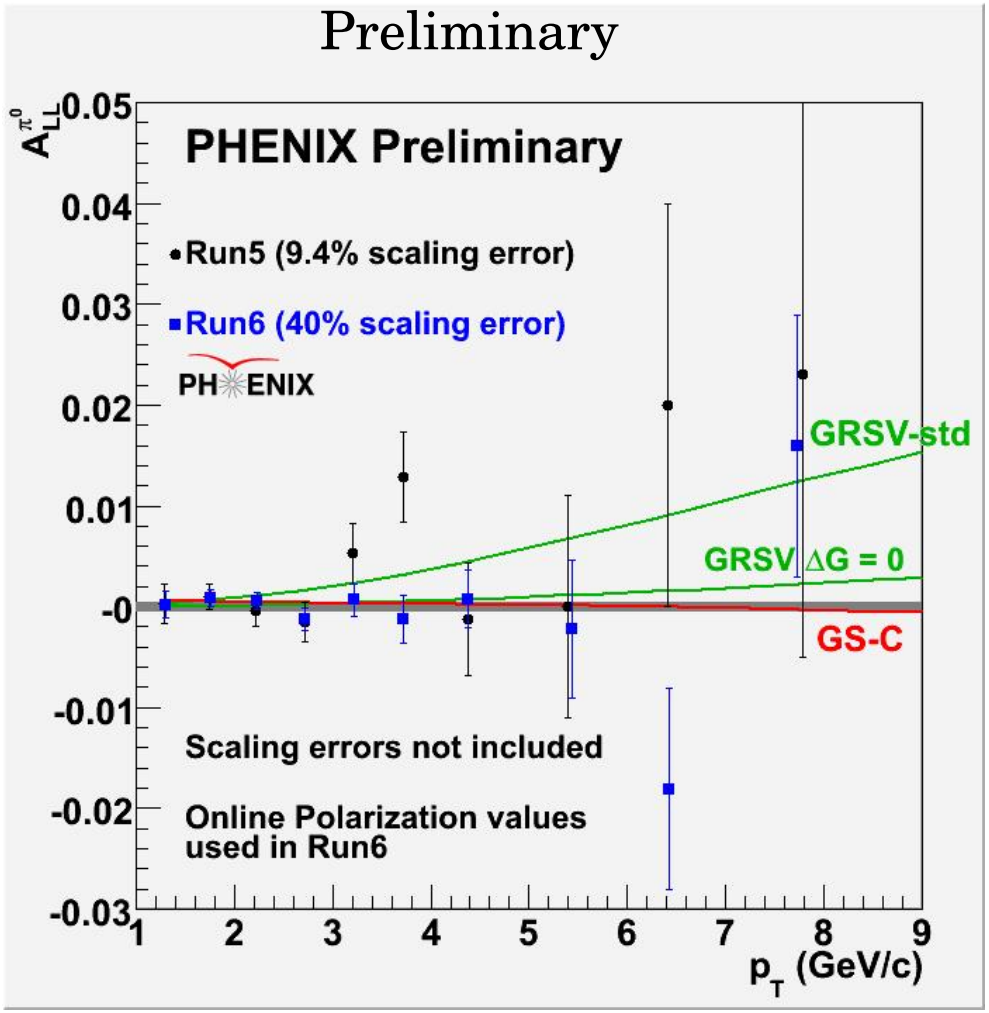
- A_{LL} measurement
  - 62.4 GeV data ... $2 < p_T < 4$ GeV/c, $0.06 < x < 0.4$
  - 200 GeV data ... $2 < p_T < 12$ GeV/c, $0.02 < x < 0.3$
  - constraint on Δg with $\sqrt{s}$ = 200 GeV data
    - $\Delta G_{\mathrm{GRSV}}^{[0.02,\ 0.3]} = 0.2 \pm 0.1\ (1\sigma) = 0.2^{+0.2}_{-0.8}\ (3\sigma)$ with ±0.1 relative lumi. error at $\mu^2 = 4$ GeV^2
    - PHENIX π^0 A_{LL} can determine $\Delta G^{[0.02,\ 0.3]}$ regardless of $\Delta g(x)$ shape
    - we can say **this size (0.2) is small** (vs GRSV-std or triangle-anomaly scenario) & **is large** (vs proton spin 1/2)

Backup Slides...

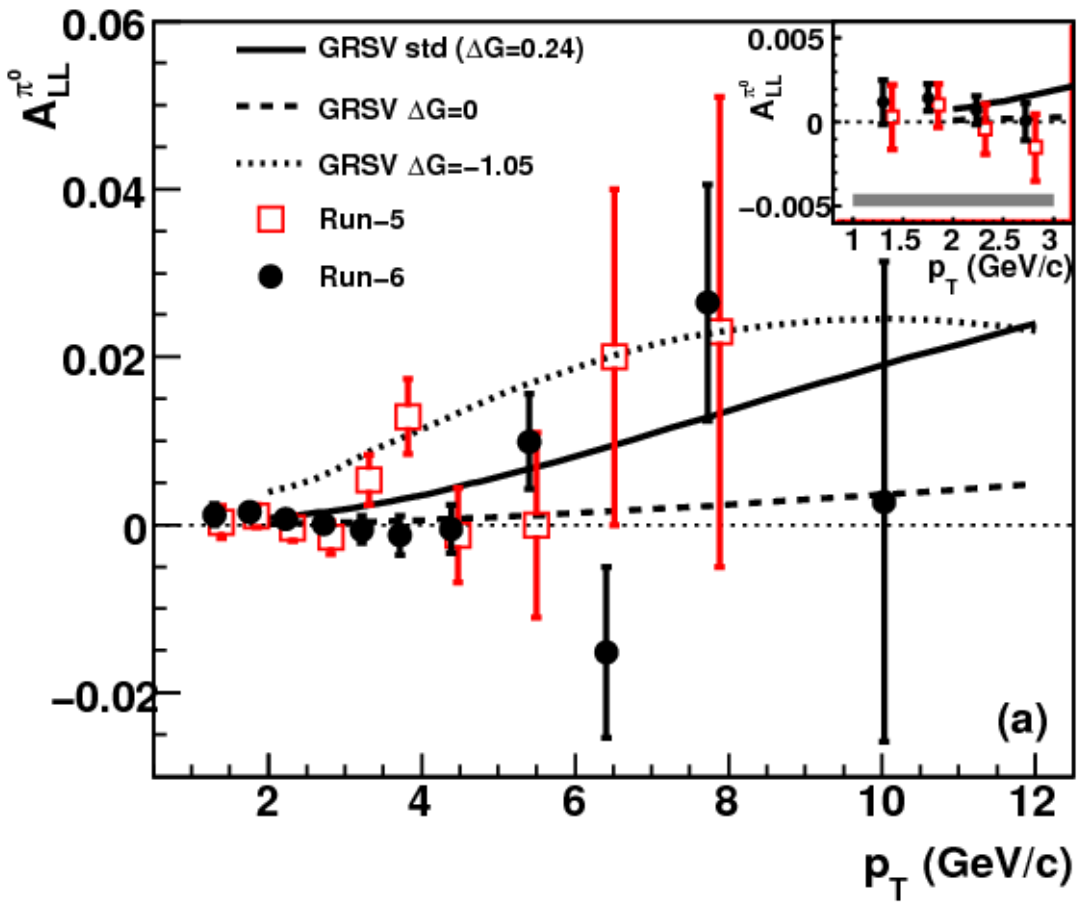
Results from 2005 & 2006 Data

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

Preliminary



Final

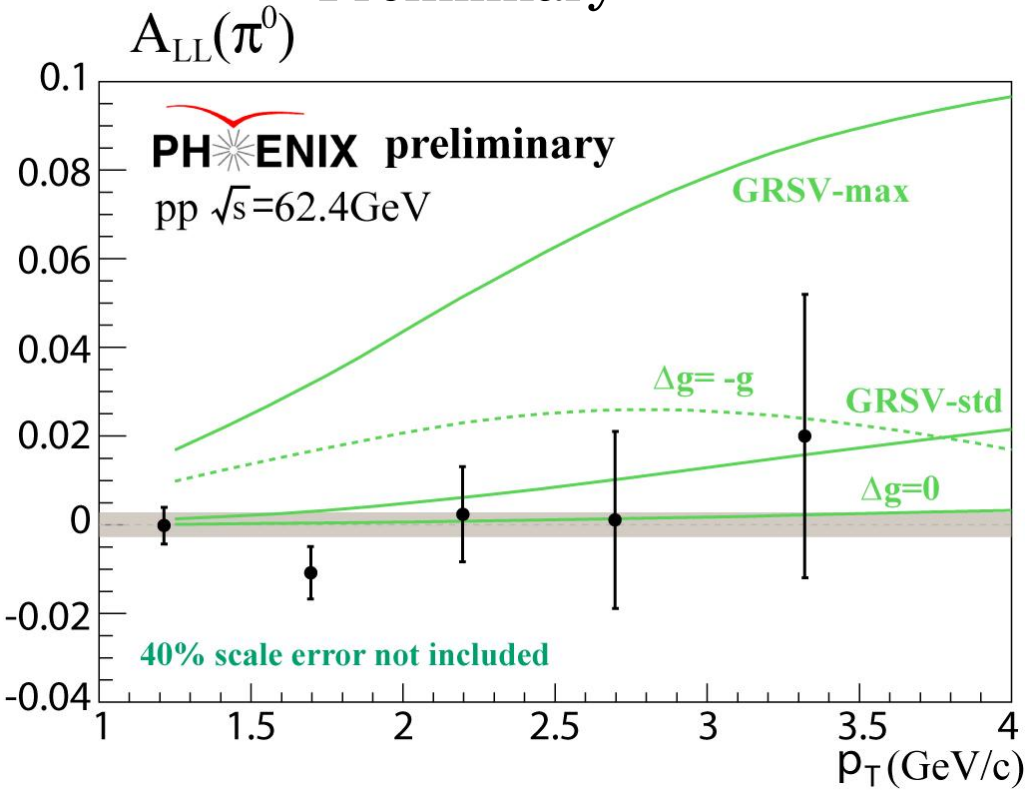


- final beam polarization used
- more data QAs done (EMCal, beam pol., etc.)
- no significant change from preliminary i.e. DSSV analysis

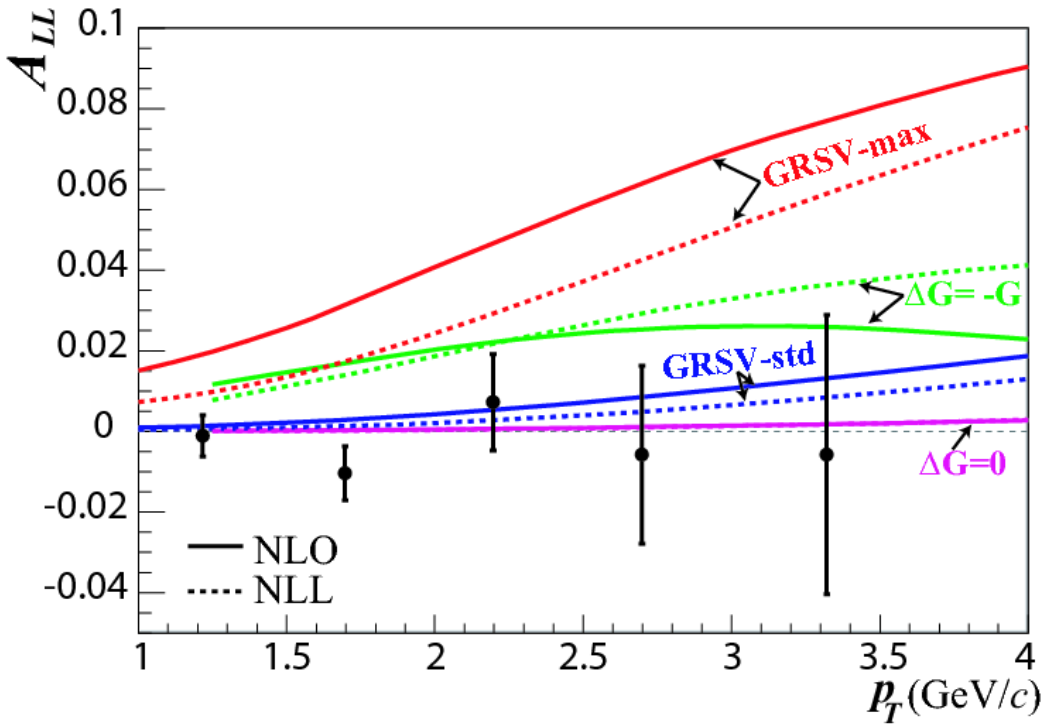
Results from 2005 & 2006 Data

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

Preliminary



Final



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