Searching for Polarized Glue at

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For the STAR Collaboration

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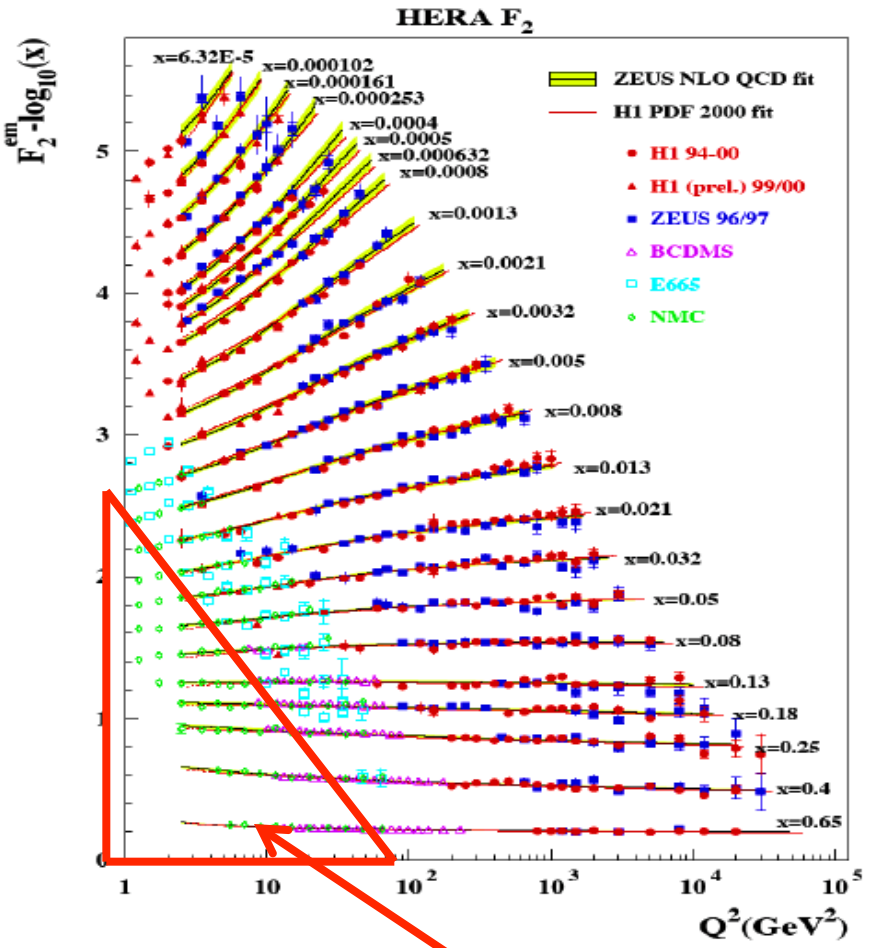
Outline

- Theoretical Overview
- Inclusive Jet Measurements
  - Brief Review of 2006
  - New 2009 Result
  - New Global Analyses
- Di-jet Correlation Measures
  - Di-jet Cross Section
  - Di-jet A_{LL} Statistical and Systematic Errors
- Future Measurements

Where's the Spin?



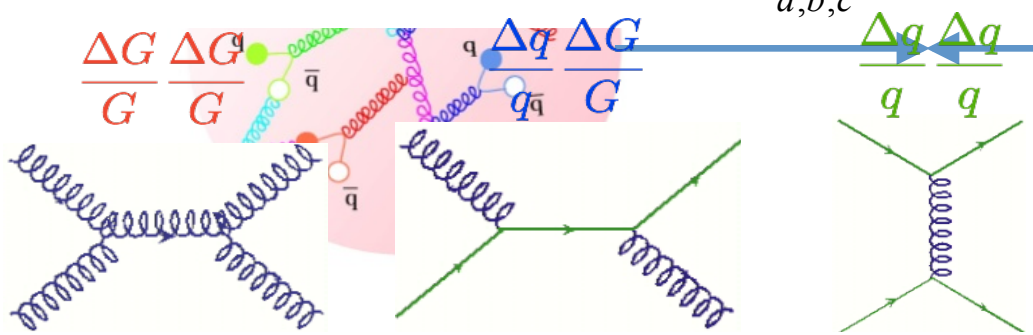
$$S = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$

- Polarized DIS tells us that $\Delta\Sigma \approx 0.3$
- Q^2 evolution in polarized DIS gives information on gluon polarization but limited kinematic coverage leaves ΔG poorly constrained
- A primary goal of RHIC Spin program is to map $\Delta g(x)$

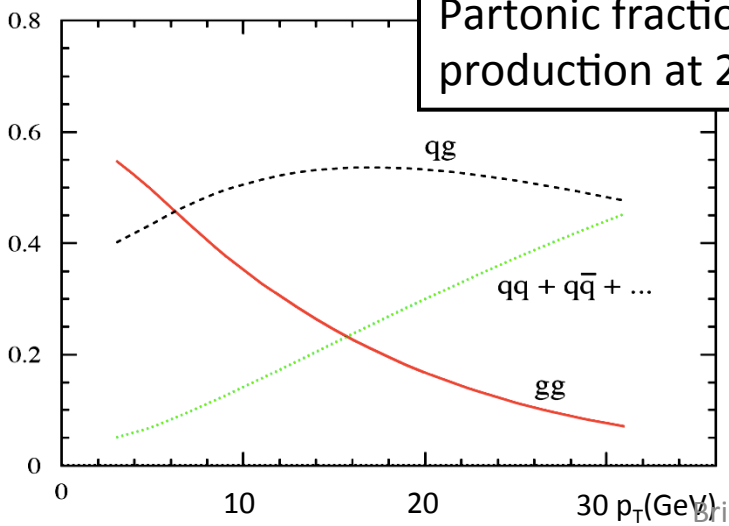
Kinematic reach of polarized DIS measurements

Proton Spin: Polarized pp Collisions

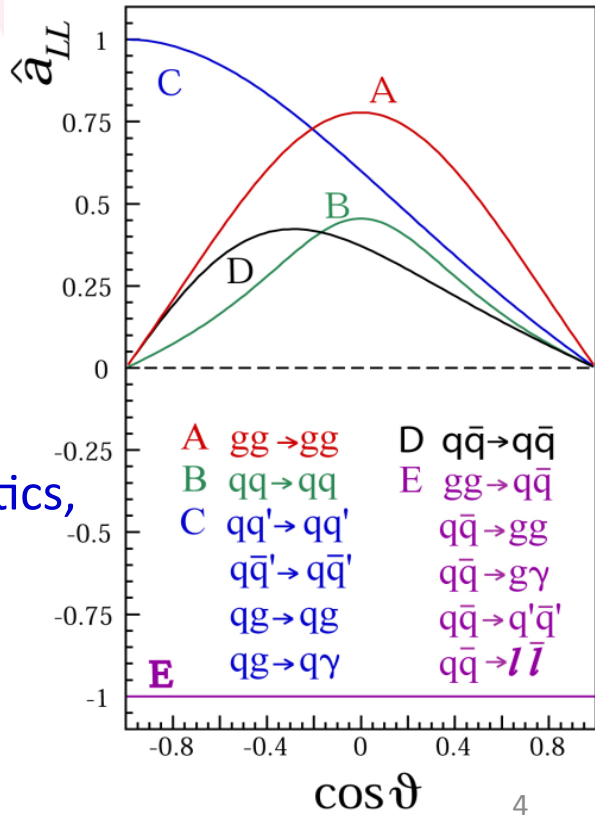
$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \frac{\sum_{a,b,c} \Delta f_a \otimes \Delta f_b \otimes d\hat{\sigma}^{f_a f_b \to f_c X} \otimes \hat{a}_{LL}^{f_a f_b \to f_c X} \otimes D_{f_c}^{h}}{\sum_{a,b,c} f_a \otimes f_b \otimes d\hat{\sigma}^{f_a f_b \to f_c X} \otimes D_{f_c}^{h}}$$



Partonic fractions in jet production at 200 GeV



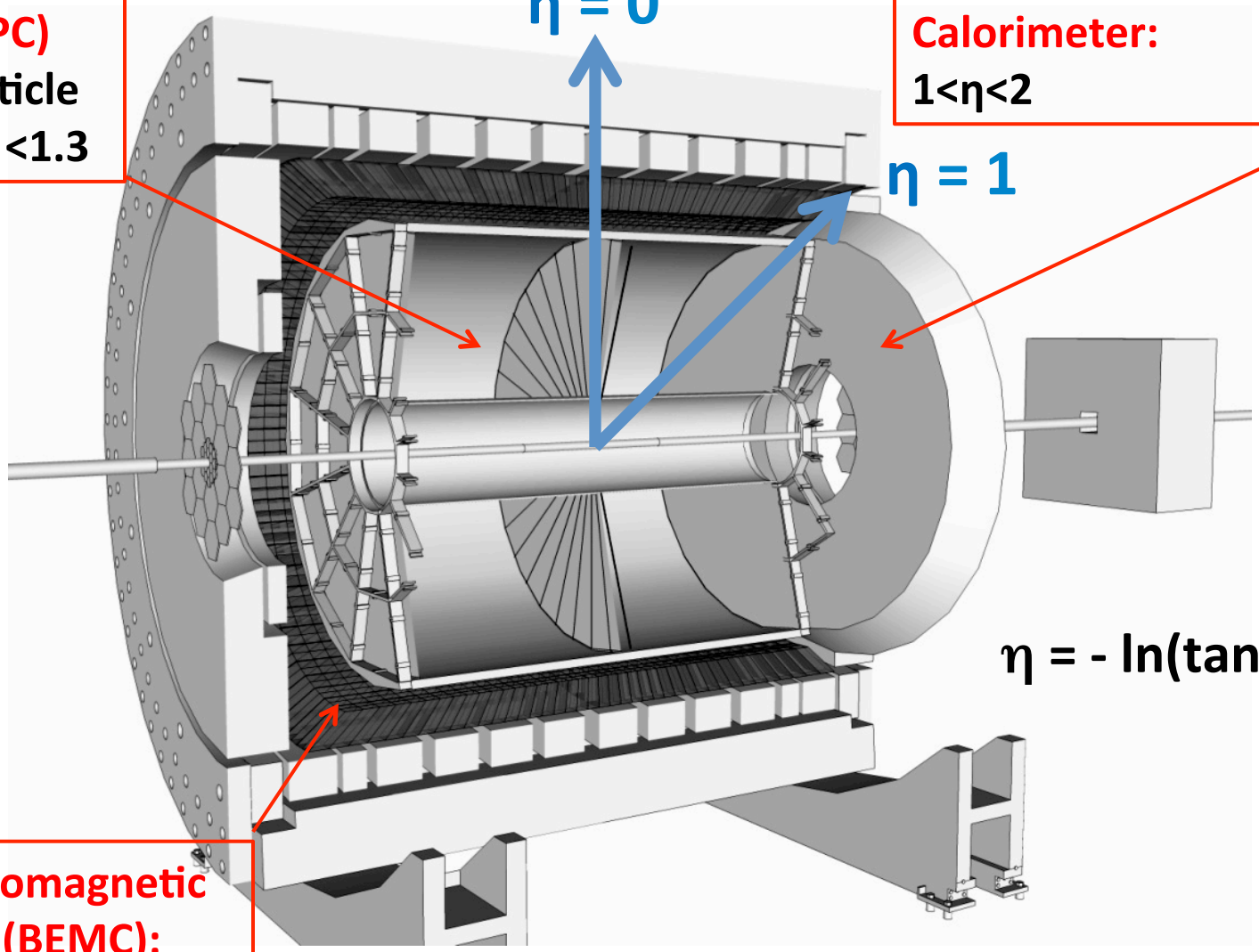
For most RHIC kinematics, **gg** and **qg** dominate, making A_{LL} for jets and hadrons sensitive to **gluon polarization**.



STAR Detector

Time Projection Chamber (TPC)
Charged Particle Tracking $|\eta|<1.3$

Endcap Electromagnetic Calorimeter:
$1<\eta<2$

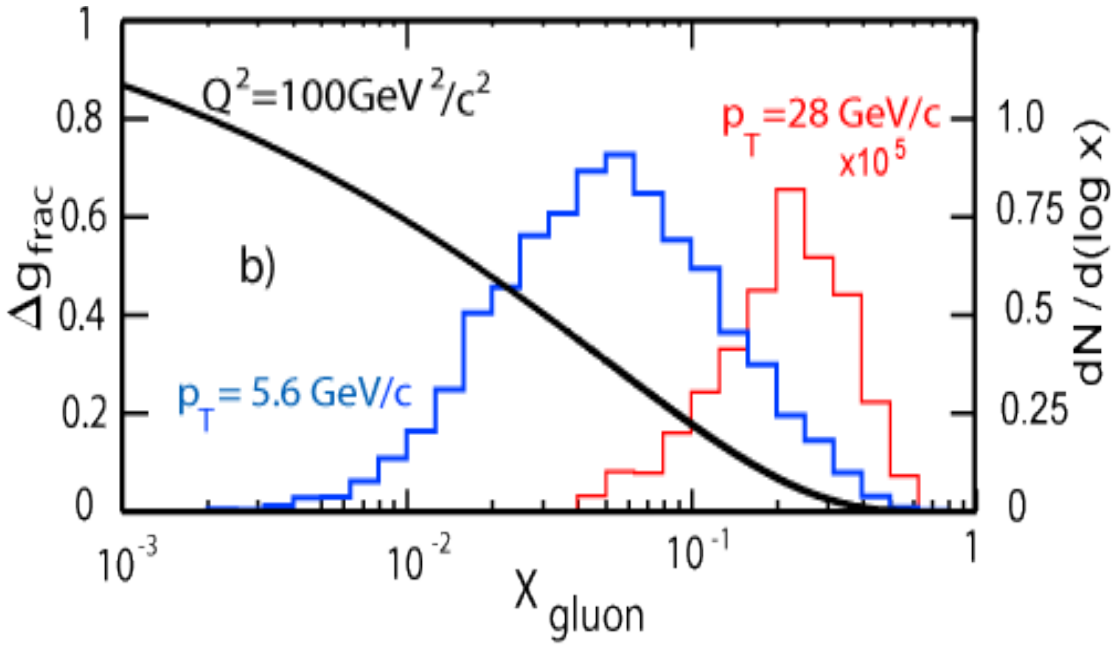


$\eta = -\ln(\tan(\theta/2))$

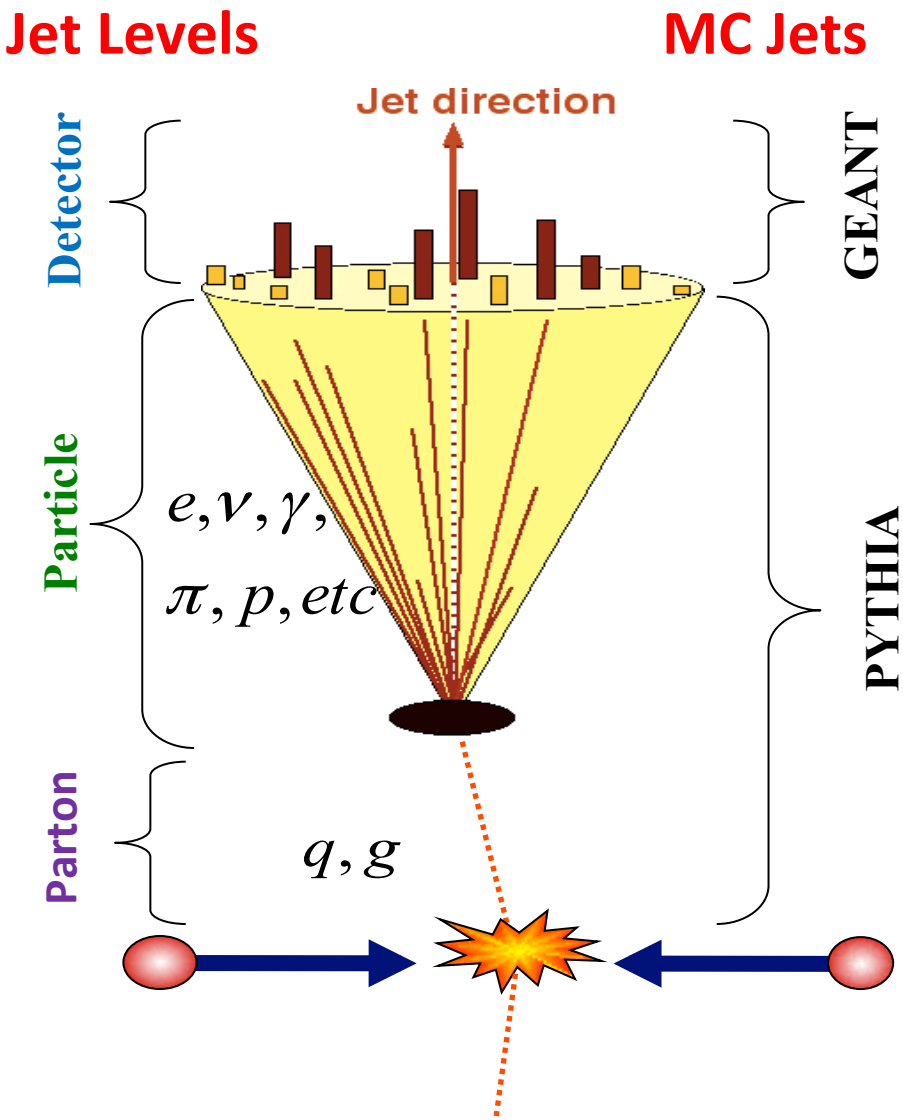
Barrel Electromagnetic Calorimeter (BEMC):
$|\eta|<1$

Inclusive Jet Measurements

- High statistics
- Multiple contributing subprocesses
- Wide range of x_{gluon} in each reconstructed bin



Jet Reconstruction



Anti-K_T Algorithm:

- Radius = 0.6
- Less sensitive to underlying event and pile-up effects
- Implemented using FastJet
- Used in both data and simulation

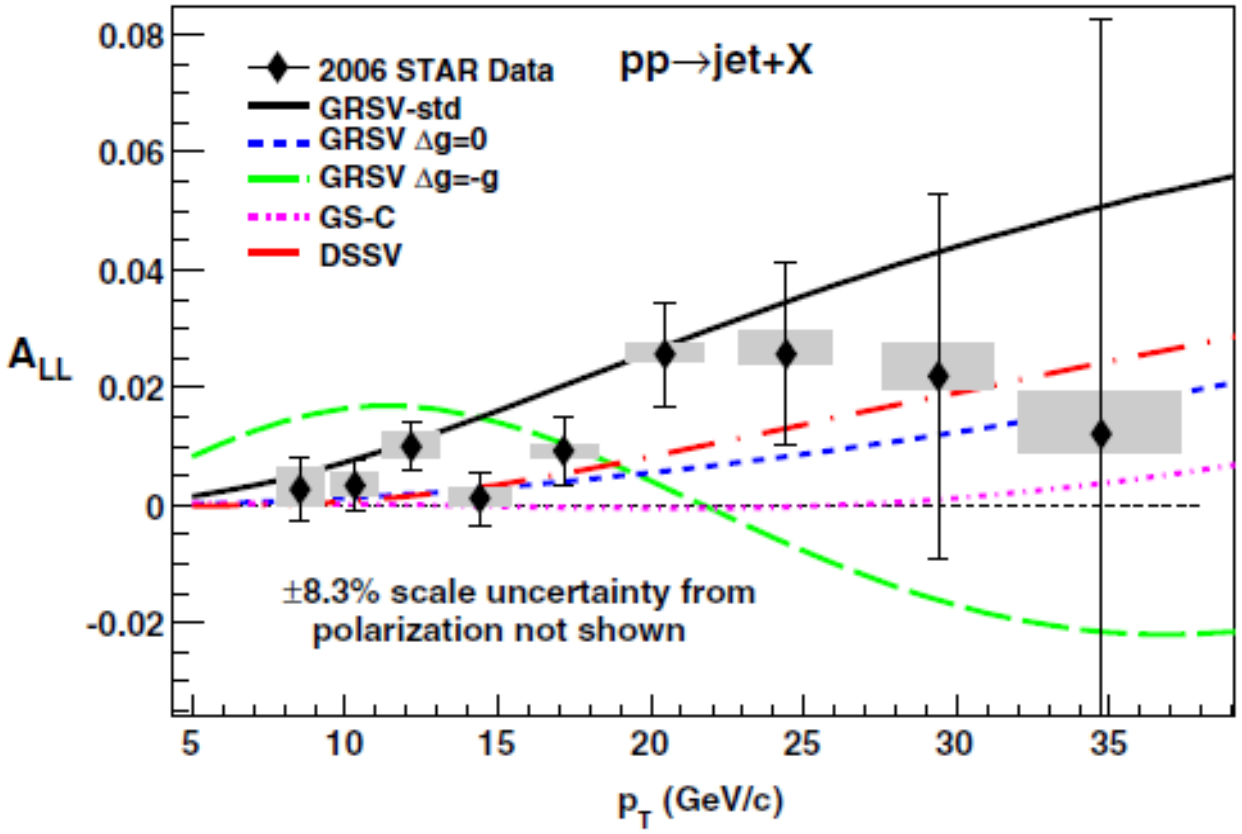
STAR Detector has:

- Full azimuthal coverage
- Charged particle tracking from TPC for $|\eta| < 1.3$
- E/BEMC provide electromagnetic energy reconstruction for $-1 < \eta < 2.0$

STAR well suited for jet measurements

2006 Inclusive Jet A_{LL}

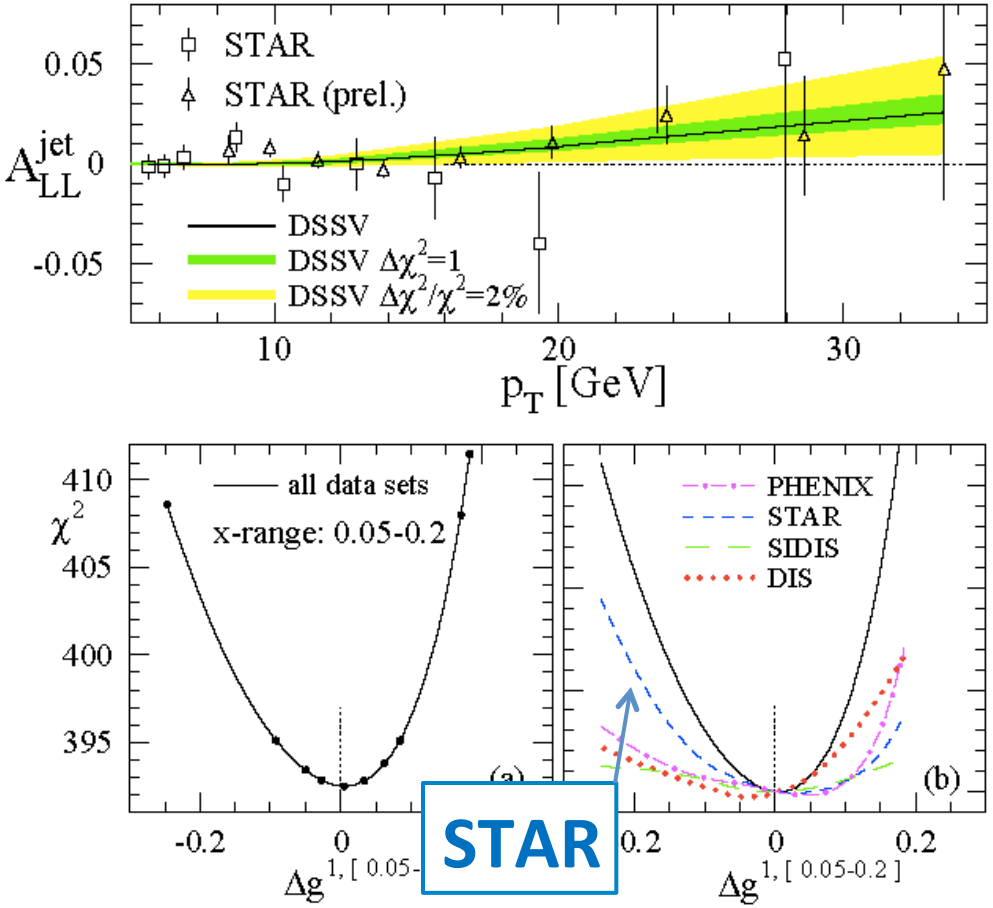
Phys. Rev. D86 032006 (2012)

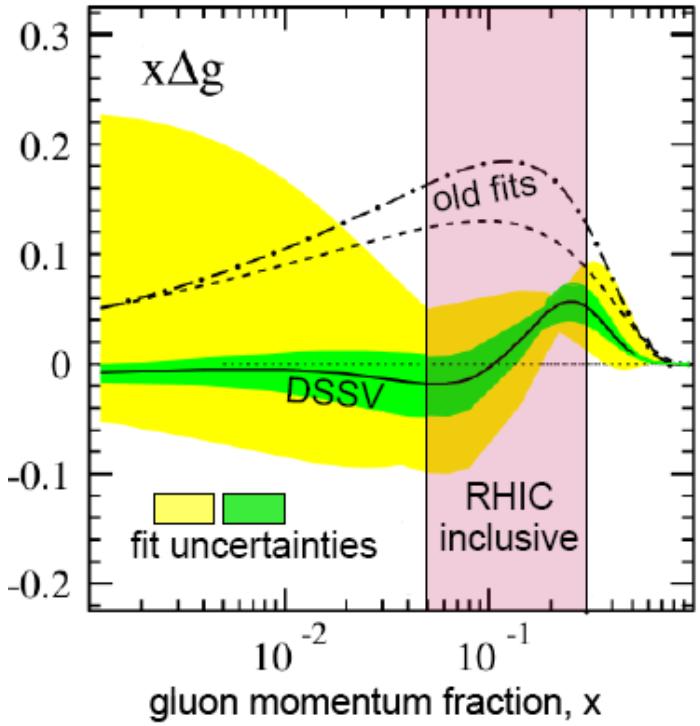


- Run 6 data rules out GRSV-Min and GRSV-Max
- Large gluon polarization in the accessible region disfavored

DSSV Global Fit

de Florian *et al.*, PRL **101**, 072001 (2008)





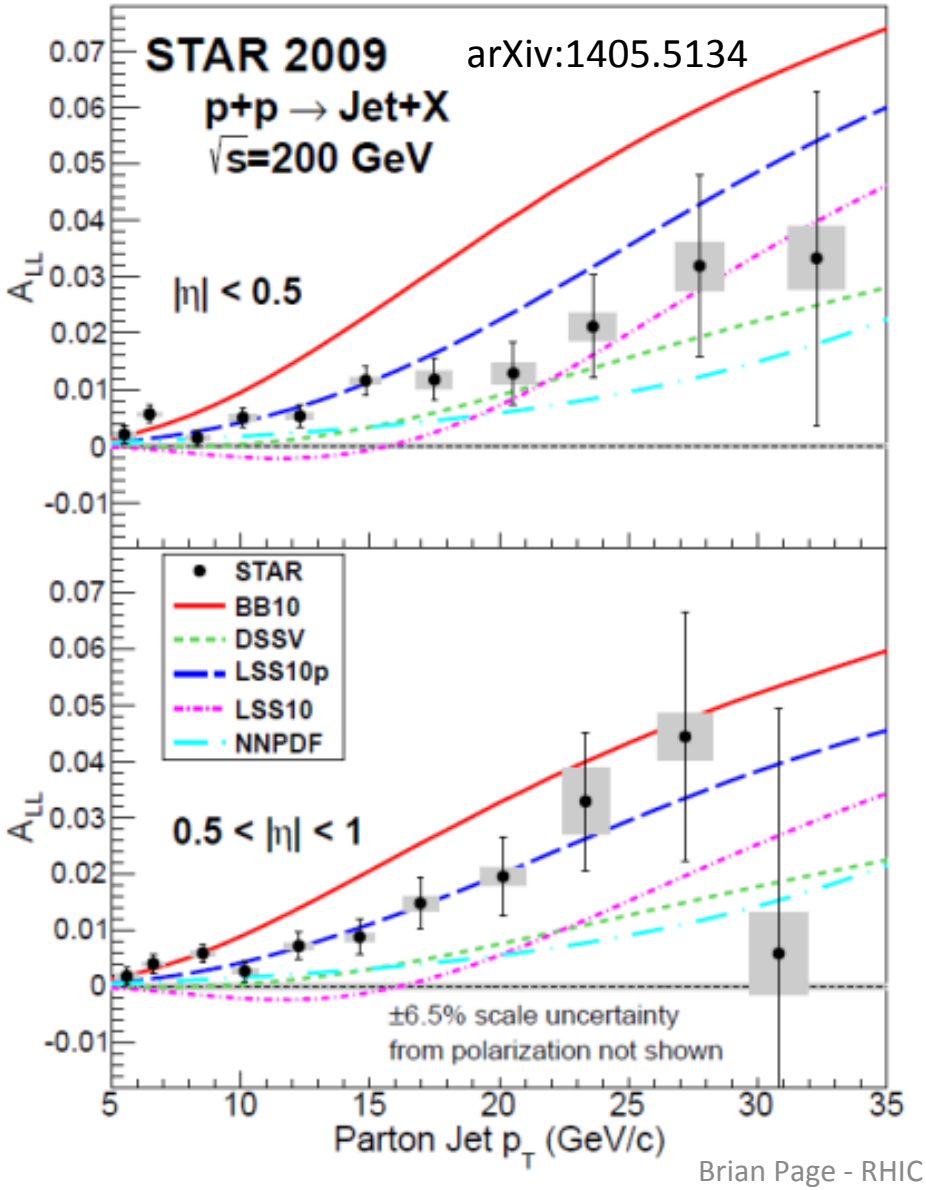
First global NLO analysis which includes DIS, SIDIS, and RHIC pp data

- Strong constraint on Δg in the range 0.05 < x < 0.2
- Low x range still poorly constrained

2006 to 2009 Improvements

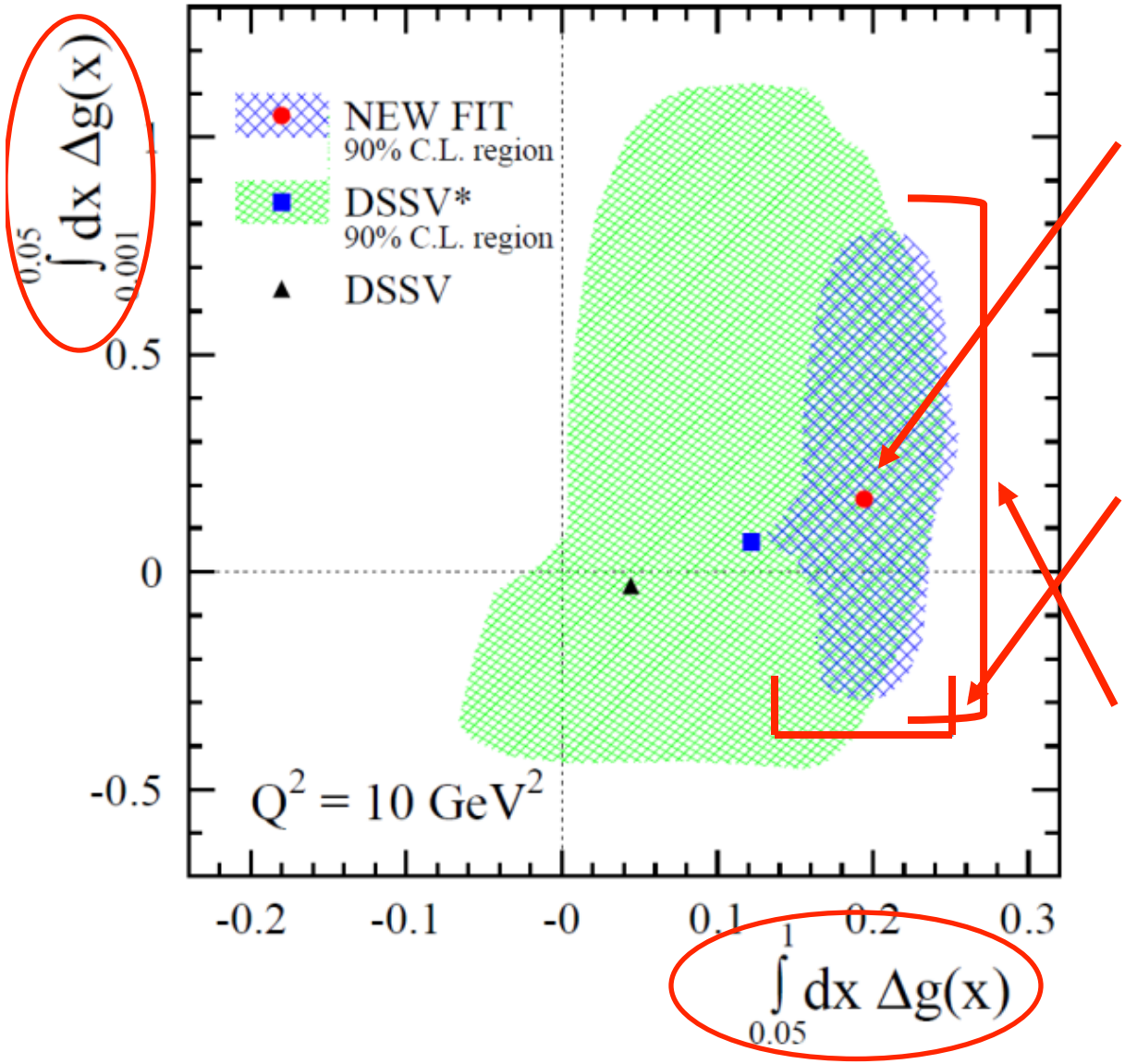
- 2009 jet patch trigger upgrades
  - Overlapping jet patches and lower E_T threshold improve efficiency and reduce trigger bias
    - Net increase of 37% in jet acceptance
  - Remove beam-beam counter trigger requirement:
    - Trigger more efficiently at high jet p_T
    - Measure non-collision background
  - Increased trigger rate enabled by DAQ1000
- Improvements in jet reconstruction
  - Subtract 100% of track momentum from struck tower energy (2009) instead of MIP (2006)
  - Overall jet energy resolution improved from 23% to 18%
- Sampled 20 pb^{-1} at 58% average beam polarization

2009 Inclusive Jet A_{LL}



- 2009 results have factor of 3 to 4 better statistical precision than 2006 results
- Result divided into two pseudorapidity ranges which emphasize different partonic kinematics
- Result lies consistently above the 2008 DSSV fit and is consistent with the LSS10p fit

New DSSV Results

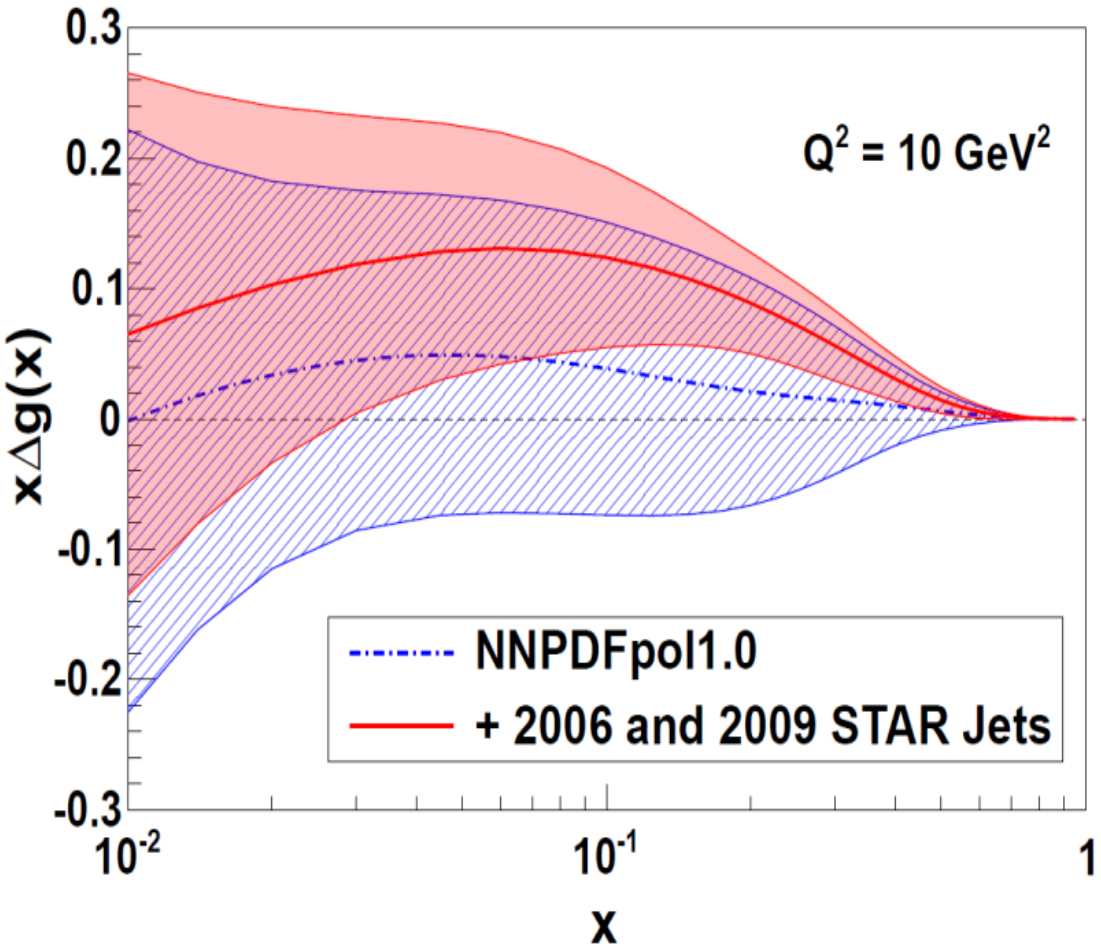


arXiv:1404.4293

- Integral of Δg(x) in range 0.05 < x < 1.0 increases from roughly 0.05 to 0.12 to 0.2
- Uncertainty shrinks substantially from DSSV* to new DSSV fit
- New DSSV fit uncertainty on integral containing region is still sizable

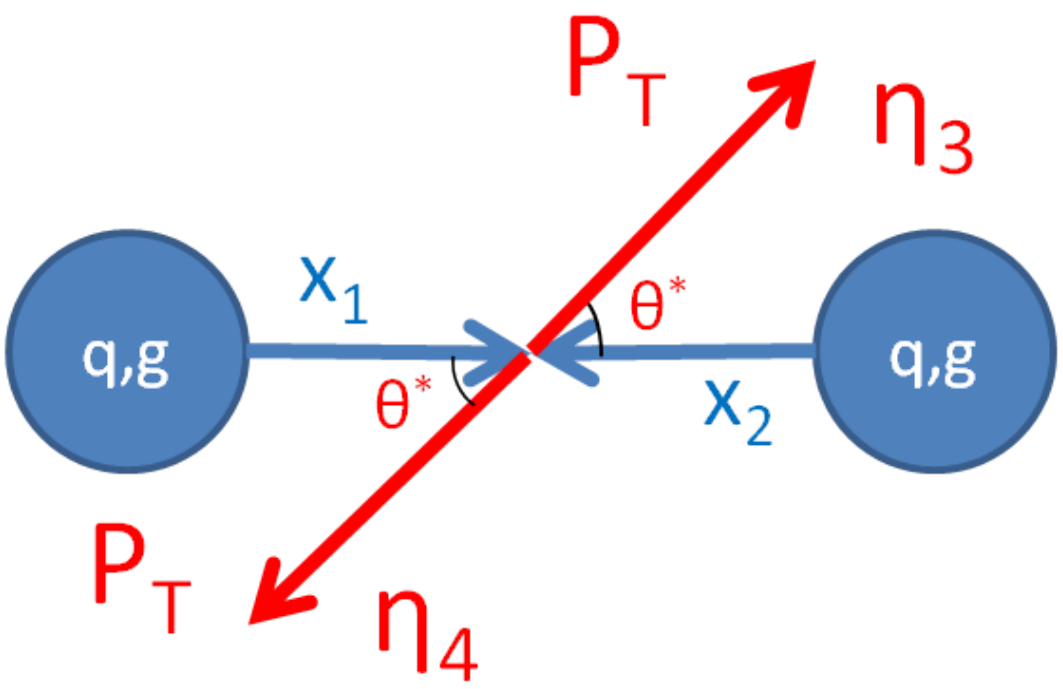
NNPDF Fit

arXiv:1405.5134



- NNPDF fit 1.0 includes only DIS data
- NNPDF group provides a weighting method which allows the effect of new experimental data to be explored without redoing full fit
- 2006 and 2009 STAR jet data increase the value of Δg(x) and decrease the uncertainty, especially at larger x

Correlation Measurements



$$x_1 = \frac{1}{\sqrt{s}}\left(p_{T3}e^{\eta_3} + p_{T4}e^{\eta_4}\right)$$

$$x_2 = \frac{1}{\sqrt{s}}\left(p_{T3}e^{-\eta_3} + p_{T4}e^{-\eta_4}\right)$$

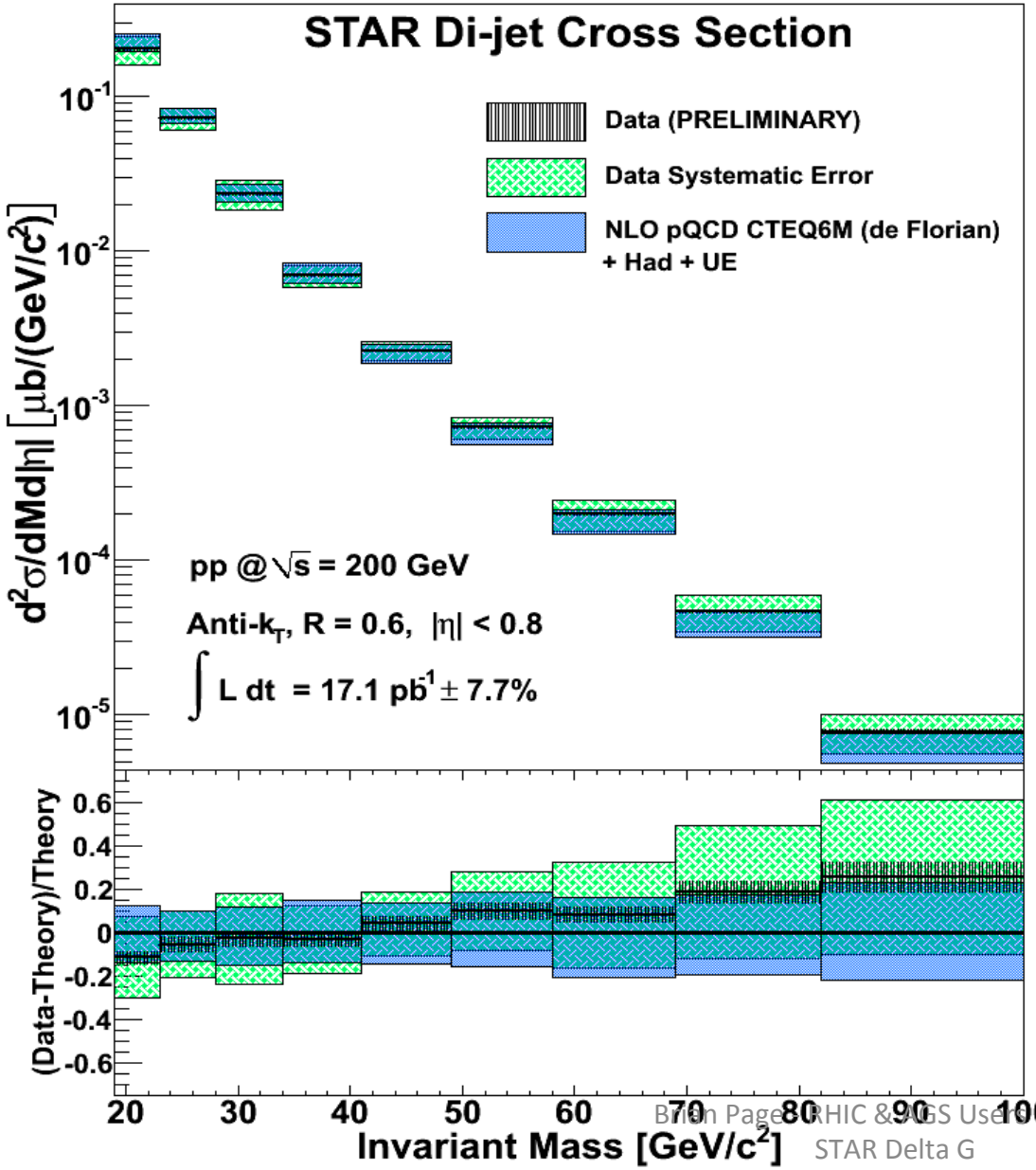
$$M = \sqrt{x_1 x_2 s}$$

$$\eta_3 + \eta_4 = \ln\frac{x_1}{x_2}$$

$$\left|\cos\theta^*\right| = \tanh\left|\frac{\eta_3 - \eta_4}{2}\right|$$

- Inclusive measurements have been the workhorse of STAR ΔG program to date
- Broad x range sampled in each p_T bin
- Correlation measurements which reconstruct the full final state are sensitive to initial kinematics at leading order

2009 Di-jet Cross Section Result

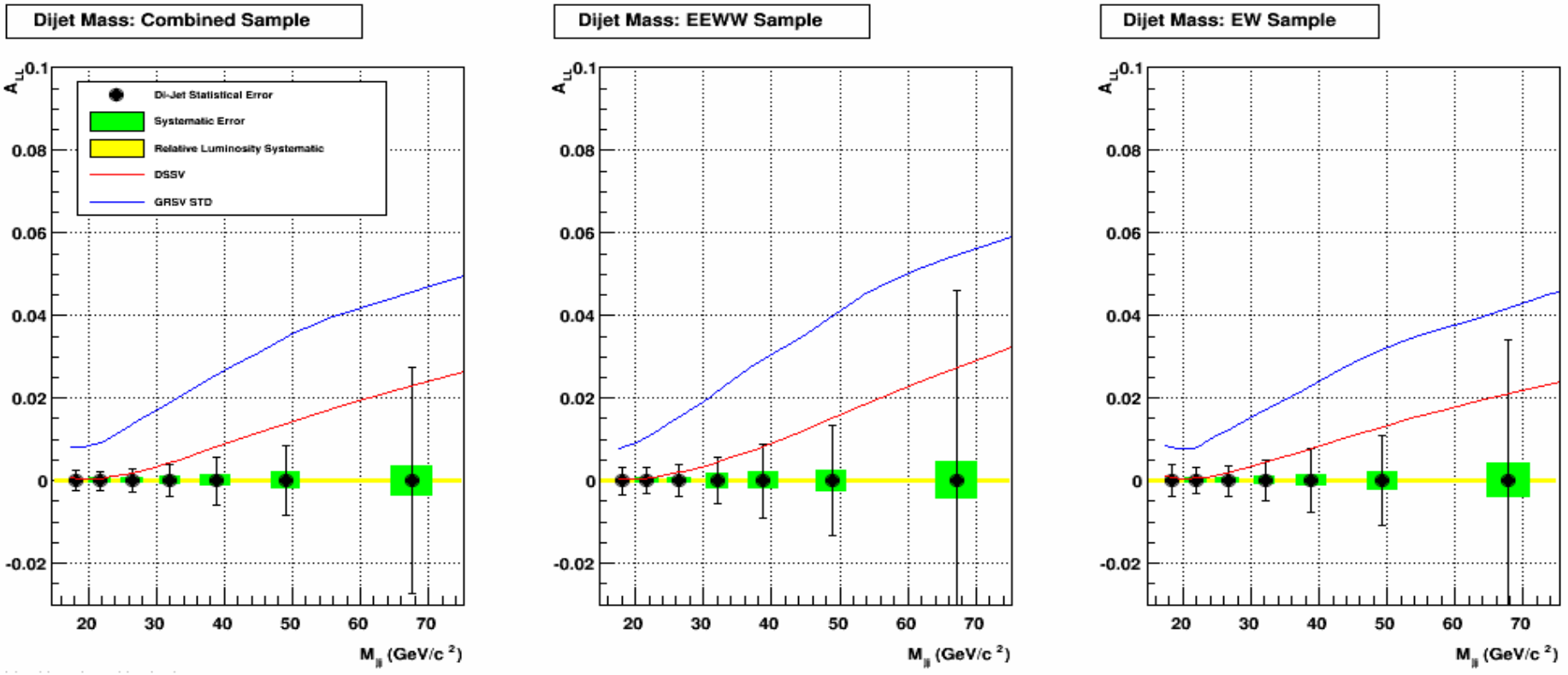


Thickness of vertical black hashing represents size of statistical error on the measurement

Green hatched box is symmetric about data point and is the quadrature sum of all systematic errors

Thickness of blue box represents error on theory determined by changing factorization and renormalization scales by factor of 0.5 and 2

2009 Di-jet A_{LL} Errors



- Di-jet statistical and systematic errors shown for two unique topologies and the combination which probe different partonic kinematics
- Systematics include contributions from JES, residual transverse polarization, and trigger / reconstruction biases
- Red curve shows 2008 DSSV best fit for A_{LL} and blue curve shows GRSV-STD fit

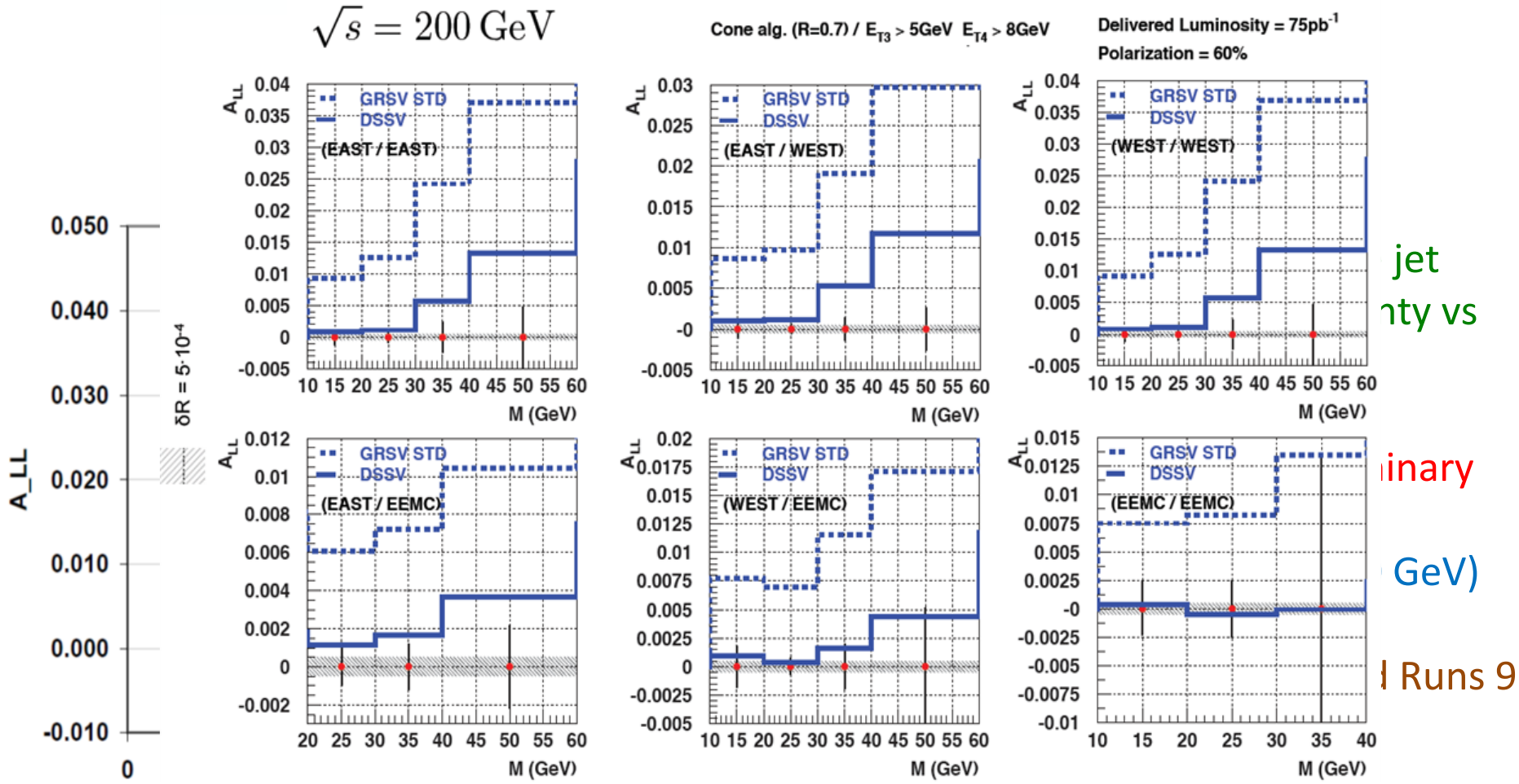
Recent and Upcoming Data Sets

Only longitudinal data sets shown

Run	√s (GeV)	Integrated Luminosity	Average Polarization
2009	200 500	25 pb^{-1} 10 pb^{-1}	55% 39%
2012	510	82 pb^{-1}	50/53%
2013	510	300 pb^{-1}	50/53%
2015*	200	50 pb^{-1}	60%

* Upcoming Data Set

Projected Jet/Dijet Sensitivity



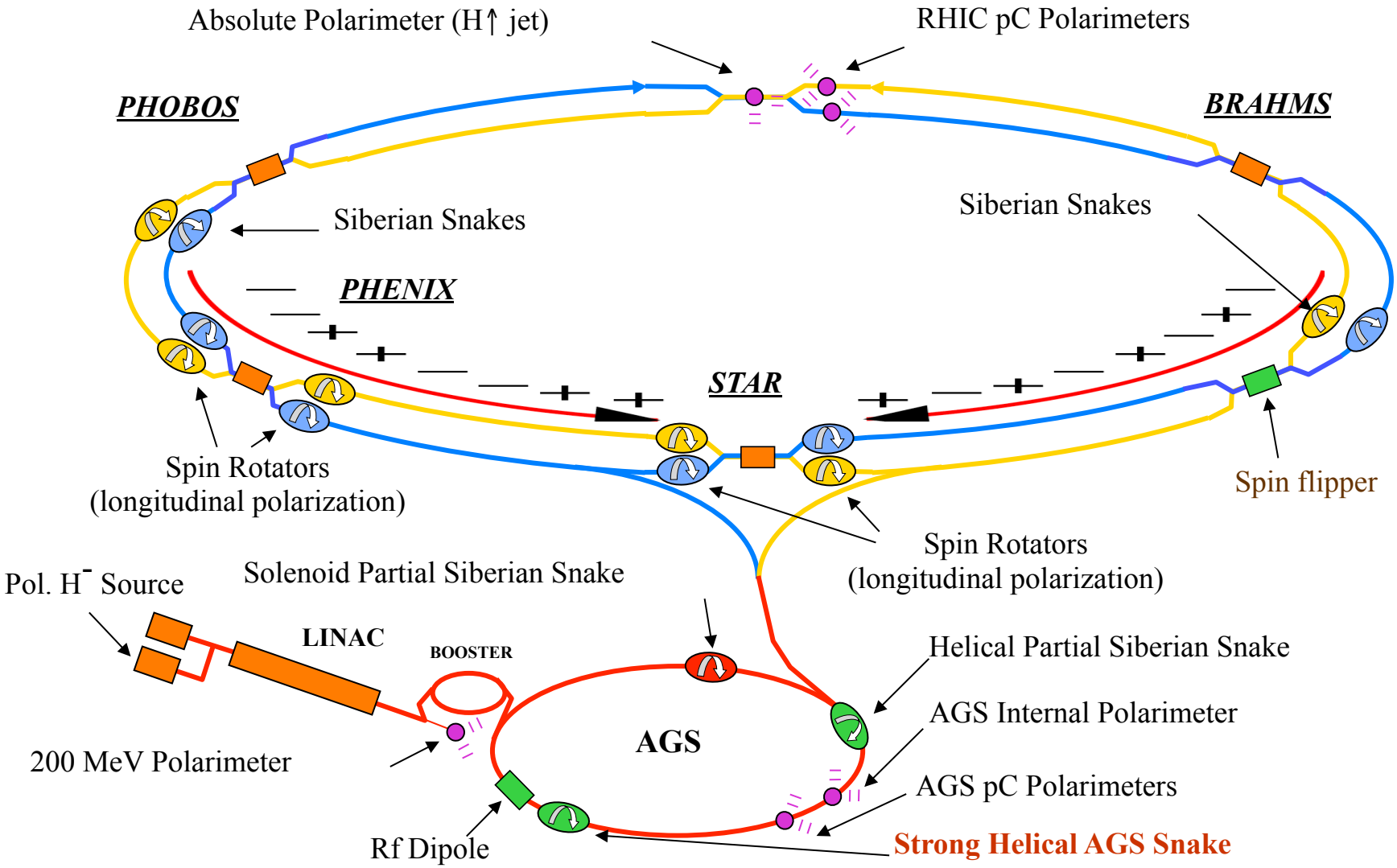
- Projected dijet statistical uncertainty at √s = 200 GeV for six topologies
- Statistics correspond to Run 9 + Run 15

Conclusions

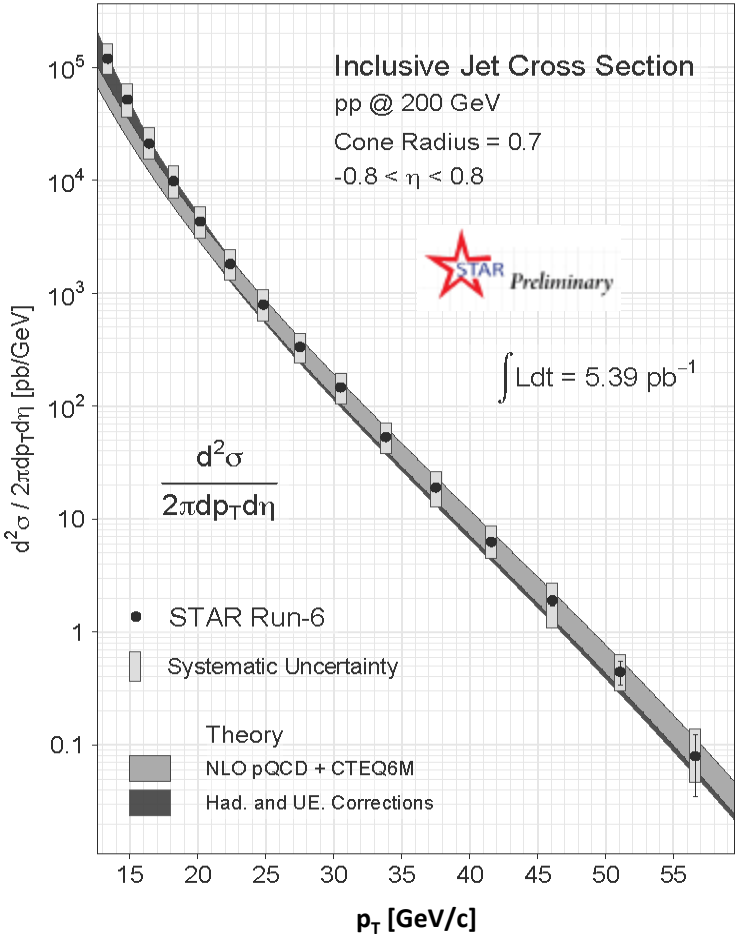
- 2009 results are 3-4 times more precise than previous 2006 results and lie consistently above the 2008 DSSV global fit
- New DSSV global analysis, which includes 2009 STAR inclusive jet data, shows non-zero value for ΔG ($0.20^{+0.06}_{-0.07}$ for x > 0.05) which is in agreement with reweighted NNPDF analysis
- Upcoming Di-Jet measurements will help to better constrain the shape of Δg(x) and forward inclusive hadron measurements will extend our reach to lower values of x
- STAR is poised for more high precision measurements with several large datasets at both 200 and 500 GeV on tape

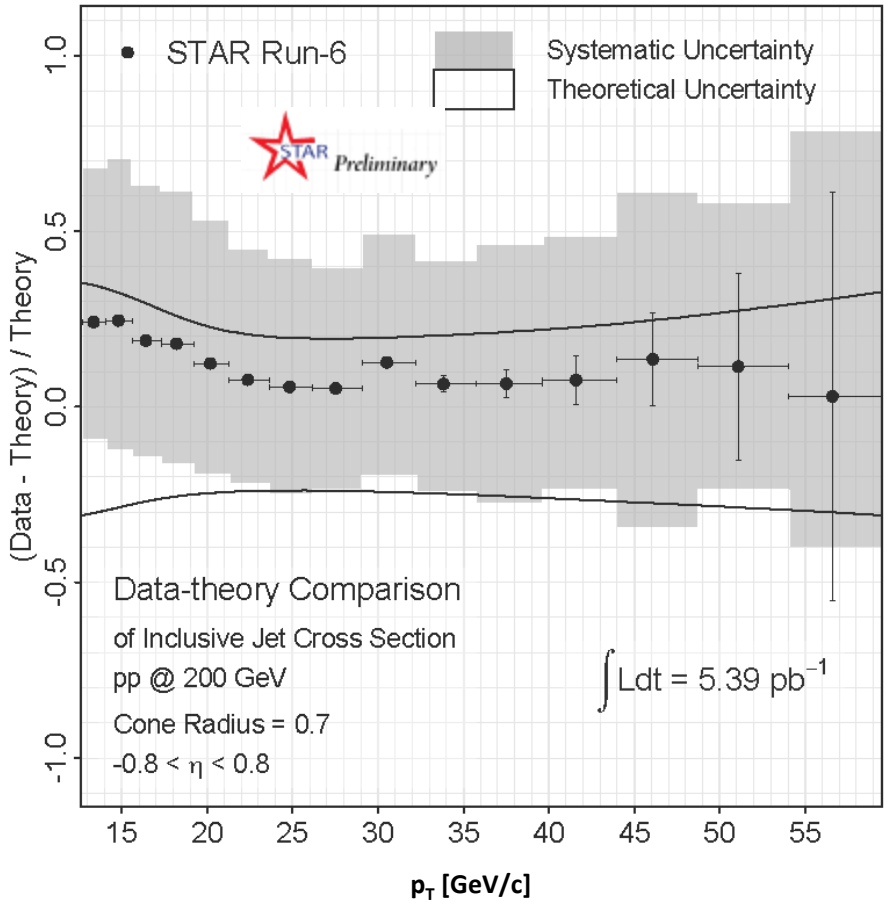
Backup Slides

RHIC


Absolute Polarimeter (H↑ jet)
RHIC pC Polarimeters
PHOBOS
BRAHMS
Siberian Snakes
Siberian Snakes
PHENIX
STAR
Spin Rotators
(longitudinal polarization)
Spin flipper
Spin Rotators
(longitudinal polarization)
Pol. H⁻ Source
Solenoid Partial Siberian Snake
LINAC
BOOSTER
Helical Partial Siberian Snake
AGS Internal Polarimeter
AGS
200 MeV Polarimeter
AGS pC Polarimeters
Rf Dipole
Strong Helical AGS Snake

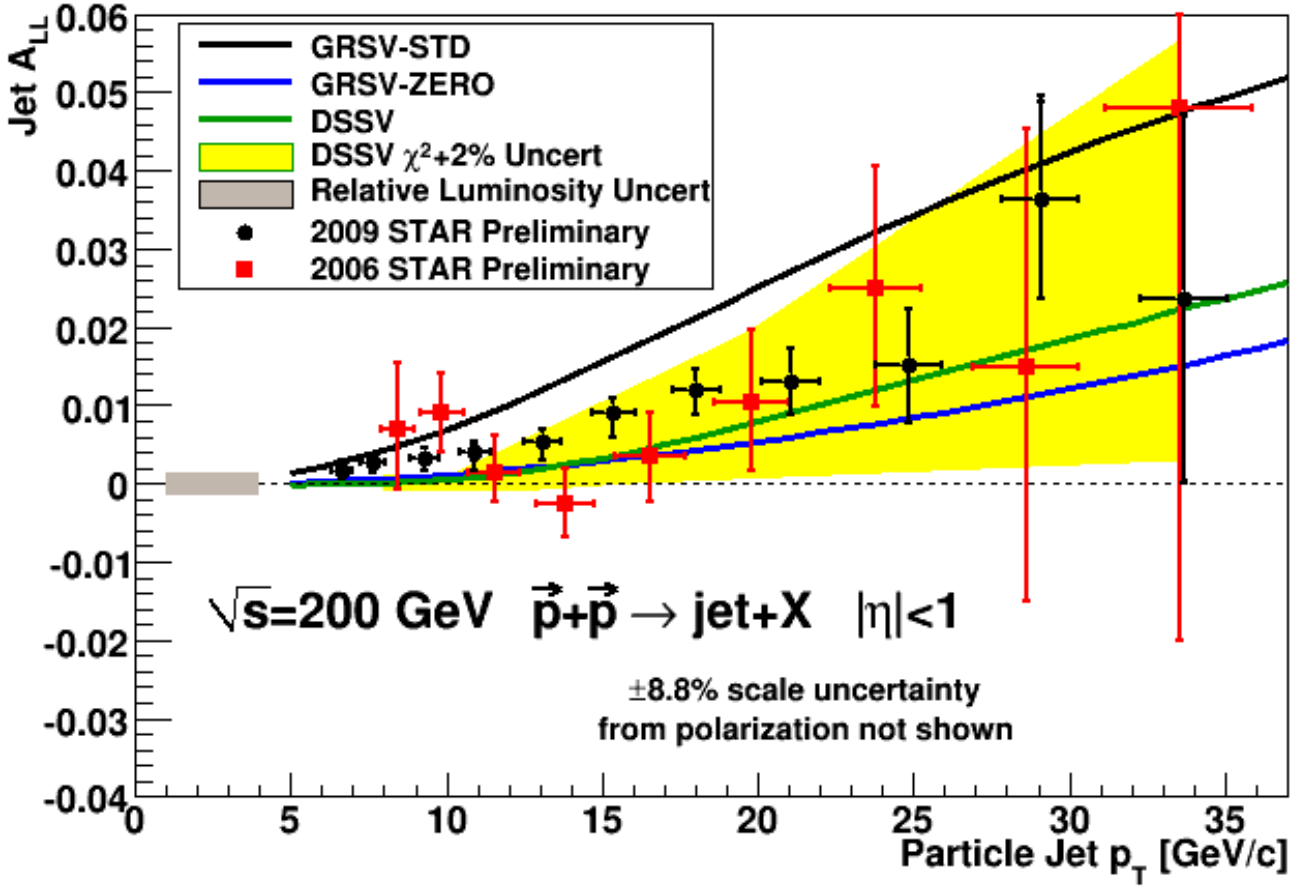
2006 Inclusive Jet Cross Section





- Data in good agreement with NLO pQCD when including hadronization and underlying event corrections
- Hadronization and UE corrections more significant at low p_T

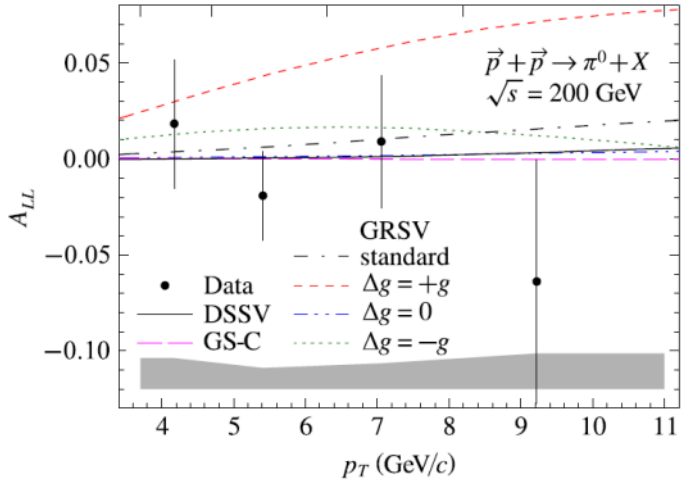
2006 vs 2009 Inclusive Jet A_{LL}



- Run 9 results are a factor of 3 or greater more precise than Run 6 results
- Data falls between DSSV and GRSV-STD

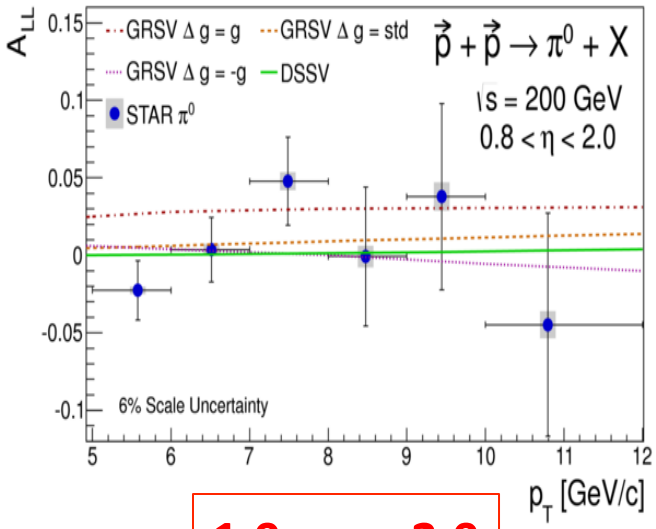
Inclusive Results: π^0 A_{LL}

PRD 80, 111108(R) (2009)

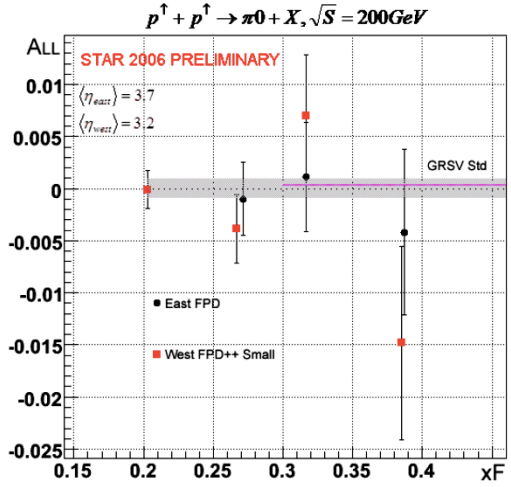


|η| < 0.95

PRD 89, 012001 (2014)



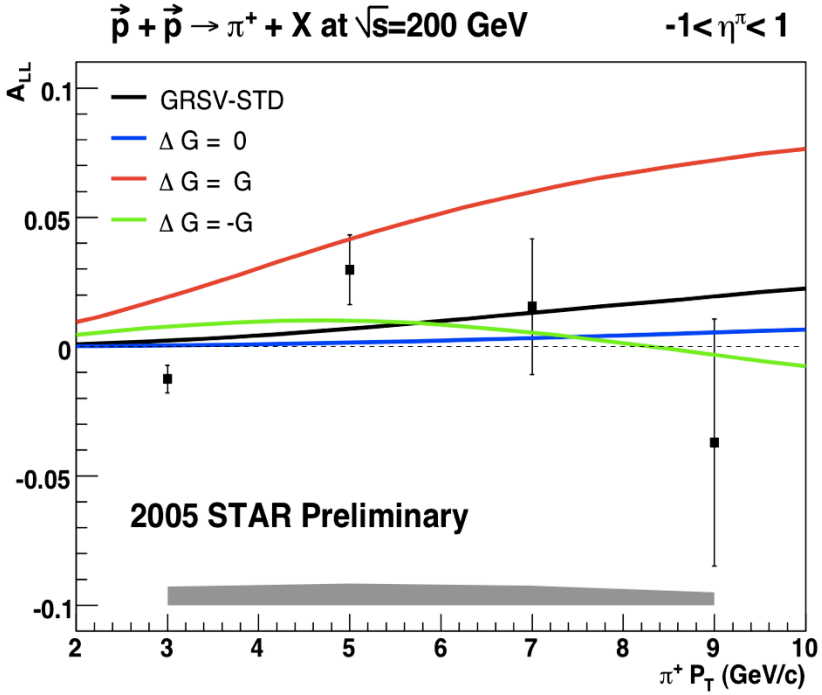
1.0 < η < 2.0

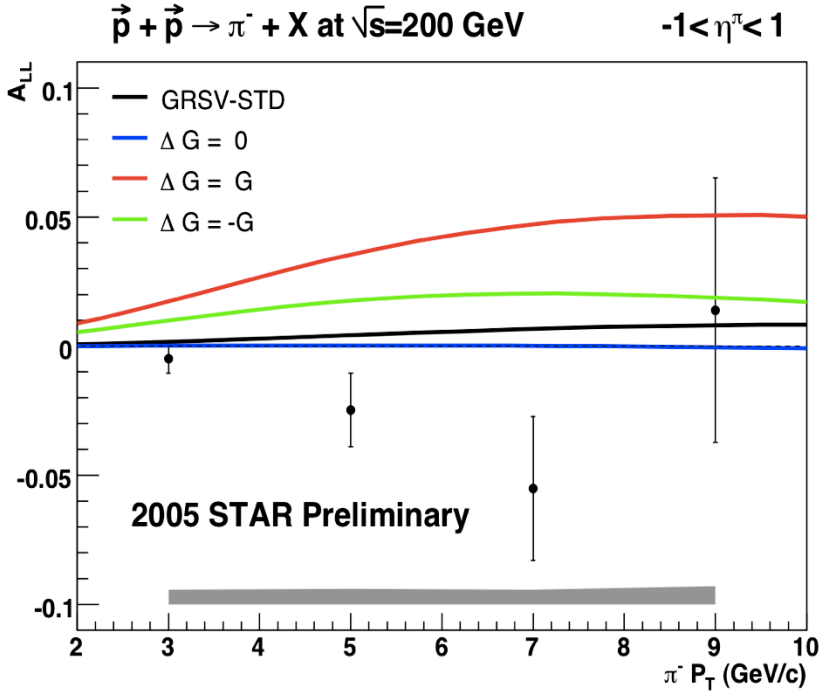


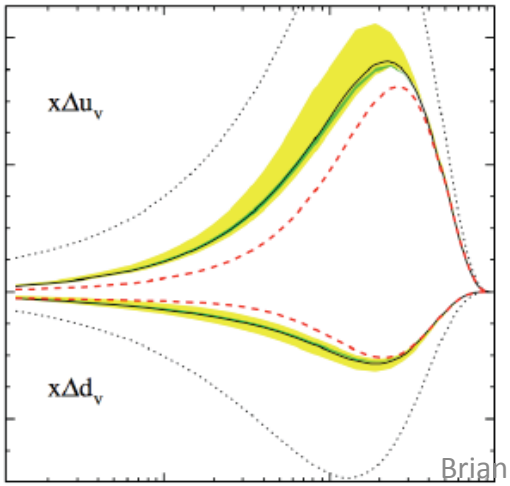
η = 3.2, 3.7

- STAR has measured π^0 A_{LL} in three different pseudorapidity ranges
- Mid rapidity results excludes maximal Δg model, consistent with EEMC result
- qg scattering dominates at high η with large x quarks and small x gluons

Inclusive Results: π^+ π^- A_{LL}





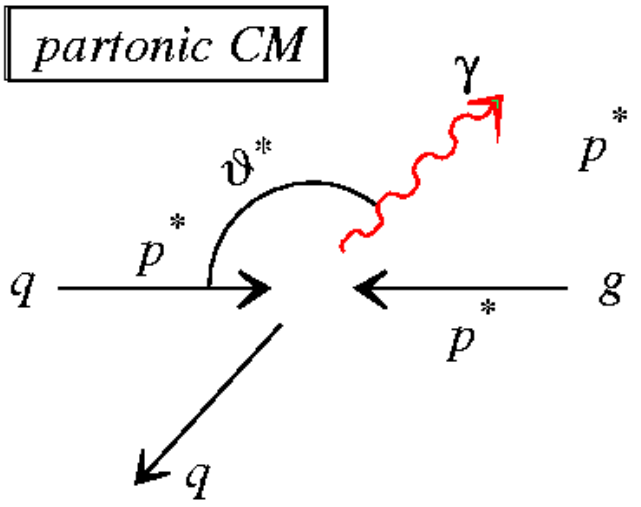
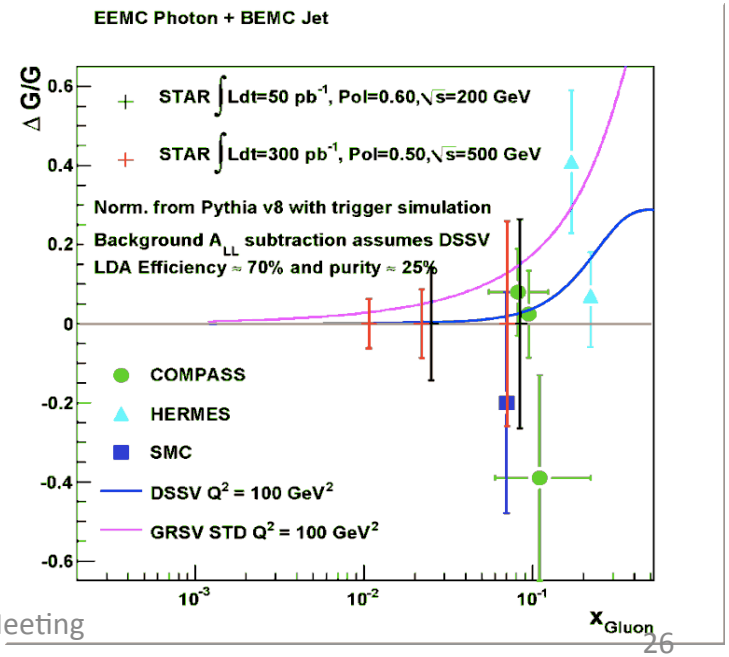


- In Run 5, STAR measured A_{LL} for inclusive charged pions
- $A_{LL}(\pi+) - A_{LL}(\pi-)$ is sensitive to the sign of ΔG
- Trigger using neutral jet patch -> Introduces significant trigger bias (charged pions often subleading particles in jets)

Gamma + Jet: A Long-Term STAR Goal

- Gamma + Jet production dominated by quark-gluon Compton scattering

- Large spin (→ 1) correlation when partons backscatter

- Events with a gamma in the EEMC and a mid rapidity jet come from the most asymmetric collisions → high x quark (with high polarization) interacting with low x gluon

- Gamma + Jet yield very small compared to QCD background → background suppression very challenging