Gluon Polarization Measurements

Brian Page
For the STAR Collaboration

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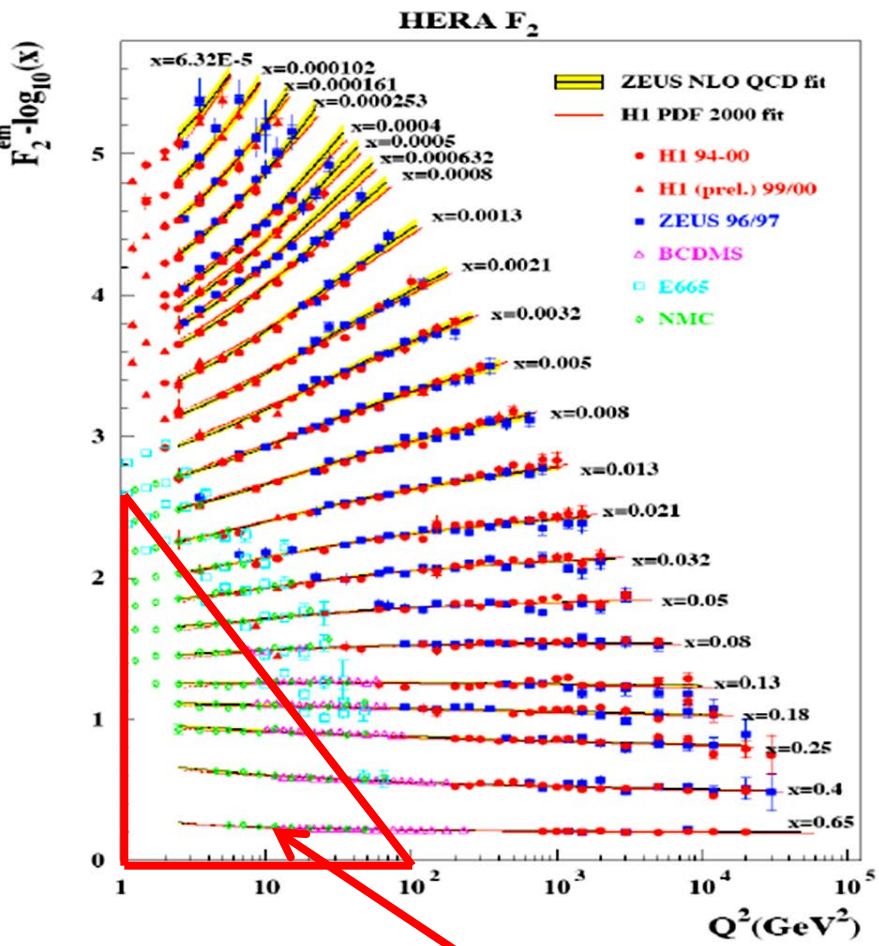
Outline

- Theoretical Overview
- Inclusive Measures
  - Neutral Pions
  - Charged Pions
  - Photons
  - Jets
- Correlation Measures
  - Dijets
  - Photon - Jet

Where's the Spin?



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

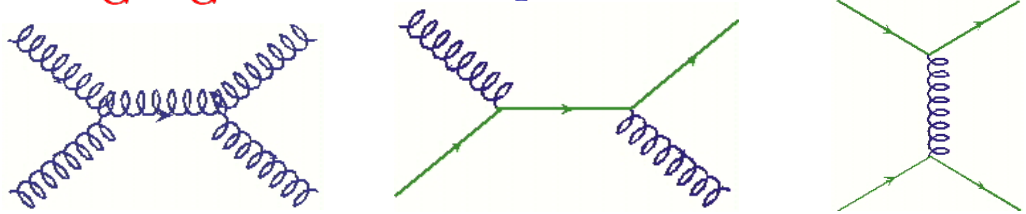
- Polarized DIS tells us that $\Delta\Sigma \approx 0.3$
- Q^2 evolution in polarized DIS gives information on gluon polarization but limited kinematic coverage leaves ΔG poorly constrained
- A primary goal of RHIC Spin program is to map $\Delta g(x)$

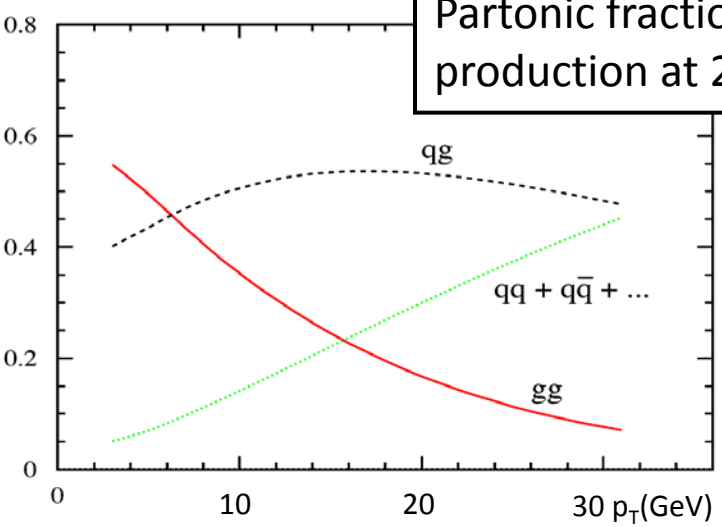
Kinematic reach of polarized DIS measurements

Probing ΔG

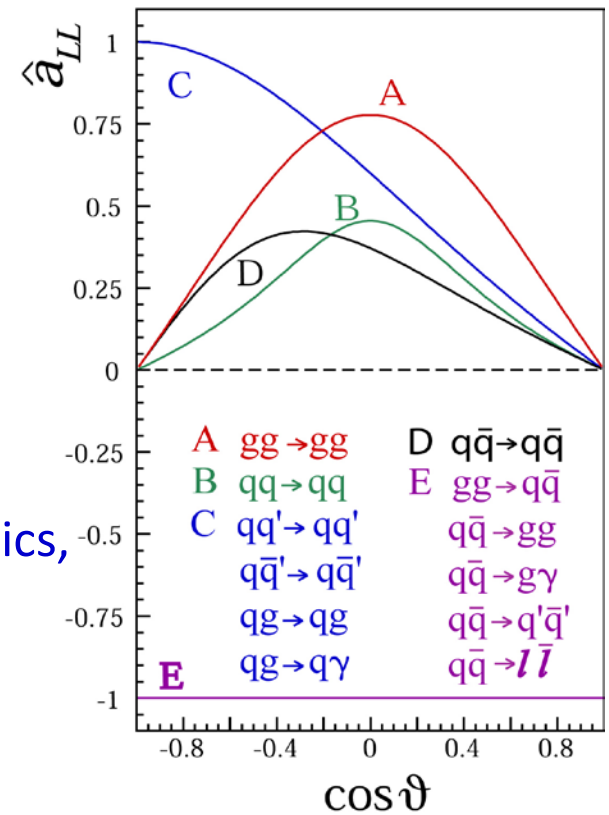
$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \frac{\sum_{a,b,c} \Delta f_a \otimes \Delta f_b \otimes d\hat{\sigma}^{f_a f_b \to f_c X} \cdot \hat{a}_{LL}^{f_a f_b \to f_c X} \otimes D_{f_c}^{h}}{\sum_{a,b,c} f_a \otimes f_b \otimes d\hat{\sigma}^{f_a f_b \to f_c X} \otimes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

$\frac{\Delta G}{G}\frac{\Delta G}{G}$ $\frac{\Delta q}{q}\frac{\Delta G}{G}$ $\frac{\Delta q}{q}\frac{\Delta q}{q}$



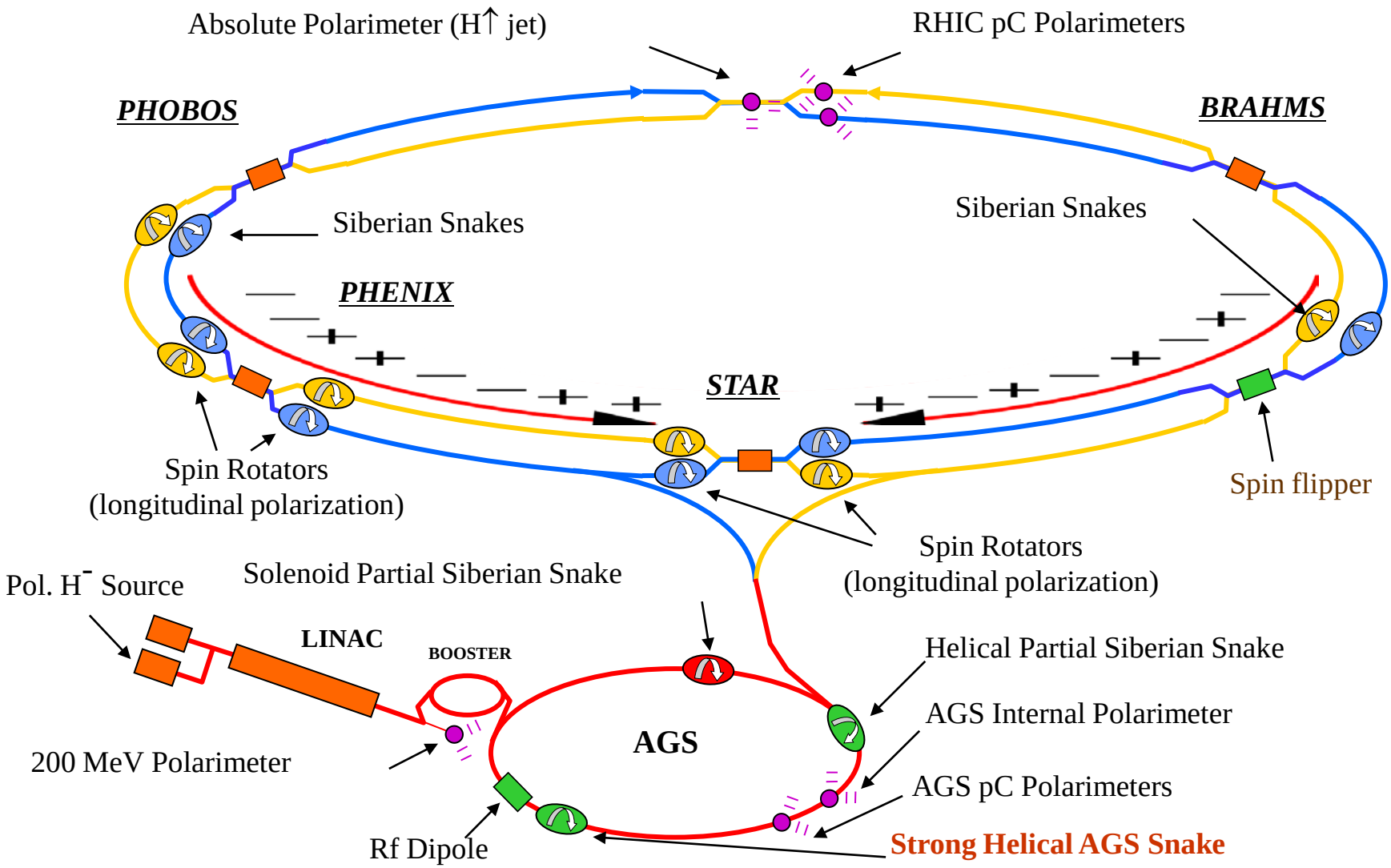


Partonic fractions in jet production at 200 GeV

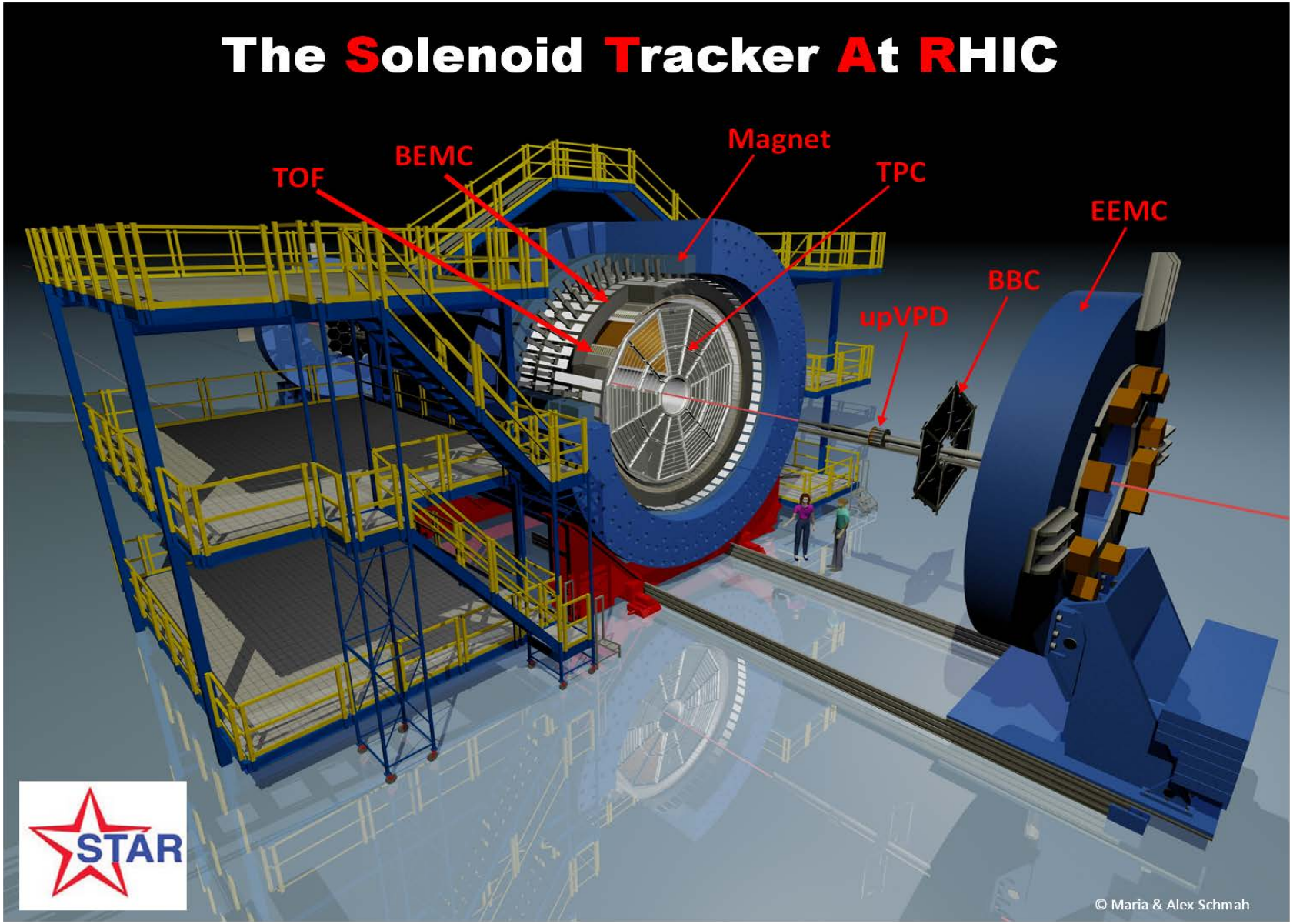


For most RHIC kinematics, **gg** and **qg** dominate, making A_{LL} for jets and hadrons sensitive to **gluon polarization**.

RHIC

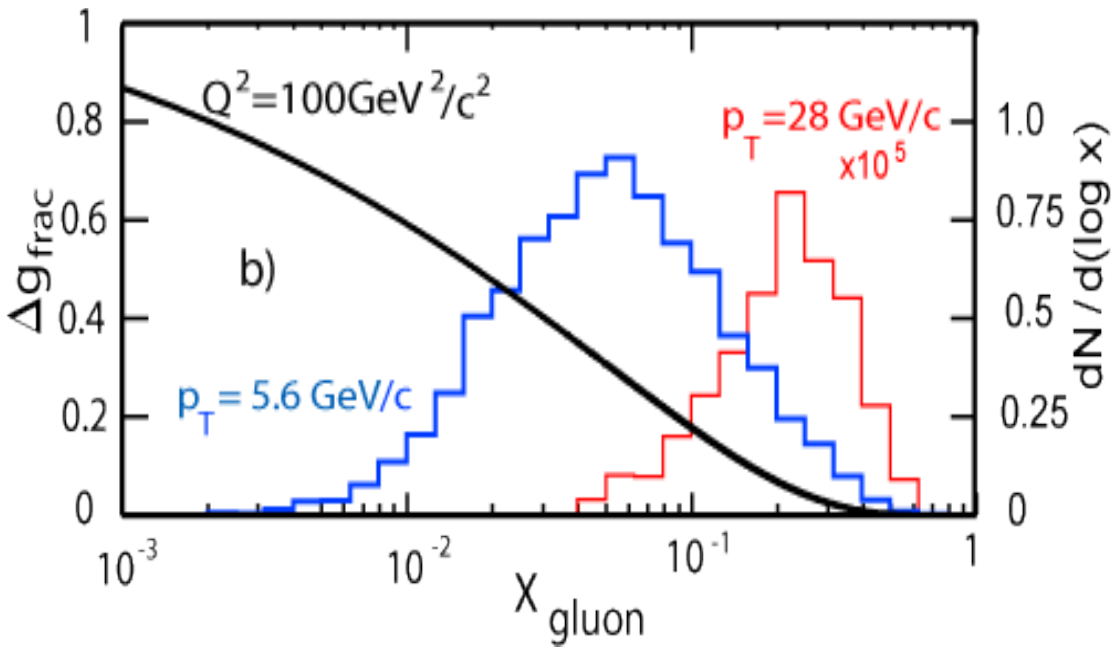

Absolute Polarimeter (H↑ jet)
RHIC pC Polarimeters
PHOBOS
BRAHMS
Siberian Snakes
Siberian Snakes
PHENIX
STAR
Spin Rotators
(longitudinal polarization)
Spin flipper
Spin Rotators
(longitudinal polarization)
Pol. H⁻ Source
Solenoid Partial Siberian Snake
LINAC
BOOSTER
Helical Partial Siberian Snake
AGS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

STAR

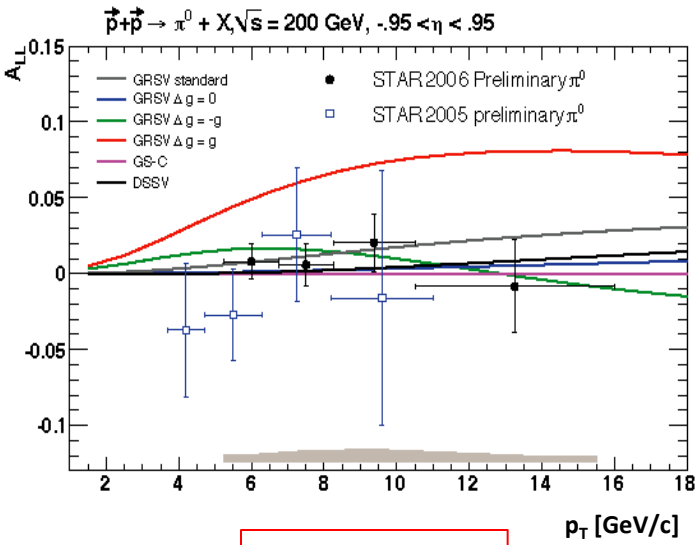

The Solenoid Tracker At RHIC
TOF
BEMC
Magnet
TPC
EEMC
BBC
upVPD
STAR
© Maria & Alex Schmah

Inclusive Measurements

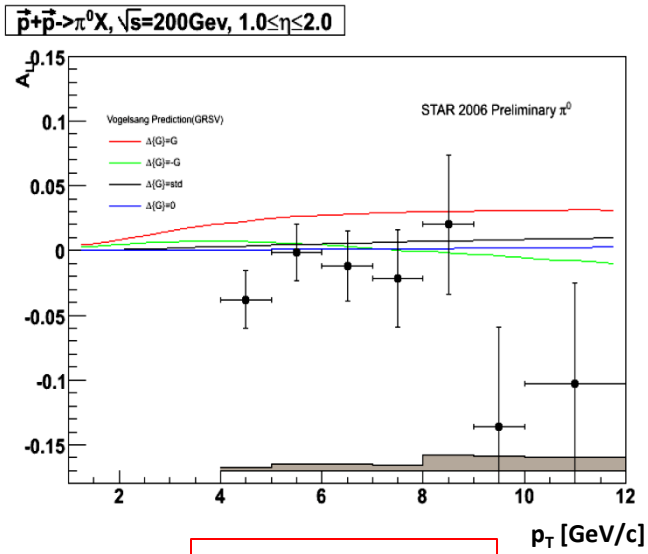
- High statistics
- Multiple contributing subprocesses
- Wide range of x_{gluon} in each reconstructed bin



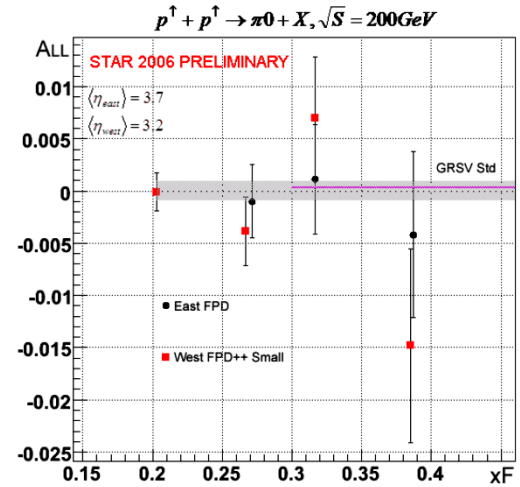
Inclusive Results: π^0 A_{LL}



$|\eta| < 0.95$



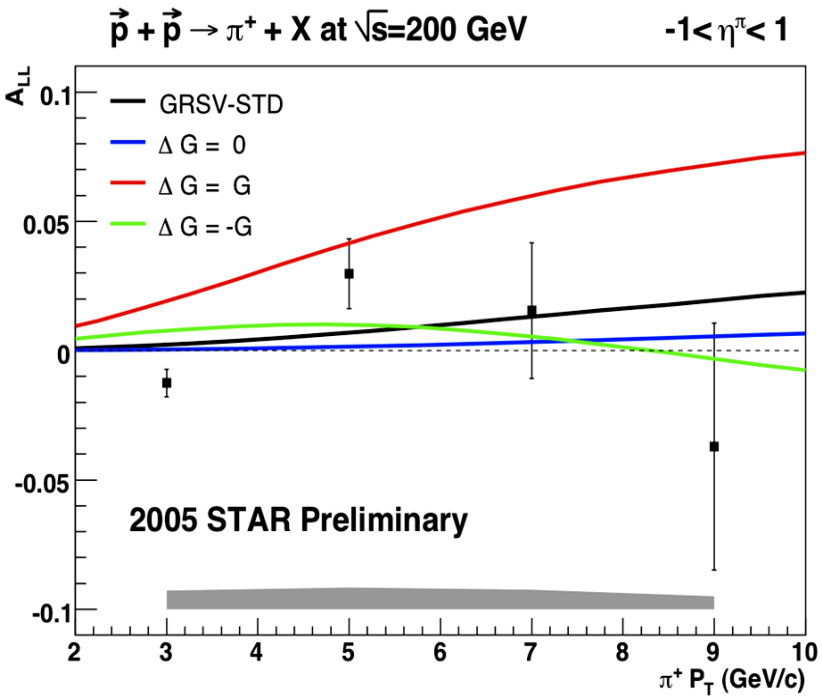
$1.0 < \eta < 2.0$

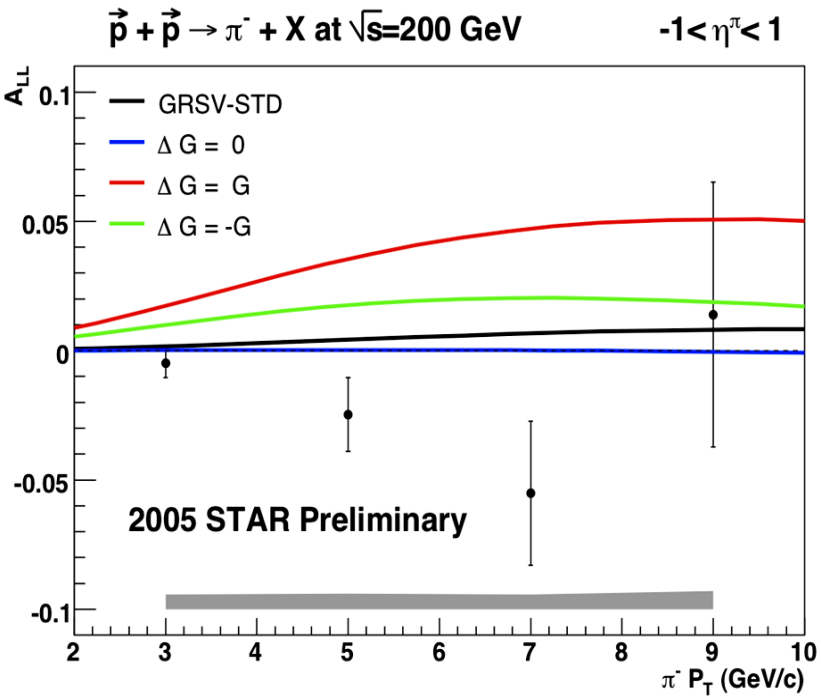


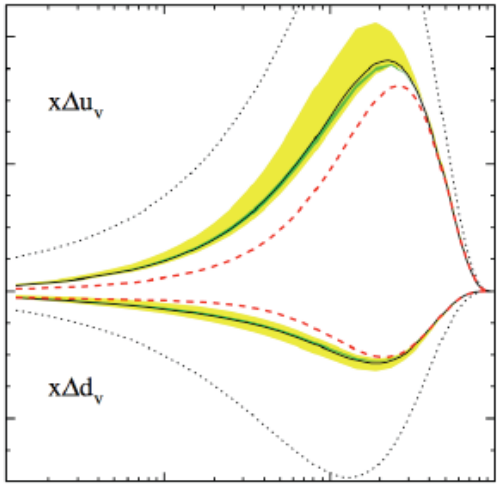
$\eta = 3.2, 3.7$

- In Run 6, STAR measured Pi0 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}







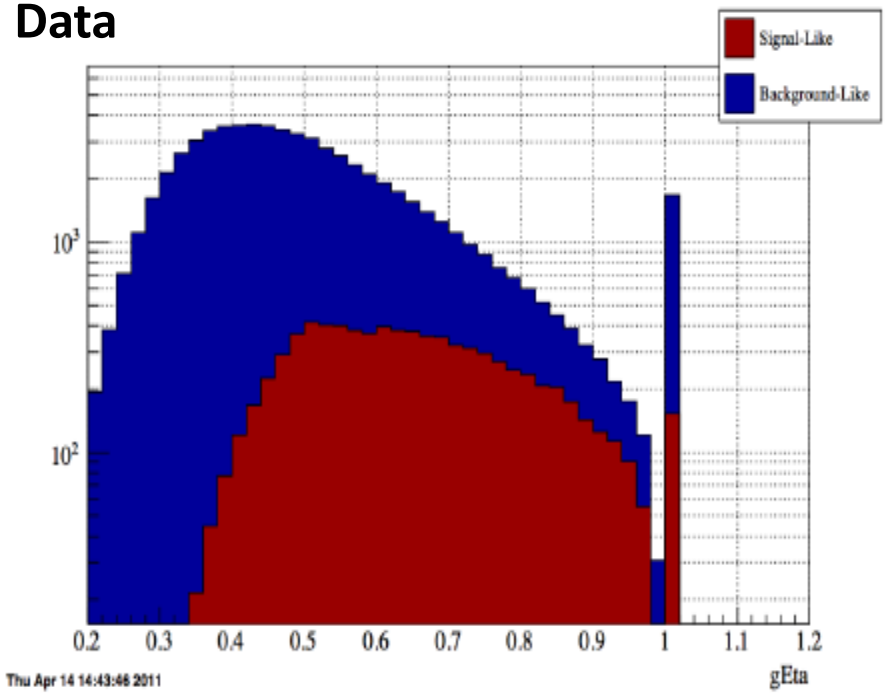
- In Run 5, STAR measured A_{LL} for inclusive charged pions
- $A_{LL}(\pi+)$ - $A_{LL}(\pi-)$ is sensitive to the sign of ΔG
- Trigger using neutral jet patch -> Introduces significant trigger bias (charged pions often subleading particles in jets)

Inclusive Photons

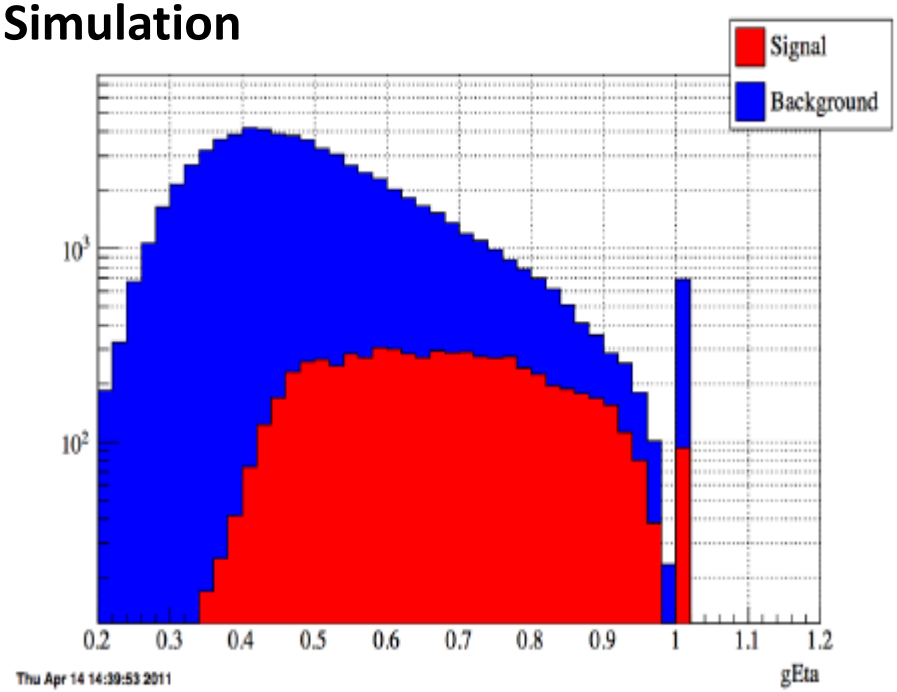
- Photons from the partonic interaction arise predominantly from quark gluon compton scattering and offer a direct probe of the partonic p_T
- Photon yield very small compared to QCD background → powerful extraction techniques required
- Mid rapidity inclusive photon analysis currently underway utilizing machine learning methods

Ratio of highest energy BSMD strip to all strips in cluster

Data

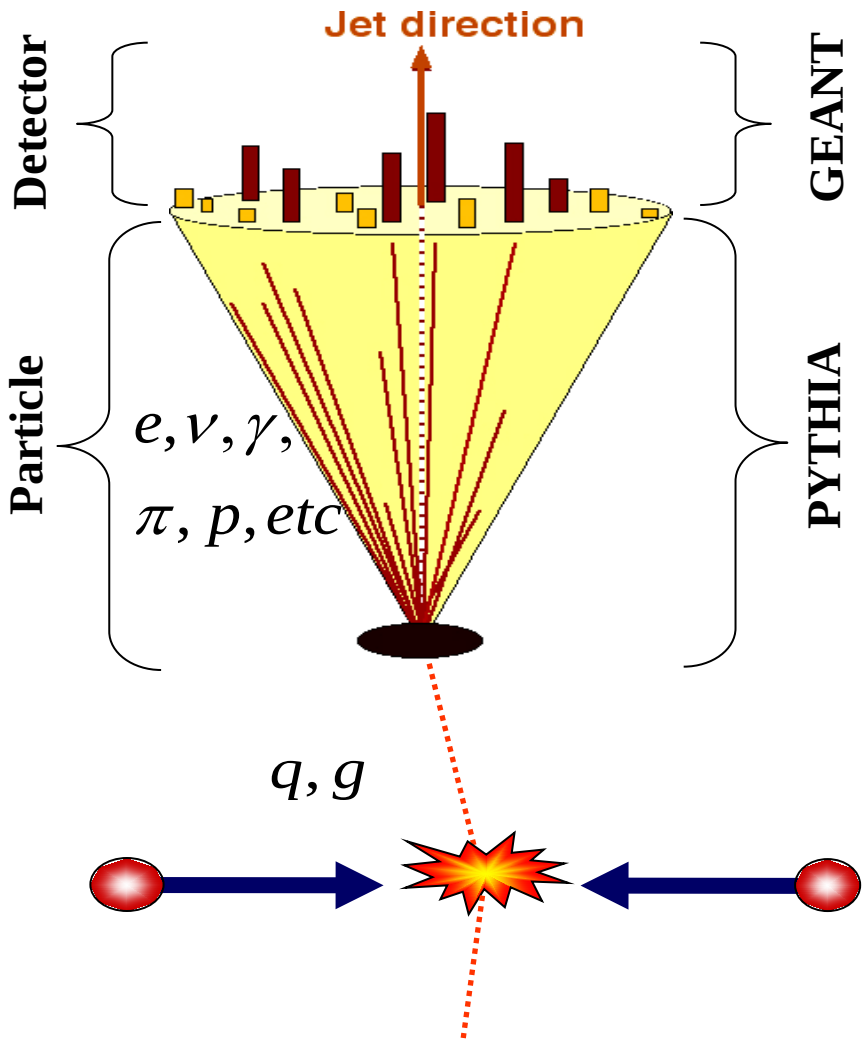


Simulation



Jet Reconstruction

Data Jets **MC Jets**



Midpoint Cone Algorithm:

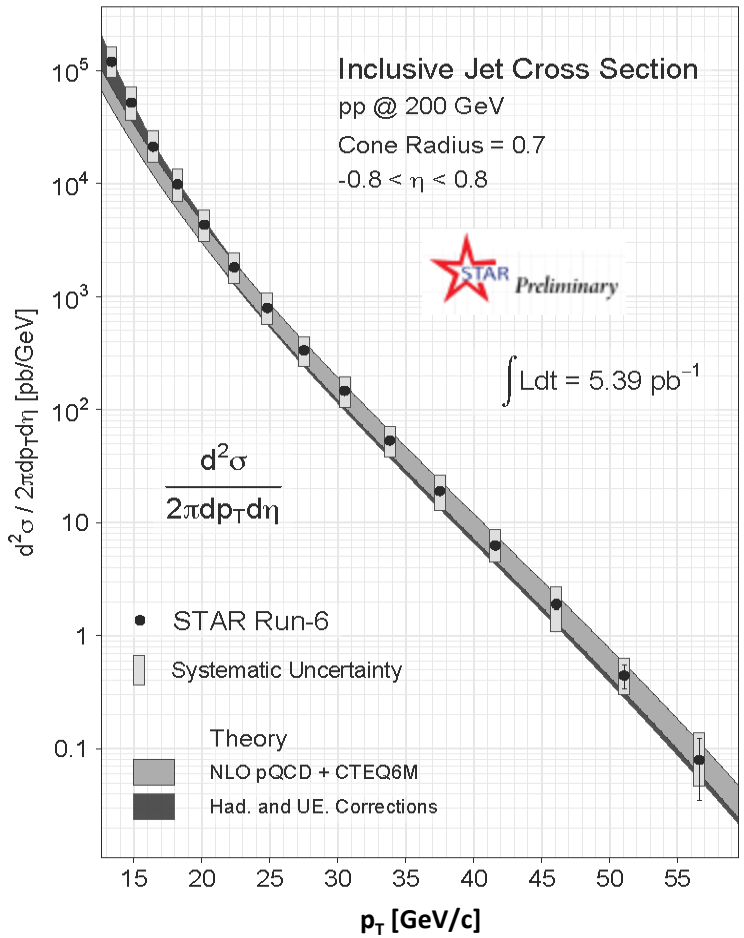
- Adapted from Tevatron II (hep-exp/0005012
- Seed energy = 0.5 GeV
- Cone radius = $\sqrt{(\Delta\eta^2+\Delta\phi^2)} = 0.7$
- Split / Merge fraction = 0.5

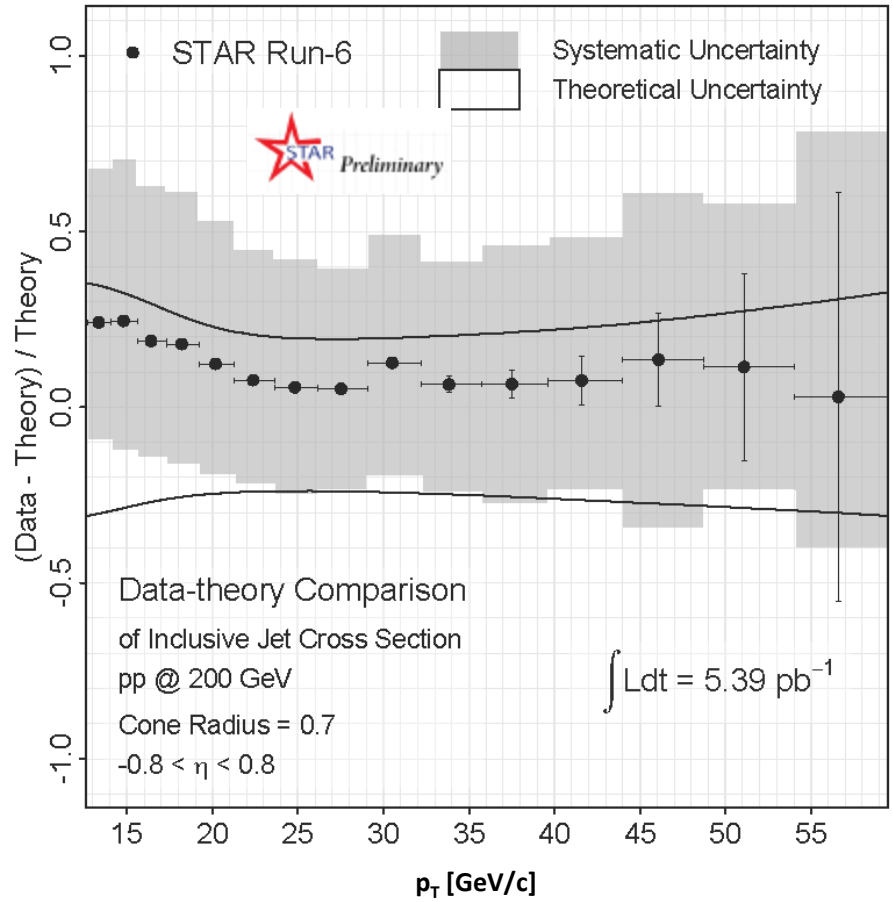
STAR Detector has:

- 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

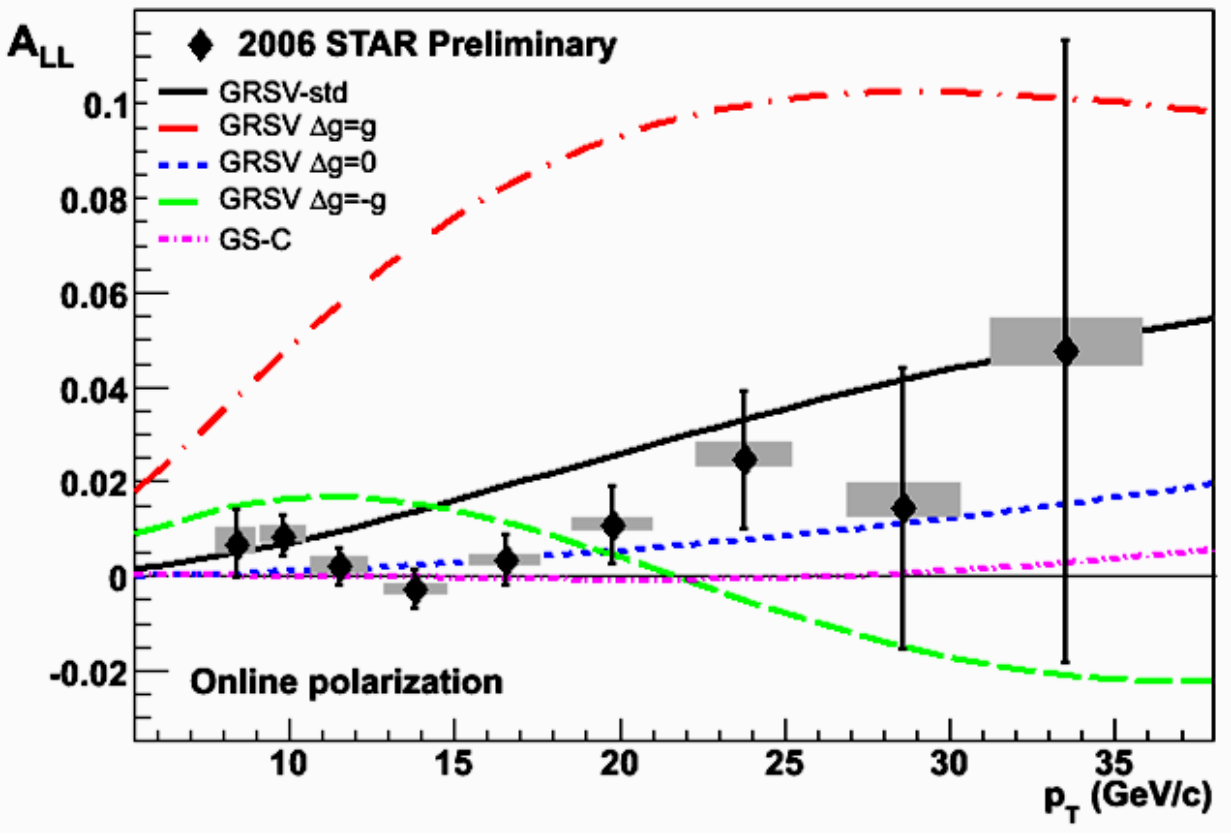
2006 Inclusive Jet Cross Section





- 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 Inclusive Jet A_{LL}

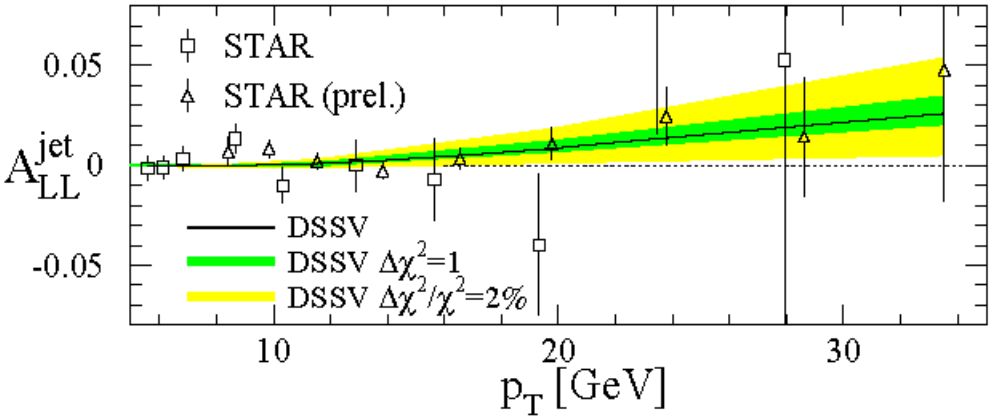


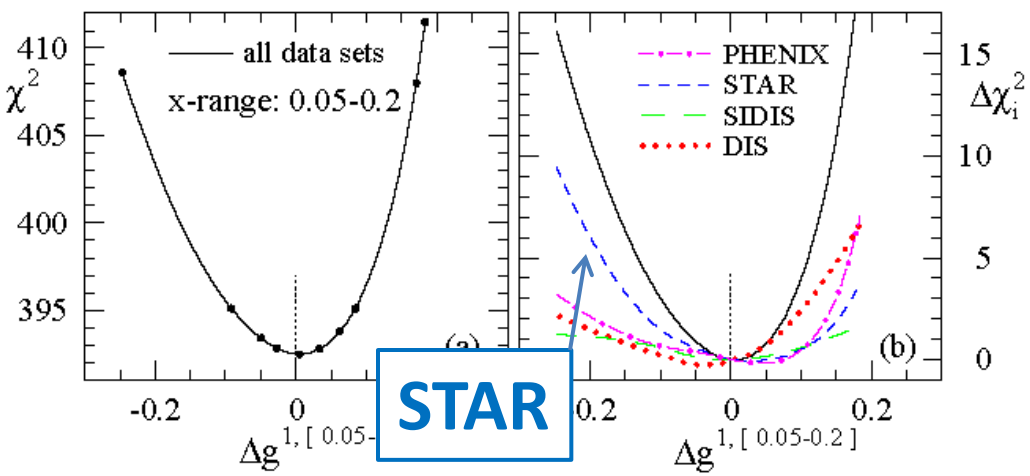
A_{LL} systematics	($\times 10^{-3}$)
Reconstruction + Trigger Bias	[-1,+3] (p_T dep)
Non-longitudinal Polarization	~ 0.03 (p_T dep)
Relative Luminosity	0.94
Backgrounds	1st bin ~ 0.5 Else ~ 0.1
p_T systematic	±6.7%

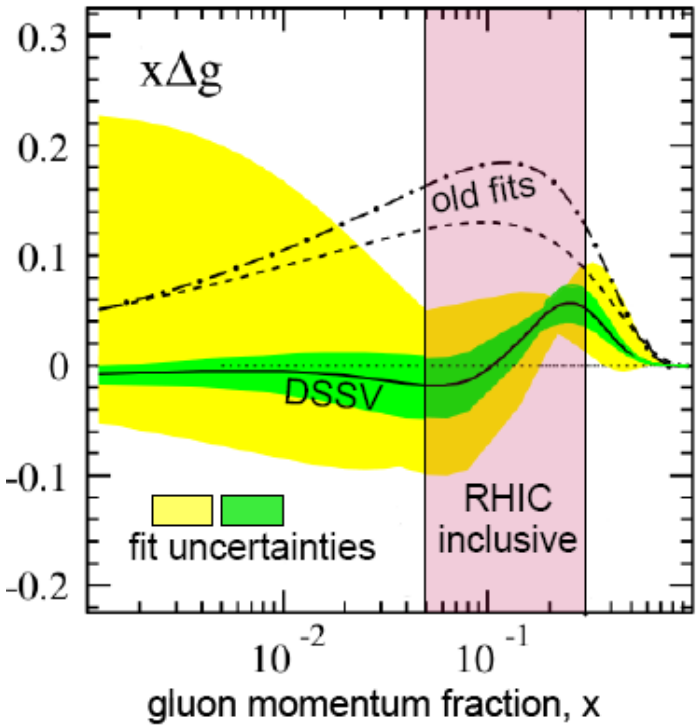
- Run 6 data rules out GRSV-Min and GRSV-Max
- Large gluon polarization in the accessible region disfavored

DSSV Global Fit

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



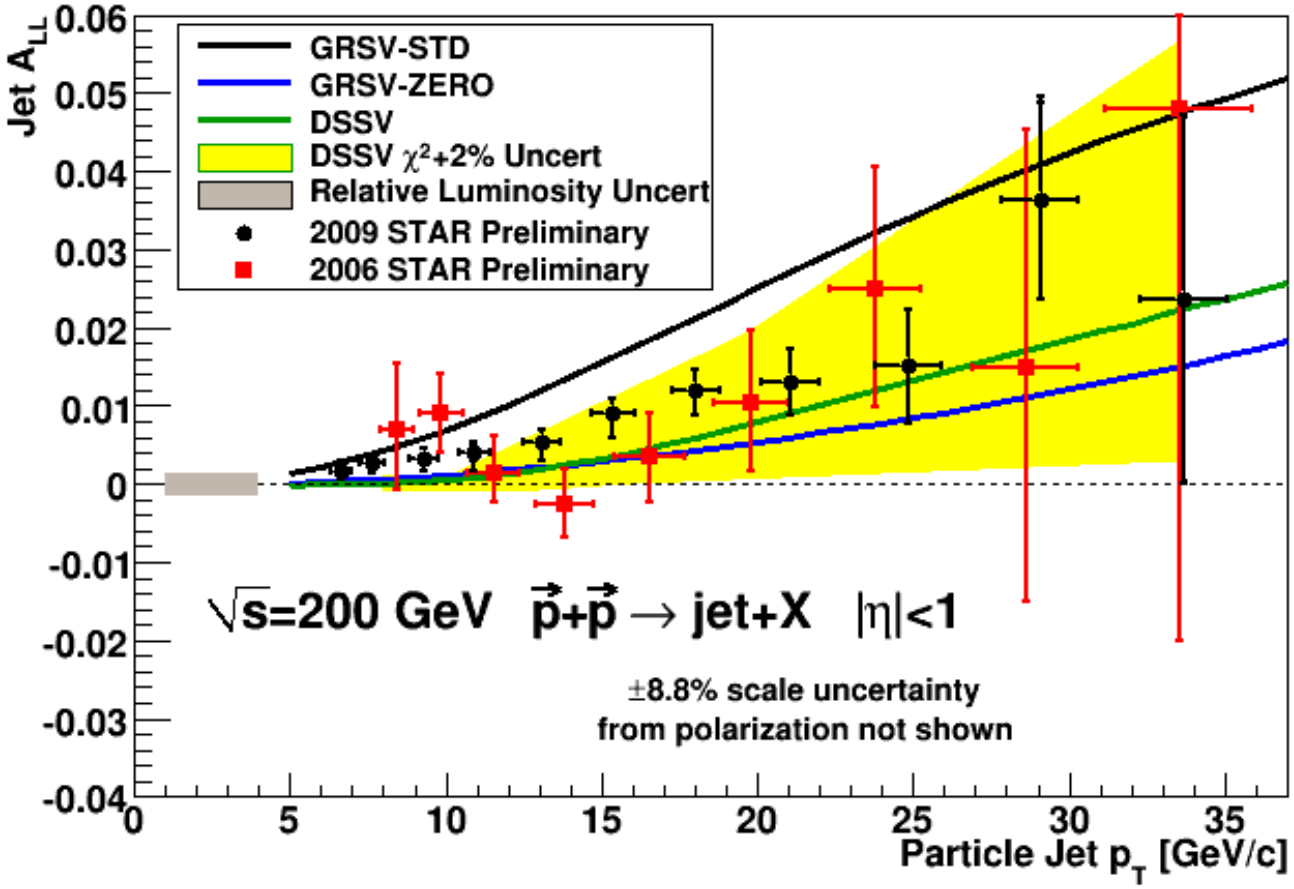




First global NLO analysis which includes DIS, SIDIS, and RHIC pp data

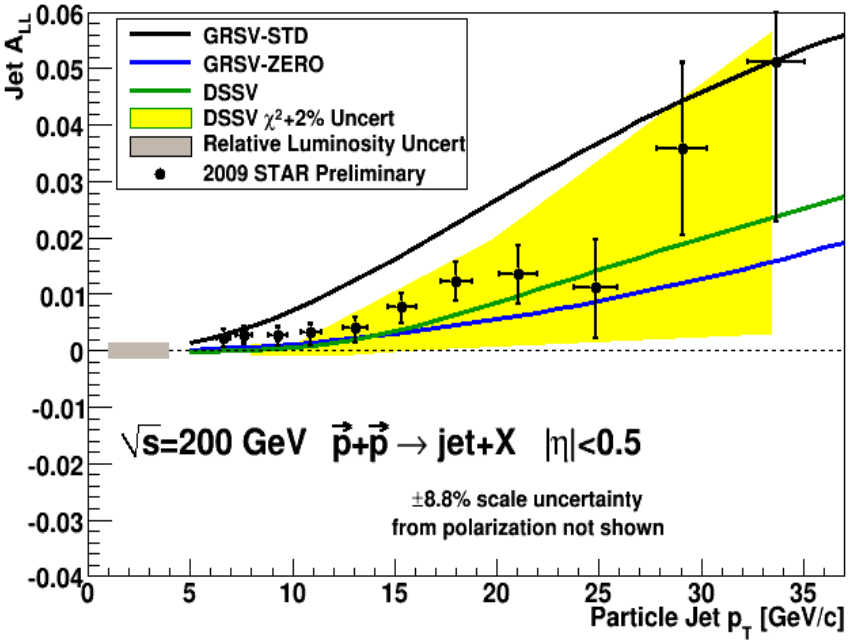
- Strong constraint on Δg in the range 0.05 < x < 0.2
- Low x range still poorly constrained

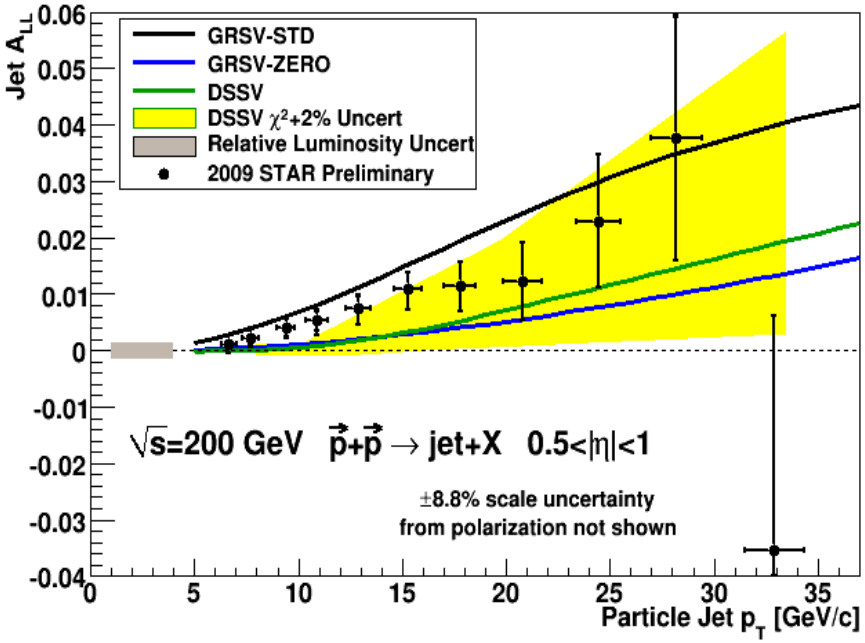
2006 vs 2009 Inclusive Jet A_{LL}



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

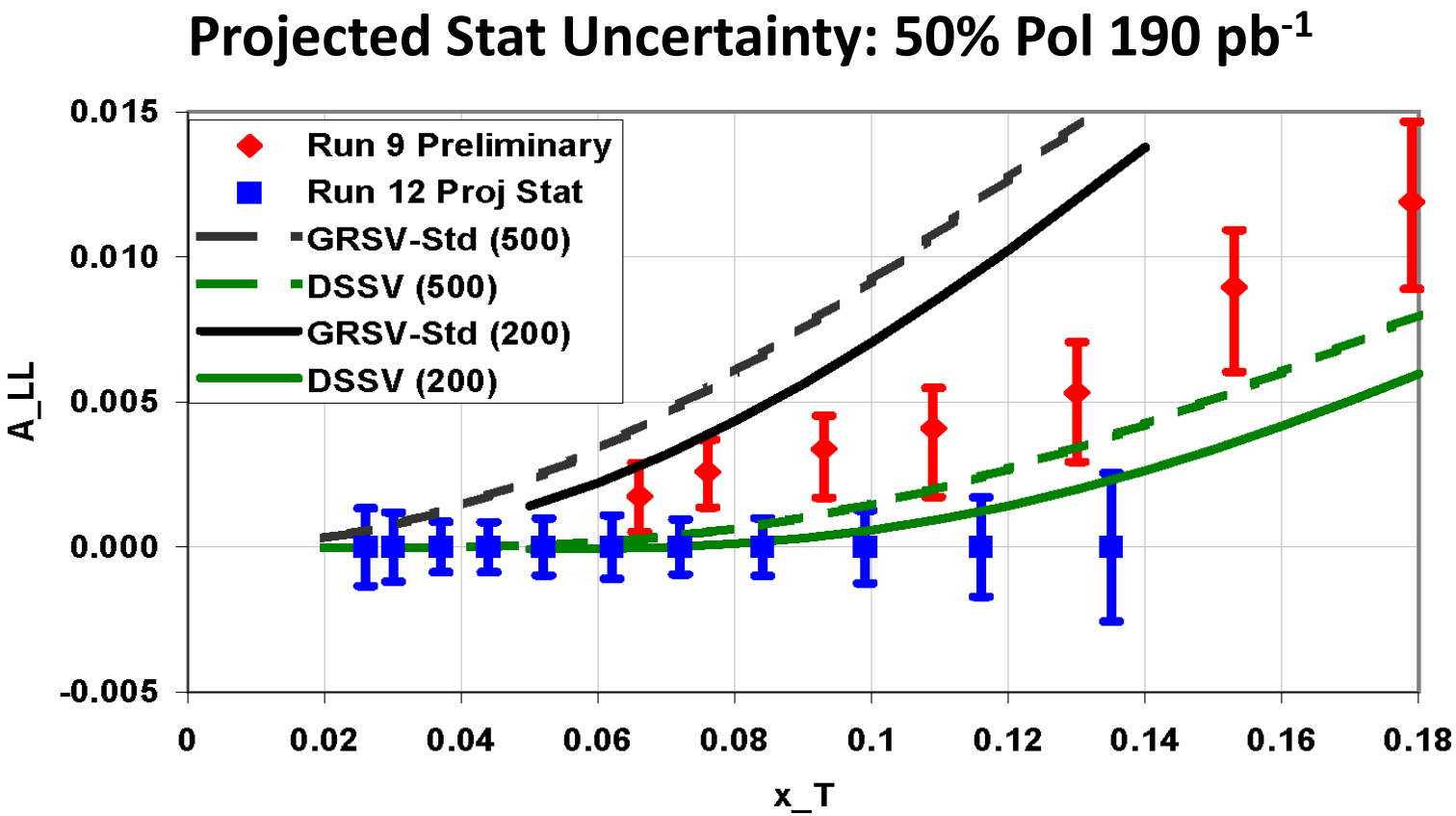
2009 Inclusive Jet A_{LL}





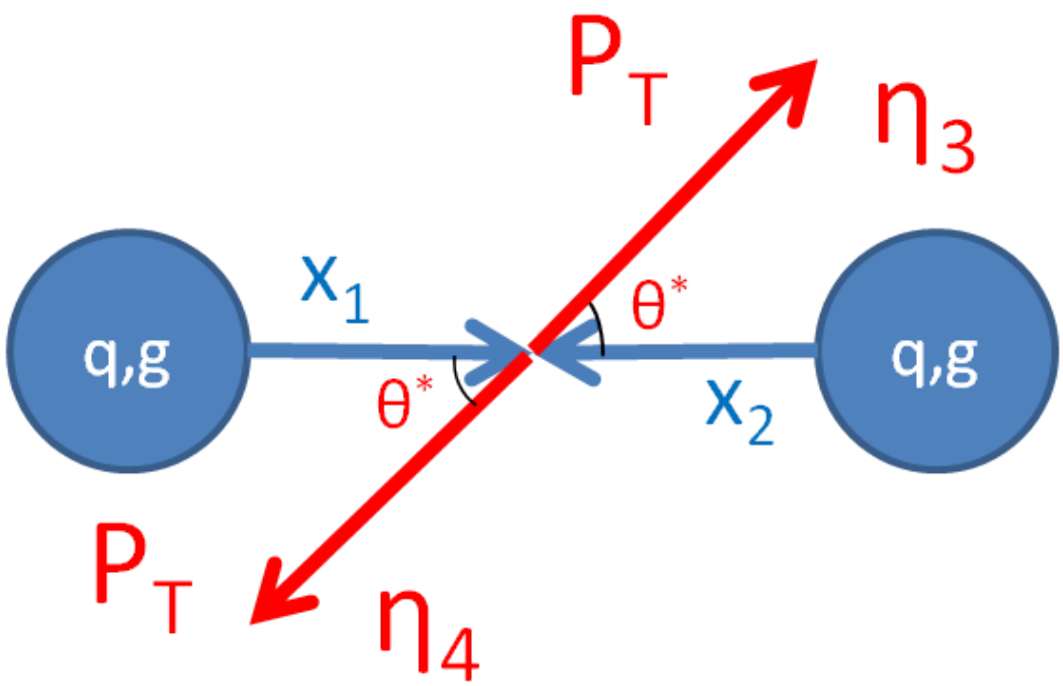
- Data divided into two pseudorapidity ranges
- Different ranges accentuate different partonic x and $|\cos\theta^*|$ values
- A_{LL} falls between DSSV and GRSV-STD in both ranges

Future 500 GeV Projected Sensitivity



- F.O.M. = $P^4 * L$ = 12 pb^{-1} : Projection of what STAR may sample in Run 12
- Collisions at 500 GeV probe smaller $x_T = 2p_T/\sqrt{s}$
- Projected statistical uncertainties based on 2009 experience
- Expect small asymmetries so control of systematics will be important

Correlation Measurements



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

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

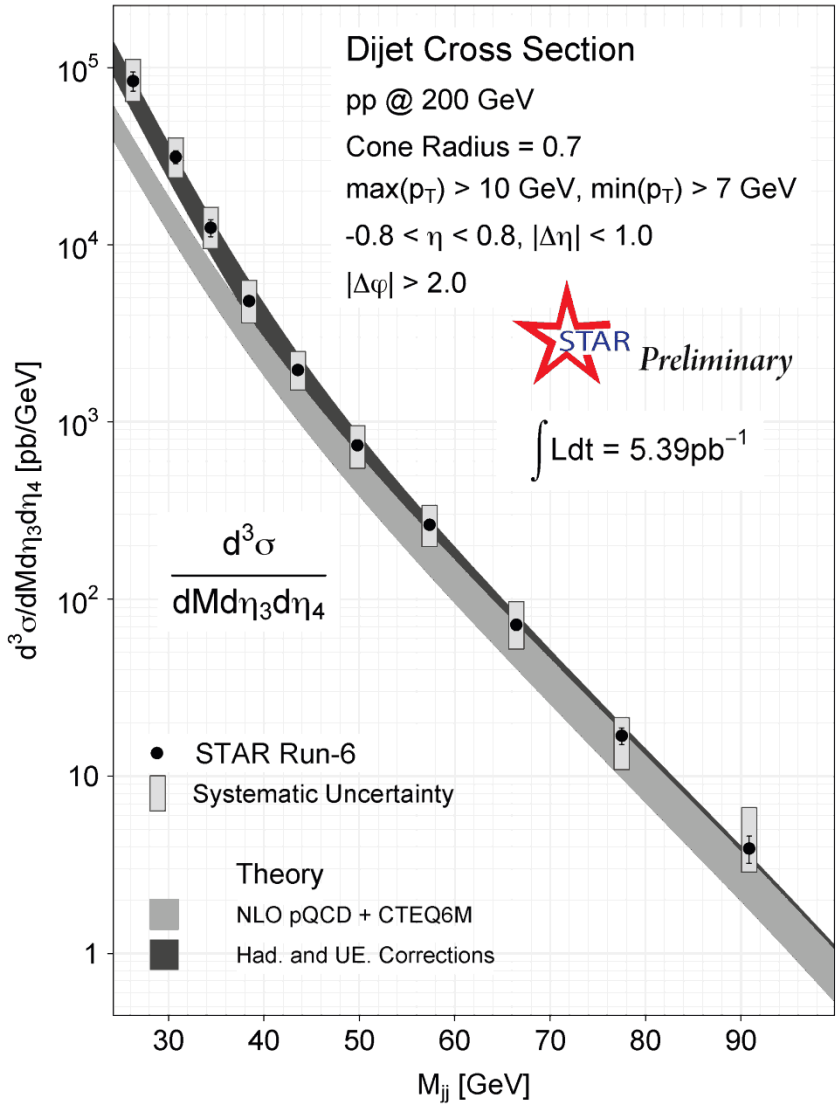
$$M = \sqrt{x_1 x_2 s}$$

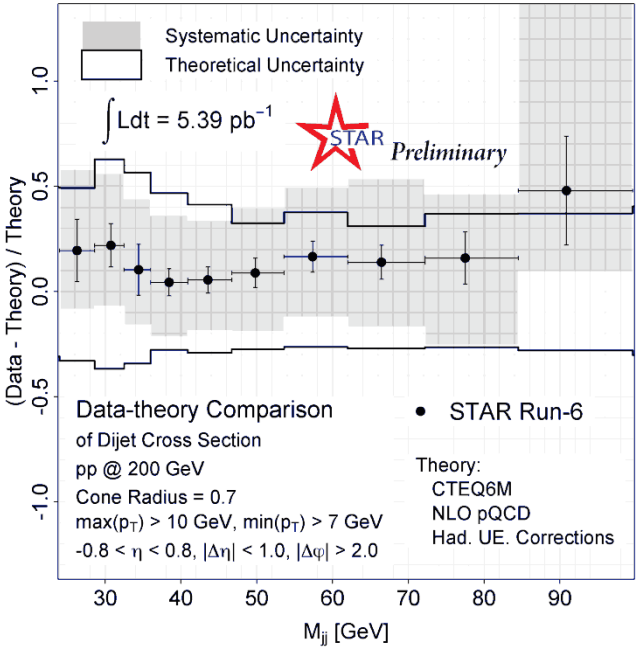
$$\eta_3 + \eta_4 = \ln\frac{x_1}{x_2}$$

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

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

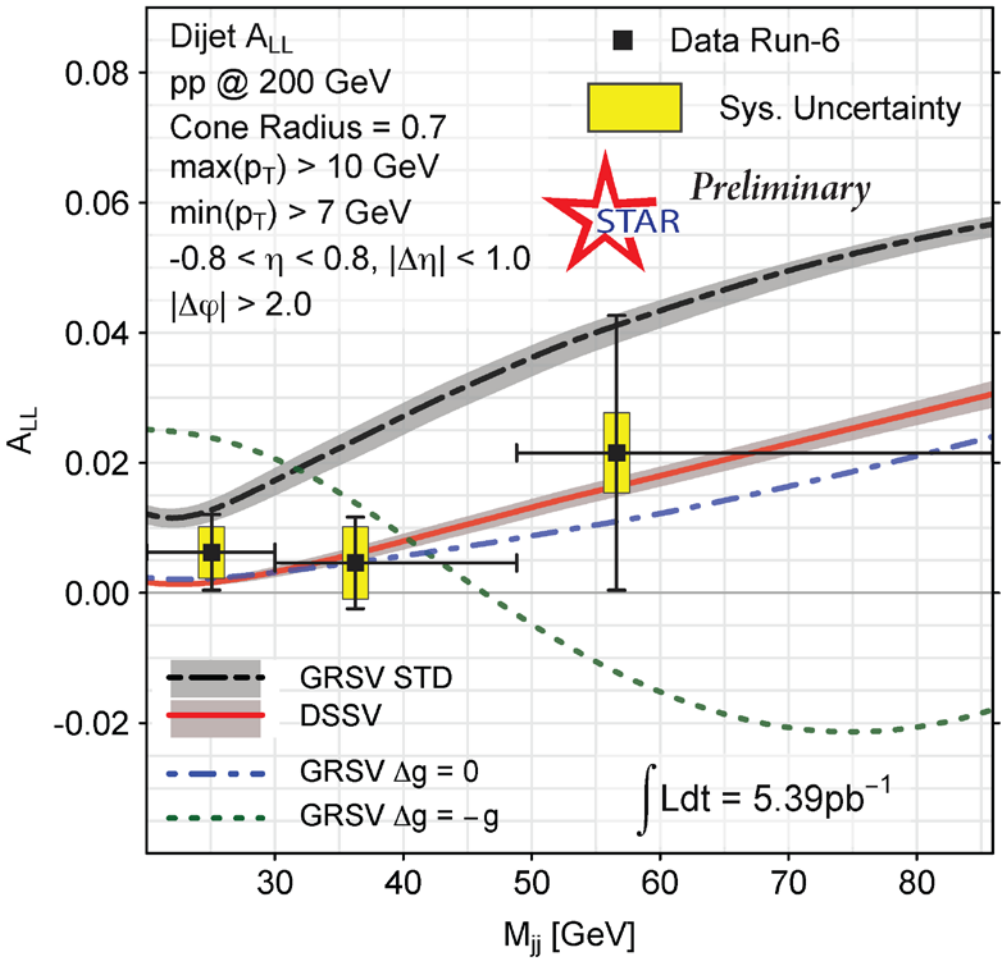
2006 Dijet Cross Section





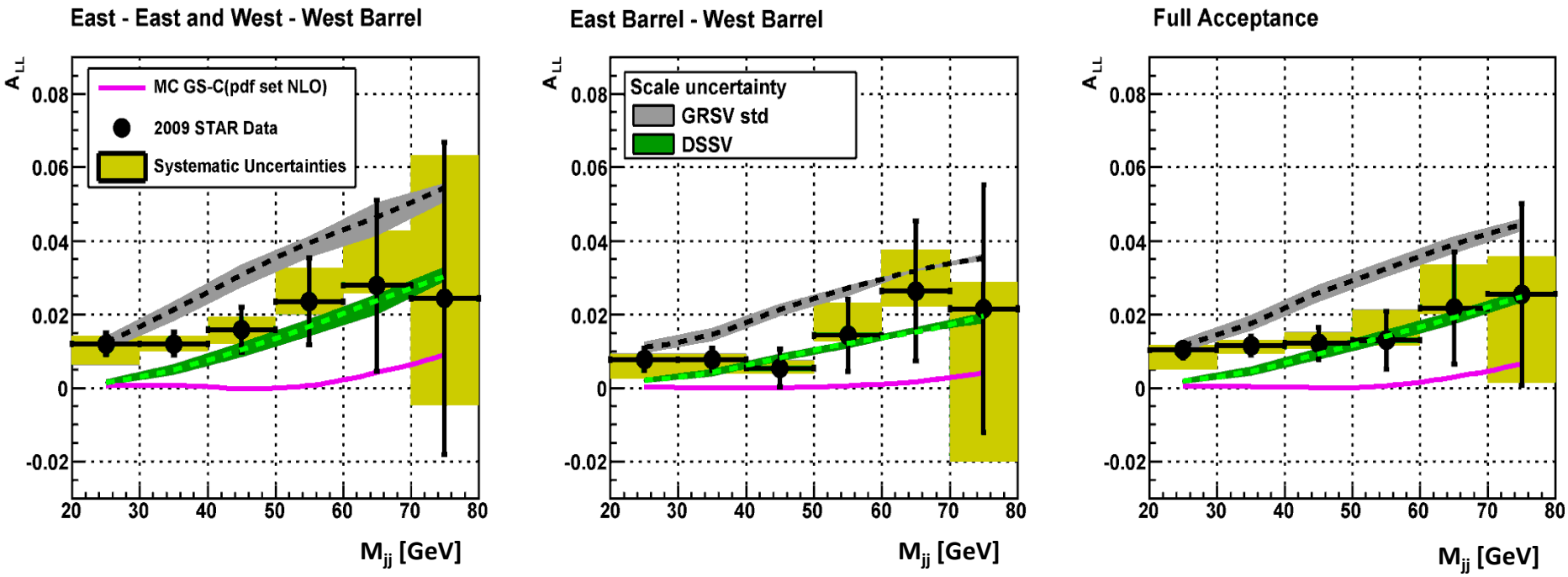
- Data and theory show good agreement within uncertainties after UE and hadronization corrections applied
- As with inclusive cross section, UE and hadronization corrections become more important at low invariant mass

2006 Dijet A_{LL}



- +/- 8.3% scale uncertainty from beam polarization not shown

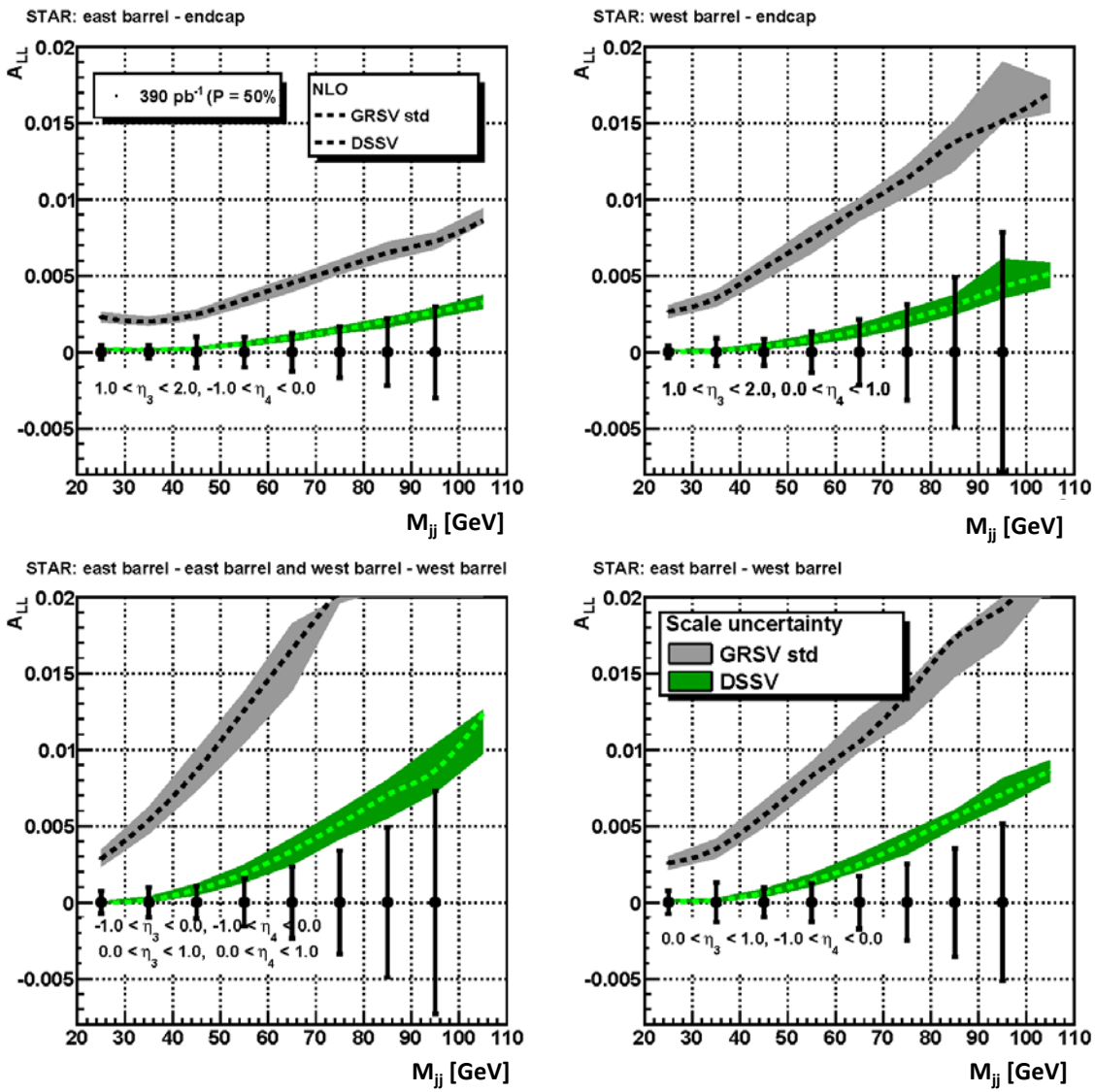
2009 Dijet A_{LL}



- 2009 data roughly a factor of 3 more precise than 2006 data
- Merits finer binning in invariant mass as well as dividing into different dijet topologies
- Results fall between DSSV and GRSV-STD
- Different topologies sensitive to different x_1 x_2 and $\cos\theta^*$ ranges

Projected Dijet Sensitivity @ 500 GeV

Projected Stat. Uncertainty: 50% Pol 390 pb^{-1}



- F.O.M. = $P^4 * L$ = 24 pb^{-1}
- Higher energies give access to lower x values
- Expect A_{LL} to be smaller
- Projections shown are purely statistical and include information about trigger rates from Run 9

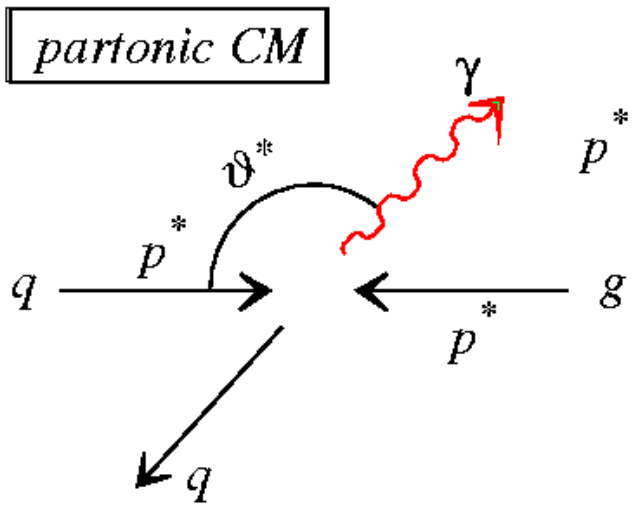
Gamma + Jet: A Long-Term STAR Goal

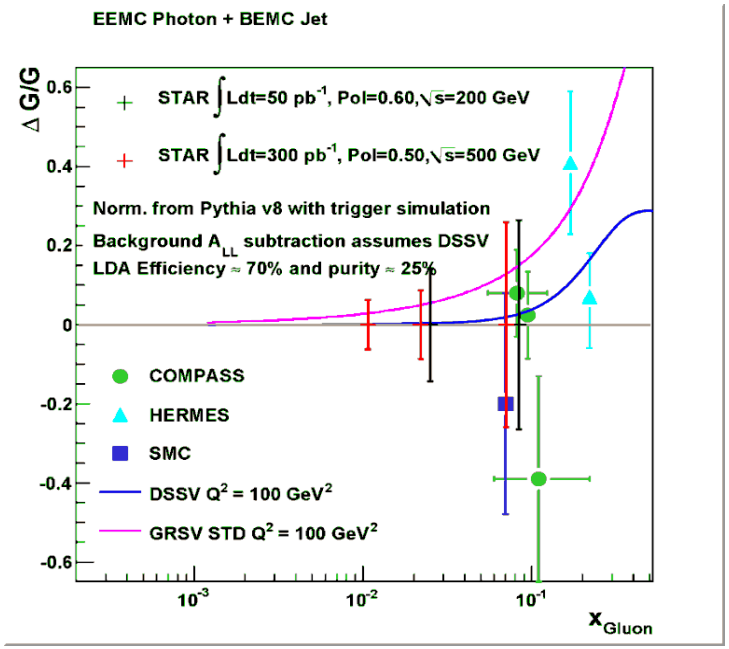
- Gamma + Jet production dominated by quark-gluon Compton scattering

- 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





Conclusions

- 2006 STAR data has played a significant role in constraining ΔG

- 2009 results are 3-4 times more precise and will have a strong impact on the determination of ΔG

- 2009 inclusive and dijet A_{LL} are consistent and fall between DSSV and GRSV-STD

- Future running at 500 GeV will allow access to lower x regions

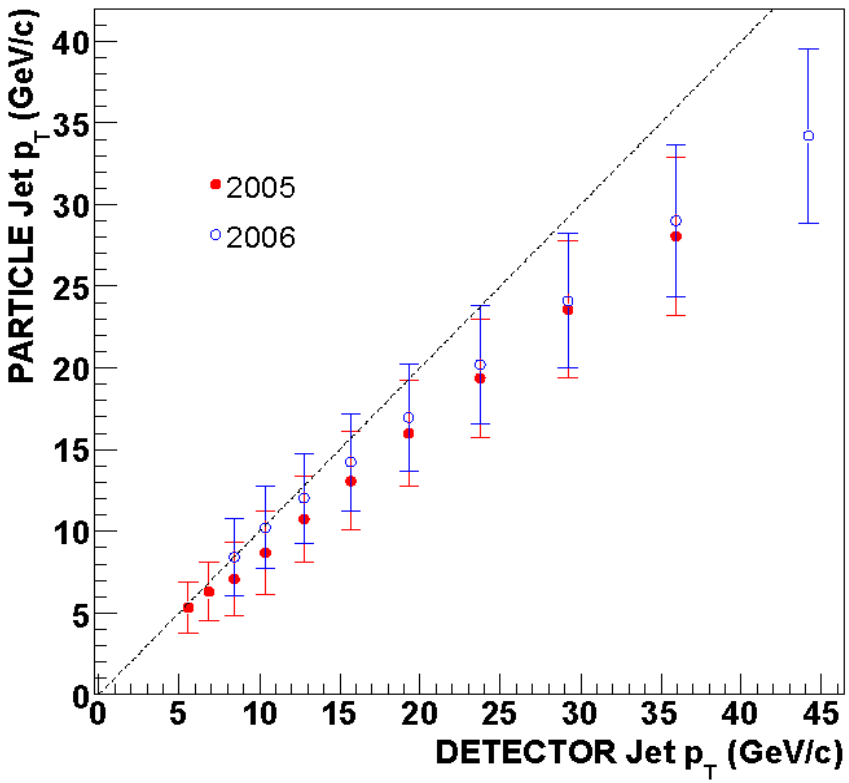
- Stay Tuned!!

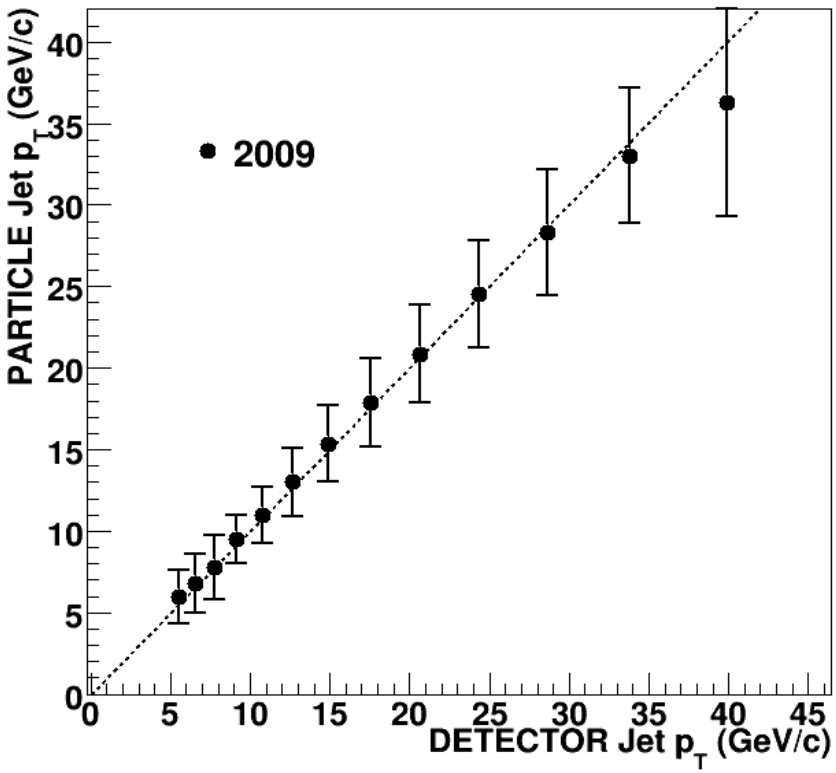
Backup Slides

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

Particle to Detector Jets





- 2009 hadronic subtraction scheme:
- Smaller mean and RMS p_T shift
- Better jet p_T resolution

- Dominant uncertainties in jet energy scale arise from calorimeter calibration and response to neutral hadrons
- Jet p_T uncertainties are highly correlated