DIS 2013

Gluon Polarization and Jet Production in *STAR*

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for the
***STAR* Collaboration**

Outline

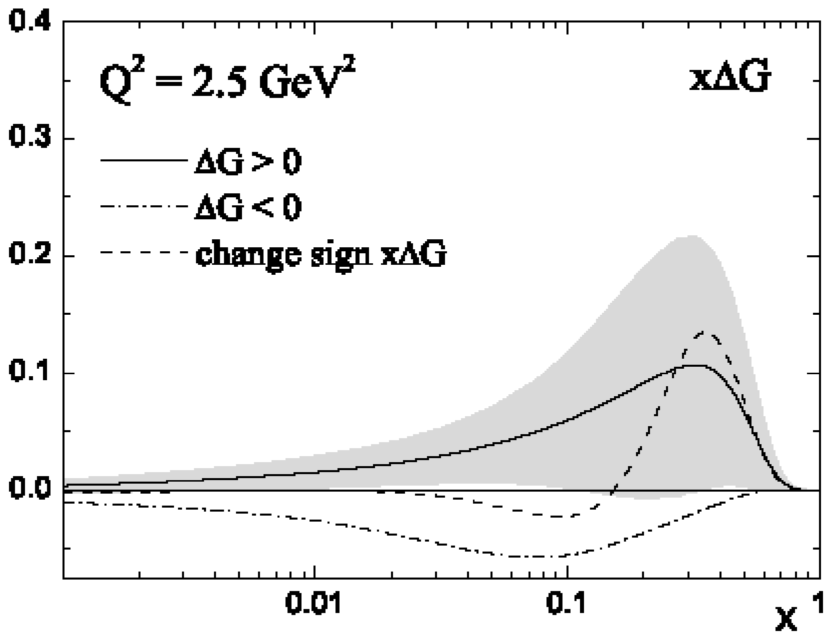
- Introduction
- Inclusive jet measurements
- Di-jet measurements

Partonic origin of the proton spin?

$$S_z = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \langle L_z \rangle$$

Polarized DIS: ~0.3

Poorly Constrained



Three 2006 fits of equal quality:

- $\Delta G = 0.13 \pm 0.16$
- $\Delta G \sim 0.006$
- $\Delta G = -0.20 \pm 0.41$

all at $Q^2 = 1$ GeV^2

Leader et al, PRD 75, 074027

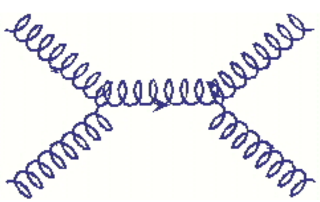
- Measuring the **gluon polarization distribution** is **a primary goal of the RHIC spin program**

Exploring gluon polarization at RHIC

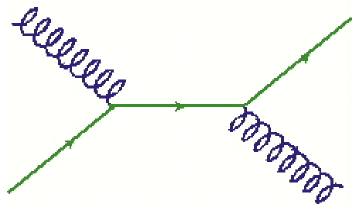
$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \propto \frac{\Delta f_a \Delta f_b}{f_a f_b} \hat{a}_{LL}$$

Δf: polarized parton distribution functions

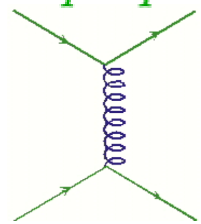
$$\frac{\Delta G}{G} \frac{\Delta G}{G}$$

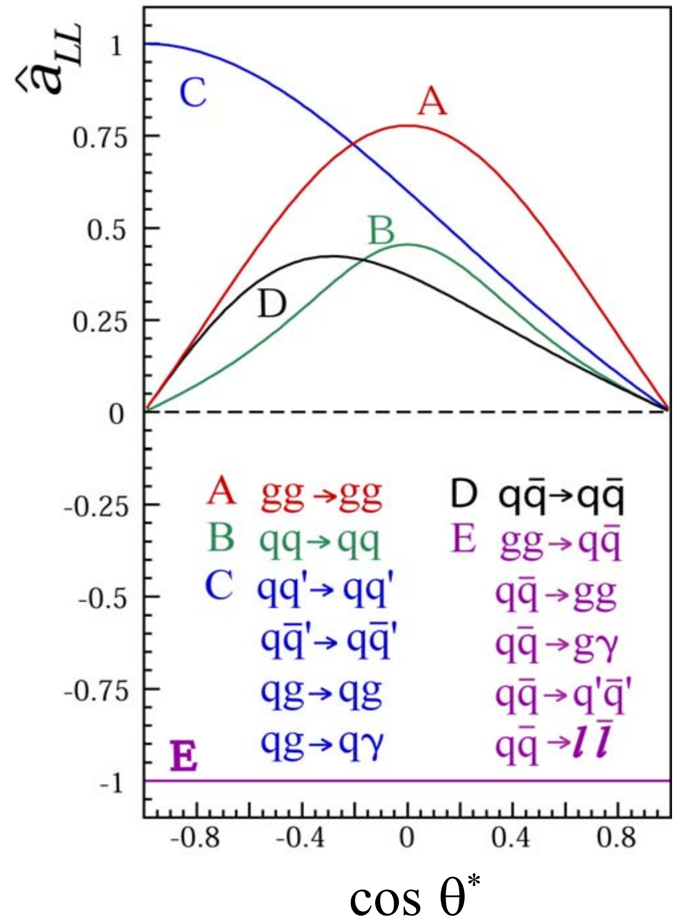


$$\frac{\Delta q}{q} \frac{\Delta G}{G}$$

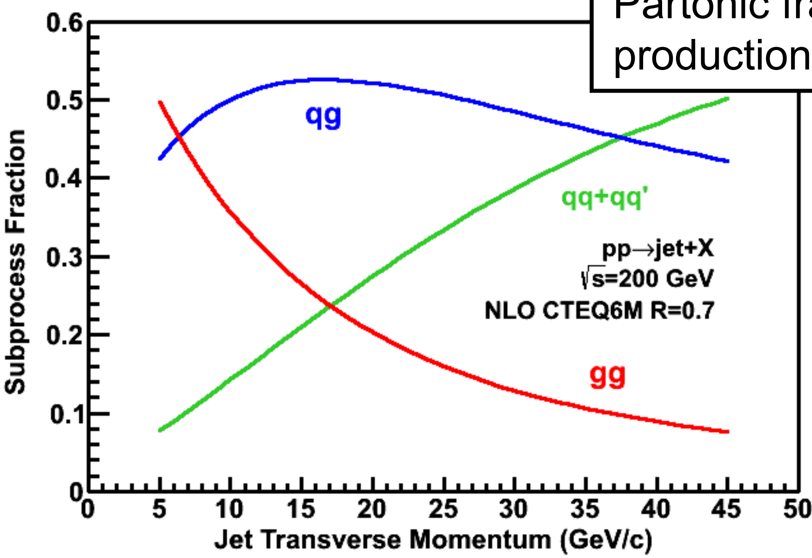


$$\frac{\Delta q}{q} \frac{\Delta q}{q}$$



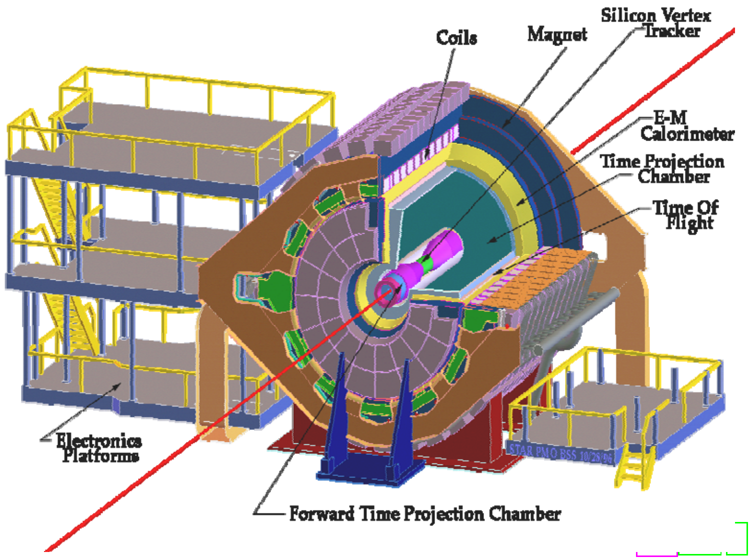


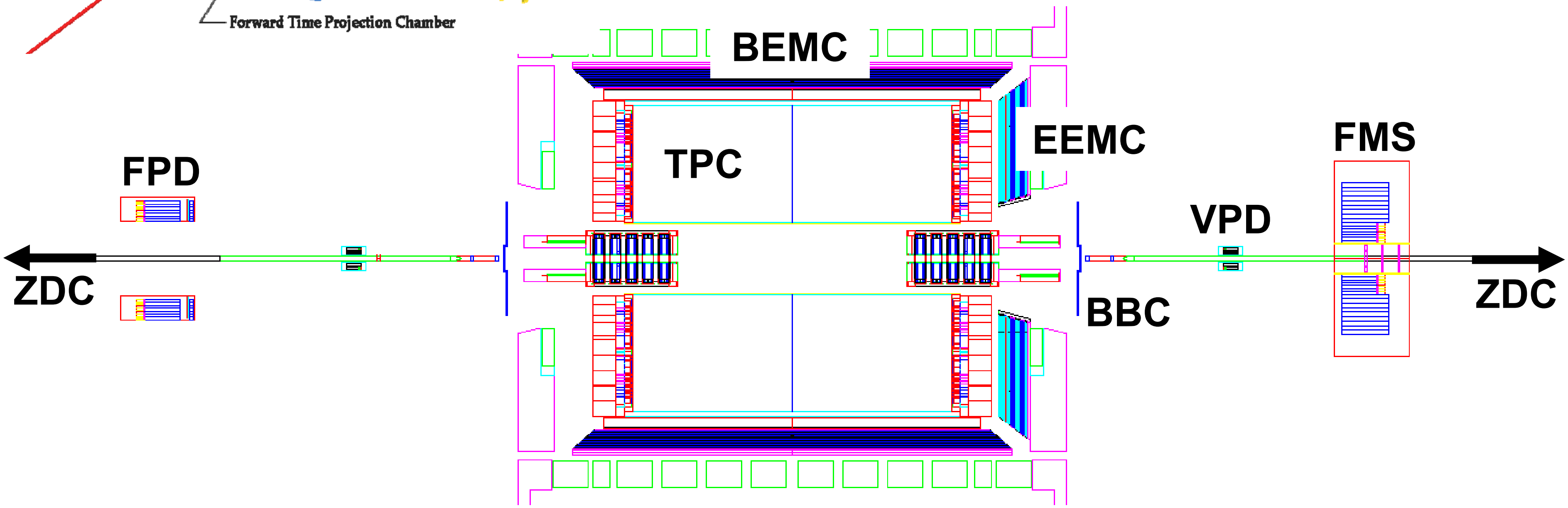
Partonic fractions in jet production at 200 GeV



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

STAR detector in two views





- High precision tracking with the TPC
- Electromagnetic calorimetry with the BEMC, EEMC, and FMS
- Additional detectors for relative luminosity, local polarimetry, and minbias triggering

Gluon polarization measurements at *STAR*

Inclusive measurements

- Features
  - High precision measurements
  - Average over partonic kinematics
  - Powerful for determining the scale of ΔG

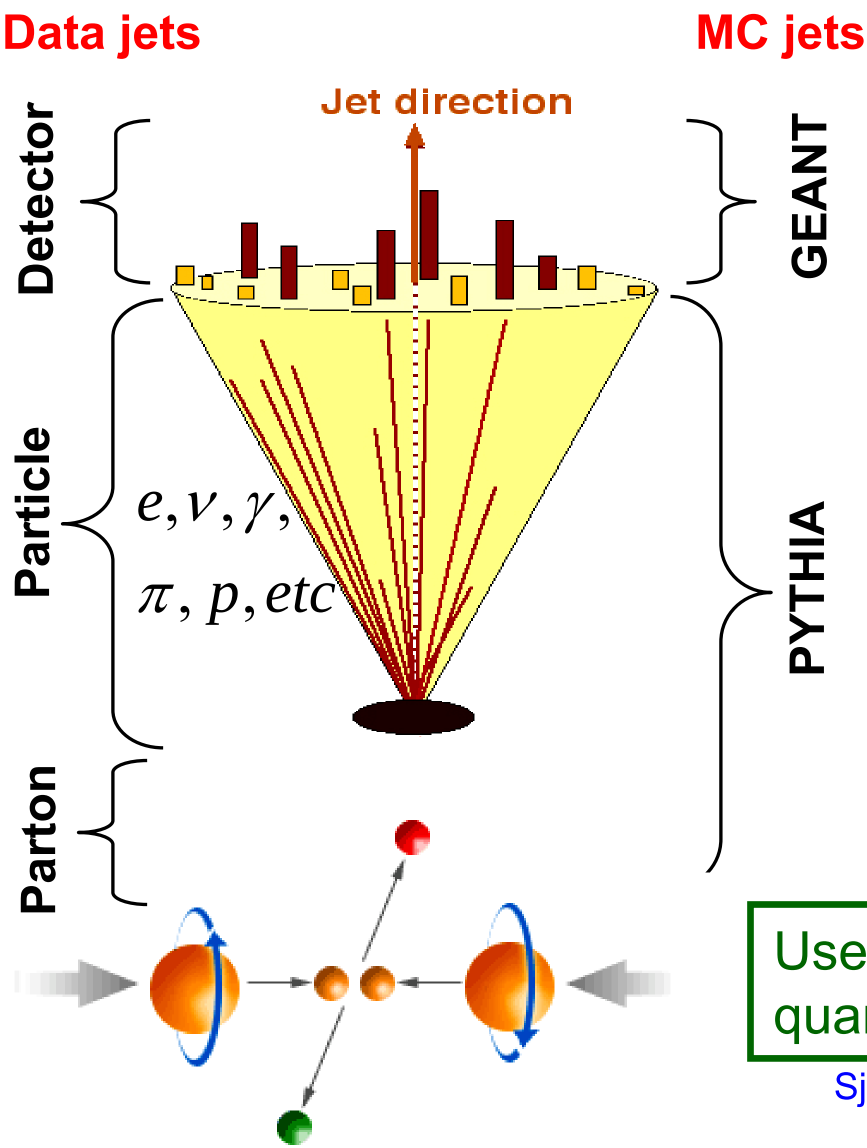
Correlation measurements

- Features
  - Less abundant
  - Resolve partonic kinematics on event-by-event basis
  - Provide information about the shape of $\Delta g(x)$

- **Both** types of measurements **provide important information for global analyses**
- Large acceptance of STAR makes **jet and di-jet measurements particularly attractive**

Additional *STAR* gluon polarization talks:
- **Grant Webb (di-jet σ at 500 GeV)**
- **Steve Gliske (π^0 σ, A_{LL}, A_N in $0.8<\eta<2$)**

Jet reconstruction in ***STAR***



For 2006 and preliminary 2009

Midpoint cone algorithm

Adapted from Tevatron II - hep-ex/0005012

- Seed energy = 0.5 GeV
- Cone radius R = 0.7 in η-φ space
- Split/merge fraction f = 0.5

For final 2009

Anti-k_T algorithm

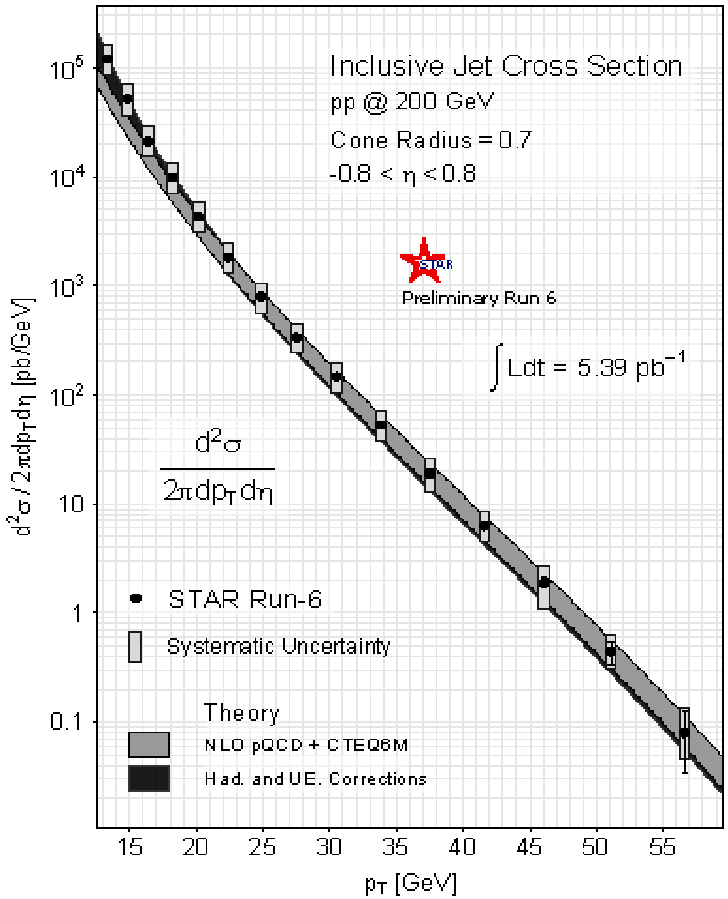
Cacciari, Salam, and Soyez, JHEP 0804, 063

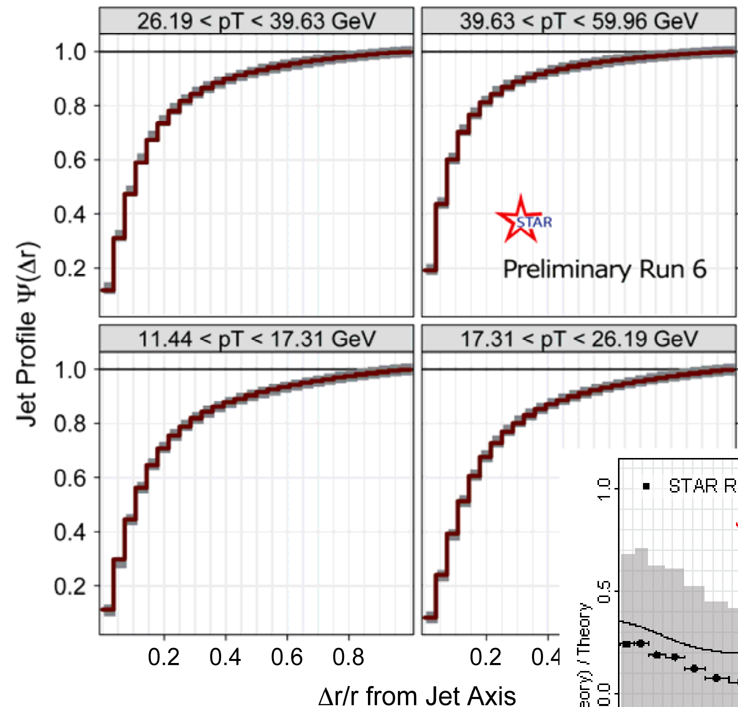
- R = 0.6

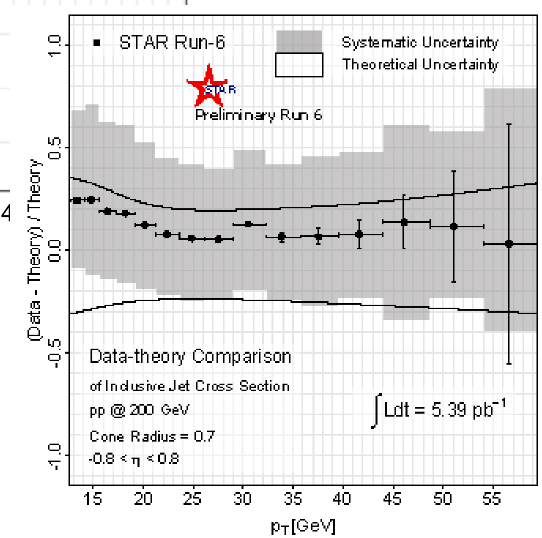
Use **PYTHIA + GEANT** to quantify detector response

Sjostrand, Mrenna, and Skands, JHEP 05, 026

Jet cross section from 2006 data

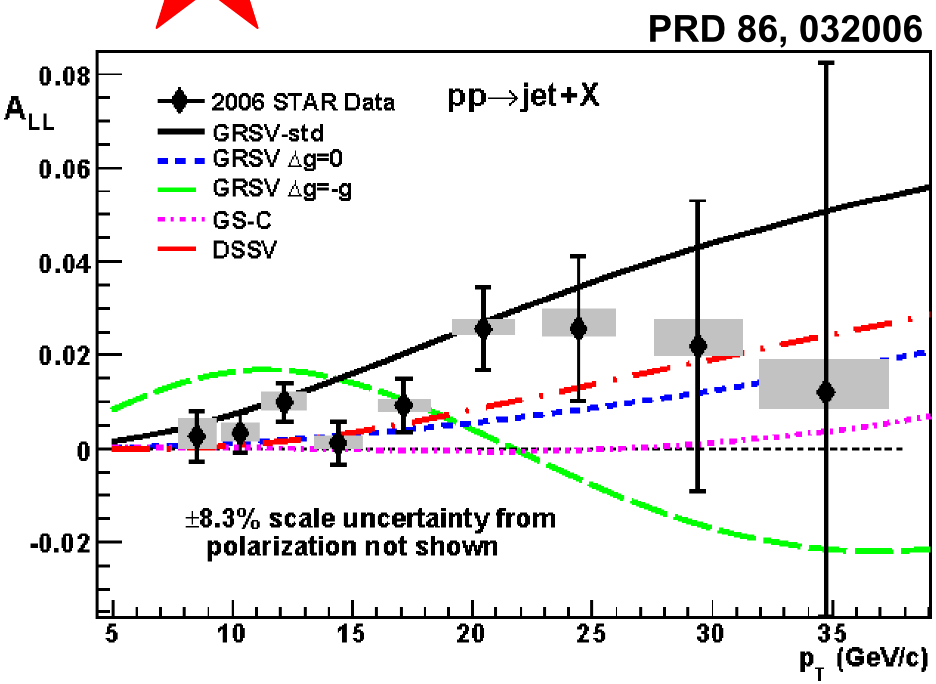


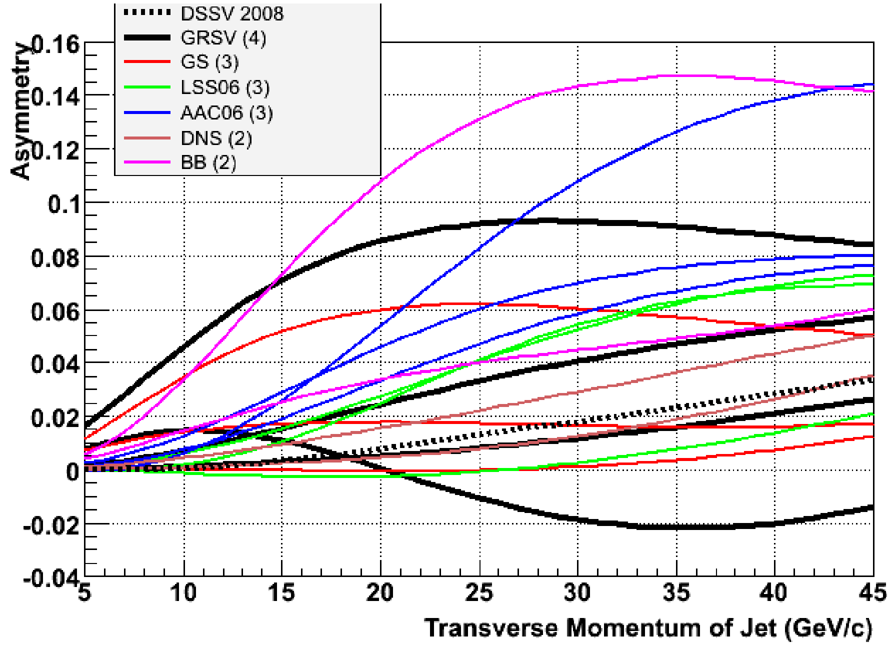




- Good agreement between data and simulation
- Good agreement with NLO pQCD calculation after hadronization and underlying event correction is applied
- Jet production is **well understood** at RHIC energies

STAR inclusive jet A_{LL} from 2006

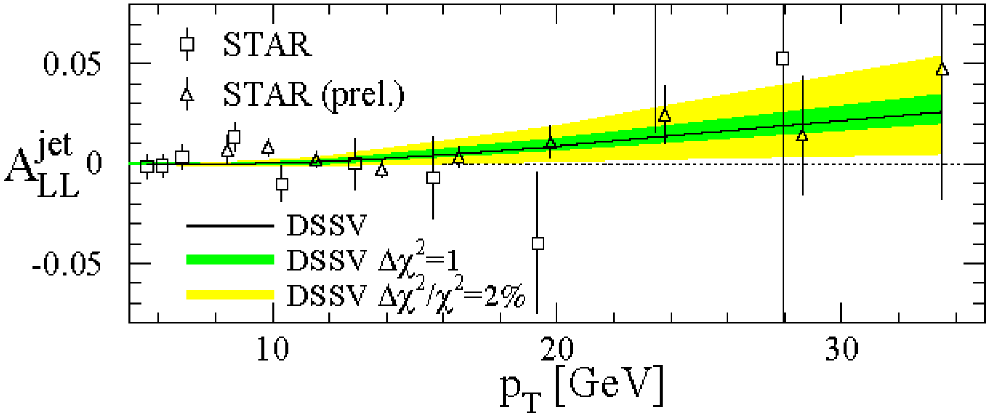


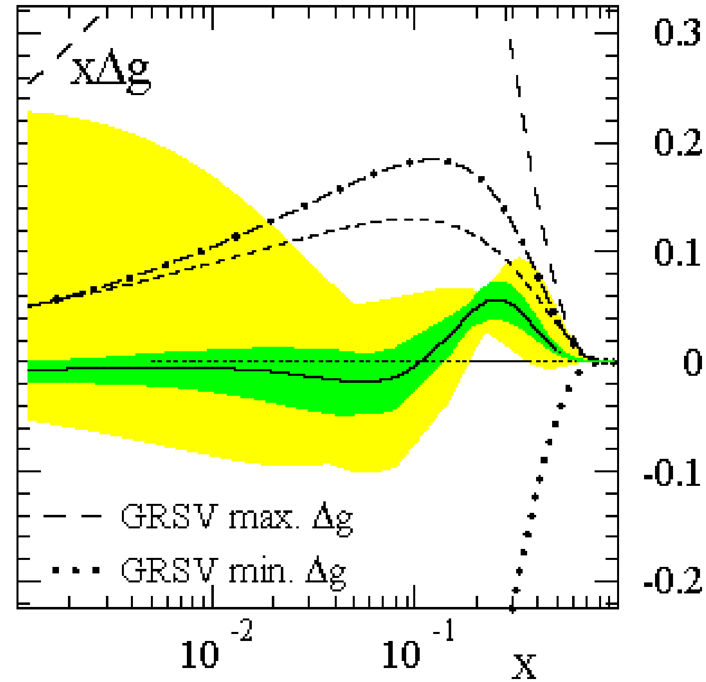


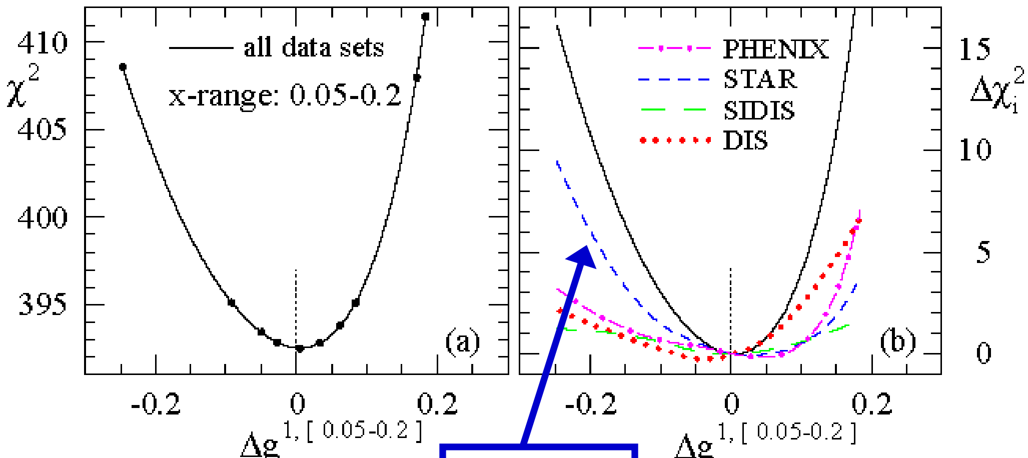
- ***STAR*** inclusive jet A_{LL} excludes those scenarios that have a large gluon polarization within the accessible *x* region

DSSV – first global analysis with polarized jets

de Florian et al., PRL 101, 072001







STAR

- The first global NLO analysis to include inclusive DIS, SIDIS, and RHIC pp data on an equal footing

2009 upgrades

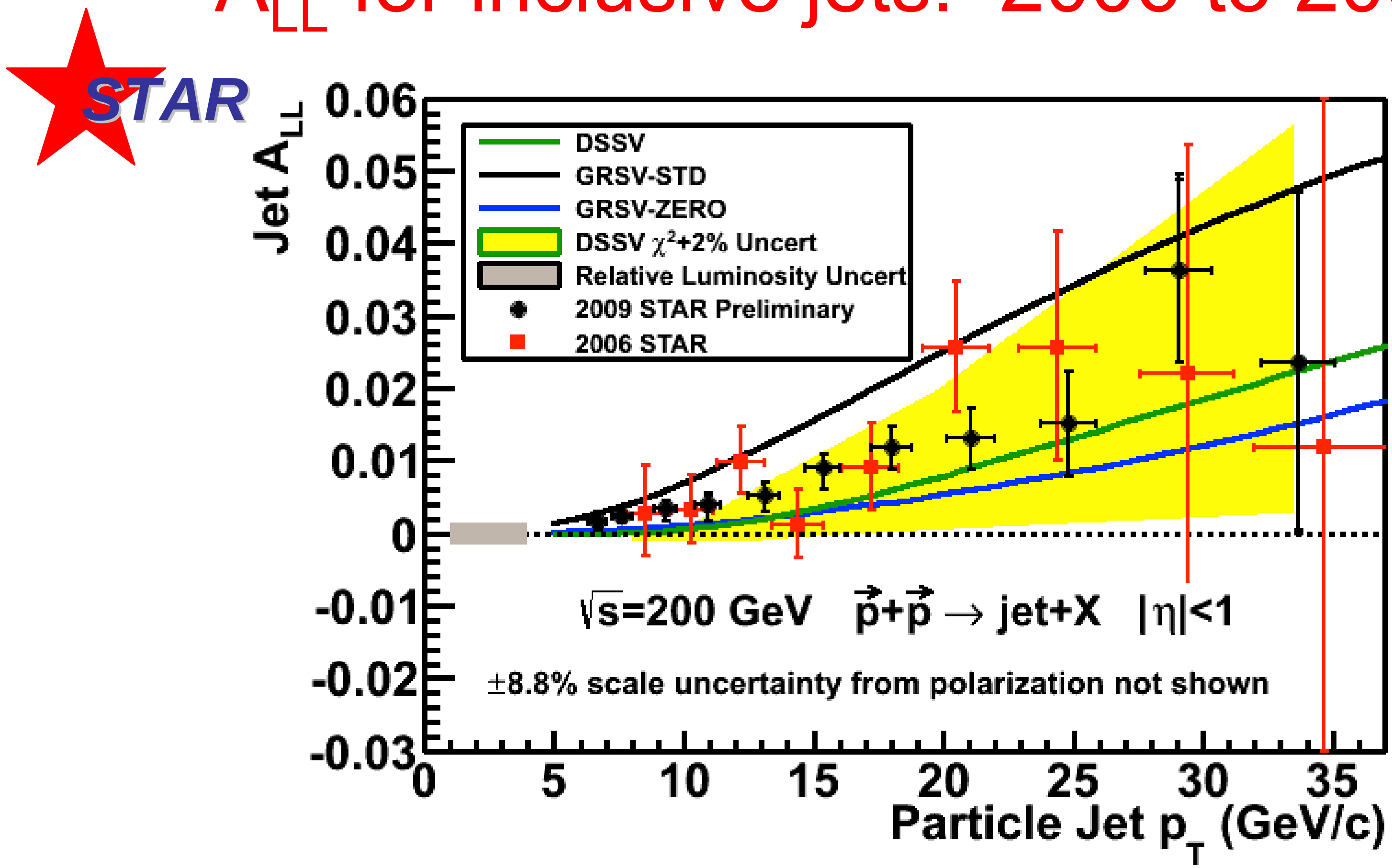
Jet specific

- 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
- 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%

Enhance all channels

- Increased trigger rate and reduced thresholds enabled by DAQ1000
- Sampled ~ 4 times the figure-of-merit relative to 2006

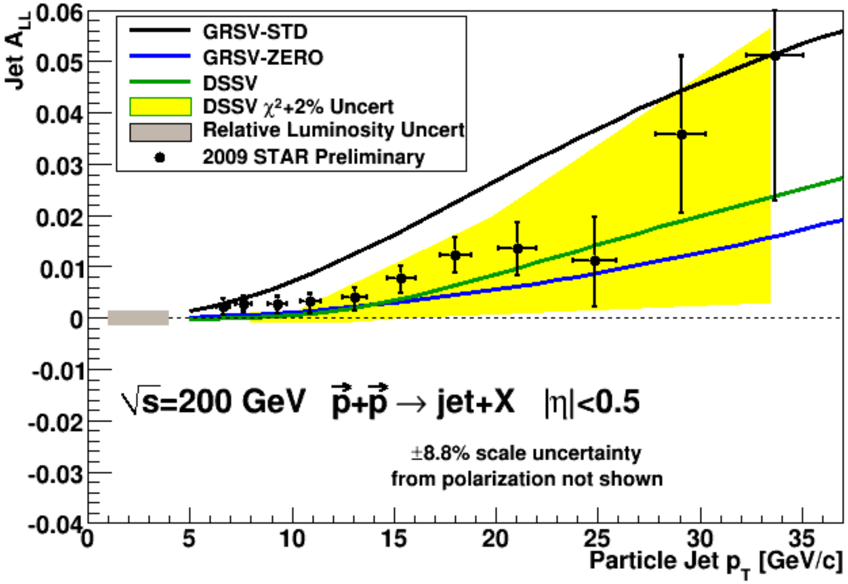
A_{LL} for inclusive jets: 2006 to 2009



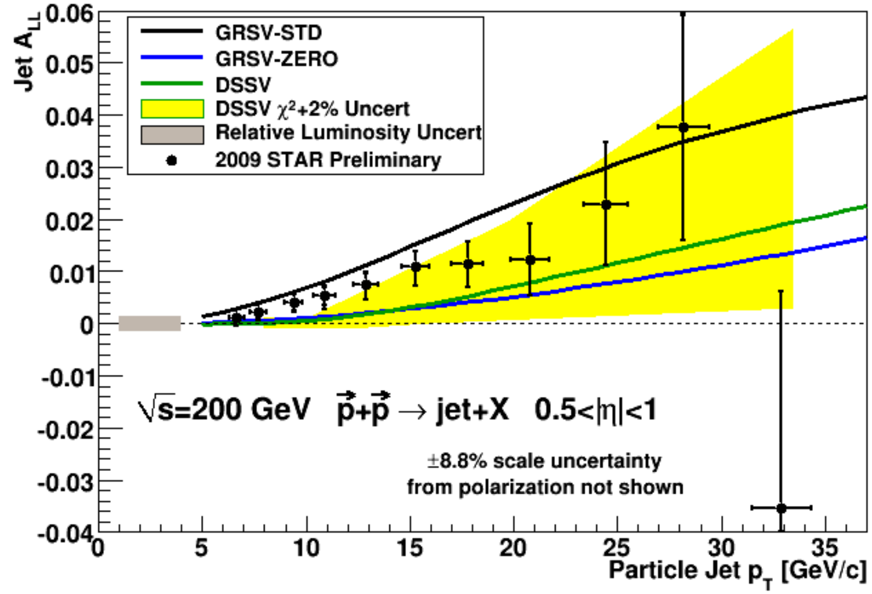
- 2009 ***STAR*** inclusive jet A_{LL} measurements are a factor of 3 (high-p_T) to >4 (low-p_T) more precise than 2006
- **Results fall between predictions from DSSV and GRSV-STD**
- Precision sufficient to merit finer binning in pseudorapidity

2009 *STAR* inclusive jet A_{LL}

Mid rapidity



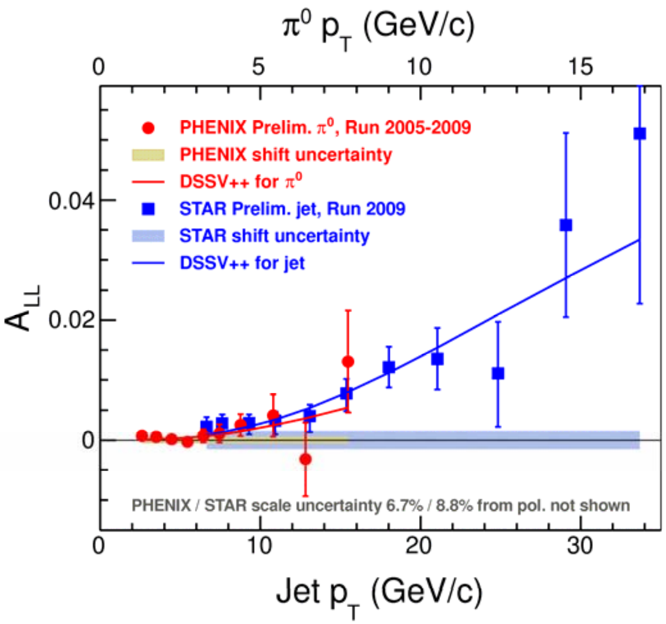
Forward rapidity

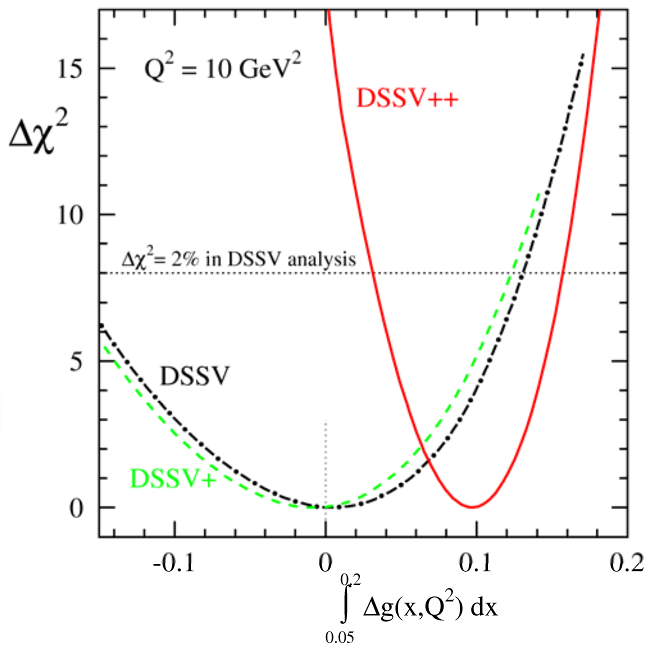


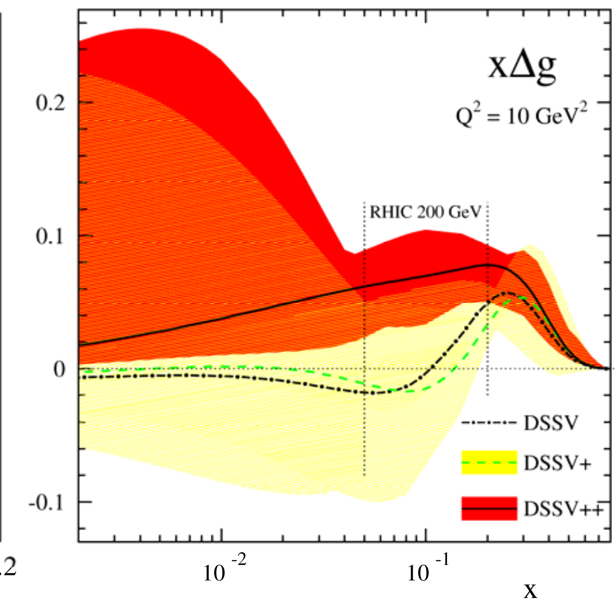
- A_{LL} separated into two pseudorapidity ranges
- Forward jets involve:
  - A larger fraction of quark-gluon scattering with:
    - Higher *x* quarks that are more polarized
    - Lower *x* gluons that are less polarized, but more abundant
  - Larger $|\cos(\theta^*)|$, which reduces $\hat{a}_{LL}$
- **A_{LL} falls between the predictions from DSSV and GRSV-STD**

New global analysis with 2009 RHIC data

Special thanks to the DSSV group!





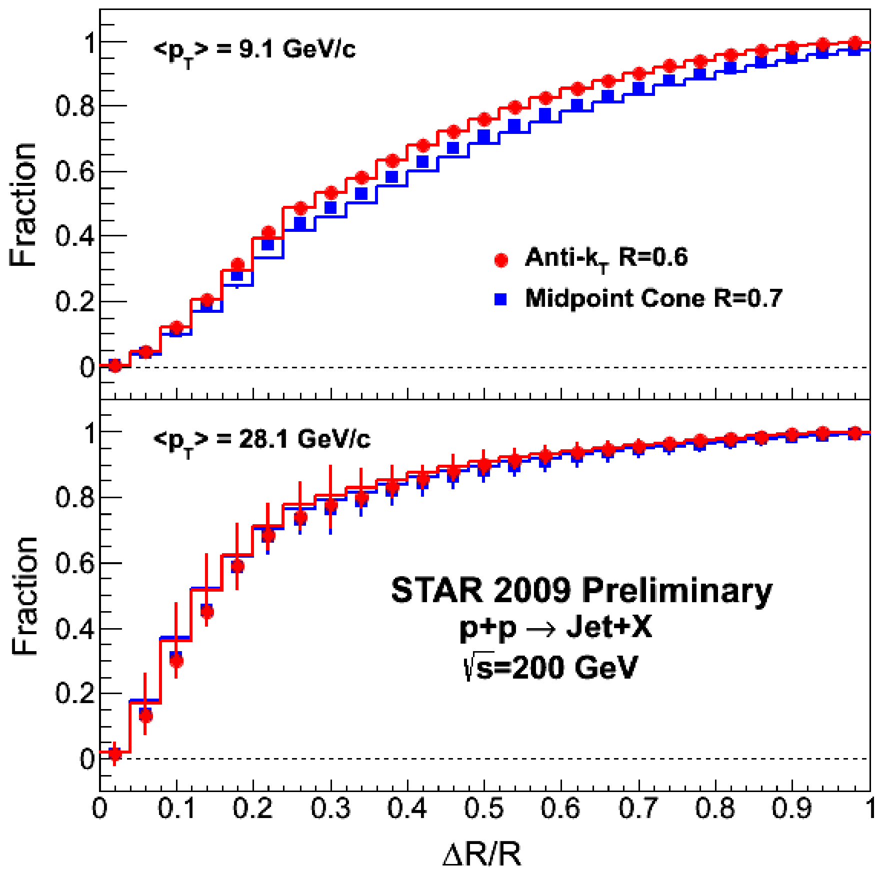


- **DSSV++** is a new, preliminary global analysis from the DSSV group that includes preliminary 2009 A_{LL} measurements from PHENIX and STAR

$$\int_{0.05}^{0.2} \Delta g(x, Q^2 = 10\,\mathrm{GeV}^2)\, dx = 0.10^{+0.06}_{-0.07}$$

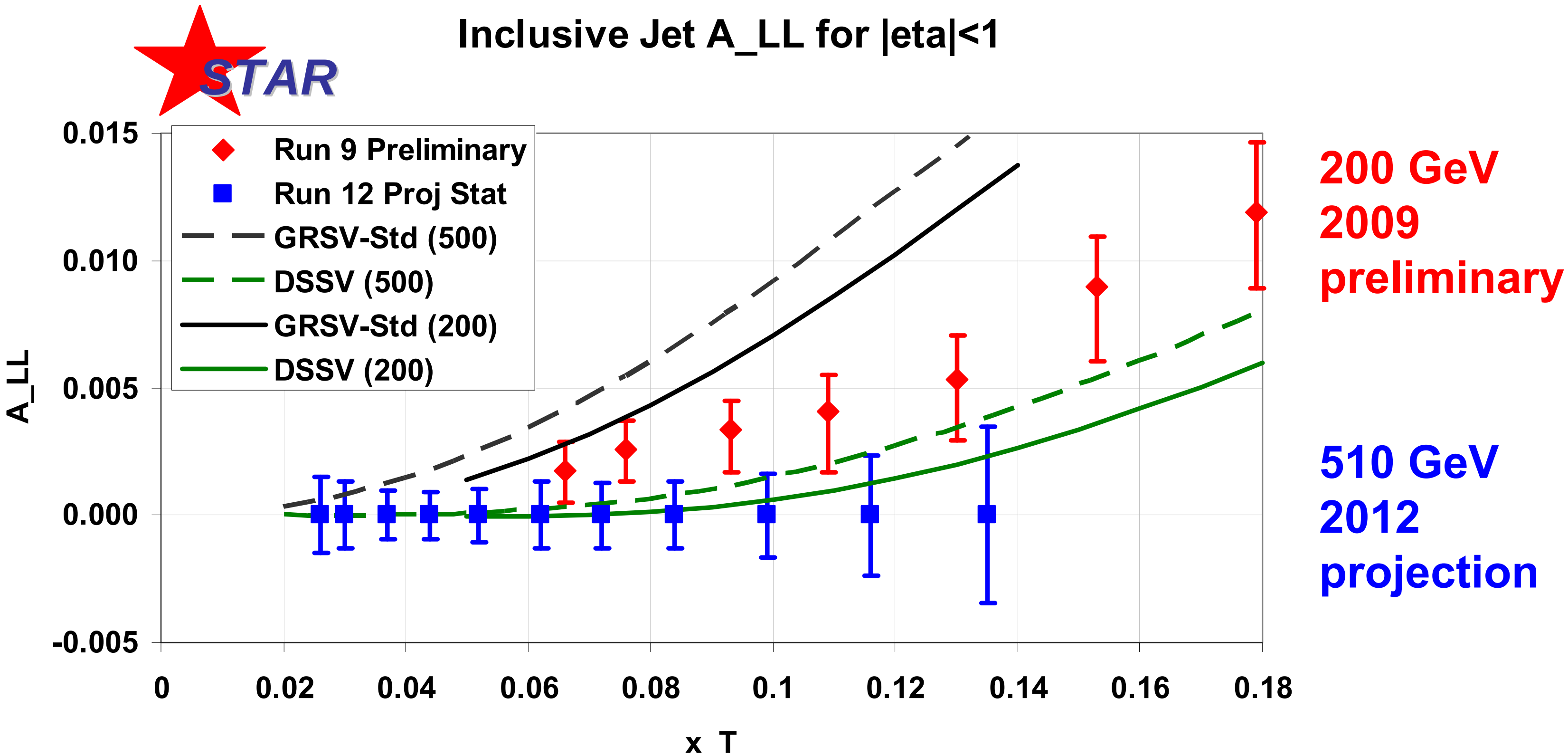
- **First experimental evidence of non-zero gluon polarization** in the RHIC range ($0.05 < x < 0.2$)

2009: from preliminary towards final



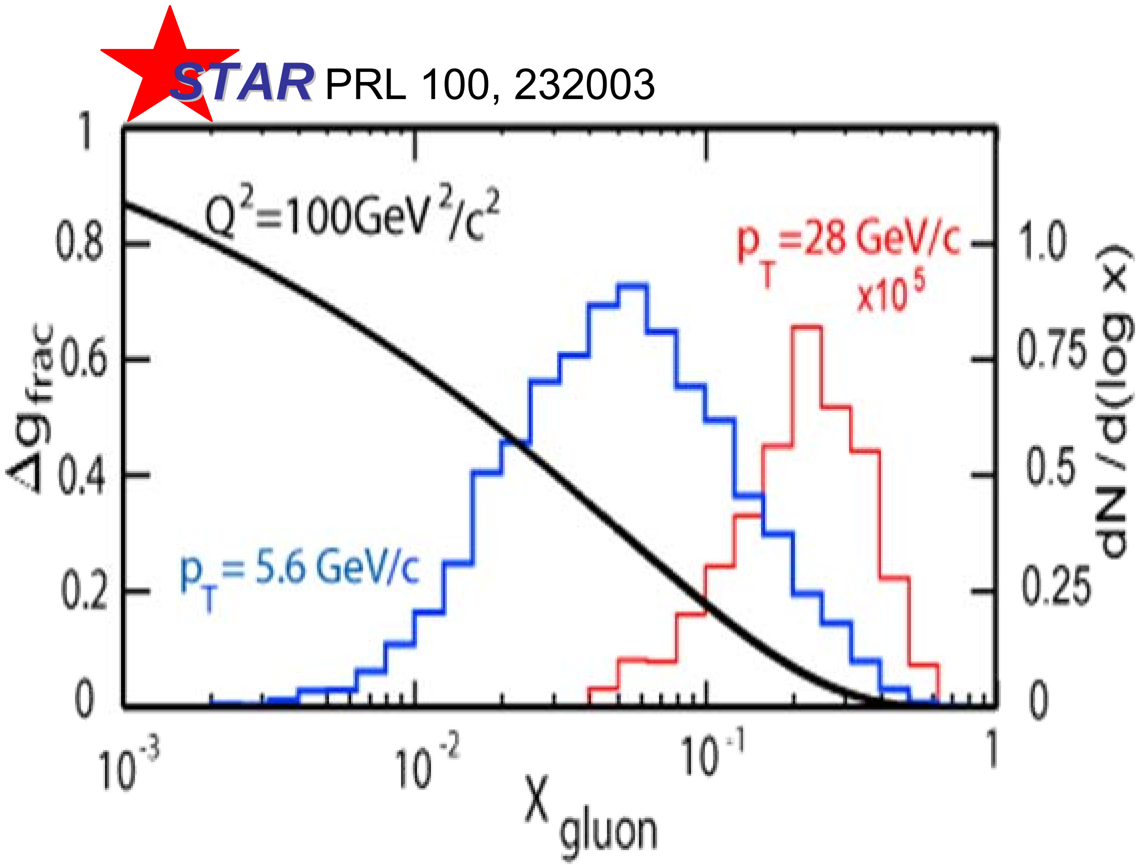
- ***STAR*** is switching from the mid-point cone algorithm to the **anti-k_T** algorithm for the final 2009 inclusive jet A_{LL} measurement
  - Anti-k_T tends to have a more rigid cone
  - Reconstructed jet energy is less sensitive to nearby underlying event contributions (and pile-up)
- Provides a significant reduction in the systematic uncertainties associated with trigger and reconstruction bias
- Final results available soon

Higher precision coming soon



- During 2012 ***STAR*** measured inclusive jet A_{LL} in **510 GeV collisions**
  - Higher beam energy provides sensitivity to smaller x_g
- ***STAR*** also anticipates **significant future reductions** in the uncertainties for **200 GeV collisions** relative to the 2009 results
  - Expect to double the existing 200 GeV data during the 2014 RHIC run

Beyond inclusive A_{LL} measurements



- Inclusive A_{LL} measurements at fixed p_T average over a **broad x range**.
- Can hide considerable structure if $\Delta g(x)$ has a node
- **Correlation measurements can constrain the shape of $\Delta g(x)$**

2006 di-jet cross section

STAR

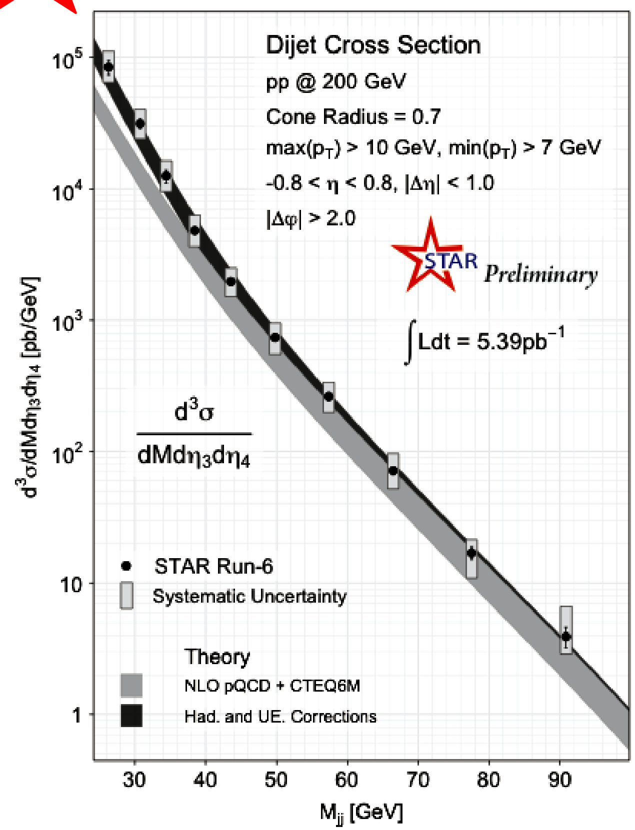
$$x_1 = \frac{1}{\sqrt{s}}\left(p_{T,3}e^{\eta_3} + p_{T,4}e^{\eta_4}\right)$$

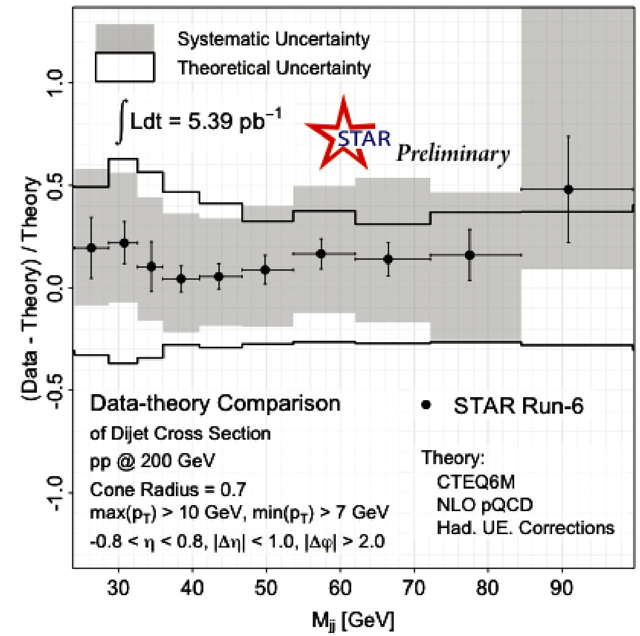
$$x_2 = \frac{1}{\sqrt{s}}\left(p_{T,3}e^{-\eta_3} + p_{T,4}e^{-\eta_4}\right)$$

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

$$y = \frac{1}{2}\ln\frac{x_1}{x_2} = \frac{\eta_3+\eta_4}{2}$$

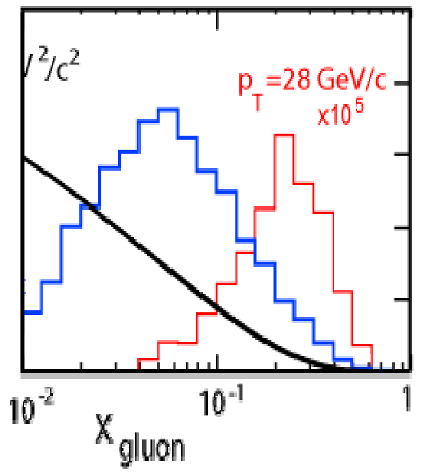
$$|\cos\theta^*| = \tanh\frac{|\eta_3-\eta_4|}{2}$$

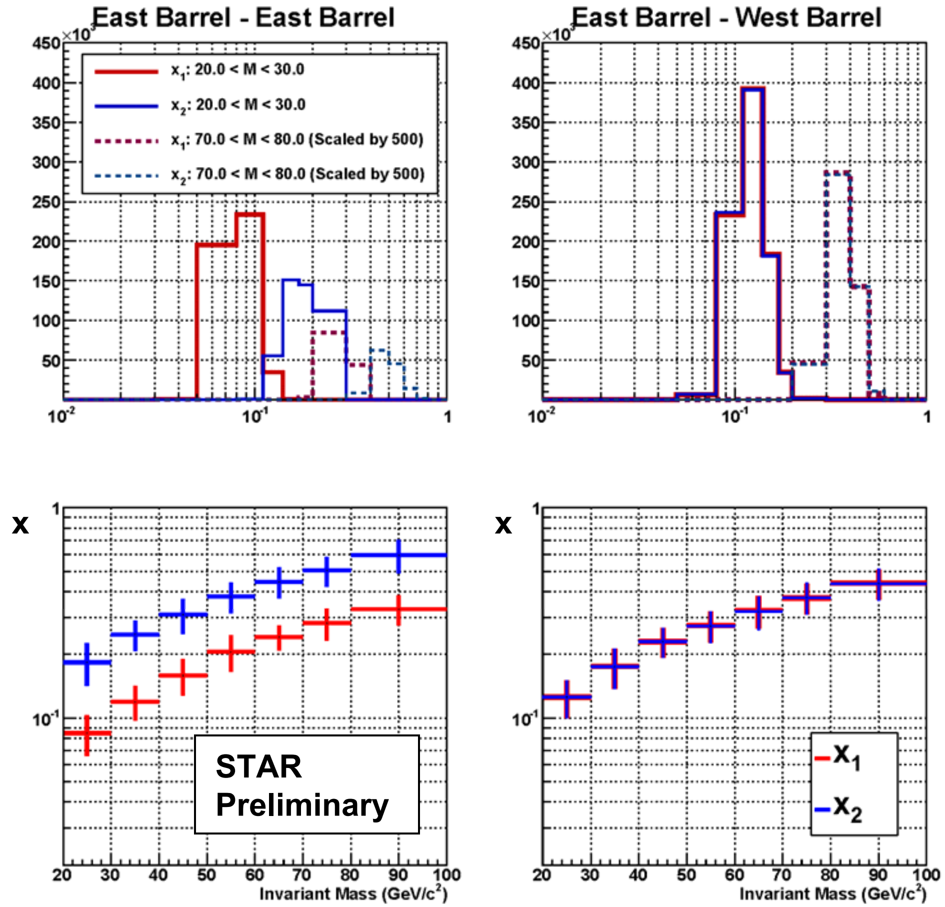




- Di-jets permit event-by-event calculations of x_1 and x_2 at LO
- Di-jet cross section is well-described by NLO pQCD with corrections for hadronization and underlying event

2009 *STAR* di-jet partonic coverage





$$x_1 = \frac{1}{\sqrt{s}}\left(p_{T,3}e^{\eta_3} + p_{T,4}e^{\eta_4}\right)$$

$$x_2 = \frac{1}{\sqrt{s}}\left(p_{T,3}e^{-\eta_3} + p_{T,4}e^{-\eta_4}\right)$$

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

$$y = \frac{1}{2}\ln\frac{x_1}{x_2} = \frac{\eta_3 + \eta_4}{2}$$

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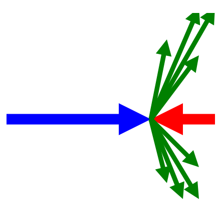
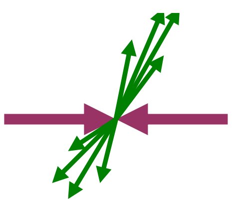
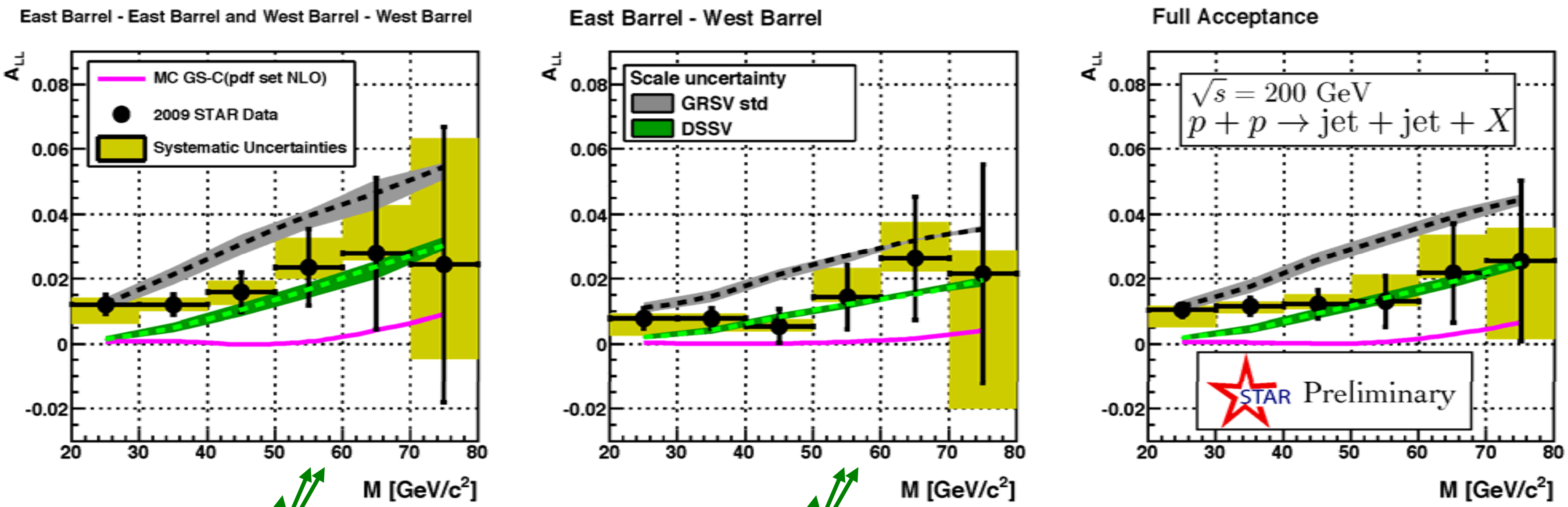


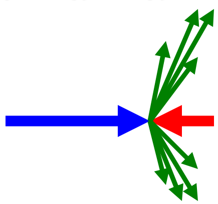
Asymmetric collisions



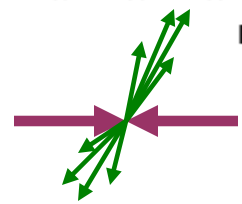
Symmetric collisions

2009 *STAR* di-jet A_{LL}





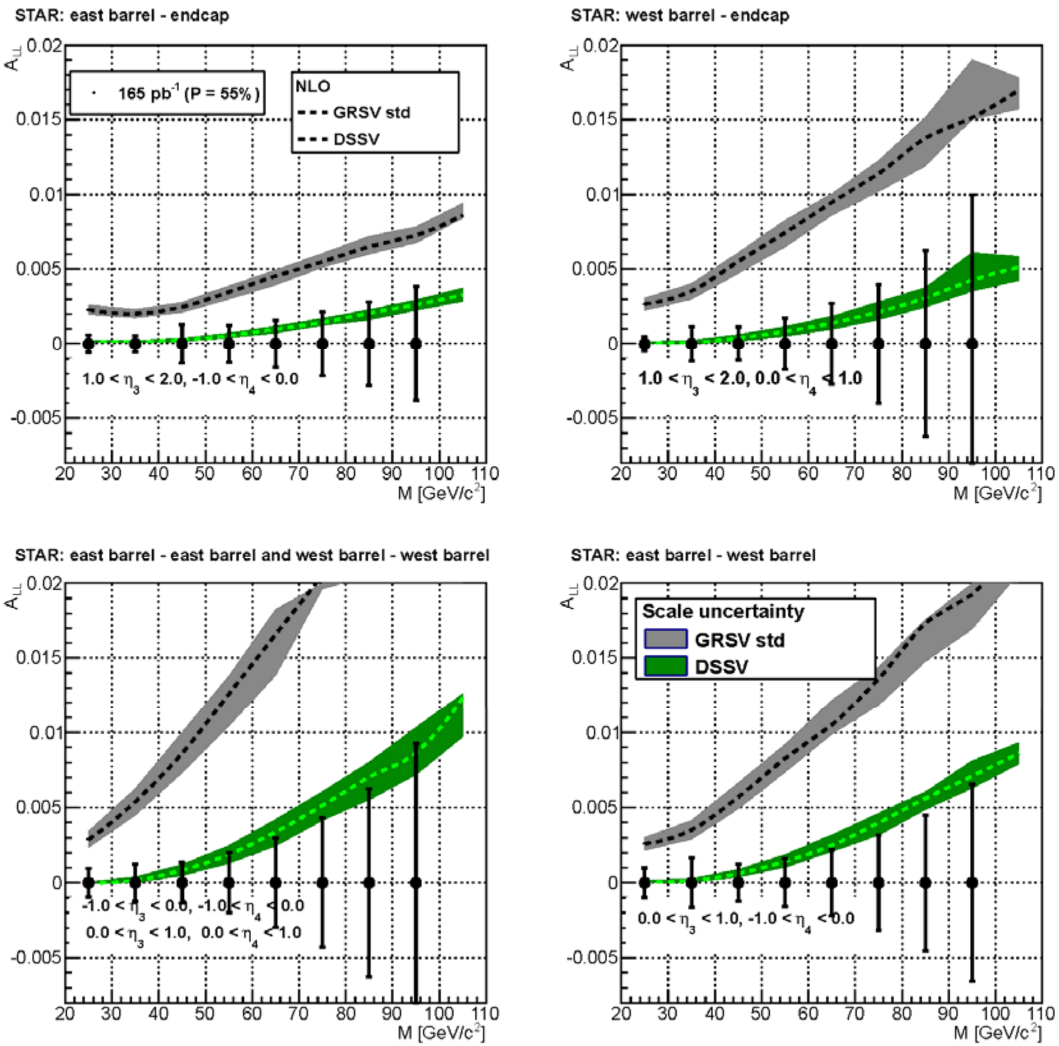
Asymmetric collisions



Symmetric collisions

- For fixed M, different kinematic regions sample different *x* ranges
- **Results fall between predictions from DSSV and GRSV-STD**

Projected sensitivity for di-jets at 510 GeV



$$x_1, x_2 = \frac{M}{\sqrt{s}} \exp\left(\pm \frac{\eta_3 + \eta_4}{2}\right)$$

- Higher energy accesses lower x_g
- Expect smaller A_{LL}
- Will add EEMC-EEMC ($1.09<\eta<2$) di-jets to reach lowest x

Projections for the 2013 run that is now underway

Conclusions

- ***STAR* 2006 results play a significant role** in recent global analysis
- ***STAR* 2009** results provide the **first experimental evidence** for **non-zero gluon polarization** in the RHIC range
- We will **reduce the uncertainties even further** in the near future
- **Stay tuned!**