Exploring Gluon Polarization in the Proton with *STAR*

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for the
STAR **Collaboration**

Outline

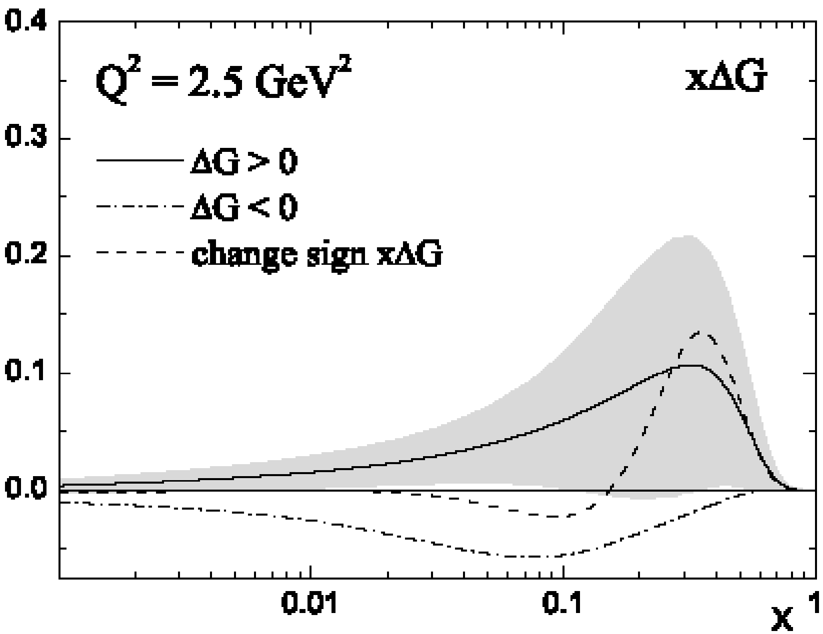
- Introduction
- Inclusive measurements
- Correlation measurements

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

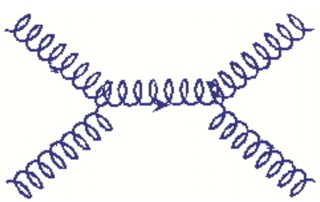
- Measuring the **gluon polarization distribution** is **a primary goal of the RHIC spin program**

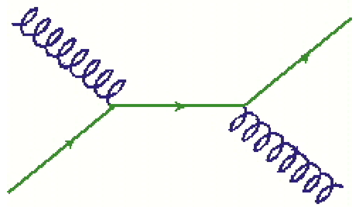
Exploring gluon polarization at RHIC

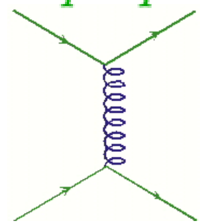
$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \propto \frac{\Delta f_a \Delta f_b}{f_a f_b} \hat{a}_{LL}$$

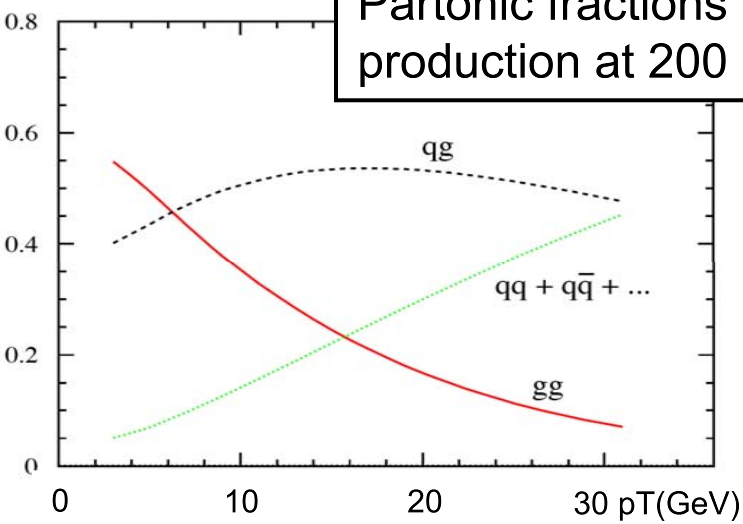
Δf: polarized parton distribution functions

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

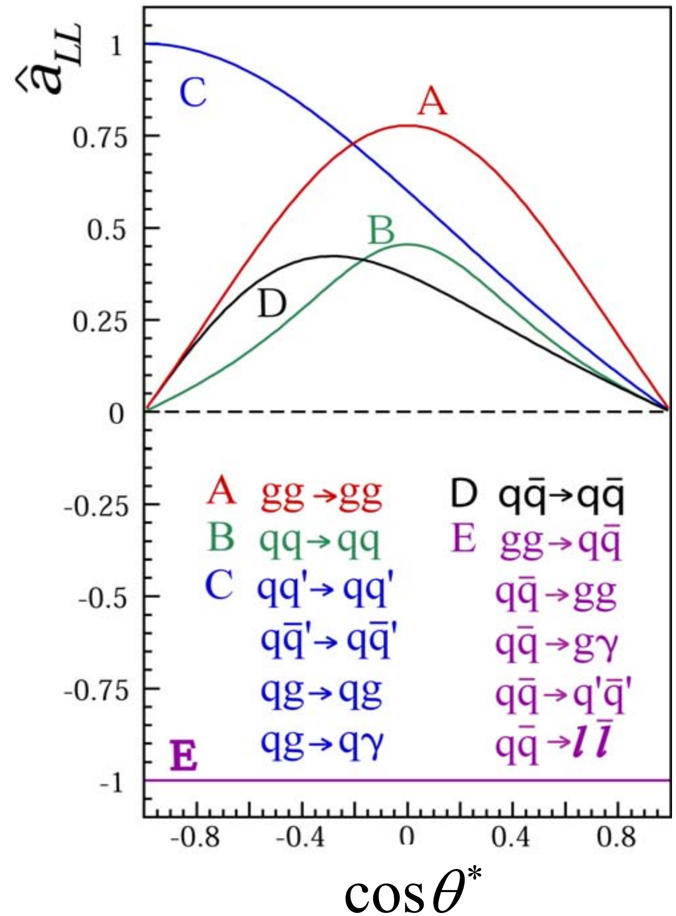






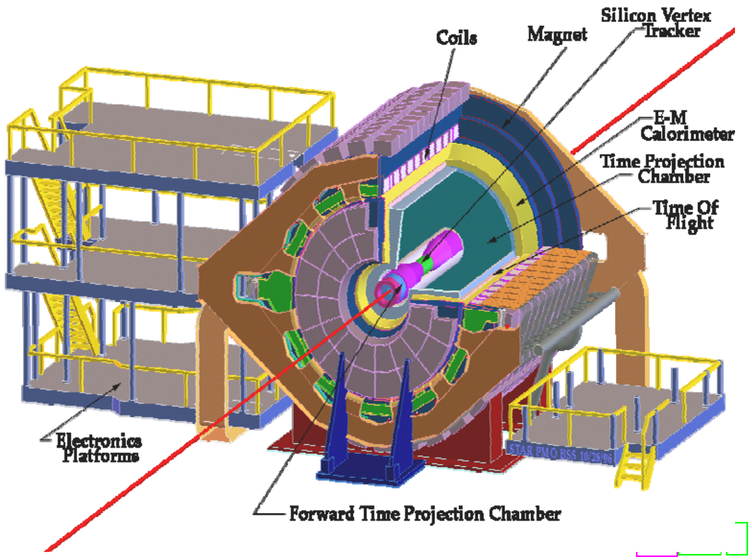


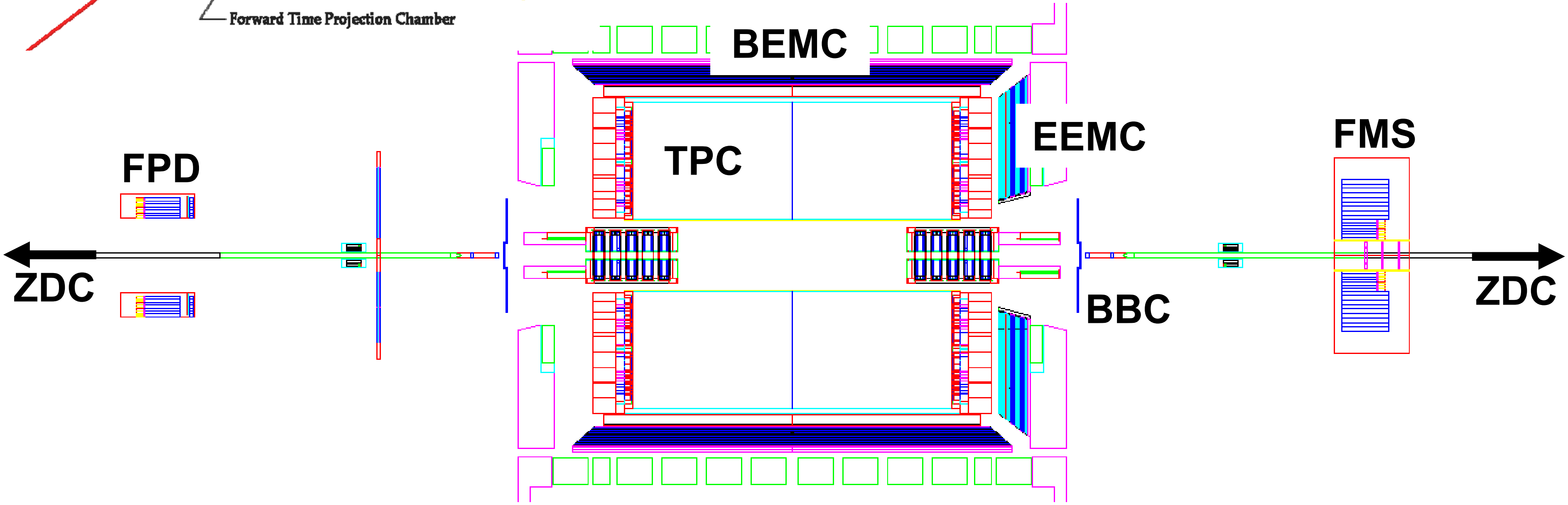
Partonic fractions in jet production at 200 GeV



For most RHIC kinematics, ***gg*** and ***qg*** dominate, making A_{LL} for hadrons, photons, and 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
- Channels
  - Neutral pions
  - Direct photons
  - Jets

Correlation measurements

- Features
  - Less abundant
  - Resolve partonic kinematics on event-by-event basis
  - Provide information about the shape of $\Delta g(x)$
- Channels
  - Charged pions opposite jets
  - γ+jet
  - Di-jets

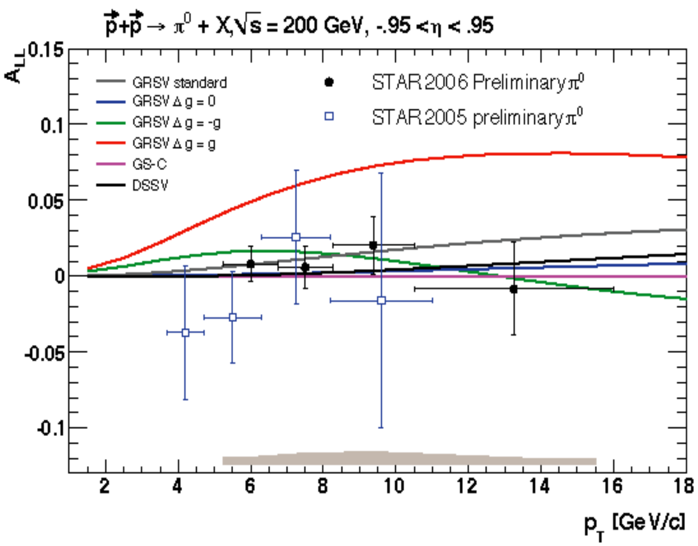
- **Both** types of measurements **provide important information for global analyses**
- Large acceptance of STAR makes **jet and di-jet measurements particularly attractive**

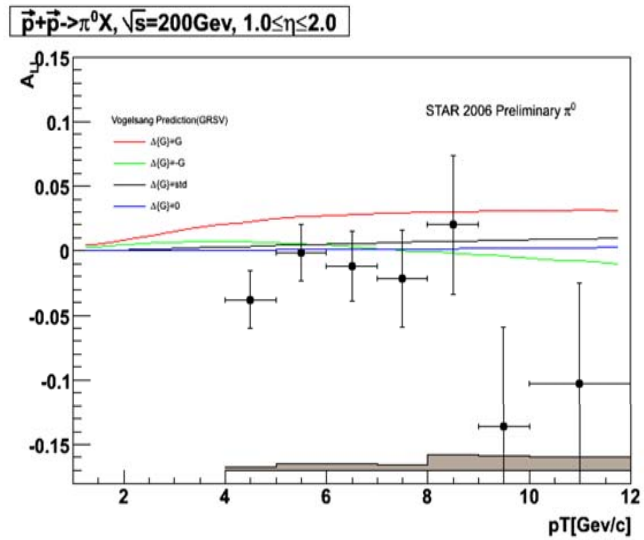
STAR inclusive π^0 A_{LL} at various rapidities

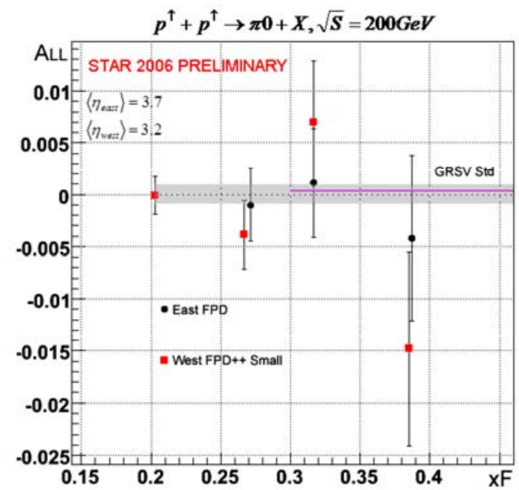
$|\eta| < 0.95$

$1 < \eta < 2$

$\eta = 3.2, 3.7$



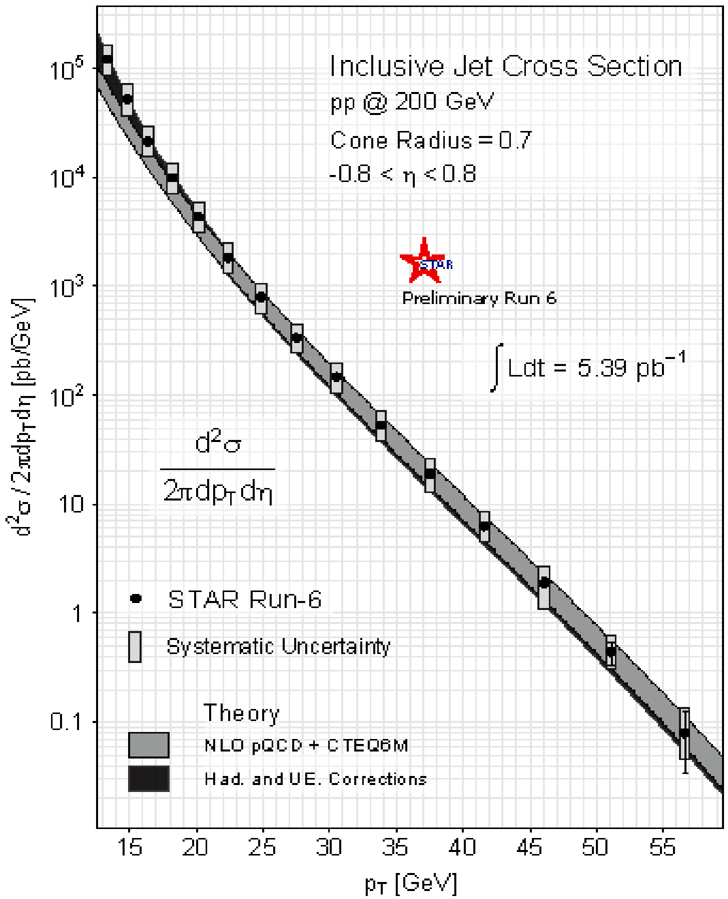


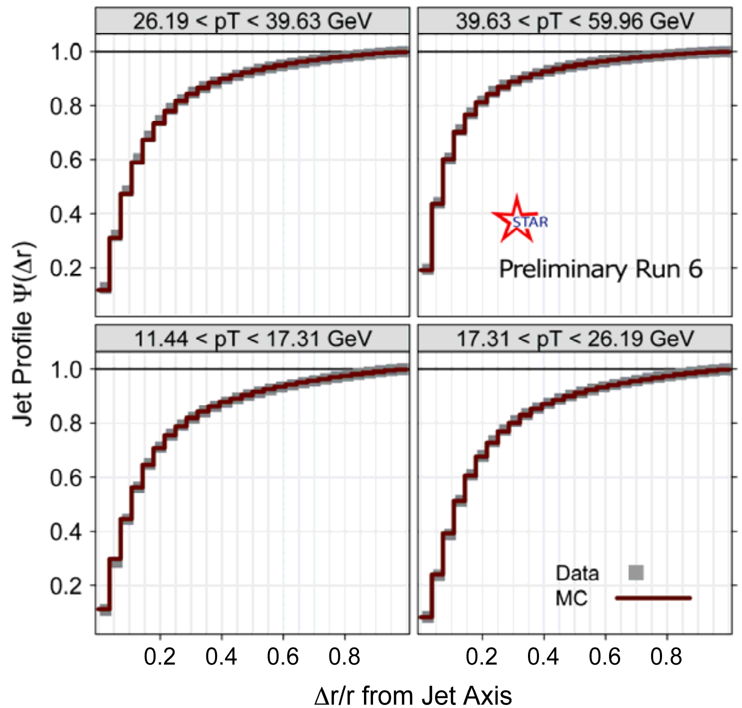


- During 2006, ***STAR*** measured A_{LL} for inclusive π^0 for three different rapidity regions
- Larger rapidity correlates to stronger dominance of *qg* scattering with larger *x* quarks and smaller *x* gluons
- Expect A_{LL} to decrease as η increases

Status of '09 data analysis:
See poster by W. Leight

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

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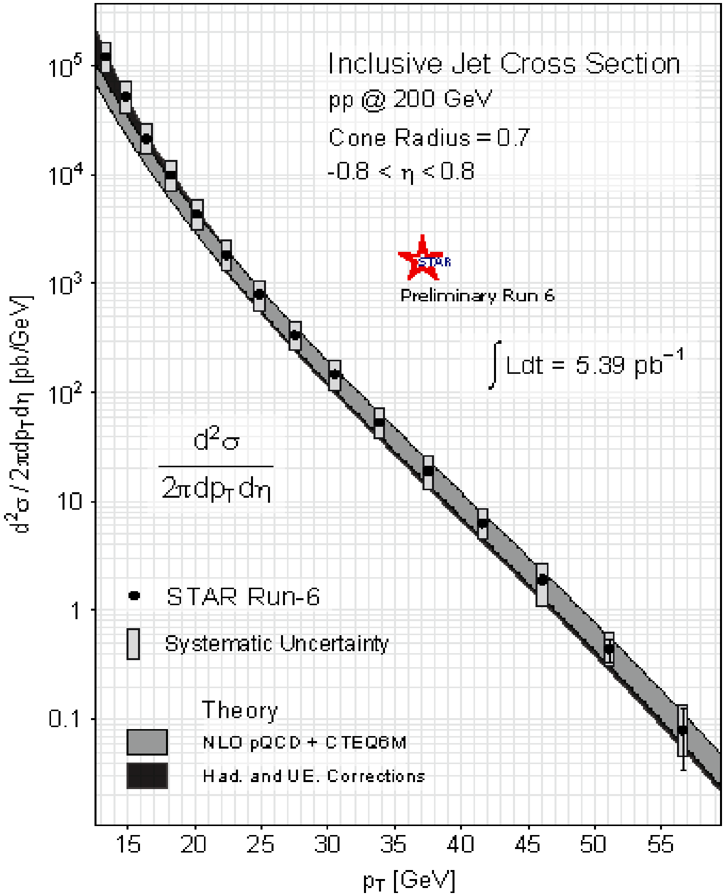

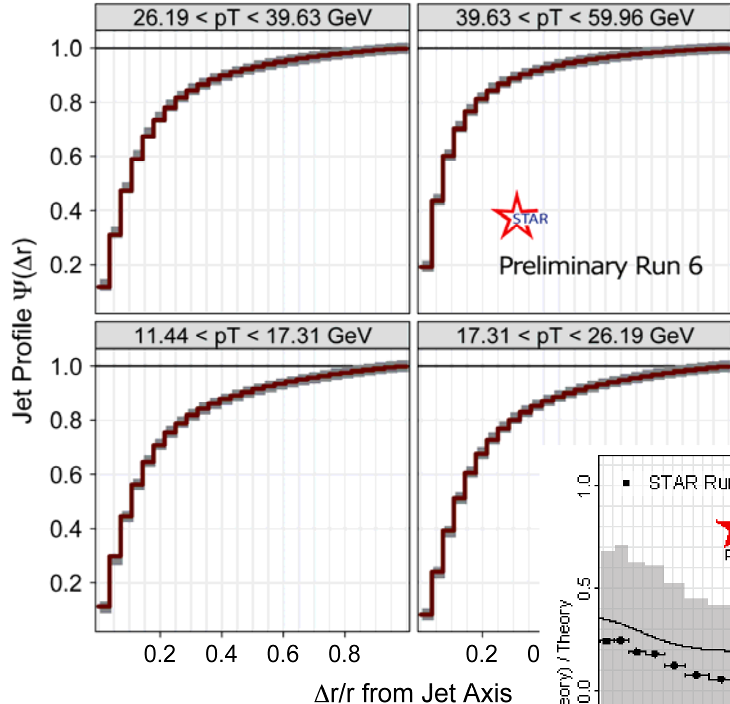

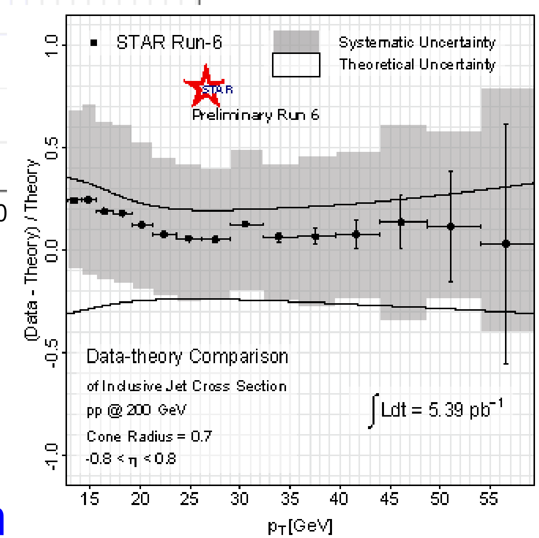

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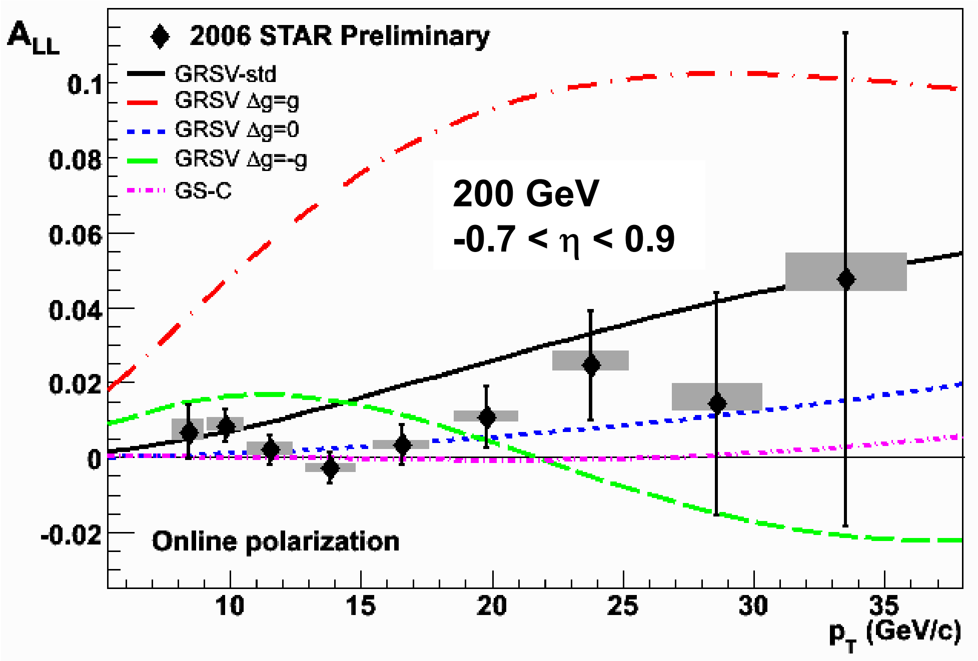
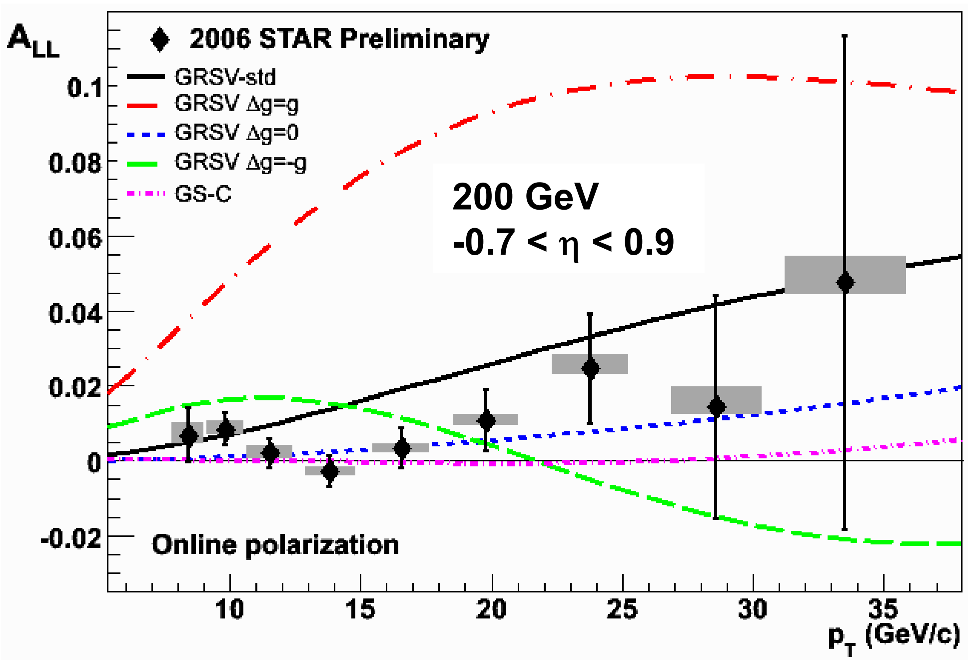
STAR inclusive jet A_{LL} from 2006

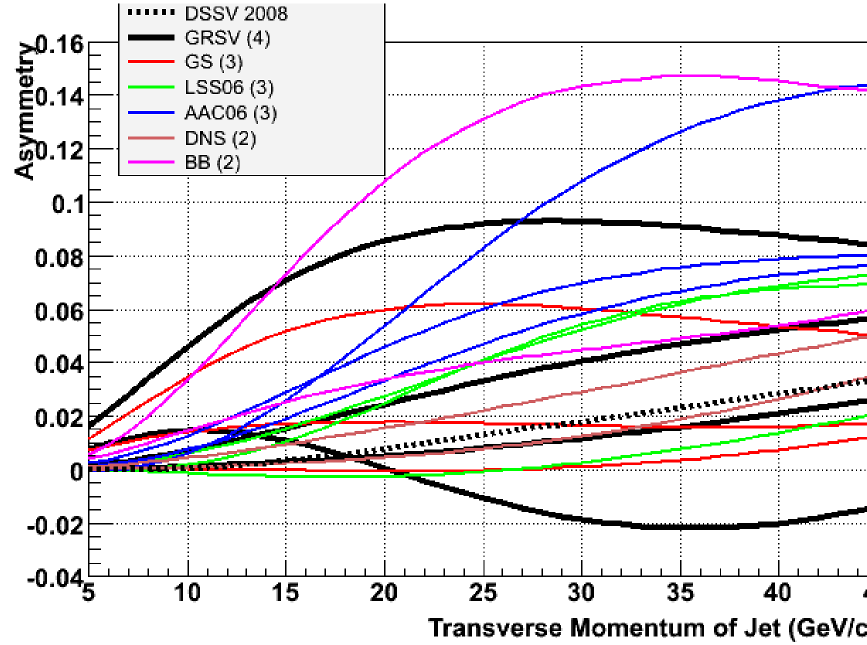


- ***STAR*** inclusive jet A_{LL} excludes those scenarios that have a large gluon polarization within the accessible *x* region

STAR inclusive jet A_{LL} from 2006

STAR





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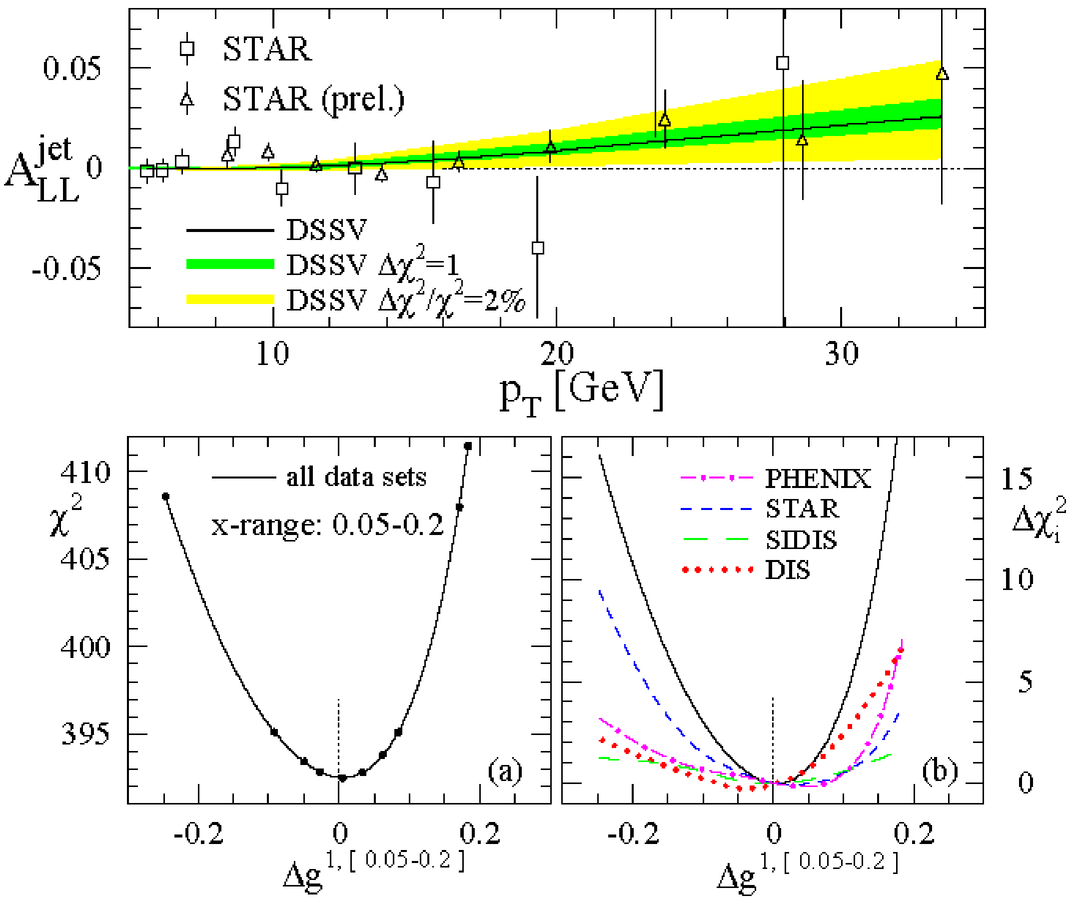
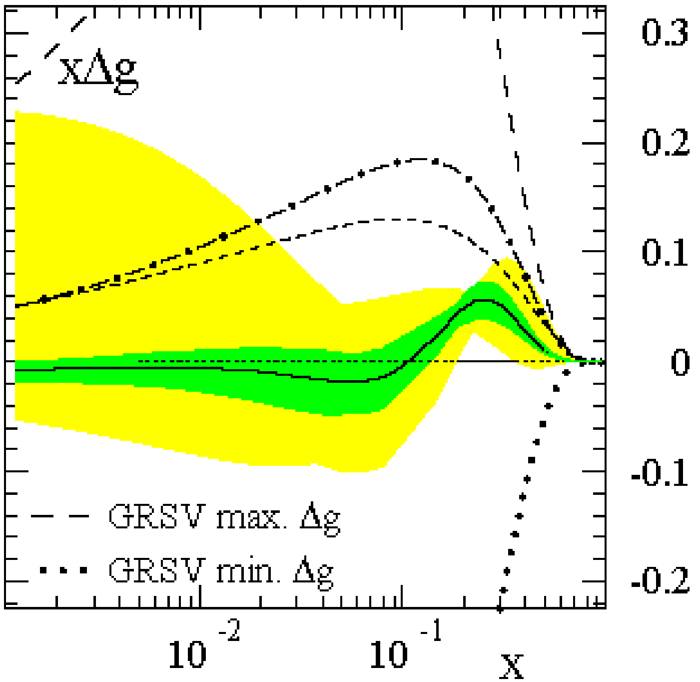
DSSV – first global analysis with polarized jets

de Florian et al., PRL 101, 072001





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

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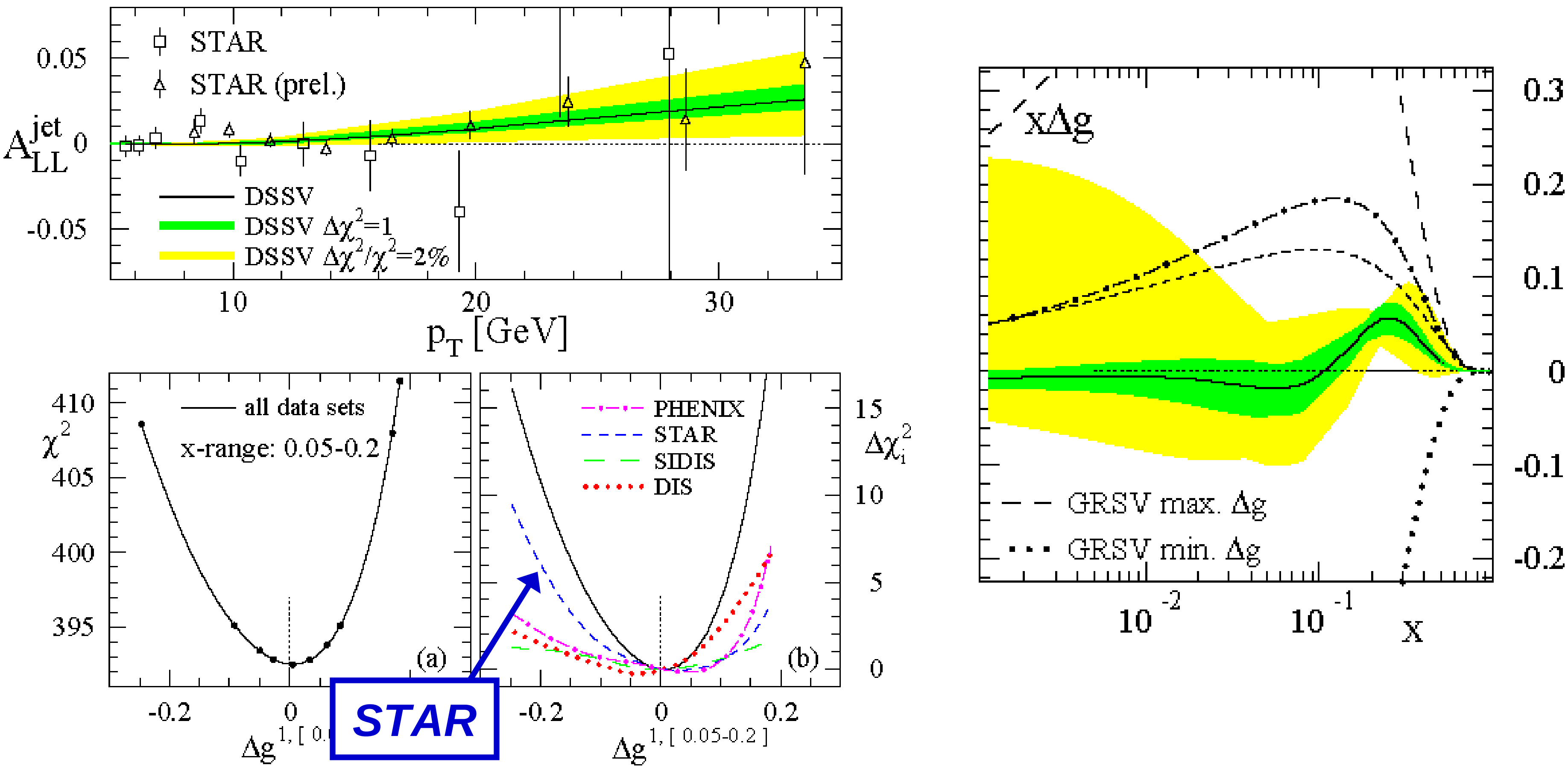

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2009 upgrades

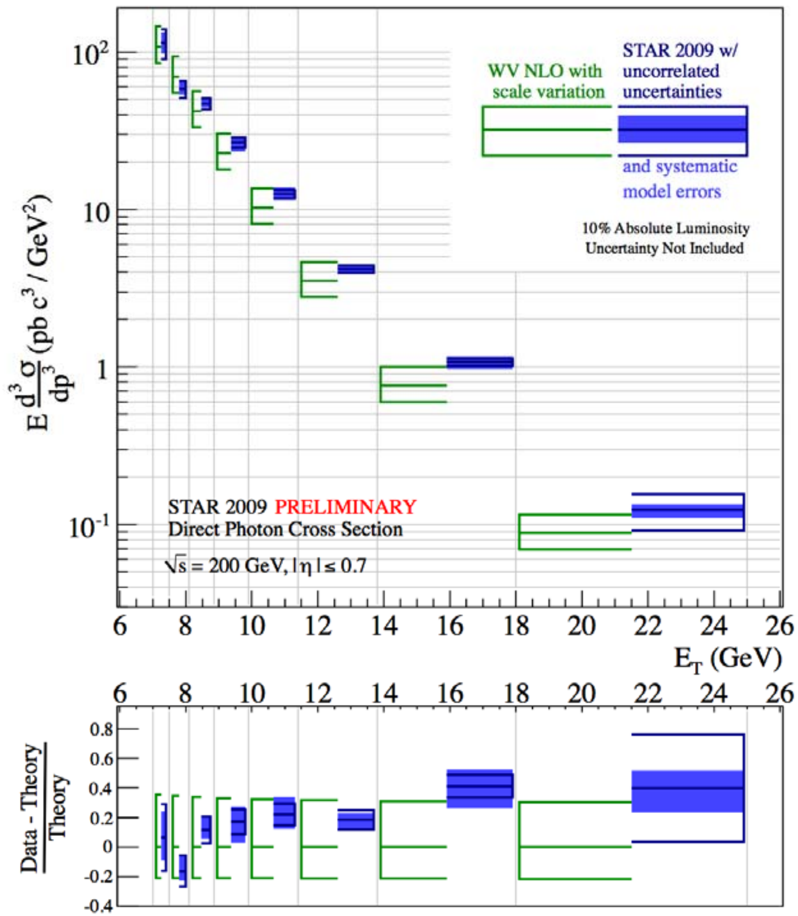
Jet specific

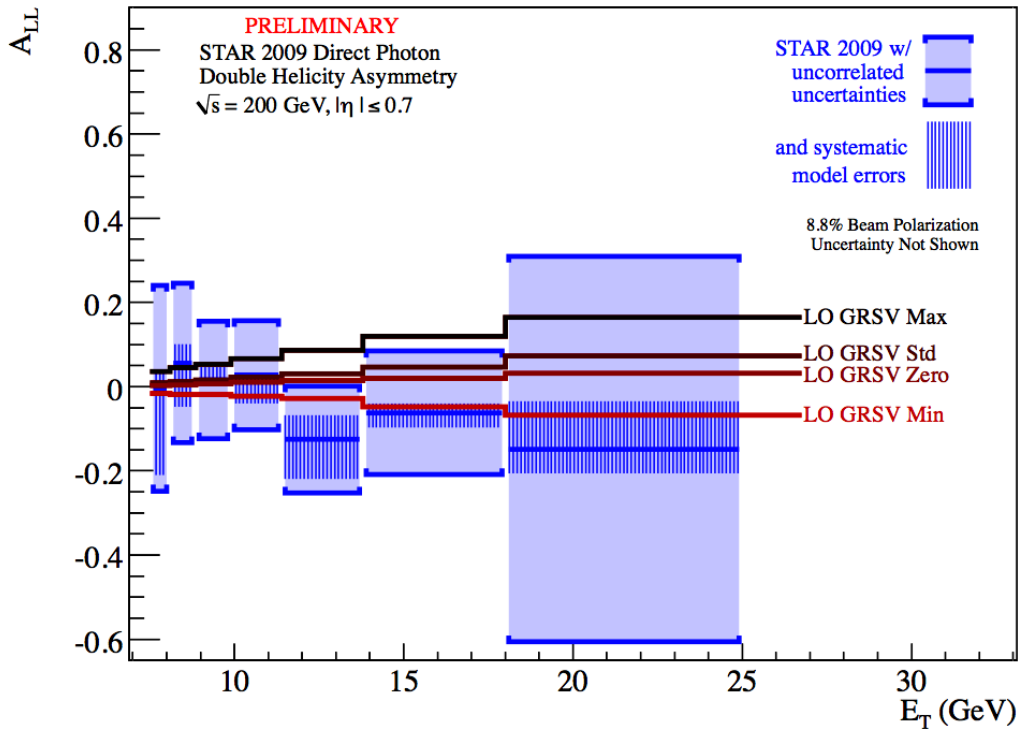
- 2009 jet patch trigger upgrades
  - Overlapping jet patches and lower E_T threshold improve efficiency and reduce trigger bias
    - Net increase of 37% in jet acceptance
  - Remove beam-beam counter trigger requirement:
    - Trigger more efficiently at high jet p_T
    - Measure non-collision background
- 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

Direct photon cross section and A_{LL} from 2009



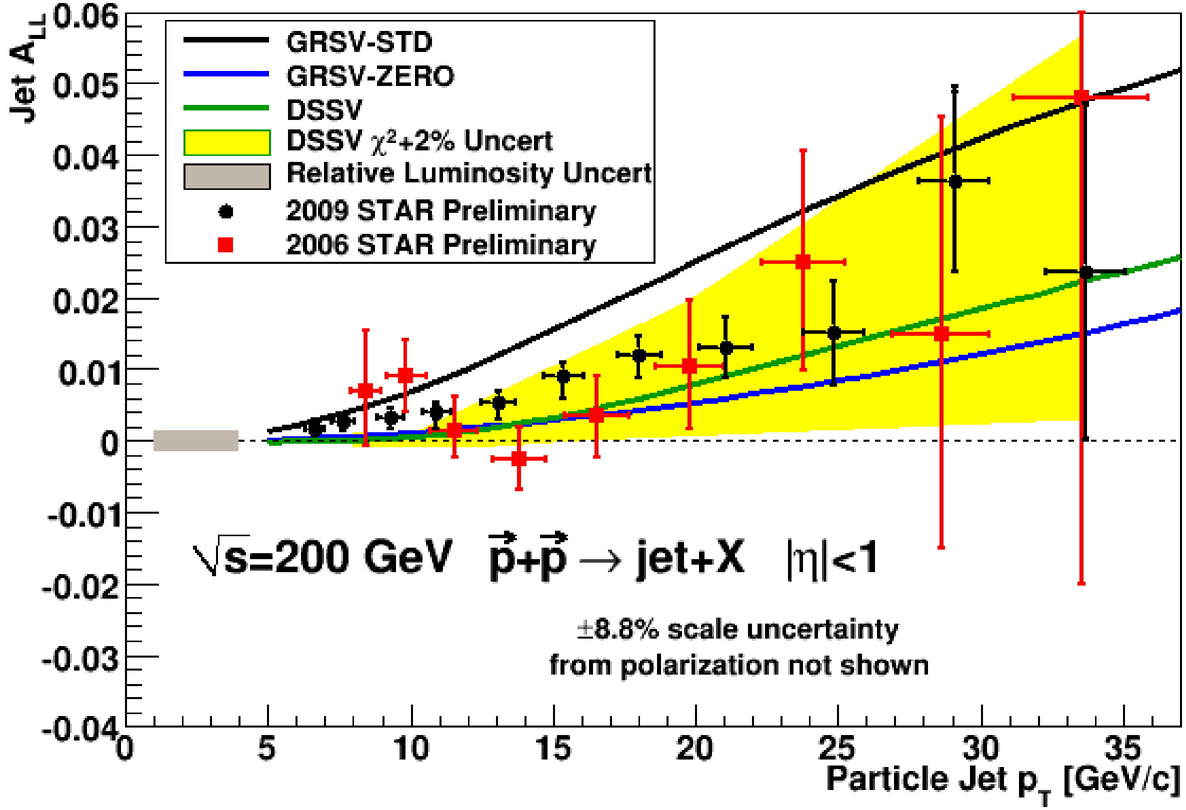


For details:
See poster by
M. Betancourt

- Cross section at 200 GeV is consistent with NLO pQCD calculations
- A_{LL} for direct photons has very clean theoretical interpretation, but
  - Cross section is very small
  - Background is very large
  - Very difficult measurement!
- Need far more statistics

A_{LL} for inclusive jets: 2006 to 2009

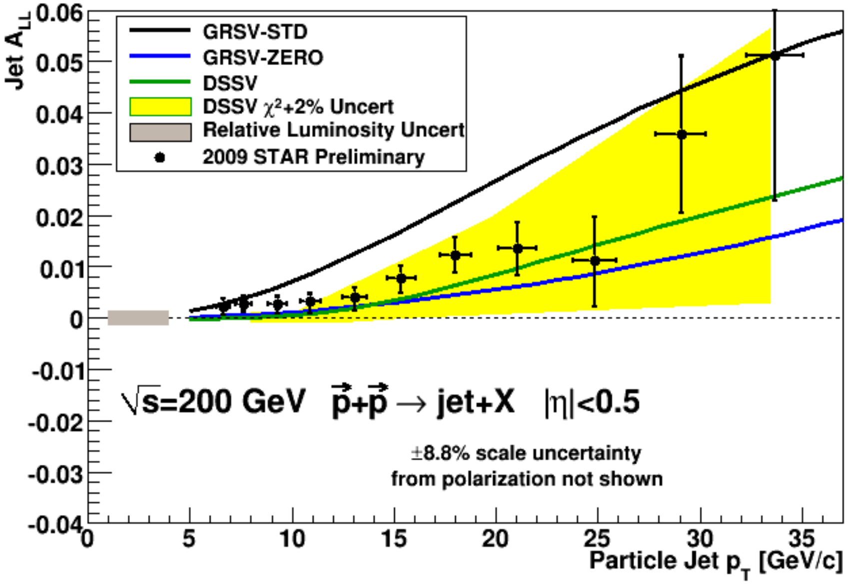
STAR



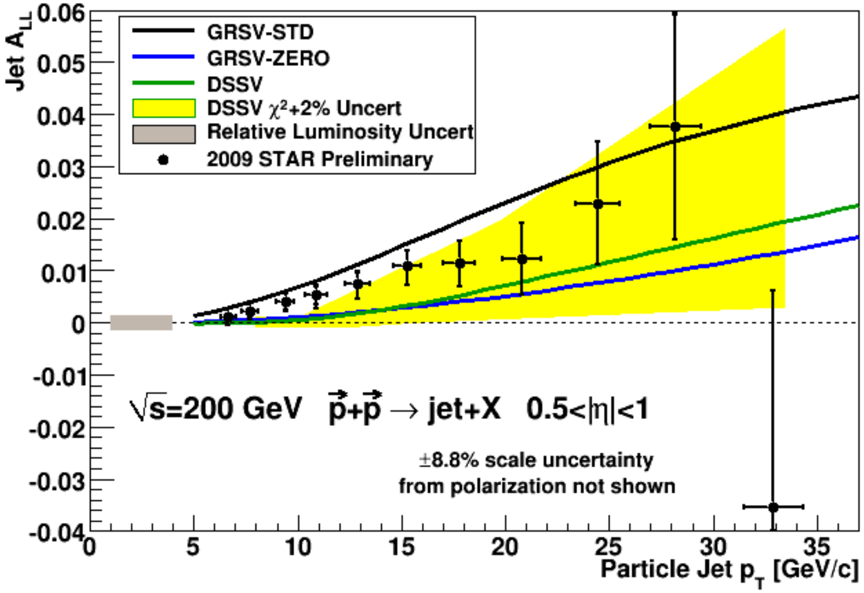
- 2009 ***STAR*** inclusive jet A_{LL} measurements are a factor of 3 (high-p_T) to >4 (low-p_T) more precise than 2006
- **Results fall between predictions from DSSV and GRSV-STD**
- Precision sufficient to merit finer binning in pseudorapidity

2009 ***STAR*** inclusive jet A_{LL}

Mid rapidity

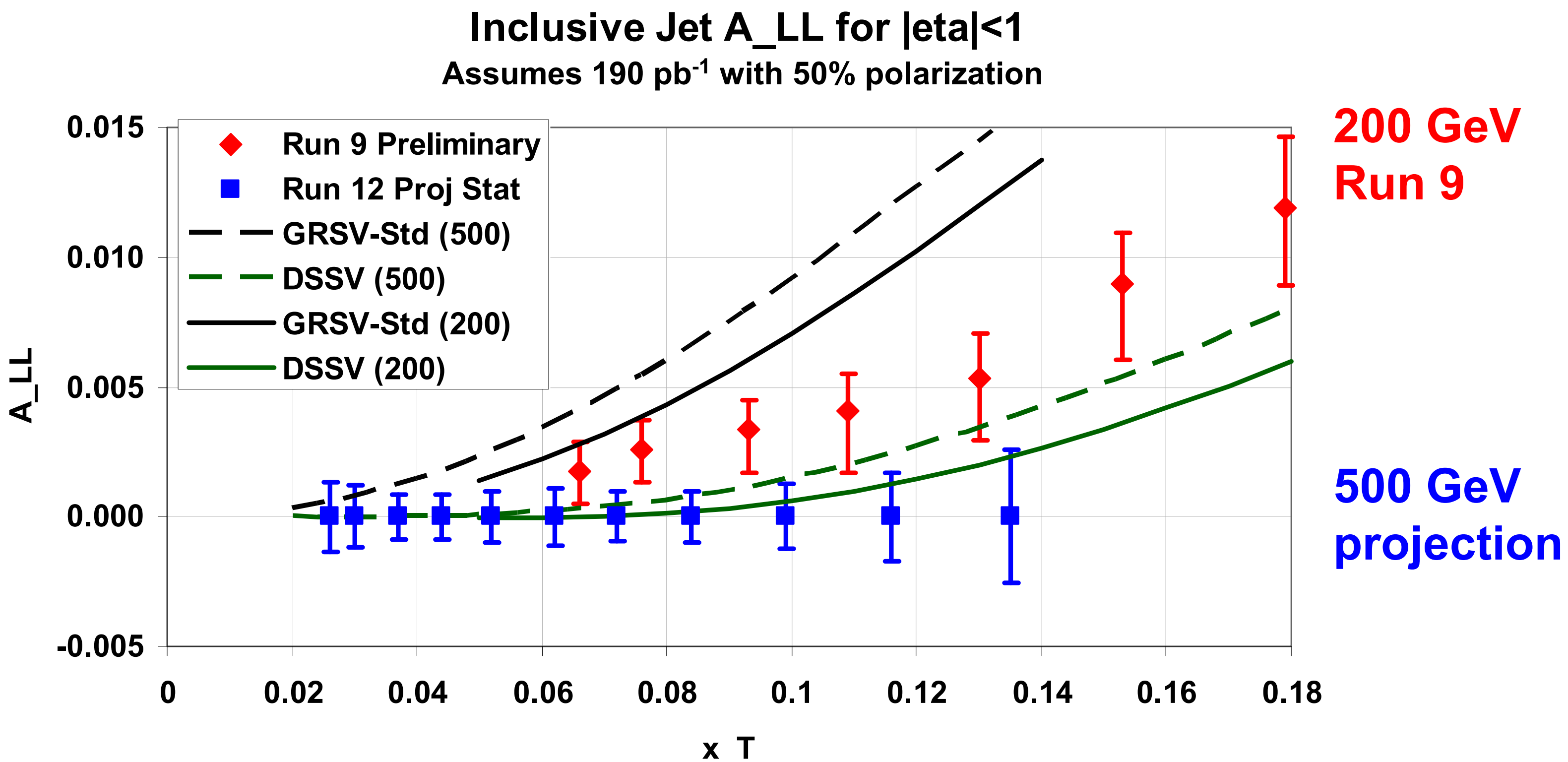


Forward rapidity



- 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
  - Larger $|\cos(\theta^*)|$, which reduces $\hat{a}_{LL}$
- **A_{LL} falls between the predictions from DSSV and GRSV-STD**

Expected future inclusive jet A_{LL} precision



- ***STAR*** will measure inclusive jet A_{LL} in **500 GeV collisions** during the 2012 and 2013 RHIC runs
  - Higher beam energy provides sensitivity to smaller x_g
  - Expect ~ 90 pb^{-1} during 2012; much more during 2013

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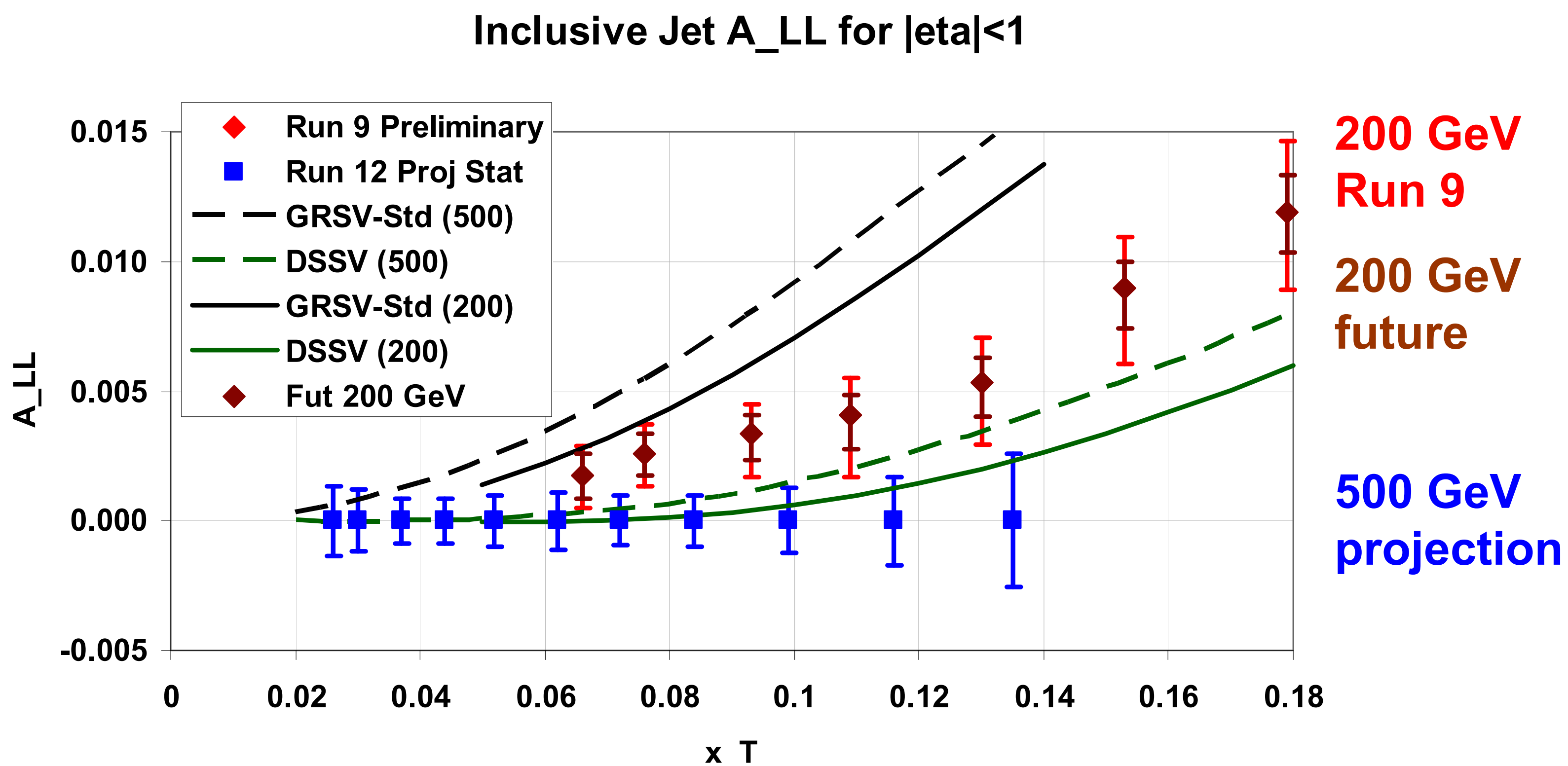

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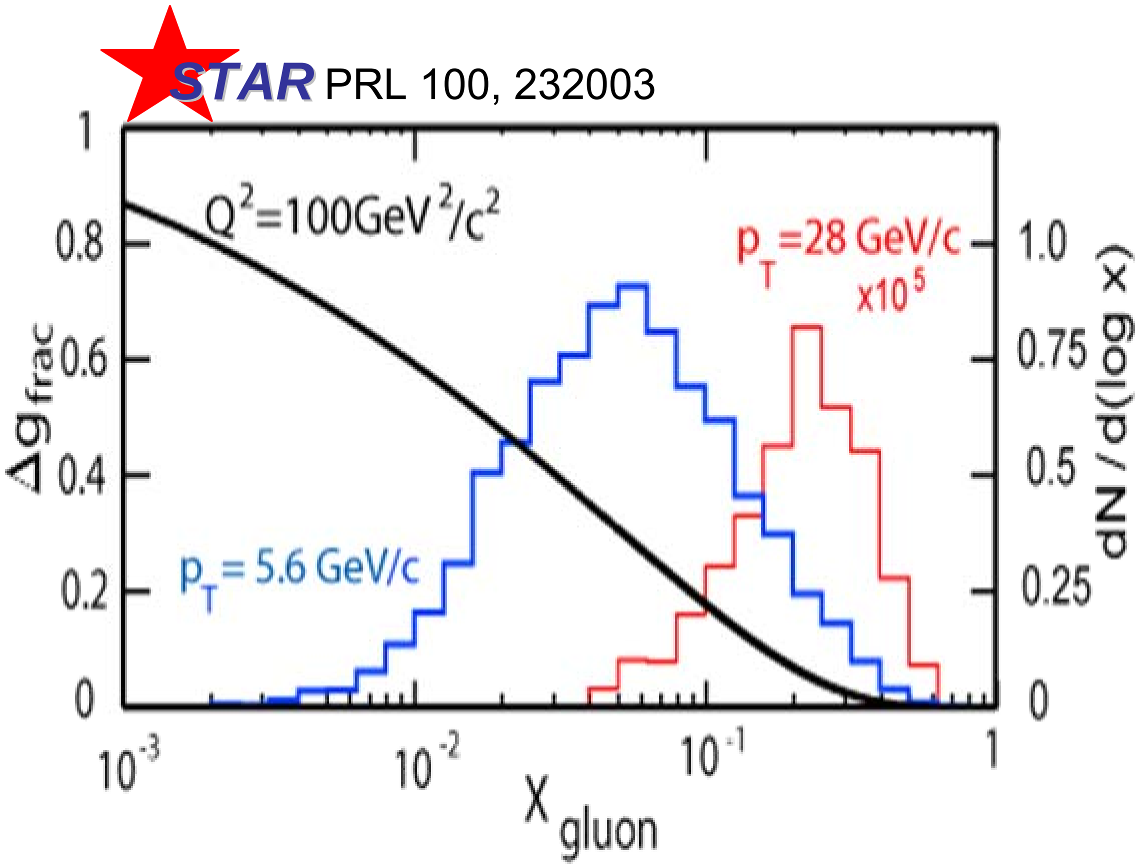
  - Higher beam energy provides sensitivity to smaller x_g
  - Expect ~ 90 pb^{-1} during 2012; much more during 2013

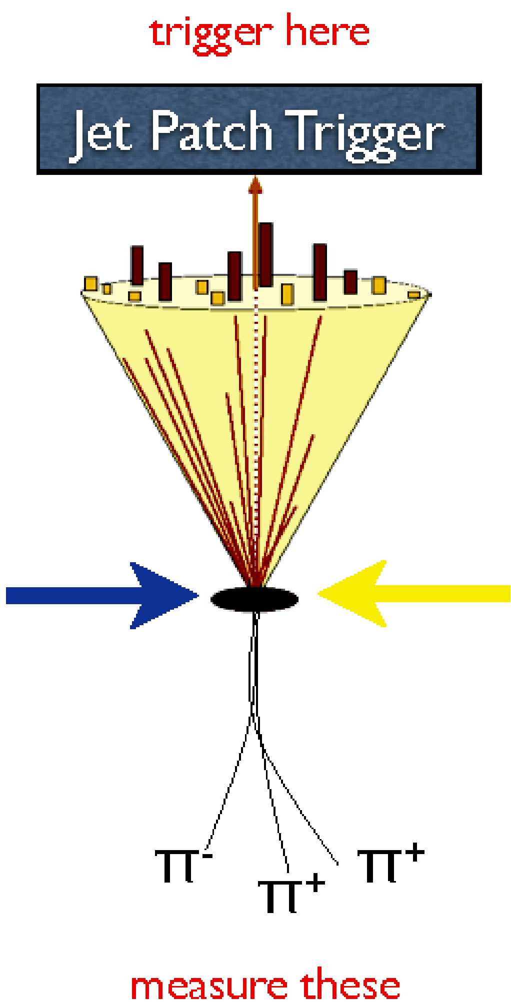
- ***STAR*** also anticipates significant **future reductions** in the uncertainties for **200 GeV collisions** relative to the 2009 results

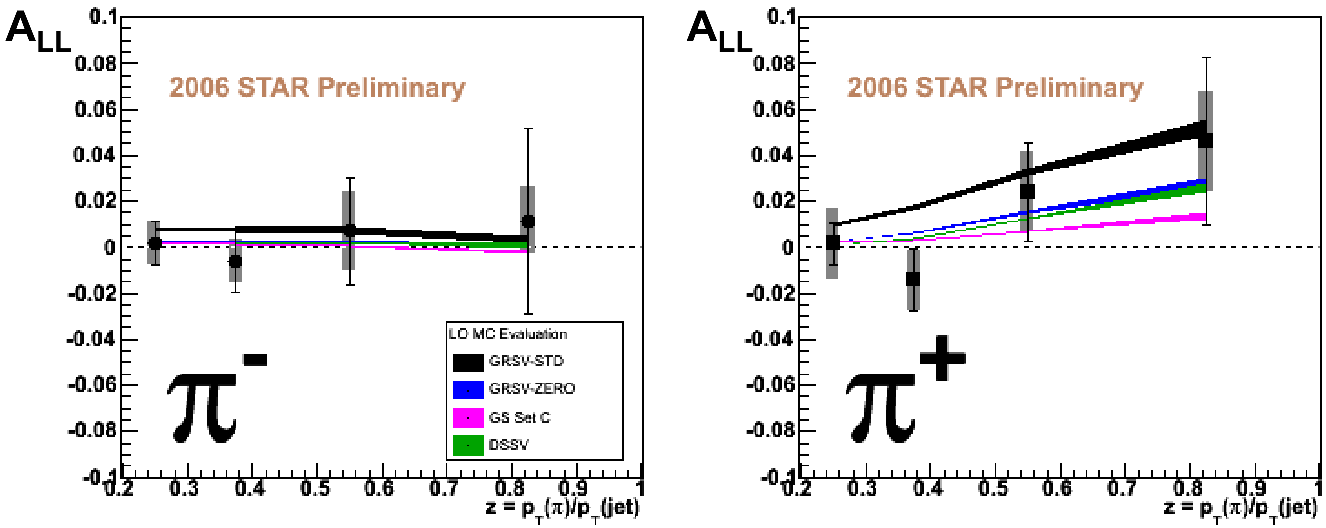
Beyond inclusive A_{LL} measurements



- 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 $\Delta g(x)$**

Charged pions opposite jets





- Trigger and reconstruct a jet, then look for a charged pion on the opposite side
- Events with high-z π^+ emphasize gluon scattering off highly-polarized *u* quarks
- **Significantly increases the sensitivity of $A_{LL}(\pi^+)$**

Status of '09 data analysis: See poster by J. Hays-Wehle

2006 di-jet cross section

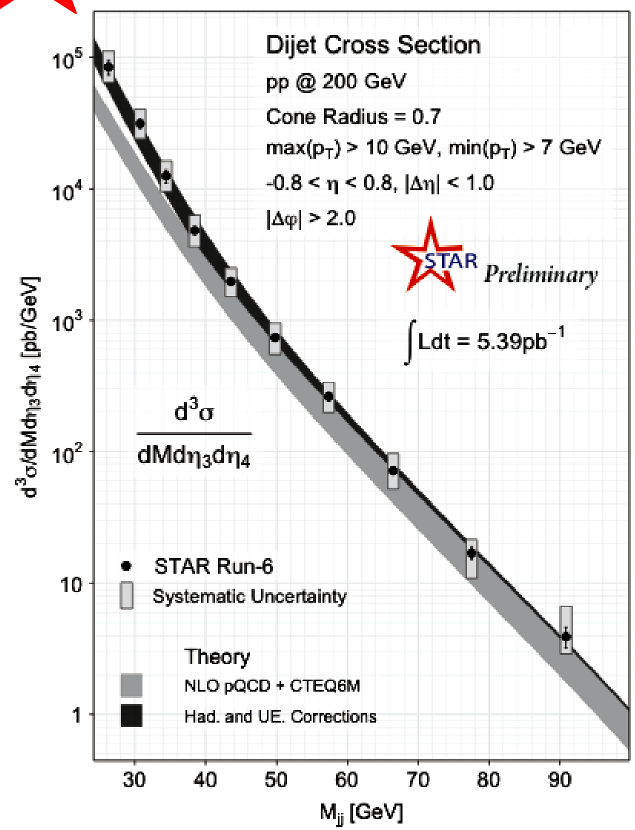
$$x_1 = \frac{1}{\sqrt{s}}\left(p_{T,3}e^{\eta_3} + p_{T,4}e^{\eta_4}\right)$$

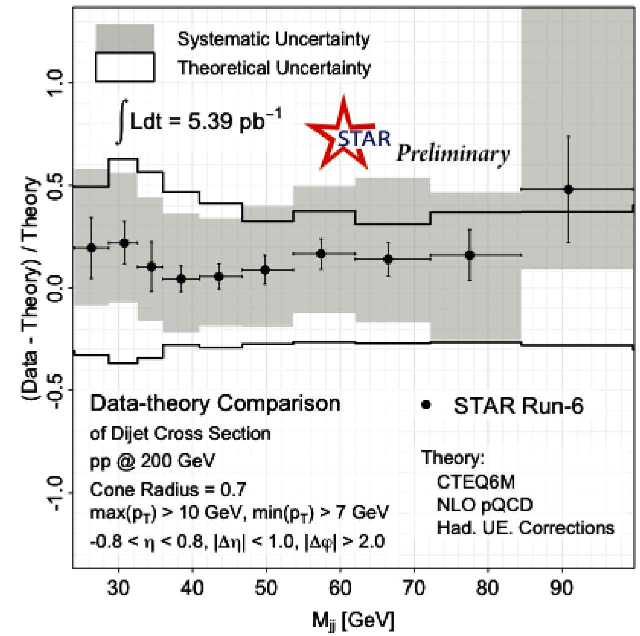
$$x_2 = \frac{1}{\sqrt{s}}\left(p_{T,3}e^{-\eta_3} + p_{T,4}e^{-\eta_4}\right)$$

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

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

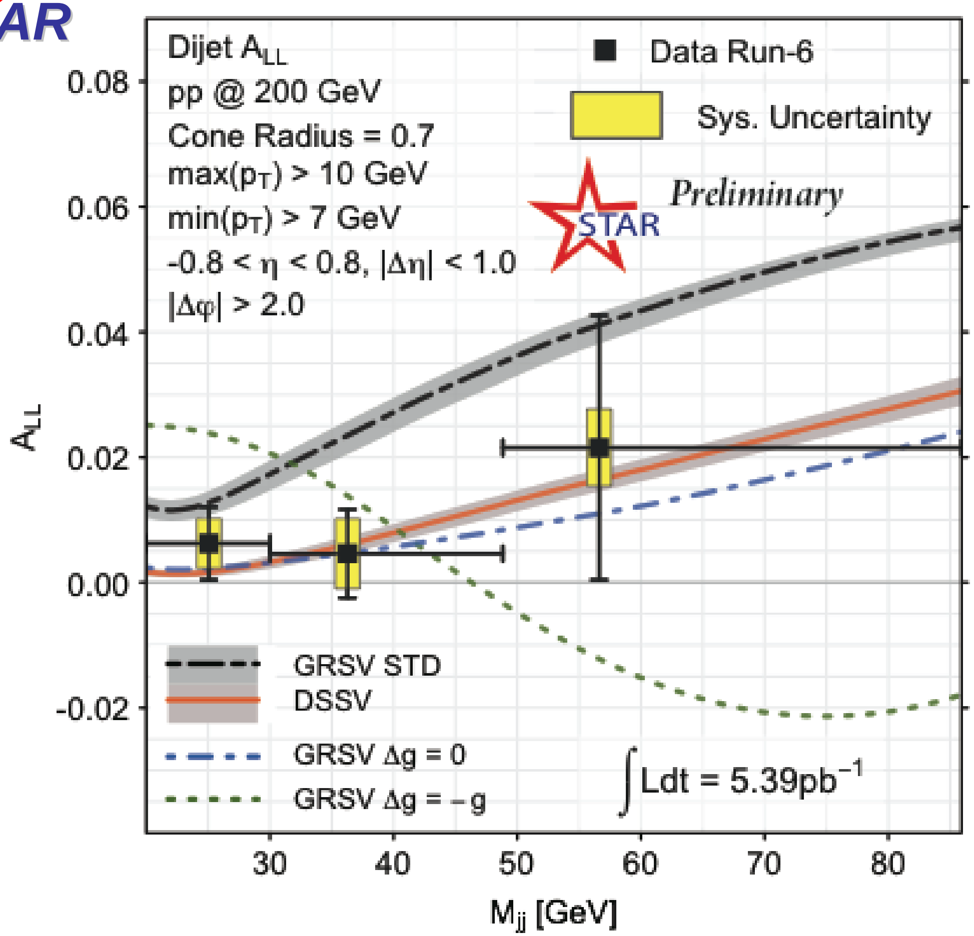
$$|\cos\theta^*| = \tanh\frac{|\eta_3 - \eta_4|}{2}$$





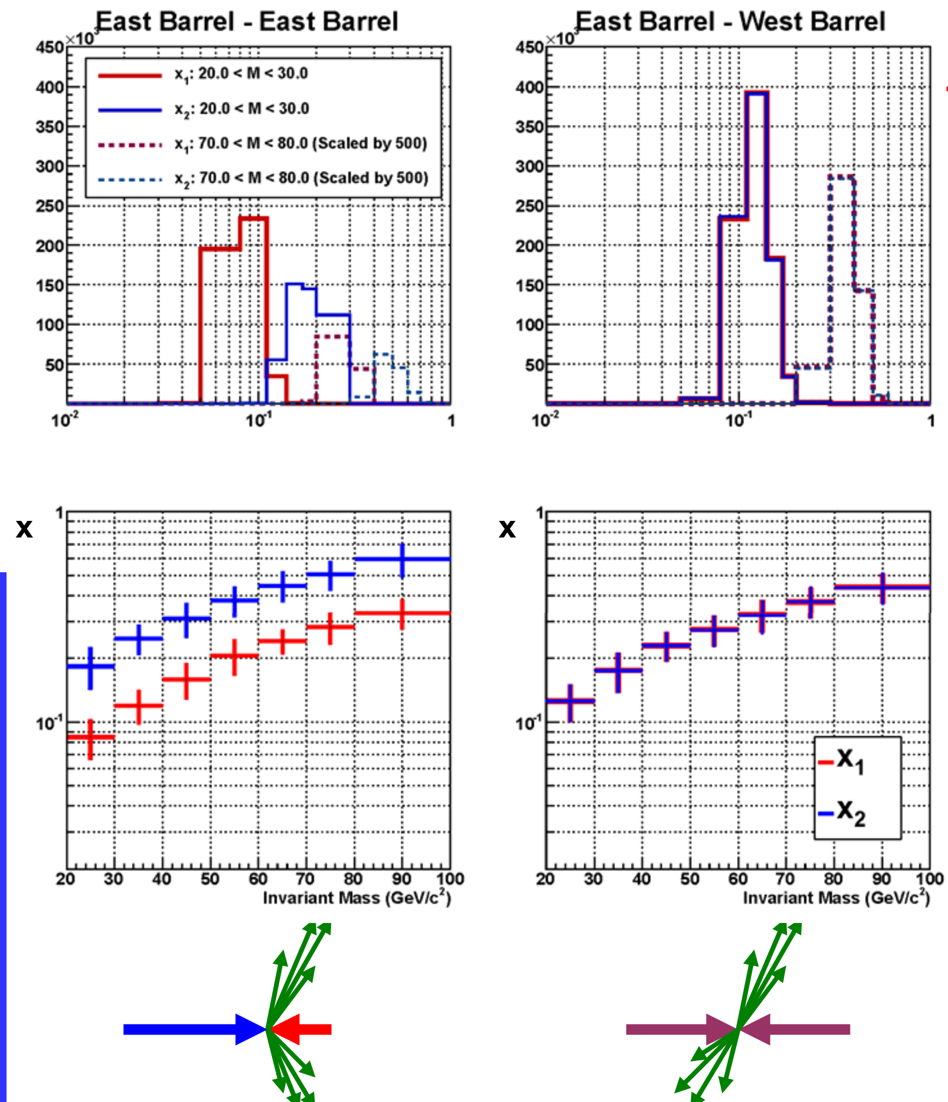
- Di-jets permit event-by-event calculations of x_1 and x_2 at LO
- Di-jet cross section is well-described by NLO pQCD with corrections for hadronization and underlying event

2006 di-jet A_{LL}



- 2006 di-jet A_{LL} provides a start at constraining the shape of $\Delta g(x)$

2009 ***STAR*** di-jet partonic coverage



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For more details: See poster by M. Walker

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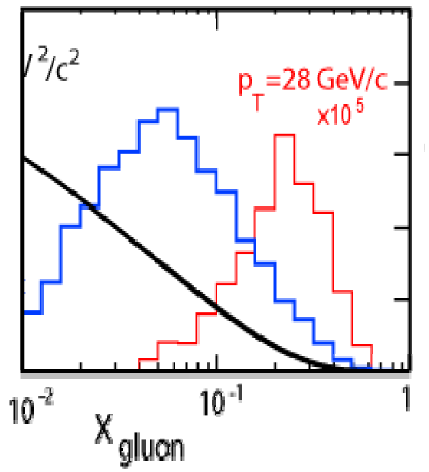

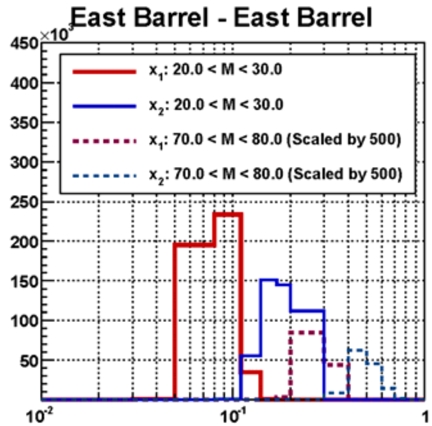

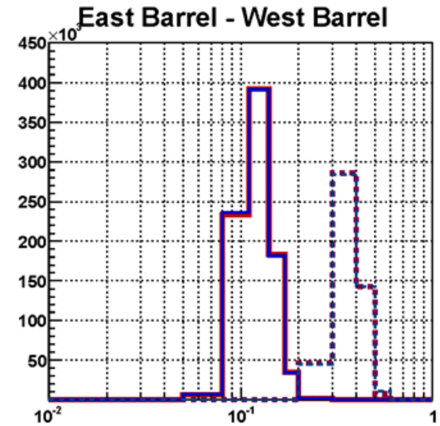

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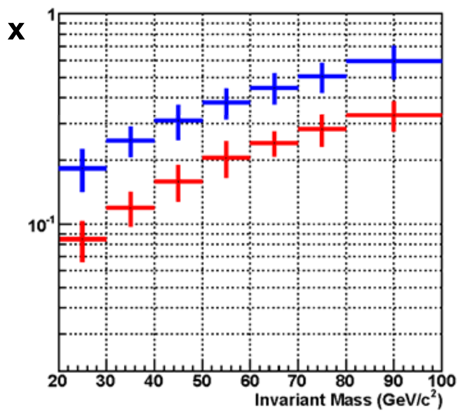
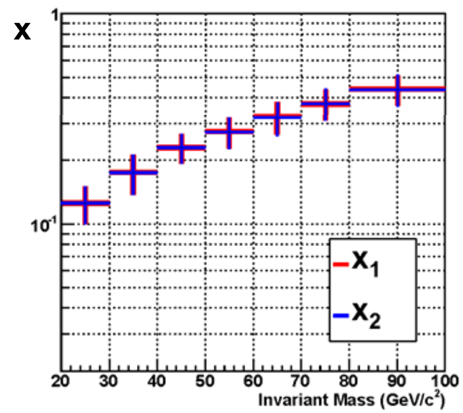
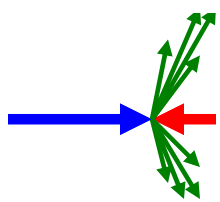
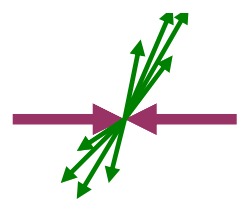


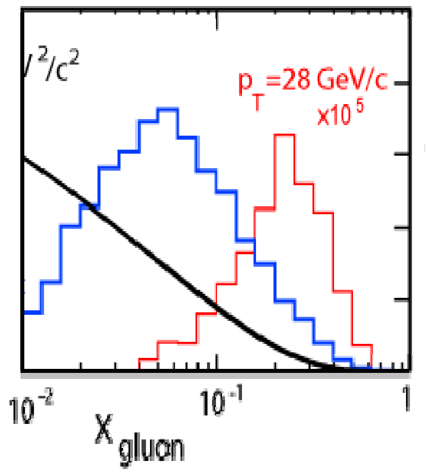


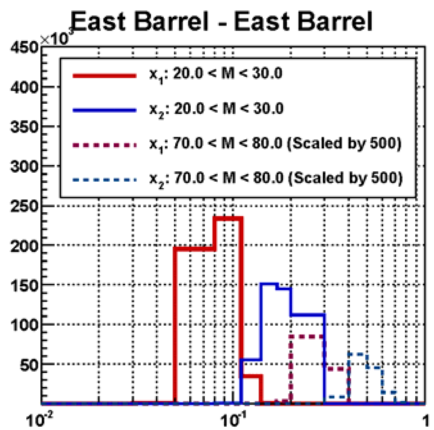


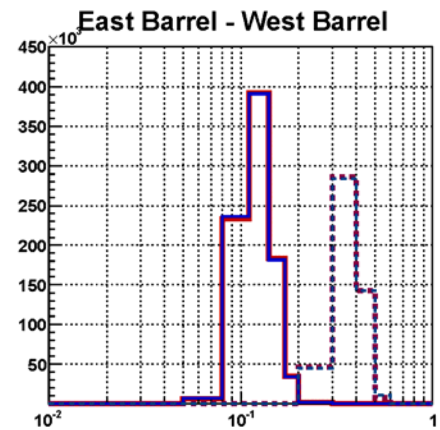


For more details: See poster by M. Walker

2009 ***STAR*** di-jet partonic coverage







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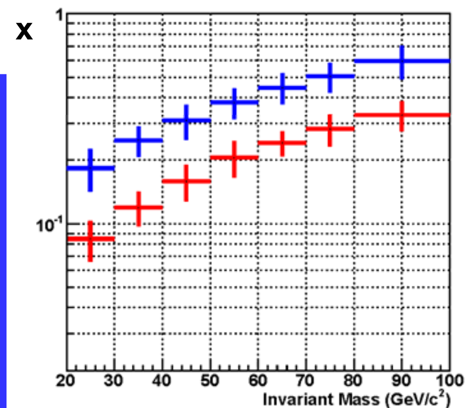
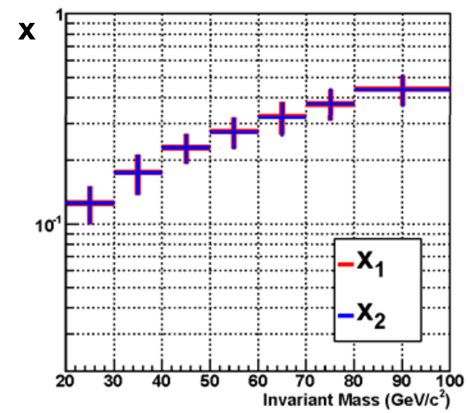
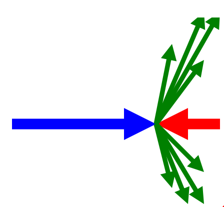
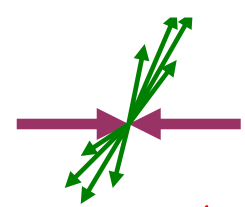






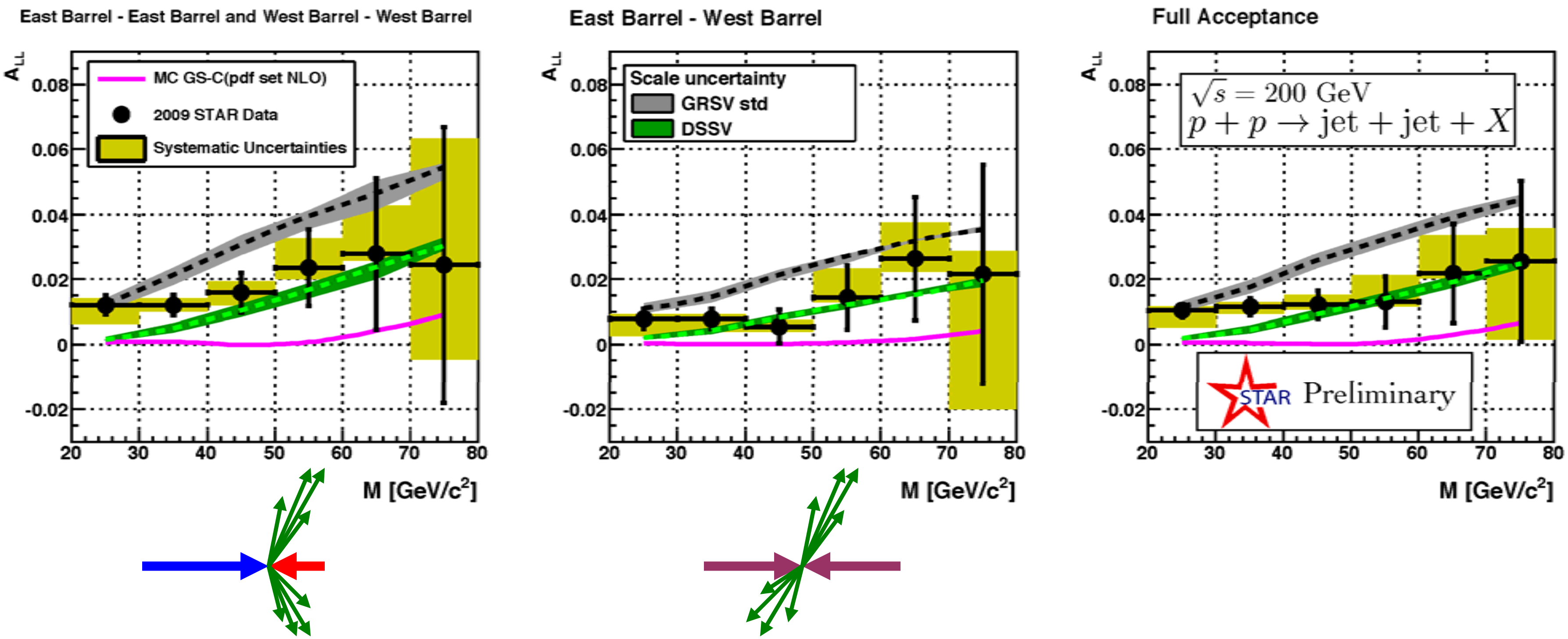
Larger $\hat{a}_{LL}$
Smaller σ



Smaller $\hat{a}_{LL}$
Larger σ

For more details:
See poster by
M. Walker

2009 ***STAR*** di-jet A_{LL}

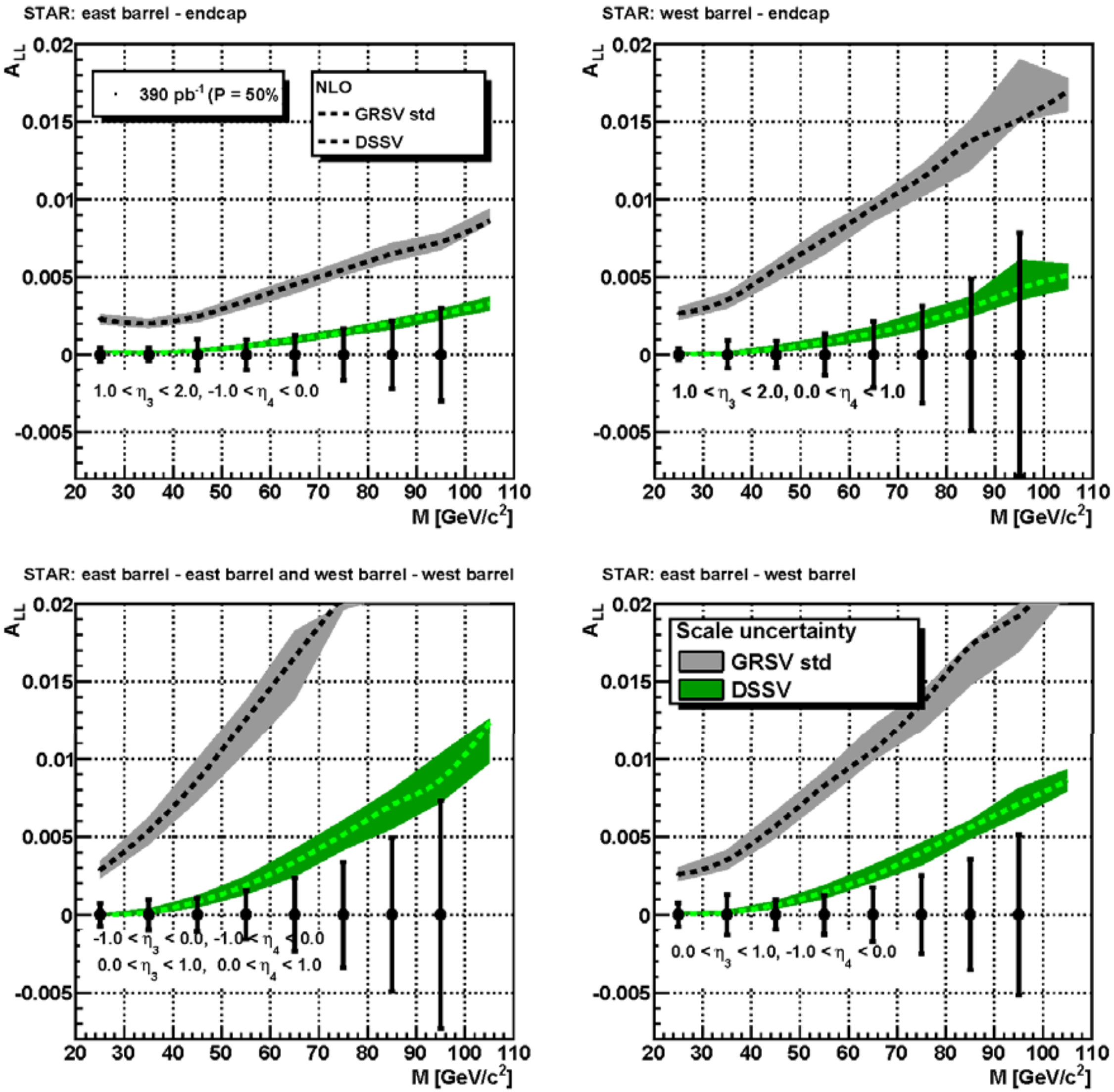


- For fixed M, different kinematic regions sample different *x* ranges
- **A_{LL} falls between DSSV and GRSV-STD**

For more details:
See poster by
M. Walker

Projected sensitivity for di-jets at 500 GeV

Assumes 600 pb^{-1} delivered @ P = 50%

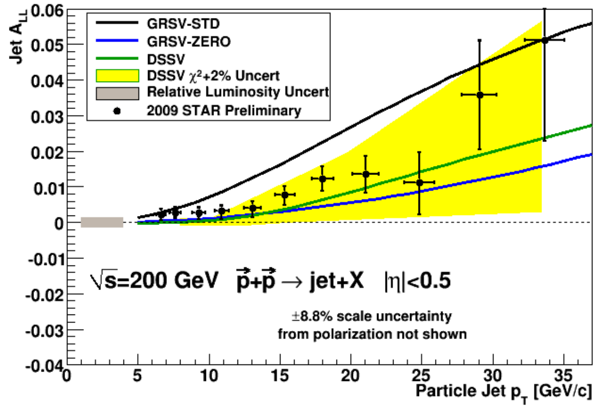


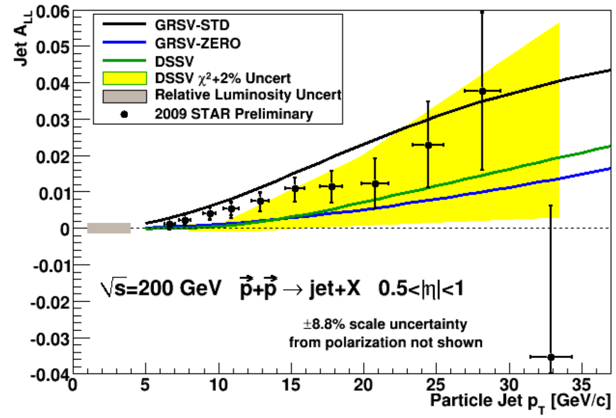
$$x_1, x_2 = \frac{M}{\sqrt{s}} \exp\left(\pm \frac{\eta_3 + \eta_4}{2} \right)$$

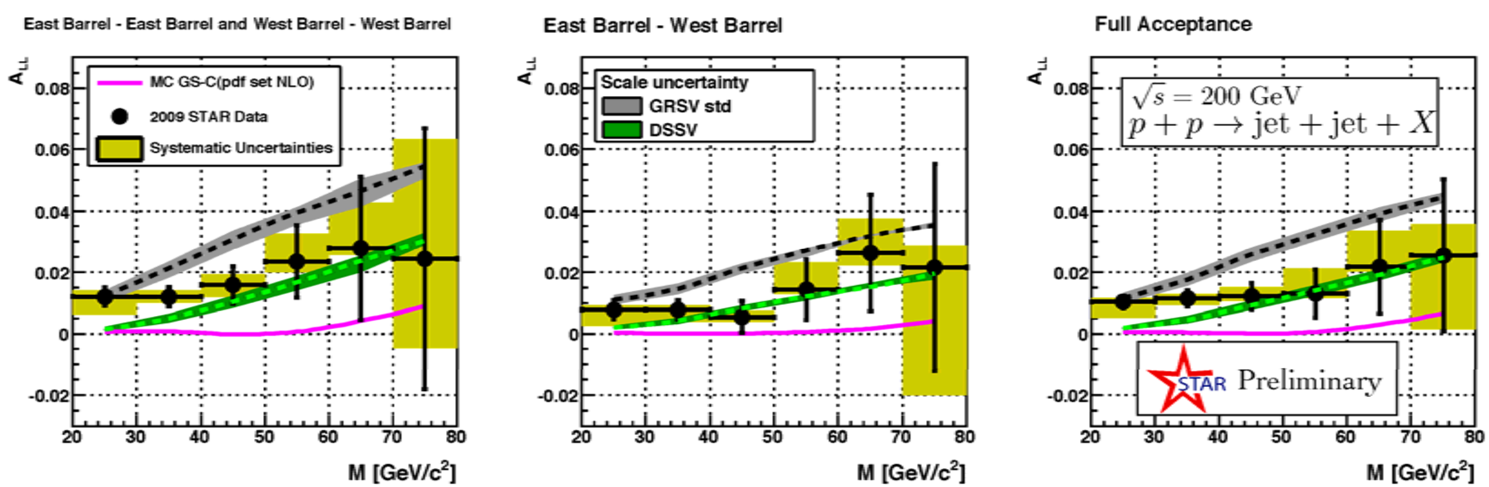
- Higher energy accesses lower x_g
- Expect smaller A_{LL}
- Uncertainties shown are purely statistical
- Maybe add EEMC-EEMC di-jets to reach lowest *x* values after FGT is installed (?)

Conclusions

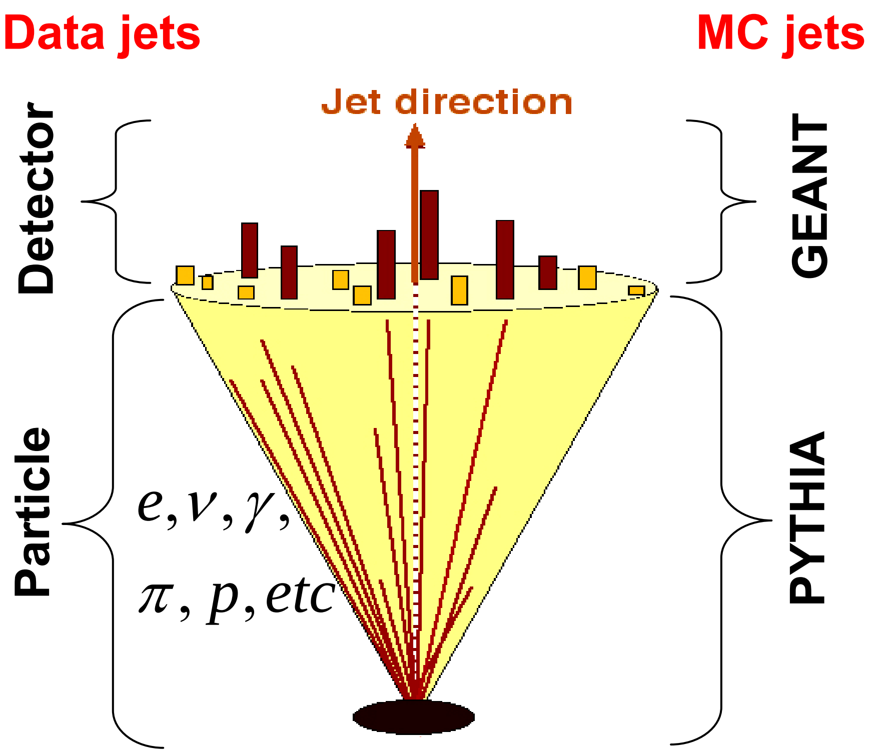
- ***STAR*** **2006 results play a significant role** in recent global analysis
- ***STAR*** **2009 results will have a strong impact** on the determination of gluon polarization
- We will **reduce the uncertainties even further** in the near future
- **Stay tuned!**







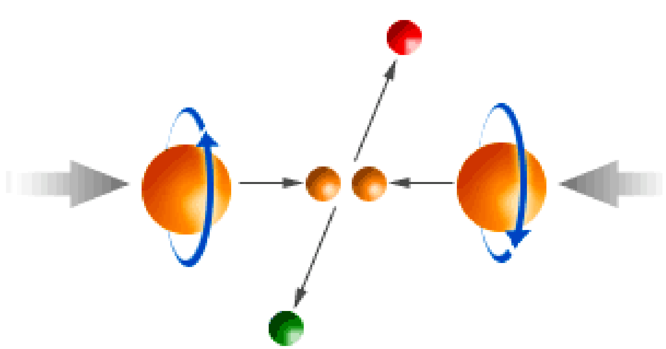
Jet reconstruction in ***STAR***



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



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

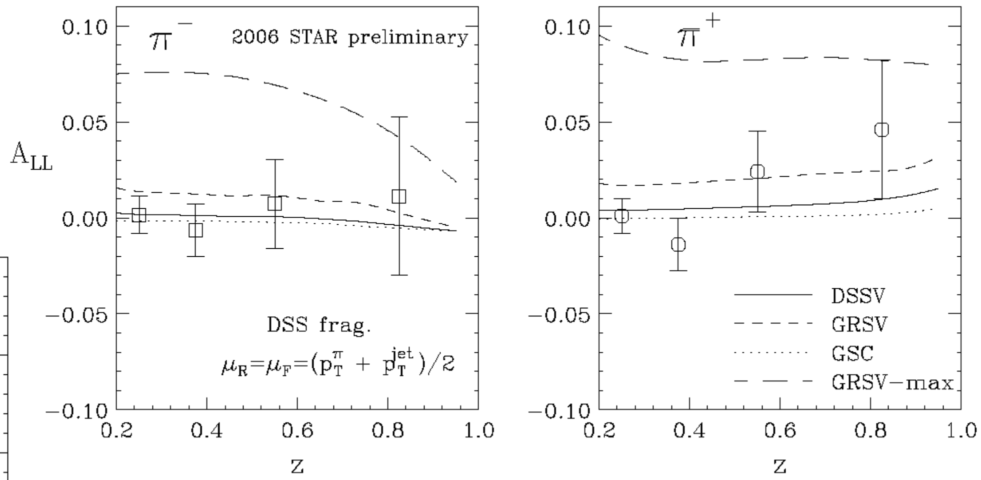
Jet+hadron correlations at NLO

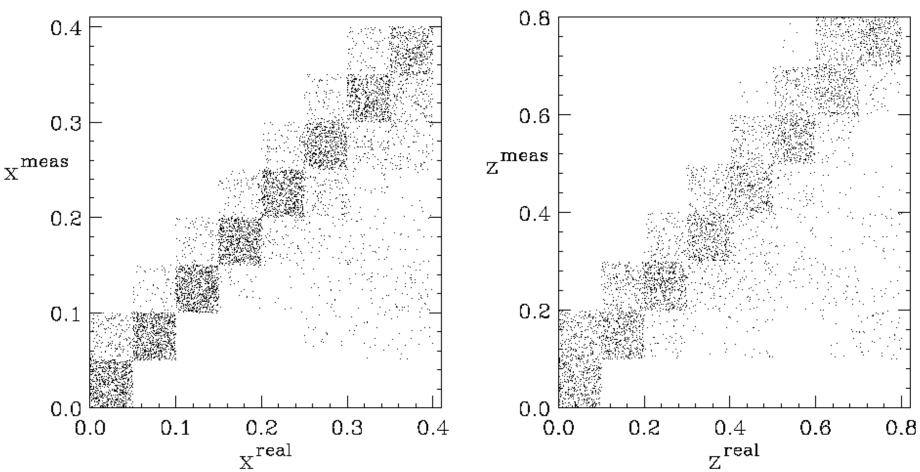
from de Florian, PRD 79, 114014

$$z \equiv \frac{p_T^h}{p_T^{jet}}$$

$$x_1 \equiv \left(p_T^{jet}\exp(\eta_{jet}) + p_T^{jet}\exp(\eta_h)\right)/\sqrt{s}$$

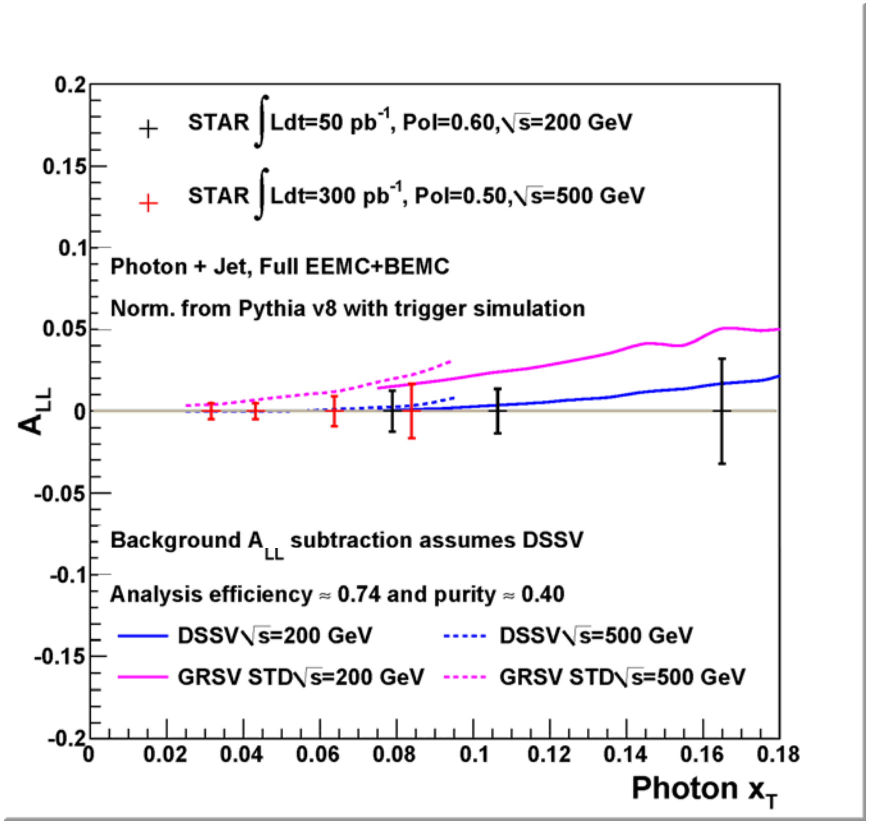
$$x_2 \equiv \left(p_T^{jet}\exp(-\eta_{jet}) + p_T^{jet}\exp(-\eta_h)\right)/\sqrt{s}.$$

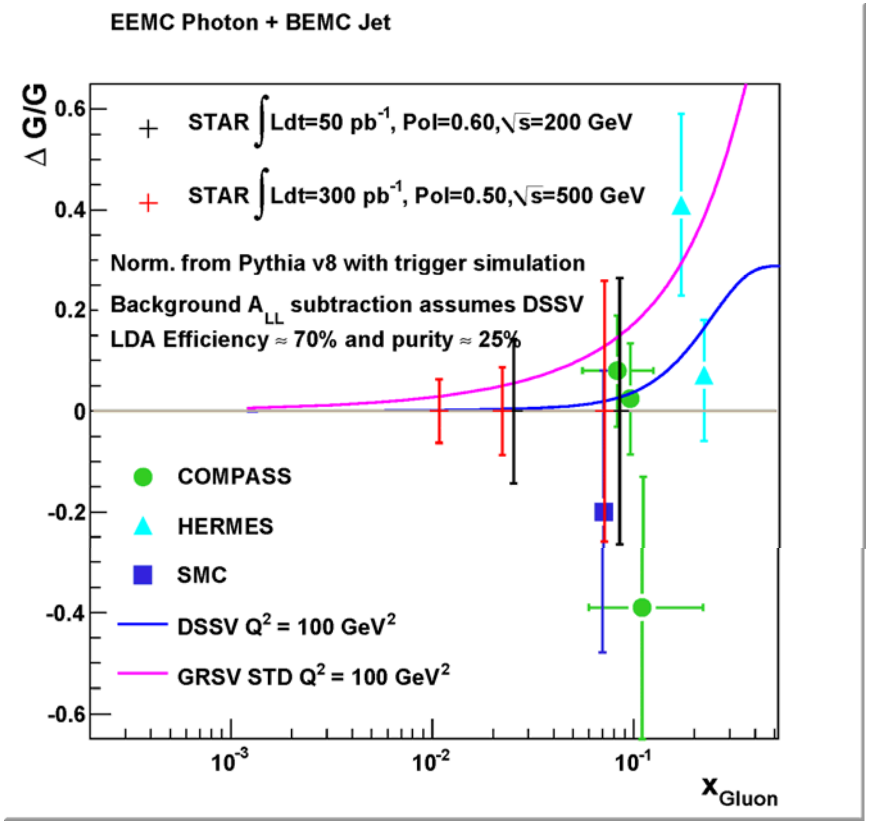




- NLO calculations show strong correlation between the real *x* and *z* values and LO estimates

Gluon polarization with gamma+jet





- Sensitivity estimates including realistic photon efficiencies and purities, benchmarked with real data
  - Maybe higher purity with future isolation cuts using FGT