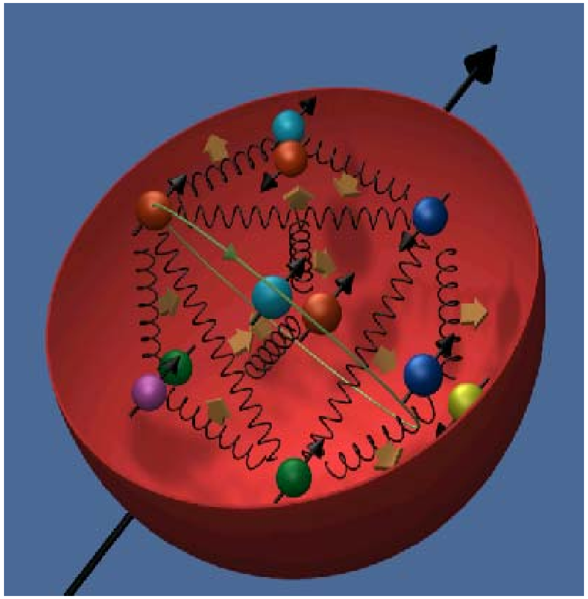
Gluon polarization measurements with STAR

Pibero Djawotho for the STAR Collaboration
Texas A&M University
28 April 2011

Outline
- Introduction
- Inclusive probes
- Correlation measurements

The proton spin sum rule

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



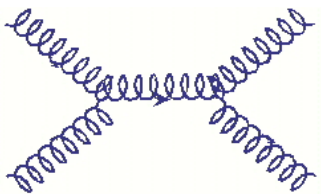
- Quark polarization $\Delta\Sigma \approx 0.3$ from polarized deep inelastic scattering
- Gluon polarization (ΔG) and orbital angular momentum (L) are poorly constrained
- A primary charge of RHIC spin physics $\Rightarrow$ map $\Delta g(x)$

Polarized pp collisions at RHIC

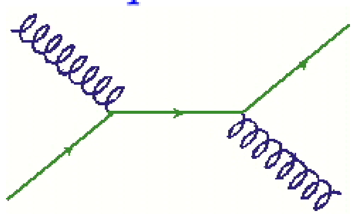
$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \propto \frac{\Delta f_a \Delta f_b}{f_a f_b} \hat{a}_{LL}$$

Δf: polarized parton distribution functions

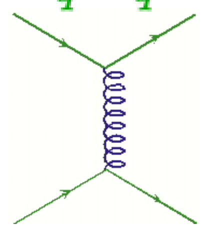
$\frac{\Delta G}{G} \frac{\Delta G}{G}$

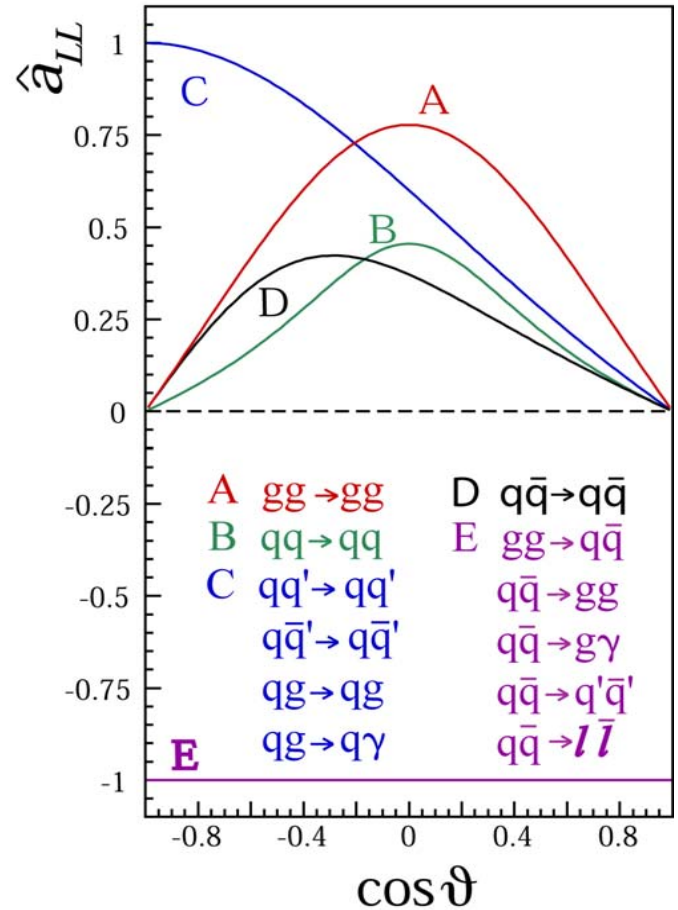


$\frac{\Delta q}{q} \frac{\Delta G}{G}$

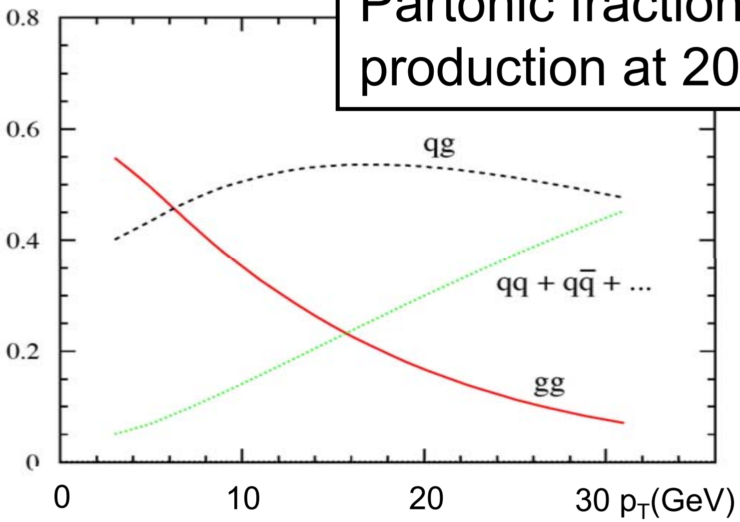


$\frac{\Delta q}{q} \frac{\Delta q}{q}$





Partonic fractions in jet production at 200 GeV

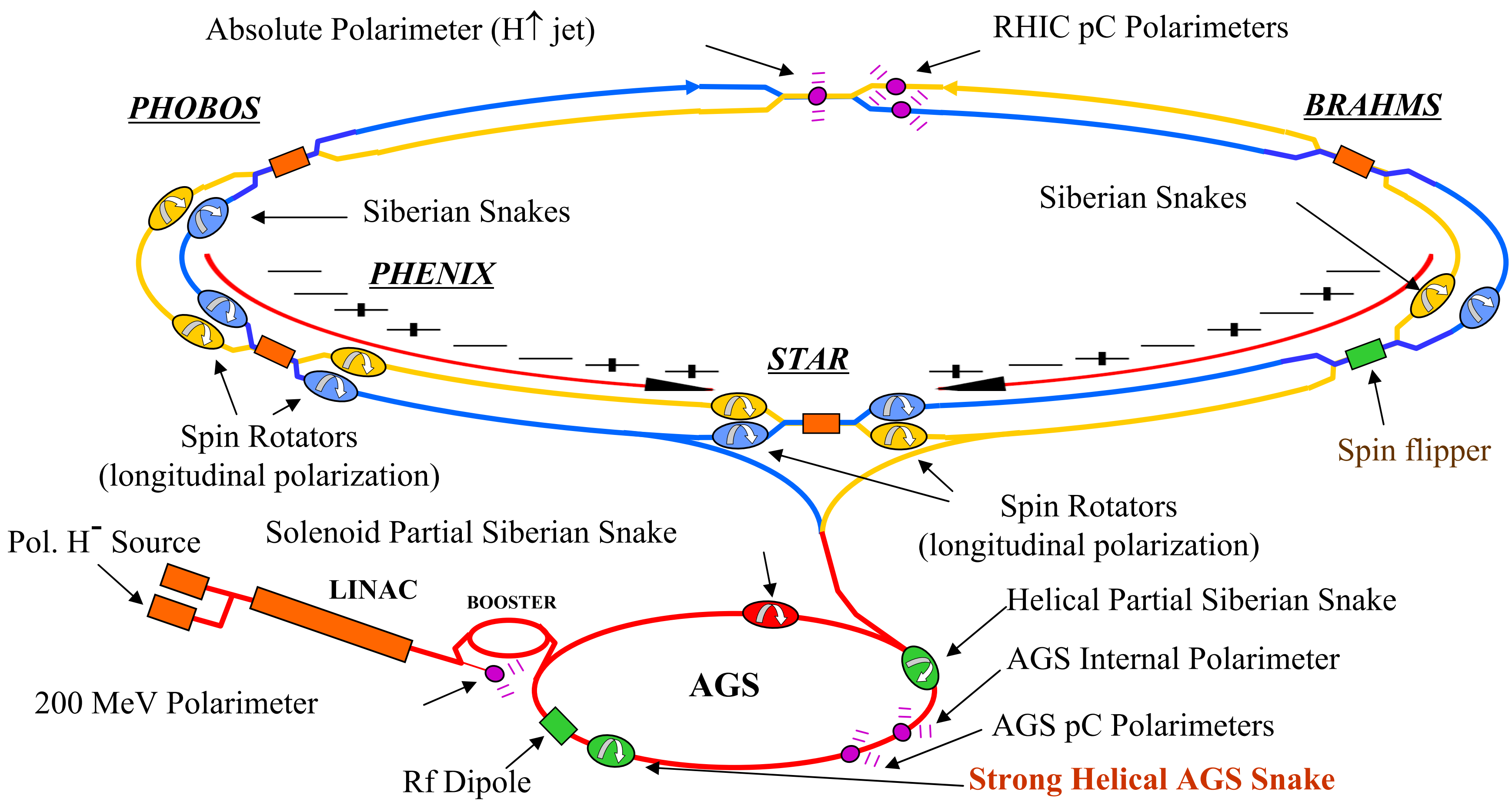


For most RHIC kinematics, ***gg*** and ***qg*** dominate, making A_{LL} for jets and hadrons sensitive to **gluon polarization**.

Overview of ΔG program at STAR

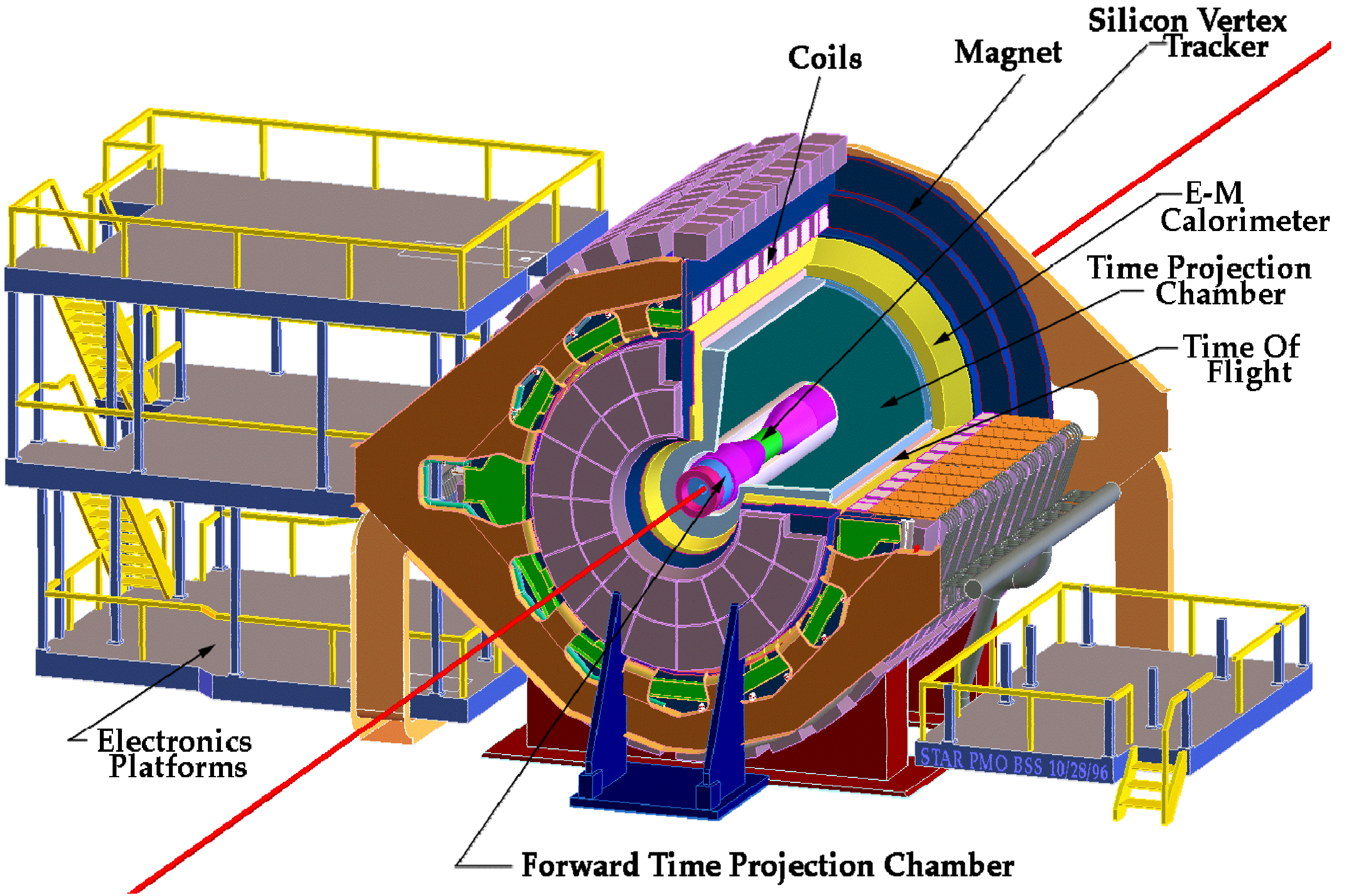
- Inclusive probes: high statistics, fixed p_T samples wide x_{gluon} range
  - Neutral pions
    - Efficient, unbiased trigger
    - Dependence on fragmentation functions
  - Charged pions
    - No dedicated trigger, use jet patch trigger instead
    - Dependence on fragmentation functions
  - Jets
    - Jet patch trigger with bias near trigger threshold ⇒ dominant systematics
    - Limited p_T resolution and large energy scale uncertainty
    - No dependence on fragmentation functions
    - Large cross section, **best statistical precision**
- Correlation measurements: low statistics, direct access to x_{gluon}
  - Charged pions opposite jets
    - Trigger on jet patch, look for charged pion on away side
  - Dijets
    - Trigger on first jet and reconstruct second jet offline
  - Photon-jets
    - Select quark-gluon Compton scattering ⇒ clean signature
    - Direct extraction of ΔG
    - Very low statistics against high background from neutral meson decays

RHIC: The world's first polarized hadron collider



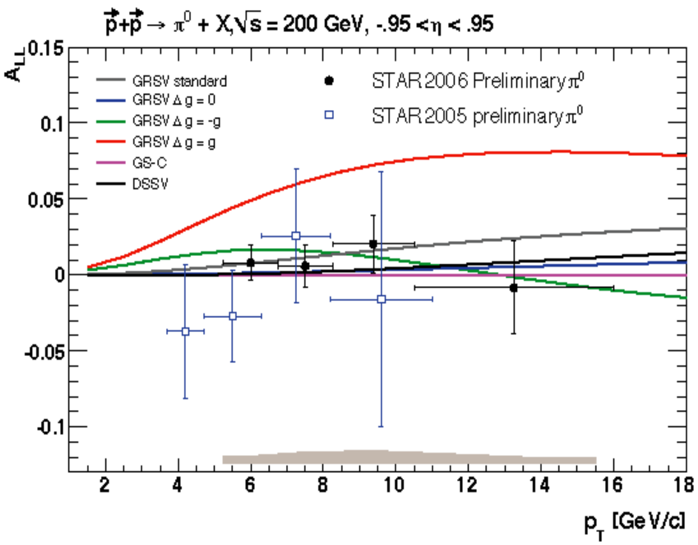
- Spin varies from rf bucket to rf bucket (9.4 MHz)
- Spin pattern changes from fill to fill
- Spin rotators provide choice of spin orientation
- Billions of spin reversals during a fill with little if any depolarization

The STAR detector

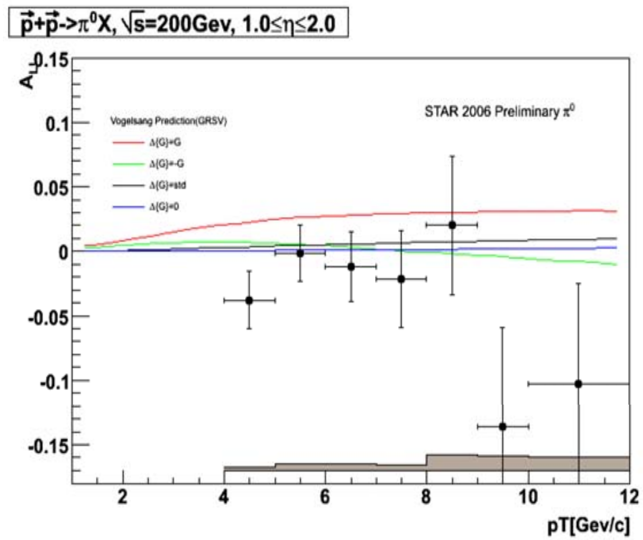


STAR inclusive π^0 A_{LL} at various rapidities

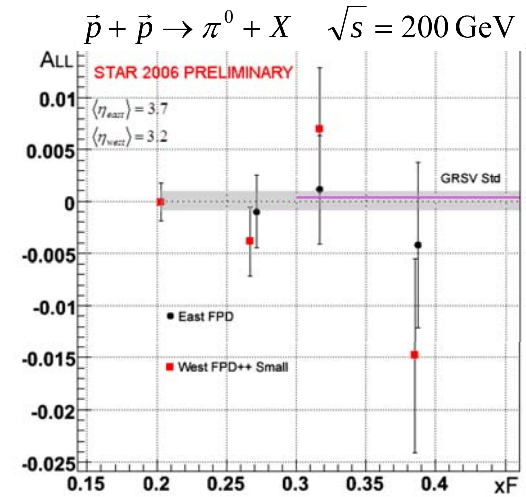
$|\eta| < 0.95$



$1 < \eta < 2$

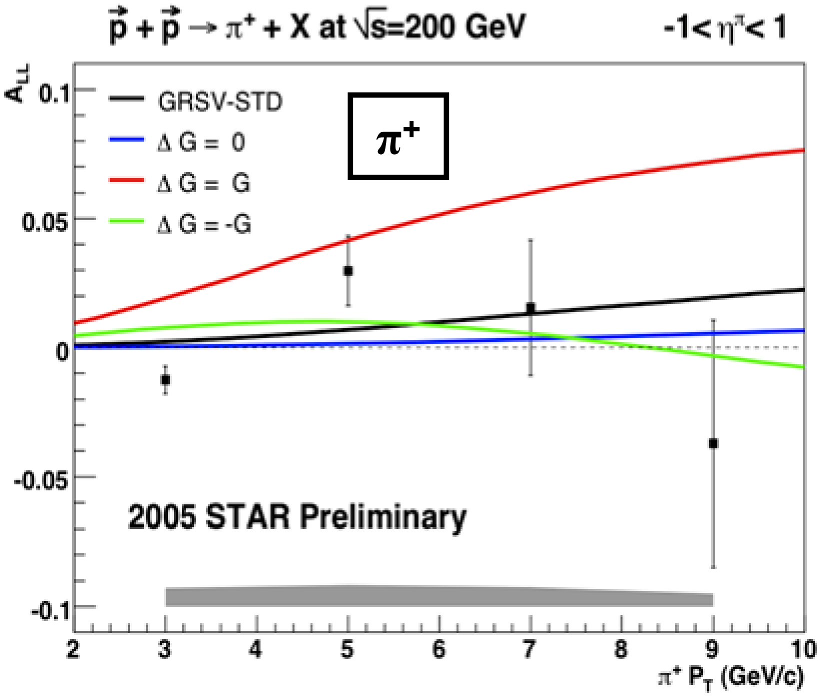


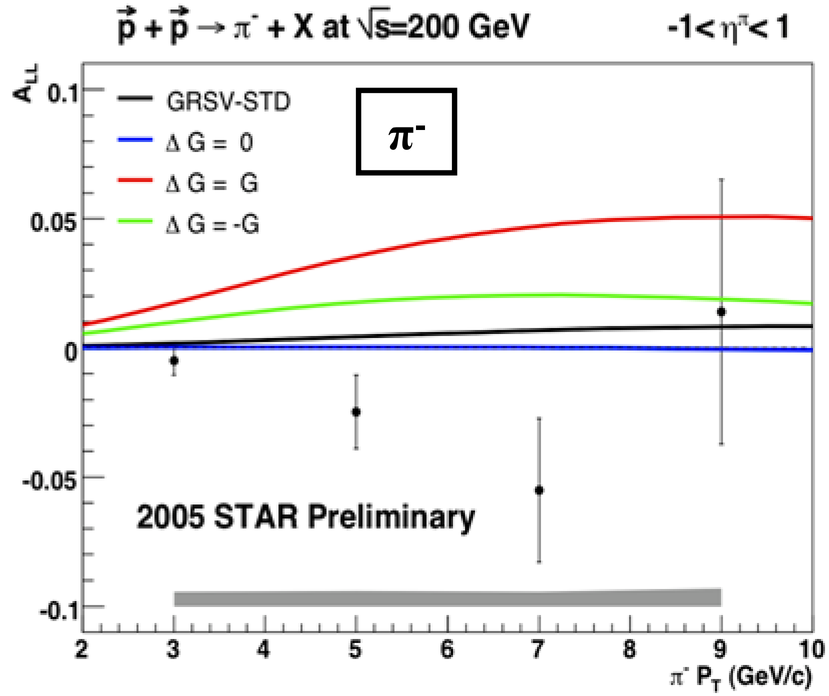
$\eta = 3.2, 3.7$



- During 2006, ***STAR*** measured A_{LL} for inclusive π^0 for three different rapidity regions
- Mid-rapidity result excludes large gluon polarization scenarios
- 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

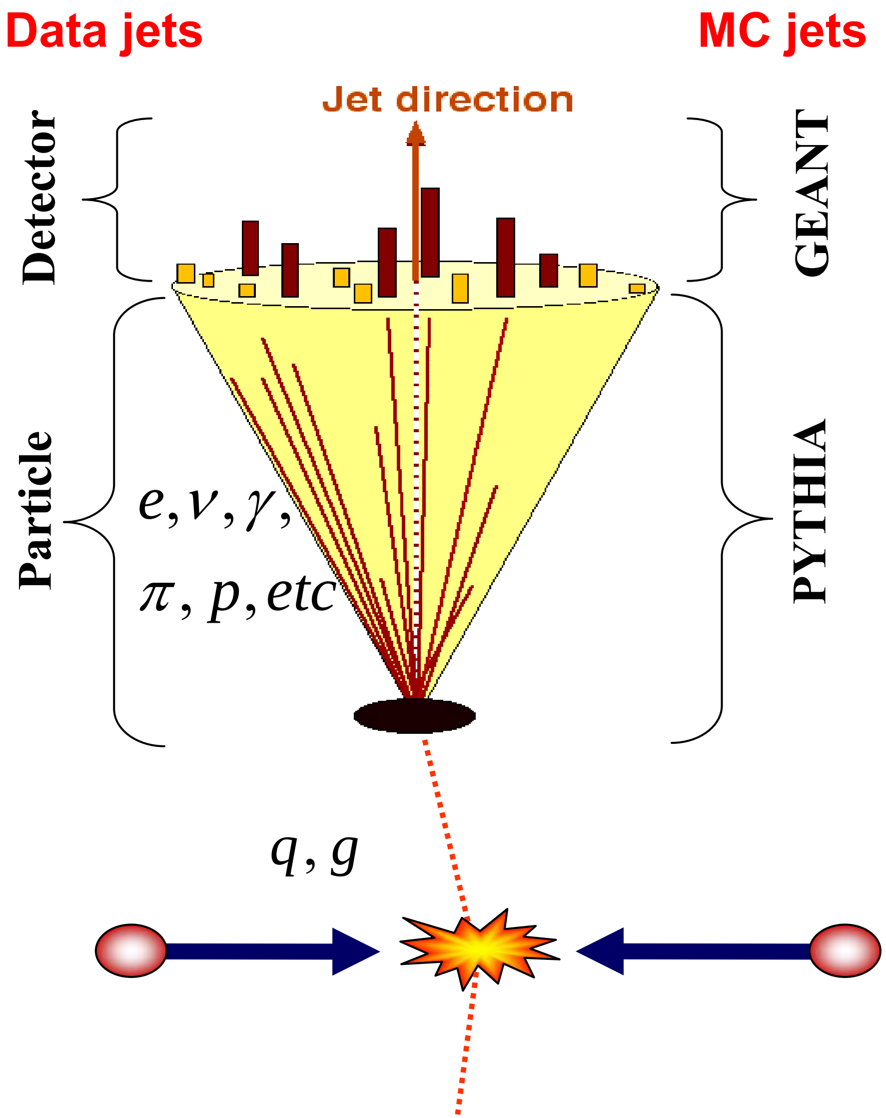
STAR inclusive charged pions





- ***STAR*** measured A_{LL} for inclusive charged pions during 2005
- $A_{LL}(\pi^+) - A_{LL}(\pi^-)$ is sensitive to the sign of ΔG
- Difficult to trigger on charged pions
- Used the EMCal jet patch trigger as a surrogate, which introduces significant trigger bias (dominates syst. error band)

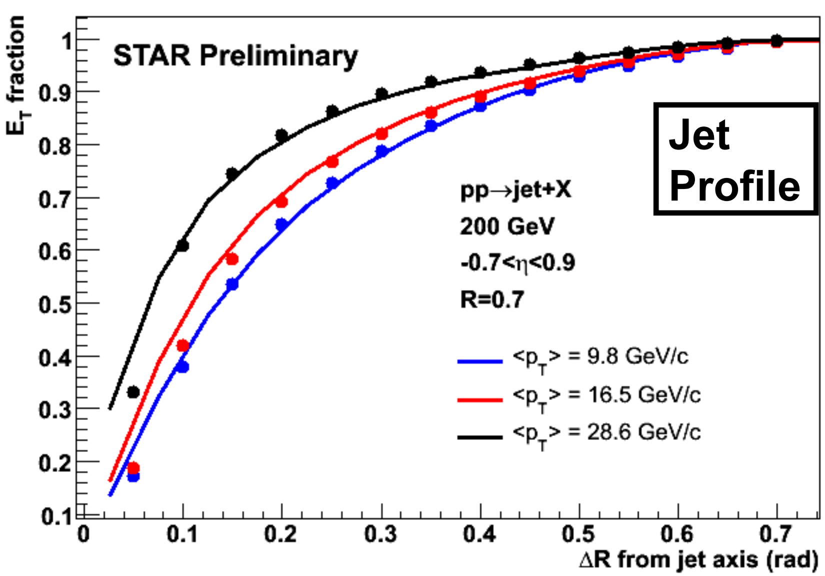
Jet reconstruction in STAR



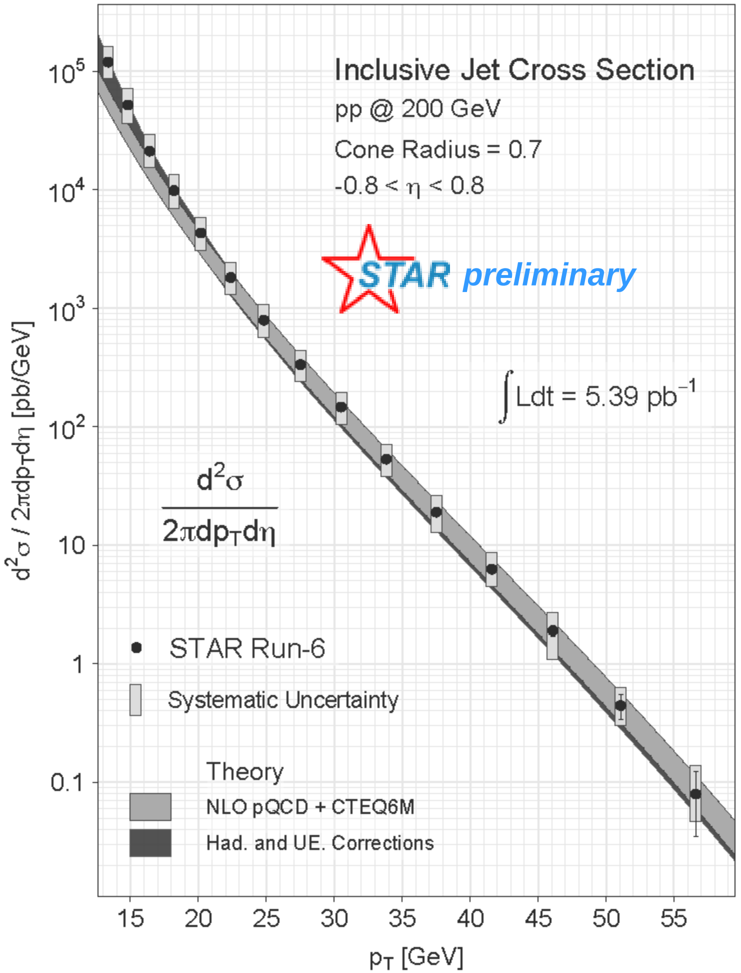
Midpoint cone algorithm
(Adapted from Tevatron II - hep-ex/0005012)

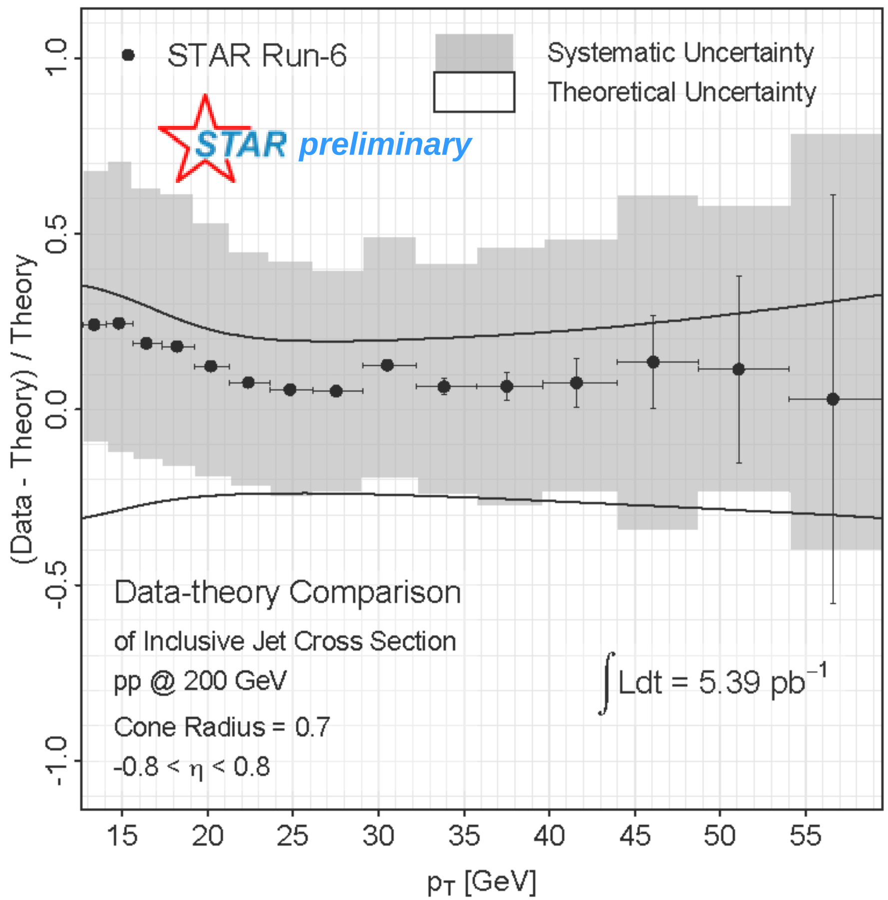
- Seed energy = 0.5 GeV
- Cone radius $R=\sqrt{(\Delta\eta^2+\Delta\varphi^2)} = 0.7$
- Split/merge fraction f=0.5

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



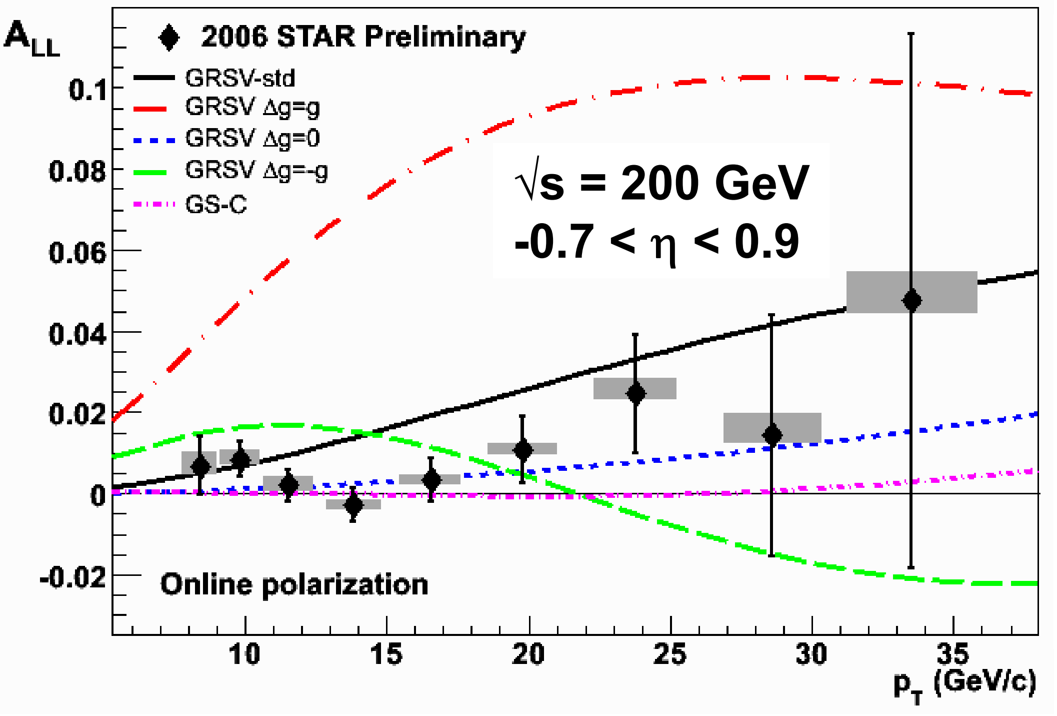
2006 inclusive jet cross section

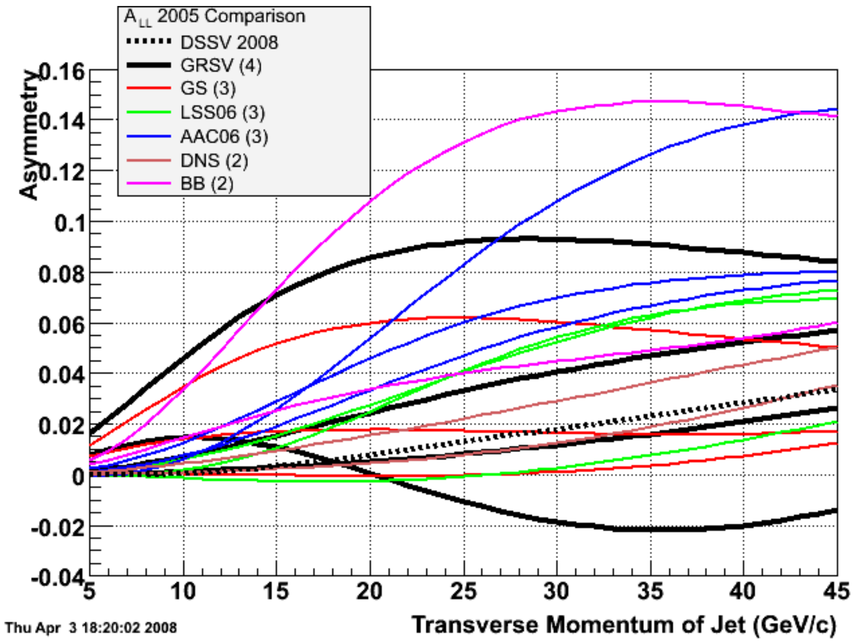




- Data well described by NLO pQCD+Hadronization+Underlying Event
- Hadronization+Underlying event corrections significant at low jet p_T

2006 inclusive jet A_{LL}



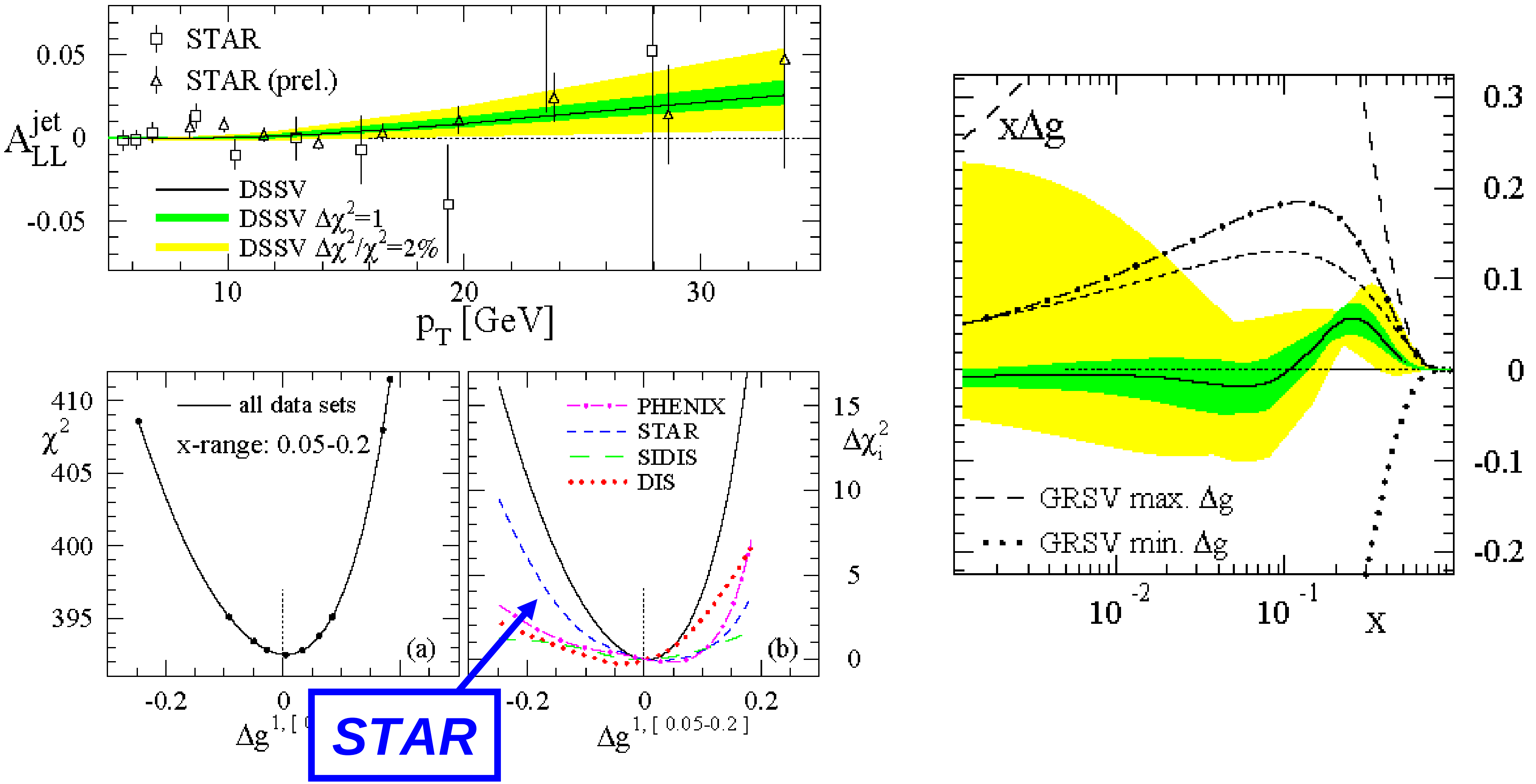


GRSV curves with cone radius 0.7 and -0.7 < η < 0.9

- Sampled 4.7 pb^{-1} at 60% average beam polarization
- STAR data rule out several previous models of gluon polarization

DSSV – First global analysis with polarized jets

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

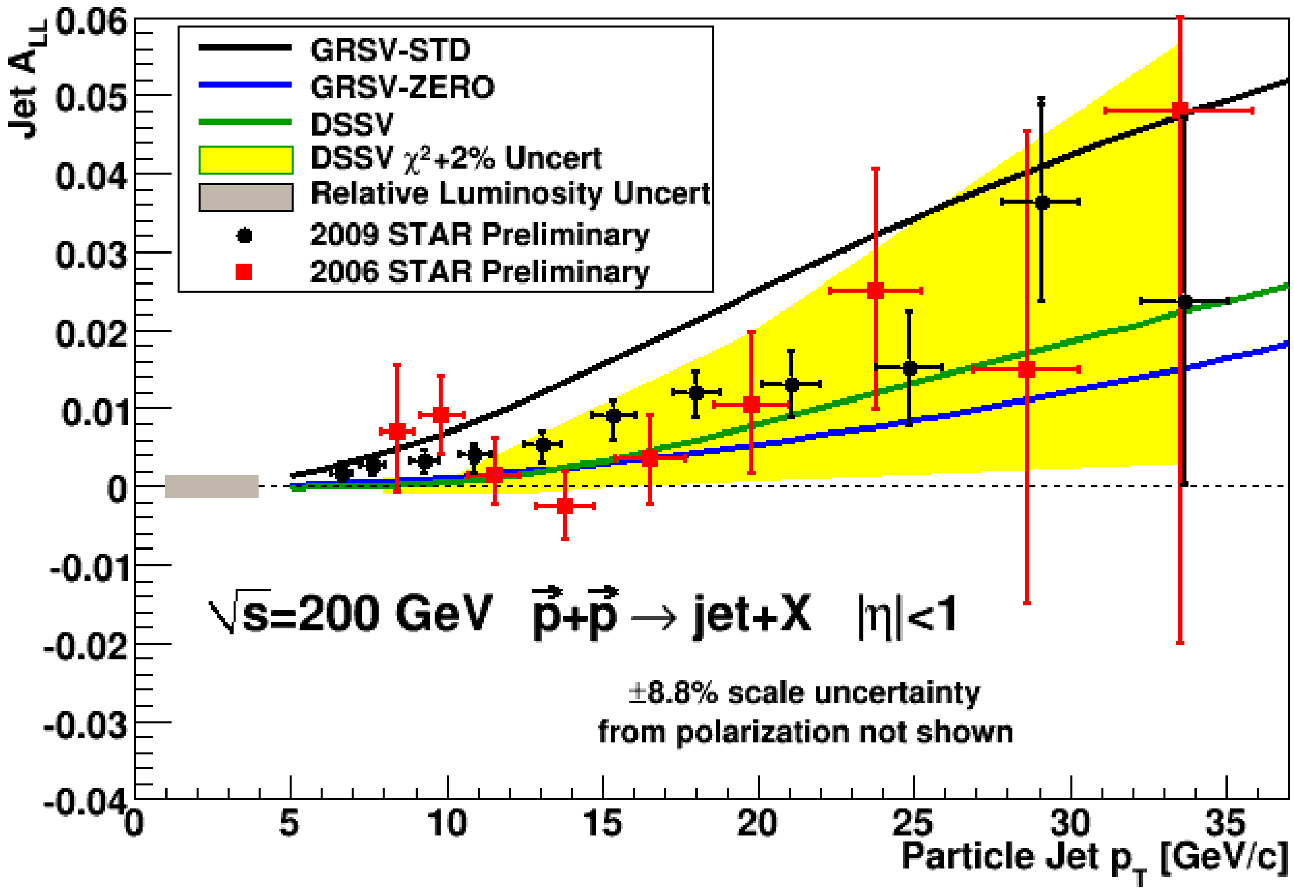


- First global NLO analysis to incorporate inclusive DIS, SIDIS, and RHIC pp data on equal footing

2009 upgrades

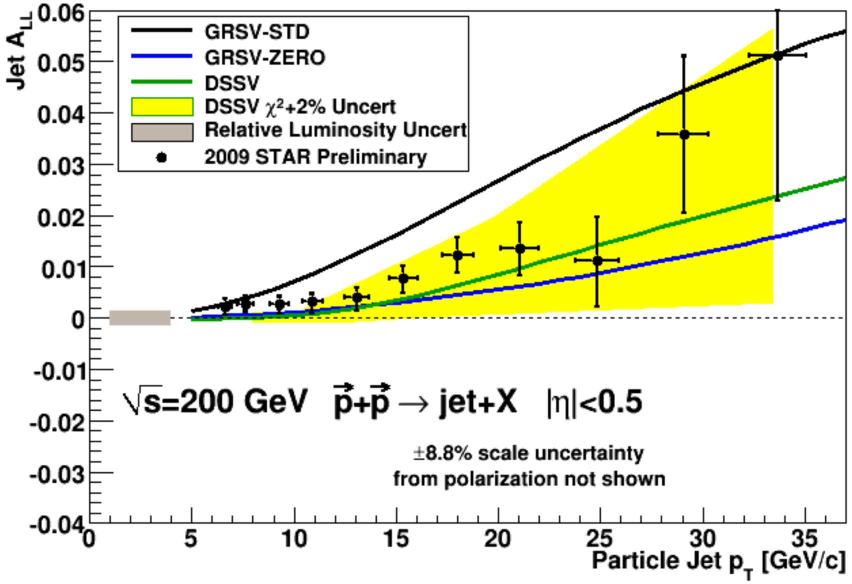
- 2009 jet patch trigger upgrades
  - Overlapping jet patches and lower E_T threshold improve efficiency and reduce trigger bias
    - Net increase of 37% in jet acceptance
  - Remove beam-beam counter trigger requirement:
    - Trigger more efficiently at high jet p_T
    - Measure non-collision background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

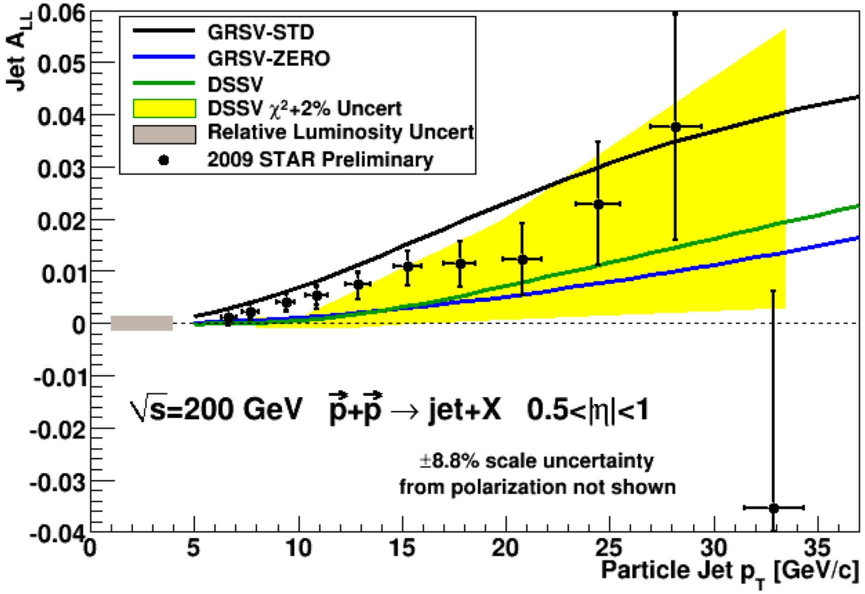
2006 vs 2009 inclusive jet A_{LL}



- 2009 STAR data is a factor of 3 (high-p_T) to >4 (low-p_T) more precise than 2006 STAR data
- Results fall between predictions from **DSSV** and **GRSV-STD**
- Precision sufficient to merit finer binning in pseudorapidity

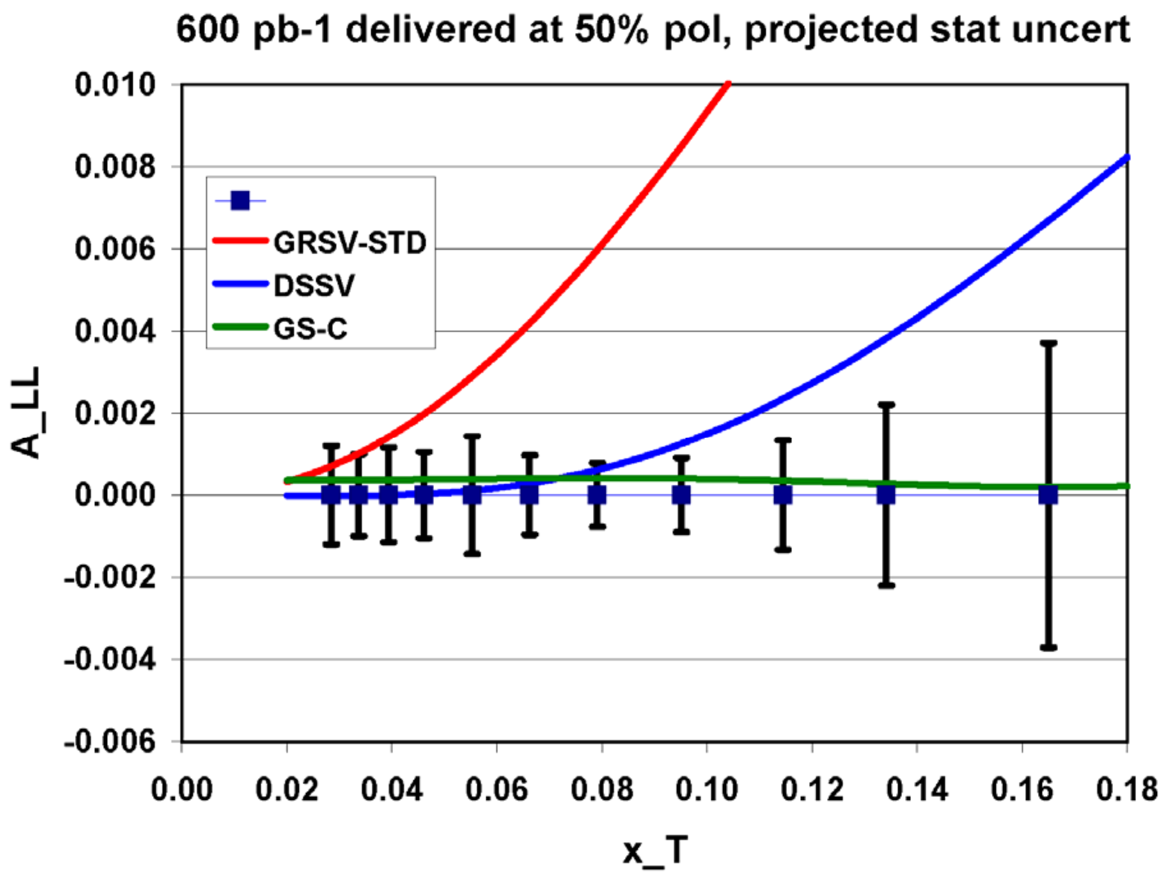
2009 inclusive jet A_{LL}





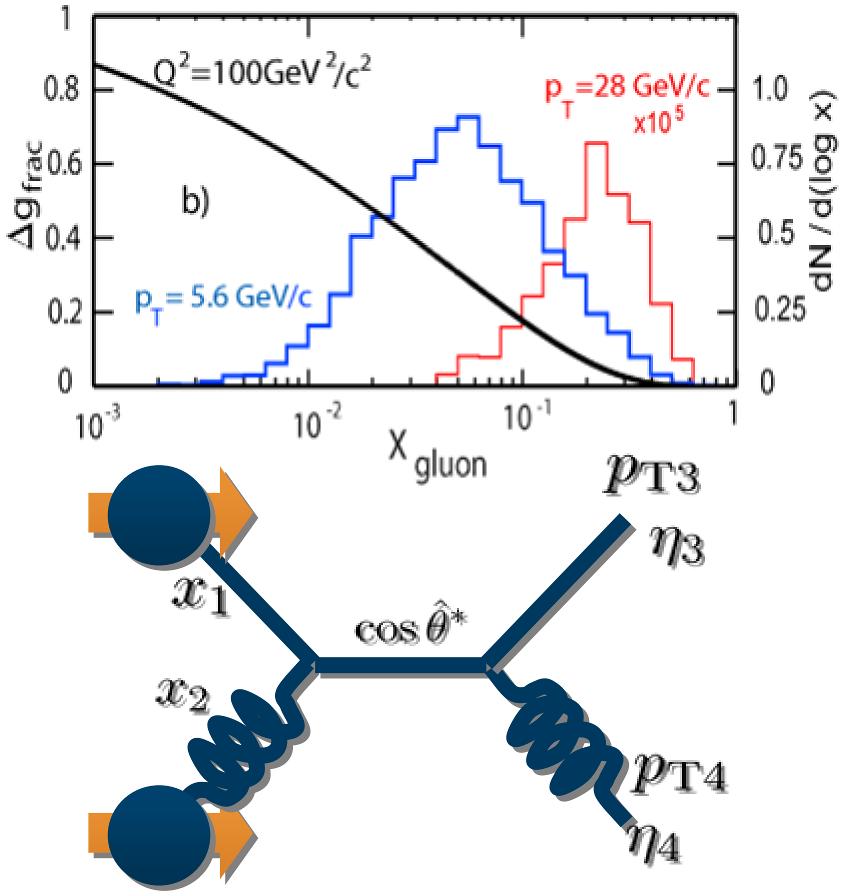
- A_{LL} separated into two pseudorapidity ranges
- Models predict a ~20% reduction in A_{LL} from |η|<0.5 to 0.5<|η|<1
- A_{LL} falls between the predictions from **DSSV** and **GRSV-STD**

Projected sensitivity for future 500 GeV running



- 500 GeV collisions sample smaller $x_T=2p_T/\sqrt{s}$
- Projected statistical uncertainties, following 2009 experience
- Expected asymmetries are quite small
  - Control of systematics (esp. relative luminosity) will be important

Correlation measurements



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

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

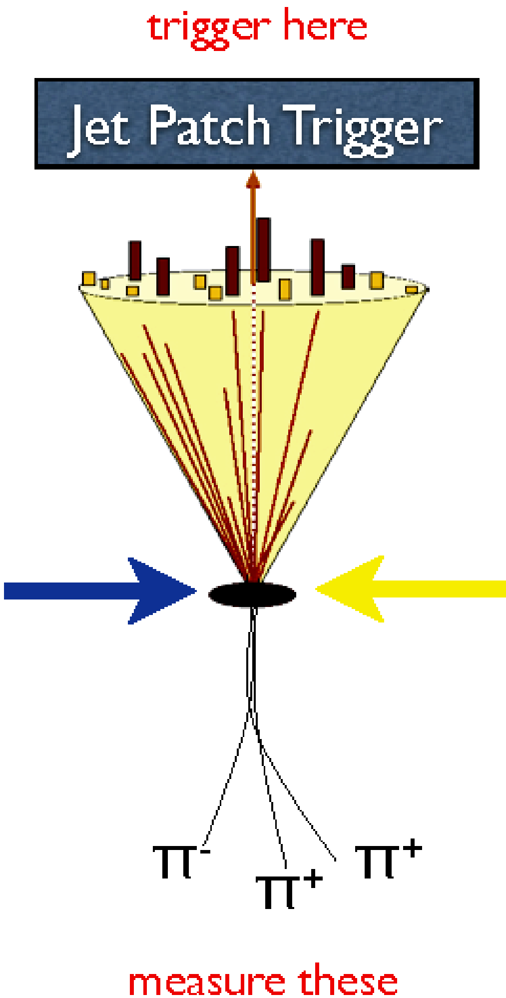
$$M = \sqrt{x_1 x_2 s}$$

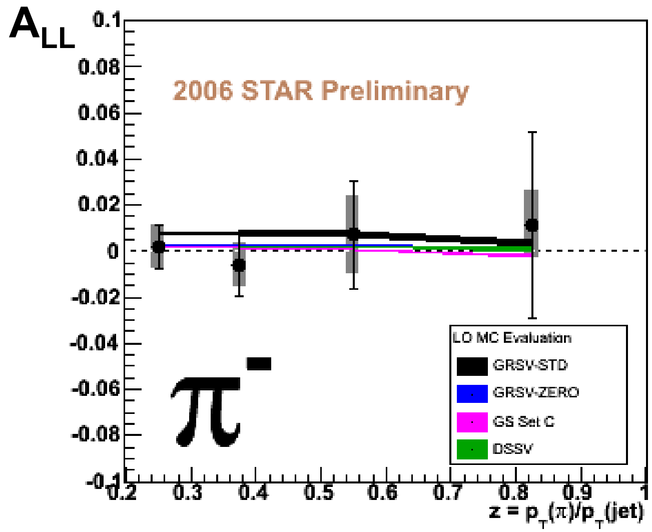
$$\eta_3 + \eta_4 = \ln\frac{x_1}{x_2}$$

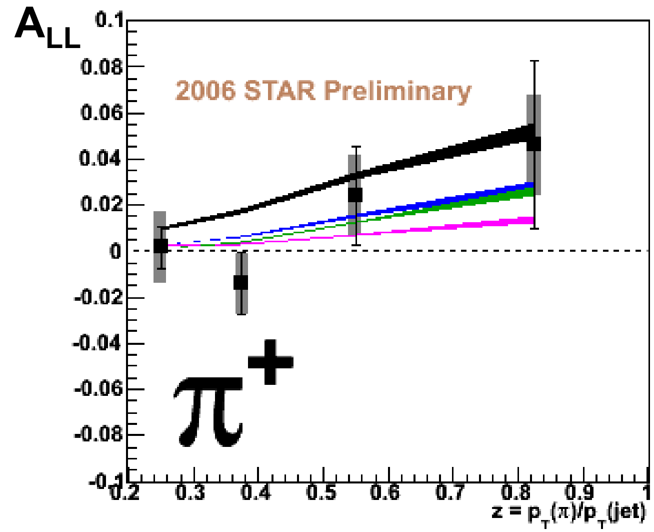
$$\left|\cos\theta^*\right| = \tanh\left|\frac{\eta_3 - \eta_4}{2}\right|$$

- Inclusive probes at fixed p_T sample broad *x* range ⇒ global analysis needed to disentangle shape of Δ*g(x)*
- Reconstructing the entire final state (jets, hadrons, photons) provides information on initial parton kinematics at LO
- STAR is well suited for correlation measurements and full jet reconstruction with its large acceptance

Charged pions opposite jets







- **Making lemons into lemonade**
- Beat the trigger bias by using it
- Trigger and reconstruct a jet, then look for a charged pion on the opposite side
- Correlation measurement significantly increases the sensitivity of $A_{LL}(\pi^{+})$

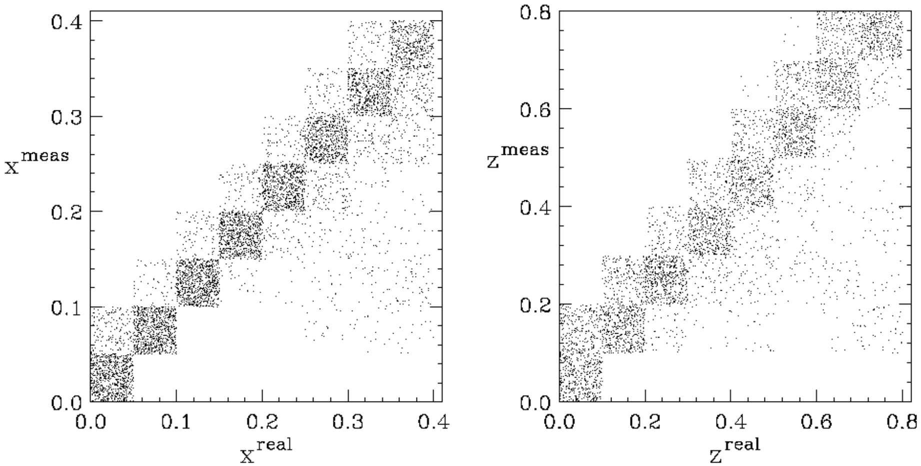
Jet+hadron correlations at NLO

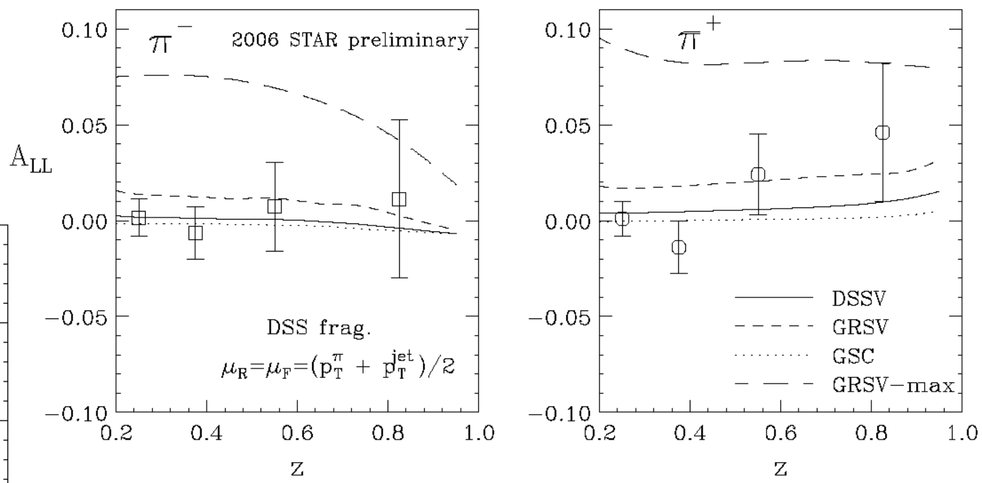
de Florian, PRD **79**, 114014 (2009)

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

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

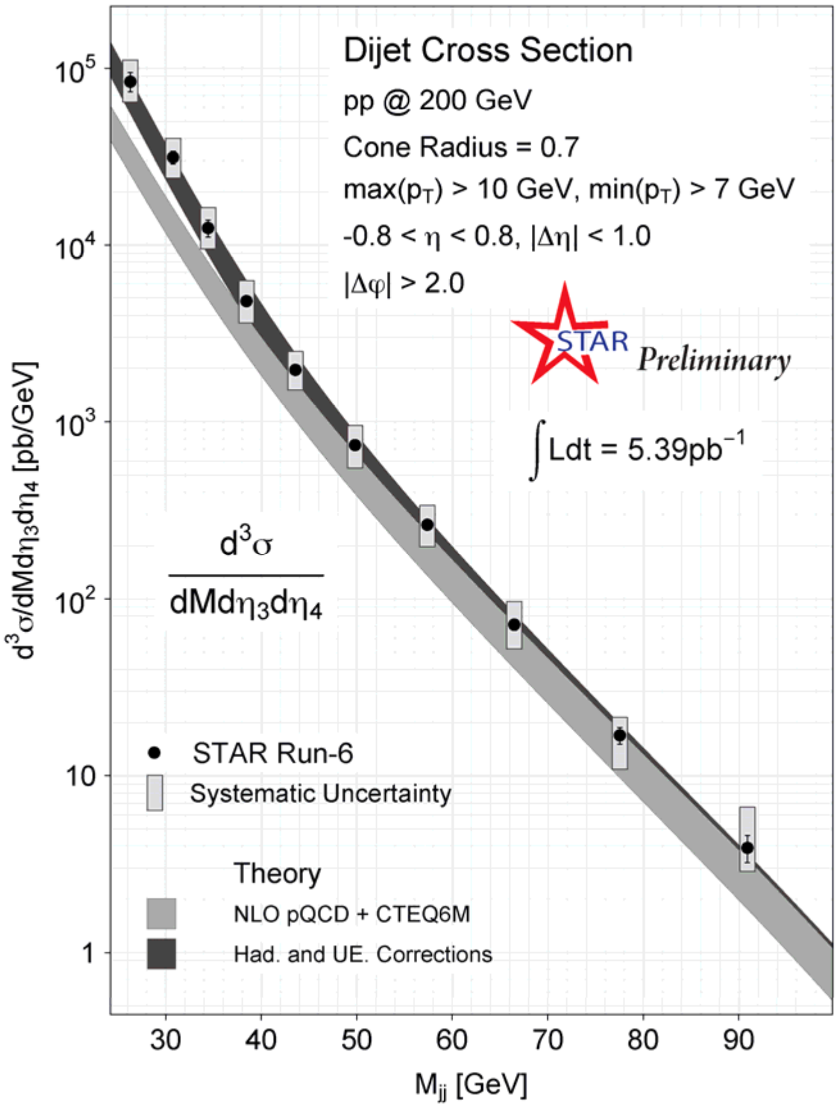
$$x_2 \equiv \left(p_T^{jet}\exp(-\eta_{jet}) + p_T^{jet}\exp(-\eta_h)\right)/\sqrt{s}.$$

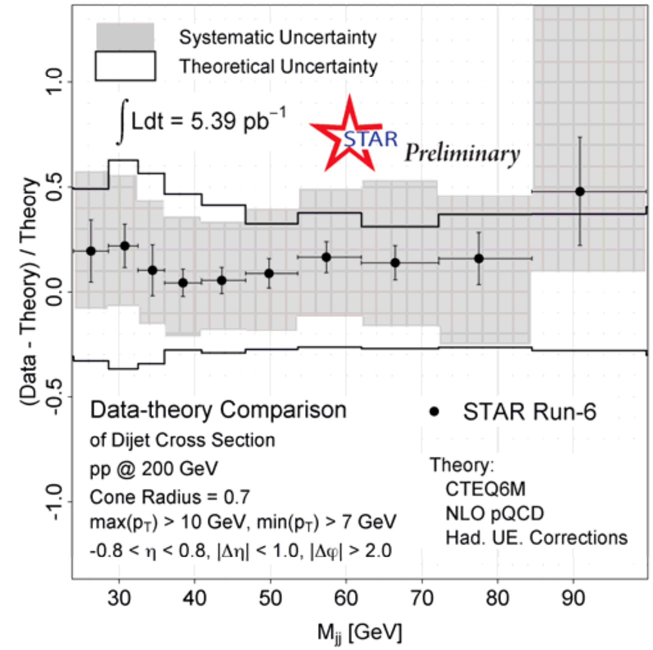




- NLO calculations show strong correlation between the real x and z values and LO estimates

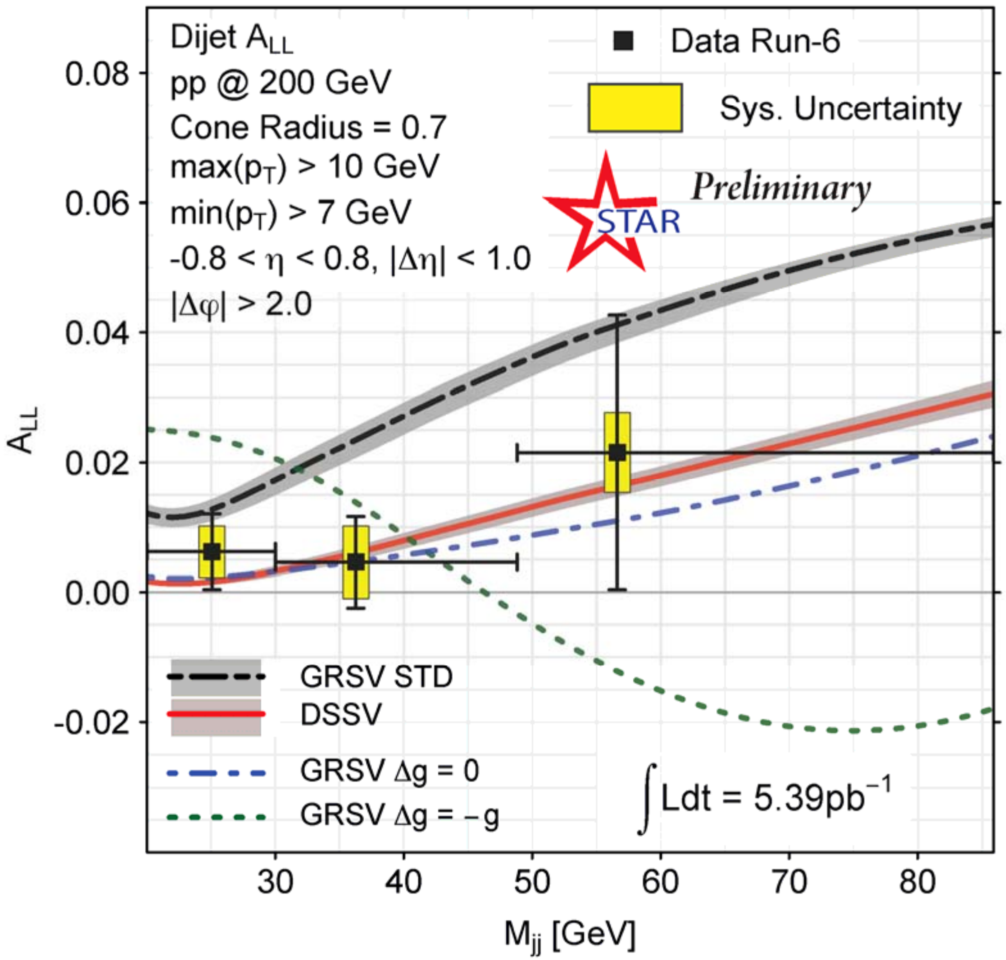
2006 dijet cross section





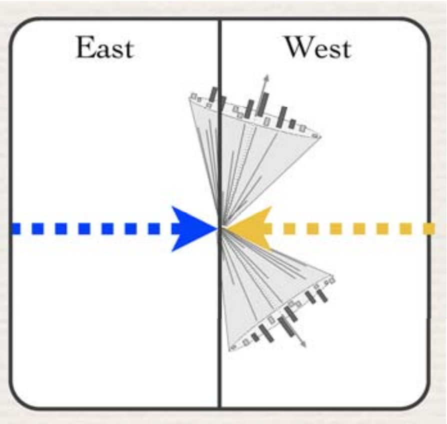
- NLO theory predictions using CTEQ6M provided by de Florian with and without corrections for hadronization and underlying event from PYTHIA
- Statistical (lines) and systematic (rectangles) uncertainties shown
- Comparison to theory when including hadronization and underlying event effects shows good agreement within uncertainties

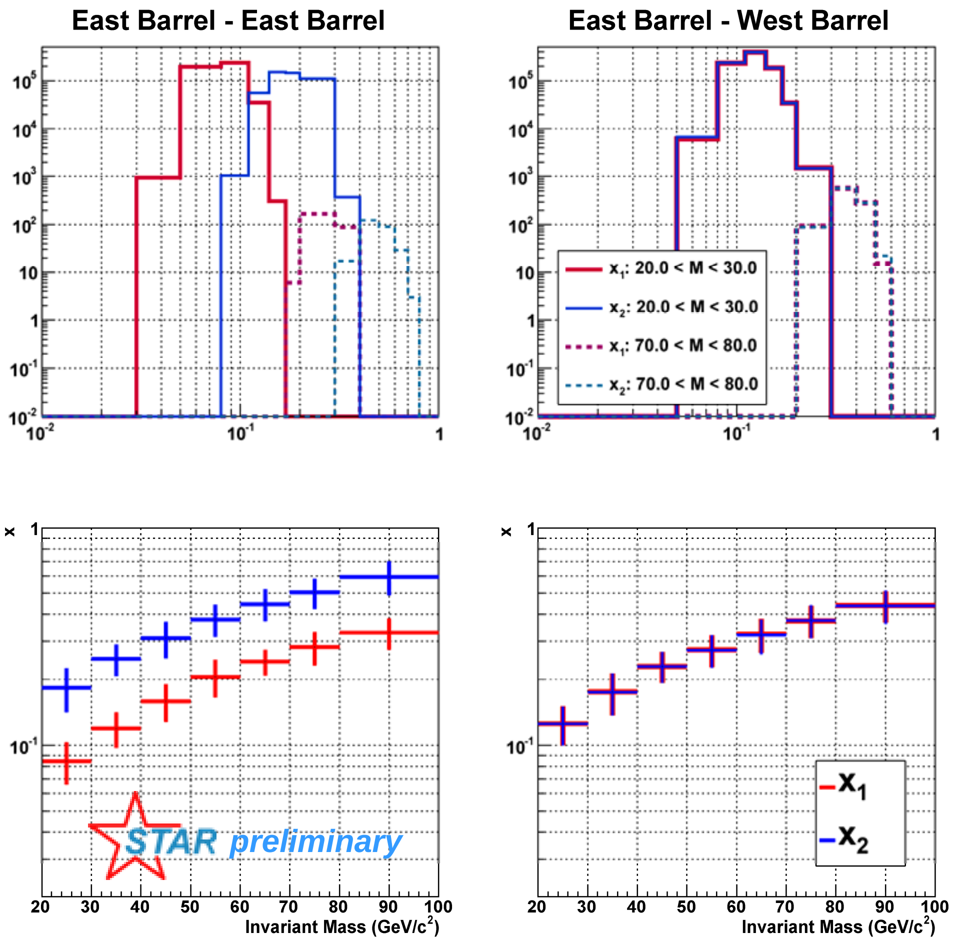
2006 dijet A_{LL}

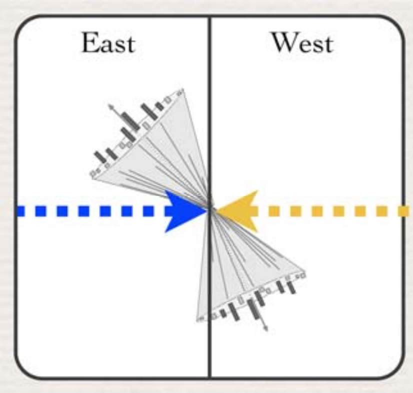


- Systematic uncertainties show effects on trigger of different theory scenarios
- ±8.3% scale uncertainty from beam polarization not shown

2009 dijet kinematic coverage

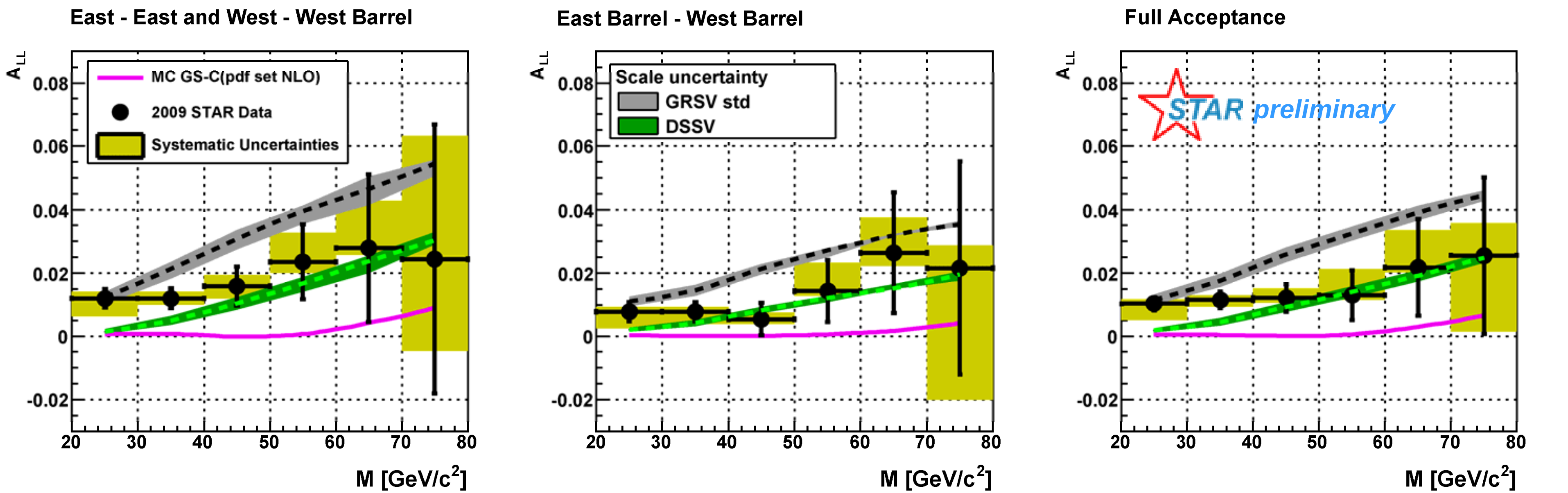


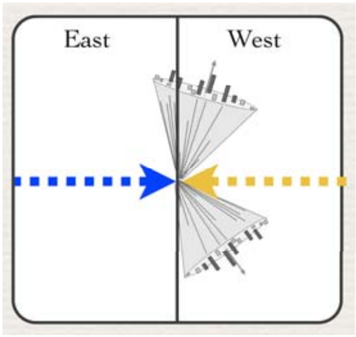


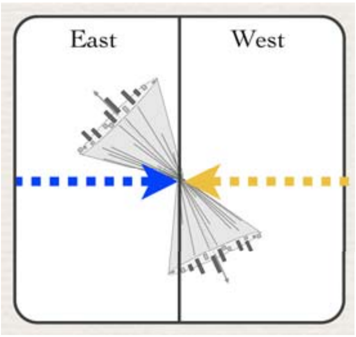


- Sufficient statistics to separate dijets into two kinematic regions
- East-East and West-West dijets sample asymmetric parton collisions ⇒ small x_{gluon} and large x_{quark}
- East-West dijets sample symmetric parton collisions ⇒ $x_{gluon} \approx x_{quark}$

2009 dijet A_{LL}





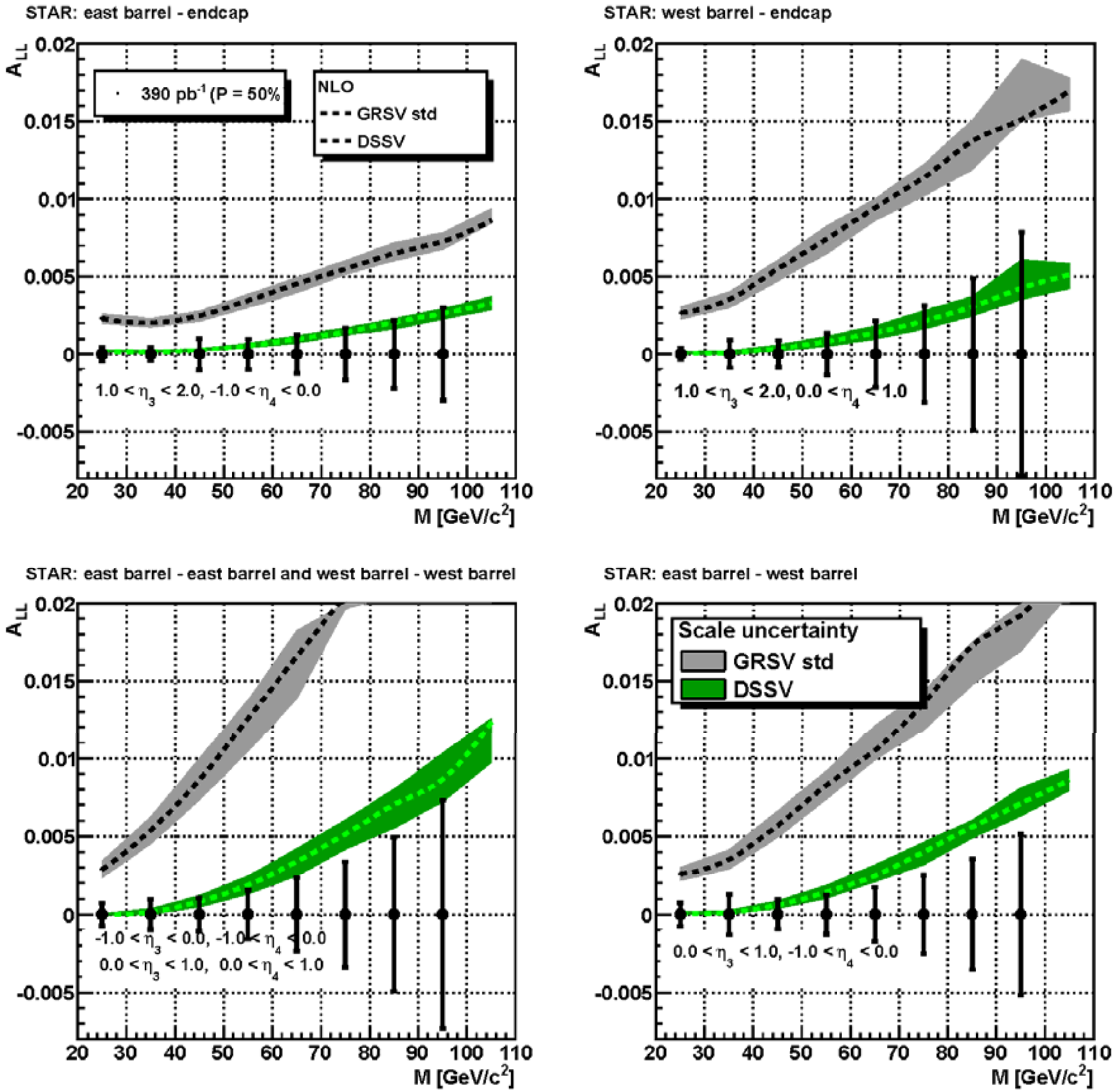


- 2009 STAR data are up to a factor of 3 more precise than 2006
- STAR data fall between predictions of **DSSV** and **GRSV-STD**

Projected sensitivity for dijets at 500 GeV

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

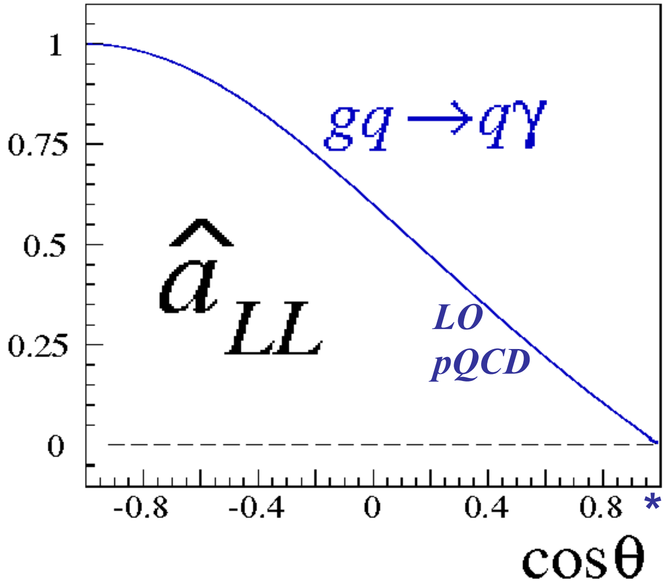
Assumes 600 pb^{-1} delivered @ P = 50%

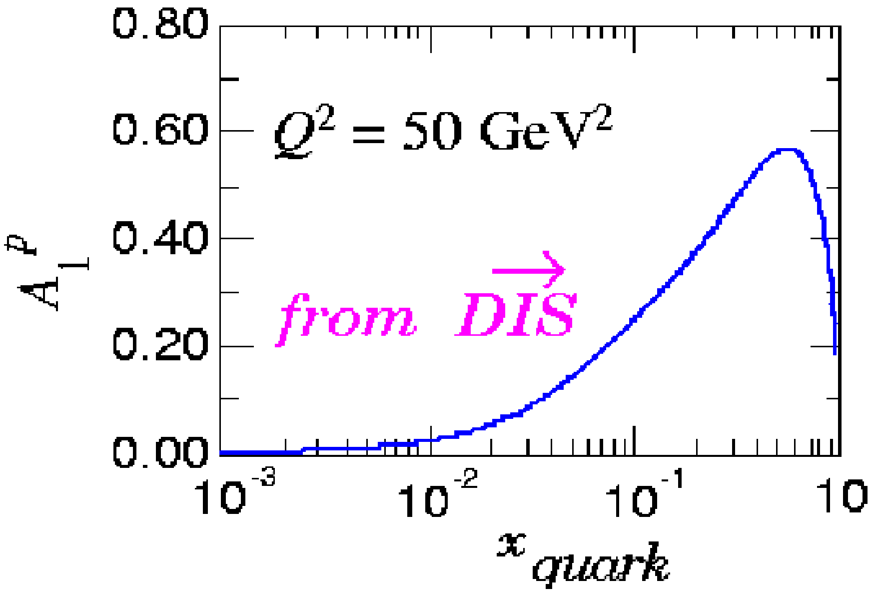


- Higher energy accesses lower x_g
- Expect smaller A_{LL}
- Projections include information on trigger rates, etc., from 2009
- Uncertainties shown are purely statistical
- Maybe add EEMC-EEMC dijets to reach lowest x values once FGT is installed (?)

Gamma+jet: a long-term *STAR* goal

See M. Betancourt APS talk, Monday, May 2, 2011, Q10.00002 10:57AM-11:09AM

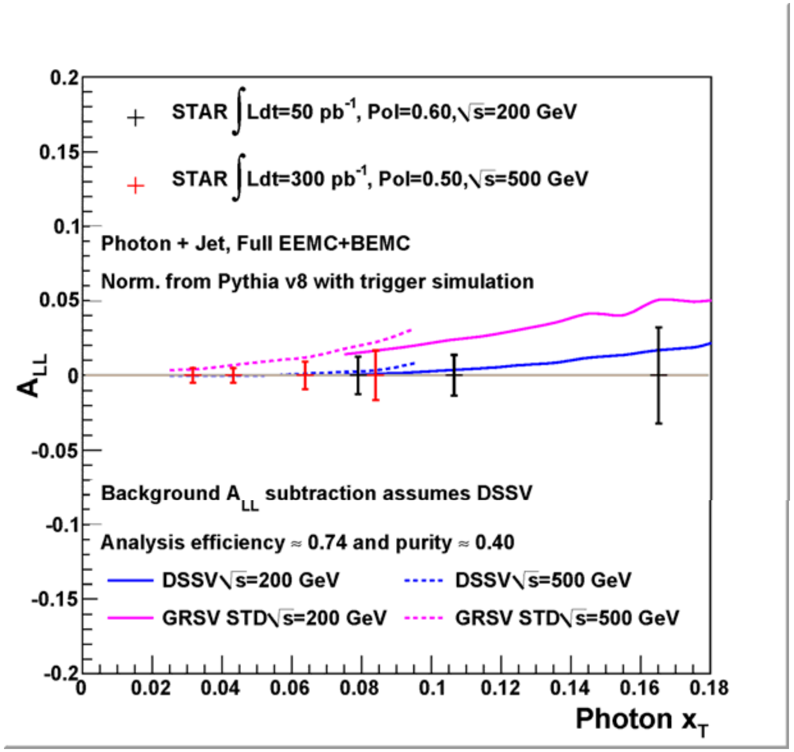


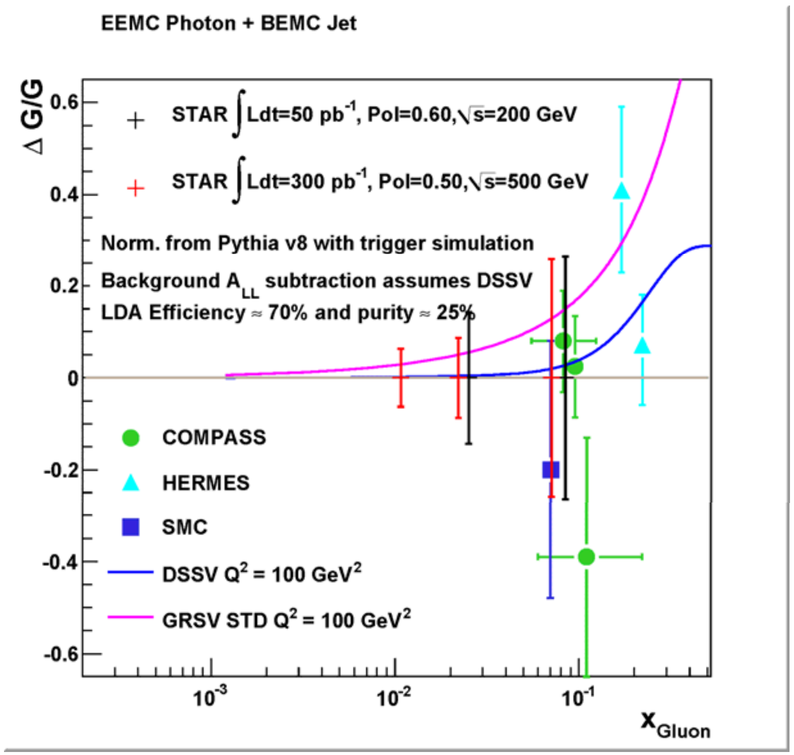


- 90% of gamma+jet yield from quark-gluon Compton scattering
- Provides the best resolution of the partonic kinematics
- Forward photons + mid-rapidity jets provide clean access to $\Delta g(x)$ via scattering off highly polarized valence quarks

- Signal yield is very small compared to dijet backgrounds
- Background suppression is **VERY CHALLENGING**

Gluon polarization with gamma+jet

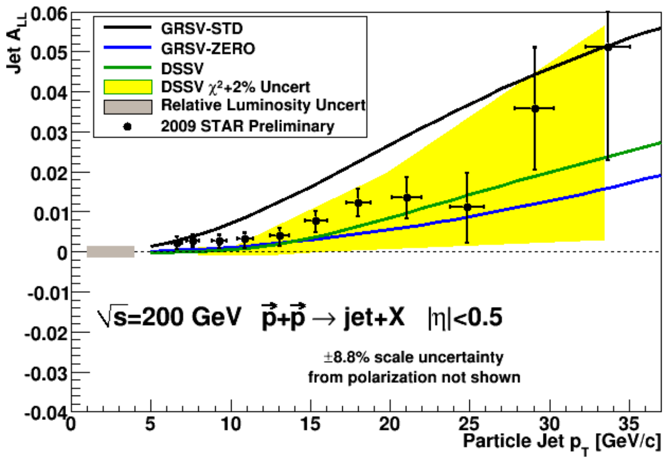


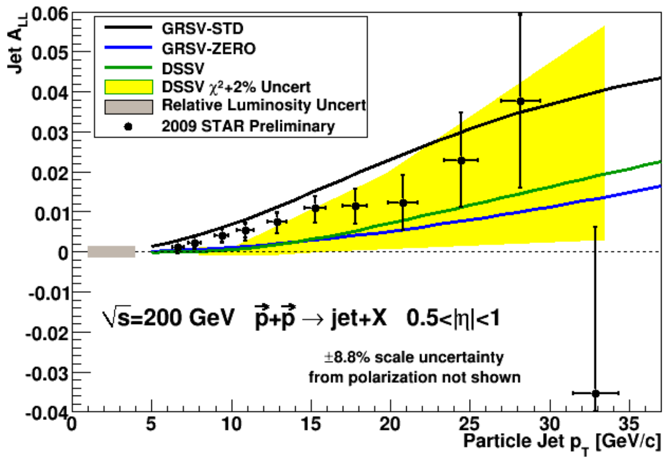


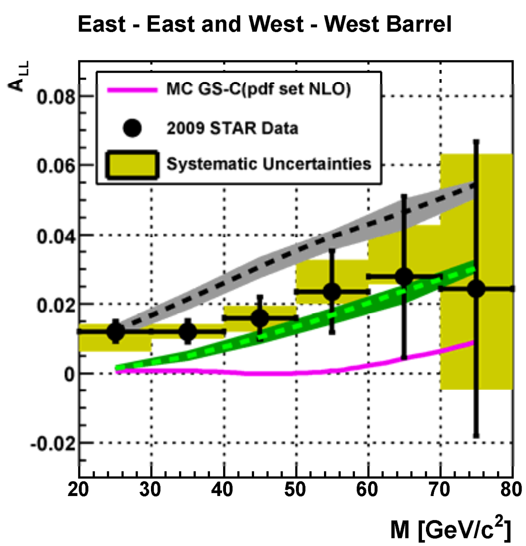
- Sensitivity estimates including realistic photon efficiencies and purities, benchmarked with real data
  - Maybe higher purity with future isolation cuts using FGT

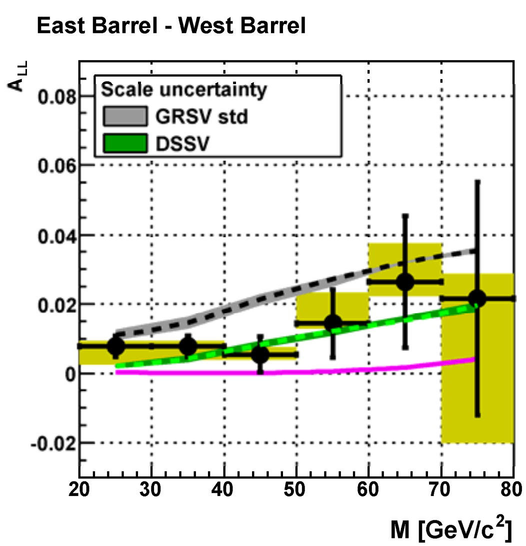
Conclusions

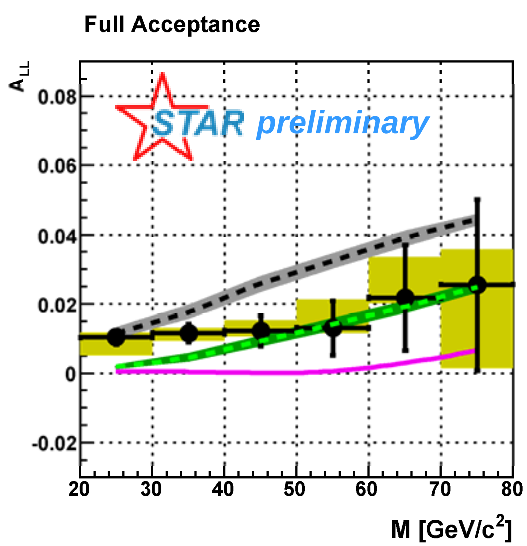
- STAR 2006 data play significant role in recent global analysis
- STAR 2009 results will have strong impact on determination of gluon polarization ⇒ ***stay tuned!***





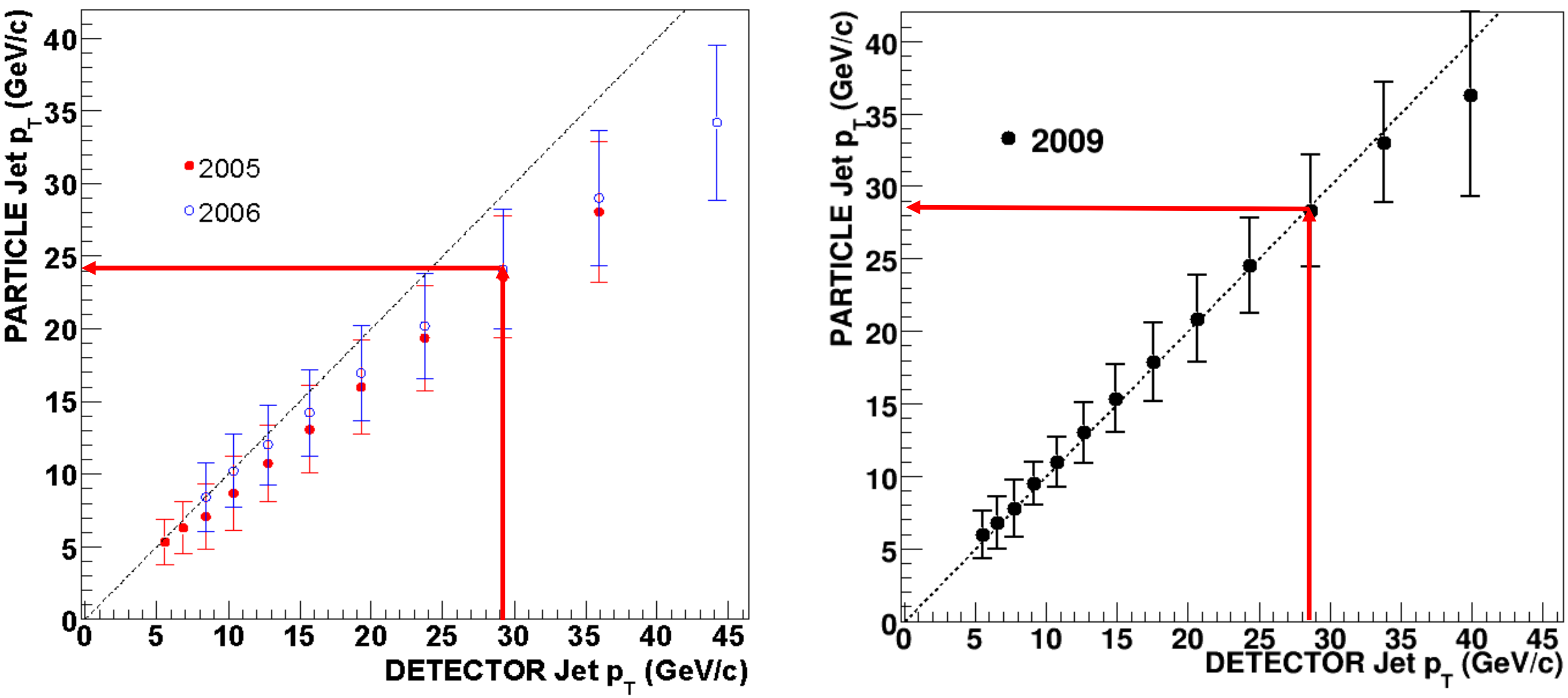






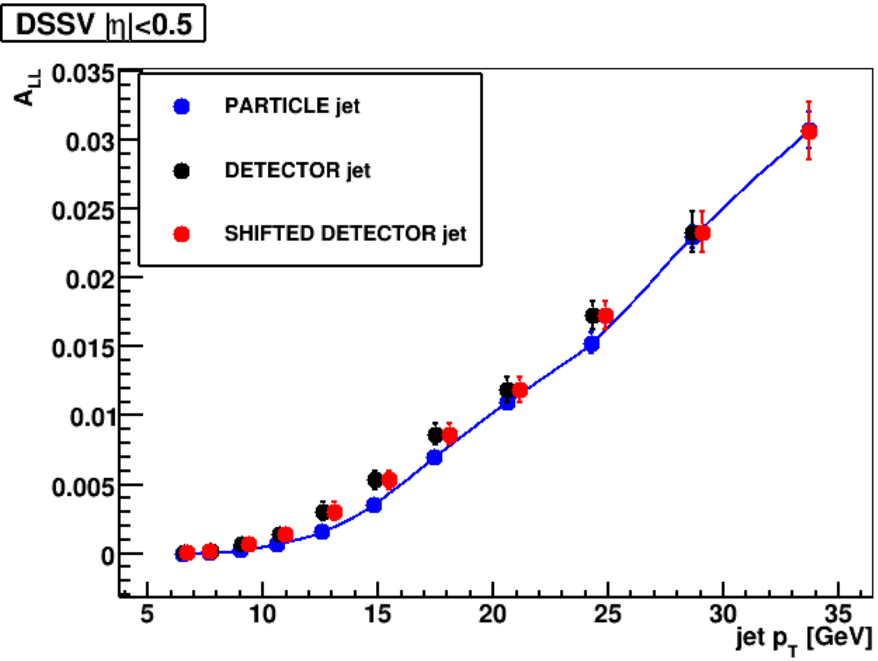
BACKUP SLIDES

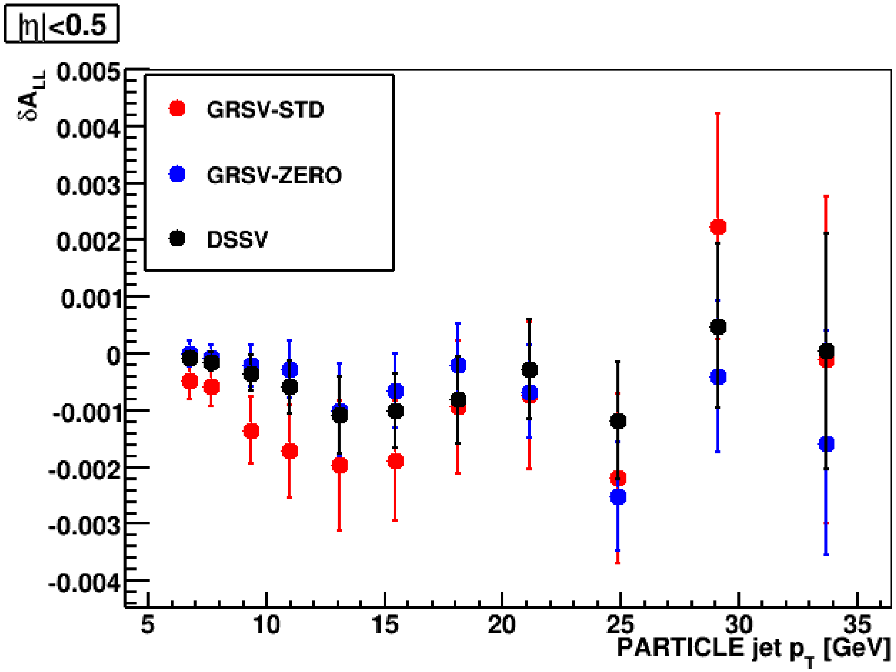
From detector to particle jets



- 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

Trigger and reconstruction bias

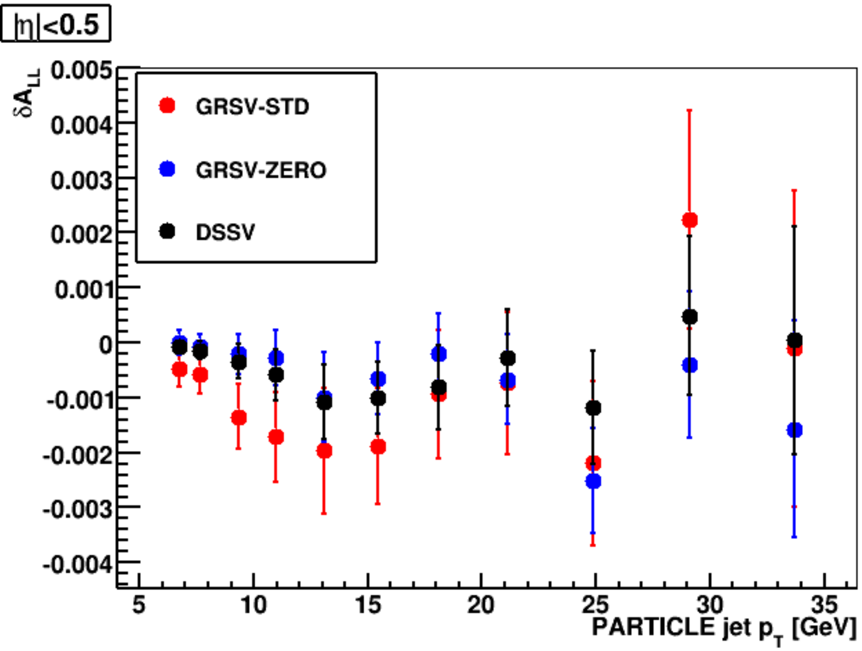




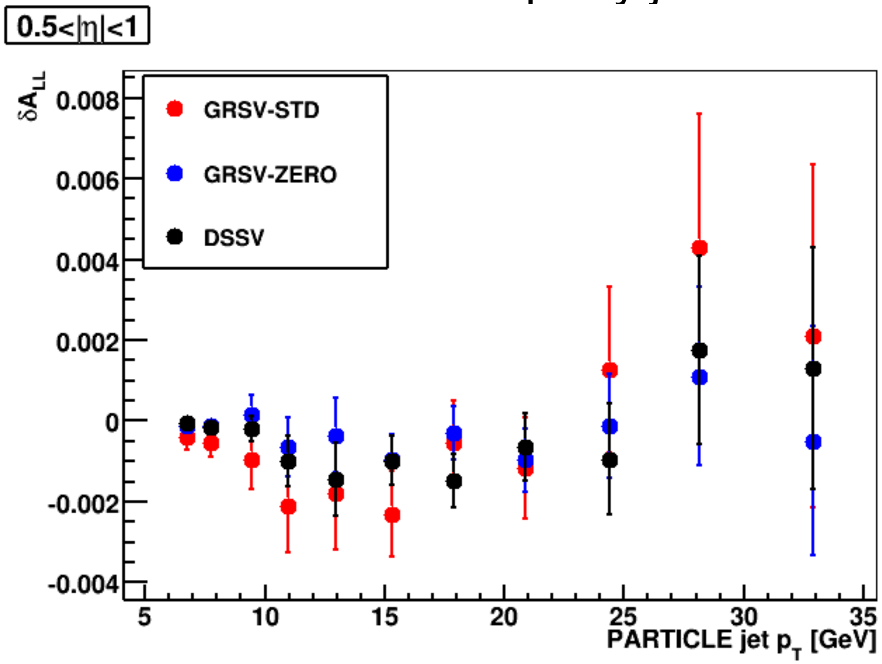
1. Calculate PYTHIA A_{LL} at PARTICLE jet p_T
2. Calculate GEANT A_{LL} at DETECTOR jet p_T
3. Move GEANT A_{LL} from DETECTOR jet p_T to appropriate PARTICLE jet p_T
4. Calculate δA_{LL}=(PYTHIA-GEANT) A_{LL} $\Rightarrow$ trigger and reconstruction bias

Trigger and reconstruction bias

Midrapidity jets

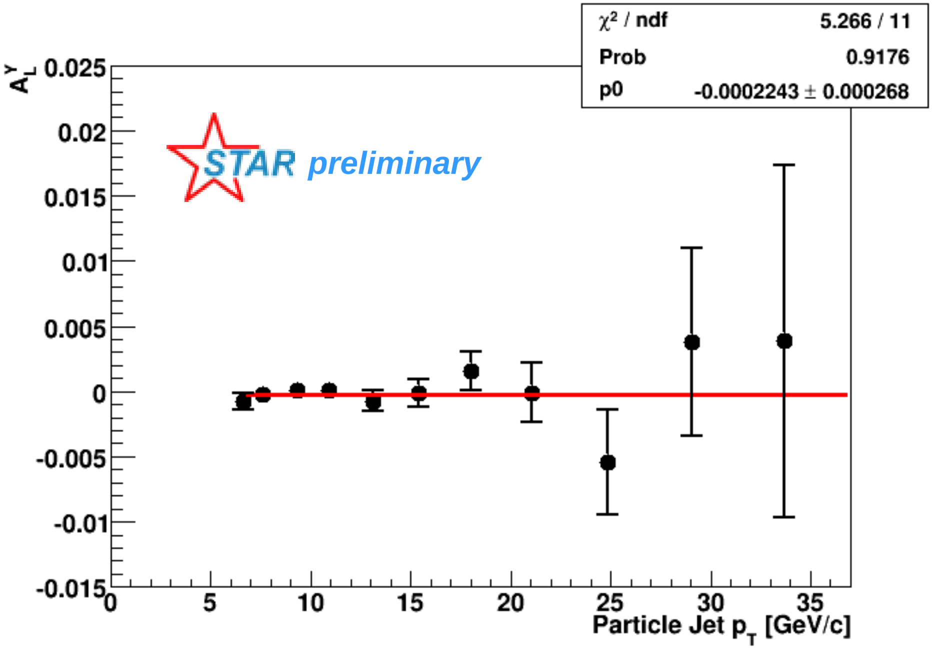


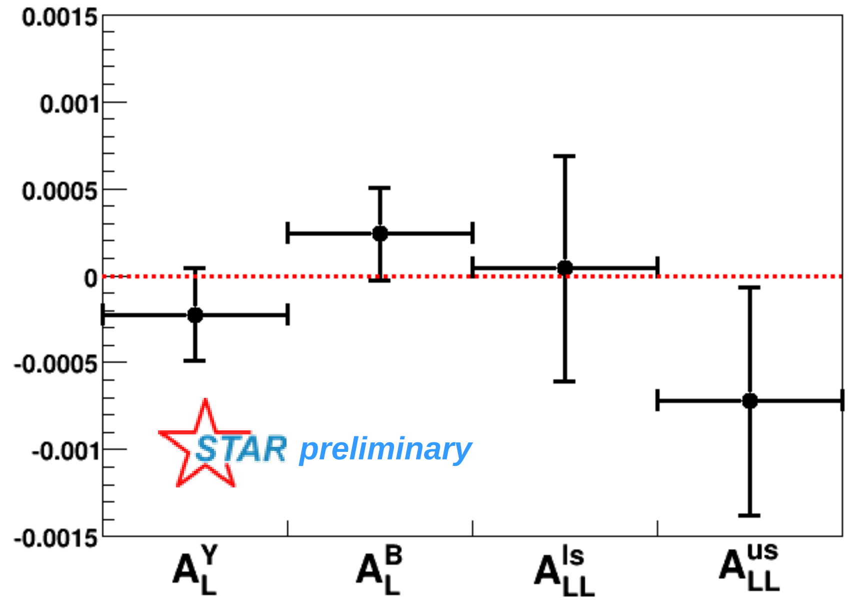
Forward rapidity jets



Uncertainty on A_{LL} is larger of maximum/minimum δA_{LL} for 3 models (GRSV-STD, GRSV-ZERO, DSSV) and positive/negative statistical error bar

Relative luminosities





- Relative luminosities are calculated using the beam-beam counters (BBC)
- Relative luminosity systematic from comparisons of BBC and zero-degree calorimeter (ZDC) rates
- Preliminary estimated systematic for A_{LL} (±0.0015) very conservative
- False asymmetries from jet data are consistent with zero

2009 dijet A_{LL}

$$A_{LL,j} = \frac{\sum_k \alpha_{jk} \left(\sum_i P_{B,i} P_{Y,i} (N_{5,i,k} + N_{10,i,k}) - P_{B,i} P_{Y,i} R_i (N_{6,i,k} + N_{9,i,k}) \right)}{\sum_k \alpha_{jk} \left(\sum_i P_{B,i}^2 P_{Y,i}^2 (N_{5,i,k} + N_{10,i,k}) + P_{B,i,j}^2 P_{Y,i,j}^2 R_i (N_{6,i,k} + N_{9,i,k}) \right)}$$

- The value of A_{LL} in a bin j is given by the above formula
  - α_{jk} are the matrix elements for the unfolding
- Changing the jet energy scale results in different unfolding matrices
- The calculation is repeated for the different matrices to get the uncertainty on A_{LL} due to the jet energy scale