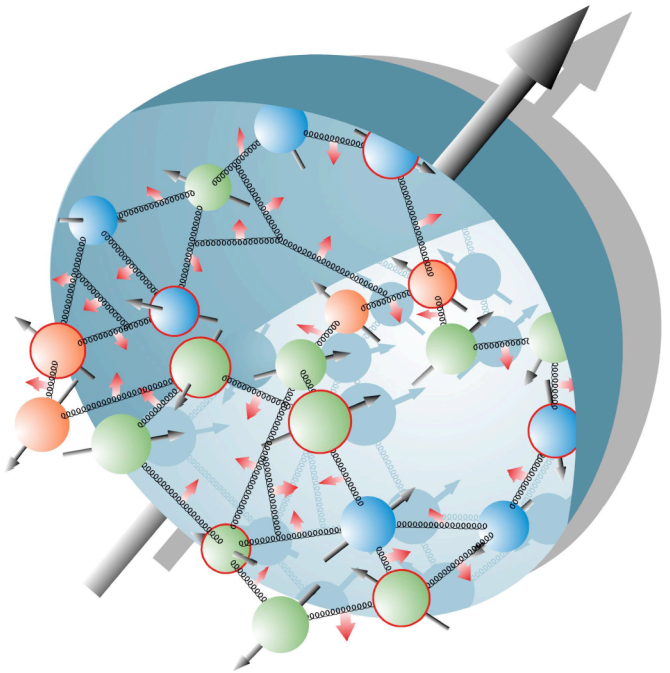
Measurements of Polarized Glue at STAR

David Staszak for the STAR Collaboration
UCLA

RHIC & AGS Users Meeting
BNL, June 1-5, 2009

The Proton Spin Structure

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \langle L_{q,g} \rangle$$



- From polarized-DIS measurements we know the quark contribution is small (*0.003 < x < 0.8*):

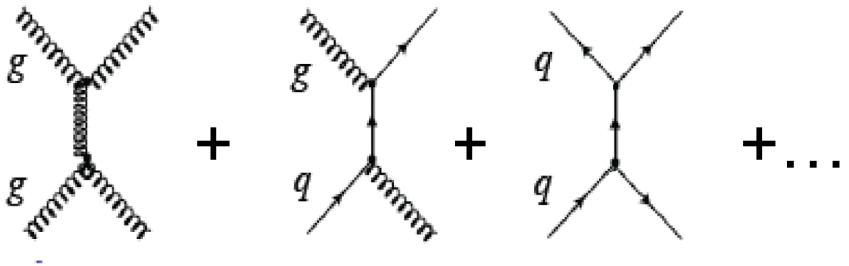
$$\Delta\Sigma \approx 20\text{-}30\%$$

- Gluon polarized distributions are not well constrained

- Access to ΔG through A_{LL} asymmetries at RHIC

$$A_{LL} = \frac{\Delta\sigma}{\sigma} \propto \frac{\Delta f_1 \otimes \Delta f_2 \otimes d\sigma^{f_1 f_2 \to fX} \cdot a_{LL}^{f_1 f_2 \to fX} \otimes D_f^h}{f_1 \otimes f_2 \otimes d\sigma^{f_1 f_2 \to fX} \otimes D_f^h}$$

Several contributing sub-processes:
→ including gluons at 1st order!



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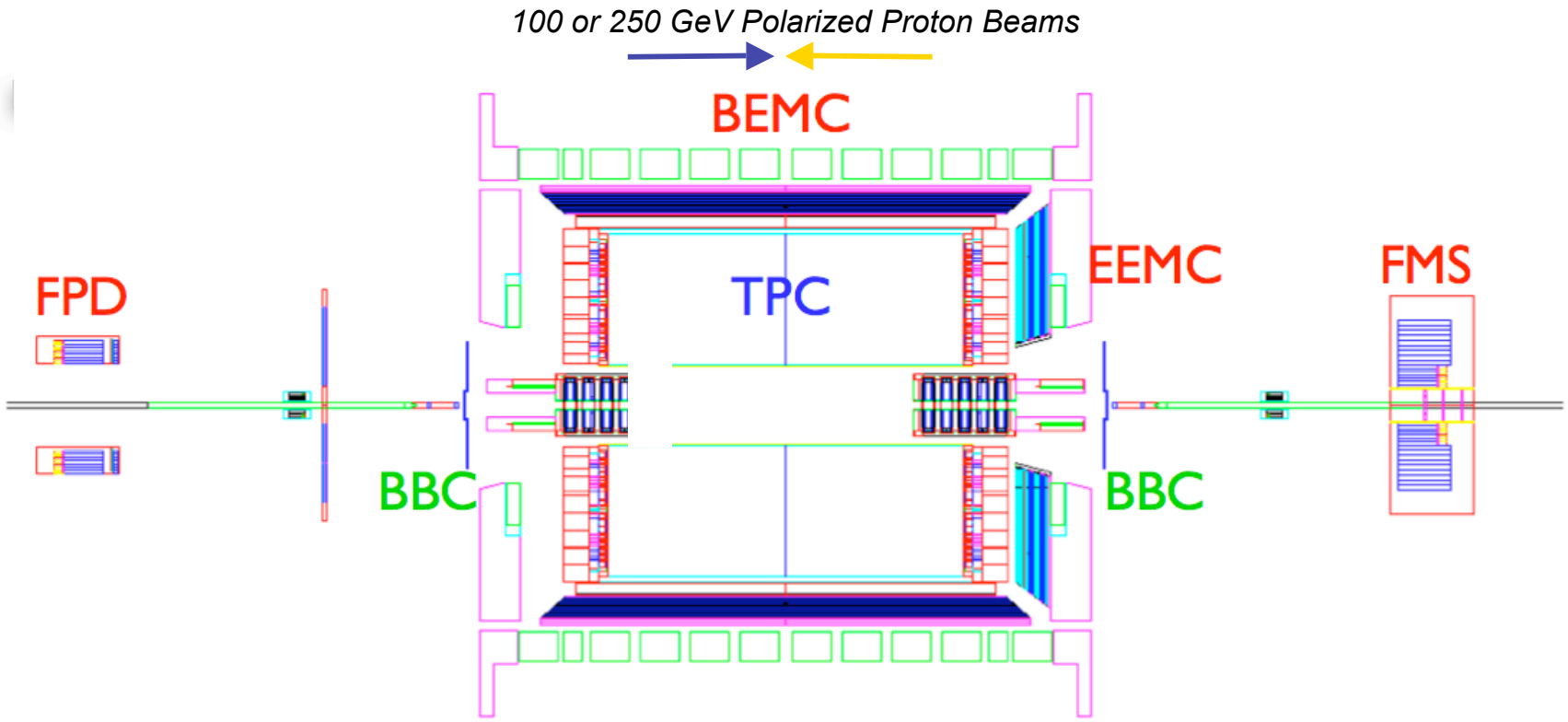
STAR Detector



Beam-Beam Counter:

- MinBias Trigger
- Relative Luminosities
- $3.4<|\eta|<5$

Calorimetry:

- Particle Neutral Energy
- Barrel EM $0<\eta<1$ (2003-2005)
  $-1<\eta<1$ (2006)
- Endcap EM $1.09<\eta<2.0$
- Forward Pion Detector $-4.1<\eta<-3.3$
- Forward Meson Spec. $2.5<\eta<4.0$

Time Projection Chamber:

- Charged Tracks P_T
- $-1.4<\eta<1.4$

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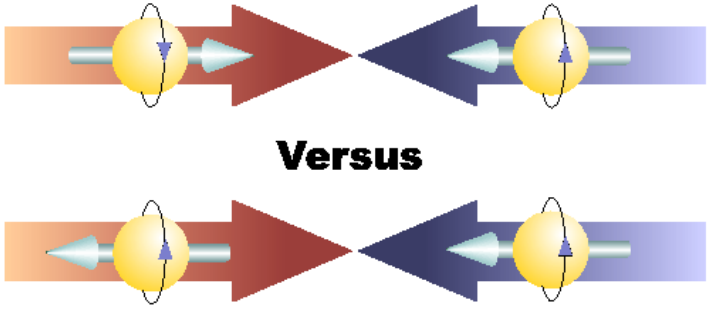
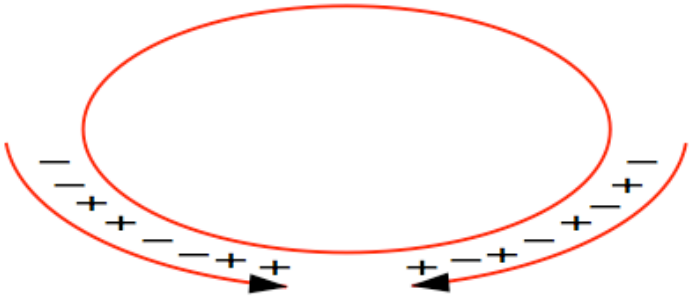
Experimentally Measuring A_{LL}

$$A_{LL} = \frac{1}{P_1 P_2} \frac{(N^{++} + N^{--}) - R(N^{+-} + N^{-+})}{(N^{++} + N^{--}) + R(N^{+-} + N^{-+})} \qquad R = \frac{L^{++} + L^{--}}{L^{+-} + L^{-+}}$$





Concurrent Measurements:

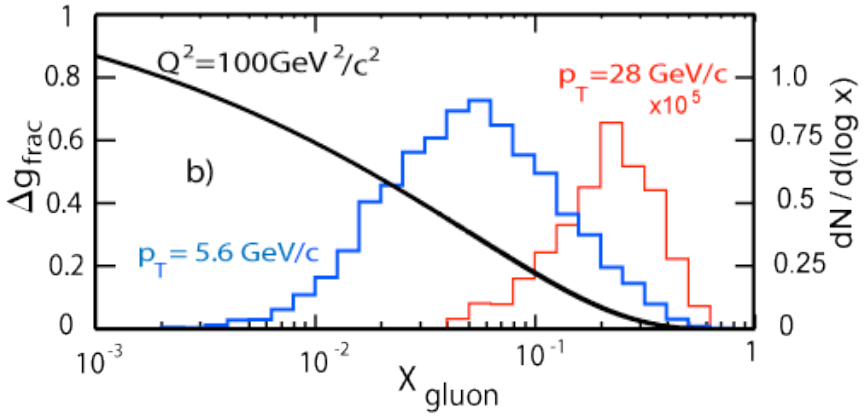
- Numbers of Observables N^{ij} Reconstructed for Different Bunch Patterns
- Relative Luminosity R from BBC Coincidence Rates for different Bunch Patterns
- Polarization of Beams (magnitude from CNI Polarimeters, direction of polarization vector from combination CNI Polarimeters, BBC)

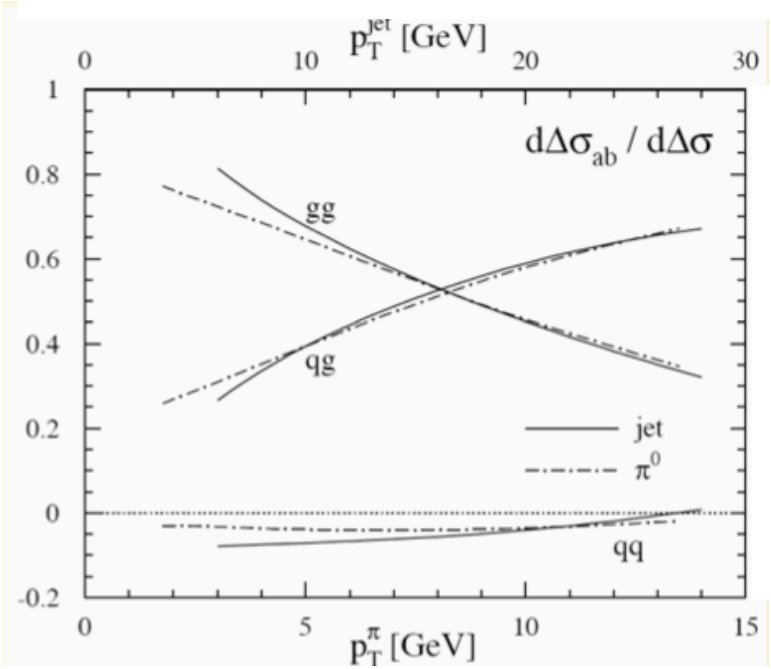
Inclusive Measurements at STAR

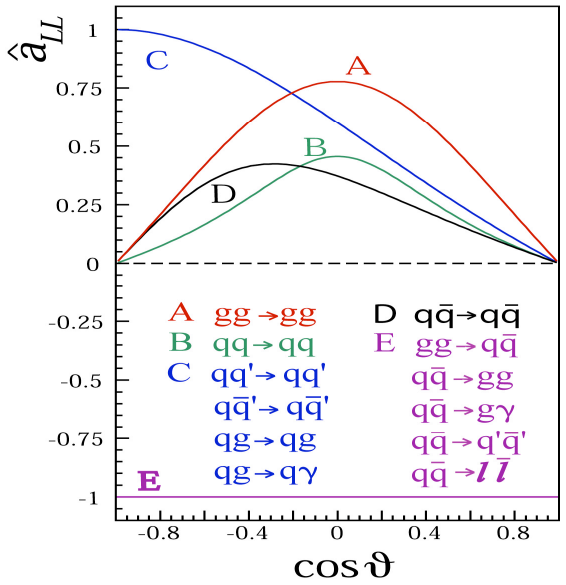
- Inclusive jets, hadrons (π^0, $\pi^{+/-}$) probe a range of partonic x values and subprocesses for a given p_T bin

- Inclusive signals have a larger cross section than correlated or exclusive signals → good first look

- STAR is well positioned (energy, kinematics) for jet and hadron asymmetry measurements







Complementary Measurements

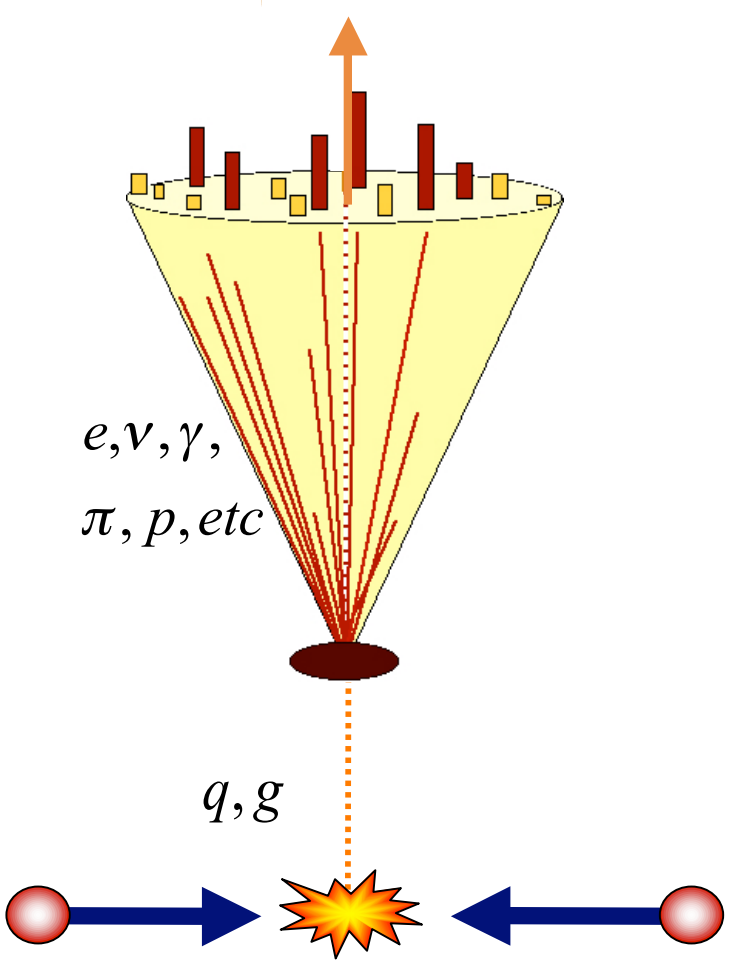
Jets:
- Independent of FFs
- Large Energy Scale Uncertainty
- Limited pT resolution
- Large trigger bias

Hadrons:
- Dependence on FFs
- Better determined p_T
- π^0 has no trigger bias

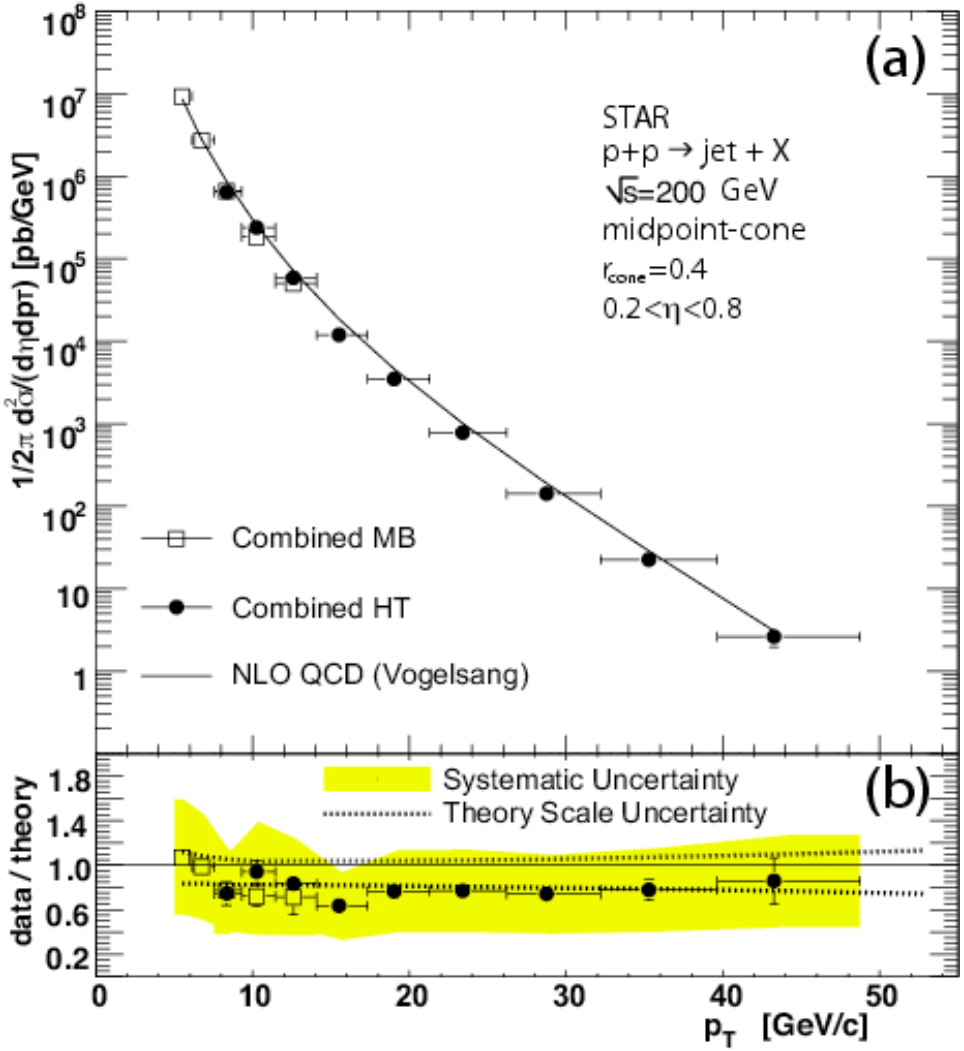
Inclusive Jet Reconstruction and Cross Section

Midpoint cone algorithm (hep-ex/0005012)

$$R_{CONE} = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$$ = 0.4 (2003-2005)
= 0.7 (2006)



PRL 97, 252001



Agrees over 7 orders of magnitude with NLO pQCD predictions

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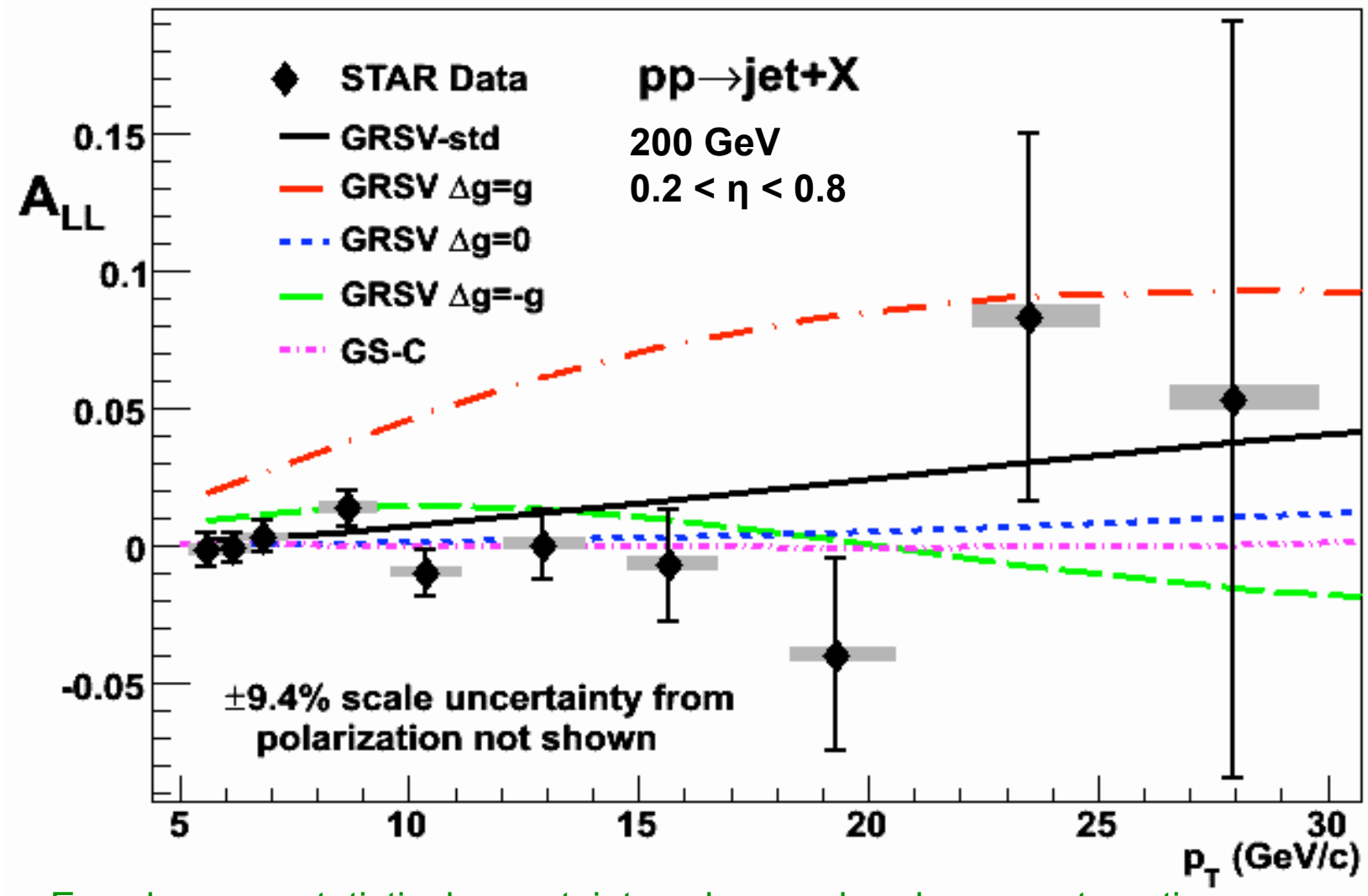
2005 Inclusive Jets A_{LL}

PRL ***100****, 232003 (2008)*



- Error bars are statistical uncertainty only, grey bands are systematic
- Data are compared to predictions within the GRSV framework with several input values of ΔG. Model calculations from:

B. Jager et. al, Phys Rev D70 034010, T Gehrmann et. al, Phys.Rev.D53 6100-6109(1996)

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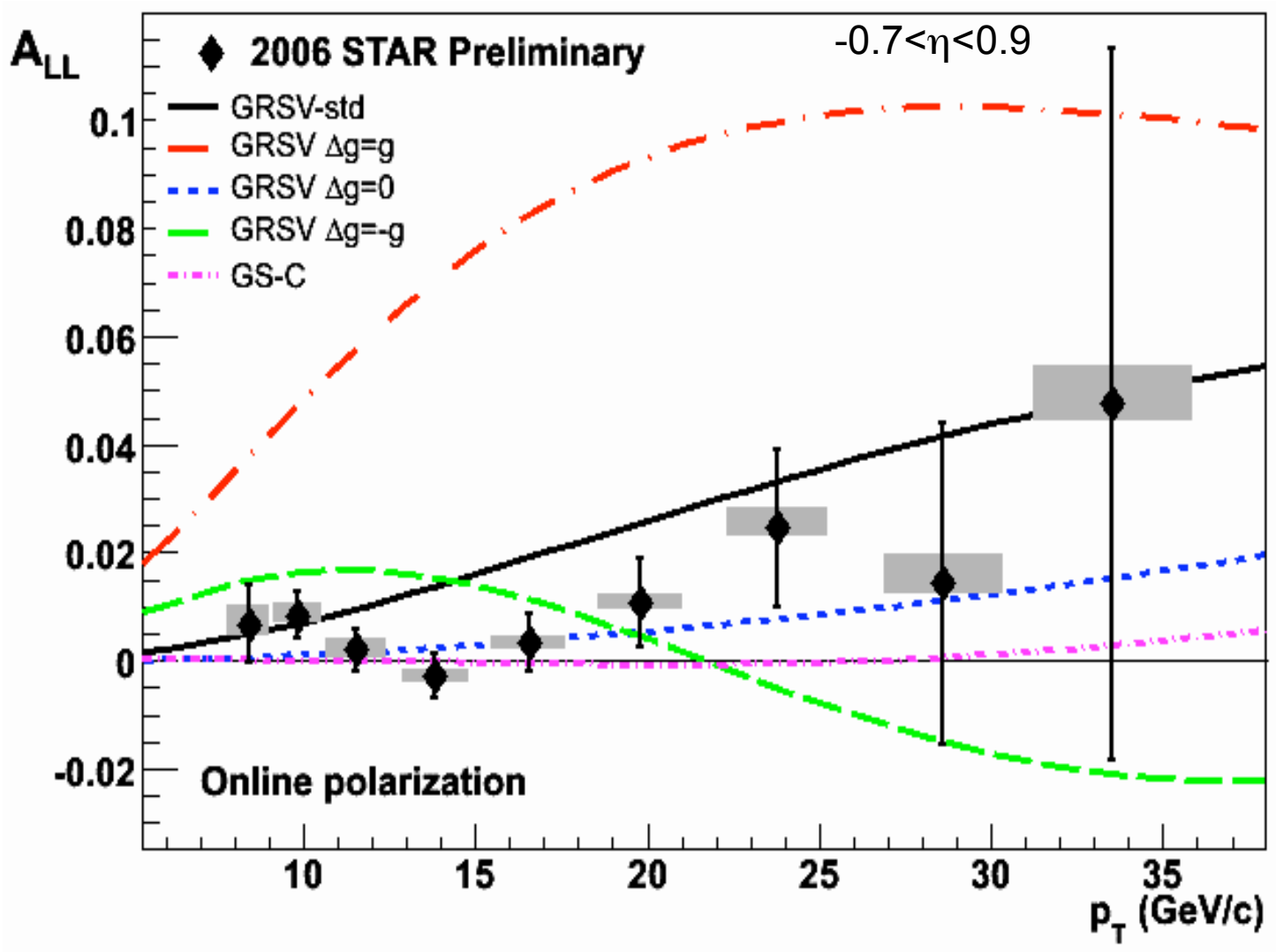
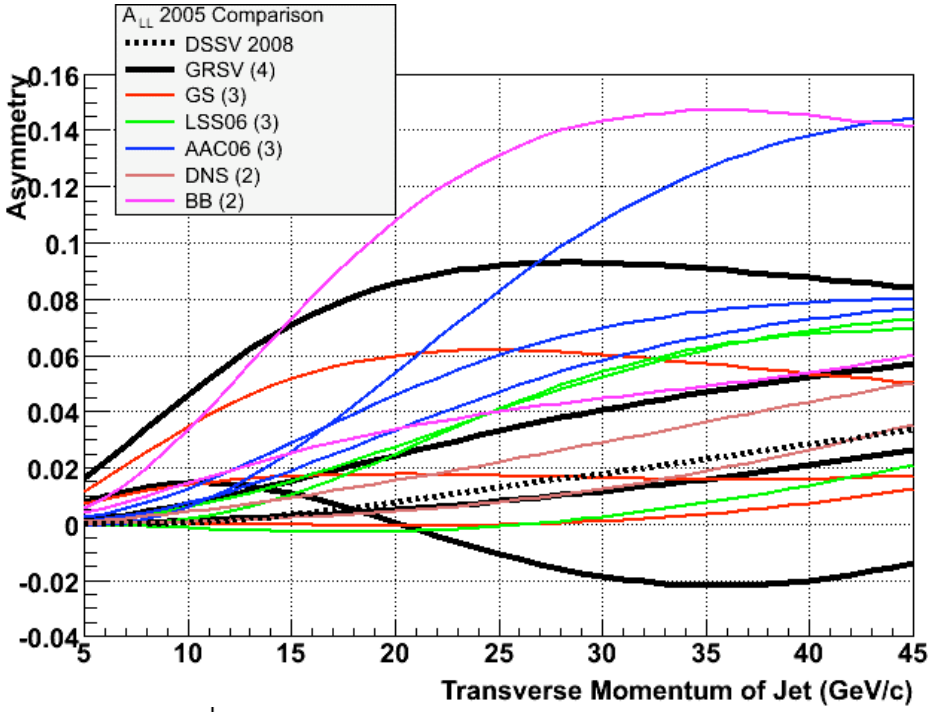
2006 Inclusive Jets A_{LL}

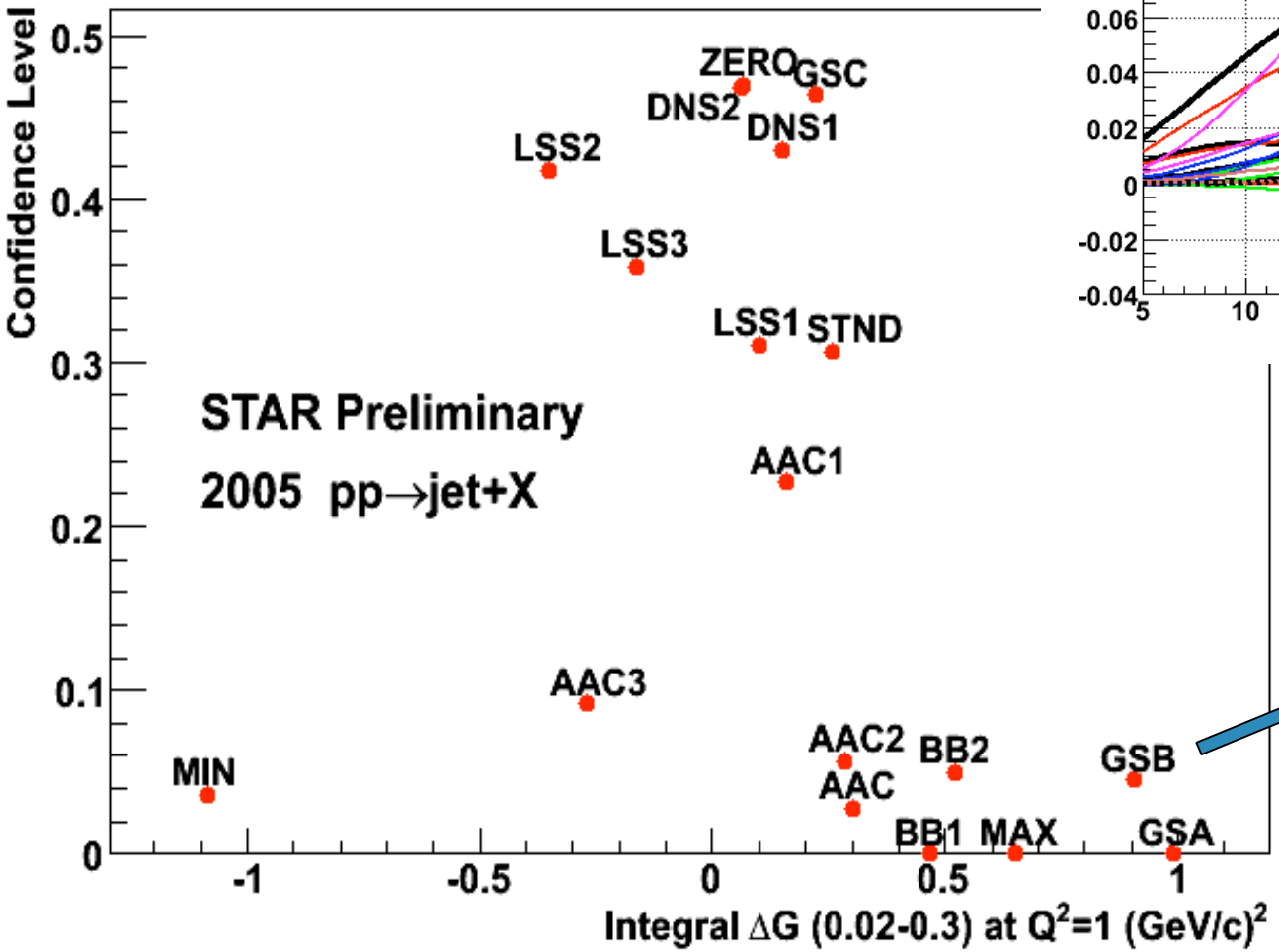


- Increased calorimeter acceptance, luminosity, and polarization over 2005
- Higher trigger thresholds to focus on higher p_T
- Factor of 3-4x improved statistical precision at higher p_T

Inclusive Jet Constraints on ΔG

Additional parameterizations of ΔG of polarized-DIS data with corresponding predictions for A_{LL} vs. p_T



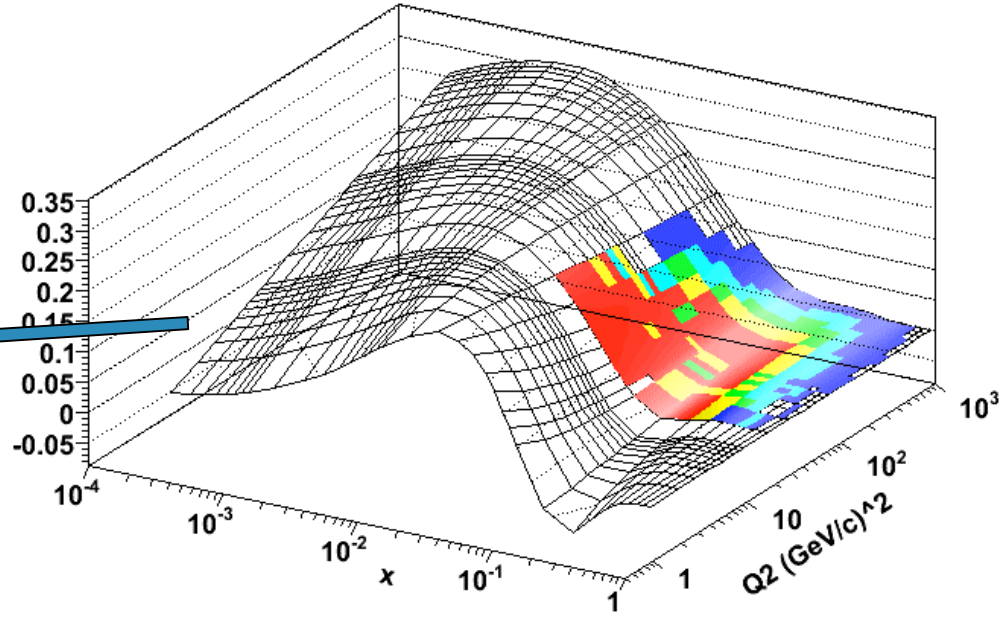


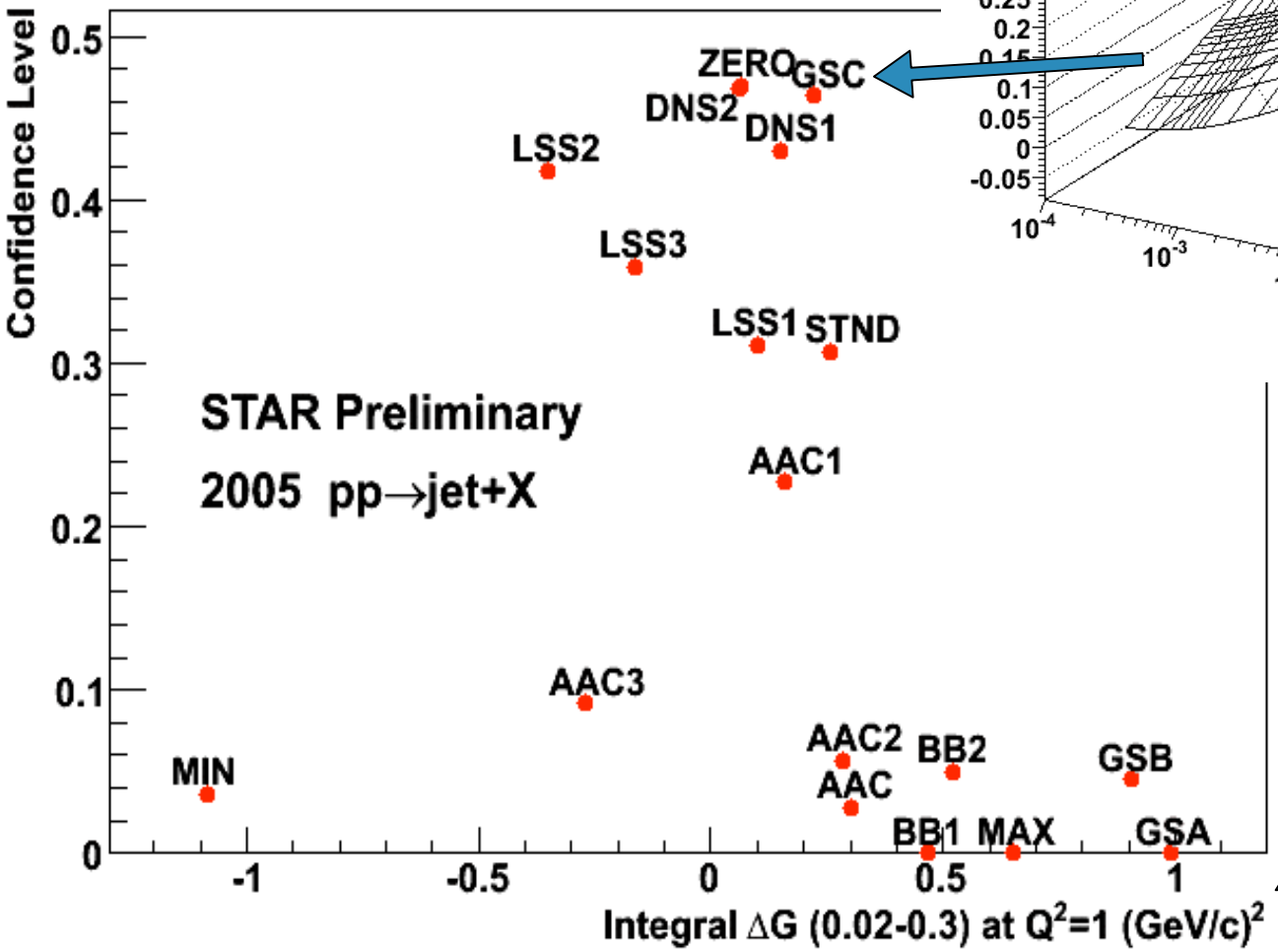
STAR data excludes a range of models with ΔG larger than GRSV-STD

Inclusive Jet Constraints on ΔG

GS-C is an example of a model which has a large integral that we are not very sensitive to in our x and Q^2 range

GS-C Polarized Gluon Structure Function

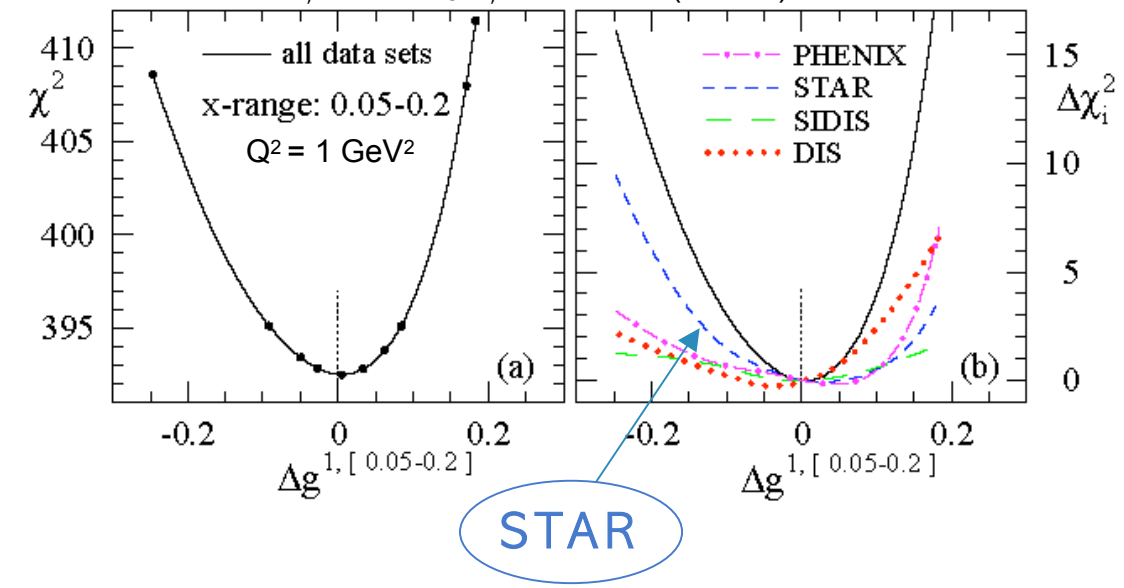


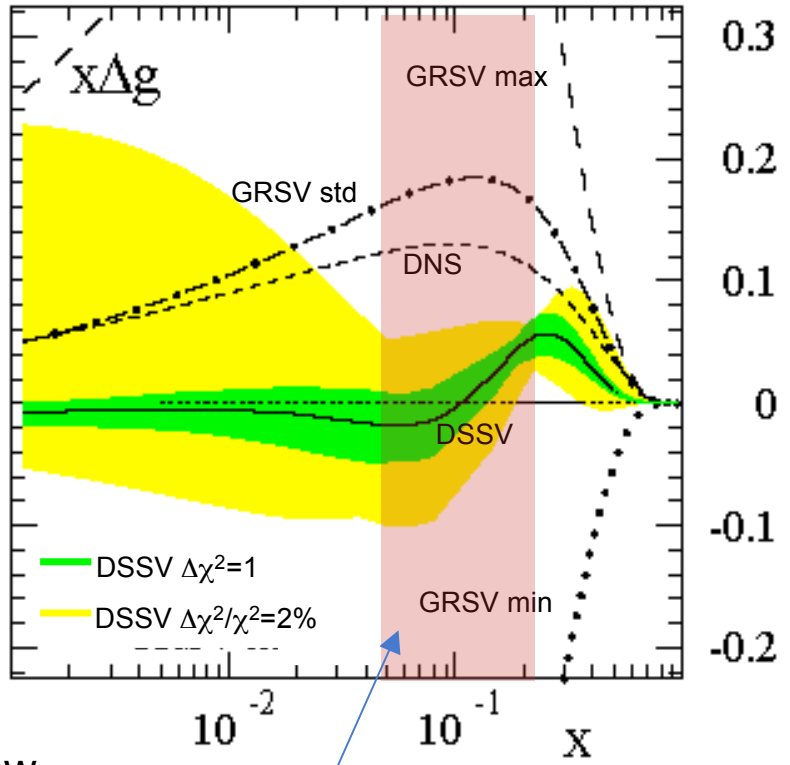


Note: ΔG values (x-axis) are plotted at partial x-integral values

Inclusive Jet Impact on DSSV Global Fit

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





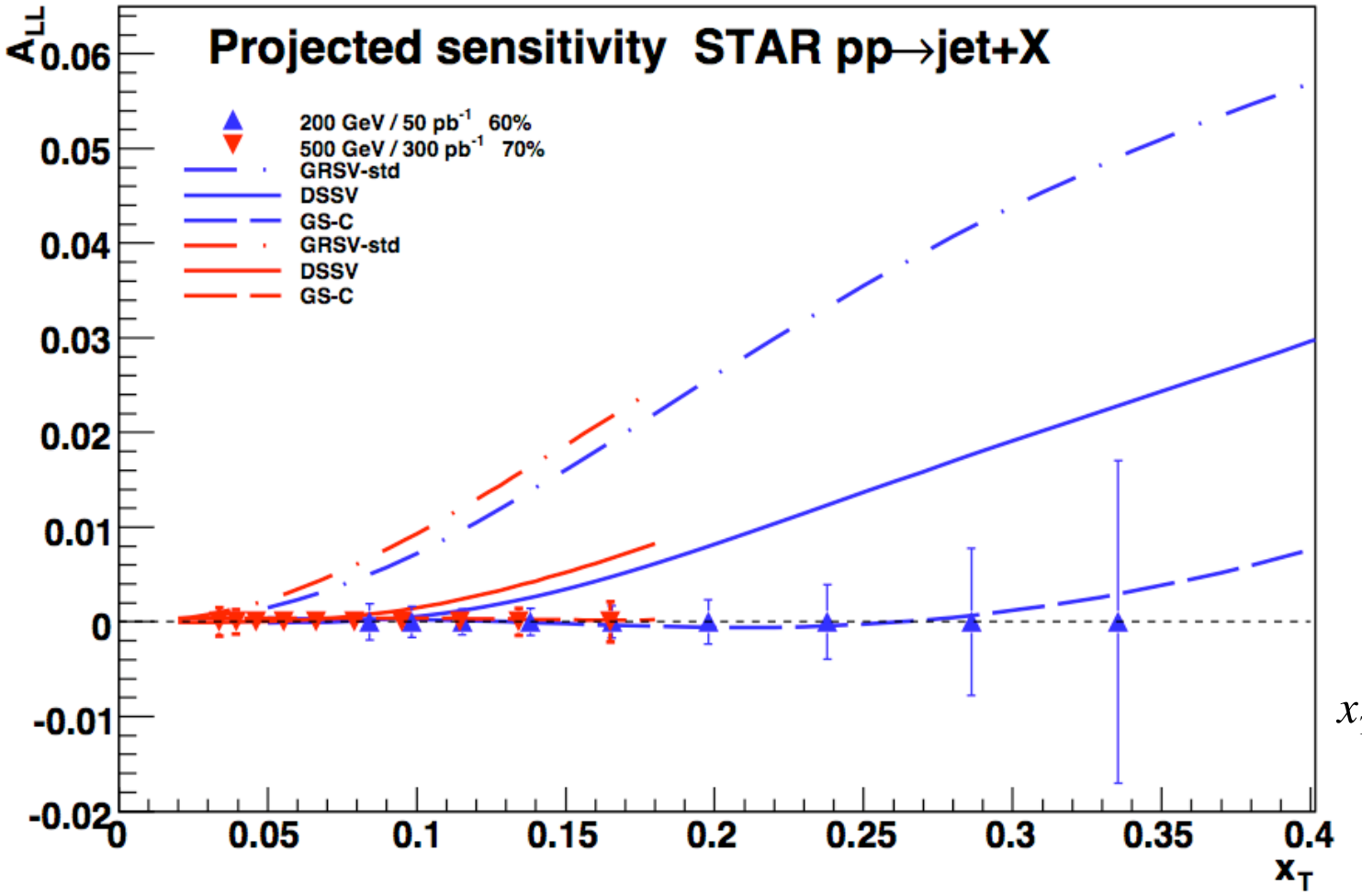
- Strong constraint on the size of Δg over RHIC/STAR kinematic coverage (0.05<x<0.2)

- Data favor a small gluon polarization in RHIC x window

- Includes only inclusive measurements which sample over a wide range in x, small A_{LL} measurements could come from cancellations → correlation measurements

- Extension of x-coverage is needed

Inclusive Jet Projected A_{LL} Sensitivities



$x_T = 2p_T/\sqrt{s}$

- Projected Run9 200 GeV (50pb^{-1}, 60%) would reduce A_{LL} uncertainties by a factor of ~4
- Projected sensitivity for 500 GeV (300pb^{-1}, 70%) shown → one way to access lower x_g

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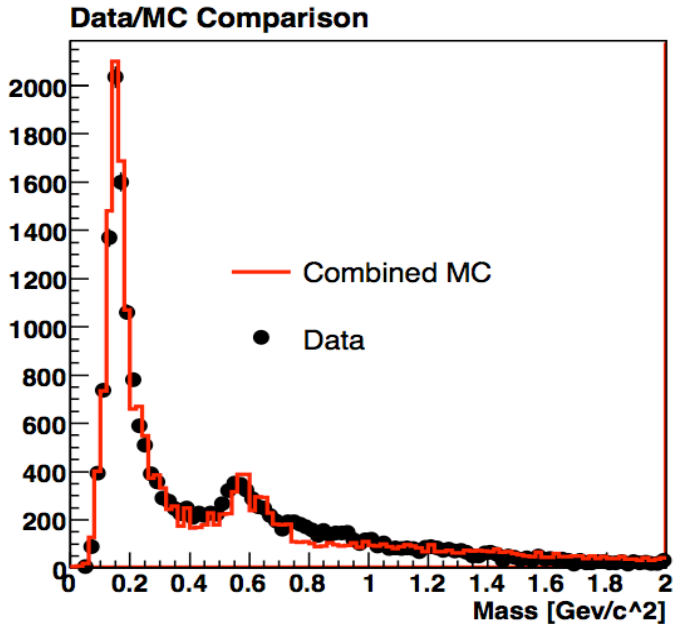
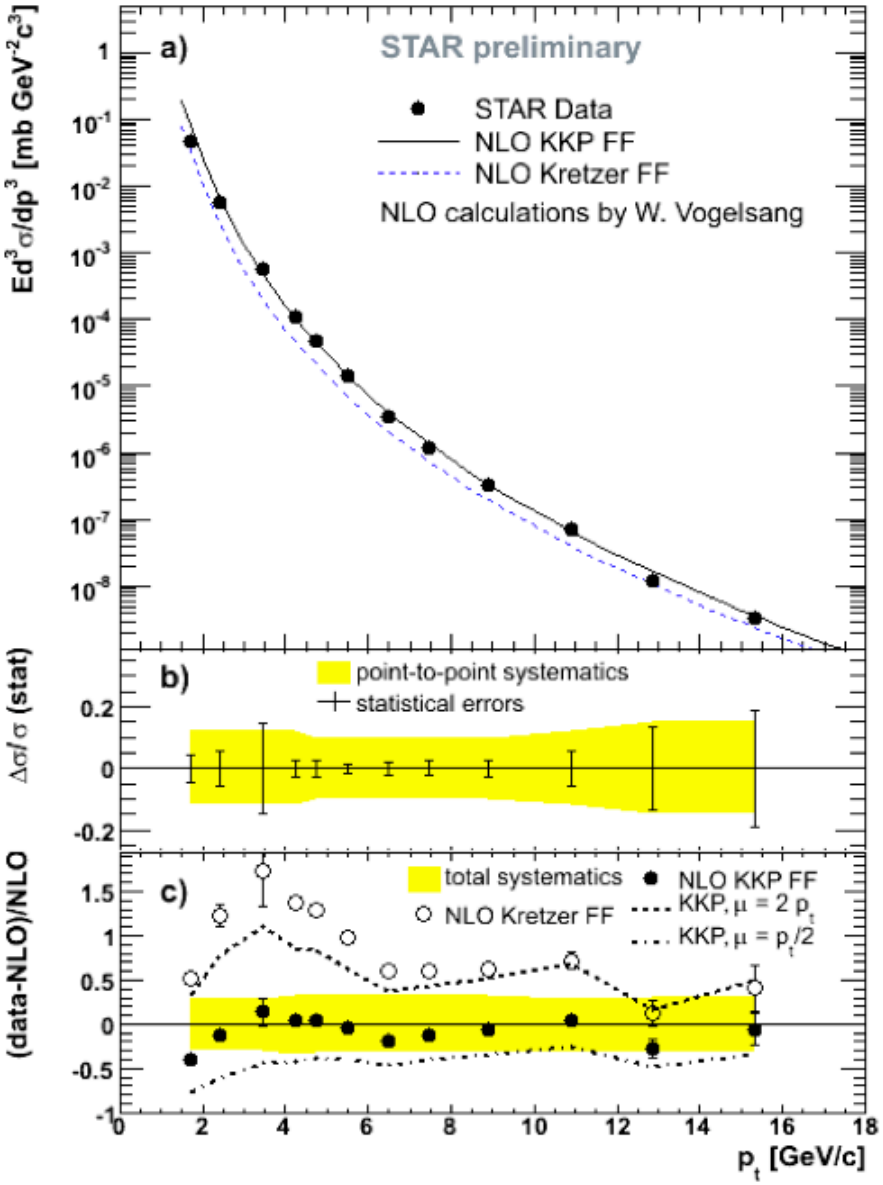
Mid-rapidity Inclusive π^0 Reconstruction and Cross Section



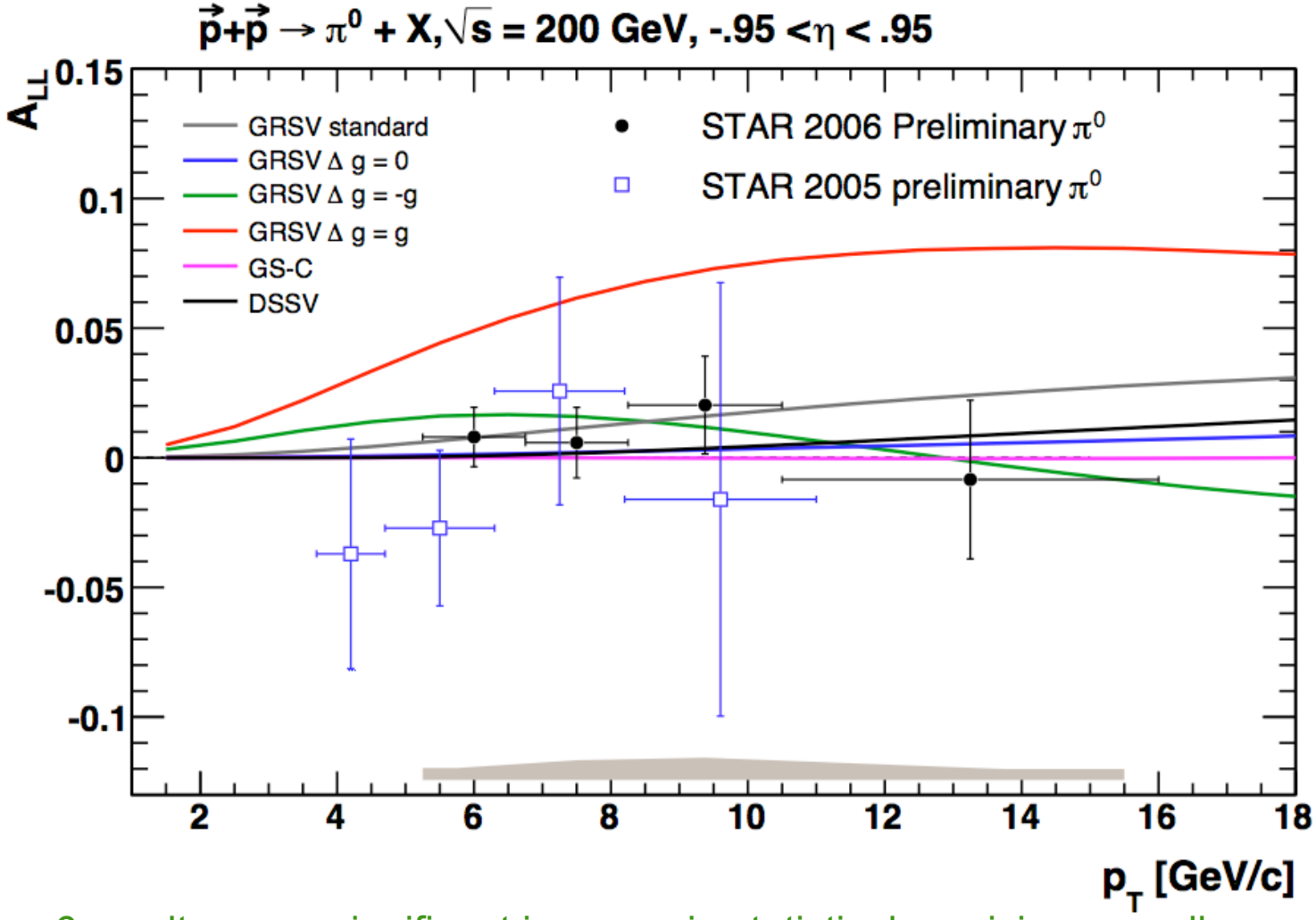
- π^0 invariant mass from two photon decay channel: $M^2_{inv} = 2E_1E_2(1-\cos\theta)$

- BEMC invariant mass spectrum is well described by simulations of single π^0, single η^0, and background

- Cross section agrees well with NLO pQCD



2006 Mid-rapidity Inclusive π^0 A_{LL}



- Run 6 result sees a significant increase in statistical precision as well as a greater reach in p_T compared to Run 5

- Agreement with jets in ruling out Maximum polarization scenario

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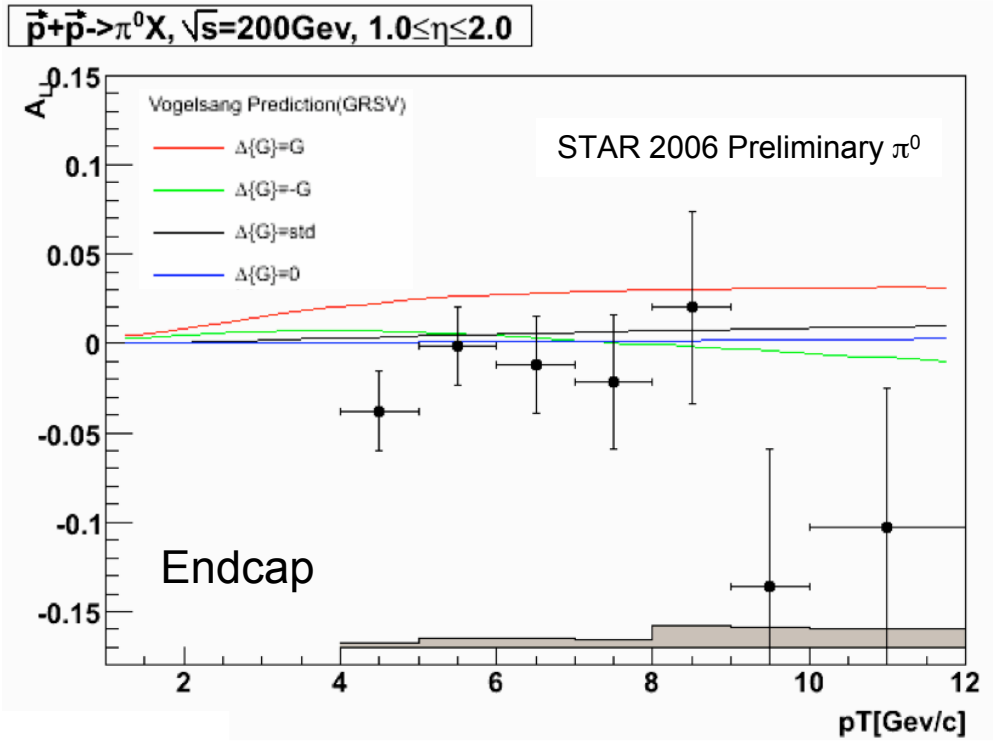
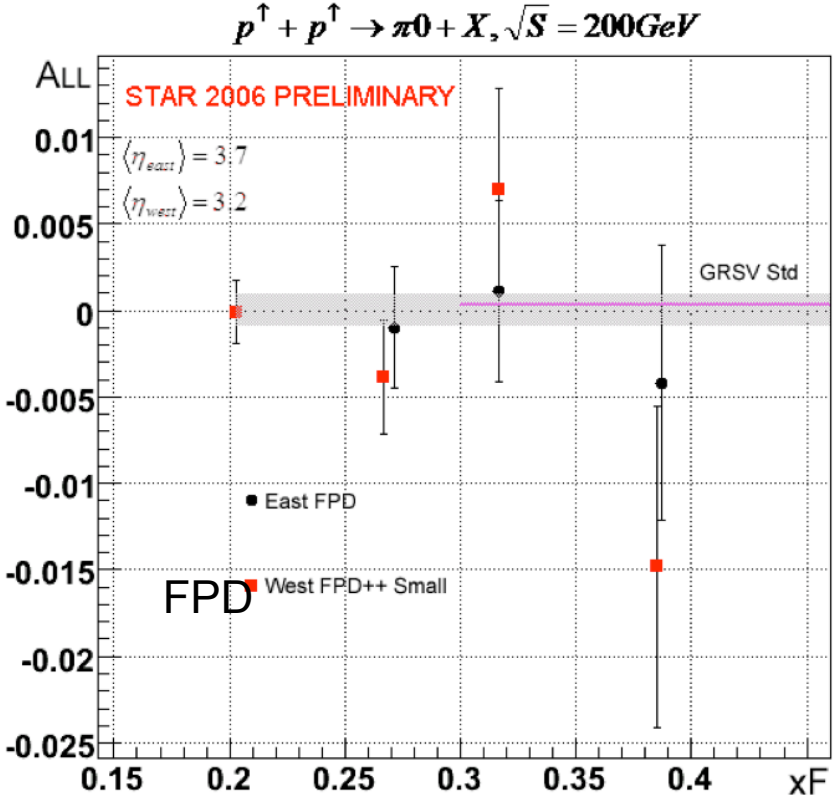
Forward rapidity π^0 A_{LL}

1.0<η<2.0

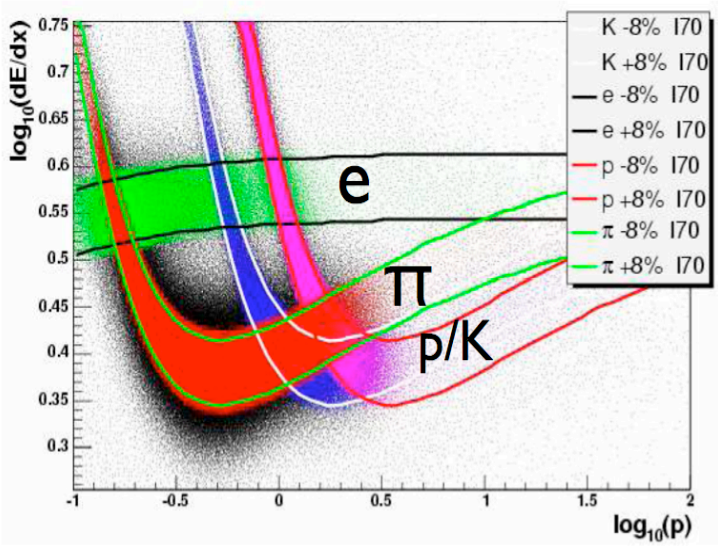


<η>=3.2, 3.7

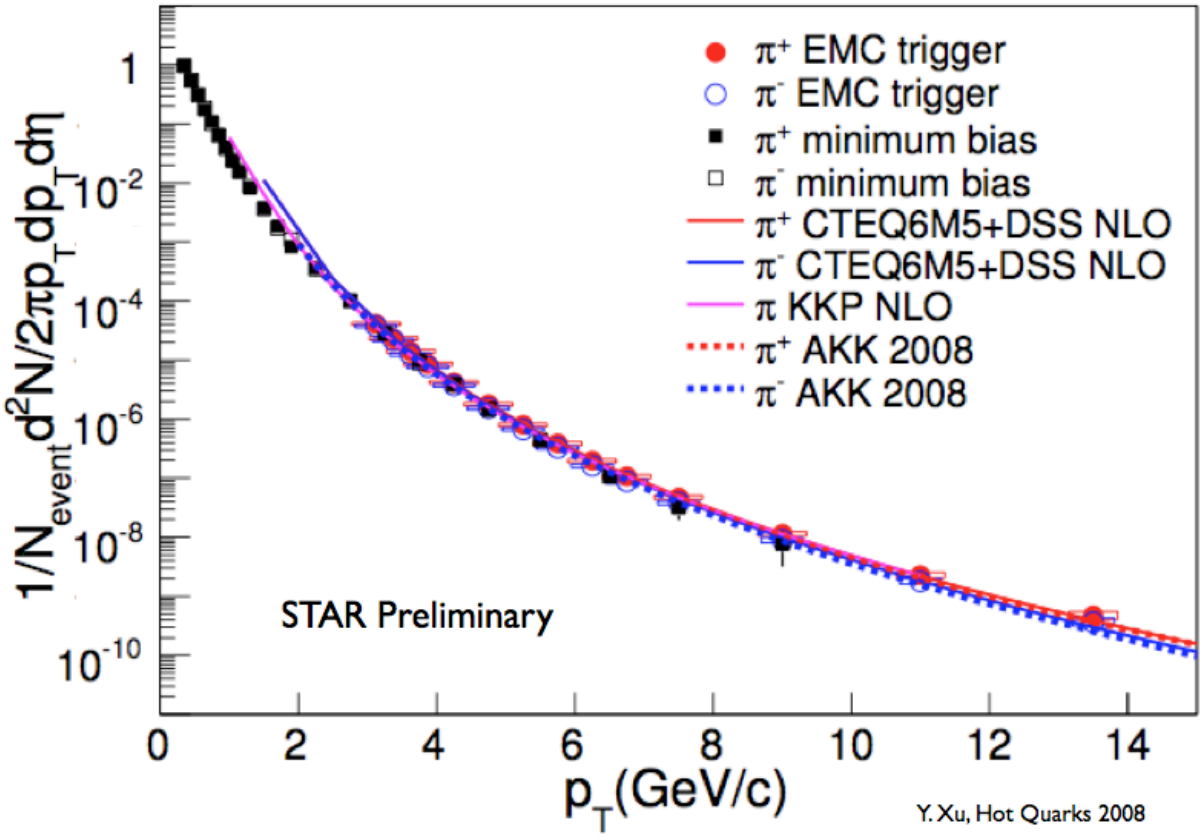


- A_{LL} results are consistent with theoretical picture that asymmetry is reduced as η increases

2005 Inclusive $\pi^{+/-}$ Reconstruction and Cross Section



Phys Lett. B 637 (2006) 161.

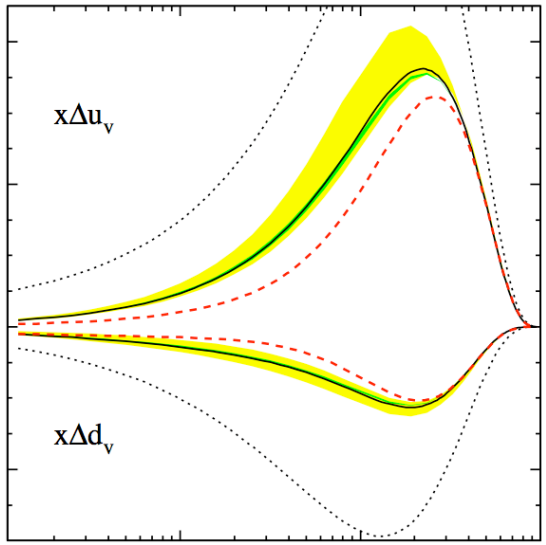


- Use TPC and PID to identify pions within $|\eta|<1.3$ & $p_T<15$ GeV/c

- TPC provides high discriminating power between pions and kaons / protons

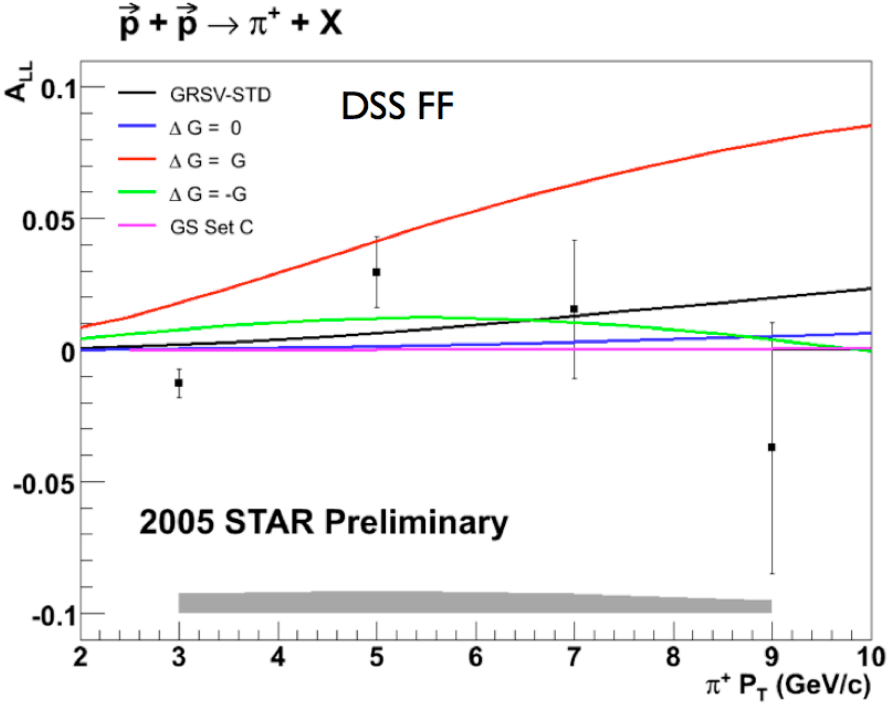
- NLO pQCD describes data well

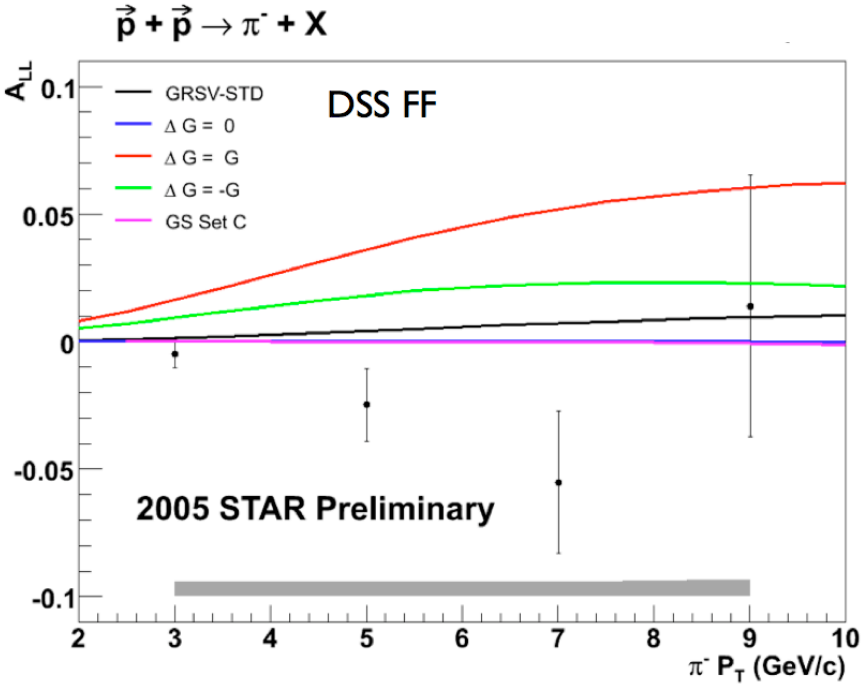
2005 Inclusive $\pi^{+/-}$ A_{LL}



- For qg processes, $A_{LL}(\pi^+)$ and $A_{LL}(\pi^-)$ can be utilized to track the sign of Δg
  - for example, if $A_{LL}(\pi^+) > A_{LL}(\pi^-) \Rightarrow \Delta g > 0$

- Dominant systematic uncertainty from the use of neutral energy triggers at STAR, most pions are sub-leading particles in the jet

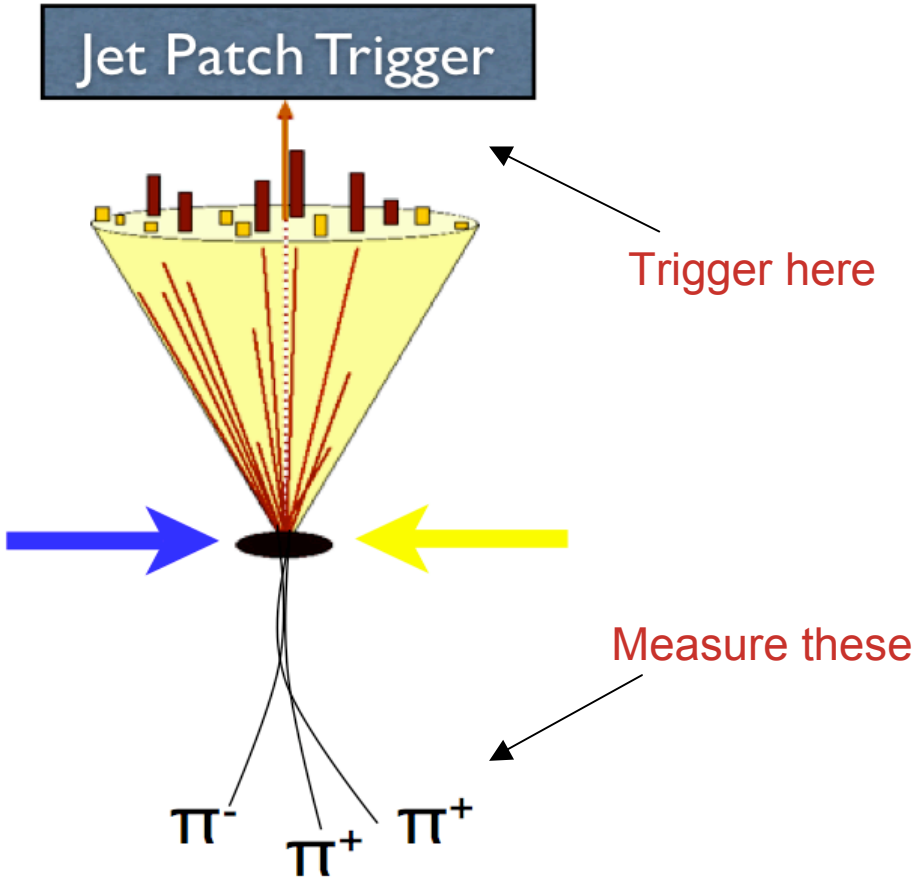


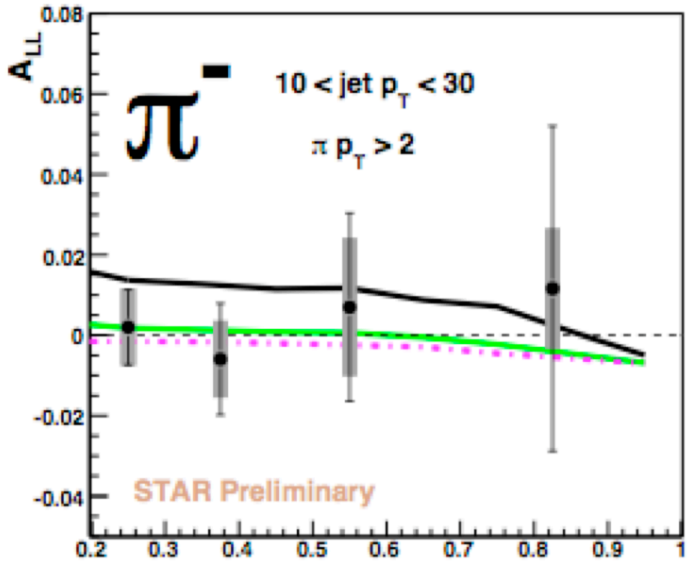


2006 Away-side $\pi^{+/-}$ A_{LL}

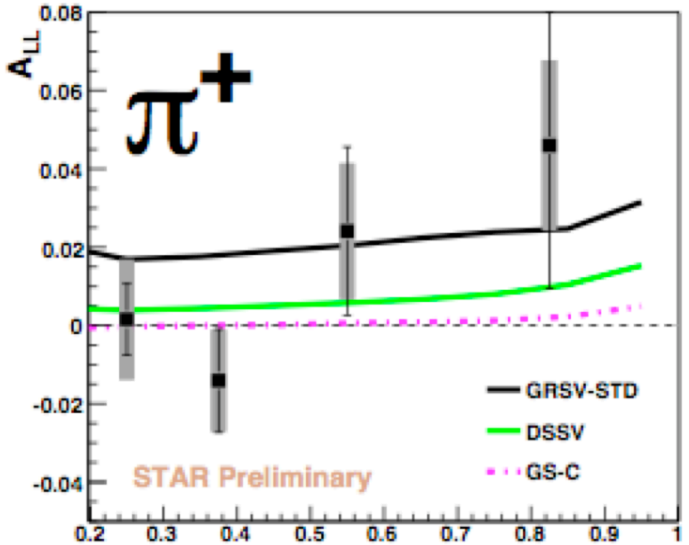
Problem: Increased JP threshold 2005 → 2006 results in a stronger fragmentation bias for charged pions in trigger jet

Solution: Analyze 'away-side' charged pions





$Z=p_T(\pi)/p_T(\text{jet})$



$Z=p_T(\pi)/p_T(\text{jet})$

NLO calculations: de Florian, arXiv:0904.4402

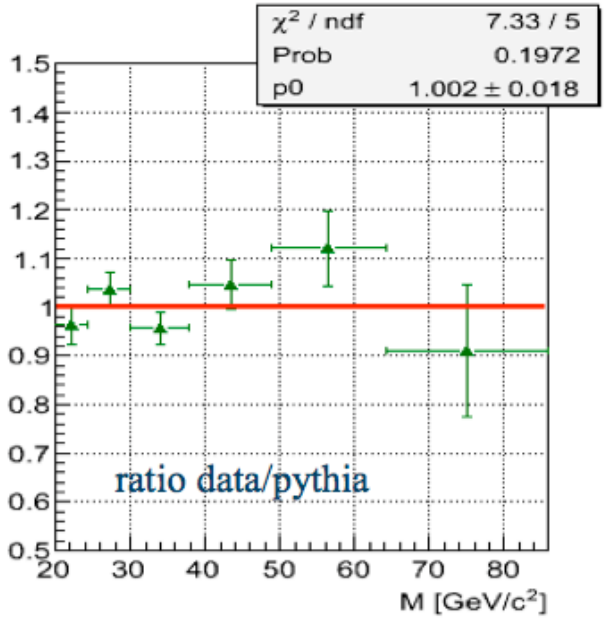
2005 Dijet Reconstruction

• Correlation measurements can be used to map out the shape of $\Delta g(x)$ via information about x_1 and x_2

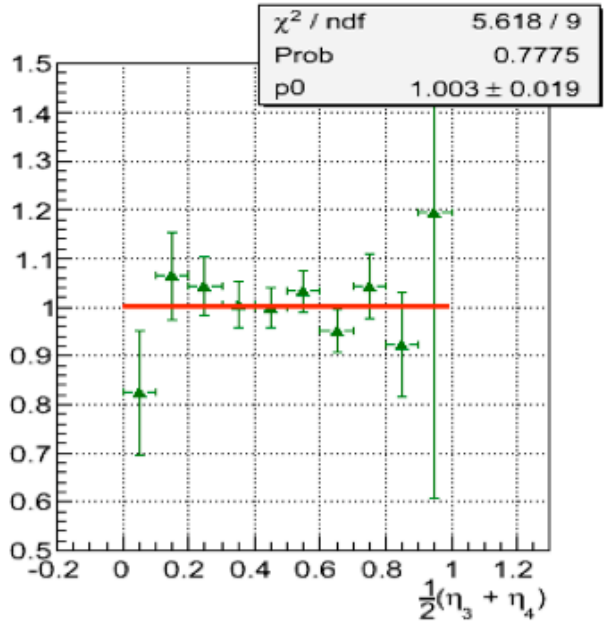
$$x_{1(2)} = \frac{1}{\sqrt{s}}\left(p_{T_3} e^{\eta_3(-\eta_3)} + p_{T_4} e^{\eta_4(-\eta_4)}\right)$$

partons jets

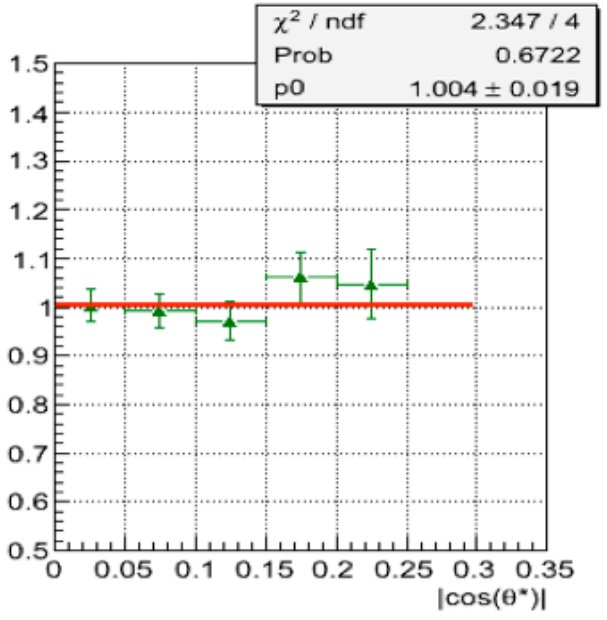
• Dijet distributions are well described by Monte Carlo…



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

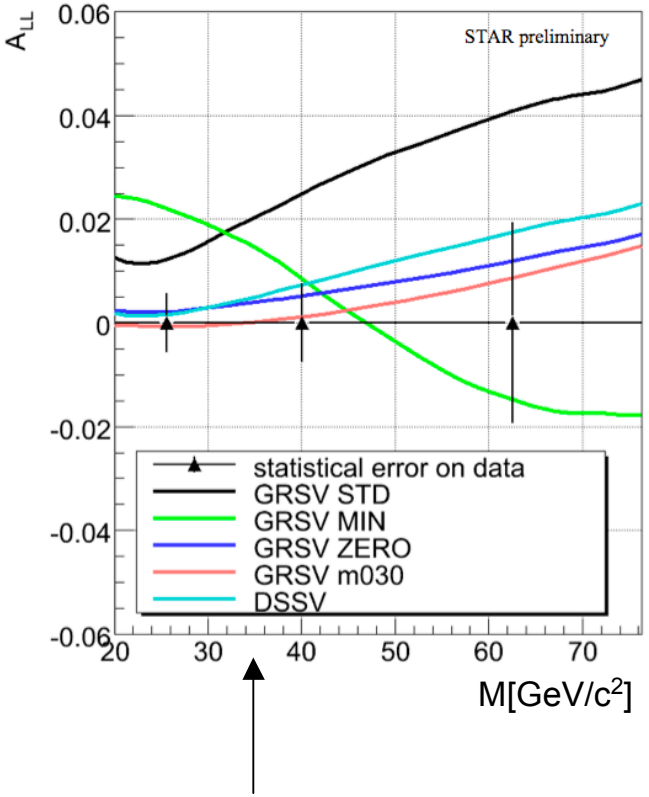


$$\eta_1 + \eta_2 = \ln\frac{x_1}{x_2}$$



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

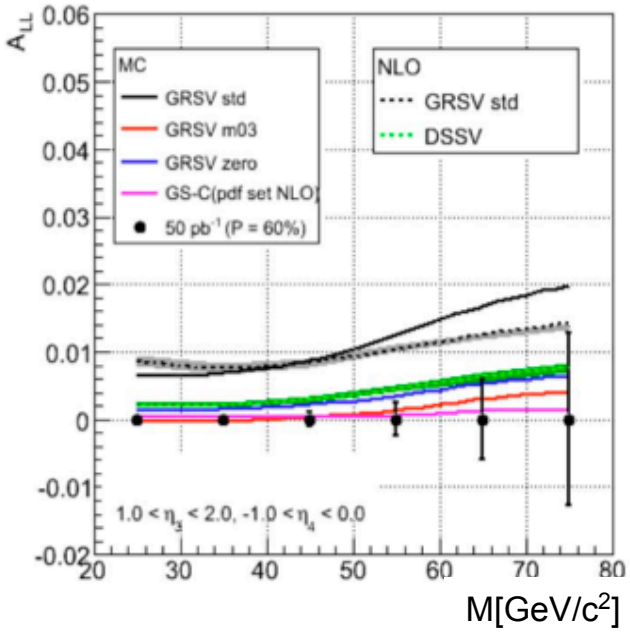
Dijet Predicted Sensitivity



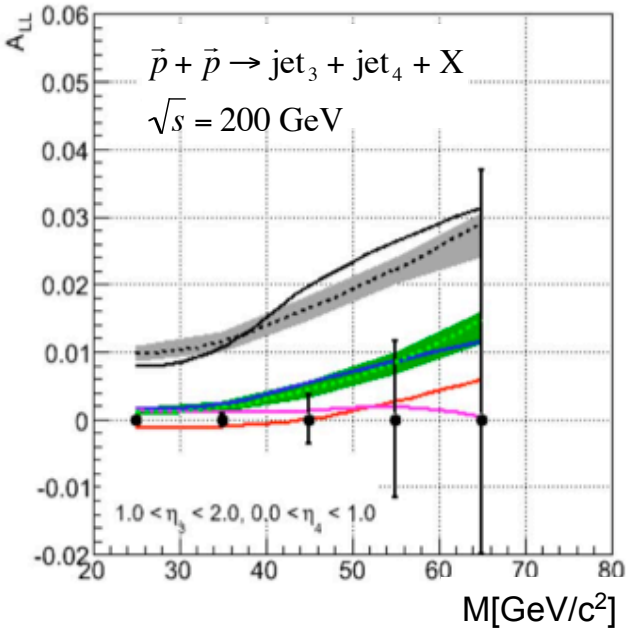
2006 200 GeV, JP1 predicted statistical precision

Run9 BUR, 50pb^{-1} with 60% polarization predicted statistical precision

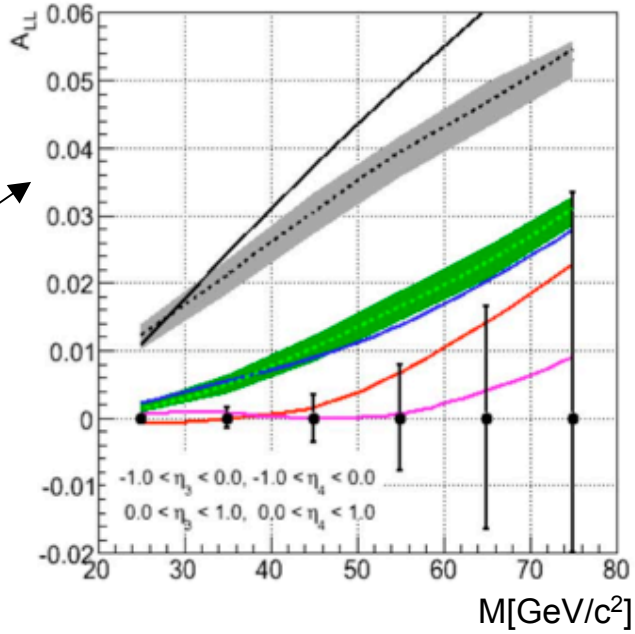
East Barrel - Endcap



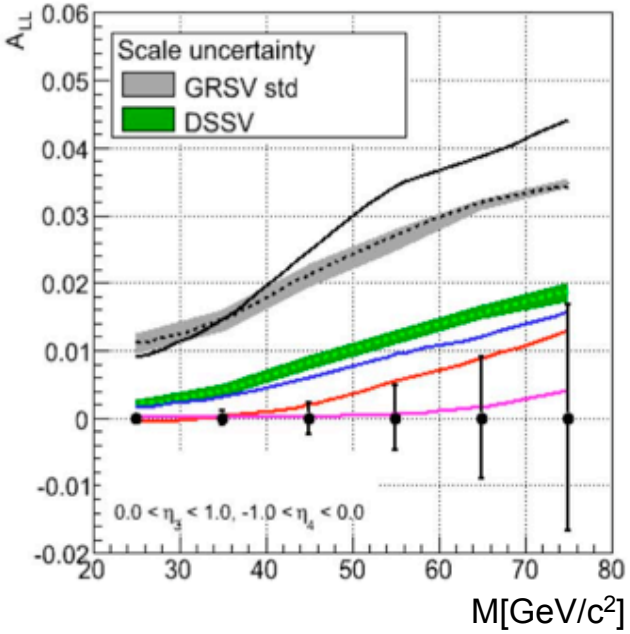
West Barrel - Endcap



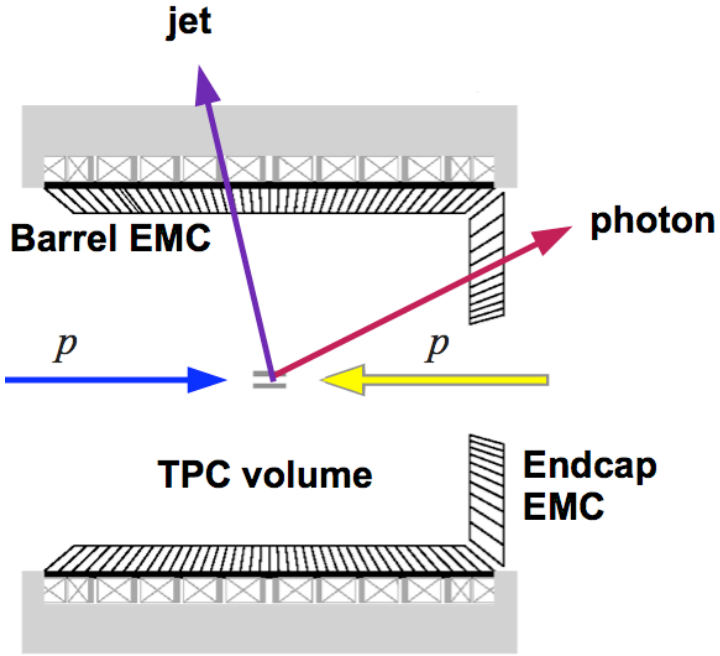
East Barrel - East Barrel & West Barrel - West Barrel



East Barrel - West Barrel



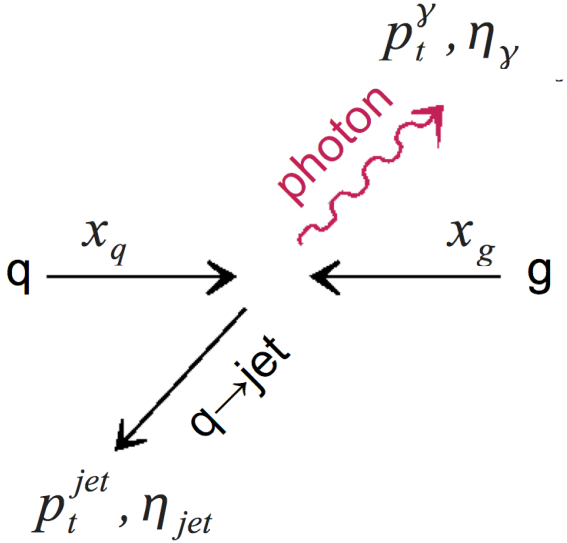
Photon-Jet at STAR



Jet: $|\eta|<0.8$, $p_T>5$ GeV

Photon: $1.08<\eta<2.0$, $p_T>7$ GeV

back to back in ϕ-plane



- Clean probe of qg interaction
- Signal requires more luminosity than dijet measurements: $\alpha_{em}{}^* \alpha_s$ vs. $\alpha_s{}^* \alpha_s$
- Want to focus on asymmetric partonic collisions: high-x quark and low-x gluons with the detected γ in the direction of the incident quark →here the cross section and asymmetry are maximized
- Shower Maximum Detector (SMD) shower shape & Monte Carlo normalization analysis in progress

Summary

• STAR has a very diverse ΔG program with several complementary A_{LL} measurements
  - Individual results agree, and are converging on the same answer

• First inclusion of RHIC data into a global fit (Inclusive jet A_{LL} from STAR, π^0 from PHENIX) has greatly constrained global knowledge of ΔG

• Future of ΔG at STAR:
  - increased precision at 200 GeV of previous A_{LL} channels
  - continuation of current measurements into 500 GeV
  - addition of correlation measurements into the mix (di-jet and gamma-jet) at 200 GeV and 500 GeV

• ΔG at STAR is one head of a multi-pronged study of proton spin at STAR, see other spin talks during this meeting:
  - W physics - Joe Seele (you already saw this one…)
  - Transverse spin results - Chris Perkins, Transverse Afternoon Session
  - STAR spin highlights, results - Carl Gagliardi, Plenary II