Accessing ΔG at STAR

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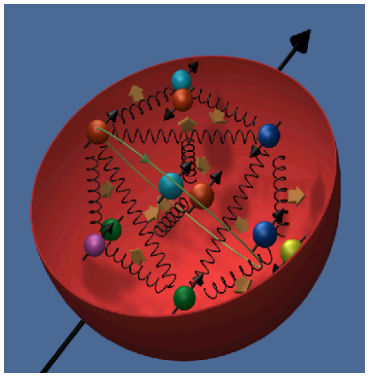
For the STAR Collaboration

The Proton Spin Puzzle

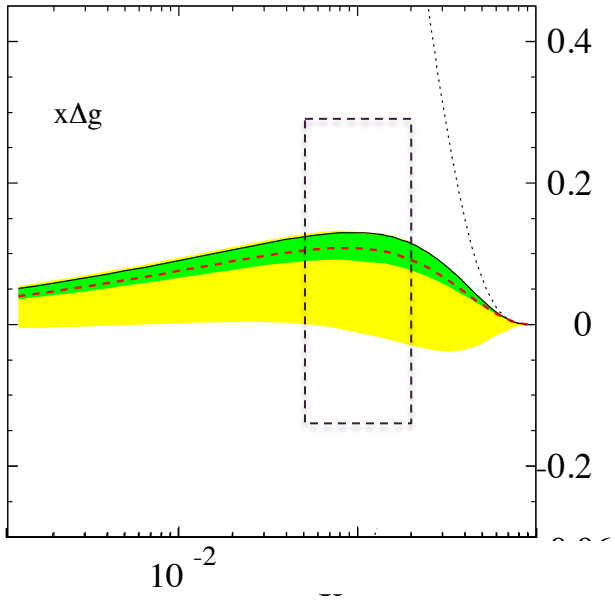
$$S = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$

Polarized DIS: ~0.3

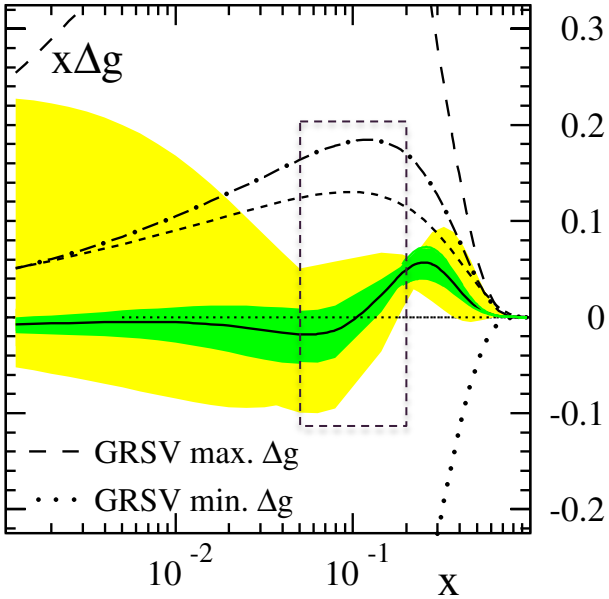
Poorly Constrained



DNS: No RHIC Data



DSSV: RHIC Data Included

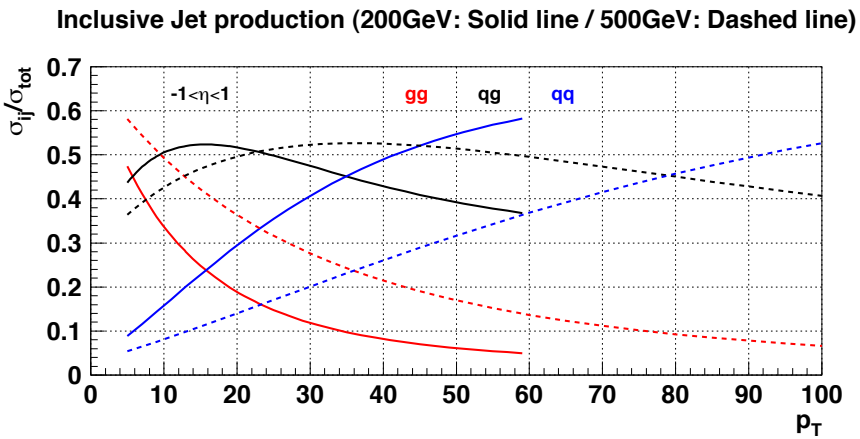


Inclusive jet and pion data from RHIC allowed for significant improvement but large uncertainties at low X remain

de Florian *et al.*, Phys. Rev. D71, 094018 (2005).

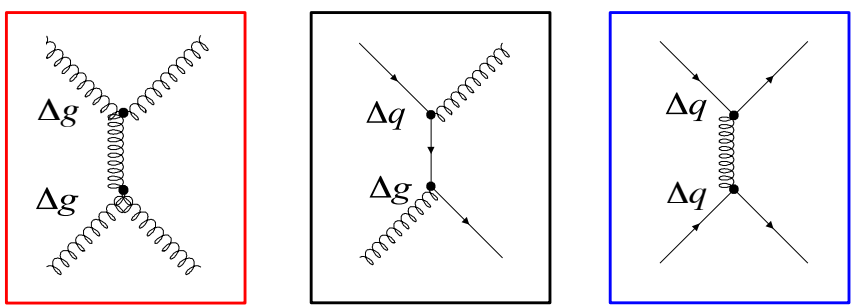
de Florian *et al.*, PRL **101** (2008) 072001

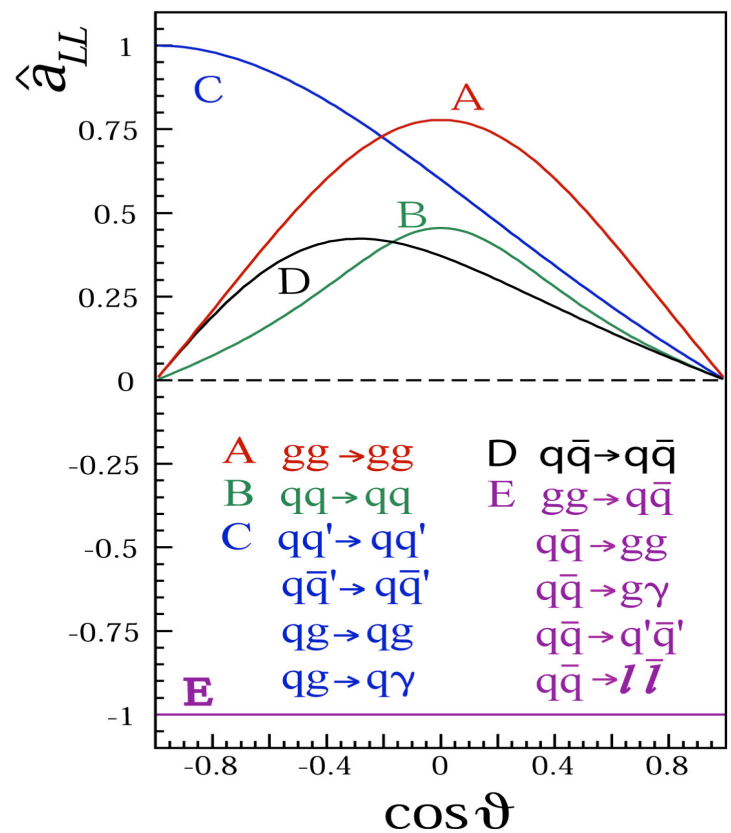
Polarized pp collisions at RHIC



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

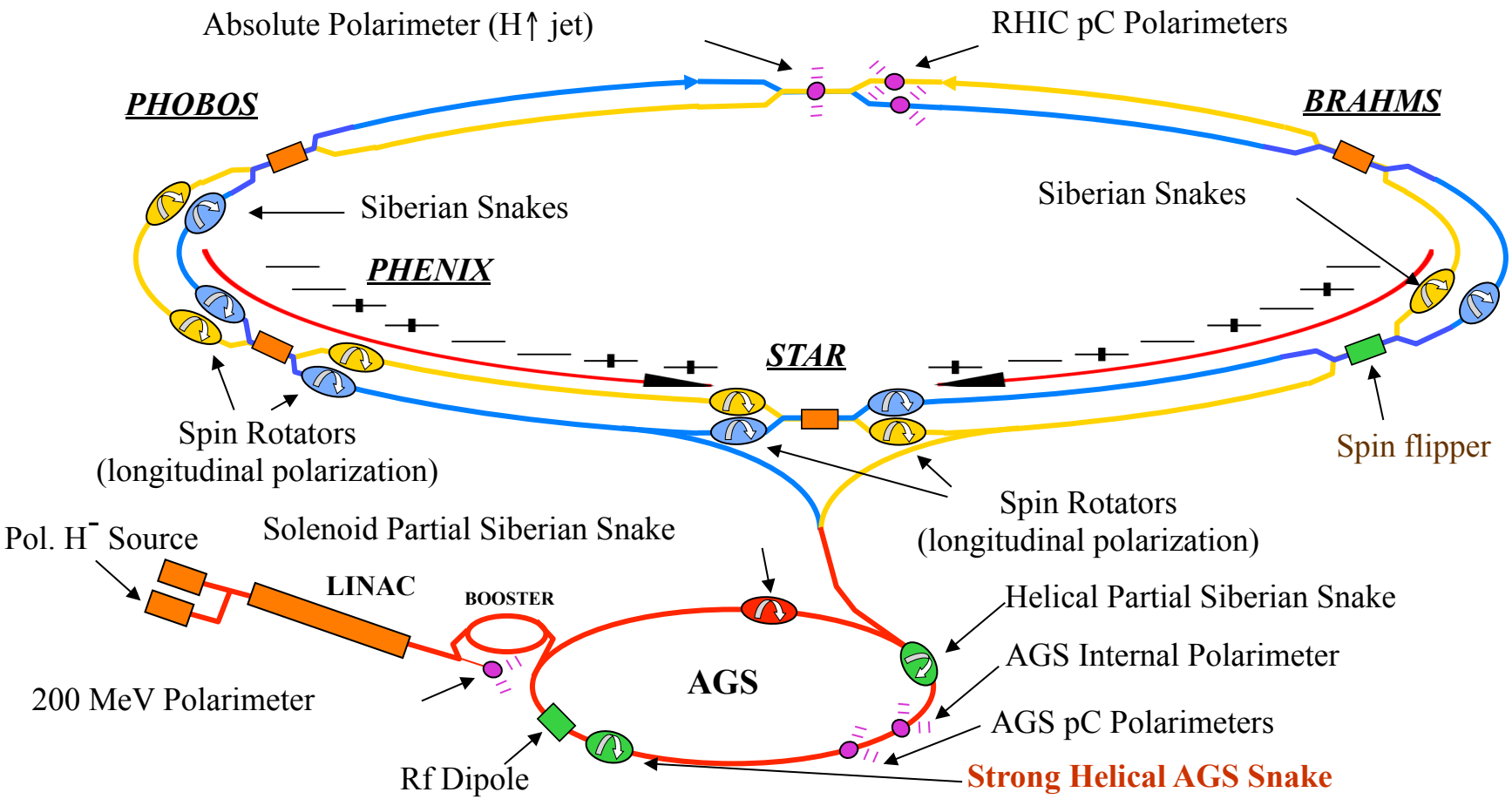
Δf: polarized parton distribution functions



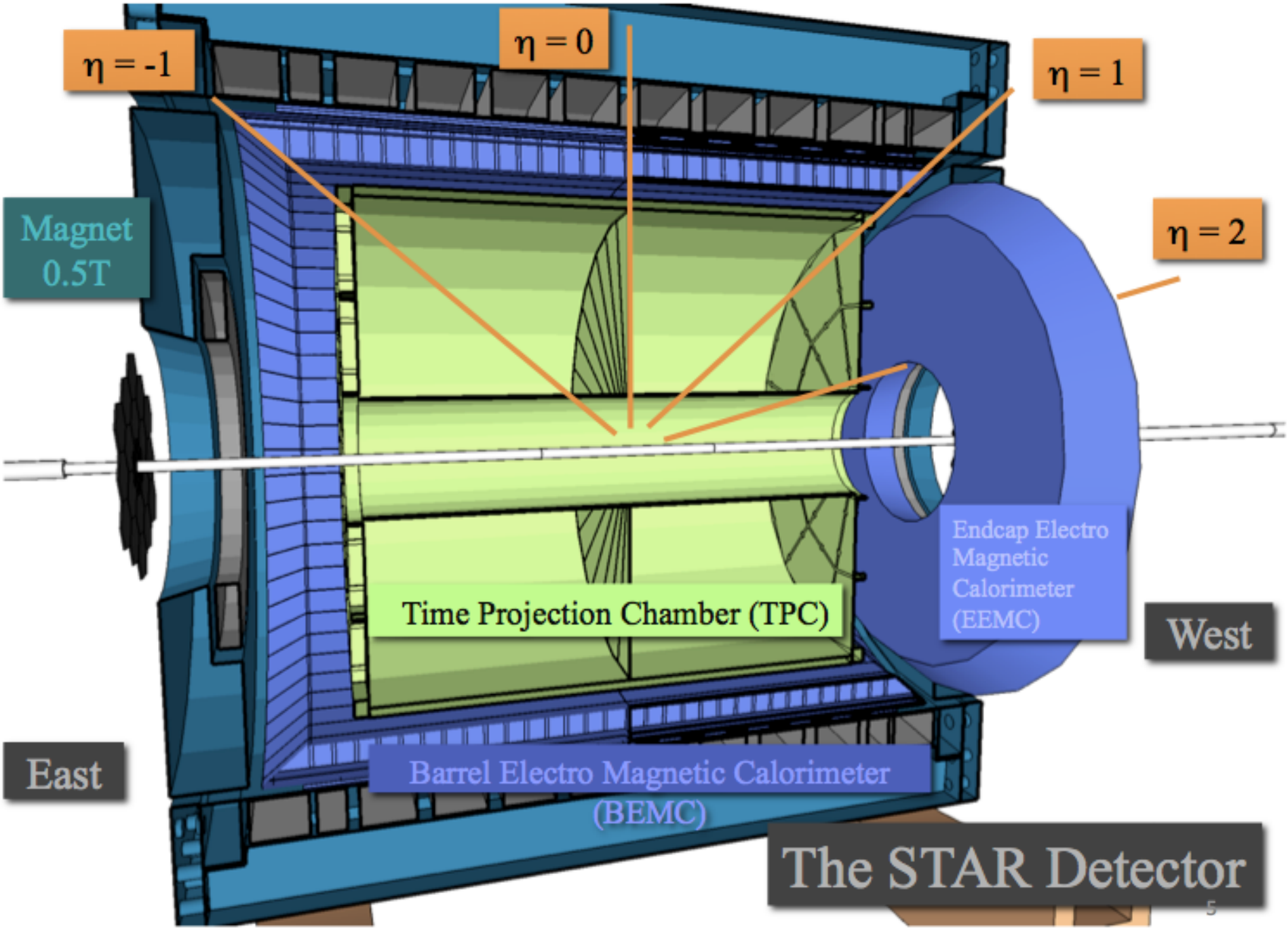


For most RHIC kinematics, ***gg*** and ***qg*** ***dominate***, making A_{LL} for jets sensitive to ***gluon polarization***.

RHIC: The World's First Polarized Hadron Collider

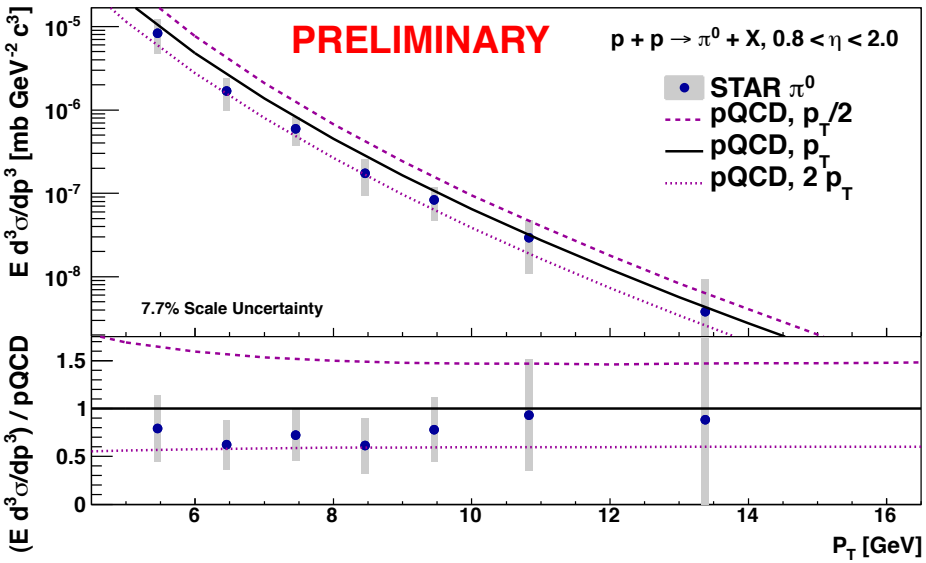


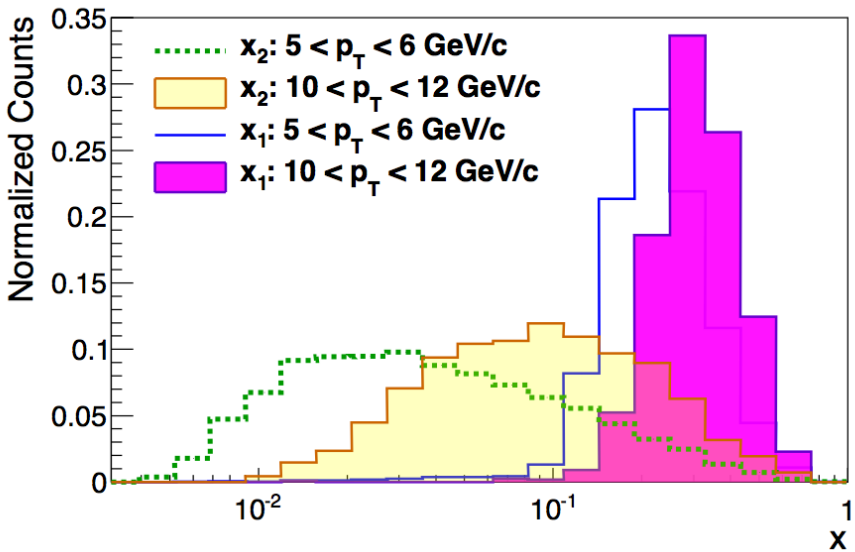
- Spin varies from rf bucket to rf bucket (9.4 MHz)
- Spin pattern changes from fill to fill
- Spin rotators provide choice of spin orientation
- Billions of spin reversals during a fill with little depolarization



Tai Sakuma, Thesis, MIT (2010)

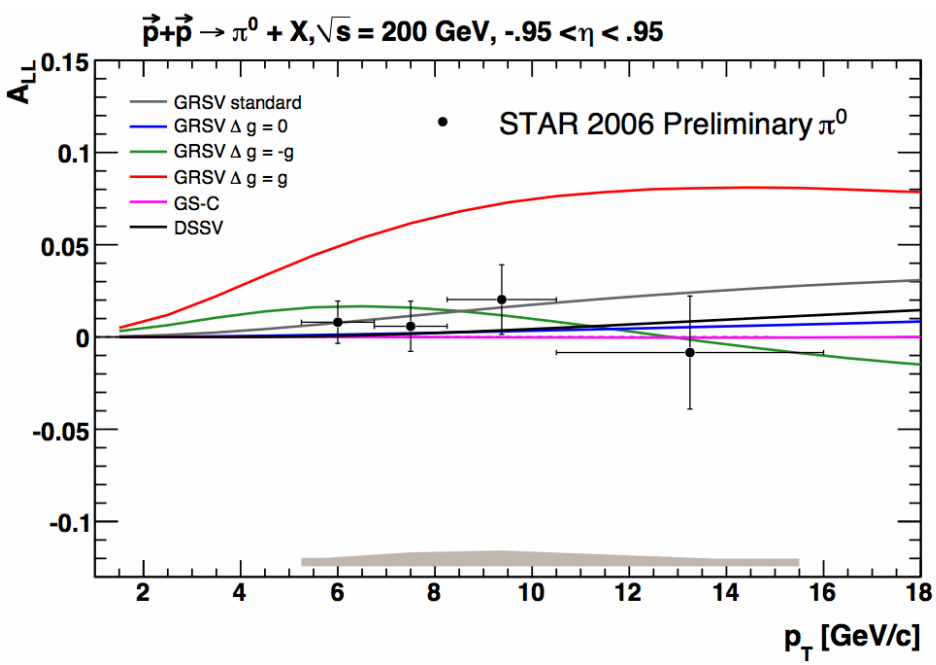
π^0 Cross Section Result



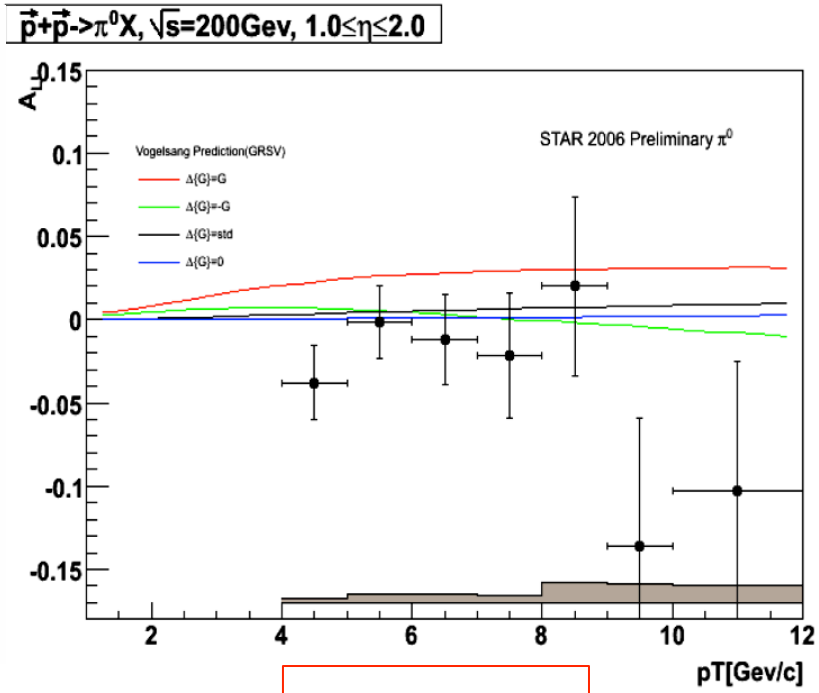


- Results cover an unmeasured region of phase space
  - $0.8 < \eta < 2.0$
- Agreement with theoretical calculations CTEQ6.5M

Longitudinal Spin π^0 Asymmetries

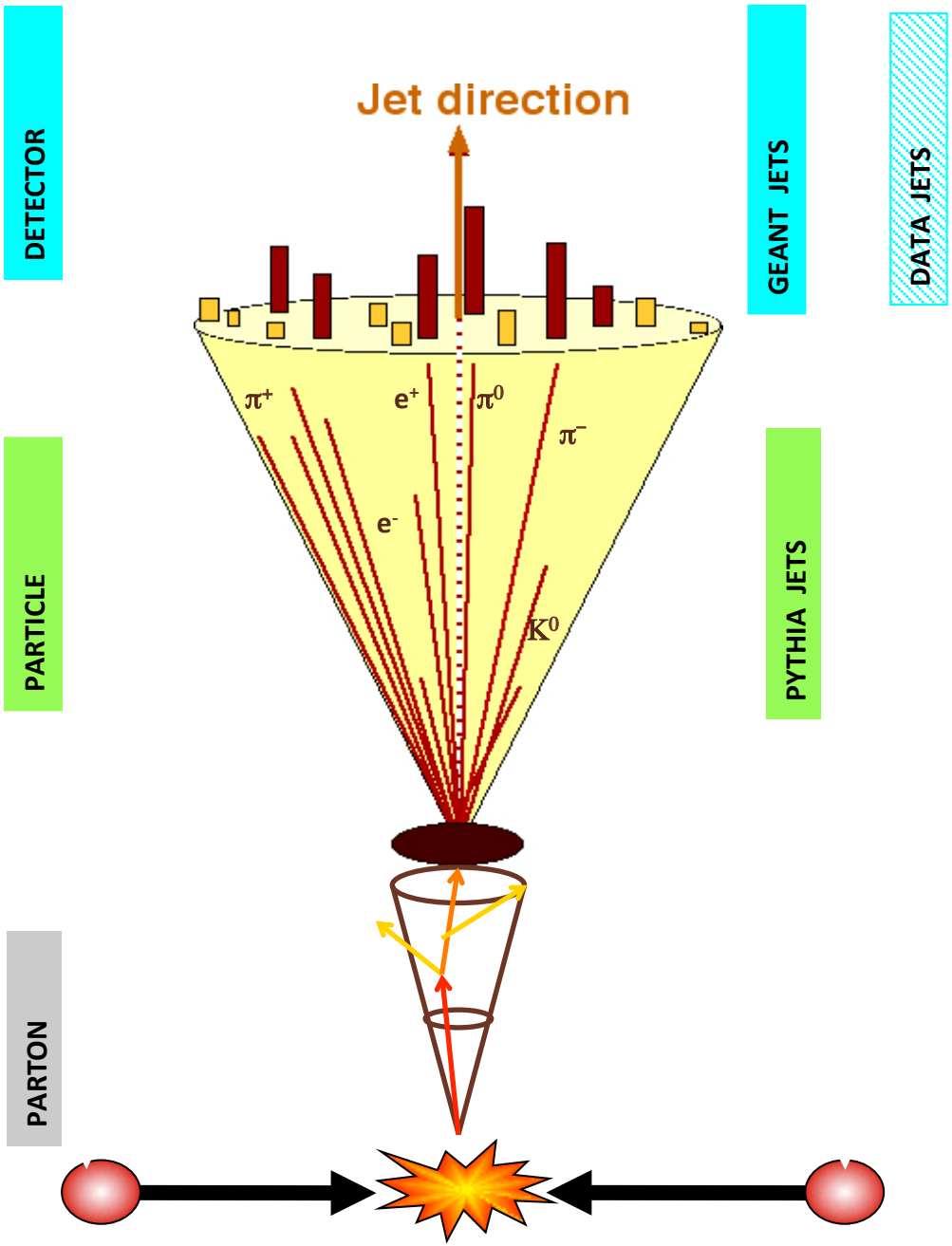


$|\eta| < 0.95$



$1.0 < \eta < 2.0$

- In Run 6, STAR measured the π^0 A_{LL} in several different pseudorapidity ranges.
- Mid rapidity results excludes maximal Δg model
- qg scattering dominates at high η with large a quarks and small x glouns



Jet Reconstruction

Midpoint cone algorithm

(Adapted from Tevatron II - hep-ex/0005012)

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

Anti-K_T algorithm

([arXiv:0802.1189])

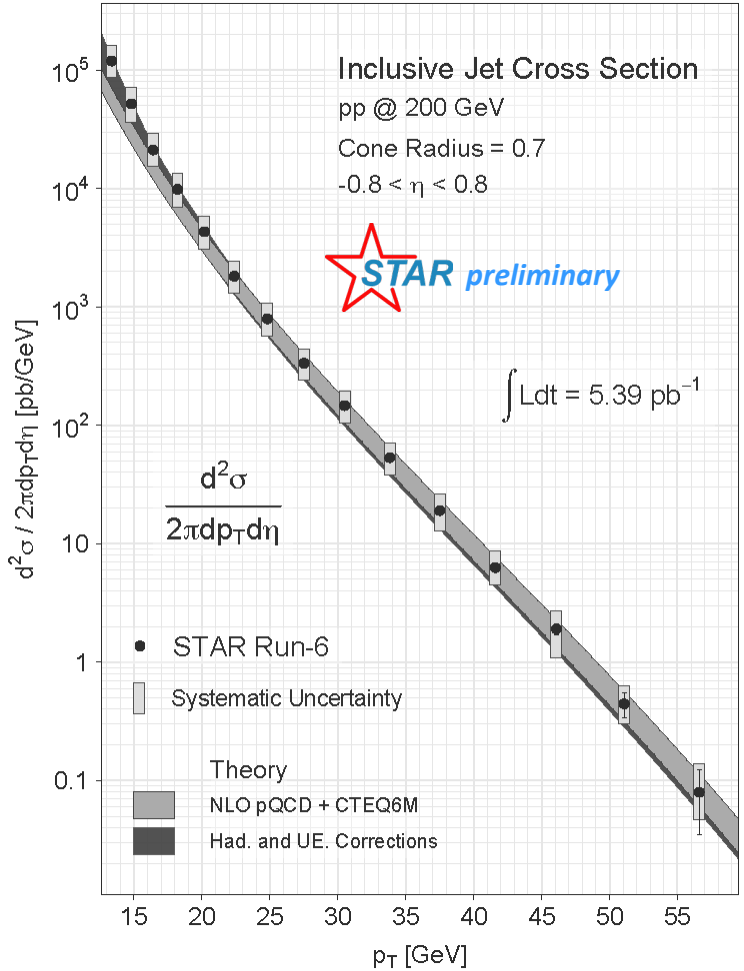
- Successive Combination
- Radius R = 0.6

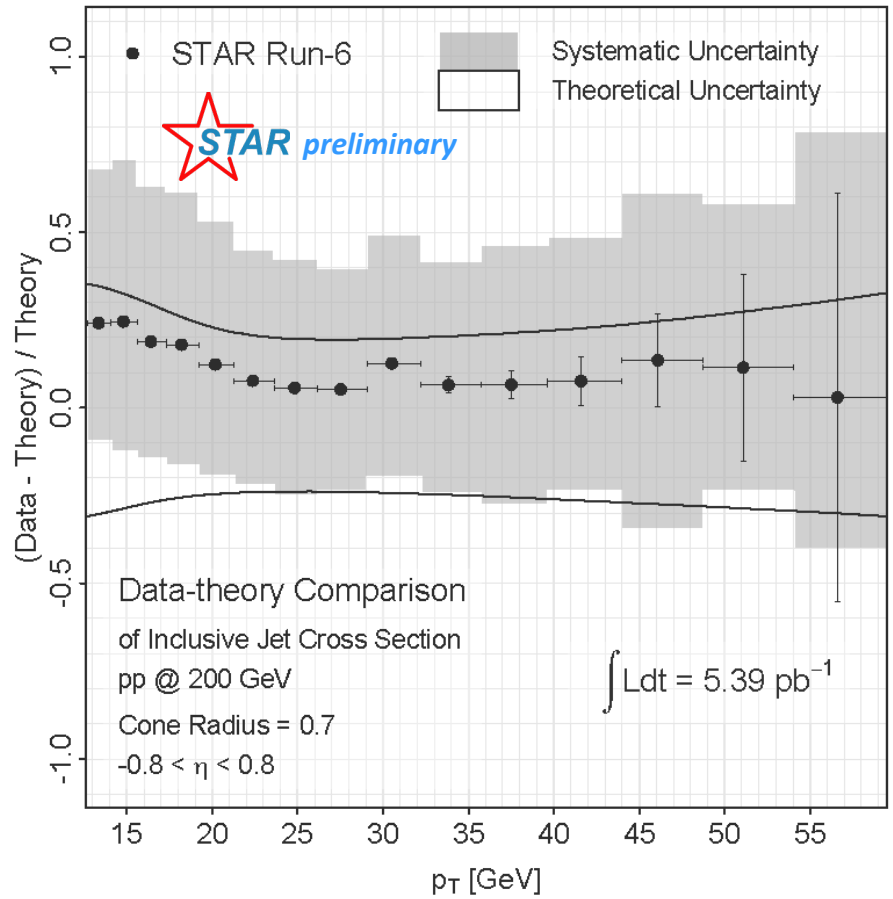
$$d_{ij} = \min\left(\frac{1}{k_{Ti}^2}, \frac{1}{k_{Tj}^2}\right)\frac{\Delta R_{ij}^2}{R^2}$$

$$d_{iB} = \frac{1}{k_{Ti}^2}$$

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

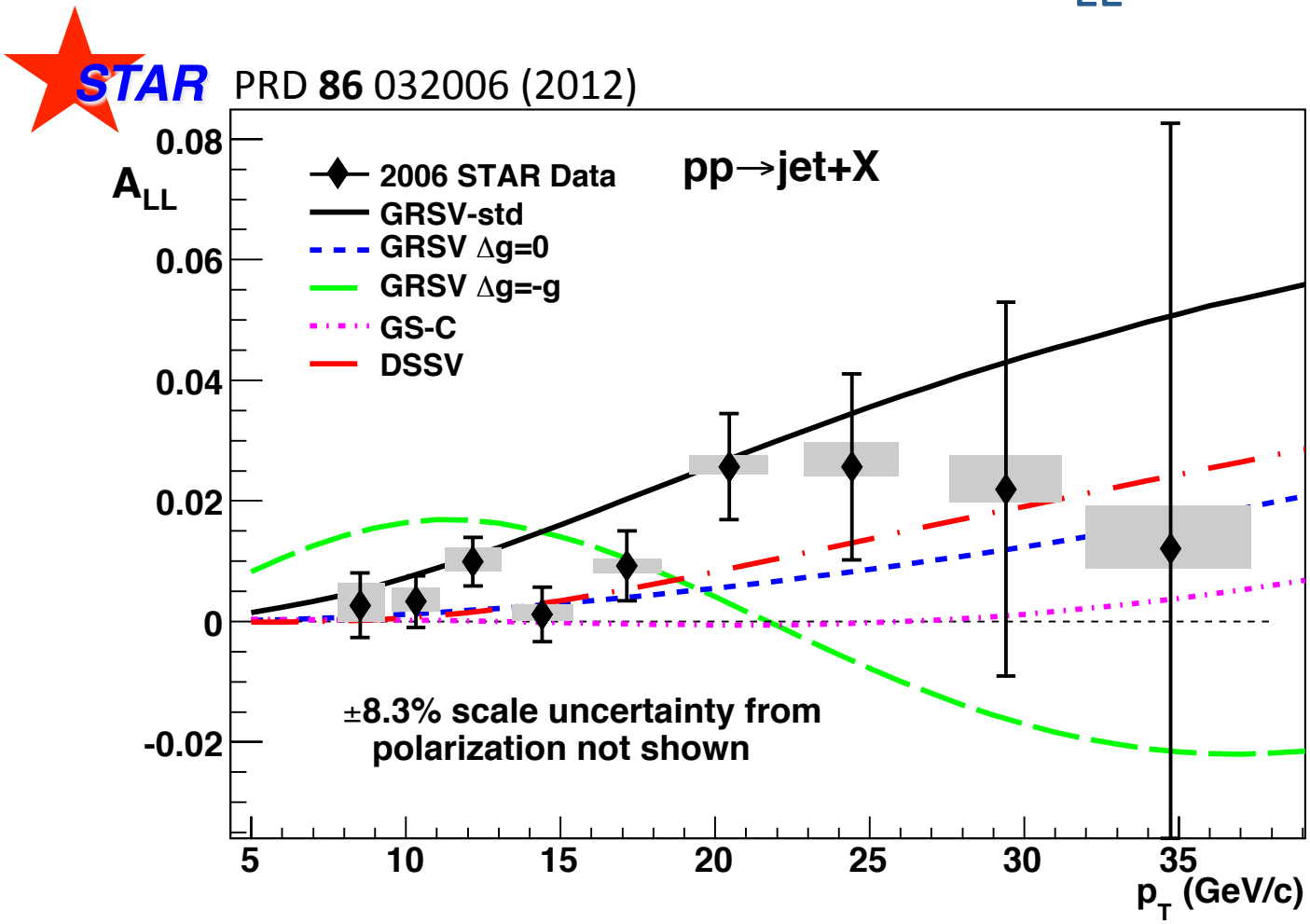
2006 inclusive jet cross section





- Data well described by NLO pQCD+Hadronization+Underlying Event

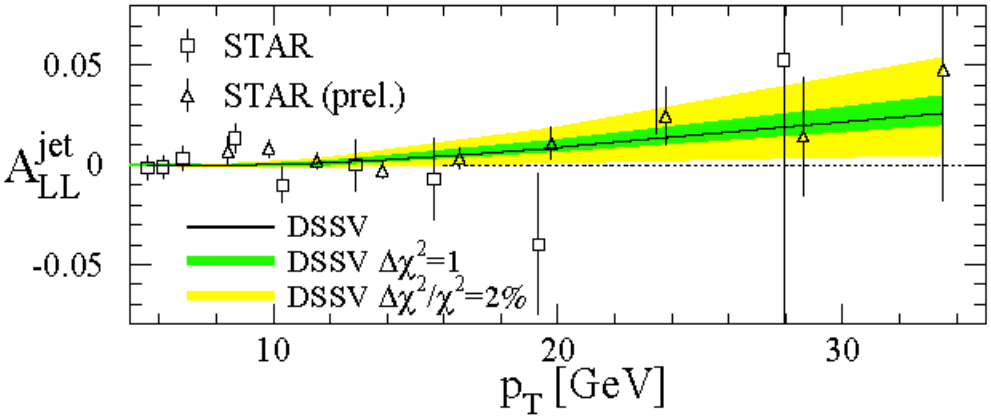
2006 inclusive jet A_{LL}

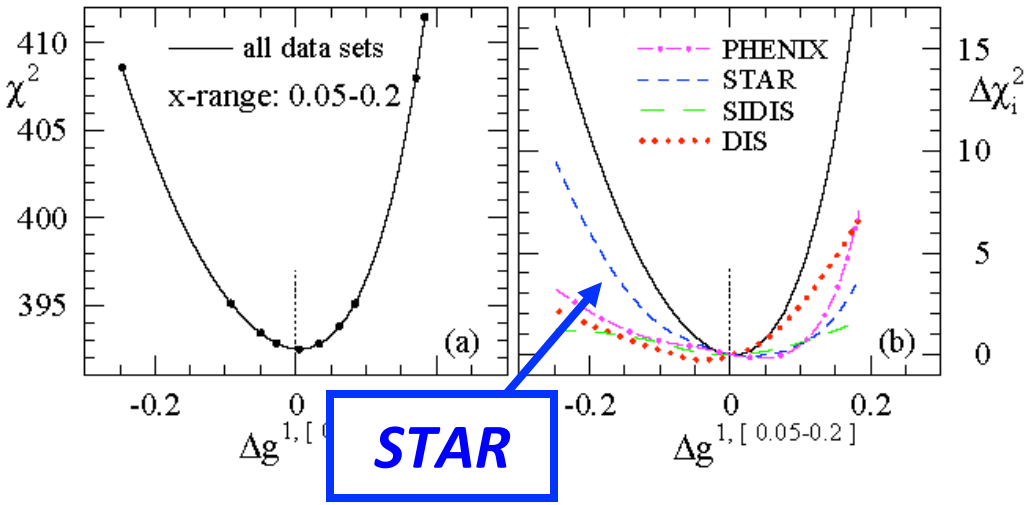


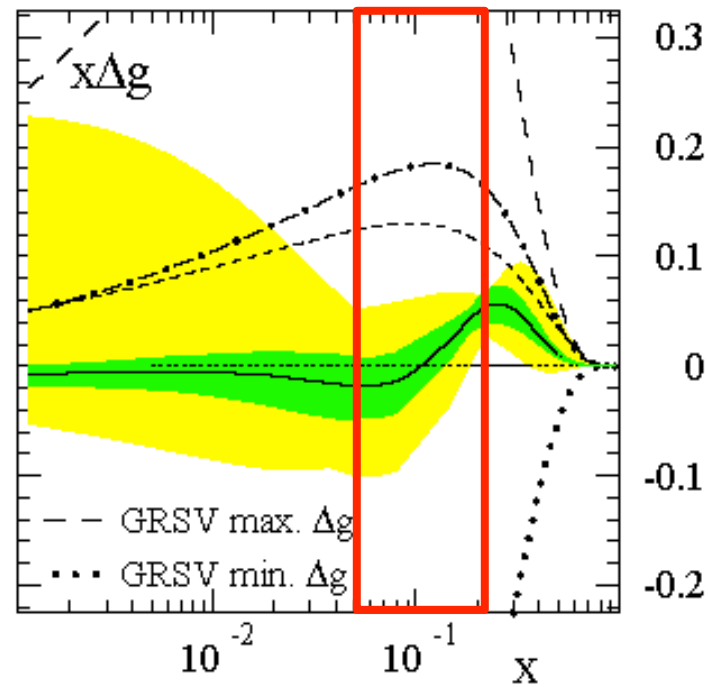
- Sampled 5.5 pb^{-1} at ~57% average beam polarization
- STAR data rule out several previous models of gluon polarization

DSSV – First Global Analysis with Polarized Jets

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







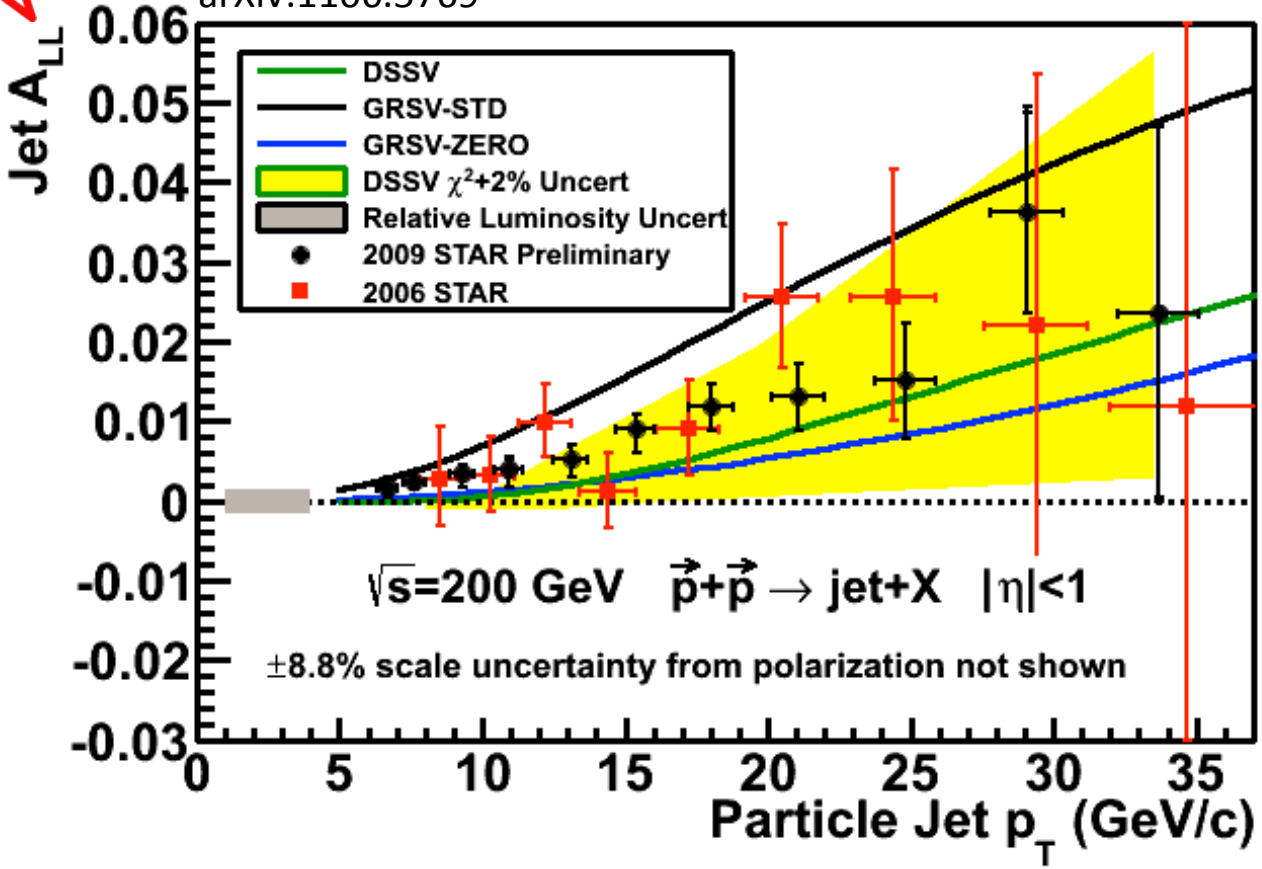
- First global NLO analysis to include DIS, SIDIS, and RHIC pp data on equal footing
- Finds node in gluon distribution near x ~ 0.1

2009 improvements

- Collected 4 times the figure-of-merit of 2006
  - Sampled 20 pb^{-1} at 58% average beam polarization
- 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%
  - Switching to anti-k_T algorithm for *final* result
    - Reduces sensitivity to underlying event effects

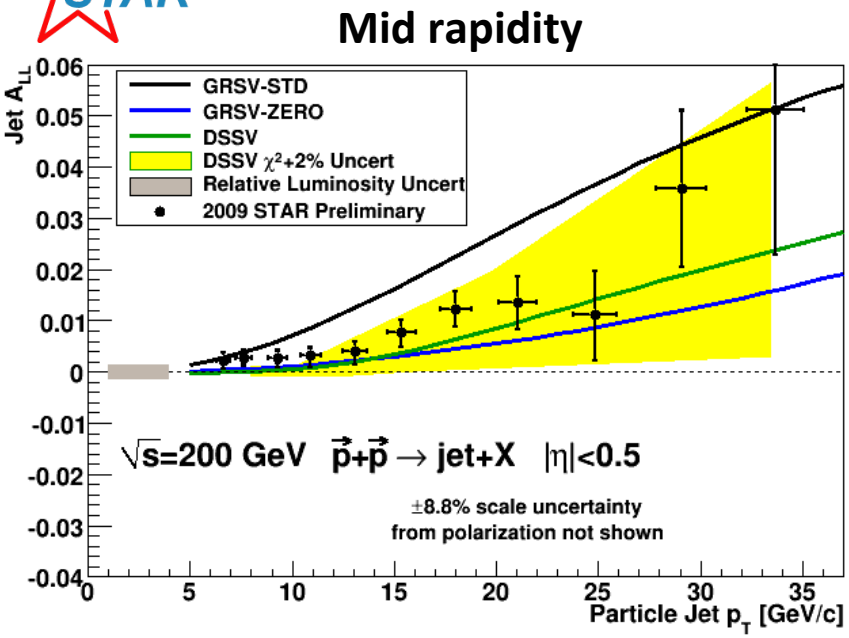
From 2006 to 2009

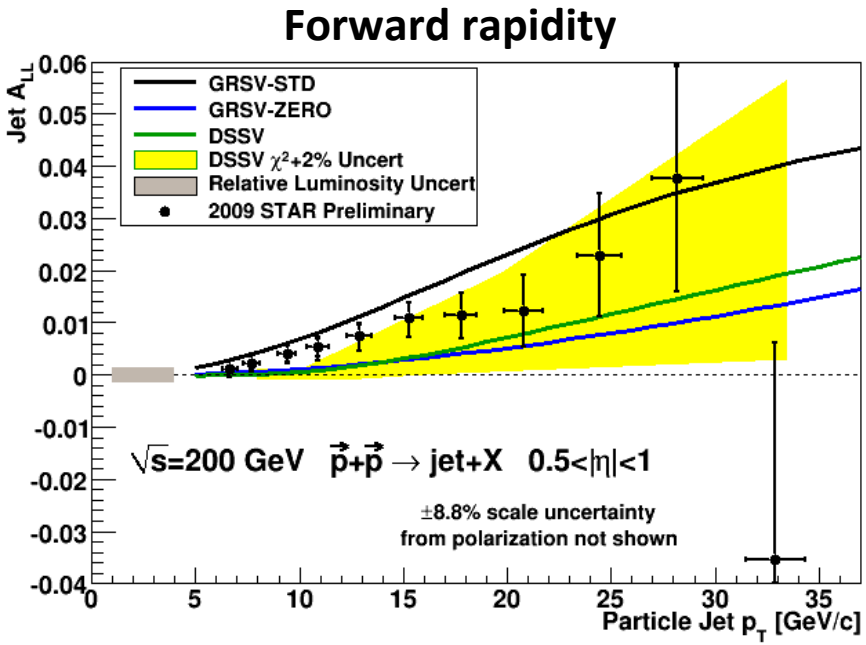
arXiv:1106.5769



- 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}



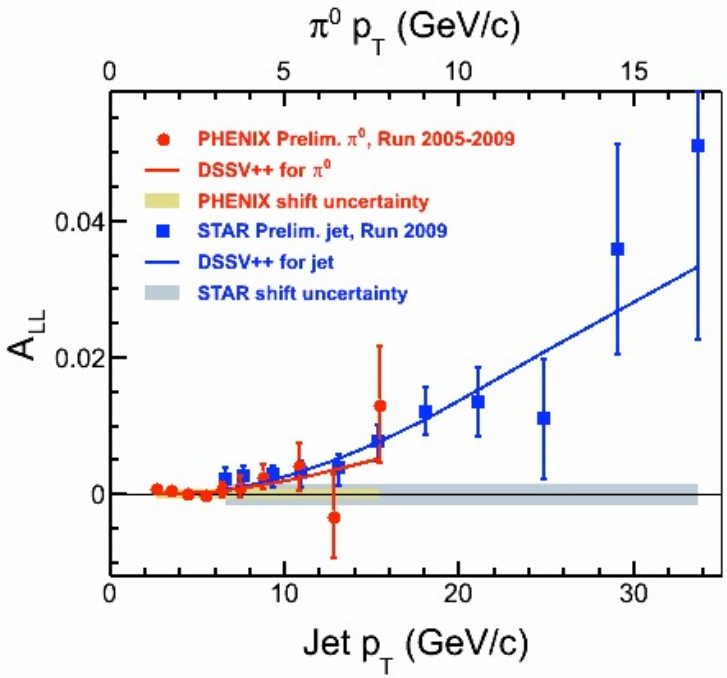


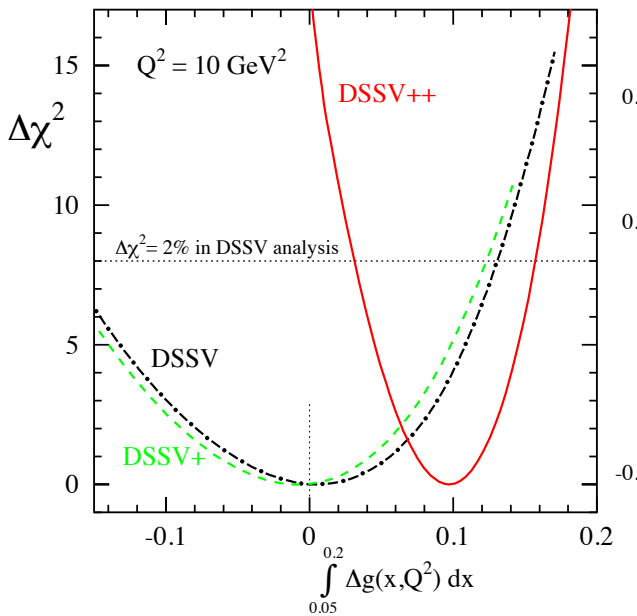
- A_{LL} separated into two pseudorapidity ranges
- Forward jets involve:
  - A larger fraction of quark-gluon scattering with:
    - Higher *x* quarks that are more polarized
    - Lower *x* gluons that are less polarized
  - Larger $|\cos(\theta^*)|$, which reduces $\hat{a}_{LL}$
- A_{LL} falls between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

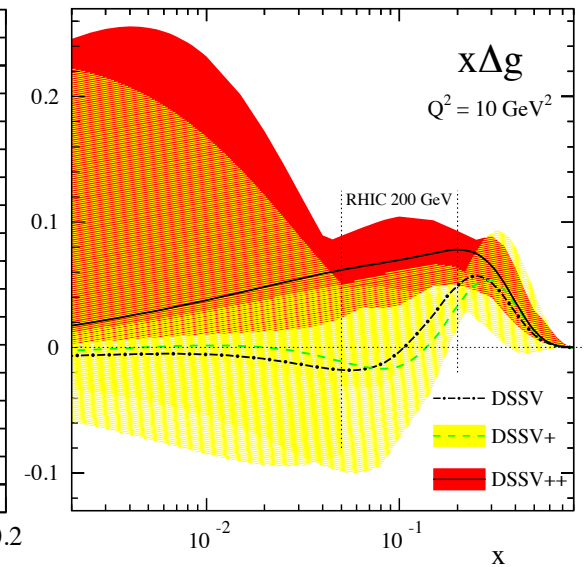
New global analysis with 2009 RHIC data

arXiv:1304.0079

Special thanks to the DSSV group!





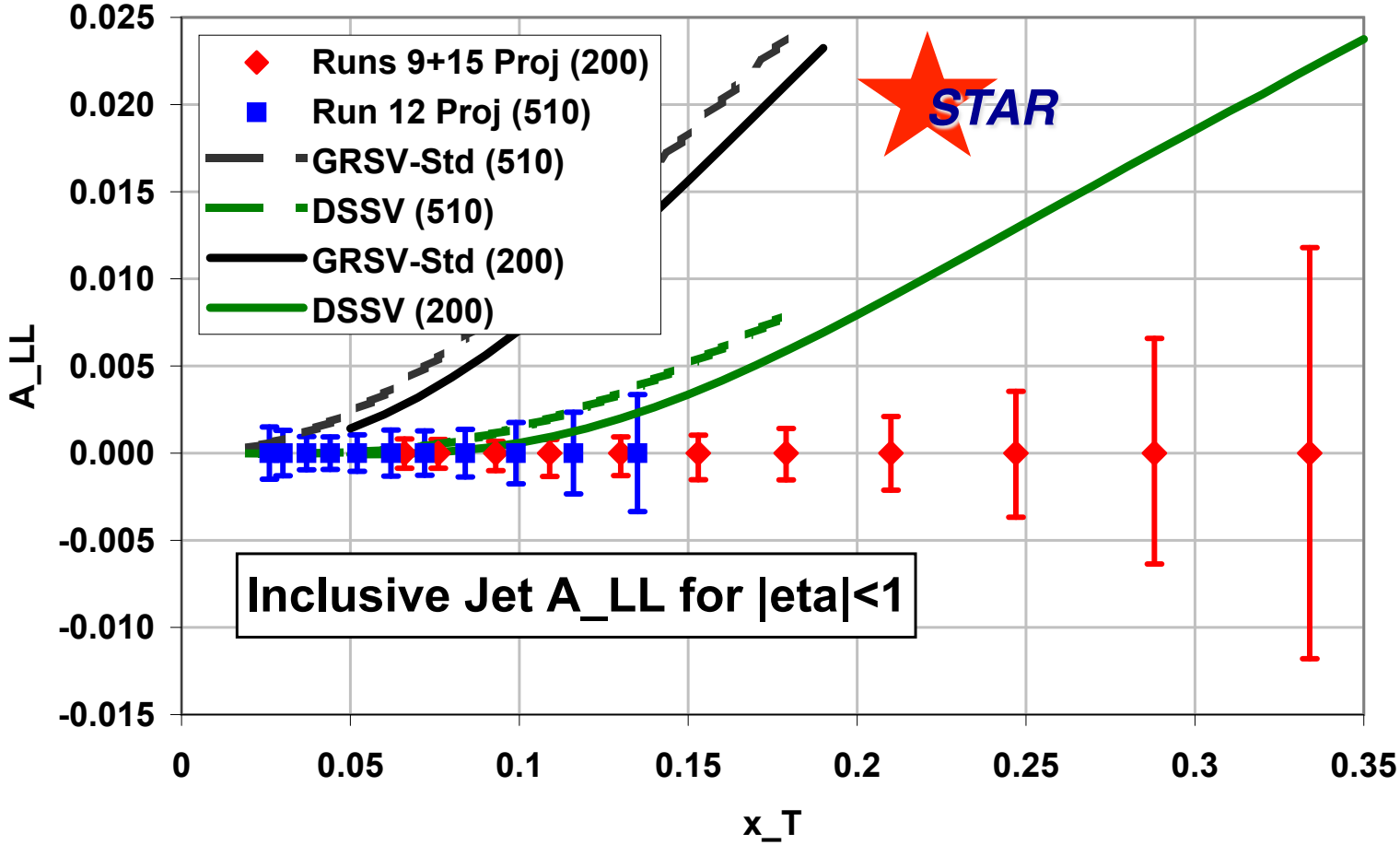


- **DSSV++** is a new, preliminary global analysis from the DSSV group that includes the 2009 RHIC A_{LL} data (STAR inclusive jets and PHENIX π^0's)

$$\int_{0.05}^{0.20} \Delta g(x, Q^2 = 10\ \mathrm{GeV}^2)\, dx = 0.10^{+0.06}_{-0.07}$$

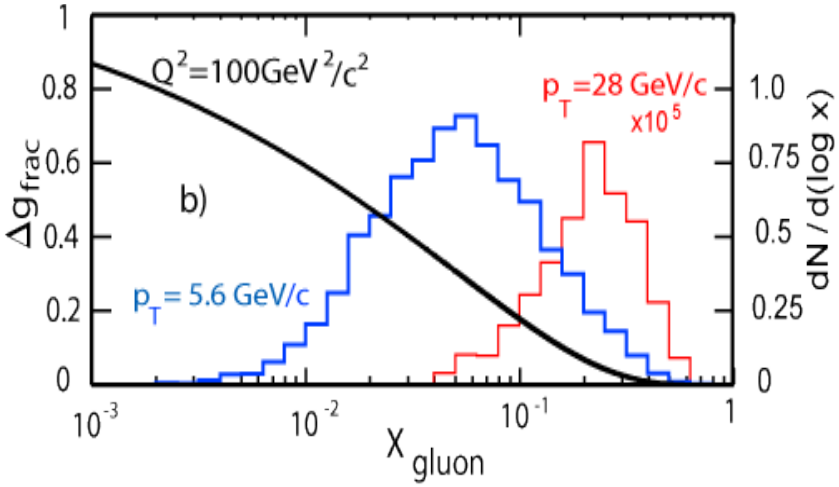
- First experimental evidence of **non-zero Δg(x)** in RHIC range ($0.05 \le x \le 0.2$)

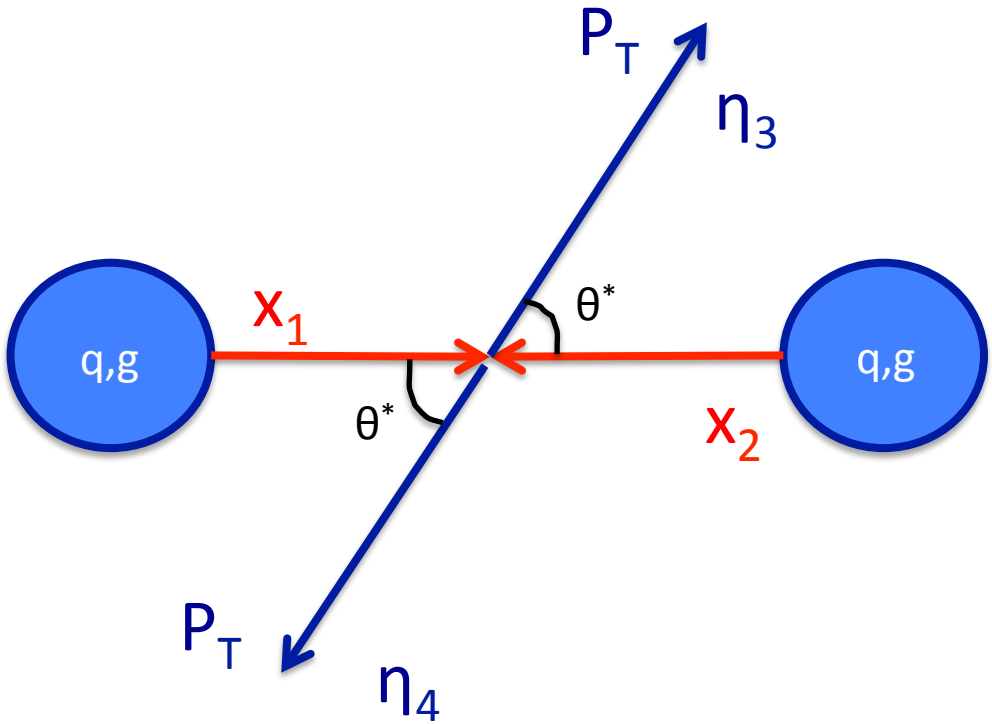
Higher Precision Coming Soon



- During 2012 STAR measured inclusive jet ALL in 510 GeV collision
- STAR also expects significant future reductions in the uncertainties for the 200 GeV collisions relative to the 2009 results
  - Anticipate doubling the existing 200 GeV data during the 2015 RHIC run

Correlation measurements



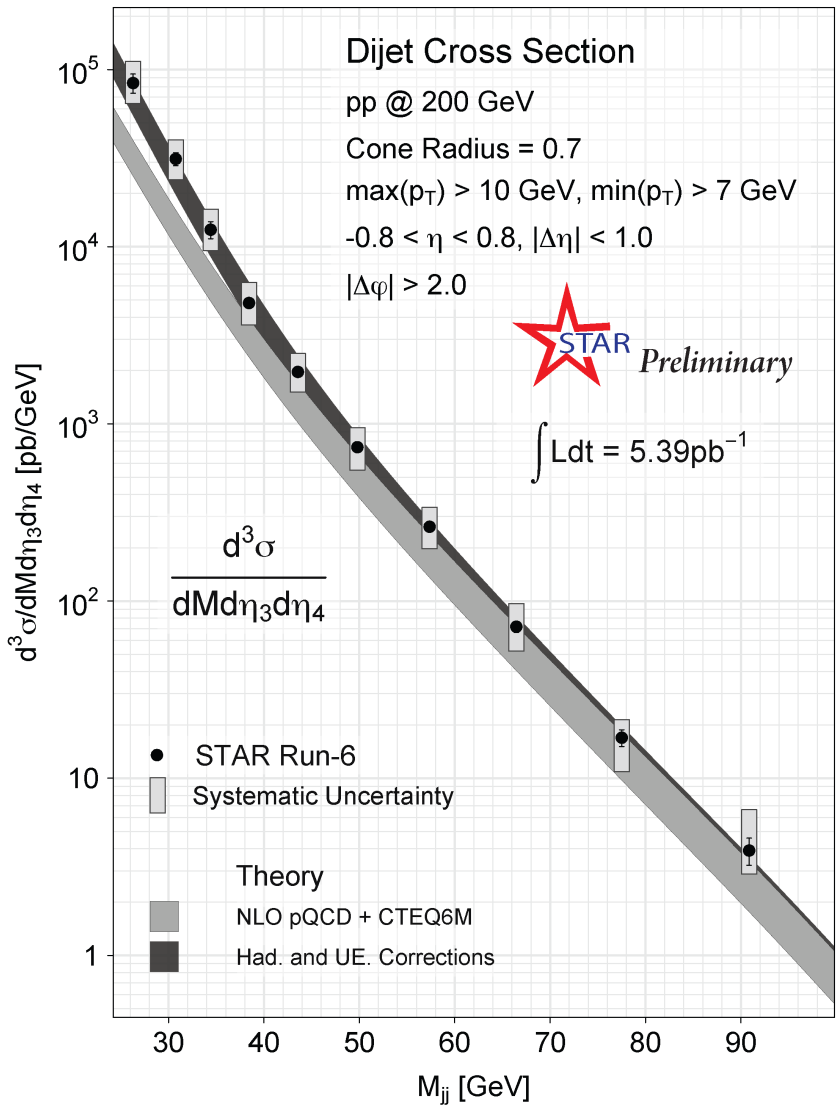


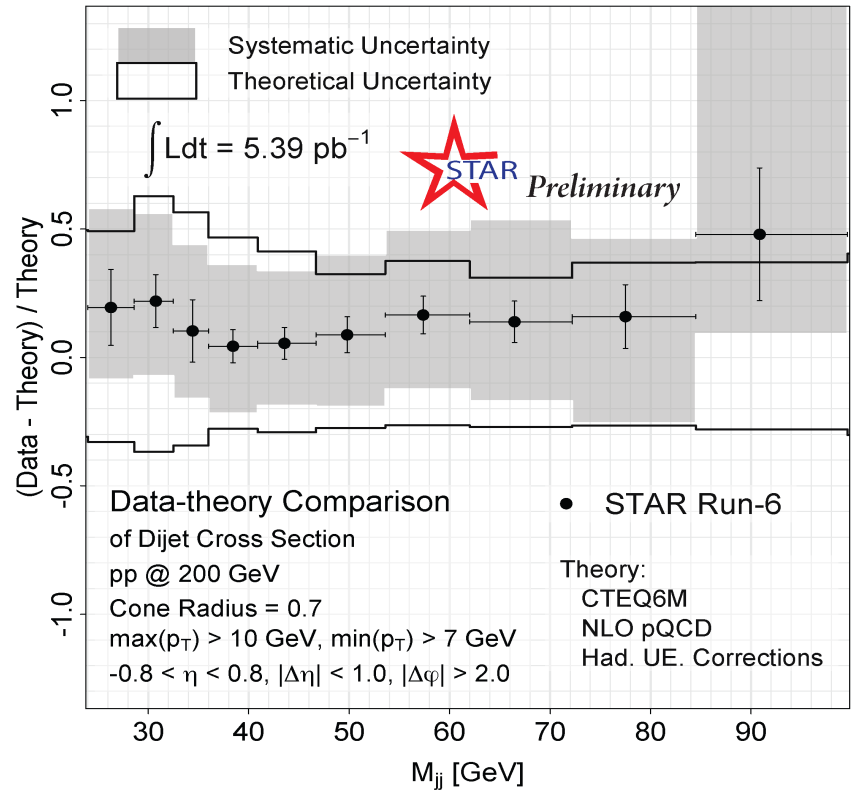
$$x_{1,2} = \frac{1}{\sqrt{s}}\left(p_{T3}e^{\pm\eta_3} + p_{T4}e^{\pm\eta_4}\right)$$

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

- Inclusive probes at fixed p_T sample broad *x* range ⇒ global analysis needed to disentangle shape of $\Delta g(x)$
- Reconstructing dijet final state (jet p_T and η) provides information on initial parton kinematics ($x_{1,2}$ and cosθ*) at LO
- The large acceptance of STAR is well suited for correlation measurements and full jet reconstruction

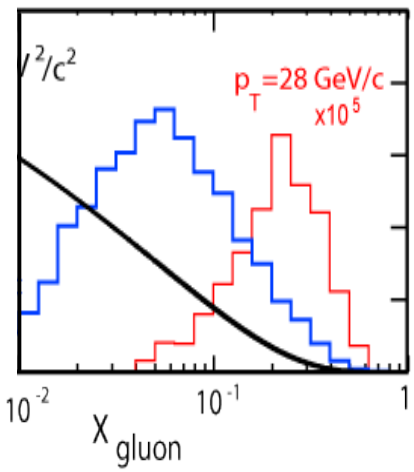
2006 dijet cross section @ 200 GeV

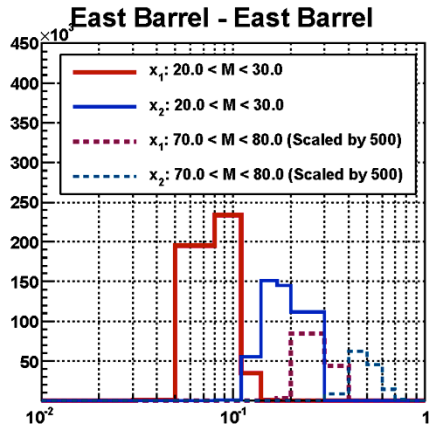


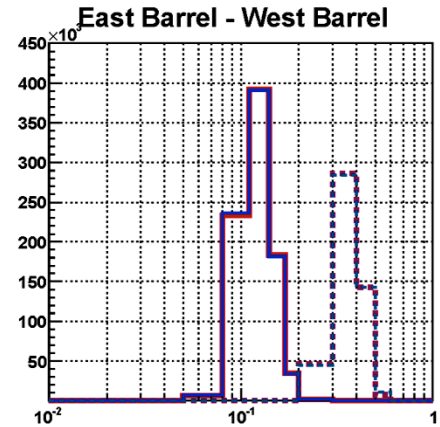


- Data shows good agreement with NLO pQCD + CTEQ6M including Hadronization + Underlying Event Corrections

2009 200GeV dijet partonic coverage







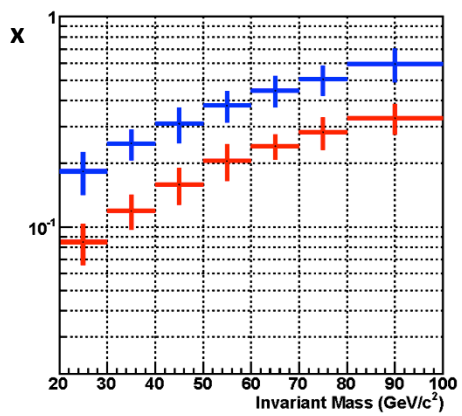
$$x_1 = \frac{1}{\sqrt{s}}\left(p_{T,3}e^{\eta_3} + p_{T,4}e^{\eta_4}\right)$$

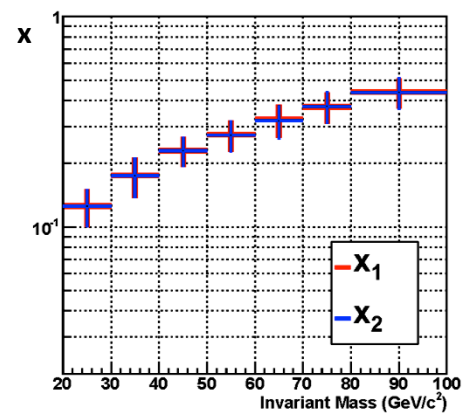
$$x_2 = \frac{1}{\sqrt{s}}\left(p_{T,3}e^{-\eta_3} + p_{T,4}e^{-\eta_4}\right)$$

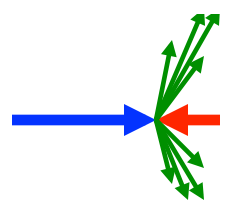
$$M = \sqrt{x_1 x_2 s}$$

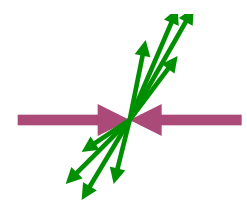
$$y = \frac{1}{2}\ln\frac{x_1}{x_2} = \frac{\eta_3 + \eta_4}{2}$$

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



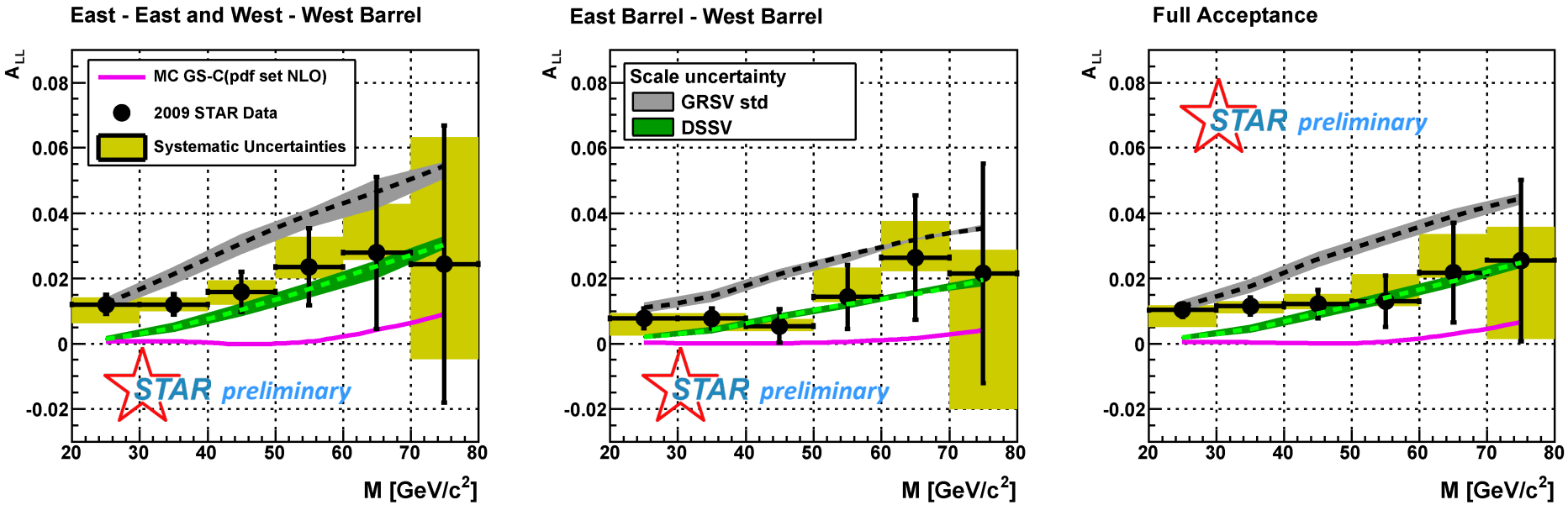


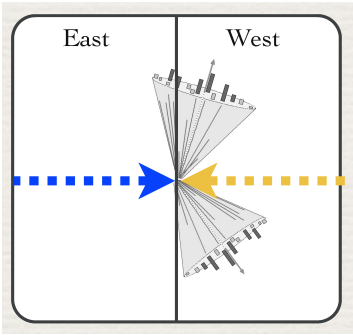


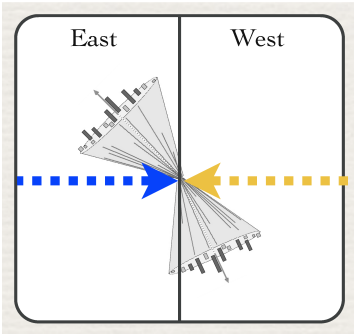


2009 dijet A_{LL} @ 200GeV

arXiv:1107.0917

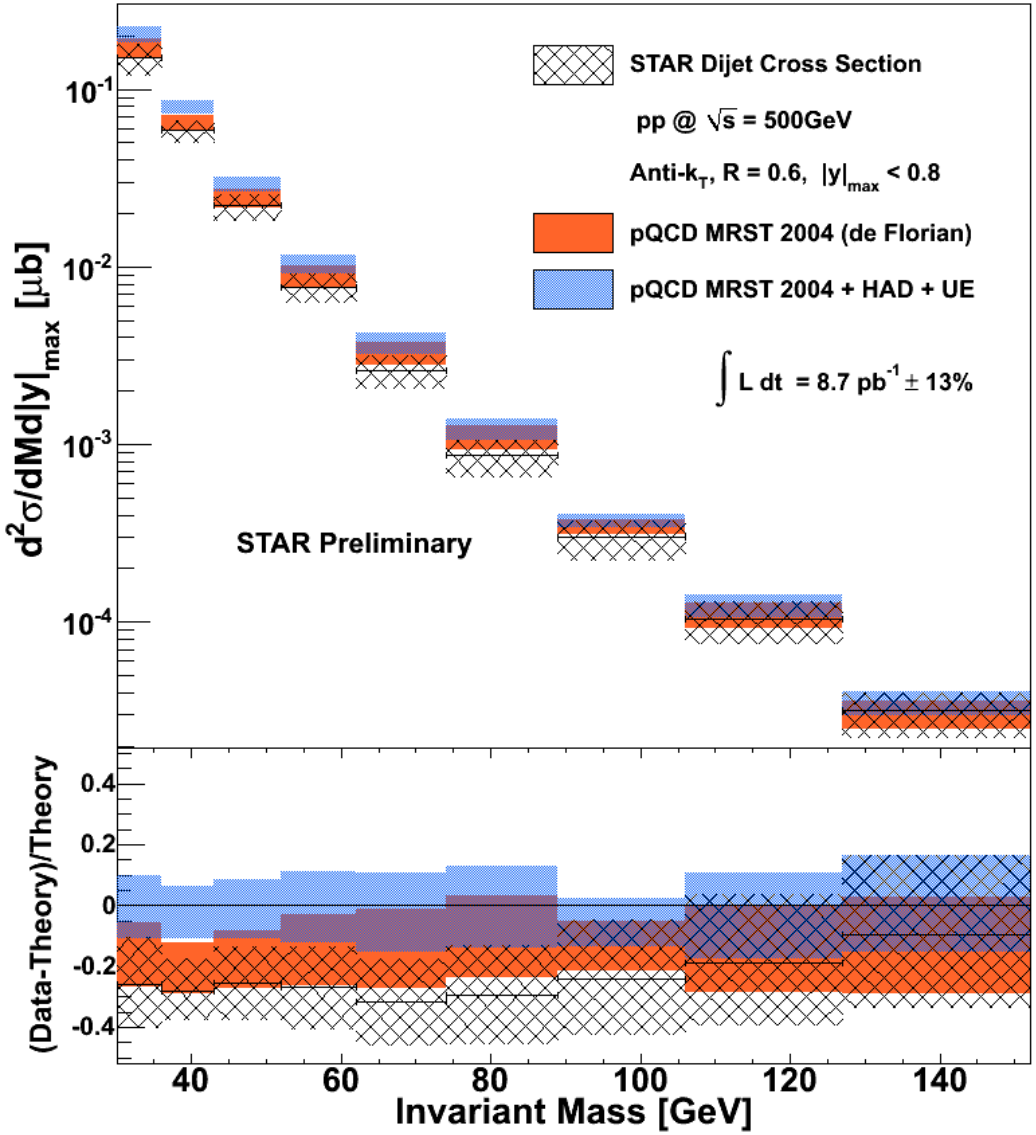






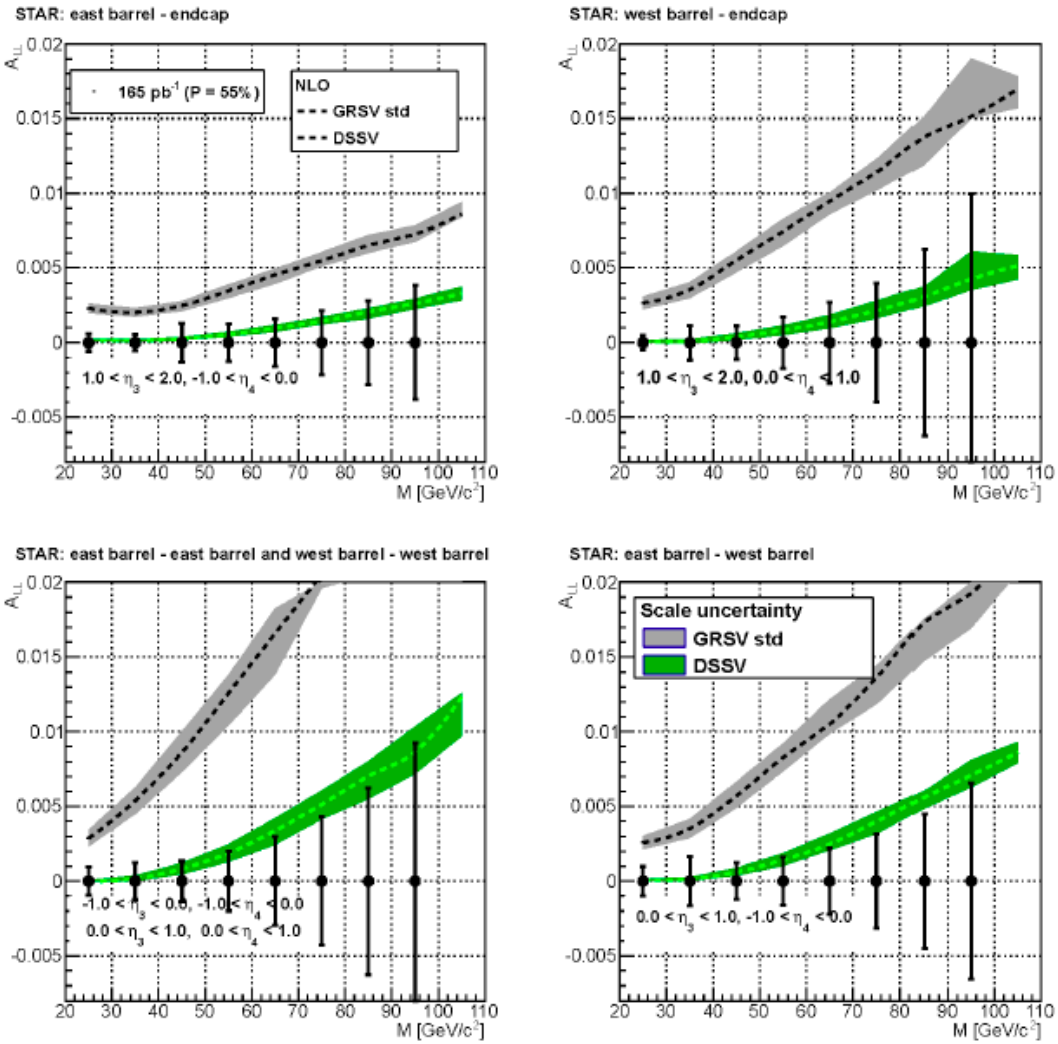
- STAR data fall between predictions of **DSSV** and **GRSV-STD**

2009 dijet cross section @ 500 GeV



- STAR has measured the proton-proton dijet cross section at 500 GeV using the anti-k_T algorithm
- Experimental measurement is systematically lower than theoretical predictions, but show good agreement within systematic errors

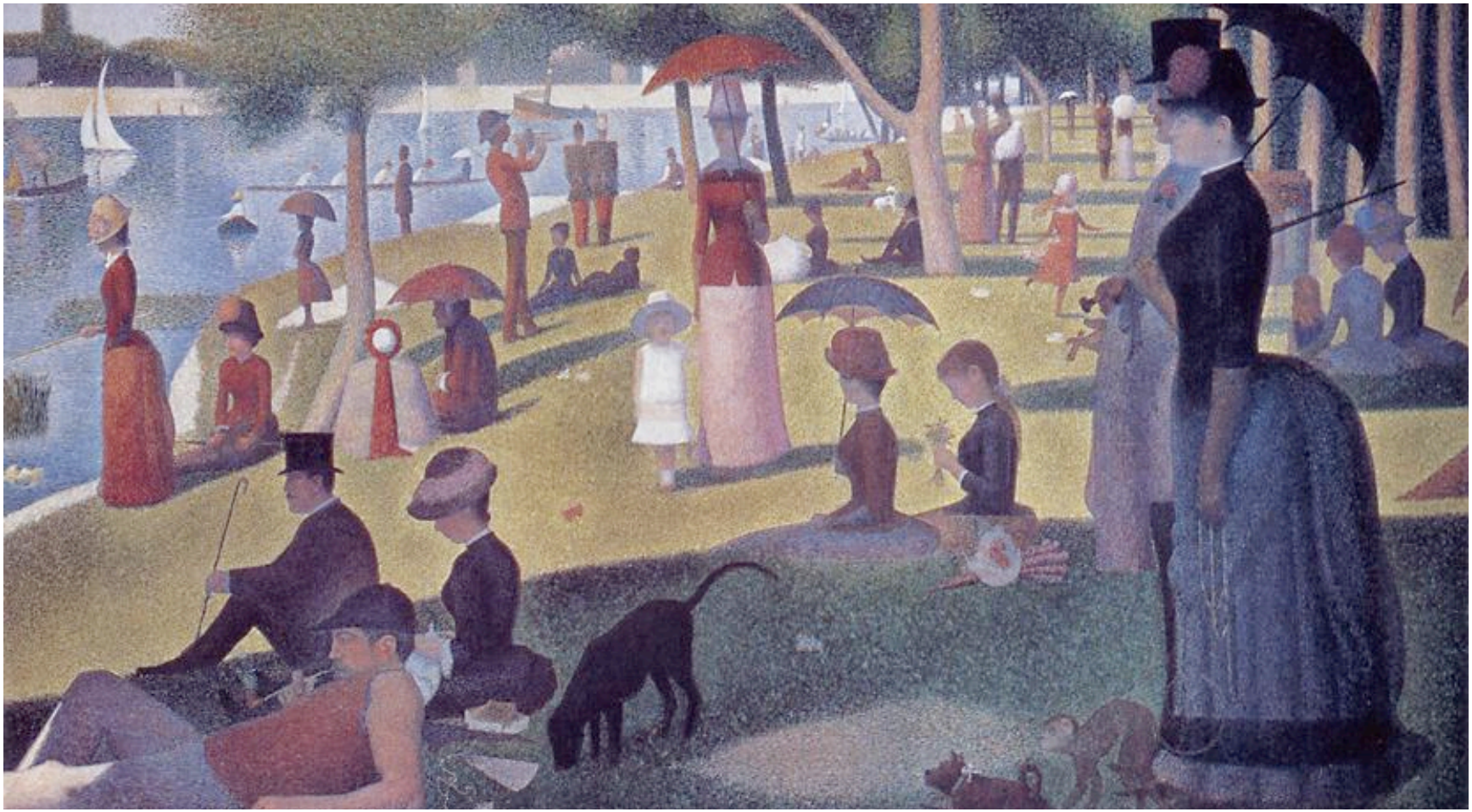
Projected sensitivity for dijet A_{LL} at 500 GeV



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

- Higher energy accesses lower x_g
- Expect smaller A_{LL}
- Projections show expected sensitivity for the recently completed 2013 run

Conclusions

- The π^0 cross section has been measured and has established a basis for future π^0 measurements in a unique intermediate η region
- The 2006 and 2009 STAR data has placed significant constrains on ΔG.
- The 2009 data verified the first experimental evidence of a non-zero value of ΔG.
- The stage is set for using 500 GeV data to access lower x regions
- Stay Tuned

Thank You