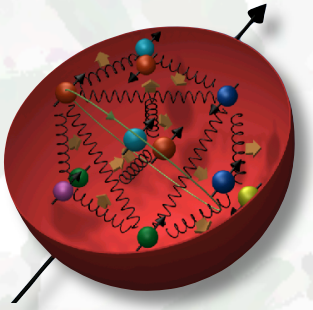
Exploring the Gluon Polarization with Inclusive and Correlation Measurements in Polarized p-p Collisions at RHIC

Bernd Surrow

Massachusetts Institute of Technology

On behalf of the STAR Collaboration



Outline

- Inclusive Measurements:

  Recent STAR Neutral and Charged Pion A_{LL} results

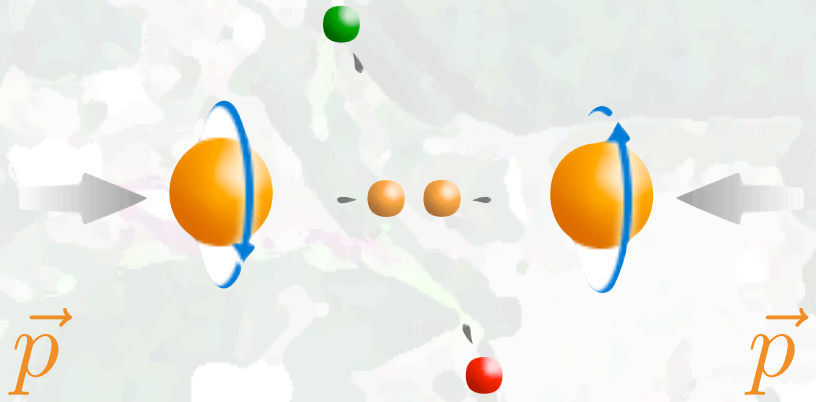
- Correlation Measurements:

  Status of STAR Di-Jet measurements

- Theoretical foundation:

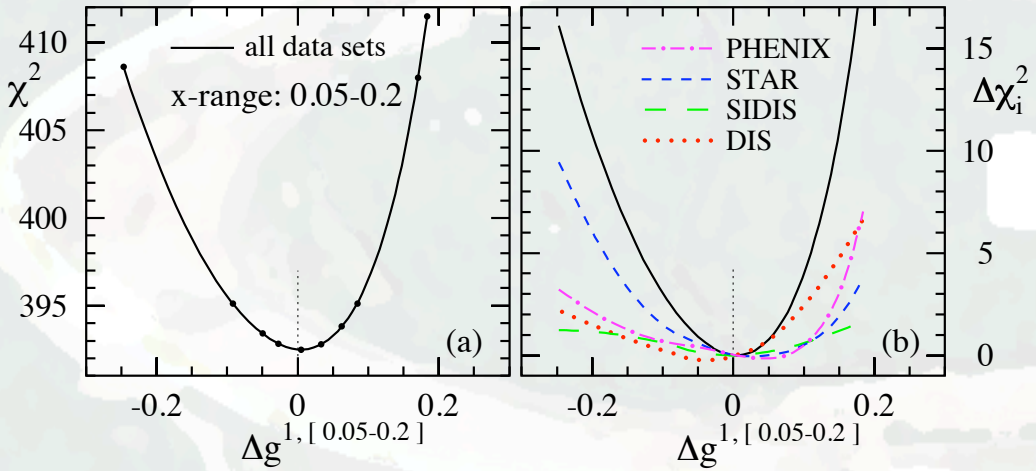
  Inclusive and correlation measurements

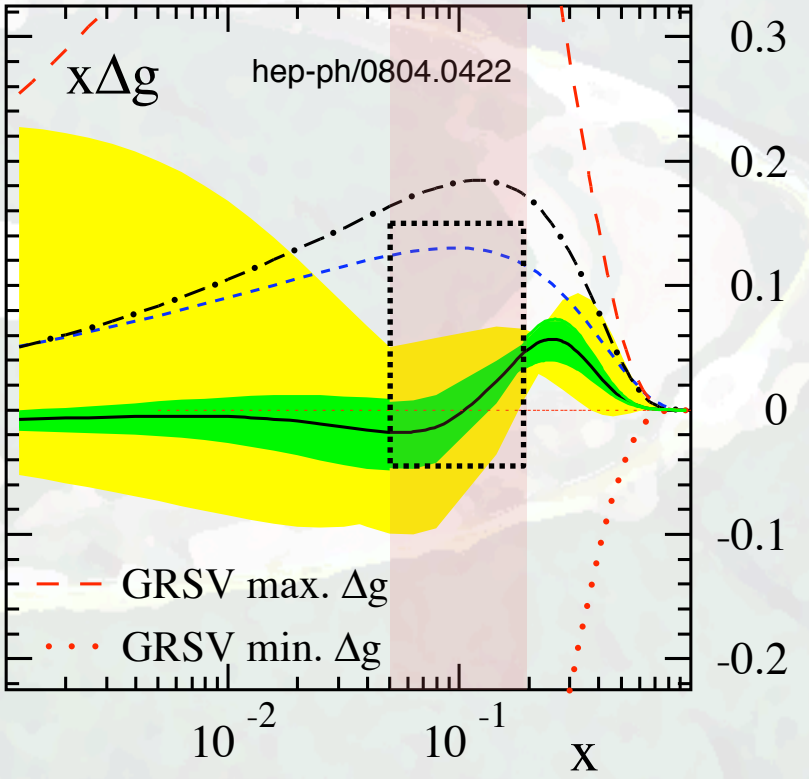
- Summary and Outlook



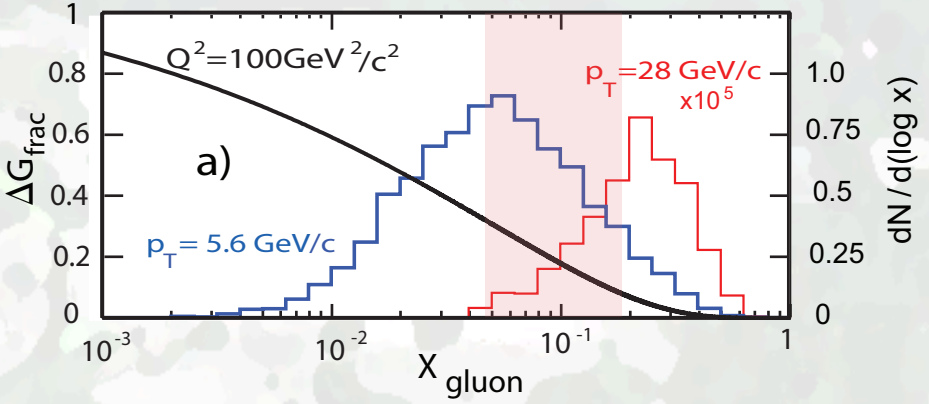
Theoretical foundation

- Global analysis incl. RHIC pp data



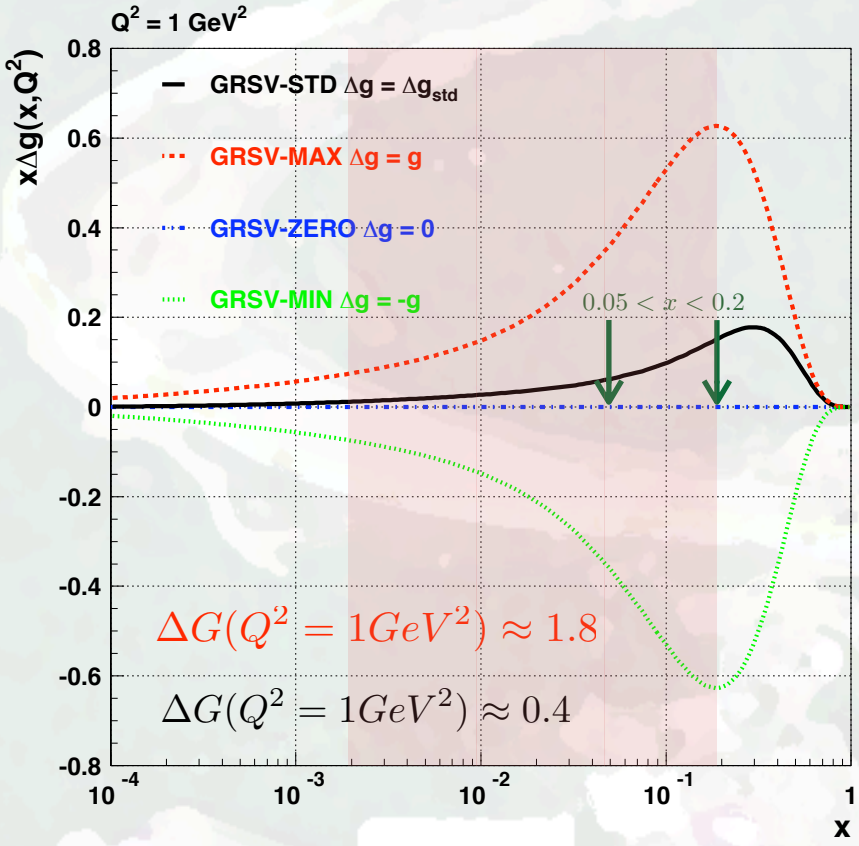


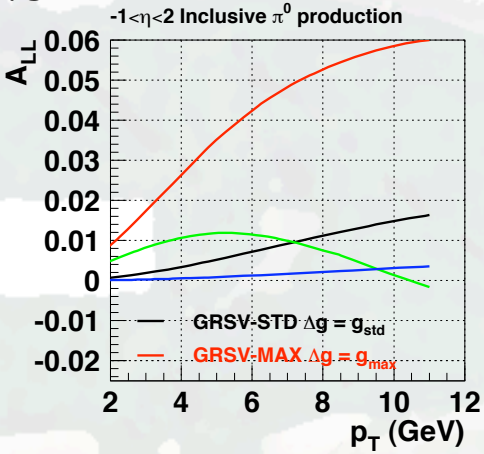
- Strong constraint on the size of Δg from RHIC data for 0.05<x<0.2
- Evidence for a small gluon polarization over a limited region of momentum fraction
- Important: Mapping of x-dependence and extension of x-coverage needed!

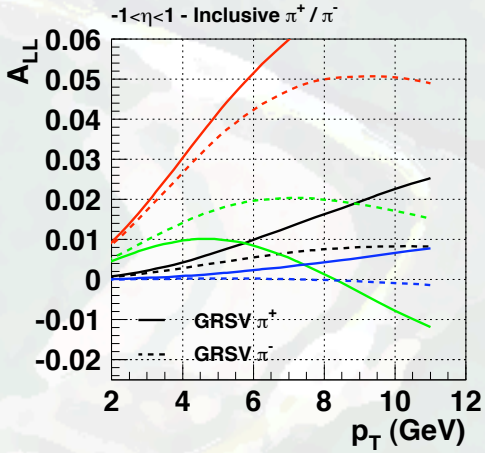


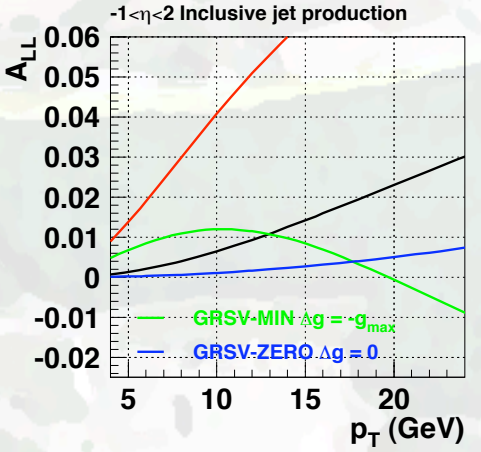
Theoretical foundation

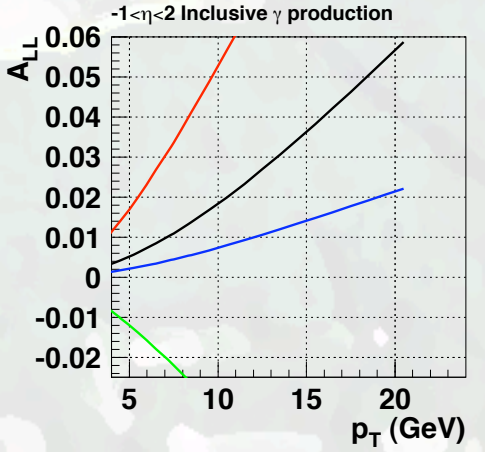
Gluon polarization - Inclusive Measurements











- Examine wide range in Δg: $-g < \Delta g < +g$
- GRSV-STD: Higher order QCD analysis of polarized DIS experiments!

$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2) dx$$

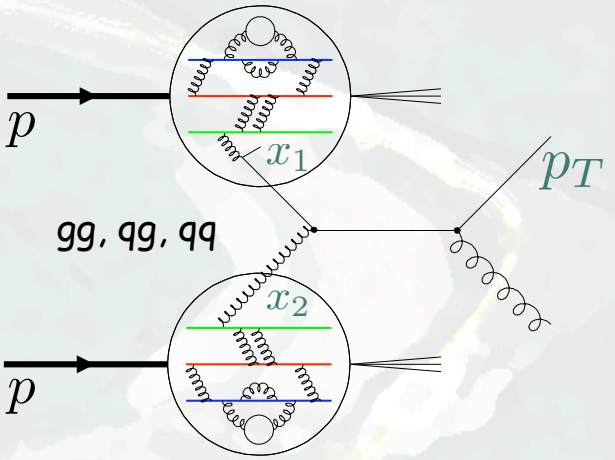
$$x_{\text{parton}} \simeq 2p_T/\sqrt{s}$$

(central rapidity)

Theoretical foundation

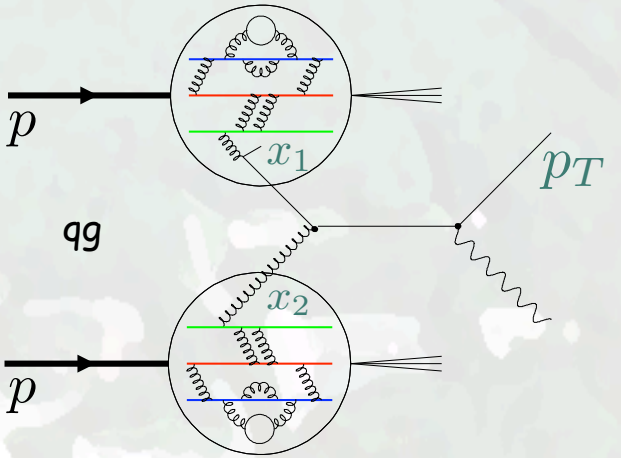
- Gluon polarization - Correlation Measurements
  - Correlation measurements provide access to partonic kinematics through Di-Jet/Hadron production and Photon-Jet production

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



Di-Jet production

  - Di-Jet production / Photon-Jet production
    - Di-Jets: All three (LO) QCD-type processes contribute: gg, qg and qq with relative contribution dependent on topological coverage
    - Photon-Jet: One dominant underlying (LO) process with large partonic a_{LL} at forward rapidity
    - Larger cross-section for di-jet production compared to photon related measurements
    - Photon reconstruction more challenging than jet reconstruction
    - Full NLO framework exists ⇒ Input to Global analysis



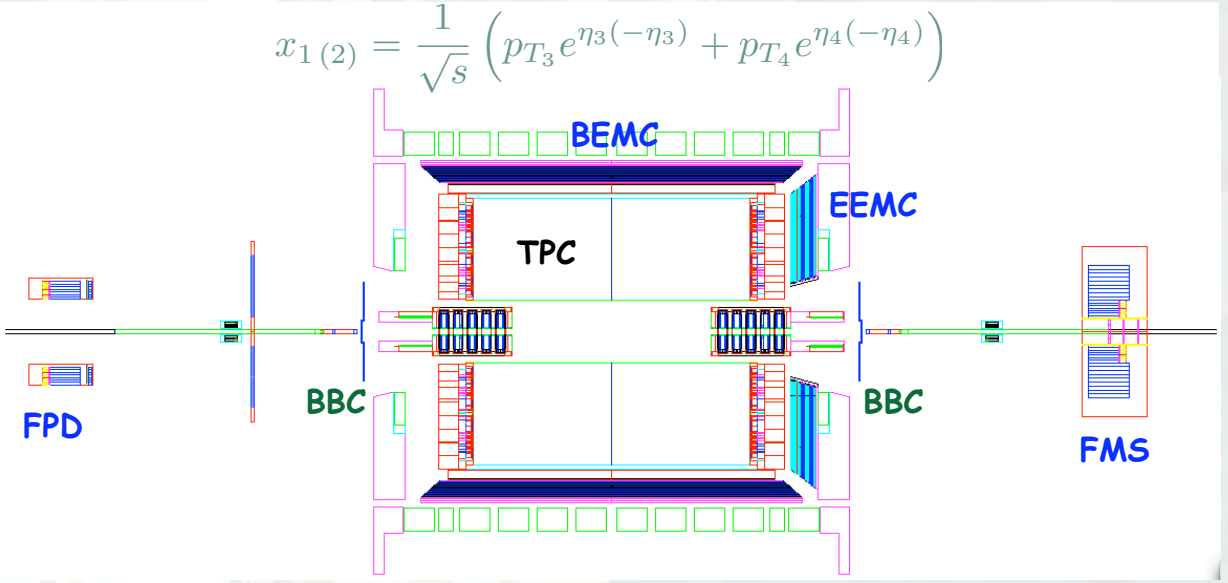
Photon-Jet production

The STAR Experiment

Overview

- Wide rapidity coverage of **STAR calorimetry (Jets /Neutral Pions / Photons) system:**
  - FPD: -4.1 < η < 3.3
  - BEMC: -1.0 < η < 1.0
  - EEMC: 1.09 < η < 2.0
  - FMS: 2.5 < η < 4.0

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

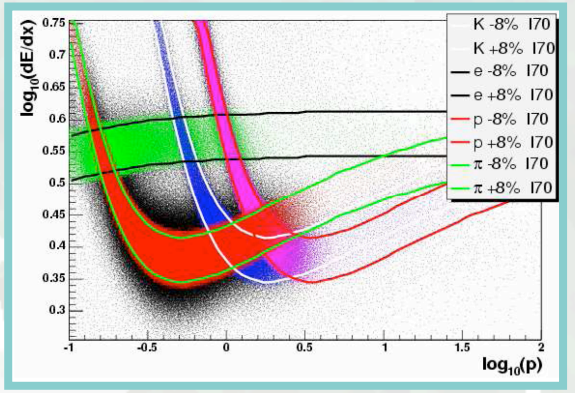


- **BBC**: Relative luminosity and Minimum bias trigger

Key elements for STAR Δg(x) program:

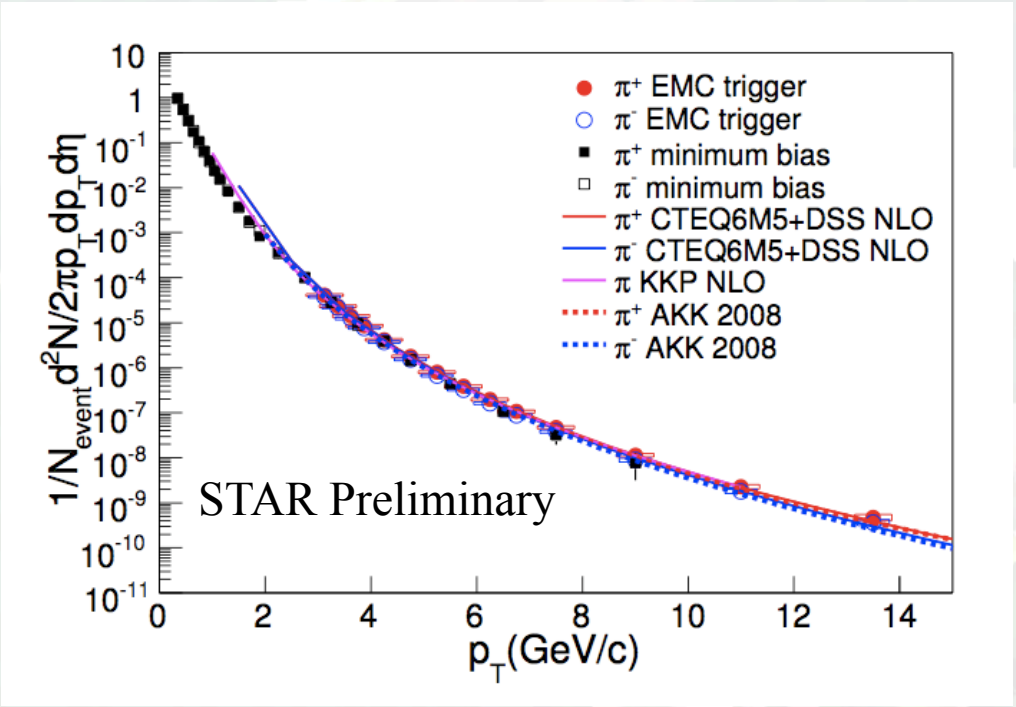
- Higher precision on Δg(x) : Luminosity / DAQ upgrade (DAQ 1000)
- Sensitivity to shape of Δg(x): Correlation measurements
- Low-x region of Δg(x): 500GeV program / Asymmetric collisions (Forward calorimetry)

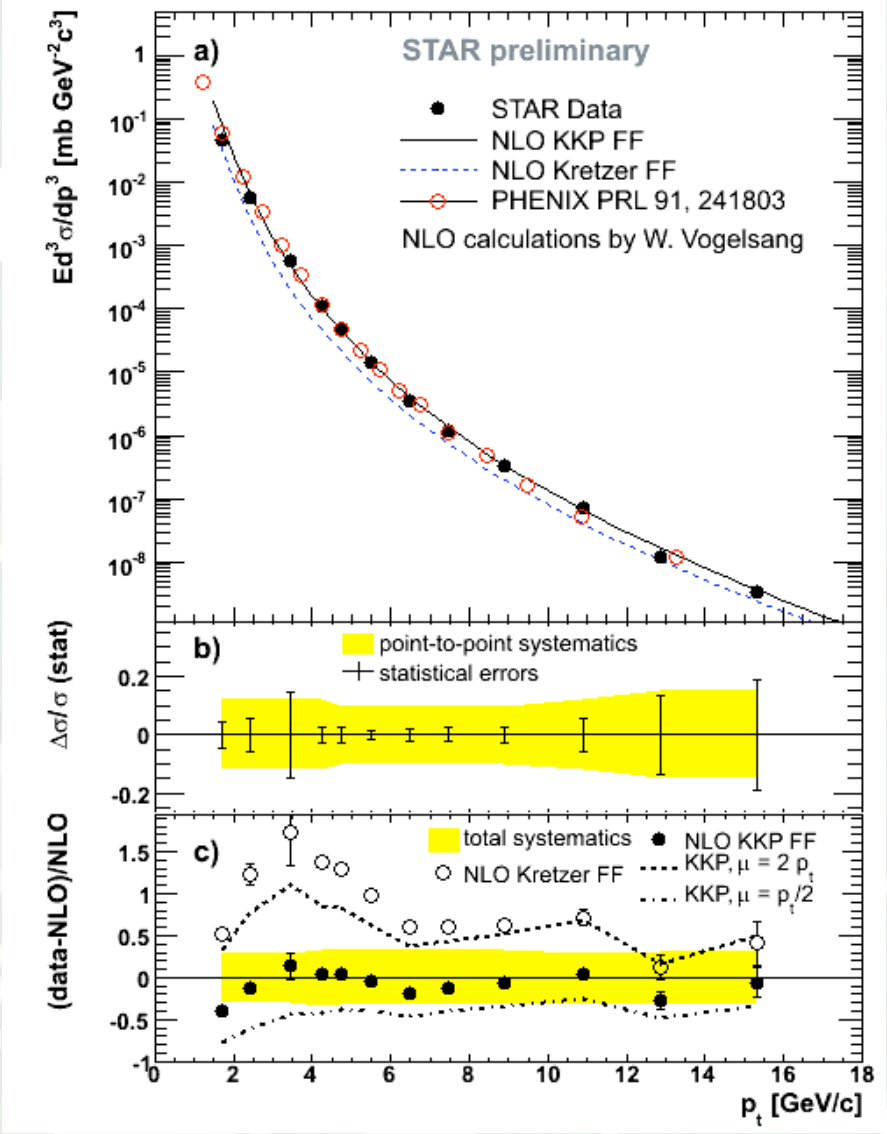
- **TPC**: Tracking and PID using dE/dx for |η| < 1.3 and p_T < 15 GeV/c



Recent results: Neutral / Charged Pion production

- STAR Run 5 Cross-section results: Mid-rapidity charged and neutral pion production

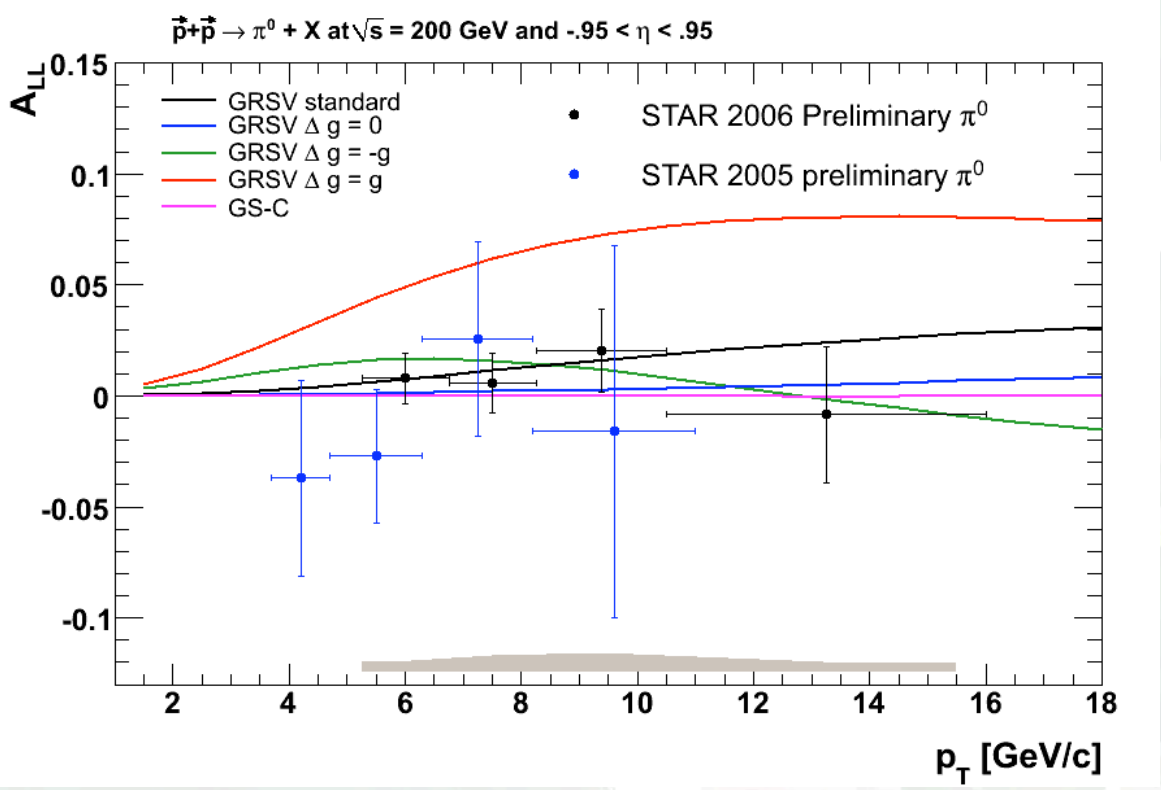




- Sophisticated TPC (dE/dx) calibrations improve precision at high p_T (arXiv:0807.4303-physics)
- Good agreement between data and NLO calculations for charged and neutral pion production

Recent results: Neutral / Charged Pion production

- STAR Run 5 / 6 A_{LL} result: Mid-rapidity neutral pion production



$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2) dx$$

$\Delta G(Q^2 = 1GeV^2) \approx 1.8$

$\Delta G(Q^2 = 1GeV^2) \approx 0.4$

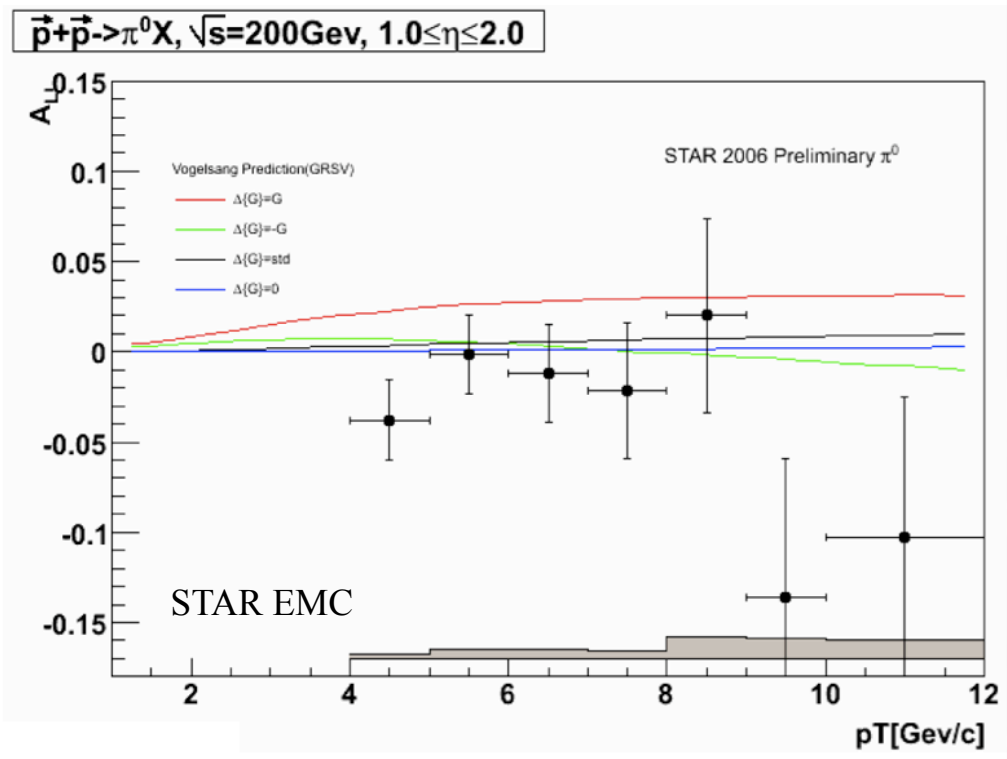
$\Delta G(Q^2 = 1GeV^2) \approx 1.0$

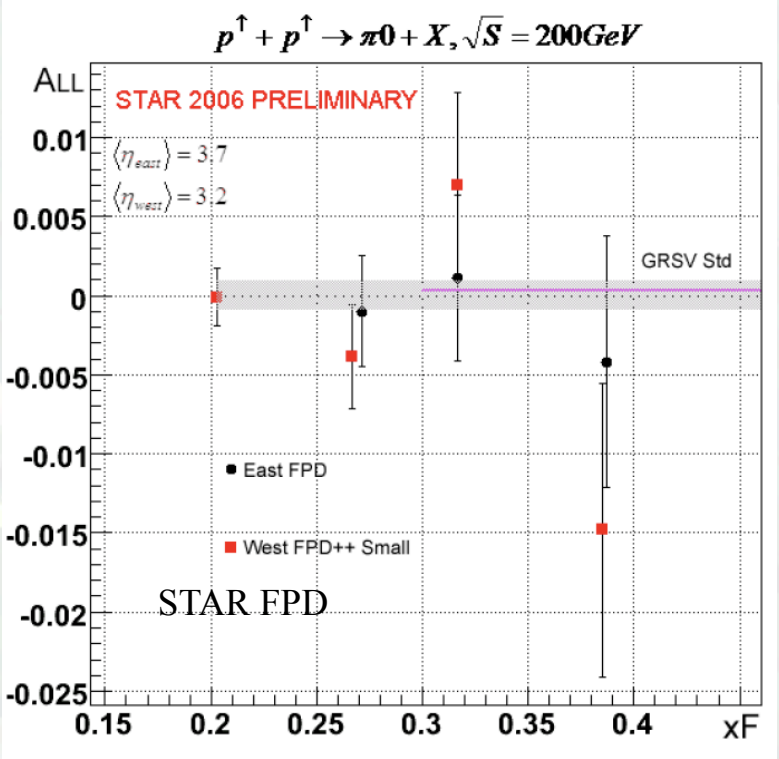
p_T range [GeV/c]	A_{LL} ± Stat. ± Sys.
5.2 - 6.75	0.0080 ± 0.0115 ± 0.002
6.75 - 8.25	0.0058 ± 0.0136 ± 0.004
8.25 - 10.5	0.0203 ± 0.0189 ± 0.004
10.5 - 16.0	-0.0084 ± 0.0306 ± 0.002

- RUN 6 results: GRSV-MAX ruled out
- Significant increase in statistical precision as well as greater p_T reach compared to previous Run 5 Neutral Pion result

Recent results: Neutral / Charged Pion production

- STAR Run 6 A_{LL} result: Forward rapidity (FPD/EEMC) neutral pion production

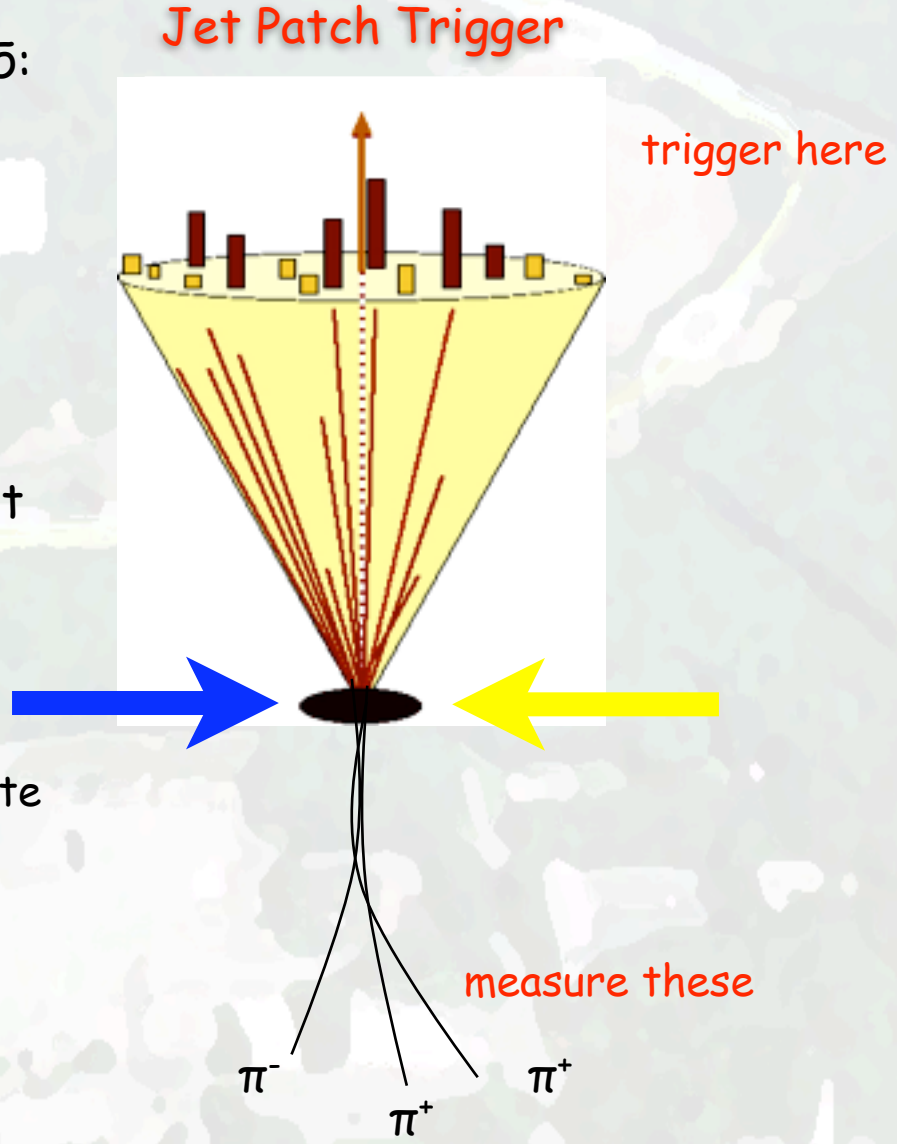




- First A_{LL} measurements at forward rapidity (STAR EEMC / STAR FPD)
- Probe small-x region (Probe smaller $\Delta g(x) \Rightarrow$ Smaller A_{LL} consistent with theoretical predictions)
- Important baseline measurements for STAR inclusive γ and γ-jet program

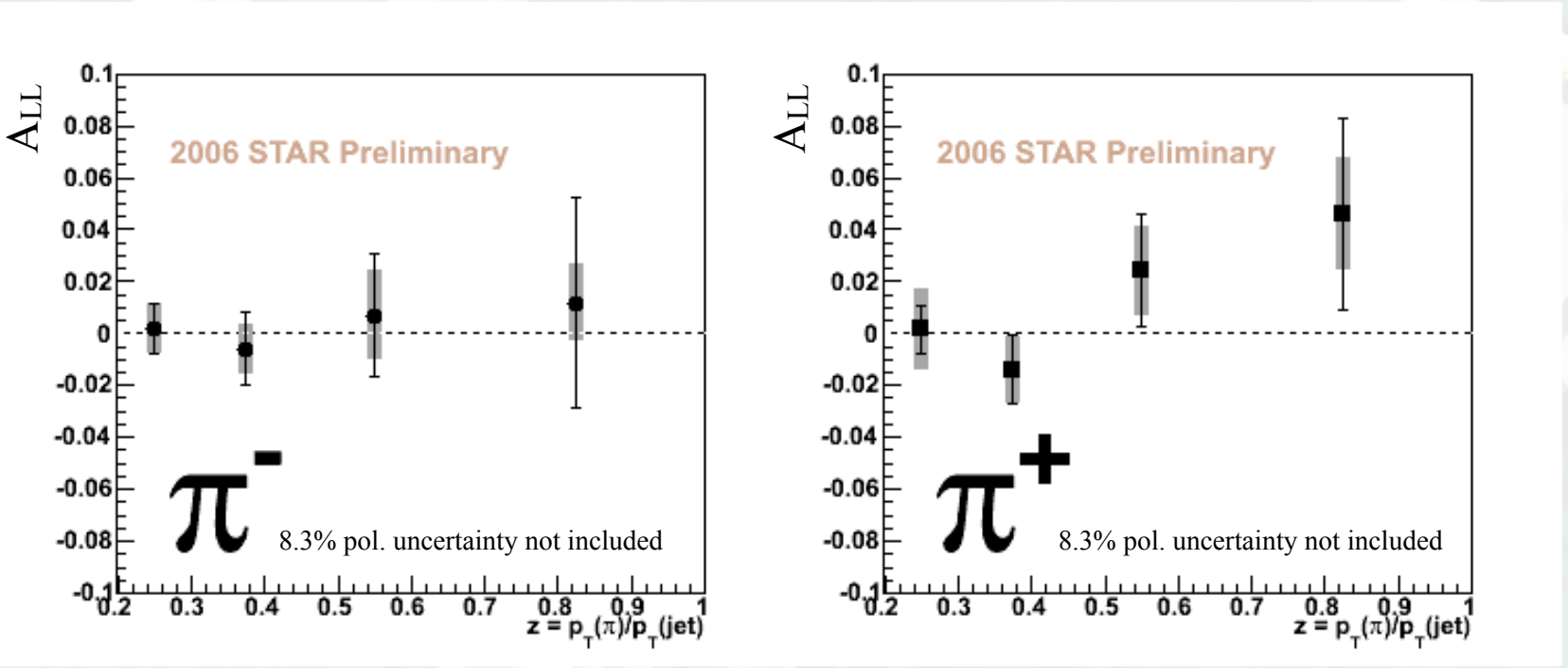
Recent results: Neutral / Charged Pion production

- STAR Run 6 A_{LL} result: Mid-rapidity charged pion production
  - Significant improvements compared to Run 5:
    - 50% ⇒ 60% beam polarization
    - 1.6 pb^{-1} ⇒ 5.4 pb^{-1}
    - BEMC η acceptance [0,1] ⇒ [-1,1]
  - But … increased JP trigger thresholds result in strong fragmentation bias for charged pions in trigger jet
    - Limit bias by measuring charged pions opposite a trigger jet
    - Plot asymmetry versus $z \equiv p_T(\pi) / p_T(\text{trigger jet})$ to cleanly isolate favored fragmentation



Recent results: Neutral / Charged Pion production

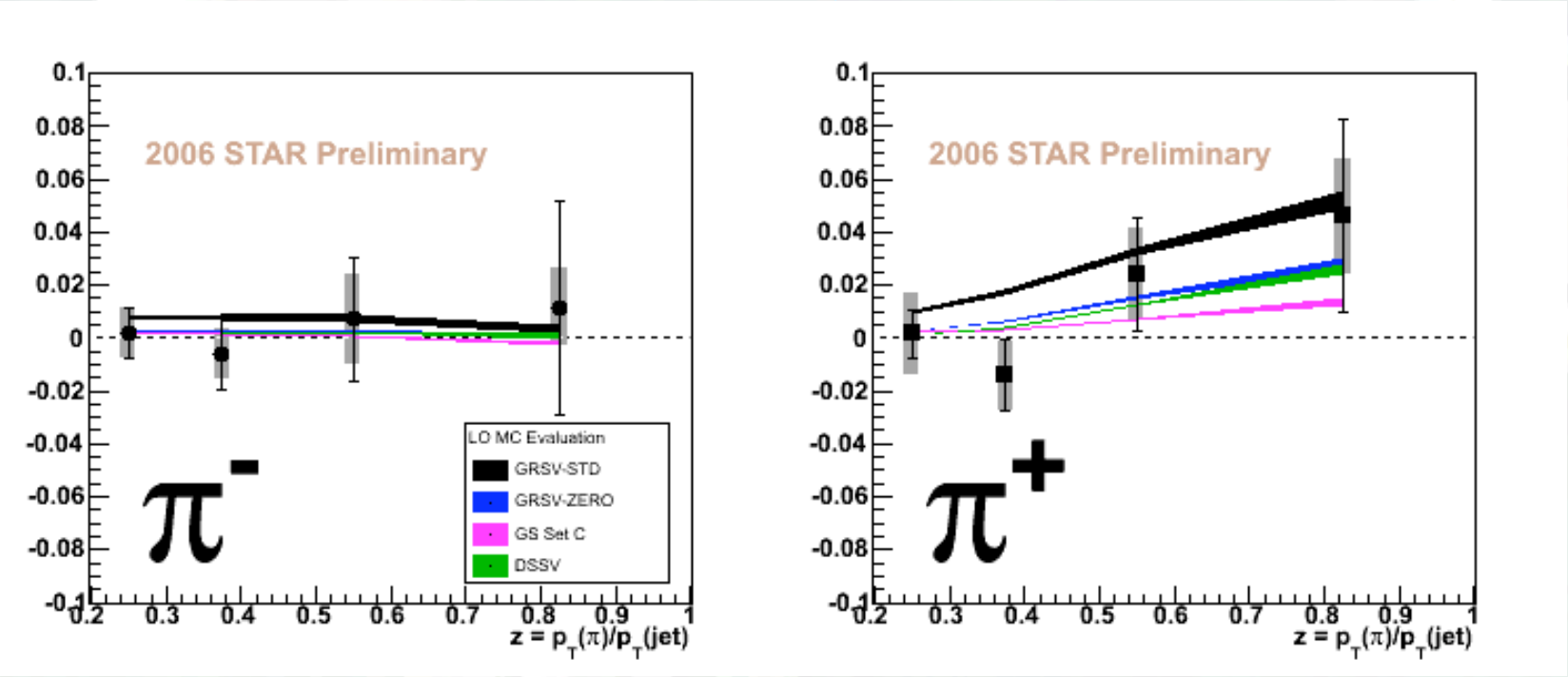
- STAR Run 6 A_{LL} result: Mid-rapidity charged pion production



- Conservative systematic uncertainties are evaluated for:
  - Trigger bias: 6 - 15 x 10^{-3}
  - PID background contamination: 2 - 10 x 10^{-3}
  - Uncertainty on the jet p_T shift: 3 - 16 x 10^{-3}
  - Non-longitudinal components, relative luminosity: small

Recent results: Neutral / Charged Pion production

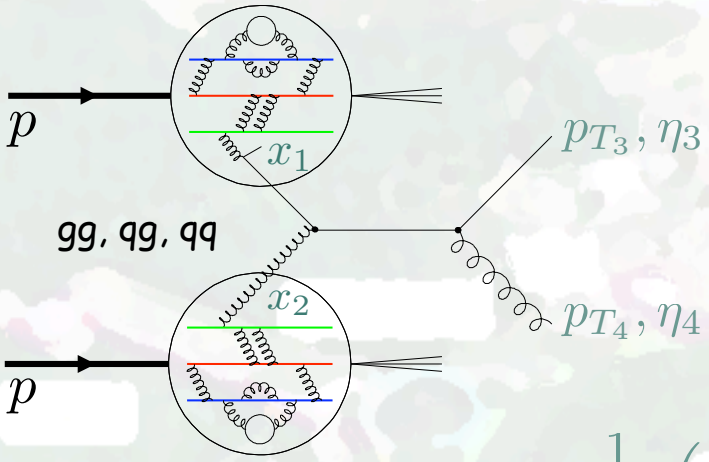
- STAR Run 6 A_{LL} result: Mid-rapidity charged pion production

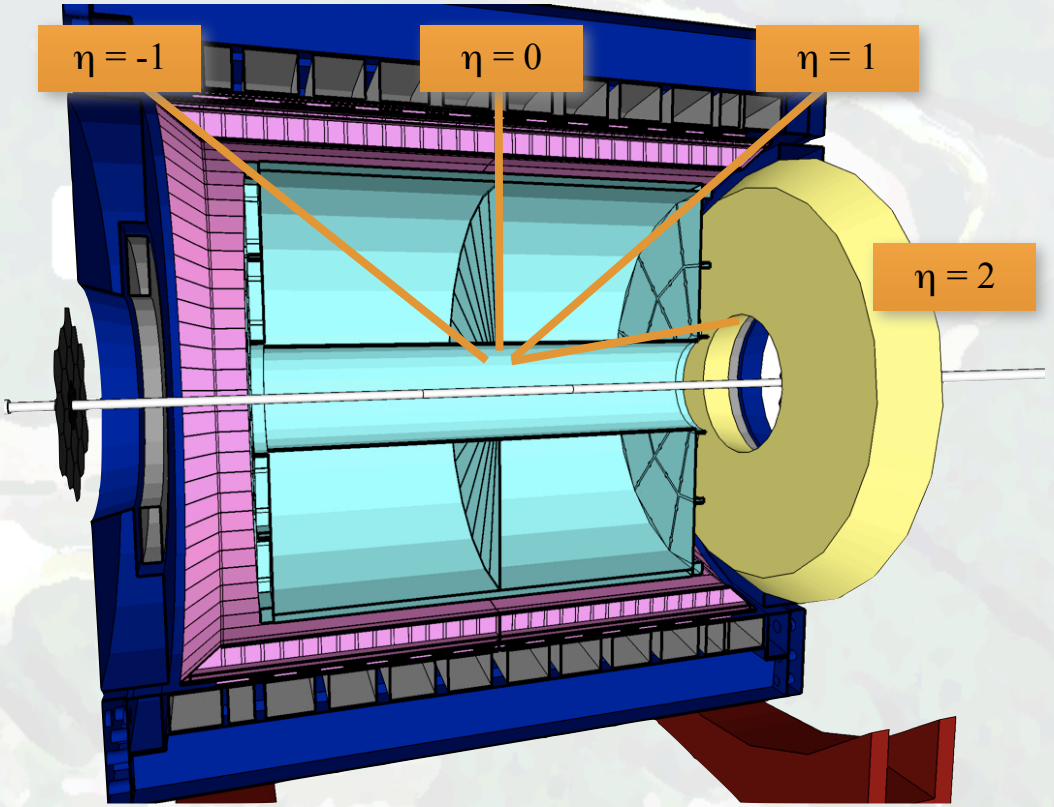


- Full NLO pQCD predictions are not yet available for this measurement
- These curves generated by sampling a_{LL} and parton distribution functions at kinematics of PYTHIA event.
- π^+ offers significant sensitivity at high z

Status of Di-Jet measurements

- Gluon polarization - Correlation Measurements
  - Correlation measurements provide access to partonic kinematics through Di-Jet/Hadron production and Photon-Jet production
  - 2-2 processes:





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

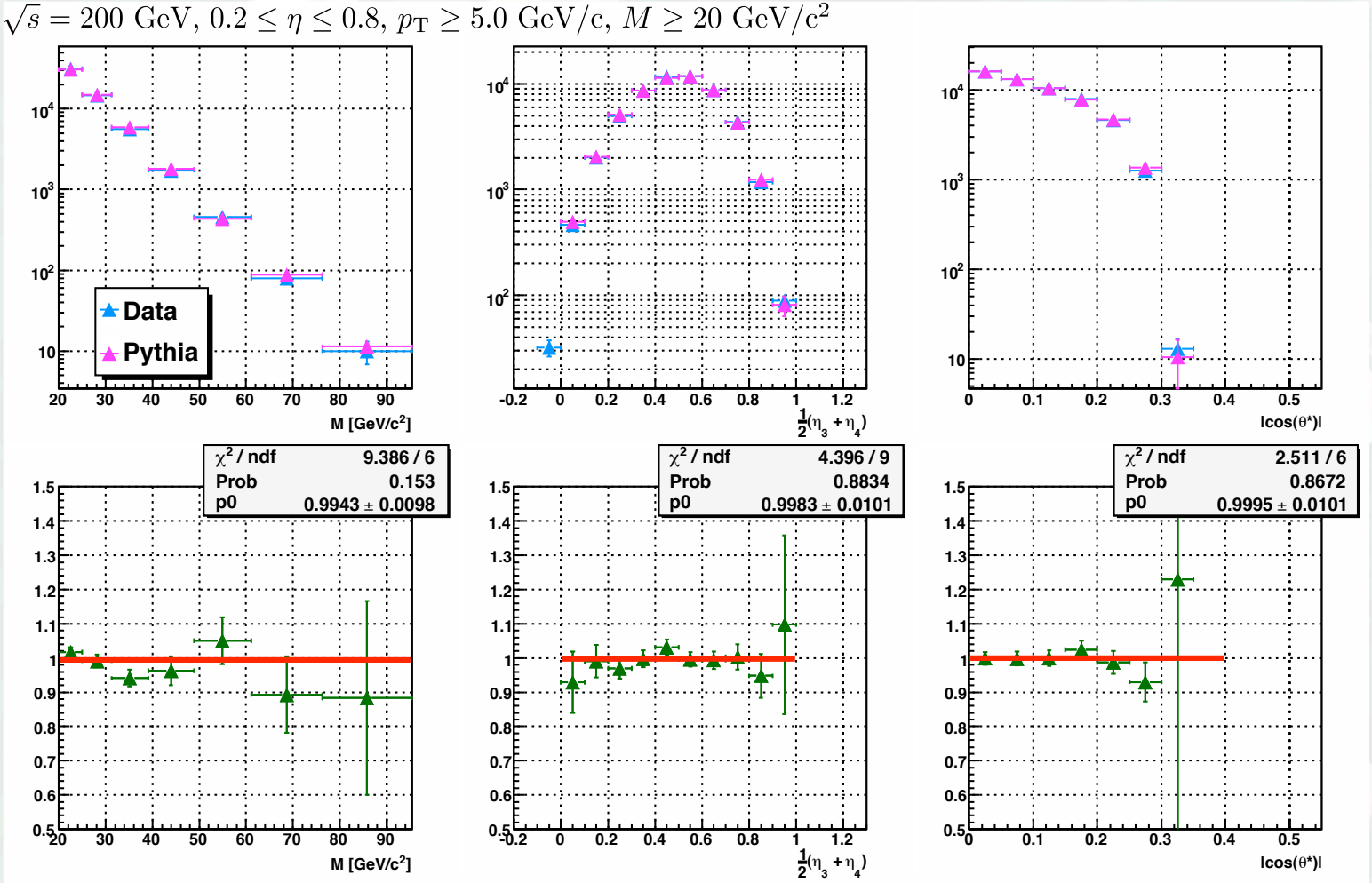
$$M = \sqrt{x_1 x_2 s}$$

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

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

Status of Di-Jet measurements

Correlation measurements: Di-Jet production - Data Understanding - Run 5

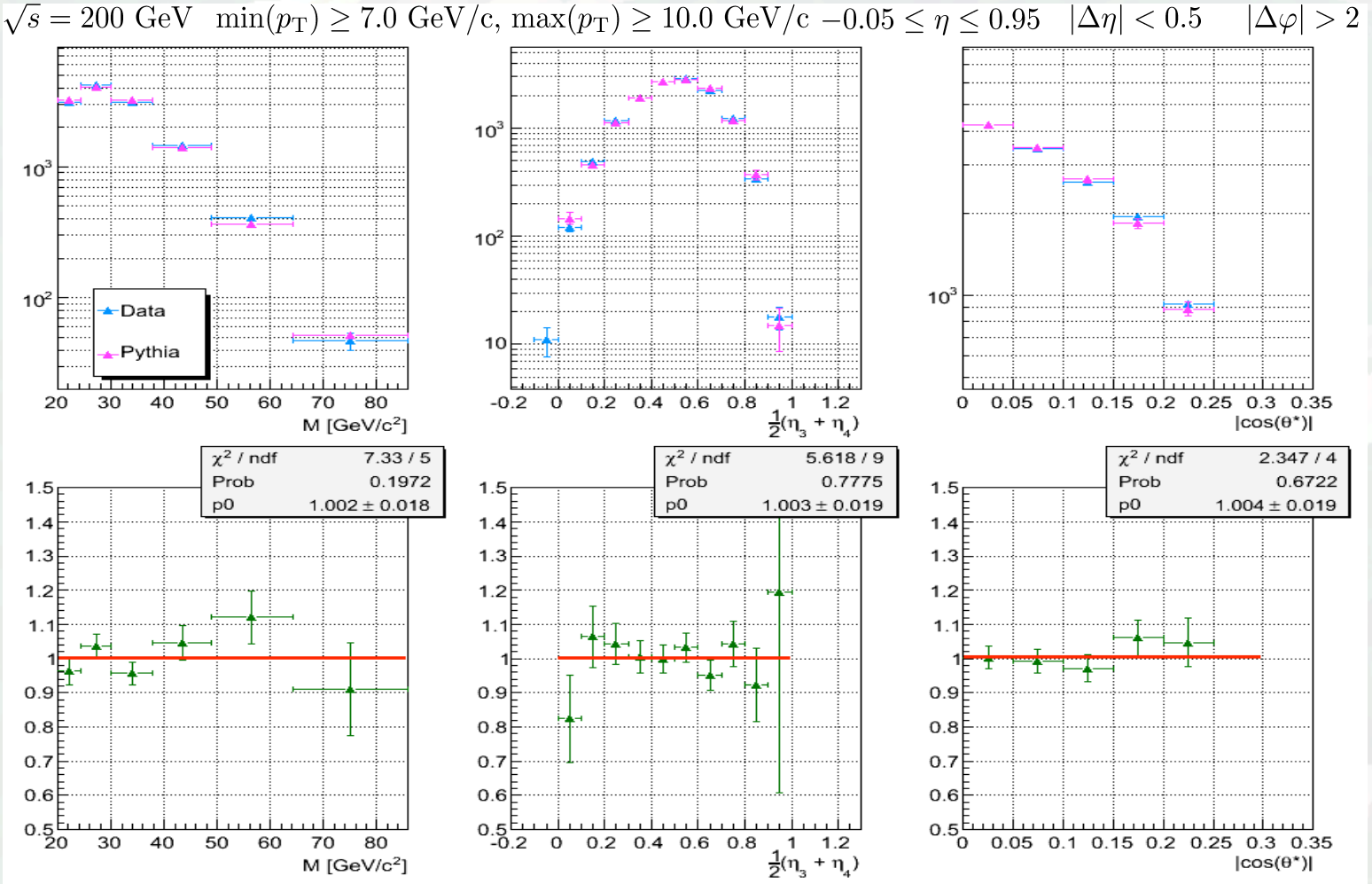


- Data/MC comparison complete - Good agreement in Di-Jet variables
- One normalization factor fixed by M distribution

$$M = \sqrt{x_1 x_2 s} \qquad \eta_3 + \eta_4 = \ln \frac{x_1}{x_2} \qquad \cos\theta^* = \tanh\left(\frac{\eta_3 - \eta_4}{2}\right)$$

Status of Di-Jet measurements

Correlation measurements: Di-Jet production - Data Understanding - Run 5

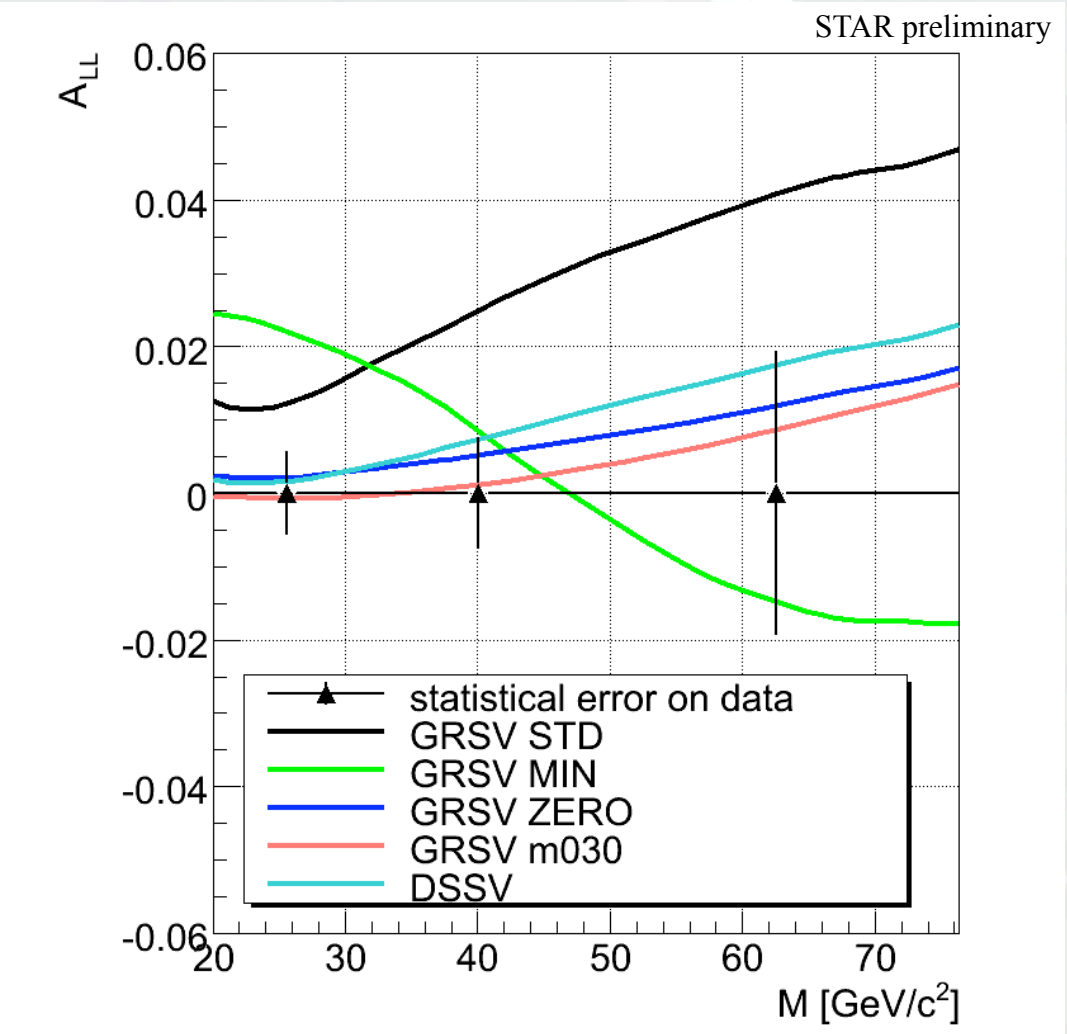


- Di-Jet distributions with asymmetric p_T cuts more appropriate for NLO comparison
- Direct comparison requires completion of hadronization and underlying event corrections

$$M = \sqrt{x_1 x_2 s} \qquad \eta_3 + \eta_4 = \ln \frac{x_1}{x_2} \qquad \cos\theta^* = \tanh\left(\frac{\eta_3 - \eta_4}{2}\right)$$

Status of Di-Jet measurements

- A_{LL} Run 6 reconstructed statistical uncertainties
  - Strong impact of Di-Jet A_{LL} based on Run 6 data on gluon polarization
  - Statistical uncertainties reconstructed from Run 6 data sample



$$M = \sqrt{x_1 x_2 s} \qquad \eta_3 + \eta_4 = \ln \frac{x_1}{x_2}$$

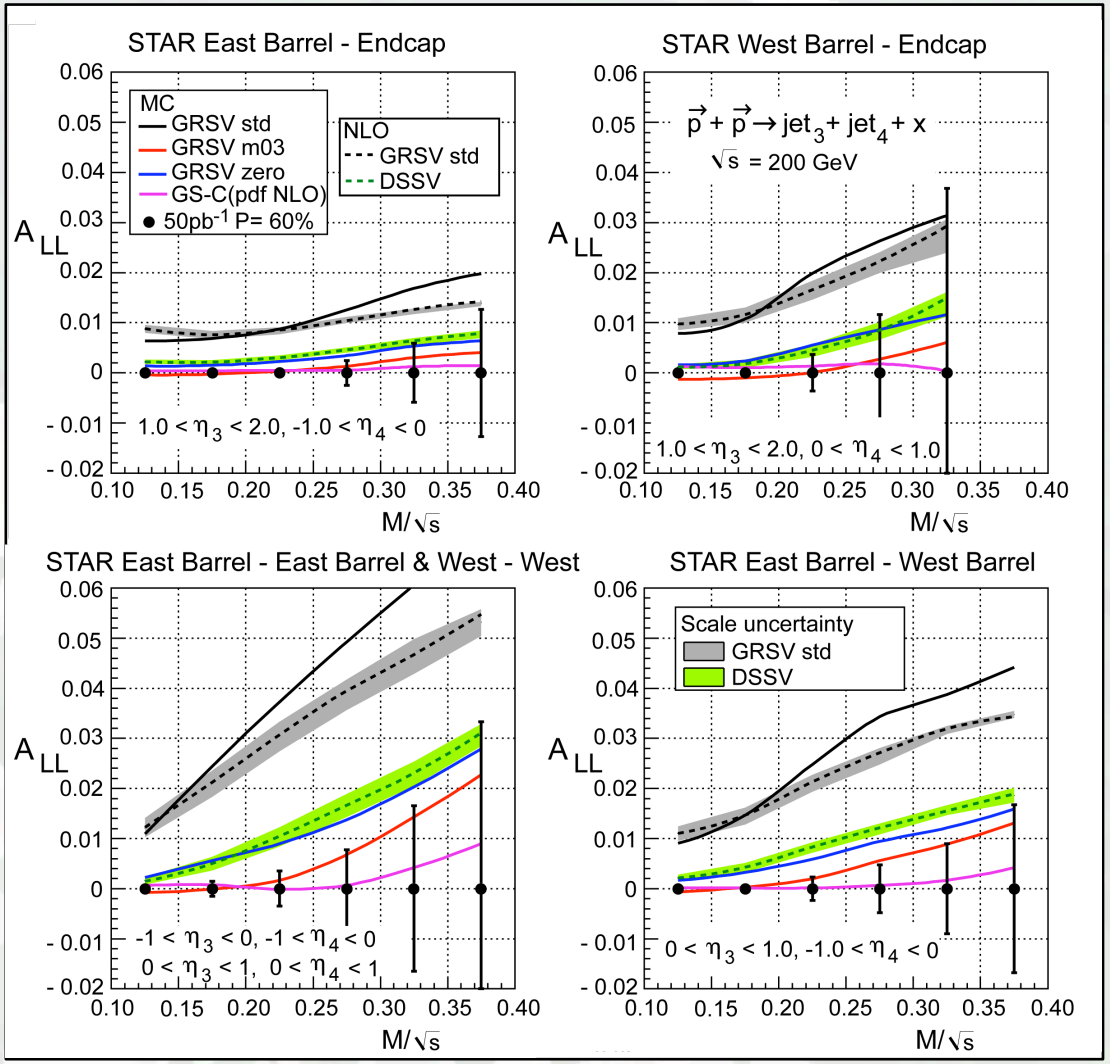
$\sqrt{s} = 200$ GeV, $-0.7 \leq \eta \leq 0.9$, $p_T \geq 5.0$ GeV/c, $M \geq 20$ GeV/c^2

Status of Di-Jet measurements

- Run 9 STAR Beam-Use Request: Di-Jet projections

  - Substantial improvement in Run 9 from Di-Jet production: 50pb^{-1} and 60% beam polarization

  - Good agreement between LO MC evaluation and full NLO calculations

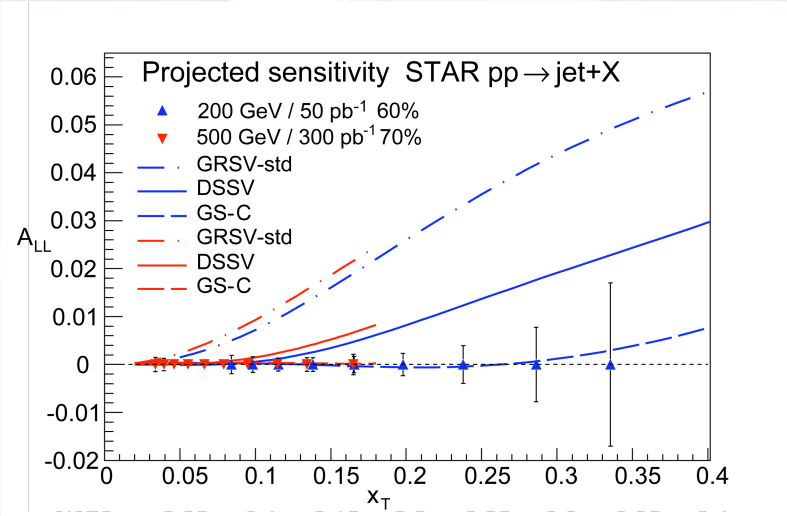


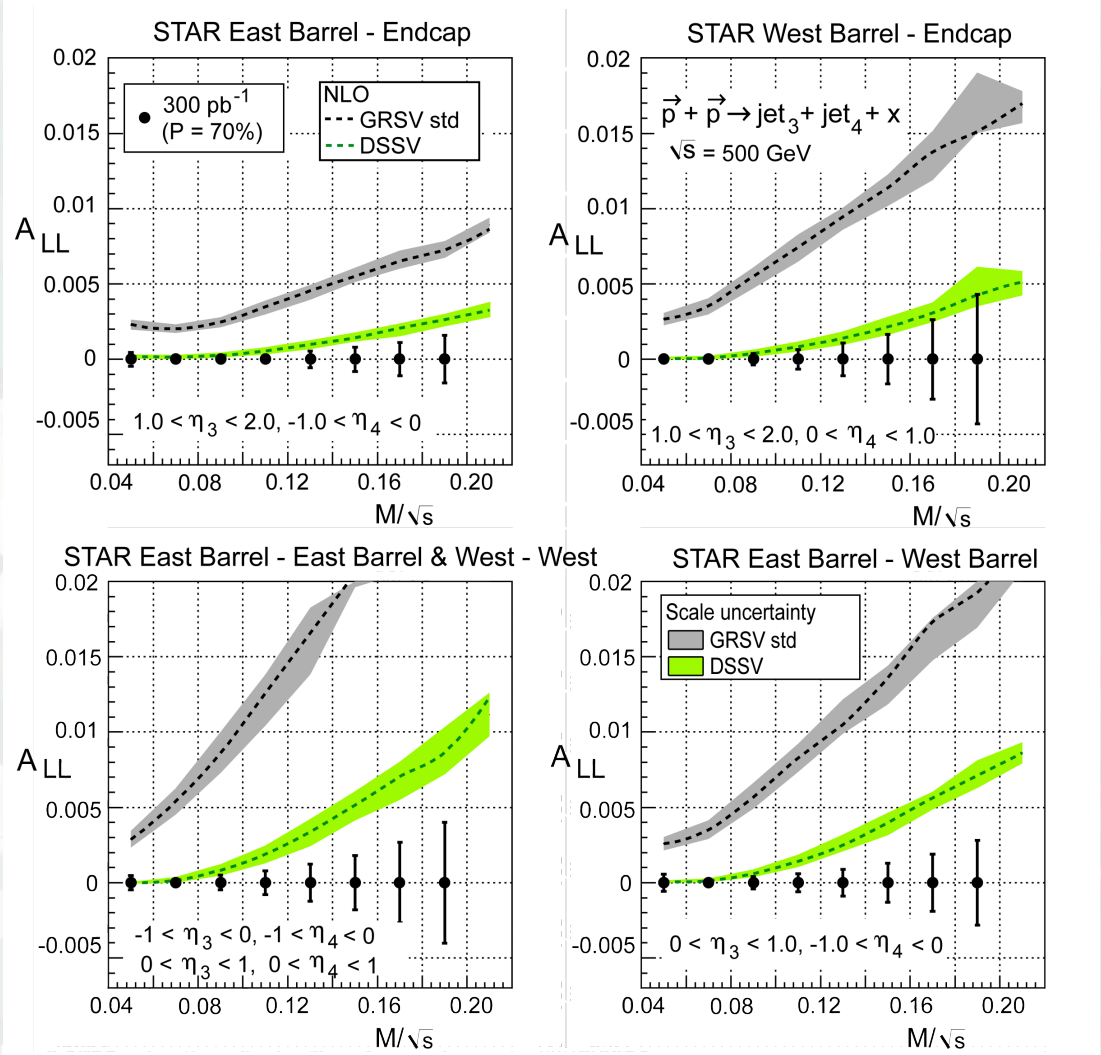
$$M = \sqrt{x_1 x_2 s} \qquad \eta_3 + \eta_4 = \ln \frac{x_1}{x_2}$$

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

Future prospects of low-x measurements

- STAR low-x program: 500GeV / Wide-rapidity coverage





- High precision at $\sqrt{s}$ = 500GeV at small x (W program demands large data sample ~300pb^{-1}) for
  - Inclusive channels (Here: Inclusive Jets)
  - Correlations measurements (Here: Di-Jets)

Summary and Outlook

Summary

- pQCD: Critical role to interpret measured asymmetries
- 2005 result: first spin asymmetry for neutral and charged pion production at STAR at mid-rapidity
- 2006 result: First A_{LL} result at forward rapidity / Improved precision at mid-rapidity / Improve π^+ analyzing power at high z
- Di-Jet cross-section and A_{LL} measurement in progress: Effects of, e.g. underlying event and hadronization corrections, are being evaluated
- Correlation measurements (Di-Jets / γ-Jets) will allow to provide needed constrain on the partonic kinematics
- 500GeV program together with wide rapidity coverage in STAR (-1<η<4) will allow to extend the currently measured kinematic region towards small-x (x ~ 10^{-3})