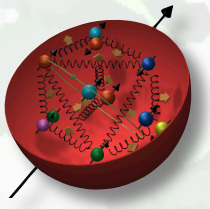
Exploring the Gluon Polarization with Inclusive and Correlation Measurements in Polarized Proton-Proton Collisions at RHIC

Bernd Surrow

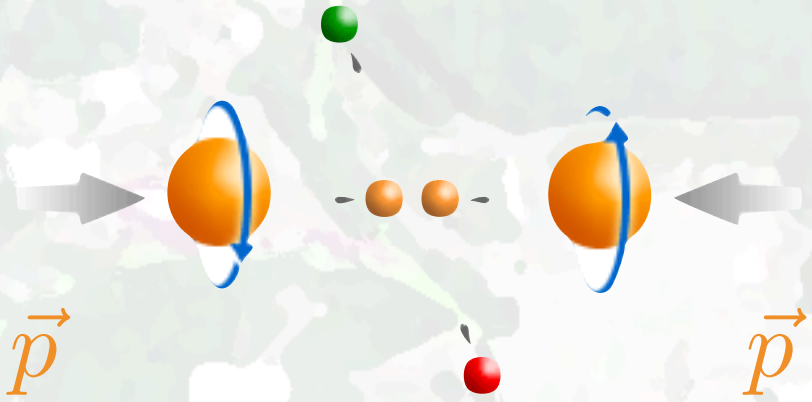
Massachusetts Institute of Technology

On behalf of the STAR Collaboration



Outline

- Experimental aspects: RHIC / STAR
- Inclusive Measurements: STAR Jet, Neutral and Charged Pion results
- Correlation Measurements: STAR Di-Jet Results
- Theoretical foundation: Inclusive and correlation measurements
- Summary Outlook



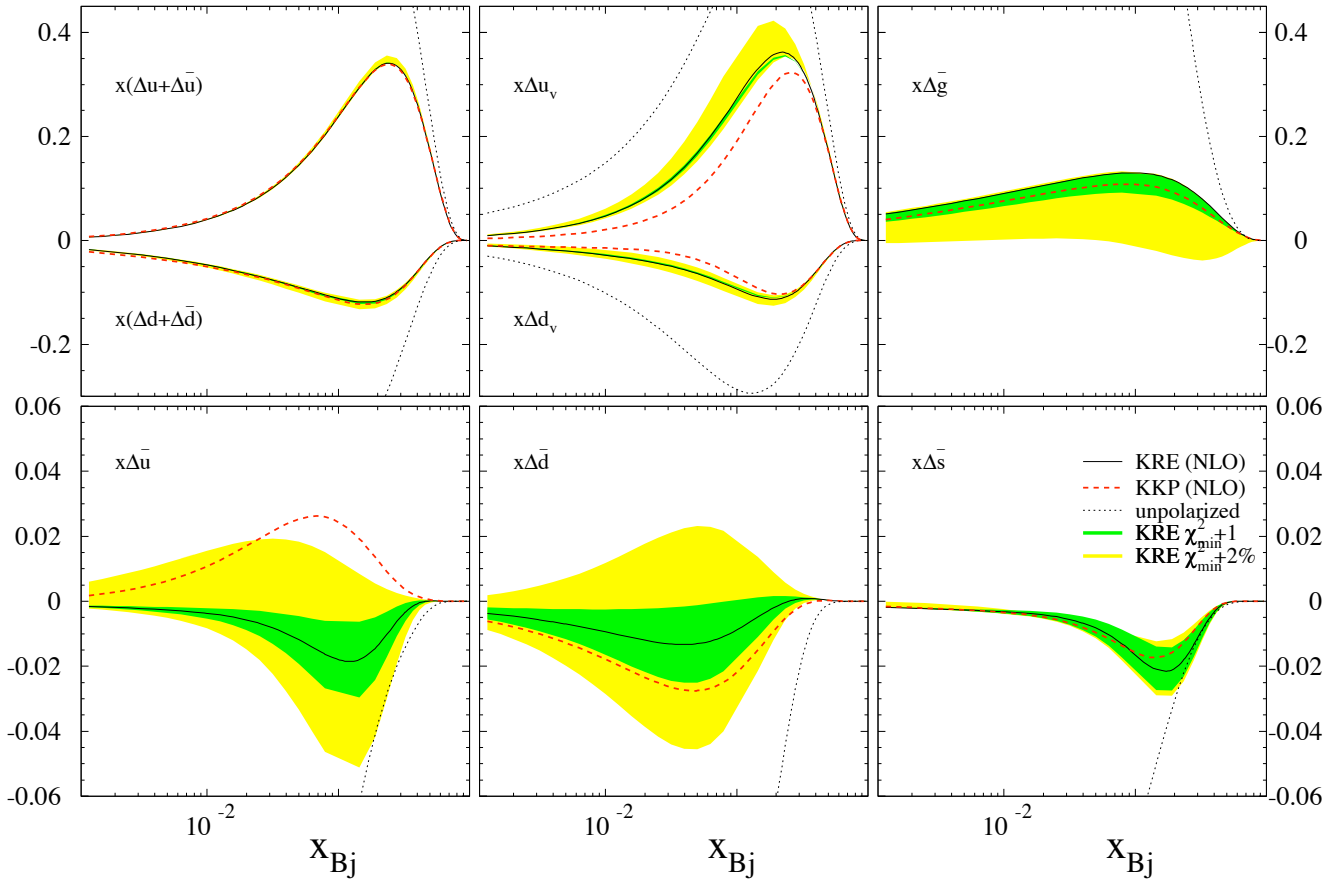
Theoretical foundation

- What do we know about the polarized quark and gluon distributions?
  - Spin carried by quarks is very small ($\Delta\Sigma \sim 0.3$)!

$$\underbrace{\frac{1}{2}\Delta\Sigma}$$

$$\frac{1}{2} = \langle S_q \rangle + \underbrace{\langle S_g \rangle + \langle L_q \rangle + \langle L_g \rangle}_{\Delta G}$$

$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$



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

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

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

$$\Delta q_i = [\Delta u, \Delta\bar{u}, \Delta d, \Delta\bar{d}, \Delta s, \Delta\bar{s}]$$

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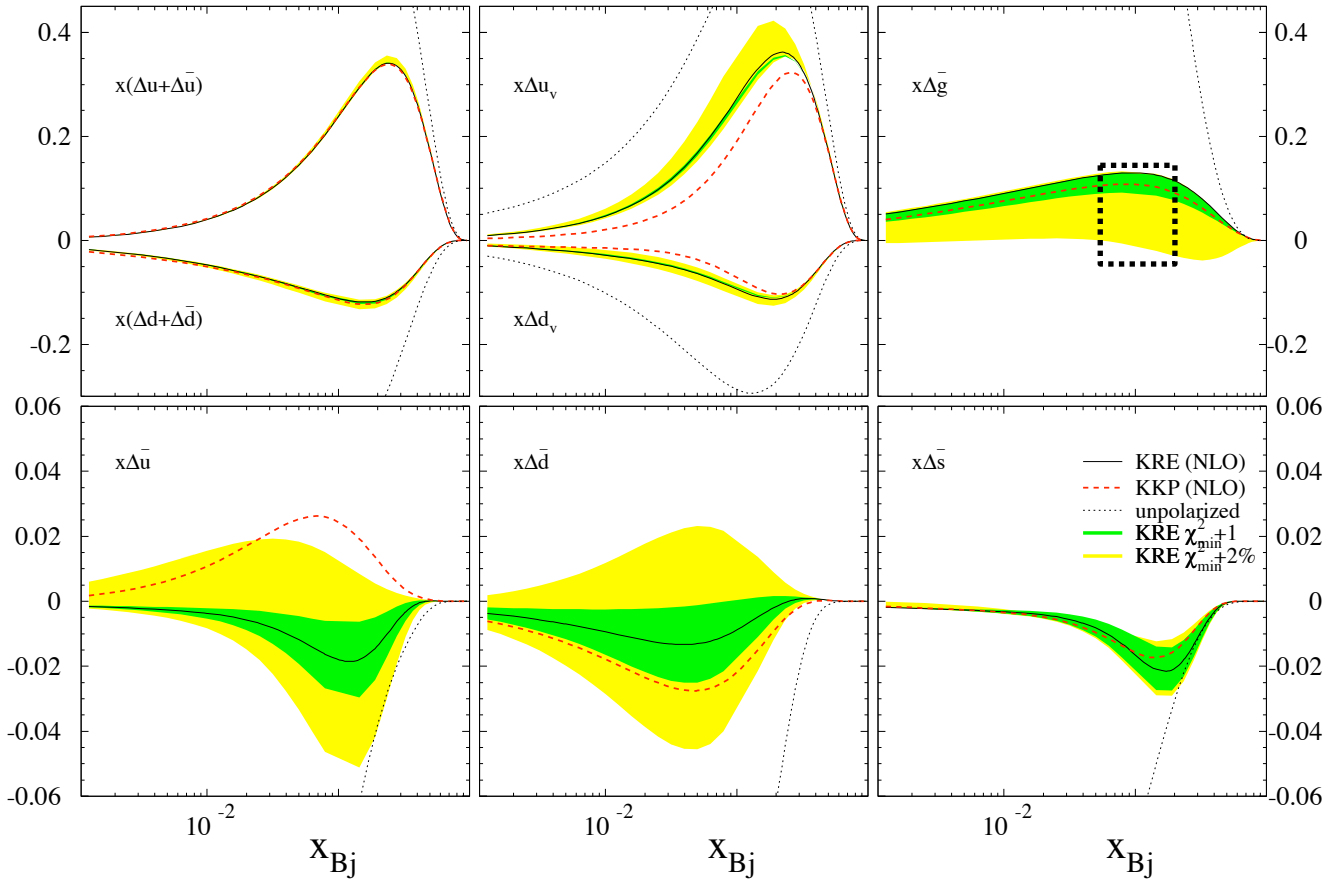

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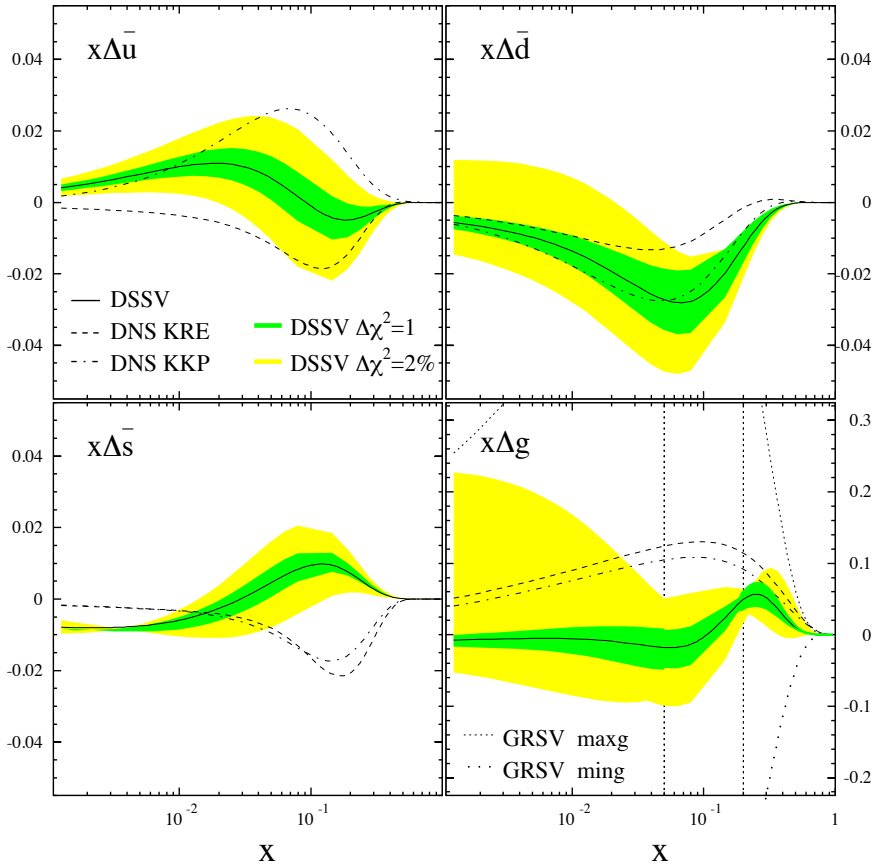

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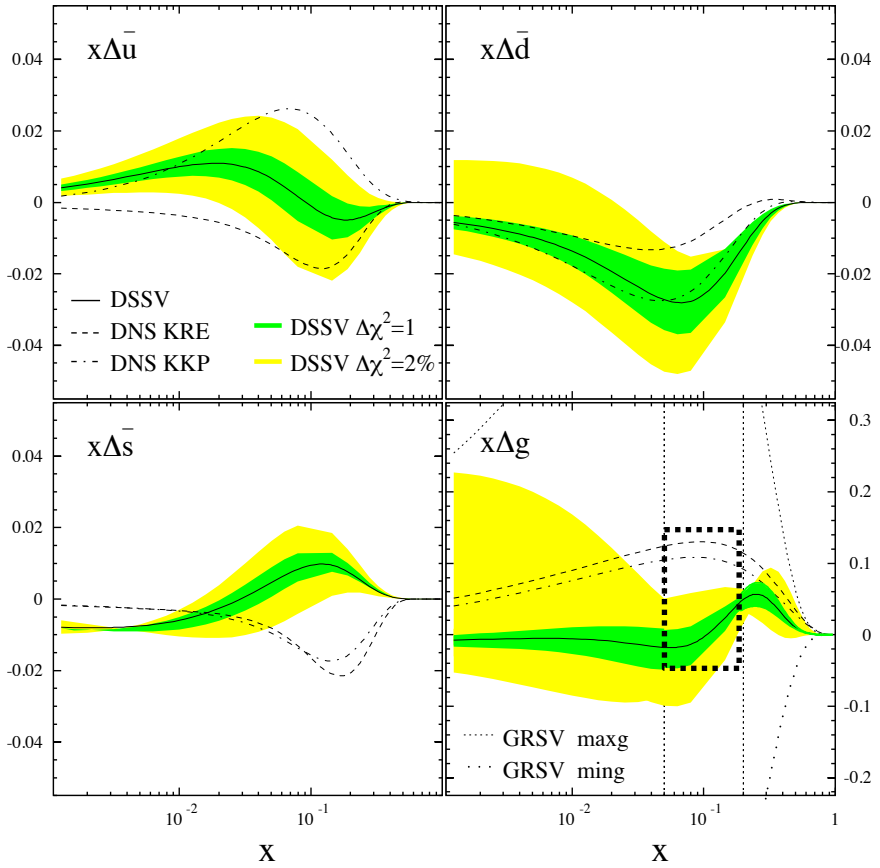

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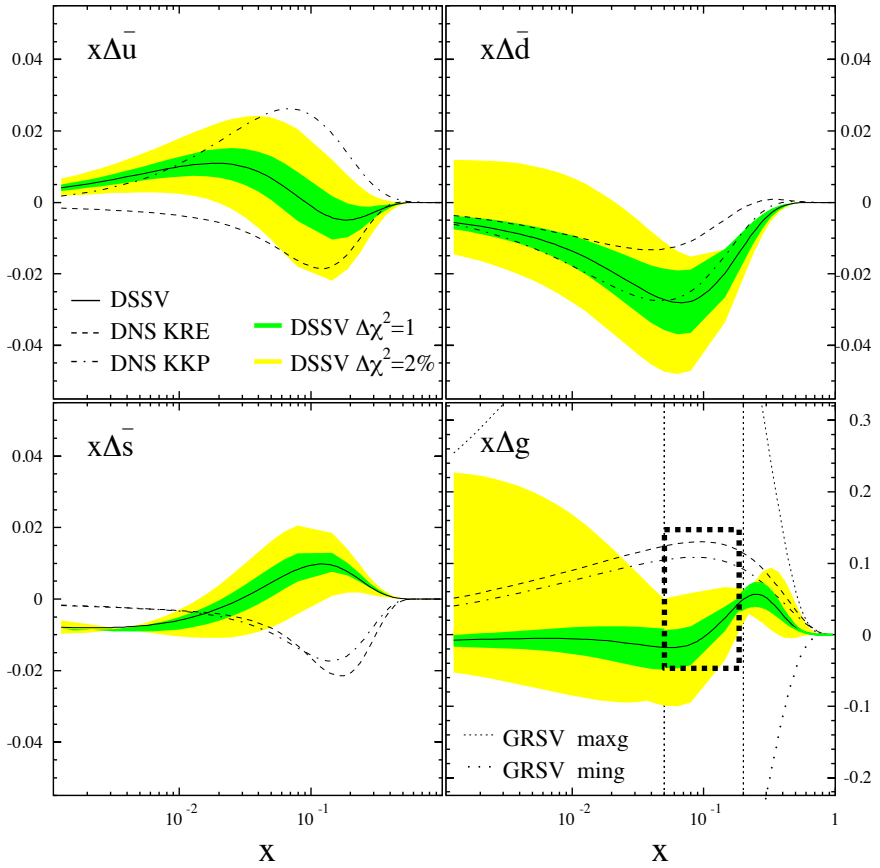

Substantial improvement for 0.05<x<0.2

Large uncertainties at low x

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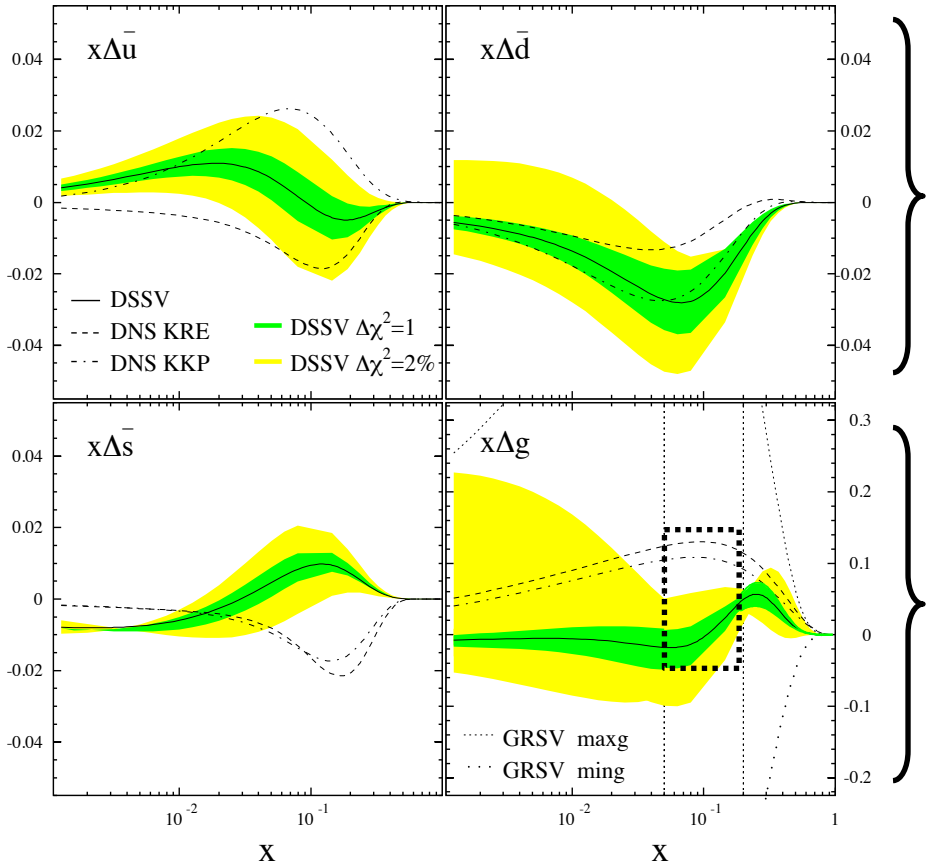

u/d sea-quarks large uncertainties!

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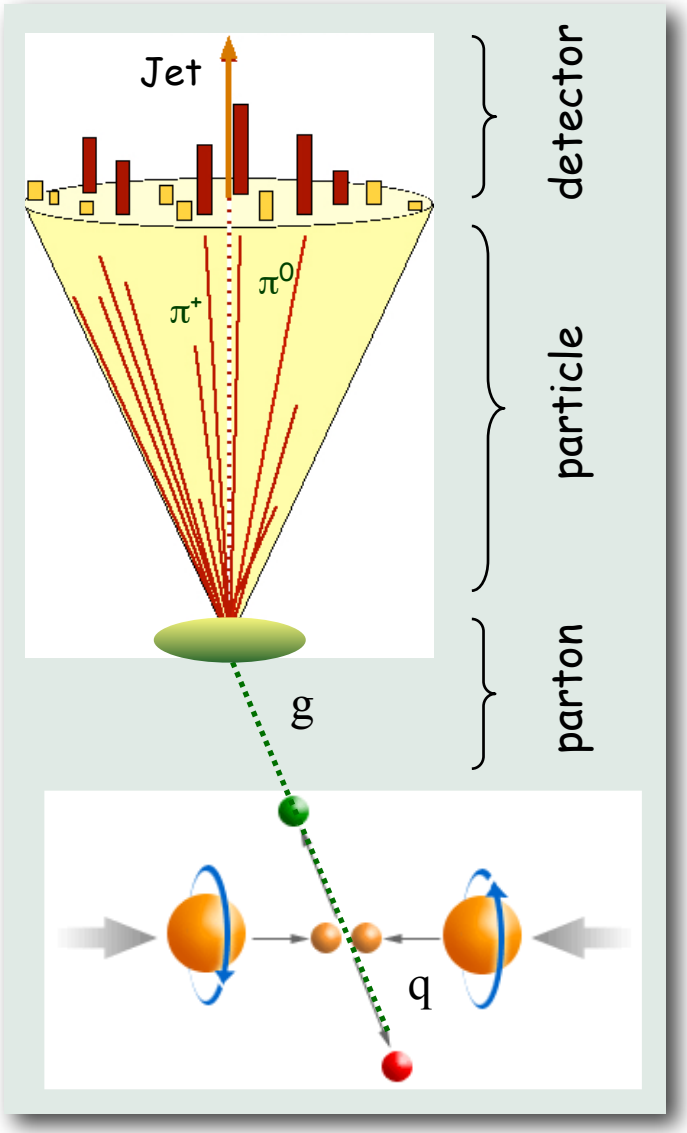
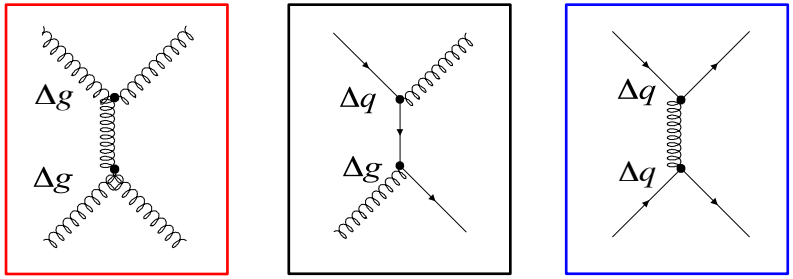
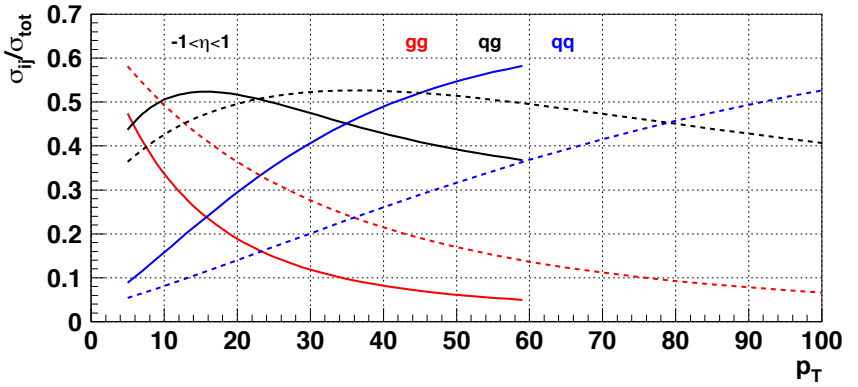
Theoretical foundation

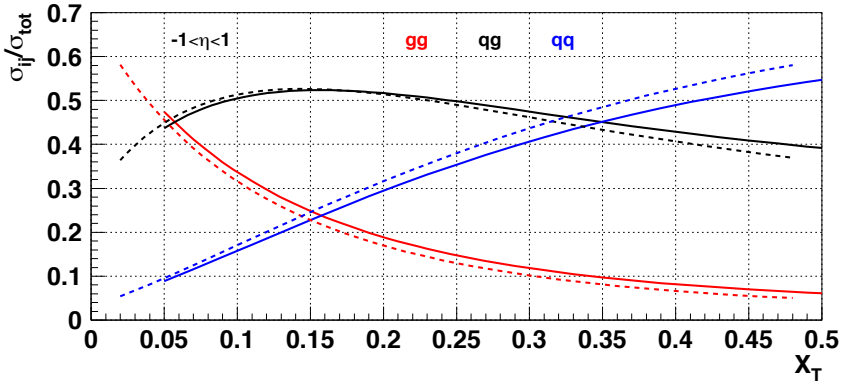
- Gluon polarization - Inclusive Measurements





Inclusive Jet production (200GeV: Solid line / 500GeV: Dashed line)



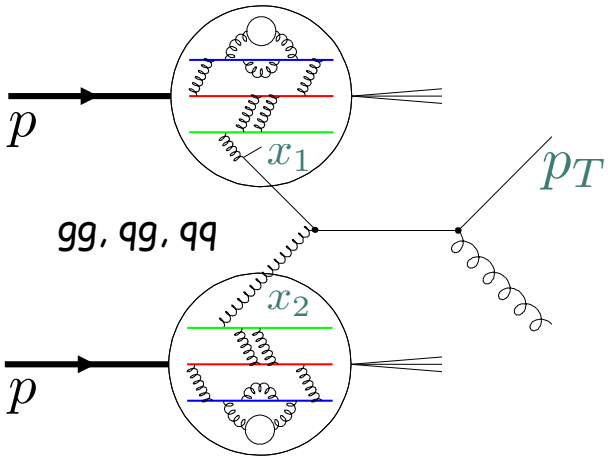


$$x_T = 2p_T/\sqrt{s}$$

Theoretical foundation

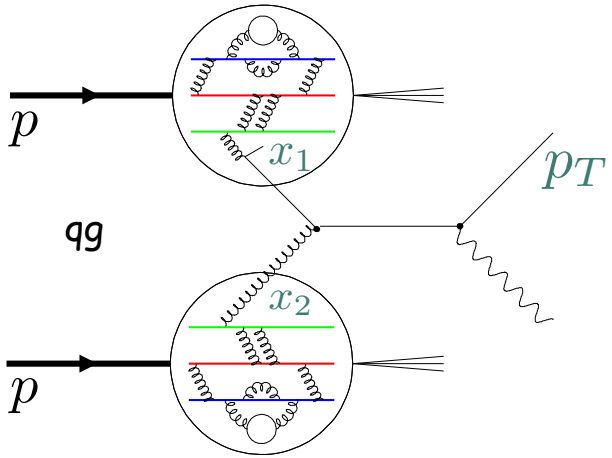
- Gluon polarization - Correlation Measurements
  - Correlation measurements provide access to partonic kinematics through Di-Jet/Hadron production and Photon-Jet production - At LO:

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



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
    - 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



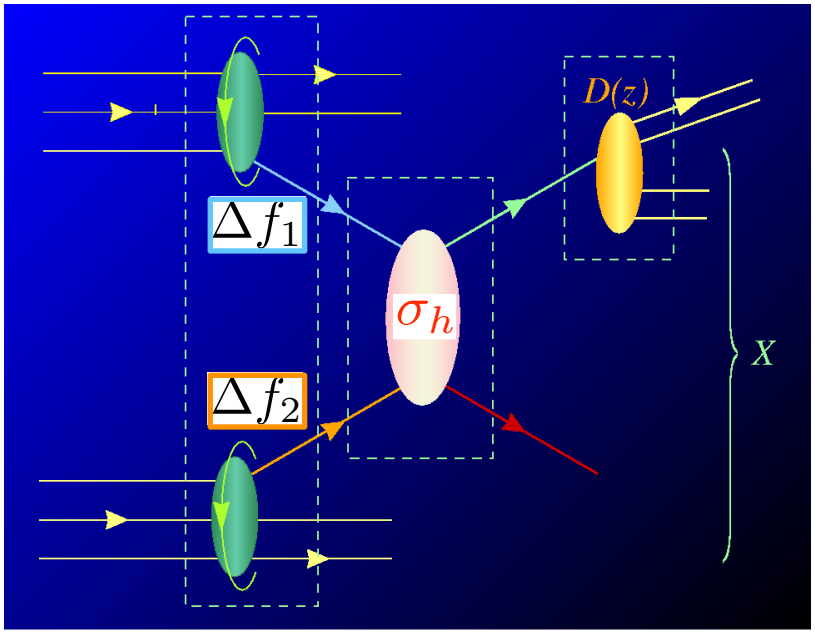
Photon-Jet production

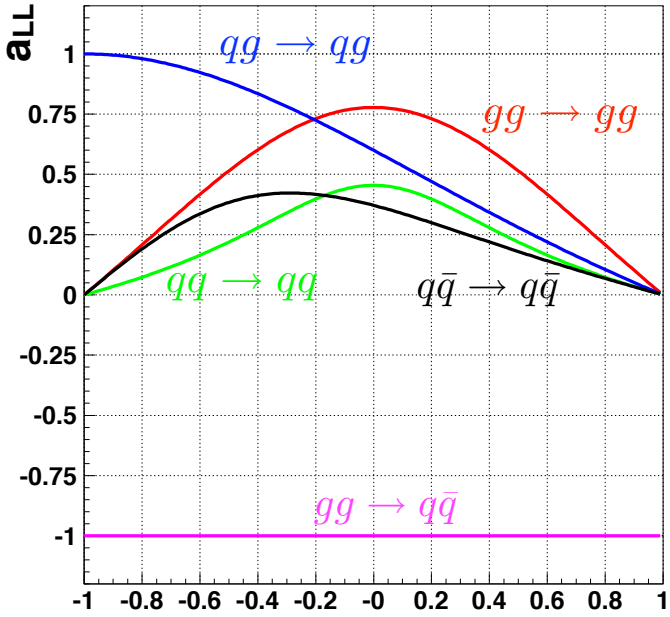
Theoretical foundation

- Gluon polarization - Extraction

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

Extract $\Delta g(x,Q^2)$ through Global Fit (Higher Order QCD analysis)!





long-range | short-range | long-range

$$a_{LL} = \frac{\Delta\sigma_h}{\sigma_h}$$

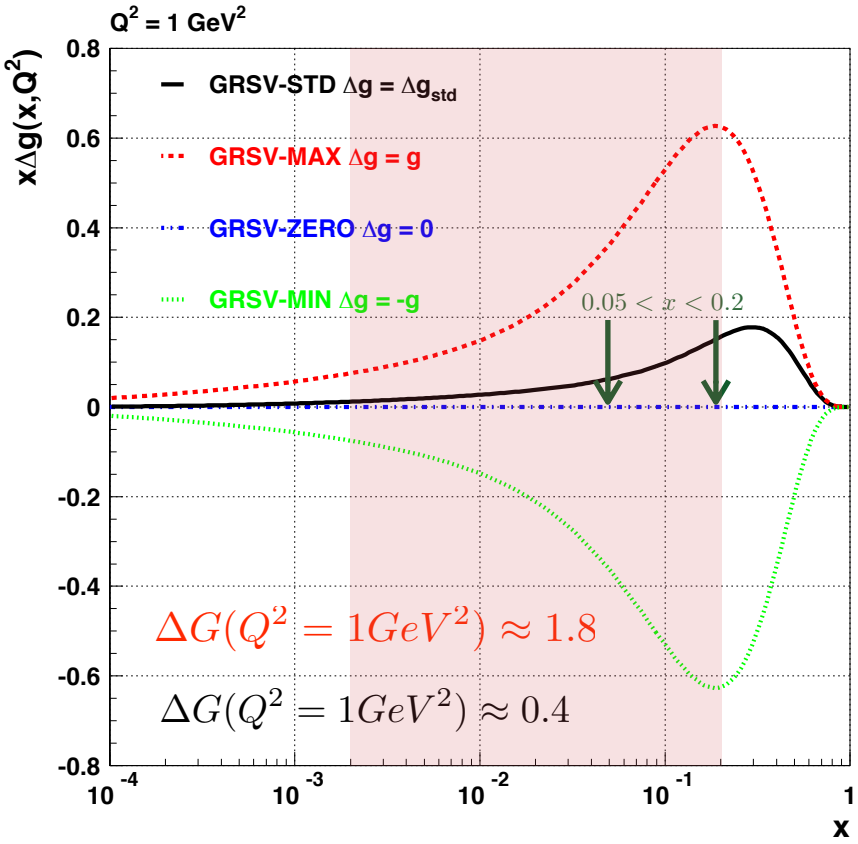
Input

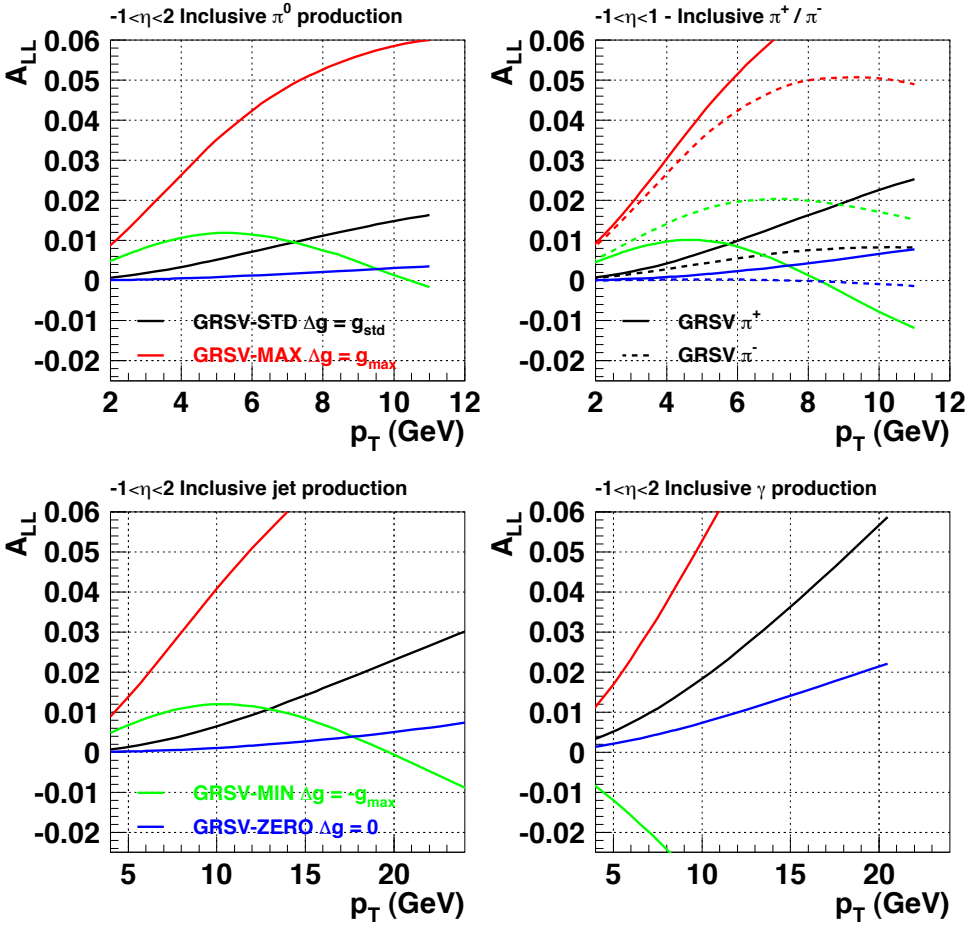
Δf_1 Δf_2

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

Theoretical foundation

Gluon polarization - Sensitivity





- Examine wide range in Δg: $-g < \Delta g < +g$

- GRSV-STD: NLO pQCD analysis of polarized DIS experiments!

M. Gluck et al. PRD 63 (2001) 094005.

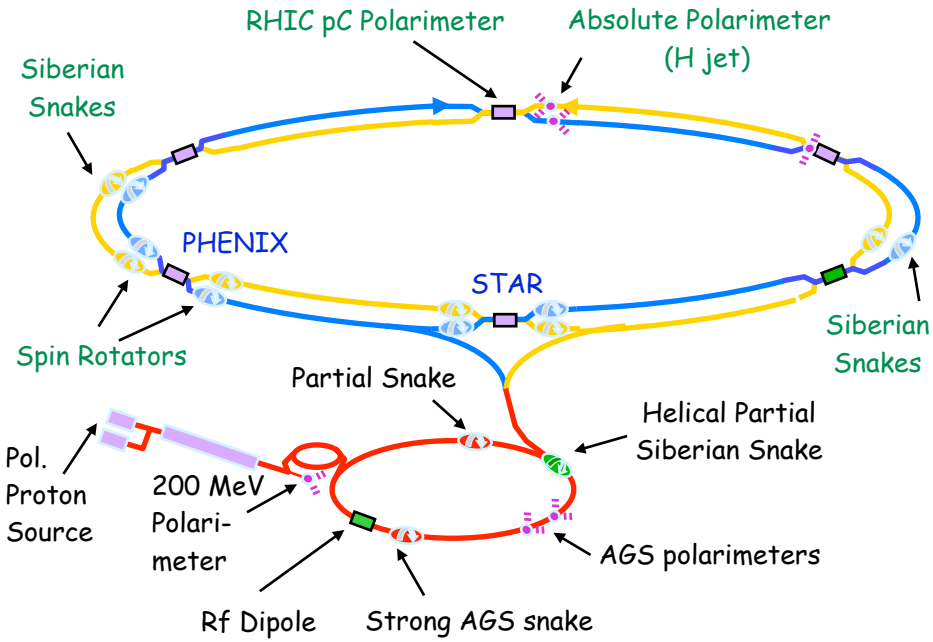
$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2) dx$$

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

(central rapidity)

Collider: The First polarized p+p collider at BNL

Performance



RHIC RUN	s [GeV]	$L_{recorded}$ [pb^{-1}] (trans.)	$L_{recorded}$ [pb^{-1}] (long.)	Polarization [%]
RUN 2	200	0.15	0.3	15
RUN 3	200	0.25	0.3	30
RUN 4	200	0	0.4	40-45
RUN 5	200	0.4	3.1	45-50
RUN 6	200	3.4/6.8	8.5	60
RUN 8	200	7.8	-	45
RUN 9	200 / 500	-	25 / 10	55 / 40

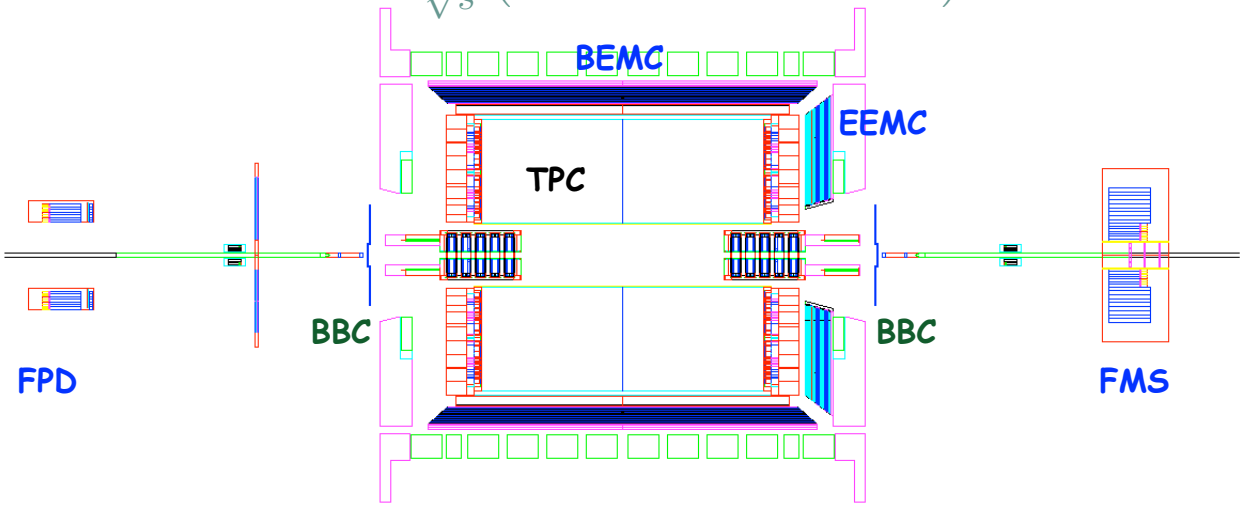
- Long 200GeV productions runs at $\sqrt{s}$=200GeV (long. polarization): Run 6 / Run 9
- First collisions of polarized proton beams at $\sqrt{s}$=500GeV (long. polarization): Run 9

The STAR Experiment

Overview

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

- 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

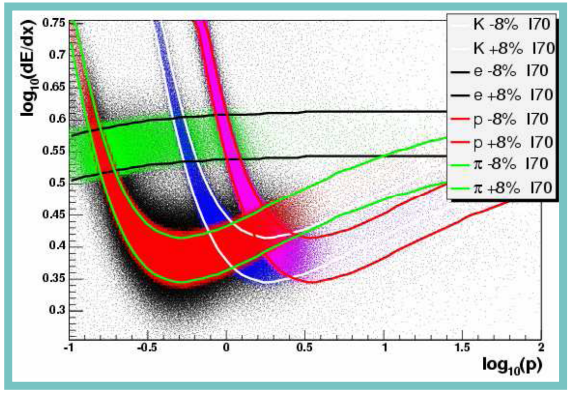


- **BBC/ZDC:** Relative luminosity and local polarimetry
- **BBC:** Minimum bias trigger

Key elements for STAR Δg(x) program:

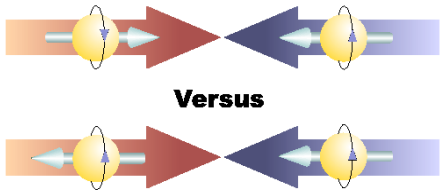
- Higher precision on Δg(x) : Luminosity / DAQ upgrade (DAQ 1000)
- Sensitivity to shape of Δg(x): Correlation measurements
- Low-x region of Δg(x): 500GeV program / Asymmetric collisions (Forward calorimetry)

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

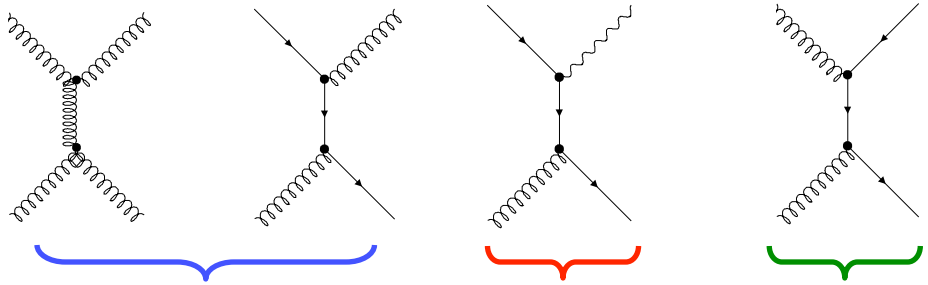


Recent results

- What is required experimentally to measure the gluon spin contribution?
  - Double longitudinal-spin asymmetry: A_{LL}



$$\vec{p} + \vec{p} \rightarrow$$



$\boxed{\text{jets} + X}$ $\boxed{\gamma + X}$ $\boxed{c\bar{c}\,(b\bar{b}) + X}$

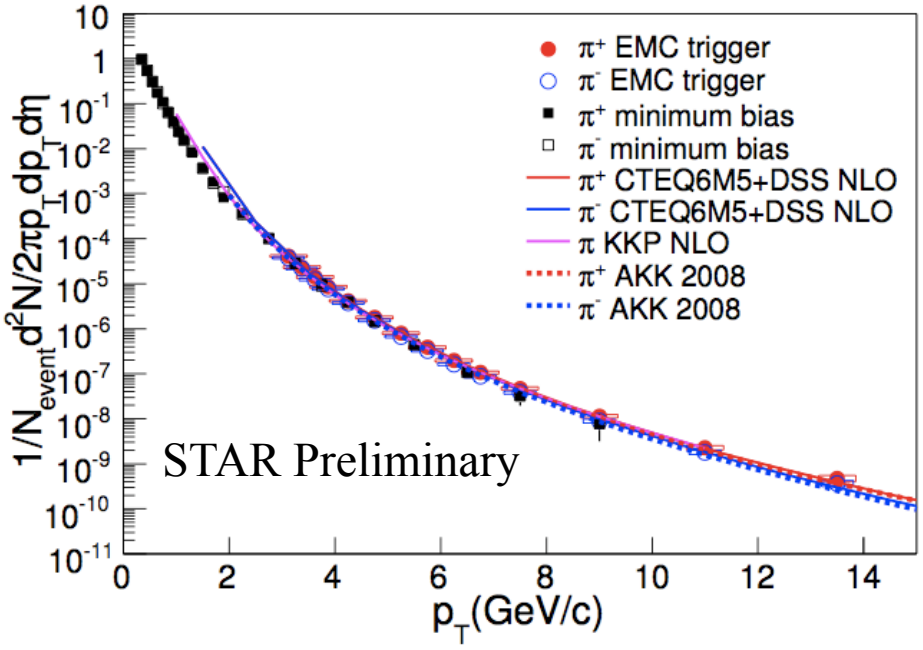
    - Study helicity dependent structure functions (Gluon polarization)!

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_1 P_2} \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}}$$

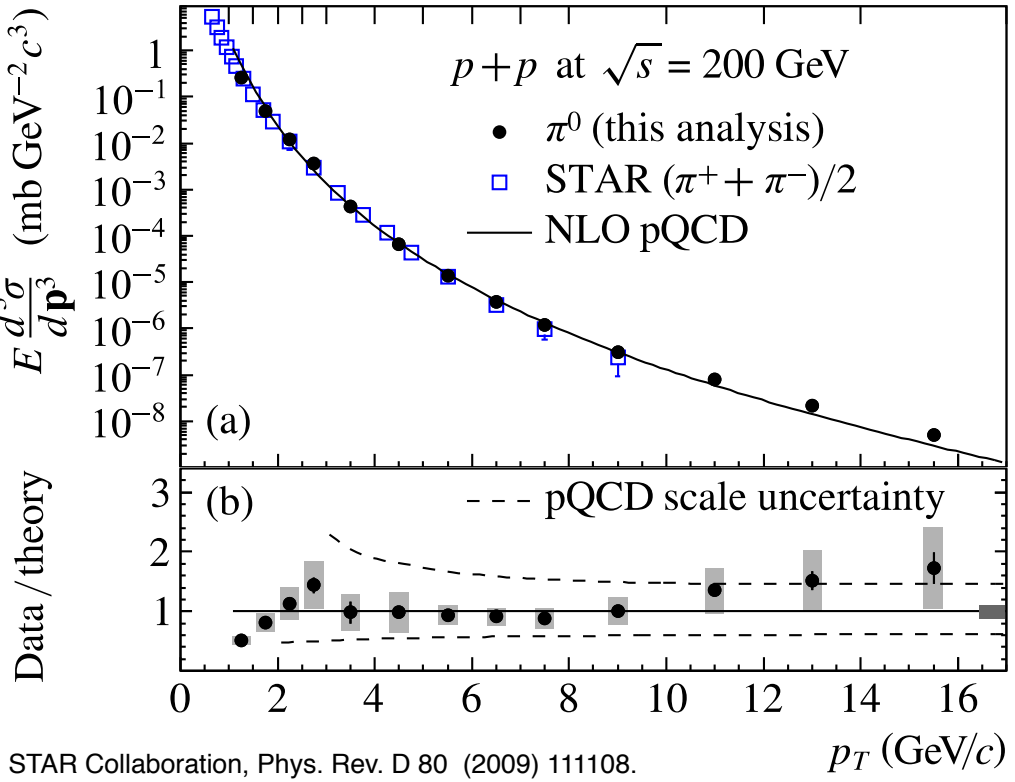
  - Require concurrent measurements:
    - Longitudinal beam polarization $P_{1(2)}$ at STAR IR } RHIC polarimeters
    - Direction of polarization vector
    - Relative luminosity R of bunch crossings with different spin directions
    - Spin dependent yields of process of interest N_{ij} } STAR experiment

Recent results: Neutral / Charged Pion production

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



STAR Collaboration, Phys. Lett. B637 (2006) 161.

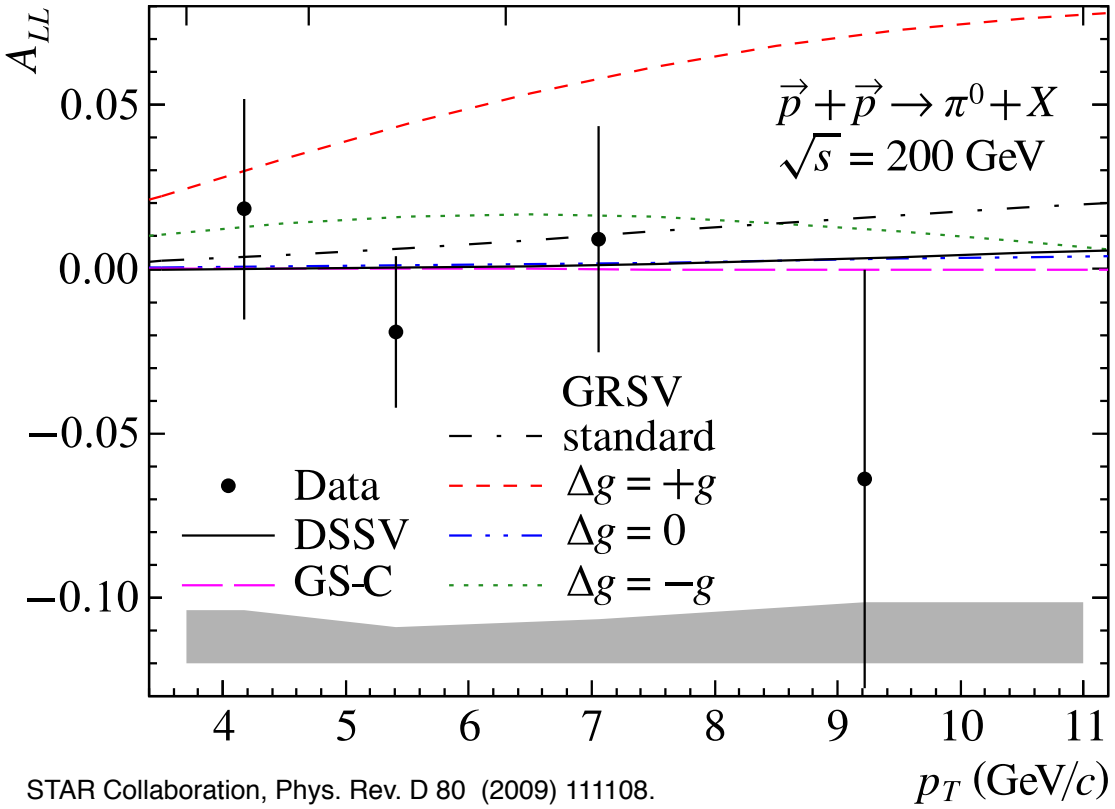


STAR Collaboration, Phys. Rev. D 80 (2009) 111108.

- Sophisticated TPC (dE/dx) calibrations improve precision at high pT (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



STAR Collaboration, Phys. Rev. D 80 (2009) 111108.

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

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

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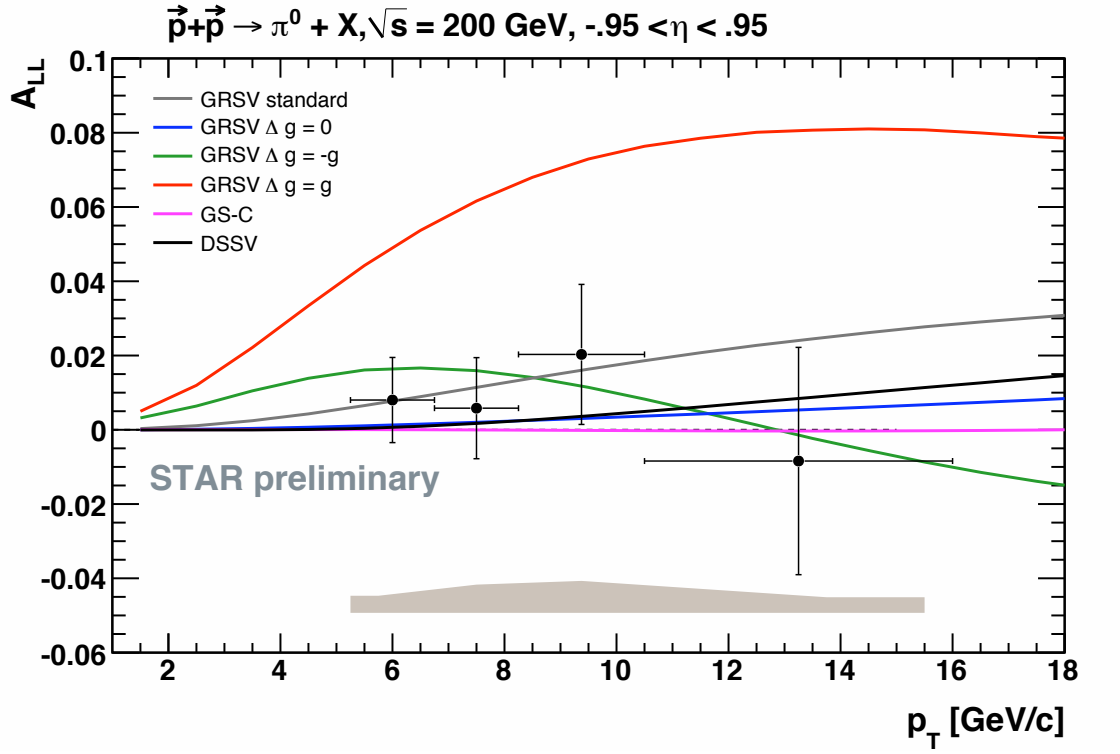

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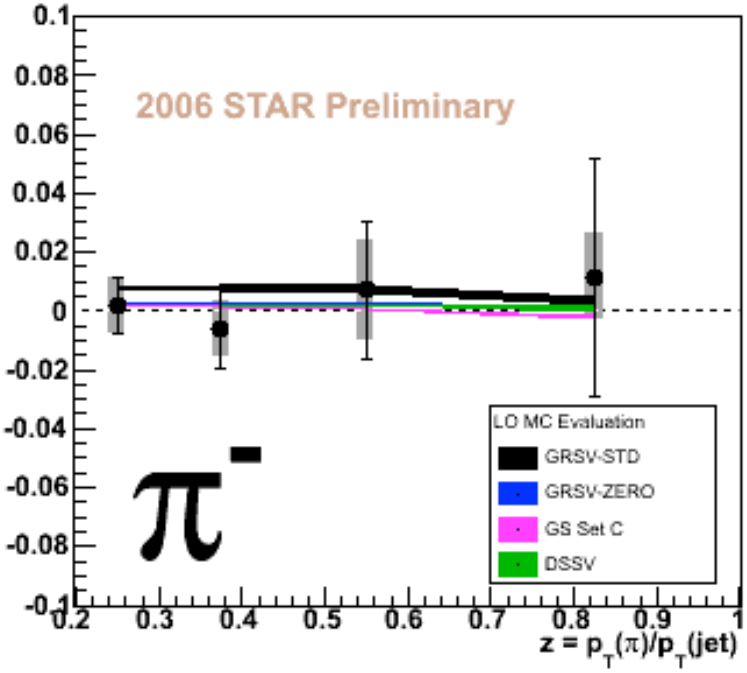
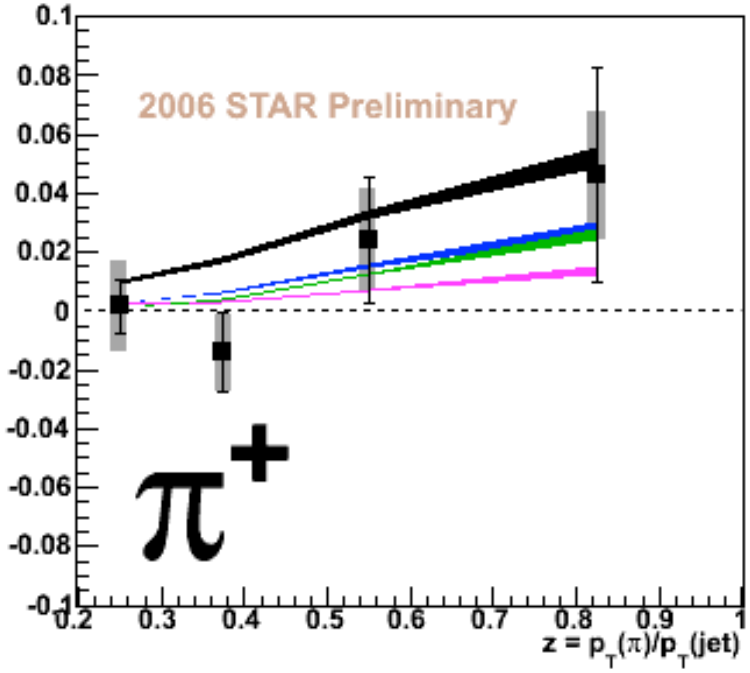
- STAR Run 6 A_{LL} result: Mid-rapidity charged pion production





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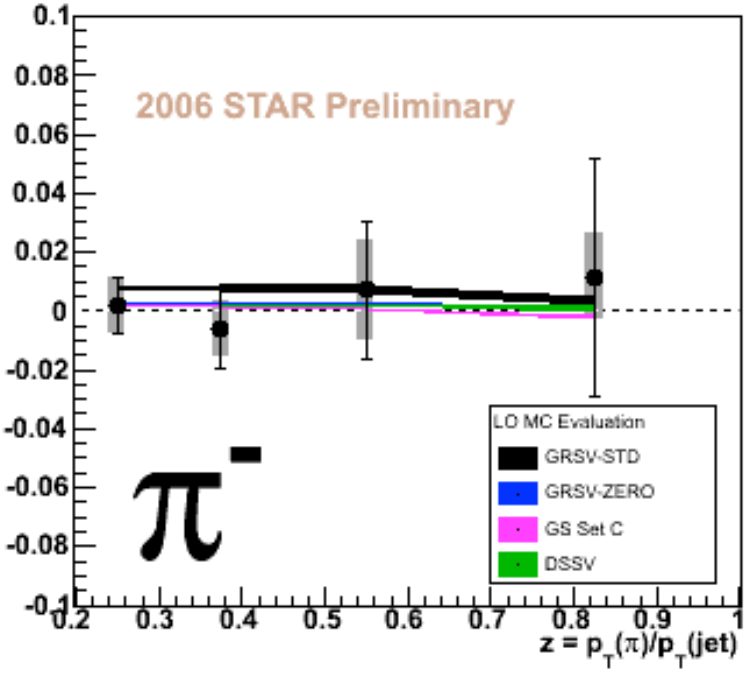

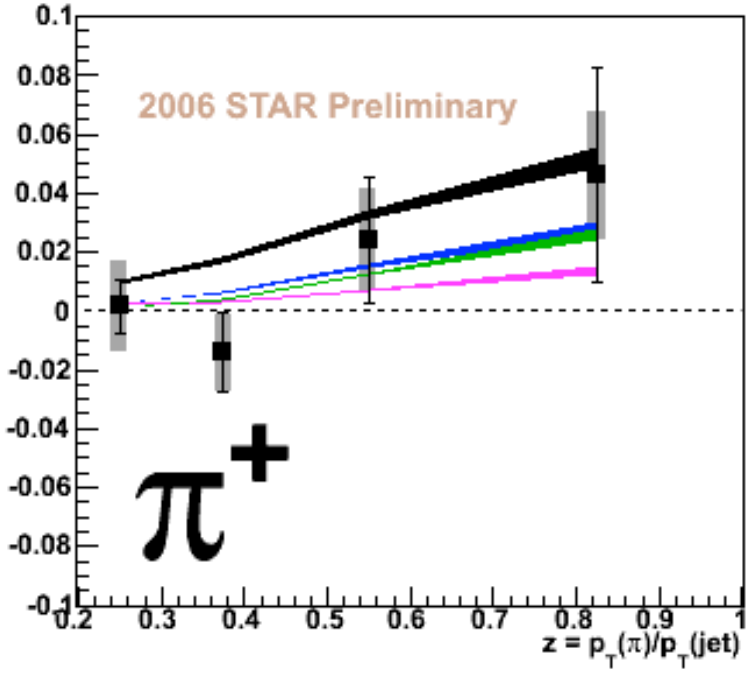

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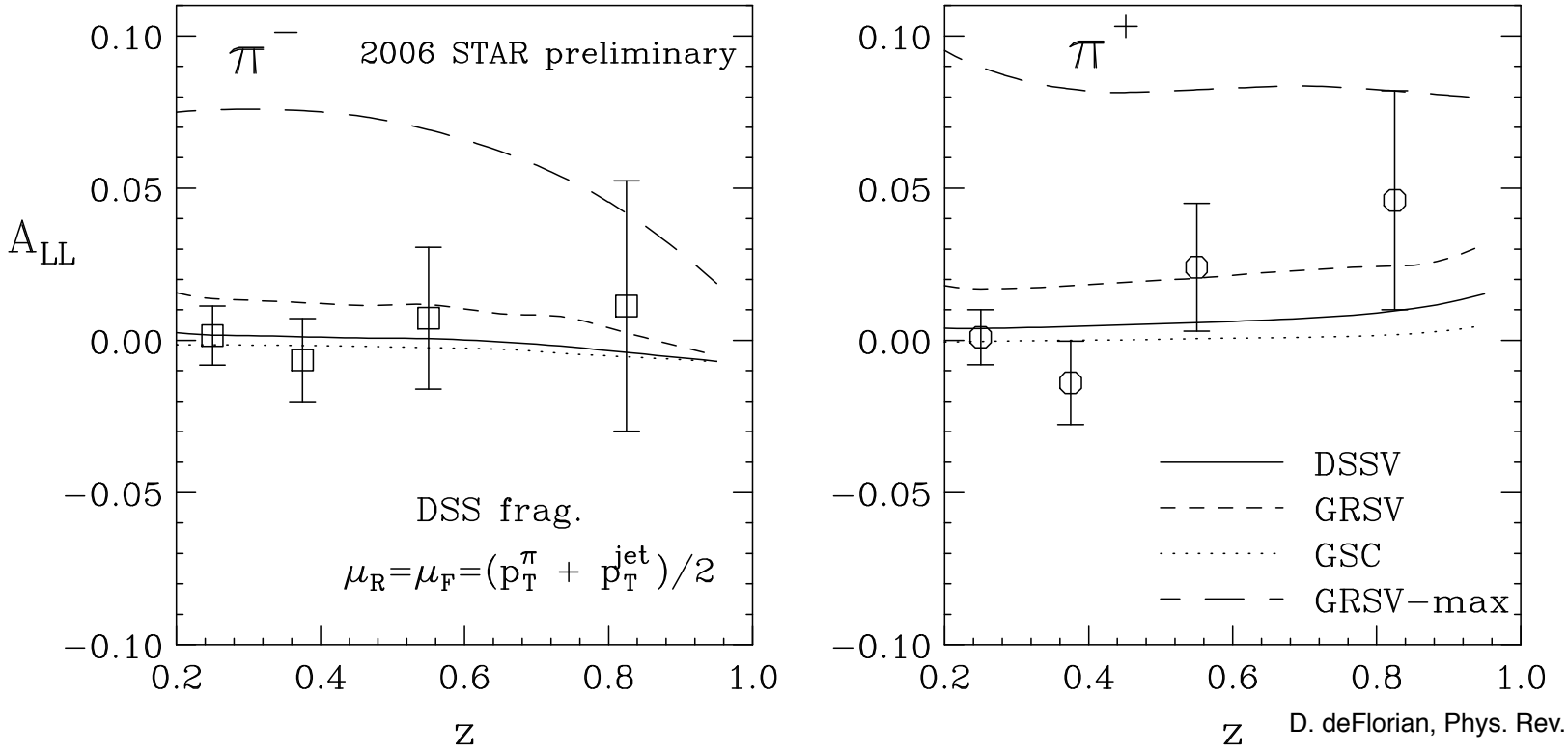
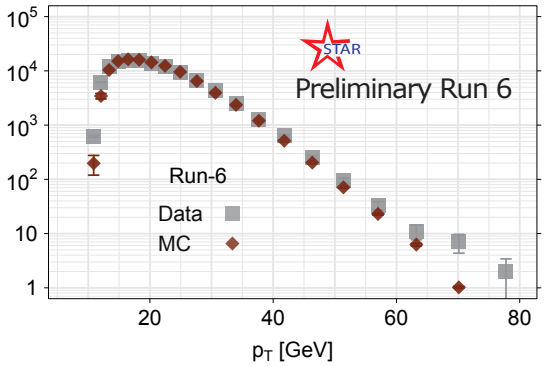


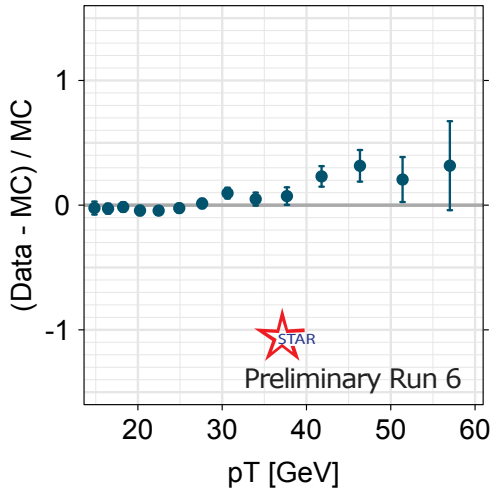
D. deFlorian, Phys. Rev. D 79 (2009) 114014.

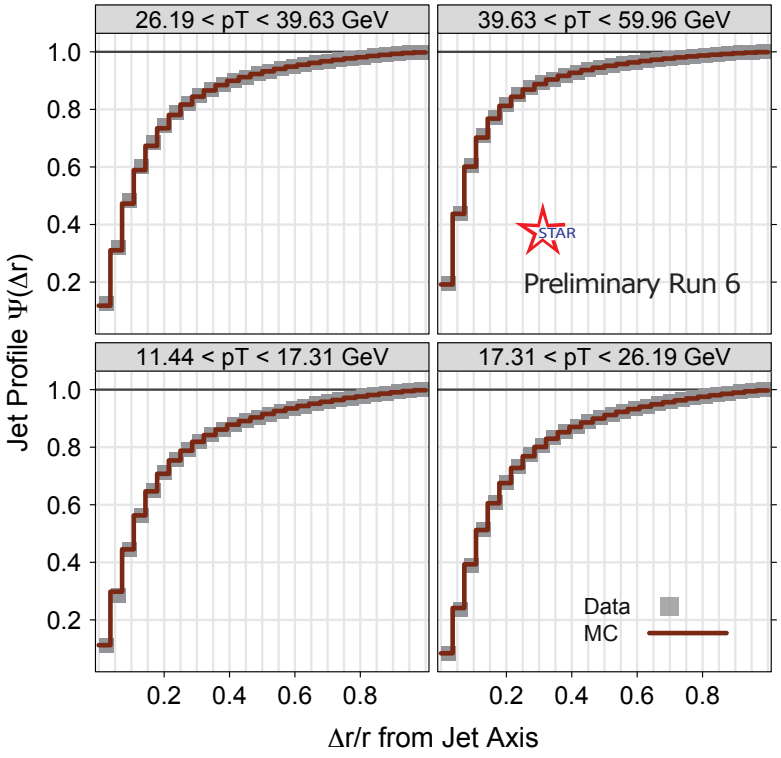
- STAR Preliminary results compared to LO A_{LL} evaluations generated by sampling partonic a_{LL} and parton distribution functions using PYTHIA events
- π^+ offers significant sensitivity at high z
- Full NLO pQCD calculations available

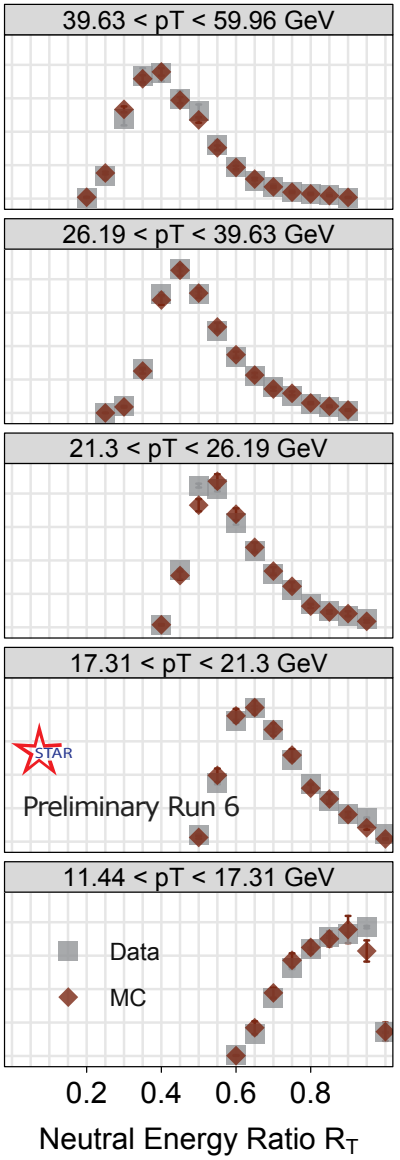
Recent results: Jet production

Inclusive Jet production - Data Understanding - Run 6









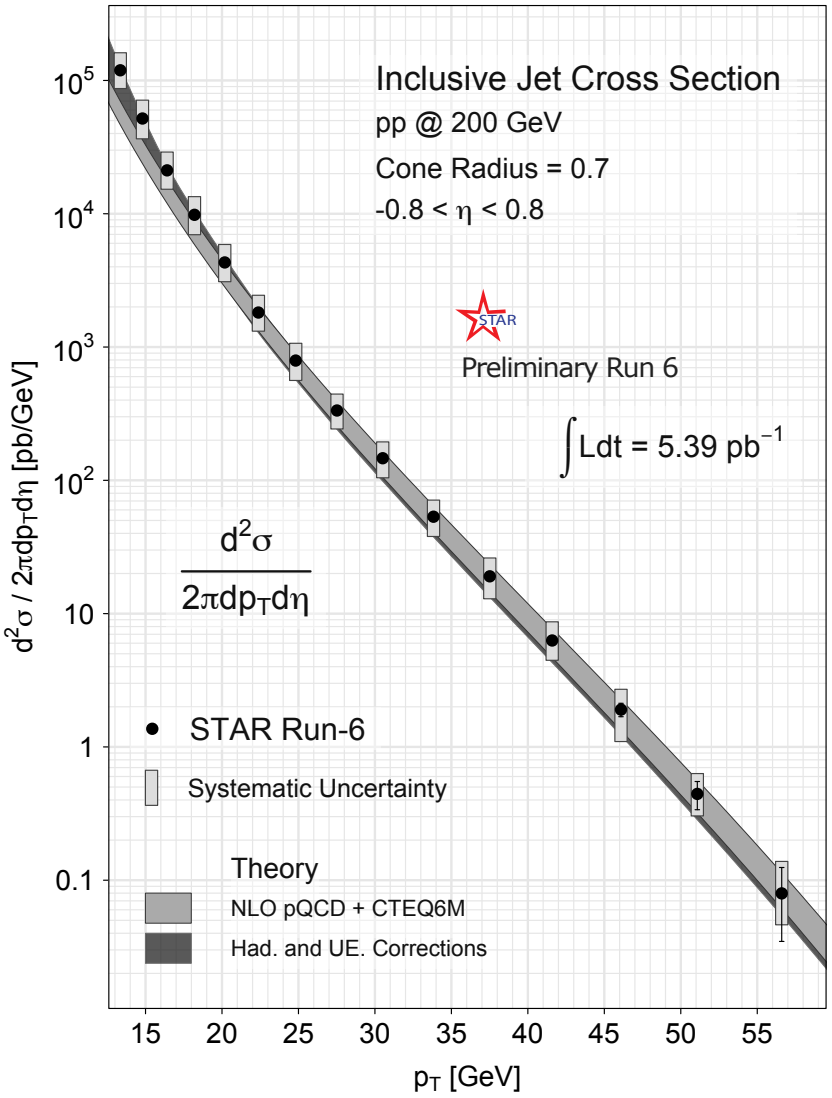
- Data correction based on PYTHIA MC samples
- Good Data/MC agreement

MC: Pythia 6.4 + Geant 3

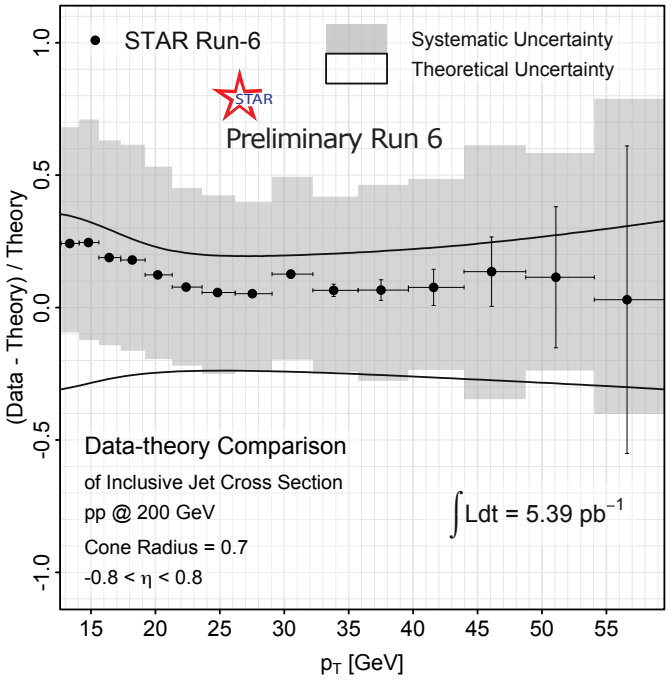
$$-0.8 < \eta < 0.8$$

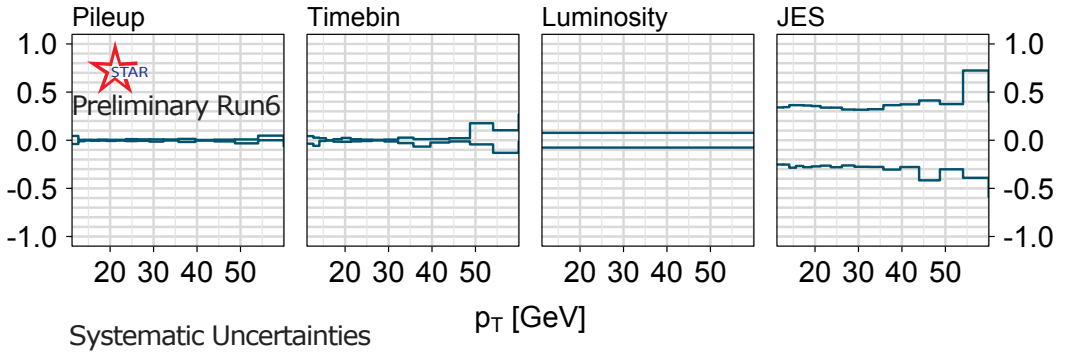
Recent results: Jet production

STAR Run 6 Cross-section result: Mid-rapidity Inclusive Jet production



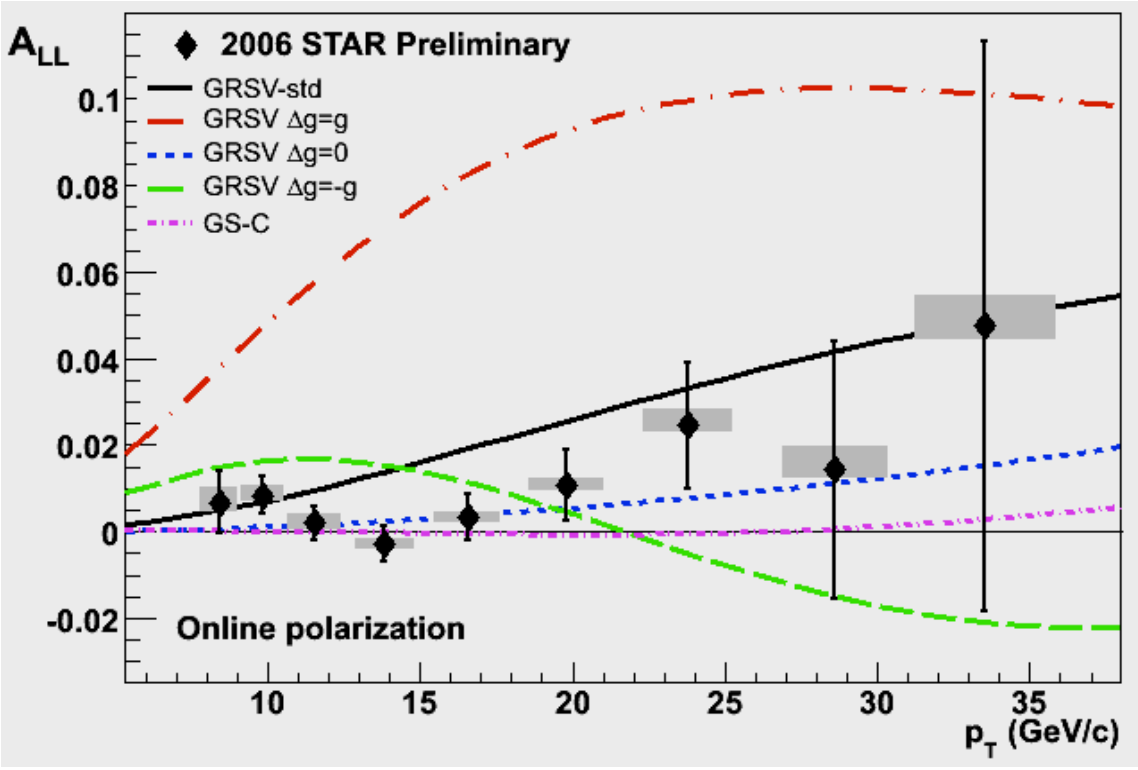
- Data are well described by NLO pQCD plus hadronization and underlying event corrections





Recent results: Jet production

- STAR Run 5 / 6 A_{LL} result: Mid-rapidity inclusive jet production



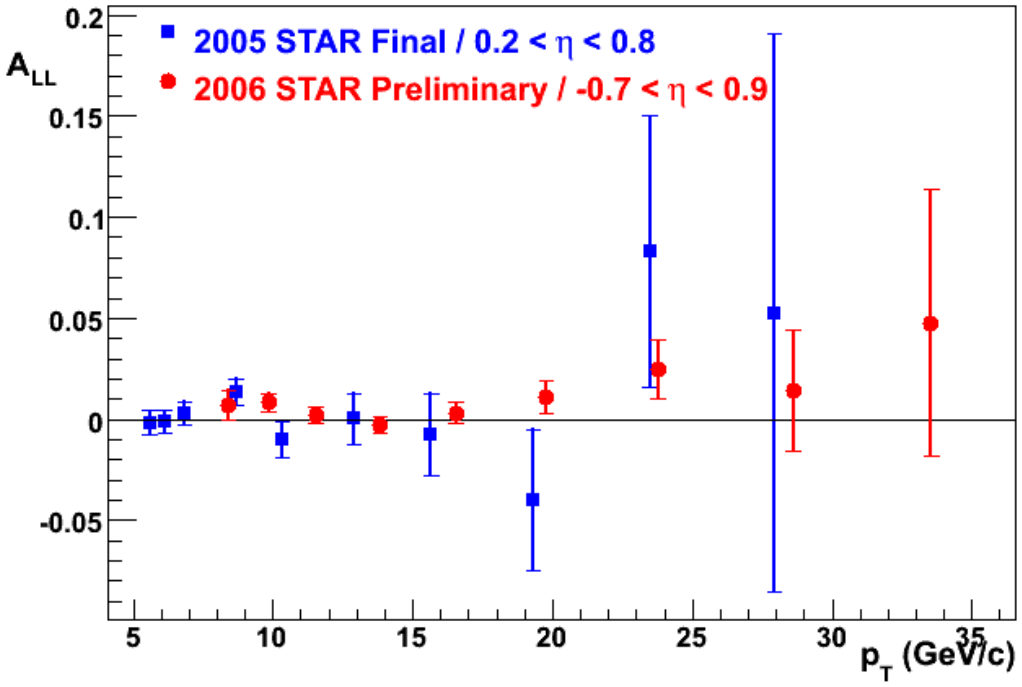
A_{LL} systematics	(x 10^{-3})
Reconstruction + Trigger Bias	[-1,+3] (p_T dep)
Non-longitudinal Polarization	~ 0.03 (p_T dep)
Relative Luminosity	0.94
Backgrounds	1^{st} bin ~ 0.5 else ~ 0.1
p_T systematic	± 6.7%

STAR Collaboration, PRL 100 (2008) 232003.

- RUN 6 results: GRSV-MAX / GRSV-MIN ruled out - A_{LL} result favor a gluon polarization in the measured x-region which falls in-between GRSV-STD and GRSV-ZERO
- Consistent with Run 3/4 and Run 5 results (Improved statistical precision)

Recent results: Jet production

- STAR Run 5 / 6 A_{LL} result: Mid-rapidity inclusive jet production



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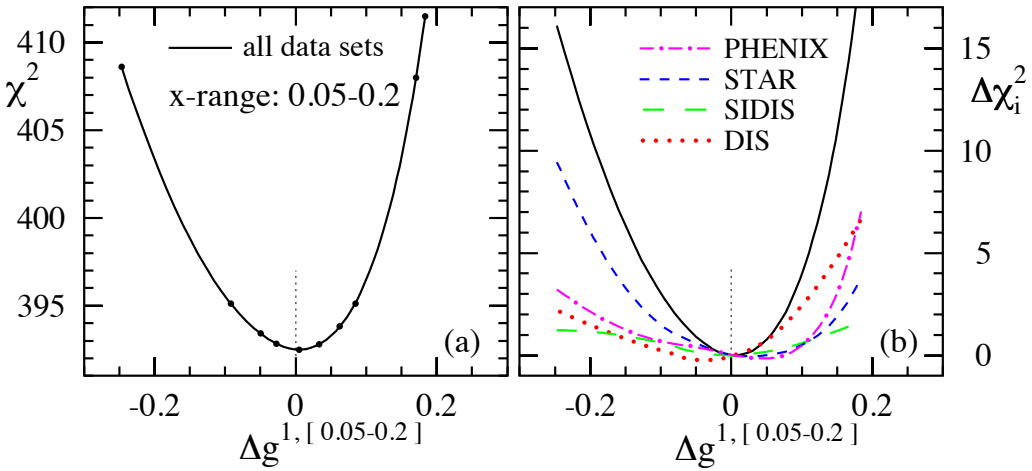
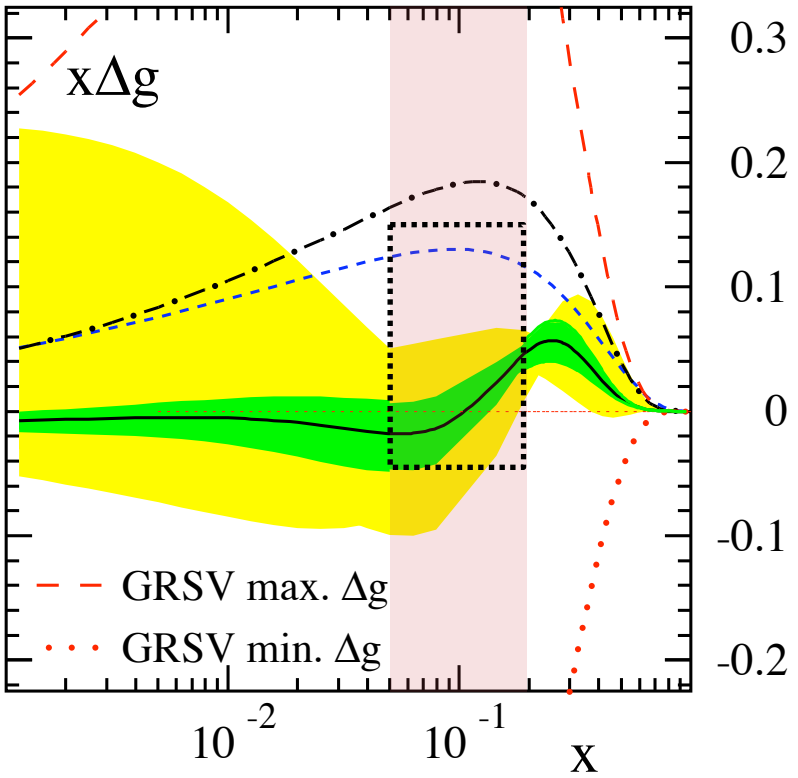
Recent results: Global analysis

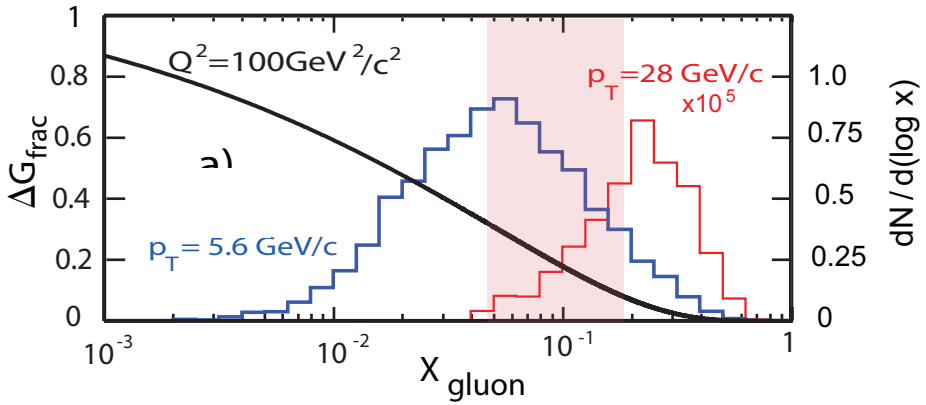
- Global analysis incl. RHIC pp data



- 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!

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

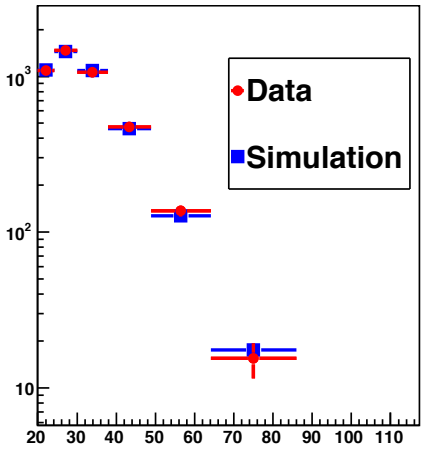


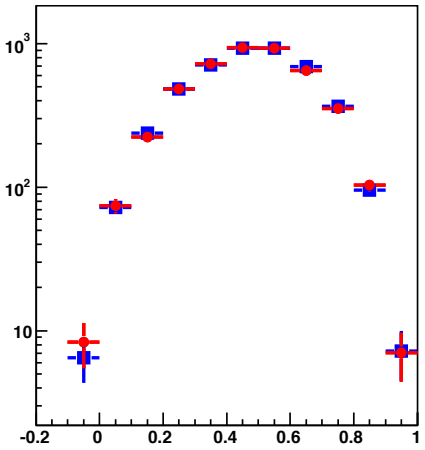


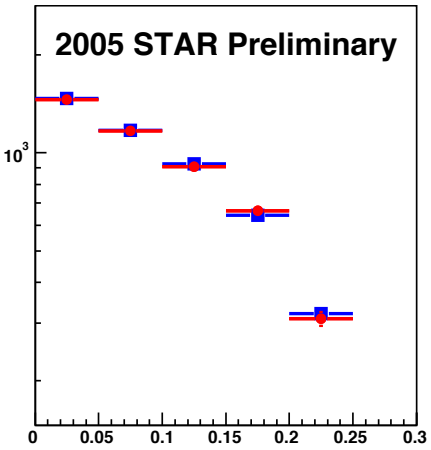
STAR Collaboration, PRL 100 (2008) 232003.

Results: Di-Jet measurements

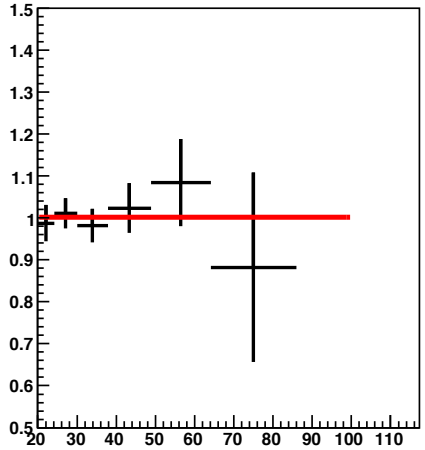
- Correlation measurements: Di-Jet production - Data Understanding - Run 5

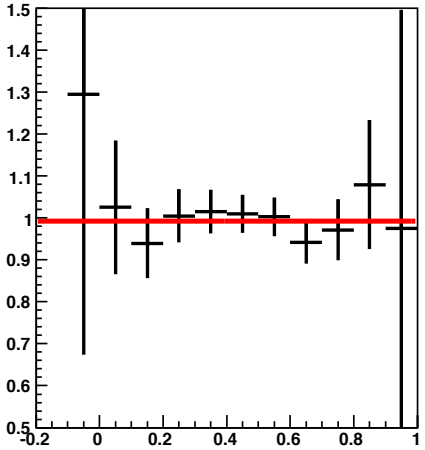


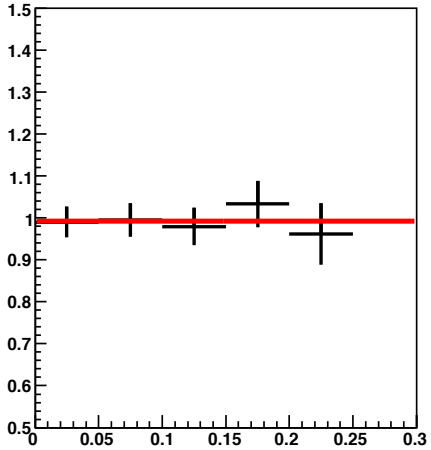




$\sqrt{s} = 200$ GeV $\quad \min(p_T) \geq 7.0$ GeV/c, $\max(p_T) \geq 10.0$ GeV/c $\quad -0.05 \leq \eta \leq 0.95 \quad |\Delta\eta| < 0.5 \quad |\Delta\varphi| > 2$







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

- Di-Jet distributions with asymmetric p_T cuts more appropriate for NLO comparison
- Very good agreement between data and PYTHIA MC simulations incl, detector effects

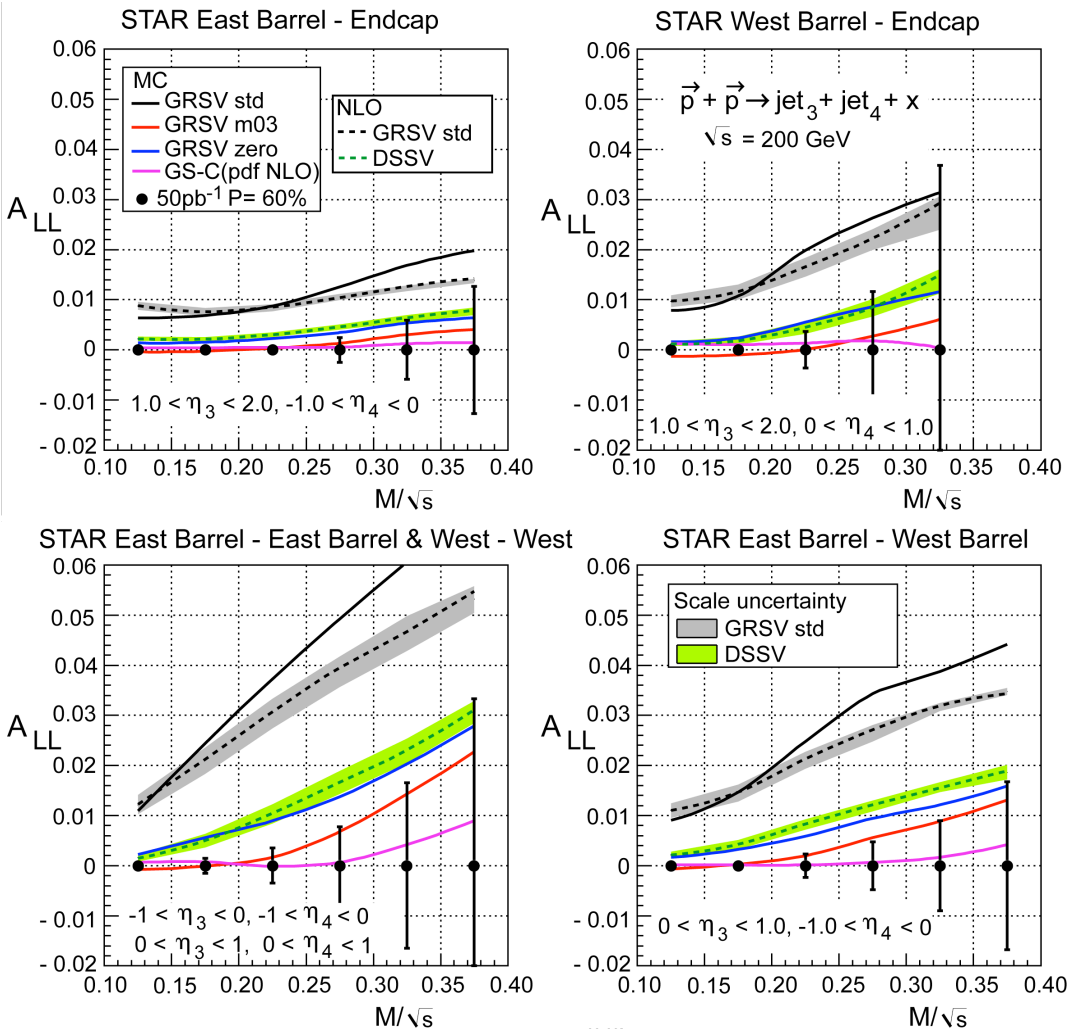
Future prospects: Di-Jet measurements

Run 9 STAR Beam-Use Request (BUR): Di-Jet projections

- Substantial improvement in Run 9 from Di-Jet production: 200GeV Run: April 21, 2009 - June 28, 2009 (Recorded: 1/3 of Run 9 FOM = $P^4L \sim 6.5 pb^{-1}$)
- Good agreement between LO MC evaluation and full NLO calculations

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

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



Summary and Outlook

- pQCD: Critical role to interpret measured asymmetries
- 2006 results: Improved precision at mid-rapidity (hadron and jet ALL) / Improve π^+ analyzing power at high z
- First global analysis incl. RHIC Spin data ⇒ Evidence for small gluon polarization for $0.05<x<0.2$
- Correlation measurements (Di-Jets / γ-Jets) will allow to provide needed constraints on the partonic kinematics ⇒ First Di-Jet cross-section measurement at RHIC at $\sqrt{s}$=200GeV
- 500GeV program together with wide rapidity coverage in STAR ($-1<\eta<4$) will allow to extend the currently measured kinematic region towards small-x ($x \sim 10^{-3}$)
- Run 9: Large 200GeV data sample / First $\sqrt{s}$=500GeV run - A_L W production result

See talk by J. Balewski (MIT)