Recent STAR results on Charged Pion Production in Polarized proton-proton Collisions at $\sqrt{s}$ = 200GeV at RHIC

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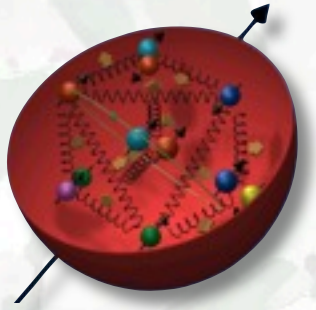
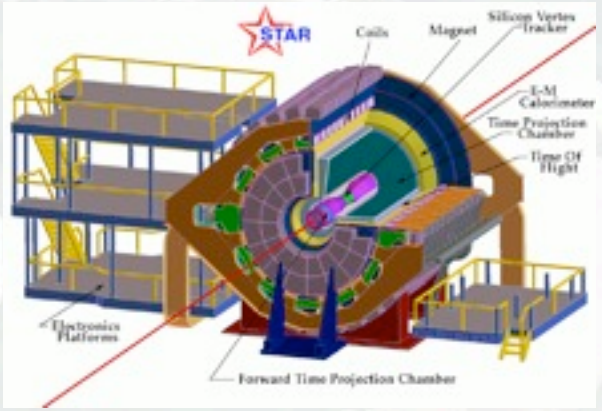
On behalf of the STAR Collaboration

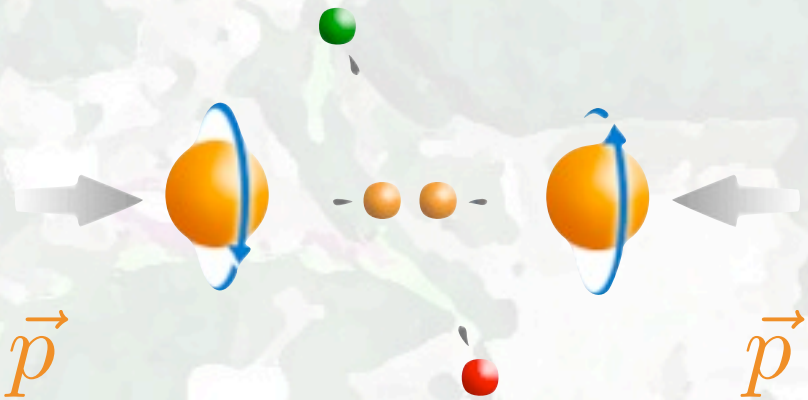


Outline

- Collider



- Experiment



- Theoretical foundation
- Recent STAR Charged Pion A_{LL} results
- Summary and Outlook

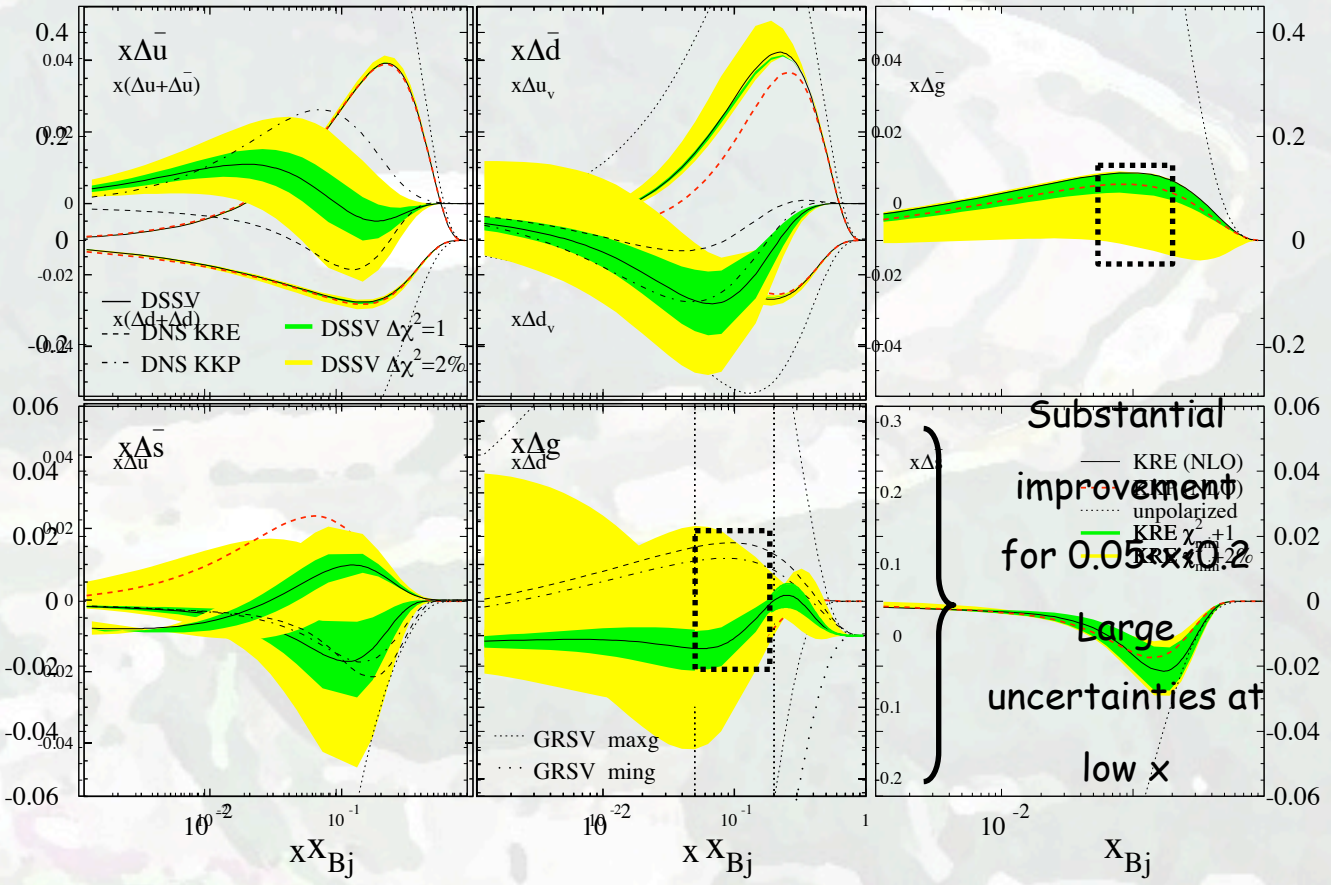
Theoretical foundation

- What do we know about polarized quark and gluon distribution?
  - Spin carried by quarks is very small ($\Delta\Sigma \sim 0.4$)!

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

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

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



D. de Florian et al., Phys. Rev. D 71, 094018 (2005).

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

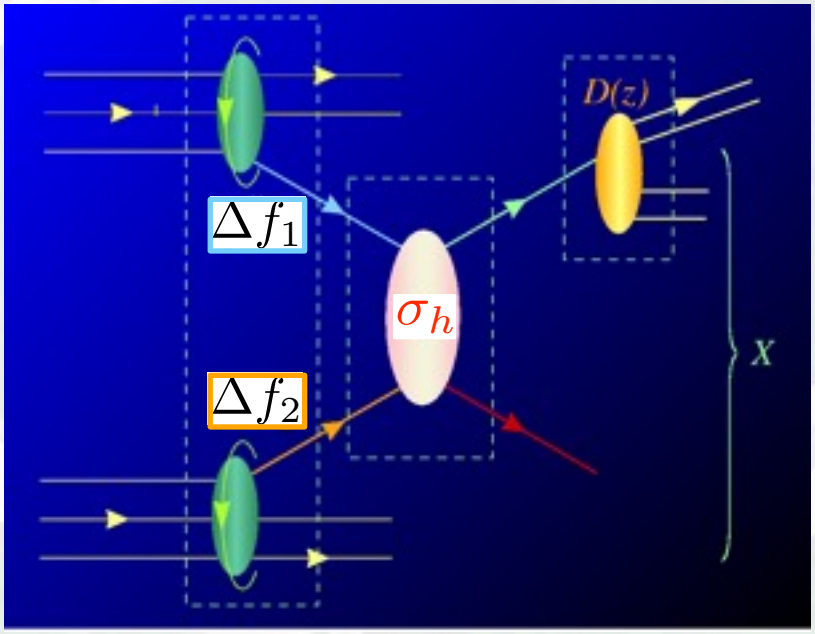
$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2)\,dx$$

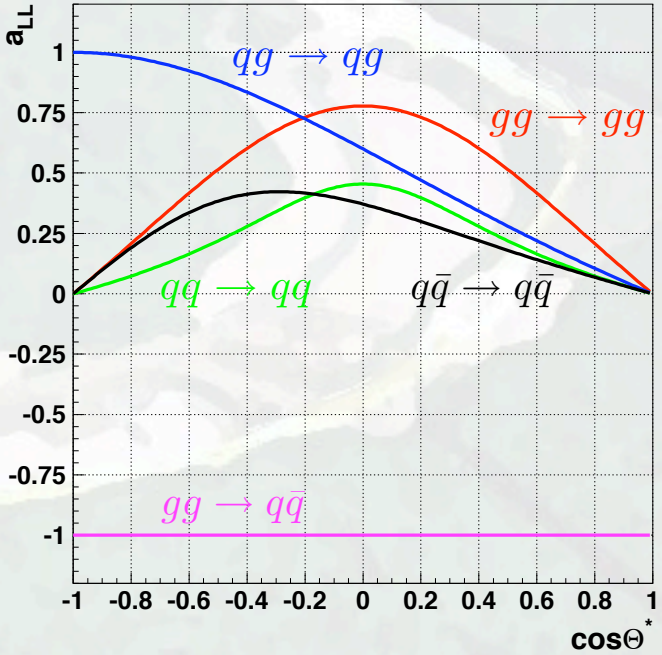
Theoretical foundation

- 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

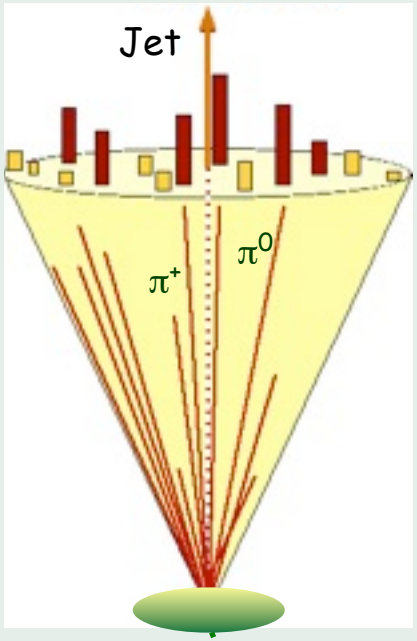
$$A_{LL} = \frac{d\Delta\sigma}{d\sigma}$$

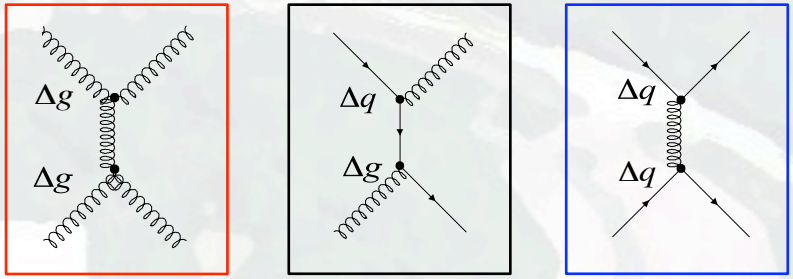
$$\propto \frac{\Delta f_1 \otimes \Delta f_2 \otimes \sigma_h \cdot a_{LL} \otimes D_f^h}{f_1 \otimes f_2 \otimes \sigma_h \otimes D_f^h}$$

Δf_1, Δf_2, $a_{LL} = \frac{\Delta\sigma_h}{\sigma_h}$ } Input

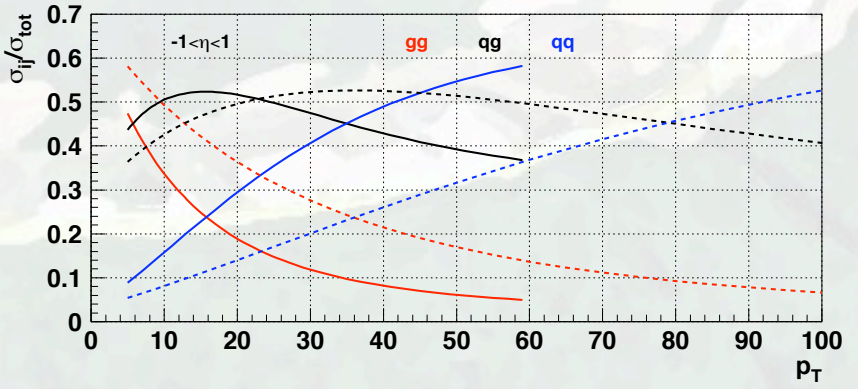
Theoretical foundation

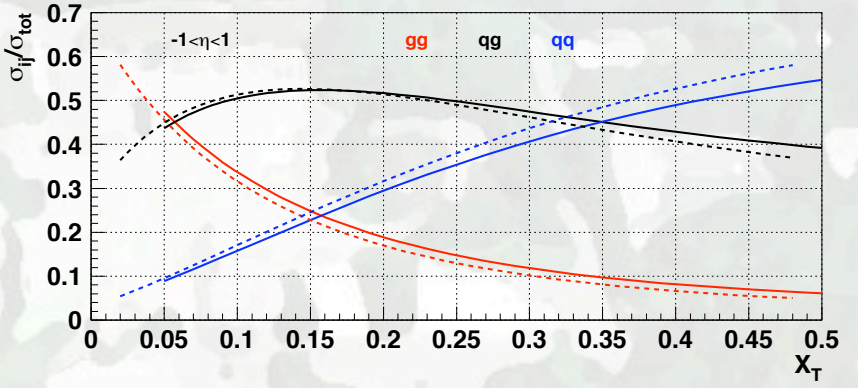
- Gluon polarization - Inclusive Measurements





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

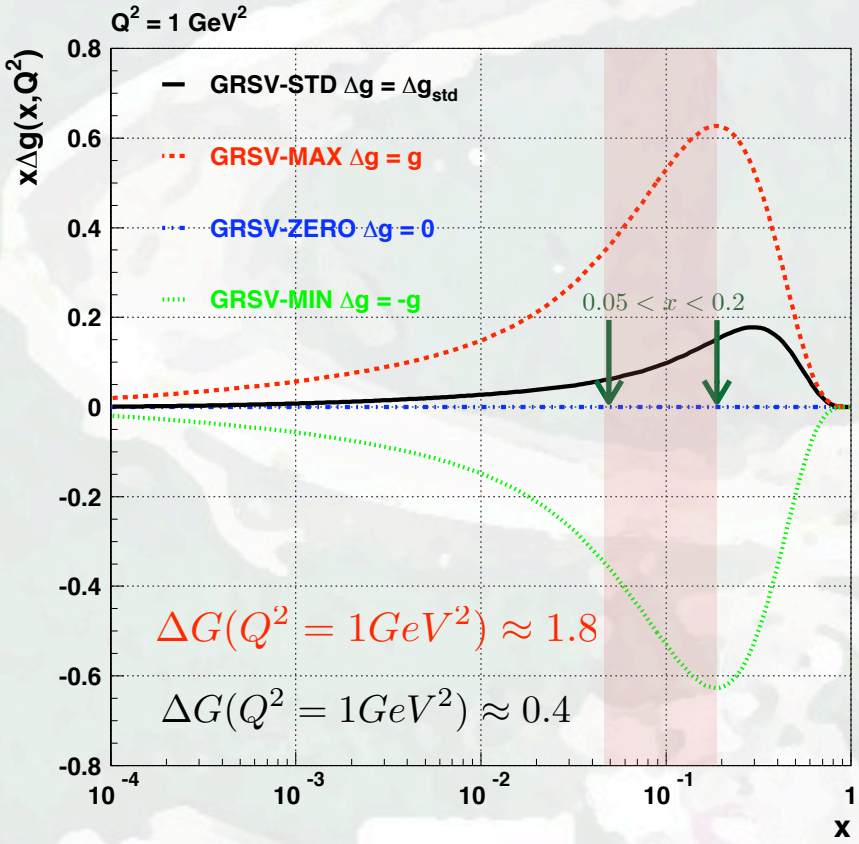


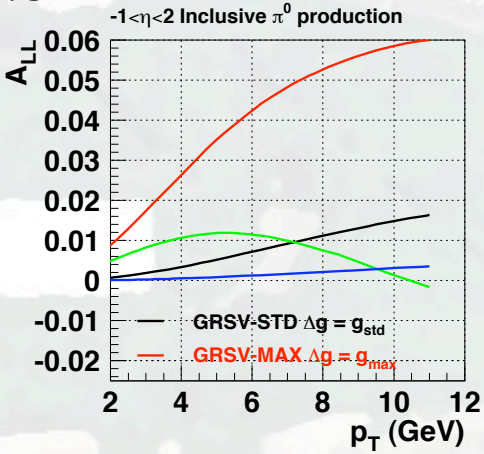


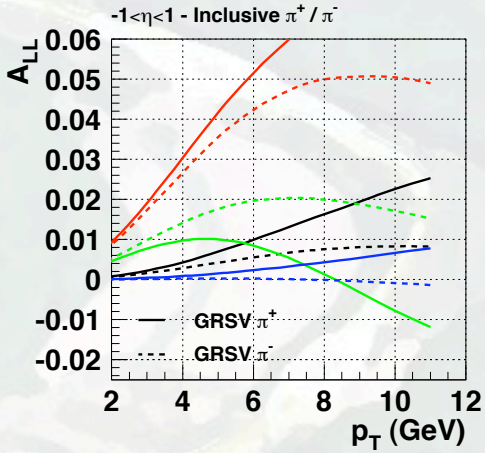
$$x_T = 2p_T/\sqrt{s}$$

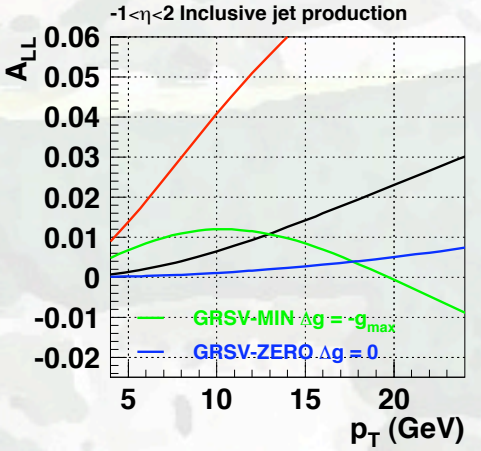
Highlights of recent results and achievements

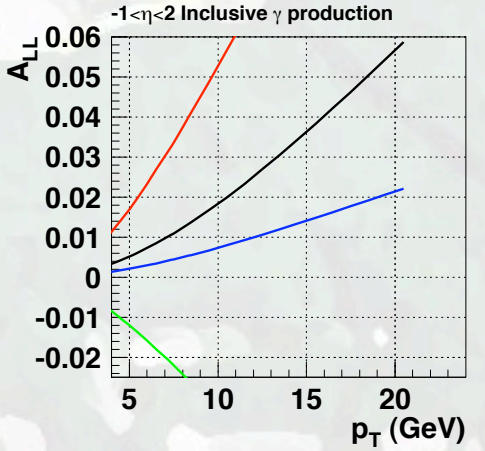
Gluon polarization - Inclusive Measurements











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

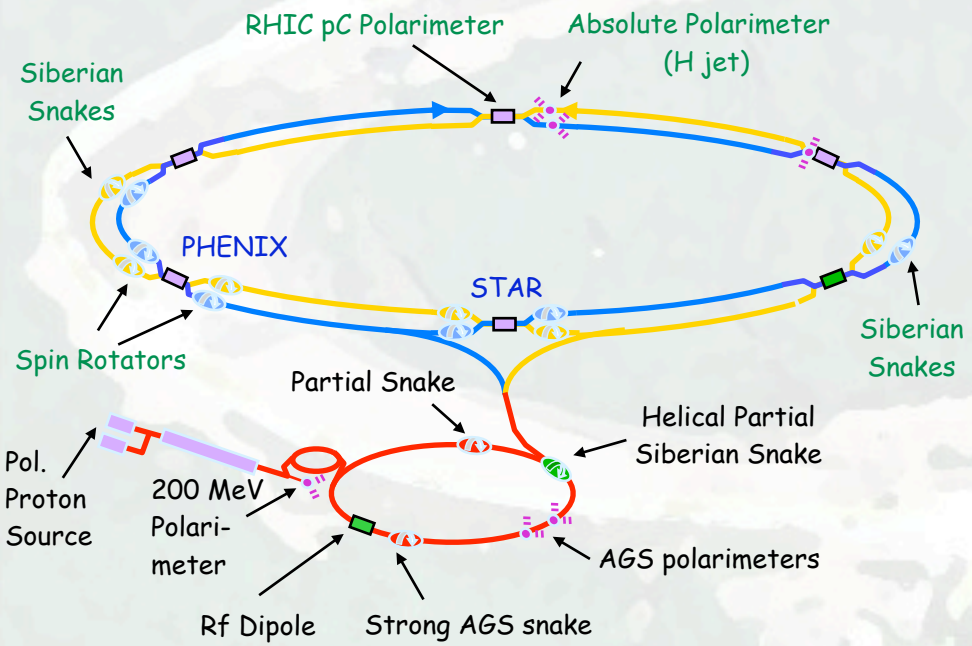
$$x_{\text{parton}} \simeq 2p_T/\sqrt{s}$$

- GRSV-STD: Higher order QCD analysis of polarized DIS experiments!

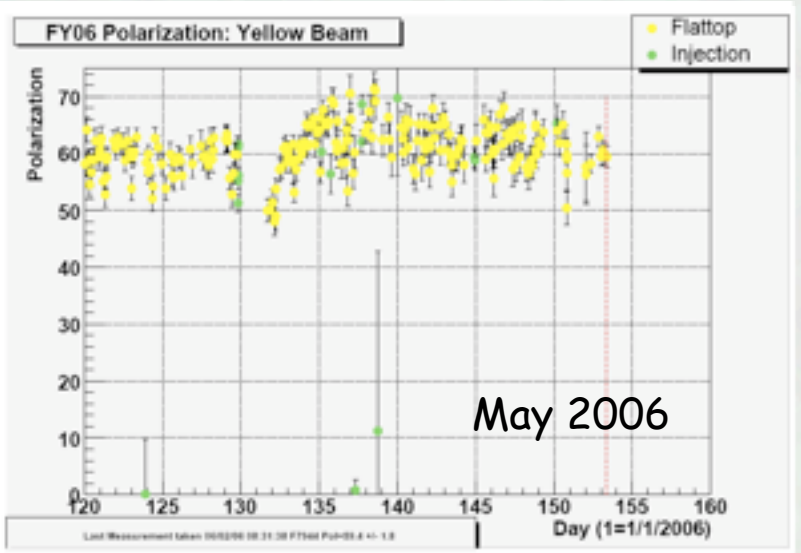
$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2) dx$$

Collider: The First polarized p+p collider at BNL

Performance



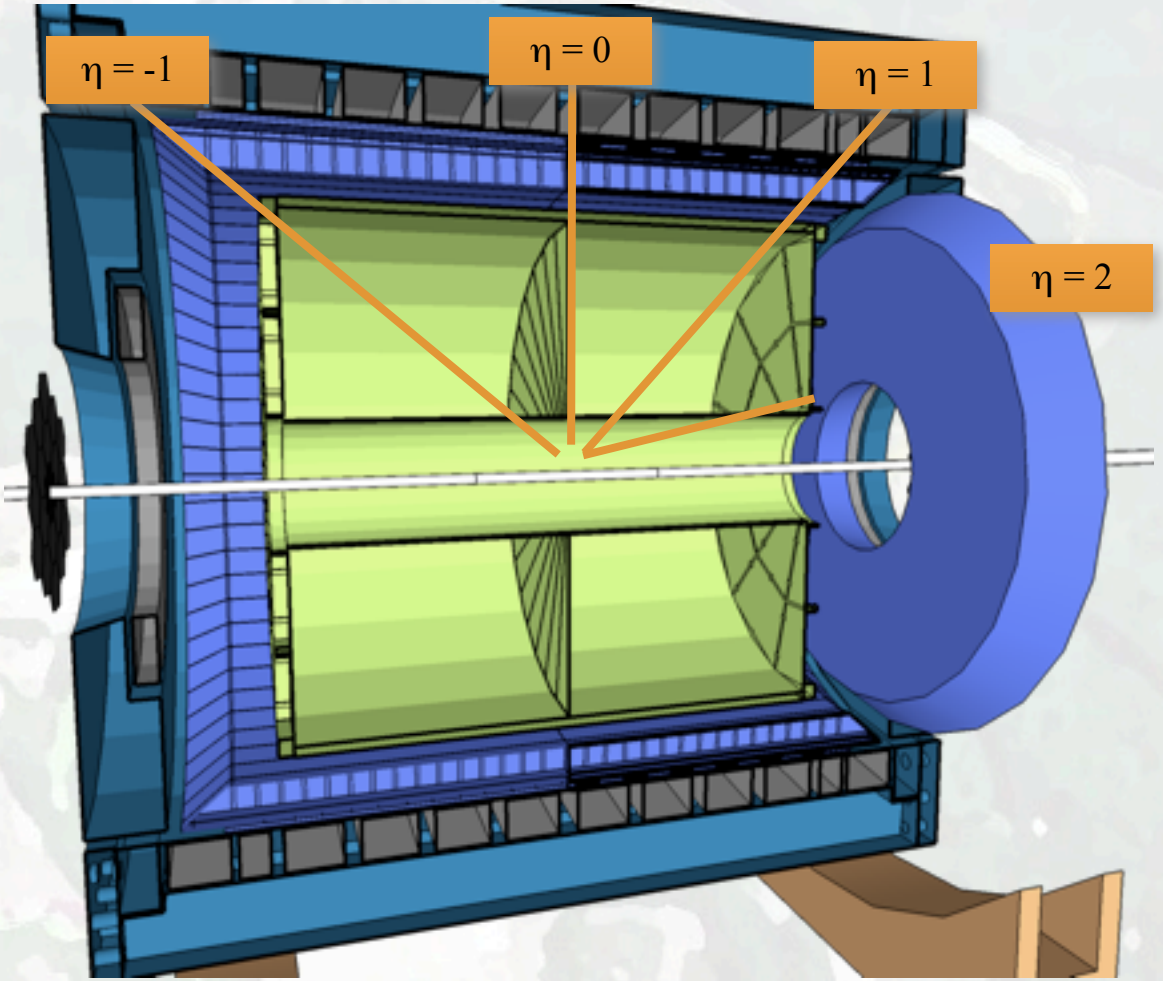
RHIC RUN	s [GeV]	$L_{recorded}$ [pb^{-1}] (trans.)	$L_{recorded}$ [pb^{-1}] (long.)	Polarization[%]
RUN 2	200	0.15	0.3	15
RUN 3	200	0.25	0.3	30
RUN 4	200	0	0.4	40-45
RUN 5	200	0.4	3.1	45-50
RUN 6	200	3.4/6.8	8.5	60

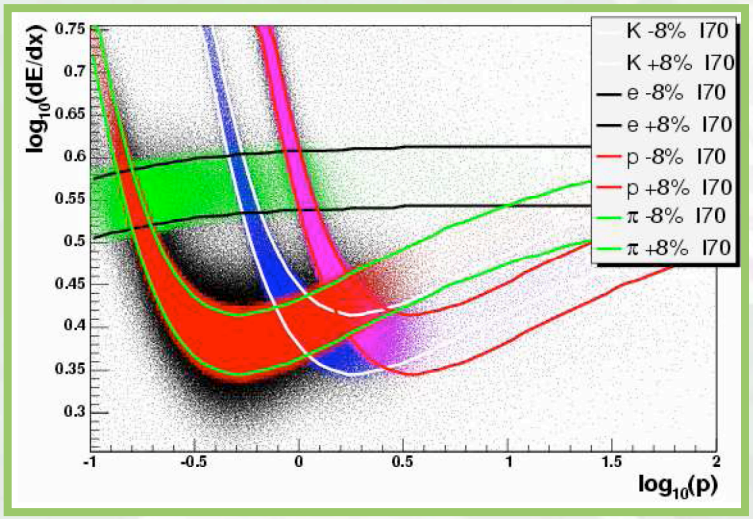


- All RHIC polarized pp accelerator components in place!
- 2006 performance (√=200GeV): ~60% polarization (70% design) and ~1pb^{-1}/day (~3pb^{-1}/day design) delivered luminosity

Experiment: The STAR detector

- Overview
  - **BBC**: Relative luminosity / Minimum bias trigger
  - **BEMC**: Jet patch trigger sums energy over fixed $\Delta\eta \times \Delta\Phi = 1.0 \times 1.0$ regions
  - **TPC**: Tracking and PID using dE/dx for $|\eta| < 1.3$ and $p_T < 15$ GeV/c

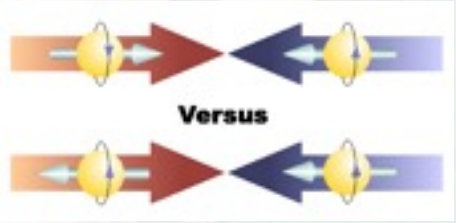




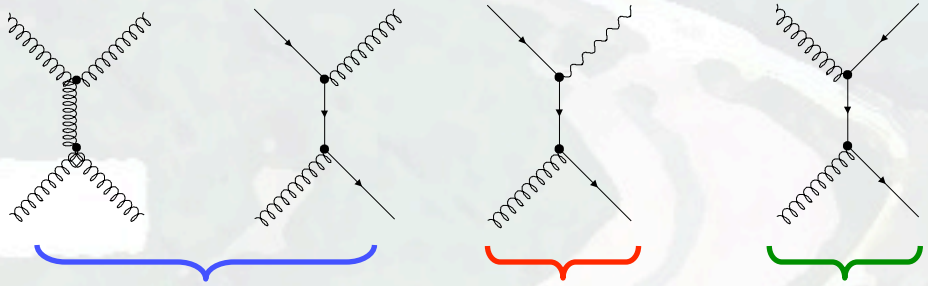
- Sophisticated TPC (dE/dx) calibrations improve precision at high p_T (arXiv:0807.4303-physics)

Recent result on Charged Pion production

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



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



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

    - Study helicity dependent structure functions (Gluon polarization)!

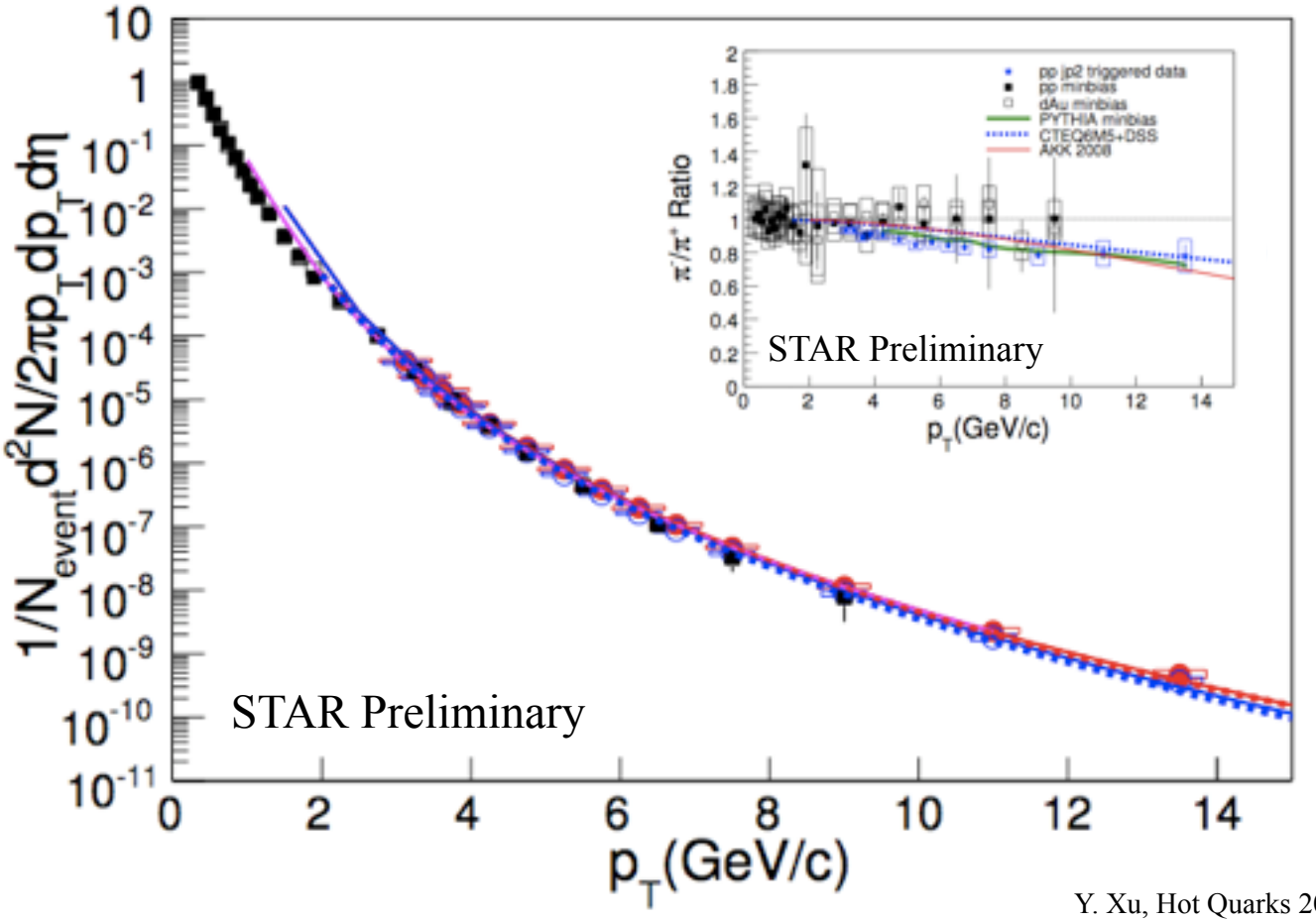
$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_1 P_2} \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}}$$

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

} STAR experiment

Recent result on Charged Pion production

- STAR Run 5 Cross section result: Mid-rapidity charged pion production

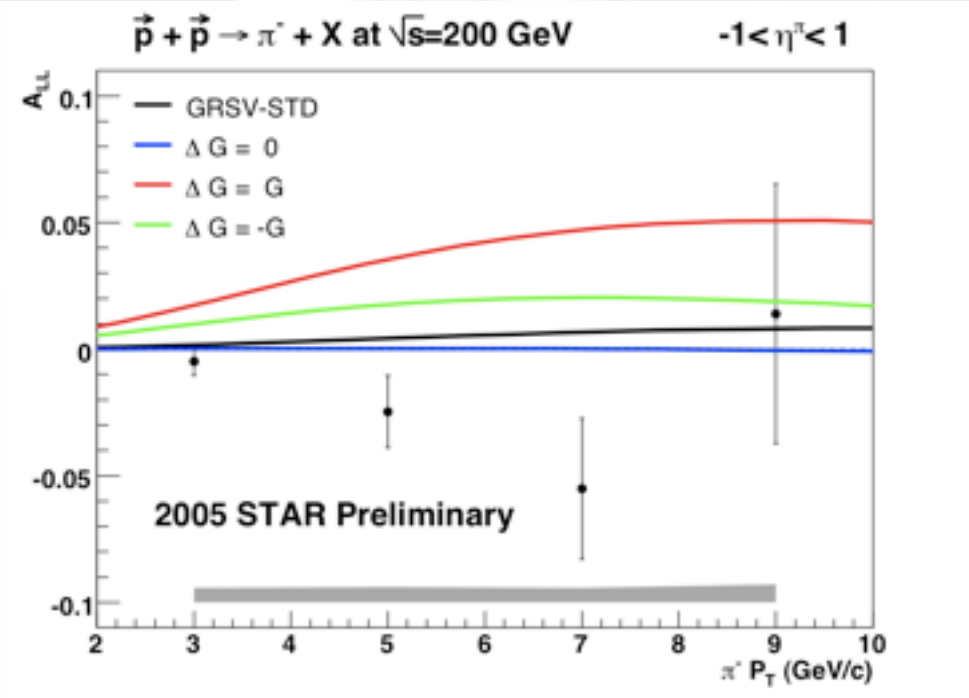


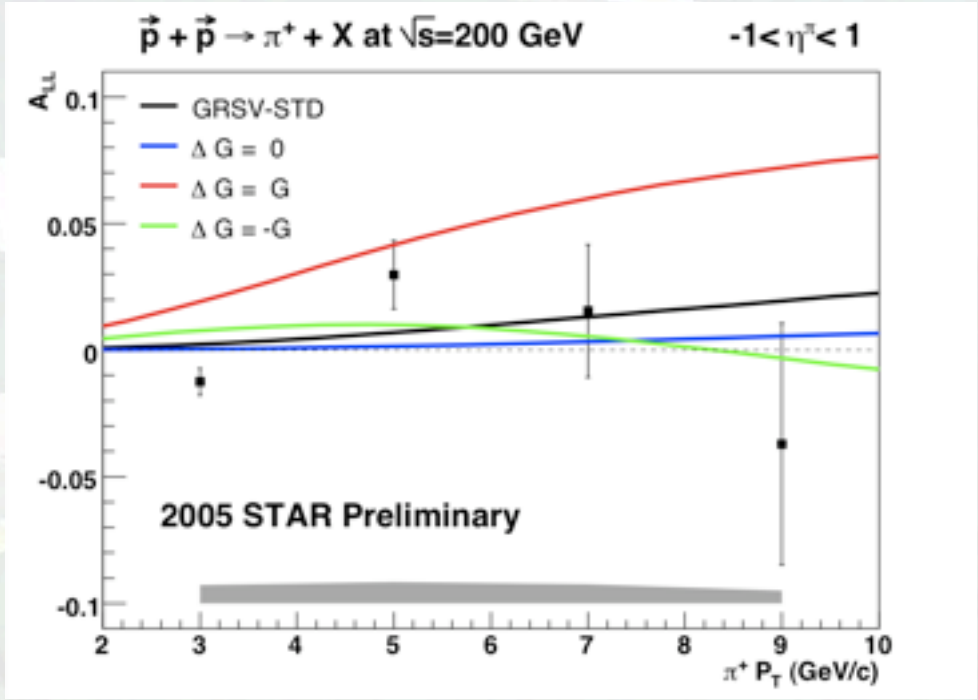
Y. Xu, Hot Quarks 2008

- Good agreement between data and NLO calculations for charged pion production ($3<p_T<15$GeV/c) incl. cross-section ratios (π^-/π^+) for $|\eta|<0.5$

Recent result on Charged Pion production

- STAR Run 5 A_{LL} result: Mid-rapidity charged pion production

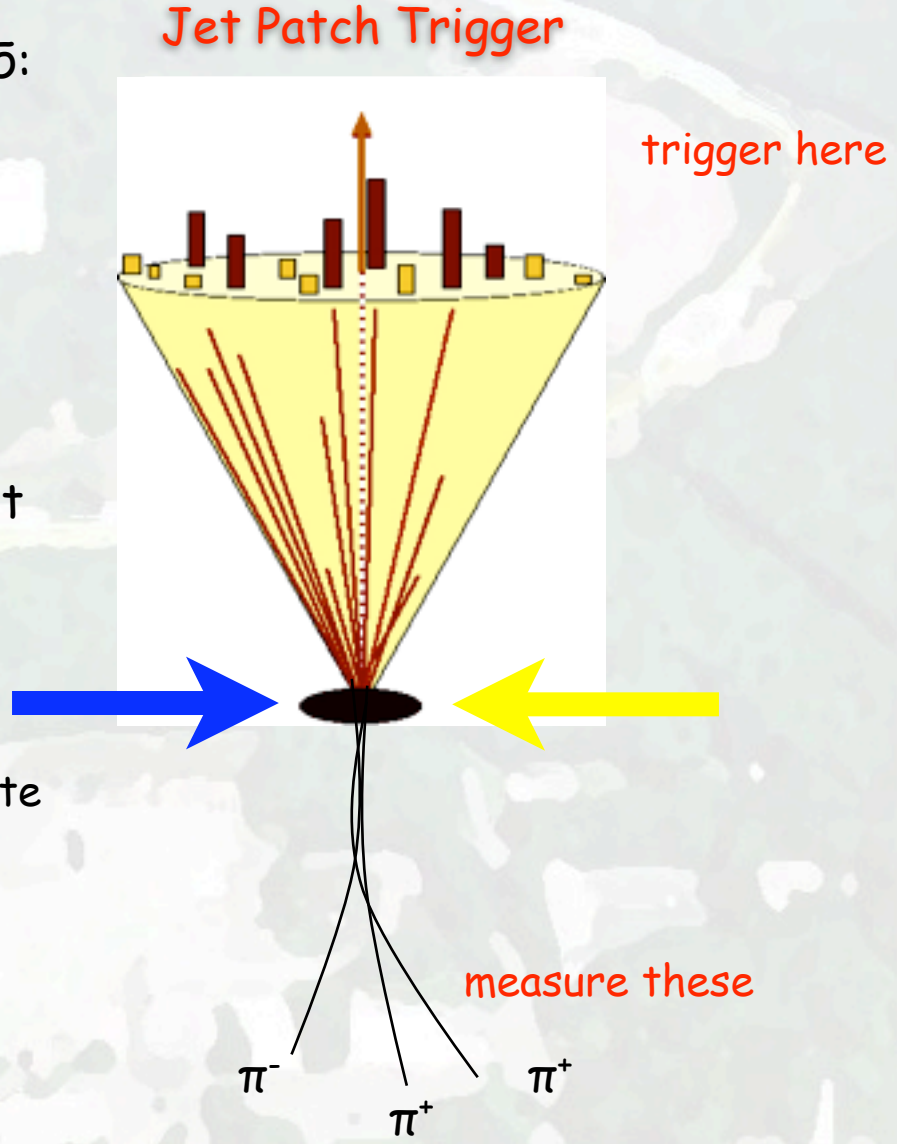




- Luminosity: 1.6 pb^{-1} / Beam polarization: 45-50%
- Maximum gluon polarization (GRSV-MAX) scenario disfavored
- Dominant systematic uncertainty arises from use of jet patch trigger which samples partonic subprocesses in a non-uniform fashion and suppresses high-z fragmentation

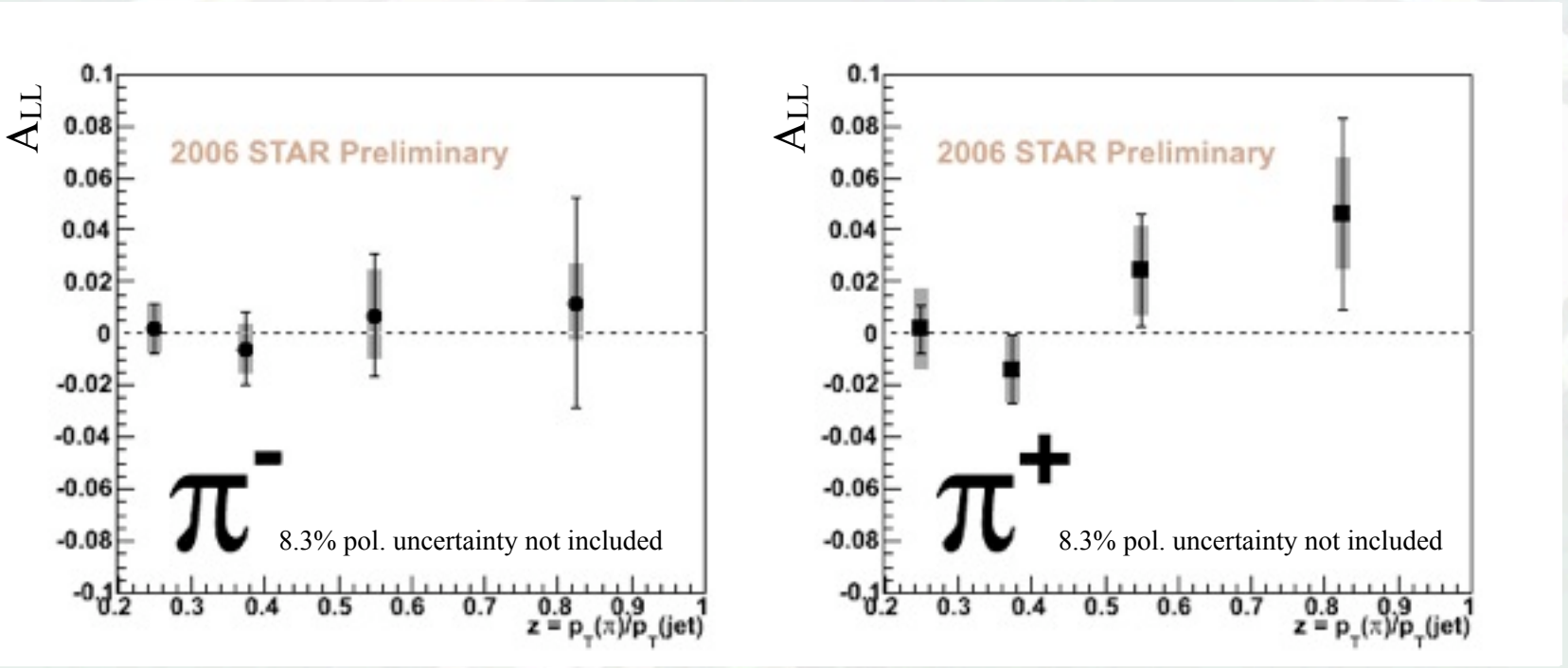
Recent result on Charged Pion production

- 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 result on Charged Pion production

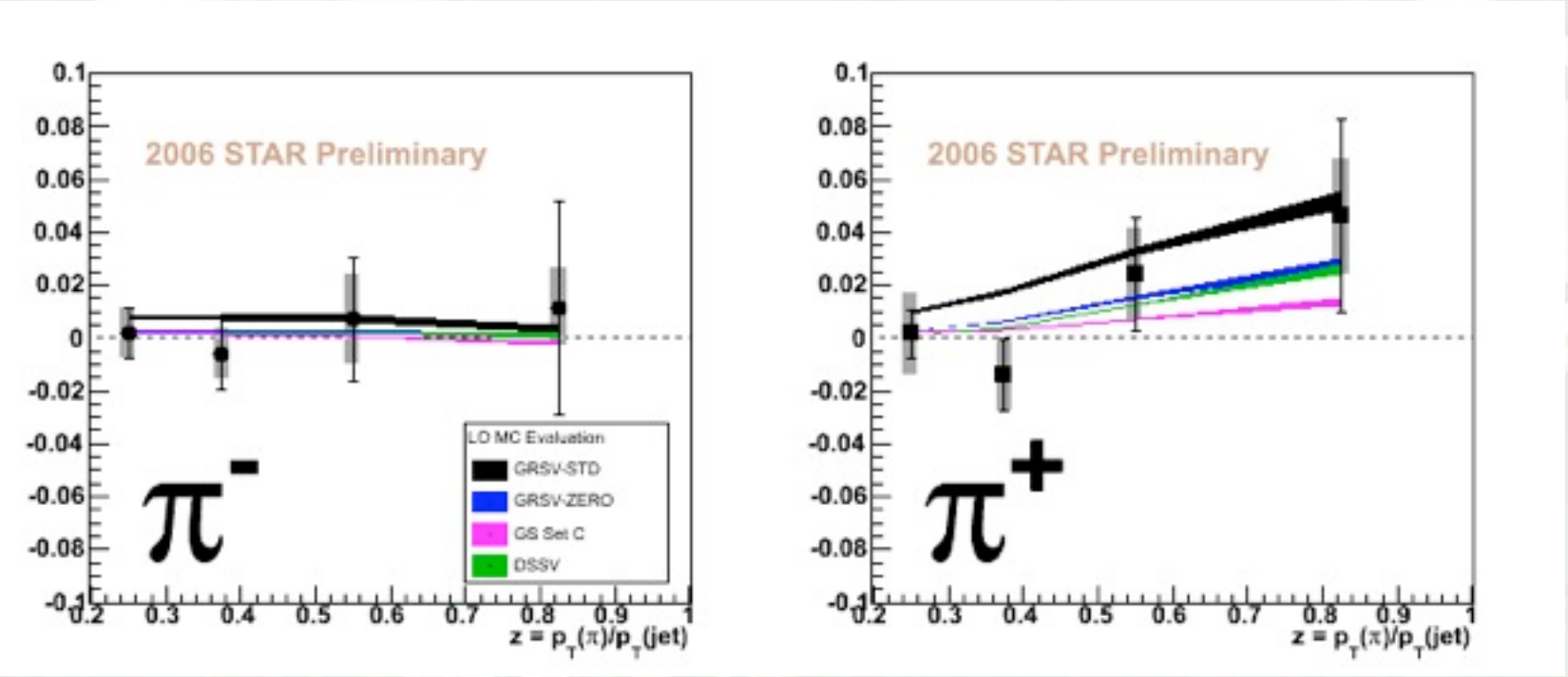
- STAR Run 6 A_{LL} result: Mid-rapidity charged pion production



- 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 result on Charged Pion production

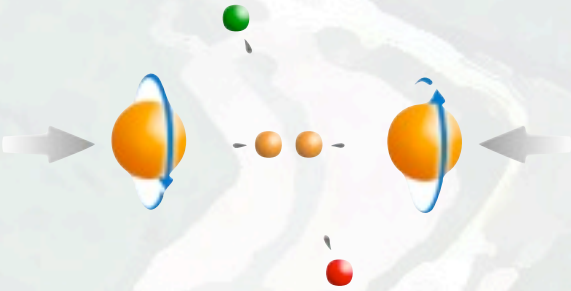
- STAR Run 6 A_{LL} result: Mid-rapidity charged pion production



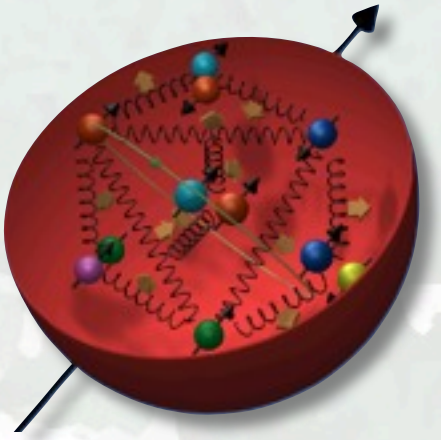
- Full NLO pQCD predictions are not yet available for this measurement
- These curves generated by sampling a_{LL} and parton distribution functions at kinematics of PYTHIA event.
- π^+ offers significant sensitivity at high z

Summary and Outlook

- Summary
  - pQCD: Critical role to interpret measured asymmetries
  - 2005 result: first spin asymmetry for inclusive charged pion production at STAR
  - 2006 measurement focuses on charged pions opposite a trigger jet to minimize fragmentation bias
  - Measurement versus z allows favored fragmentation to improve π^+ analyzing power at high z
  - Theoretical predictions for A_{LL} are forthcoming, and future RHIC runs will allow for additional precision at high z

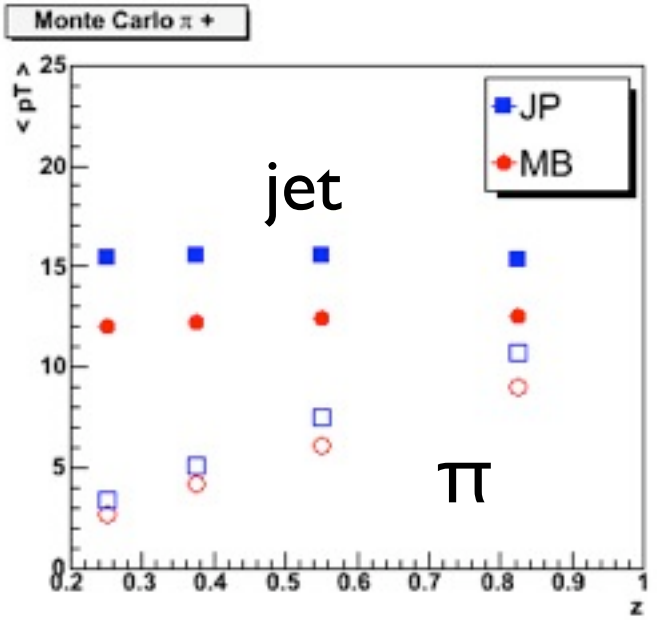


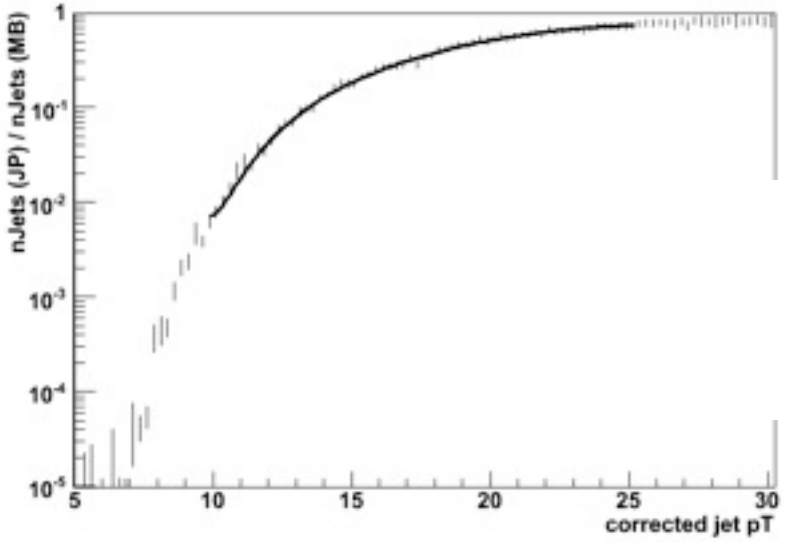
$$\frac{1}{2} = \langle S_q \rangle + \langle S_g \rangle + \langle L_q \rangle + \langle L_g \rangle$$



Trigger Bias

- Jet patch trigger samples subprocesses non-uniformly
- Traditionally, LO MC evaluation of A_{LL} is used to assign model-dependent systematic
- This measurement integrates over a wide range in jet p_T, so triggered dataset samples different kinematic range too
- Factor out the difference in <jet p_T> by reweighting the Monte Carlo
- Bias assigned assuming GRSV-STD





PID Background Asymmetry

- use triple Gaussian fits to estimate p/K background at 10%
- Select sideband starting at -2σ and calculate its A_{LL}
- Systematic assigned as

$$\delta A_{LL} = f_{bg} \times (A_{LL}^{meas} - A_{LL}^{bg})$$