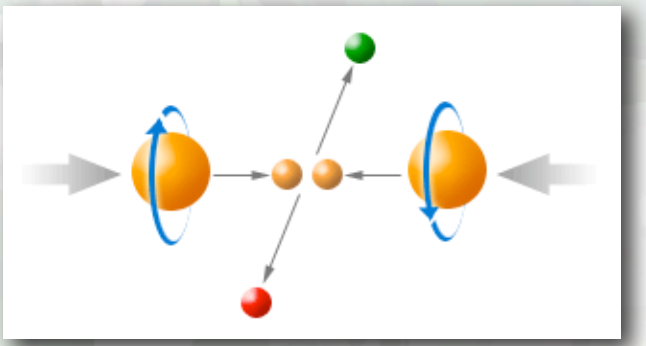
STAR longitudinal spin program
Status and Perspectives

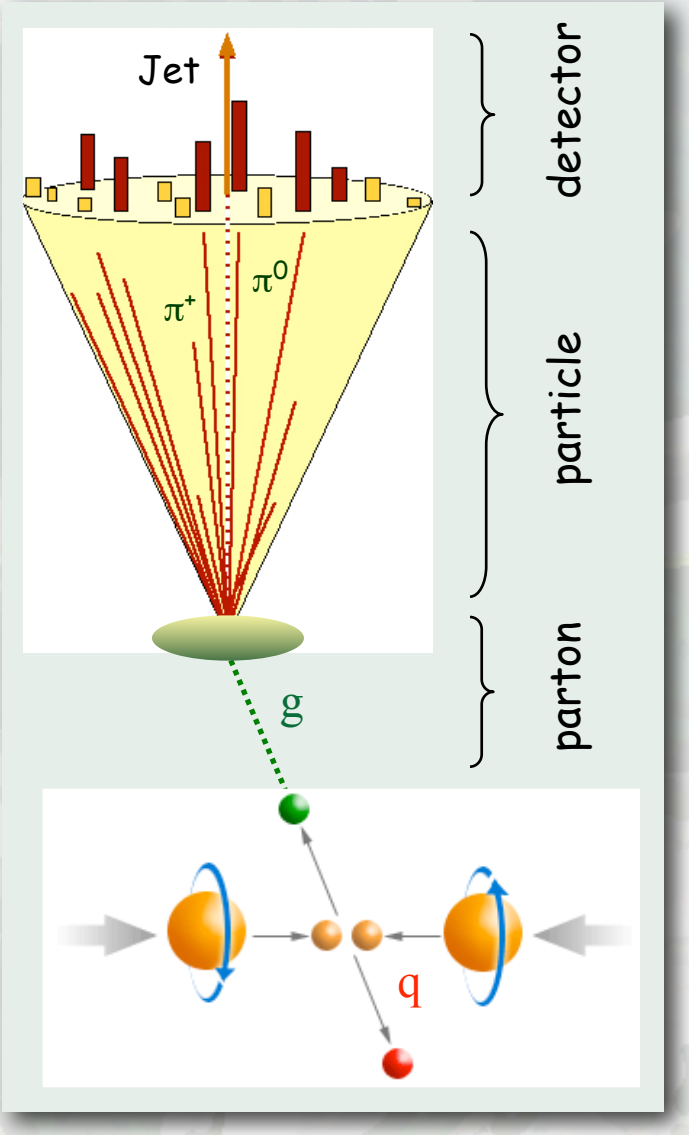
Bernd Surrow

Massachusetts Institute of Technology



Outline

- Correlation measurements - Di-hadron / Di-Jet production (2005/2006)
- Hadron / Jet production (2005/2006)

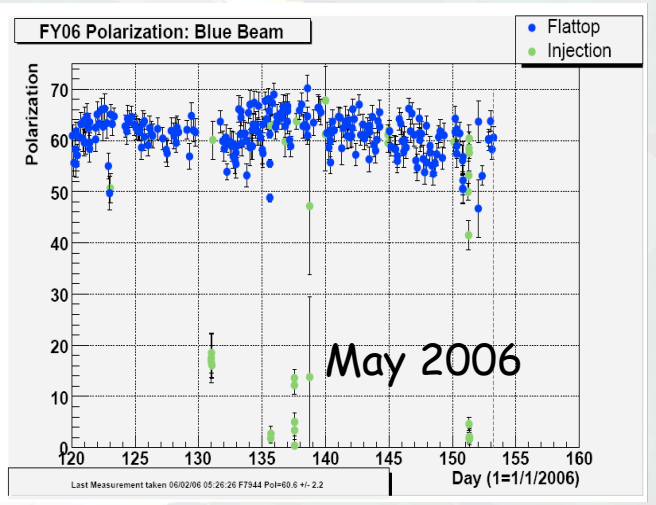


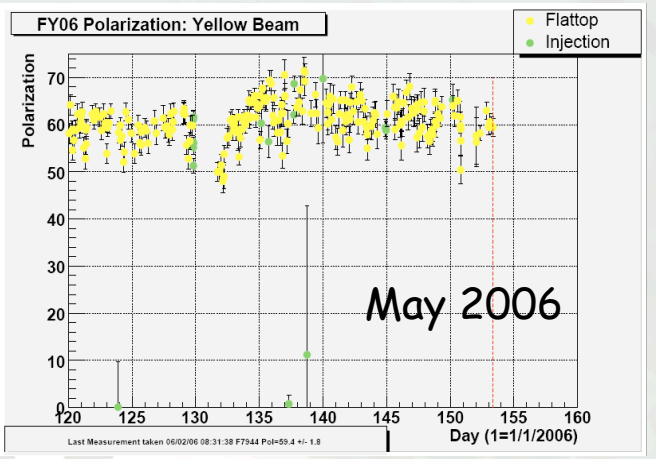
- Prompt photon production (2006 and beyond)
- Summary and Outlook

The polarized proton collider RHIC

- Luminosity (STAR recorded) and polarization performance

RHIC RUN	s [GeV]	$L_{recorded}$ [pb^{-1}] (transverse)	$L_{recorded}$ [pb^{-1}] (longitudinal)	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 (2.0+6.5)	60

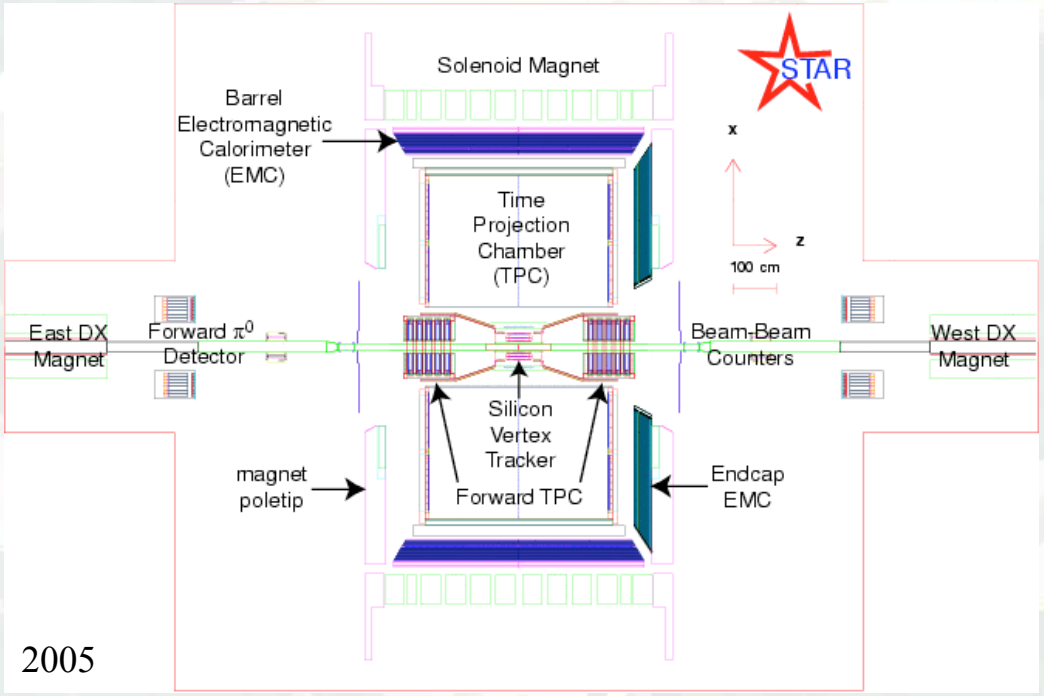




- All RHIC polarized pp accelerator components are in place!
- 2006 performance (√=200GeV): ~60% polarization (70% design) and ~1pb^{-1}/day (~3pb^{-1}/day design) delivered luminosity

The STAR detector

Overview

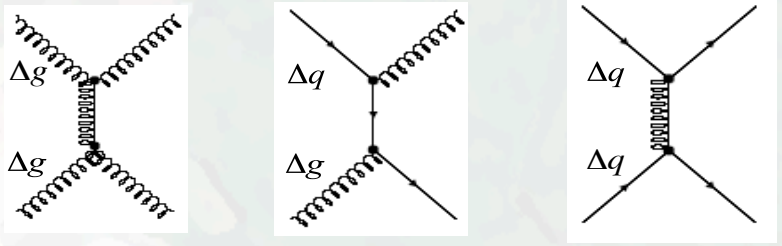


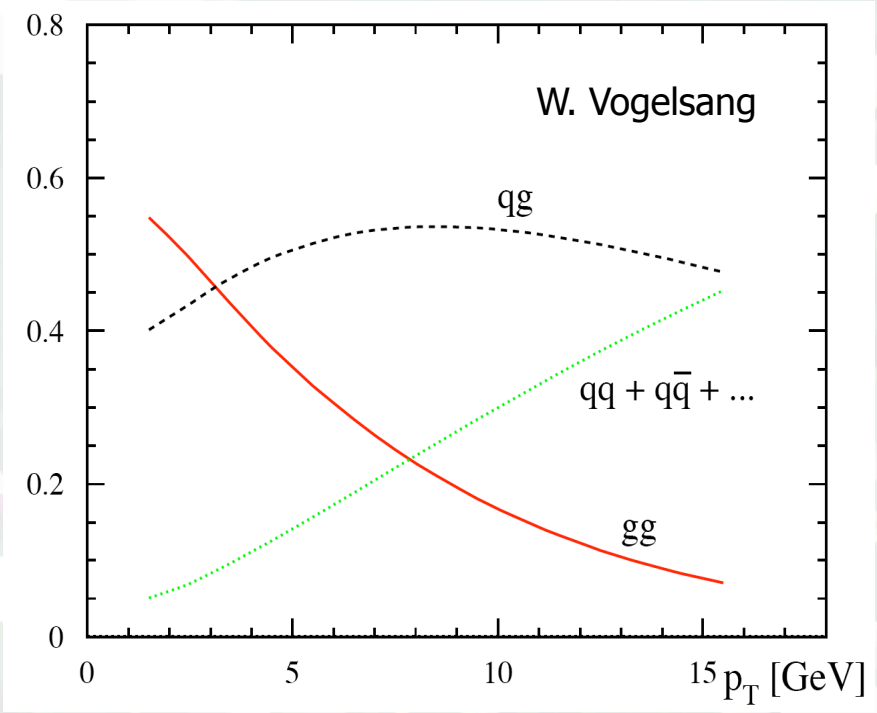
- Forward-Pion Detector (FPD) ($3 < |\eta| < 4$)
- FPD++ (Extended coverage for Run 6 with $3 < \eta < 4$)
- FMS upgrade (Run 7 and beyond with $2.5 < \eta < 4$)

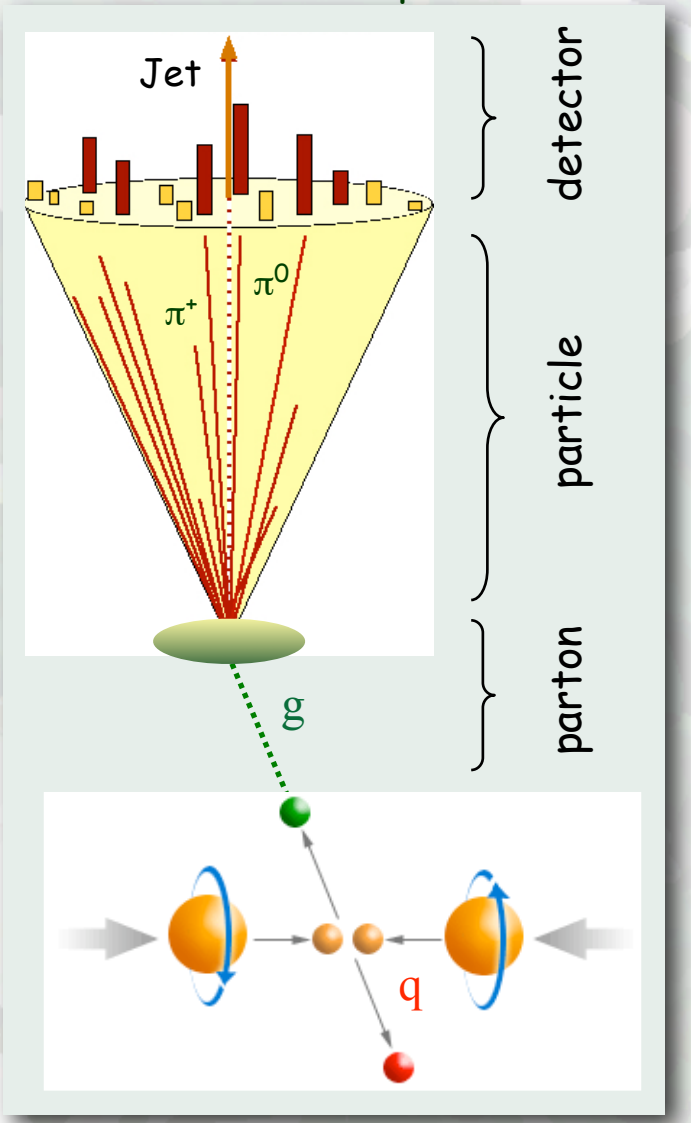
- Beam-Beam Counter (BBC): ($3.4 < |\eta| < 5$)
  - Relative luminosity measurement
  - Absolute luminosity measurement
  - Local polarimeter (A_N for charged particles)
- EM-Calorimeter: (Barrel - BEMC : $-1 < \eta < 1$ & Endcap - EEMC: $1.09 < \eta < 2$)
  - Reconstruction of γ, $e^{\pm}$ and π^0
  - Jet-reconstruction in combination with TPC

Hadron / Jet production

- Hadron / Jet production: Jet and Hadron production
  - Underlying processes contributing to inclusive jet production and π^0 / $\pi^\pm$ production

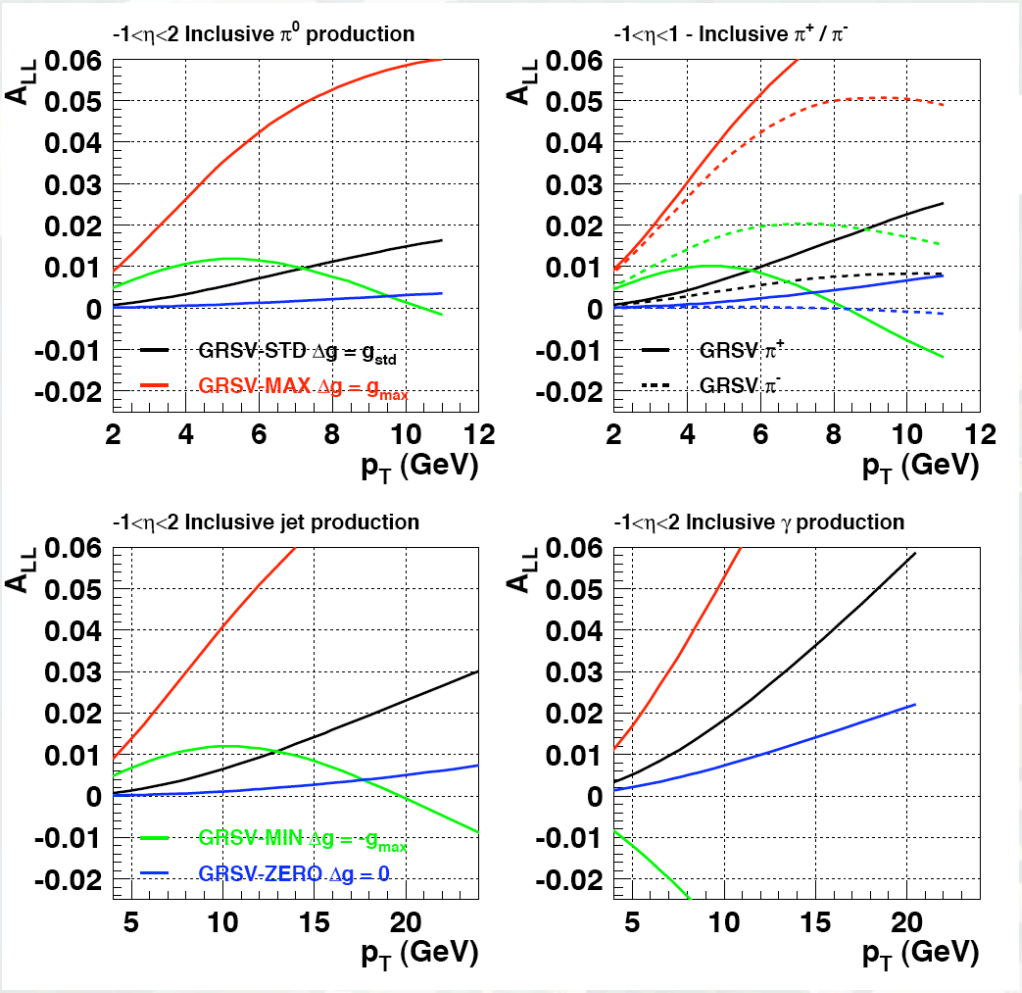


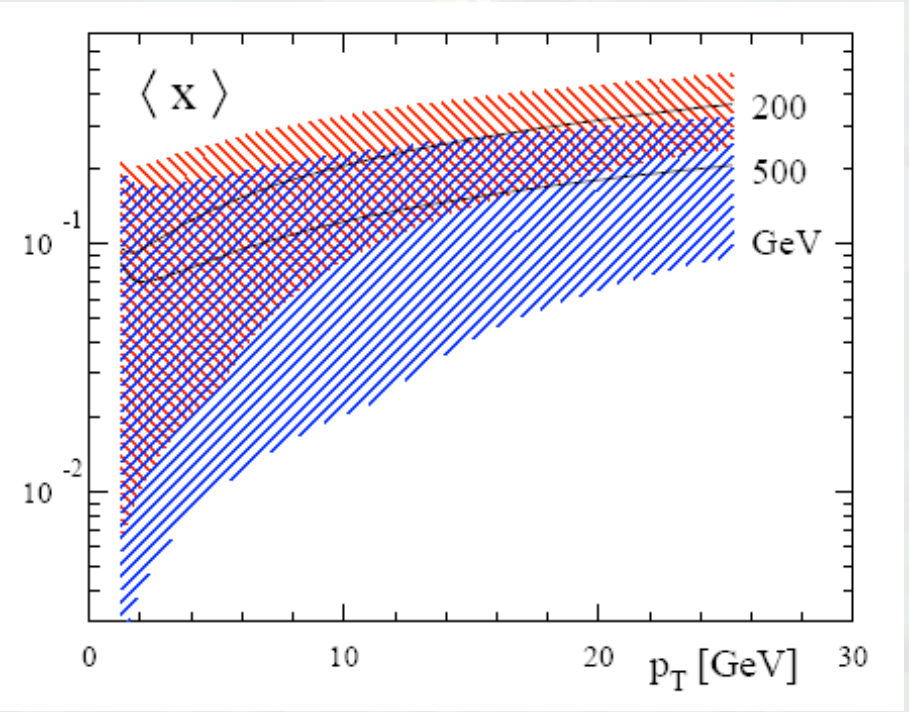




Hadron / Jet production

- Hadron / Jet production: Jet / π^0 / $\pi^{\pm}$ production
  - A_{LL} sensitivity for different ΔG scenarios





- Mean Bjorken-x and rms-spread as a function of p_T for inclusive π^0 production
- Central production ($\eta \approx 0$):

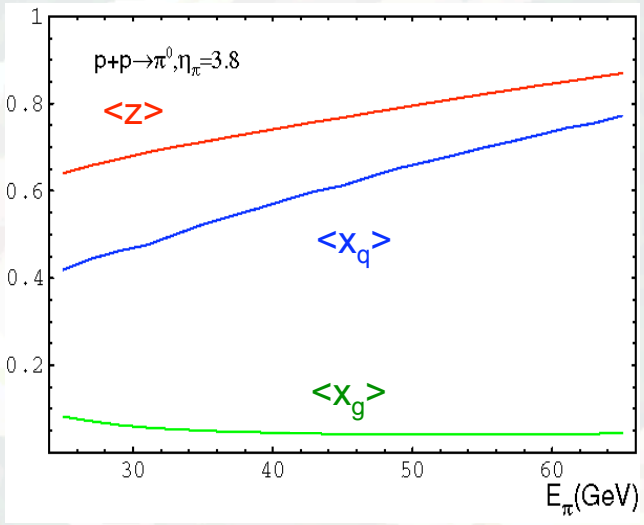
$$x_{\mathrm{parton}} \simeq 2p_T/\sqrt{s}$$

Hadron / Jet production

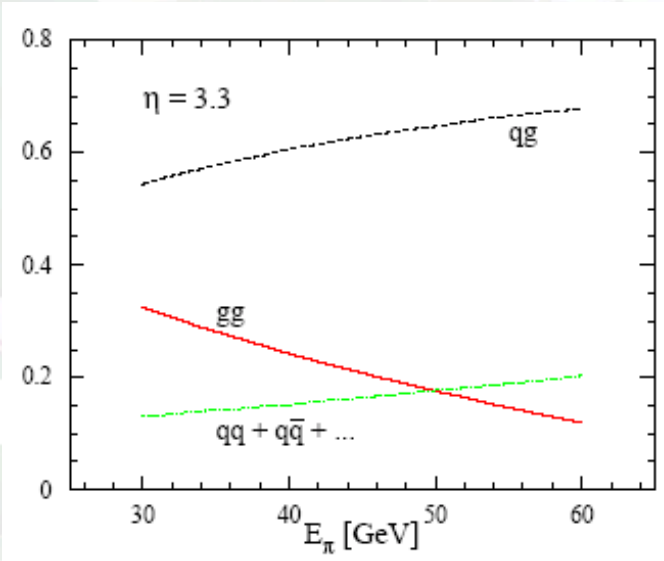
Cross-section measurement: Forward neutral pion production

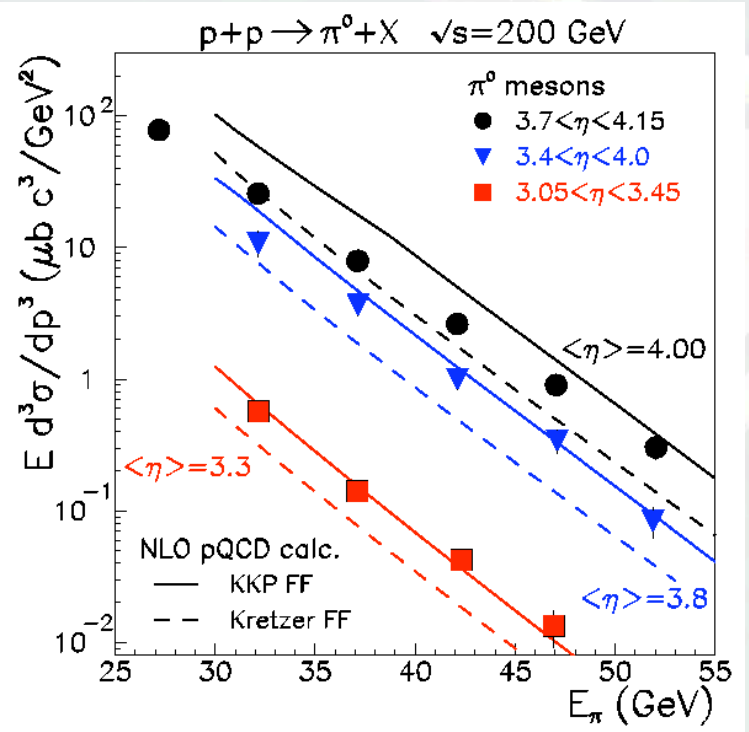
L.Nogach (Protvino) - SPIN2006

Jaeger, Stratmann, Vogelsang and Kretzer



V. Guzey, M. Strikman and W. Vogelsang, Phys. Lett. B**603** (2004) 173.



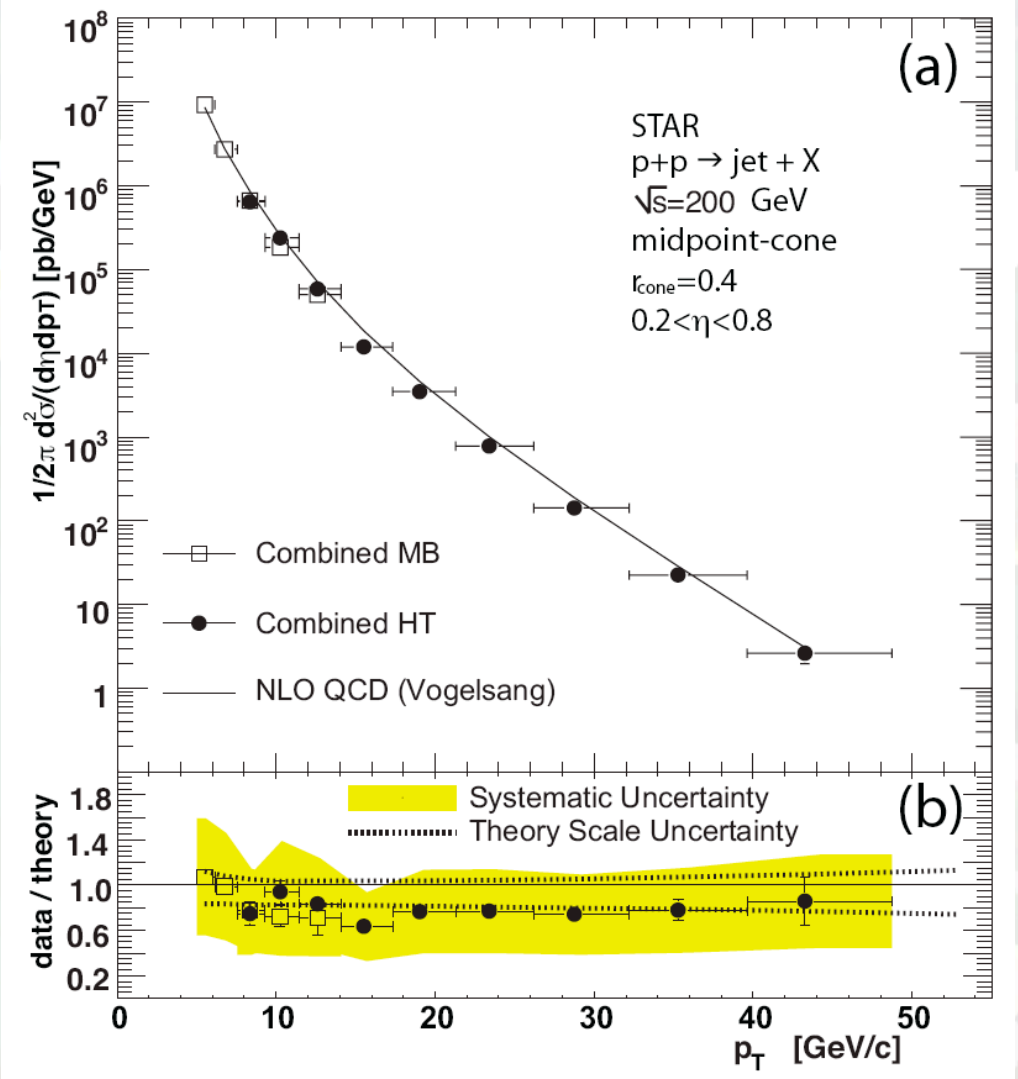


- Forward π^0 production : Dominated by asymmetric qg collisions
- NLO pQCD calculations for two sets of fragmentation functions
- Data compares favorably to NLO pQCD at $\sqrt{s}$ = 200GeV in contrast to fixed-target or ISR energies

Hadron / Jet production

- Cross-section measurement: Inclusive jet production

D. Relyea (CalTech) - SPIN2006

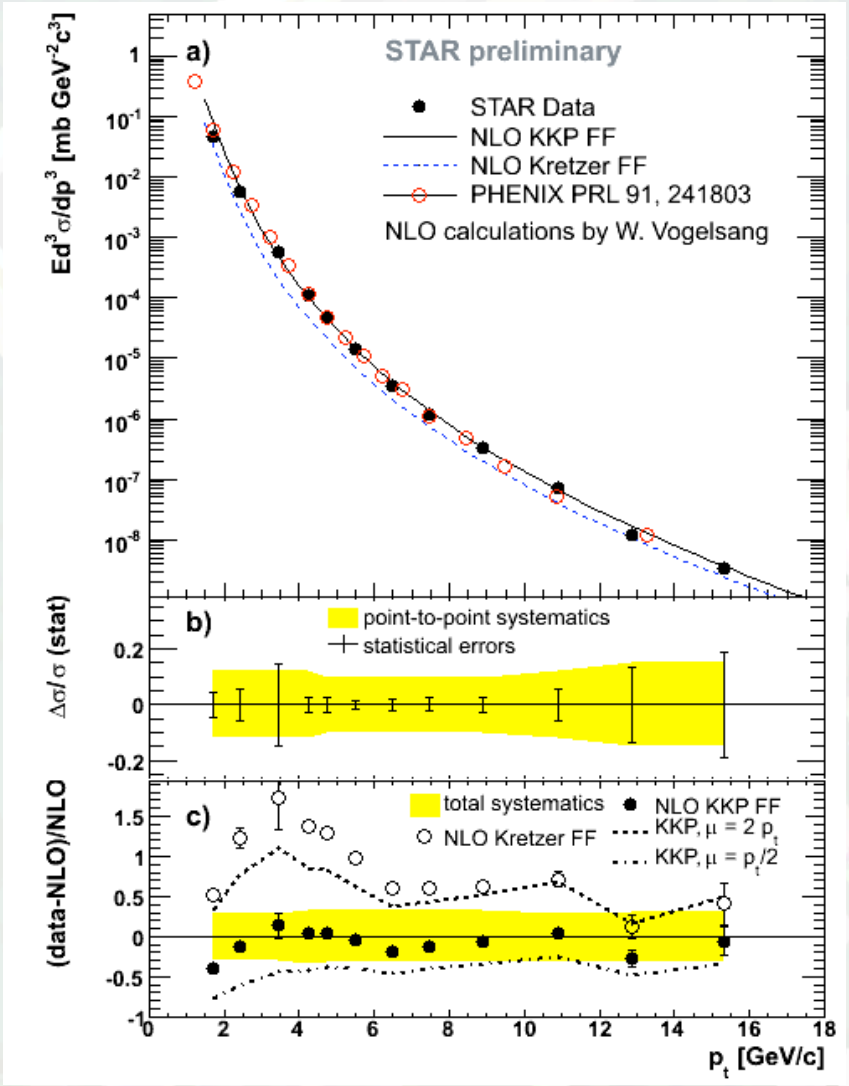


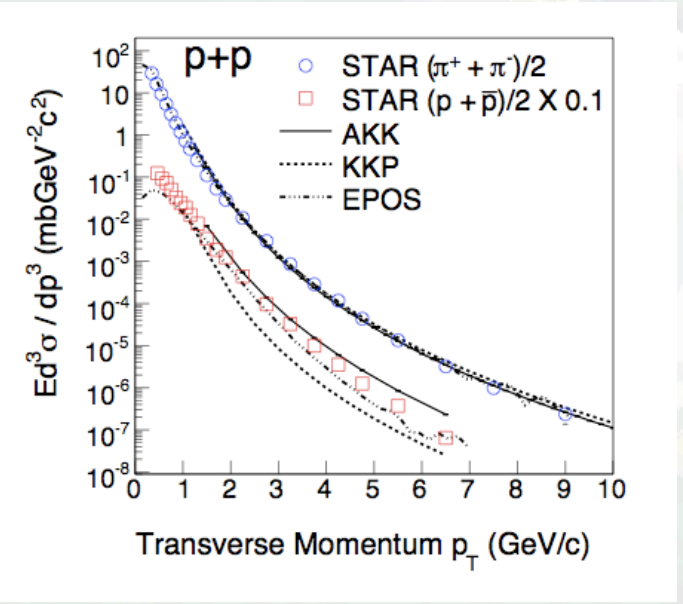
- First measurement of inclusive jet cross-section at RHIC
- Good agreement of data with NLO pQCD calculations over 7 orders of magnitude within large systematic uncertainties

Hadron / Jet production

Cross-section measurement: Hadron production

F. Simon (MIT) - SPIN2006





- Good agreement of data with NLO pQCD calculations over several order of magnitude for neutral and charged pion cross-section
- KKP fragmentation preferred
- Scale uncertainties at the level of systematic uncertainties (Shown here for neutral pion cross-section)

Hadron / Jet production

- A_{LL} measurement: Neutral pion production (STAR BEMC)

F. Simon (MIT) - SPIN2006

Hadron / Jet production

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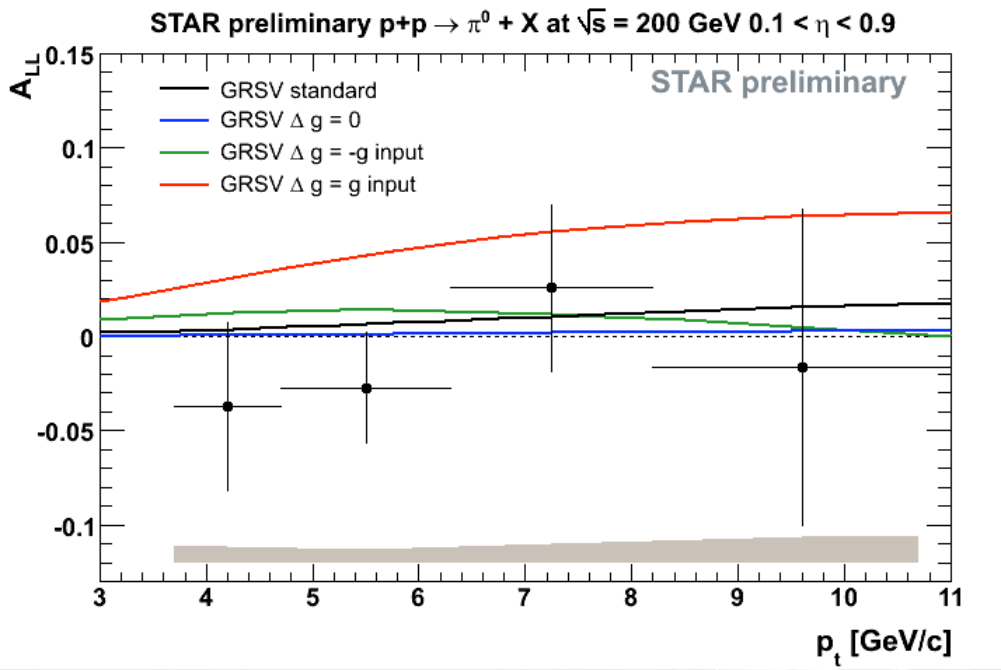

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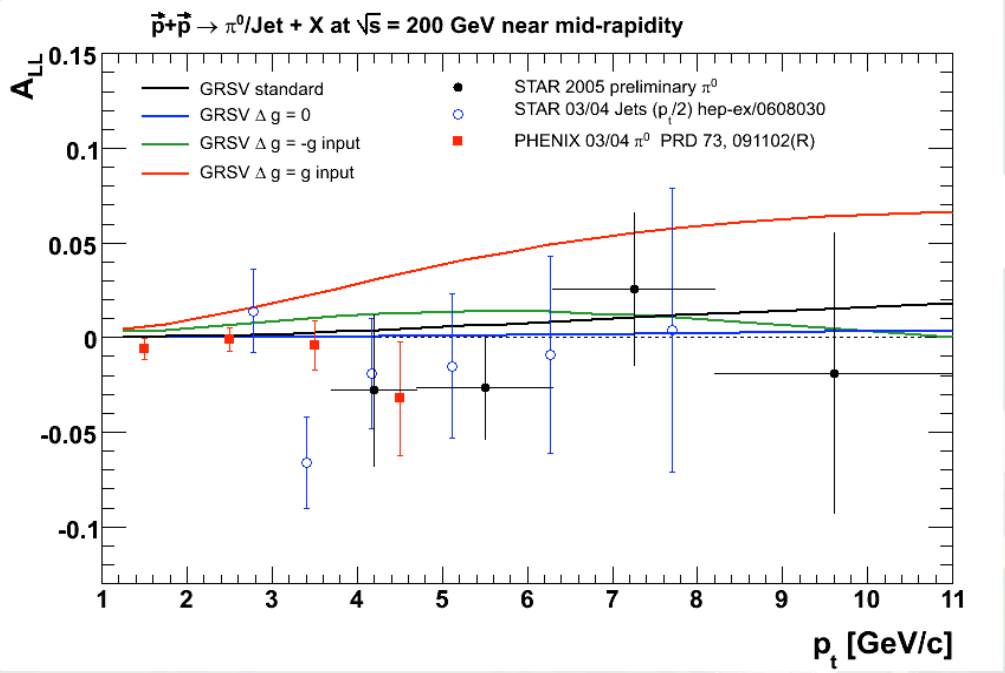

$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2) dx$$

$$\Delta G(Q^2 = 1\,\mathrm{GeV}^2) \approx 1.8$$

$$\Delta G(Q^2 = 1\,\mathrm{GeV}^2) \approx 0.4$$

χ^2 / ndf to curves: (no sys. errors included)

GRSV-STD: 0.8

DG = G: 2.4

DG = 0: 0.8

DG = -G: 0.5

- A_{LL} π^0 result (Run 5) with Run 3/4 jet result and PHENIX π^0 result
- Maximum gluon polarization (GRSV-MAX) scenario ruled out

Hadron / Jet production

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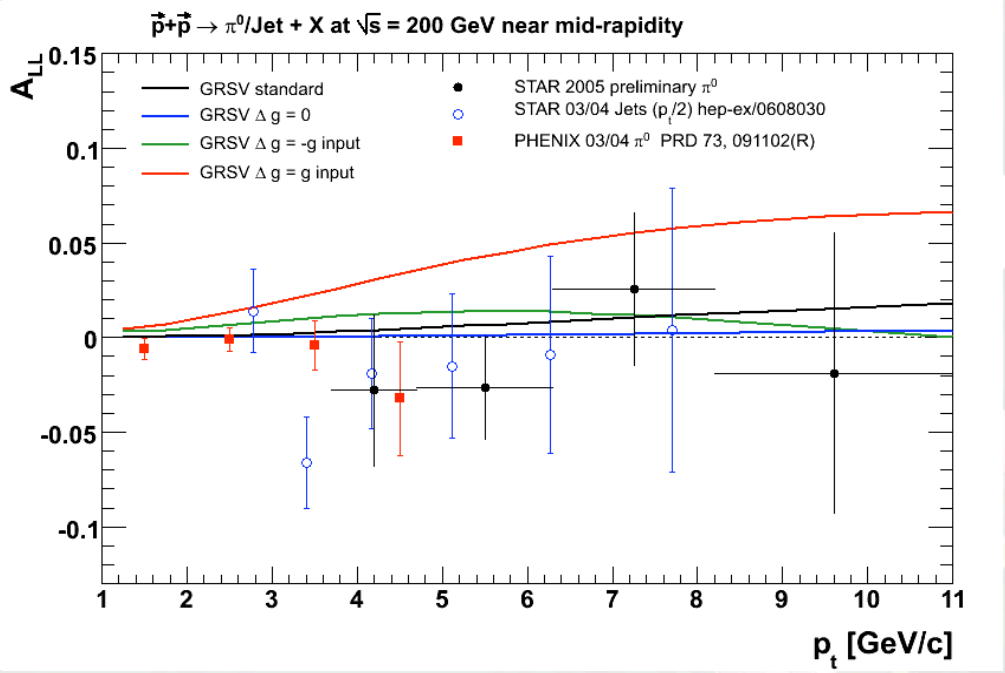
F. Simon (MIT) - SPIN2006



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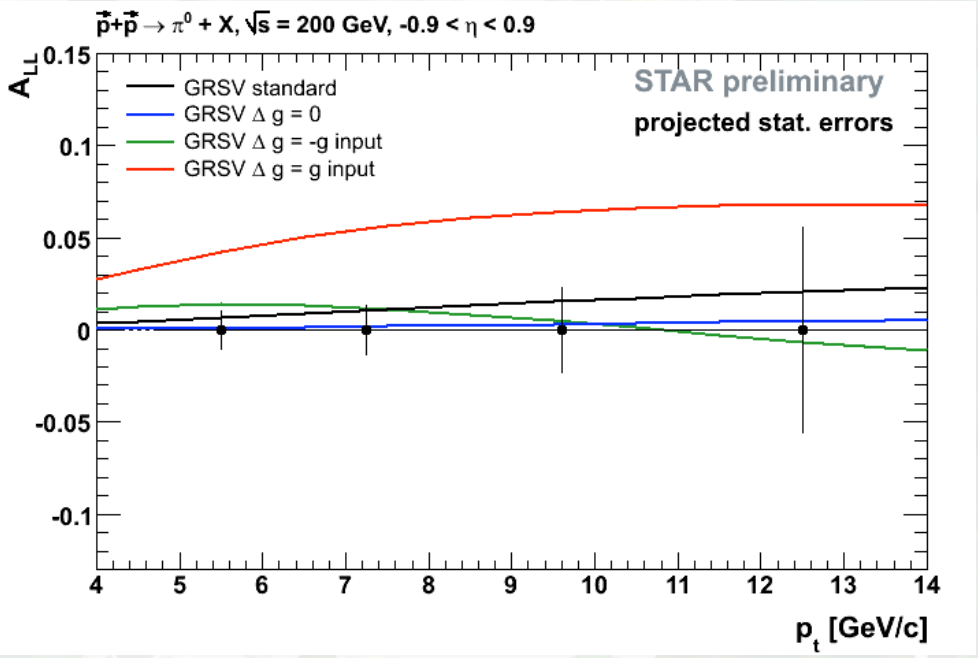

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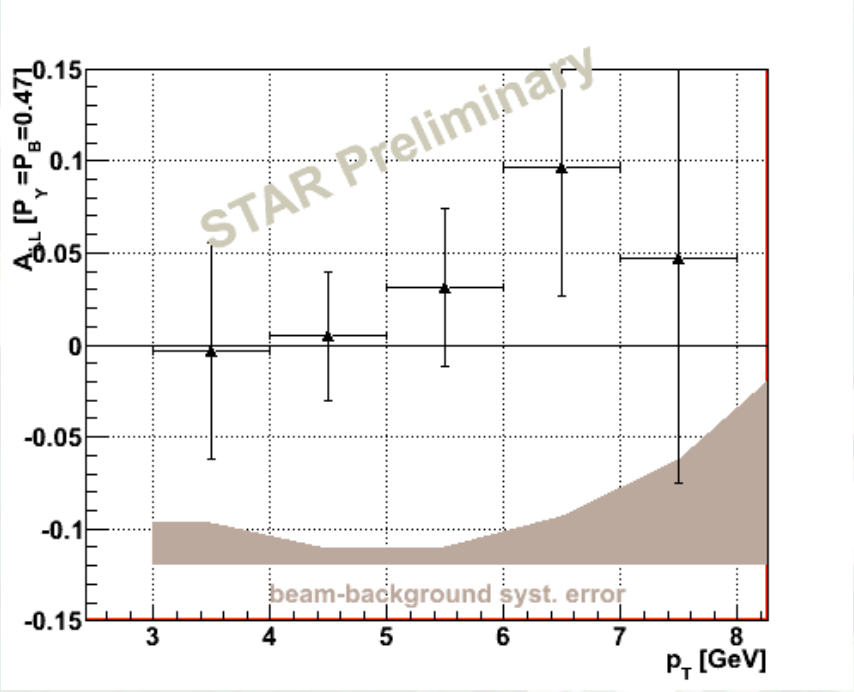
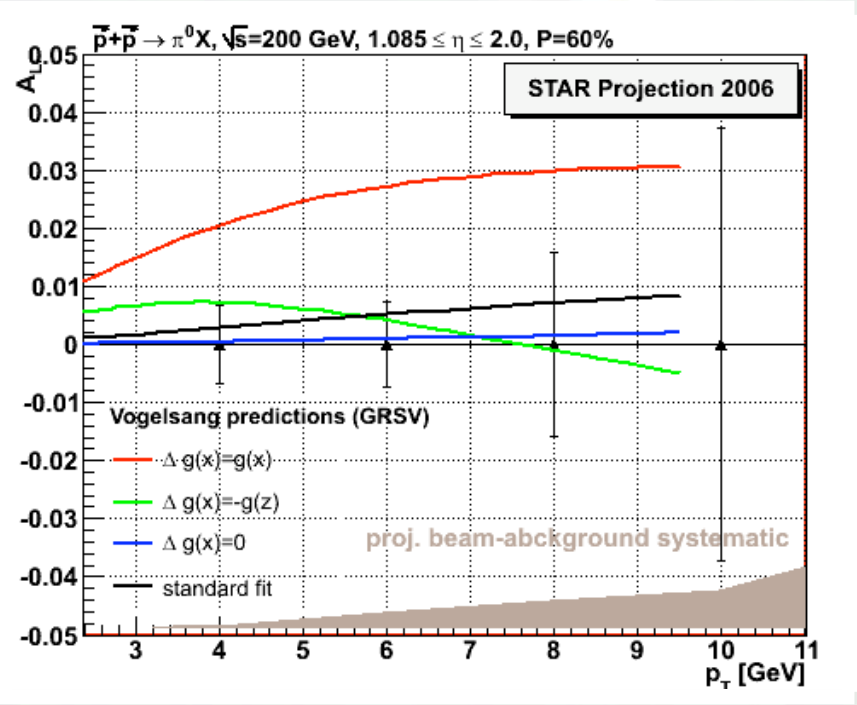
- Improved measurement with Run 6 data

A_{LL} measurement: Neutral pion production (STAR BEMC)

J. Webb (Valparaiso University) - SPIN2006





- Forward direction probes different q/g sub-process mixture
- Current analysis (Run 5) in STAR EEMC region ($1.09 < \eta < 2$) dominated by beam background
- Several improvements in Run 6 such as reduction in beam background
- Important baseline measurement for future prompt photon measurements

Hadron / Jet production

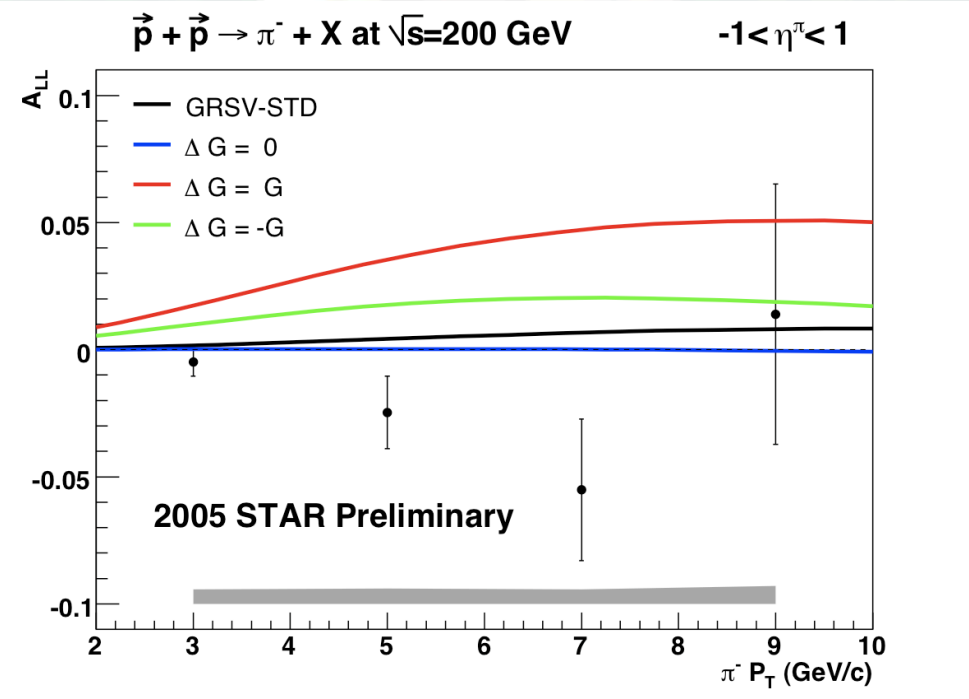
- A_{LL} measurement: Charged pion production ($-1 < \eta < 1$)

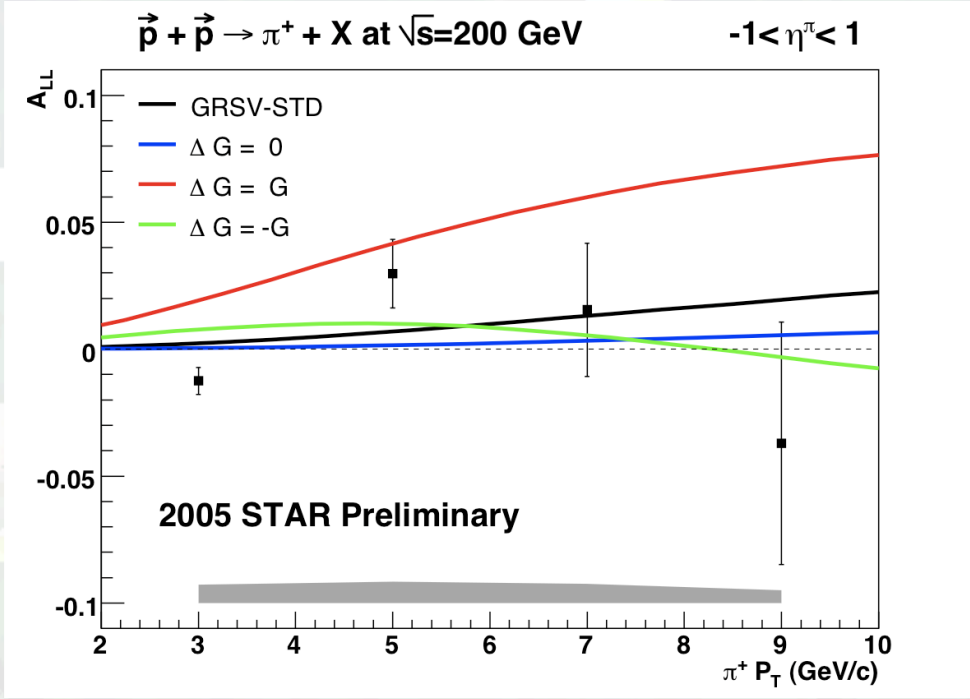
A. Kocoloski (MIT) - SPIN2006

Hadron / Jet production

A_{LL} measurement: Charged pion production ($-1 < \eta < 1$)

A. Kocoloski (MIT) - SPIN2006





- $A_{LL}(\pi^-)$ / $A_{LL}(\pi^+)$ allows to track sign of ΔG at high p_T (qg process dominates)
- Maximum gluon polarization (GRSV-MAX) scenario disfavored

Hadron / Jet production

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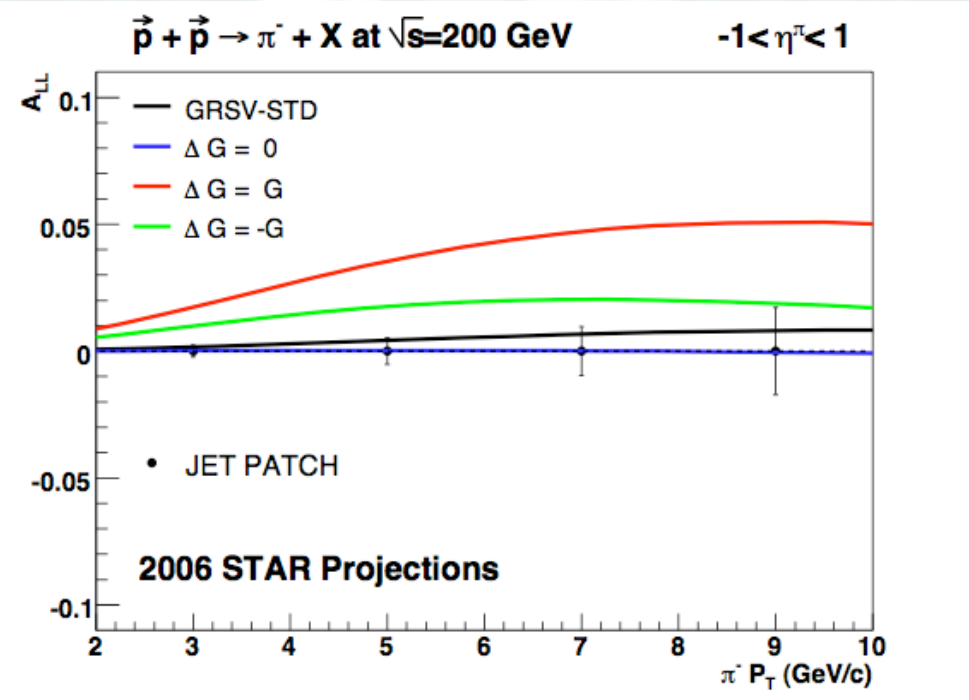
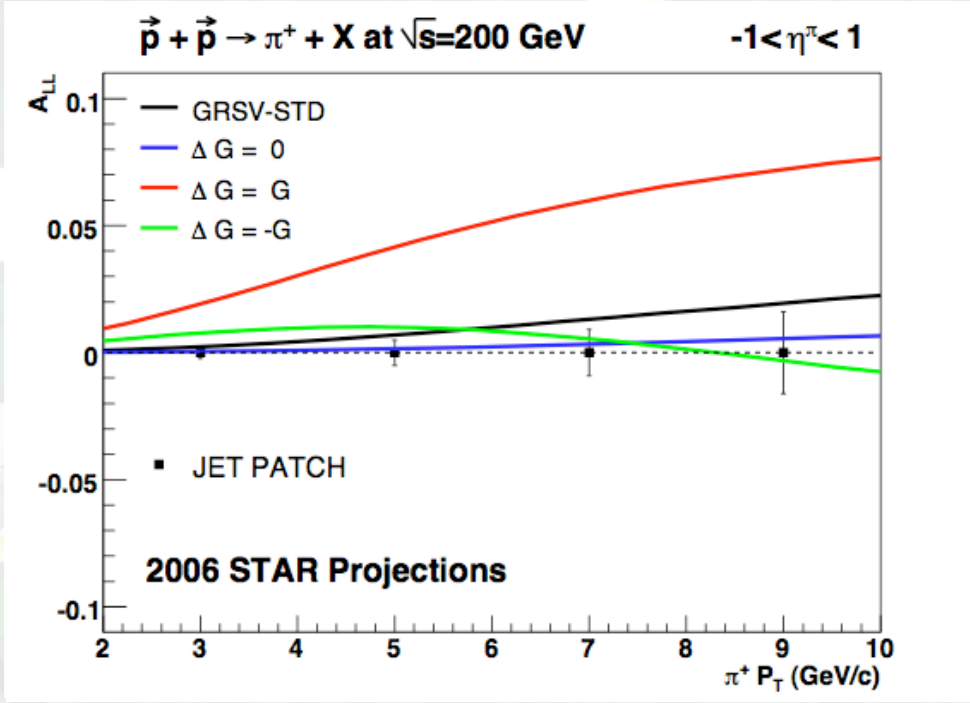
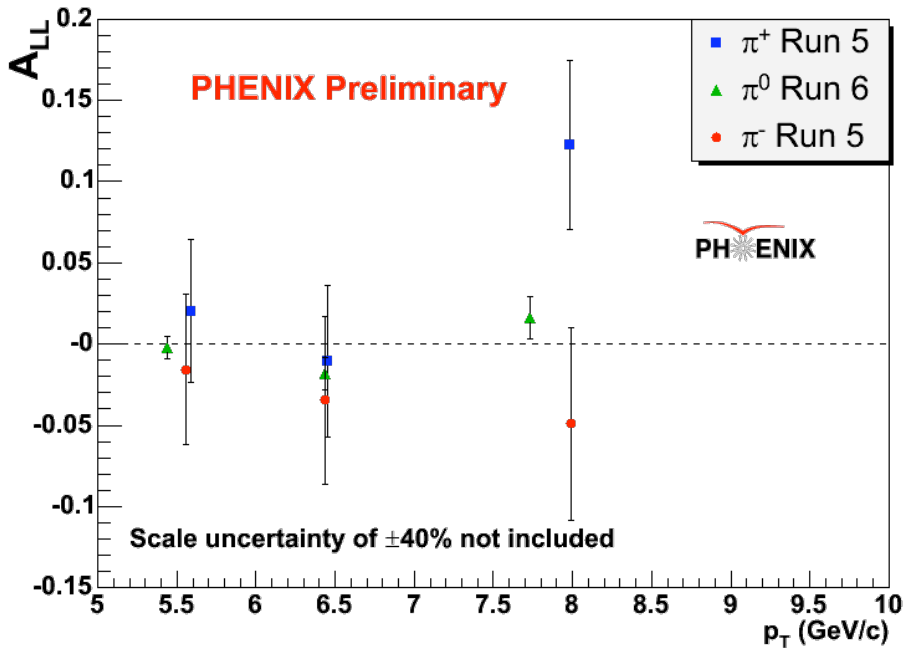
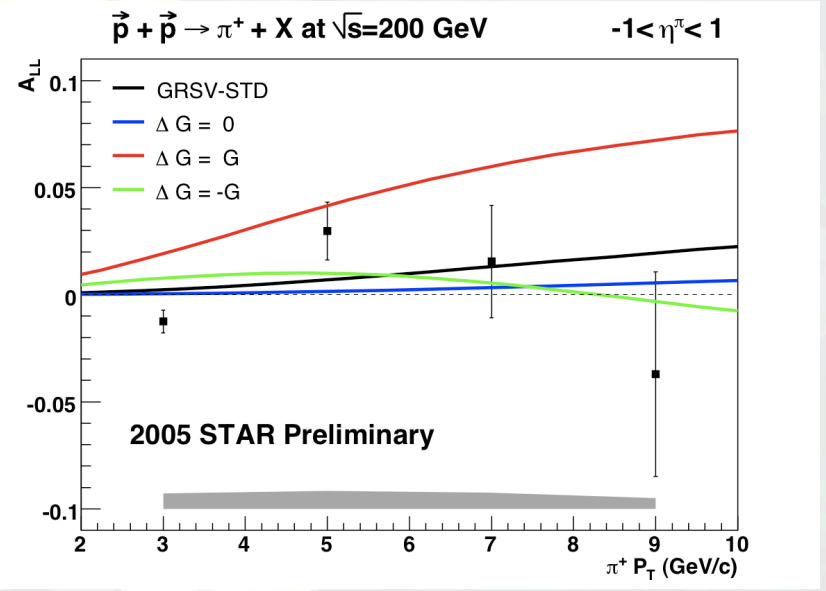


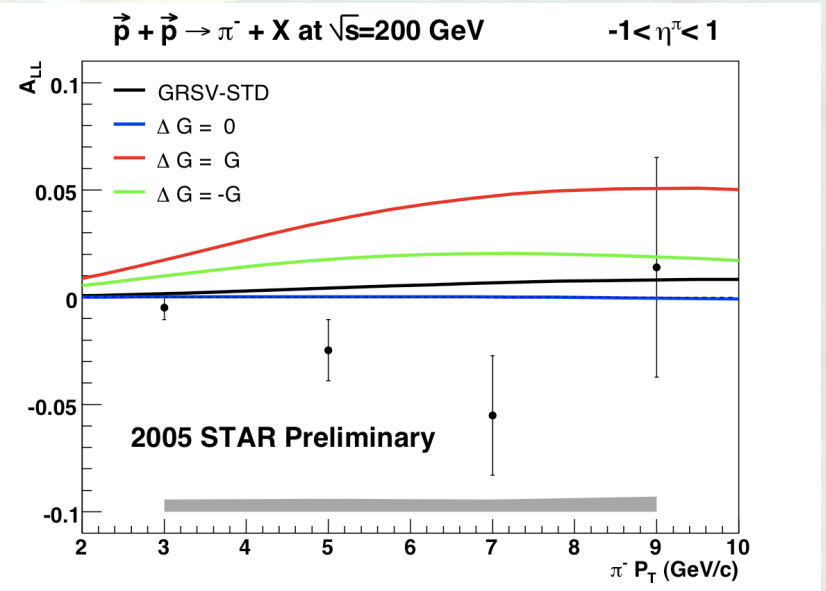


- $A_{LL}(\pi^-)$ / $A_{LL}(\pi^+)$ allows to track sign of ΔG at high p_T (qg process dominates)
- Maximum gluon polarization (GRSV-MAX) scenario disfavored
- Improved precision with Run 6 data - Study of charged pions based on away-side jet to reduce jet trigger bias (Leading systematic uncertainty in Run 5 analysis)

Comparison: Charged hadrons (STAR/PHENIX)







Hadron / Jet production

- A_{LL} measurement: Inclusive jet production (STAR BEMC)

D. Relyea (CalTech) - SPIN2006

Hadron / Jet production

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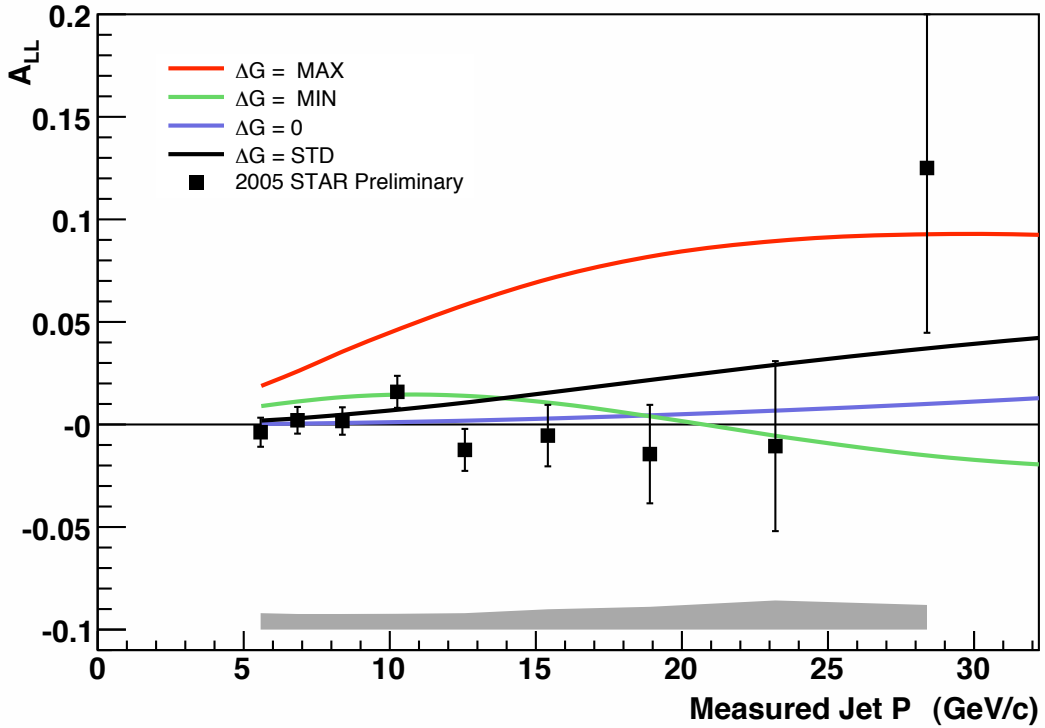

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χ^2 / ndf to curves: (stat.+sys. error in quadrature)

GRSV-STD: 1.1

DG = G: 12

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Hadron / Jet production

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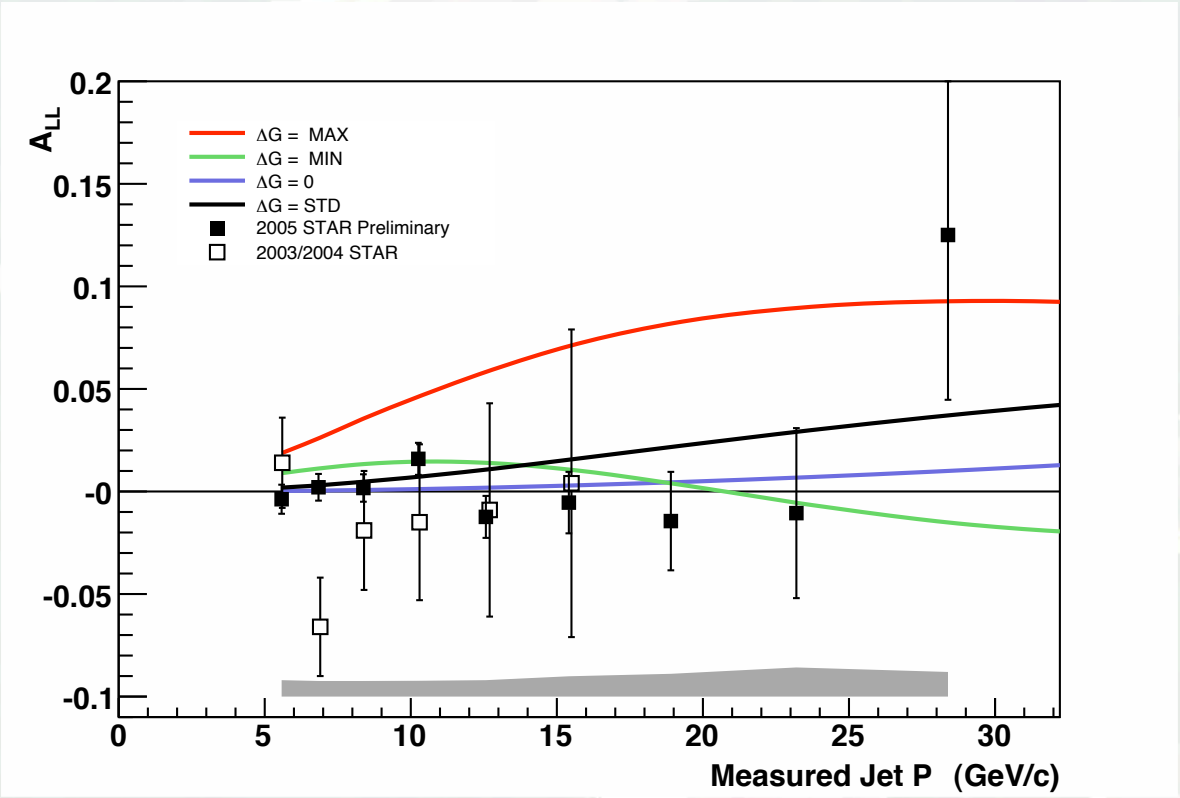

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Hadron / Jet production

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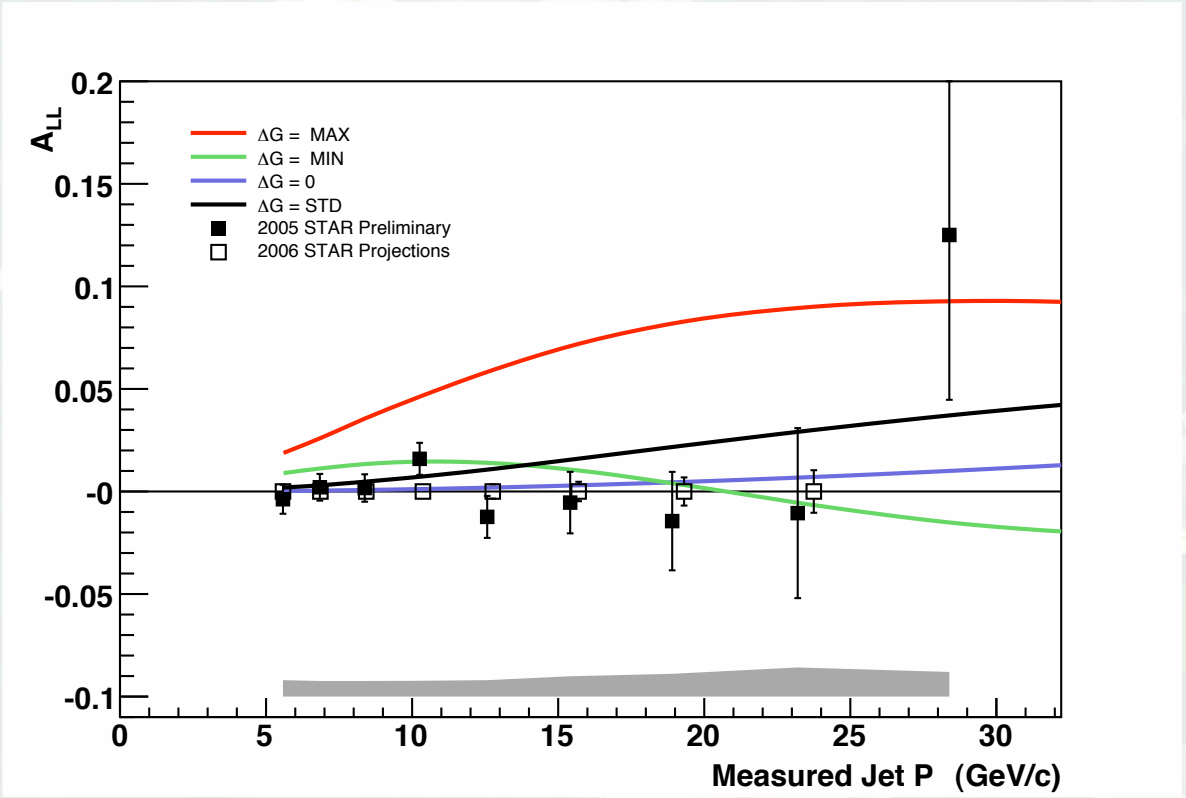
D. Relyea (CalTech) - SPIN2006



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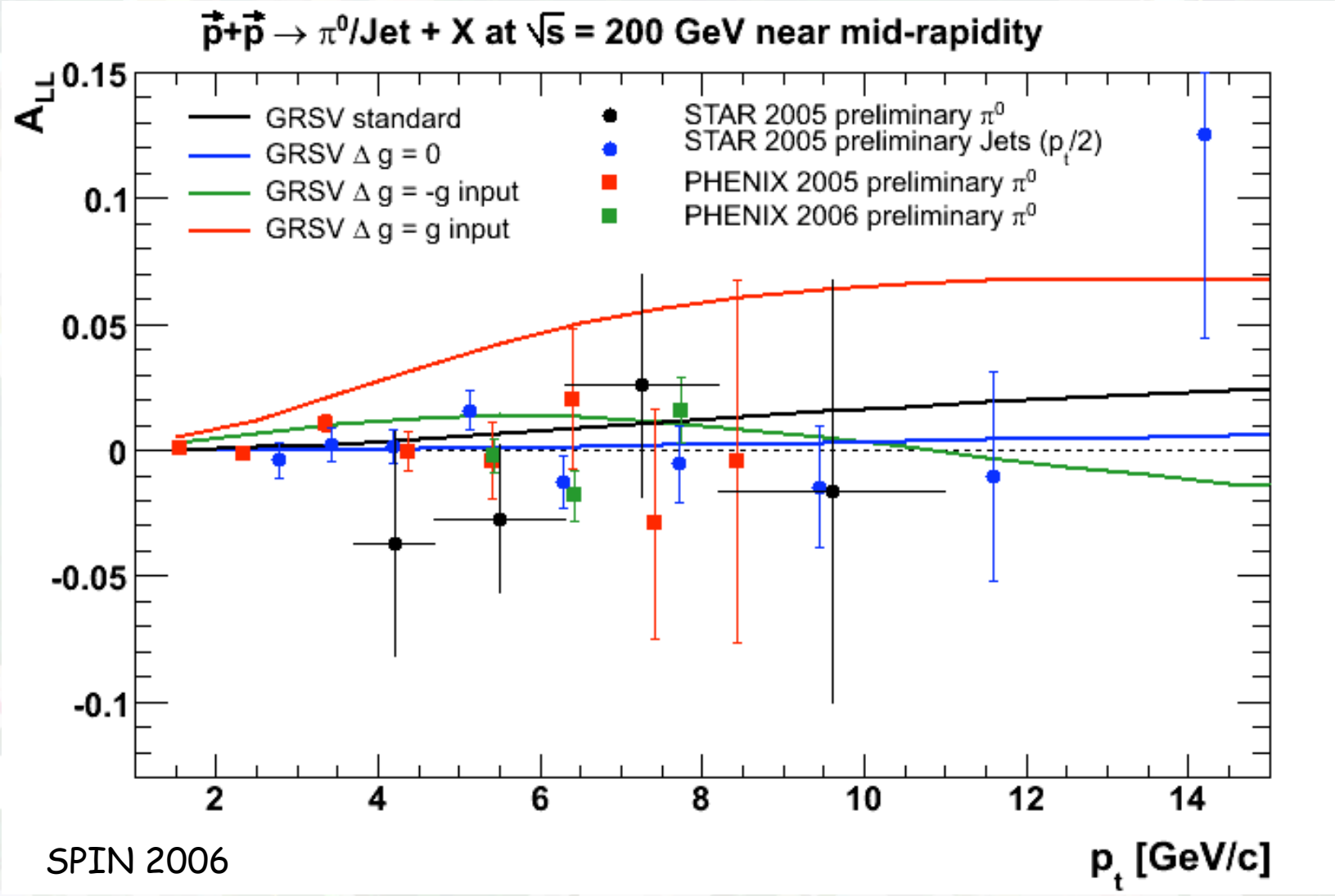
- A_{LL} inclusive jet result (Run 5) consistent with previous Run 3/4 result
- Precise measurement of A_{LL} inclusive jets with Run 6 data

Hadron / Jet production

- Overview of A_{LL} measurements at RHIC

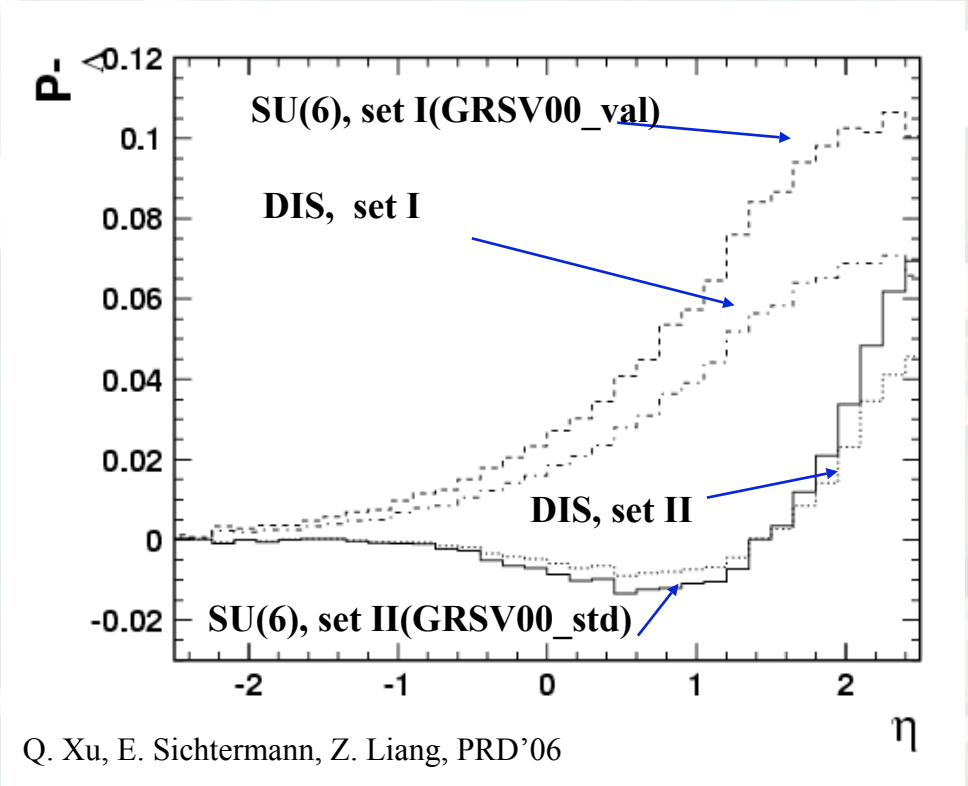
Hadron / Jet production

- Overview of A_{LL} measurements at RHIC



Lambda production

- The measurement of Λ polarization at RHIC can give insights into polarized fragmentation and parton distribution functions

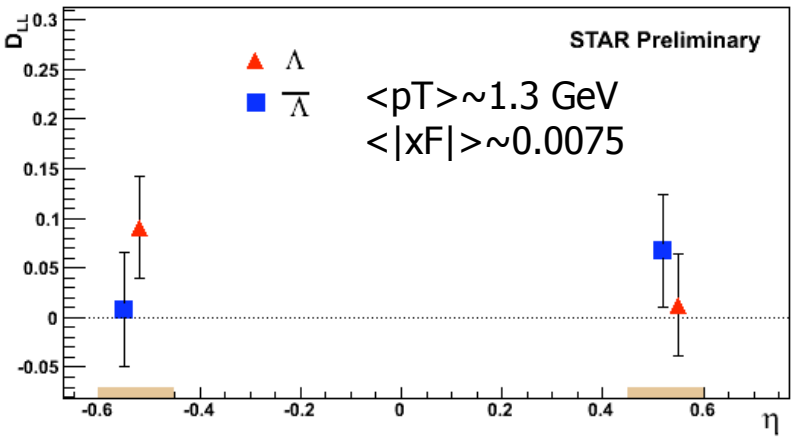


Q. Xu, E. Sichtermann, Z. Liang, PRD'06

$$\vec{p}p \rightarrow \vec{\Lambda}X$$
$$(\Lambda \rightarrow p + \pi)$$

$$D_{LL} \equiv \frac{\sigma_{p^+p^\uparrow \rightarrow \Lambda^+X} - \sigma_{p^+p^\uparrow \rightarrow \Lambda^-X}}{\sigma_{p^+p^\uparrow \rightarrow \Lambda^+X} + \sigma_{p^+p^\uparrow \rightarrow \Lambda^-X}}$$

- Longitudinal spin transfer D_{LL}



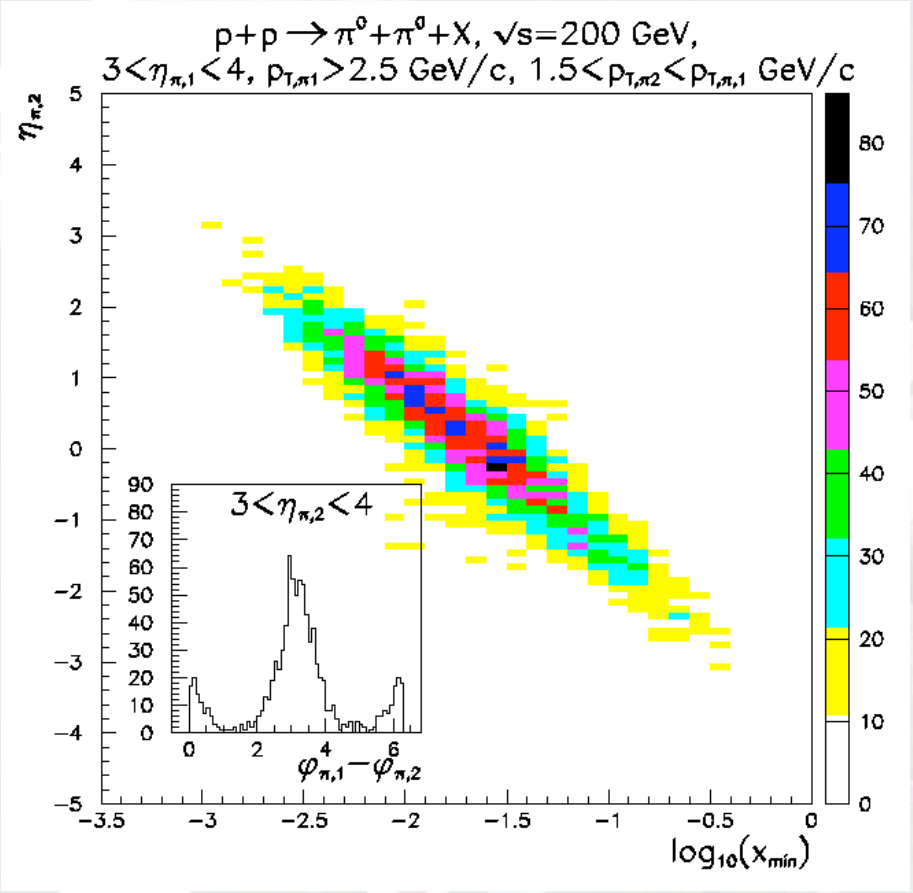
- Lambda-bar polarization is sensitive to $\Delta\bar{s}(x)$ at large p_T (p_T > 5GeV/c)

- Proof-of-principle measurement from 2005 minimum-bias data

Di-hadrons / Di-Jet production

- Di-hadron production

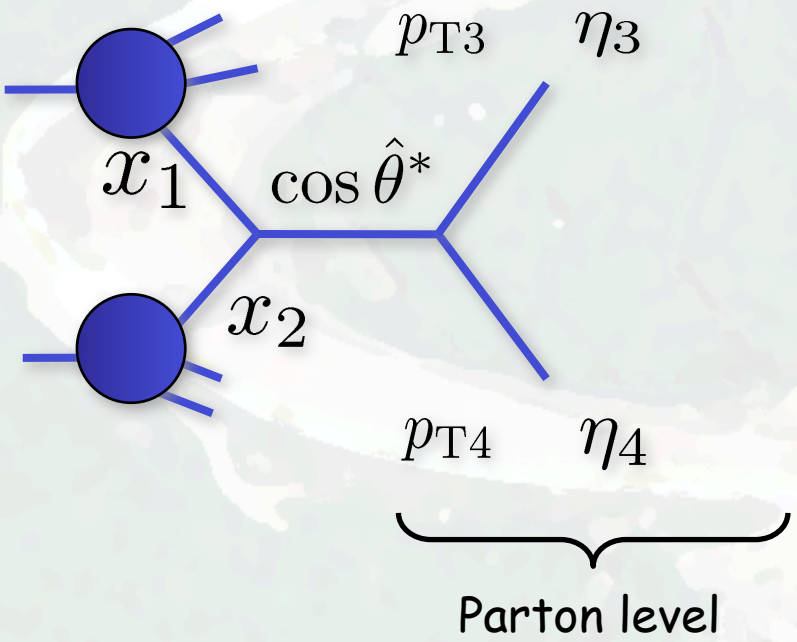
L. Bland (BNL)



- Recent study for pp → π π X
- Can dial x_2 by choosing different η_2!
- Continuous coverage in η with STAR FMS upgrade ($2 < \eta < 4$): $-1 < \eta < 4$

Di-hadrons / Di-Jet production

- Kinematics



Constraint on event kinematics:

A_{LL} (M)

A_{LL} ($\eta_3+\eta_4$)

A_{LL} ($\cos\theta^*$)

2005 Di-Jet analysis

124,325 Di-jet Events	
14,951	(HT1)
25,077	(HT2)
10,962	(JP1)
107,294	(JP2)

$$x_1 = \frac{1}{\sqrt{s}}(p_{T3}e^{\eta 3} + p_{T4}e^{\eta 4})$$

$$x_2 = \frac{1}{\sqrt{s}}(p_{T3}e^{-\eta 3} + p_{T4}e^{-\eta 4})$$

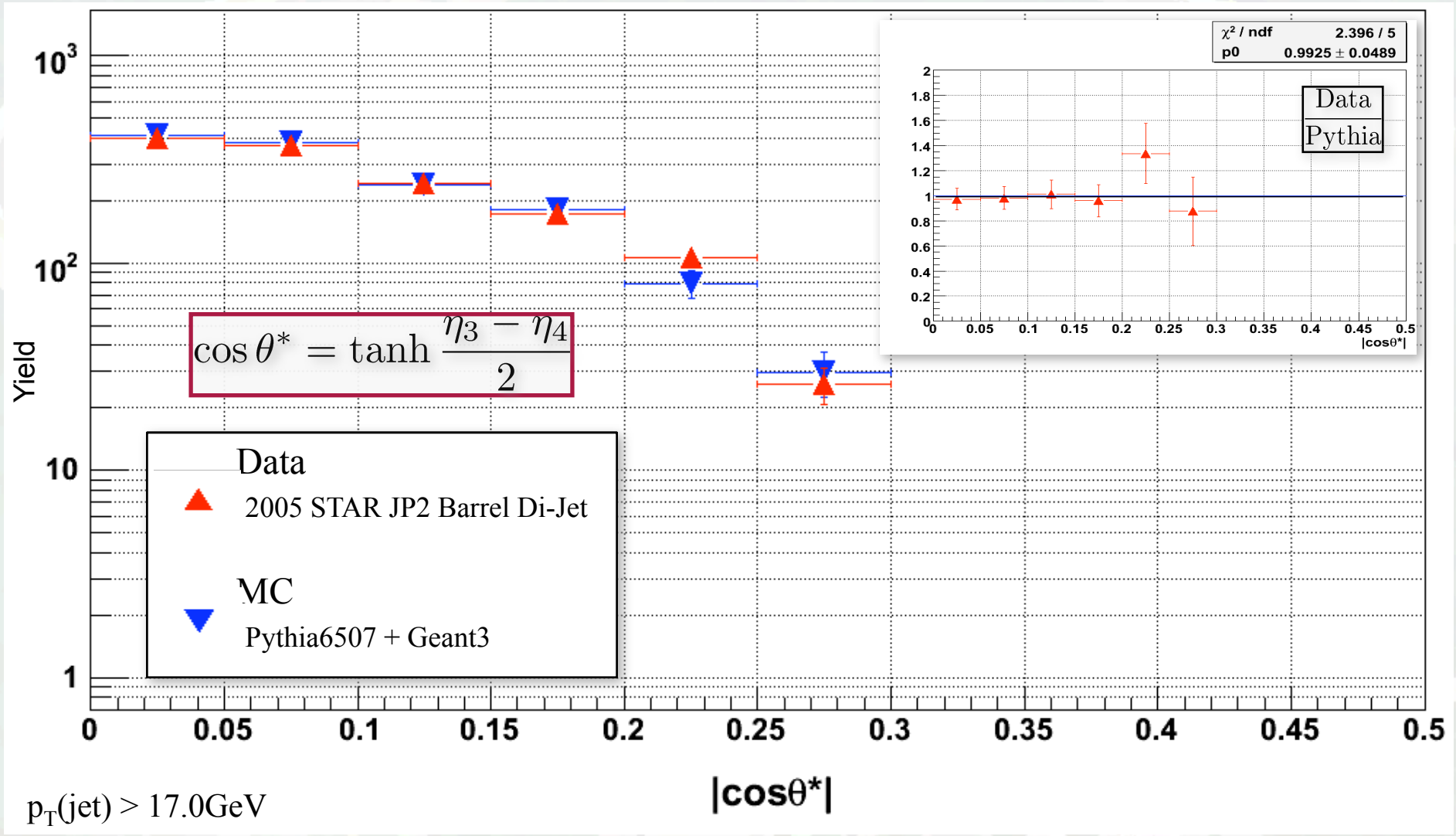
$$\cos\theta^* = \tanh\frac{\eta_3 - \eta_4}{2}$$

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

Di-hadrons / Di-Jet production

- Data/MC comparison

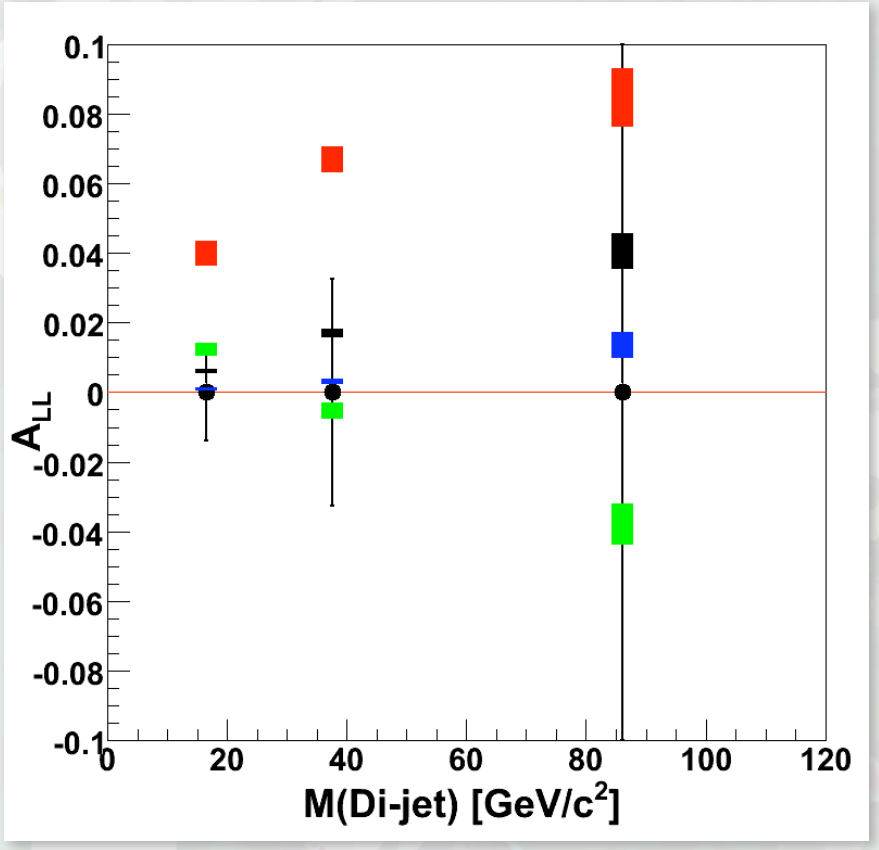
T. Sakuma (MIT) - DNP2006



Di-hadrons / Di-Jet production

- A_{LL} projected uncertainties: 2005

T. Sakuma (MIT) - DNP2006



Statistical Error for 2005 Di-jet

Center values are set to zero

$$A_{\mathrm{LL}} = \frac{\sum P_{\mathrm{Y}} P_{\mathrm{B}} \left\{ \left(\frac{N_{++}}{R_4} + N_{--} \right) - \left(\frac{N_{+-}}{R_5} + \frac{N_{-+}}{R_6} \right) \right\}}{\sum P_{\mathrm{Y}}^2 P_{\mathrm{B}}^2 \left\{ \left(\frac{N_{++}}{R_4} + N_{--} \right) + \left(\frac{N_{+-}}{R_5} + \frac{N_{-+}}{R_6} \right) \right\}}$$

- GRSV STD
- GRSV Δg=0
- GRSV Δg=-g
- GRSV Δg=g

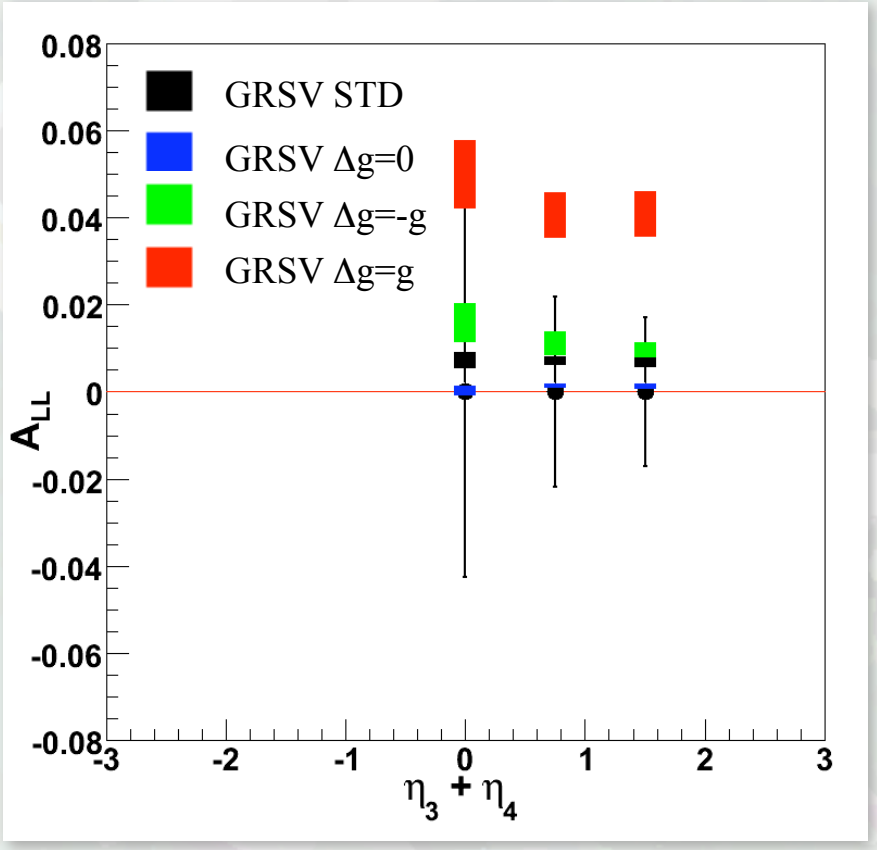
LO MC(Pythia) A_{LL} Evaluation

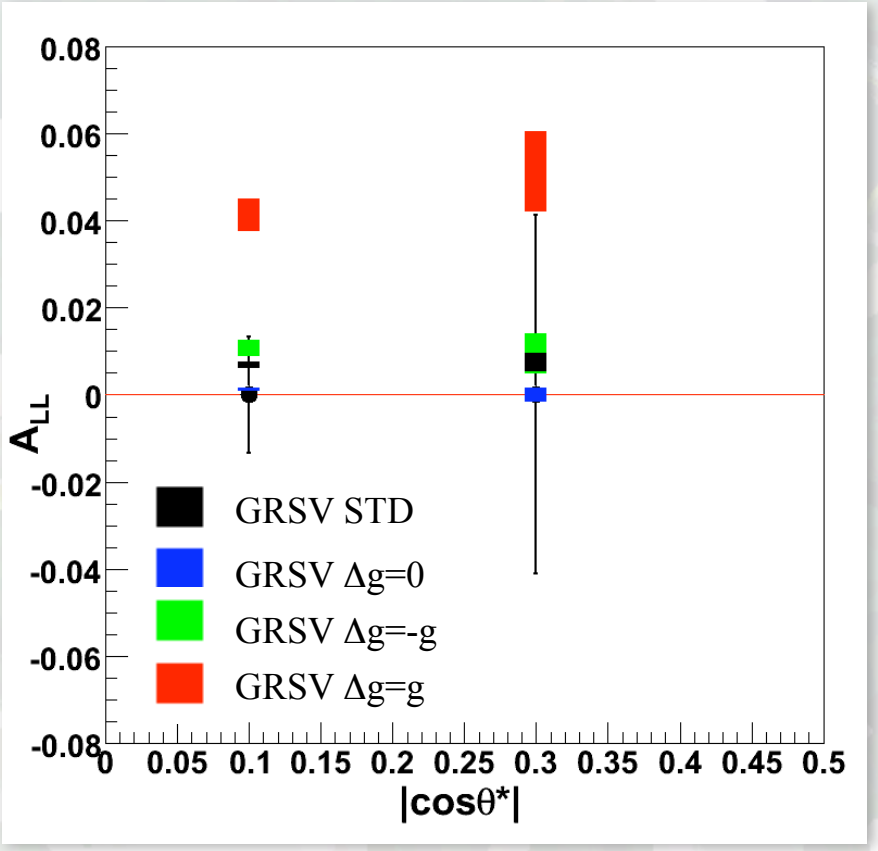
$$\frac{\Delta f_1(x_1, Q^2)}{f_1(x_1, Q^2)} \frac{\Delta f_2(x_2, Q^2)}{f_2(x_2, Q^2)} \hat{a}_{LL}(\cos\theta^*)$$

Di-hadrons / Di-Jet production

- A_{LL} projected uncertainties: 2005

T. Sakuma (MIT) - DNP2006





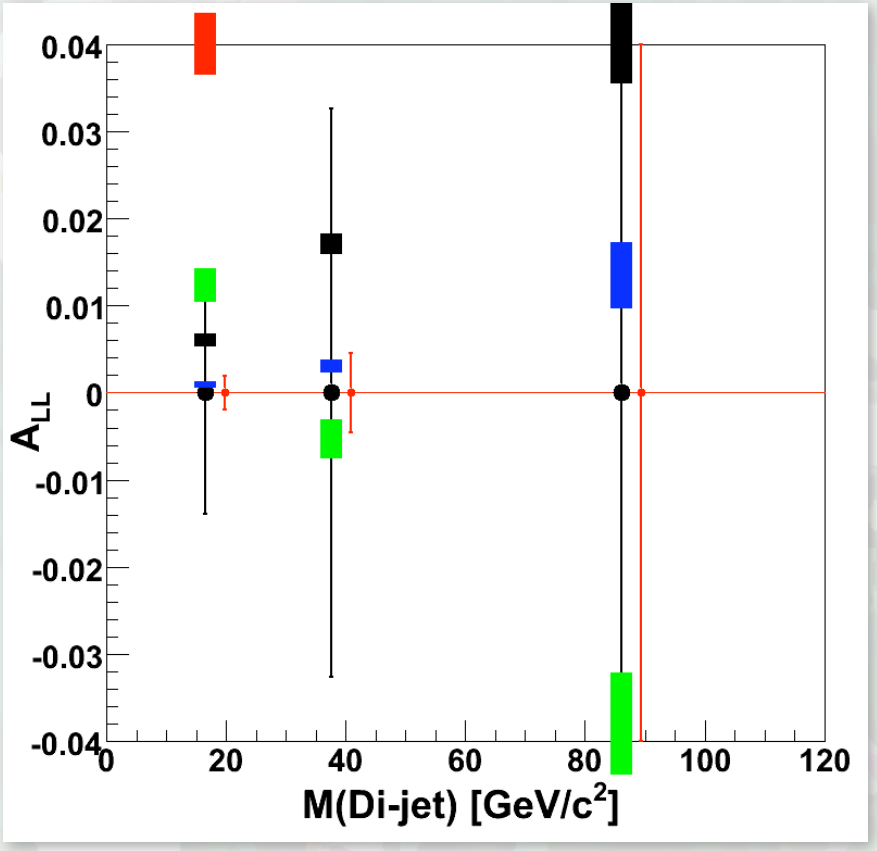
$$\log \frac{x_1}{x_2} = \eta_3 + \eta_4$$

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

Di-hadrons / Di-Jet production

- A_{LL} projected uncertainties: 2006

T. Sakuma (MIT) - DNP2006



Statistical Error for 2005 Di-jet

- GRSV STD
- GRSV Δg=0
- GRSV Δg=-g
- GRSV Δg=g

Projections for 2006 Di-jet

	2005	2006
# of di-jets	124,325	~2,000,000
Barrel EMC	$0 < \eta < 1$	$-1 < \eta < 1$
Polarization	40%~50%	~60%

Dedicated level 2 Di-jet Trigger

Yields will be higher if endcap emc is included

Prompt photon production

Quark-Gluon Compton scattering

- A_{LL} for QGC scattering interpreted in LO QCD: $gq \rightarrow \gamma g$

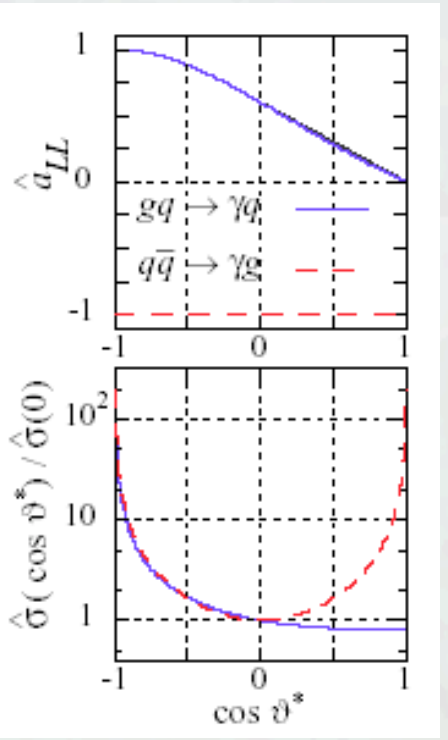
$$A_{LL} \cong \frac{\Delta G(x_g)}{G(x_g)} \cdot A_1^p(x_q) \cdot \hat{a}_{LL}^{(g+q\rightarrow\gamma+q)}(\cos\vartheta^*)$$

Gluon polarization

Measured asymmetry from polarized DIS

pQCD result for QGC scattering

- Polarized cross-section is strongly peaked when photon is emitted in direction of incident quark
- Best determination of ΔG for: final-state photon || to initial-state quark



- Note: QGC scattering dominates over competing background process: $q\bar{q} \rightarrow \gamma g$

- Reconstruction of initial-state partonic kinematics:
  - Event-by-event determination of p_T (photon energy), η_γ (photon direction) and η_{jet} (jet direction) allows to reconstruct:

$$x_{1(2)} \cong \frac{p_{T,\gamma}}{\sqrt{s}}\left(e^{\pm\eta_\gamma} + e^{\pm\eta_{jet}}\right)$$

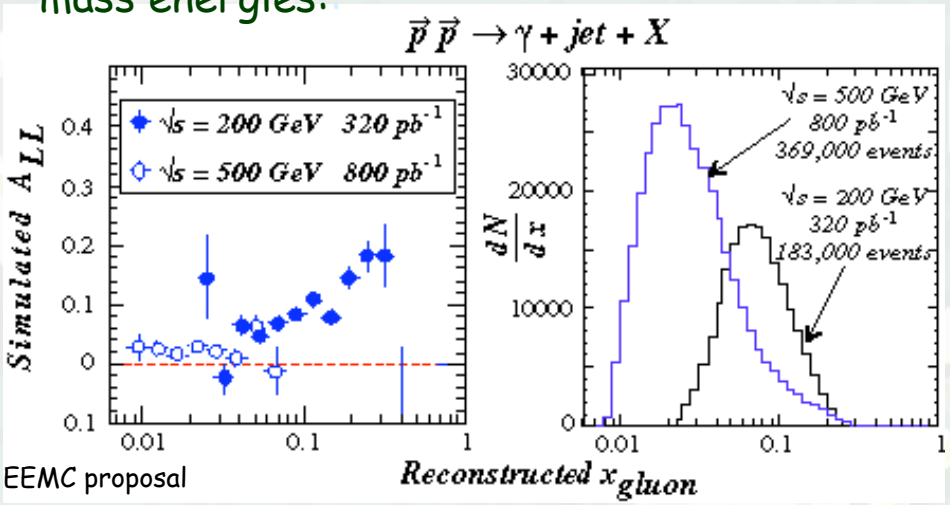
$$x_q^{recon} = \max\left[x_1, x_2\right]$$
$$x_g^{recon} = \min\left[x_1, x_2\right]$$

  - Large x quark (large quark polarization) analyzes small-x gluons (gluon-rich)
  - Asymmetric QGC scattering (forward boost in direction of incident quark)

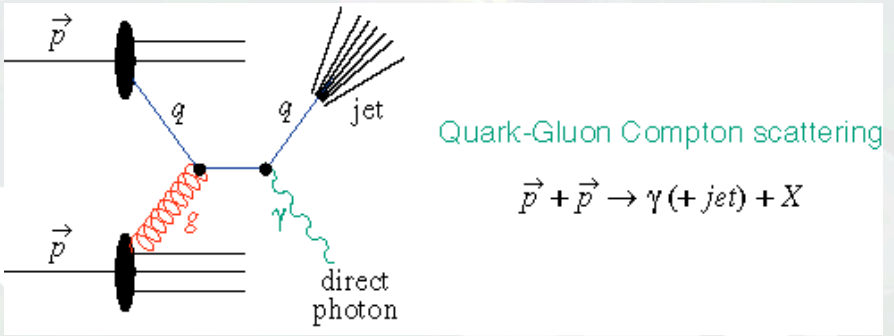
- Background:
  - $\pi^0 \rightarrow \pi^0/\gamma$ discrimination needed
  - Isolation cone requirement

Prompt photon production

- Quark-Gluon Compton scattering: Prospects at STAR
  - Simulated A_{LL} at two different RHIC center-of-mass energies:



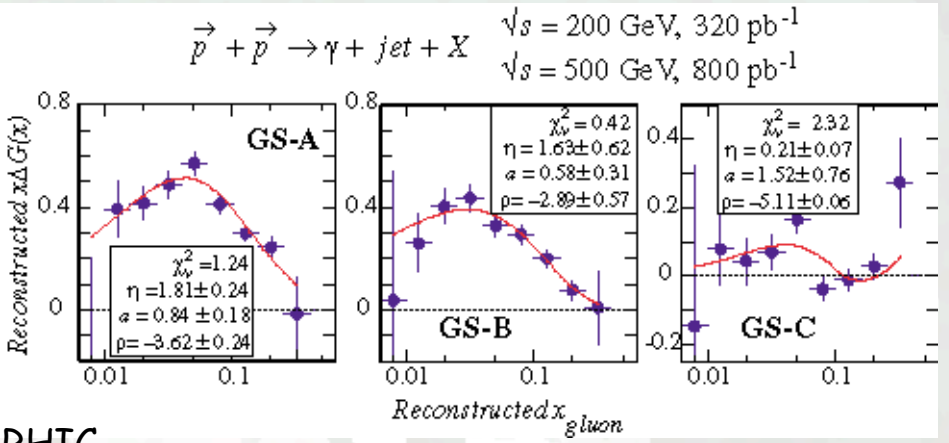
EEMC proposal



$$A_{LL} \cong \frac{\Delta G(x_g)}{G(x_g)} \cdot A_1^p(x_q) \cdot \hat{a}_{LL}^{(g+q\rightarrow\gamma+q)}(\cos\vartheta^*)$$

- Combined data sample at 200 GeV and 500 GeV is essential to minimize extrapolation errors in determining ΔG:

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



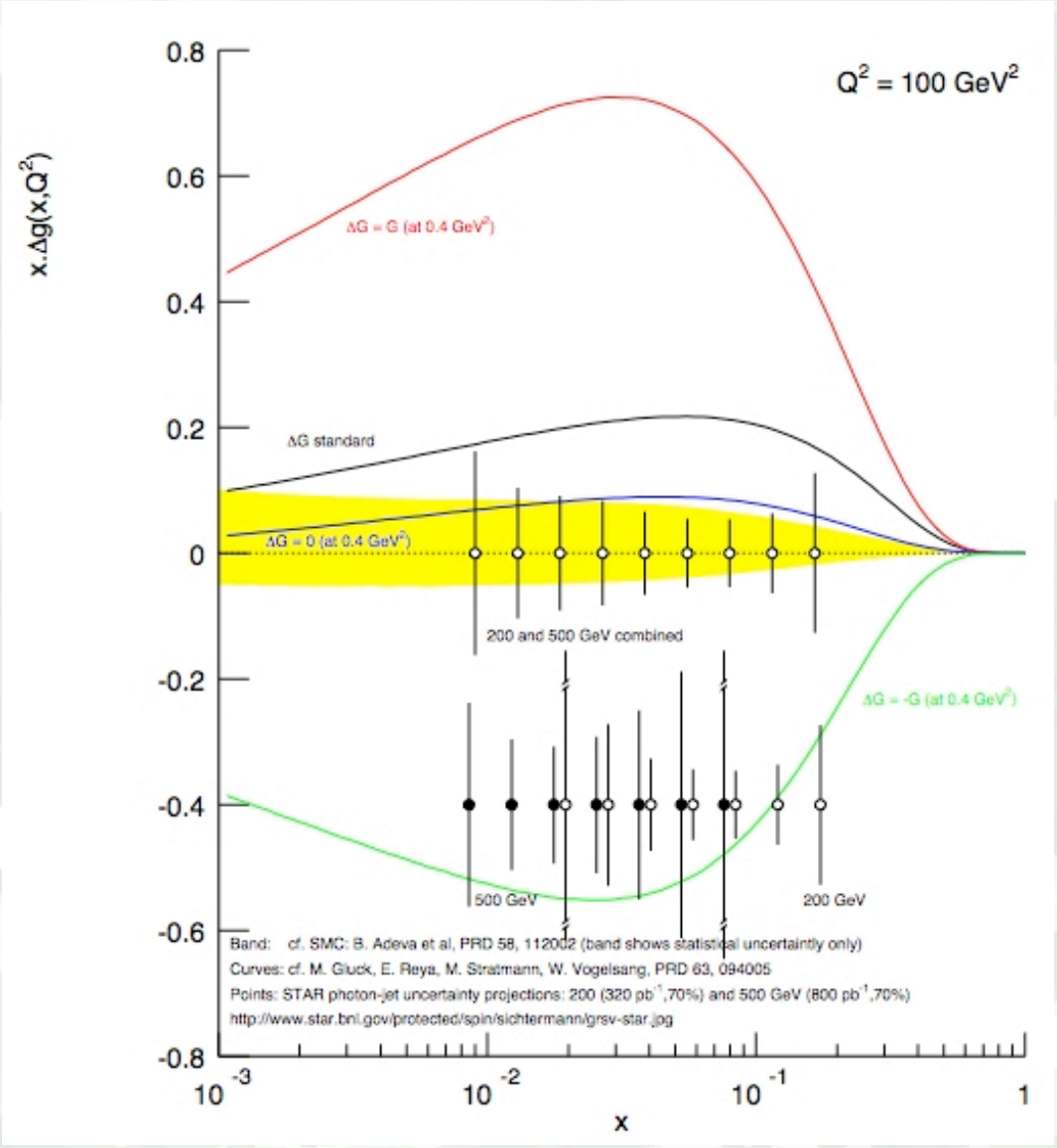
EEMC proposal

- Ultimately: **Global analysis** of several data sets from RHIC (STAR, PHENIX) and DIS (HERMES, COMPASS)!

Prompt photon production

- 200GeV / 500GeV data sample impact on A_{LL}

E. Sichtermann (LBL)



Summary and Outlook

- STAR longitudinal spin program
  - pQCD NLO calculations describe measured cross-sections (Jets, Neutral pions and Charged pions)
  - Consistent picture emerging to disfavor large gluon polarization scenario
  - STAR A_{LL} measurements: Important contribution to understanding of ΔG!
  - Next critical step: Global analysis incorporating various A_{LL} measurements
  - Run 6 data: Improved measurements on A_{LL} inclusive processes: Inclusive jets, Neutral pions and Charged pions and new results on correlation measurements: Di-jets and Di-hadrons (Constrain parton kinematics)
  - Future:
    - Prompt photons (Medium term)
    - Flavor decomposition through W production (Long term)