Status of the Gluon Spin Program at STAR

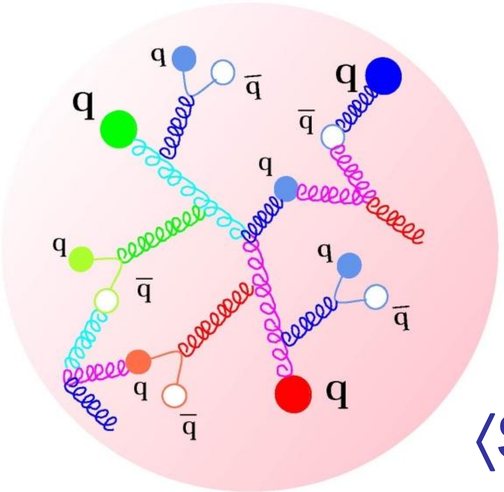
Scott Wissink

for the STAR Collaboration

<u>Outline</u>

- **Brief motivation: the *why* and *how* of ΔG**
- **Inclusive studies: pions and jets**
- **Coincidence studies: di-jets and γ-jets**
- **Status and Outlook**

The Spin Puzzle: Why is ΔG still interesting?



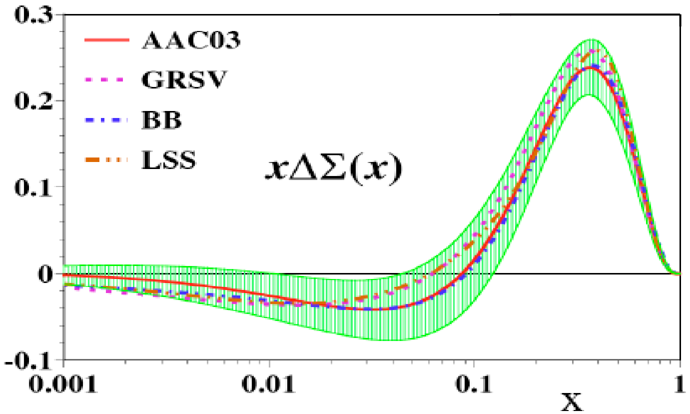
The RHIC spin program:

Study hard partonic scattering processes in polarized pp collisions, using polarization of one parton to probe helicity preferences of the other

→ Provides a "snapshot" of spin distributions:

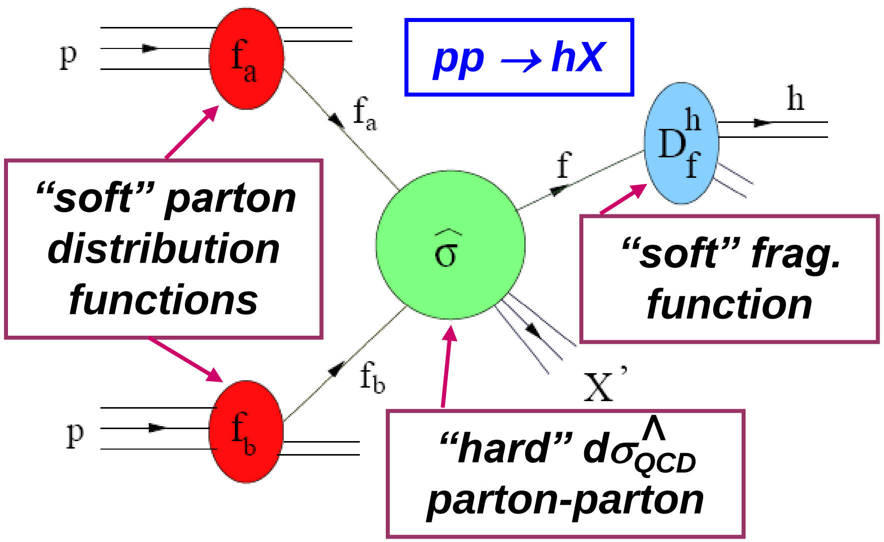
$$\langle S_z^p \rangle = \tfrac{1}{2} = \underbrace{\tfrac{1}{2}\,\Delta\Sigma}_{\text{quark helicity}} + \underbrace{\Delta g}_{\text{gluon helicity}} + \langle L_z^{quarks} \rangle + \langle L_z^{gluons} \rangle$$

Electroweak probes are only indirectly sensitive to gluons
→ DIS studies provide limited constraints on gluonic spin …
but are consistent with quark helicity contributions of ~30%!



Hirai, Kumano, Saito

The Spin Puzzle: What RHIC brings to the table

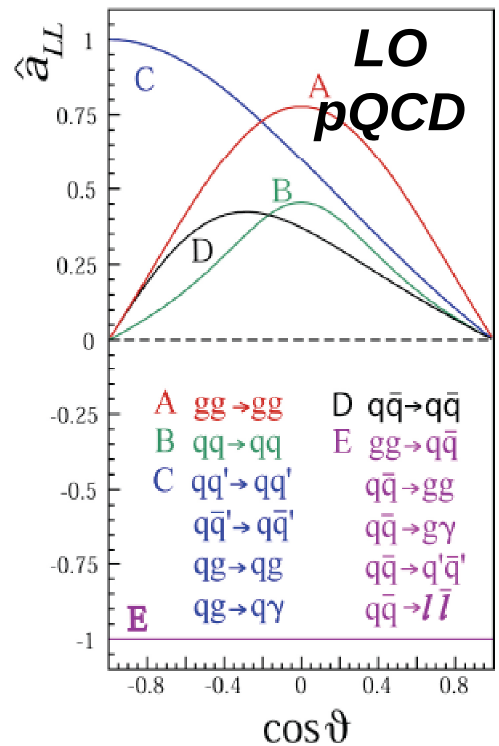


Provides pQCD probes of spin-dependent partonic structure!

Assumes factorization works

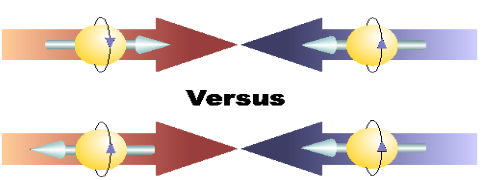
+

large spin correlations at partonic level



All the pieces are in place to ask:

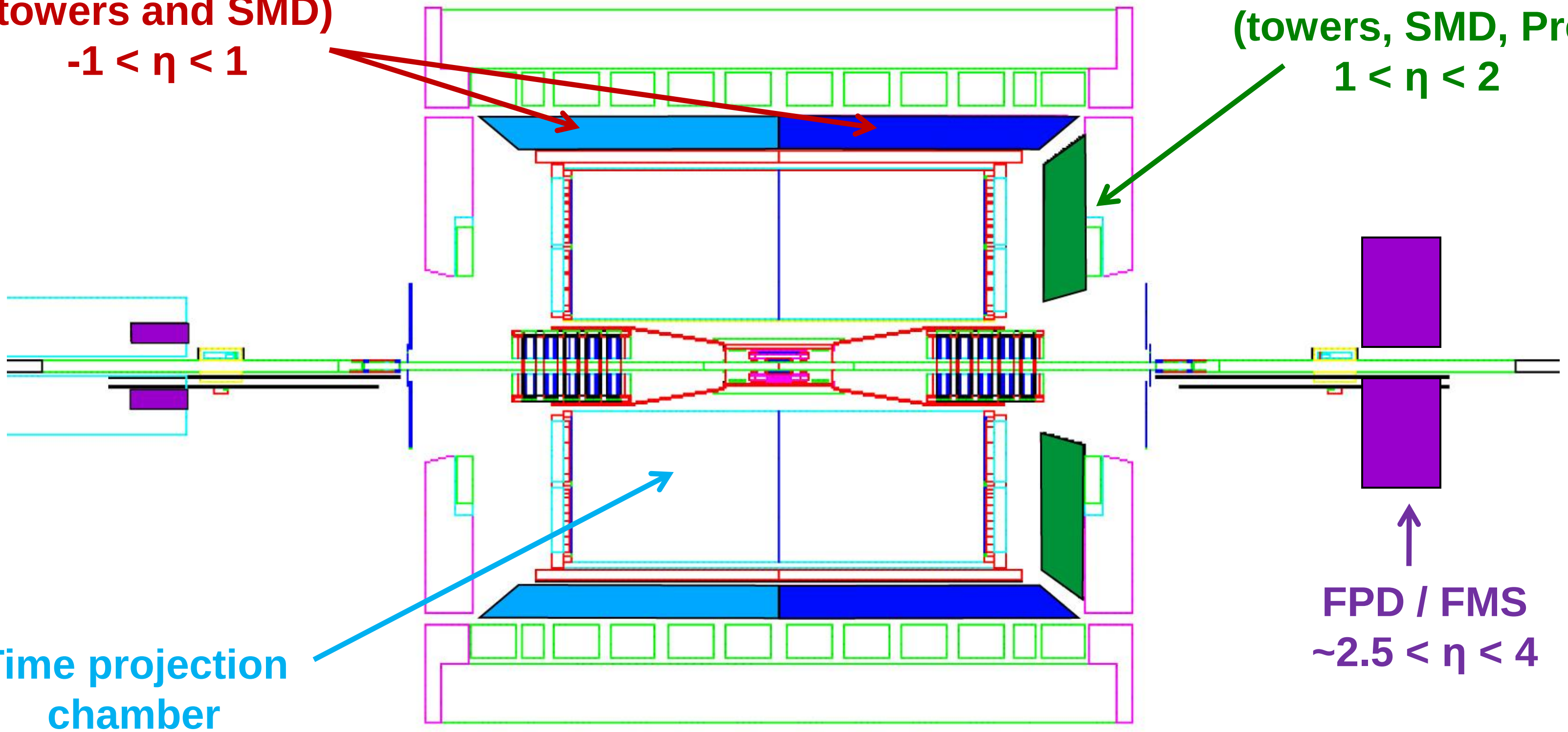
Does the gluon spin contribute <u>significantly</u> to that of the proton?



STAR

Progress in High-PT Physics at RHIC

The STAR Detector: What we need for these studies

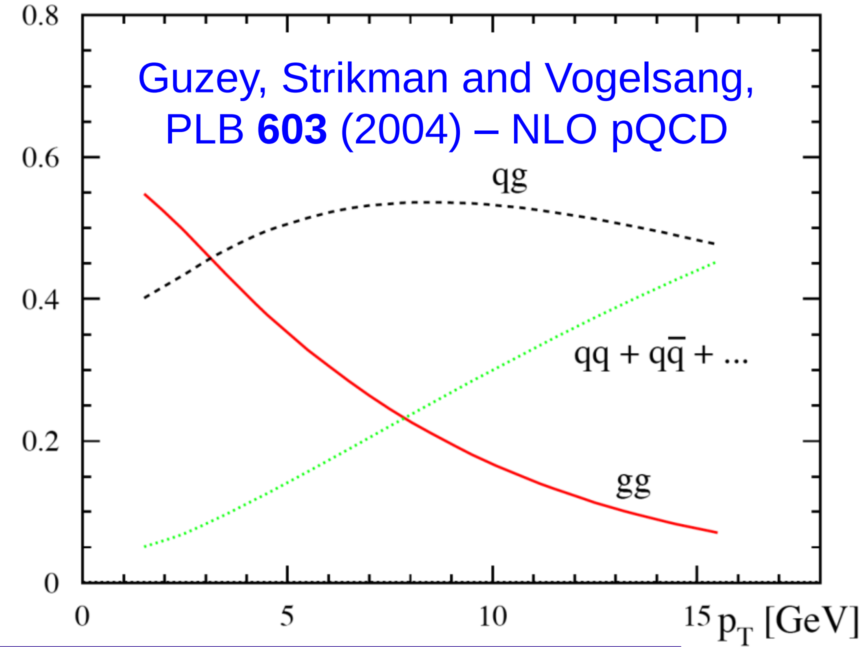


Triggering on E deposition in EMC's at tower and 'patch' level

Inclusive Measurements: Strengths and limitations

"First generation" efforts

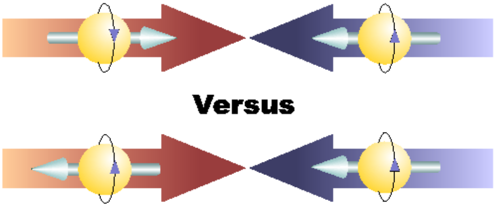
- **High yield for pions and jets**
- **Relatively simple triggering**
- **Relatively simple reconstruction**



But: must untangle (or account for) contributions from several partonic subprocesses, and broad range of x_g for a given p_T bin → hard to interpret!

$$A_{LL} = \frac{1}{P_Y P_B} \frac{N^{parallel} - R \cdot N^{antiparallel}}{N^{parallel} + R \cdot N^{antiparallel}}$$

Plan of attack: ***detect outgoing particle/jet, extract spin-dependent yields, form the longitudinal double-spin asymmetry***



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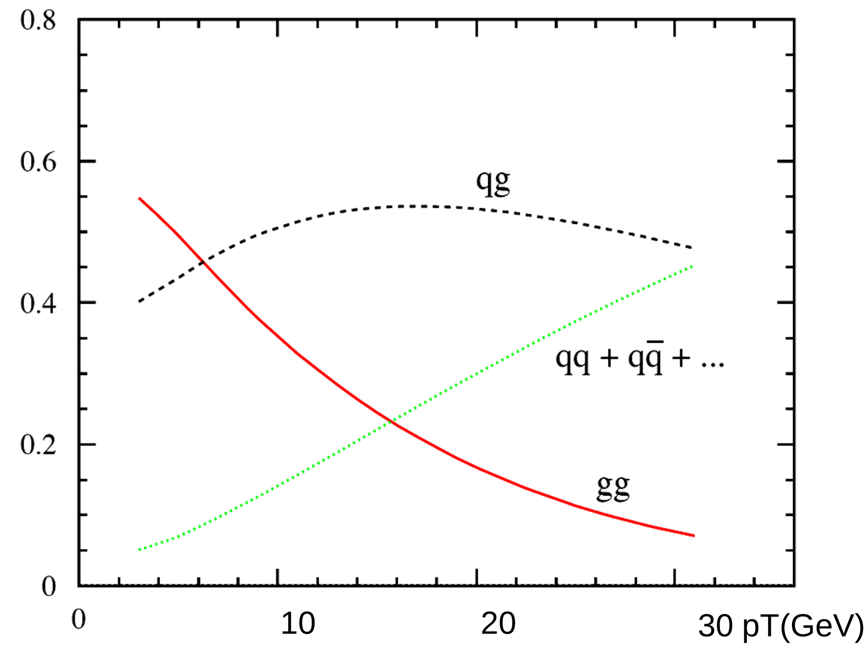

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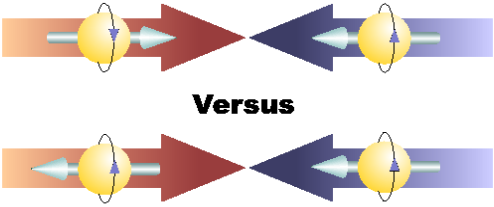
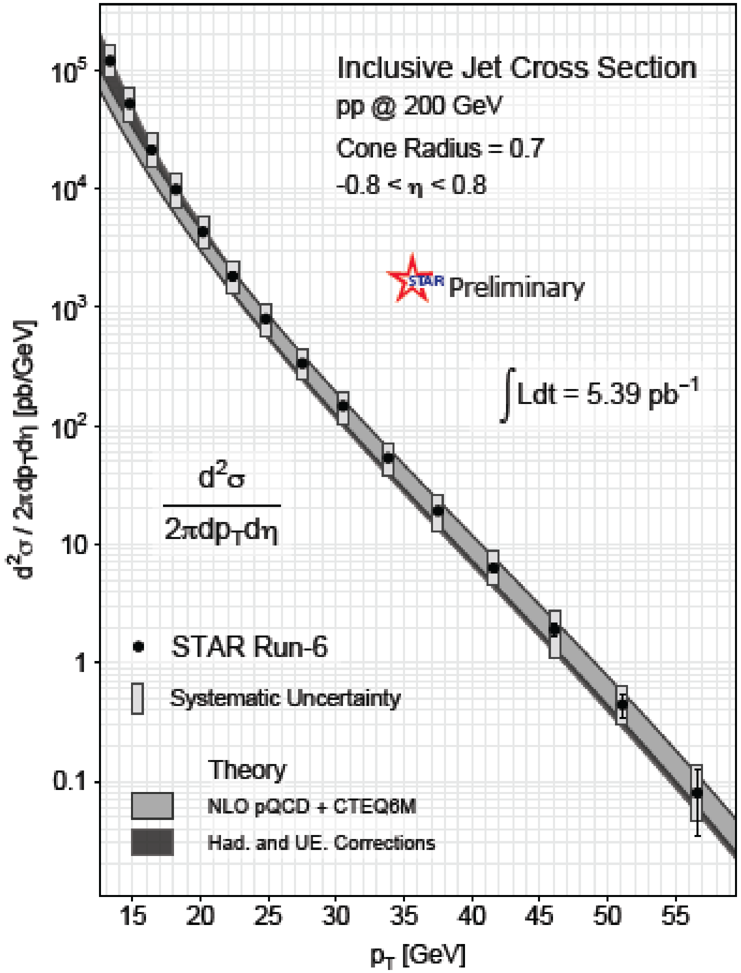
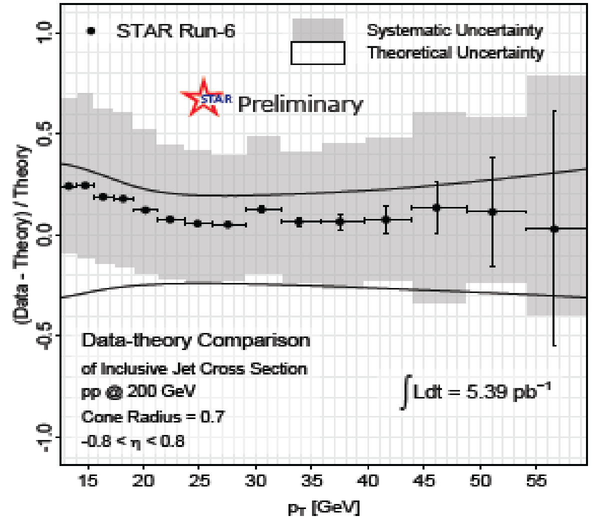


Inclusive Measurements: Get the cross section right!



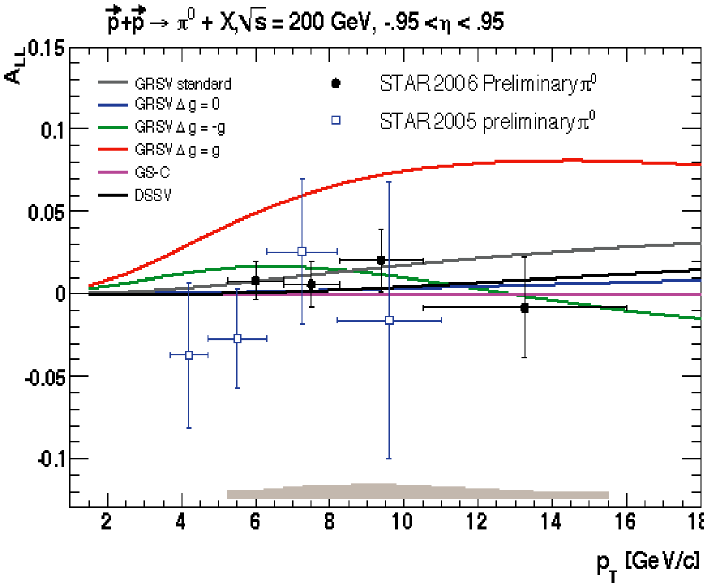
- **Mid-rapidity jet cross section consistent with NLO pQCD over *7 orders of magnitude***
- **Forward rapidity π^0 cross section also consistent with NLO pQCD**
- **Many other examples**

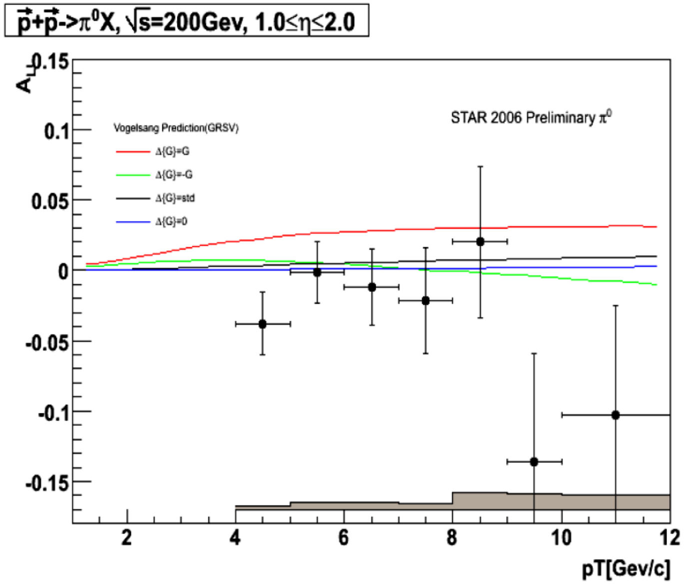
✓ **pQCD works over a very broad kinematic range at RHIC energies!**

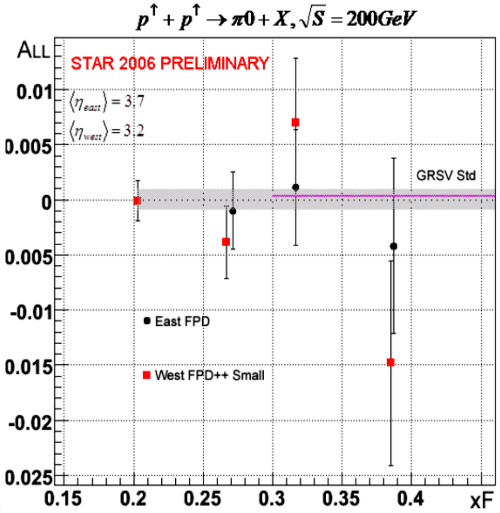


Inclusive neutral pions: a broad range of rapidity

-1 < η < 1 | 1 < η < 2 | η = 3.2, 3.7



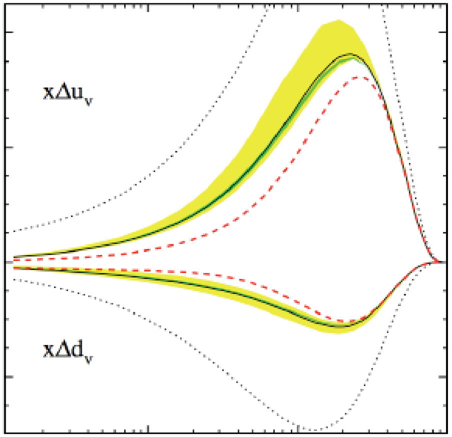




In Run 6, ***STAR*** measured A_{LL} for inclusive π^0 for three different rapidity regions:

- **Mid-rapidity excludes models with large Δg, consistent with EEMC results**
- ***qg* scattering dominant at forward η → larger *x* quarks, smaller *x* gluons**
  - **Theoretically, expect A_{LL} to decrease substantially as η increases**
    - **Forward rapidity: baseline for γ and γ-jet measurements**

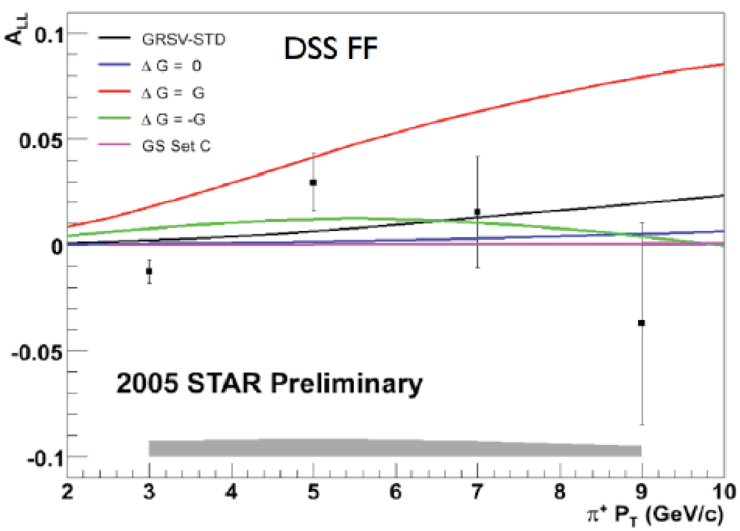
Inclusive charge-separated pions at mid-rapidity



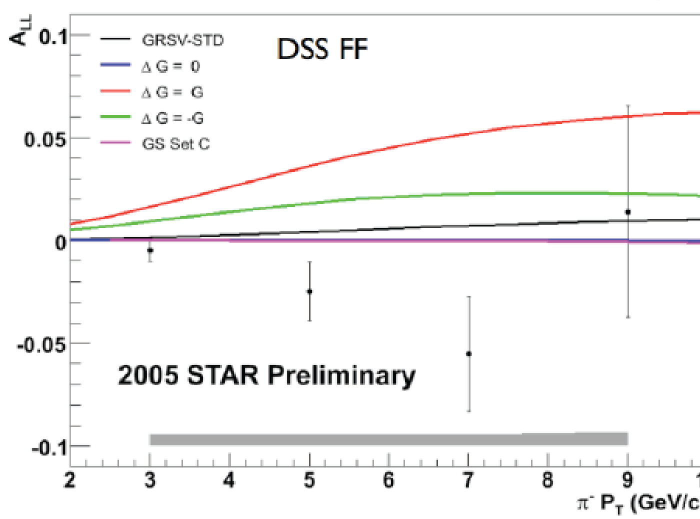
- For qg processes, $A_{LL}(\pi^+)$ and $A_{LL}(\pi^-)$ can be utilized to track the sign of Δg
  - for example, if $A_{LL}(\pi^+) > A_{LL}(\pi^-) \Rightarrow \Delta g > 0$

- Dominant systematic uncertainty from the use of neutral energy triggers at STAR, most pions are sub-leading particles in the jet

$\vec{p} + \vec{p} \rightarrow \pi^+ + X$



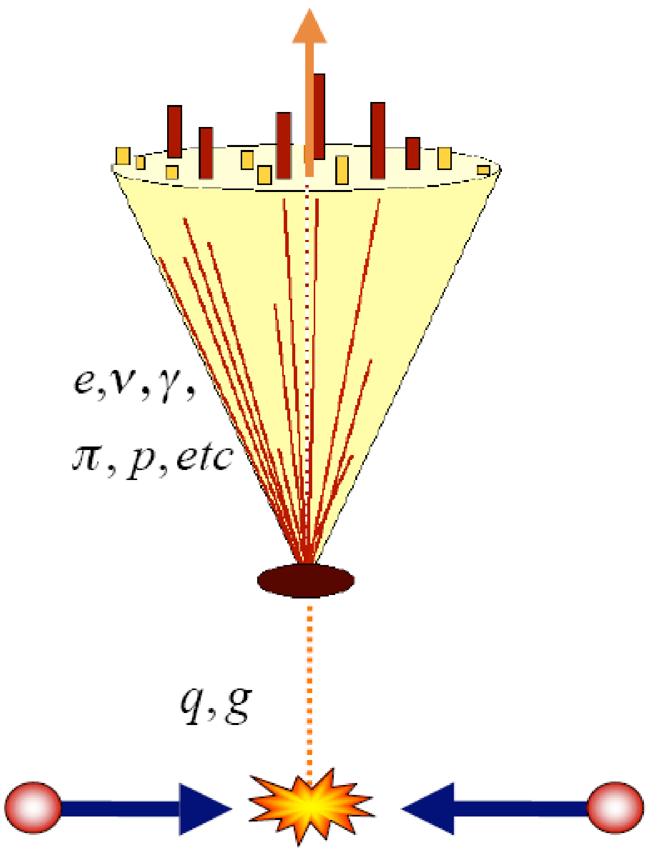
$\vec{p} + \vec{p} \rightarrow \pi^- + X$



Inclusive jets: the Workhorse of STAR so far

Midpoint cone algorithm (hep-ex/0005012)

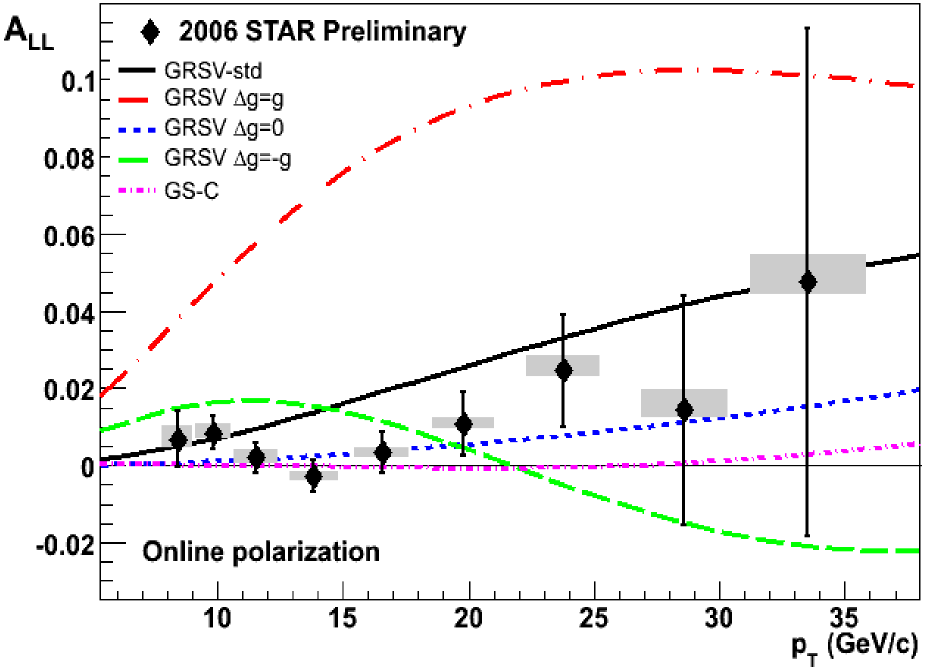
$$R_{CONE} = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = 0.4 \ (2003\text{-}2005)$$
$$= 0.7 \ (2006)$$

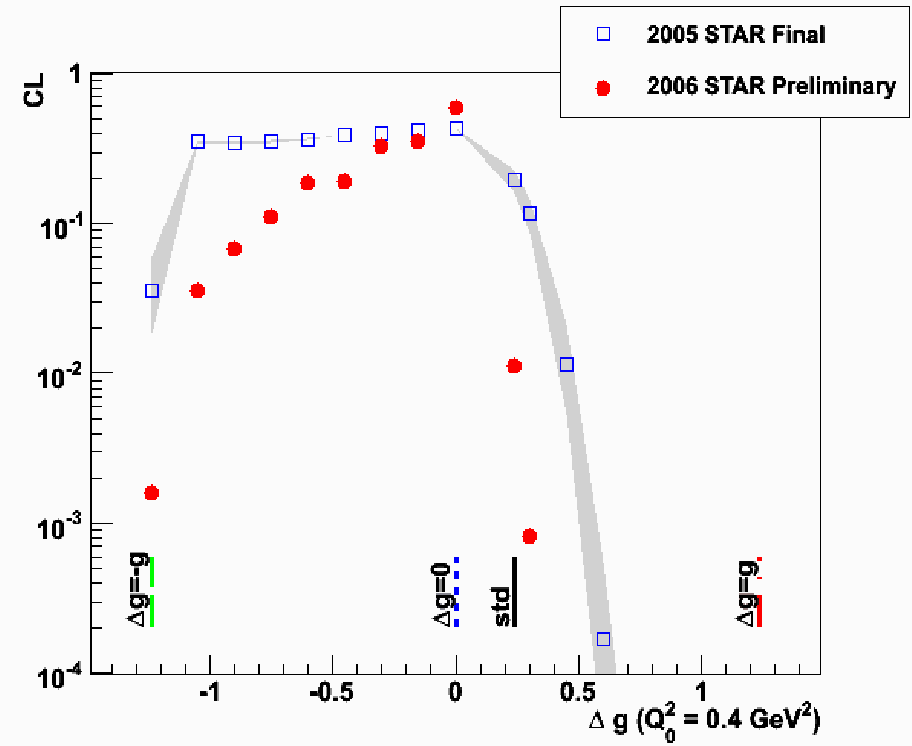


***STAR** is well suited for jet measurements:*

- ***TPC provides excellent charged-particle tracking and p_T information over broad range in η***
- ***Extensive EM calorimetry over full 2π in azimuth and for -1 < η < 2***
- ***Sophisticated multi-level triggering on EMC info. at tower and patch scale***

Inclusive jets: Asymmetry results from Run 6





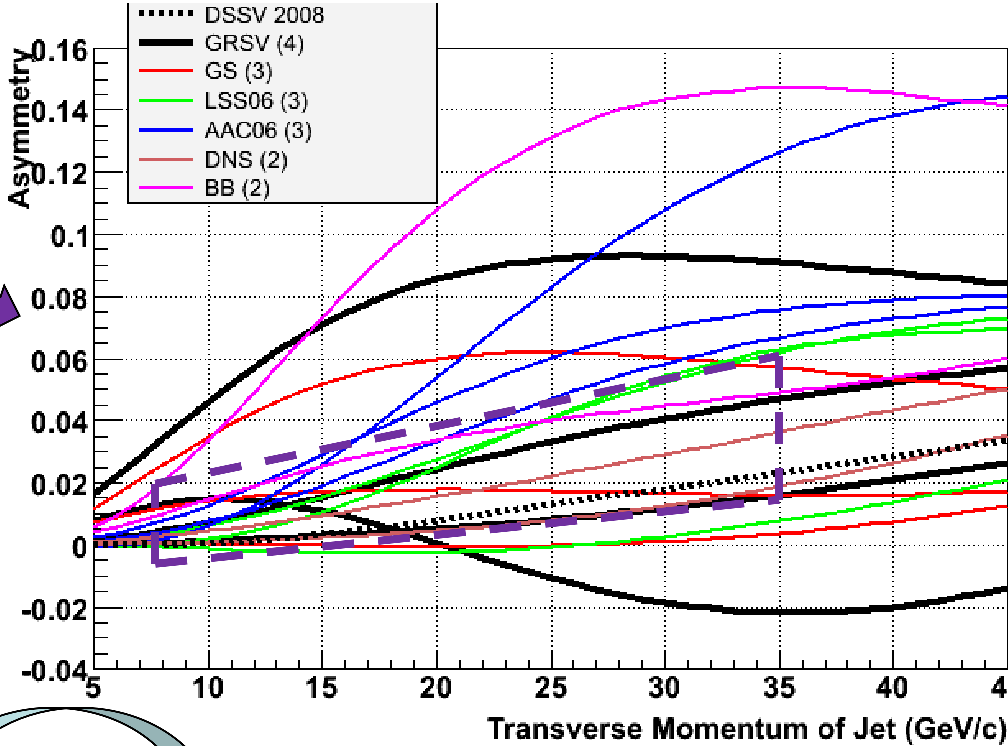
Quality of results greatly improved over those of Run 5 (2005)!

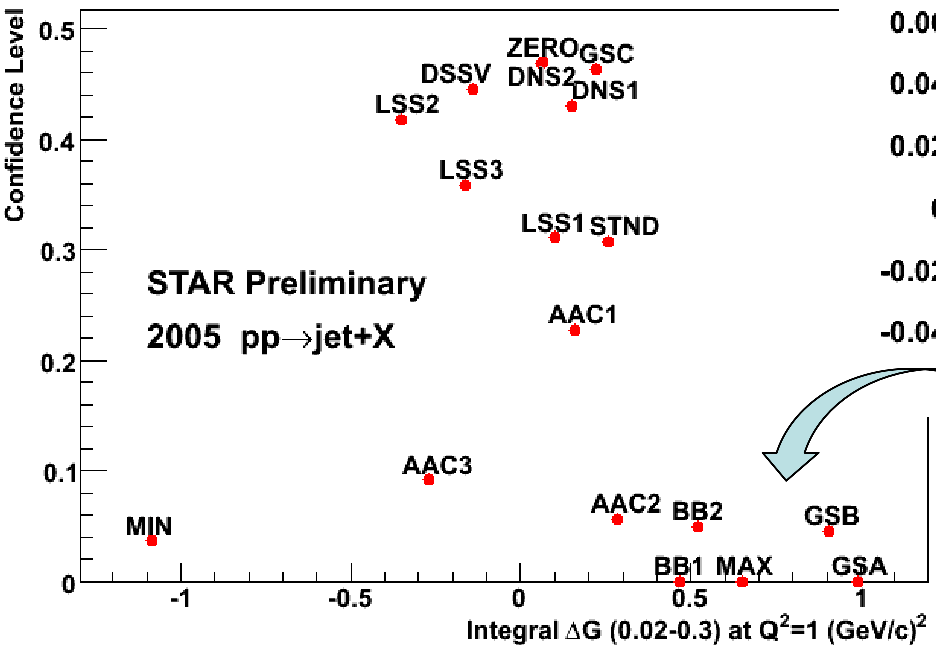
- Increased EM calorimeter acceptance (in η), luminosity, polarization
- Higher EMC trigger thresholds → increased focus on high-p_T region
- Combination of above → factor of 3-4 in stat. precision at high p_T

Confidence level peaks (in GRSV scenario) at Δg = 0

Inclusive jets: Constraints on ΔG

Many parameterizations of DIS data → many predictions of jet A_{LL} vs p_T

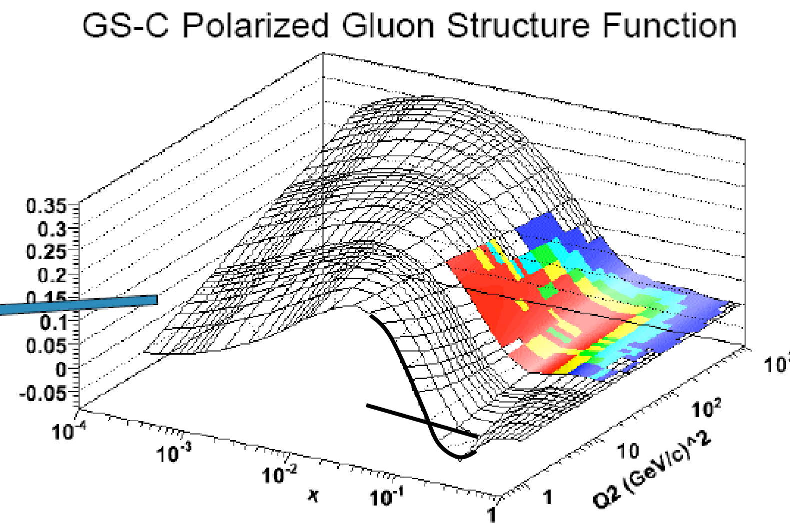


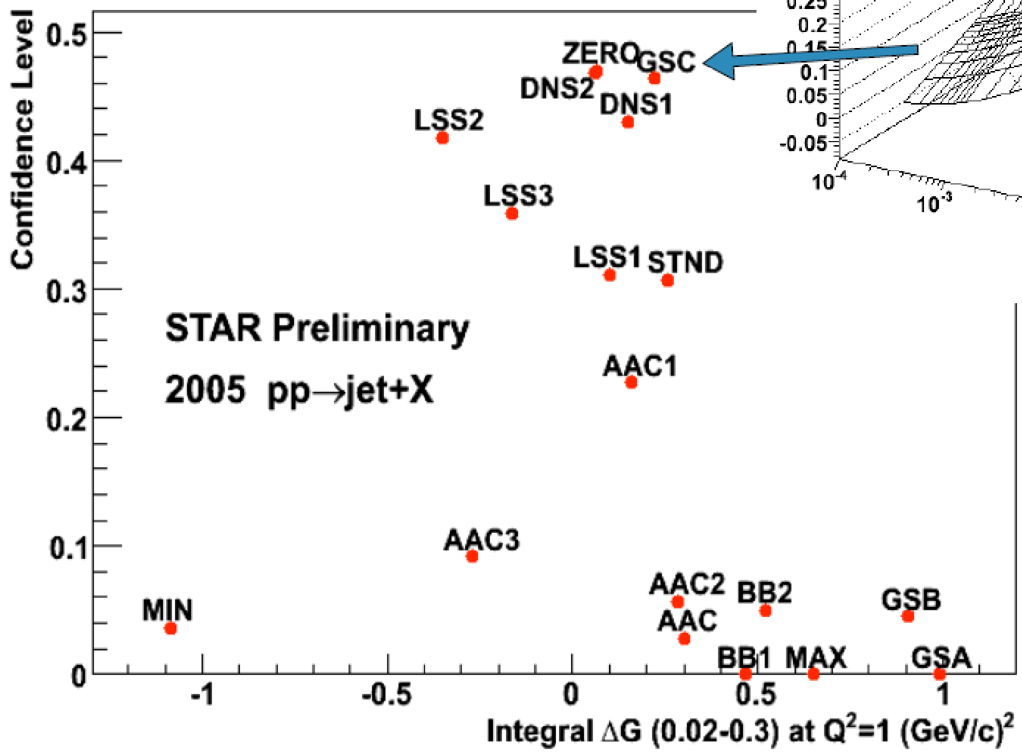


… but those with ΔG greater than GRSV-std are *largely excluded* by new STAR results!

One way out: Assume a node!

GS-C is an example of a model which has a large integral that we are not very sensitive to in our x and Q^2 range



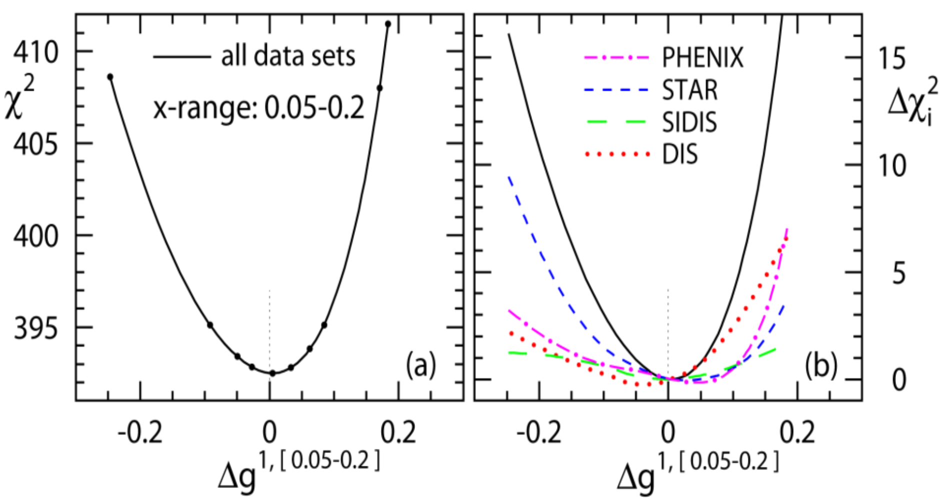


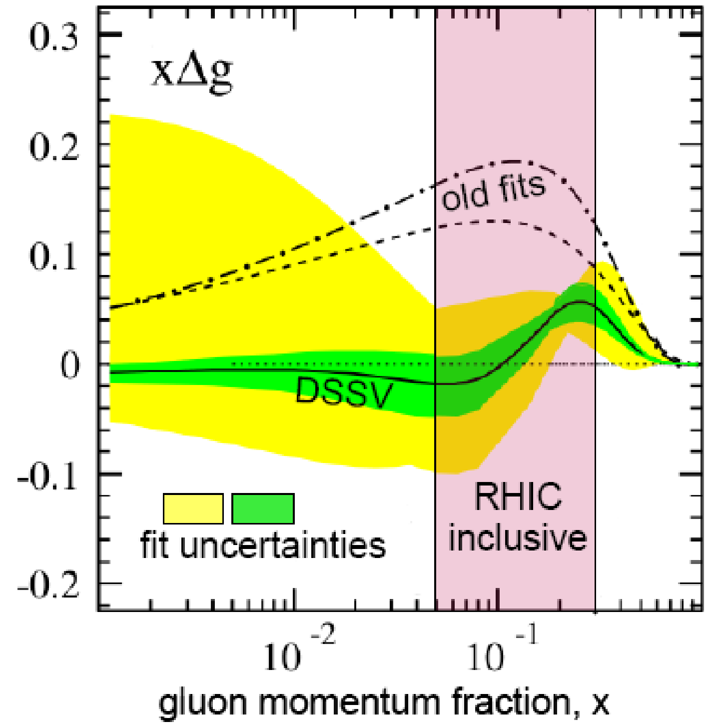
Note: ΔG values (x-axis) are plotted at partial x-integral values

STAR Inclusive jets: Impact on (first) global analysis

Represents the *first global NLO analysis* to include **inclusive DIS, SIDIS, and RHIC pp data** on an equal footing.

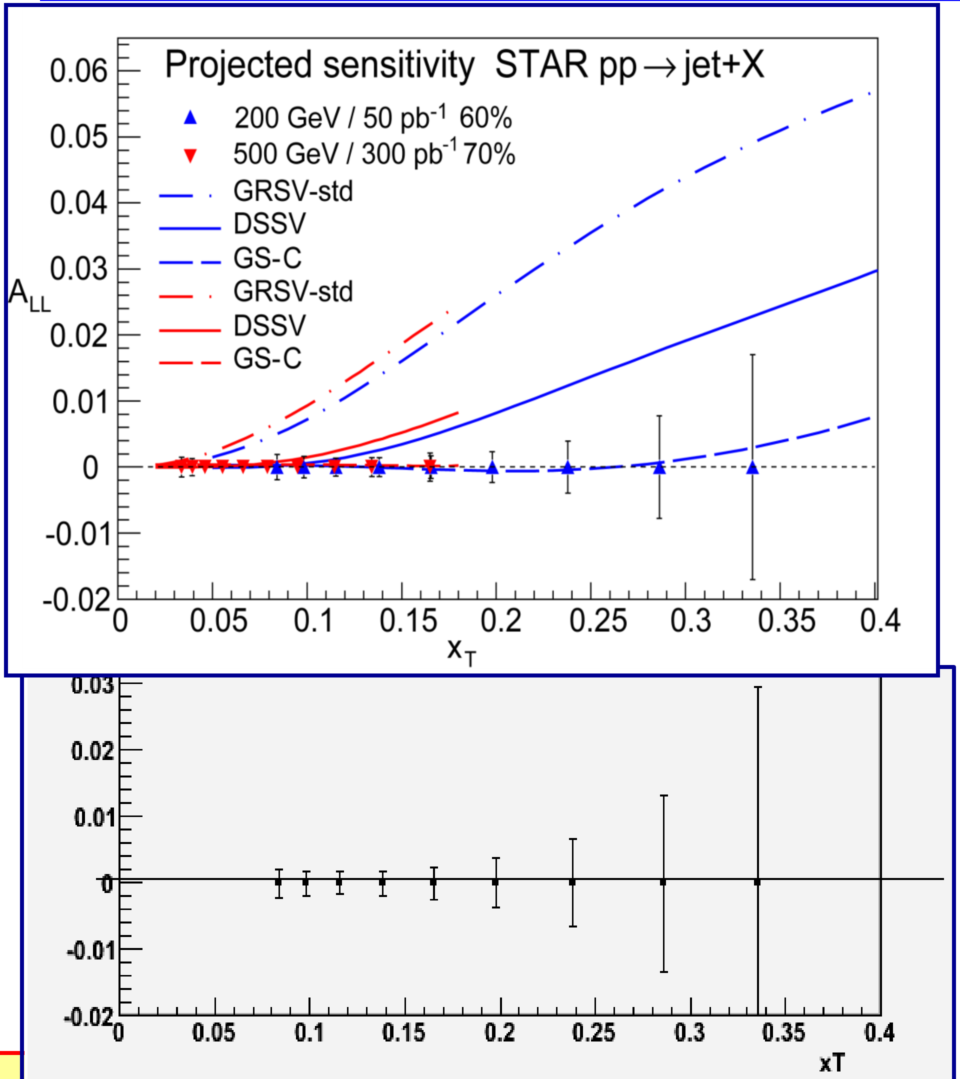
- Strong constraint on the magnitude of Δg over kinematic range 0.05 < *x* < 0.2 probed by *STAR* at √*s* = 200 GeV
- Data favor a **small Δg** in this window

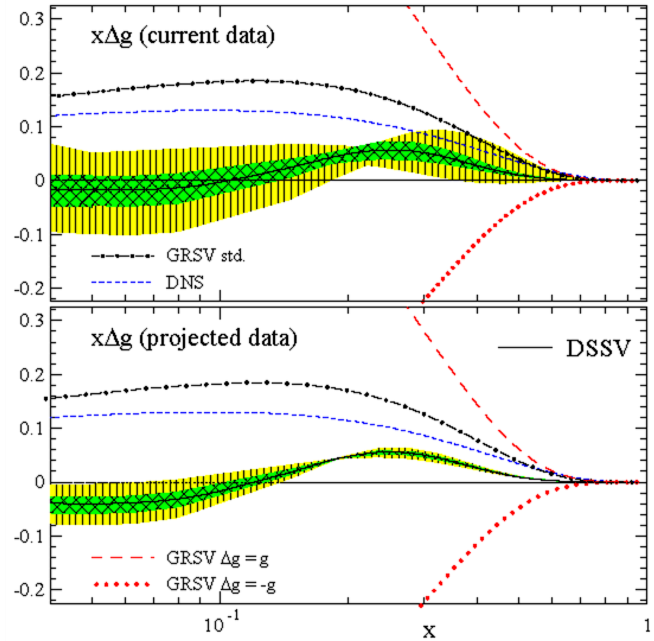




→ Best fit solution finds a node in the gluon distribution near *x* ~ 0.1 but with the *opposite phase* from that found in GS-C

Inclusive jet projections: 200 and 500 GeV





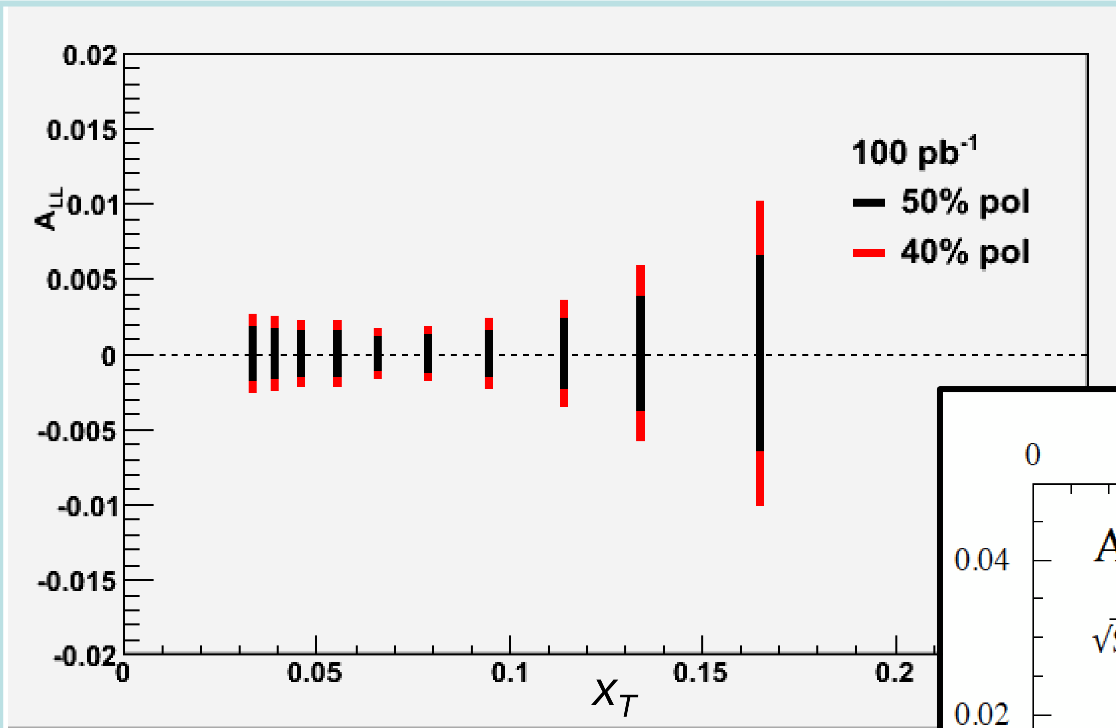
<u>200 GeV component of Run 9:</u>

Reduce A_{LL} uncertainties by factor of ~4 relative to Run 6

→ Provide much stronger constraints on gluon polarization

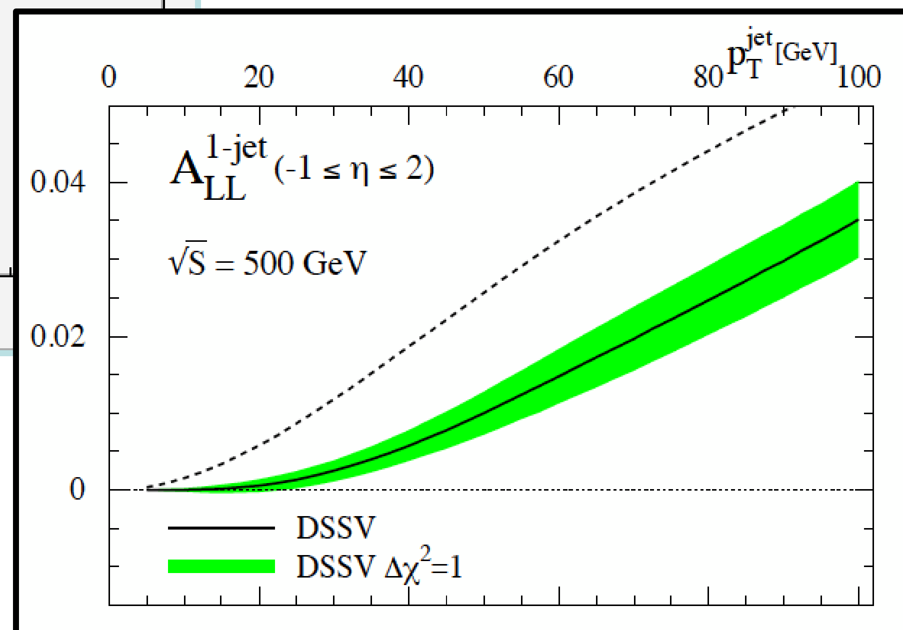
Progress in High-PT Physics at RHIC

Inclusive jet projections: 500 GeV, 100 pb^{-1}



Should be able to achieve very high statistical precision …

… but spin asymmetries expected to be small, very well constrained!

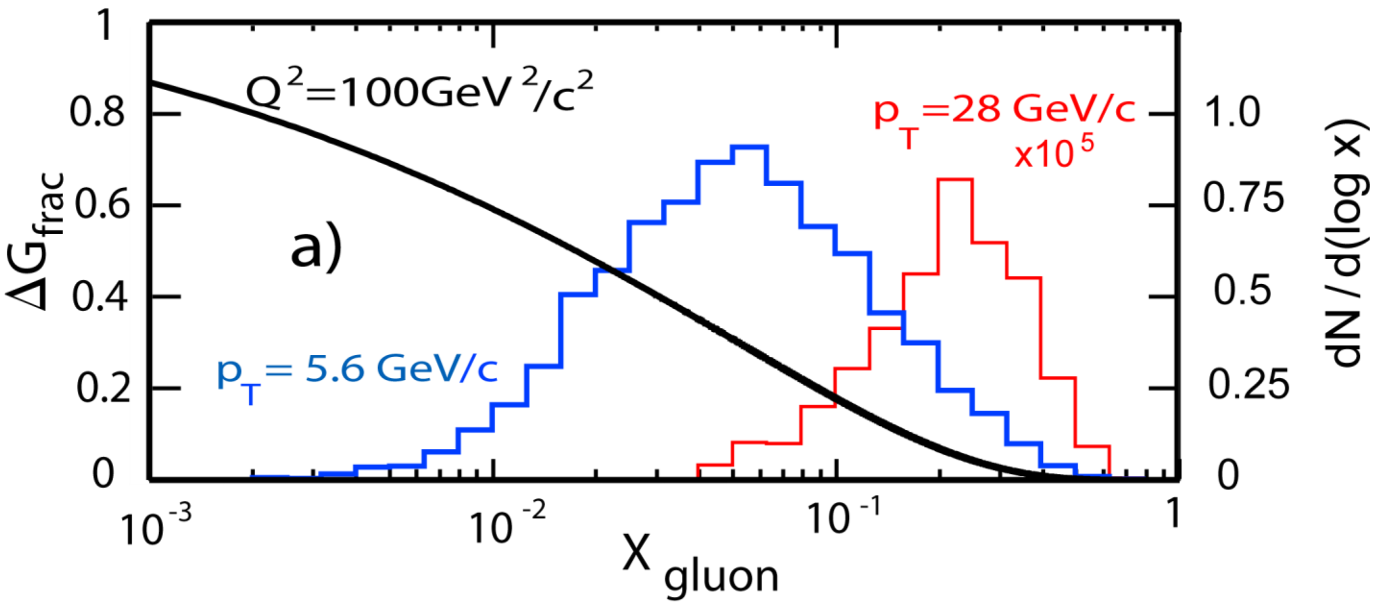


Mapping out Δg(x): the need for correlations

Despite great advances made via study of inclusive processes:

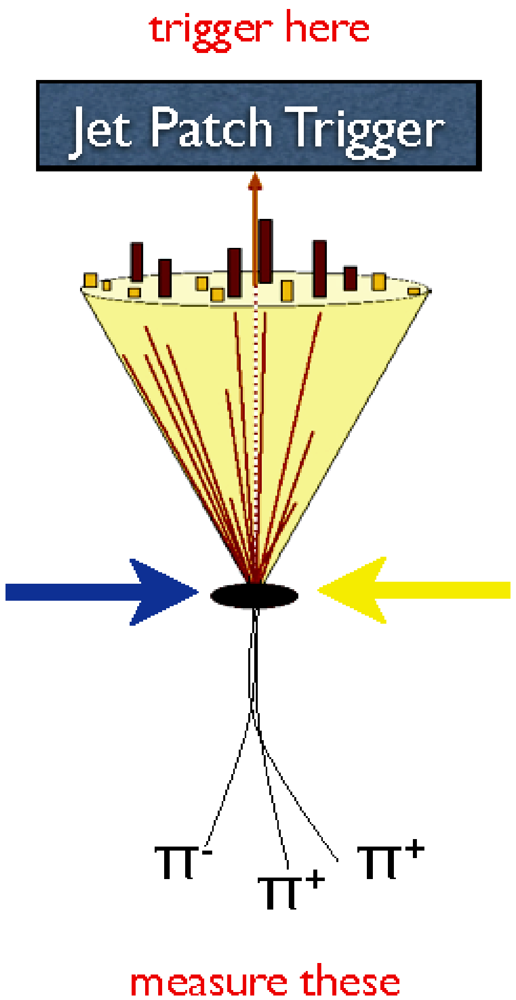
- **Measurements average over a broad range in x_g at a given p_T**
- **Provide minimal information on partonic subprocess involved**

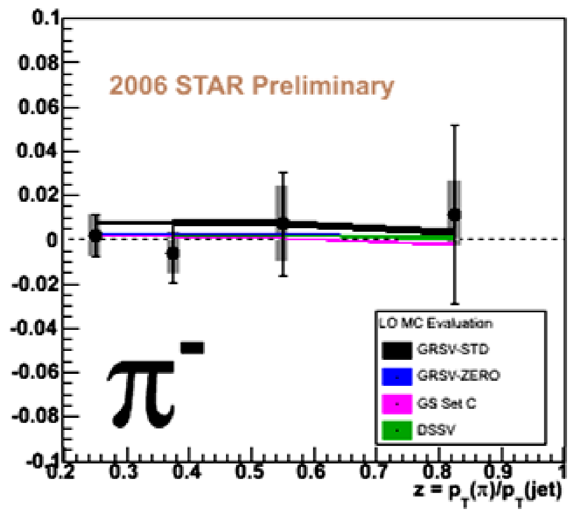
→ Could 'hide' non-trivial behavior of Δg(*x*), esp. if a node exists!

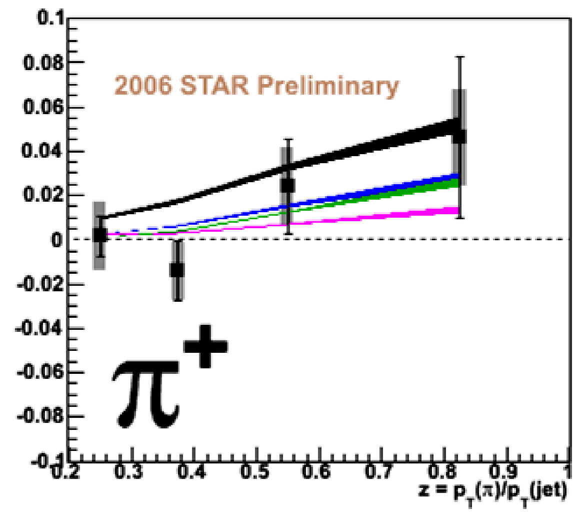


→ Need correlation measurements to help constrain the shape of Δg(x)

Correlations: charged pions opposite a jet





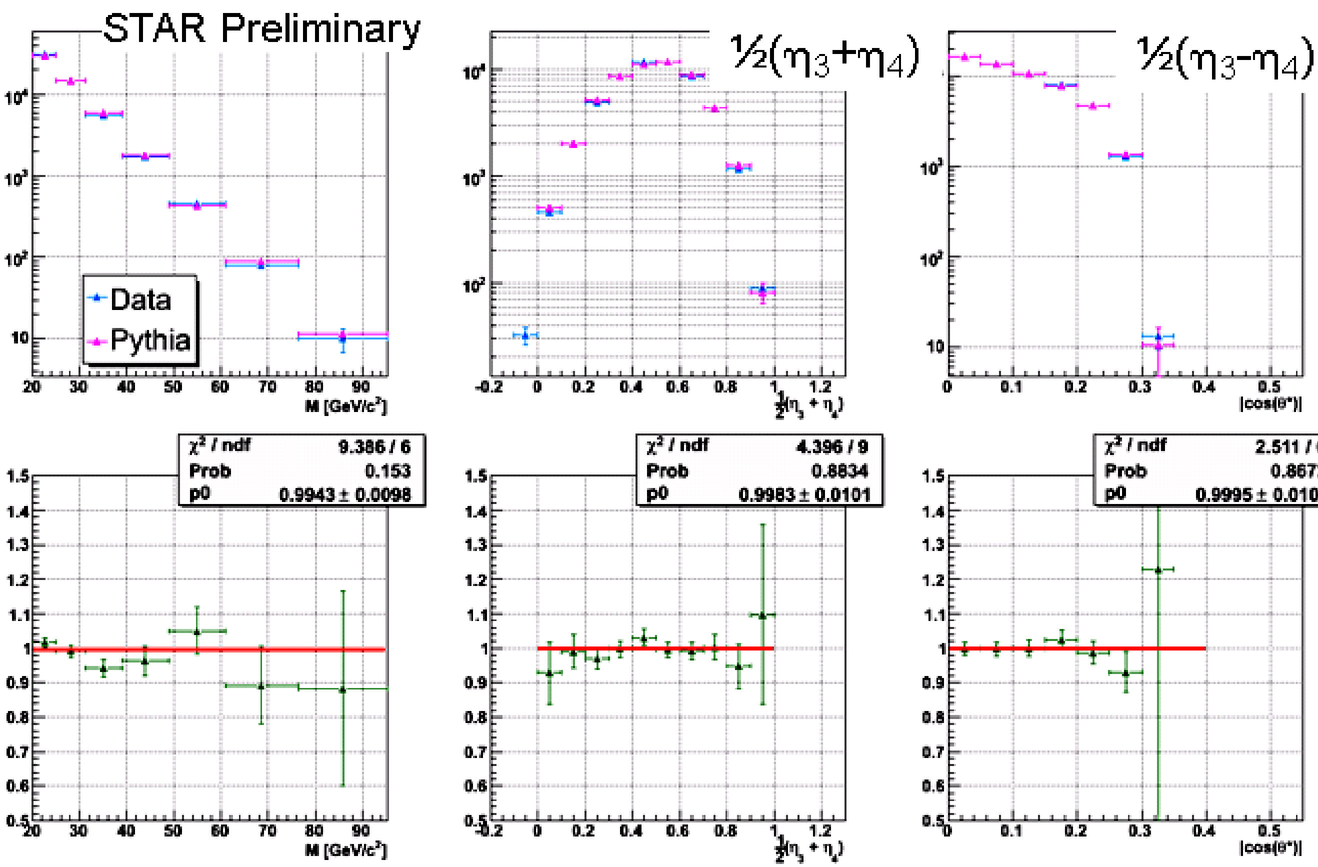


Problem: Higher trigger thresholds in Run 6 result in a larger fragmentation bias for $\pi^{\pm}$ in triggered jet

Solution: Trigger on and reconstruct jet, then look for a charged pion on the opposite ("away") side

Result: Correlation measurement **significantly increases the sensitivity of $A_{LL}(\pi^{+})$**

Di-jets in Run 5: Kinematics for 2 → 2 collisions



$$x_1 = \frac{p_T}{\sqrt{s}}\left(e^{\eta_3} + e^{\eta_4}\right)$$

$$x_2 = \frac{p_T}{\sqrt{s}}\left(e^{-\eta_3} + e^{-\eta_4}\right)$$

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

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

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

Excellent agreement between full PYTHIA MC and Run 5 data

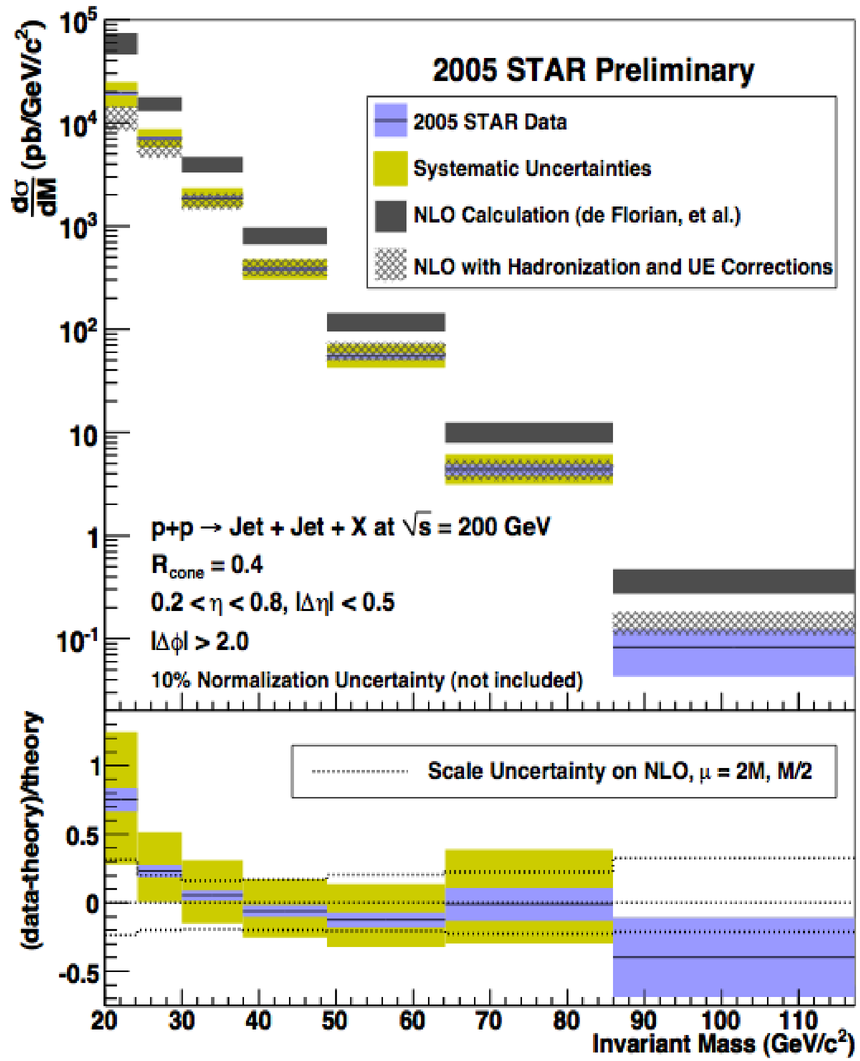
Di-jets require large coincident solid angle – *STAR* well suited for these studies
High yields allow near triple differential distributions in dM, dη, dcos(θ*)

→ *select kinematics for x_g dependence*

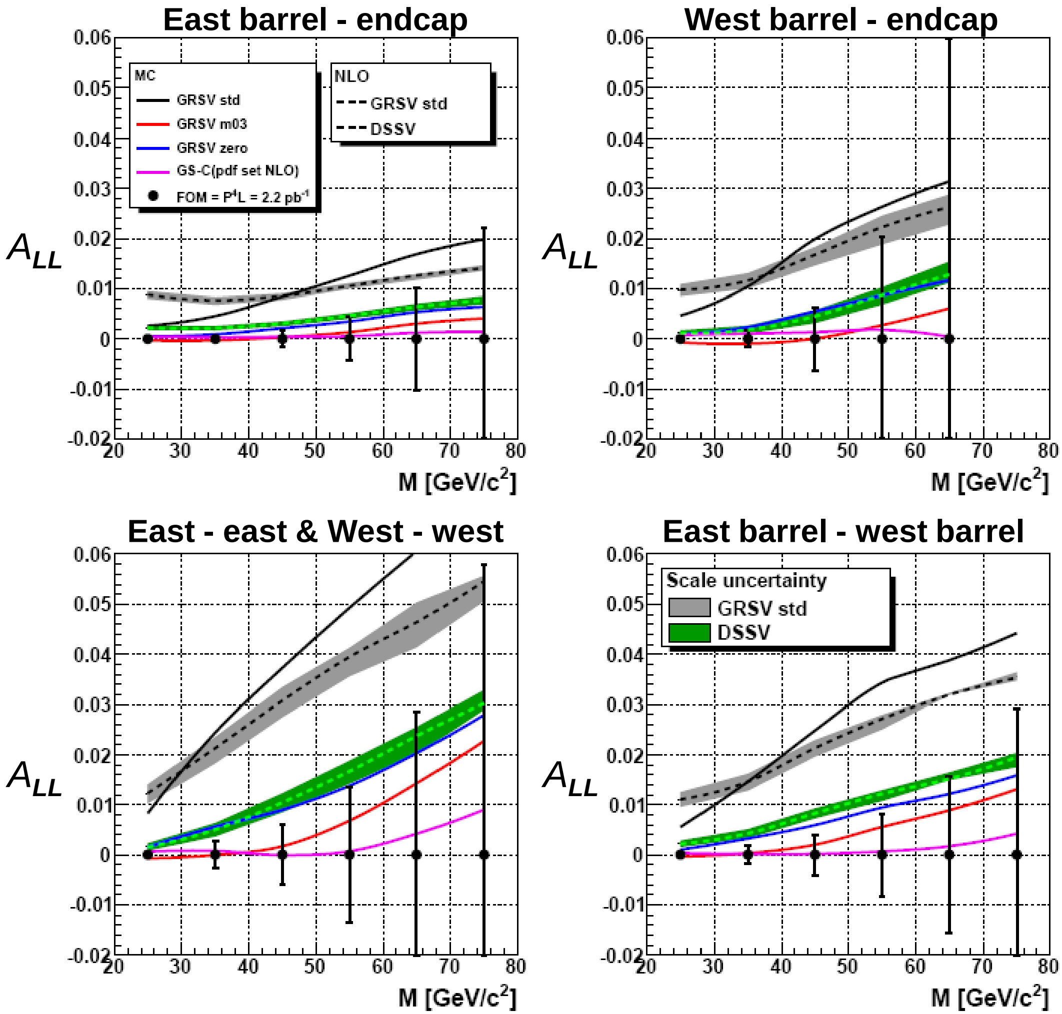
→ *select kinematics for high-x quarks and favorable a_{LL}*

Results: First di-Jet cross section!

- Unpolarized differential cross-section vs. invariant mass M above 20GeV/c2
- NLO theory predictions by D. deFlorian et al. using MRST2004 pdfs with ( ) and without ( ) Hadronization / UE Corrections over data inv. mass bins
- Statistical uncertainties are shown in blue ( )
- Energy scale uncertainty is shown in yellow ( )
- Comparison to theory together with theory scale uncertainties



Di-jets in Run 9, 200 GeV: Expected sensitivity to Δg



To leading order, di-jets provide direct access to initial-state parton kinematics (x_1, x_2)

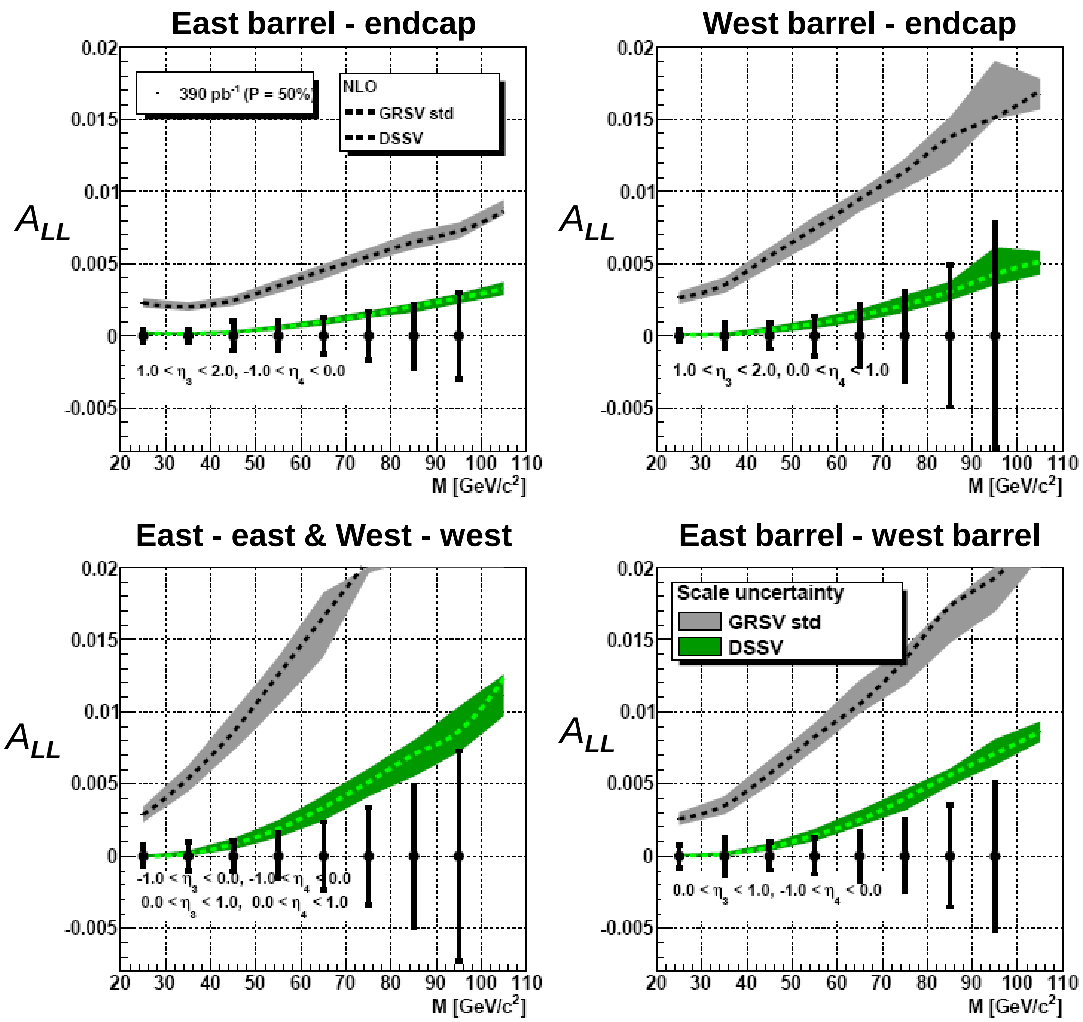
By detecting di-jets in different regions (η,ϕ) of the *STAR* detector, we

- **sample different mixtures of *qq*, *qg*, *gg***
- **sample different ranges of x_g**

→ Provides much tighter constraints on theoretical models

Errors shown are statistical only!

Di-jets at 500 GeV: projections for 390 pb^{-1}, P = 50%



Going to higher $\sqrt{s}$ will:

- provide access to lower values of gluonic *x*
- measured asymmetries expected to be smaller than at 200 GeV
- should be compensated by smaller statistical uncertainties due to higher luminosities

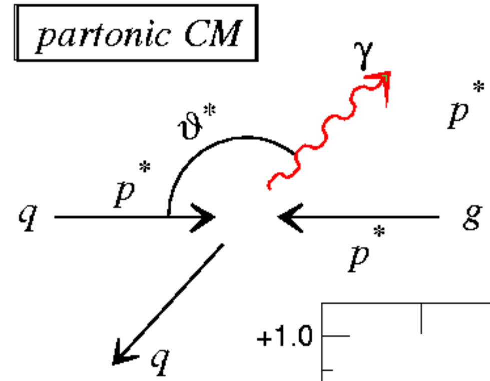
De Florian, Frixione, Signer and Vogelsang, NPB 539 (1999) 455 and private comm.

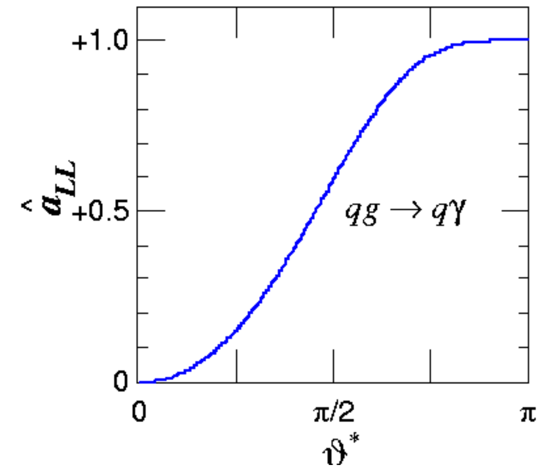
Errors shown are statistical only!

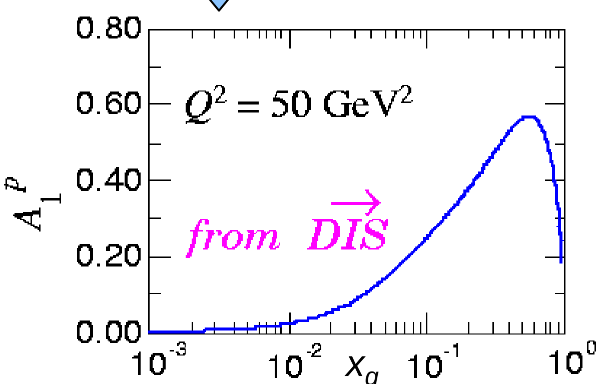
Photon-jet coincidences: Still the 'golden channel'?

Despite low yield, γ-jet studies offer several key advantages:

- **Dominance of a single LO pQCD subprocess: $qg \rightarrow q\gamma$**
- **Large spin correlation ($\rightarrow$ 1) when partons are back-scattered**
- **Most asymmetric collisions involve high-*x* (highly polarized) quarks that Compton scatter from low-*x* (abundant, interesting) gluons**
- **Direct photon should provide most precise estimate of partonic p_T, → combined with η_γ and η_{jet}, yields robust information on x_q, x_g**







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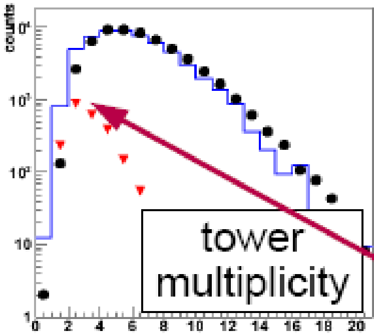
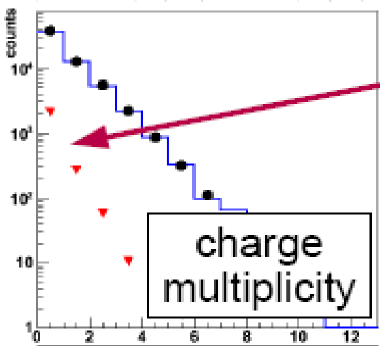
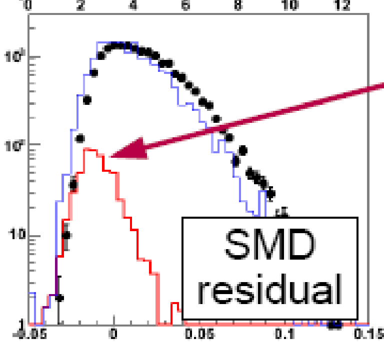
Photon-jet coincidences: finding the events!



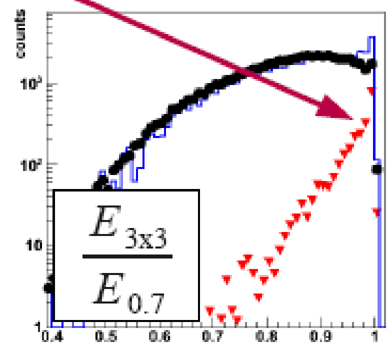


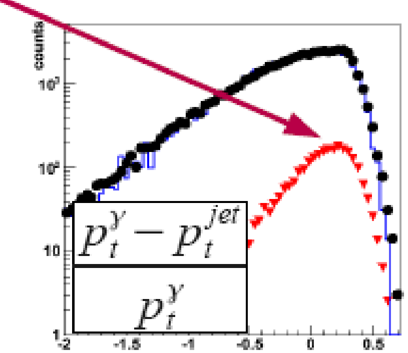


Main photon-jet signatures

- > 95% of energy deposition localized in small Δη-Δφ radius
- photon deposits all energy in small (<4) number of towers
- (almost) no charge particles accompanying photon
- good matching between photon momentum and that of the away side jet
- Small residual: photon shower is narrow and symmetric

pp2006 **g-jet**
g-jet + QCD
raw yields before background suppression



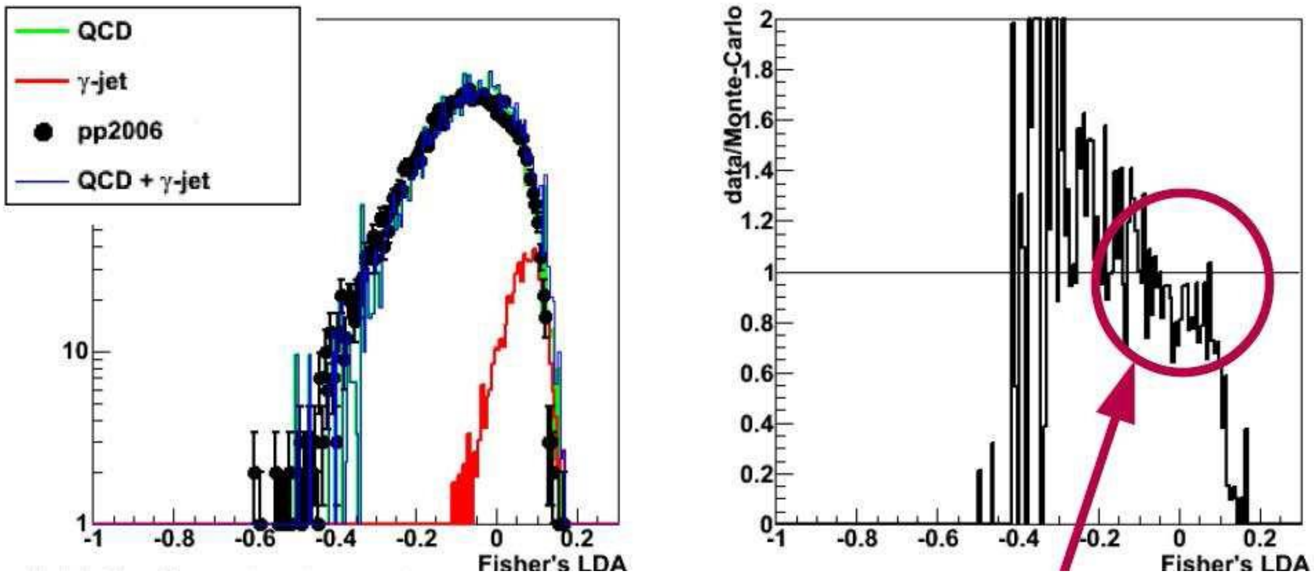


data and Monte-Carlo match within 5-10%

Progress in High-PT Physics at RHIC

Photon-jet coincidences: LDA analysis

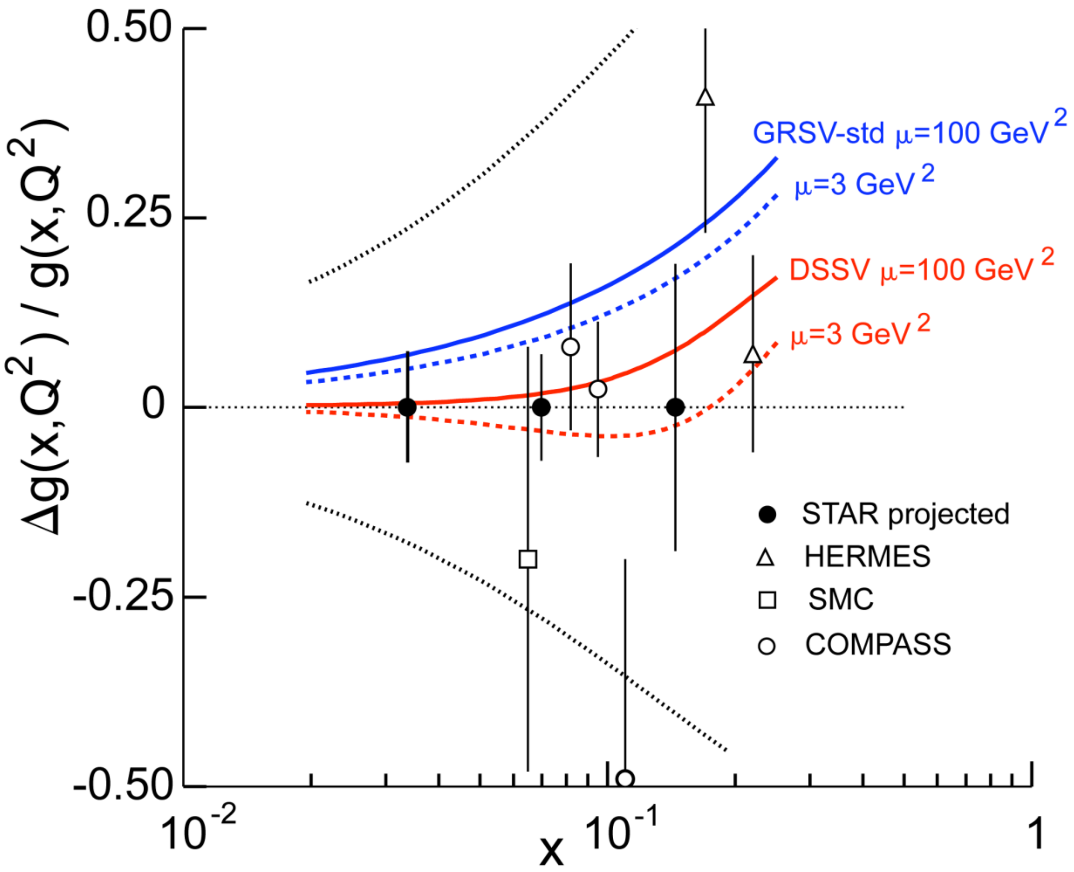
$$p_t^{\gamma} > 7\text{GeV}, \;\; 0 < E_{pre1} < 4\text{MeV}$$



Use high E_{dep} in Endcap "pre-shower" layers to veto QCD background + full linear discriminant analysis incorporating other detector components

→ ***Yields a high efficiency (~70%), photon-enriched sample, plus a high-statistics, photon-depleted (QCD background) sample***

Photon-jet: projections for 50 pb^{-1} at 200 GeV

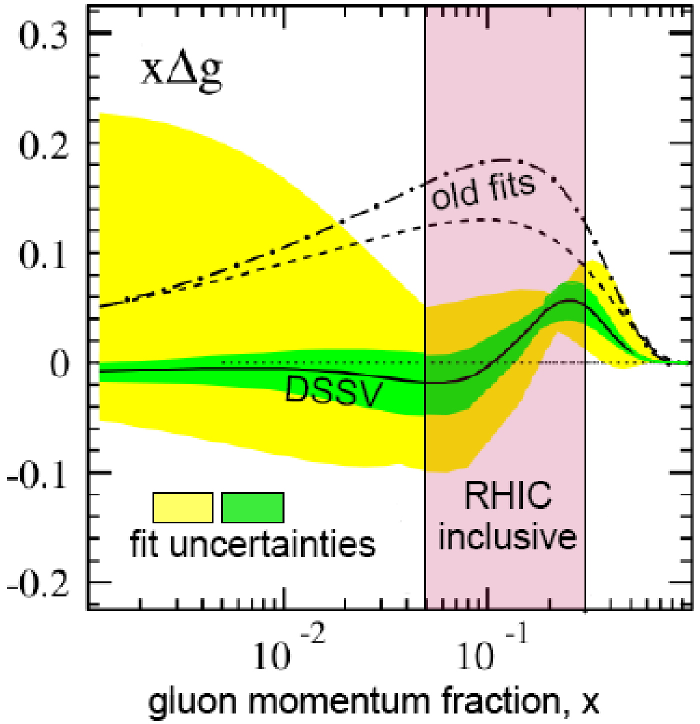


A_{LL} for forward photons and coincident mid-rapidity jets

- ***Cleanest assignment of $(x_1,x_2) \Leftrightarrow$ (quark,gluon)***
- ***Error bars show statistical uncertainties only, no bkgd subtraction, but …***
- ***do not include expected improvements due to FGT***
- ***Probes gluons at smaller x than other competing exp'ts***
- ***Can push to even lower x_g via photon detection in FMS***

Summary and Outlook

- ***STAR*** **has developed a broad and diverse program for studying ΔG**
  → Complementary measurements support small gluon polarization over the range 0.05 < x_g < 0.2
- **Over next 2-3 years expect greater precision in inclusive channels at 200 GeV, plus new results at 500 ...**
- **… and increased focus on di-jet and γ-jet correlations to more fully map out gluon helicity distribution**



→ Must view ΔG studies as <u>one component</u> of broader program to understand <u>all aspects</u> of parton spin behavior in the nucleon!