Recent Results from the *STAR* Longitudinal Spin Program at RHIC

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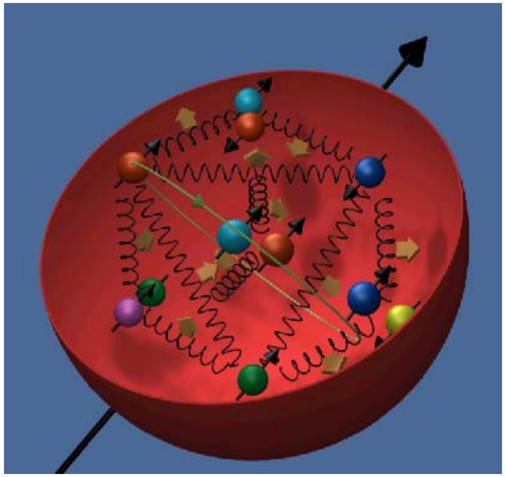
Outline :

1. ***Introduction***
2. ***Experimental setup***
3. ***Recent results from longitudinal spin program***
4. ***Summary & Outlook***



Proton Spin Structure

Spin Crisis : Origin of the proton spin?

Polarized DIS ~ 0.25

Poorly Constrained

$$\langle S_z^p \rangle = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \overbrace{\Delta G + \langle L_z^q \rangle + \langle L_z^g \rangle}$$

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

- $\vec{p}\vec{p}$ ***at RHIC ⇒ New QCD lab: strongly interacting probes***
- ***High √s and p_T make NLO pQCD analysis more reliable***
- ***STAR longitudinal spin program ⇒ Gluon polarization distribution***
- ***STAR transverse spin program ⇒*** *Di-Sivers (Steve Vigdor)*
Recent STAR Results (Len Eun) } *Tomorrow's Transverse Session*

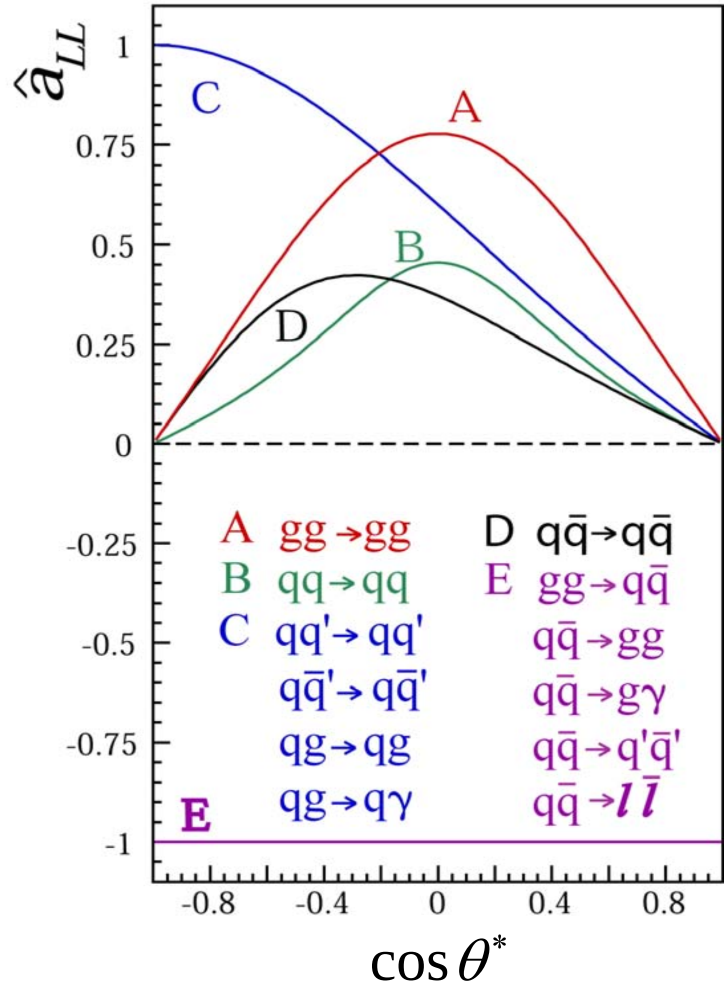
Inclusive A_{LL} measurements (π^o, $\pi^\pm$, and jets)

- *Good tool to study the gluon polarization but with no direct parton kinematics reconstruction...*
  To be used in a global analysis to obtain ΔG.

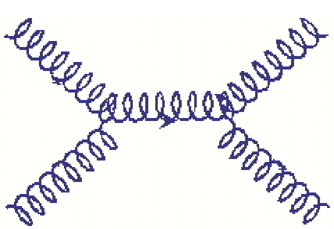
- *We measure asymmetries ⇒ Many systematic effects cancel out*

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \propto \frac{\Delta f_a \Delta f_b}{f_a f_b} \hat{a}_{LL}$$

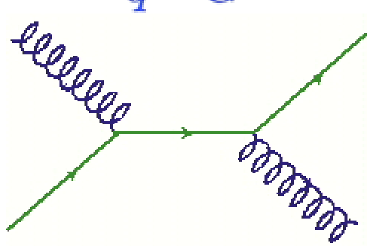
Δf: polarized parton distribution functions



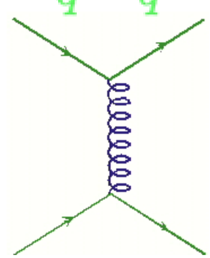
$\frac{\Delta G}{G} \frac{\Delta G}{G}$



$\frac{\Delta q}{q} \frac{\Delta G}{G}$

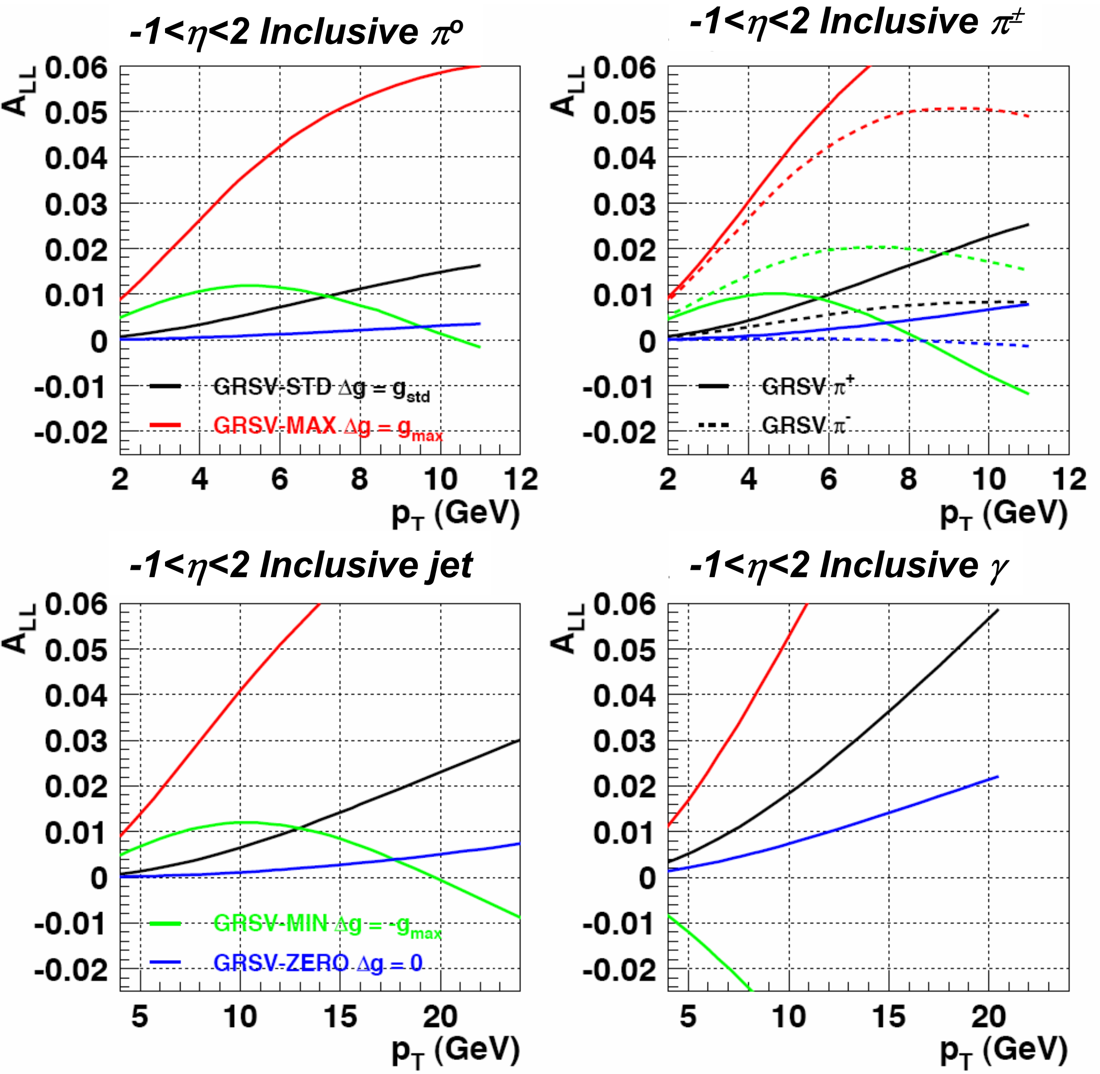


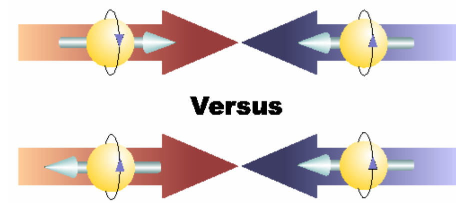
$\frac{\Delta q}{q} \frac{\Delta q}{q}$



Inclusive A_{LL} measurements (π^o, $\pi^\pm$, and jets)

❖ *Predicted A_{LL} sensitivity for different ΔG scenarios*

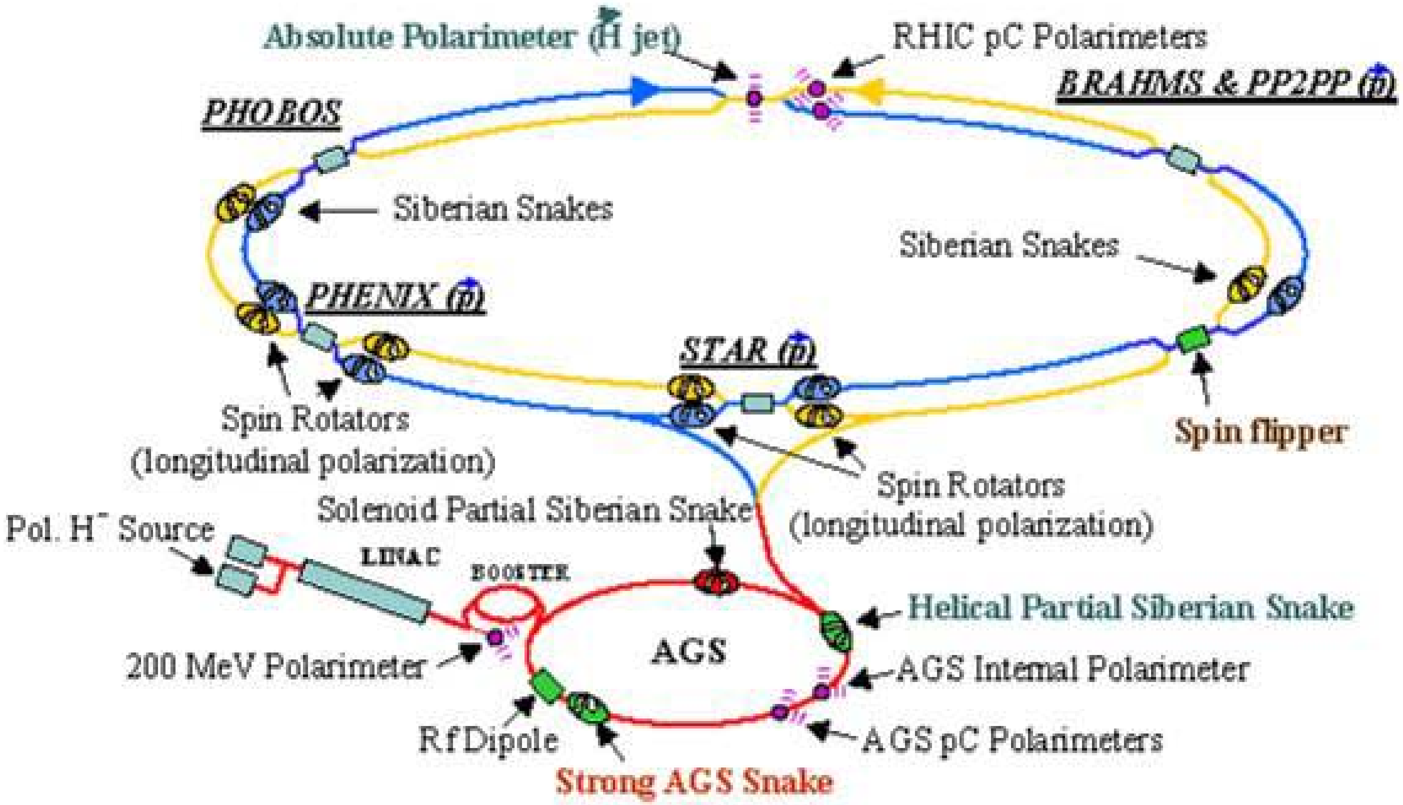




$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_1 P_2} \times \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}$$

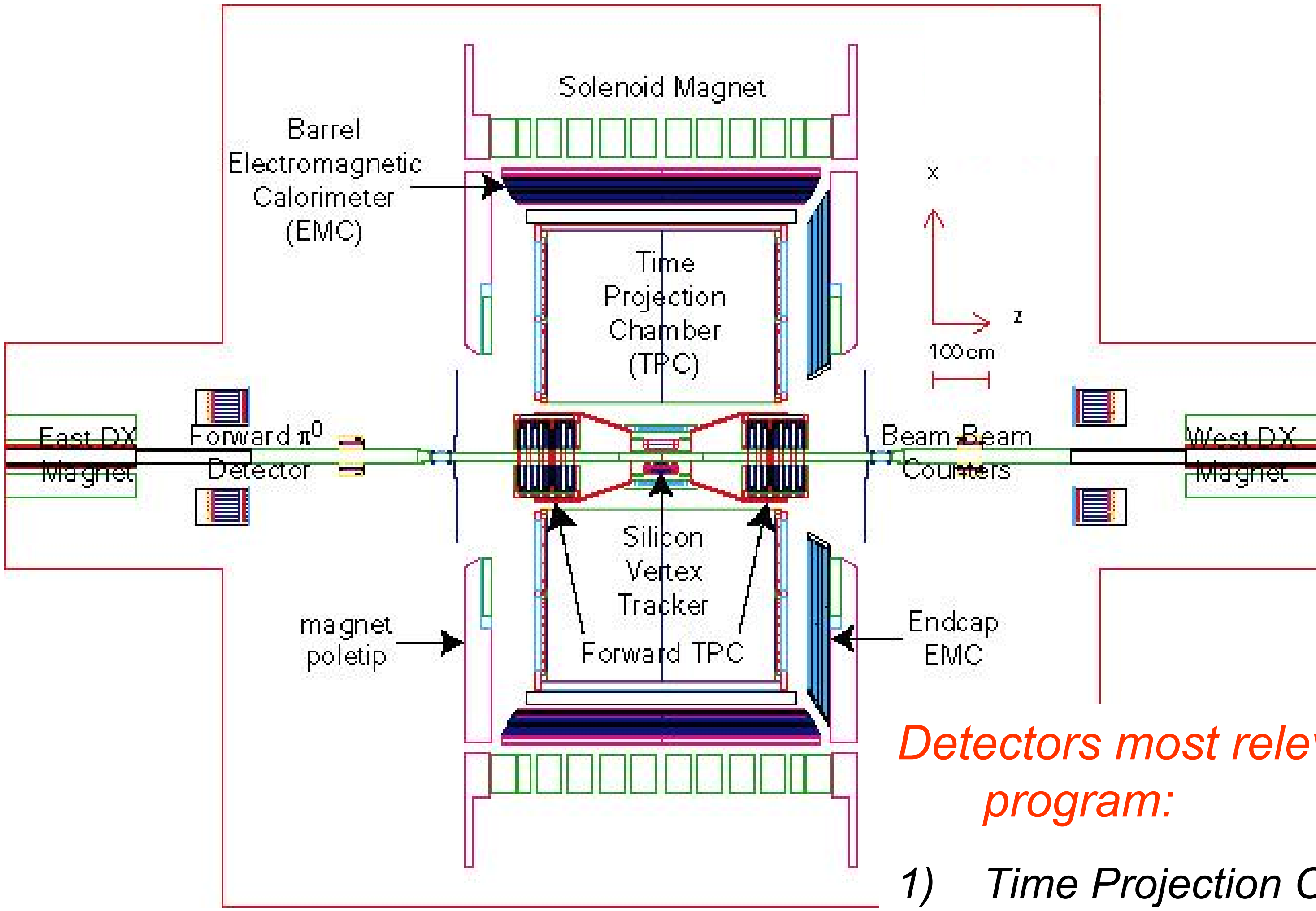
N : Spin dependent yields (# of reconstructed jets/pions)
P : Beam polarization (measured by RHIC Polarimeter)
R : Relative luminosities between different spin states

Polarized protons at RHIC



RHIC RUN	√s [GeV]	L_{Rec} [pb^{-1}] Long.	L_{Rec} [pb^{-1}] Tran.	Pol. (%)
2002	200	0.3	0.15	15
2003	200	0.3	0.25	30
2004	200	0.4	0	40-45
2005	200	3.1	0.1	45-50
2006	200	8.5	3.4/6.8	60

STAR detector layout

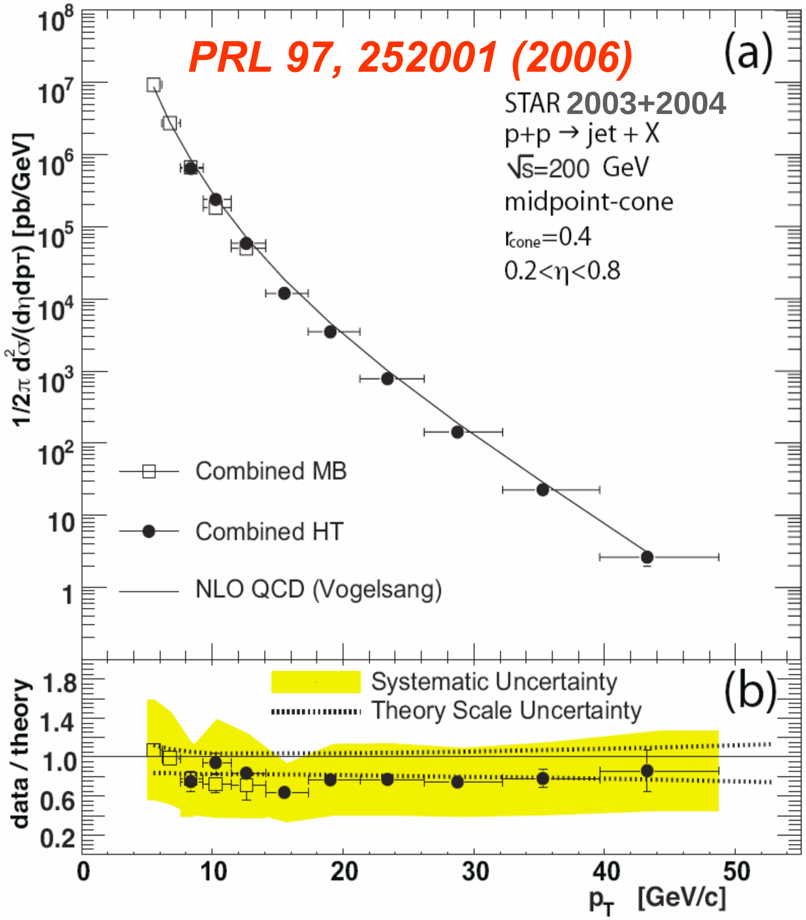


Detectors most relevant for the spin program:

1) Time Projection Chamber, $|\eta|<1.4$
2) Barrel EM Calorimeter, $|\eta|<1$
3) EndCap EM Calorimeter, $1.09<\eta<2$
4) Forward-Pion Detectors, $3<|\eta|<4$
5) Beam-Beam Counters, $3.4<|\eta|<5$

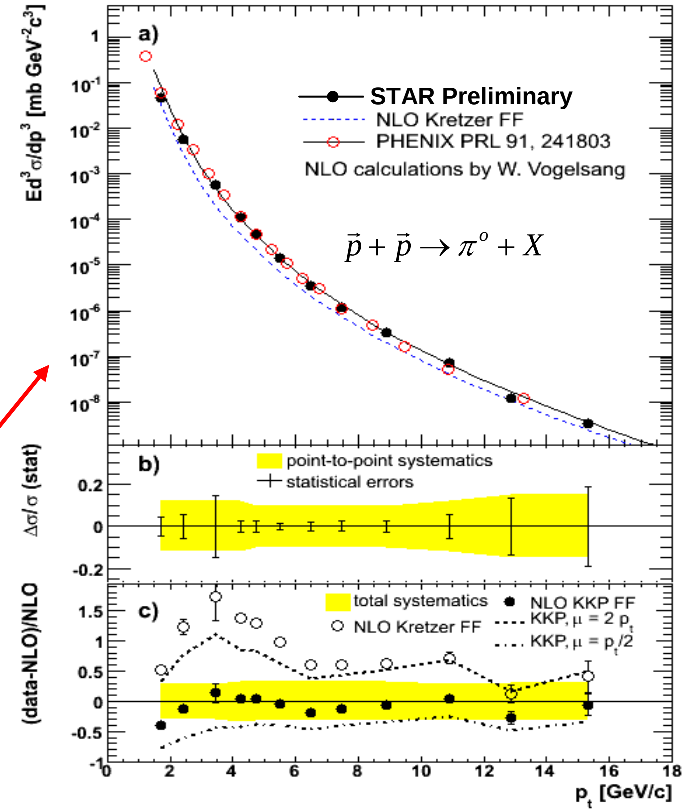
Inclusive cross-section (jets, π^o, and $\pi^{\pm}$)

First inclusive jet cross section result at RHIC

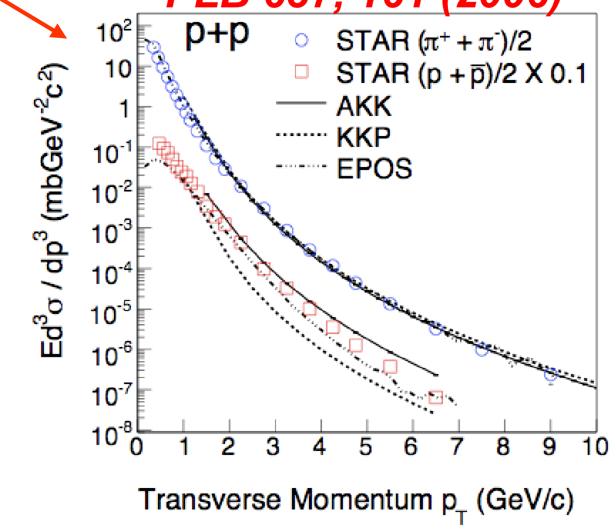


STAR

Hadron production



PLB 637, 161 (2006)

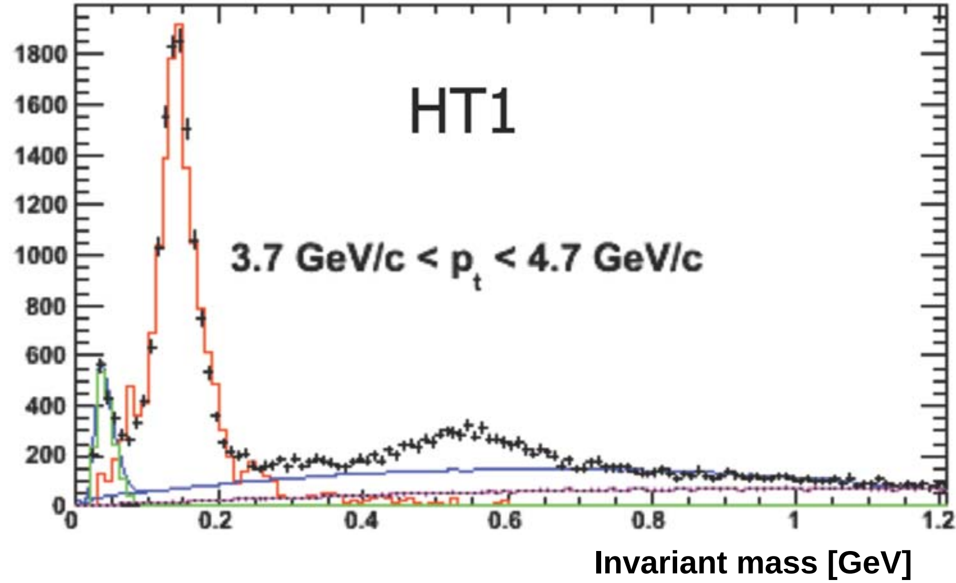


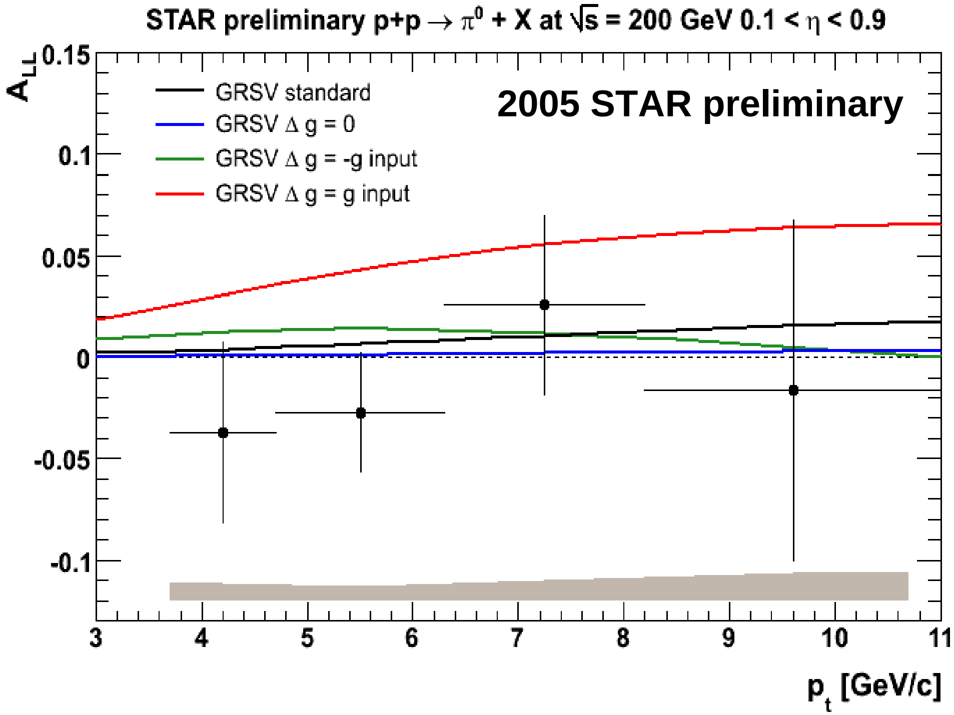
Good agreement with NLO pQCD over many orders of magnitude

pQCD works!

Inclusive π^o production at mid-rapidity

- *$\gamma\gamma$ invariant mass spectrum near π^0 mass described by:*
  - *MC π^0 line shape*
  - *Low invariant mass background (caused by cluster splitting in the SMD)*
  - *Combinatory background & residual fit*



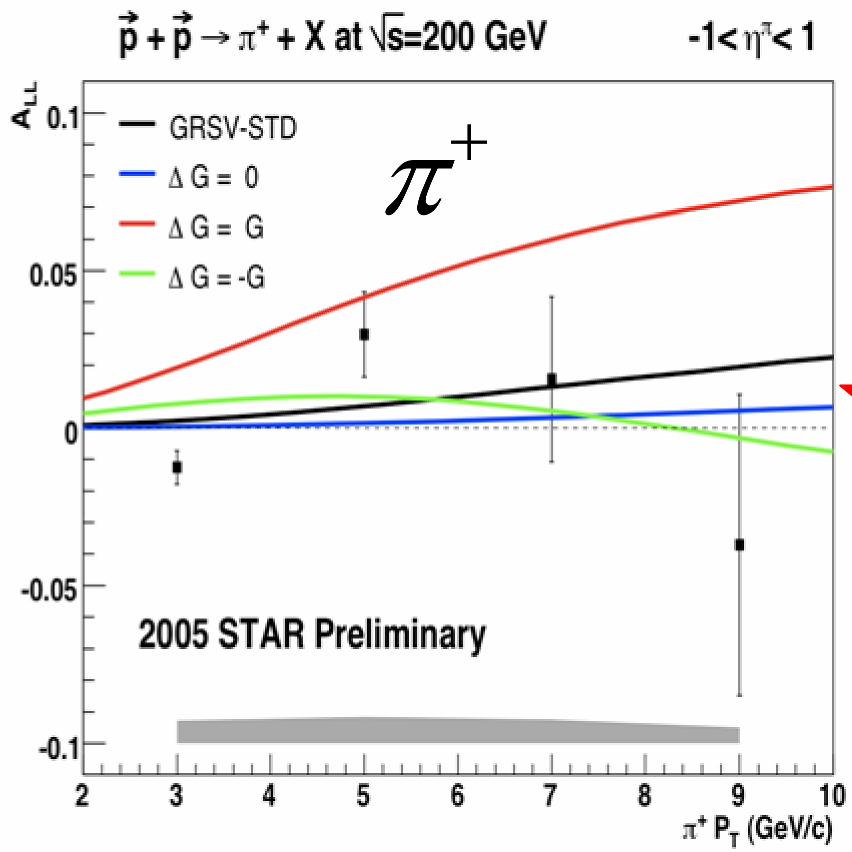


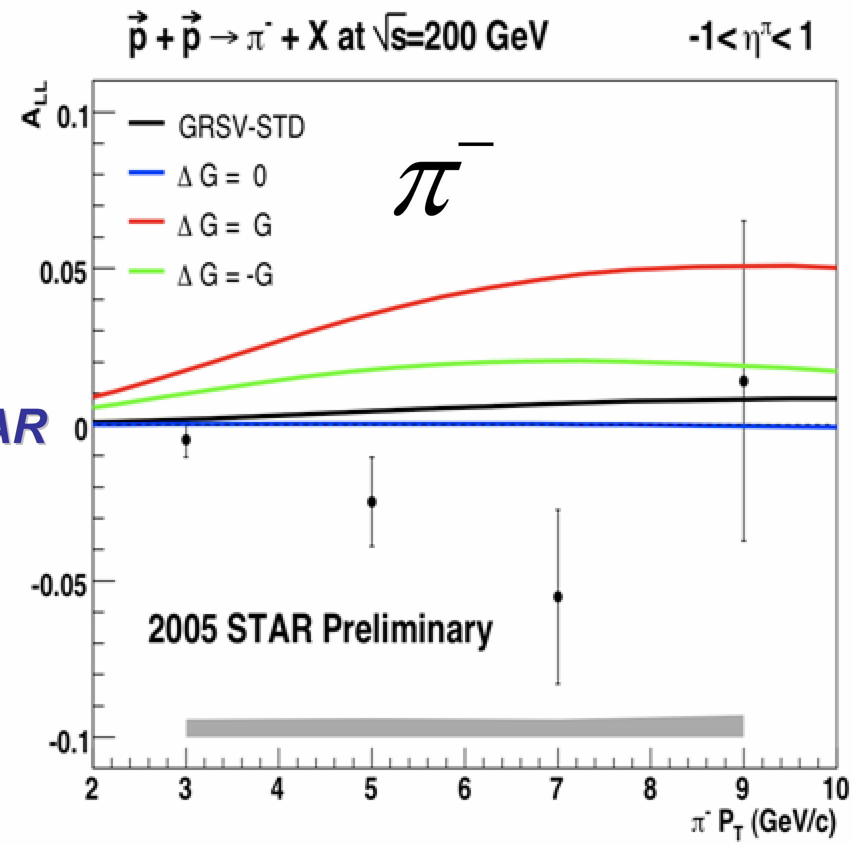
- *The dominant systematic is from beam backgrounds (p_T dependent), ~5-11 x10^{-3}*

- ***Run 2005 $A_{LL}(\pi^o)$ results disfavor maximum gluon polarization (GRSV-MAX) scenario***

Inclusive $\pi^{\pm}$ production at mid-rapidity

- Sensitivity to the sign of ΔG…. e.g. positive ΔG ⇒ $A_{LL}^{\pi^+} > A_{LL}^{\pi^o} > A_{LL}^{\pi^-}$

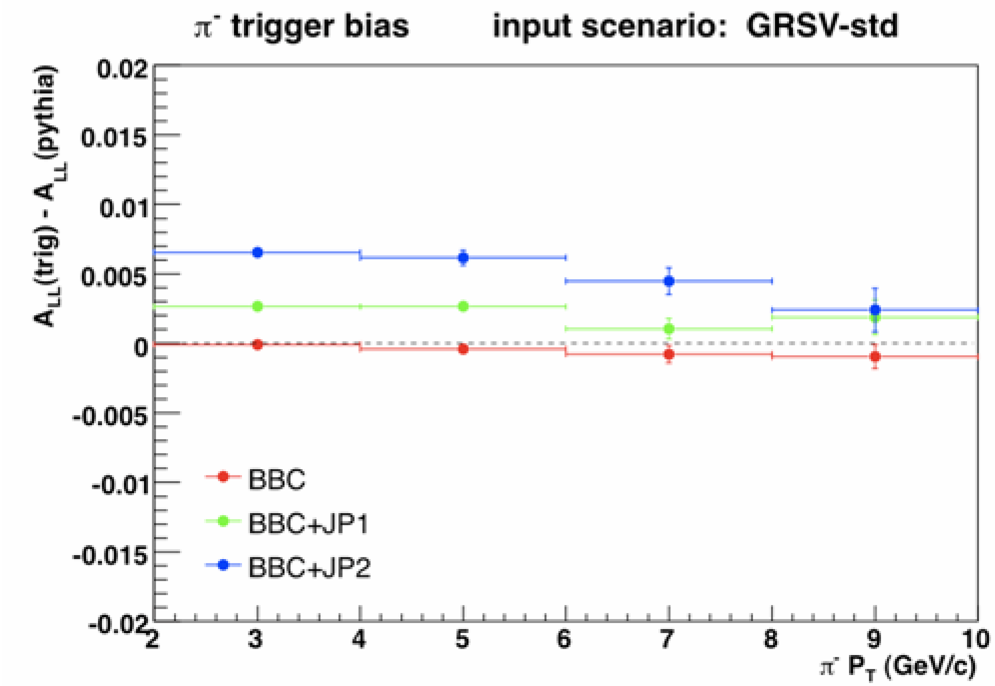




- *Also disfavors GRSV-MAX scenario*

Trigger bias in inclusive $\pi^{\pm}$ production at mid-rapidity

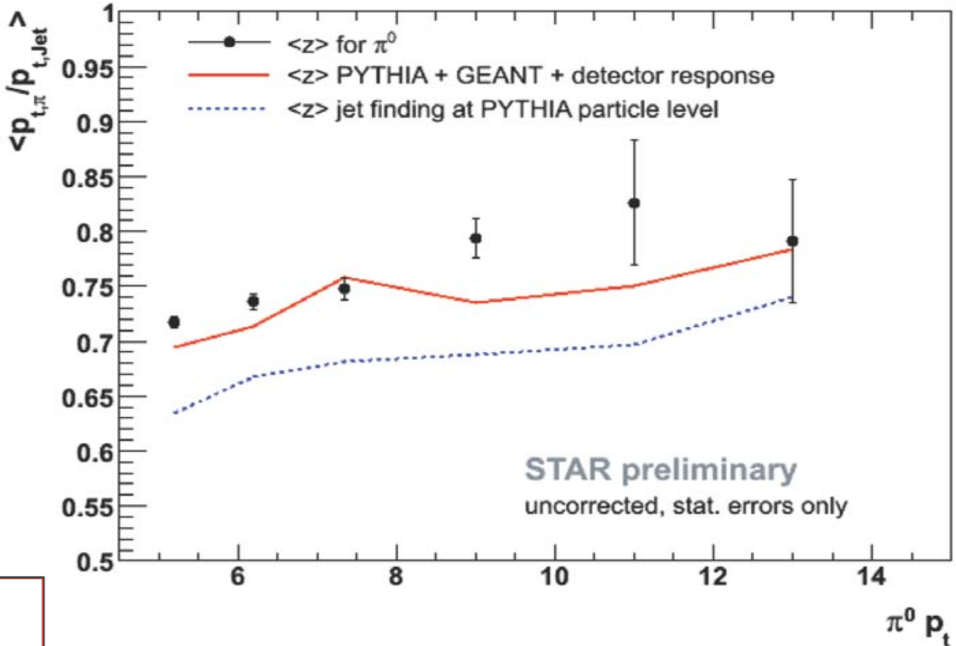
- *Majority of pions are sub-leading particles in trigger jet*
  - *Significant statistics from "away-side", un-triggered jet as well*
- *Calculate A_{LL} in simulation with and without trigger requirement*
- *Bias estimated using average of GRSV-min and GRSV-std scenarios*
- *3.0 - 7.3 x 10^{-3} as a function of p_T and charge sign*

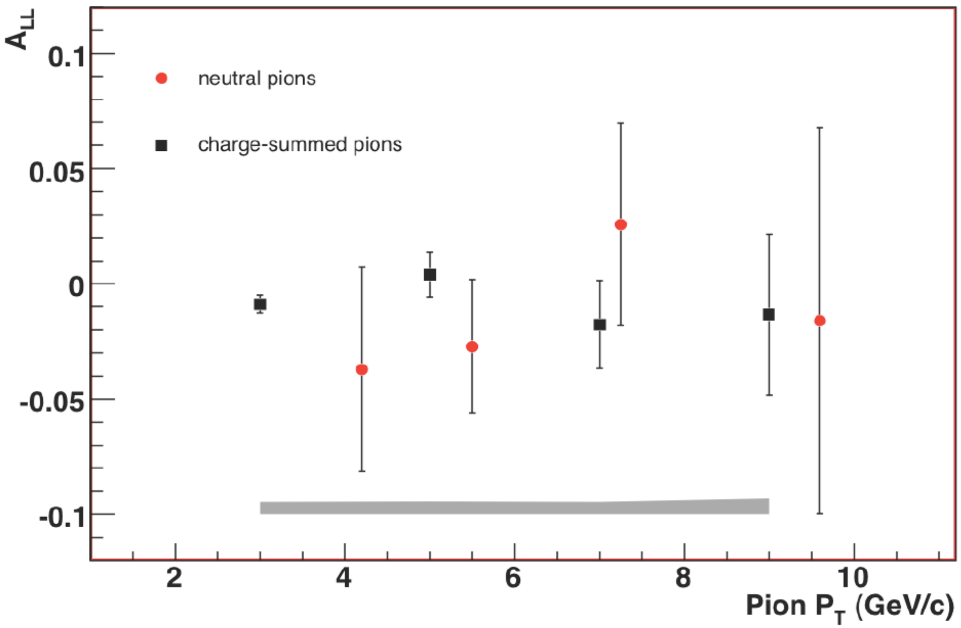


Charged and neutral pions at mid-rapidity

❖ <z> is the mean ratio of π^0 p_T to Jet p_T

❖ *Energetic π^0 carry a significant fraction of the total transverse momentum of their associated jet*

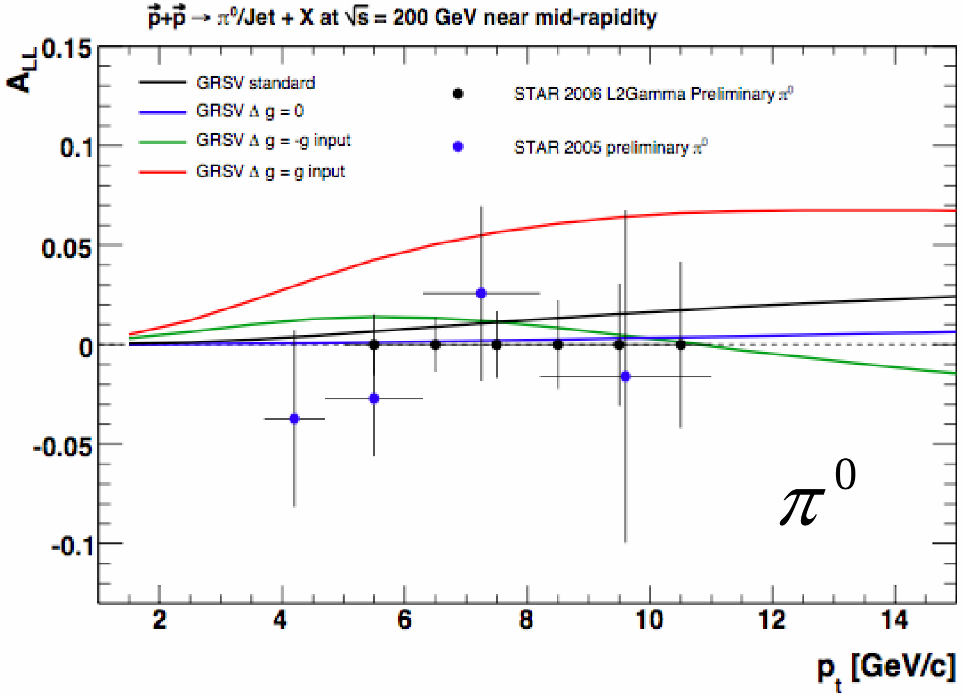


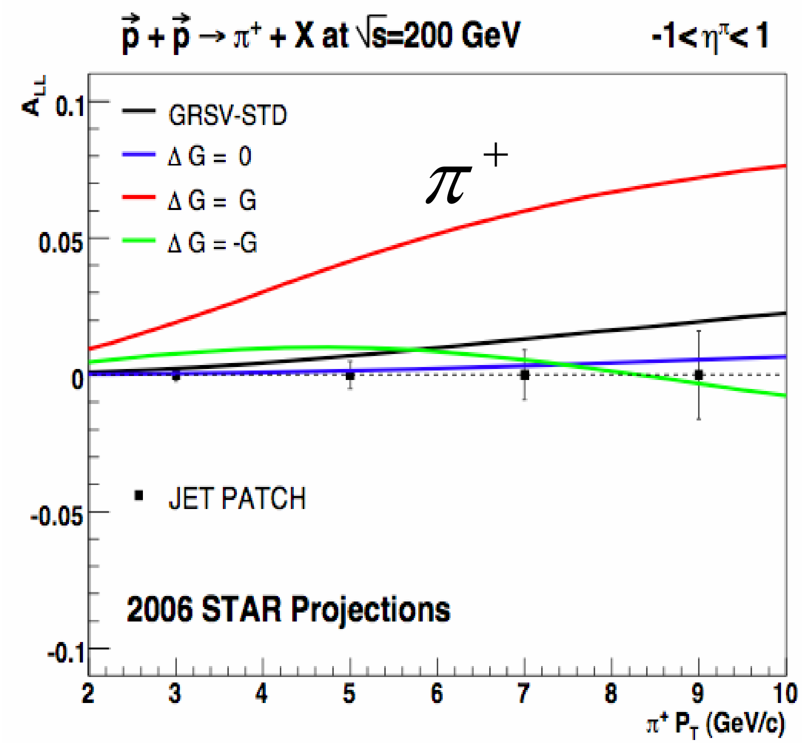


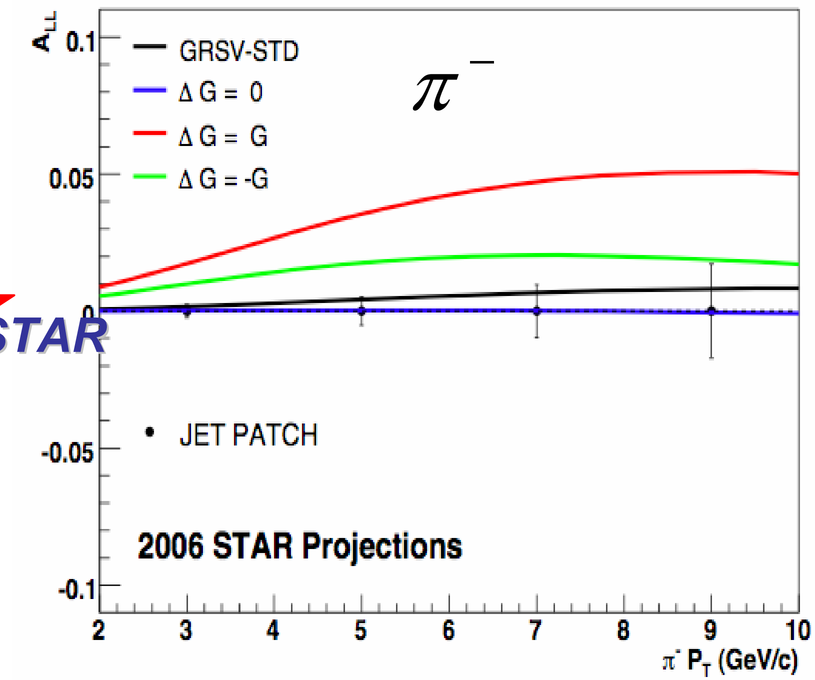
❖ *Asymmetries between charged (averaged between π^+ and π^- asymmetries) and neutral poins are consistent*

Inclusive π A_{LL} Sensitivity in 2006 Data at mid-rapidity

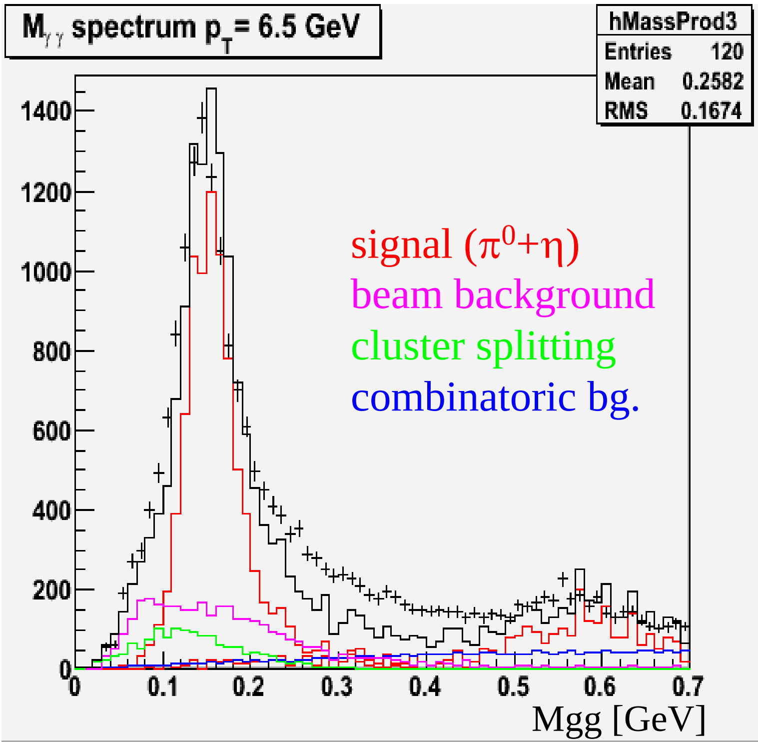
- *Dramatic increase in precision in Run 2006*





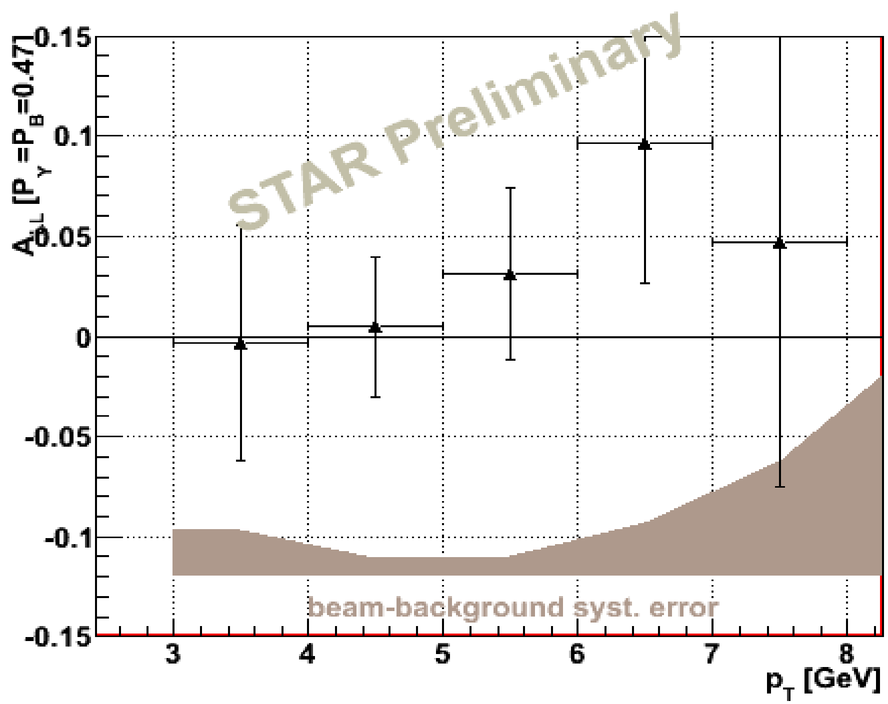


Inclusive π^o production in the EEMC



$M_{\gamma\gamma}$ invariant mass (π^o+η) with different background scenarios :

- *Beam background (dedicated runs with : HT2+no BBC coincidence)*
- *Cluster splitting*
- *Combinatory background*



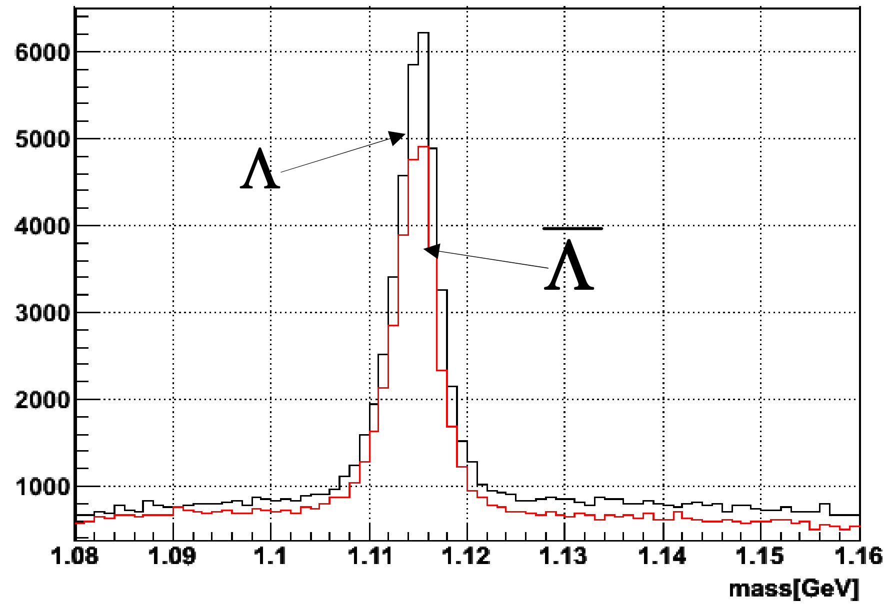
- *Systematic uncertainties dominated by beam background*

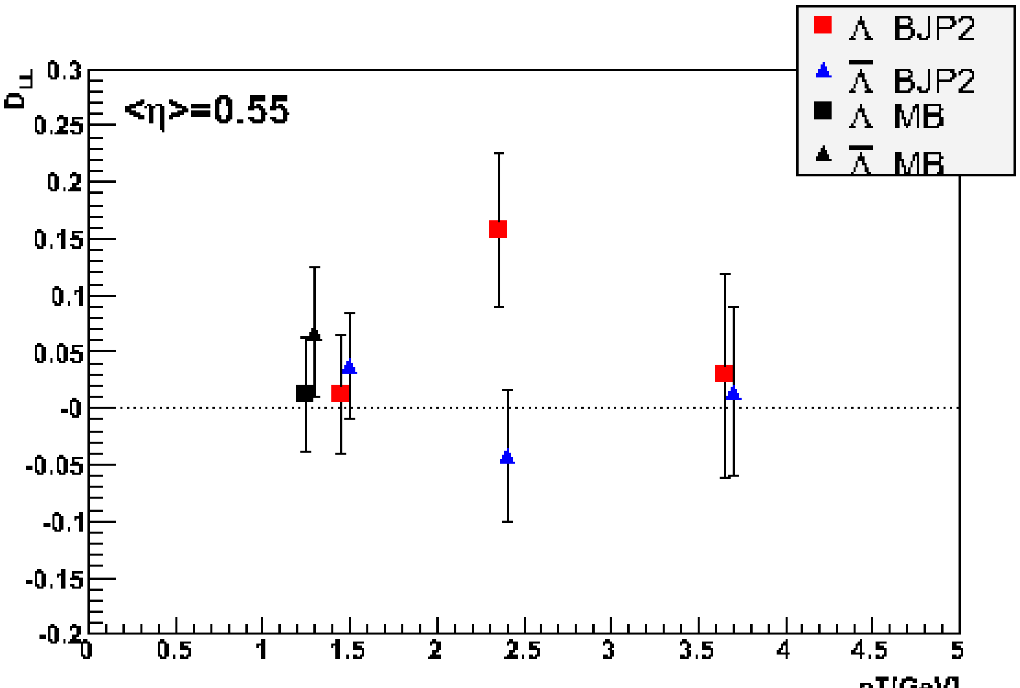
- *Several improvements in Run 6 such as reduction in beam background (due to added shielding in the tunnels) and increase in luminosity and polarization*

Inclusive Λ / $\bar{\Lambda}$ production

- *Measurement of the transfer of beam polarization to $\Lambda(\bar{\Lambda})$ hyperon which provides sensitivity to $\Delta s(\Delta \bar{s})$*
- *Λ is expected to be dominated by u quark, while $\bar{S}$ plays a dominant role for $\bar{\Lambda}$ production.*

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

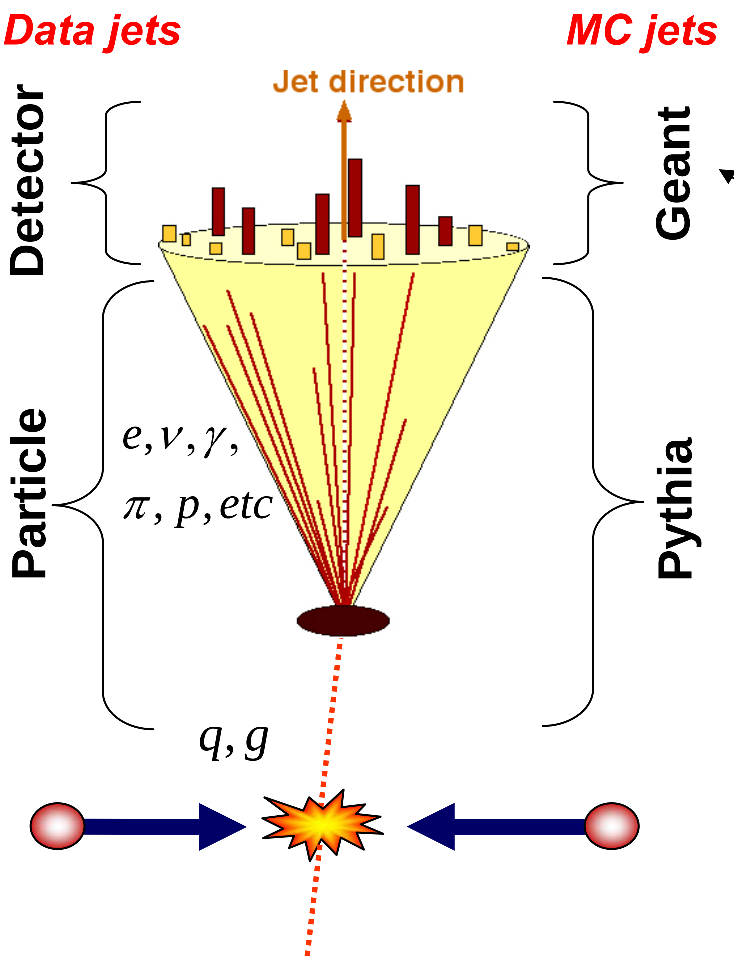




- *$\Lambda(\bar{\Lambda})$ is reconstructed by pairing TPC tracks + topological cuts at STAR ($|\eta|<1$)*
- *K^0_s (spin=0) sample used for systematic check*

Jet reconstruction in STAR

✓*STAR is capable of full jet reconstruction*

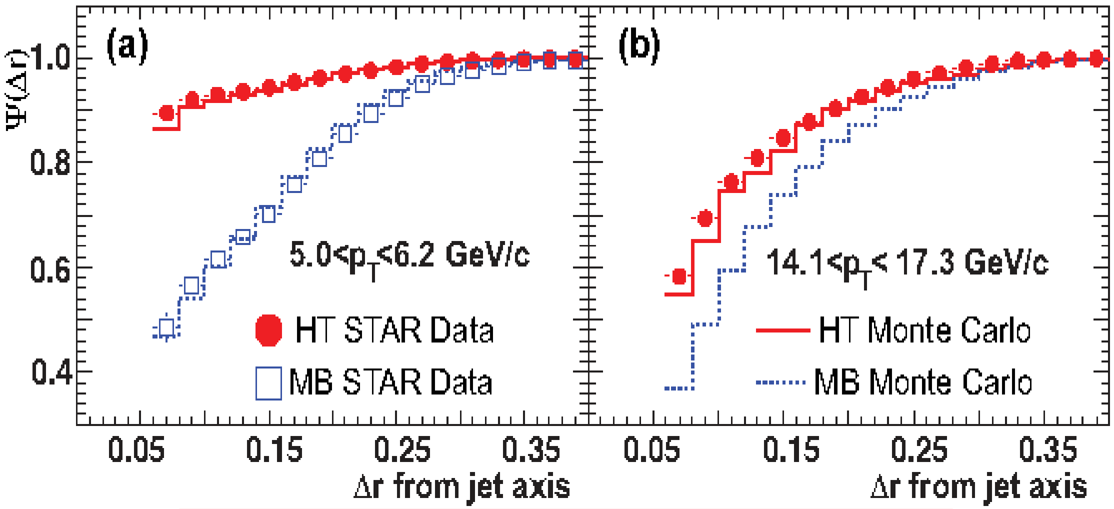


Midpoint cone algorithm

(*Adapted from Tevatron II* - ***hep-ex/0005012***)

- ***Seed energy = 0.5 GeV***
- ***Cone radius (R)=0.4 in η-ϕ***
- ***Splitting/merging fraction f=0.5***

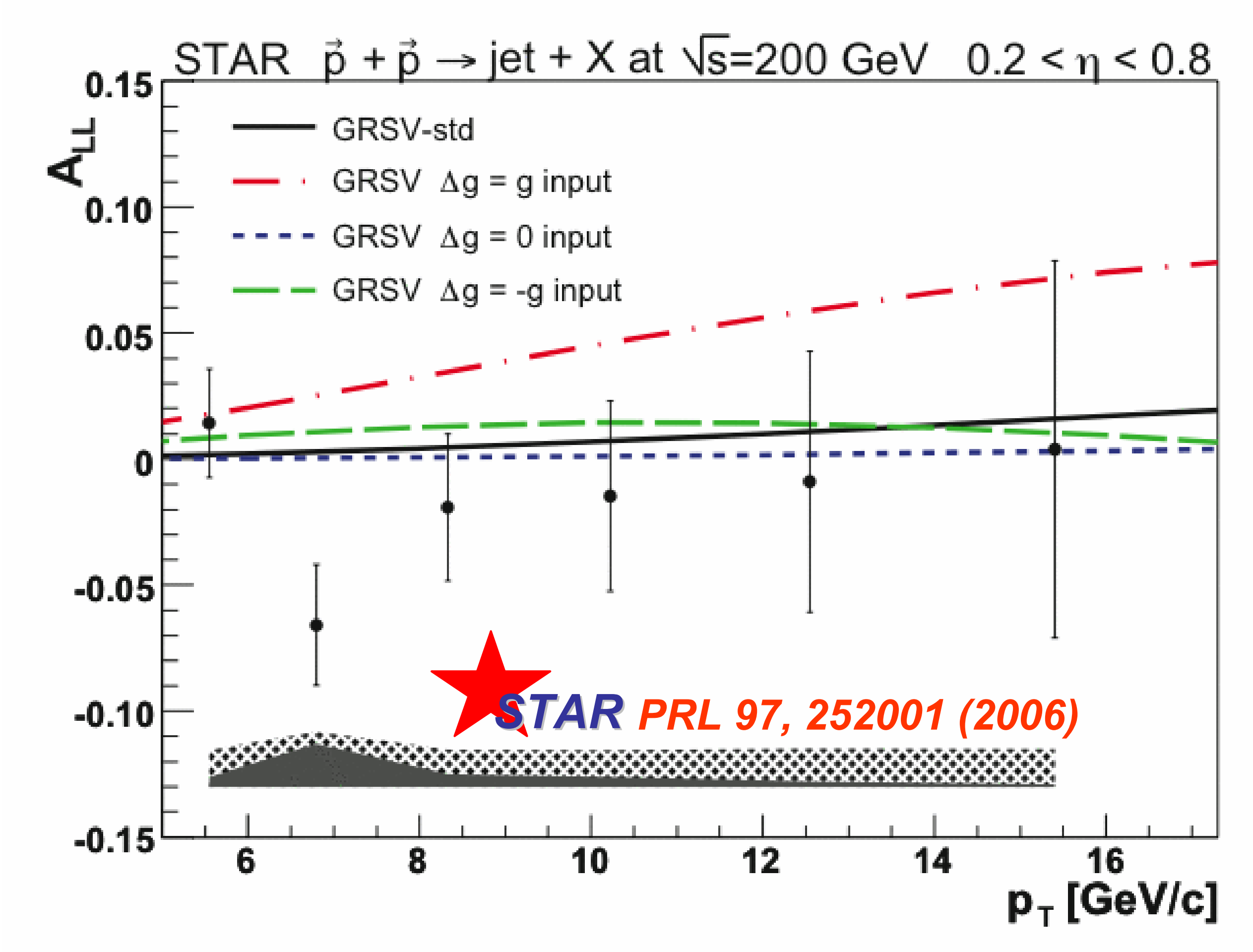
Use Pythia** (6.205 - CDF Tune A)**+GEANT** (Geisha) **to quantify detector response



❖ ***Data well described by MC***

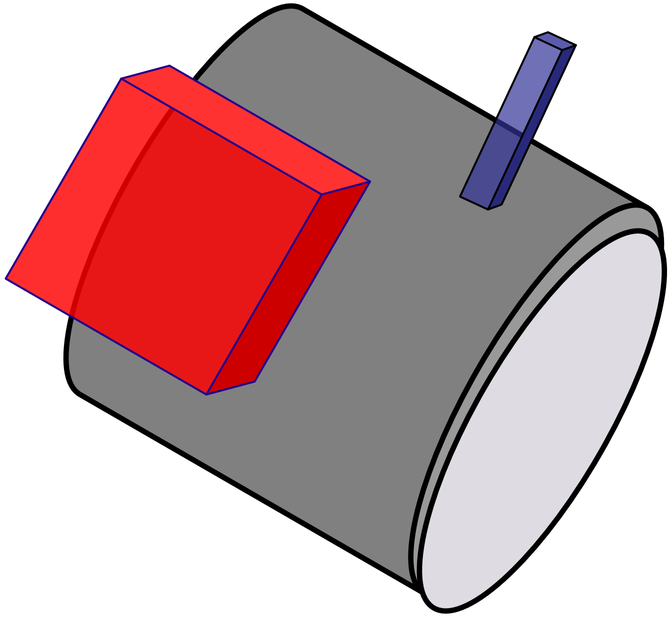
First inclusive jet results at RHIC

➢ **Inclusive A_{LL}^{jets} from 2003+2004 data**



❖ ***A_{LL}^{jet} disfavors GRSV-max (Δg=g) evaluation (χ^2/ndf≅3)***

STAR jet reconstruction -- 2005



Triggers

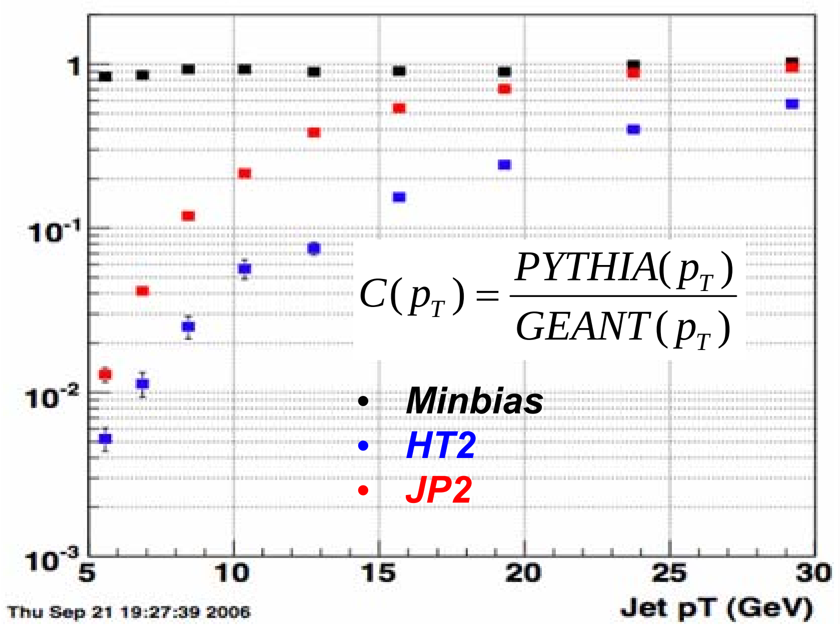
- *BBC coincidence required for all triggers*
- **High Tower** *(0.05x0.05) : H1/2 (E_T^{thr} > 2.8 / 3.8 GeV)*
  Requires hard neutral fragmentation
- **Jet Patch** *(1.0 x 1.0) : JP1/2 (E_T^{thr} > 4 / 5.5 GeV)*
  Allows for cluster of softer fragmentation

Cuts

- *BBC time bin (~a vertex cut) + recons. vertex found*
- *Software trigger: select jets responsible for event triggers*
- *Jet centroid: 0.2 < η < 0.8 (reduces detector edges)*
- *Jet neutral energy fraction: $E_{jet}(BEMC)/E_{jet}(total) < 0.8$*

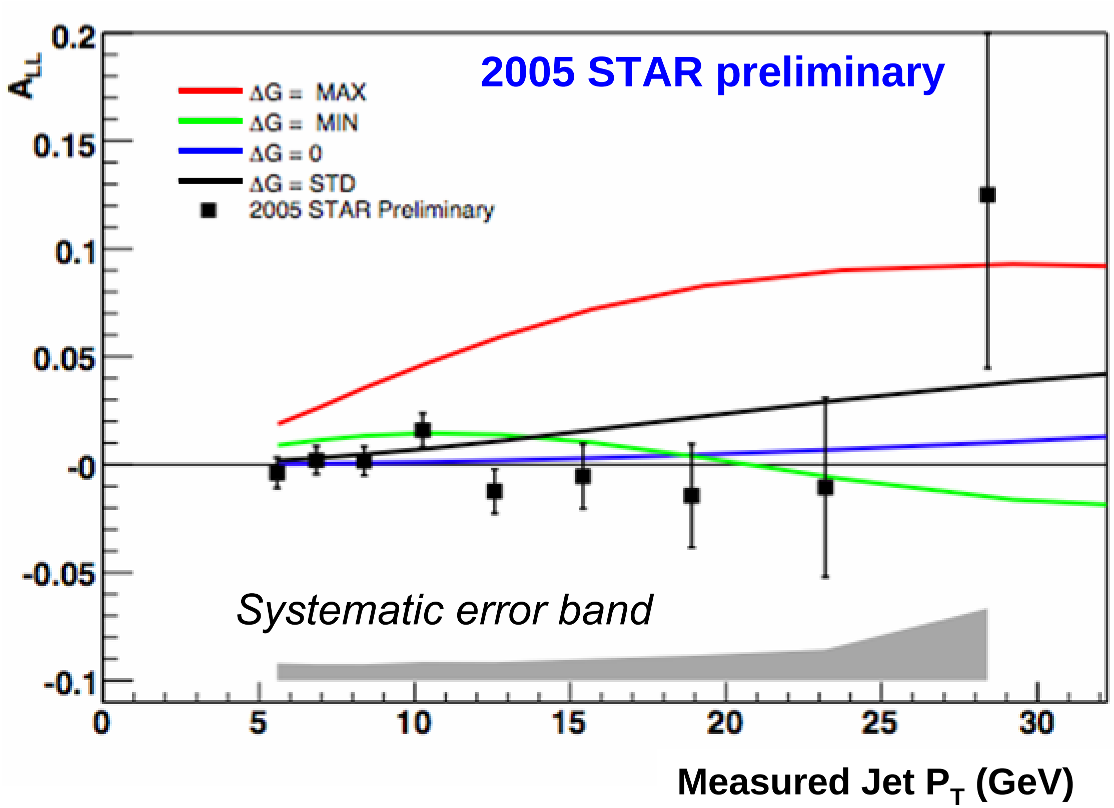
Statistics

- *1.6 pb^{-1} after run selection*
- *$\langle P_B P_Y \rangle \approx 0.25$*
- *1.97 M events (post-cuts)*
- *1.39 M in JP2*
- *~2% of jet events contain multiple jets*



2005 Inclusive jet ALL at mid-rapidity

Systematic	*(x 10 $^{-3}$)*
False Asymmetries	*<6.5 (pT dept*
Reconstruction + Trigger Bias	*2-12 (p_T dependent)*
Non-long Polarization	*3*
Relative Luminosity	*2*
Backgrounds	*<1*

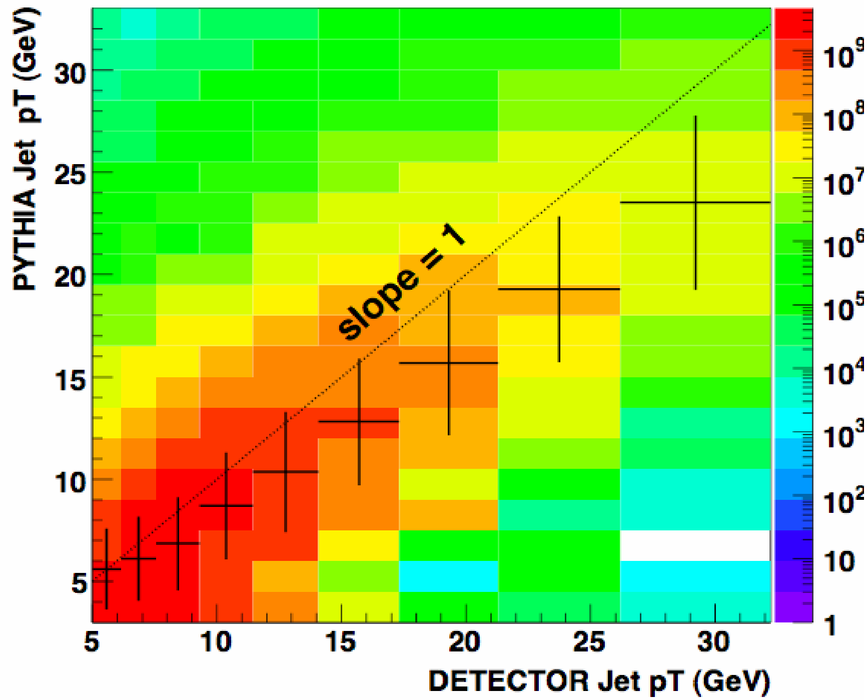


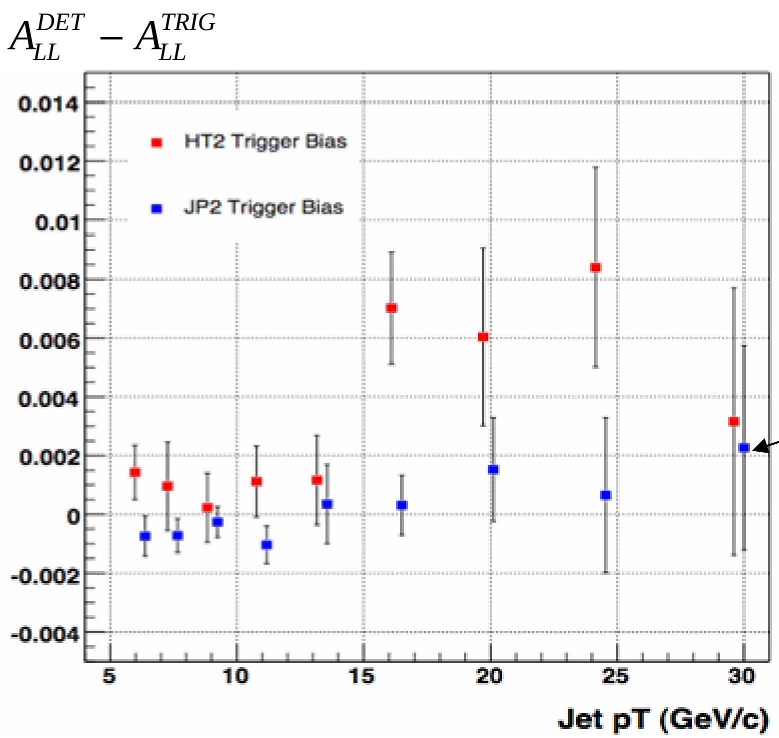
- ***Error bars are statistical***
- ***Systematic band includes 25% scale error from polarization***

Reconstruction + Trigger Bias *(dominant systematic)*

- *Jet reconstruction bias : Detector and jet reconstruction algorithm overestimate jet p_T.*
- *25% Jet Resolution and Steeply falling jet p_T distribution causes a 20% increase in p_T*

❖ *Difference between A_{LL}(detector) and A_{LL}(particle)*



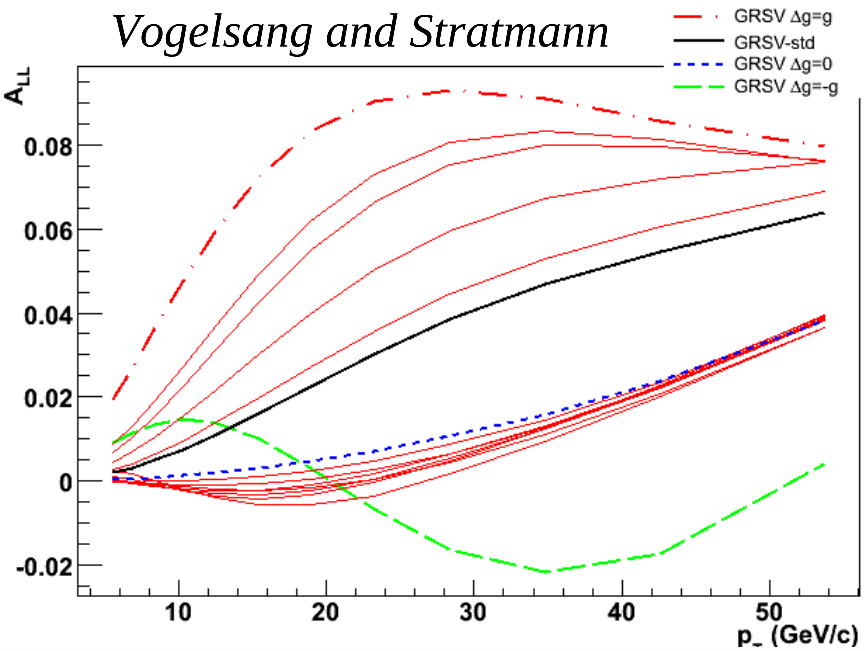


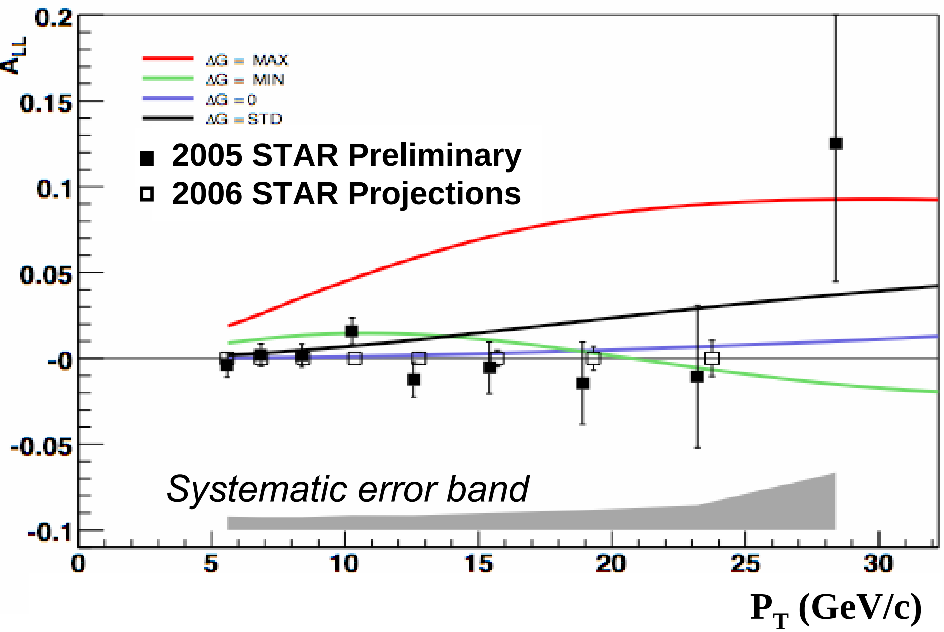
- *Trigger bias : Each trigger is sensitive to different sub-processes (qq/qg/gg).*
- *Small variations as a function of the trigger or underlying partonic process*

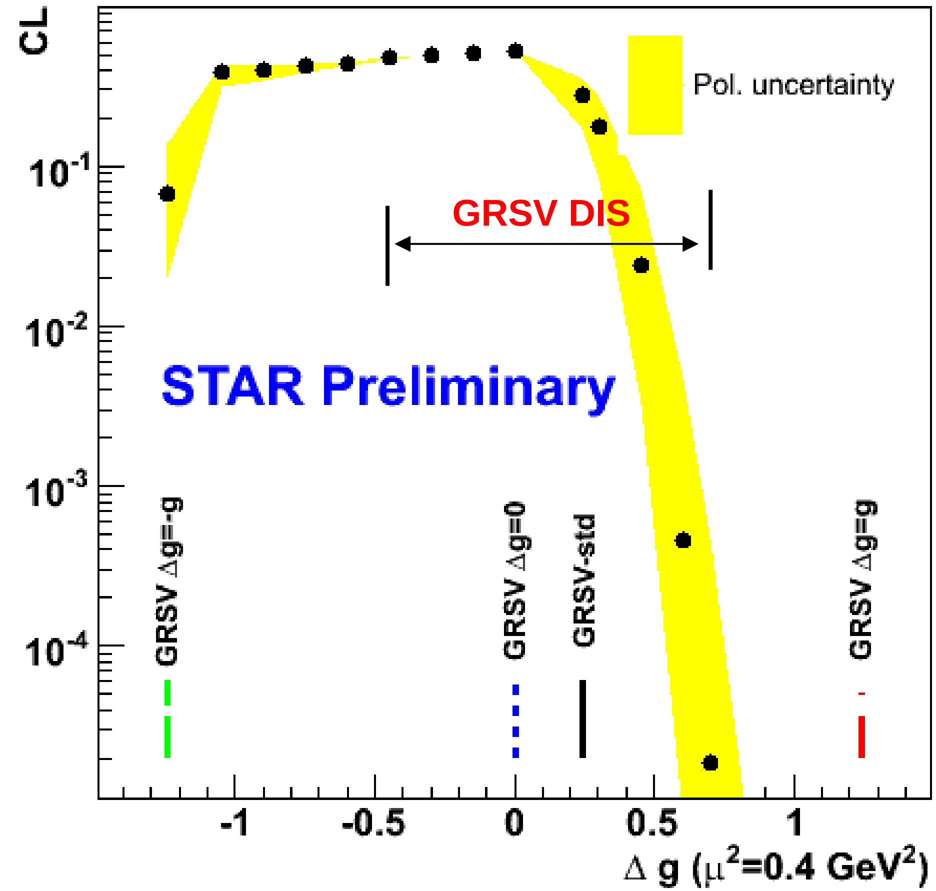
❖ *Difference between A_{LL}(trigger) and A_{LL}(detector)*

Total systematic : $\delta A_{LL} = A_{LL}^{PARTICLE} - A_{LL}^{TRIGGER}$

Constraint on ΔG



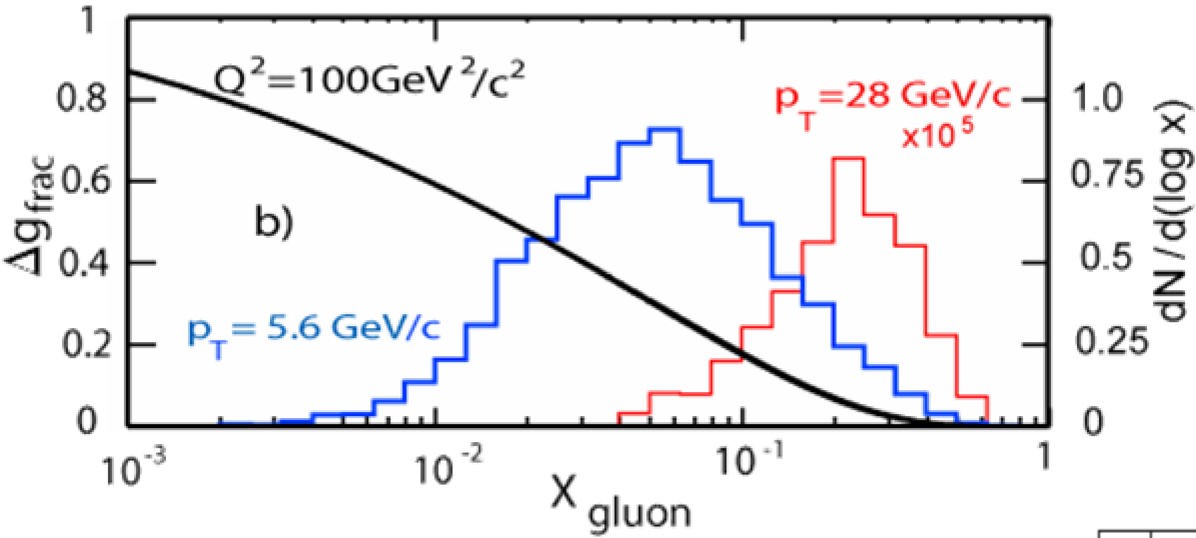




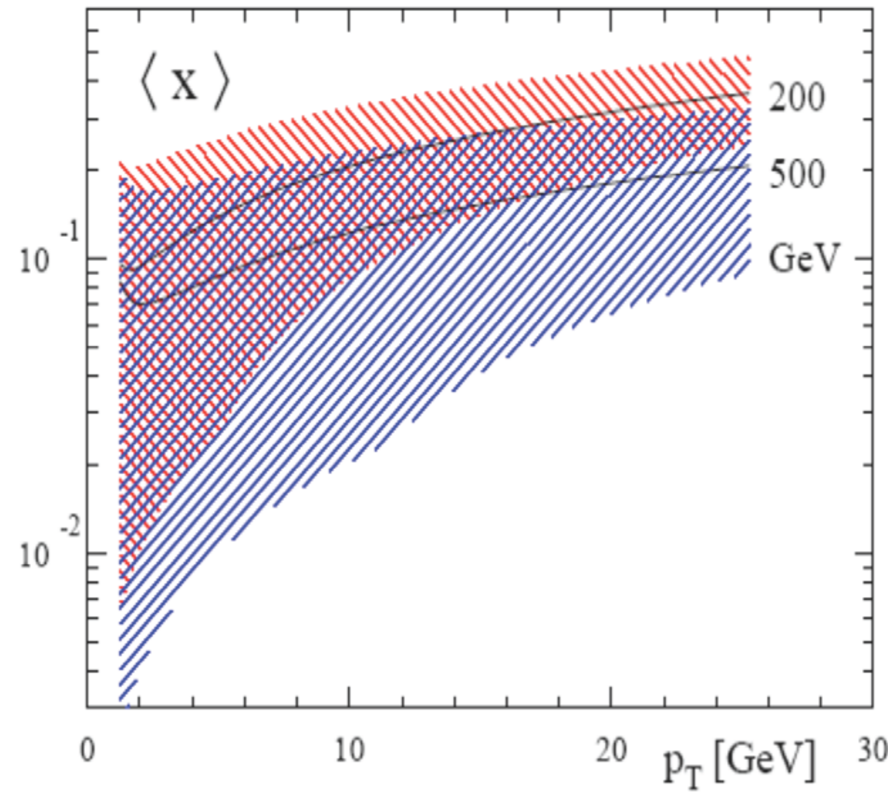
GRSV DIS best fit=0.24
1σ = -0.45 to 0.7
PRD 63, 094005 (2001)

- *Significant new constraints on ΔG when compared to predictions derived from one global fit to DIS data*

Fundamental Limit



❖ *The inclusive measurements give sensitivity to the integral of ΔG over a broad range*



➢ *Need coincidence measurements (di-jets and γ+Jets) to determine ΔG(x).*

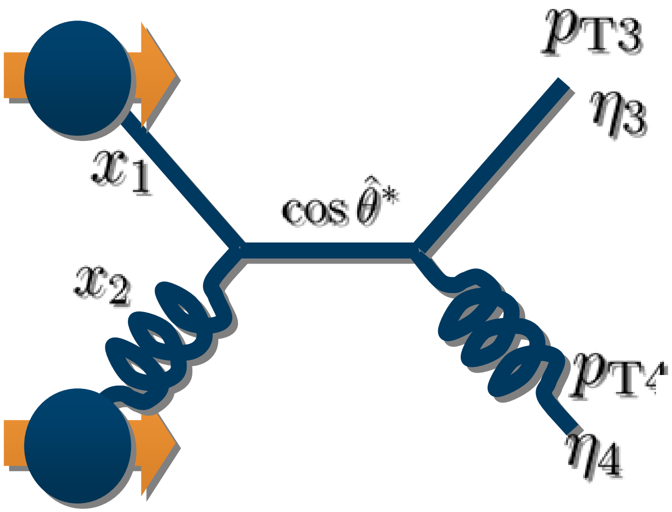
➢ *γ+Jets are easier to interpret but require larger statistics than have been sampled to date*

- ❑ *Run 6 data will be used for algorithm development*
- ❑ *Physics in Run8+*

➢ *Di-Jets are more plentiful and we started on them in Run6*

Di-Jets

- *Access to parton kinematics*



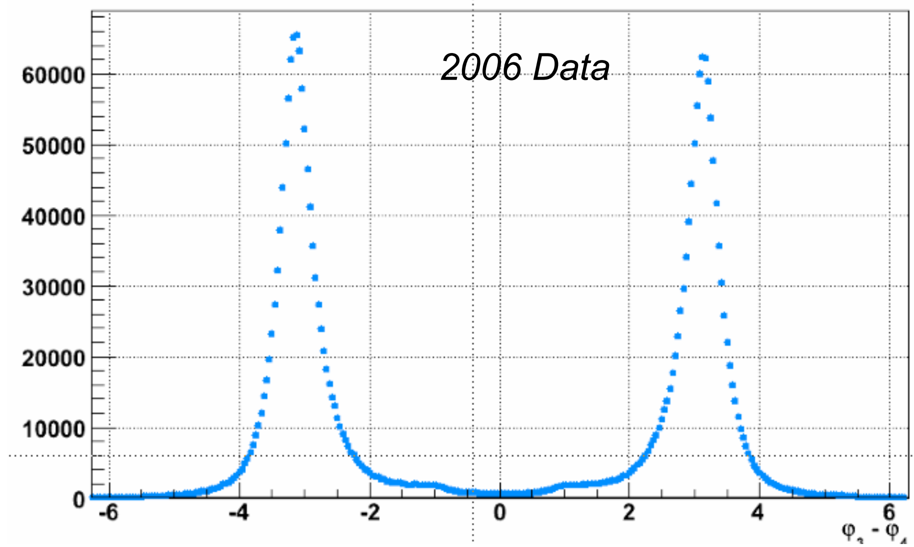
$$x_1 = \frac{1}{\sqrt{s}}(p_{T3}e^{\eta 3} + p_{T4}e^{\eta 4})$$

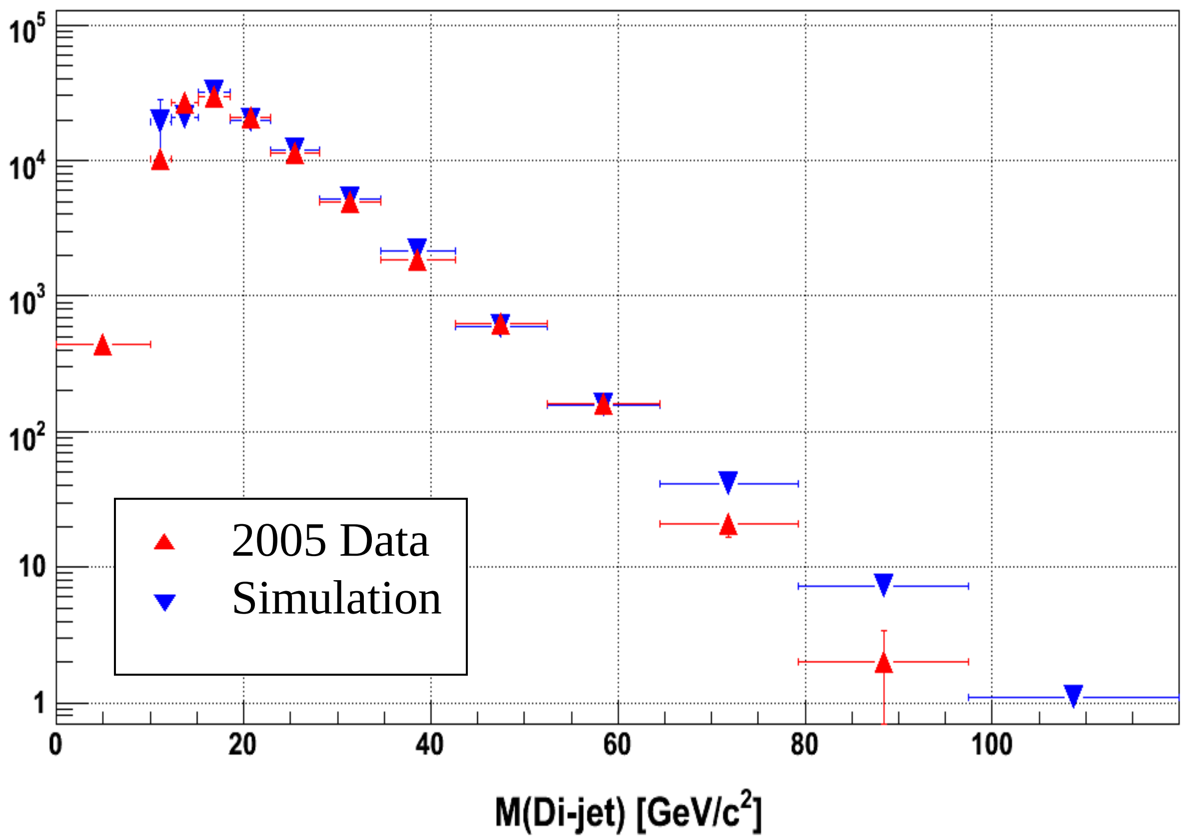
$$x_2 = \frac{1}{\sqrt{s}}(p_{T3}e^{-\eta 3} + p_{T4}e^{-\eta 4})$$

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

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

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

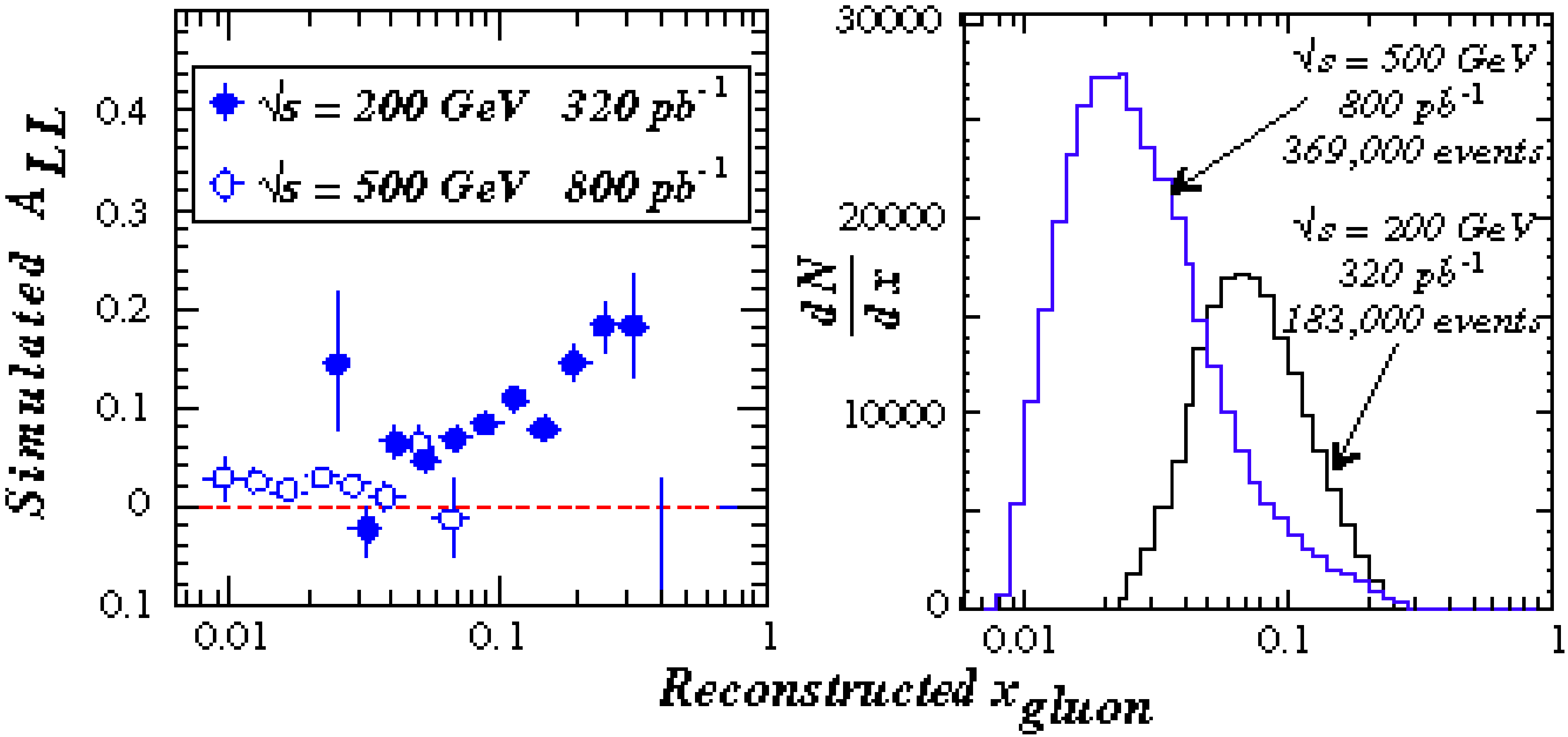




$\Delta G(x)$ determination via A_{LL} in

$$\vec{p} + \vec{p} \rightarrow \gamma + jet + X$$

See talk by Jason Webb this afternoon



- Run 2006 ⇒ first good γ and γ-jet samples to tune algorithms, test γ/π^0 vs. p_T
- *80 pb^{-1} at 200 GeV with 70% mean polarization during the next two years.*

We need to optimize triggers between di-jets and γ-Jets to maximize our sensitivity to $\Delta G(x)$.

Summary & Outlook

- ***NLO pQCD describes hadron cross sections at RHIC***
  - *Jets, π^o, $\pi^\pm$ at mid-rapidity*

- ***STAR longitudinal spin program***
  - *We have ruled out maximum gluon polarization (GRSV-MAX) scenario in 2003/2004 data*
  - *2005 data provide significant new constraints on ΔG when compared to predictions derived from one global fit to DIS data*
  - *STAR A_{LL} measurements: Important contribution to understanding of ΔG!*

- ***Outlook***
  - *In 2008-09, STAR longitudinal spin measurements will focus on A_{LL} for di-jet and γ+jet production – leading order sensitivity to $\Delta G(x)$*