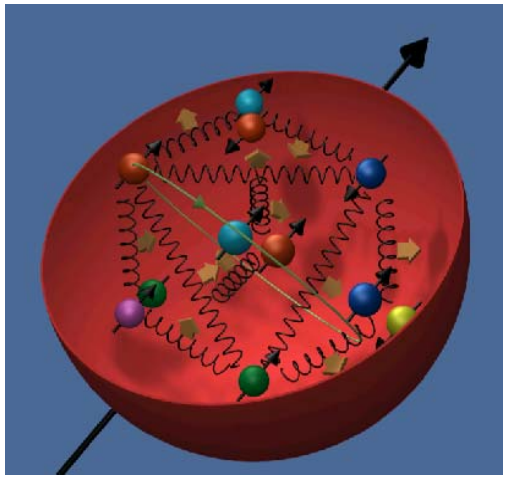
Longitudinal Double Spin Asymmetry for Inclusive Jet Production in Polarized p+p Collisions at 200 GeV

M. Sarsour

Texas A&M University

for the STAR Collaboration



Outline :

1. ***Introduction***
2. ***2005 results***
3. ***Preliminary 2006 results***
4. ***Summary***

Proton Spin Structure

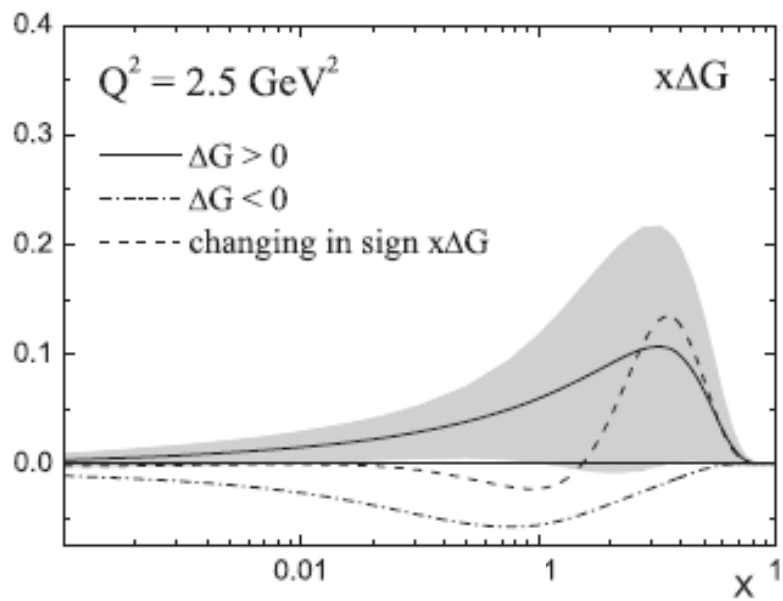
Spin Crisis : Origin of the proton spin?

Polarized DIS ~ 0.3

Poorly Constrained

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

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



(Leader et al, PRD 75, 074027 (2007))

Three recent fits of equal quality:

- $\Delta G = 0.13 \pm 0.16$
- $\Delta G \sim 0.006$
- $\Delta G = -0.20 \pm 0.41$

all at $Q^2 = 1$ GeV^2

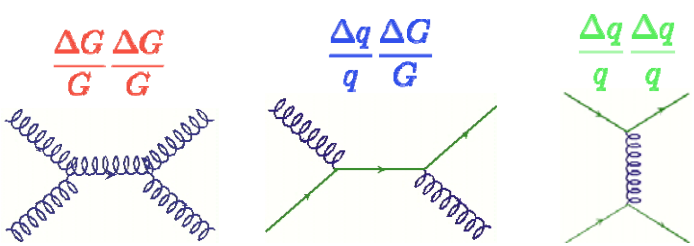
Proton Spin Structure at RHIC

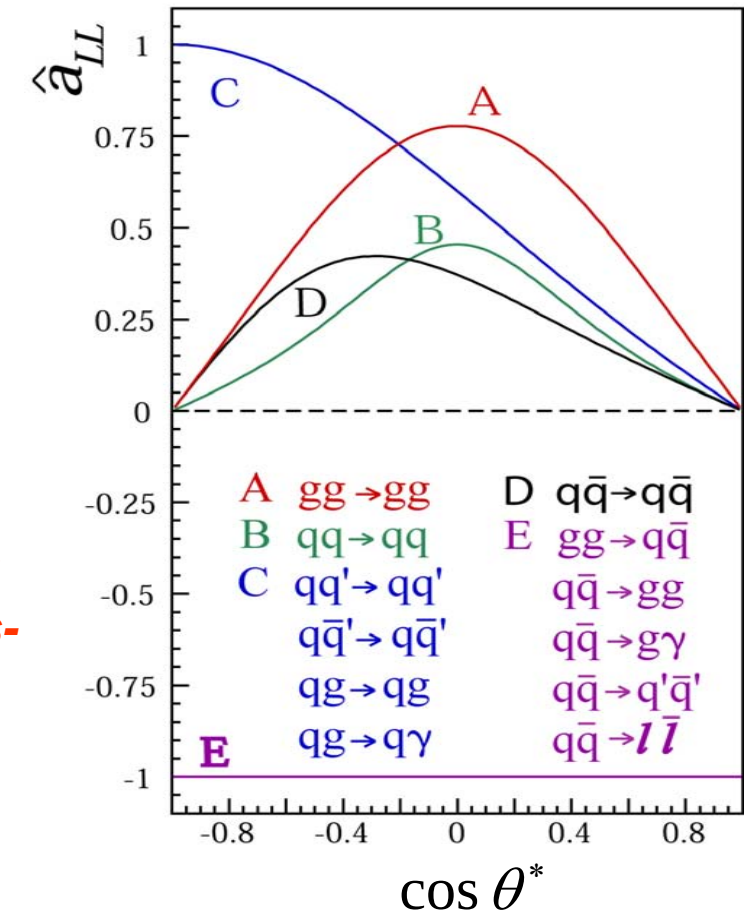
- ***Polarized pp collisions at RHIC ⇒ New QCD lab: strongly interacting probes***
- ***High √s and p_T make NLO pQCD analysis reliable***
- ***STAR longitudinal spin program ⇒ Gluon polarization distribution***

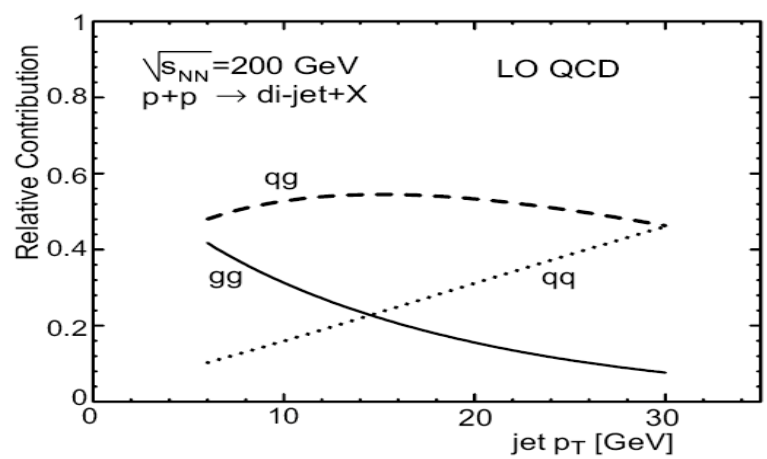
❖ ***Inclusive jet asymmetries are an excellent tool to study gluon polarization: Large cross-sections and relative independence from fragmentation functions***

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

Δf: polarized parton distribution functions

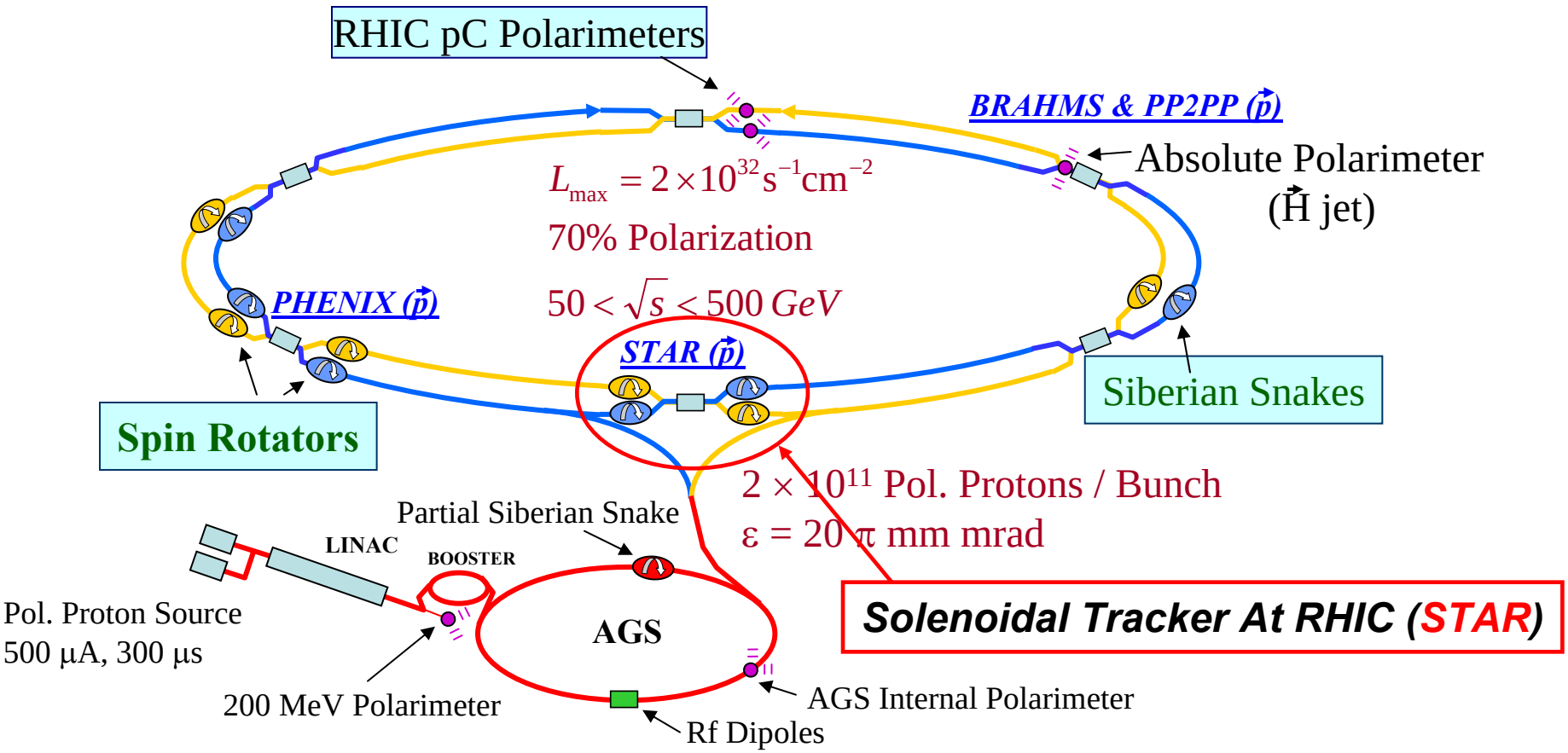






Relativistic Heavy Ion Collider

…worlds 1st $\vec{p}\,\vec{p}$ Collider



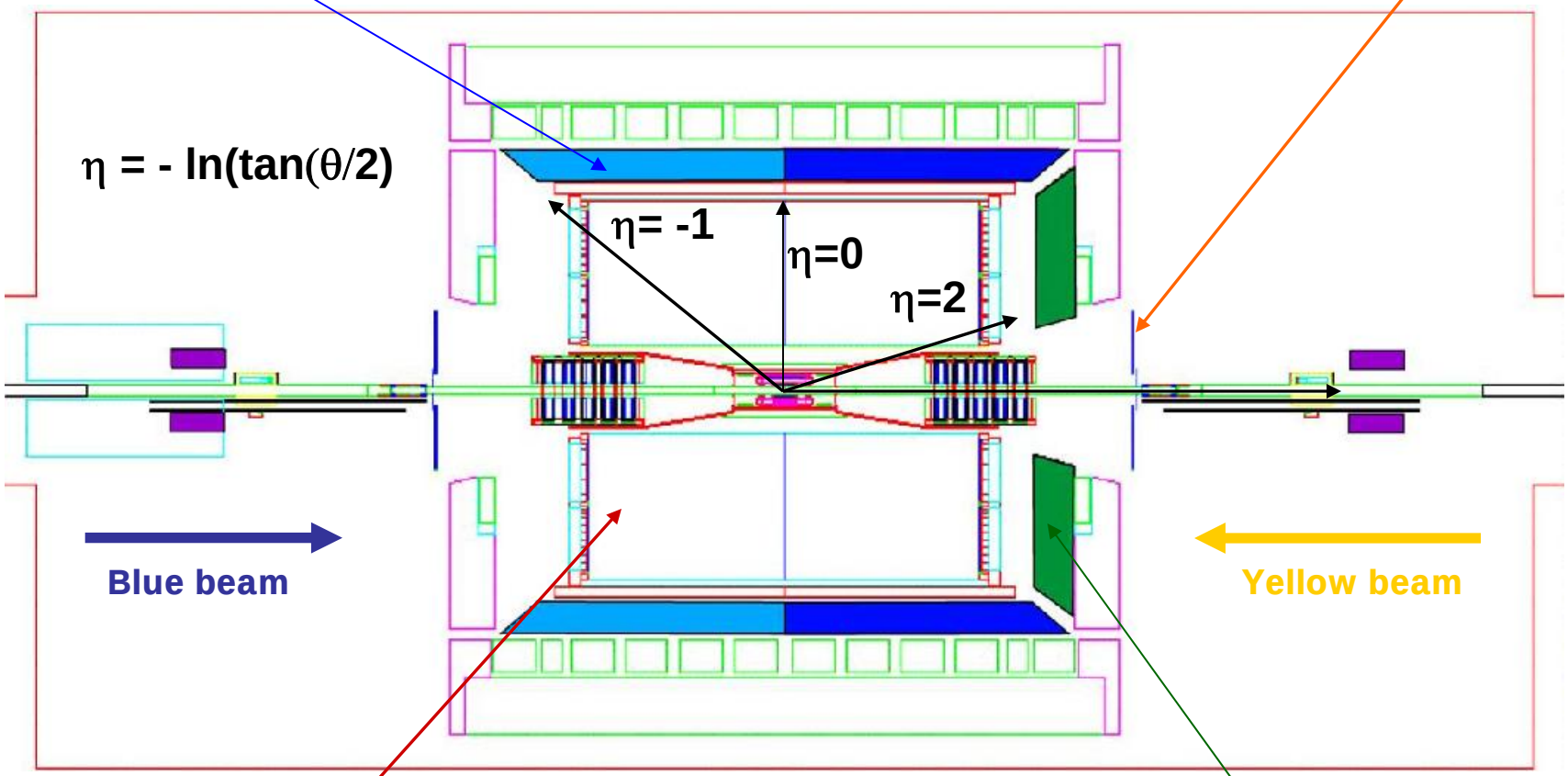
RHIC accelerates heavy ions to 100 GeV/A
and polarized protons to 250 GeV

STAR Detector Layout

Special interest for spin

▪*Barrel EM Calorimeter,*
$-1<\eta<1$
Triggering & Calorimetry

▪*Beam-Beam Counters,*
$2<|\eta|<5$
Triggering, Luminosity, local Polarimetry



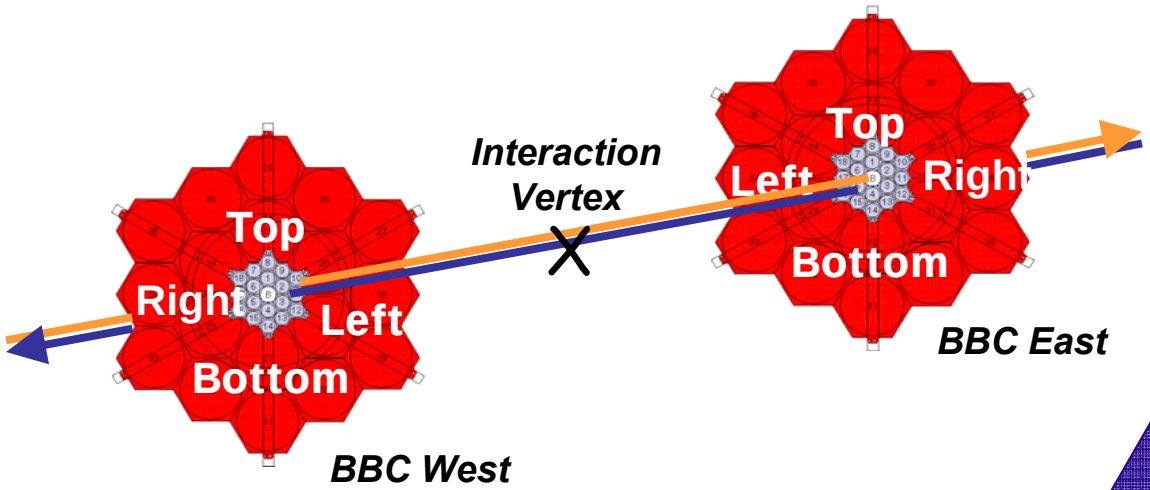
Time Projection Chamber,
$|\eta|<1.4$
Tracking

▪*Endcap EM Calorimeter*
$1.08<\eta<2$
Triggering & Calorimetry

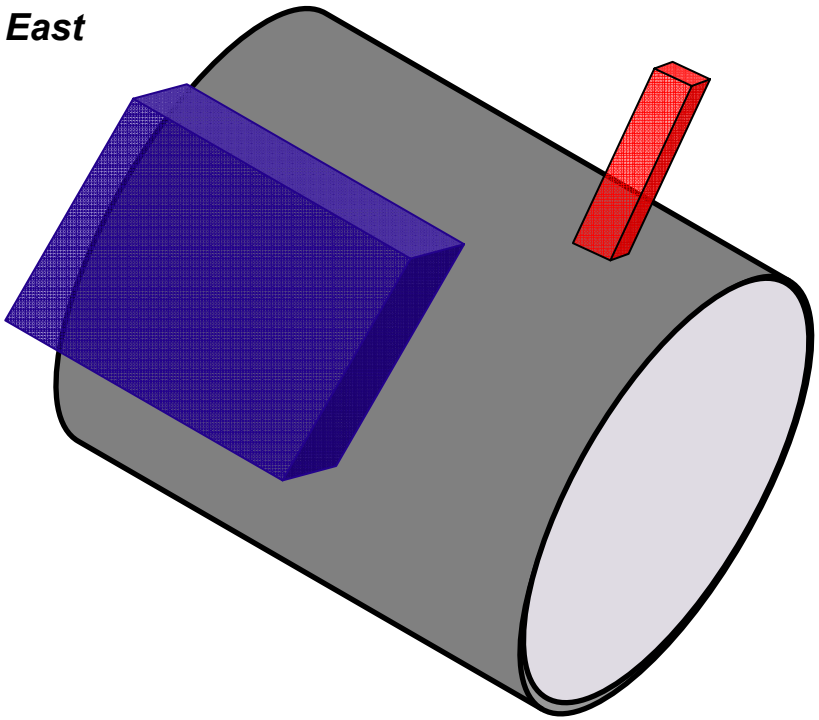
STAR's Trigger

Natural mix	Elastic, single+double diffractive, hard scattering $(qq + qg + gg + \bar{q}q)$

- **To select hard scattering :**



Beam Beam Counters (BBC) coincidence of both sides of the interaction



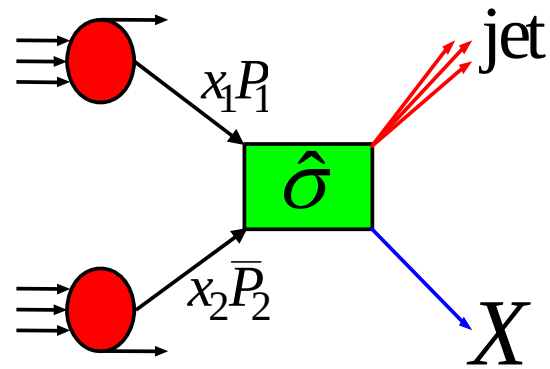
High Tower (HT) $(\Delta\eta = \Delta\phi = 0.05)$

Jet Patch (JP) $(\Delta\eta = \Delta\phi = 1)$

STAR Analysis Plan

❑ Cross-sections

- *Establish validity of Next to Leading Order perturbative QCD for RHIC kinematics.*
- *Test understanding of detector, measured observable and quality of simulations*



❑ Asymmetries

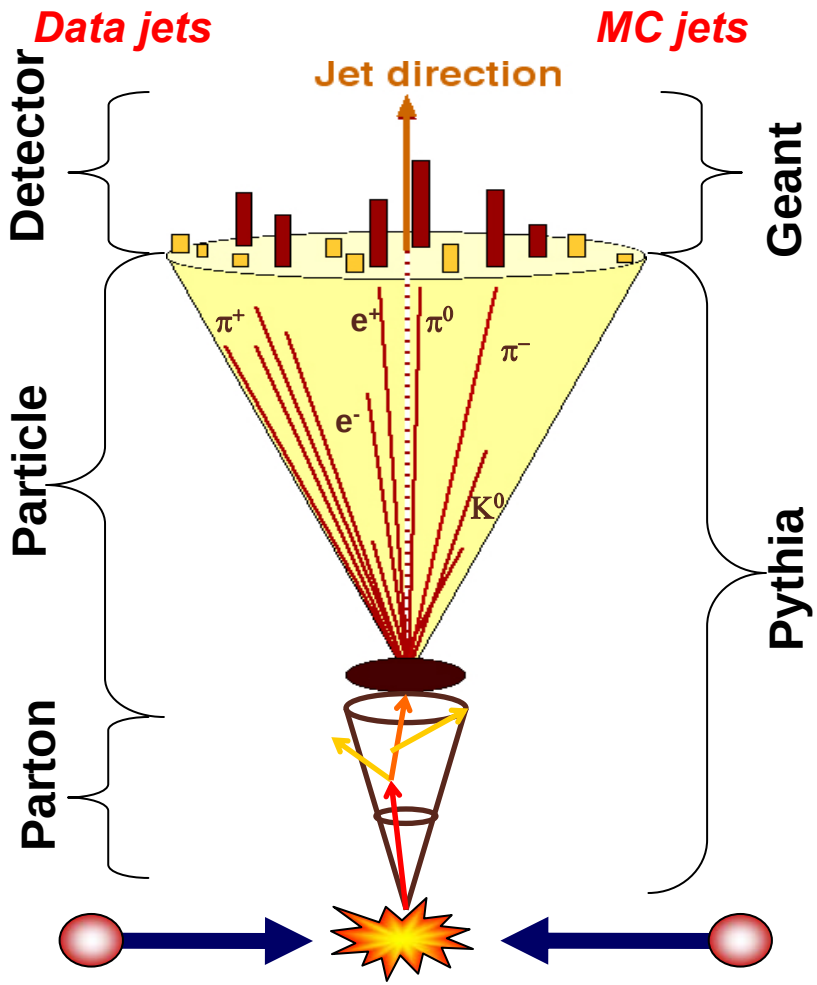
- *Provide access to polarized parton distributions*

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

N: *Spin Yields*
P: Beam Polarization
R: Relative Luminosity

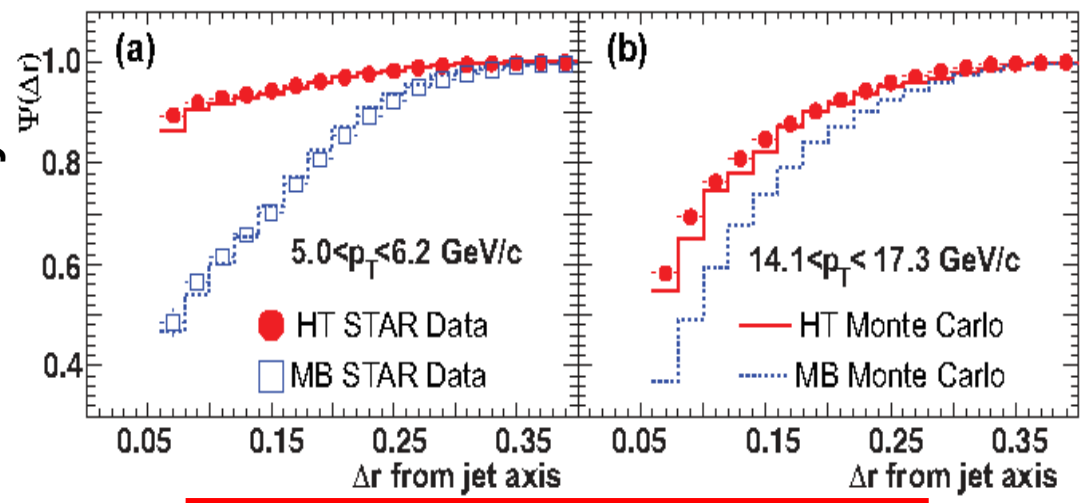
STAR's Jet Algorithm

✓*STAR is capable of full jet reconstruction*



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

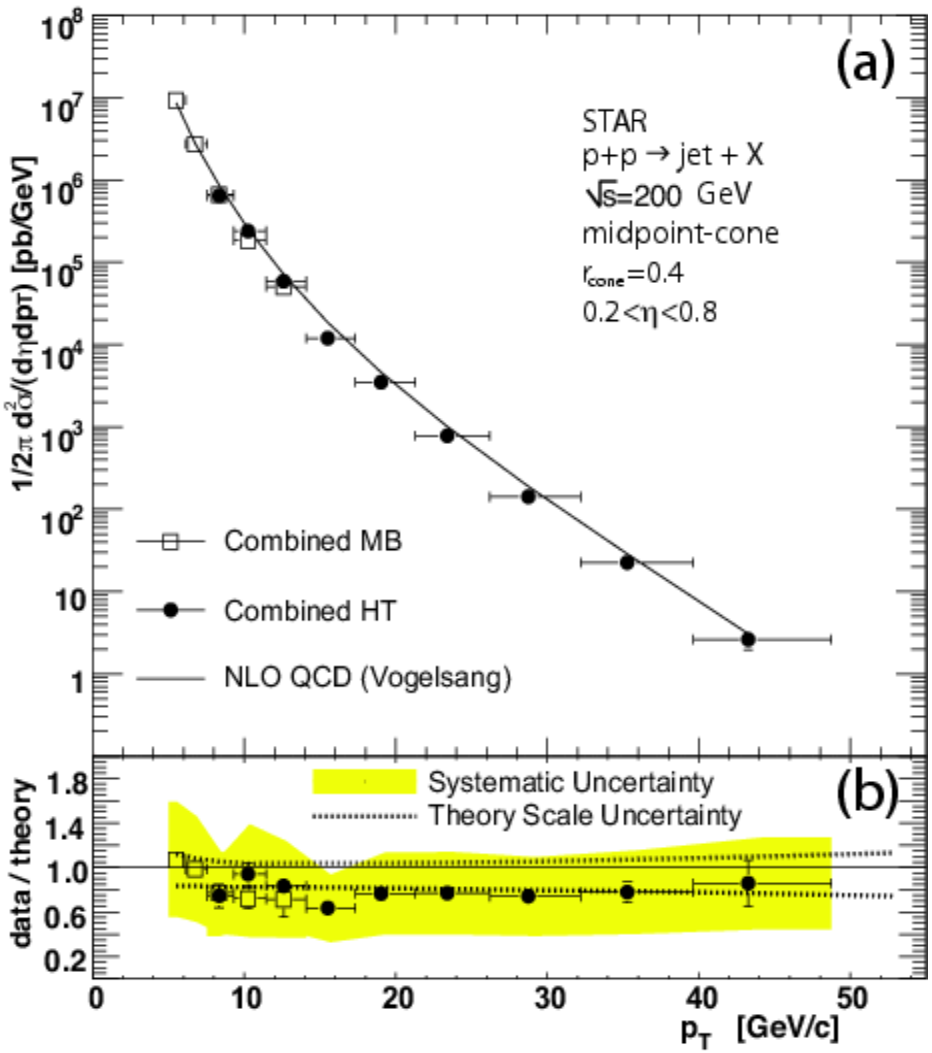
- ***Seed energy = 0.5 GeV , Splitting/merging fraction f=0.5***
- ***Cone radius in η-ϕ***
  - ***R=0.4 & 0.2<η<0.8 (2005)***
  - ***R=0.7 & -0.7<η<0.9 (2006)***



❖ ***Data well described by MC***

Inclusive jet cross section & A_{LL} (2003+2004)

STAR *PRL **97**, 252001 (2006)*



Corrected Jet Yield = **DATA JETS** X $\frac{\textbf{PYTHIA JETS}}{\textbf{GEANT JETS}}$

- *Correction factor incorporates detector resolution, and energy losses due to fiducial cuts and undetected neutral energy*

- *50% systematic shown in yellow band comes from uncertainty in jet energy scale.*

- *Good agreement with NLO pQCD over many orders of magnitude*

  ⇒ ***pQCD works!***

2005 Inclusive A_{LL}^{jets} Analysis

- *2 pb-1 after run selection*
- *$\langle P_B P_Y \rangle \approx 0.25$*
- *2.38 M events (post-cuts), 50% from newly commissioned **Jet Patch** (1x1 rad) trigger*
- *Jet cone radius = 0.4*
- *0.1 < Neutral Energy Fraction < 0.8*
- *0.2 < Jet Detector η < 0.8*

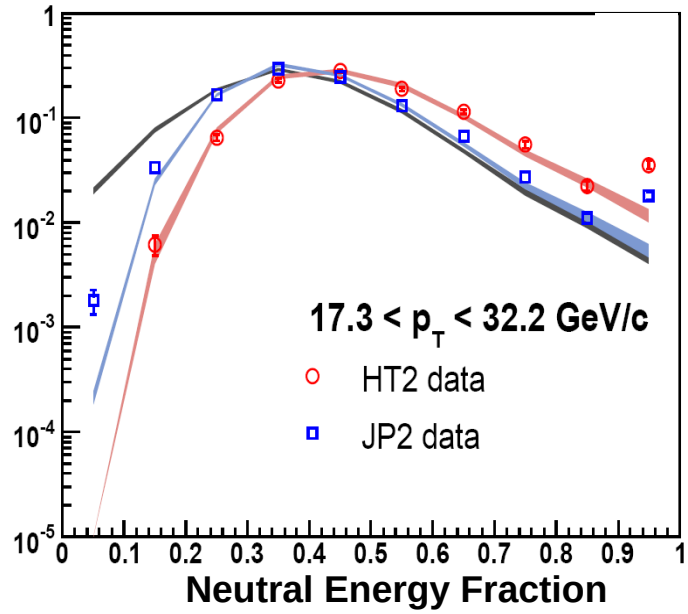
A_{LL} systematics	(x 10^{-3})
Reconstruction + Trigger Bias	2-5 (p_T dep)
Non-longitudinal Polarization	0.1-0.8 (p_T dep)
Relative Luminosity	0.94
Backgrounds	0.70

p_T systematic	[-5.4%,+6.7%]

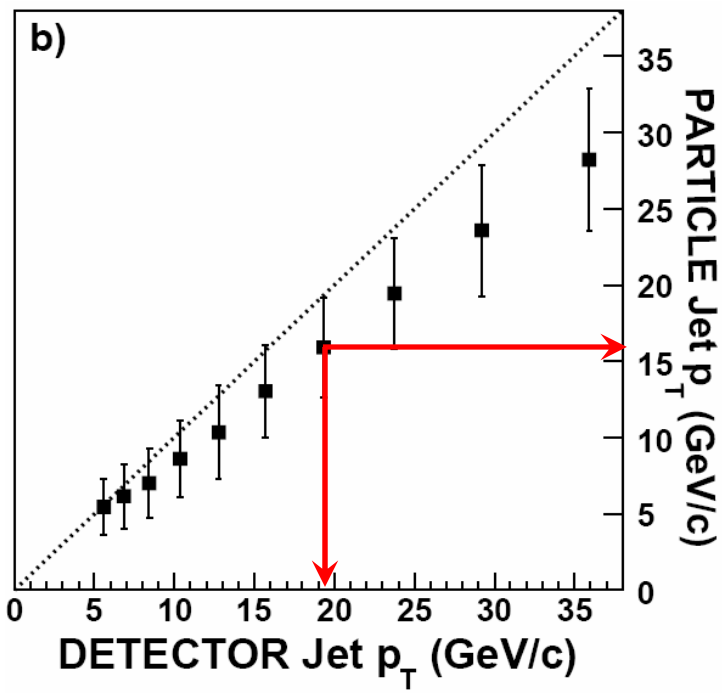
❑ *Dominated by **Jet Reconstruction** & **Trigger Bias** :*

➢ *Jet reconstruction bias: ~25% jet resolution and steeply falling jet p_T distribution causes measured p_T to average 20% larger than true p_T*

➢ *Trigger bias : each trigger samples the sub-processes (qq/qg/gg) differently.*



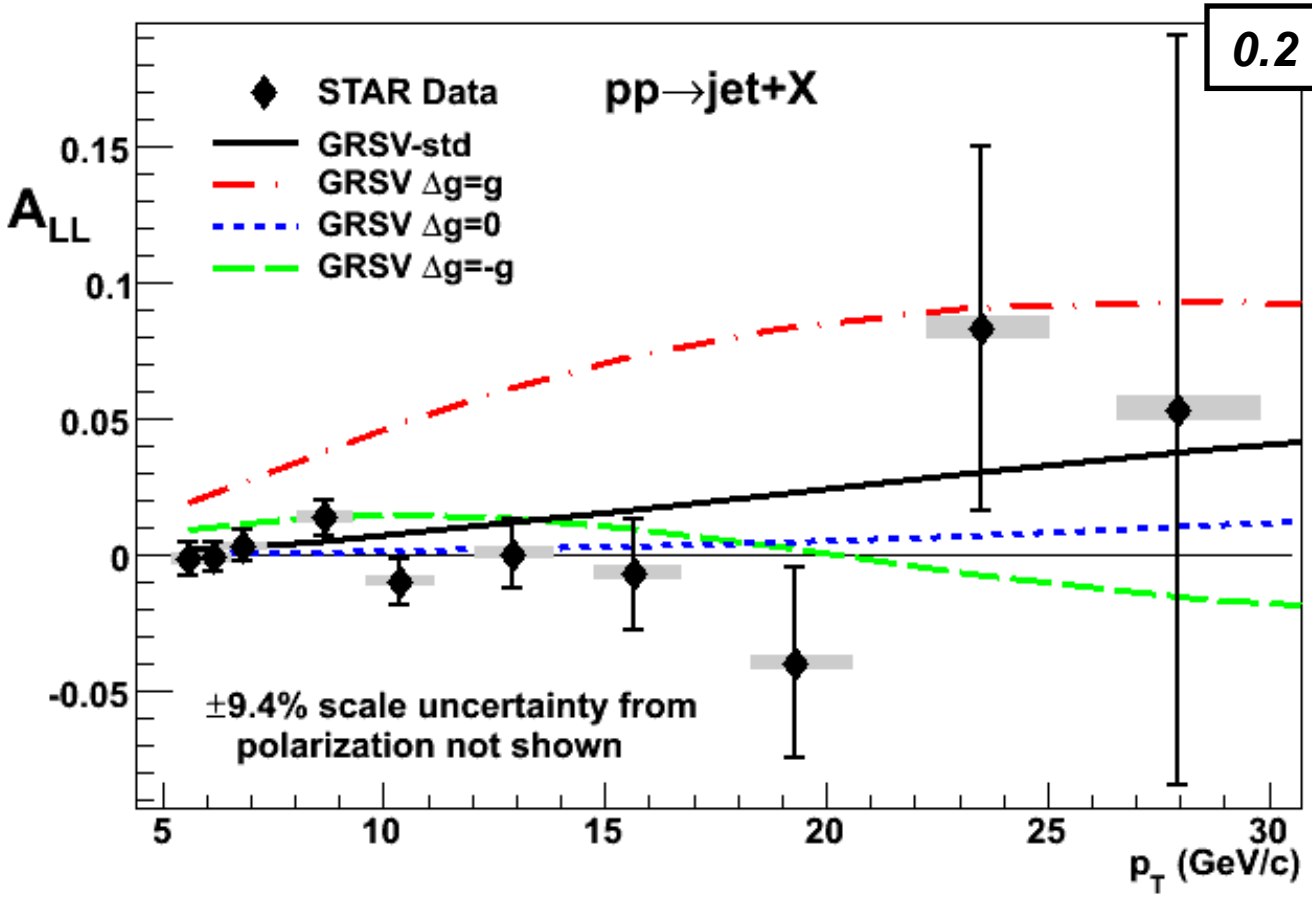
❖ ***Data well described by MC***



2005 Inclusive A_{LL}^{jets} Results

STAR PRL **100**, 232003 (2008)

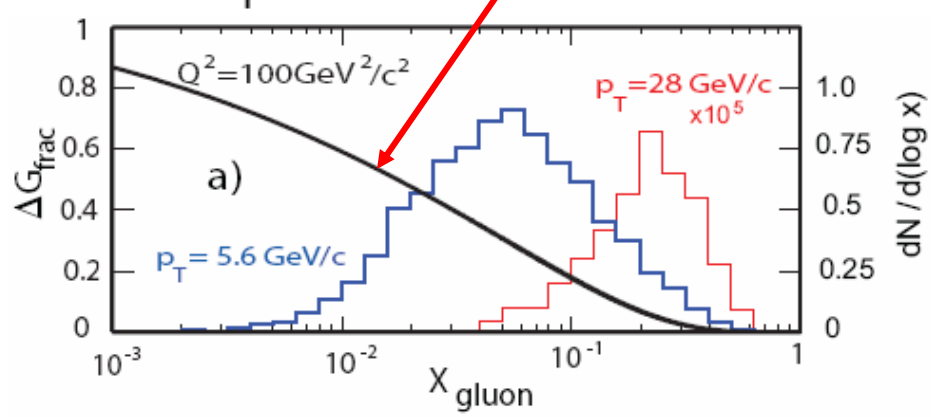
$0.2 < \eta < 0.8$



❖ Data are compared to predictions within the GRSV framework with several input values of ΔG.

B. Jager et.al, Phys.Rev.D70, 034010

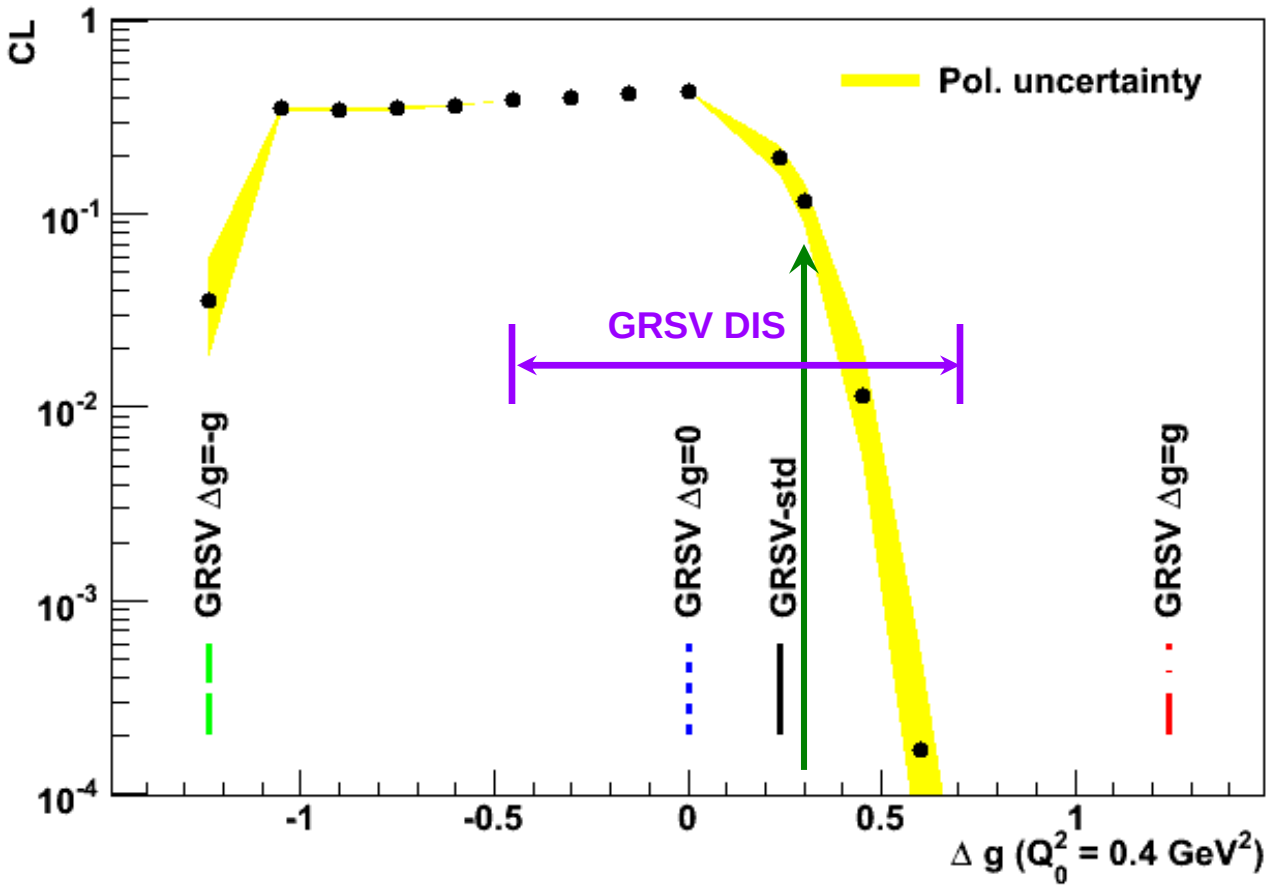
GRSV-std



❖ ***The inclusive measurements give sensitivity to gluon polarization over a broad momentum range***

Confidence Levels

STAR PRL **100**, 232003 (2008)



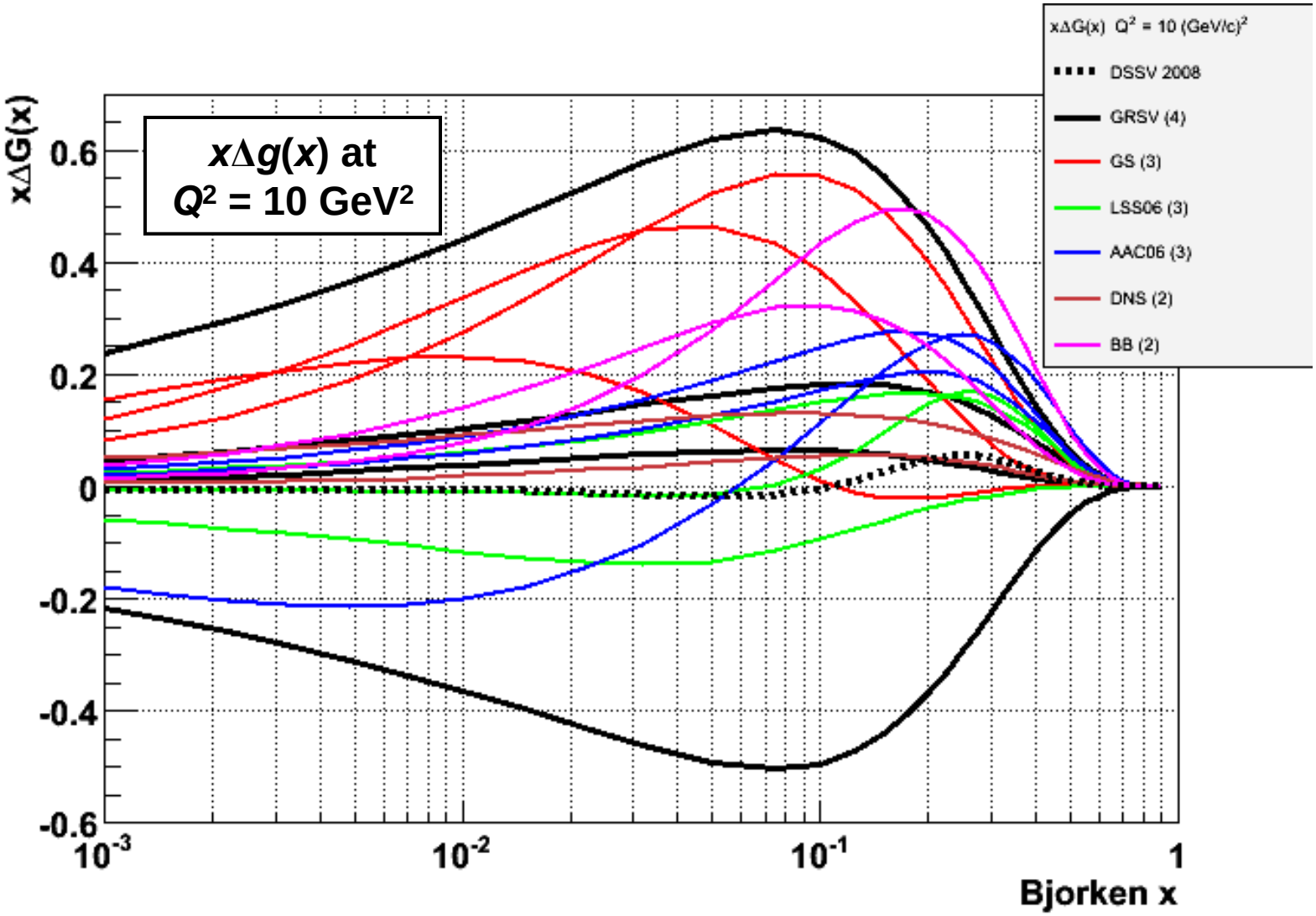
**Theoretical uncertainties not included*

1. $\Delta G > 0.45$ 95% [2σ]
2. $\Delta G > 0.3$ 66% [1σ]
3. DIS best fit = 0.24 with ~1σ range from -0.45 to 0.7 at input scale

PRD 63, 094005 (2001)

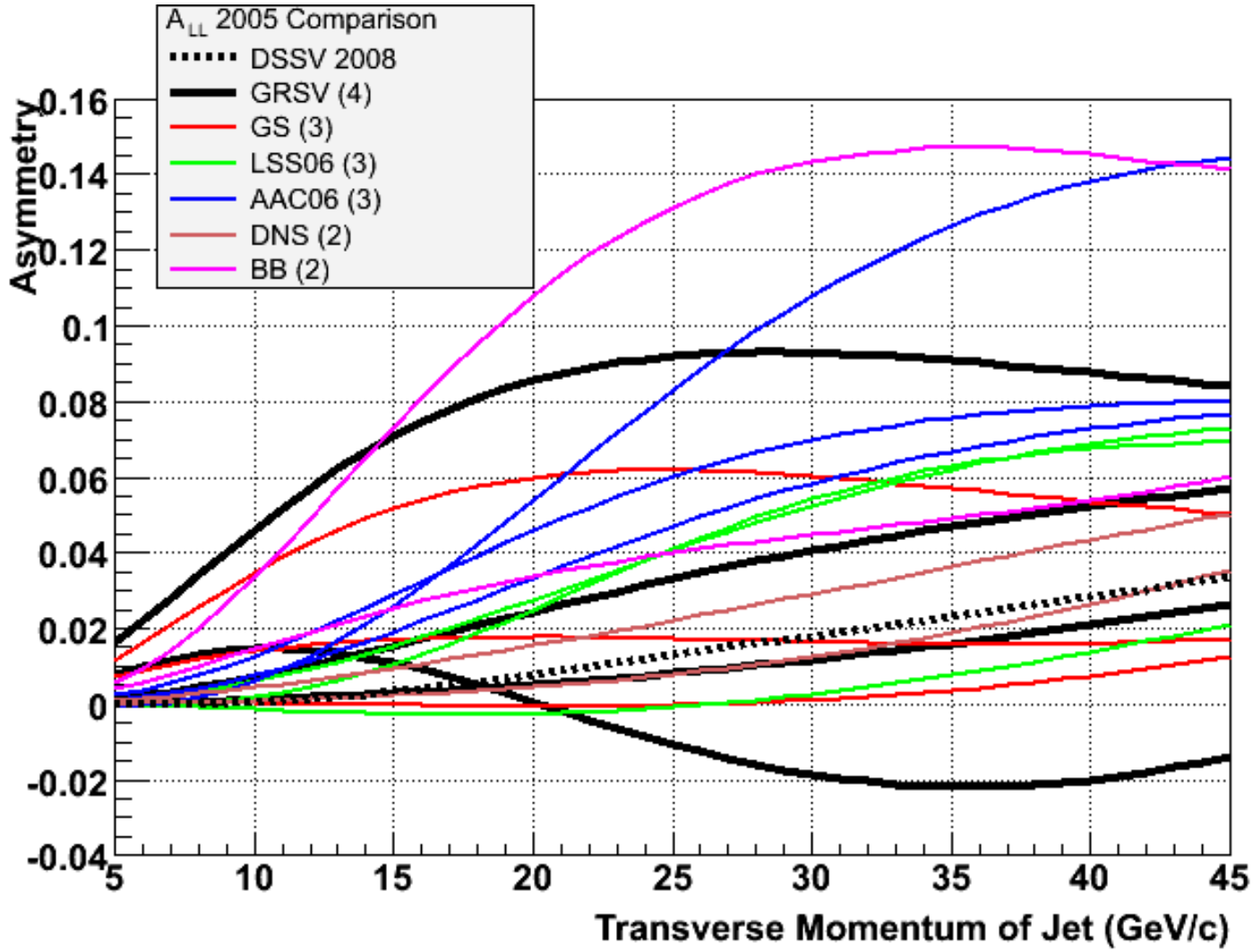
❖ ***Significant new constraints on ΔG when compared to predictions derived from one global fit to DIS data***

Other global analyses



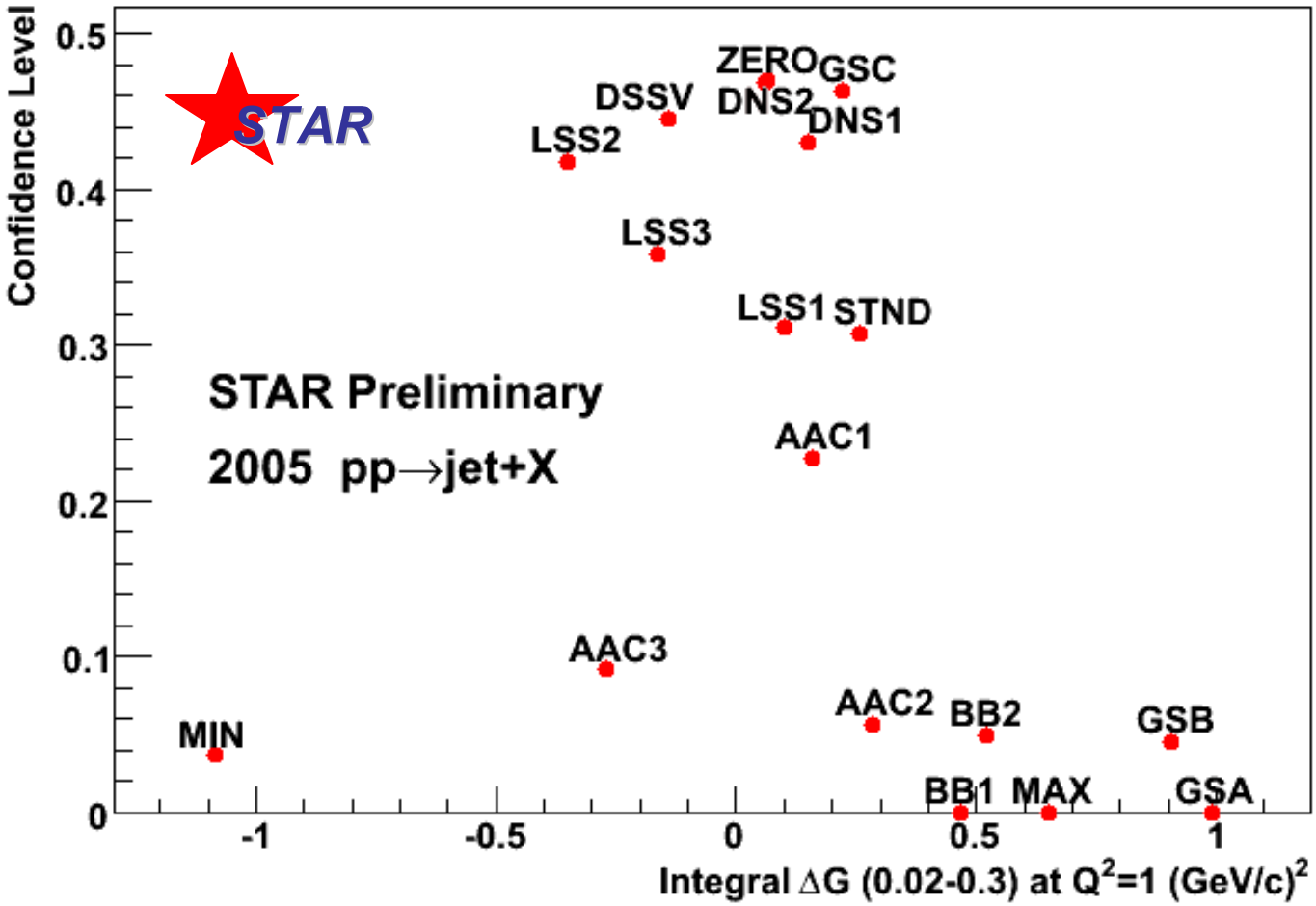
- ***There are many other global analyses of the polarized DIS data***

Additional A_{LL} predictions for 2005



- ***Many predictions for A_{LL} vs. p_T***
- ***Is the sensitivity unique to GRSV?***

Comparison to other global analyses



- ***The STAR data exclude a broad range of models that have ΔG larger than that in GRSV-std***
- ***The counterexample is GS-C, which is negative at large x, has a node near x ~ 0.1, and has a large first moment at small x***

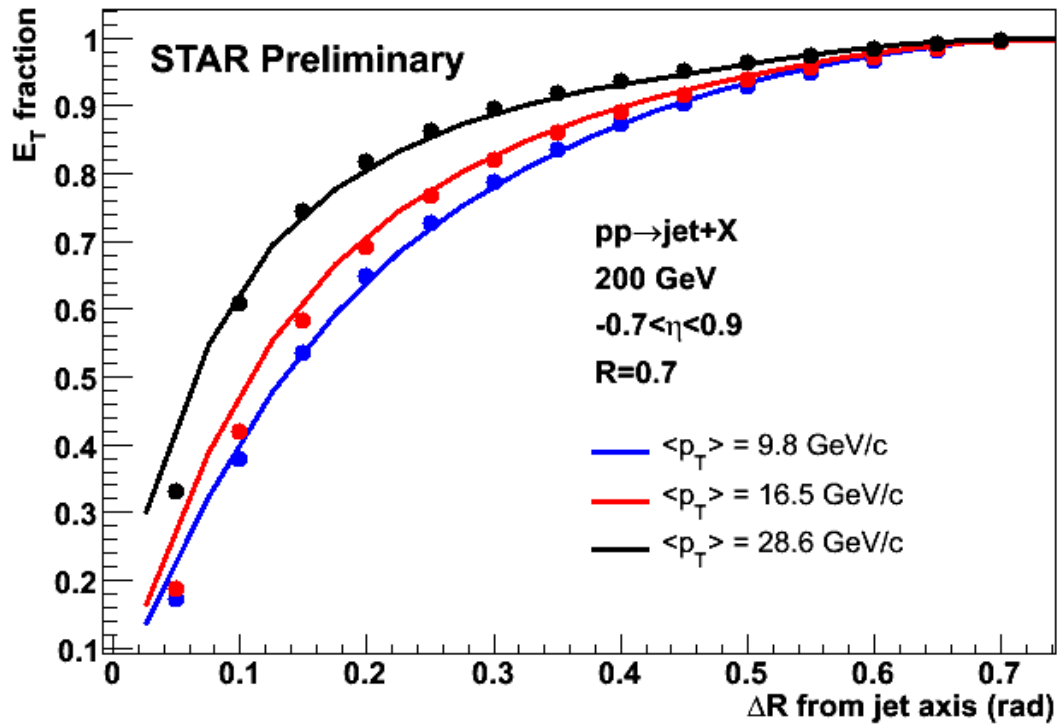
Run 2006 Data

Improved FOM

- *Luminosity :* *2 → 4.7 pb^{-1}*
- *Polarization:* *50% → 60% (online polarization)*
- *Barrel EMC η coverage:* *[0,1] → [-1,1]*

In addition

- *Jet Cone Radius: 0.4 → 0.7*
- *$-0.7 < \eta_{jet\ axis} < 0.9$*
- *Neutral Energy Fraction < 0.85*
- *Increased trigger thresholds*
- *Inclusion of Endcap EMC towers*
- *Improved tracking at large $|\eta|$*
- *Shielding from backgrounds*



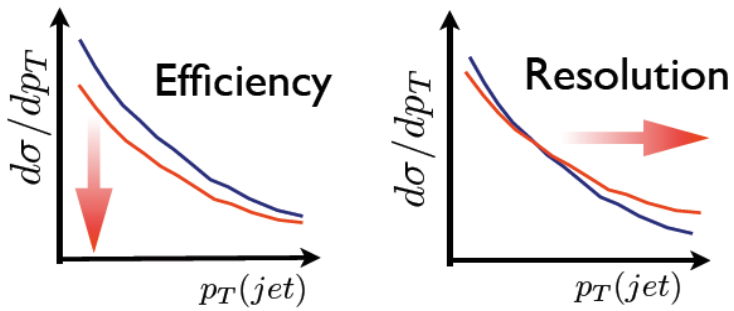
Jet p_T Scale Corrections & Systematics

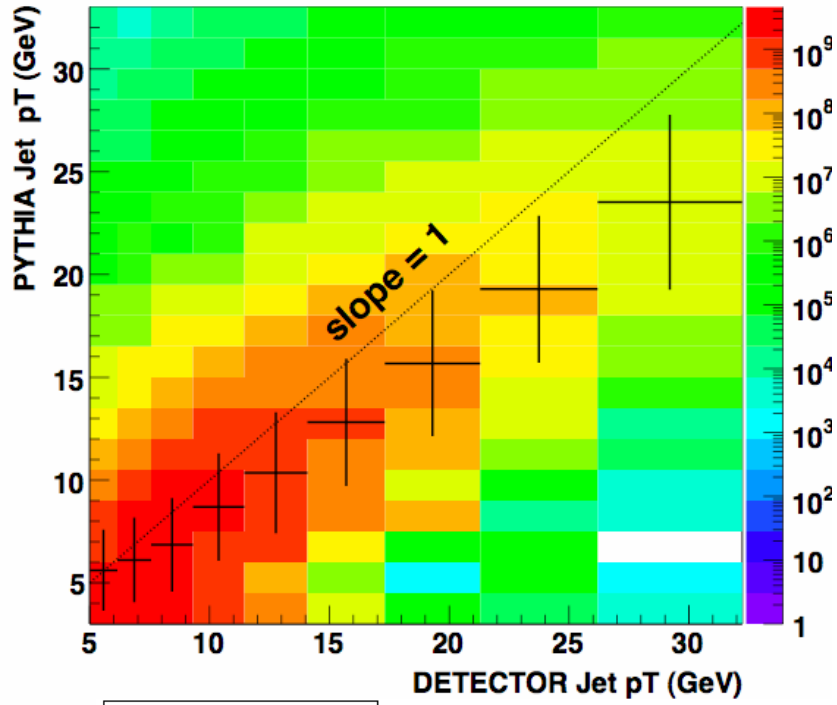
(Resolution and Efficiency)

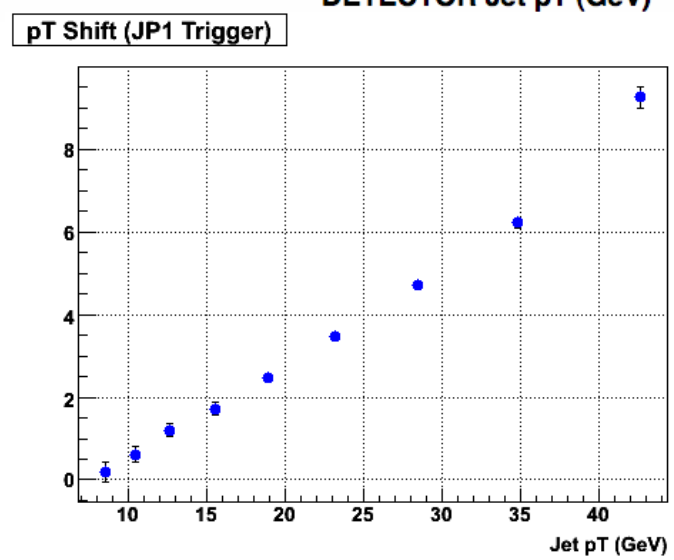
Largest effects are Detector Related:

Inefficiency: ~10% + Resolution: ~25%

true vs. *observed*



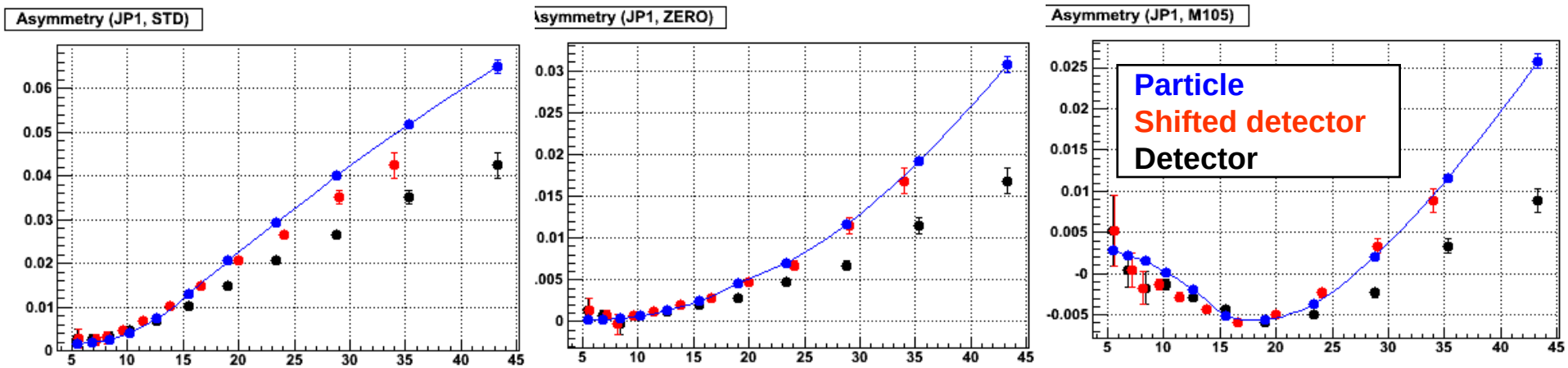




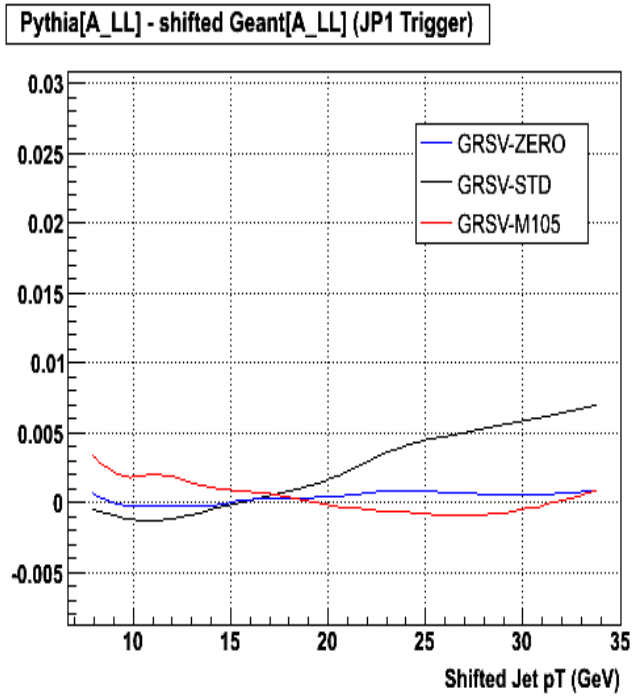
❖ ***Use PYTHIA+GEANT to estimate the p_T shift from detector jets to particle jets***

Trigger Bias

(Dominates A_{LL} Systematics)

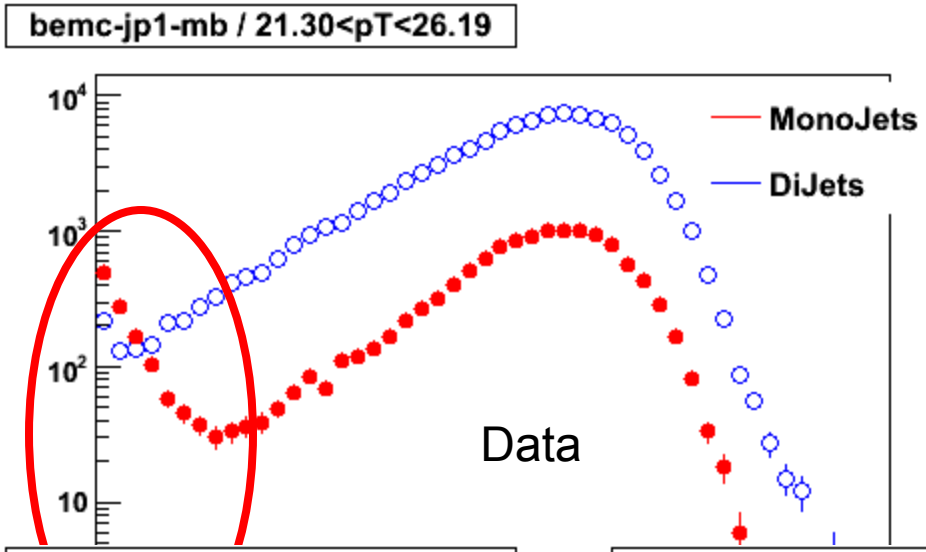


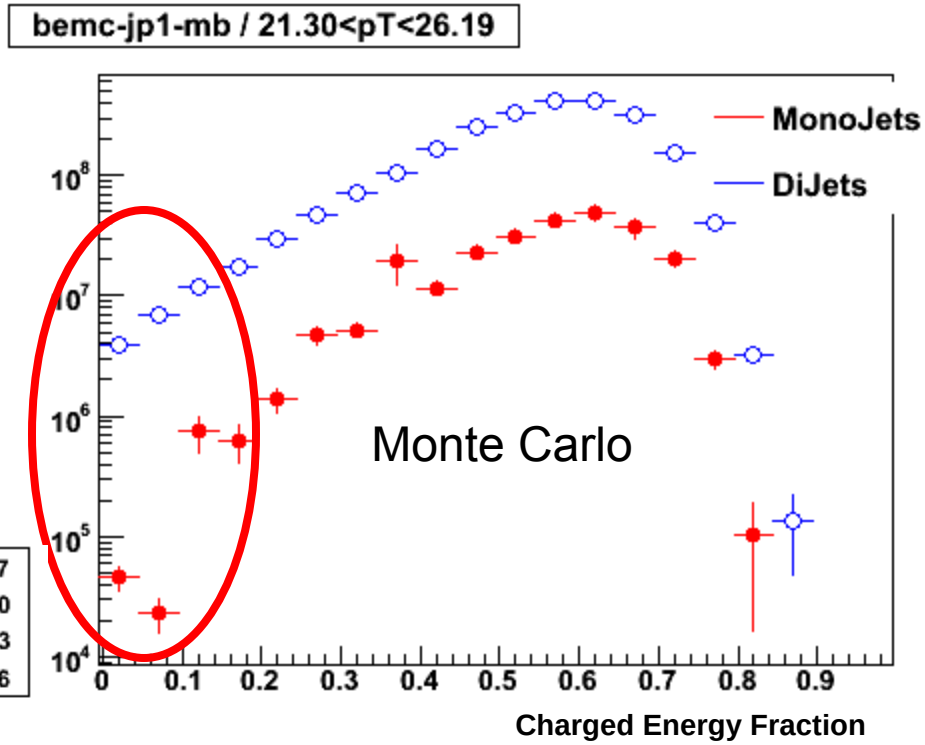
- ***Simulate the difference in A_{LL} between particle and detector jets for various gluon polarization scenarios***

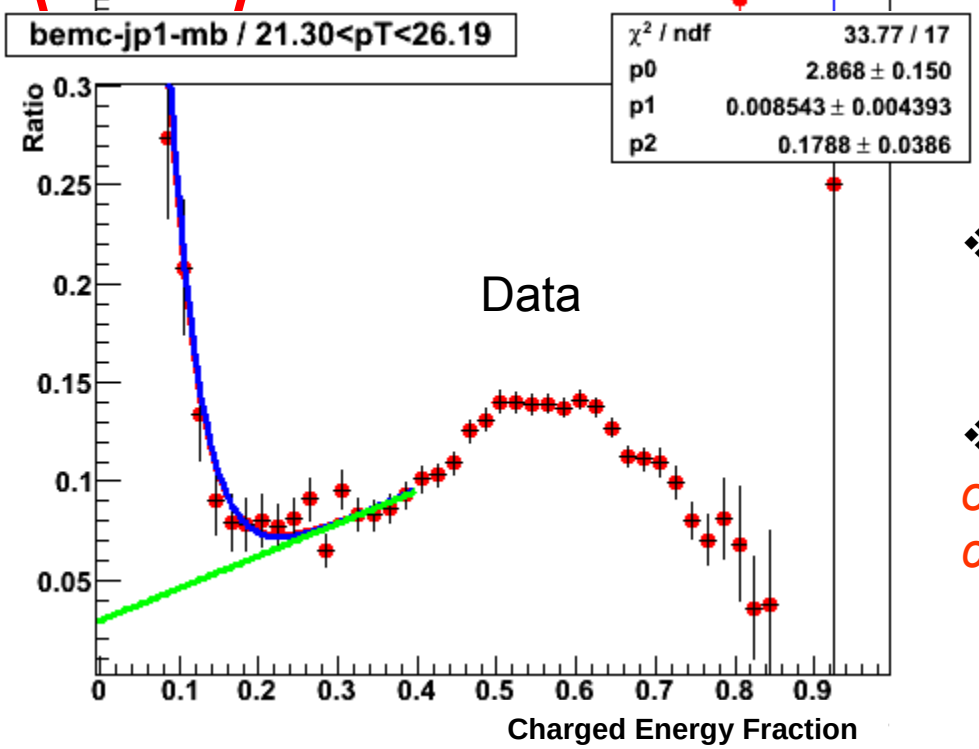


- *Maximum deviation determines A_{LL} systematic*
- *Confidence level calculations take account of any residual*

Estimating the non-jet background





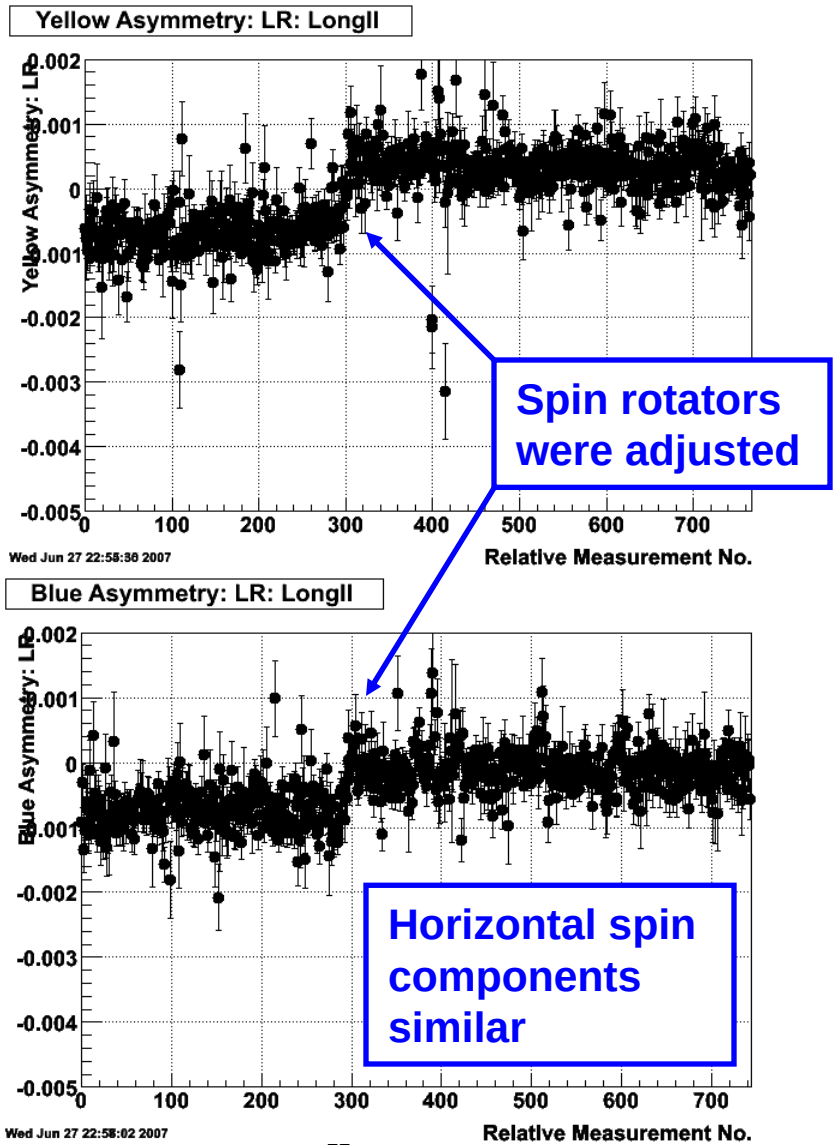


- *Non-jet backgrounds stand out in the data as single-jet events that have a small charged energy fraction*
- *Isolate the background in the ratio of mono-jet to di-jet events vs. charged energy fraction*

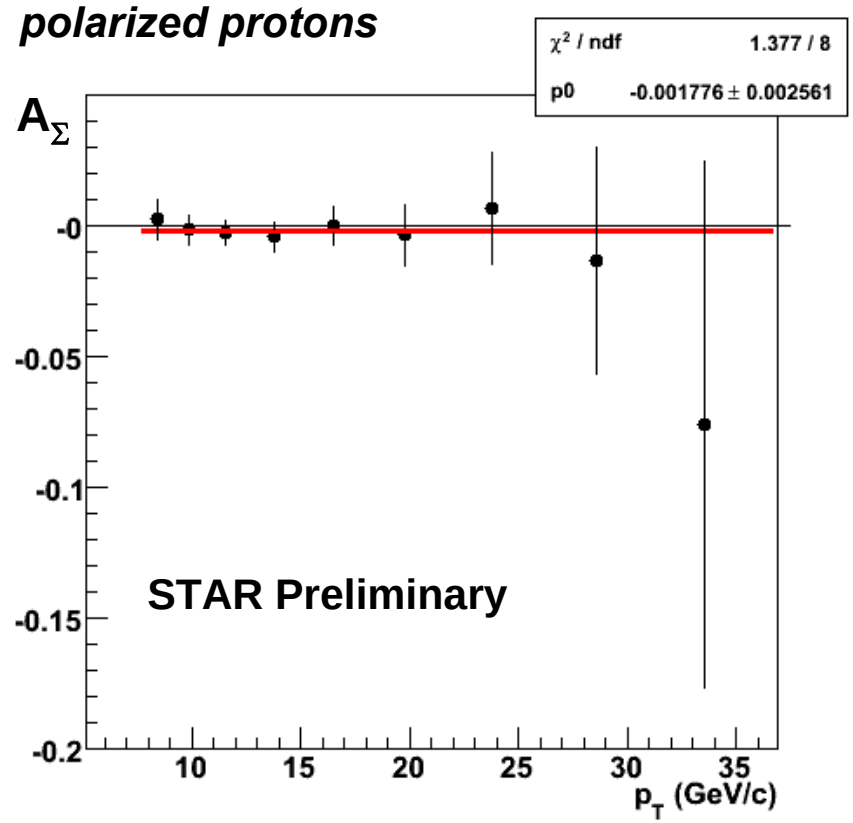
$$\delta A_{LL}^{Bkgd} \sim 4\times10^{-4}$$

Effects of Residual Transverse Polarization

BBC measurements of residual transverse components during longitudinal run (analyzing power 6~7 x 10^{-3})



Measured sensitivity to transversely polarized protons



Combine them to set an upper limit on the contribution to the A_{LL} measurement from non-longitudinal polarization components

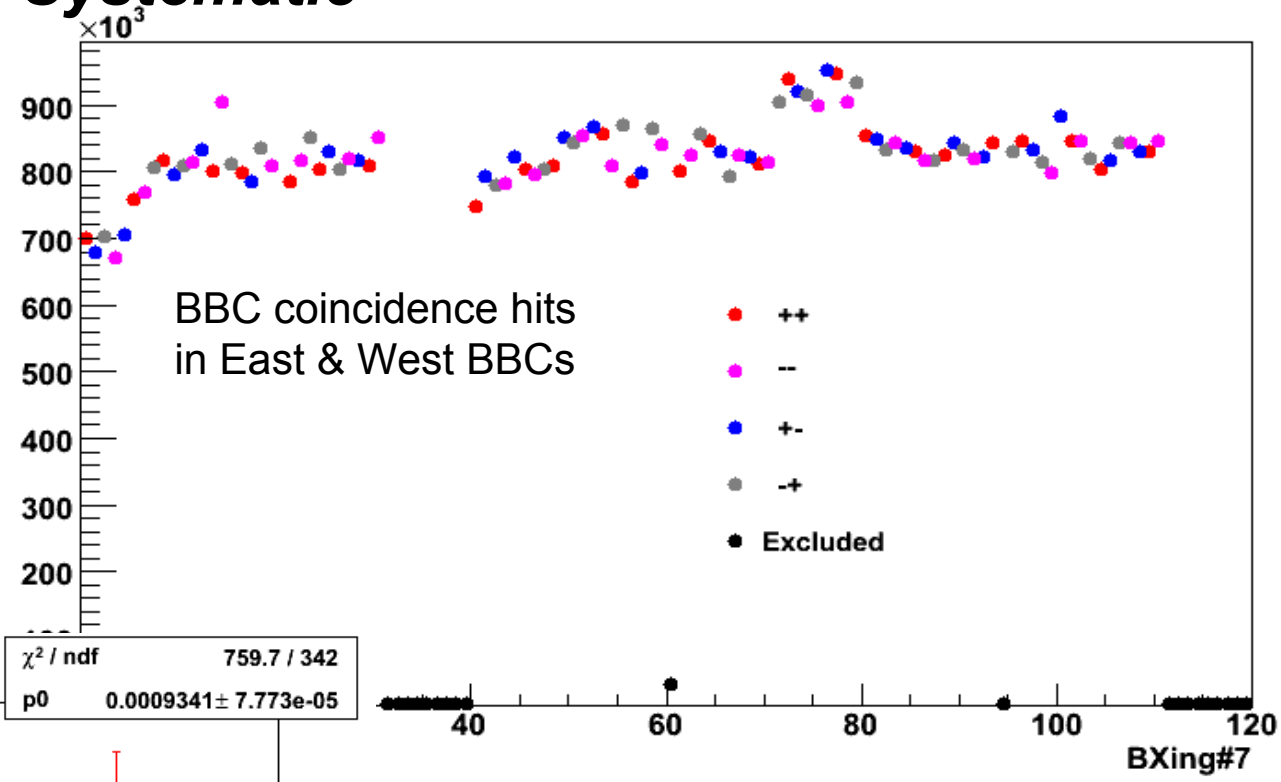
$$\delta A_{LL}^{NonLongPol} = \left|\tan\theta_B \tan\theta_Y \cos\left(\phi_Y - \phi_B\right) A_\Sigma\right|$$

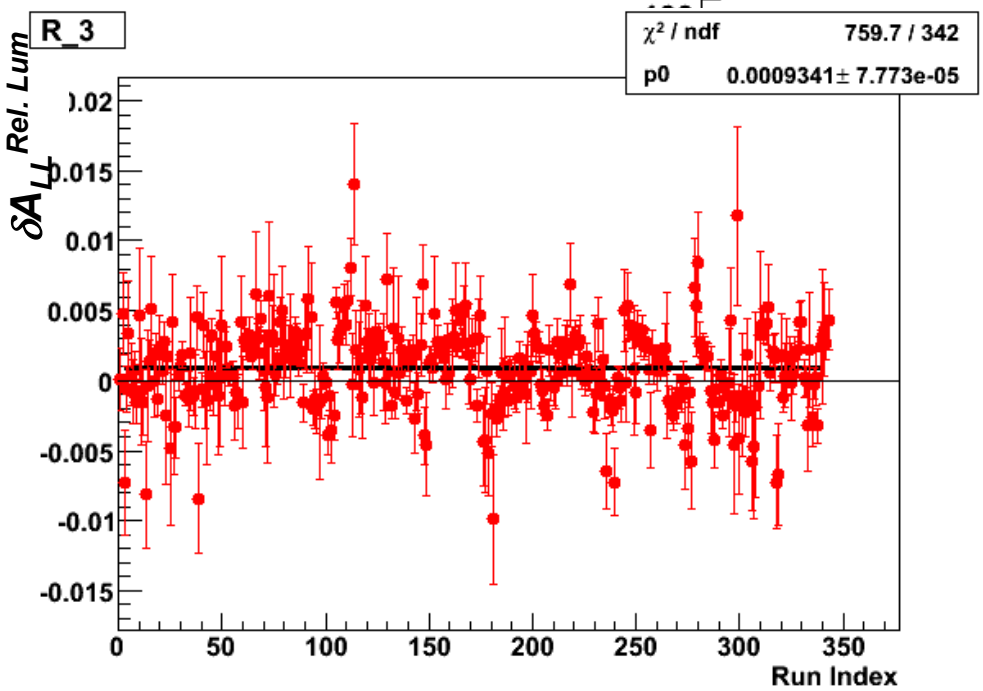
~10^{-4}

Relative luminosity Systematic

Relative luminosity systematic is calculated from comparisons between the BBC and ZDC asymmetries

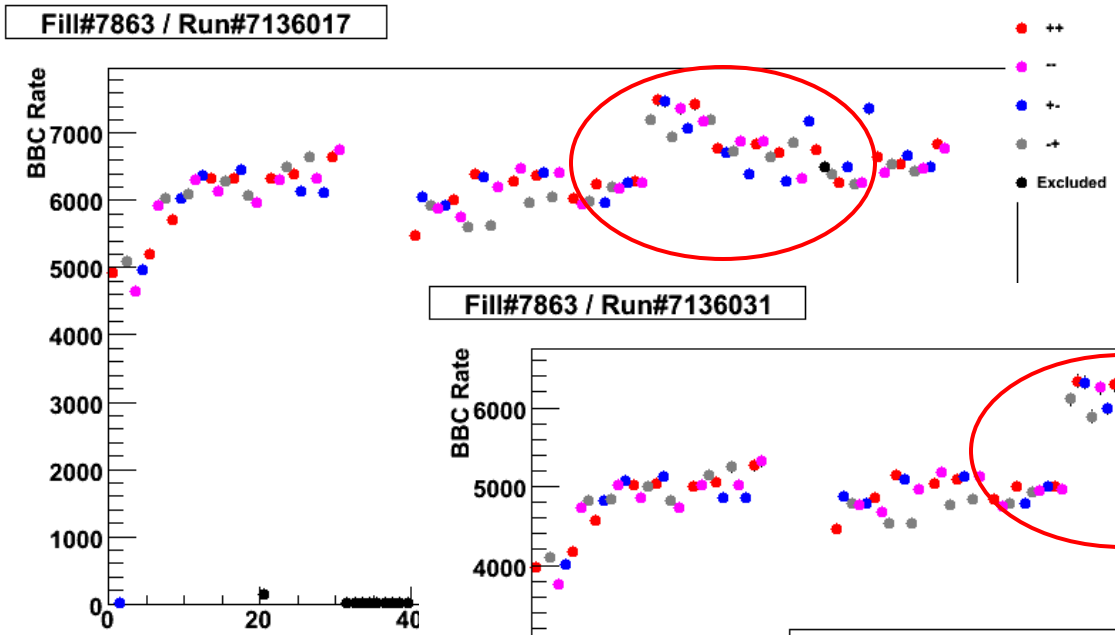
$$A_{LL} = \frac{1}{P_1 P_2} \times \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}$$



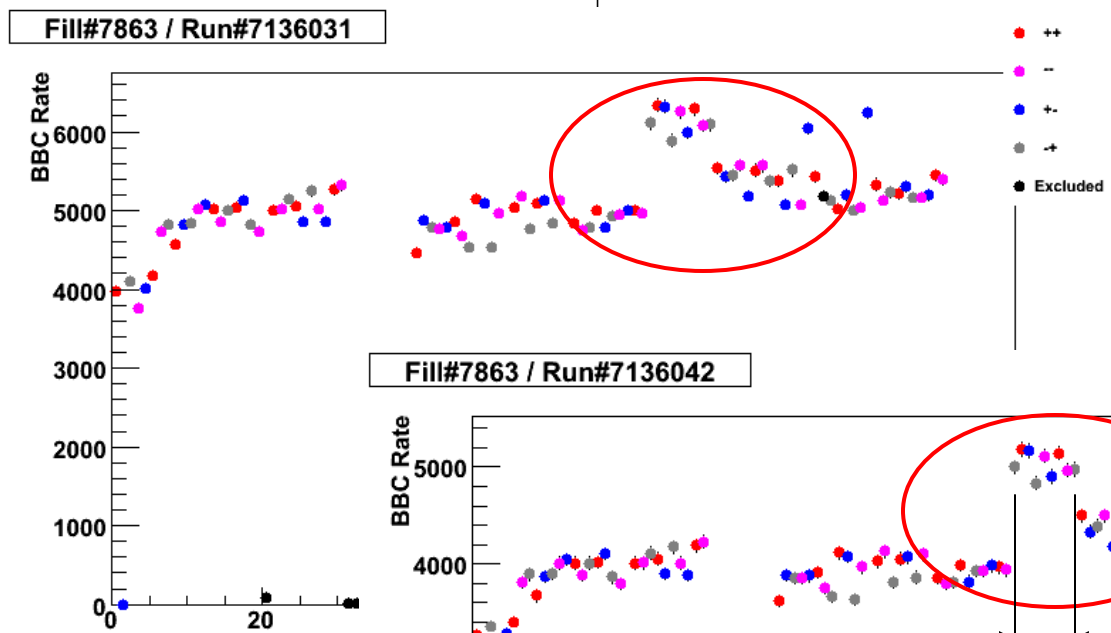


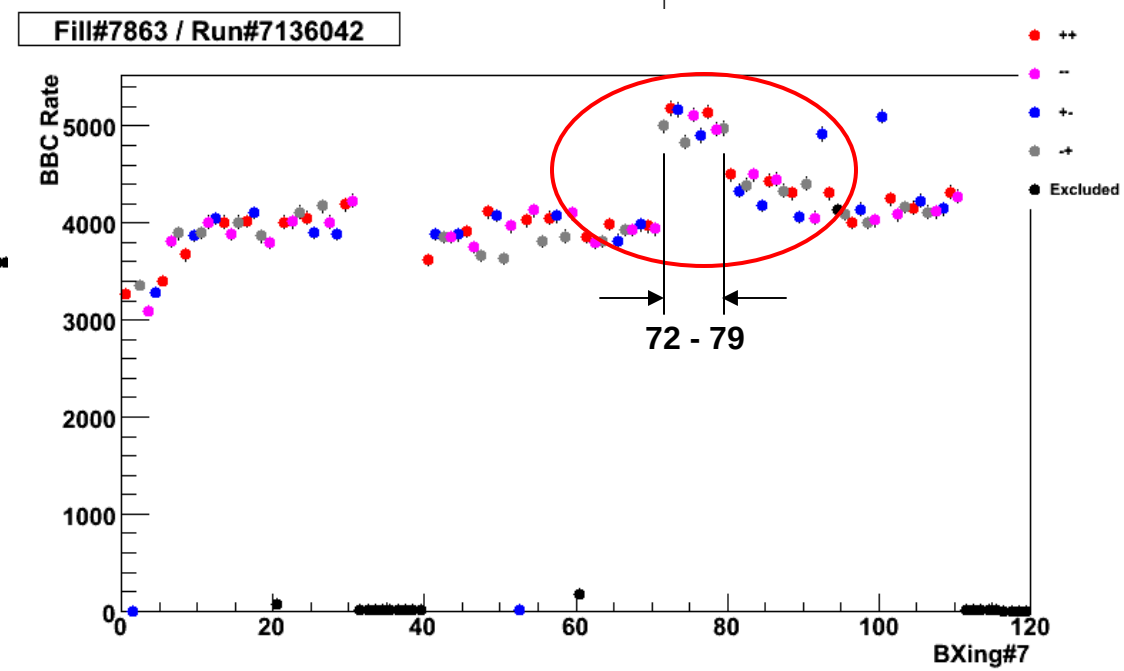
$$\delta A_{LL}^{Rel.Lum} \sim 9.4 \times 10^{-4}$$

Effect of Beam-Beam Interactions on Beam Lifetime



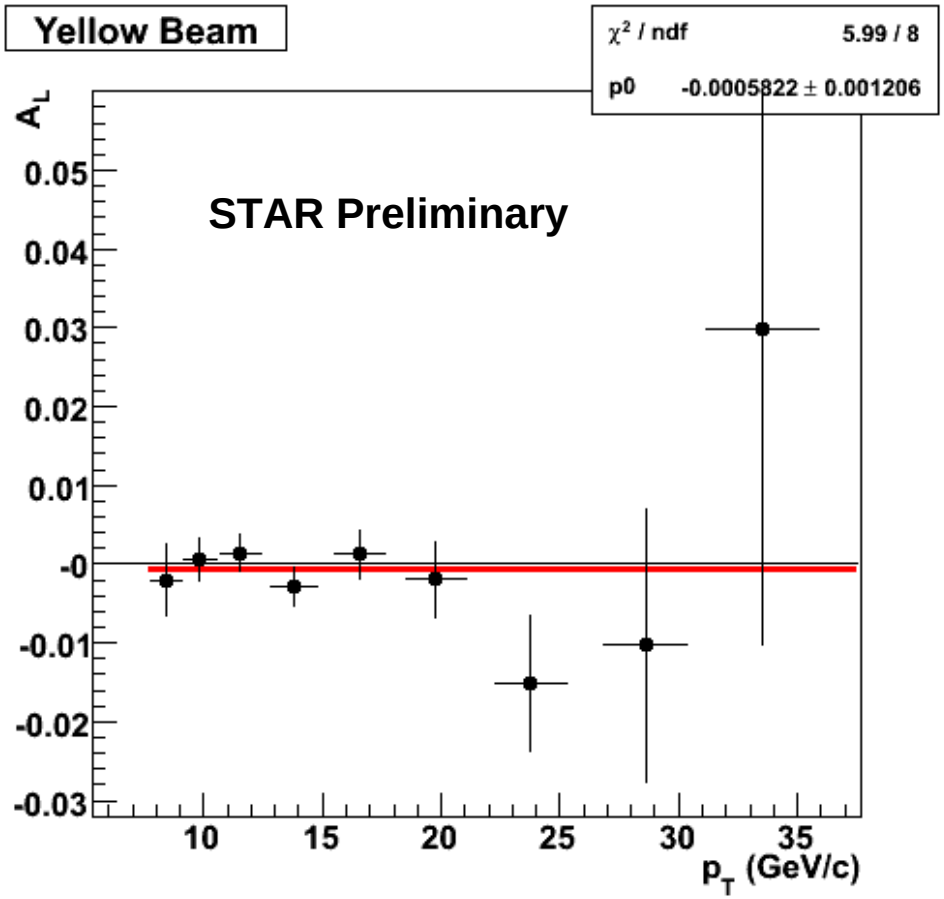
Total wall clock time from the beginning of the run 017 to the end of run 042 was ~7:14

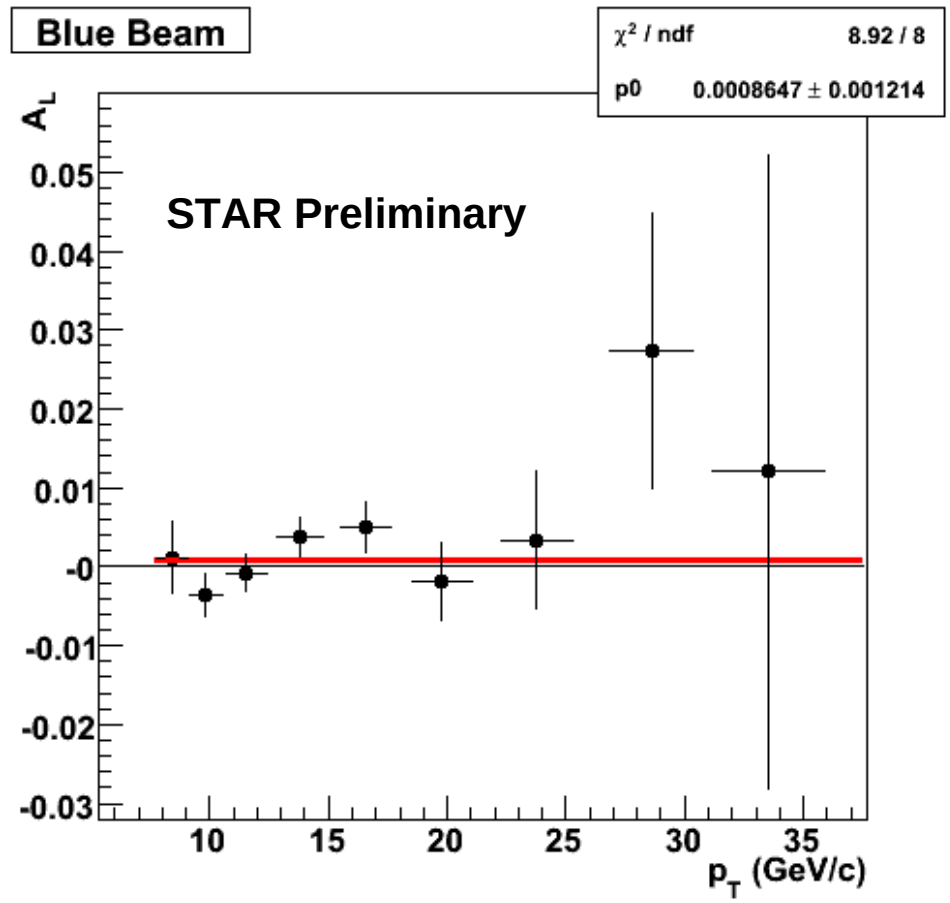




❖ ***Yellow and Blue beams overlap with Blue and Yellow abort gaps at PHENIX, respectively***

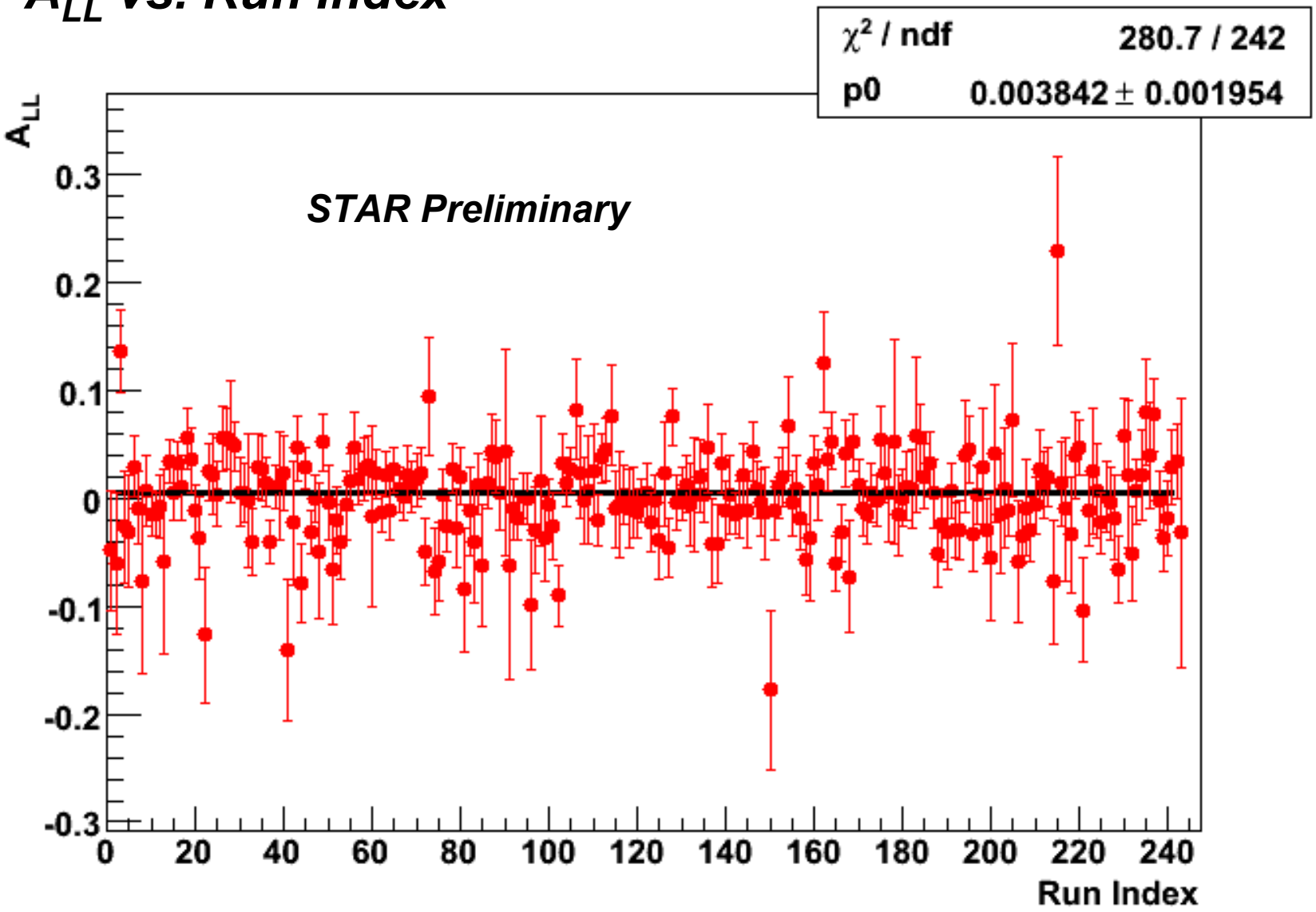
False Asymmetries



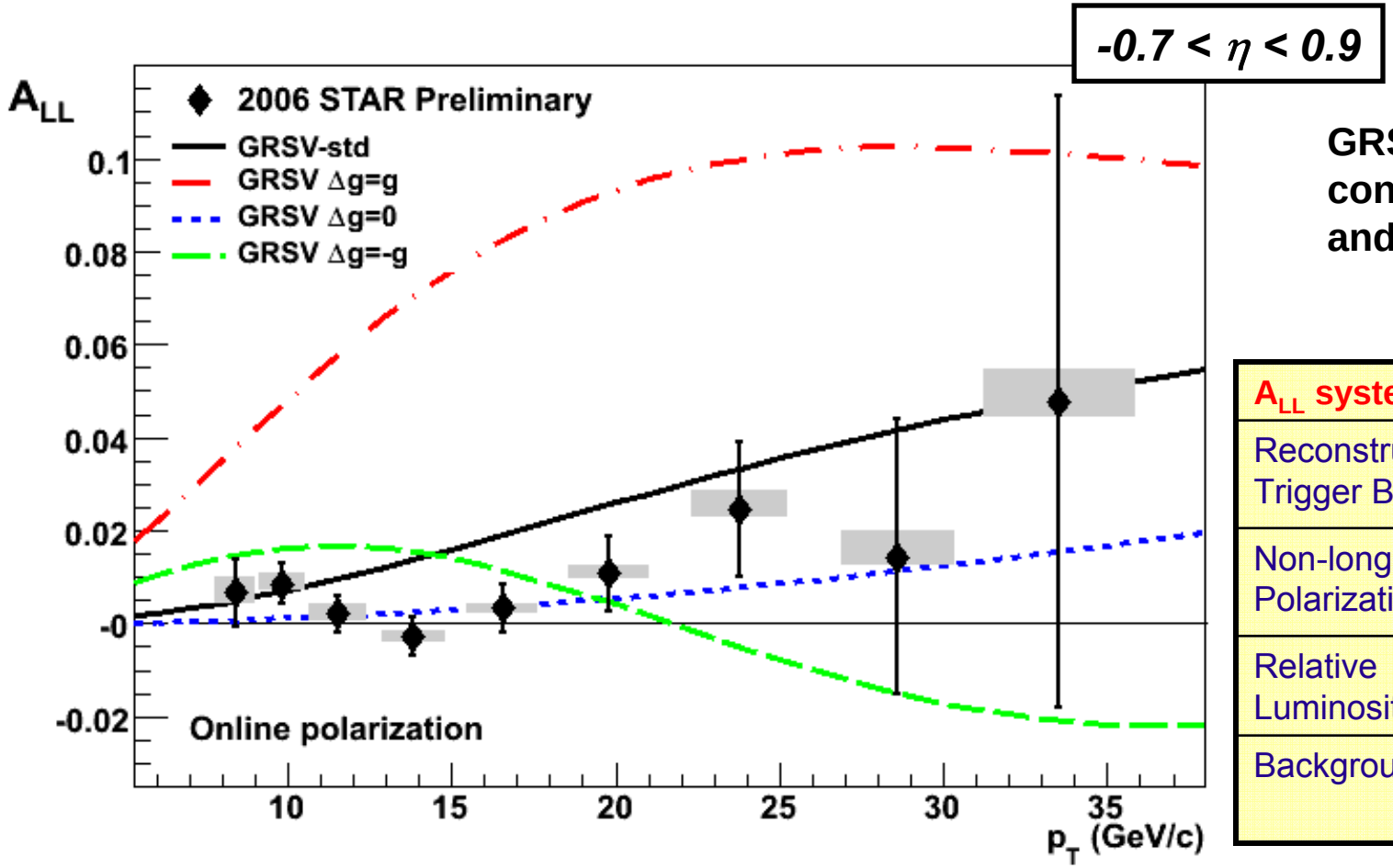


❖ ***Consistent with zero***

A_{LL} vs. Run Index



2006 Inclusive A_{LL}^{jets}



GRSV curves with cone radius 0.7 and -0.7 < η < 0.9

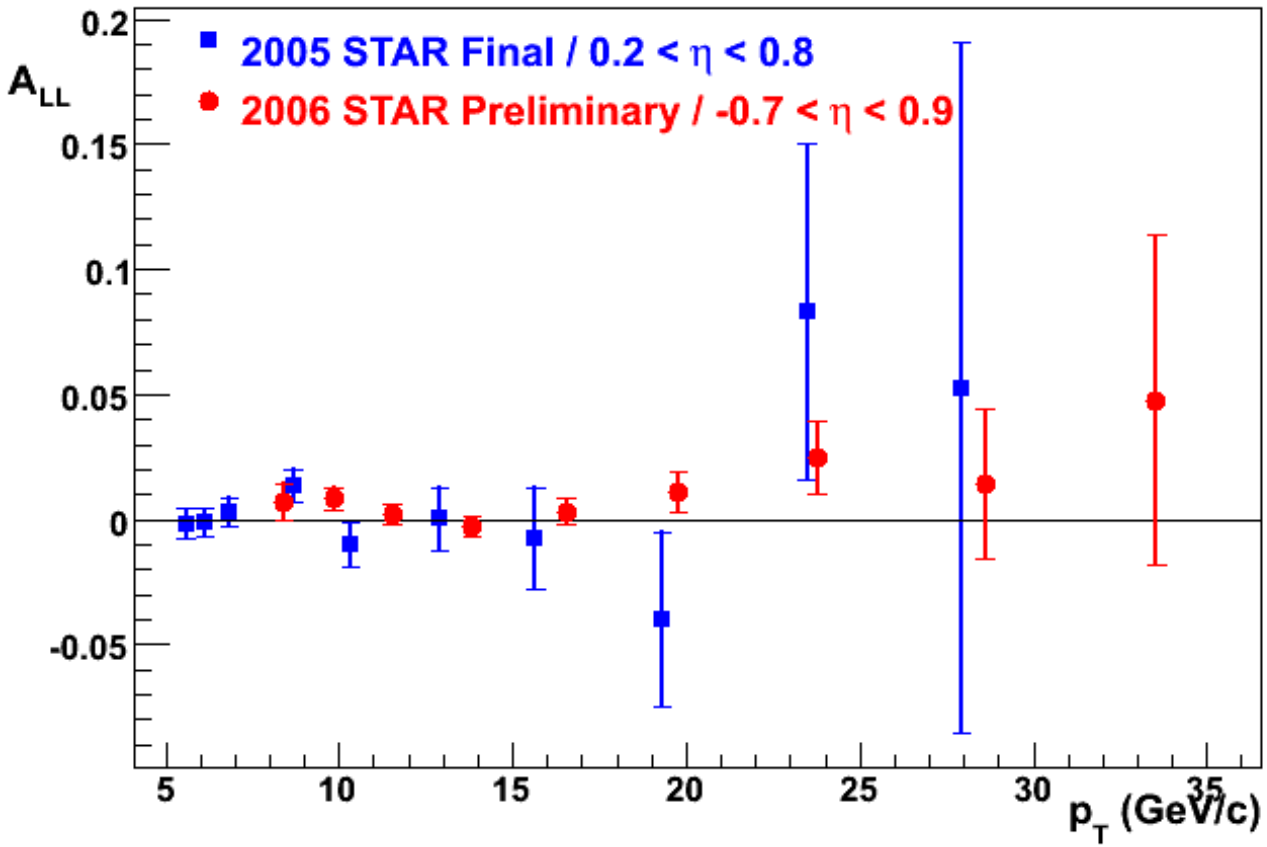
A_{LL} systematics	(x 10^{-3})
Reconstruction + Trigger Bias	[-1,+3] (p_T dep)
Non-longitudinal Polarization	~ 0.03 (p_T dep)
Relative Luminosity	0.94
Backgrounds	1st bin ~ 0.5 Else ~ 0.1

p_T systematic	±6.7%

- Using jet patch trigger ($\Delta\eta x \Delta\phi$ = 1x1 patch of towers) only

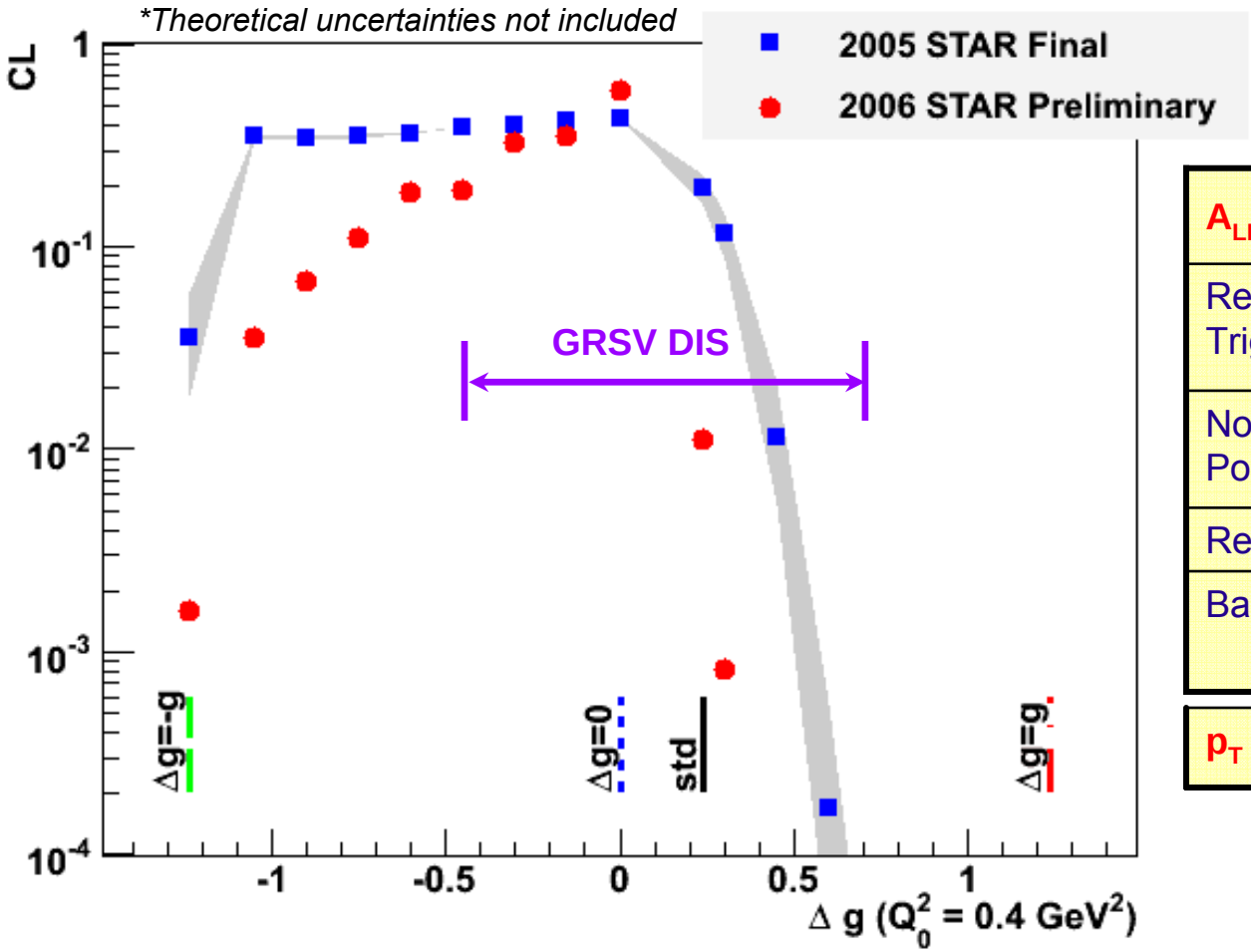
❖ ***Statistical uncertainties are 3-4 times smaller than 2005 in high p_T region (p_T>13 GeV/c)***

2005 and 2006 Inclusive A_{LL}^{jets}



- ***Consistency between 2005 and 2006 A_{LL}^{jets}***
- ***2006 A_{LL}^{jets} extends the precision to higher p_T region***

2006 Inclusive A_{LL}^{jets}



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	1st bin ~ 0.5 Else ~ 0.1

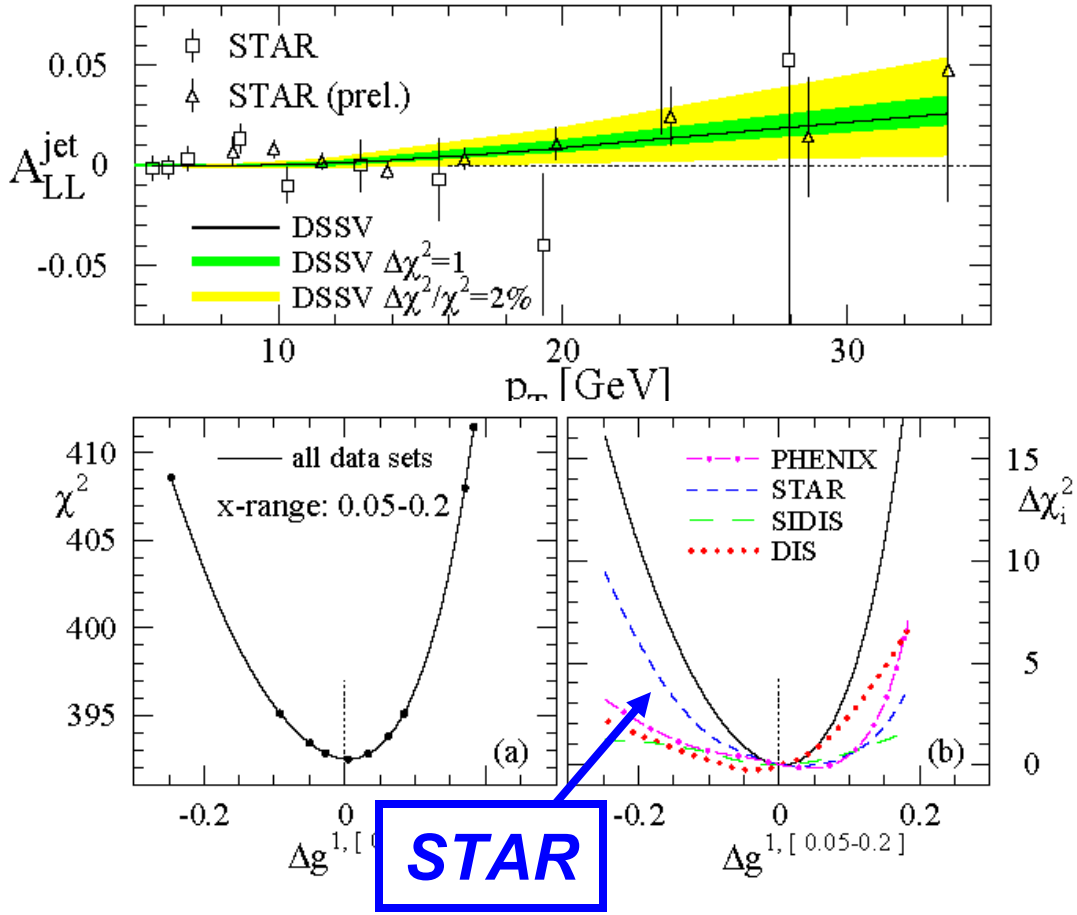
p_T systematic	±6.7%

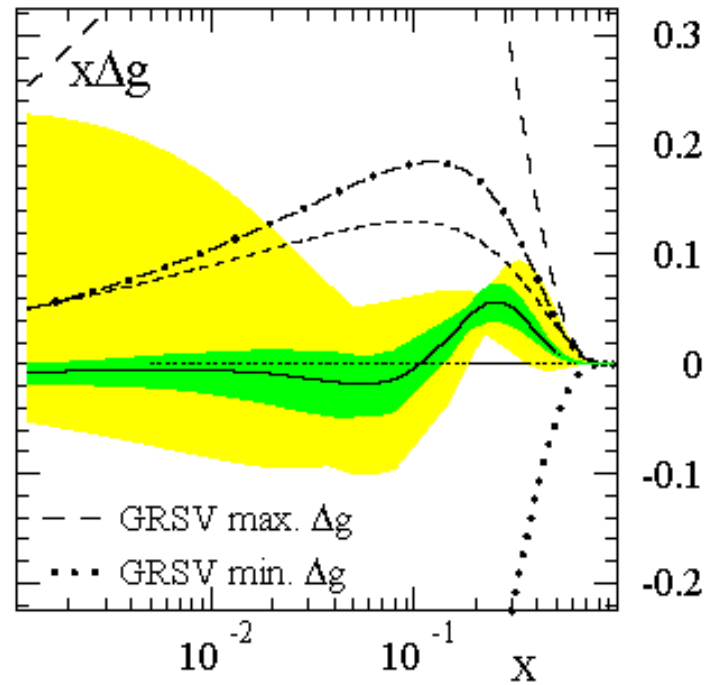
GRSV DIS best fit=0.24
1σ = -0.45 to 0.7
PRD 63, 094005 (2001)

- ***Within GRSV framework:***
  - ***Δg_std excluded with 99% CL***
  - ***Δg<-0.7 excluded with 90% CL***

DSSV – first global analysis with polarized jets

de Florian et al., arXiv:0804.0422 [hep-ph]





- ***The first global NLO analysis to include inclusive DIS, SIDIS, and RHIC pp data on an equal footing***
- ***Finds a node in the gluon distribution near x ~ 0.1, but with the opposite phase from GS-C***

Summary

- ***NLO pQCD describes inclusive jet cross section at RHIC***
- ***Within GRSV framework, 2005 results constrain ΔG to less than 65% of the proton spin with 90% confidence***
- ***Significant increase in precision in Run 2006 data provides even stronger constraints on gluon polarization***
- ***STAR inclusive Jets rule out substantial phase space but do not yet determine sign of ΔG***
- ***STAR inclusive Jets results are in good agreement with other competitive measurements***
- ***STAR inclusive jets play a significant role in the first global NLO analysis to consider DIS, SIDIS, and RHIC data together***