Measurement of the Double Longitudinal Spin Asymmetry in Inclusive Jet Production in Polarized p-p Collisions at $\sqrt{s}$ = 200 GeV at STAR

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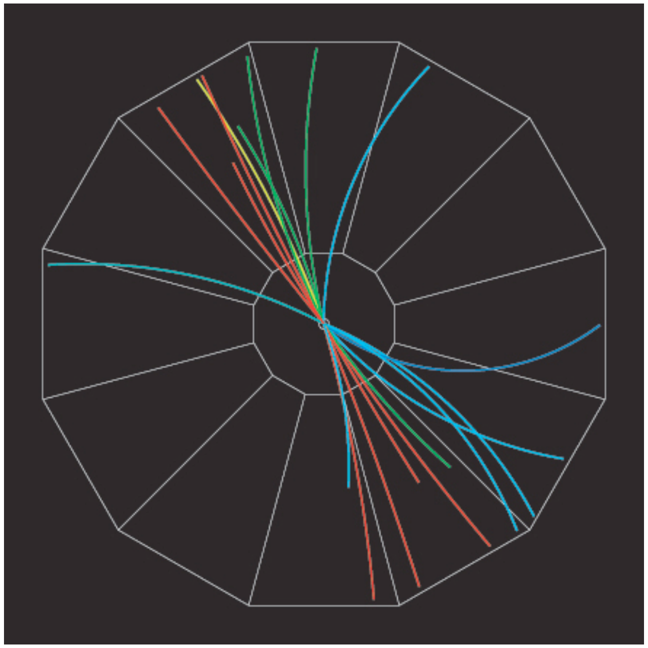
for the STAR Collaboration

SPIN 2006
Kyoto University

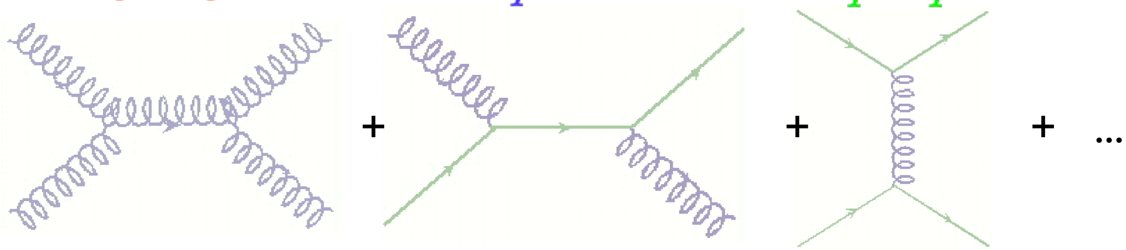


Outline:
- **Motivation**
- **Experimental Setup**
- **Analysis**
- **Systematics**
- **Summary**

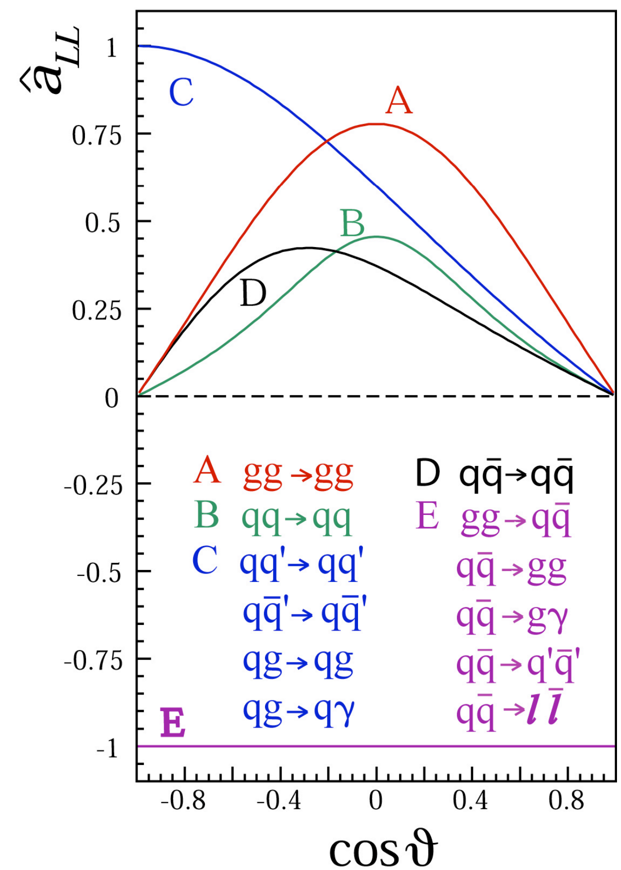
Constraining ΔG: pp → Jet + X

Sensitive to:

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



with large partonic asymmetries at midrapidity (θ=90)



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

Δf: polarized parton distribution functions

How to Measure A_{LL}

Collide two polarized proton beams, (Y)ellow and (B)lue

Measure the *double-spin asymmetry*:

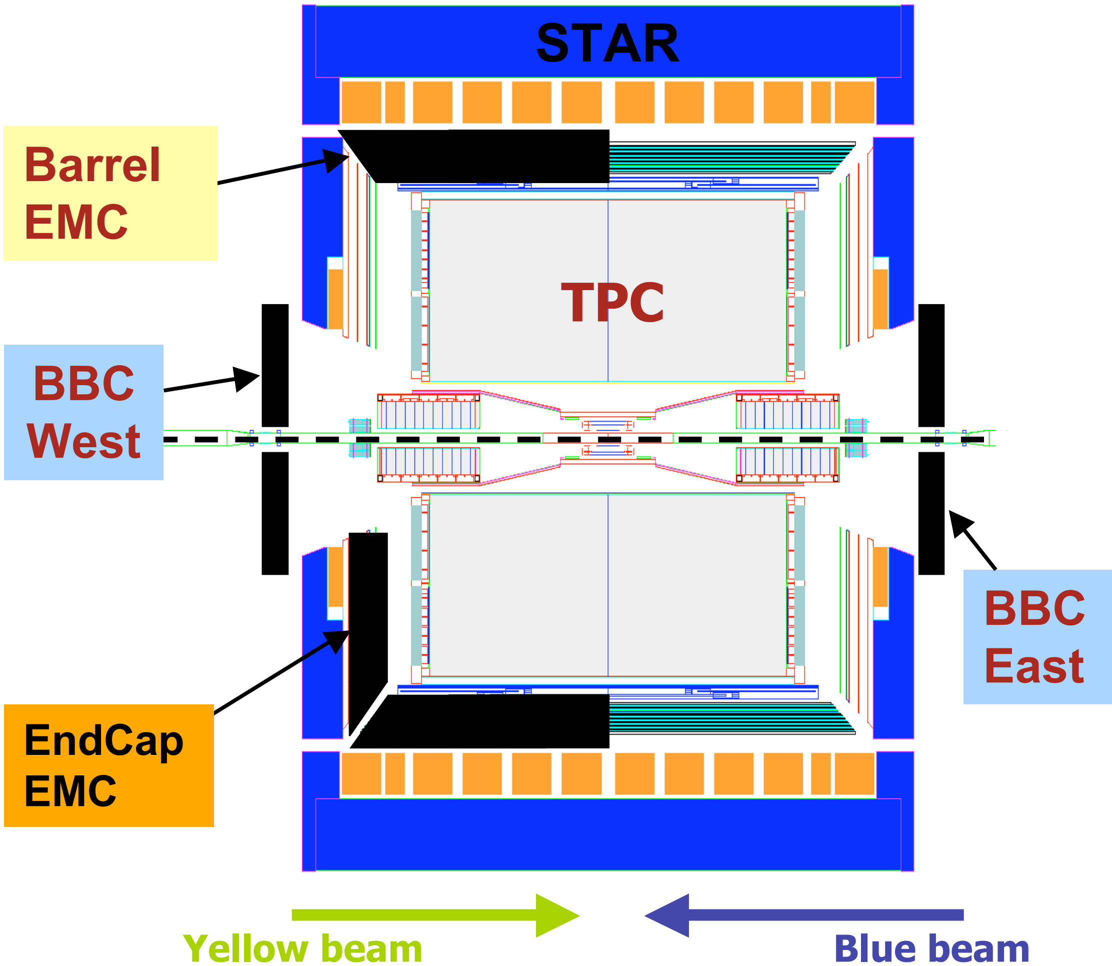
$$A_{LL} = \frac{1}{P_Y P_B} \frac{N^{parallel} - R \cdot N^{antiparallel}}{N^{parallel} + R \cdot N^{antiparallel}}$$

N: Spin dependent yields (# of reconstructed jets)

P: Beam polarization (determined by RHIC Polarimeter)

R: Relative luminosities between different spin states

STAR Detector at RHIC



Detectors used in 2005 jet analysis:

Time Projection Chamber
Tracking

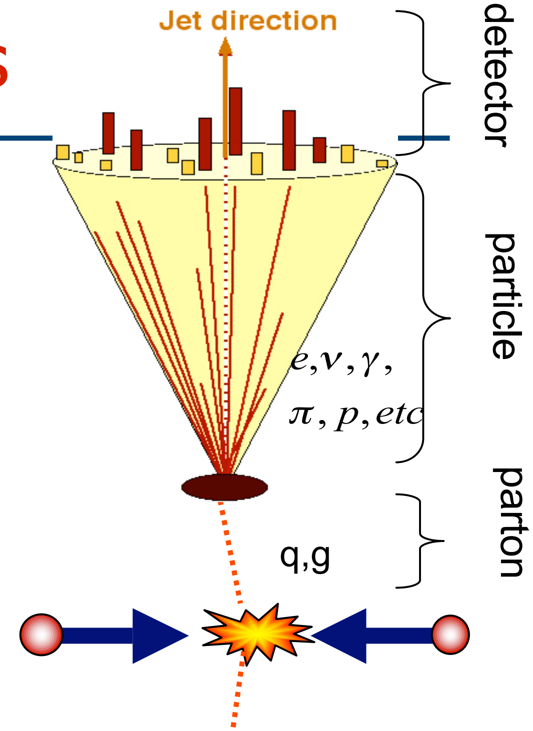
Barrel EMC
Triggering, Calorimetry

Beam-Beam Counters
Triggering, Local Polarimetry

Full azimuthal coverage
in all detectors

Unique capability at RHIC for complete jet reconstruction!

STAR Jets: Reconstruction and Triggers



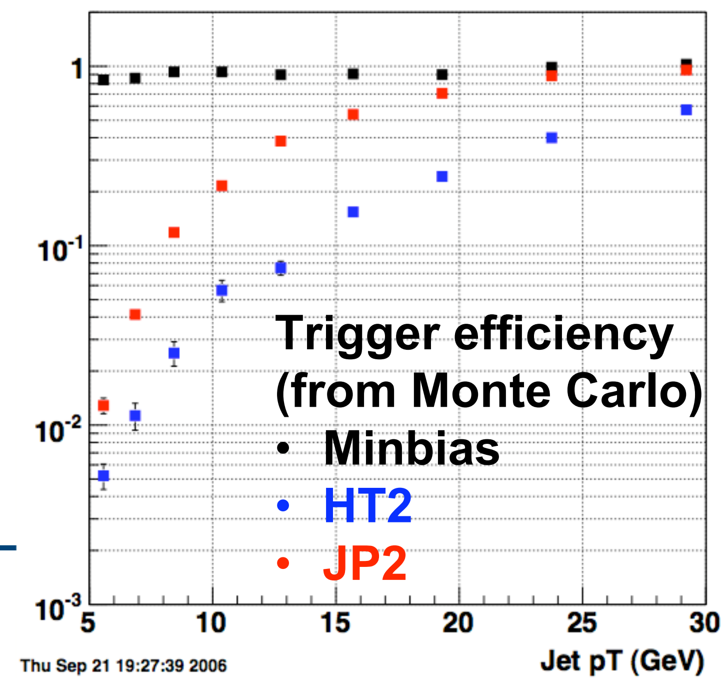
1) **Midpoint cone algorithm**

- Adapted from Tevatron II
- Seed energy = 0.5 GeV, cone angle = 0.4 in $\eta-\phi$

2) **Triggers**

- BBC coincidence required for all triggers
- High Tower: HT1 (HT2)
  - E_T > 2.8 (3.8) GeV deposited in one tower
  - $(\Delta\eta \text{ x } \Delta\phi) = (0.05 \text{ x } 0.05)$

✓ **Jet Patch: JP1 (JP2)** - new for 2005!
  - E_T > 4 (5.5) GeV deposited in one tower patch
  - $(\Delta\eta \text{ x } \Delta\phi) = (1.0 \text{ x } 1.0)$



STAR Jets: Cuts and Statistics

3) **Cuts**

- BBC time bin (~a vertex cut)
- Z vertex reconstruction requirement
- Software trigger: selects jets responsible for event triggers
- Jet centroid: $0.2 < \eta < 0.8$ (removes detector edges)
- Jet neutral energy fraction: $E_{jet}(BEMC)/E_{jet}(total) < 0.8$ (same as 2003)

4) **Statistics**

I. 3.1 pb^{-1} sampled
   $\Rightarrow$ 1.6 pb^{-1} after run selection

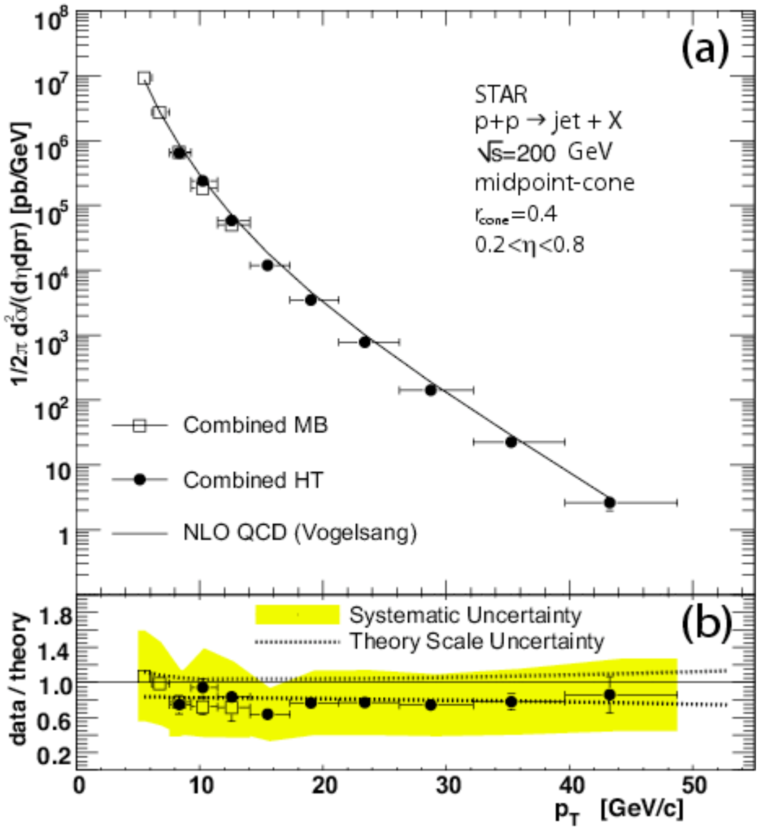
II. $\langle P_B P_Y \rangle \approx 0.25$

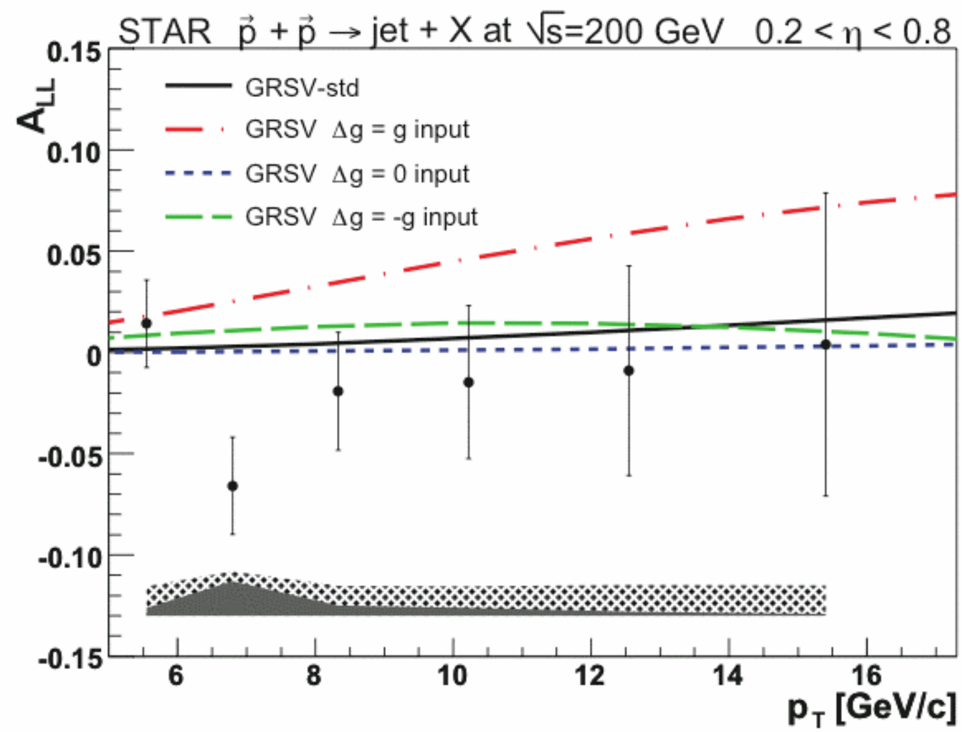
III. 1.97 M events (post-cuts)
   $\Rightarrow$ 1.39 M in JP2

IV. ~2% of jet events contain multiple jets

Previous Results: 2003/2004

First inclusive jet cross section result at RHIC





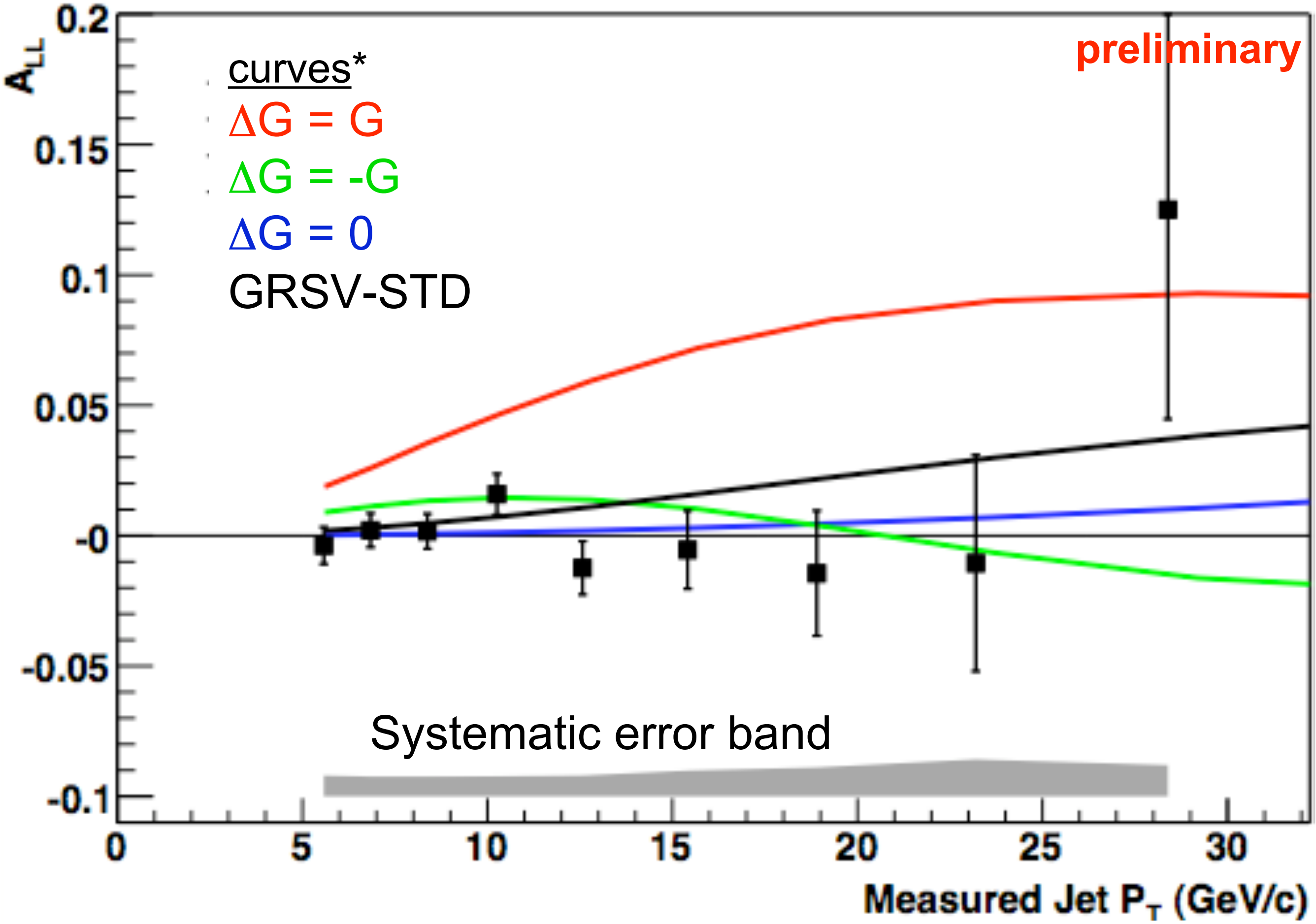
First inclusive jet A_{LL} result at RHIC

- Curves are theory predictions based on DIS parameterizations of ΔG

arXiv:hep-ex/0608030

Submitted to PRL

2005 Results, Inclusive Jet A_{LL}



χ^2 fit to curves:
(stat+syst error in quadrature)

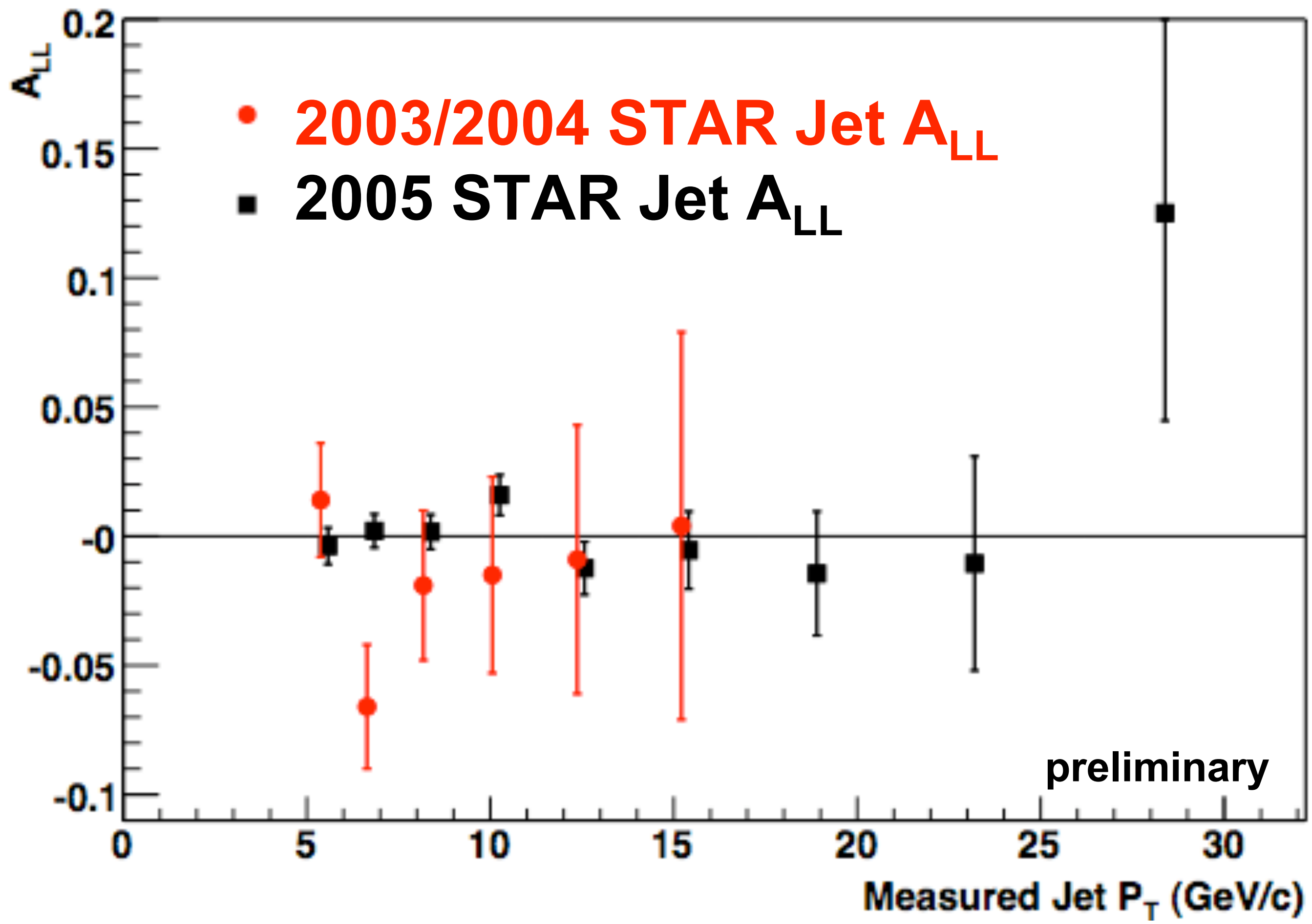
GRSV-STD:	1.1
ΔG = G:	12
ΔG = 0:	0.7
ΔG = -G:	1.4

Rules out ΔG=G

Error bars are statistical
Systematic band does not include 25% scale error from polarization

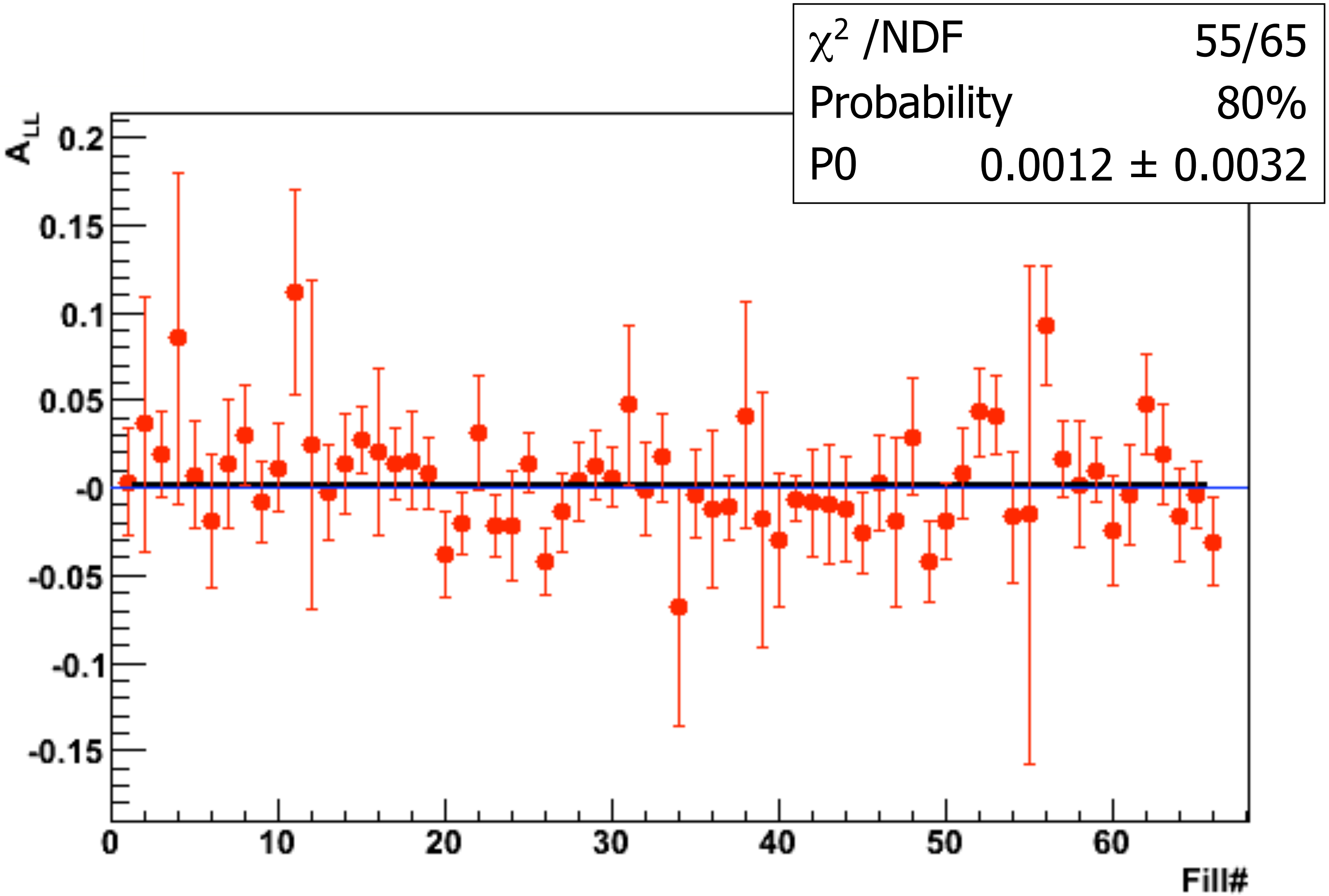
*Theory curves from B.Jager et. al., PRD70 (2004)034010

STAR Jet A_{LL}: 2003/2004 vs 2005



2003/2004 and 2005 results consistent

2005 Jet A_{LL} vs Fill



Jet A_{LL} Systematics: Reconstruction + Trigger Bias

Reconstruction Bias

- Detector + Jet Reconstruction Algorithm overestimate jet p_T (~20-30% high)

Trigger Bias

- Each trigger sensitive to different subprocesses (qq/qg/gg)

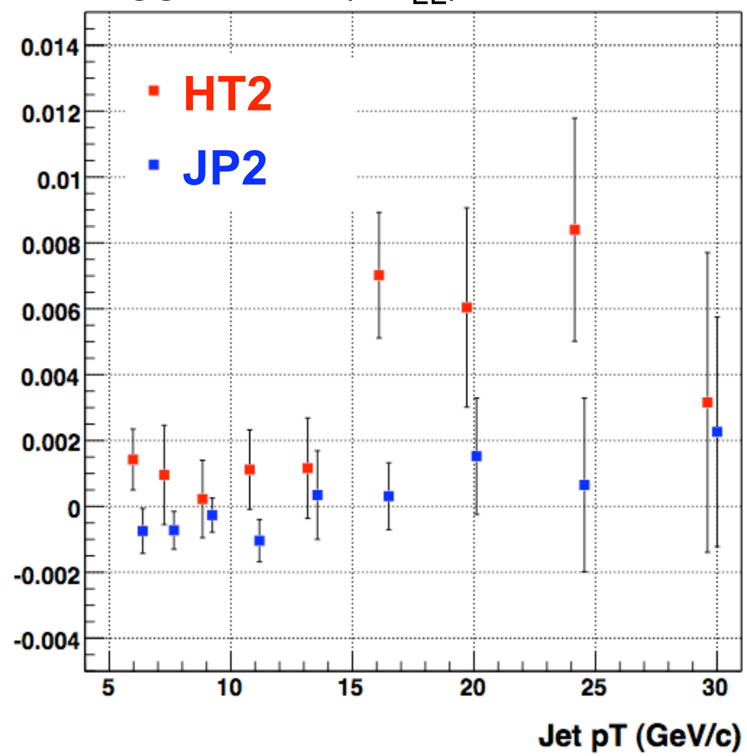
DIS ΔG parameterizations combined with partonic information from PYTHIA to estimate:

1. A_{LL} (jet) [PYTHIA],
2. A_{LL} (detector) [PYTHIA+GEANT], and
3. A_{LL} (detector+triggers)

Difference between A_{LL}(detector) and A_{LL}(jet) is reconstruction bias

Difference between A_{LL}(detector+triggers) and A_{LL}(detector) is trigger bias

Trigger bias (δA_{LL}), GRSV-STD



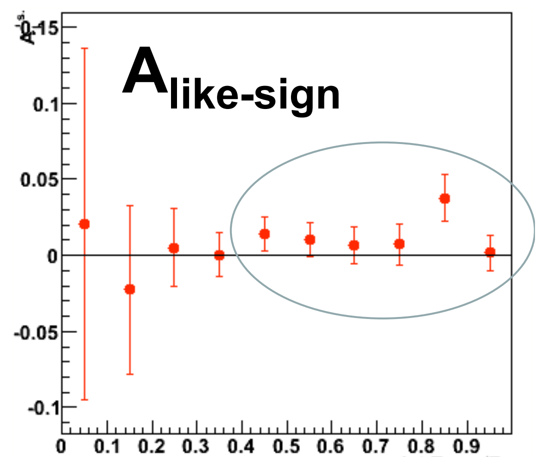
Jet A_{LL} Systematics: False Asymmetries

- We observe 1-3σ single spin asymmetries (SSAs), depending on cuts

  - Yellow beam and "like sign" (++,--) asymmetries both non-zero

    ⇒ Suggests SSA caused by one anomalous spin state

- Source of these asymmetries still unclear



Jet E(EMC)/E(total)

- Uncertainty bounded by $A_{like\text{-}sign}$

  - $\delta A_{LL} \propto A_{l.s.}/2$

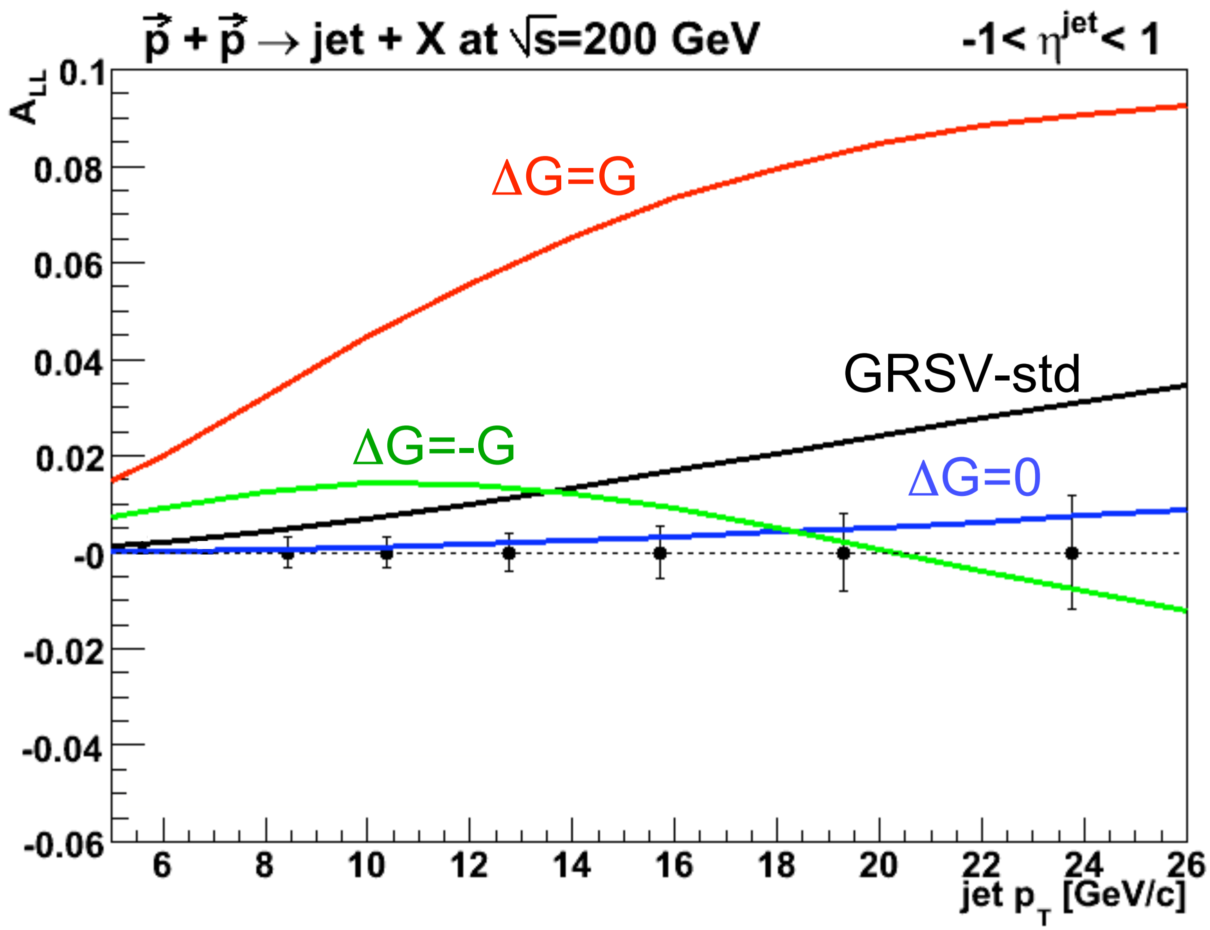
  - $A_{l.s.} = 7.9 \pm 5.2 \times 10^{-3} \Rightarrow \boxed{\delta A_{LL} < 0.0065}$

2005 Jet A_{LL}, Systematics

effect	(x 10^{-3})
False Asymmetries	<6.5
Reconstruction + Trigger Bias	2-12 (p_T dependent)
Non-longitudinal Polarization	3
Relative Luminosity	2
Backgrounds	<1

Outlook: 2006 Jet A_{LL} Projection

- Increase in sampled luminosity over 2005
- Polarization ~ 60% (FOM is P^4L)
- Entire BEMC instrumented
- Beamline shielding installed
- Greater emphasis on high p_T jets and dijets with triggers

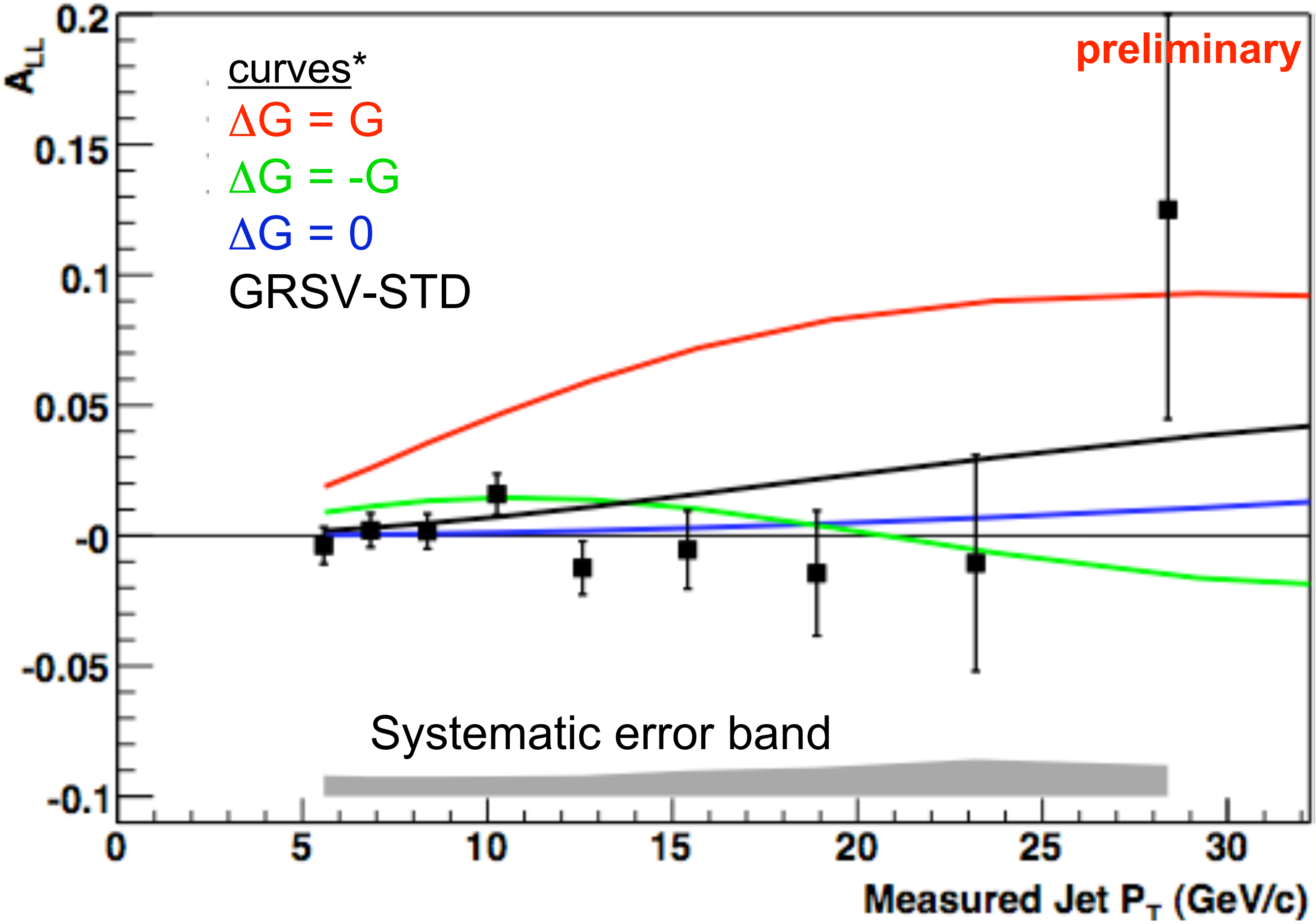


Summary

- 2005 Jet A_{LL} Preliminary Result
  - 1.6 pb^{-1}, $\langle P_B P_Y \rangle \approx 0.25$
  - ~10x larger sample than 2003/2004 with higher polarization
  - A significant contribution to global understanding of ΔG!

- Present/Near Future
  - 2003/2004 results submitted to PRL
  - 2006 data collection finished
    - Larger FOM than 2005
      - Full calorimeter coverage from $-1 < \eta < 2$
    - Emphasis on dijets and high p_T jets
  - ⇒ Expect to publish 2005 data in ~6 months

2005 Results, Inclusive Jet A_{LL}



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Backup

A_{LL} Systematics and Cross-checks: Backgrounds

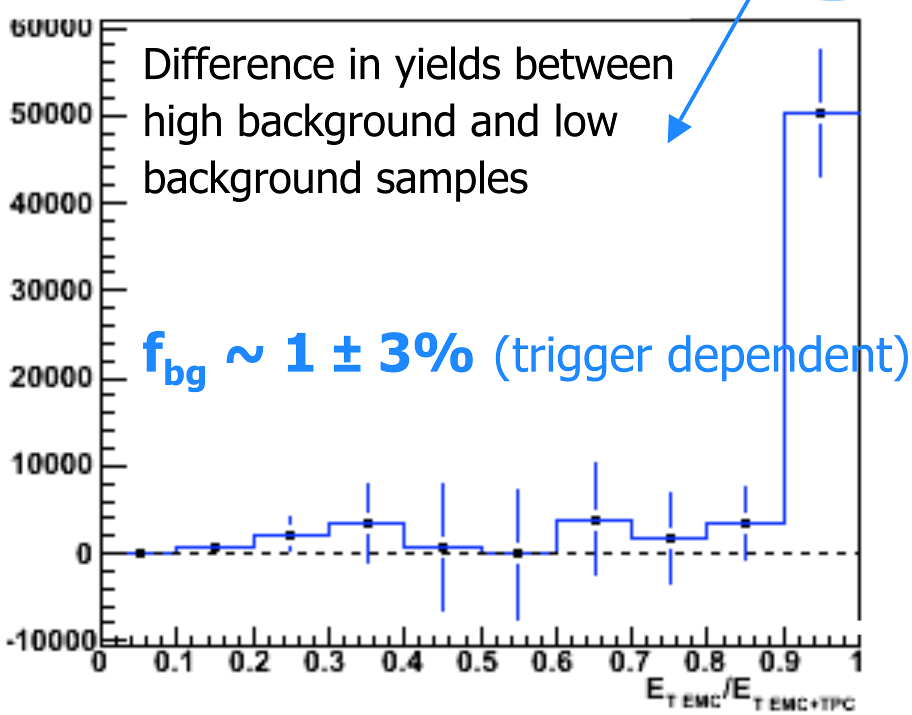
Jet background contribution estimated by measuring:

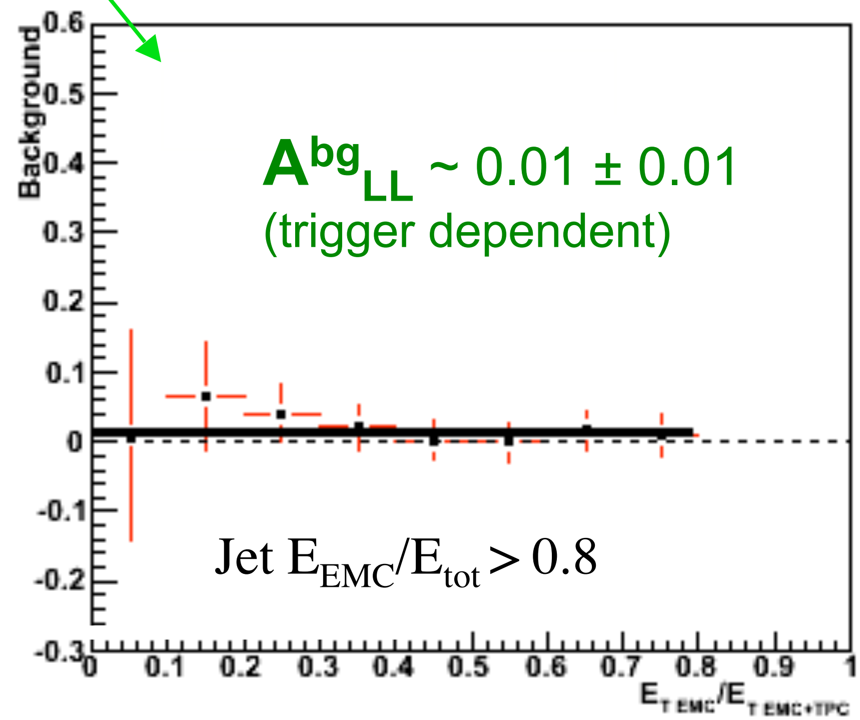
- Background fraction
  - Difference in the distribution of the jet neutral energy fraction for runs with "high" and "low" background
- Asymmetry of high background jets

$$A_{LL}^{meas}(p_T) = \frac{A_{LL}(p_T) + f_{bg}(p_T) \times A_{LL}^{bg}(p_T)}{1 + f_{bg}(p_T)}$$

averaging over triggers,

$\delta A_{LL} < 0.001$



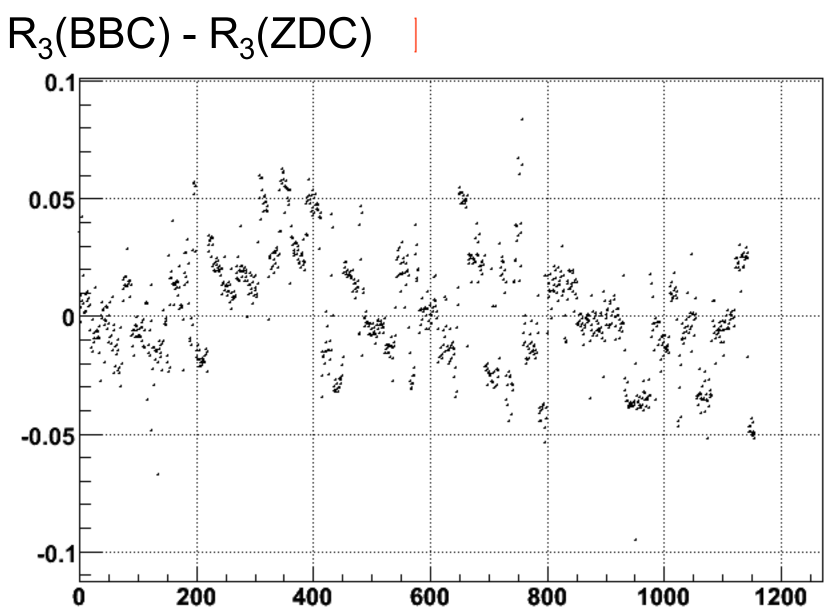


A_{LL} Systematics and Cross-checks: Relative Luminosity

Calculated using the BBC: $$R_3 = \frac{L^{parallel}}{L^{antiparallel}}$$

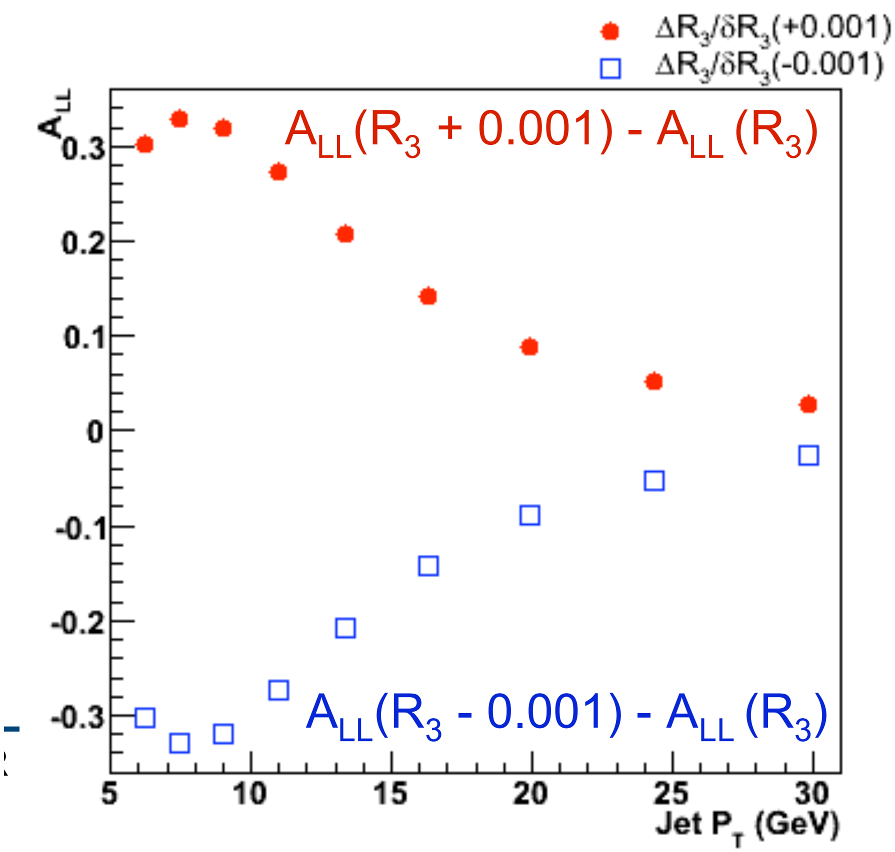
Cross-checked using the Zero Degree Calorimeter (ZDC), another luminosity monitor

Difference (below) interpreted as a systematic on the relative luminosity



Difference between BBC and ZDC is 0.001

Systematic estimated as the difference between $A_{LL}(R_3)$ and $A_{LL}(R_3 \pm 0.001)$



A_{LL} Systematics and Cross-checks: Non-longitudinal Beam Polarization

Non-longitudinal beam polarization changes A_{LL}:

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

To bound this effect,

⇒ Calculate A_Σ from transverse data: **$|A_\Sigma| \leq 0.1$**

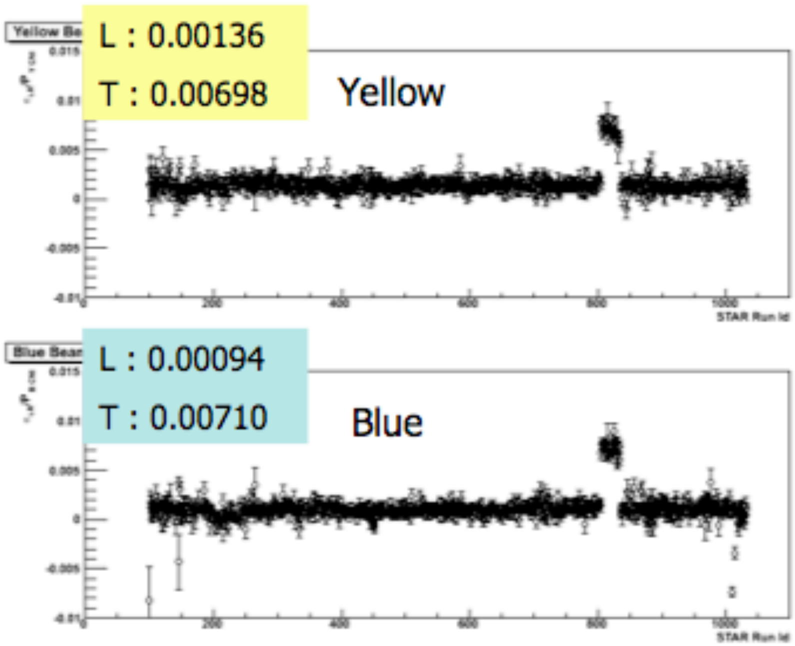
⇒ Estimate the beam transverse polarization component

- Local polarimetry (BBC up-down and left-right asymmetries)

$$\Rightarrow |\delta A_{LL}^{A_\Sigma}| \leq 0.003$$

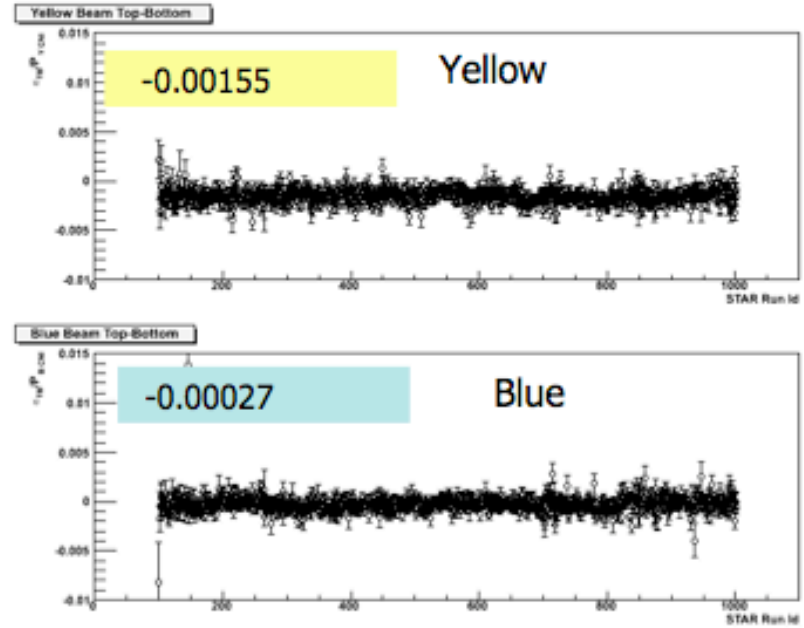
Local Polarimetry

Left Right BBC Asymmetry/ P CNI



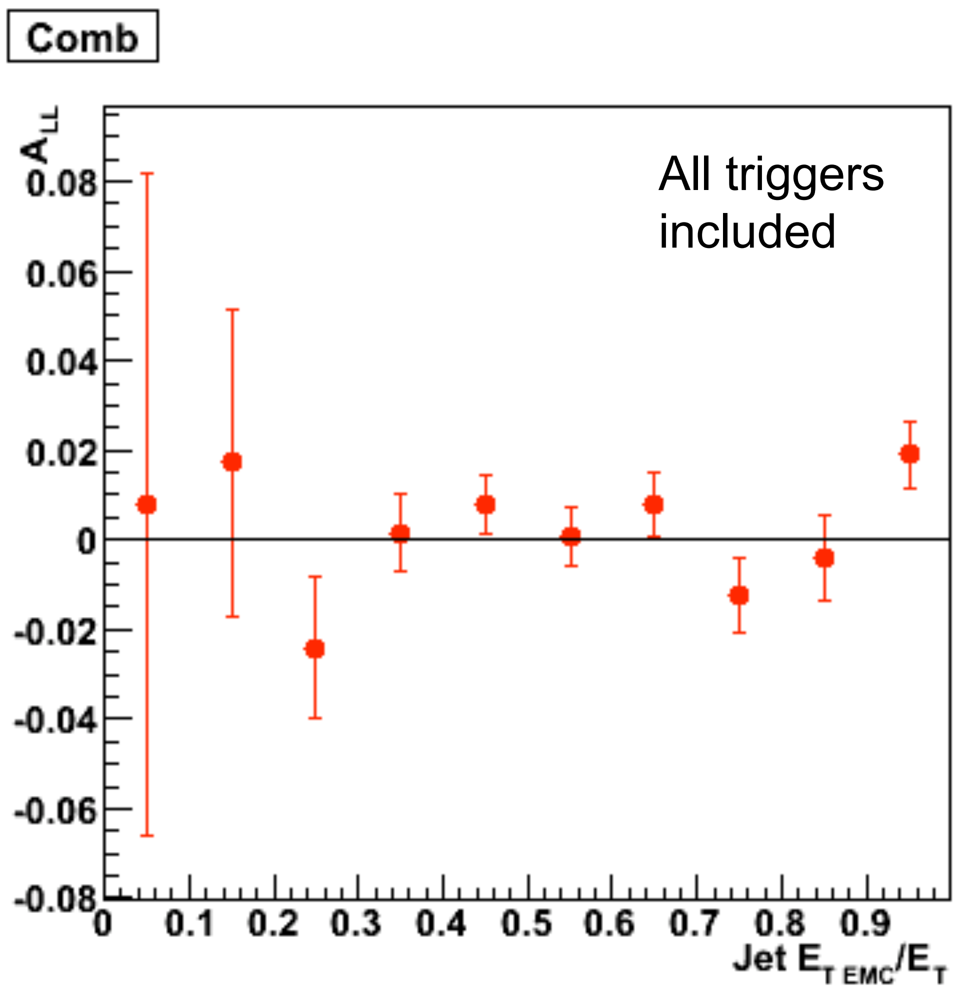
Vertical Component : Yellow 19% , Blue 13%

Top-Bottom BBC Asymmetry/ P CNI

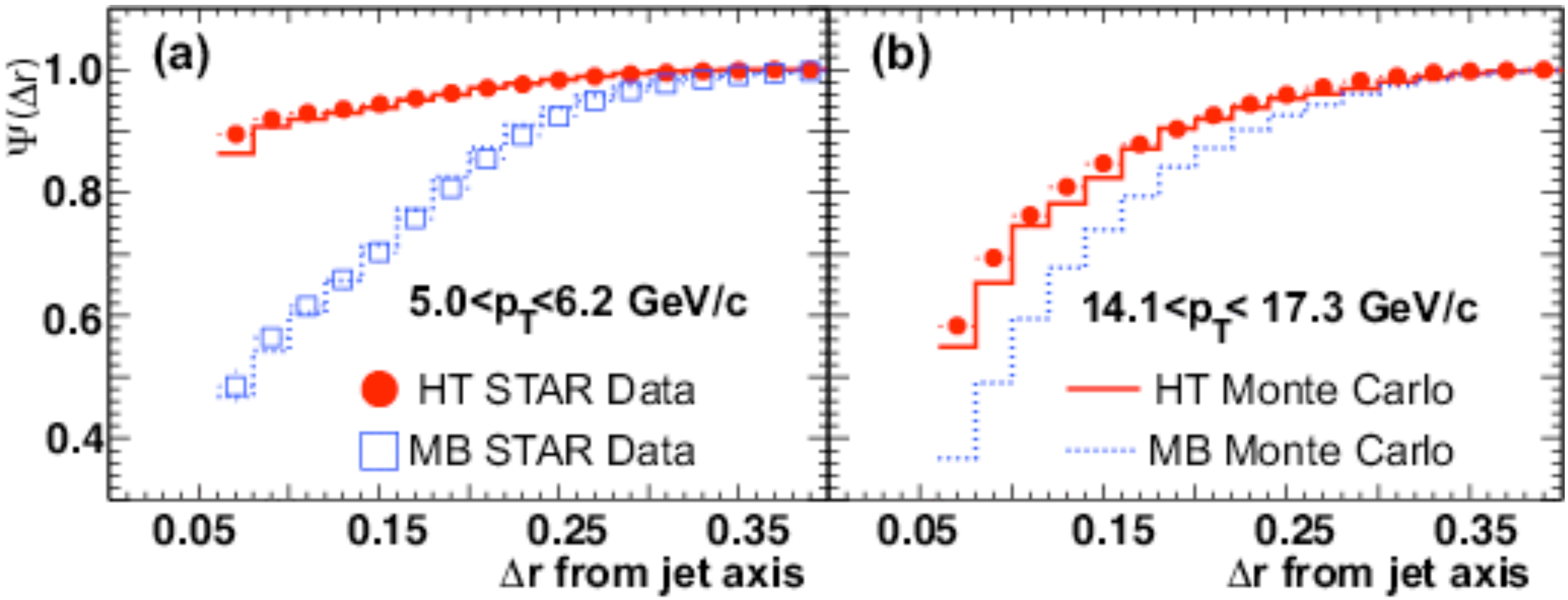


Radial Component: Yellow 22%, Blue 4%

SSA backup: A_{LL} vs Jet Neutral Energy



Jet Ψ(Δr) vs Δr, 2004



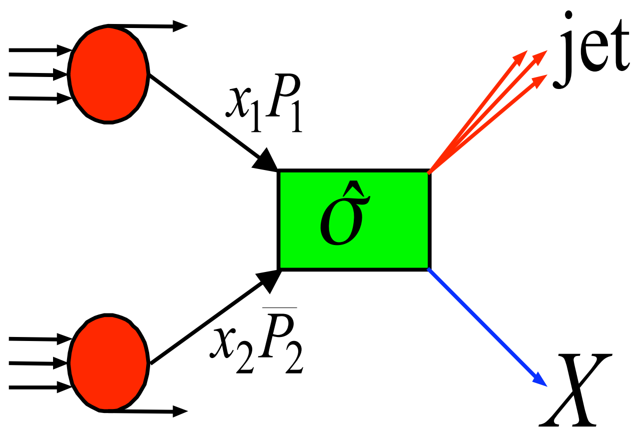
Jet Cross Section and Asymmetry

The polarized cross section for jet production is a convolution:

$$\Delta\sigma(\vec{p}\vec{p} \rightarrow jet + X) = \sum_{a,b,X} \int dx_1 dx_2 \Delta f_{a/A} \Delta f_{b/B} \Delta\sigma(ab \rightarrow cX)$$

Parton distribution: Object of study

Parton-level cross section, fully calculable in pQCD



Reduced sensitivity to fragmentation functions for jet production

Partonic Asymmetry: $\hat{a}_{LL} = \frac{\Delta\hat{\sigma}}{\hat{\sigma}}$

Experimentally relevant: $A_{LL} = \frac{\Delta\sigma}{\sigma} = \frac{\sigma^{\uparrow\uparrow} - \sigma^{\uparrow\downarrow}}{\sigma^{\uparrow\uparrow} + \sigma^{\uparrow\downarrow}} \propto \frac{\Delta f_a \Delta f_b}{f_a f_b} \hat{a}_{LL}$

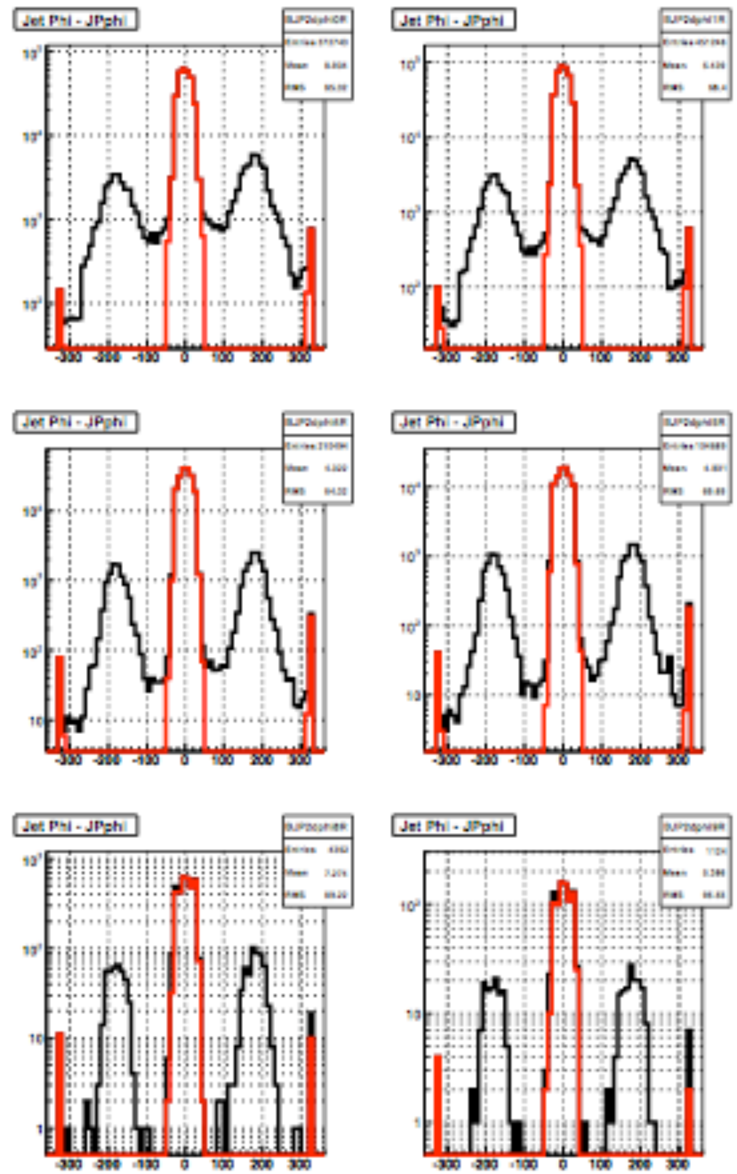
2005 Results: Inclusive Jet A_{LL}

	Spin 2006, preliminary result, STAR inclusive jets								
	All numbers in units of 1e-3 absolute on A_{LL}								
	bin 1	bin 2	bin 3	bin 4	bin 5	bin 6	bin 7	bin 8	bin 9
pt*	5.6	6.9	8.4	10.4	12.8	15.7	19.3	23.8	29.2
A_{LL}	-3.8	2.1	1.7	15.9	-12.4	-5.4	-14.4	-10.6	125.1
stat uncertainty	7.1	6.5	6.7	7.8	10.2	15.0	24.0	41.4	80.4
A_{L}	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Trigger + Smear	3.9	3.7	1.7	0.3	2.7	4.3	6.9	10.9	8.8
Non-longitudinal	3	3	3	3	3	3	3	3	3
Relative Luminosity	2	2	2	2	2	2	2	2	2
Bgd effect on lumi	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Bgd effect on yield	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Random Pattern	0	0	0	0	0	0	0	0	0
dominant sys	6.5	6.5	6.5	6.5	6.5	6.5	6.9	10.9	8.8
quad sys sum	8.5	8.4	7.7	7.5	8.0	8.6	10.2	13.2	11.6
	* Middle point of the histogram bin: = max - min								

Cuts: Software trigger

Removes jets which (depending on trigger)

1. sit outside 40 degrees from the triggering jet patch center, or
2. do not contain a trigger tower



Reduces statistics by 6.5%

- Reduces monojet events by 1.2%
- Reduces multiple jet events by 76.5%

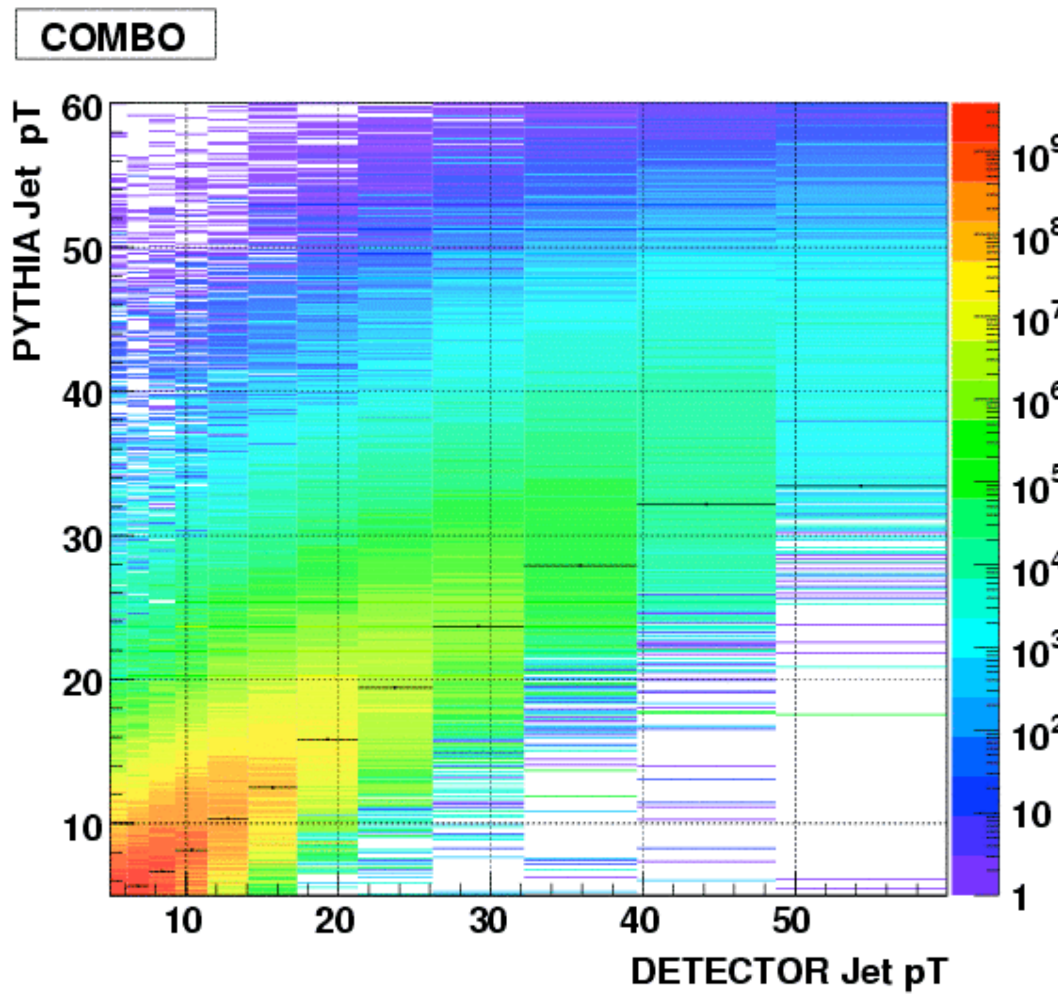
Plots are PYTHIA simulation

Black is the distribution of $(\varphi_{jet} - \varphi_{jet\ patch})$ without the cut

Red is with the cut

pT bin smearing

The detector gives a biased measurement of jet pT.
The amount of this bias has been calculated using PYTHIA:



The overall shift of each p_T bin is ~20-30%

Random Pattern Analysis

The random pattern analysis randomly creates new spin states for every run. 1000 random patterns were used. The RMS of the distribution of the ε_{LL}s is smaller (within error) than the statistical error, so the systematic error from bunch-dependent correlations is zero.