

Extracting the Gluon Piece of the Spin Puzzle

*New Inclusive Jet
Results From*



Renee Fatemi

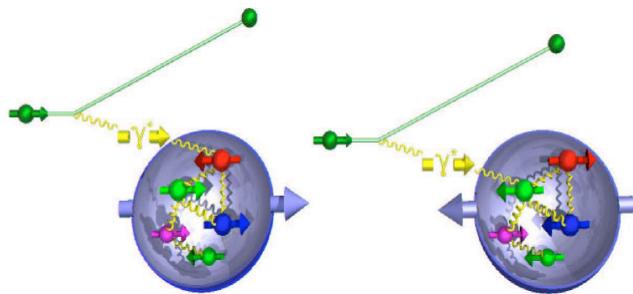
Massachusetts Institute of Technology

April 17, 2007

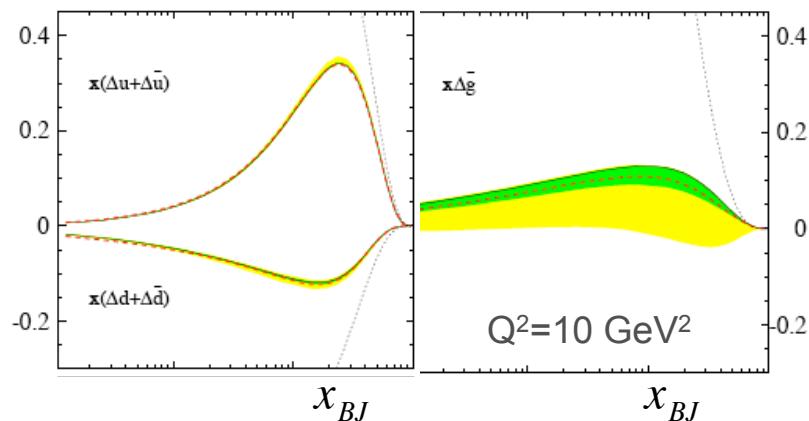


Asymmetries Access Spin Degrees of Freedom

30 years of DIS

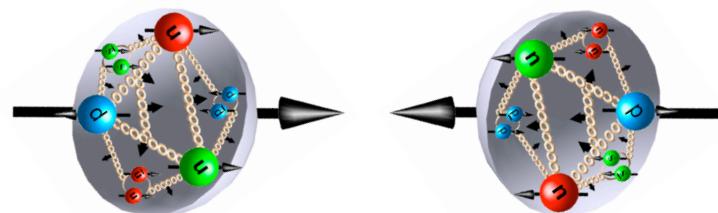


$A_{LL} \rightarrow \text{Quarks} = 25\%$

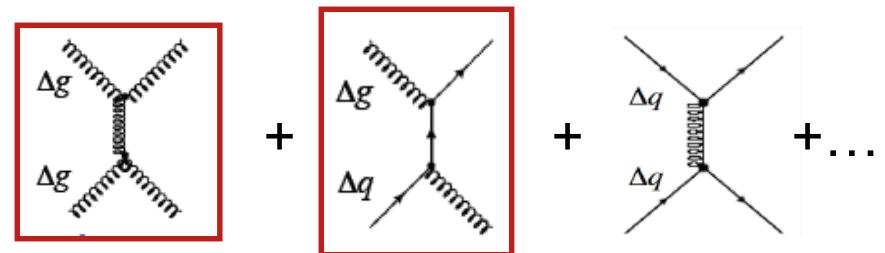


de Florian et al. Phys. Rev. D71 094018 (2005)

RHIC



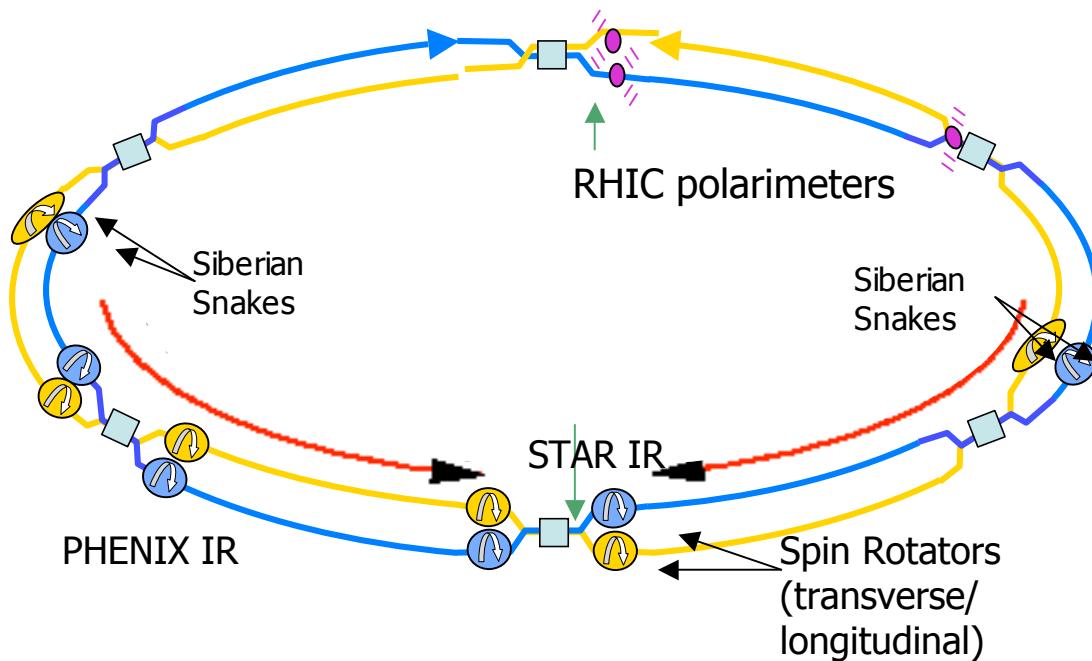
$$A_{LL} = \sum_{f_A f_B f_C} \frac{\Delta f_A \Delta f_B \times \Delta \sigma_{AB \rightarrow CX} \times D_C}{f_A f_B \times \sigma_{AB \rightarrow CX} \times D_C}$$



Access Gluon at Leading Order!

Relativistic Heavy Ion Collider

...world's 1st $\vec{p}\vec{p}$ Collider

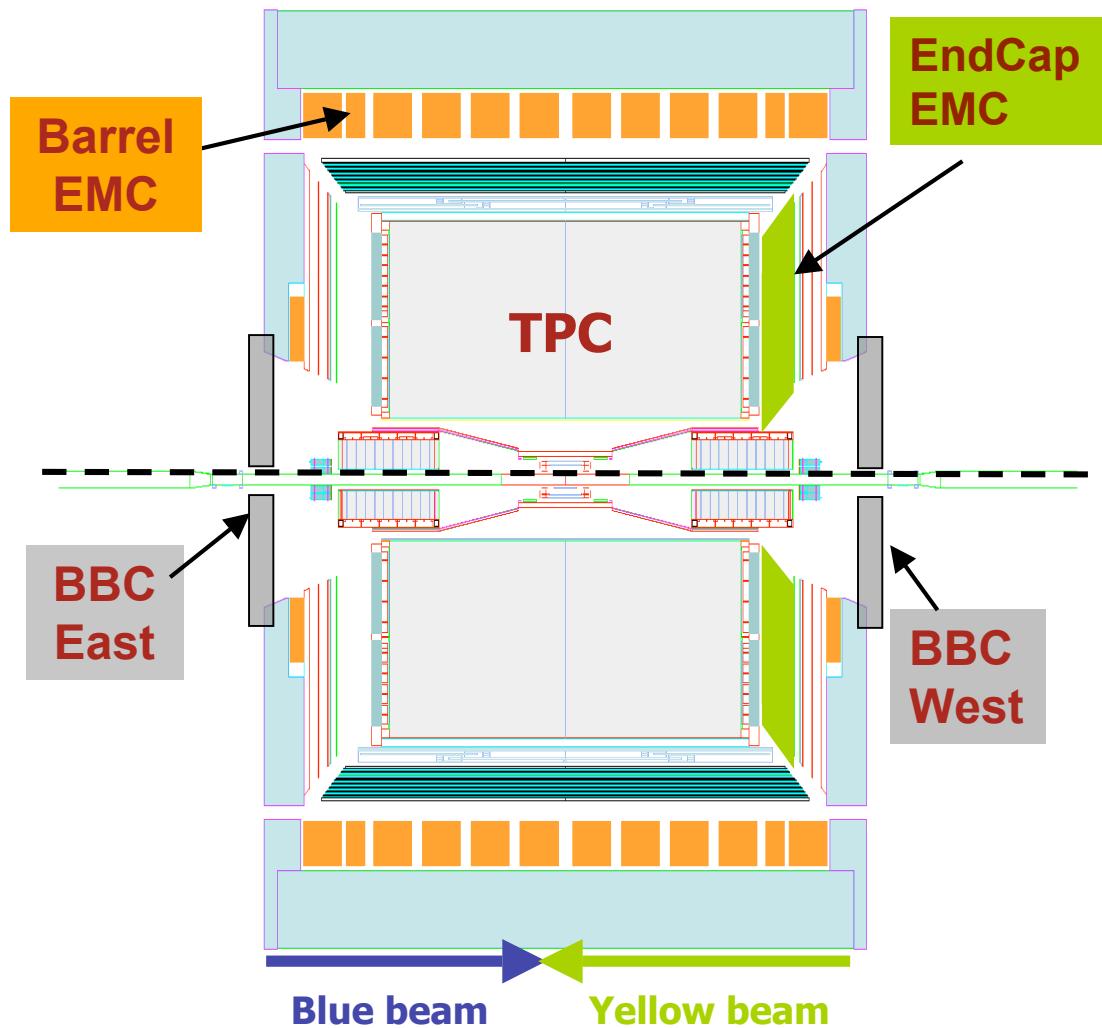


- 100 GeV beam proton beams
- Each bunch filled with a distinct polarization state
- Spin Rotators at STAR IR allow for transverse and longitudinal spin orientation
- Bunch Xings every 100-200ns
- CNI polarimeters + Hydrogen Jet target provide run by run & absolute polarization

pp Run Year	FOM= P^4L	2002	2003	2004	2005	2006
< Polarization> %		15	30	40-45	45-50	60
L_{max} [$10^{30} \text{ s}^{-1} \text{cm}^{-2}$]		2	6	6	16	30
L_{int} [pb^{-1}] at STAR (L/T)		0 / 0.3	0.3 / 0.25	0.4 / 0	3.1 / 0.1	8.5 / 3.4, 6.8



Detector at RHIC



TPC $ \eta < 1.4$	Charged particle momentum
BEMC $ \eta < 1.0$	Neutral Energy High pT Trigger
EEMC $1 < \eta < 2$	Neutral Energy High pT Trigger
BBC $3.4 < \eta < 5$	MinBias Trigger Relative Lumi (also ZDC)

$$\eta = -\ln[\tan(\Theta/2)]$$



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Trigger

Composition of $\vec{p}\vec{p}$ Events

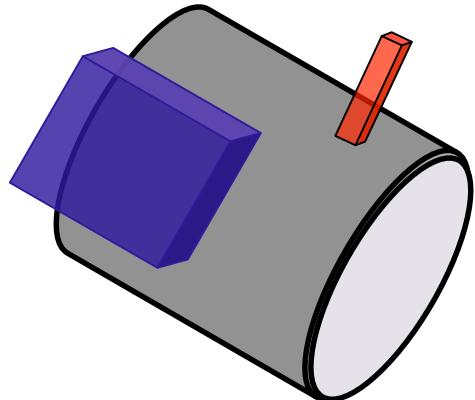
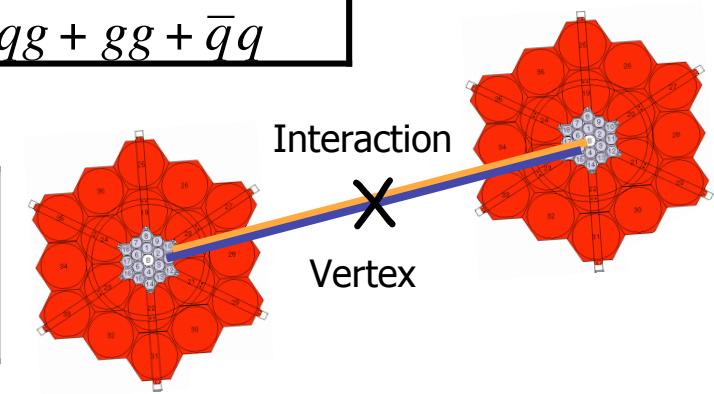


Mother Nature

Elastic, single+doubly diffractive,
hard scattering $\rightarrow qq + qg + gg + \bar{q}q$

Minimum Bias

Requires in-time hit in ExW BBC.
Very little change in hard
scattering process mix



High Tower

1 tower ($\Delta\eta = \Delta\phi = 0.05$) above threshold
Requires hard neutral fragmentation

Jet Patch (2005/6 only)

400 localized towers ($\Delta\eta = \Delta\phi = 1$) above
threshold. Allows for cluster of softer
fragmentation

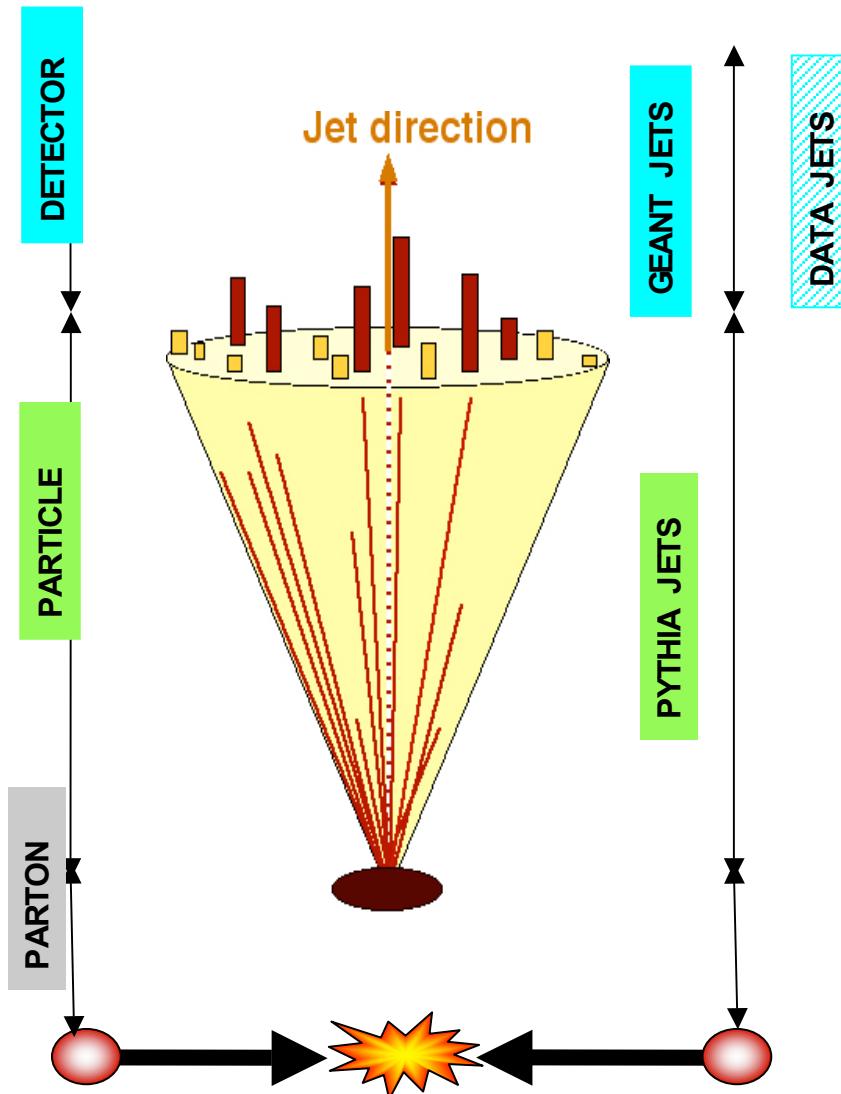




STAR Jet Algorithm

Midpoint Cone Algorithm (hep-ex/0005012)

- Collinear and infrared safe -



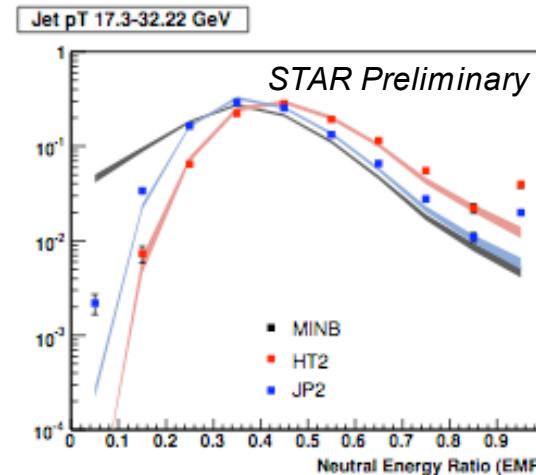
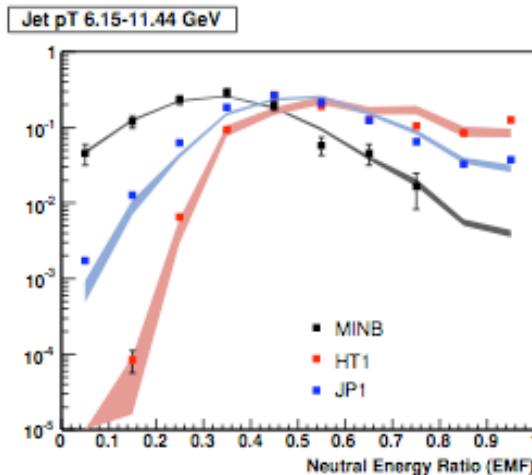
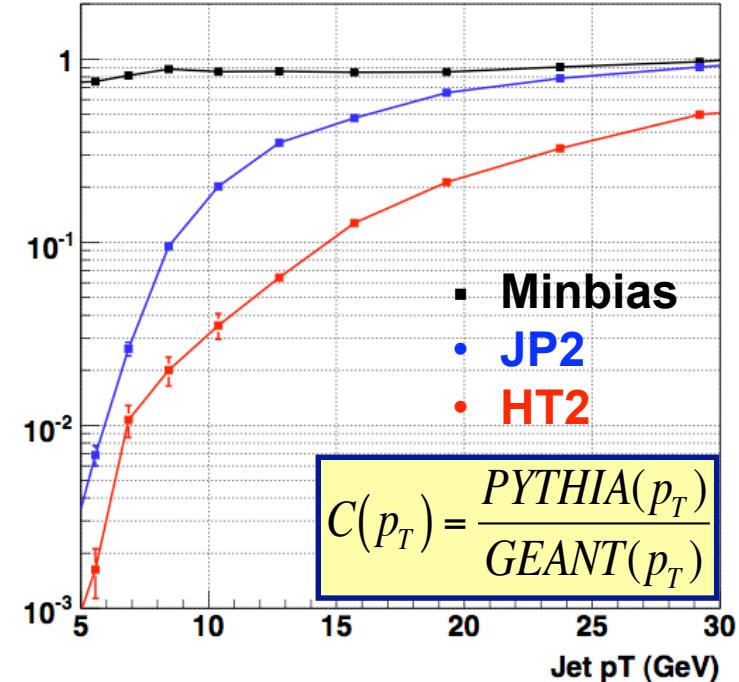
- Jet Cone Radius = 0.4
- Split/Merge = 0.5
- Neutral Energy Cut $R < 0.8(0.9)$ to remove backgrounds
- Use Simulation (MC) to provide correction to RAW jet yield
PYTHIA 6.205 (CDF Tune A) + GEANT (Geisha)

$$\text{Corrected Jet Yield} = \frac{\text{DATA JETS}}{\text{PYTHIA JETS}} \times \frac{\text{PYTHIA JETS}}{\text{GEANT JETS}}$$

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Inclusive Jet Cross-Section Analysis

- Use Simulation (MC) to provide correction to RAW jet yield
 - trigger and jet inefficiencies
 - jet resolution & bin migration
 - undetected particles ($n + \nu$)
 - PYTHIA 6.205 CDF Tune A
 - GEANT (Geisha)
- Verification of DATA/MC agreement essential

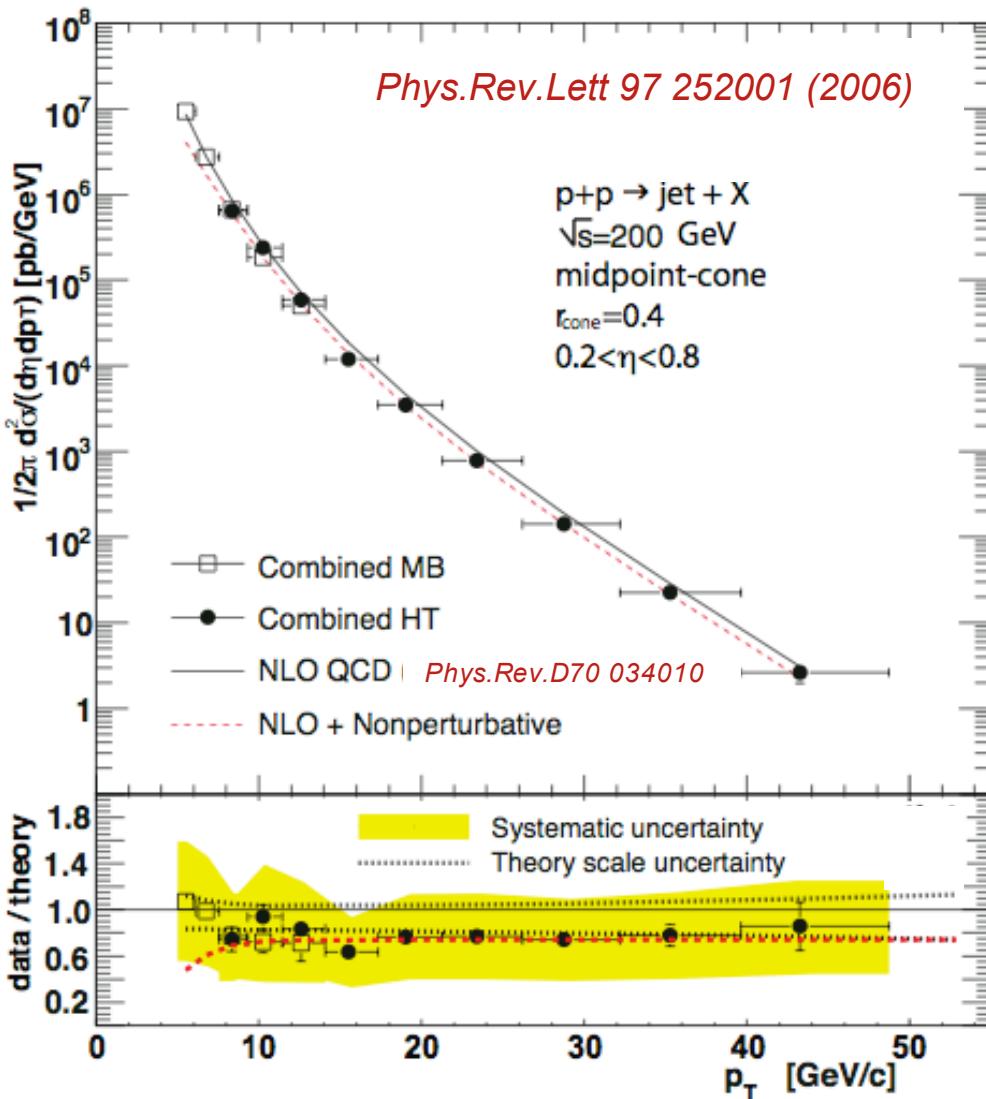


The shape of the Fraction of Neutral Energy in the Jet (EMF) is sensitive to the trigger bias as well as contributions from beam background.



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2003/2004 Inclusive Jet Cross-Section Results

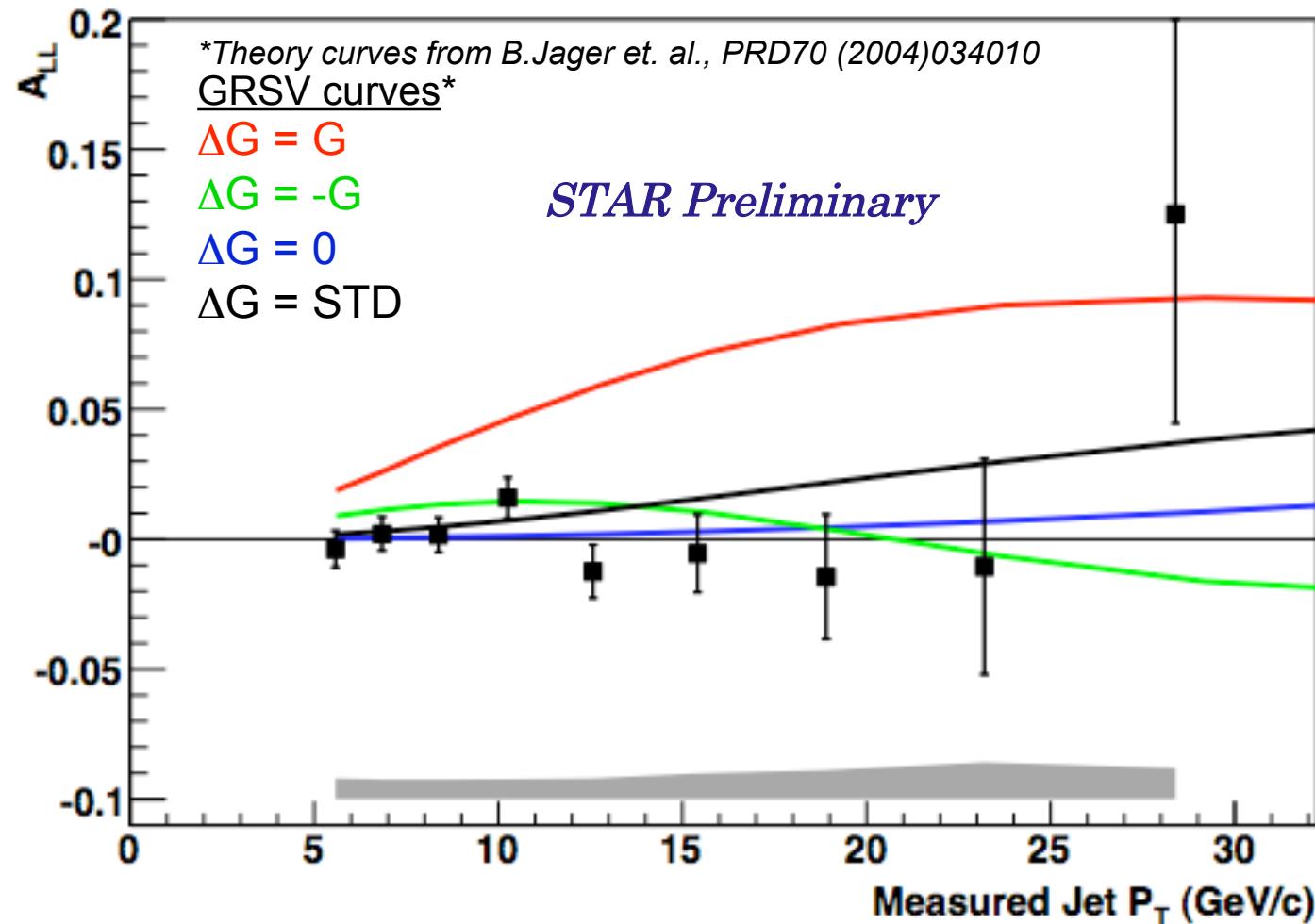


$$\frac{1}{2\pi} \frac{d^2\sigma}{d\eta dp_T} = \frac{1}{2\pi} \cdot \frac{N_{\text{jets}}}{\Delta\eta \Delta p_T} \cdot \frac{1}{\int L dt} \cdot \frac{1}{c(p_T)}$$

- 3 point overlap between HT and MINB show good agreement.
- 50% systematic shown in yellow band comes from uncertainty in jet energy scale. Need π^0 and/or gamma-jet to reduce this error.
- Application of hadronization correction removes systematic offset from NLO and data.
- **Agreement good within systematics over 7 orders of magnitude**

2005 Inclusive Jet A_{LL}

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



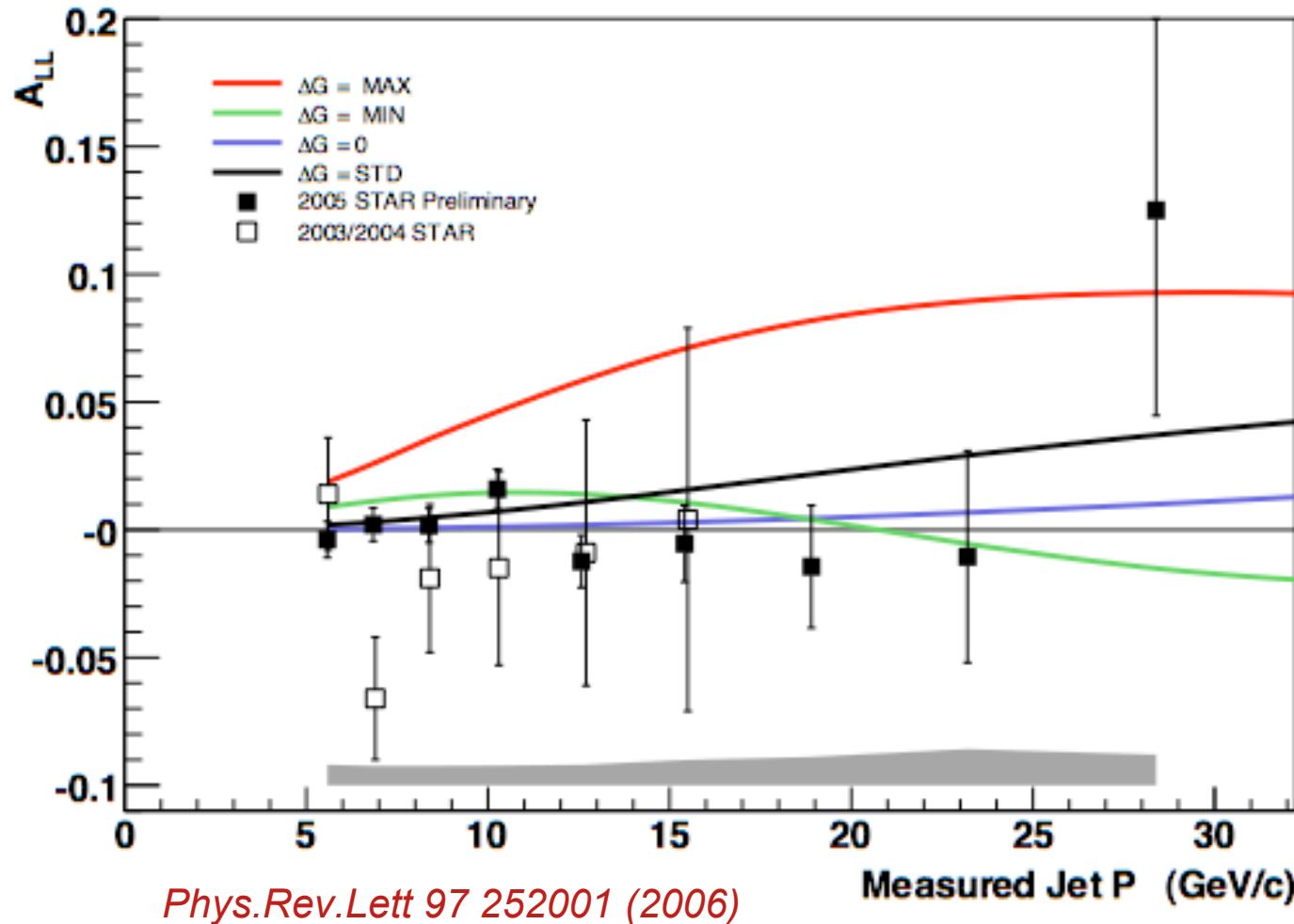
Systematic band does not include 25% scale error from polarization



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2005 Inclusive Jet A_{LL}

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



2005 A_{LL} is consistent with previous 2003/2004 results.

2005 Jet A_{LL} Systematics

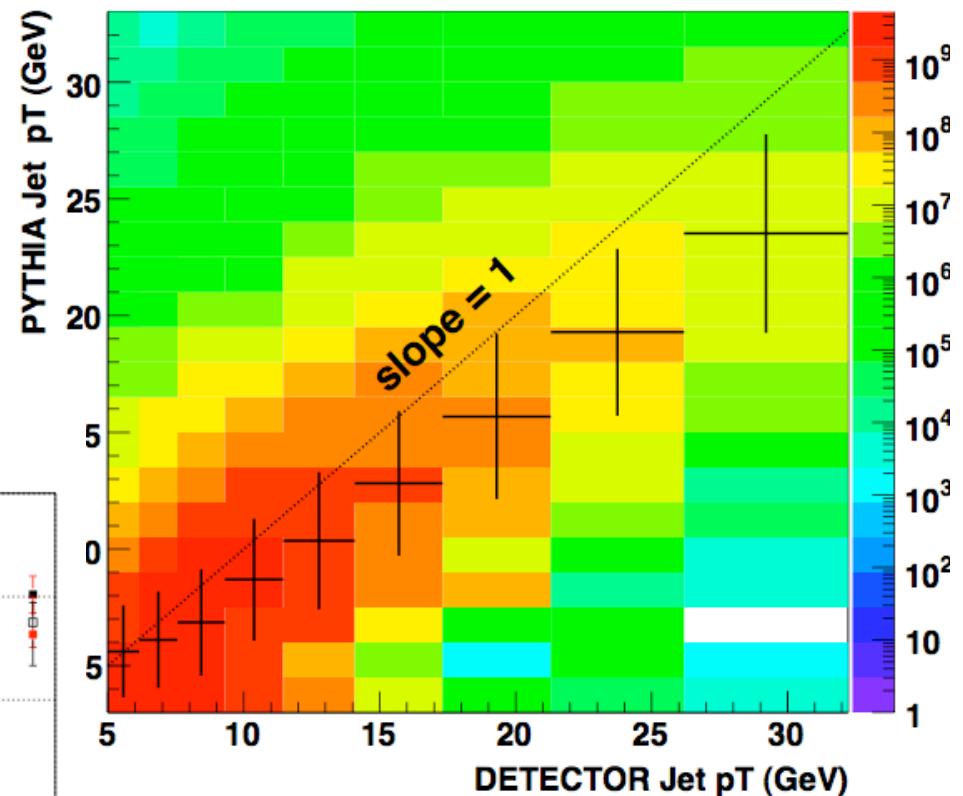
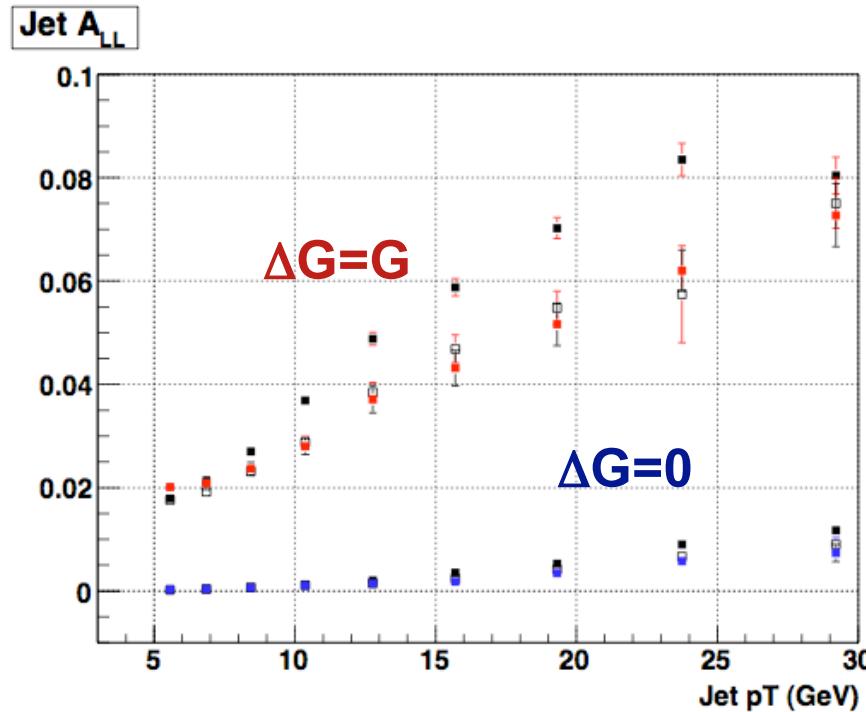
effect	(x 10 $^{-3}$)
False Asymmetries	<6.5
Reconstruction + Trigger Bias	2-12 (p_T dependent)
Non-longitudinal Polarization	3
Relative Luminosity	2
Backgrounds	<1



Jet Resolution

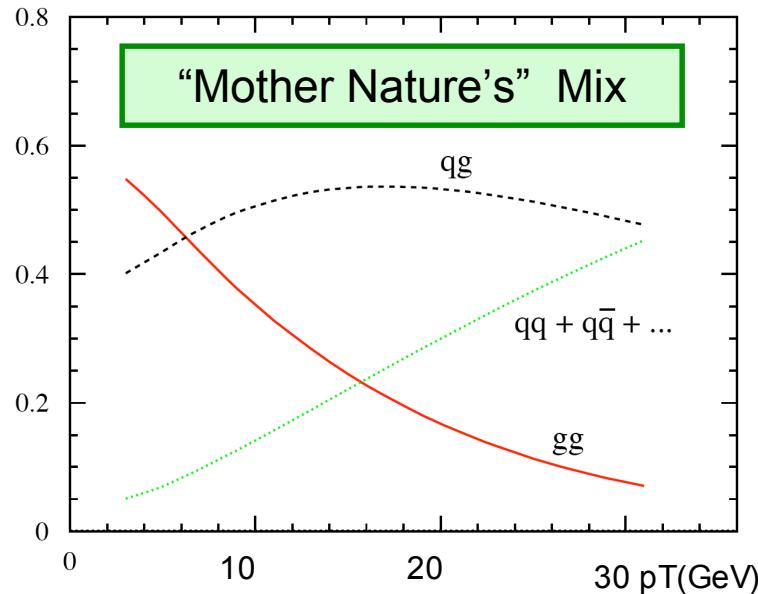
On average PARTICLE Jets are reconstructed in the DETECTOR with **20% increase in pT**

REASON: ~25% Jet Resolution +
Steeply falling jet pT distribution

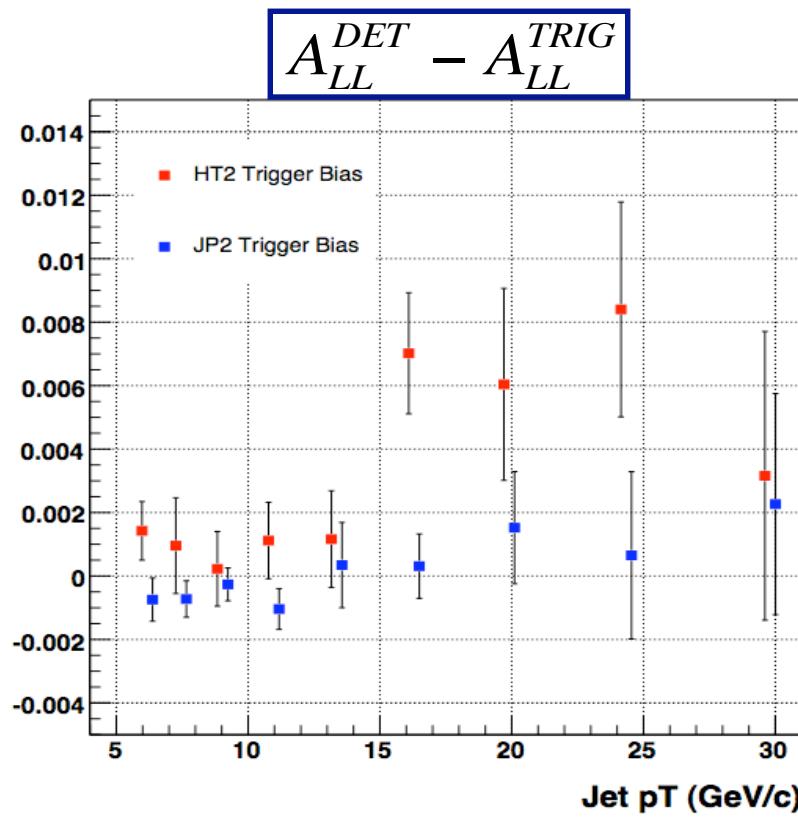


Systematic offsets in pT cause dilutions of the jet asymmetry which depend on the size of the asymmetry!

Jet A_{LL} Systematics: Trigger Bias



The trigger biases jets toward higher neutral energy. This may change nature's mix of $qq+qg+gg$ and therefore change the asymmetries



Trigger Bias:

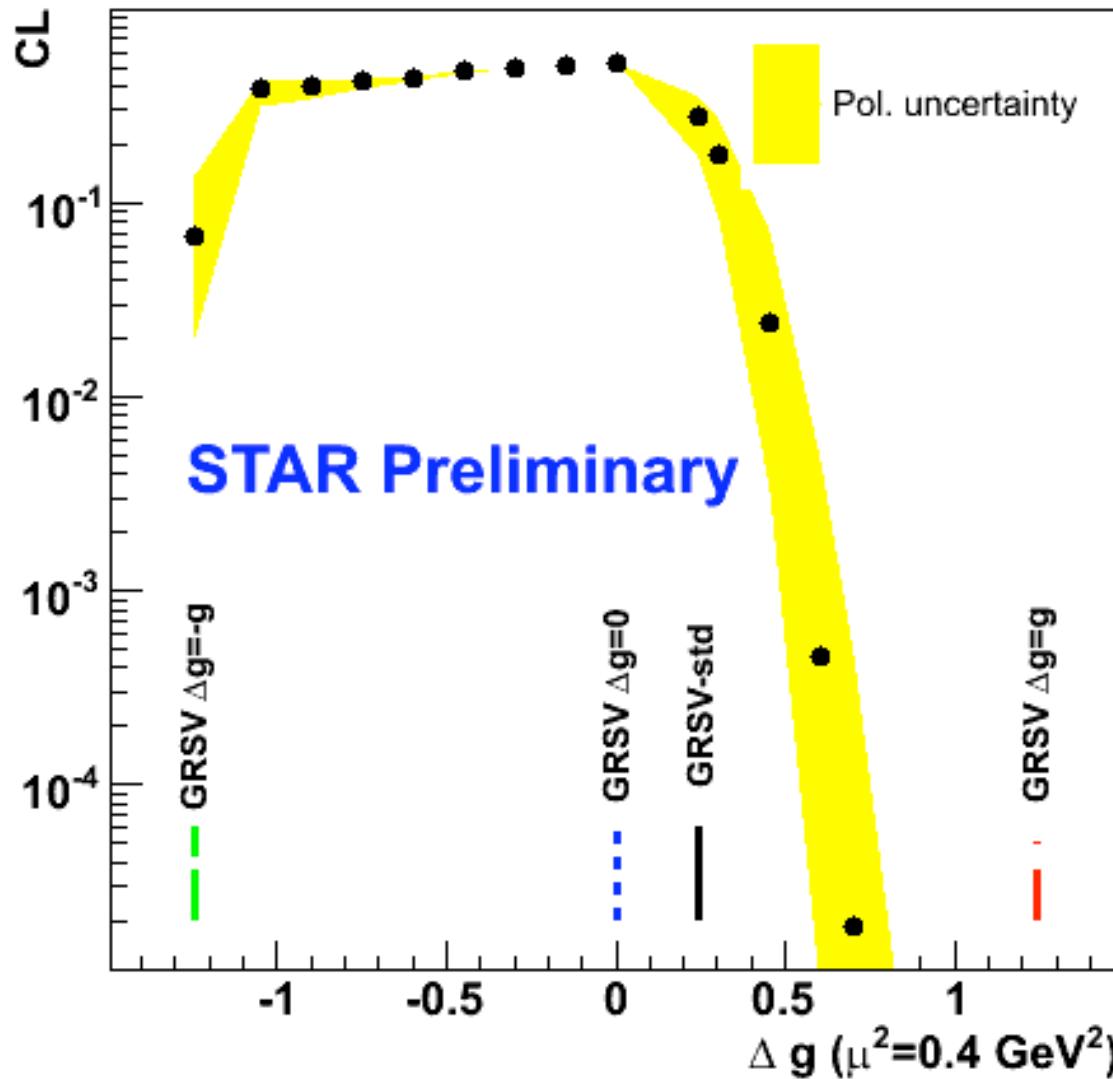
- $JP \ll HT$
- $\Delta A_{LL}/A_{LL} \rightarrow$ larger at low pT

Total Systematic:

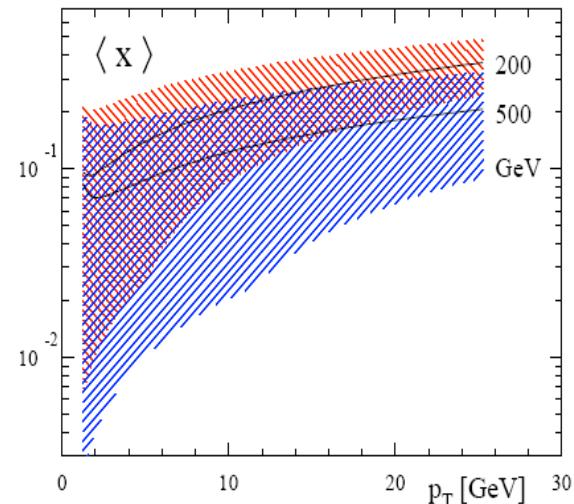
$$\delta A_{LL} = A_{LL}^{PARTICLE} - A_{LL}^{TRIGGER}$$



Constraints on ΔG



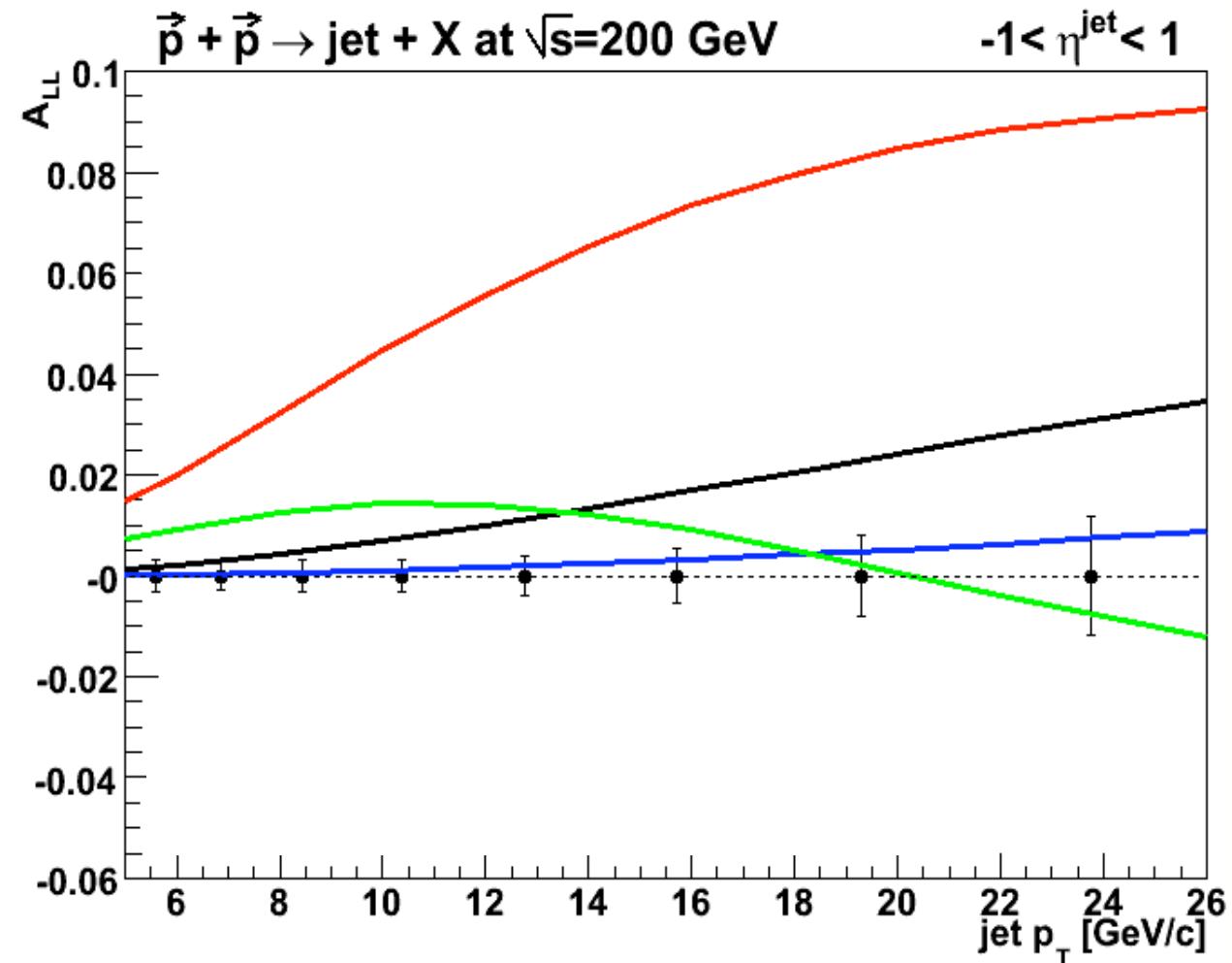
*Uncertainties from $\Delta g(x)$
shape and pQCD scale
not included*



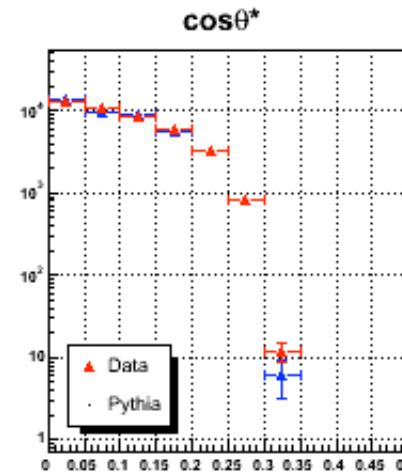
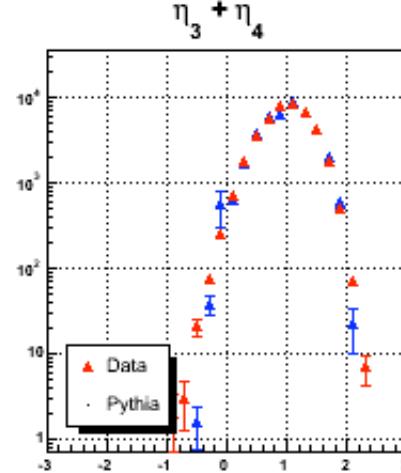
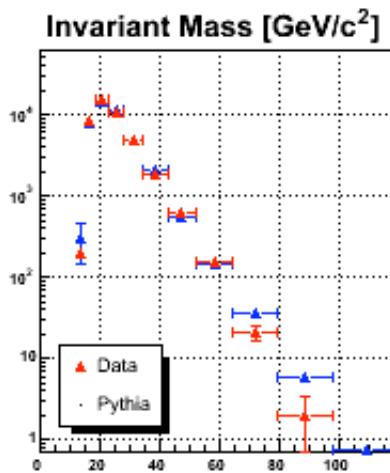
GRSV DIS best fit = 0.24
 $1\sigma = -0.45 \text{ to } 0.7$
Phys.Rev.D63 094005 (2001)

Estimated 2006 Inclusive Jet Asymmetry Sensitivity

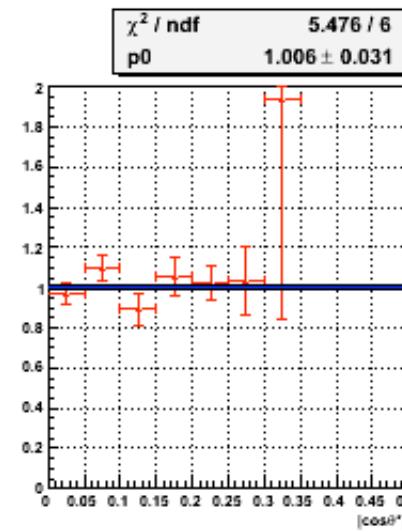
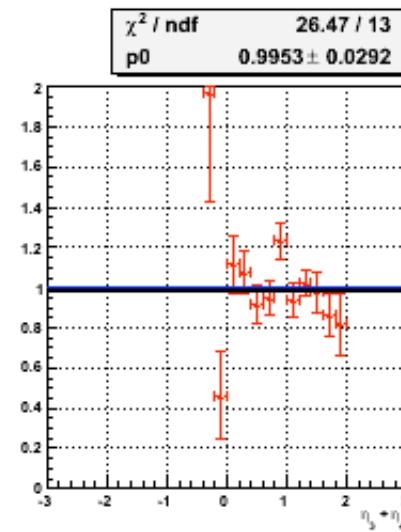
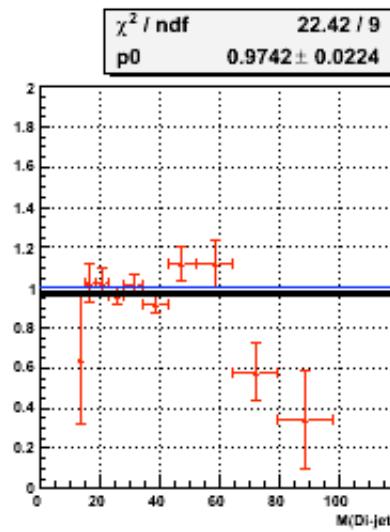
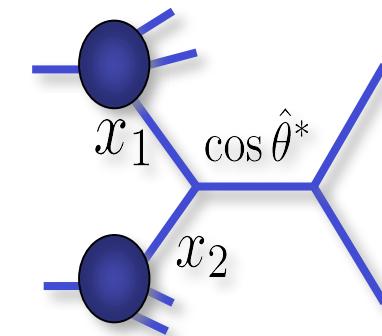
- Increase in sampled luminosity
- Polarization $\sim 60\%$ (FOM is P^4L)
- Entire BEMC instrumented
- Beamline shielding installed
- Greater emphasis on high p_T jets and dijets with triggers



Di-jet Analysis \Rightarrow Access to Partonic Kinematics



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



Data/MC comparison complete.
'05+'06 X-sec & A_{LL} in progress!



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Take Away

- The RHIC spin program accesses ΔG directly through inclusive jets as well as charged and neutral hadrons
- STAR inclusive Jet Asymmetries provide a significant contribution to the global understanding of ΔG
- The inclusive jet measurement is still statistics limited
- The STAR Spin program is entering a very rich phase of correlation and direct photon measurements, while continuing to expand the p_T reach of the inclusive channels.
- A Global Analysis incorporating the world dataset, along with future precision measurements in x space, are needed to provide a complete and definitive answer.



BACKUP

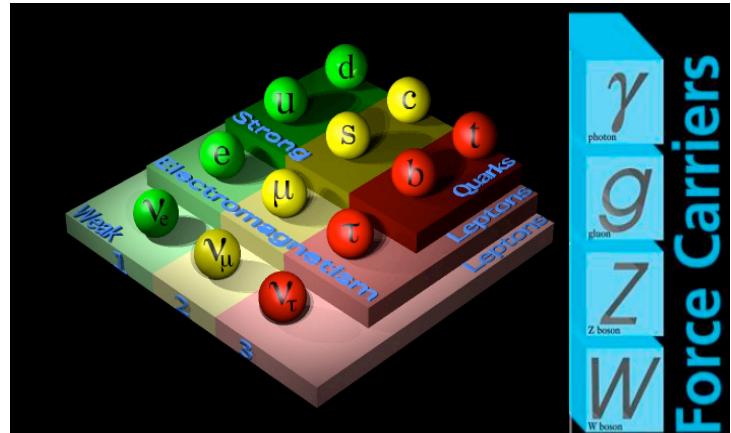


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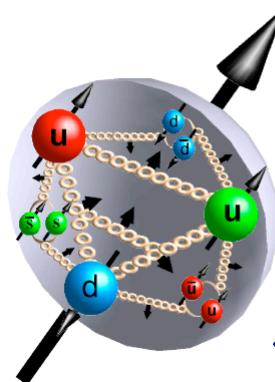
The Spin Puzzle → Key Question in Standard Model QCD



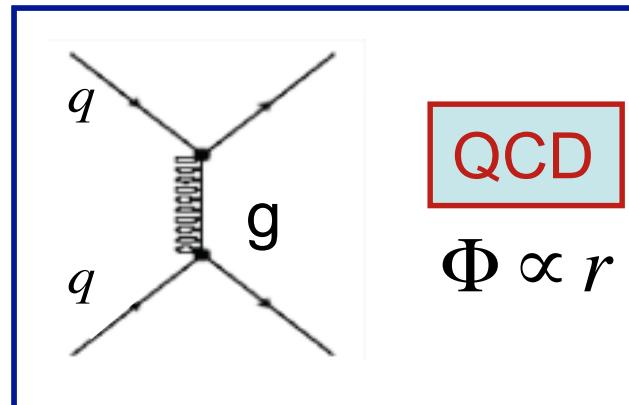
spin 1/2 spin 1



How do partonic degrees of freedom - mass, charge, color, **SPIN** - manifest as the nucleon degrees of freedom?

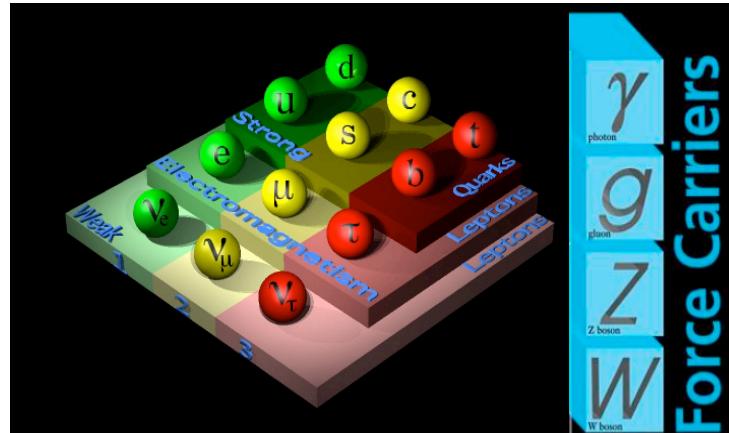


99.5% of mass of the visible universe composed of quarks and gluons - the building blocks of the nucleon



No access to free partons due to confinement! The proton is a stable and abundant source of partons

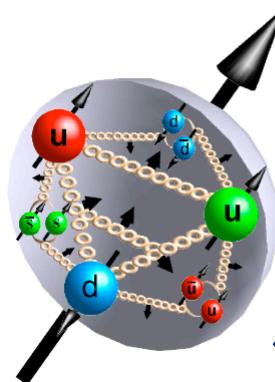
The Spin Puzzle → Key Question in Standard Model QCD



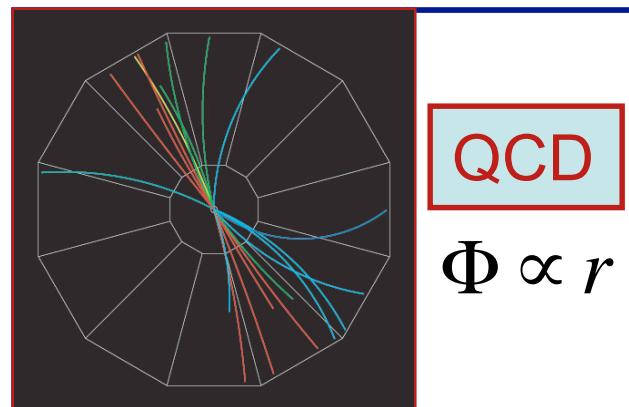
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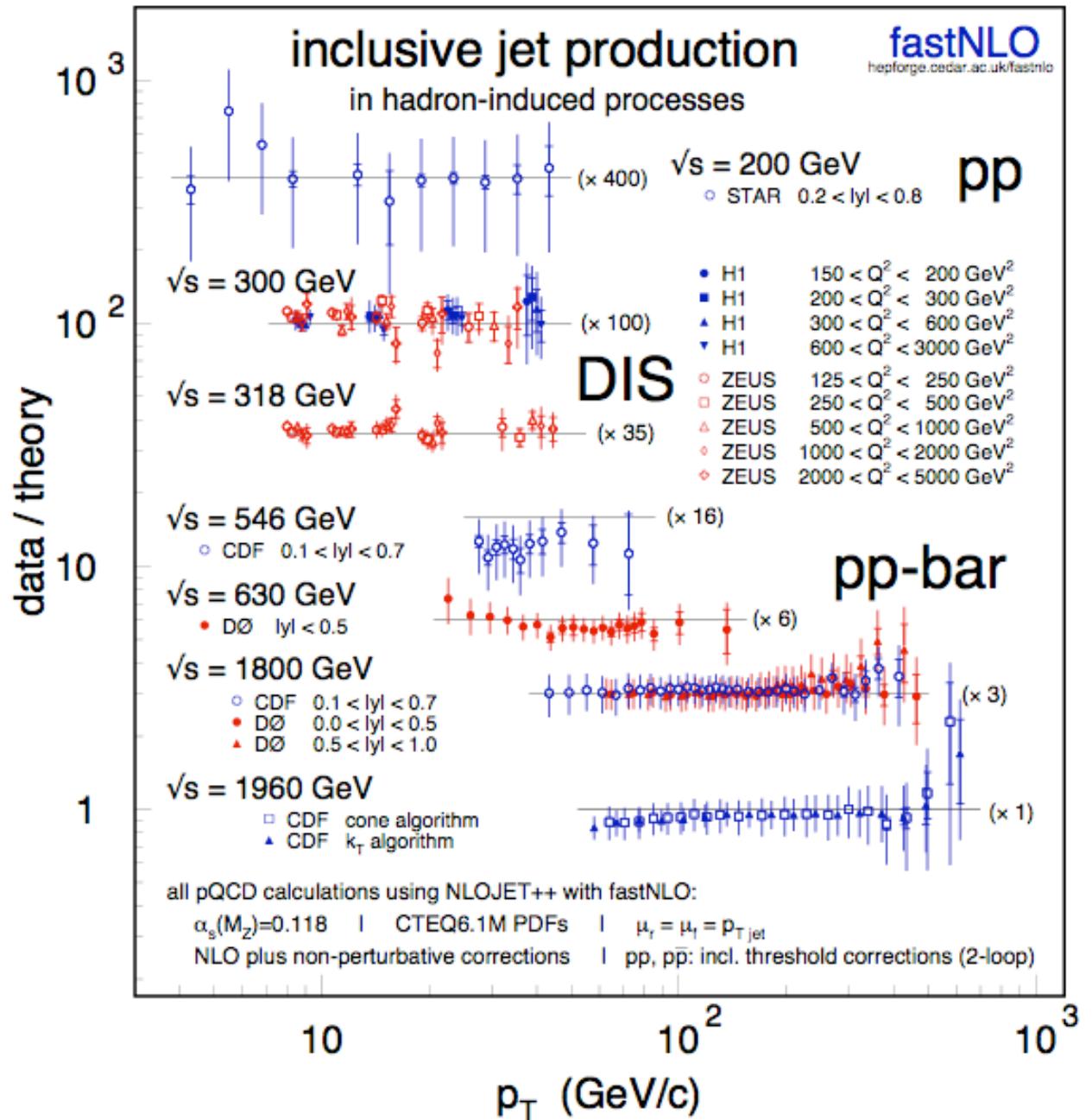


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Comparison to World Data

STAR results are in good agreement with fastNLO theory
(hep-0609285)

Essential to provide high x pdfs as A_{LL} results push to higher pT!



A_{LL} Systematics: False Asymmetries

$$A_{LS} = \frac{N^{++} - N^{--}}{N^{++} + N^{--}}$$

$$A_{US} = \frac{N^{+-} - N^{-+}}{N^{+-} + N^{-+}}$$

Parity Violating and Single Spin Asymmetries should be negligible at current RHIC energies and statistics

$$A_L^Y = \frac{N^{Y+} - N^{Y-}}{N^{Y+} + N^{Y-}}$$

$$A_L^B = \frac{N^{B+} - N^{B-}}{N^{B+} + N^{B-}}$$

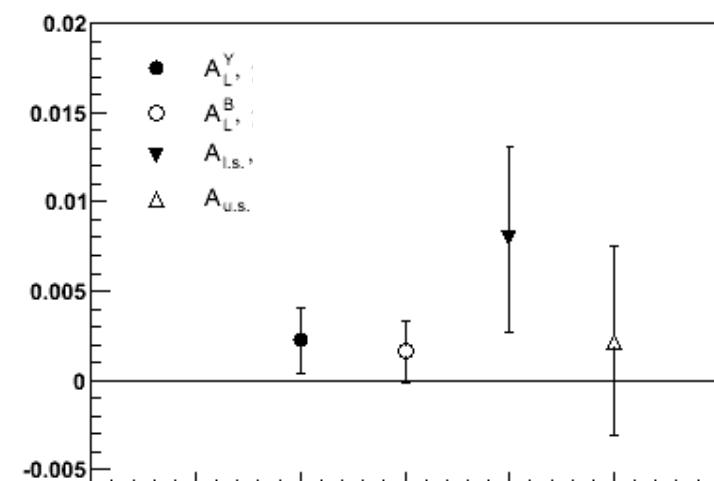
We observe **1-3 σ** single spin asymmetries, depending on the neutral energy cut.

Source of these asymmetries still unclear

A^Y and A_{LS} non zero - Suggests caused by **one anomalous spin state**

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

- $\delta A_{LL} \propto A_{\text{l.s.}}/2$
- $A_{\text{l.s.}} = 7.9 \pm 5.2 \times 10^{-3} \Rightarrow \delta A_{LL} < 0.0065$



A_{LL} Systematics: 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)

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



A_{LL} Systematics: Relative Luminosity

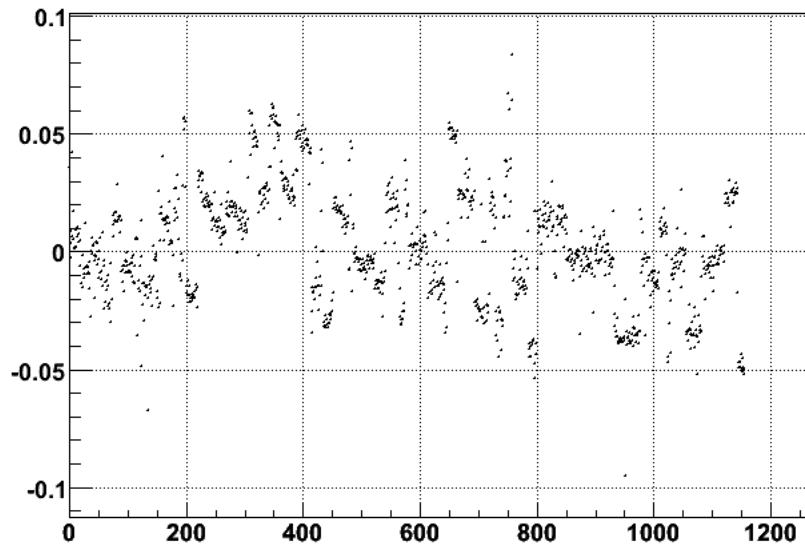
Calculated using the BBC:

$$R_3 = \frac{L^{parallel}}{L^{antiparallel}}$$

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

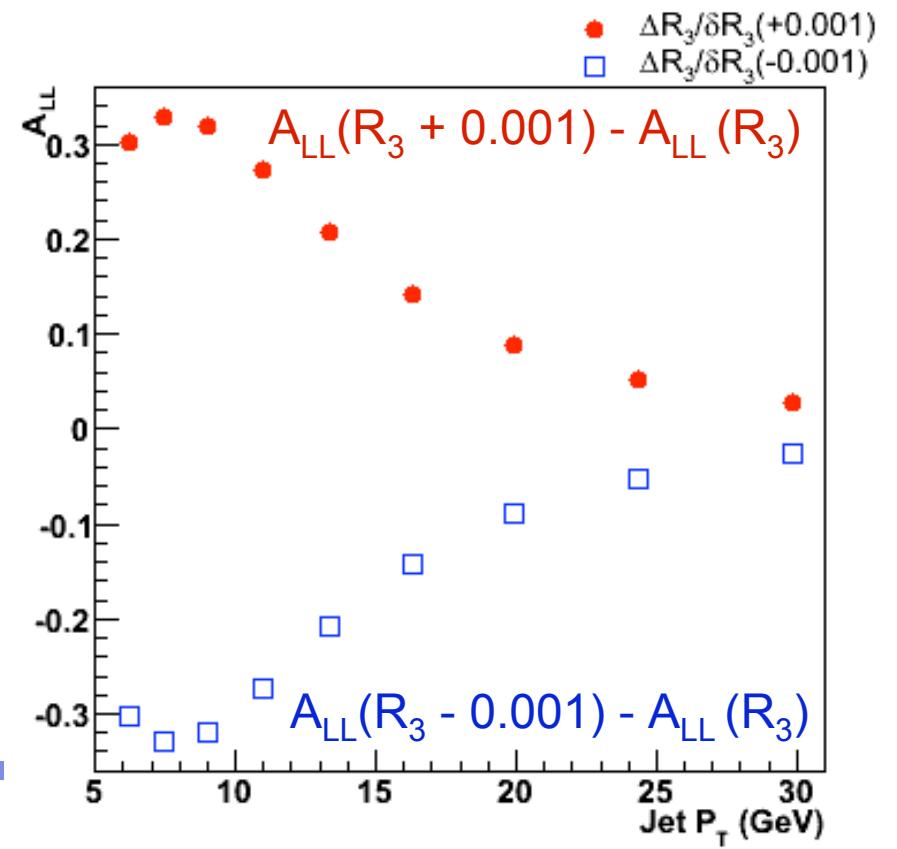
Difference (below) interpreted as a systematic on the relative luminosity

$R_3(\text{BBC}) - R_3(\text{ZDC})$



Difference between BBC and ZDC is 0.001

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



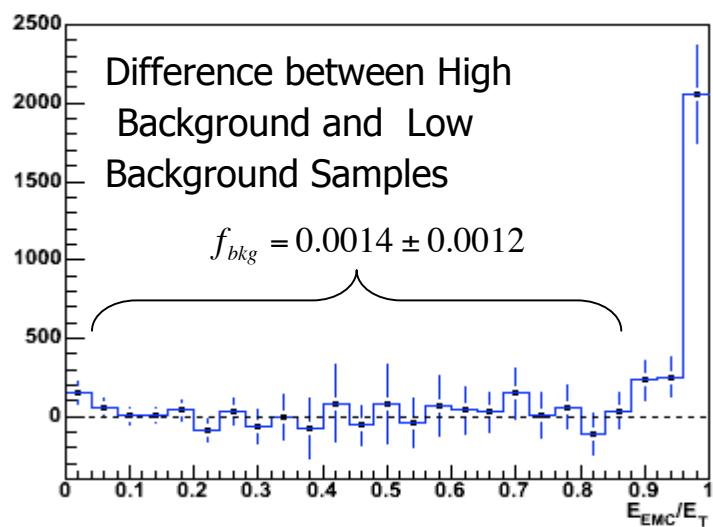
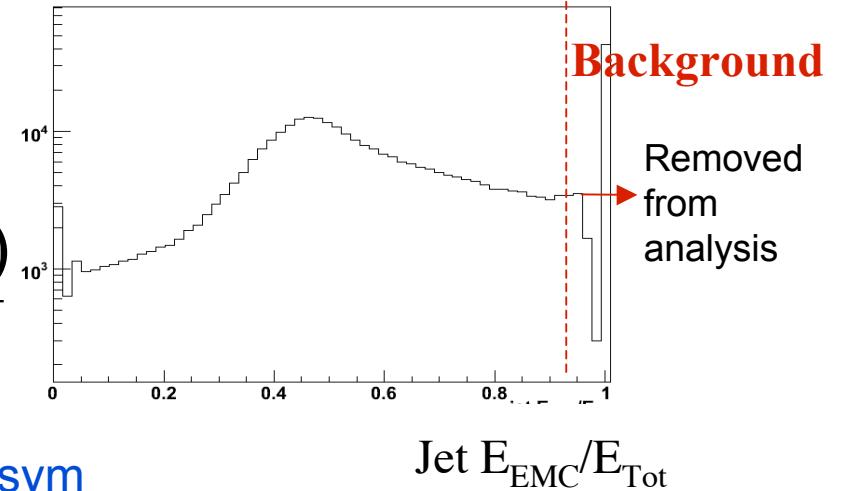
A_{LL} Systematics: Background Estimate

Background manifests itself as jets with large neutral energy deposit

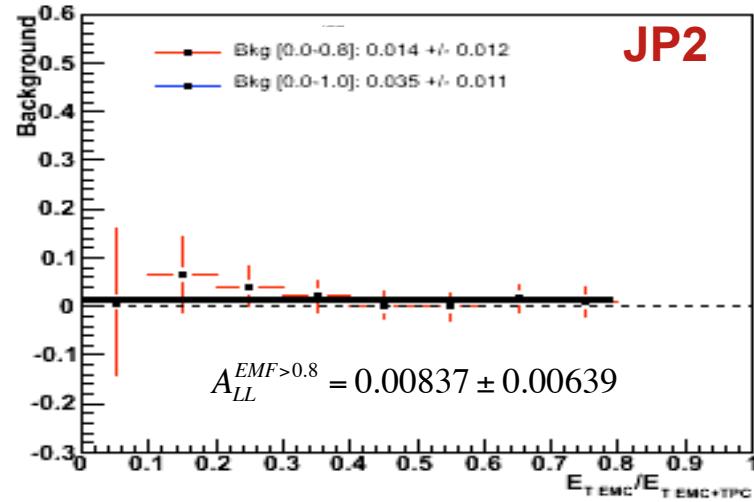
$$A_{LL}^{meas}(p_T) = \frac{A_{LL}(p_T) + f_{bg}(p_T) \times A_{LL}^{bg}(p_T)}{1 + f_{bg}(p_T)}$$

Background Fraction

Background Asym

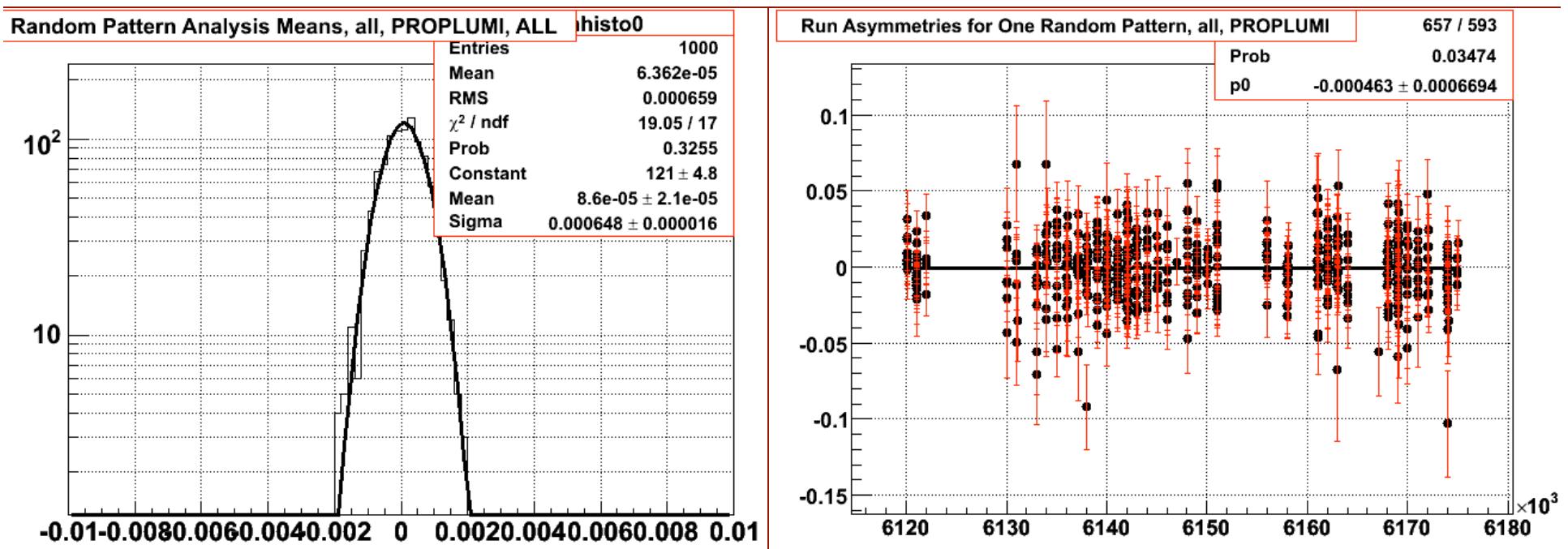


A_{LL}^{bg}



A_{LL} Systematics: 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.



Theoretical Scale Uncertainties

Vary x_2 Factorization and Renormalization Scale ($\mu_F = \mu_R$)

