Extracting the Gluon Piece of the Spin Puzzle

New Inclusive Jet Results From ***STAR***

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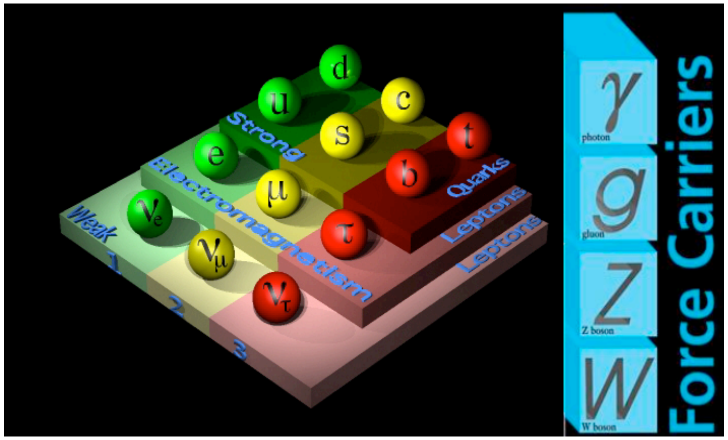
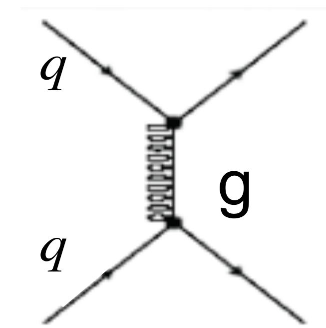
The Spin Puzzle → Key Question in **Standard Model QCD**



spin 1/2 ↔ spin 1

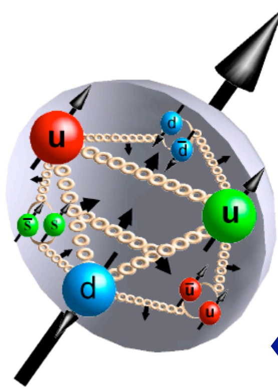
99.9% of mass of the visible universe composed of quarks and gluons - the building blocks of the nucleon



QCD

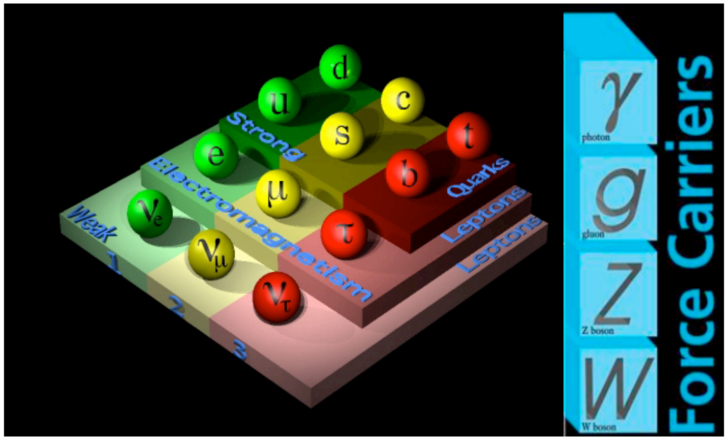
$\Phi \propto r$

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



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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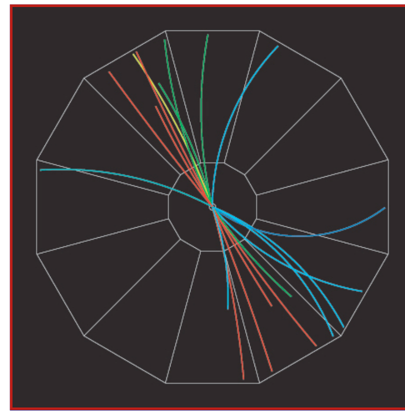

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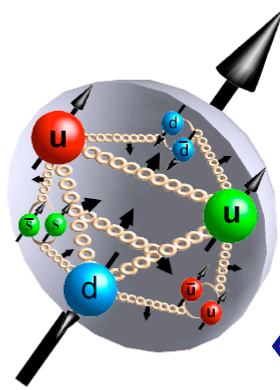
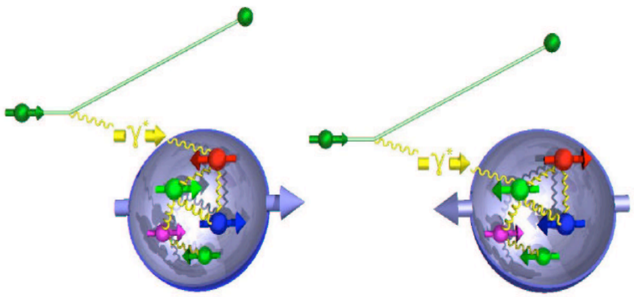


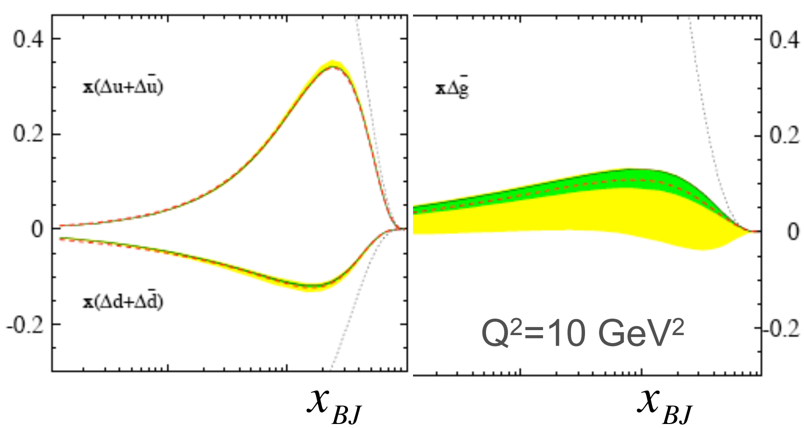
How do partonic degrees of freedom - mass, charge, color, **SPIN** - manifest as the nucleon degrees of freedom?

Asymmetries Access Spin Degrees of Freedom

30 years of DIS

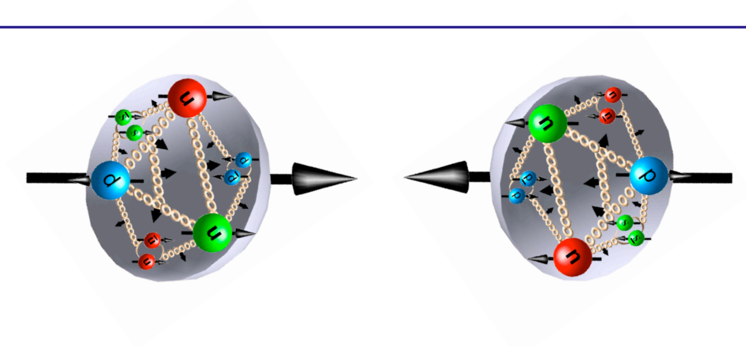


$A_{LL} \rightarrow$ Quarks = 25%

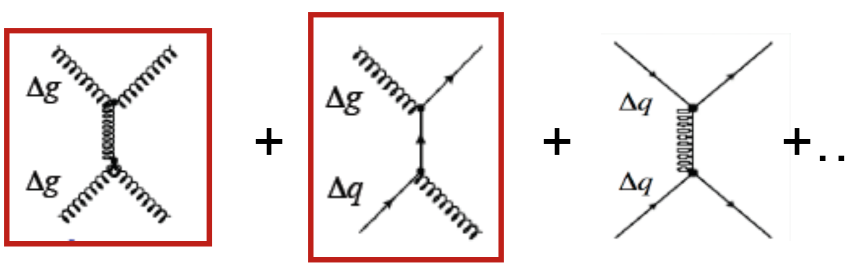


de Florian et al. Phys. Rev. D71 094018 (2005)

RHIC



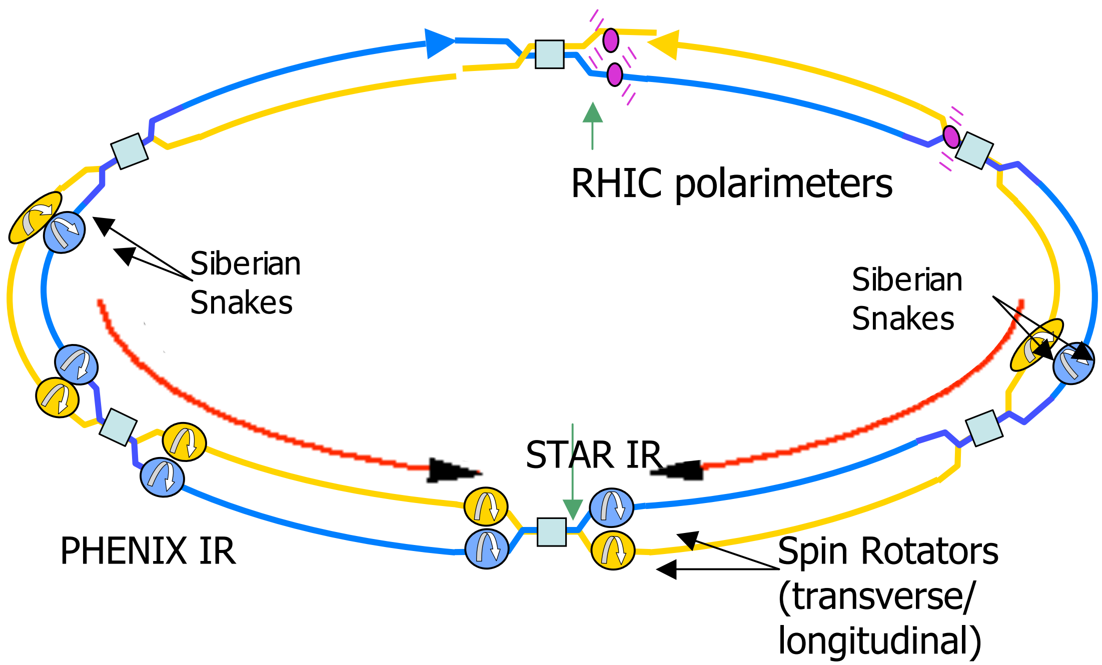
$$A_{LL} = \sum_{f_A f_B f_C} \frac{\Delta f_A \Delta f_B \times \Delta\sigma_{AB\rightarrow CX} \times D_C}{f_A f_B \times \sigma_{AB\rightarrow CX} \times D_C}$$



Access Gluon at Leading Order!

Relativistic Heavy Ion Collider

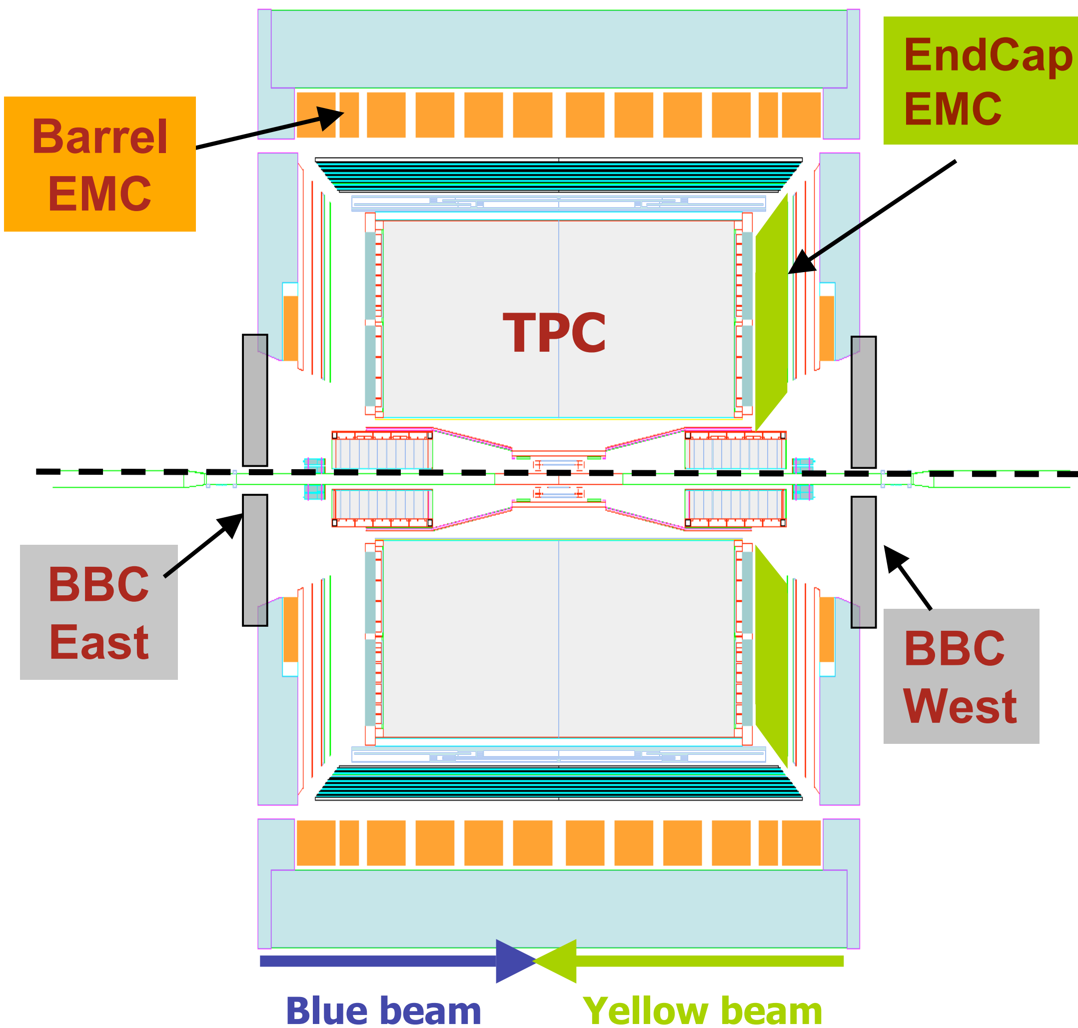
…worlds 1st $\vec{p}\vec{p}$ Collider



- 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} $s^{-1}cm^{-2}$]	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

STAR 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)

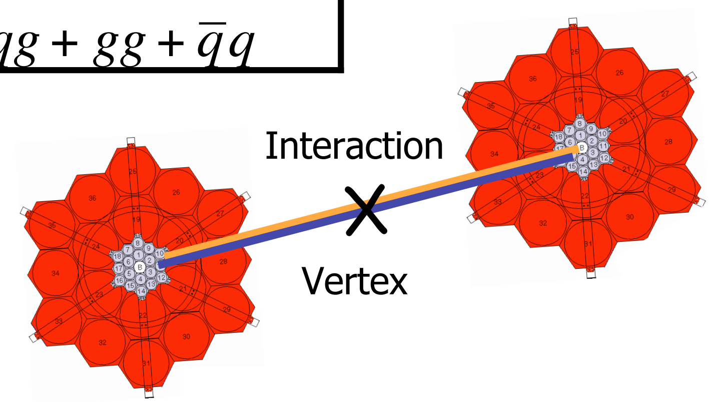
$$\eta = -\ln[\tan(\Theta/2)]$$

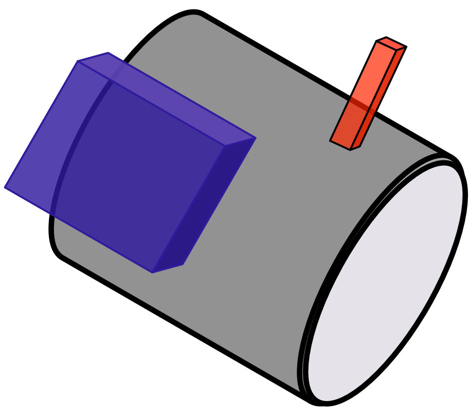
Trigger

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





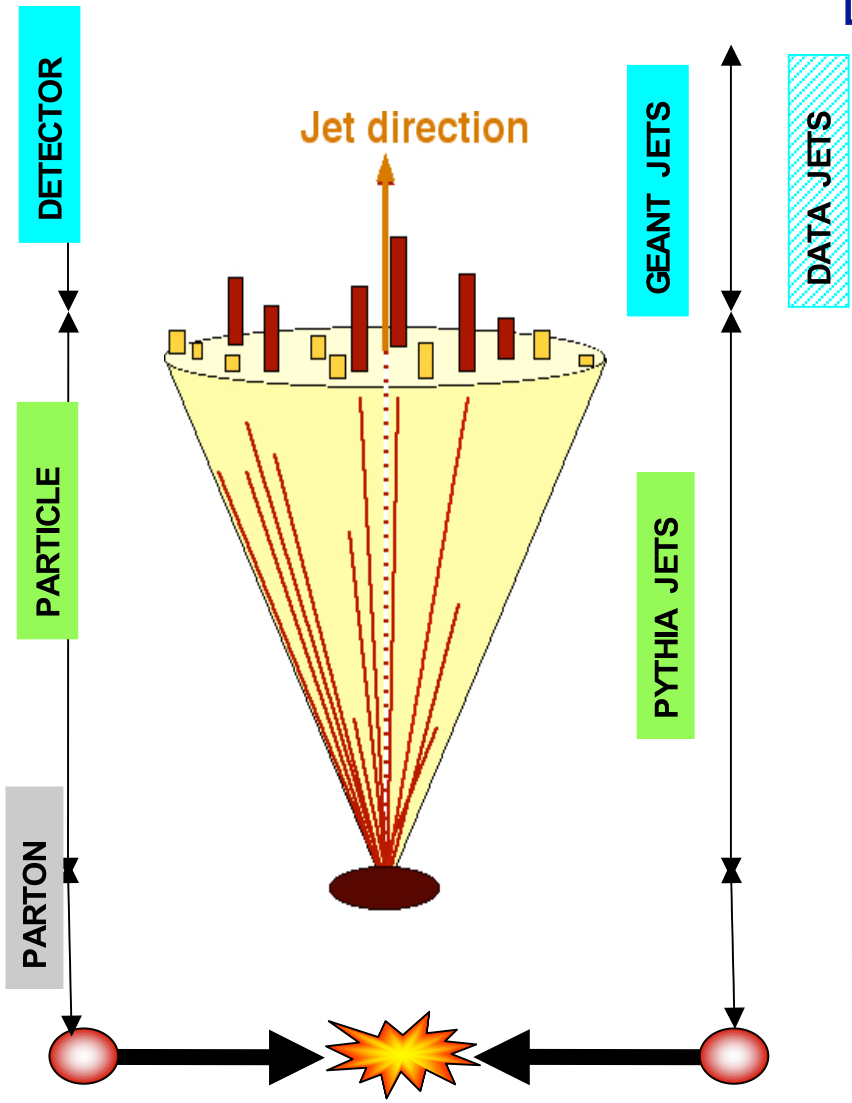
High Tower	1 tower $(\Delta\eta = \Delta\phi = 0.05)$ above threshold Requires hard neutral fragmentation

Jet Patch (2005/6 only)	400 localized towers $(\Delta\eta = \Delta\phi = 1)$ above threshold. Allows for cluster of softer fragmentation

Jet Algorithm

Midpoint Cone Algorithm (hep-ex/0005012)

- Collinear and infrared safe -



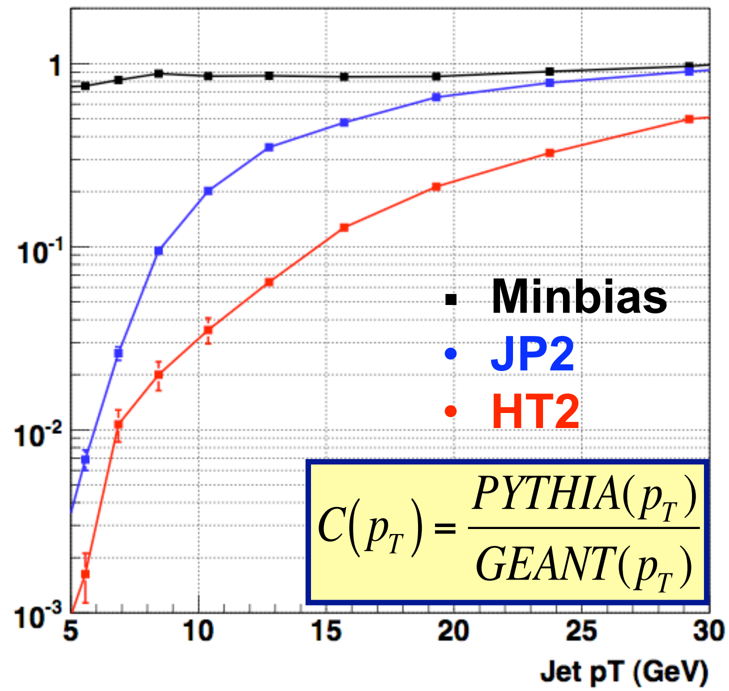
- Jet Cone Radius = 0.4
- Split/Merge = 0.5
- Neutral Energy Cut R < 0.8(0.9) to remove backgrounds
- Use Simulation (MC) to provide correction to RAW jet yield
  PYTHIA 6.205 (CDF Tune A) + GEANT (Geisha)

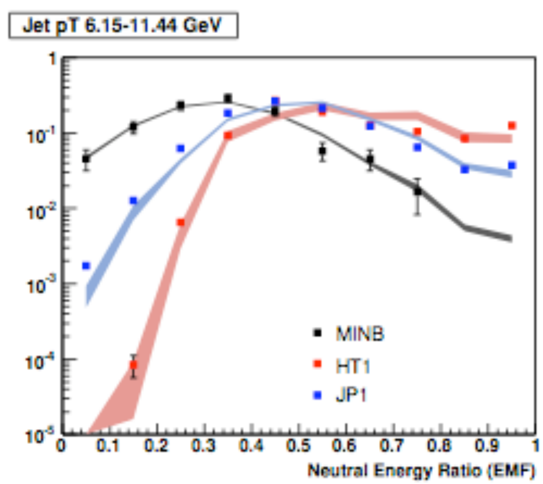
Corrected Jet Yield = **DATA JETS** X $\frac{\textbf{PYTHIA JETS}}{\textbf{GEANT JETS}}$

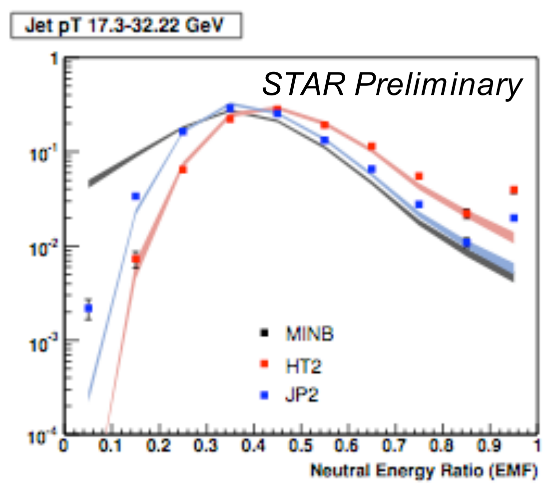
8

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 + ν)
  - PYTHIA 6.205 CDF Tune A
  - GEANT (Geisha)
- Verification of DATA/MC agreement essential

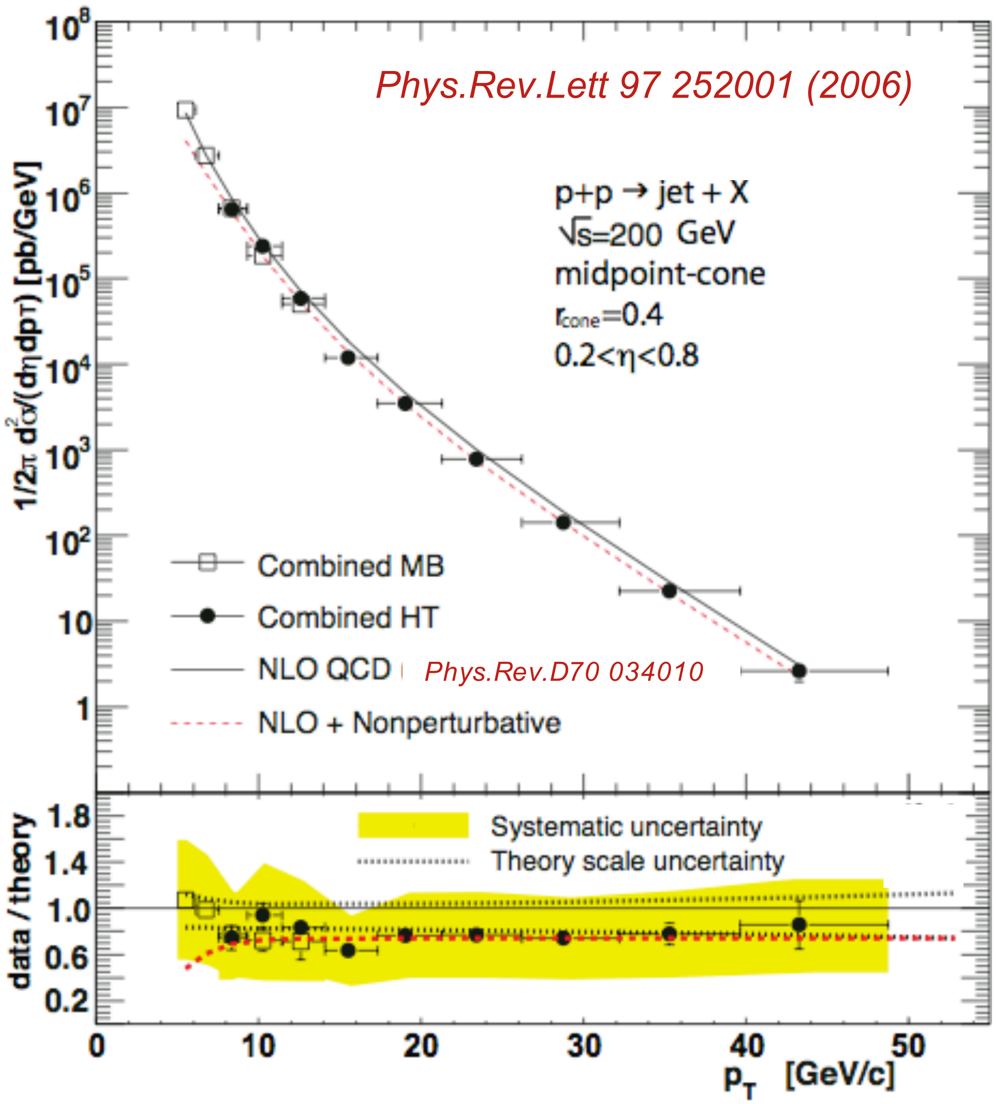






The shape of the Fraction of Neutral Energy in the Jet (EMF) is sensitive to the trigger bias as well as contributions from beam background.

2003/2004 Inclusive Jet Cross-Section Results

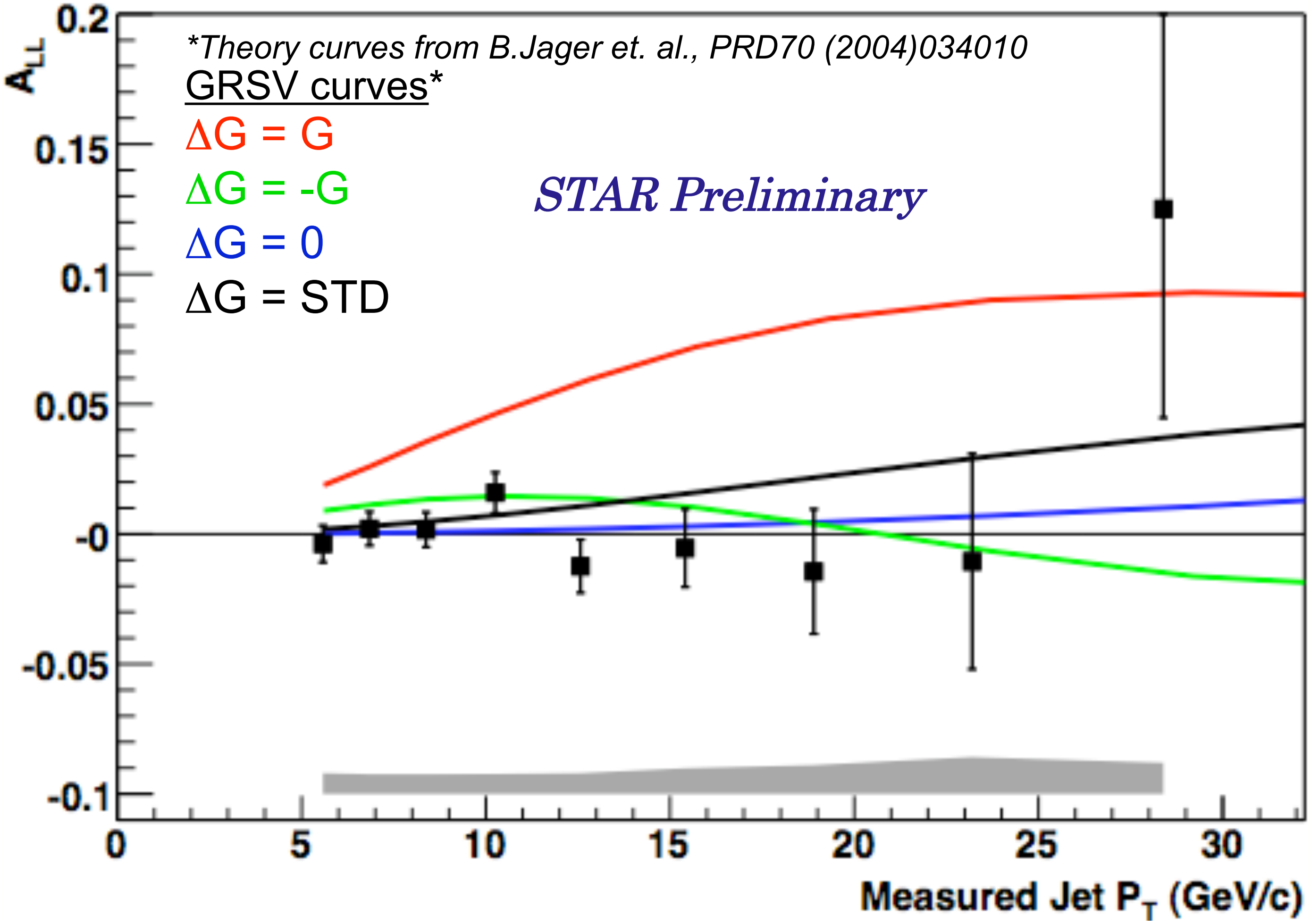


$$\frac{1}{2\pi}\frac{d^2\sigma}{d\eta dp_T} = \frac{1}{2\pi}\cdot\frac{N_{Jets}}{\Delta\eta\Delta p_T}\cdot\frac{1}{\int Ldt}\cdot\frac{1}{c(p_T)}$$

- 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}

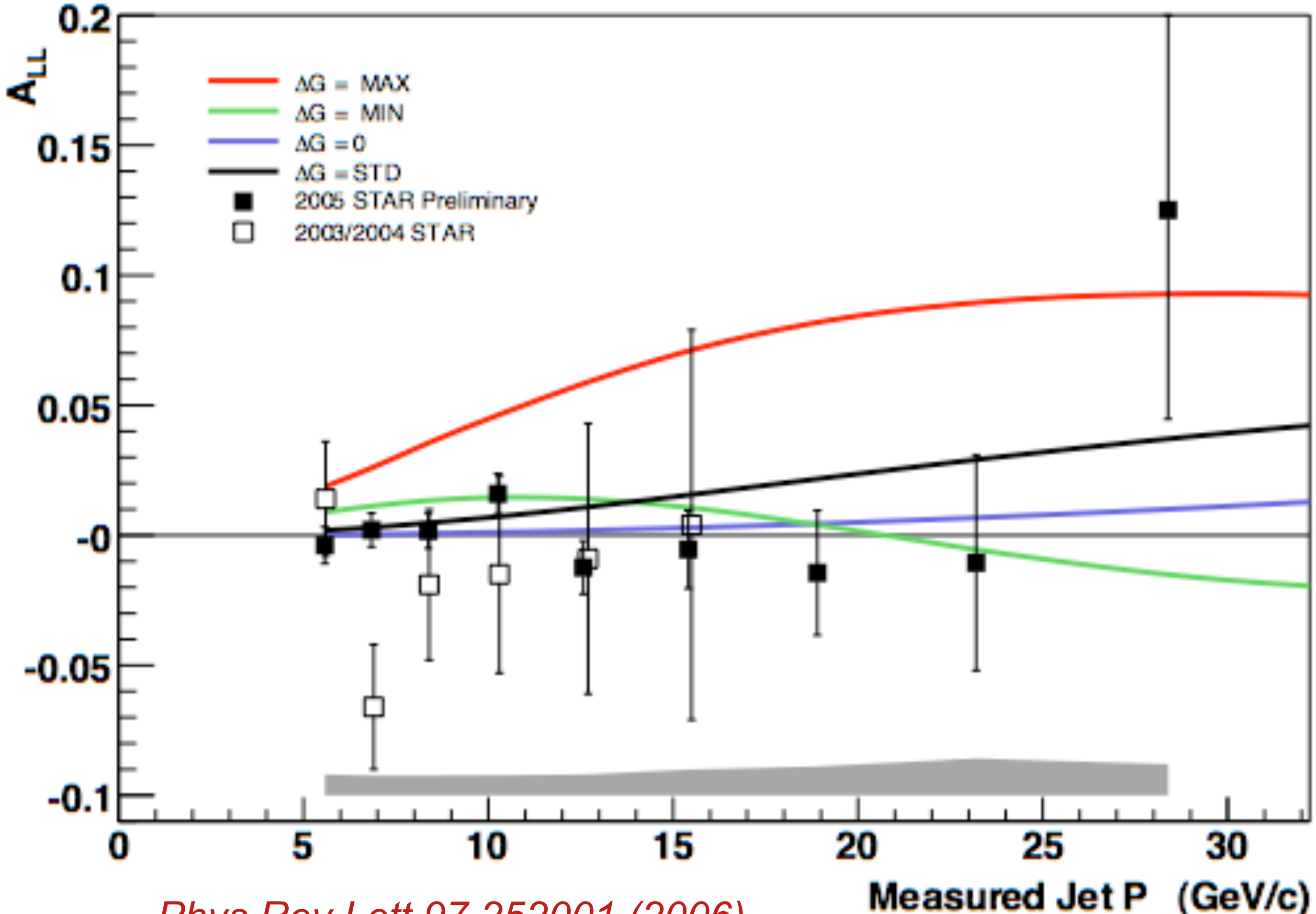
$$\frac{1}{P_Y P_B} \frac{N^{parallel} - R \cdot N^{antiparallel}}{N^{parallel} + R \cdot N^{antiparallel}}$$



Systematic band does not include 25% scale error from polarization

2005 Inclusive Jet A_{LL}

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



Phys.Rev.Lett 97 252001 (2006)

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

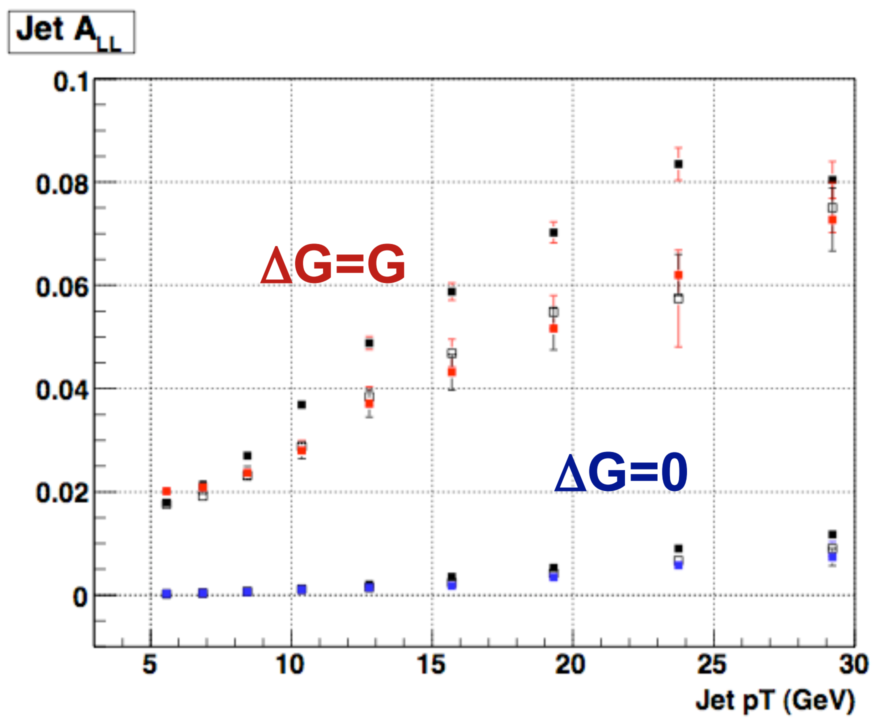
2005 Jet A_{LL} Systematics

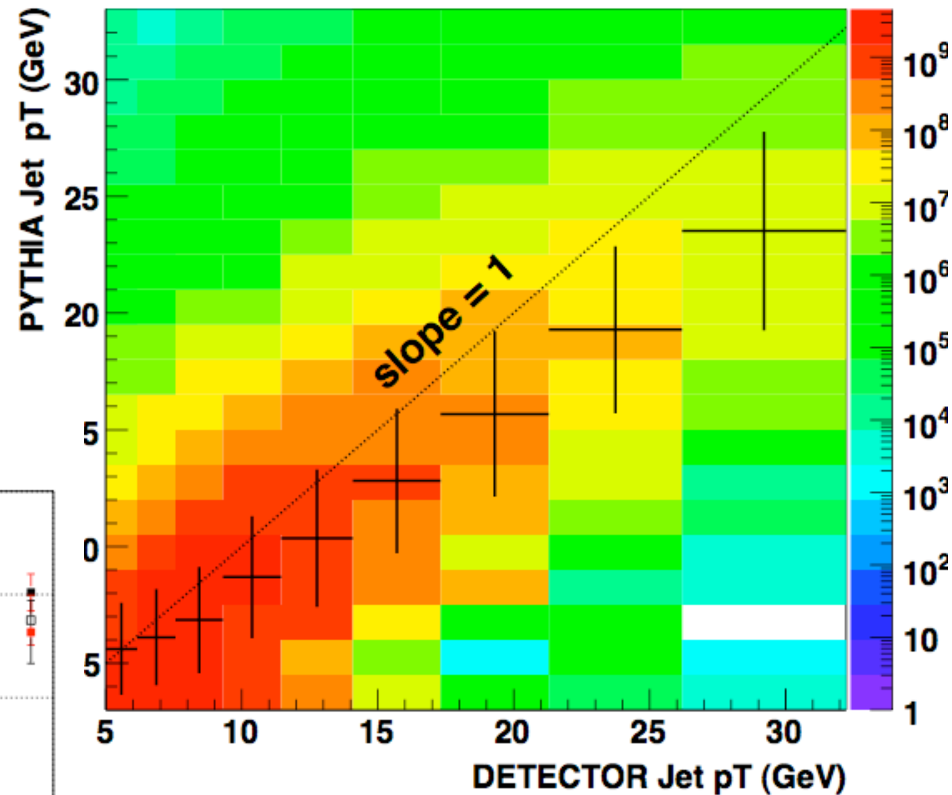
effect	$(x\ 10^{-3})$
False Asymmetries	<6.5
Reconstruction + Trigger Bias	2-12 (p_T dependent)
Non-longitudinal Polarization	3
Relative Luminosity	2
Backgrounds	<1

Jet Resolution

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

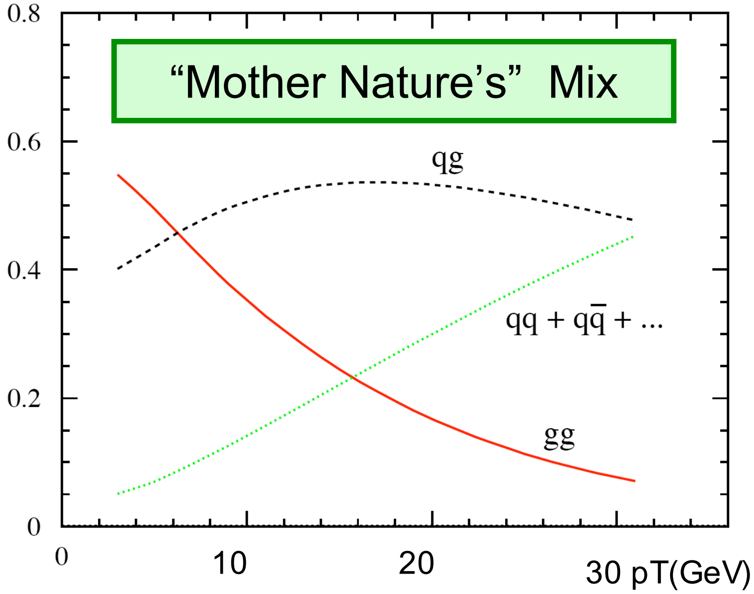
REASON: ~25% Jet Resolution + Steeply falling jet pT distribution



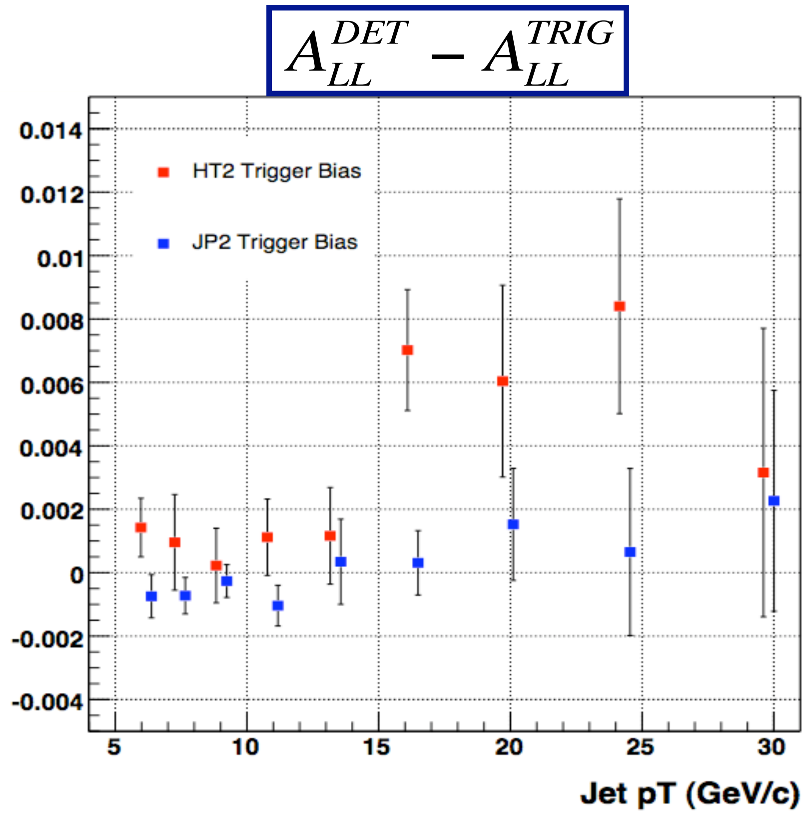


Systematic offsets in pT cause dilutions of the jet asymmetry which depend on the size of the asymmetry!

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



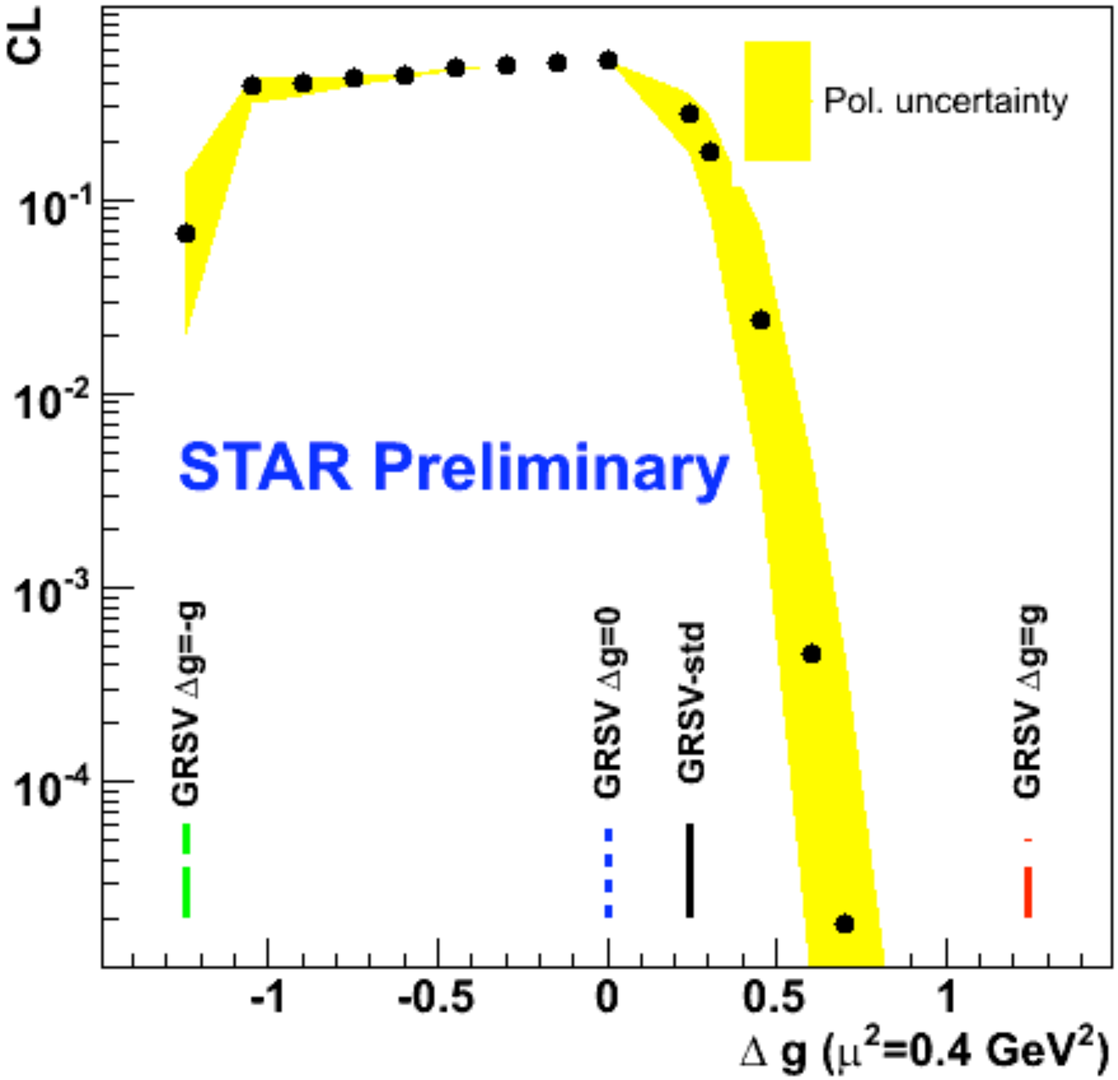
Trigger Bias:

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

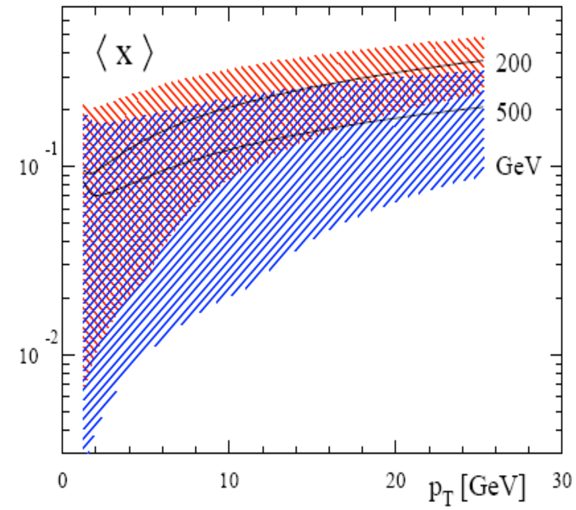
Total Systematic:

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

Constraints on ΔG



Uncertainties from Δg(x) shape and pQCD scale not included

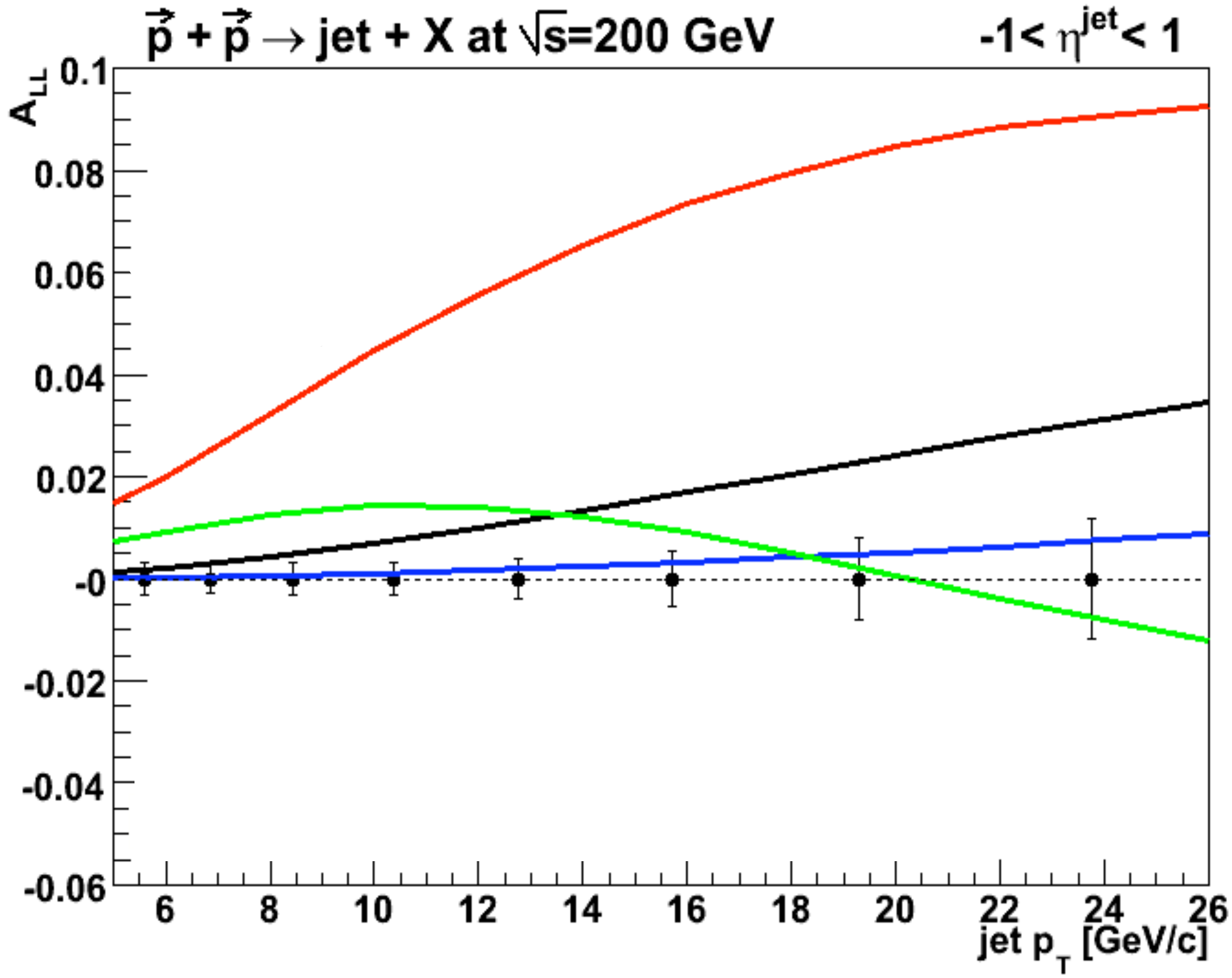


GRSV DIS best fit = 0.24
1σ = -0.45 to 0.7

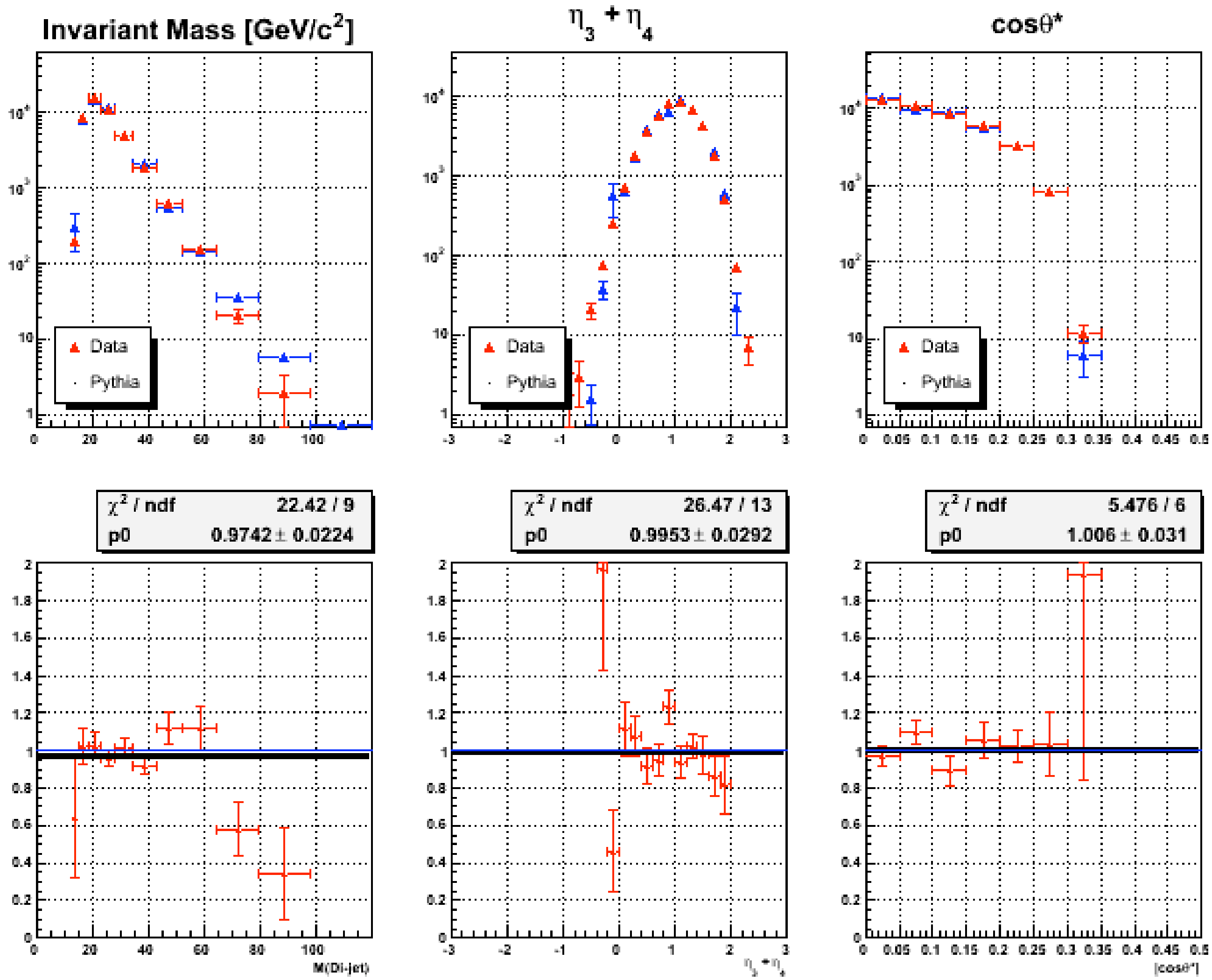
Phys.Rev.D63 094005 (2001)

Estimated 2006 Inclusive Jet Asymmetry Sensitivity

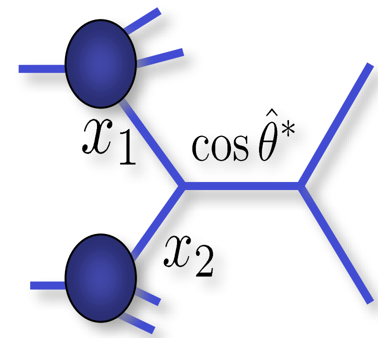
- Increase in sampled luminosity
- Polarization ~ 60% (FOM is P^4L)
- Entire BEMC instrumented
- Beamline shielding installed
- Greater emphasis on high p_T jets and dijets with triggers



Di-jet Analysis ⇒ 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!

Take Away

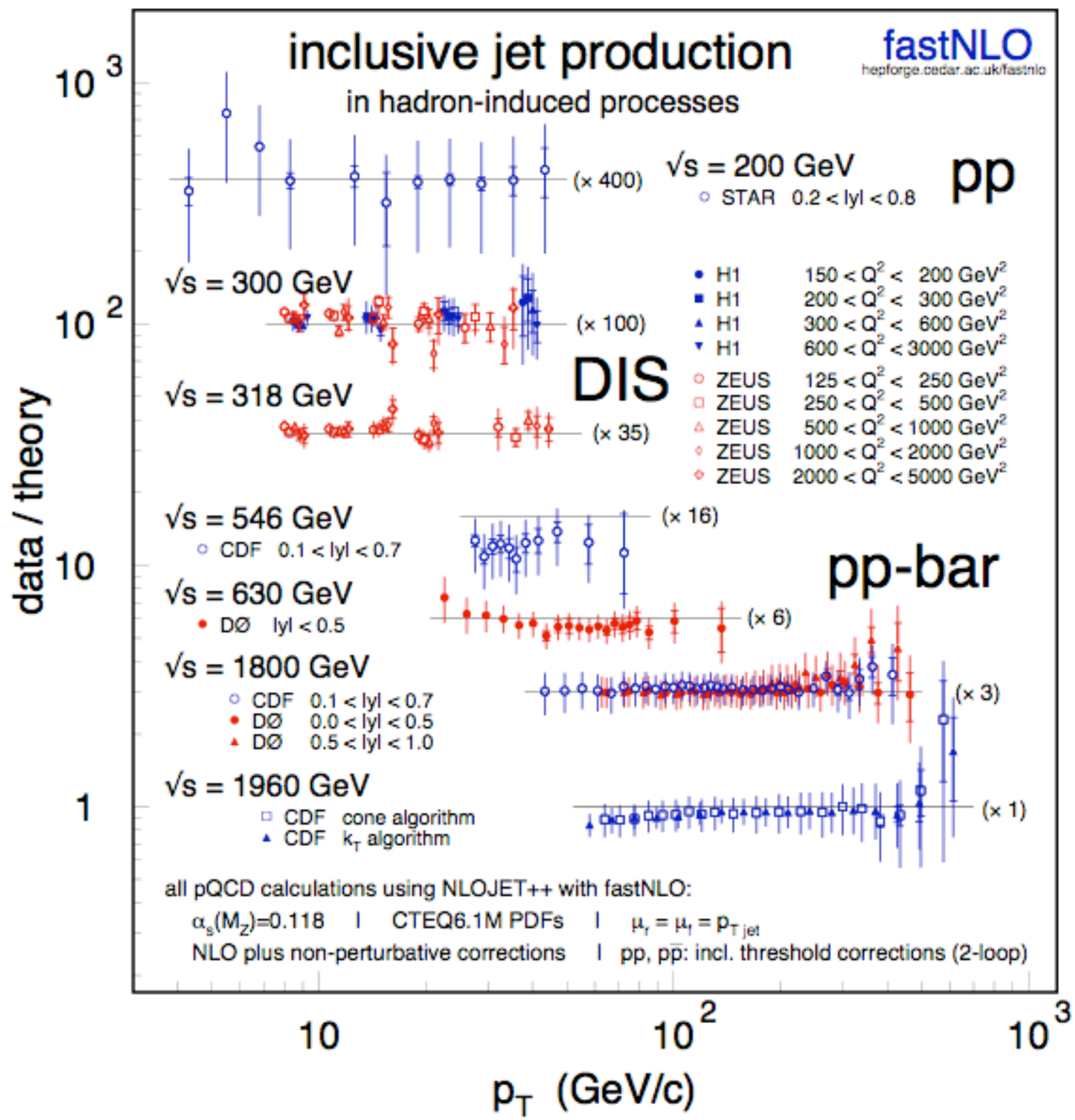
- The RHIC spin program accesses ΔG directly through inclusive jets as well as charged and neutral hadrons
- STAR inclusive Jet Asymmetries provide a significant contribution to the global understanding of ΔG
- The inclusive jet measurement is still statistics limited
- The STAR Spin program is entering 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

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

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

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

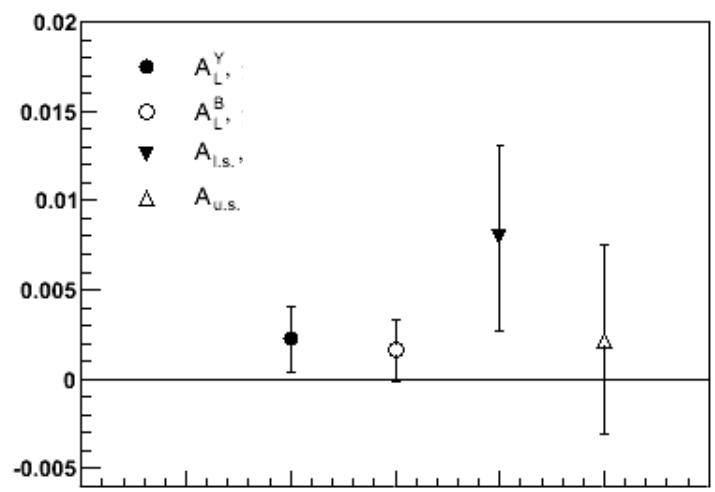
We observe **1-3σ** single spin asymmetries, depending on the neutral energy cut.

Source of these asymmetries still unclear

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

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

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



A_{LL} Systematics: Non-longitudinal Beam Polarization

Non-longitudinal beam polarization changes A_{LL}:

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

To bound this effect,

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

$\Rightarrow$ Estimate the beam transverse polarization component

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

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

A_{LL} Systematics: Relative Luminosity

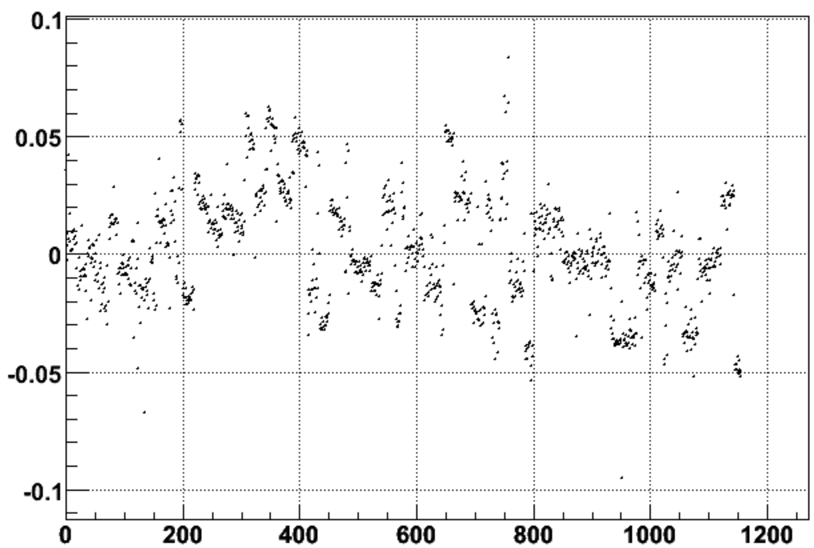
Calculated using the BBC: $$R_3 = \frac{L^{parallel}}{L^{antiparallel}}$$

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

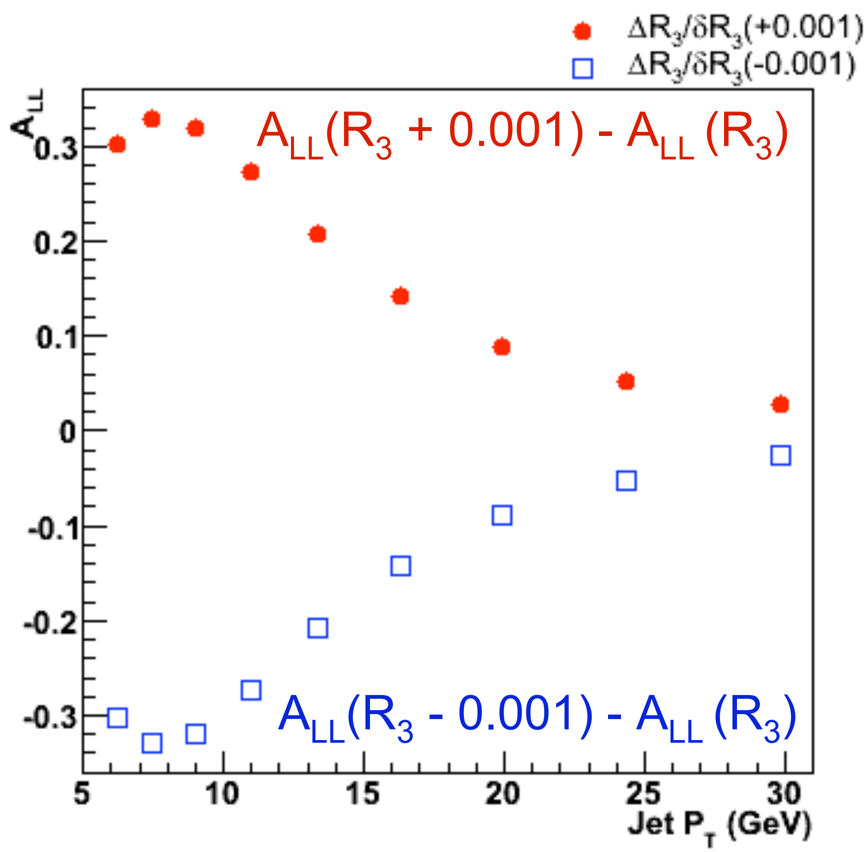
Cross-checked using the Zero Degree Calorimeter (ZDC), another luminosity monitor

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

$R_3(BBC) - R_3(ZDC)$



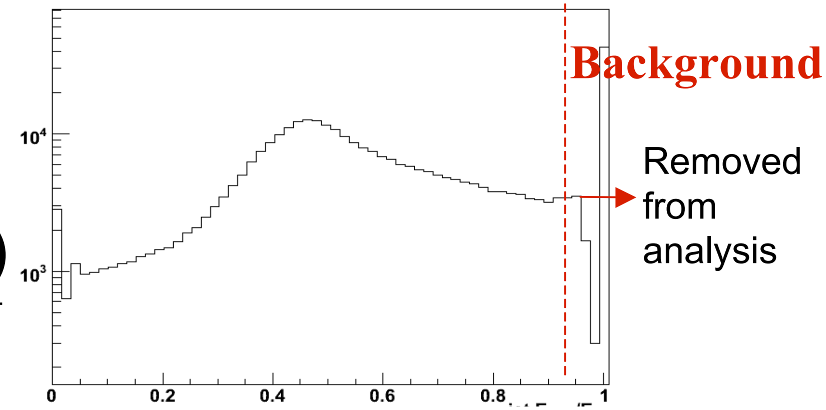
Difference between BBC and ZDC is 0.001



A_{LL} Systematics: Background Estimate

Background manifests itself as jets with large neutral energy deposit

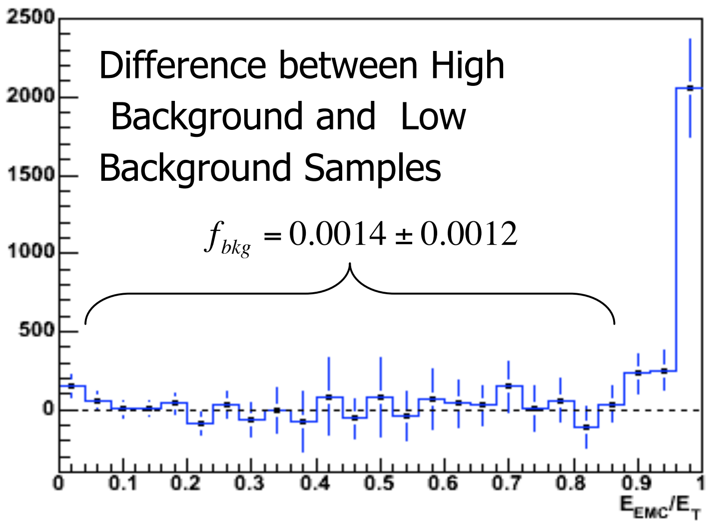
$$A_{LL}^{meas}(p_T) = \frac{A_{LL}(p_T) + f_{bg}(p_T) \times A_{LL}^{bg}(p_T)}{1 + f_{bg}(p_T)}$$

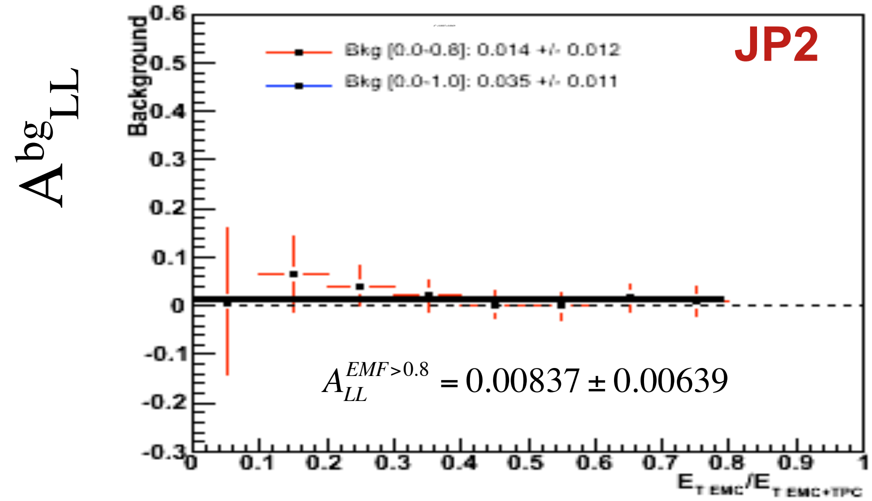


Jet E_{EMC}/E_{Tot}

Background Fraction

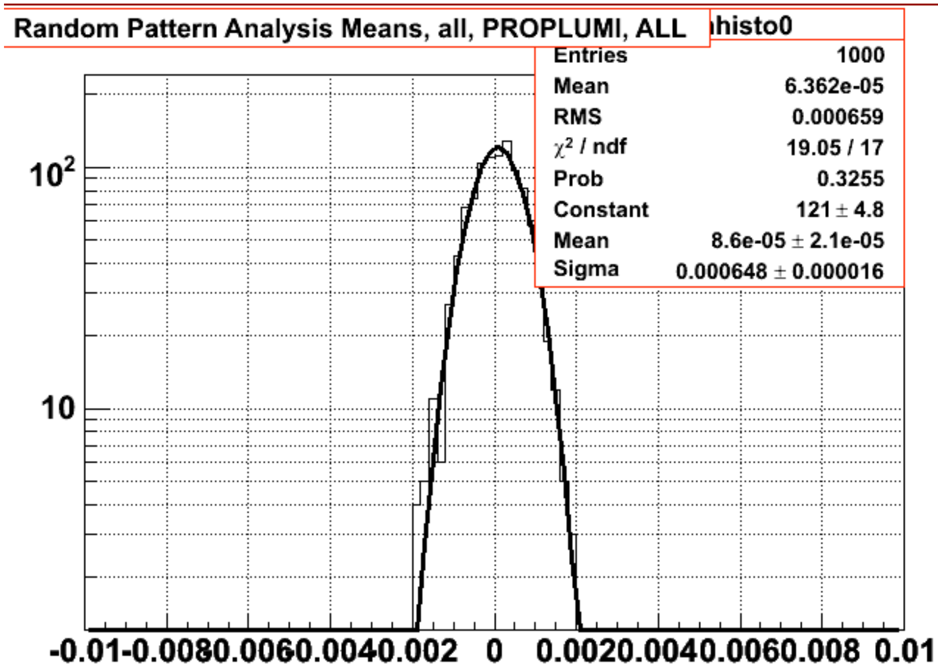
Background Asym

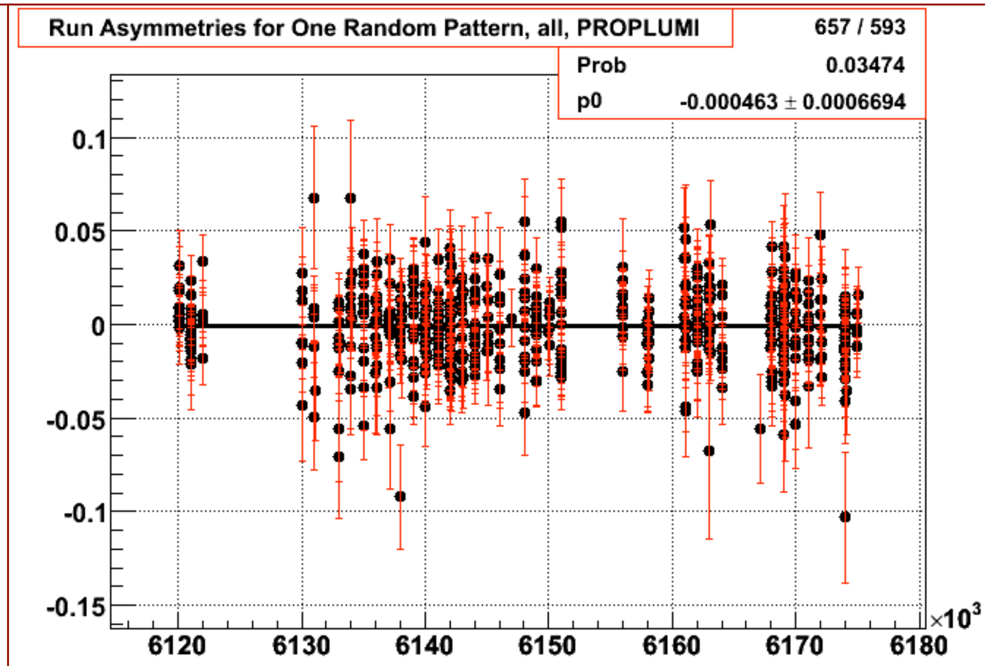




A_{LL} Systematics: Random Pattern Analysis

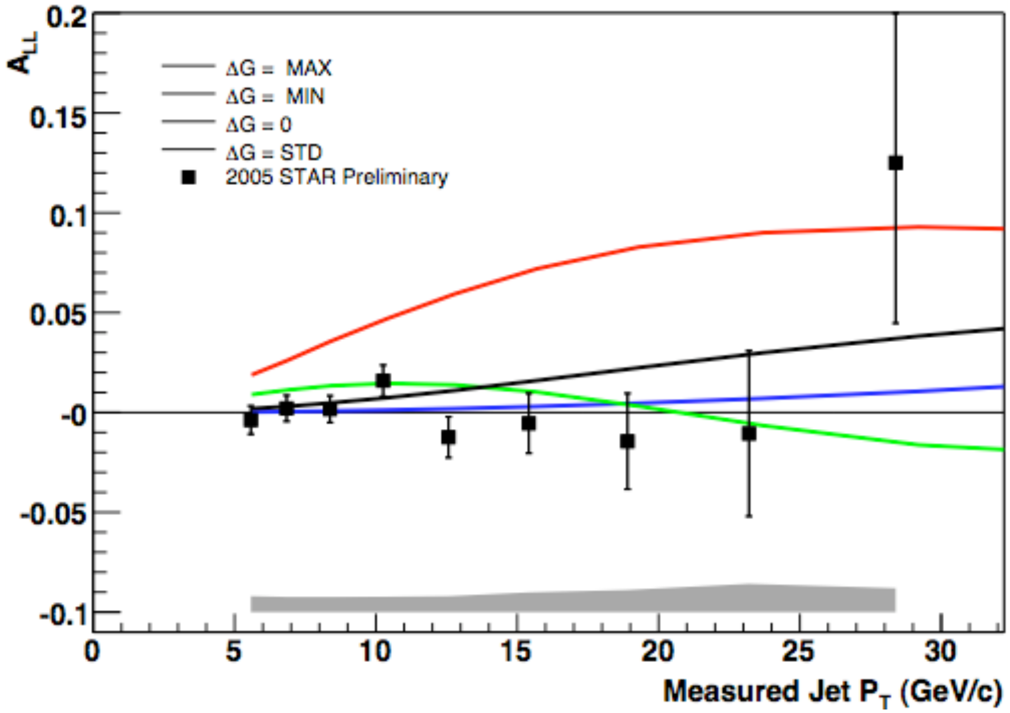
The random pattern analysis randomly creates new spin states for every run. 1000 random patterns were used. The RMS of the distribution of the ε_{LL}s is smaller (within error) than the statistical error, so the systematic error from bunch-dependent correlations is zero.

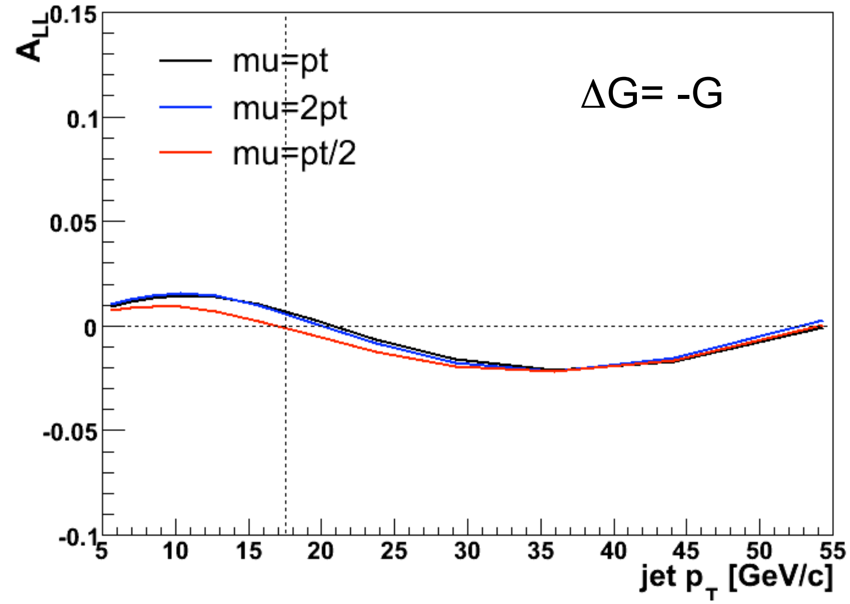


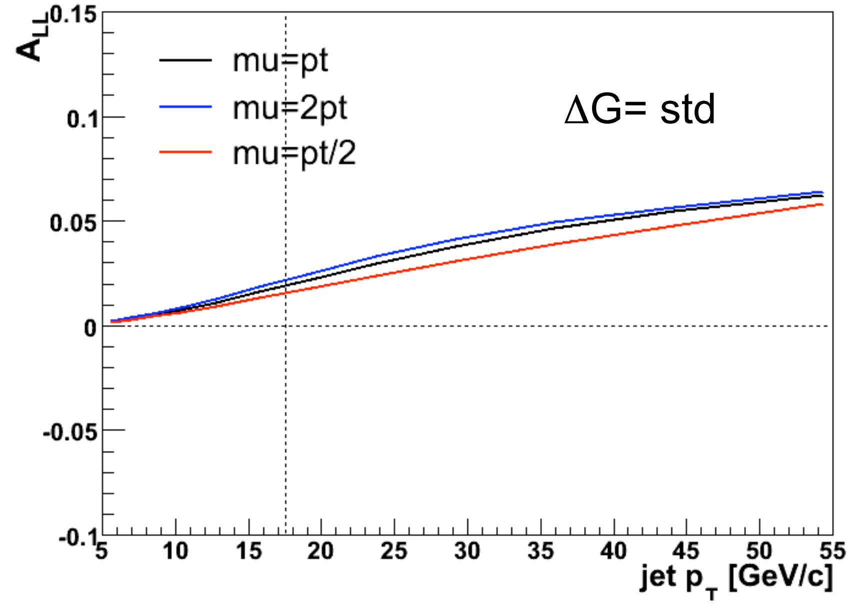


Theoretical Scale Uncertainties

Vary x2 Factorization and Renormalization Scale ($\mu_F = \mu_R$)

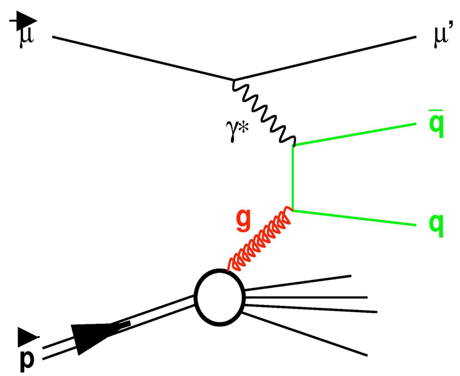




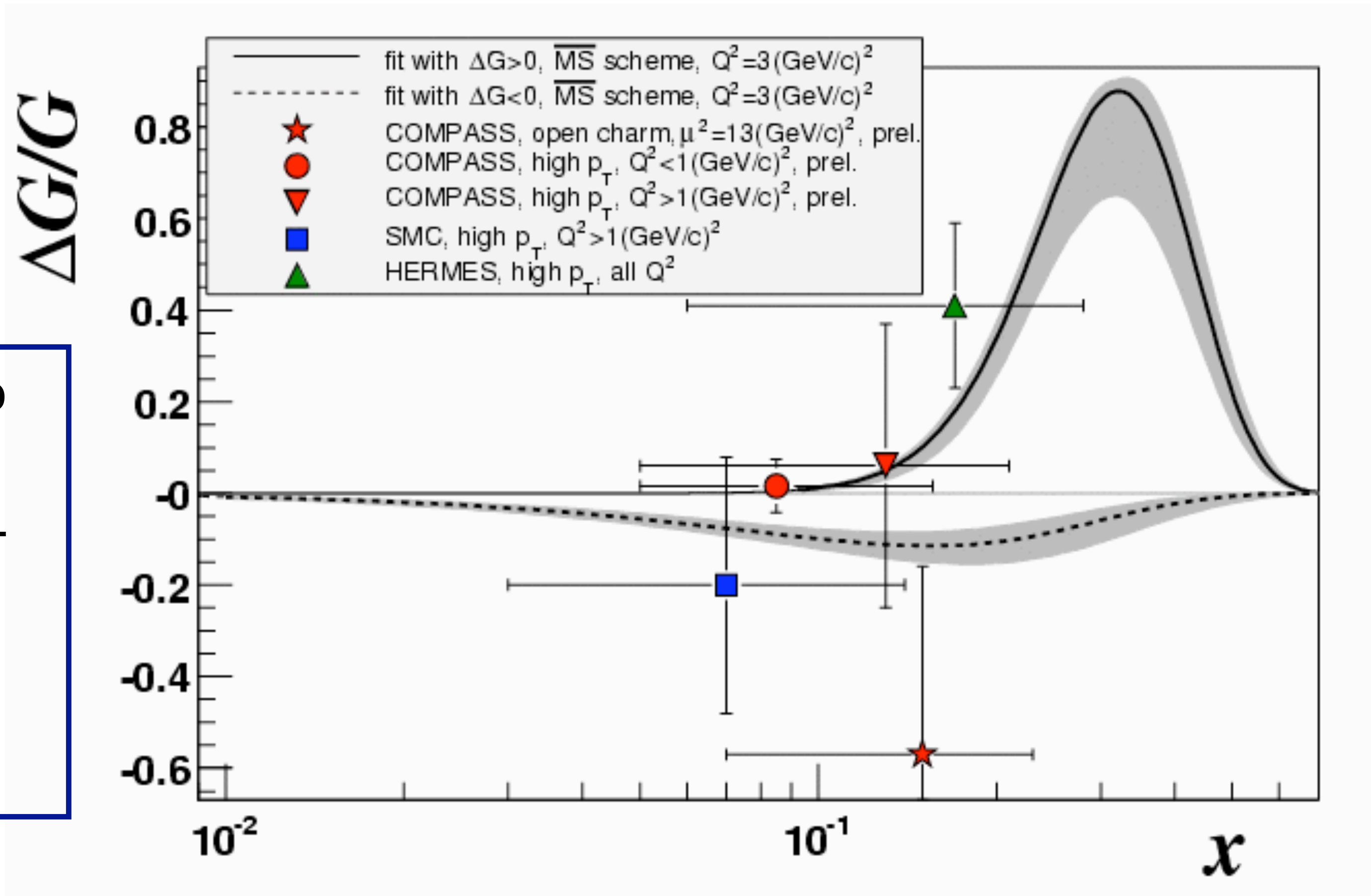


Dedicated DIS ΔG Measurements

…from SPIN 2006

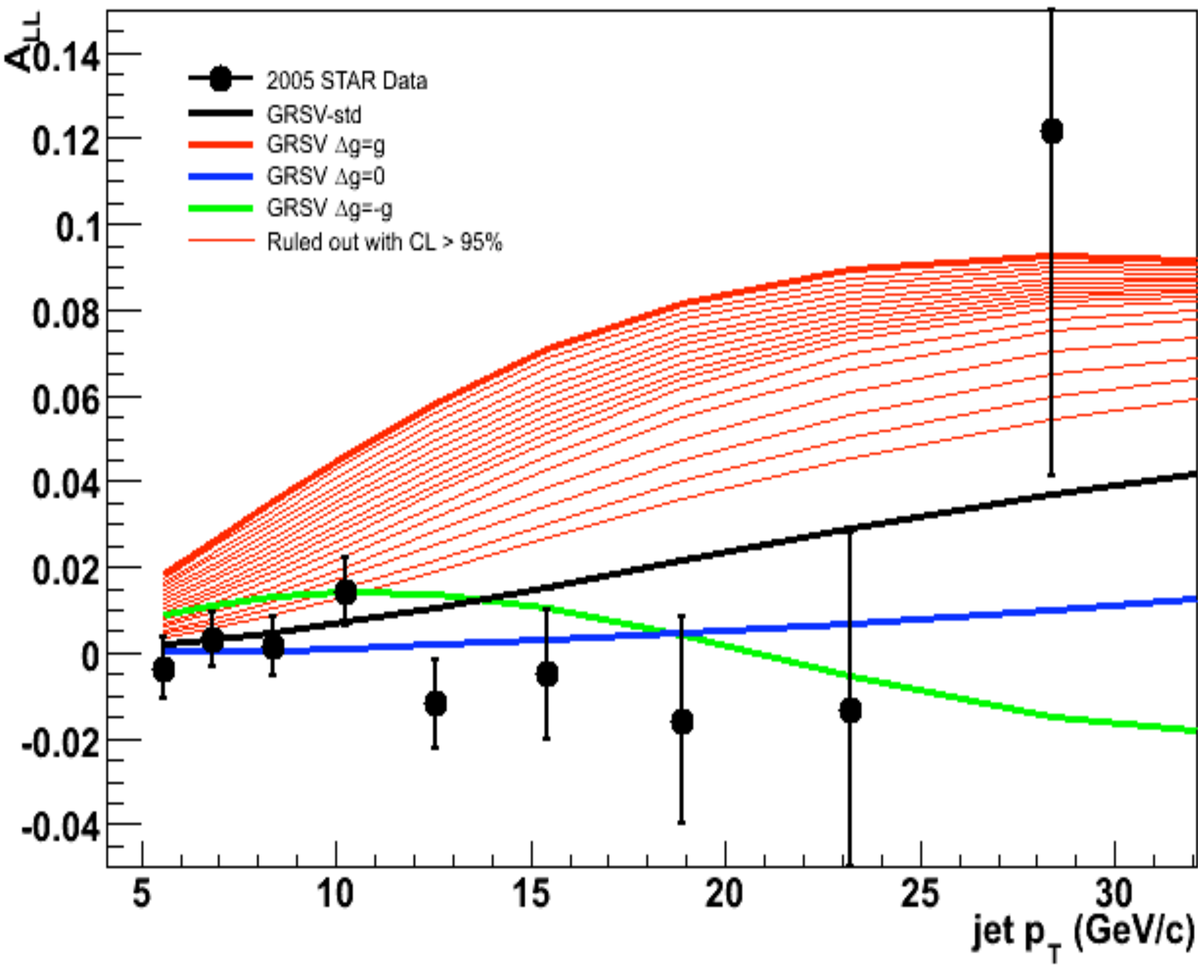


- PGF is access to ΔG in DIS
- Look for high-pT pairs
- Open Charm is golden channel



Disfavors maximal scenario but cannot determine sign

Constraints on ΔG II



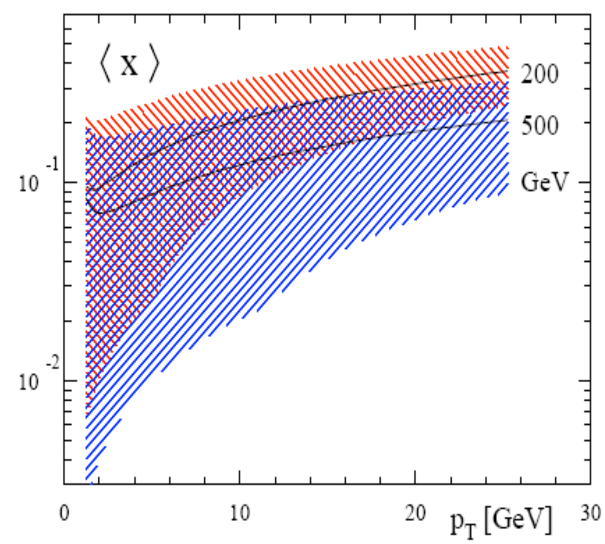
Preliminary analysis by Vogelsang & Stratmann

$\Delta G = 1.2\hbar$

$\Delta G = 0.4\hbar$

$\Delta G = 0.24\hbar$

Q^2=0.4 GeV



GRSV DIS best fit = 0.24   1σ = -0.45 to 0.7

How RHIC works for $\vec{p}\vec{p}$

1. Optically pumped Polarized H- source
2. H- source is stripped and pumped into Booster - a fast cycling cyclotron
3. Injected into Alternating Gradient Synchrotron at 2.35 GeV and accelerated to 24.3 GeV
4. Injected into RHIC ring at 24.3 GeV and accelerated to 100 GeV
5. The H- jet target was installed in 2004 to calibrate the CNI polarimeter
6. Two Siberian Snakes are used to preserve polarization of beams
7. Challenge for the future is to overcome expected resonances and preserve polarization beyond beam energies of 100 GeV.
8. CNI provides 10% error
9. Absolute normalization from Jet Target provides 20 % error per beam.