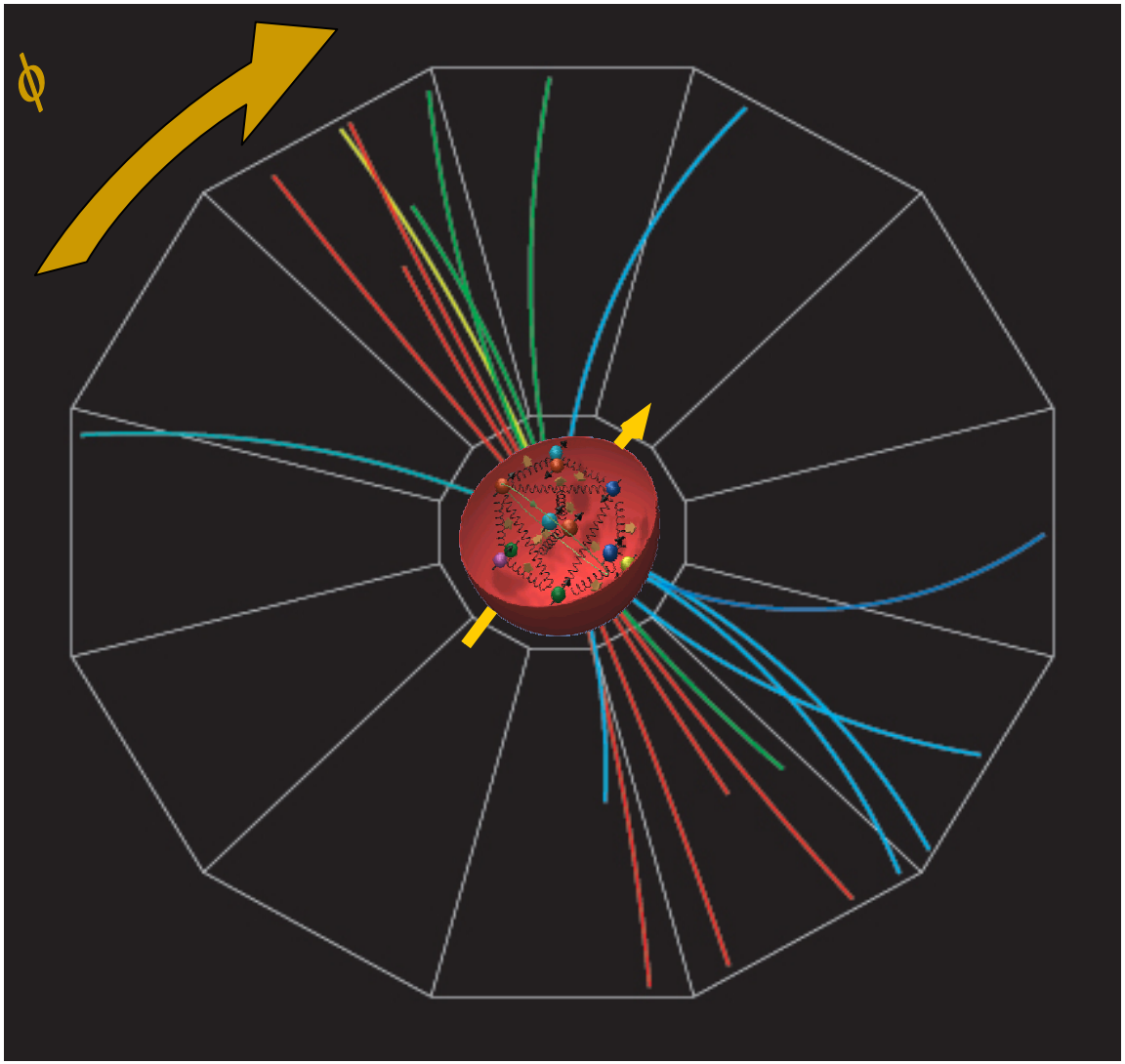
Spin Physics With Jets at STAR

S. Vigdor, BNL, Ides of March 2007



I. **RHIC Spin Goals**

II. **RHIC Spin Infrastructure**

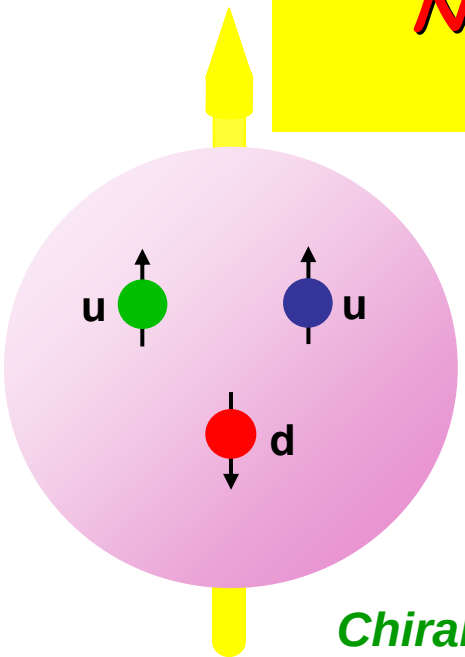
III. **STAR Jet Infrastructure**

IV. **Inclusive Jet Results 2003-5: Constraining the Gluon Contribution to Proton Spin**

V. **Single-Spin Asymmetry for Di-jets 2006: Looking for Parton Orbital Momentum Effects**

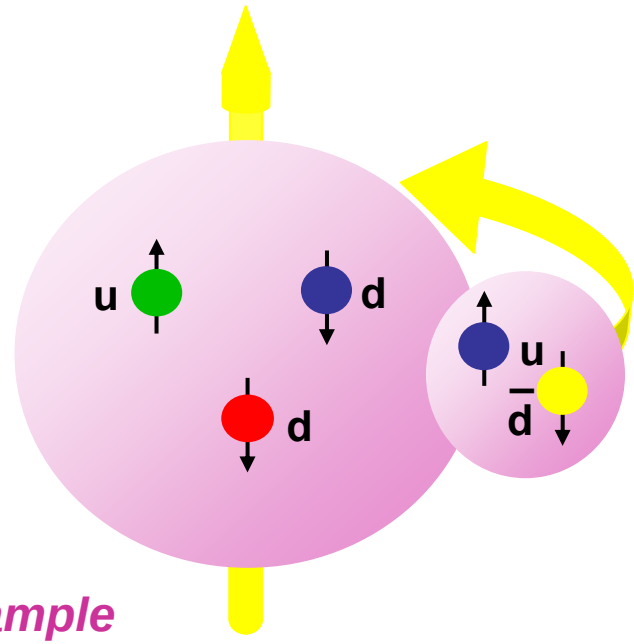
VI. **Next Stages of Jet Program**

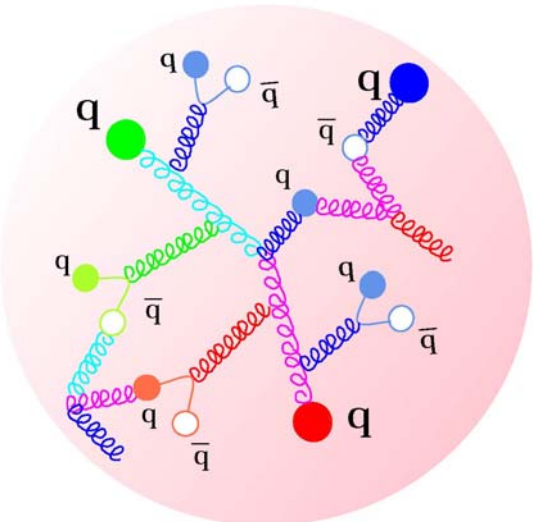
Nucleon Structure Goal: How are Various Degrees of Freedom Interrelated?



Three constituent quarks in s-states ⇒ good account for baryon magnetic moments -- attributes nucleon spin to quark spin alignment in rest-frame wave function.

Chiral symmetry breaking associated with pseudoscalar meson cloud ⇒ $\bar{d}/\bar{u}$ asymmetry, sea-quark orbital motion, sea quark spin opposes nucleon's.





Hard high-energy probes sample light-cone wave function, provide momentum & spin "snapshots" of teeming assembly of partons ⇒

$$\langle S_z^p \rangle = \tfrac{1}{2} = \underbrace{\tfrac{1}{2}\,\Delta\Sigma}_{\text{quark helicity}} + \underbrace{\Delta g}_{\text{gluon helicity}} + \langle L_z^{\text{quarks}} \rangle + \langle L_z^{\text{gluons}} \rangle$$

How do these quantities relate to above pictures?

RHIC $\vec{p}+\vec{p}$ ⇒ Unique Insights Into Selected Questions

⇒ Access to spin observables in hard partonic scattering processes treatable via perturbative QCD

⇒ probe non-perturbative nucleon spin structure via partonic degrees of freedom:

- ***Do gluons account for "missing" proton spin?***

  Gluons provide ~ half of proton's mass, momentum; do they also play important role in spin? If not Δg, then orbital contributions!

- ***Transverse quark motion and spin preferences in transversely polarized nucleon?***

  Transverse motion ⇔ orbiting mesons? Transverse spin decoupled from gluons, relativistically distinct from helicity preferences.

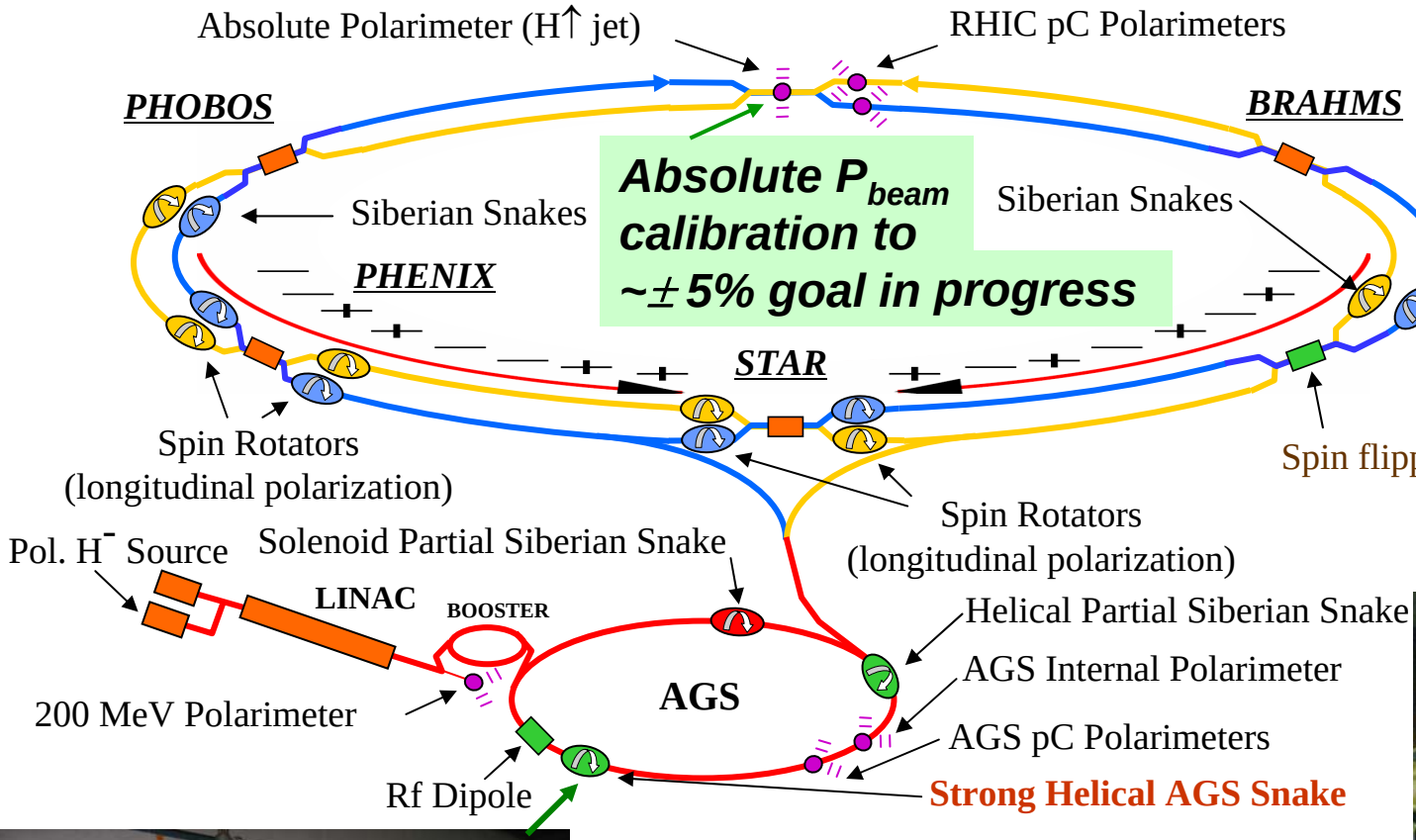
- ***Gluon splitting vs. Goldstone bosons and flavor-dependent sea quark polarization?***

Jet production studies illuminate first two major questions!

RHIC Spin Infrastructure

RHIC → Riken-BNL Helicity-Identified Collider

Pioneering accelerator development ⇒ unique spin capabilities!



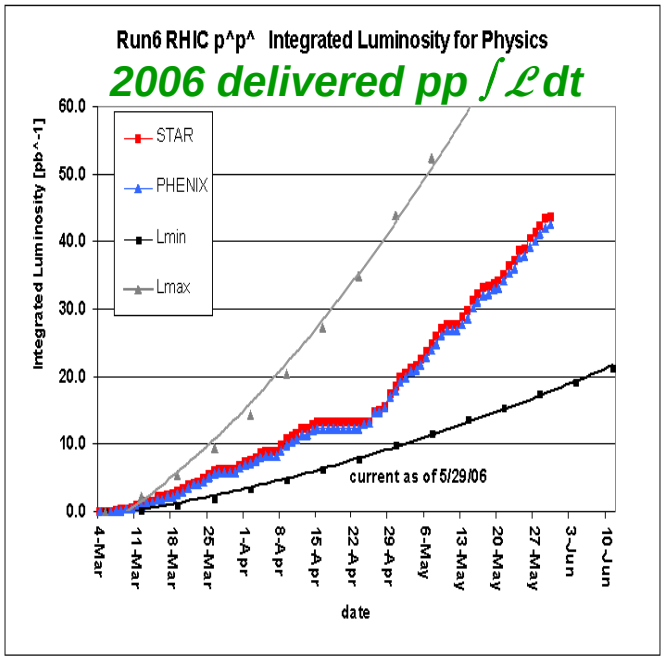
Absolute P_{beam} calibration to ~±5% goal in progress

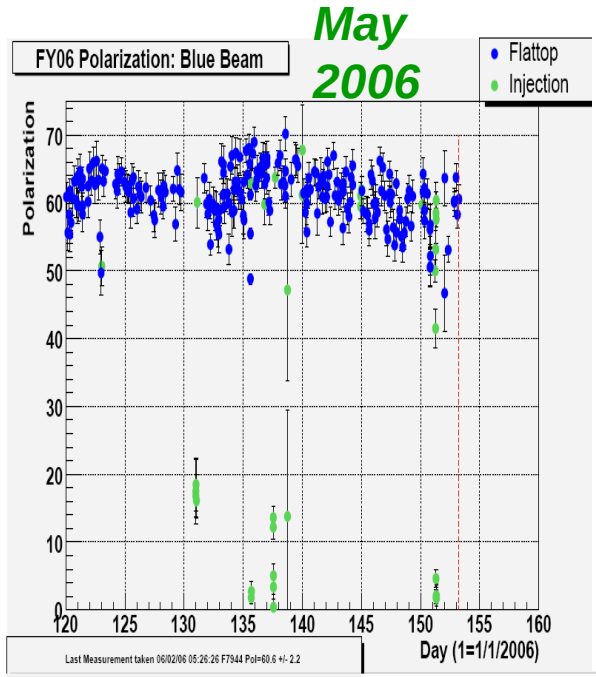
RHIC uses super-conducting helical dipole magnets for Snakes and spin rotators

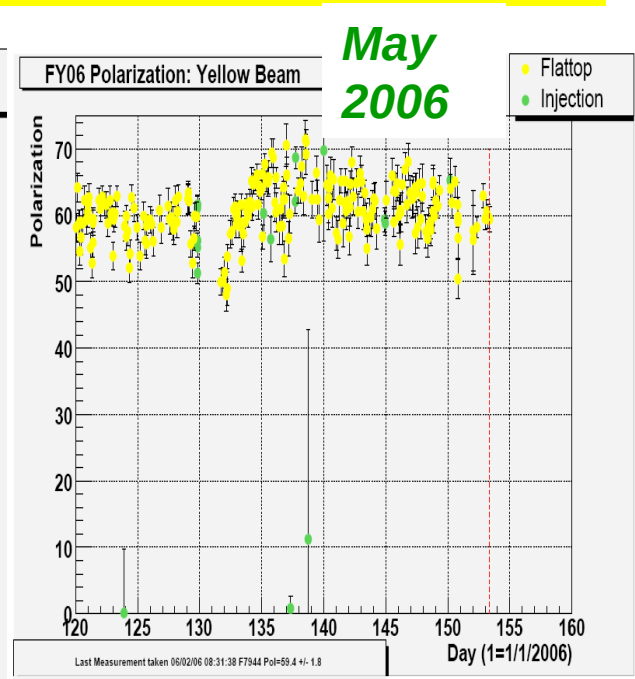
Cold Siberian snake in AGS, March 31, 2005

Polarization survival has been demonstrated to 250 GeV beam momentum (from 24 GeV injection)

Steady Improvements in Polarized Beam Performance







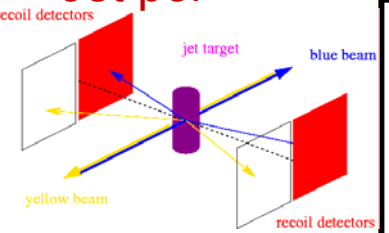
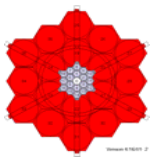
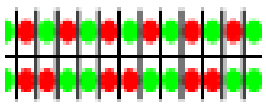
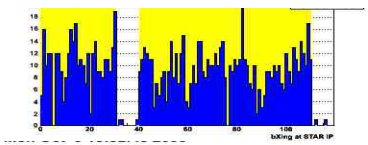
2003 → 2006 ⇒ > 2 orders of magnitude improvement in $P^4\mathcal{L}$ relevant to 2-spin asymmetries!

Factor ~ 5--6 remains to reach "enhanced design" goals

STAR $\sqrt{s}$ = 200 GeV pp Sampled Luminosities

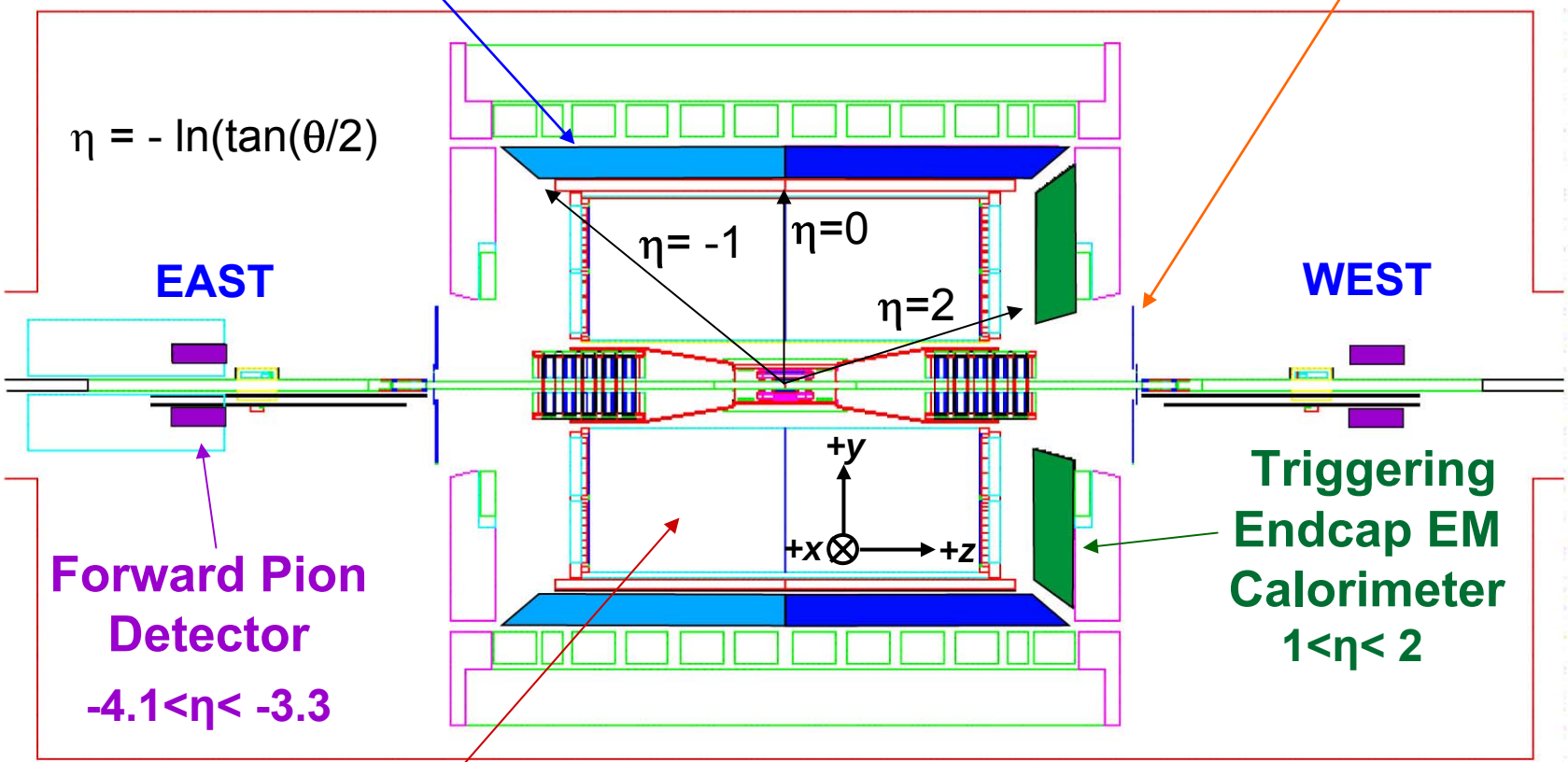
Year	Long. $\int\mathcal{L}\,dt$ [pb^{-1}]	Trans. $\int\mathcal{L}\,dt$ [pb^{-1}]	P_{beam}
2002	0.3	0.15	15%
2003	0.3	0.25	30%
2004	0.4	0	40-45%
2005	3.1	0.1	45-50%
2006	8.5	3.3 (slow det.) 6.8 (fast det.)	60%

The Beam Polarization Monitoring Chain

	Physics process	Type of polarimeter	Accuracy, limitations
Jet pol 	A_N in *pp* elastic scattering in CNI region	Polarized hydrogen gas jet target (calibrate P_{beam} against P_{target})	**Absolute (~6%) calib.,** Some dedicated fills **1 value per year**
CNI pol	p+^{12}C CNI elastic scattering	Carbon μ-ribbon target in RHIC beam, Recoil carbon detection in Si	Absolute ~20% (so far) **Rel. ~3% + spin orient'n** ~1 minute, affects beam, **few per RHIC fill**
BBC pol 	p+p → hadrons at forward rapidity	Beam-Beam counters @ STAR Min-bias trigger	relative 10%, ~20 minutes **every STAR run, Tune spin rotators**
	**Polarization pattern** of bunches	3 bits encode +,-,0 1bit : filled/empty for every beam	**8bit word in every event** Sometimes bits get stuck or lose sync
	Finding bunch #1	Localize **abort gap**	Needs ~5 minutes Sometimes 'filled' bunches are empty

STAR Jet Infrastructure

STAR Detector

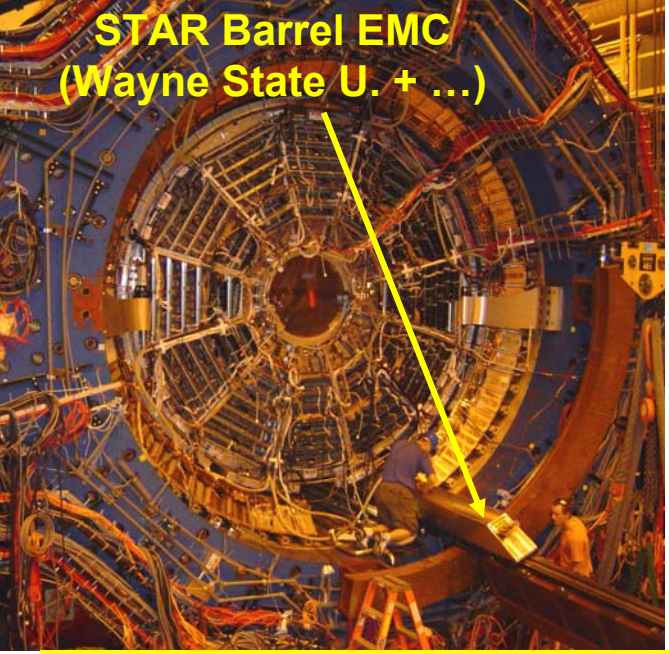


Time Projection
Chamber
-2<η< 2

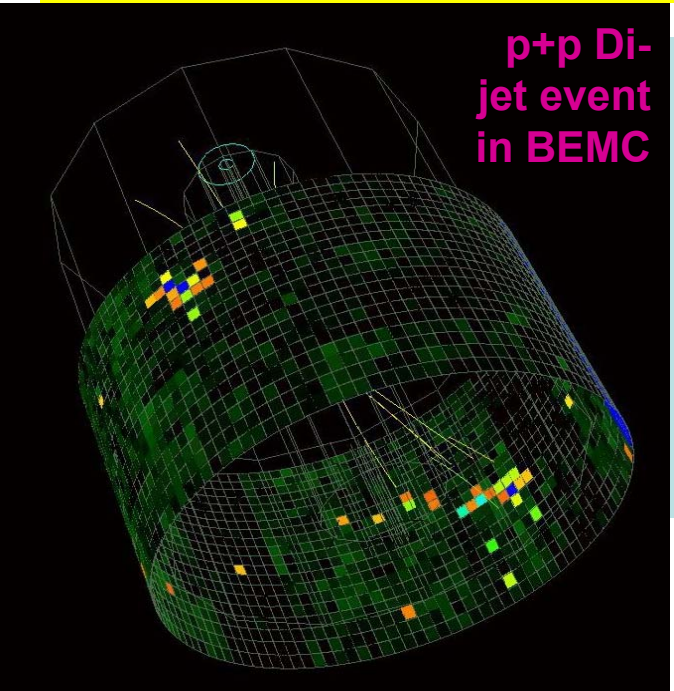
Tracking

Solenoidal Magnetic
Field 5kG

2005

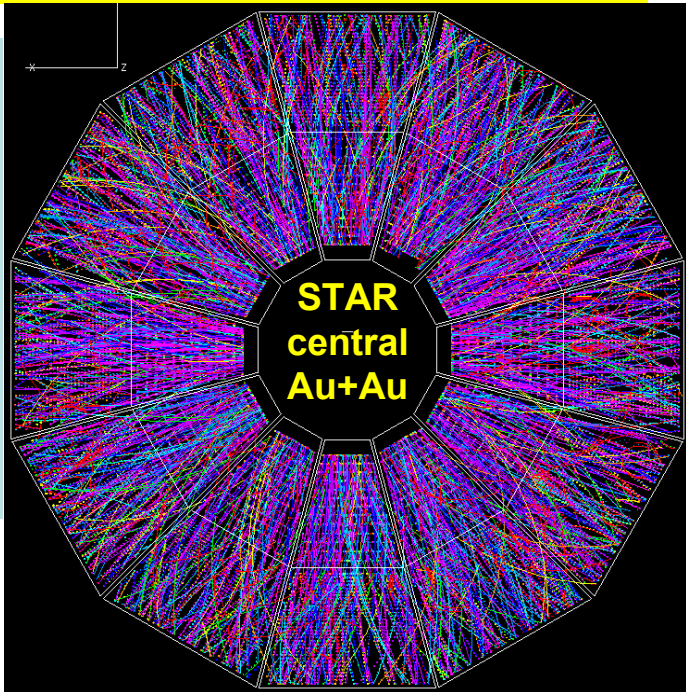


EMC's Essential for the Spin Program and Jet Detection

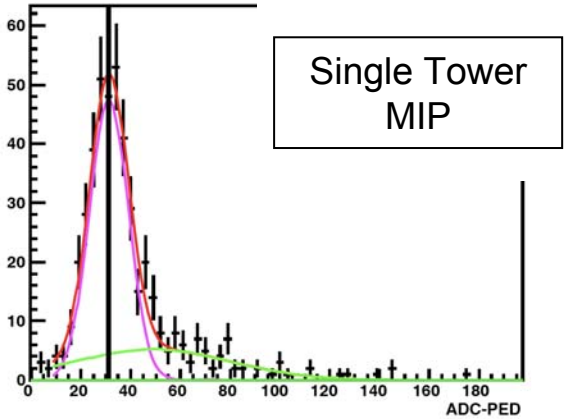


STAR barrel (completed 2006), endcap (completed 2005) and forward (upgraded 2006) em calorimeters permit triggering/reconstruction for jets, γ, π^0, …

… in HI as well as $\vec{p}+\vec{p}$ collisions!

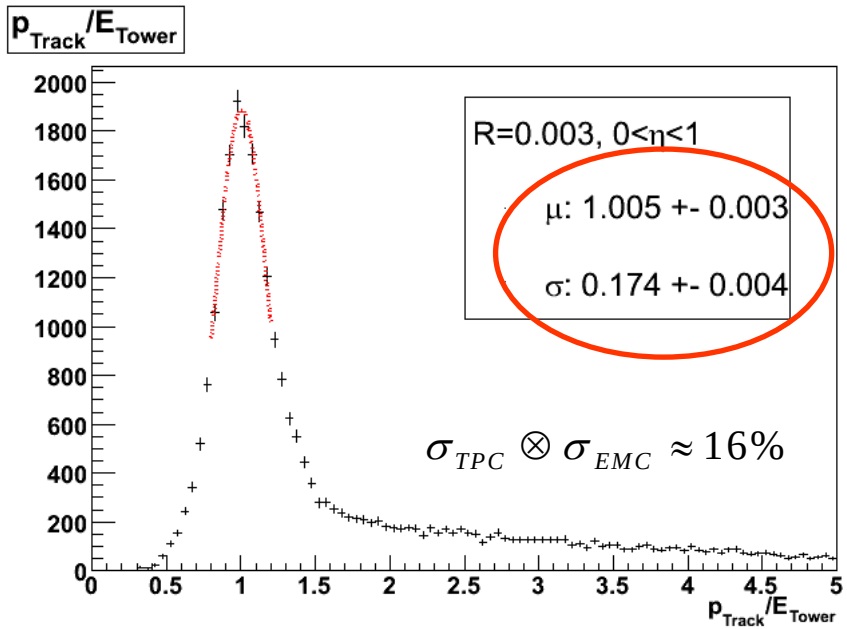


Jet Energy Scale Relies on EMC Calibration

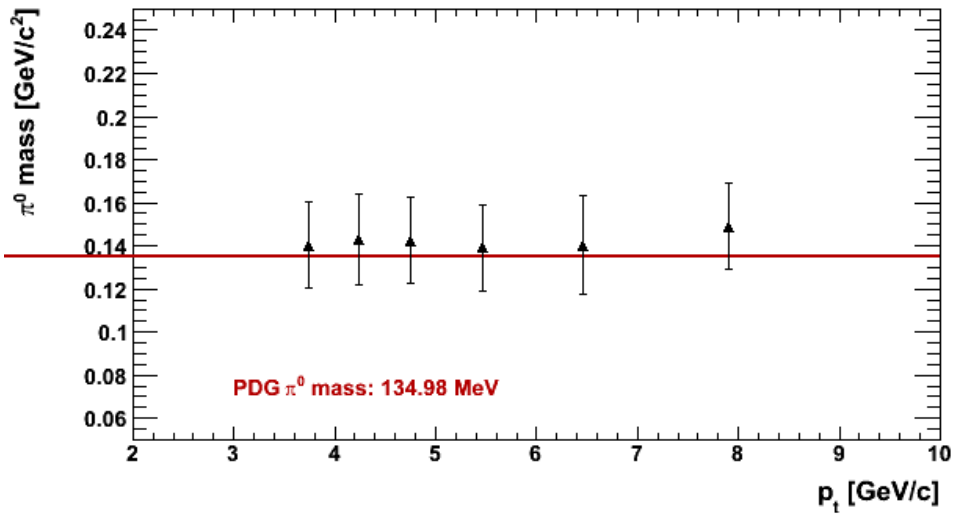


Relative gain of every tower (4800 for BEMC, 720 for EEMC) determined from MIP response. Identify MIP's via tracks for BEMC, via SMD + preshower + postshower response for EEMC

Set E-scale using 1.8<*p*<8 GeV/*c* electrons



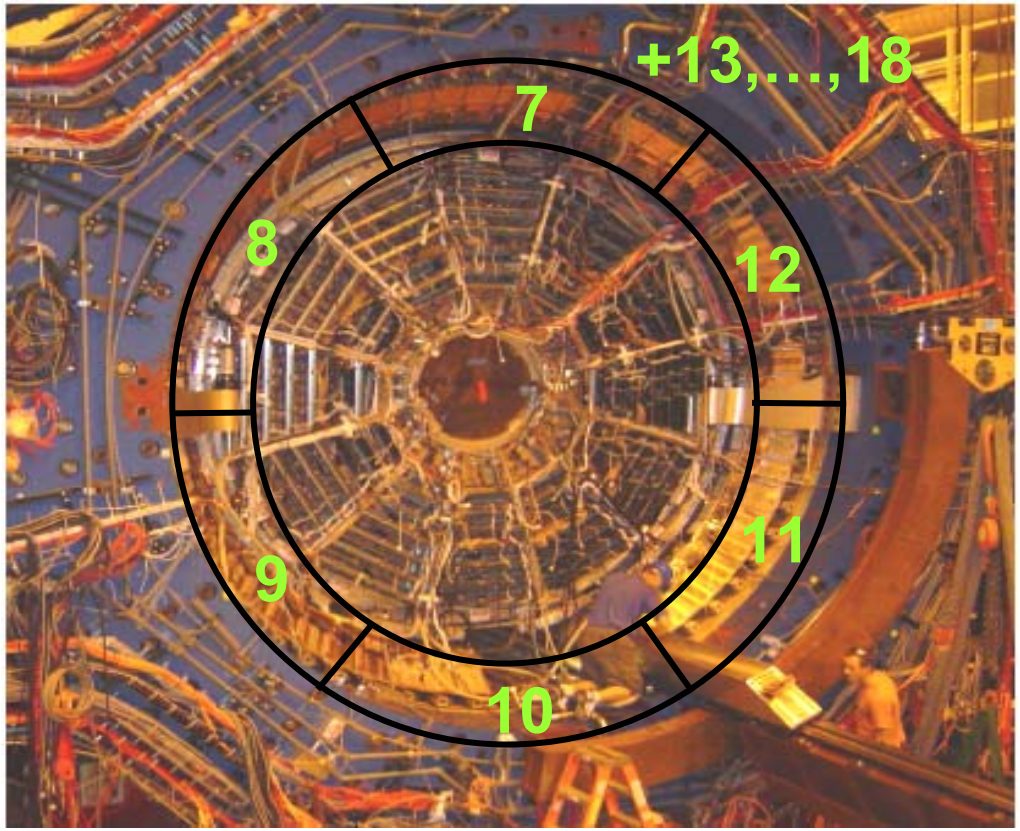
Absolute E scale set by comparison to track momentum for identified electrons

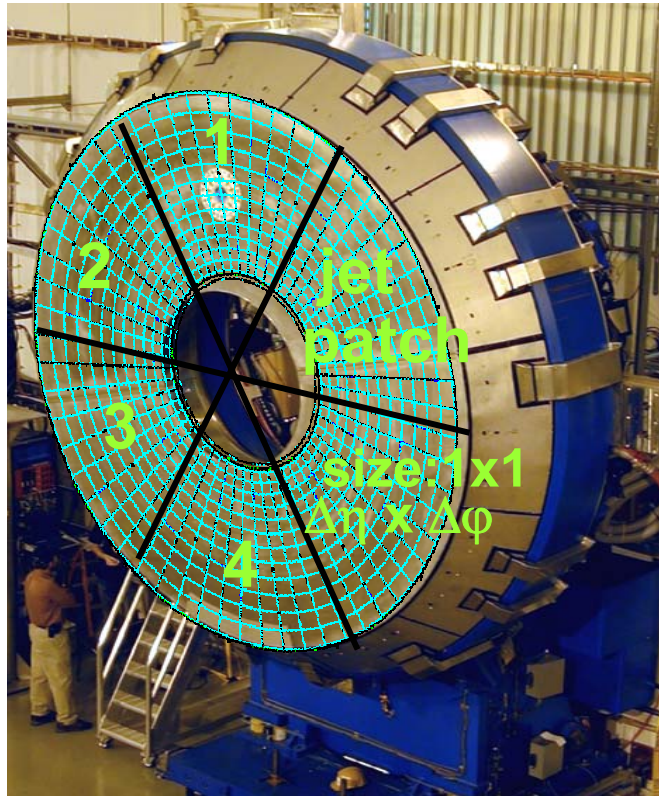


Cross-check from reconstructed π^0 invariant mass.

Overall gain precision = $\pm$5% presently. Aim for 2% in near future.

Jet Triggering in STAR





Trigger either on

***HT*: ≥1 (of 4800 BEMC or 720 EEMC) tower E_T > thresh.**

Or

***JP*: ≥1 (of 12 BEMC or 6 EEMC) hard-wired jet patch $\sum E_T$ > thresh.**

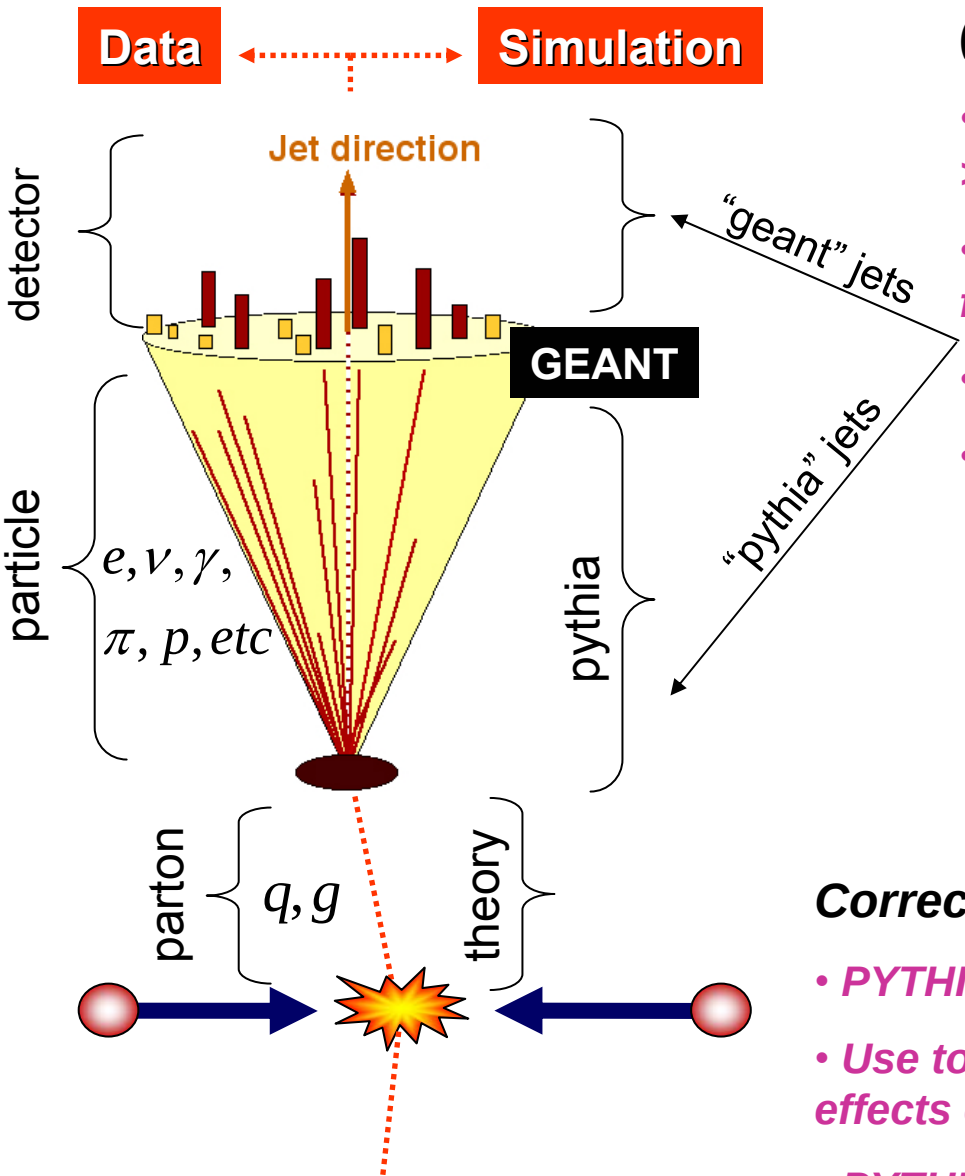
1x1 Jet patch $\sum E_T$/GeV

2006 rate ~ 150 Hz, combine with L2 trigger to fit in limited bandwidth

2006 rate ~ 2.5 Hz, sent to tape without prescaling

Allocated Jet Rate to tape: ~15 Hz

Jet Reconstruction in STAR



Use "midpoint-cone" algorithm (hep-ex/0005012):

- *Search over all possible seeds (p_T^{seed} > 0.5 GeV) for stable groupings*
- *Check midpoints between jet-jet pairs for stable groupings*
- *Split/merge jets based on $E_{overlap}$*
- *Add all track/tower 4-momenta*

Use cone radius:

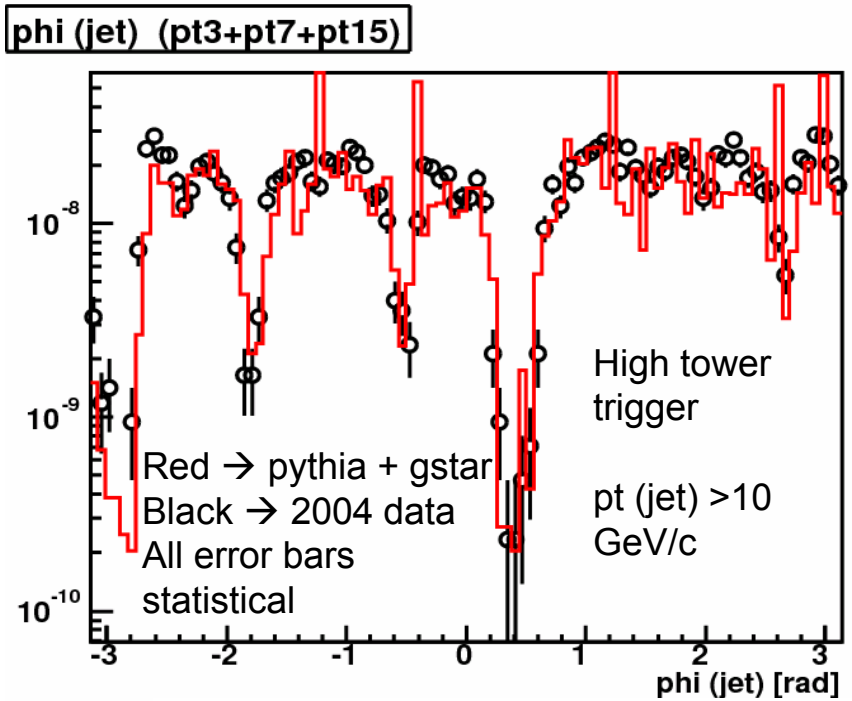
$$R_{cone} \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

- *= 0.4 for half-BEMC 2003-5*
- *= 0.7 for full B+EEMC 2006*

Correction philosophy:

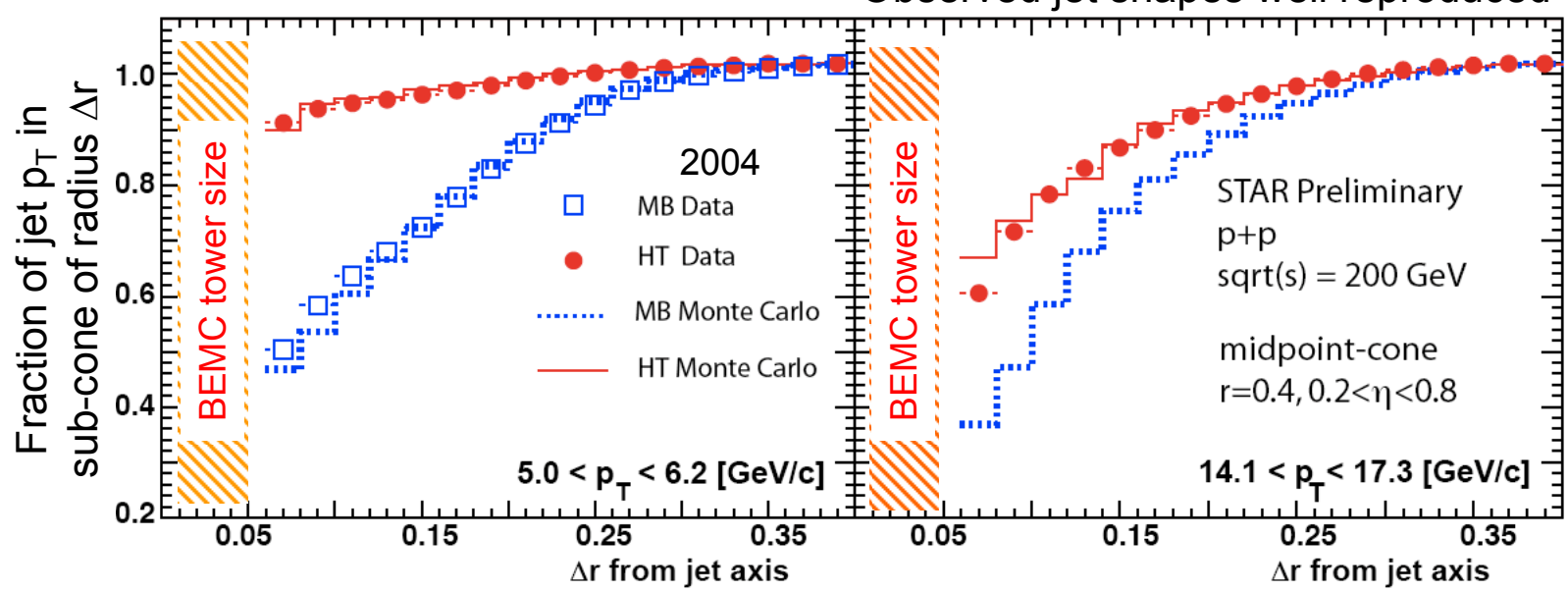
- *PYTHIA+GEANT ⇒ detector response*
- *Use to correct for "particle" → "detector" effects of resolution, efficiency, bias*
- *PYTHIA also ⇒ study "parton" → "particle" effects of hadronization, event energy*

Simulations Use Same EMC Status Tables as Data Analysis to Reproduce Details of Response

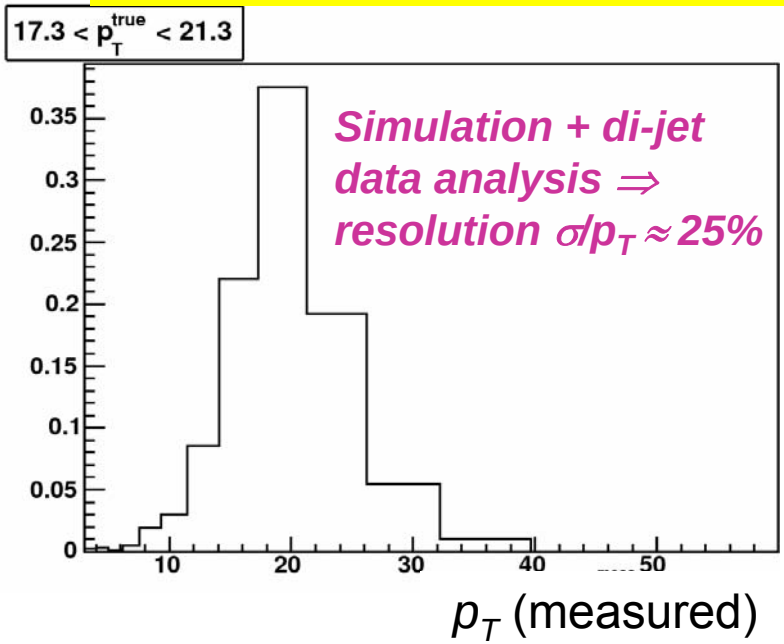


Efficiency dips between jet patches, sometimes enhanced by FEE hardware problems, reflected in status tables

Observed jet shapes well reproduced

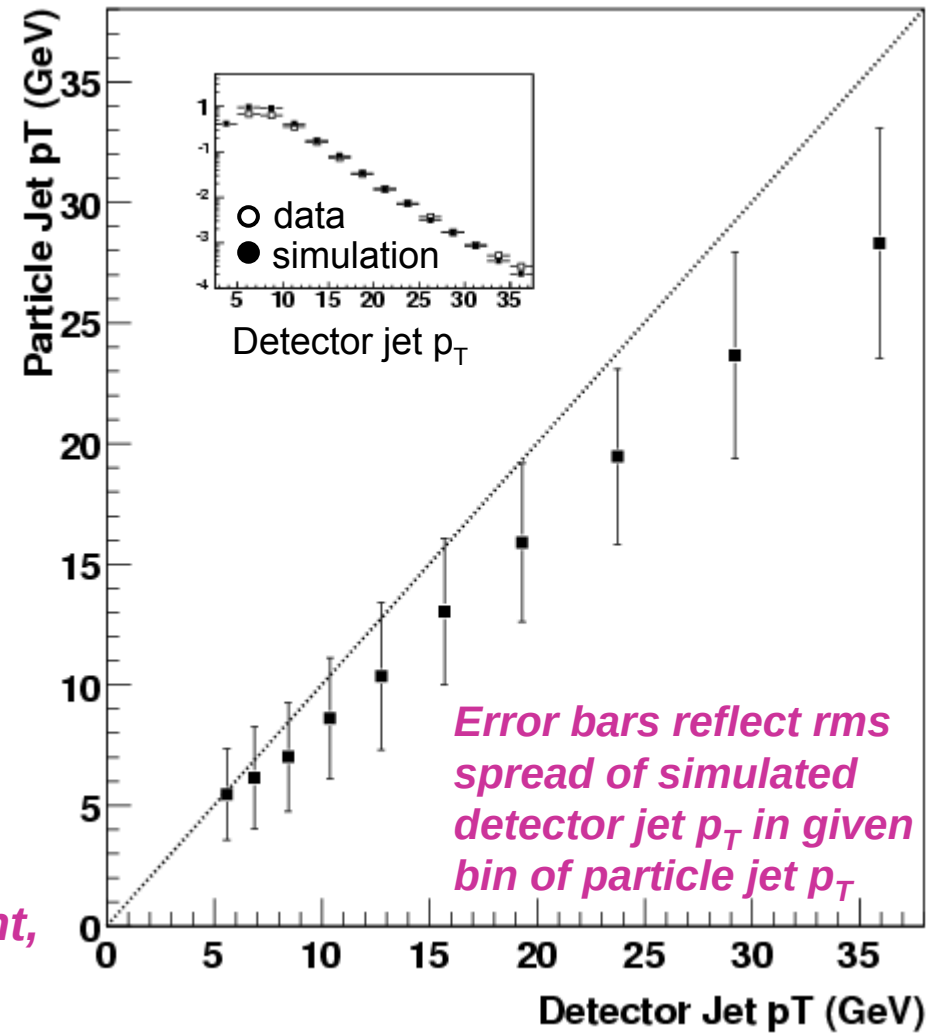


Subtleties of Jet Analysis: Jet Energies



Simulation + di-jet data analysis ⇒ resolution $\sigma/p_T \approx 25\%$

Steep p_T spectrum + crude jet energy resolution ⇒ detector jets spawned, on average, by lower-p_T particle jets (despite loss of neutral hadrons w/o hadron calorimeter).



Error bars reflect rms spread of simulated detector jet p_T in given bin of particle jet p_T

- ***p_T shift incorporated to date by cross section corrections, A_{LL} syst. errors***
- ***Future pubs. to correct E scale, with uncertainties in horizontal errors***
- ***"Particle" → "detector" jet shift ≈ same for gg vs. qg vs. qq***
- ***"Parton" → "particle" shifts from hadronization (E loss) and underlying event (E gain) are subprocess-dependent, to be incorporated in syst. errors***

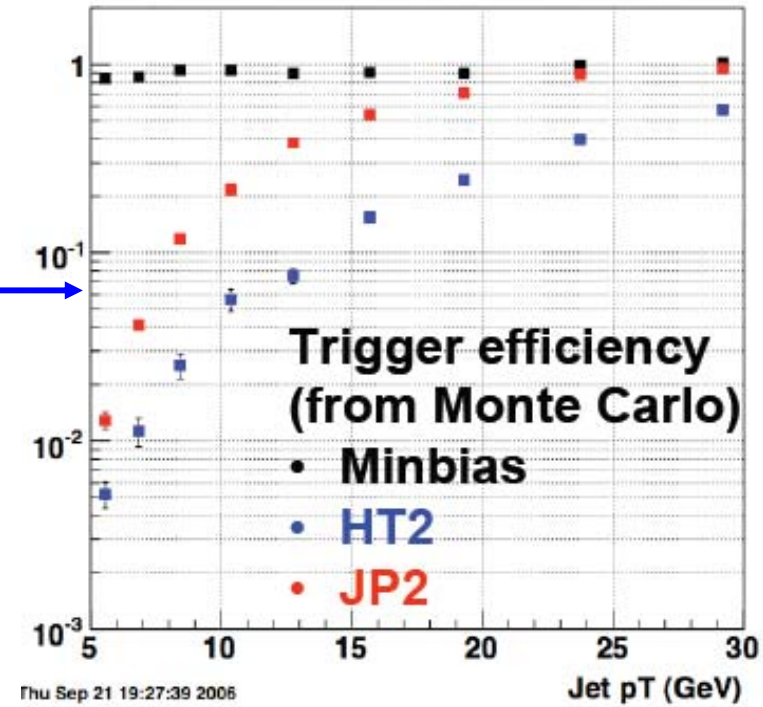
Subtleties of Jet Analysis: Trigger Bias

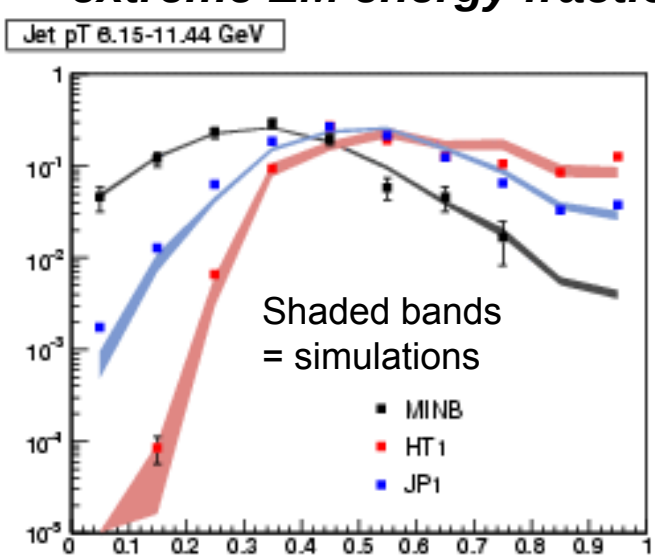
High Tower and Jet Patch triggers require substantial fraction of jet energy in neutral hadrons

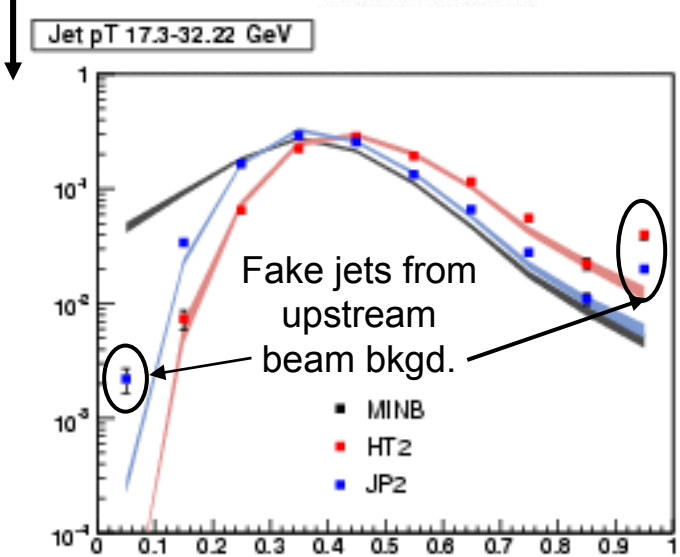
⇒Trigger efficiency turns on slowly above nominal threshold

⇒ Efficiency differs for quark vs. gluon jets, due to different fragmentation features

Simulations reproduce measured bias well, except for beam background at extreme EM energy fraction







Conclude:

- ***Cut out jets at very high or very low EMF***
- ***Use simulations to estimate syst. errors from trigger bias***

EMF ≡ Electromagnetic Energy Fraction ≡ $\sum E_T(\text{EMC}) / \text{total jet } p_T$

Inclusive STAR Jet Results 2003-5

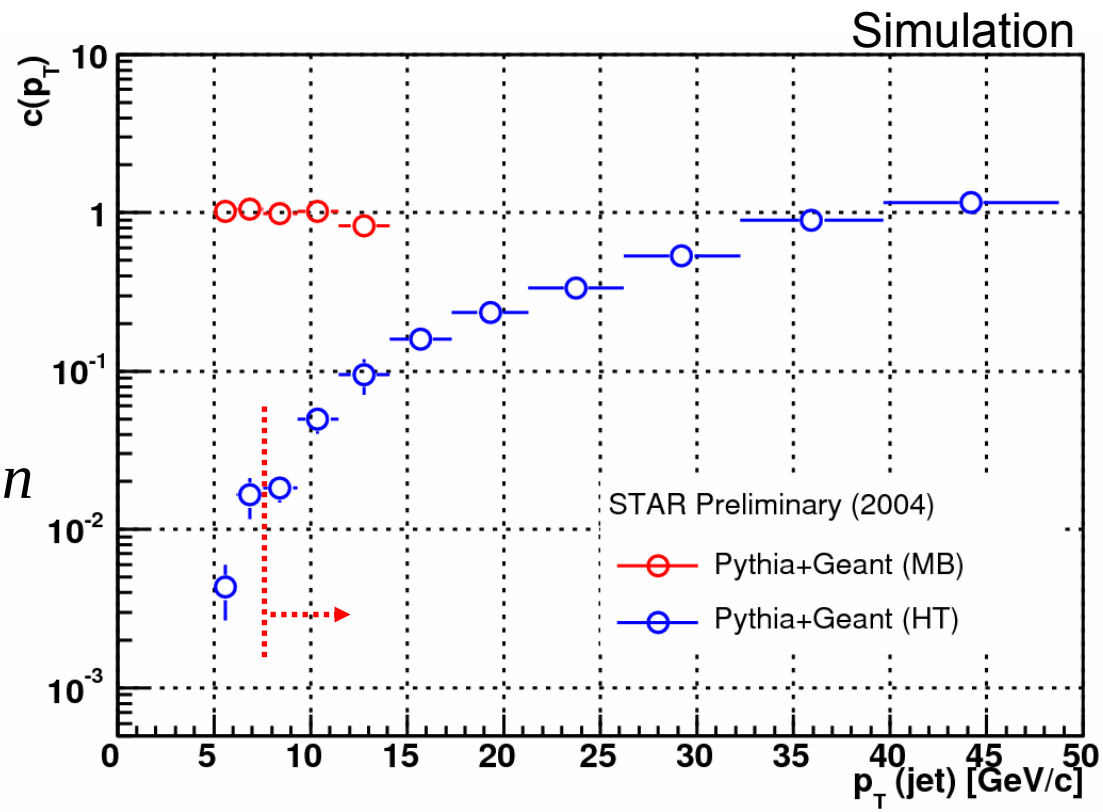
Published Jet Production Cross Sections (2003+4) Rely on Simulated Correction Factors

"measured"

$$c(p_T) = \frac{M_{geant}\left(p_T^{geant}\right)}{N_{pythia}\left(p_T^{pythia}\right)}$$

"true"

$$c(p_T):\ \varepsilon_{trigger} \otimes \varepsilon_{jet} \otimes resolution$$



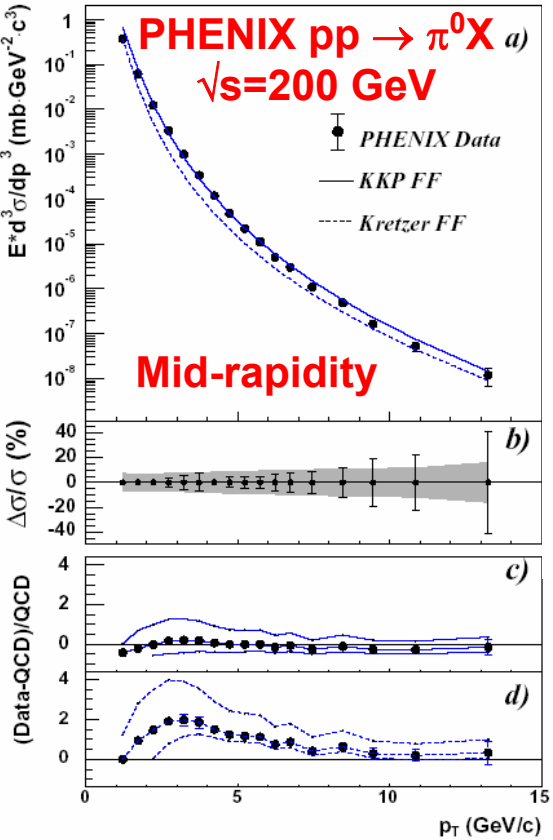
ε_{jet} : decreases $c(p_T)$

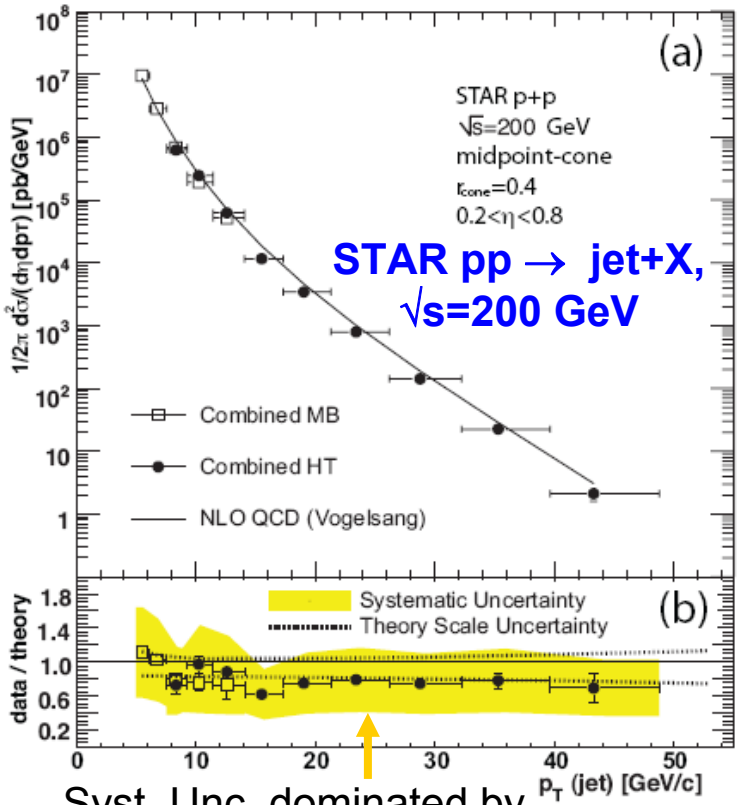
resolution: increases $c(p_T)$

ε_{Trig}: ~1 e-2 at $p_{T\text{-}jet}$ = 5 GeV
~1 at $p_{T\text{-}jet}$ = 50 GeV

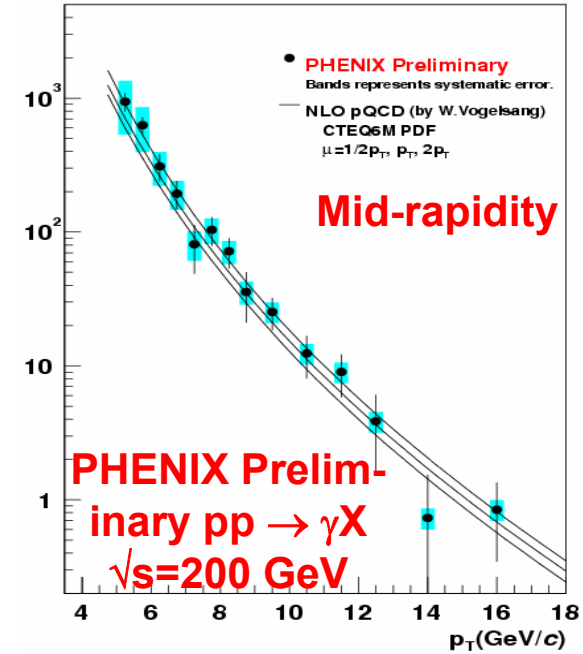
- Jet p_T resolution ~ 25%
- HT efficiency changes by 2 orders of magnitude!
- Consistent results from both PYTHIA and HERWIG

Early RHIC pp Absolute Cross Section Results

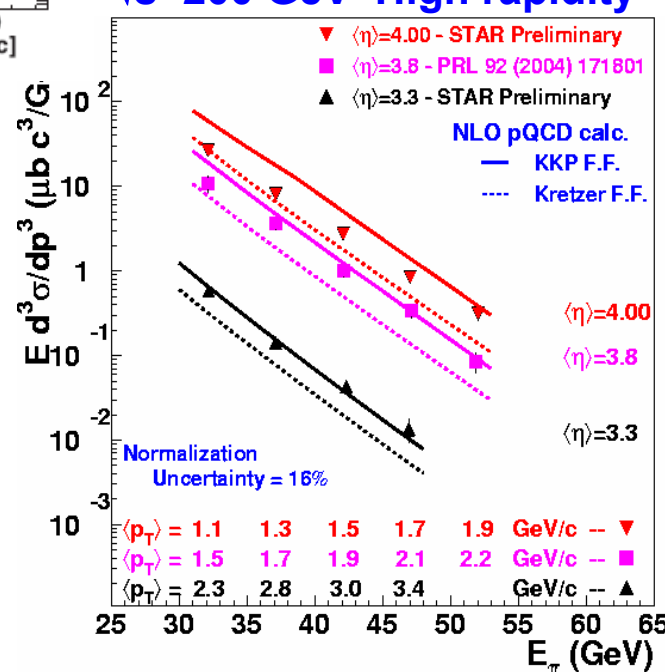




Syst. Unc. dominated by jet E scale uncertainty



STAR pp → π^0X,
√s=200 GeV High rapidity

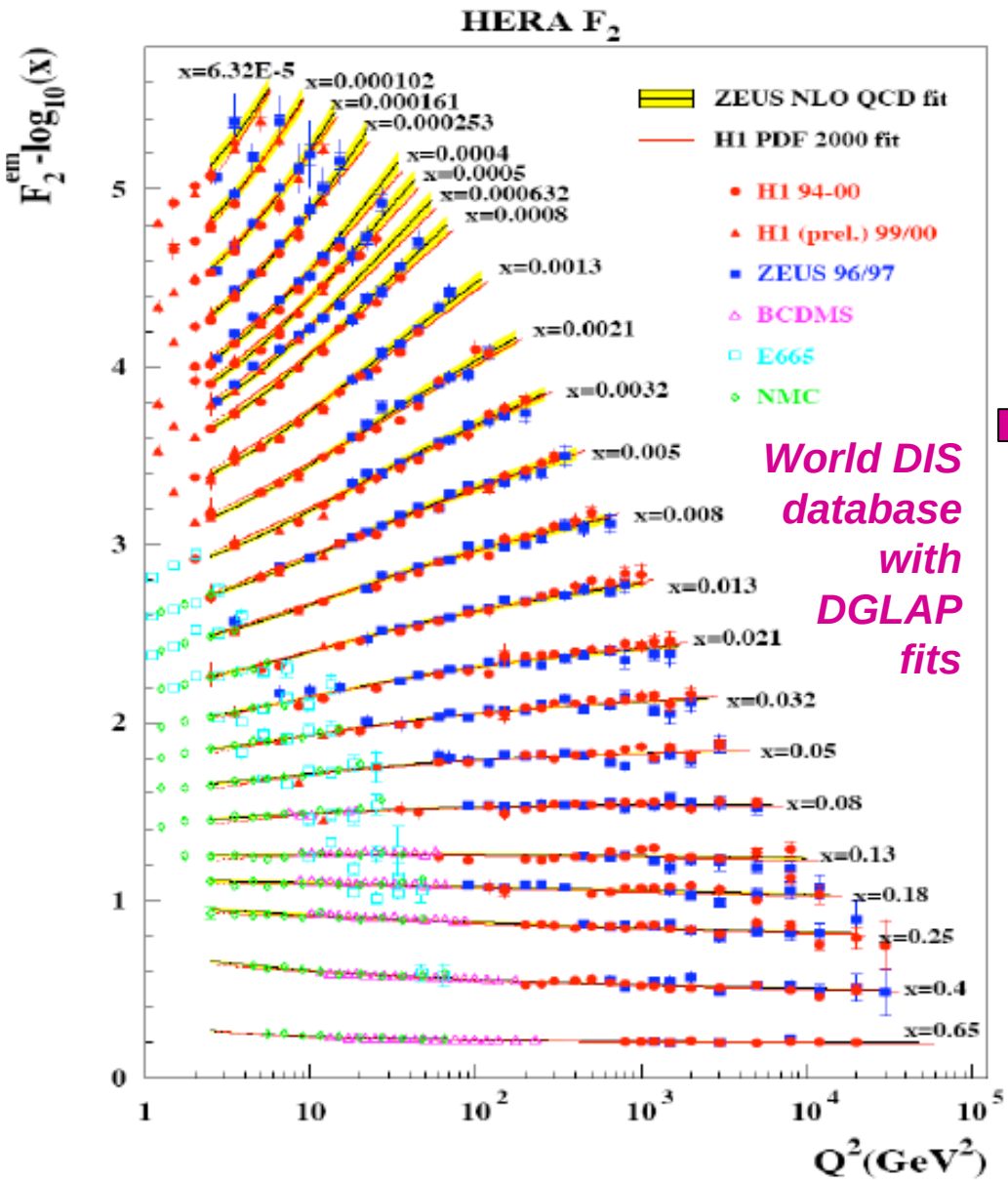


Low-p_T reach of robust pQCD account was not anticipated!

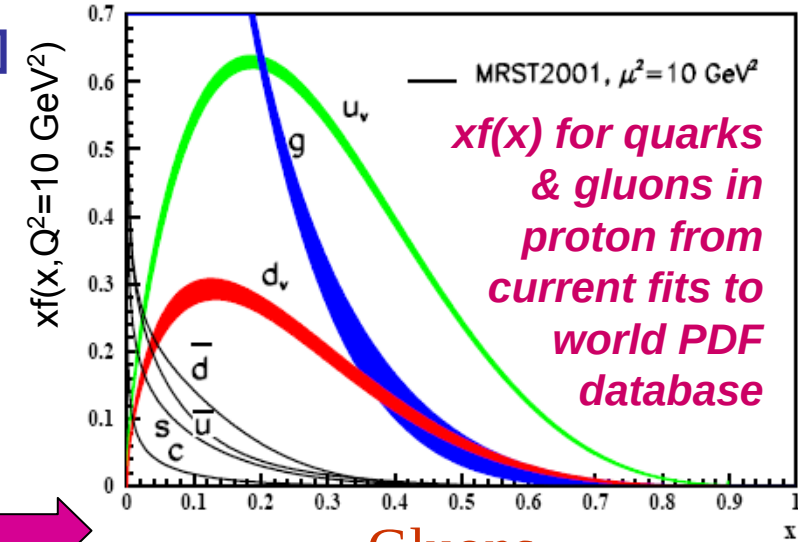
pQCD works! ***Absolute cross sections for channels critical to gluon polarization determination -- p+p → π^0+X, jet + X, γ+X at $\sqrt{s}$ = 200 GeV – are well reproduced in NLO pQCD calcs. down to p_T ~ few GeV/c.***

Current Info on Unpolarized Quark & Gluon Distrib'ns

Parton Model $\Rightarrow F_2^p(x,Q^2) = \sum e_i^2\, x\, [q_i(x,Q^2) + \bar{q}_i(x,Q^2)]$

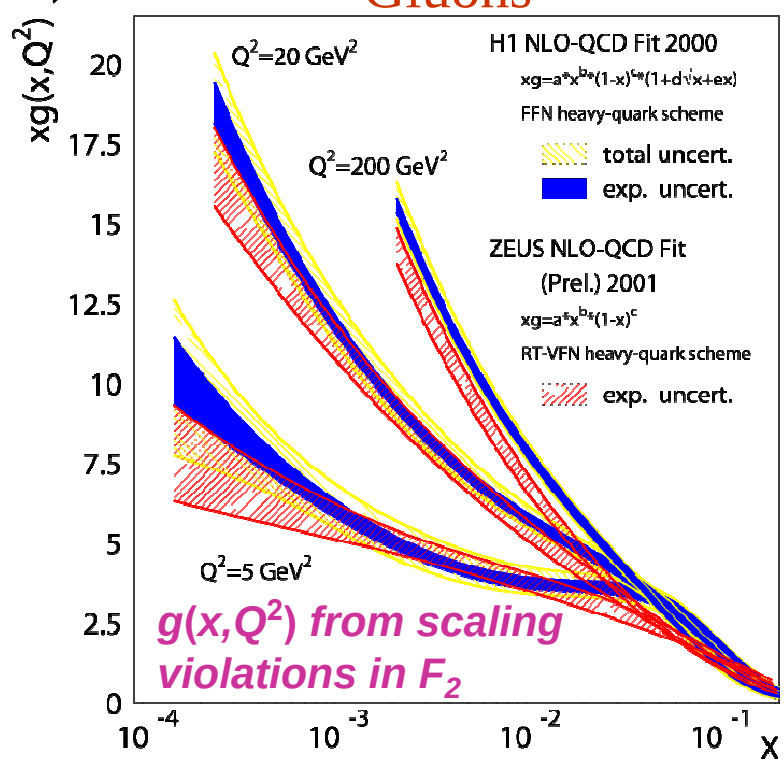


World DIS database with DGLAP fits



xf(x) for quarks & gluons in proton from current fits to world PDF database

Gluons

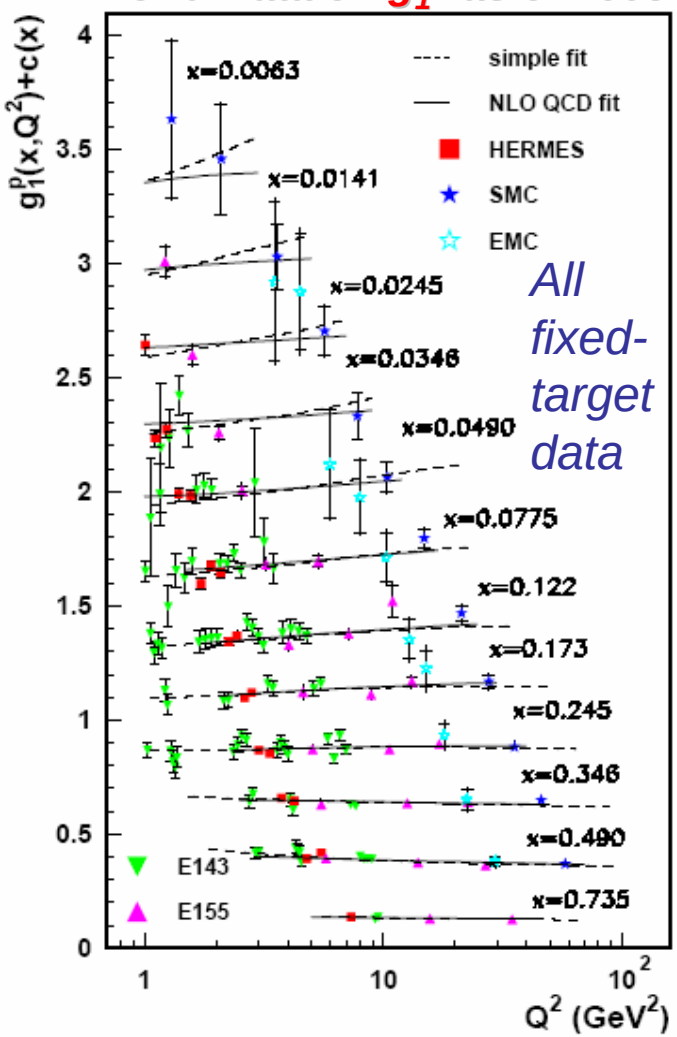


$g(x,Q^2)$ from scaling violations in F_2

Polarized DIS Data Are Too Sparse to Constrain Gluon Helicity Preferences Well:

Parton Model $\Rightarrow g_1^p = \frac{1}{2} \sum e_i^2 [\Delta q_i(x,Q^2) + \Delta \bar{q}_i(x,Q^2)]$

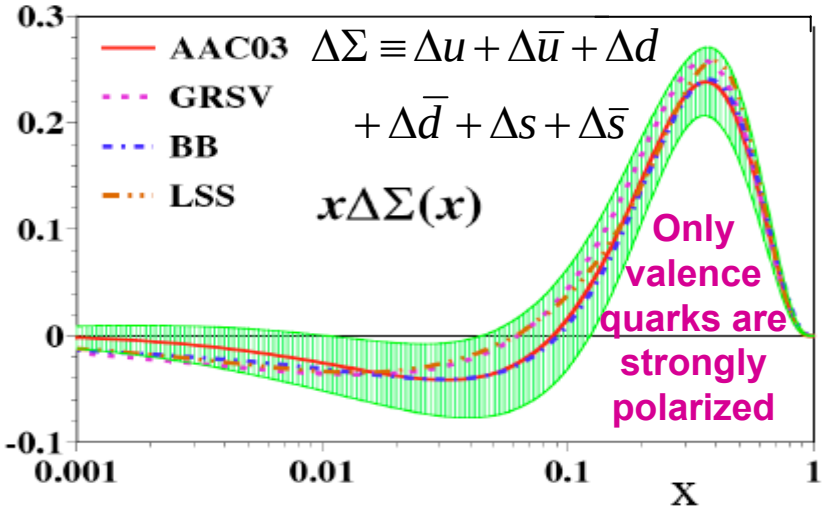
World Data on g_1^p as of 2005



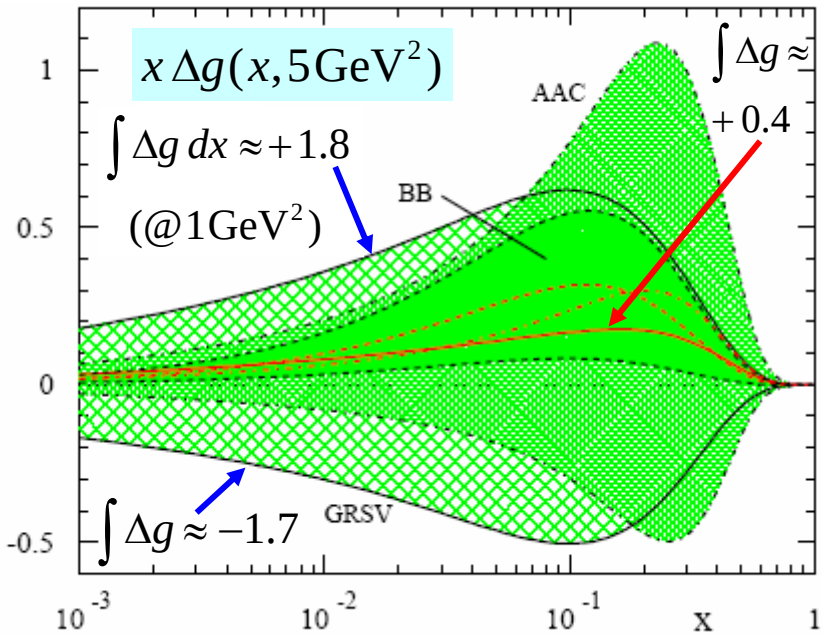
All fixed-target data

Only ~20-30% of proton spin arises from q and $\bar{q}$ helicity preferences !

limited info on scaling violations, .: on shape or integral of gluon helicity preference $\Delta g(x,Q^2)$.

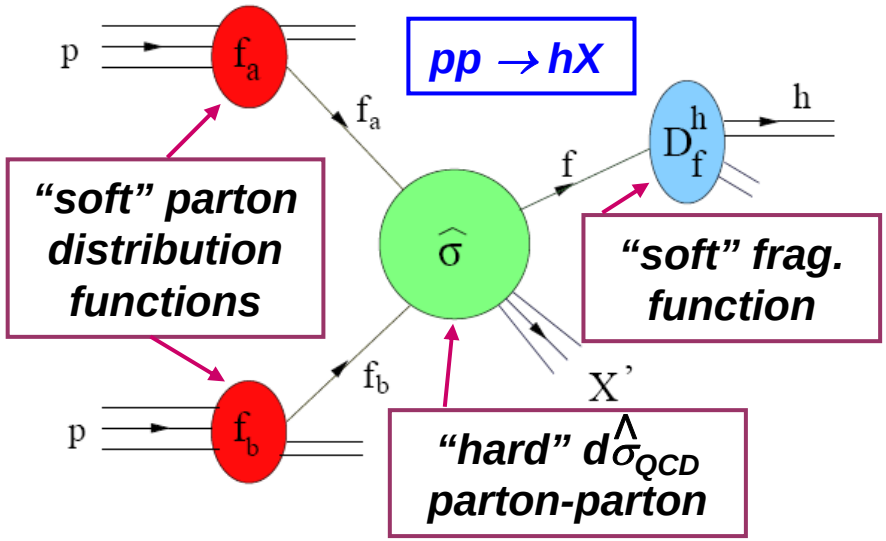


Hirai, Kumano, Saito

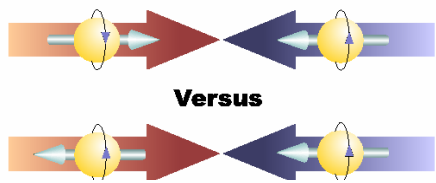


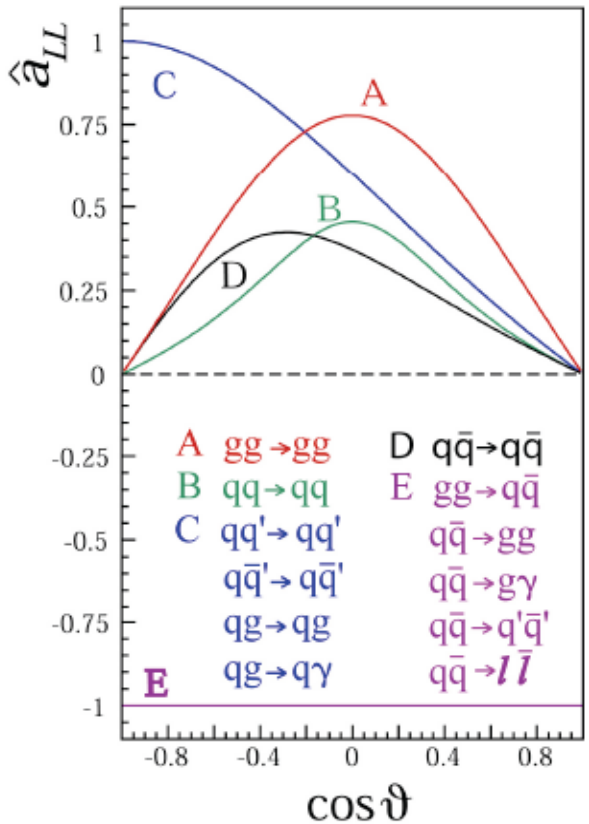
Constraining Δg Via $\vec{p}+\vec{p} \rightarrow$ jet + X Spin Correlations

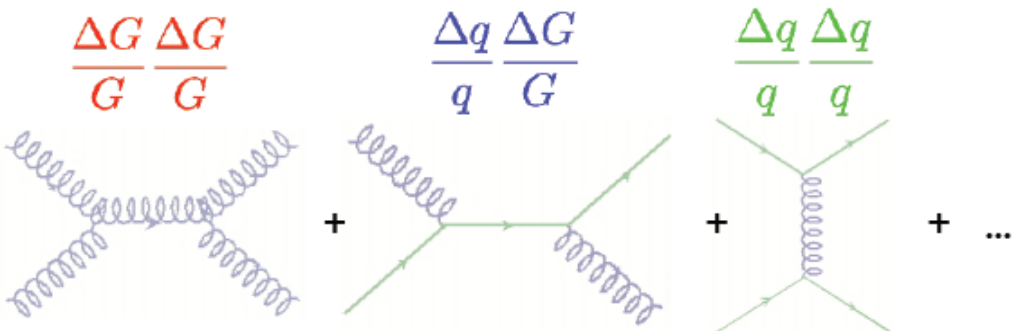
Theory ingredients: pQCD factorization



+ LO + NLO pQCD 2-spin asymmetries







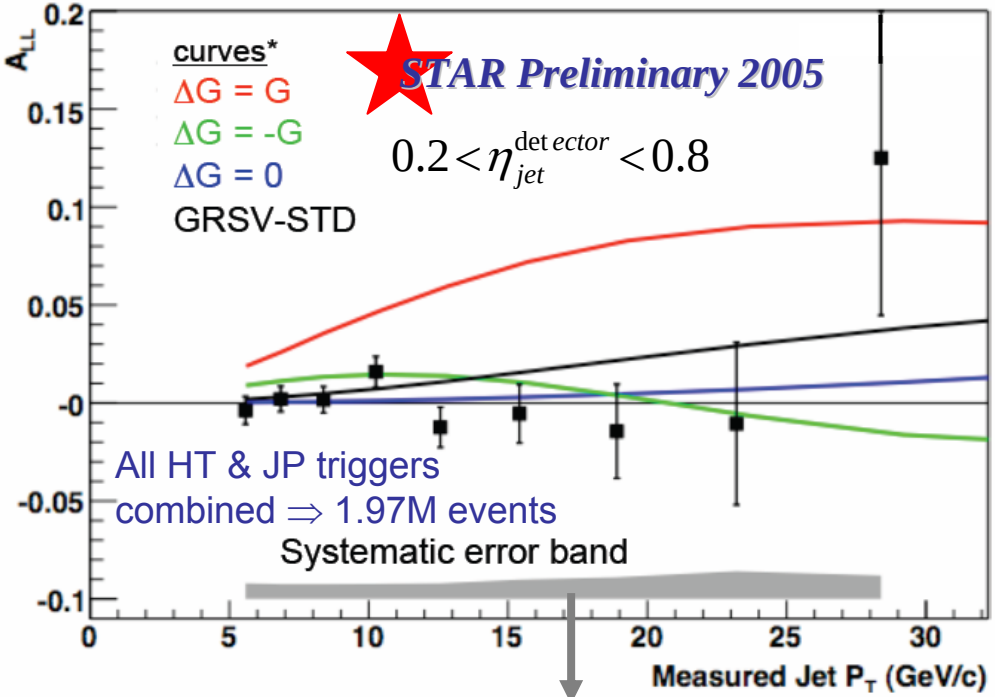
pQCD factoriz'n $\Rightarrow$ $A_{LL} = \dfrac{d\Delta\sigma_{pp\rightarrow\pi+X}}{d\sigma_{pp\rightarrow\pi+X}}$

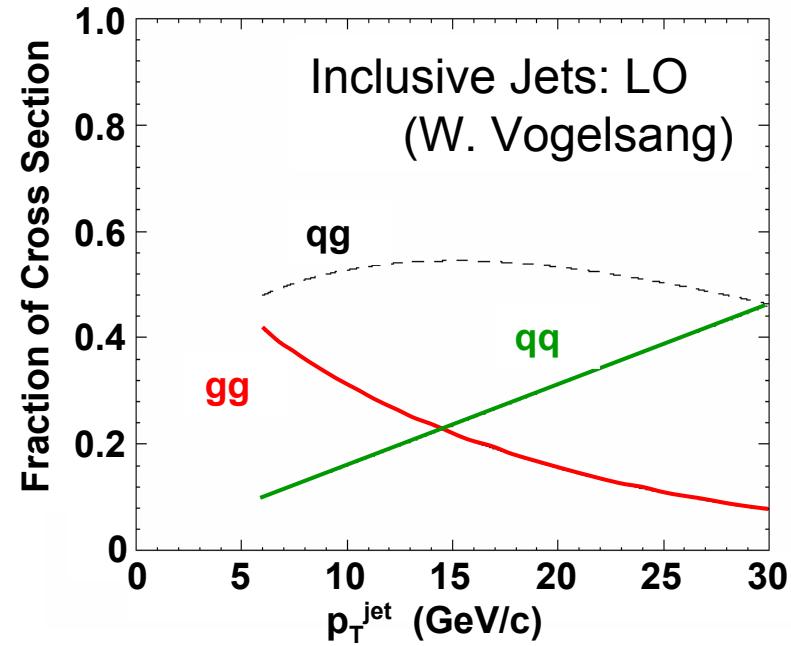
$$= \frac{\sum_{f_1,f_2} \Delta f_1 \otimes \Delta f_2 \otimes d\hat{\sigma}^{f_1 f_2 \rightarrow fX} \cdot \hat{a}_{LL}^{f_1 f_2 \rightarrow fX} \otimes D_f^\pi}{\sum_{f_1,f_2} f_1 \otimes f_2 \otimes d\hat{\sigma}^{f_1 f_2 \rightarrow fX} \otimes D_f^\pi}$$

Fragmentation functions not needed for jet calcs.

STAR 2005 Inclusive Jet A_{LL} Results

3.1 pb^{-1} sampled → 1.6 pb^{-1} after run selection; $\langle P_B P_Y \rangle \approx 0.25$



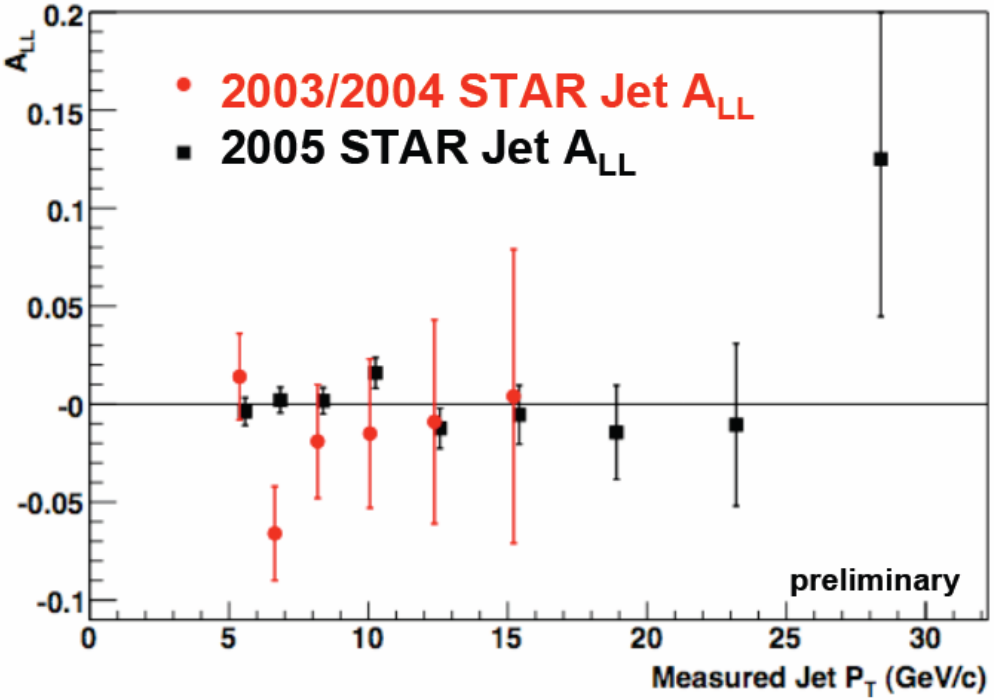


effect	(x 10^{-3})
False Asymmetries	<6.5
Reconstruction + Trigger Bias	2-12 (p_T dependent)
Non-longitudinal Polarization	3
Relative Luminosity	2
Backgrounds	<1

Ongoing analysis is:

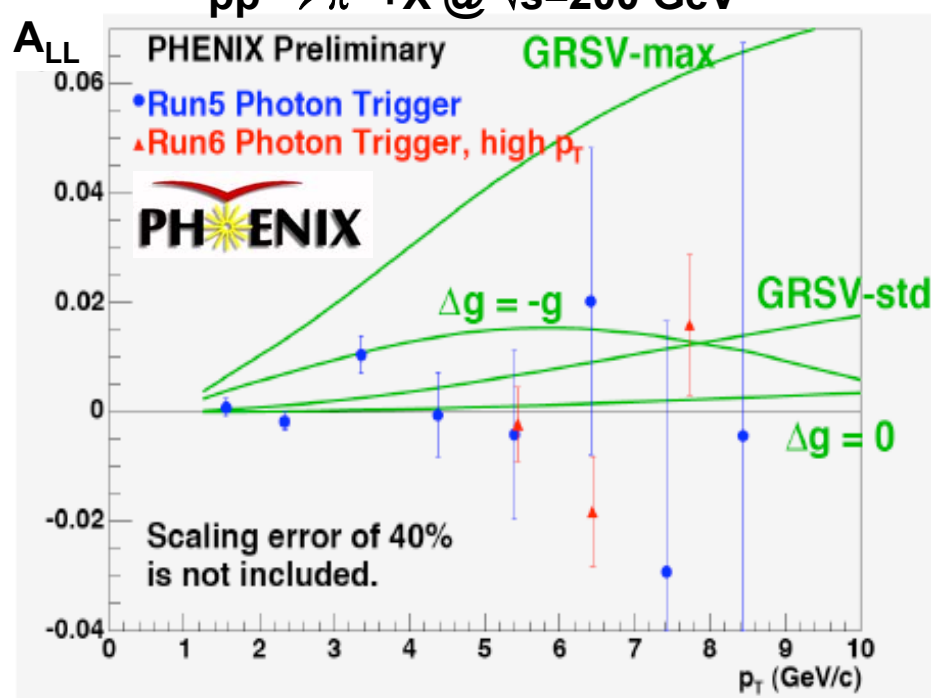
- ***recovering more runs***
- ***correcting to particle jet E scale***
- ***reducing systematic errors***
- ***quantifying constraint on Δg***

Results do not support Δg(1.0 GeV^2) much > 0.4 within GRSV shape ansatz



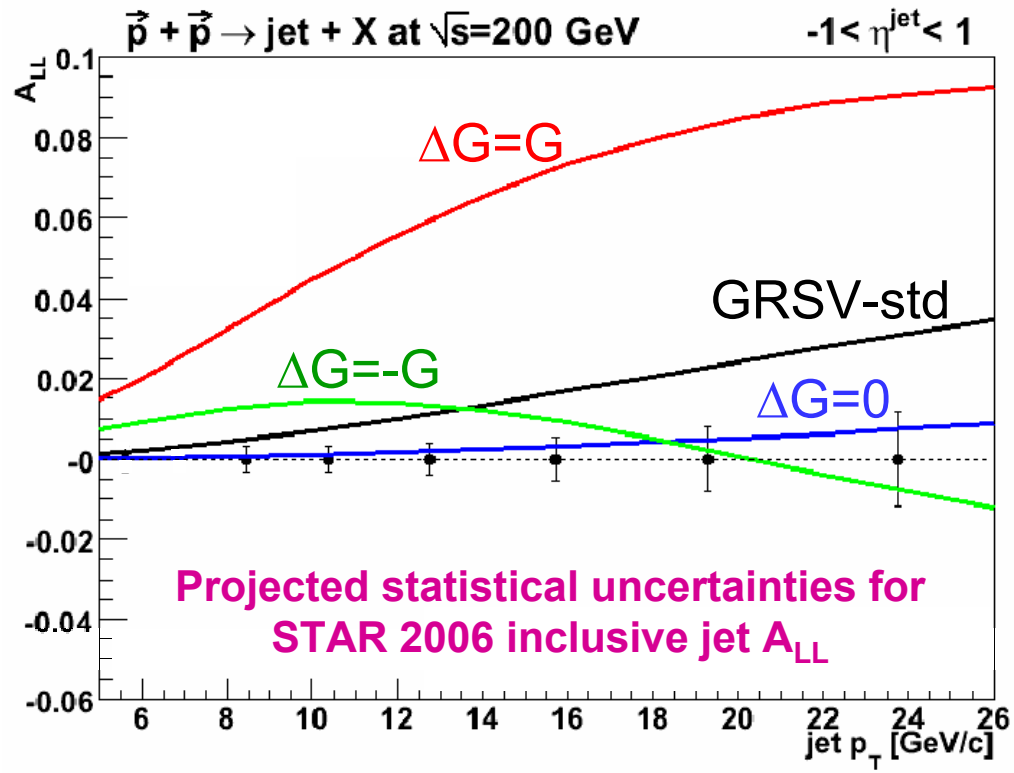
STAR 2005 Inclusive Jet A_{LL} Results are Consistent Among Different Jet Triggers, and With 2003+4 STAR Results and 2005+6 PHENIX A_{LL} for Inclusive π^0

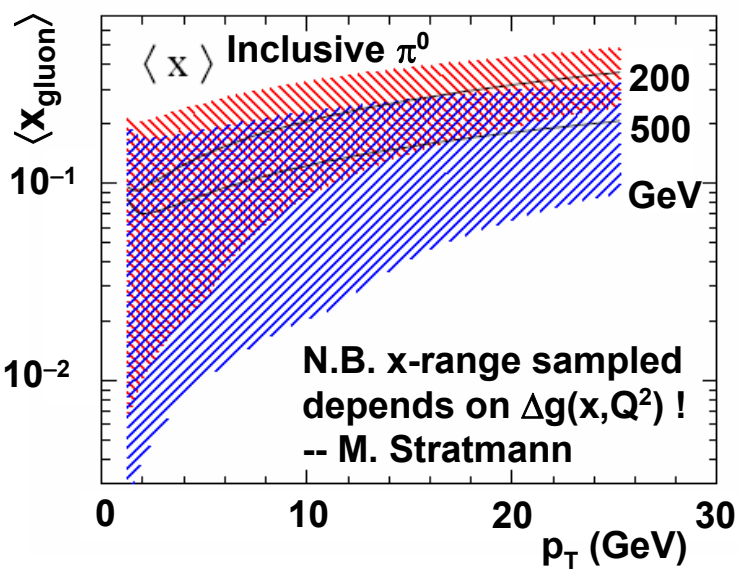
$pp \rightarrow \pi^0 + X$ @ $\sqrt{s}$=200 GeV



Inclusive Jet Data from 2006 Will Provide Far Greater Discriminating Power for Δg

- ***High-statistics (esp. at high p_T) inclusive jet and π^0 A_{LL} data from 2006 will select among Δg models, assuming a shape of $\Delta g(x,Q^2)$.***
- ***Inclusive channels suffer from integration over x $\Rightarrow$ model-dependent ΔG extraction.***





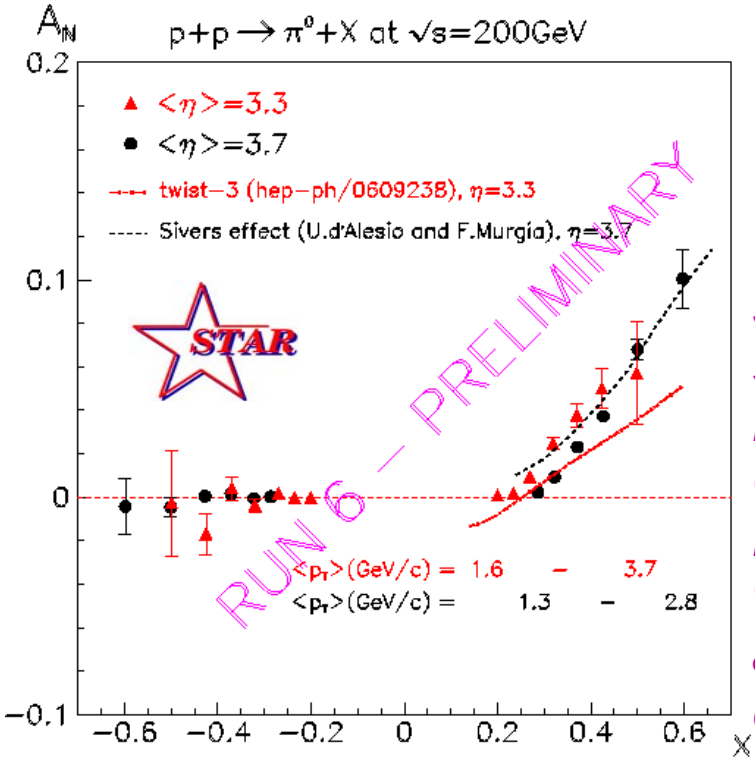
- ***With improved beam & detector performance, focus is now shifting to jet-jet and γ-jet coincidences for event-by-event constraints on colliding parton $x_{1,2}$:***

$$x_1 = \frac{x_T}{2}\left(e^{\eta_1} + e^{\eta_2}\right); \quad x_2 = \frac{x_T}{2}\left(e^{-\eta_1} + e^{-\eta_2}\right);$$

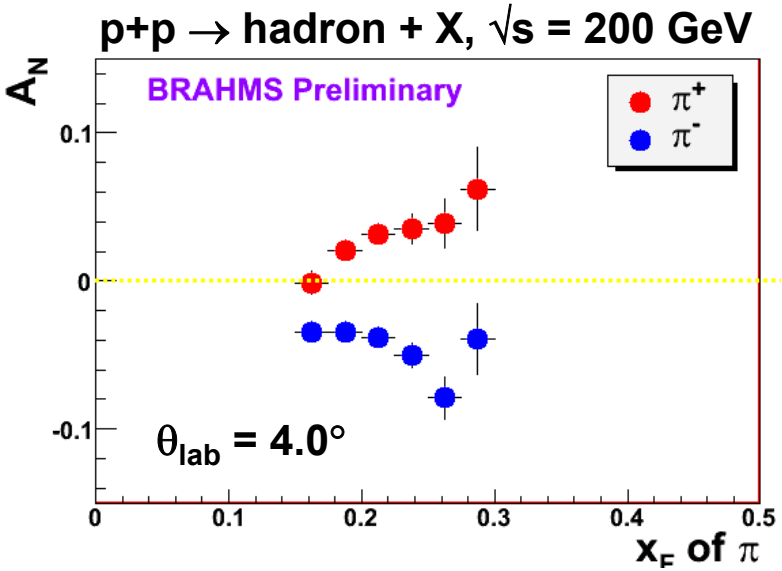
$$\cos\theta^* = \tanh\left[\pm\frac{1}{2}\left(\eta_1 - \eta_2\right)\right]; \; with \;\; x_T \equiv \frac{2p_T}{\sqrt{s_{pp}}}.$$

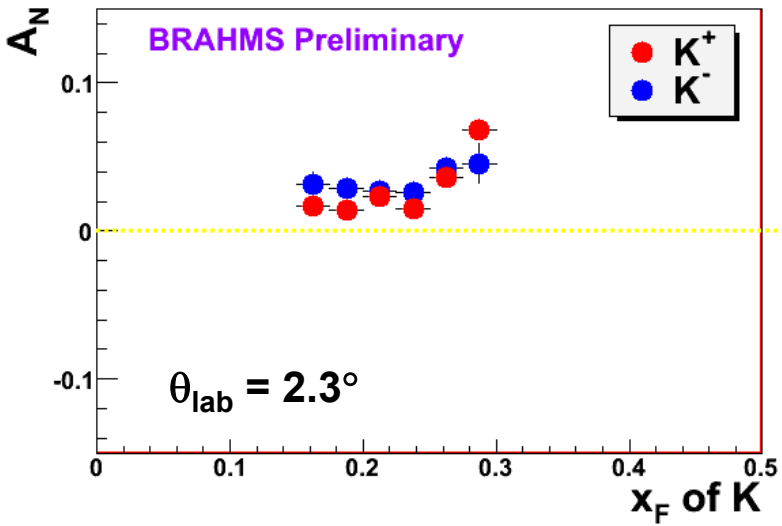
Single-Spin Asymmetry for Di-Jets 2006

Sizable Transverse Single-Spin Asymmetries Seen for Forward Hadron Production

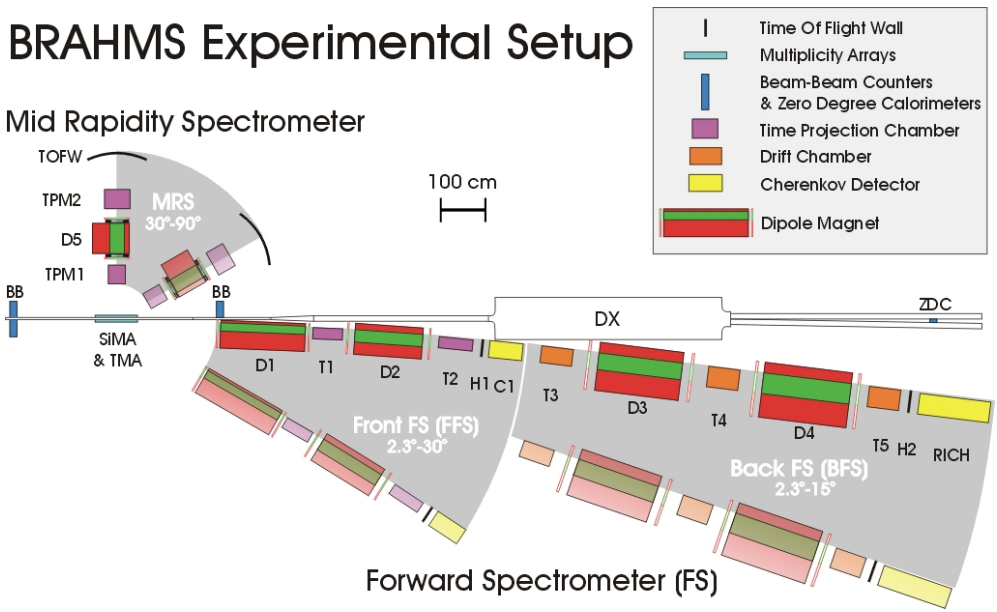


Similar to SSA seen in FNAL E704 @ √s = 20 GeV, but here in regime where pQCD accounts for cross section!





BRAHMS Experimental Setup



Transverse Spin Measurements Have Stimulated Rapid Development of Theory

Factorization:

Non-pert. pQCD Non-pert.

Hard hadronic $d\sigma$ = PDF's $\otimes$ hard partonic $d\hat{\sigma}$ $\otimes$ fragment'n fcn.

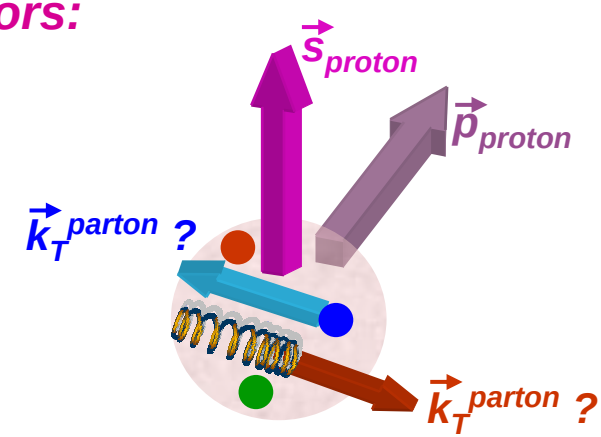
- ***Observed A_N values orders of magnitude too large to arise from explicit chiral-symmetry breaking quark mass terms in QCD Lagrangian.***

- ***Steep p_T -dependence of $d\sigma \Rightarrow$ sensitivity to spin-correlated transverse momentum preferences in non-perturbative factors:***

a) Partons in the initial state -- Sivers effect:

$$\left\langle \vec{s}_{proton} \cdot \left(\vec{p}_{proton} \times \vec{k}_T^{parton} \right) \right\rangle_{observed \quad process} \neq 0$$

Sensitive to parton orbital components in proton wave function, but also needs initial- and/or final-state interactions to evade TRV.



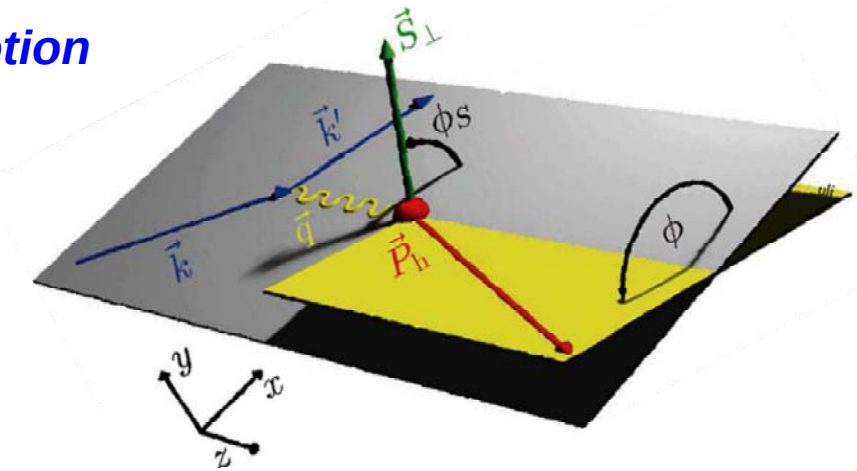
b) Hadrons emerging off-axis in quark $\rightarrow$ jet fragmentation --

Collins effect: $$\left\langle \vec{s}_{quark} \cdot \left(\vec{p}_{quark} \times \vec{k}_T^{fragment} \right) \right\rangle_{jet \quad formation} \neq 0$$

Requires quark transverse spin orientation preference in transversely polarized proton (“transversity”) + spin transfer to outgoing quark in pQCD scattering.

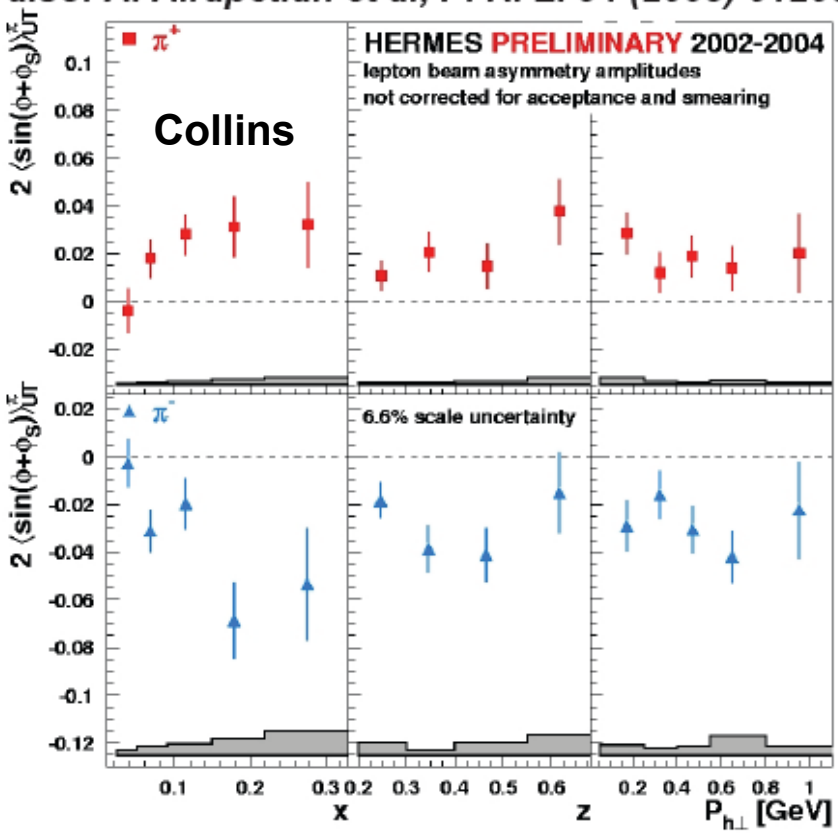
Distinguishing Sivers from Collins Asymmetries

In SIDIS, can distinguish transverse motion preferences in PDF's (Sivers) vs. in fragmentation fcns. (Collins) via asym. dependence on 2 azimuthal angles:

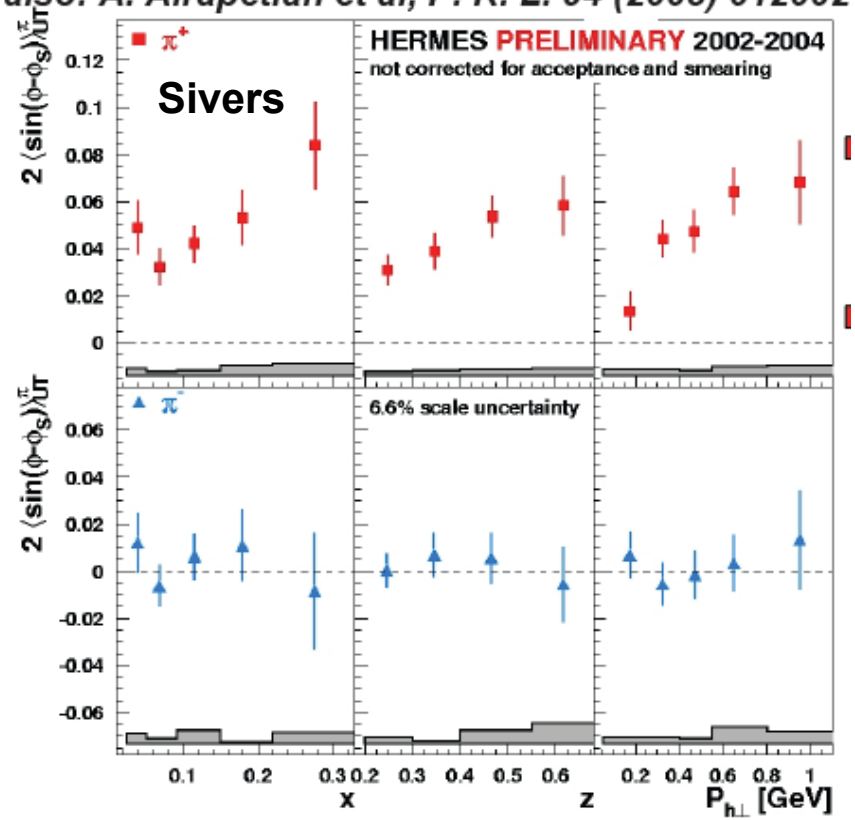


HERMES results ⇒ both non-zero, but π^+ vs. π^- difference suggests Sivers functions opposite for u and d quarks.

also: A. Airapetian et al, P. R. L. 94 (2005) 012002



also: A. Airapetian et al, P. R. L. 94 (2005) 012002



Motivation for pp → Di-Jet Measurement

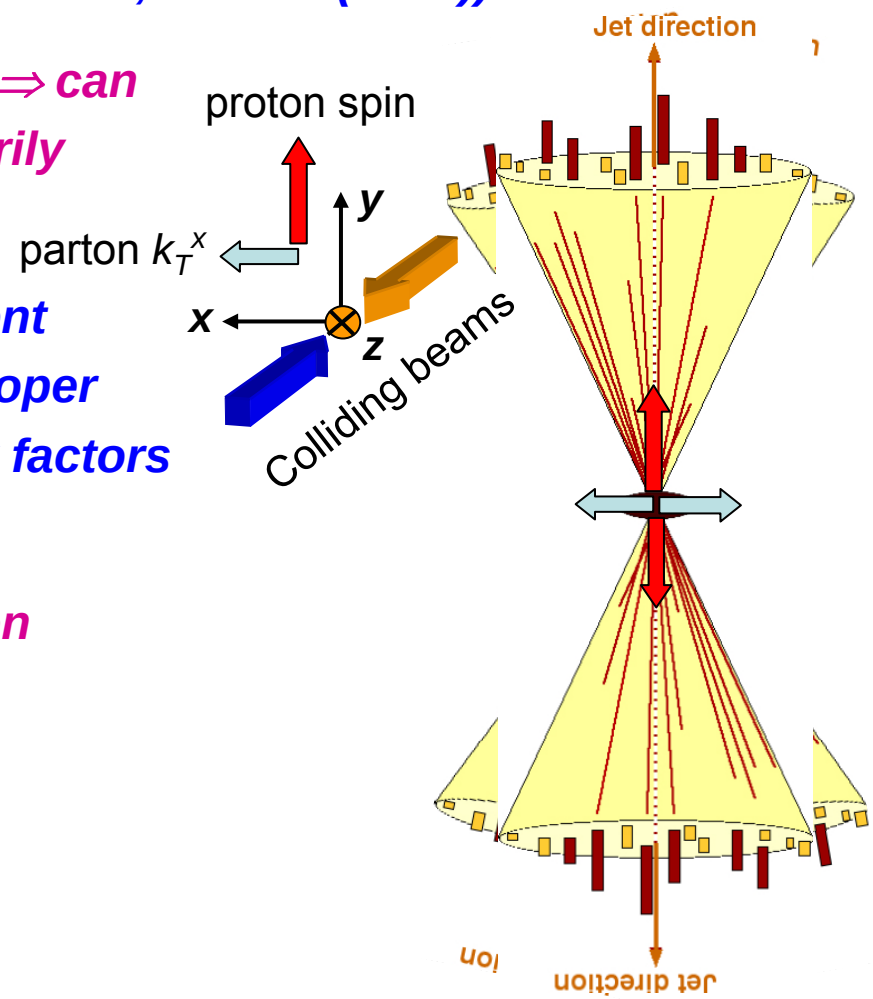
- HERMES transverse spin SIDIS asymmetries ⇒ u and d quark Sivers functions of opposite sign, different magnitude.

- Sivers effect in $\vec{p}p$ ⇒ spin-dependent sideways boost to di-jets, suggested by Boer & Vogelsang (PRD 69, 094025 (2004))

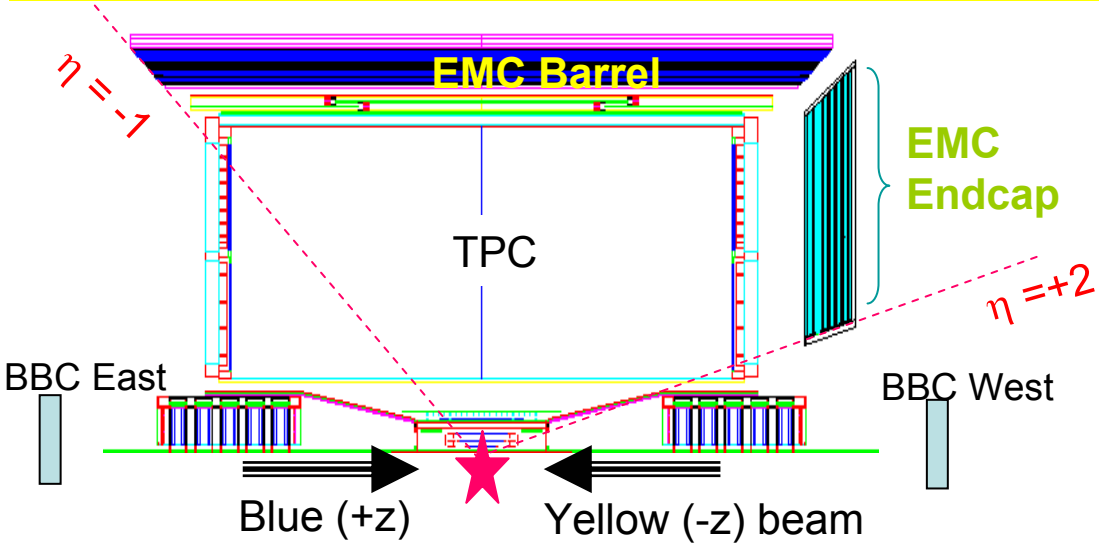
- Both beams polarized, $x^{+z} \neq x^{-z}$ ⇒ can distinguish high-x vs. low-x (primarily gluon) Sivers effects.

- Do we observe q Sivers consistent with HERMES, after inclusion of proper pQCD-calculable ISI/FSI gauge link factors for pp → jets? Tests universality.

- First direct measurement of gluon Sivers effects.



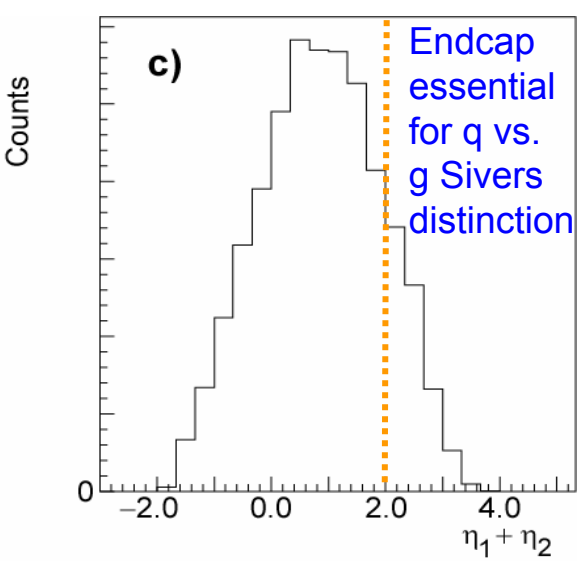
STAR EMC-Based (Level 0 + 2) Di-Jet Trigger in 2006



- *2006 $\vec{p}$+p run, 1.1 pb^{-1}*
- *2.6M di-jet triggered events*
- *2 localized clusters, with $E_T^{EMC} > 3.5$ GeV, $|\Delta\phi| > 60°$*

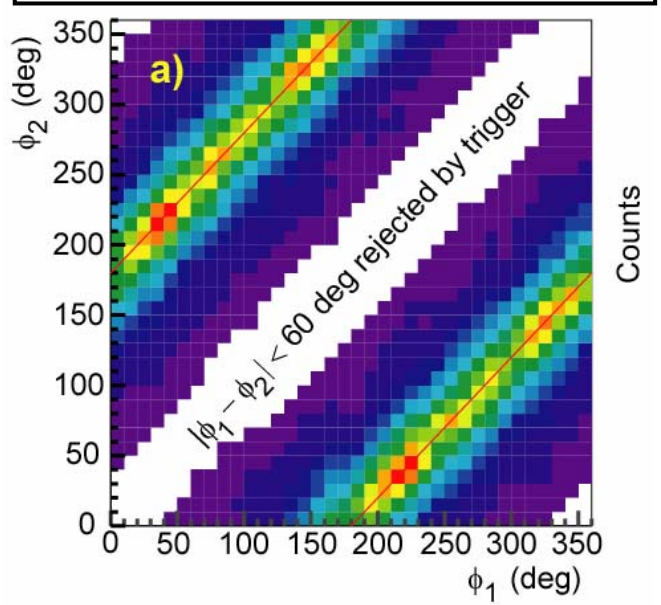
Reco cos($\varphi_{bisector}$) measures sign of net k_T^x for event

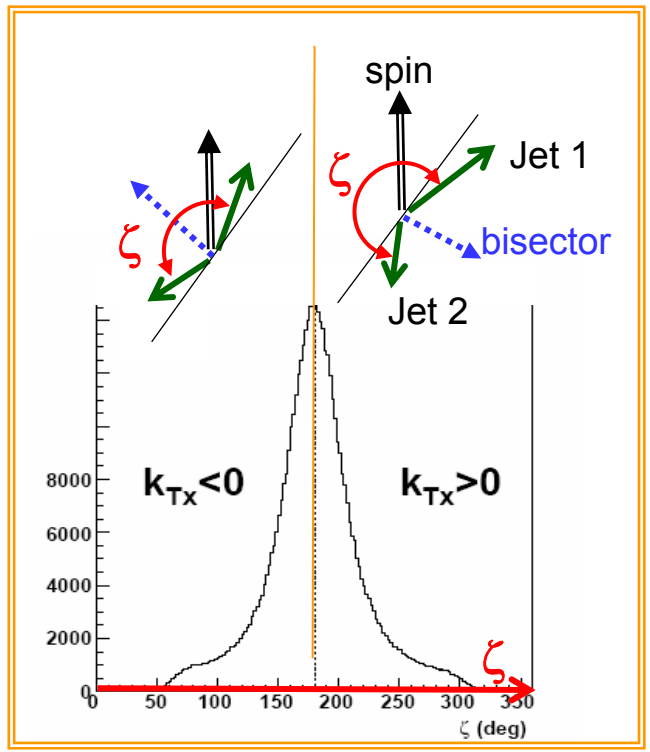
Broad $\eta_{1,2}$ coverage



$$\eta_1 + \eta_2 = \ln\left(x^{+z} / x^{-z}\right)$$

Full, symmetric $\phi_{1,2}$ coverage

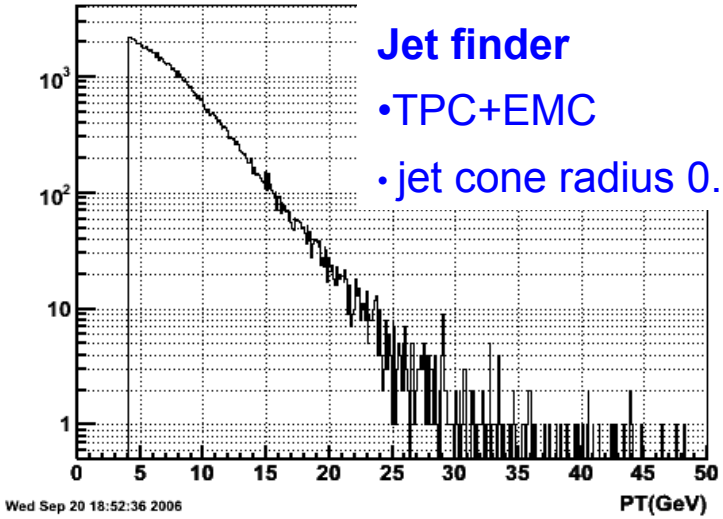




Signed azimuthal opening angle ζ

EMC-Only Information OK For 1st Dijet Sivers Asymmetry

Full offline di-jet reconstruction for ~2% of all runs shows triggered jet p_T spectrum:



Jet finder

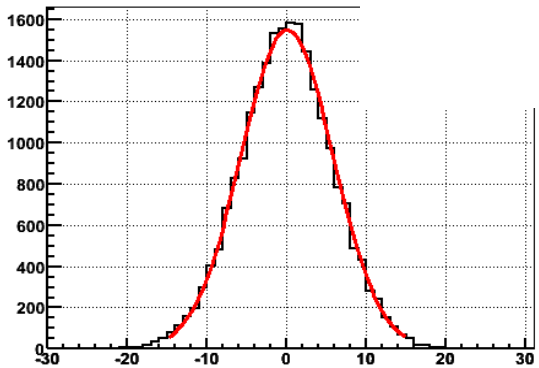
- TPC+EMC
- jet cone radius 0.6

Typical x_T ~ 0.05 - 0.10;

$\eta_1+\eta_2$ range $\Rightarrow$ $0.01 < x_{Bj} < 0.4$

and $\Rightarrow$ angle resolution loss @ L2 OK:

$[\sigma(\phi)=3.9°, \sigma(\zeta)=5.8°]_{\text{L2 vs. full jet}} << \sigma_{\text{observed}}(\zeta) \approx 20°$,
mostly from k_T



ζ (full reco) – ζ (L2) [deg]

PYTHIA+GEANT $\Rightarrow$ full jet reconstruction vs. parton-level resolution:

$[\sigma(\phi)=5.0°, \sigma(\eta)=0.10]_{\text{full reco. jet vs. parton angles}}$

Net L2-to-parton $\sigma(\phi_{jet}) = 6.3°$, $\sigma(\zeta_{di\text{-}jet}) = 9.0°$

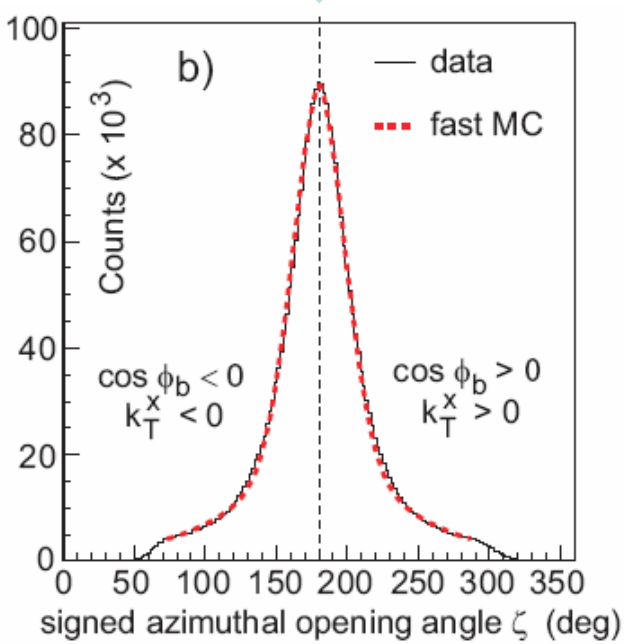
Fast MC Simulations Illustrate Di-Jet Sivers Effects

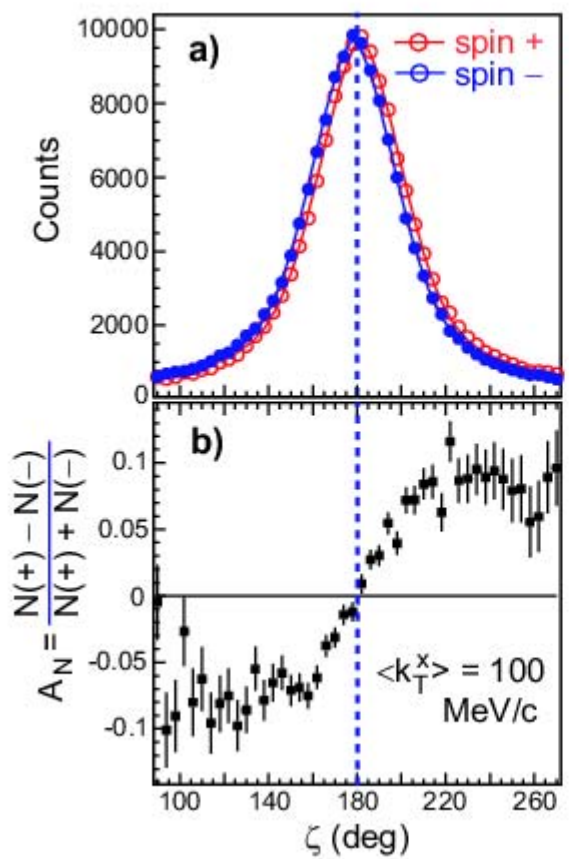
- *2-parton events, transverse plane*
- *match full jet reco. p_T distribution*
- *Gaussian + exp'l tail k_T distribution fits ζ distribution*

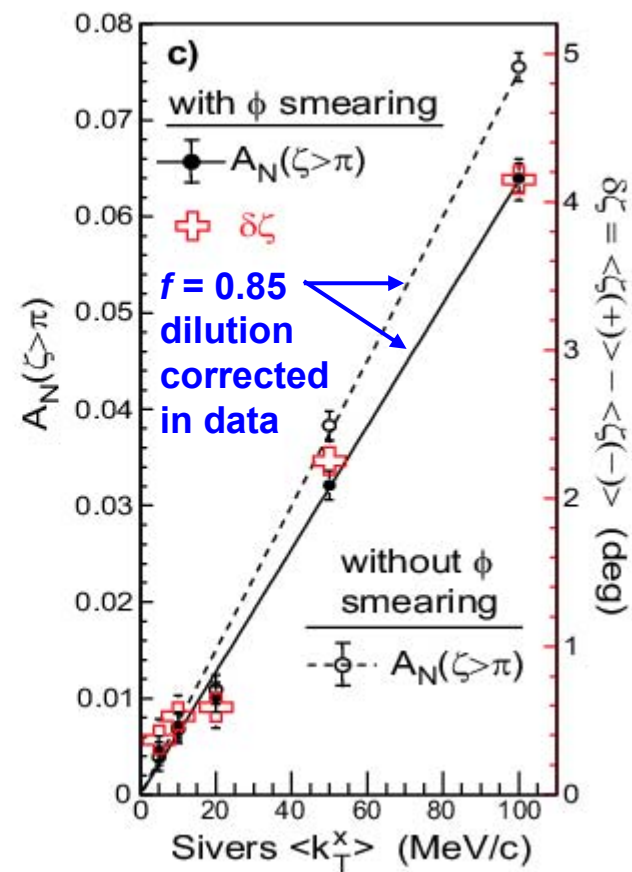
- *random $k_T^{x,y}$ (rms = 1.27 GeV/c) for each parton*
- *Sivers spin-dep. k_T^x offset $\Rightarrow \zeta$ shift, L-R di-jet bisector asym.*
- *1-spin effects vary linearly with k_T^x offset*

$$f\, P_{\pm z} |\cos\phi_b| A_N^{\pm z}(\varsigma > \pi) = \left[r_{\pm z}(\phi_b) - 1\right] / \left[r_{\pm z}(\phi_b) + 1\right] \text{ with}$$

$$r_{+z}(\phi_b) \equiv \sqrt{\frac{\sum N_{+j}(\varsigma > \pi, \phi_b)}{\sum N_{-j}(\varsigma > \pi, \phi_b)}} \bullet \sqrt{\frac{\sum N_{-j}(\varsigma < \pi, \phi_b)}{\sum N_{+j}(\varsigma < \pi, \phi_b)}}, \text{ etc.}$$

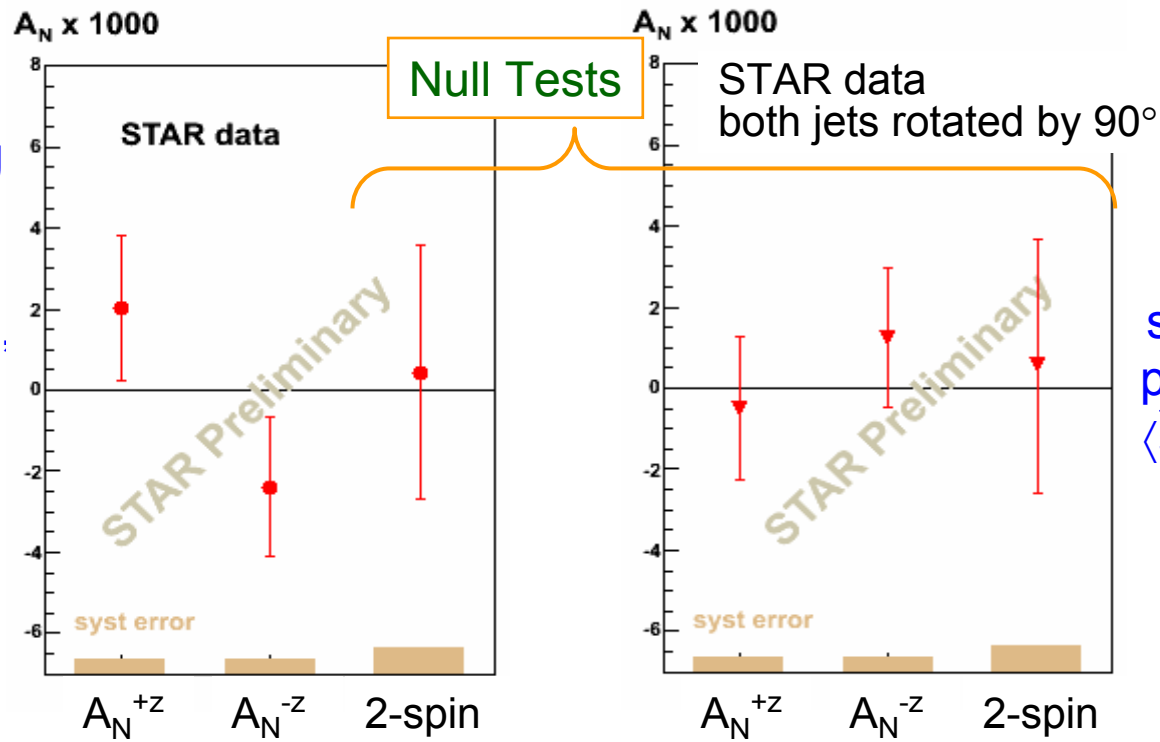






STAR Results Integrated Over Pseudorapidity

Error-weighted avg of 16 independent $A_N(\zeta>\pi)$ values for $|\cos(\phi_{bisector})|$ slices, with effective $\perp$ beam polarization for each = $P_{beam}\times|\cos(\phi_{bisector})|$



ϕ rotation samples $\langle k_T^y\rangle$, parity-violating $\langle \vec{s}_p \bullet \vec{k}_T\rangle$ correl'n

- ***Sivers asymmetries consistent with zero with stat. unc. = ±0.002***
- ***Fast MC ⇒ sensitivity to Sivers $\langle k_T^x\rangle$ offset ≈ few MeV/c ≈ 0.002 $\langle (k_T^x)^2\rangle^{1/2}$***
- ***Systematic uncertainties smaller than statistics***
- ***All null tests, including forbidden 2-spin asym. ∝ $\cos(\phi_{bisector})$, consistent with zero, as are physics asymmetries for all polarization fill patterns***
- ***Validity of spin-sorting confirmed by reproducing known non-zero A_N for inclusive forward charged-particle production (STAR BBC's)***

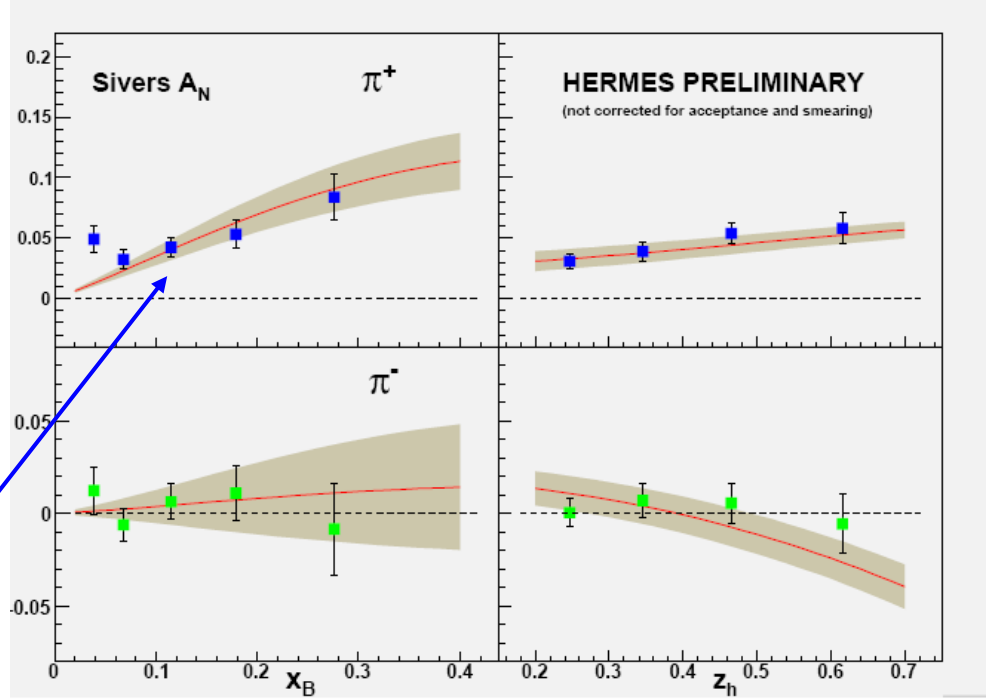
What Did We Expect? Constraints from SIDIS Results

Fits to HERMES SIDIS Sivers asymmetries constrain u and d quark Sivers functions, for use in $\vec{p}p \rightarrow$ dijet + X predictions.

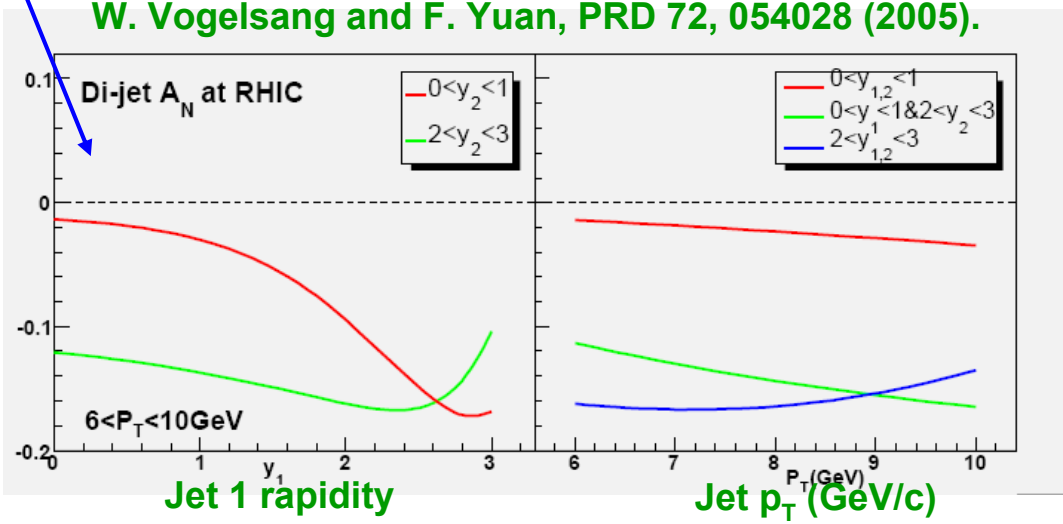
E.g., Vogelsang & Yuan use two different models of Sivers fcn. x-dependence:

$$\boxed{VY\ 1:}\quad u_T^{(1/2)}/u(x) = -0.81\,x(1-x)$$
$$d_T^{(1/2)}/u(x) = 1.86\,x(1-x)$$

$$\boxed{VY\ 2:}\quad u_T^{(1/2)}/u(x) = -0.75\,x(1-x)$$
$$d_T^{(1/2)}/d(x) = 2.76\,x(1-x)$$



W. Vogelsang and F. Yuan, PRD 72, 054028 (2005).



Jet 1 rapidity

Jet p_T (GeV/c)

Dijet calcs. include:

- ***no hadronization***
- ***no gluon Sivers fcns.***
- ***$5 < p_T^{parton} < 10$ GeV/c***
- ***Initial-state interactions only (à la Drell-Yan)***
- ***Trento sign convention (opposite Madison)***

≥1 jet forward, expected $|A_N| \sim 0.1$, little p_T - dep.

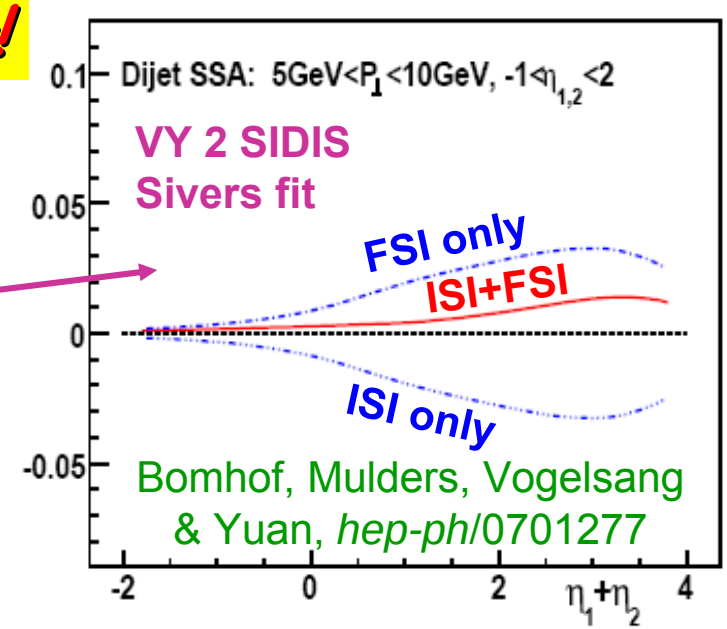
Theory of Transverse SSA Developing Very Rapidly!

Di-jet SSA Post-dictions shrinking!

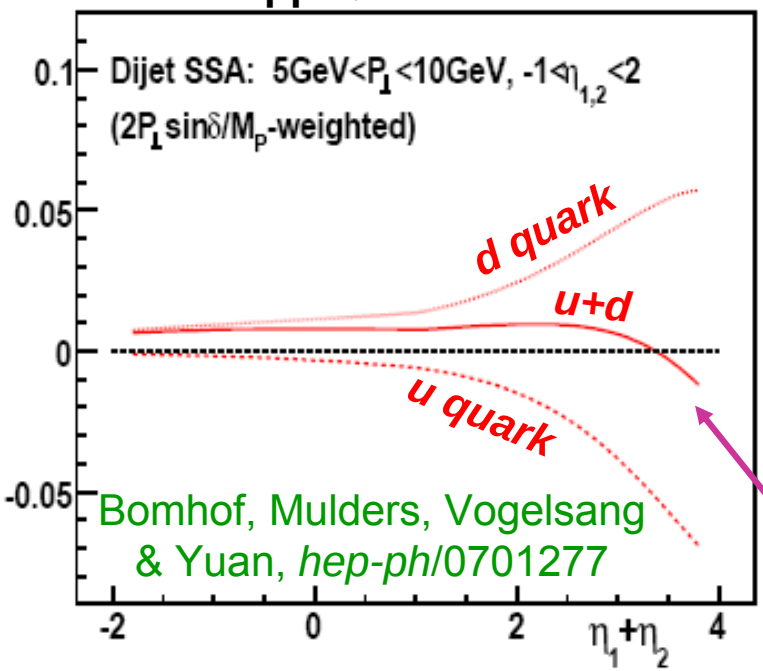
Bacchetta, Bomhof, Mulders & Pijlman* [PRD 72, 034030 (2005)] *deduce gauge link structure for pp → jets, hadrons:

$\Rightarrow A_N(\text{ISI+FSI}) \approx -0.5\, A_N(\text{ISI})$

⇒ Gauge links more robust for SSA weighted by $\sum p_T$ for 2 jets, or $|\sin\zeta|$



Sivers fcns. from twist-3 qg correl'n fits to $\vec{p}p \rightarrow$ forward hadron

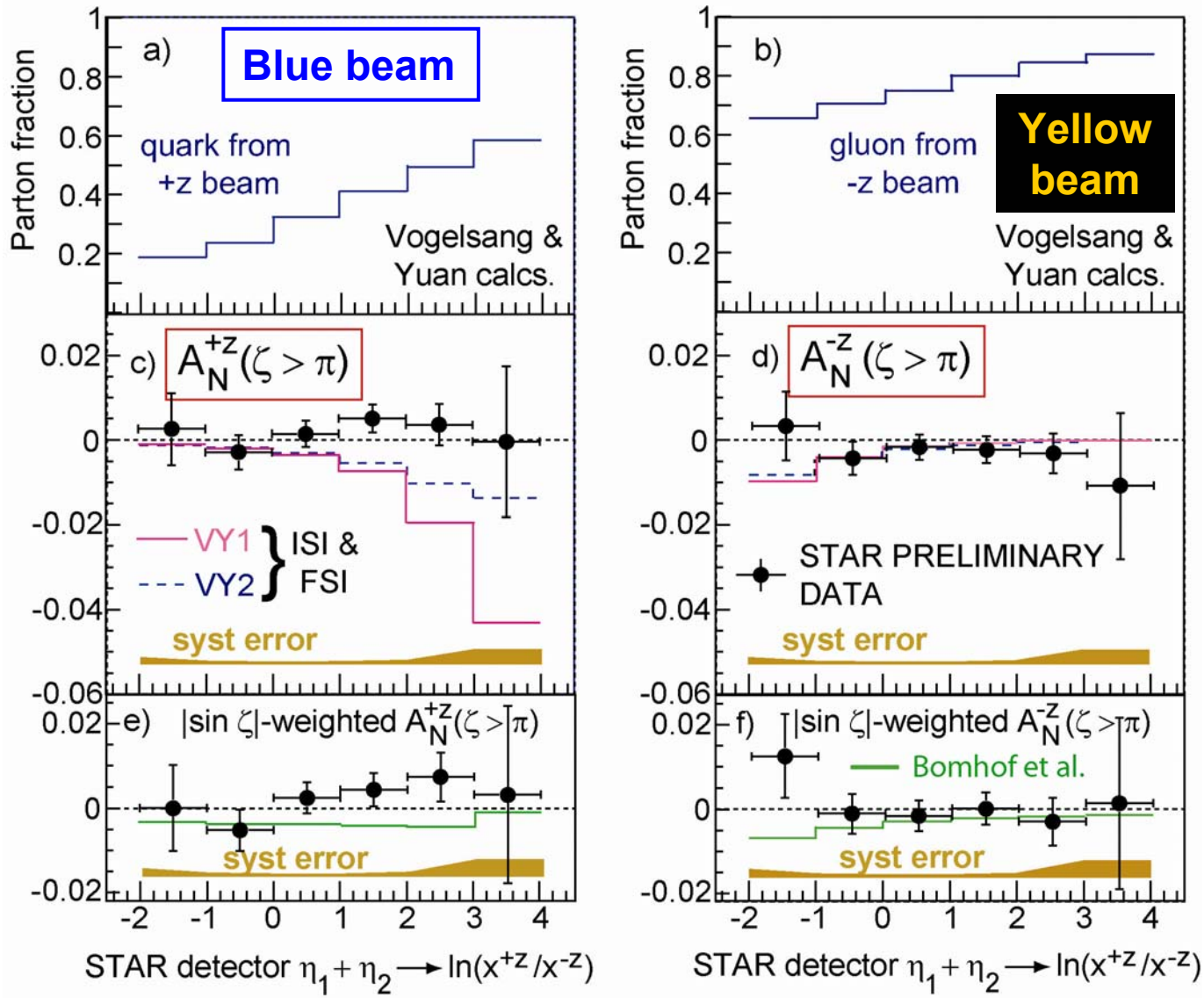


Ji, Qiu, Vogelsang & Yuan* [PRL 97, 082002 (2006)] *show strong overlap between Sivers effects & twist-3 quark-gluon (Qiu-Sterman) correlations:

⇒ twist-3 fits to $A_N(\vec{p}+p \rightarrow$ fwd. h) can constrain Sivers fcn. moment relevant to weighted di-jet SSA

⇒ Kouvaris et al. [PRD 74, 114013 (2006)] *fits give nearly complete u vs. d cancellation in weighted di-jet SSA*

STAR Di-Jet Sivers Results vs. Jet Pseudorapidity Sum

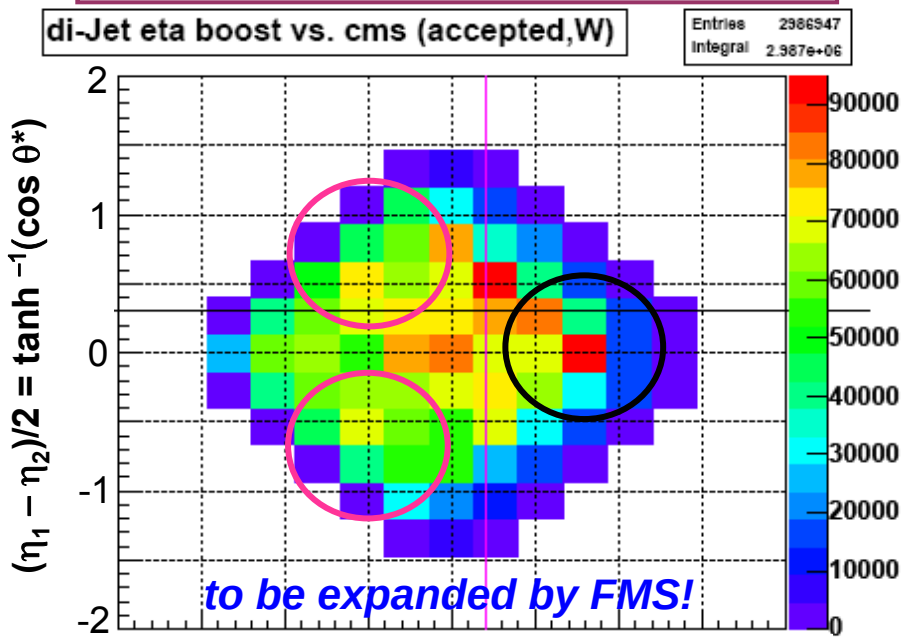


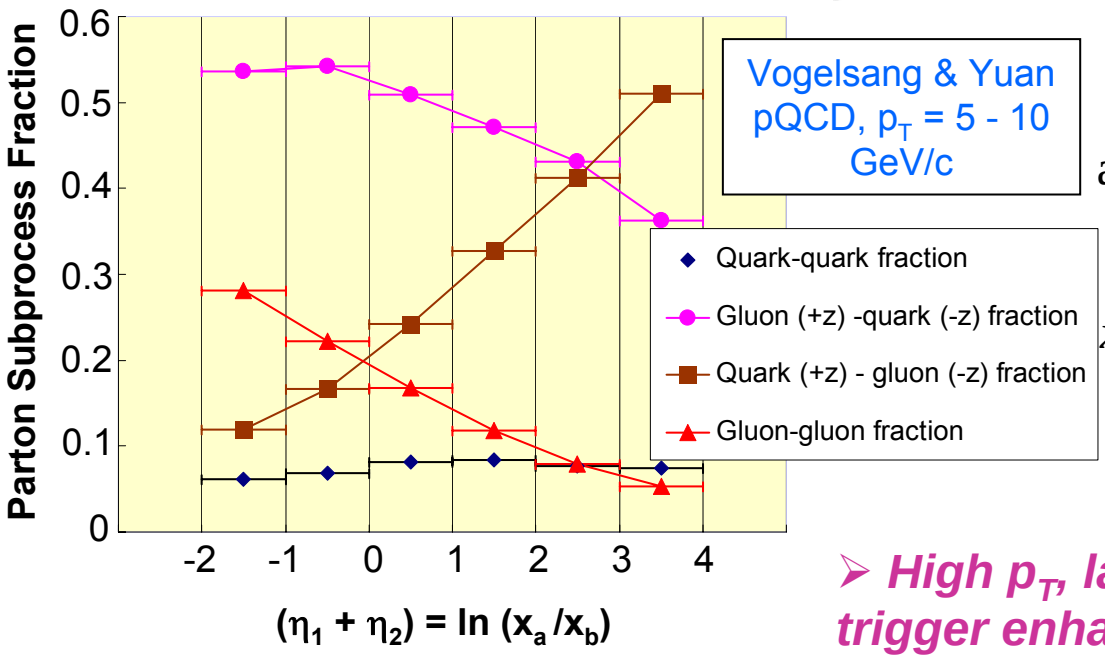
- ***All calcs. for STAR η acceptance***
- ***Reverse calc. A_N signs for Madison convention***
- ***Scale Bomhof calcs by $1/\langle|\sin\zeta|\rangle \approx 3.0$ to get A_N of unit max. magnitude***
- ***u vs d and FSI vs ISI cancellations $\Rightarrow$ sizable SSA in inclusive fwd. h prod'n and SIDIS (weighted SSA) compatible with small weighted di-jet SSA -- test via LCP flavor select***

STAR A_N all consistent with zero $\Rightarrow$ both net high-*x* parton and low-*x* gluon Sivers effects ~10x smaller in $\vec{p}p \rightarrow$ di-jets than SIDIS quark Sivers asym.!

Next Stages of STAR Jet Spin Program

2006 L2 di-jet EMC η acceptance





Transverse spin:

- ***Full jet reconstruction for 2006 di-jets for p_T - sorting, leading hadron charge determ. for flavor selectivity***
- ***New Forward (η = 2.5 - 4) Meson Spectrometer extends coverage to region where large inclusive A_N seen***

Longitudinal spin:

- ***Exploit full di-jet kinematic range to enhance sensitivities:***

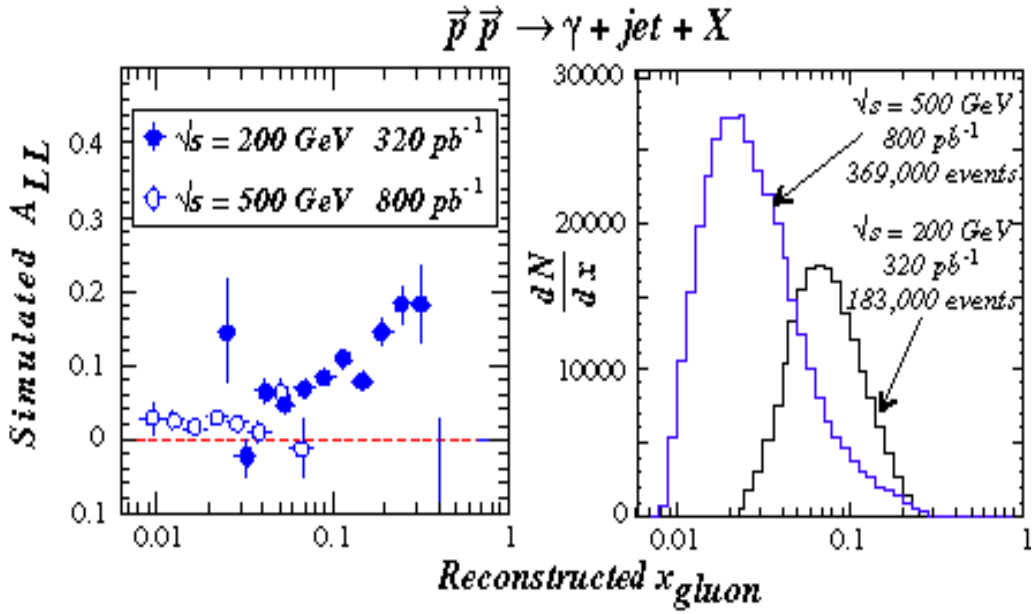
$$\text{at LO:} \qquad \eta_1 + \eta_2 = \ln(x_a / x_b)$$

$$(\eta_1 - \eta_2)/2 = \tanh^{-1}(\cos\theta^*)$$

$$x_T \equiv 2p_T/\sqrt{s} = \sqrt{2x_a x_b/[1+\cosh(\eta_1 - \eta_2)]}$$

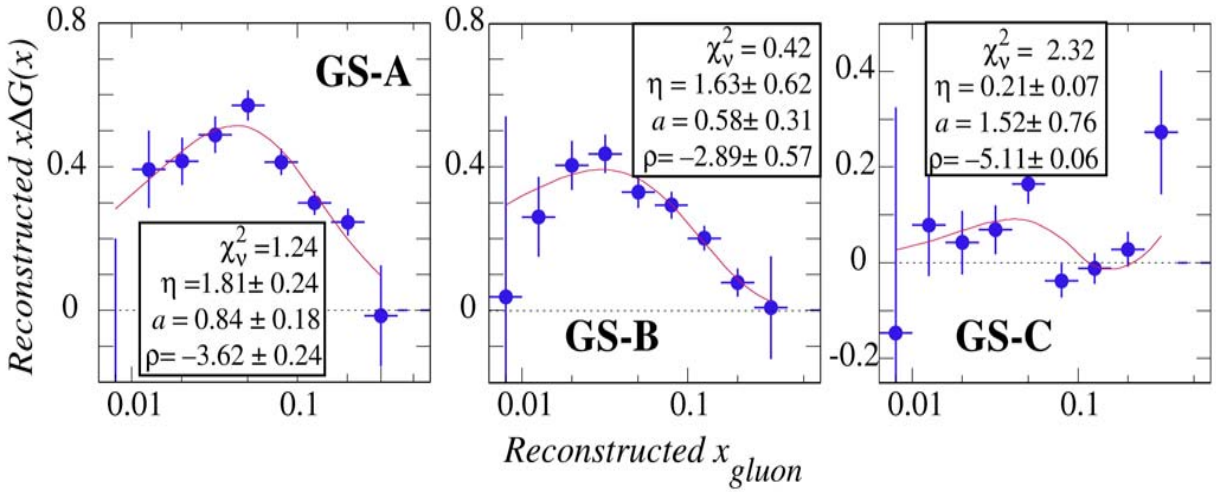
- ***E.g., $\eta_1 \approx \eta_2 > 1$ enhances qg scattering sensitivity to Δg(low x)***
- ***High p_T, large $|\eta_1 - \eta_2|$, $\eta_1 + \eta_2 \approx 0$, HT trigger enhances qq sensitivity to test pQCD***

2006-10: Coincidence Measurements to Map Δg(x) Fully



- E.g., detect γ-jet coincidences in polarized proton collisions at $\sqrt{s}$ = 200 and 500 GeV
- Measure two-spin asymmetry in production rates between equal vs. opposite helicities, as function of η(jet), η(γ), $p_T(\gamma)$
- Assuming 2-body parton kinematics, can infer initial x values of gluon and quark

- Next-Leading-Order (NLO) pQCD analyses of data, with DIS database, can extract Δg(x) for Q^2 ~ 100 GeV ^{2}
- LO pQCD analysis of simulations at right ⇒ STAR sensitivity for 3 diff. models of initial gluon helicity distributions



GS-A,B,C models of $x\Delta G(x)$ from Gehrmann and Stirling, PR **D53**, 6100 (1996).

Summary & Conclusions

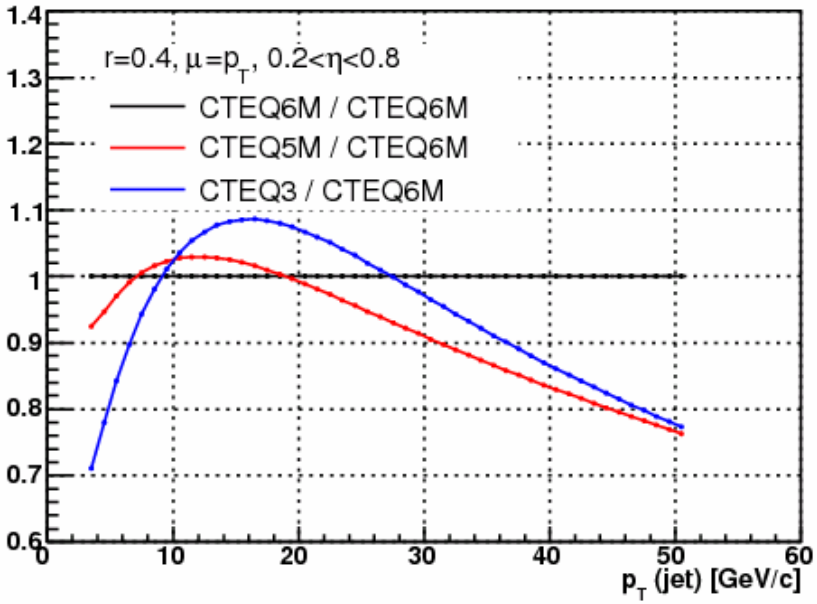
- *STAR jet spin program is well under way, fueled by ample cross sections, large STAR acceptance & efficient EMC triggering.*
- *NLO QCD describes cross section well over 7 orders of magnitude.*
- *Inclusive jet A_{LL} beginning to provide best constraints on gluon polarization in the proton. 2006 data will $\Rightarrow$ dramatic improvement.*
- *Di-jet A_N^{Sivers} all consistent with zero $\Rightarrow$ compatible with sizable A_N for inclusive forward hadrons and SIDIS? Add flavor enhancement to test u vs. d cancellation.*
- *Early successes $\Rightarrow$ shift focus now to:*

- *Improve EMC calibration and quantitative understanding of syst. errors from energy scale ambiguities, trigger/reconstruction bias*
- *Extend coincidence acceptance with Forward Meson Spectrometer*
- *Exploit full kinematic characterization of parton scattering in di-jet and γ - jet coincidences to enhance interpretation of gluon polarization and transverse motion preferences in polarized proton*
- *Extend measurements to 500 GeV c.m. energy $\Rightarrow$ smaller x*

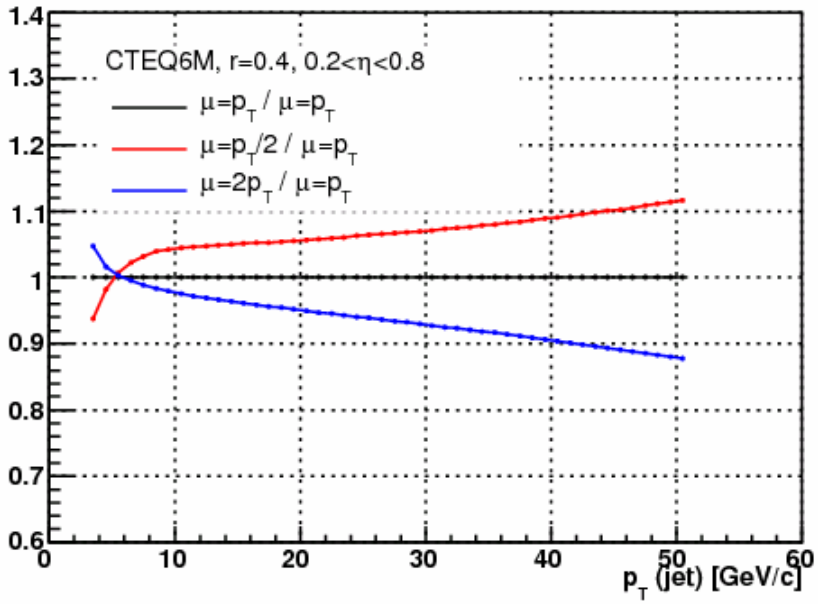
Backup Slides

Theory Systematics

Changing the pdf



Changing the scale

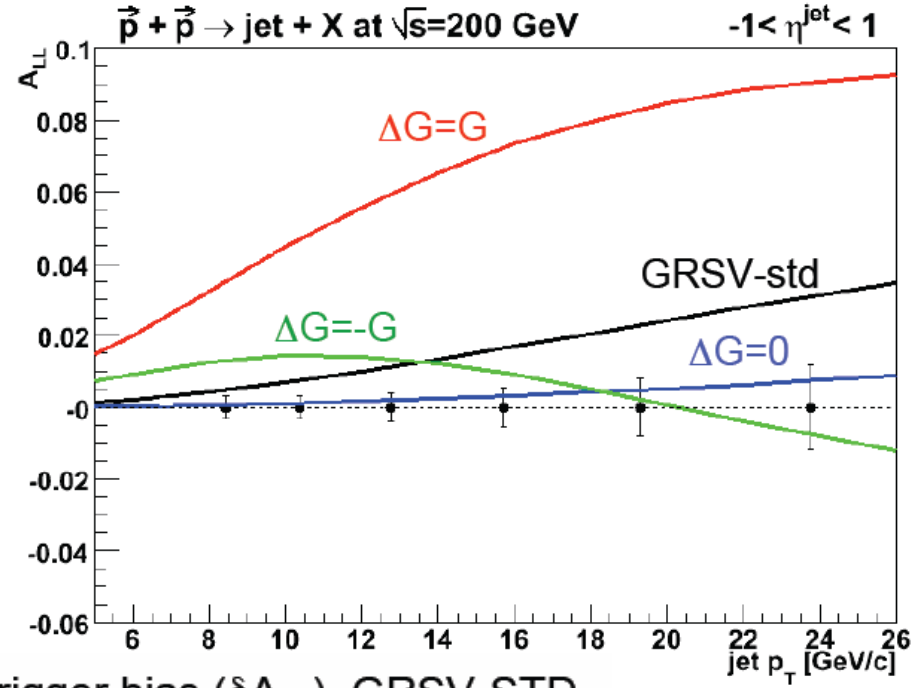


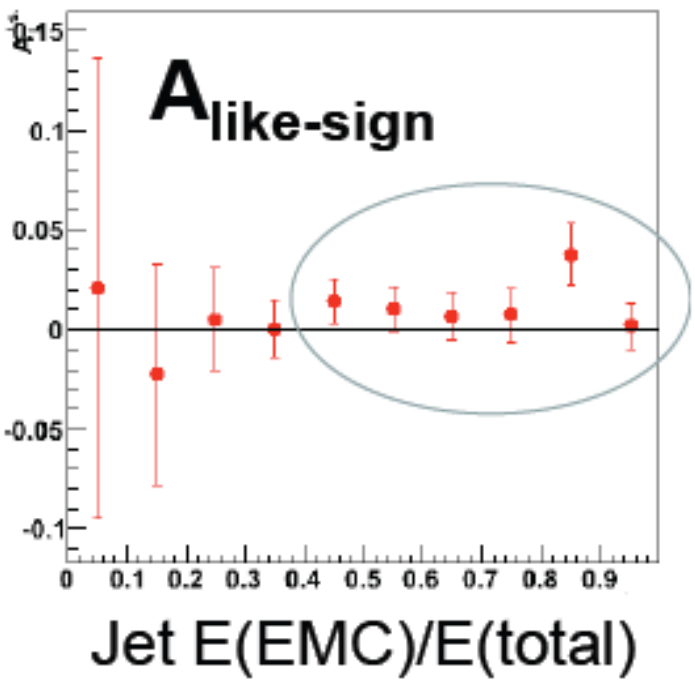
Jet Energy Scale Systematics

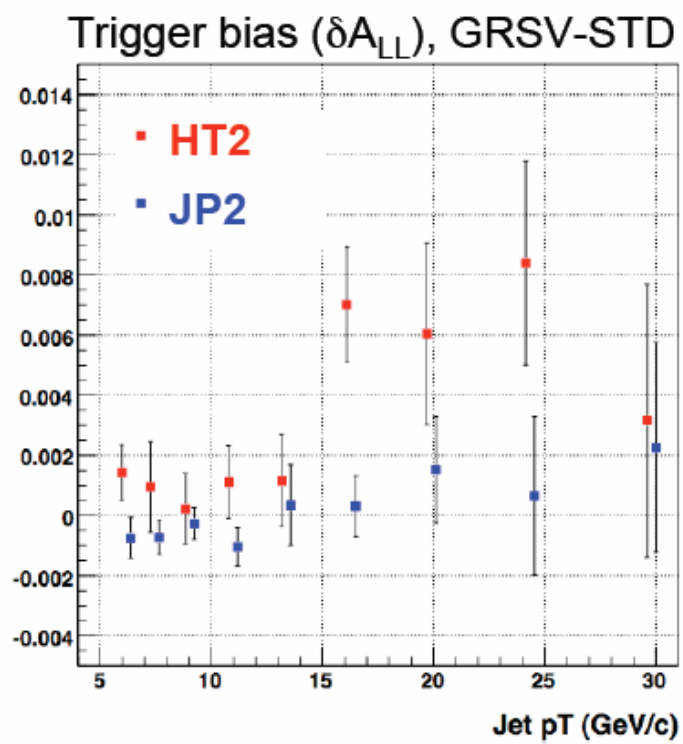
Charged Track Momentum	$\Delta p/p$ TPC	1%
Charged Track Inefficiency	10% x 60% jet	6%*
Neutral Tower Energy	$\Delta G_{ain}/G_{ain}$ = 10%	40% in yield
Neutral Energy Inefficiency	$\sum E_T$ from $n+K^0_{L/S}+\eta+\Omega+\nu$	6-10%*
MIP Subtraction	10% Correction to Jet E_T	1%
Fiducial Detector Effects	Edges/Dead regions	2%
Jet η calculation	1 tower = $\Delta\eta$=0.05	3%
Background Trigger	Background trigger +MINBIAS event	5% in yield
Background Energy	Jet + underlying Background	0
Underlying Event	Work in Progress	NA
Fragmentation	Comparison to HERWIG ongoing	NA

**** Included in Correction Factor***

- 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



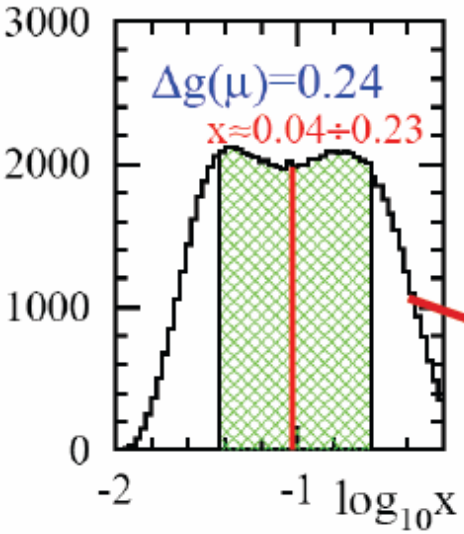




2005 Results: Inclusive Jet A_{LL}

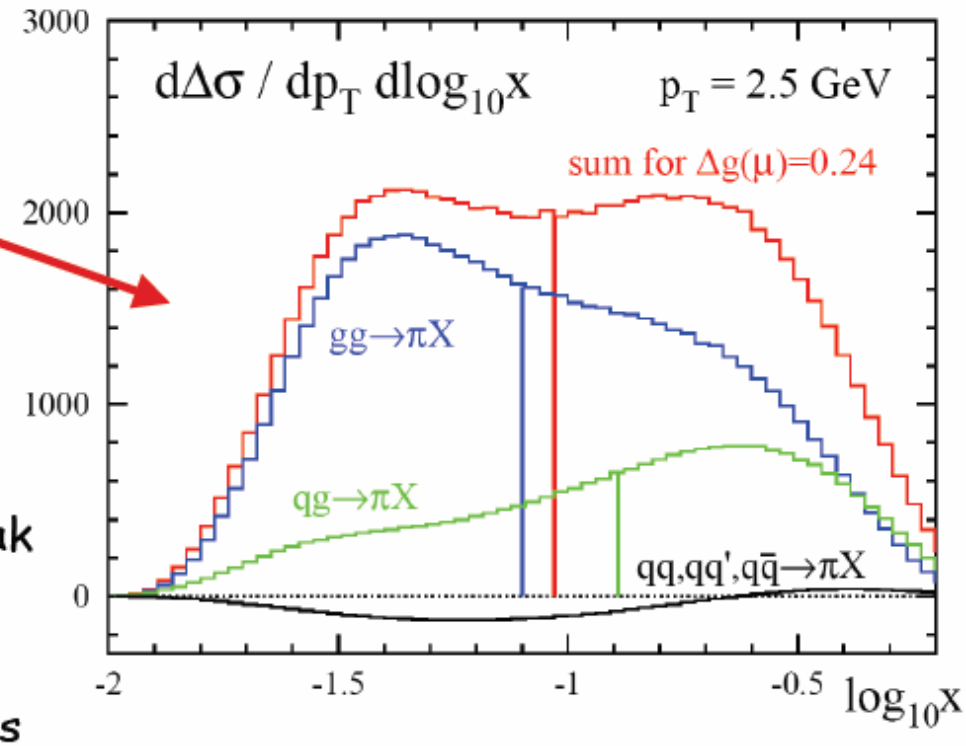
	Spin 2006, preliminary result, STAR inclusive jets								
	All numbers in units of 1e-3 absolute on A_{LL}								
	bin 1	bin 2	bin 3	bin 4	bin 5	bin 6	bin 7	bin 8	bin 9
pt*	5.6	6.9	8.4	10.4	12.8	15.7	19.3	23.8	29.2
A_{LL}	-3.8	2.1	1.7	15.9	-12.4	-5.4	-14.4	-10.6	125.1
stat uncertainty	7.1	6.5	6.7	7.8	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								

data ↔ x-range probed



a closer look:

diff. subprocesses populate different x-ranges



gg vs. qg interplay explains all:

- large pos. Δg → pronounced gg peak
- small pos. Δg → double peak
- not too large neg. Δg → oscillations

estimates of $x\pm dx$ very difficult w/o knowing Δg