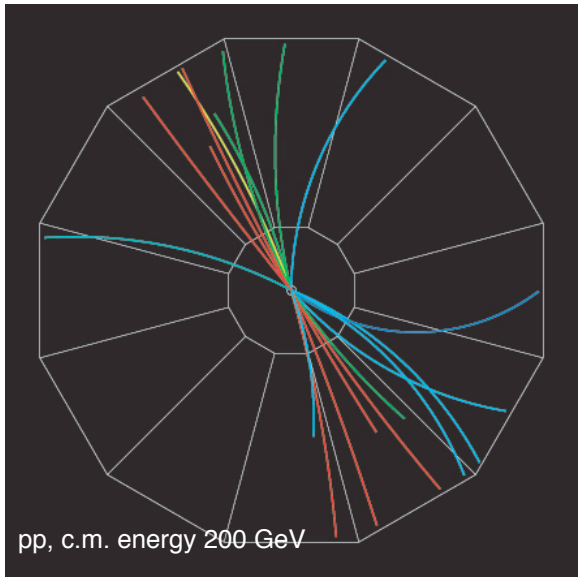
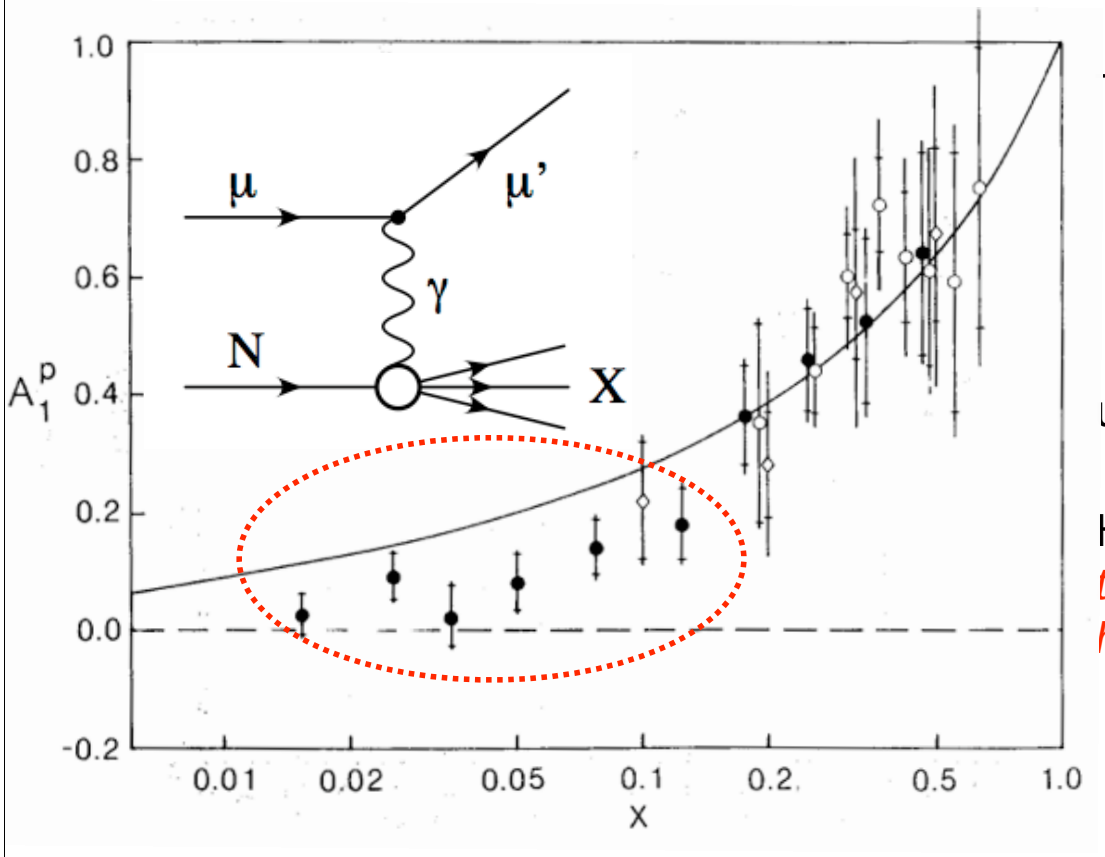
SPIN: Progress and Prospects

Ernst Sichtermann (LBL), *for the STAR Collaboration*



History and Motivation

Nucleon Spin Structure - Renewed Interest



The spin asymmetry,

$$A_1^{\mathrm{p}} \simeq \frac{\Delta\sigma}{\sigma} \simeq \frac{\sum e_q^2(q^{\uparrow} - q^{\downarrow})}{\sum e_q^2(q^{\uparrow} + q^{\downarrow})}$$

undershoots expectation.

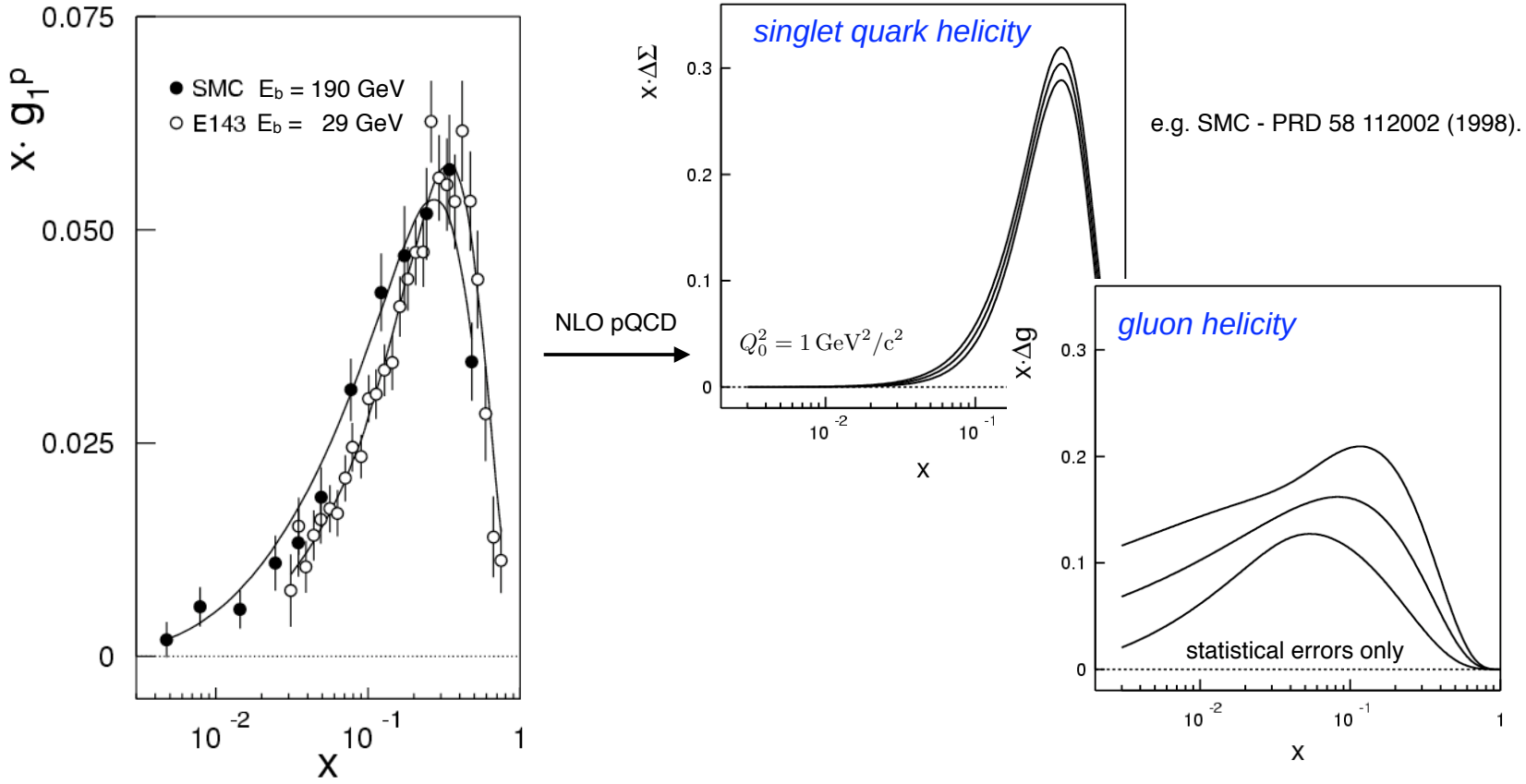
Hence, *quark spins contribute little to the proton spin (and the strange sea has negative polarization).*

European Muon Collaboration (1989)

Experiments have since confirmed the EMC measurement, for both p and n, and down to $x \sim 3.10^{-3}$. *Small(er)-x, Quark-Sea, Gluons?*

Precision - Scale Dependence

SMC, E142, E143, E154, E155, Hermes, COMPASS, JLAB,... measurements have achieved the precision to see scaling violations,



- The singlet and non-singlet quark helicity distributions are well-known for $x > 3.10^{-3}$,
- The gluon helicity is poorly constrained, although its value is probably not huge.

Nucleon Spin Structure - Present

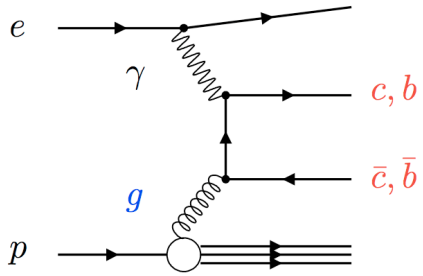
The un-knowns in nucleon spin structure,

- gluon polarization,

- flavor composition of quark spins,

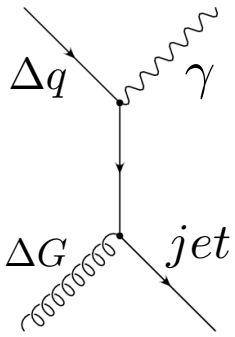
...

Call for *alternative* methods/techniques,



semi-inclusive DIS

or



proton-proton

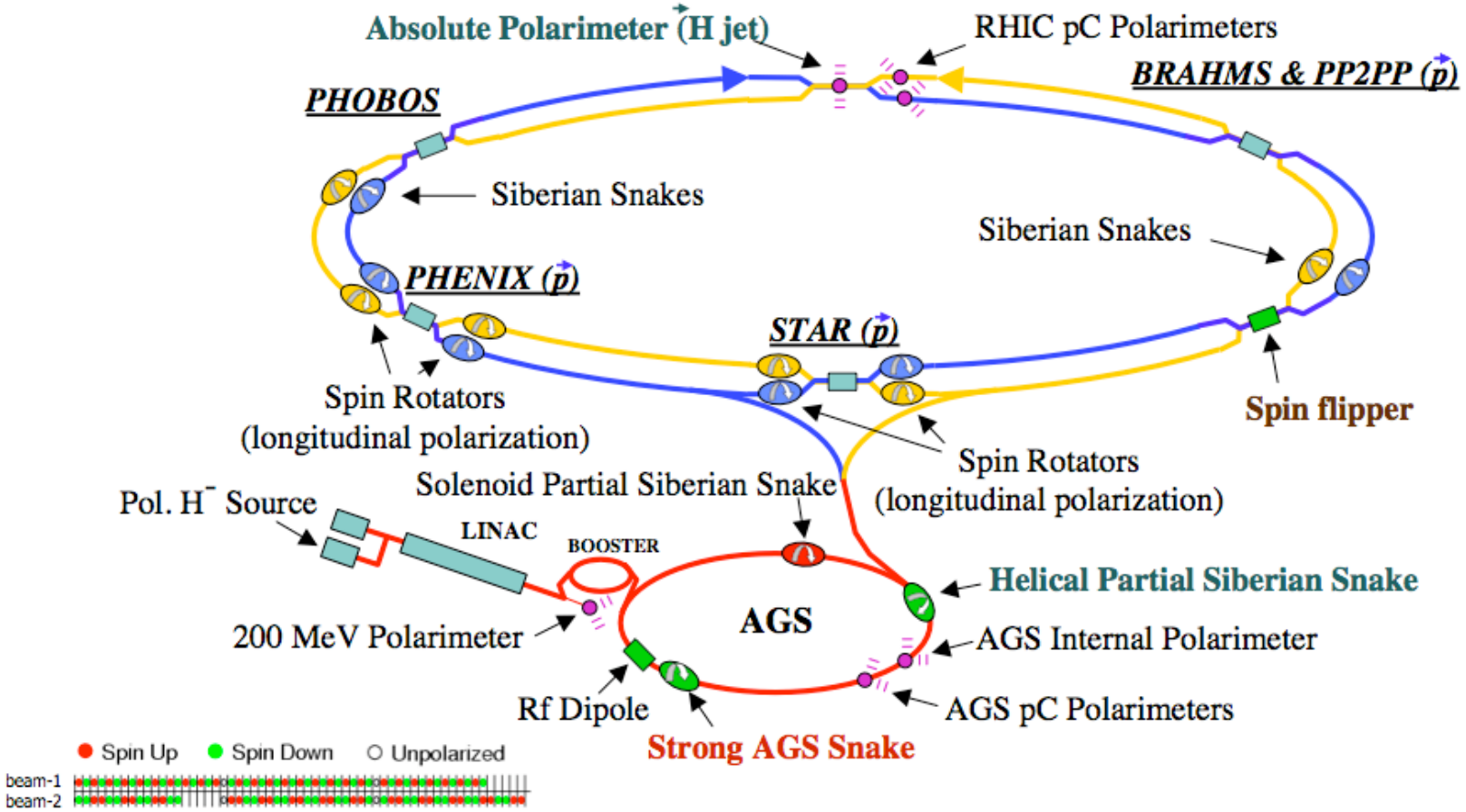
or

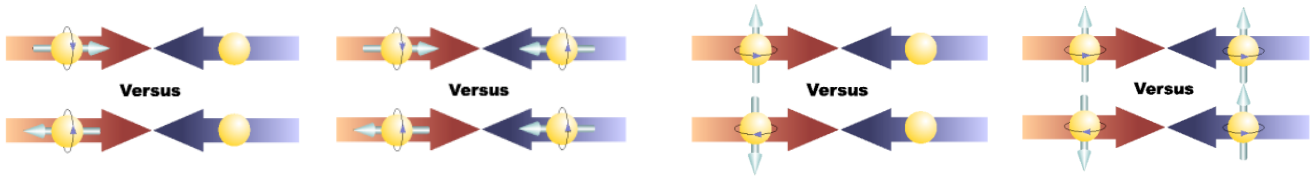
...

EIC, neutrino-nucleon, ...

RHIC, STAR, and 2006

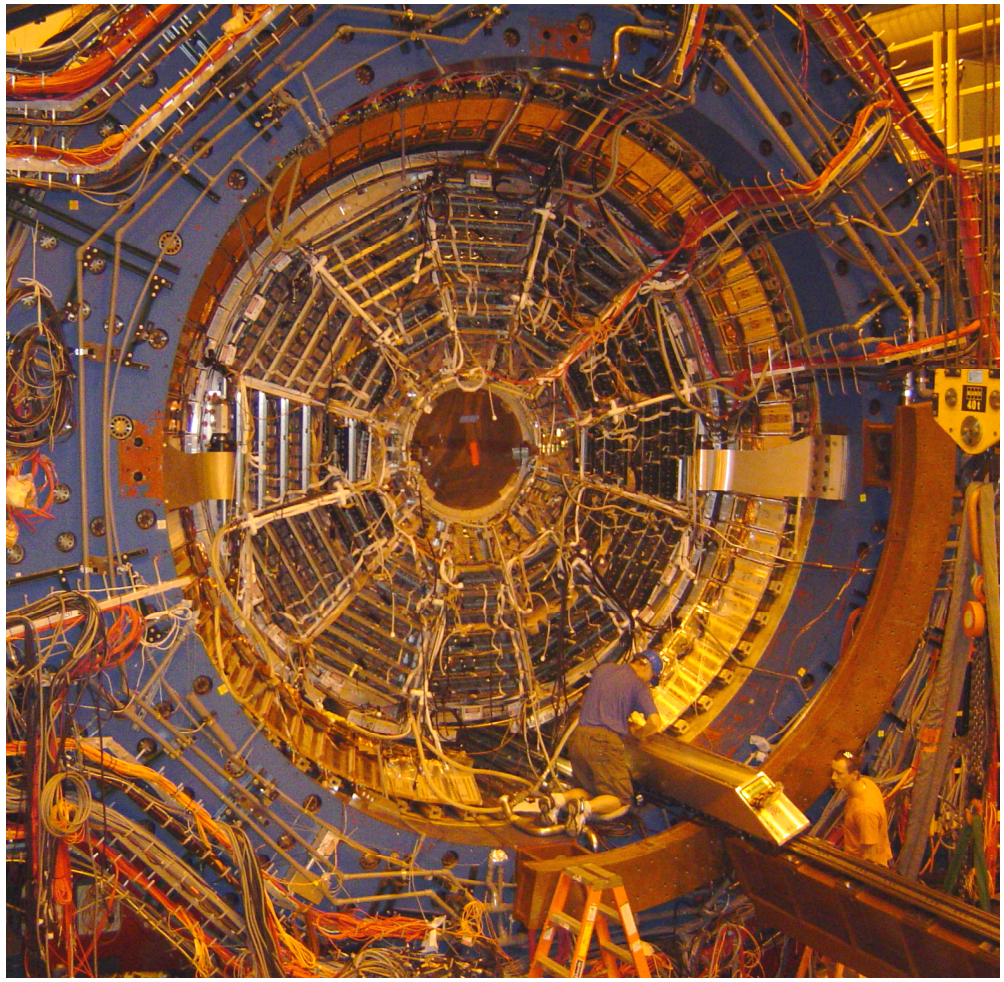
RHIC - a New Laboratory to Study Spin in QCD





$\sqrt{s} = 200 - 500\,\mathrm{GeV}$

- Solenoid Tracker at RHIC



Time Projection Chamber, $-1.4 < \eta < 1.4$

0.5 T magnetic field,

Barrel EM Calorimeter, $-1 < \eta < 1$

Endcap EM Calorimeter, $1 < \eta < 2$

Beam-Beam Counters,

Forward Pion Detector,

...

Ongoing and proposed upgrades:

- DAQ-1000, Time-of-Flight barrel, Forward Meson Spectrometer,
- Heavy Flavor Tracker, Inner-Silicon Tracker, Forward Tracker.

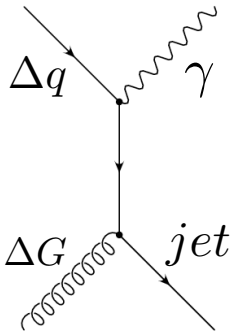
STAR's jet-reconstruction capability is unique at RHIC!

- Gluon Spin Objective

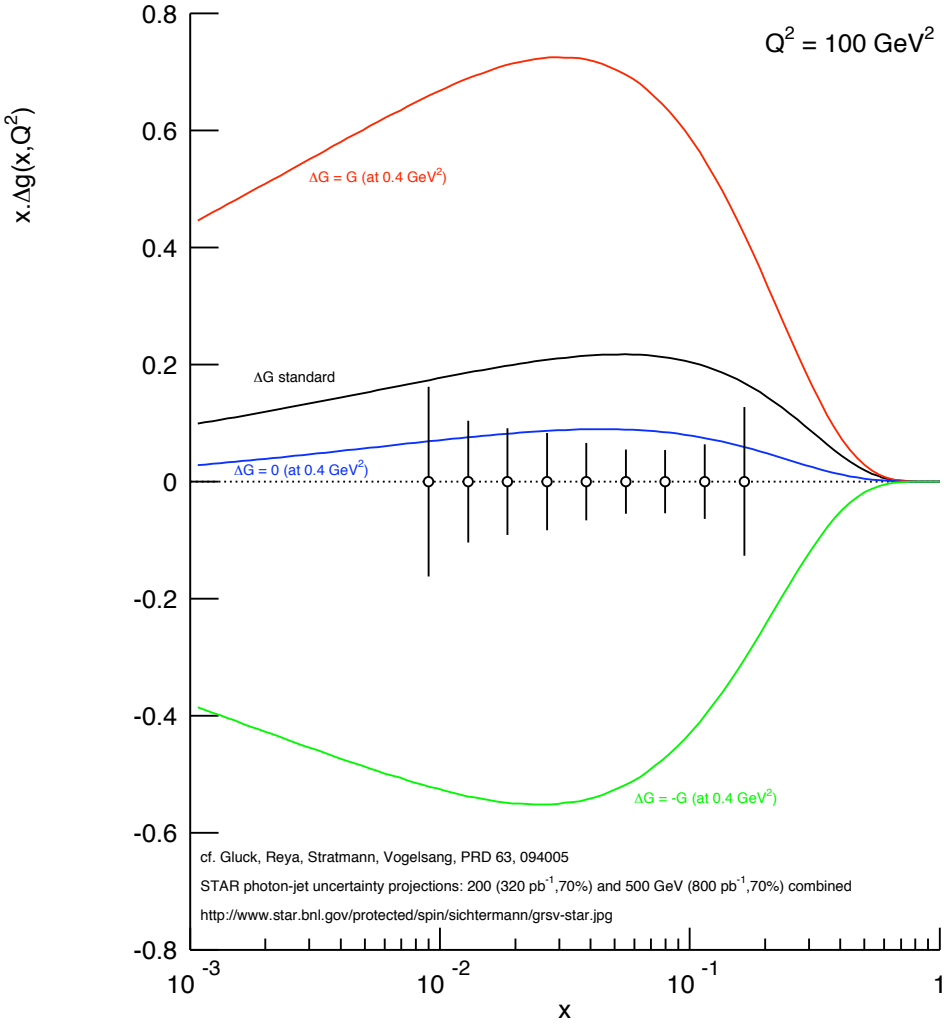
Gluon polarization is a high-priority spin measurement in STAR.

STAR aims for measurements that are *robust* and *selective*, and cover a *wide* and *resolved* kinematic range.

Prompt-photon jet coincidences form a "golden channel",

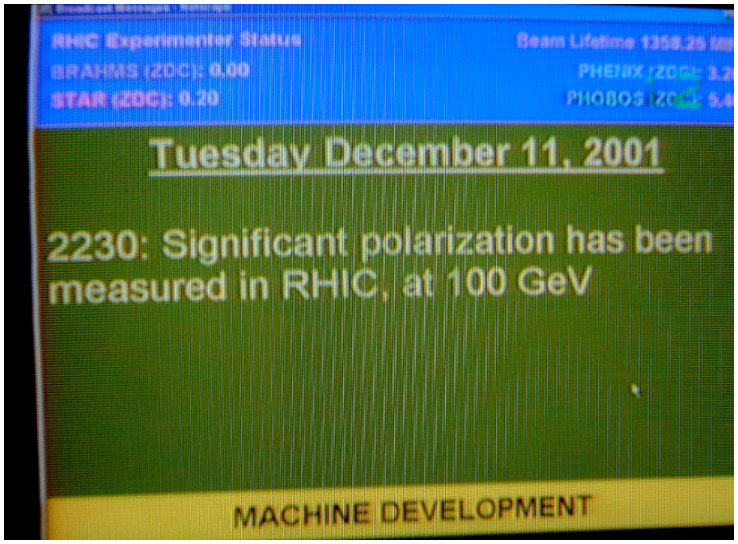


requiring high beam polarization (~70%), high integrated luminosity (10^2-10^3 pb^{-1}), and E_{cms} of 200 and 500 GeV.



A multi-year and multi-channel program!

Selected Milestones for Spin at RHIC



FY02: proton collisions with transverse spins,

FY03: proton collisions with longitudinal spins,

FY04: absolute polarization measured, luminosity and polarization development,

FY05: 200 GeV spin physics-production run (~3 pb^{-1}), successful test of 410 GeV,

FY06: >10 pb^{-1} sampled at STAR, ~60% polarization,

~2009: Complete 200 GeV program, start 500 GeV (?)

STAR

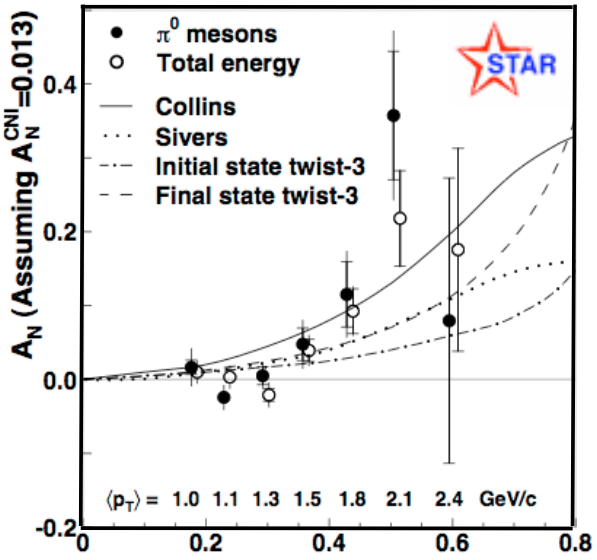
SPIN-2002: first spin physics result from RHIC,

2005 run: STAR Endcap E.M. Calorimeter 100% complete,

DNP-2005: double-helicity asymmetry for inclusive jets,

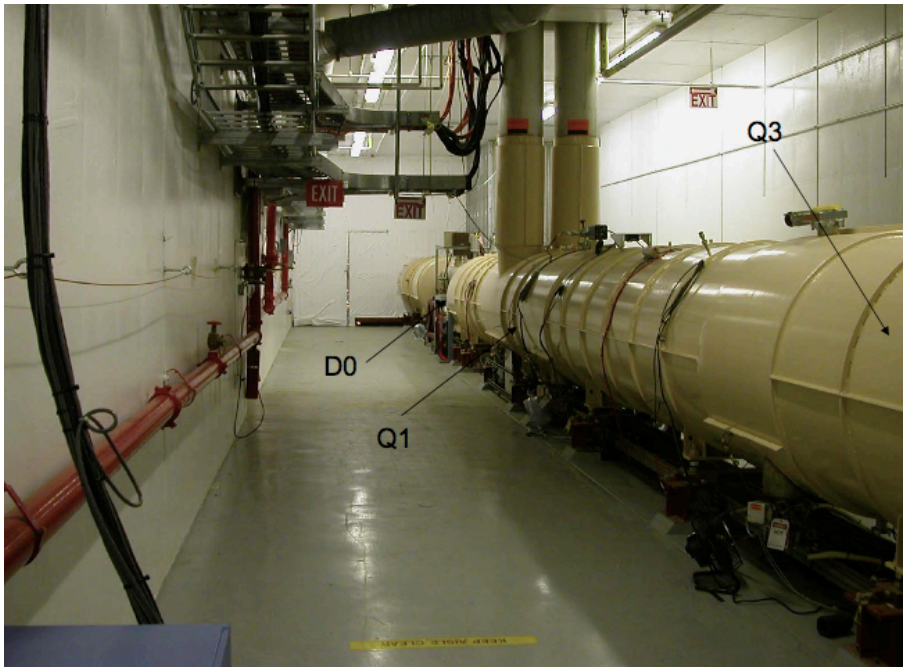
2006 run: STAR Barrel E.M. Calorimeter 100% complete,

...



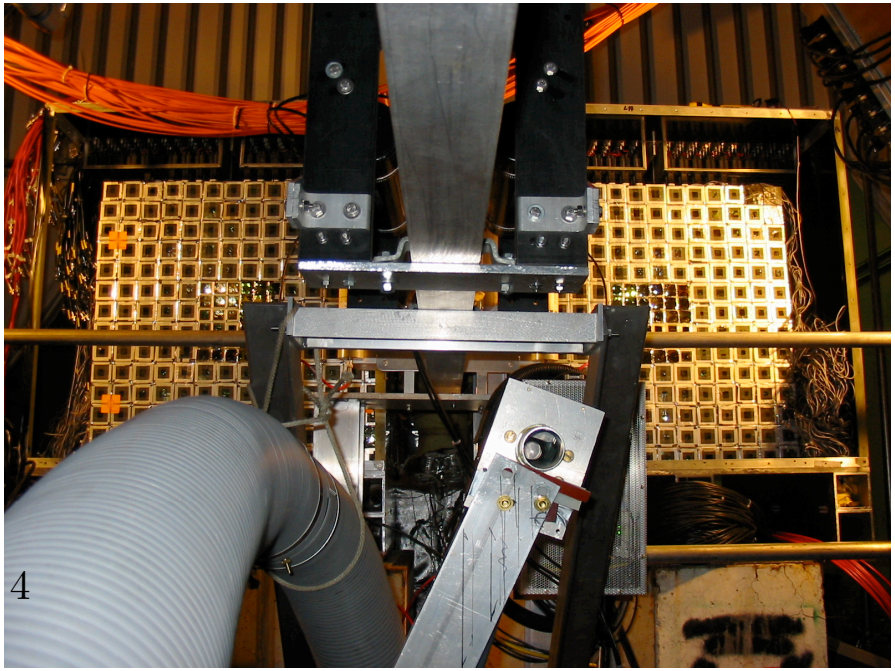
J. Adams et al, PRL 92: 171801 (2004)

Some Highlights for 2006



Shielding of the STAR IR,

AGS cold snake (c.f. V. Ptitsyn's talk),

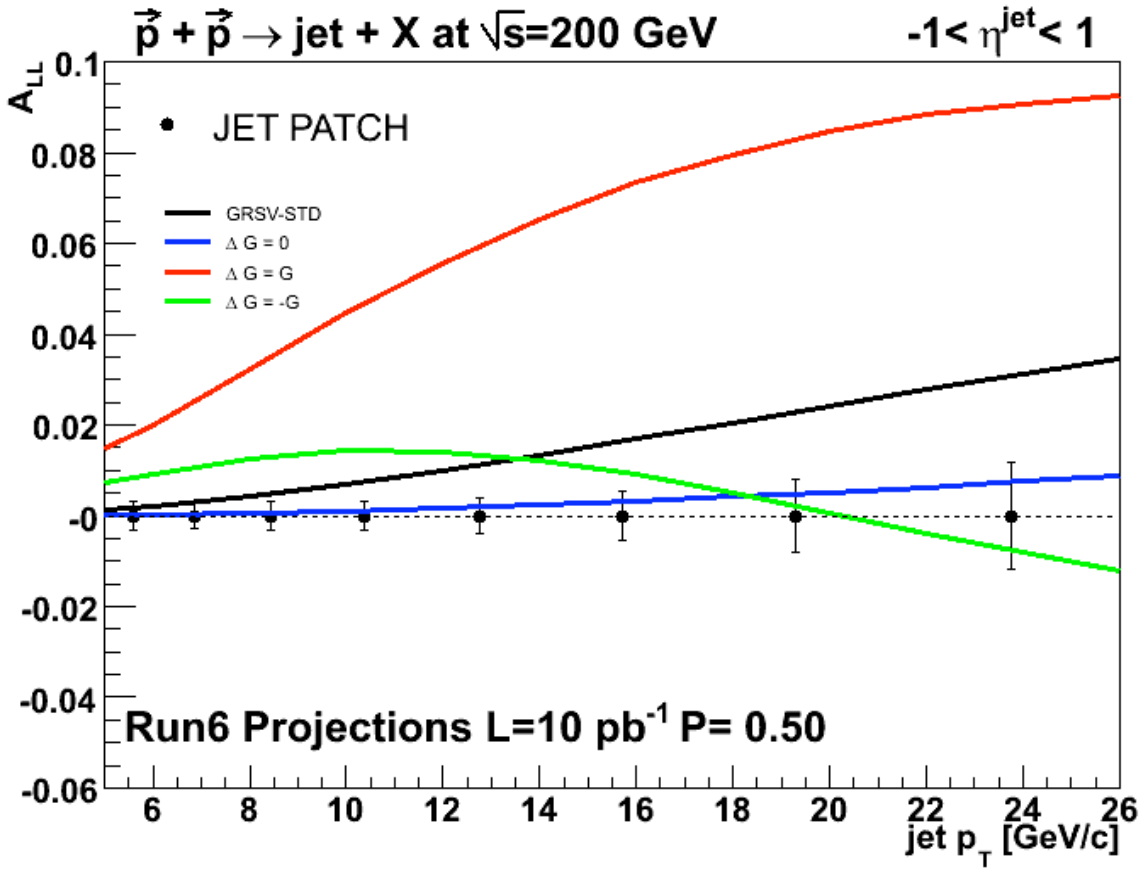


Barrel E.M. Calorimeter fully complete,

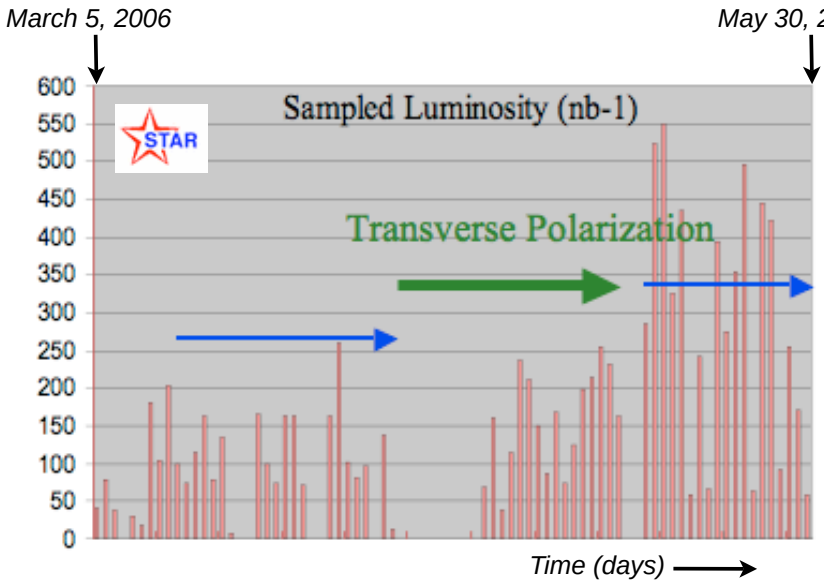
Di-jet trigger (c.f. J. Balewski's talk),

First stage of high-resolution forward E.M. Calorimeter, ultimately having full azimuthal coverage for photons and pions with $2.5 < \eta < 4$

Longitudinal Spin Goal for 2006



2006 Data Collection



As of 11 am Tuesday 5/30/06.

N.B. 10 pb^{-1} @ 50% P ⇒ FOM = 625 nb^{-1}

5.45 @ 60% ⇒ FOM ~ 706 nb^{-1}

Sampled Luminosity:

Longitudinal Polarization: (prior to trans.)

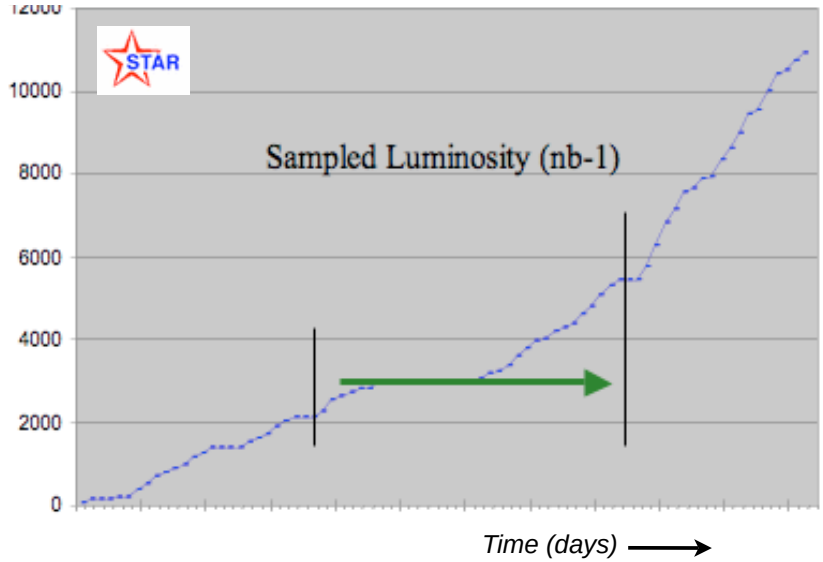
2.1 pb^{-1} Goal 10 pb^{-1}

Transverse Polarization:

3.34 pb^{-1} Goal ~3 pb^{-1} (Di-Jets)

Longitudinal Polarization: (after trans.)

5.45 pb^{-1} (FOM ~ 706 nb^{-1})



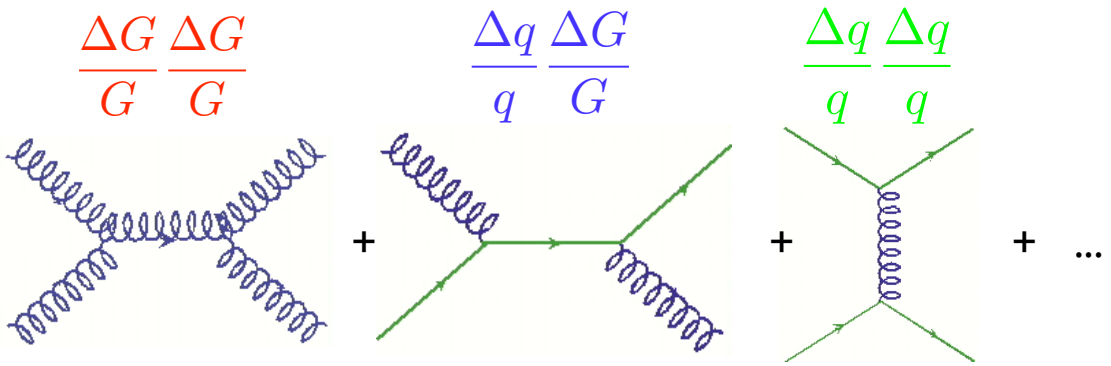
Courtesy B. Christie

Goals for 20-week RHIC operation reached!

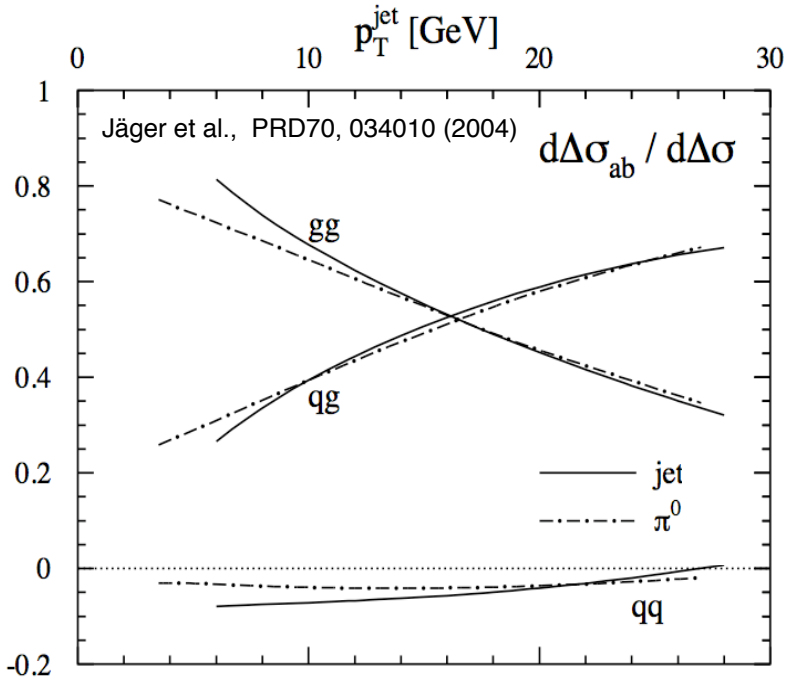
Analysis Progress and Results

Longitudinal Spin Asymmetries and Inclusive Channels (jets, pions)

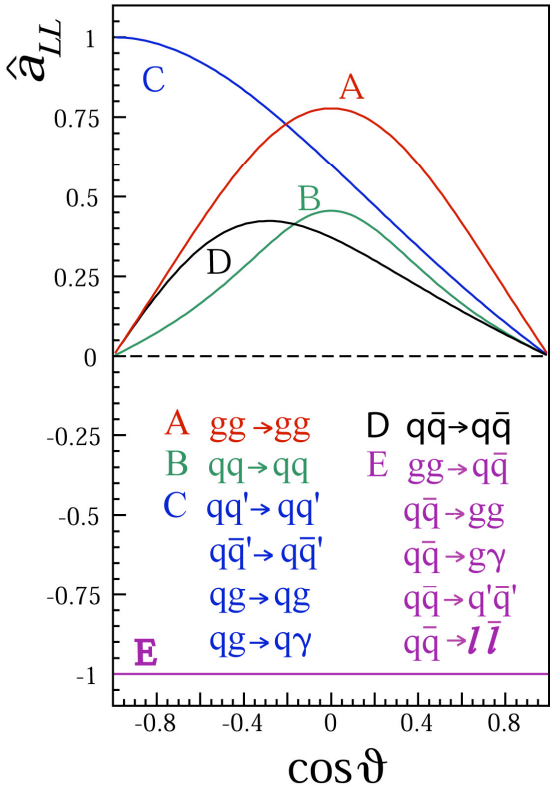
Sensitivity to:



with large contributions from gluon-gluon and quark-gluon scattering,



with large partonic asymmetries at 'midrapidity',

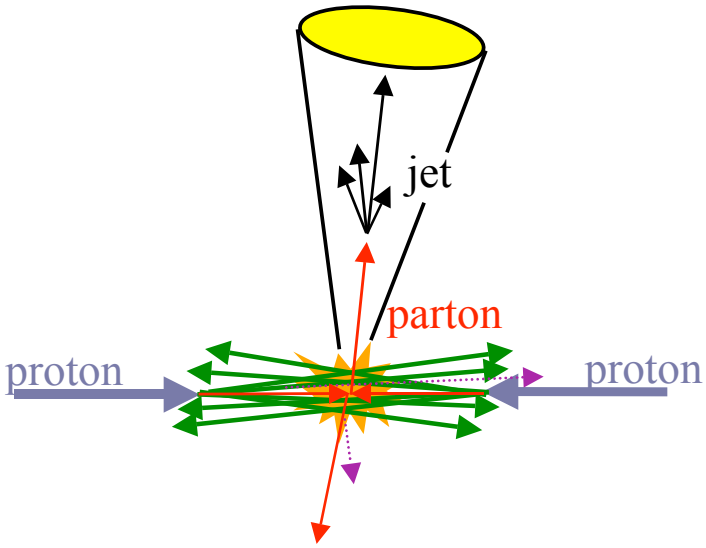


and, in the case of (unbiassed) jets, without fragmentation uncertainties,

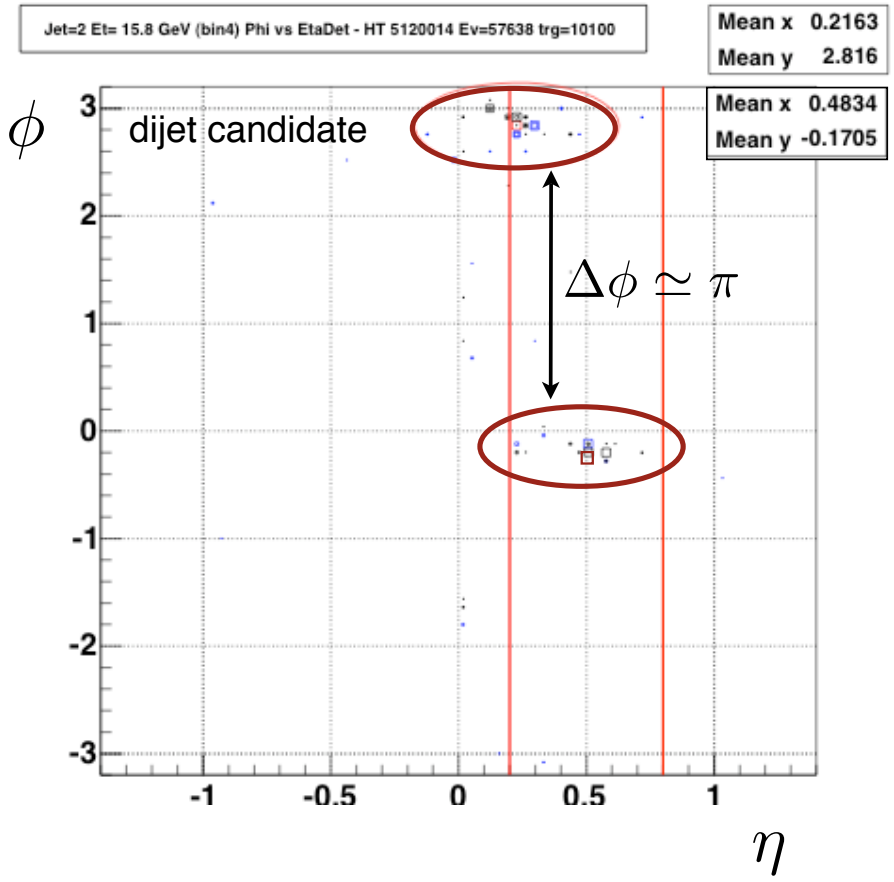
$$A_{LL} \propto \frac{\Delta f_a}{f_a}\frac{\Delta f_b}{f_b}\hat{a}_{LL}$$

Analysis: Jet Finding and Reconstruction

STAR reconstructs jets via TPC p_T for charged hadrons and (B)EMC E_T for E.M.-showers, using the Tevatron run-II (cone) algorithm, c.f. Blazey et al, hep-ex/0005012.



TPC	track p_T > ~0.2 GeV/c track letal ≤ ~1.4
BEMC	tower E_T > ~0.1 GeV
Jet	p_T > ~5 GeV/c 0.2 < leta^{det}l < 0.8 (2003-5) R = 0.4



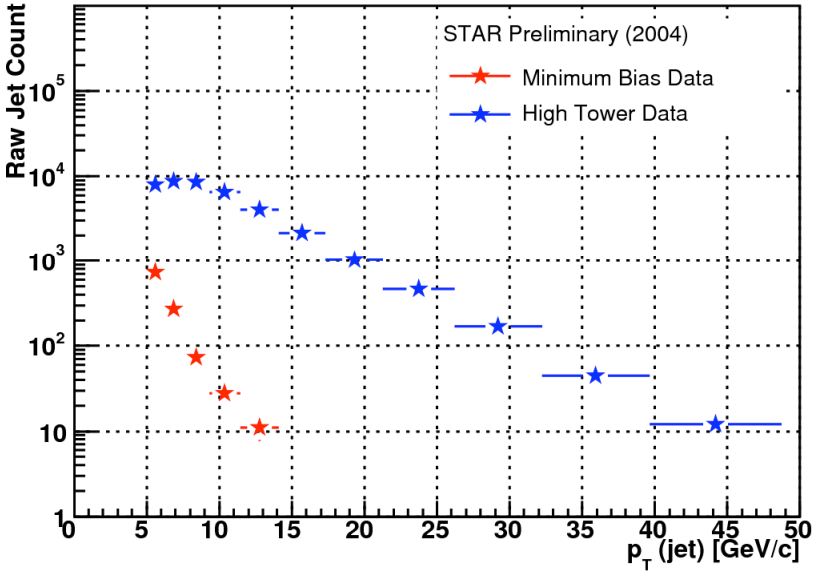
E_T^{rec} = 16 GeV

E_T^{rec} = 22 GeV

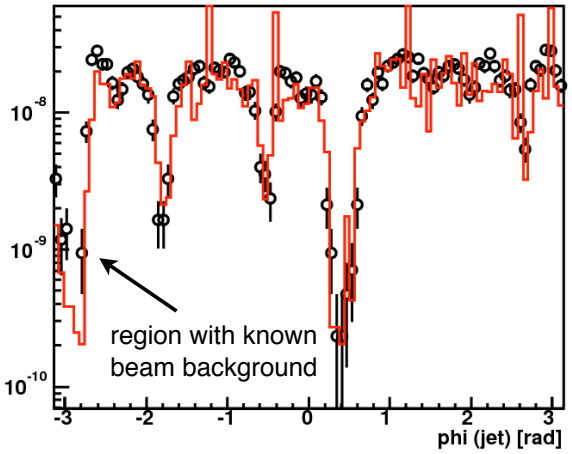
Analysis: Inclusive Jet Cross Section

Raw Jet Count

2004 data: ~0.16 pb^{-1}, 200 GeV, R=0.4, 3.5 GeV BEMC trigger threshold



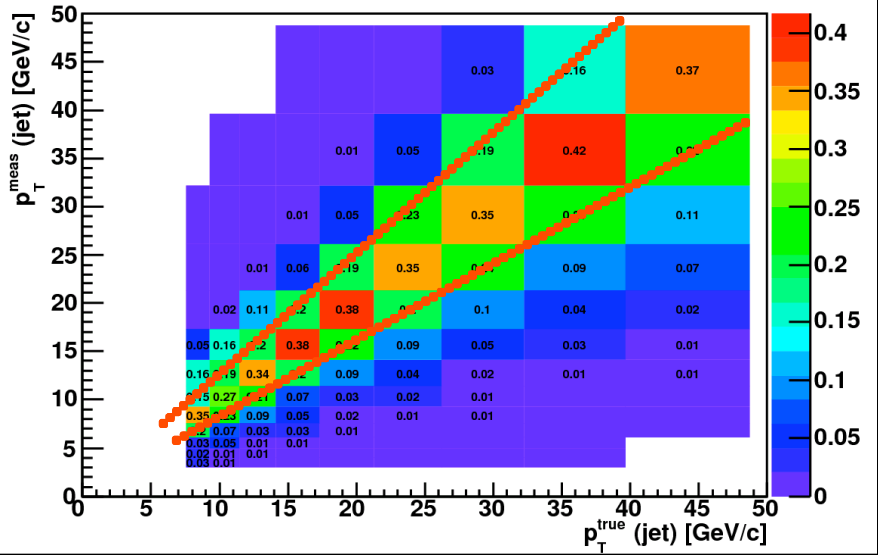
Data and M.C. compared:



Use Pythia (Herwig) + GEANT to:

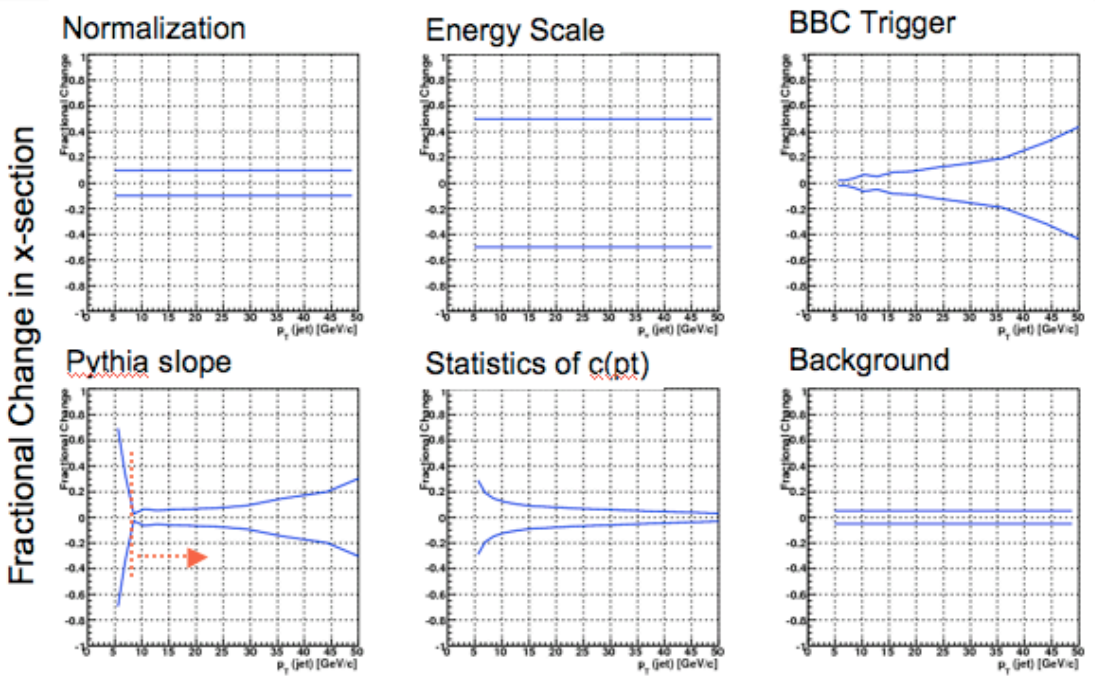
- quantify detector response, and
- estimate corrections in going from detector signal to particles in the jet

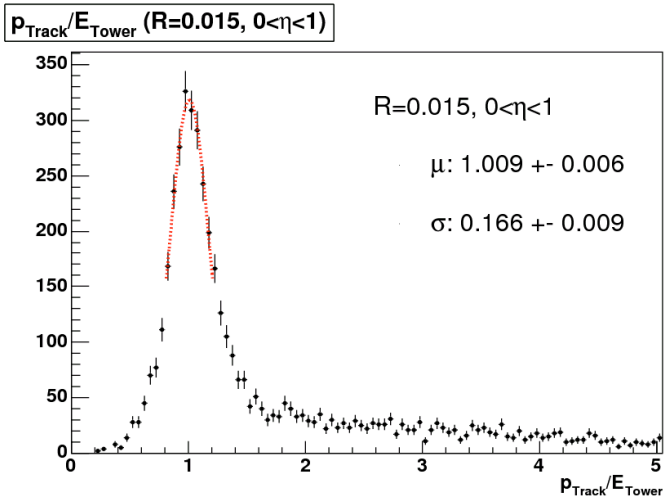
Simulated Purity



Analysis: Inclusive Jet Cross Section

Uncertainties in the Jet Cross section are mostly systematic and are presently dominated by the jet-energy scale, which receives a sizable contribution from the BEMC calibration.



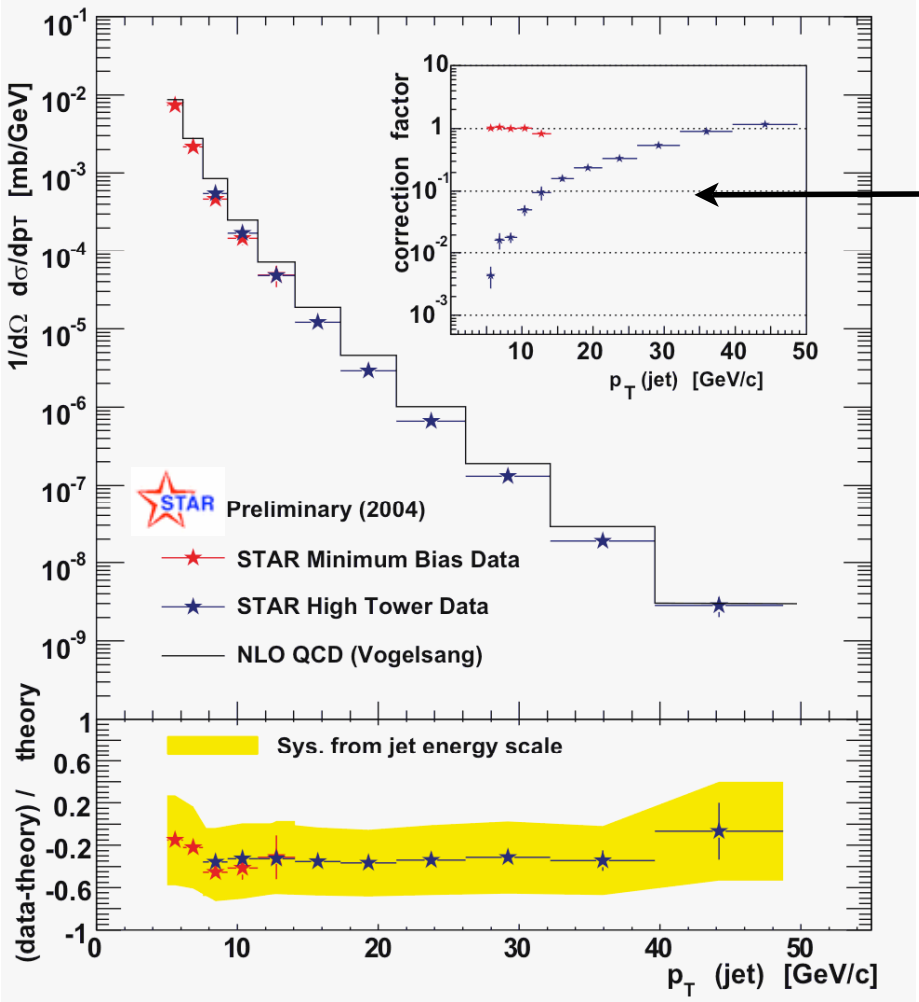


For 2004, the BEMC absolute gain calibration was performed using electrons with $2 < p < 6$ GeV/c collected in Au+Au collisions.

Expect improvement for future data from pions, di-jets, photon-jets, ...

Analysis: Inclusive Jet Cross Section

Preliminary Inclusive Jet Cross section



M.C. bin-by-bin correction for:
- trigger inefficiency,
- detection and reconstruction inefficiencies,
- bin migration,
- undetected energy,

...

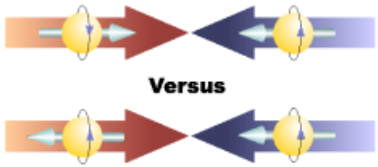
Good agreement on the cross section from triggers with very different corrections,

Leading uncertainty from jet energy scale,

Reasonable agreement of theory@NLO and data over 7 decades.

Analysis: Double-Helicity Asymmetry for Inclusive Jets

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



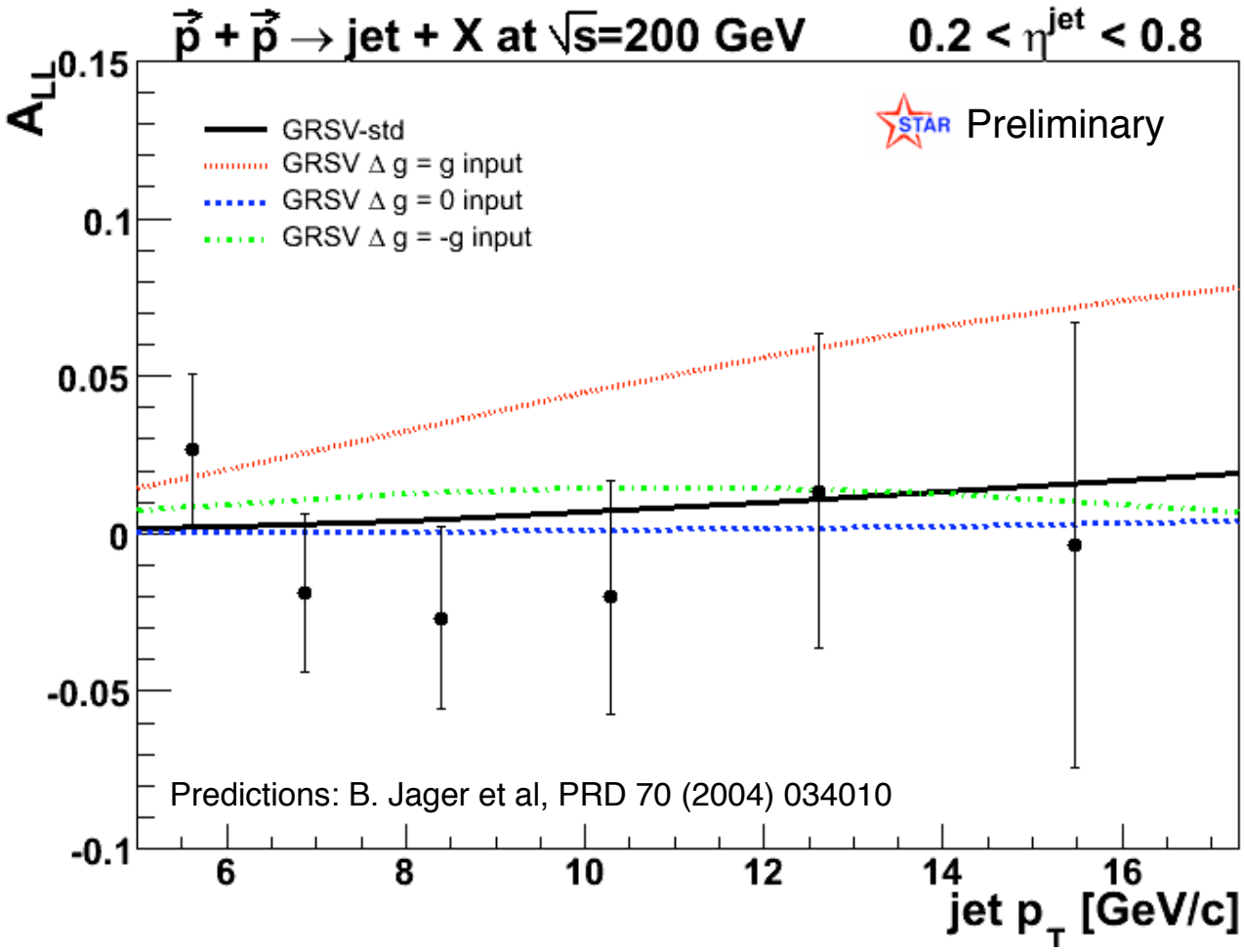
Statistical significance: $P_1^2 P_2^2 \cdot \int \mathcal{L} dt$

Require concurrent measurements:

- magnitude of beam polarization, $P_{1(2)}$ → RHIC polarimeters
- direction of polarization vector at interaction point } BBC + scalers
- relative luminosity of bunch crossings with different spin directions: $R = \frac{L_{++}}{L_{+-}}$ } BBC + scalers
- spin dependent yields of process of interest N_{ij}

} STAR experiment

Analysis: Double-Helicity Asymmetry for Inclusive Jets



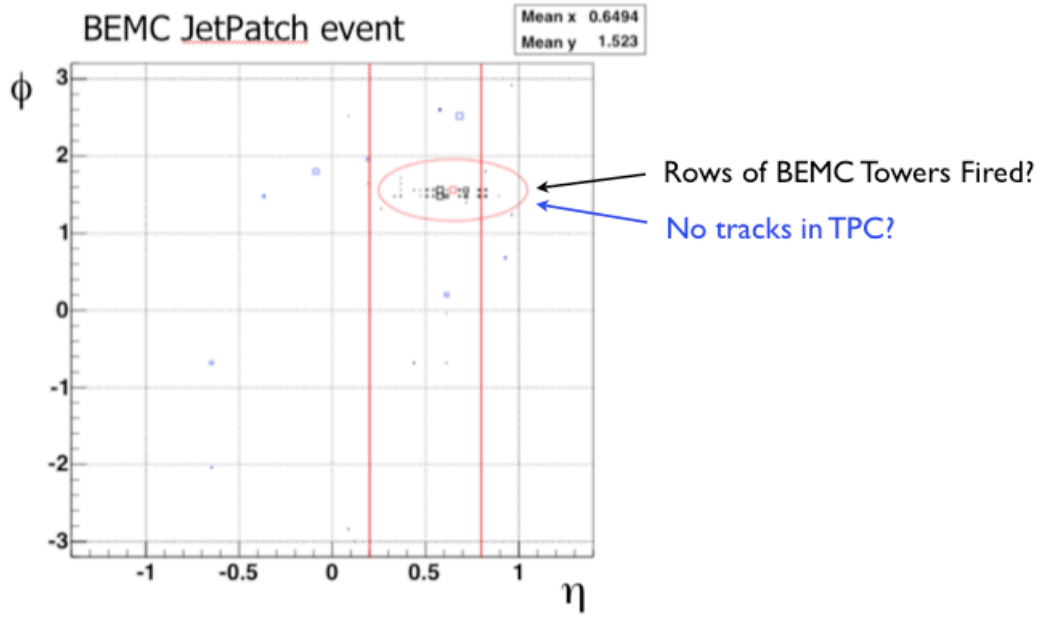
Results from 2003 and 2004 consistent with expectations from fits to inclusive DIS,

Large positive gluon polarization disfavored.

Indicated uncertainties are statistical only. In addition,

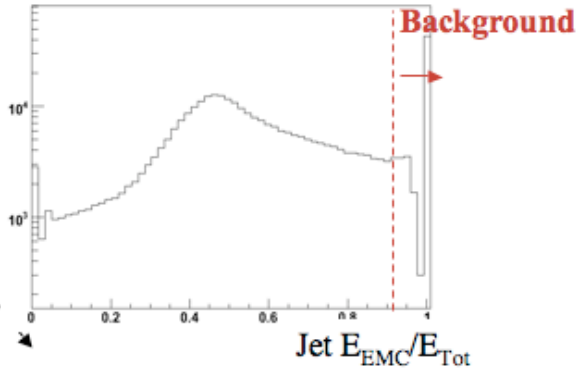
- there is ~25% scale uncertainty from the RHIC polarization measurement,
- ~0.01 total systematic uncertainty from the relative luminosity measurement, residual non-longitudinal polarization, trigger-bias, beam-background, ...

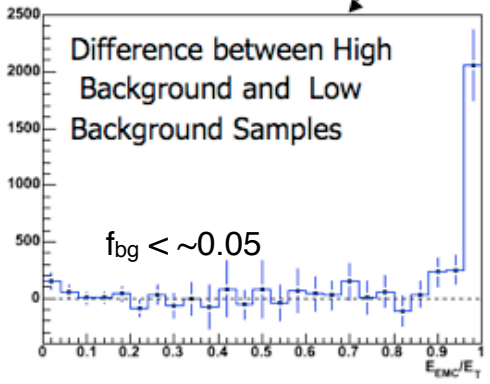
Analysis: Double-Helicity Asymmetry for Inclusive Jets

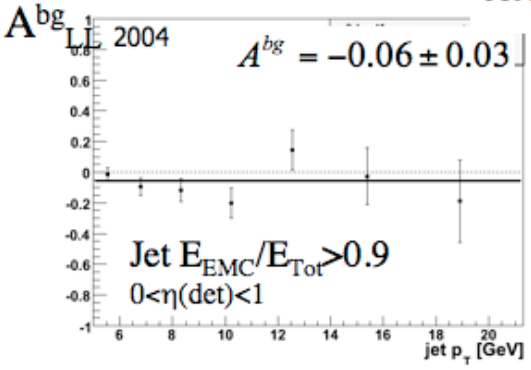


Beam background manifests itself as "jets" with a large neutral to total energy ratios,

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





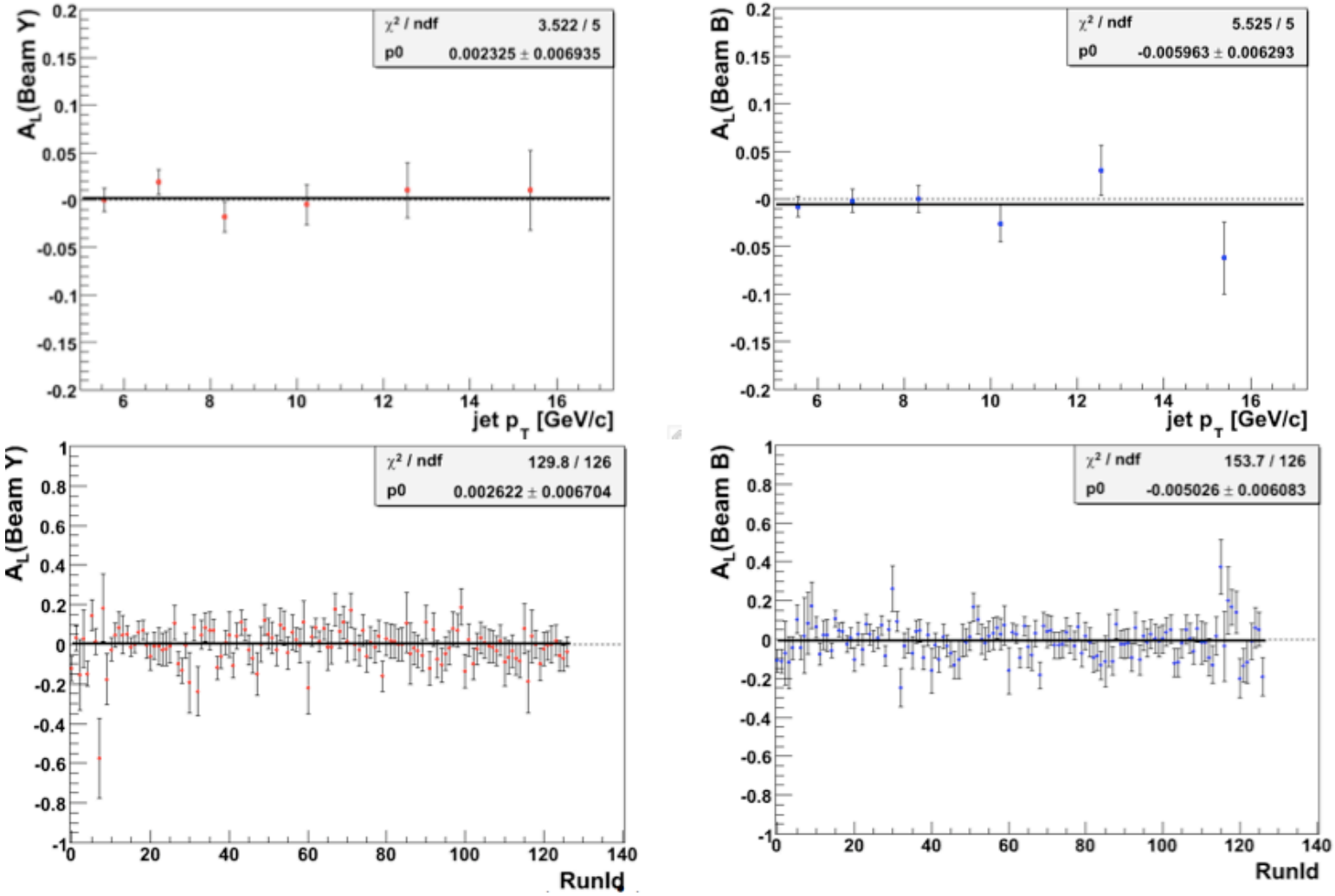


~ 0.003 uncertainty in A_{LL},

Shielding of STAR IR in 2006

Analysis: Double-Helicity Asymmetry for Inclusive Jets

Extensive cross-checks, e.g. single-spin asymmetries:



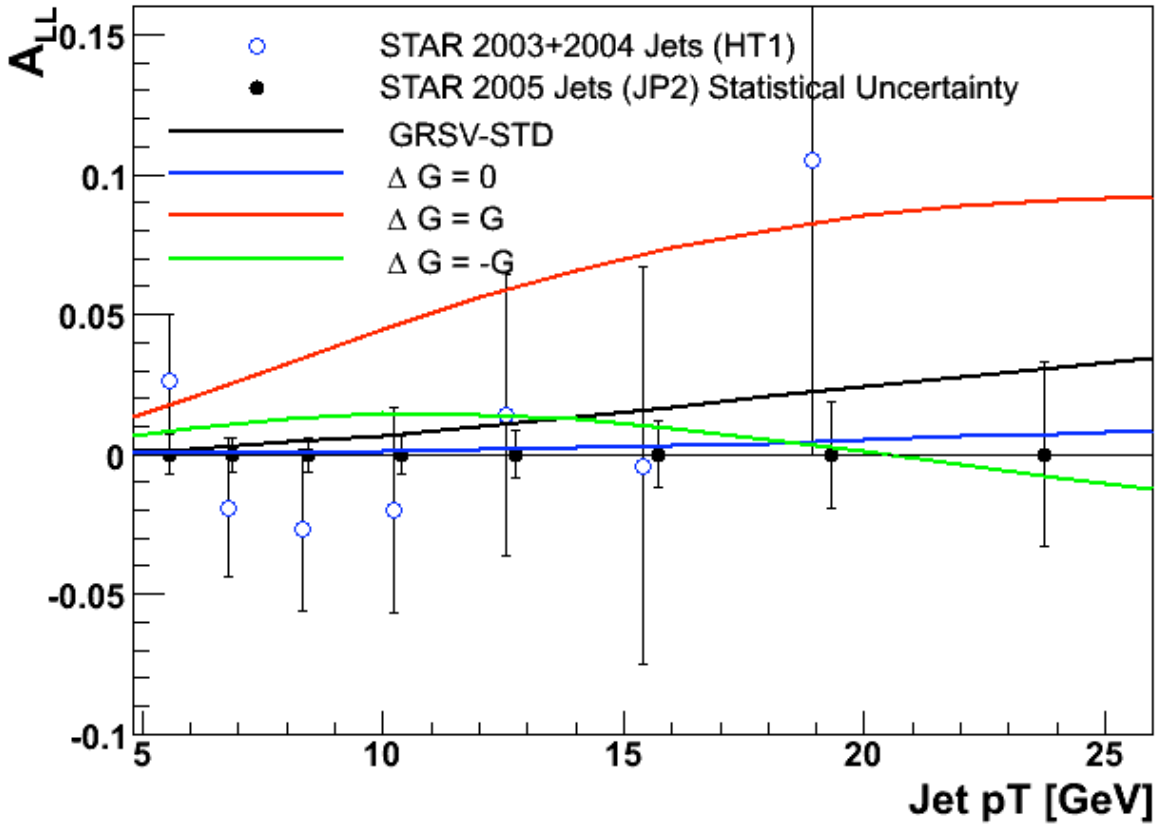
are consistent with 0, as expected. All other cross-checks show no evidence for “hidden systematics” either.

Inclusive Jets - Projected uncertainty for 2005 data

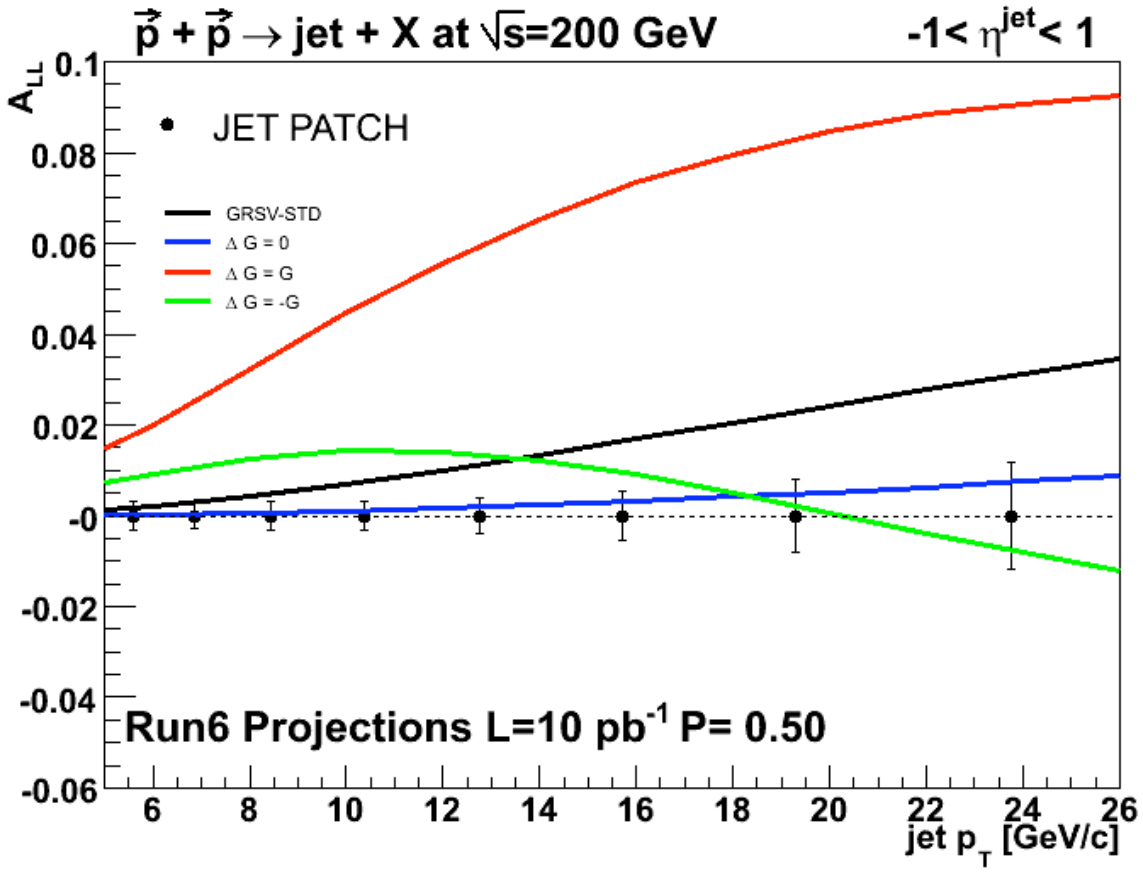
3 x better uncertainty,

extended p_T range,

finalizing studies and systematic uncertainties



Jets - Prospects for 2006 data



FoM was reached in 2006,

Data should discriminate between the GRSV gluon polarizations,

Start of:

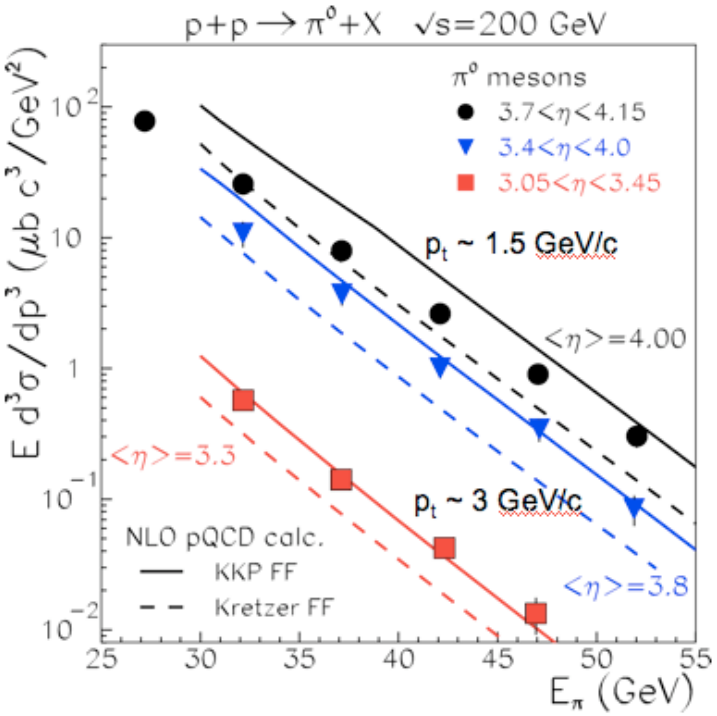
- *(sensitive) jet-correlation analyses,*
- *prompt-photon channel,*

to resolve parton kinematics and select qg scattering.

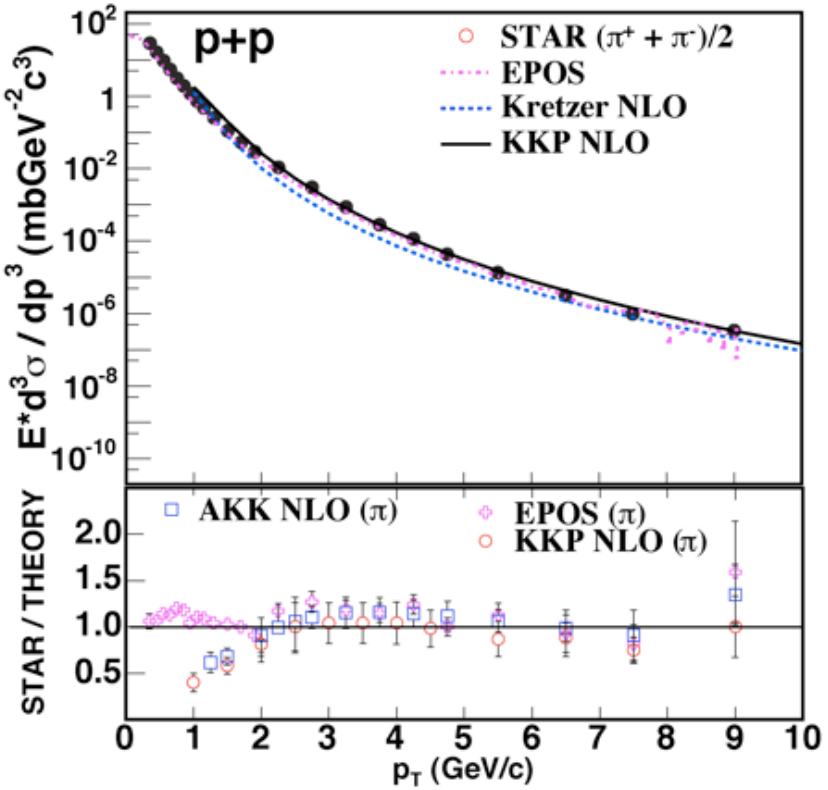
Its successful pursuit requires continued substantial running periods.

- Inclusive Pions

FPD-based, neutral forward pions



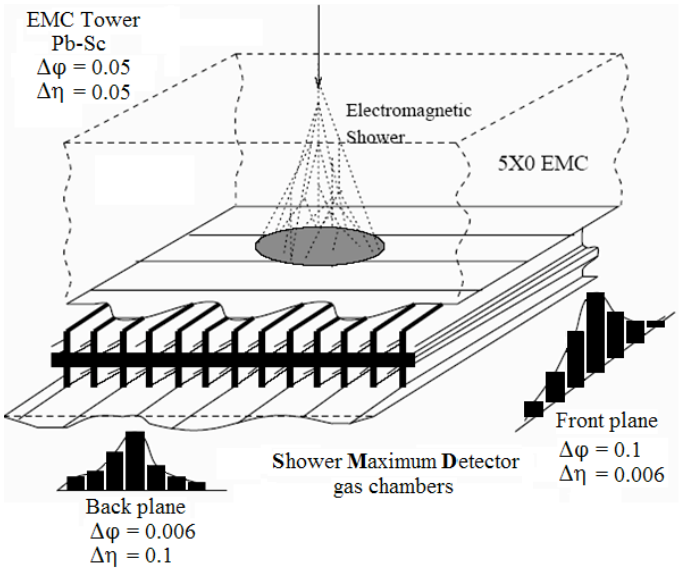
TPC-based, charged central pions



- Inclusive Pions

A new, for 2005, analysis is that of inclusive neutral pions at central rapidities,

based on the Barrel E.M. Calorimeter,



Pb-scintillator sampling calorimeter,

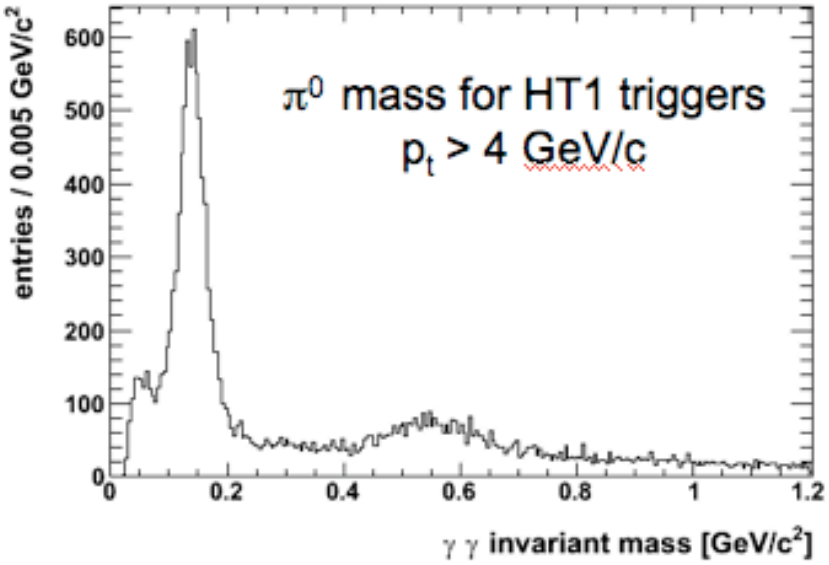
0.05 x 0.05 (eta x phi) tower size,

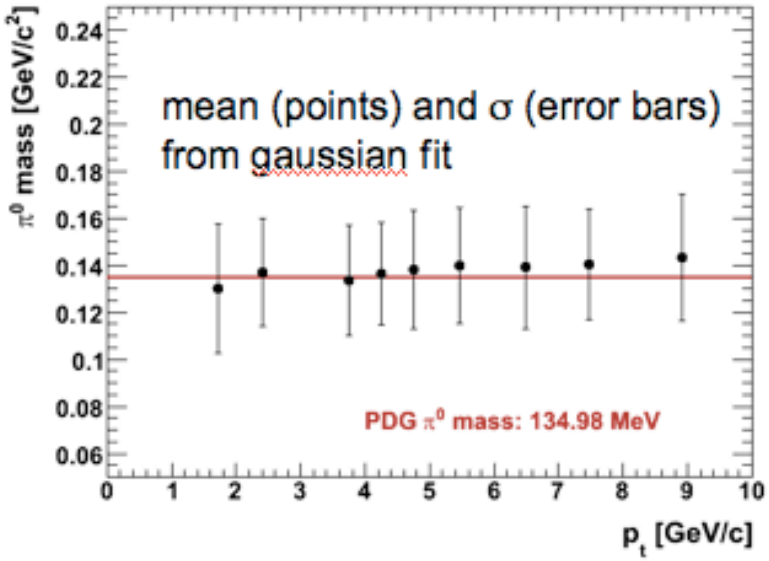
Shower-Max Detector (SMD) at 5 X_0,
important for p_T > ~5 GeV/c

SMD half-instrumented before 2005, hence the analysis is restricted to $0.1 < \eta < 0.9$

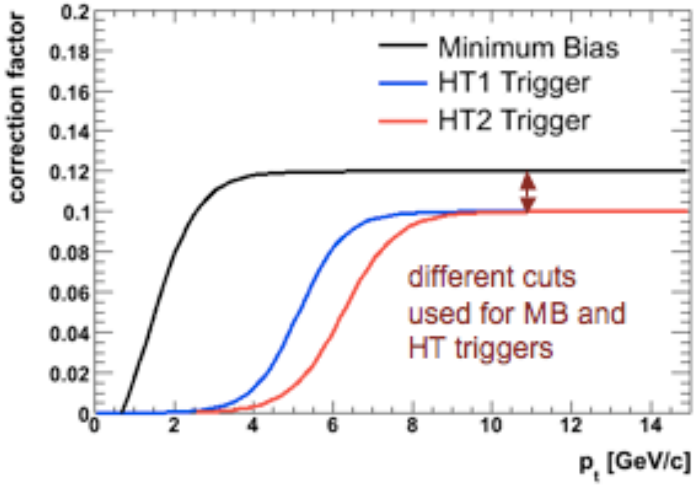
Veto BEMC hits pointed at by TPC track.

- Inclusive Pions



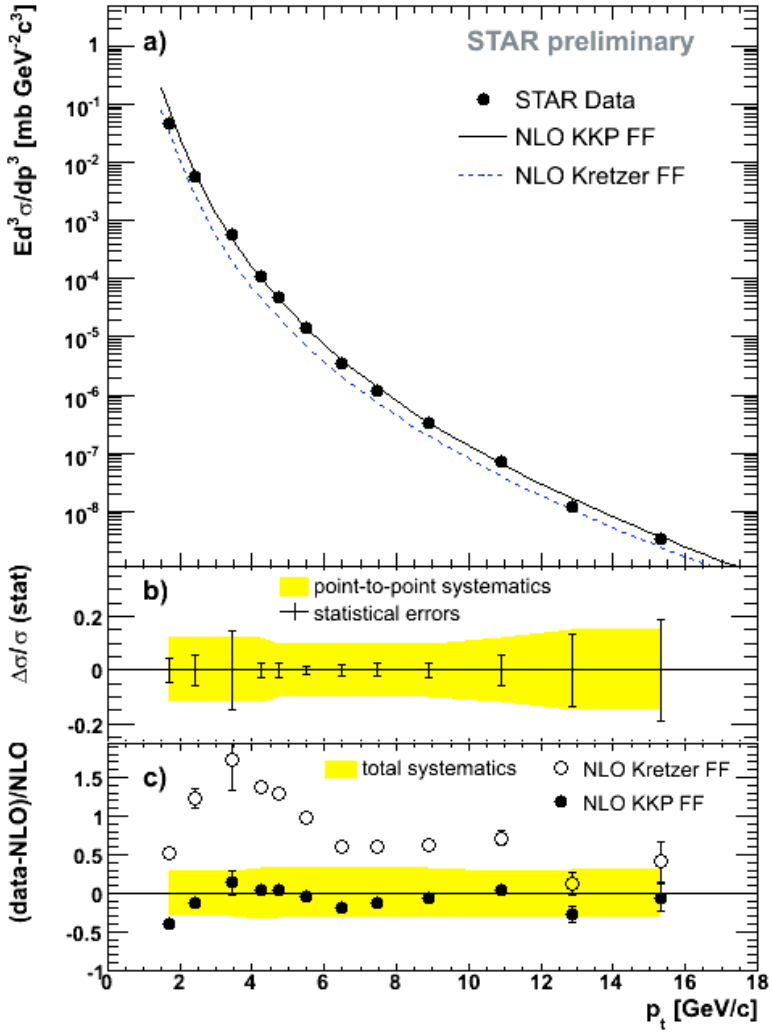


- π^0 mass in good agreement with expected value, overestimation at high pt expected due to small opening angle
- Correction factor (includes trigger efficiency) determined from simulations (single π^0 and PYTHIA/HERWIG)



- Inclusive Pions

CIPANP 2006: F. Simon for the STAR Collaboration



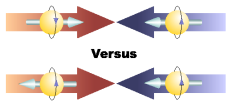
10% normalization uncertainty from luminosity measurement not shown.

Good Agreement with theory@NLO using CTEQ6M pdfs + KKP ff for pT > 2 GeV/c,

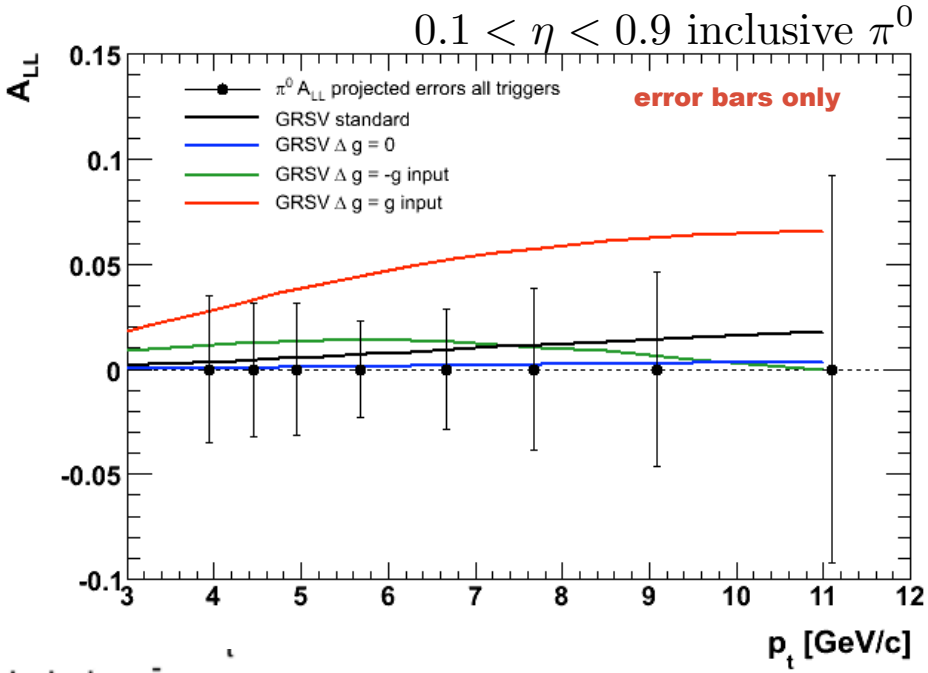
Kretzer ff systematically below the data,

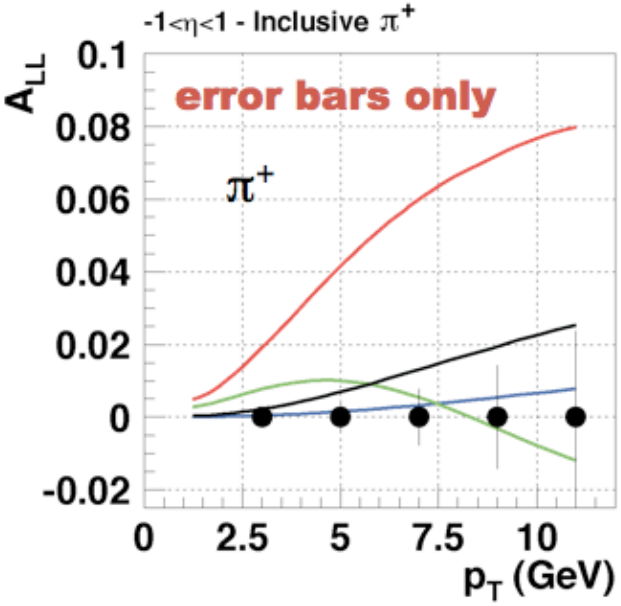
Experiment systematics dominated by ~5% BEMC energy scale uncertainty,

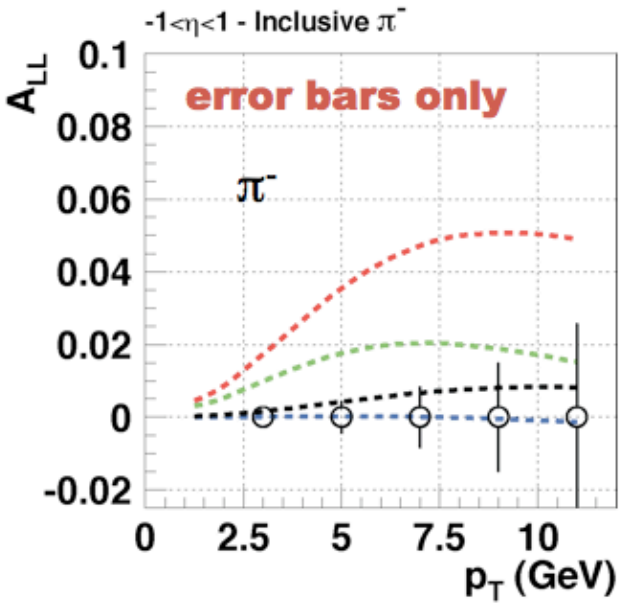
Prospects for Inclusive Pion Asymmetries from 2005 data



$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}}$$





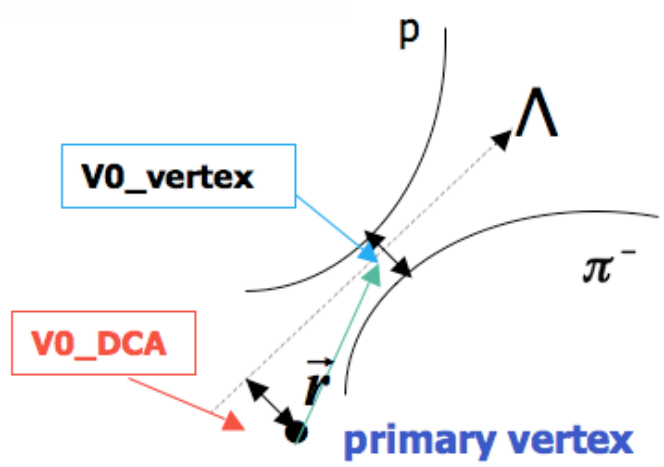


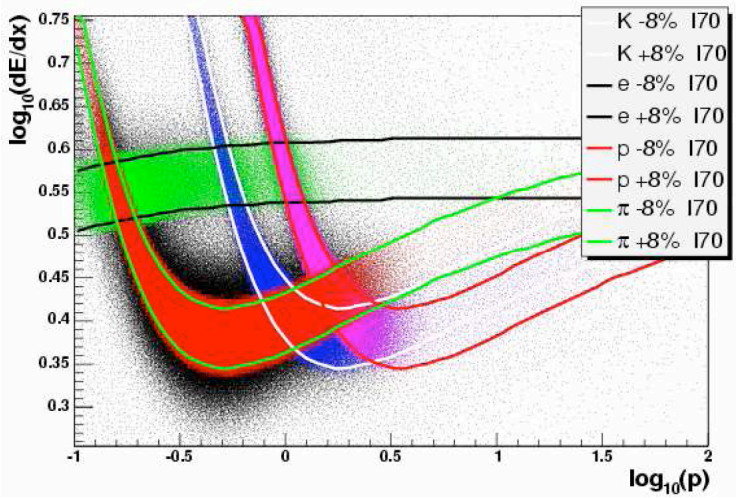
Complementary sensitivity to gluon polarization,

Cross-section measurement essential

Prospects for Inclusive (anti-)Lambda's

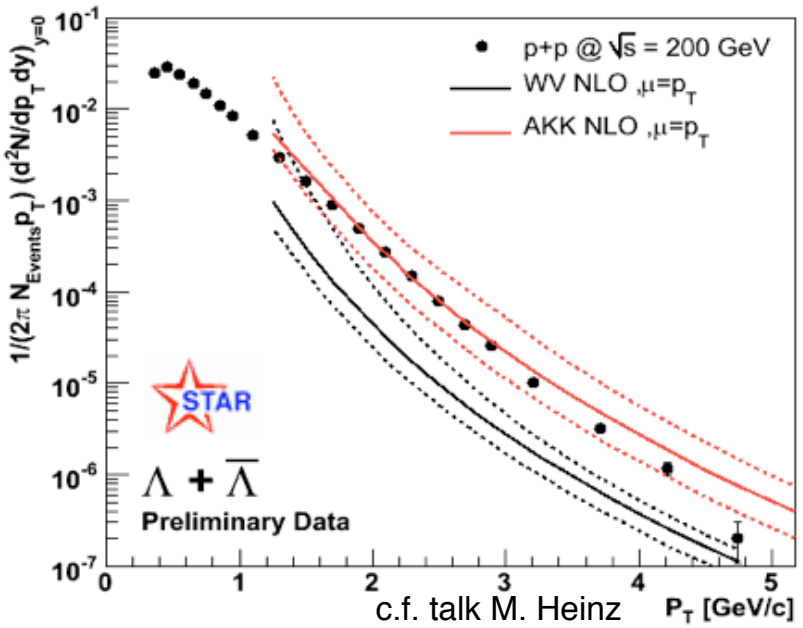
Time-Projection-Chamber based Topological reconstruction using particle-ID,





STAR has measured the inclusive (anti-)Lambda reconstruction up to $p_T \sim 4$ GeV/c.

Theory@NLO is a reasonable description for pT > 2 GeV/c and the AKK choice of ff.



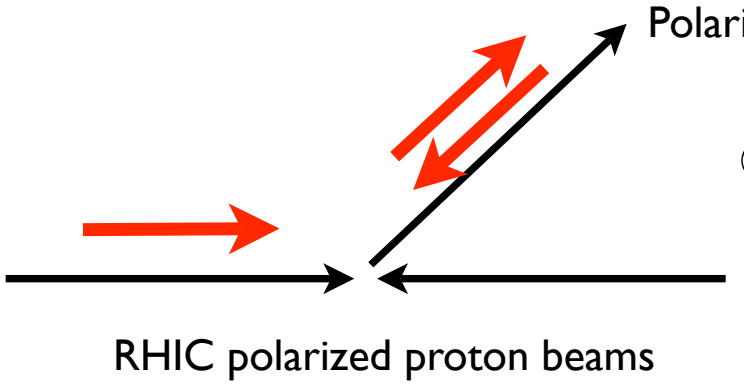
c.f. talk M. Heinz

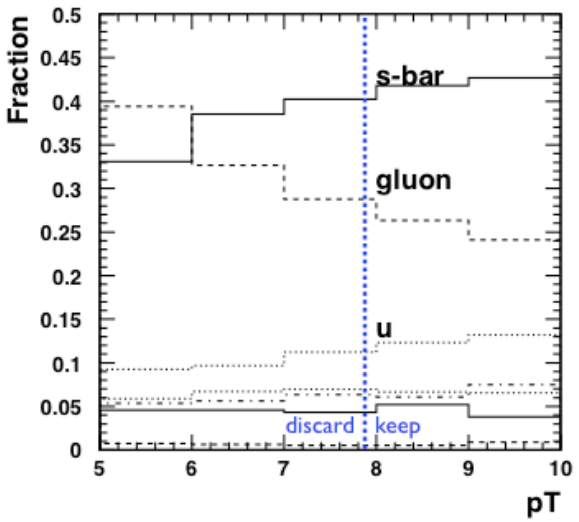
Prospects for Inclusive (anti-)Lambda's

Why might this be interesting?

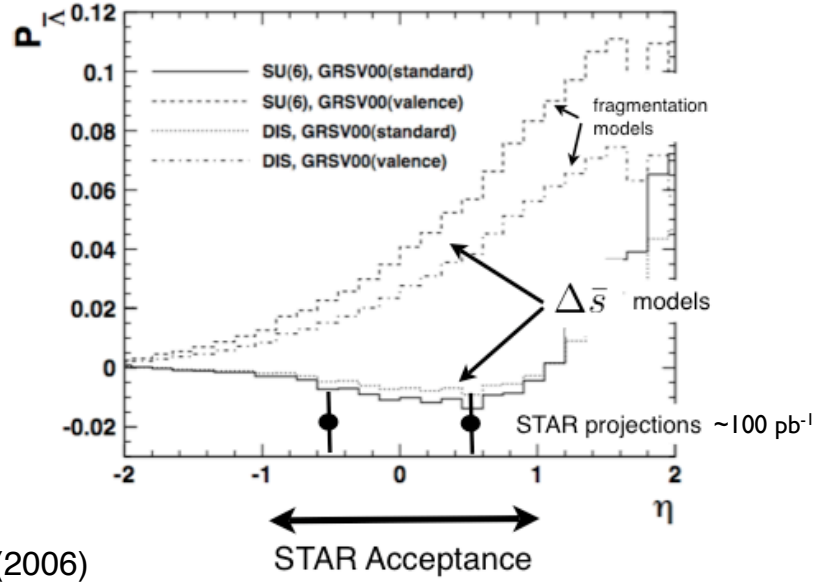
Hyperons contain strange quarks,

Longitudinal spin-transfer measurements may be sensitive to strange-quark polarization





Q.H. Xu et al, PRD 70 73, 077503 (2006)



Anti-Lambda's at high p_T are sensitive to anti-strange polarization, more so than to spin-transfer and fragmentation models

Cross-section will be key!

Prospects for Inclusive (anti-)Lambda's

Redundancy of *two* polarized beams at RHIC,

with *identical* protons

and *parity-conservation in hard production,*

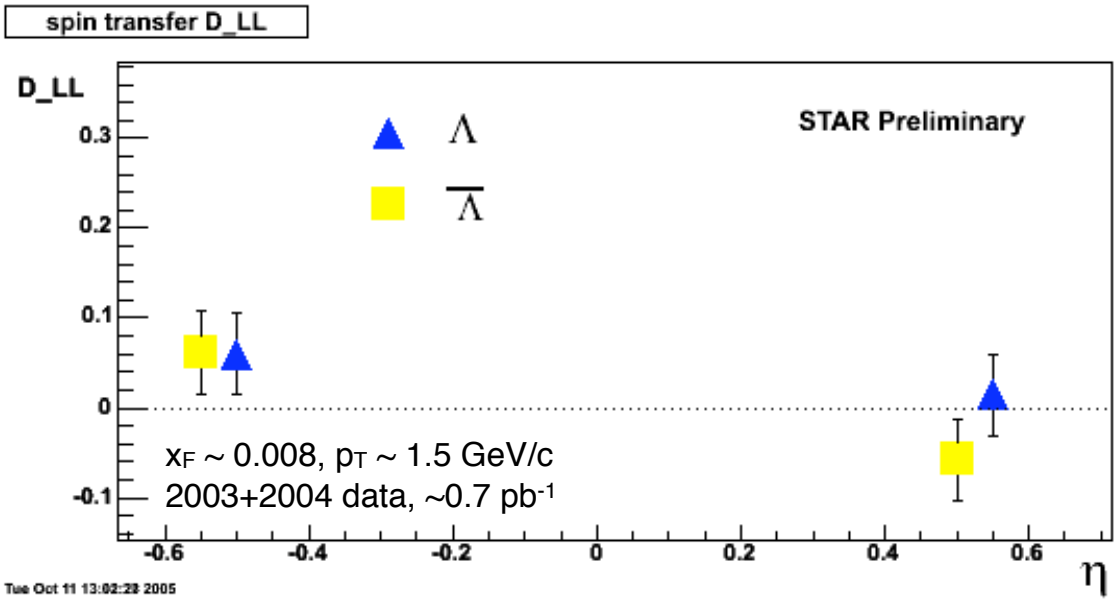
=>

lead to P relations:

$$P_{\Lambda}^{++}(\eta) = -P_{\Lambda}^{--}(\eta),$$

$$P_{\Lambda}^{+-}(\eta) = -P_{\Lambda}^{-+}(\eta)$$

and allow one to cancel the STAR acceptance in extracting D_{LL}



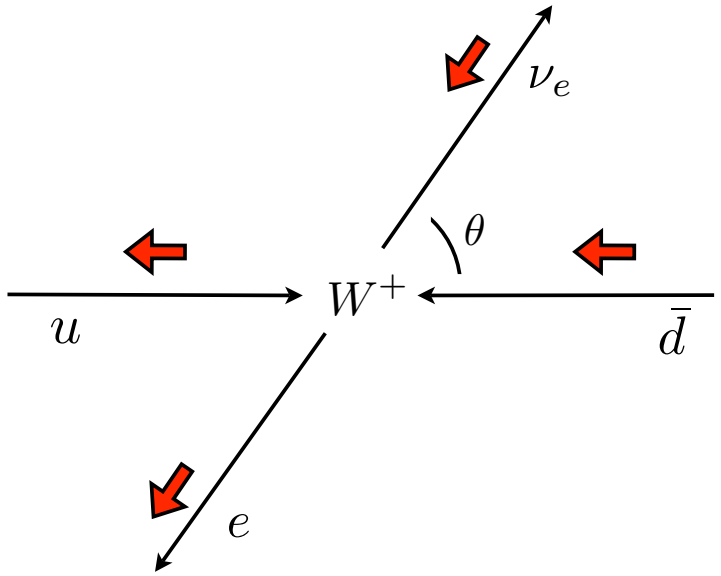
Proof-of-principle measurement, consistent with 0-expectation and limited by:

- statistics, and
- p_T range,

Potential for ~10^2 pb^{-1}, 70%

500 GeV and Quark Spins

W-bosons as Polarimeters



Experiment Signature:
large p_T lepton, missing E_T

$$\Delta\sigma^{\mathrm{Born}}(\vec{p}p \to W^+ \to e^+\nu_e) \propto -\Delta u(x_a)\bar{d}(x_b)(1+\cos\theta)^2 + \Delta\bar{d}(x_a)u(x_b)(1-\cos\theta)^2$$

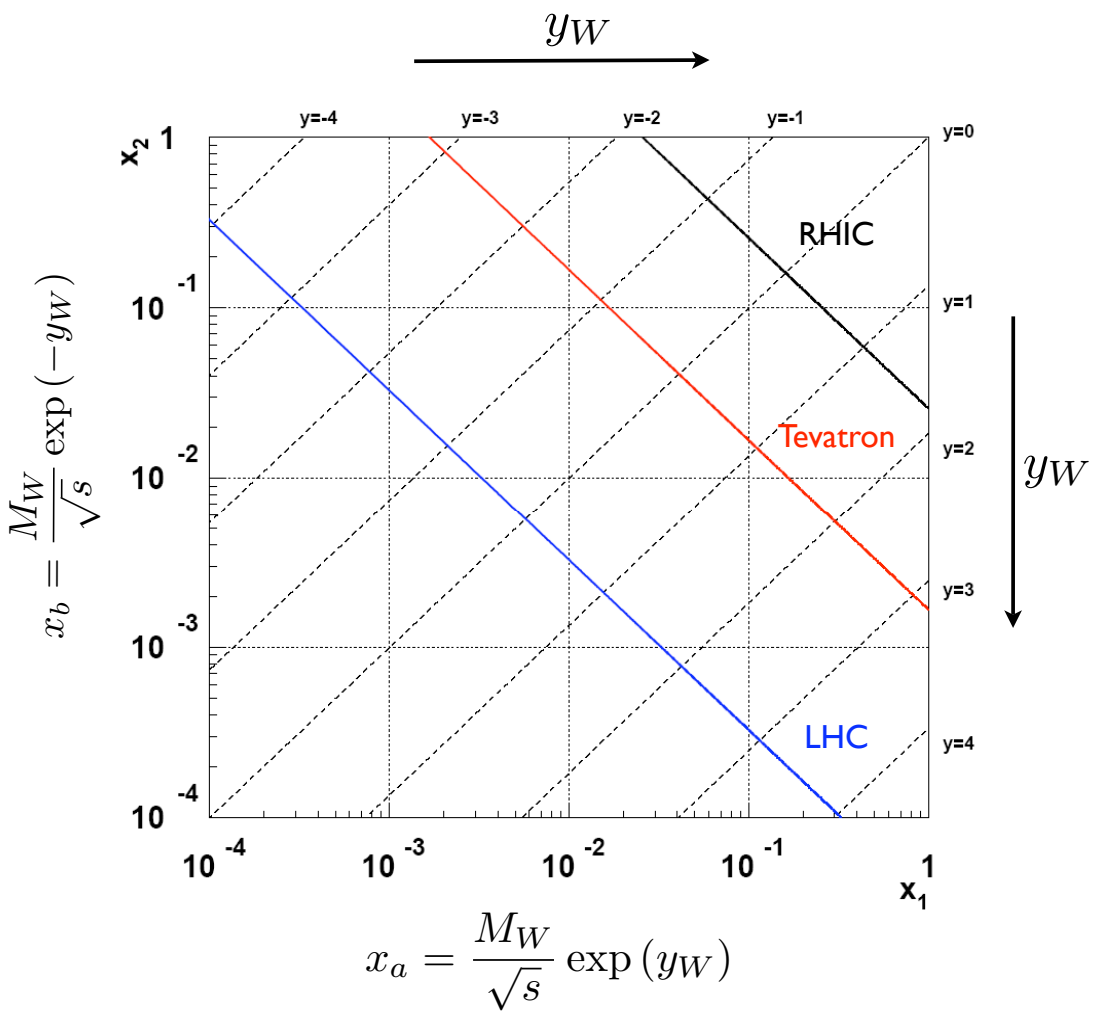
Spin Measurements:

$$A_L(W^+) = \frac{-\Delta u(x_a)\bar{d}(x_b) + \Delta\bar{d}(x_a)u(x_b)}{u(x_a)\bar{d}(x_b) + \bar{d}(x_a)u(x_b)} = \begin{cases} -\dfrac{\Delta u(x_a)}{u(x_a)}, & x_a \to 1 \\ \dfrac{\Delta\bar{d}(x_a)}{\bar{d}(x_a)}, & x_b \to 1 \end{cases}$$

$$A_L(W^-) = \begin{cases} -\dfrac{\Delta d(x_a)}{d(x_a)}, & x_a \to 1 \\ \dfrac{\Delta\bar{u}(x_a)}{\bar{u}(x_a)}, & x_b \to 1 \end{cases}$$

charge-ID at large |rapidity|
and hadron-rejection

W's and PDFs at Colliders

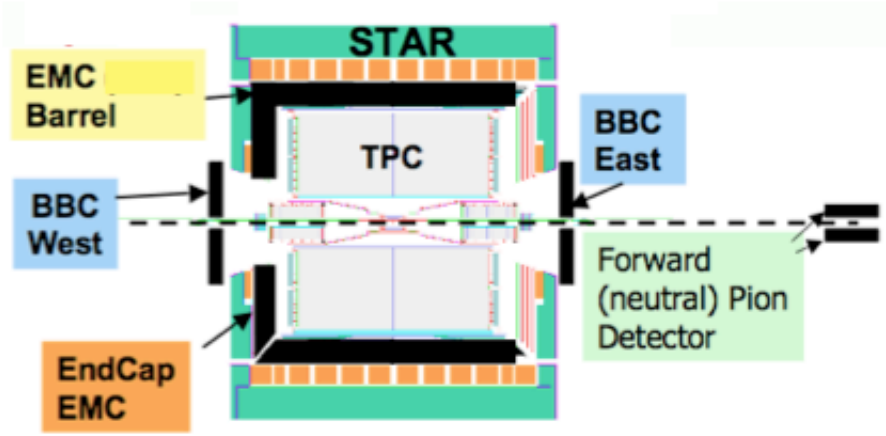


$$pp \longrightarrow u, \bar{d} \quad \bar{u}, d$$

$$p\bar{p} \longrightarrow u, d$$

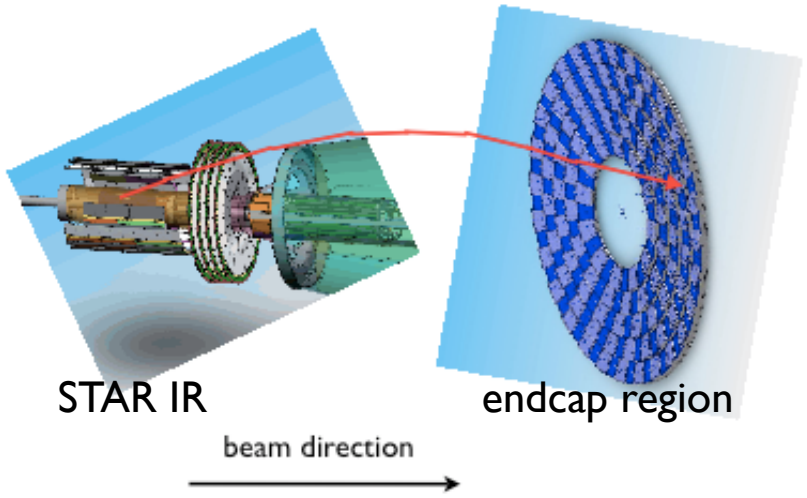
STAR - Experiment Challenges/Needs

STAR:



E/p selection	~10,
Isolation	~10,
Missing E_T	~10,
Longitudinal shower profile	
	$>10^3$

TPC tracking breaks down in forward region, i.e. need forward tracking upgrade.

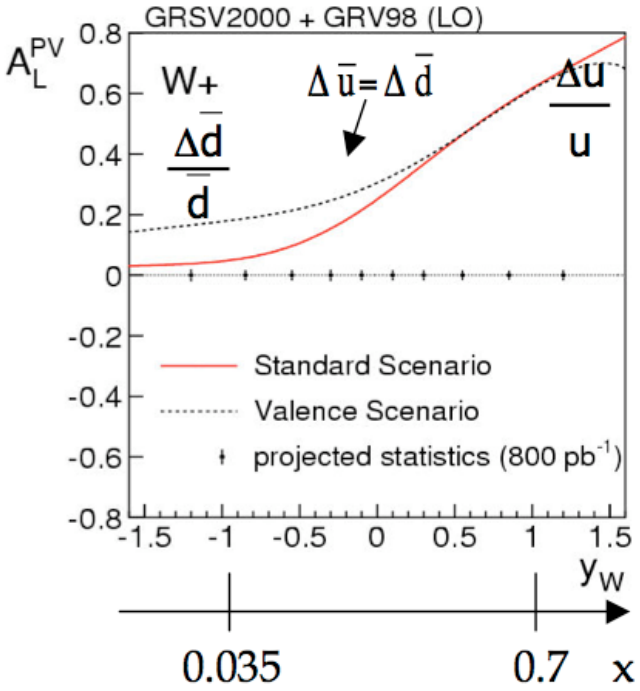


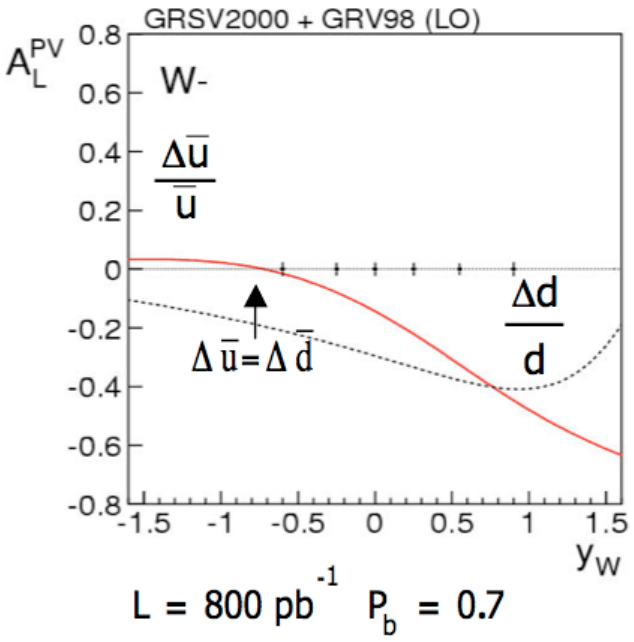
Current technology choice:
Forward Silicon Strip Disks,
GEM Endcap Calorimeter Tracker,

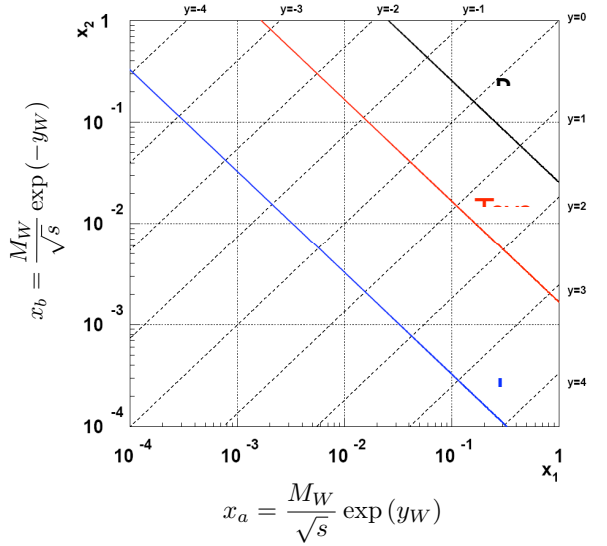
Aim for detailed proposal late 2006,

Integration in STAR ~end of the decade.

STAR - Projected Uncertainties







500 GeV High integrated luminosity measurements of leptonic decay in W production yield sensitive and fragmentation-free insights in the up, down, quark and anti-quark spins.

Concluding Remarks

Concluding Remarks

Ongoing 2006 run:

- is going very well in terms of longitudinal goals; higher than anticipated polarizations compensate the lower luminosities,
- have exceeded also the transverse goals - STAR talk by J. Balewski tomorrow,

Analyses are well-advanced,

- preliminary inclusive jet cross-section and double-helicity asymmetry,
- preliminary inclusive π^0 cross section interesting in itself, and a key-step to photons,
- interesting prospects for charged pions even from low-luminosity running, Lambda's

Very real need for extensive continued running, at 200 and 500 GeV

Thanks!