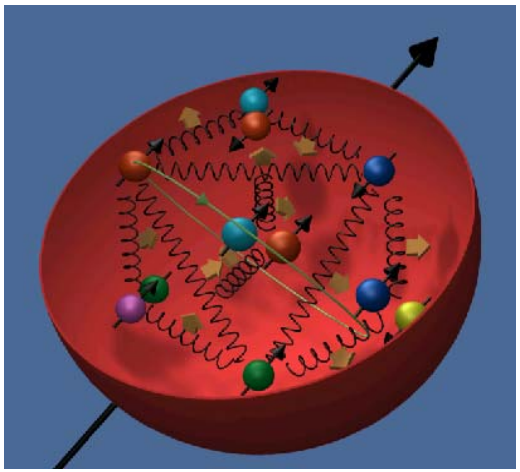
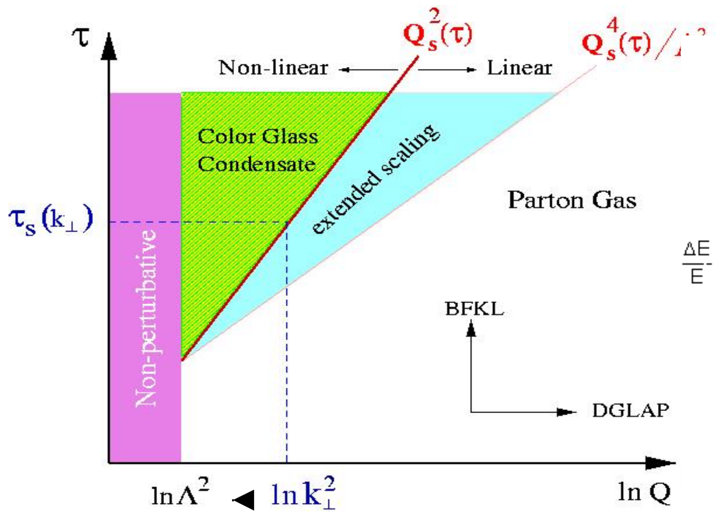
STAR Multi-Year Beam Use Request For Runs:

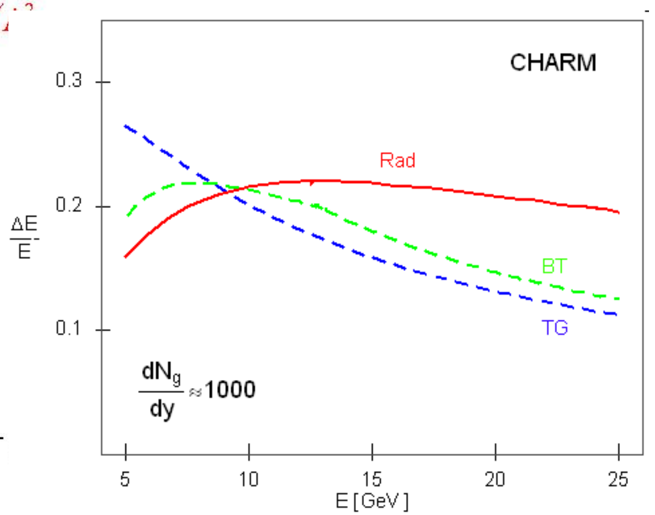
VI & VII



VII



VIII (& IX)



Tim Hallman for the STAR Collaboration

Brookhaven National Laboratory

November 3, 2005

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Philosophy Behind the STAR BUR

To allocate beam time to measurements that will provide qualitatively new insights into the properties of

- the nucleon
- the nucleus
- dense QCD matter

Specifically:

Run VI — Place a world-class constraint on gluon polarization in the proton, Δg

Delineate the roles of parton orbital motion/transversity in creating the transverse single spin asymmetry (A_N) observed for inclusive forward π° production

First significant measurement of Sivers effect asymmetry in di-jet production

Run VII — Decisive test of existence of the Color Glass Condensate in relativistic heavy nuclei

Detailed mapping of the x dependence of gluon polarization in the proton, $\Delta g(x)$

Run VIII — Precision tests of the properties of quark-gluon matter

The STAR 3 year Beam Use Request

Run	Energy	System	Goal
VI	$\sqrt{s}$ = 200 GeV $\sqrt{s}$ = 200 GeV $\sqrt{s_{NN}}$ = 19.6, 31 GeV	$p\uparrow p\uparrow$ $p_{\rightarrow}\, p_{\rightarrow}$ Au + Au	10 pb^{-1} sampled 20 pb^{-1} sampled 1 + 1 weeks* (10M + 10M evts)
VII	$\sqrt{s_{NN}}$ = 200 GeV $\sqrt{s}$ = 200 GeV	d + Au $p_{\rightarrow}\, p_{\rightarrow}$	11 weeks 10 weeks
VIII	$\sqrt{s_{NN}}$ = 200 GeV $\sqrt{s}$ = 200 GeV	Au + Au $p_{\rightarrow}\, p_{\rightarrow}$	15 weeks 6 weeks

The philosophy: focus on qualitative, rather than only quantitative steps forward as the machine and detector capability afford these to maximize the scientific impact and discovery potential in the next 3 years

The Physics Driving Run VI

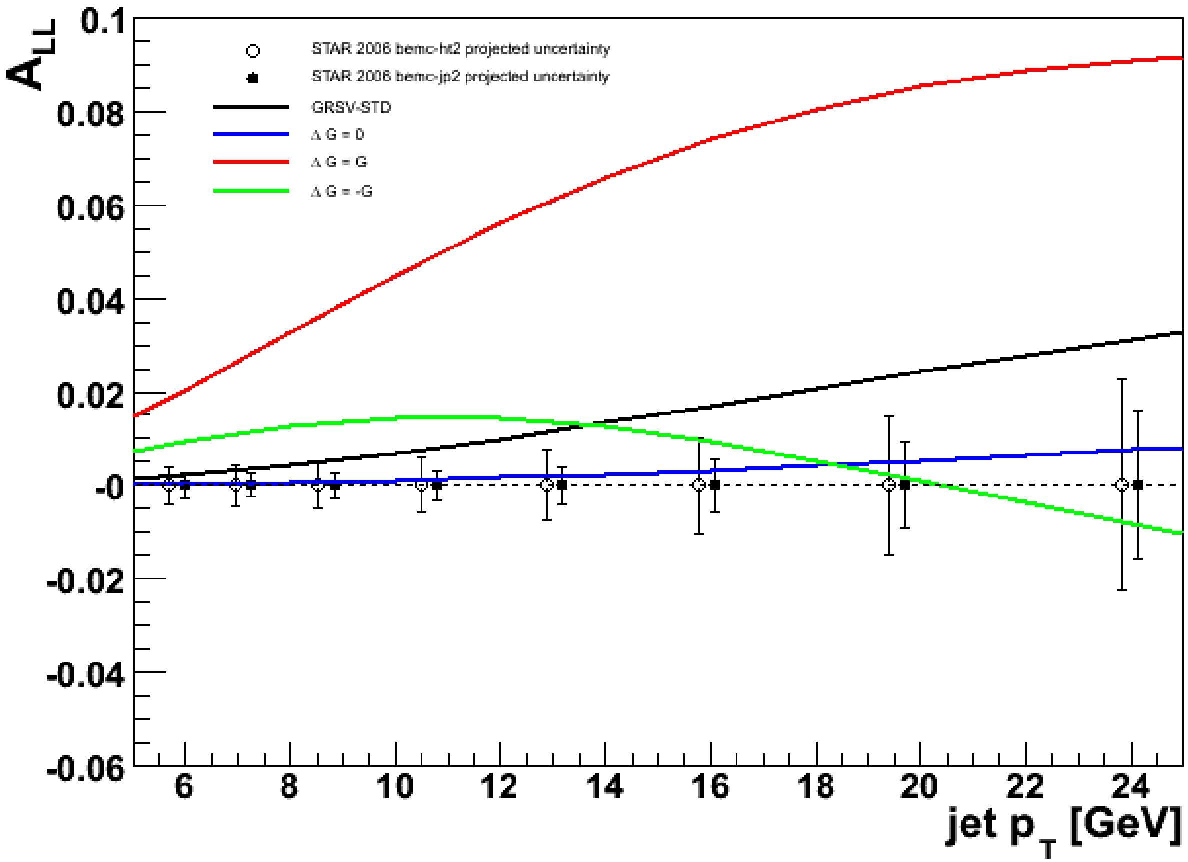
- What is the gluon contribution to the proton spin?
- What is the role of orbital motion in the structure of the proton?
- What is the role of transversity in the proton?

Measurements at RHIC in Run VI which address these questions can result in a sea change in our understanding of the spin structure of the proton

All the pieces in STAR and RHIC necessary to accomplish this are in place now; international competition (COMPASS) makes this timely

No extraordinary assumptions about machine capability beyond what C-AD has projected or already achieved are necessary

What is the gluon contribution to the proton spin: A_{LL}(preliminary) results in inclusive jet production in p+p collisions at sqrt(s)=200GeV



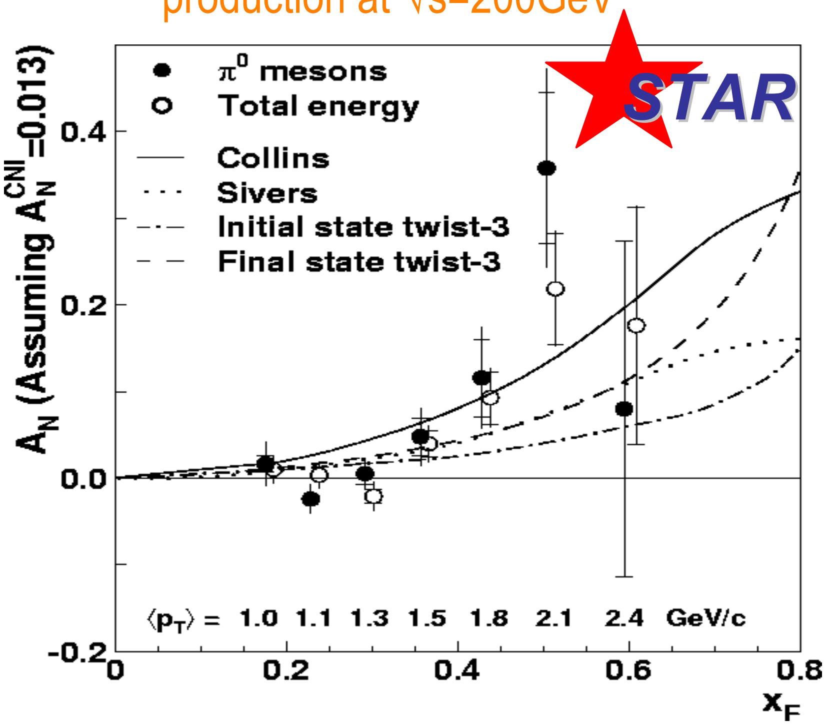
Run VI A_{LL} for incl. jets: FOM ~ 10 (2) high E_T (low E_T) x 3 (2) (detector improvements) ~ 30

Run VI A_{LL} for inclusive π°s in BEMC: FOM ~ 10 x 4 (detector improvements) ~ 40 overall

The role of orbital motion in the structure of the proton

STAR collaboration, hep-ex/0310058,
Phys. Rev. Lett. **92** (2004) 171801

First measurement of A_N for forward π^0 production at $\sqrt{s}$=200GeV

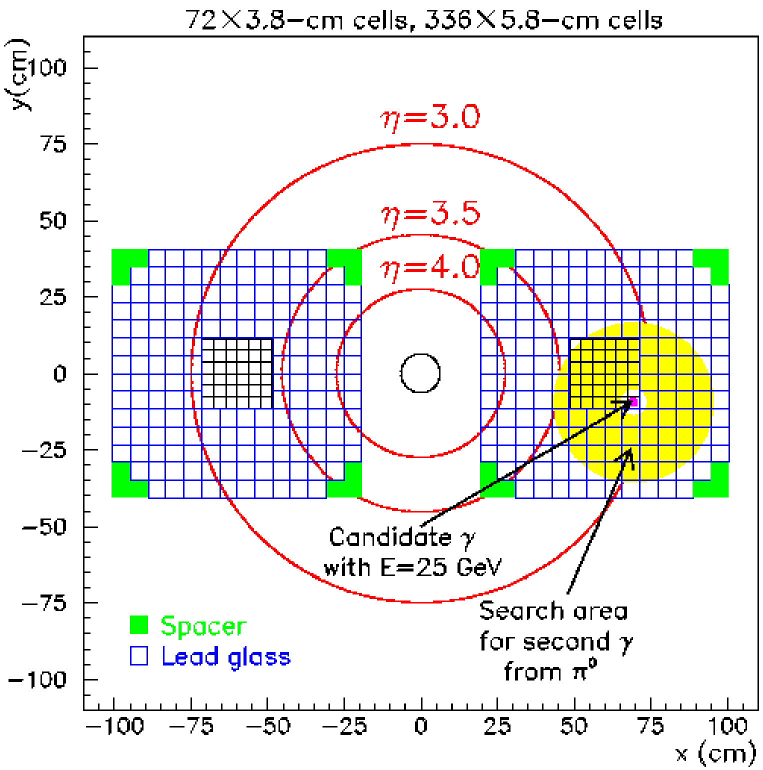


Similar to **FNAL E704** result at $\sqrt{s}$ = 20 GeV

In agreement with several models including different dynamics:

- Sivers: spin and $k_\perp$ correlation in initial state (related to orbital angular momentum?)
- Collins: Transversity distribution function & spin-dependent fragmentation function
- Qiu and Sterman (initial-state) / Koike (final-state) twist-3 pQCD calculations

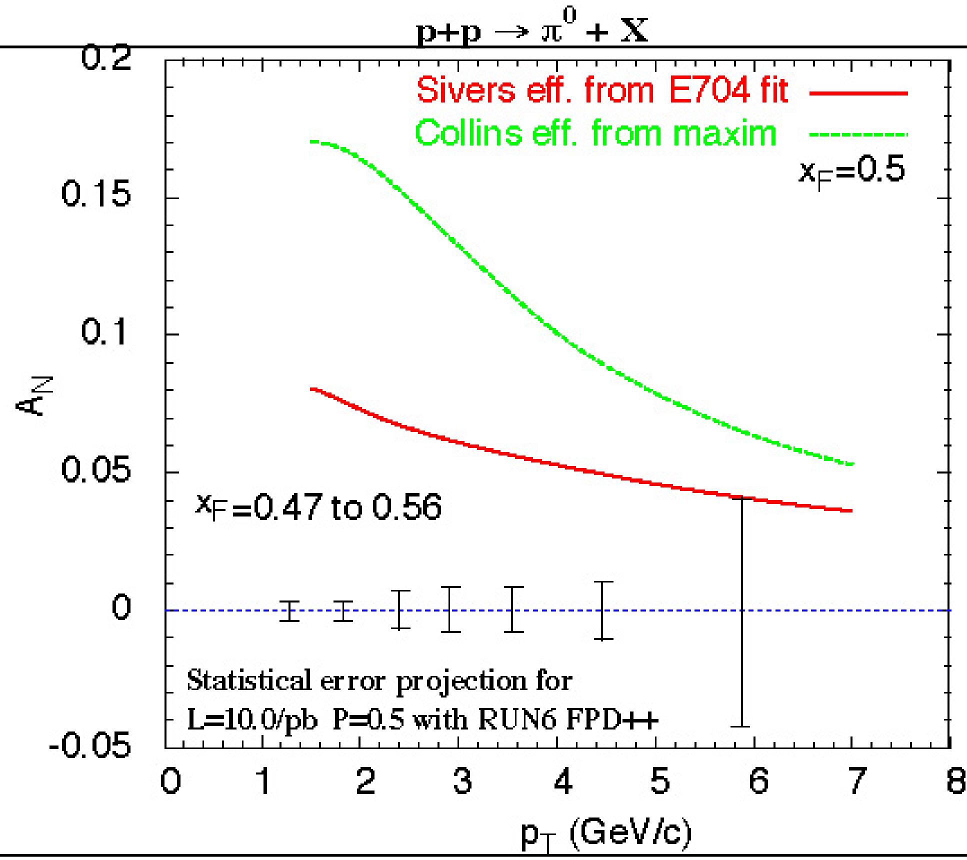
New Detection Capability in Run VI for Transverse Studies



Larger acceptance of FPD++ brings:

- Direct Photon capability
  - *- No fragmentation ⇒ if asym. observed it must come from Sivers*
- Multi particle correlations
  - *- If Jet asymmetry observed then there must be a Sivers contribution*
  - *- Ability to look inside Jet for signatures of Collins fragmentation*
- Increased phase space in X_F and p_t
  - *- Study p_t dependence to confirm whether or not this is a pQCD process (i.e. A_N drops as $1/p_t$)*

A qualitative advance in understanding the role of orbital motion in the structure of the proton



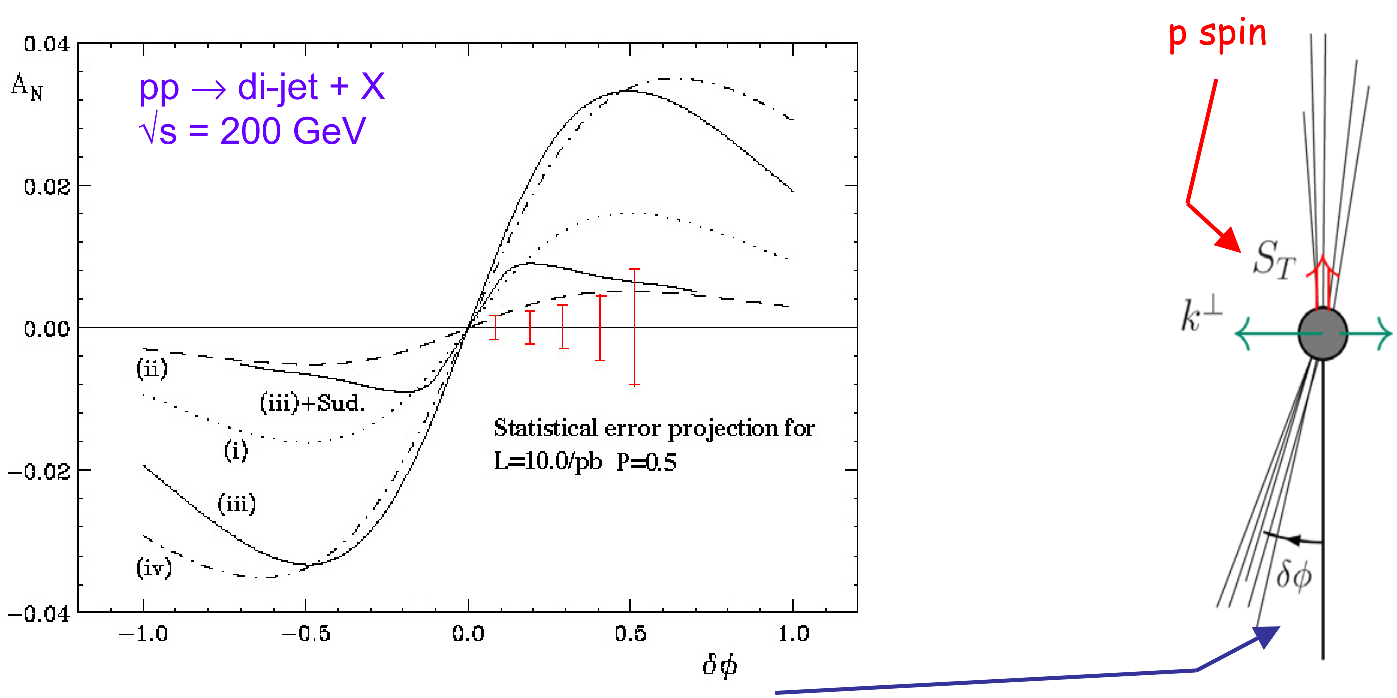
Statistical error projection for A_N for inclusive π^0 production as function of p_T at fixed x_F during Run 6, together with two theory predictions. These projections assume 10 pb^{-1} with 50% polarization and the acceptance of the FPD++.

The role of transverse spin dynamics in the proton

Back-to-back di-jet production: access to gluon Sivers function

- Search for spin-dependent transverse motion preferences inside proton (related to parton L_{orbit}) via predicted spin-dependent deviation (not power-suppressed) from back-to-back alignment of di-jet axes ⇒ study unique to RHIC spin: Access Sivers function

D. Boer & W. Vogelsang predictions



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Quality Factors for Run VI Longitudinal Studies

Measurement	Increase from FOM	Increase from Detector Improvements	Increase from Trigger Improvements	Bottom Line
A_{LL} of jets	x 10 at high E_T (x 2 at low E_T) compared to Run 5	x 3 at high E_T (x 2 at low E_T) due to completion of the BEMC		First measurement to distinguish between favored models of gluon polarization
A_{LL} of π^0 in the EEMC	x 10 compared to Run 5	x 1.3 from shielding in tunnel; x 2 from fast detector data	Significant enrichment at low pT from L2 trigger	Meaningful measurements in multiple channels
A_{LL} of π^0 in the BEMC	x 10 compared to Run 5	x 2 from completion of BEMC; x 2 from fast detector data	Significant enrichment at low pT from L2 trigger	Meaningful measurements in multiple channels
A_{LL} of di-jets	x 10 at high E_T (x 2 at low E_T) compared to Run 5	x 9 at high E_T (x 3 at low E_T) due to completion of the BEMC	Enrichment at low E_T from L2 trigger	First measurement that is sensitive to x dependence of $\Delta G/G$
A_{LL} of direct photons at mid-rapidity	x 10 compared to Run 5	x 1.5 from completion of BEMC	Increased efficiency near threshold from L2 trigger	250K direct photons for 20 pb^{-1} Sensitive to the sign of ΔG
A_{LL} of direct photons at forward rapidity		FPD++ will allow isolation cuts for the first time		200K direct photons for 20 pb^{-1} Sensitive to gluon polarization at low x
γ+jet coincidences				Enough events to optimize trigger and analysis algorithms before Run 7

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Quality Factors for Run VI Transverse Studies

Measurement	Increase from FOM	Increase from Detector Improvements	Increase from Trigger Improvements	Bottom Line
A_N of π^0 at forward rapidity	x 20 compared to previous measurements	FPD++ acceptance ~9 times that of the FPD		Are we seeing quark orbital motion and/or transversity?
A_N of direct photons at forward rapidity		FPD++ will allow isolation cuts for the first time		100K direct photons for 10 pb^{-1} Direct measure of the quark Sivers function
A_N for jets at forward rapidity and asymmetry of forward jets about thrust axis		FPD++ will encompass the jet cone for the first time		Direct sensitivities to the Sivers (jet A_N) vs. Collins (jet anisotropy) effects
A_N for back-to-back di-jet opening angle			x 4 when compared to previous sensitivity estimates due to di-jet selection by L2 trigger	Measure gluon Sivers function

The Physics Driving Run VII

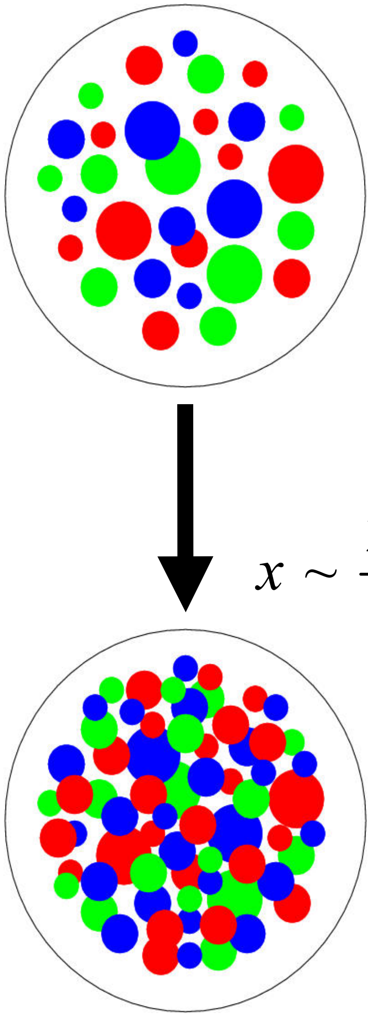
- Is the Color Glass Condensate present in nuclei at small x_{BJ}? (if so, where does it set in?)
- What is the x dependence of the gluon polarization in the proton?

Measurements at RHIC in Run VII which address these questions can result in a sea change in our understanding of the initial state of RHIC collisions

The STAR Forward Meson Spectrometer (FMS) will be in place by Run VII; international competition and interest (LHC startup) makes this timely (Forward hadron production at RHIC samples similar *x* values as mid-rapidity production at the LHC).

No extraordinary assumptions about machine capability beyond what C-AD has projected or already achieved are necessary

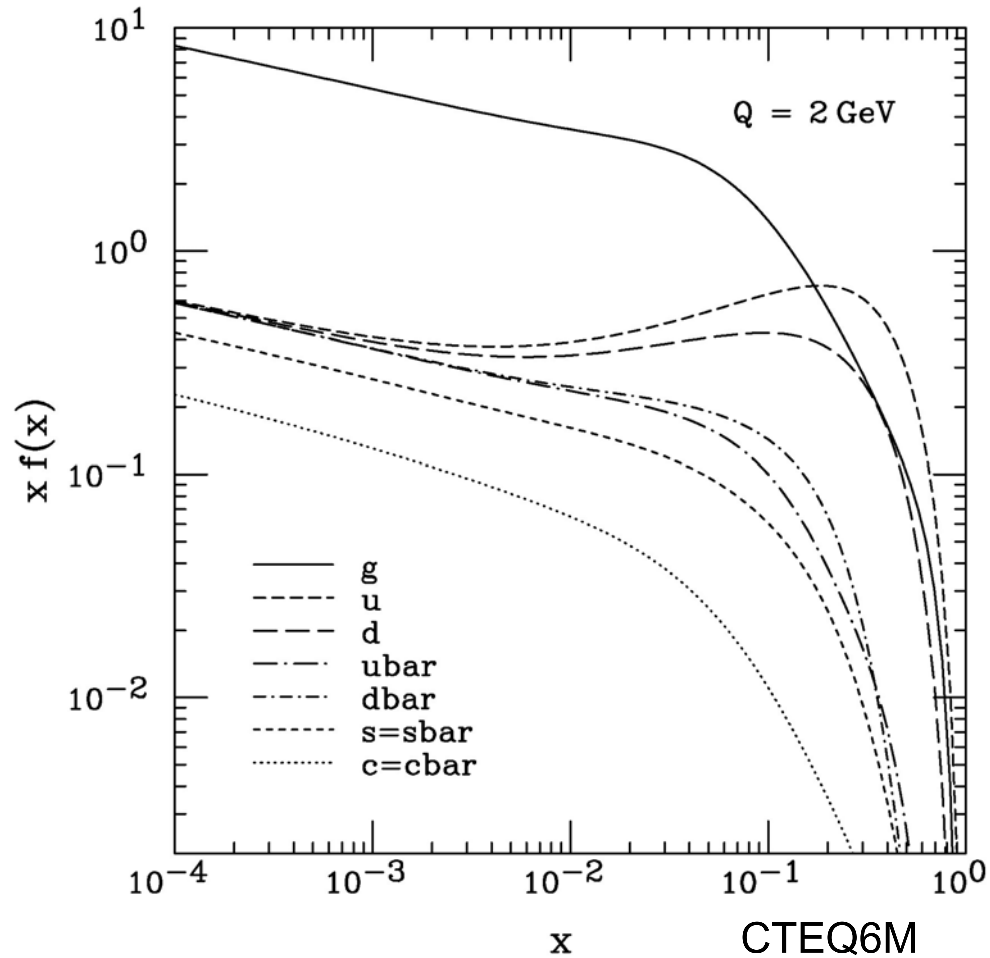
Mid-rapidity vs. forward rapidity



Mid Rapidity

$$x \sim \frac{2\,p_T}{\sqrt{s}}\,e^{-y}$$

Forward Rapidity



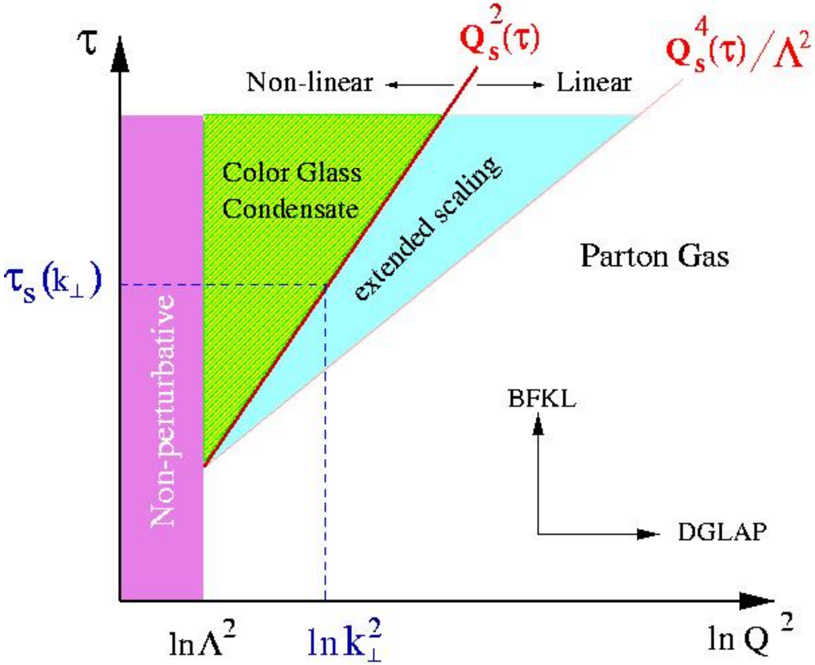
CTEQ6M

Gluon density can't grow forever.

Saturation may set in at forward rapidity when gluons start to overlap.

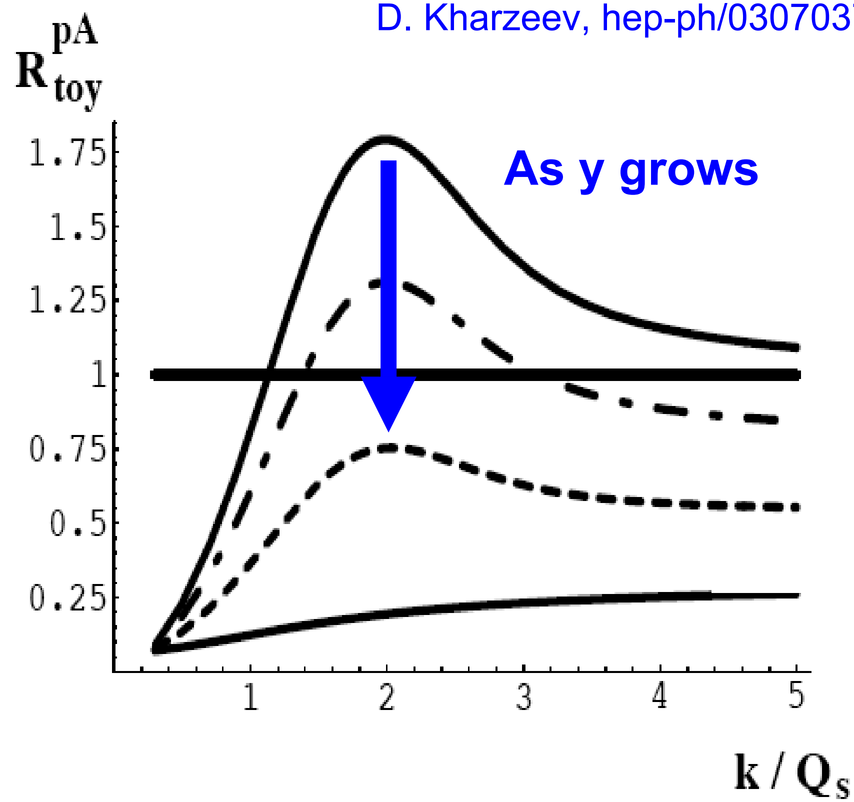
Expectations for a Color Glass Condensate

τ related to rapidity of produced hadrons.



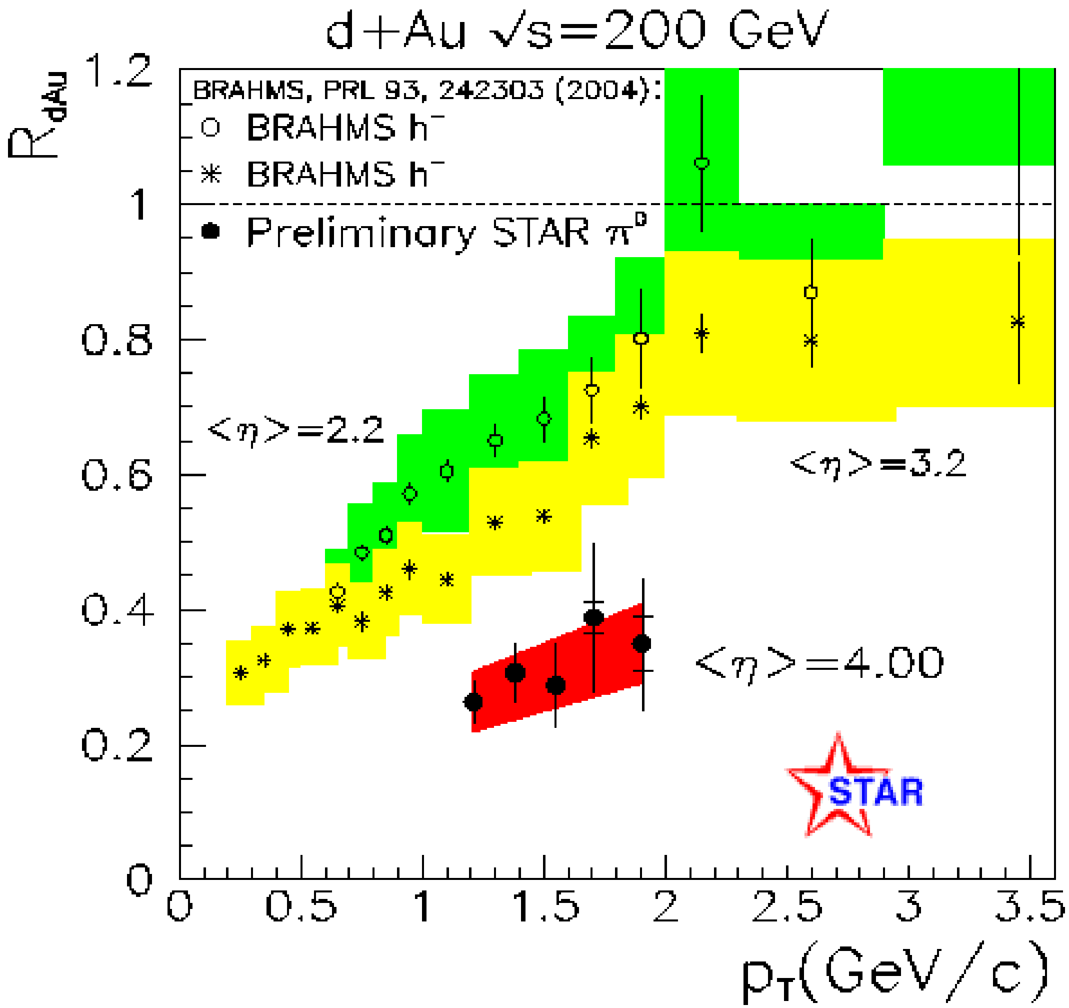
Iancu and Venugopalan, hep-ph/0303204

D. Kharzeev, hep-ph/0307037



Is there evidence for gluon saturation at RHIC energies?

η dependence of R_{dAu}



Observe **significant rapidity dependence**, similar to BRAHMS measurements and expectations from saturation framework.

Correlations, a more sensitive test; any difference between p+p and d+Au?

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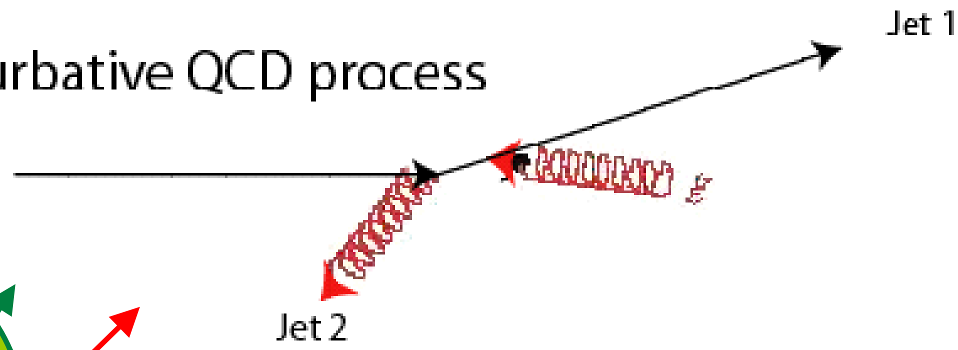
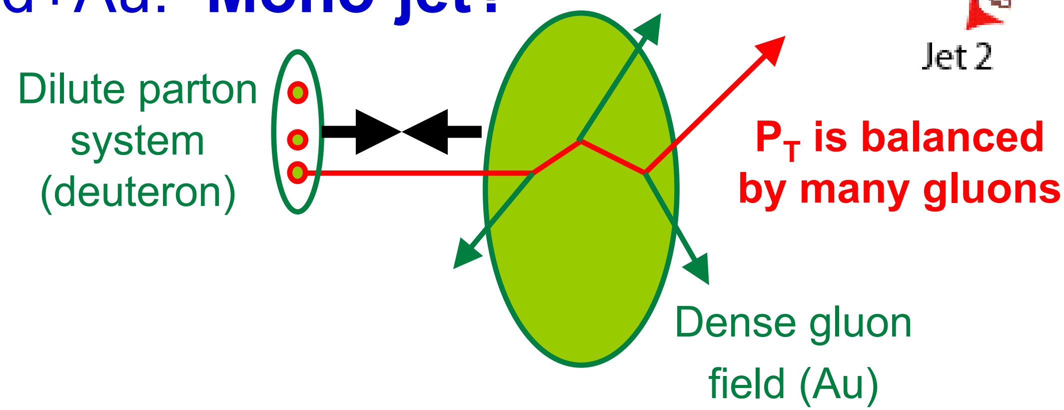
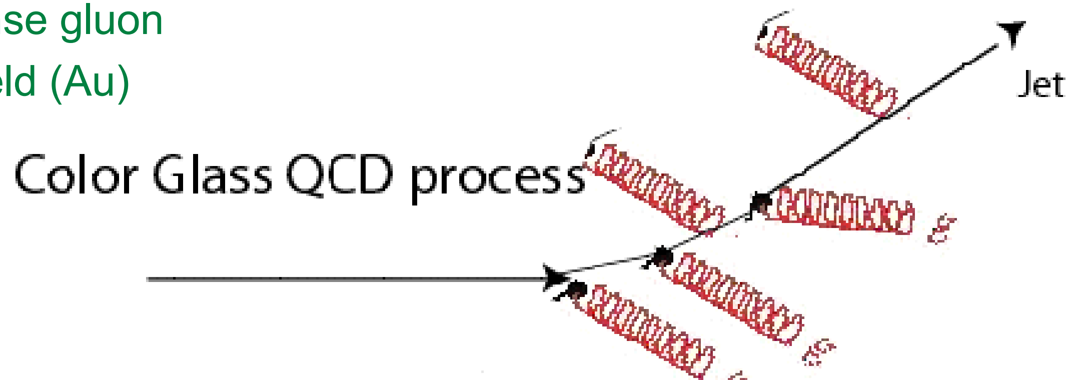
p+p: **Di-jet**



d+Au: **Mono-jet?**

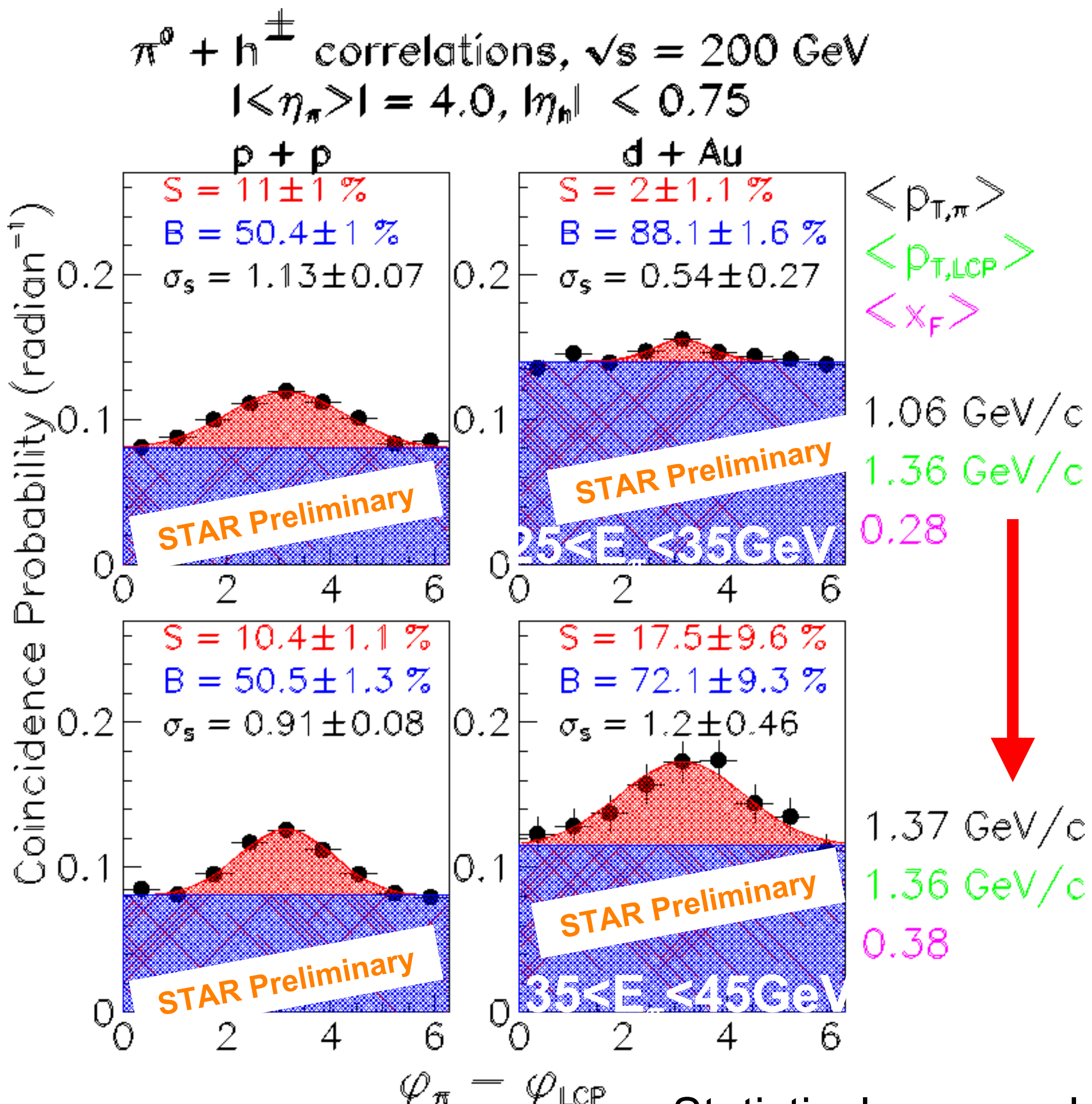


Kharzeev, Levin, McLerran gives physics picture (NPA748, 627)



Color glass condensate predicts that the back-to-back correlation from p+p should be suppressed

An initial glimpse: correlations in d+Au

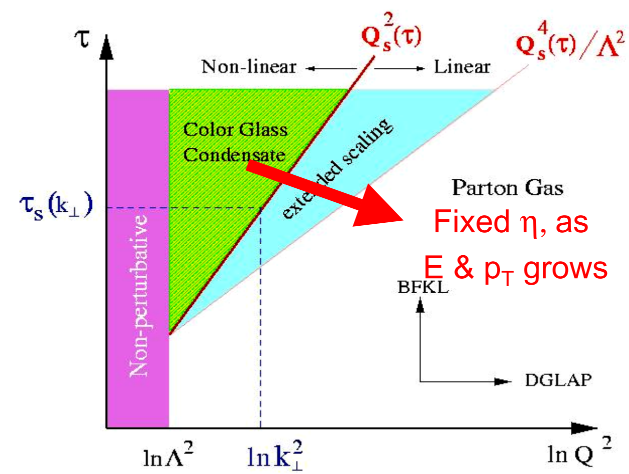


Statistical errors only

- suppressed at small $\langle x_F\rangle$ and $\langle p_{T,\pi}\rangle$

$S_{pp}-S_{dAu} = (9.0 \pm 1.5)$ %

consistent with CGC picture



- are consistent in d+Au and p+p at larger $\langle x_F\rangle$ and $\langle p_{T,\pi}\rangle$

as expected by HIJING

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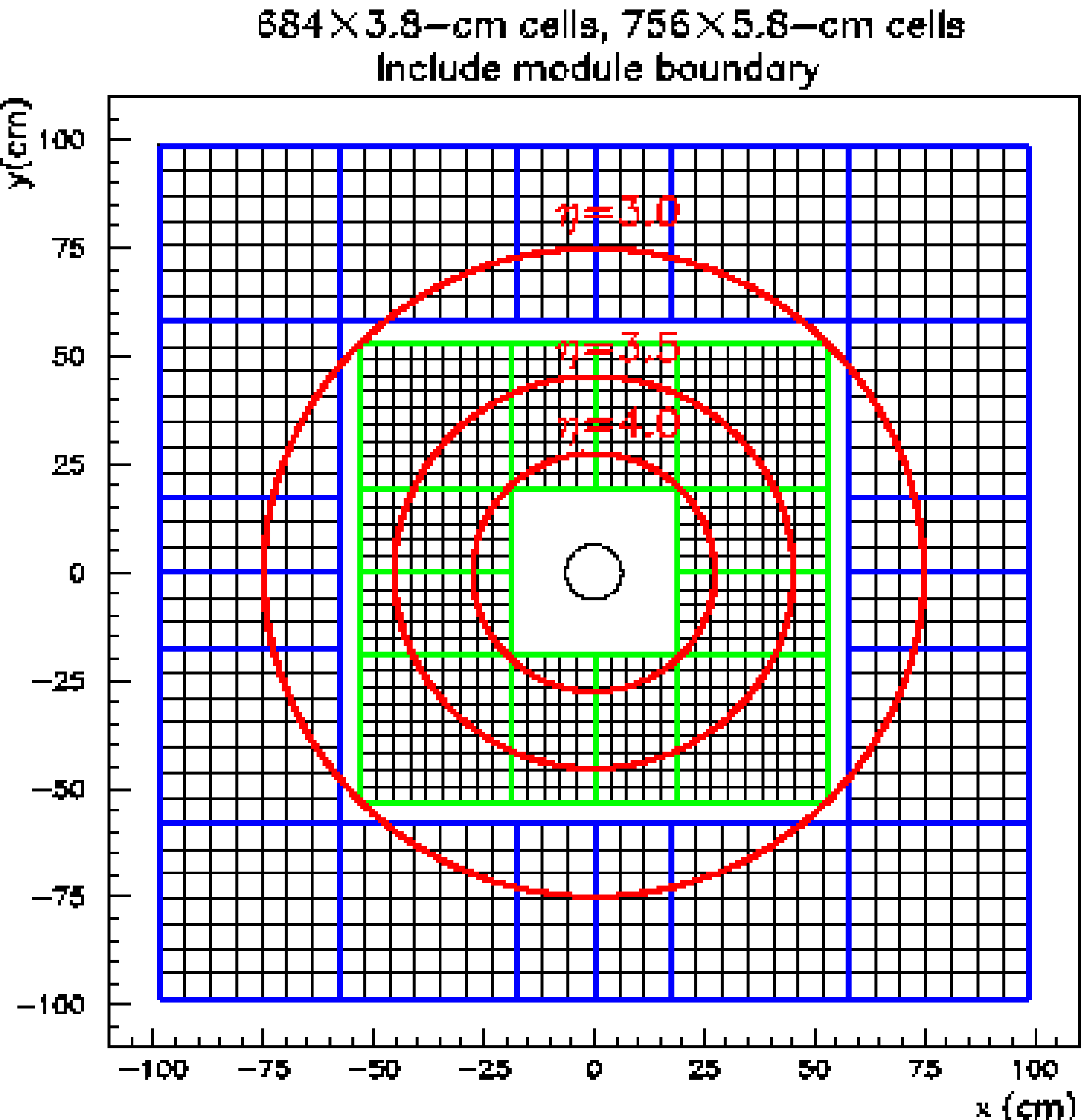
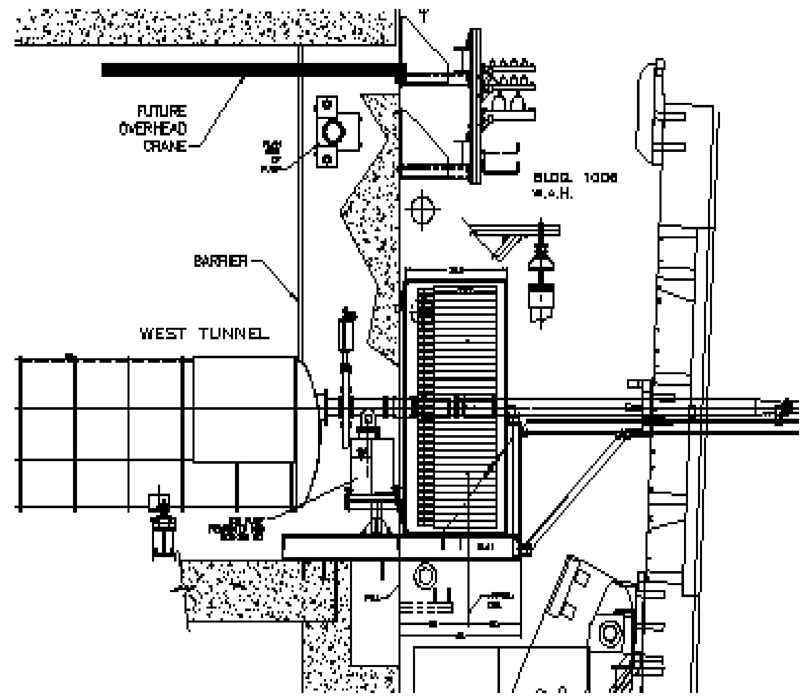
STAR Forward Meson Spectrometer upgrade





- FMS increases areal coverage of forward EMC from 0.2 m^2 to 4 m^2
- Addition of FMS to STAR provides nearly continuous EMC from $-1<\eta<+4$

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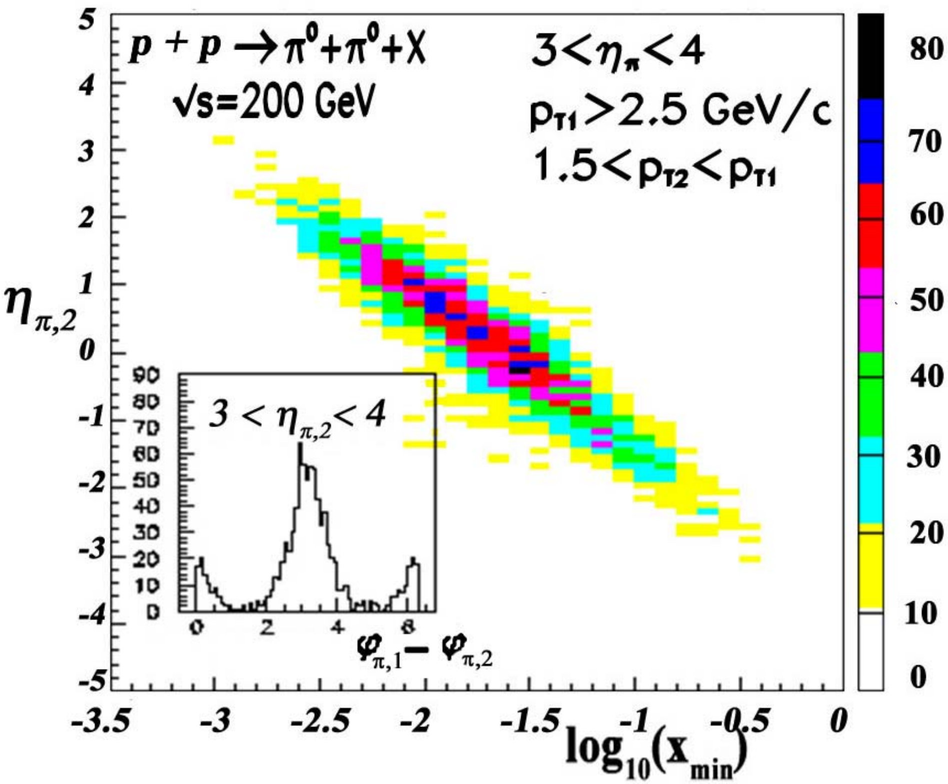
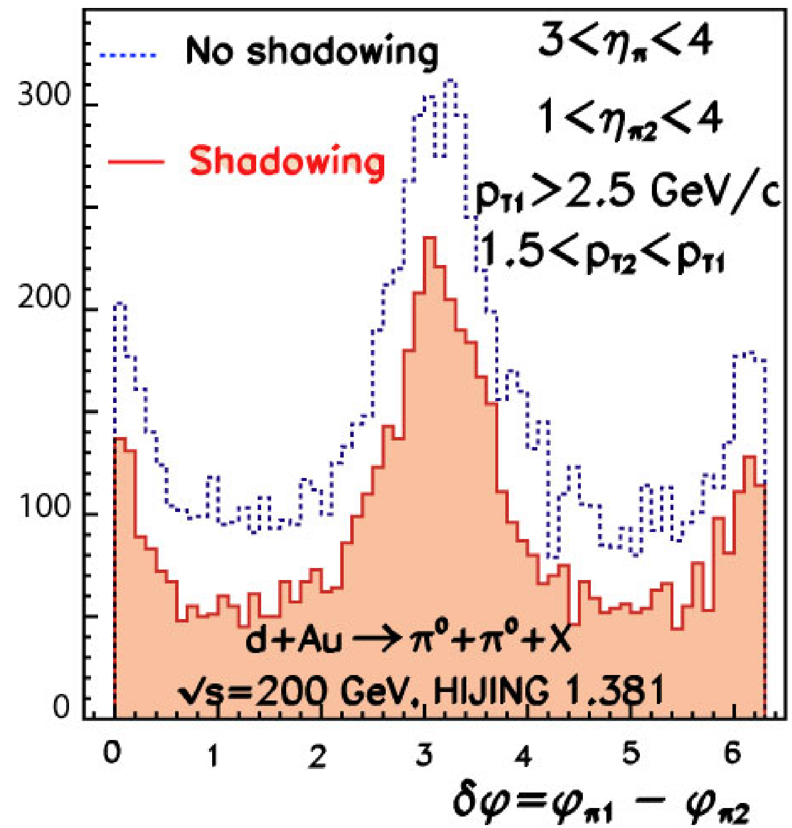
p+p and d+Au → $\pi^0+\pi^0+X$ correlations with forward π^0

p+p in PYTHIA



d+Au in HIJING hep-ex/0502040



Conventional shadowing will **change yield, but not coincidence structure**.

Coherent effects such as CGC evolution will **change the structure**.

Sensitive to $\boldsymbol{x_g \sim 10^{-3}}$ **in pQCD** scenario; **few x $\mathbf{10^{-4}}$ in CGC** scenario.

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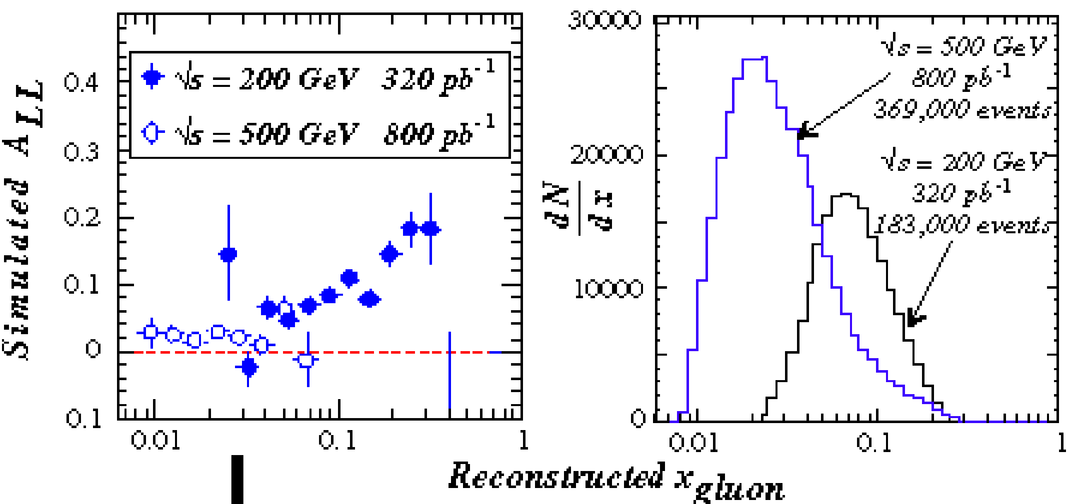
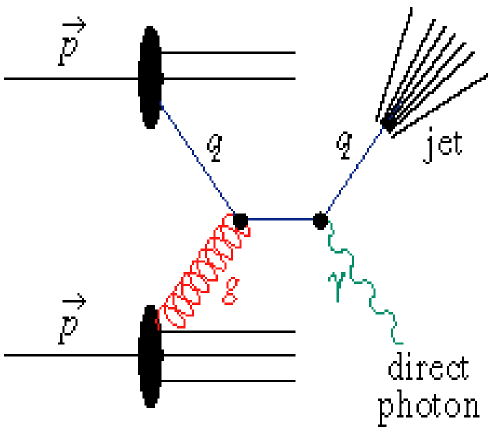
STAR Sensitivity to ΔG

STAR's wide acceptance = Coincident detection of γ and away-side jet direction

→ Determination of initial-state partonic kinematics.

$\vec{p}\,\vec{p} \rightarrow \gamma + jet + X$





200 and 500GeV

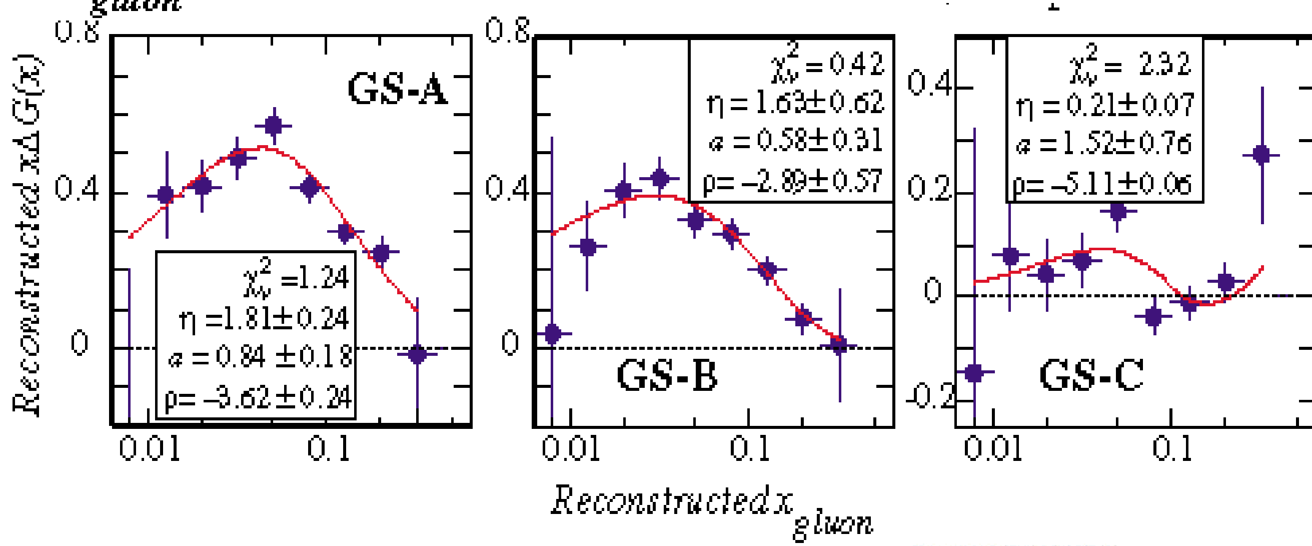
Going to forward rapidity

Better sensitivity

Wider x range

to determine integral

$$\Delta G\,(Q^2) = \int_0^1 \Delta G(x, Q^2)\, dx$$



The Physics Driving Return to AuAu (Run VIII & IX)

- What are the relative yields of charm and bottom?
- What is "really going on" at intermediate p_T?
- What will PID'd correlations reveal?
- What will higher precision for short wavelength probes tell us?

The STAR DAQ upgrade, and half of the TOF Barrel planned to be available for in Run VIII. Full TOF barrel and prototype heavy flavor tracker planned to be available in Run IX. These upgrades will provide a qualitative advance in STAR detector capability for heavy ion studies.

New Electron Identification Capability in STAR: MRPC ToF

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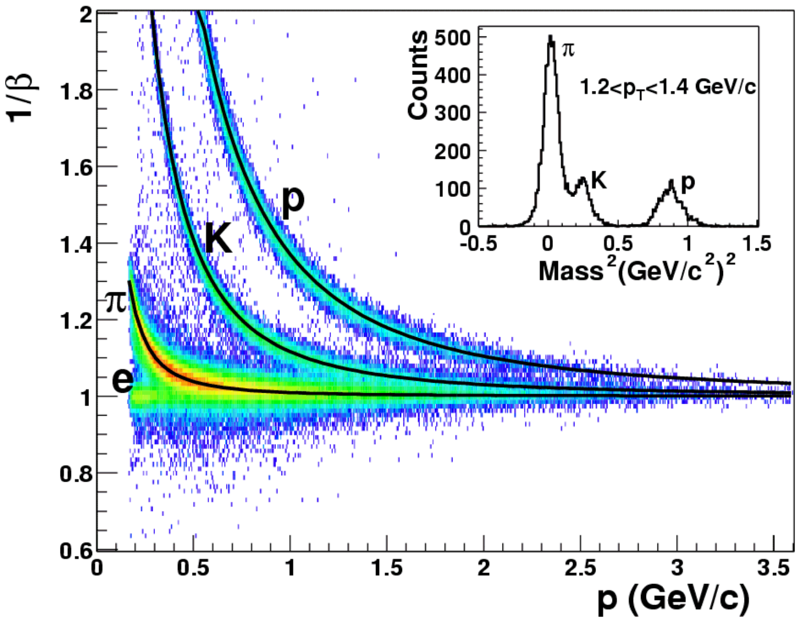
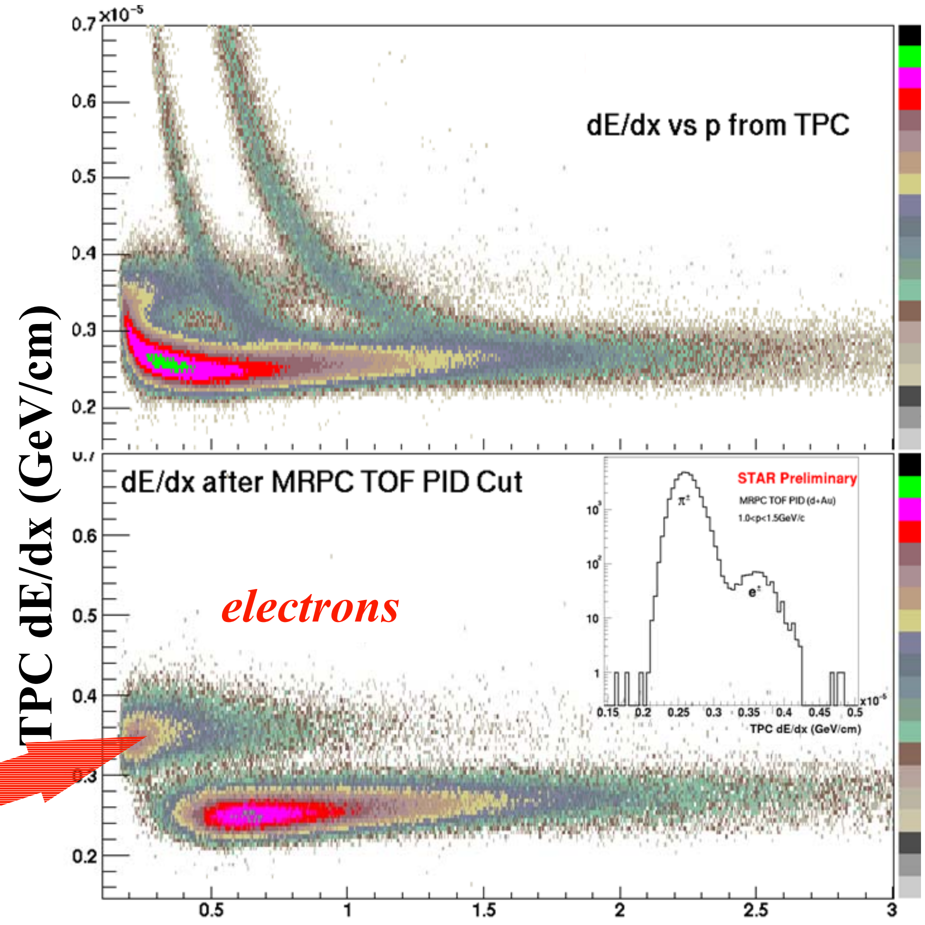


Phys. Rev. Lett. 94 (2005) 062301
Phys. Lett. B 616 (2005) 8.

Electron identification:

TOFr $|1/\beta-1| < 0.03$
TPC dE/dx electrons!!!



Particle momentum p (GeV/c)

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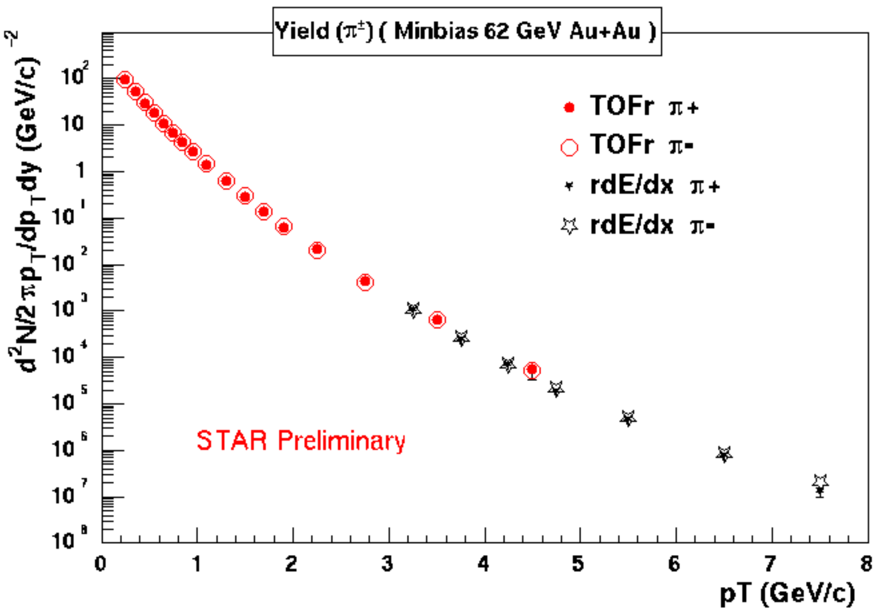
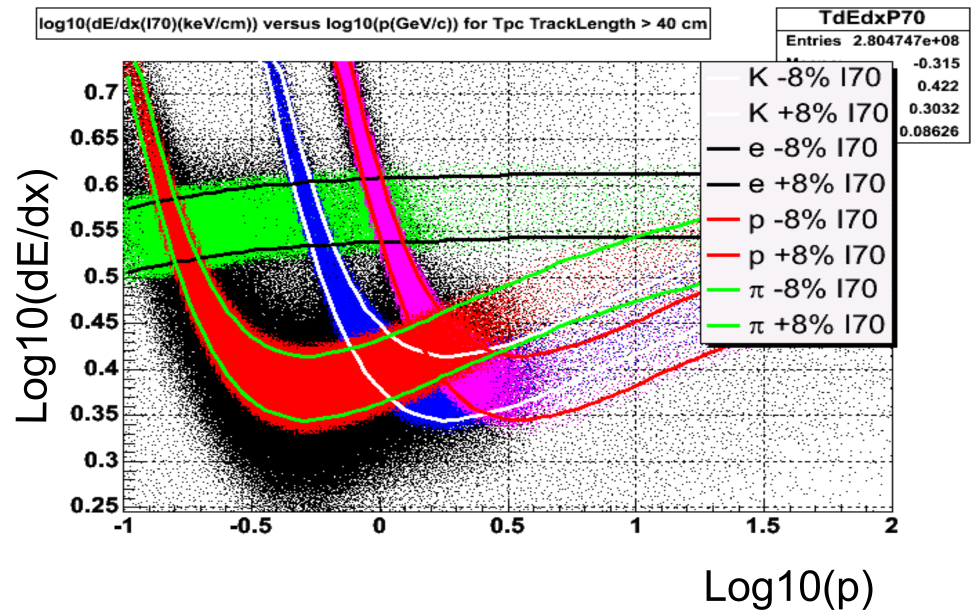
Extending STAR Particle ID





Methods paper submitted to NIM A, nucl-ex/0505026.

Results to 12 GeV in Au+Au

- TPC:
  - Pion: 0-~0.6GeV/c
  - Kaon: 0.2-~0.6GeV/c
  - Proton: 0.2-~1 GeV/c
- TOF:
  - Pion: 0.2-~1.6GeV/c
  - Kaon: 0.2-~1.6GeV/c
  - Proton: 0.2-~3 GeV/c
- TPC+TOF:
  - Pion: 0.-~10 GeV/c
  - Kaon: 0.2-~3GeV/c
  - Proton: 0.2-~? GeV/c

DAQ – TPC Readout Upgrade

- Acquisition of very large data samples for precision and rare process studies: e.g., symmetry restoration/breaking, $\gamma\gamma$ HBT, …
- Space for end cap tracker for W physics

Make use of CERN developments for ALICE/LHC:

PASA (preamp/shaper amp)

ALTRO (digitizer, digital filter, zero suppression, buffer)

SIU (RDO, optical data sender)

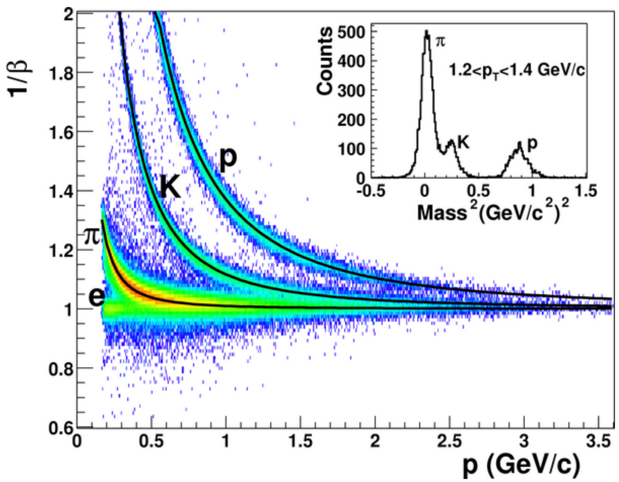
D-RORC (PCI receiver board)

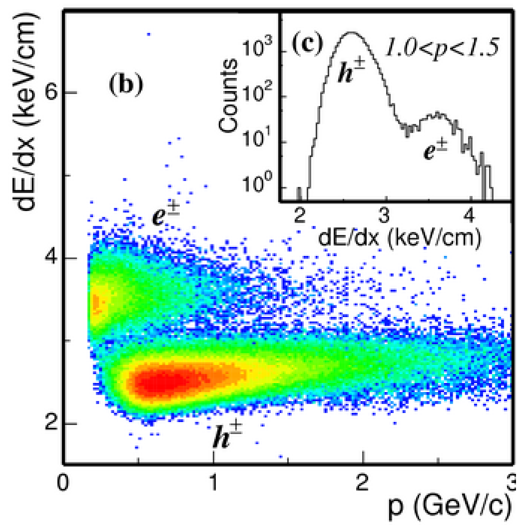
Goal: Increase data rate for most detectors to ≥ 1kHz

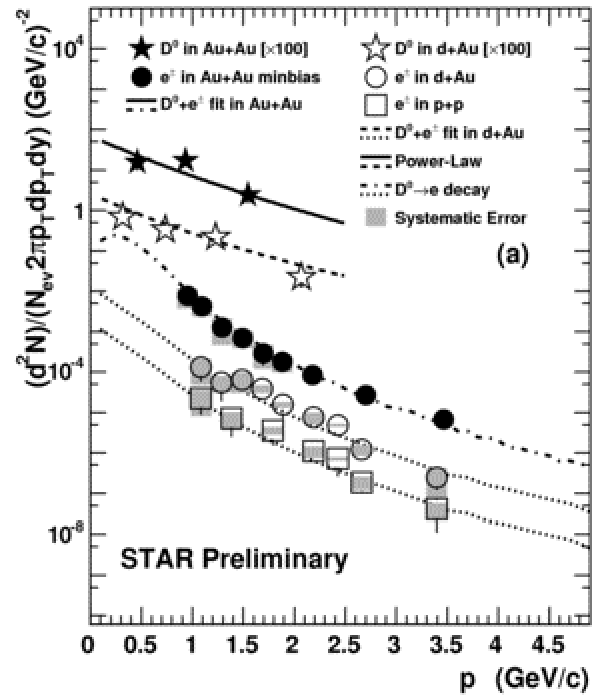
Dead time reduced to zero for triggered data sets

Triggered and untriggered data acquired without DAQ bandwidth constraint

Measurements with upgraded capability in RUN VIII





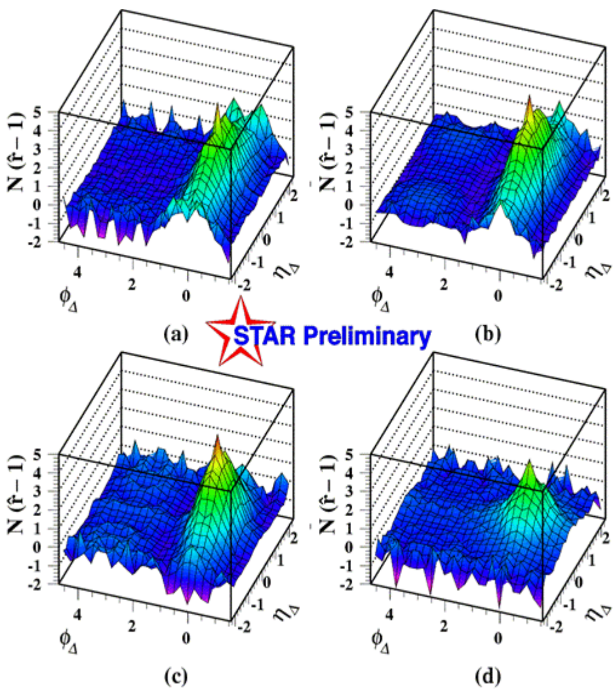


Upgrades in place: DAQ1000, Half-barrel TOF

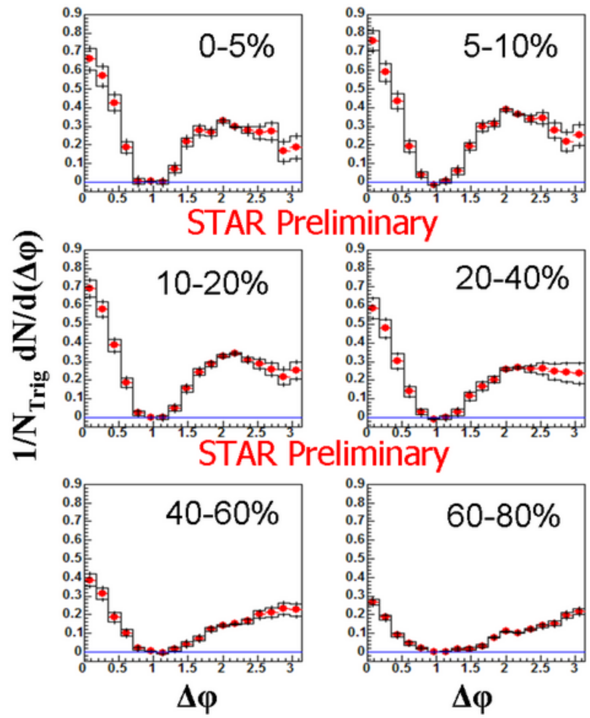
- DAQ1000: untriggered AND triggered at same time
  - 15 weeks: ~900 ub^{-1} sampled AND few x 100M minbias events
- Significant capabilities brought by large-acceptance TOF
  - Identified particle correlations in the intermediate p_T regime
  - Dileptons: Significant (~10 σ) signal in $\phi \to e^+e^-$
  - Initial survey (statistical) measurement of $D^0 \to K + \pi$ to 4-5 GeV/c

Upgraded Detector Capability in Run VIII

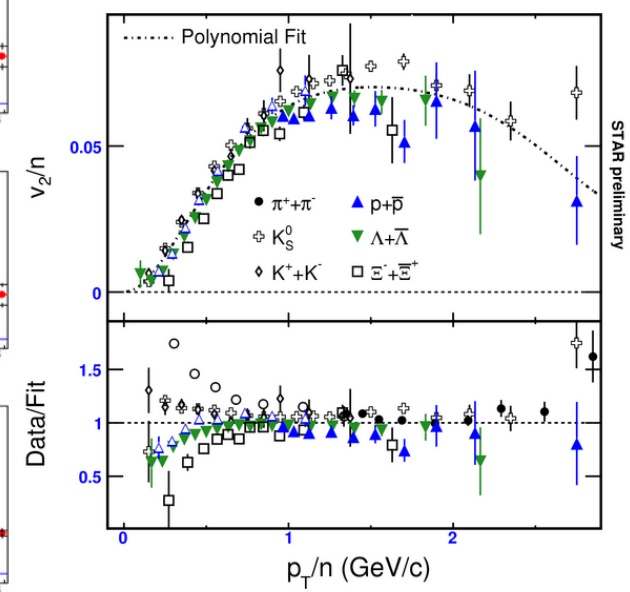
Two particle correlations at low p_T



Two (3) particle correlations at intermediate p_T



Constituent-quark-scaled v_2 at intermediate p_T



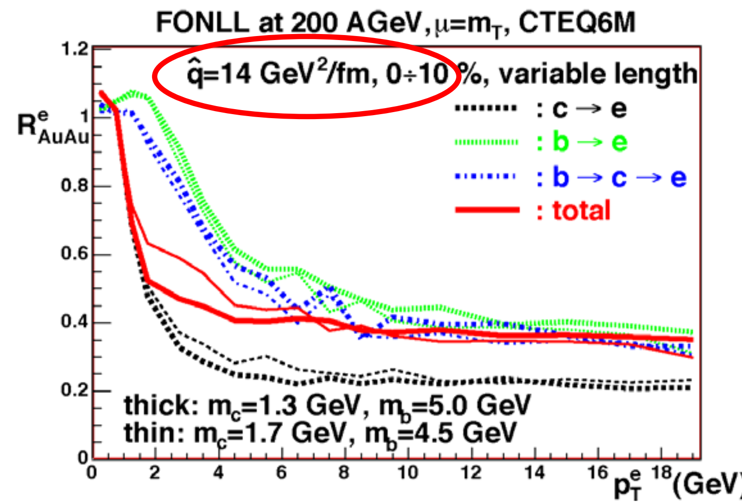
Further examples of the types of measurements which will make a major advance with the combination of upgraded PID capability and increased DAQ throughput in Run VIII

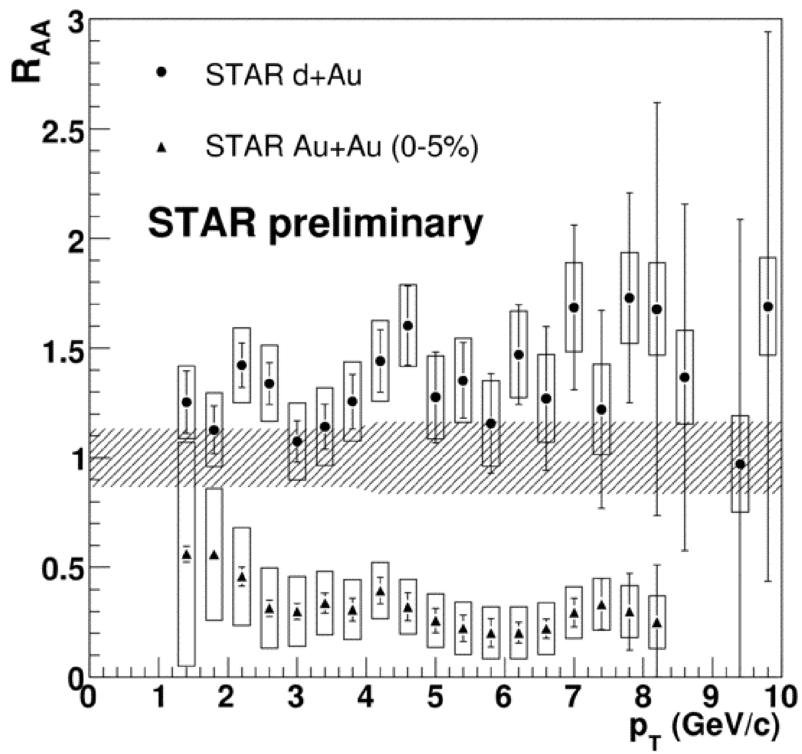
A central question: the relative yield of c and b

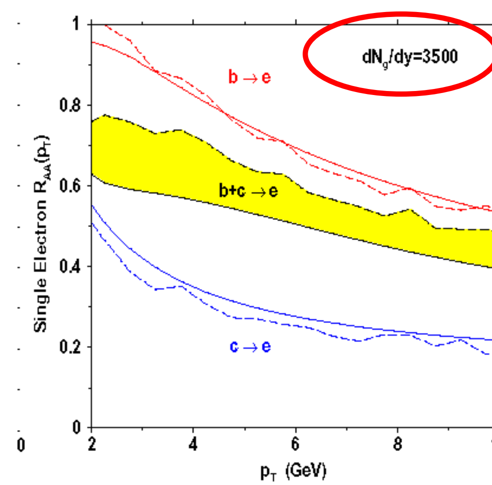
The observed suppression of NPEs is not presently understood!

Attempts to reproduce it have completely changed the paradigm for the energy loss of light and heavy quarks

Armesto et al, private comm.



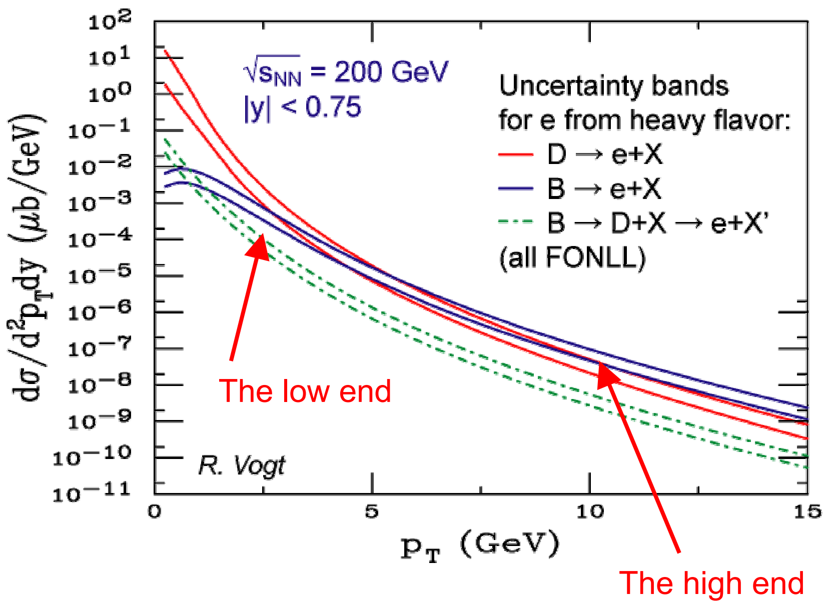




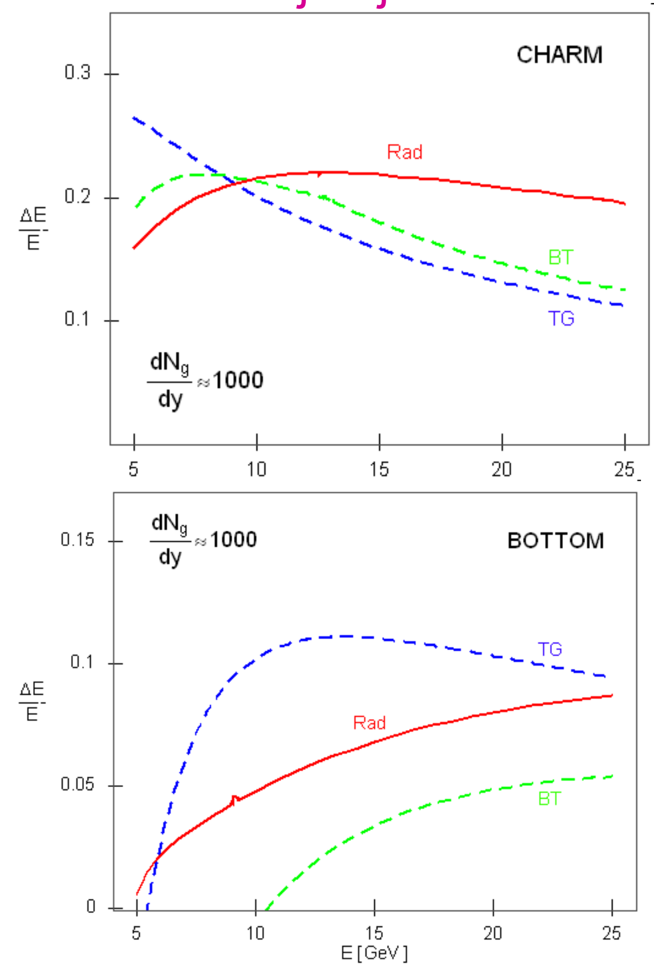
Resolving this is a crucial next step

Djordjevic et al, nucl-th/0507019

Further measurements of NPEs alone won't solve the problem



M. Djordjevic et al



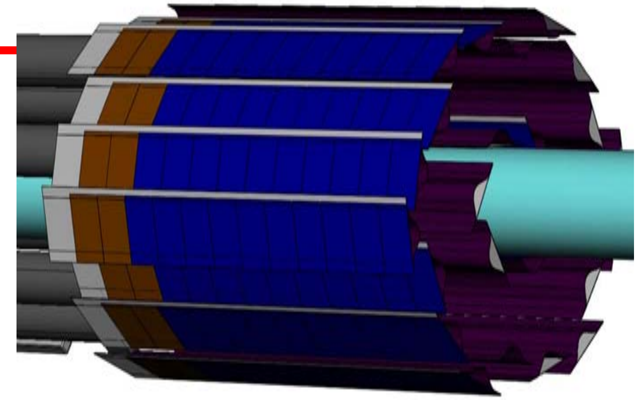
The relative yield of charm and bottom is highly uncertain

The collisional and radiative energy loss for the two is predicted to be different

The charm spectra must be measured directly to untangle the two contributions
(Bears on the interpretation of the suppression for light quarks as well)

An enabling technology for event-by-event charm measurement in STAR: the Heavy Flavor Tracker

STAR



- **Heavy flavor collectivity**
- **Charm quark kinetic equilibration**
- **Heavy flavor (c,b) energy loss**
- **Vector mesons → e^+e^-**

- Two layers of CMOS pixel detector around a new thin (0.5mm) small radius (14 mm) beam pipe
- 10^8 pixels, $(30\ \mu m)^2$
- 50 μm thick
- 10 μm point resolution

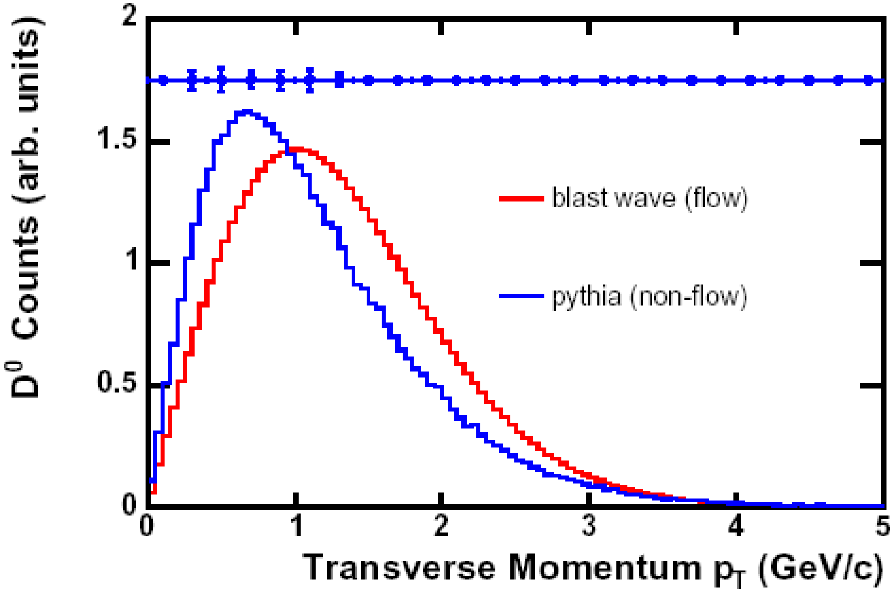
Significant progress on:

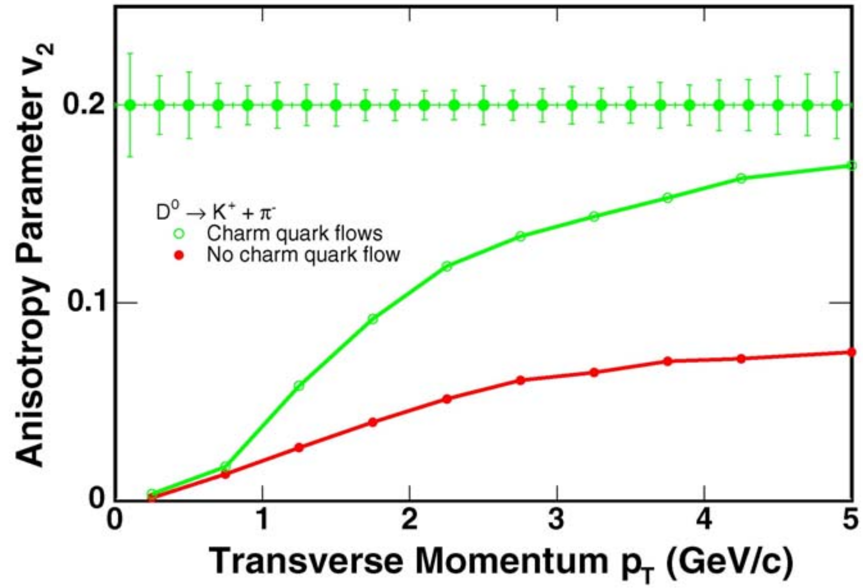
- Simulations
- Mechanical design
  - integration and installation
  - support
  - alignment
  - calibration
- Sensor prototype
- Readout design

D Measurements with HFT: Run IX

Simulated statistical uncertainties from 50M central Au+Au events w/ HFT

$D^0 \rightarrow K + \pi$

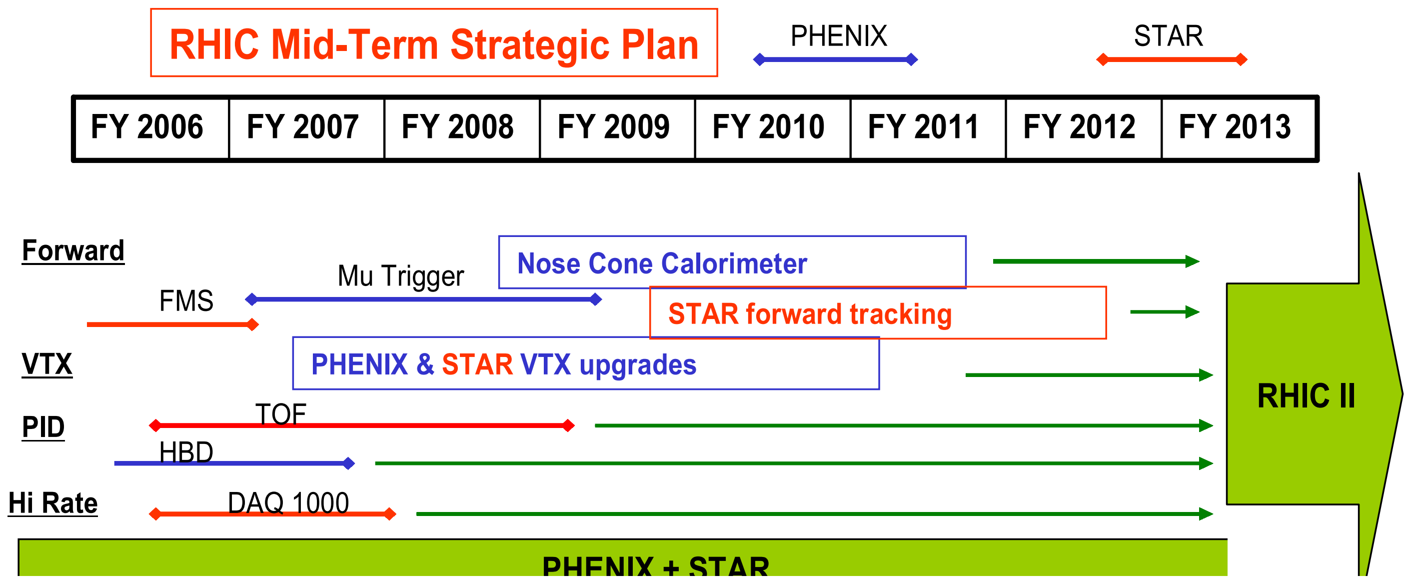




D^0 v_2-predictions: D. Molnar, J. Phys. G31, S421.

- $D^0 \rightarrow K + \pi$ direct reconstruction becomes extremely clean
- Event-by-event identification of charm
- Identified suppression, flow, correlations with no ambiguity from semi-leptonic decay and bottom contributions

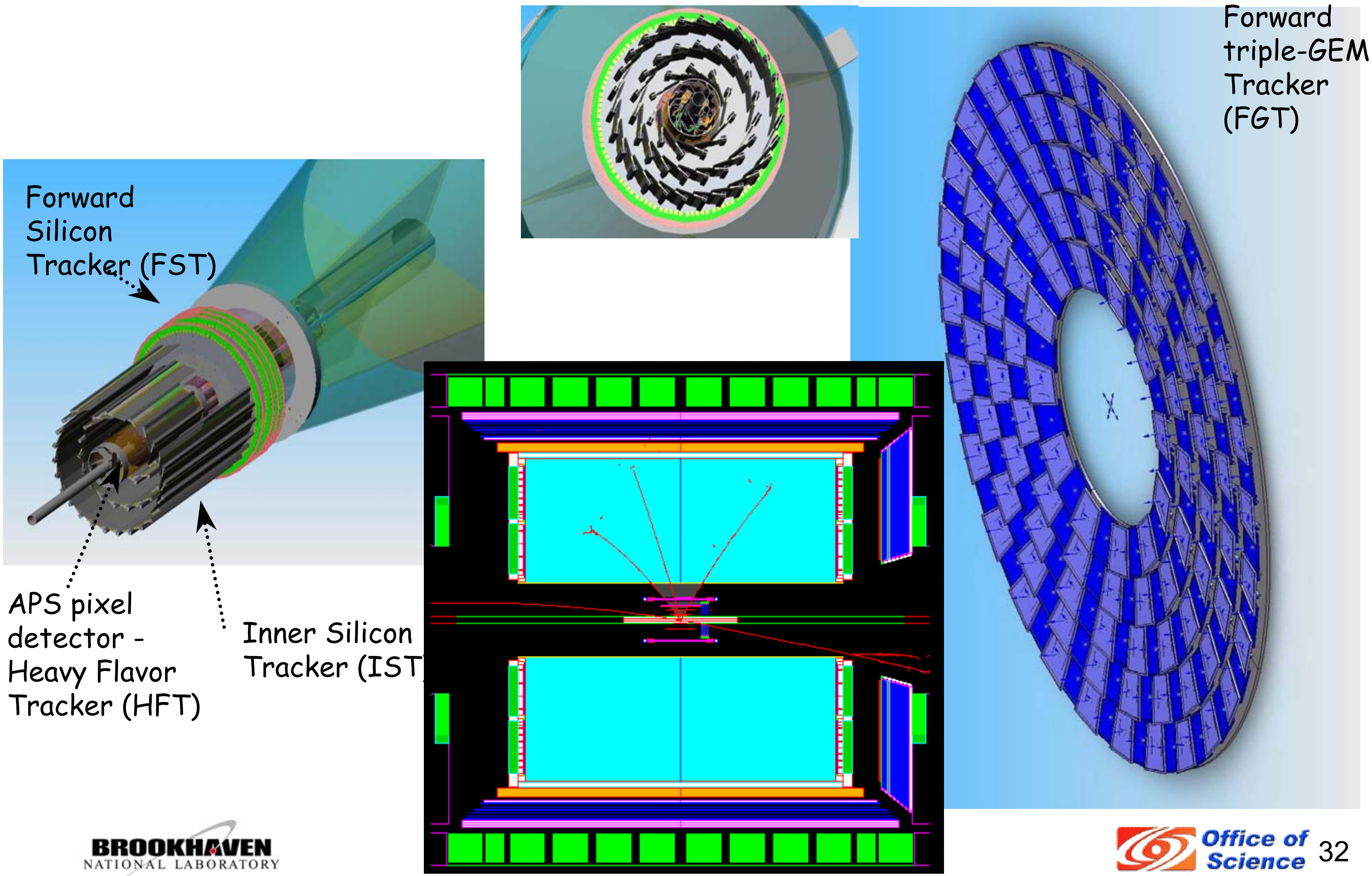
Taking upgrade strategy into account is central to optimizing the plan



STAR will make <u>much</u>, <u>much</u> more effective utilization of AuAu beams in the 2008-2009 timeframe once several key upgrades have come on-line

Future STAR physics prospects

STAR tracking upgrade: conceptual layout



Conclusions

- The STAR Collaboration strongly believes the proposed plan will provide for qualitative advances in our understanding of the nucleon, the nucleus, and dense QCD matter in a way that make maximal use of RHIC beams and STAR/RHIC capability as it evolves.

- STAR maintains this is an optimal plan for maximizing the scientific impact and discovery potential in the next 3 years

The STAR Collaboration: 51 Institutions, 14 countries, ~ 550 People

U.S. Labs:
Argonne, Berkeley, and Brookhaven National Labs

U.S. Universities:
UC Berkeley, UC Davis, UCLA, Caltech, Carnegie Mellon, Creighton, Indiana, Kent State, MSU, CCNY, Ohio State, Penn State, Purdue, Rice, Texas A&M, UT Austin, Washington, Wayne State, Valparaiso, Yale, MIT

Brazil:
Universidade de Sao Paolo

China:
IHEP - Beijing, IPP - Wuhan, USTC, Tsinghua, SINR, IMP Lanzhou

Croatia:
Zagreb University

Czech Republic:
Institute of Nuclear Physics

England:
University of Birmingham

France:
Institut de Recherches Subatomiques Strasbourg, SUBATECH – Nantes

Germany:
Max Planck Institute – Munich University of Frankfurt

India:
Bhubaneswar, Jammu, IIT-Mumbai, Panjab, Rajasthan, VECC

Netherlands:
NIKHEF

Poland:
Warsaw University of Technology

Russia:
MEPHI – Moscow, LPP/LHE JINR – Dubna, IHEP – Protvino

South Korea:
Pusan National University

Switzerland:
University of Bern

STAR is a vital, growing, international collaboration

Science productivity of the STAR Collaboration

Published:

	Papers	Spires	Citebase
PRL	30	2594	2331
PRC	16	348	282
PLB	4	126	112
NPA	1	63	60
Total	51	3131	2785

Submitted

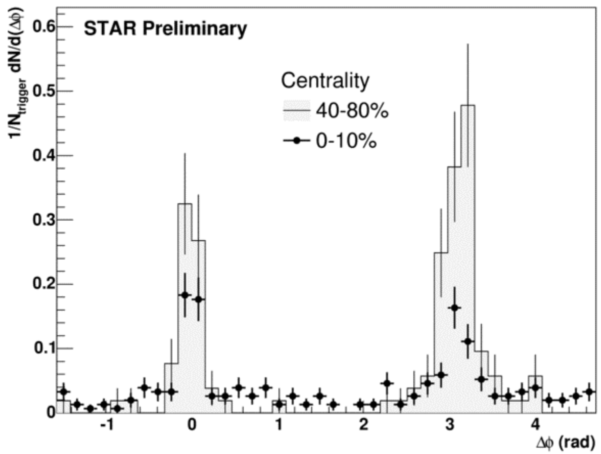
Papers	Spires	Citebase
5	37	38

Thus far, 74 advanced degrees awarded on STAR work:

56 Ph.D.'s
11 Master's
7 Diploma

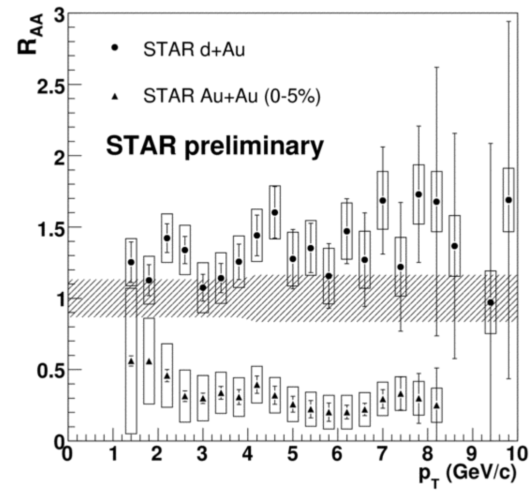
What could STAR get from run 6 Au+Au?

Achieved run 4 with 25 ub^{-1} sampled (additional 25 ub^{-1} still being analyzed)



γ-h, $E_T^{\gamma}>10$ GeV/c, $p_T^{assoc}>4$ GeV/c

No Upsilon signal,
Upper limit



Non-photonic electron R_{AA}

- Total sampled luminosity from run 4 on tape: ~50 ub^{-1}
- Run 6: ~400 ub^{-1} if devote 10 weeks completely to triggered data
  - Lose completely untriggered dataset (including D)
  - Increased reach in γ-h, non-photonic electrons
    - Some progress towards separating direct γ-h signal from π^0 γ-h
    - No separation of bottom from charm contribution in non-photonic electrons
  - Effective signal in Upsilon: few hundred particles