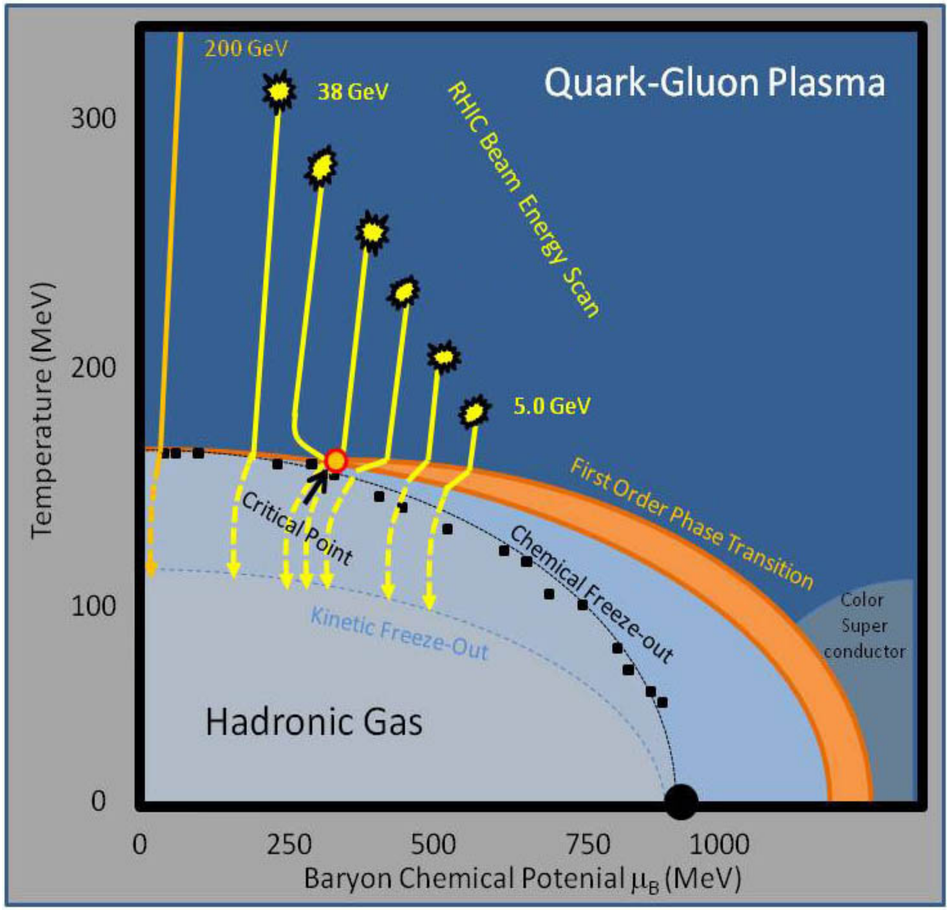
STAR Perspectives for RHIC Energy Scan

STAR

Theory ⇨ searches need to cover a broad region of phase diagram



MAIN TOPICS

- ★ What physics drives STAR's Beam Energy Scan (BES) Run Plan?
- ★ The above is a subset of a much large set of analyses that will be carried out
- ★ Results from short tests at low energies demonstrate STAR's readiness
- ★ STAR's BES program is highly complementary to CBM

Declan Keane, Kent State University, Ohio

"Laundry List" of BES Analyses - I

(in alphabetical order)

- Antiproton-to-proton ratio
- Baryon to meson ratios
- Charged-particle elliptic flow
- Charged-particle directed flow
- DCC searches
- Elliptic flow for identified charged particles & for photons
- Femtoscopy relative to 1^{st}-order reaction plane
- Fluctuations of particle ratios, esp. K/π & p/π
- Fluctuations of $< p_T >$, $< v_2 >$, photon multiplicity, &c
- Long-range forward-backward correlations
- Net-proton & net-charge kurtosis
- Nuclear modification factors
- p_T spectra of identified particles
- Production of light nuclei and antinuclei

"Laundry List" of BES Analyses - II

- Standard femtoscopy source parameters
- Strange to non-strange ratios for mesons and for baryons
- Strong parity violation
- Triggered correlations & "the ridge"
- Untriggered pair correlations in $\Delta\phi$ & $\Delta\eta$
- Yields of strange particles
- Yields of various species & statistical model fits

'In the field of observation, chance favors the prepared mind' — *Louis Pasteur*

Sample Size Needed for Each Analysis at Each Energy

$\sqrt{s_{NN}}$ (GeV)	Analysis #1	Analysis #2	Analysis #3	Analysis #4	Etc.
39					
27					
17					
Etc.					
-					
-					

Many entries are already known; we plan to have most settled by time of the RHIC PAC meeting in June 2009

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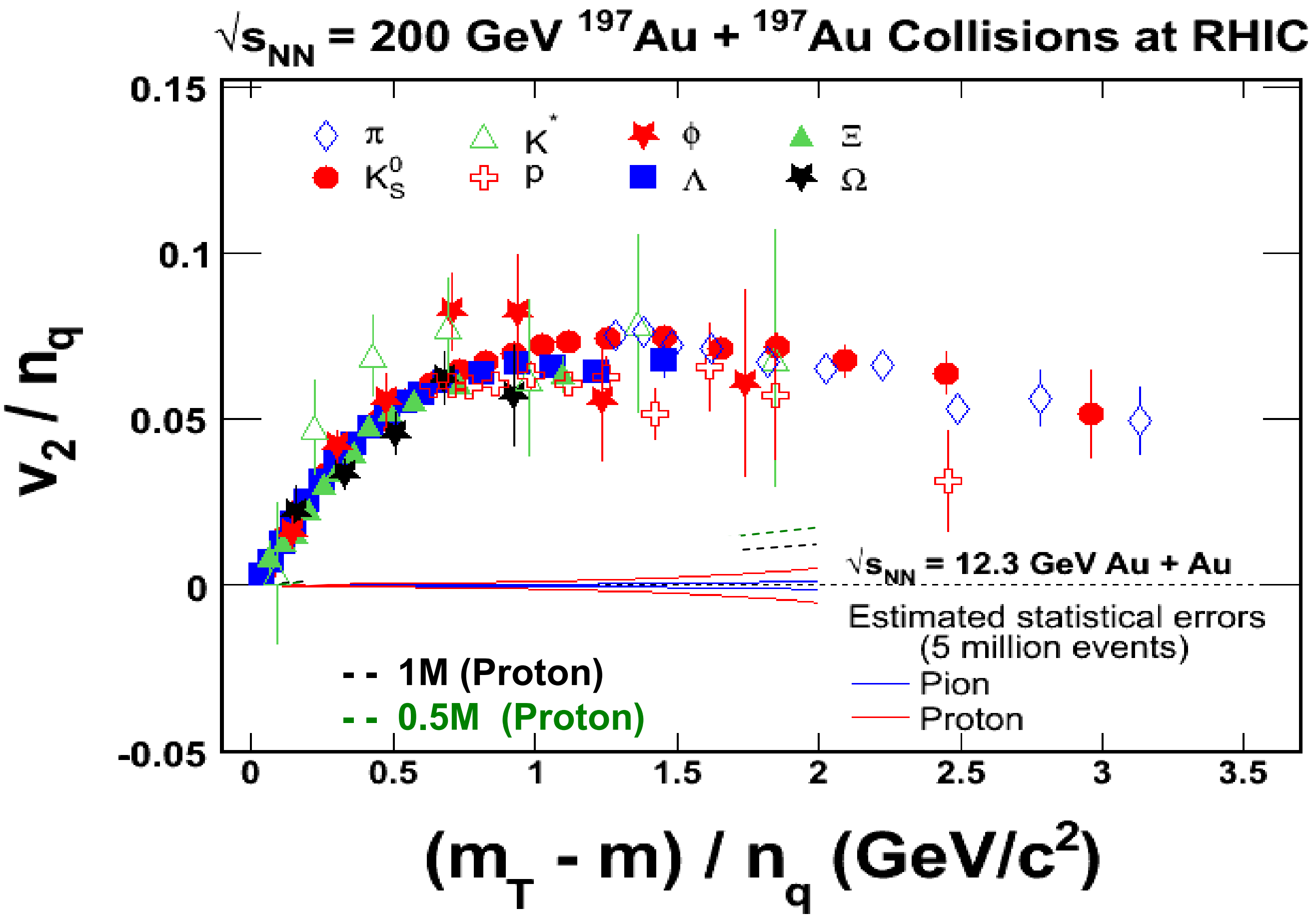
BES Analyses that Drive the Run Plan

A. Search for turn-off of major sQGP signatures already established at top RHIC energies (our least speculative objective).
- NCQ scaling
- Hadron suppression
- Untriggered pair correlations in $\Delta\phi$ & $\Delta\eta$

B. Search for phase transition signatures of the type that appear and then disappear as the beam energy is scanned.
- Elliptic flow (charged-particle & proton)
- Directed flow (charged-particle & PID)
- Azimuthally-sensitive femtoscopy

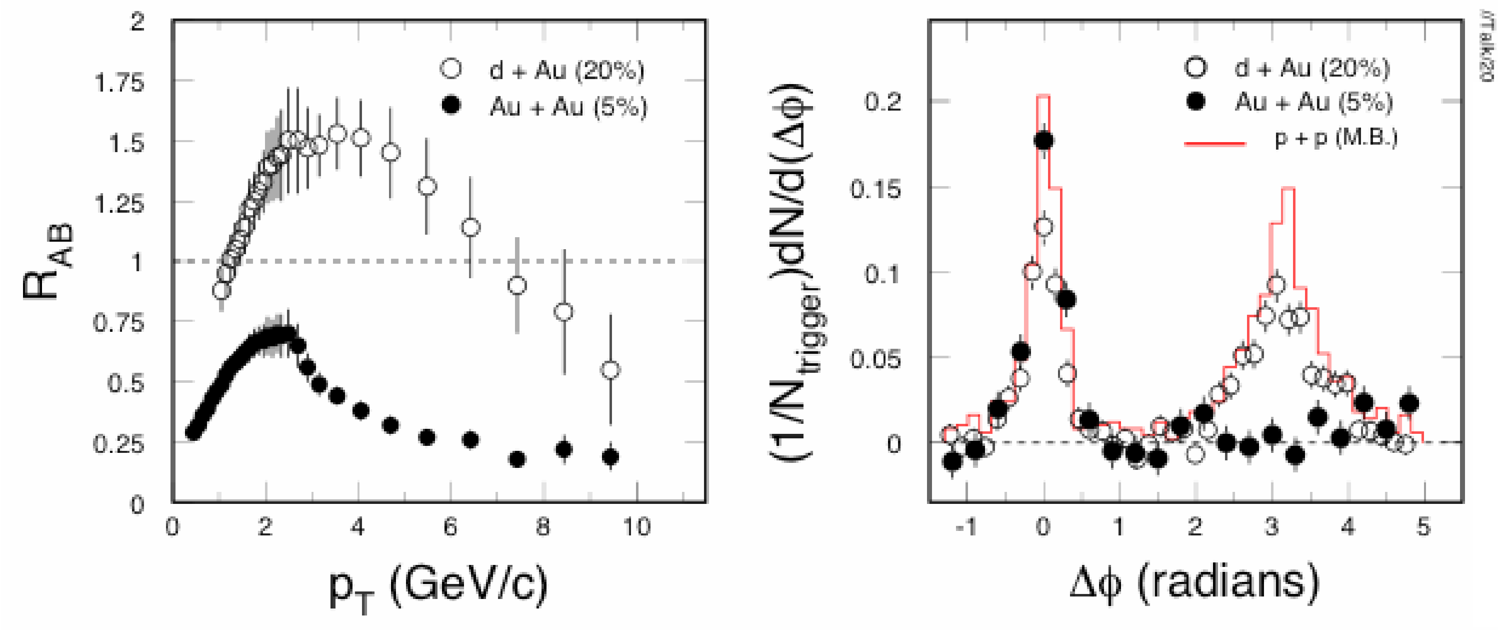
C. Search for evidence of critical point.
- Details below

A-1: Turn-off of NCQ Scaling?



We anticipate being able to test this scaling all the way down to SPS energies

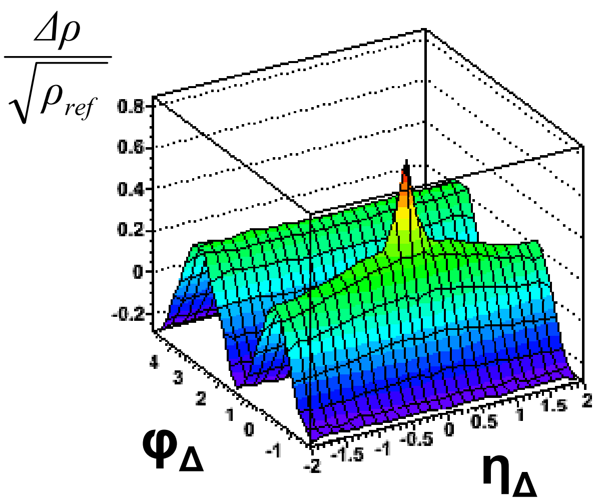
A-2: Suppression and Correlation

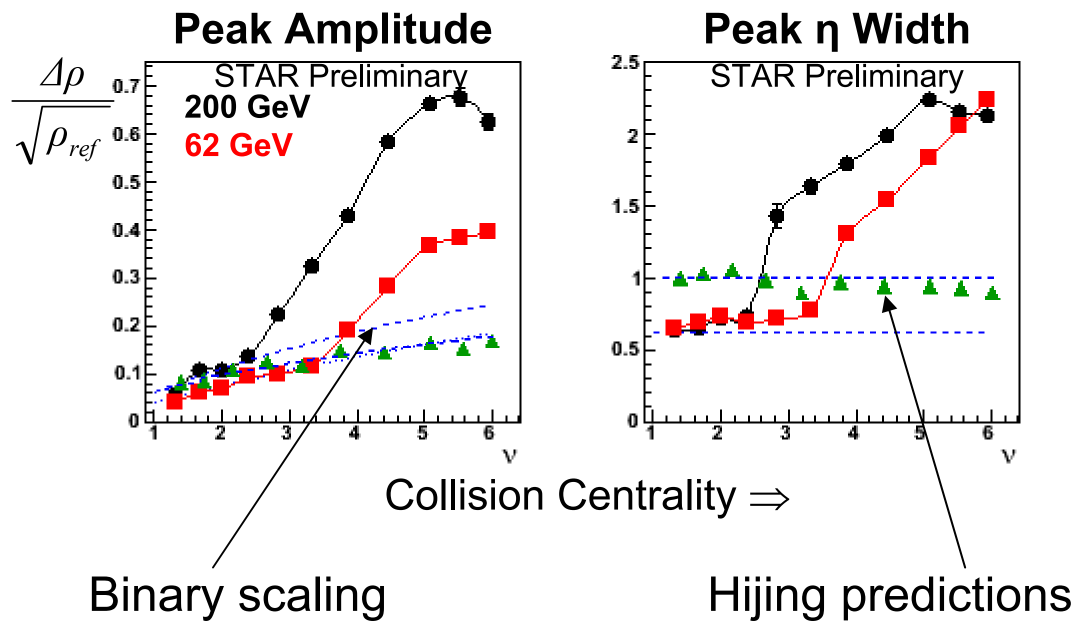


Central AuAu: hadrons suppressed & back-to-back jets disappear, in contrast to pp & dAu collisions

Hadron suppression can be pursued only in the upper range of the proposed scan energies

A-2: Correlations in phi & eta





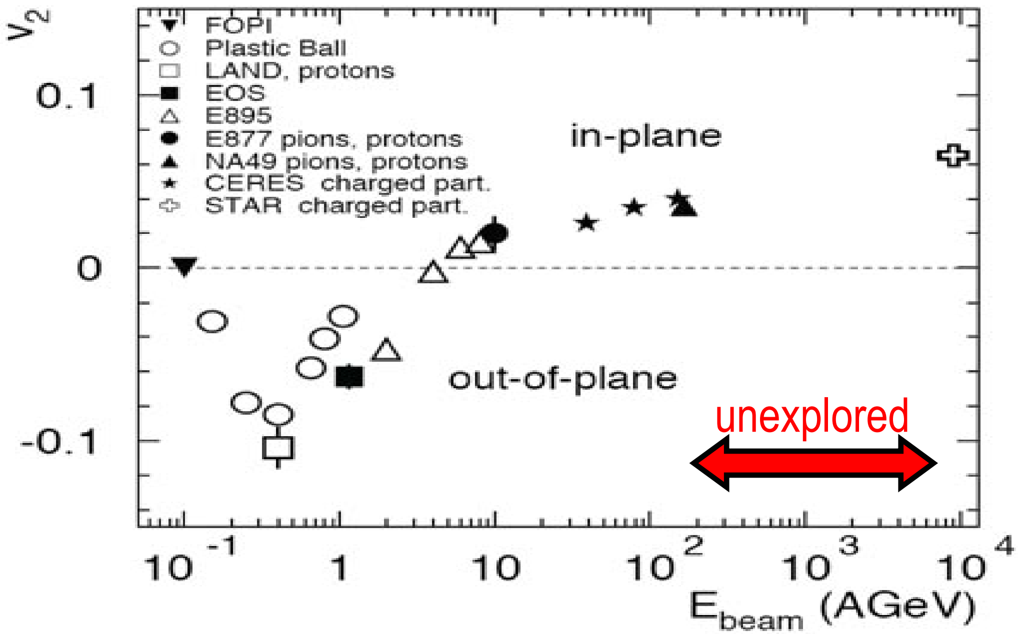
(from QM 2008)

1) Amplitude and η widths: ***sharp transition***
2) Deviations from binary scaling: ***physics unique to HI collisions***
3) The observed correlation: ***Hijing under predicted*** the correlation
4) Inconsistent with the medium thermalization(?)

Modification of energetic 'jets' in the medium!

Can probably be pursued below injection energy

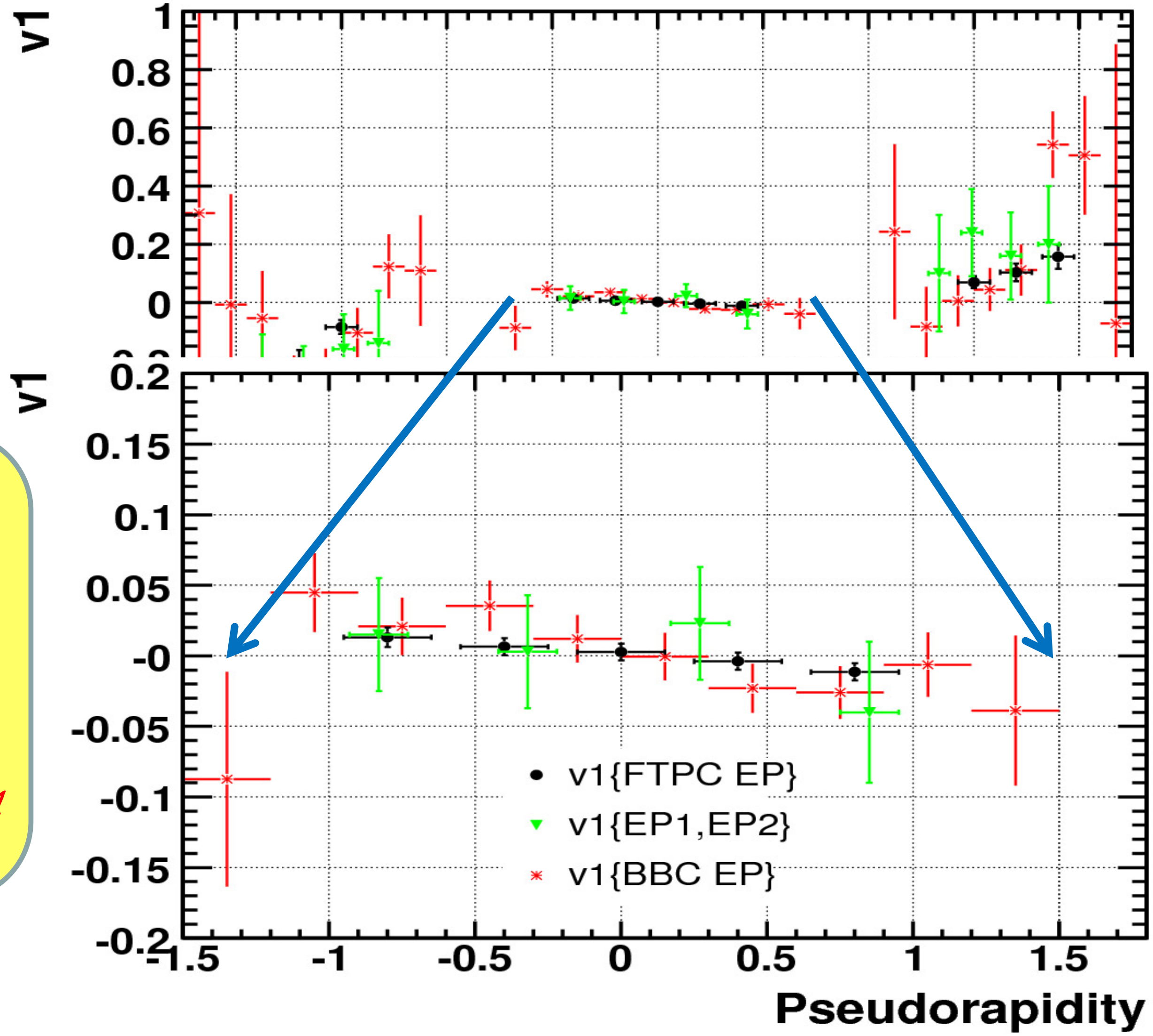
B-1: Elliptic Flow



The charged-particle v_2 excitation function needs to be scanned carefully in the important unexplored region where it rises & approaches the hydro limit; proton elliptic flow is also of special interest.

B-2: Charged-Particle Directed Flow

9.2 GeV AuAu
2008 test run

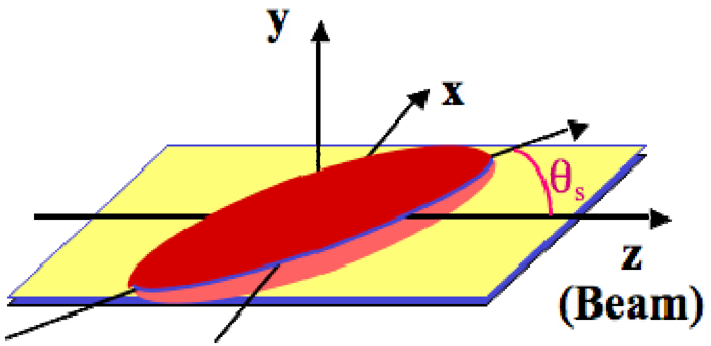


A few thousand events taken during brief machine development test are almost enough to extract publishable v_1 physics

"Wiggle" would be a promising signature; important to distinguish pion from proton v_1, which new ToF will allow. Can be pursued to lowest BES energies.

B-3: HBT Excitation Function

HBT radii as a function of angle w.r.t. Ψ[1st-RP] yield size and shape and tilt angle at Freeze-out



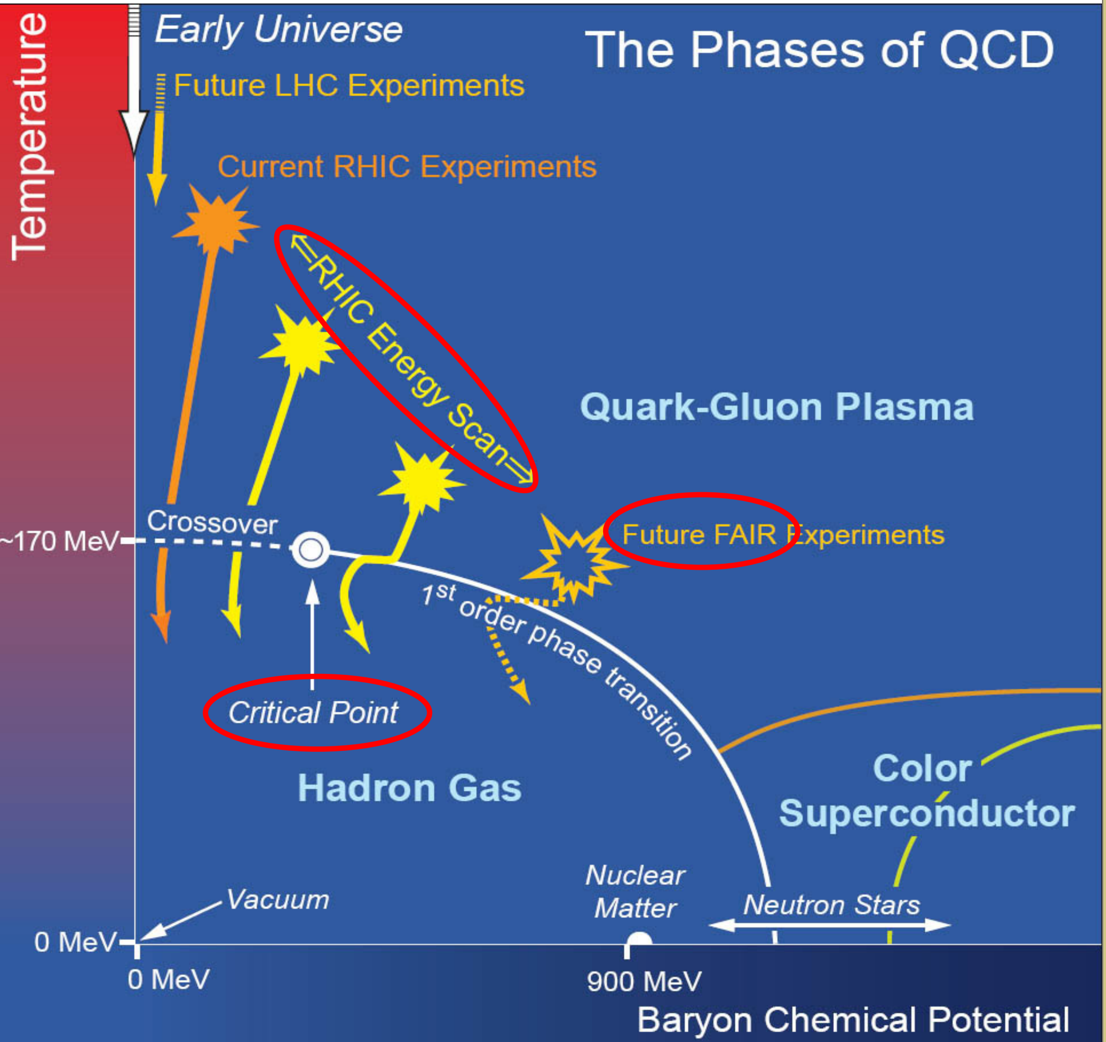
- Crucial quantities for P.T.
  - timescale
  - collective flow
- HBT relative to 1st-order RP:
  - spatial substructure of directed flow
  - existence of soft point in densest phase from tilt
- HBT relative to 2nd-order RP:
  - spatial substructure of elliptic flow
  - timescale from shape
  - early pressure response (EoS) from shape
- Azimuthally-integrated HBT
  - timescale from magnitudes (R_{long})
  - changing nature of flow from shape
  - p_T-dep: spatial substructure of radial flow

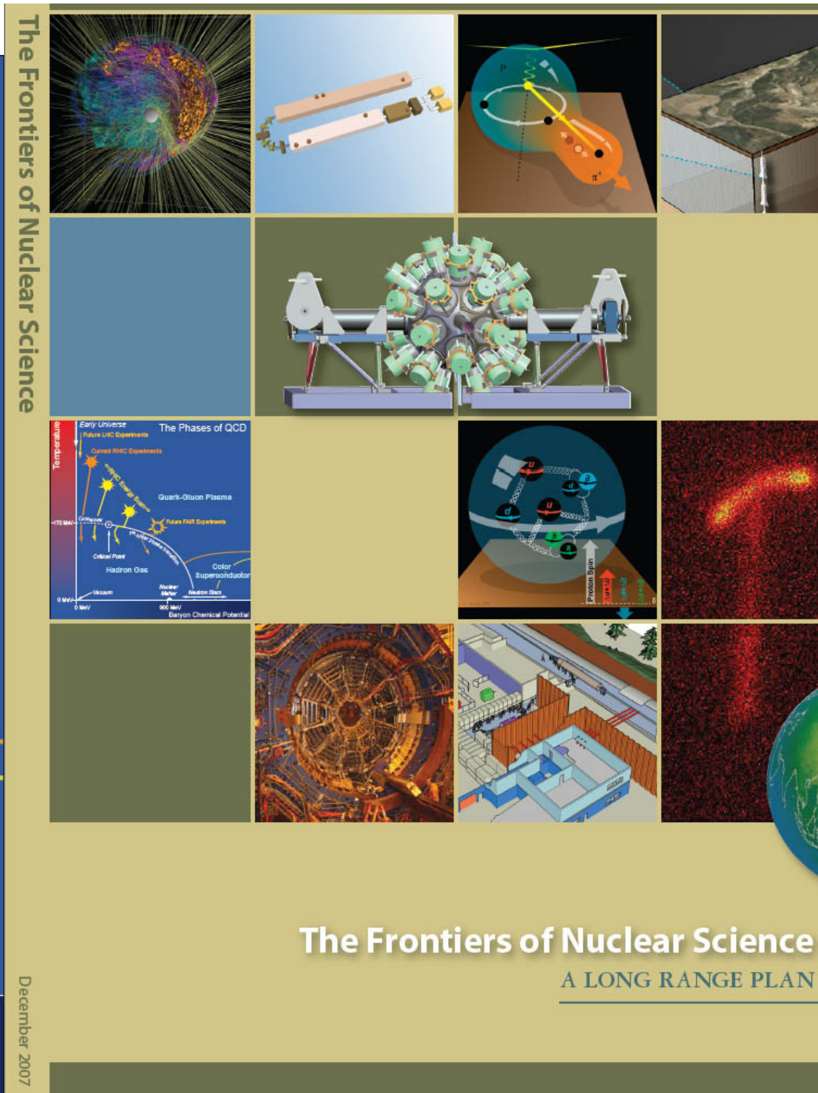
Will map them all, but pay special attention to geometric **signals of soft point**

C: Search for Critical Point

‘The search for the QCD critical point is a “must do” experiment’

— Recommendations of BNL PAC, May 2008





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C: Search for Critical Point

Researchers of the phase diagram & the CP can learn many valuable lessons from decades of study of the liquid-vapor phase transition

Nuclear Multifragmentation and Phase Transition for hot nuclei

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(e-print arXiv:0812.3524)

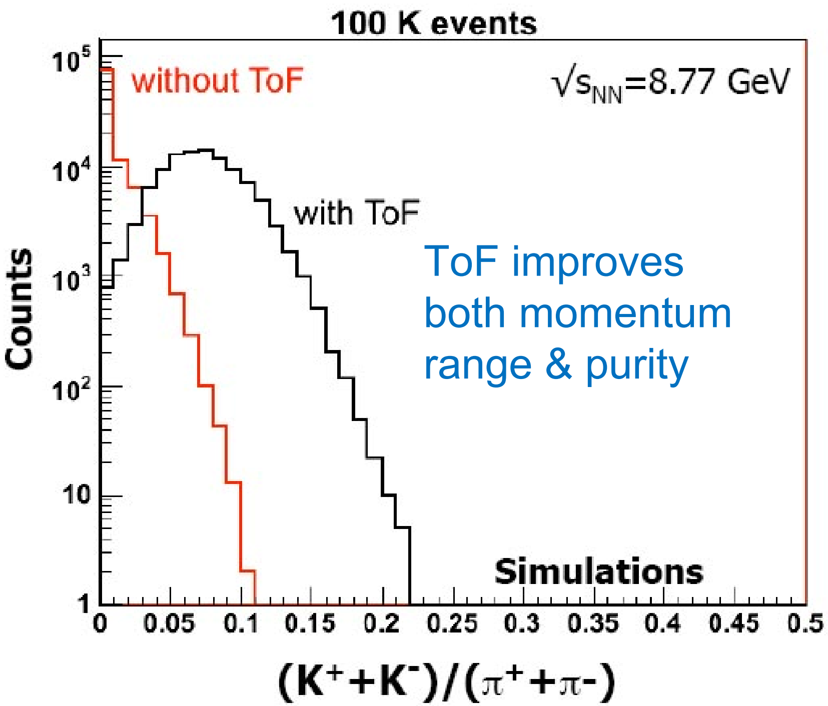
Abstract

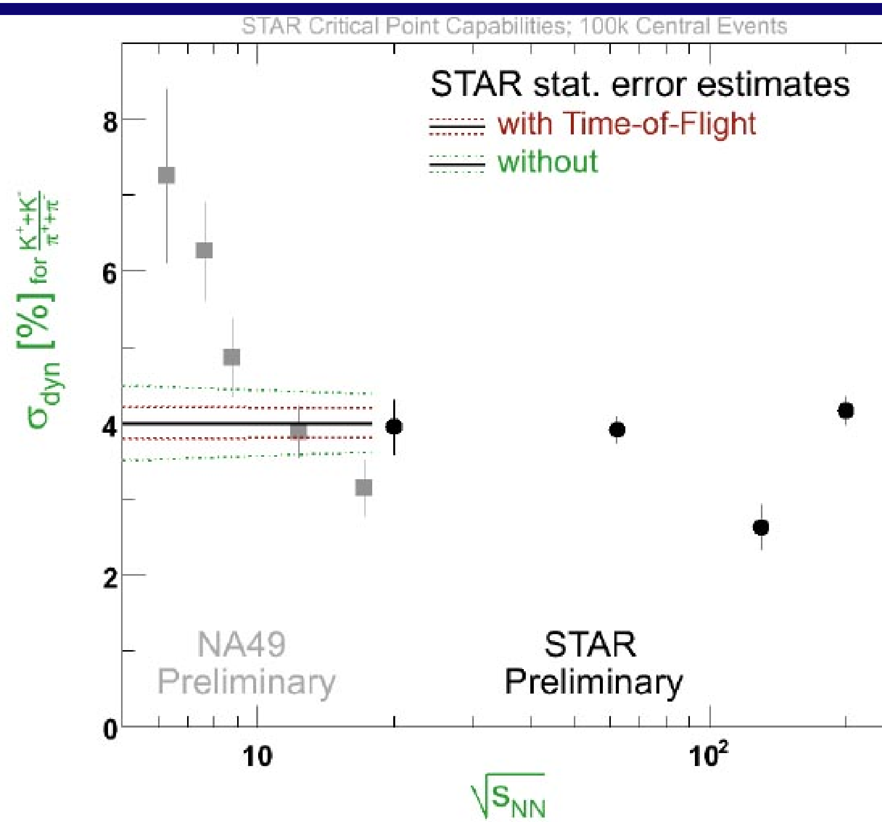
That review article is focused on the tremendous progresses realized during the last fifteen years in the understanding of multifragmentation and its relationship to the liquid-gas phase diagram of nuclei and nuclear matter. The explosion of the whole nucleus, early predicted by Niels Bohr [1], is a very complex and rich subject which continues to fascinate nuclear physicists as well as theoreticians who extend the thermodynamics of phase transitions to finite systems.

Conclusions

Today a rather coherent picture has been reached for few exhaustive studies and some semi-quantitative estimates of the transition region become available. However the order and the nature of the transition is still subject to debate. For a large part this debate is related to finite-size effects, which remain an important challenge.

C-1: Hadron Ratios & Fluctuations





Advantages of STAR over SPS:

- Large acceptance: full azimuthal coverage and |y| < 1.0
- Clean particle identification: (TPC, ToF, EMC)
- Continuity from high to low energy scan, systematic errors under control

Easily pursued down to SPS energies

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CBM physics book - Part IV

I don't need to "preach to the choir" about the CP search .....CBM and the RHIC Energy Scan share the same goal & bring highly complementary capabilities to the search

RHIC: cannot do many studies that require FAIR's high luminosity, but has the benefit of smoothly following down from high energies + collider environment

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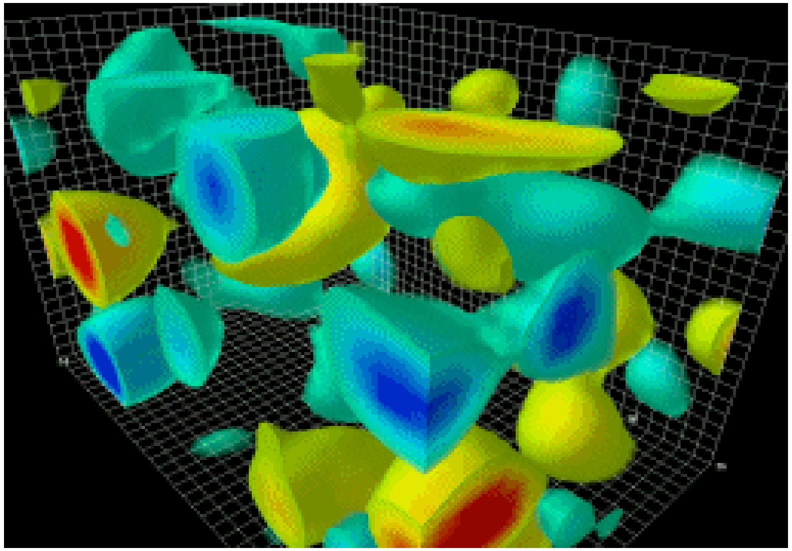
Strong Parity Violation - I

In QCD, chiral symmetry breaking is due to nontrivial topological solutions; among the best evidence for this physics would be *event-by-event strong parity violation*

This lattice-based animation of topological charge density illustrates 4-D structure of gluon-field configurations describing the vacuum properties of QCD.
Box volume = 2.4 X 2.4 X 3.6 fm^3.

Animation by *Derek Leinweber*



Non-central heavy-ion collisions ➡ Large orbital angular momentum (*L*) 90^o to RP ➡ Strong localized *B* field (due to net charge of system) ➡ If system is deconfined, can have strong P-violating domains & different no. of left- & right-hand quarks ➡ Preferential emission of like-sign charged particles along *L*

$$\frac{dN_\pm}{d\phi} \propto 1 + 2a_\pm \sin(\phi - \Psi_{RP}) + \ldots \Rightarrow \langle\cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP})\rangle \approx (v_{1,\alpha}v_{1,\beta} - a_\alpha a_\beta)$$

Averages to zero due to random domains

Doesn't average to zero

Strong Parity Violation - II

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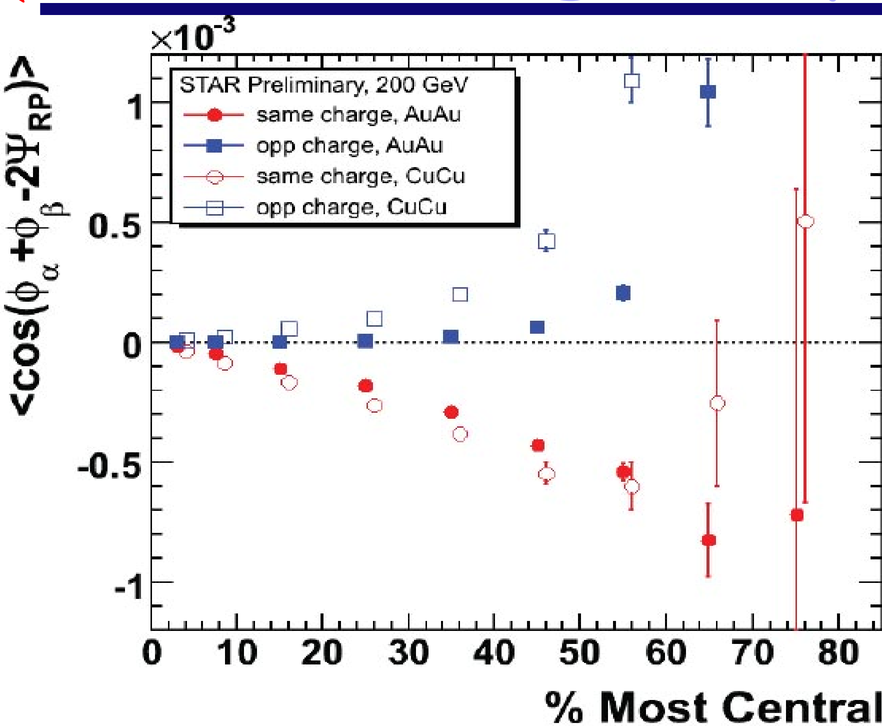
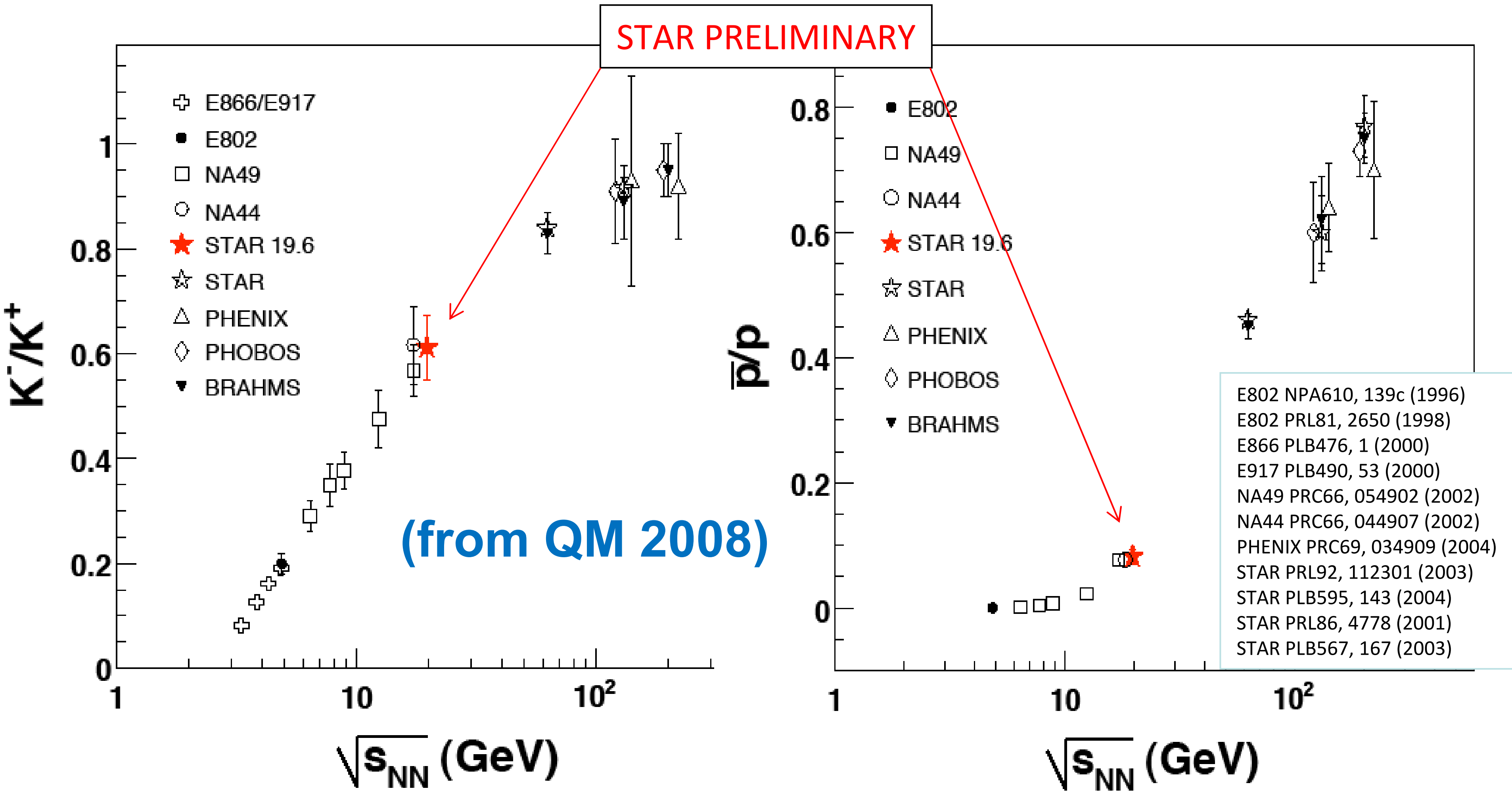


- Observed signature has excellent statistical significance for AuAu and CuCu at top RHIC energies, and follows the expected trends.
- Caveat: parity-even observable.
- Other effects, esp. resonance decays, can also lead to a signal, but so far, no background effect can explain observed signal size & centrality dependence.

IMPORTANCE OF ENERGY SCAN:

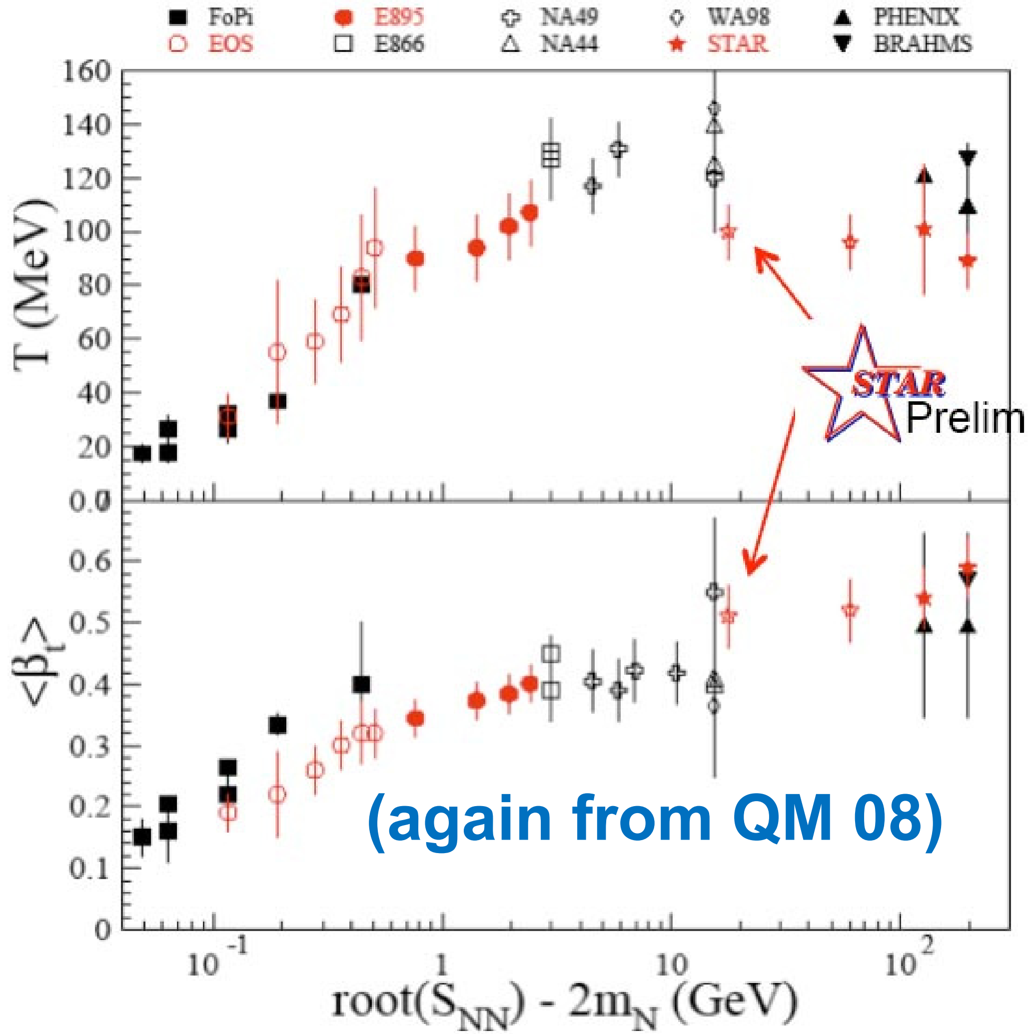
- Combination of intense *B* & deconfinement needed for parity violation; disappearance of signal is a new signature of turn-off of deconfinement.
- Resonance decays and other backgrounds have a different expected dependence on beam energy; energy scan will strengthen our certainty that these backgrounds have been decisively ruled out.

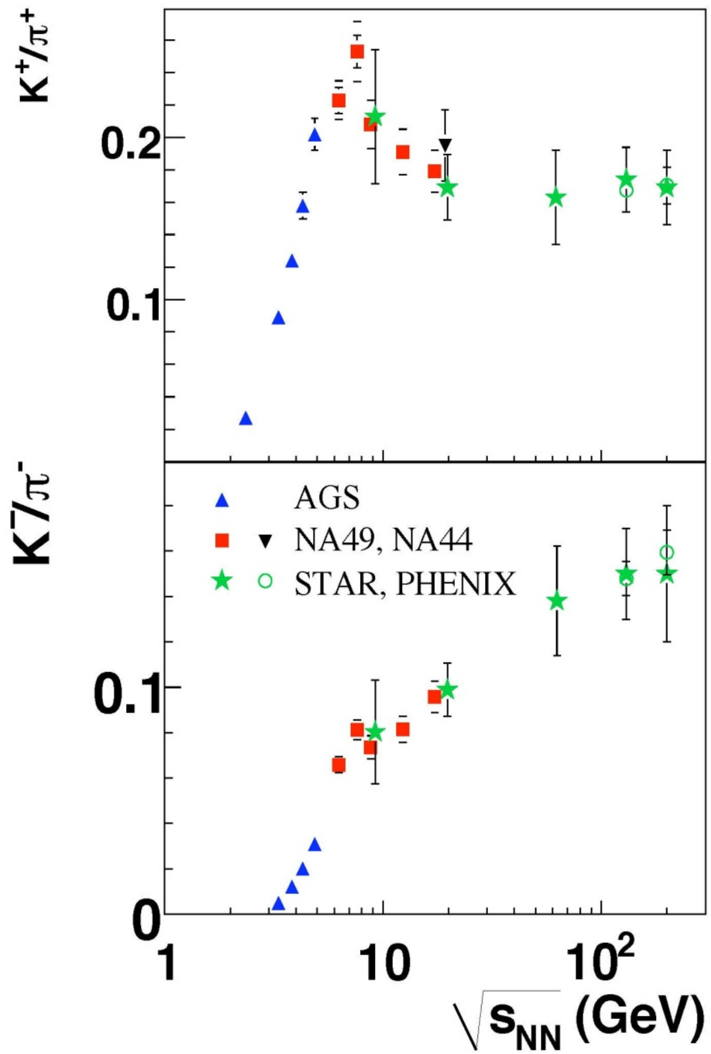
RHIC Energy Scan Began at 19.6 GeV in 2001



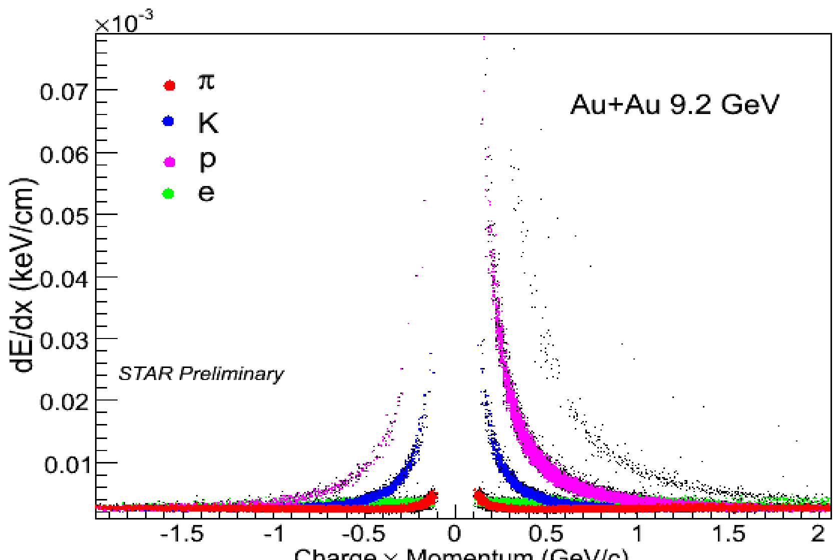
Particle ratios based on ~ 42K good events

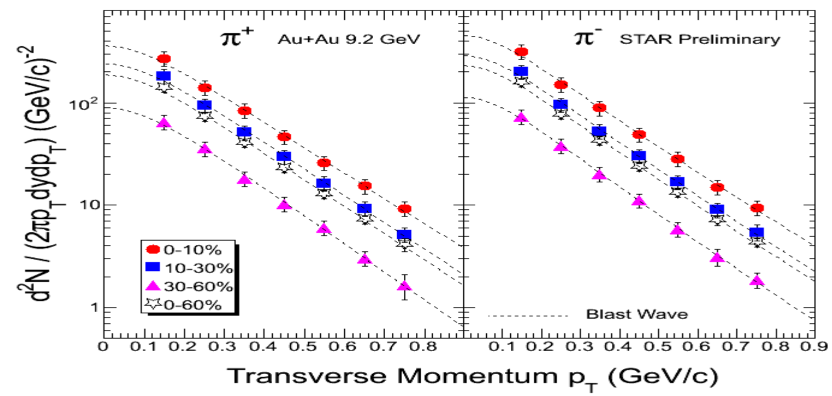
More 19.6 GeV from 2001

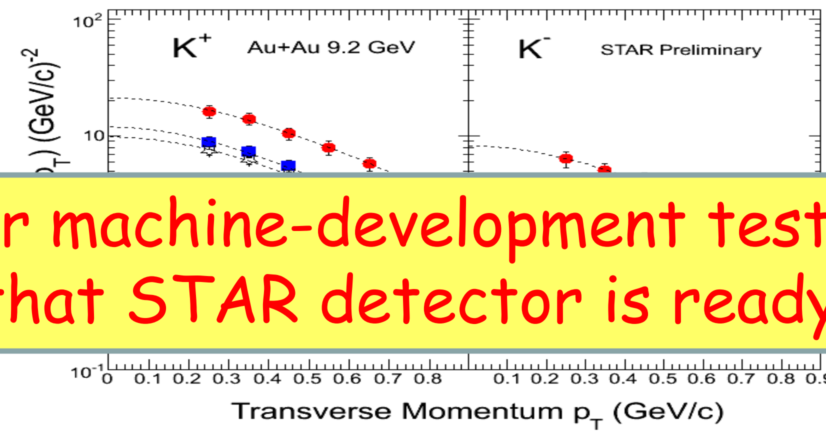




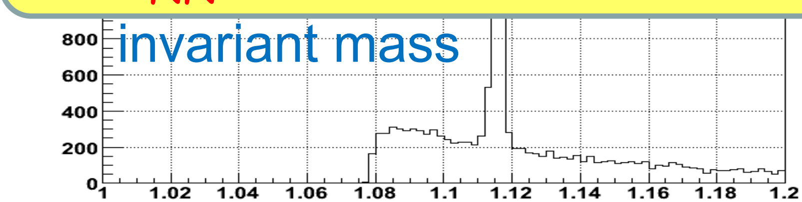
Preliminary Analysis of 2008 Test at 9 GeV

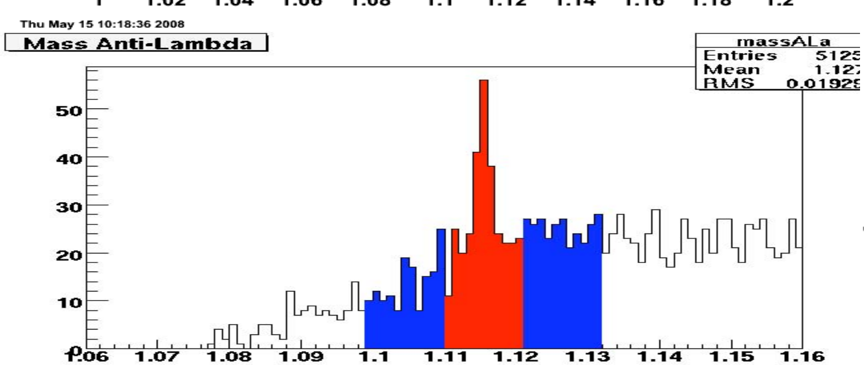


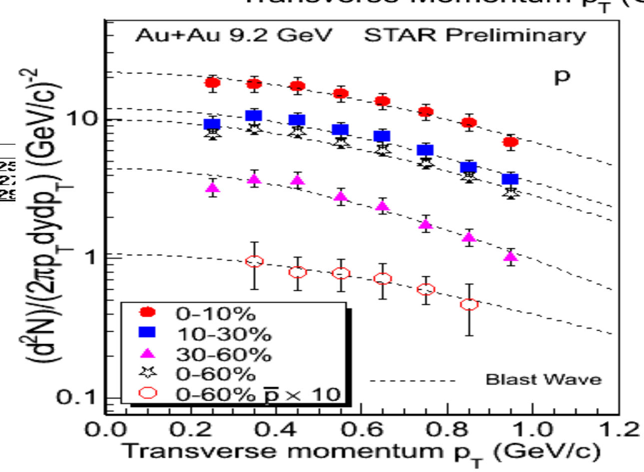




Physics results from ~4-hour machine-development test at $\sqrt{s_{NN}}$ = 9.2 GeV illustrate that STAR detector is ready







(all from SQM 2008)

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RHIC Performance at lower Energies

- Below injection energy of $\sqrt{s_{NN}}$ =19.6 GeV:

$$Time(10\text{ hr days}) = \frac{4.3\times10^{3}\{\#\,of\;\;Events(\text{Mevts})\}}{\left(\sqrt{s_{NN}}\right)^{3}}$$

- Above injection energy of $\sqrt{s_{NN}}$ =19.6 GeV:

$$Time(10\text{ hr days}) = \frac{2.2\times10^{2}\{\#\,of\;\;Events(\text{Mevts})\}}{\left(\sqrt{s_{NN}}\right)^{2}}$$

Formulae above are based on proven RHIC performance using current hardware. Future cooling upgrades would offer further gains at the lowest energies.

Run-10 Energies Likely to be Proposed by STAR

$\sqrt{s_{NN}}$ (GeV)	Rate (Evts/sec)	10 hr days for 1 M Evts
5.0	0.8	34
7.7	3	9
11.5	10	3
17.3	33	0.8
27	92	0.3
39	190	0.15

These energies are spaced a constant multiplicative factor of ~1.5 between $\sqrt{s_{NN}}$ = 5.0 and 62.4 GeV, except for 39 GeV, which is shifted slightly from 41 GeV to match existing pp data.

Planning for BES Runs

- BES run plan is constrained by many factors, e.g.: new HFT & FGT subsystems displacing Forward TPCs + the smaller beam pipes coming to both PHENIX (Run-11) & STAR (later). Immediate priority is to have 1st BES survey in Run-10 (early 2010) before 4-cm diameter PHENIX pipe is installed.
- Informal discussions are taking place between STAR & PHENIX to explore common physics interests & advance mutual understanding of the different priorities of the two experiments.
- Late-breaking news: likely $4.5M Economic Stimulus funding for RHIC electron cooling, with an order of magnitude luminosity increase down to $\sqrt{s_{NN}} \sim 5$ GeV, coming online in 2012-13 (a "shovel ready" project).

Summary

- Main themes for the STAR Beam Energy Scan:
  A. Search for turn-off of major sQGP signatures already established at top RHIC energies
  B. Search for phase transition signatures of the type that appear and then disappear as the beam energy is scanned
  C. Search for evidence of critical point
  D. "Other": Tracking strong parity violation with descending beam energy is also a priority
- We will carry out a large number of separate analyses, but a subset of them related to A-D above are the ones that drive our proposed Run Plan
- Short tests at low energy (esp. $\sqrt{s_{NN}}$ = 9.2 GeV) have already demonstrated readiness of STAR detector to deal with special challenges of sub-injection-energy running at RHIC
- Beam Energy Scan program at RHIC: different strengths from CBM, with some overlap…. overall, the ideal complementary situation

EXTRAS

Upgrades: RHIC Electron Cooling

Fermilab Pelletron (courtesy A. Warner)

- **Required if high statistics at $\sqrt{s_{NN}}$ < 5-6 GeV/u are desired**
- **Planned RHIC-II electron cooling does not work at these energies**
- **Existing stochastic cooling does not work below transition, and is too slow**

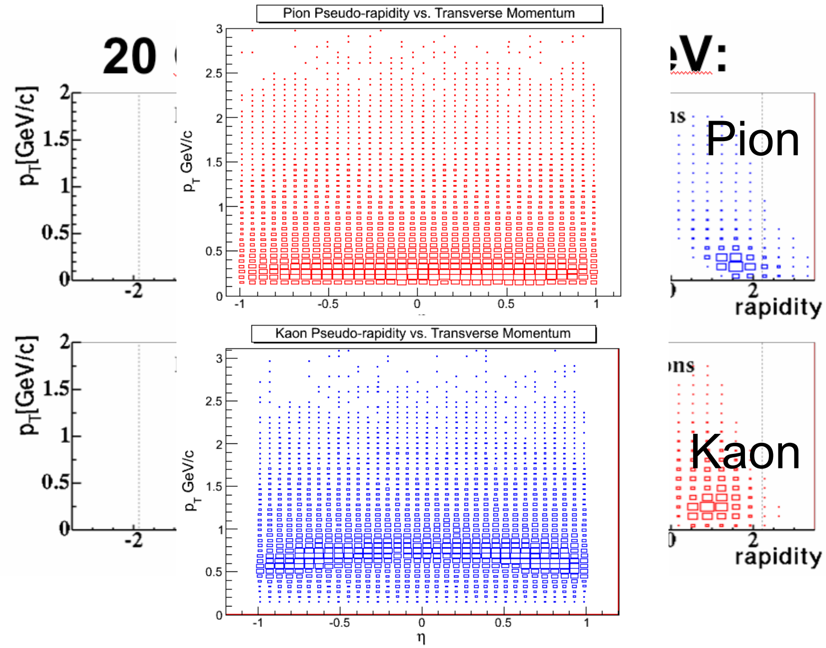
- **Option 1: acquire Pelletron from FNAL when Tevatron operations end c. 2010**
  - **20 m cooling area (fits existing straights)**
  - **Designed for cooling 0-9 GeV/c beams**
  - **~10m tall; install in experiment hall?**

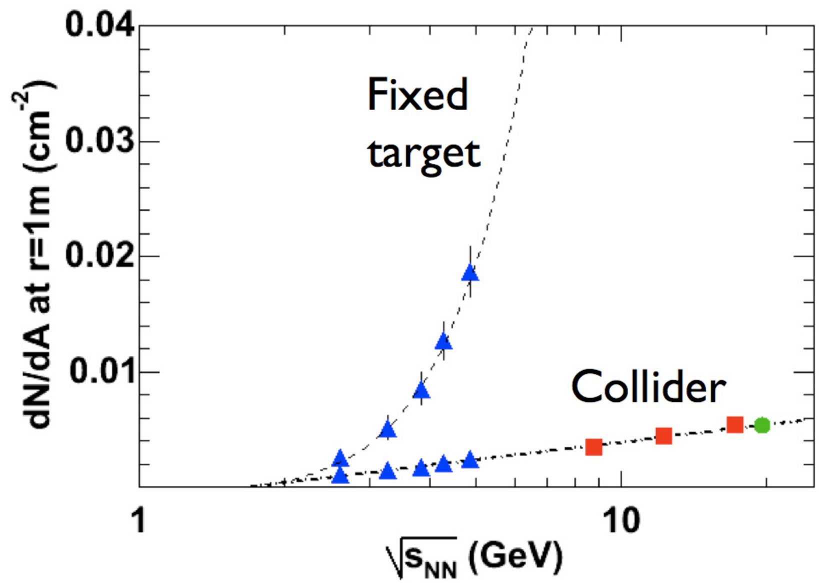
- **Option 2: construct cooler based on prototype RHIC-II ERL electron gun**
  - **In fabrication phase for ERL project**

- **Both options being investigated**
  - **~x10 integrated luminosity improvement**

Why is a collider the best choice?

STAR acceptance
NA49 acceptance





Big advantage that acceptance for collider detectors is totally independent of beam energy

Big advantage that occupancy for collider detectors is much less dependent on beam energy