Low Energy Physics With RHIC

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Massachusetts Institute of Technology

RHIC
relativistic heavy ion collider

BROOKHAVEN
NATIONAL LABORATORY

A brief reminder

~~Fixed Target~~ @ RHIC

Plenary Session - Friday, June 22, 2007
Physics Building, Large Seminar Room - Bldg. 510

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AGENDA

09:00	**Plenary Session IVA-- Invited Physics Talks** Chair: Rene Bellwied	
09:00 - 09:30	news from non-RHIC related experiments	Gerco Onderwater (KVI)
09:30 - 10:15	The eRHIC physics case	Abhay Deshpande (SUNY @ SB)
10:15 - 11:00	Low energy physics with RHIC	George Stephans (MIT)
11:00 - 11:15	15 minute break	
11:15	**Plenary Session IVB-- RHIC Upgrade plans** Chair: Brant Johnson	
11:15 - 11:45	STAR physics and upgrade plans for low energy running and RHIC-II	Jim Thomas (LBNL)
11:45 - 12:15	PHENIX physics and upgrade plans for low energy running and RHIC-II	Ed O'Brien (BNL)
12:15 - 01:00	CAD talk on low energy, RHIC-II and eRHIC running	Wolfram Fischer (BNL)

G.S.F.Stephans BNL Nuclear Physics Town Meeting 14-Oct-2003

How could I possibly be so wrong?

Low Energy Collider Mode??

- In principle, RHIC can circulate and collide beams at below the normal injection energies.
  - AGS has experience running at lower energies.
  - Would use existing experiments most efficiently.

BUT…

- May require significant machine development.
- Certainly requires dedicated beam program.
- If luminosity drops like $1/(\text{Energy})^4$, the rate could be a serious issue, requiring a long program.
- However: If electron cooling for RHIC-II is installed, it works even better at lower energy.

Well, not entirely wrong…

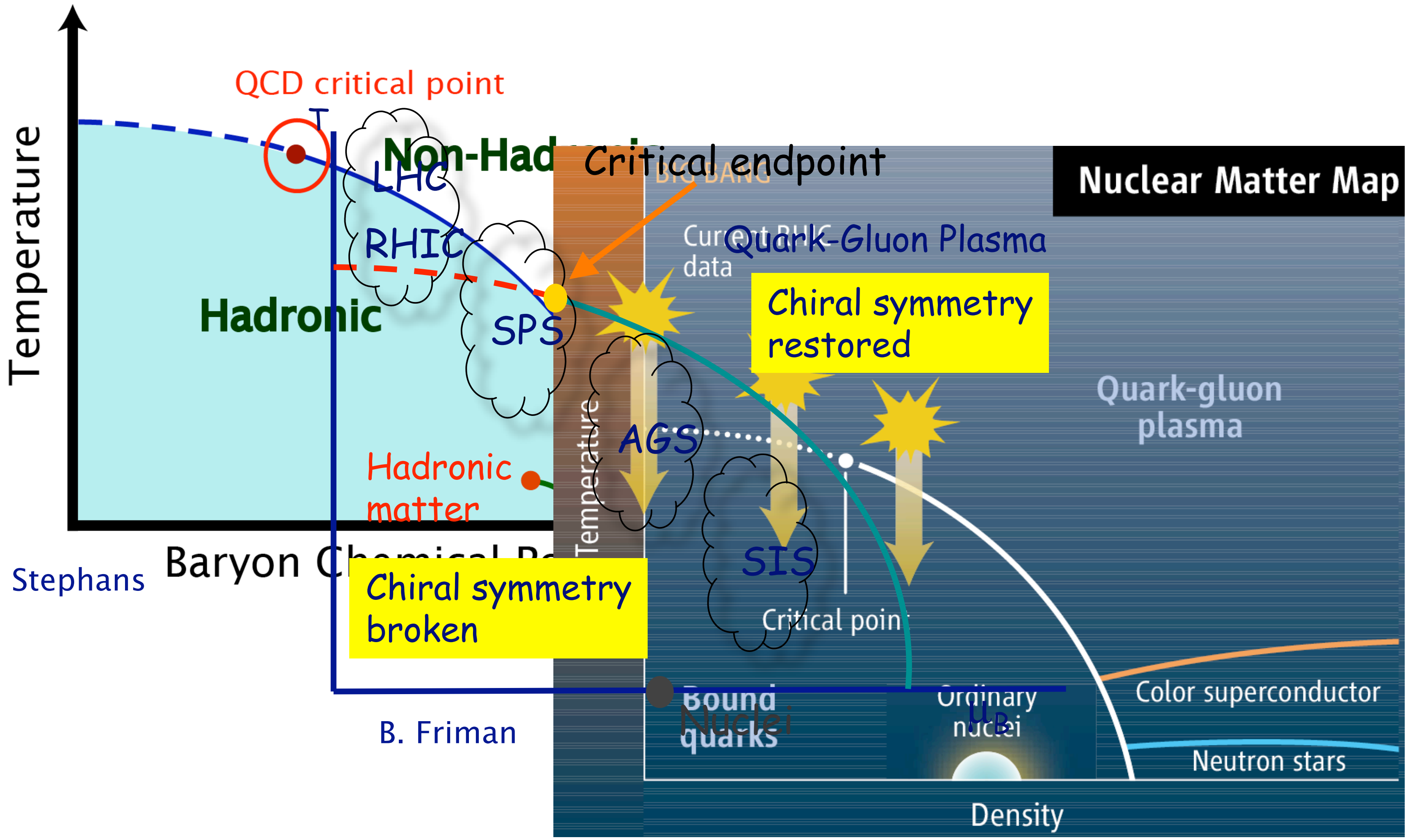
Why this program has developed

- Accelerator physicists who view “machine development” as an exciting challenge, not as an expletive
  - Also, an extensive record of accomplishment at successfully achieving new running conditions
- Lab and facility management eager to push the limits of the physics capabilities of RHIC into the future
  - Most of today’s session amply demonstrates this

Motivation

- Lower center of mass energies produce systems with (slightly) lower freezeout temperatures and significantly higher baryon densities
- Therefore, with lower energies a large span of the QCD phase diagram can be mapped using a single facility
- Theoretical calculations (still very much in flux) suggest that a critical point may exist in an experimentally accessible region of the phase diagram
- SPS energy scan results show some unexpected (unexplained??) features, especially for kaons

Typical examples of phase diagrams



G. Stephans

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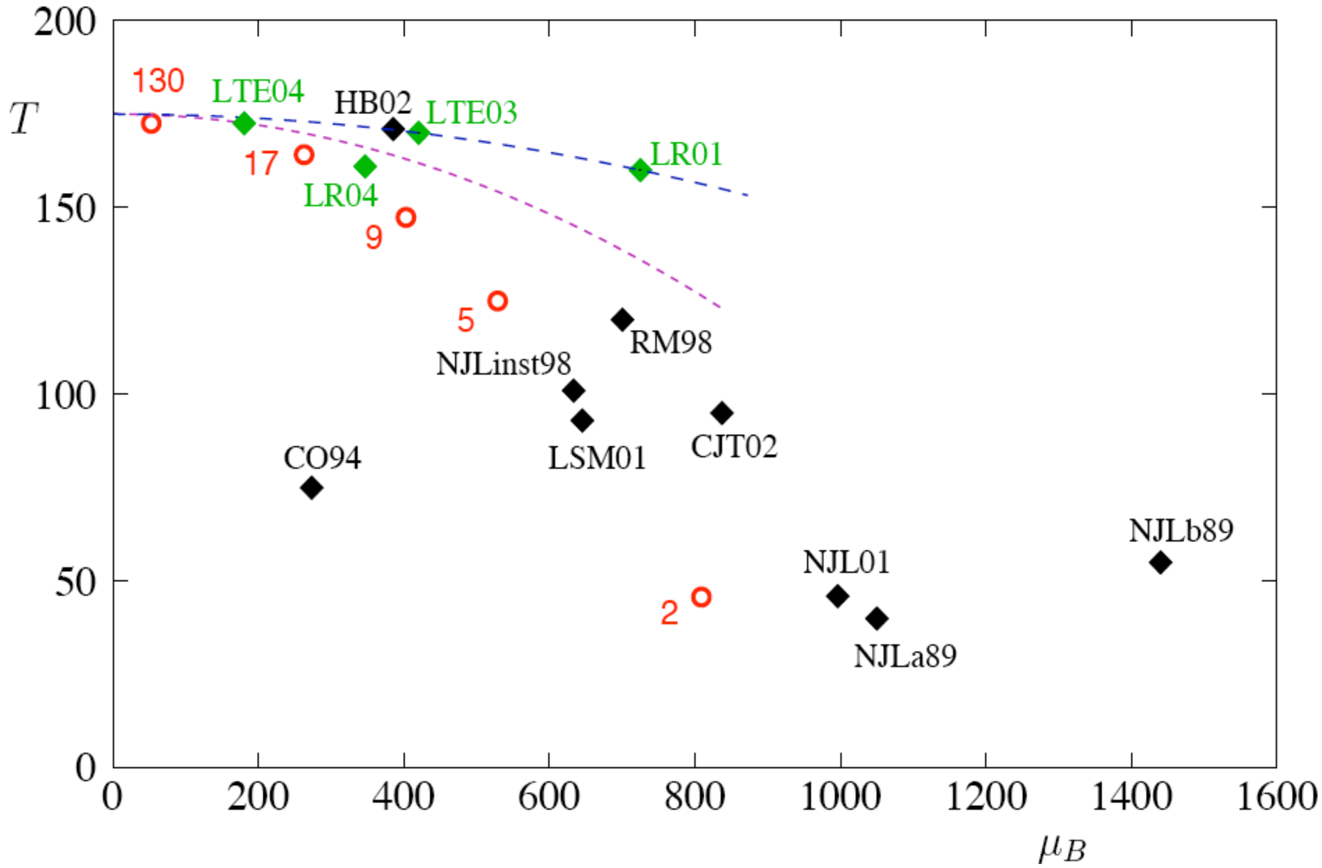
Science **312**, 190 (2006)

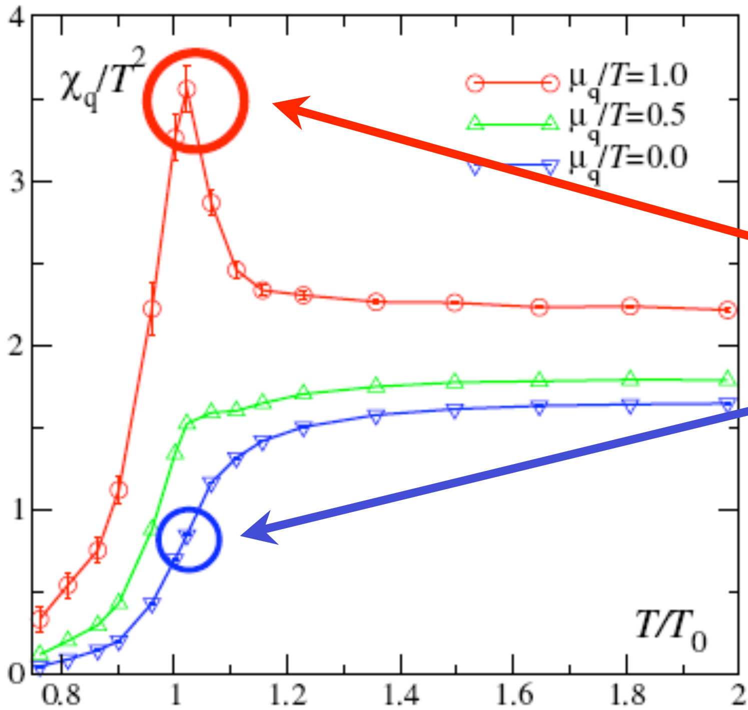
Towards a quantitative result



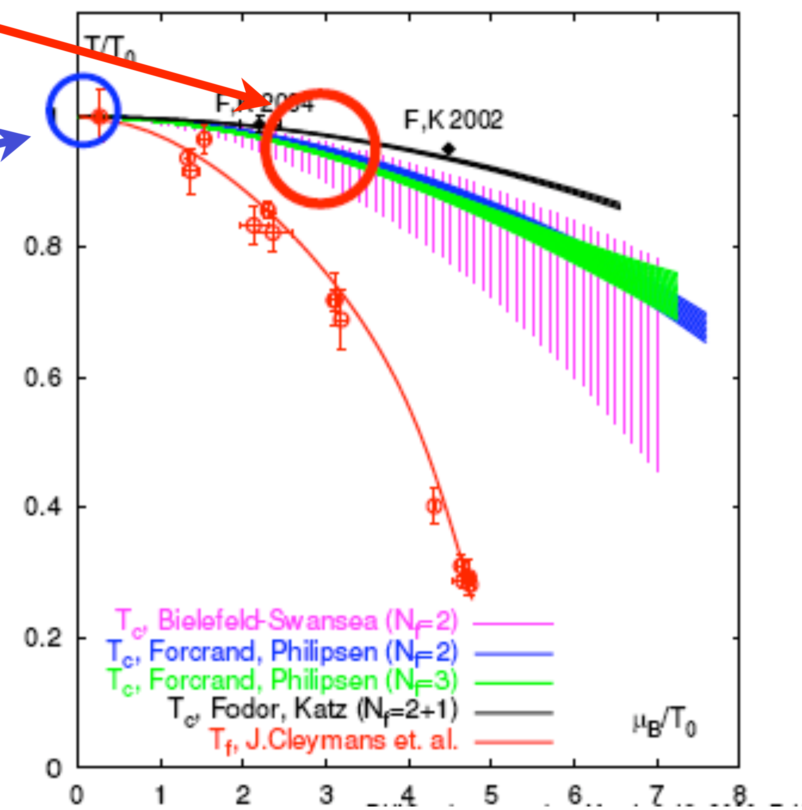
Large sensitivity to model inputs (such as quark masses), lattice sizes, and other assumptions

M. Stephanov hep-lat/0701002

Examples of what theorists look for



Sudden changes in susceptibilities taken as evidence for critical point



Images courtesy of F.Karsch

But wait, not so fast…

Towards the QCD phase diagram

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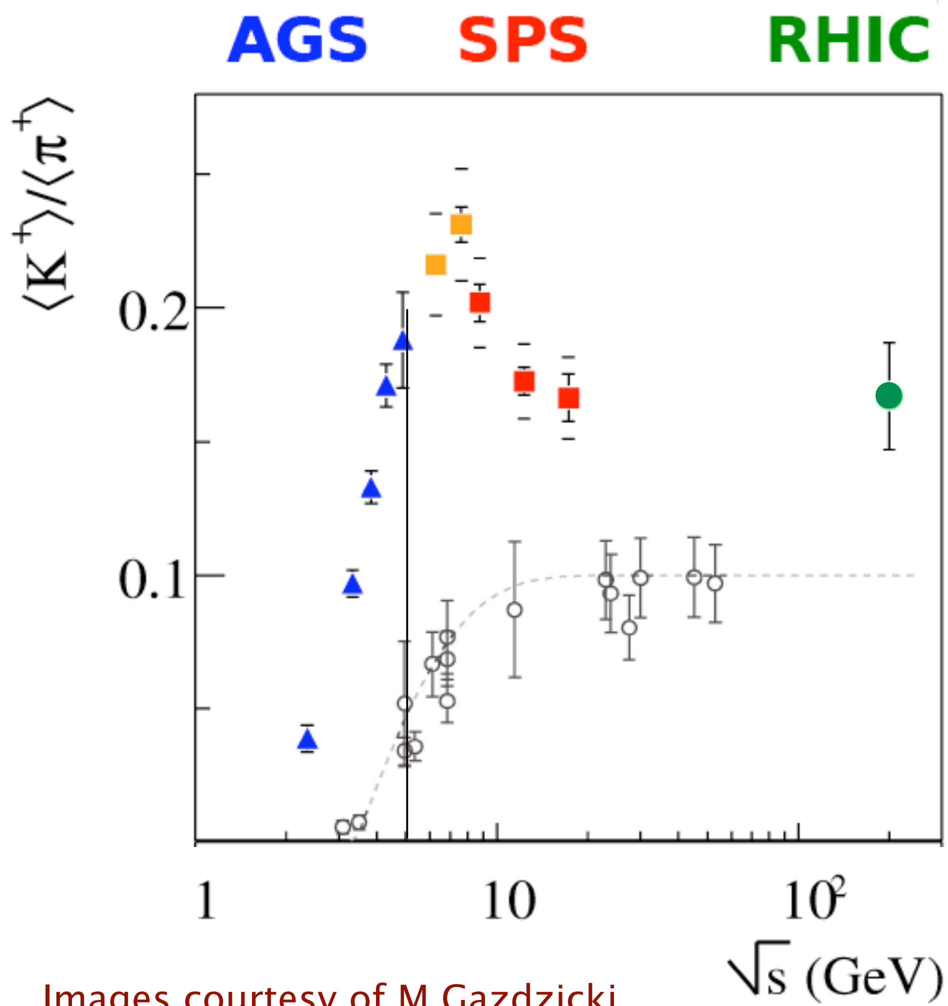
Owe Philipsen

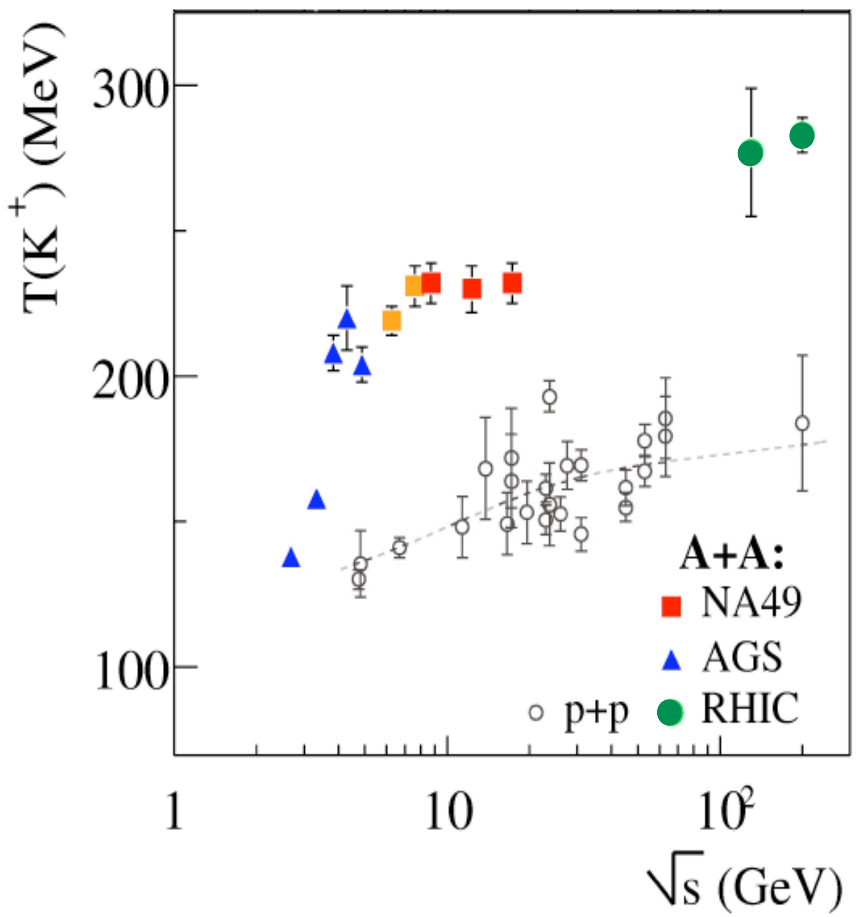
Is it a mistake to call this program critRHIC?

Then, using an imaginary chemical potential, we determine in which direction this second-order line moves as the chemical potential is turned on. Contrary to standard expectations, we find that the region of first-order transitions shrinks in the presence of a chemical potential, which is inconsistent with the presence of a QCD critical point at small chemical potential.

the quark mass plane $(m_{u,d}, m_s)$ where the finite temperature transition at $\mu = 0$ is second order. We confirm that the physical point lies on the crossover side of this line. Our data are consistent with a tricritical point at $(m_{u,d}, m_s) = (0, \sim 500)$ MeV.
Then, using an imaginary chemical potential, we determine in which direction this second-order line moves as the chemical potential is turned on. Contrary to standard expectations, we find that the region of first-order transitions shrinks in the presence of a chemical potential, which is inconsistent with the presence of a QCD critical point at small chemical potential.
The emphasis is put on clarifying the translation of our results from lattice to physical units, and on discussing the apparent contradiction of our findings with earlier lattice studies.

However, there is something strange…





Images courtesy of M.Gazdzicki

And, if there, a critical point doesn't hide…

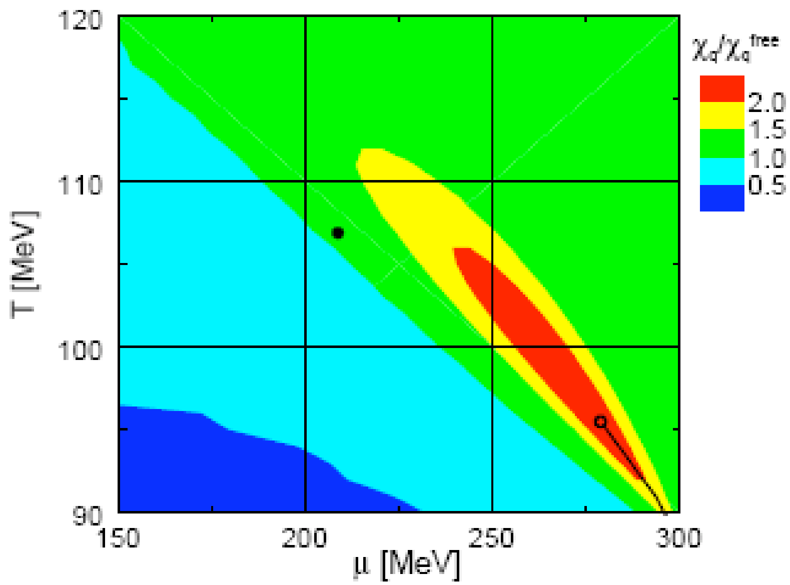


Image courtesy of Y.Hatta

Enhanced susceptibilities over an extended region

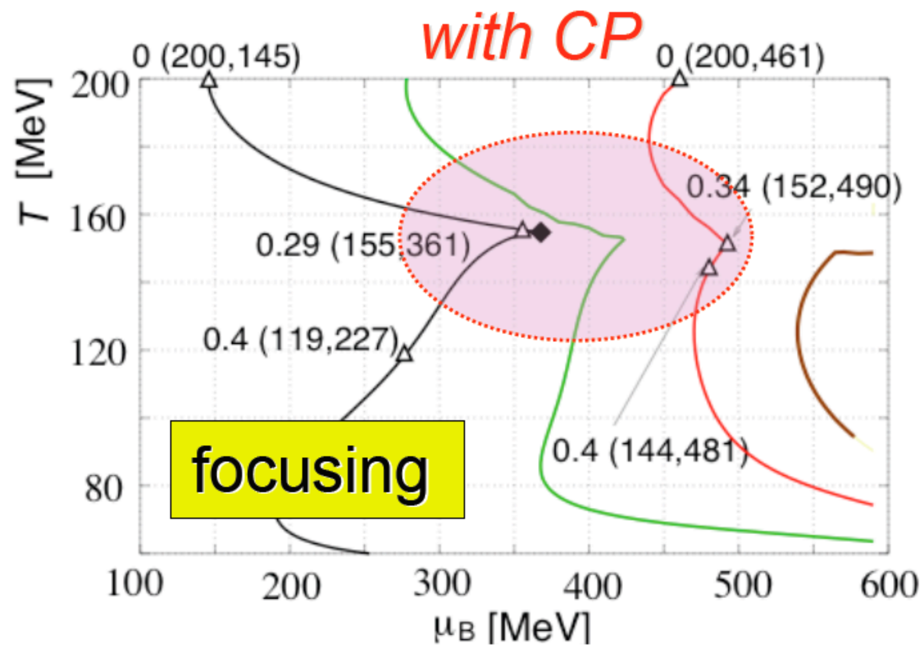


Image courtesy of C.Nonaka

Hydro predicts that the evolution of the system is attracted to the critical point

And, we can certainly explore further

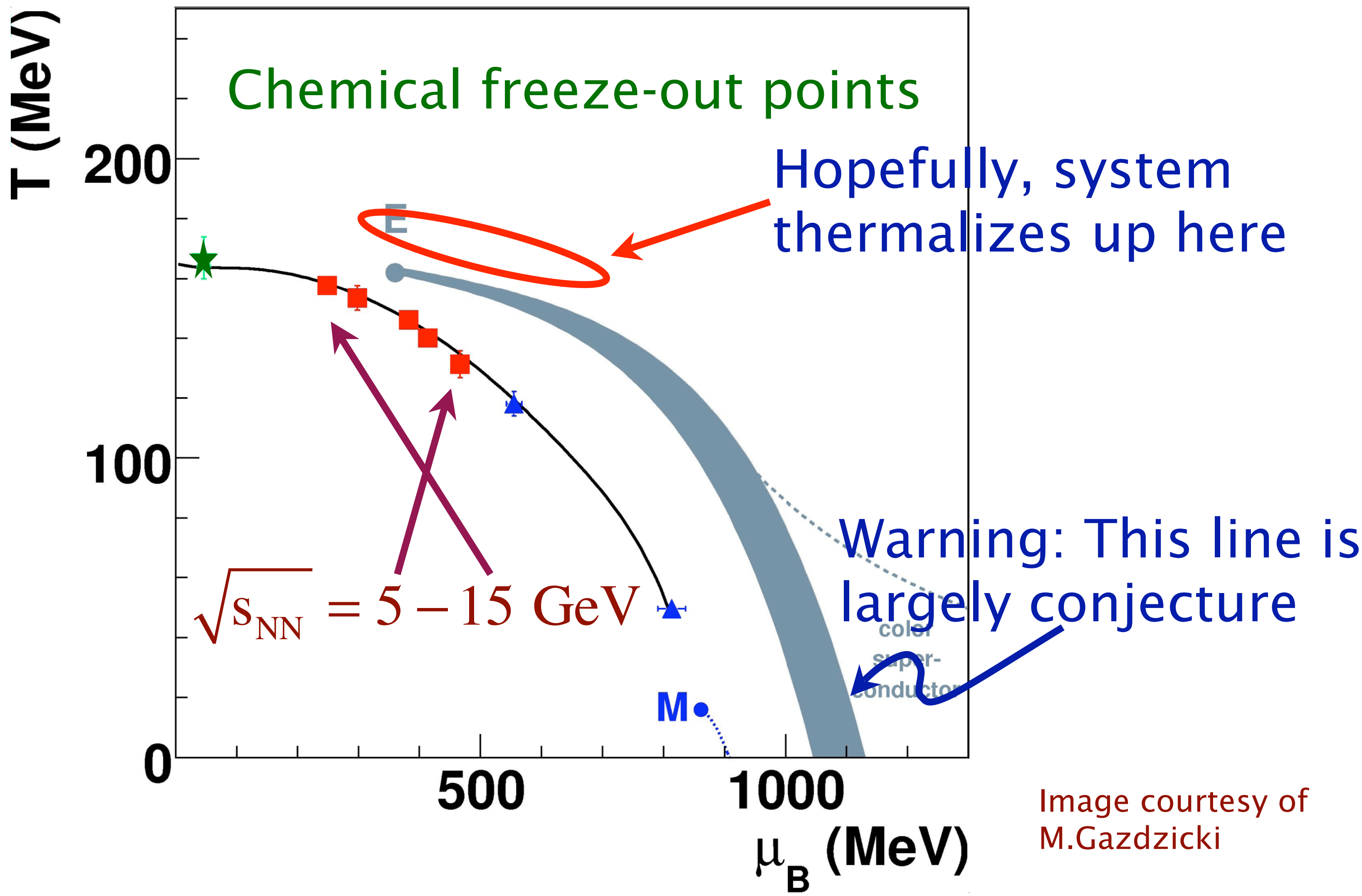


Image courtesy of M.Gazdzicki

Luminosity is the key issue

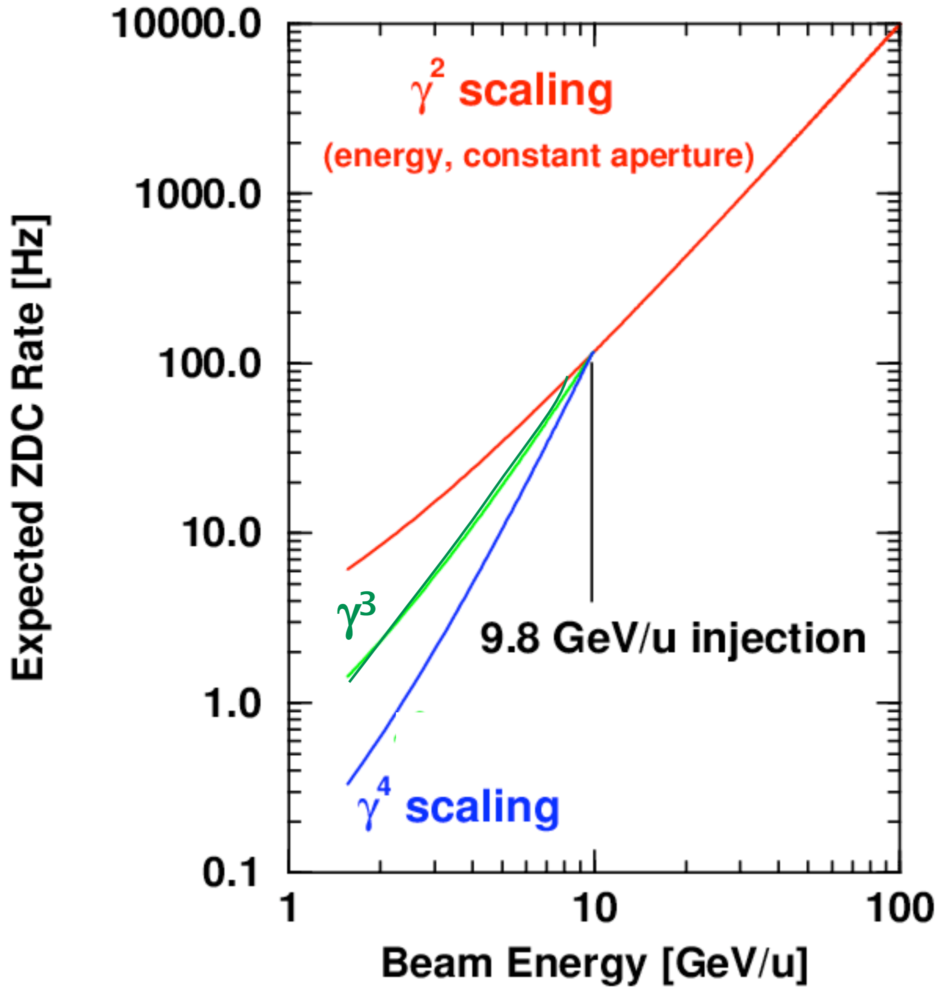


Image courtesy of T.Satogata

No apparent show-stoppers

Low current field quality and power supply stability OK

Electron cooling (done in AGS and/or RHIC) could improve rate enormously

Au ions at 5 GeV/u

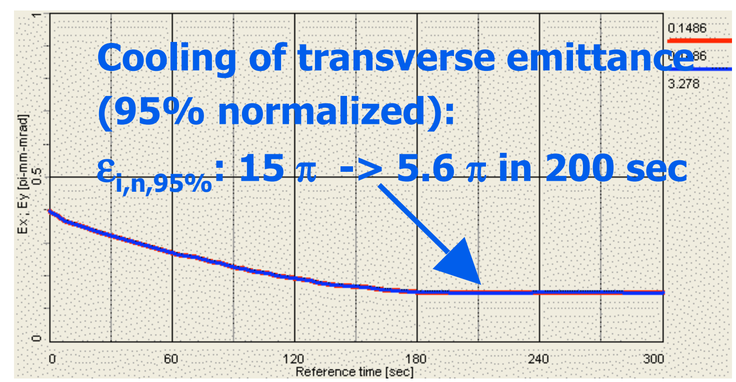
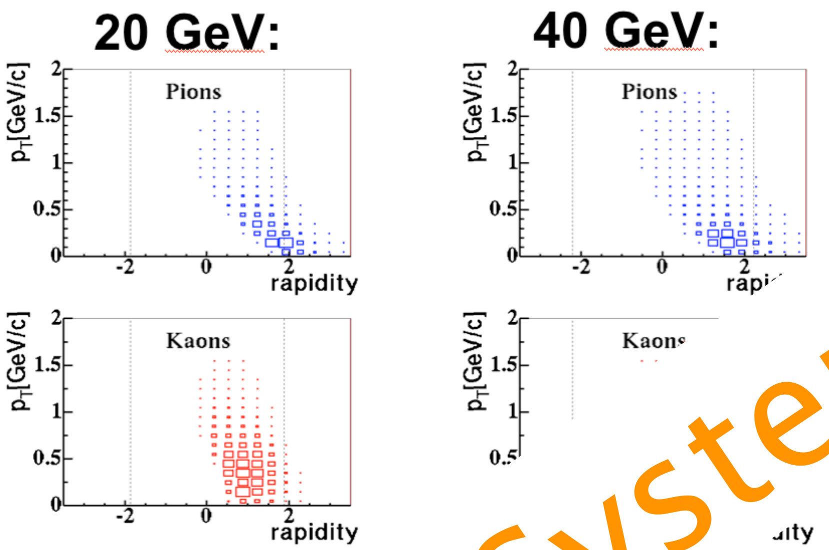


Image courtesy of A.Fedotov

What compensates for the lower event rate?

NA49 acceptance



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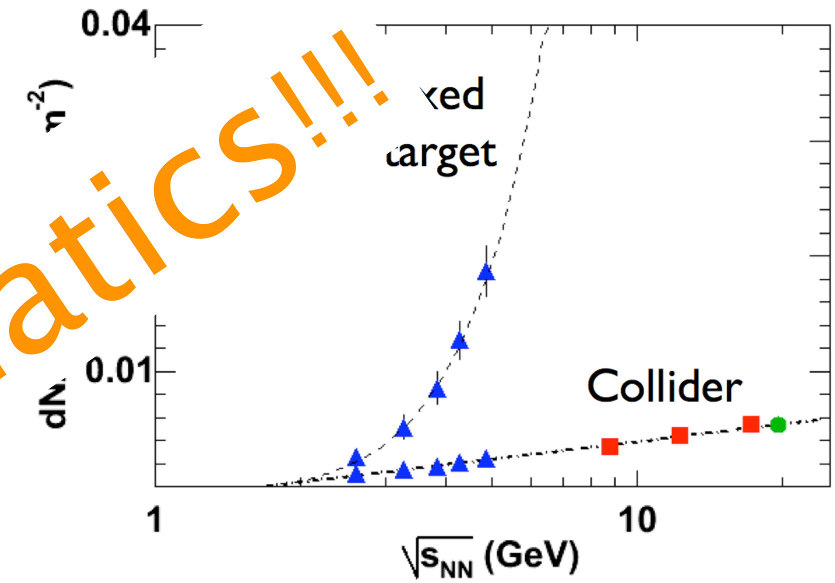


Image courtesy of G.Roland

Systematics!!!

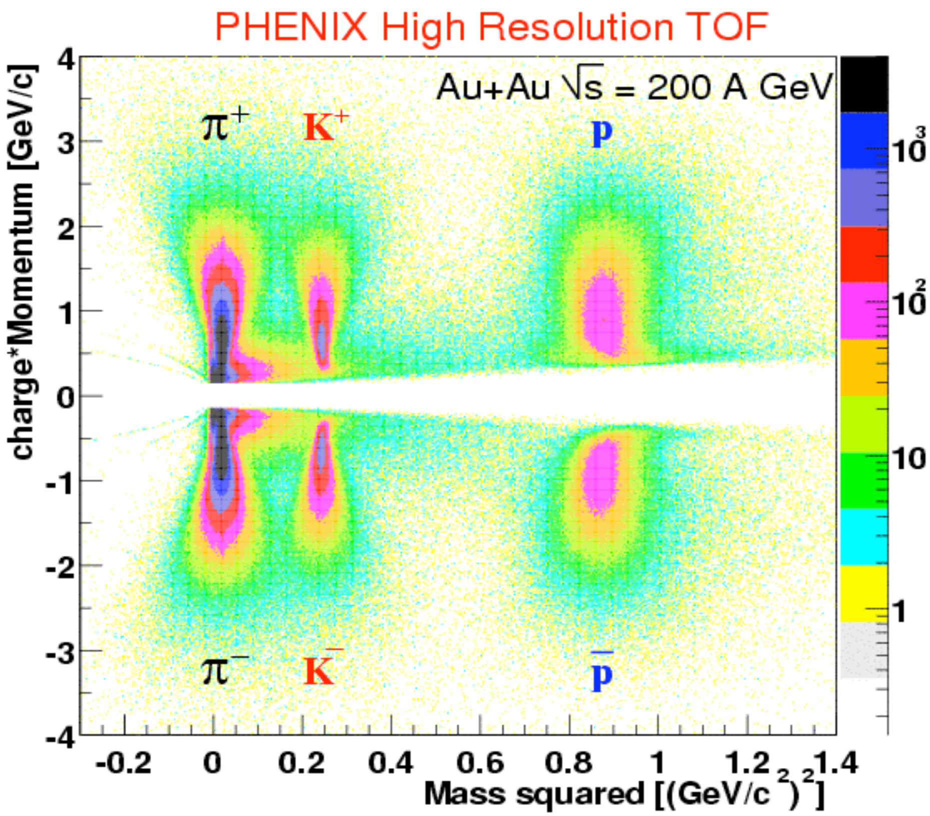
Big advantage that acceptance for collider detectors is totally independent of beam energy

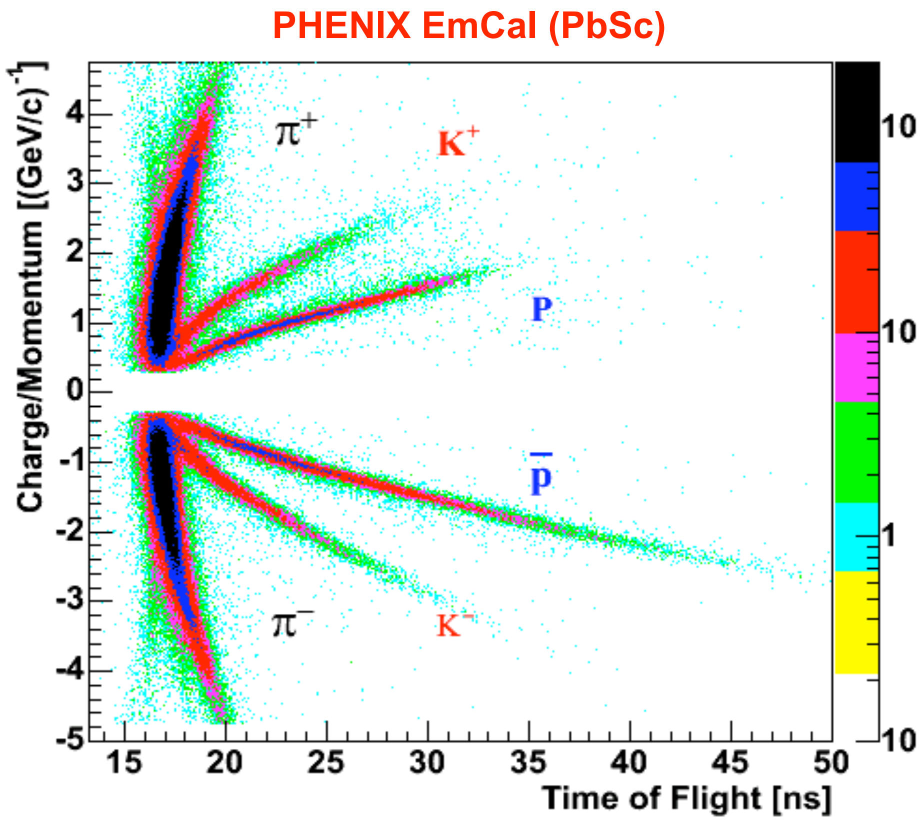
Big advantage that occupancy for collider detectors is much less dependent on beam energy

What must be done differently?

- Two excellent detectors exist already
  - Particle acceptance, detection & identification largely independent of beam energies
  - Capabilities well established
  - Significant upgrades planned or in progress
- Most significant changes will likely be in triggering
  - For example, transverse spread of neutrons at the ZDC increases with decreasing beam energy
  - Other triggering detectors see fewer particles, possibly with lower average energy and different angular distribution
- Some DAQ timing changes required (discussed later)

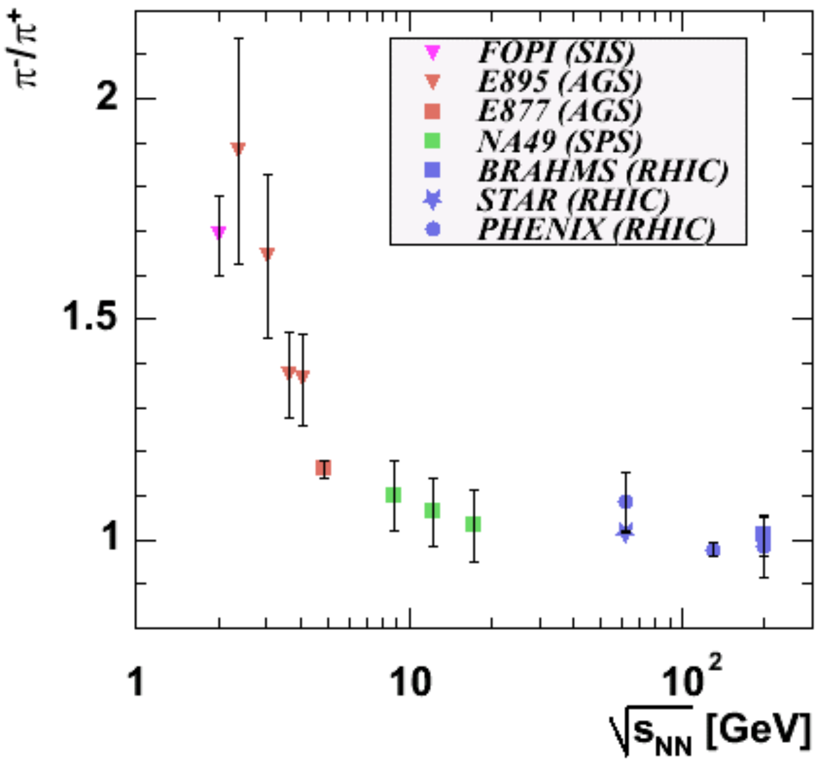
Charged particle identification

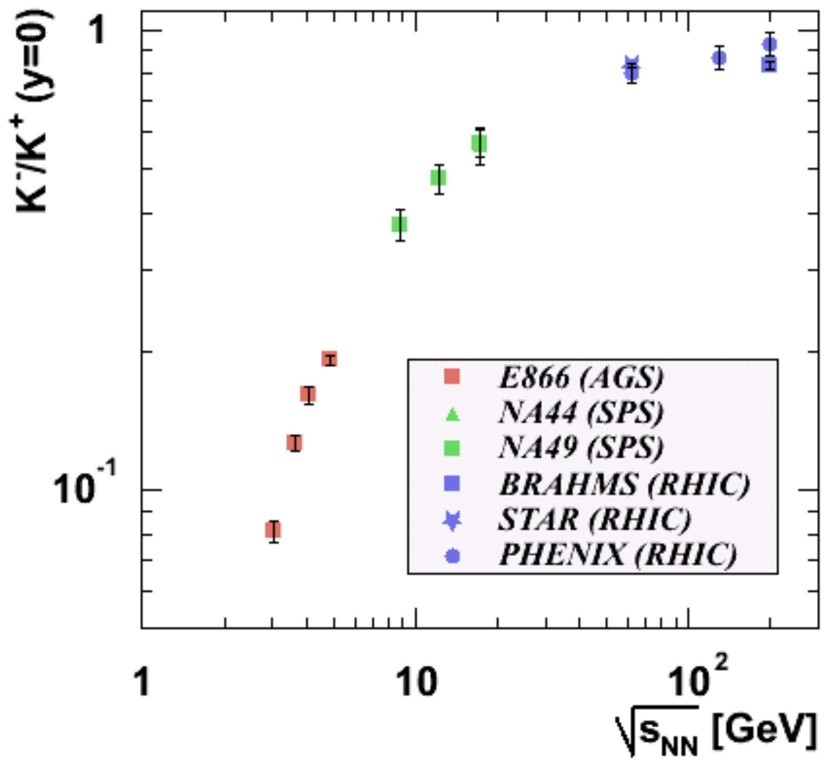




Images courtesy of J.Mitchell

Particle ratios





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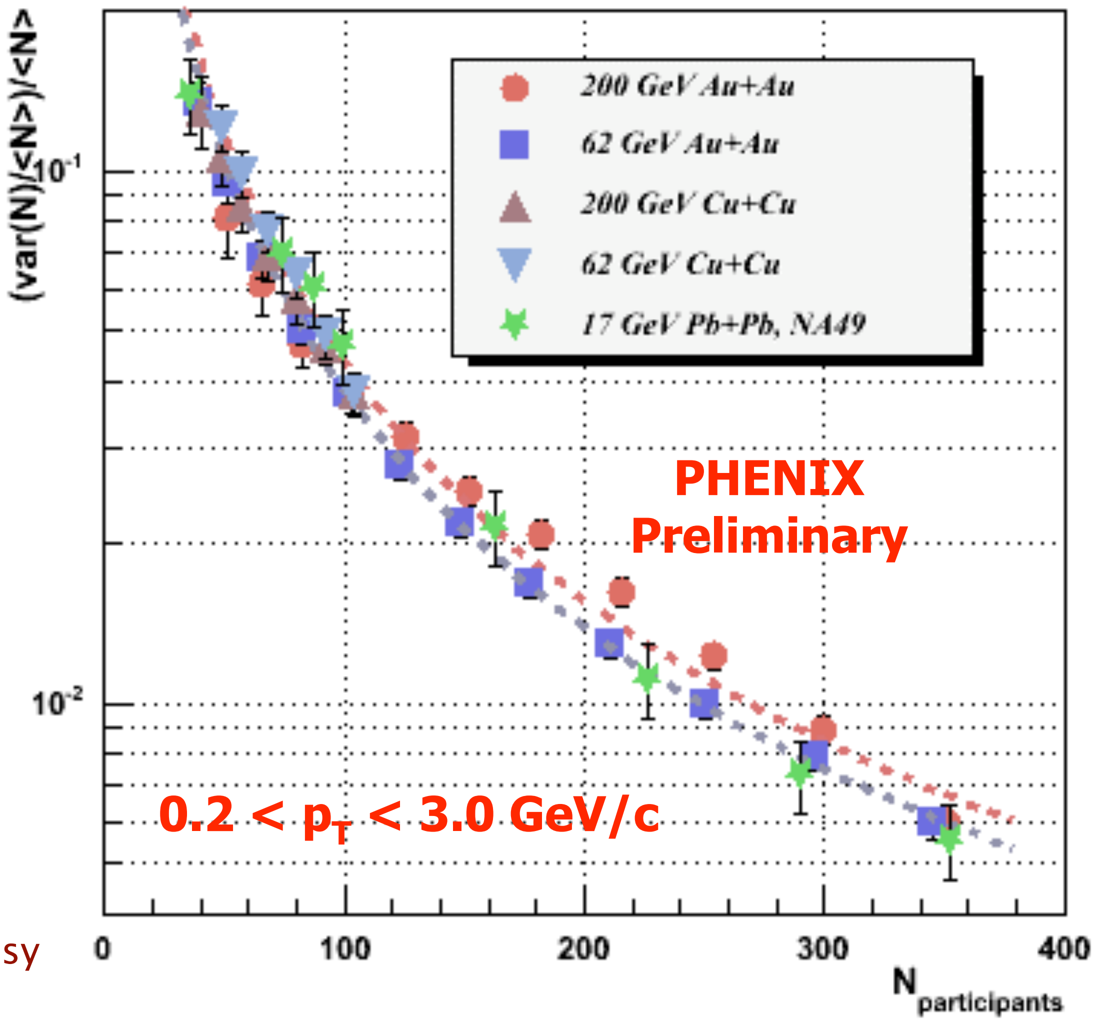
Fluctuations



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Triggering

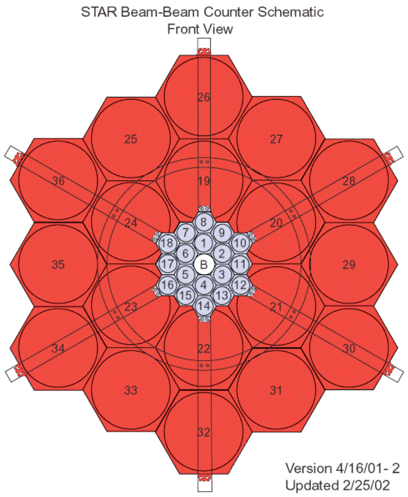


Image courtesy of T.Nayak

Number of particles within BBC coverage

Centrality (b in *fm*)	AuAu $E_{c.m.}$= 5 GeV		AuAu $E_{c.m.}$= 8.75 GeV	
	BBC Inner $3.3<\eta<5.0$	BBC Outer $2.1<\eta<3.3$	BBC Inner $3.3<\eta<5.0$	BBC Outer $2.1<\eta<3.3$
b<3	5	27	12	54
3<b<6	11	30	21	57
6<b<9	22	35	39	40
b>9	44	30	66	8

Particle identification

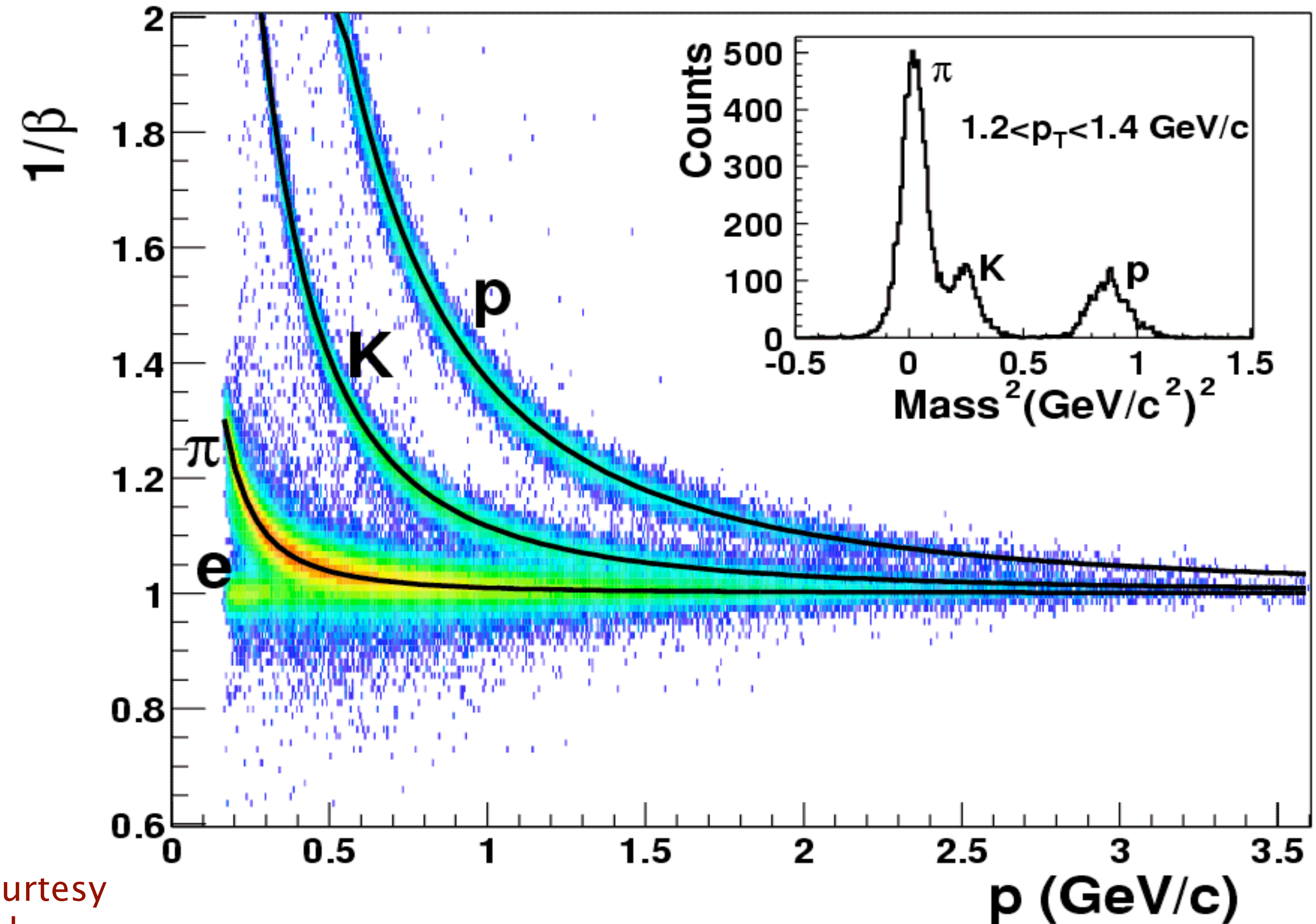


Image courtesy
of T.Nayak

Event plane resolution for elliptic flow

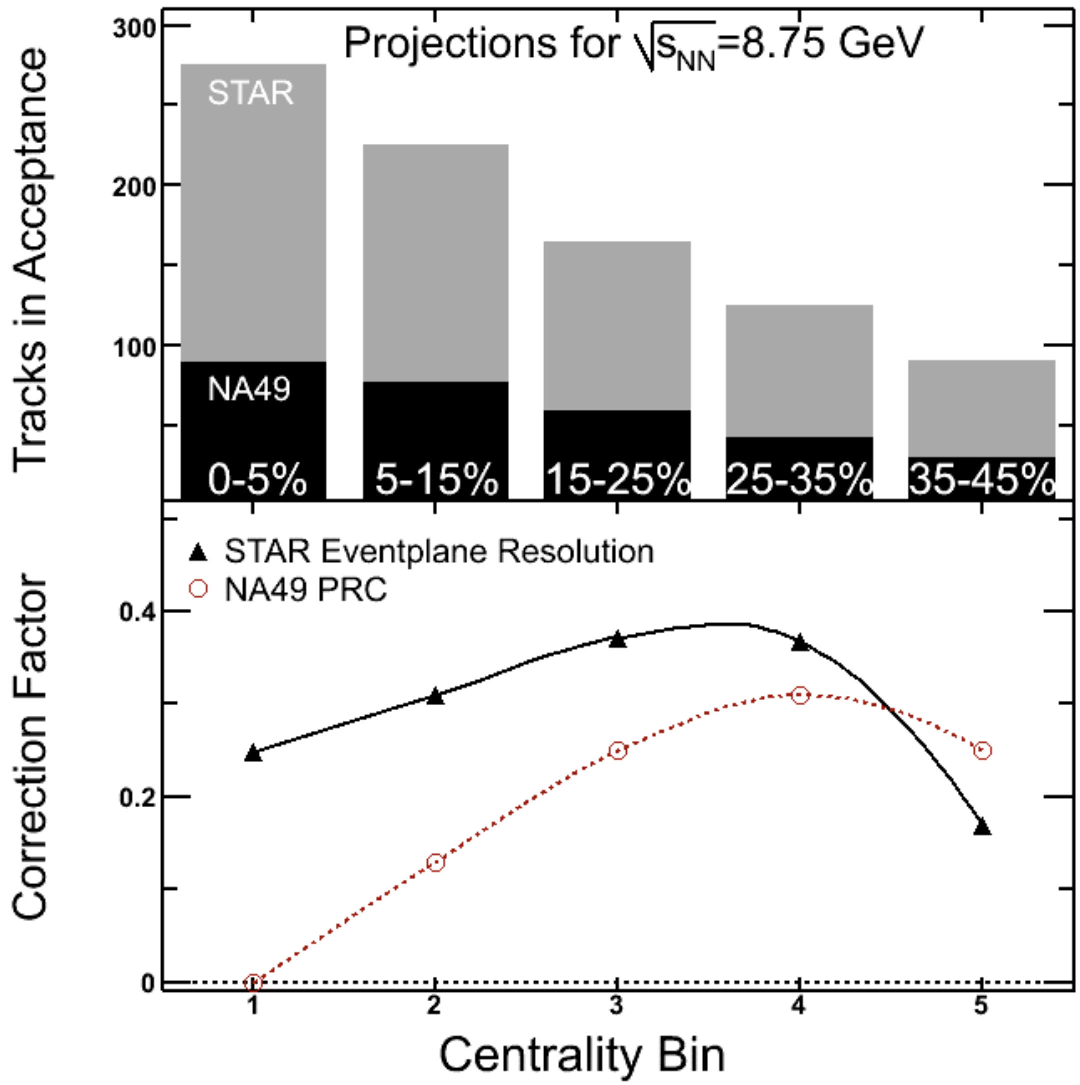


Image courtesy of P.Sorensen

<pT> fluctuations

PHYSICAL REVIEW C **72**, 044902 (2005)

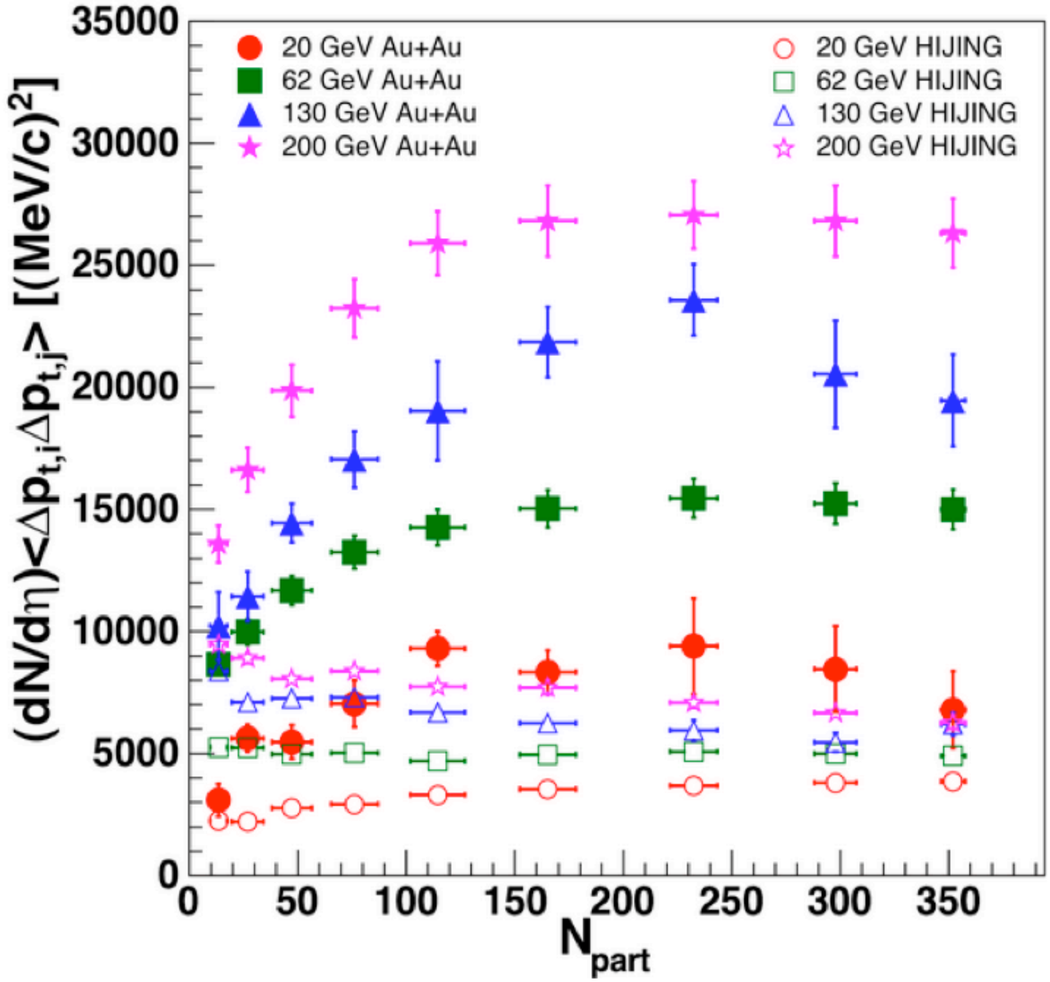


Image courtesy of P.Sorensen

First low energy beam test (2006)

- One day of machine studies with protons
  - Proton+proton @ center of mass energy of 22 GeV
    - Magnet settings appropriate for Au+Au @ nucleon-nucleon center of mass of ~9 GeV
    - Equivalent to fixed target with a beam of ~40 AGeV
    - Half of what had been done before then, would like to go 2x lower
- Results: Encouraging!
  - 4–5 hour beam life-time with collisions
  - “Found challenges that we know how to approach”
  - Got optics measurements needed to go lower in E

RHIC low energy Au+Au program begins!!!

- Injecting and colliding Au+Au @ $\sqrt{s_{NN}} = 9.2$ GeV
- Test was run June 6-7, 2007 (~7 years after RHIC start)
- Same magnetic rigidity as 2006 low energy proton test
- Overall, the run was a major success
- However, at the same rigidity, the β of the Au beam is lower than it was for the protons (.979 vs .997)
  - For the first time at RHIC, the RF frequency limits no longer could accommodate 360 RF buckets
  - New harmonic number h=366 caused some setup problems and serious experimental DAQ problems

Beam lifetime

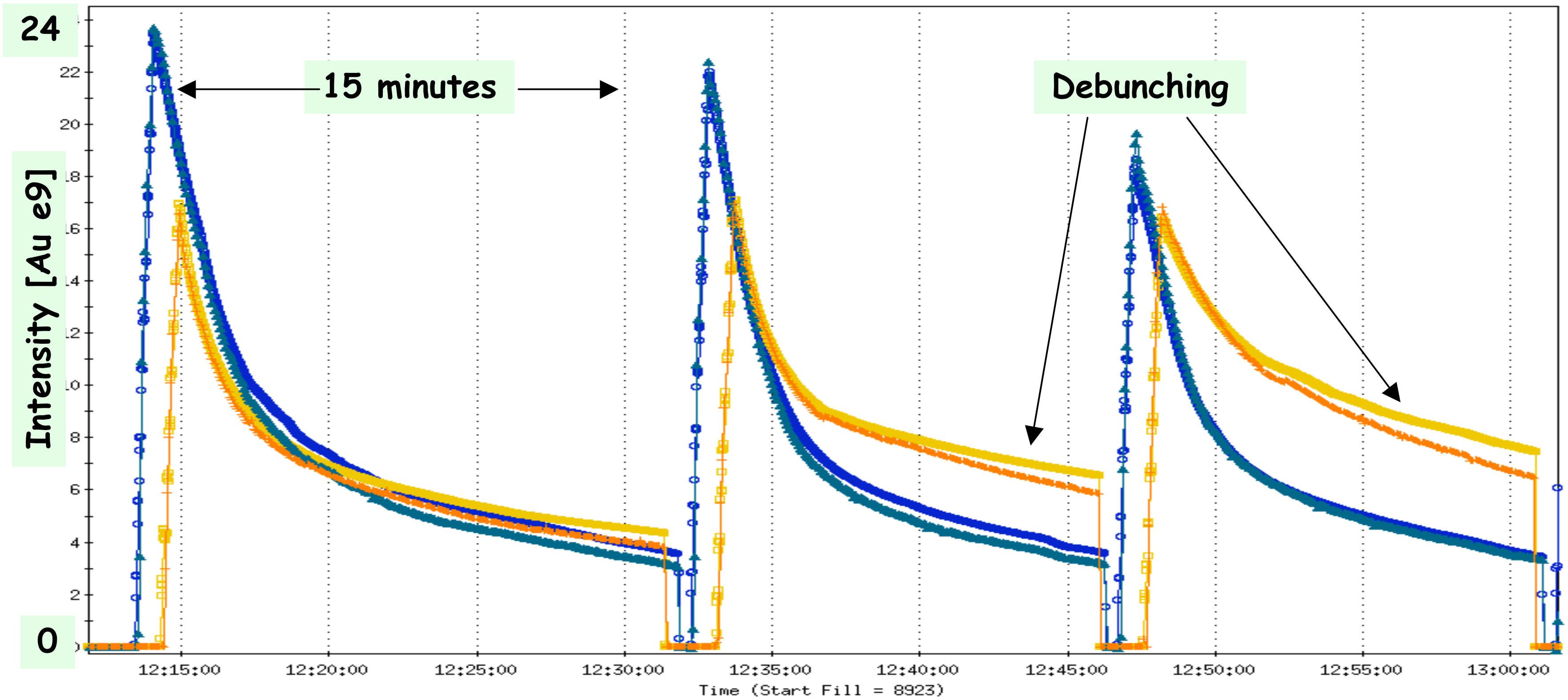
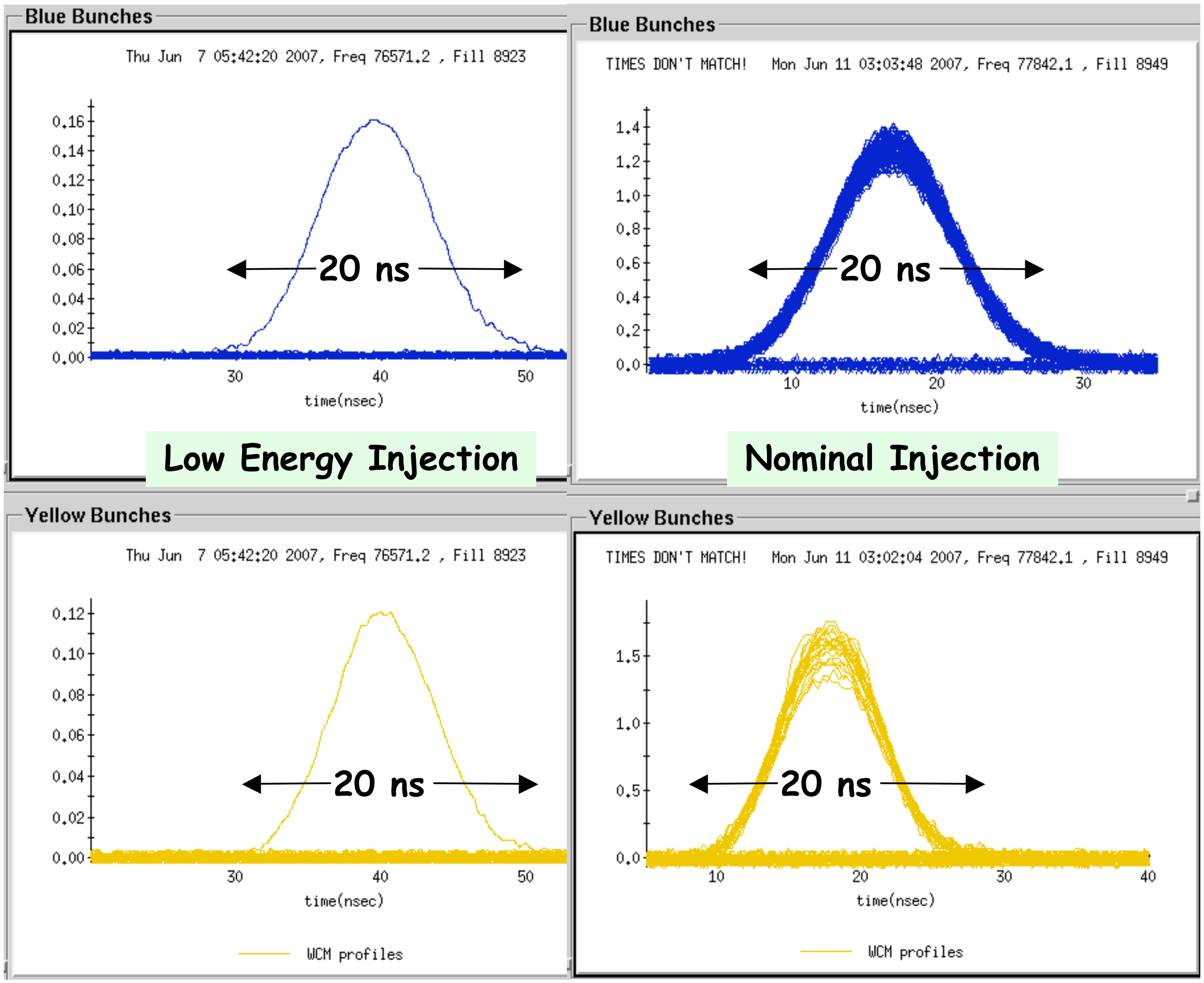


Image courtesy of T.Satogata

- Fast component lifetime: ~2 minutes
- Slow component lifetime: ~20 minutes (consistent with IBS prediction)

Bunch length



Very similar for high and low energy running! Encouraging, perhaps too good? Not yet understood…

Image courtesy of T.Satogata

Vernier scan

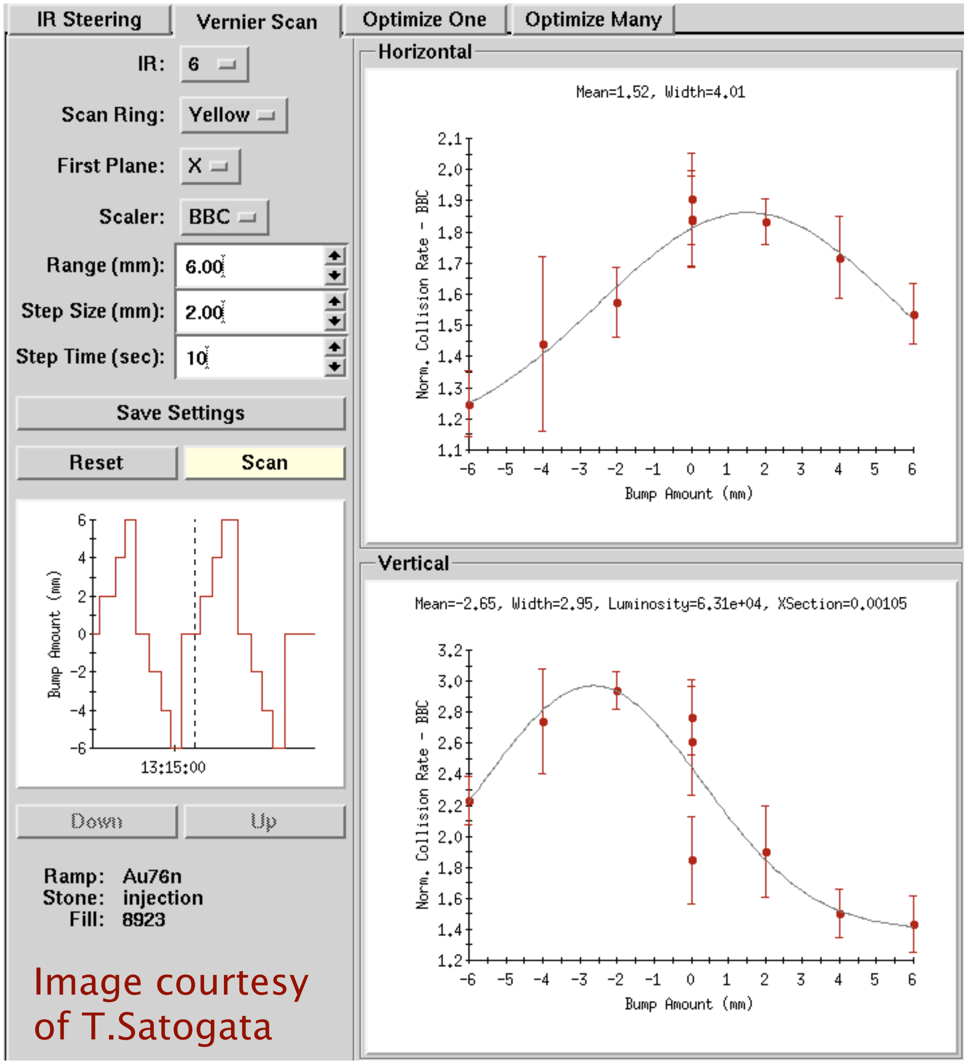
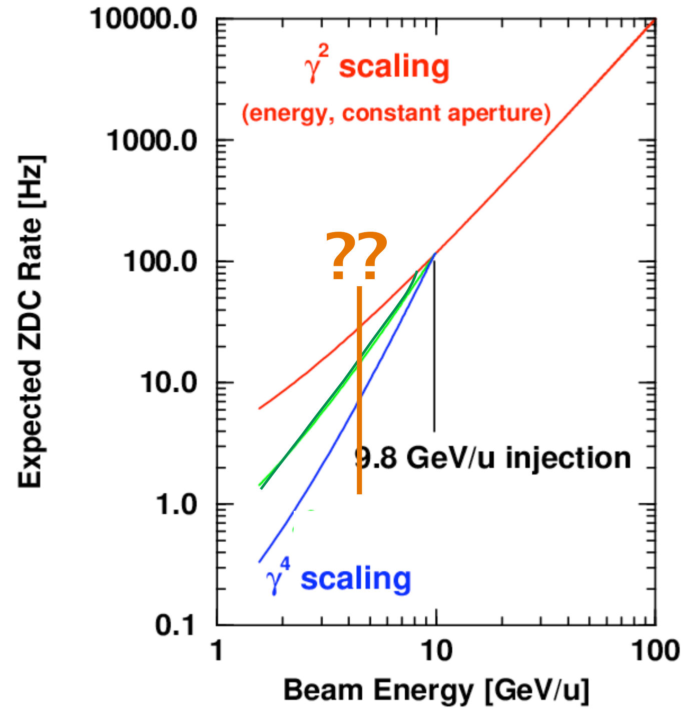
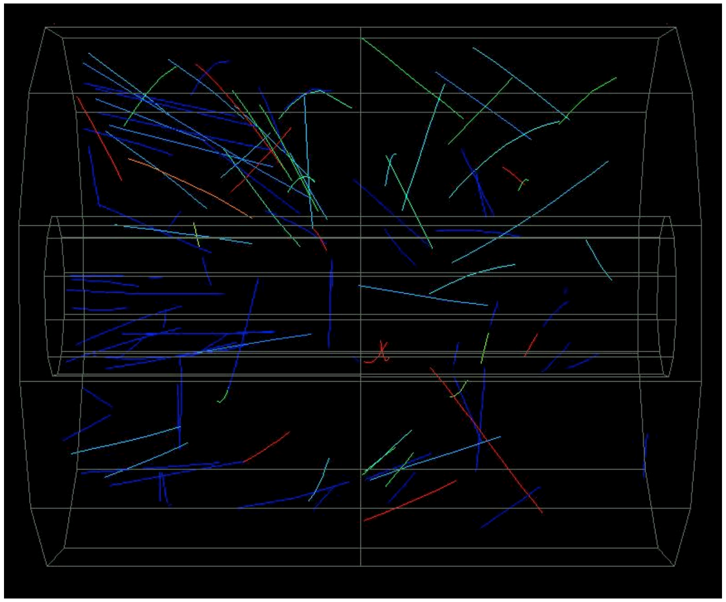


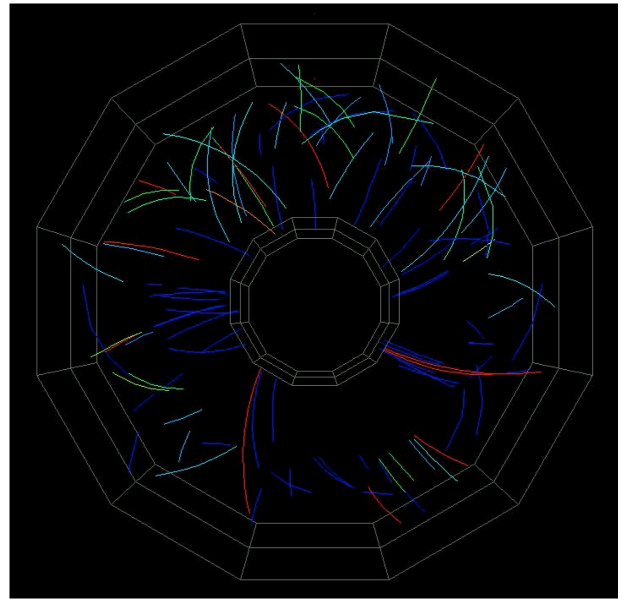
Image courtesy of T.Satogata

Can be used to find luminosity but a quantitative result is not yet available

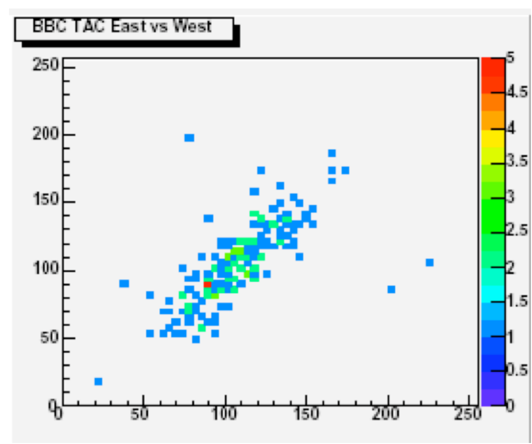


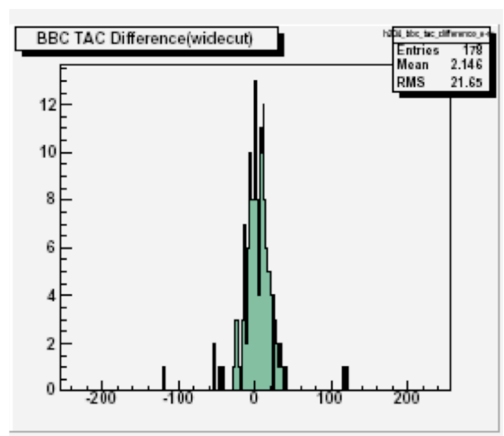
And experimental data!!!





Images courtesy of W.Christie





Au+Au test run summary

- Successes
  - LLRF worked like a charm, RF capture quick with phase detectors
  - Instrumentation worked remarkably well with h=366 timing
  - Orbit correction, coupling corrections worked well
  - Longitudinal beam distribution shorter than expected (scraping?)
  - Vernier scans still feasible even with 2-20 minute beam lifetimes
  - Have data for luminosity measurement
- Challenges
  - h=366 invalid events stopped PHENIX, nearly stopped STAR
  - Unipolar defocusing sextupoles limited chromaticity to near zero
  - Minor online model issues prevented full range of tune adjustment
- All challenges are solvable either offline or during test run setup

What should be done next (& when) ?

- Proposal submitted to test Au+Au @ $\sqrt{s_{NN}} = 5$ GeV (~ equal to top AGS energy) during the next RHIC run
  - Highest priority is determining the luminosity and lifetime
  - Issues with larger harmonic number should be largely solvable without beam (i.e. during the upcoming shutdown)
  - With some luck, a very small data sample may be possible
- The results of this test will provide critical input to the development of a low energy physics program
- Ongoing detector upgrades (especially the STAR TOF) will substantially improve the physics capability
- Low energy runs must mesh with other RHIC priorities

What should be measured?

- Lots of ideas, mostly qualitative or semi-quantitative
- Largely related to bulk properties, not rare probes
- Fluctuations & correlations of many varieties
- Energy dependence of flow characteristics, both v_1 and v_2, and especially pions compared to protons
- "Lumpy" ("clumpy"?) final states

- Ideally, continuing work and impending appearance of real data will "encourage" theorists to be more specific
- Of course, data will likely point to new directions...

Related worldwide experimental efforts

- RHIC @ high energy
  - Study formation and properties of "perfect liquid"
- FAIR @ lower energies
  - Add an excellent capability for rare probes
- SPS @ similar energies
  - Continue NA49 energy scan with lighter systems
- LHC @ very high energy
  - Extend study at $\mu_B \approx 0$ and also scaling properties
  - critRHIC+LHC: QCD over 3 decades in energy

Some closing thoughts

- Lower energy collisions at RHIC will greatly broaden the experimental exploration the QCD phase diagram
- Existing SPS energy scan data are very intriguing
  - Colliding beam setup will produce data with dramatically different (probably much better) systematic errors
- Current theory of the QCD phase structure is a bit confusing but suggestive that a critical point may exist in an experimentally accessibly location
  - Opportunity to settle the question with data instead of lattice?
- All machine tests done to date are very encouraging
- Machine capabilities and future experimental program are under very active development