Results From the Recent Lowest Energy ($\sqrt{s_{NN}}$ = 9.2 GeV) Collisions at RHIC

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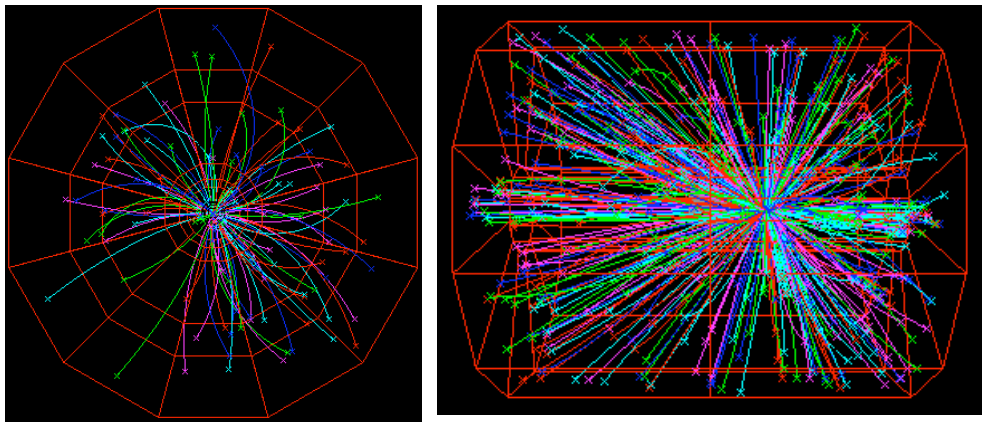
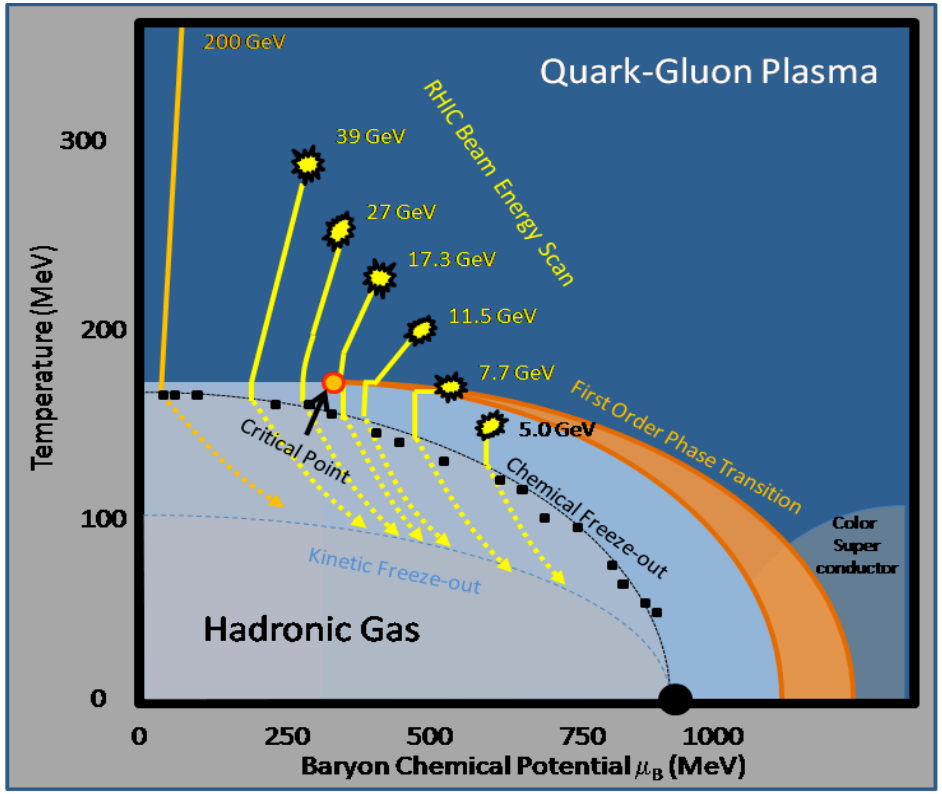
Outline:

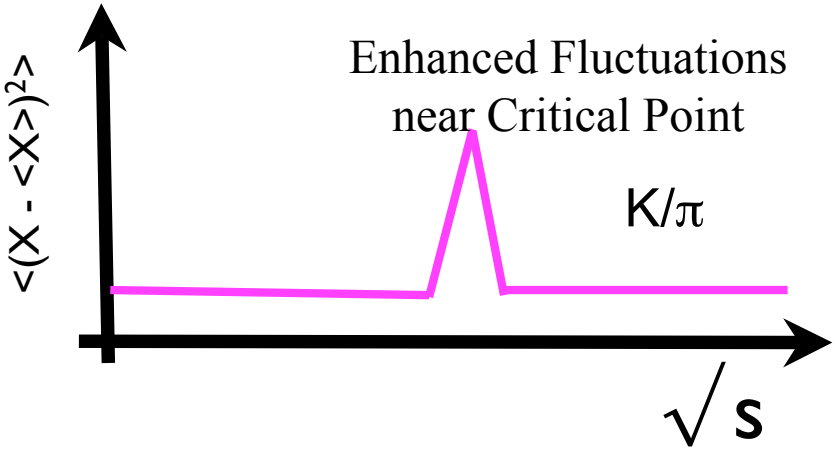
- ✓ Introduction
- ✓ Selected Bulk properties at $\sqrt{s_{NN}}$ = 9.2 GeV
- ✓ K/π Ratio Comparison to Theory
- ✓ Beam Energy Scan Program at RHIC



Introduction

STAR Internal Note - SN0493, 2009





Motivation of the BES program at RHIC is to map the QCD phase diagram -

- ✓ QCD phase boundary
- ✓ QCD critical point

Plan :

Access to phase diagram

- ✓ T and μ_B varies with $\sqrt{s_{NN}}$
- ✓ T and μ_B measured from spectra and ratios of produced particles

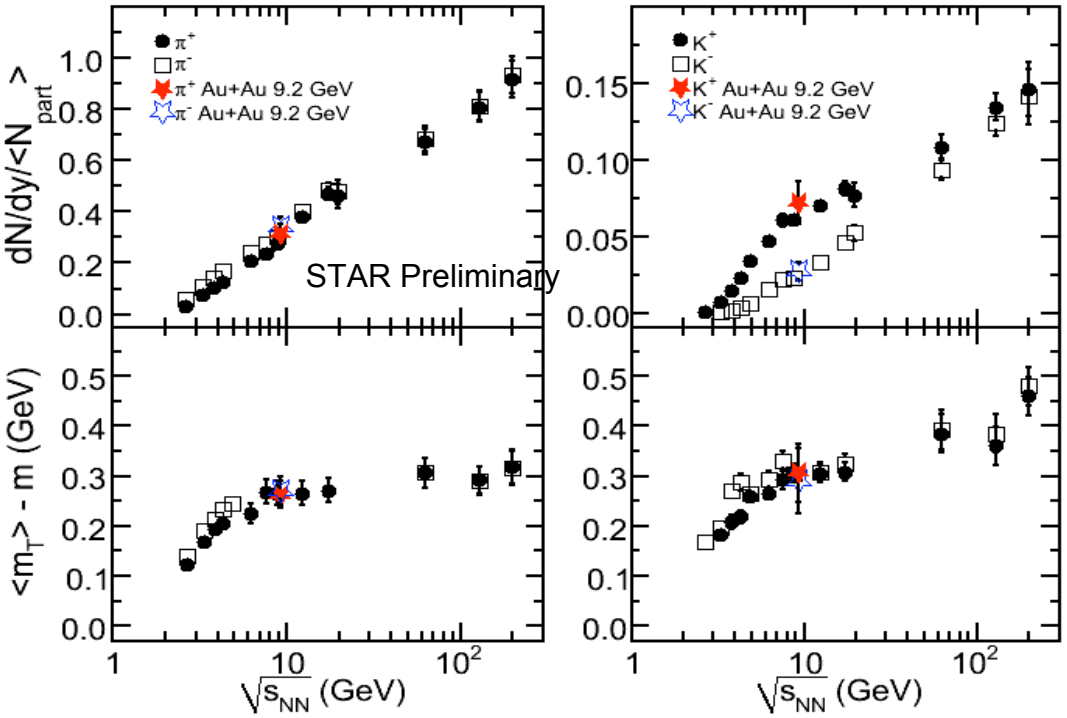
Signatures

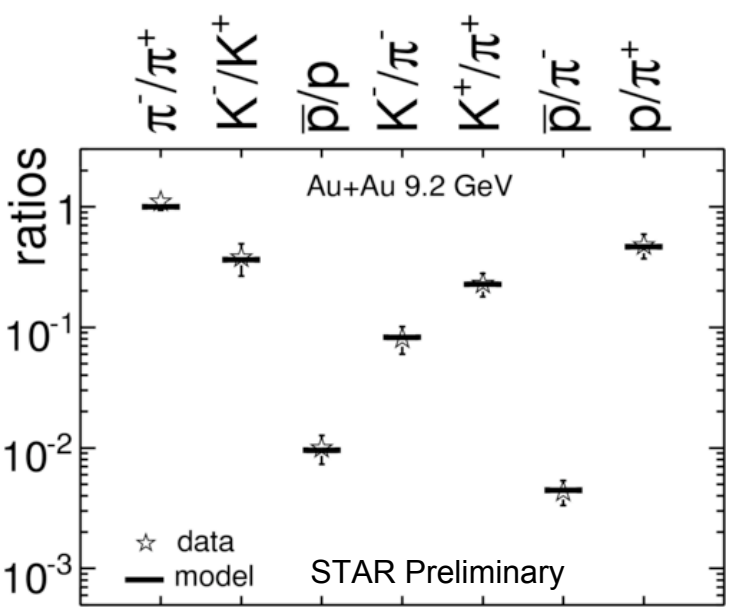
- ✓ For locating different phases
- ✓ For locating critical point

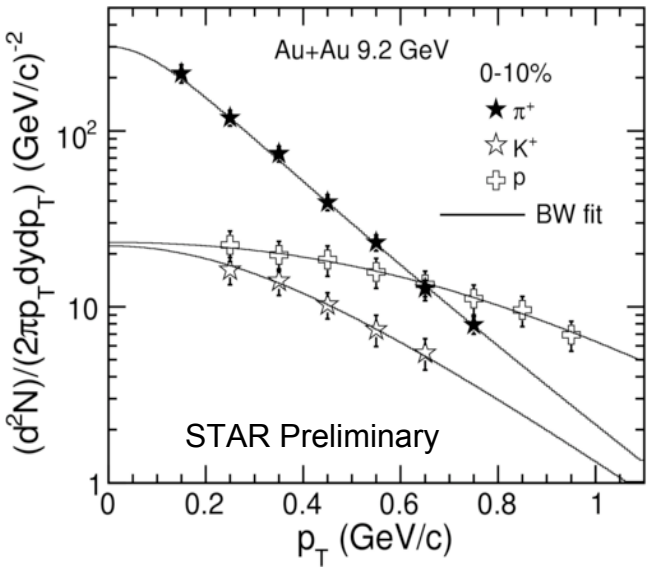
Typical example:

Strangeness enhancement and the fluctuation in K/π ratio

Bulk Properties at 9.2 GeV







T_{ch} = 151 +/- 2 +/- 7 MeV

μ_B = 354 +/- 7 +/- 30 MeV

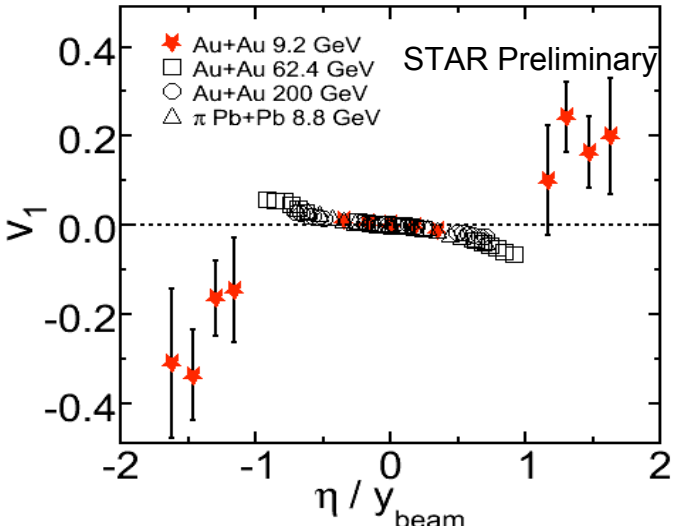
T_{kin} = 105 +/- 10 +/- 16 MeV

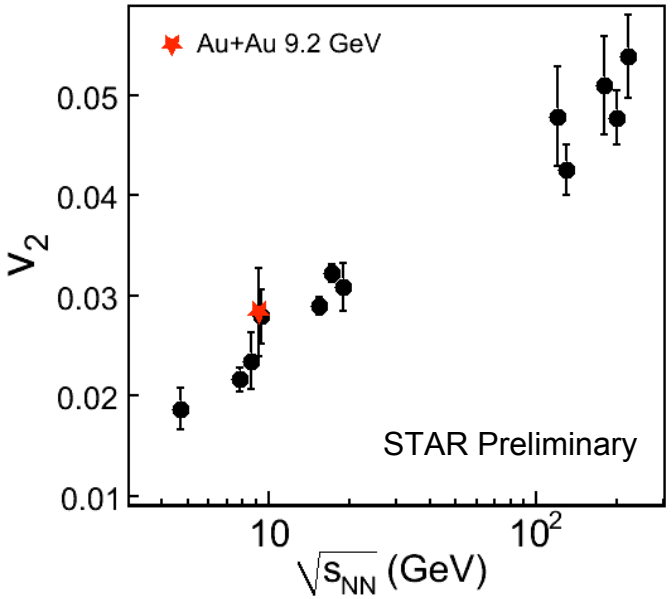
$\langle\beta\rangle$ = 0.46c +/- 0.01c +/- 0.04c

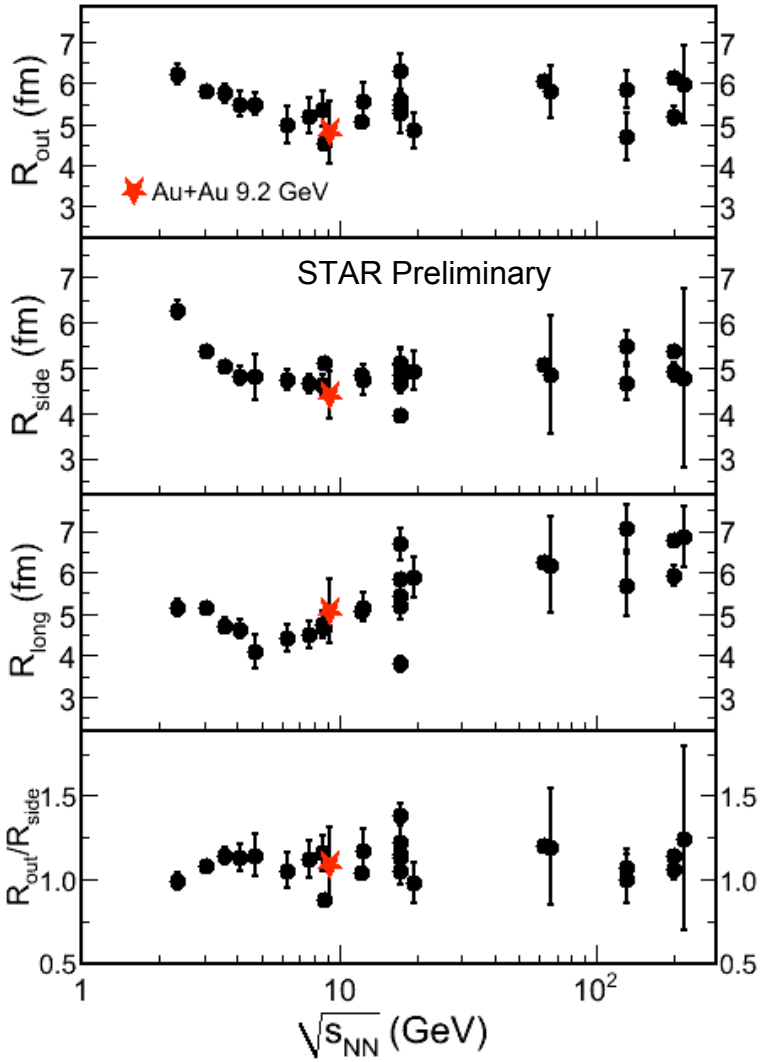
arXiv:0909.4131v1

Bulk Properties at 9.2 GeV

arXiv:0909.4131v1

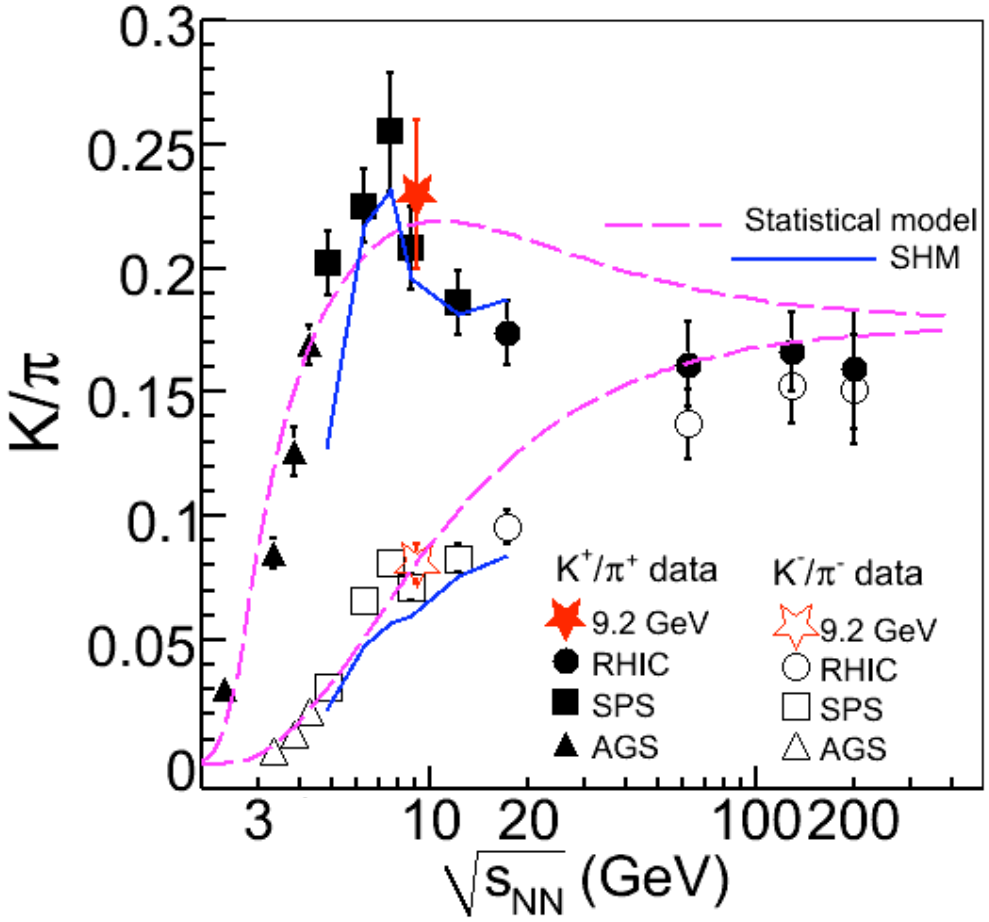






- ✓ Energy dependence of azimuthal anisotropy and pion interferometry measurements
- ✓ Results comparable to SPS results at similar beam energy

Current Understanding of the K/π ratio - I



Statistical Model

J. Cleymans, H. Oeschler, K. Redlich and S. Wheaton, Eur. Phys. J. A 29, 119 (2006)

- ✓ Entropy/T^3 as function of collision energy - increases for mesons, and decreases for baryons
- ✓ Thus, a rapid change is expected at the crossing of the two curves, as the hadronic gas undergoes a transition from a baryon-dominated to a meson-dominated gas, T=140 MeV, μ_B=410 MeV, energy ~ 8.2 GeV

Statistical Hadronization Model

J. Rafelski, I. Kuznetsova and J. Letessier, J. Phys. G 35, 044011 (2008)

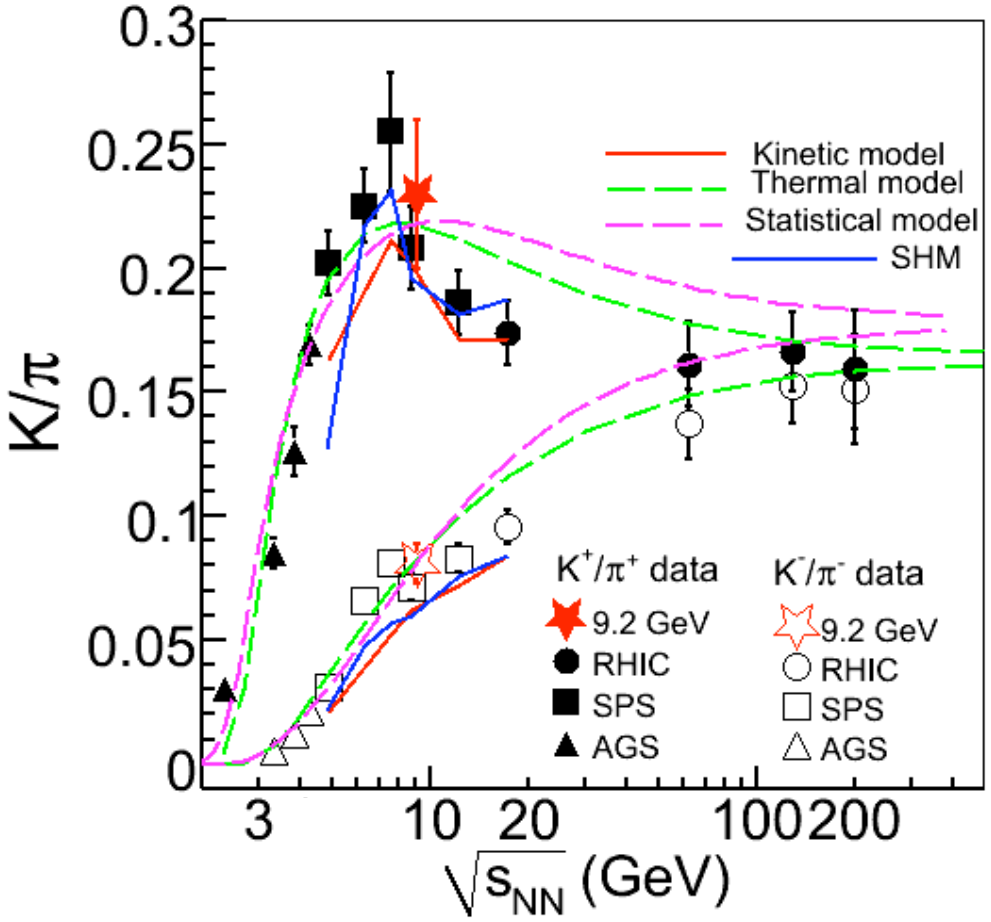
- ✓ Strong interactions saturate particle production matrix elements
- ✓ Below 7.6 GeV system in chemical non-equilibrium, above over saturation of chemical composition

K/π ratio also reflects the strangeness enhancement in heavy-ion collisions. Recent 9.2 GeV results (only 3000 events) follow the observed beam energy dependence trend

Current Understanding of the K/π ratio - II

Thermal Model

A. Andronic, P. Braun-Munzinger and J. Stachel , Phys. Lett B 673, 142 (2009)



- ✓ This model includes many higher resonances (m > 2 GeV) and σ-meson which is neglected in most of the models

Hadronic non-equilibrium Kinetic Model

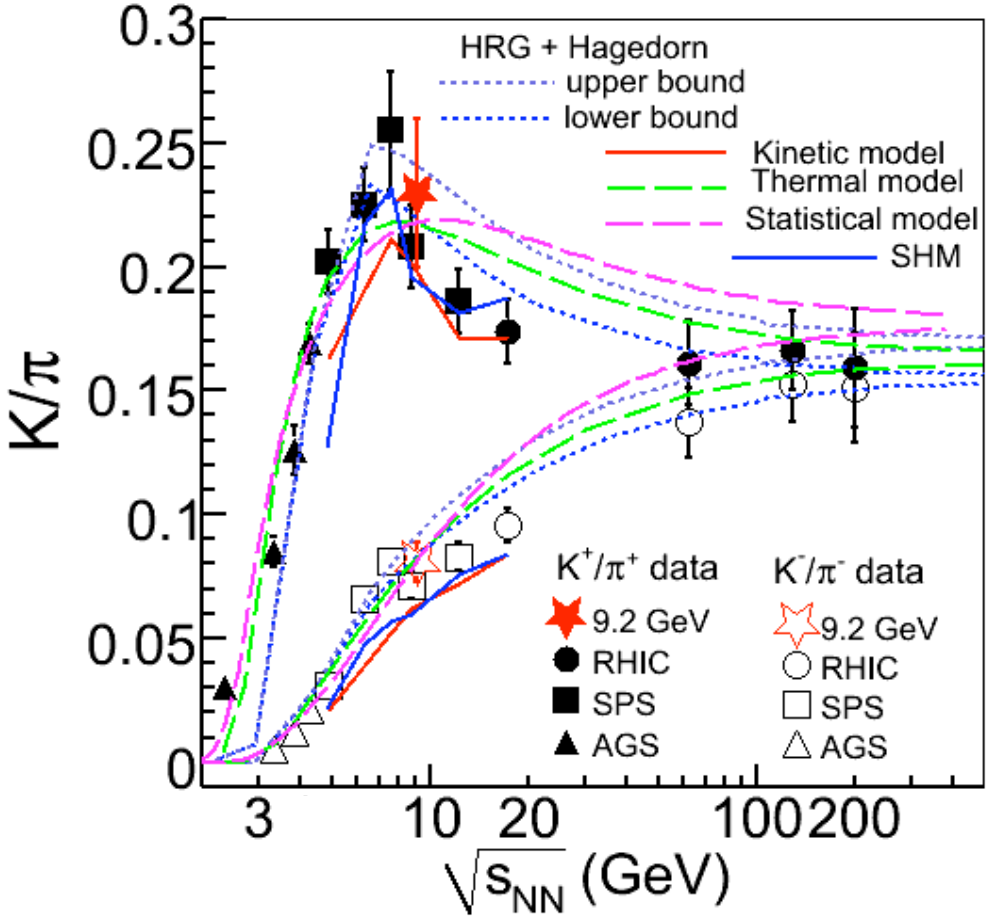
B. Tomasik and E. E. Kolomeitsev, Eur. Phys. J. C 49, 115 (2007)

- ✓ Surplus of strange particles are produced in secondary reactions of hadrons generated in nuclear collisions.
- ✓ Amount of kaons depend on the lifetime of the whole system

Current Understanding of the K/π ratio - III

Hadron Resonance Gas + Hagedorn Model

S. Chatterjee, R. M. Godbole, and S. Gupta, arXiv:0906.2523v1



- ✓ Model assumes a bag of hadron gas
- ✓ The model includes all hadrons up to masses 2 GeV as given in PDG
- ✓ Unknown hadron resonances are included in the model through Hagedorn formula
- ✓ The model assumes that the strangeness in the baryon sector decays to strange baryons and does not contribute to kaon production

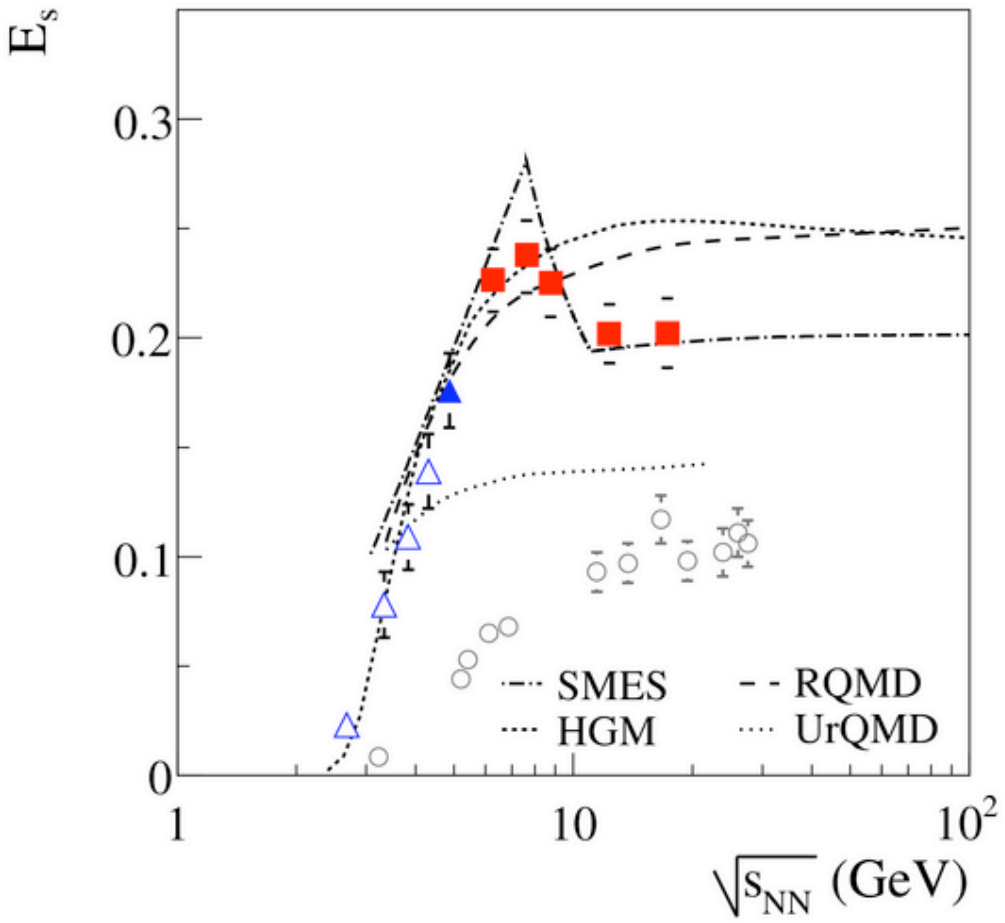
9.2 GeV is close to the maximum baryon density region predicted by models PRC 74, 047901 (2006)

STAR plans to measure the K/π ratio at beam energies 11.5, 7.7, and 5 GeV in the year 2010 with high precision

Current Understanding of the K/π ratio - IV

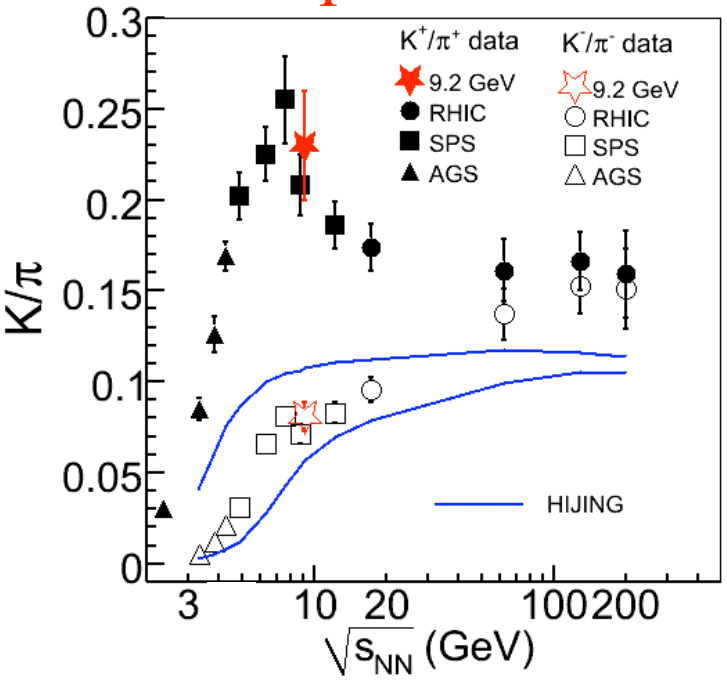
Statistical Model of the Early Stage (QGP)

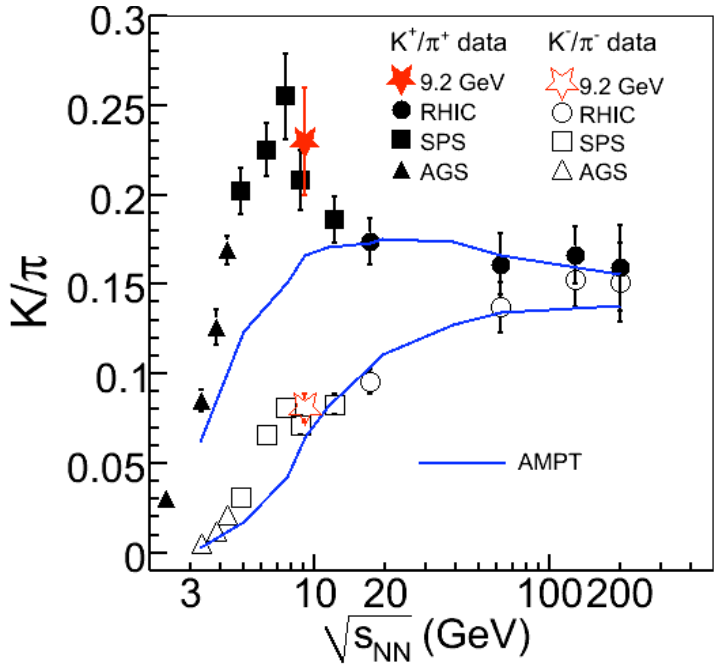
Plot from NA49 collaboration

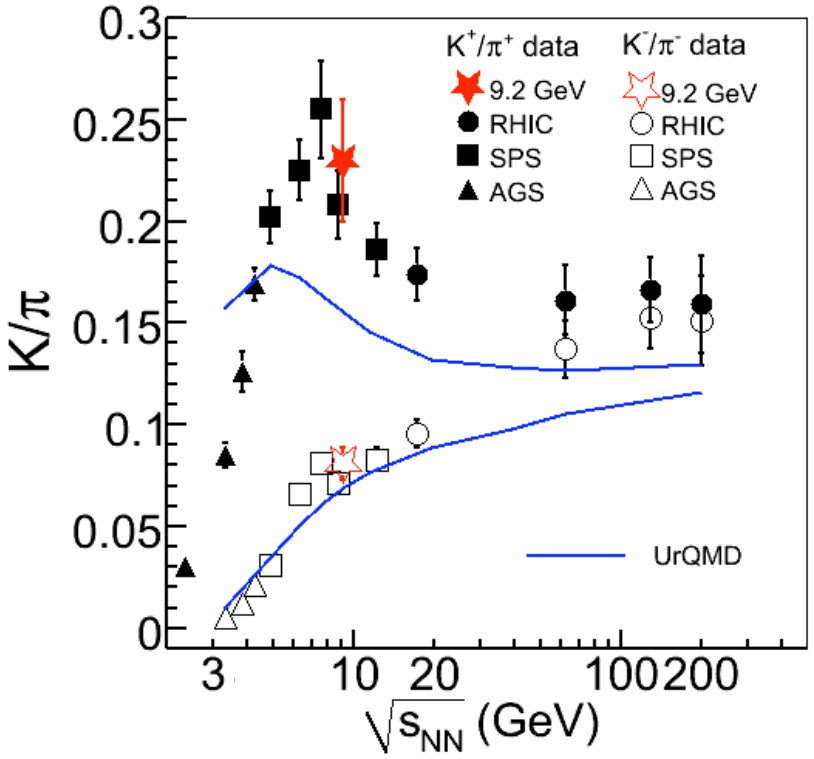


- ✓ Model assumes a phase transition
- ✓ $E_s \propto$ ratio of strangeness to entropy density
- ✓ Strange particles increase with Temperature and in QGP scenario masses of strangeness carriers decrease
- ✓ "Horn" is due to QGP formation in this model

Comparison with UrQMD, HIJING and AMPT







Models give comparable values for K^-/π^- vs. $\sqrt{s_{NN}}$ as data but fail to match the experimental data for K^+/π^+

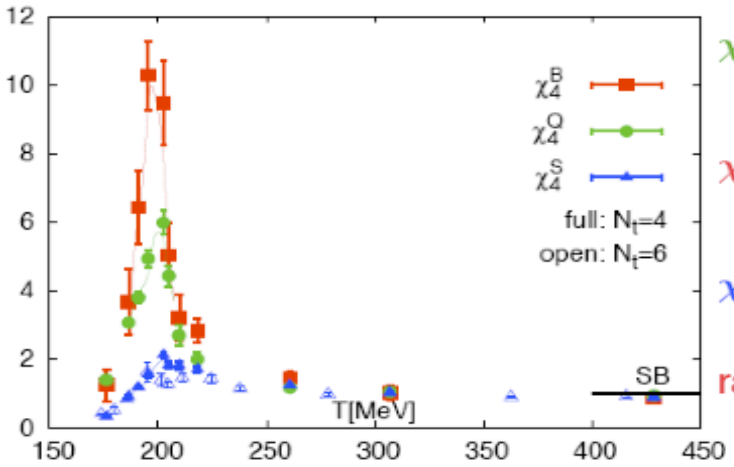
Recent STAR 9.2 GeV K^+/π^+ results are higher compared to UrQMD, HIJING, and AMPT models

Outlook of BES Program

Look for QCD critical point through fluctuation studies-

vanishing chemical potentials:

RBC-Bielefeld, arXiv:0805.0236



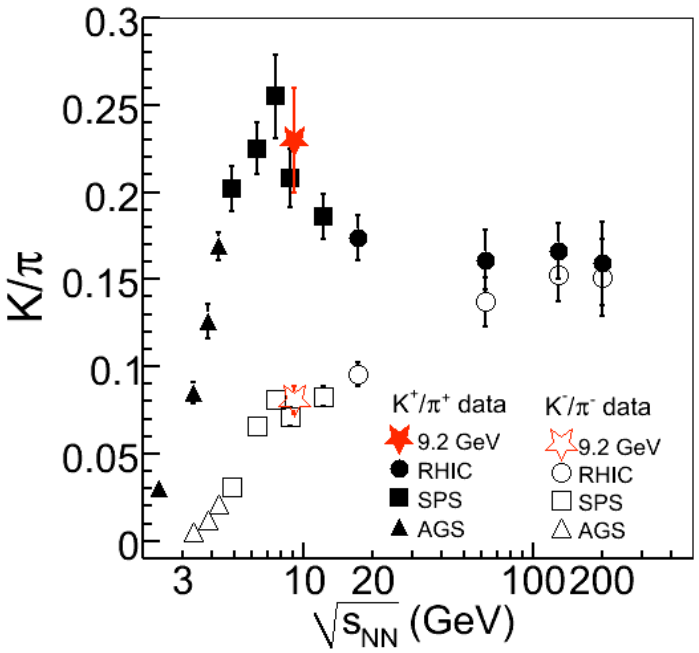
$$\chi_4^Q = \frac{1}{VT^3}\left(\langle Q^4\rangle - 3\langle Q^2\rangle^2\right)$$

$$\chi_4^B = \frac{1}{VT^3}\left(\langle N_B^4\rangle - 3\langle N_B^2\rangle^2\right)$$

$$\chi_4^S = \frac{1}{VT^3}\left(\langle N_S^4\rangle - 3\langle N_S^2\rangle^2\right)$$

rapid approach to SB limit

$\Rightarrow$ large light quark number & charge fluctuations across transition region



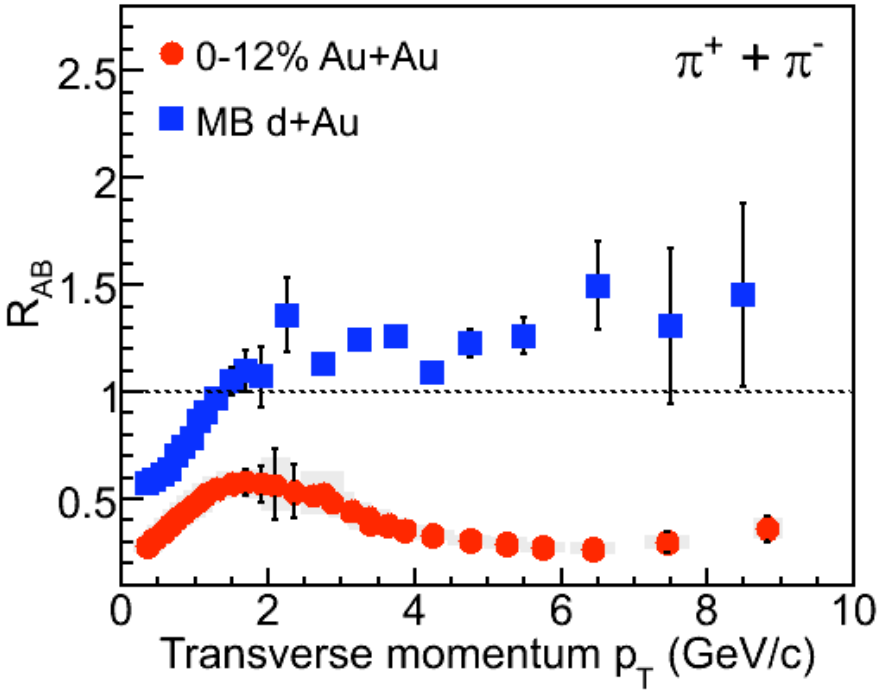
Energies for coming Run: 11.5, 7.7 and 5 GeV

Energy dependence of K/π ratio will be used to study strangeness enhancement in high baryon density region

K/π fluctuation will also be studied in detail

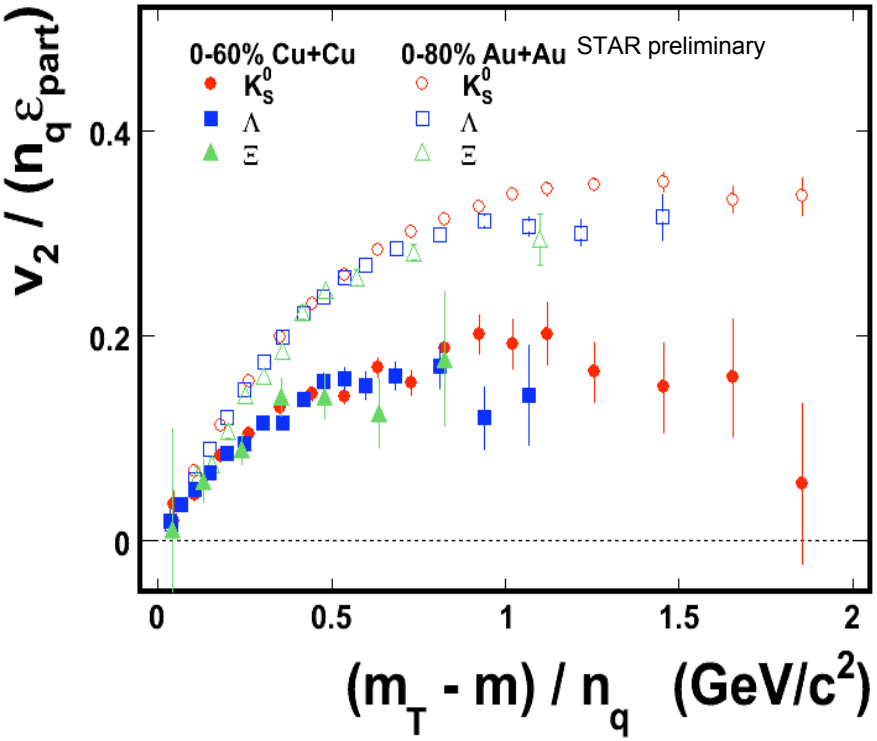
Outlook of BES Program

✓ Onset of high p_T suppression



STAR : PLB 655 (2007) 104,
PLB 637 (2006) 161,
PRL 97 (2006) 152301

✓ Onset of NCQ scaling in v_2 measurements



STAR : PRC 77 (2008) 54901

Summary

- ✓ Results from the lowest energy ($\sqrt{s_{NN}}$ = 9.2 GeV) data at RHIC for various bulk observables e.g. v_1, v_2, HBT, dN/dy, and $\langle m_T \rangle$-m are presented.
- ✓ Most of the bulk properties are consistent with previously established beam energy dependence trend.
- ✓ Important observables to locate the QCD critical point and QCD phase boundary: event-by-event fluctuations of higher moments of conserved quantities, high-p_T particle suppression, constituent quark scaling , K/π fluctuations etc.
- ✓ This talk focuses on beam energy dependence of K/π ratio and comparison with various models. This is an important measurement for the beam energy scan program as it reflects the strangeness enhancement in heavy-ion collisions.
- ✓ We observe K^+/π^+ vs. $\sqrt{s_{NN}}$ is best explained using Thermal+Hagedorn model. Event generator models e.g. UrQMD, HIJING and AMPT fail to explain energy dependence of K^+/π^+ ratio.
- ✓ Our current measurement of 9.2 GeV is close to the maximum attained K^+/π^+ value observed in heavy-ion collisions so far.
- ✓ STAR with excellent particle identification using TPC and TOF will measure K/π ratios at several beam energies of $\sqrt{s_{NN}}$ = 5, 7.7, 11.5, 27, 39 GeV and measurements exist at 9.2, 19.6, 62.4, 130, and 200 GeV.

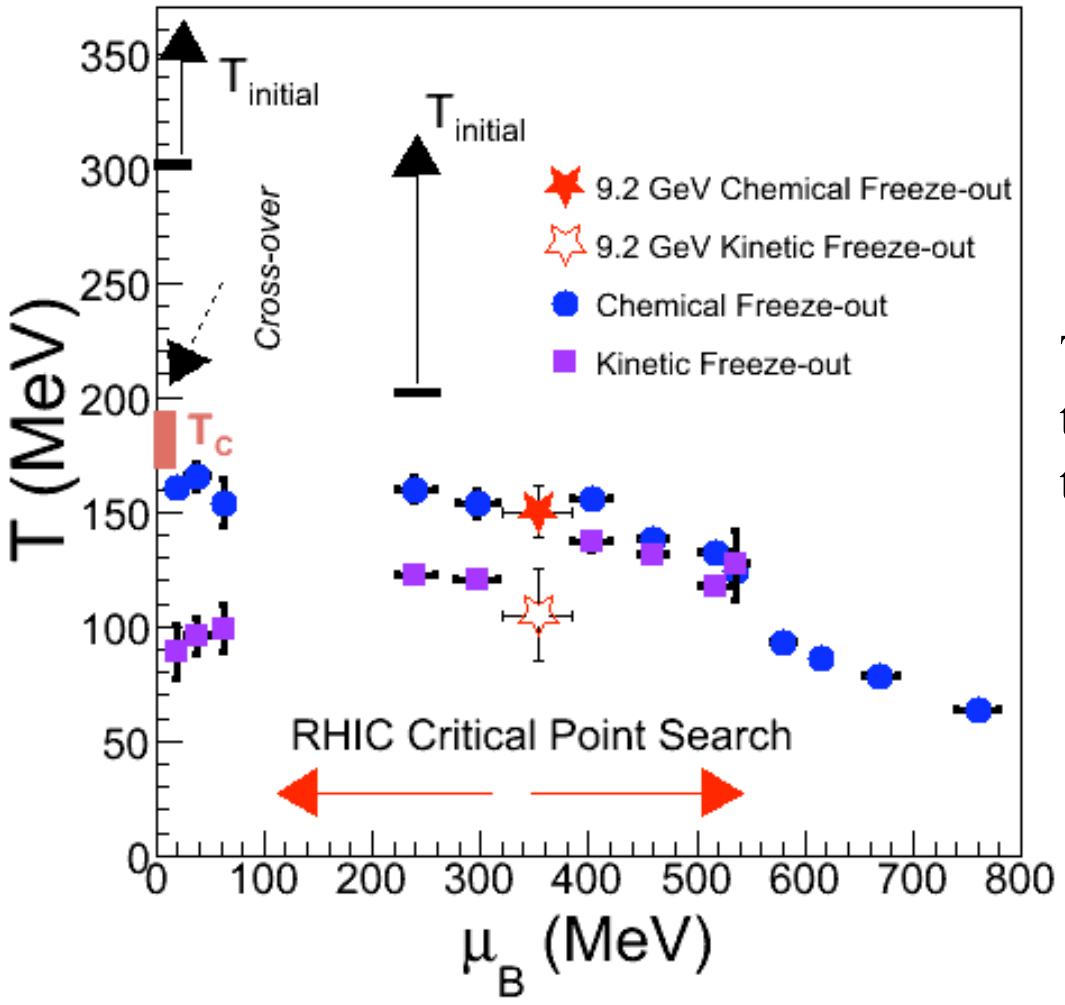
Thanks

Thanks to STAR Collaboration

Argonne National Laboratory
Institute of High Energy Physics - Beijing
University of Birmingham
Brookhaven National Laboratory
University of California, Berkeley
University of California - Davis
University of California - Los Angeles
Universidade Estadual de Campinas
Carnegie Mellon University
University of Illinois at Chicago
Creighton University
Nuclear Physics Inst., Academy of Sciences
Laboratory of High Energy Physics - Dubna
Particle Physics Laboratory - Dubna
Institute of Physics. Bhubaneswar
Indian Institute of Technology. Mumbai
Indiana University Cyclotron Facility
Institut Pluridisciplinaire Hubert Curien
University of Jammu
Kent State University
University of Kentucky
Institute of Modern Physics, Lanzhou
Lawrence Berkeley National Laboratory
Massachusetts Institute of Technology
Max-Planck-Institut fuer Physics
Michigan State University
Moscow Engineering Physics Institute
City College of New York
NIKHEF and Utrecht University
Ohio State University
Panjab University. Chandigarh
Pennsylvania State University
Institute of High Energy Physics - Protvino
Purdue University
Pusan National University
University of Rajasthan
Rice University
Instituto de Fisica da Universidade de Sao Paulo
University of Science and Technology of China
Shanghai Institue of Applied Physics
SUBATECH
Texas A&M University
University of Texas - Austin
Tsinghua University
Valparaiso University
Variable Energy Cyclotron Centre. Kolkata
Wayne State University
Warsaw University of Technology
University of Washington
Institute of Particle Physics
Yale University
University of Zagreb

Back Up

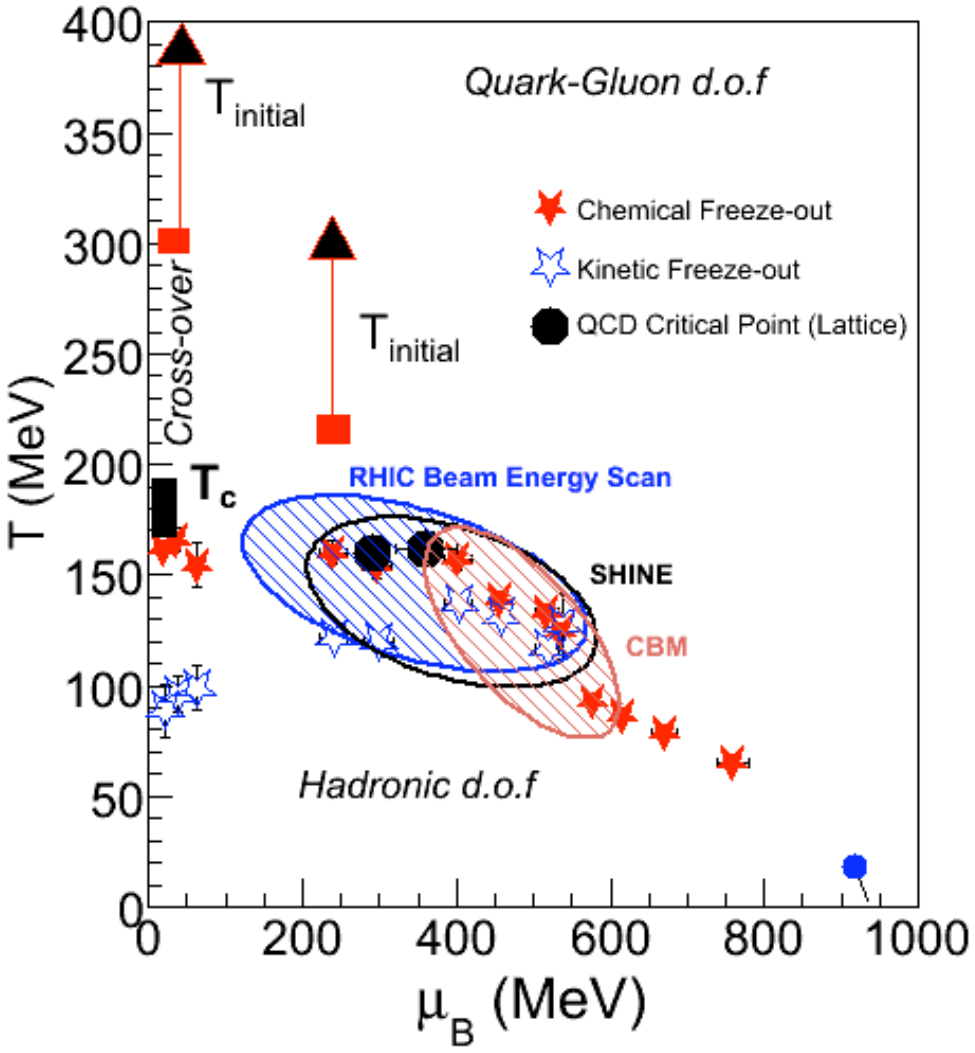
Freeze-out Parameter - Energy Dependence



STAR : 0909.4131

The 9.2 GeV results fits well with the energy dependence trend for the freeze-out parameters

Current Status : Phase Diagram



Lattice and other QCD based models :

$\mu_B = 0$ - Cross-over

$T_C \sim 170\text{-}195$ MeV

$\mu_B > 160$ MeV - QCD critical point

Experiments :

See distinct signatures that relevant d.o.f are quark and gluons

[$T_{initial}$(direct photons) > T_C(Lattice)]

No signatures of QCD critical point established, possible hints at SPS.

New distinct signatures proposed by Lattice and QCD based model calculations.

Future program :

Exploring the QCD phase diagram needs to be vigorously pursued to know properties of basic constituents of matter under extreme conditions.