First Results From Au+Au Collisions at $\sqrt{s_{NN}}$ = 9.2 GeV in STAR

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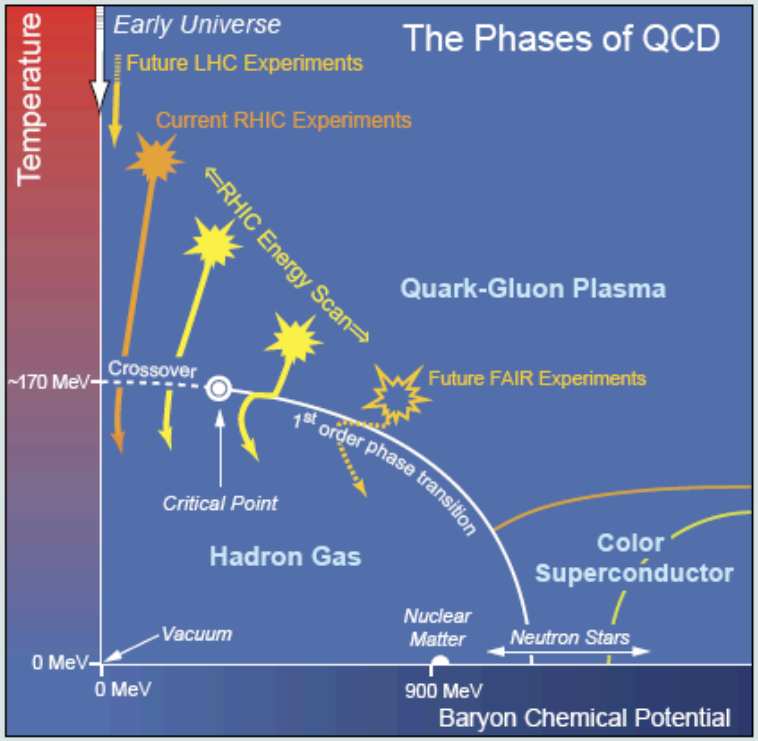
Outline

- ✓Motivation
- ✓STAR Experiment and Collisions at $\sqrt{s_{NN}}$ = 9.2 GeV
- ✓Results and Systematics : PID Spectra, Ratios, v_1, v_2 and $C_2(Q)$
- ✓Summary and Outlook (RHIC Energy Scan)

Motivation



Schematic QCD phase diagram for nuclear matter. The solid lines show the phase boundaries for the indicated phases. The solid circle depicts the critical point. Possible trajectories for systems created in the QGP phase at different accelerator facilities are also shown.

NSAC 2007 Long-range Plan

Map the QCD phase diagram through experiments

- Draw the QCD phase boundary
- Locate the 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

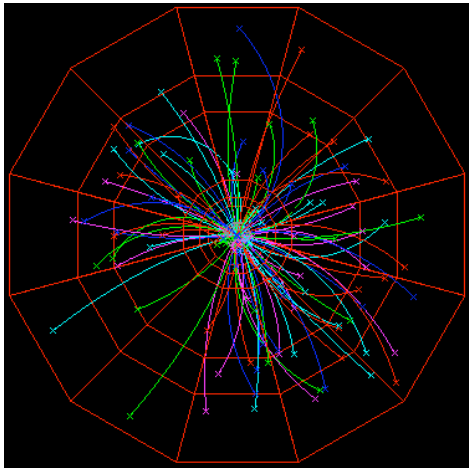
For locating different phases

For locating critical point

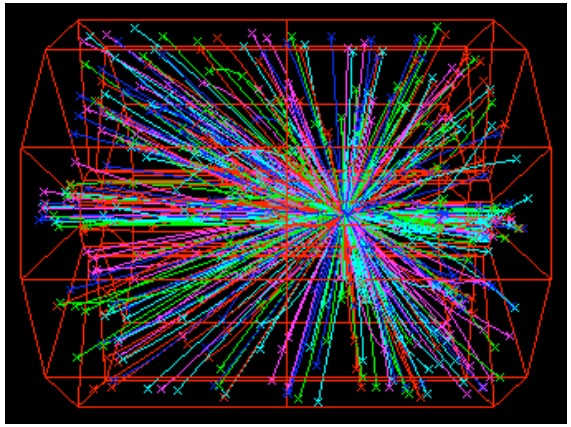
Aim of this talk is to discuss results from successful data taking in STAR with the Au+Au collisions at 9.2 GeV and demonstrate our preparedness for the future Beam Energy Scan program at RHIC

STAR Experiment and Collisions at $\sqrt{s_{NN}}$ = 9.2 GeV

Collisions recorded in STAR Time Projection Chamber

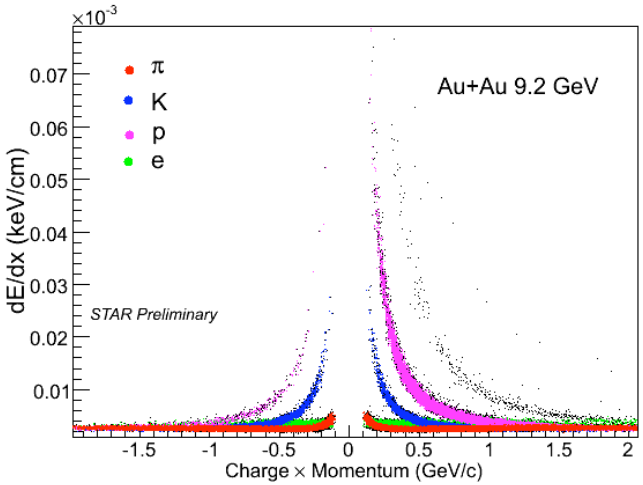


Non-central Collision



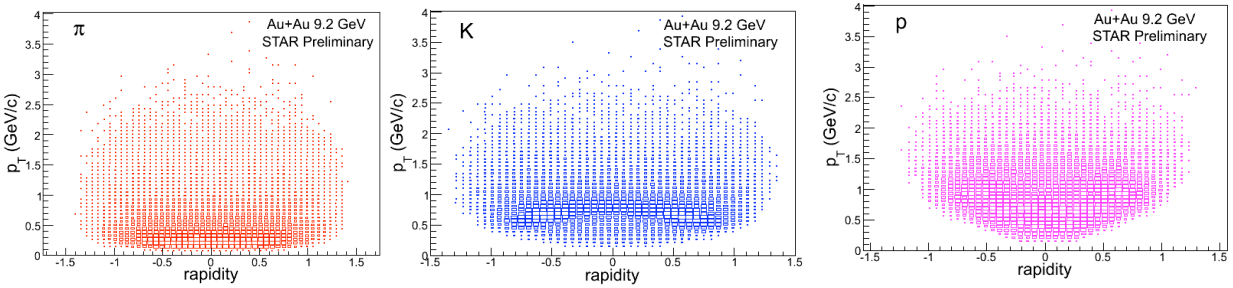
Central Collision

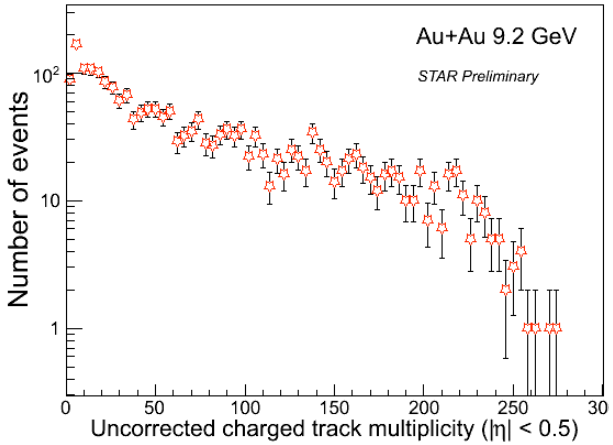
Excellent Particle Identification



Analysis based on ~ 3000 good events collected at ~ 0.7 Hz in year 2008

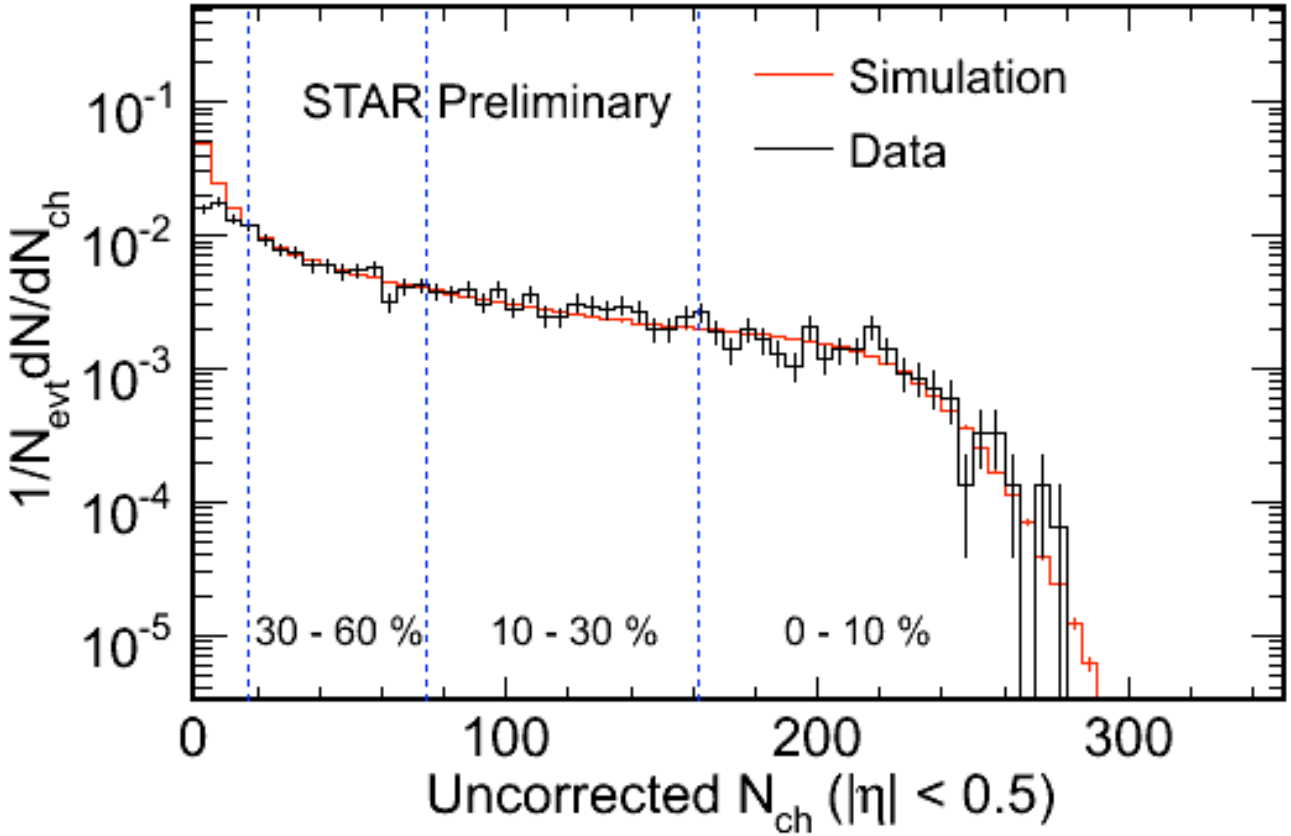
Collider experiment : Uniform Acceptance for all beam energies





Lokesh Kumar for STAR

Collision Centrality Selection



Monte-Carlo Glauber Model :

$\sqrt{\sigma_{NN}}$ = 31.5 mb

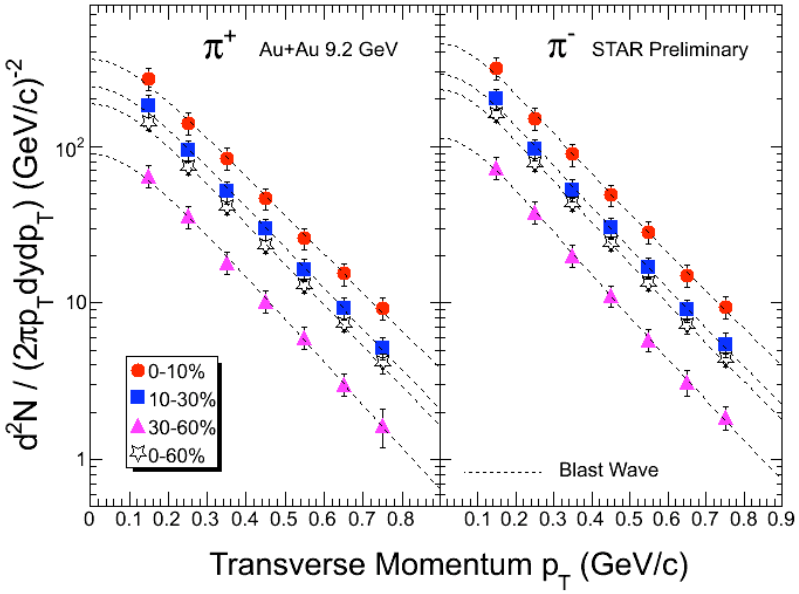
Negative Binomial Distribution fitted to the data

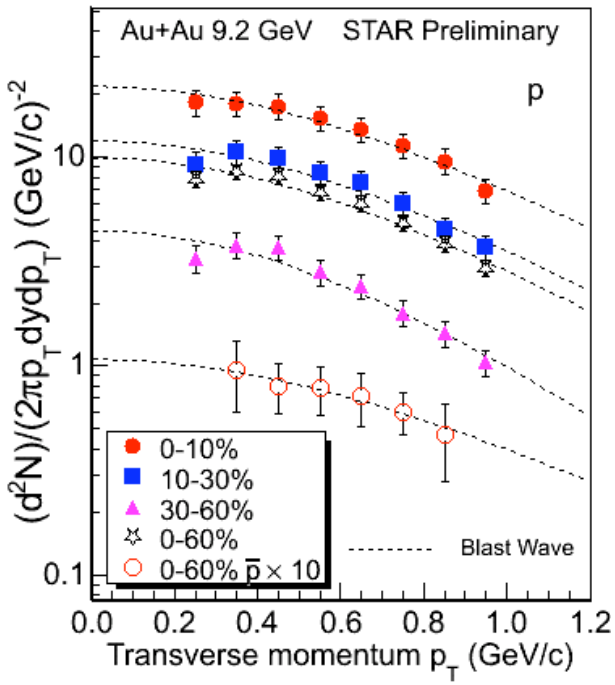
Fraction of hard component, x = 0.11

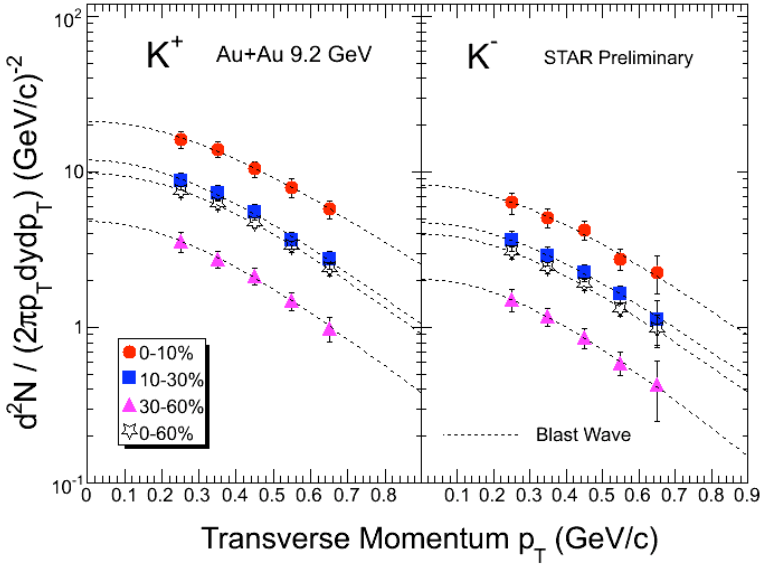
NBD parameters : μ = 1.12, k = 2.1

% cs	: N_{part}
0 - 10%	: 318
10 - 30%	: 203
30 - 60%	: 89

Identified hadron spectra at mid-rapidity







The slope of the spectra follows

$p < K < \pi$

Spectra characterized by dN/dy and $\langle m_T \rangle$

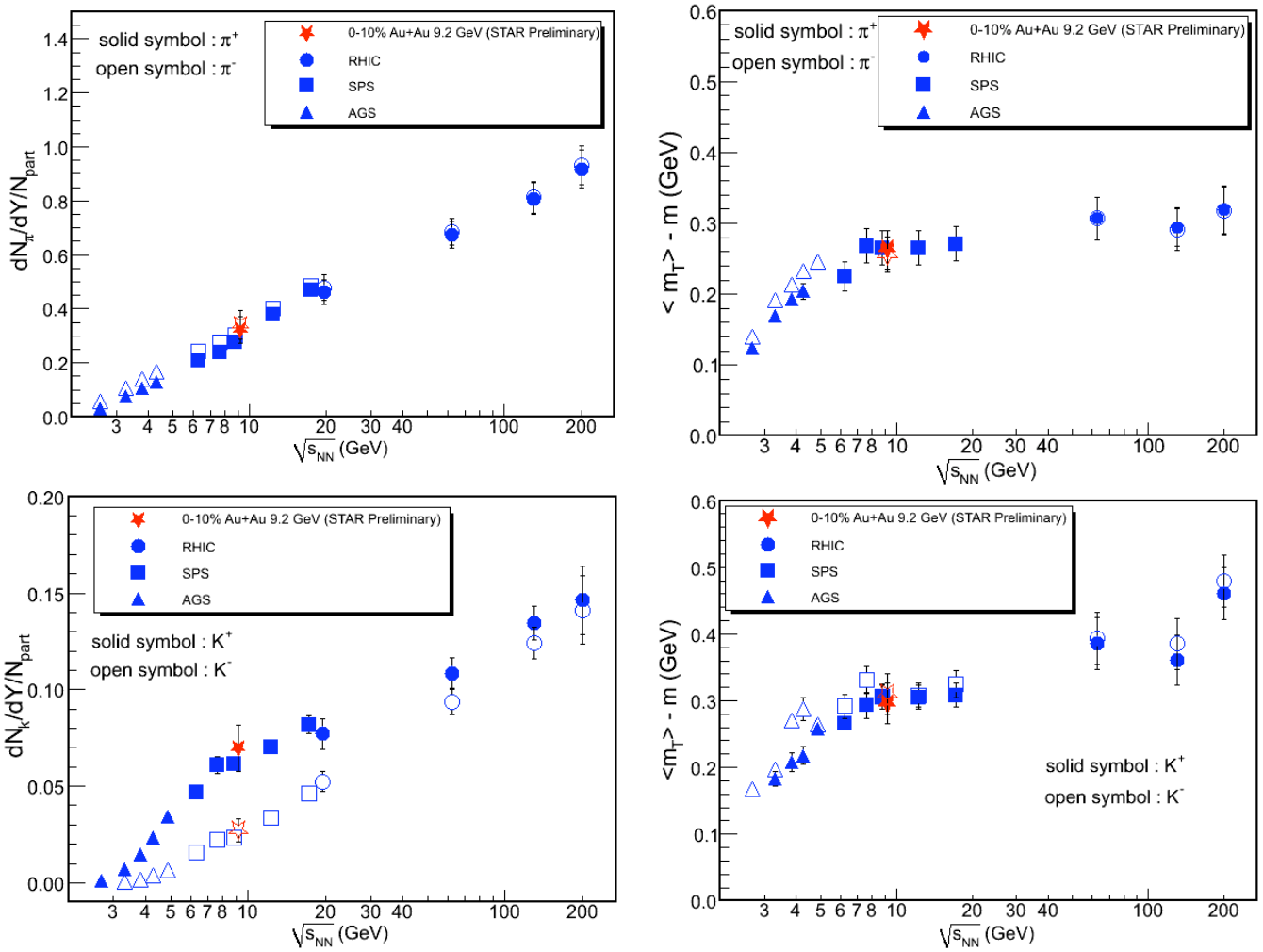
We measure within our p_T acceptance at mid-rapidity

~ 82 % of total π produced

~ 47 % of total K produced

~ 75 % of total p produced

Yield and $\langle m_T \rangle$ - Mesons at mid-rapidity



Yield and $\langle m_T \rangle$ beam energy dependence consistent with the published data

Assuming a thermodynamic system :

$T \sim \langle m_T \rangle - m$

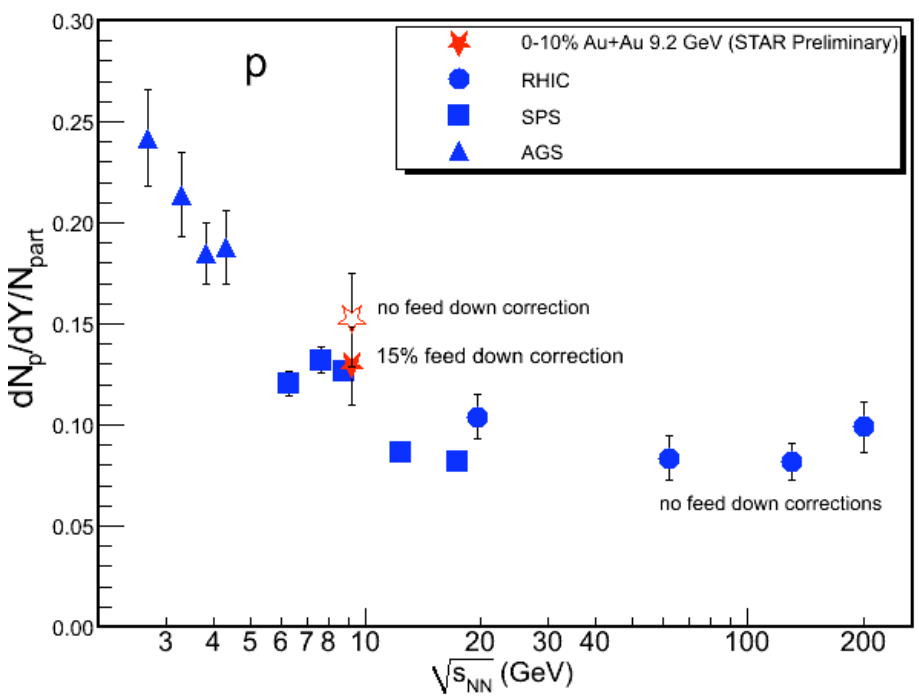
entropy ~ dN/dy

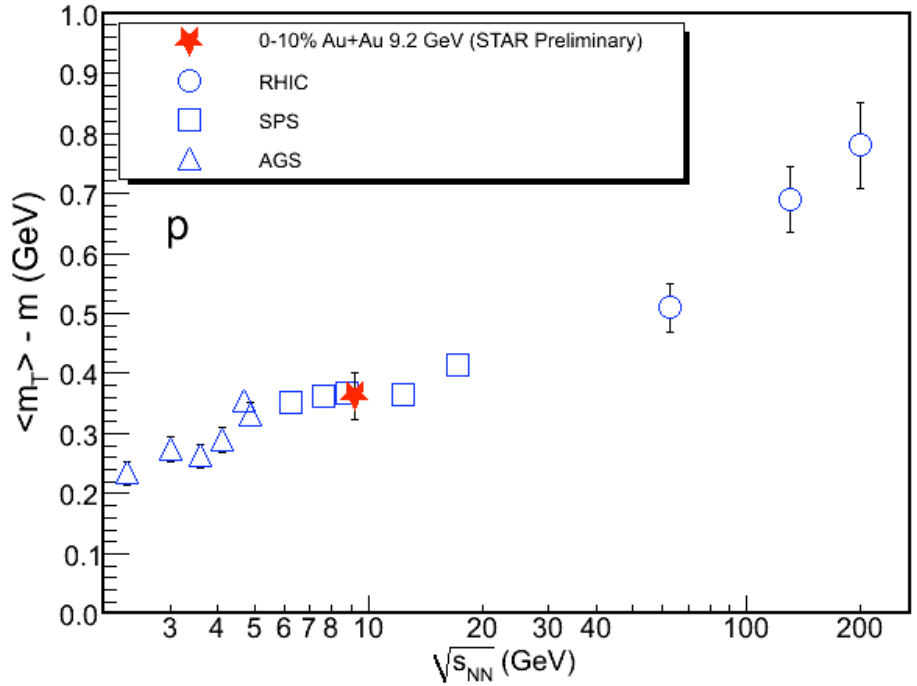
$\alpha \log(\sqrt{s_{NN}})$

All errors are statistical and systematic added in quadrature

NA49 : PRC 66 (2002) 054902, PRC 77 (2008) 024903, PRC 73 (2006) 044910
STAR : ArXiv : 0808.2041, QM2008
E802(AGS) : PRC 58 (1998) 3523, PRC 60 (1999) 044904
E877(AGS) : PRC 62 (2000) 024901
E895(AGS) : PRC 68 (2003) 054903

Yield and $\langle m_T \rangle$ - Baryons at mid-rapidity

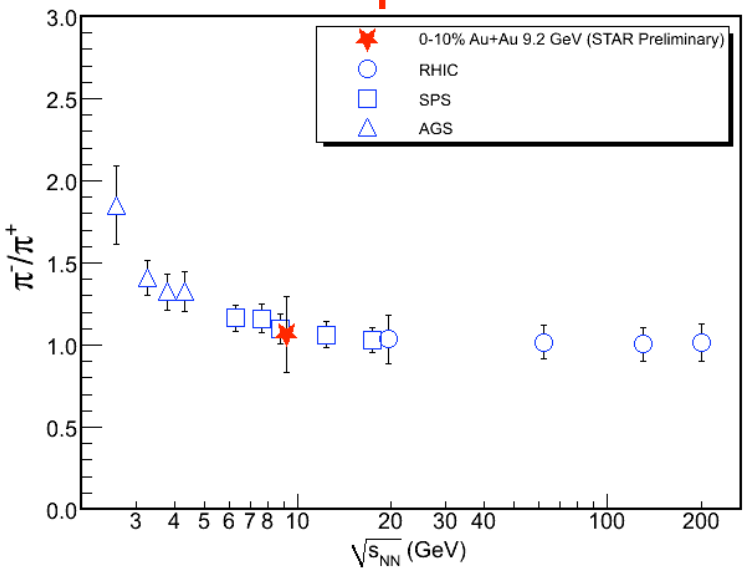


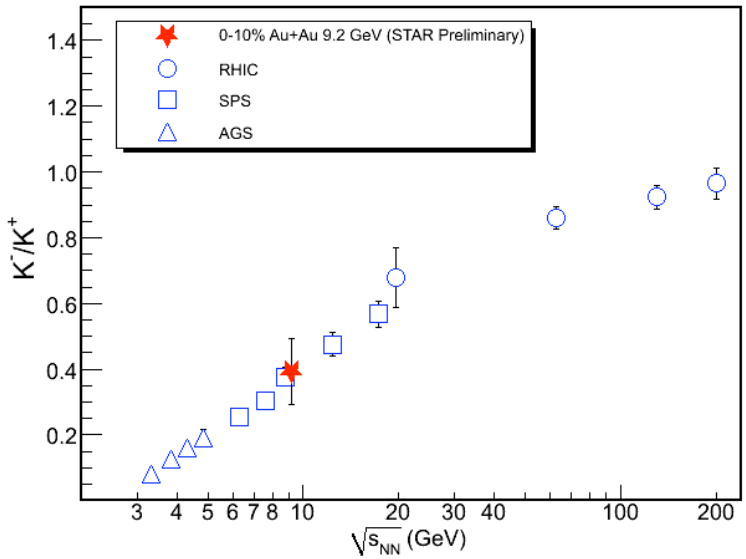


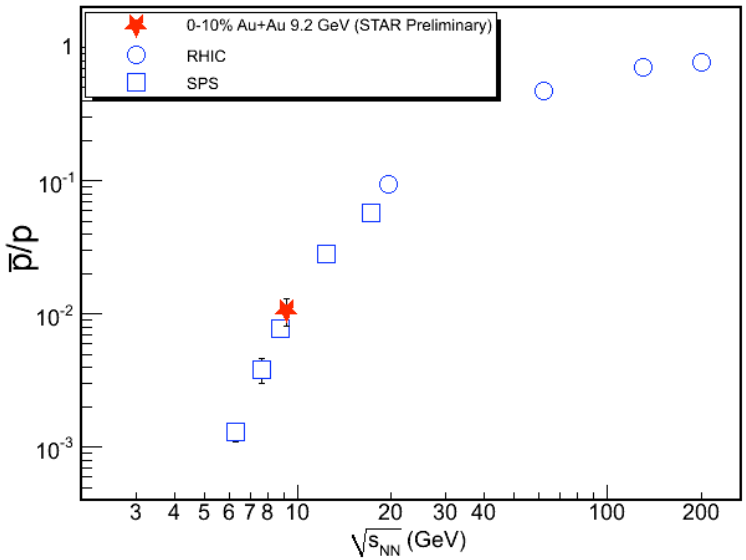
STAR : ArXiv : 0808.2041, QM2008
NA49 : PRC 73 (2006) 044910
E802(AGS) : PRC 60 (1999) 064901
E877(AGS) : PRC 62 (2000) 024901
E895(AGS) : PRL 88 (2002) 102301

Both the yield and $\langle m_T \rangle$ are close to the SPS results at similar energies

Anti-particle to Particle ratios at mid-rapidity







The ratios follow the general $\sqrt{s_{NN}}$ trend

pbar/p << 1 : Large baryon stopping
Large net protons
High μ_B

$K^-/K^+ \sim 0.4$: ~ 60% of K^+ from associated production with Λ

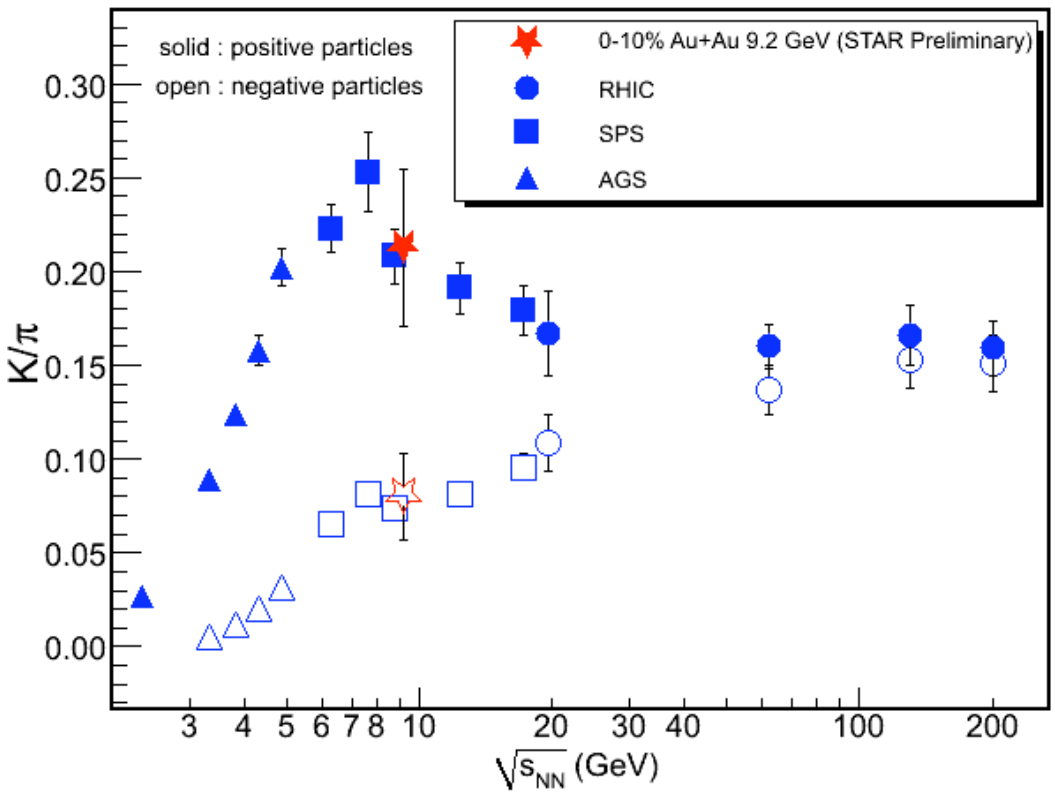
$\pi^-/\pi^+ \sim 1$: similar source of production for π^+ and π^-

✓ At low energy pions are dominantly produced from Δ resonance

E802(AGS) : PRC 58 (1998) 3523, PRC 60 (1999) 044904, PRC 62 (2000) 024901, PRC 68 (2003) 054903

NA49 : PRC 66 (2002) 054902,
PRC 77 (2008) 024903,
PRC 73 (2006) 044910
STAR : ArXiv : 0808.2041, QM2008

Beam Energy Dependence of Particle Ratios

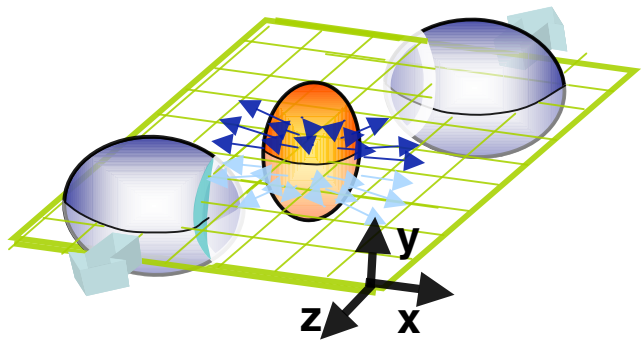


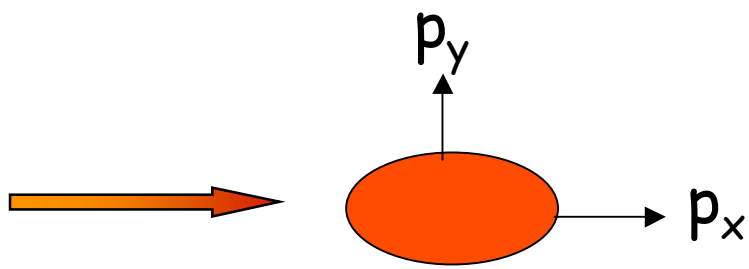
Total number of events for Au+Au 9.2 GeV ~ 3000

These ratios follow the observed beam energy dependence
K/π ratios reflect strangeness production in heavy ion collisions

NA49 : PRC 66 (2002) 054902, PRC 77 (2008) 024903, PRC 73 (2006) 044910
STAR : ArXiv : 0808.2041, QM2008; E802(AGS) : PRC 58 (1998) 3523, PRC 60 (1999) 044904, 064901, PRC 62 (2000) 024901, E895(AGS) : PRC 68 (2003) 054903

Azimuthal Anisotropy Measurements





$$\phi = \mathrm{atan}\frac{p_y}{p_x}$$

$$\varepsilon = \frac{\langle y^2 \rangle - \langle x^2 \rangle}{\langle y^2 \rangle + \langle x^2 \rangle}$$

initial spatial anisotropy

$$v_2 = \left\langle \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2} \right\rangle$$

anisotropy in momentum space

$$E\frac{dN^3}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1 + 2v_1\cos(\phi - \Psi_R) + 2v_2\cos(2(\phi - \Psi_R)) + \ldots\right)$$

directed **elliptic**

$$v_n = \left\langle \cos\left(n(\phi - \psi_n)\right)\right\rangle = \left\langle e^{in(\phi - \psi_n)}\right\rangle$$

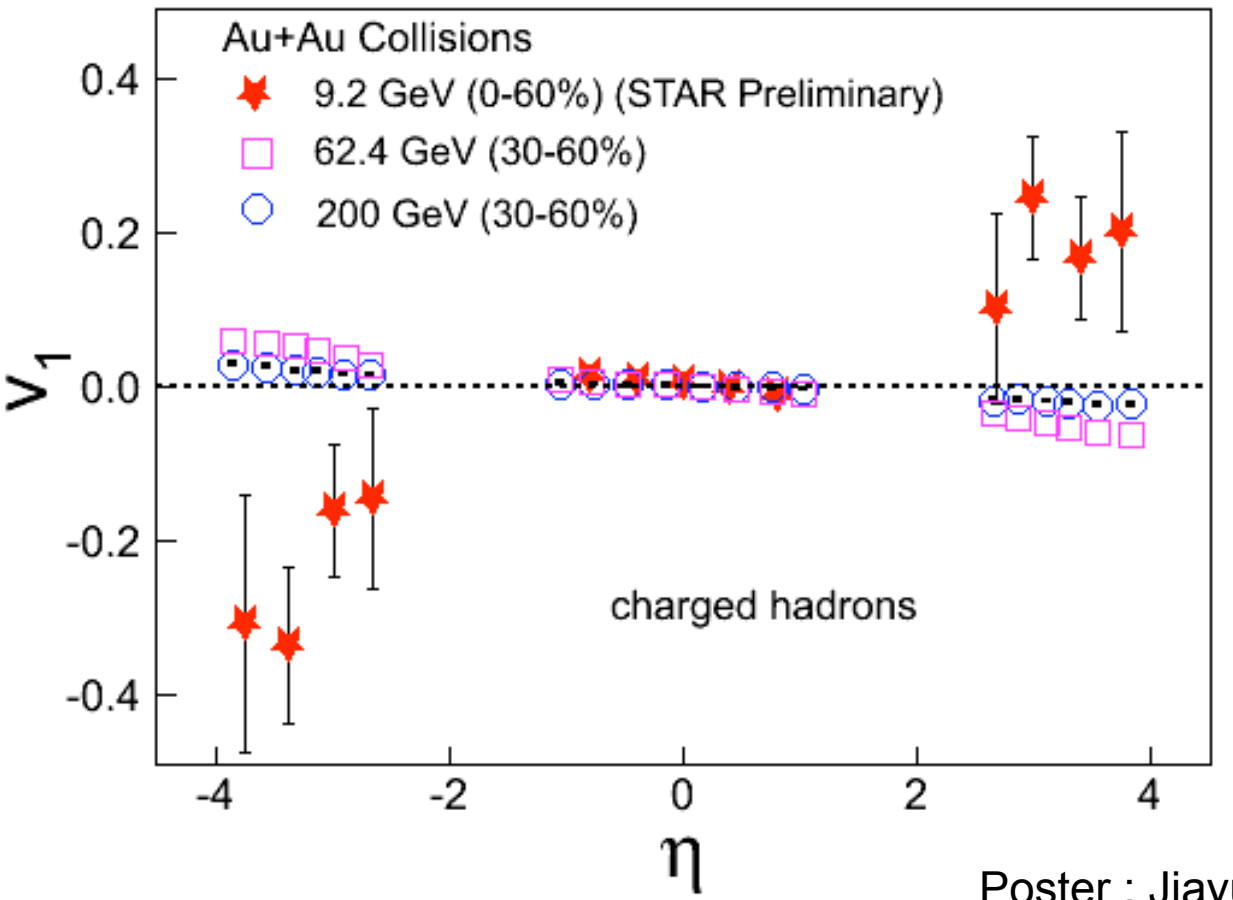
= Correlation to the reaction plane

≡"anisotropic flow"

Within the assumptions of hydrodynamical calculations - Azimuthal Anisotropy measurements could be related to Equation Of State

v_1, v_2 = f(p_T, centrality) ~ ΔP = f(T, ε(or V)) –> EOS

Azimuthal Anisotropy - Directed Flow



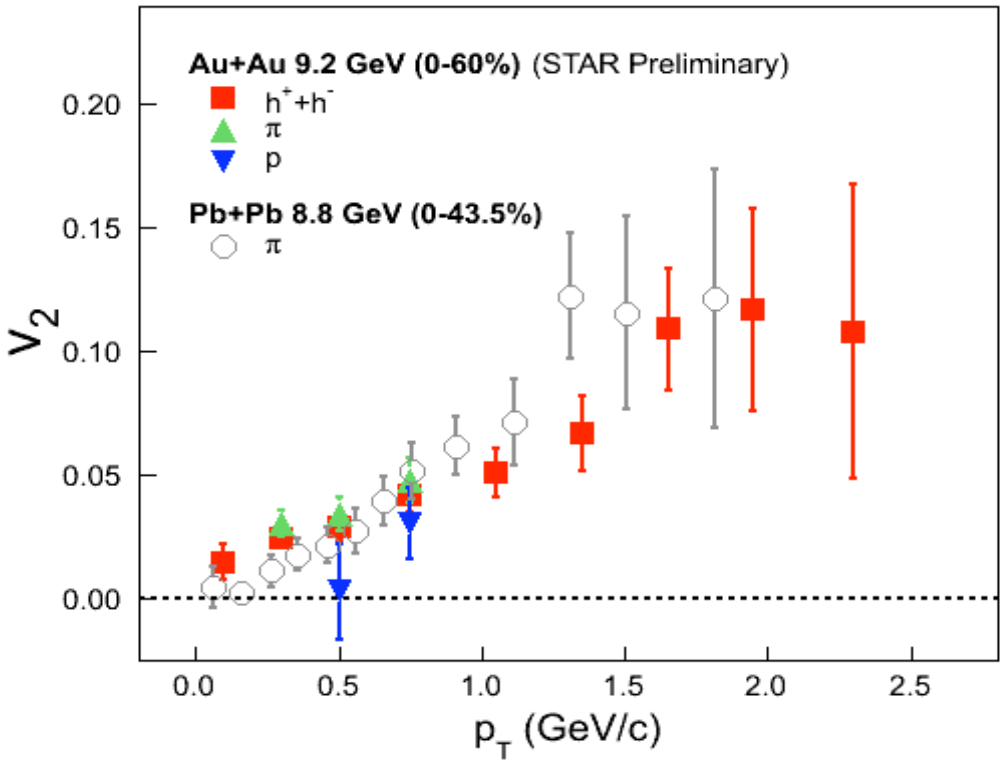
STAR : PRL 92 (2004) 062301
arXiv:0807.1518[nucl-ex]

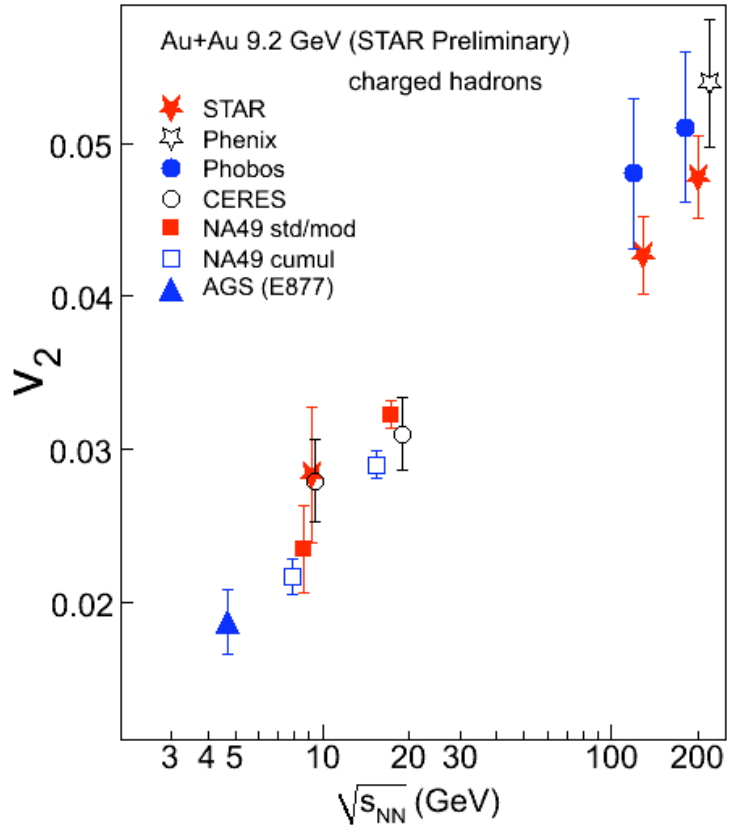
y_{beam} for 9.2 GeV ~ 2.3
y_{beam} for 200 GeV ~ 5.4
y_{beam} for 62.4 GeV ~ 4.2

Poster : Jiayun Chen (STAR Collaboration)

v_1 for Au+Au 9.2 GeV shows different trend compared to Au+Au 200 and 62.4 GeV - possibly due to spectators

Azimuthal Anisotropy - Elliptic Flow

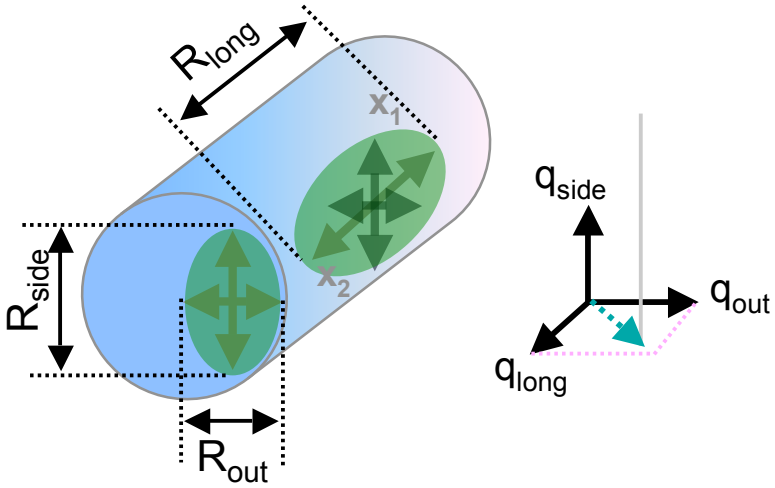




Au+Au 9.2 GeV : |η|<1,
only statistical errors are shown.
Results comparable to SPS results at similar beam energy.

NA49 : PRC 68 (2003) 034903
AGS : PLB 474 (2000) 27
STAR : PRC 77 (2008) 054901 : PRC 75 (2007) 054906, PRC 72 (2005) 014904
PHOBOS : PRC 72 (2005) 051901 : PRL 98 (2007) 242302
PHENIX : PRL 98 (2007) 162301
CERES : NPA 715 (2003) 615

Interferometery Measurements



HBT measurements provides

Source dimensions (homogeneity region) - R
Source is chaotic or coherent - λ

R_{out} - spatial + temporal extension of source
R_{side} - only the spatial extension
R_{out} / R_{side} - emission duration of source

R_{out}/R_{side} >> 1 for a phase transition
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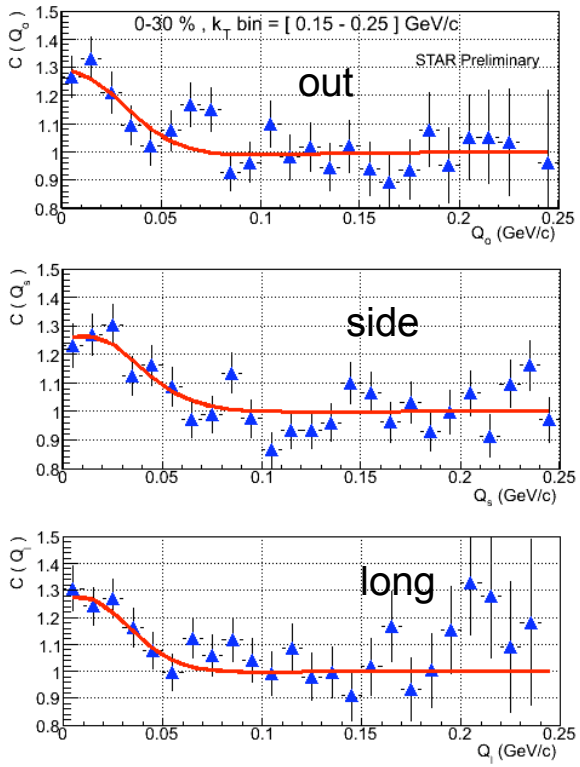
Rischke & Gyulassy, NPA 608, 479 (1996)

Study HBT as a function of Beam Energy ~ energy density

π^- Pion Interferometery Measurements



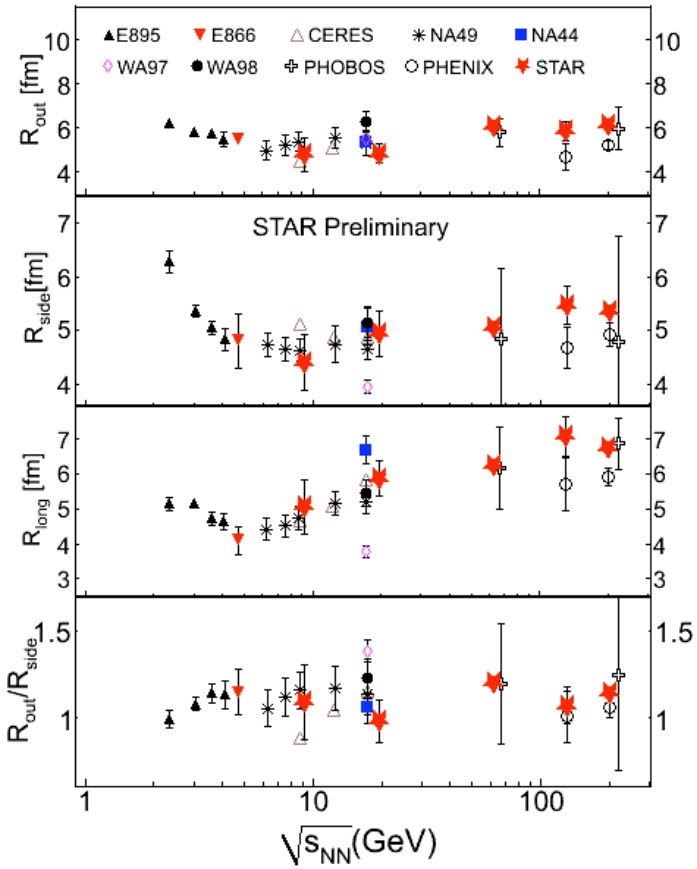
Source parameters :

Centrality : 0 - 30%

Error bars for Au+Au 9.2 GeV are statistical .

Systematic errors expected to be < 10 % for each out, side and long

E802 : PRC 66 (2002) 054906
CERES : NPA 714 (2003) 124
E895 PRL 84 (2000) 2798



Kt bin(GeV/c)	R_{out}(fm)	R_{side}(fm)	R_{long}(fm)	λ
0.15-0.25(GeV/c)	4.81 +/- 0.8	4.41 +/- 0.5	5.06 +/- 0.8	0.548 +/- 0.1

Previously observed trend on beam energy followed

STAR : PRC 71 (2005) 044906, PRL 87 (2001) 082301
PHENIX : PRL 88 (2002) 192302, PRL 93(2004) 152302
PHOBOS : PRC 73 (2006) 031901
WA97 : JPG 27 (2001) 2325

NA44 : PRC 58 (1998) 1656
E866 : NPA 661 (1999) 439
NA49 : PRC 77 (2008) 064908

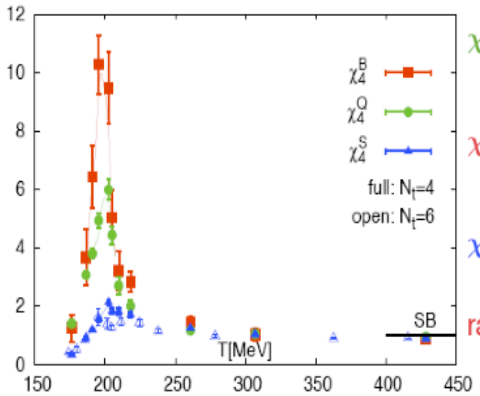
Proposed Beam Energy Scan Program from STAR

STAR Beam User Request

$\sqrt{s_{NN}}$ [GeV]	μ_B [MeV]	Goal [Events]
5.0	550	
6.1	491	1 M
7.7	410	2 M
8.6	385	2 M
12.3	300	5 M
17.3	229	10 M
27	151	10 M
39	112	10 M

vanishing chemical potentials:

RBC-Belefild, preliminary



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

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

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

rapid approach to SB limit

⇒ large light quark number & charge fluctuations across transition region

Key measurements:

(1) All PID hadron spectra/ratios and v_2
(2) Net-proton number Kurtosis
(3) K/π, $\langle p_T \rangle$ … fluctuations

One potential measurable signature -

Large jump in 4th moment of the event by event net-proton distribution expected

STAR has large acceptance,measures protons cleanly up to p_T ~ 1 GeV/c in TPC.

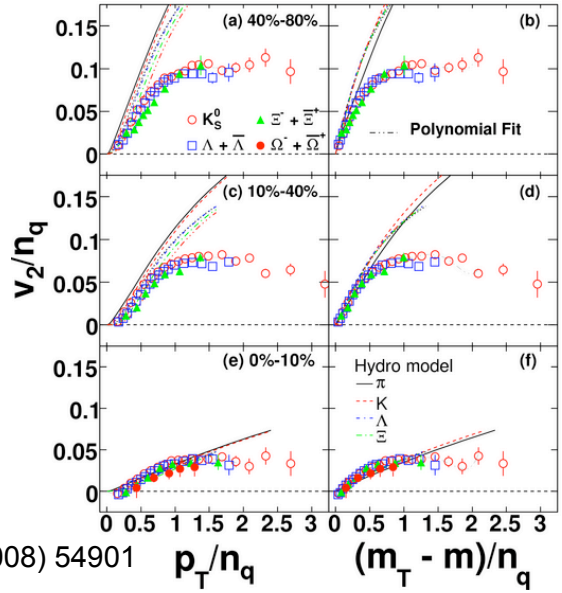
With Time Of Flight (2010) proton identification up to p_T ~ 3 GeV/c

Outlook

Locating the onset of several observations in high energy heavy-ion collisions at RHIC can be done in the beam energy scan program

Au+Au 200 GeV

Onset of Number of Constituent Quark Scaling in v_2 measurements and strange hadron v_2

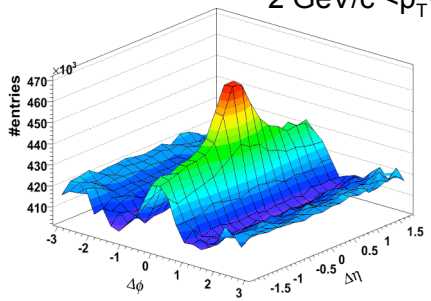


STAR : PRC 77 (2008) 54901

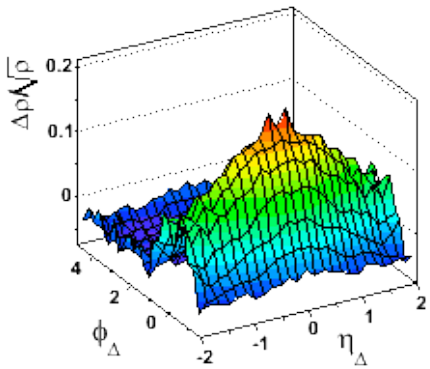
Onset of Ridge

Enhanced correlated yield at large Δη on near side

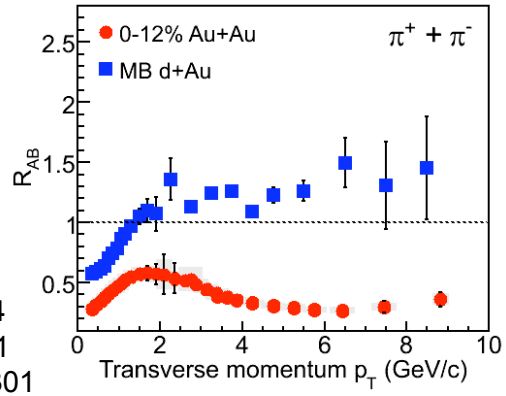
p_T^{trig}=3-6 GeV/c,
2 GeV/c <p_T^{assoc}< p_T^{trig}



STAR : J. Putschke QM2006
M. Daugherity QM2008



Onset of High p_T Suppression



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

Summary

- Identified particle spectra obtained from Au+Au collisions at 9.2 GeV, the hadron yields and ratios are similar to those obtained from SPS experiments at similar beam energies.
- Anti-proton to proton ratio ~ 0.01 indicating significant baryon stopping at mid-rapidity in these collisions
- K^-/K^+ ~ 0.4 indicating associated production for K^+

- Azimuthal Anisotropy (v_1 and v_2) measurements are similar to those obtained at SPS from collisions at similar energies
- Pion interferometry results follow the established beam energy trends

These results from the lowest beam energy collisions at RHIC demonstrate STAR experiment's readiness to take up the proposed Beam Energy Scan Program.

Large and uniform acceptance for all beam energies in a collider set up, excellent particle identification (TPC+TOF) and higher statistics will help doing qualitative improvement on SPS results.

Beam Energy Scan Program will allow us to map the QCD phase diagram and locate the onset of several interesting observations at RHIC

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 Slides

Beam Scan

$\sqrt{s_{NN}}$ [GeV]	μ_B [MeV]	Rate [Hz]	Goal [Events]	Duration [Days]
5.0	550	0.5		7
6.1	491	1.4	1 M	20
7.7	410	2.7	2 M	20
8.6	385	4	2 M	15
12.3	300	10	5 M	15
17.3	229	25	10 M	12
27	151	30	10 M	7
39	112	50	10 M	6