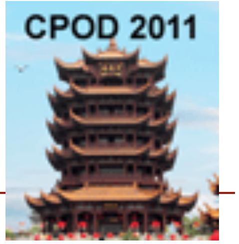
Centrality dependence of freeze-out parameters from Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7, 11.5, and 39 GeV



Lokesh Kumar (for the STAR Collaboration)

KENT STATE
UNIVERSITY

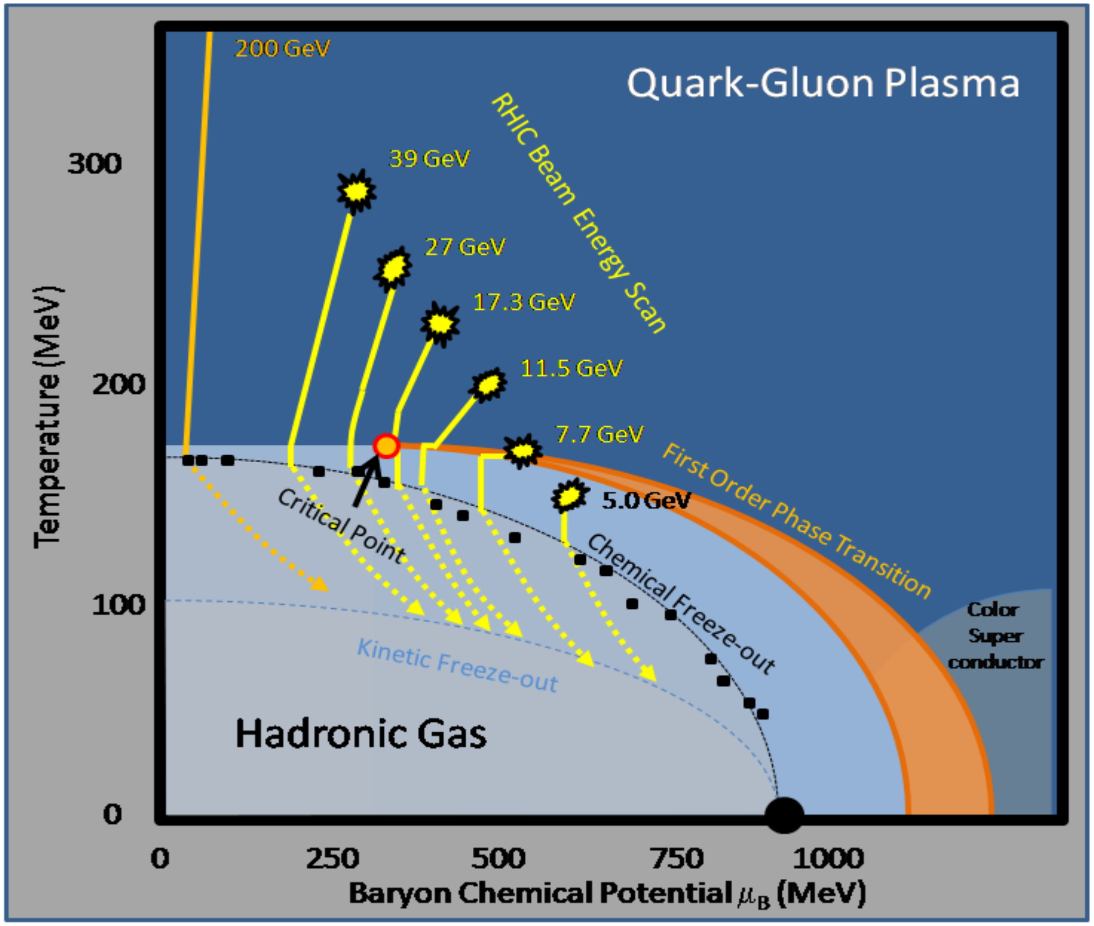
Outline:

Motivation
PID Selection
Particle ratios
Freeze-out parameters
Summary

Critical Point and Onset of Deconfinement (CPOD)
7 - 11 November 2011 at Institute of Particle Physics (CCNU)

Motivation

QCD Phase Diagram (Hadrons-Partons):



http://drupal.star.bnl.gov/STAR/starnotes/public/sn0493: arXiv:1007.2613

Experimental study: Heavy-ion collisions at varying beam energies

Goals of RHIC BES program:

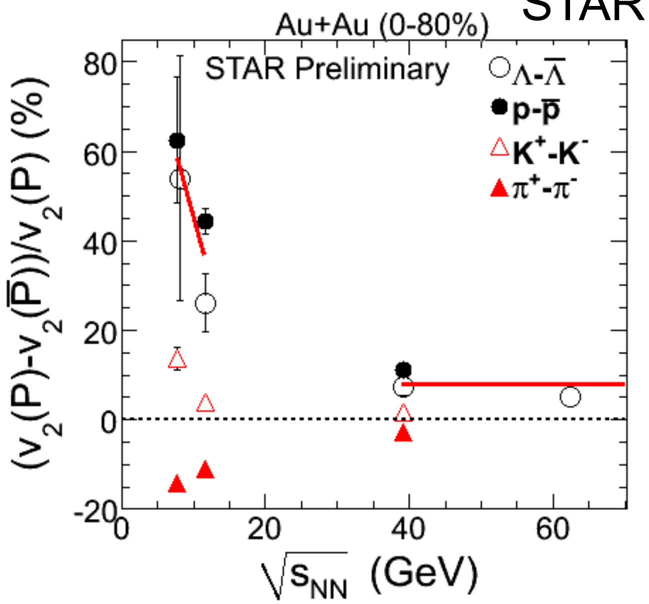
- Search for the signals of phase boundary

- Search for the possible QCD Critical Point

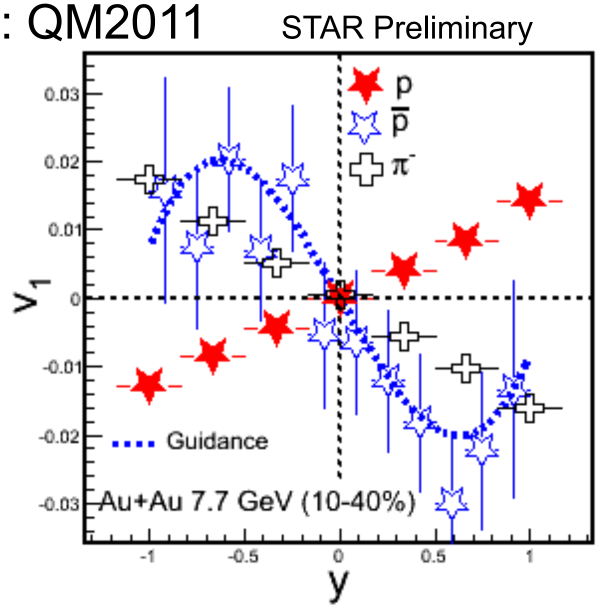
Extracting freeze-out parameters from spectra and ratios at BES

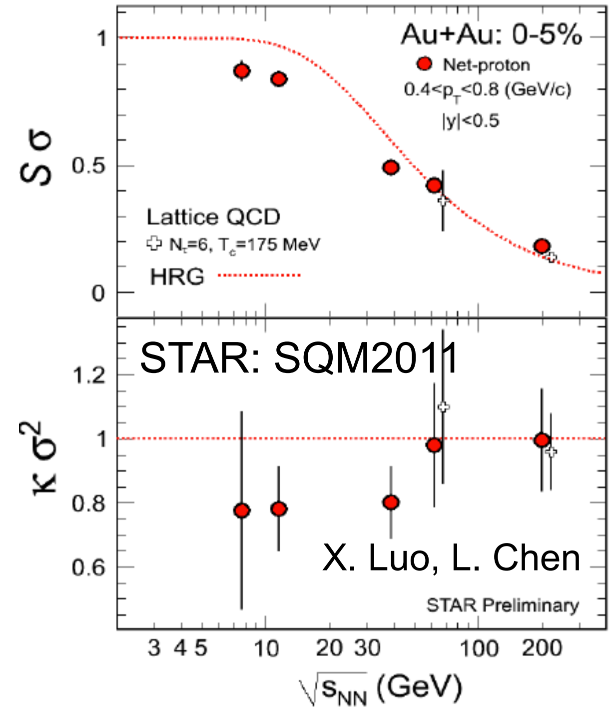
Some Other Highlights from BES

A. Schmah, S. Shi



STAR: QM2011



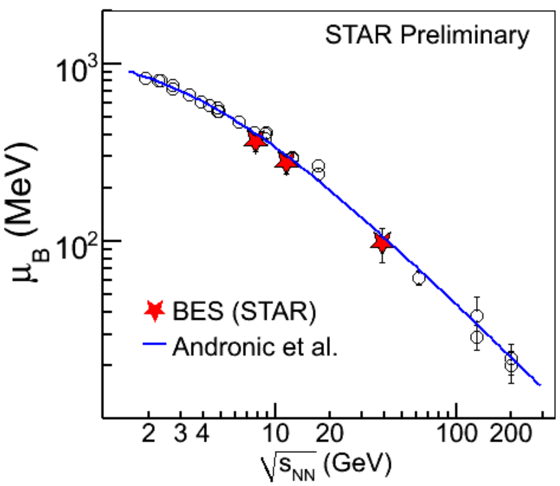


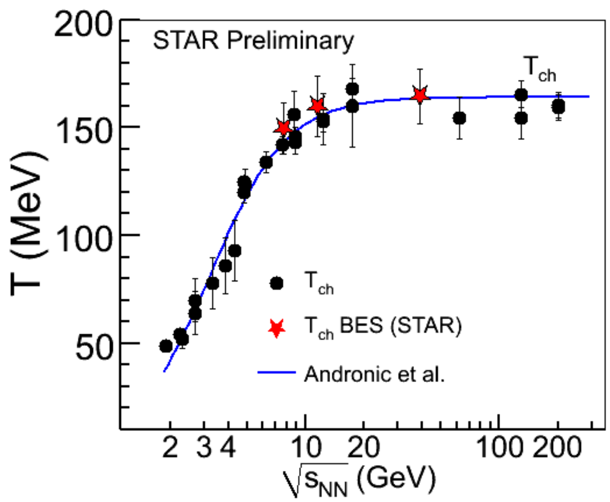
- ✧ Difference in v_2 of particles and anti-particles
- ✧ Change in sign of proton v_1 compared to $\bar{p}$ and π^-
- ✧ Higher moments of net-proton distribution will be used for critical point search

Focus:
Ratios and freeze-out parameters

Chemical Freeze-out Picture

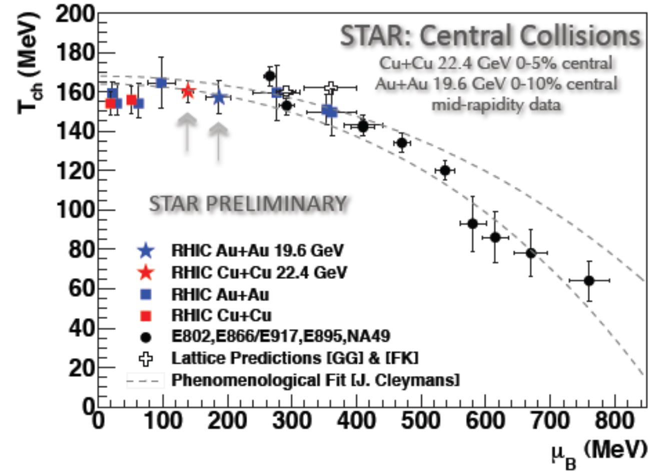
Presented at QM2011 for central collisions:



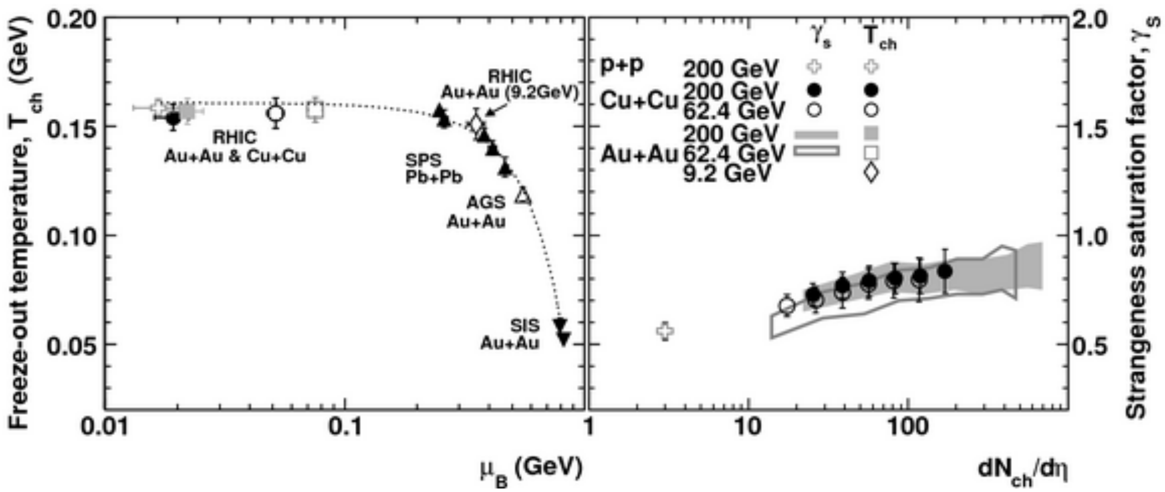


System size effect:

STAR: SQM2011



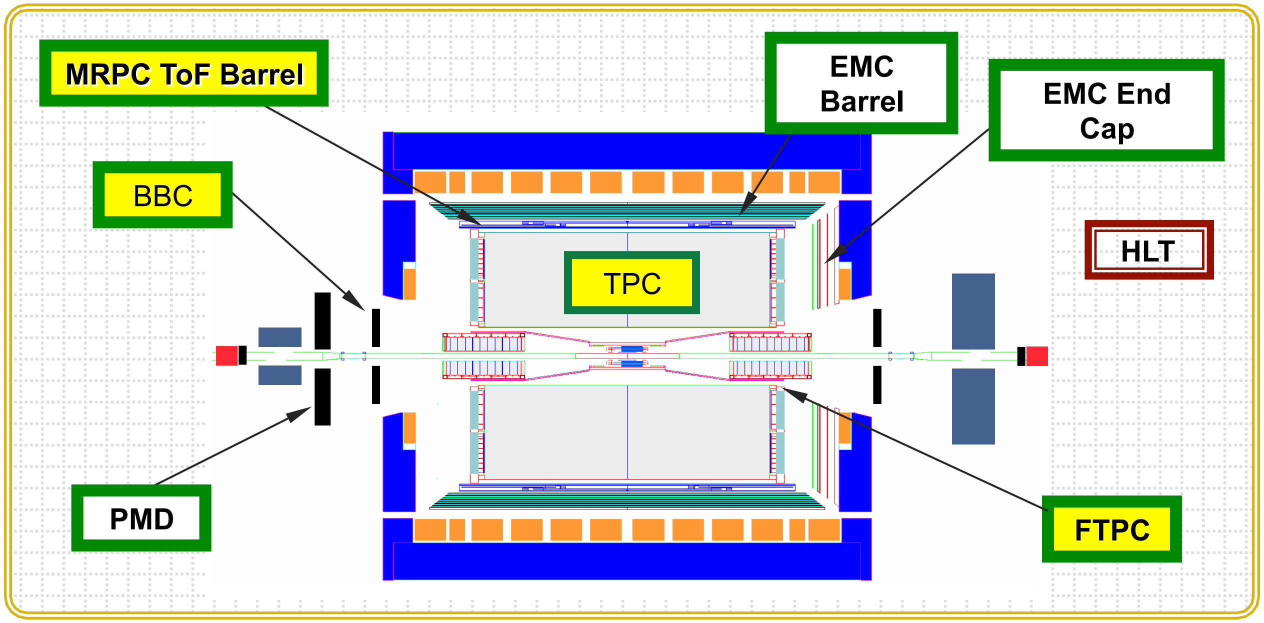
Results at High Energies: STAR: Phys. Rev. C 83 (2011) 34910



Not much change in T_{ch} values with system size (pp, Cu+Cu, and Au+Au)

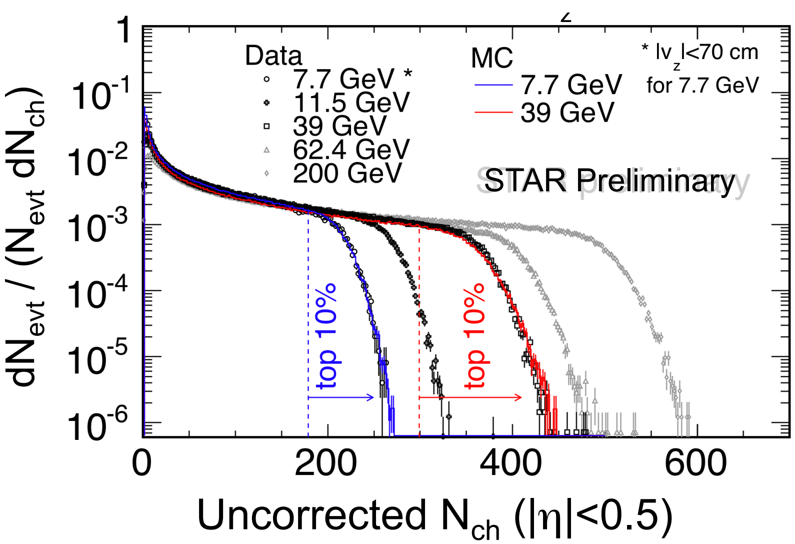
Discuss in this talk: Centrality dependence

Data Set and Detectors



Particle identification over 2π in azimuthal angle and more than two units in rapidity

Au+Au Collisions:
7.7, 11.5 and 39 GeV
$|y| < 0.1$
$p_T > 0.1$ GeV/c
Centrality: 0-80%

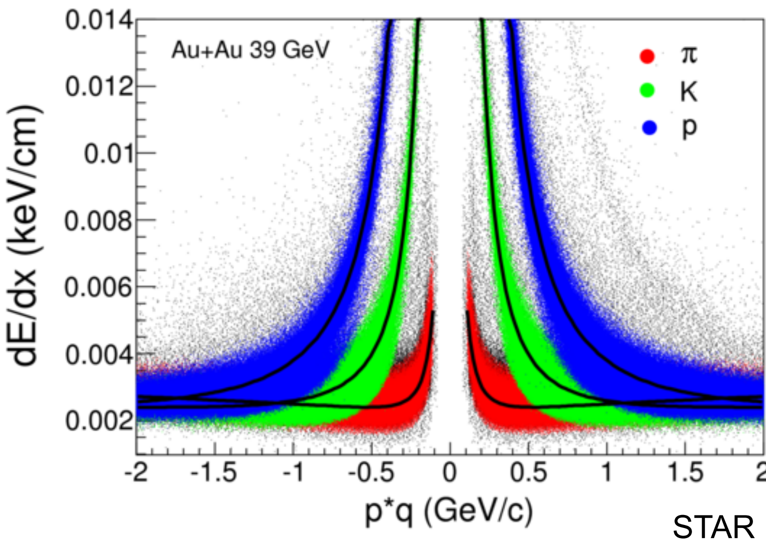


$\sqrt{s_{NN}}$ (GeV)	Events Analyzed (M)
7.7	~ 4
11.5	~ 8
39	~ 10

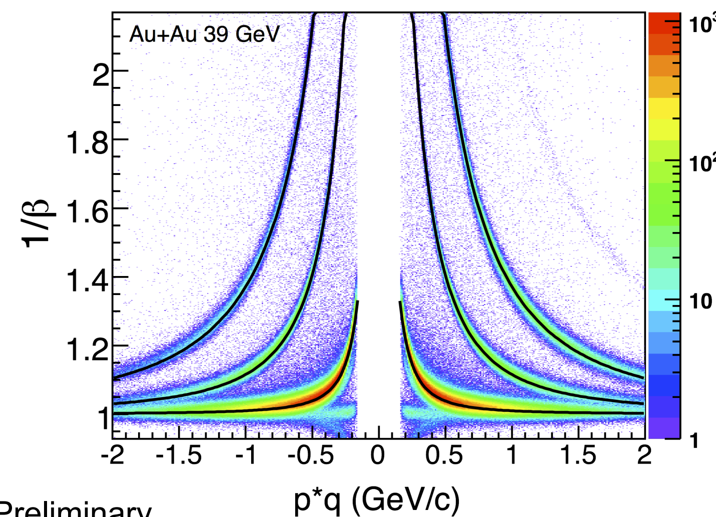
Particle Identification

$\sqrt{s_{NN}}$ = 39 GeV Au + Au Collisions

TPC



TPC+ToF

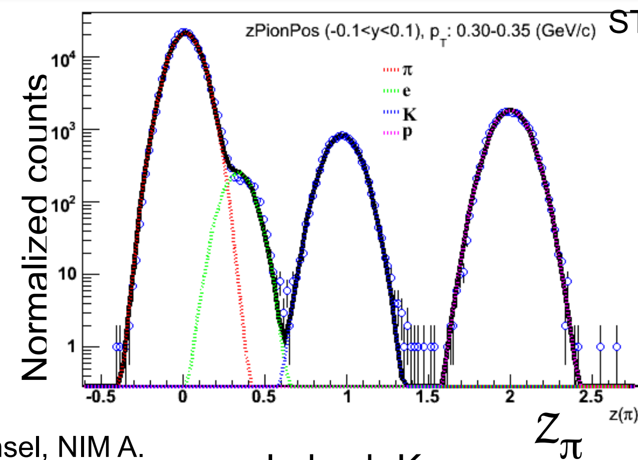


STAR Preliminary

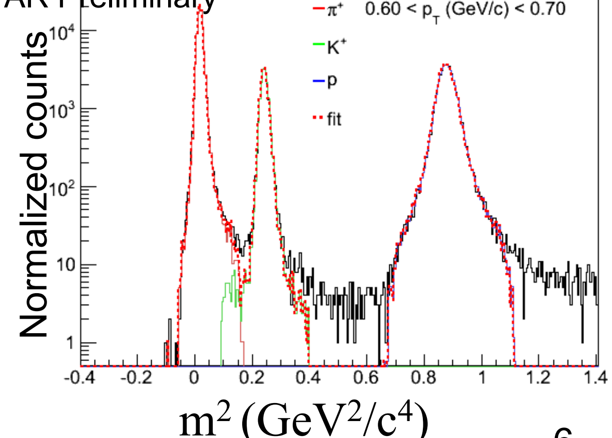
$$z = \log\left(\frac{(dE/dx)_{meas.}}{(dE/dx)_{theory}}\right)$$

$$m^2 = p^2\left(\frac{c^2t^2}{L^2} - 1\right)$$

p= momentum,t=time-of-flight
c=velocity of light, L=path length



STAR Preliminary

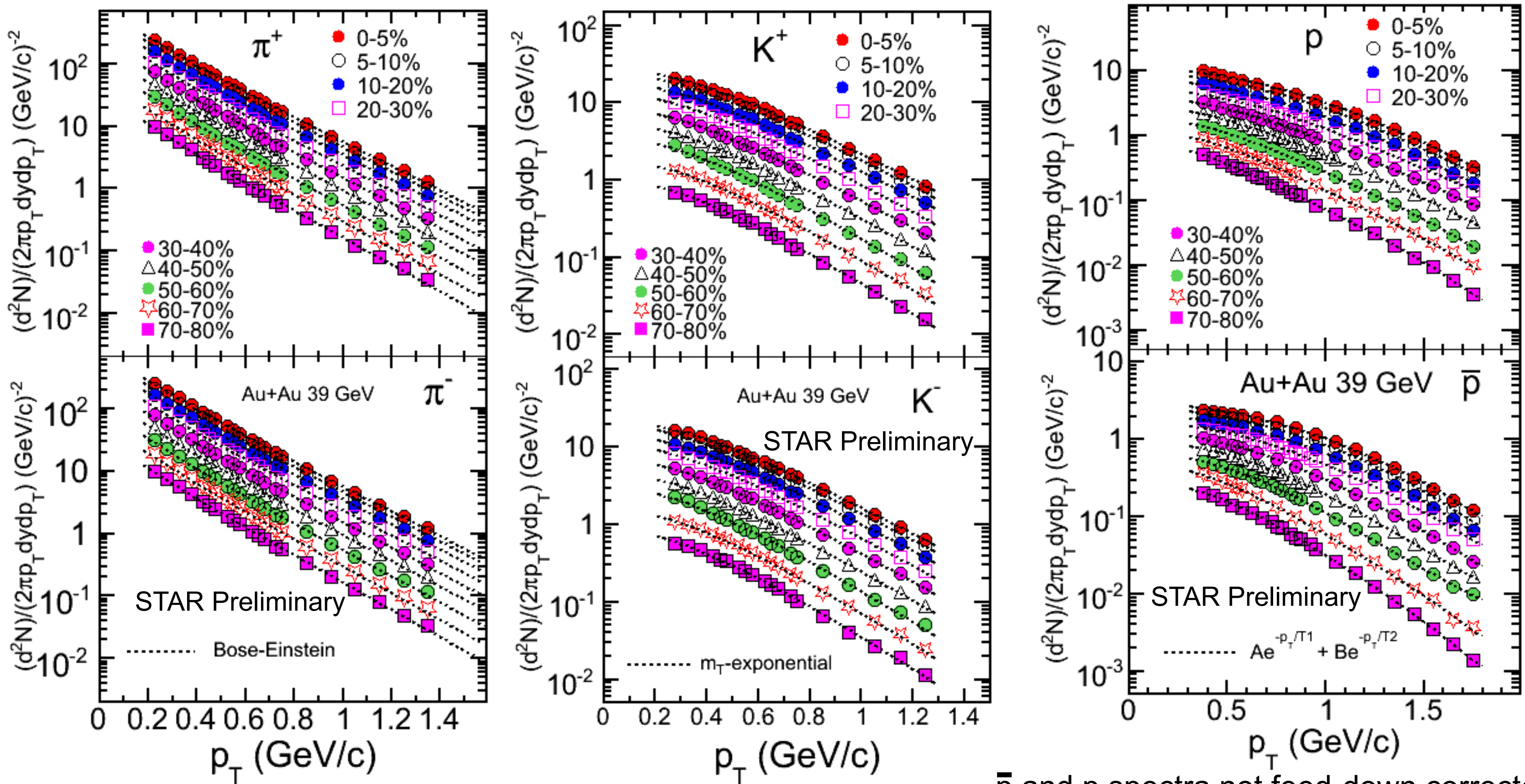


H. Bichsel, NIM A. 562 (2006) 154

Lokesh Kumar

Invariant Yield

Au+Au 39 GeV:

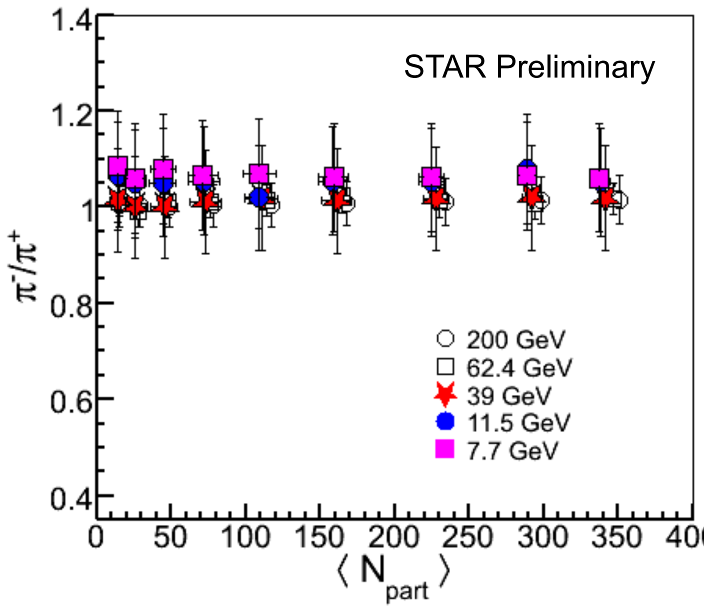


$\bar{p}$ and p spectra not feed-down corrected

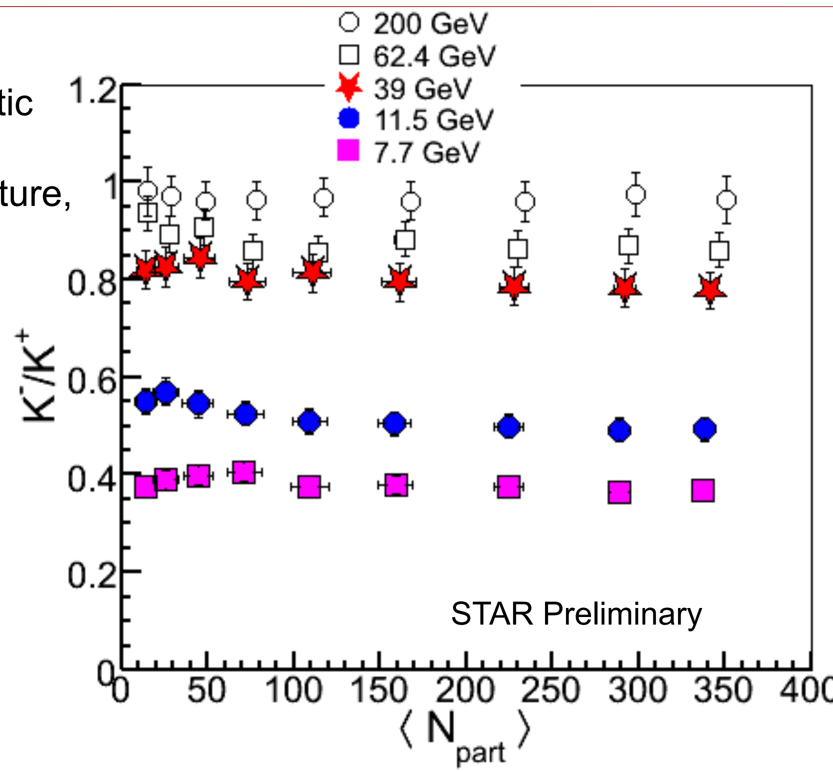
We measure ~ 70-80% of π, K and p within our p_T acceptance at mid-rapidity

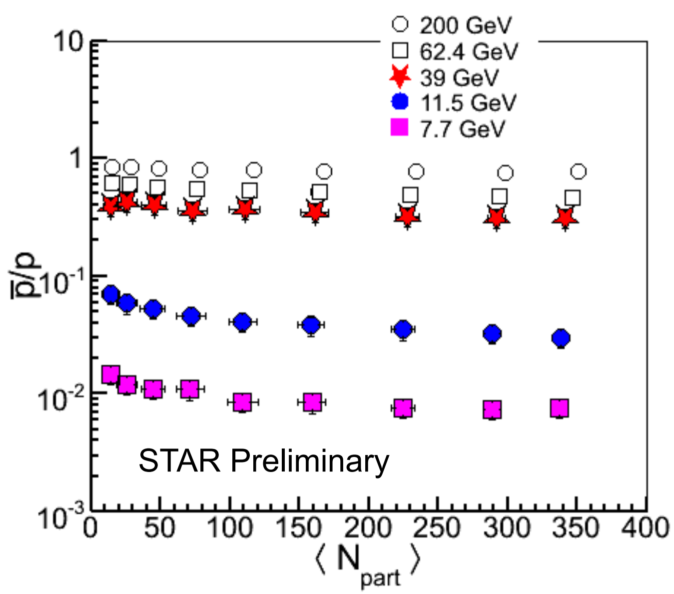
Similar measurements are carried out for 7.7 and 11.5 GeV collisions

Centrality Dependence of Antiparticle to Particle Ratios



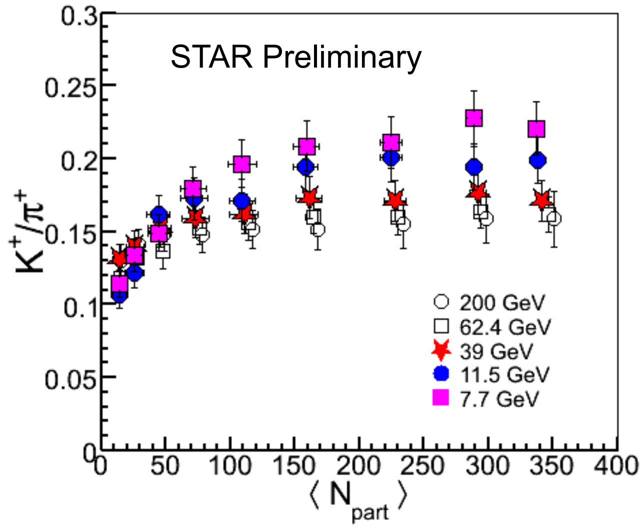
Errors: Systematic and statistical added in quadrature, dominated by extrapolation to low p_T spectra

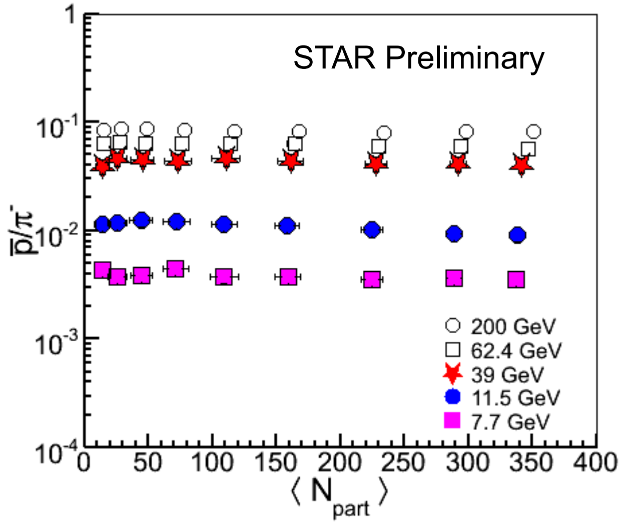


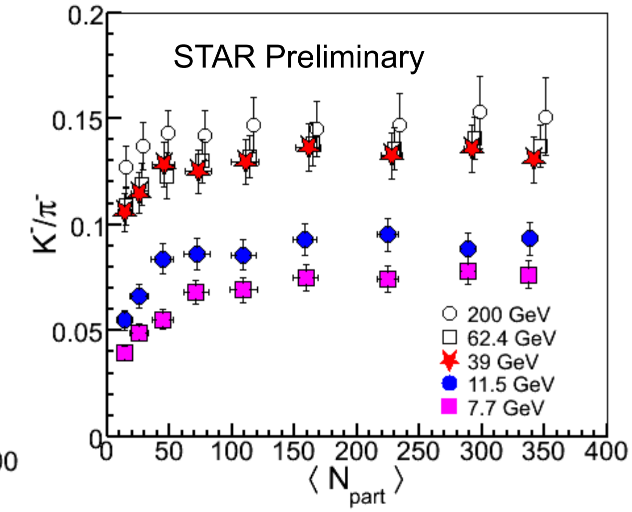


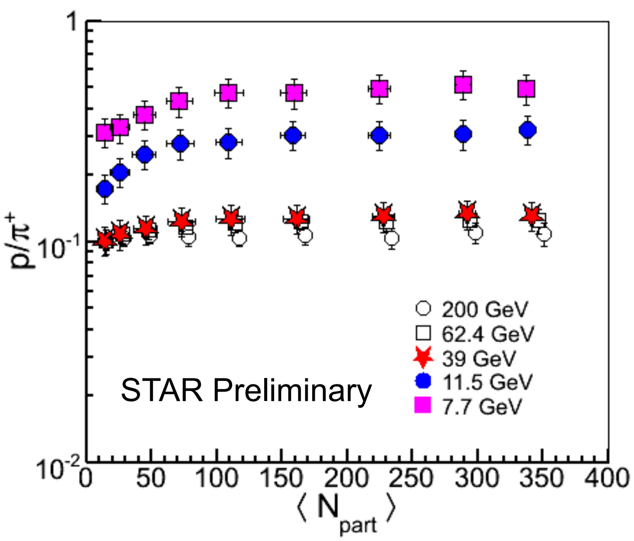
- ✧π^-/π^+ slightly increases with decrease in energy below 39 GeV
- ✧$\bar{p}/p$ and K^-/K^+ increase with increase in energy

Centrality Dependence of Particle Ratios









Errors: Systematic and statistical added in quadrature, dominated by extrapolation to low p_T sectra

- ✧ K^+/π^+ and p/π^+ increase with decrease in energy
- ✧ $\bar{p}/\pi^-$ and K^-/π^- increase with increase in energy

Strange particle ratios: X. Zhang, X. Zhu

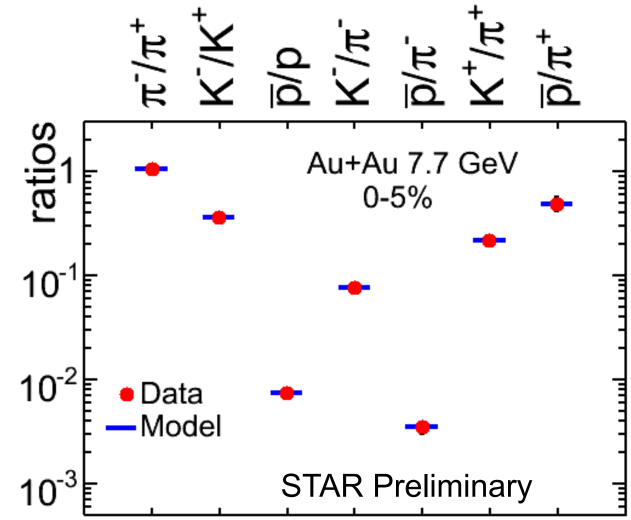
Chemical Freeze-out

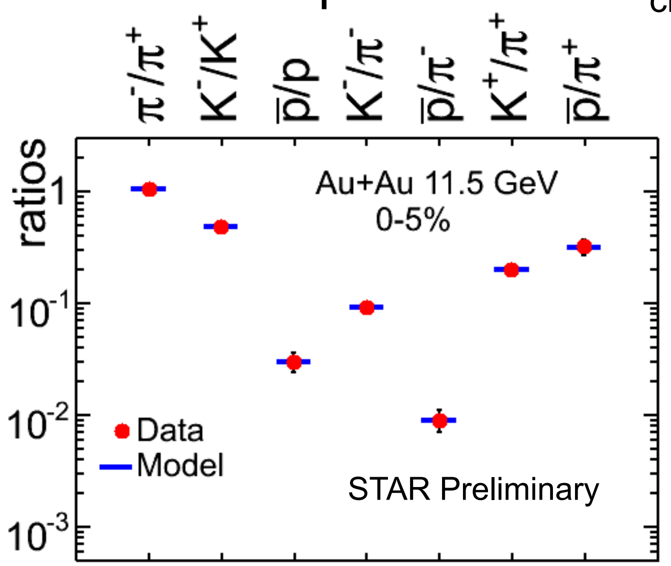
Statistical-Thermal Model (THERMUS):

$$n = \frac{1}{V}\frac{\partial(T\ln Z)}{\partial\mu} = \frac{VTm_i^2 g_i}{2\pi^2}\sum_{k=1}^{\infty}\frac{(\pm1)^{k+1}}{k}\left(e^{\beta k\mu_i}\right)K_2\left(\frac{km_i}{T}\right)$$

β=1/T; -1(+1) for fermions (bosons), Z=partition function; m_i = mass of hadron species i; V = volume; T = Temperature; K_2= 2nd order Bessel function; g_i = degeneracy; μ_i = chemical potential

- ✧Fitted particle ratios with THERMUS
- ✧Used grand-canonical approach
- ✧Two main parameters: T_{ch} and μ_B

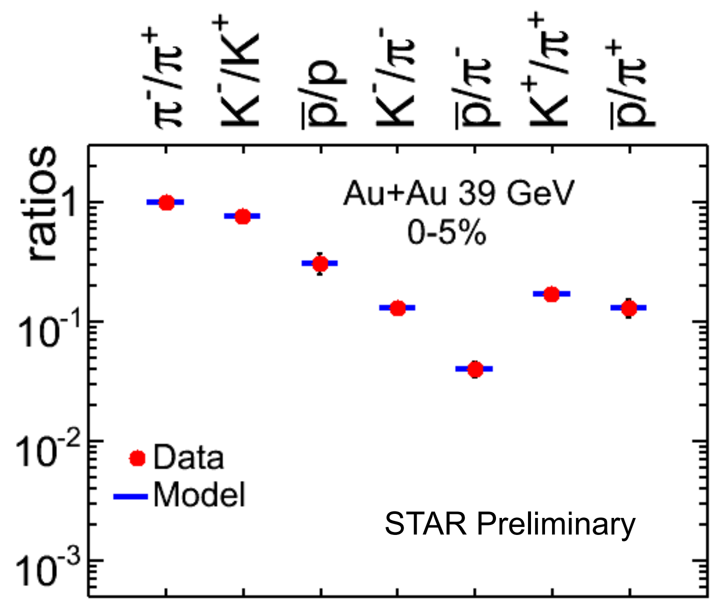




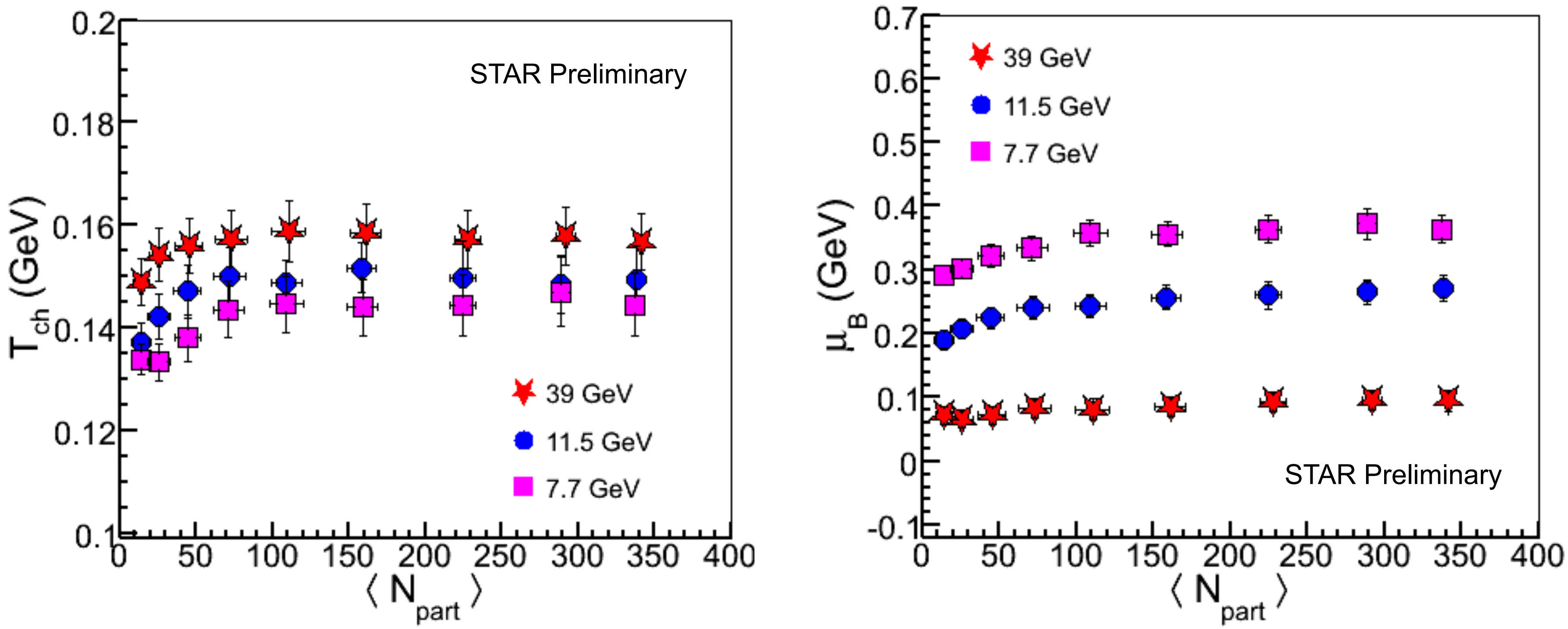
Use strange particles also in future

S. Wheaton & J. Cleymans, hep-ph/0407174;
S. Wheaton, J. Cleymans & M. Hauer, comp. phys. Comm. 180 (2009) 84.

Lokesh Kumar



Centrality Dependence: T_{ch} and μ_B



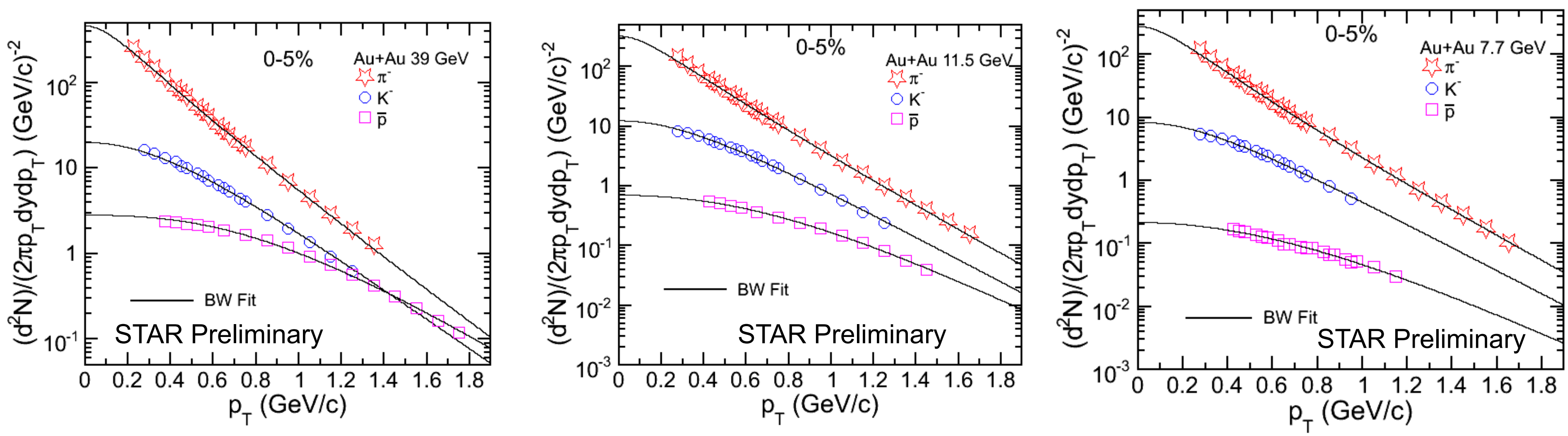
- ✧ The chemical freeze-out temperature increases slightly with increase in energy
- ✧ Baryon chemical potential decreases with increase in energy

Kinetic Freeze-out

Blast-Wave (BW) Model:

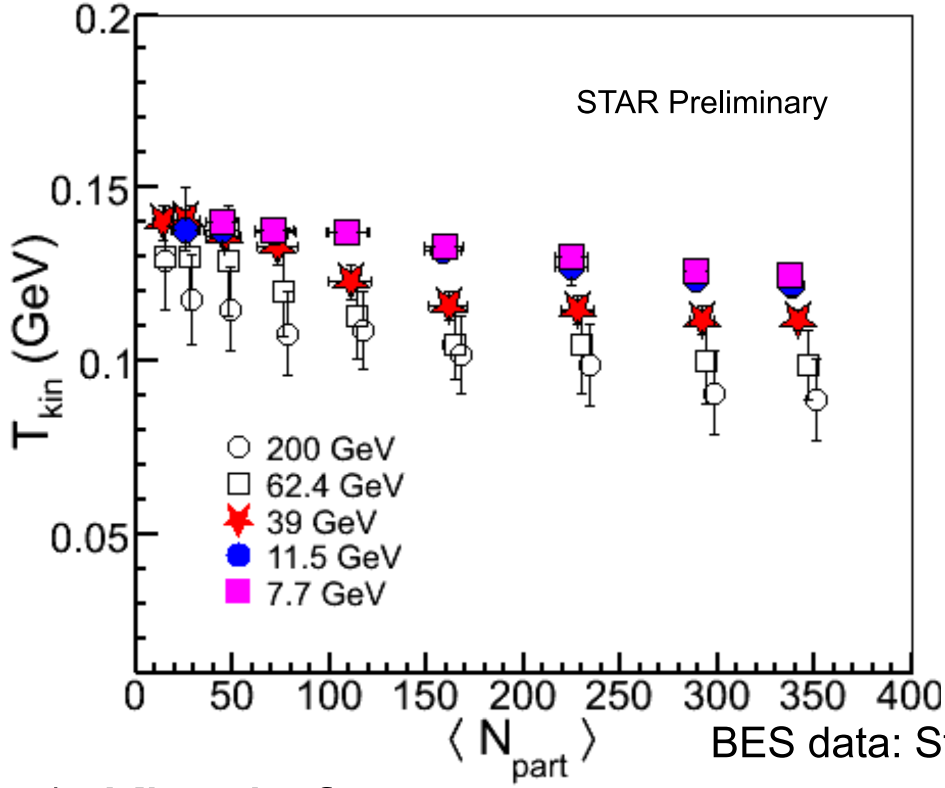
$$\frac{dN}{p_T dp_T} \propto \int_0^R r dr m_T I_0\left(\frac{p_T \sinh\rho(r)}{T_{kin}}\right) \times K_1\left(\frac{m_T \cosh\rho(r)}{T_{kin}}\right)$$

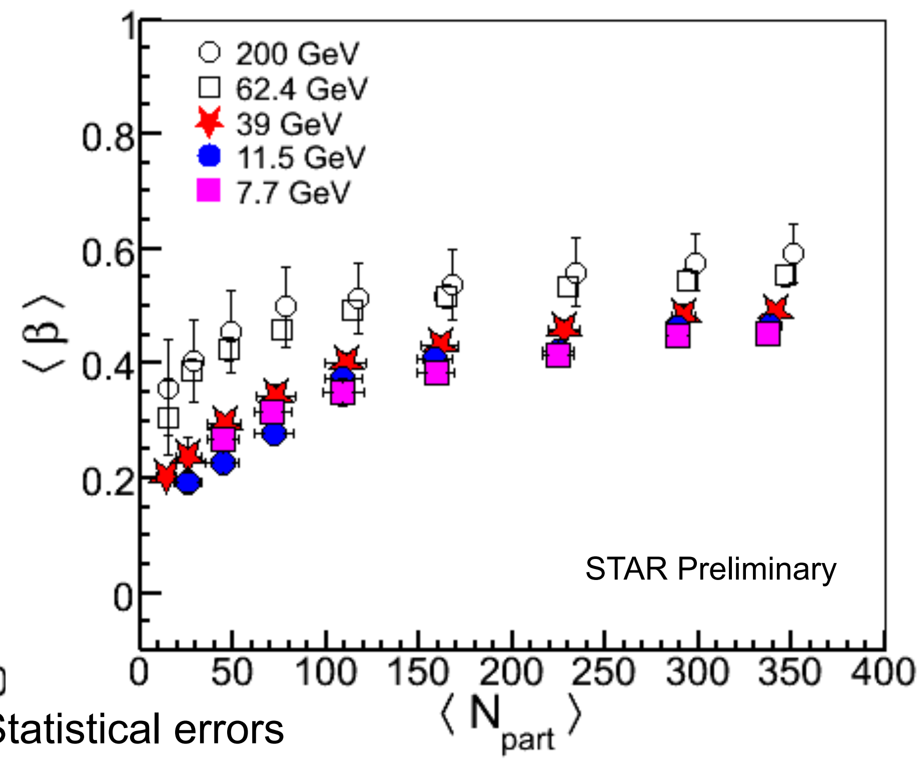
- ✧ Spectra are fitted simultaneously with BW
- ✧ Two main parameters: T_{kin} and $<\beta>$



$\chi^2/ndf \sim 0.8$

Centrality Dependence: T_{kin} and $<\beta>$

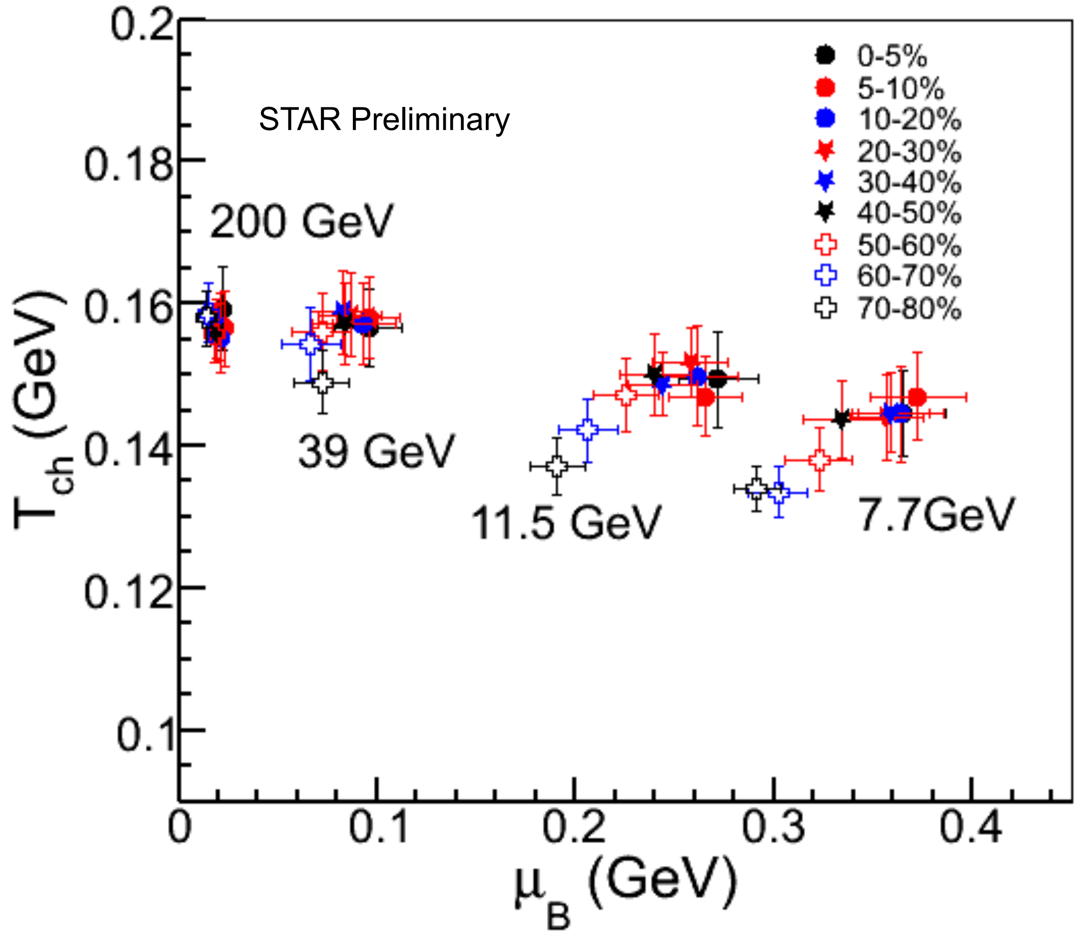




BES data: Statistical errors

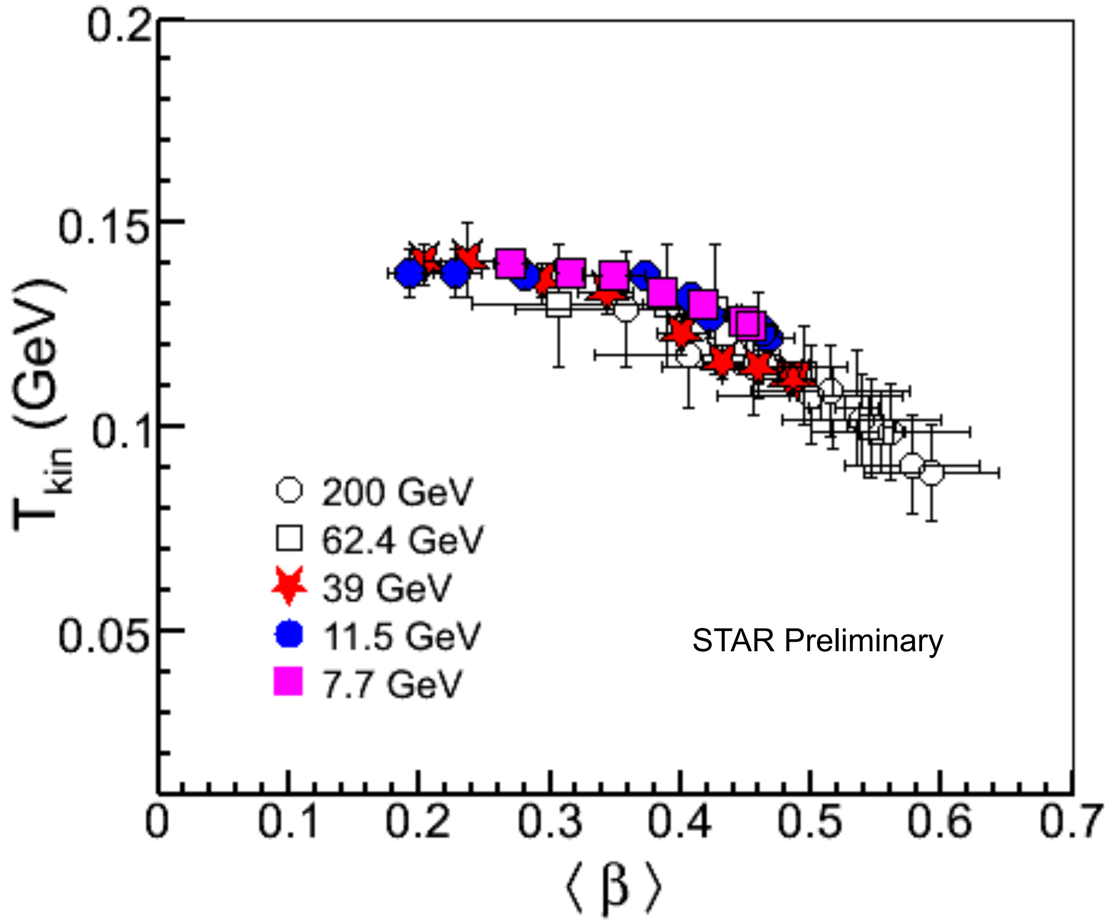
- Kinetic freeze-out temperature decreases with increase in energy and centrality
- Average flow velocity increases with increase in energy and centrality

T_{ch} vs. μ_B



✧First time observed, a clear centrality dependence of freeze-out temperature with baryon chemical potential at lower energies

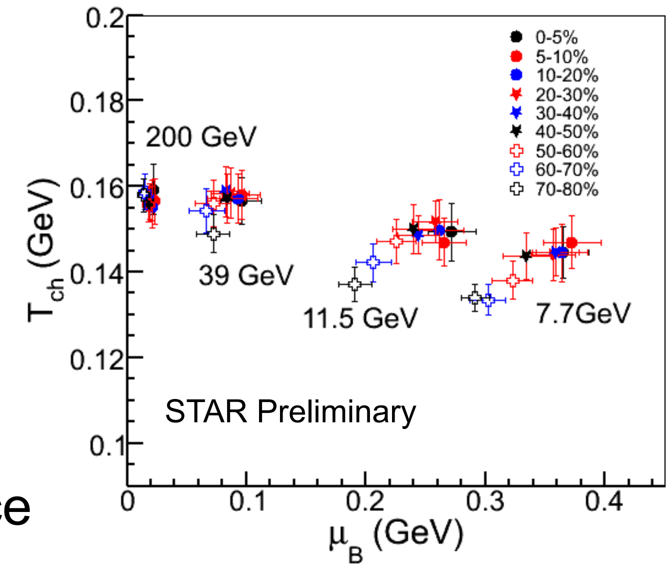
T_{kin} vs. <β>



✧Higher kinetic temperature corresponds to lower value of average flow velocity and vice-versa

Summary

- Centrality dependence of identified hadrons (π, K, p, antiparticles) p_T spectra and particle ratios are presented for BES energies (7.7, 11.5, and 39 GeV)



- Particle ratios are used to extract T_{ch} and μ_B
  - First observation of clear centrality dependence of freeze-out parameters at low energies
  - New measurements have extended the μ_B range covered by RHIC data from 20-400 MeV in the phase diagram

- p_T spectra are used to extract the kinetic freeze-out parameters
  - T_{kin} decreases with increase in energy and centrality
  - Average flow velocity increases with increase in energy and centrality

Thanks

Thanks to STAR Collaboration

Argonne National Laboratory, Argonne, Illinois 60439
Brookhaven National Laboratory, Upton, New York 11973
University of California, Berkeley, California 94720
University of California, Davis, California 95616
University of California, Los Angeles, California 90095
Universidade Estadual de Campinas, Sao Paulo, Brazil
University of Illinois at Chicago, Chicago, Illinois 60607
Creighton University, Omaha, Nebraska 68178
Czech Technical University in Prague, FNSPE, Prague, 115 19, Czech Republic
Nuclear Physics Institute AS CR, 250 68 \v{R}e\v{z}/Prague, Czech Republic
University of Frankfurt, Frankfurt, Germany
Institute of Physics, Bhubaneswar 751005, India
Indian Institute of Technology, Mumbai, India
Indiana University, Bloomington, Indiana 47408
Alikhanov Institute for Theoretical and Experimental Physics, Moscow, Russia
University of Jammu, Jammu 180001, India
Joint Institute for Nuclear Research, Dubna, 141 980, Russia
Kent State University, Kent, Ohio 44242
University of Kentucky, Lexington, Kentucky, 40506-0055
Institute of Modern Physics, Lanzhou, China
Lawrence Berkeley National Laboratory, Berkeley, California 94720
Massachusetts Institute of Technology, Cambridge, MA
Max-Planck-Institut f\"ur Physik, Munich, Germany
Michigan State University, East Lansing, Michigan 48824
Moscow Engineering Physics Institute, Moscow Russia
NIKHEF and Utrecht University, Amsterdam, The Netherlands
Ohio State University, Columbus, Ohio 43210
Old Dominion University, Norfolk, VA, 23529
Panjab University, Chandigarh 160014, India
Pennsylvania State University, University Park, Pennsylvania 16802
Institute of High Energy Physics, Protvino, Russia
Purdue University, West Lafayette, Indiana 47907
Pusan National University, Pusan, Republic of Korea
University of Rajasthan, Jaipur 302004, India
Rice University, Houston, Texas 77251
Universidade de Sao Paulo, Sao Paulo, Brazil
University of Science \& Technology of China, Hefei 230026, China
Shandong University, Jinan, Shandong 250100, China
Shanghai Institute of Applied Physics, Shanghai 201800, China
SUBATECH, Nantes, France
Texas A\&M University, College Station, Texas 77843
University of Texas, Austin, Texas 78712
University of Houston, Houston, TX, 77204
Tsinghua University, Beijing 100084, China
United States Naval Academy, Annapolis, MD 21402
Valparaiso University, Valparaiso, Indiana 46383
Variable Energy Cyclotron Centre, Kolkata 700064, India
Warsaw University of Technology, Warsaw, Poland
University of Washington, Seattle, Washington 98195
Wayne State University, Detroit, Michigan 48201
Institute of Particle Physics, CCNU (HZNU), Wuhan 430079, China
Yale University, New Haven, Connecticut 06520
University of Zagreb, Zagreb, HR-10002, Croatia