Study the production of identified charged hadrons in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV using the STAR detector

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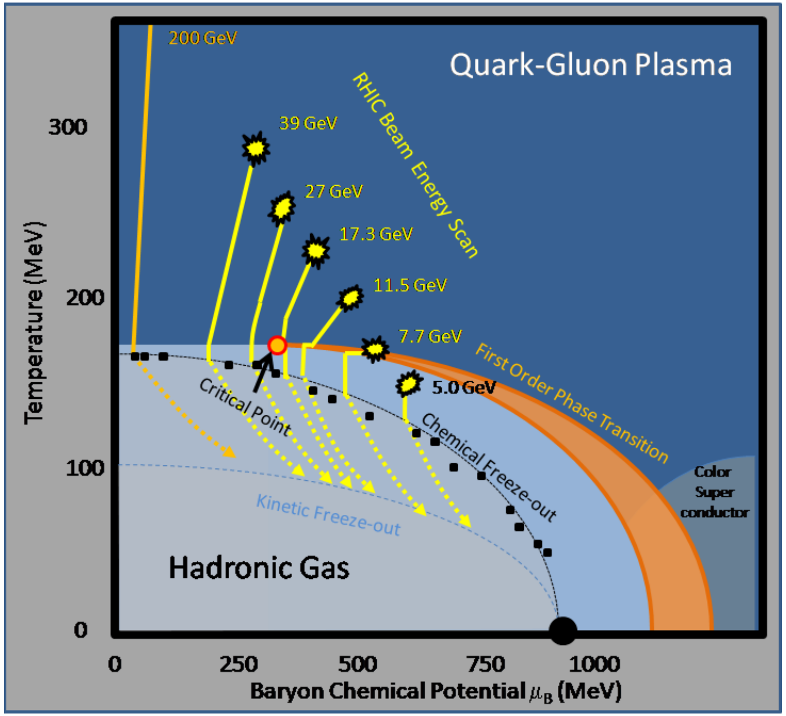
Introduction

Aims of the BES Program at RHIC

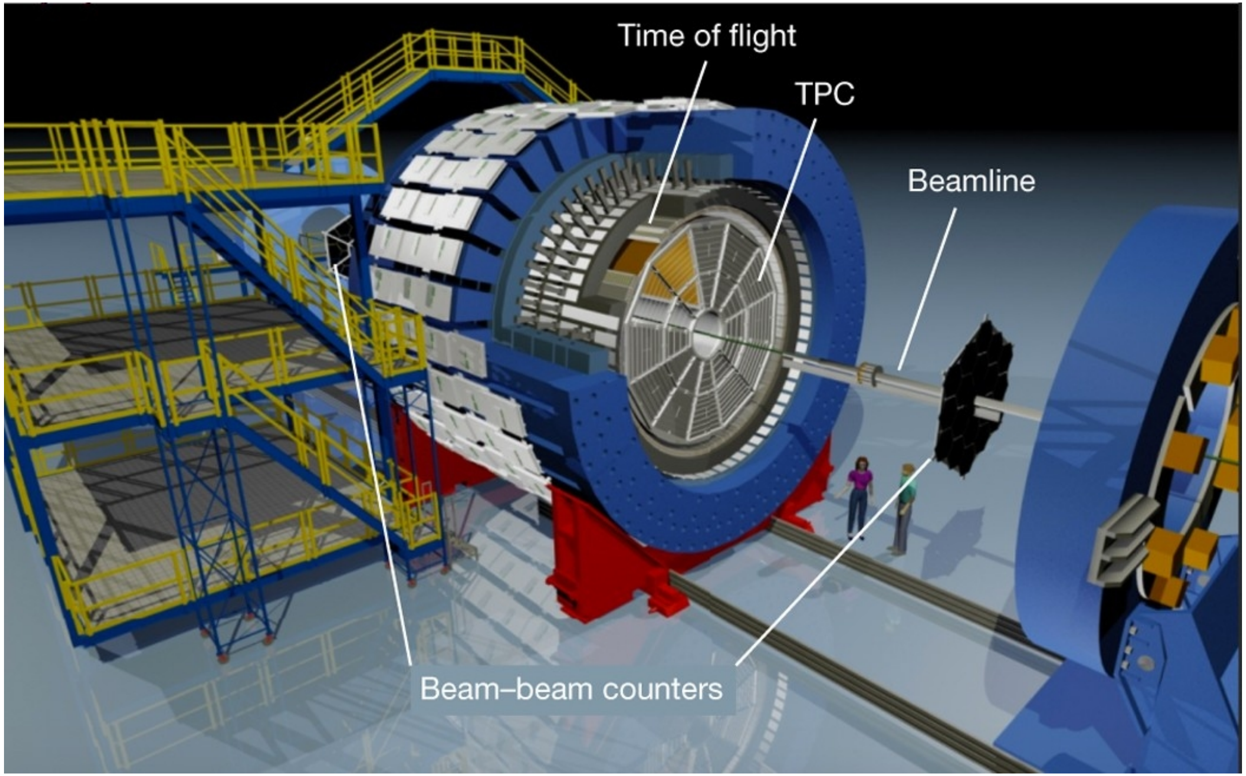
- Study of QCD phase diagram
- Search of the QCD critical point and first-order phase transition

- **BES I (2010-2014)**
  $\sqrt{s_{NN}}$ = 62.4, 39, 27, 19.6, 14.5, 11.5, 7.7 GeV
- **BES II (2017-2021)**
  Collider mode: $\sqrt{s_{NN}}$ = **54.4,** 27, 19.6, 17.3, 14.6, 11.5, 9.2, 7.7 GeV
  Fixed target mode: $\sqrt{s_{NN}}$ = 13.7, 11.5, 9.2, 7.7, 7.2, 6.2, 5.2, 4.5, 3.9, 3.5, 3.2, 3.0 GeV



The main idea behind the BES program is to vary the collision energy and look for the signatures of the QCD phase boundary and QCD critical point.

The STAR Detector

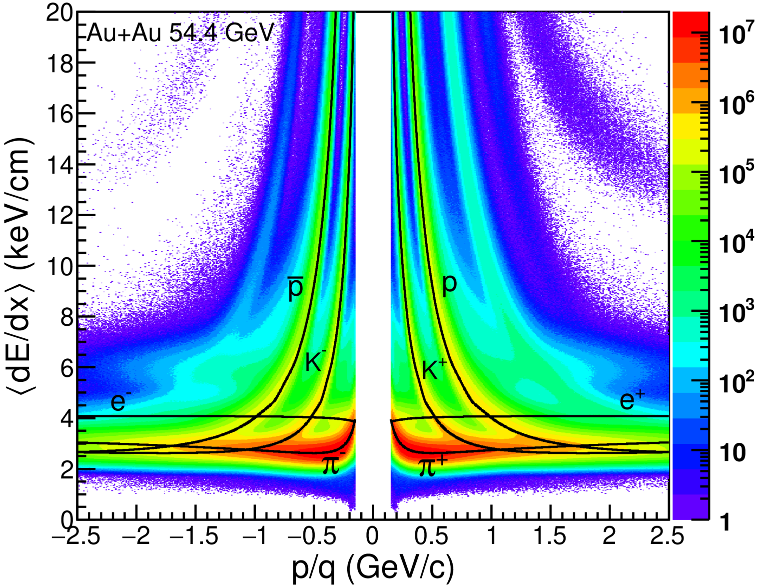


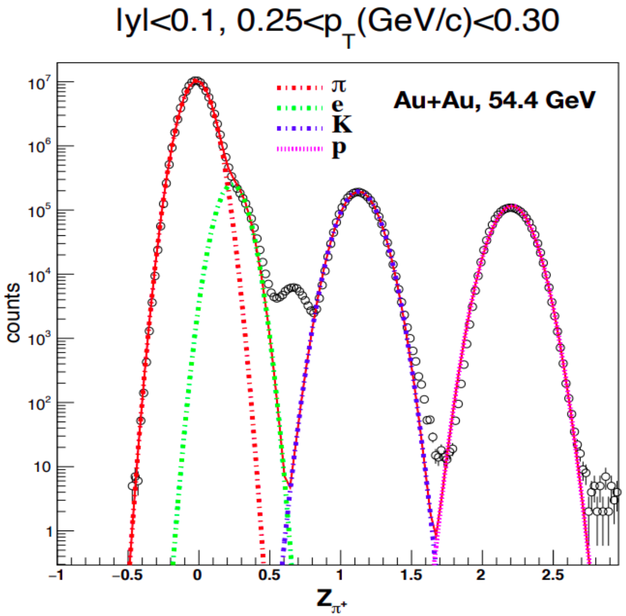
- The Solenoidal Tracker at RHIC, known as STAR, tracks the thousands of particles produced by heavy-ion collisions at RHIC.
- STAR is used to search for signatures of the formation of matter that RHIC was designed to create: the Quark-Gluon Plasma.
- Particle identification (PID) is performed by using the Time Projection Chamber (TPC) and the Time-Of-Flight (TOF) detector together at STAR.

Data Set and Particle Identification

Data set: Au+Au $\sqrt{s_{NN}}$ = 54.4 GeV **Particles studied:** $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ **Sub-detectors used:** TPC + TOF

PID using TPC:





Particle identification is accompalished in the TPC by measuring the <dE/dx>.

The dE/dx distribution, for a given particle type, can be transformed to the *z* variable which is given by $z_X = \ln\left(\frac{\langle dE/dx \rangle}{\langle dE/dx \rangle_X^B}\right)$, where *X* is particle type and *B* is Bichsel function.

Data Set and Particle Identification

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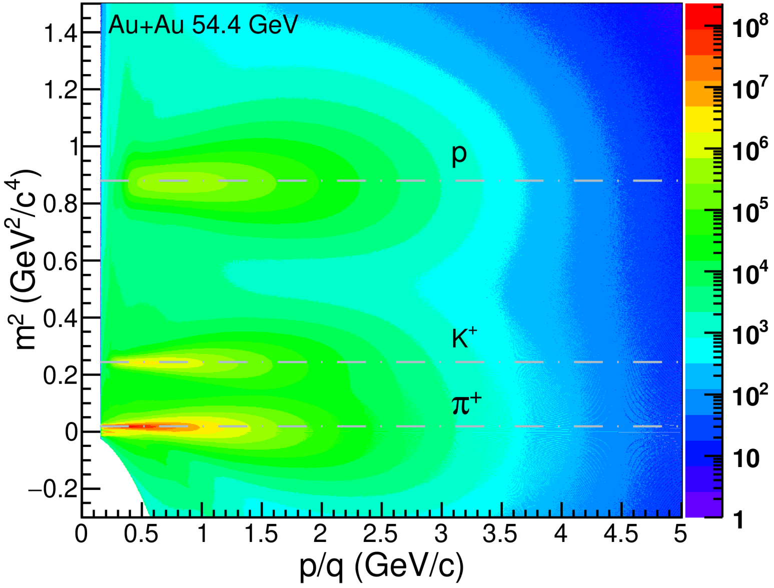
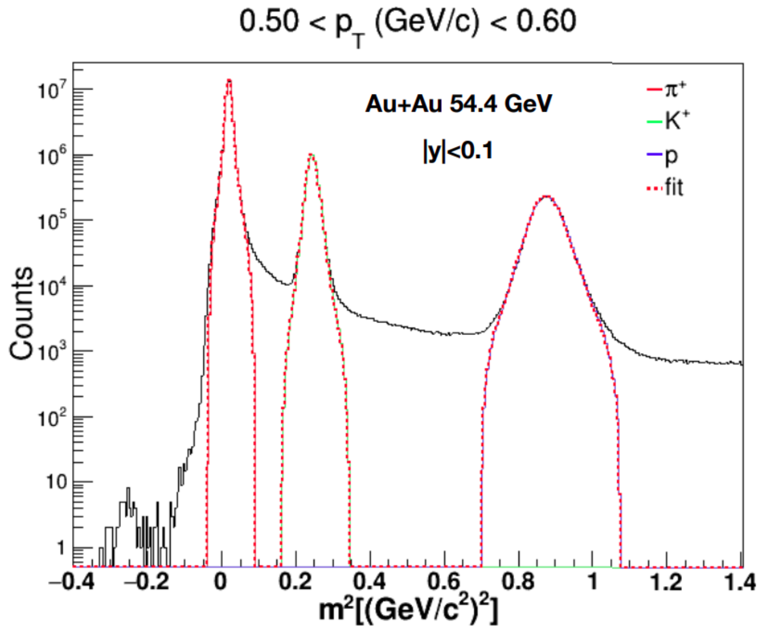
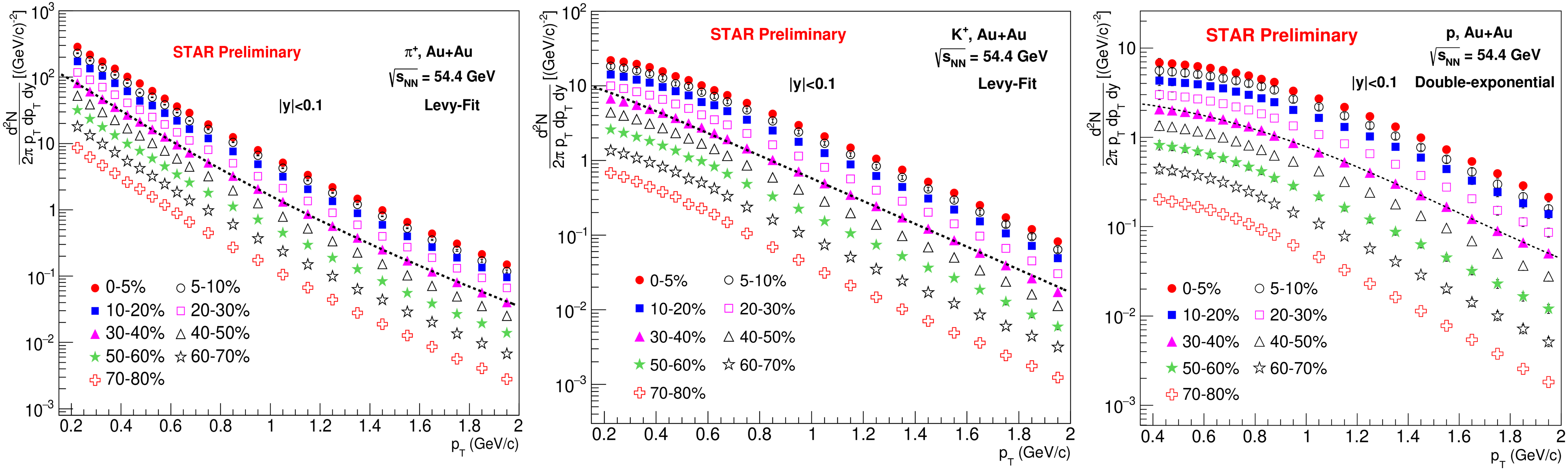
PID using TOF:





The raw yields from TOF are obtained using the variable mass square (m^2), given by, $m^2 = p^2\left(\frac{c^2T^2}{L^2} - 1\right)$

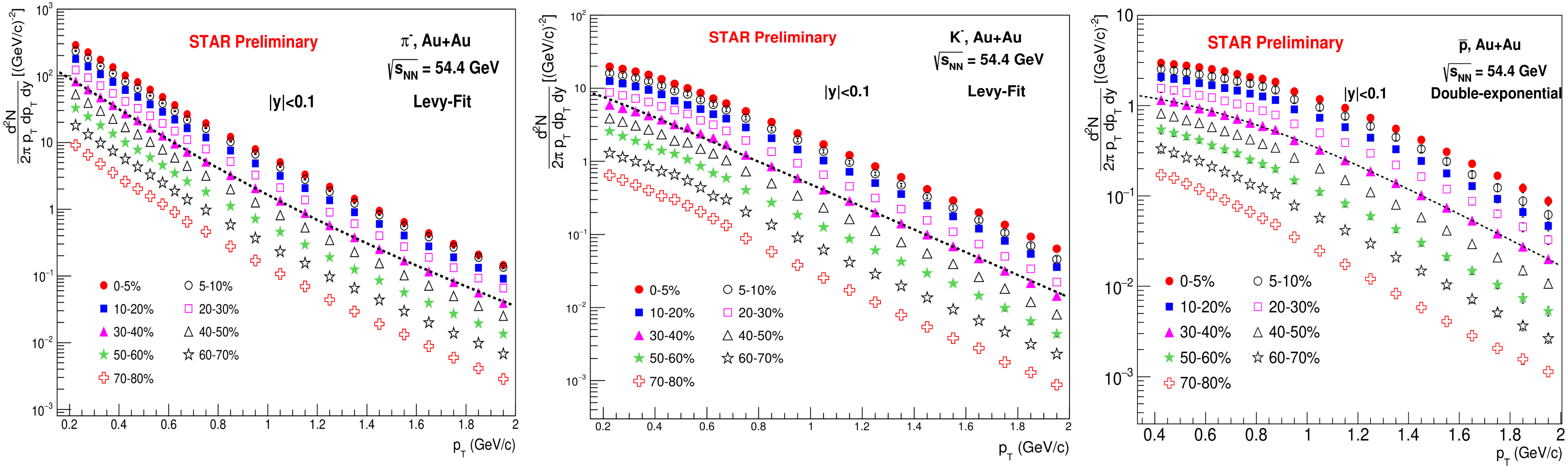
Transverse Momentum Spectra



The yields from TPC are obtained for $p_T < 0.75$ GeV/c for π^+ and K^+, and $p_T < 0.85$ GeV/c for p. The yields from TOF are obtained within rapidity $|y| < 0.1$ for $p_T > 0.7$ GeV/c for π^+ and K^+, and $p_T > 0.9$ GeV/c for p.

The transverse momentum spectra show clear centrality and p_T dependence

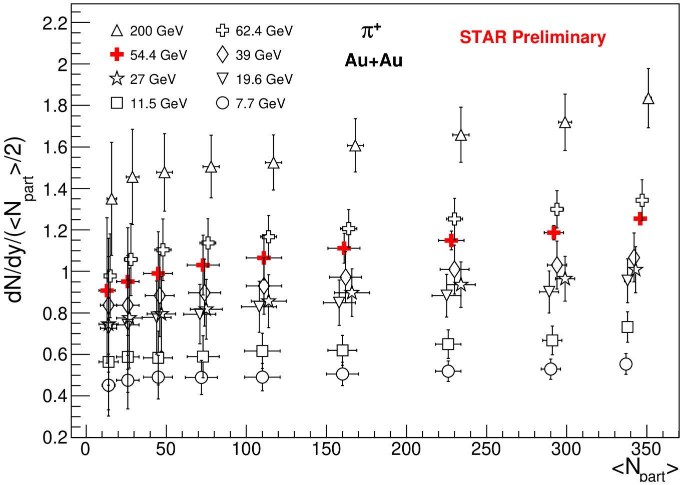
Transverse Momentum Spectra

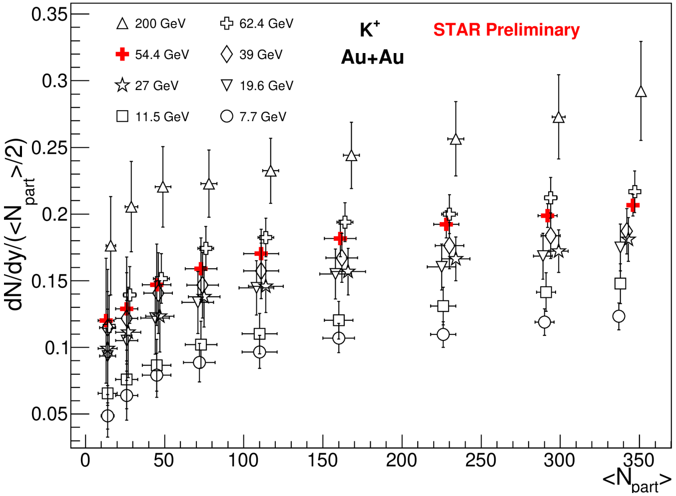


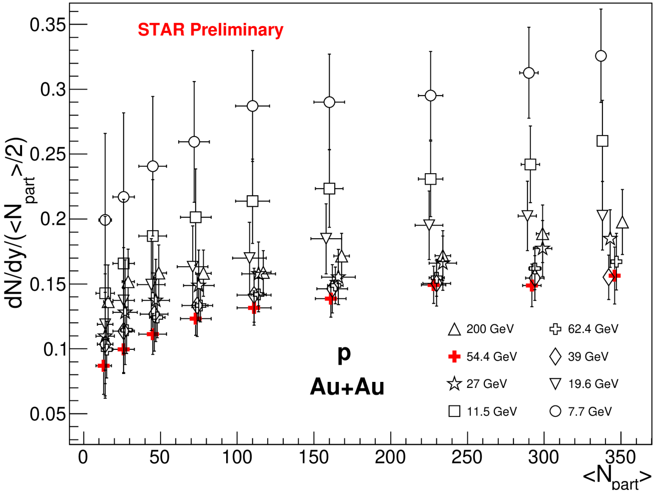
The yields from TPC are obtained for p_T < 0.75 GeV/c for π^- and K^-, and p_T < 0.85 GeV/c for $\bar{p}$. The yields from TOF are obtained within rapidity |y| < 0.1 for p_T > 0.7 GeV/c for π^- and K^-, and p_T > 0.9 GeV/c for $\bar{p}$.

The transverse momentum spectra show clear centrality and p_T dependence.

Centrality Dependence of Particle Yields

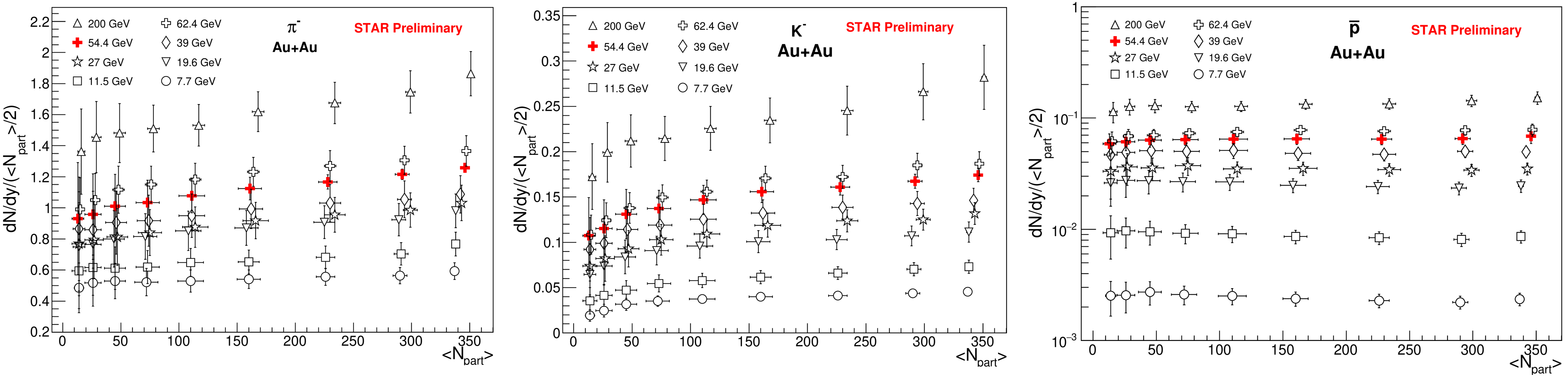






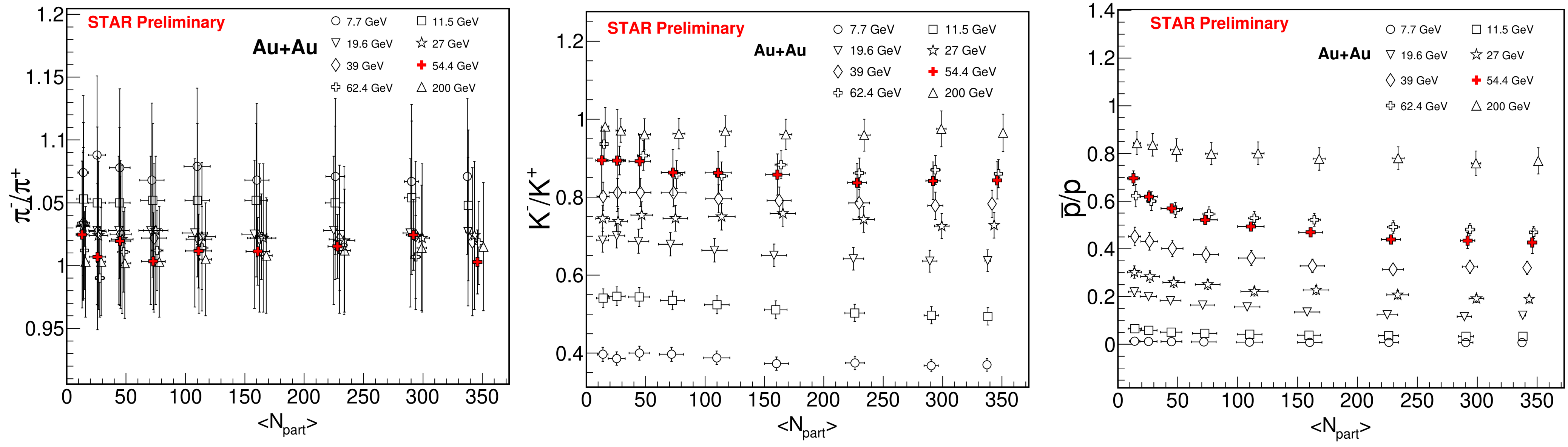
- Normalized yields for π^+ and K^+ show clear energy and centrality dependence.
- The normalized yield for p show clear centrality dependence. The observed energy trend is due to the interplay between pair production and baryon stopping.

Centrality Dependence of Anti-Particle Yields



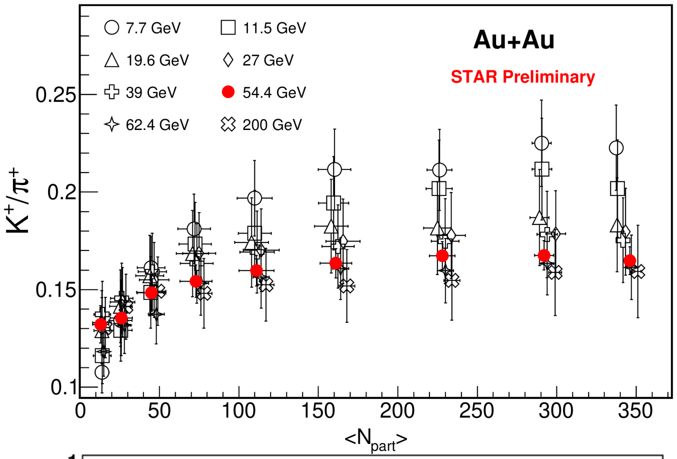
- Normalized yields for π^- and K^- show clear energy and centrality dependence.
- Normalized yield for $\bar{p}$ shows clear energy dependence but not centrality dependence.

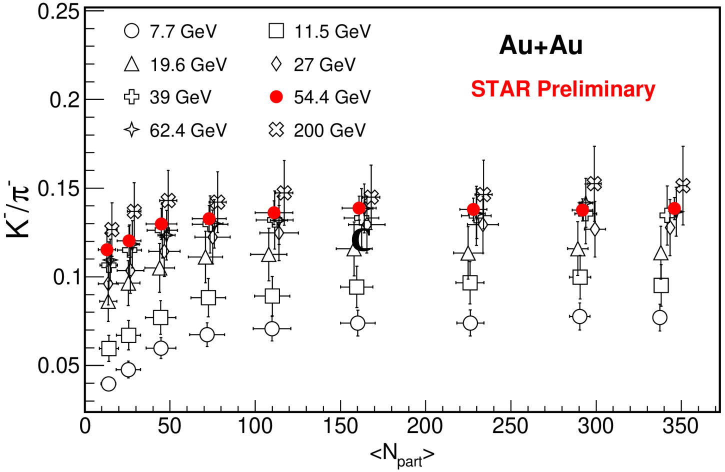
Centrality Dependence of Particle Ratios

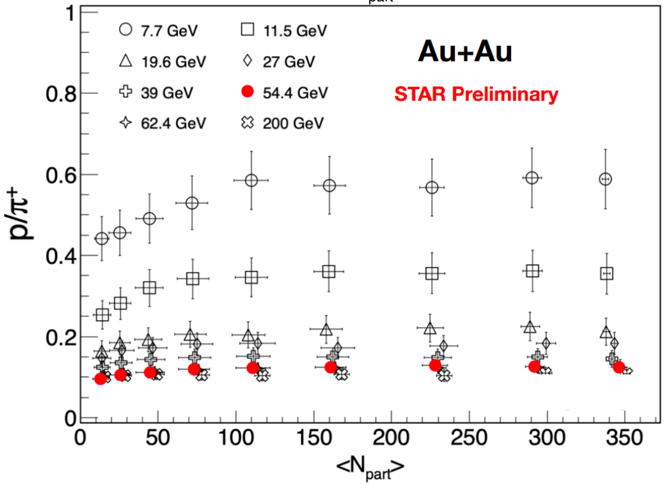


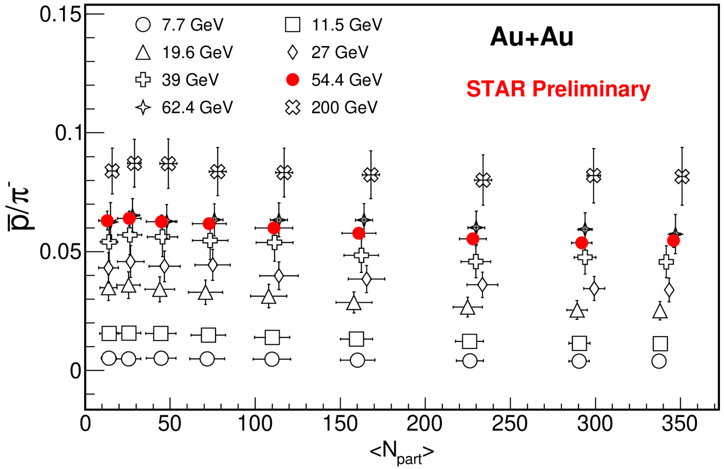
- π^-/π^+ ratio is close to unity for all the centralities.
- K^-/K^+ ratio shows clear energy dependence but weak centrality dependence.
- $\bar{p}/p$ ratio shows energy dependence. The ratio decreases as we move towards central collisions which could be due to the baryon stopping.

Centrality Dependence of Mixed Ratios



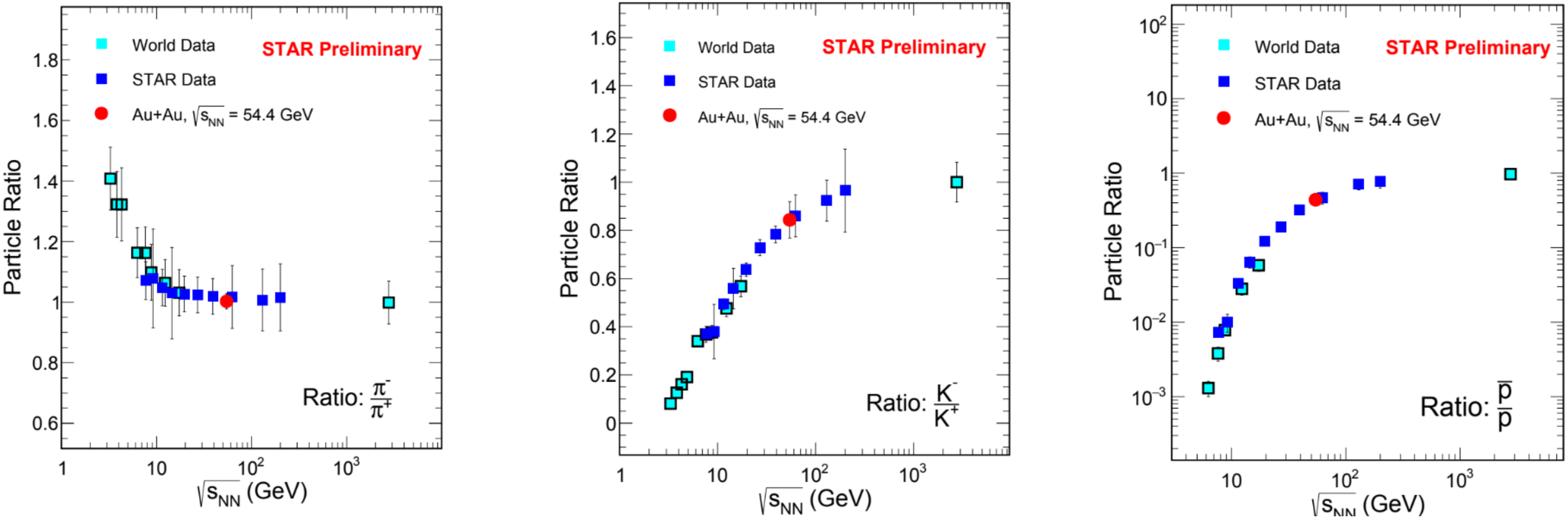






- K^+/π^+ ratio is maximal at 7.7 GeV due to dominating associated production which is a result of large baryon stopping at low energies.
- K^-/π^- ratio increases with increasing energy.
- p/π^+ ratio decreases with the increasing energy due to larger baryon stopping at lower energies.
- $\bar{p}/\pi^-$ ratio increases with increasing energy and shows little centrality dependence.

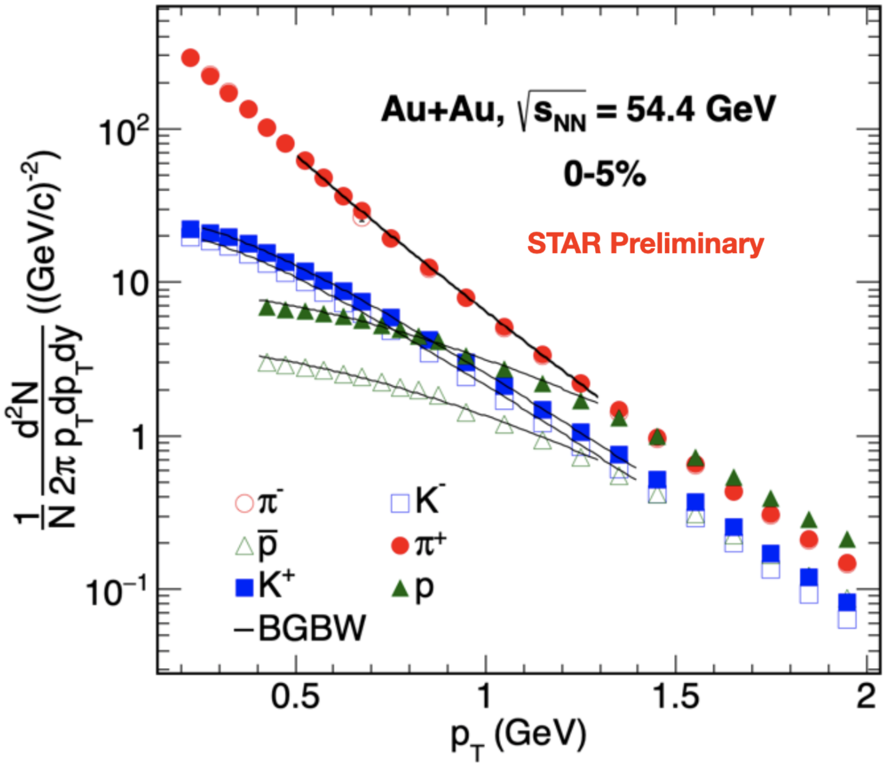
Energy Dependence of Particle Ratios



- The anti-particle to particle ratios measured at 54.4 GeV follow the world data trend.

B. Abelev et al. (STAR Collaboration), Phys. Rev. C 81, 24911 (2010)
L. Adamczyk et al. (STAR Collaboration), Phys. Rev. C 96, 044904 (2017)
J. Adam et al. (STAR Collaboration), Phys. Rev. C 101, 24905 (2020)

Blast Wave Model



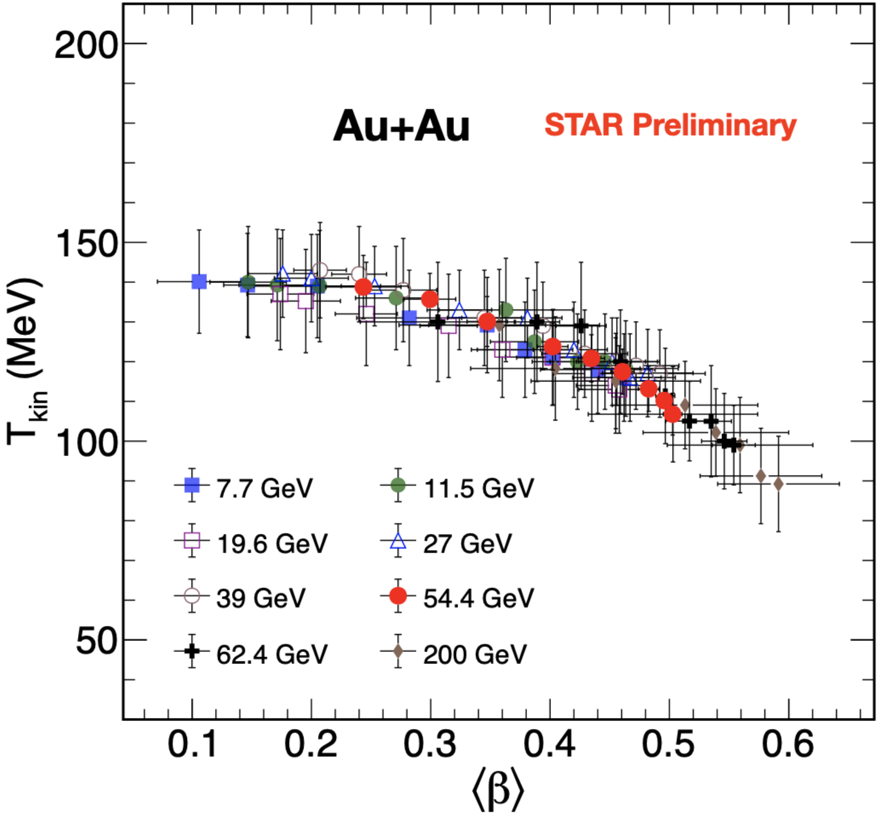
- A hydrodynamics-inspired model which describes the dynamics of the freeze-out phase.
- Transverse momentum distribution of the particles is described by:

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

where $m_T = \sqrt{p_T^2 + m^2}$, m is mass of hadron,
I_0 and K_1 are modified bessel functions,
$\rho(r) = \tanh^{-1}(\beta)$,
β is the transverse radial flow velocity,
n is the exponent of flow velocity profile,
T_{kin} is the kinetic freeze-out temperature.

E. Schnedermann, J. Sollfrank, and U. W. Heinz, Phys. Rev. C 48, 2462 (1993)

Kinetic Freeze-Out Parameters



- The transverse momentum spectra are fitted simultaneously for all the particles and anti-particles to obtain the freeze-out parameters.
- T_{kin} and β are anti-correlated to each other.
- T_{kin} and β follow the trend with other energies.

L. Adamczyk et al. (STAR Collaboration) Phys. Rev. C 96, 044904 (2017)
B. Abelev et al. (STAR Collaboration) Phys. Rev. C 79, 034909 (2009)

Summary

- The transverse momentum spectra of $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ in 54.4 GeV Au+Au collisions using the STAR data have been studied.
- Centrality and energy dependence for all the particles and anti-particles are studied.
- The centrality and energy dependence of particle ratios are studied which follow the world data trend as a function of energy.
- The spectras are fitted with the Blast-wave model to obtain the freeze-out parameters.
- T_{kin} and β are anti-correlated and follow the trend with other energies.

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