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

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July 22, 2023

Abstract

Exploring the QCD phase diagram and searching for the QCD critical point are some of the main goals of the Beam Energy Scan program at RHIC. In 2017, the STAR experiment collected a large dataset of Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV. The identified particle spectra and yields provide information about the bulk properties of the hot medium created in these collisions. Furthermore, the rapidity dependence study is essential for exploring the boost-invariant regions of the system.

We present the measurements of the production of $\pi^{\pm}$, $\mathrm{K}^{\pm}$, p, and $\bar{p}$ in various centralities and rapidity intervals. The results for the transverse momentum spectra, particle yields $\mathrm{d}N/\mathrm{d}y$, average transverse momentum $\langle \mathrm{p}_T \rangle$, and particle ratios will be presented for different centrality classes and rapidity intervals. The kinetic freeze-out parameters will be obtained for different rapidity intervals and the results will be compared to similar measurements at other energies. The physics implications of the results will be discussed.

1 Introduction

The Beam Energy Scan (BES) Program at Relativistic Heavy Ion Collider (RHIC) aims to explore the Quantum Chromodynamics (QCD) critical point and phase boundary by varying collision energy [1]. The identified spectra and yields of charged hadrons provide insights into the bulk properties of the hot medium created in heavy-ion collisions [2]. In this study, we present charged hadron production ($\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$) at mid-rapidity ($|y| < 0.1$) from Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV, collected by the STAR experiment as part of the BES II program at RHIC.

2 Results and Discussion

Figure 1 illustrates the transverse momentum spectra for identified charged hadrons (π^+, K^+, and p) across nine centrality classes. The spectra are fitted using the Levy-Tsallis function for pions and kaons, and the double-exponential function for protons, enabling extraction of total particle yield to the full p_T region.

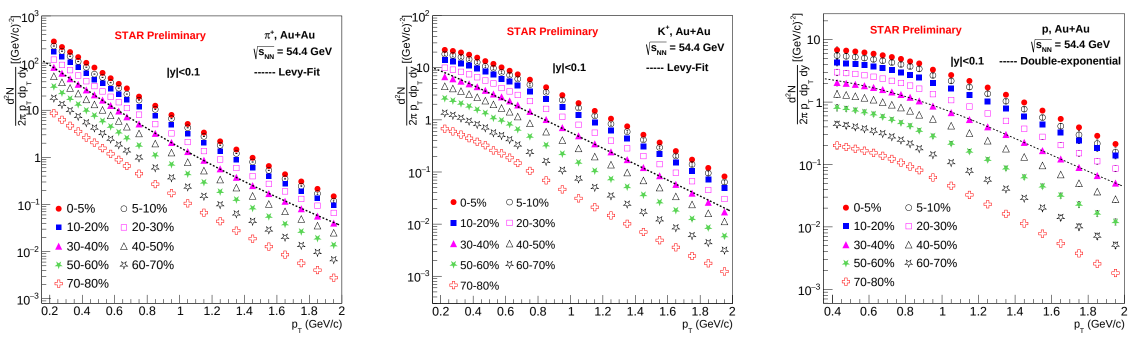

Figure 1: Transverse momentum spectra of π^+, K^+ and p measured in Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV at mid-rapidity in STAR.

Figure 2 shows the normalized yield for different particles, demonstrating their dependencies on energy and centrality. π^+, π^-, K^+ and K$^-$ exhibit clear dependencies on both energy and centrality. The proton yield is maximum at 7.7 GeV and then decreases until 39 GeV, after which it slightly increases up to 200 GeV. The significant proton yield at 7.7 GeV can be attributed to the baryon stopping at lower energies, whereas as the energy increases, pair production becomes dominant. Conversely, $\bar{p}$ displays a clear energy dependence but a weak centrality dependence. In Figure 3, the energy dependence of antiparticle-to-particle ratios is compared to global data at various colliding energies [1–4]. At lower energies, the π^-/π^+ ratio exceeds unity due to isospin effects and significant contributions from resonance decays. As the energy increases, the K^-/K^+ ratio also rises, indicating a growing contribution from pair production in kaon production. In contrast, associated production dominates at lower energies. The energy-dependent $\bar{p}/p$ ratio increases with rising energy, indicating substantial contributions from baryon stopping at low energies.

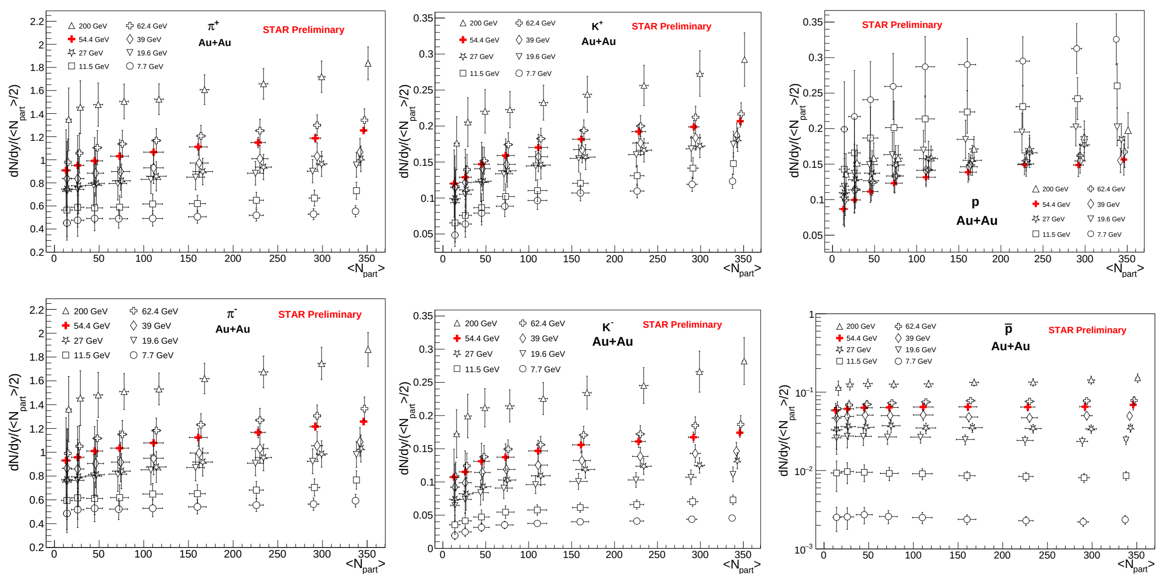

Figure 2: The normalized integrated particle yield of π^+, π^-, K^+, K^-, p and $\bar{p}$ as a function of $\langle N_{part}\rangle$ in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV at mid-rapidity in STAR. Results are compared to STAR published data [1, 2].

The kinetic freeze-out parameters were obtained using the hydrodynamics based Blast-wave model [2]. The transverse momentum spectra of $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ were fitted simultaneously to extract the kinetic freeze-out temperature (T_{kin}) and average transverse radial flow velocity ($\langle\beta\rangle$). Figure 4 illustrates the comparison of these results with other energy data, revealing an inverse relationship between the parameters suggesting longer lived fireball in central collisions.

The Bjorken energy density provides insights into particle interactions in high-energy collision experiments. It is defined as the energy per unit transverse area in the transverse plane of a collision. Mathematically, it is given by the equation:

$$\epsilon_{BJ} = \frac{dE_T}{dy} \times \frac{1}{S_{\perp}\tau} \tag{1}$$

Here, $S_\perp$ represents the transverse overlap area of the colliding nuclei, τ is the formation time, and $\frac{dE_\perp}{dy}$ is calculated using the integrated particle yield and mean transverse momentum [2, 5, 6]. Figure 5 shows the rise in Bjorken energy density times τ with centrality at various colliding energies (left) and an increase with collision energy in the most central collisions (right).

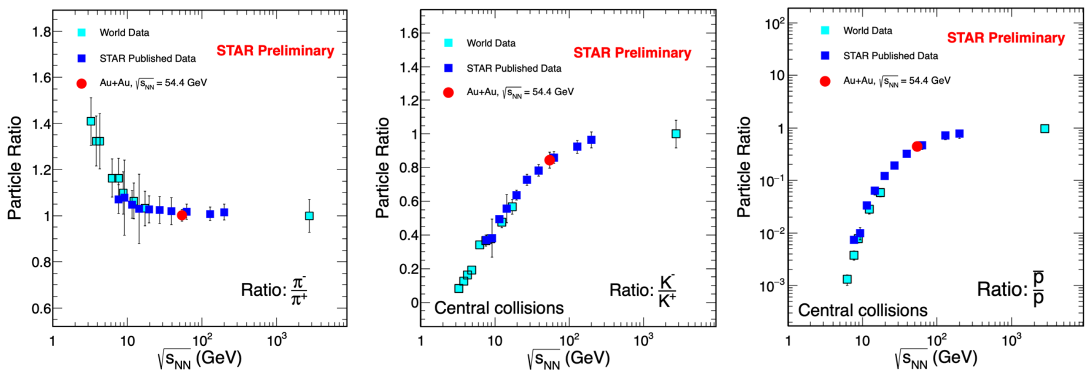

Figure 3: The anti-particle to particle yield ratio of π^-/π^+, K^-/K^+, and $\bar{p}/p$ as a function of energy for most central Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV at mid-rapidity in STAR. Results are compared to STAR published data [1, 2] and world data. The data points corresponding to energies other than BES energies are taken from Refs. [3, 4].

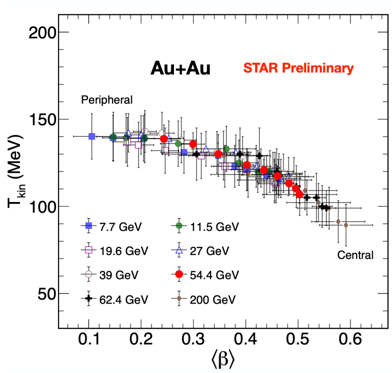

Figure 4: The variation of T_{kin} with $\langle\beta\rangle$ in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV at mid-rapidity in STAR. Results are compared to STAR published data [1, 2].

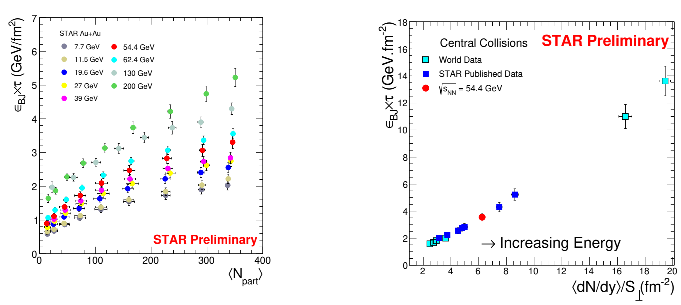

Figure 5: Bjorken energy density times the formation time as a function of $\langle N_{part}\rangle$ (left) and ⟨dNdy⟩/S$_\perp$ (right) for Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV at mid-rapidity in STAR. Results are compared to the STAR published results [1, 2] and world data [3–5].

3 Summary

We present measurements of identified particles ($\pi^{\pm}$, $K^{\pm}$, p, and $\bar{p}$) at mid-rapidity ($|y| < 0.1$) in Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV using the STAR detector. The normalized yields of pions and kaons exhibit clear energy and centrality dependence. The proton yield peaks at 7.7 GeV, declines until 39 GeV, then experiences a slight increase up to 200 GeV. The proton yield at low energies is mainly attributed to baryon stopping and increasing energy favours the dominance of the pair production mechanism. The ratio of anti-particles to particles yields in Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV follow the trend observed in worldwide data. The kinetic freeze-out parameter T_{kin}, increases from central to peripheral collisions, while $\langle\beta\rangle$ decreases. At $\sqrt{s_{NN}} = 54.4$ GeV, there is a two-dimensional anti-correlation between T_{kin} and $\langle\beta\rangle$, which follows the trend observed for other BES energies at STAR. The Bjorken energy density depicting the energy density at initial stages of collision, increases with both colliding energy and centrality.

References

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