Study of bulk properties in Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV using the STAR detector

Arushi Dhamija (for the STAR Collaboration)*
Department of Physics, Panjab University, Chandigarh - 160014, INDIA

Introduction

Colliding heavy ions at high energies allow us to generate and investigate the Quark-Gluon-Plasma (QGP). Quantum Chromo Dynamics (QCD) in the standard model describes the strong interactions between quarks and gluons. Heavy-ion collision experiments at relativistic energies aim to explore the QCD critical point and phase boundary by varying collision energy [1]. The transition from partonic degrees of freedom to a phase dominated by hadronic degrees of freedom is expected to be a first-order phase transition at high μ_B, as indicated by various QCD-based models, whereas at very low μ_B, it becomes a rapid crossover [2]. The point where the first-order phase transition terminates, and the phase boundaries no longer exist, is referred to as the QCD critical point.

The Beam Energy Scan (BES) Program, conducted at the Relativistic Heavy Ion Collider (RHIC), seeks to explore the QCD critical point and phase boundary. Analyzing the transverse momentum spectra of charged hadrons provides information about the kinetic freeze-out, while the integrated particle yields offer insights into the chemical freeze-out. Both these observables provide information about the bulk properties of the hot medium produced in heavy-ion collisions [1]. The first phase of the BES program was conducted from 2010 to 2014 with Au+Au collisions at various energies. After the successful completion of BES-I, STAR undertook the BES-II program providing significantly high statistics datasets for analysis.

The transverse momentum spectra of identified charged hadrons provides important information about the various aspects of the system, such as thermalization, particle production, collective flow behavior, as well as the dynamics and properties of the produced particles. Bjorken energy density is known to provide information about the extreme conditions of temperature and energy density at the early stages of collision.

*Electronic address: arushidhamija507@gmail.com

Analysis details

The STAR experiment collected large dataset of Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV in the year 2017 with the minimum bias trigger. We present the systematic measurements of pions ($\pi^{\pm}$), kaons ($K^{\pm}$), protons (p) and anti-protons ($\bar{p}$) at $\sqrt{s_{NN}} = 54.4$ GeV at mid-rapidity ($|y|<0.1$). The detectors that played a major role in the particle identification were the Time Projection Chamber (TPC) and the Time Of Flight (TOF) detector. The raw spectra obtained for $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ (using the $\langle$dE/dx$\rangle$ information from TPC and mass square (m^2) information from TOF) were corrected for acceptance and efficiency to obtain the final spectra.

Results and discussion

The transverse momentum spectra (p_T) of $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ were fitted simultaneously with the Blast-wave model [4] to extract the kinetic freeze-out parameters like temperature (T_{kin}) and average transverse radial flow velocity ($\langle\beta\rangle$). Figure 1 illustrates the comparison of the results for Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV with other STAR published data at various energies, revealing an anti-correlated relationship between the parameters suggesting longer lived fireball in central collisions.

The Bjorken energy density provides insight to the behaviour of particle interactions in

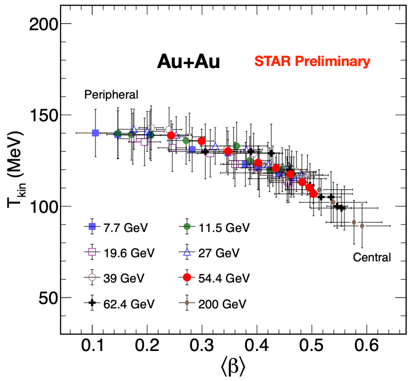

FIG. 1: The variation of T_{kin} and $\langle\beta\rangle$ at various centralities in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV compared with other STAR energies [1, 3].

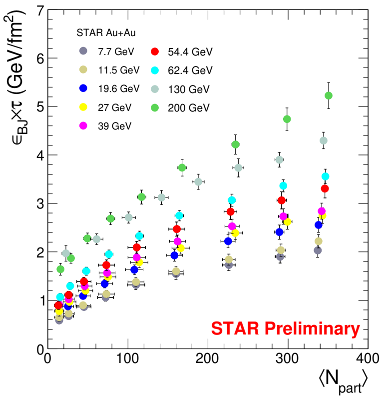

FIG. 2: The Bjorken energy density times τ as a function of $\langle N_{part}\rangle$ for Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV compared with other STAR energies [1, 3].

high energy collision experiments. In the central rapidity region of the collision zone at formation time τ, the Bjorken energy density can be estimated as

$$\epsilon_{BJ} = \frac{dE_T}{dy} \times \frac{1}{S_\perp \tau} \text{ where,}$$

$$\frac{dE_T}{dy} \approx \frac{3}{2}\left(\langle m_T\rangle \frac{dN}{dy}_{\pi^\pm}\right) + 2\left(\langle m_T\rangle \frac{dN}{dy}_{K^\pm,p,\bar{p}}\right),$$

where $\langle m_T\rangle$ is the mean transverse mass, dN/dy is the integrated particle yield and $S_\perp$ is the transverse overlap area of the two colliding nuclei [3]. By employing the above equations, the Bjorken energy density is computed for all energies and presented as a function of number of participants. Figure 2 depicts the Bjorken energy density as a function of $\langle N_{part}\rangle$ for various energies, showing it increases with rising collision energy and centrality. In Figure 3, the Bjorken energy density for the most central collisions is plotted as a function of $\frac{\langle dN/dy\rangle}{S_\perp}$ for various energies, suggesting that the Bjorken energy density increases with collision energy.

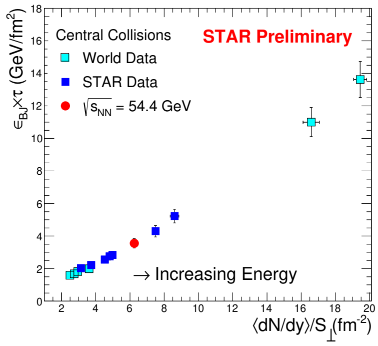

FIG. 3: The variation of Bjorken energy density with $\frac{\langle dN/dy\rangle}{S_\perp}$ for the central collisions in Au+Au at $\sqrt{s_{NN}}$ = 54.4 GeV compared with other energies [5].

Acknowledgments

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