Strange Hadron Production in Au+Au Collisions at $\sqrt{s_{NN}}$ = 54.4 GeV

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Abstract. The RHIC Beam Energy Scan (BES) program was proposed to study the QCD phase transition. As a sensitive probe to the transition from the hadron gas to the Quark-Gluon Plasma, the particle ratios of strange hadrons are measured to study the properties of nuclear matter. Recently, the production of strange hadrons (K^0_s, Λ, Ξ, Ω, and ϕ) at mid-rapidity (|y|<0.5) in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV were measured by the STAR experiment at RHIC. In this paper nuclear modification factor, baryon-to-meson ratio, as well as the overall integrated yields of these strange hadrons at $\sqrt{s_{NN}}$ = 54.4 GeV are presented. In particular, the multi-strange baryon-to-meson ratio $N(\Omega^- + \bar{\Omega}^+)/[2N(\phi)]$ is studied and compared to previous measurements from other BES energies. The strange-hadron-to-pion ratios versus charged hadron multiplicity are also studied and compared to the measurements in heavy-ion collisions at higher energies.

1 Introduction

The main goal of the RHIC BES Program is to map the quantum chromodynamics (QCD) phase diagram, including locating the onset of deconfinement, searching the critical point and the phase boundary of the first order phase transition [1]. The multi-strange hadrons are sensitive probes to study the initial stage of the collision as they freeze out early and are expected to have a small hadronic interaction cross section [2, 3]. The central-to-peripheral nuclear modification factor R_{cp} is less than unity at high p_T for various particles at top RHIC energy [4, 5], indicating that there is a significant energy loss of the scattered partons in QGP. Different trends in baryon/meson ratio at intermediate $p_T \approx 2.5$ GeV/c can give information about the parton recombination [6, 7]. The enhancement of Ω/ϕ ratio at intermediate p_T indicates hadron formation through parton recombination [8], therefore the study of Ω and ϕ particles offers the knowledge of the transition from partonic to hadronic matter.

The Solenoidal Tracker At RHIC (STAR) is a multi-purpose detector at the RHIC collider at Brookhaven National Laboratory. It provides measurements with full azimuthal coverage, uniform acceptance and excellent particle identification capability [9, 10]. This work presents strangeness production in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV, collected by the STAR experiment during the first phase of RHIC BES program in 2017.

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2 Results and discussion

The strange hadrons $K^0_s, \Lambda(\bar{\Lambda}), \Xi^-(\bar{\Xi}^+), \Omega^-(\bar{\Omega}^+)$, and ϕ are reconstructed using the invariant mass technique with the corresponding decay channels:

$K^0_s \rightarrow \pi^+ + \pi^-$ ($B.R.$ 69.20%) $\quad \Lambda(\bar{\Lambda}) \rightarrow p(\bar{p}) + \pi^-(\pi^+)$ ($B.R.$ 63.90%)

$\Xi^-(\bar{\Xi}^+) \rightarrow \Lambda(\bar{\Lambda}) + \pi^-(\pi^+)$ ($B.R.$ 99.887%) $\quad \Omega^-(\bar{\Omega}^+) \rightarrow \Lambda(\bar{\Lambda}) + K^-(K^+)$ ($B.R.$ 67.8%)

$\phi \rightarrow K^+ + K^-$ ($B.R.$ 49.1%)

Weak decay feed-down correction was carried on for Λ hyperons. The daughter particles of these strange hadrons, π, K, and p are identified by dE/dx in TPC to reconstruct the secondary vertex. More details of the strange particle reconstruction can be found in Ref. [7]. In the following, the particle yields, R_{cp}, Ω/ϕ ratio, and particles/pions ratio of the strange hadrons are presented and discussed.

2.1 Particle yields

The integrated yield dN/dy per half of average number of participating nucleon ($<N_{part}>/2$) as a function of $<N_{part}>$ at $\sqrt{s_{NN}}$ = 54.4 GeV are plotted in Fig. 1. We can see the normalized yields of K^0_s, Ξ, Ω, and ϕ increase with $<N_{part}>$ and energy. The feed down corrected $\bar{\Lambda}$ normalized yield has weak centrality dependence similar to other BES energies, which can be understood by the possible annihilation processes on anti-baryon production in more central collisions.

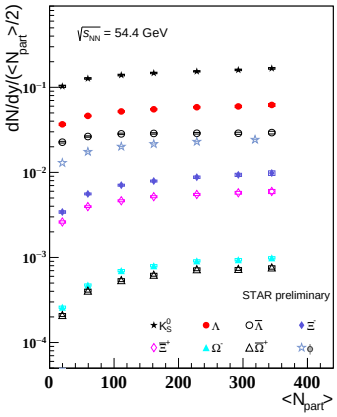

Figure 1: The integrated yield dN/dy per half of average number of participating nucleon ($<N_{part}>/2$) as a function of $<N_{part}>$. The box on each data point denotes the systematic error.

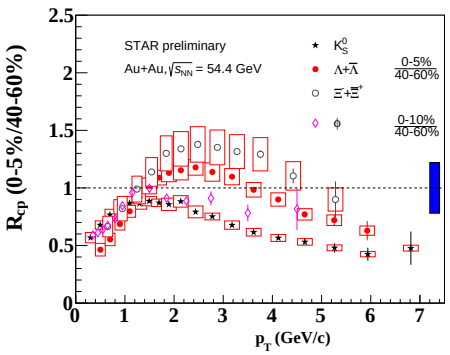

Figure 2: R_{cp}(0-5%)/(40-60%) of K^0_s, Λ, Ξ, and R_{cp}(0-10%)/(40-60%) of ϕ at mid-rapidity |y|<0.5 at $\sqrt{s_{NN}}$ = 54.4 GeV. The box on each data point of K^0_s, Λ, and Ξ denotes the systematic error. There are only statistical error for ϕ.

2.2 Nuclear modification factor R_{cp}

The nuclear modification factor R_{cp} is defined as the ratio of $(dN/dp_T)/<N_{coll}>$ in central collisions to that in peripheral ones. Here N_{coll} is determined from Glauber Monte Carlo

simulations [7]. R_{cp} of strange hadrons at $\sqrt{s_{NN}}$ = 54.4 GeV are presented in Fig .2. There is a strong suppression at high p_T for all particles indicating energy loss effect of scattered partons in QGP. A separation of baryon/meson at intermediate p_T suggests the hadron formation through parton recombination. Considering the R_{cp} results at other BES energies shown in Fig. 28 from Ref. [7], one can see that there is no suppression at highest measured p_T at $\sqrt{s_{NN}} \leq 11.5$ GeV, more statistics are needed for high p_T and results from BES phase -II program are expected.

2.3 Ω/ϕ ratio

Figure 3 (a) shows the centrality dependence of $N(\Omega^- + \bar{\Omega}^+)/[2N(\phi)]$ ratio as a function of transverse momentum at mid-rapidity (|y|<0.5) at $\sqrt{s_{NN}}$ = 54.4 GeV, the ratios keep increasing from peripheral to central collisions at intermediate p_T, this can be interpreted as a consequence of hadron formation through parton recombination and parton collectivity in central collisions. Figure 3 (b) presents the Ω/ϕ ratio for different energies in central collision (0-10%) [8]. An enhancement at intermediate p_T at $\sqrt{s_{NN}}$ = 54.4 GeV is apparently observed, indicating hadron formation through parton recombination. More statistics are needed for $\sqrt{s_{NN}}$ = 11.5 GeV to make a conclusion and this is one of the aims of BES-II program.

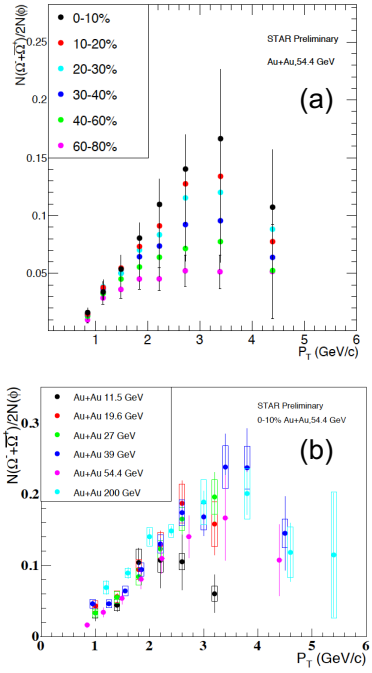

Figure 3: Centrality dependence of Ω/ϕ ratio at $\sqrt{s_{NN}}$ = 54.4 GeV (a), and energy dependence of that for central collisions 0-10% (b). Statistical and systematic errors are shown.

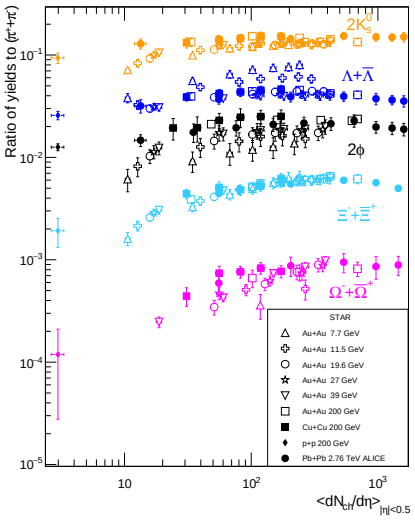

Figure 4: The ratio of yields of strange particles to that of pions [12, 13]. The errors are statistical and systematic.

2.4 Strange particles/pions ratio

The measurements by the ALICE experiment show particle ratios in p+p and p+Pb are identical at the same $dN_{ch}/d\eta$ [11], indicating that the final-state particle density might indeed be a good scaling variable between different systems. Figure 4 presents the ratio of yields of strange particles to that of pions [12, 13]. Here the charged-particle multiplicity density $dN_{ch}/d\eta$ is the sum of $k^{\pm}, \pi^{\pm}, p$, and $\bar{p}$ $dN/d\eta$. The ratios with $dN_{ch}/d\eta$ are system and energy independent, except for Λ and ϕ at lower energies. More statistics are needed for a firm conclusion for Ω.

3 Conclusion

The yield measurement of strange hadrons ($K^0_s, \Lambda, \Xi, \Omega$, and ϕ) at mid-rapidity (|y|<0.5) in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV has been presented. The normalized yields of K^0_s, Ξ, Ω, and ϕ increase with average number of participating nucleons and energy. The corrected $\bar{\Lambda}$ normalized yield has weak centrality dependence, indicating the possible annihilation processes on anti-baryon production. The strong suppression at high p_T of R_{cp} can be interpreted by the energy loss of parton in QGP. The separation of baryon and meson R_{cp} and the enhancement in Ω/ϕ ratio at intermediate p_T give information about parton recombination. This study on strange particles/pions ratio shows that $dN_{ch}/d\eta$ is a good scaling independent of system and energy for K^0_s and Ξ.

4 Acknowledgement

This work is supported by the Ministry of Science and Technology under GrantNo. 2020YFE0202001, 2018YFE0205200, 2016YFA0400100. The work is also supported by National Natural Science Foundation of China under Grant No. 11927901, 11420101004, 11735009, 11890710, 11890712, U1832118.

References

[1] STAR white paper, https://drupal.star.bnl.gov/STAR/starnotes/public/sn0598
[2] J. Rafelski and B. Muller, Phys.Rev.Lett. **56**, 2334 (1986).
[3] STAR, NPA **757**, 102(2005).
[4] STAR, Phys. Rev. Lett. **98**, 062301 (2004).
[5] STAR, Phys. Rev. Lett. **92**, 052302 (2004).
[6] STAR, Phys. Rev. Lett. **108**, 072301 (2012).
[7] STAR, Phys. Rev. C **102**, 034909 (2020).
[8] STAR, Phys. Rev. C **93**, 021903(R) (2016).
[9] STAR, Nucl. Instrum.Meth. A **499**, 624 (2003).
[10] M. Anderson et al., Nucl. Instrum. Meth. A **499**, 659 (2003).
[11] ALICE, Nature Physics volume **13**, 535-539 (2017).
[12] STAR, Phys. Rev. C **96**, 044904 (2017).
[13] ALICE, Phys. Rev. C **88**, 044910 (2013).