Recent results on strangeness production at STAR

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Abstract.

We report on the measurements of strange hadrons ($\mathrm{K}^{\pm}$, K^0_S, Λ, Ξ, Ω and ϕ) production at mid-rapidity in Au+Au collisions at $\sqrt{\mathrm{s_{NN}}}$ = 7.7 – 39 GeV from the STAR beam energy scan (BES) program. The collision energy dependence of strange hadron yields are presented. The strange hadron related particle ratios are compared with calculations from statistical and hadronic cascade models. The nuclear modification factors and baryon to meson ratios ($\overline{\Lambda}/\mathrm{K}^0_\mathrm{S}$ and Ω/ϕ) are presented. The physics implications for collision dynamics are discussed.

1. Introduction

The main motivation of STAR beam energy scan program is to study the QCD phase diagram [1]. Systematic study of Au+Au collisions from $\sqrt{\mathrm{s_{NN}}}$ = 39 GeV down to 7.7 GeV in the RHIC BES program may help to achieve the following goals: 1) searching for the QCD critical point where the first order phase transition at finite μ_B ends and identifying the phase boundary of the first order phase transition; 2) locating the particular collision energy where the deconfinement starts to happen, i.e. the onset of deconfinement.

Strange hadrons are excellent probes for identifying the phase boundary and onset of deconfinement. Strangeness enhancement in A+A with respect to p+p collisions has long been suggested as a signature of Quark-Gluon Plasma (QGP) formation in these collisions [2]. Until now, strangeness has been extensively measured in many experiments at different accelerator facilities [3–19]. Generally, the yields of strange hadrons in nuclear collisions are close to those expected from statistical models [20–23]. The precise measurement of strange hadrons yield in heavy ion collisions in BES will certainly lead to a better understanding of strangeness production mechanism in nuclear collisions and a more reliable extraction of the possible phase boundary.

On the other hand, it has been observed at RHIC that, at high p_T, the nuclear modification factor R_{CP} of various particles is much less than unity for Au+Au collisions at $\sqrt{\mathrm{s_{NN}}}$ = 200 GeV [24], indicating the significant energy loss of the scattered partons in the dense matter ("jet quenching"). By measuring the R_{CP} of strange hadrons in BES, one can potentially pin down the beam energy at which interactions with the medium begin to affect hard partons [1]. At intermediate p_T, it was found at RHIC that, the p/π and $\Lambda/\mathrm{K}^0_\mathrm{S}$ ratios are larger than unity in more central events. These ratios are much higher than that observed in elementary collisions [24–26]. These phenomena hint toward different hadronization mechanisms in this p_T range. There are recombination/coalescence models which allow soft partons to coalesce into hadrons, or soft and hard partons to recombine into hadrons [27]. They naturally reproduce an enhanced baryon to meson ratio when the parton p_T distribution is exponential. Such models require constituent quarks to coalesce or recombine, and hence the observation of coalescence or recombination behavior is one of the corner-stone pieces of evidence for the formation of the strongly interacting Quark-Gluon Plasma. It is also interesting to investigate at which collision energies these phenomena are prevalent [1], in order to locate the energy point at which the onset of the deconfinement happens.

In this paper, we present the strangeness data obtained from the high statistics Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 7.7$, 11.5, 19.6, 27 and 39 GeV, collected during the first phase of the STAR Beam Energy Scan (BES) program in 2010 and 2011.

2. Results

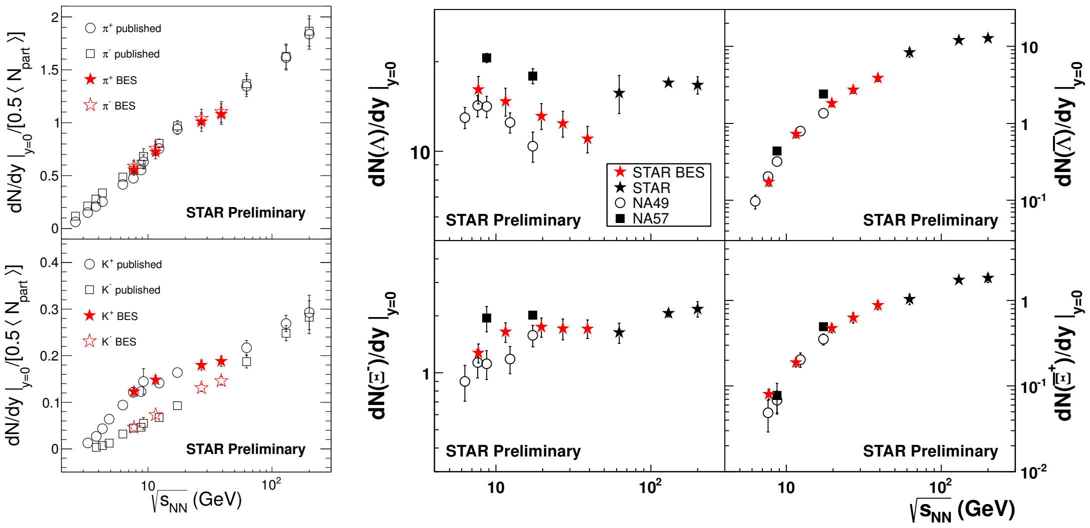

Figure 1. Collision energy dependence of strange hadron yields at mid-rapidity in most central (0-5%) Au+Au collisions. Also shown are the results from most central heavy ion collisions at STAR [13, 15–17, 28], NA57 [8], NA49 [9, 29] and AGS [30]. Errors are the quadratic sum of statistical and systematic errors.

Figure 1 shows the collision energy dependence of the particle yield (dN/dy) at mid-rapidity for $\pi^{\pm}$, $\mathrm{K}^{\pm}$, Λ, $\overline{\Lambda}$, Ξ^{-} and $\overline{\Xi}^{+}$ from the most central (0-5%) Au+Au collisions, compared to corresponding data from AGS, NA49, NA57, as well as the STAR data at higher energies. $\pi^{\pm}$, $\mathrm{K}^{\pm}$ yields have been divided by the number of participants in the most central collisions. Figure 1 shows that STAR BES data lie on a trend established by the corresponding data from NA49, NA57 and previous STAR data. There seems to be a non-monotonic $\sqrt{s_{\mathrm{NN}}}$ dependence in the Λ dN/dy, which may originate from the interplay of slow rise of Λ total multiplicity and the change of shape in rapidity distribution in the same energy range [9].

Figure 2 shows the $\sqrt{s_{\mathrm{NN}}}$ dependence of the ratios of $\mathrm{K}^{\pm}$, Λ, $\overline{\Lambda}$, Ξ^{-} and $\overline{\Xi}^{+}$ at mid-rapidity to that of pions in STAR BES, as well as the existing data from various experiments at different energies and the calculations from hadronic transport models (UrQMD v1.3 and HSD) [35] and a statistical hadron gas model (SHM) [22]. The BES data are in good agreement with the trend of the published results. Though the hadronic models seem to reproduce the Λ/π data, the default UrQMD (v1.3) fails in reproducing the Ξ^{-}/π and $\overline{\Xi}^{+}/\pi$ ratios due to a smaller Ξ yield in the model. On the other hand, the SHM model predictions agree well with data across the whole energy range from AGS to top RHIC energies. The K^{+}/π^{+}, Λ/π and Ξ^{-}/π ratios all show a maximum at $\sqrt{s_{\mathrm{NN}}} \sim 8$ GeV, which seems to be consistent with the picture of maximum net-baryon density at freeze-out at this collision energy [36].

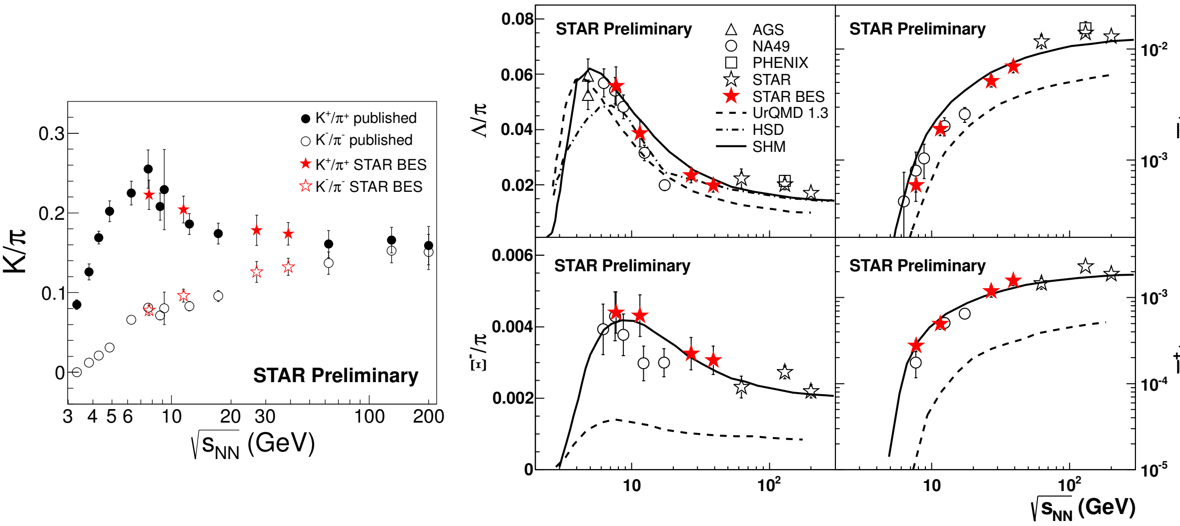

Figure 2. (left) Energy dependence of $\mathrm{K}^{\pm}/\pi^{\pm}$ ratio for central collisions at mid-rapidity. Also shown are previous published data from RHIC [28], AGS [30], SPS [29]. (right) Energy dependence of Λ, $\overline{\Lambda}$, Ξ^{-} and $\overline{\Xi}^{+}$to pions $(1.5(\pi^{+}+\pi^{-}))$ ratios at mid-rapidity in central Au+Au and Pb+Pb collisions. The pion yield in STAR BES is taken from [31]. Also shown are AGS [3,4,6,7], NA49 [9], PHENIX [18,32] and STAR [13,15–17,33,34] data, as well as calculations from two hadronic transport models: HSD and UrQMD (v1.3) [35] and a statistical hadron gas model (SHM) [22]. Errors are the quadratic sum of statistical and systematic errors.

Figure 3 (left) shows the R_{CP} of K^0_S, Λ, Ξ and Ω at mid-rapidity from STAR BES. At $\sqrt{s_{\mathrm{NN}}}$ $\geq$ 19.6 GeV, the K^0_S R_{CP} $\leq$1 for $p_\mathrm{T} > 1.5$ GeV/c and much less than those of baryons. This K^0_S high-p_T suppression and baryon/meson separation is qualitatively consistent with results from higher RHIC energies [24]. However, for $\sqrt{s_{\mathrm{NN}}} \leq 11.5$ GeV, although the maximum accessible p_T is smaller at these two energies, the R_{CP} data seem qualitatively different from that at $\sqrt{s_{\mathrm{NN}}} \geq$ 19.6 GeV: there is no suppression for K^0_S at $p_\mathrm{T} > 1.5$ GeV/c; and the baryon/meson separation becomes less significant at intermediate p_T. Figure 3 (right) shows the $\overline{\Lambda}/\mathrm{K}^0_\mathrm{S}$ ratios as a function of p_T in different centralities from Au+Au collisions in STAR BES. At $\sqrt{s_{\mathrm{NN}}} \geq$ 19.6 GeV, the $\overline{\Lambda}/\mathrm{K}^0_\mathrm{S}$ can reach a maximum value of unity at $p_\mathrm{T} \sim 2.5$ GeV/c in the most central collisions, while in the peripheral collisions, the maximum value is only about 0.3 – 0.5. This shows that there is baryon enhancement at intermediate p_T for $\sqrt{s_{\mathrm{NN}}} \geq$ 19.6 GeV, which is similar to that observed at higher energies. However, for Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} \leq$ 11.5 GeV, the maximum values of $\overline{\Lambda}/\mathrm{K}^0_\mathrm{S}$ in the measured p_T range is much smaller than unity, and the difference between 0-5% and 40-60% is also less significant. This indicates much less baryon to meson enhancement at intermediate p_T in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} \leq$ 11.5 GeV.

Figure 4 shows the baryon-to-meson ratio, $N(\Omega^{-}+\Omega^{+})/2N(\phi)$, as a function of p_T in Au+Au central collisions at $\sqrt{s_{\mathrm{NN}}}$ = 11.5 – 200 GeV. The 200 GeV data are from previous STAR measurements [37]. In central Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV, the intermediate-p_T (2 – 4 GeV/c) Ω to ϕ ratio is explained by mainly thermal strange quark recombination in the deconfined matter [38]. The $N(\Omega^{-}+\Omega^{+})/2N(\phi)$ ratios in $\sqrt{s_{\mathrm{NN}}}$ = 19.6, 27, and 39 GeV are close to that in 200 GeV. However, the ratios at 11.5 GeV seem to deviate from the trend with a χ^2/ndf of 8.3/2 for $p_\mathrm{T} > 2.4$ GeV/c. The difference in the ratios between 11.5 GeV data and those above 19.6 GeV may indicate a significant change in the underlying p_T distributions for strange quarks which recombine/coalesce to form the final Ω and ϕ particles in our measurement,

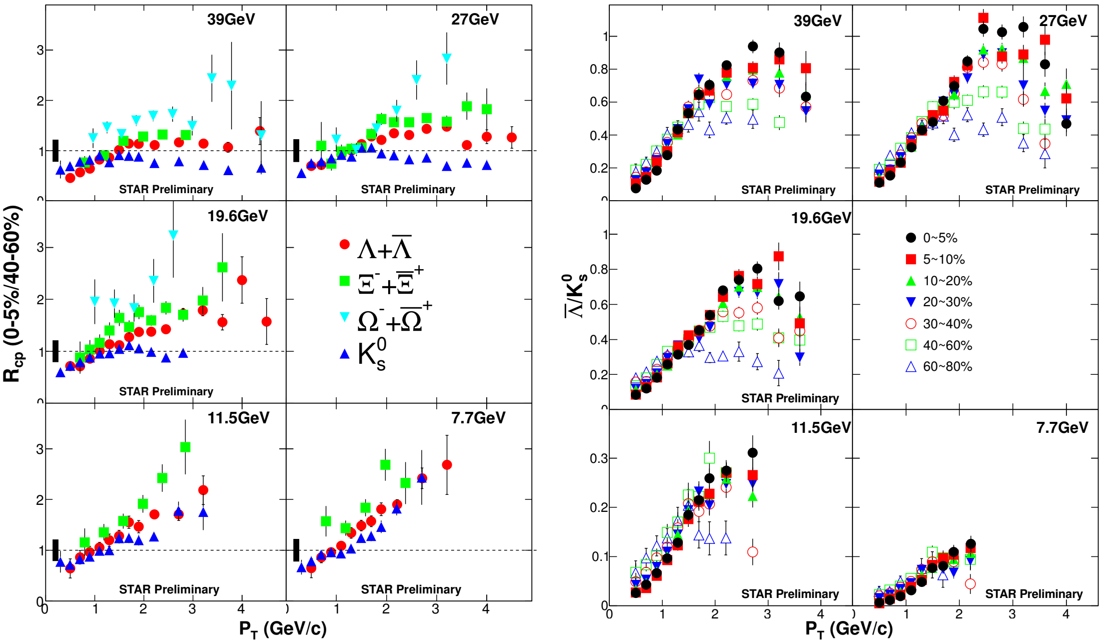

Figure 3. (left) K^0_S, Λ, Ξ and Ω R_{CP}(0-5%)/(40-60%) at mid-rapidity ($|y| < 0.5$) in Au+Au collisions at $\sqrt{s_{NN}} = 39 - 7.7$ GeV. Errors are statistical. The left black band is the normalization error from N_{bin}. (right) $\overline{\Lambda}/K^0_S$ ratio as a function of p_T at mid-rapidity ($|y| < 0.5$) in different centralities from Au+Au collisions at $\sqrt{s_{NN}} = 39 - 7.7$ GeV. Errors are statistical.

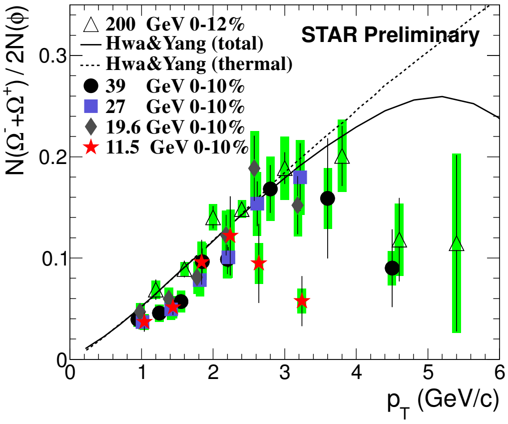

Figure 4. The baryon-to-meson ratio, $N(\Omega^-+\Omega^+)/2N(\phi)$ as a function of p_T at mid-rapidity ($|y| < 0.5$) from central Au+Au collisions at $\sqrt{s_{NN}} = 11.5 - 200$ GeV. Green bands denote systematical errors. The solid and dashed lines represent recombination model calculations for central collisions at $\sqrt{s_{NN}} = 200$ GeV [38] with total and thermal strange quark contributions, respectively.

or indeed that there is no substantial deconfined phase in 11.5 GeV collisions.

3. Summary

We presented recent measurements on strange hadrons production in the STAR beam energy scan. The strange hadron yields from STAR BES seem to follow a trend with published data from RHIC, SPS and AGS. The ratios of Λ, $\overline{\Lambda}$, Ξ^- and $\overline{\Xi}^+$ to pions at mid-rapidity agree well with the calculations of the statistical hadron gas model. For $\sqrt{s_{\mathrm{NN}}} \leq 11.5$ GeV, we also observe: $\mathrm{K}^0_{\mathrm{S}}$ R_{CP} are larger than unity for $p_{\mathrm{T}} > 1.5$ GeV/c; $\overline{\Lambda}/\mathrm{K}^0_{\mathrm{S}}$ ratio in the most central collisions is much less than unity at intermediate p_{T} and the difference between central and peripheral collisions gets reduced; Ω to ϕ ratio seems to turn down much earlier. These measurements point to a beam energy region between 11.5 and 19.6 GeV as a favored range for further investigation of the deconfinement phase transition.

Acknowledgments

X. Zhu thanks the support by the National Natural Science Foundation of China (Grant Nos. 11035009, 11335005), the Major State Basic Research Development Program in China (No. 2014CB845400) and the Foundation for the Authors of National Excellent Doctoral Dissertation of P.R. China (FANEDD) (No. 201021).

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