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Recent Results on Strangeness Production from STAR

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Abstract

We report recent results of strangeness production in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV and Al+Au fixed-target collisions at $\sqrt{s_{NN}}$ = 4.9 GeV from the STAR experiment at RHIC. The collision energy dependence of strange hadron yields are presented. The p_T dependance of nuclear modification factors (R_{CP}) and baryon to meson ratios ($\overline{\Lambda}/K^0_S$) are measured to understand the recombination and parton energy loss mechanisms. The STAR fixed-target data are compared to the previous published data from different AGS experiments and is consistent. The physics implications for collision dynamics are discussed.

Keywords:
Strangeness, Quark-gluon plasma, Heavy-ion collisions, fixed-target, AGS

1. Introduction

Ultra-relativistic heavy-ion collisions are the most promising tool for the formation of a deconfined high temperature and density state of nuclear matter where partonic interactions dominate, the Quark-Gluon Plasma (QGP). Lattice quantum chromodynamics (QCD) calculations suggest that, there is smooth and continuous cross-over transition from the QGP to the state of hadron gas at high temperature (T) and low baryon chemical potential (μ_B) [1]. Theoretical calculations predict a first order phase transition at lower temperature and high $\mu_B$which may end at QCD critical point [2, 3]. The main motivation of the RHIC heavy-ion program is to map the QCD phase diagram.

Due to the fact that the mass of the strange quark is presumably much higher than the temperature of the system in hadronic phase, but lower than the temperature of the system in partonic phase, the production of strange quark is expected to be sensitive probe to study phase transition [4]. This also suggests the enhancement in the yields of the strange hadron in comparison to the light hadrons in the partonic phase, which has been observed in central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 7.7 – 17.3 GeV at Super Proton Synchrotron (SPS) [5]. Additionally, the production of strange quark has significant importance due to the smaller hadronic cross-section and sensitivity to the partonic phase of the collision dynamics. The differential measurements of strange and multi-strange hadrons are performed at top RHIC energy of $\sqrt{s_{NN}}$ = 200 GeV in order to understand the dynamics of partons in the QGP.

The systematic study of Au+Au collisions during the Beam Energy Scan (BES) program allow us to cover a broad range of temperature and $\mu_B$in the QCD phase diagram and pin down the energy region where the underlying dynamics of the collision system are different to those of partonic matter which is observed in top RHIC energy of $\sqrt{s_{NN}}$ = 200 GeV [6]. The precise measurements of strange hadron yields will certainly lead to a better understanding of strangeness production mechanism in nuclear collisions in BES. Furthermore, In 2015, STAR experiment had conducted a dedicated fixed-target test run of Al+Au at $\sqrt{s_{NN}}$ = 4.9 GeV by installing an internal Au-target inside the beam-pipe of the STAR detector to further extend the $\mu_B$range and enhance our understanding of strangeness production at further lower energies.

In this paper, we present the recent STAR results on the strange hadron production (K^0_S, Λ ($\overline{\Lambda}$), Ξ^- ($\overline{\Xi}^+$)) obtained from the high statistics Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV and (K^0_S and Λ) production in Al+Au fixed-target collisions at $\sqrt{s_{NN}}$ = 4.9 GeV collected in 2017 and 2015 respectively. The 54.4 GeV high statistics data will allow us to do precise measurements of these strange hadrons especially at intermediate to high p_T. Previous measurement on strange hadron production in $\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5, 19.6, 27 and 39 GeV has been reported in Refs [7, 8]. The fixed-target results are reported in Ref [9].

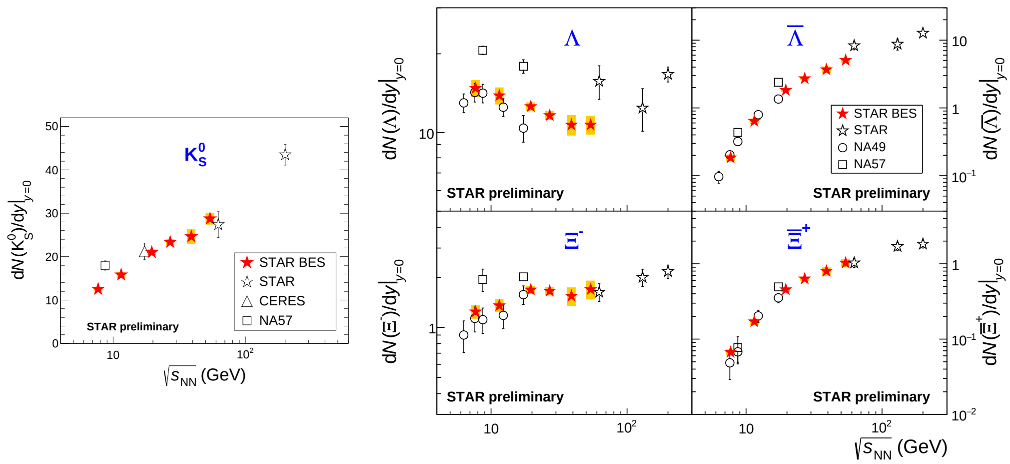

Fig. 1. The strange hadrons (dN/dy) at mid rapidity in the most central Au+Au collisions as a function of $\sqrt{s_{NN}}$. The results at higher energies from the STAR experiment are also shown. Systematic uncertainties are shown in yellow band. The rapidity ranges are $|y| < 0.5$ for STAR and NA57, $|y| < 0.4$ for NA49 Λ ($\overline{\Lambda}$) and $|y| < 0.5$ for NA49 Ξ^- ($\overline{\Xi}^+$) [8].

2. Results

Figure 1 shows the collision energy dependence of the particle yield (dN/dy) at mid rapidity for K^0_S Λ ($\overline{\Lambda}$) and Ξ^- ($\overline{\Xi}^+$) from the most central (0–5%) Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV, compared to the corresponding data from NA49, NA57, CERES as well as the STAR data at higher energies. Fig. 1 shows that the STAR K^0_S data at $\sqrt{s_{NN}}$ = 54.4 GeV lie on a trend established by the previous STAR BES measurements and data from NA49 and NA57. There is monotonic increase in the yields of anti-baryons ($\overline{\Lambda}$, $\overline{\Xi}^+$) with increase in the beam energy, however, the Λ and Ξ^- yields shows non-trivial energy dependence. Λ production is enhanced at low energy due to the large amount of baryon stopping at mid-rapidity and this effect start to decrease with increasing beam energy. Therefore, the observed energy dependence in the Λ dN/dy is due to the possible cross-over between $\Lambda - \overline{\Lambda}$ pair production, which strongly increases with the increase in collision energy and the associated production of Λ with kaons in nucleon-nucleon scattering, which strongly increases with the increase in net baryon density and/or decrease in beam energy [8, 10].

Figure 2 (left) shows the R_{CP} of K^0_S, $\Lambda + \overline{\Lambda}$ and $\Xi^- + \overline{\Xi}^+$ in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV. The R_{CP} is the N_{bin} scaled ratio of particle yields in central collisions to those in peripheral ones.If the nucleus-nucleus

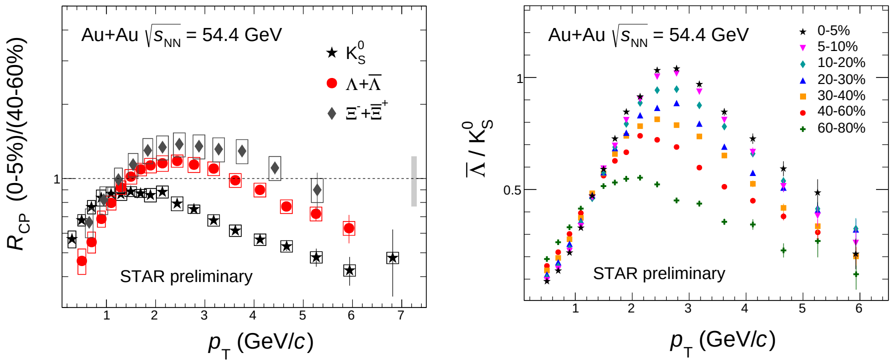

Fig. 2. (left) The nuclear modification factor R_{CP} of K^0_S, Λ and Ξ^- as a function of p_T in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV at mid rapidity ($|y| < 0.5$). The right gray band is the normalization error from N_{bin}. (Right) The $\overline{\Lambda}/K^0_S$ ratio as a function of p_T at mid-rapidity ($|y| < 0.5$) from Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV. Errors are statistical and systematic.

collision is simple superposition of the nucleon-nucleon interaction then the R_{CP} will be equal to unity and the deviation from unity would imply the contributions from nuclear or medium effects. For $p_T \sim 4$ GeV/c, one can see from Fig. 2 (left) that the K^0_S R_{CP} is suppressed below unity indicating the significant amount of partonic energy loss in the medium, however this effect becomes less significant at lower beam energies. As a result of energy evolution of the R_{CP} of strange hadron, the partonic effects starts to decrease with decreasing beam energies [8]. Additionally, the particle type (baryon/meson) R_{CP} show clear difference in Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV and this difference becomes smaller at $\sqrt{s_{NN}} = 14.5$, 11.5 and almost vanish at $\sqrt{s_{NN}} = 7.7$ GeV, which may be due to the reason that system created in these energies is different from those created in high energies $\sqrt{s_{NN}} \geq 19.6$ GeV [7, 8].

At intermediate p_T the baryon-to-meson ratios enhancement in central A+A collisions compared to p+p collisions can be interpreted as the hadron is formed from parton collectivity and parton recombination [12]. Therefore, these ratios are predicted to be sensitive to the parton dynamics of the collision system. Figure 2 (right) shows $\overline{\Lambda}/K^0_S$ ratio as a function of p_T in Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV in different centralities. It can be seen that, in most central (0–5%) collisions, at $p_T \sim 2.5$ GeV/c, the $\overline{\Lambda}/K^0_S$ ratio reach the maximum value of unity, while the maximum value in the peripheral collisions is only ~ 0.5 indicating baryon enhancement at intermediate p_T similar as observed at higher energies. A sudden decrease at intermediate p_T has been observed in $\overline{\Lambda}/K^0_S$ ratio between 19.6 and 14.5 GeV, indicating a possible change in the mechanism of underlying hadron formation and/or parton dynamics between these two energies [**?**].

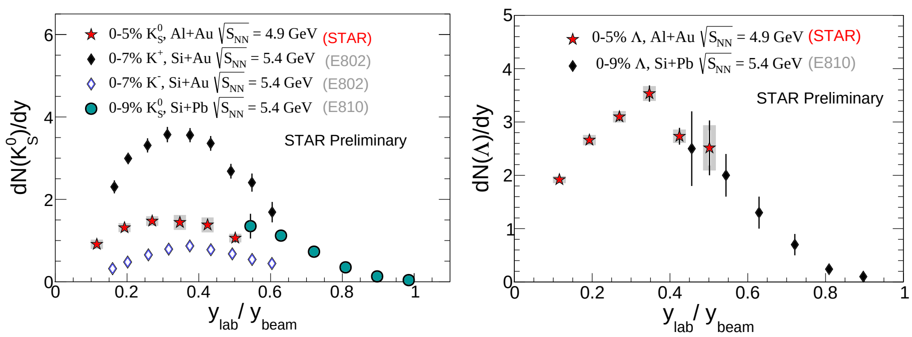

Fig. 3. (left) K^0_S rapidity density (0-5%) from STAR fixed-target Al + Au collisions $\sqrt{s_{NN}}$ = 4.9 GeV. STAR fixed-target data are plotted as red stars. K^+ and K^- from E802 (0-7%) [14, 15] and K^0_S from E810 (0-9%) [16] are plotted for comparison. (right) Λ rapidity density (0-5%) from STAR fixed-target Al + Au collisions $\sqrt{s_{NN}}$ = 4.9 GeV. STAR fixed-target data are plotted as red stars. E810 points for Λ (0-9%) [16] are plotted for comparison. Systematic error are shown as gray bars.

Figure 3 (left) shows the comparison of the K^0_S rapidity density distributions from 0-5% STAR fixed-target Al+Au collisions at $\sqrt{s_{NN}} = 4.9$ GeV to that of 0-7% K^+ and K^- mesons from Si+Au collisions at $\sqrt{s_{NN}} = 5.4$ GeV from AGS-E802 experiment and the 0-9% K^0_S mesons from AGS-E810 from Si+Au collisions at $\sqrt{s_{NN}} = 5.4$ GeV. Overall, the ordering and relative magnitudes of the K^-, K^0_S and K^+ is as expected indicating that the current results are consistent with the previous AGS results from E802 and with higher rapidity results from E810. Figure 3 (right) shows a comparison of the Λ rapidity density distributions to the published results from E810 experiment from AGS. It should be noted that almost all Λ's at this energy are produced in associated production with a kaon (anti-baryon production is extremely small); therefore we expect the overall Λ yield is equal to the associated production components of the K^+ and the K^0. The observed Λ yield is consistent with the expectations based on the E802 K^+ and the K^0_S yields observed in the current results and from E810. In addition, the trend of the Λ dN/dy is consistent with the higher rapidity results from E810.

3. Summary

We report the recent results on the strangeness production in Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV and Al+Au fixed-target collisions at $\sqrt{s_{NN}} = 4.9$ GeV from the STAR experiment. The non-trivial energy dependence of the Λ and $\overline{\Lambda}$ yields suggests that their could be a possible cross-over between two mechanisms i.e. $\Lambda - \overline{\Lambda}$ pair production and associated production. K^0_S R_{CP} shows suppression at high p_T indicating partonic energy loss in the medium and the energy evolution of strange hadron R_{CP} results decrease in partonic effects with decreasing beam energies. At intermediate p_T , clear difference in particle type (baryon/meson) has been observed at $\sqrt{s_{NN}} = 54.4$ GeV. $\overline{\Lambda}/K^0_S$ ratio shows clear separation at intermediate p_T indicating baryon enhancement at $\sqrt{s_{NN}} = 54.4$ GeV. The STAR experiment has measured the K^0_S and Λ from the fixed-target Al+Au collisions at $\sqrt{s_{NN}} = 4.9$ GeV and results are in a good agreement with previous published results from AGS.

4. Acknowledgement

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