Beam Energy Dependence of Strange Hadron Production from STAR at RHIC

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Abstract. We report the STAR measurements of K_s, Λ, Ξ, and Ω at mid-rapidity from Au+Au collisions at the beam energies of 7.7, 11.5, 19.6, 27 and 39 GeV per nucleon from the RHIC Beam Energy Scan (BES) program. Nuclear modification factors and ratios of baryon to meson yields are discussed. We also investigate the strangeness enhancement and ratios of anti-baryon to baryon yields as a function of beam energy at RHIC, and compare the results with the statistical thermal model.

1. Introduction

Strangeness production is sensitive to the collision dynamics in heavy ion collisions, and it is used as a probe to study the nuclear medium created in the collisions [1]. The nuclear medium varies with the collision energy. In RHIC Au+Au 200 GeV collisions, the modification factors (R_{CP}) of baryons and mesons at intermediate p_T follow different trends, and the baryon-to-meson ratios have a strong centrality dependence and are enhanced in the intermediate p_T range in central collisions [2, 3]. Those phenomena may be explained by the recombination/coalescence model [4, 5, 6, 7, 8], which is an indication of the formation of the strongly coupled quark-gluon plasma (sQGP). At high p_T, the R_{CP} is much less than unity, presumably due to the partonic energy loss in the medium. Our measurement of strange particle R_{CP} and baryon-to-meson ratios may reveal how the collision dynamics changes with the beam energy.

The statistical thermal model has been used to describe the particle yields in nuclear collisions. However, one of the problematic uncertainties in the statistical thermal model comes from complicated feed-down contributions to light hadrons (π, K, p) from multiple strong decay resonances whose masses, widths, and decay properties are not well determined. It will be important to only use the yields of strange particles reconstructed from weak decay channels to test the statistical thermal model. We compare the anti-baryon to baryon ratios with the statistical thermal model.

STAR has collected high statistics data in year 2010 and 2011 in the RHIC Beam Energy Scan Program at 7.7, 11.5, 19.6, 27, and 39 GeV Au+Au collisions. In STAR, we reconstruct the strange hadrons (K^0_S, Λ, Ξ, Ω) using the topology of their weak decay channels [9, 10], $K^0_S \to \pi^+\pi^-$ (69.2% branching ratio), $\Lambda \to p\pi$ (63.9% branching ratio), $\Xi \to \Lambda\pi$ (99.9% branching ratio), and $\Omega \to \Lambda K$ (67.8% branching ratio). The decay daughters π, K, and p are identified by the Time Projection Chamber (TPC) [11] of the STAR detector system.

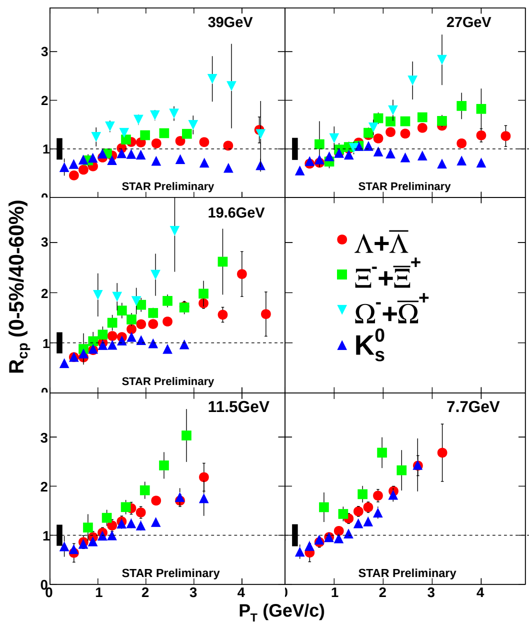

Figure 1. The nuclear modification factor (R_{CP}), as a function of p_T for K^0_S, $\Lambda(\bar{\Lambda})$, $\Xi^-(\bar{\Xi}^+)$, and $\Omega^-(\bar{\Omega}^+)$ at $|y| < 0.5$ from Au+Au collisions at $\sqrt{s_{NN}}$ from 39 to 7.7 GeV. Errors are statistical only.

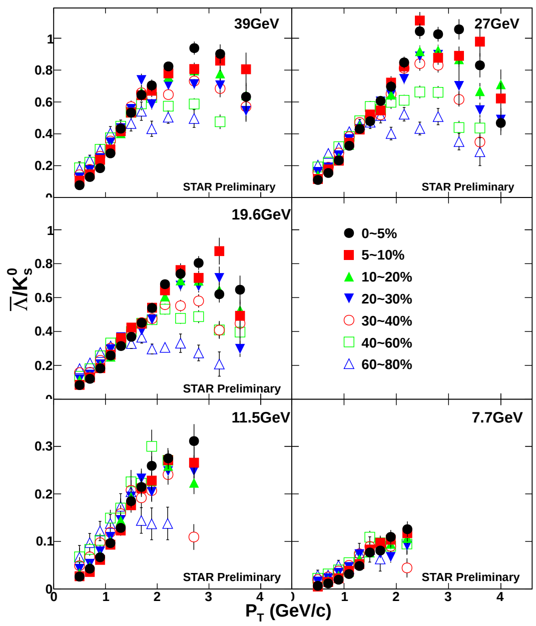

Figure 2. The $\bar{\Lambda}/K^0_S$ ratio as a function of p_T at $|y| < 0.5$ from Au+Au collisions at $\sqrt{s_{NN}}$ from 39 to 7.7 GeV. Errors are statistical only.

2. Results

The strange particle p_T spectra and yields (dN/dy) at mid-rapidity are obtained after correcting for geometrical acceptance and the reconstruction efficiency [12]. The $\Lambda(\bar{\Lambda})$ spectra have been corrected for the feed-down contribution from Ξ and Ξ^0 weak decays.

2.1. Strange Hadron Nuclear Modification Factor (R_{CP}) and Baryon-to-Meson Ratios

Figure 1 shows the R_{CP} for K^0_S, $\Lambda(\bar{\Lambda})$, $\Xi^-(\bar{\Xi}^+)$, $\Omega^-(\bar{\Omega}^+)$ as a function of p_T at beam energies from 7.7 to 39 GeV. The R_{CP} is calculated as the ratio of particle yields at most central collisions (0-5%) to yields at peripheral collisions (40-60%) scaled by the number of inelastic binary collisions (N_{bin}). The R_{CP} data are from Refs. [12, 13, 14]. The strange baryon R_{CP} has a similar behavior at 19.6, 27, and 39 GeV. There seems to be a difference between K^0_S R_{CP} and strange baryon R_{CP}. At lower energies (7.7 and 11.5 GeV), the R_{CP} of K^0_S, Λ, Ξ^- all increase with p_T. The R_{CP} of K^0_S with a p_T above 2 GeV/c is below or consistent with unity at 19.6, 27, and 39 GeV, however it is above unity at 7.7 and 11.5 GeV. Figure 2 shows the $\bar{\Lambda}/K^0_S$ ratios for different centralities from 7.7 to 39 GeV. There is an enhancement of $\bar{\Lambda}/K^0_S$ ratios at p_T around 3 GeV/c at 19.6, 27, and 39 GeV. And there is a strong centrality dependence of $\bar{\Lambda}/K^0_S$ ratios at the three energies. At 7.7 and 11.5 GeV, $\bar{\Lambda}/K^0_S$ ratios increase monotonically with increasing p_T, and the $\bar{\Lambda}/K^0_S$ ratios have a weaker centrality dependency than at higher collision energies. Figure 3 shows the $N(\Omega^- + \bar{\Omega}^+)/(2N(\phi))$ ratios scaled by the number of constituent quarks, n_q, as a function of p_T/n_q from central collisions. At high p_T/n_q, the ratios at 11.5 GeV are systematically lower than those at higher collision energies.

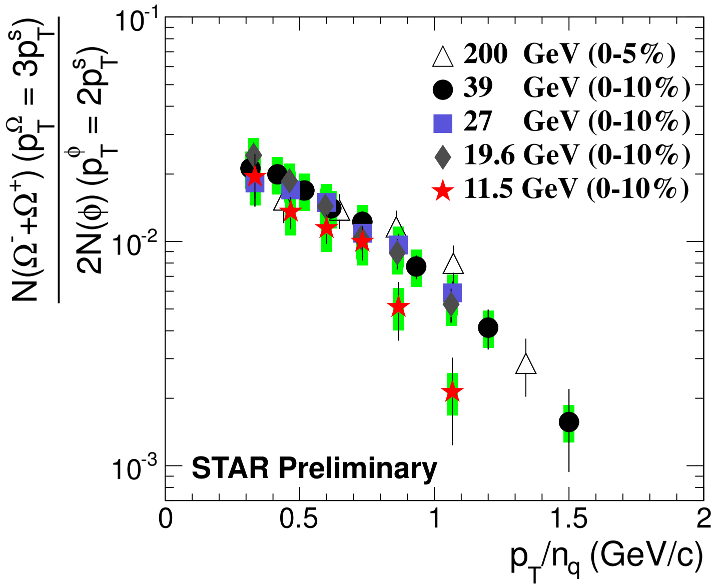

Figure 3. $N(\Omega^- + \bar{\Omega}^+)/(2N(\phi))$ ratios scaled by the number of constituent quarks (n_q), as a function of p_T/n_q from central Au+Au collisions from 11.5 to 200 GeV. The black error bars are the statistical errors, and the green bands are systematic errors.

2.2. Anti-baryon to Baryon Ratios and Statistical Thermal Model

In the statistical thermal model, particle yields can be described by invariant mass, degeneracy factor and chemical potential (μ) of each particle type, strangeness-suppression factor (γ_S), and chemical freeze-out temperature (T) [15]. When we take the anti-baryon to baryon ratios, the parameters are cancelled except μ_B/T and μ_S/T: $ln(ratio) = -2\frac{\mu_B}{T} + \frac{\mu_S}{T}\Delta S$, where μ_B is the baryon chemical potential, and μ_S is the strangeness chemical potential. The ΔS in the formula is the strangeness-number difference between baryon and anti-baryon. The above formula describes, for each particle type, a straight line described by the parameters $\frac{\mu_B}{T}$ and $\frac{\mu_S}{T}$. The $\frac{\mu_B}{T}$ and $\frac{\mu_S}{T}$ are the properties of the collision system, independent of the particle type. When we draw the $ln(ratio)$ of $\frac{\bar{\Lambda}}{\Lambda}$, $\frac{\bar{\Xi}^+}{\Xi^-}$, and $\frac{\bar{\Omega}^+}{\Omega^-}$ in one plot, with $\frac{\mu_B}{T}$ on the x-axis and $\frac{\mu_S}{T}$ on the y-axis, the three lines should cross at one point, if the statistical thermal model assumptions are valid [16]. With this method, we can test the statistical thermal model. The 7.7, 11.5, 19.6, 27, and 39 GeV results are shown in Fig. 4, and the statistical thermal model seems to describe our measurements well. For each collision energy, we use linear regression to determine the crossing point ($\frac{\mu_B}{T}$, $\frac{\mu_S}{T}$). The $\frac{\mu_B}{T}$ and $\frac{\mu_S}{T}$ from 7.7 to 39 GeV are shown in Fig. 5, and the $\frac{\mu_B}{T}$ values fall on the curve of parameterization with μ_B and T fitting of AGS, SPS, and RHIC 130 GeV central collision data [17].

3. Summary

In summary, we presented the strange particle R_{CP} and baryon-to-meson ratios at 7.7, 11.5, 19.6, 27 and 39 GeV. The behaviors of R_{CP} and baryon-to-meson ratios at 11.5 GeV are different from those at 19.6 GeV, which may indicate a change of collision dynamics from 19.6 GeV to 11.5 GeV. The statistical thermal model has been tested with the measured strange anti-baryon to baryon ratios, and describes the data well.

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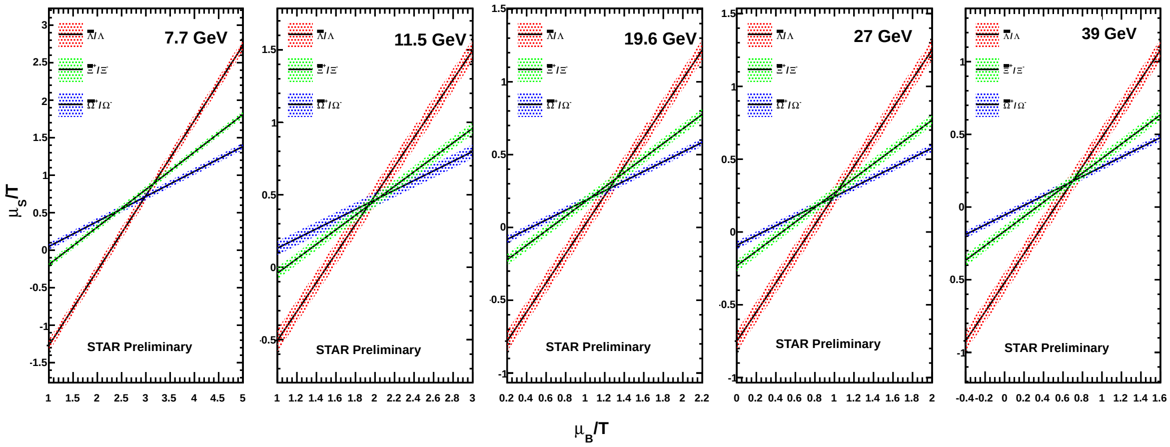

Figure 4. Testing of statistical thermal model in $\frac{\mu_B}{T}$ and $\frac{\mu_S}{T}$ parameter space with strange anti-baryon to baryon ratios in 7.7, 11.5, 19.6, 27, and 39 GeV Au+Au central collisions. Errors are statistical only.

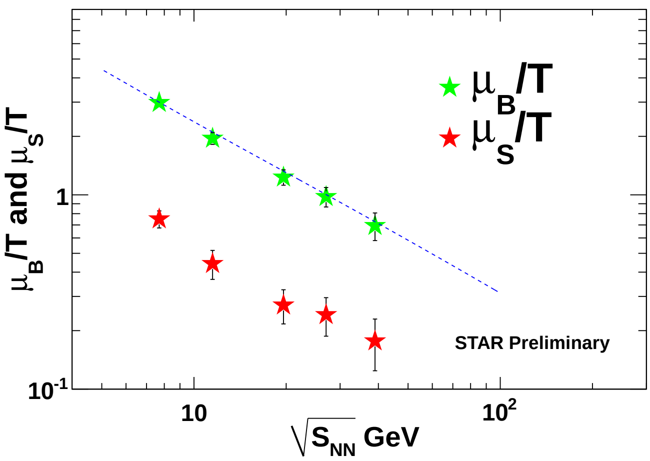

Figure 5. The $\frac{\mu_B}{T}$ and $\frac{\mu_S}{T}$ parameters as a function of beam energy. The curve is the parameterization with μ_B and T fitting of AGS, SPS, and RHIC 130 GeV data [17]. Errors are statistical only.

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