Strangeness Production in Heavy-Ion Collisions at STAR

Anthony R. Timmins\textsuperscript{a} for the STAR Collaboration

\textsuperscript{a}Department of Physics and Astronomy, Wayne State University, 666 W. Hancock, Detroit, MI 48201, USA

Abstract

We report an overview of strangeness production in Cu\textsuperscript{+}Cu and Au\textsuperscript{+}Au collisions at the energies $\sqrt{s_{NN}} = 62.4$ and 200 GeV. We show new mid-rapidity $dN/dy$ results for the $K^0_S$, $\Lambda$, $\Xi$, $\Omega$ particles in Cu\textsuperscript{+}Cu $\sqrt{s_{NN}} = 62$ GeV collisions and compare to results in Au\textsuperscript{+}Au $\sqrt{s_{NN}} = 62$ GeV collisions. We show new results for mid-$p_T$ $\Lambda/K^0_S$ ratios in Cu\textsuperscript{+}Cu $\sqrt{s_{NN}} = 62$ GeV collisions and again compare to ratios in Au\textsuperscript{+}Au $\sqrt{s_{NN}} = 62$ GeV collisions. Finally, we show the high-$p_T$ ($\sim 6.2$ GeV/c) $R_{AA}(K^0_S)$ as a function of system size in Au\textsuperscript{+}Au $\sqrt{s_{NN}} = 200$ GeV collisions and compare to $R_{AA}(\pi)$.

1. Introduction

Measurements of strangeness production in heavy-ion collisions were originally conceived to be the smoking gun of Quark Gluon Plasma (QGP) formation \cite{1, 2}. It was argued that due to a drop in the strange quark's dynamical mass and increased production cross section, strangeness in the QGP would saturate on small time scales relative to a hadronic gas. Such an abundance of strangeness quarks may lead to the bulk strange hadrons being enhanced in heavy-ion collisions relative to p\textsuperscript{+}p, and allow for production mechanisms such as coalescence or jet flavor conversions to contribute to strange hadron yields in heavy-ion collisions at mid and high-$p_T$ respectively.

In these proceedings, we show new results of mid-rapidity $dN/dy$ for the $K^0_S$, $\Lambda$, $\Xi$, $\Omega$ particles in Cu\textsuperscript{+}Cu $\sqrt{s_{NN}} = 62$ GeV collisions and compare to $dN/dy$ values in Au\textsuperscript{+}Au $\sqrt{s_{NN}} = 62$ GeV collisions. These yields are expected to be dominated by soft processes. We then move to new mid-$p_T$ measurements of the $\Lambda/K^0_S$ ratios in Cu\textsuperscript{+}Cu $\sqrt{s_{NN}} = 62$ GeV collisions where soft and hard processes may compete. Finally, we take advantage of new high-$p_T$ measurements of identified particle production in p\textsuperscript{+}p $\sqrt{s_{NN}} = 200$ GeV \cite{3}, and compare strange and non-strange Au\textsuperscript{+}Au $\sqrt{s_{NN}} = 200$ GeV $R_{AA}$ as a function of system size for $p_T > 5.5$ GeV/c where hard processes are expected to dominate.

2. Results

The enhancement factor for a strange hadron is defined as the yield per participant, $\langle N_{\text{part}} \rangle$, in heavy-ion collisions, divided by the respective value in p\textsuperscript{+}p collisions at the same center of mass energy per nucleon. It contrasts strangeness production per unit of available energy ($\langle N_{\text{part}} \rangle$) in heavy-ion collisions with p\textsuperscript{+}p collisions. When the enhancement factor is observed to be above one, this indicates the dynamical processes in heavy-ion collisions are much better at liberating the available energy for strangeness production compared to p\textsuperscript{+}p collisions. Indeed,
the enhancement factors for strange hadrons have been shown to be significantly above one for Pb+Pb √s_{NN} = 17.3 GeV, Cu+Cu √s_{NN} = 200 GeV, and Au+Au √s_{NN} = 200 GeV collisions with a hierarchy with respect to the strangeness content [4, 5, 7]. Whether this is due to QGP formation as per the introduction, or phase space suppression in smaller systems [3], is an ongoing debate [7, 8].

Figure 1: dN/dy per ⟨N_{part}⟩ for the K_{S}^{0}, Λ, Ξ, Ω particles in Cu+Cu and Au+Au √s_{NN} = 62 GeV collisions. The uncertainties on the Cu+Cu data points are the statistical uncertainties from the yield and the systematic uncertainties from ⟨N_{part}⟩ added in quadrature. The systematic uncertainties regarding the Cu+Cu yields are under investigation. The uncertainties on the Au+Au data are the full statistical and systematic uncertainties added in quadrature. The Λ yields have not subtracted for feeddown from Ξ decays; this contribution is typically ~ 13%. The curves are described in the text.

In figure 1 we show dN/dy per ⟨N_{part}⟩ for the K_{S}^{0}, Λ, Ξ, Ω particles in Cu+Cu and Au+Au √s_{NN} = 62 GeV collisions. We are unable to calculate an enhancement factor due to the lack of a p+p reference. Becattini and Manninen have recently proposed dN/dy per ⟨N_{part}⟩(therefore the enhancement factor) may be proportional to the fraction of participants that undergo multiple collisions, f, in a core-corona description of strangeness production for Au+Au √s_{NN} = 200 GeV collisions [9]. Hadron production from the core gives strangeness yields expected in the QGP saturation scenario, while corona production is p+p like. The curves in figure 1 are from the following relation:

\[ \frac{dN}{dy} \text{ per } ⟨N_{part}⟩ = D_i f(N_{part}) + E_i \]  

where D_i and E_i are constants for particle i chosen to describe the data. Those constants are independent of system for a given particle. f(N_{part}) is obtained from Monte Carlo Glauber calculations and is typically higher in Cu+Cu compared to Au+Au at a given ⟨N_{part}⟩. It is clear that the above relation provides a reasonable description of dN/dy per ⟨N_{part}⟩ in Cu+Cu and Au+Au √s_{NN} = 62 GeV collisions. However, it was also shown that the above relation is not unique to the core-corona scheme, as it is expected for string excitation/breaking hadron production models [7].

In figure 2 we show the Λ/K_{S}^{0} ratios as a function of p_{T} for Cu+Cu and Au+Au √s_{NN} = 62 GeV collisions. Large values at mid-p_{T} in central Au+Au √s_{NN} = 200 GeV collisions may be attributed to quark coalescence boosting baryon production relation to meson production [10, 11, 12, 13]. At the lower energy, we observe central values at mid-p_{T} being roughly a factor of 2 higher than peripheral values. To widen current theoretical comparisons, we show predictions from the EPOS model which also describes particle production in the core-corona scheme [14].
After formation, the core is given a blast-wave velocity profile which boosts the $p_T$ of heavier particles relative to the lighter particles upon hadronization. Corona production is again p+p like, and the relative core contribution to particle production increases with centrality. We can see EPOS gives a qualitative description of the data. This was also shown for the $\Lambda/K^0_S$ ratios in Cu+Cu and Au+Au $\sqrt{s_{NN}} = 200$ GeV collisions. In particular, it predicts the mid-$p_T$ $\Lambda/K^0_S$ ratio should be approximately the same in central Cu+Cu and Au+Au collisions despite the large difference in $\langle N_{part} \rangle$ (∼96 vs. ∼344 respectively). Finally, it was shown EPOS described the $\Omega/\phi$ ratios well in Cu+Cu and Au+Au collisions with $\sqrt{s_{NN}} = 200$ GeV.

In figure 3 we show the integrated $R_{AA}(K^0_S)$ and $R_{AA}(\pi)$ in Au+Au $\sqrt{s_{NN}} = 200$ GeV collisions for particles with $p_T > 5.5$ GeV/c. It this therefore defined as:

$$R_{AA}(p_T > 5.5 GeV/c) = \frac{dN_{AA}/dy per \langle N_{bin} \rangle}{dN_{p+p}/dy}$$ (2)

The mean $p_T$ of particles in this range is ∼6.2 GeV/c. It has recently been proposed that hard scattered partons may change flavor in the medium altering jet chemistry compared to p+p collisions [18]. The abundance of strange quarks created in heavy-ion collisions allow for the leading parton to be replaced a strange quark via elastic interactions, and such a mechanism is predicted to boost $R_{AA}(K^0_S)$ for particles with $p_T > 5$ GeV/c in central Au+Au $\sqrt{s_{NN}} = 200$ GeV collisions by a factor 2 relative to $R_{AA}(\pi)$. We indeed observe such an increase in figure 3 however we also note that $R_{AA}(K^0_S) > R_{AA}(\pi)$ in peripheral collisions. This raises the question whether parton flavor conversions are prevalent in the smaller systems, or whether there is some other soft A+A production mechanism contributing in this $p_T$ range for all centralities. Measurements at higher $p_T$ from future higher statistics RHIC A+A runs may help in addressing these questions.

3. Conclusions

We have presented new results for the $K^0_S$, $\Lambda$, $\Xi$, $\Omega$ particles in Cu+Cu $\sqrt{s_{NN}} = 62$ GeV collisions, and shown in conjunction with Au+Au 62 $\sqrt{s_{NN}} = 62$ GeV data, the centrality dependance...
Figure 3: Integrated $R_{AA}(K^0_S)$ and $R_{AA}(\pi)$ for $p_T > 5.5$ GeV/c in Au+Au $\sqrt{s_{NN}} = 200$ GeV collisions. The uncertainties on the data points are statistical and systematic added in quadrature with respect to the yields. The left and right grey bands represent the typical uncertainties on $\langle N_{bin} \rangle$ for peripheral and central Au+Au $\sqrt{s_{NN}} = 200$ GeV collisions respectively.

of $dN/dy$ per $\langle N_{part} \rangle$ has similar trends to a parameterisation based on the fraction of participants that undergo multiple collisions. We also have shown the $p_T$ dependance of the $\Lambda/K^0_S$ ratio can be qualitatively described by the EPOS model in Cu+Cu and Au+Au collisions with $\sqrt{s_{NN}} = 62$ and 200 GeV. Both observations provide evidence for core-corona effects. Finally, we have shown at $p_T > 5.5$ GeV/c $R_{AA}(K^0_S) > R_{AA}(\pi)$ for all centralities in Au+Au $\sqrt{s_{NN}} = 200$ GeV collisions. This may provide evidence for parton flavor conversions in heavy-ion collisions.

References

[1] J Rafelski and B Müller, Phys. Rev. Lett. 48 (1982) 1066
[2] P Koch, B Müller and J Rafelski, Phys. Rep. 142 (1986) 167
[3] Y Xu for the STAR Collaboration, these proceedings
[4] J Adams et al. (STAR Collaboration), Phys. Rev. Lett. 98 (2007) 62301
[5] B I Abelev et al. (STAR Collaboration), Phys. Rev. C 77 (2008) 044908
[6] S Hamieh, K Redlich and A Tounsi, Phys. Lett. B. 486 (2000) 61
[7] A Timmins for the STAR collaboration, Eur. Phys. J. C. 62 (2009) 249
[8] B I Abelev et al. (STAR Collaboration), Phys. Lett. B 673 (2009) 183
[9] F Becattini and J Manninen, J. Phys. G 35 (2008) 104013
[10] J Adams et al. (STAR Collaboration), nucl-ex/0601042
[11] J Adams et al. (STAR Collaboration), Phys. Rev. Lett. 97 (2006) 152301
[12] B I Abelev et al. (STAR Collaboration), Phys. Lett. B 655, 104 (2007)
[13] J Adams et al. (STAR Collaboration), Phys. Rev. Lett. 92 (2004) 52302
[14] K Werner, Phys. Rev. Lett. 98 (2007) 152301
[15] B I Abelev et al. (STAR Collaboration), Phys. Rev. Lett. 99 (2007) 112301
[16] B I Abelev et al. (STAR Collaboration), Phys. Lett. B 655 (2007) 104
[17] X Wang for the STAR Collaboration, J. Phys. G 35 (2008) 104074
[18] W Liu and R L Fries, Phys. Rev. C 77 (2008) 054902