Multi-strange particle production in relativistic heavy ion collisions at $\sqrt{s_{NN}} = 62.4$ GeV

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Abstract. We present preliminary STAR results on measurements of multi-strange particles $\Xi$, $\Omega$ and their anti-particles from Au+Au and Cu+Cu at $\sqrt{s_{NN}} = 62.4$ GeV collisions. In order to better understand the role of strangeness enhancement in nucleus-nucleus collisions and its scaling properties with system size, we compare the results from Au+Au and Cu+Cu reactions for different event centrality classes. Strangeness enhancement is discussed in the context of multi-strange to pion ratios. Finally, $\Omega/\phi$ ratio is shown for different systems and energies for a systematic study.

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1. Introduction

For more than 20 years strangeness enhancement has been proposed as one of the signatures of the Quark Gluon Plasma (QGP) formation [1]. Currently there are many experimental results from SPS and RHIC showing the enhancement of strange particles, such as $\Lambda$, $\Xi$, $\Omega$ and $\phi$ from different energies in A+A collisions when compared to p+p results [2, 3, 4, 5].

The intermediate transverse momentum range ($2 < p_T < 5$ GeV/c) plays an important role in understanding hadronisation mechanisms. In this $p_T$ range, an anomalous increase of the $p/\pi$ ratio was observed in heavy ion collisions compared to p+p collisions in the RHIC data [6, 7]. The enhancement of the baryon to meson ratio at intermediate transverse momentum has been also confirmed in the strangeness sector using ($\Lambda/K^0$) [8]. In this context, the $\Omega/\phi$ ratio is an important measurement because it involves only strange quarks [9]. One of the theoretical models that try to explain the enhancement of baryon to meson ratio is the coalescence model, which assumes that hadrons are formed by free quarks [10]. Calculation from Hwa and Yang [11] shows that the production of $\Omega$ and $\phi$ arises mainly from the recombination of thermal partons, thus exhibiting exponential $p_T$ dependence. Baryons at a certain $p_T$ come from partons of a lower average $p_T$ ($\sim p_T/3$) than mesons (formed by partons with $\sim p_T/2$).

In this proceedings, we show recent results of multi-strange baryons for Au+Au and Cu+Cu at $\sqrt{s_{NN}} = 62.4$ GeV at mid-rapidity ($|y| < 1$). With their high mass
and strange quark content, $\Xi$ and $\Omega$ are important measurements of strange particle production and the formation of those should be less influenced by the net-baryon density. A comparison between Au+Au and Cu+Cu allows to probe the system size dependence, and the collisions at $\sqrt{s_{NN}} = 62.4$ GeV provide an important connection between the energy available at SPS ($\sqrt{s_{NN}} = 17.3$ GeV) and the top RHIC energy ($\sqrt{s_{NN}} = 200$ GeV).

2. Data analysis

To perform the analysis presented here, we used minimum-bias Au+Au and Cu+Cu collision events at $\sqrt{s_{NN}} = 62.4$ GeV taken by the STAR experiment during run 2004 ($\sim 7$ $M$ events from Au+Au) and run 2005 ($\sim 9$ $M$ events from Cu+Cu).

In the STAR detectors, charged particle tracks were reconstructed by a large cylindrical Time Projection Chamber (TPC) and the ionization energy loss in the TPC gas was used for identification of charged particles. Strange particles were reconstructed using their weak decay topology: $\Lambda \to p + \pi^-$ (branching ratio of 63.9% [12]); $\Xi^- \to \Lambda + \pi^-$ (branching ratio of 99.887% [12]) and $\Omega^- \to \Lambda + K^-$ (branching ratio of 67.8% [12]). The association of two or three daughter particles leads to a large amount of combinatorial background. To reduce the background, some geometrical cuts were applied to obtain a significant signal. However, some background remained underneath the mass peak and was therefore subtracted by making an interpolation of the spectrum on either side of the mass peak. Detector acceptance, tracking and selection inefficiencies were corrected by factors estimated using Monte Carlo generated particles that were propagated through a full GEANT [13] simulation of the STAR detector and were added into real events. Then, this embedded event was processed with the standard event reconstruction chain.

3. Results

Transverse momentum distributions of $\Xi$, $\Omega$ and their anti-particles at mid-rapidity ($|y| < 1$) are shown in figure 1 for different centrality classes. The Boltzmann function was used to fit those spectra in the low $p_T$ region allowing the determination of the integrated yield ($dN/dy$) as well as the inverse slope parameter. We noted that the $dN/dy$ monotonically increases with centrality and table 1 summarizes the centralities used in this analysis as well as the yields and the inverse slope parameter.

Figure 2 shows the anti-baryon to baryon ratio as a function of charged particle multiplicity, $dN_{ch}/dy$ [1]. The left panel on figure 2 shows those ratios for Au+Au at $\sqrt{s_{NN}} = 200$ GeV and it can be noted that all particle species have the same constant behavior as a function of centrality. A different behavior is observed at lower energy, as can be seen in the right panel, where the same ratios mentioned before are shown, but now for Au+Au and Cu+Cu at $\sqrt{s_{NN}} = 62.4$ GeV. For a given particle ratio, we observe

$\dagger$ Values of $dN_{ch}/dy$ were taken from [14].
Figure 1. Transverse momentum spectra for $\Xi^-(\Xi^+)$ on the left panel and $\Omega^-(\Omega^+)$ on the right for Au+Au and Cu+Cu at $\sqrt{s_{NN}} = 62.4$ GeV. For better visualization, the spectra were divided by factors of 10 and the centralities are listed in table 1. Errors are statistical only.

Table 1. Yields and inverse slope parameter (in MeV) for $\Xi^-$ and $\Omega^-$. 

|        | Au+Au | Cu+Cu |
|--------|-------|-------|
|        | Centrality | Inv. Slope | $dN/dy$ | Centrality | Inv. Slope | $dN/dy$ |
| $\Xi^-$ | 0 – 5%  | 336 ± 4  | 1.75 ± 0.07 | 0 – 10%  | 322 ± 3  | 0.32 ± 0.01 |
|        | 5 – 10%  | 339 ± 5  | 1.38 ± 0.06 | 10 – 20% | 328 ± 4  | 0.188 ± 0.008 |
|        | 10 – 20% | 336 ± 3  | 1.07 ± 0.03 | 20 – 40% | 313 ± 4  | 0.107 ± 0.005 |
|        | 20 – 40% | 329 ± 3  | 0.57 ± 0.01 | 40 – 60% | 303 ± 7  | 0.039 ± 0.003 |
|        | 40 – 60% | 313 ± 5  | 0.200 ± 0.008 | 60 – 80% | 298 ± 7  | 0.043 ± 0.003 |
| $\Omega^-$ | 0 – 10%  | 347 ± 26 | 0.26 ± 0.07 | 0 – 20%  | 353 ± 29 | 0.038 ± 0.008 |
|        | 10 – 20% | 381 ± 26 | 0.12 ± 0.02 | 20 – 40% | 317 ± 38 | 0.015 ± 0.006 |
|        | 20 – 40% | 349 ± 19 | 0.06 ± 0.01 | 40 – 60% | 352 ± 31 | 0.018 ± 0.005 |

no difference between Cu+Cu and Au+Au when using $dN_{ch}/dy$ as the scaling factor. The $\bar{p}/p$ and $\bar{\Lambda}/\Lambda$ ratios measured at $\sqrt{s_{NN}} = 62.4$ GeV decrease as the collisions become more central that could be an indication of a higher net-baryon density for central collisions. Multi-strange baryons have flat behavior for collision systems which shows they are less sensitive to changing net-baryon densities as a function of centrality.

Originally, the strangeness enhancement is defined as the ratio of strange particle yields from A+A collisions with p+p at the same energy. As we do not have results from p+p collisions at $\sqrt{s_{NN}} = 62.4$ GeV for $\Lambda$, $\Xi$ and $\Omega$, the $\pi^-$ yield was used as our reference. Figure 3 shows the ratio between baryons and charged pion ($\pi^-$) as a function of $dN_{ch}/dy$ normalized to the most peripheral centrality bin. As the proton
contains no strange quark, the \( p/\pi^- \) can be taken as a baseline for comparison. We observe that \( \Lambda/\pi^- \) and \( p/\pi^- \) present the same behavior and the same enhancement within uncertainties. Increasing the strange quark content we expect to observe a more pronounced enhancement which is confirmed by the multi-strange relative ratios showed. The \( \Xi^-/\pi^- \) and \( \Omega^-/\pi^- \) ratios have larger increase rates than other ratios in figure 3. For Au+Au (left panel), the enhancement rate seems to follow the hierarchy of strange quark content as obtained in previous analysis for \( \sqrt{s_{NN}} = 200 \text{ GeV} \) [3]. The Cu+Cu data show the same trend compared to Au+Au data. In the Cu+Cu data it is difficult to conclude that there is still a hierarchy of the strangeness enhancement with the strange quark content.

Finally we discuss the baryon over meson ratio. As mentioned in the introduction, an increase of baryon over meson ratio has been observed at intermediate \( p_T \). Previous results from STAR at \( \sqrt{s_{NN}} = 200 \text{ GeV} \) showed the \( \Omega/\phi \) and a recombination model proposed by Hwa and Yang [11] described the enhancement of \( \Omega/\phi \) ratio for \( p_T \) up to 4 GeV/c successfully [15]. Basically, this theoretical prediction showed a linear dependence on \( p_T \). For high \( p_T \) the baryon over meson ratio starts to decrease due to the
contribution from jet fragmentation. Figure 4 presents the $\Omega/\phi$ ratio at $\sqrt{s_{NN}} = 62.4$ GeV and $\sqrt{s_{NN}} = 200$ GeV. The data still show the linear dependence on transverse momentum for $p_T$ smaller than 4 GeV/$c$ for data at lower energy. There is no statistical difference on absolute value for Au+Au and Cu+Cu collisions at the same energy, but there is a difference in the rate of increase of each energy where the rate of increase of $\sqrt{s_{NN}} = 200$ GeV is about 50% higher than in $\sqrt{s_{NN}} = 62.4$ GeV.

4. Summary

We have presented new results for multi-strange baryons production measured at Au+Au and Cu+Cu collisions at $\sqrt{s_{NN}} = 62.4$ GeV. The transverse momentum spectra of $\Xi$, $\Omega$ and their anti-particles were showed for different collision centrality classes at mid-rapidity. According to anti-baryon over baryon ratio, different trend was noted at $\sqrt{s_{NN}} = 62.4$ GeV compared to $\sqrt{s_{NN}} = 200$ GeV. The slightly decrease observed at $\bar{p}/p$ and $\bar{\Lambda}/\Lambda$ but not seen on multi-strange ratios as a function of $dN_{ch}/dy$ could be an indication of a higher net-baryon density for central collisions. For both colliding systems, the multi-strange particle yields relative to pion showed a higher increase rate with centrality which is consistent with the enhancement of the $s\bar{s}$ pair production at central collisions. Finally, a linear increase of $\Omega/\phi$ ratio for intermediate $p_T$ was observed and follows the same trend compared to previous results at $\sqrt{s_{NN}} = 200$ GeV.

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