$\rho^0$ Production in Cu+Cu Collisions at $\sqrt{s_{NN}} = 200$ and 62.4 GeV in STAR

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Abstract

The results on $\rho^0(770)$ production in Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ and 62.4 GeV in STAR are presented. The $\rho^0$ is measured via its hadronic decay channel and used as a sensitive tool to examine the collision dynamics in the hadronic medium.

1. Introduction

The study of the $\rho^0$ vector meson in relativistic heavy-ion collisions provides information on the properties of the hot and dense medium created in such collisions. The $\rho^0$ measured via its hadronic decay channel can be used as a sensitive tool to examine the collision dynamics in the hadronic medium through its decay and regeneration.

The resonances that decay before kinetic freeze-out may not be reconstructed due to the rescattering of the daughter particles. In this case, the resonance survival probability is relevant and depends on the time between chemical and kinetic freeze-outs, the source size, and the $p_T$ of the resonance. On the other hand, after chemical freeze-out, elastic interactions may increase the resonance population compensating for the ones that decay before kinetic freeze-out. This resonance regeneration depends on the hadronic cross-section of their daughters. For example, the $K^*$ regeneration depends on $\sigma_{\pi\pi}$ and $\sigma_{\eta\eta}$, which are larger (factor $\sim3$) than the $\sigma_{K\pi}$ $[1]$. In the case of the $\rho^0$, the regeneration probability that depends on the $\sigma_{\pi\pi}$ is expected to be of the same order of the rescattering of the daughters. Thus, the study of resonances can provide an independent probe of the time evolution of the source from chemical to kinetic freeze-outs and yield detailed information on hadronic interaction at later stages.

The measurement of the elliptic flow ($v_2$) of hadrons shows that the $v_2$ scales with the number of constituent quarks. It has been proposed that the measurement of the $v_2$ of resonances can distinguish whether the resonance was produced at hadronization via quark coalescence or later in the collision via hadron re-scattering $[4]$. The measurement of the $\rho^0$ $v_2$ can potentially provide information on the $\rho^0$ production mechanism.

2. Results

The $\rho(770)^0$ production corresponding to 20 – 60% of the hadronic cross-section was measured via its hadronic decay channel at midrapidity ($|y|\leq0.5$) in Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ and 62.4 GeV using the STAR detector at RHIC. In this analysis, the small signal to background ratio ($\sim 1/1000$) prevents the measurement of the $\rho^0$ in central Cu+Cu collisions.

Preprint submitted to Nuclear Physics A

April 25, 2019
The $\pi^+\pi^-$ invariant mass distributions after background subtraction for a particular centrality of the hadronic Cu+Cu cross-section is shown in Fig. 1. The solid black line in Fig. 1 is the sum of all the contributions in the hadronic cocktail. The $K_0^0$ was fit to a Gaussian (dotted line). The $\omega$ (light grey line) and $K^*(892)^0$ (dash-dotted line) shapes were obtained from the HIJING event generator [5], with the kaon being misidentified as a pion in the case of the $K^*$. The $\rho^0(770)$ (dashed line) and the $f_0(980)$ (dotted line) were fit by relativistic Breit-Wigner functions times the phase space function described in [6]. The masses of $K_0^0$, $\rho^0$, and $f_0$ were free parameters in the fit, and the widths of the $\rho^0$ and $f_0$ were fixed according to the values in the PDG [7]. The uncorrected yields of $K_0^0$, $\rho^0$, $\omega$, and $f_0$ were free parameters in the fit while the $K^*$ fraction was fixed according to the $K^*(892)^0 \rightarrow \pi K$ measurement. The $\rho^0$, $\omega$, $K^*$, $f_0$, and $f_2$ distributions were corrected for the detector acceptance and efficiency determined from a detailed simulation of the detector response. This measurement does not have sufficient sensitivity to permit a systematic study of the $\rho^0$ width.

Figure 1: The $\pi^+\pi^-$ invariant mass distributions after background subtraction for a particular centrality of the hadronic Cu+Cu cross-section.

The $\rho^0$ mass is shown as a function of $p_T$ in Fig. 2 for four different centralities. The $\rho^0$ mass seems to increase as a function of $p_T$ and is systematically lower than the value reported by the PDG of 775.49 ± 0.34 MeV/c$^2$[7]. A mass shift has also been observed in $e^+e^-$, $p+p$ and peripheral Au+Au collisions, as described in [6]. Dynamical interactions with the surrounding matter, interference between various $\pi^+\pi^-$ scattering channels, phase space distortions due to the rescattering of pions forming $\rho^0$, and Bose-Einstein correlations between $\rho^0$ decay daughters and pions in the surrounding matter are possible explanations for the apparent modification of the $\rho^0$ meson properties [6].

The corrected invariant yields $[d^2N/(2\pi p_T dy)]$ at $|y|<0.5$ as a function of $p_T$ for Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ and 62.4 GeV for four different centralities are shown in Fig. 3. An exponential fit was used to extract the $\rho^0$ yield per unit of rapidity around midrapidity.

The $\rho^0/\pi^-$ ratio together with the $K^+/K^-$ ratio are plotted in Fig. 4 as a function of the number of participants ($N_{part}$) for $\sqrt{s_{NN}} = 200$ and 62.4 GeV [8][9]. The $\rho^0/\pi^-$ and the $K^+/K^-$ ratios behave differently as a function of $N_{part}$. The $K^+/K^-$ ratio decreases with $N_{part}$, while the $\rho^0/\pi^-$ ratio is independent or slightly increases with $N_{part}$. This can be understood in terms of hadron cross-sections ($\sigma$). The $\sigma_{K^+}$ is smaller than $\sigma_{\pi^+}$. Therefore, it is more probable for a pion to scatter with another pion and form a $\rho^0$ than it is for a kaon to scatter with a pion and form $\rho^0$. The $\rho^0/\pi^-$ ratio is shown as a function of $p_T$ for Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ and 62.4 GeV for four different centralities are shown in Fig. 3. An exponential fit was used to extract the $\rho^0$ yield per unit of rapidity around midrapidity.
a $K^*$. So, in the case of the $K^*$, the rescattering of the daughters will destroy the $K^*$. However, in the case of the $\rho^0$, the rescattering of the daughters will most probably generate another $\rho^0$ and the regeneration will compensate the rescattering of the daughters and even increasing the number of $\rho^0$.

The $\rho^0 v_2$ as a function of $p_T$ is shown in Fig. 5. In the same figure it is also plotted the $K^0_S$, $\Lambda$ and charged hadron $v_2$ for comparison, where all the measurements are from the same hadronic cross section [10]. We observe a non-zero $\rho^0 v_2$ of about 13 ± 3% for $p_T > 1.2$ GeV/c. In order to calculate the contributions to the $\rho^0$ production from either direct quark or hadron combinations, we use the function proposed in [11] to fit the $\rho^0 v_2$ distribution (0.3 ≤ $p_T$ ≤ 2.3 GeV/c) and we obtain $n = 4.7 ± 2.9$, where $n$ is a free parameter standing for the number of constituent quarks and the $\chi^2/ndf = 10.3/9$. Only the statistical error was considered in the fit. Due to the large statistics and the limited $p_T$ range measured, it is difficult to identify the $\rho^0$ production fractions from direct quark ($n = 2$) or hadron combinations ($n = 4$).

3. Conclusions

We measure significant $\rho^0$ production in Cu+Cu collisions at at $\sqrt{s_{NN}} = 200$ and 62 GeV and the production measured corresponds to 20 − 60% of the hadronic cross-section. We observe a mass shift of about −45 MeV/$c^2$ possibly due to medium modifications, phase space, interference and Bose-Einstein correlations. The rescattering of the daughters and the regeneration of the
resonances are driven by the hadron cross-sections where the $K^*$ is dominated by the rescattering of its daughters and in the case of the $\rho^0$ the regeneration is compensating for the rescattering of the daughters. We presented the first measurement of the $\rho^0 v_2$ showing that the $\rho^0$ flows for $p_T > 1.2 \text{ GeV}/c$. However, the $p_T$ range covered is not sufficient for a conclusive remark on the production mechanism of the $\rho^0$ measured in the hadronic decay channel. This measurement will improve with the STAR Time-of-Flight that will allow increasing the $p_T$ range covered.

References

[1] S. D. Protopopescu et al., Phys. Rev. D 7 (1973) 1279.
[2] M. J. Matison et al., Phys. Rev. D 9 (1974) 1872.
[3] K. Hagiwara et al., Phys. Rev. D 66 (2002) 010001.
[4] C. Nonaka et al., Phys. Rev. C 69 (2004) 031902.
[5] X. N. Wang and M. Gyulassy, Phys. Rev. D 44 (1991) 3501; Compt. Phys. Commun. 83 (1994) 307.
[6] J. Adams et al., Phys. Rev. Lett. 92 (2004) 92301.
[7] C. Amsler et al., Physics Letters B 667 (2008) 1.
[8] J. Adams et al., Phys. Rev. C 71 (2005) 64902.
[9] B. I. Abelev et al., Phys. Rev. C 78 (2008) 44906.
[10] S. Shi for the STAR Collaboration, arXiv:0806.0763v2.
[11] X. Dong et al., Phys.Lett. B 597 (2004) 528.