$K^*(892)$ Production in Au+Au and pp Collisions at $\sqrt{s_{NN}}=200\text{GeV}$ at STAR

Haibin Zhang† for the STAR Collaboration §

† Yale University, Physics Department, P.O.Box 208121, New Haven, CT 06520-8121, USA, Email: zhang@hepmail.physics.yale.edu

Abstract.

Mid-rapidity $K^{*0}(892)\rightarrow K\pi$ and $K^{*\pm}(892)\rightarrow K^0_S\pi^\pm$ are measured in Au+Au and pp collisions at $\sqrt{s_{NN}}=200\text{GeV}$ using the STAR detector at RHIC. The $K^{*0}(892)$ mass is systematically shifted at small transverse momentum for both Au+Au and pp collisions. The $K^{*0}(892)$ transverse mass spectra are measured in Au+Au collisions at different centralities and in pp collisions. The $K^{*0}(892)$ mean transverse momentum as a function of the collision centrality is compared to those of identified $\pi^-$, $K^-$ and $\bar{p}$. The $K^*/K$ and $\phi/K^*$ ratios are compared to measurements in A+A, pp, $\bar{p}p$, $e^+e^-$ collisions at various colliding energies. The physics implications of these measurements are also discussed.

PACS numbers: 25.75, 25.75, 25.75

Submitted to: J. Phys. G: Nucl. Phys.

1. Introduction

Resonance particles, which have very short lifetime (few fm/c) comparable to the time scale for the evolution of the hot-dense matter formed in ultra-relativistic heavy-ion collisions, can be a very unique tool to probe the dynamics and properties of the high density matter [2, 3, 4]. In particular, the $K^*(892)$ has a lifetime of $\sim 4\text{fm/c}$, and can be produced at the chemical freeze-out stage. The $K^*$ short lifetime makes it possible for the newly-formed $K^*$ to undergo a period of re-interaction in the hadronic gas phase. A portion of $K^*$ may decay before the kinetic freeze-out stage and their kaon and pion daughter particles might be re-scattered by other particles in the hadron gas. This effect of the $K^*$ daughter particles re-scattering can destroy part of the overall $K^*$ signal. On the other hand, kaon and pion particles in the hadron gas can regenerate $K^*$ through the so-called pseudo-elastic collisions [6]. This regeneration effect can compensate for the rescattering effect. Thus the measurement of $K^*$ yields and their centrality dependence in heavy-ion collisions can provide information to estimate the time between chemical

§ See reference [1] for the full collaboration list.
and kinetic freeze-out in relativistic heavy-ion collisions [5, 6].

In the strongly interacting matter at high temperature and high densities, characteristics of the short-lived $K^*(892)$ resonance might be modified in the medium, with shifted mass, broadened width and even significantly changed line shapes. In the hadron gas, kaon and pion particles can regenerate $K^*$ signals through $K\pi \to K^* \to K\pi$. This regeneration channel can also interfere with the kaon and pion elastic scattering channel through $K\pi \to K\pi$. Thus the $K^*$ meson may be modified not only due to this interference but also due to the kaon and pion initial phase space distributions [7]. In addition, dynamical interactions of the $K^*$ meson with the surrounding matter may also cause the modification of the $K^*$ mass, width and line shape [8, 9]. Even though the size of the system formed in pp collisions is smaller than in Au+Au collisions, interactions that may modify the $K^*$ resonance are also expected. Thus a measurement of $K^*(892)$ mass, width and line shape in Au+Au and pp collisions can provide very interesting information on possible in-medium effects.

2. Data Analysis and Results

Preliminary measurements on $K^{*0}(892) \to K\pi$ and $K^{*\pm}(892) \to K^0\pi^\pm$ in Au+Au and pp collisions at $\sqrt{s_{NN}}=200\text{GeV}$ are presented. These measurements were made at the Solenoidal Tracker at RHIC (STAR) with the main detector Time Projection Chamber (TPC). In Au+Au collisions, the minimum bias trigger was defined by coincidences between two Zero Degree Calorimeters (ZDC). A scintillator Central Trigger Barrel (CTB) was used to select central collision events. In pp collisions, the minimum bias trigger was defined using coincidences between two beam counters that measured the charged particles multiplicity near beam rapidity. After requiring the collision vertex to be within $\pm 50\text{cm}$ along the beam line, about 2M top 10% central triggered, 2M minimum bias triggered Au+Au collision events and 6M minimum bias triggered pp collision events were used in this analysis. The events from minimum bias Au+Au collisions were divided in four centrality bins from the most central to peripheral collisions: 0%-10%, 10%-30%, 30%-50% and 50%-80%.

Through energy loss ($dE/dx$) in the TPC gas, charged pions and kaons were identified. In the case of $K^{*0}$, charged kaons were selected by requiring their $dE/dx$ to be within two standard deviations ($2\sigma$) of the expected value. A looser $dE/dx$ cut of $3\sigma$ was used for charged pions. In the case of $K^{*\pm}$, $K^0_S$ candidates were selected from their decay vertex geometries via $K^0_S \to \pi^+\pi^-$. The invariant mass was then calculated for each kaon and pion pair in an event. The invariant mass distribution derived in this manner was then compared to a reference distribution calculated using uncorrelated kaons and pions from different events. In this analysis, $K^{*0}$ and $\bar{K}^{*0}$ are added together due to limited statistics. The term $K^{*0}$ refers to the average of $K^{*0}$ and $\bar{K}^{*0}$ unless
Figure 1. The raw $K\pi$ invariant mass distribution after subtraction of the mixed-event reference distribution for Au+Au and pp collisions. a) $K^*_0$ in top 10% central Au+Au collisions; b) $K^*_0$ in minimum bias pp collisions; c) $K^{*\pm}$ in 50%-80% hadronic cross section Au+Au collisions; d) $K^{*\pm}$ in minimum bias pp collisions.

Figure 1 shows the $K\pi$ invariant mass distribution after subtraction of the mixed-event reference distribution in Au+Au and pp collisions. The invariant mass distributions are fit to a combination of a p-wave Breit-Wigner function and a linear function representing the background. In Figure 1 (a), there is a large amount of residual background in the invariant mass distribution after subtracting the reference distribution. Reference [10] discussed possible sources of this residual background. In addition, while mixing Au+Au collision events, different events will have different reaction planes so that the reference invariant mass distribution might have slightly different shapes from the same event distribution. After subtracting the reference distribution, this slight difference will appear as part of the residual background [17]. In Figure 1 (b), in order to precisely measure the $K^*_0$ mass and width as a function of transverse momentum in pp collisions, we only selected the kaon candidates with momentum between 0.2 GeV/c and 0.7 GeV/c to minimize the residual background. In Figure 1 (c) and (d), $K_0^*$ candidates were first reconstructed via decay vertex geometries requiring $|M_{K_0^*} - M_{\pi^+\pi^-}| < 15$MeV/c$^2$. Then, after pairing $K_0^*$ candidates with charged pion candidates in same events and mixed events, invariant mass distribution for the $K^{*\pm}$ were obtained after reference distribution subtraction.

The $K^*_0$ mass and width as a function of transverse momentum from Au+Au and
Figure 2. $K^*$ mass and width as a function of transverse momentum for both Au+Au and pp collisions. The solid straight lines stand for the standard $K^*$ mass (896.1 MeV/c$^2$) and width (50.7 MeV/c$^2$). The dashed curves represent the MC results for $K^*$ mass and width in pp collisions after considering detector effects and kinematic cuts. The dotted curves represent MC results in Au+Au collisions. The grey shadows are for systematic uncertainties in pp.

pp collisions are shown in Figure 2. In pp collisions, the $K^*$ masses in low $p_T$ region are systematically smaller than the Monte Carlo (MC) results which account for detector effects and all kinematic cuts. The mass shift is $p_T$ dependent, with the $K^*$ mass increasing as a function of $p_T$. In Au+Au collisions, the $K^*$ mass shift is also observed at low $p_T$. In the case of the $K^*$ width, there is no significant difference between the measured results and the MC results in both Au+Au and pp collisions. As already discussed in the introduction section, there are various physical effects which may cause this $K^*$ mass shift. However, a soft $K^*$ resonance (low $p_T$) is more likely to be modified in the medium and thus a larger mass shift is expected for soft $K^*$ than for hard $K^*$ (high $p_T$). A similar mass shift for the $\rho^0(770)$ meson has also been observed in both pp and Au+Au collisions[11].

The detector acceptance and efficiency corrected $K^*$ transverse mass ($m_T = \sqrt{p_T^2 + m^2}$) spectra at mid-rapidity ($|y| < 0.5$) are shown in the left plot of Figure 3. The spectra are fit with exponential functions and $K^*$ yields $dN/dy$ and inverse slopes are extracted from the exponential fit. The $K^*$ $dN/dy$ increases from pp collisions to peripheral Au+Au collisions and to central Au+Au collisions. The inverse slopes in Au+Au collisions are systematically larger than that in pp collisions. In the right plot of Figure 3, the $K^*$ mean $p_T$ as a function of number of charged hadrons is compared to that of $\pi^-$, $K^-$ and $\bar{p}$ [12]. In pp collisions, the $K^*$ mean $p_T$ is comparable to the mean $p_T$ of $\bar{p}$. In Au+Au collisions, the $K^*$ mean $p_T$ are systematically larger than that in pp collisions. The larger $K^*$ inverse slopes and mean $p_T$ in Au+Au collisions than in pp collisions might be explained by the fact that in the hadronic phase of Au+Au collisions, $K^*$ with higher $p_T$ are more likely to escape and decay outside the fireball thus avoiding the daughter particles’ re-scattering. A low $p_T$ $K^*$ has more chances to be destroyed by daughter particles’ re-scattering in the hadron gas medium in Au+Au collisions.
Figure 3. \((K^{*0} + \bar{K}^{*0})/2 \) \(m_T\)-distributions at mid-rapidity (\(|y| < 0.5\)) in Au+Au and pp collisions (left). \(K^{*0}\) mean \(p_T\) as a function of number of charged hadrons and compared to \(\pi^-, K^-\) and \(\bar{p}\) (right).

Figure 4. \(K^*/K\) and \(\phi/K^*\) ratios as a function of number of charged hadrons for both pp and Au+Au collisions (left). \(K^*/K\) and \(\phi/K^*\) ratios compared to different collision systems (e⁺e⁻ [14], pp [15] and pp [16]) at various collision energies (right).

\(K^*\) and \(K\) mesons of the same charge have identical quark content and only differ in mass and spin so that the \(K^*/K\) ratio might reflect the fireball evolution conditions from chemical to kinetic freeze-out. Figure 4 shows that the \(K^*/K\) ratios in Au+Au collisions are significantly reduced compared to the ratio in pp collisions. This ratio reduction may indicate that in Au+Au collisions, \(K^*\) daughter particles’ re-scattering might destroy more \(K^*\) than the amount of \(K^*\) which are regenerated by the \(K\pi\) inter-
actions in the hadron gas. The upper right panel of Figure 4 shows the $K^*/K$ ratio as a function of the colliding energy from different collision systems. The $K^*/K$ ratio from elementary collisions does not change noticeably in the presented $\sqrt{s}$ region. However, the ratio in Au+Au collisions is significantly smaller. The $K^*$ and $\phi$ mesons have a small mass difference and $\Delta S=1$. Thus, the $\phi/K^*$ ratio might also be a good signature to study the strangeness enhancement effect in ultra-relativistic heavy ion collisions. The bottom right panel of Figure 4 shows that the $\phi/K^*$ ratio increases as a function of the colliding energy. We may need more statistics to identify any possible $\phi/K^*$ ratio differences between Au+Au collisions and pp collisions at $\sqrt{s_{NN}}=200$GeV. In this analysis, $K$ results are from [12] and $\phi$ results are from [13]. $K^*$ results for Au+Au collisions at $\sqrt{s_{NN}}=130$GeV are from [10].

3. Summary

In summary, we have measured the $K^{*0}(892)$ and $K^{*\pm}(892)$ production from Au+Au and pp collisions at $\sqrt{s_{NN}}=200$GeV at STAR. Possible in-medium dynamical effects might have modified the $K^*$ mass line shape and thus systematically smaller $K^*$ masses are observed at the low $p_T$ region in pp and Au+Au collisions. In Au+Au collisions, the $K^*$ daughter particles’ re-scattering effect is dominant over the regeneration effect. This picture is consistent with our measurements that the $K^*$ inverse slopes and mean $p_T$ in Au+Au are larger than in pp and the $K^*/K$ ratios in Au+Au are smaller than in pp.

[1] H. Caines, these proceedings.
[2] R. Rapp et al., Adv. Nucl. Phys. 25, 1 (2000).
[3] R. Rapp et al., Phys. Rev. C 63, 054907 (2001).
[4] J. Schaffner-Bielich, Phys. Rev. Lett. 84, 3261 (2000).
[5] G. Torrieri and J. Rafelski, hep-ph/0112195.
[6] M. Bleicher et al., QM02 proceedings.
[7] R. Longacre, paper in preparation.
[8] E. Shuryak and G. Brown, Nucl.Phys. A717 (2003) 322-335.
[9] E. Shuryak, hep-ph/0304145.
[10] C. Adler et al., Phys. Rev. C 66, 061901(R) (2002).
[11] P. Fachini, these proceedings.
[12] O. Barannikova and F. Wang, QM02 proceedings.
[13] J. Ma, these proceedings.
[14] H. Albrecht et al., Z. Phys. C 61 (1994)1; M. Derrick et al., Phys. Lett. B 158 (1985) 519; K. Abe et al., Phys. Rev. D 59 (1999) 052001; Y. J. Pei et al., Z. Phys. C 72 (1996) 39.
[15] J. Canter et al., Phys. Rev. D 20 (1979) 1029.
[16] T. Akesson et al., Nucl. Phys. B203, 27 (1982); D. Drijard et al., Z. Phys. C 9, 193 (1981); M. Aguilar-Benitez et al., Z. Phys. C 50, 405 (1991).
[17] L. Gaudichet, STAR note SN446.