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THE K^* and ϕ RESONANCES OBSERVABILITY AT THE TOP RELATIVISTIC HEAVY ION COLLIDER ENERGY

The paper deals with the problem of $K^*(892)$ strange resonance observability, affected by the interaction of its decay products with the hadronic medium formed in the relativistic heavy ion collisions. The results address the STAR Collaboration experiment at the top energy Au+Au collisions ($\sqrt{s_{NN}} = 200$ GeV)at the Relativistic Heavy Ion Collider. The K^* observabilities together with those of $\phi(1020)$ resonance, which possesses a hidden strange quark composition and has a fairly large life time as compared to the $K^*(892)$, are analyzed within the integrated hydrokinetic model. The results on $K^*(892)/K$ and $\phi(1020)/K$ particle number ratios, which can be considered as the source of additional information about the hadronic stage of collision, are presented as well.

Keywords: observability, production, hadron, resonance, rescattering.

1. Introduction

Strange hadrons can play an important role in understanding the final hadronic stage of the matter evolution in $A+A$ collisions. One can expect that after the hadronization happens, the expanding system formed in a nuclear collision is still in chemical and thermal local equilibrium until its temperature reaches the value (near $160\,\mathrm{MeV}$ [1]), below which both chemical and local thermal equilibrium are destroyed, and the system comes to the final afterburner stage. At this non-equilibrium stage particles still collide and annihilate, the resonances decay, and hadrons gradually escape from the system and travel freely to the detectors. Strange hadrons, such as the resonance $K^*(892)$, living for a time interval about 4 fm/*c*, can be used as a probe of the processes taking place at this afterburner stage if one studies the corresponding yield, registering the hadronic decay channel $K^*(892) \to K\pi$. The fraction of restored $K^*(892)$'s depends strongly on the intensity of the interactions between the daughter hadrons and medium at the final stage of collision, which prevent complete identification of all produced $K^*(892)$'s in the experiment. Consequently, some particle number ratios, calculated in the experimental analysis to give the information about the matter properties at chemical freeze-out (at $T \approx 160\,\mathrm{MeV}$) and the collision dynamics, will also deviate from their true values. In the current paper we study the effects produced by the hadronic rescatterings on the K^* resonance observability within the integrated hydrokinetic model (iHKM) for the case of $Au+Au$ collisions at the top Relativistic Heavy Ion Collider (RHIC) energy $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$.

2. Integrated hydrokinetic model

The integrated hydrokinetic model (iHKM) [2, 3] is an improved version of the well-known HKM model [4], which now includes viscous (not ideal as in HKM) of relativistic nuclear collision and an energy-momentum transport model for the pre-thermal stage of the matter evolution. As well as HKM, the iHKM model is capable of simultaneous description of a wide class of bulk observables in heavy ion collisions, such as particle momentum spectra, interferometry radii, flow harmonics, source functions, etc. [5, 6]. The matter evolution process in the model starts from the formation of the initial non-thermal energy-momentum tensor, which serves as a starting point for the subsequent pre-thermal dynamics. The latter results in thermalization of the matter, so that its further expansion is described hydrodynamically. At the next stage the particlization takes place (switching to the description of the system's evolution in terms of particles) and then the system finally proceeds to the hadronic cascade stage. The initial conditions for the simulation of the pre-thermal stage of matter evolution are attributed to a quite early proper time τ_0 = 0.1 fm/*c*. The choice of this value for τ_0 is motivated by the estimates of the Glasma formation time and also the comparison of the iHKM simulation results with the data of heavy ion collision experiments. Assuming the longitudinal boost-invariance, we present the initial (generally non-equilibrium) parton distribution function for the midrapidity region at τ_0 in the following factorized form:

$$f(x,p)=\varepsilon(r_T)f_0(p) \tag{1}$$

In our simulations the initial energy density profile can be written as $\varepsilon(r_T)=\varepsilon_0\cdot\varepsilon^{MC}(r_T)$, where $\varepsilon^{MC}(r_T)$ is the profile, obtained from the Monte Carlo Glauber generator GLISSANDO [7] and ε_0 is the coefficient of proportionality, ensuring the reproduction of the experimental mean charged particle multiplicity in our simulations. Actually, the ε_0 is the main iHKM free parameter. The GLISSANDO code allows the utilization of two different approaches to the calculation of $\varepsilon^{MC}(r_T)$, namely, the so-called wounded nucleon and the binary collision models. The resulting transverse energy density distribution can be associated with a combination of profiles, obtained within two approaches. The weight of each model's contribution to the resulting energy density is regulated by the parameter, $0\le\alpha\le1$.

The function $f_0(p)$ in (1) describes the possible momentum anisotropy of the initial parton distribution, that typically arises in the approaches based on the Color Glass Condensate effective field theory (see [2, 3] for details):

$$f_0(p)=g\cdot\exp\left(-\sqrt{\frac{(p\cdot U)^2-(p\cdot V)^2}{\lambda_\perp{}^2}+\frac{(p\cdot V)^2}{\lambda_\parallel{}^2}}\right) \tag{2}$$

where $U^\mu=(\cosh\eta,0,0,\sinh\eta)$, $V^\mu=(\sinh\eta,0,0,\cosh\eta)$. The parameters $\lambda_\parallel{}^2$ and $\lambda_\perp{}^2$ can be thought of as the two temperatures – along the beam axis and along the direction, orthogonal to it, correspondingly. The ratio Λ of these temperatures describes the momentum anisotropy of the initial state. For each concrete type of simulated collisions, the normalization factor ε_0 for the initial transverse energy density distribution and the parameter α, regulating the proportion of contributions from the wounded nucleons and nucleon binary collision mechanisms to the initial energy density, are fixed in GLISSANDO calculations based on the experimental value of mean charge particle multiplicity. It turns out that these two parameters do not depend on the collision centrality at given collision energy [2, 3]. The initial distribution (1) gives us the non-thermal energy-momentum tensor which is then subject for the pre-thermal evolution, described within the relaxation time approximation [2, 3]. Eventually, at some time τ_{th} (the thermalization time) the matter reaches approximate local thermal equilibrium and thus becomes thermalized. The system's energy-momentum tensor takes the Israel-Stewart form, and the further matter expansion is described within the relativistic viscous hydrodynamics approach. We assume the shear viscosity to the entropy density ratio to have the minimal possible value, $\eta / s = 1/4\pi$. We also utilize the lattice QCD inspired Laine-Schröder equation of state at the hydrodynamic stage, that ensures the smooth (without leaps in pressure and energy density) transition from the continuous medium evolution to the hadron gas. The hydrodynamic description is applied while the matter can be considered being in local chemical and thermal equilibrium. Then at some temperature T_p both types of equilibrium are assumed to get lost, so that the system decouples into particles. The system's particlization can be described either as gradual process within the hydrokinetic approach or as a sudden switching from continuous medium evolution to the expansion of the system that consists of particles. After the particlization follows the hadron cascade stage, which includes multiple collisions between produced particles and the decays of resonances. This stage is described within the UrQMD model [8, 9].

3. Results and discussion

In what follows we discuss the results of the calculations, performed in iHKM and corresponding to the simulation of Au+Au collisions at RHIC energy $\sqrt{s_{NN}} = 200\,\text{GeV}$ for the four centrality classes, namely $c = 0-10\%$, $c = 10-30\%$, $c = 30-50\%$, and $c = 50-80\%$. In the experiment the $K(892)^{*0}$ resonances are identified by the products of their decays into $K^+\pi^-$ pairs. Such identification is complicated by several factors. First, due to comparably small $K^*(892)$ lifetime (about 4 fm/*c*) the intensive rescatterings, taking place between particles, born in course of hadronization, lead to the two opposed effects: a reduction of the number of $K\pi$ pairs identified as K^* because of rescattering of mesons forming such a pair and, on the other hand, an enhancement of identified K^* because of possible recombination processes. Apart from that, different types of correlations, including event-by-event elliptic flow and residual ones, which exist between kaons and pions, can be misinterpreted as their bound resonance state. The common misidentification problem, when particles of one species are identified as those of another one, also contributes to this effect. Let us investigate the influence of the first two competing effects within iHKM. Since iHKM includes hadron cascade stage of system's evolution modeled within UrQMD, one can calculate two numbers: the number of actual K^{*0}'s, produced in the course of medium particlization (it happens at the temperature near $T = 165\,\text{MeV}$ in iHKM) plus those coming from subsequent resonance decays, and – on the other hand – the number of $K^+\pi^-$ pairs, which can be identified as coming from the K^{*0} decays. For our analysis we select the $K^+\pi^-$ pairs with rapidity $|y| < 0.5$ and $0.2 < k_T < 10\,\text{GeV}/c$. The criterion utilized to tell whether a pair comes from the desired decay is the following: it is required that all the spatial coordinates of the particle last collision points have to differ by less than $0.01\,\text{fm}$, $|x_i^K - x_i^\pi| < 0.01\,\text{fm}$, and the pair invariant mass should differ from the $K(892)^{*0}$ invariant mass,

$M_{K^*} = 895.94\,\mathrm{MeV}$, by less than $125\,\mathrm{MeV}$. As a result, we obtain the dependence of the fraction of identified K^* resonances on the Au+Au collision centrality at the RHIC energy $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$. It is presented in fig. 1.

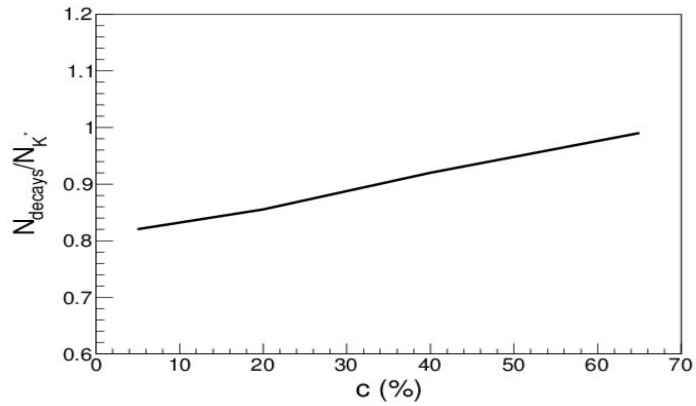

Fig. 1. The fraction of $K(892)^*$ resonances, which can be identified by the products of its decay into $K^+\pi^-$ in iHKM simulations (the particle rescattering stage is modeled within the UrQMD). The simulations correspond to Au+Au collisions at the RHIC energy $\sqrt{s_{NN}} = 200\mathrm{GeV}$ with different centralities.

As one can see, this fraction increases from 0.82 for the 10 % most central collisions to unity for the near peripheral collisions with *c*=50-80%. Such a behavior is expected, since at periphery collisions most of the nucleons of the colliding nuclei pass without intensive interaction and therefore the system they form is not so extensive, hot, dense and long-living, as in central collisions, where the formation of such fireball leads to the mentioned K^* identification issues. As for the longer living $\phi(1020)$ resonance with lifetime about 50 fm/*c*, which decays into K^+K^- and $K_L^0 K_S^0$ pairs, one cannot expect that the rescatterings of daughter particles will be noticeable to reduce observed resonance number. Since KK interaction cross-section is not very large, the recombination effect is also not big. The results of iHKM simulations are in agreement with these considerations. Actually, the fraction of restored $\phi(1020)$ in our simulations for all the centralities is about 25 % larger than unity. We connect such an enhancement with the manifestation of $K\bar{K}$ correlations. In order to clarify the dynamics of resonance production in the process of evolution of the systems, formed in the heavy ion collisions, we calculate also the K^*/K^+ and ϕ/K^+ particle number ratios in the iHKM model. We perform the calculations at two different stages: near the hadronization hypersurface, where the particles and resonances are still chemically equilibrated (chosen to be an isotherm $\mathrm{T} = 165\,\mathrm{MeV}$ in iHKM simulations), and at the end of the hadron cascade stage. In the first case K^*/K ratio is about 0.52 and ϕ/K ratio is about 0.27 for all the considered centralities, that is physically clear, since this ratio depends only on the temperature, baryon (strange) chemical potential and particle masses which in the model are the same at different centralities. For the second case the results for top RHIC energy Au+Au collisions are presented in Table 1. The kaons with pseudorapidity $|\eta|<0.8$ and $0.2 < p_T < 10\mathrm{GeV}/c$ were chosen for the analysis. The latter results depend on many factors: numbers of primary

K^*, ϕ and K mesons, the contributions to the meson numbers from resonance decays, ability to identify K^* etc. One can see, that the considered ratios decrease approximately twice after the rescattering stage as compared to the hadronization stage. The afterburner K^*/K ratio slightly increases at decreasing collision centrality and the ϕ/K ratio behaves oppositely (fig. 2, 3). The results are compared with the corresponding experimental data [10]. As one can see, our modeling results are in agreement with the RHIC experiment within the errors, maybe except for the last point for ϕ/K .

Table 1

The K^*/K^+ and ϕ/K^+ ratios for different centrality classes, obtained in iHKM simulations of Au+Au collisions at RHIC energy $\sqrt{s_{NN}} = 200$ GeV together with the experimental data [10].

c	K^*/K STAR	K^*/K iHKM	ϕ/K STAR	ϕ/K iHKM
0-10%	$0.23 \pm 0.01 \pm 0.05$	0.21	$0.15 \pm 0.01 \pm 0.02$	0.15
10-30%	$0.24 \pm 0.02 \pm 0.05$	0.21	$0.16 \pm 0.01 \pm 0.02$	0.14
30-50%	$0.26 \pm 0.02 \pm 0.06$	0.22	$0.16 \pm 0.01 \pm 0.02$	0.13
50-80%	$0.26 \pm 0.02 \pm 0.05$	0.23	$0.16 \pm 0.01 \pm 0.02$	0.11

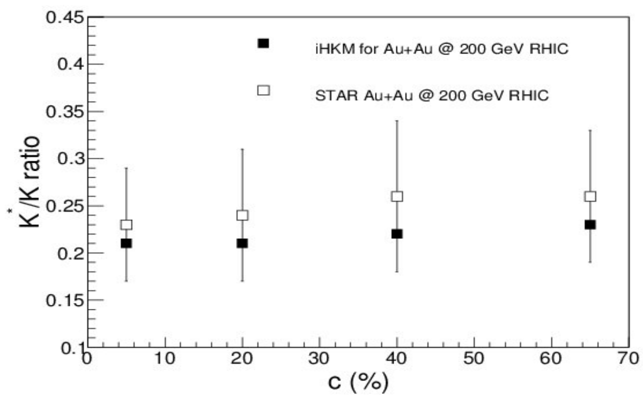

Fig. 2. The K^*/K^+ ratio for different centrality classes, obtained in iHKM simulations of Au+Au collisions at RHIC energy $\sqrt{s_{NN}} = 200$ GeV together with the experimental data [10].

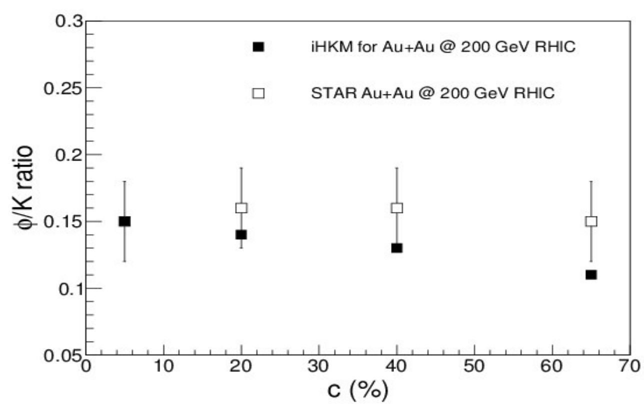

Fig. 3. The ϕ/K^+ ratio for different centrality classes, obtained in iHKM simulations of Au+Au collisions at RHIC energy $\sqrt{s_{NN}} = 200$ GeV together with the experimental data [10].

3. Conclusions

In this paper we studied the possibility for the identification of $K^*(892)$ resonances in the top RHIC energy *-relativistic $\mathrm{Au+Au}$ collisions at different centralities within the integrated hydrokinetic model (iHKM). The analysis showed that the intensive particle rescatterings, which occur at the afterburner stage of the collision, result in decreased observable yields of K^* resonance. This observed K^* suppression grows with the collision centrality and reaches 18% for the 10% most central events, while for the peripheral events it is almost absent.

In contrast, the similar study for the $\phi(1020)$ resonances demonstrated the excessive amount of registered $\phi(1020)$, by up to 25% exceeding their number on chemical freeze-out. Such an enhancement can be explained by the effect of $K\bar{K}$ correlations at the final stage of the collision, realized in the model through the UrQMD coalescence mechanism.

Also the K^*/K and ϕ/K particle number ratios were calculated in the model and compared to the experimental values. The iHKM simulation results are in agreement with the data presented by the STAR Collaboration.

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