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Resonances from a hadronic fireball

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Abstract
The production of $\phi(1020)$, $\Lambda^*(1520)$ and $\overline{\mathrm{K}^*}(892)$ resonances at the final stage of a heavy-ion collision is considered. It is shown that original momentum distributions and abundance of resonances formed during the process of heavy-ion collisions may differ significantly from their measured spectra and yields. The reconstruction probability of resonances decaying inside the fireball can be strongly suppressed because of interactions of their hadronic decay products in the fireball medium. We investigate the dependence of the degree of suppression on the fireball size, dynamics and the resonance decay width in the medium. Quantitative results are presented for lead–lead collisions at 158 GeV SPS beam energy.

1. Introduction

Present experimental information available in the field of heavy-ion collisions allows for the systematic investigation of strongly interacting hadronic matter under extreme conditions. High statistics accumulated in various experiments facilitate reconstruction of hadronic resonances via their decay products. At CERN-SPS experiments several resonances have been identified so far: $\phi(1020)$ mesons were detected by the NA49 Collaboration via $\phi \to \mathrm{K}^+\mathrm{K}^-$ decay [1] and by the NA50 Collaboration via $\phi \to \mu^+\mu^-$ channel [2], $\Lambda^*(1520)$ and $\overline{\mathrm{K}^*}(892)$ were seen by NA49 in their dominant decay modes [3–5], the ρ and ω mesons were measured by NA50 in a dimuon channel [6]. Already the first preliminary data were surprising. The total averaged ϕ-meson multiplicity extracted from the NA49 data was found to be significantly smaller than that obtained from the extrapolation of preliminary NA50 data. Another interesting observation is that the preliminary NA49 data on $\Lambda^*(1520)$ multiplicity reveal significant suppression of the yield per participating nucleon when compared to inelastic proton–proton collisions. This contradicts the systematics of other strange particle yields at SPS energies.

A suggested explanation of the ϕ-meson puzzle [7] was that ϕ mesons decaying inside a fireball can disappear from the K^+K^- mass peak due to rescattering and absorption of secondary kaons in the surrounding medium. Such a mechanism has been quantitatively studied in [8] where suppression at the level 40–60% (for $m_T \to m_\phi$) was obtained by simulation using RQMD code. A similar mechanism could also account for $\Lambda^*(1520)$ suppression. In [9] 25% suppression for $\phi(1020)$ and 50% for $\Lambda^*(1520)$ particles were obtained within the URQMD model. Therefore, the rescattering of resonance decay products can indeed explain in part some experimental observations. However, besides the lack of a quantitative explanation for the difference in the extrapolated ϕ-meson yields, another caveat was issued in [10]: since the vacuum width of $\overline{K^*}(892)$ mesons is more than three times larger than the $\Lambda^*(1520)$ width, $\overline{K^*}(892)$ mesons decay inside a fireball more frequently and should therefore be suppressed even more strongly than $\Lambda^*(1520)$. The preliminary data of NA49 [4] do not show such a suppression for $\overline{K^*}(896)$.

In this paper we discuss to what extent the in-medium modifications of the resonance decay width can affect the resonance suppression and allow us to accommodate the experimental results.

2. Global picture of a collision

In our study we consider a two-stage picture of the hadronic phase of heavy-ion collisions at SPS energies which can be characterized by the notions of chemical and thermal freeze-outs [11–13]. At the initial stage of the hadronic phase we assume the temperature T to be close to the QCD phase transition temperature $T_c \approx 170 \pm 10$ MeV. Then the system expands up to the point when a number of different kinds of particles freeze in a chemical freeze-out. The thermodynamical parameters of this stage could be obtained by fitting the final total hadron multiplicities. The typical temperature is found to be $T_{\rm chem} \sim 160 \pm 10$ MeV [11, 12]. During the second stage of collision, elastic scattering processes change momentum distributions of hadrons in accord with decreasing temperature until they cease and distributions freeze in. The freeze-out temperature can be extracted from a simultaneous fit to the single-particle m_T-spectra of different particles supplemented by the analysis of particle correlation data. Typical temperatures are found to be $T = T_{\rm therm} \sim 110 \pm 30$ MeV [13].

The key assumption behind the decay product rescattering (DPR) mechanism of [7] is that the final resonance distribution is formed at some stage between the chemical and thermal freeze-outs. At this moment, mean free paths of the resonance, λ_r, pions, kaons and nucleons, $\lambda_{\pi,\rm K,N}$, and the characteristic size of the fireball, R, should satisfy

$$\lambda_\pi, \lambda_{\rm K}, \lambda_{\rm N} \ll R \lesssim \lambda_r. \qquad (1)$$

This implies that at this stage resonances stream freely out from the fireball. However, for their decay products, pions and kaons, the surrounding medium is still opaque. Therefore, if a resonance decays inside a fireball via hadronic channels, its decay products can be rescattered or absorbed, and consequently the resonance remains unobserved experimentally. It is now obvious that the possible increase of a resonance decay width in the medium will enlarge the probability of its decay inside a fireball thereby enhancing the DPR mechanism. Besides the total decay width of the resonance and the typical size of the fireball, one of the crucial parameters controlling the efficiency of the DPR mechanism is, the lifetime of the fireball after the resonance freeze-out, $\tau_{\rm fo}$.

3. Apparent resonance distribution

We denote the phase-space distribution of the resonance (r) in the centre-of-mass system of two colliding nuclei at the moment of its thermal freeze-out as $f^{(r)}(\vec{x}, \vec{p})$. Then the primary momentum distribution of the resonance is

$$\eta_0^{(r)}(p) = \langle 1 \rangle, \qquad \text{where} \quad \langle \cdots \rangle = \int_\Sigma \mathrm{d}^3\sigma^\mu p_\mu f^{(r)}(\vec{x}, \vec{p})(\cdots) \tag{2}$$

and integration goes over the fireball volume within a freeze-out hyper-surface Σ. In the absence of any in-medium modifications of the resonance properties and without the final-state interactions of its decay products, the momentum distribution of the resonance *observed* via its decay channel j is $\eta_0^{(r)}(p)\Gamma_j^{(r)0} / \Gamma_{\mathrm{tot}}^{(r)0}$, where $\Gamma_j^{(r)0}$ and $\Gamma_{\mathrm{tot}}^{(r)0}$ are the partial and total decay widths of the resonance, respectively. (In the experimental analysis, the momentum distribution of the resonance is reconstructed from the momentum distribution of decay products multiplied by the corresponding inverse branching ratio.)

Taking into account modifications of partial and total widths of the resonance and in-medium rescattering of its decay products we write the expression for the observed resonance momentum distribution in the decay channel j as

$$\eta_j^{(r)}(p) = \left\langle D(\tau) + \frac{\tilde{\Gamma}_{\mathrm{tot}}^{(r)0}}{\tilde{\Gamma}_j^{(r)0}} \int_0^\tau \mathrm{d}t\, D(t) \tilde{\Gamma}_j^{(r)*}(t) \mathrm{P}_{j\lambda}^{(r)}(t) P_{\mathrm{rec}} \right\rangle . \tag{3}$$

Here

$$D(t) = \exp\left[- \int_0^t \tilde{\Gamma}_{\mathrm{tot}}^{(r)*}(t')\, \mathrm{d}t' \right] \tag{4}$$

is the probability that resonance will fly for a time t starting from a position $\vec{x}$ where it suffers the last interaction. $\tilde{\Gamma}_{\mathrm{tot}}^{(r)} = \Gamma_{\mathrm{tot}}^{(r)} m_r / E_r$ is the total width of a moving particle with energy $E_r = \left(m_r^2 + p^2\right)^{1/2}$, where m_r is the resonance mass. Here and below the asterisk denotes the in-medium values of the quantities, which are determined by the current local temperature and density. The probability that the decay products leave the fireball without any rescattering is $P_{j\lambda}^{(r)}$. For the explicit form of $P_{j\lambda}^{(r)}$ we refer to [14], where it is expressed for the case of two-particle decays. The quantity P_{rec} stands for the probability of identifying a resonance from the non-rescattered decay products. Without the in-medium effects we put $P_{\mathrm{rec}} = 1$. If the spectra of resonance decay products differ in the medium from the vacuum spectra, the momenta of secondary particles will change on the way out from the fireball even without being rescattered, since in this case a fireball serves well as a potential. This effect can be especially strong for strange resonances since the properties of kaons in the final state are strongly modified in nuclear matter and/or isospin asymmetrical pion gas [16–18]. For a rough estimation of the maximal suppression effect we put in this case $P_{\mathrm{rec}} = 0$. The timescale τ in (3) is the time spent by the resonance in the medium. It is given by $\tau = \min\{\tau_r(\vec{v}, \vec{x}), \tau_{\mathrm{fo}}\}$, where $\tau_r(\vec{v}, \vec{x})$ is the time during which the resonance with a velocity $\vec{v}$ flies from the position $\vec{x}$ to the border of the fireball. Finally, in (3) we integrate over all initial resonance positions $\vec{x}$ using the phase-space distribution (2).

In the case when the partial width of the decay channel j does not change in the medium $\Gamma_j^{(r)*} = \Gamma_j^{(r)0}$, the momenta of decay products are not altered $P_{j\lambda}^{(r)} = P_{\mathrm{rec}} = 1$ and the total width $\Gamma_{\mathrm{tot}}^{(r)*} \neq \Gamma_{\mathrm{tot}}^{(r)0}$, we have

$$\eta_j^{(r)}(p) = \left\langle D(\tau) + \tilde{\Gamma}_{\mathrm{tot}}^{(r)0} \int_0^\tau \mathrm{d}t\, D(t) \right\rangle . \tag{5}$$

This expression corresponds, e.g. to the case when resonances are reconstructed in leptonic channels. Note that for $\Gamma_{\rm tot}^{(r)*} = \Gamma_{\rm tot}^{(r)0}$ we have $\eta_\mu^{(r)} \equiv \eta_0^{(r)}$, for $\Gamma_{\rm tot}^{(r)*} > \Gamma_{\rm tot}^{(r)0}$ we have $\eta_\mu^{(r)} < \eta_0^{(r)}$ and if $\Gamma_{\rm tot}^{(r)*} < \Gamma_{\rm tot}^{(r)0}$ then $\eta_\mu^{(r)} > \eta_0^{(r)}$.

After these general considerations we specify the model of the hadronic fireball expansion, which is used in our numerical calculations. We assume a homogeneous spherical fireball with constant density and temperature profiles. The primordial resonance momentum distribution

$$f_r(\vec{x}, \vec{p}) = \exp\left[-\frac{E_r - \vec{p}\cdot\vec{u}(\vec{x})}{T_0\sqrt{1-u^2(\vec{x})}}\right], \tag{6}$$

is determined by the temperature T_0, flow velocity profile $\vec{u}(\vec{x}) = v_f\vec{x}/R_0$ and radius R_0. The fireball expands $R(t) = R_0 + v_f t$, its density evolves as $\rho(t) = \rho_0 R_0^3\big/R^3(t)$ and the temperature decreases as $T(t) = T_0R_0/R(t)$ as expected for relativistic pion gas, see [15]. The time of flight of a resonance created inside the fireball at the position $\vec{x}$ until it reaches the border is given by

$$\tau_r(\vec{v}, \vec{x}) = \left(\sqrt{(\vec{v}\cdot\vec{x} - v_fR_0)^2 + \left(R_0^2 - \vec{x}^2\right)\left(\vec{v}^2 - v_f^2\right)} - (\vec{v}\cdot\vec{x} - v_fR_0)\right)\left(\vec{v}^2 - v_f^2\right)^{-1}, \tag{7}$$

which is valid for $|\vec{x}| < R_0$ and $|\vec{v}| > v_f$. In the case $|\vec{v}| < v_f$ we put $\tau_r = \infty$. Parameters R_0, T_0, v_f, serve as input for numerical evaluations below.

Final momentum distribution of resonances calculated with (3) might seem to be a rather crude approximation. However, numerical results [14] are found to be rather insensitive to the details of hydrodynamical evolution of a fireball, being determined mainly by the values of $\Gamma_{\rm tot}^{(r)*}R_0$, $\Gamma_{\rm tot}^{(r)*}\tau_{\rm fo}$, and v_f.

4. Applications

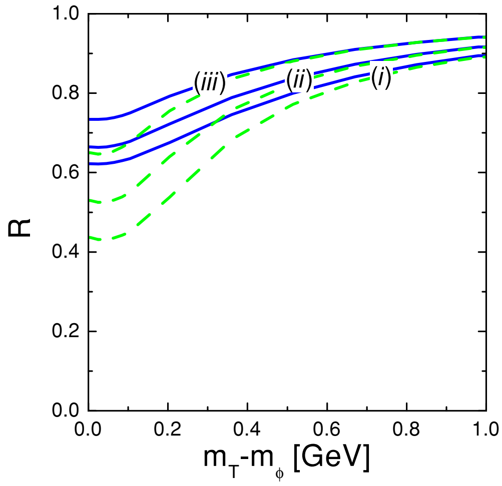
First we discuss the numerical results obtained in [14] for ϕ-meson yields reconstructed via K^+K^- and $\mu^+\mu^-$ channels in central Pb+Pb collisions at 158 GeV/n SPS energy. Being dominantly an $s\bar{s}$ state, the ϕ mesons can decouple quite early, since their interaction with non-strange matter is suppressed according to the OZI rule. The mean free path λ_ϕ of ϕ mesons in hadron gas has been estimated in [19]. Comparison with mean free paths of pions and kaons, $\lambda_{\pi,K}$, from [20] gives $\lambda_\pi \gtrsim \lambda_K < \lambda_\phi$ for temperatures $T_{\rm therm} < T < T_{\rm chem}$. Therefore, condition (1) can be satisfied.

For a comparison with the experimental data we define the following suppression factors

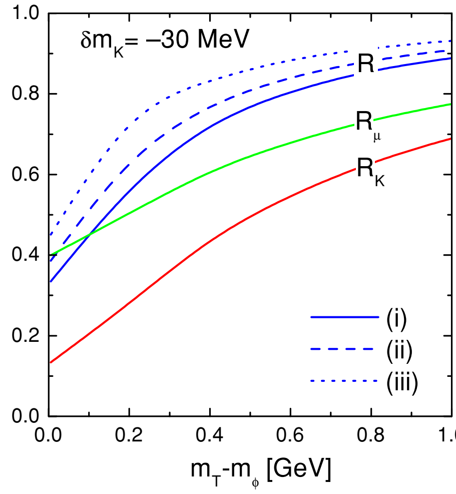
$$\mathcal{R}(m_T) = \mathcal{R}_K(m_T)/\mathcal{R}_\mu(m_T), \qquad \mathcal{R}_{K,\mu}(m_T) = \left\langle\eta_{K,\mu}^{(\phi)}(p)\right\rangle_y\Big/\left\langle\eta_0^{(\phi)}(p)\right\rangle_y, \tag{8}$$

where $\langle\cdots\rangle_y$ means the integration over rapidity interval observed in the detector. The apparent distribution of ϕ mesons in the hadronic channel ($K\bar{K}$), $\eta_K^{(\phi)}$, is calculated according to (3). For the leptonic decay channel, $\eta_\mu^{(\phi)}$ is estimated using expression (5).

First, we evaluate suppression factor (8) without any modification of ϕ properties in the medium. In this case we have $\mathcal{R}_\mu(m_T) \equiv 1$ and $\mathcal{R}(m_T) = \mathcal{R}_K(m_T)$. We use several combinations of input parameters (T_0, R_0, v_f) chosen consistently with the ϕ-meson freeze-out temperature T_0 which we vary between $T_{\rm chem}$ and $T_{\rm therm}$: (i) (150 MeV, 20 fm, 0.5), (ii) (160 MeV, 15 fm, 0.46), (iii) (170 MeV, 10 fm, 0.41). The size of the fireball R_0 at the moment of ϕ freeze-out has to be comparable with ϕ-meson mean free path λ_ϕ. The above values for different temperatures are taken according to the estimations of λ_ϕ in [19]. Flow velocities are adjusted to reproduce the slope of ϕ-meson m_T distribution measured by the NA50 Collaboration: $T_{\rm eff} = 218$ MeV. The fireball lifetime is determined by equation $T(\tau_{\rm fo}) = T_{\rm therm}$.



(a)



(b)

Figure 1. (a) Ratio $\mathcal{R}$ calculated for cases (i)–(iii) described in the text without the medium effects. Solid lines are calculated with $T_{\rm therm} = 80$ MeV and dashed lines correspond to $T_{\rm therm} = 40$ MeV. (b) Thick lines show the ratio $\mathcal{R}(m_T)$ calculated accounting for the in-medium modification of meson properties associated with a decreasing kaon mass $\delta m_{\rm K}^0 = -30$ MeV. Results for different parameter sets (i)–(iii) are depicted by solid, dashed and dotted lines, respectively. Thin lines illustrate the suppression factors in the muon $\mathcal{R}_\mu$ and kaon $\mathcal{R}_{\rm K}$ channels calculated for the parameter set (i).

To reproduce the results of RQMD calculations described in [8] we take freeze-out temperature $T_{\rm therm} = 80$ MeV, the kaon mean free path $\lambda_{\rm K}(t) = \lambda_{\rm K}^0 R_0^3 / R^3(t)$ with $\lambda_{\rm K}^0 = 0.5$ fm and $P_{\rm rec} = 1$. The temperature corresponds to the lowest limit allowed by the analysis [13]. The kaon mean free path, which we tune to get results [8], is somewhat smaller than that obtained in [20] for the pion gas. This can be attributed to the finite baryon admixture in the fireball.

Our results, which we take as a reference point for our further investigation of the in-medium effects, are shown in figure 1(a) by solid lines. The limiting scenario considered in [8], when the freeze-out volume is determined by the last kaon interactions, can be reproduced with $T_{\rm therm} = 40$ MeV. This case is shown by dashed lines.

Let us now consider the case when the ϕ-meson width increases strongly in the hadronic medium. We simulate this effect by decreasing the kaon mass, which can result, e.g. from rescattering of kaons on pions through $\overline{\rm K^*}$ and heavier kaonic resonances [21]. The modification of kaon properties in the medium prevents the ϕ-meson reconstruction even when the kaons can leave the fireball without hard rescattering. Escaping from the fireball, kaons have to come back to their vacuum mass shell. Due to the energy conservation the momenta of kaons change together with the invariant mass and momentum of the kaon pairs. We account for this effect by putting $P_{\rm rec} = 0$. Then both the suppression factors $\mathcal{R}_{\rm K}$ and $\mathcal{R}_\mu$ depend only on the total ϕ-meson width. The ϕ total width is $\Gamma_{\rm tot}^{(\phi)}(\delta m_{\rm K}) = \Gamma_{\rm KK}\, p_{\rm KK}^3(m_{\rm K}+\delta m_{\rm K}) / p_{\rm KK}^3(m_{\rm K}) + \Gamma_{\rho\pi}$ with $p_{\rm KK}(m_{\rm K}) = \frac{1}{2} m_\phi \big(1 - 4m_{\rm K}^2/m_\phi^2\big)^{1/2}$. The vacuum widths of $\phi \to {\rm K}\bar{\rm K}$ and $\phi \to \rho\pi$ decay processes are equal to $\Gamma_{\rm KK} = 3.68$ MeV and $\Gamma_{\phi\pi} = 0.76$ MeV. We do not consider here the in-medium change of the $\Gamma_{\rho\pi}$ width, which weakly affects the resulting suppression factor [14]. We restrict ourselves to a rather conservative modification of kaon masses. At the ϕ-meson freeze-out time we put

$\delta m_K^0 = -30$ MeV, and then the mass of a kaon diminishes linearly with the decreasing fireball density $\delta m_K(t) = \delta m_K^0 R_0^3 / R(t)^3$. It corresponds to the initial ϕ width $\Gamma^*_{tot} \simeq 20$ MeV. In this case $\mathcal{R}_\mu < 1$ and at small $m_T - m_\phi$ region $\mathcal{R}_\mu$ can be suppressed up to 40–60%. Thus, for a given freeze-out temperature T_0 we have to readjust the flow velocity v_f^0 for reproducing the slope of the m_T distribution measured in the dimuon channel by NA50 [2]. For our three sets of parameters specified above we obtain new flow velocities: (i) $v_f^0 = 0.38$, (ii) $v_f^0 = 0.35$, (iii) $v_f^0 = 0.28$.

The results for a relative suppression of hadronic and leptonic channels are presented in figure 1(b). Thick solid, dashed and dotted lines drawn for cases (i)–(iii) should be compared with the solid lines in figure 1(a). We observe that the increase of the ϕ width results in the overall increase of the suppression effect by about 20%. The suppression factors for leptonic and hadronic channels, separately, are shown in figure 1 as well. The increase of the ϕ-meson width provides a strong suppression of $\mathcal{R}_K(m_T \to m_\phi) \sim 0.15$. However, since the dimoun channel is also suppressed the resulting ratio $\mathcal{R}$ remains on the level ~0.3 for small $m_T - m_\phi$.

Let us now consider more closely the dependence of the suppression factor on the fireball parameters τ_{fo} and R_0. First, we simplify the time dependence of the total width. We use a linear density interpolation between the initial value at the freeze-out moment, $\Gamma_{in}^{(r)}$ and the vacuum value

$$\Gamma_{tot}^{(r)*}(t) = \Gamma_{tot}^{(r)0} + \left(\Gamma_{in}^{(r)} - \Gamma_{tot}^{(r)0}\right)(R_0/R(t))^3. \tag{9}$$

This approximation still works well and can reproduce figure 1(a), using $\Gamma_{in} = 20$ MeV within 5–10% accuracy. We will vary parameters R_0 and τ_{fo} keeping the other parameters fixed: $T_0 = 150$ MeV, $v_f = 0.5$ and $P_{rec} = 0$. In figure 2 we present the contour plot of the value $\mathcal{R}_K(m_T = m_\phi)$ as a function of the dimensionless variables $\Gamma_{in}\tau_{fo}$ and $\Gamma_{in}R_0$, calculated for $\Gamma_{in}^{(\phi)} = 10, 20, 30$ MeV. The thin solid line shows the level $\mathcal{R}_K(m_T = m_\phi) = 0.5$ for the vacuum width $\Gamma_{in}^{(\phi)} = \Gamma_{tot}^{(\phi)0} = 4.43$ MeV. We see that for the vacuum width 50% suppression can be reached only for rather large $\tau_{fo} \simeq 40$ fm. From this plot we can also read out the minimal combinations of parameters (R_0, τ_{fo}) required to attain a certain degree of suppression. For instance, $\mathcal{R}_K(m_\phi) < 0.2$ will be reached (we pick out the points closest to the origin on the lines labelled with 0.2) for $\Gamma_{in}^{(\phi)} = 10$ MeV if ($\tau_{fo} > 67$ fm, $R_0 > 15$ fm), for $\Gamma_{in}^{(\phi)} = 20$ MeV if ($\tau_{fo} > 44$ fm, $R_0 > 15$ fm) and for $\Gamma_{in}^{(\phi)} = 30$ MeV if ($\tau_{fo} > 33$ fm, $R_0 > 12$ fm). Having fixed the size of a fireball to be about 20 fm, the level $\mathcal{R}_K(m_\phi) = 0.2$ can be achieved at $\tau_{fo} = 63, 39, 26$ fm for $\Gamma_{in}^{(\phi)} = 10$, 20 and 30 MeV, respectively. We emphasize here that the estimates deduced from the plots in figure 2 are to be combined with condition (1), which constrains the size and lifetime of the fireball according to the resonance mean free path.

We now turn to the $\Lambda^*(1520)$ and $\overline{K^*}(892)$ resonances. Their mean free paths in the hot hadronic matter have not been studied so far. There is also no such additional mechanism as the OZI rule for ϕ mesons which would suppress the Λ^* and $\overline{K^*}$ interaction with the surrounding pions, kaons and nucleons. Moreover, $\pi\Lambda^*$ scattering has contributions from s-channel hyperon exchange processes, particularly the reaction $\pi\Lambda^* \to \Sigma^*(1385) \to \pi\Lambda^*$ should be operative due to the s-wave $\pi\Lambda^*\Sigma^*$ coupling. Therefore, we can expect that the mean free paths of Λ^* and $\overline{K^*}$ are comparable with those of pions and kaons. Hence, their final momentum distribution should be formed rather close to the common break-up of the fireball.

Figure 2 shows contour plots of the quantity

$$\mathcal{R}^{(r)}(m_T) = \left\langle \eta_{hadr}^{(r)}(p) \right\rangle_y \Big/ \left\langle \eta_0^{(r)}(p) \right\rangle_y \tag{10}$$

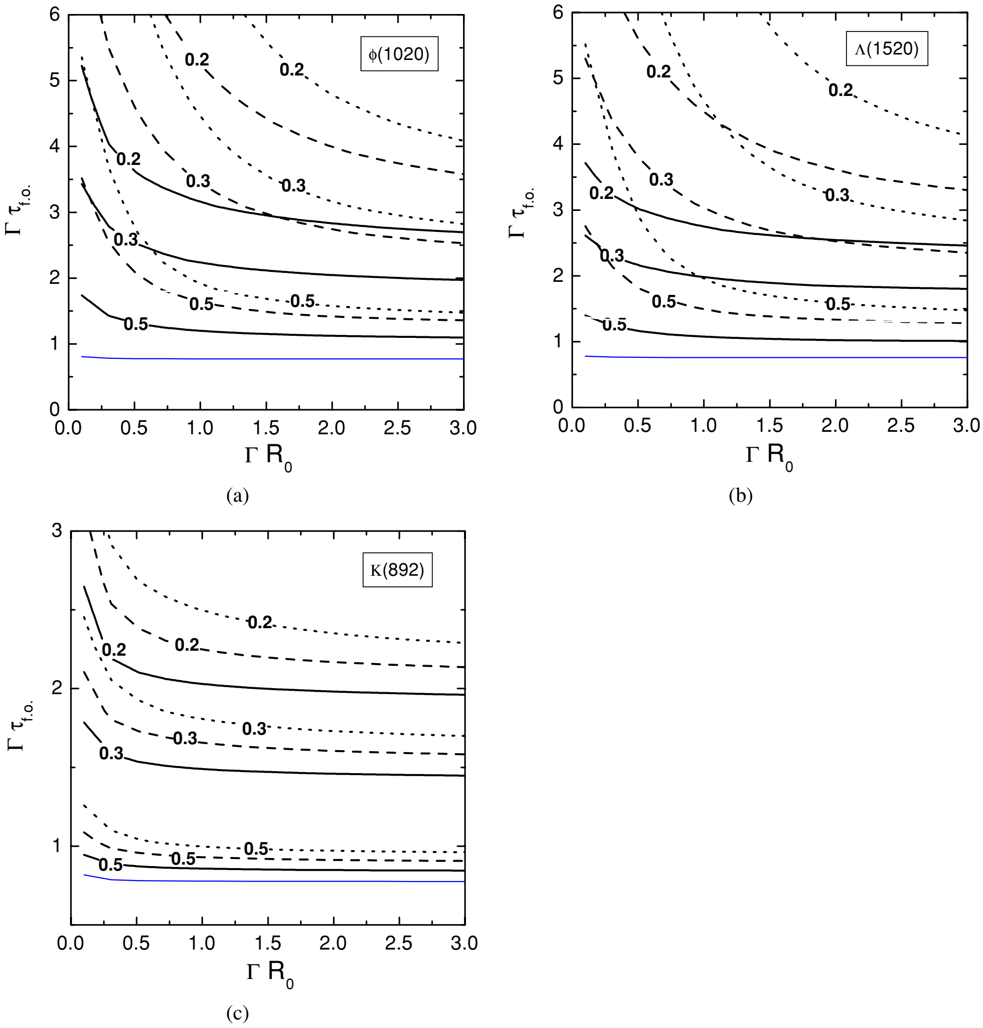


Figure 2. Contour plots of ratios $\mathcal{R}^{(r)}(m_r)$ in (10) for ϕ, $\Lambda^*(1520)$ and $\overline{\mathrm{K}^*}(892)$ particles on the plane $\Gamma_{\mathrm{in}}^{(r)} R_0$–$\Gamma_{\mathrm{in}}^{(r)} \tau_{\mathrm{fo}}$. Different line styles correspond to the different initial resonance widths Γ_{in} in (9). Thick solid, dashed and dotted lines are drawn, respectively, for $\Gamma_{\mathrm{in}}^{(\phi)} = 10, 20, 30$ MeV, $\Gamma_{\mathrm{in}}^{(\Lambda^*)} = 30, 60, 120$ MeV, and $\Gamma_{\mathrm{in}}^{(K^*)} = 60, 70, 80$ MeV. The thin solid lines are calculated with the vacuum width of the resonance and stand for the level $\mathcal{R}^{(r)} = 0.5$. All calculations are done for $T = 150$ MeV, $v_f = 0.5$, and $P_{\mathrm{rec}} = 0$.

evaluated for $m_T = m_r$, $T = 150$ MeV, $v_f = 0.5$. The apparent distribution in the dominant hadronic channel $\eta_{\mathrm{hadr}}^{(r)}$ is calculated according to expression (3) with $P_{\mathrm{rec}} = 0$ and depends only on the total width of the resonance. The time dependence of the resonance width is given by expression (9) with $\Gamma_{\mathrm{in}}^{(r)}$ varying in the broad range separately for each resonance. Figure 2(c) shows that in order to obtain the suppression factor $\mathcal{R}^{(\mathrm{K}^*)}(m_{\mathrm{K}^*}) > 0.5$ for $\overline{\mathrm{K}^*}$ mesons one needs $\Gamma_{\mathrm{in}}^{(\mathrm{K}^*)}\tau_{\mathrm{in}} \sim 0.6$–1. This translates for $\Gamma_{\mathrm{in}}^{(\mathrm{K}^*)} \sim 50$–80 MeV into $\tau_{\mathrm{fo}} \sim 2$–2.4 fm. Hence the $\overline{\mathrm{K}^*}$ mesons should indeed be produced close to the fireball break-up. Using these values for Λ^* we find from figure 2(b) that the ratio $\mathcal{R}^{(\Lambda^*)}(m_{\Lambda^*})$ becomes less than 0.5 only if

$\Gamma_{\rm in}^{(\Lambda^*)} \gtrsim 120$ MeV. This is a very large value. Although there are indications that $\Lambda^*(1520)$ properties suffer strong modifications in the nuclear medium acquiring the total width of the order 100 MeV at normal nuclear matter density [17], calculations have been made so far for cold nuclear matter only. At high temperatures these effects might be reduced. Alternatively we can suggest that $\Lambda^*(1520)$ hyperons decouple from the fireball at some earlier stage than $\overline{\rm K^*}$ mesons. Then we obtain the following estimates for the time between Λ^* freeze-out and the fireball break-up: $\tau_{\rm fo} \sim 6$ fm for $\Gamma_{\rm in}^{(\Lambda^*)} \sim 30$ MeV and $\tau_{\rm fo} \sim 9$ fm for the vacuum width.

Finally, we do not exclude the possibility that the formation of $J = \frac{3}{2}^{(-)}$ baryonic state $\Lambda^*(1520)$ in heavy-ion collisions is already primarily suppressed. The purpose of the present work is to find to what extent the DPR suppression mechanisms enhanced by the in-medium modification of the resonance width are able to accommodate the experimental data.

5. Summary

We investigate the dependence of the decay-product rescattering mechanism, which suppresses apparent yields of resonances observed in heavy-ion collisions, on the size of the hadronic fireball and on the time between resonance freeze-out and fireball break-up. Possible modification of the resonance width in the medium is shown to enhance the suppression effect. The model is applied to the production of $\phi(1020)$, $\Lambda^*(1520)$ and $\overline{\rm K^*}(892)$ particles at SPS energies. We conclude that in the case of $\phi(1020)$ mesons the discrepancy between ϕ-momentum distributions observed in $\rm K^+K^-$ (NA49) and leptonic (NA50) channels can be explained, assuming that at the moment of the ϕ-meson freeze-out the ϕ total decay width is about 30 MeV and after the freeze-out the hadronic fireball lives about 20 fm/c until the final break-up. The observed (NA49) signals of $\overline{\rm K^*}(892)$ meson production suggest that $\overline{\rm K^*}$ mesons escape from the fireball at the moment very close to the break-up (not further than 2.0–2.4 fm/c). Otherwise their apparent distribution would be strongly suppressed. We can obtain the attenuation of the $\Lambda^*(1520)$ on the level of 50% assuming either a very large width of the resonance $\gtrsim$120 MeV at the freeze-out moment close to the fireball break-up or that Λ^* particles leave the fireball at least 6–9 fm/c before the break-up.

We conclude that the resonance production in heavy-ion collisions can serve as an indicator of the fireball dynamics at the last stage of heavy-ion collisions. To draw precise quantitative conclusions careful investigation of the modification of resonance properties in hadronic medium is necessary.

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