Phi meson propagation in a hot hadronic gas

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Abstract. The Hidden Local Symmetry Lagrangian is used to study the interactions of ϕ mesons with pseudoscalar and vector mesons in a hadronic gas at finite temperature. We have found a small ϕ mean free path ($\sim$2 fm at $T = 175$ MeV). This implies that ϕ mesons produced after hadronization in relativistic heavy ion collisions will not leave the system without scattering. The effect of these interactions on the time evolution of the ϕ yield in the expanding hadronic fireball is investigated.

Keywords: relativistic heavy-ion collisions, hadronic gas, mesons, mean free path
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Phi mesons are a valuable source of information about the properties of the matter formed in relativistic nucleus-nucleus collisions. If the quark-gluon plasma is created, $s\bar{s}$ pairs would coalesce to form ϕ mesons, while their production in pp and πp collisions should be OZI suppressed [1]. A ϕ can be detected through its decay into dileptons (e^+e^-, $\mu^+\mu^-$) or K^+K^- pairs. Dileptons have negligible final state interactions with the medium, so they sense the entire evolution of the system while detectable kaons from ϕ decay emerge mainly at freezeout.

An important question is whether ϕ mesons participate in the radial flow together with other hadrons or freeze-out early. Previous calculations supported the idea of a large ϕ mean free path (MFP) in a hot hadronic gas. In Ref. [2] the ϕ MFP was calculated taking into account its scattering with different mesons. Phenomenological Lagrangians with couplings extracted from the experimental decay rates were used. The obtained MFP at $T = 150$ MeV is large (14 fm) compared to the standard size of the fireball. However, this model does not take into account mechanisms with vertices that cannot be extracted empirically, but are allowed by the symmetries of QCD, such as $\phi K^* K$, $\rho K^* K^*$, etc.

The Hidden Local Symmetry (HLS) model provides a natural framework for describing the interactions between pseudoscalar and vector mesons. Vector mesons (ρ, ω, K^*, ϕ), the gauge bosons of the $U(3)_V$ HLS, acquire a mass $m_V^2 = 2g^2 f_\pi^2$ by spontaneous symmetry breaking. Here g is the coupling between a vector and two pseudoscalar mesons (VPP vertex). Flavor symmetry breaking has been incorporated as well. The anomalous part of the Lagrangian contains also a VVP interaction. Finally, the kinetic term for the vector mesons includes VVV and VVVV vertices.

Using these Lagrangians, one can compute all possible binary reactions of ϕ's with other mesons at tree level [3]. There are three classes of Feynman diagrams: s, t channel processes and contact interactions due to the VVVV terms. The OZI rule manifests itself in the absence of direct couplings of ϕ's with π, ρ or ω.

Assuming Boltzmann distributions for all particles, we get the collision rates $\Gamma_{coll}^{(a)} = n_a \langle \sigma v_{rel} \rangle$, i.e. the number of collisions per unit time of a ϕ with $a = \pi, K, \rho, \omega, K^*, \phi$.

They are shown in Fig. 1. At high temperatures, the rates from K^* and K are higher than those from ρ and π. The absence of s channel contributions due to OZI rule in the case of ρ and π explains this feature. On the other side, the ϕ rates with K^* (ρ) are larger

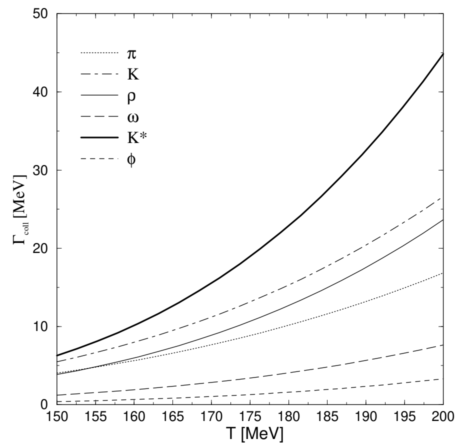

FIGURE 1. Collision rates of ϕ with π, K, ρ, ω, K^* and ϕ as a function of temperature.

than those with K (π). In order to understand this let us notice that

$$\frac{n_{K^*}}{n_K} = \frac{3m_{K^*}^2 K_2(m_{K^*}/T)}{m_K^2 K_2(m_K/T)}\,; \tag{1}$$

at $T = 200$ MeV this ratio is equal to 0.77. This number is bigger than what one would naively expect. Therefore, a larger $\Gamma_{coll}^{(K^*)}$ can be achieved by a *moderately* larger cross section. The reactions involving all four vector mesons make the difference, and the mechanisms involving VVVV and VVV vertices are responsible for it.

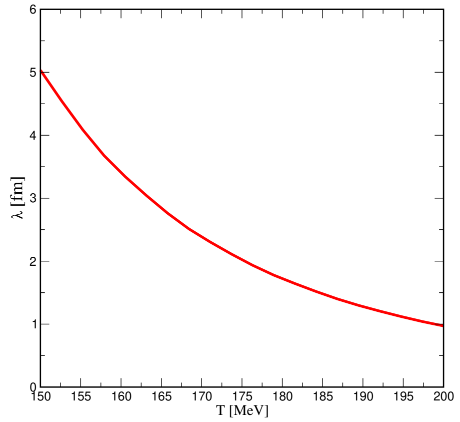

FIGURE 2. Temperature dependence of the ϕ mean free path in hot hadronic matter.

Dividing the average ϕ velocity in medium by the total Γ_{coll} we get the MFP. It is less than 2.4 fm at $T > 170$ MeV. Therefore, the ϕ mesons that are created after hadronization, at temperatures presumably between 150 and 200 MeV, will not leave the fireball without interacting; they will rather remain in kinetic equilibrium at least during the early stage of the evolution in the hadronic phase. The fact that PHENIX ϕ data exhibit a hydrodynamic behavior at low p_T [4] is consistent with this conclusion.

We proceed then to study the implication of the previous result for the time evolution of the ϕ density in an expanding medium using a simple model. We consider an ideal gas composed of π, K, ρ, ω, K^* and ϕ in kinetic equilibrium from hadronization to freezeout. Chemical equilibrium has also been assumed for all species except ϕ's. In these conditions, the ϕ density is the solution of the following rate equation

$$\partial_\mu \left(n_\phi u^\mu\right) = -\Gamma \left(n_\phi - n_\phi^{eq}\right) , \tag{2}$$

where $\Gamma(T)$ is the sum of the total collision rate and the free decay width. Boost invariance and a uniform density distribution in the transverse plane are assumed. The system expand in the transverse radial directions with a flow velocity inspired by hydrodynamics. The relation between T and the proper time τ is dictated by entropy conservation.

Figure 3 shows the τ dependence of the ratio of the ϕ yield at midrapidity and the number of them right after hadronization (N/N_0). We have taken a freezeout temperature of 100 MeV. At the early stages of the expansion, the system is hot and the collision

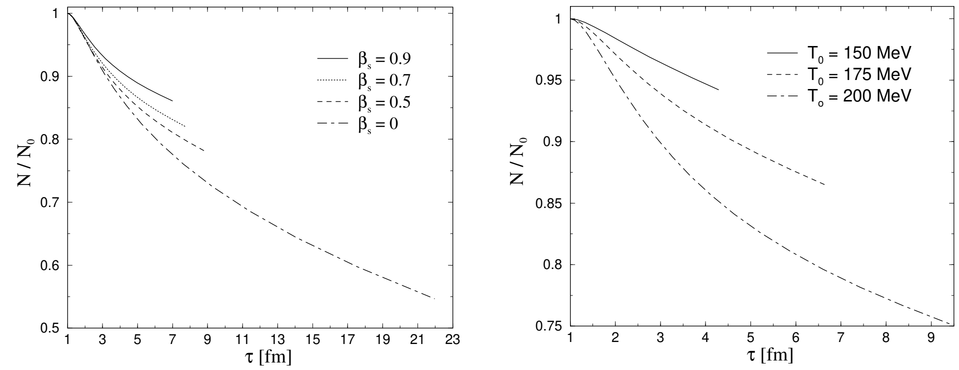

FIGURE 3. Time dependence of the ratio of the ϕ number to its value at hadronization for different flow velocities (left panel) and hadronization temperatures (right panel).

rates are high, so that ϕ's are pushed towards equilibrium making its number decrease fast. As the system cools down, the collision rates become small and their contribution to the ratio starts to saturate. The model exhibits a notable dependence on the flow velocity. The bigger β_s, the faster the temperature drops and, hence, the closer N/N_0 gets to one. We have also considered different hadronization temperatures. If the hadronization temperature is low, the collision rates are small from the very beginning, and the interactions are less relevant.

Our cross sections of ϕ's with other mesons have also been implemented in the AMPT transport model [5]. It was obtained that, as a result of the hadronic rescattering, the ϕ yield decreases towards its equilibrium value, corroborating our findings.

REFERENCES

1. A. Shor, *Phys. Rev. Lett.* **54**, 1122–1125 (1985).
2. K. Haglin, *Nucl. Phys.* **A584**, 719–736 (1995).
3. L. Alvarez-Ruso, and V. Koch, *Phys. Rev.* **C65**, 054901 (2002).
4. S. S. Adler, et al., *Phys. Rev.* **C72**, 014903 (2005).
5. S. Pal, C. M. Ko, and Z.-w. Lin, *Nucl. Phys.* **A707**, 525–539 (2002).