Vol. 40 (2009) *ACTA PHYSICA POLONICA B* No 4

DIFFERENT DECAY MODES RATIOS IN RELATIVISTIC HEAVY ION COLLISIONS*

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(Received February 24, 2009)

Different decay modes ratio study for φ and ω mesons are proposed to estimate the nuclear density integral along meson trajectory within strongly interacting matter between hadronization point and kinetic freeze-out.

PACS numbers: 21.65.Qz, 25.75.Nq

1. Introduction

In the high energy collision of heavy ions, an excited region of matter is created where novel states of matter are expected to exist. The transition from hadronic matter (from normal nuclear matter) to a deconfined system of quarks and gluons, the Quark Gluon Plasma (QGP) as well as properties of the high temperature phase have been studied extensively in lattice calculations over recent years. These transient states, which occupy region with size $r \sim 10$ fm, are expected to dissolve on a time scale of $t \sim 10$ fm$/c$. Only the collision debris is experimentally accessible. Its multiplicity, angular and momentum spectra, correlations, yield ratios and A-dependencies are extensively studied to understand the properties of matter under such unusual conditions. A long list of instruments for such study is argued by complexity of the collision process (large number of degree of freedoms, space-time evolution *etc.*) Each an instrument (signature) has different sensitivity for different process characteristics and then complement each other. In this work we propose to add one more instrument into the set — ratios of different decay modes abundance for resonances with $c\,c\tau \sim r$.

* Presented at the IV Workshop on Particle Correlations and Femtoscopy, Kraków, Poland, September 11–14, 2008.

2. The idea of the proposed method

Within QGP scenario, it is supposed, the initial stage of high energy heavy ion collisions can be described as the interpenetration of the nuclei with partonic interactions. With the interactions of the partons in the system, chemical and thermal equilibrium of the system is reached. As the system expands and cools, it will hadronize. After a period of hadronic interactions, the system reaches the kinetic freeze-out stage when all hadrons stop interacting. After the kinetic freeze-out, particles free-stream toward the detectors where our measurements are performed. Alternative is pure hadronic scenario, when quark and gluon only serve strong interaction between hadrons and do not create a special new state of matter. Resonance measurements in the presence of a dense medium can be significantly affected by the rescattering of the daughter particles. Resonances that decay before kinetic freeze-out may not be reconstructed owing to this rescattering. In this case, the lost efficiency in the reconstruction of the parent resonance is relevant and depends on the time between hadronization and kinetic freeze-out, the medium density, the resonance daughters' hadronic interaction cross sections, *etc*. Thus, the study of different resonances modes can provide an important probe of the system properties from hadronization to kinetic freeze-out and detailed information on hadronic interactions in the final stage. In the case when a resonance has different decay modes: hadronic, leptonic, and hadron–photon, their hadronic daughters can interact with other hadrons in the medium in contrast to photons and leptons. Thus, the final observable yields measured by hadronic modes may decrease compared to the leptonic ones. The yield measured by hadron–photon modes are expected to be between hadronic and leptonic ones. Since the low momentum resonances are less likely to escape the hadronic medium before decaying, compared to high momentum resonances, effect is expected to be resonance momentum dependent.

What are resonances most adequate for this study? Resonances that decay mostly after kinetic freeze-out are not sensitive to the effect. Wide resonances are hardly to be reconstructed by hadronic and hadron–photon modes due to large combinatorial background. It seems the optimal resonance width is between 4 and 40 MeV. In this case $v\tau \sim r \sim 10$ fm. φ and ω mesons with a lifetime of 44 and 22 fm$/c$ are good candidates for such study because they have all different needed decay modes: hadronic, leptonic, and hadron–photon. $K*(892)$ ($c\tau \sim 4$ fm) and $\Lambda(1520)$ ($c\tau \sim 8$ fm) also can be considered as candidates for such study, but only with hadronic and hadron-photon modes. The presence of three different modes is important to have additional internal test of validity of interpretation of the measured effect.

The φ and ω decay channels proposed for the study are

$$\begin{aligned}
\varphi &\rightarrow K^+K^-(49\%)\,,\\
\varphi &\rightarrow \eta\gamma(1.3\%)\,,\\
\varphi &\rightarrow e^+e^-(\mu^+\mu^-)(\sim 0.03\% \quad \text{each})\,,\\
\omega &\rightarrow \pi^+\pi^-(1.7\%)\,,\\
\omega &\rightarrow \pi\gamma(8.9\%)\,,\\
\omega &\rightarrow e^+e^-(\mu^+\mu^-)(\sim 0.01\% \quad \text{each})\,.
\end{aligned}$$

3. Sensitivity estimate of the proposed method

To estimate the sensitivity of the proposed method a toy-model calculations have been made. We suppose that the length of the resonance trajectory within dense hadronic matter between hadronization and kinetic freeze-out is L. Suppose each hadron (we neglect for simplicity the difference between different hadrons in the mean free path length) has mean free path length 2 fm and each pair of hadrons -1 fm. Resonance is considered as undetectable one if at least one of the decay products interacts within dense matter. Two competing effects — parents interactions and regenerations within dense matter are neglected. First effect provides effective increasing of L, second its effective decreasing.

Fig. 1 shows the decreasing for hadronic decay modes for $\varphi, \omega, \Lambda(1520)$, and K^* (from up to down, respectively) as a function of L. It looks that for realistic values of $L \sim 5$ fm the effect is accessible experimentally for

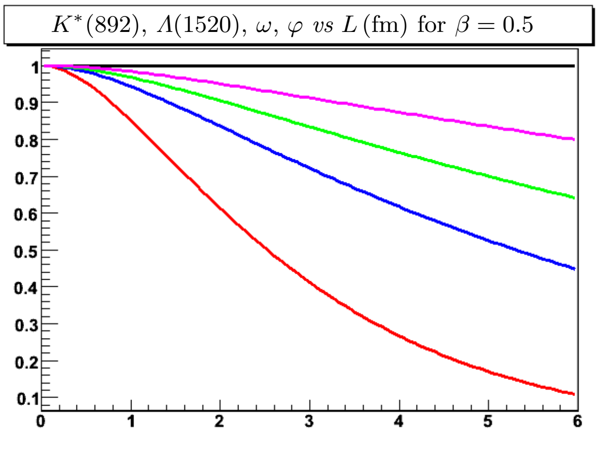

Fig. 1. The decreasing for hadronic decay modes of $\varphi, \omega, \Lambda(1520)$, and K^* (from up to down, respectively) as a function of L(fm).

$\varphi(\sim 15\%)$ and $\omega(\sim 30\%)$ in comparison with undistorted leptonic modes. For $\Lambda(1520)$ and K^* effect is even stronger, but it should be compared with photon–hadron modes, which are also suppressed.

Fig. 2 shows the decreasing for hadronic and photon–hadron decay modes for $\Lambda(1520)$ and K^* (from up to down, respectively) as a function of L. One can see that hadronic modes suppressions for $\Lambda(1520)$ and K^* with respect to photon–hadron modes are of the same order of value that for φ and ω suppressions with respect to undistorted leptonic modes.

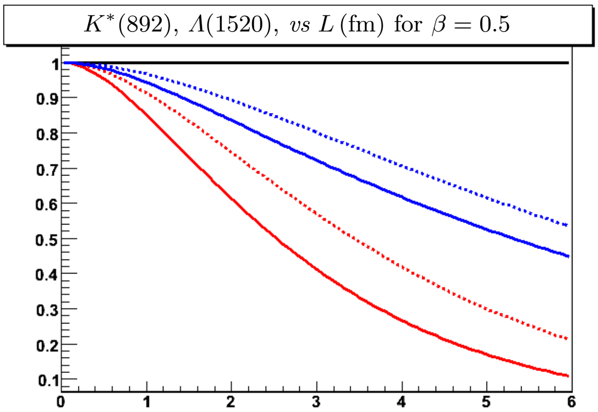

Fig. 2. The decreasing for hadronic (solid lines) and photon–hadron (dash lines) decay modes of $\Lambda(1520)$, and K^* (from up to down, respectively) as a function of L(fm).

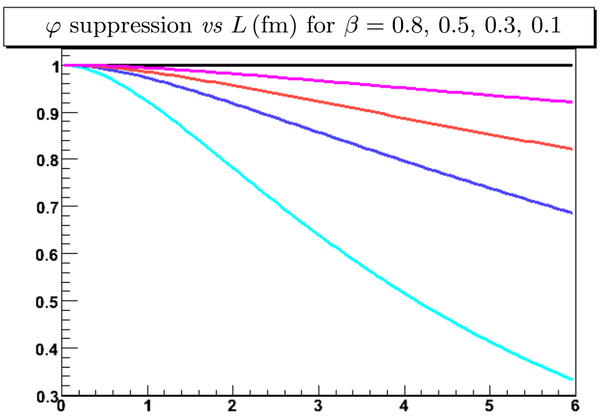

Fig. 3. The decreasing for hadronic decay mode of φ ($\beta = 0.8, 0.5, 0.3, 0.1$ from up to down, respectively) as a function of L(fm).

Fig. 3 shows the dependence of the effect for φ meson on particle velocity as a function of L. One can see that suppression decreases with velocity increasing.

Fig. 4 shows the possibility to measure the difference between hadronic modes suppression and photon–hadron modes suppressions for φ and ω. One can see that for such study both modes must to be measured with the accuracy better than 10%, which is nontrivial experimental task.

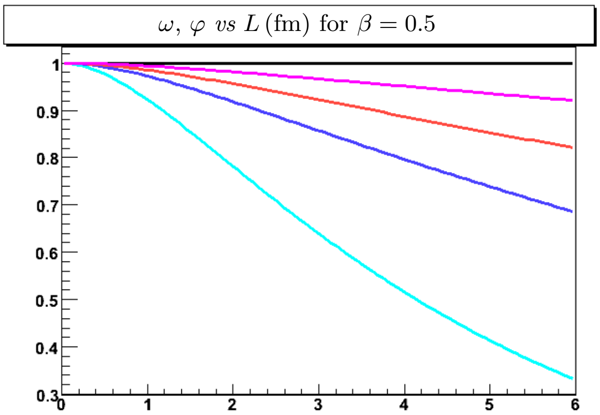

Fig. 4. The decreasing for hadronic (solid lines) and photon–hadron (dash lines) decay modes of φ and ω for $\beta = 0.3$ (from up to down, respectively) as a function of L(fm).

4. Conclusion

In summary we can conclude that decay modes ratio measurements especially for φ, ω, and probably for $\Lambda(1520)$ and K^* also provide new important information on the reaction mechanism for heavy ion collisions. Expected value of the effect for realistic value of parameters is of the order of 10–30% and experimentally accessible.

The work was supported by the Federal Agency for Atomic Energy and the Russian Foundation for Basic Research (grant numbers 06-08-01555, 08-02-00676-a,08-02-92496-NCNIL-a).