A Remark on the Low Mass Dilepton Yield

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The recent data on the enhancement of the low mass dilepton yield in heavy ion collisions are interpreted as an effect of the "prolonged life" of resonances in the hadron gas phase. The value of the enhancement factor gives an upper limit for the duration time of this phase.

Keywords: Heavy ion collisions; Dileptons

I. INTRODUCTION

In the last decade a lot of attention has been paid to the spectra of dileptons produced in heavy ion collisions. In particular, CERES data of 1995-1996 [1] were extensively analyzed and discussed both by the CERES collaboration (which released only recently the definite version of their results [2]) and by many theorists [3]. Whereas the spectra from *pBe* and *pAu* collisions agree satisfactorily with a "decay cocktail" $R_c(m)$ (R calculated from the known yield of various hadrons and their decay processes, dominated by ρ in the mass range $0.6-0.9\ GeV/c^2$), already the *SAu* collisions show a clear excess of dileptons with masses in the range $0.2-0.8\ GeV/c^2$, and no clear peak at the ρ mass [2]. More recently, the dimuon spectra from the In-In ion collisions were presented [4] from an experiment which collected thousand times as many events. However, these data are not normalized to the charged hadron spectra. The excess of dileptons was established assuming no excess for the ω and ϕ peaks and the standard ratio $\rho/\omega \simeq 1.2$ for the "cocktail" contribution. In this note we suggest to use the dilepton results for a very simple test of basic assumptions concerning the space-time development of particle production in heavy ion collisions.

Let us remind first that many hadron-nucleus data are reasonably described if the process is treated in the first approximation as a superposition of nucleon-nucleon interactions (more precisely, an idea of "wounded nucleons" is used, where the number of interacting - "wounded" - nucleons, and not the number of interactions, determines the multiplicity) [5, 6]. This idea was also implemented successfully in the string-like MC generators [7]. On the other hand, nucleus-nucleus (heavy ion) collisions are known to produce more particles, than the "wounded nucleon model" predicts, and many "collective effects" contradicting the superposition picture were found to exist [8]. There are many proposals to cure this problem ("wounded quarks" [9], string interactions leading to "color ropes" [10] etc.), but no satisfactory global description of data in this framework was presented.

Therefore the different description is used, where the collision is supposed to produce (after some preliminary stages) a "hadron gas" expanding and cooling thermodynamically (in a chemical equilibrium?) until the "freeze-out" stage, from which hadrons flow freely to the detectors (obviously subject to decays on their way) [11]. Both the transverse spectra and the relative hadron multiplicities were successfully described in this picture [12] as well as many other data [13]. However, this fact cannot be regarded as disqualifying definitely a "superposition" picture, as it is possible to imitate "thermal spectra" of transverse momenta by the string decays, when the string tension fluctuations are taken into account [14] (in fact, similar spectra are seen for elementary collisions [15]). Also the "chemical composition" of hadrons may be explained similarly.

In the last decade the majority of physicists accepted the suggestion that the collision leads to a "quark-gluon plasma formation" [16] (possibly preceded by a "color glass condensate" state [17], whose interaction explains some features of the plasma state). The evolution of this plasma, ruled by the equations of QCD, leads eventually to the hadronization, possibly followed by a "hadron gas" phase before the "freeze-out". However, some characteristics of plasma survive in measured hadron quantities [18].

Dileptons belong to the small class of signals which may collect the contributions from all the stages of the process, since the lack of strong interactions allows them to escape both from "quark-gluon plasma" and from "hadron gas", and, obviously, they may result from the electromagnetic decays of hadrons on their way to detectors. In the case of neutral pions, for which no competition from strong decays exists, this last process is certainly a dominant component, and the "lowest mass" dilepton spectrum is simply proportional to the number of final pions (and thus rather independent of the adopted assumptions on production process). This is, however, not the case for heavier mesons, for which the branching ratios for the electromagnetic decays are small. In particular, the dileptons from ρ decay were investigated and their yield was found to depend crucially on the process.

II. DATA AND THEIR INTERPRETATION

The data are usually shown as the ratio of the dilepton yield (as a function of dilepton mass) to the charged hadron yield for the same range of rapidity and transverse momentum

$$R(m) = \frac{\int dyd^2p_t \frac{dN_{ee}}{dyd^2p_t dm}}{\int dyd^2p_t \frac{dN_{ch}}{dyd^2p_t}}.$$

As already noted, the *SAu* CERES data show a clear excess of dileptons with masses in the range $0.2-0.8\ GeV/c^2$, and no clear peak at the ρ mass [2]. This contradicts the "superposition" scenario, unless very serious corrections are introduced.

The *PbAu* data for semi-central events (28%) [2] reinforce this conclusion. Below the mass of 0.2 GeV/c (where the π^0 decay dominates) the data agree well with the "decay cocktail" and the ratio of the integrated yields is compatible with one

$$\overline{R} = \frac{\int_0^{0.2} R^{PbAu}(m)dm}{\int_0^{0.2} R^c(m)dm} = 0.92 \pm 0.17$$

with the error dominated by systematical effects.

However, for the mass range between 0.2 and 0.9 GeV/c^2 the ratio of integrated yields is significantly bigger than 1

$$\overline{R} = \frac{\int_{0.2}^{0.9} R^{PbAu}(m)dm}{\int_{0.2}^{0.9} R^c(m)dm} \simeq 2.5$$

(with combined systematic and decay uncertainty of the order of 1). The excess seems to grow with centrality. Again, no clear peak at the ρ mass is visible. The data for transverse pair momenta below 0.5 GeV/c are obviously similar to the spectra integrated over full p_t range (which they dominate); for higher p_t the shape is more similar to the "cocktail" curve, but the enhancement factor for the yield integrated over all the $0.3-0.9$ GeV/c^2 mass range does not depend visibly on p_t.

These results are interpreted by the CERES group [2] as an evidence for two effects. "Medium-modification" of the ρ spectral function is responsible for the disappearance of the peak at ρ mass. The enhancement of the global dilepton yield is interpreted as due to the binary ππ (or $q\overline{q}$) annihilation processes (growing faster than linearly with the pion density).

We agree that the strong change of shape of the mass spectrum suggests the need of some modification of the ρ contribution (mass decrease and/or width increase). However, we would like to point out that there is an obvious reason for the enhancement of the global yield other than the "binary annihilation processes".

This reason is the very existence of "chemical equilibrium" phase, where the ratio of ρ/π is governed by the temperature and thus strong decays of ρ are effectively balanced by the formation of ρ in the ππ collisions. If for the freely decaying ρ the branching ratio for decay into dielectrons is about $5 \cdot 10^{-5}$, the number of electromagnetic decays from the ρ "forced to live longer" will be obviously higher. In the first approximation, one expects in this mass range the enhancement factor

$$\overline{R} = t/\tau,$$

where t is the lifetime of "hadronic gas" phase, and τ the free ρ lifetime ($\tau \simeq 1 fm/c$). In fact, an effective Lorentz factor should be included here, but for the central rapidity bin its value is not much different from one.

The remark equivalent to the relation proposed above was made recently by Renk and Ruppert [19], who argue that the dilepton data may be successfully described and used to discriminate between various models of "in-medium modifications of vector mesons". However, we are convinced that simple relation may be useful without invoking any specific model.

Obviously, our reasoning is rather simplistic. The spectral function is modified strongly in the hadron gas phase. If the ρ mass is reduced and/or its shape changed "in-medium", the branching ratio for electromagnetic decay may be also changed; the ρ/π ratio should not be constant, but rather decrease with decreasing temperature during the evolution of "hadron gas" phase. However, we feel that the suggested value of $t \simeq 2.5$ fm/c (much smaller than the global lifetime of the "fireball" measured by Bose-Einstein interference effects) is rather intriguing.

Let us stress here once more that we discuss only the dilepton yield integrated over rather wide mass range, and not the shape. Thus the detailed changes of the spectral function are irrelevant for our argument. We compare just the dilepton yield (proportional to the four dimensional volume) and the hadron yield (proportional to the three dimensional volume), thus estimating the life time of the hadron gas phase.

If the significant part of the observed dilepton spectra originates from the "binary annihilation processes", as suggested in [2], the value of t should be even smaller, since obviously

$$R^{AA}(m) = R^{AA}_{hg}(m) + R^{AA}_{ann}(m)$$

and thus

$$\frac{t}{\tau} = \frac{R^{AA}_{hg}}{R^c} < \frac{R^{AA}}{R^c} \simeq 2.5.$$

The moderate value of the "enhancement factor" makes the statement about the rejection of "superposition scenario" less categorical. One may imagine that some coalescence of "color strings" into "color ropes" characterized by larger transverse dimensions, higher string tension and its fluctuations may lead to the states quite similar to the "hadron gas phase" (and/or "quark gluon plasma phase"). Their lifetime may be easily of the order of few fm/c, but still much shorter than the global time of the hadroproduction process.

In the high statistics NA60 experiment [4] a similar value of the enhancement factor (increasing with centrality from $\simeq 1.5$ to 4) was found. The new data suggest, however, that the ρ peak is broadened rather than moved to lower mass values in comparison to the free ρ decay.

The NA60 analysis agrees qualitatively with the naive expectations from the "hadron gas enhancement effect". If the duration time of hadron gas phase is of the order of few fm/c, the enhancement of the ω contribution is very mild, and for the φ, η or η′ completely negligible, as the lifetimes of these particles are much longer (however, the annihilation processes contribute significantly for higher masses increasing the experimental value of $\overline{R}$). Thus the NA60 data seem to support our suggestions that the main reason of the enhancement of the dilepton yield in the ρ mass region is the "extended lifetime" of ρ.

III. COMMENTS AND CONCLUSIONS

Our suggestion tells nothing about the "quark-gluon plasma phase", if it does not contribute dominantly to the low mass dilepton production. However, the small lifetime of "hadron gas" phase suggests that the plasma phase (and possibly other state) is likely to precede it.

An intriguing difference between the spectra for dilepton transverse momenta below- and above 0.5 GeV/c (qualitatively explained within the formalism of the "in-medium modification" [2]) does not extend, as noted above, to the integrated yield. The "enhancement factors" for the full mass range are nearly the same in both cases. Thus no significant difference between the freeze-out times for two ranges of p_t is suggested. The NA60 data, on the other hand, imply a stronger p_t dependence of the enhancement factor.

Summarizing, we suggest that main reason for the enhancement of the ratio of the number of the low mass dilepton pairs to the charged hadron density for heavy ion collisions is just the existence of the "hadron gas phase" in which there is a chemical equilibrium between pions and heavier mesons. However, the observed moderate value of the "enhancement factor" leads to the conclusion that this phase is rather short-lived. A detailed quantitative analysis of this problem may be very helpful for the proper description of the space-time development of the hadroproduction processes in heavy ion collisions.

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[1] G. Agakichiev *et al.*, CERES Collaboration, Phys. Rev. Lett. **75**, 1272 (1995); P. Wurm, CERES Collaboration, Nucl. Phys. A **590**, 103c (1995).
[2] G. Agakichiev *et al.*, CERES Collaboration, e-print nucl-ex/0506002 v1.
[3] E.g. G.E. Brown and M. Rho, Phys. Rev. Lett. **66**, 2720 (1991), Phys. Repts.**363**, 85 (2002); R. Rapp and J. Wambach, Adv. Nucl. Phys. **25**, 1 (2000). An extensive bibliography is listed in the previous reference.
[4] R. Arnaldi *et al*, NA60 Collaboration, Phys. Rev. Lett. **96**, 162302 (2006).
[5] A. Bialas, M. Bleszynski, and W. Czyz, Nucl. Phys. B **111**, 461 (1976).
[6] For a recent applicationa see e.g. A. Bialas and W. Czyz, Acta Phys. Pol. B **36**, 905 (2005).
[7] B. Andersson, *The Lund model*, Cambridge Univ. Press, Cambridge 1998.
[8] E.g. G. Roland, Acta Phys. Pol. B **34**, 5751 (2003).
[9] A. Bialas, L. Lesniak, and W. Czyz, Phys. Rev. D **25**, 2328 (1982); for a recent application see e.g. R. Nouicer, Proc. of the XXXV ISMD, V. Simak *et al., Eds.*, AIP Conf. Proceedings 828, 11 (2006).
[10] T.S. Biro, H.B. Nielsen, and J. Knoll, Nucl. Phys. B **245**, 449 (1984); H. Sorge, Phys. Rev. C **52**, 3291 (1995).
[11] R. Hagedorn, Nuovo Cim. Suppl. **3**, 147 (1965); F. Cooper and G. Frye, Phys. Rev. D **10**, 1186 (1974).
[12] E.g. W. Broniowski and W. Florkowski, Phys. Rev. Lett. **87**, 272302 (2002); Phys. Rev. C **65**, 024905 (2002).
[13] For a recent review see e.g. P. Huovinen and P.V. Ruuskanen, Annu. Rev. Nucl. Particle Science **56**, 163 (2006).
[14] A. Bialas, Phys. Lett. B **466**, 301 (1999)
[15] See e.g. F. Becattini and G. Passaleva, Eur. Phys. J., C **23**, 551 (2002).
[16] E.g. E.V. Shuryak, Phys. Rep., **61**, 71 (1980).
[17] E. Iancu, A. Leonidov, and L.D. McLerran, Nucl. Phys. A **692**, 553 (2001).
[18] E.g. J.P. Blaizot, Nucl. Phys. A **661**, 3 (1999).
[19] T. Renk and J. Ruppert, *What the NA60 dilepton data can tell*, e-print hep-ph/0605130.