Abstract. The present status of our understanding of low mass dilepton production in relativistic heavy ion collisions is discussed. The focus of the discussion will be the sensitivity of dilepton measurements to in medium changes of hadrons and the restoration of chiral symmetry. We will finally discuss how the presence of strong long wavelength pion modes, i.e. disoriented chiral condensates can be seen in the dilepton spectrum.

INTRODUCTION

Electromagnetic probes, such as photons and dileptons are especially useful to investigate the early stage of an ultrarelativistic heavy ion collision, since they leave the system without any final state interaction. However, as measurements by the DLS collaboration at the BEVALAC, and more recently by the CERES collaboration at the CERN-SPS have shown, a large fraction of the dilepton yield arises from the decay of long lived states, such as the π0, eta, or the omega. These resonances decay well outside the hot and compressed region and thus careful analysis of the dilepton spectra is needed in order to extract the information about the properties of the hot and dense matter, such as e.g. possible in medium changes of hadrons. In the low mass region, below the phi-meson, the most important production channels are: (i) Dalitz decays of η, Δ, ω, a1. (ii) Direct decays of the vector mesons, such as ρ, ω and Φ. Unique to heavy-ion collisions are rescattering channels such as pion annihilation and bremsstrahlung due to secondary collisions. These latter channels certainly carry information about the hot and dense region and due to the vector dominance formfactor pion annihilation may reveal possible in medium changes of the ρ-meson. (For an review of in medium changes of hadronic properties see e.g. [1]).
DILEPTON PRODUCTION AT SPS-ENERGIES

As discussed in detail in the contribution by A. Dress [2] dilepton measurements for nucleus-nucleus collisions at 200 GeV per nucleon by the CERES collaboration show a considerable enhancement over the expected yield from hadronic decays. For p+Be as well as p+Au collisions, on the other hand, the data are consistent with the hadronic decays only. Certainly a large fraction of this enhancement is due pion annihilation, which is unique to heavy-ion experiments since they create a dense system of pions which then can annihilate. Thus the CERES data are proof that heavy ion collisions are more than the simple superposition of individual nucleon-nucleon collisions and that indeed an interacting hadronic system is formed (similar evidence is also derived from the measurement strange particle production).

Aside from measuring in medium modifications of hadrons, dilepton measurements may provide complementary information about the reaction dynamics and may thus help to further specify the properties of the hadronic system generated in these collisions. This question has been addressed in [3], where the dilepton spectrum has been calculated for a large variety of initial conditions under the constraint the the final hadronic spectra are in agreement with experiment. Within the CERES acceptance, the variation of the resulting dilepton mass spectra is rather small (see fig. 1). Thus the measurement of an dilepton invariant mass spectrum is unlikely to further specify the configuration of the hadronic phase. On the positive side this result shows that large deviations of the data from the hadronic calculation cannot simply be attributed to the lack of knowledge of the specific configuration of the hadronic phase. And indeed, as compared with the central points of the CERES measurement for S+Au, there is a considerable deviation at invariant masses of about 400 MeV. However, one should also point out, that within the systematic and statistical error quoted by the CERES collaboration, the data can be understood by simply including pion annihilation without any further in medium modifications. However, if one seeks to reproduce the central values of the CERES data, certain in medium modifications have to be included. One is follow the conjecture of Brown and Rho [4] that the mass of the $\rho$ meson scales with the quark condensate, which is expected to be reduced at the densities and temperatures reached in these collisions. As a consequence the mass of the $\rho$ drops, providing more strength in the low mass region of the dilepton spectrum. Following this prescription, Li et al. can reproduce the central points of the CERES measurements [5]. However, at least at low temperatures, the Brown-Rho scaling hypothesis can be ruled out by simple current algebra arguments [6], which shows that to order $T^2$ the mass of the $\rho$ does not change while to this order the quark condensate drops.

More conventional calculations of in medium effects on the dilepton production determine the properties of the $\rho$-meson or more precisely the current-current correlator in a system of pions and nucleons/deltas. So far essentially three different in medium correction have been considered, which are schematically depicted in fig. 2.
FIGURE 1. CERES data of S+Au in comparison with calculation based on different initial hadronic configurations.

(1) The $\rho\gamma$ coupling is screened due to pion loops [7,8]. This effect is a direct consequence of the partial restoration of chiral symmetry and it reduces the strength below the $\rho$ peak.

(2) If one understands the $\rho$ as a $\pi - \pi$ resonance, its properties are changed due to medium modifications of the pions. These include a change of the pion dispersion relation due to thermal pions [3,9] and due to the coupling to delta-hole and nucleon-hole states [10–12] once baryons are taken into account. These states also give rise to additional inelasticities at low invariant resulting in an increased strength around 400 MeV in the imaginary part of the current-current correlator. One should note, however, that to leading order in the density, these contributions are nothing else but typical bremsstrahlung diagrams. Furthermore, these additional inelasticities at low masses seem to be sufficient to saturate the QCD-sum rules [11], without an explicit change in the mass of the $\rho$ meson.

(3) The $\rho$ can also couple to $N^*(1720)$-hole states. This effect, originally proposed by Friman and Pirner [13] leads to a softening of the dispersion relation of the $\rho$ meson and provides additional strength in the dilepton spectrum at low invariant masses. Since the coupling to the $N^*(1720)$-hole state is p-wave, only dileptons with finite momentum with respect to the matter restframe are enhanced.

A combination of effects (2) and (3) seems leads to an improved description of
DILEPTONS FROM DCC-STATES

The restoration of chiral symmetry in relativistic heavy ion collisions can, under certain circumstances, lead to a strong enhancement of low momentum pion modes which form a so called disoriented chiral condensate (DCC) [14,15]. So far, proposed observables which are sensitive to these DCC states have been in the pion sector only, where strong final state interactions may destroy them. However, the presence of a DCC state also leads to a strong and unique signal in the dilepton channel. Assume a thermal pion annihilates with a pion from a DCC. Since the DCC represents a large phase space density localized at small momenta, one would expect that this phase space distribution is reflected in the dilepton invariant mass as well as momentum spectrum. This is indeed the case as one can see in figures 3 and 4. (for details see [16]). In fig. 3 we show the resulting invariant mass distribution for thermal initial conditions and for so called quench initial conditions; the latter lead to the formation of DCC-states. The resulting momentum spectrum for an invariant mass of $M = 300$ MeV is shown in fig. 4. Clearly a strong enhancement (about a factor of 100) can be seen close to twice the pion mass. The enhancement is localized in invariant mass as well as in momentum, reflecting the localized phase space distribution of the DCC-state. Since this enhancement is confined to momenta below 300 MeV, it does not affect the CERES measurement, where an acceptance cut of $p_t \geq 200$ MeV for each individual dilepton is imposed. However, if this cut could be relaxed to $p_t \geq 100$ MeV a factor of 10 enhancement in the invariant mass spectrum should be visible.

FIGURE 2. Dilepton invariant mass (left) and momentum (right) spectra for thermal (full lines) and quench (dashed lines) initial conditions. The momentum spectrum is for an invariant mass of $M = 300$ MeV.
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