Thermal Dilepton-production in S+Au collisions at E$_{lab}$=200 AGeV

C.Gale[1]*, U. Ornik[2]†, M. Plümer[2]‡, A. Timmermann[3]§ and R.M. Weiner[2]¶

[1] Physics Dept., McGill University, CANADA

[2] Physics Dept., Univ. of Marburg, Marburg, FRG

[3] Max-Planck Institute of Meteorology, Hamburg, FRG

Abstract

We calculate thermal dilepton production in S+Au collisions at E$_{lab}$=200 AGeV, using a three-dimensional hydrodynamical simulation and an equation of state, exhibiting a first order phase transition to the quark-gluon plasma (QGP). We reproduce the dilepton data obtained from the CERES with excellent agreement, suggesting that the excess of dileptons can be explained by the formation of a quark-gluon plasma. The dilepton spectra of HELIOS can not be reproduced in such a good manner. One possible reason discussed here is baryonic dilepton production, which was not considered in this calculation. Collective dynamical effects may provide another explanation, yielding uncertainies in the estimation of the thermal signal. Compared

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[*] E. Mail: gale@hendrix.physics.mcgill.ca

[†] E.Mail: ornik@clri6k.gsi.de

[‡] E. Mail: pluemer@mailer.uni-marburg.de

[§] E. Mail: timmermann@dkrz.d400.de

[¶] E. Mail: weiner@mailer.uni-marburg.de

to previous calculations of thermal photon production with the same hydrodynamic scenario, dileptons seem to probe the QGP-stage in this energy-range, rather than the hadronic stage, suggesting that dileptons may serve as a deeper probe of quark-matter than thermal photons.

Recently, an excess of dilepton production above the hadronic background has been reported by the CERES [1], HELIOS [2] and NA38 [3] collaborations for several ultrarelativistic heavy-ion-collsions. One of the most fascinating questions at SPS-energies, whether this excess might be attributed to the transient formation of quark-gluon plasma (QGP), was already adressed in ref. [4]. In ref. [4] the excess emission of dileptons at the CERES and HELIOS experiment can be reproduced by assuming the system undergoing a first order phase transition and evolving in a boost-invariant manner in space-time. Our intention is to present an alternative approach, in order to reproduce the experimental dilepton data. This approach has recently suceeded [5] in explaining the photon emission, measured by the WA80 experiment for S+Au collsions [6]. However, this photon excess - after a reanalysis - turned out to exhibit experimental errors as large as the data.

We adopt the space-time development of the S+Au collision at E_{lab} = 200 AGeV from a 3-dimensional hydrodynamical calculation, performed with the numerical code HYLANDER [7]. As an alternative approach to 1-dimensional Bjorken-hydrodynamics [8] and its minimal extention [9], as used in ref. [4], we assume full 3-dimensional asymmetric nucleus stopping. Stopping is simulated in such a way, that 3-dimensional relativistic shock-waves heat up the system during its compression stage. Using an EOS with a 1 first order phase transition (obtained from lattice gauge calculations [11] with a critical temperature of T_c=200 MeV) the simulation of the compression stage leads to initial temperatures of $T_i \sim 265$ MeV. The preceding space-time evolution of the hydrodynamical system is characterized by the dilution of the system, also calculated 3-dimensionally. The freeze-out takes place locally, if a fluid cell appraoches the freeze-out temperature of T_f=140 MeV. The complete system freeze-out is reached, when all fluid cells have been frozen out locally. A more detailed illustration of this space-time development can be found in ref. [5].

The dilepton emission rate in the QGP is considered to be dominated by the $q\bar{q} \rightarrow l\bar{l}$ processes, not accounting for higher order mechanisms [12]. The dilepton emission in the mixed phase is treated as a linear superposition of QGP and hadronic phase contribution. Dilepton emission in the hadronic phase is governed by a great variety of processes. We adopted the dilepton rates in hadronic matter from ref.[13], which were also used in [4]. The essence of all these processes is the introduction of an effective form-factor $F_{eff}(M,T)$. In order to obtain the single-inclusive dilepton spectra, the rates per space-time volume have to integrated over the 3-dimensional thermodynamical space-time history of the system and also with the detector acceptance in the canonical way as described in previous studies. The detector phase-space covered by the CERES-experiment is characterized by the pseudo-rapidity window of $2.1 < \eta < 2.65$, a $p_\perp$ cut of 210 MeV and an opening angle of $\Theta_e > 35$ mrad. HELIOS on the other hand is focussed to more forward rapidities. Their rapidity acceptance spans the interval $3.7 < \eta < 5.2$. The transverse mass is limited by $M_\perp/GeV > 4(7-2y)$ and $M_\perp > [(2m_\mu)^2 + (2P_{min}/coshy)^2]^{1/2}$ with P_{min} =7.5 GeV/c^2. Fig.1 shows the thermal dilepton yields for each phase calculated with our hydrodynamical model for the CERES phase-space configuration, the sum of the thermal contributions and also the sum of the hadronic background plus the total thermal contribution for S+Au collisions at E$_{lab}$=200 AGeV. The comparison with the CERES-data reveals an excellent agreement between our model results and reality. Most strikingly, the dominant contribution is emitted from the QGP in disagreement with previous calculations [4]. This surprising results might be attributed to the fact that the initial temperature in our calculation is significantly higher than in ref. [4] and also the transverse expansion in our model leads to a shorter-living hadronic phase, whereas the QGP is not affected strongly by transverse-expansion effects, since these become important only later in the evolution. Moreover, one should note, that in our photon calculation, which was mentioned above, the thermal photons from hadronic matter outshine the QGP-contribution. Compared to our photon calculation, it seems as if dilepton production in the QGP is competing more strongly against the hadronic contribution than photon production in the QGP, indicating that dileptons might be a deeper probe of quark-matter,thus carrying more information about the early stages of the evolution than photons. The outshining QGP also explains the smeared resonance peaks in the observations, which is also consistent with CERES-data, although a mass miss-identification in the experiment is smearing out sharp resonances additionally.

The HELIOS-data (see Fig.2) show some interesting features, which might be due to the fact that physics is probed in a more forward rapidity-region. The soft dilepton enhancement, which was observed in the CERES experiment for electron-pairs and which is probably due to Bremsstrahlung is not present in the HELIOS experiment. Moreover the ρ-resonance region is represented by a gap in the dimuon-spectra, rather than by a weak peak, as was observed in the CERES experiment for electron-pairs. As can be seen from Fig.2 our model is not able to reproduce the HELIOS-spectrum, apart from two data-points; one corresponds to the strange gap in the ρ-region, the other point which is in the range of our model is the last data point of the observed spectrum. Although our model takes into account the baryons, it fails in explaining these data, whereas the minimal-extention hydrodynamical model used in ref. [4] reproduces the data quite well, espacially in the low mass region. As was already mentioned in ref. [4], the definition of excess dimuons used by the HELIOS collaboration contains principal uncertainties, because it does not take into account that particle production in the S+W system may be qualitatively very different from that in p+W collisions. It is quite reasonable to assume that collective dynamical effects play an important role in ultrarealtivistic heavy-ion collisions and heavy-ion collisions can not be regarded just as a linear superposition of p+W collisions plus thermal excess. Therefore the dimuon spectrum of HELIOS contains two contributions: one coming from thermal excess dimuon-pairs, the other originating from collective dynamical effects. This circumstance would provide an explanation for the underestimation of our model, since our calculation accounts only for the thermal excess.

Another possibility to explain the difference between our calculation and the data is that our calculation simultanously solves the hydrodynamical equations and the equation for baryon-number conservation. On the other hand there is a great lack of understanding dilepton production in a baryonic medium, particularly during the hadronic stage. Additional channels for dilepton production may be open in SPS-collisions, which have not been investigated so far. This argument was suggested already in ref. [5]. Maybe this could also explain the discrepancy of our model and the HELIOS-data. The CERES-measurements should not be affected by this effect.

Summarizing our results, we found that the CERES-data can be explained within a hydrodynamical space-time framework undergoing a first-order phase-transition. Hence, the observed excess might be an indication of the transient existence of a QGP in S+Au collisions at E_{lab}=200 AGeV. On the other hand, the dimuon-data from HELIOS could not be reproduced with this framework. We suppose that this might be due to collective dynamical effects and partly due to the underestimation of baryonic dilepton channels. As compared to previous photon calculations with the same model thermal dileptons seem to be a deeper probe of quark matter than thermal photons.

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Figure Captions

Fig. 1

Fig. 2

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