# Production of Dileptons in Heavy Ion Collisions at SPS-Energies[1]

Volker Koch
Lawrence Berkeley National Laboratory,
Berkeley CA 94720, USA

**Abstract**

In this contribution we will discuss the production of low mass dileptons in SPS-energy heavy ion collisions. We briefly review the current theoretical situation before we turn to the analysis of the recent data for Pb+Au. We also will discuss the role of baryons as a source for dileptons.

## 1 Introduction

The study of low mass dileptons has recently received considerable interest. This has been triggered by the observation of enhanced production of dileptons with invariant mass around $400 - 500$ MeV in relativistic heavy ion collisions by the CERES collaboration [1, 2]. This enhancement has been studied in various approaches, ranging from thermal model to complicated transport models. All those calculations include the known hadronic decay channels into lepton pairs and, in addition, dilepton production via re-interaction of particles, most prominently pion annihilation. They find that pion annihilation accounts for a large part of the observed enhancement, while other channels such as the pion-rho scattering or the Dalitz decay of the a$_1$-meson are less important (see e.g. [3, 4]). In ref. [3] a large variety of initial conditions for the hadronic fireball has been considered under the constraint that the final state hadronic spectra are in agreement with experiment. Surprisingly little variation has been found in the resulting dilepton spectra (see

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[1] e-mail: vkoch@lbl.gov

fig. 1). Certain initial conditions would agree with the lower end of the sum of statistical and systematic errors of the CERES data for the sulfur on gold reactions. In [3, 5] in medium modifications of pions and the pion nuclear from-factor in a pion gas have been considered and have been found to be small. The conclusion of [3] and many other works (see [6] for a list of references) is that in order to reach the central data points of the $\mathrm{S} + \mathrm{Au}$ measurement, additional in medium modifications need to be considered. Most of the attention received the suggestion of Li et al. [8], that a dropping of the mass of the $\rho$-meson with density, – following, with some modifications, the original conjecture of Brown and Rho [7] – can reproduce the central data points. On the other hand, Rapp et al. [9] have extended the work of [3, 10] to include also the effect of baryons for the in medium modification of pions. The present status of those considerations is that the in medium change of the pion dispersion relation leads only to a small enhancement, whereas the inclusion of baryon resonances which couple directly to the rho meson appear to be able to increase the yield substantially. Most important is here the $\mathrm{N}^*(1520)$ resonance, as first pointed out by the Giessen group [13]. The p-wave resonances, which have been first considered by Friman and Pirner [14] appear to play a lesser role. We should note, however, that the calculation of Steele et al. [15, 16], although similar in spirit, finds a much smaller effect due to baryons.

In this contribution we want to revisit the CERES data, in particular those for the system $\mathrm{Pb} + \mathrm{Au}$ [2]. These data have been analyzed to provide not only an invariant mass spectrum but also transverse momentum spectra and thus may give new insight into the relevant production mechanisms. Recently, new (preliminary) results from the '96 run have been shown [17]. These data have much improved statistics as compared to the published data from the '95 run. We also will present arguments concerning the importance of baryons. According the work of Rapp et al. baryons seem to be the most important source for the low mass enhancement. In contradiction to that, our estimates in [3] found the baryons to be irrelevant.

# 2 The $\mathrm{Pb} + \mathrm{Au}$ data

In this section we present some new results for the dilepton spectra for $\mathrm{Pb} + \mathrm{Au}$. The calculation is similar to that carried out in [3] and we refer to this reference for details. A new element is the inclusion of the channel $\pi + \rho \to \pi + e^+e^-$ [18]. Using vector dominance this process is related to the elastic $\pi + \rho \to \pi + \rho$ scattering, which gives rise to the a collisional broadening of the rho meson, as first discussed in [19]. We have attempted to include the effect of the collisional broadening into our transport model, by calculating the collisional width as a function of the local pion density. This certainly is a crude method and needs to be refined in the future. While there is some reduction of strength below the rho-omega peak due to the collisional broadening of the rho, the overall effect is small and the difference to the previous calculations [3] are well within the theoretical uncertainties as discussed in [3].

In fig. 2 we show the resulting invariant mass spectra together with the CERES

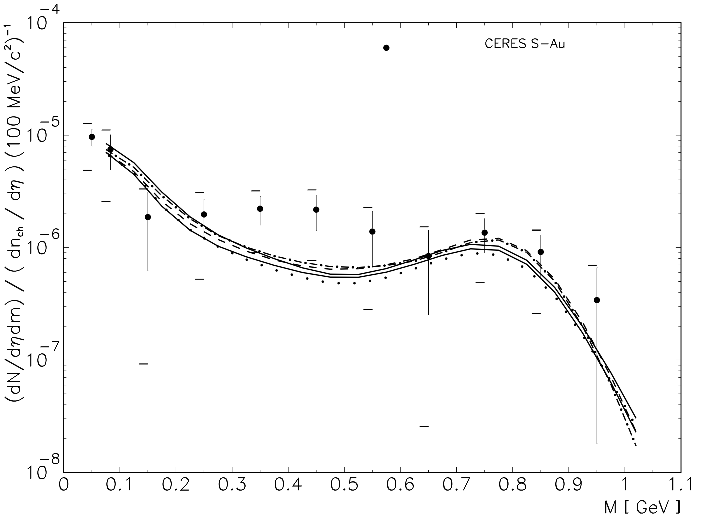


Figure 1: Dilepton invariant mass spectrum for S+Au. The curves are the results of [3] for different initial hadronic configurations. Data are from [1]

data [2], where only the statistical errors are shown. We have also included the *preliminary* data from the '96 run (full circles) [17]. We find a reasonable overall agreement, especially with the new, preliminary data.

In fig. 3 we show the invariant mass spectra for the tranverse momentum interval $p_t < 400\,\mathrm{MeV}$ (left panel) and $p_t > 400\,\mathrm{MeV}$ (right panel). Again the agreement is quite reasonable. Some discrepancy might possibly be around the rho-omega peak where our calculation overshoots the data somewhat. However, as already pointed out in [3] the strength around the rho-omega peak is dominated by the omega decay contribution, which depends on the abundance of omegas in the final state. This, however, is not very well constrained by other data.

Finally in fig. 4 we compare the *prediction* from [3] for central Pb+Au collisions with the central '96 data [17]. Again good agreement with the data is found. Also shown in this figure is the invariant mass spectrum after in medium modification in a pion gas are taken into account. These in medium modification also include the effects of chiral symmetry restoration on the coupling of the photon to the rho meson [11, 10]. Notice, that it will be extremely difficult to extract those effects from the data.

To summarize this section, provided the still preliminary '96 data remain unchanged it seems the the Pb+Au data are consistent with a simply hadronic scenario without any large in medium modifications. As already pointed out, in medium modification due to the presence of a pion gas are small and thus their presence/absence can not be decided on from the present data. This situation could be improved considerably if the mass resolution would allow to separate out the omega decay. This could then be 'subtracted' and the effects of chiral symmetry restoration should lower the remaining spectrum by about a factor of two around the rho-peak [3]. The recently completed upgrade of the CERES detector should allow for exactly that. But certainly the present Pb+Au data to not seem to call for sizable corrections as

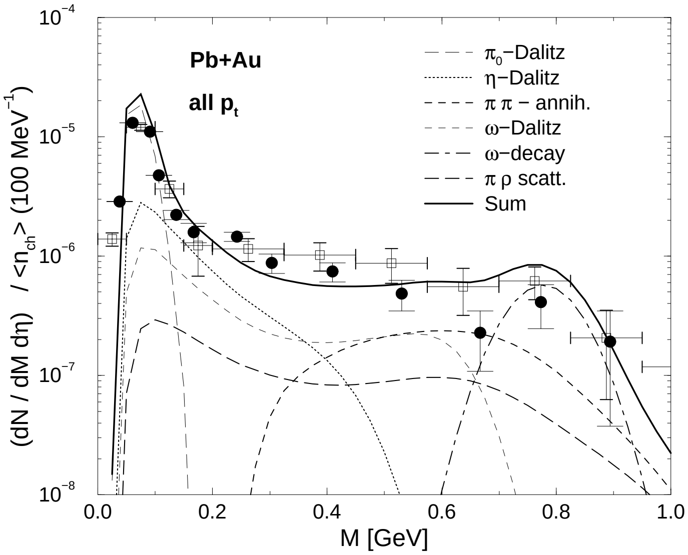


Figure 2: Dilepton invariant mass spectrum for semi central. The '95 data (open squares) are from [2] and the '96 data (full circles) are from [17].

they were predicted by the dropping rho mass scenario [12].

# 3 The role of baryons

The work of Rapp et. al has emphasized the role of baryons as a possible source for additional dileptons. They consider in medium modifications of the current-current correlator, the imaginary part of which is directly related to the dilepton production rate. Following the suggestion of the Giessen group [13] Rapp et al. also find that the contribution of the $N^*(1520)$-hole diagram, depicted in fig. 3 is the most important one. However, as illustrated in fig. 3, the imaginary part of this diagram is nothing but the Dalitz - decay of the $N^*(1520)$.

The contribution of the Dalitz decays of baryons has already been estimated in ref. [3]. In this estimate, the formula for the branching ratio of photon to Dalitz decay of the Delta [20] has been extended to higher masses. In order to arrive at an conservative estimate of an upper limit the fraction of higher lying resonances has purposely been overestimated by a factor of two. The photon decay width has been chosen to be 1 MeV, which again is on the large side. The resulting dilepton spectrum has then been compared with that of the omega, in order to minimize the effect of the detector acceptance. The ratio of these yields is shown in fig. 5. The baryons hardly contribute half as much as the omega Dalitz. Considering the contribution of the omega Dalitz as shown in fig. 2 it seems that the baryons are anything but irrelevant.

So what is the difference between this estimate and the results of Rapp et al. Several possibilities come to mind:

- The $N^*(1520)$ has a considerably larger Dalitz decay width than the the ex-

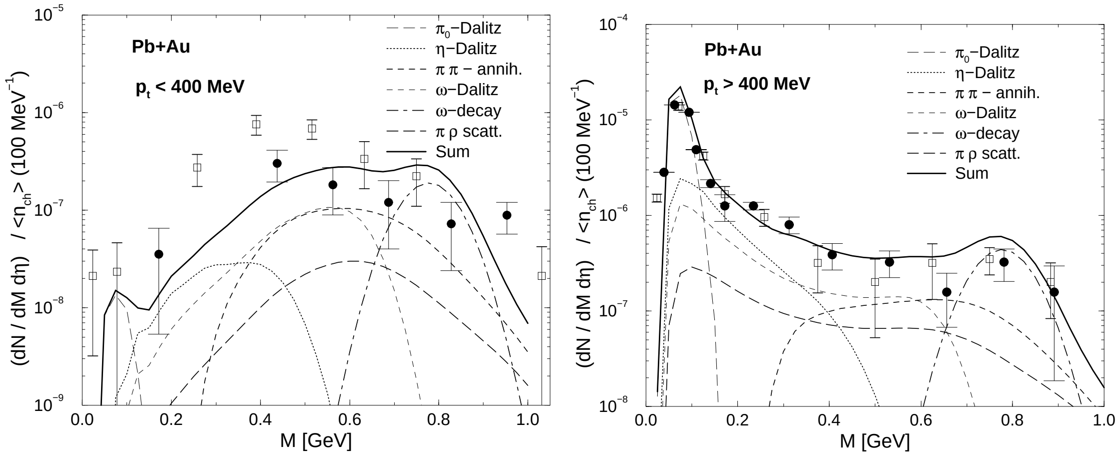


Figure 3: Dilepton invariant mass spectra for transverse momenta smaller than 400 MeV (left panel) and larger than 400 MeV (right panel). The data are from ref. [17]. Open squares are the '95 data and full circles are the '96 data.

trapolation from the Delta decay width would predict. This might be possible, in particular, because the $N^*(1520)$ couples rather strongly to the $\rho$-meson. This is presently being investigated [21] and we find that in both a relativistic as well as a nonrelativistic description the Dalitz decay is well in line with fig. 5. Similar results are also found by [16].

- Rapp et al. sum the RPA-type Dyson-series for these diagrams. So in principle there could be collective effects, which are ignored in the simple calculation of the Dalitz decay. It appears, however, rather unlikely that at the temperatures under consideration, collectivity can play an important role.

- Another source of discrepancy is the baryon to pion ratio assumed in the calculations. Using the freeze out parameters of [9] we find a pion to baryon ratio for $Pb + Au$ of about 3, whereas a ratio of close to 6 is observed in experiments. The estimate of [3], on the other hand was based on a realistic pion/baryon ratio.

All this points are specific to the environment created in a CERN energy heavy ion collision. At lower energies or in proton/pion nuclear reactions the density effects could very well be large. This will be investigated in the near future by the HADES detector at the GSI.

# 4 Conclusions

At this point it is very hard to draw any firm conclusions as the new CERES data are still preliminary. Taking these data at face value, however, it appears that no or only small in medium corrections are needed in order to explain the data. This would be somehow unfortunate, although, as shown in [3] in medium modifications

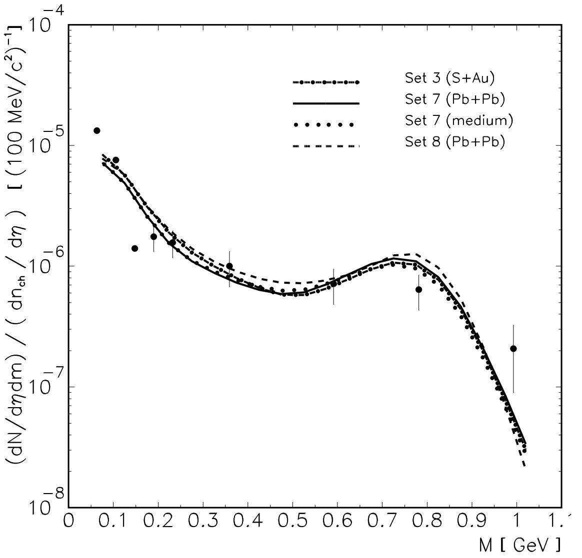
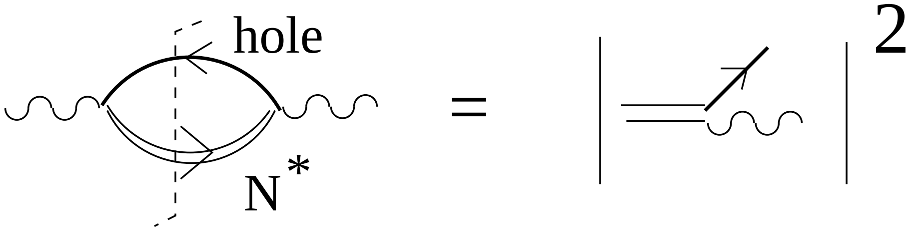


Figure 4: Dilepton invariant mass spectrum central collisions. Curves are a prediction from [3]. The dotted line is the result including in medium correction in a pion gas. The data are from the '96 data set [17].



due to the presence of pions indeed give rise only to small corrections. Certainly, all these calculations are rather unconstraint. For instance the number of omegas can be chosen within a considerably wide range. While these uncertainties have already been addressed, a measurement with a mass resolution which is sufficient to constrain the number of omegas in the final state would reduce these uncertainties to a large extent. This would then provide the basis for the search for the more subtle effects which, one would think, should be there.

# 5 Acknowledgments

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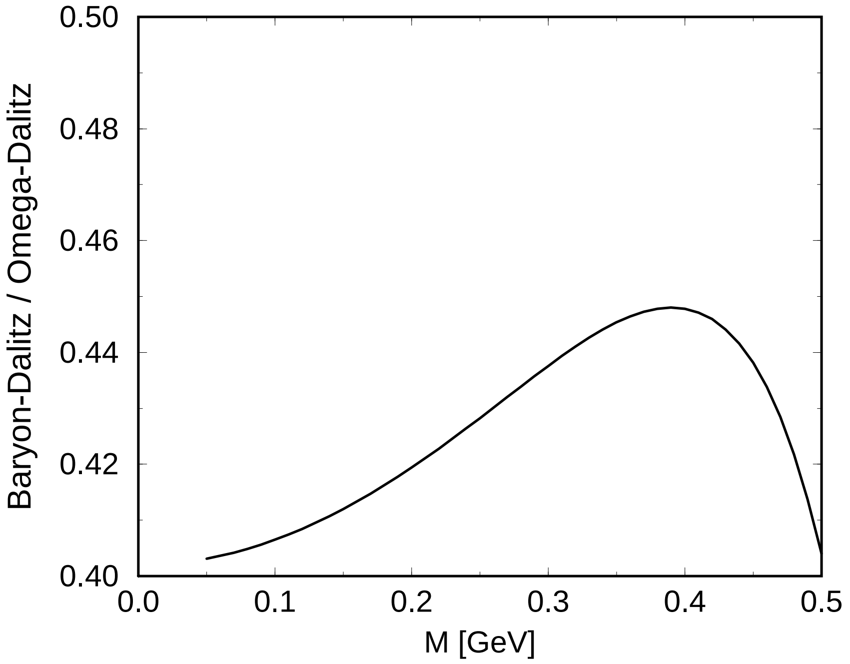

Figure 5: Ratio of baryon-Dalitz decay over $\omega$-Dalitz decay

# References

[1] G. Agakichiev *et al.*, Phys. Rev. Lett. 75 (1995) 1272.

[2] G. Agakichiev *et al.*, Phys. Lett. B422 (1998) 405.

[3] V. Koch and C. Song, Phys. Rev. C 54 (1996) 1903.

[4] K. Haglin, Phys. Rev. C 53 (1996) R2606.

[5] C. Song and V. Koch, Phys. Rev. C54 (1996) 3218.

[6] C. M. Ko, V. Koch, and G. Q. Li, Ann. Rev. Nucl. Part. Sci., 47 (1997) 505.

[7] G. E. Brown and M. Rho, Phys. Rev. Lett. 66 (1991) 2720.

[8] G. Q. Li, C. M. Ko, and G. E. Brown, Phys. Rev. Lett. 75 (1995) 4007; Nucl. Phys. A 606 (1996) 568; A 611 (1996) 539.

[9] R. Rapp, G. Chanfray, and J. Wambach, Nucl. Phys. A 617 (1997) 472.

[10] C. Song *et al.*, Phys. Lett. B366 (1996) 379.

[11] M. Dey et al., Phys. Lett. B252 (1990) 620.

[12] C.M. Ko et al., Nucl. Phys. A610 (1996) 342c.

[13] W. Peters, M. Post, H. Lenske, S. Leupold, and U. Mosel, Nucl. Phys. A 632 (1998) 109.

[14] B. Friman and H. Pirner, Nucl. Phys. A617 (1997) 496.

[15] J. Steele *et al.*, Phys.Rev.D56:5605-5617,1997

[16] J. Steele and I. Zahed, hep-ph/9901385

[17] Björn Lenkeit, PhD-thesis Heidelberg, 1998; B. Lenkeit, Proc. Int. Nuclear Physics Conf., Paris, August 1998; Nucl. Phys. A, to be published.

[18] P.W. Xia *et al.* in preparation.

[19] K. Haglin, Nucl.Phys. A584 (1995) 719.

[20] Gy. Wolf *et al.*, Nucl. Phys. A517 (1990) 615.

[21] C. Gale, A. Kanti Dutt-Mazumder, C.M. Ko and V. Koch, in preparation.