e^+e^- pairs from π^-A reactions reexamined

M. Effenberger, E. L. Bratkovskaya, W. Cassing, and U. Mosel
Institut für Theoretische Physik, Universität Giessen, Heinrich-Buff-Ring 16, D-35392 Giessen, Germany
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We calculate dilepton production for the reactions π^-C and π^-Pb at 1.3 GeV within a semiclassical BUU transport model and compare our results to a previously published calculation. We show that a modified treatment of the ρ meson production and propagation gives substantially different results. We, furthermore, discuss uncertainties related to the electromagnetic decay of the ρ meson and the elementary $\pi^-N\to e^+e^-X$ channels. [S0556-2813(99)02008-7]

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The spectroscopy of vector mesons (ρ,ω,ϕ) by their dileptonic decay in finite or dense nuclear matter is of great interest [1] and new spectrometers are currently being built [2]. Whereas dileptons from nucleus-nucleus collisions are complicated to interpret due to the complex dynamical evolution, e^+e^- pairs from photon-nucleus, proton-nucleus, or pion-nucleus reactions essentially probe vector meson properties at normal nuclear matter density provided that appropriate cuts on the (low) momentum-spectrum of the dileptons are applied.

In Ref. [3] dilepton production in pion-nucleus reactions has been calculated within the framework of a BUU transport model [4]. For the production and propagation of vector mesons a ''perturbative'' scheme was imposed where the perturbative particles were treated different from the nonperturbative ones. Especially the finite width of the ρ meson was neglected in the production part and only taken into account for the dilepton spectrum by means of a form factor. Meanwhile we have developed, starting from the very same transport model, a computer algorithm which incorporates the properties of perturbative particles in a dynamical way in line with our treatment of nonperturbative particles. Within this model we have calculated photoproduction of dileptons in nuclei in the energy range from 500 MeV to 2.2 GeV [5]. Since this model, that also contains a number of other improvements, gives different results for pion induced dilepton production than previously published [3] we want to discuss these differences in this article.

For a complete description of the underlying model we refer to Ref. [5]. Here we only briefly describe the main differences with respect to the earlier calculations.

For the elementary meson-nucleon interaction we have meanwhile adopted all resonance parameters from Manley *et al.* [6] including some additional high-mass resonances. Especially the decay channel $R\to\Delta\rho$ is now included.

The finite widths of the ρ and ω mesons are taken into account dynamically. In-medium changes of their spectral functions due to collisional broadening are treated analogously to our description of baryonic resonances [7,8].

The production and absorption of ρ mesons are now consistently described within the resonance model of Manley *et al.* [6].

For the electromagnetic decay of the ρ meson to e^+e^- we use now a width proportional to M^{-3}, as resulting from vector meson dominance (VMD) [9], instead of one proportional to M from extended VMD [10], with M being the invariant mass of the ρ meson. For our calculations this is more appropriate since we neglect a direct coupling of the virtual photon and cannot treat the resulting interference terms properly within a semiclassical transport approach.

In Fig. 1 we show the results of our calculations for e^+e^--production in π^-C and π^-Pb reactions at a kinetic energy of 1.3 GeV. Here neither collisional broadening nor an in-medium mass shift of the vector mesons are taken into

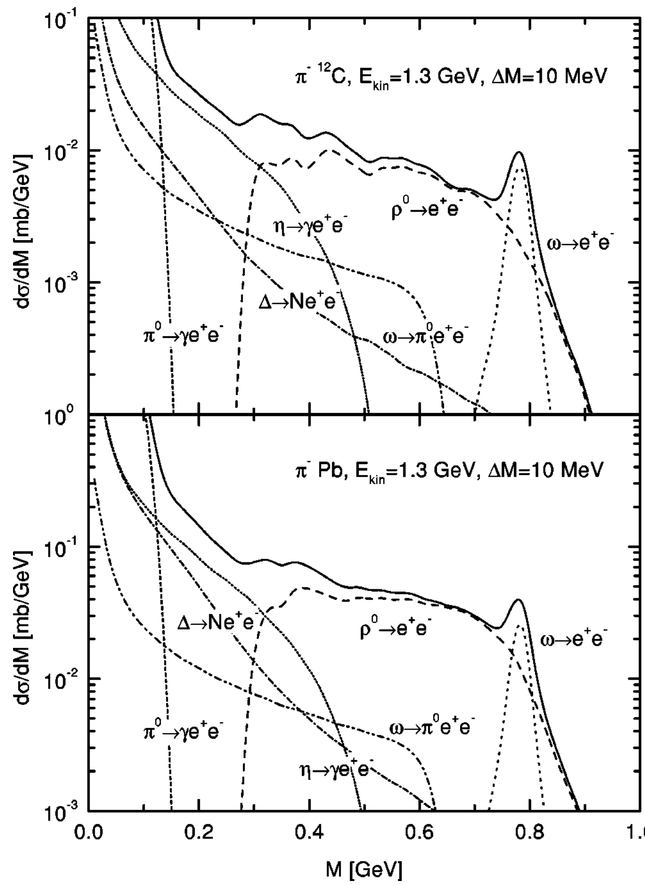

FIG. 1. The dilepton invariant mass spectrum for π^-C (upper part) and π^-Pb (lower part) at a kinetic energy of $E_{\rm kin}=1.3$ GeV calculated without collisional broadening and with vacuum masses for the vector mesons employing a mass resolution $\Delta M=10$ MeV. Fluctuations in the curves are caused by low statistics.

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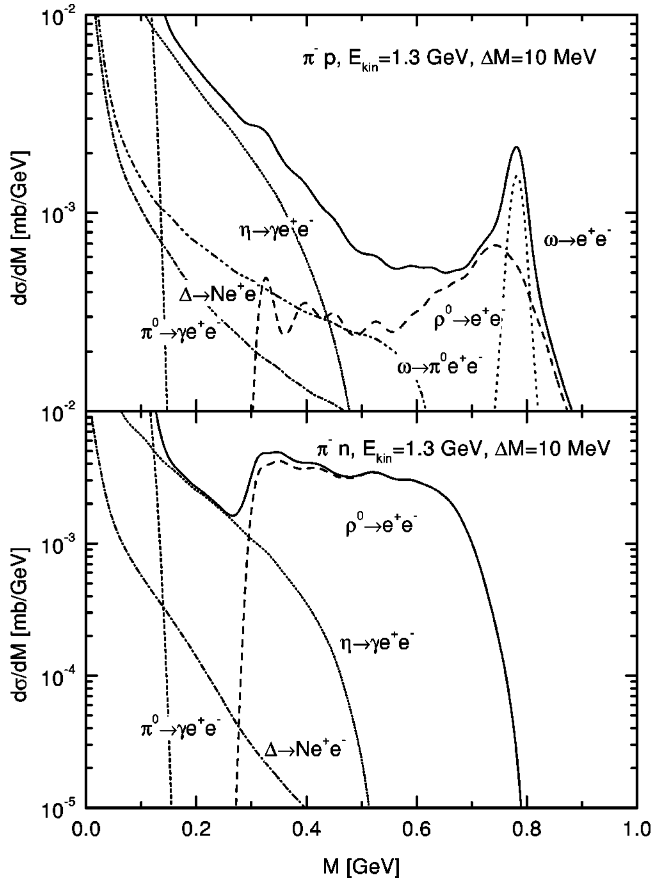

FIG. 2. The dilepton invariant mass spectrum for $\pi^- p$ (upper part) and $\pi^- n$ (lower part) at a kinetic energy of $E_{\mathrm{kin}}=1.3$ GeV employing a mass resolution of $\Delta M=10$ MeV.

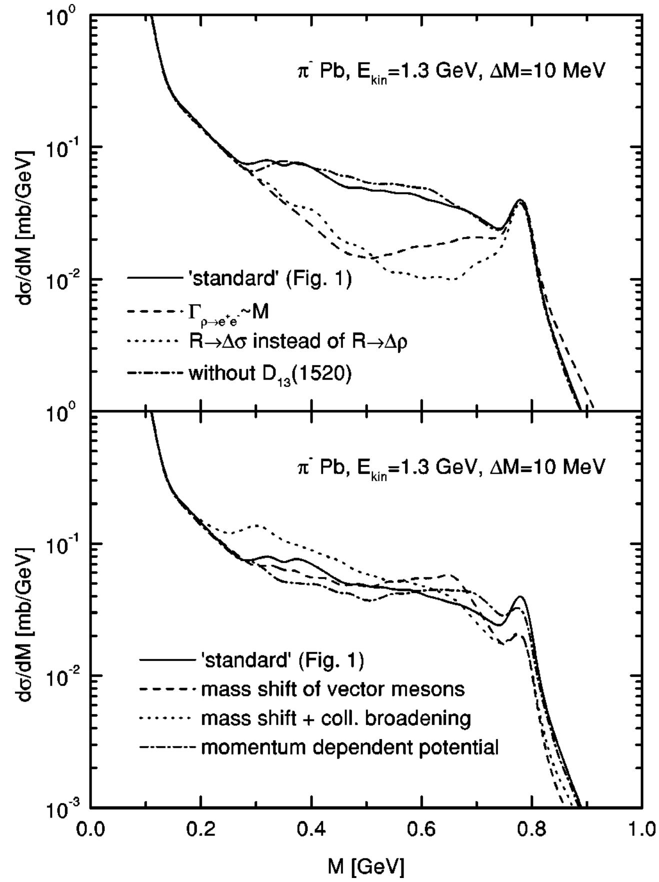

FIG. 3. Same as Fig. 1 for π^-Pb with different model assumptions (upper part, see text for a detailed explanation). The lower part shows the influence of ''dropping masses'' and collisional broadening for the vector mesons.

account. In the figure the various contributions to the total dilepton yield stemming from $(\pi^0, \eta, \omega, \Delta)$ Dalitz decays as well as from vector meson decays (ρ^0, ω) are displayed. Compared to the previous calculations from Ref. [3], but also to those of Ref. [11], our calculations give results which are up to an order of magnitude larger at intermediate invariant masses M for both the light and heavy system. The contributions from the ρ meson and the Δ resonance are very different in size and in shape. The ρ meson contribution is shifted to lower energies and much broader. This is basically due to three reasons. First, the modified dilepton decay width introduces a factor $(M_\rho/M)^4$ which, for example, at $M=0.5$ GeV gives a factor 5.6. Secondly, in our new calculations some of the higher-lying resonances, especially the $D_{35}(1930)$ and the $F_{37}(1950)$, decay strongly into the $\Delta\rho$ channel. These decays give predominantly low-mass ρ's and lead to a stronger contribution of the Δ resonance. Thirdly, secondary pions can, especially through the $D_{13}(1520)$ resonance, more easily contribute to ρ production in the low mass tail. In the earlier calculations this was strongly suppressed because ρ's could only be produced with their pole mass.

The deviations of the new calculations from the earlier ones are therefore mainly related to different descriptions of the elementary $\pi N \to e^+e^- X$ process for which neither experimental data nor a reliable theoretical prediction exist. In Fig. 2 we, therefore, show the dilepton spectrum for elementary $\pi^- p$ and $\pi^- n$ collisions which enter our calculations as input. The ρ^0 contribution on the neutron is very different from that on the proton. This is due to the fact that, because of isospin, on the neutron only the $\Delta\rho$ channel contributes while on the proton the $N\rho$ channel is dominant. The discontinuity of the spectrum at the two-pion mass is caused by our neglect of off-shell ρ mesons with invariant masses below the two-pion mass.

However, it is questionable if the contributions coming from the $\Delta\rho$ decay of some resonances are realistic since in the analysis of Manley *et al.* [6] only data for exclusive one- and two-pion production were taken into account and the channel $\Delta\rho$ was only included in order to absorb inelasticity. One should note that the incoherent resonance contributions to the reaction $\pi^+ p \to p \pi^+ \pi^+ \pi^-$ via intermediate $\Delta^{++}\rho^0$ states already exceed the experimental data [12] by about a factor of 2. In Fig. 3 (upper part) we, therefore, show the result of a calculation for which we replaced the $\Delta\rho$ decay by the channel $\Delta\sigma$ where the σ meson parametrizes a scalar, isoscalar two-pion state with mass $M=0.8$ GeV and width $\Gamma=0.8$ GeV. This gives a reduction of the dilepton yield at intermediate masses by about a factor 3.

In Fig. 3 (upper part) we also show the result of a calculation where we used an e^+e^- width of the ρ meson propor-

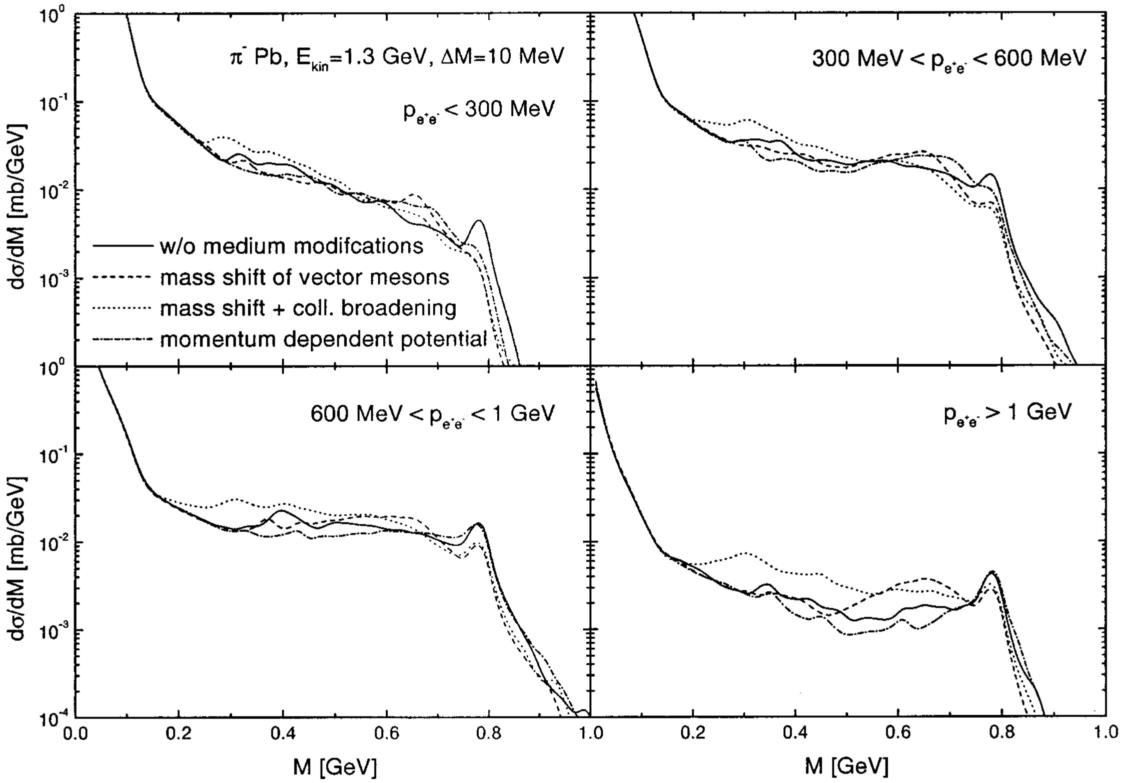

FIG. 4. Same as Fig. 3 for different laboratory momenta of the dilepton pair.

tional to M instead of the more consistent M^{-3}. This also gives a result which is more than a factor of 2 different for dilepton masses around 500 MeV.

Apart from the uncertainties discussed above it is questionable if our description of dilepton production in elementary pion-nucleon collisions is valid since we neglect interference terms between the different contributions as well as all processes that cannot be described by a two-step process, such as the so-called πN bremsstrahlung.

In view of all these uncertainties in the theoretical description of the elementary cross section it is necessary that the inclusive cross sections for dilepton production on the nucleon are measured. Until then the following results for dilepton production on nuclei are only an educated guess—although state of the art.

During the last two years the $D_{13}(1520)$ resonance has received great interest in connection with medium-modifications of the ρ meson [13–16]. In our calculations this resonance contributes to the production of low-mass ρ mesons as well as to their absorption. About 30% of the ρ mesons in our calculations are produced via an intermediate D_{13} resonance. In Fig. 3 (upper part) we show the result of a calculation where we excluded the D_{13} resonance. Here we get a slight enhancement of the dilepton yield because absorption through this resonance is even more important than production.

In Fig. 3 (lower part) we show the result of a calculation where we assumed ''dropping masses'' for the ρ and ω meson [17]. We find a reduction of the vector meson peak around 770 MeV by about a factor 2. The enhancement of the dilepton yield for masses around 600 MeV is quite small because we already started from a quite flat ρ-meson contribution due to our implementation of the $\pi^- n$ channel and neglected medium-modifications of the $N\rho$ widths of the baryonic resonances. Therefore the total cross section for elementary ρ-meson production remains unchanged.

In Ref. [5] we describe in full detail how we implement the collisional broadening of the ρ and ω mesons in our transport calculations in a dynamical way. In Fig. 3 (lower part) we show the result of a calculation in which we took into account collision broadening in addition to the mass shift. One sees that the effect of collisional broadening is small.

In Fig. 3 (lower part) we also present the result of a calculation with a momentum dependent potential [18] for the vector mesons instead of the constant mass shift. This potential gives the previously used mass shift for $p=0$, increases linearly with momentum, and crosses zero for $p=1$ GeV; for details see Ref. [5]. The result for the dilepton spectrum is quite close to the calculation without medium modifcations because the vector mesons are produced with rather large momenta in pion-nucleon collisions.

In order to discriminate between these ''scenarios'' of in-medium modification it is helpful to look on the spectra for different momenta of the dilepton pair. In Fig. 4 we show the results of our calculations for four different momentum bins. For low momenta ($p<300$ MeV) the ''dropping mass'' scenario leads to a complete disappearance of the vector meson peak around 780 MeV because a large fraction of the ω mesons with small momenta decays inside the nucleus. With increasing momentum the fraction of ω mesons decaying outside the nucleus increases and therefore the ''vacuum peak'' becomes more pronounced in the ''dropping mass'' scenarios. The calculation with a momentum dependent potential is getting closer to the calculation without medium modifications for larger momenta since the momentum dependent potential vanishes for $p=1$ GeV.

In our calculations we assume an isotropic production of the vector mesons in the pion-nucleon center of mass system because there are only experimental data on the angular distribution for larger energies. The spectra shown in Fig. 4 depend strongly on the angular distribution in the elementary production step since different angles in the pion-nucleon center of mass system correspond to different momenta in the laboratory frame. However, a different angular distribution would primarily rescale the spectra but hardly influence the qualitative effects of the medium modifications.

In summary, we have presented a calculation of dilepton production in π^-C and π^-Pb collisions at 1.3 GeV and compared our results to previously published calculations. We have discussed the uncertainties concerning the elementary $\pi N \rightarrow e^+e^- X$ cross section and want to stress the importance of an experimental measurement of the elementary process as prerequisite for reliable calculations in nuclei. The results shown in Fig. 2, for example, could be checked with the new spectrometer HADES [2], presently under construction at GSI. Here it would be quite desirable if measurements for lower pion energies could also be performed since the contributions from secondary pions are important for pion-nucleus collisions.

We have, furthermore, investigated the effects of different scenarios of in-medium modifications for the vector mesons ρ and ω. Cuts on the momentum of the dilepton pair might be helpful to distinguish between different scenarios.

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