New results on low-mass lepton pair production in Pb-Au collisions at 158 GeV per nucleon

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The CERES/NA45 experiment at the CERN-SPS is dedicated to study the production of e^+e^--pairs in ultrarelativistic heavy ion collisions. Compared to extrapolations from results obtained in proton-induced reactions, it has previously observed an enhanced production in S-Au [1] and Pb-Au [2] collisions. To verify this enhancement and to study its properties, higher statistics were accumulated during a runtime in 1996. We report here, for the first time, on the results of this analysis (for details see ref. [3]).

1. Introduction

In heavy ion collisions at the CERN-SPS, hadronic matter is investigated at high temperature and large density. The prime motivation is to find evidence for a confinement/deconfinement phase transition of hadronic matter and/or for the restoration of the spontaneously broken chiral symmetry. Such a transition could happen in the early stages of the collision. Since lepton pairs only interact electromagnetically, their mean free path is considerably larger than the size of the collision system. They are, therefore, the most promising tool to study the entire evolution of the collision system. Most lepton pairs, however, are produced after freeze-out by decays of hadrons. These contributions can be estimated from proton-induced collisions. A significant deviation from these expected dilepton rates could indicate a signal from an earlier time of the collision.

2. Experimental Setup and Data Analysis

The main experimental challenge is to filter from some hundred charged hadrons produced in each collision the small amount of leptons. This is realized by using two ring imaging Cherenkov detectors, with a threshold ($\gamma_{th} \simeq 32$) such that 95% of all hadrons are not visible. In order to minimize the conversion probability of the large amount of photons produced in the collision, the spectrometer was constructed under the constraint of a small radiation length within the acceptance. Still, photon conversions, together with π^0-Dalitz decays, are the dominant source of e^+e^--pairs. Both types of pairs have small pair-opening angles and invariant masses well below 150 MeV/c^2. Since one can hardly hope to observe a new signal in this environment, our main interest belongs to pairs with $m > 150$ MeV/c^2. The main background in this mass region are combinatorial pairs. They arise if an event contains more than one photon conversion and/or Dalitz decay which are not recognized as such, e.g. if only one track of a pair is reconstructed. The combinatorial background extends much above 150 MeV/c^2. It can be significantly reduced by a cut on the transverse momentum of the electron/positron track, we chose 200 MeV/c. To reduce the background further each reconstructed track is inspected for relics of the partner track in the detectors in front of the magnetic field. This background rejection has to be optimized under the constraint of keeping a high efficiency for the true pairs. This optimization was achieved by a Monte Carlo simulation of the pattern of the various lepton pair sources in the spectrometer. With this rejection strategy we achieve a signal-to-background ratio of 1/13 for pair masses $m > 200$ MeV/c^2. 70% of the tracks responsible for the residual background originate from π^0-Dalitz decays, 30% from photon conversions. The signal is extracted by subtracting like from unlike-sign pairs. The simulation also allows to apply efficiency corrections.
The RICH detectors are complemented by three external tracking detectors, two radial silicon drift detectors before the first RICH and a multi-wire proportional chamber at the end of the spectrometer. They improve the spatial resolution and, therefore, the accuracy for the momentum determination, which is achieved by measuring the deflection in a magnetic field between the two RICH detectors. The momentum resolution of the spectrometer is $\Delta p/p = ((2.3\% \cdot p)^2 + (3.5\%)^2)^{1/2}$, p in GeV/c.

3. Results

Fig. 1. shows the resulting invariant mass distribution of e^+e^--pairs normalized to the number of charged particles measured in the same acceptance. For comparison also the earlier results [2] are shown.
To extract lepton pairs from earlier stages of the collision a reference measurement from p-induced collisions is needed to estimate the contributions from hadronic decays. CERES has accumulated inclusive lepton pair data in p-Be collisions in the year 1993 [4]. By an exclusive measurement of the π^0- and η-Dalitz decays in the same run it was observed that the inclusive pair yield can be fully understood by decays of hadrons. Based on this measurement a generator was developed which needs as input the production cross

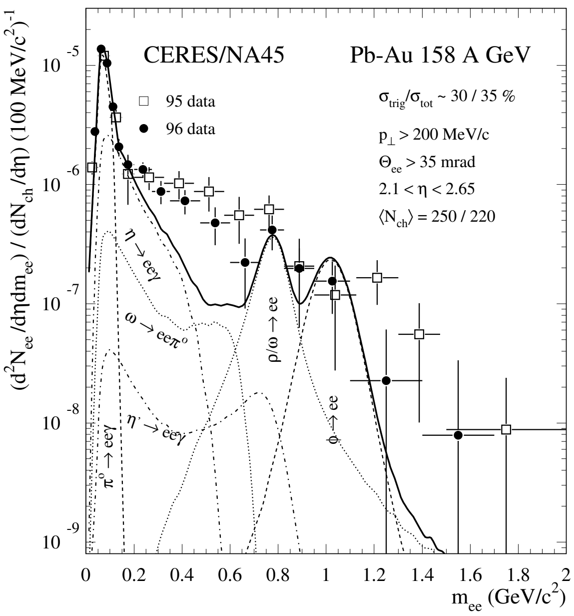

Figure 1. Inclusive e^+e^- mass spectrum obtained from the '95 and '96 data analyses. The data are compared to the sum of the expected contributions from hadron decays (solid line).

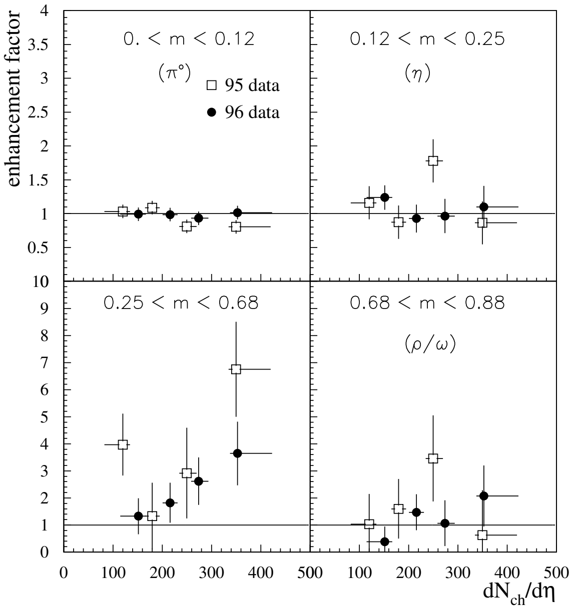

Figure 2. Enhancement factor defined by $N^{e^+e^-}_{measured}/N^{e^+e^-}_{hadronic\ sources}$ as a function of the charged multiplicity of the collision for different pair mass windows.

sections of hadrons, their kinematic properties and the branching ratios for the decay into e^+e^--pairs. While the branching ratios are expected to be unchanged in heavy ion collisions, the relative production rates and the spectral slopes are changed systematically [5] as observed by several experiments. Extrapolations of these changes are implemented into the generator and Fig. 1. shows a comparison to the experimental data. We observe good agreement below 200 MeV/c^2, where the π^0- and η-Dalitz decays dominate the yield. In the adjacent mass range up to the ρ/ω region we observe a significantly higher pair production, while in the region of the ρ/ω- and Φ resonances the data are again consistent with the predictions from hadron decays. Integrated over the mass range 0.25 GeV/c^2 $<$ m $<$ 0.7 GeV/c^2 the pair-yield is enhanced by a factor of 2.6 $\pm$0.5(stat.)$\pm$0.5(syst.) for '96 and 3.9 $\pm$0.9(stat.)$\pm$0.9(syst.) for '95. A comparison to a generator scaled from p-p collisions would indicate enhancement factors which are higher by 30%. The centrality selection of the two data sets is slightly different, the mean number of charged particles per unit of rapidity is $<N_{ch}>$ = 250/220 for '96/'95.

The pair-yield as a function of the accompanying number of charged particles is a tool to disentangle different production mechanism for the pairs. This dependence is shown in Fig. 2 where the ratio between the measured and generator pair-yield as a function of multiplicity is shown. Since the expectations from hadron decays grow linearly with the multiplicity, a constant enhancement indicates a linear $dN/d\eta$ dependence. While in the mass bins without enhancement such a dependence is visible, in the mass bin 0.25 MeV/c^2 $<$ m $<$ 0.68 MeV/c^2 it grows stronger than linear.

Both data sets show that the enhancement is most pronounced for small pair transverse momenta (Fig. 3.). However, this enhancement at low $p_\perp$ appears stronger in the '95

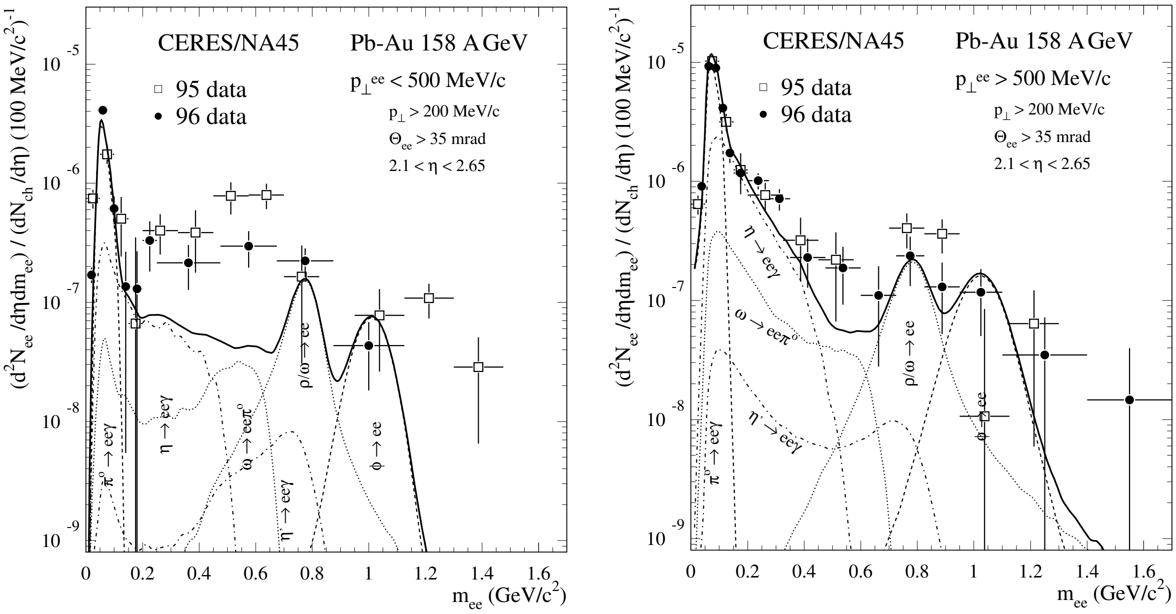

Figure 3. Inclusive e^+e^- mass spectra obtained from the '95 and '96 data analyses, separated into samples with high and low pair-$p_\perp$. The data are compared to the expected contributions from hadron decays. The enhancement is most pronounced for low pair-$p_\perp$.

data. We are investigating this systematic deviation.

4. Conclusion and Outlook

The analysis of the '96 data set has confirmed the observations of the previous CERES analyses of a low mass dilepton enhancement. Various theoretical approaches explain the observed enhancement (for an overview see ref. [6]). Most theorists agree that the additional dilepton yield originates from $\pi\pi$-annihilation in the hot hadron gas. The debate whether the yield shows a signal for the restoration of spontaneously broken chiral symmetry is still inconclusive. For definite conclusions better experimental information is needed. Therefore CERES has upgraded the spectrometer by an additional radial TPC [7] to improve the mass resolution and the signal-to-background ratio of the measurement, as well as by a new data acquisition system to provide significantly higher rate capabilities.

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