Recent results from CERES

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Abstract

A di-electron spectrum, measured by CERES in Pb-Au collisions at 40 GeV per nucleon, exhibits an enhancement over the level expected from hadron decays. The enhancement is similar to the one seen previously in the data acquired with the full SPS energy. In addition, the upgraded CERES allows for high statistics hadron measurements. Some results from these measurements at various beam energies are presented.

1 Introduction

CERES is a dilepton experiment at the CERN SPS [1]. Built and commissioned in the early nineties, it became known for its observation of enhanced production of low mass di-electron pairs in S-Au and Pb-Au collisions at the respective full SPS energies of 200 and 160 A·GeV[2, 3, 4]. The enhancement turned out to be absent in proton induced collision – there, the measured pair distributions agreed well with the ones expected from hadron decays [5]. The fact that the enhancement is characteristic to heavy ion systems and, moreover, limited to invariant masses above approximately twice the pion mass, indicates that pion annihilation $\pi\pi \rightarrow \rho \rightarrow e^+e^-$ might be the underlying process. However, the shape of the enhancement is not consistent with the spectral shape of the ρ meson. To account for the data, the ρ peak needs to be shifted and/or broadened. On the other hand, according to theory, this is exactly what happens when the ρ is immersed in high density hadronic matter. The two most prominent theoretical approaches predict a shift of the peak to lower masses [6] or a broadening and a slight shift up [7]. The beam energy dependence may help to distinguish between these two scenarios. This is why CERES took data in a low energy (40 A·GeV) run at the SPS in 1999. Preliminary results from this run were presented at the Quark Matter 2001 conference [8]. In this contribution I show an updated dilepton spectrum and some of the recent hadronic results.

2 Experiment

The upgrade of CERES by a radial time projection chamber (TPC) allowed to separate two key functions of the apparatus, tracking and particle identification, while retaining the cylindrical symmetry. The upgraded experiment is shown in Fig. 1. Charged particles emitted from the segmented target with pseudorapidity $2.1<\eta<2.65$ first pass through two silicon drift detectors (SDD) located at 100 mm and 138 mm from the target. The combined information of these detectors gives the interaction vertex with accuracy $\Delta z = 200\ \mu$m, z being along the beam axis, and allows to select products of weak decays. Subsequently, the particles traverse two RICH detectors with γ_{THR}=32 for electron identification. In the upgraded CERES the magnetic field between the two RICHes has been switched off and thus the rings became aligned. The efficiency of the combined RICHes for electrons and hadrons is 0.94 and 0.05, repectively, the remaining hadrons being hard pions. Finally, the particles cross the newly built TPC [9]. The ionisation electrons drift outward towards readout chambers. The electric field is inversely proportional to the radius and thus the drift is fastest where the hit density is highest. The semi-radial magnetic field bends particle tracks in azimuthal direction. The design momentum resolution is such that the reconstructed ω mass peak should have a 2% width. The

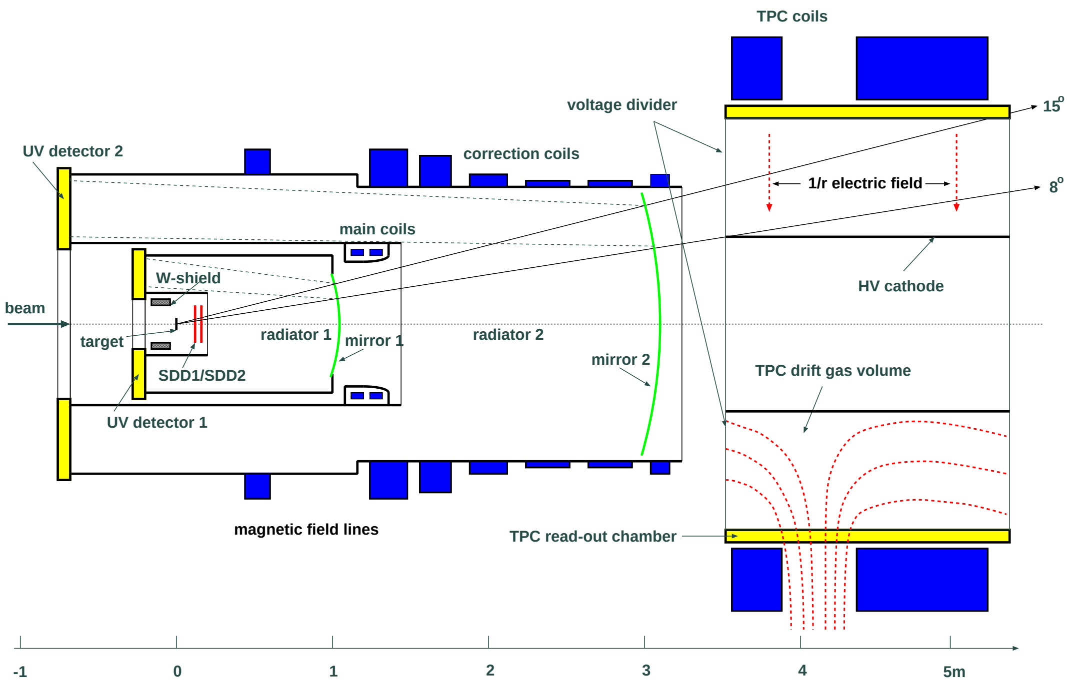


Figure 1: The upgraded CERES setup in 1999 and 2000. The apparatus has a cylindrical symmetry. The beam enters from the left. The silicon detectors give tracking and vertex reconstruction, the RICHes particle identification, and the TPC measures momentum and energy loss.

energy loss in the TPC can be used for additional particle identification. A typical central Pb-Au event, after zero suppression, has a size of 0.5 MByte. Typical data acquisition rate is 200-600 events per SPS burst, depending on the centrality trigger threshold.

3 Leptons in Pb-Au collisions at 40 A·GeV

The 40 A·GeV Pb-Au run took place in fall 1999. About $8 \cdot 10^6$ events with 30% centrality were recorded. A malfunctioning TPC readout seriously limited the efficiency. The invariant mass distribution for e^+e^- pairs is obtained in the following way. First, electrons are identified by requiring that ten or more photon hits in RICH1 and RICH2 form a ring with an appropriate (i.e. asymptotic) radius. Second, a transverse momentum of at least 0.2 GeV/c is requested in order to suppress e^+e^- pairs from π^0 Dalitz decay as well as pairs produced via photon conversion in target and in the silicon detectors. Third, misidentified pions are removed by a cut on energy loss in the TPC. Fourth, those conversion and Dalitz pairs, which are too close to make two separated rings in RICHes, are removed by an upper limit on the energy loss in the silicon detectors. Fifth, electron tracks which have another SDD-RICH track candidate within 70 mrad are removed. Sixth, electron tracks are combined in pairs and for each pair the invariant mass is calculated. Unlike-sign pairs with invariant mass below 0.2 GeV/c^2 are assumed to be Dalitz pairs. These pairs are kept but the two legs are excluded from further combinatorics. Seventh, twice the geometrical average of the two like-sign invariant mass distributions is subtracted from the unlike-sign one. Under the assumption that there are no sources of correlated like-sign pairs this removes the combinatorial background. A detailed description of the electron analysis can be found in [10] and [11].

The cuts suppress unwanted background by orders of magnitude while the efficiency for open pairs is still about 50%. This number, combined with the losses during identification and tracking, gives an overall pair efficiency of 0.05. The efficiency corrected invariant mass distribution shows an enhancement over the cocktail of pairs expected from hadron decays (Fig. 2, left panel). The excess is similar to (or even somewhat larger than) the one observed at full SPS energy. Calculations which include the modification of the ρ spectral function [12] agree quite well with the data, as shown in the right panel of Fig. 2. The lowest (thin solid) curve represents a cocktail without ρ. The calculations based on $\pi^+\pi^-$ annihilation with an unmodified ρ, a dropping, and a broadened ρ mass are shown as a thin dashed, a thick solid, and a thick dashed line, respectively. The cocktail and the theoretical calculations have the current experimental mass resolution (twice the design value) folded in. The statistical errors of the measurement do not allow to falsify any of

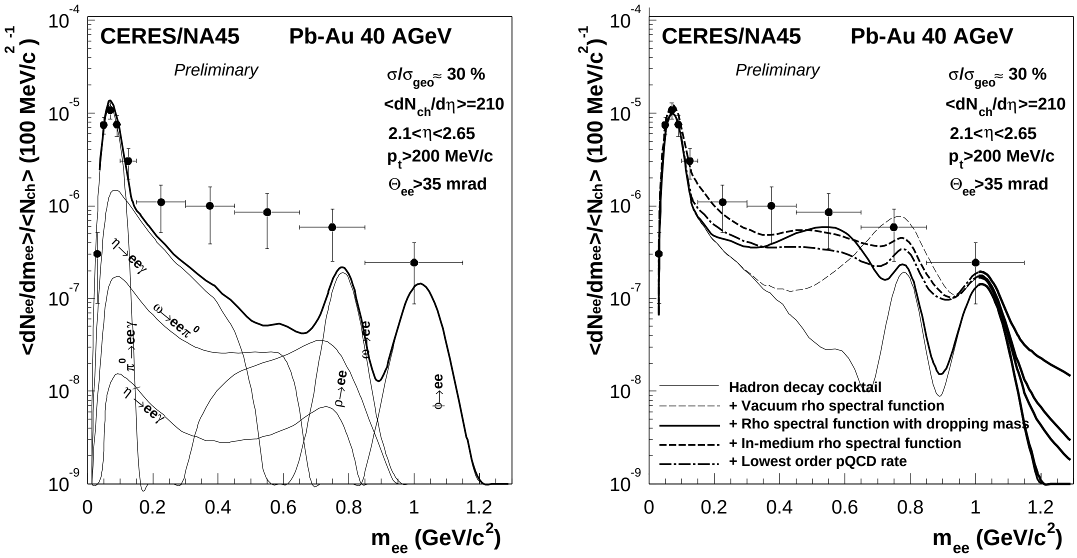


Figure 2: Invariant mass distribution of e^+e^- pairs recorded in central Pb-Au collisions at 40 A·GeV. Left: the data exceed the level expected from hadron decays ("cocktail") in the mass range between 0.2 GeV/c^2 and m_ρ. Right: reasonable agreement with calculations which include pion-pion annihilation with medium modifications of the ρ spectral function.

the two considered ρ modification scenarios. Both kinds of modification bring the shape of the distribution closer to the data and also to the calculation based on $q\bar{q}$ annihilation (thick dash-dotted line in the right panel of Fig. 2). In fact, as was no-

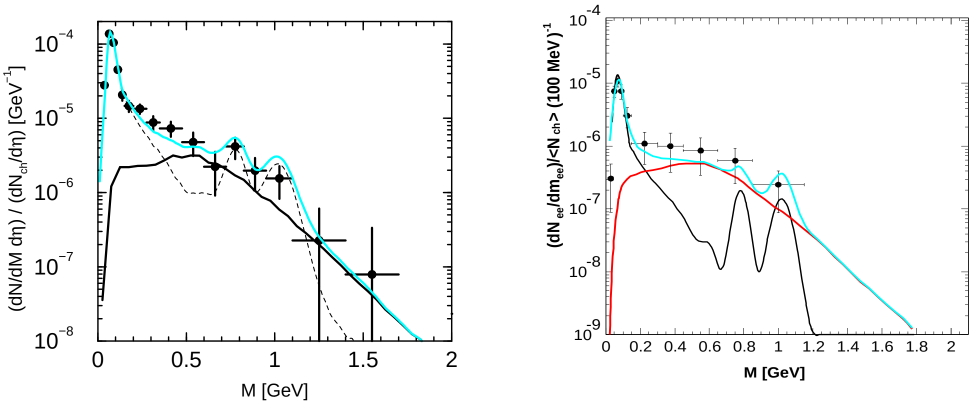


Figure 3: CERES e^+e^- mass distribution from central Pb-Au collisions at 160 A·GeV (left) and at 40 A·GeV (right), compared to a calculation including thermal radiation from QGP [13].

ticed by B. Kämpfer, adding the thermal $q\bar{q}$ annihilation channel to the hadron decay cocktail allows to reproduce nicely the di-electron spectra measured by CERES at 40 and at 160 A·GeV (Fig. 3). At 160 A·GeV the same calculation explains the dimuon excess at intermediate masses seen in NA50, otherwise attributed to enhanced open charm production, and the direct photons observed by WA98 [13].

4 Centrality dependence of hadron yields in Pb-Au collisions at 40 A·GeV

The negative hadron yield, measured in Pb-Au collisions at 40 A·GeV, showed a faster-than-linear increase with the number of participants [8]. The measurement covered the top 30% of the geometrical cross section of 6.9 barn. The number of participants was determined using the UrQMD 1.2 event generator [14]. The result, shown in the left panel of Fig. 4, was intriguing because a similar effect had been observed at the AGS [15], was shown to be practically absent at the full SPS energy [16], and finally reappeared at RHIC where it was interpreted as the signature of hadron production in hard processes [17]. However, the number of participants N_{part}, and with it the considered effect, is obviously model dependent. When the nuclear overlap model [18] is used to determine N_{part} for each centrality class, the

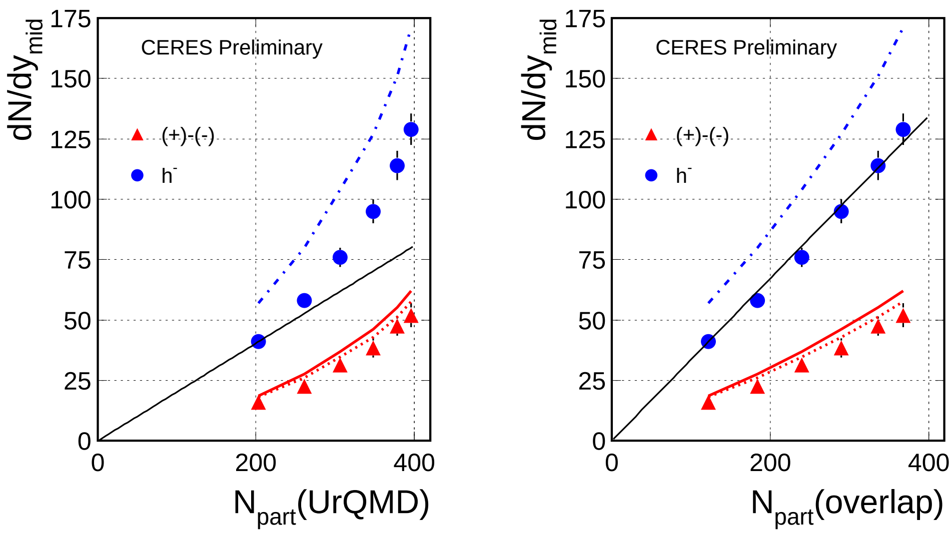
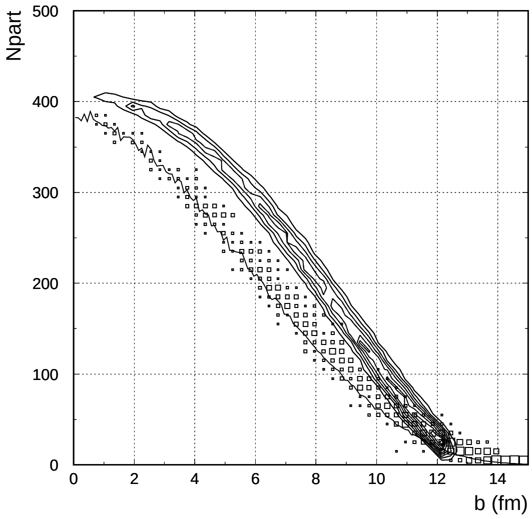


Figure 4: Dependence of the hadron yield on centrality. The number of participants N_{part} was determined using UrQMD 1.2 (left) and via a nuclear overlap calculation (right).



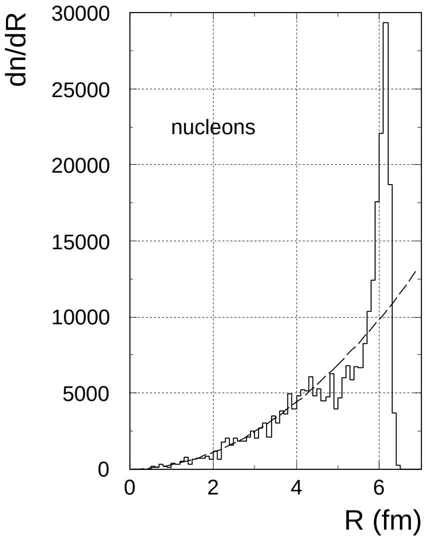


Figure 5: Left: Number of participants in UrQMD (contour) and in the geometrical overlap model (line). For comparison, VENUS event generator is shown as boxes. The collision system is Pb+Au at 40 (UrQMD) or 80 (VENUS) A·GeV. Right: distribution of nucleons within a Pb nucleus used in UrQMD 1.2 (arbitrary units). The dashed line corresponds to a constant density of 0.17 fm^{-3}.

non-linear increase nearly disappears, as shown in the right panel of Fig. 4. In fact, a comparison of the two models demonstrates that UrQMD has a systematically higher number of participants than the overlap model at the same impact parameter (Fig. 5). The discrepancy is much larger than the N_{part} fluctuations in UrQMD and, as it seems, has two reasons. The first reason is that the distribution of nucleons within a nucleus, used in UrQMD 1.2, exhibits a spurious peak close to the edge of the nucleus as shown in the right panel of Fig. 5. The peak is a side effect of an attempt to implement the Pauli principle. The problem is currently under investigation and will be fixed in the next release of UrQMD [19]. The second reason for a difference between UrQMD and a geometrical overlap model is of a more general nature. While in the overlap model the nucleon trajectories are straight and to become a participant a projectile (target) nucleon has to collide with one of the target (projectile) nucleons, in UrQMD the nucleons can, in addition, become participants by getting hit by a secondary particle. This leads to the question which of these two different physical quantities one wants to normalize hadron yields to. Since a secondary particle punching through the spectator matter does not significantly contribute to hadron production, the N_{part} from the overlap model seems to be more appropriate for normalization purposes. In fact, the overlap approach is widely used for this at RHIC.

The popularity of the geometrical overlap approach grew enormously in the recent years. Trying to be useful and fashionable at the same time we put our version on the web [20]. The number of participants and the number of binary collisions for a given collision system and a given centrality can be calculated using a web interface. The beam energy enters only via the inelastic nucleon-nucleon cross section which increases from about 30 mb at SPS to about 60 mb at LHC. The user has a choice between the sharp sphere and the Woods-Saxon density profile.

5 Λ production in Pb-Au collisions at 40 A·GeV

Using negative charge tracks with p_T>0.25 GeV/c and positive ones with p_T>0.5 GeV/c and assuming for them, respectively, to be π^- and protons, Λ decays were reconstructed in the CERES data from Pb-Au collisions at 40 A·GeV [21]. The two tracks were requested to come from a common vertex. A requirement for this vertex to be displaced by at least 50 cm from the target was optionally used to obtain a clean Λ sample. With all the cuts the acceptance for Λs with p_T=2 GeV/c was about 1%. The reconstructed Λ mass and lifetime (Fig. 6) agree with the PDG values. The Λ mass peak is wider than expected based on simulations because the calibration of the TPC is still in progress and the design momentum resolution has not yet been reached.

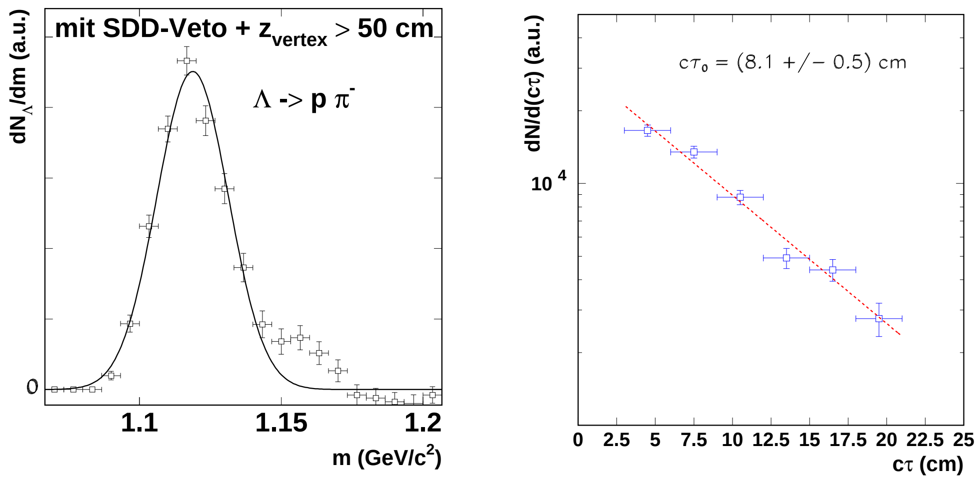


Figure 6: The reconstructed mass and lifetime of the measured Λ's.

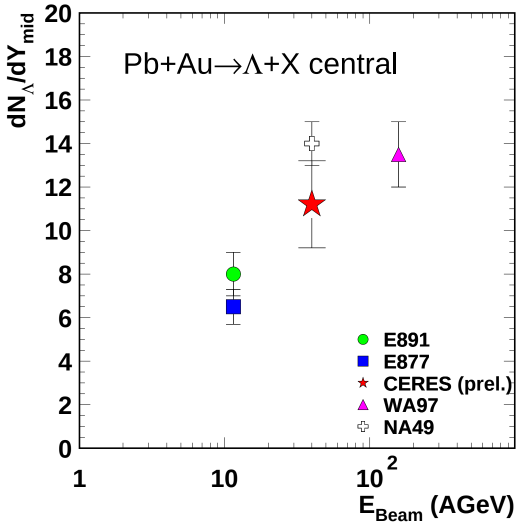


Figure 7: Λ yield plotted versus beam energy. The 40 A·GeV CERES point smoothly follows the systematics without indication of any structure.

The Λ measurement is interesting because of the peak in the strangeness-to-entropy ratio predicted to be there around this beam energy [22]. However, the slopes and the yields determined in our measurement smoothly follow the beam energy systematics and do not support this expectation (Fig. 7).

6 Event by event fluctuations of transverse momentum and of electric charge

A preliminary analysis of transverse momentum fluctuations in the CERES Pb-Au data at 160 A·GeV gave a Φ_{pt} of 9±2 MeV/c. The Φ_{pt} variable was introduced in [23] and is defined such that it should be zero if the fluctuations were of purely statistical nature. The non-zero value of Φ_{pt}, obtained from analysis of CERES data, was somewhat surprising because it apparently contradicted the well known zero-result of NA49 [24]. The discrepancy is lifted when the data is plotted versus rapidity: the zero-result of NA49 and the non-zero one of CERES were obtained for forward- and mid-rapidities, respectively. Recent preliminary analysis of the NA49 data, performed in rapidity bins of the 0.5 unit width, gives a Φ_{pt} smoothly decreasing from 10-15 MeV/c at midrapidity to about zero in forward rapidity, in agreement with both the CERES result and the earlier NA49 one.

It has been suggested recently that the magnitude of charge fluctuations observed event-by-event can be used as a QGP signature [25, 26]. The D observable, defined as four times the ratio between the variance of net charge and the mean charged particle multiplicity, after correcting for acceptance and for the initial isospin asymmetry was predicted to be 4 for hadron gas, 3 for hadron gas with resonances, and 1 for QGP. A preliminary analysis of CERES data at 80 and 160 A·GeV yields a value of slightly above 4, in agreement with the preliminary NA49 result. This value is in contradiction with the theoretical expectation, given the common belief that at 160 A·GeV the collision system goes through the QGP phase.

7 Summary

Analysis of the 40 A·GeV data, taken in 1999, has been practically completed. The low mass dilepton spectrum at 40 A·GeV shows an excess similar or larger than the one observed previously at full SPS energy. The previously reported enhanced hadron production in central collisions at 40 A·GeV strongly depends on the model used to obtain N_{part} and is much reduced when a simple geometrical overlap model is being used instead of UrQMD. The Λ yield at 40 A·GeV shows no indication of strangeness enhancement above the level expected from the interpolation between the full energy AGS and SPS measurements. Non-statistical event-by-event fluctuations of transverse momentum were observed in the CERES data, subsequently confirmed by NA49. The amount of charge fluctuations is characteristic to hadron gas. This has not yet been understood.

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