New results from CERES

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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.

I. 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 [2–4]. 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 $\pi\pi \to \rho \to e^+e^-$ 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 those results of hadron measurement which have changed in the meantime.

II. 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< η <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 $\Delta z = 200$ μm, 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. 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. In

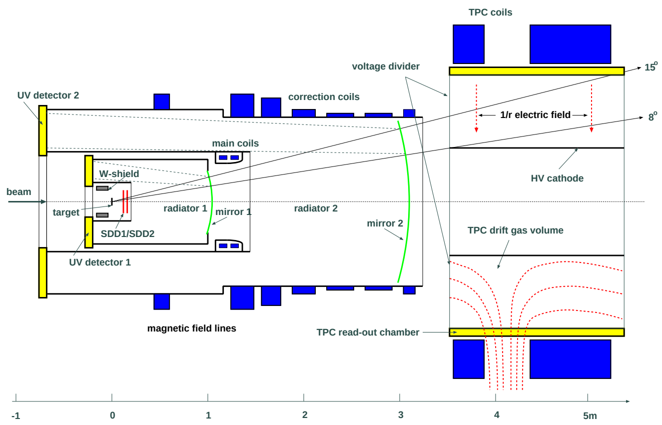

FIG. 1. The upgraded CERES setup in 1999 and 2000. The apparatus has cylindrical symmetry. The beam enters from the left. The silicon detectors give tracking and vertex reconstruction, the RICHes particle identification, and the TPC measures momentum and energy loss.

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

III. 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 required 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.

The cuts suppress unwanted background by orders of magnitude while the efficiency for open pairs is still about 50 % (Fig. 2). 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. 3). The excess is similar to the one observed at full SPS energy. Calculations which include the modification of the ρ spectral

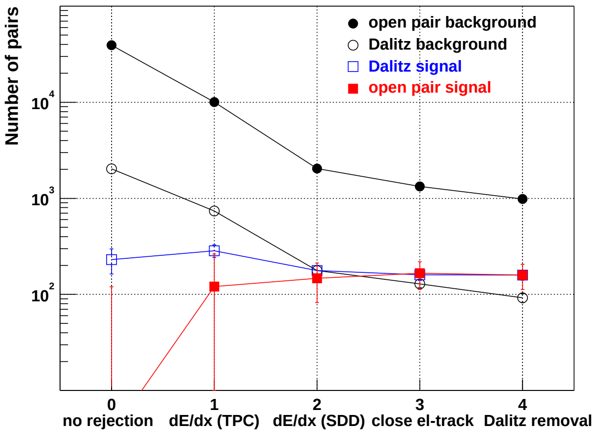

FIG. 2. Number of electron pairs after each analysis step. The cuts reduce the Dalitz signal to half and the background by more than one order of magnitude.

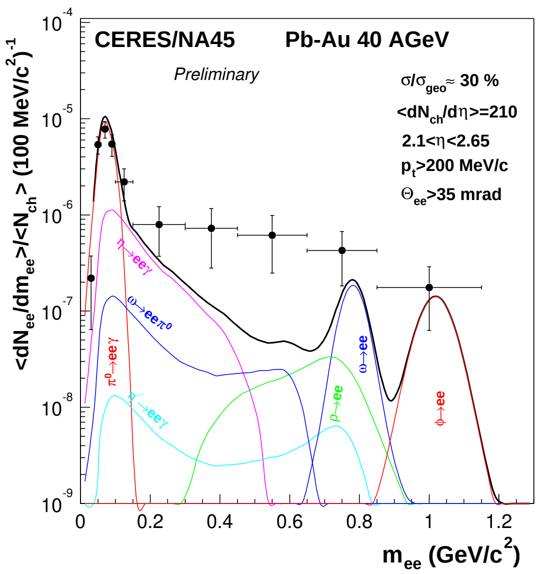

FIG. 3. Invariant mass distribution of e^+e^- pairs recorded in central Pb-Au collisions at 40 A·GeV. The measured yield (points) exceeds the expected one (uppermost line) in the mass range between 0.2 GeV/c^2 and m_ρ.

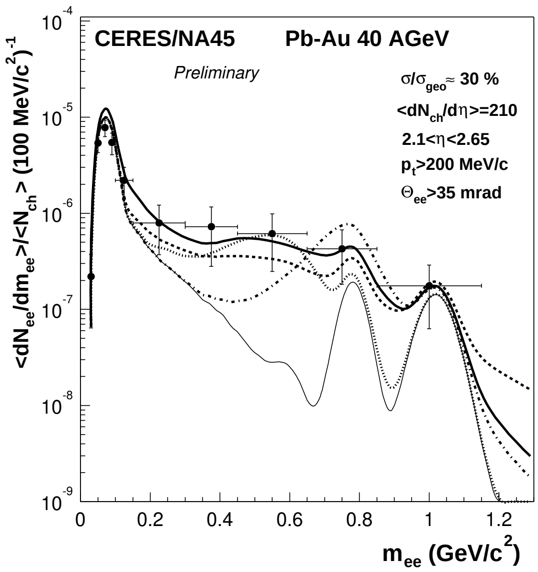

FIG. 4. Invariant mass distribution of e^+e^- pairs recorded in central Pb-Au collisions at 40 A·GeV compared to theoretical calculations. For description of the curves see text.

function agree quite well with the data, as shown in Fig. 4. The lowest 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 dashed-dotted, a dotted, and a thick solid line, respectively. Both kinds of ρ modification bring the shape of the distribution closer to the calculation based on $q\bar{q}$ annihilation (thick dashed line). All calculations are from [9].

The cocktail and the theoretical calculations in Fig. 3 and 4 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 the considered scenarios. A more detailed description of the electron analysis and a discussion of the mentioned theories can be found in [10].

IV. CENTRALITY DEPENDENCE OF HADRON YIELDS IN PB-AU COLLISIONS AT 40 A·GeV

The negative hadron yield, measured by CERES 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 event generator [11]. The result, shown in the upper panel of Fig. 5, is intriguing because a similar effect was observed at the AGS [12], shown to be practically absent at the full SPS energy [13], and finally reappeared at RHIC where it was interpreted as the signature of hadron production in hard processes [14].

The number of participants N_{part}, and with it the considered effect, is obviously model dependent. When the nuclear overlap model [15] is used to determine N_{part} for each centrality class, the non-linear increase nearly disappears, as shown in the lower panel of Fig. 5. 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. 6). The discrepancy is much larger than the N_{part} fluctuations in UrQMD.

The most probable explanation is that 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,

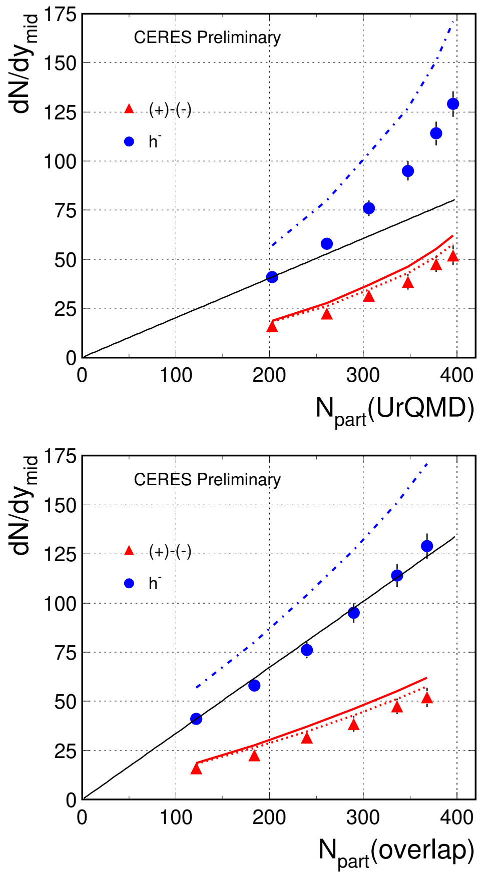

FIG. 5. Dependence of the hadron yield on centrality. The number of participants N_{part} was determined using UrQMD (upper panel) and via a nuclear overlap calculation (lower panel).

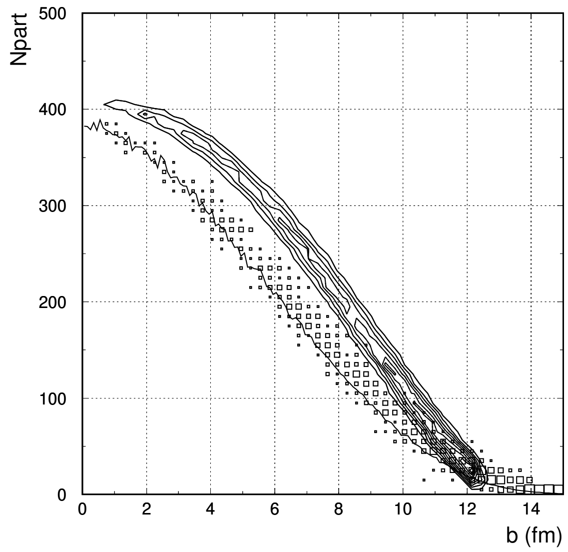

FIG. 6. Number of participants in UrQMD (contour) and in the geometrical overlap model (line). For comparison, VENUS event generator is shown as boxes.

the geometric overlap approach is widely used for this at RHIC.

The popularity of the easy-to-follow geometrical overlap calculation made us put our version on the web. 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 [16]. 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.

V. 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 [17]. The invariant mass distribution is shown in Fig. 7. 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 Λ mass and lifetime (Fig. 8) are consistent with the table values. The TPC calibration is still in progress and the design momentum resolution has not yet been reached. Consequently, the width of the Λ mass peak is larger than expected based on simulations.

The Λ measurement is particularly interesting because of the predicted peak in the strangeness-to-entropy ratio which should be located at approximately this beam energy [18]. The slopes and the yields determined in our measurement tightly follow the beam energy systematics and do not support this expectation (Fig. 9).

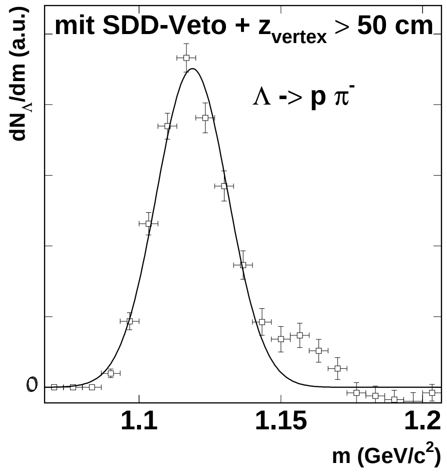

FIG. 7. Reconstructed Λ peak in the invariant mass distribution with a vertex cut.

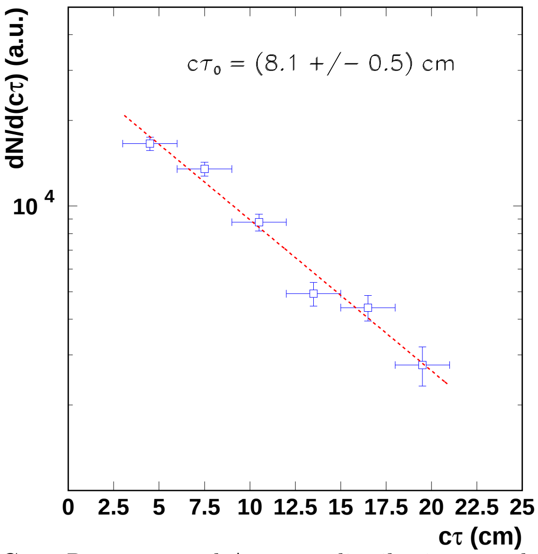

FIG. 8. Reconstructed Λ vertex distribution translated to lifetime. The mass and the lifetime of the reconstructed Λs are consistent with the PDG values.

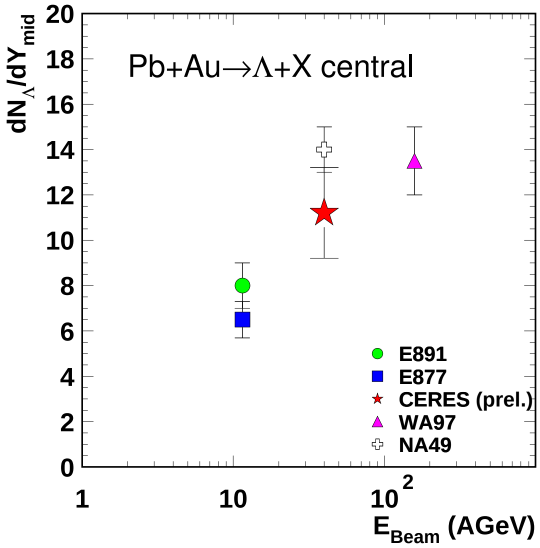

FIG. 9. Λ yield plotted versus beam energy. The 40 GeV point smoothly follows the systematics without an indication of any structure.

VI. TWO-PARTICLE CORRELATIONS IN PB-AU COLLISIONS AT 80 A·GeV

In fall 2000, in addition to the five weeks measurement at full SPS energy CERES took a one-night-run of central Pb-Au collisions at 80 GeV per nucleon. The results of the preliminary analysis of two-particle correlations from this run are shown in Fig. 10. The hadrons were not identified. The positive and negative like-sign pairs were combined. The three-dimensional correlation functions were generated according to the Bertsch-Pratt formalism, corrected for finite size Coulomb, and fitted by Gaussian. The extracted radii parameters are shown as a function of p_T. $R_{\rm out}$, which is affected by the finite momentum resolution much more than the other two radii, is not shown. Following [19], the total duration of the expansion τ_0 of about 7 fm (independent on centrality) was deduced from the $R_{\rm long}$ dependence on p_T:

$$R_{\rm long} = \tau_0 \sqrt{T/m_T} \tag{1}$$

with

$$m_T = \sqrt{m_\pi^2 + p_T^2}\ . \tag{2}$$

The p_T dependence of $R_{\rm side}$ gave a transverse expansion velocity β_T=0.22 and 0.55, as well as a geometrical size $R_{\rm geo}$=5 fm and 8 fm for the most peripheral and the most central bin, respectively. For this, the radii were fitted by [20]

$$R_{\rm side} = \frac{R_{\rm geo}}{\sqrt{1 + m_T \beta_T^2/T}}. \tag{3}$$

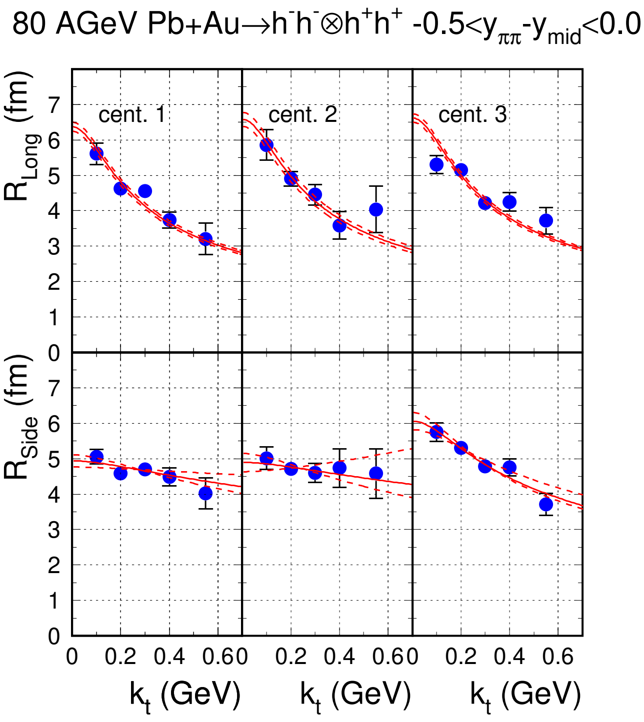

FIG. 10. Radius parameters obtained in the fit to three-dimensional, Coulomb corrected two-particle correlation functions. The p_T dependence of the radii gives the expansion duration and the transverse flow velocity.

In both cases a temperature T=0.12 GeV was assumed. The obtained expansion duration τ_0 and transverse velocity β_T are similar to the ones seen at 40 A·GeV [8]. Thus, based on this very preliminary analysis there is no indication of anything unusual in the expansion phase at 80 A·GeV.

VII. SUMMARY AND OUTLOOK

In this contribution I presented the CERES analysis results obtained since the Quark Matter conference in January 2001.

The 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 to 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 collision geometry in the model used to obtain $N_{\rm part}$. The effect 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.

Finally, first analysis of the two-particle correlation at 80 A·GeV gives radii similar to those at 40 and 160 A·GeV.

The CERES collaboration plans to participate in the 20/30 A·GeV runs at the SPS in fall 2002. The lower initial temperature and the higher net baryon density, expected at these energies, may help to distinguish between the baryon-density and temperature driven dilepton production scenarios. Also, according to [21] at approximately this energy the significant fraction of the evolution time of the fireball is spent in the mixed phase of quark gluon plasma (QGP) and hadronic gas (HG). Since the mixed phase is softer than both QGP and HG, the duration of the reaction should be higher than at other beam energies ("softest point"). The duration can be accessed via hadronic observables. This run, presumably, would conclude the experimental program of the CERES experiment.

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