

## Study of dielectron production in C+C collisions at 1 AGeV

HADES Collaboration

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## Abstract

The emission of  $e^+e^-$  pairs from C+C collisions at an incident energy of 1 GeV per nucleon has been investigated. The measured production probabilities, spanning from the  $\pi^0$ -Dalitz to the  $\rho/\omega$  invariant-mass region, display a strong excess above the cocktail of standard hadronic sources. The bombarding-energy dependence of this excess is found to scale like pion production, rather than like eta production. The data are in good agreement with results obtained in the former DLS experiment.

*Key words:* Dilepton spectroscopy, heavy-ion reactions, excess yield, excitation function, DLS puzzle  
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## 1. Introduction

An enhanced yield of dileptons with masses below the vector-meson (i.e.  $\rho^0$  and  $\omega$  meson) pole mass appears to be a general feature of heavy-ion reactions, from bombarding energies as low as 1 AGeV, studied by the former DLS experiment [1] at the Bevalac, through the range of SPS energies (40–158 AGeV) used by the CERES [2] and NA60 [3] experiments at CERN, up to the highest energies (with  $\sqrt{s_{NN}} = 200$  GeV) employed by the PHENIX experiment [4] at the RHIC collider. This enhancement is defined as the excess of the measured pair yield over the summed-up cocktail of dileptons from long-lived sources, namely the decays of  $\pi^0$ ,  $\eta$ , and  $\omega$  mesons. It is hence expected to probe the early phase of the collision and, in particular, the in-medium behavior of short-lived hadronic resonances, as e.g. the  $\rho$  and  $\Delta$  [5,6,7]. However, while the dilepton enhancement observed at the SPS has been related to modifications of the  $\rho$ -meson spectral function in the hadronic medium [8,9], the large pair yields found by DLS in 1 AGeV C+C and Ca+Ca collisions remain to be explained satisfactorily [10,11,12,13].

The High-Acceptance DiElectron Spectrometer HADES at GSI, Darmstadt, has started a systematic investigation of dilepton production in the SIS/Bevalac energy regime of 1–2 AGeV. First re-

sults obtained in 2 AGeV C+C collisions [14] confirmed indeed the general observation of enhanced emission of  $e^+e^-$  pairs with invariant masses of 0.15 – 0.50 GeV/ $c^2$ . In this Letter we report on a measurement of inclusive electron-pair emission from  $^{12}\text{C}+^{nat}\text{C}$  collisions at a kinetic beam energy of 1 AGeV, i.e. the energy of the DLS experiment. Together with our results obtained at 2 AGeV, this allows to discuss the beam-energy dependence of the pair yield. In addition, a direct comparison with the DLS results [1] becomes now possible.

## 2. Experiment

In the experiment, a  $^{12}\text{C}$  beam of  $10^6$  particles/s was incident on a target of natural carbon with a thickness corresponding to 4.6% of one nuclear interaction length. The configuration of the HADES spectrometer, described in detail in Refs. [15,16], was basically identical to the one used in our former 2 AGeV C+C run [14]. To increase the acquired pair statistics, besides a charged-particle multiplicity trigger (LVL1), an online electron identification (LVL2) has been operated as part of the two-level trigger system [14]. All results presented here were obtained from events with a positive LVL2 trigger decision, with a total statistics corresponding to  $1.1 \times 10^9$  LVL1 triggered events. One major difference to the former run was the presence of up to four planes of tracking drift chambers (two inner and one or two outer), of which, however, only the two inner

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planes were used in the extraction of the results presented here. This modus operandi was motivated by the goal to simplify any comparison with the results of our 2 AGeV run obtained within a low-resolution mode. In the latter the reconstruction of outer track segments is based solely on the position information obtained from the Time-of-Flight and Pre-Shower detectors (see [14] for details). The lepton identification and dilepton-reconstruction were done following the same scheme as used for the 2 AGeV data. All this resulted in a momentum and mass resolution, as well as a pair acceptance very similar to those characteristic of the former run, making the comparison of the two data sets unproblematic. As will become apparent below, the achieved mass resolution of  $\sigma_{M_{ee}}/M_{ee} = 9\%$  at  $M_{ee} = 0.8 \text{ GeV}/c^2$  is largely sufficient to resolve all spectral features. Results from a high-resolution analysis based on all four drift-chamber planes will, however, be presented in another, forthcoming publication.

In the pair analysis [17], opposite-sign  $e^+e^-$ , as well as like-sign  $e^+e^+$  and  $e^-e^-$  pairs were formed and subjected to common selection criteria, in particular to an opening-angle cut of  $\theta_{ee} > 9^\circ$ . From the reconstructed like-sign distributions, e.g. the invariant mass  $dN^{++}/dM_{ee}$  and  $dN^{--}/dM_{ee}$ , the combinatorial background (CB) of uncorrelated pairs was calculated bin by bin as  $N_{CB} = 2\sqrt{N^{++}N^{--}}$ . For masses  $M_{ee} > 0.2 \text{ GeV}/c^2$ , where statistics is small, the CB was obtained by an event-mixing procedure. Finally, after subtracting the CB, a total of  $\simeq 18000$  signal pairs ( $\simeq 650$  with  $M_{ee} > 0.15 \text{ GeV}/c^2$ ) was thus reconstructed.

Detector and reconstruction efficiencies  $\epsilon_{\pm}(p, \theta, \phi)$  were determined from Monte-Carlo simulations by embedding electron and positron tracks into  $^{12}\text{C}+^{12}\text{C}$  events generated with the UrQMD transport model [18]. The experimental data were then corrected on a pair-by-pair basis with the weighting factor  $1/E_{+-}$ , with  $E_{+-} = \epsilon_+ \cdot \epsilon_-$ . The geometrical pair acceptance of the HADES detector was obtained in analogy to the pair efficiency as the product of two single-electron acceptances  $A_{\pm}(p, \theta, \phi)$ . The resulting matrices, together with a momentum resolution function, constitute the HADES acceptance filter (for more details see [14]). These acceptance matrices are available from the authors on request.

### 3. Results on pair production

Fig. 1(a) shows the  $e^+e^-$  invariant-mass distribution of the signal pairs after efficiency correction and normalized to the average number of charged pions  $N_{\pi} = \frac{1}{2}(N_{\pi^+} + N_{\pi^-})$ , measured as well with HADES and extrapolated to  $4\pi$  solid angle. In the isospin-symmetric system  $^{12}\text{C}+^{12}\text{C}$ , and for small contributions from  $\eta$  and  $\omega$  decays,  $N_{\pi}$  is also a good measure of the  $\pi^0$  yield, i.e.  $N_{\pi} = N_{\pi^0}$ . This way of normalizing the pair spectra compensates to first order the bias caused by the implicit centrality selection of our trigger. Indeed, simulations based on UrQMD events show that LVL1 events have an average number of participating nucleons  $A_{part} = 8.6$ , instead of 6 for true minimum-bias events. The pion multiplicity per number of participating nucleons  $M_{\pi}/A_{part} = 0.061 \pm 0.009$  obtained in our experiment agrees with previous measurements of charged and neutral pions [19,20] within the quoted error of 15%. The latter is dominated by systematic uncertainties in the acceptance and efficiency corrections of the charged-pion analysis, and it represents our overall normalization error. In addition, the uncertainties caused by the lepton-efficiency correction and the CB subtraction add up quadratically to point-to-point systematic errors of 22% on  $dN^{+-}/dM_{ee}$ .

In Fig.1 we compare the data with a pair cocktail calculated from free  $\pi^0 \rightarrow \gamma e^+e^-$ ,  $\eta \rightarrow \gamma e^+e^-$ ,  $\omega \rightarrow \pi^0 e^+e^-$ , and  $\omega \rightarrow e^+e^-$  meson decays only (cocktail A). This cocktail aims at representing all contributions from decays of mesons in vacuum after the chemical and thermal freeze-out of the fireball. While the first two of these sources are directly constrained by published data [19] with uncertainties of 10% ( $\pi^0$ ) and 25% ( $\eta$ ), respectively, the (small) multiplicity of the  $\omega$  meson is taken from an  $m_{\perp}$ -scaling ansatz [21]. We followed here the same procedure as applied for our 2 AGeV data [14], making use of the PLUTO event generator [22]. Meson production was modeled assuming emission from a thermal source with an effective temperature  $T = 55 \text{ MeV}$ ; C+C being a very small system, zero radial expansion ( $\beta_r=0$ ) has been assumed. Furthermore, for  $\pi^0$  and  $\eta$  mesons, an anisotropic polar distribution of the type  $dN/d\cos(\theta_{CM}) \sim 1 + a_2 \cdot \cos^2(\theta_{CM})$  was used: with  $a_2 = 0.5$  for  $\pi^0$ , consistent with our charged-pion analysis, and  $a_2 = 0.8$  for  $\eta$ , as inspired by transport calculations [21,18]. Effects due to a possible polarization of the virtual photon [23] were not

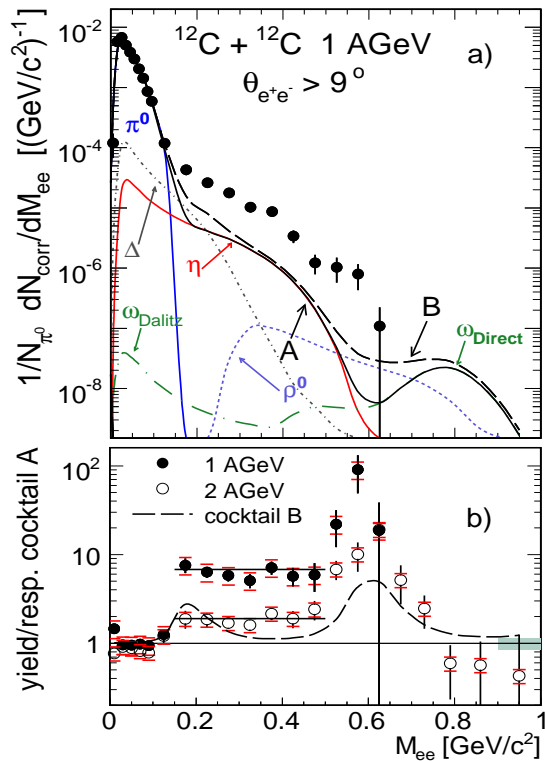


Fig. 1. (a) Normalized, background-subtracted and efficiency-corrected  $e^+e^-$  invariant-mass distribution compared to thermal dielectron cocktails of free  $\pi^0$ ,  $\eta$  and  $\omega$  decays (cocktail A, solid line), as well as including  $\rho$  and  $\Delta$  resonance decays (cocktail B, long-dashed line). Only statistical errors are shown. (b) Ratio of data and cocktail A (full symbols), compared to the corresponding ratio from the 2 AGeV C+C run [14] (open symbols). Statistical and systematic errors of the measurement are shown as vertical and horizontal bars, respectively; the shaded area depicts the 15% normalization error. Averages over the 0.15–0.50  $\text{GeV}/c^2$  mass range are indicated by lines; they correspond to the  $F$  factors discussed in the text. The dashed curve corresponds to the ratio cocktail B/cocktail A for 1 AGeV.

considered. For the  $\omega$  we have simply assumed an isotropic decay pattern. The accepted  $\pi^0$  ( $\eta$ ) Dalitz yield was found to change by less than 15% (10%) when varying the source parameters over a broad range, namely 0 – 0.3 for  $\beta_r$ , 0 – 0.8 for  $a_2$ , and 40 – 70 MeV for  $T$ . The cocktail does hence not depend much on our particular choice of these parameters.

Whereas experimental data and simulated cocktail A (solid line in Fig. 1(a)) are in good agreement in the  $\pi^0$  region, the cocktail strongly undershoots the data for  $M_{ee} > 0.15 \text{ GeV}/c^2$ , much more so than in our previous 2 AGeV data set, clearly calling for additional dilepton sources. This conclusion had also been reached by the authors of Ref. [24] who showed

that their data on  $\eta$  production fix the contribution of  $\eta$  Dalitz decays to pair production. Additional contributions are of course expected from the decay of short-lived resonances, mainly the  $\Delta(1232)$  and the  $\rho$ , excited in the early phase of the collision, and we have made an attempt to account for them, schematically at least, in our simulation as well. To include in the dilepton cocktail pairs from  $\Delta^{0,+} \rightarrow Ne^+e^-$  decays, we assumed that in the beam-energy regime of 1–2 AGeV the  $\Delta$  yield scales with the  $\pi^0$  yield measured at freeze-out and we employed the  $\Delta$  decay rate calculated in [10]. To determine the  $\rho$ -meson contribution, we used a similar prescription as for the  $\omega$ . For this broad resonance ( $\Gamma_\rho = 0.15 \text{ GeV}/c^2$ ), described in our simulation by a relativistic Breit-Wigner function with mass-dependent width (following [11]),  $m_\perp$  scaling, as well as the additional  $1/M^3$  dependence of  $\Gamma(M)_{\rho \rightarrow e^+e^-}$  (imposed by vector dominance [25]) strongly enhance the low-mass tail, resulting in the skewed spectral shape visible in Fig. 1(a). Finally, Dalitz contributions from the heavier baryon resonances ( $N^*(1520)$ ,  $N^*(1535)$ , etc.) turned out to be negligible in our thermal framework. The full cocktail thus generated (cocktail B) is shown in the figure as a long-dashed line. One can see that the simulated yield increases somewhat above  $0.15 \text{ GeV}/c^2$ , but obviously our second calculation also remains far from reproducing the data.

The features of the dielectron mass spectrum are to some extent obscured by its very steep fall, and in order to take this global trend out and make the characteristics of the excess pair yield more visible, we display in Fig. 1(b) the ratio of the data and cocktail A. This ratio is basically unity at low masses, dominated by the  $\pi^0$  Dalitz pairs, but above  $M=0.15 \text{ GeV}/c^2$  it is very much larger, indicating the onset of processes not accounted for in our simple-minded cocktail calculation. Fig. 1(b) also shows the corresponding ratio obtained from our previous 2 AGeV measurement [14], i.e. dividing those data by their respective cocktail A. As already pointed out above, it is evident that at 1 AGeV the overshoot of the data is much stronger than at 2 AGeV. To quantify this behavior in the plateau region of  $M = 0.15 - 0.50 \text{ GeV}/c^2$ , we define for this mass range an average enhancement above the known  $\eta$  Dalitz contribution as  $F = Y_{tot}/Y_\eta$ . This ratio, indicated in the figure by horizontal lines, amounts to  $F(1.0) = Y_{tot}(1.0)/Y_\eta(1.0) = 6.8 \pm 0.6(stat) \pm 1.3(sys) \pm 2.0(\eta)$  at 1 AGeV, and to  $F(2.0) = 1.9 \pm 0.2(stat) \pm 0.3(sys) \pm 0.3(\eta)$  at

2 AGeV. The third error, labeled ( $\eta$ ), gives the uncertainty caused by the quoted errors on the  $\eta$  multiplicities. Due to a re-evaluation of our pion normalization, the value given here for  $F(2.0)$  is by 10% lower than the one cited in [14]. Assuming now that the excess pairs have in this mass region an overall acceptance close to that of  $\eta$  Dalitz pairs, one can also compare  $F(1.0)$  to the enhancement factor observed in C+C by DLS at a beam energy of 1.04 AGeV [1]. As the HADES and DLS geometric acceptances do not fully overlap (see discussion below), this assumption is indeed necessary to make a meaningful comparison of the ratios obtained within the respective acceptances. Using the DLS data and a DLS-filtered PLUTO cocktail generated for 1.04 AGeV, we obtain a factor of  $F(1.04) = 6.5 \pm 0.5(stat) \pm 2.1(sys) \pm 1.5(\eta)$ . The DLS result is hence in good agreement with our 1 AGeV measurement. Table 1 summarizes all pair excess factors, together with their uncertainties.

Table 1

Dielectron excess factor ( $F$ ) and inclusive excess multiplicity ( $N_{exc}$ ) from  $^{12}\text{C}+^{nat}\text{C}$  in the pair mass range  $M = 0.15 - 0.50 \text{ GeV}/c^2$  as a function of bombarding energy ( $E_b$ ). Errors given from left to right are statistical (1), systematic (2), and due to the  $\eta$  multiplicity (3).

$E_b$ [AGeV]	$F = Y_{tot}/Y_\eta$	$N_{exc} [10^{-6}]$
1.0	$6.8 \pm 0.6 \pm 1.3 \pm 2.0$	$6.8 \pm 0.7 \pm 1.5 \pm 0.3$
2.0	$1.9 \pm 0.2 \pm 0.3 \pm 0.3$	$18 \pm 4 \pm 7 \pm 4$
1.04	$6.5 \pm 0.5 \pm 2.1 \pm 1.5$	$8.4 \pm 0.7 \pm 3.4 \pm 0.3$

Continuing the discussion of Fig. 1(b), at masses above  $0.50 \text{ GeV}/c^2$  the ratio of data and cocktail A develops for both beam energies a pronounced maximum around  $M_{ee} \sim 0.60 \text{ GeV}/c^2$ . This is mainly due to the lack of yield in the cocktail at these masses and can hence be considered to be an artifact of the chosen way of presenting our data. On the other hand, the mass region between the  $\eta$  and the  $\omega$  pole is expected to be dominated by the low-mass tail of the broad  $\rho$  resonance, whose population is favored by the available phase space. Cocktail B, which includes  $\rho$  and  $\Delta$  decays, shows indeed some enhancement with respect to cocktail A, as visible in Fig. 1(b), but also at large masses it lies far below the observed pair yield.

#### 4. Evolution with bombarding energy

It is interesting to compare the beam-energy dependence of the pair excess with that of neu-

tral meson production in the C+C system. The latter has been investigated systematically with photon calorimetry [19,24], revealing that between 1 and 2 AGeV inclusive  $\pi^0$  and  $\eta$  multiplicities increase by factors  $N_\pi(2.0)/N_\pi(1.0) = 2.4 \pm 0.3$  and  $N_\eta(2.0)/N_\eta(1.0) = 17 \pm 5$ , respectively. The excitation functions of inclusive  $\pi^0$  and  $\eta$  production are shown in Fig. 2, together with the corresponding pair multiplicity from  $\eta$  Dalitz decays (with  $\text{BR}(\eta \rightarrow \gamma e^+ e^-) = 0.6\%$ ) within the  $0.15-0.50 \text{ GeV}/c^2$  mass range, amounting to 11.6% of all such pairs. The energy scaling of the inclusive excess pair multiplicity, i.e. for full solid angle and minimum bias, ( $N_{exc}$ ) has been obtained from the measured excess factors  $F(2.0)$  and  $F(1.0)$  and the corresponding inclusive, i.e. minimum bias  $\eta$  multiplicities (assuming similar detector acceptances for  $\eta$  Dalitz and excess pairs) in the following way:  $N_{exc} = N_{tot} - N_\eta = (F - 1) N_\eta$ . The resulting excess multiplicities are depicted in Fig. 2 for both energies studied with HADES, together with the 1.04 AGeV DLS point; they are also listed with their uncertainties in Table 1. From our data it follows that  $N_{exc}(2.0)/N_{exc}(1.0) = 2.6 \pm 0.6(stat) \pm 0.6(sys) \pm 0.5(\eta)$ . This energy dependence is hence remarkably similar to the evolution of pion production, but very different from that of  $\eta$  production. It is also apparent in Fig. 2 in the direct comparison of the excess with the pion multiplicity scaled to hit the 2 AGeV point (dotted line), as well as with the absolute eta Dalitz contribution (dashed line). This surprising behavior suggests that, at the bombarding energies discussed here, the pair excess is not driven by the excitation of heavy resonances, but rather by low-energy processes, like pion production and propagation, involving e.g.  $\Delta$  and low-mass  $\rho$  excitations, and possibly bremsstrahlung processes.

Recent one-boson exchange (OBE) calculations [27,28] of nucleon-nucleon bremsstrahlung continue and extend the realistic treatment of interactions in the pp channel of [29]. They indicate a much more important role of bremsstrahlung in low-mass dilepton production than hitherto suspected. According to these models, in nucleon-nucleon collisions the quasi-elastic bremsstrahlung contribution is of similar size as the  $\Delta$  Dalitz part, accounting together for the total dilepton yield above the  $\pi^0$  Dalitz peak at beam energies below the  $\eta$  production threshold ( $E_{th} = 1.27 \text{ GeV}$ ). The OBE calculations also show that a consistent treatment of both processes is not straightforward. Conclusions on their validity can

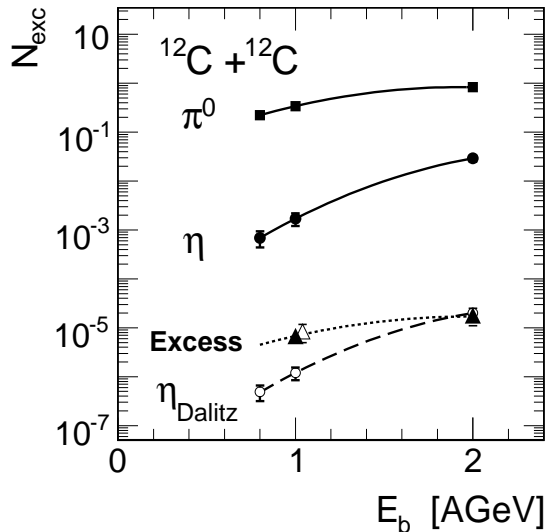


Fig. 2. Inclusive multiplicity of the pair excess ( $N_{exc}$ ) in the mass range  $M_{ee} = 0.15 - 0.50$   $\text{GeV}/c^2$  as function of bombarding energy  $E_b$  (full triangles: HADES, open triangle: DLS). Also shown are the  $\pi^0$  and  $\eta$  inclusive multiplicities in  $^{12}\text{C} + ^{nat}\text{C}$  collisions [19] (full squares and circles), as well as the corresponding  $\eta$  Dalitz decay contribution (open circles) summed over  $M_{ee} = 0.15 - 0.50$   $\text{GeV}/c^2$ . For comparison with  $N_{exc}$ , scaled-down  $\pi^0$  (dotted) and absolute  $\eta$  Dalitz (dashed) curves are shown (see discussion in the text).

hence be drawn only once more results on the elementary reactions pp and dp will become available [31].

## 5. Comparison with DLS

We have already shown above that our pair excess at 1 AGeV agrees well with the DLS measurement performed at 1.04 AGeV. In the last section of this Letter we want to present, however, a more comprehensive comparison of the two data sets, done by projecting the dielectron yield observed with HADES into the DLS acceptance. The particular geometry of the two-arm setup of DLS [1], combined with its pair trigger requiring coincident lepton hits in both arms resulted in an acceptance for low-mass pairs ( $M_{ee} < 0.2$   $\text{GeV}/c^2$ ) confined to mostly small transverse momenta ( $p_{\perp} < 0.2$   $\text{GeV}/c$ ) and large rapidities ( $y > 0.6$ ). Although the overall coverage in  $p_{\perp}$  and  $y$  of HADES is much wider, because of its toroidal magnetic field configuration, we have collected only small statistics for low-mass pairs with  $p_{\perp} < 0.1$   $\text{GeV}/c$  and  $y > 1.8$ . This affects strongly

$\pi^0$  Dalitz pairs, but only weakly the pair yield at masses  $M_{ee} > 0.2$   $\text{GeV}/c^2$ . A direct comparison of the two data sets hence needs an extrapolation of the HADES pair yield to that particular part of phase space. The whole procedure entails in addition the conversion of multiplicities, measured by HADES, into production cross sections, as given by DLS.

The published pair acceptance filter of DLS [1] acts in a three-dimensional (3d) phase space ( $M - p_{\perp} - y$ ) and therefore the extrapolation of the HADES data to full solid angle was performed in a 3d representation as well. For practical reasons, this has been done by (1) projecting out 2d slices ( $p_{\perp}$  vs.  $y$ ) of the efficiency- and acceptance-corrected pair yield for different mass bins, (2) fitting a reasonable 2d function to those projections, and (3) using the resulting fits to extrapolate in 3d phase space, mass slice by mass slice, to small  $p_{\perp}$  and large  $y$ . The sparse statistics resulting from spreading the data counts in three dimensions forced us to use two mass slices only, emphasizing the  $\pi^0$  and the  $\eta$  Dalitz mass regions, respectively.

The 2d function employed to fit the pair mass slices has been inspired by the following constraints only:

- $dN/dy$  is gaussian and symmetric around mid-rapidity ( $y_{1/2} = 0.68$  at 1 AGeV),
- $dN/dp_{\perp}$  has a quasi-thermal behavior,
- the limited statistics imposes a small number of fit parameters.

Consequently the function chosen to fit the acceptance-corrected data matrix was:

$$1/p_{\perp} d^2N/dp_{\perp} dy = \exp[-c_0 - c_1 p_{\perp} - c_2 (y - y_{1/2})^2]$$

An advantage of this approach over that based on comparing acceptance-filtered dilepton cocktails with the respective data sets is that it makes, apart from the above, no assumptions about the dilepton sources involved.

Statistical errors of the data were taken into account in the fit, resulting in corresponding errors on the fit parameters and accordingly on the extrapolated pair yield. The effect of using for the fit a  $1/p_{\perp}^2 d^2N/dp_{\perp} dy$  form instead was investigated as well and has been taken into account in the systematic error assigned to the procedure. The fitted functions were next used to amend the 2d data slices for the yield missing in the region of the acceptance mismatch. In this operation no attempt was made to compensate for the somewhat larger beam energy of the DLS experiment, expected to lead to about

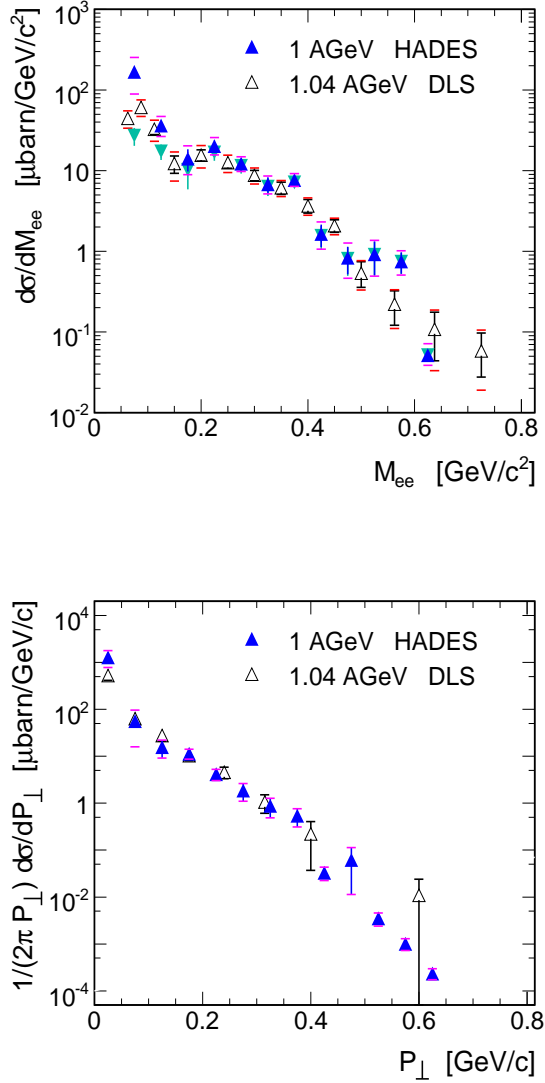


Fig. 3. Direct comparison of the dilepton cross sections measured in C+C at 1 AGeV by HADES and at 1.04 AGeV by DLS [1,26]. Pair mass distributions (upper frame) and pair transverse-momentum distributions (lower frame) are compared within the DLS acceptance. For  $d\sigma/dM_{ee}$ , both, statistical and systematic errors are shown, for  $1/(2\pi p_{\perp}) d\sigma/dp_{\perp}$ , only statistical; for the latter data, systematic errors are expected to be large below 0.2 GeV/c [30]. Overall normalization errors (not shown) are 20% for the HADES and 30% for the DLS data points. In the upper frame, the HADES data corresponding to the two fit forms discussed in the text are shown as upright ( $1/p_{\perp}$ ) and reverted ( $1/p_{\perp}^2$ ) full triangles, respectively.

5% (25%) more  $\pi^0$  ( $\eta$ ) production [19,24]. We proceeded by filtering the patched 3d HADES pair ma-

trix through the DLS pair filter. The extrapolated part of the reconstructed yield is reasonably small ( $\leq 25\%$ ) in the mass region where we discuss the excess yield. At low masses, however, the DLS pair acceptance being quite different from the HADES acceptance, the correction is sizeable ( $\approx 90\%$ ), with accordingly large systematic errors.

In a final step the HADES multiplicities were converted into cross sections by multiplying with a total C+C reaction cross section of 900 mbarn and by renormalizing our LVL1 pion multiplicity (0.53) to its minimum bias value (0.36). The result of the procedure is given in Fig. 3, together with the published DLS  $d\sigma/dM$  [1] and  $1/(2\pi p_{\perp}) d\sigma/dp_{\perp}$  [26] differential cross sections. Errors, in particular the systematic effect due to a different choice of the fit function ( $1/p_{\perp}$  vs.  $1/p_{\perp}^2$  forms) are indicated as well. From both parts of the figure it is apparent that, within statistical and systematic uncertainties, the HADES and the DLS data are in good agreement, in particular in the mass region of the excess yield, namely for  $M_{ee} = 0.15 - 0.50$  GeV/ $c^2$ .

## 6. Conclusions

In summary, we report on a measurement of inclusive dielectron production in C+C collisions at 1 AGeV. At low masses, i.e.  $M_{ee} < 0.15$  GeV/ $c^2$ , the pair yield is in agreement with the known  $\pi^0$  production and decay rates. For masses of  $0.15$  GeV/ $c^2$   $< M_{ee} < 0.50$  GeV/ $c^2$  it exceeds, however, expectations based on the known production and decay rates of the  $\eta$  meson by a factor of about 7. This excess yield is consistent with that measured by DLS at 1.04 GeV and a comprehensive comparison of differential cross sections gives overall good agreement between the two experiments. The excitation function of the pair yield between 1 and 2 AGeV demonstrates that the excess scales with bombarding energy like pion production, rather than like the production of the much heavier  $\eta$  meson.

Additional sources associated with the radiation from the early collision phase ( $\Delta^{0(+)} \rightarrow Ne^+e^-$ ,  $\rho \rightarrow e^+e^-$ , bremsstrahlung) are clearly needed to account for the excess observed at  $M > 0.15$  GeV/ $c^2$ . In this context, our recent studies of pp and pd reactions [31] will help by adding information on dilepton production in elementary reactions, a mandatory input to any transport calculation. Indeed, transport models, besides offering a realistic treatment of the collisions dynamics, also handle the propagation of

broad resonances, related off-shell effects and multi-step processes, all known to play a crucial role at our bombarding energy. Better insight is therefore expected once more refined dynamic calculations become available.

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