Dielectron Production in $^{12}\text{C} + ^{12}\text{C}$ Collisions at 1 GeV/u and the Solution to the DLS Puzzle

Y. C. Pachmayer (for the HADES collaboration)

Institut für Kernphysik, Johann Wolfgang Goethe-Universität, Frankfurt, Germany
E-mail: Y.Pachmayer@gsi.de

G. Agakishiev$^8$, C. Agodi$^1$, A. Balanda$^{3,e}$, G. Bellia$^{1,a}$, D. Belver$^{15}$, A. Belyaev$^6$, A. Blanco$^2$, M. Böhmer$^{11}$, J. L. Boyard$^{13}$, P. Braun-Munzinger$^4$, P. Cabanelas$^{15}$, E. Castro$^{15}$, S. Chernenko$^6$, T. Christ$^{11}$, M. Destefanis$^8$, J. Díaz$^{16}$, F. Dohrmann$^5$, A. Dybczak$^3$, T. Eberl$^{11}$, L. Fabbietti$^{11}$, O. Fateev$^6$, P. Finocchiaro$^1$, P. Fonte$^{2,b}$, J. Friese$^{11}$, I. Fröhlich$^7$, T. Galatyuk$^4$, J. A. Garzón$^{15}$, R. Gernhäuser$^{11}$, A. Gil$^{16}$, C. Gilardi$^8$, M. Golubeva$^{10}$, D. González-Díaz$^4$, E. Grosse$^{5,c}$, F. Guber$^{10}$, M. Heilmann$^7$, T. Hennino$^{13}$, R. Holzmann$^4$, A. Ierusalimov$^6$, I. Iori$^{9,d}$, A. Ivashkin$^{10}$, M. Jurkovic$^{11}$, B. Kämpfer$^5$, K. Kanaki$^5$, T. Karavicheva$^{10}$, D. Kirschner$^8$, I. Koenig$^4$, W. Koenig$^4$, B. W. Kolb$^3$, R. Kotte$^5$, A. Kozuch$^{3,e}$, A. Krása$^{14}$, F. Krizek$^{14}$, R. Krücken$^{11}$, W. Kühn$^8$, A. Kugler$^{14}$, A. Kurepin$^{10}$, J. Lamas-Valverde$^{15}$, S. Lang$^4$, J. S. Lange$^8$, K. Lapidus$^{10}$, L. Lopes$^2$, M. Lorenz$^7$, L. Maier$^{11}$, A. Mangiarotti$^2$, J. Marín$^{15}$, J. Markert$^7$, V. Metag$^8$, B. Michalska$^3$, J. Michel$^7$, D. Mishra$^8$, E. Morinière$^{13}$, J. Mousa$^{12}$, C. Müntz$^7$, L. Naumann$^5$, R. Novotny$^8$, J. Otwinowski$^3$, M. Palka$^4$, Y. Parpottas$^{12}$, V. Pechenov$^8$, O. Pechenova$^8$, T. Pérez Cavalcanti$^8$, J. Pietraszko$^4$, W. Przygoda$^{3,e}$, B. Ramstein$^{13}$, A. Reshetin$^{10}$, M. Roy-Stephan$^{13}$, A. Rustamov$^4$, A. Sadovsky$^{10}$, B. Sailer$^{11}$, P. Salabura$^3$, A. Schmah$^4$, R. Simon$^4$, Yu.G. Sobolev$^{14}$, S. Spataro$^8$, B. Spruck$^8$, H. Ströbele$^7$, J. Stroth$^{7,4}$, C. Sturm$^7$, M. Sudol$^4$, A. Tarantola$^7$, K. Teilab$^7$, P. Thusty$^{14}$, M. Traxler$^4$, R. Trebacz$^3$, H. Tsertos$^{12}$, I. Veretenkin$^{10}$, V. Wagner$^{14}$, H. Wen$^8$, M. Wisniowski$^3$, T. Wojcik$^3$, J. Wüstenfeld$^5$, S. Yurevich$^4$, Y. Zanevsky$^6$, P. Zhou$^5$, P. Zumbruch$^4$

(HADES collaboration)

1 Instituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud, 95125 Catania, Italy
2 LIP-Laboratório de Instrumentação e Física Experimental de Partículas, 3004-516 Coimbra, Portugal
3 Smoluchowski Institute of Physics, Jagiellonian University of Cracow, 30-059 Kraków, Poland
Abstract. The production of $e^+e^-$ pairs in $^{12}$C + $^{12}$C collisions at 1 GeV/u was investigated with the HADES experiment at GSI, Darmstadt. In the invariant-mass region $0.15 \text{GeV}/c^2 \leq M_{ee} \leq 0.5 \text{GeV}/c^2$ the measured pair yield shows a strong excess above the contribution expected from hadron decays after freeze-out. The data are in good agreement with the results of the former DLS experiment for the same system and energy.

1. Introduction

Dilepton spectra taken in heavy-ion collisions exhibit an enhancement of yield, independent of the bombarding-energy, compared to the superposition of free hadronic...
Dielectron Production in $^{12}$C + $^{12}$C Collisions at 1 GeV/u

decays in the invariant-mass region $0.2 \text{GeV}/c^2 \leq M_{ee} \leq 0.6 \text{GeV}/c^2$. While the dilepton enhancement found at SPS energies has been related to modifications of the $\rho$-meson spectral function in the hadronic medium [1], the large pair yields observed by DLS [2] in C+C and Ca+Ca collisions at 1 GeV/u remain to be explained satisfactorily [3]. The High-Acceptance DiElectron Spectrometer HADES [4] at GSI, Darmstadt, is presently the only dilepton spectrometer operational in the SIS energy regime of 1-2 GeV/u, succeeding the DLS experiment. First results obtained in C+C collisions at 2 GeV/u confirmed the general observation of an enhanced pair yield above the contribution expected from hadron decays after freeze-out [5]. In this note we report on a measurement of inclusive electron-pair emission from $^{12}$C+$^{12}$C collisions at 1 GeV/u. Taken together, both results allow to discuss the beam energy dependence of the pair yield. Furthermore a direct comparison with the DLS results [2] has become possible, thus addressing (and solving experimentally) the long-standing ”DLS puzzle”.

2. Dielectron Production at 1 GeV/u kinetic beam energy

The dielectron yield measured in HADES in $^{12}$C+$^{12}$C collisions at 1 GeV/u was corrected for detection and reconstruction inefficiencies as described in [6]. Fig. 1 shows the resulting $e^+e^-$ invariant-mass distribution of true pairs normalized to the average number of charged pions $N_{\pi^0} = 1/2(N_{\pi^+} + N_{\pi^-})$, as measured also in HADES and extrapolated to the full solid angle. The obtained pion multiplicity per participant nucleon, i.e. $M_\pi/A_{\text{part}} = 0.061 \pm 0.009$, agrees well with previous measurements of charged and neutral pions [7]. The quoted error of 15% is dominated by systematic uncertainties in the pion efficiency correction and the extrapolation procedure. In addition to this overall normalization error, uncertainties caused by the electron-efficiency correction and by the subtraction of the combinatorial background add up quadratically to point-to-point systematic errors in the pair yield of 22% (also shown in Fig. 1). We compare our data with a pair cocktail (cocktail A), which was calculated from $\pi^0$, $\eta$ and $\omega$ meson decays to represent the radiation from long-lived mesons (decaying mostly outside the fireball). The $\pi^0$ and $\eta$ Dalitz yields are constrained by published data [7]; for the production rate of the $\omega$ meson we apply $m_T$-scaling [8]. The cocktail calculation was performed with the PLUTO generator assuming anisotropic meson emission from a Boltzmann-like thermal source (for details cf. [6]). While experimental data and cocktail A agree in the $\pi^0$ Dalitz region, the cocktail strongly underestimates the measured pair yield for $M_{ee} > 0.15 \text{ GeV}/c^2$. This is not surprising, since one expects additional contributions from short-lived resonances, e.g. $\Delta$(1232) and $\rho$. For the $\Delta$, we assumed that its contribution scales with the $\pi^0$ yield at freeze-out and that the $\Delta \rightarrow N e^+e^-$ differential decay rates of [3] are applicable. We modeled the broad resonance $\rho$ as a Breit-Wigner shape, with mass-dependent width $\Gamma(M) = \Gamma_0/M^3$ ($\Gamma_0 = 0.15 \text{ GeV}$) [3], additionally modified by $m_T$-scaling accounting for the strongly reduced phase space at low beam energies. The resulting cocktail B is shown in Fig. 1 (long-dashed line). Adding these short-lived contributions increases the simulated yield.
Figure 1. Dielectron yield (corrected for inefficiencies) in the HADES acceptance. In a) the measured yield is compared to a cocktail calculated from sources assuming vacuum properties only. The cocktail is divided into contributions from long-lived mesons $\pi^0, \eta, \omega$ (full line, cocktail A) and contributions from short-lived resonances $\rho, \Delta$; the sum of all defines cocktail B. b) shows the experimental yield divided by cocktail A for 1 GeV/u (full symbols) and 2 GeV/u (open symbols) data. In addition, the ratio of cocktail B and A for 1 GeV/u data is indicated (dashed line).

above 0.15 $GeV/c^2$, but obviously our second calculation also falls short of reproducing the data. More sophisticated calculations, e.g. based on transport models, are clearly needed.

For better visualization of the character of the excess yield, the ratio of data and cocktail A is shown in Fig. 1(b). This ratio is basically unity at low masses, where $\pi^0$ Dalitz pairs dominate, but above $M_{ee} = 0.15 \ GeV/c^2$ it is large, indicating the onset of processes not accounted for by our cocktail A. Fig. 1(b) also shows the corresponding ratio observed at 2 GeV/u [5]. It is evident that at 1 GeV/u the overshoot of the data is much stronger than at 2 GeV/u. A detailed analysis shows that the beam energy dependence of the excess yield above the known $\eta$ contribution [7], integrated over the $0.15 \ GeV/c^2 \leq M_{ee} \leq 0.5 \ GeV/c^2$ mass range, scales like $\pi$ production [6].

Fig. 2 shows the pair transverse momentum ($P_{ee}^\perp$) distribution for the excess region $0.15 \ GeV/c^2 \leq M_{ee} \leq 0.5 \ GeV/c^2$. Note that in comparison to cocktail A the excess factor is constant at high $P_{ee}^\perp$, but increases steeply towards lower $P_{ee}^\perp$.

A direct comparison of HADES and DLS [6] results can be achieved by a mapping of the measured HADES pair yield onto the DLS acceptance, defined in the 3-d space spanned by the pair variables $M_{ee}, P_{ee}^\perp$ and the rapidity $Y_{ee}$. Although the acceptances of both apparatuses do not fully overlap for low-mass, low-$P_{ee}^\perp$ pairs, in the excess region, the HADES coverage is larger and almost fully contains the DLS acceptance. Transforming the multiplicities measured by HADES to cross sections, this mapping allows for an almost model-independent comparison of the two data sets (for details cf. [6]).
Dielectron Production in $^{12}\text{C} + ^{12}\text{C}$ Collisions at 1 GeV/u

Figure 2. Dielectron yield as a function of pair $P_{ee}^\perp$ for the invariant-mass region $0.15 \text{ GeV/c}^2 \leq M_{ee} \leq 0.5 \text{ GeV/c}^2$. Line codes as in Fig. 1.

Figure 3. Direct comparison of the dielectron cross sections measured in the reaction $^{12}\text{C} + ^{12}\text{C}$ at 1 GeV/u by HADES (full triangles) and at 1.04 GeV/u by DLS [2] (empty triangles). The invariant-mass distributions are compared within the DLS acceptance. Statistical and systematic errors are shown. Overall normalization errors (not shown) are 20% for the HADES and 30% for the DLS data points.

Fig. 3 the HADES-mapped invariant-mass distribution is shown together with the DLS result [2]. It is apparent that, within statistical and systematic uncertainties, both measurements are in agreement, in particular in the region of the excess yield. The same conclusion is obtained from the comparison of the $P_{ee}^\perp$ distributions [6].

3. Conclusion

The agreement of the present data with the – for a long time disputed – results in [2] solves the "DLS puzzle" experimentally. It poses, however, again the question of the origin of the pair excess. In this context, studies of the elementary reactions $p + p$ and $d + p$ are important steps. Indeed, recent calculations within a One Boson Exchange (OBE) model [9] suggest significantly larger than heretofore assumed contributions from...
Dielectron Production in $^{12}C + ^{12}C$ Collisions at 1 GeV/u

$p - p$ and, mostly, $p - n$ quasi-elastic bremsstrahlung. Moreover, transport calculations done with the Hadron String Dynamics (HSD) model [10] using a parametrization of bremsstrahlung inspired by the new OBE result [9] seem to match both the HADES and the DLS $^{12}C + ^{12}C$ data. In this situation it is evident that the direct confrontation of the OBE model calculations with $p + p$ and $d + p$ dilepton data measured with HADES [11] is mandatory to reach firm conclusions on the origin of dileptons at SIS energies.

References

[1] H. v. Hees et al., Phys. Rev. Lett. 97, 102301(2006); T. Renk et al., Eur. Phys. J. C 49, 219(2007).
[2] R. J. Porter et al., DLS Collaboration, Phys. Rev. Lett. 79, 1229 (1997).
[3] C. Ernst et al., Phys. Rev. C58, 447 (1998); W. Cassing et al., Phys. Rep. 308, 65 (1999); K. Shekhter et al., Phys. Rev. C68, 014904 (2003); M. Cozma et al., Phys. Lett. B640, 150 (2006).
[4] R. Schicker et al., Nucl. Instrum. Methods Phys. Res. A380, 586 (1996); P. Salabura et al., Prog. Part. Nucl. Phys. 53, 49 (2004), Nucl. Phys. A749, 150 (2005); http://www-hades.gsi.de.
[5] G. Agakichiev et al., HADES Collaboration, Phys. Rev. Lett. 98, 052302 (2007).
[6] G. Agakichiev et al., HADES Collaboration, arXiv:0711.4281 [nucl-ex], Phys. Lett. B in print; Y. C. Pachmayer, doctoral thesis, J. W. Goethe University Frankfurt, 2008.
[7] R. Averbeck et al., TAPS Collaboration, Z. Phys. A359, 65 (1997).
[8] E. L. Bratkovskaya, W. Cassing, R. Rapp and J. Wambach, Nucl. Phys. A634, 168 (1998).
[9] L. Kaptari and B. Kämpfer, Nucl. Phys. A764, 338 (2006).
[10] E. L. Bratkovskaya, W. Cassing, arXiv:0712.0635 [nucl-th].
[11] I. Fröhlich et al., HADES Collaboration, arXiv:0712.1505 [nucl-ex]