Dielectron production in $^{12}\text{C}+^{12}\text{C}$ collisions at 2 A GeV with HADES

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Online at stacks.iop.org/JPhysG/34/S1041**Abstract**

We report on a measurement of electron pair production in $^{12}\text{C}+^{12}\text{C}$ collisions at an incident energy of 2 GeV per nucleon with the HADES spectrometer. The measured pair production probabilities span over five orders of magnitude from the π^0 -Dalitz to the ρ/ω invariant-mass region. Dalitz decays of π^0 and η account for all the yield up to 0.15 GeV/ c^2 , but for only about 50% above this mass. The excess yield is in agreement with the former DLS result if one assumes that it scales with beam energy like pion production. A preliminary analysis of $^{12}\text{C}+^{12}\text{C}$ collisions at an incident energy of 1 A GeV, measured with the HADES detector, supports this scenario.

(Some figures in this article are in colour only in the electronic version)

The High-Acceptance DiElectron Spectrometer HADES at GSI, Darmstadt, operates in the SIS/Bevalac energy regime of 1–2 A GeV. In this contribution we report on the first measurement of inclusive electron-pair production in $^{12}\text{C}+^{12}\text{C}$ collisions at a kinetic beam energy of 2 A GeV [1]. The HADES spectrometer, described in detail in [2, 3], provides a large and smooth dielectron acceptance of about 30%. Uncorrelated electrons from $\pi^0 \rightarrow \gamma\gamma$ decays followed by photon conversion and/or from $\pi^0 \rightarrow e^+e^-\gamma$ Dalitz decays form most of the combinatorial background (CB). They are rejected efficiently by applying conditions on the opening angle $\theta_{e^+e^-} > 9^\circ$ of the reconstructed track segments, removing 95% of the conversion pairs while reducing the dielectron signal with $M_{ee} > 0.15$ GeV/ c^2 by less than 10%.

Figure 1(a) shows the M_{ee} distribution of the signal pairs after efficiency correction and normalization to the average number of charged pions $N_\pi = \frac{1}{2}(N_{\pi^+} + N_{\pi^-})$. The charged pion yield was measured in the HADES acceptance [3] and extrapolated to the full solid angle. The extrapolation takes into account measured angular distributions, found to be in agreement with UrQMD calculations [4]. The obtained pion multiplicity per number of participating nucleons $M_\pi/A_{\text{part}} = 0.137 \pm 0.015$ ($A_{\text{part}} = 9.0$) agrees with previous measurements of charged and neutral pions [5, 6] within the quoted error of 11%. The error represents an overall normalization error, dominated by systematic uncertainties in the acceptance and efficiency corrections of the charged-pion analysis. The systematical uncertainties for the dielectron yield from the efficiency correction and the CB subtraction add up quadratically to a nearly constant error of 18%.

A pair cocktail (cocktail A) was calculated from free π^0 , η and ω meson decays only to represent all contributions emitted after the chemical freeze-out of the fireball and compared to our resulting M_{ee} distribution (figure 1(a)). While π^0 and η sources are directly constrained by data [5], the production rate of the ω meson is taken from an $m_\perp$ -scaling ansatz [7]. In our event generator (PLUTO [8]) meson production was modelled assuming emission from a thermal source with a temperature $T = 80$ MeV, but no radial expansion velocity. The anisotropic

Figure 1. (a) Efficiency- and background-corrected e^+e^- invariant-mass distribution for $\theta_{e^+e^-} > 9^\circ$ (symbols) compared to a thermal dielectron cocktail of free π^0 , η and ω decays (cocktail A, solid line), as well as including ρ and Δ resonance decays (cocktail B, long-dashed line). Only statistical errors are shown. (b) Ratio of data and cocktail A (dots), compared to ratios of various model calculations and cocktail A. All calculations have been filtered and folded with the HADES acceptance and mass resolution. Statistical and systematic errors of the measurement are shown as vertical and horizontal lines, respectively. The overall normalization error of 11% is depicted by the shaded area.

angular distribution, obtained from our charged-pion analysis, was used for the π^0 mesons. While experimental data and the simulated cocktail A are in good agreement in the π^0 region, the cocktail undershoots the data for $M > 0.15 \text{ GeV}/c^2$. Decays of short-lived resonances (as ρ , $\Delta(1232)$), excited in the early phase of the collision, will additionally contribute here. Assuming that the $\Delta^{0,+} \rightarrow N e^+ e^-$ decays were added to the cocktail. Furthermore, the ρ was treated in analogy to the ω . For the latter broad resonance ($\Gamma_\rho = 150 \text{ MeV}$), $m_\perp$ scaling and available phase space strongly enhances the low-mass tail, resulting in the skewed shape visible in figure 1(a). Comparing the full thermal cocktail (cocktail B) with our data, the simulated yield above $0.15 \text{ GeV}/c^2$ is now increased and the high-mass region is populated with dielectrons from $\rho \rightarrow e^+ e^-$ decays, but the calculation still falls short of reproducing the data.

In figure 1(b) the ratio of the data and cocktail A is shown. In the intermediate mass range of $0.15\text{--}0.50 \text{ GeV}/c^2$, the enhancement factor above the dominant η contribution amounts to $F(2.0) = 2.07 \pm 0.21(\text{stat}) \pm 0.38(\text{sys})$. Assuming that the excess pairs have an overall acceptance close to that of eta-Dalitz pairs in the selected mass region, one can compare $F(2.0)$ to the enhancement factor measured in C+C by DLS at a beam energy of 1.04 A GeV [10]. Using the DLS data and a PLUTO cocktail filtered through the DLS acceptance, we

Figure 2. Invariant mass distribution of electron pairs emitted into the acceptance of HADES in $^{12}\text{C}+^{12}\text{C}$ collisions at 1 A GeV. The data are not corrected for detector and reconstruction efficiency. The full lines represent the expected yield for meson decay based on π^0 and η measurements of the TAPS collaboration. The dashed line shows the η scaled as to fit the data.

obtain a factor of $F(1.04) = 6.5 \pm 0.5(\text{stat}) \pm 2.1(\text{sys})$. Going from 1.04 to 2 A GeV, the inclusive η production in C+C collisions increases by a factor 13 ± 3 [5, 11]. Hence, the energy scaling factor of the excess pair yield can be deduced from the two measurements to be $Y_{\text{exc}}(2.0)/Y_{\text{exc}}(1.04) = 2.5 \pm 0.5(\text{stat}) \pm 1.5(\text{sys})$. This energy scaling is remarkably similar to the known scaling of pion production, i.e. $Y_{\pi}(2.0)/Y_{\pi}(1.04) = 2.3 \pm 0.3$ [5, 11]. It suggests that the pair excess is indeed driven by pion dynamics, involving e.g. Δ and ρ excitations (see also [12]). We hope to find more evidence for unexpected contributions from resonance Dalitz decays for the M_{ee} range 0.15–0.50 GeV/c^2 from the results of our $^{12}\text{C}+^{12}\text{C}$ run at 1.0 A GeV. Figure 2 depicts our preliminary M_{ee} distribution, which is not yet corrected for efficiency. In analogy to the DLS data previously discussed, an enhancement factor $F(1.0) = 5.8$ over the η in the M_{ee} range 0.15–0.50 GeV/c^2 can be extracted. Both results agree well within the errors.

At $M_{ee} \sim 0.6 \text{ GeV}/c^2$ the ratio of data and cocktail A (figure 1(b)) develops a pronounced maximum, caused by the lack of ρ decays in cocktail A. Especially the mass region between the η and the ω pole is expected to be dominated by the thermally populated low-mass tail of the broad ρ resonance. Cocktail B includes this component, but still does not fully explain the observed pair yield.

Expected dielectron distributions were calculated with the HSD [13], RQMD [14] and UrQMD [4] transport models (assuming vacuum spectral functions), filtered with the HADES acceptance and normalized to their respective π^0 yields. The ratios of the calculated dielectron yields to cocktail A are shown in figure 1(b). As all distributions have been normalized in the π^0 mass region, they give ratios consistent with unity for $M_{ee} < 0.15 \text{ GeV}/c^2$. Within 20% all models agree on the η contribution itself, but fall short in the intermediate mass region. Hence, the discrepancy can be traced back to differences in the treatment of population and decay of the baryonic resonances [4, 13, 14]. At higher masses, $M_{ee} > 0.5 \text{ GeV}/c^2$, the trend given by the data is reproduced qualitatively by all models. The yields, however, differ due to different amplitudes used for the couplings to intermediate resonances [4, 14]. All transport models overestimate the pair yield at the ρ , ω meson poles. Final conclusions can be drawn only when more refined calculations with in-medium spectral functions become available.

In summary, we report on the first measurement of inclusive dielectron production in $^{12}\text{C}+^{12}\text{C}$ collisions at $E_{\text{beam}}^{\text{kin}} = 2$ A GeV, spanning five orders of magnitude in yield [1]. For masses $M_{\text{ee}} < 0.15$ GeV/ c^2 our measured pair yield is in agreement with the known π^0 production and decay probabilities. In the intermediate mass range 0.15 GeV/ $c^2 < M_{\text{ee}} < 0.5$ GeV/ c^2 an enhancement over the known production and decay rates of the η meson of $2.07 \pm 0.21(\text{stat}) \pm 0.38(\text{sys})$ is observed. Assuming that the energy scaling of the excess yield is similar to that of the pion production, one can conclude that our established excess is in agreement with the results of DLS at 1.04 A GeV. Additional sources associated with the radiation from the early collision phase ($\Delta^{0(+)} \rightarrow N e^+ e^-$, $\rho \rightarrow e^+ e^-$) still do not fully explain the measured yield. Transport calculations based on vacuum spectral functions also fail to quantitatively describe the excess yield in the full invariant-mass range.

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