Measurement of the di-electron mass spectrum in $^{12}C+^{12}C$ collisions at 2 AGeV by HADES

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The physics program of the High Acceptance Di-Electron Spectrometer HADES at GSI is largely motivated by the aim to study medium modifications of hadrons predicted by many theoretical approaches, as well as by the need to shed light on the still unexplained results of the former DLS experiment. In this contribution the HADES experiment is outlined and first results obtained in $^{12}C+^{12}C$ collisions at 2 AGeV are presented.

1. Introduction

The study of hadron properties inside the nuclear medium is of utmost interest as, from a very fundamental point of view, the partial restoration of the QCD chiral symmetry is expected to lead to a mass reduction of vector mesons at finite temperature and/or finite nuclear density. More specifically, QCD sum rules [1,2], as well as hadronic models [3–6] predict significant changes in mass and resonance width of vector mesons, like the ρ, the ω, and the ϕ, when embedded in nuclear matter. Besides photon- and hadron-induced reactions, these mesons are produced in heavy-ion collisions and they are short-lived enough ($\tau_{free} \leq 44$ fm/c) to decay to a large extend while still inside the reaction volume. And, as decay leptons do not undergo strong final-state interactions, lepton pair spectroscopy is the tool of choice for investigating these medium effects.

First dilepton spectra were reported from proton and pioninduced elementary reactions at typical center-of-mass energies of 6 GeV $< \sqrt{s} <$ 30 GeV. The measured di-electron distributions are explained by decays of free (i.e. in-vacuum) hadrons: at low invariant masses (M < 0.6 GeV/c^2) the spectrum is characterized by the Dalitz decay of π^0, η and ω mesons, whereas at higher masses the contributions from direct decays of the ρ^0, ω and ϕ dominate. The situation is similar for pA reactions where data were taken at 450 GeV by the HELIOS1 [7], the CERES [8], and the NA38 [9] collaborations, and at 1-5 GeV by the DLS collaboration [10]. Again the dielectron yields can be understood quantitatively by a superposition of freely decaying hadrons [11–13].

The experimental situation changes however drastically when going from proton to heavy-ion reactions. In all data taken, independent of the bombarding energy, a strong enhancement compared to the simple superposition of free hadronic decays appears in the dilepton mass region of 0.2 GeV/c^2 $< M_{inv} <$ 0.6 GeV/c^2. This was first observed in SPS

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experiments for di-electrons in S + Au [14] and for dimuons in S + W [15] reactions, and, later on, even more convincingly in Pb + Au reactions at 158 and 40 AGeV [16,17], and finally in central In + In collisions at 158 AGeV [18]. Analogously, the DLS collaboration has observed a significant enhancement in the systems C + C and Ca + Ca at a beam energy of 1.0 AGeV [19]. Various theoretical transport calculations including decaying baryon resonances and mesons, as well as pion annihilation cannot fully reproduce the DLS enhancement, even if medium effects in the propagation are taken into account (see e.g. [11,20,21]). This is in sharp contrast to the situation at SPS energies where the fireball is, however, dominated by mesons and where contributions from baryon resonances, as well as from πnucleon and pn Bremsstrahlung are therefore mostly irrelevant.

2. The HADES experiment

With the new High Acceptance DiElectron Spectrometer HADES [22] having become operational, the technique of electron-positron pair spectroscopy is now available at GSI for corresponding studies in the 1-2 AGeV energy regime. These energies, together with a proper choice of the collision system, allow to access a wide region in the nuclear matter phase diagram, ranging from ground state matter density ρ_0 up to about $3\rho_0$. The reaction volume is heated up to rather moderate temperatures $\leq$90 MeV without reaching the QGP phase transition boundary, characteristic for SPS and RHIC energies. Therefore, the long-range physics program of HADES [23,24] consists in a systematic study of e^+e^- pair production in heavy-ion reactions, as well as in proton- and pion-induced reactions, searching for precursor effects of chiral symmetry restoration.

HADES is a second-generation experiment for high-resolution electron-pair spectroscopy (for details see [22,23]). Due to the weak electromagnetic coupling constant, the di-electron decay channel accounts for typically only 10^{-5} – 10^{-4} of all hadron decays. Consequently the key features of the HADES spectrometer are: (a) an excellent lepton/hadron discrimination; (b) a designed resolution for invariant-mass reconstruction comparable to the natural width of the light vector mesons ($\sigma_M/M \simeq 1-2\%$); (c) a signal-to-background ratio significantly larger than unity for pair masses up to 1 GeV/c^2; (d) a large geometrical acceptance in combination with an advanced count rate capability; and (e) a high granularity to cope with heavy collision systems up to Au + Au (with the RPC upgrade described in [24]). These features result in a potentially manyfold increase in sensitivity over the former DLS setup.

The HADES setup is rotationally symmetric, covering polar angles of 18° – 85°. A fast, hadron-blind ring-imaging Cherenkov counter (RICH) is used for electron identification, enhanced with a set of electromagnetic Pre-Shower detectors, as well as a plastic-scintillator time-of-flight wall (TOF). Four tracking planes of multiwire drift chambers (MDC) combined with a toroidal 6coil superconducting magnet form the magnetic spectrometer for charged-particle momentum analysis. The LVL1 trigger decision is obtained as a fast multiplicity signal from the TOF wall and a LVL2 trigger decision is made by combining pattern-recognition results from the RICH, PreShower and TOF detectors in specially designed image processing boards. The latter allow to enrich the event stream with lepton-pair candidates by up to one order of magnitude.

3. First results from 2 AGeV C+C reactions

We report here on first results obtained in 2 AGeV $^{12}C+^{12}C$ collisions. These data have been gained in the so-called low-resolution mode for which tracking relies on the inner MDC planes only, as well as on position information from the TOF and pre-shower counters, resulting in a mass resolution of 10%. The TOF wall also provided a fast LVL1 trigger decision, wereas the lepton content of the recorded events was enriched by a factor 8 in a LVL2 trigger. A total of 150 million events (50% LVL1 dowscaled 1:10 and 50% LVL2) was thus recorded and analyzed. For a more detailed account of the experimental conditions and of the data analysis procedures see ref. [23]. The analysis was done for the data and in parallel also for a sample of simulated events in order to control the efficiencies of the various analysis steps. In brief: 1) single lepton spectra were generated for e^+ and for e^-, 2) from these opposite-sign and like-sign lepton pairs were recontructed, and 3) combinatorial background was subtracted using the geometric mean of both like-sign spectra to obtain the e^+e^- signal. The resulting mass spectrum, background and signal are depicted in figure 1. Shown are only the statistical error bars, on top of which an estimated systematic error of the procedure of ±30-40% has to be added quadratically. The experimental signal-to-background ratio is shown in figure 2.

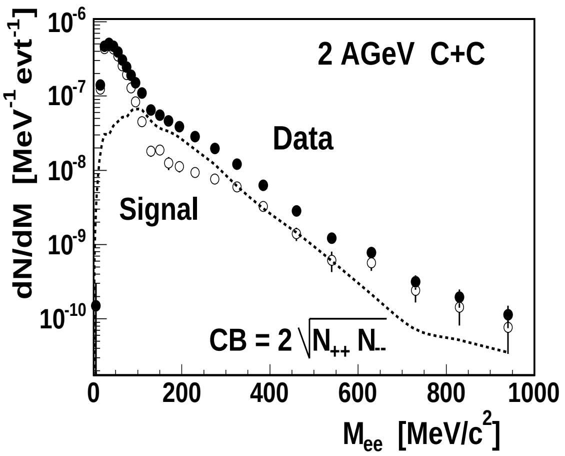

Figure 1. Reconstructed e^+e^- invariant mass spectrum for 2 AGeV C+C, where dashes = CB, open symbols = signal.

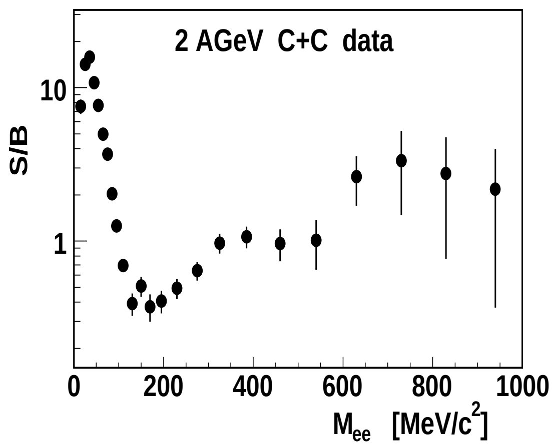

Figure 2. Signal-to-background ratio.

In figure 3 the pair signal is compared with a simulated cocktail of meson and baryon decays transported through the full detector simulation, i.e. folded with the spectrometer acceptance and efficiency. The π^0 and η multplicities used, with quoted errors of 10% and 16%, respectively, have been taken from [25], whereas vector meson production was estimated with an m_t-scaling ansatz. From this figure it is clear that the data agree with the cocktail, within our 30–40% systematic errors, at low masses (dominated by π^0 Dalitz decays), but show an excess at intermediate masses, indicative of effects due to the collision dynamics and/or the nuclear medium. Simulations with better statistics are still ongoing and a comparison with various full-fledged transport theories has been started.

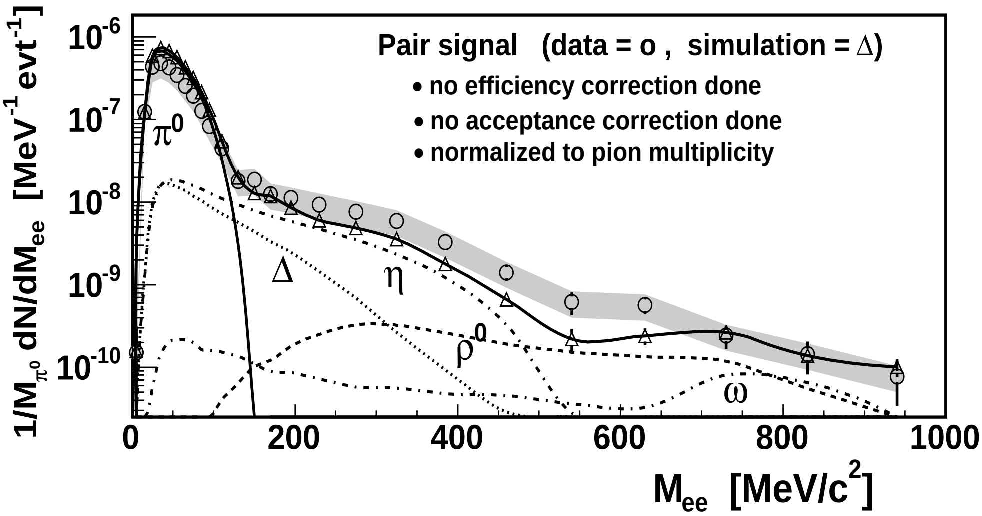

Figure 3. Comparison of data normalized to π^0 multiplicity with a simulated cocktail of various pair sources. The band shows systematic errors in data.

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