Dilepton production in p+p collisions at 1.58 GeV and 4.5 GeV beam kinetic energy with HADES

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Abstract. In this contribution, preliminary dilepton spectra from p+p collisions at 1.58 GeV and 4.5 GeV beam kinetic energy, measured with the High Acceptance DiElectron Spectrometer (HADES) in February 2022, are presented and compared with model calculations.
The upgraded HADES RICH detector, equipped with a new photon detection camera, significantly improves electron identification efficiency and conversion-pair rejection, leading to a signal-to-background ratio above 1 for both data sets. The 0.5 billion collisions at 1.58 GeV show clear π^0 and η contributions up to 0.6 GeV/c^2, while ω and ϕ contributions become visible at 4.5 GeV. A differential cross-section normalization based on elastic p+p collisions was established, with the resulting spectra showing good agreement with GiBUU and SMASH calculations. Both data sets provide NN reference spectra for heavy-ion studies, while the 4.5 GeV data additionally enable a multi-differential analysis of dielectron production mechanisms.

1 Introduction

Electromagnetic probes provide direct access to all stages of heavy-ion collisions, with the possibility to access radiation spectra from the hot and dense medium, by subtracting a simulated hadronic freeze-out cocktail and NN (nucleon-nucleon) reference spectrum. The resulting excess can be used to determine the mean medium temperature (by measuring the inverse slope of the spectrum) and its lifetime (by integrating the excess yield).

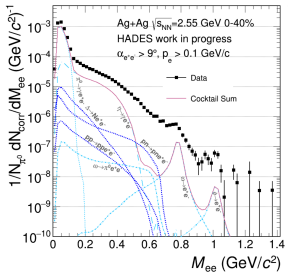


Figure 1. Dielectron signal of Ag+Ag collisions with hadronic cocktail and relevant NN channels from simulation [1]. The excess yield was calculated using a hadronic cocktail simulation provided by PLUTO [2] and NN reference spectra from GiBUU [3], where possible contributions were normalized to data. One of the main contributions to the systematic uncertainty of the in-medium component is the NN reference.

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In March 2019, the High-Acceptance-DiElectron-Spectrometer (HADES) [4] recorded Ag+Ag collisions at the beam energy of 1.58*A* GeV (Figure 1). To reduce the systematic uncertainties related to the NN reference subtraction, HADES measured p+p collisions with a liquid hydrogen target (LH_2) at 1.58 GeV beam kinetic energy in February 2022.

A second p+p measurement at 4.5 GeV beam kinetic energy provides a reference for future experiments at the SIS100 accelerator at FAIR. Its multi-differential analysis will further help to disentangle the underlying dielectron production mechanisms.

2 The HADES Experiment

HADES is a fixed-target experiment at the SIS18 accelerator at GSI in Darmstadt, Germany, operating with hadron and ion beams at energies of a few GeV per nucleon. Its large acceptance, covering polar angles between 18° and 85°, and more than 85 % of the azimuth, enables precise measurements of hadrons and leptons, including rare dilepton decays.

Charged-particle momenta are reconstructed from their deflection in the toroidal magnetic field using four layers of Mini Drift Chambers (MDC). Particle identification is provided by the START, TOF scintillators and the Resistive Plate Chamber (RPC). The RICH detector is essential for efficient electron identification, particularly at low momentum. An Electromagnetic Calorimeter (ECAL) provides additional electron identification at high momentum and photon detection.

For the p+p data collected in February 2022, events are selected based on trigger and event-vertex information. A cut on the z-component of the vertex suppresses interactions with the Mylar target mounting, which are studied separately using an empty-target event sample. Additional cuts are applied to the x- and y-components of the event-vertex coordinates. A minimum-bias trigger is used for the elastic-collision analysis, while a more restrictive trigger requiring at least three charged tracks inside HADES is used for the dielectron analysis.

High velocity particles are identified as electrons using RPC/TOF information and RICH ring properties. The RICH suppresses pion contamination and conversion electrons based on the ring-track matching quality, fired PMT multiplicities, and the reconstructed ring radius. For high-momentum electrons above 0.4 GeV/c, ECAL information is additionally used for electron-pion separation, particularly for the 4.5 GeV data.

3 Results for 1.58 GeV beam kinetic energy

The dielectron signal at 1.58 GeV beam kinetic energy (Figure 3) was obtained after acceptance and efficiency corrections and subtraction of the combinatorial background (for details, see [5]). It extends to an invariant mass of 0.6 GeV/c^2. In the π^0 Dalitz region ($M \leq 0.14\,\mathrm{GeV}/c^2$), 56800 signal pairs were counted, compared to 1853 in the η Dalitz region ($M > 0.14\,\mathrm{GeV}/c^2$). The signal-to-background ratio exceeds 1 across the entire spectrum.

The dielectron cross section is obtained by normalizing the signal with the integrated luminosity of elastic p+p collisions, $L = 367.4\,\mathrm{nb}^{-1}$ [6], and applying a bias factor accounting for event and trigger selection effects on the reconstructed dielectron yield.

Based on observations from previous beam times, the single-electron efficiency correction was validated using SMASH [7] simulations (Figure 2). Efficiency-corrected model spectra were compared with the input spectra within the detector acceptance, revealing an undercorrection at low invariant masses due to reconstruction effects for closely spaced tracks. The extracted additional correction factor (Figure 2) is applied to the experimental data.

The final efficiency-corrected cross section was compared with previous HADES p+p measurements [8] without correcting for geometrical acceptance, but assuming that it is very

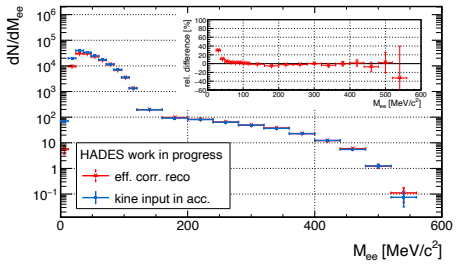


Figure 2. Comparison of the efficiency-corrected signal from the SMASH simulation with the input distribution within the detector acceptance. The relative difference is shown in the inset, revealing an under-correction for invariant masses below 50 MeV/c^2. The cross-section distribution is corrected using the extracted factor.

similar for all data sets, as shown in Figure 3. With increasing beam energy, the continuum above the π^0 mass becomes more pronounced, and the ω meson contribution emerges at higher energies.

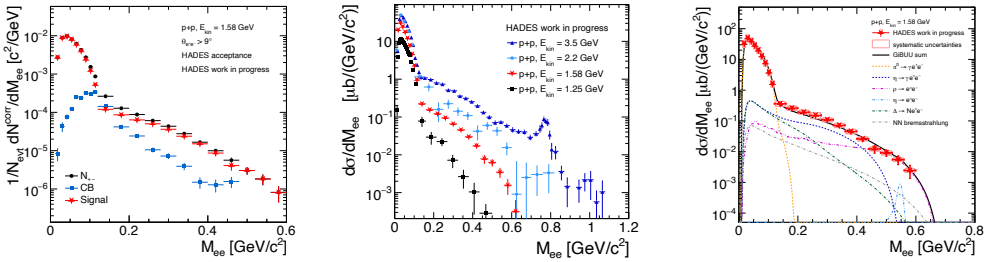


Figure 3. Dielectron signal at 1.58 GeV beam kinetic energy (left), comparison of the extracted cross-section distribution with previous HADES p+p measurements at various beam energies (middle), and comparison with GiBUU simulations (right). The middle panel is corrected for efficiency losses only, whereas the other panels are additionally corrected for detector acceptance losses.

For comparison with theoretical expectations, p+p simulations were performed with GiBUU. The same geometrical acceptance window used to correct the HADES data for acceptance and efficiency losses was applied to the simulations. In addition, a momentum-smearing matrix was generated from HADES simulations with PLUTO [2]. The resulting GiBUU spectra are therefore directly comparable to the experimental data, revealing a high degree of agreement with the experimental data.

4 Results for 4.5 GeV beam kinetic energy

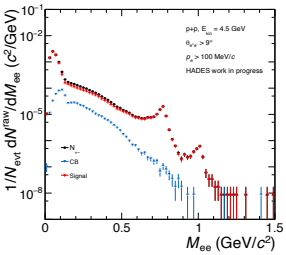


Figure 4. The dielectron signal at 4.5 GeV beam kinetic energy was obtained using the same procedure as for 1.58 GeV. The signal extends to an invariant mass of 1.2 GeV/c^2, with a signal-to-background ratio exceeding 5 across the entire spectrum. The ω and ϕ resonances are clearly visible.

The efficiency-corrected dielectron cross section for 4.5 GeV beam kinetic energy (Fig. 4, 5) was compared with SMASH predictions [9]. The high statistics of the data enable detailed multi-differential studies, with transverse-momentum and rapidity distributions used to disentangle the various resonances. To improve the agreement with the data, the SMASH cross sections were adjusted accordingly. Studies using more realistic simulations are ongoing.

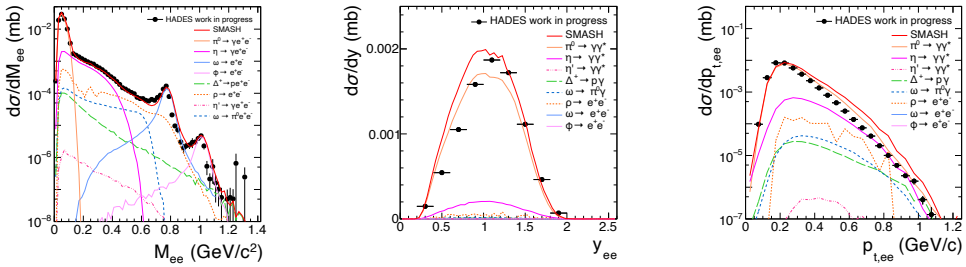


Figure 5. The dielectron cross section for 4.5 GeV beam kinetic energy has been compared with scaled SMASH simulations. The comparison of the rapidity (middle) and transverse-momentum (right) distributions is performed for the π^0 mass region up to 0.15 GeV/c^2.

5 Outlook

Dielectron signals were successfully reconstructed for p+p collisions at beam kinetic energies of 1.58 and 4.5 GeV. At 1.58 GeV, the experimental data show good agreement with GiBUU predictions. A future study of empty target collisions will be used to derive a p+n reference. Together with the p+p reference, the p+n spectrum enables the extraction of the medium temperature and excess yield in Ag+Ag collisions. For the 4.5 GeV data, future studies will focus on more realistic SMASH simulations. The experimental particle multiplicities in hadronic channels will be used to constrain the SMASH input, followed by a GEANT simulation of the detector response. The resulting reference spectrum will support future experiments at the SIS100 accelerator.

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