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Calibration of the electromagnetic calorimeter ECal of the HADES experiment

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On behalf of the HADES collaboration

Abstract. HADES is a large acceptance spectrometer operating at SIS18, GSI, Germany. It is aimed at exploration of QCD phase diagram at the ion beam energies of 1-2 AGeV in the region of high baryonic densities. The new segmented electromagnetic calorimeter (ECal) was built to extend experimental opportunities of the HADES detector. The electromagnetic calorimeter will allow to study new reaction channels involving the production of neutral mesons and neutral resonances in elementary and heavy-ion reactions via detection of their two photon decay. An additional advantage of such a device is the resulting improvement of the electron-to-pion separation at large momenta.

The detector is based on 978 Cherenkov lead glass modules divided into 6 sectors, and it covers forward angles of $12^\circ < \theta < 45^\circ$ and almost full azimuthal angle. Currently four out of six sectors planned are assembled in the experimental area. The first raw beam data obtained with the ECal detector in Ag+Ag reactions at 1.65 AGeV beam are presented.

1. Physics motivation

The High Acceptance Di-Electron Spectrometer (HADES) experiment [1] operates since September 2001. Spectrometer consists of a diamond START detector, a Ring Imaging Cherenkov (RICH), four sets of Multiwire Drift Chambers (MDC), a superconducting toroidal magnet, a scintillator based time-of-flight wall (TOF) and the RPC wall built of resistive plate chambers, and up to 2014 a Pre-Shower detector. Spectrometer is divided into six sectors covering polar angle $12^\circ < \theta < 88^\circ$. ECal is located at forward angles ($12^\circ < \theta < 45^\circ$), replacing the HADES Pre-Shower detector. It allows measurements of neutral meson production cross-sections by detecting the gamma pair from its decay. These data will allow one to properly account for corresponding dilepton yield from Dalitz decay of neutral mesons and hence reveal other non-trivial sources of dileptons. Combining the two photon detection in the ECal calorimeter with a charge particle detection in HADES it will also be possible to investigate ρ production via the $\pi^0\pi^+\pi^-$ and the $\pi^0 e^+ e^-$ decays (the latter being of importance for the still unsettled question of the ω electromagnetic transition form factor). Furthermore, photon measurements would be of large interest for the HADES strangeness program which addresses also spectroscopy of neutral $\Lambda(1405)$ and $\Sigma(1385)$ resonances in elementary and heavy ion reactions. An additional advantage of ECal would be the improvement of the electron/pion separation at large momenta over 400 MeV/c (at lower momenta good electron/hadron identification is provided by the RICH, RPC and TOF detectors already available in HADES).

2. ECal detector

Electromagnetic calorimeter (ECal) is a newly built detector with a homogeneous lead glass block as a radiator and PMT as a photodetector. It has time resolution around 300 ps and energy resolution $5.5\%/\sqrt{E[GeV]}$. The detector is separated into six sectors with 163 modules each. Time over threshold (TOT) method is used to measure the amplitude of the output signal from PMTs. The detailed description of the ECal detector can be found in [2].

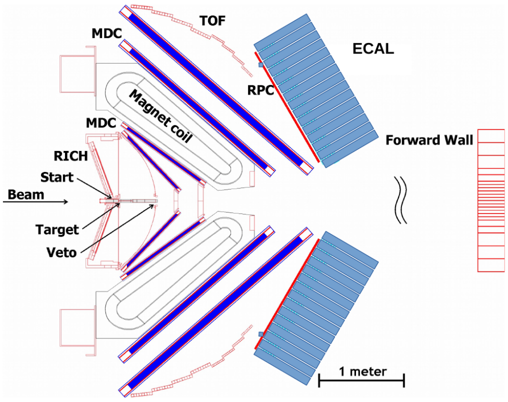

Figure 1. HADES schematic view with ECal detector

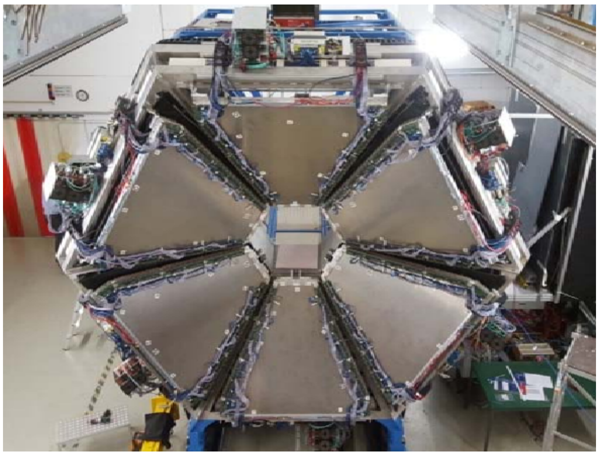

Figure 2. Assembled 4 sectors of ECal detector. The upper- and lower-most sectors are equipped only with the RPC detector

3. Tests of ECal detector

Before the ECal went into operation its characteristics were studied in a set of tests.

(i) Each module was tested with cosmic muons. The dedicated stand for such tests was developed and assembled in the GSI detector lab. Two scintillator detectors were placed above and below the ECal module standing in vertical position. In coincidence they provided the trigger signal, while the amplitude of the output from the tested module was digitized by CAEN sampling analog-to-digital converter [3]. The main goal of the test was to find out such voltage that the response of the module to the minimal ionizing particle (MIP) was a pulse with amplitude of 1.5 V at 50 Ohm to secure the needed dynamical energy range. For details see [4].

(ii) Several modules were tested with γ-beam at MAMI, Mainz to compare different options of PMTs, to check linearity and resolution of the modules. It was found that 1.5 inch EMI 9903KB and 3 inch Hamamatsu R6091 photomultipliers give resolution close to 5% at 1 GeV, which suits the needs of the experiment, while 1 inch Hamamatsu R8619 has too poor resolution. The results can be found in [5].

(iii) Dedicated measurement at CERN was carried out to evaluate electron/pion separation power and to assess time resolution, which is essential for removing hits caused by neutrons. Five identical modules with EMl photomultiplier were irradiated by secondary π^-/e^- beam at T 10 test beam line of the PS synchrotron. The electron/pion separation was found to be better than 80% at $E > 400$ MeV, where the time-of-flight technique becomes inefficient [6].

(iv) In second half of 2018 four sectors of the ECal detector were assembled in the experimental hall, see Fig. 2. Runs with cosmic muons in a self-trigger mode allowed to check HV supply and readout of the detector.

4. Time calibration

In December 2018 first data from Ag+Ag collisions at 1.65 AGeV beam energy were collected. The quality of data was checked during the runs and in off-line analysis. Amplitude vs Time distribution plots were drawn for each module. One can see an example of such plot in Fig. 3.

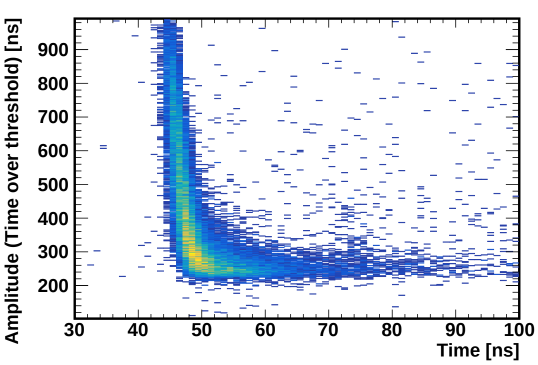

Figure 3. Amplitude - Time distribution

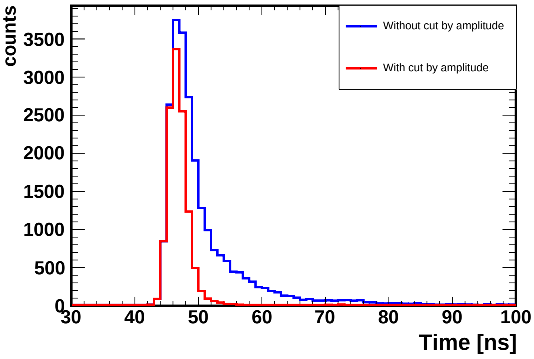

Figure 4. Time distribution with (red) and without (blue) cut by amplitude

Depending on the length of signal cables and response time of electronics, the delays of the channels are different. To equalize the time delays and to get the time of flight more precisely, time calibration has been performed. During the tests in December 2018 the magnetic field was switched off. In this case trajectories of all particles are straight, which means the paths from the interaction point to the ECal are equal.

The time of flight of γ-s and relativistic electrons is known and equal roughly to 8 ns depending on the distance of the individual module from the target. By plotting time spectra of each module and selecting large amplitudes to remove the time dependence (see Fig. 4) the delay of each channel is evaluated. This delay is then subtracted from the measured time and the resulting value is increased by 8 ns. As a result the measured time is equalized to the real time of flight.

5. Energy calibration

In March 2019 first Ag+Ag data at 1.58 AGeV beam energy were collected with ECal detector. The magnetic field was switched on. This allowed to provide energy calibration of the detector. Electrons are the best candidates for this procedure. Inside the material of Cherenkov radiator they produce electromagnetic shower with the same properties as if it were γ-quants with equal energy. Unlike γ-s, electrons and positrons are registered by all detectors of HADES. Their trajectories are reconstructed using information from MDC planes and RPC+TOF system. Curvature of a trajectory in magnetic field determines momentum of a particle. RICH detector distinguishes e^- and e^+ from pions and other kinds of particles, while Time-of-flight technique improves the efficiency of particle identification at low momenta ($p < 400 MeV/c$). Assignment of a track to ECal hit is done using coordinates of hit in the RPC detector, which is placed close to ECal.

The energy of electron E_e was plotted as a function of the amplitude of ECal signal A. It was found that this dependence can be roughly estimated as $E_e = c_0 + c_1 * A + c_2 * A^2$. Determination of the indices c_0, c_1 and c_2 for each individual module provided the energy calibration of ECal detector. The quality of calibration can be checked on Fig. 5, where the energy of electrons measured by ECal is plotted as a function of their momentum measured by other detectors. This dependence is linear with a good precision.

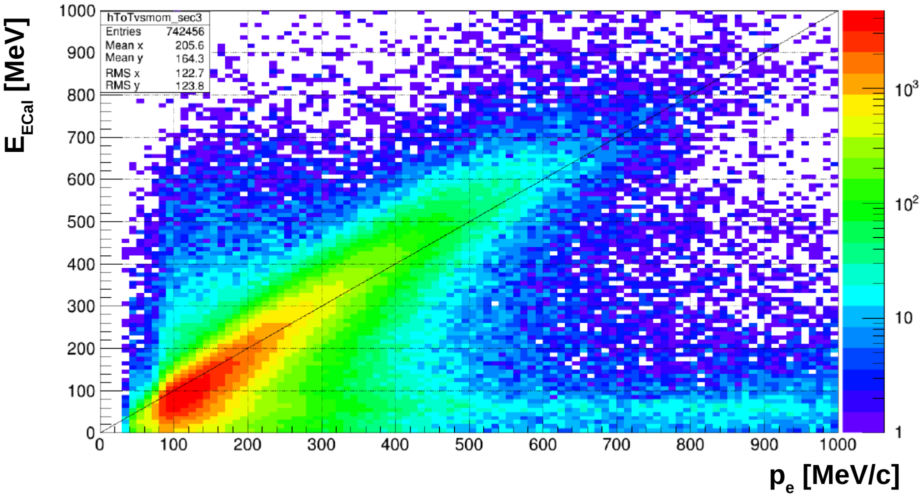

Figure 5. Energy deposited in ECal vs momentum of e^-

6. Conclusions

The newly built Electromagnetic Calorimeter ECal was developed to extend experimental possibilities of the HADES experiment. Its modules successfully passed all necessary tests. Currently four out of six sectors are assembled in the experimental hall. The remaining two sectors will be assembled at the end of 2020. Time calibration was carried out using fast electrons and γ-quants from Ag+Ag collisions. To provide ECal with amplitude calibration the electrons were identified in RICH and their energy was measured via momentum reconstruction with

MDC chambers. The next step will be the reconstruction of diphoton invariant mass spectra and consequent study of the neutral meson production.

7. Acknowledgment

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