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Verification of Electromagnetic Calorimeter Concept for the HADES spectrometer

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Abstract. The HADES spectrometer currently operating on the beam of SIS18 accelerator in GSI will be moved to a new position in the CBM cave of the future FAIR complex. Electromagnetic calorimeter (ECAL) will enable the HADES@FAIR experiment to measure data on neutral meson production in heavy ion collisions at the energy range of 2-10 A GeV on the beam of the new accelerator SIS100. Calorimeter will be based on 978 massive lead glass modules read out by photomultipliers and a novel front-end electronics. Secondary gamma beam with energies ranging from 81 MeV up to 1399 MeV from MAMI-C Mainz facility was used to verify selected technical solutions. Relative energy resolution was measured using modules with three different types of photomultipliers. Two types of developed front-end electronics as well as energy leakage between neighbouring modules under parallel and declined gamma beams were studied in detail.

1. Introduction – HADES experiment

The HADES detector (High Acceptance DiElectron Spectrometer) is focused on precise measurement of electron-positron pairs coming from the high energy interactions. A wide range of reactions ranging from proton – proton, pion – proton, pion - nucleus up to gold on gold [1] collisions were examined in the past decade. HADES is currently operating on the beamline of SIS18 accelerator at GSI Darmstadt, Germany. The current setup consists of a diamond start detector (START), Ring Imaging Cherenkov detector (RICH), four layers of multiwire drift chambers (MDC), a superconducting toroidal magnet (ILSE), time of flight walls from resistive plate chambers (RPC) and plastic scintillators (TOF), pre-shower detector (SHOWER) and Forward Wall detector [2].

Within the international project FAIR being built next to GSI, a brand new accelerator SIS100 will start to deliver heavy ion beams after 2018. The Hades spectrometer will be moved to a newly build cave shared with the CBM experiment and plans to continue in di-electron mass spectra measurements with beams of accelerated protons up to 10 GeV and heavier ions up to 8 AGeV.

2. Motivation and limits for a build-up of calorimeter

The electromagnetic calorimeter (ECAL) will extend the HADES experimental possibilities in several directions. First of all, the ECAL will enable measurement of gamma photons from various decays of mesons or neutral $\Lambda(1405)$ and $\Sigma(1385)$ resonances. The ECAL will also improve electron/pion separation at large momenta over 400 MeV/c (at lower momenta sufficient electron/hadron identification is provided by the RICH, RPC and TOF detectors).

Basic design of the ECAL was given by the HADES geometry – six separate sectors covering almost full azimuthal angle and polar angle 18° to 45°, more detailed description in [3]. Lead glass was loaned from the OPAL collaboration from the former endcup detector [4], so the size of the modules is fixed. More than 600 pieces of 1.5” EMI 9903KB photomultipliers were obtained from former MIRAC experiment [5].

3. ECAL module

Each module will consist of 92x92x420 mm^3 lead glass crystal. The glass is of CEREN 25 type with density of 4.06 g/cm^3 (weight of a single glass crystal is 14.4 kg). More details on glass properties can be found in [4]. Lead glass will be wrapped in white TYVEK paper 1060B, Cherenkov light will be read out by a photomultiplier (PMT). Beside the available 1.5” EMI PMTs a new 3” Hamamatsu R6091 PMTs are being bought to cover the missing number of pieces. The high price of new 3” PMTs invoked a study of possible use of 1” Hamamatsu R8619 PMTs . Photomultipliers will be shielded against residual magnetic field using a magnetic shielding. Each module will be also equipped with an optical fiber of CERAMOPTEC multimode type, which will guide well defined light pulses for stability and monitoring purposes directly to the glass. The module will be held together by a brass can with a wall thickness of 0.45 mm and an aluminum closing at the end. More information about the module layout can be found in [3].

4. Beam tests

Two beam tests of ECAL modules were already performed in the past. In September 2009, a gamma beam at MAMI Mainz was used to measure energy resolution of ECAL modules equipped with different light collector and reflector configurations. Modules with silver Mylar foil, white paint and Tyvek paper were tested. Light collector from the same lead glass placed between the glass and 1.5” EMI photomultiplier was also tested, but does not resulted in significantly better results. An electron/pion separation power was measured using a secondary e^-/π^- beam from T10 beam line at CERN in May 2010. More details about both two tests can be found in [3] and [6].

4.1. Motivation for a new beam test

Only measurements with cosmics muons and LED monitoring pulses were done since the two beam tests of ECAL modules. To conclude all laboratory tests and verify selected technical solutions, a new

gamma beam test at MAMI-C Mainz was proposed. Main tasks of this test were measurement of relative energy resolution of modules with different PMT sizes, test the novel front-end boards, which were not tested with real beam data before, and to study energy leakage between neighboring modules.

4.2. Experiment layout

A new beam test of calorimeter modules and read-out concepts was performed at Institute für Kernphysik, Johannes Gutenberg Universität Mainz. Primary electron beam of 1508.4 MeV was directed to a copper target, energy of produced photons was determined using the method of tagged electrons in dedicated TAGGER [7] detector in MAMI A2 hall. Recoiled electrons from the copper target were bended in a magnetic field of 1.83204T inside the TAGGER and detected by a set of scintillation detectors. The Tagger has 352 detector channels representing photon energies from 1401 MeV down to 81 MeV. For the ECAL measurements only eight channels were selected according to the table 1.

Table 1. Selected TAGGER channels and corresponding photon energies.

Tagger channel	E_γ Low (MeV)	E_γ High (MeV)	E_γ Mean (MeV)	E_γ Bite (MeV)
2	1398.322	1400.327	1399.325	2.005
66	1216.127	1219.411	1217.769	3.284
121	1030.452	1034.414	1032.433	3.962
170	841.208	845.549	843.379	4.341
210	675.710	680.453	678.081	4.743
261	458.898	463.720	461.309	4.821
306	268.440	273.348	270.894	4.907
352	78.992	83.746	81.369	4.754

Four ECAL modules were placed on a movable platform 1m behind the tagger shielding. Gamma beam was shaped using collimators of 2mm diameter placed inside the tagger shielding. The beam spot on the module front surface was approximately 6 mm.

One ECAL module was equipped with 1.5" PMT (same module as in previous beam tests at MAMI and CERN was used, so a direct comparison of results is possible). Two modules were equipped with 3" PMTs and last module contained 1" PMT. High voltage for the photomultipliers was tuned to get the same output amplitude on cosmic muons for all three types of photomultipliers.

4.3. Comparison of different read-out boards

To have an independent ADC measurement, a standard CAEN DT5742 digitizer was used. This CAEN ADC stores 1024 values in a 1 μs window for each of the 16 input channels. Output from the four ECAL modules were read by the first four ADC channels. The 8 trigger signals were put to the last eight ADC channels and also stored to the data. Common trigger signal for starting the read-out was produced as an OR of the individual eight trigger signals, the lowest (and the most frequent) energy was downscaled four times, the second lowest energy was downscaled two times. Active trigger signal representing corresponding gamma energy in each event was determined in the off-line analysis of the last eight ADC channels. Both direct pulses from PMTs and pulses shaped in MA8000 shaper with shaping time of 1 μs (production of GSI Darmstadt) were collected. The Rhode&Schwarz oscilloscope RTO 1044 with histogramming function was used for high resolution pulse storage and amplitude measurement (analog to CAEN ADC device). Stored pulse shapes were compared to pulses collected in measurements with cosmic muons and LED monitoring systems and they were found to be identical. Relative energy resolution of "Cracow" and PaDiWa Amps readout boards was measured and it is comparable in the full energy range, see Figure 1. Energy resolution is slightly better in

comparison with the MA8000 + CAEN setup. This was caused by former optimizing of both two readout boards on the PMT pulses.

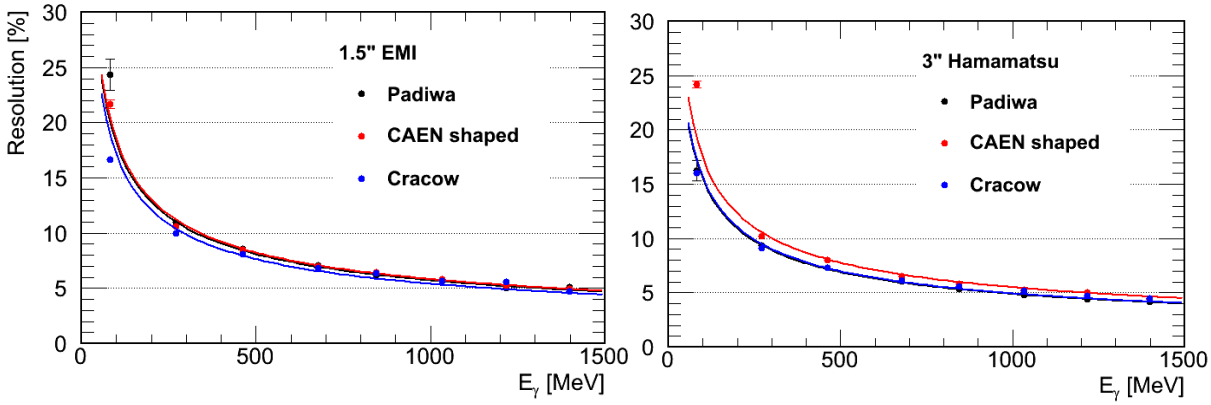

Figure 1. Relative energy resolution measured with the standard CAEN ADC and novel front-end boards "Cracow" and PaDiWa Amps. Data are measured using the module with 1.5" photomultiplier (left) and 3" photomultiplier (right).

4.4. Relative energy resolution of modules with different photomultipliers

As already mentioned in the section 3, three types of PMTs with different size were under considerations. Energy resolution with all three types of modules was intensively measured using cosmic muons and LED induced signals in the past ([3] or [6]), but real beam data were missing to make the final decision. Using different gamma beam energies at MAMI Mainz and three different types of pulse processing systems we got a decisive data set.

Module with 1.5" as well as with 3" PMT showed comparable energy resolution (5.8% at 1 GeV photon with 1.5" EMI and 5.5% with 3" Hamamatsu), please see Figure 3 - left. Module with 1" PMT had worse relative energy resolution by ~ 1.6%. Moreover, the 1" PMT has to work at higher input voltage to compensate for lower output amplitudes. At this voltage, the response of the PMT starts to be nonlinear, see Figure 2 left. Dependence of relative energy resolution on high voltage supplied to 1" PMT and measured with shaper MA8000 and CAEN ADC are in Figure 2 - right.

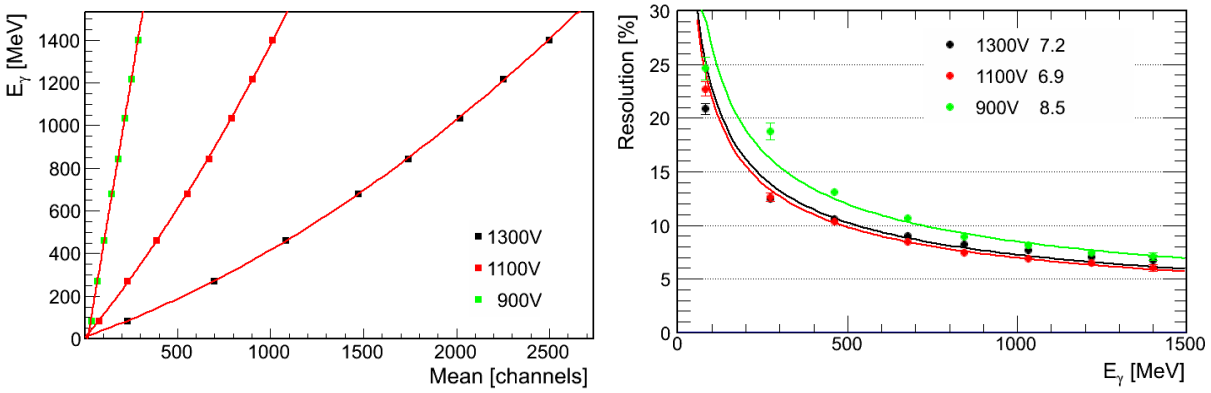

Figure 2. The (non)linear response of 1" Hamamatsu R8619 photomultiplier as a function of high voltage (left). Relative energy resolution of ECAL module equipped with 1" Hamamatsu R8619 photomultiplier as a function of high voltage (right). Numbers behind the names stand for resolution with 1 GeV photons.

4.5. Energy leakage between the modules

Two identical modules equipped with 3" PMTs were irradiated with gamma beam parallel with the module longitudinal axis. Three measurements were done with the beam position in the center of one

module, 2 cm from the center closer to the second module and 4 cm from the module center closer to the other module (only 0.7 cm from the module border). The same measurement was repeated also with a gamma beam declined by 6° and 12° from the longitudinal module axis. The Figure 3 - right shows only a modest deterioration of the relative energy resolution in dependence on the beam angle.

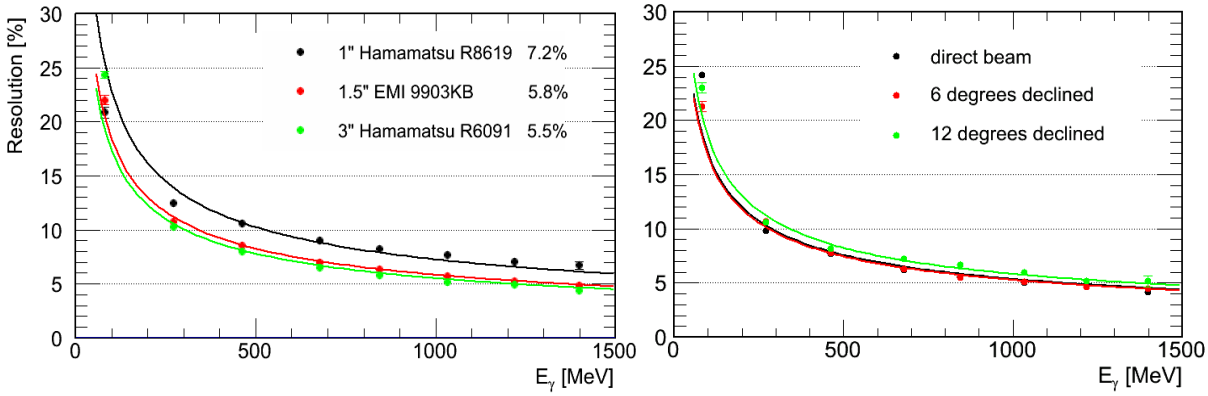

Figure 3. Comparison of relative energy resolution for modules with PMTs of different size (left). Relative energy resolution of the ECAL module equipped with 3" PMT with respect to the various declination of the incident photon (combination of measurements with different angle) (right).

5. Summary

Electromagnetic calorimeter ECAL is being built to enhance experimental possibilities and physics program of the HADES experiment. The ECAL will enable to measure gamma photons coming from various neutral particle decays.

Gamma beam test at MAMI-C Mainz showed that both two novel front-end boards have comparable relative energy resolution and are able to operate under real beam conditions. The ECAL modules equipped with 1.5" and 3" photomultipliers deliver similar relative energy resolution, whereas the module with 1" photomultiplier gives by 1.6% worse energy resolution and non-linear response.

Energy leakage between the neighbour modules was tested with parallel and declined beams. Energy of original photon was successfully recovered as a sum of energies deposited in each of the modules. Some part of the original energy was lost only in the case of parallel gamma beam hitting close to module boarder.

Design of single ECAL module was settled and successfully verified in beam tests. Mass production of modules and final setup of the calorimeter depends on the completion of the CBM cave, which is planned beyond the year 2018.

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