Commissioning of the electromagnetic calorimeter ECAL of the HADES experiment

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Abstract. HADES (High Acceptance Di-Electron Spectrometer) is located at the GSI (Helmholtzzentrum für Schwerionenforschung) Darmstadt. It is an experiment focused on the study of the hot and dense nuclear matter mainly via the detection of the di-lepton pairs. Electromagnetic CALorimeter (ECAL) was recently added to the HADES setup. This new subdetector allows measuring of photons from the decay of neutral mesons and resonances. It also allows to discriminate between electrons and pions in the high-momenta region over 400 MeV/c. ECAL follows same hexagonal geometry as HADES, i.e. it consists of six sectors in azimuth. The first four sectors were finished and commissioned in 2018. The first experiment with ECAL included in HADES setup took place on March 2019, investigating the Ag+Ag reaction at beam energy of 1.65 A GeV. During the commissioning, several issues popped up and they were addressed. The issues and their solution will be described in the article.

1. HADES - brief description

The HADES spectrometer [1] is divided into 6 sectors around the beam axis. It has almost full azimuthal coverage, between 18° and 85° of the polar angle. It consists of several sub-systems: START and VETO systems which utilize diamond sensors, Ring Imaging Cherenkov detector (RICH) with gas radiator and pixel PMTs for read-out, four planes of Multiwire Drift Chambers (MDC) which provide tracking abilities, two layers are located before a two after the magnetic field, superconducting toroidal magnet with six coils which produces the magnetic field that allows measuring the momenta of charged particles, Time of Flight (TOF) wall and Resistive Plate Chambers (RPC) provide the time of flight and multiplicity information. The newest sub-system is the Electromagnetic Calorimeter (ECAL) which is discussed in more detail further.

2. Description of calorimeter

Each of the six sectors of the calorimeter consists of 163 modules arranged in the trapezoidal shape. For polar angles, proposed coverage is between 12° and 45° the azimuthal angle is almost fully covered. Up to now, four sectors are finished. The detector and more detailed view of one sector are shown in figures 1 and 2. Designed resolution, verified by beam tests, is $\Delta E/E = 5.5\%$ for 1 GeV photons.

The detection principle is based on a detection of the Cherenkov light generated by charged particles, which in the case of photons came from the electromagnetic shower. The modules are based on a lead-glass prism acting as radiator and photomultiplier (PMT) read-out. The module in an exploded form is shown in Figure 3. The full module assembly is visible in the figure. The only thing missing is an optical fiber for a laser monitoring system. Magnetic shielding is made from MUMETALL® and is needed due to a residual magnetic field due to toroidal HADES superconducting magnet coils. There are two types of modules one with 3" PMT Hamamatsu R6091 and the second type with 1.5" PMT Thorn EMI 9903KB. In case of R6091 version, the PMT was used in bare form, i.e. without anything on the PMT bulb. Figure 3 shows the variant with 3" PMT. The 1.5" variant has an analog design to the 3" variant. More detailed description and motivation can be found in [2, 3].

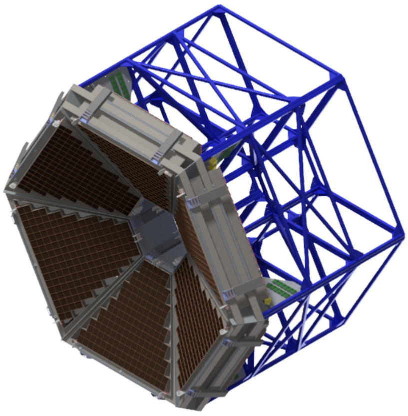

Figure 1. Picture of full ECAL detector without supporting rails.

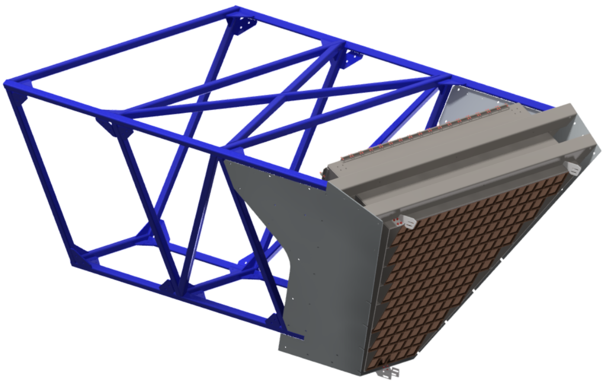

Figure 2. Detailed picture of one ECAL sector with installed modules.

3. Commissioning and initial calibration of the modules

After assembly complete functionality of the modules was tested. Together with the test, an initial calibration took place. The goal of the calibration was to set the high voltage for each module in a way that all modules have the same response. Cosmic muons were used in order to do that. A special triggering system was introduced to ensure that the muon will go through the whole length of the lead glass. It consisted of two scintillator plates coupled with PMTs and connected into a coincidence circuit. One scintillator was above the module and one under the module. The orientation of the module was vertical with the PMT detection window facing up. More detailed description of the calibration setup can be found in [3].

After installation into the calorimeter frame, the modules were tested again. Also, the calibration was checked. However, after a few months in the frame, some of the certain modules started to express unexpected behavior. The first clue was represented by cross-talk through almost all channels in one PaDiWa amplifier [4]. Closer investigation showed up that the cross-talk was caused by huge signals with amplitude up to 50 V. Expected amplitudes were up to

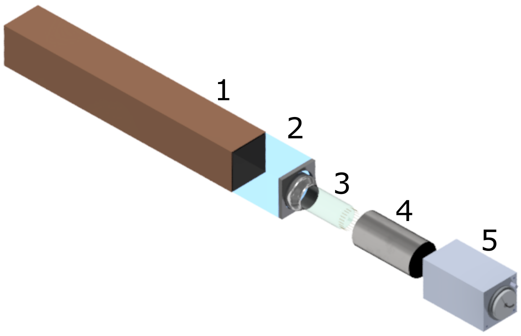

Figure 3. Picture of the module in the exploded form. 1 – brass envelope, 2 – lead-glass, 3 – PMT, 4 – magnetic shielding and 5 – aluminum housing for the PMT and shielding.

5 V. Figure 4 shows examples of such signals. The second clue was represented as very wide signal in the ToT (time over threshold) spectra from long-time test measurements. The cause of this was identified in oddly shaped wide signals. The example can be seen in Figure 5.

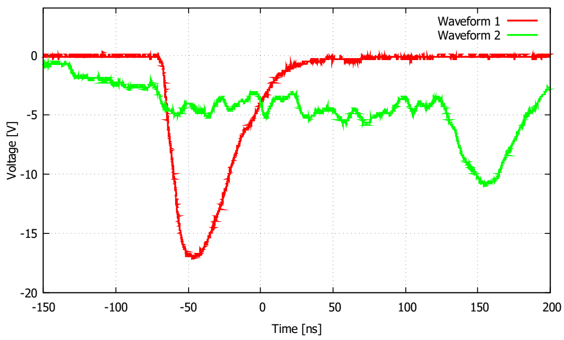

Figure 4. Examples of high-amplitude waveforms.

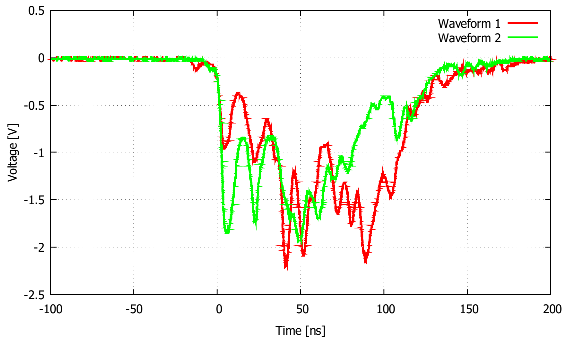

Figure 5. Examples of wide and oddly shaped waveforms.

4. Identification of the issue

The source of the problems was identified by disassembling the module and assembling it back piece by piece with test after each step. The problem was identified to the magnetic shielding. More precisely to the position and alignment between magnetic shielding and the PMT. When the magnetic shielding was nicely round and aligned with the PMT the issues did not occur. But when the shielding was deformed or moved in a way that the spacing was reduced the issues gradually started to propagate itself. The issues were gaining on the severity with increasing high voltage for the PMT. With high voltage over 2000V the issues slowly (after a week or more) occurred even for aligned magnetic shielding.

According to Hamamatsu PMT Handbook [5] grounded objects might cause such effects when positioned close to the PMT. But it was not our case since there is no conductive connection between the housing and magnetic shielding. However, it became clear that there are some effects and possible discharges between the PMT which has photo-cathode on a negative high voltage and the magnetic shielding even when it is not grounded. The easiest solution would be to significantly increase the diameter of the magnetic shielding and to place some kind of spacer

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between the PMT and the magnetic shielding. But this was not possible since the magnetic shielding has to be as close as possible to the photomultiplier in order to avoid leakage of the magnetic field into the shielding and the PMT. Improving the electric isolation with a Kapton® layer did not solve the issue either.

The only suitable possibility how to shield the photo-cathode and the whole PMT from the potential difference was to introduce *active* electrostatic shielding on the same potential as the photo-cathode similar to HA treatment described in [5]. The potential difference between the electrostatic and magnetic shielding is not an issue as both are passive components in the sense of signal generation.

5. Development of the electrostatic shielding

Due to the fact that the modules were already installed in the calorimeter frame, the possibilities of how to add the electrostatic shielding were very limited. It is impossible to take out the PMT out of the module without disassembling it and to disassemble the module it is necessary to take it out of the frame first. This would be a very complicated operation with uncertain result in the time which was available before planned beamtime. For this reason, we created a flexible version of the shielding which was possible to insert via the cap on the PMT housing. The shielding is made of 125 μm thick Kapton foil which serves as a support and electric isolation and 50 mm wide copper tape as it is shown in Figure 6. It was inserted rolled in small diameter and then it expanded and was pushed to the position relative to the PMT shown in Figure 7.

Figure 6. Electrostatic shielding in the expanded form.

Figure 7. Electrostatic shielding wrapped around the PMT.

The Kapton-copper shielding was applied to all affected modules and it successfully worked during an experiment. However, due to the complicated and not fully controlled insertion procedure, occasional discharges from the shielding occurred. For that reason, more advanced shielding was developed. In the case of this new approach, the conductive layer is applied directly on the PMT by means of graphite paint. The connection to the photo-cathode is made via line made from paint based on silver guided from photo-cathode pin to the graphite conductive layer. The PMT with the conductive layer together with the interconnecting line is shown in Figure 8. On top of the conductive layer, the PMT is coated with black paint with the exception of the detection window. The black paint serves as a protective layer for the conductive paint and to block any residual light which might leak to the module or be generated by some unexpected discharge. Shrinkable foil is added as mechanical protection to avoid damage when inserting the PMT into the magnetic shielding. Additional Kapton layer is also added to the inner side of the magnetic shielding to act as an electrical insulator. The fully treated PMT is shown in Figure 9.

Figure 8. Conductive coating on the PMT together with the interconnecting line.

Figure 9. Fully treated PMT with protective foil.

The PMTs with such treatment were tested even during the experiment in beam conditions for almost one month. They behaved as expected without any signs of issues experienced without the electrostatic shielding. The modules with these PMTs were also completely free of discharges. With this knowledge, all originally affected PMTs were retrofitted with the electrostatic shielding based on the conductive coating. All new modules are going to be treated with this method as well.

6. Conclusion

During commissioning of the ECAL calorimeter some issues appeared after the installation of the modules into the calorimeter frame. It showed up that when using bare PMT, there is huge sensitivity on the relative position between the PMT and the magnetic shielding. And in close geometries like ours discharges and a current flowing through the PMT glass can occur even without direct conductive connection between the shielding and ground potential. To mitigate this effects two versions of the electrostatic shielding were developed. The first based on a combination of Kapton foil and the copper tape was used due to the possibility to install it without disassembling the modules. The second more advanced version based on conductive coating was developed in order to mitigate even some side effects of the Kapton-copper shielding. All affected modules were retrofitted with this more advanced version.

Acknowledgment

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References

[1] Agakichiev G et al. 2009 *The European Physical Journal A* **41** 243–277 ISSN 1434-601X
[2] Svoboda O et al. 2014 *Journal of Instrumentation* **9** C05002–C05002
[3] Petukhov O et al. 2019 *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* ISSN 0168-9002
[4] Rost A, Galatyuk T, Koenig W, Michel J, Pietraszko J, Skott P and Traxler M 2017 *Journal of Instrumentation* **12** C02047–C02047
[5] *HAMAMATSU, Photomultiplier Tubes - Photomultiplier Tubes and Related Products* URL `https://www.hamamatsu.com/resources/pdf/etd/PMT_TPMZ0002E.pdf`