Installation and commissioning of the Electromagnetic Calorimeter in the HADES experiment

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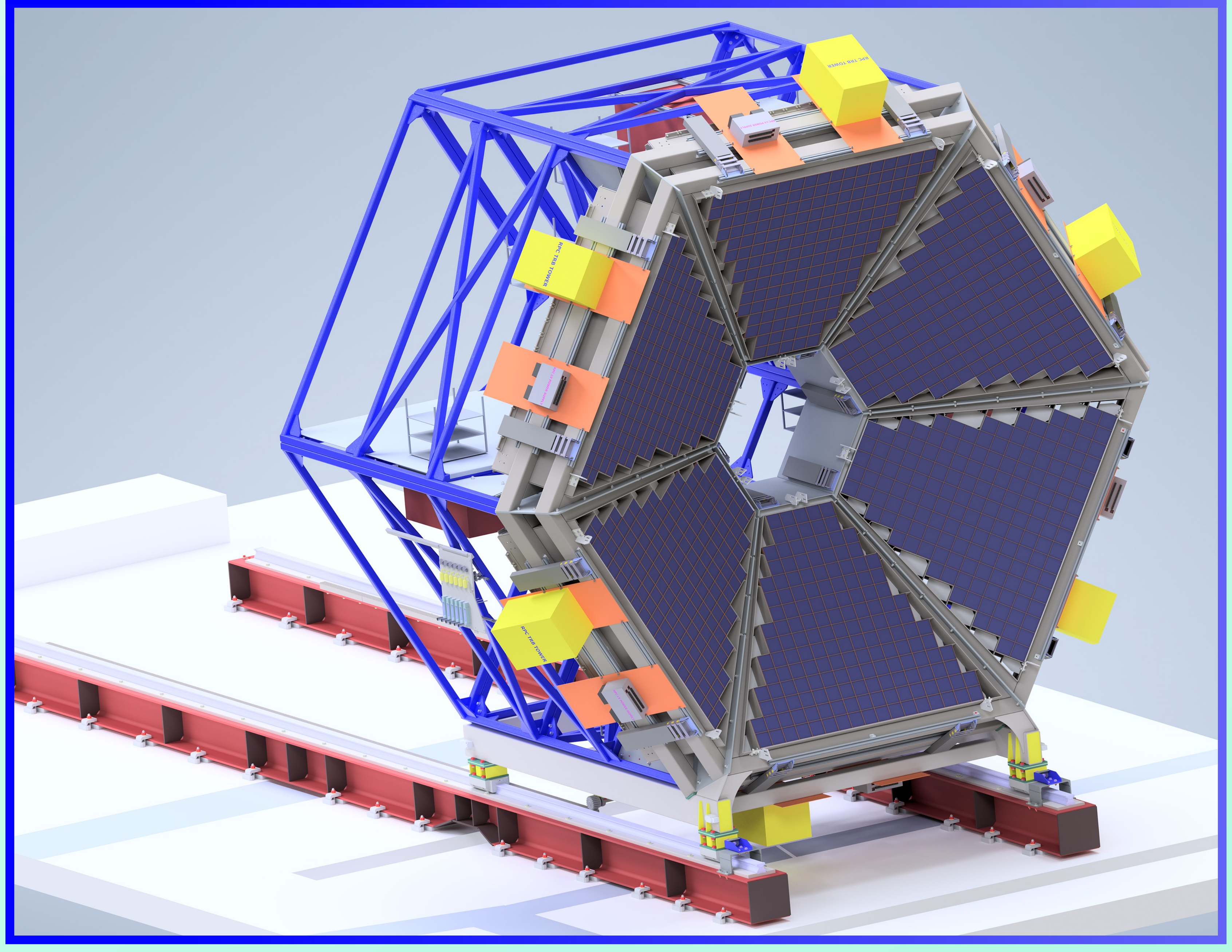
Introduction

The Electromagnetic Calorimeter (ECAL) serves as a subdetector for the HADES (High Acceptance Di-Electron Spectrometer) experiment, located at the FAIR-GSI in Darmstadt, Germany. The HADES experiment aims to study the QCD phase diagram at high baryonic densities and low temperatures, primarily via the di-lepton decay of vector mesons. The primary function of the ECAL is to measure the energy of γ-quanta. The detector's implementation allows for the study of the production of neutral mesons via their two photon decay, as well as hyperons and improves electron-to-hadron separation in fixed-target nuclear reactions at 1-4 A GeV beam energies. The ECAL detector's key milestones were achieved, including the successful installation and commissioning of the final 6th sector, comprehensive maintenance of the entire detector, and precise gain settings of the photomultiplier tubes (PMTs) using cosmic muon measurements. This gain settings procedure ensures the proper dynamic range settings, the detector's readiness for beam time, and allows for preliminary energy calibration. The detector was successfully prepared for the latest beam time at February 2024, preliminary results of π^0 invariant mass reconstruction from its double gamma decay from C+C 800 A MeV experimental run, are shown below.

Complete setup of electromagnetic calorimeter ECAL

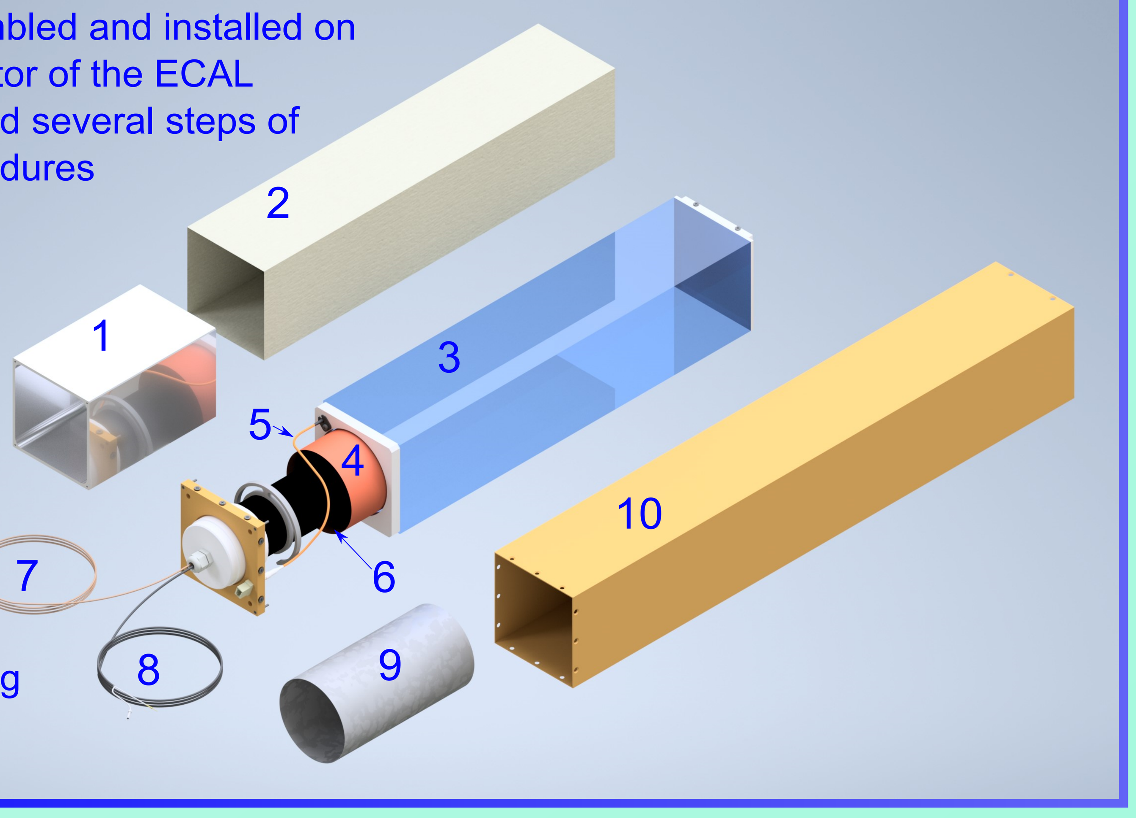


Hexagonal geometry of the ECAL setup consists of six sectors covering polar angles between 16° and 45°, each with 163 modules, and utilizes Cherenkov light detection via lead-glass prisms refurbished from OPAL calorimeter (Energy resolution ~ 5.5%/√E [GeV]). Two sectors are equipped with EMI 9903KB (1.5") PMTs and 4 sectors with Hamamatsu R6091 (3") PMTs. Read out electronics is based on TRBv3 family TDCs with PaDiWa-AMPS front-end. The time-of-flight RPC detector is placed in front of ECAL, and serves as a charged-particle veto in photon identifcation.

Cell assembly

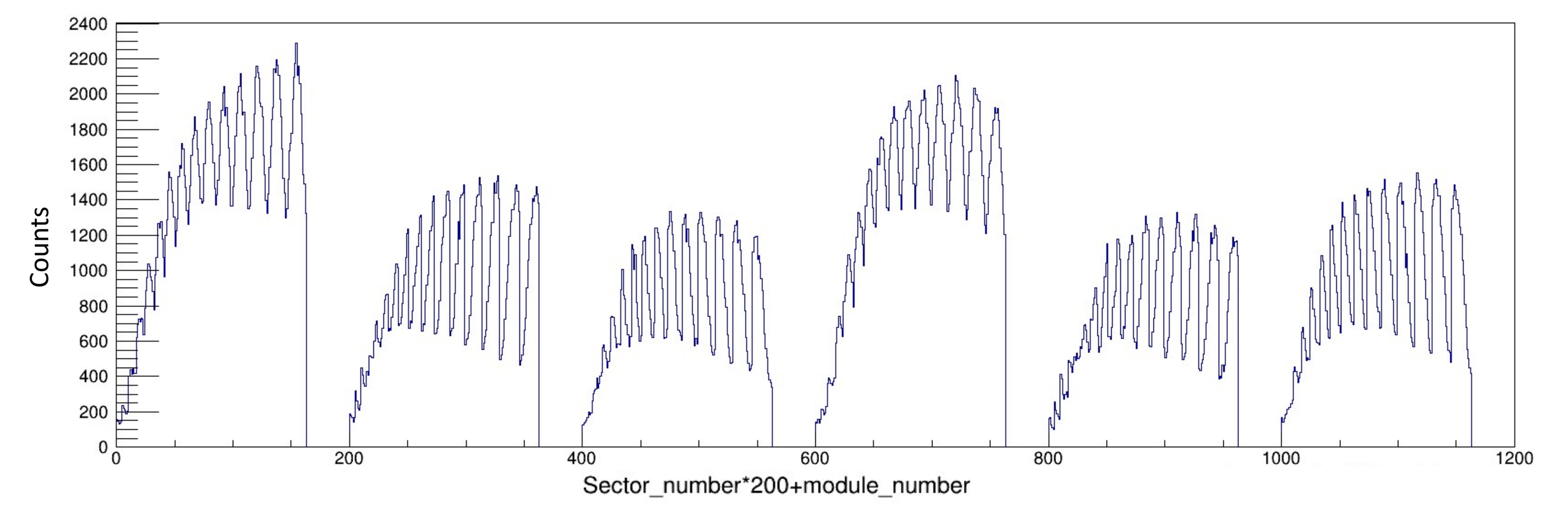
163 new modules were assembled and installed on the frame to complete 6th sector of the ECAL detector. Each module required several steps of treatment and mounting procedures

1-Aluminium electric shielding
2-Tyvek paper envelope
3-Lead glass prism
4-Kapton electric insulation
5-Optical fiber
6-Photomultiplier tube
7-Signal cable
8-High voltage cable
9-Permalloy magnetic shielding
10-Brass envelope



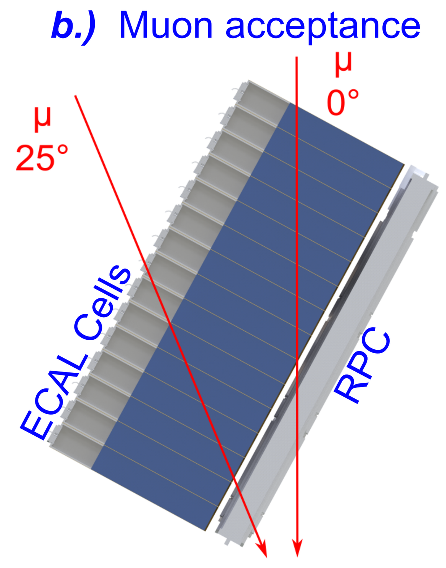
Gain settings with cosmic muons

a.) Counts vs cell number (cosmic, RPC trigger, Multiplicity 4)

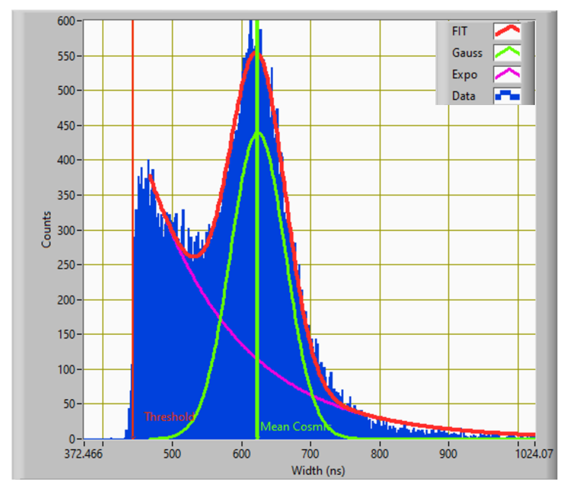


Cosmic muons were triggered by the RPC (Resistive Plate Chamber) detector to eliminate false triggers from PMT noise. The acceptance angle, set by the multiplicity, ranged from zero to approximately 25 degrees from the zenith for a multiplicity of 4 in vertical columns ***b.)***. The RPC triggering and multiplicity settings defined the count vs. cell number histogram pattern ***a.)***. This histogram was used during commissioning to identify malfunctioning cells.

b.) Muon acceptance



c.) Cosmic muon spectrum



d.) Gain vs High Voltage equation

$$\left(\frac{G_2}{G_1}\right) = \left(\frac{U_2}{U_1}\right)^{11}$$

G_2 - desired gain, G_1 - measured gain

U_2 - needed voltage, U_1 - set voltage

e.) Energy calibration function

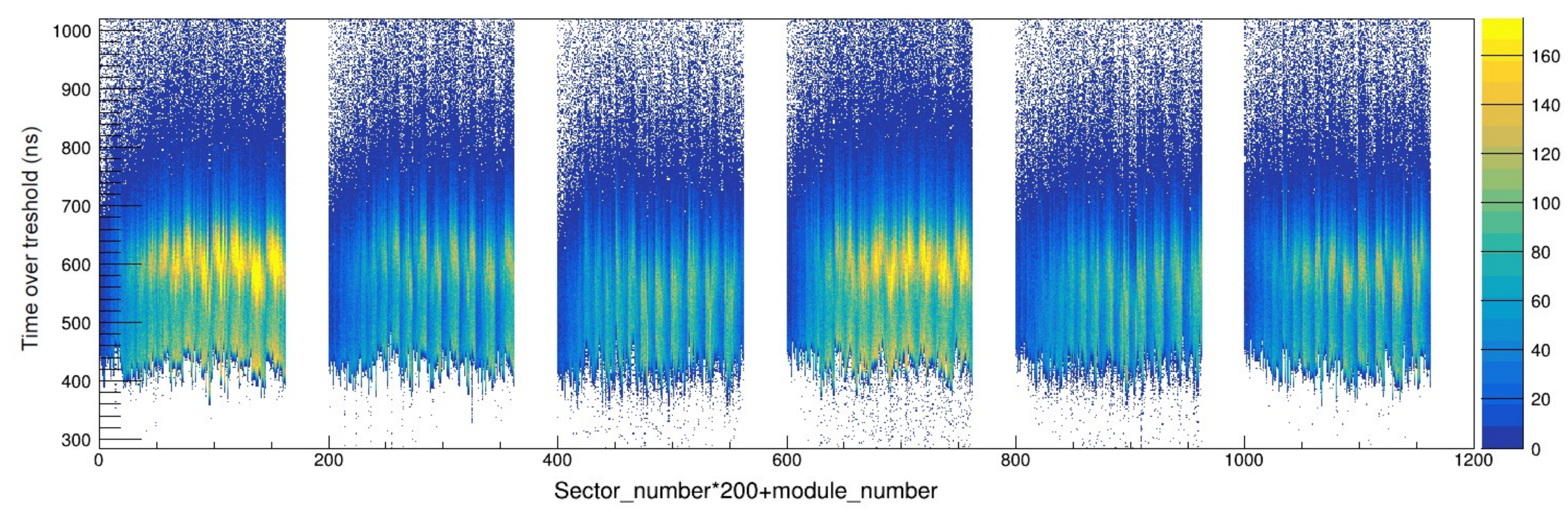
$$Energy = a + e^{b} * e^{Tot*c}$$

a - intercept, b – slope, c – shape

Tot – time over threshold

The measured spectra from cosmic muons ***c.)*** show a peak from muons passing through the entire cell width and an exponential background from muons passing through cell corners. The energy loss for muons passing through the full cell width is equivalent to a 75 MeV lepton. Fitting these spectra and determining the mean enabled proper PMT gain-setting ***d.)***. All the cosmic mean times over threshold were set to the same (pedestal subtracted) value 180 ns for 3" and 150 ns for 1.5" PMTs ***f.)*** by adjusting the HV. The threshold position at 8 MeV and the mean at 75 MeV were used for the detector's energy precalibration ***e.)*** before beam time.

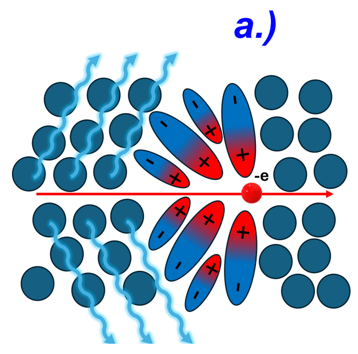
f.) Time over Threshold vs cell number (cosmic, RPC trigger, Multiplicity 4)



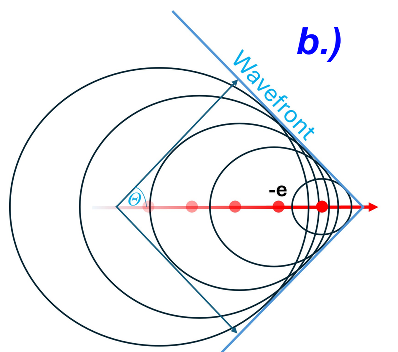
Electromagnetic shower and induced Cherenkov radiation

1 GeV lepton initiated shower in lead glass

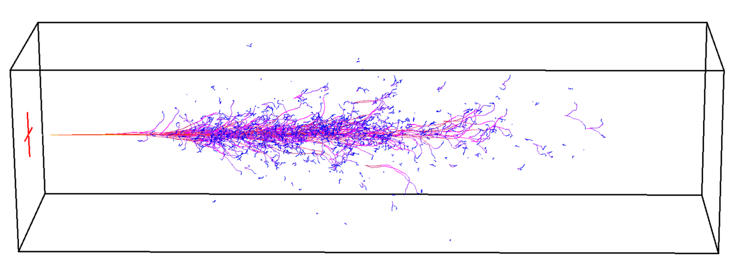
a.)



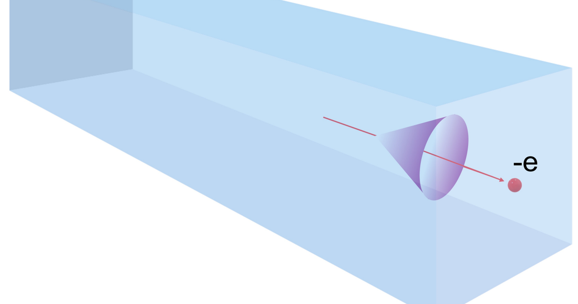
b.)



10 GeV lepton initiated shower in lead glass



c.)

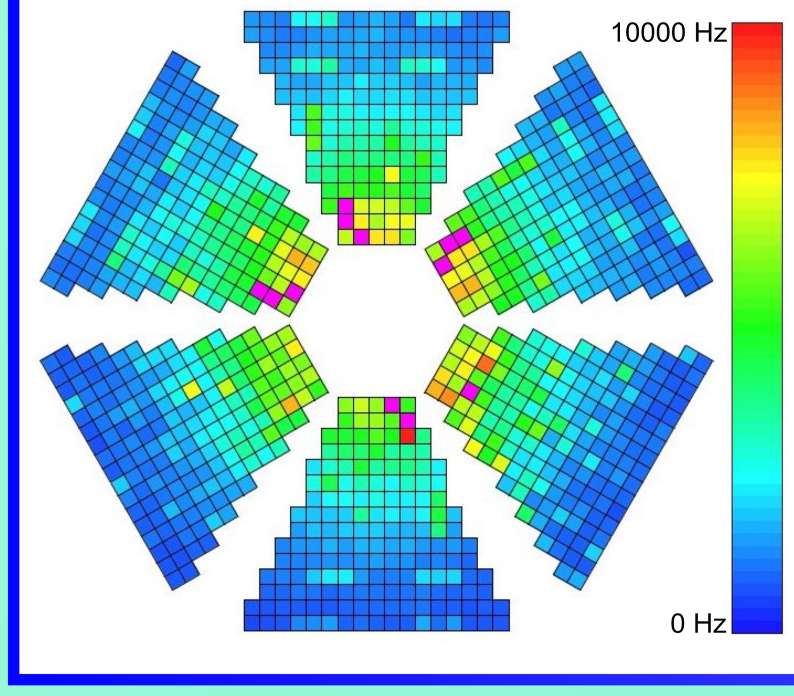


Gamma or lepton induces an electromagnetic shower in lead glass material. The number of produced positron-electron pairs is proportional to the initial particle energy. Charged particles passing through a dielectric medium polarize the molecules. The excited molecules subsequently de-excite and emit photons ***a.)***. If the charged particle is faster than the speed of light in the medium, the created photon wavefronts result in constructive interference ***b.)***, producing a specific Cherenkov light cone ***c.)***. The intensity of Cherenkov light inside the glass prism is proportional to an amount of p.e. pairs, i.e. to the initial particle energy.

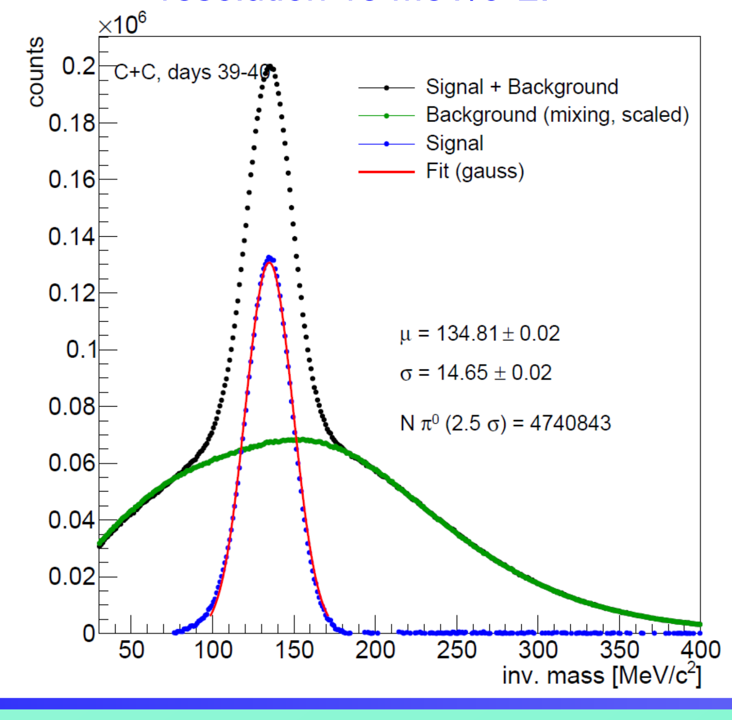
Results from the recent HADES beamtime

The full ECAL setup was for the first time used in the beamtime in February-March 2024, where particle production in C+C and Au+Au at 800 A MeV was studied. The C beam with intensity 1x10^6/sec and Au beam with intensity 2.7x10^6/sec was impinging on the 9% interaction C and 1.4% interaction Au segmented targets, respectively.

Count rate in ECAL modules during the Au+Au at 800 A MeV run. Count rate reached up to 10 kHz at inner cells (at lowest polar angles).



The invariant mass distribution from two photons detected in ECAL measured in C+C at 800 A MeV. π^0 mass peak was reconstructed with expected resolution 15 MeV/c^2.



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