Reconstruction of $\gamma\gamma$ mass spectra in Ag+Ag collisions at 1.23 and 1.58 AGeV beam energies with ECal detector of the HADES experiment

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On behalf of the HADES collaboration

Abstract. HADES is a high acceptance di-electron spectrometer operating at SIS18, GSI, Germany aimed at study of hadron-proton, hadron-nucleus and nucleus-nucleus collisions at 1-4 AGeV beam energies. The new electromagnetic calorimeter (ECal) was added to the experimental setup in order to measure γ-quanta and thus extend its capabilities in study of π^0-, η-mesons, production of neutral hyperons and to improve electron-to-hadron separation for the partcles with momenta $p > 300$ MeV/c. The first data taking with the ECal detector was carried out in March 2019 when Ag+Ag collisions at 1.23 AGeV and 1.58 AGeV beam energies were studied. The methods of reconstruction of the $\gamma\gamma$ invariant mass spectra from these data are discussed. The analysis includes several steps: calibration of each module of the ECal detector, identification of γ-quanta, reconstruction of $\gamma\gamma$ invariant mass spectra and subtraction of combinatorial background. The obtained results show experimental capabilities of the new detector and, after efficiency corrections, will allow to normalize yields of other particles.

1. HADES experiment

High Acceptance DiElectron Spectrometer [1] studies the properties of hadronic matter at high net-baryon densities and relatively low temperatures. It operates at the SIS18 accelerator in GSI, Darmstadt for more than 10 years. The overview of recent results can be found at [2]. It is composed of several detectors (see Fig. 1): START+VETO diamond sensors, Ring Imaging Cherenkov (RICH) detector, a set of four Microwire Drift Chambers (MDC) with a superconducting solenoid in between, Time Of Flight (TOF), Resistive Plate Chamber (RPC), Electromagnetic Calorimeter (ECal) and Forward Wall (FW).

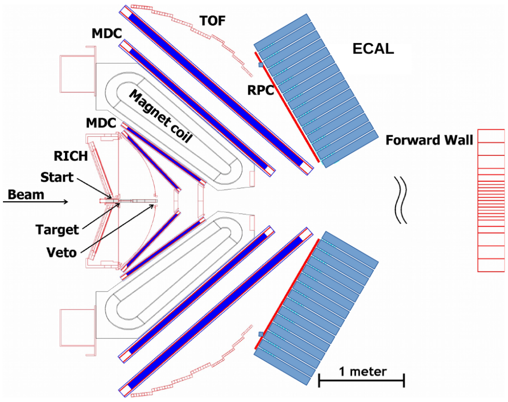


Figure 1. HADES schematic view with the ECal detector

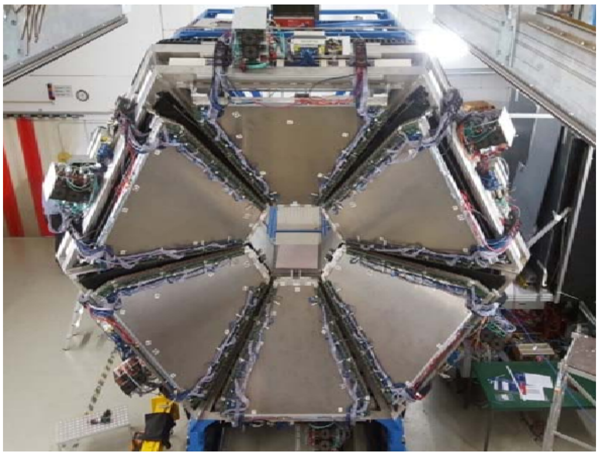


Figure 2. Assembled 4 sectors of ECal detector. The upper- and lower-most sectors are equipped only with the RPC detector

2. ECal

The Electromagnetic calorimeter (ECal) is a newly built detector focused on measurements of γ-quanta. It is composed of 978 modules divided into 6 sectors. Each module has a homogeneous lead glass block as a radiator and PMT as a sensor. 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 [3].

By March 2019 four sectors had been assembled in the experimental hall (see Fig. 2). These days one more sector is ready and the last one is under construction.

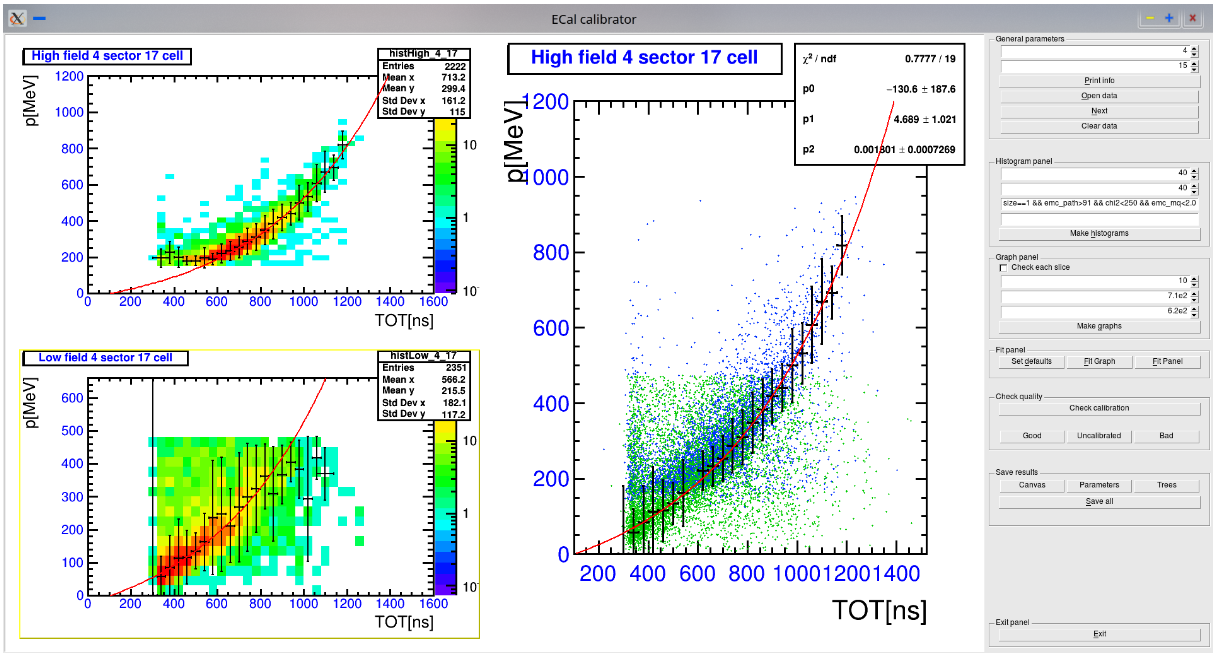
3. Calibration procedure

The quality of calibration plays a key role in the ECal energy resolution. In order to improve resolution of the ECal detector the interactive software application with graphical user interface (GUI) has been developed (see Fig.3). It allows to tune precisely the parameters of energy calibrations for each module individually and thus improve quality of the calibration of the ECal.

Electrons and positrons are used for the energy calibration. Traversing the module they produce the electromagnetic shower with the same properties as if it were γ-quant with equal energy. This allows to make a correspondence between the response of the ECal detector and the energy of an incident γ-quant. Selection of e^+ and e^- for the calibration is done using information from RICH, MDC and RPC detectors, while their momentum is defined by the curvature of the trajectory in magnetic field. Continuation of the trajectory until the intersection with the ECal detector allows to find a cluster of fired modules where the energy of electron is deposited. For calibration only clusters with single fired module were selected.

At high magnetic field the energy of electrons is defined with higher presision, but the electrons with low momenta are reversed and don't reach ECal detector (see Fig. 3, upper left plot). This is the reason why measurements at low magnetic field (Fig. 3, lower left plot) are also needed for calibration. Both sets of data are concatenated as it is shown in Fig. 3 on the right plot. Blue dots here correspond to the high-field data, green ones to the low-field. The approximation function with three free parameters p_0, p_1 and p_2 describes this dependence.

$$E_e = p_0 + exp(p_1 + p_2 \cdot TOT)$$



4
15
40
40
size==1 && emc_path>91 && chi2<250 && emc_mq<2.0
10
7.1e2
6.2e2

Figure 3. GUI application for calibration of the ECal detector

4. Reconstruction of the $\gamma\gamma$ invariant mass spectrum

Reconstruction of $\gamma\gamma$ invariant mass spectra includes several steps. The first step is selection of photons. This is done via applying two criteria: there must be no track corresponding to the hit in ECal to cut off all charged particles and $\beta > 0.95$ to distinguish γ from neutrons. An additional cut by energy $E_\gamma > 150$ MeV is needed to reduce the background.

As a second step the photons in the event are combined into all possible pairs. Supposing we have n photons, $n(n-1)/2$ pairs will be composed. In order to reduce the noise it was required that the angle between two γ-quanta were more than 5° (it is a size of one module looking from the interaction point). For each such pair invariant mass m, transverse momentum p_t and pseudorapidity η are calculated:

$$m = \sqrt{(E_1 + E_2)^2/c^4 - (\vec{p}_1 + \vec{p}_2)^2/c^2},$$

$$p_t = (\vec{p}_1 + \vec{p}_2)_\perp, \quad \eta = \frac{1}{2}\ln\left(\frac{(E_1+E_2)+c(\vec{p}_1+\vec{p}_2)_\parallel}{(E_1+E_2)-c(\vec{p}_1+\vec{p}_2)_\parallel}\right)$$

In Monte-Carlo simulation it is possible to separate photons coming from π^0 (yellow line on Fig. 4) or η decay from those originating from uncorrelated sources. However, in experiment this is impossible. Spectra of all possible $\gamma\gamma$ pairs (black line on Fig. 4, 5, 6, 7) contain contamination of accidental coincidence of γ-quants. To evaluate the background spectra the mixed event technique was used. For this purpose the γ-quanta from different events are combined in pairs and their invariant mass is calculated. The resulting background spectrum (shown by blue filled area on Fig. 4, 5, 6, 7) is scaled and subtracted from the original one. The excess of original spectrum over background has a peak structure (red filled area on Fig. 4, 5, 6, 7) interpreted as decay of short-lived particle. The mean value of the peak allows to identify it. The Monte-Carlo simulation, carried out with UrQMD event generator and full HADES geometry, represents good coincidense between spectra obtained with the described algorithm and direct detection of π^0 decay products (see Fig. 4).

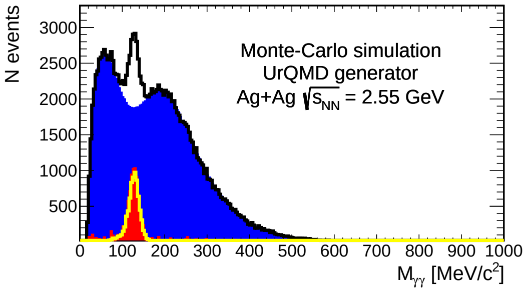


Figure 4. Monte-Carlo simulation of $\gamma\gamma$ invariant mass spectrum. Yellow line represents direct observation of π^0 decay, red area – spectrum reconstructed with discussed technique

5. Results

In March 2019 Ag+Ag collisions at 1.23 AGeV and 1.58 AGeV beam energies were studied. The magnetic field and duration of corresponding data taking can be found in table 1. Only data with 3200 A and 2500 A current in solenoid were used for the reconstruction of $\gamma\gamma$ invariant mass spectra, while data with 200 A current were used for calibration in the region of low energies. The preliminary results without efficiency corrections are represented at Fig. 5, 6 and 7. The π^0 peak is clearly visible at both energies. The peak corresponding to η-meson is visible on log scale spectrum at 1.58 AGeV, but more research is needed to conclude definitively. At 1.23 AGeV this peak is not observed.

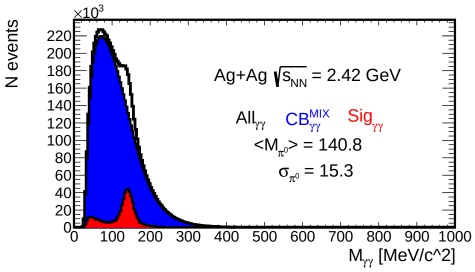


Figure 5. $\gamma\gamma$ invariant mass spectrum at 1.23 AGeV beam energy

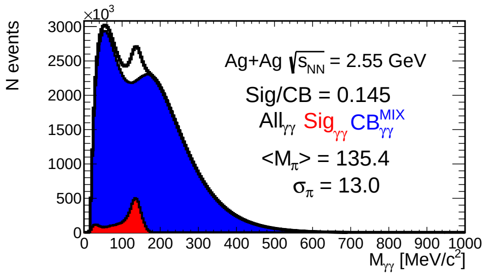


Figure 6. $\gamma\gamma$ invariant mass spectrum at 1.58 AGeV beam energy

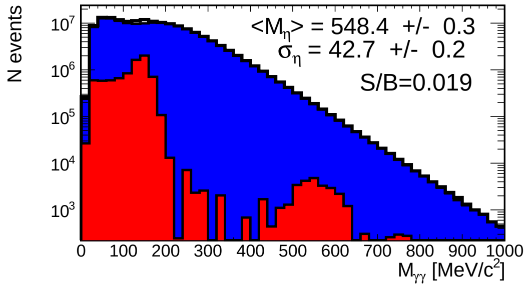


Figure 7. $\gamma\gamma$ invariant mass spectrum at 1.58 AGeV beam energy, logarithmic scale

Table 1. Analyzed data.

beam energy	1.58 AGeV	1.23 AGeV		
current in solenoid	3200 A	2500 A	200 A	0 A
duration of data taking	28 days	3 days	2 days	2 days

6. Conclusions

The π^0 peak is clearly visible at 1.23 and 1.58 AGeV beam energies. High statistics and collision energy allow to observe η-meson peak at 1.58 AGeV, while at 1.23 AGeV this peak is not visible. For multivariate analysis the efficiency corrections need to be done. This work is in progress.

7. Acknowledgment

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References

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