ISSN 1063-7796, Physics of Particles and Nuclei, 2022, Vol. 53, No. 2, pp. 513–518. © Pleiades Publishing, Ltd., 2022.

New Approach to Measure Centrality in the HADES Heavy-Ion Experiments

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Received March 11, 2021; revised July 8, 2021; accepted July 18, 2021

Abstract—One of the important tasks in studying the properties of the strongly interacting matter in nucleus-nucleus collisions is the experimental determination of event centrality classes. A new approach for event centrality selection based on the particle charge distributions measured with the Forward Wall hodoscope at the HADES experiments will be discussed.

DOI: 10.1134/S1063779622020897

1. INTRODUCTION

The HADES is a fixed target experiment at the SIS-18 accelerator complex (FAIR, GSI, Darmstadt, Germany), designed to study dielectron production in pion, proton and heavy-ion induced collisions. The physical program is aimed mainly at studying medium modifications of the light vector mesons produced in heavy-ion reactions in the 1 to 2 *A* GeV energy range [1].

In order to relate experimental data to the collision geometry and to compare the results of different experiments the collision centrality has to be determined. To classify events by centrality in the HADES experiment, distribution of charged particles multiplicity measured by time-of-flight detectors TOF and RPC is used. The centrality is obtained from the Glauber model fit of this distribution [2].

This paper proposes independent estimation of events centrality using the spectator charges measured by the forward scintillation hodoscope (FWall). A new methodology for centrality assessment in the HADES experiment employing the machine learning technique (ML) is offered. It is based on the dividing of the events into centrality classes taking into account the spatial distribution of fragment charges in the FWall cells. Utilizing this method, the collision centrality for Au + Au at 1.23 *A* GeV data measured in the HADES experiment was compared with the standard MC Glauber approach. The same method was applied for Ag + Ag at 1.58 *A* GeV in simulations.

The paper is organized as follows. In the next section, a short description of the main HADES detector subsystems and the FWall detector is given. In Section 3, a new approach for assessing the centrality of events in heavy-ion collisions based on the machine learning method is discussed. The results of this technique applying to the experimental and simulated data are shown in Section 4. In Section 5 concluding remarks are presented.

2. THE HADES SETUP

The HADES facility is located at the SIS18 accelerator in GSI (Darmstadt, Germany) and is a wide-acceptance dielectron magnet spectrometer. It was developed for the reconstruction of the dielectrons in light vector mesons decays in hadron and heavy-ion interactions at beam energies 1–4 *A* GeV. The HADES setup is shown in Fig. 1a.

The HADES has the toroidal superconducting magnet, which consists of six superconducting coils surrounding the beam axis. The magnet creates a toroidal field that deflects particles in the first approximation only in the polar direction. HADES spectrometer consists of 6 sectors located around beam axis. The polar angle between 18 and 45 deg is equipped with resistive plate chambers (RPC). Between 44 and 88 deg, there is a time-of-flight (TOF) scintillation wall consisting of 64 scintillation rods in each sectors with PMTs readout. The TOF + RPC detector system was used to measure charged particles multiplicity and to

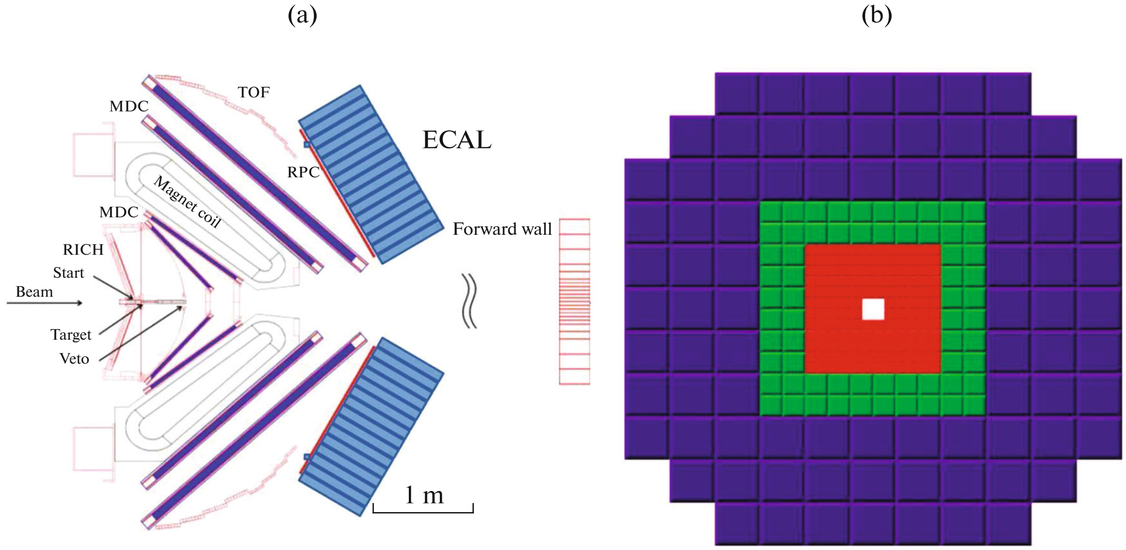

Fig. 1. Schematic view of the HADES experimental setup (a) and the Forward Wall detector (b).

select most central events on the trigger level. The trigger selects up to 43% of most central events in Au + Au reaction at 1.23 *A* GeV. Each sector has a Ring-Imaging Cherenkov (RICH) detector. These detectors are used for particle identifications. Four layers of multiwired Drift Chambers (MDCs), two in front of and two behind the magnetic field are utilized for momentum reconstruction. Electromagnetic calorimeter (ECAL) at first time employed in the Ag + Ag experiment allows to study the production of neutral mesons in heavy-ion reactions and covers forward angles between 16 and 45 deg and almost the full azimuthal angle. The forward scintillation hodoscope Forward Wall (FWall) [3] is designed to be utilized for estimation of the reaction plane orientation in heavy-ion collisions.

This paper presents how FWall can be used for centrality determination. The FWall is located at a distance of 7 m from the target and covers the polar angle from 0.3 to 7 deg. The FWall scheme is presented in Fig. 1b. It consists of 288 scintillation cells. Cell's sizes are varied depending on the expected particles occupancies and rates. The central part of FWall consist of 140 small cells (4×4 cm^2); the middle part consist of 64 middle cells (8×8 cm^2) and the outer part consist of 84 large cells (16×16 cm^2). The FWall has the beam hole with sizes 8×8 cm^2 in the center. This detector system provides information on the position, charge and time-of-flight of secondary particles and projectile spectators.

3. MACHINE LEARNING APPROACH FOR CENTRALITY SELECTION WITH FORWARD WALL

The HADES experiment uses multiplicity of produced particles to determine events centrality. Another method of centrality estimation is based on charge distributions in the Forward Wall cells. Since the most heavy fragments leave through the beam hole, there is an ambiguity in total charge dependence measured with FWall on impact parameter (Fig. 2). This dependence is shown for minimum bias events generated with DCM-QGSM-SMM model for Ag + Ag at 1.58 *A* GeV.

The transverse granularity of the FWall allows to measure the spatial distribution of charged particles and nuclei fragments in nucleus-nucleus reactions. Figure 3 shows an example of spatial distribution of FWall amplitudes for simulated Ag + Ag at 1.58 *A* GeV data (DCM-QGSM-SMM model) for 5% of the most central events and for semiperipheral events with centrality in 35–40% range determined according to impact parameter. Based on this difference, the centrality of each event can be estimated applying the machine learning (ML) technique.

Training of ML algorithms are different for experimental and simulated data. Experimental TOF+RPC multiplicity distribution is divided into 8 equal-sized groups. Due to known monotonic multiplicity dependence on centrality, these groups correspond to eight 5% centrality classes. This information is used for centrality class index determination in ML. In case of simulated data centrality class index corresponds to

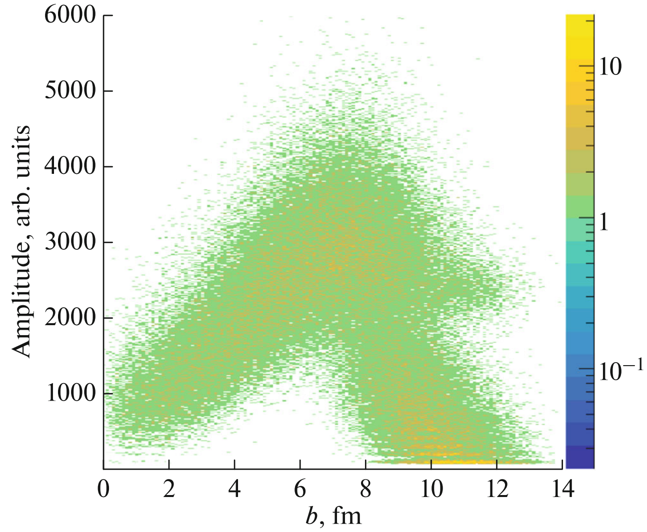

Fig. 2. Correlation between FWall amplitude and impact parameter obtained for MB events generated with DCM-QGSM-SMM model for Ag + Ag at 1.58 *A* GeV.

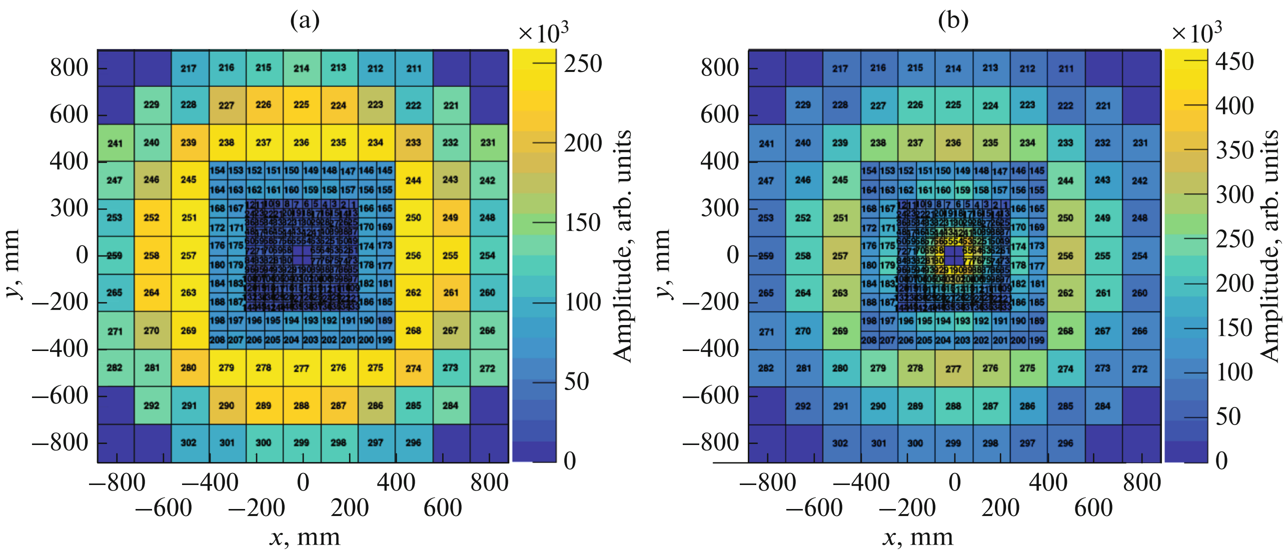

Fig. 3. Spatial distribution for Ag + Ag at 1.58 *A* GeV simulation for 0–5% the most central (a) and semiperipheral events (35–40%) (b) determined according to impact parameter values.

impact parameter value. Randomly selected part of the data is employed to train the model with FWall cell positions and corresponding charges. Then the trained model is applied to the remaining part of data.

4. RESULTS OF THE MACHINE LEARNING IMPLEMENTATION

The results of applying the ML approach to simulated Ag + Ag at 1.58 *A* GeV data are shown in Fig. 4 for two models, DCM-QGSM-SMM and DCM-QGSM (SHIELD). In Fig. 4a impact parameter mean values dependencies on centrality are shown. The results are similar for both models. Impact parameter resolutions on centrality are presented in Fig. 4b, showing that DCM-QGSM model gives better resolution. The confusion matrices for both models are presented in Figs. 4c and 4d, correspondingly. Its diagonal components show the probability that the corresponding centrality range is estimated correctly.

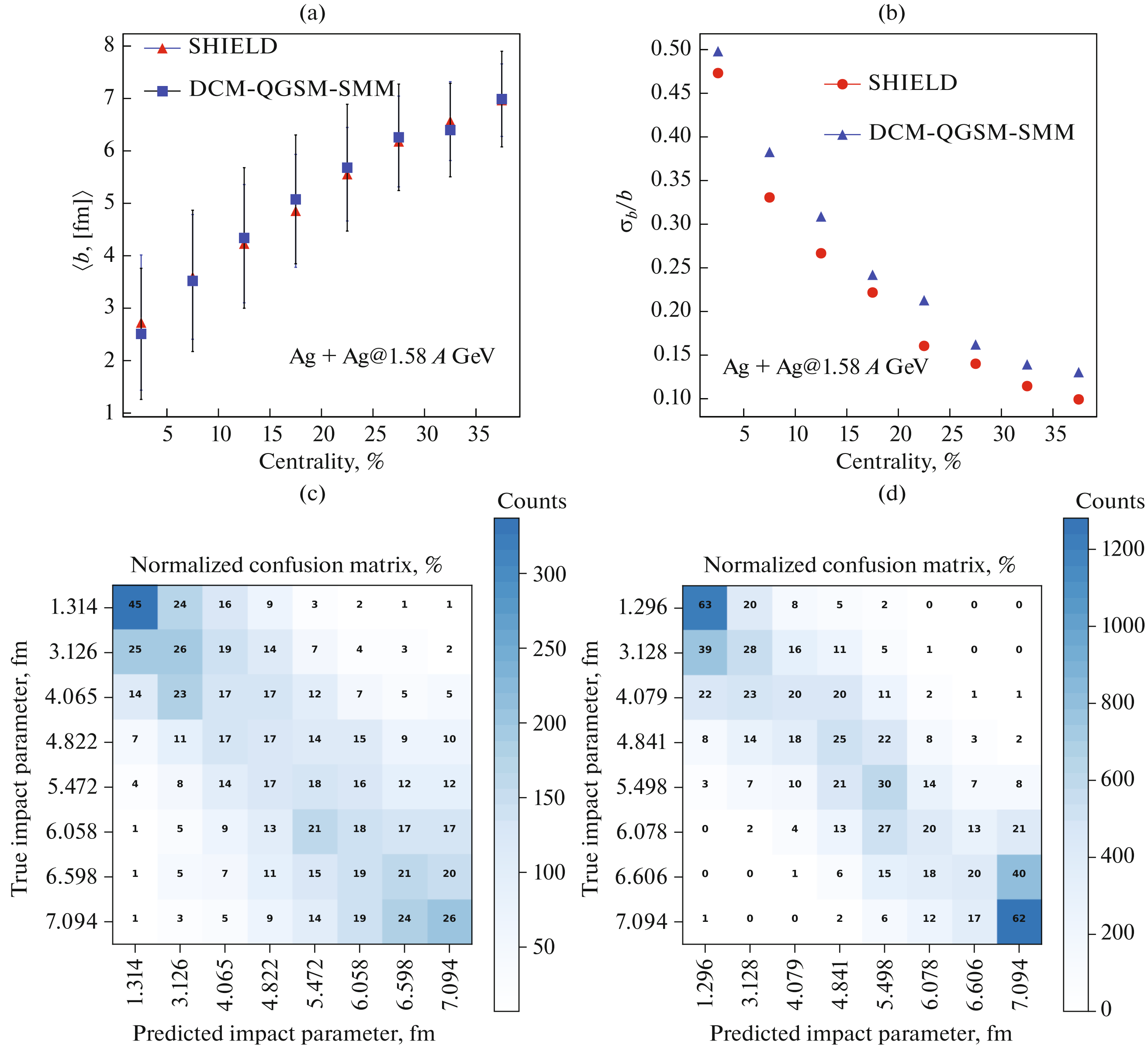

Fig. 4. ML approach to simulated Ag + Ag at 1.58 *A* GeV data: (a) Impact parameter mean values in centrality classes as a function of centrality (both models). (b) Impact parameter resolutions in centrality classes as a function of centrality (both models). (c) Confusion matrix for DCM-QGSM-SMM model. (d) Confusion matrix for DCM-QGSM model.

Applying this method to new Ag + Ag, 1.58 *A* GeV experimental data measured in March 2019 for centrality selection with FWall is in progress.

ML approach was applied to the experimental Au + Au data at 1.23 *A* GeV. Figure 5 shows TOF + RPC multiplicity distributions in different centrality classes obtained with ML.

Figure 6a illustrates a comparison of the mean values of TOF + RPC multiplicity in various centrality classes obtained from [2] and determined with ML approach. The results are in a good agreement within the errors. In Fig. 6b a confusion matrix is shown.

5. CONCLUSIONS

New approach for centrality estimation in the HADES experiment based on ML technique with FWall charge spatial distribution has been developed. Comparison of the results of ML approach application to simulations of Ag + Ag at 1.58 *A* GeV with two models DCM-QGSM-SMM and DCM-QGSM shows

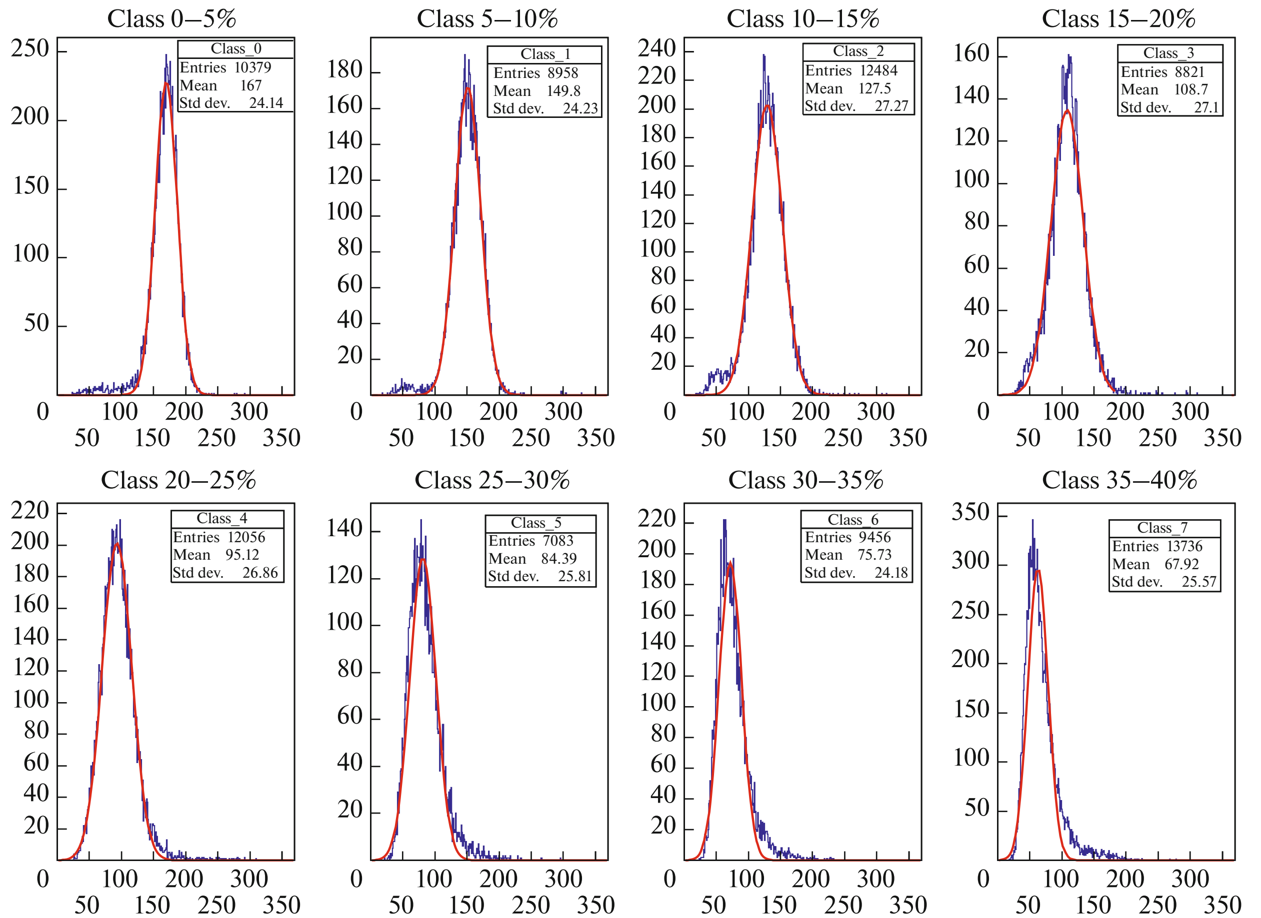

Fig. 5. Multiplicity of TOF + RPC hits in 5% centrality classes determined with ML approach to experimental Au + Au at 1.23 *A* GeV data.

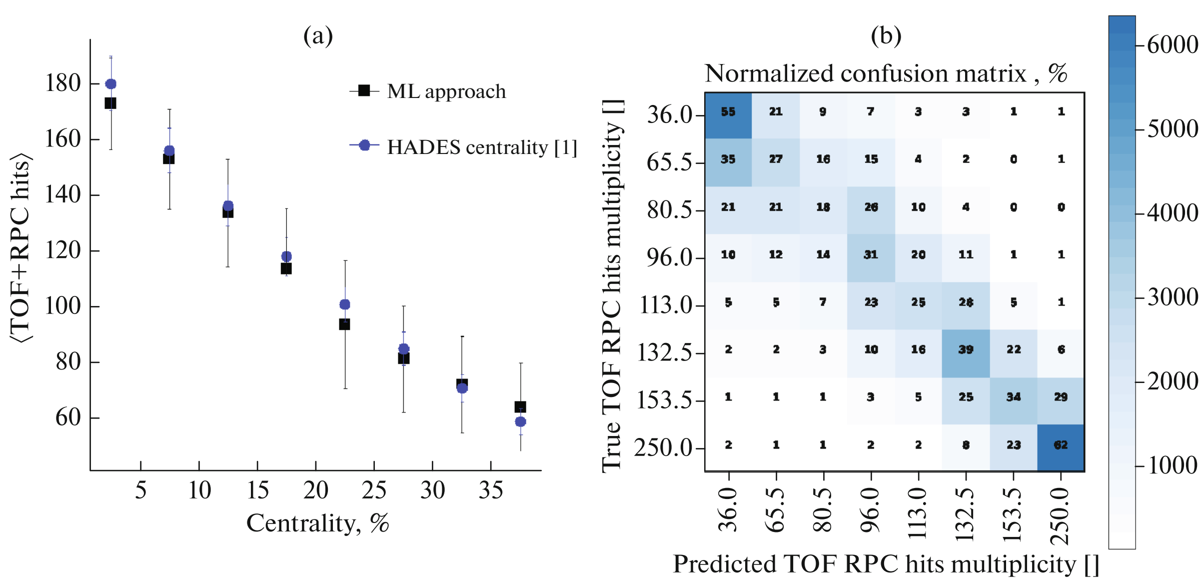

Fig. 6. ML approach to experimental Au + Au at 1.23 *A* GeV data: (a) Mean values of TOF + RPC hits multiplicity in centrality classes as a function of centrality. (b) Confusion matrix.

better impact parameter resolution for DCM-QGSM model. Comparison of applying ML to the experimental data (Au + Au at 1.23 *A* GeV) with centrality classes obtained in [2] are shown. They are in a good agreement with Glauber model method used in the HADES experiment.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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