The KM3NeT real-time analysis framework

V. Cecchini, S. Celli, J. De Favereau de Jeneret, D. Dornic, F. Filippini, E. Giorgio, G. Illuminati, M. Lamoureux, E. Le Guirriec, S. Le Stum, M. Mastrodicasa[a], J. Palacios Gonzalez, G. Vannoye, A. Veutro, A. Zegarelli on behalf of the KM3NeT Collaboration

[a]Sapienza Università di Roma & INFN-Sezione di Roma

massimo.mastrodicasa@roma1.infn.it

ABSTRACT

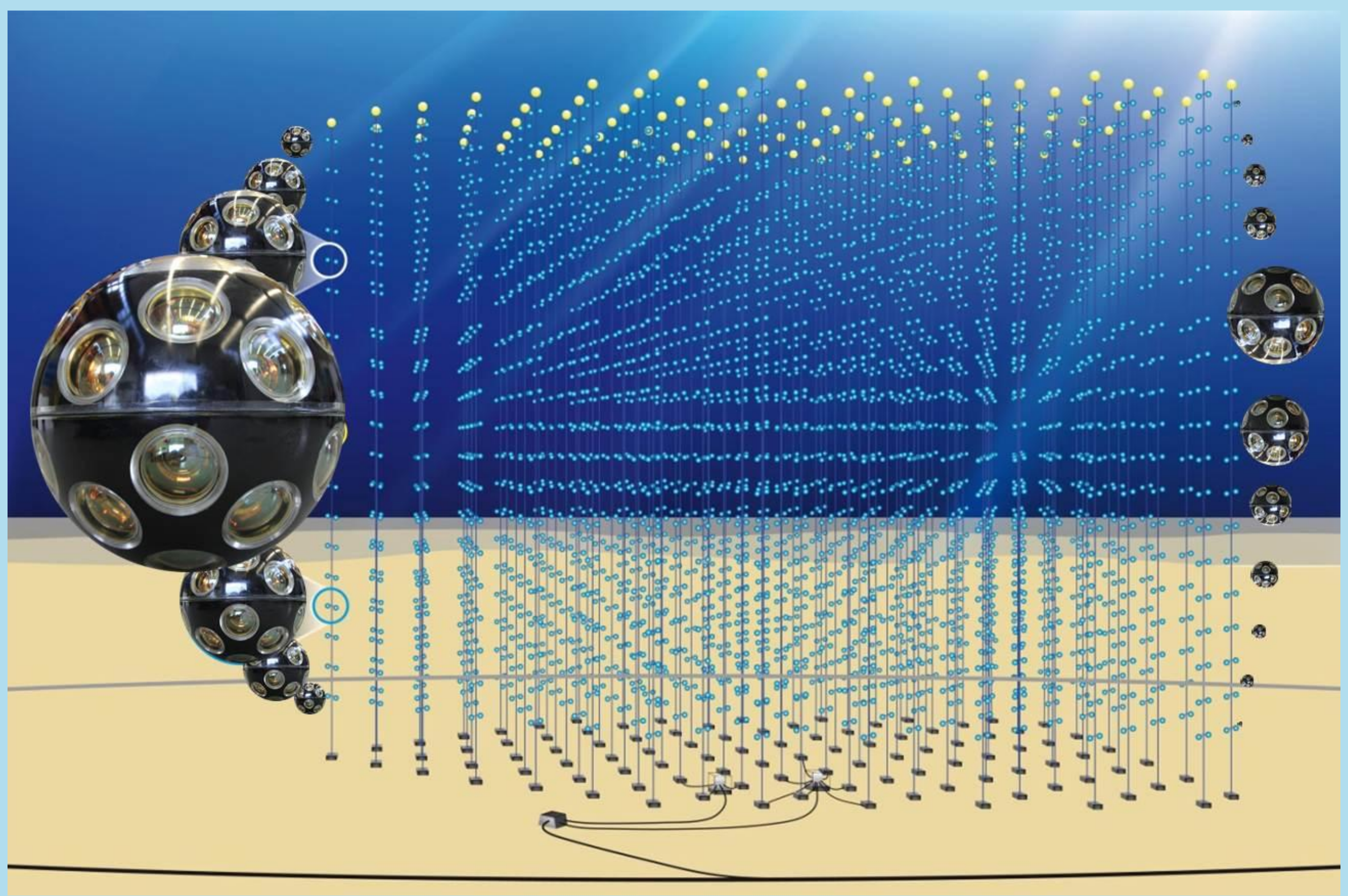
KM3NeT is a deep-sea research infrastructure composed of two water-Cherenkov neutrino telescopes under construction in the Mediterranean Sea: ARCA (Italy), designed to identify and study TeV-PeV astrophysical neutrino sources, and ORCA (France), aiming at studying the intrinsic properties of neutrinos in the few-GeV range. Despite their different primary goals, both telescopes can be used to perform neutrino astronomy across an energy spectrum ranging from a few MeV to a few PeV, owing to the complementary energy ranges they are optimised for. Real-time multi-messenger searches are a key aspect of the KM3NeT program. These searches aim at combining information from complementary cosmic messengers, simultaneously measured by different observatories, in order to study transient phenomena. In this respect, the real-time distribution of alerts when potentially interesting events are detected can enhance the discovery potential of transient sources and refine the localization of poorly localized triggers, such as gravitational waves. In this context, the KM3NeT real-time analysis framework is continuously reconstructing all ARCA and ORCA events, performing core-collapse supernova analyses and searching for spatial and temporal coincidences with alerts received from other operating multi-messenger instruments. The definition of a sample of interesting events to send alerts to the external multi-messenger community is still in progress. We present the current status of the KM3NeT real-time analysis framework.

1. KM3NeT

The Kilometre Cube Neutrino Telescope (KM3NeT) [1] is a deep-sea research infrastructure located in two sites of the Mediterranean Sea consisting of a three dimensional grid of Digital Optical Modules (DOMs) [2] detecting the Cherenkov light produced by relativistic particles arising from neutrino interactions, arranged in vertically aligned Detection Units (DUs) each hosting 18 DOMs:

- the Astroparticle Research with Cosmics in the Abyss (ARCA) telescope is placed 100 km off-shore Portopalo di Capo Passero, Sicily, Italy at a depth of 3500 m with a DU horizontal spacing of 90 m and a DOM vertical spacing of 36 m. It is optimised for the detection of high-energy cosmic neutrinos;
- the Oscillation Research with Cosmics in the Abyss (ORCA) telescope is situated 40 km off-shore Toulon, France at 2450 m depth with a DU horizontal spacing of 20 m and a DOM vertical spacing of 9 m. It is optimised for the detection of low-energy atmospheric neutrinos;

The final goal of KM3NeT is to operate 3 Building Blocks (BBs), 2 for ARCA and 1 for ORCA, each containing 115 DUs. Currently, the number of operating DUs is 28 for ARCA (ARCA28) and 23 for ORCA (ORCA23).



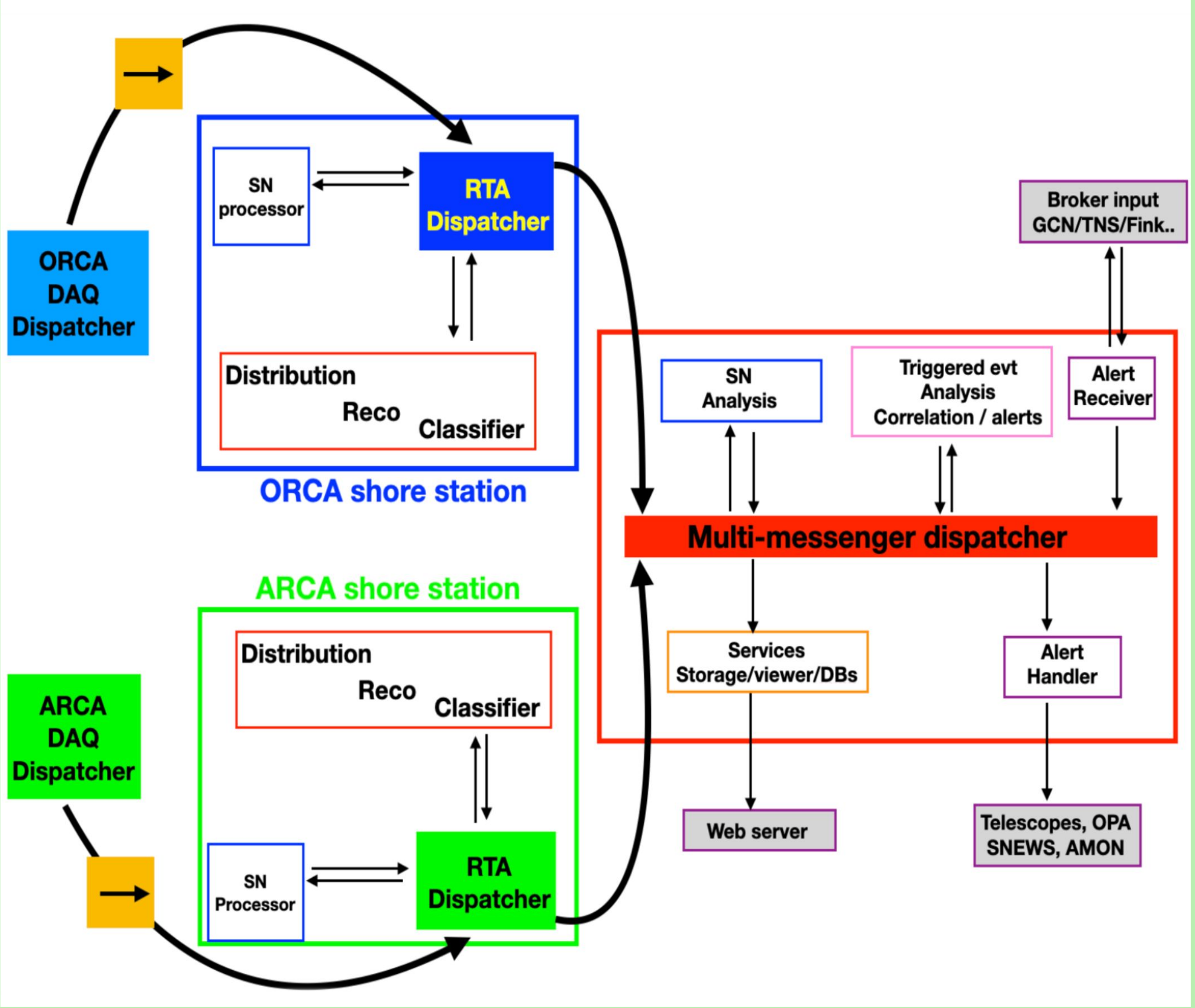
2. The RTA framework

The KM3NeT Real-Time Analysis (RTA) framework [3] consists of a dispatcher specific to ARCA, a dispatcher specific to ORCA and a dispatcher common to both detectors. A schematic view of the KM3NeT RTA framework is shown in the figure below. Each specific dispatcher, located at the corresponding shore station, continuously sends data to two modules:

- the MeV supernova analysis module [4] aims at identifying core-collapse supernova events and early notifying other facilities;
- the GeV-PeV online processing module performs multi-core event reconstruction and classification of triggered events.

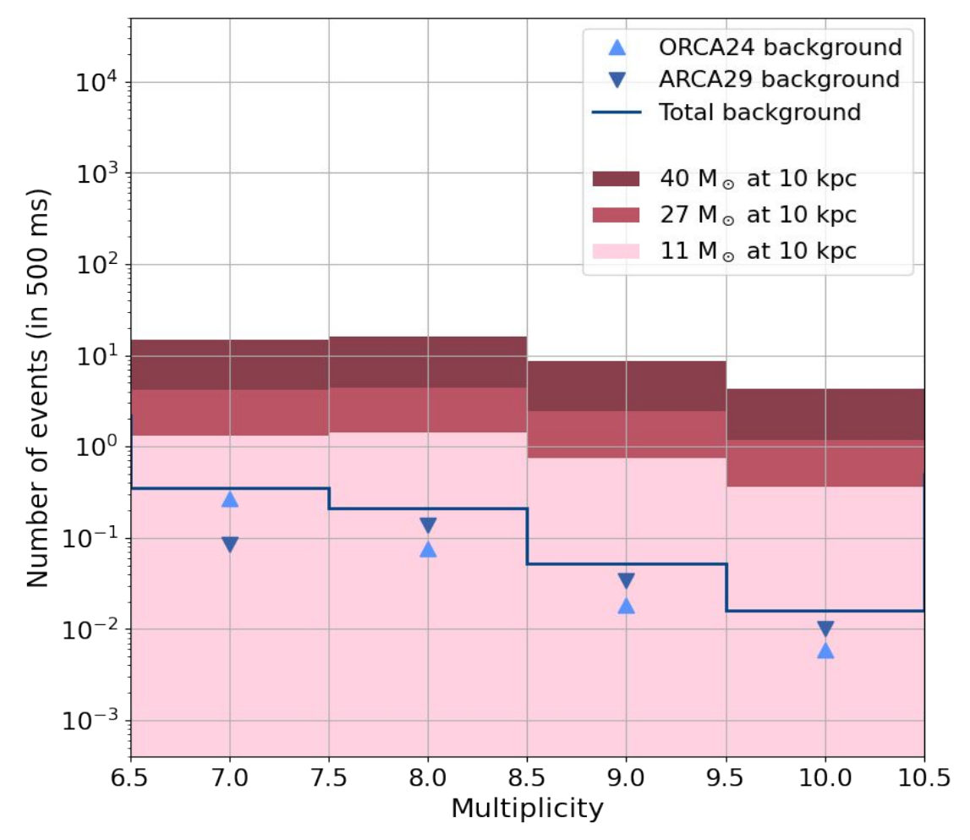
Data from both the detector are transmitted to the common dispatcher and then used for auto-correlation and external alerts follow-up searches [5]. The following six follow-up analyses are currently implemented and are automatically activated every time an interesting multi-messenger alert is received, in order to search for KM3NeT events in spatial and temporal coincidence:

- Gravitational Waves (GWs) [6];
- Gamma Ray Bursts (GRBs);
- high-energy neutrinos from IceCube;
- Fast radio bursts (FRBs);
- µ-Quasars;
- general transients.



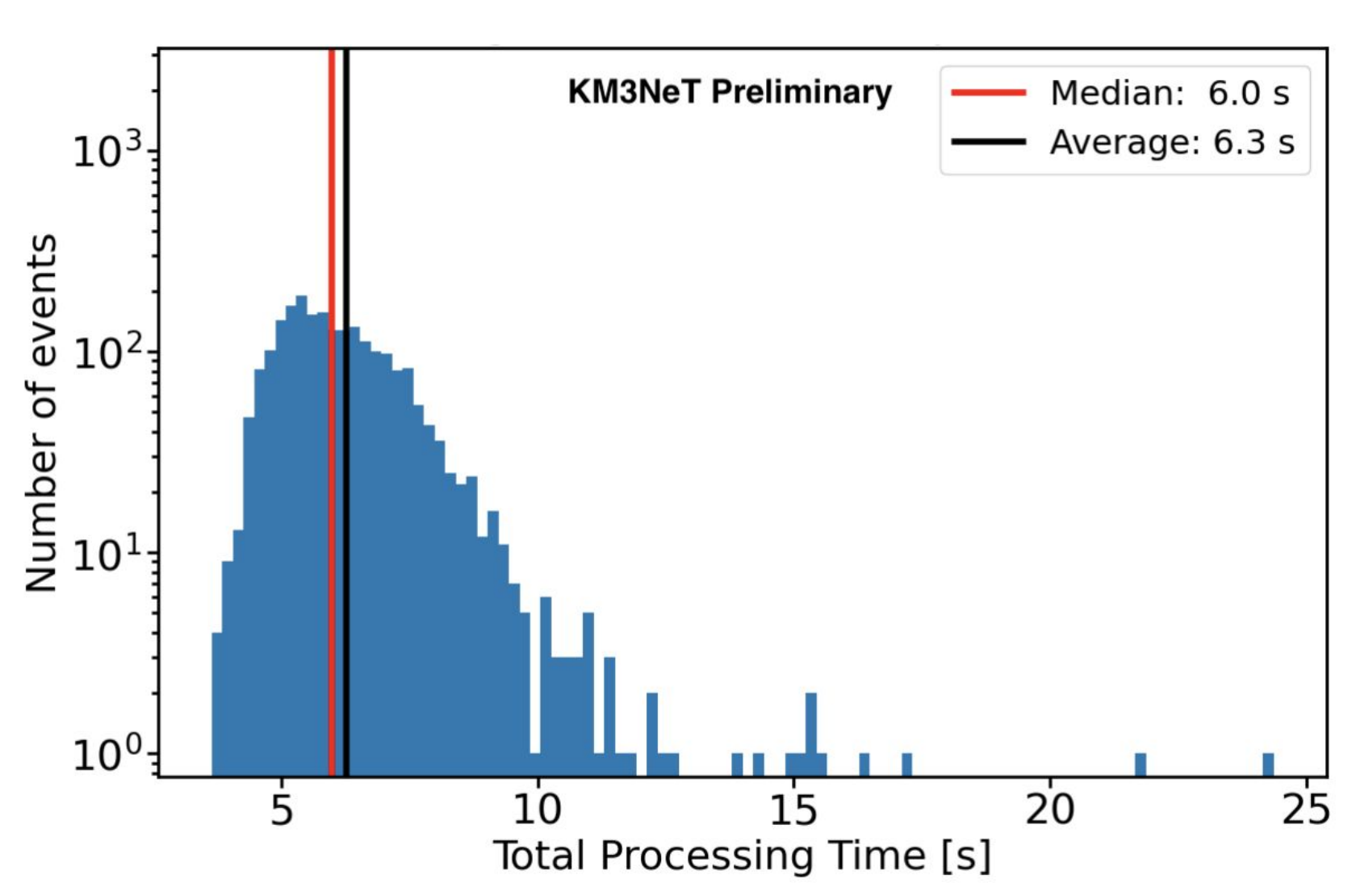
3. Online core-collapse supernova analysis

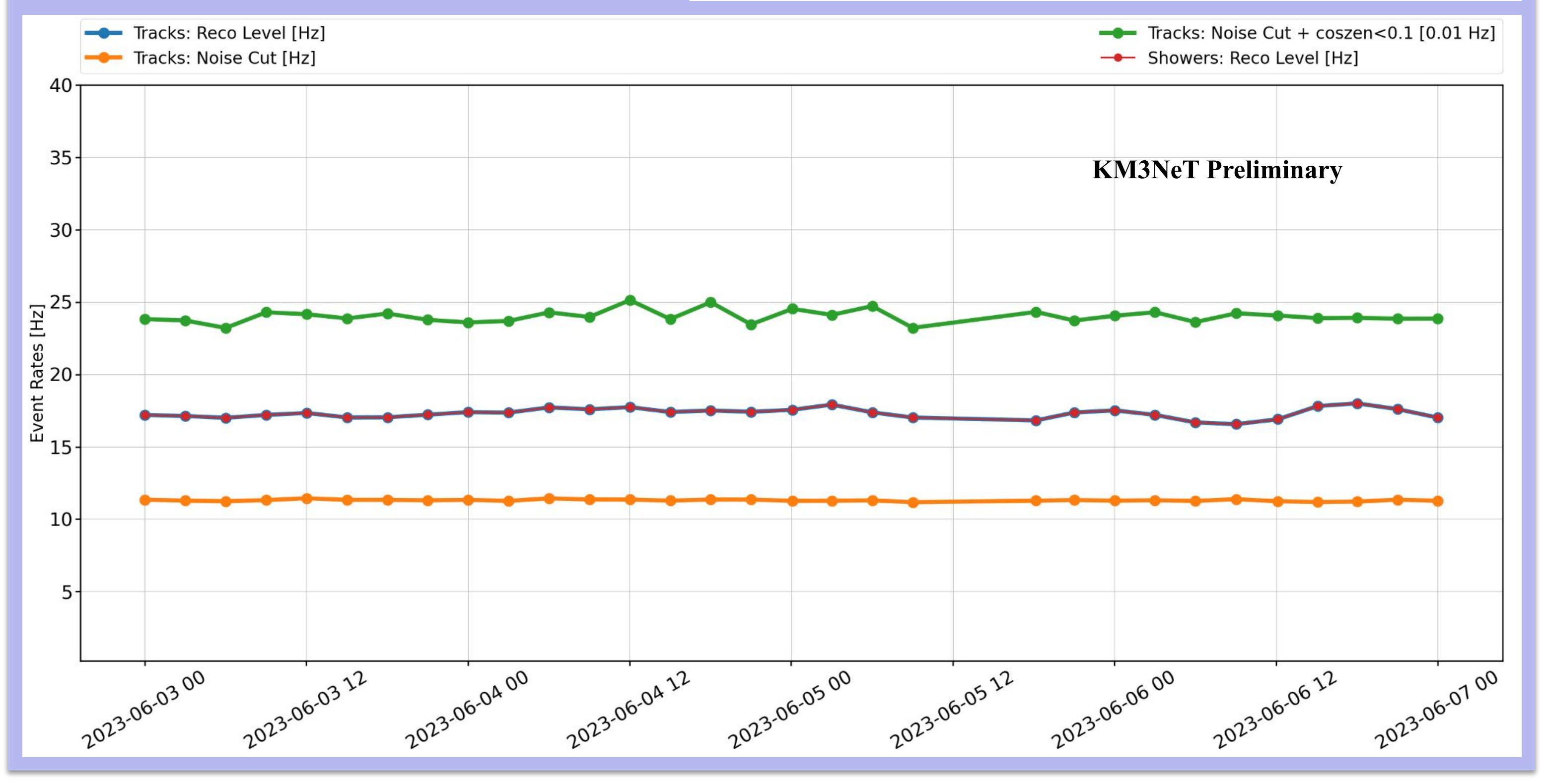
The KM3NeT main detection channel for core-collapse supernova neutrinos is the inverse beta decay of $\bar{\nu}_e$ on free protons in the water. Since KM3NeT is optimised for energies above the GeV scale, the online core-collapse supernova analysis [4] is performed by searching for an excess of coincidences between PMTs in single DOMs above the expected background [7], such that each single DOM acts as a standalone detector. The number of unique PMTs involved in a coincidence is defined as multiplicity. The expected number of events in a 500 ms time interval as a function of the multiplicity for ARCA29 and ORCA24 from 11 $M_\odot$, 27 $M_\odot$ and 40 $M_\odot$ core-collapse supernova progenitors, compared with the estimated backgrounds after muon background rejection and Boosted Decision Tree selection, is shown in the figure on the right (I. Goos et al., these posters).



4. ORCA online event processing

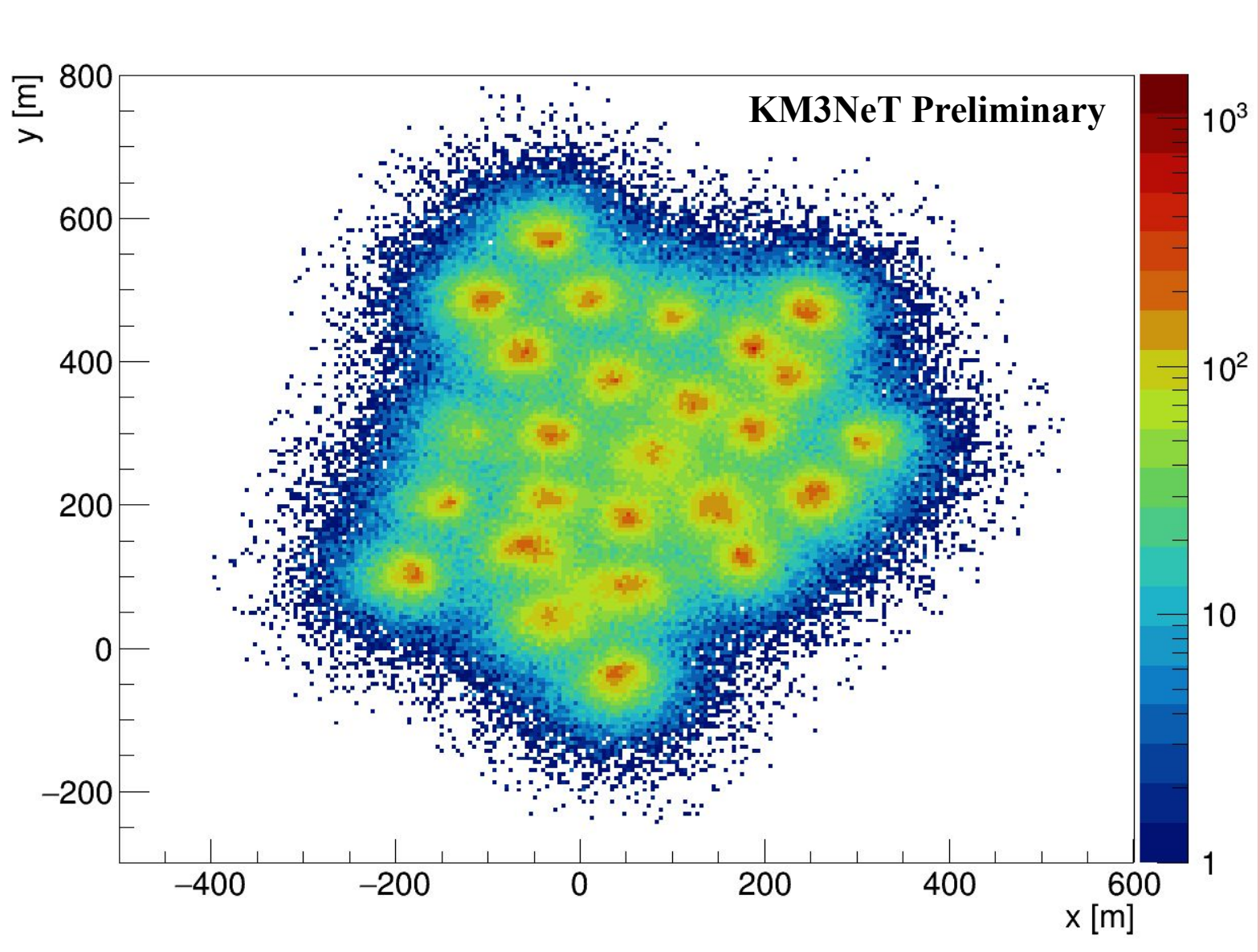
The ORCA online event processing consists in the sequential application of track reconstruction, shower reconstruction and classification to each triggered event. Classification is performed with a Boosted Decision Trees (BDT) method aiming at separating atmospheric neutrinos from the atmospheric muon background. As a result of the ORCA18 (2023) sequential processing, events are reconstructed and classified in a median time of ~6 s, as shown in the plot on the right [8]. Online event rates for ORCA18 (2023) are shown below.

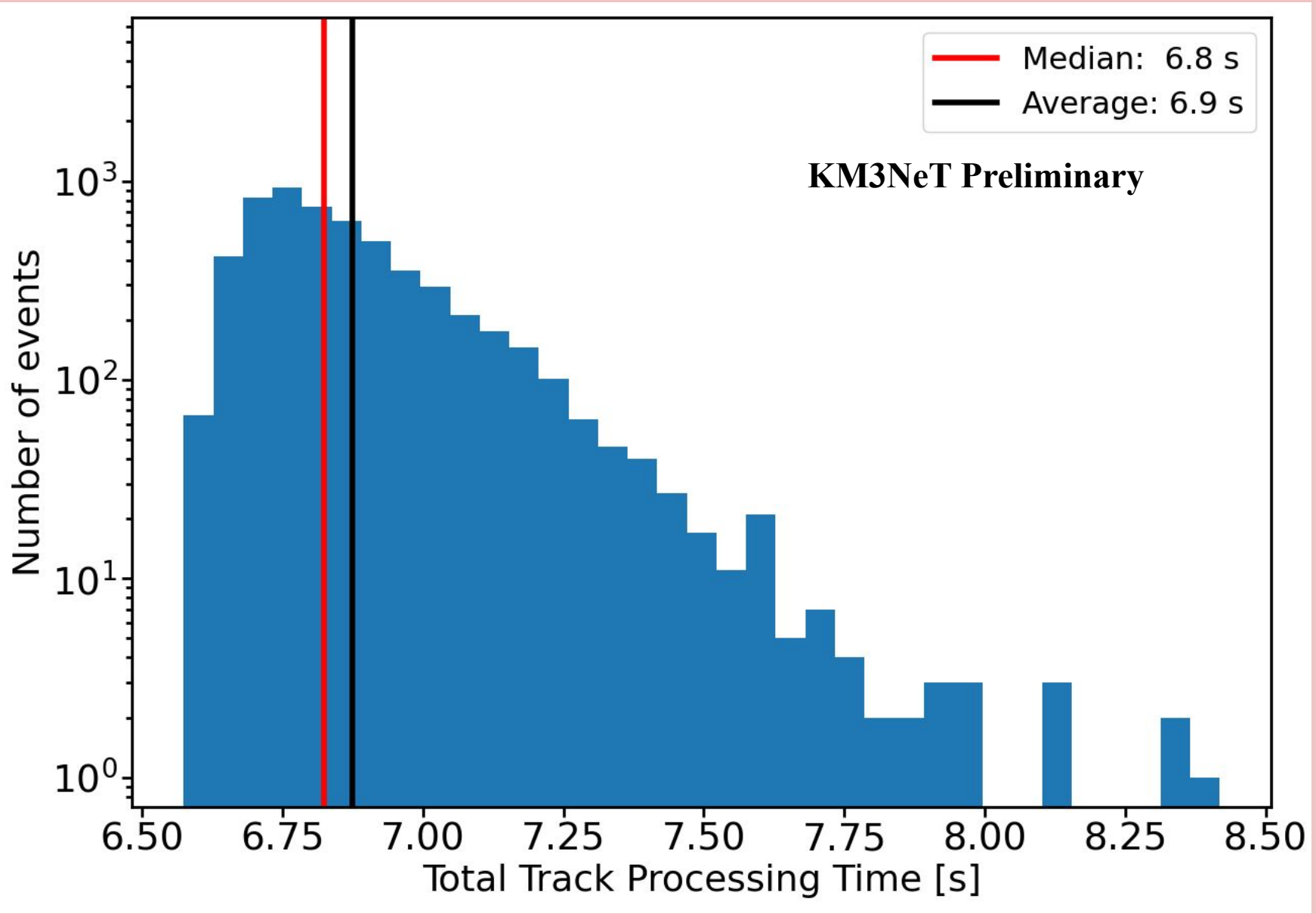


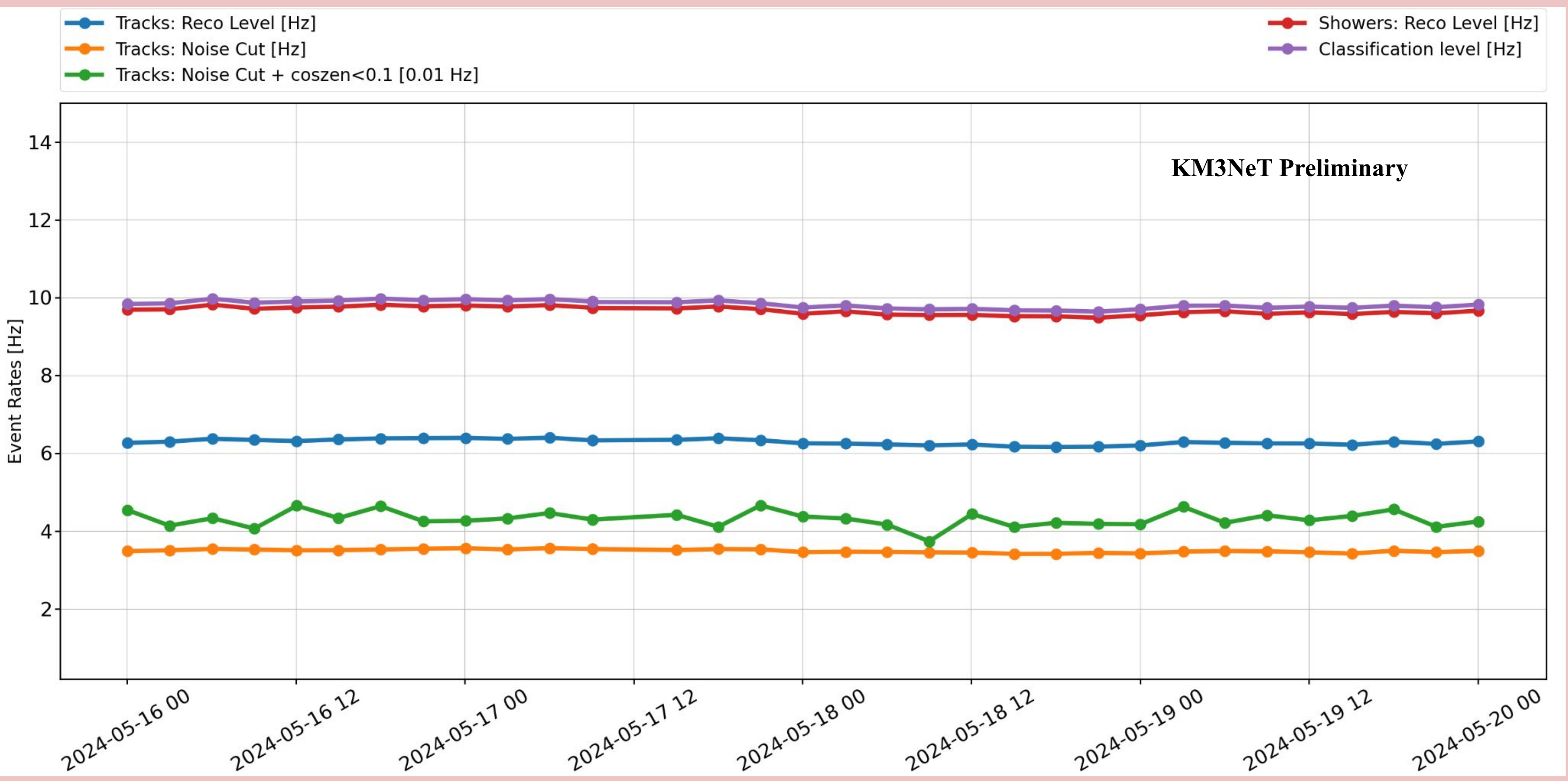


5. ARCA online event processing

Differently from that of ORCA, ARCA event processing relies on a parallel implementation of track reconstruction, shower reconstruction and classification. A Graph Neural Network (GNN) method is used to perform classification of events, aiming at both separating neutrinos from muons and identifying which is the most likely topology between tracks and showers. The ARCA28 parallel implementation allows to process triggered events in a median time of ~7 s, as shown in the figure at the top right corner. ARCA28 detector footprint and online event rates are also reported.







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