

# The data acquisition system for the complete KM3NeT/ARCA neutrino telescope

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on behalf of the KM3NeT Collaboration

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## 1. Introduction

KM3NeT/ARCA is an underwater neutrino telescope being deployed at 3500 m depth offshore Sicily, Italy. It consists of a 3D array of Digital Optical Modules (DOMs) [1], each equipped with photomultiplier tubes (PMTs) that detect Cherenkov light from charged particles produced by neutrino interactions, enabling reconstruction of neutrino direction and energy.

Each DOM contains a Central Logic Board (CLB) that manages data acquisition from 31 PMTs, an acoustic positioning sensor, and environmental monitors. Data is transmitted via optical fibers to the shore station. DOMs are arranged in vertical Detection Units (DUs) anchored to the seabed. At the base, a pressure-resistant titanium vessel called Base Module houses power distribution electronics and a dedicated CLB for managing the DU's power systems.

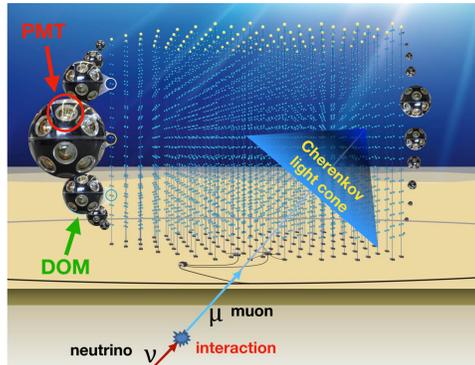


Fig. 1: Artistic view of KM3NeT/ARCA detector

Precise timing ( $O(1\text{ns})$ ) is achieved using the White Rabbit protocol: a GPS-referenced clock is distributed via onshore switches to the CLBs, which implement the protocol in their FPGA.

The Data Acquisition System (DAQ) handles DOM control, PMT configuration, data collection, and processing. A triggerless, Ethernet-based optical network continuously streams  $\sim 250$  Mbps per DU to shore. There, C++ software modules (DataQueues) aggregate packets into time frames, while DataFilters apply physics-based filtering algorithms. Filtered data is stored and backed up to off-site facilities. A web-based Control Unit manages configuration, data-taking sessions, and system monitoring.

## 3. Standard White Rabbit sector

For the other DUs, the *Standard* White Rabbit architecture is employed. In this setup, each Base Module houses two *Wet* White Rabbit switches that communicate bidirectionally with onshore *Dry* White Rabbit switches over just two optical fibers, handling both timing and data. The two Wet switches provide full White Rabbit synchronization to the DOMs of the string and offer redundancy through dual DOM connections and an inter-switch link. The system ensures high reliability and sufficient bandwidth (1 Gbps uplinks vs.  $\sim 250$  Mbps DU throughput).



Fig. 3: KM3NeT/ARCA Base Modules: Broadcast (in the foreground) and Standard White Rabbit (in the background). The red backplanes of the Wet White Rabbit switches are clearly visible in the Standard White Rabbit Base Module

## 4. Hybrid scenario

All timing is disciplined by a GPS-referenced Grand-Master switch onshore, which synchronizes both the Standard and Broadcast White Rabbit sectors. Data is routed to the processing systems via standard Ethernet switch fabrics.

The ARCA detector is designed to operate simultaneously with DUs of both the Broadcast and Standard White Rabbit architectures, treating them as a unified system. The scheme of the hybrid network is shown in Fig. 3. To manage this, specific DataQueue processes are assigned to handle the data from the Broadcast DUs, while others handle the data from Standard White Rabbit DUs. All DataQueues forward the assembled data to the DataFilter processes, which apply trigger algorithms across the entire detector dataset. At the shore station, a dedicated standard switch, named STRIDAS, aggregates and routes raw data traffic from both DU architectures, as well as communication with the Control Unit and the filtered data exchanged between the DataQueues, DataFilters, and the data writing processes. Because of the architectural differences between the Broadcast and Standard White Rabbit networks, their respective data streams are isolated using separate VLANs configured on the STRIDAS switch. Additionally, the Central Logic Boards in each sector are assigned distinct IP address ranges to prevent cross-traffic. The Control Unit, which interfaces with both network sectors, connects to the STRIDAS switch via two separate network interfaces, each assigned to a different IP subnet.

## References

- [1] S. Aiello et al. "The KM3NeT multi-PMT optical module". In: *Journal of Instrumentation* 17.07 (July 2022), P07038.
- [2] E. Giorgio [KM3NeT] T. Chiarusi. "The Software Defined Networking in KM3NeT". In: *EPJ Web Conf.*, 207, 06009 (2019) ().
- [3] S. Aiello et al. [KM3NeT]. "KM3NeT broadcast optical data transport system". In: *INST* 18, no.02, T02001 (2023). ().

## 2. Broadcast sector

The Broadcast architecture [3] is used for the first 30 installed DUs (Phase 1) and features an asymmetric communication scheme: timing and control signals are sent from shore to groups of DUs via a single optical broadcast channel, while each detector CLB sends data back over a dedicated uplink. CLBs in DOMs use a modified White Rabbit protocol that lacks return timestamps, so precise delay compensation is not possible and must be corrected later during data processing.

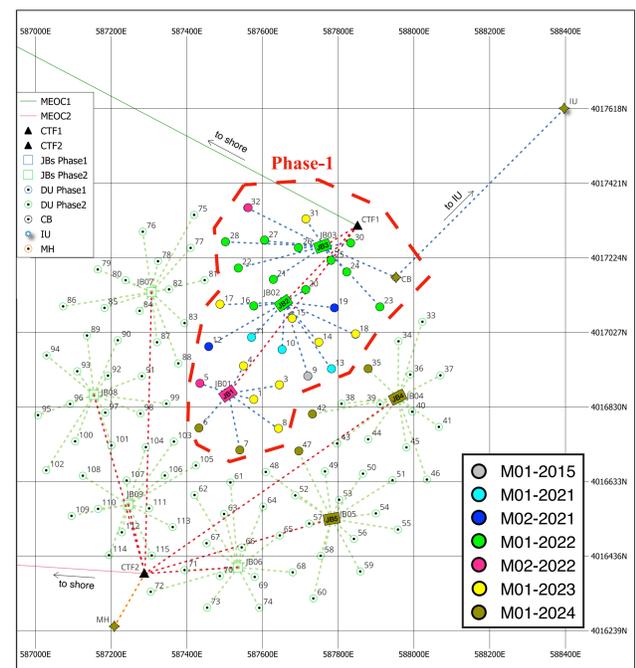


Fig. 2: Seafloor map of the ARCA detector, with the Broadcast sector highlighted by the red contour.

In contrast, Base Module CLBs use a full bidirectional White Rabbit protocol via a separate *Level 1* switch, allowing quasi-standard timing synchronization. All network traffic is managed using Software Defined Networking (SDN) [2] to enforce strict routing rules and prevent packet loops in the switching fabric.

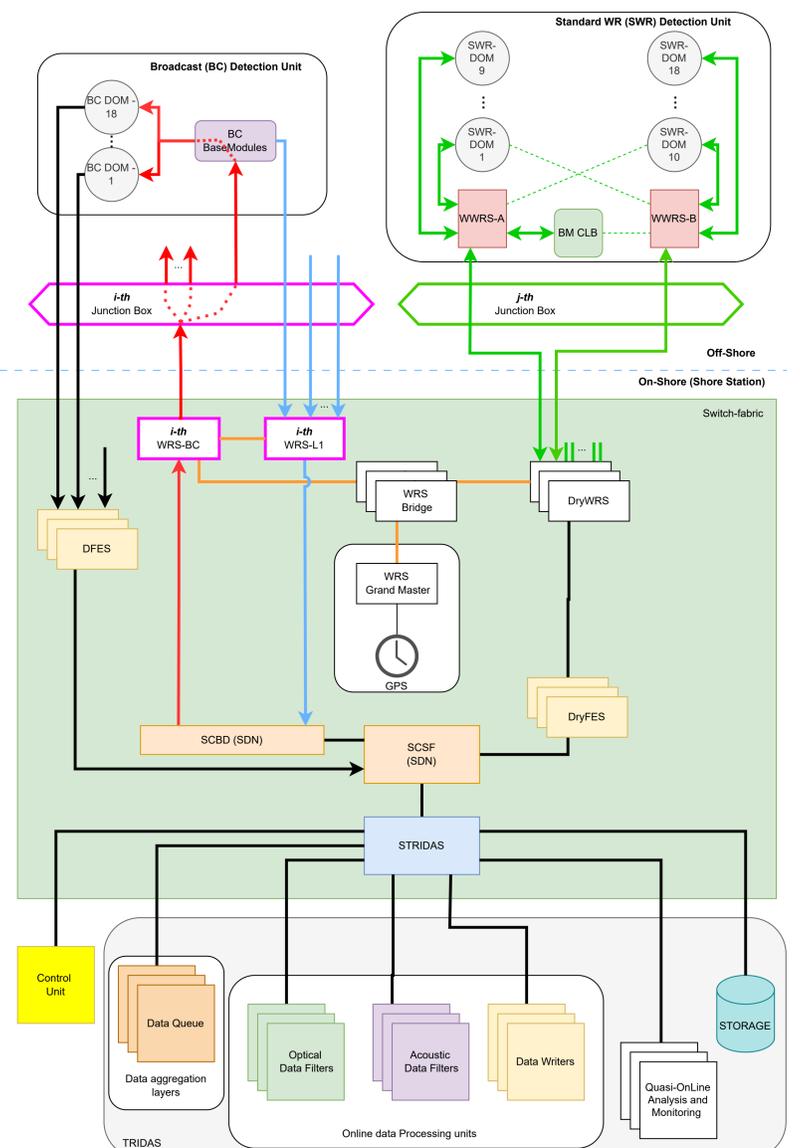


Fig. 4: Scheme of the hybrid KM3NeT/ARCA network.