The deep-sea Neutrino telescope KM3NeT
Timing and Readout

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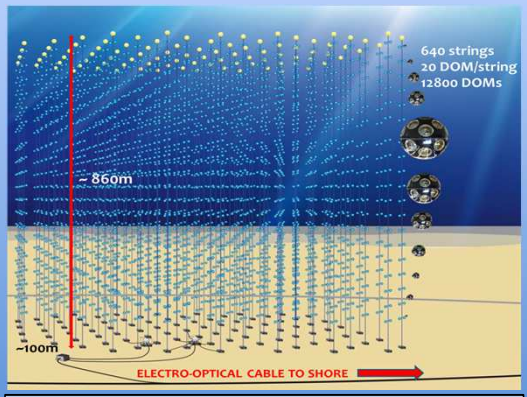
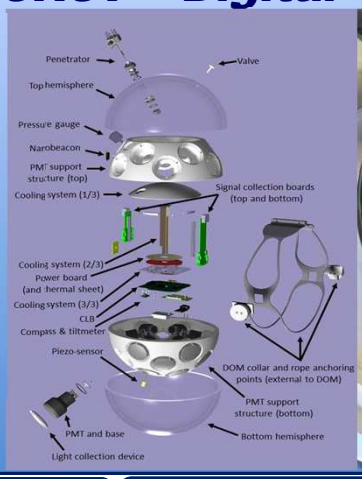
ABSTRACT

KM3NeT is large scale deep-sea neutrino telescope to be deployed and operated in the Mediterranean Sea. Neutrino induced muons are detected by measuring their Cherenkov light in sea-water using photomultiplier-tubes inside transparent and pressure resistant housings. KM3NeT aims at instrumenting a large volume of several cubic-km with tens of thousands of optical sensors, each one interconnected with the shore through electro-optical cables with distances up to 100km. The KM3NeT collaboration has successfully developed, as an optical sensor the Digital Optical Module (DOM), by placing multiple 31 3" photomultipliers (PMTs) in a 17" glass sphere including the power and readout electronics, providing the basic detection unit for the telescope. The DOM concept allows to maximize the photo-cathode area inside the sphere while the segmentation provided by individual PMTs allows better rejection of the ubiquitous K40 photon background in the sea. To ensure a high level of flexibility with minimal bias in the observations, all data from each DOM is sent to shore for on-line analysis. While the shore receives from each DOM continuously digitized data, each DOM needs to be synchronized with a global shore clock at the nano-second level. To make best use of the resources for power and data transfer in KM3NeT we have adopted an integrated timing and readout scheme between each DOM and the shore station , by employing synchronous Gbit-Ethernet link, and precision-time protocol and clock phase tracking, in a transparent way, through the open source hardware implementation "White Rabbit". Here we present the PMTs readout in a single DOM and the time synchronization scheme at the nano-second level for all DOMs in the deep-sea neutrino telescope KM3NeT.

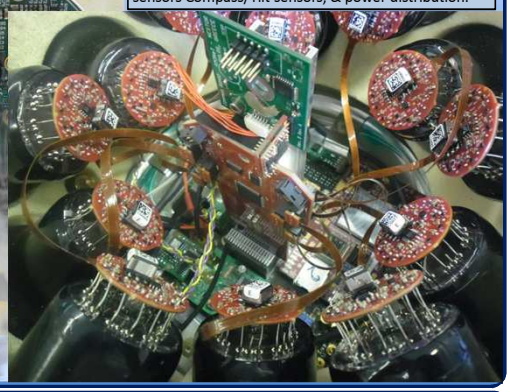
KM3NeT – Digital Optical Module



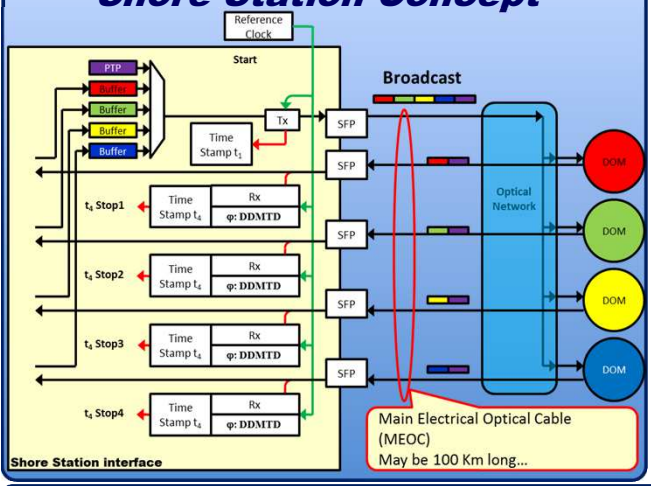
KM3NeT consists of Digital Optical Modules on vertical structures which are anchored on the sea floor and connected via electro-optical cables for power distribution and data transmission to shore.



KM3NeT Digital Optical Module a 17-inch sphere hosts: 31 3-inch PMTs each with own base, digitizing the Time-Over-Threshold, a single FPGA-board, Acoustic sensors Compass/Tilt sensors, & power distribution.



Shore Station Concept

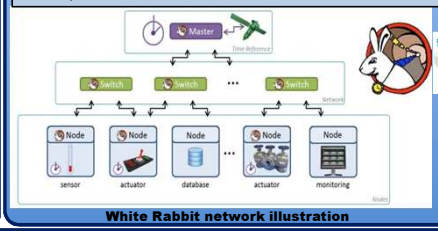


KM3NeT Requirements

- Broadcast link to all DOMs using a common optical channel (λSC)
- Point to point links from each DOM to shore, unique optical channel per DOM
- Achieve sub nanosecond accuracy
- All data from each DOM send to shore
- Asymmetric links TX/RX, to/from DOMs
- Distance to DOMs up to 100km
- Max. Data flow per DOM: 200Mbps
- Round-trip time measurements with optical calibration in-situ

White Rabbit

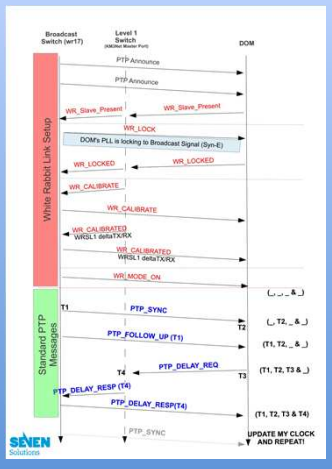
- **What is White Rabbit?**
  - An Ethernet extension which provides:
    - **Sub-nanosecond accuracy** in synchronization.
    - **Scalability**: More than 1000 nodes via fiber connections.
    - **Deterministic** routing latency
- **Synchronization**
  - **Synchronous Ethernet**
  - **Precision Time Protocol (PTPv2 - IEEE1588)**
  - **Digital Dual Mixer Time Difference (DDMTD) clock phase detection**
- **Development model**
  - Collaborative, industry and research centers (CERN, GSI, …)
  - Open source



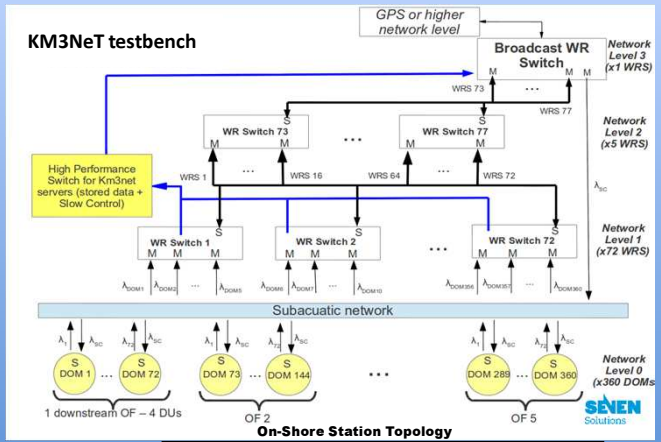
White Rabbit network illustration

White Rabbit Switch
(commercially available)

White Rabbit testbench for KM3NeT

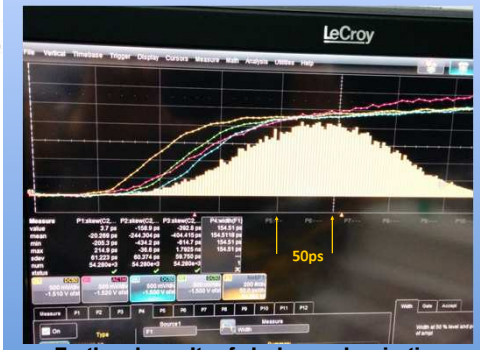


White Rabbit message flow customized for KM3NeT



On-Shore Station Topology

Shore station consists of 3 levels
- WR switch **lvl1**: Connections from DOMs and uplink
- WR switch **lvl2**: Split the network into timing and data network
- WR switch **lvl3**: Timing master switch and broadcast to all DOMs



Testbench results of clocks synchronization from shore to DOM emulators (width ~150ps)

- CH1: WRS Grand Master
- CH2: DOM emulator 1
- CH3: DOM emulator 2
- CH4: DOM emulator 3

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References: KM3NeT collaboration (http://www.km3net.org), 7Solutions (http://www.sevensols.com)