Laboratori Nazionali del Sud - INFN

KM3NeT

Introduction to

The KM3NeT data acquisition system

Tommaso Chiarusi

Emidio Giorgio

Francesco Benfenati Gualandi

INFN

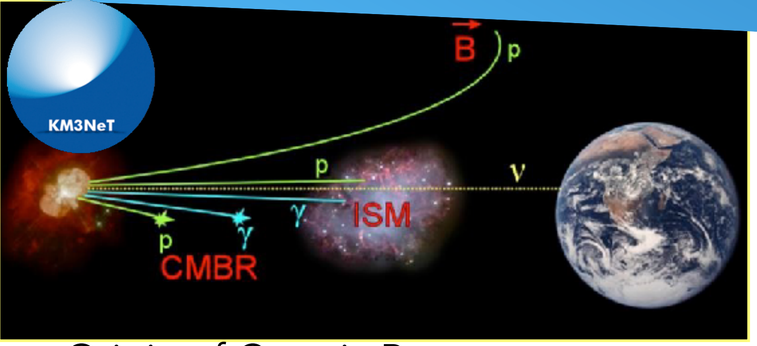
Sezione di Bologna

Laboratori Nazionali del Sud

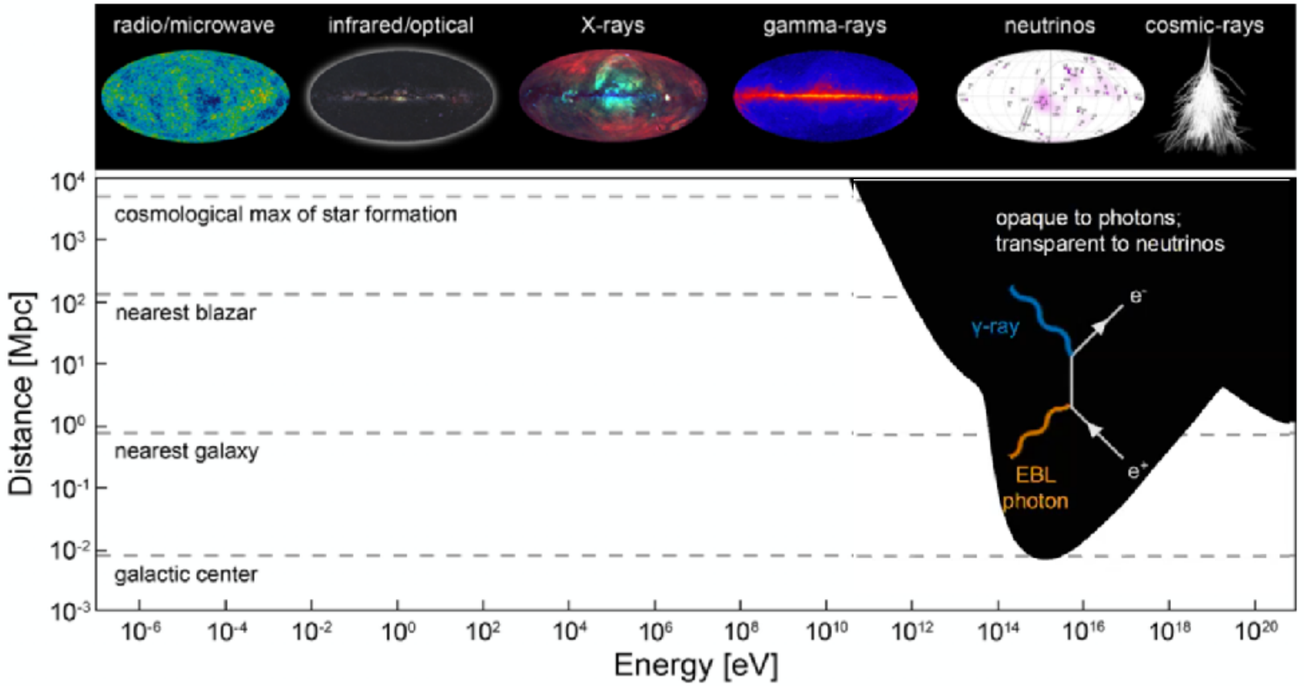
KM3NeT

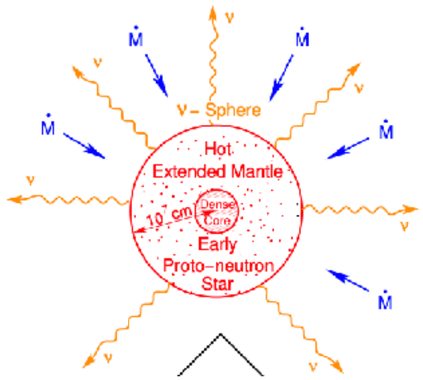
- The KM3NeT **Data Acquisition System**, a general overview
- The detection element, **the DOM**
- Details about the **data transfer**: UDP packets and timeslice
- **PMT signal** (hit digitization, TT, ToT, delayed, afterpulses)
- **Trigger**, data writing (event concept)
- **Control** and **Monitoring**
- **On-line** for **Multi-messenger program**
- **Outlook**

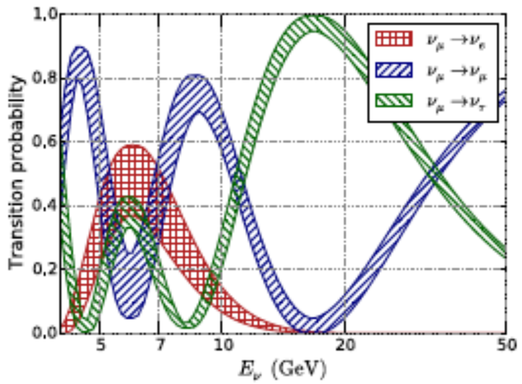

BCI
DU
Calibrations
Positioning
JDataWriter
Broadcast
TMCH
FW
Runsetup
Shore Stations
ToT
MUSEDIP
WORS
PMT
On-Line
AIACE
Readout
Full-WR
HRV
Triggerless
Hydrophone
Rack
CU
DAQ
SFP
CLB
DataQueue
OOS
Asymmetric
SDN
Detector Manager
TAES
CU-BM
JDataFilter
Control Unit
BM
NG-fw
Networking
DOM
TTDC
Trigger
Data Base
Monitoring
Switch
ADF
Hit
JLigier

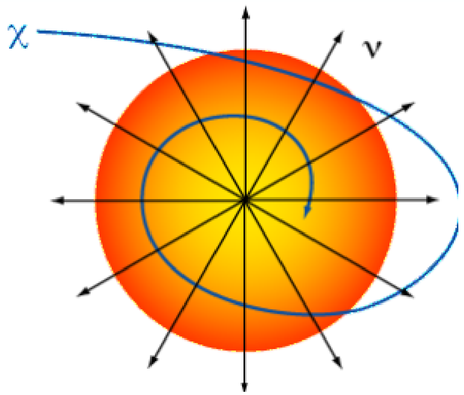


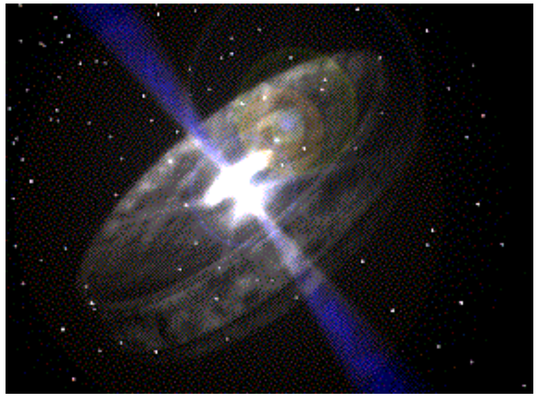
- Origin of Cosmic Rays
- Neutral messengers point back to their sources
  - Neutrons are short-lived, photons are likely to interact
    ⇒ **Neutrinos as cosmic probe**
- Neutrinos are produced at sources via hadronic interactions
  - Cosmic diffuse flux
  - Point-like sources
  - Multi-messenger approach









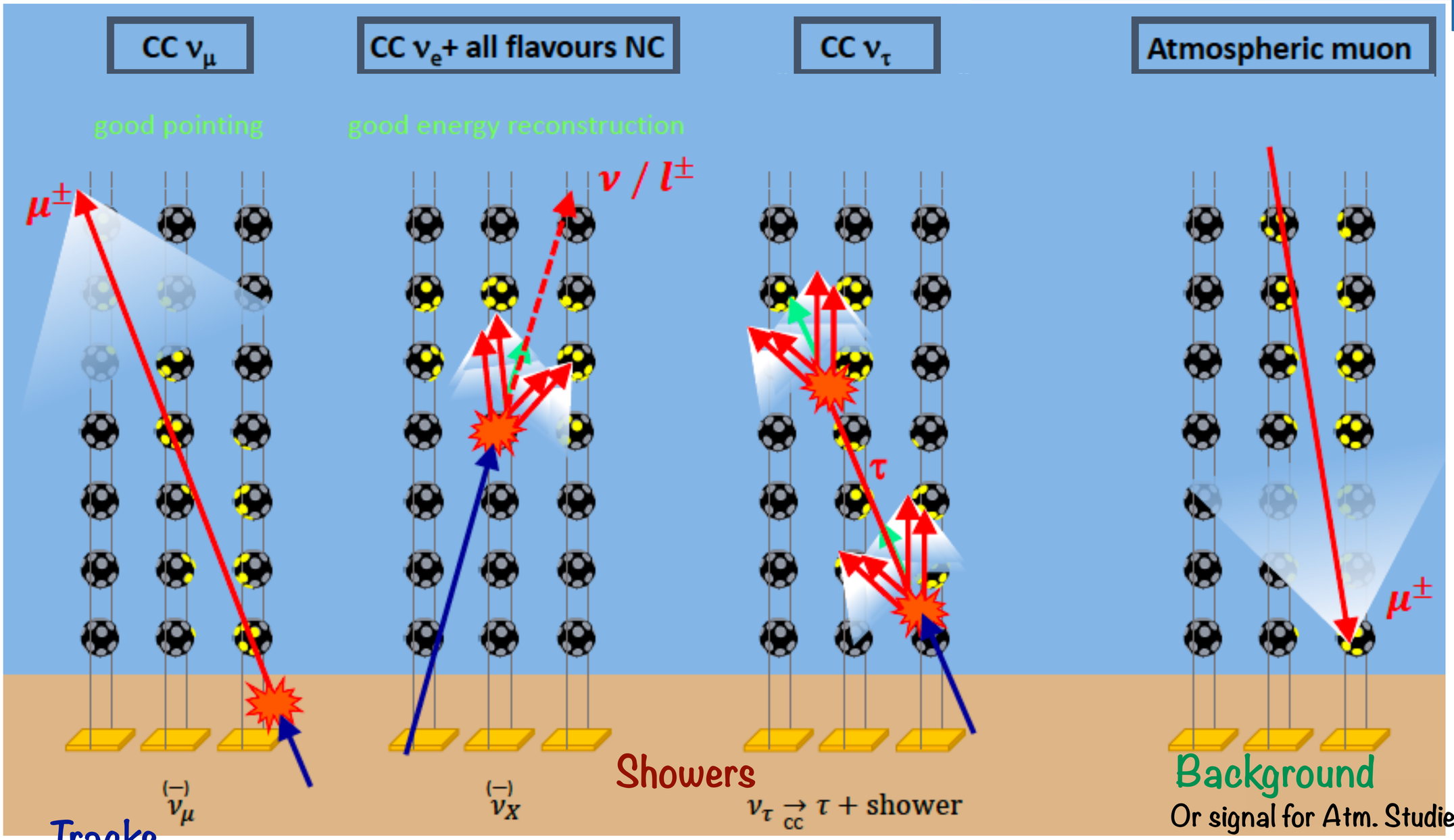


Super Novae explosion MeV	Neutrino oscillation GeV	Dark Matter GeV-TeV	HE neutrinos, CRs Multi-messenger program TeV-PeV

ORCA

ARCA

ARCA


CC ν_μ
CC ν_e+ all flavours NC
CC ν_τ
Atmospheric muon
good pointing
good energy reconstruction
$\mu^\pm$
ν / $l^\pm$
τ
$\mu^\pm$
$\overset{(-)}{\nu}_\mu$
$\overset{(-)}{\nu}_X$
$\nu_\tau \underset{CC}{\rightarrow} \tau$ + shower
Tracks
Showers
Background
Or signal for Atm. Studies (CRs)

- big volumes
- water optical properties (absorption & scattering of blue-green photons ~ 50-100 m)
- good angular resolution O(.1°) for sky pointing (that's neutrino ASTRONOMY)

➠ Many detection elements (N. OMs > O(1000)/km^3) deployed in bunches

➠ **SCALABLE DAQ design**

- No "beam crossing" reference such as for experiments at Colliders
- complex DAQ structures in extreme conditions (mandatory: minimal underwater complexity)

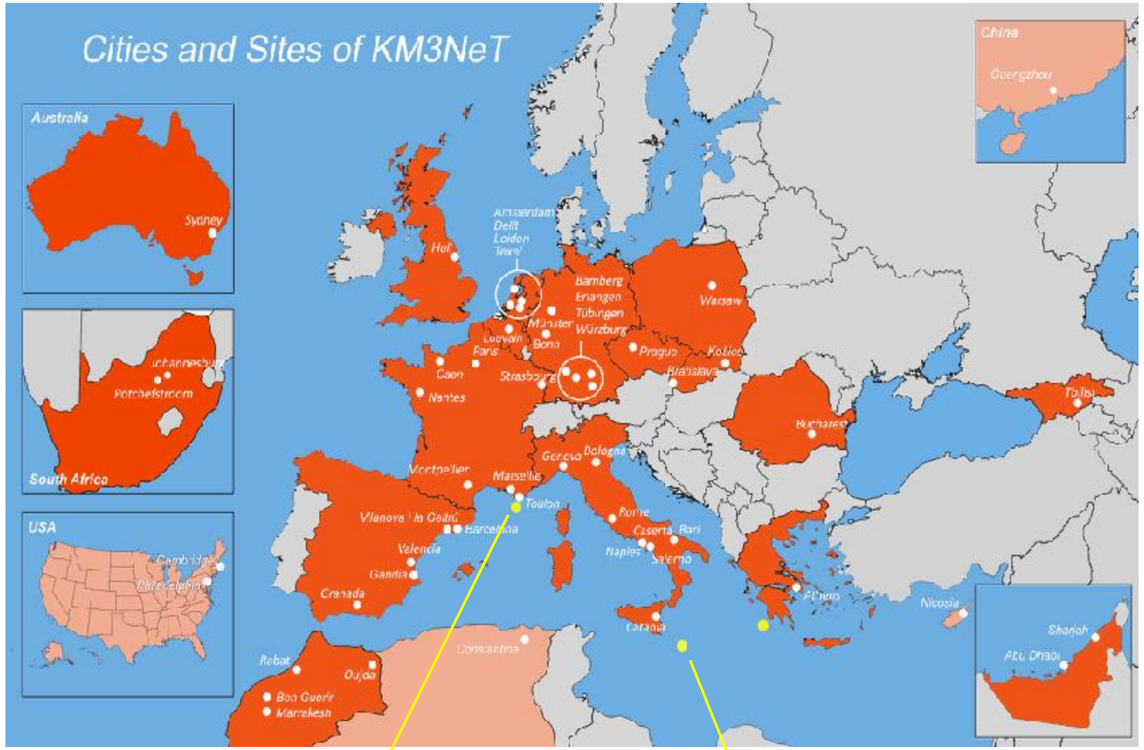
➠ **ALL DATA TO SHORE (a.k.a. *trigger-less streaming readout*) approach**

DRAWBACKS

signal-to-noise ratio extremely disfavoured :

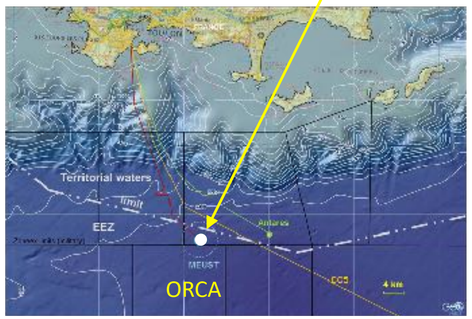
muon rate (atmospheric dominating)	:	O(100) Hz/km^3
^{40}K decays (~constant)	:	O(10) kHz/PMT(3", 0.5 p.e. threshold)
Bioluminescence (occasional)	:	O(100) kHz/PMT(3", 0.5 p.e. threshold)

➠ High continuous throughput to shore, needed **large bandwidth switching infrastructure and a strong data reduction**

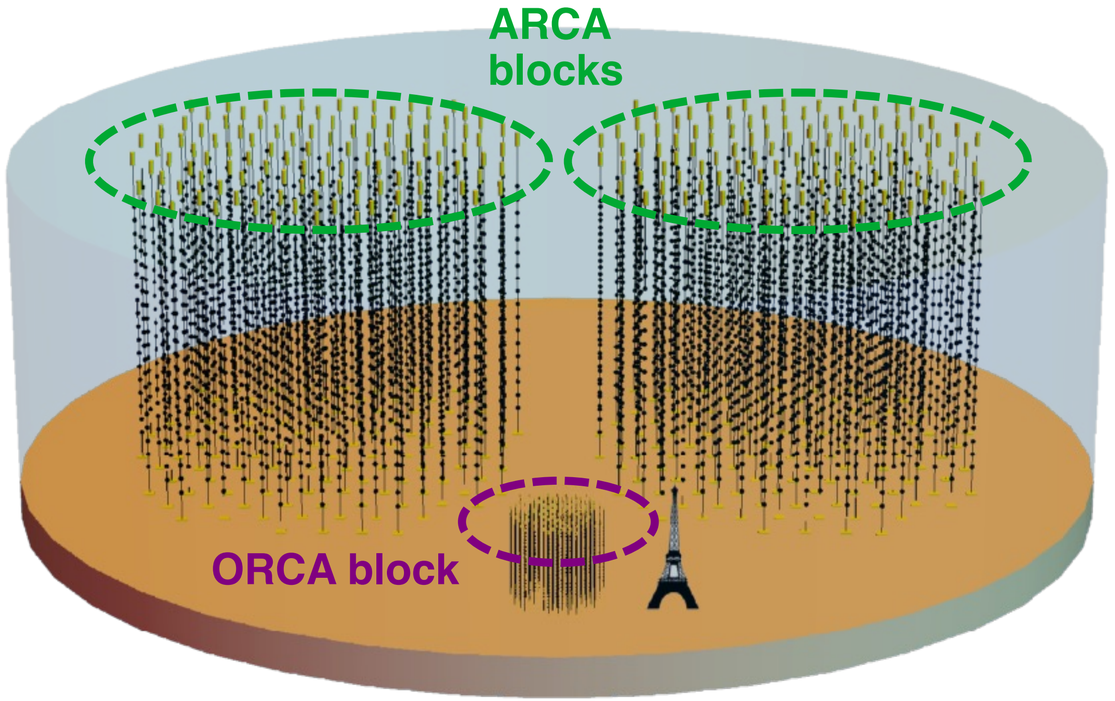


62 institutes ; 22 countries; 5 continents

Oscillation **R**esearch
with **C**osmics in the **A**byss



Astroparticle **R**esearch
with **C**osmics in the **A**byss



	ARCA	ORCA
Location	Italy (Sicily)	France (Toulon)
Anchor depth	3450 m	2450 m
Distance from shore	100 km	40 km
DUs	115×2 blocks	115
DU horizontal spacing	90 m	20 m
DOM vertical spacing	36 m	9 m
DOMs/DU	18	18
PMTs/DOM	31	31
Instrumented water mass	1 Gton	7 Mton
DUs deployed so far	28→33	23

Detection Unit

115 DUs per Building Block

DU Paper: Eur. Phys. J. C 76 (2016) 76:54

18 DOMs/DU

Digital Optical Module (DOM)

31x 3” ***PMTs*** (Physics)

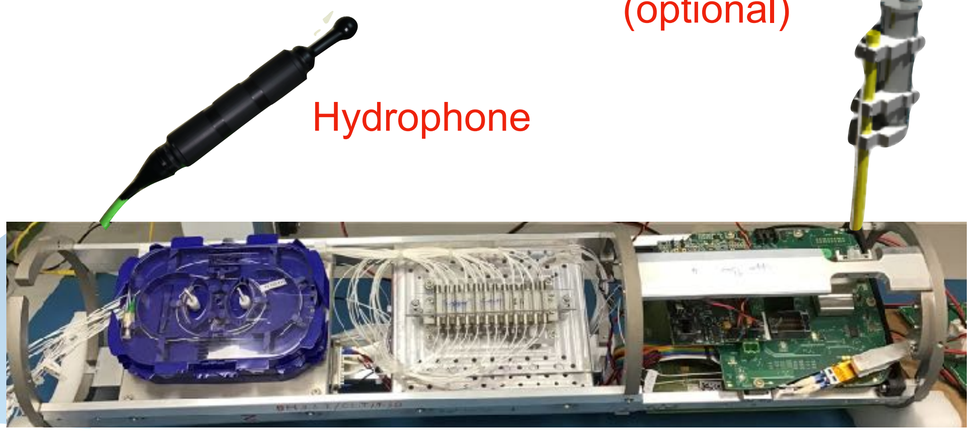
piezo acoustic sensor (positioning)

system ***sensors*** (monitoring)

DOM Paper: 2022 *JINST* **17** P0703

Acoustic beacon (optional)

Hydrophone



Acoustic beacon

DU-Base Module *(DU-BM) - Instruments -* ***no*** *PMT*

Calibration Unit

O(1) CUs per Building Block

Not to scale

Instrumentation Unit

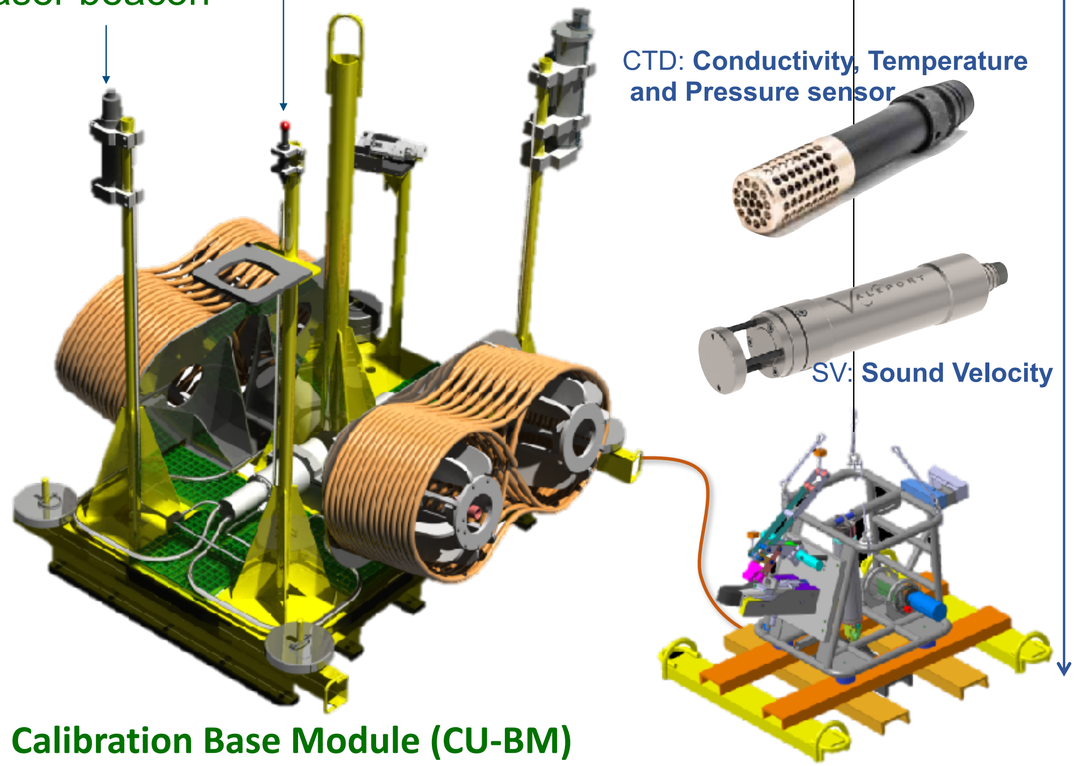
Acoustic beacon

ADCP: **Curent Profiler**

Hydrophone

Laser beacon

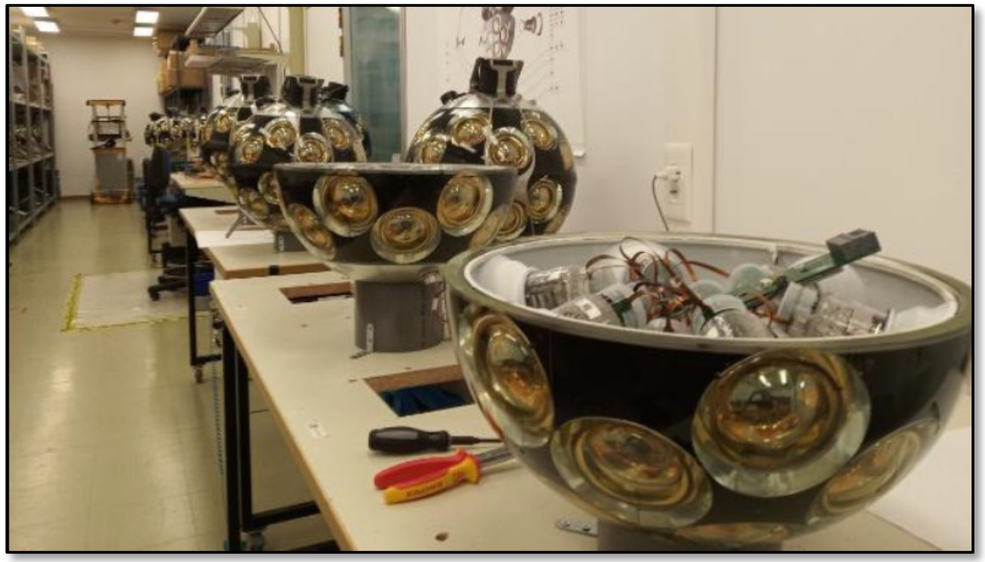
CTD: **Conductivity, Temperature and Pressure sensor**



SV: **Sound Velocity**

Instrumentation Line

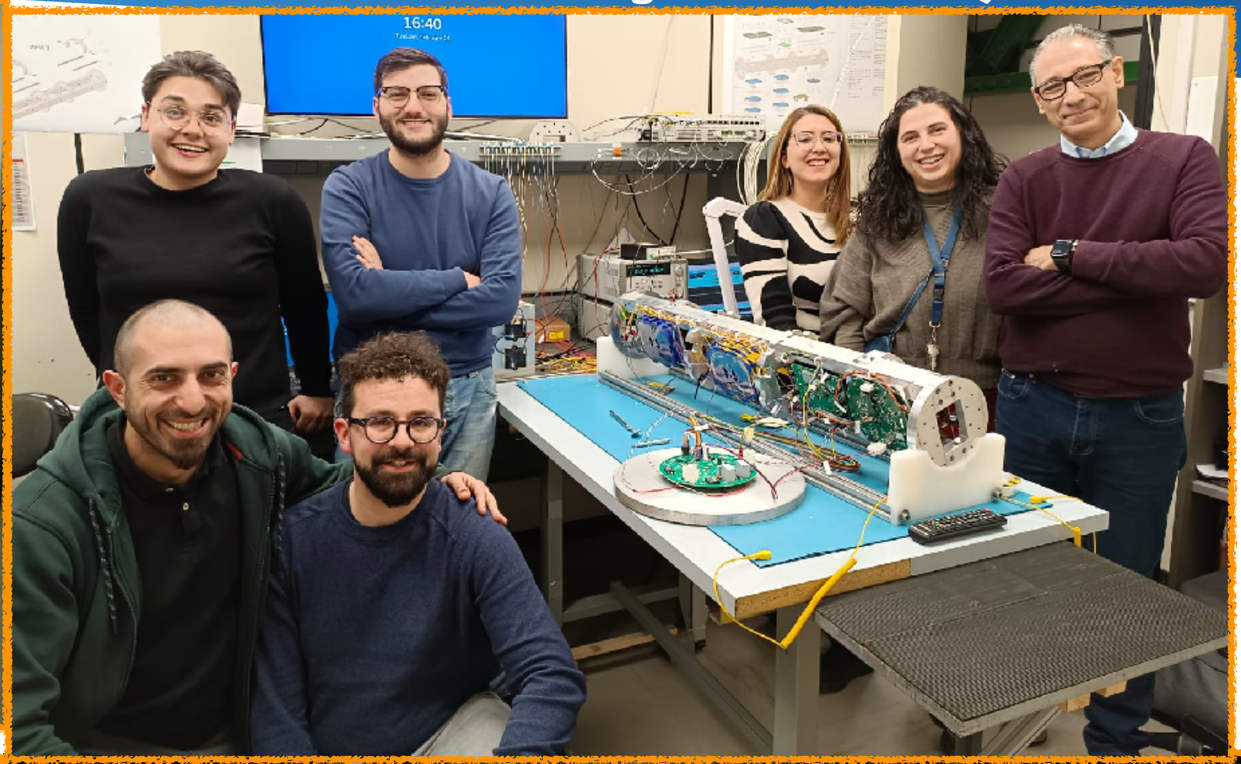
Calibration Base Module (CU-BM)

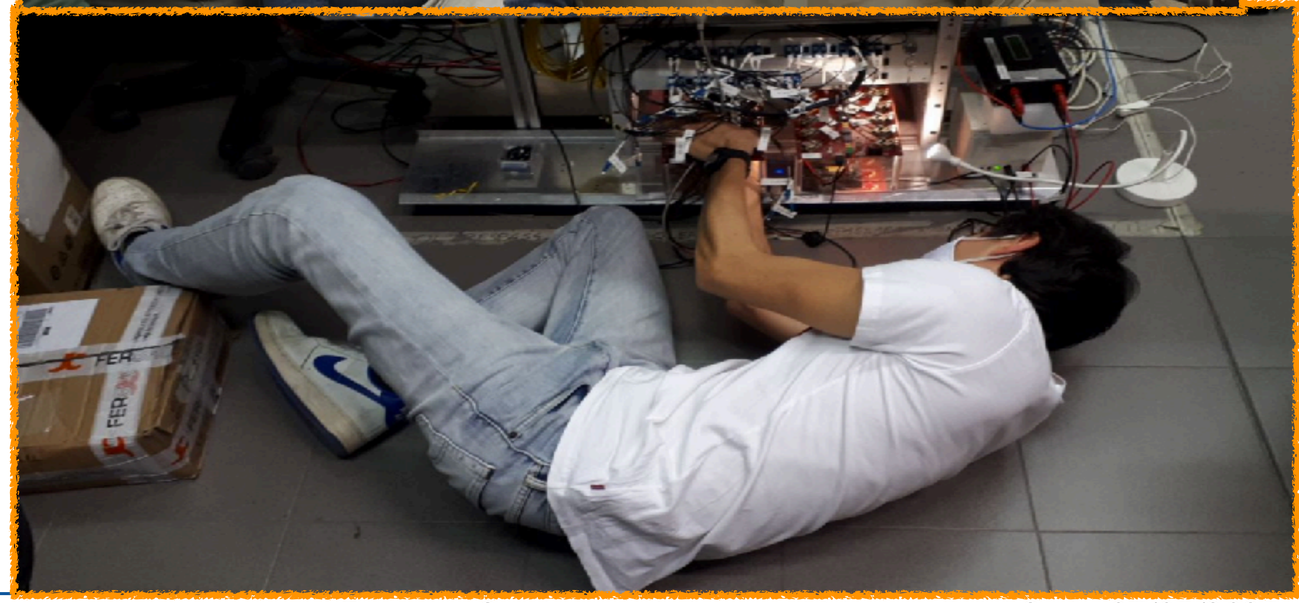


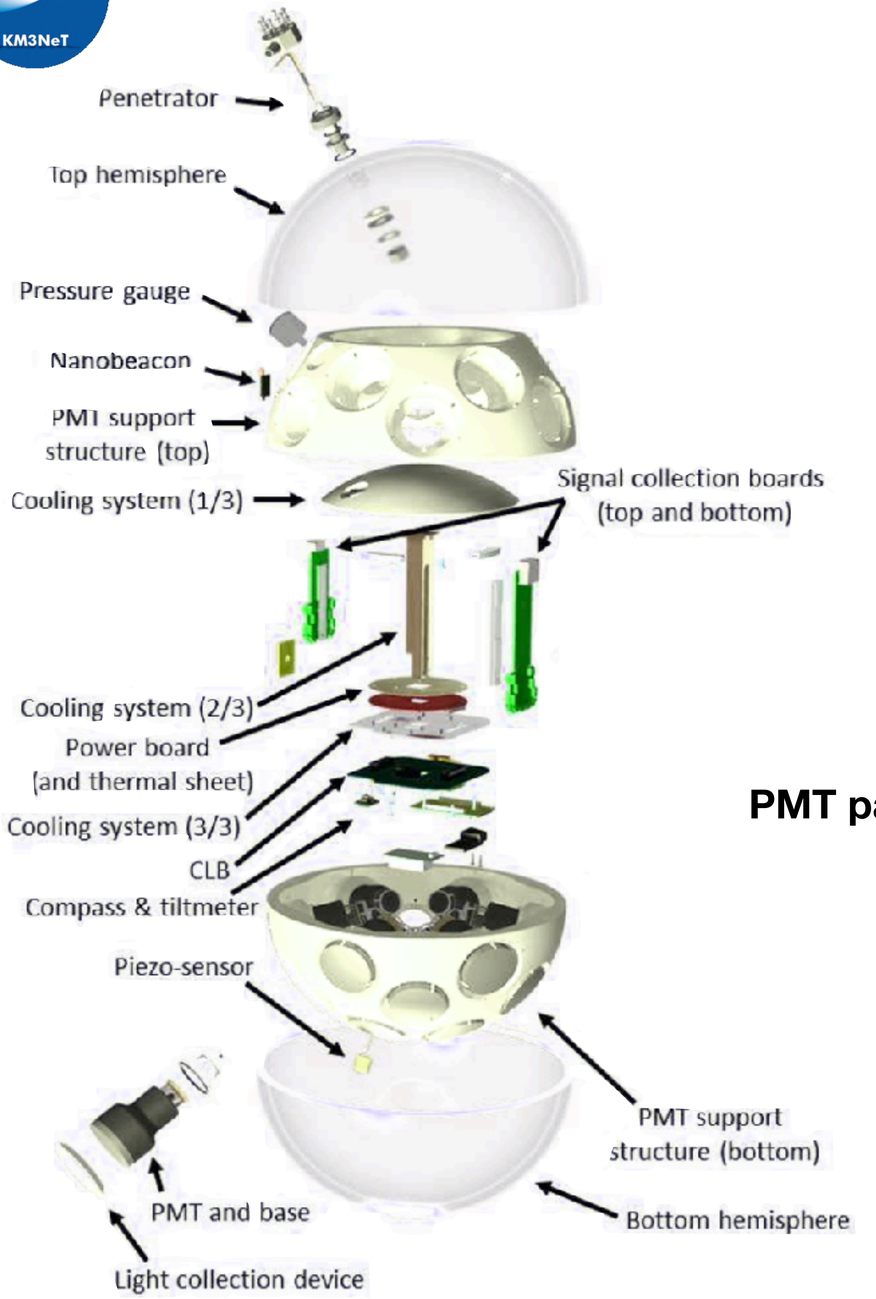
DOM: 8 sites
DU: 5 sites

+ sites for
base containers,
electronics,
testing

LOM Paper: 2020 JINST 15 P11027

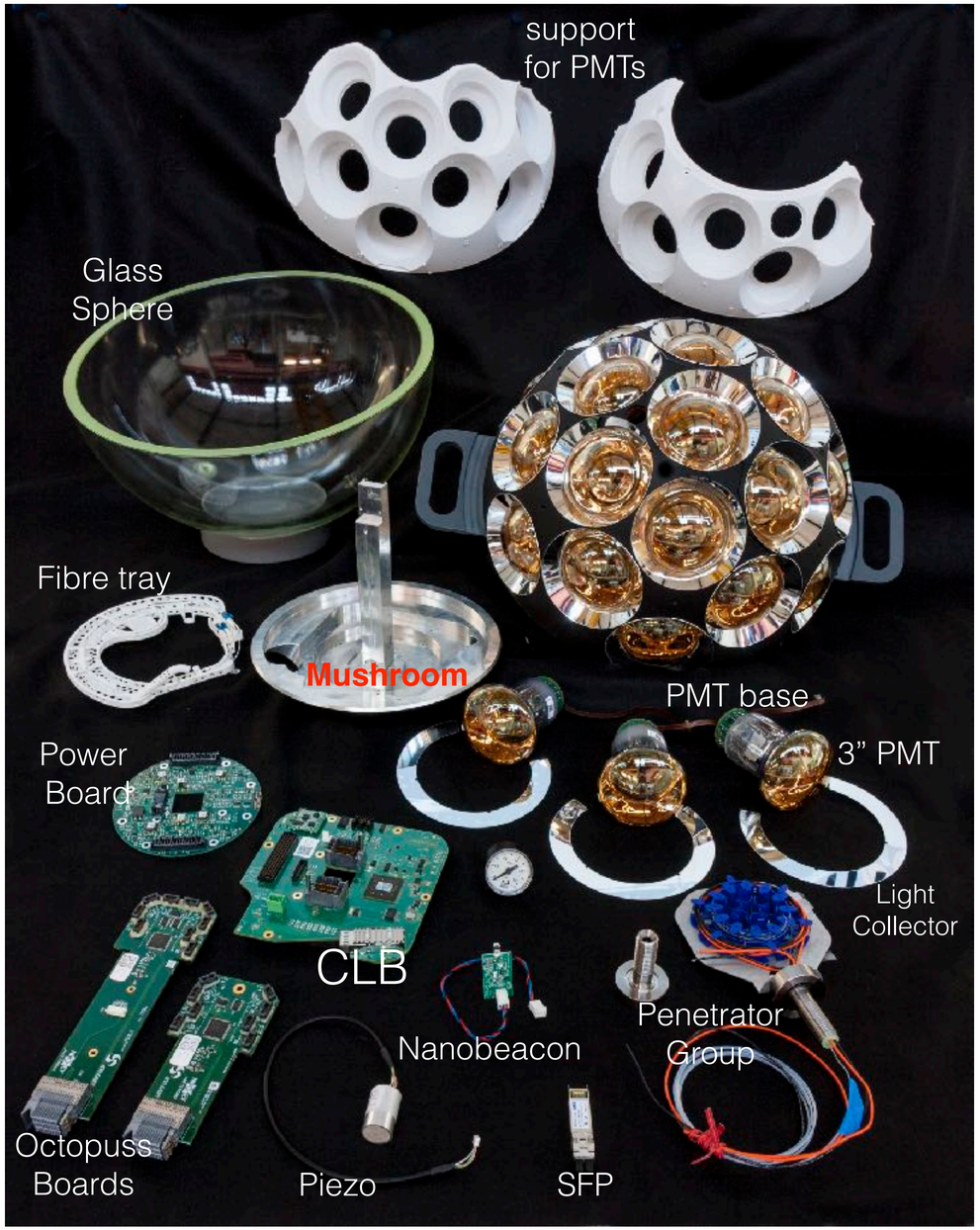

16:40

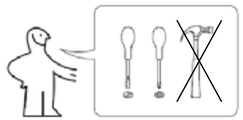




A DOM it is a host in the Layer 2 submarine network

PMT paper: [JINST13 (2018) P05035]





Fast-acquisition data

- The **optical data-stream (TDC channel)** is composed of the digitised signals (the hits) produced by all the 3" PMTs of the DOMs. The optical information provides with the observables needed for the principal Physics and Astrophysics measures performed with the KM3NeT telescope. The basic information of the optical hit is its time of occurrence and the time-over-threshold (ToT), a quantity which is related to the intensity of the PMT signal.

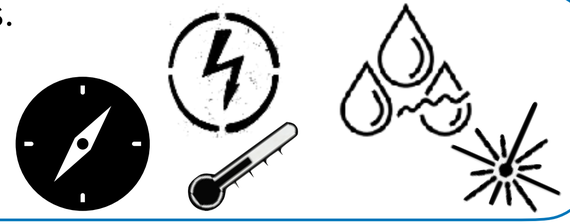
- The **acoustic data-stream (AES channel)** is composed of the digitised signals of the acoustic sensors (piezo-electric sensor, on the DOMs, and hydrophones on the string-bases and Calibration units). The acoustic information is used to retrieve the position of each element of the strings.

- The **monitoring channel (MON channel)** is composed of a stream of subsequent data-frames from every DOM, each of the same duration (generally 100 ms) and containing a summary of the DOM records and status occurred during the data-frame time interval.

Slow control data

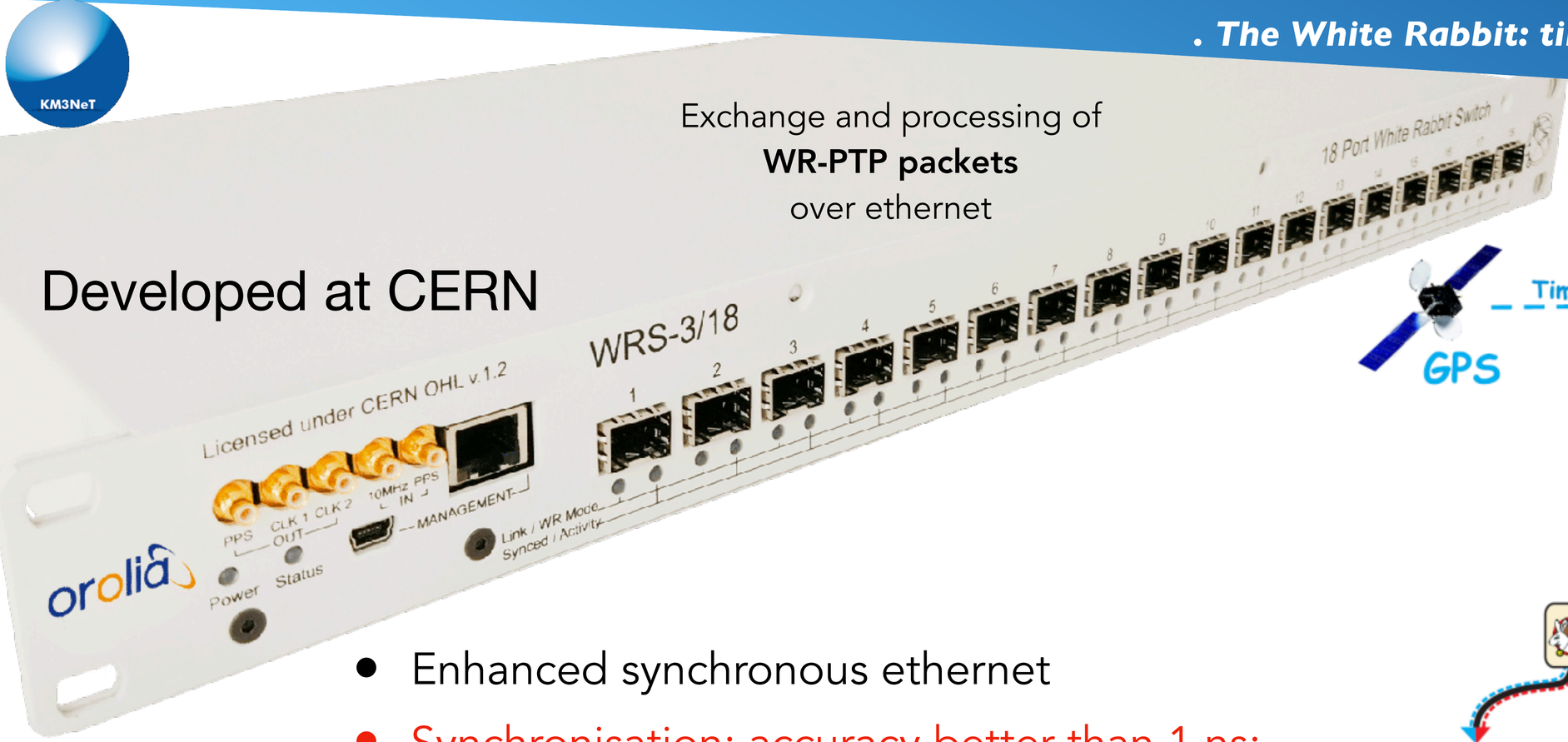
- The **slow control data-stream** is composed of all the broadcasts, multicasts or direct-casts for distributing commands from the shore-station to the offshore detector, and the possible feedbacks from the DOMs.

- The **instrument data-stream** is composed of data from compass, temperature and relative humidity sensors. In addition, the DOM uses this data stream to send to shore a number of status parameter related to all the subsystem of the implemented electronics.

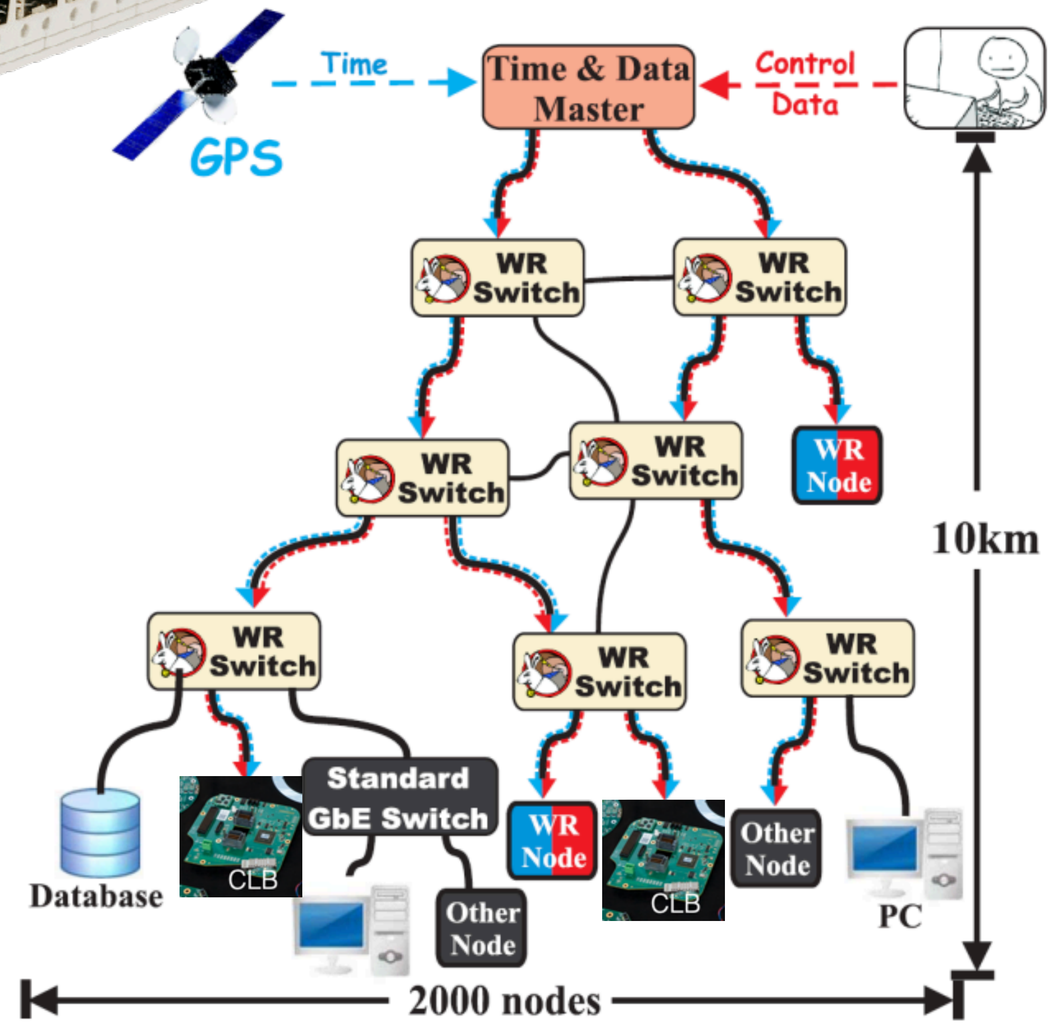


Exchange and processing of
WR-PTP packets
over ethernet

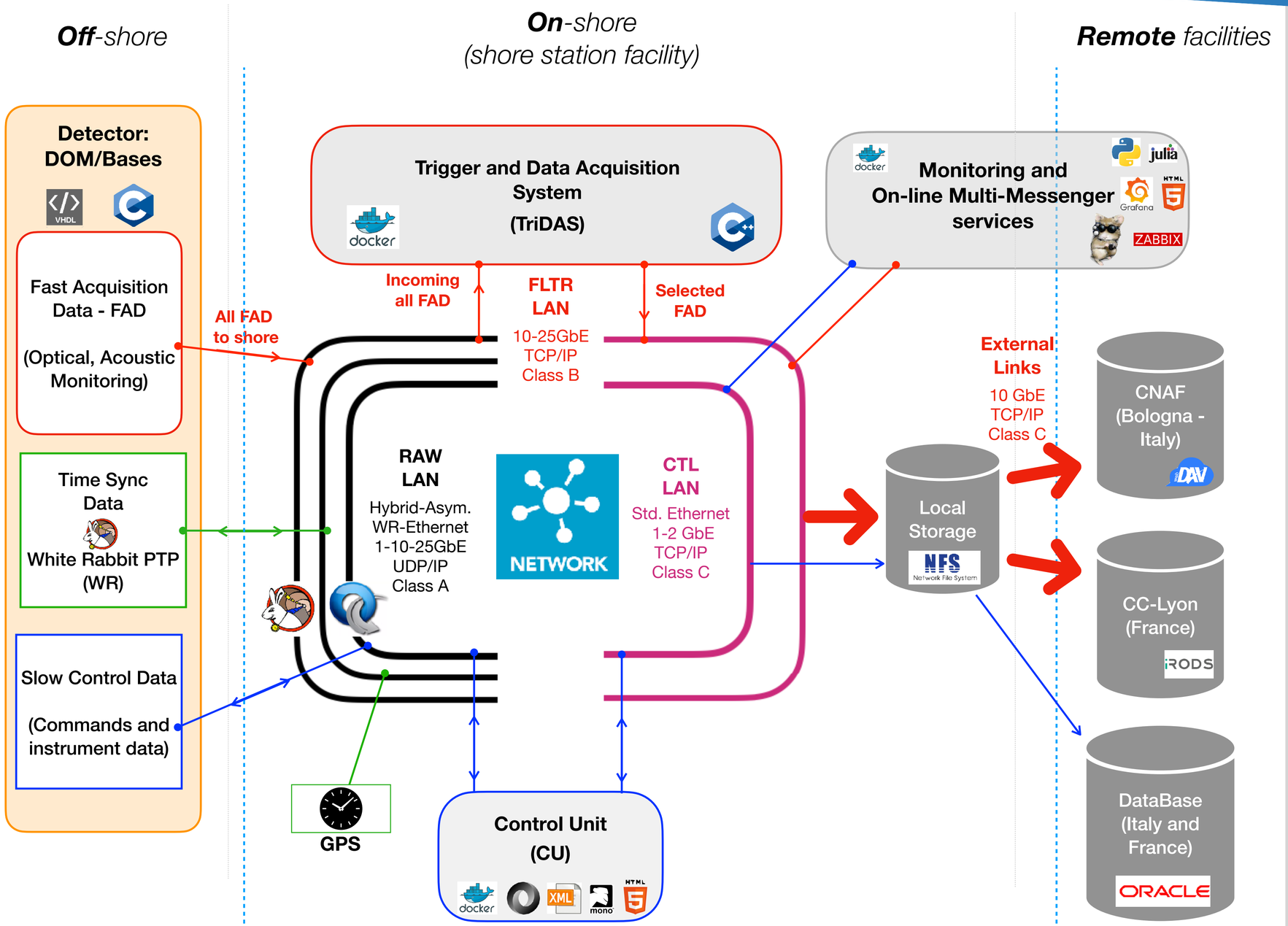
Developed at CERN



- Enhanced synchronous ethernet
- Synchronisation: accuracy better than 1 ns; precision (tens of ps stdev skew max)
- Deterministic reliable and low latency control-data delivery



Currently used releases in KM3NeT DAQ:
Hardware: **WRS-18p-hw-v3.4**
Firmware: WR-Core **v4.2** (**customised** by Seven Solutions for KM3NeT); **v6.1_xxx**
Ongoing evaluation of **v7 or 8**.x

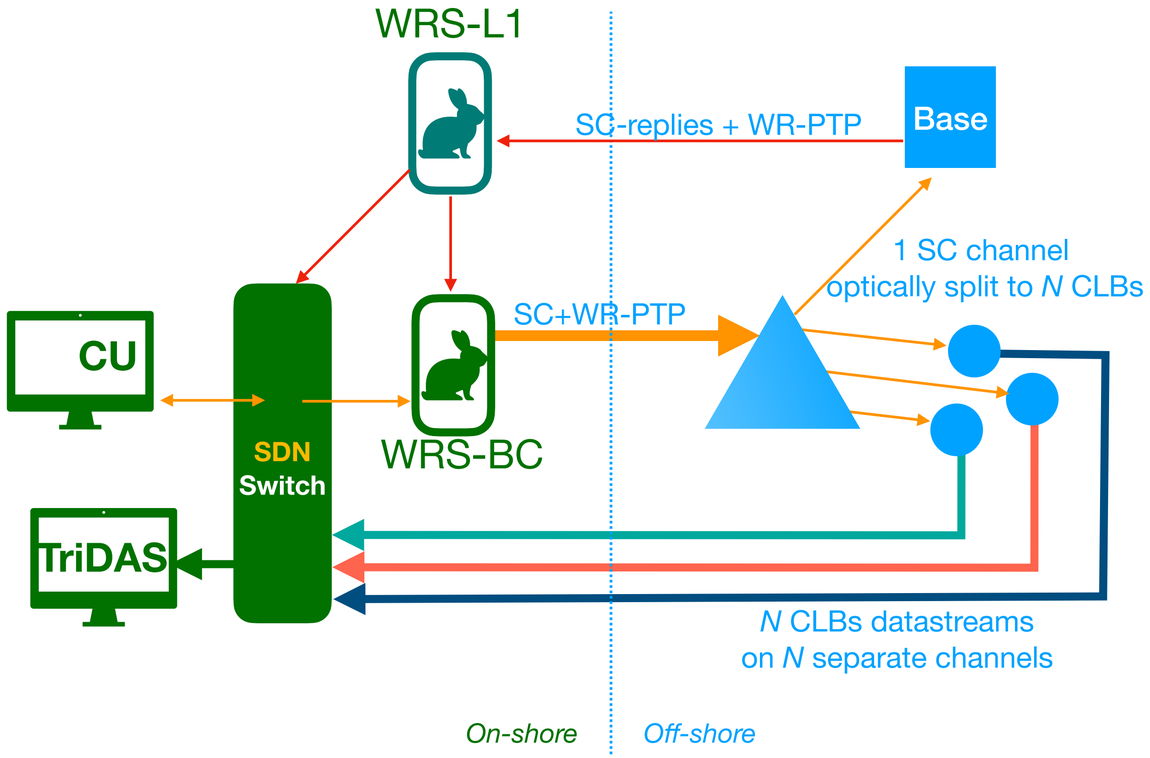


White Rabbit

Openflow

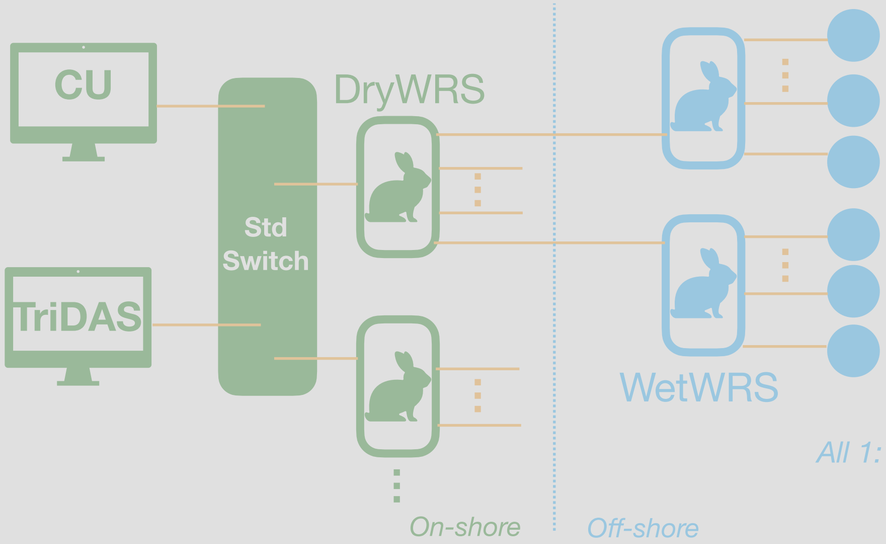
Observium

Broadcast (ARCA 32 strings; ORCA 48 strings *at least*)



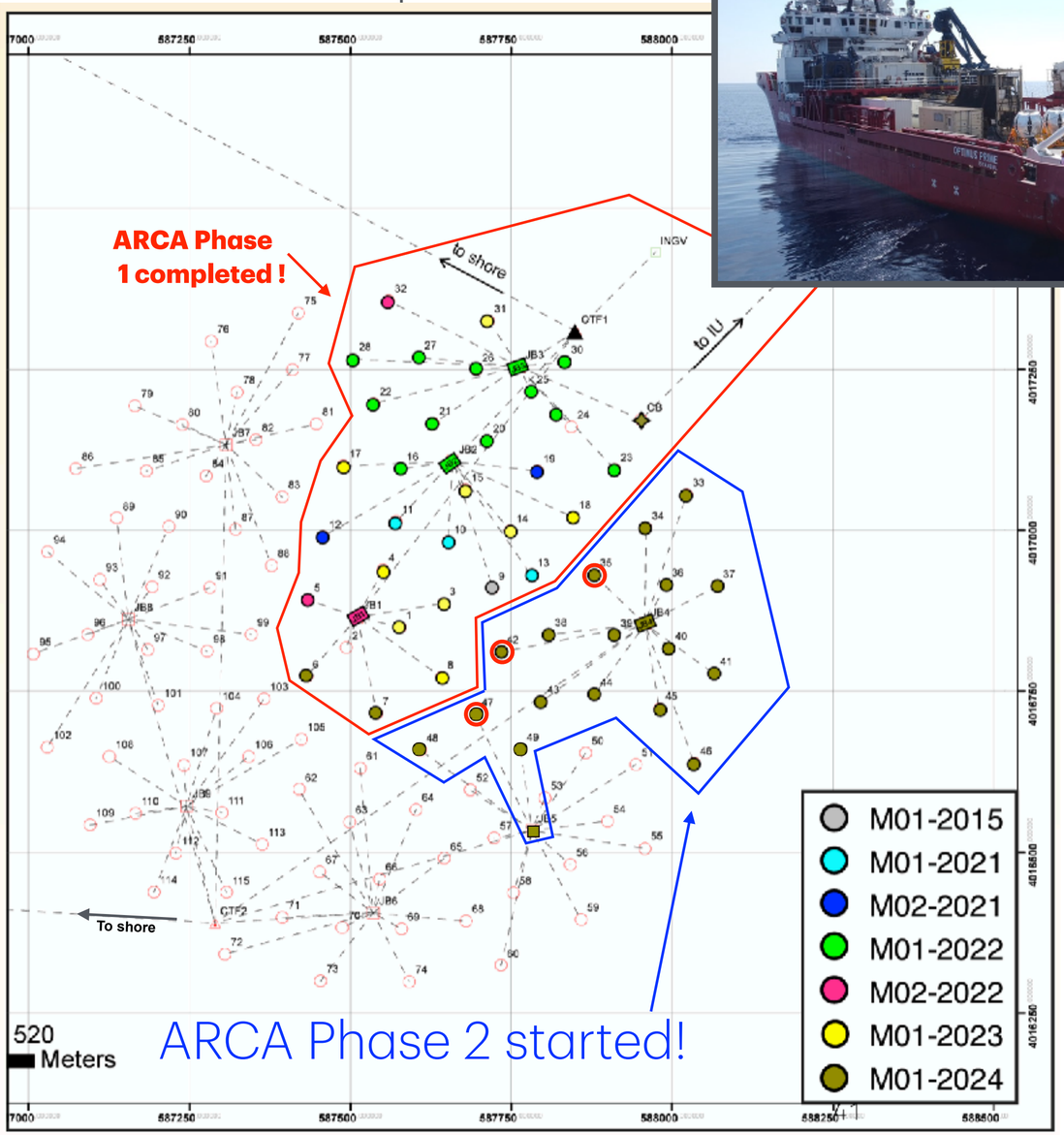
Current implementation in both ORCA/ARCA
(as well as other test-installations)

Full White Rabbit (necessary for ARCA 2 BB)



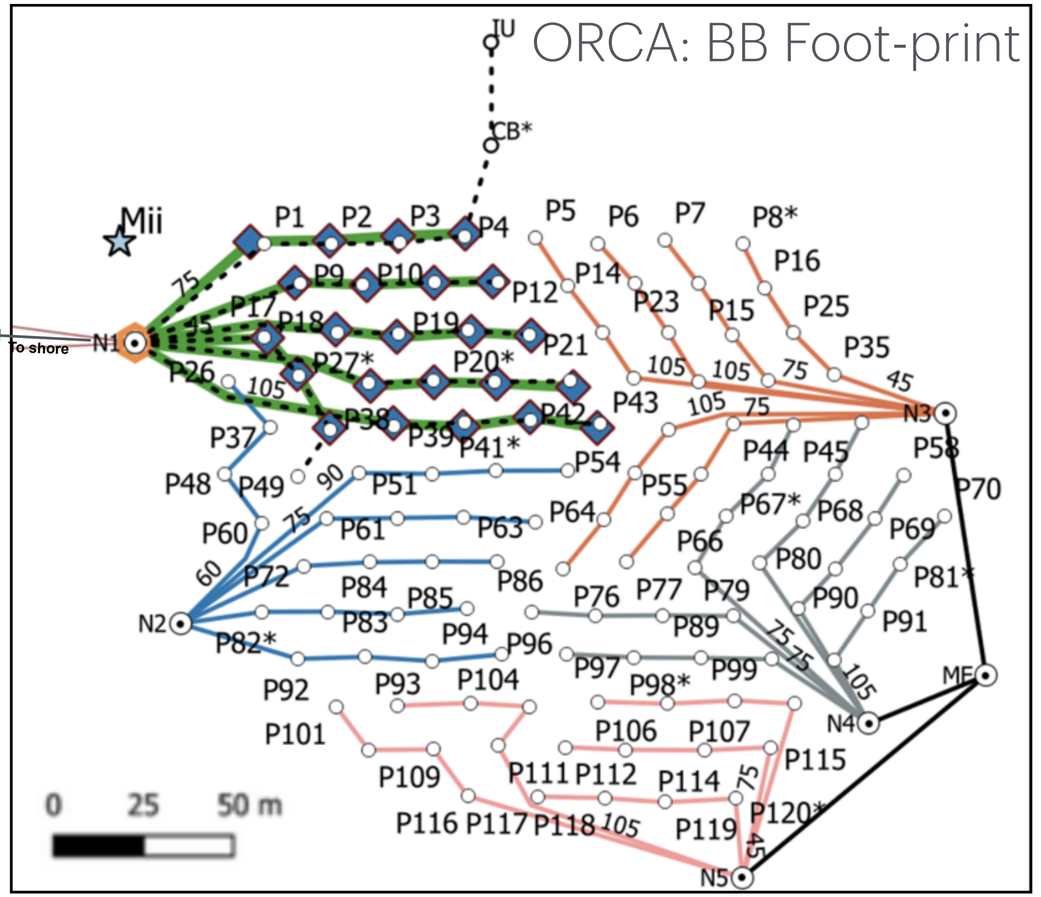
Future evolutions

ARCA BB#1 Foot-print



ARCA Phase 2 started!

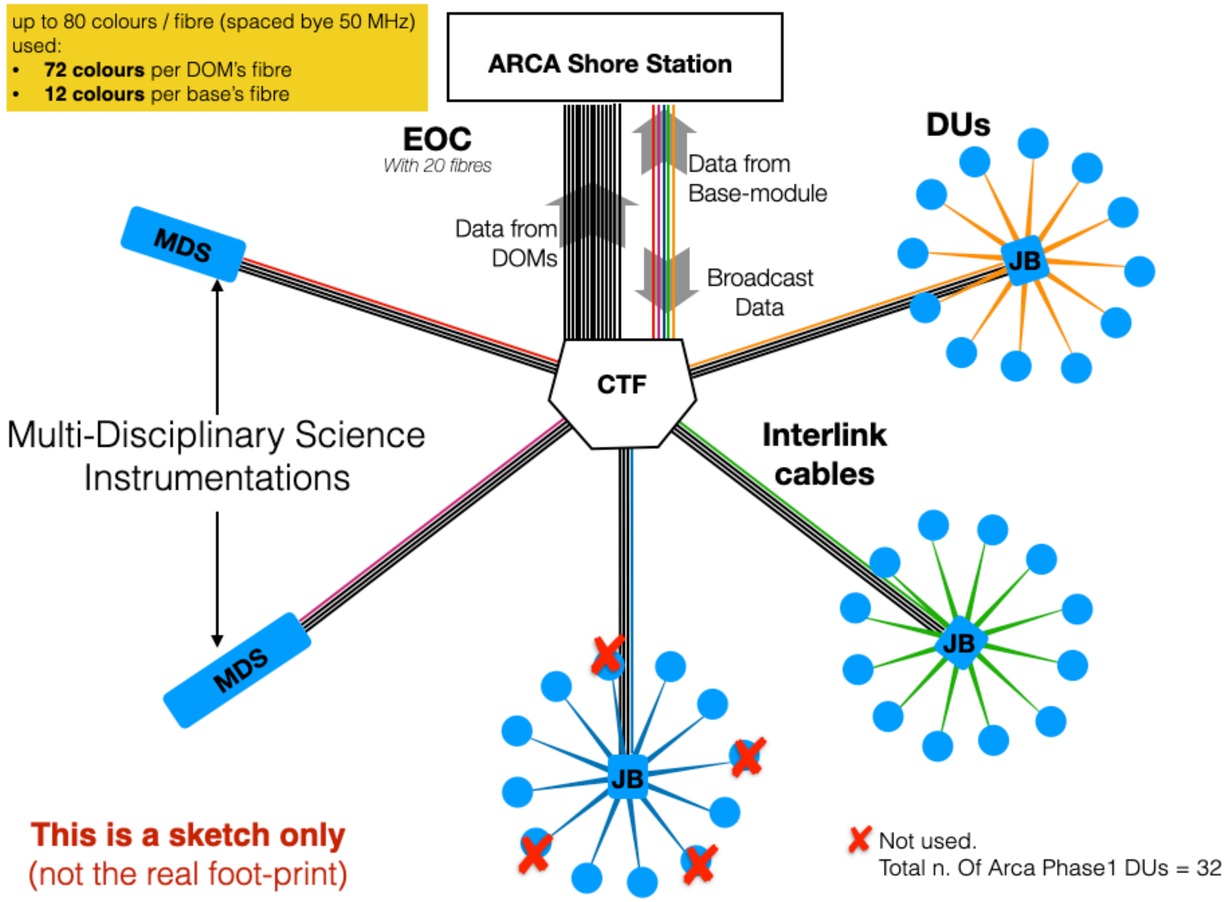
ORCA: BB Foot-print



Almost completed the first node ~ 20% ORCA

M01-2024 operatons ended 21/10/2024 ~0.14 km^3 Next ARCA sea operations: July 2025

DAQ Overview: ARCA - Phase 1 sea infrastructure (asymmetric network)

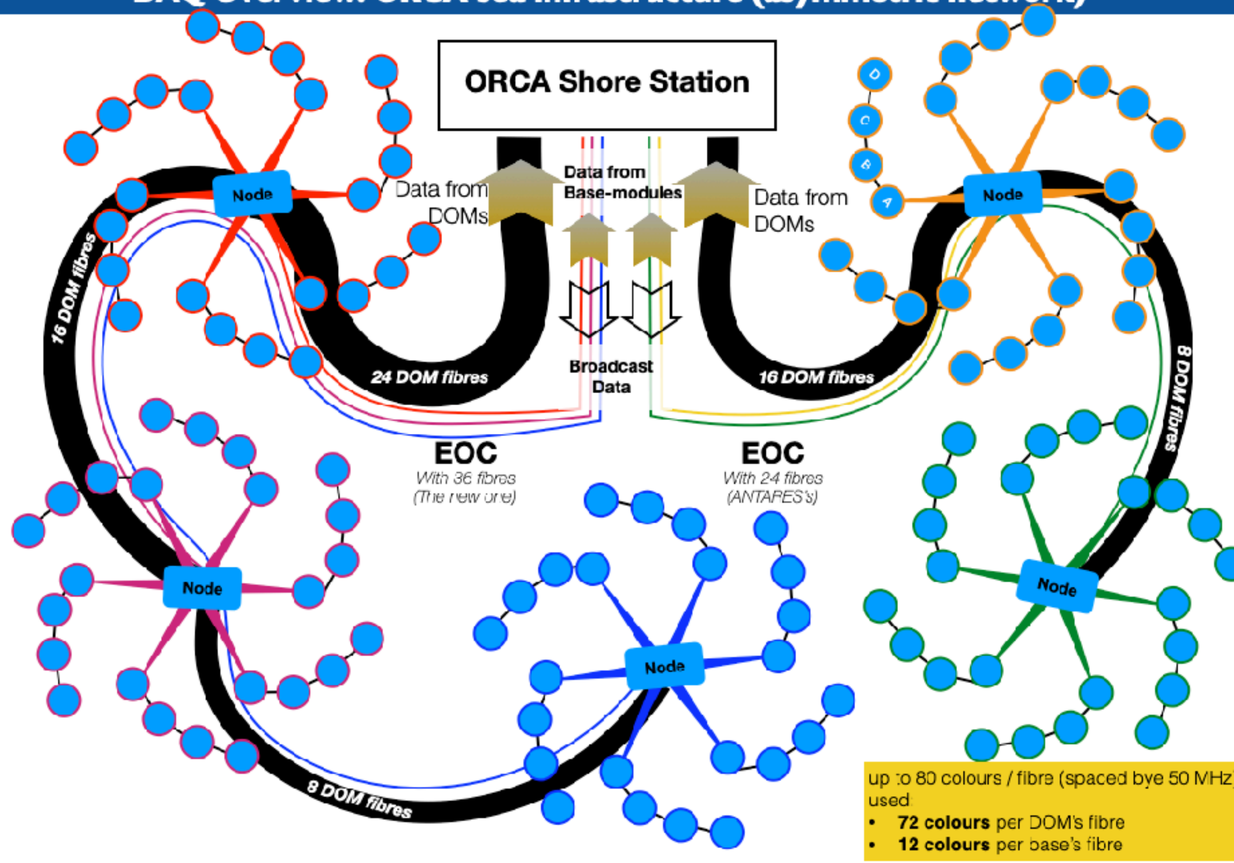


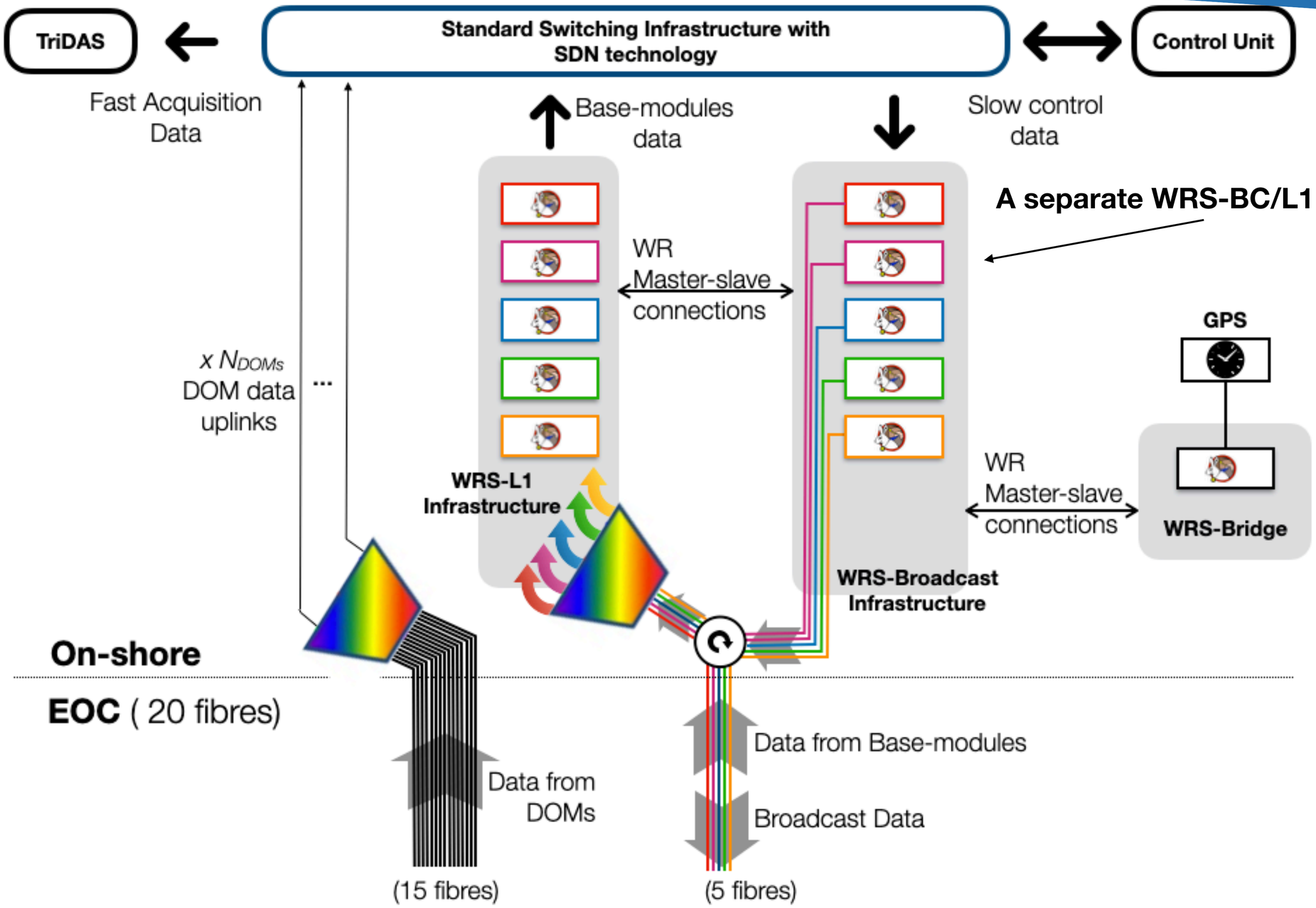
32 ARCA DUs only
(ARCA-Phase 1)

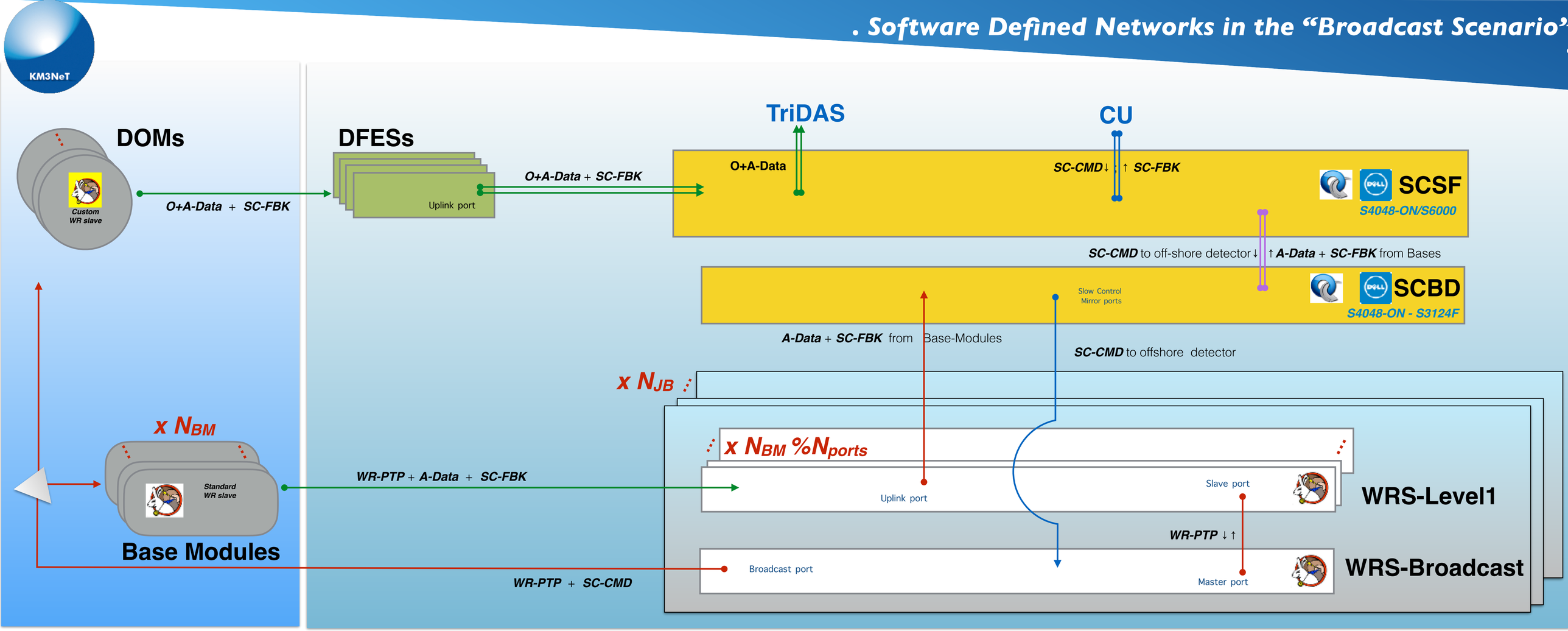
Same layout for the rest of the DUs in the BBs.

115 ORCA DUs

DAQ Overview: ORCA sea infrastructure (asymmetric network)

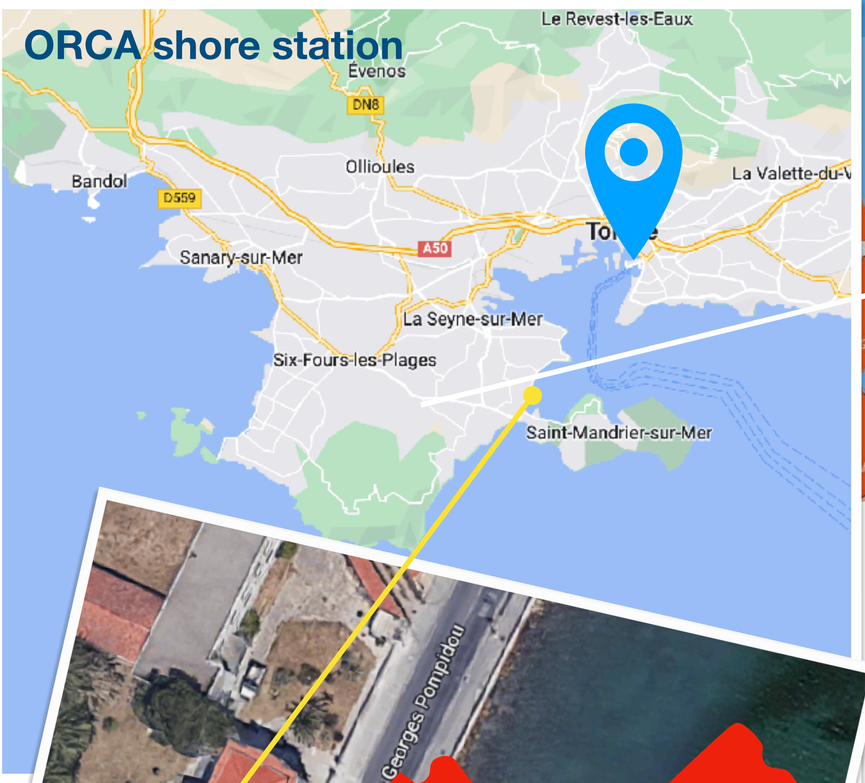



TriDAS
Standard Switching Infrastructure with SDN technology
Control Unit
Fast Acquisition Data
Base-modules data
Slow control data
A separate WRS-BC/L1 branch for each JB
WR Master-slave connections
x N_{DOMs} DOM data uplinks
GPS
WRS-L1 Infrastructure
WR Master-slave connections
WRS-Bridge
WRS-Broadcast Infrastructure
On-shore
EOC (20 fibres)
Data from DOMs
Data from Base-modules
Broadcast Data
(15 fibres)
(5 fibres)

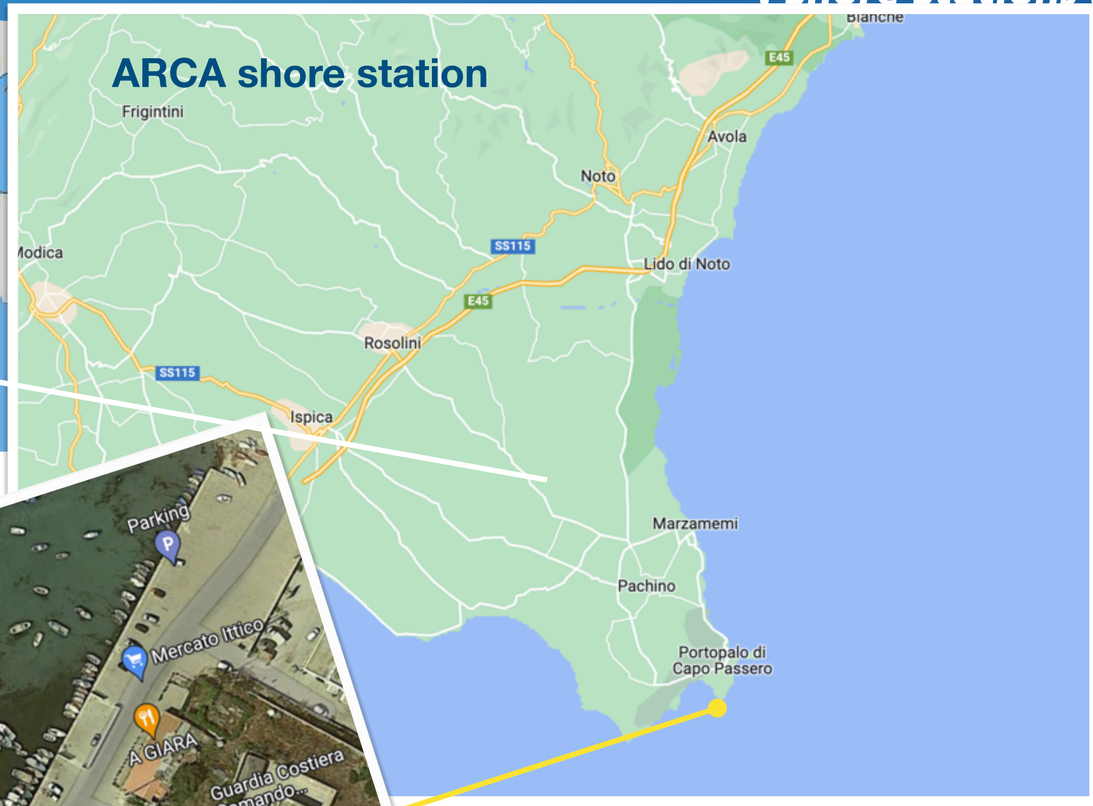


The ***Broadcast*** **WRS customisation for KM3NeT** differs from the standard point-to-point (Master-Slave) WR protocol connections.

The **Software Defined Networking** (SDN) solves the scalability issue of this asymmetric scenario with a hybrid shore-station in the Broadcast scenario.


ORCA shore station
Le Revest-les-Eaux
Évenos
DN8
Ollioules
Bandol
D559
La Valette-du-V
Sanary-sur-Mer
A50
La Seyne-sur-Mer
Six-Fours-les-Plages
Saint-Mandrier-sur-Mer

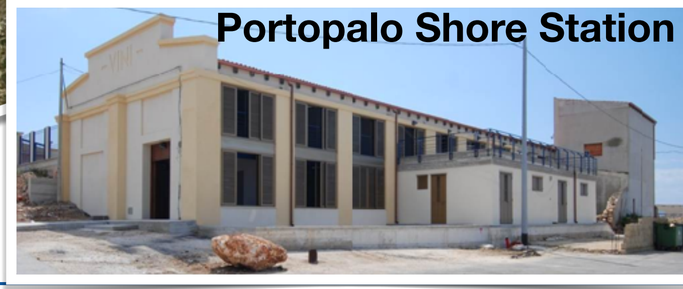

Tübingen
Würzburg
Caen
Nantes
Strasbourg
Mulhouse
Montpellier
Marseille
Genova
Bologna
Pisa
Rome
Caserta
Bari
Naples
Salerno
Valencia
Granada
Constantine
Ouida
ORCA
ARCA


ARCA shore station
Frigintini
Avola
Noto
SS115
Lido di Noto
E45
Rosolini
Ispica
Marzamemi
Pachino
Portopalo di
Capo Passero


Cor Georges Pompidou
Institut Michel Pacha
Cor Georges Pompidou


ichel Pacha

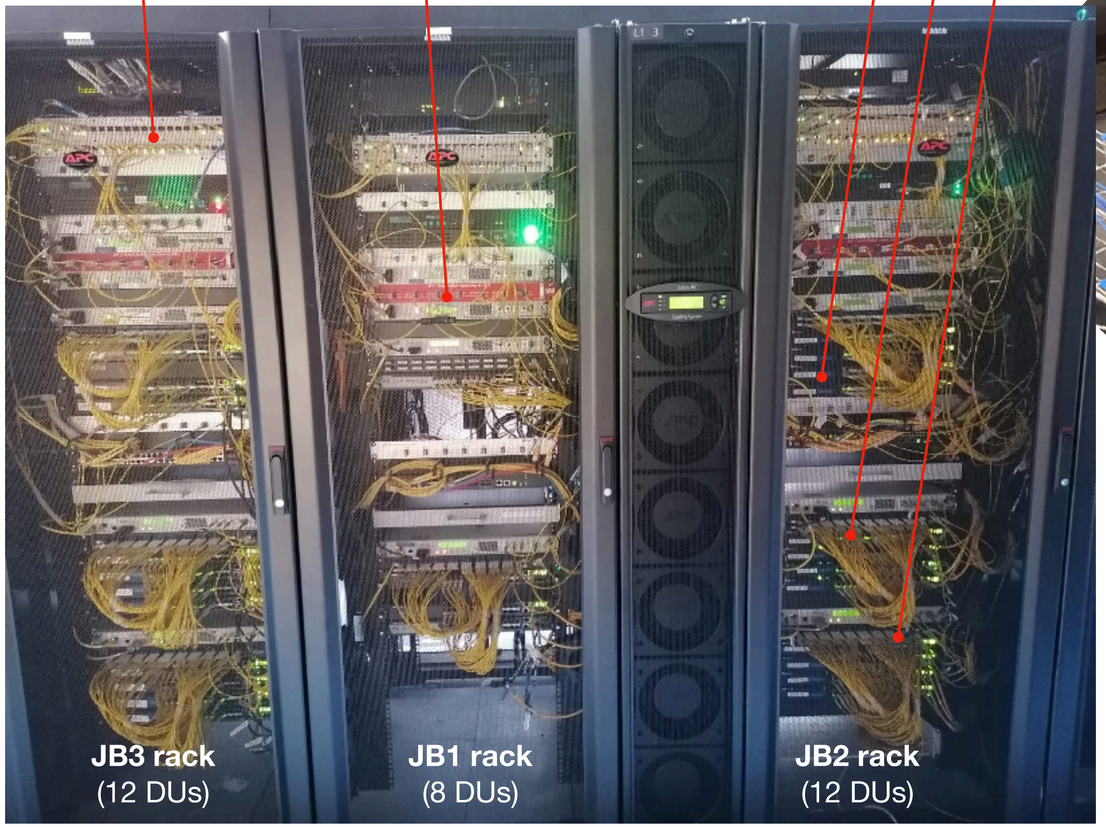

Parking
Mercato Ittico
A GIARA
Guardia Costiera
Comando...

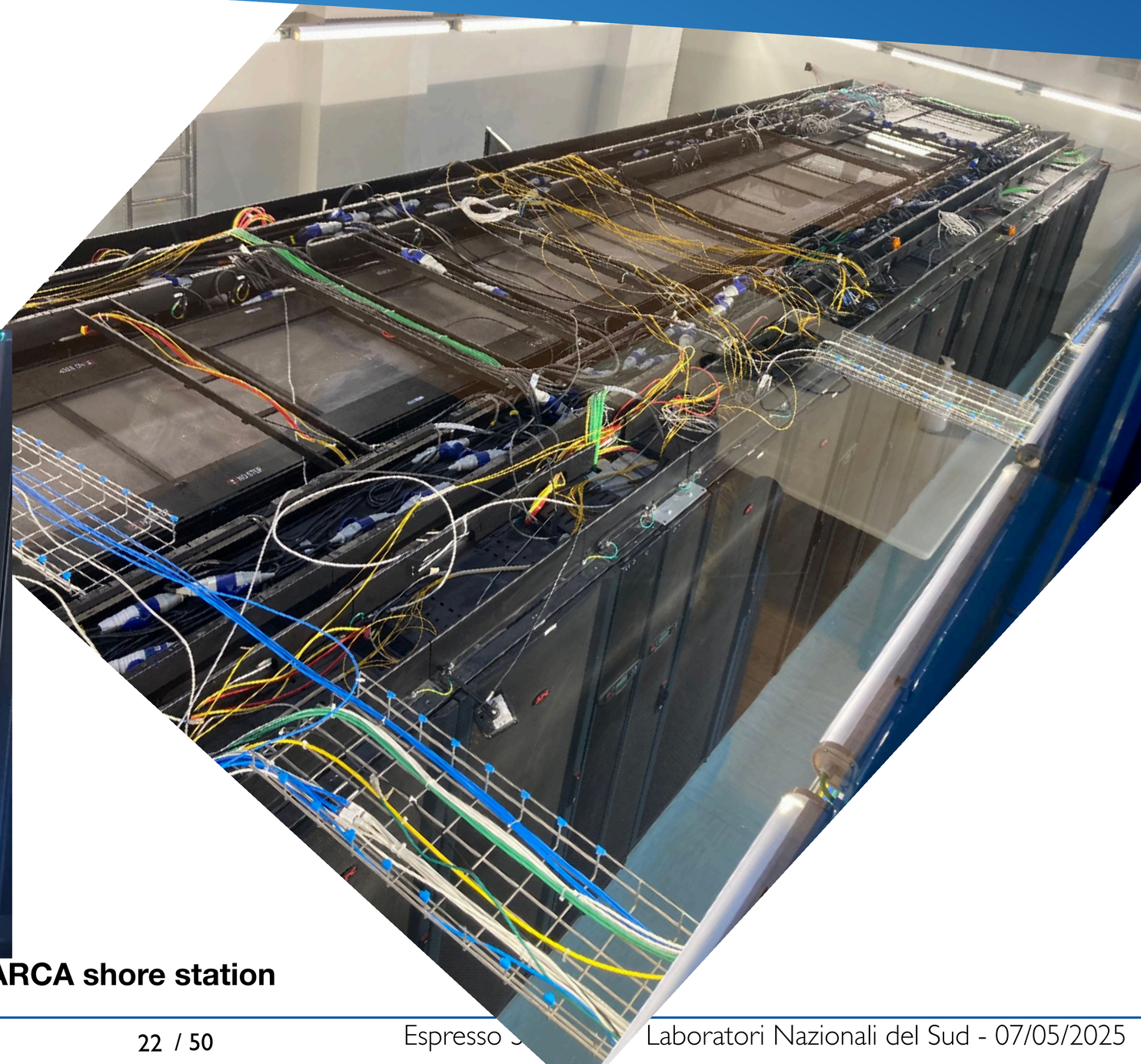

Portopalo Shore Station

White Rabbit switch sector

Optical sector
(mux/demux/amplifier)

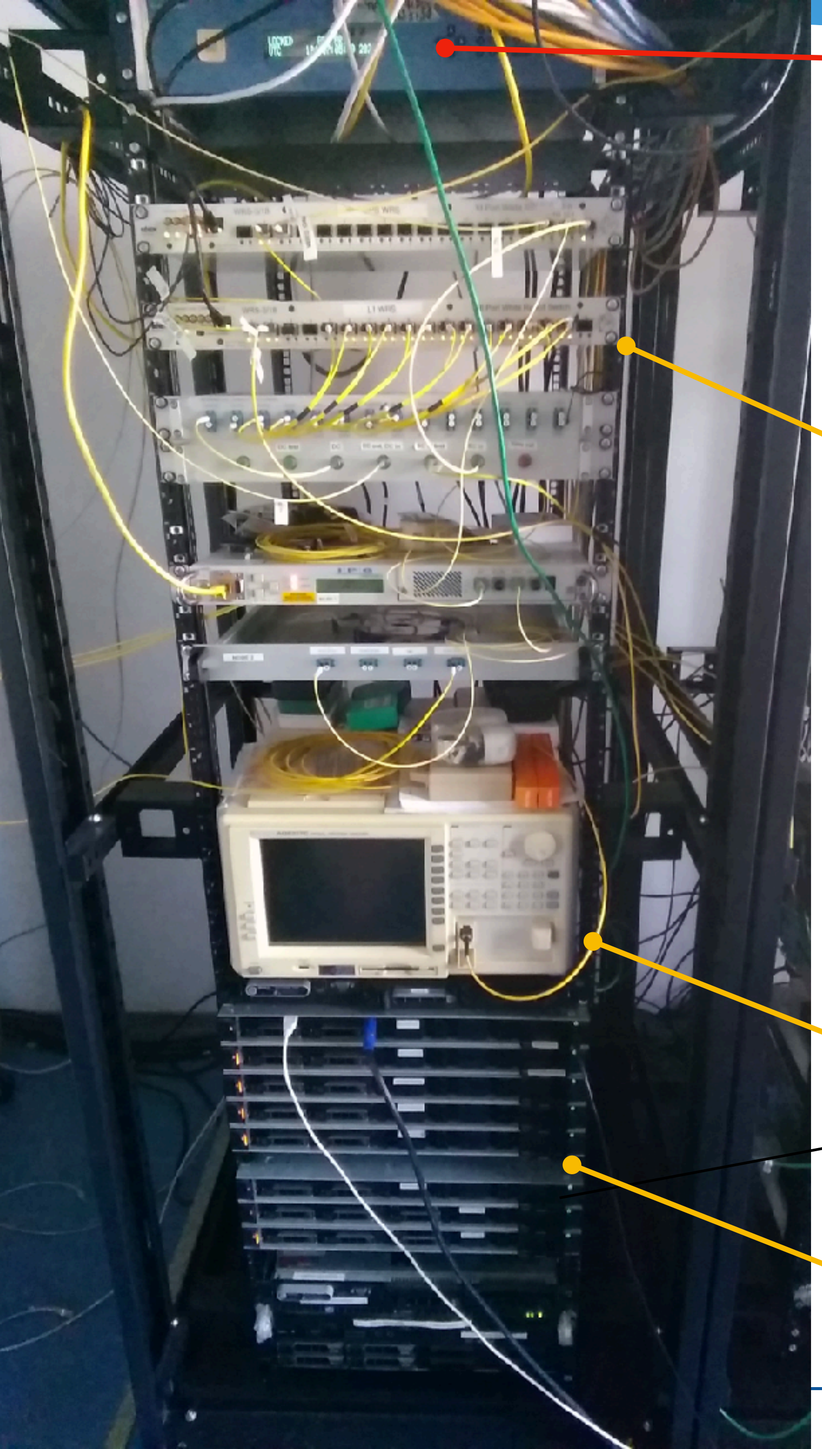
DOM Front End
Switch sectors





ARCA shore station


KM3NeT
IDMAR
Laboratorio
Multidisciplinare
sul mare
INFN
credits: e.giorgio



GPS

White Rabbit fabric

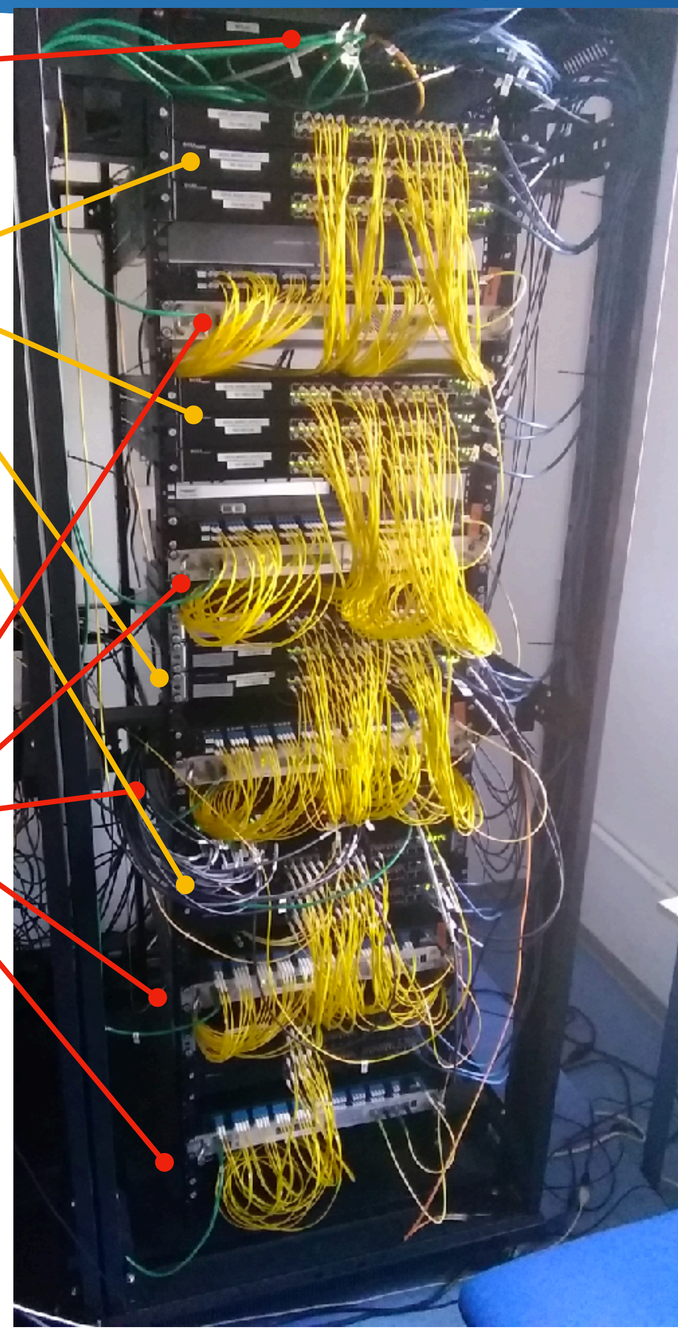
OSA (optical spectral analysis)

Computing servers

SCSF and SCBD
SDN switch fabric

DOM Front-end Sectors

Demultiplexing stages for the
incoming optical signals



Electronics paper: J. Astron. Telesc. Instrum. Syst. 5(4), 046001 (2019)
J. of Astronomical Telescopes, Instruments, and Systems, 7(1), 016001 (2021)

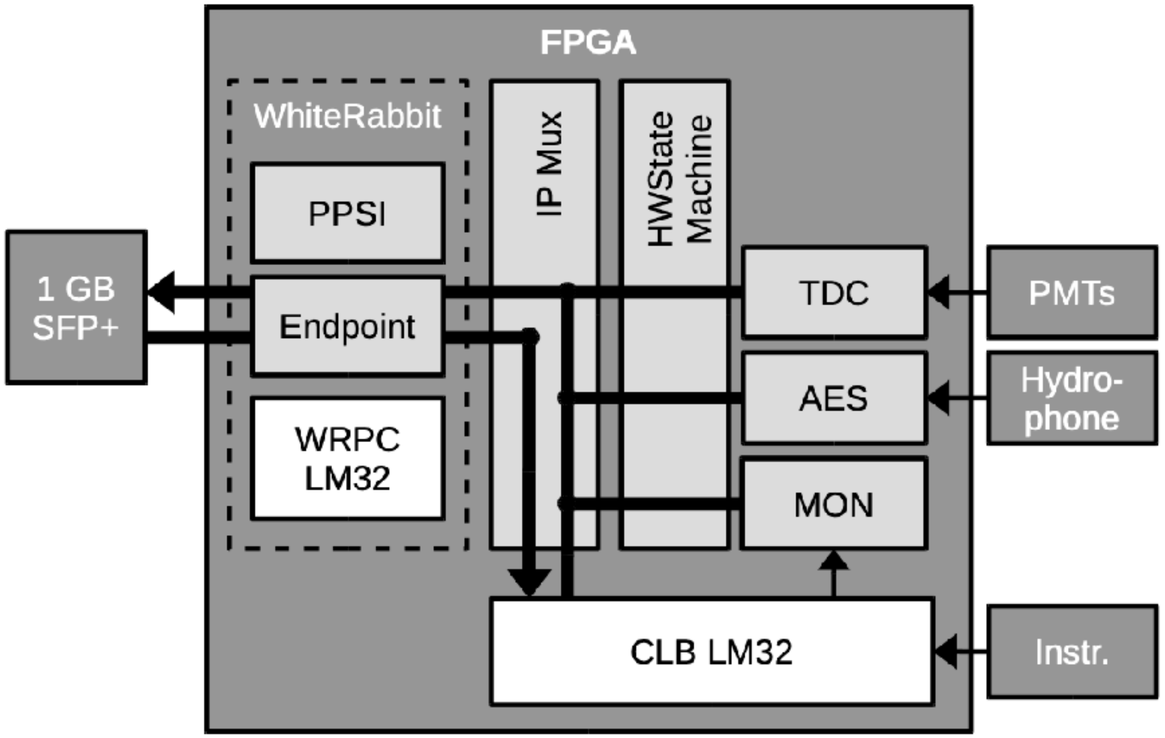
CLB FIRMWARE ARCHITECTURE

Two LM32 cores

- WhiteRabbit LM32 for timing control
- KM3NeT CLB for DAQ control / instrumentation readout

Three DAQ modules

- Time to Digital Converter (TDC) – from Photo Multiplier Tubes (PMTs)
  AES-standard receiver - from Hydrophone
- MONitoring, for performance information



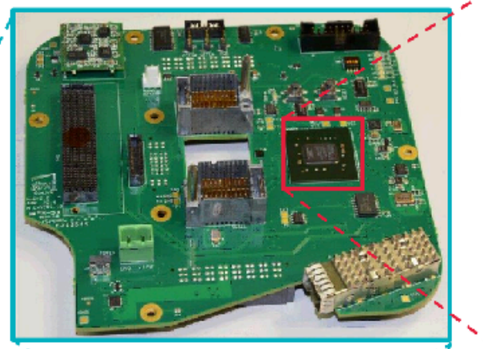
High-level diagram of CLB gateware and network data-path

Network path

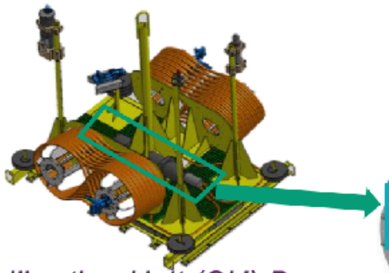
- WhiteRabbit is used for timing and intercepts and transmits timing related Ethernet packets. The remaining data is sent over IPMux to the CLB LM32
- DAQ modules generate data, subsequently annotated and framed by the HWStateMachine, wrapped as UDP packets and dispatched by the IPMux

EMBEDDED SOFTWARE IN KM3NET DETECTOR

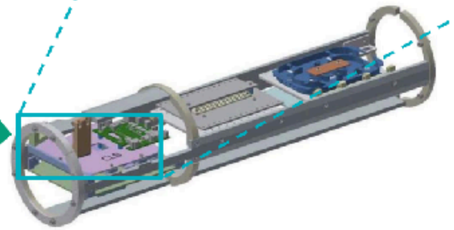
Three different detector modules feature a Central Logic Board (CLB) running the KM3NeT Embedded Software inside a SoftCPU*



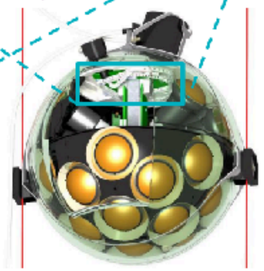
Central Logic Board (CLB) v2



Calibration Unit (CU) Base
(contains DU Base as controller)

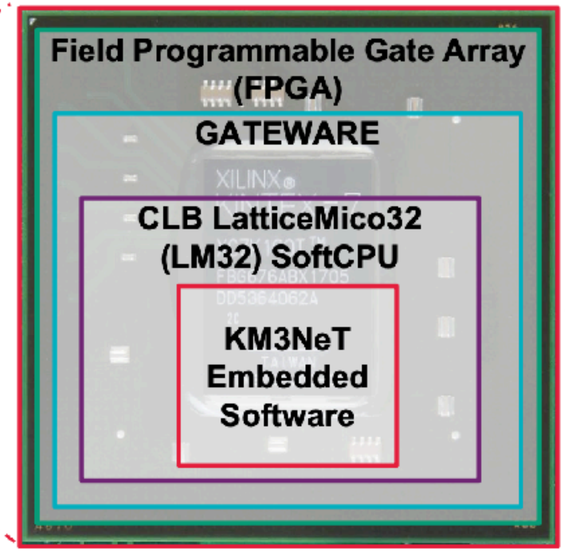


Detector Unit (DU) Base



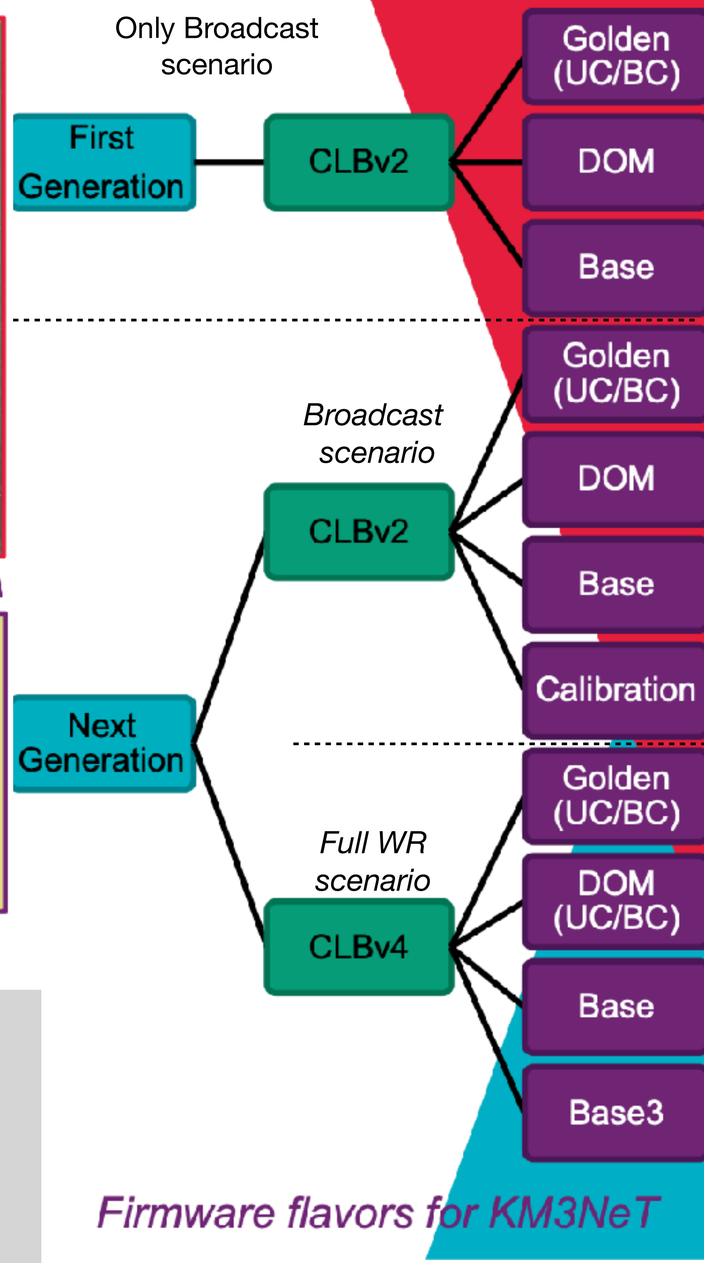
Digital Optical Module (DOM)

* A CPU coded in a hardware language, running on FPGA programmable logic



Xilinx Kintex 7 FPGA

Note on terminology used in this presentation:
- Gateware: Programmable Logic running inside an FPGA
- Embedded Software: Instructions running on an Embedded Controller (CPU)
- Firmware: The combination of Gateware and Embedded Software



Firmware flavors for KM3NeT

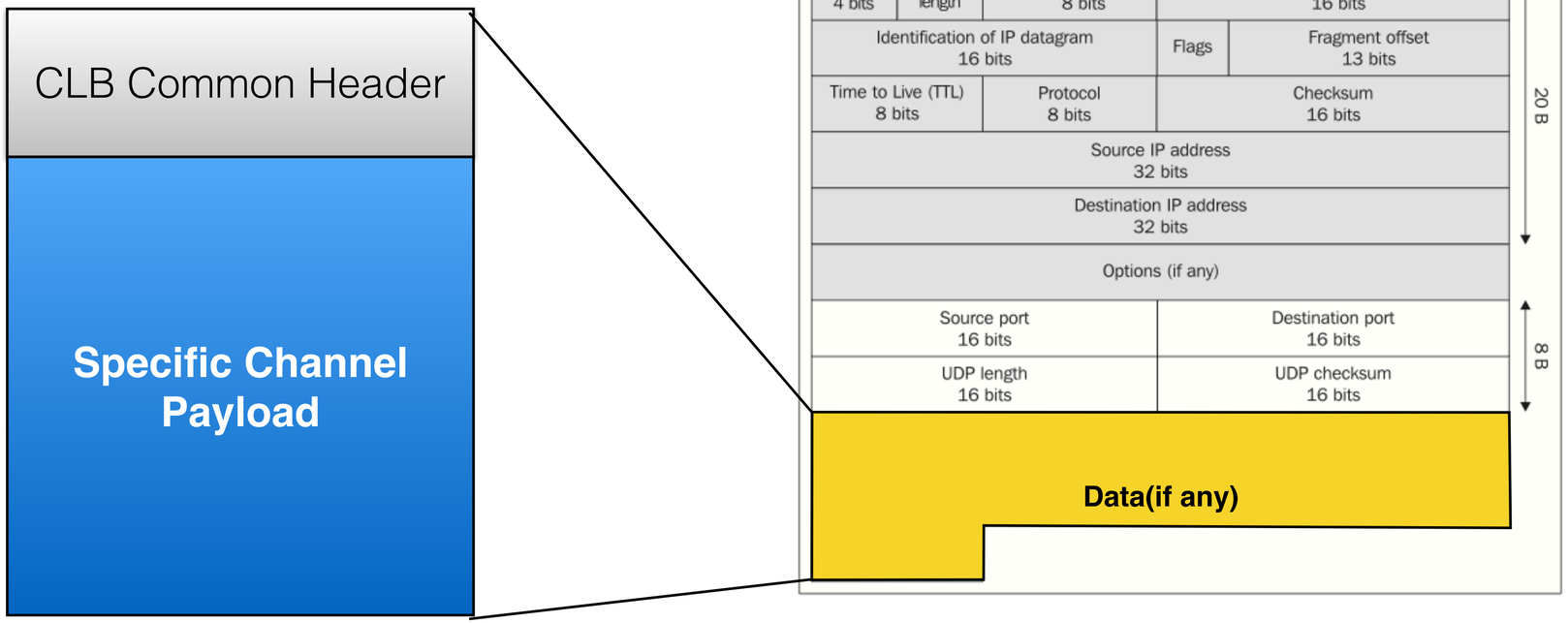
FW Timeline

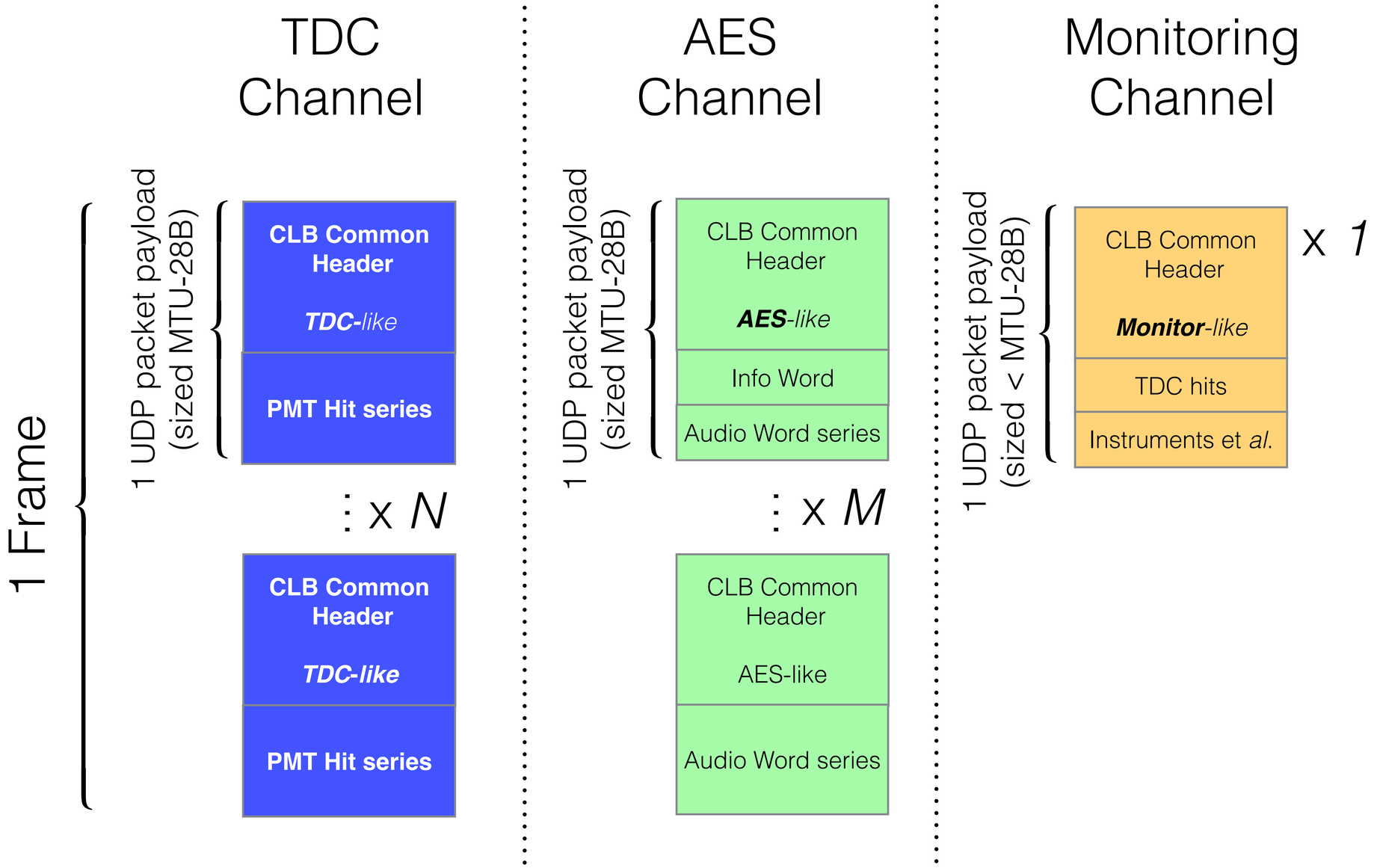
- 2014 — First Gen prototype
- 2016 — First Gen release with ARCA DU #1
- 2020 — Next-Gen prototyping
- 2021 — First-Gen Last release
- 2022 — Next—Gen Deployment

KM3NeT DAQ DataFormat : https://wiki.km3net.de/index.php/DAQ_Data_Format

Layer	Preamble	Start of frame delimiter	MAC destination	MAC source	802.1Q tag (optional)	Ethertype (Ethernet II) or length (IEEE 802.3)	Payload	Frame check sequence (32-bit CRC)
	7 octets	1 octet	6 octets	6 octets	(4 octets)	2 octets	MTU	4 octets
Layer 2 Ethernet frame			← MTU + 18(22) octets →					
Layer 1 Ethernet packet	← MTU + 26(30) octets →							

Channel	UDP SRC Port	UDP DST Port	0x.....
TDC	56015	56015	DACF
AES	56016	56016	DAD0
Monitoring	56017	56017	DAD1
Slow Control	56014	Reply to sender	DACE




TDC Channel
AES Channel
Monitoring Channel
1 Frame
1 UDP packet payload (sized MTU-28B)
CLB Common Header
TDC-like
PMT Hit series
x N
CLB Common Header
TDC-like
PMT Hit series
1 UDP packet payload (sized MTU-28B)
CLB Common Header
AES-like
Info Word
Audio Word series
x M
CLB Common Header
AES-like
Audio Word series
1 UDP packet payload (sized < MTU-28B)
CLB Common Header
Monitor-like
TDC hits
Instruments et al.
x 1

CLB Optical Format Structure

Size (bit)	Description
448	DAQ Common Header
8	TDC channel
32	Time Stamp
8	Pulse Width
8	TDC channel
32	Time Stamp
8	Pulse Width
...	...
8	TDC channel
32	Time Stamp
8	Pulse Width

One hit (6B)

- TDC (PMT) channel: 0 to 31
- Timing: counter of ns ∈ [0,1e8]
- Pulse width: Time over Threshold in ns ∈ [1,256]

Timing

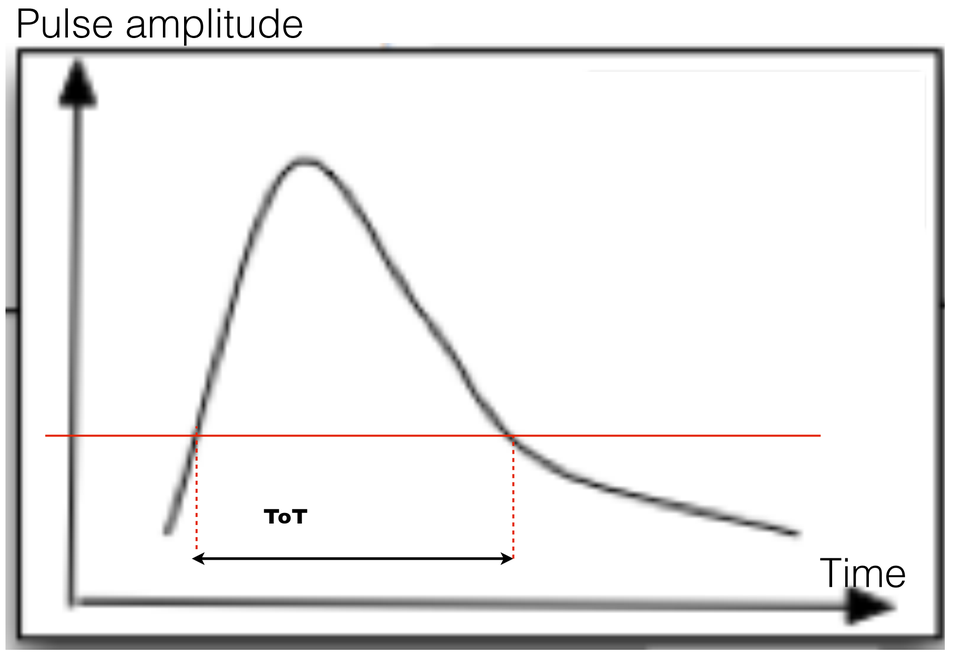
Absolute time of a hit, with the precision of **1 ns.**

Time over Threshold

ToT <=> pulse amplitude.

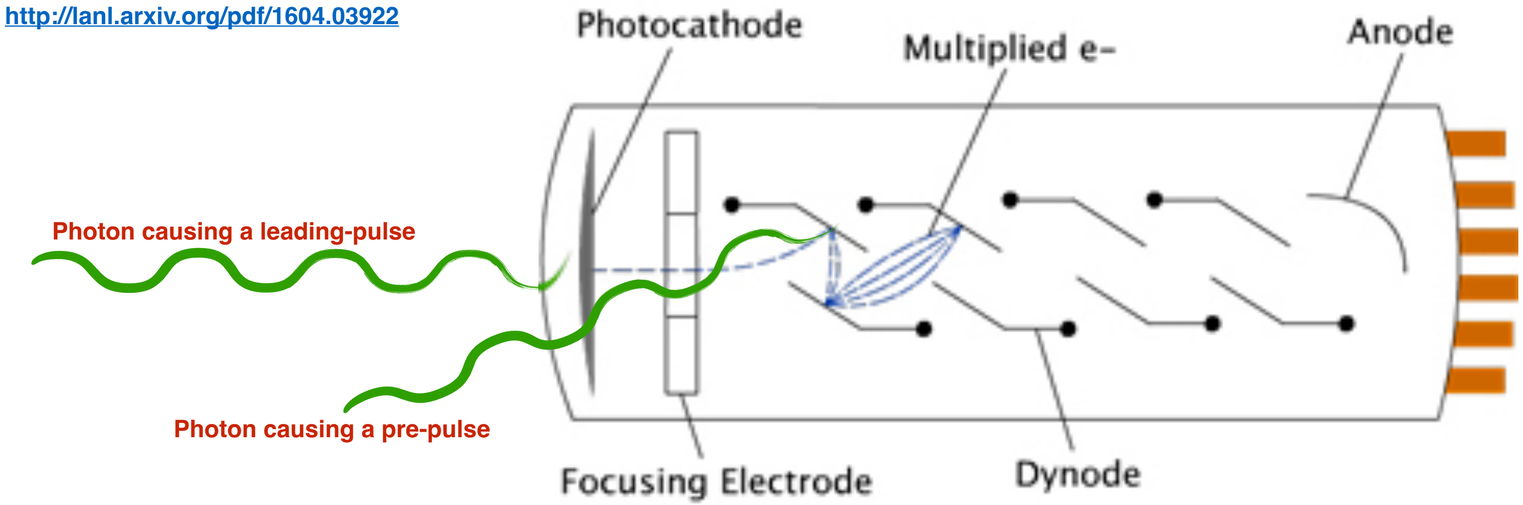
Optimal gain (~10^6) => **ToT of 26,4 ns for single photo-electron**

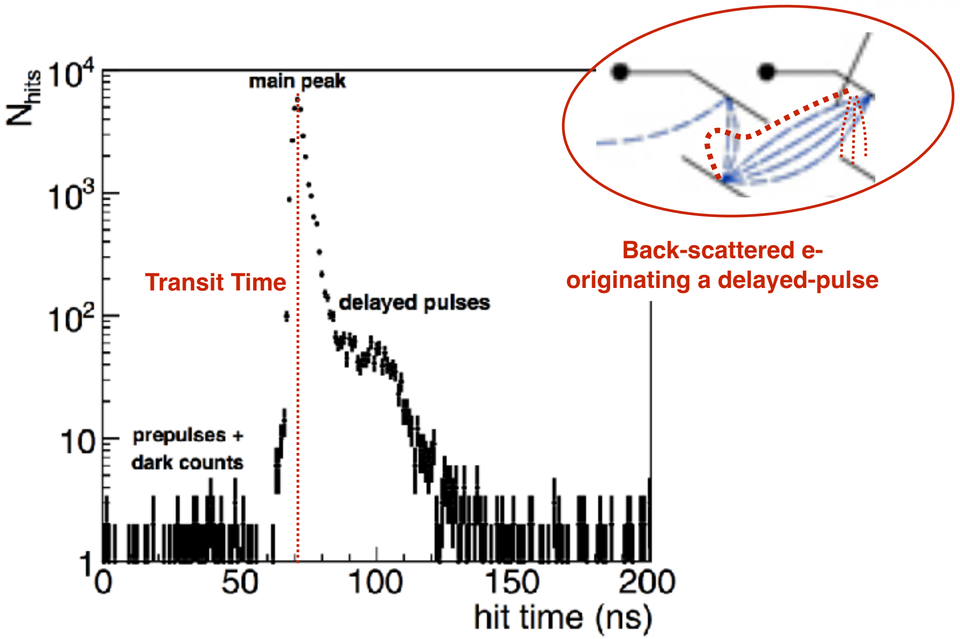
Possibility to activate the ***Multi-Hit* feature** for longer pulses



C. M. Mollo et *al.*, Journal of Instrumentation, Vol 11, n. 8, 2016

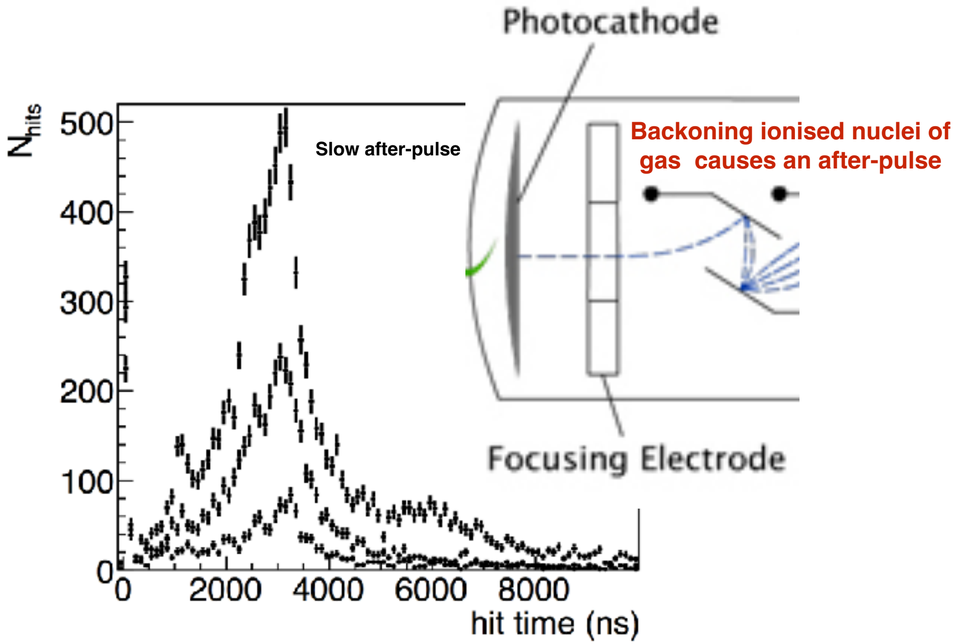
http://lanl.arxiv.org/pdf/1604.03922





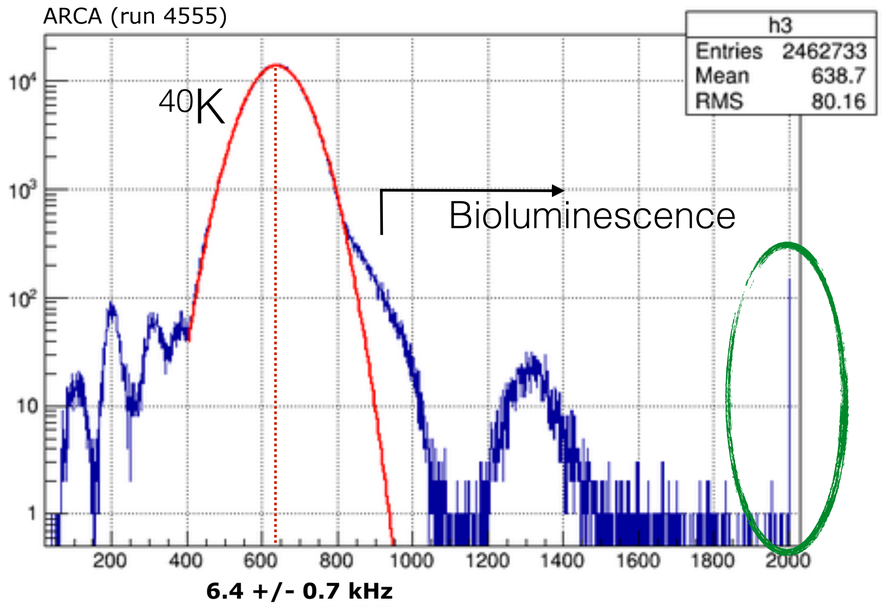
Back-scattered e- originating a delayed-pulse

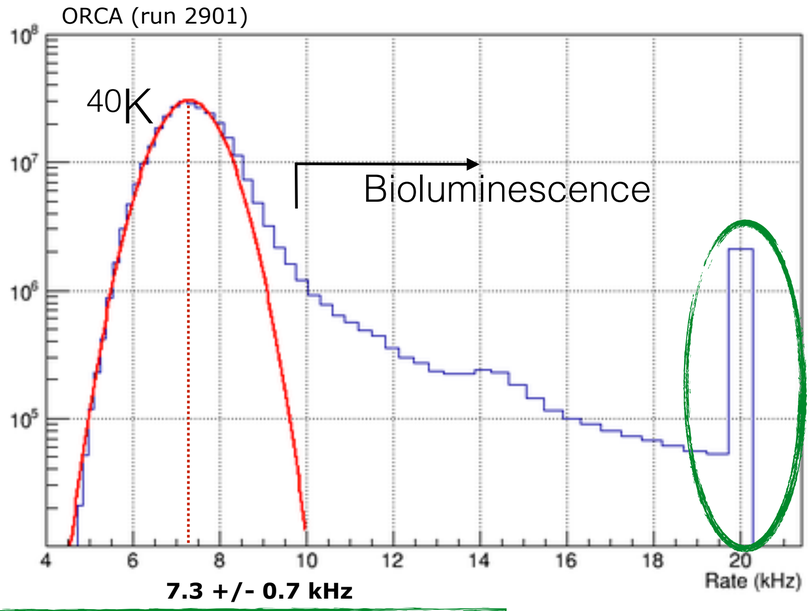
Transit Time Spread = FWHM of main peak ~1.5 ns



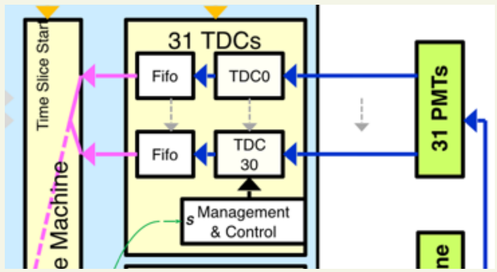
Backoning ionised nuclei of gas causes an after-pulse

http://elog.km3net.de/Operations+FR/955





High Rate Veto: in TDC data, the number of recorded hits is limited to a maximum.
In the plot above is set to 2000 hits/PMT/Timeslice



FIFO *almost* full

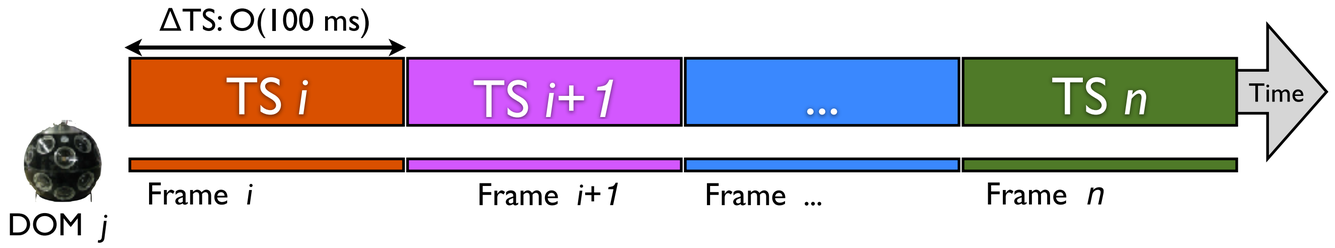
The CLB spends **~48 ns** for transferring 1 hit from the FIFO in the buffer to send.

At present, the size of FIFO accepts 1000 hits.

The transfer is not parallel, but sequential looping over all the TDC FIFOs.

Depending on the number of shooting PMTs, the maximum rates can span from **678 kHz/PMT** (31 shooting PMTs) **up to 21 MHz.** (~ 1 shooting PMT)

- **Timeslice** (TS): it is the abstract subdivision of the continuity in the time-line of the experiment.
- **Frame**: it is the group of information of a certain flavour (TDC, AES, MON) occurred in a DOM during a TS.

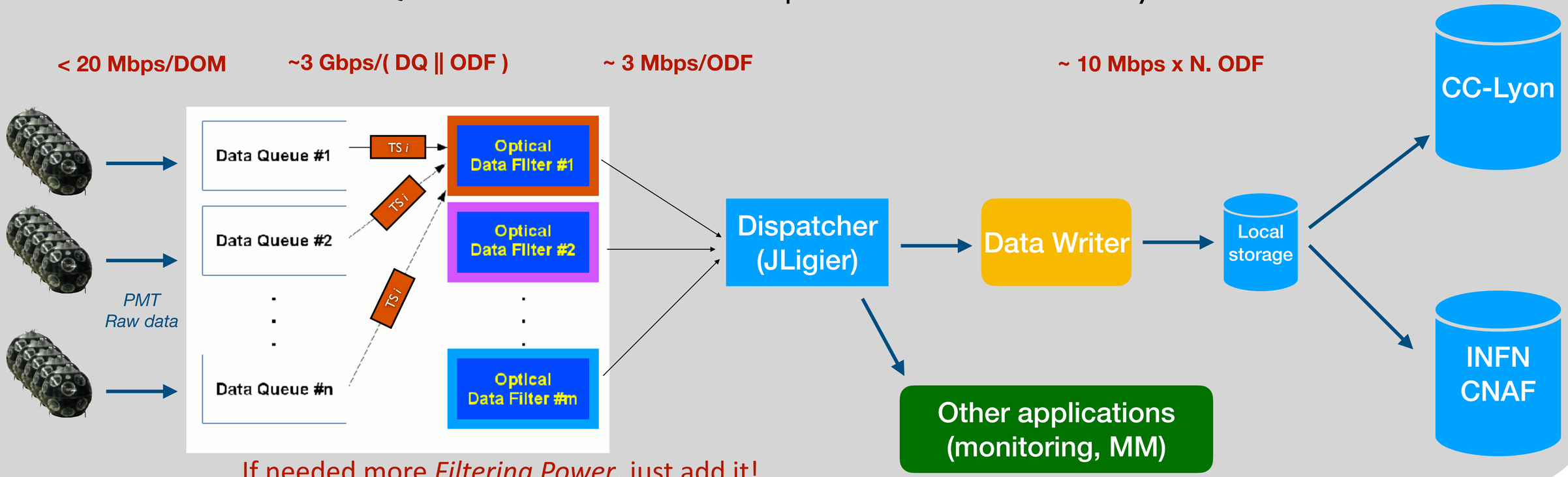


Distributing the computational load

- Each trigger algo applied to one full set of frames of one TS.
- Multiple TSs handled in parallel

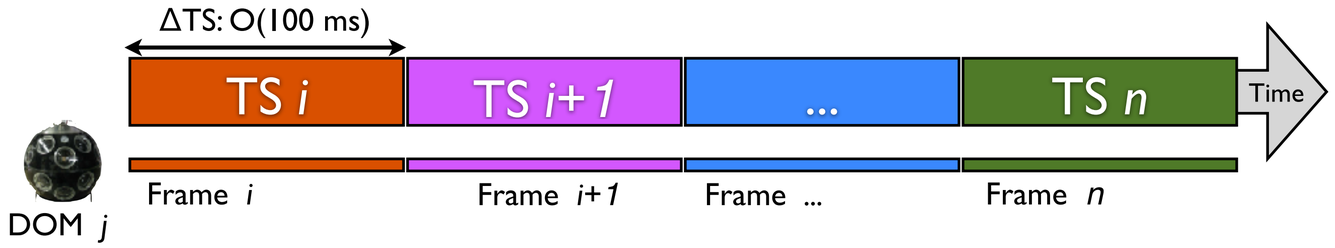
Optical World

A DQ collects data from a sector of DOMs and DU-BMs.
All DQs transfer all their data from a precise Time Slice to the very same oDF.



If needed more *Filtering Power*, just add it!

- **Timeslice** (TS): it is the abstract subdivision of the continuity in the time-line of the experiment.
- **Frame**: it is the group of information of a certain flavour (TDC, AES, MON) occurred in a DOM during a TS.

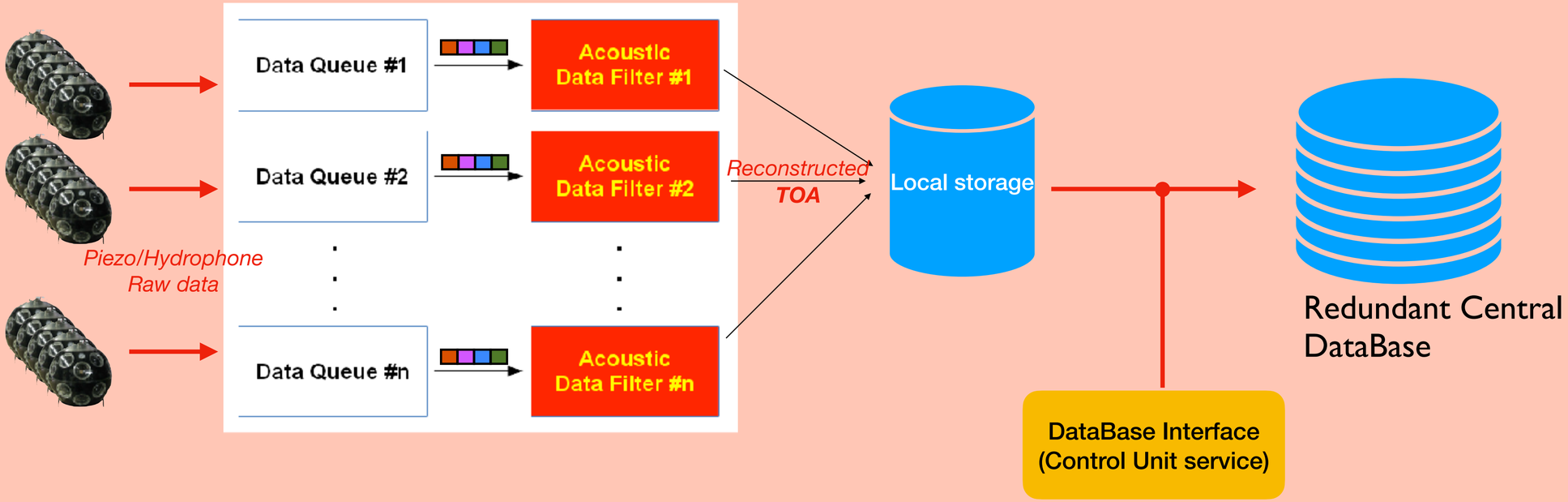


Distributing the computational load

- Each trigger algo applied to one full set of frames of one TS.
- Multiple TSs handled in parallel

Acoustic World

Acoustic data must be sent in a continuous stream, addressing all data from one DQ to a single Acoustic DF.
Independent reconstruction of the *Time Of Arrival* (**TOA**) of acoustic signals from various beacons



Basic triggers

L0: all hits over threshold (i.e. all hits sent by the CLBs)
L1: pairs of hits of the same DOM within 25(10)ns.
L2: further constraints applied to L1 hits (e.g. space angles btw PMT axes)

Higher-trigger level

- **3D-Trigger** - general concept:

1. A minimum n. of ***consecutive*** L2 s ≥ N_{th} within a ΔT (at least $n_{DOM} \geq 2$ or 5)
2. *3D*-causality filter : $|t_i - t_j| \leq |\vec{x}_i - \vec{x}_j| \frac{n}{c} + T_{MaxExtra}$
3. The trigger is set if the n. of satisfying hits is ≥ N'_{th}

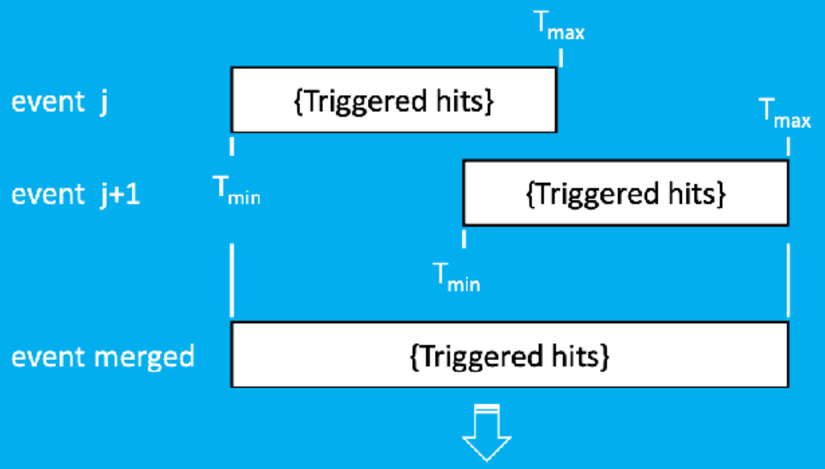
- **3D-Muon/Shower**
  Assumes an extended track-like / short pulse shape for the event topology
- **MX-Shower**
  Cluster one L2 with causality-combined L0s.
- **Supernova (SN)**
  Combines L1 with additional constraints (e.g. multiplicity of L0 hits)

Trigger settings passed to the Data Filters via the run setups by the Control Unit

Trigger algorithms developed within a large C++ software framework, ***Jpp***. The same codes are used for the on-line DAQ as well as off-line analysis.

Jpp
Click here
The Jpp Git repository.

Event merging

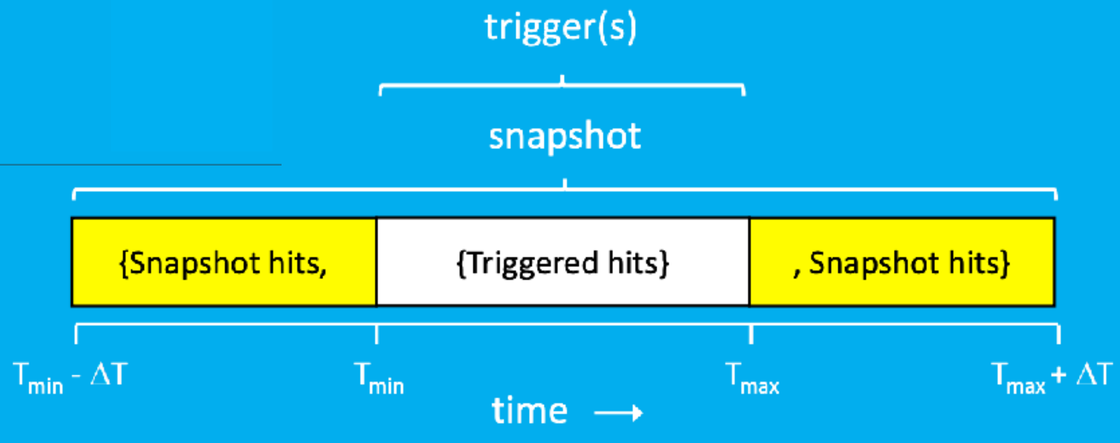


Triggered hit :
trigger mask; // OR-ed

DAQ Event :
trigger mask; // OR-ed
number of overlays; // incremented

```
[[root@arca-cu-03 data]# JPrintTree -f KM3NeT_00000133_00013486.root
KM3NeT_00000133_00013486.root
KM3NET_TIMESLICE          KM3NETDAQ::JDAQTimeslice              2097    509 [MB]
KM3NET_TIMESLICE_L0       KM3NETDAQ::JDAQTimesliceL0               0      0 [MB]
KM3NET_TIMESLICE_L1       KM3NETDAQ::JDAQTimesliceL1            1050    938 [MB]
KM3NET_TIMESLICE_L2       KM3NETDAQ::JDAQTimesliceL2               0      0 [MB]
KM3NET_TIMESLICE_SN       KM3NETDAQ::JDAQTimesliceSN          107732   2957 [MB]
KM3NET_EVENT              KM3NETDAQ::JDAQEvent                 87069    546 [MB]
KM3NET_SUMMARYSLICE       KM3NETDAQ::JDAQSummaryslice         107735   1934 [MB]
```

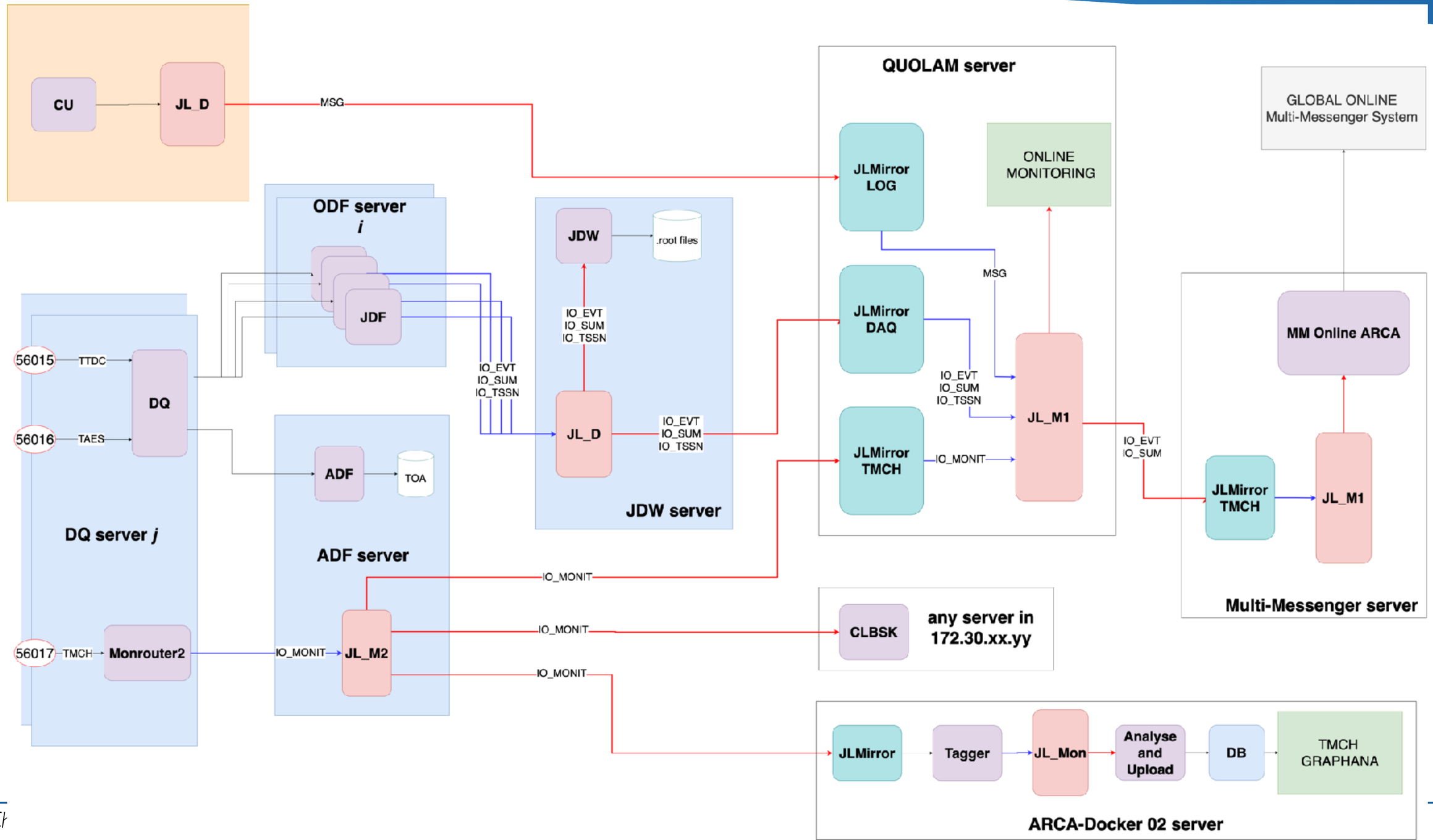
Event data

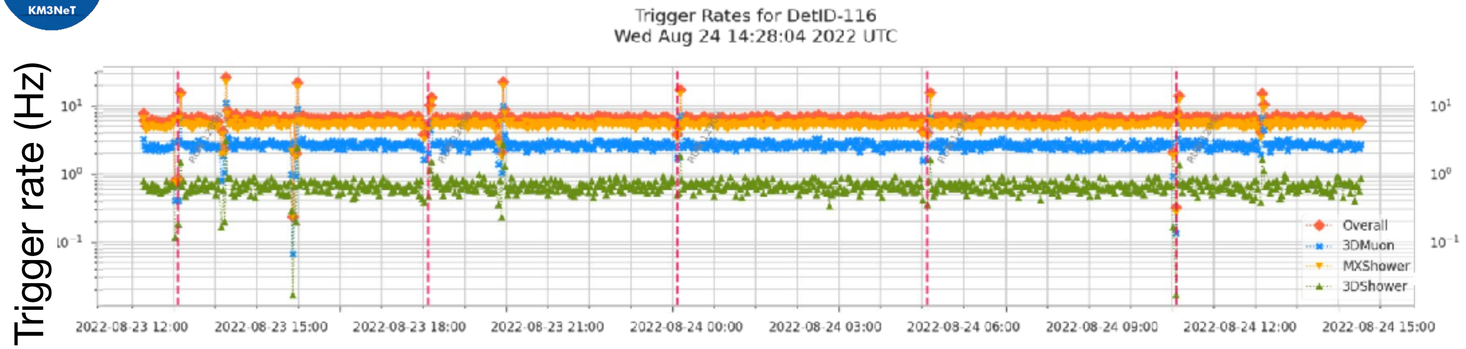


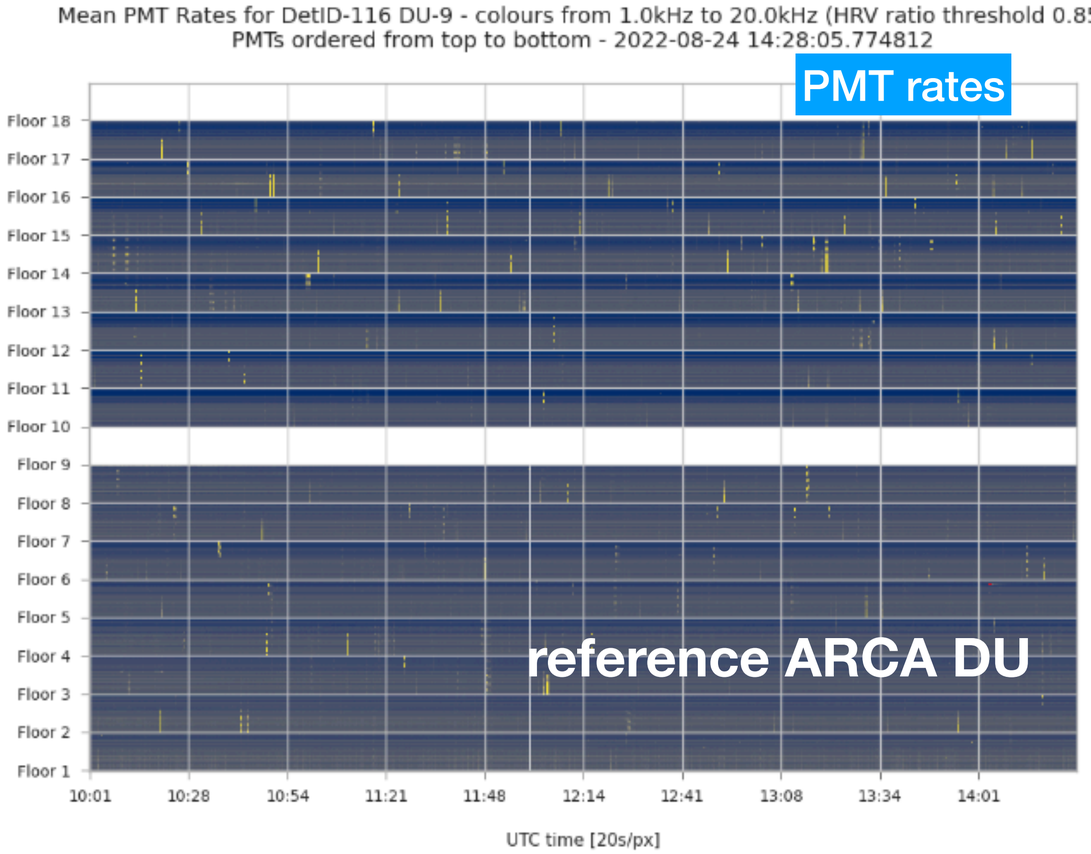
snapshot¶ = All raw data between [T_{min} - ΔT, T_{max} + ΔT]

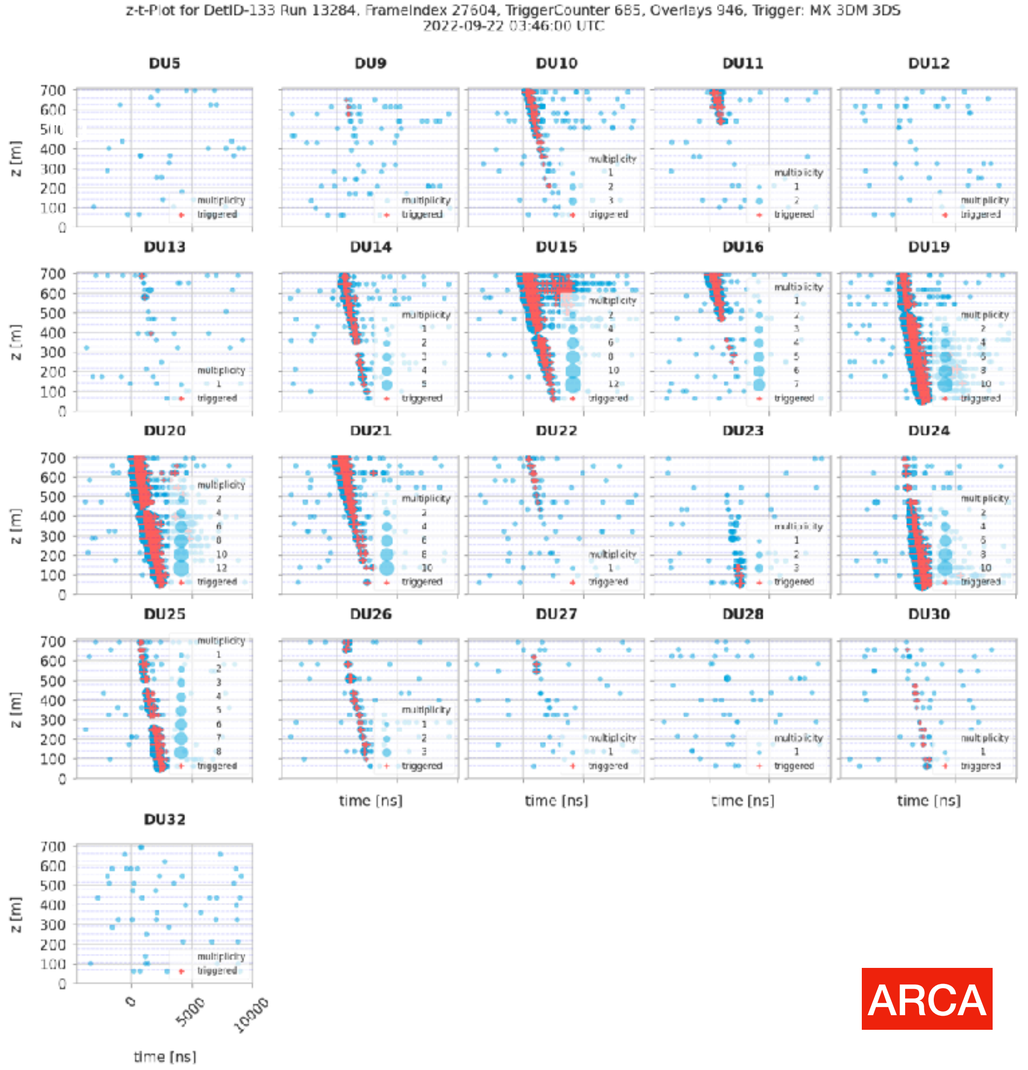
¶ ΔT = nD/c (where D corresponds to size of detector)

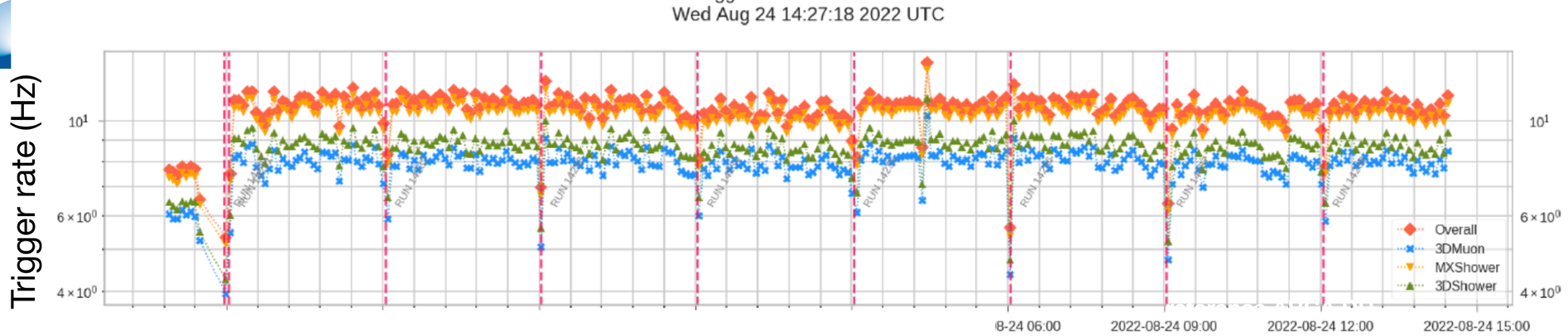
Further details here (MdJ 2021)


CU
JL_D
MSG
QUOLAM server
JLMirror LOG
ONLINE MONITORING
GLOBAL ONLINE Multi-Messenger System
ODF server i
JDF
JDW
.root files
IO_EVT IO_SUM IO_TSSN
JLMirror DAQ
MSG
MM Online ARCA
56015 TTDC
DQ
56016 TAES
IO_EVT IO_SUM IO_TSSN
JL_D
IO_EVT IO_SUM IO_TSSN
JLMirror TMCH
IO_MONIT
JL_M1
IO_EVT IO_SUM
JDW server
ADF
TOA
DQ server j
ADF server
JLMirror TMCH
JL_M1
Multi-Messenger server
IO_MONIT
56017 TMCH
Monrouter2
IO_MONIT
JL_M2
IO_MONIT
IO_MONIT
CLBSK
any server in 172.30.xx.yy
JLMirror
Tagger
JL_Mon
Analyse and Upload
DB
TMCH GRAPHANA
ARCA-Docker 02 server

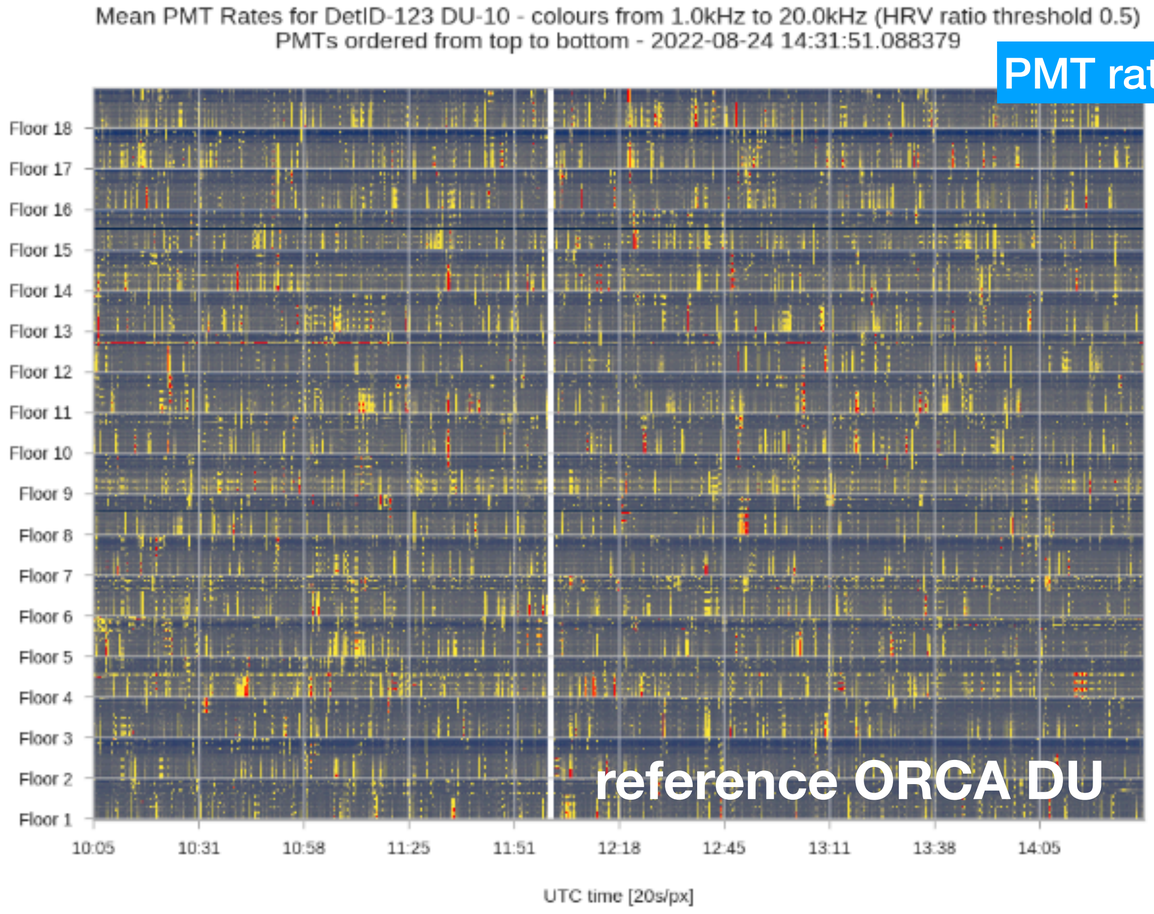

Trigger Rates for DetID-116
Wed Aug 24 14:28:04 2022 UTC
Trigger rate (Hz)
Overall
3DMuon
MXShower
3DShower
2022-08-23 12:00
2022-08-23 15:00
2022-08-23 18:00
2022-08-23 21:00
2022-08-24 00:00
2022-08-24 03:00
2022-08-24 06:00
2022-08-24 09:00
2022-08-24 12:00
2022-08-24 15:00

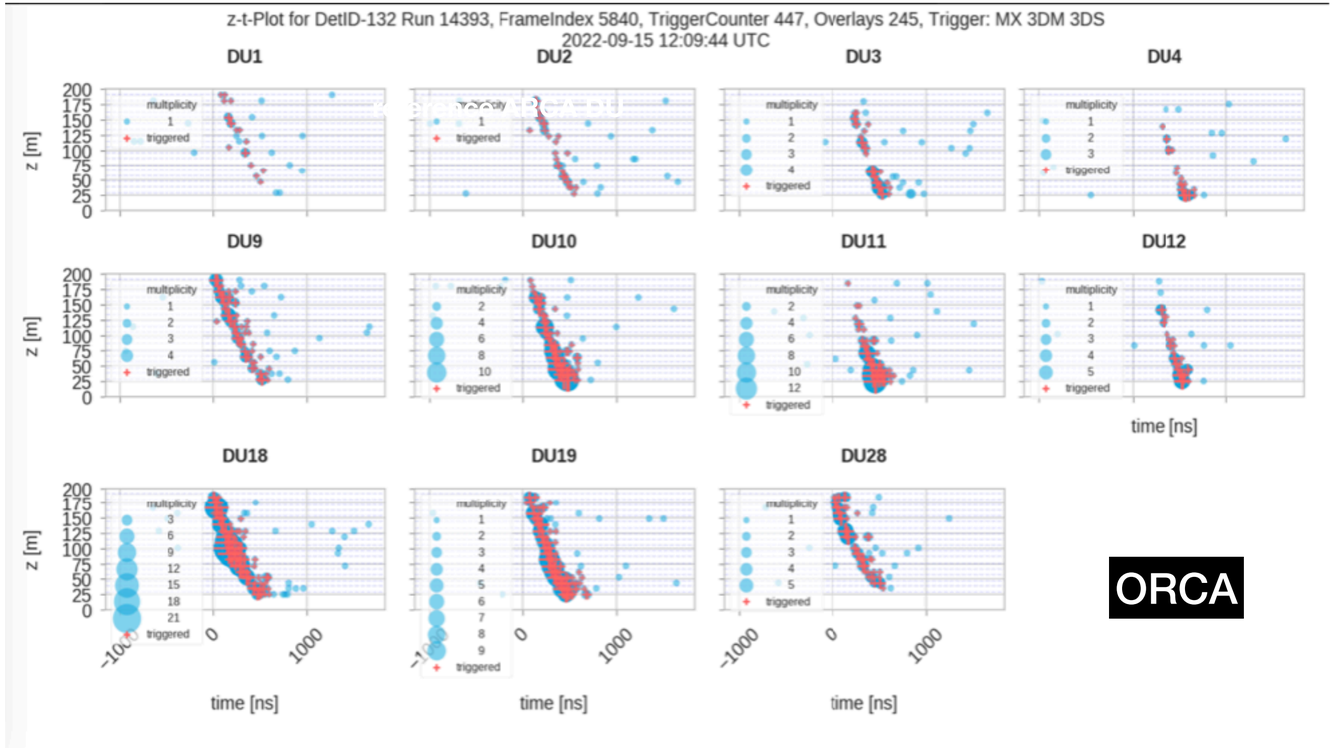

Mean PMT Rates for DetID-116 DU-9 - colours from 1.0kHz to 20.0kHz (HRV ratio threshold 0.85
PMTs ordered from top to bottom - 2022-08-24 14:28:05.774812
PMT rates
reference ARCA DU
Floor 18
Floor 17
Floor 16
Floor 15
Floor 14
Floor 13
Floor 12
Floor 11
Floor 10
Floor 9
Floor 8
Floor 7
Floor 6
Floor 5
Floor 4
Floor 3
Floor 2
Floor 1
10:01
10:28
10:54
11:21
11:48
12:14
12:41
13:08
13:34
14:01
UTC time [20s/px]


z-t-Plot for DetID-133 Run 13284, FrameIndex 27604, TriggerCounter 685, Overlays 946, Trigger: MX 3DM 3DS
2022-09-22 03:46:00 UTC
DU5
DU9
DU10
DU11
DU12
DU13
DU14
DU15
DU16
DU19
DU20
DU21
DU22
DU23
DU24
DU25
DU26
DU27
DU28
DU30
DU32
z [m]
time [ns]
multiplicity
triggered
ARCA

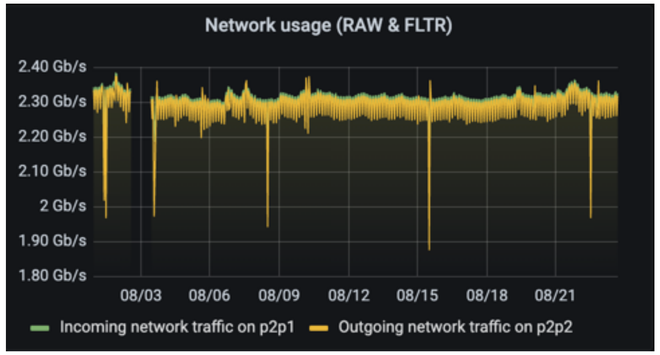


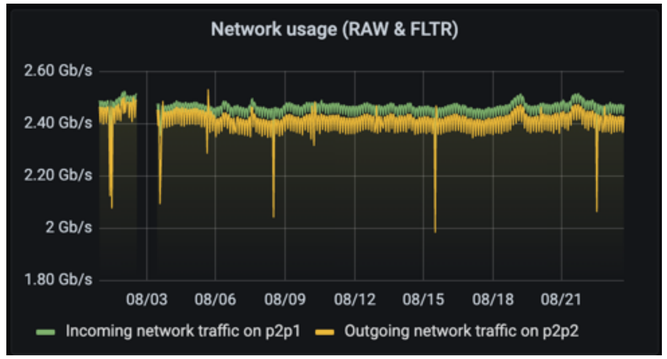
PMT rates



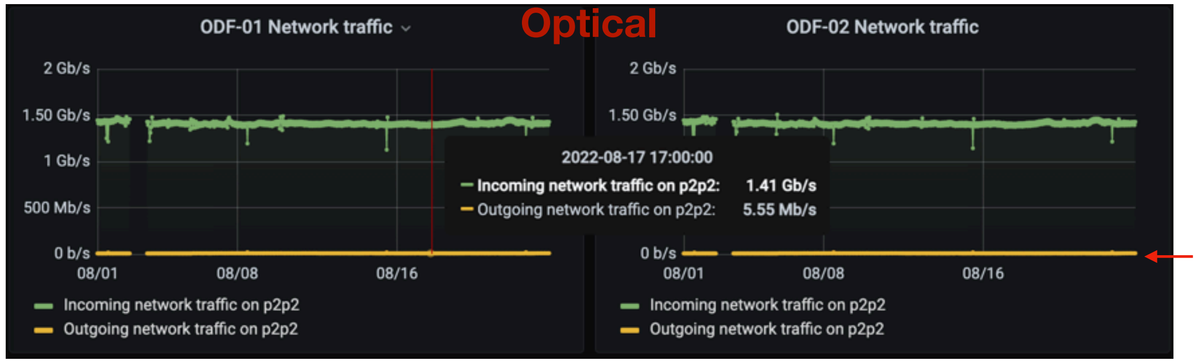


ORCA

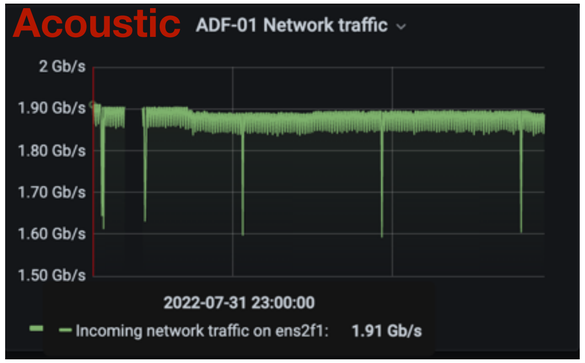


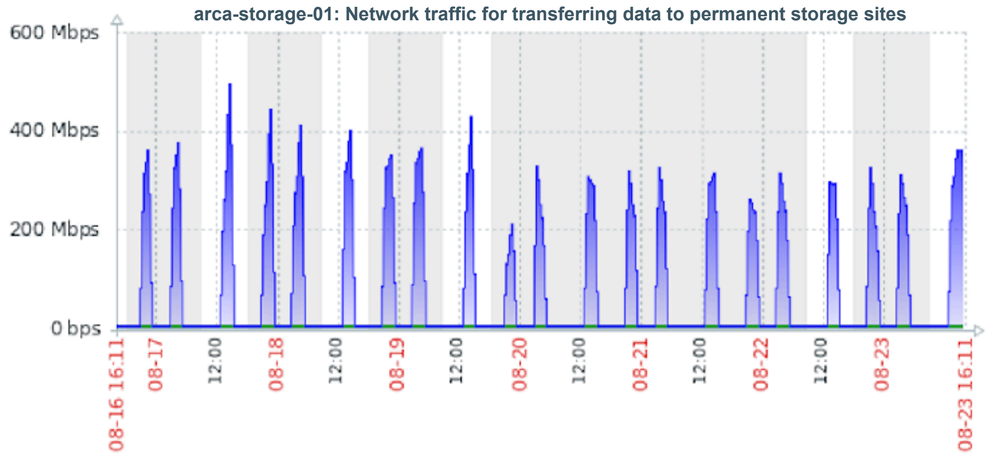


DataQueue level:
- receive and route to Data Filters (O+A)



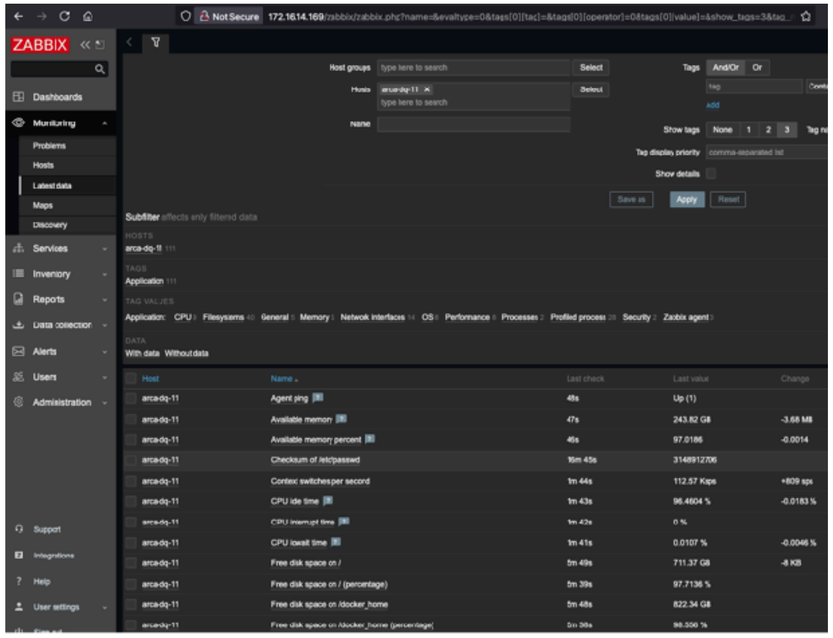
data to Data Writer
(i.e. data filtered by
~3 order of magnitued)

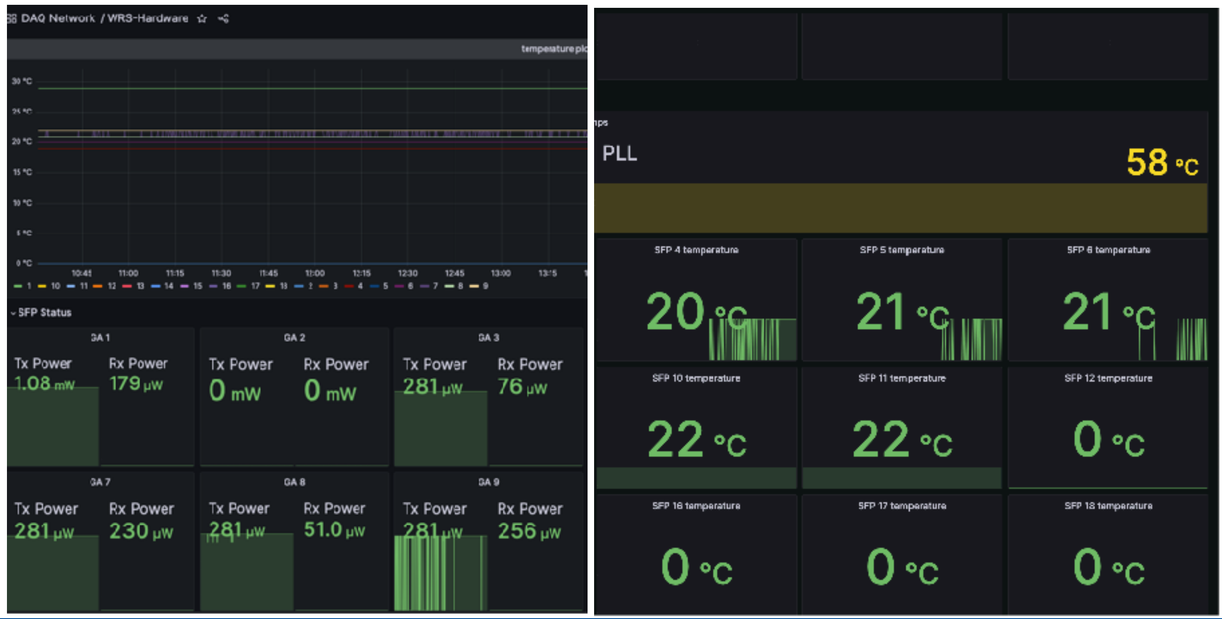




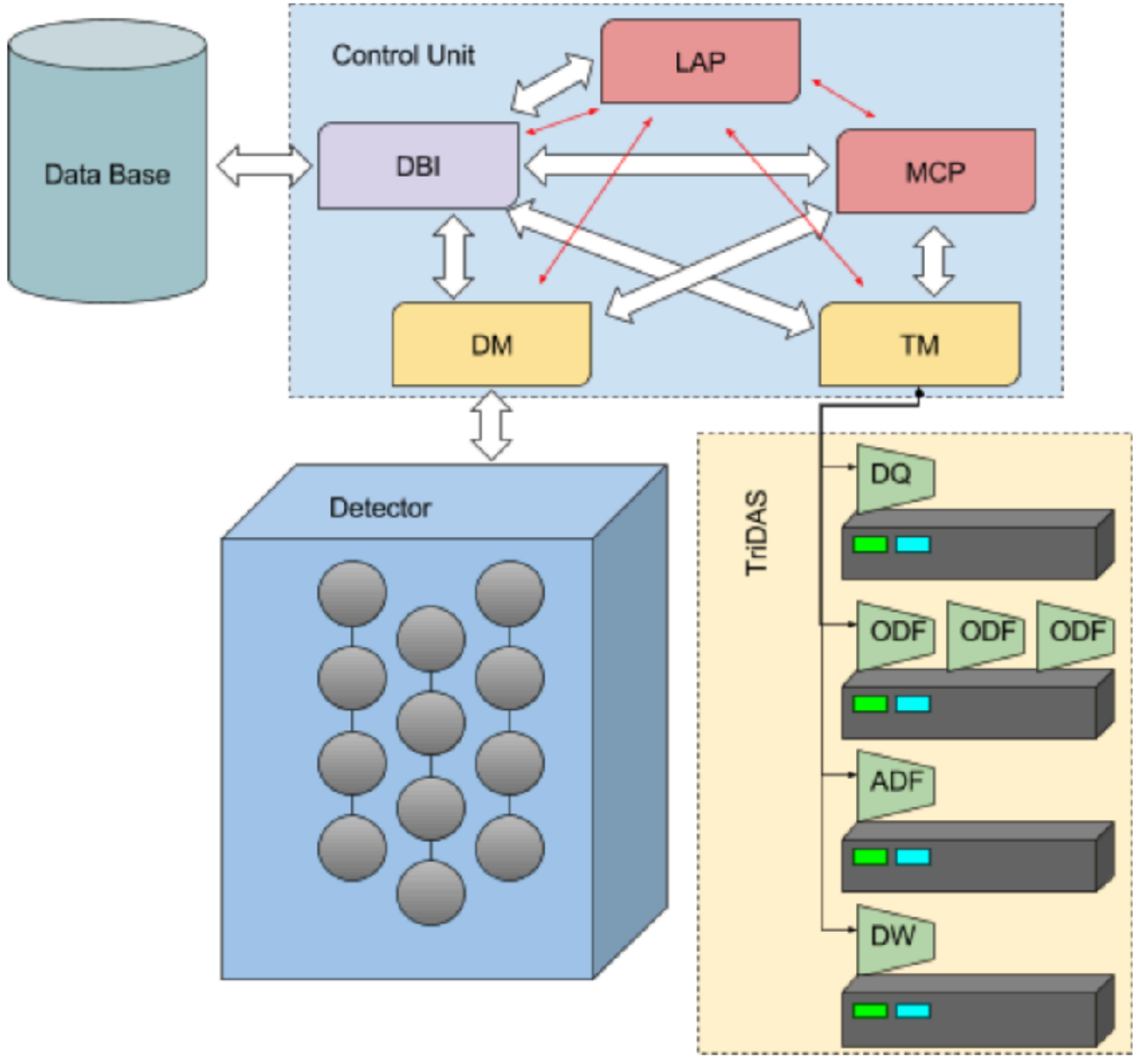
Periodic data transfer to permanent storage @CC-Lyon and @CNAF

- Continuous monitoring of computing resources, to promptly detect failures, prevent failures and detect trends
  - Metrics collection from all switches and servers (zabbix, prometheus)
  - Visualisation with grafana

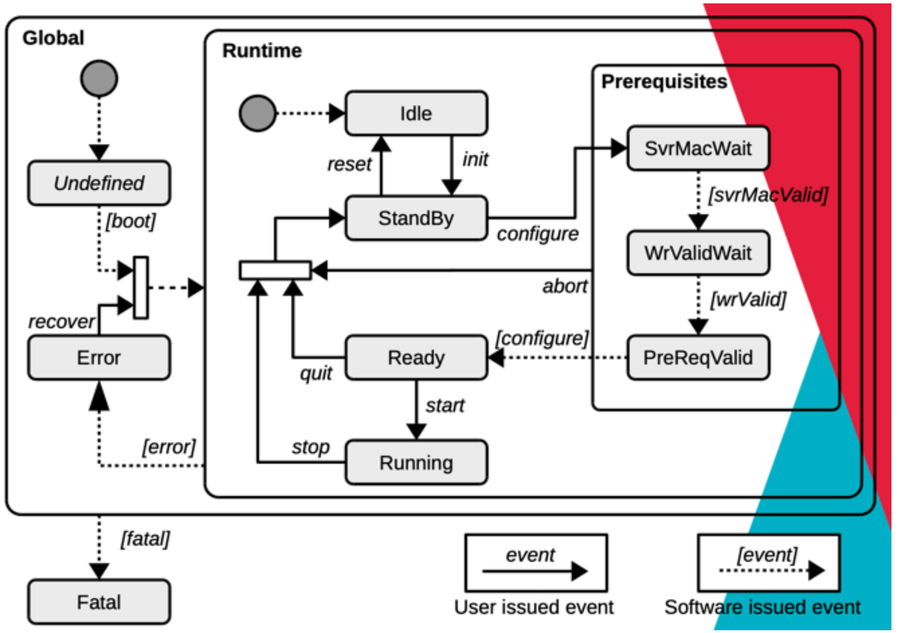




CU Paper: Computer Physics Communications 256 (2020) 107433 - https://doi.org/10.1016/j.cpc.2020.10743

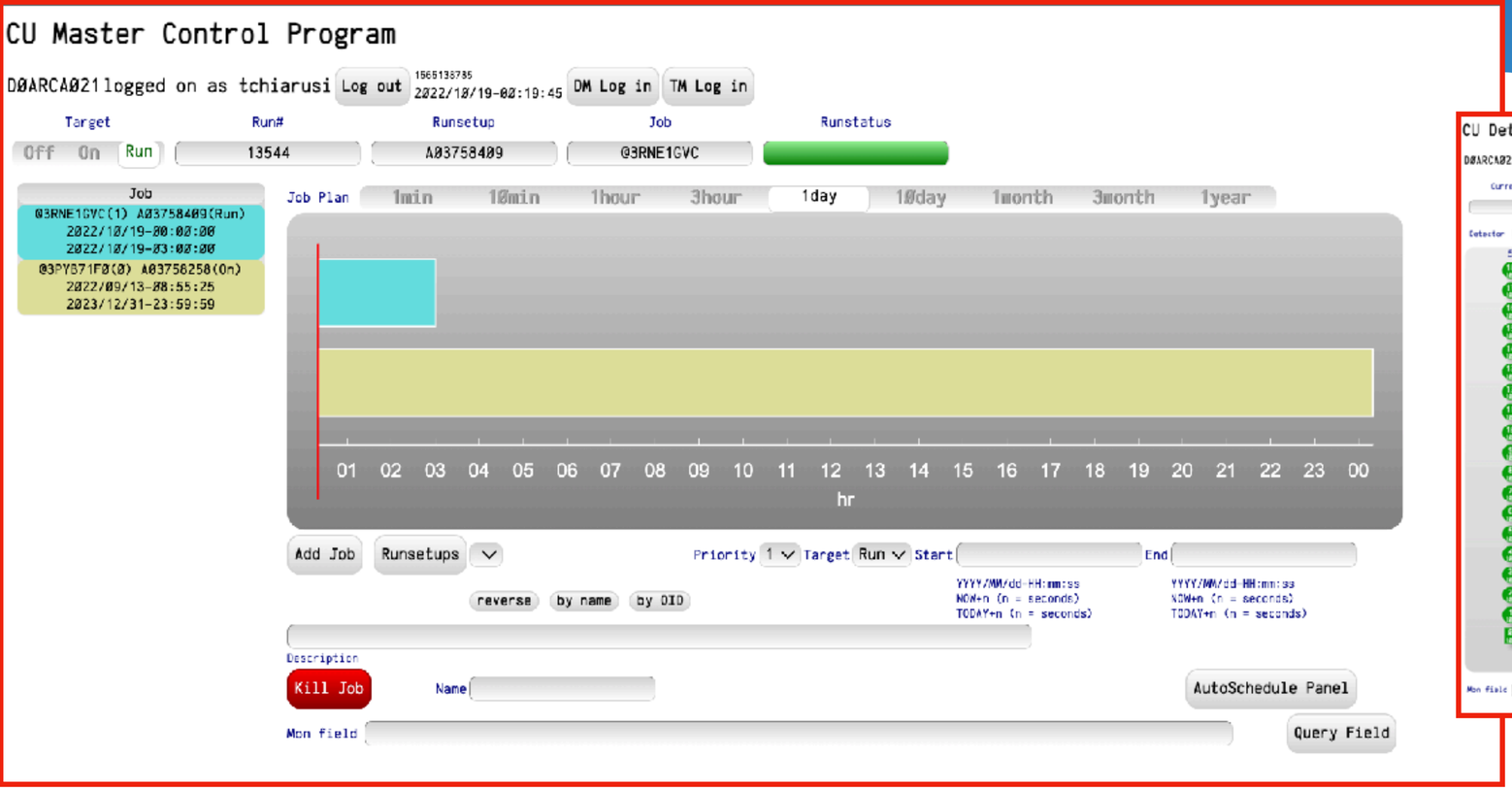


The Control Unit components and their relationships. White and black arrows represent flows of information and/or control signals. Red arrows show the flow of authentication information. The flow of data from the TriDAS to the final storage is not shown.

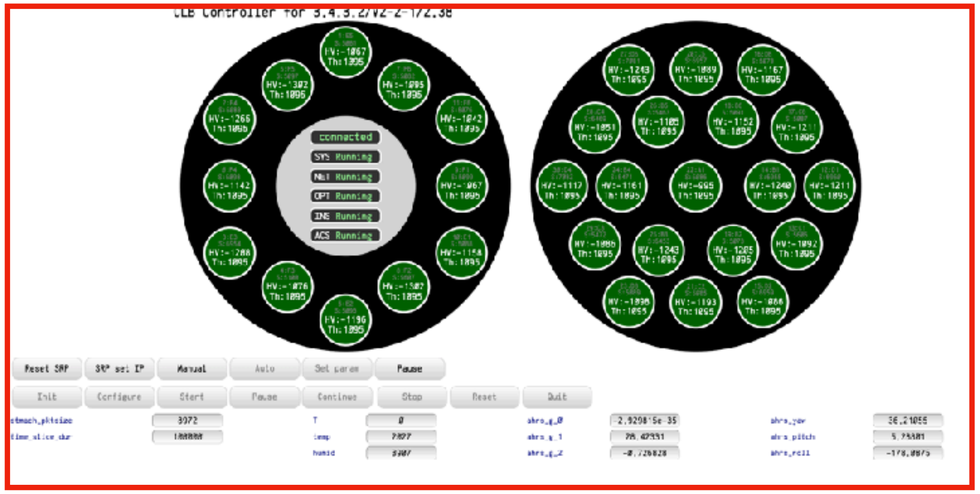


The CU is a collection of (web) services which, via a state machine, drive

- the Detector
- the computing processes
- the interactions with DB for
  - runsetups, calibrations
  - Instruments data logging


CU Master Control Program
DØARCAØ21 logged on as tchiarusi
Log out
DM Log in
TM Log in
Target
Run#
Runsetup
Job
Runstatus
Off On Run
13544
Job
Job Plan
1min 10min 1hour 3hour 1day 10day 1month 3month 1year
01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00
hr
Add Job
Runsetups
Priority
Target
Run
Start
End
reverse
by name
by DID
Description
Kill Job
Name
AutoSchedule Panel
Mon field
Query Field


CU Detector Manager
Current status
Current run number
Run
13544
Ping
Mon field
Query Field


connected
SYS Running
NAI Running
OPT Running
INS Running
ACS Running


CU TriDAS Manager
Current status
Run
Queues
Filters
Writers
Monitors

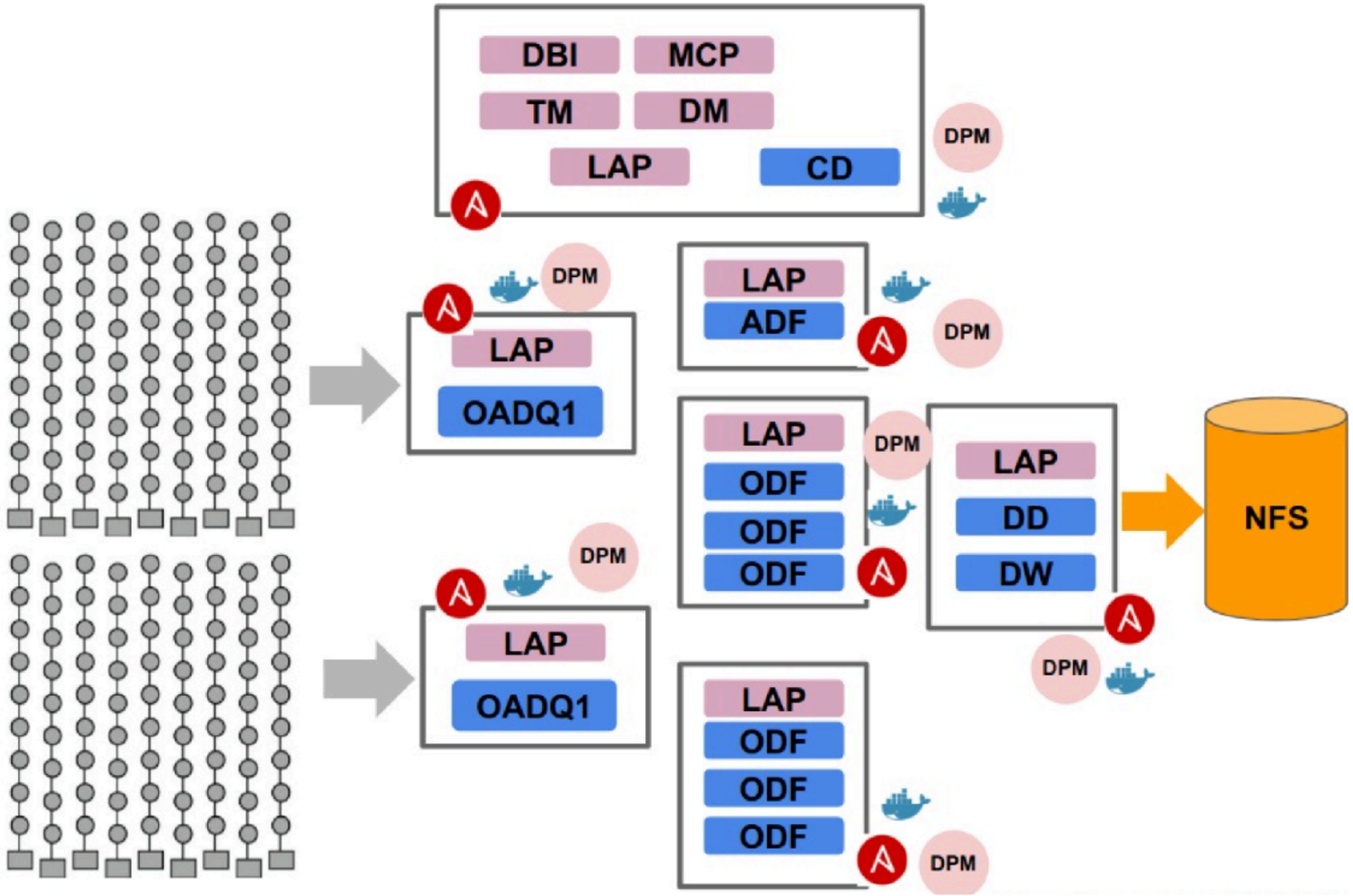
AIACE is an ANSIBLE-based collection of *playbook* for installing and configuring the computing resources and network devices.

DOCKER images -> independent container for each DAQ process, their deployment is handled via AIACE

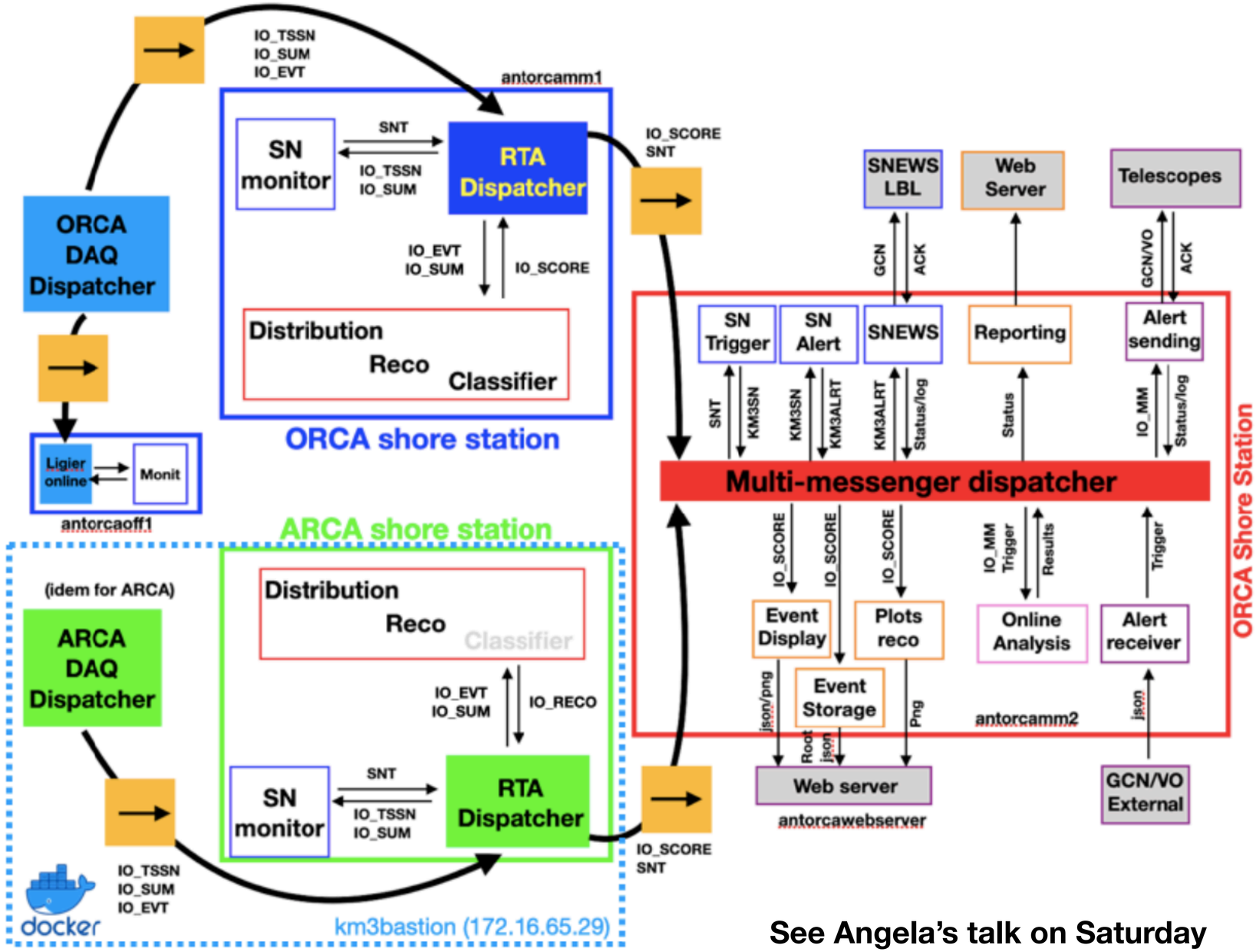
Dynamic Provisioning Manager (DPM) system for "keeping-alive" the DAQ processes and role manager

At present, both for **ARCA19** and **ORCA11**:

- 2x DataQueue processes (on 2 independent server)
- 30x Optical Data Filter processes (on 2 independent server)
- 1x Acoustic Data Filter (on 1 independent server)
- 1x DataWriter together with 1 DataDispatcher (on 1 independent server)

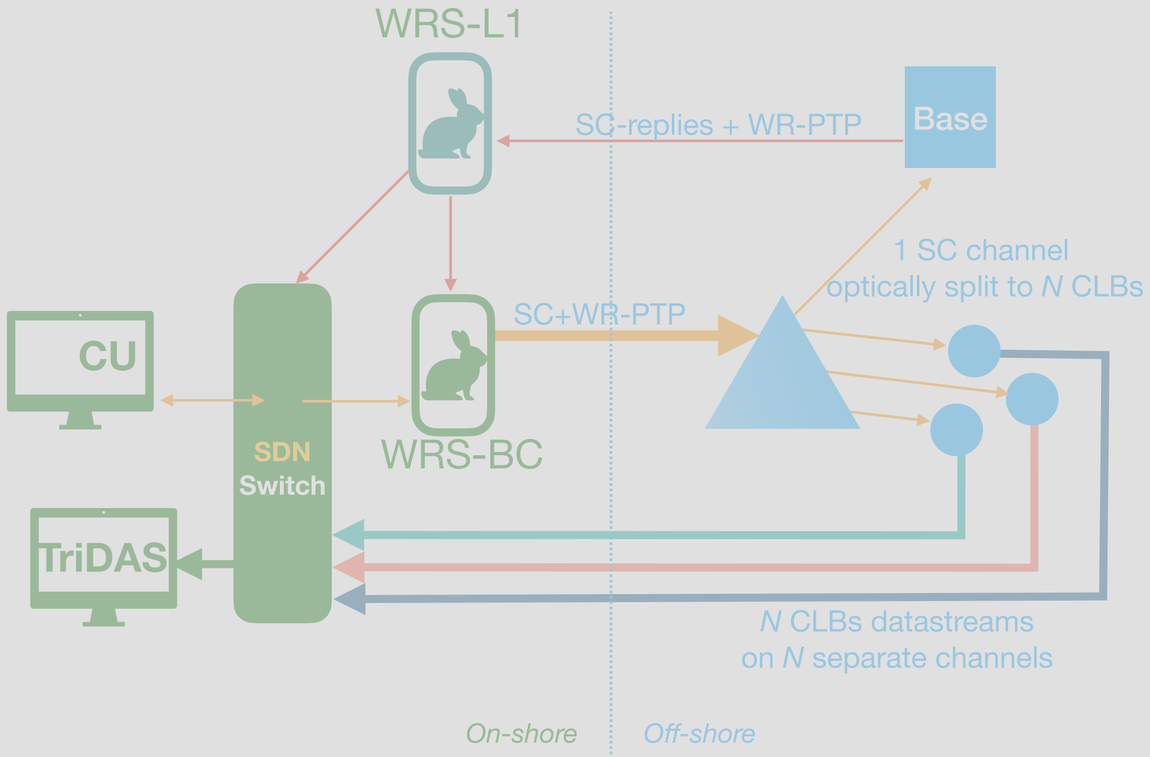


- Event processing done separately for ARCA and ORCA at each shore station
- Same **processing structure** but different software organisation (in ARCA the docker approach is adopted).
- The output of the reconstructed events by ARCA and ORCA at the end of each run (.json files) is stored in a common dispatcher (MM dispatcher)



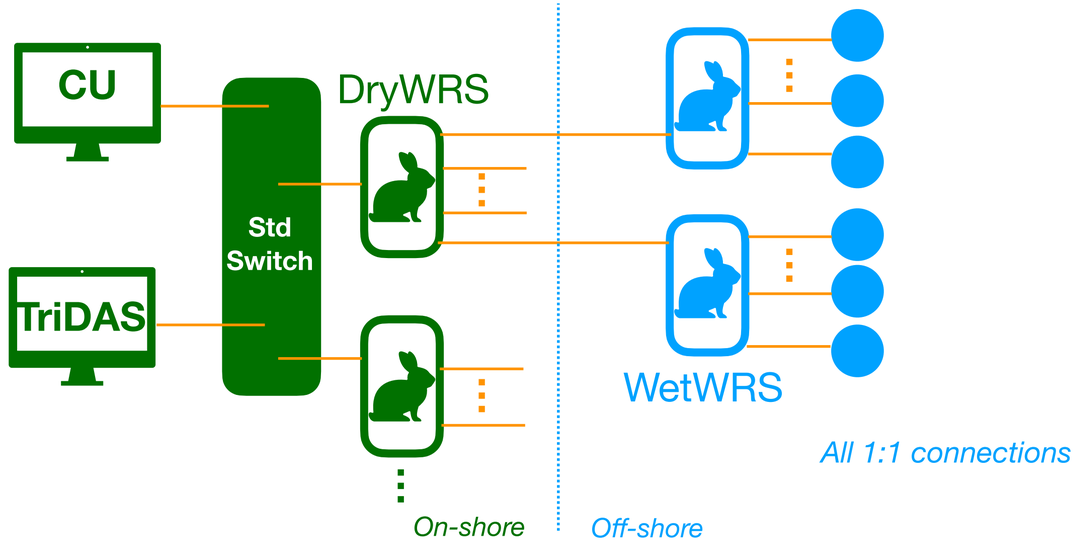
See Angela's talk on Saturday

Broadcast (ARCA 32 strings; ORCA 48 strings *at least*)



Current implementation in both ORCA/ARCA
(as well as other test-installations)

Full White Rabbit (necessary for ARCA 2 BB)



Future evolutions

Broadcast
(ARCA - Phase 1 only;
ORCA - entirely)

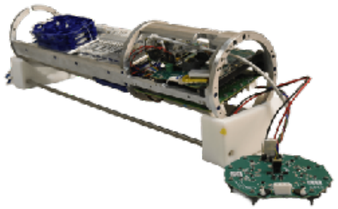
GPS

White Rabbit
switches
(custom)

Back to the
Shore Station

clock

DOM



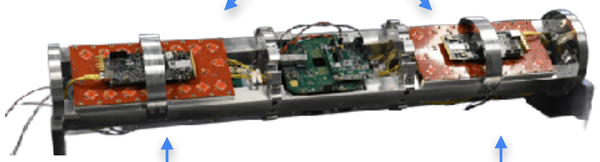
Base Module

Standard
(ARCA Phase 2)

GPS

White Rabbit
switches

clock+data

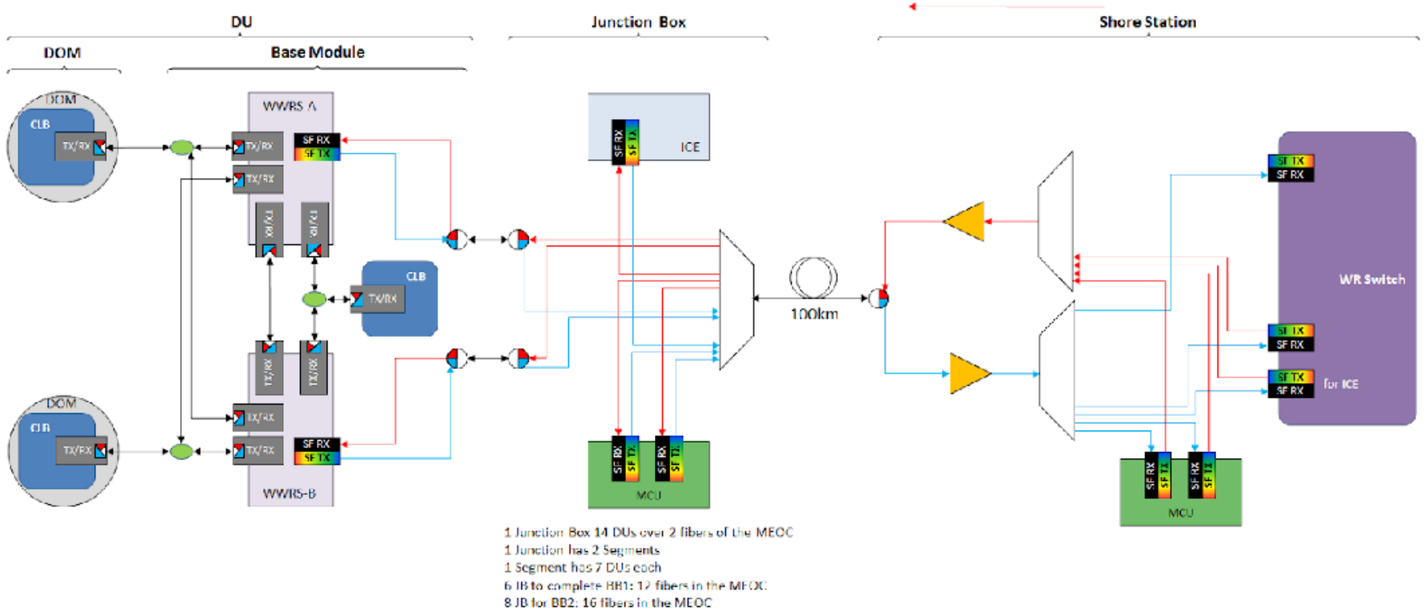


Base Module
White Rabbit
switches

clock+data

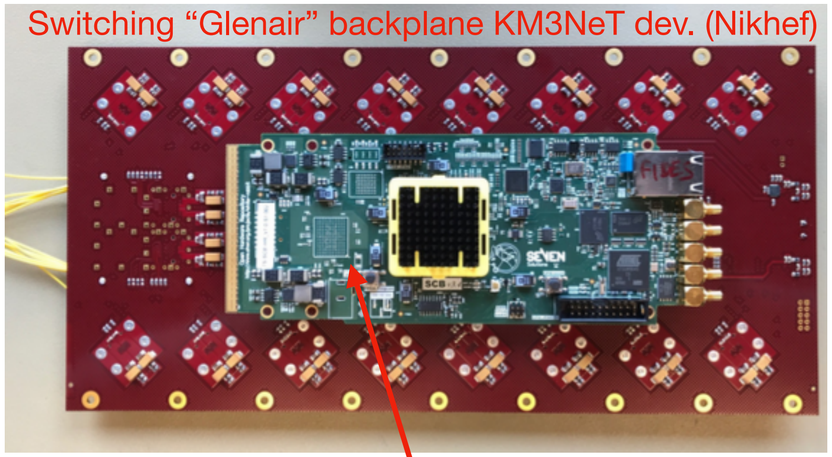
DOM

KM3NeT Phase 2.0 - ARCA Optical System - Overview

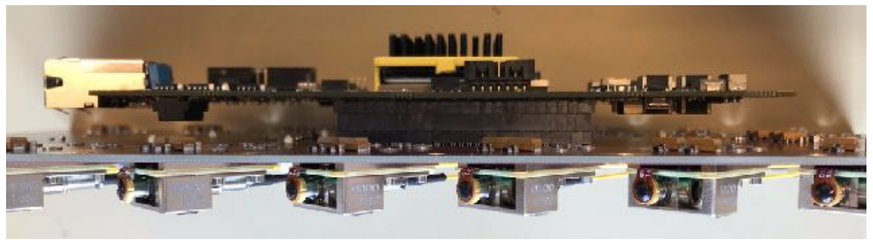


CLBv4 KM3NeT dev (IFIC)

Switching “Glenair” backplane KM3NeT dev. (Nikhef)



SCB by SevenSolutions



- 2 tunable SFP+DWDM long range transceivers for connecting with the on-shore station
- 2 *Wet*WRS per DU: 9 DOMs each
- 1 BM CLB connected to both of the two WRSs (cold redundancy applied)
- 23 bidirectional short range transceivers (**high reliability**) for DOM connections (9x2), CLB connection (3), inter-WRS connection

One full DU with CLBv4 boards and GA transceivers/connections

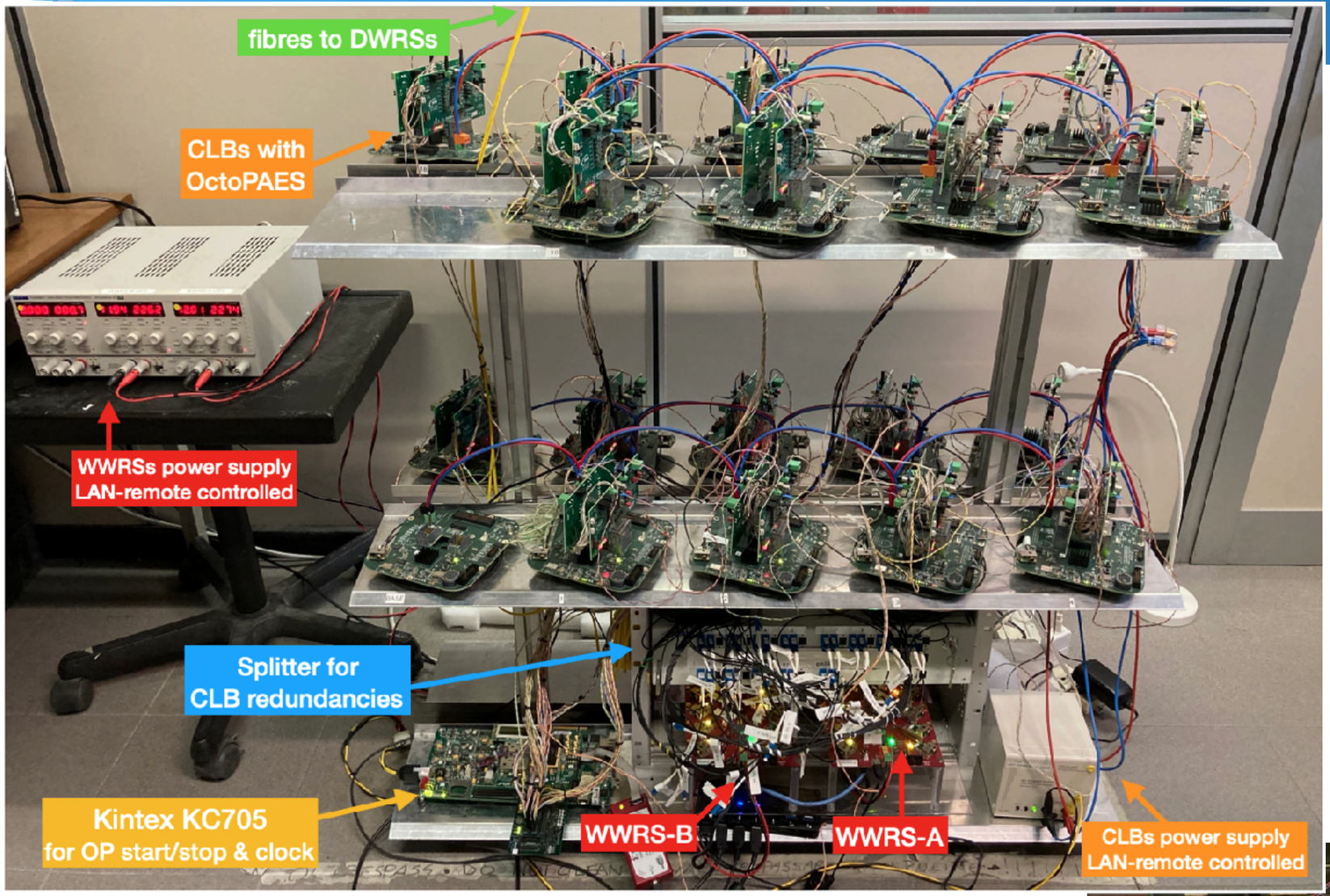
One integrated DU-BM with the WetWRS

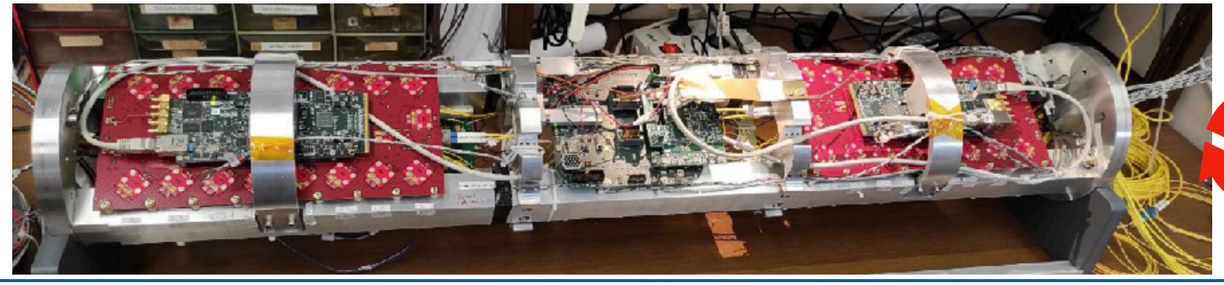
Custom electronic boards by INFN-Bo, the *OctoPAES* (emulation PMT and piezo/hydro), => tested runtime conditions of the DU:

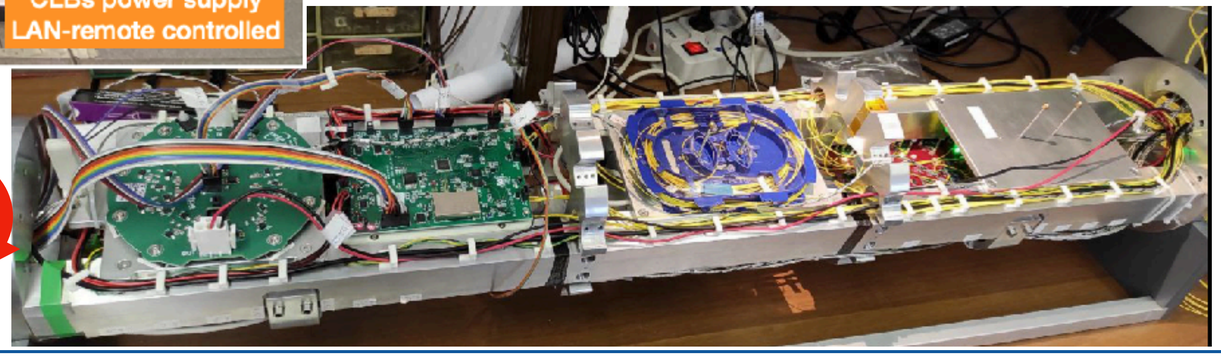
- throughputs of various channels (PMT/ACU/MON)
- effectiveness of NG-Firmware for CLBv4
- control of DU and BM CLBv4 boards
- temperatures and power consumptions

Main boards (WWRS, power borards) subjected to HALT test

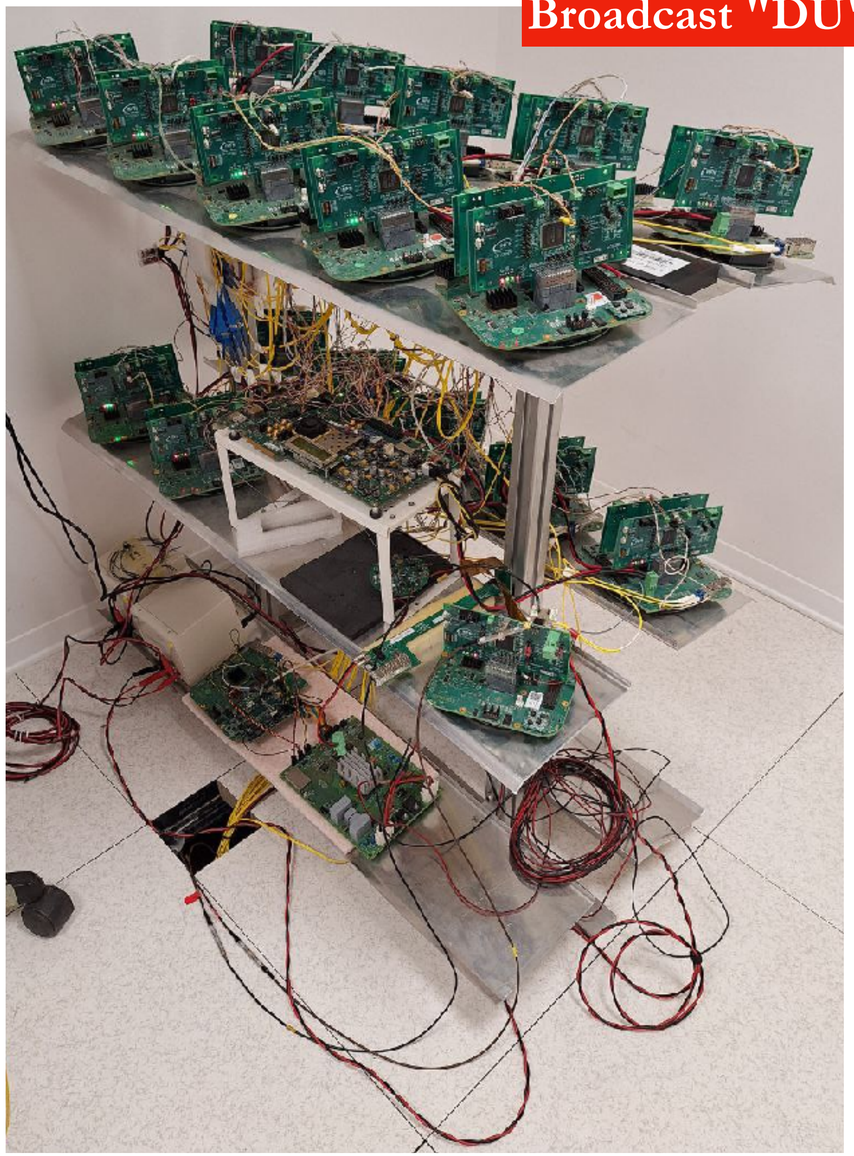
The full design has passed the *Product Readiness Review* (June 2024).



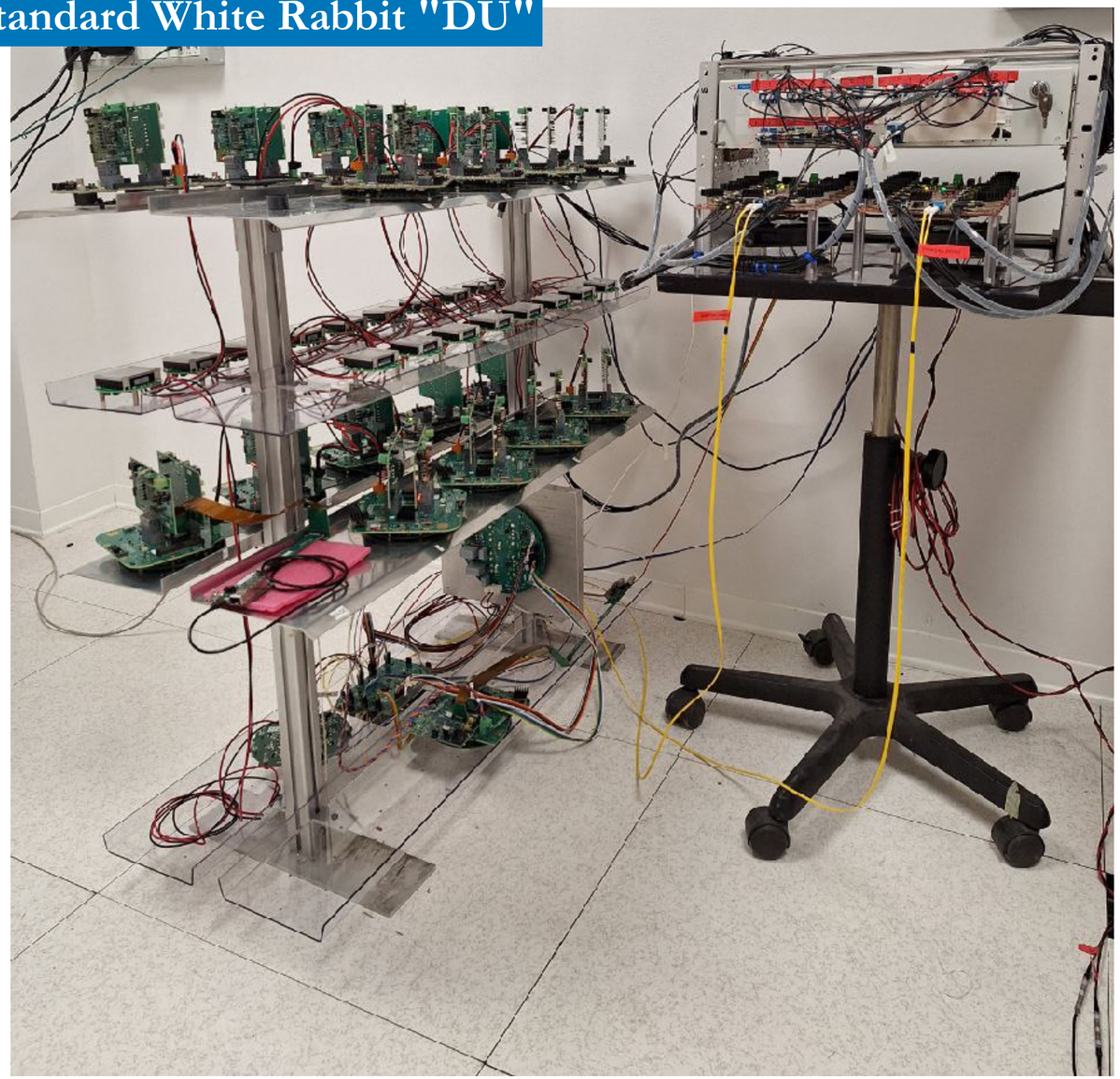




Broadcast "DU"

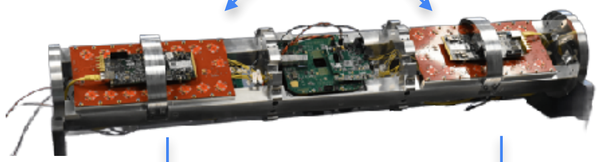


Standard White Rabbit "DU"



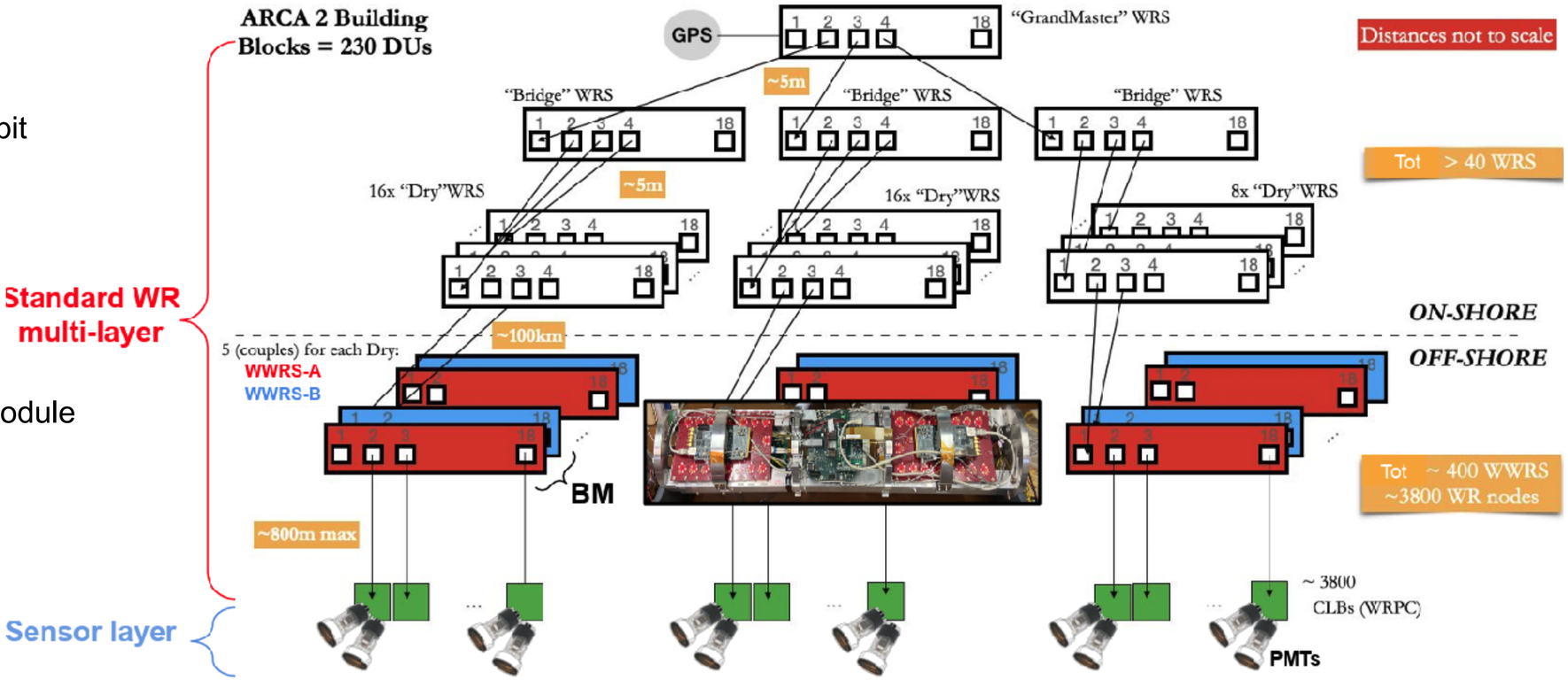
GPS

White Rabbit switches

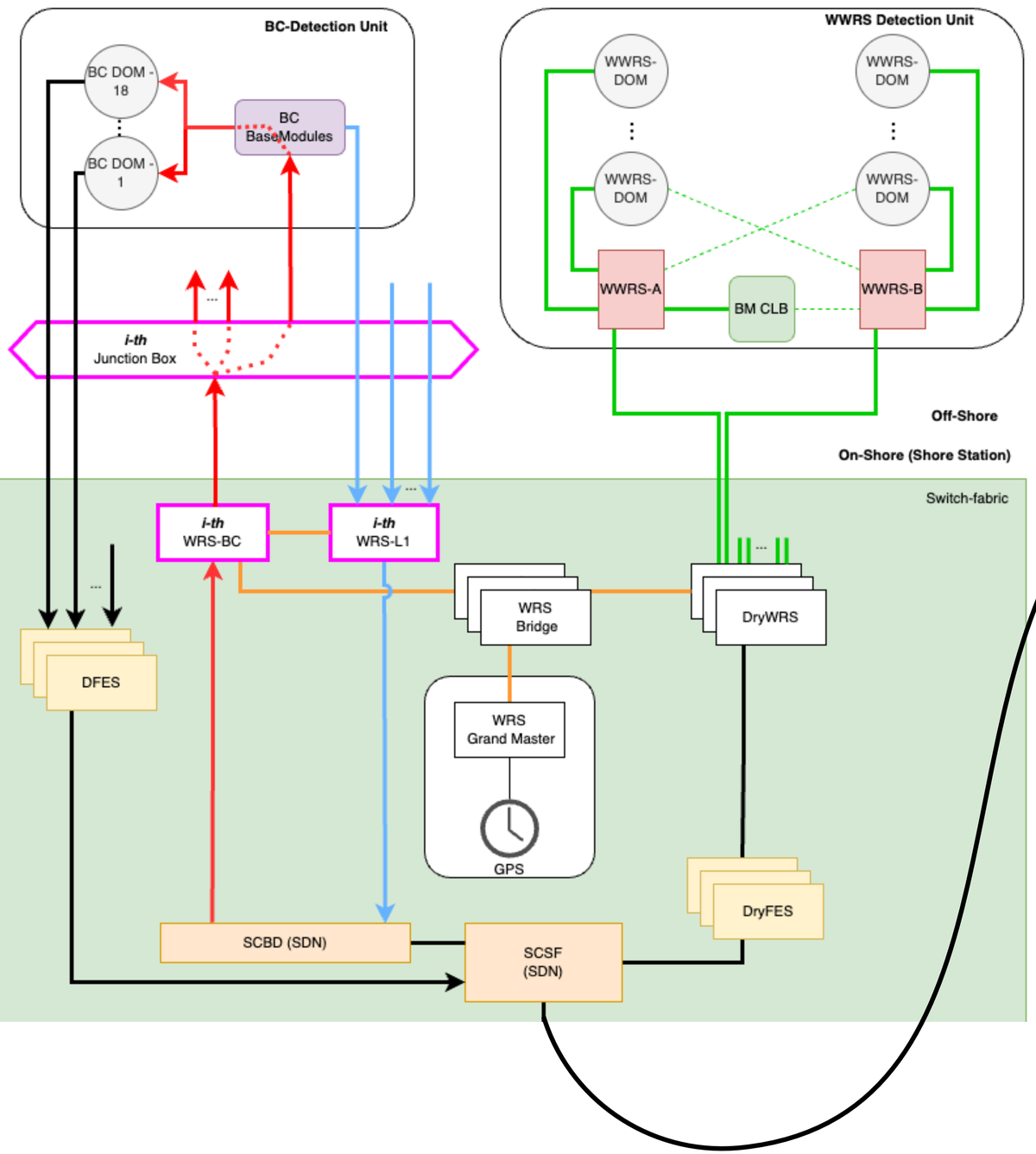


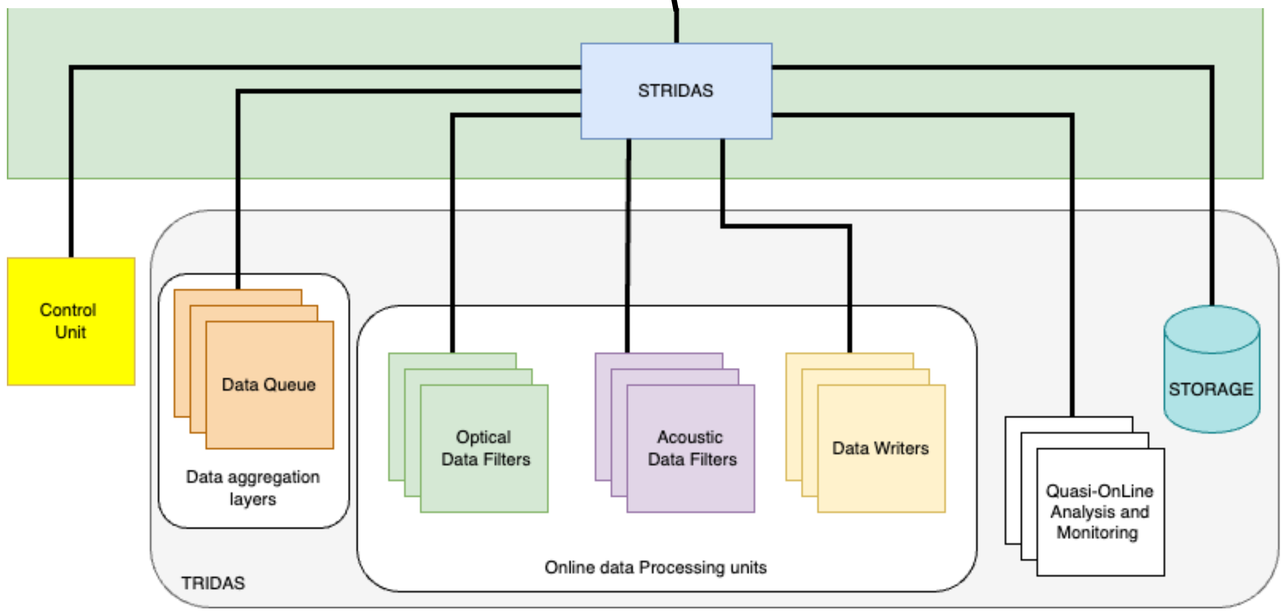
Base Module

DOM



ARCA Merged DAQ System Layout





- **Scalable and modular** DAQ model
- **Dimensioned for large scale undersea neutrino detectors**, at least 2 building blocks with O(5000) endpoints
- **High throughput network** extending from on-shore to off-shore for O(100) km in a wide O(km3) volume
- Frontier technologies such as
  - **White Rabbit** for sub nanosecond precision distribution over ethernet
  - **Software Defined Networks**, for dealing with a highly asymmetric network technologies
- **Most reliable and modern technologies** used for handling the data taking control, the processing of the streaming readout and the monitoring
- Served software deployment and configuration within a **docker containerised computing infrastructure**.
- Big innovations with WRS infrastructure:
  1. Detection Units “(r)evolution” from the **“Broadcast” to the “Standart-WR”** scenario (integration of the 2 scenarios)
  2. **Next Generation firmware** for the Central Logic Boards.

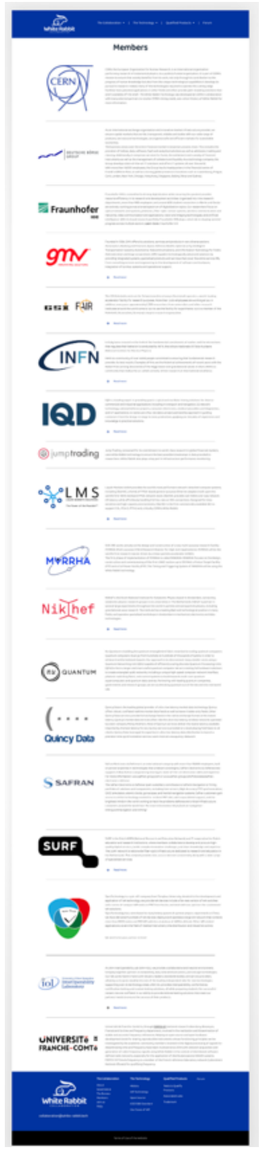
White Rabbit COLLABORATION

The Collaboration | The Technology | Qualified Products | Forum

INFN is a member of the WRC

—> occasion to
- contribute to the WR developments
- influence the WR developments
- get support from the WRC experts and share resources

Tasks for short term:
- form a WR community in INFN
- Share and get expertise



Note:
- **First INFN National Course on WR —> most likely 8-10 September 2025 in Bologna. Stay tuned!**

Thanks for your attention !

..see you in **Bologna** for

the *6th DAQ/Readout* ***workshop***, 5-7 December!

Email-me: tommaso.chiarusi@bo.infn.it

Backup Slides

General

TDR (2014): http://wiki.km3net.physik.uni-erlangen.de/index.php/DAQ/Readout_Technical_Design_Report_(TDR)

DAQ wiki page: http://wiki.km3net.physik.uni-erlangen.de/index.php/On-line_Readout/DAQ_systems

Under preparation: DAQ proceedings to RICAP2022 => DAQ Paper

Networking

SDN: https://drive.google.com/file/d/0B_W_29RPdGhaYnQ5Z1BnbVI2MnM/view

SDN: https://pos.sissa.it/301/940/pdf

White Rabbit : https://www.ohwr.org/projects/white-rabbit

White Rabbit for KM3NeT: https://drive.google.com/file/d/0Bx3CnH6v7dBVYmhPdmVhMVgteWs/view

Data Format

https://wiki.km3net.de/index.php/DAQ_Data_Format

Monitoring

ARCA: http://arca.mon.km3net.de/

ARCA: Grafana - computing resources

ARCA: Grafana - TMCH - timing checks

Within LNS-VPN

ORCA: http://orca.mon.km3net.de/

ORCA: Observium - computing resources

Towards an harmonisation between shore stations

DAQ Live

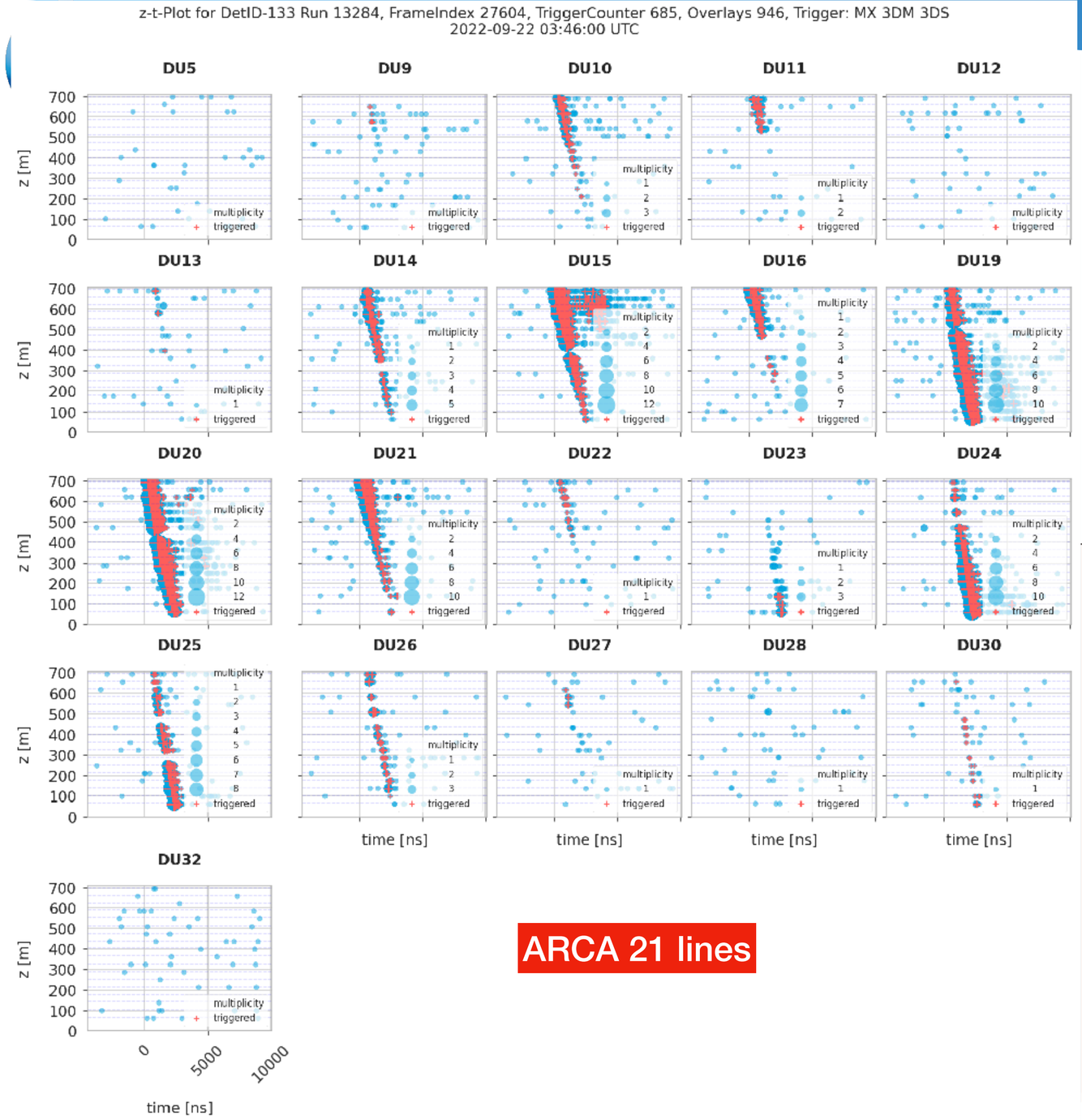
DAQ WG breakdown structure (w.i.p. —> manpower needed)

DAQ Issues and Commitments

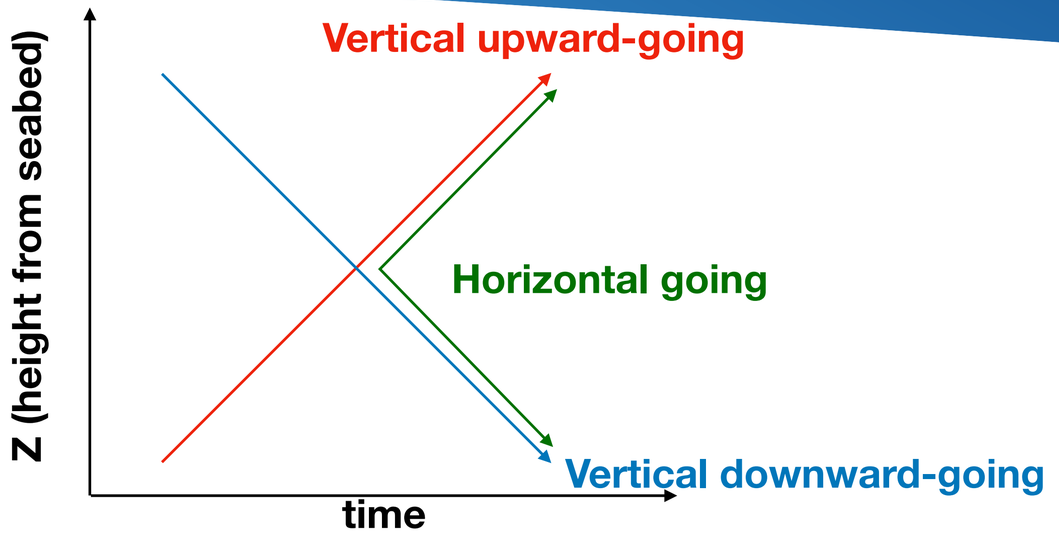
DAQ Priority List

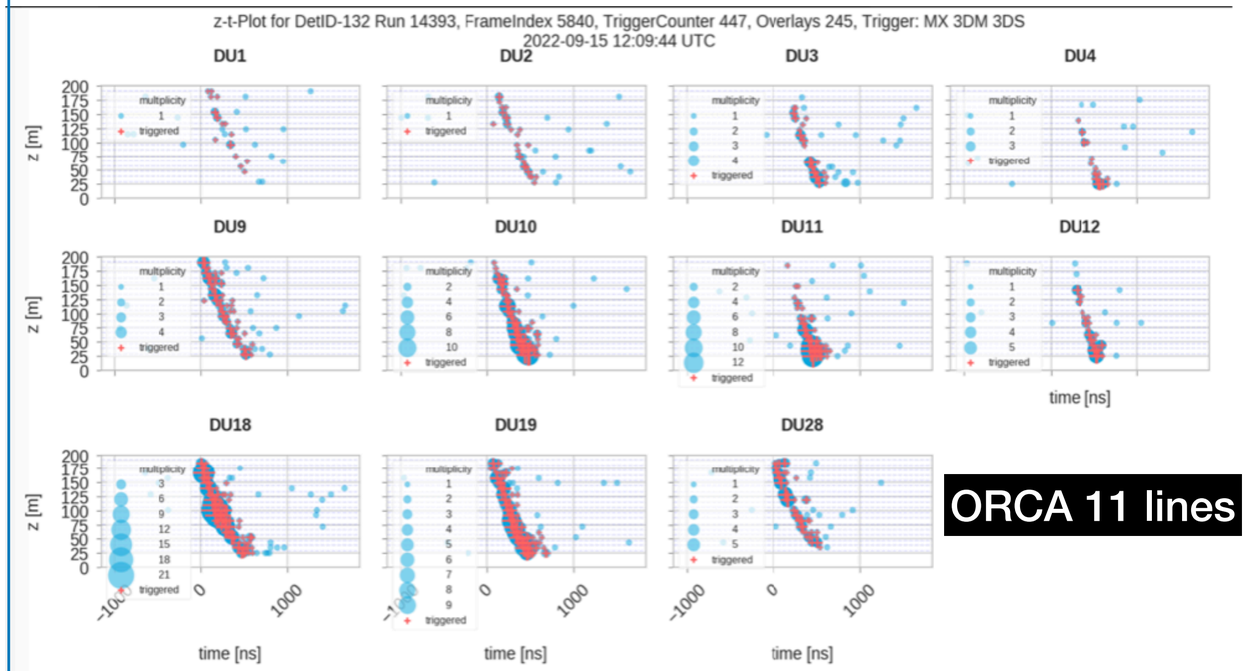
DAQ Indico page

DAQ Open Hour minutes

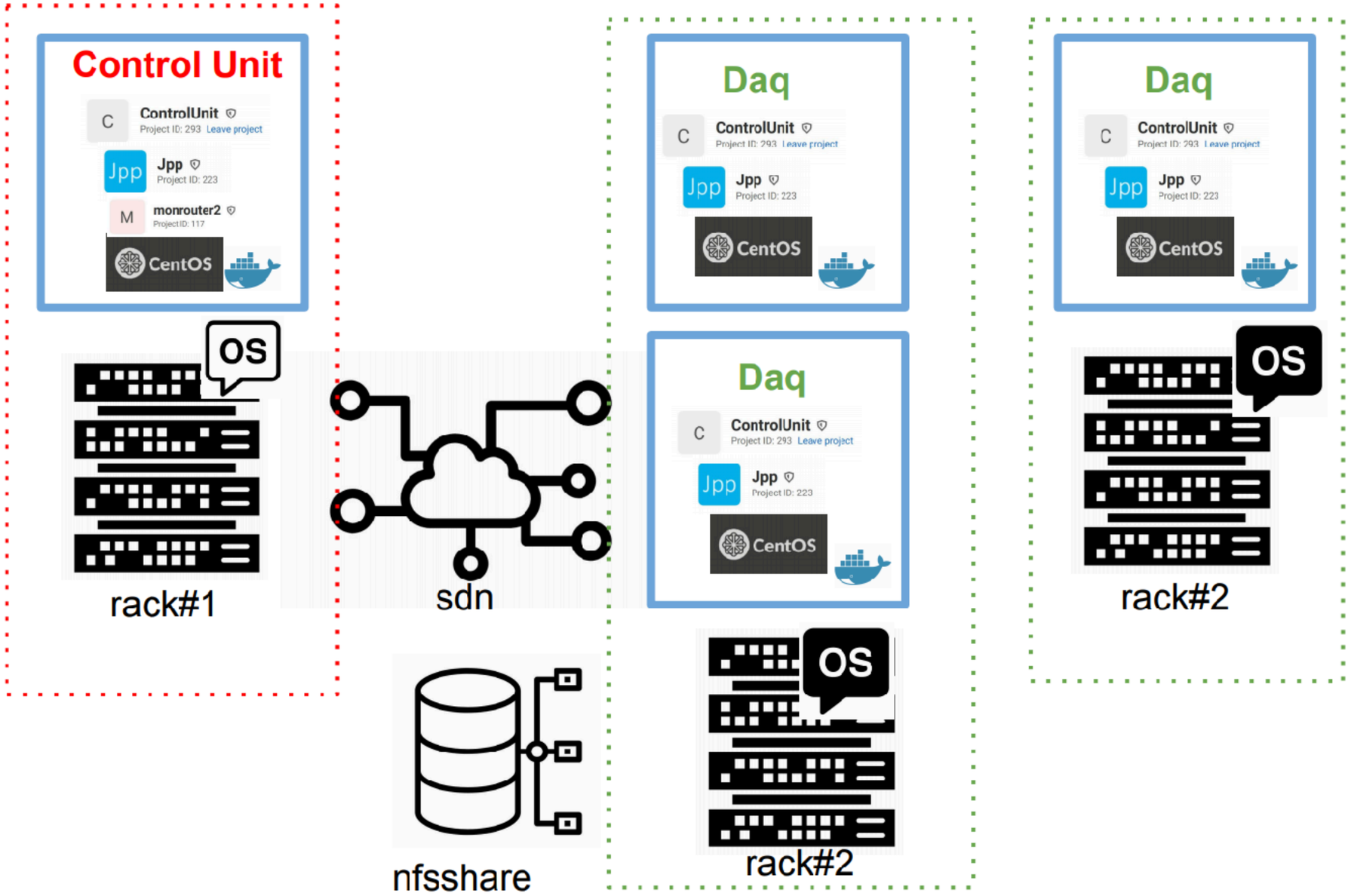


ARCA 21 lines





ORCA 11 lines


Control Unit
ControlUnit
Project ID: 293 Leave project
Jpp
Project ID: 223
monrouter2
Project ID: 117
CentOS
OS
rack#1
sdn
Daq
ControlUnit
Project ID: 293 Leave project
Jpp
Project ID: 223
CentOS
Daq
ControlUnit
Project ID: 293 Leave project
Jpp
Project ID: 223
CentOS
OS
rack#2
nfsshare
OS
rack#2
Daq
ControlUnit
Project ID: 293 Leave project
Jpp
Project ID: 223
CentOS

Optical data for Physics

Case	n_{DU}	n_{DOMs}	$n_{pmt/DOM}$	ν_{single}/PMT (kHz)	hit size (bit)	$\nu_{trigger}$ (Hz)	Event window (μs)
KM3NeT–Ph1, It	24	18	31	15	50	40	6
KM3NeT–Ph1, *Fr*	7	18	31	15	50	13	6
KM3NeT–1 Block (Ph2, *Fr*)	115	18	31	15	50	220	6
KM3NeT–2 Blocks (Ph2, *It*)	230	18	31	15	50	440	6

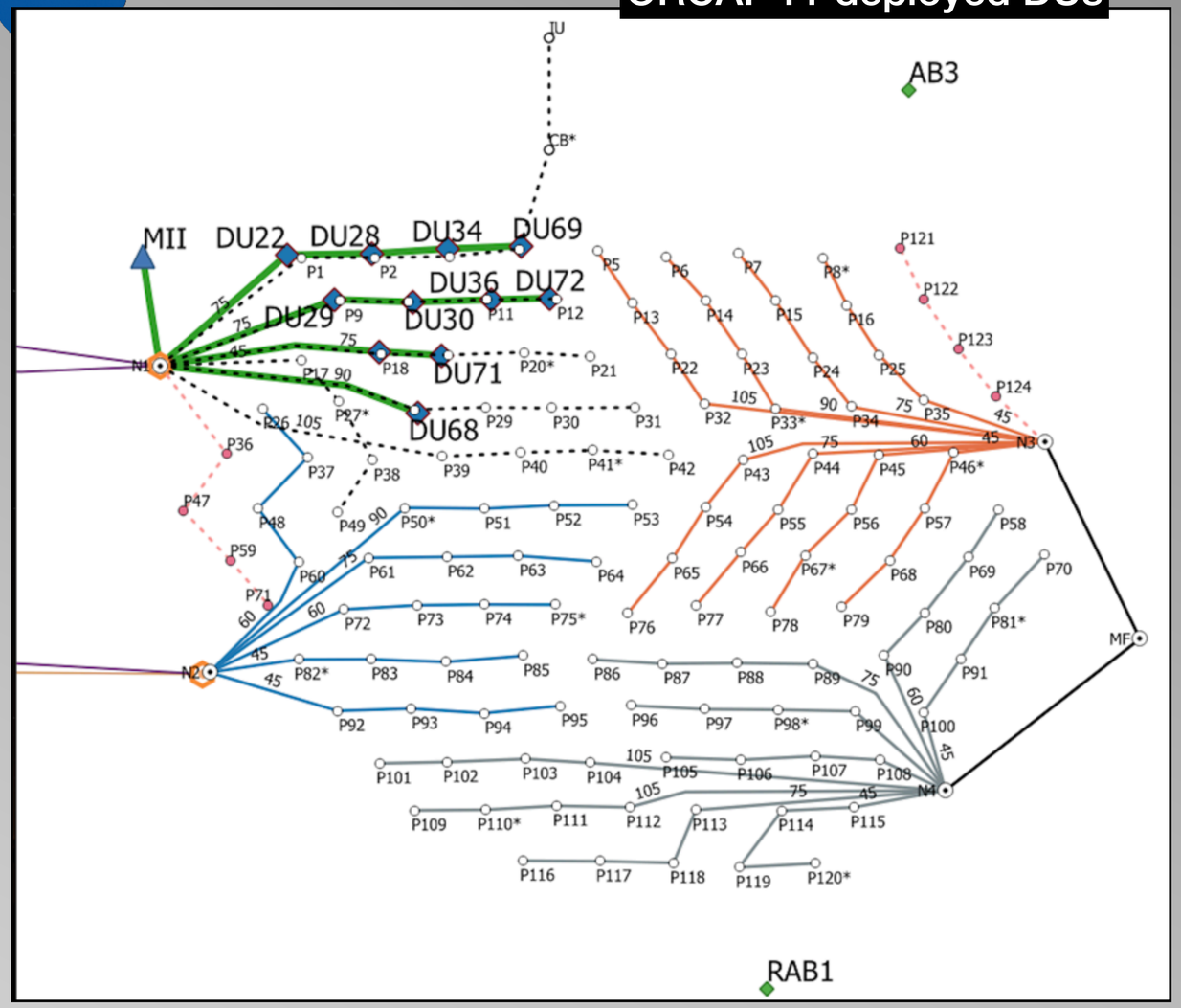
Case	DOM thp (Mb/s)	DU thp (Gb/s)	Det thp (Gb/s)	Sel thp (MB/s)	Sel thp (TB/day)	Stored (TB/y)	event size(kB)
KM3NeT–Ph1, It	23.0	0.4	10.0	1.6	0.13	49.0	7.5
KM3NeT–Ph1, *Fr*	23.0	0.4	2.9	0.4	0.03	12.0	2.2
KM3NeT–1 Block (Ph2, *Fr*)	23.0	0.4	48.0	14.0	1.20	440.0	36.0
KM3NeT–2 Blocks (Ph2, *It*)	23.0	0.4	96.0	44.0	3.80	1400.0	72.0

Acoustic data for positioning

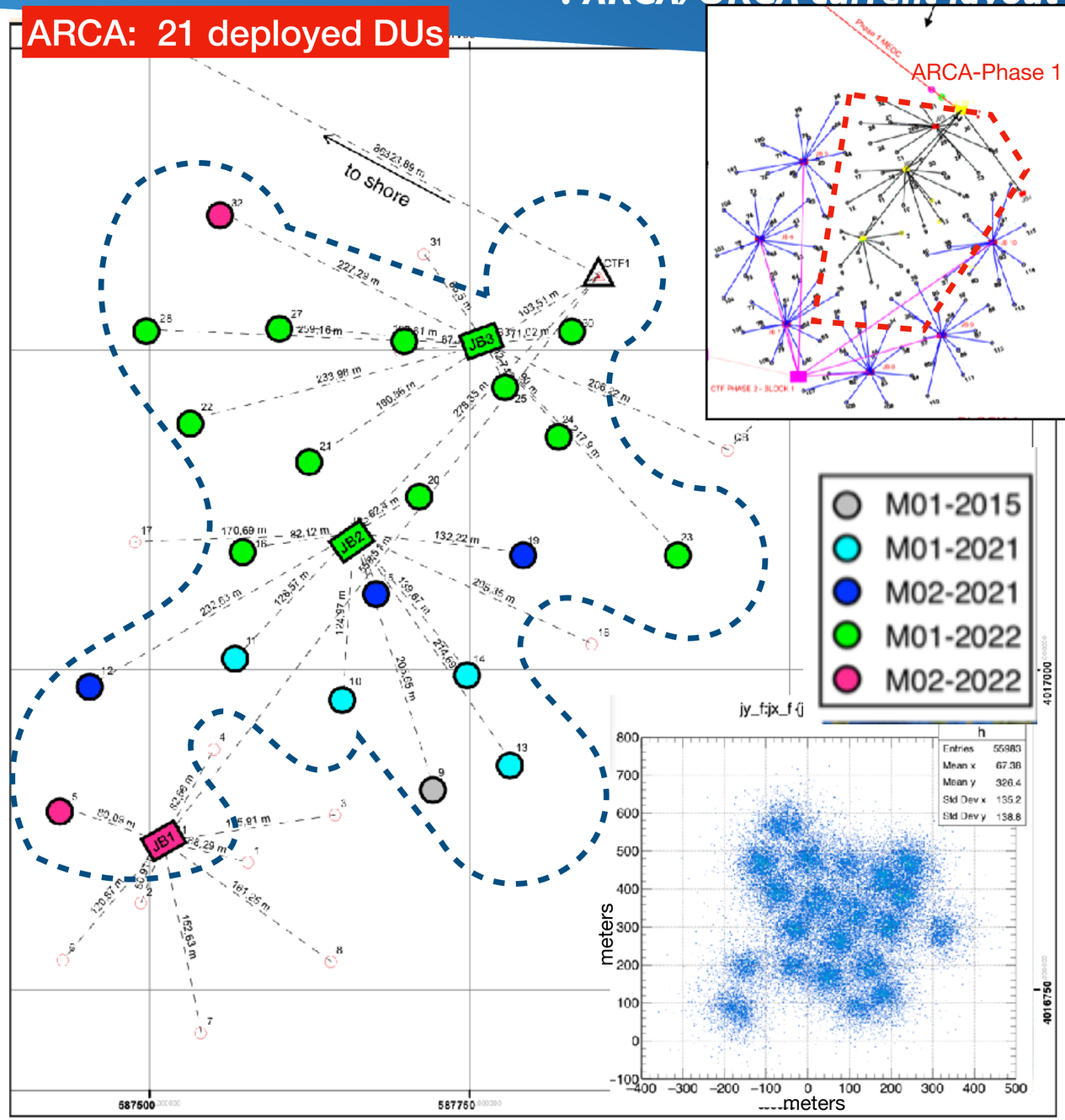
Case	Raw Thp/Sensor (Mb/s)	Raw Thp/DU (Mb/s)	Raw Thp/Detector (Gb/s)	TOA (Mb/s)	Positions (Mb/s)	Storage (TB/y)
Phase 1–*It*	13.0	240.0	5.7	0.20	0.08	1.10
Phase 1–*Fr*	13.0	240.0	1.7	0.06	0.02	0.32
1 Block, Ph2 *Fr*	13.0	240.0	27.0	0.94	0.38	5.20
2 Blocks, Ph2 It	13.0	240.0	55.0	1.90	0.75	10.00

```
SamplingRateHz = 195.3 × 10^3;
ResolutionBit = 24;
NChannels = 2;
```

ORCA: 11 deployed DUs

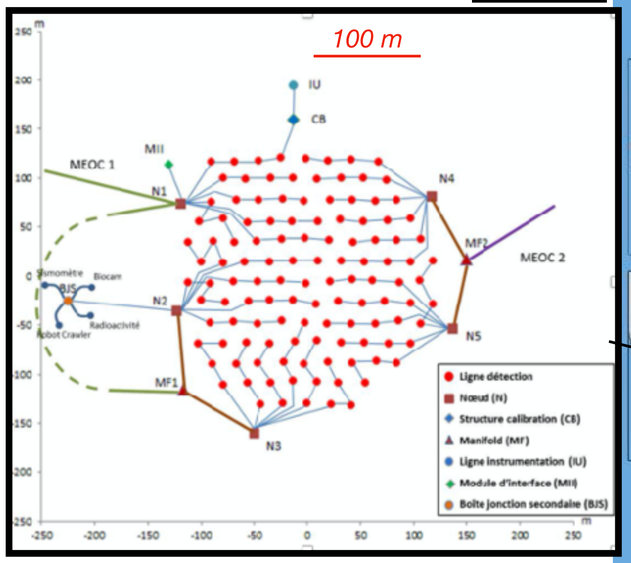


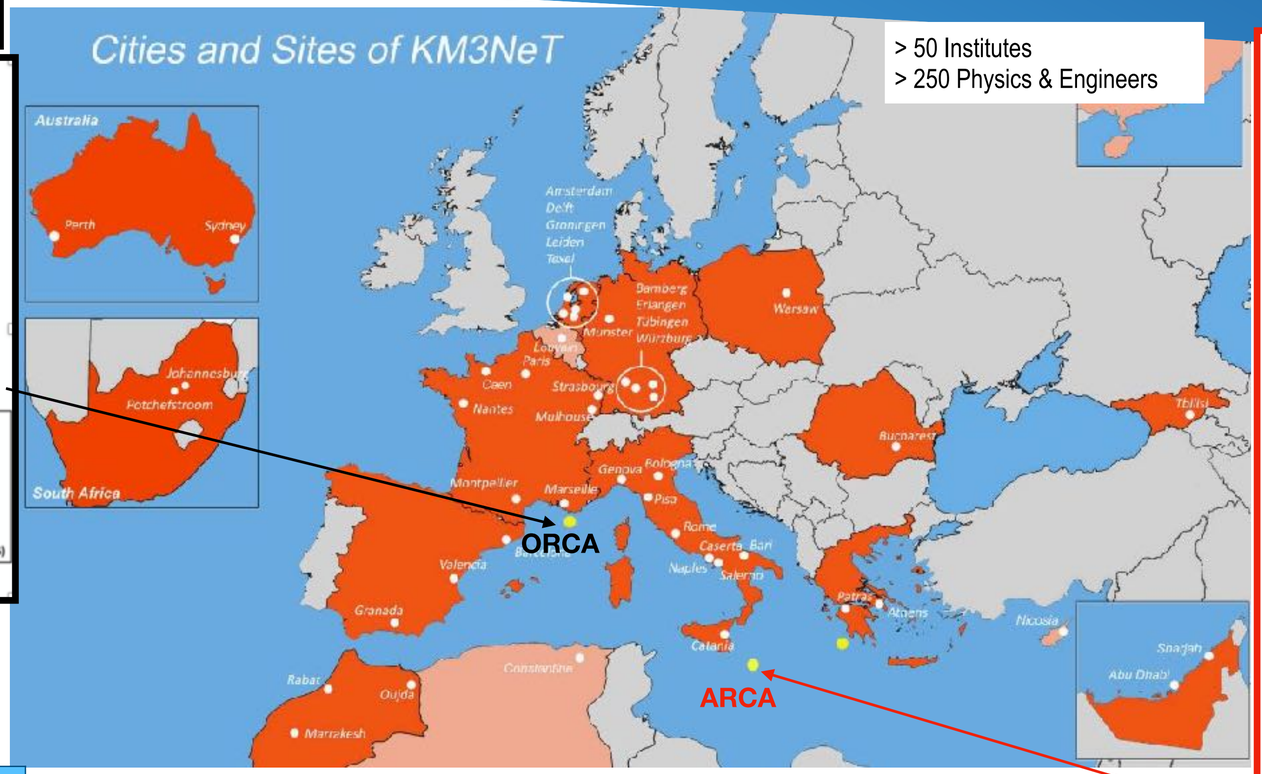
ARCA: 21 deployed DUs

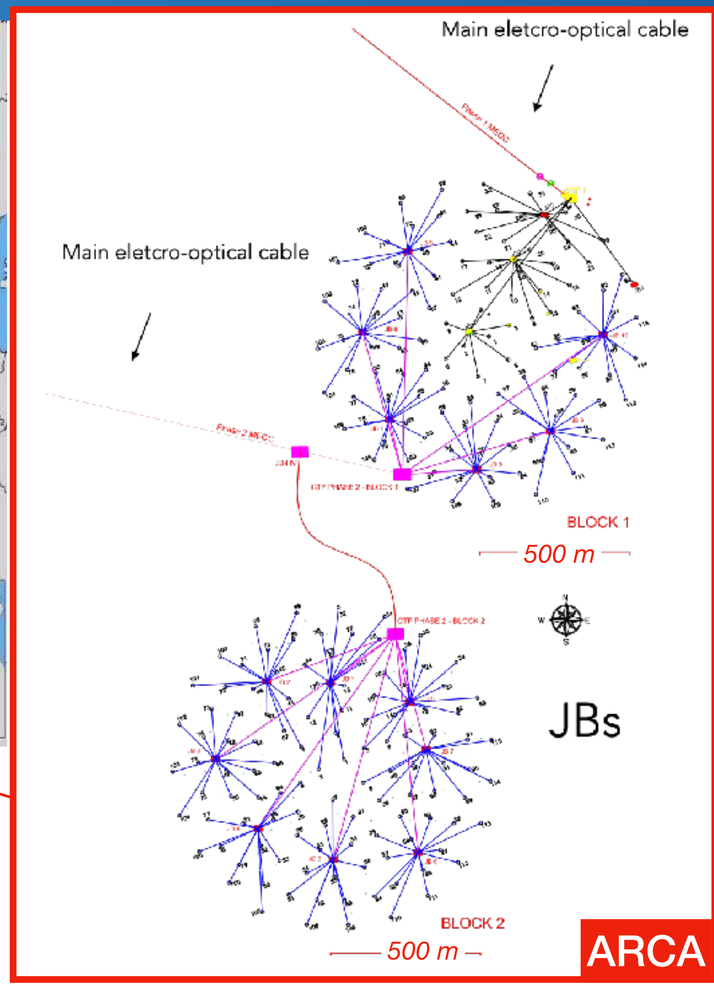


Latest Marine Operations in September 2022, new deployments for both ARCA and ORCA. Accumulating data with growing detector.

ORCA

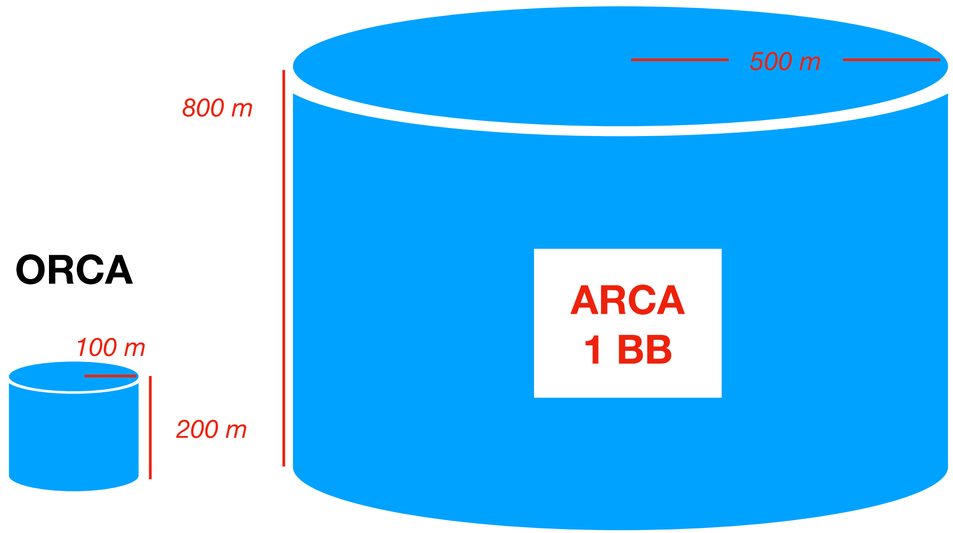






Two detectors, same technology, different layout and physics objectives

	ARCA	ORCA
Location	Italy	France
N. building blocks	2	1
N. DU per b.b.	115	115
N. DOM per DU	18	18
DU distance	90 m	20 m
DOM spacing	36 m	9 m
DU height	~ 800 m	~ 200 m
Instrumented mass (Mton/km³)	2*650 / **1**	7/ **0.01**
Depth	3500 m	2500 m



Telescope Footprints
Dots: Detection (or Calibration) Units
Lines: Main/Interlink electro-optical cables
Squares: junction boxes