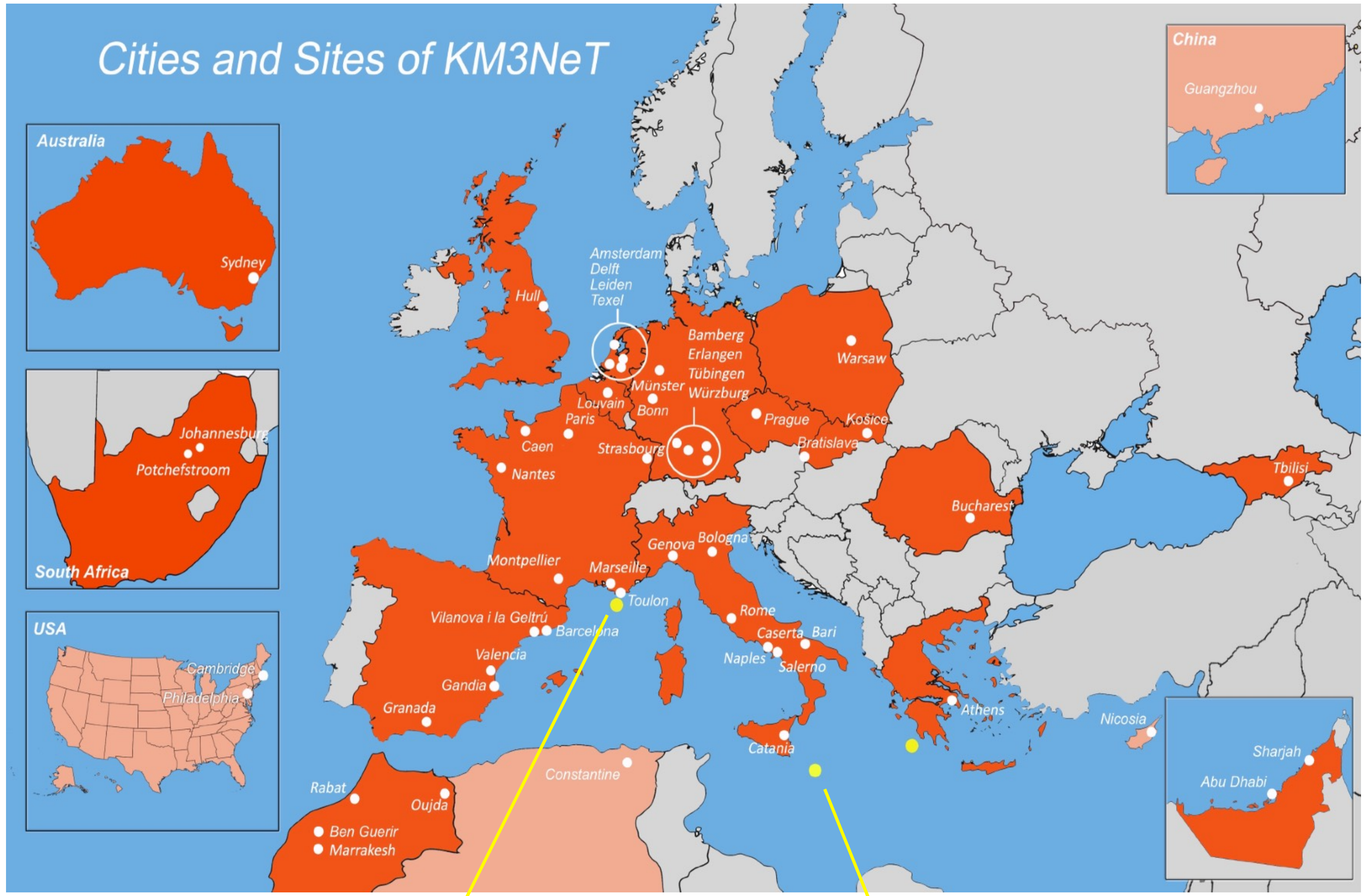
Quick overview on KM3NeT DAQ/Readout system

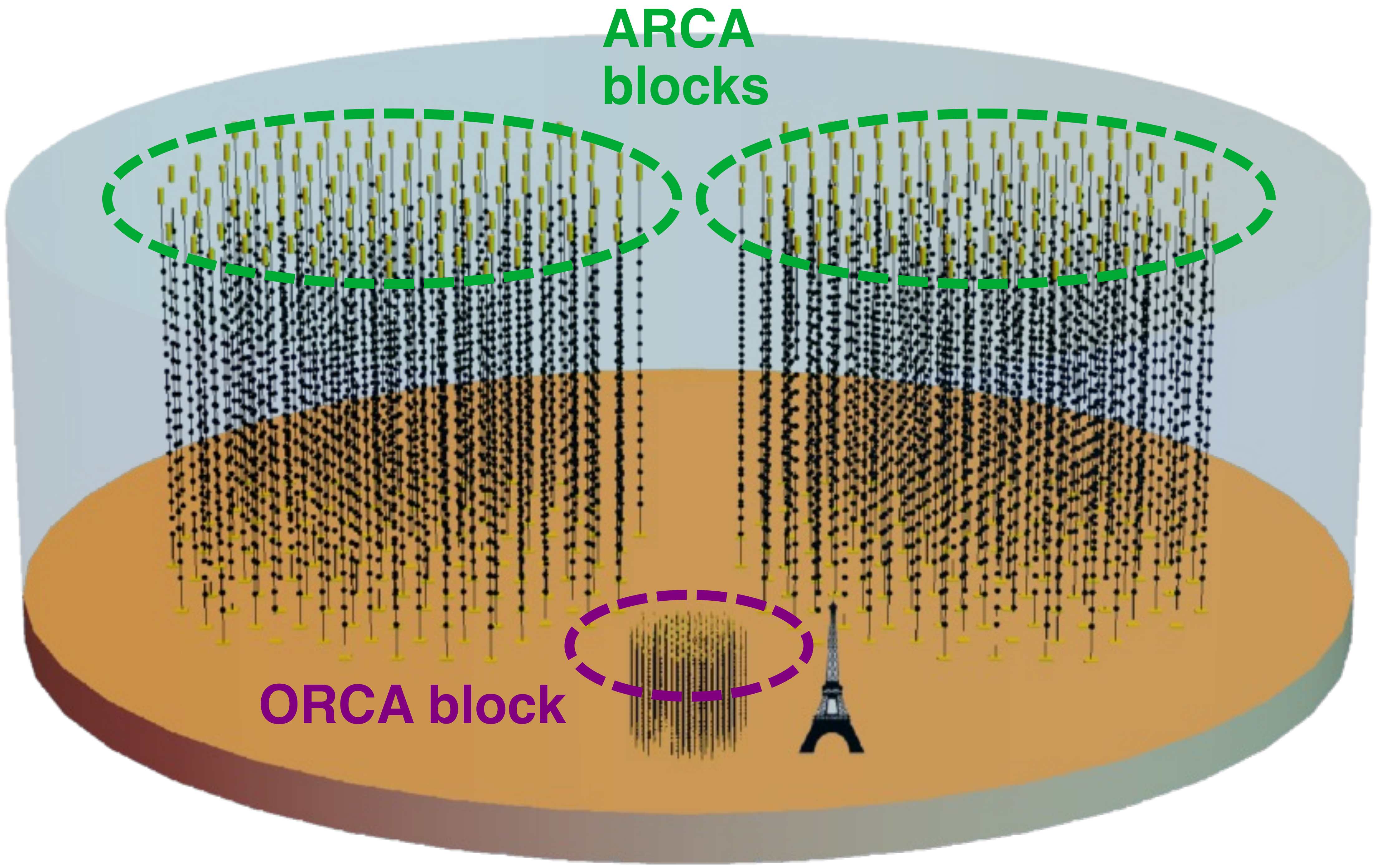
Tommaso Chiarusi

INFN-Sezione di Bologna

MPC Software Meeting - EGO 30/6-1/7 2025

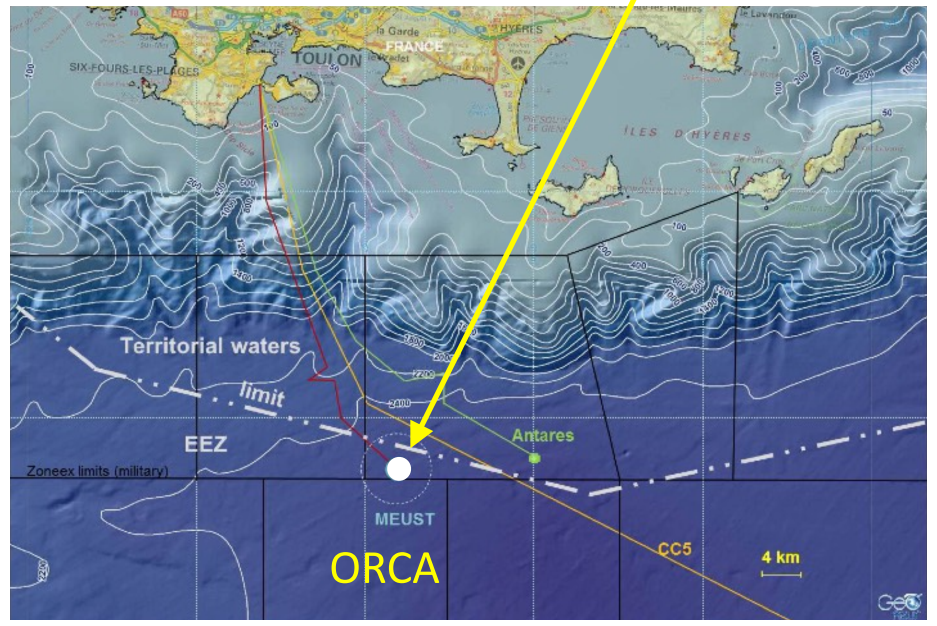


62 institutes ; 22 countries; 5 continents

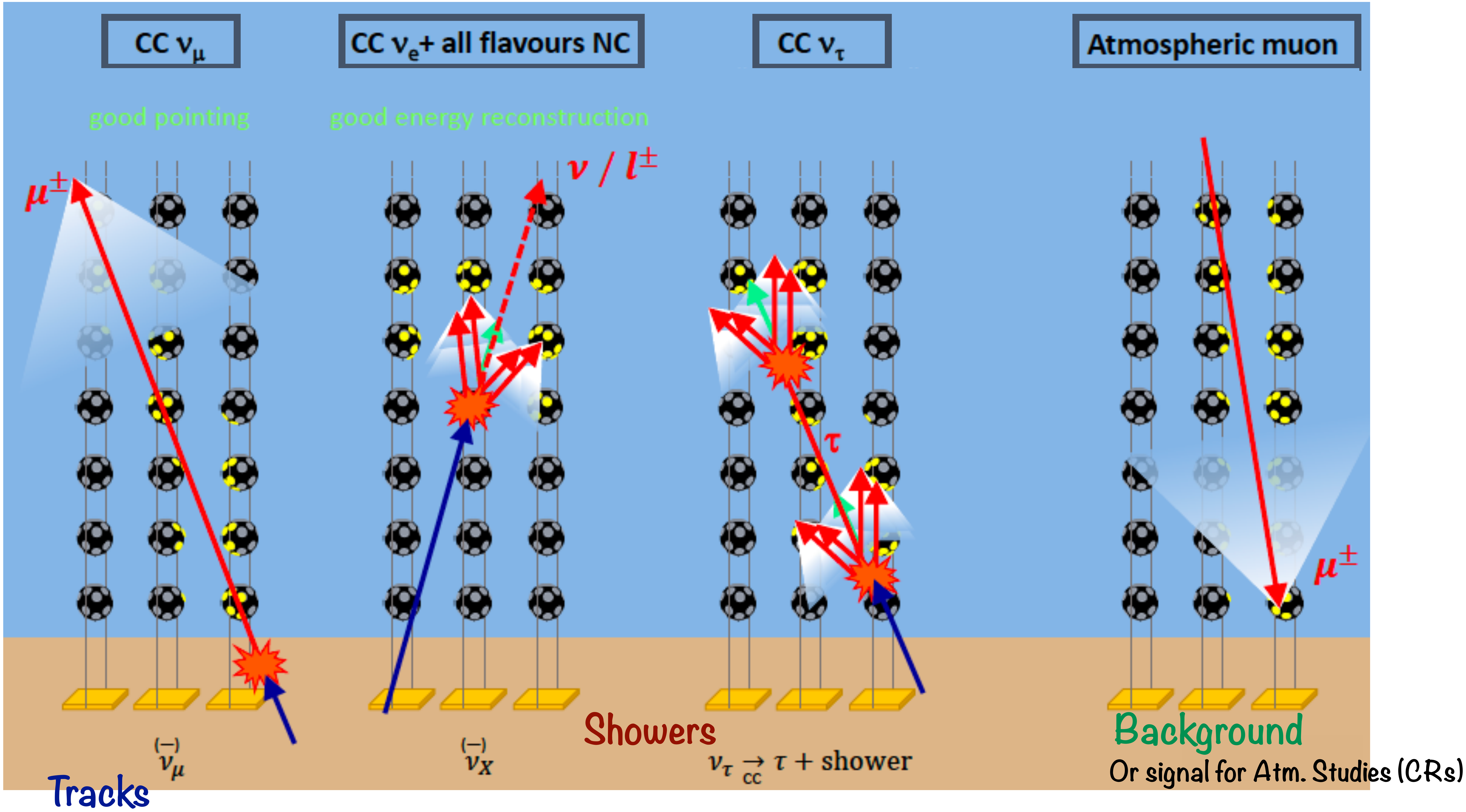


	ARCA	ORCA
Location	Italy (Sicily)	France (Toulon)
Anchor depth	3450 m	2450 m
Distance from shore	100 km	40 km
DUs	115×2 blocks	115
DU horizontal spacing	90 m	20 m
DOM vertical spacing	36 m	9 m
DOMs/DU	18	18
PMTs/DOM	31	31
Instrumented water mass	1 Gton	7 Mton
DUs deployed so far	28→33	23

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



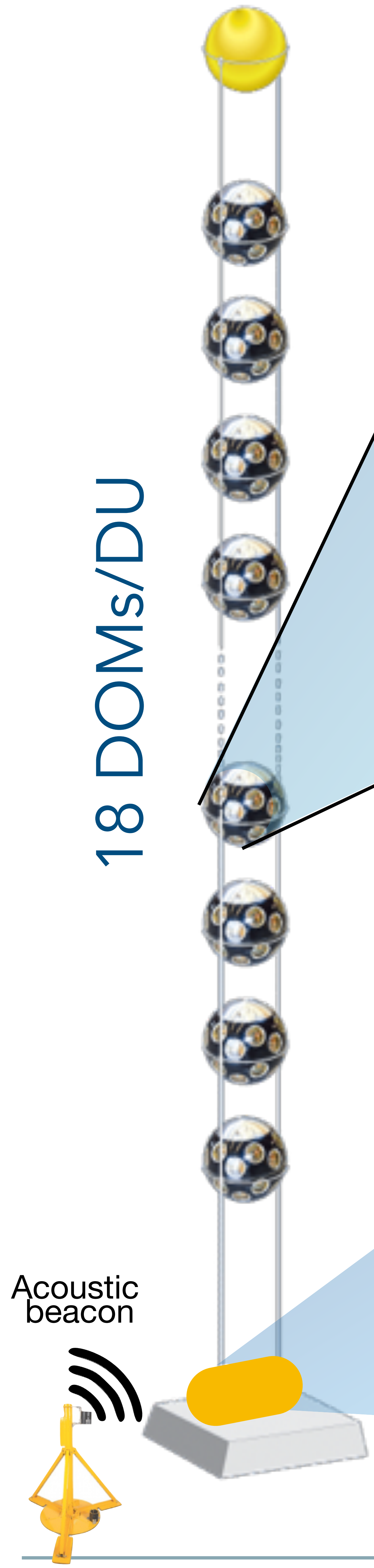
Astroparticle **R**esearch with **C**osmics in the **A**byss

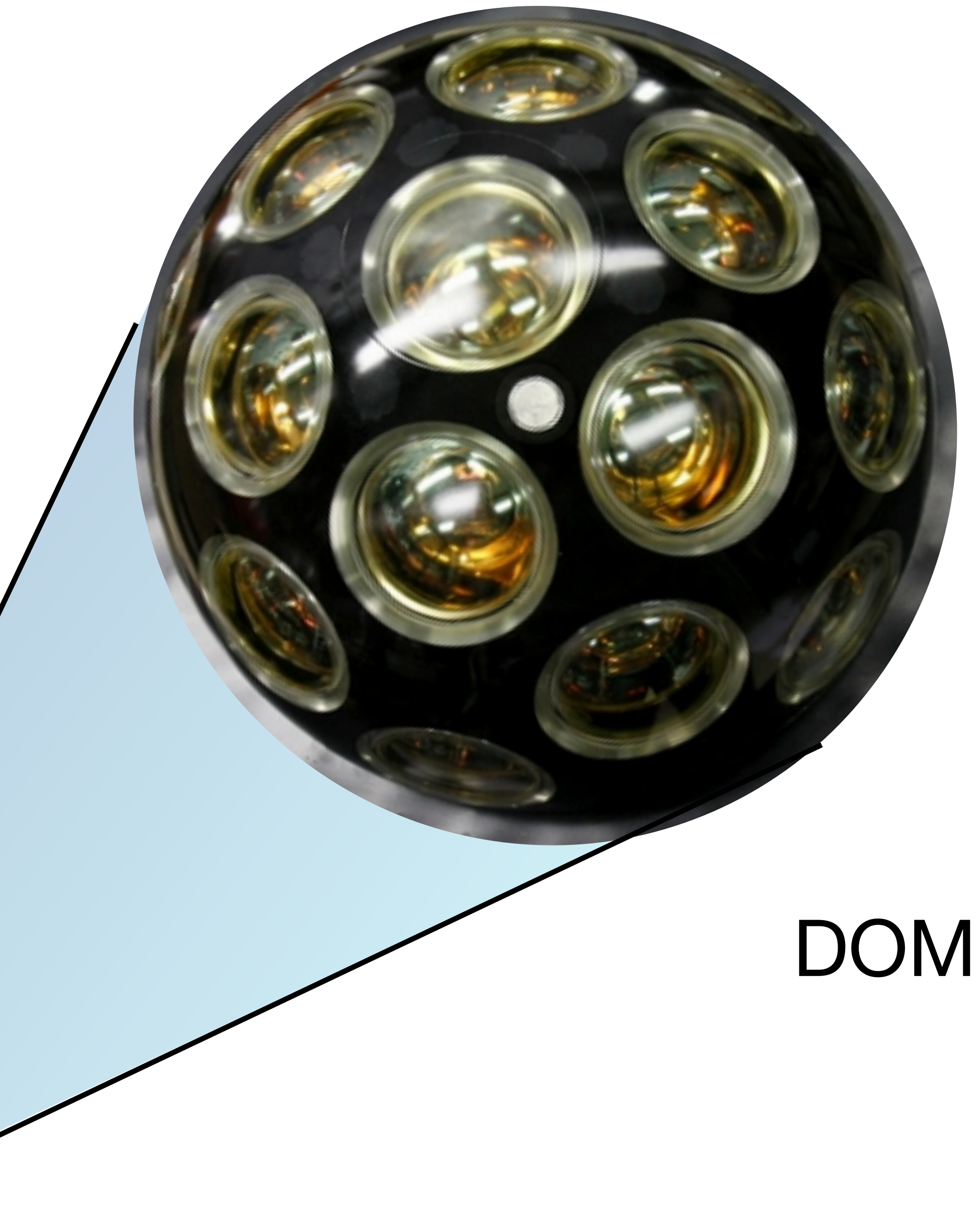

CC ν_μ
CC ν_e+ all flavours NC
CC ν_τ
Atmospheric muon
good pointing
good energy reconstruction
$\mu^\pm$
ν / $l^\pm$
τ
$\mu^\pm$
$\overset{(-)}{\nu}_\mu$
$\overset{(-)}{\nu}_X$
Showers
$\nu_\tau \xrightarrow[CC]{} \tau + \text{shower}$
Background
Or signal for Atm. Studies (CRs)
Tracks

Detection Unit

115 DUs per Building Block

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



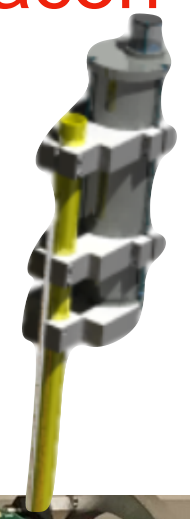


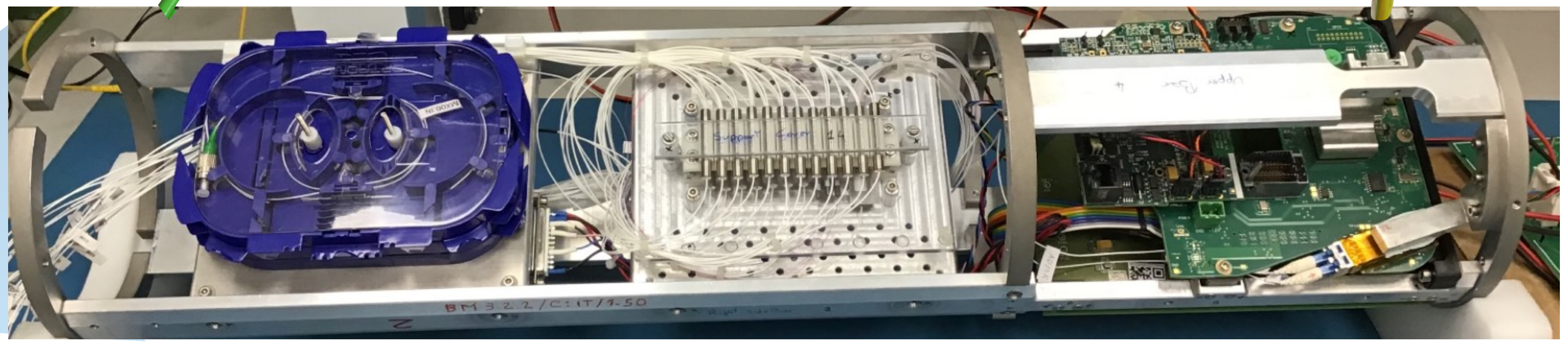
Not to scale

Digital Optical Module (DOM)

31x 3" ***PMTs*** (Physics)
piezo acoustic sensor (positioning)
system ***sensors*** (monitoring)

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

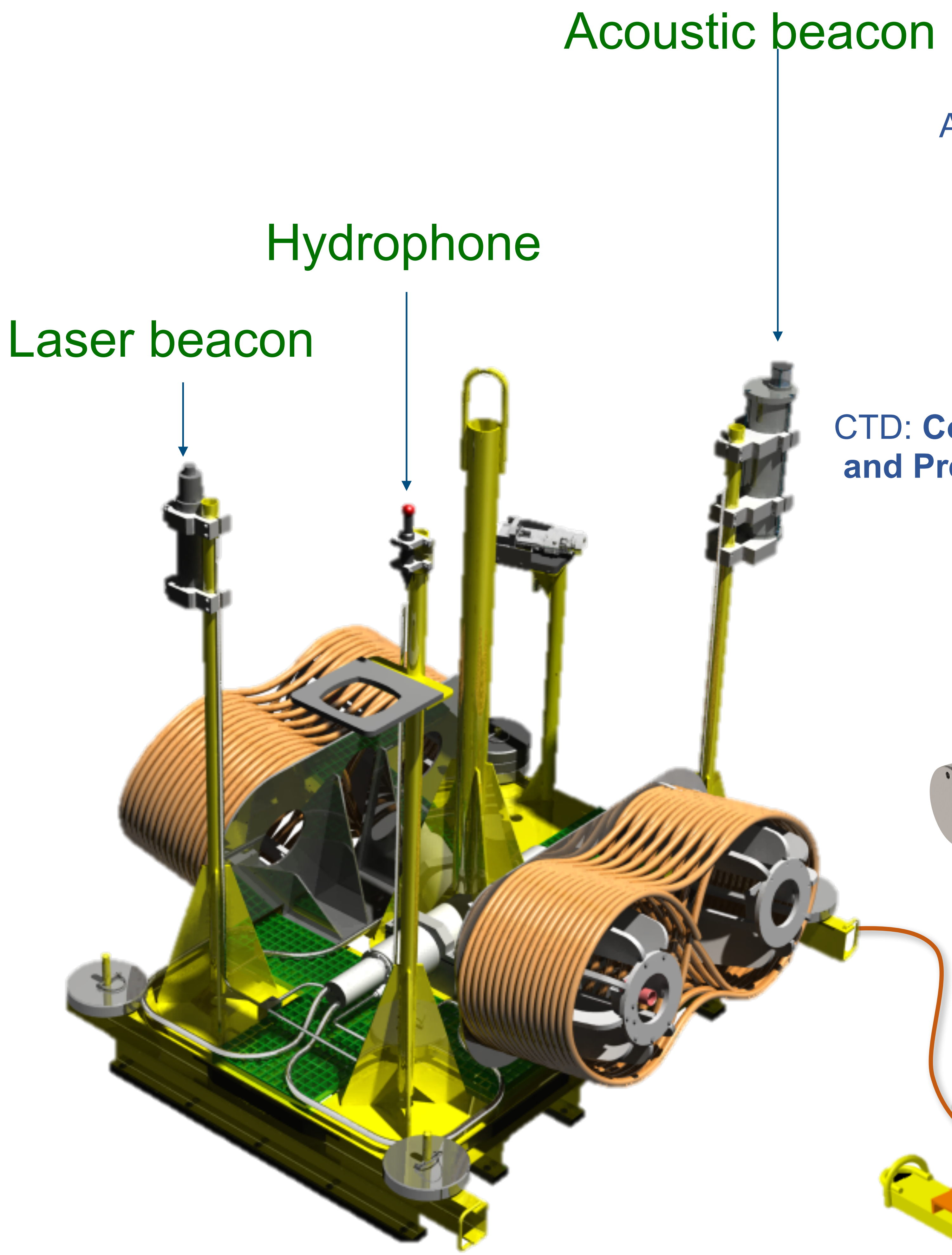




***DU-Base Module** (DU-BM) - Instruments - **no** PMT*

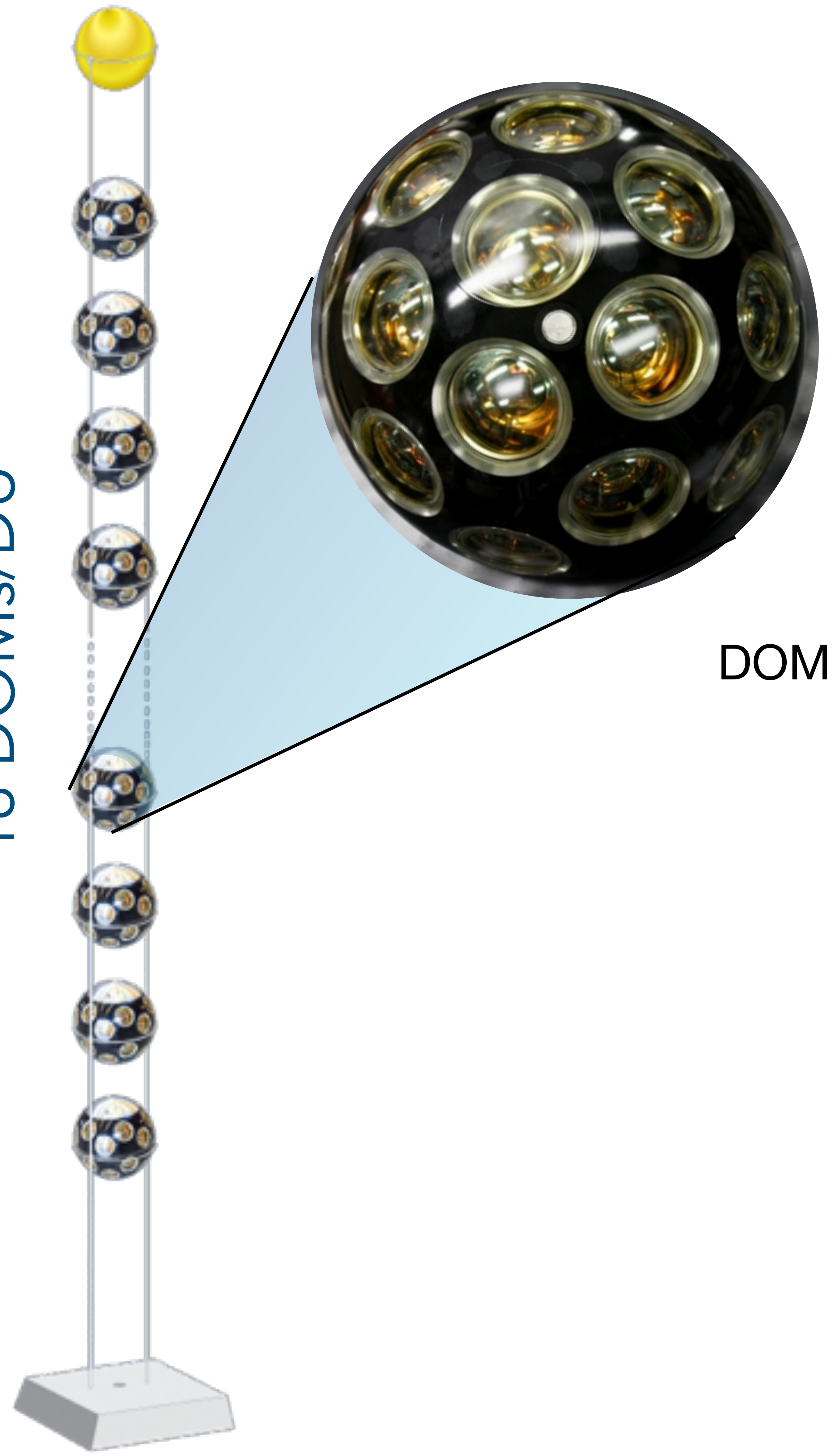
Calibration Unit

O(1) CUs per Building Block



Calibration Base Module (CU-BM)

18 DOMs/DU



Digital Optical Module
(DOM)

31x 3” ***PMTs*** (Physics)
piezo acoustic sensor
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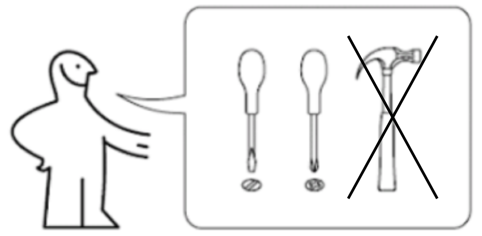
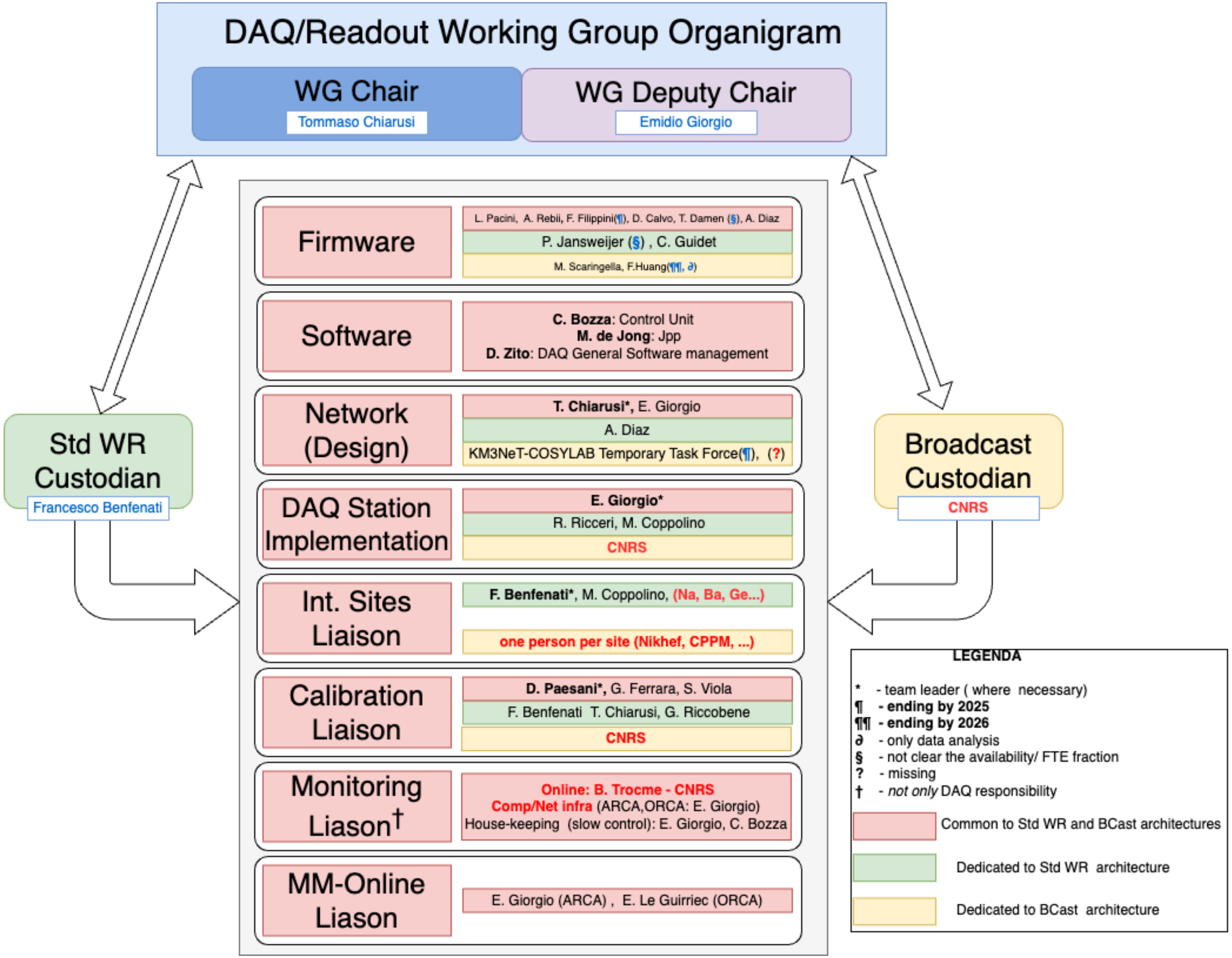
system ***sensors*** (monitoring)

DOM Paper: [2022 *JINST* **17** P0703]()



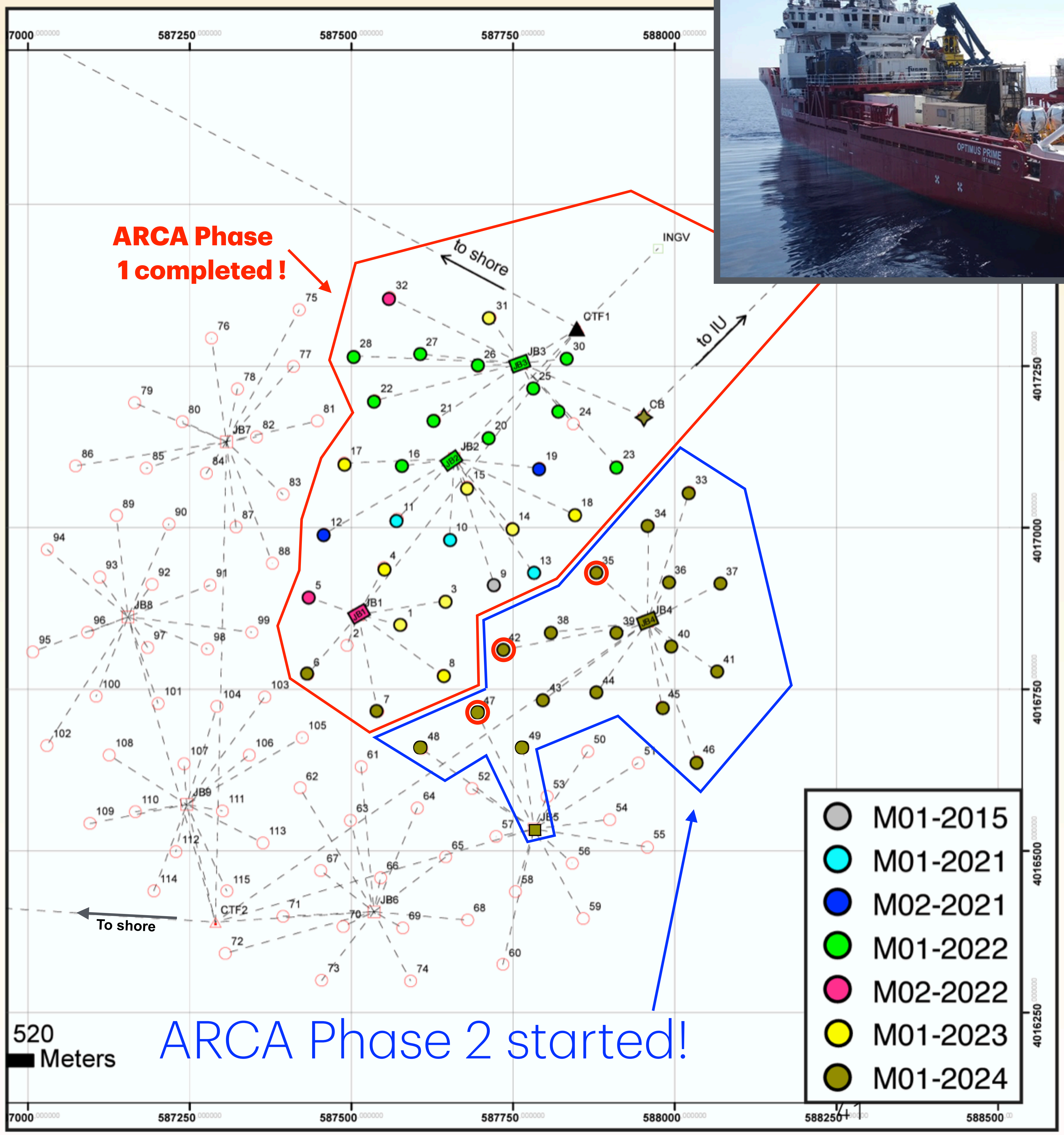
First of all: **what does DAQ mean, in KM3NeT context?**

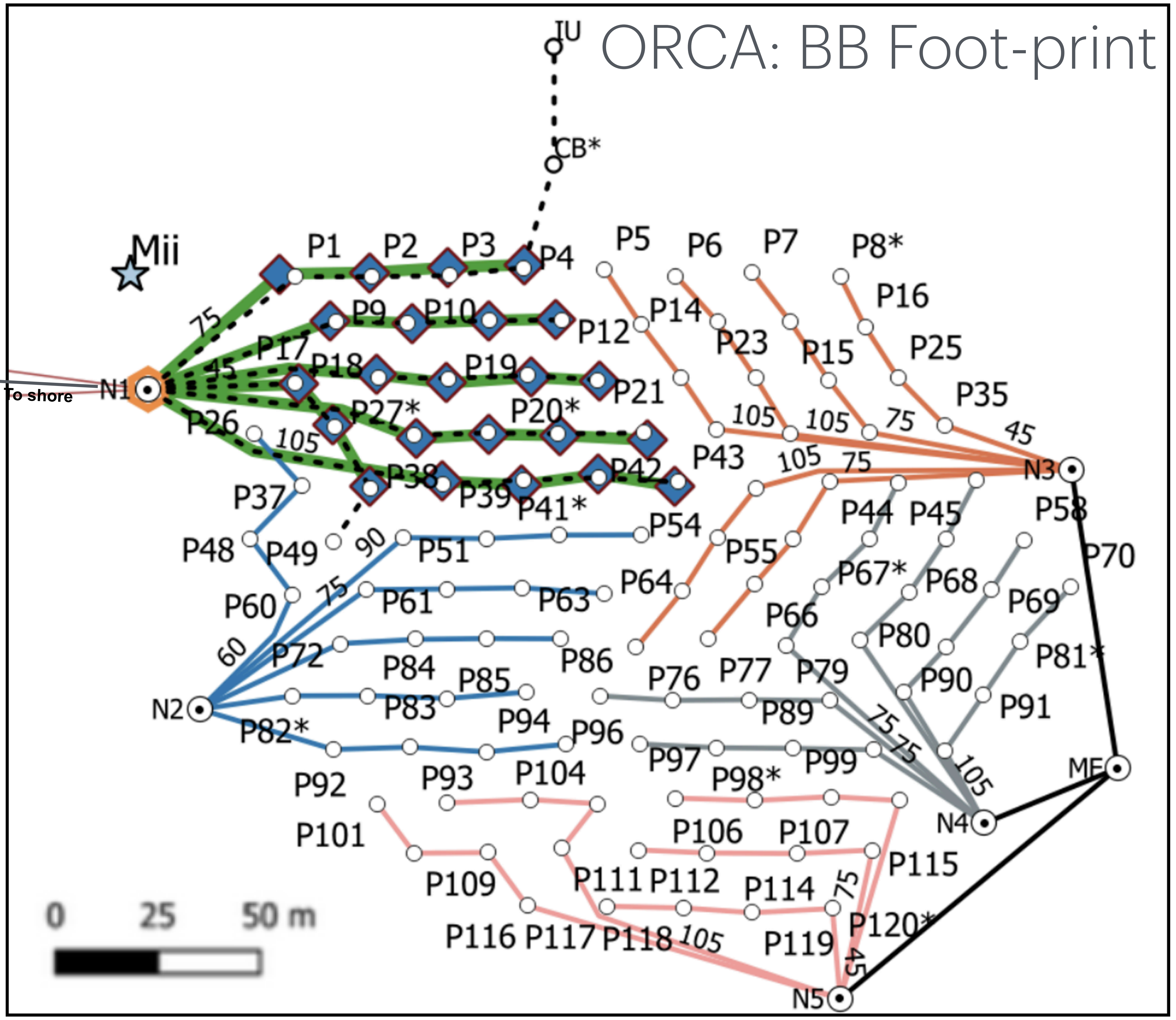

Off-shore
On-shore
(shore station facility)
Remote facilities
Detector:
DOM/Bases
VHDL
Fast Acquisition
Data - FAD
(Optical, Acoustic
Monitoring)
Time Sync
Data
White Rabbit PTP
(WR)
Slow Control Data
(Commands and
instrument data)
All FAD
to shore
GPS
Trigger and Data Acquisition
System
(TriDAS)
docker
Incoming
all FAD
FLTR
LAN
10-25GbE
TCP/IP
Class B
Selected
FAD
RAW
LAN
Hybrid-Asym.
WR-Ethernet
1-10-25GbE
UDP/IP
Class A
NETWORK
CTL
LAN
Std. Ethernet
1-2 GbE
TCP/IP
Class C
Control Unit
(CU)
Monitoring and
On-line Multi-Messenger
services
julia
Grafana
HTML
ZABBIX
External
Links
10 GbE
TCP/IP
Class C
Local
Storage
NFS
Network File System
CNAF
(Bologna -
Italy)
DAV
CC-Lyon
(France)
iRODS
DataBase
(Italy and
France)
ORACLE
White Rabbit
Openflow
ORACLE
HTML
XML
JSON
mono
VHDL
docker
python
julia
ANSIBLE
Grafana
ZABBIX
NFS
Network File Systen
webDAV
Observium
CentOS
iRODS



DAQ/Readout Working Group Organigram
WG Chair
Tommaso Chiarusi
WG Deputy Chair
Emidio Giorgio
Std WR Custodian
Francesco Benfenati
Broadcast Custodian
CNRS
Firmware
L. Pacini, A. Rebii, F. Filippini(¶), D. Calvo, T. Damen (§), A. Diaz
P. Jansweijer (§) , C. Guidet
M. Scaringella, F.Huang(¶¶, ∂)
Software
C. Bozza: Control Unit
M. de Jong: Jpp
D. Zito: DAQ General Software management
Network (Design)
T. Chiarusi*, E. Giorgio
A. Diaz
KM3NeT-COSYLAB Temporary Task Force(¶), (?)
DAQ Station Implementation
E. Giorgio*
R. Ricceri, M. Coppolino
CNRS
Int. Sites Liaison
F. Benfenati*, M. Coppolino, (Na, Ba, Ge...)
one person per site (Nikhef, CPPM, ...)
Calibration Liaison
D. Paesani*, G. Ferrara, S. Viola
F. Benfenati T. Chiarusi, G. Riccobene
CNRS
Monitoring Liason†
Online: B. Trocme - CNRS
Comp/Net infra (ARCA,ORCA: E. Giorgio)
House-keeping (slow control): E. Giorgio, C. Bozza
MM-Online Liason
E. Giorgio (ARCA) , E. Le Guirriec (ORCA)
LEGENDA
* - team leader (where necessary)
¶ - ending by 2025
¶¶ - ending by 2026
∂ - only data analysis
§ - not clear the availability/ FTE fraction
? - missing
† - not only DAQ responsibility
Common to Std WR and BCast architectures
Dedicated to Std WR architecture
Dedicated to BCast architecture

ARCA BB#1 Foot-print

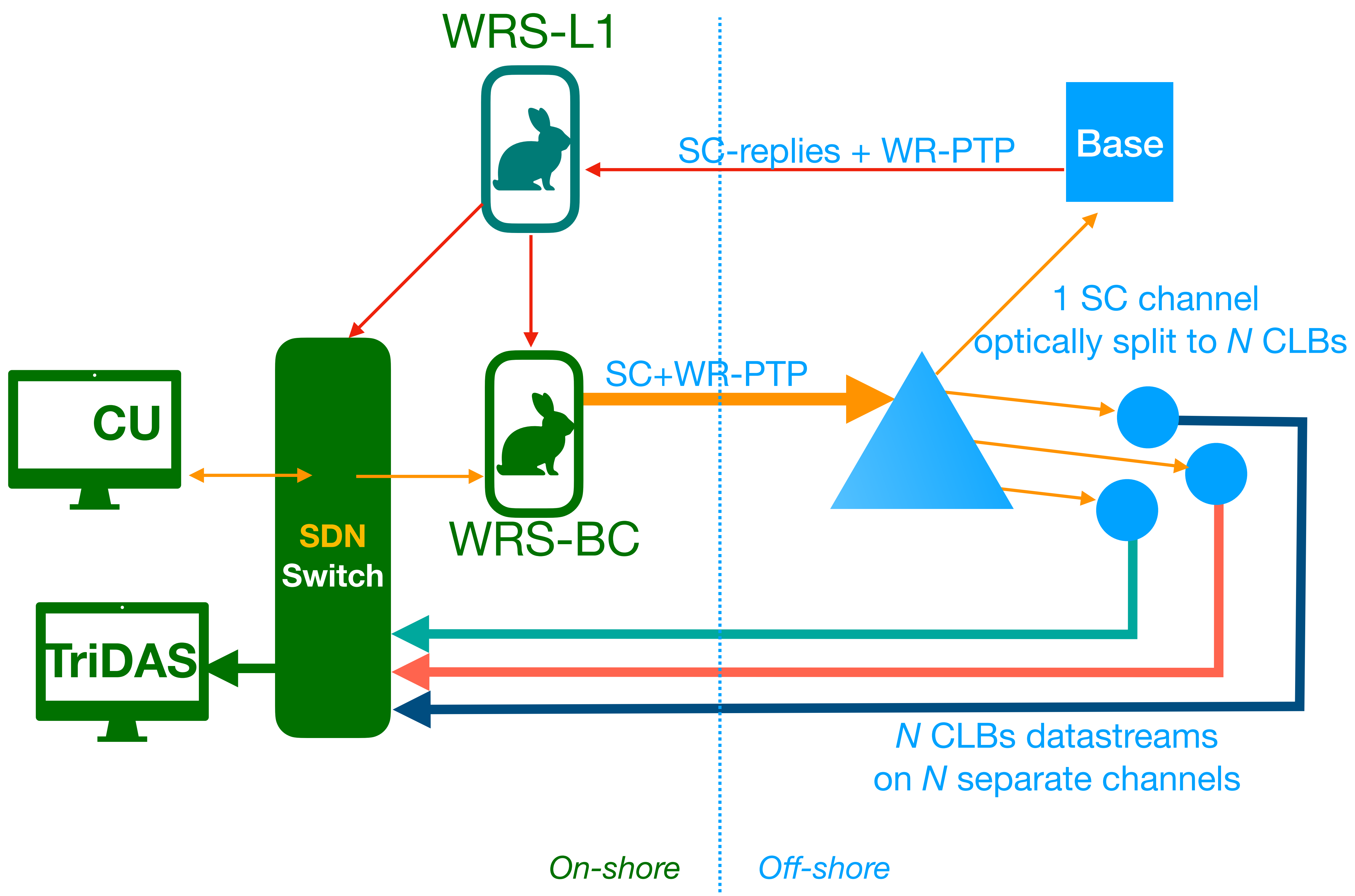




Almost completed the first node ~ 20% ORCA

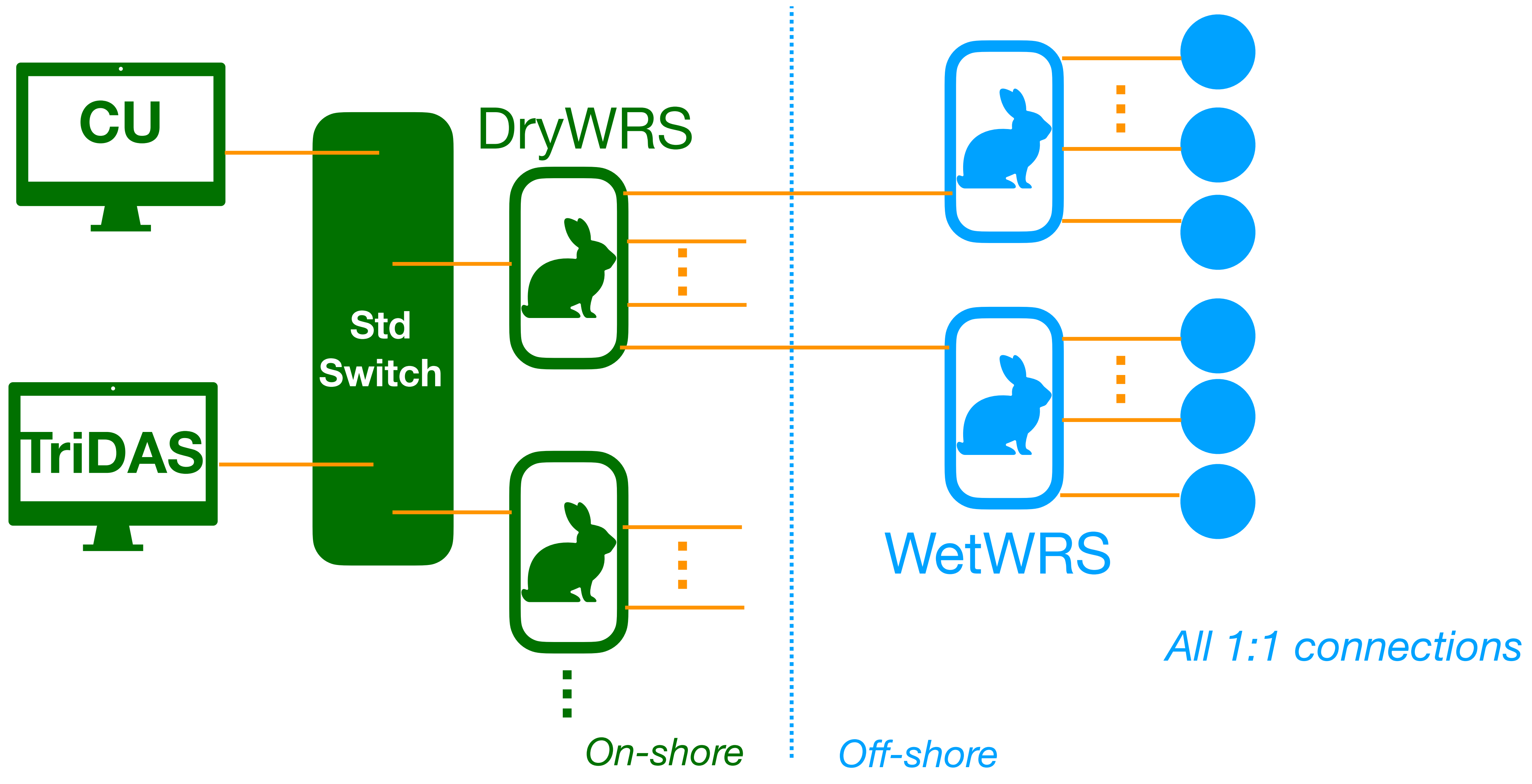
M01-2024 operatons ended 21/10/2024 ~0.14 km^3 Next ARCA sea operations: July 2025

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

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

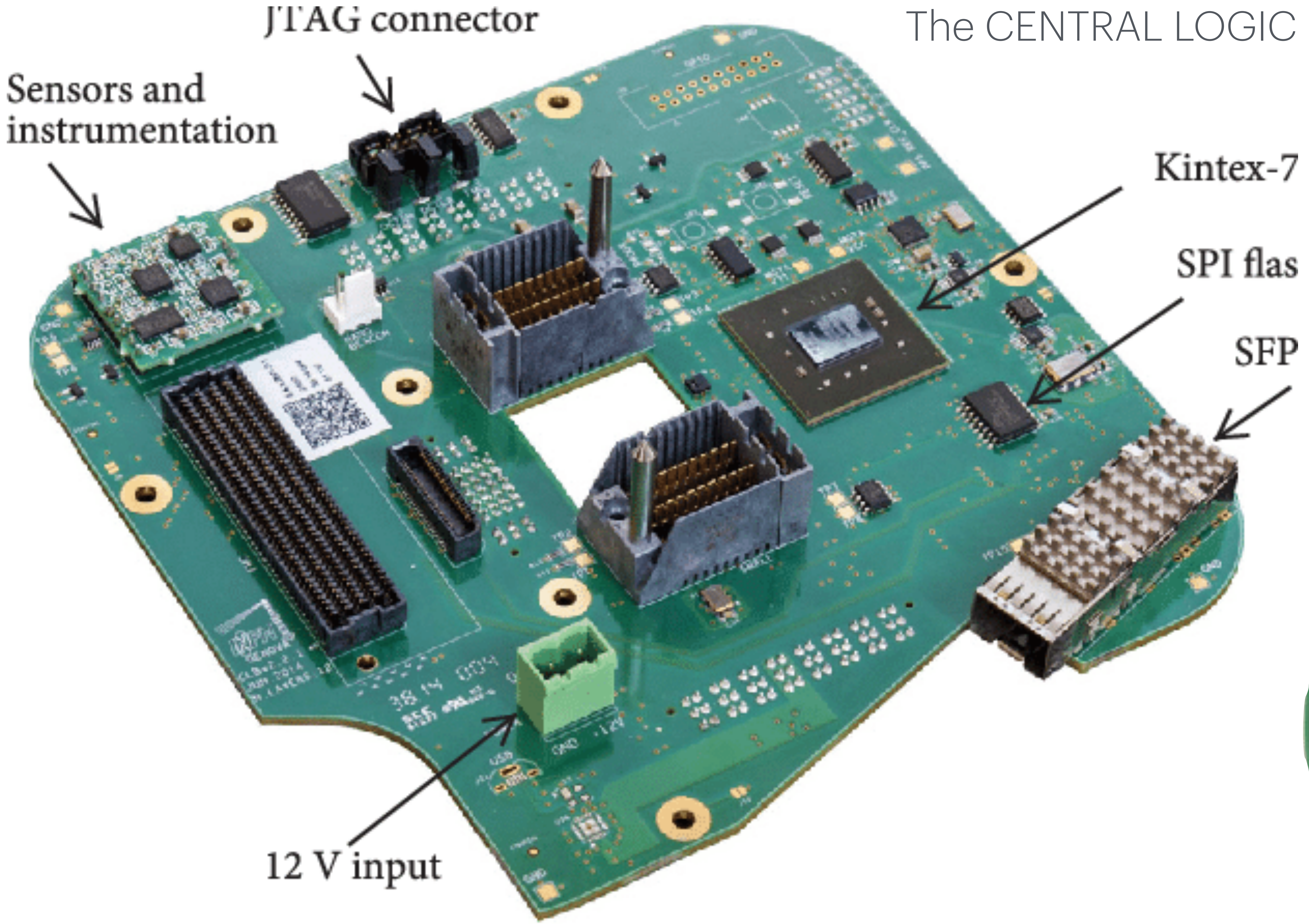
Case	DOM thp (Mb/s)	DU thp (Gb/s)	Det thp (Gb/s)	Sel thp (MB/s)	Sel thp (TB/day)	Stored (TB/y)	event size(kB)
KM3NeT–Ph1, It	23.0	0.4	10.0	1.6	0.13	49.0	7.5
KM3NeT–Ph1, *Fr*	23.0	0.4	2.9	0.4	0.03	12.0	2.2
KM3NeT–1 Block (Ph2, *Fr*)	23.0	0.4	48.0	14.0	1.20	440.0	36.0
KM3NeT–2 Blocks (Ph2, *It*)	23.0	0.4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

Acoustic data for positioning

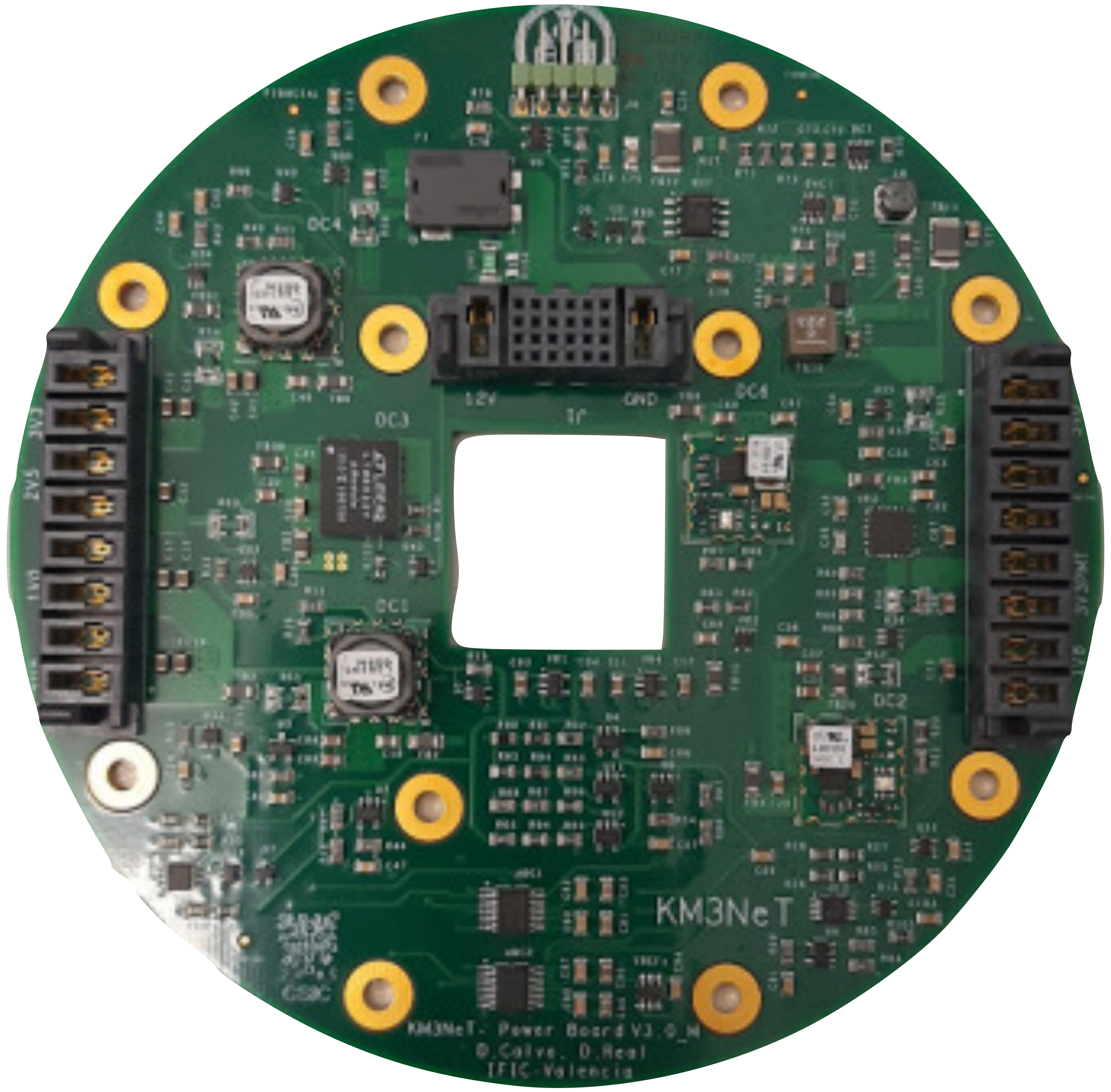
Case	Raw Thp/Sensor (Mb/s)	Raw Thp/DU (Mb/s)	Raw Thp/Detector (Gb/s)	TOA (Mb/s)	Positions (Mb/s)	Storage (TB/y)
Phase 1–*It*	13.0	240.0	5.7	0.20	0.08	1.10
Phase 1–*Fr*	13.0	240.0	1.7	0.06	0.02	0.32
1 Block, Ph2 *Fr*	13.0	240.0	27.0	0.94	0.38	5.20
2 Blocks, Ph2 It	13.0	240.0	55.0	1.90	0.75	10.00

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

The CENTRAL LOGIC BOARD (CLB)



The CLB Power Board



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

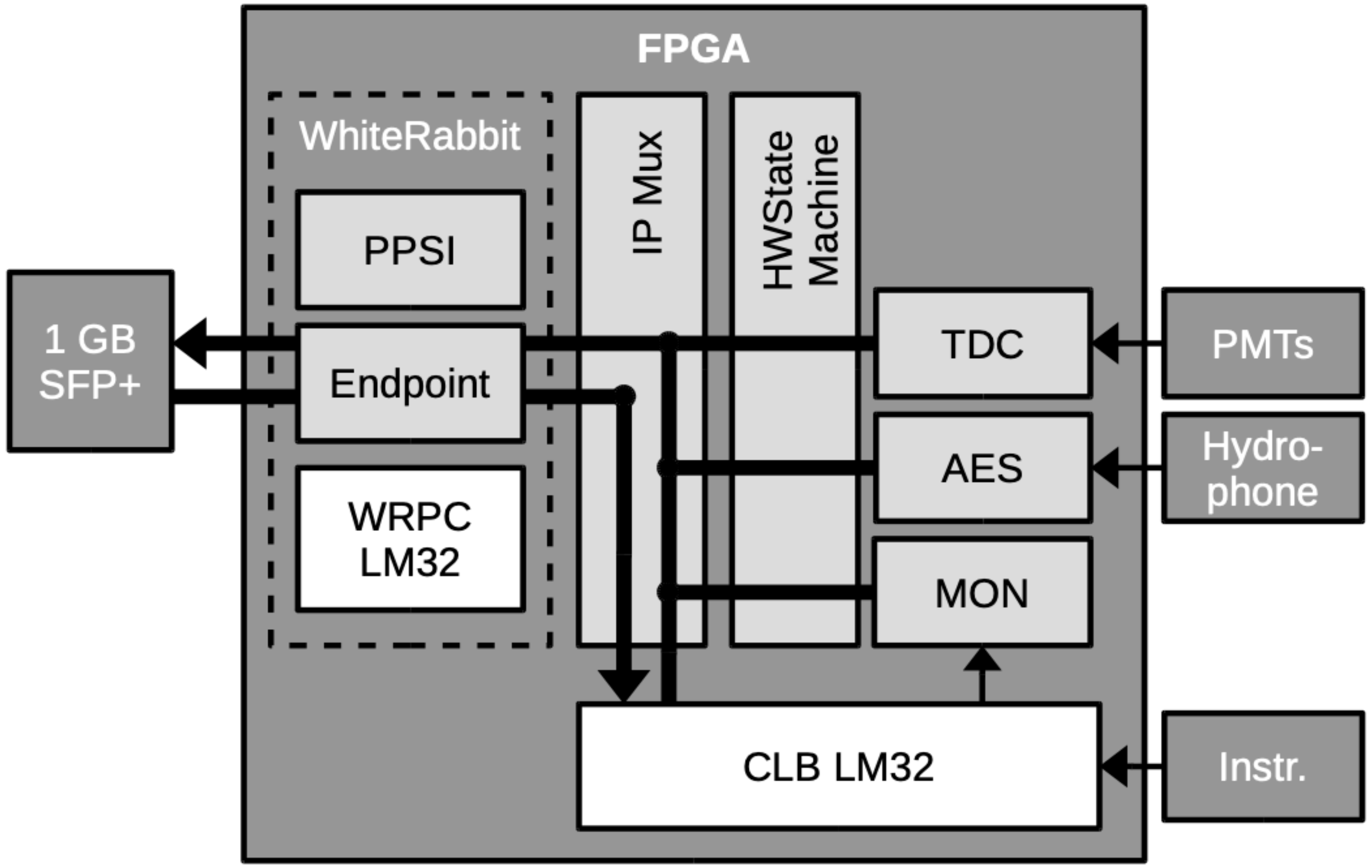
CLB FIRMWARE ARCHITECTURE

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

CLB firmware maintained in a GIT KM3NeT repo

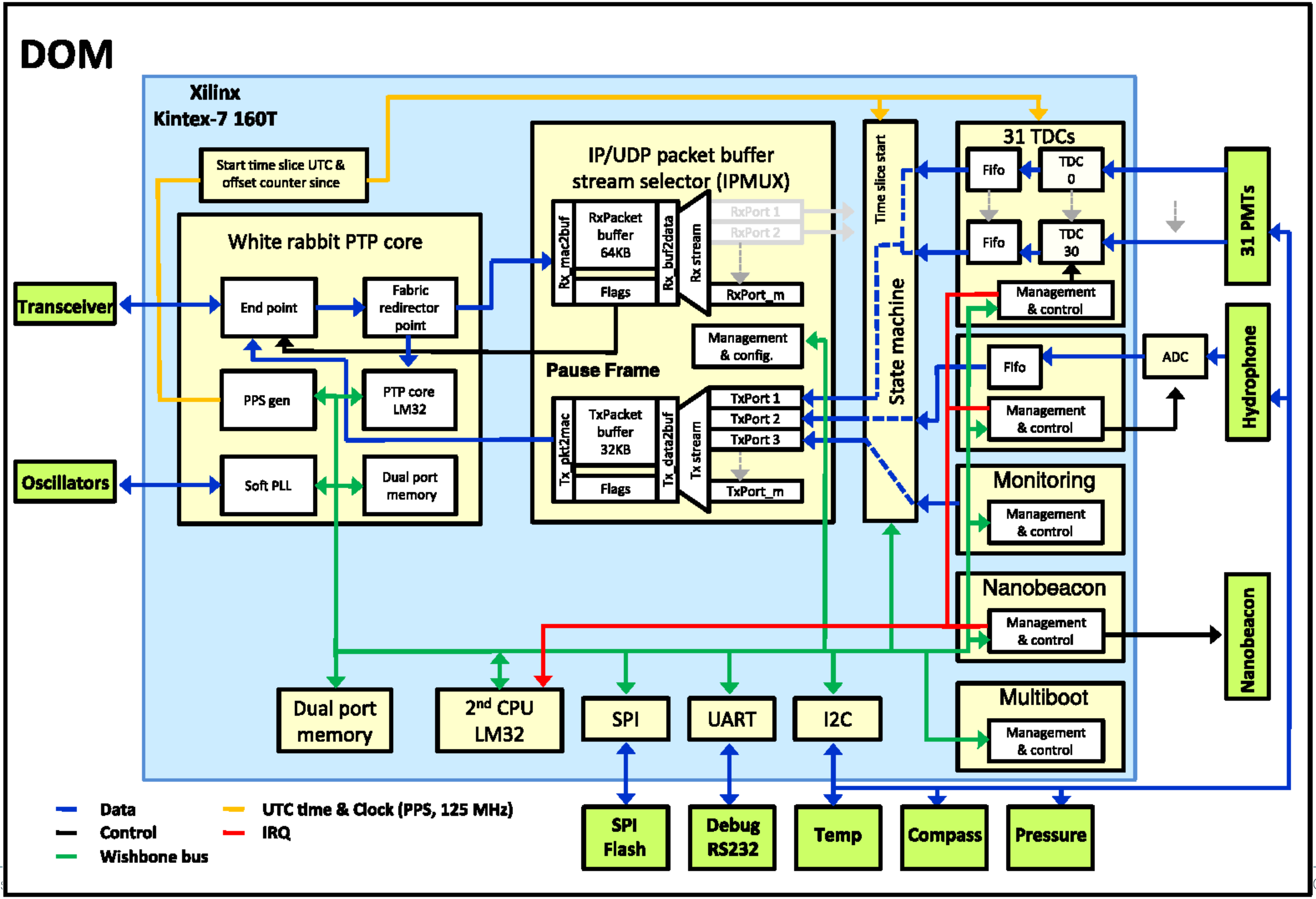
Development environment based on Docker-containers (with dedicated VIVADO installation)

Continuous Integration schedules in place

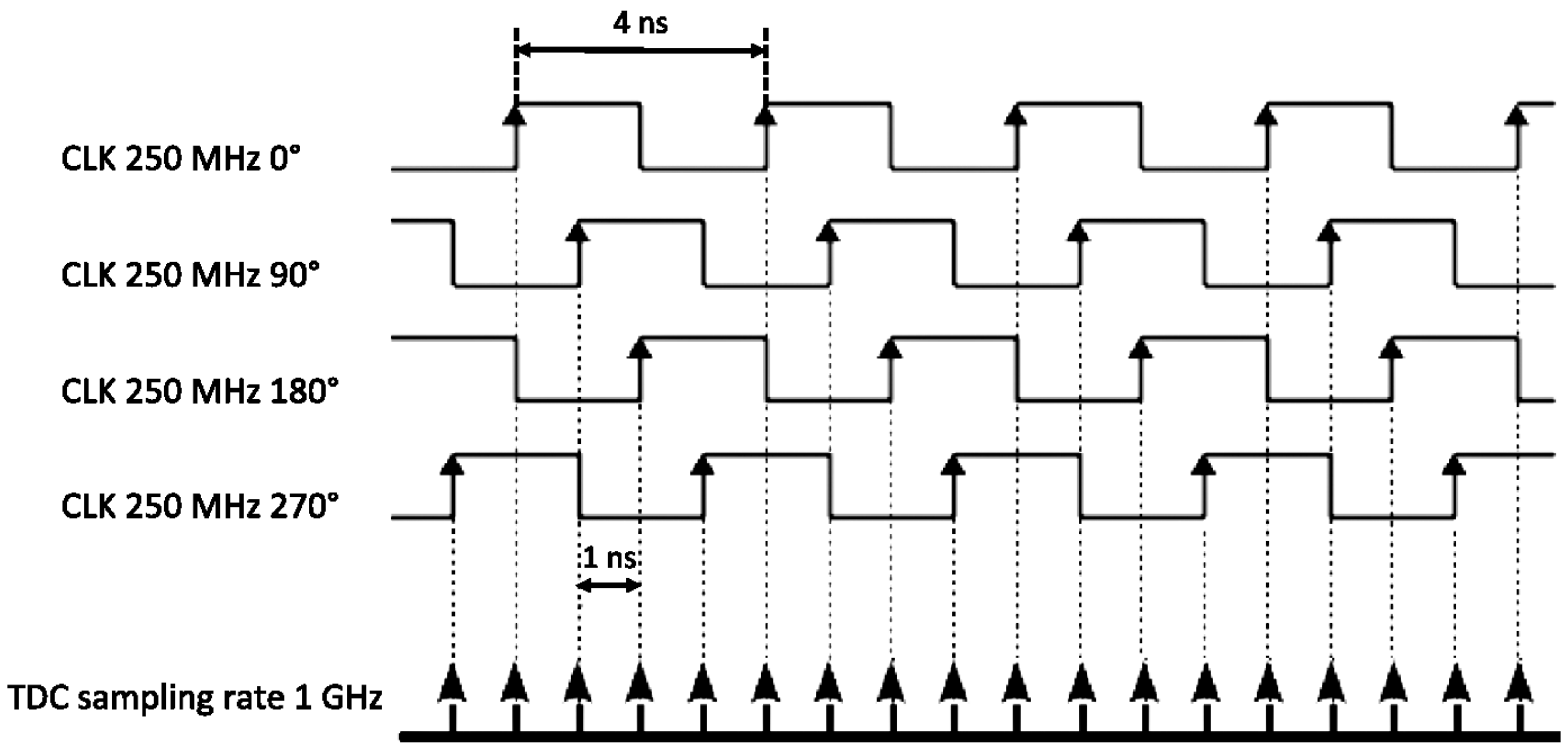
Tag/release versioning via GIT

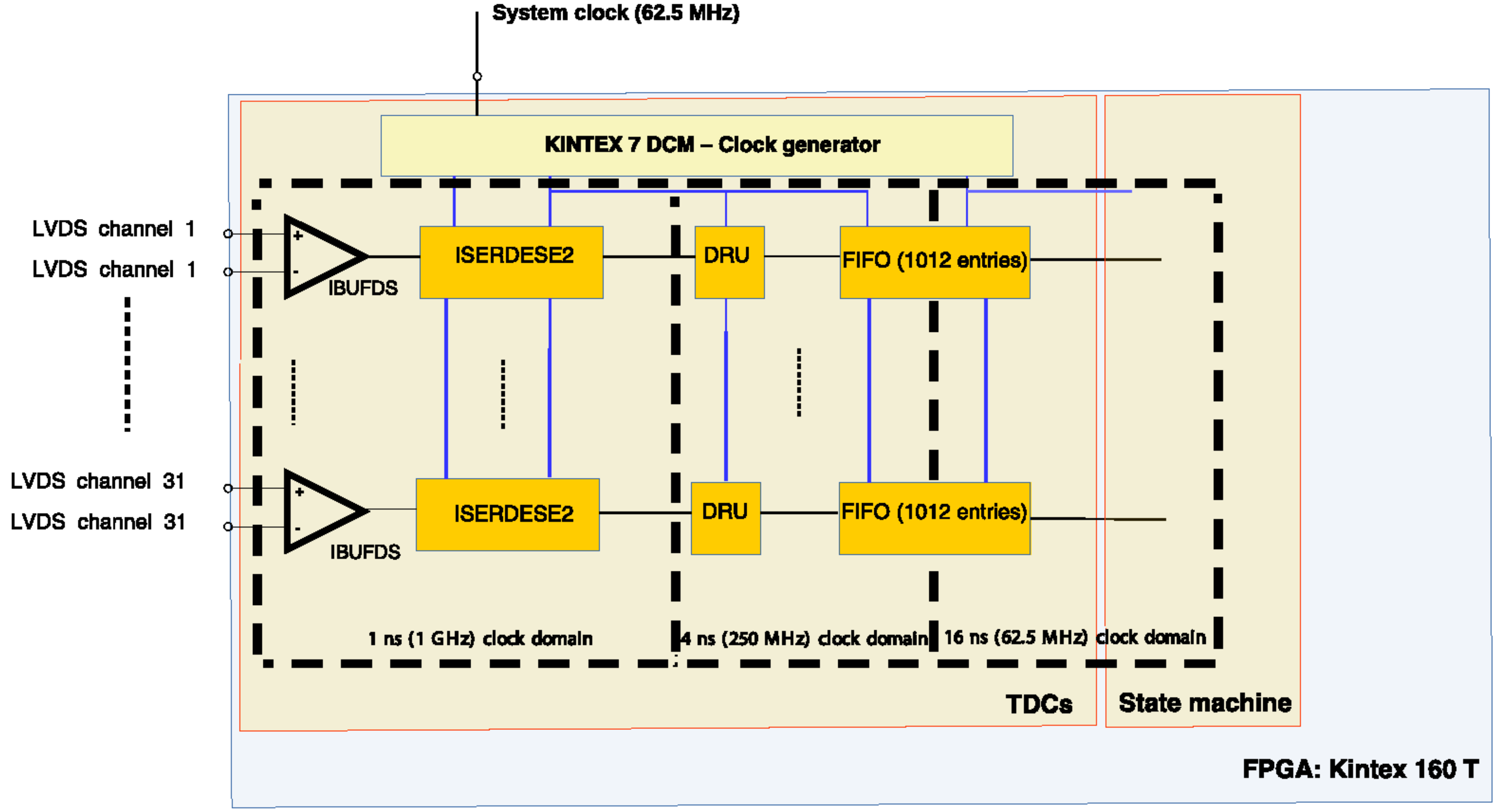
Fw archived in KM3NeT DB with proper PBS, variant, version, serial coding
(the Unique Product Identity)

(Implementing now) —>> DB-based flashing tools


DOM
Xilinx
Kintex-7 160T
Start time slice UTC & offset counter since
White rabbit PTP core
End point
Fabric redirector point
PPS gen
PTP core LM32
Soft PLL
Dual port memory
Transceiver
Oscillators
IP/UDP packet buffer stream selector (IPMUX)
Rx_mac2buf
RxPacket buffer 64KB
Flags
Rx_buf2data
Rx stream
RxPort 1
RxPort 2
RxPort_m
Management & config.
Pause Frame
Tx_pkt2mac
TxPacket buffer 32KB
Flags
Tx_data2buf
Tx stream
TxPort 1
TxPort 2
TxPort 3
TxPort_m
Time slice start
State machine
31 TDCs
Fifo
TDC 0
Fifo
TDC 30
Management & control
31 PMTs
Fifo
Management & control
ADC
Hydrophone
Monitoring
Management & control
Nanobeacon
Management & control
Nanobeacon
Multiboot
Management & control
Dual port memory
2nd CPU LM32
SPI
UART
I2C
SPI Flash
Debug RS232
Temp
Compass
Pressure
Data
Control
Wishbone bus
UTC time & Clock (PPS, 125 MHz)
IRQ

Scheme of the 4×4×-oversampling technique. The sampling quadruples the clock frequency using four phases of the original clock, shifted by 90 deg each, thus obtaining a sampling frequency of 1 GHz when using a clock with a period of 4 ns.





The architecture of the KM3NeT TDCs. Three different subsystems can be identified in the TDC.

The first one, running at 1 ns, contains the differential input to the FPGA, the IBUFDS, together with the IOSERDES, where the acquisition is performed.

The second one contains the DRU, with the logic to adapt the hits to the format required and to store them in the FIFOs. It works at 4 ns.

The third one consists of the logic to read out the FIFOs and provides the obtained hits to the next acquisition level, the SM, running in this case at 16 ns. The interface between the second and the third subsystem is done by means of the FIFOs.

CLB Optical Format Structure

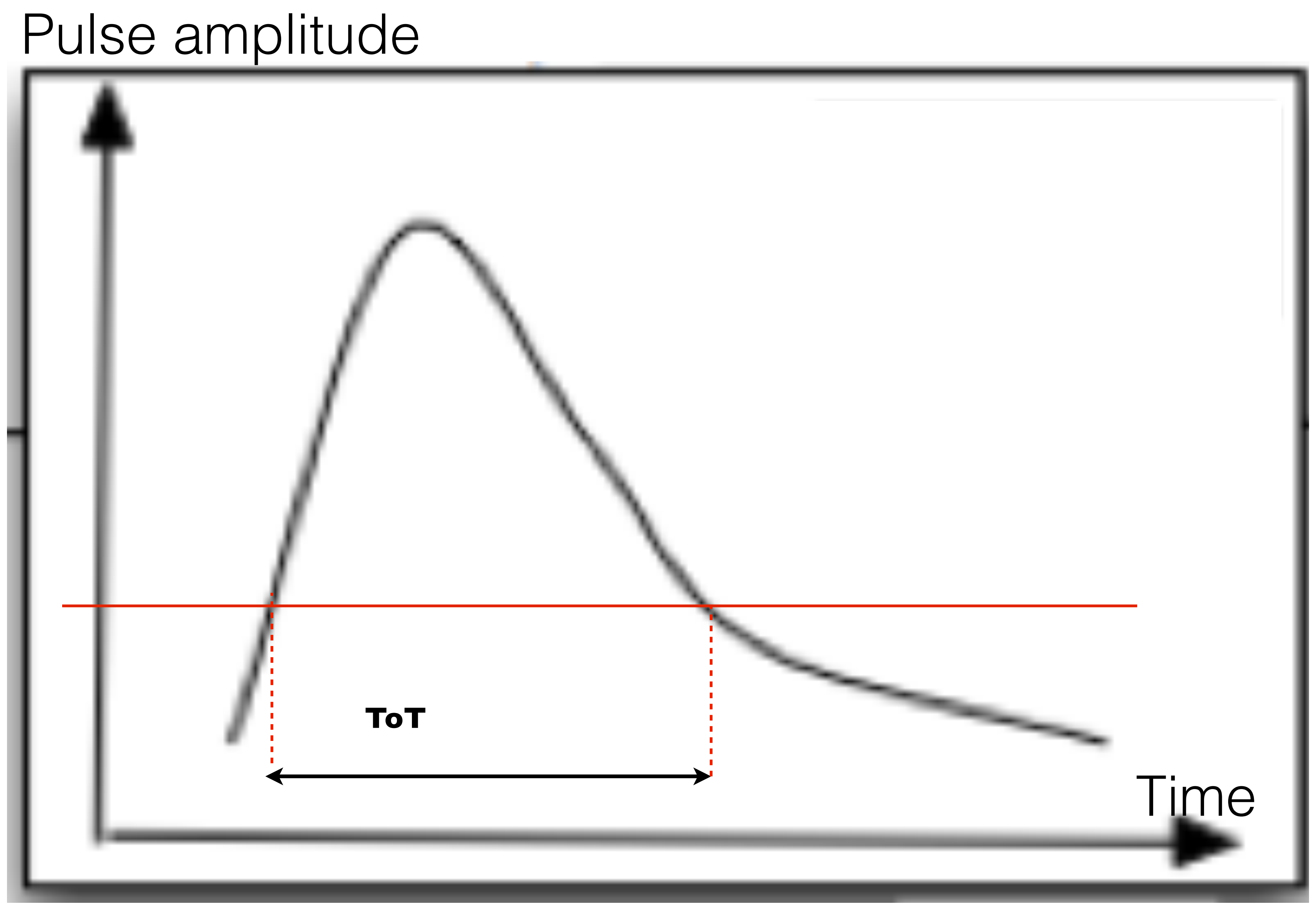
Size (bit)	Description
448	DAQ Common Header
8	TDC channel
32	Time Stamp
8	Pulse Width
8	TDC channel
32	Time Stamp
8	Pulse Width
...	...
8	TDC channel
32	Time Stamp
8	Pulse Width

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.**



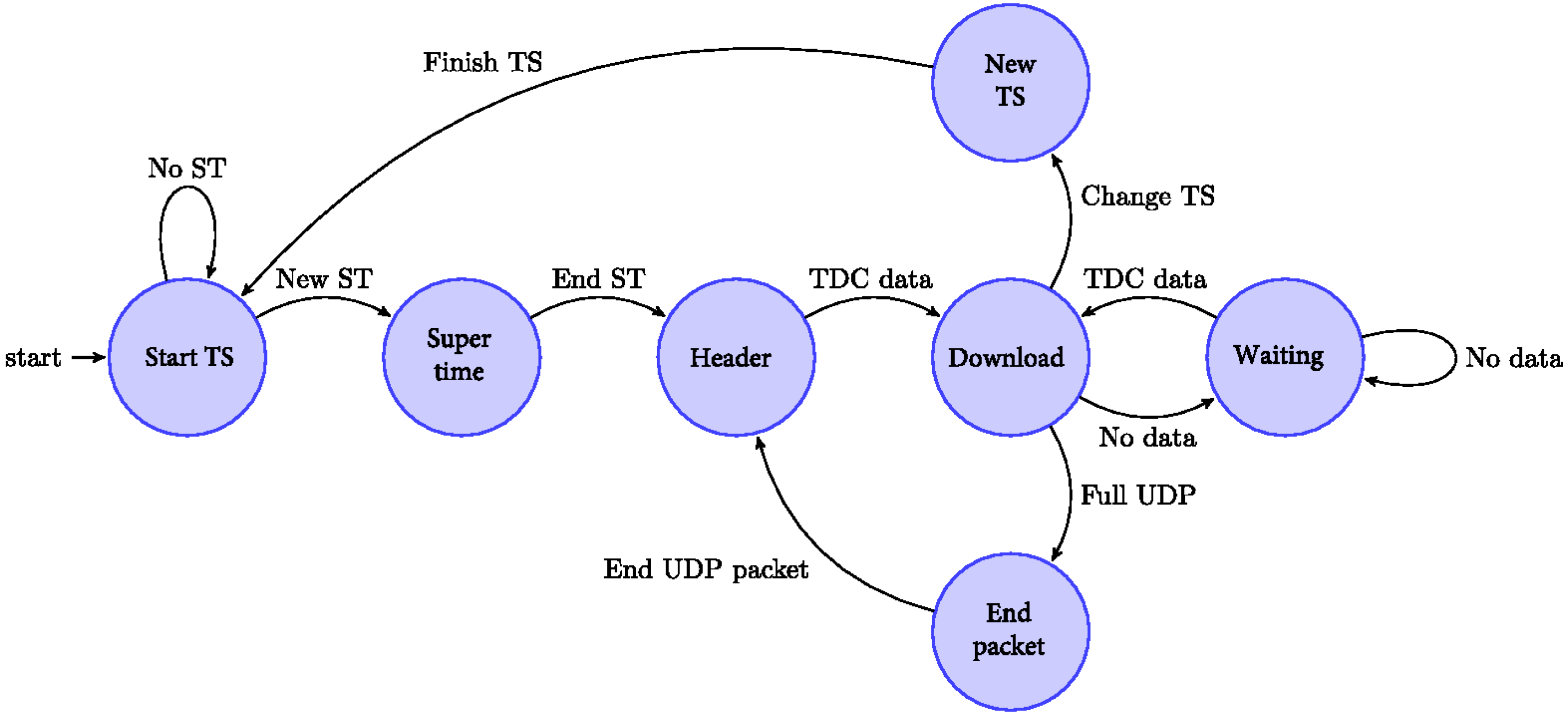
Time over Threshold

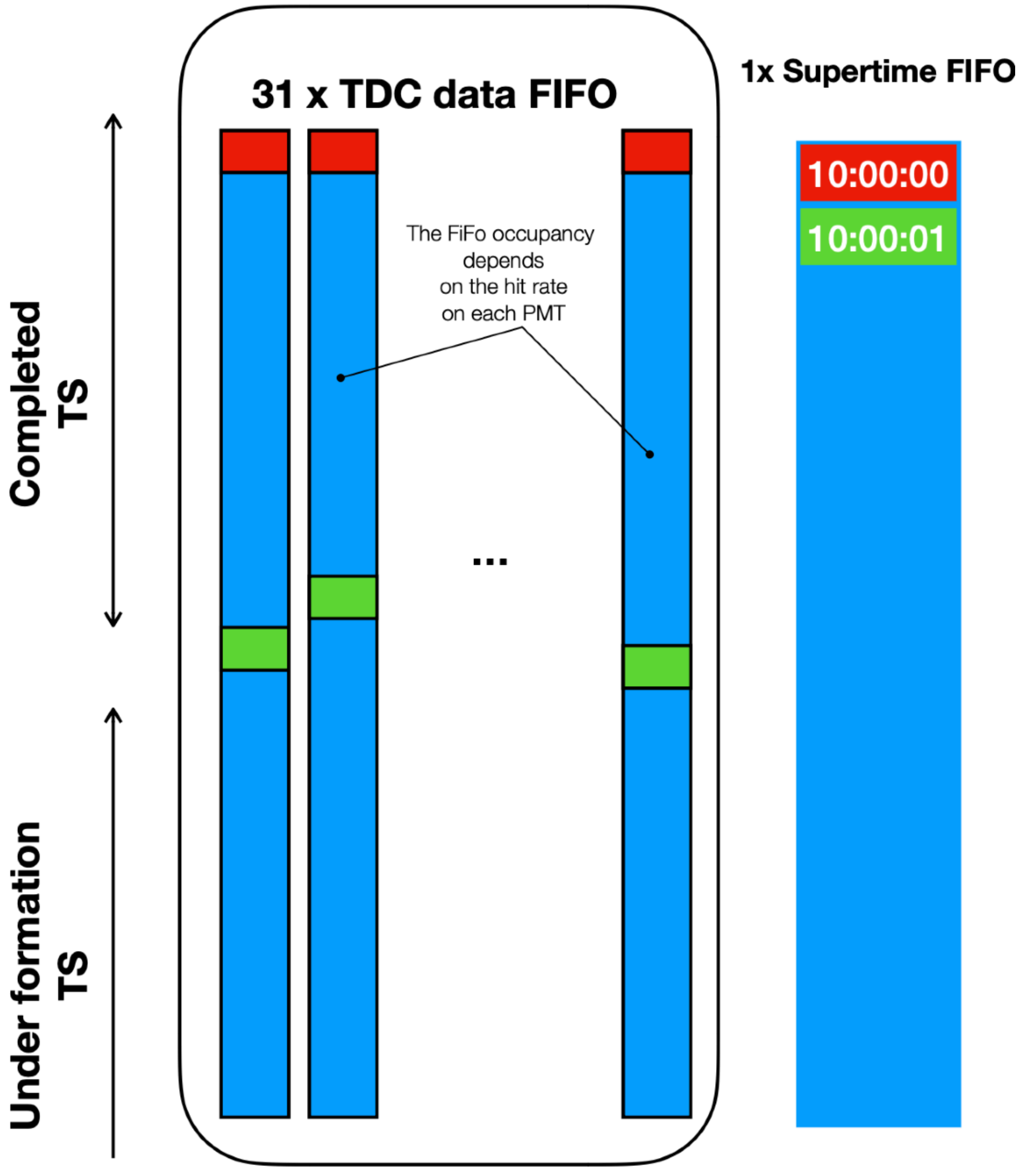
ToT <=> pulse amplitude.

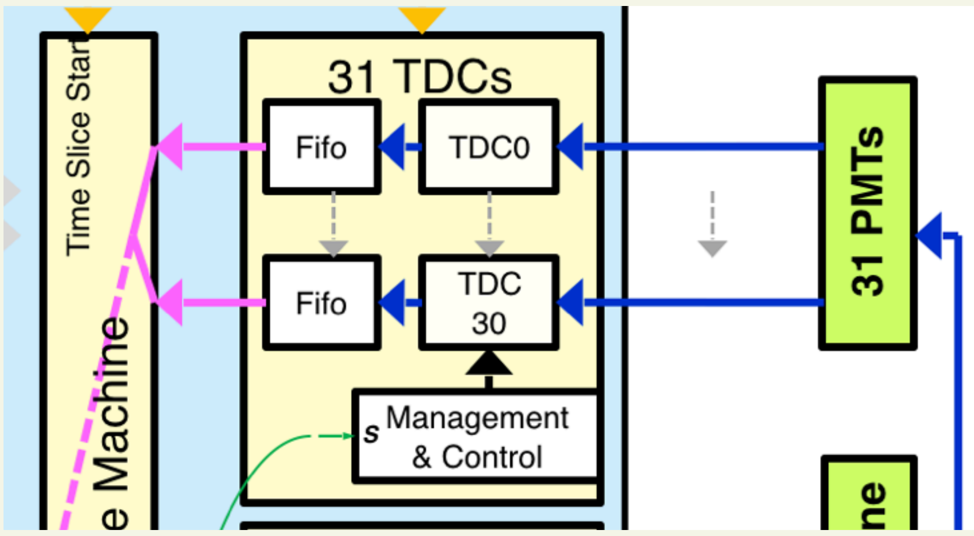
Optimal gain (~10^6) => **ToT of 26,4 ns for single photo-electron**

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

TDC STATE MACHINE







FIFO *almost* full

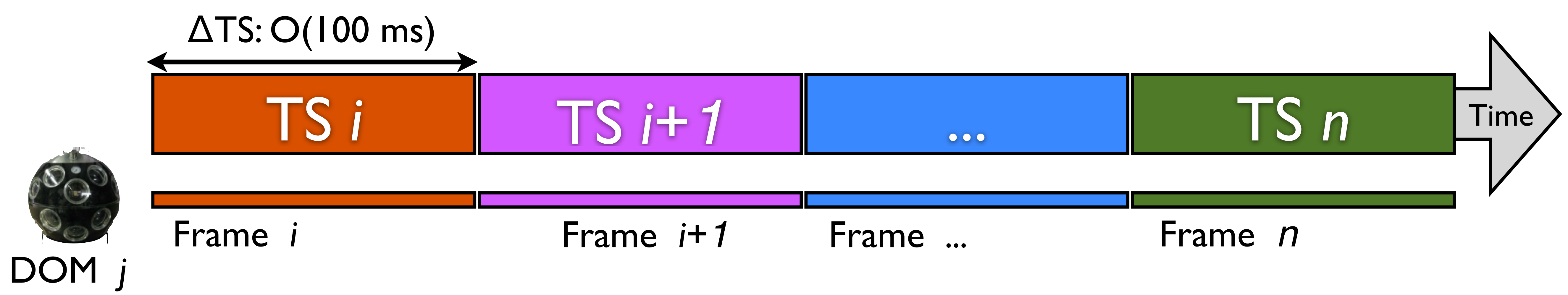
The CLB spends **~48 ns** for transferring 1 hit from the FIFO in the buffer to send.

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.

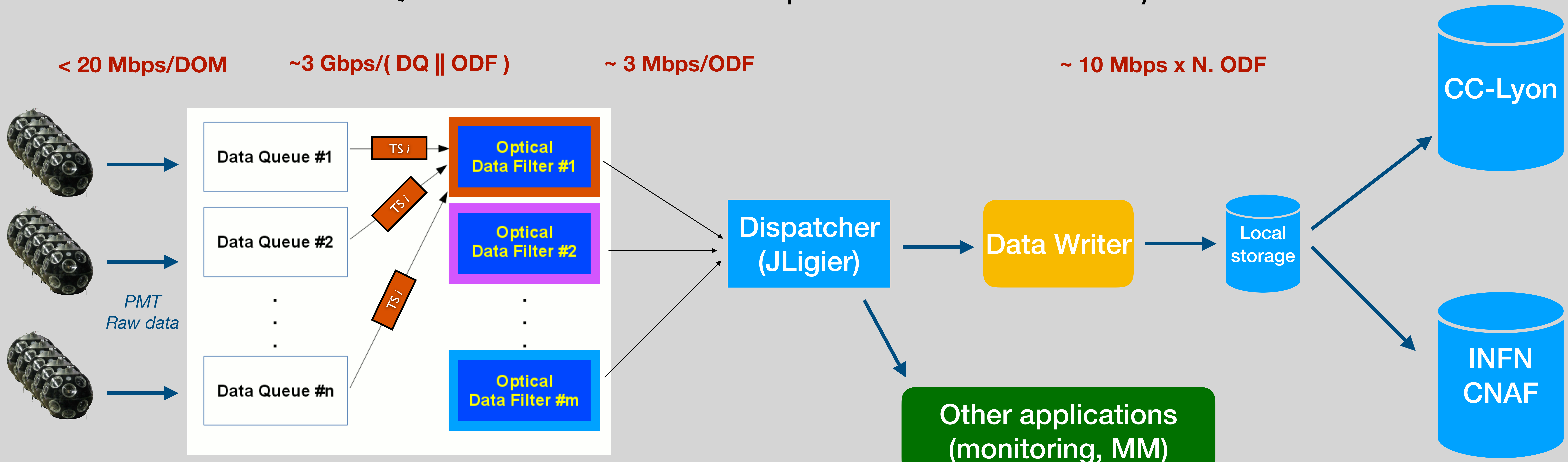


Distributing the computational load

- 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!

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}

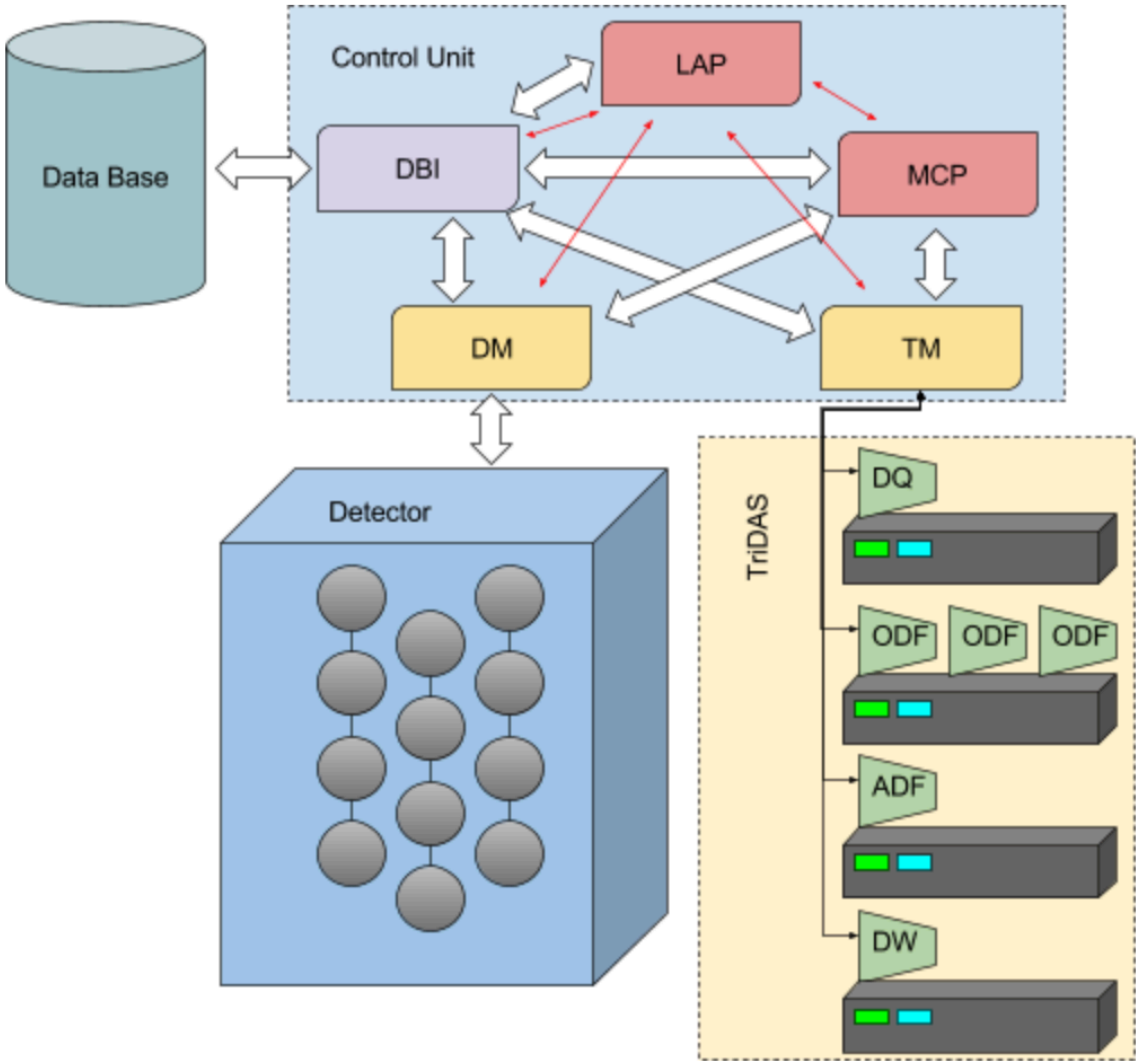
- **3D-Muon/Shower**
  Assumes an extended track-like / short pulse shape for the event topology
- **MX-Shower**
  Cluster one L2 with causality-combined L0s.
- **Supernova (SN)**
  Combines L1 with additional constraints (e.g. multiplicity of L0 hits)

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

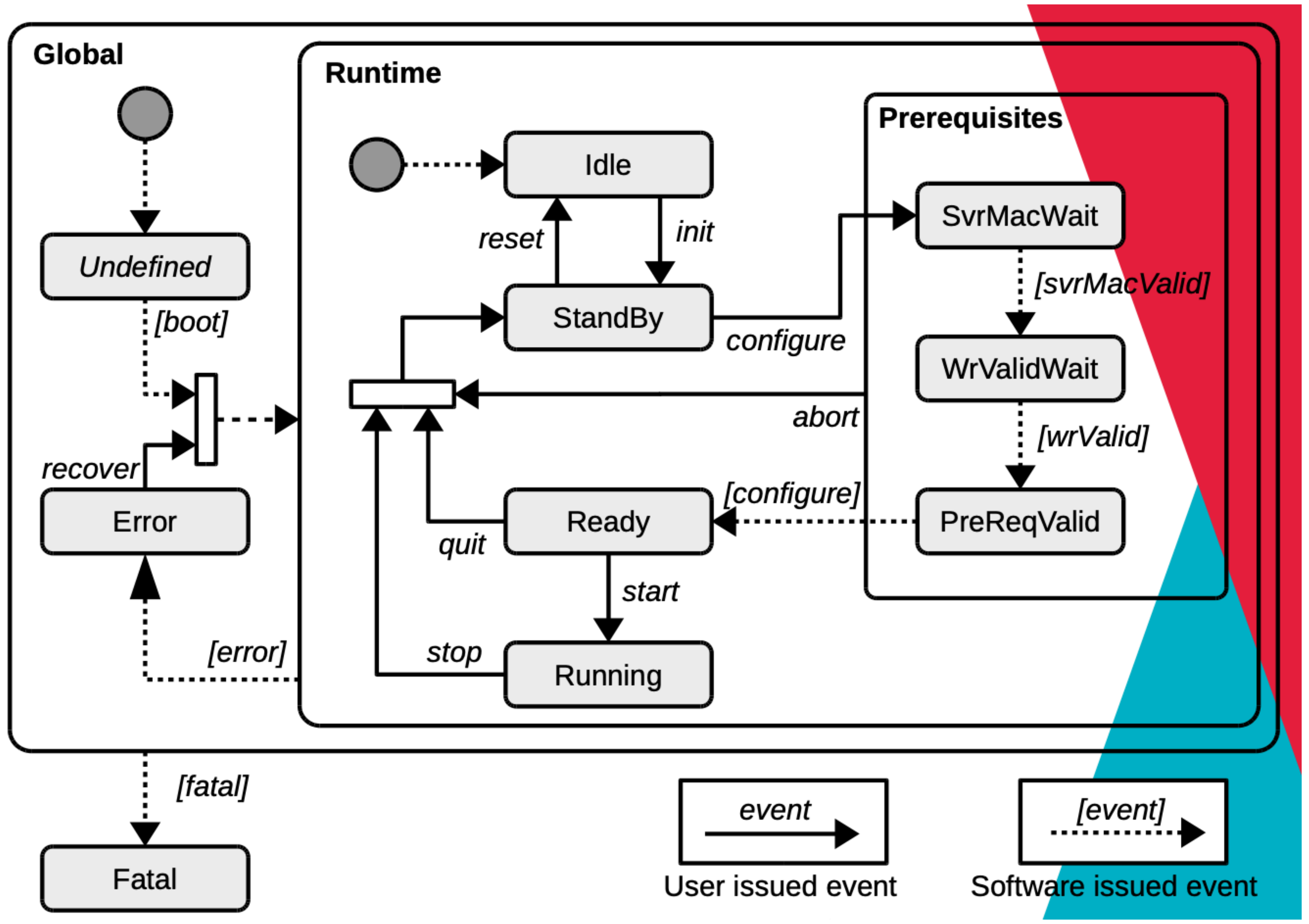
Trigger algorithms developed within a large C++ software framework, *Jpp.* The same codes are used for the on-line DAQ as well as off-line analysis.

Jpp
The Jpp Git repository.
Click here

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.

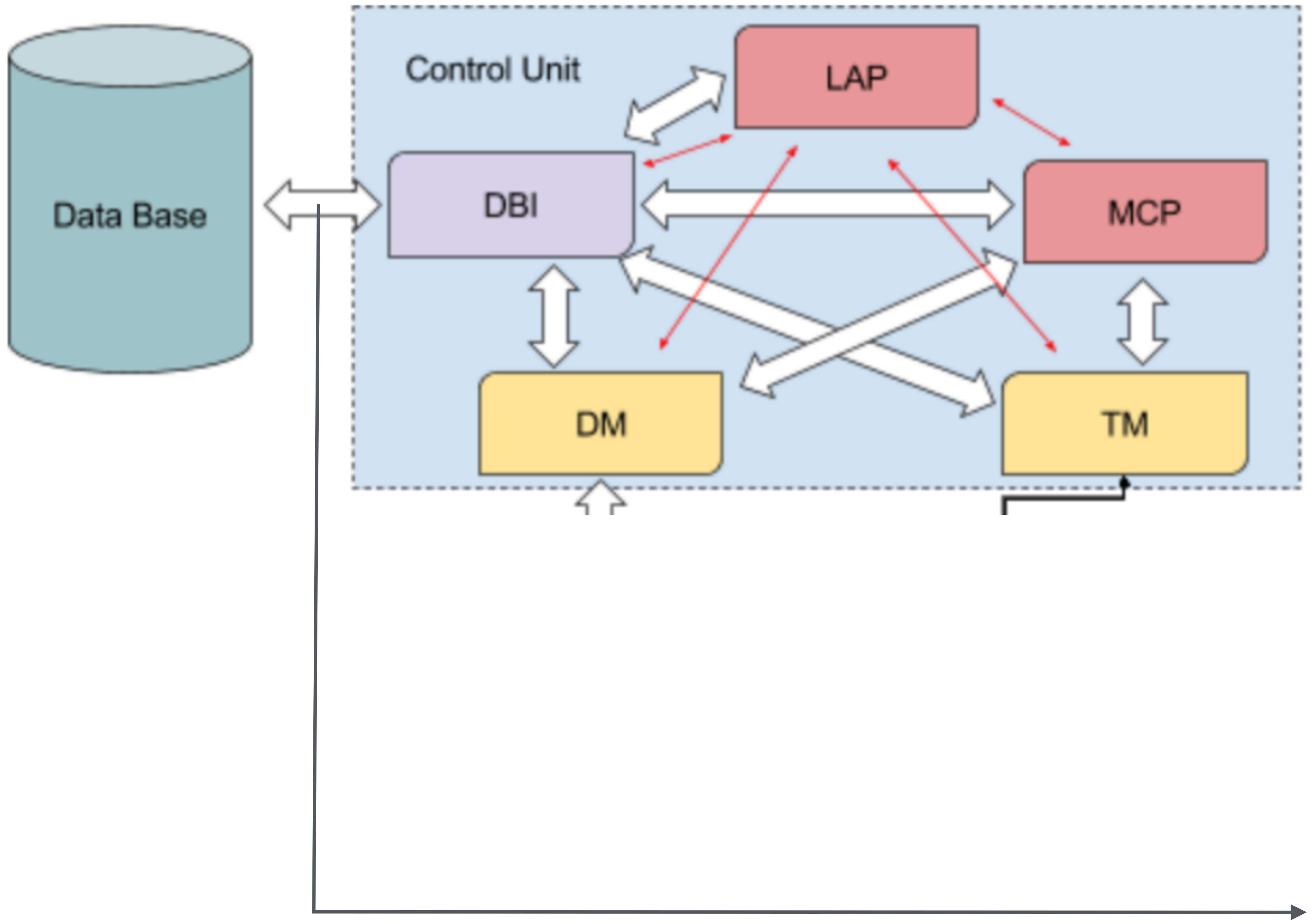


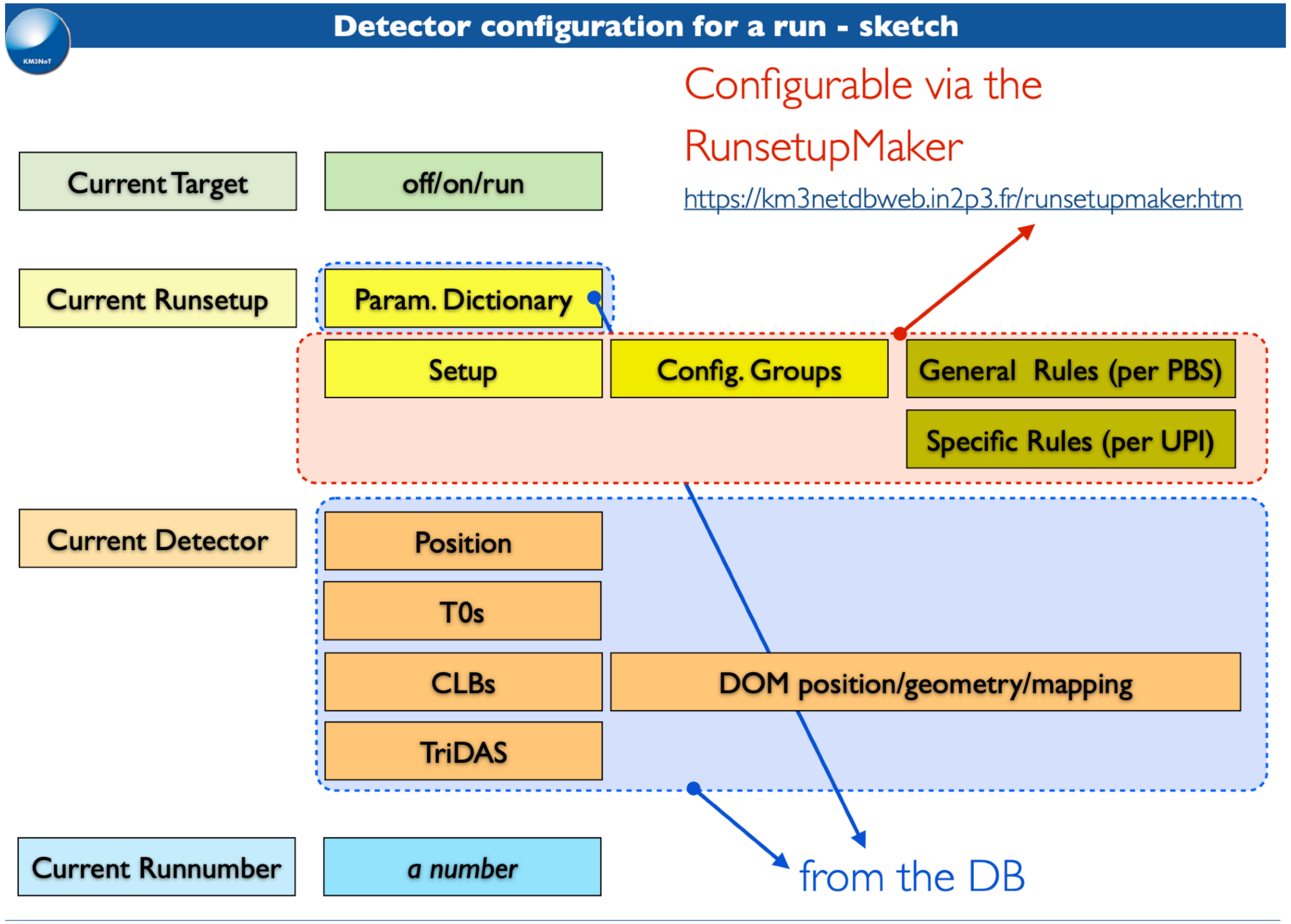
The CU is a collection of (web) services which, via a state machine, drive

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

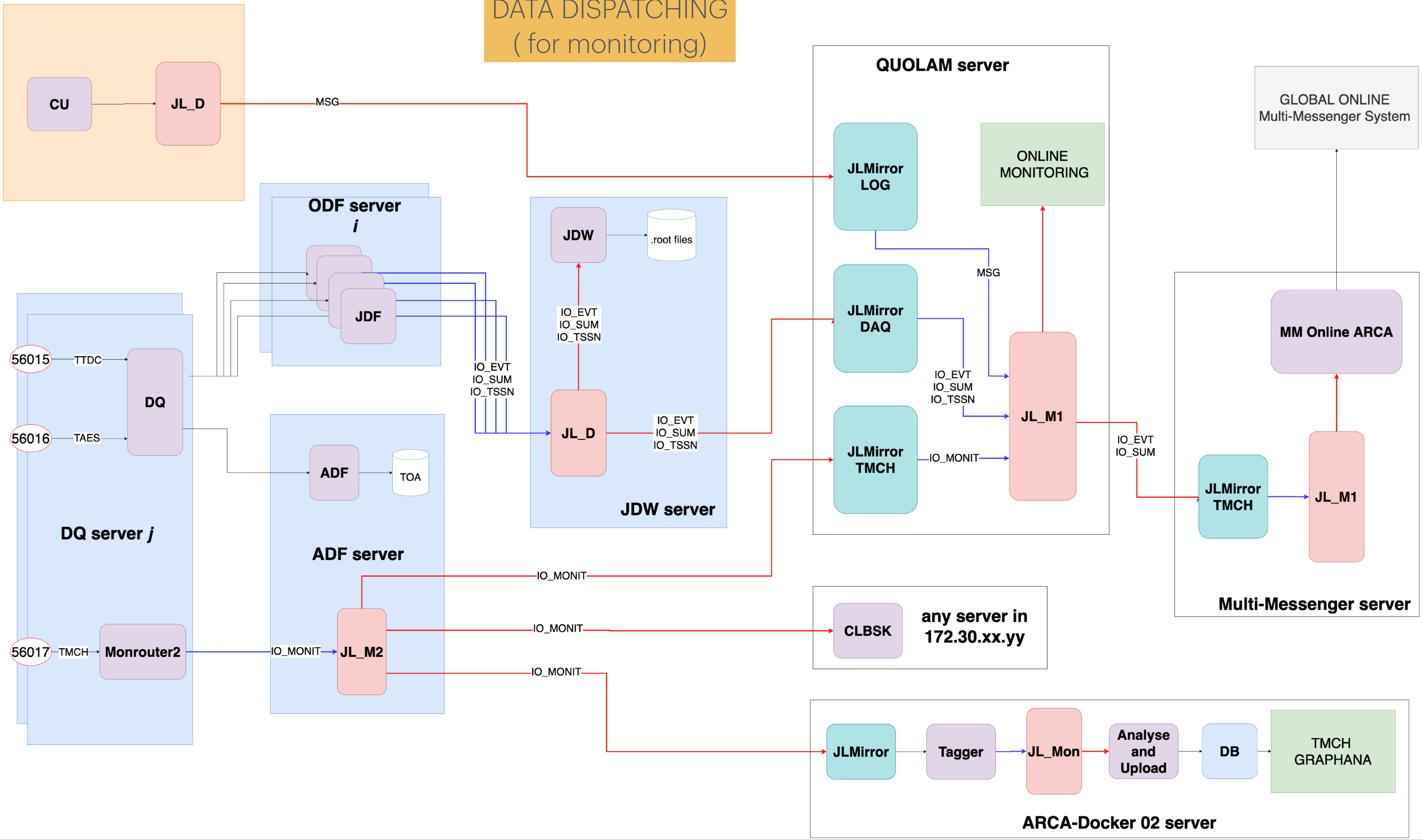
Control Unit and run setup

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





DATA DISPATCHING (for monitoring)



GRAFANA approach