Trigger in underground experiments

S. Mastroianni, INFN Napoli

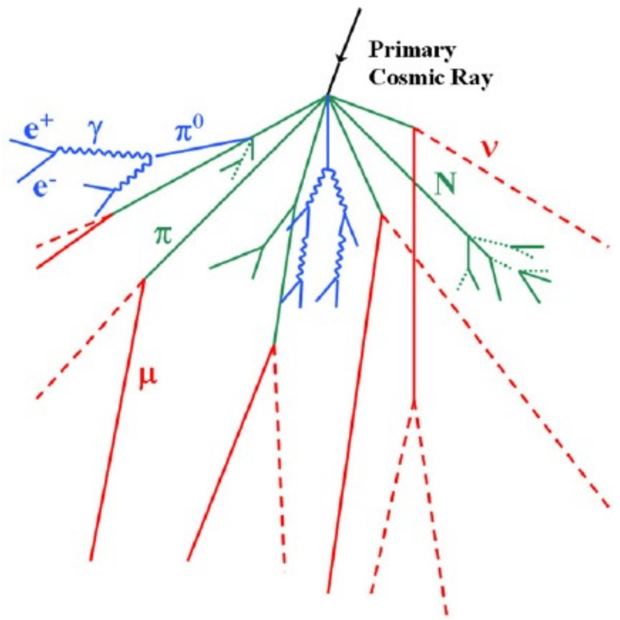
Introduzione alle Tecniche di Trigger e Data Acquisition in Esperimenti di Fisica

Napoli, October 9-12, 2023

Outline

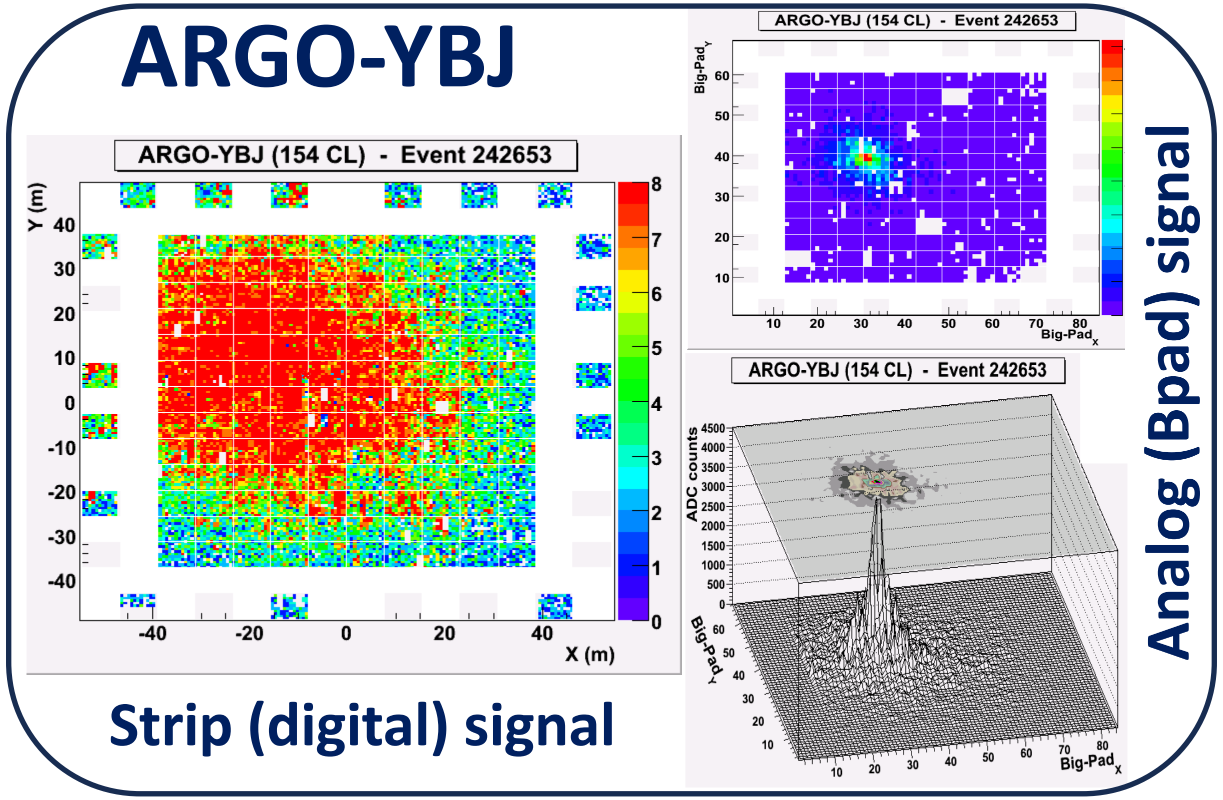
- Introduction to the Trigger Architectures
  - Global vs trigger-less
- Trigger-less DAQ in underground experiments: two case studies
  - KM3NeT experiment
    - DAQ constraints
    - A modular readout
    - Time synchronization
    - Trigger & DAQ system
      - Software trigger & Data filtering
  - XENONnT experiment
    - Low background experiment
    - A streaming DAQ without any online trigger
      - Architecture & readout modules
    - Time synchronization
    - Event builder servers and live processing
    - OnLine Monitor
- Summary

Trigger Requirements



Trigger

The goal is to select events of interest and suppress background as efficiently as possible…

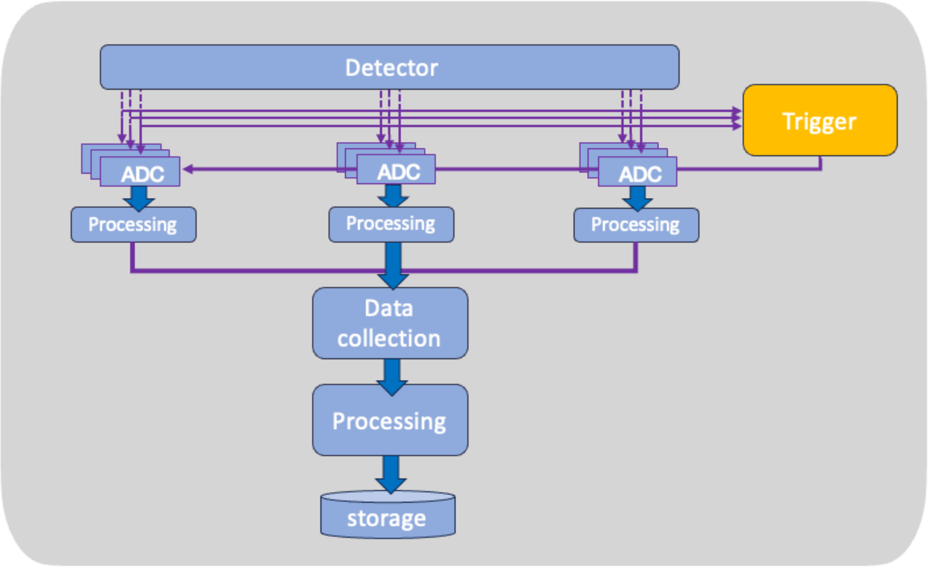


Trigger basic requirements

- High efficiency for selecting processes for physics analysis
- Good reduction of rate from unwanted high-rate processes
- Robustness is essential
- Highly flexible, to react to changing conditions
- System must be affordable

A trigger system must match the physics event rate to the data acquisition rate

Global Trigger

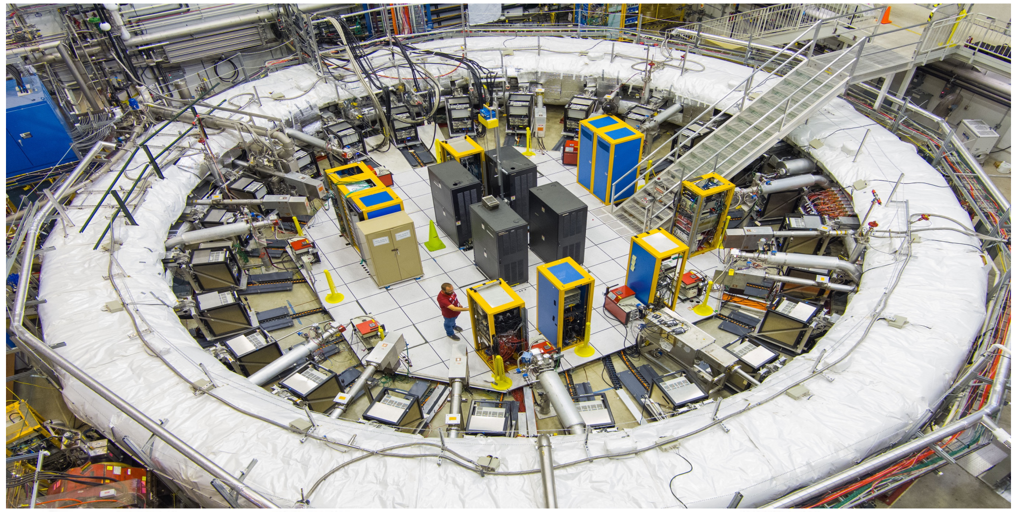


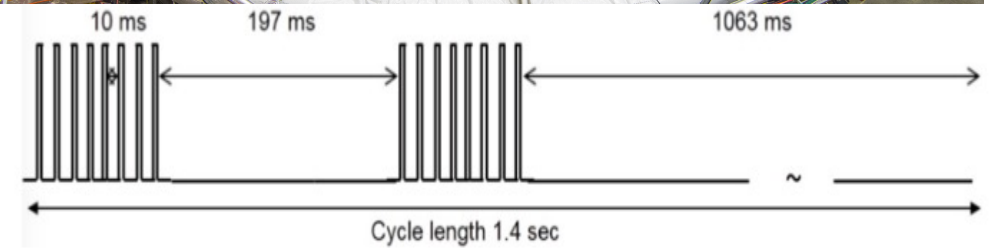
Muon G-2 at FNAL (data taking 2018-2023)

- FE readout manages 12 Hz average rate of muon fills that consist of two sequences (with a ~ 200 ms gap) of eight successive 700 μs fills with 10 ms fill-separations.
- The TTC protocol provides synchronous triggering (Begin-of-fill signals) to the WFD AMCs to start data collection (**hardware**)
- Time-averaged rate of raw ADC samples is 20 GB/s
  - EB throughput ~ 200 MB/s by selecting regions of interest or “islands” for recording (**software**, reduced by a factor of 100)

Globally triggered:

- An “**external device**” decides that data are interesting
- There is a **coherent event ID** throughout the readout
- Front-end data are organized into fragments associated to the event ID
- A Front-end pipeline must “buffer” events while waiting for trigger decision
- Can be implemented in multiple levels realized in hardware or software



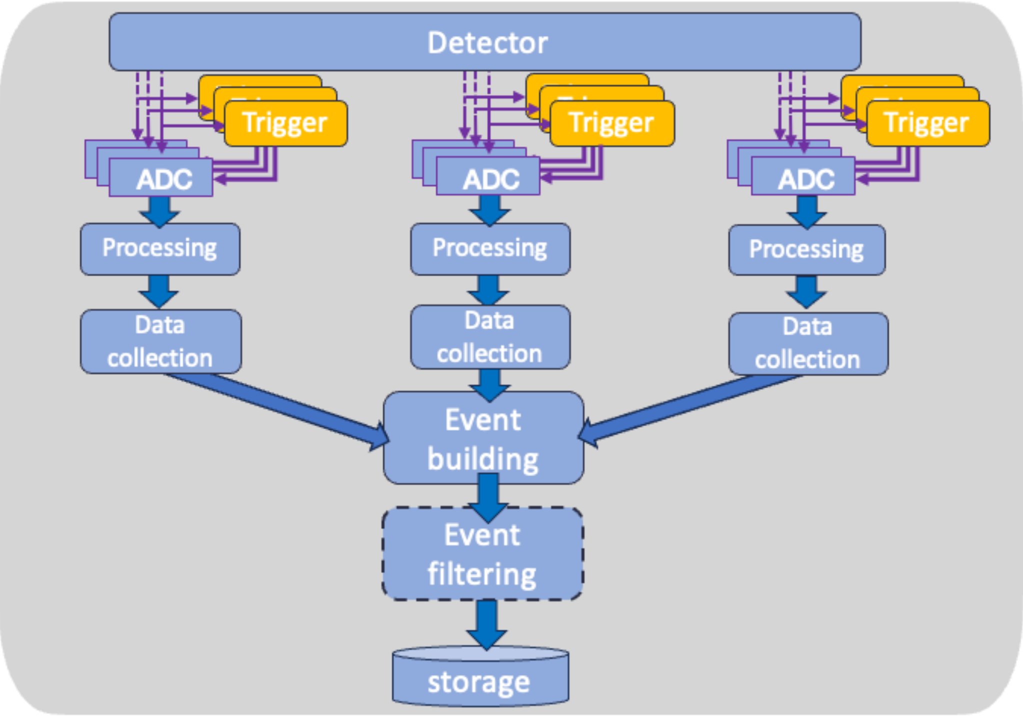


Trigger-less readout

…. but in experiments

- without beam crossing reference and where
- Physics signals occur at arbitrary times extracted from huge background and detector noise

Trigger-less readout very attractive



- A local trigger component decides the data readout (e.g. signal above th.)
  - **per-channel triggering**
- There is **no concept of a global event ID** at the readout level
- Several benefits:
  - **no bias** due to the trigger decision
  - **more flexible** relying on online/offline algorithms
  - streaming DAQ allows the **parallelization** ..
- but some challenges:
  - higher data rate to the Event Builder/CPU farm
  - time-stamped needed for each fragment => same timing for all the subdetectors

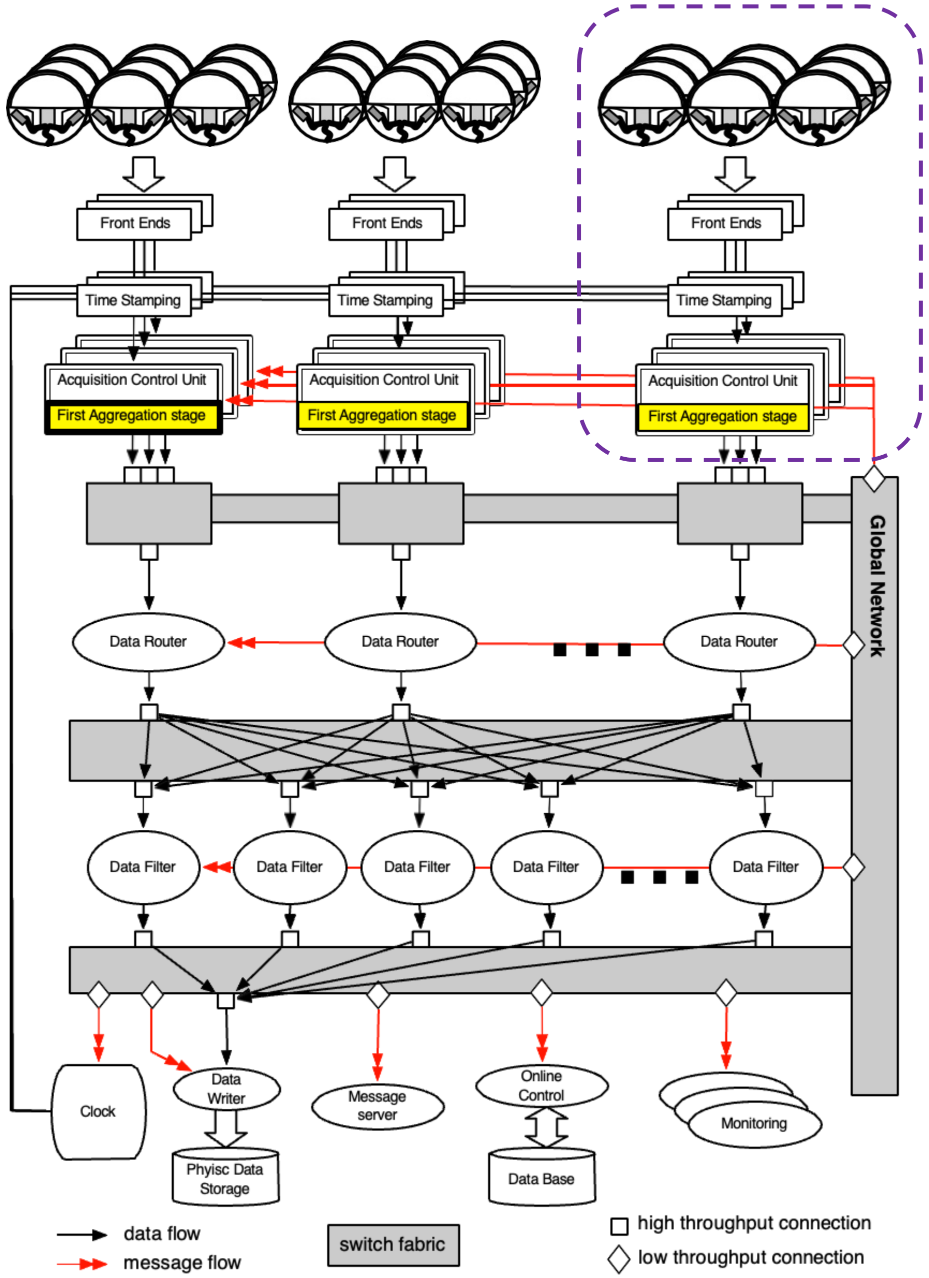
- **Event filtering** for data reduction => **with the online trigger** (KM3NeT experiment)
- **All data long term stored => without the online trigger** (XENON experiment)

Trigger-less readout: KM3NeT

OFF-shore acquisition

Electro Optical Cable O(100 km)

ON-shore Data handlng



aggregation and routing

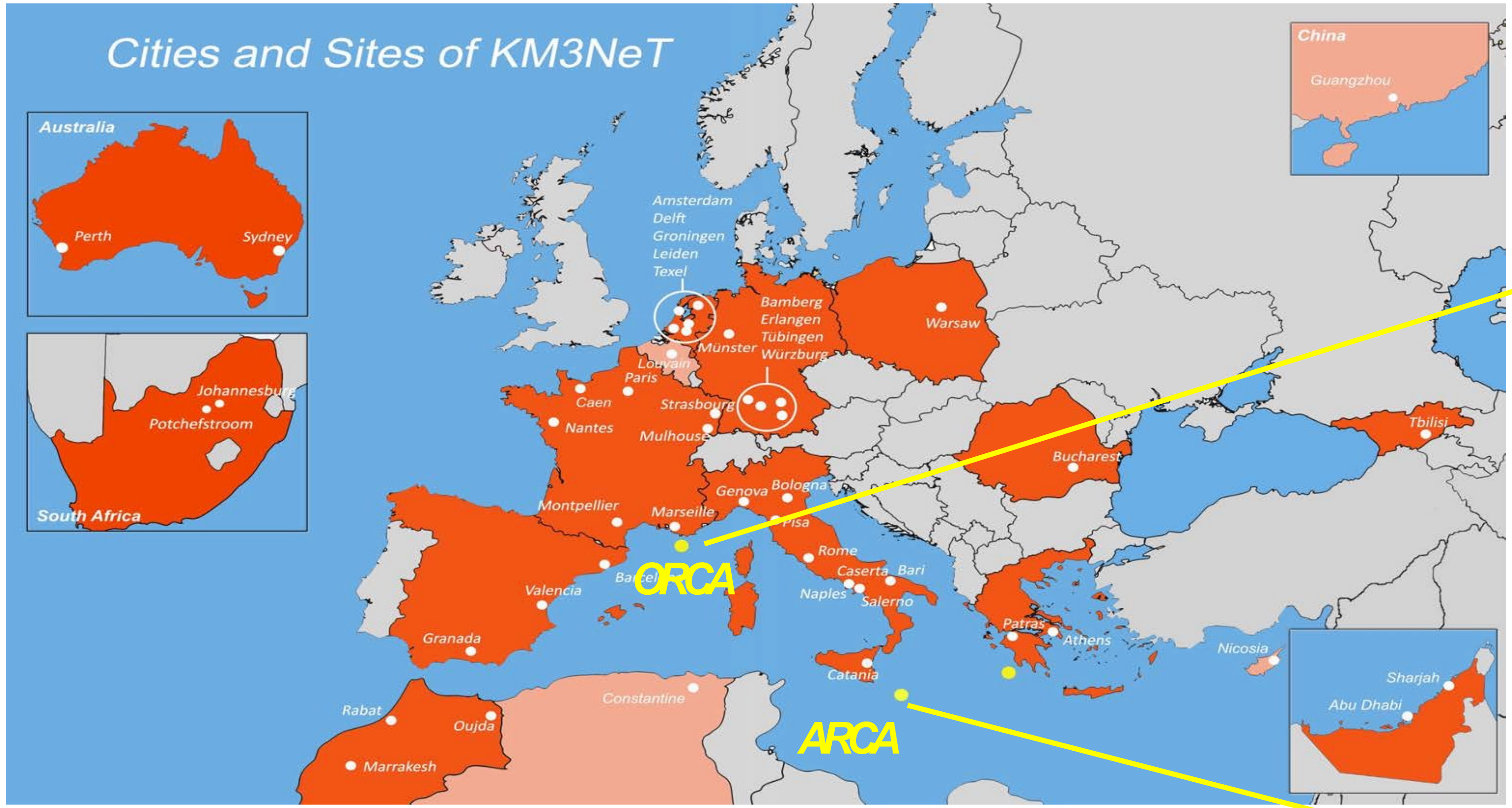
filtering processes

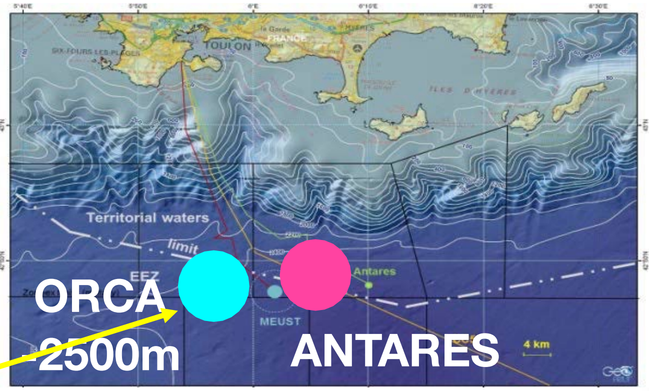
storage & control

DAQ Model:
- all data to shore
- **triggering on-shore**

The KM3NeT collaboration

55 institutes in 16 countries
4 continents — 2 detectors

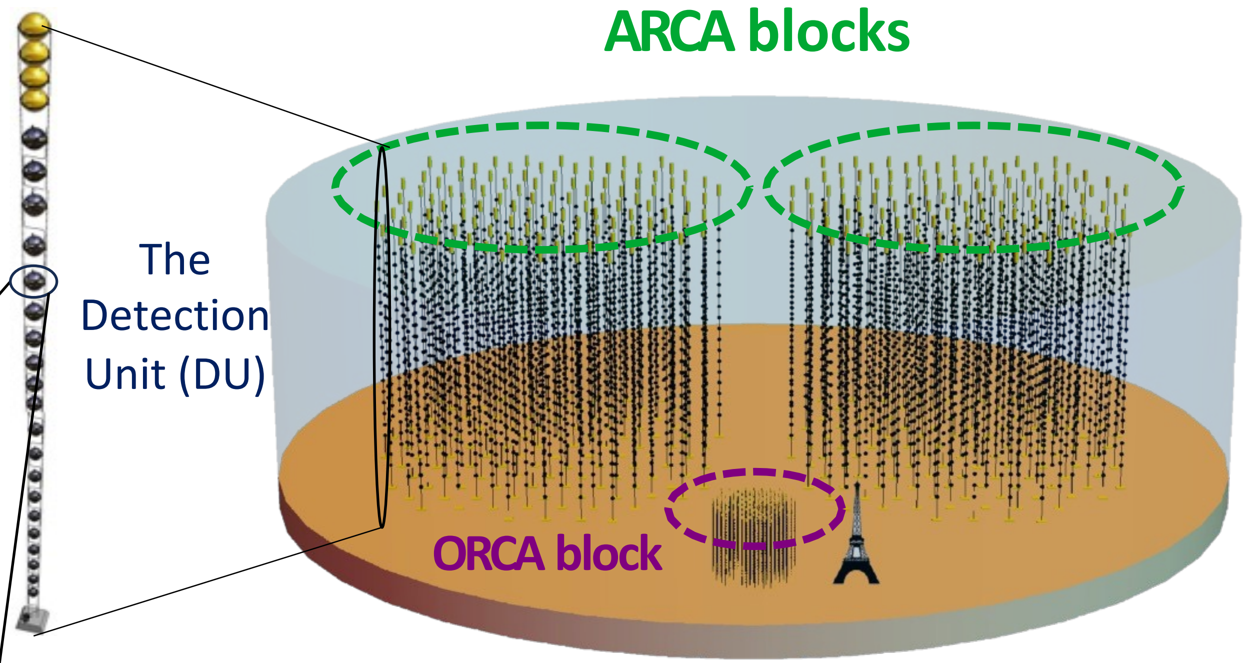


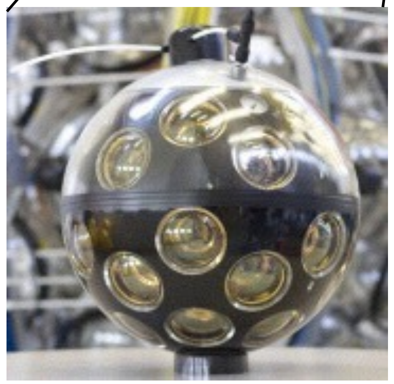


~ GeV ⟷ ~10 PeV

Oscillation **R**esearch with **C**osmics in the **A**byss	**A**stroparticle **R**esearch with **C**osmics in the **A**byss
Designed for **low-E** studies	Designed for **high-E** studies

- KM3NeT is the neutrino research infrastructure under construction in two sites of the deep Mediterranean Sea
  -ARCA(offshore Capo Passero, It@3500mdepth)
  -ORCA(offshore Toulon, Fr@2500mdepth)
- Same collaboration,same technology





Neutrino detection technology in KM3NeT

Modular, incremental telescopes **Detection Unit**: a string of 18 **Digital Optical Modules (**DOM), each one with:
12 3” PMTs in the top hemisphere
19 3” PMTs in the bottom hemishere

	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	28	18

DAQ constraints

- ⊙ big volumes
- ⊙ water optical properties (absorption & scattering of blue-green photons ~ 50-100 m)
- ⊙ good angular resolution O(.1°) for pointing (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**

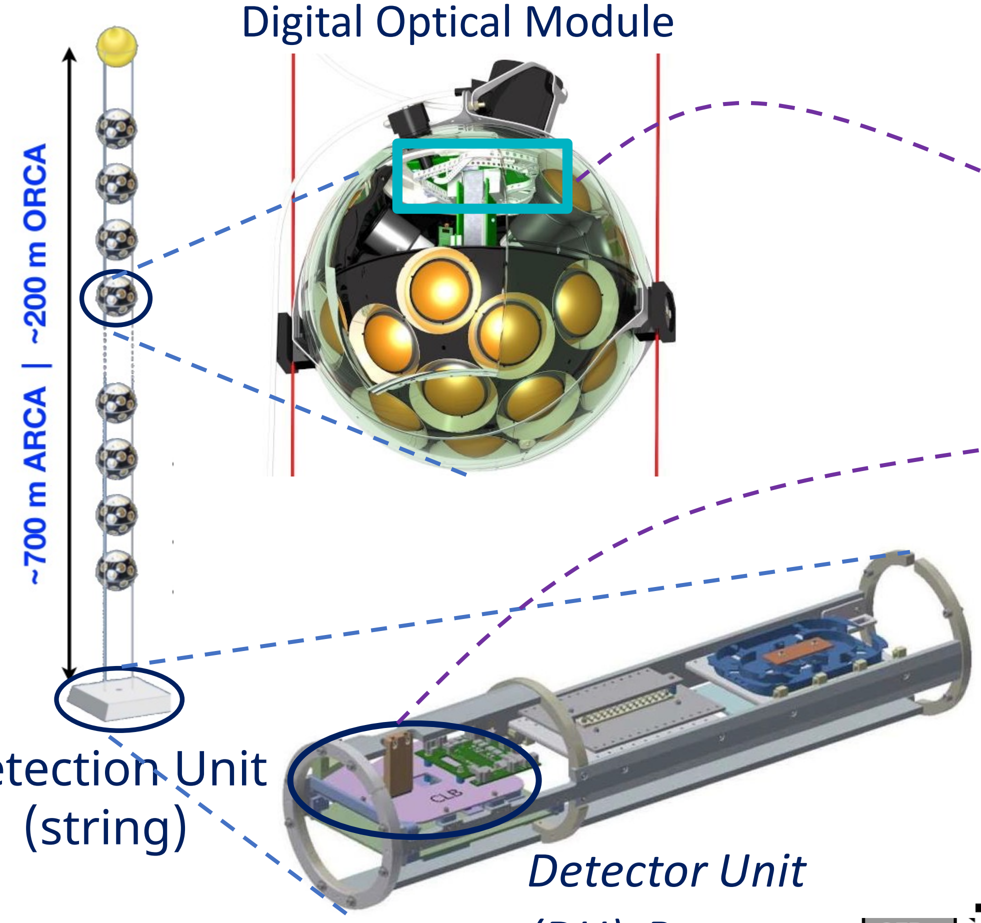
DRAWBACKS

signal-to-noise ratio extremely disfavoured :

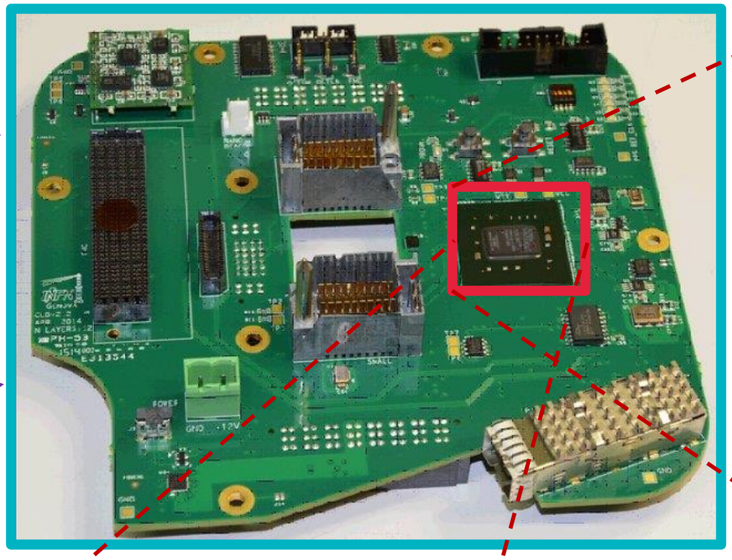
muon rate (atmospheric dominating)	:	O(100) Hz/km^3
^{40}K decays (~constant)	:	O(10) kHz/PMT(3", 0.5 p.e. threshold)
Bioluminescence (occasional)	:	O(100) kHz/PMT(3", 0.5 p.e. threshold)

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

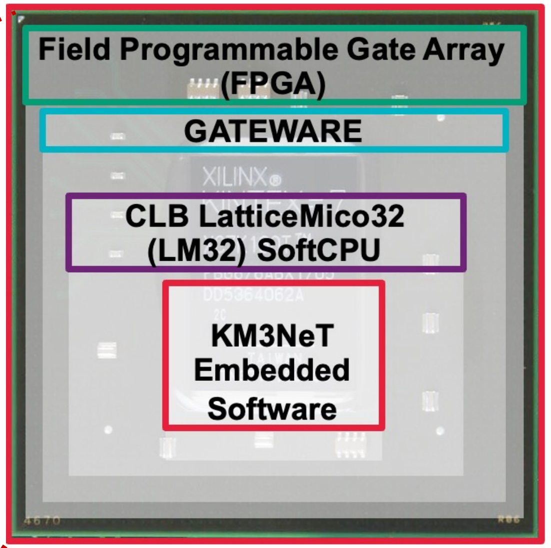
DOM modular readout



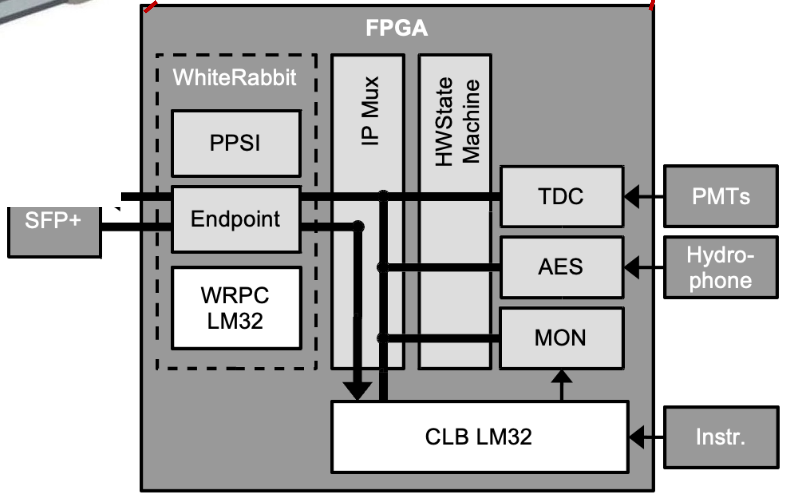
Central Logic Board (CLB)



Xilinx Kintex 7 FPGA



- Gateware: Programmable Logic running inside an FPGA
- Embedded Software: Instructions running on an Embedded Controller (CPU)
- Firmware: The combination of Gateware and Embedded Software

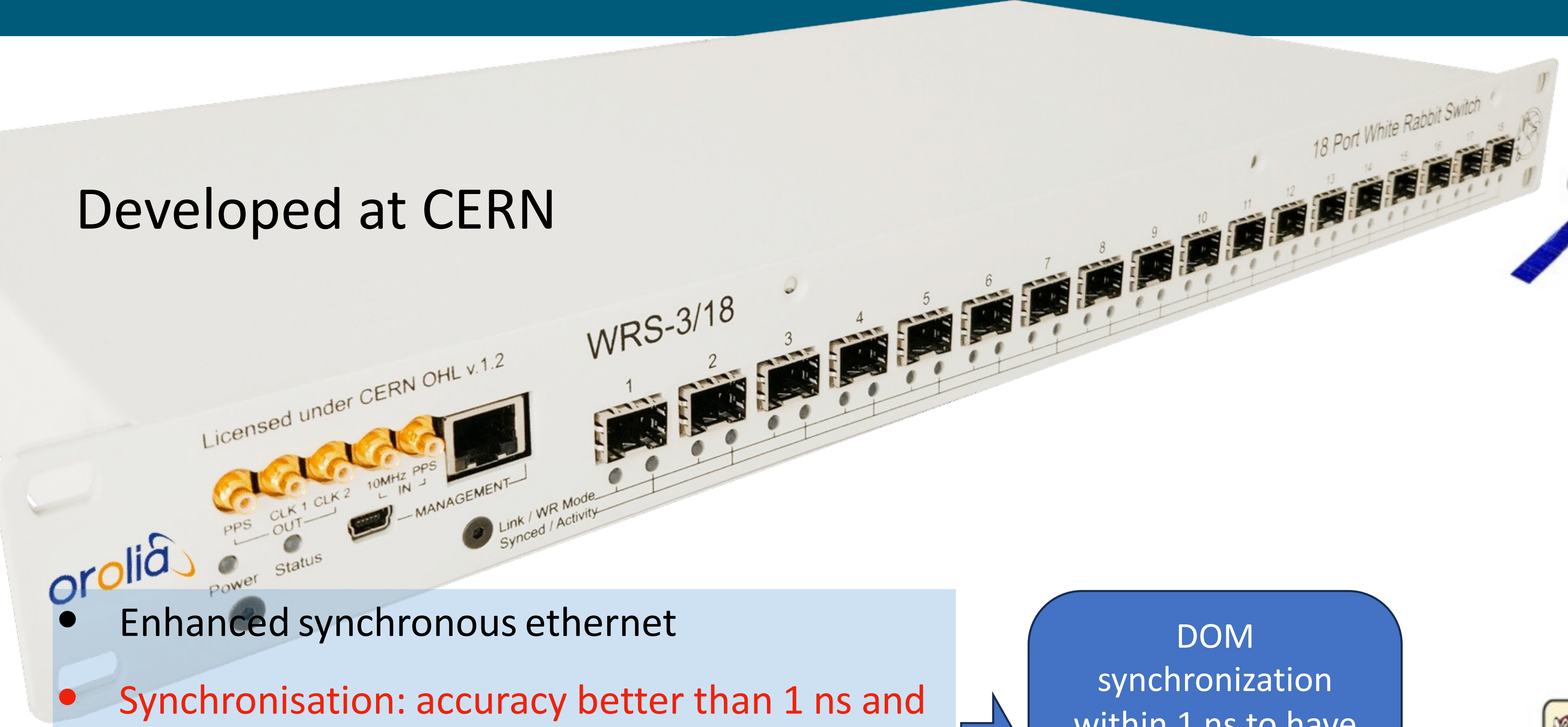


CLB implemented with FPGA (Kintex 7) for:

- TDC (time & time over threshold);
- Acoustic channel readout
- Absolute time stamping (1 ns precision);
- Interface for time synchronisation (White Rabbit)
- Control of calibration devices (I2C bus);
- Ethernet communication via SFP (1 Gbps)
- UDP transport protocol;

The WR protocol synchronizes all CLB clocks in the detector ==> **The protocol is based on the synchronous Ethernet (SyncE) and Precision Time Protocol standards.**

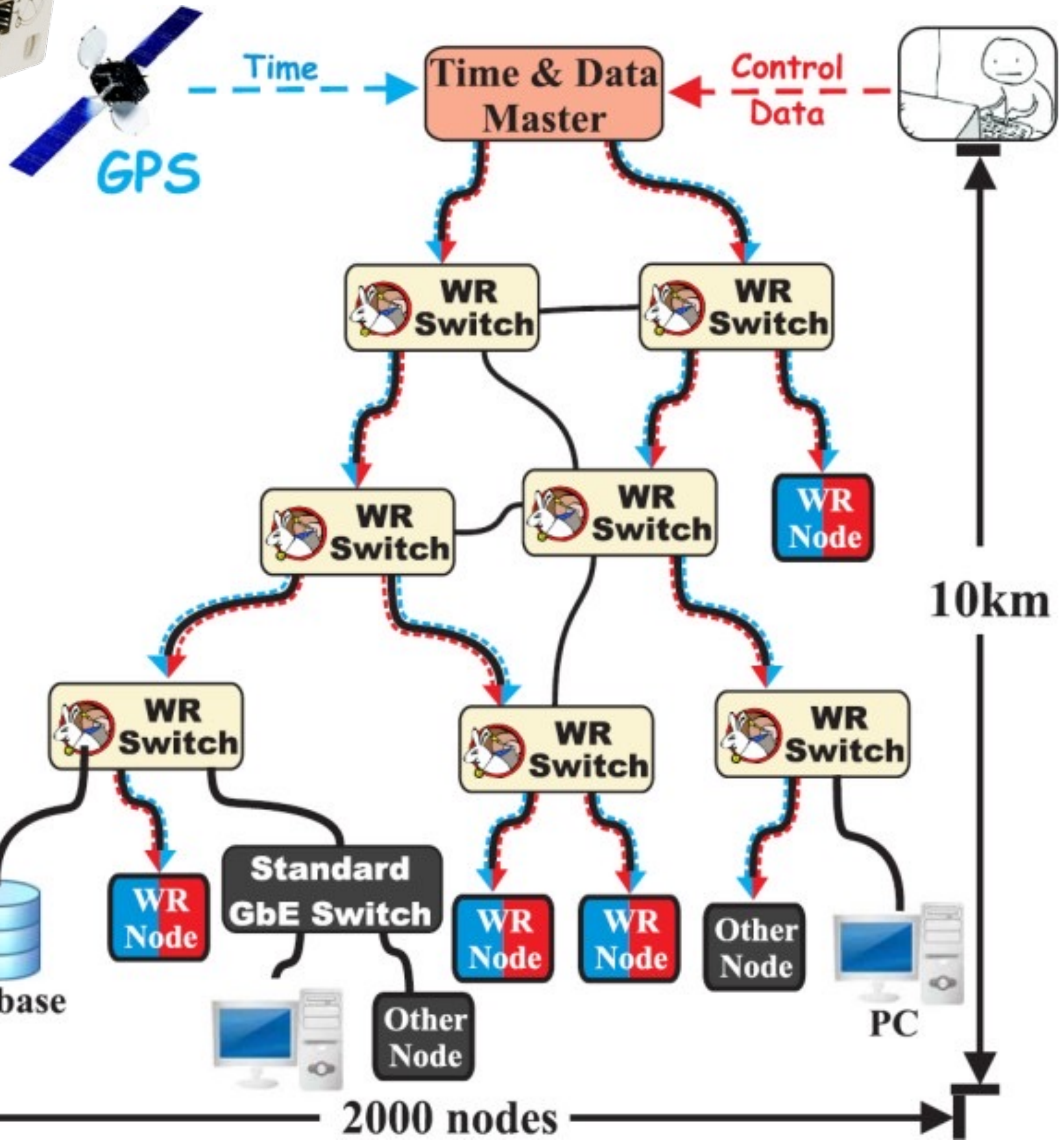
The White Rabbit: time synchronisation over network



Developed at CERN

- Enhanced synchronous ethernet
- Synchronisation: accuracy better than 1 ns and a precision better than 50 ps
- Deterministic latency for distributed real-time controls and data acquisition

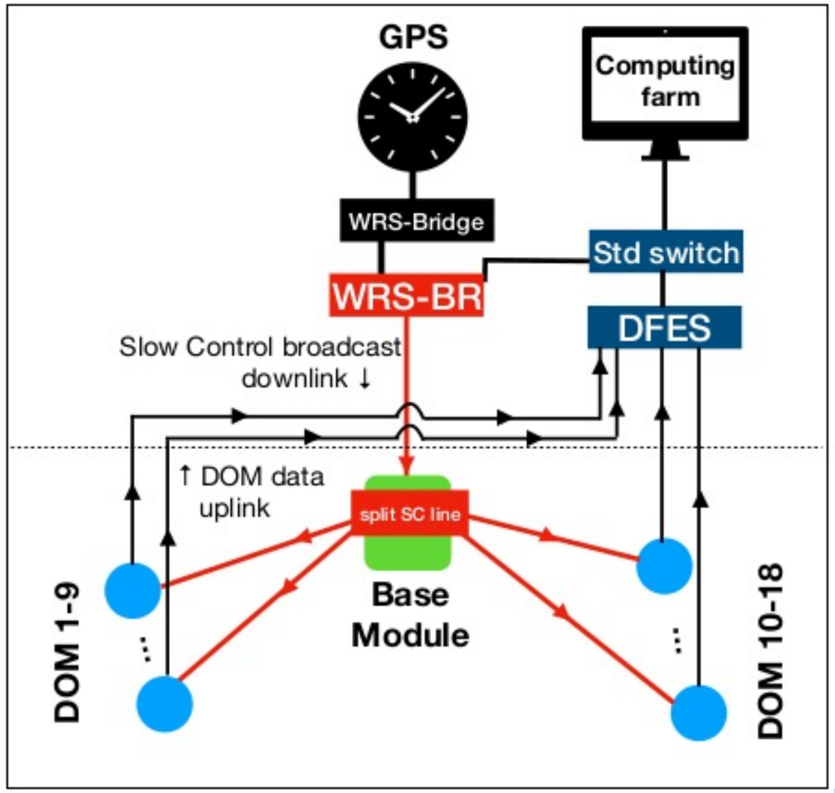
DOM synchronization within 1 ns to have good pointing accuracy for the event reconstruction

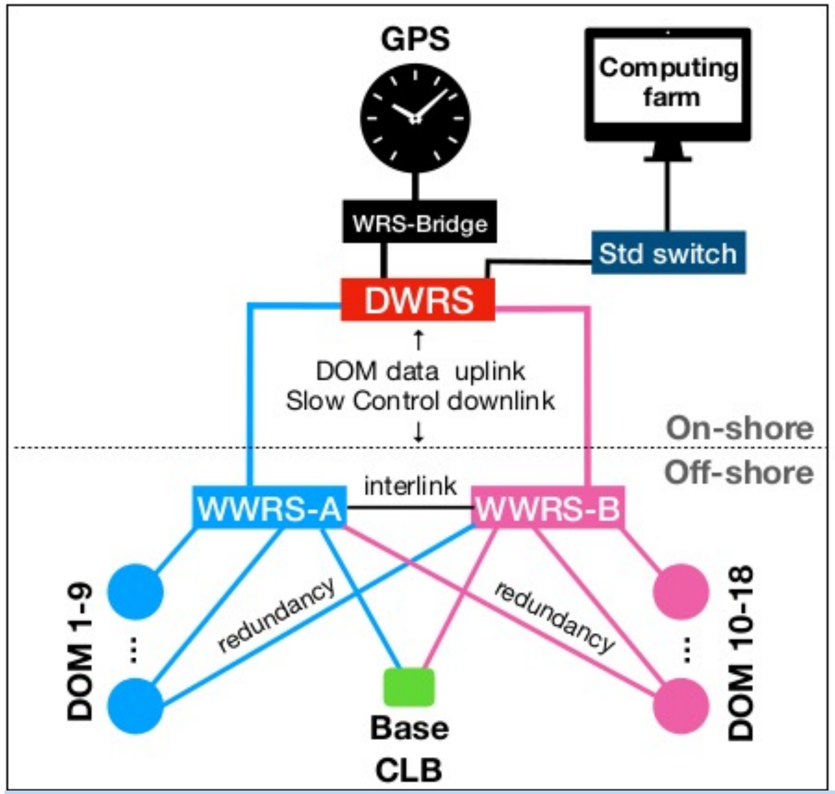


Currently used releases in KM3NeT DAQ:
Hardware: **WRS-18p-hw-v3.4**
Firmware: WR-Core **v4.2** (**customised** by Seven Solutions for KM3NeT); **v5.0.1**
Ongoing evaluation of **v6**.x

DAQ network for a DU detector

Broadcast scenario





Full White Rabbit

Broadcast scenario (asymmetric scheme)

-one downstream link broadcasts slow control and clock signal to DOMs and BM by a WRPC.

-data from the 18 DOMs are routed through a separate group of fibers (upstream kink)

- one link for data from the BM

=> 20 fibers in total connecting to off-shore

Future evolutions: Full White Rabbit

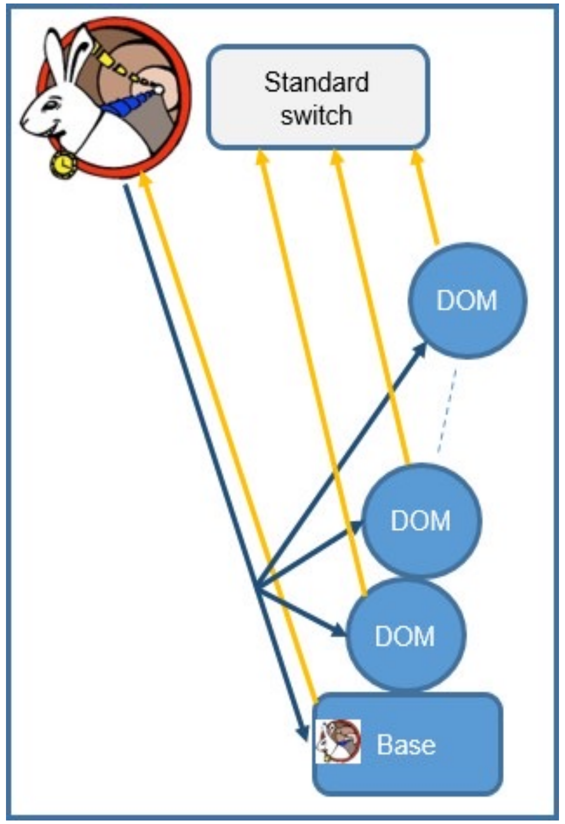
- 2 tunable SFP+DWDM long range transceivers for connecting with the on-shore station
- 2 WetWRS per DU: 9 DOMs each
- 1 BM CLB connected to both of the two WRSs
- 23 bidirectional short range transceivers (high reliability) for DOMs

=> 2 fibers in total connecting to off-shore

A factor 10 of reduction

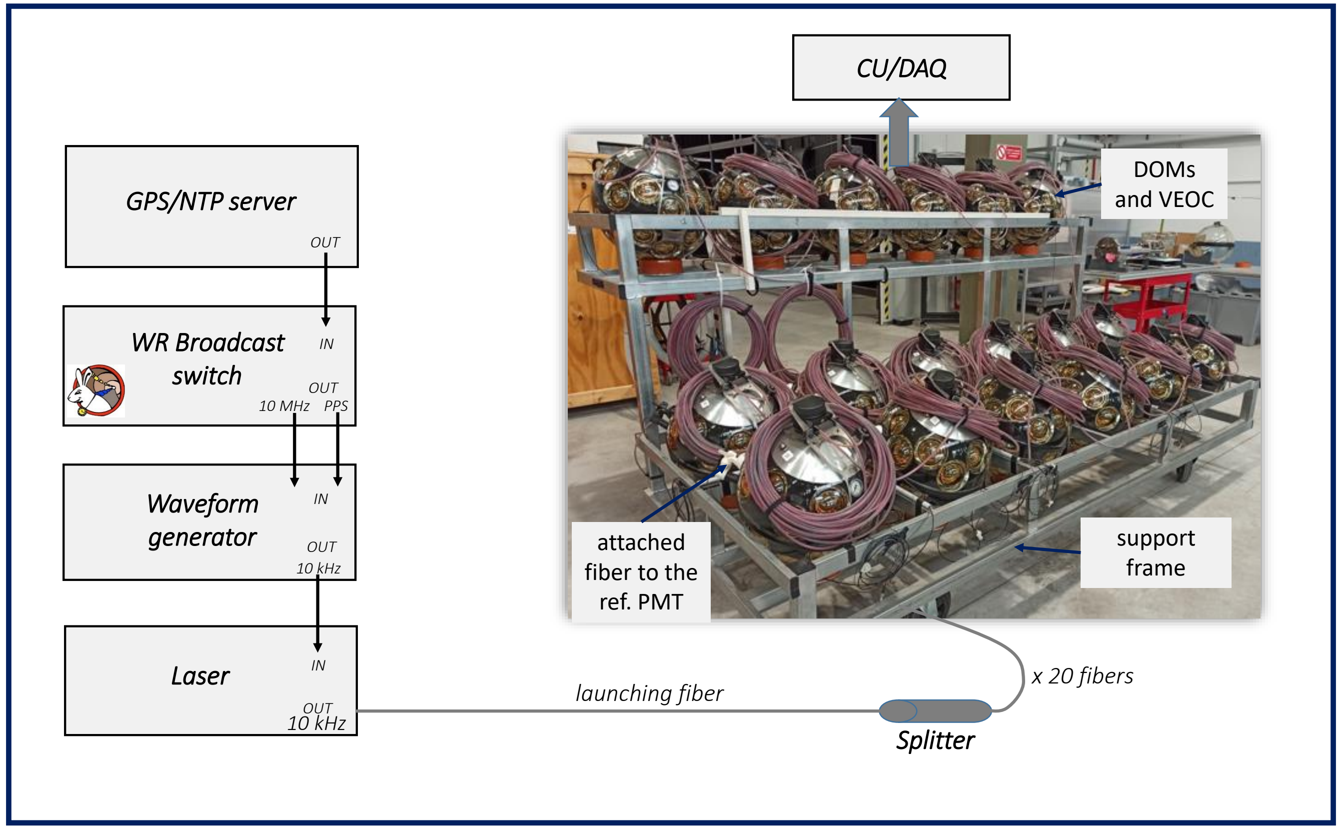
DU time calibration in dark box

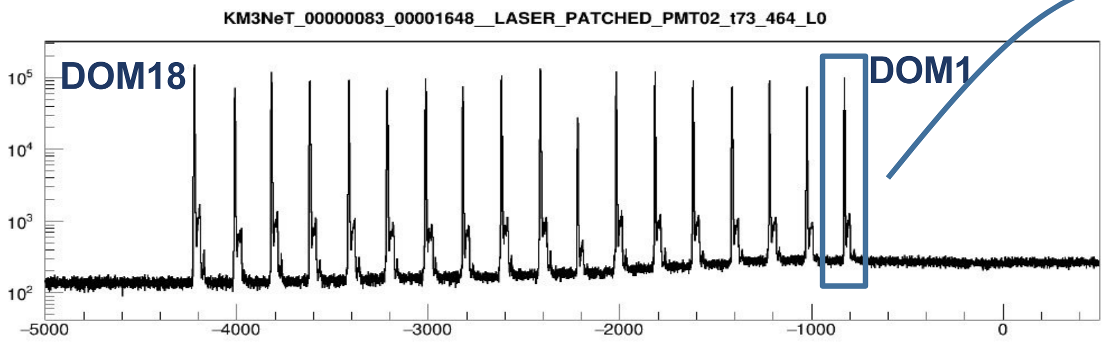
Full time calibration of all the DOMs in the DU before deployment ➔dark box calibration

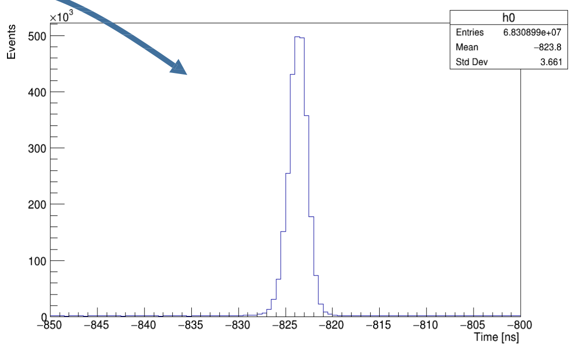


Inter-DOM time calibration:

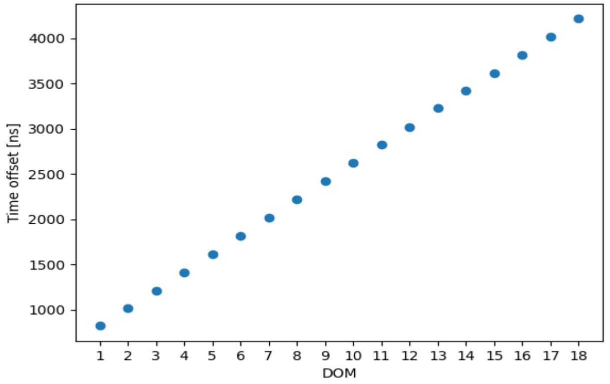
- **to measure** the time delays between DOMs of a single DU due to the different propagation time of the clock to reach each DOM.
- **method:** blue laser source that illuminates simultaneously 2 PMTs of each DOM at SPE levels
  - light pulses time stamped ==> estimate the correction offset to add to each DOM so that the full string is calibrated with respect to the DU Base.



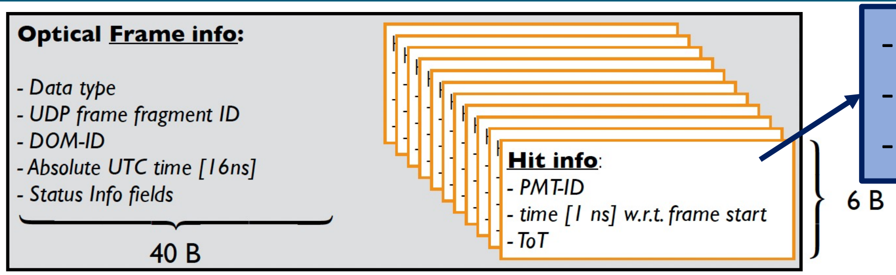




For ARCA :
36 m inter-DOM at
≈ 5 ns/m ==> 180 ns
time delay

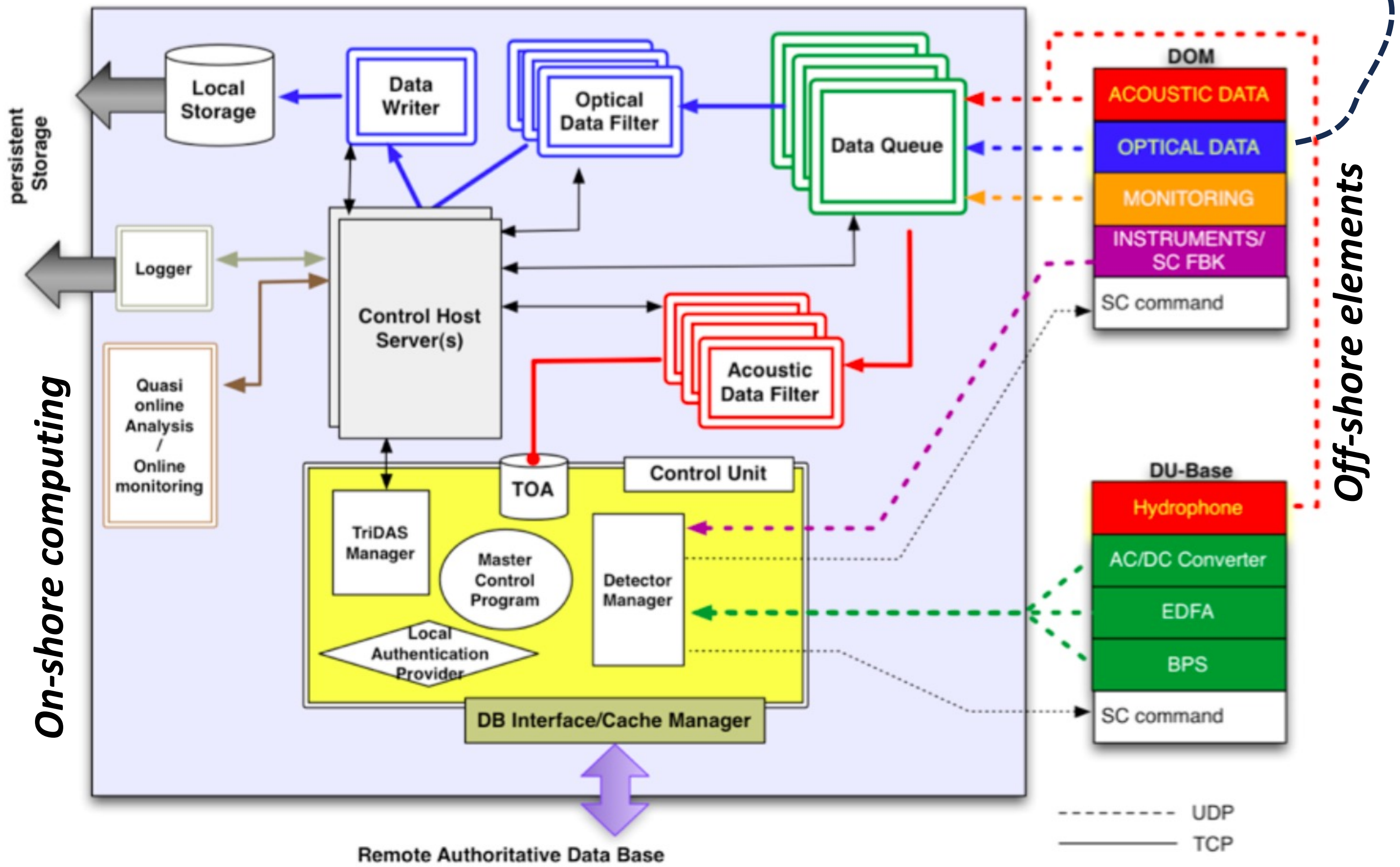


Trigger and DAQ System (TriDAS)



Same size for the acoustic data frame

- PMT-ID: 0 to 31
- time: counter of ns ∈ [0,1e8]
- ToT: Time over Th. in ns ∈ [1,256]



Fast-acquisition data

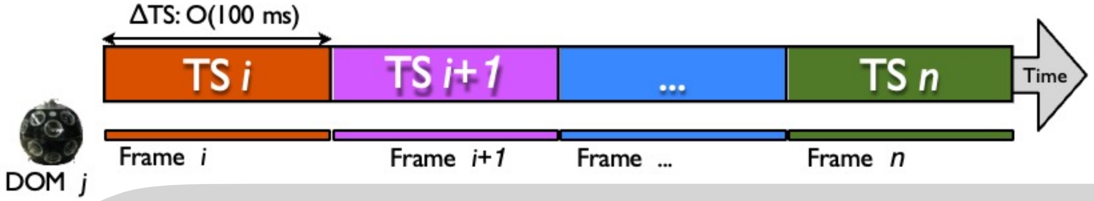
- The **optical data-stream** (TDC channel) is composed of the digitised signals (the hits, time of occurrence and the time-overthreshold) .
- The **acoustic data-stream** (AES channel) is composed of the digitised signals of the acoustic sensors (piezo-electric sensors on the DOMs, hydrophones on the BM). The acoustic information is used to retrieve the position of each element of the strings.
- The **monitoring channel** is composed of a stream of subsequent data-frames from every DOM, each of the same duration (generally 100 ms) and containing the status occurred during the dataframe time interval.

SC data

- The **slow control data-stream** is composed of all the broadcasts, multicasts 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.

Optical (TDC) Data Processing

- **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.



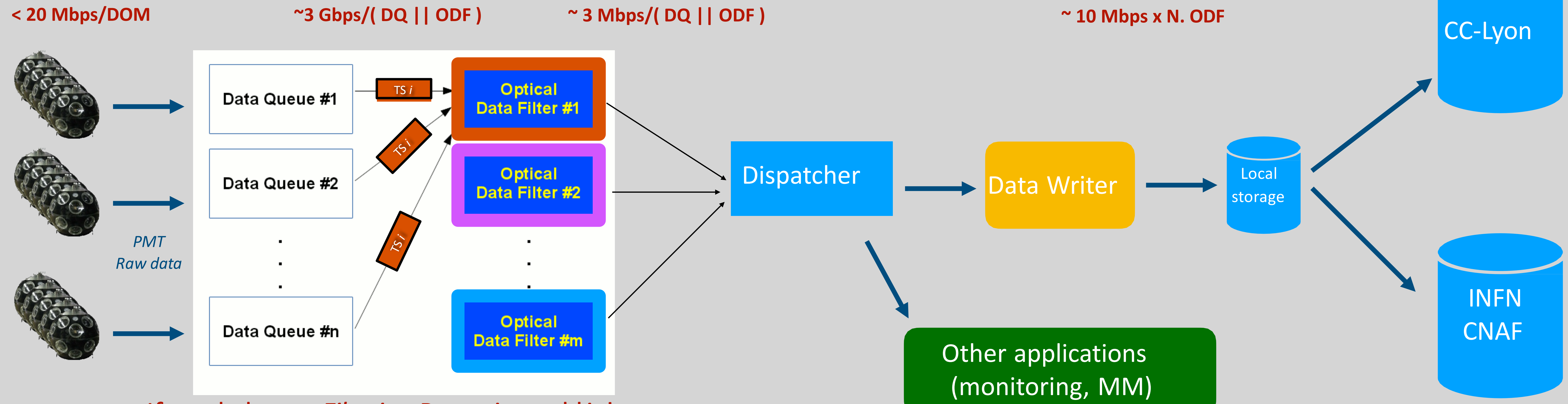
Distributing the computational load

- Each trigger 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

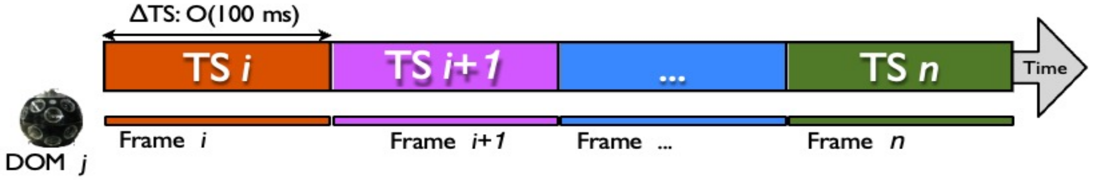
All DQs transfer all their data from a precise Time Slice to the very same ODF



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

Acoustic (AES) Data Processing

- **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.

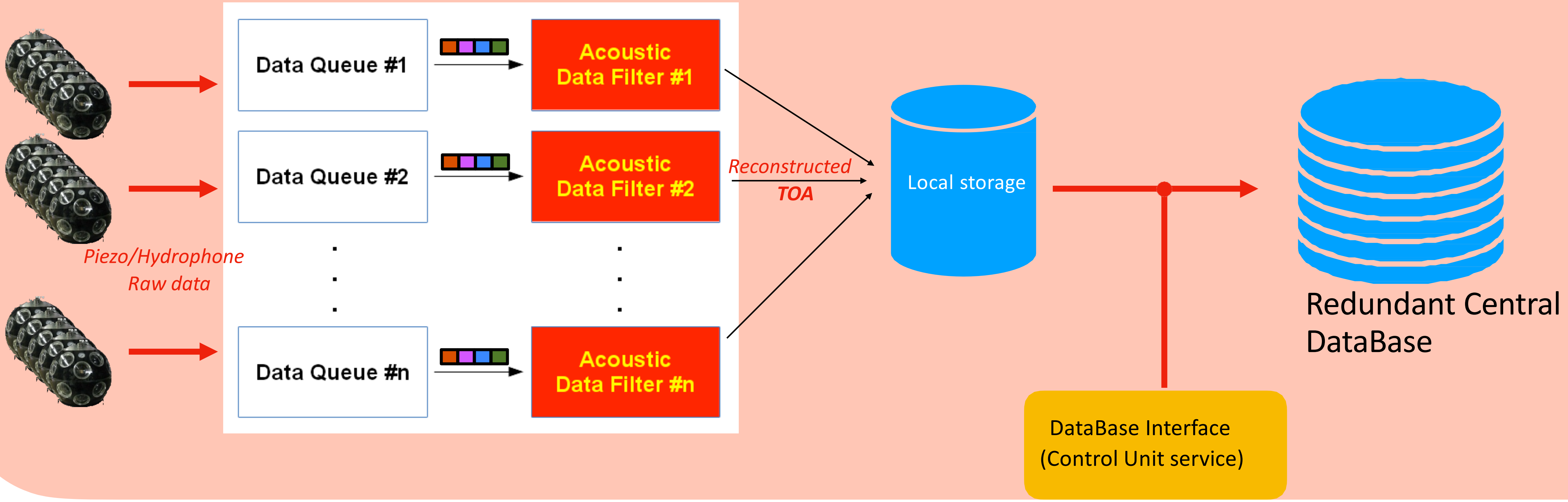


Distributing the computational load

- Each trigger also 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



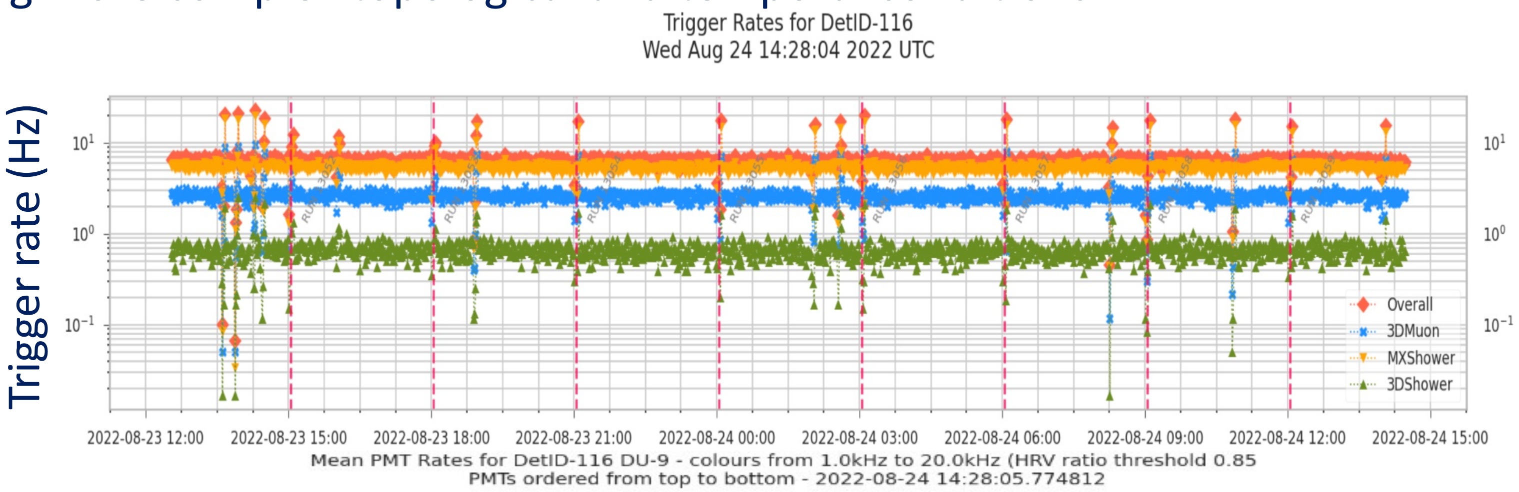
Triggering for data filter

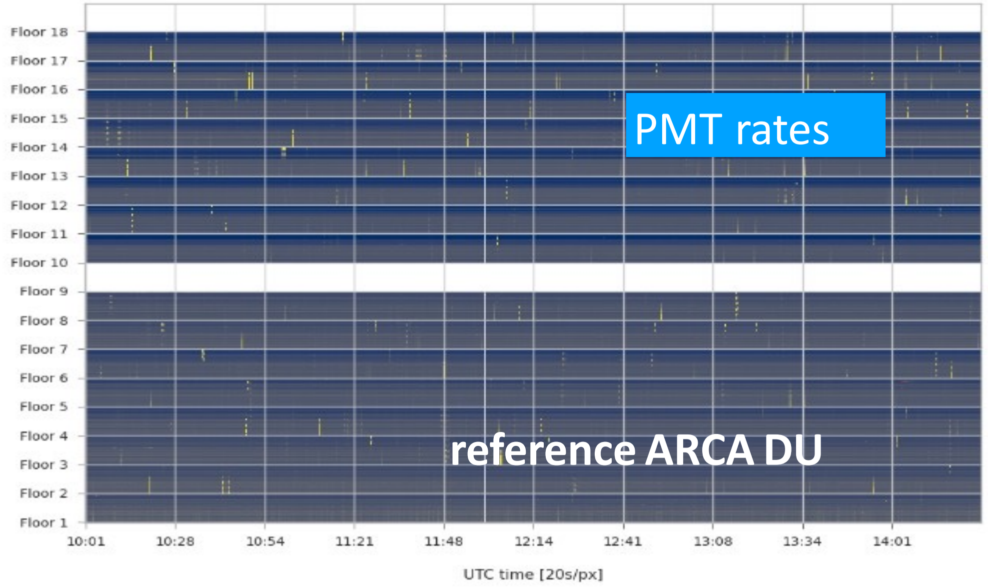
Trigger Levels:

Level 0 : all hits over threshold (i.e. all hits sent by the CLBs)

Level 1 : local coincidence in the same DOM within 25 (10) ns

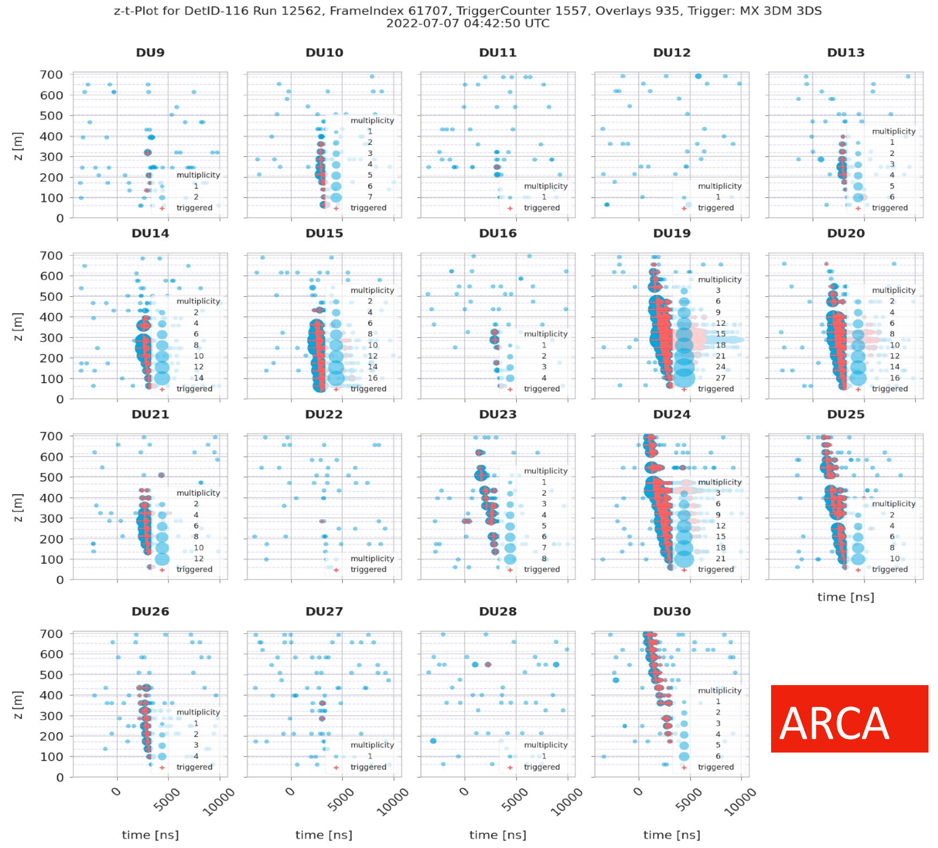
Level 2 : combinations of Level 1 seeds (and occasionally also L0 hits)
using more complex topological and temporal conditions



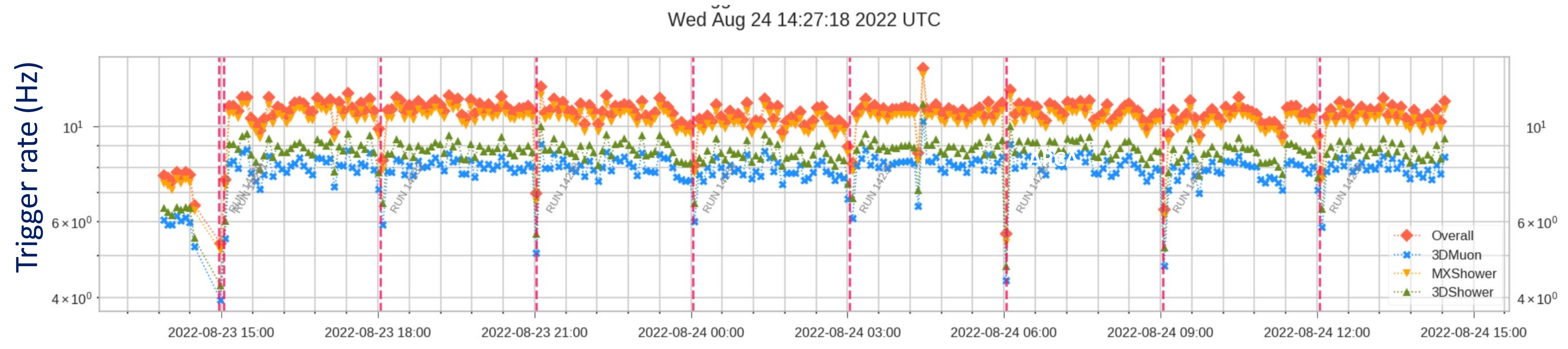


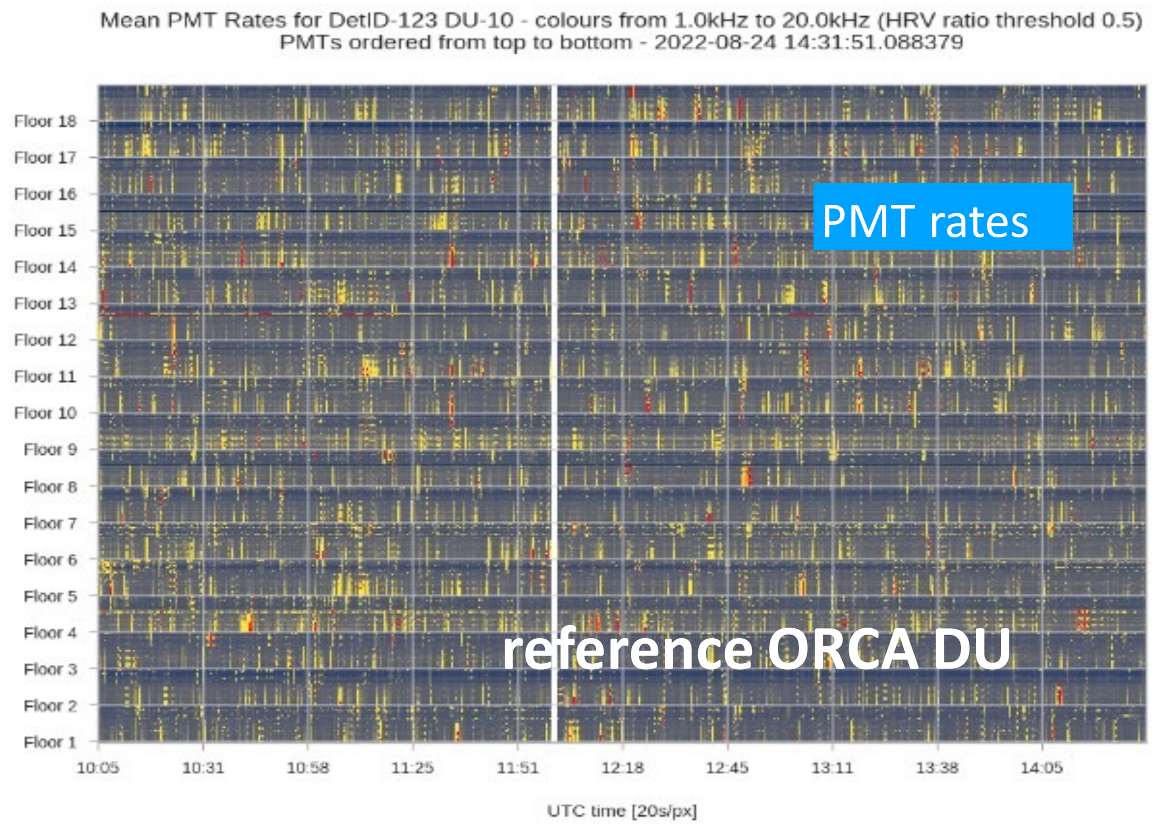
Target \ Approach	Topological Trigger	Simple Causality Trigger	Sky Scan Trigger	Tracking	Vertex / Inertia
muon	✔	✔	✔	✔	✔
cascades	✔	✔	✔	✔	✔
slowly moving particles	✔	✔	✔	✔	✔
sources	✔			✔	✔
External alerts	✔	✔		✔	✔

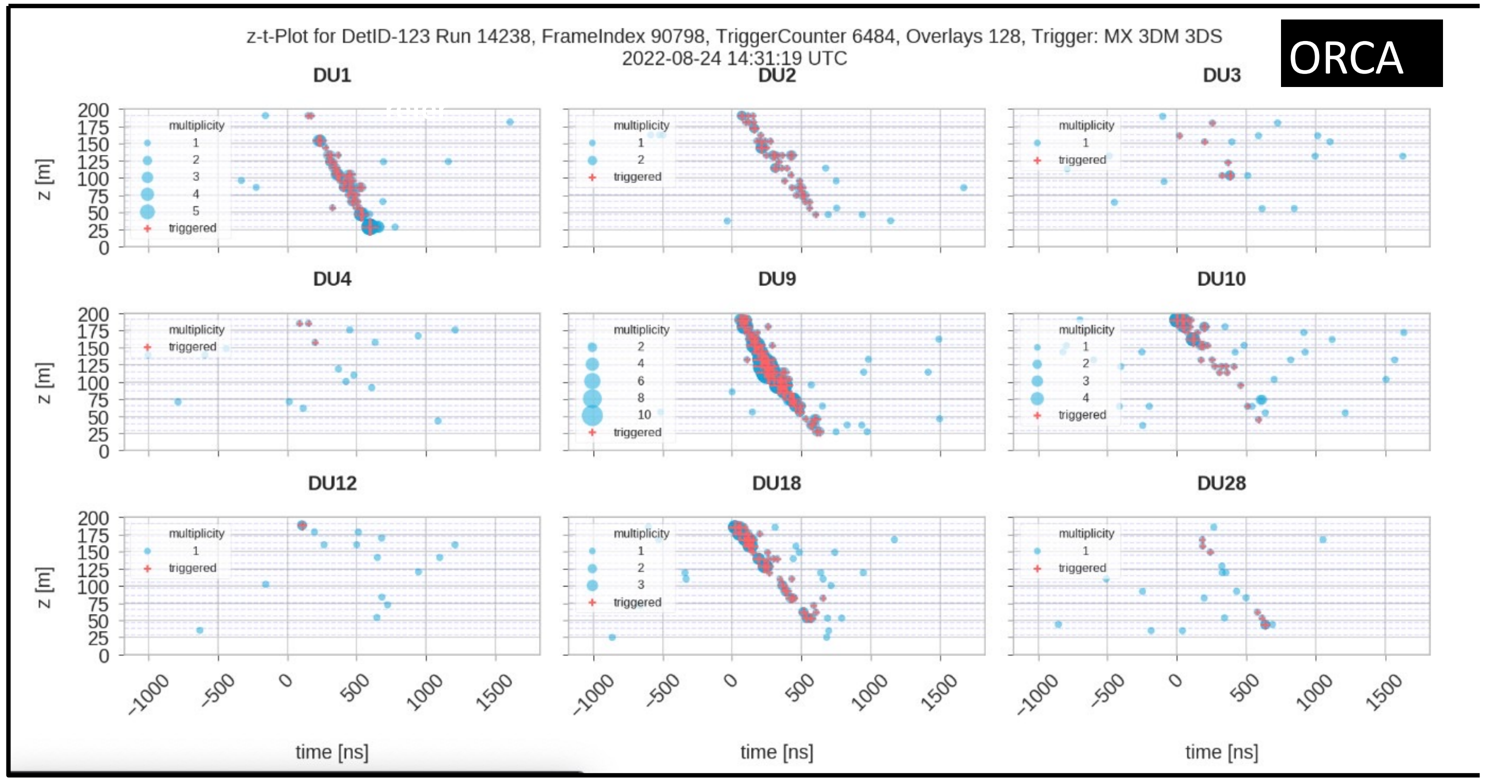
trigger seed: every hit that satisfies one of the L1 trigger conditions



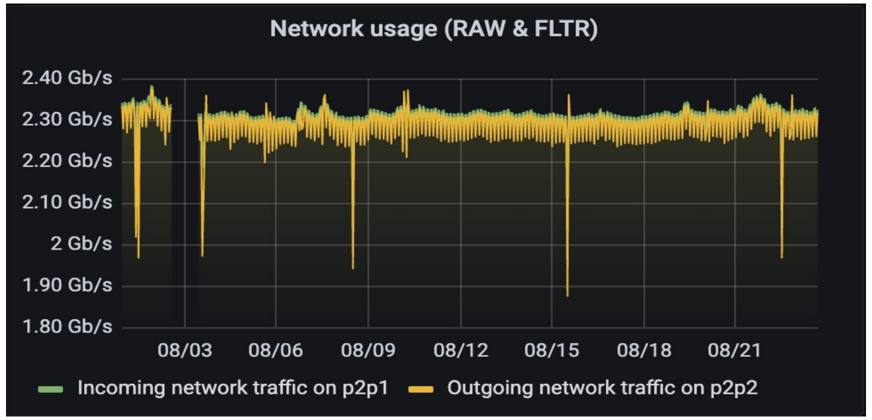
Triggering for data filter

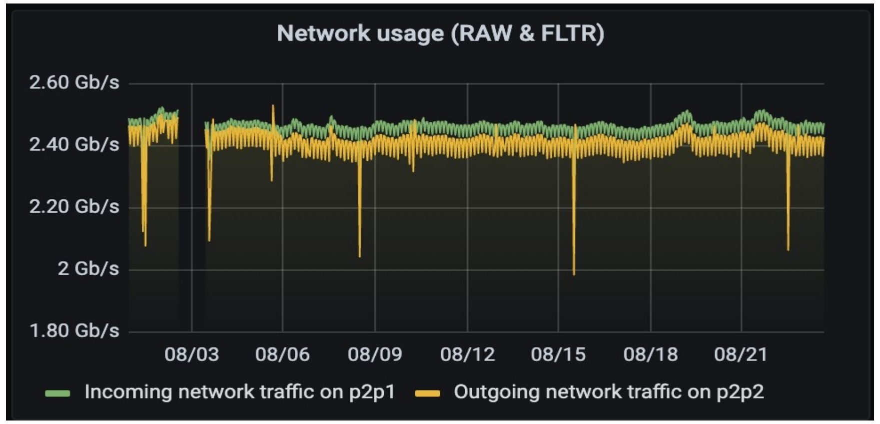






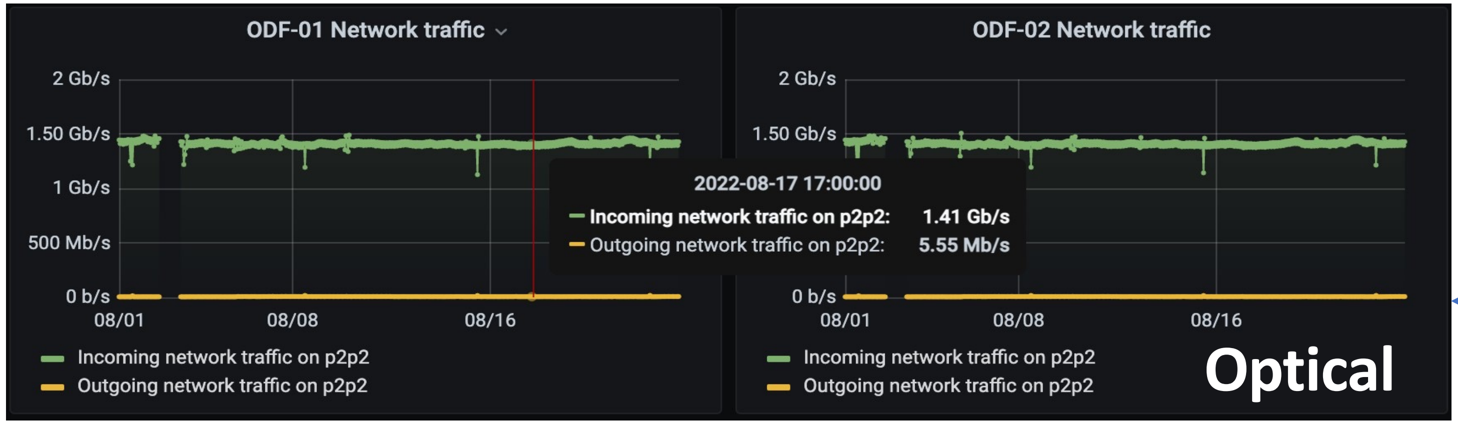
ARCA 19 throughputs



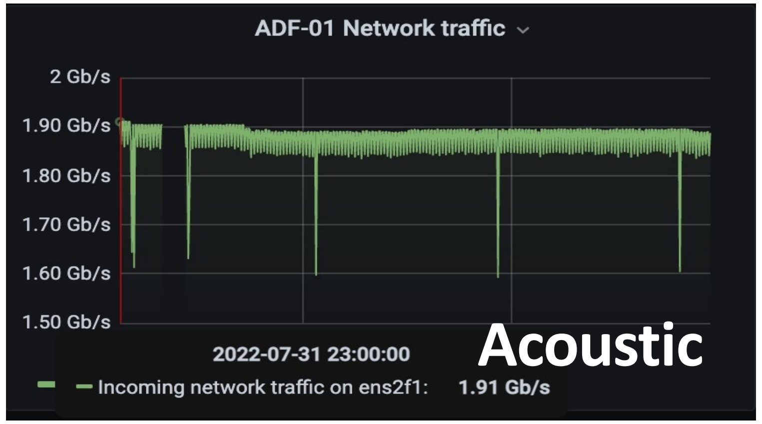


DataQueue level:

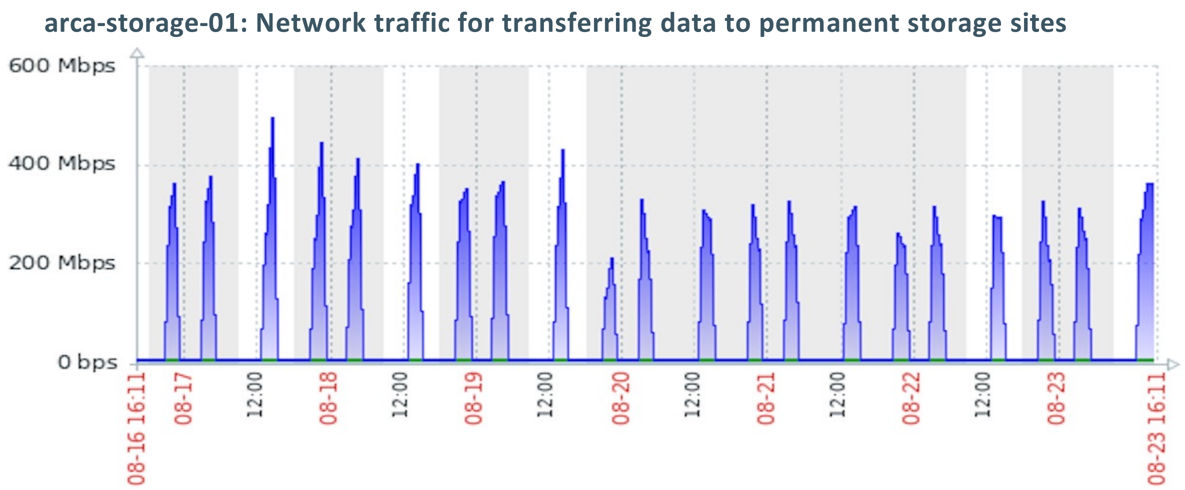
- receive and route to Data Filters (O+A)



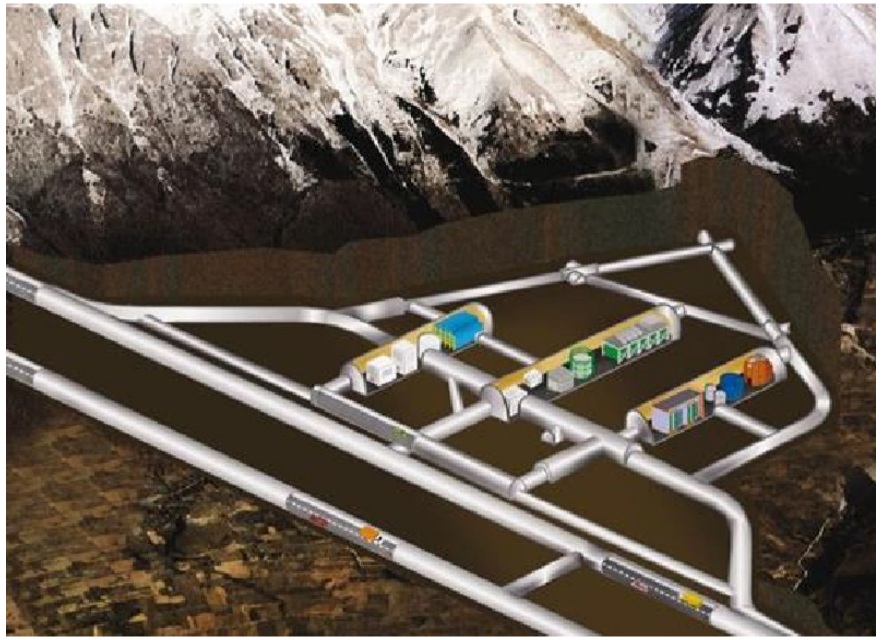
data to Data Writer (i.e. data filtered by ~3 order of magnitue)



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



Dark matter direct detection with the XENONnT experiment



XENONnT experiment

- Located @LNGS in Italy
- Depth of 3600 m water equivalent
- Muon Veto and Neutron Veto (~700 t ultrapure water, prepared for Gd-loading)
- Time Projection Chamber with **5.9 t** of LXe in the active region and 8.5 t in total in the system

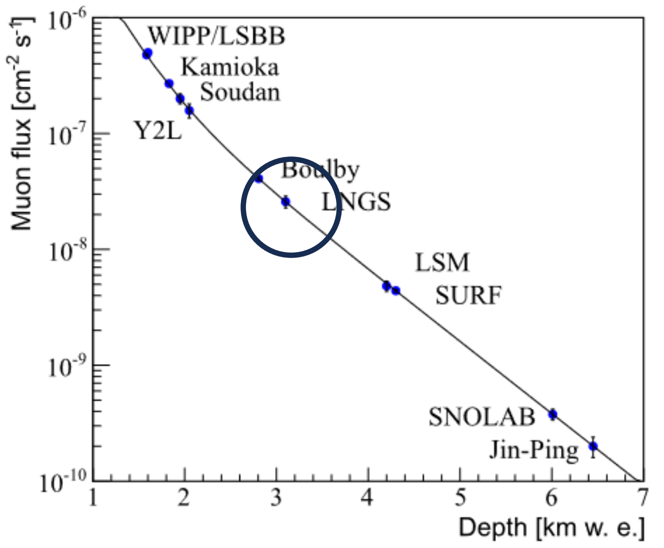
The XENON collaboration

Dark matter direct detection experiment

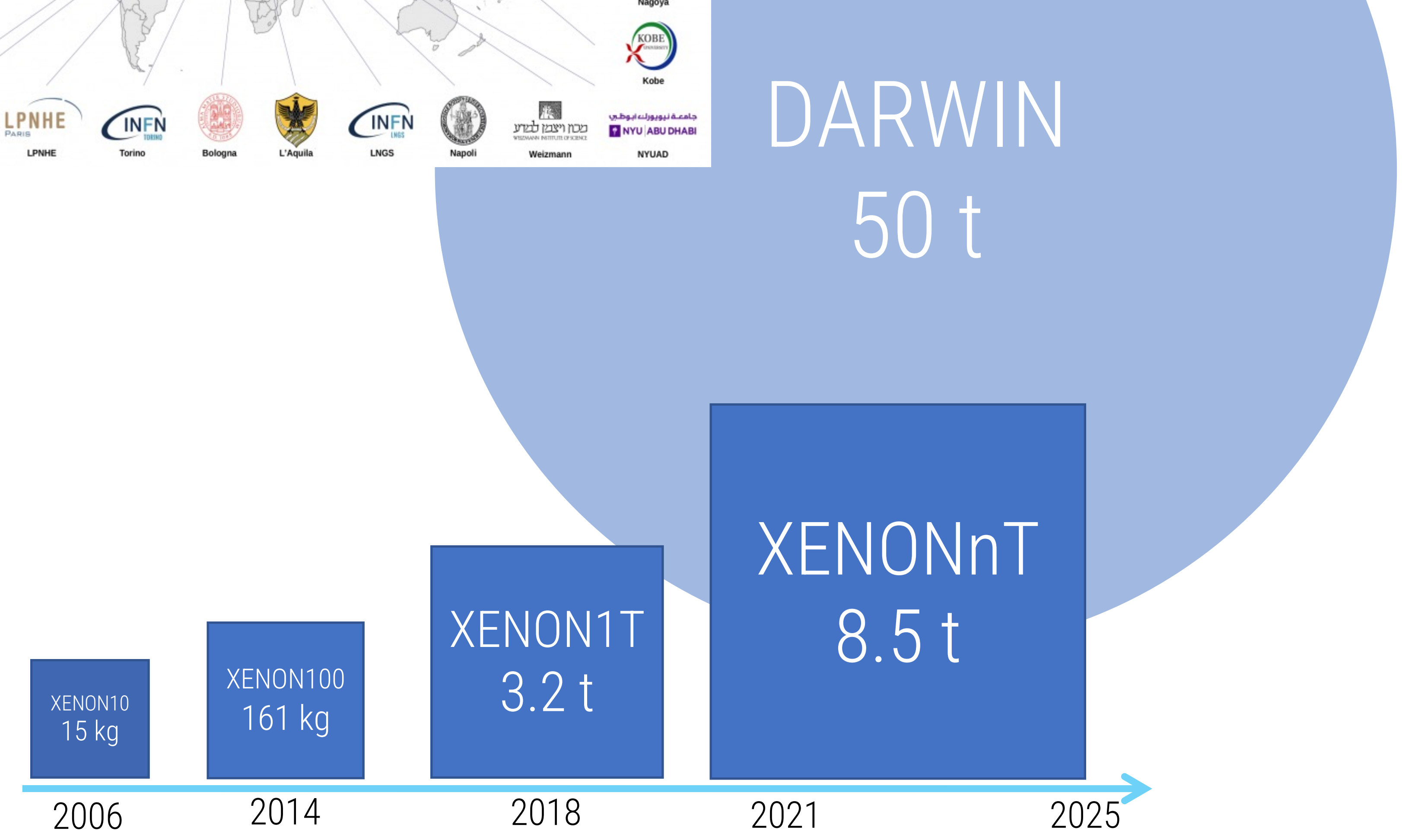
Laboratori Nazionali del Gran Sasso (LNGS)

Dual phase xenon time projection chamber

170 scientists, 27 institutions, 12 countries

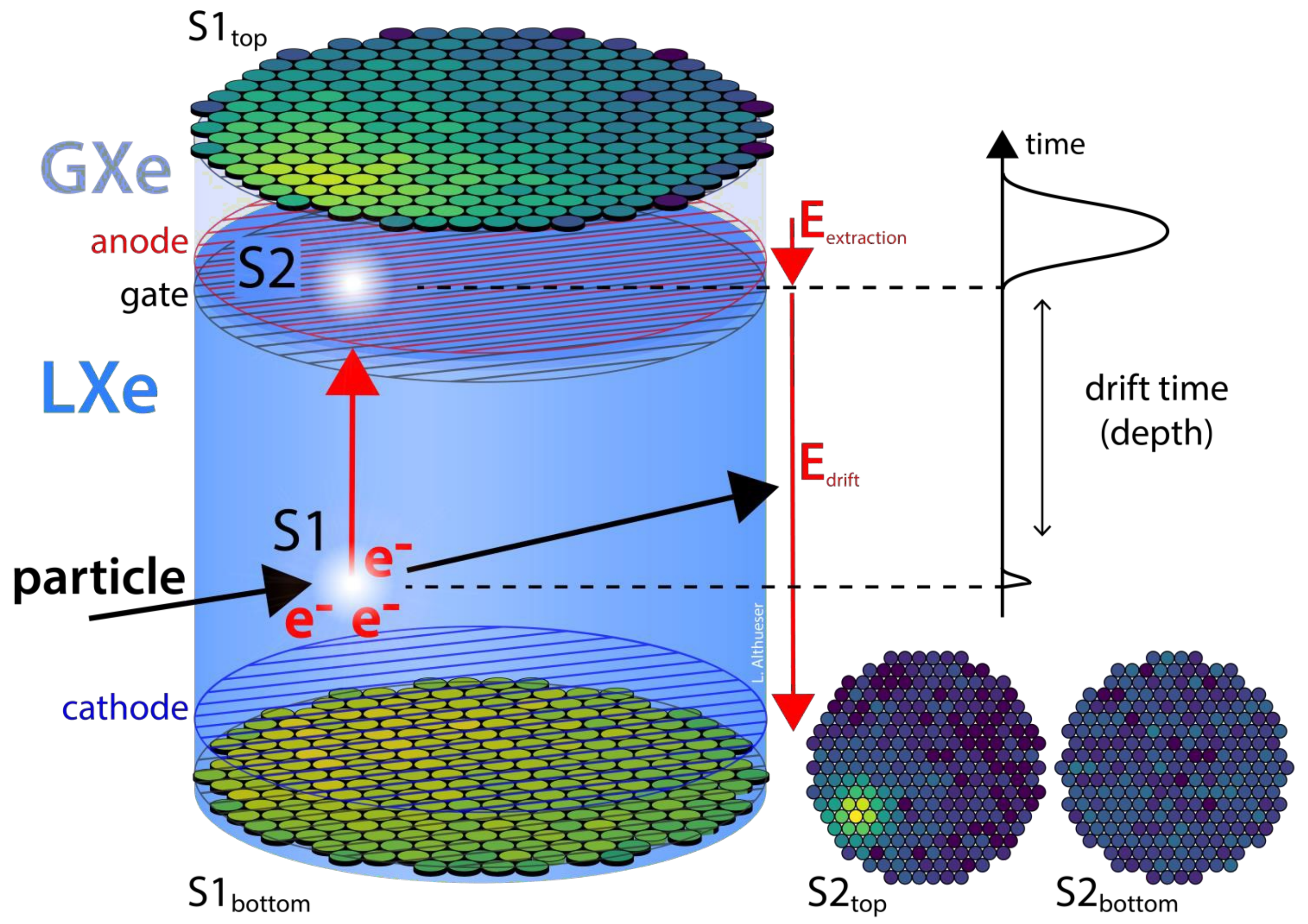


Muon flux @LNGS ~ 3.0 10^{-8} μ cm^{-2} s^{-1}



Working Principle

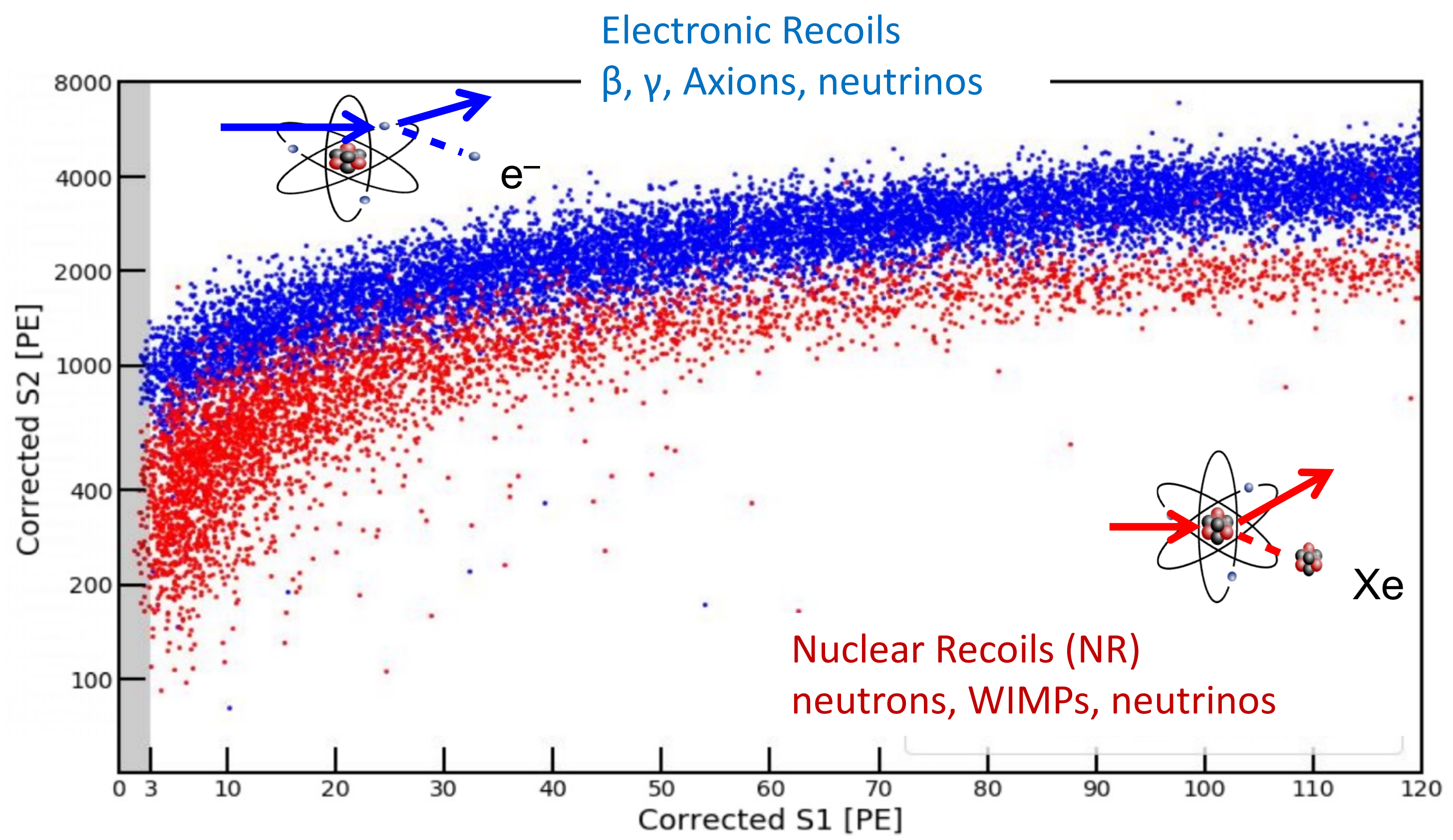
The XENON detectors were conceived and designed to search for **nuclear recoil signals from WIMPs**



Scintillation photons (S1) and free electrons (S2) are produced from an impinging particle.

Working principle of dual-phase liquid noble gas time projection chambers (TPCs)

- ✓ Prompt light signal (**S1**)
- ✓ Secondary light in GXe from drifted charges (**S2**)
- ✓ Energy reconstruction using the combined S1 and S2 signal
- ✓ Position reconstruction
  - **z** from S1-S2-delay time
  - **x-y** from S2 hit pattern



Low background: ER component

Since WIMP scattering off target nuclei is due to a **low energy interaction**, the research requires an ultra-low bkg:

- shielding the detector from the environmental radioactivity;
- enhancing the radiopurity of all the detector materials;
- placing the detector underground to reduce cosmic rays background.

ability to recognize and mitigate the bkg sources.

ER component

- Background from **intrinsic** radioactive isotopes
  - ^{214}Pb a daughter of ^{222}Rn
  - Beta decay of ^{85}Kr
- Additional components:
  - Solar neutrino electron-scattering
  - Background from internal radioactive isotopes (^{137}Cs, ^{40}K, ^{60}Co U/Th decay chain) from detector material

    => reduced by a detector component selection in terms of high radio-purity following an extensive screening campaign

=> Factor x5 improved background compared to XENON1T

Unprecedented low **ER background (15.8±1.3) events/(t·y·keV)**

Distillation + New pumps

Remove by cryogenic distillation

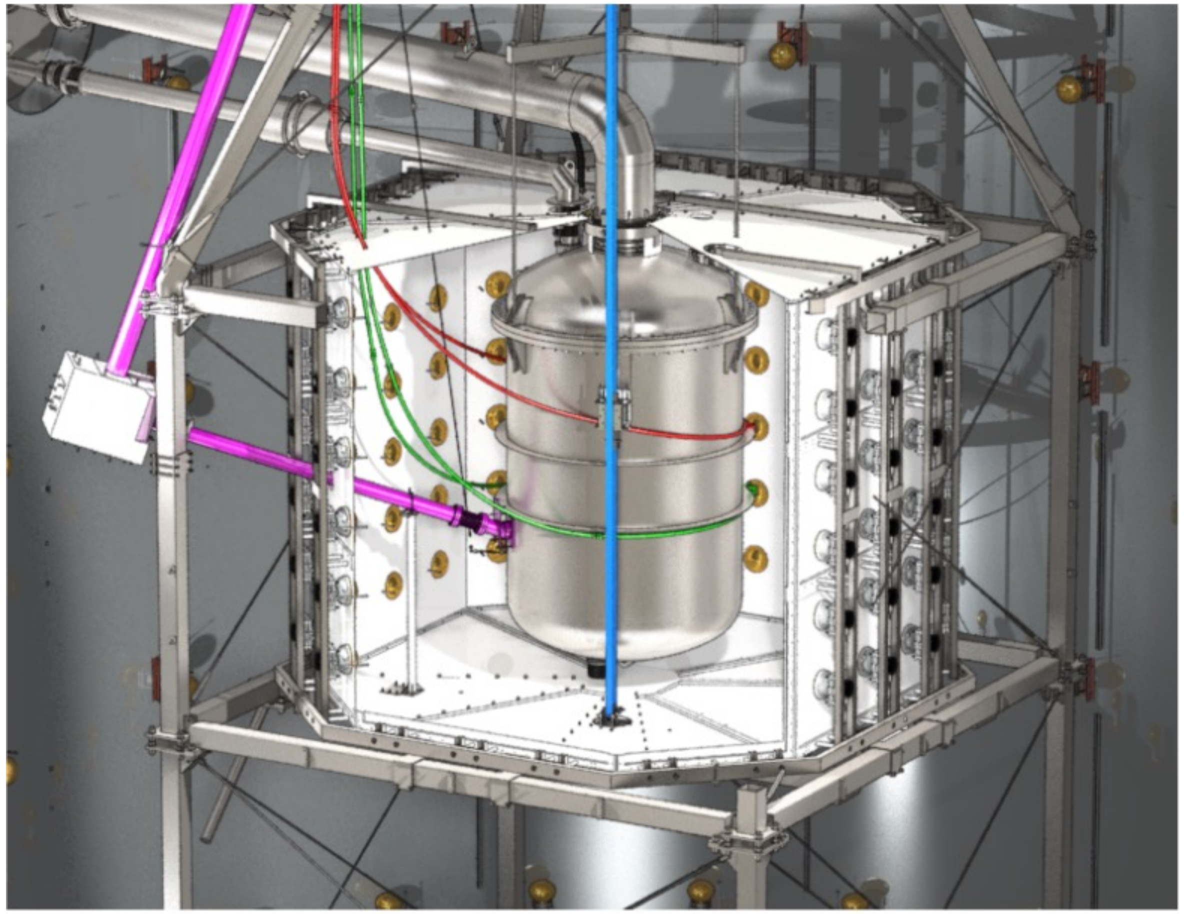
Low background: NR component

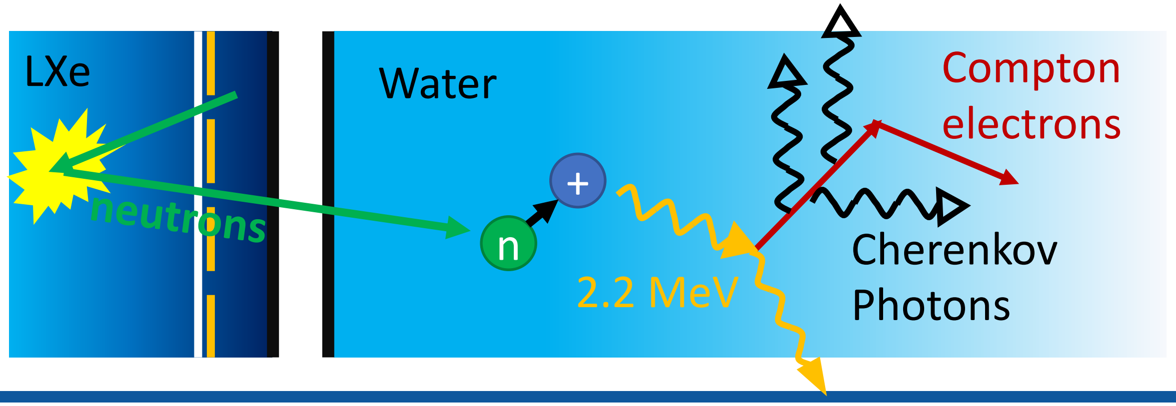
NR backgrounds

- Isotopes, like ^{238}U and ^{232}Th are present in the **detector materials** as well as in the **environmental materials**.
    - Muon Veto: water tank (passive) shields
- **Cosmogenic neutrons:**
    - neutrons from CR up to tens of GeV (might cross the water tank and penetrate inside the TPC and mimic a WIMP-like interaction, contributing to the NR background).

  => Muon Veto exploits the Cherenkov light emitted along the muon path and detected by the PMTs => tagging the muon event.
- **CEvNS** constrained from solar 8B neutrino flux: ~ **0.2 events**
    - astrophysical neutrinos can cause NRs as the result of the Coherent Elastic Nucleus scattering (CEvNS).
- **Radiogenic neutron:** Neutron background from spontaneous fission and (α, n)-reactions (from detector materials etc..). That is the major contribution generated in the MeV energy range through spontaneous fission of ^{238}U, ^{235}U and ^{232}Th

  => NV tagging: 1.3±0.3 neutron events/yr in 4t fiducial volume without NV to **0.17 ± 0.05** evt/yr (with NV) ➔ **factor 6 reduction**



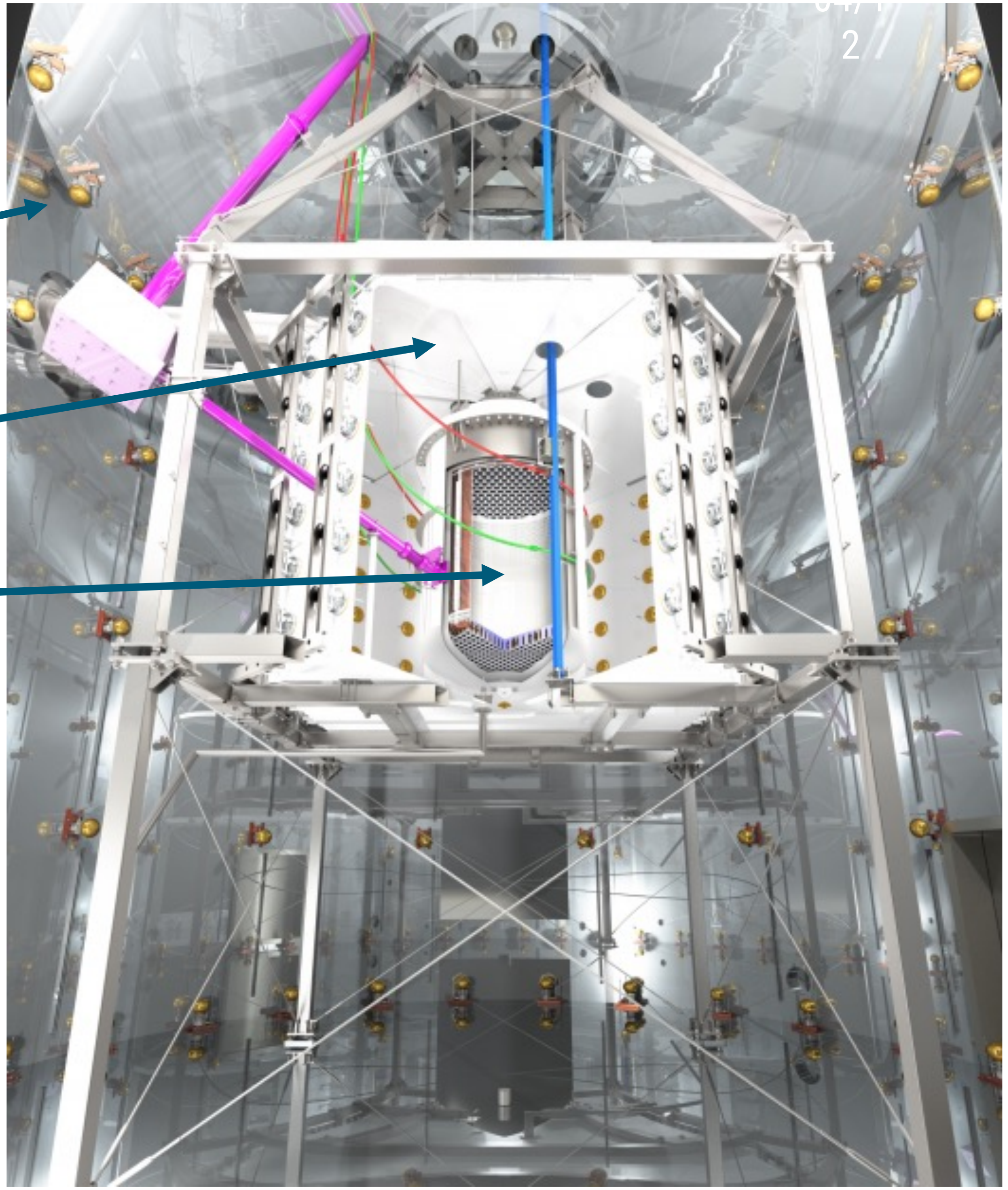


The XENONnT experiment

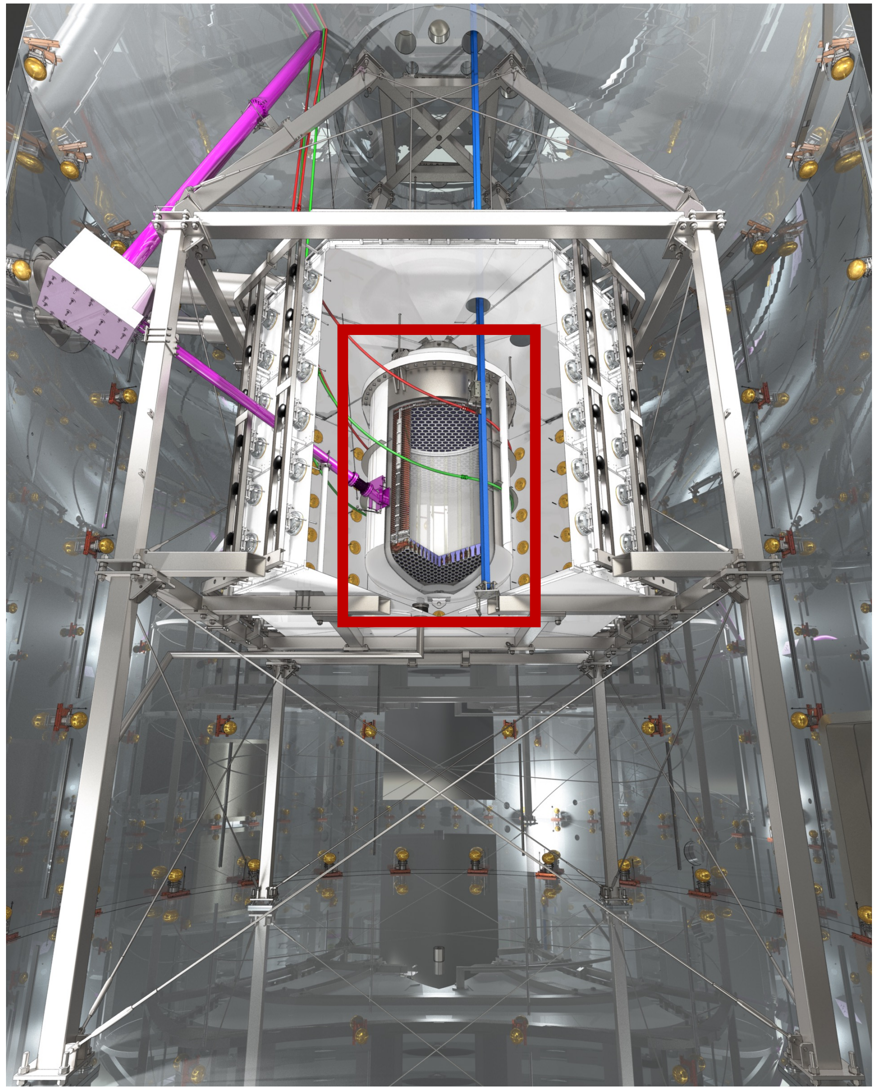
Three nested detectors:

- Water Cherenkov muon veto (MV)
- Gd-loaded water-based neutron veto (NV)
- Dual phase time projection chamber (TPC)

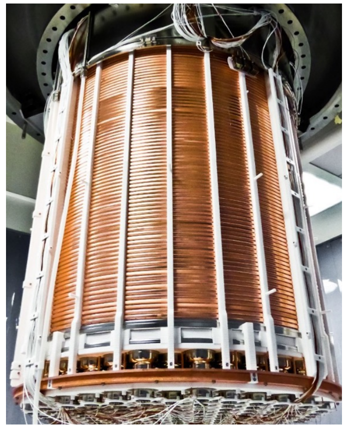
Service building facility provides the systems for the auxiliary components (Cryogenics and purification, DAQ and SC, …)

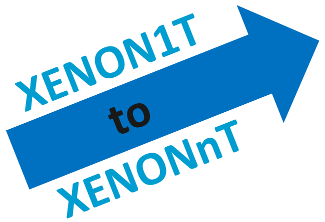


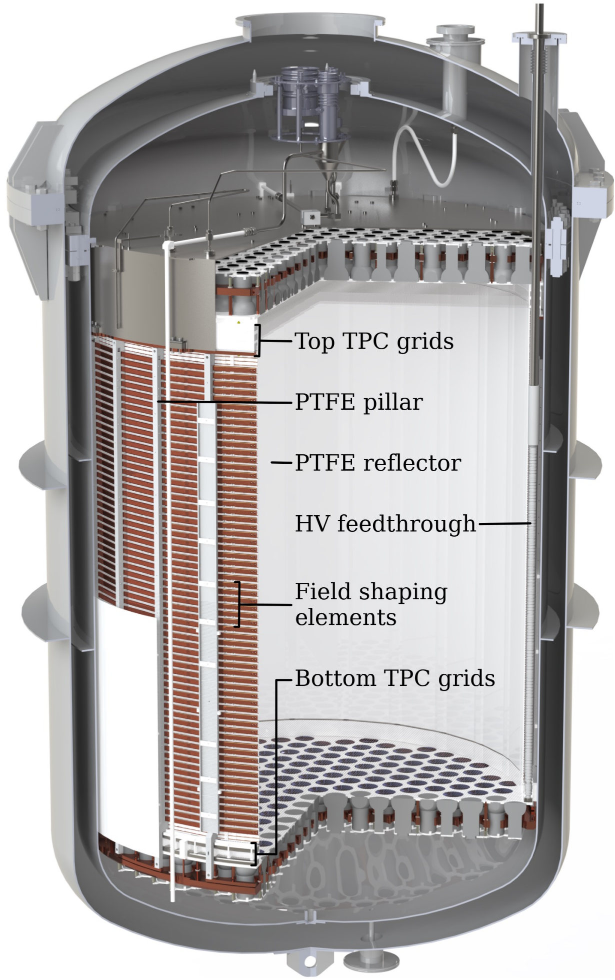
XENONnT TPC



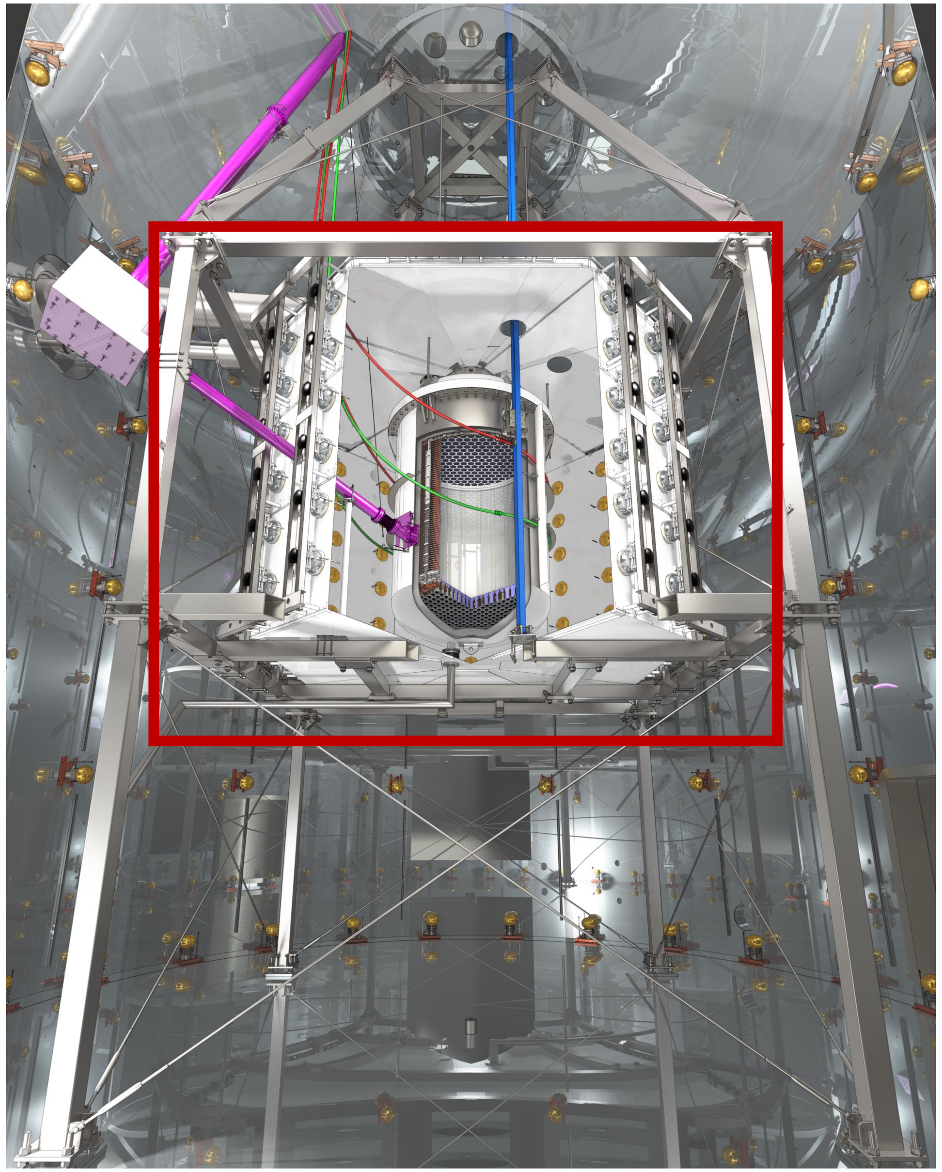
- **Increases the TPC** drift length to 1.5 m (from 1m)
- Contains a **5.9 t** active mass (from 2 t)
- High reflectivity PTFE panels
- 5 **electrodes**
- Two sets of field shaping rings
- Doubles the number of **PMTs to 494**, and has a larger light detection efficiency (34->36%)
- Carefully selected materials to **minimize backgrounds**
- Field shaping rings, tuneable potential for the top ring for fine tuning



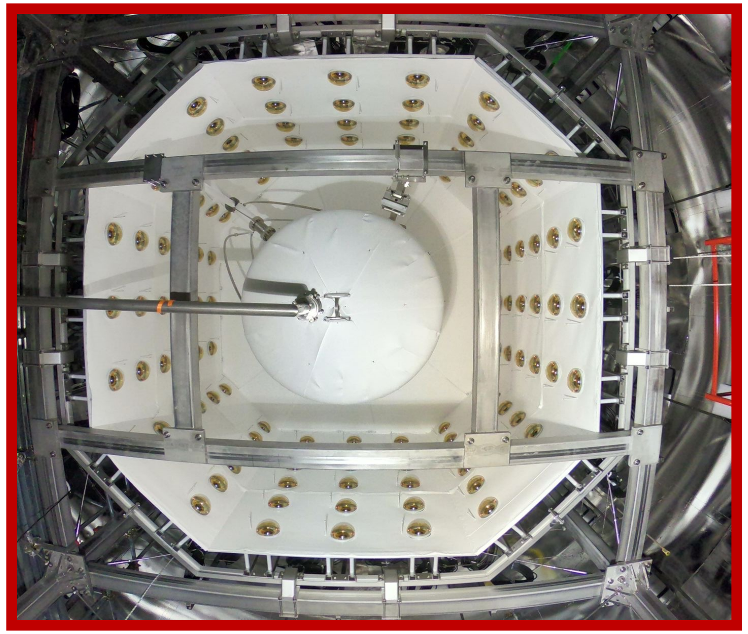




XENONnT: Neutron Veto



- **Cherenkov Muon veto** from 1T
- New **Neutron veto** of 4m x 3m is enclosing the TPC, with 120 PMTs placed inside an enclosure of reflective panels
- NV optically separated from MV by high reflectivity PTFE panels cage
- Neutron tagging efficiency projected to 87% with (planned) Gd-doping, ~53% with current pure water
- The Neutron veto is vital for WIMP search by tagging neutrons, we expected ~0.2 neutrons per t·y



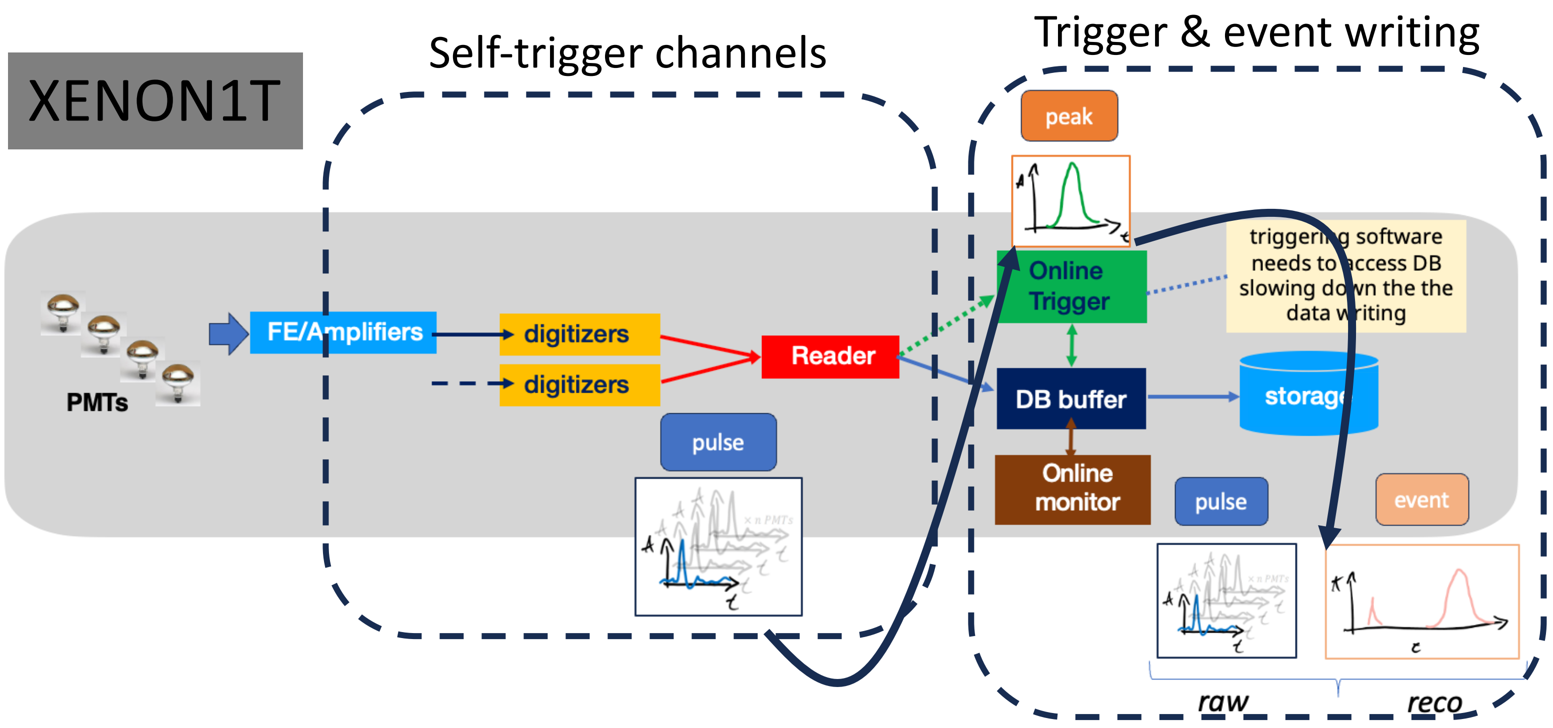
XENONnT a continuous DAQ

XENON1T to XENONnT

XENON1T based on **self-trigger** readout with an **online trigger** for data reduction and the definition of physical interactions

New requirements:

- The increasing of TPC size => increasing of front-end channels and maximum drift time
  - a continuous drift length exceeds several ms
- Several searches (in Xenon1T) complicated or less sensitive by the enforced event trigger definition
  - science data vs calibration data
  - 3 sub-detectors operated as an unique system
- Buffer database would not scale effectively to match the increased load foreseen by the demands of a larger system



The solution is to forego the software trigger, **saving all the data** and **leaving the determination of events only offline**:

- facilitating a wide range of scientific searches, calibration options and detailed background studies

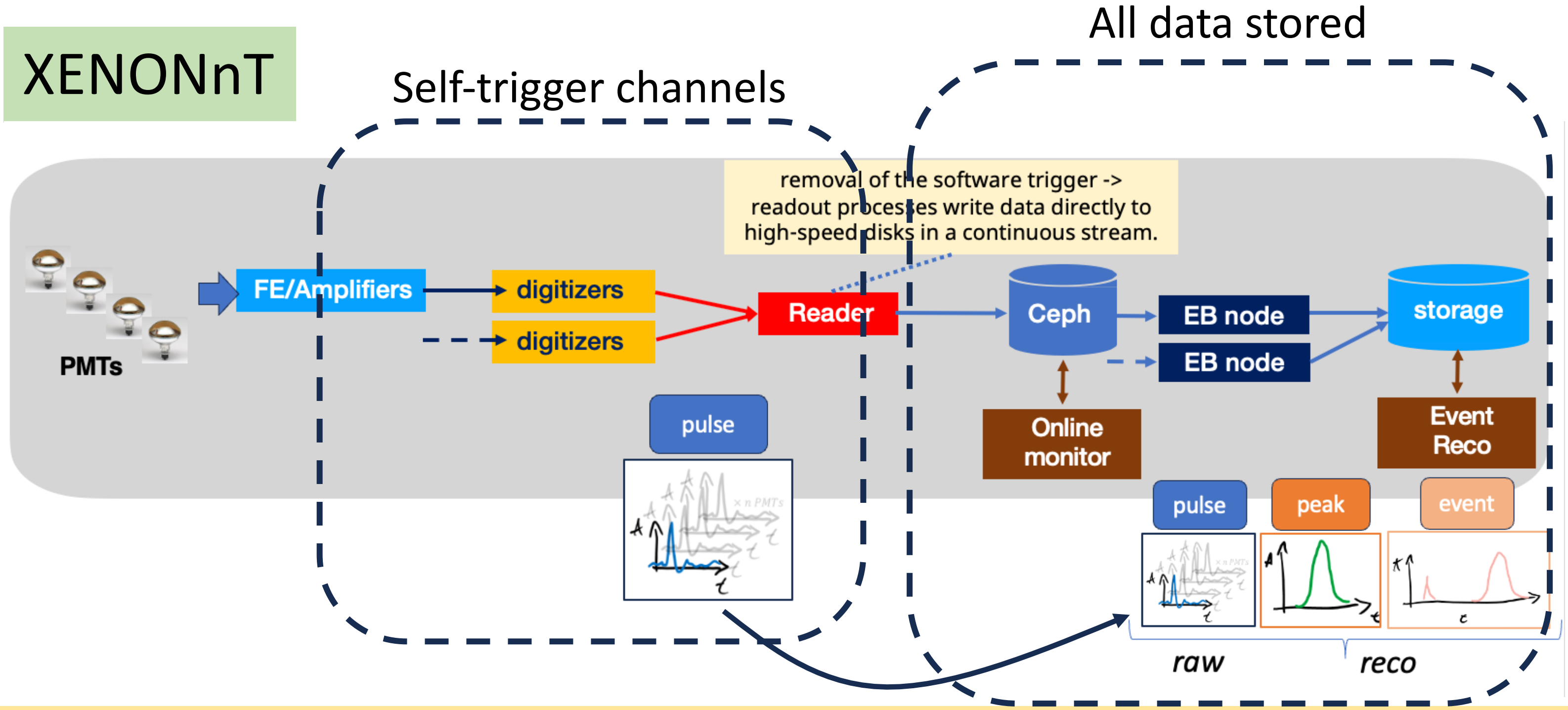
XENONnT a continuous DAQ

XENON1T to XENONnT

XENON1T based on **self-trigger** readout with an **online trigger** for data reduction and the definition of physical interactions

New requirements:

- The increasing of TPC size => increasing of front-end channels and maximum drift time
  - a continuous drift length exceeds several ms
- Several searches (in Xenon1T) complicated or less sensitive by the enforced event trigger definition
  - science data vs calibration data
  - 3 sub-detectors operated as an unique system
- Buffer database would not scale effectively to match the increased load foreseen by the demands of a larger system

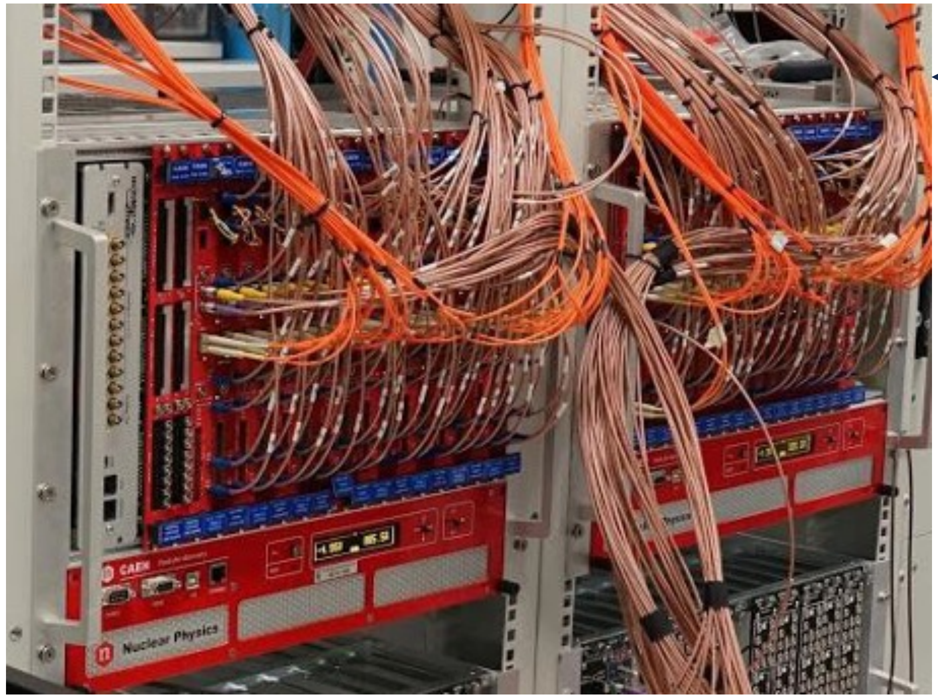


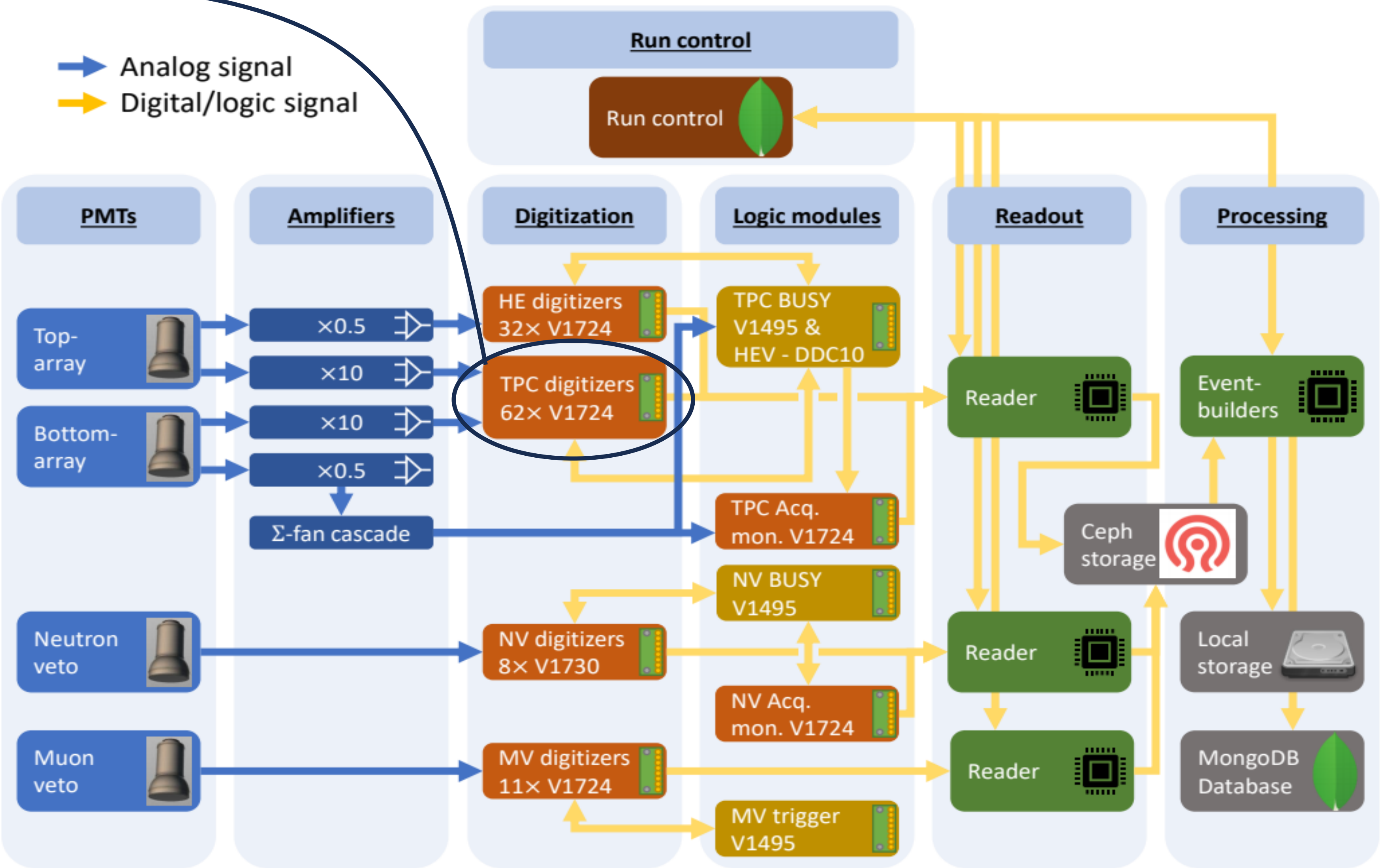
Removing all triggers except the per-channel digitization threshold does **not lead to significantly increased storage requirements**.
Large part of data rate is not PMT dark counts or other small signals seen by only a few channels, rather large S2 signals with wf above threshold for ~ms for a large number of channels

Events rate vs data volume		
th	% of tot event rates	% of tot data volume
1 SPE	~30	2
10^3	1-2	~30

DAQ system

VME crates with 1724s/1730s





- 1st stage PMT signal Front-End electronics and digitization with CAEN V1724/V1730
- 2nd stage data readout and writing on Ceph f.s. (raw data)
- 3rd stage OnLine processing for S1/S2 peaks and events reconstructions, Online Monitor steps can be easily benefit from high level processing
- AUX custom logic for busy management and Acquisition Monitor

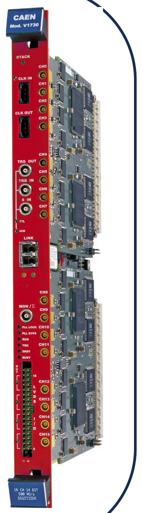
Digitizers

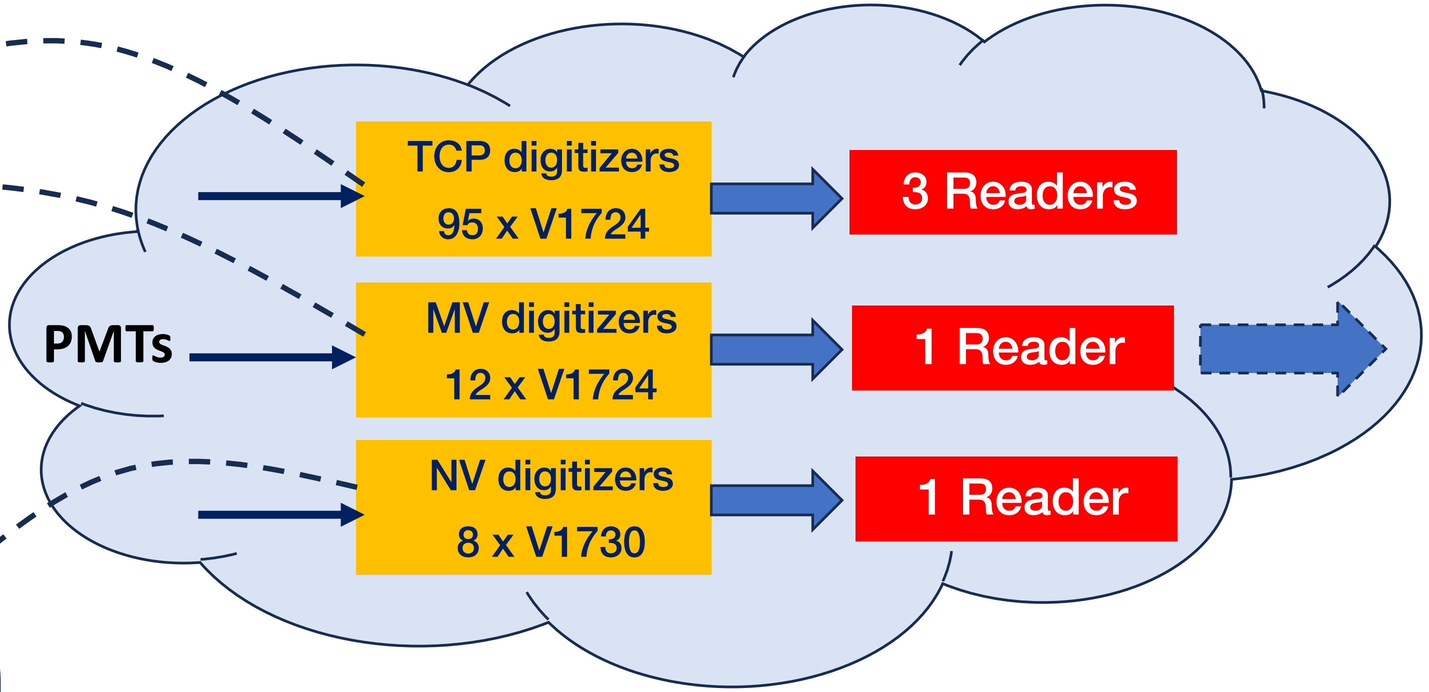
CAEN V1724

- *8-ch board with 100MHz sample rate – 14 bits resol*
- (DPP-DAW) fw: dynamic acquisition windows
- *Independent and continuous readout of each channel*
- Input signal baseline (pedestal) calculation

CAEN V1730

- *16-ch board with 500MHz sample rate – 14 bits resol*
- (DPP-DAW) fw: dynamic acquisition windows
- *Independent and continuous readout of each channel*
- Input signal baseline (pedestal) calculation

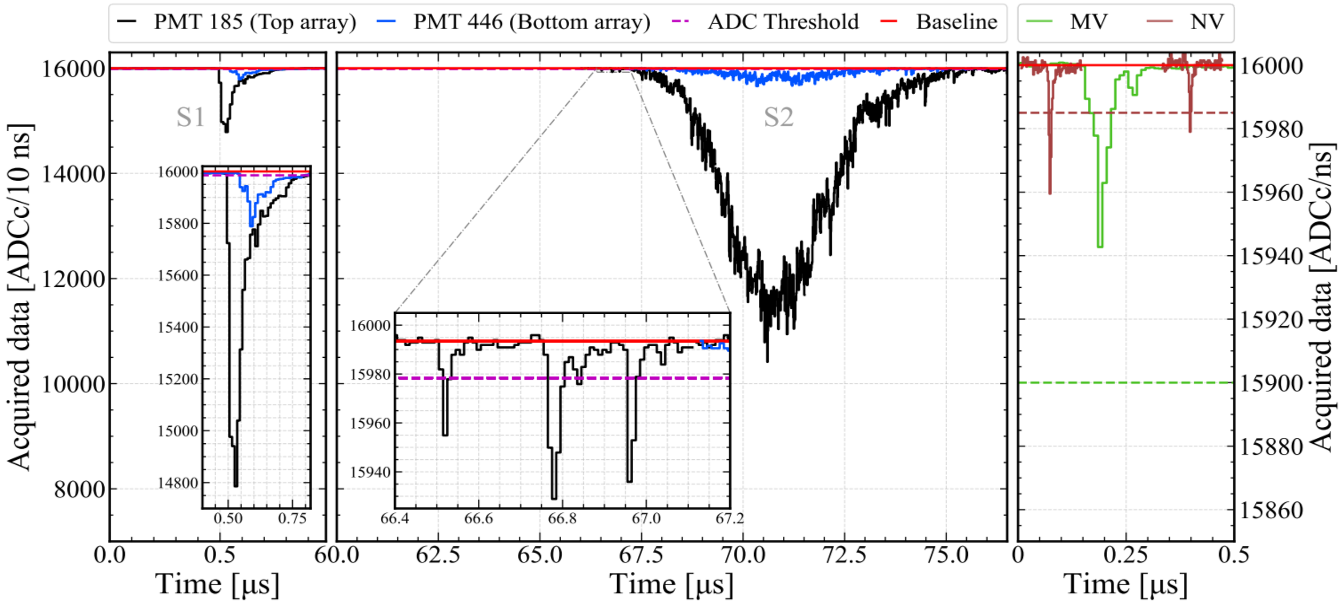




signals read out by the XENONnT DAQ in ADC counts (ADCc).

PMT signals:

- *Behaviour of S1/S2 signals for 2 PMTs (top and bottom array of TPC)*
- *red and purple dashed lines represent the baseline and digitizer threshold, respectively*
- *MV and NV signals; higher sample rate of the NV digitizers*



Readout servers

TPC

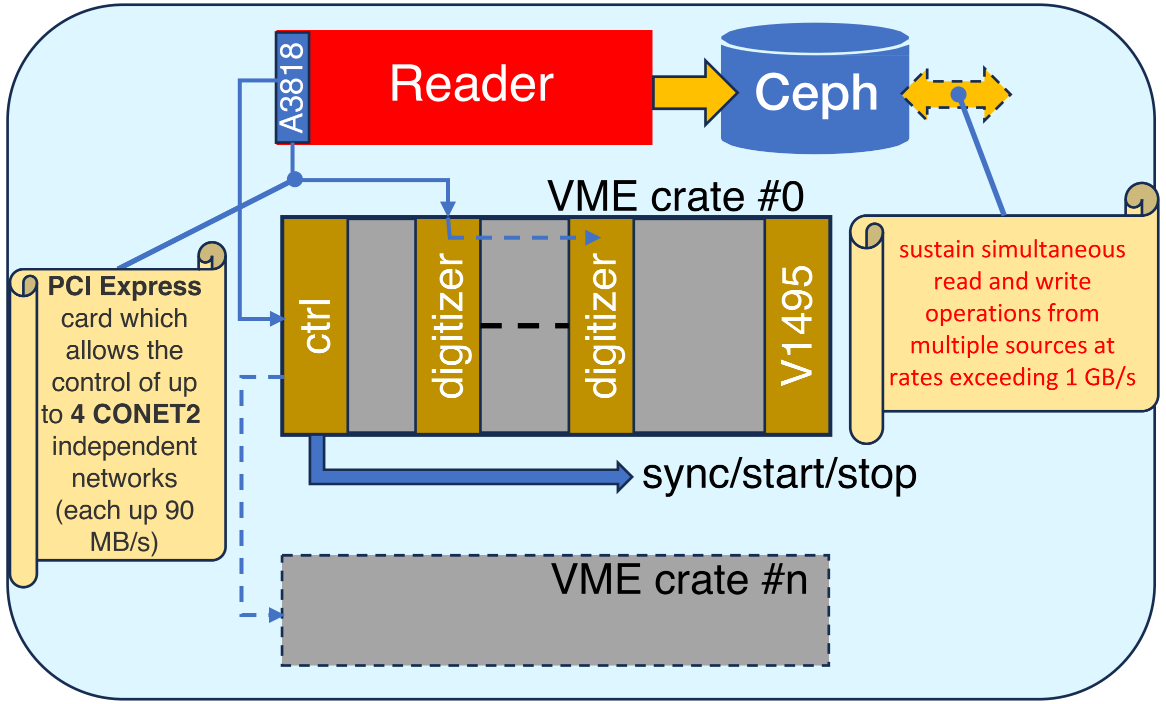
- 5 VME crates, 95 boards (CAEN V1724) connected to readout servers via daisy-chained optical links based on CAEN A3818 PCIe (4 - 1 Gb/s links sustaining ~ 90 MB/s)
- One CAEN V2718 crate control module to synchronize data acquisition (sync/start/stop signals)
- A general-purpose CAEN V1495 board running custom firmware, which manages the busy subsystem

MV

- 1 VME crate, 12 boards (CAEN V1724) connected to readout server
- One CAEN V2718 crate control module for acquisition signal distribution
- A general-purpose CAEN V1495 board for busy management

NV

- 1 VME crate, 8 boards (CAEN V1730) connected to readout servers
- One CAEN V2718 crate control module for acquisition signal distribution
- A general-purpose CAEN V1495 board for busy management



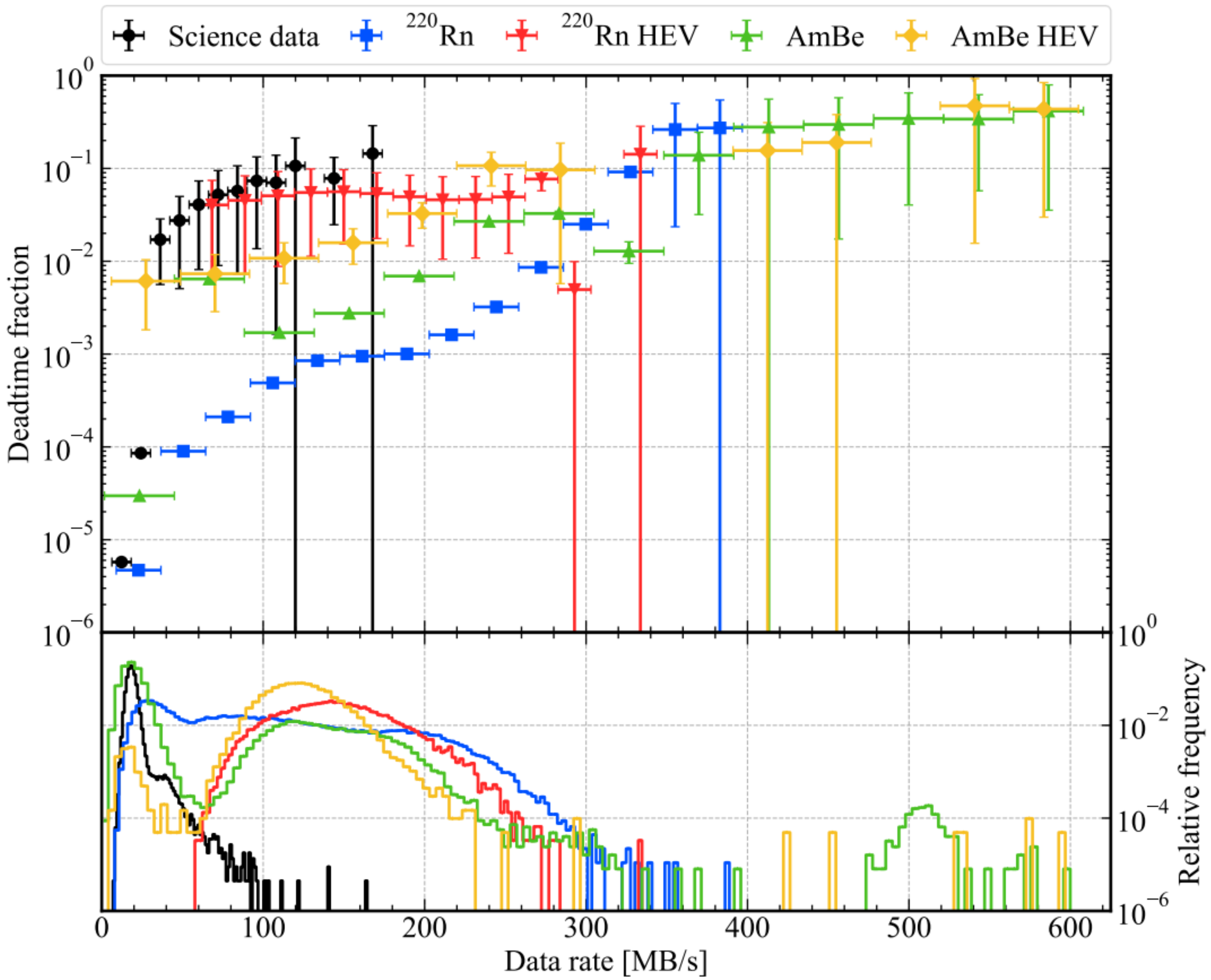
Readers

- 7 readout (2 backup) servers to read data from digitizers in block transfers via the CAENVMElib C++ library
- The readout threads **transfer data asynchronously** to processing threads. Each processing thread periodically **compresses** its buffered output data and writes it to the Ceph buffer in 0.5 s chunks
- Ceph cluster is a single **high-speed buffer disk** with approximately 10 TB of capacity that is accessible from all servers within the DAQ network.

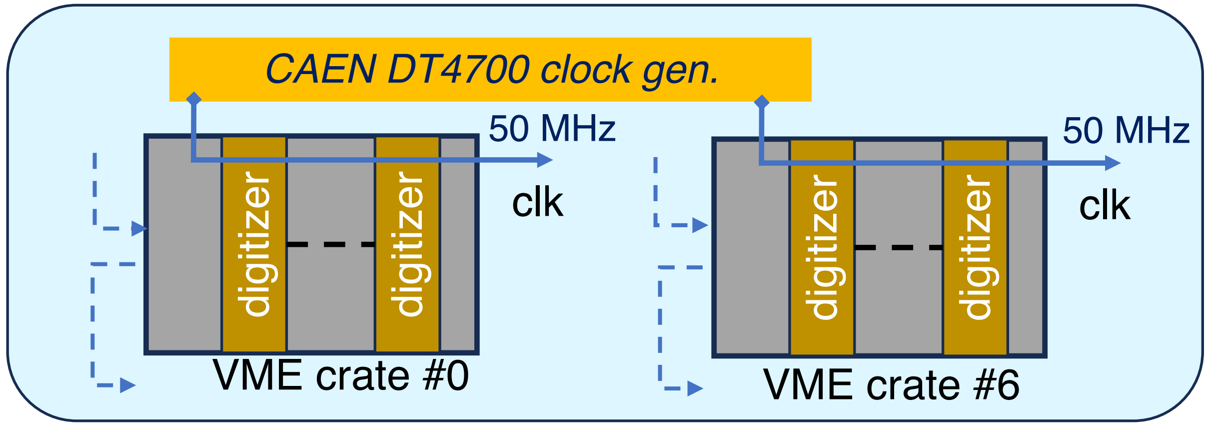
Performance: livetime

During Science Run0 (2021) all three DAQ subsystems operated stably, collecting in total more than 200 days of commissioning and science data, and close to 100 days of various calibration data.

- The deadtime fraction induced by the operation of the **busy veto is 2×10^{-5}** for the majority of SR0 science data (which is typically ≲25 MB/s)
- The average deadtime fraction for all SR0 science data is 3×10^{-4} .
- During high-rate ^{220}Rn and AmBe calibration periods the deadtime resulting from the combined operation of the busy and HEV on average amounts to ∼ 10%.

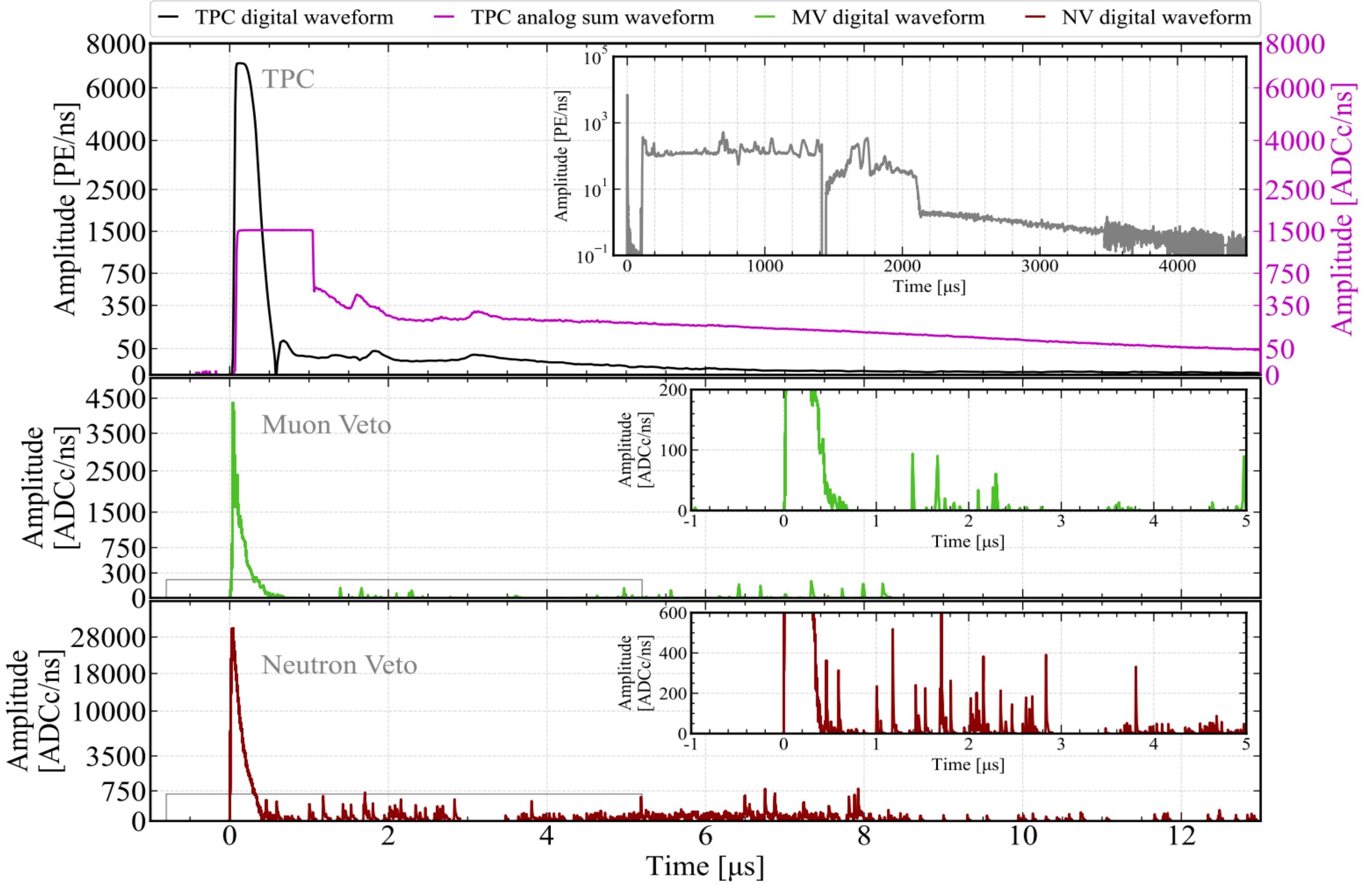


Time synchronization



3 DAQ subsystems (TPC/MV/NV) are operated in linked mode with full time synchronization (115 digitizers in 7 VME crates):

- XENONnT DAQ relies on a **CAEN DT4700 clock generator** module.
- 50 MHz LVDS clock signals via 7 shielded custom-manufactured cables to the first digitizer in each VME crate.
- The distribution within each VME crate is made through the board **chain via clk-in** and **clk-out** connectors.
- **Time offsets** in these clock chains **manually calibrated** out, securing synchronization well below the digitizer temporal resolution (≲ 1 ns).



The time synchronization across all sub-detectors verified:

- with 0.1 Hz GPS signal distributed with high precision (<0.1 ns) to several digitizers and measuring the timestamps of these signals
- with a muon event passing through all XENONnT sub-detectors

Event builder servers and live processing

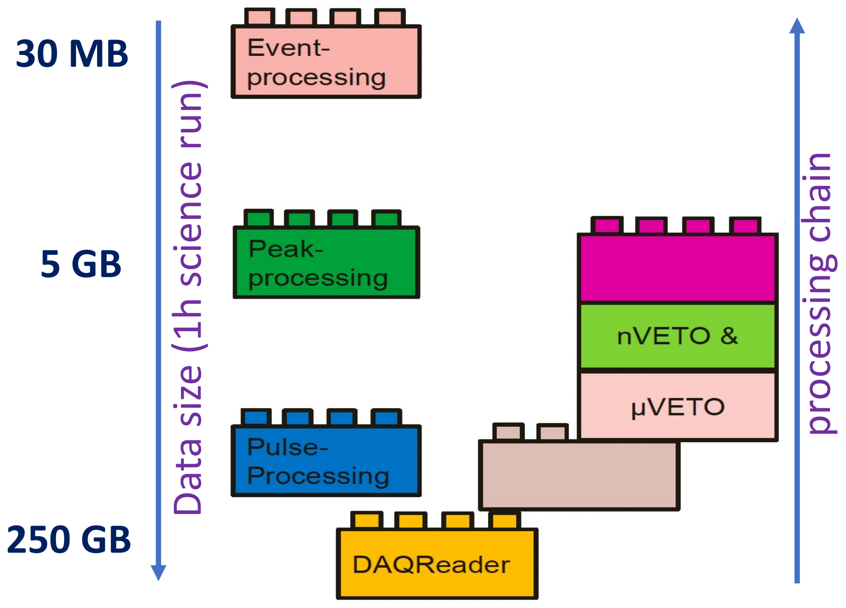
Strax/Straxen: **Streaming** analysis for **xenon** experiments

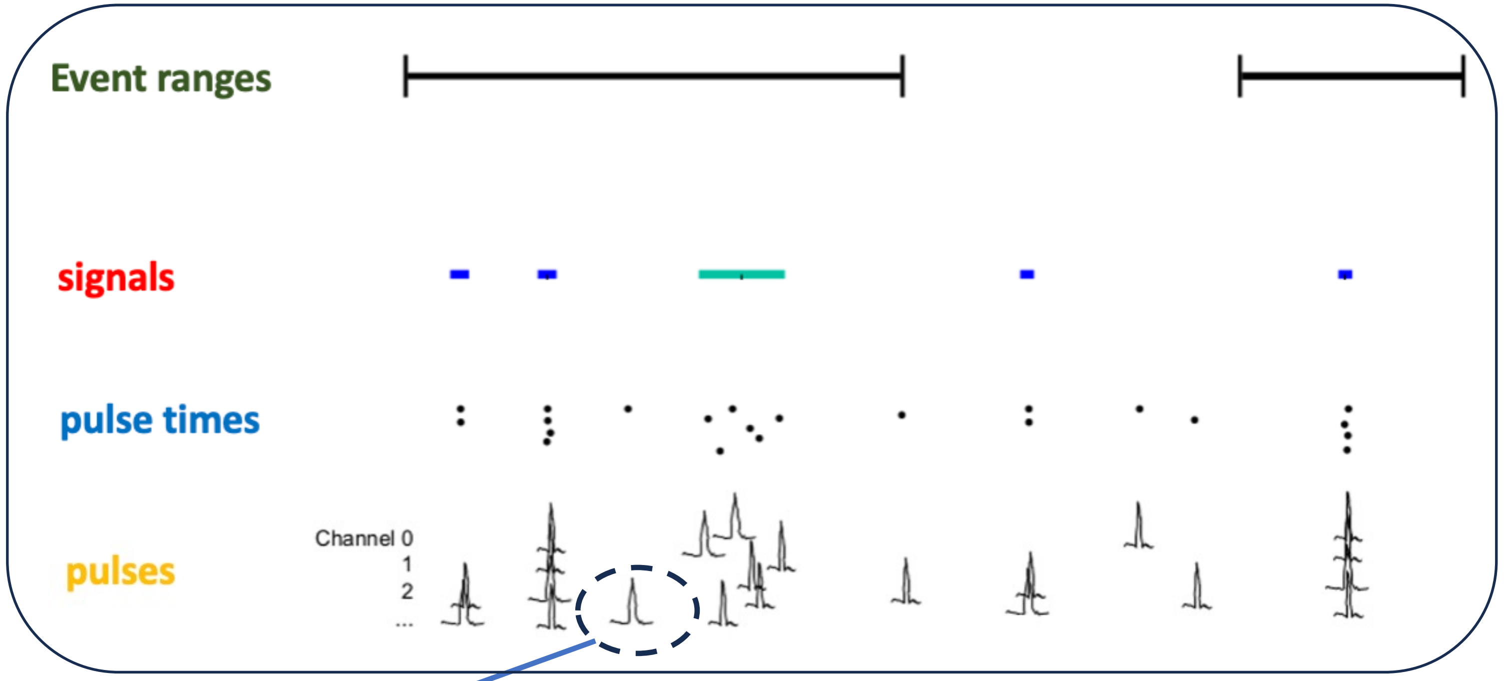
The data stream of raw data from digitizers is **fully processed onsite** at LNGS → STRAX

Event (S1 and S2) → time region last up to 2.2 ms (drift time)

S1/S2 → peaks level data tipically 10-100 μs

PMT-traces → raw data (long term stored) tipically 1 μs

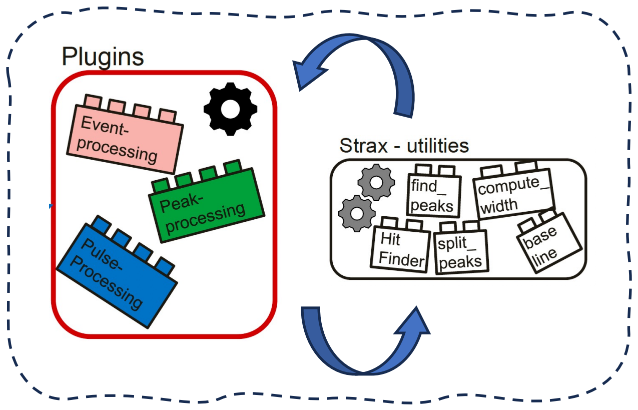


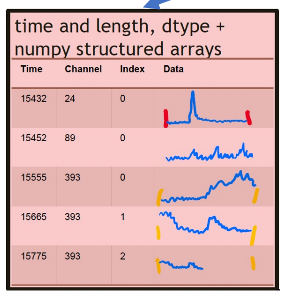


Strax data format

- different levels of data processing are organized in software modules (plugins)
- chunk processeing: transferreing between threads to any higher level plugins requiring it as input.
- reprocessing doesn't affect any lower level datatypes
- during processing, auxiliary information (like PMT gains) are queried from a dedicated collection within the MongoDB database.

Strax





Data organized in chunks (~ 0.5 s) with a tabular format allowing the **parallelization**.

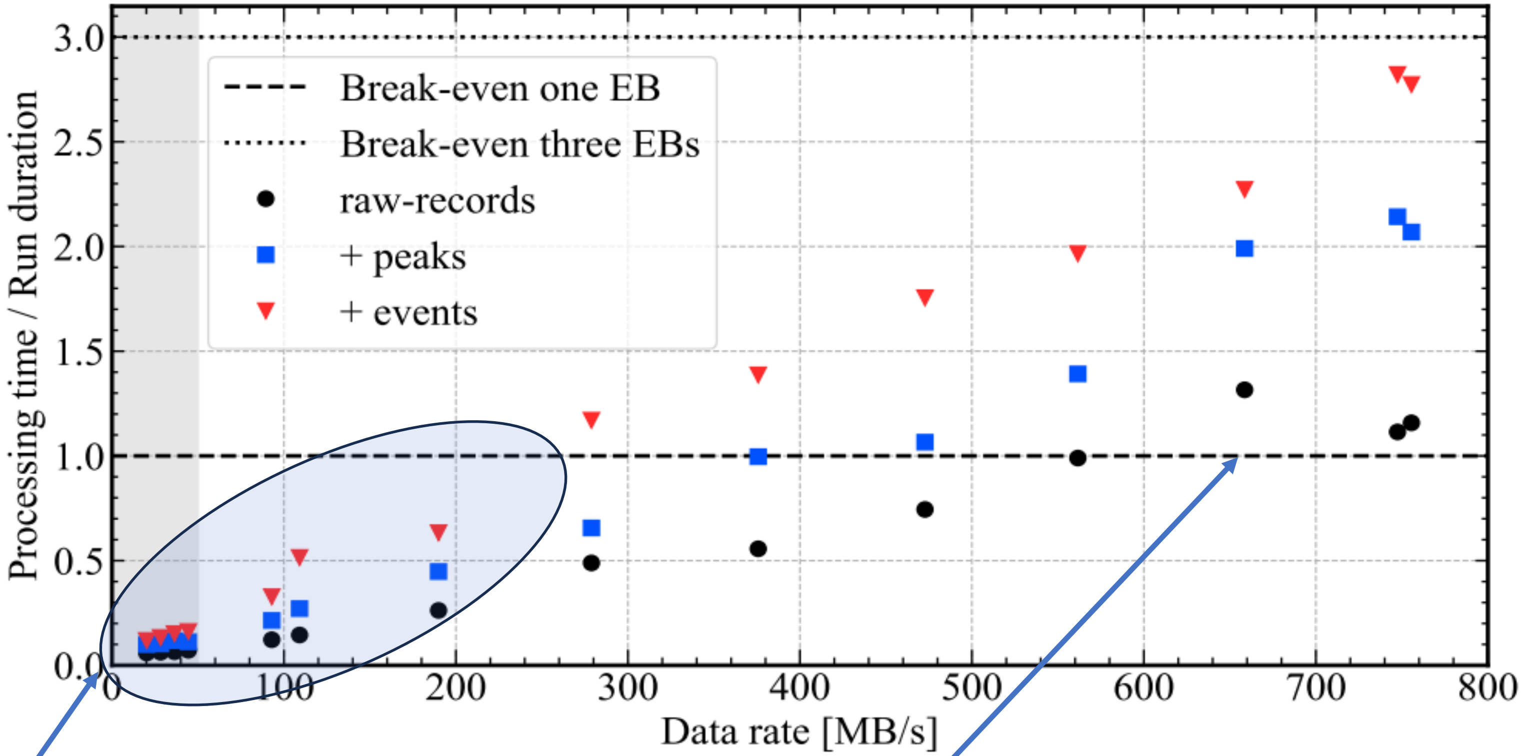
The raw data stream from the digitizers is fully processed onsite at LNGS by 6 EB servers (PRIMERGY RX2540 M4 Fujitsu servers with 2 Intel Xeon Gold)

Performance*:* Live processing

Processing time for different datatypes: raw-records (the lowest level), peaks and events.

The **total processing** time consists of:

- the time of starting bootstrax for a given run
- decompressing the redax data
- processing the data until the specified datatypes
- compressing and writing all the processed data to disk



For data rates below 250 MB/s **a single EB can manage** the entire data stream regardless of the datatype considered.
- in case of higher rate more EBs

The break-even line for 1 EB lies around		
Events	Peaks	Raw-rec
250 MB/s	400 MB/s	550 MB/s
3 EBs fulfil all the data rates		
A higher level datatype processing implies all the lower level datatypes		

OnLine monitor

- The use of **fully reconstructed data to monitor** the state of the detector during the data collection.
- Several datatypes are uploaded during data collection:
  - acquisition monitor data
  - all the fully reconstructed events and selections of data from the MV and NV
  - selection of the peaks data from the TPC

a period of intermittent light emission ("flash") of PMT313

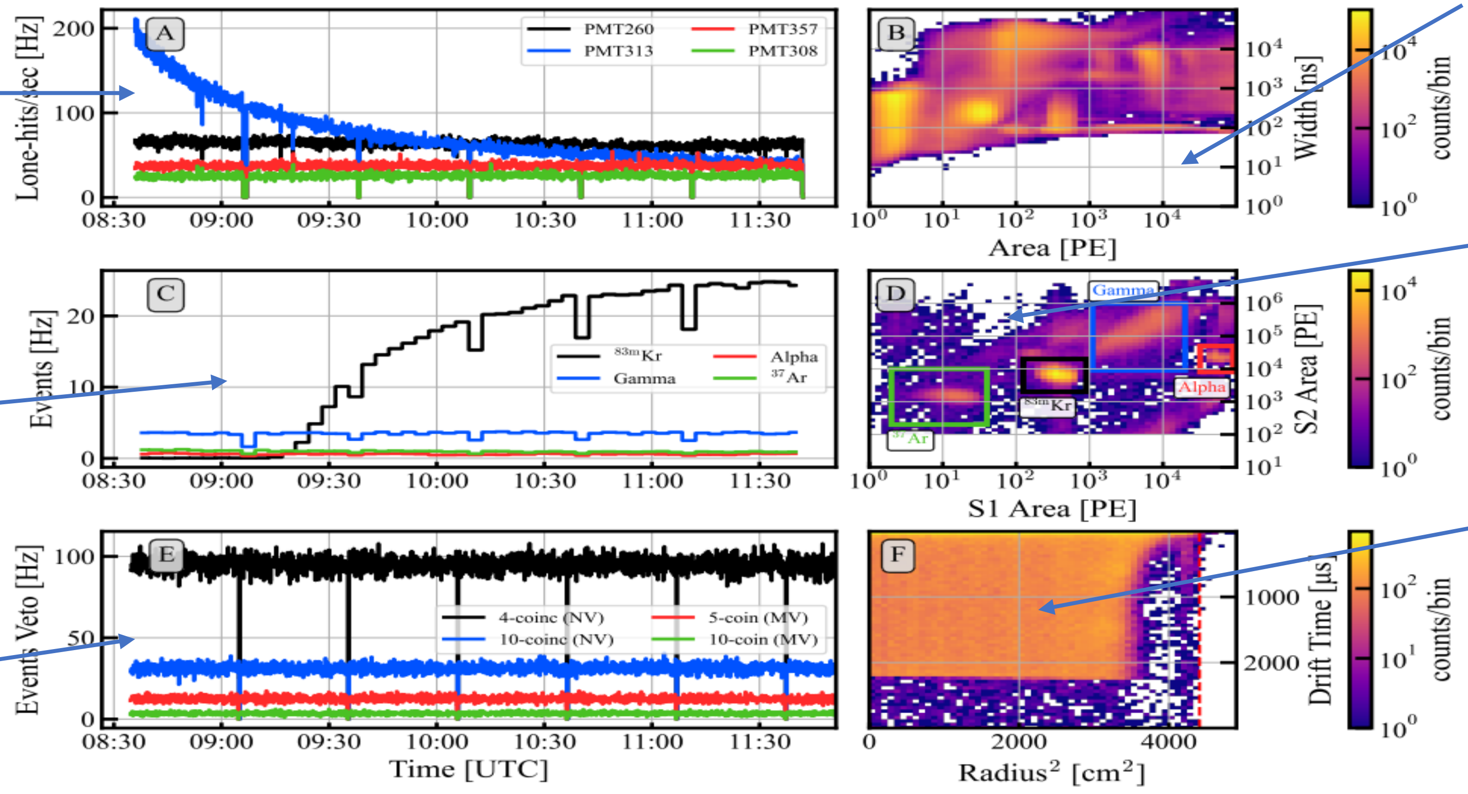
start of a calibration period with ^{83m}Kr

evolution of the number of veto events in the veto-systems over time.

area of peaks vs width of the sum-waveform of a peak; useful for identifying peak populations.

S1 and S2 area

reconstructed event positions throughout the TPC

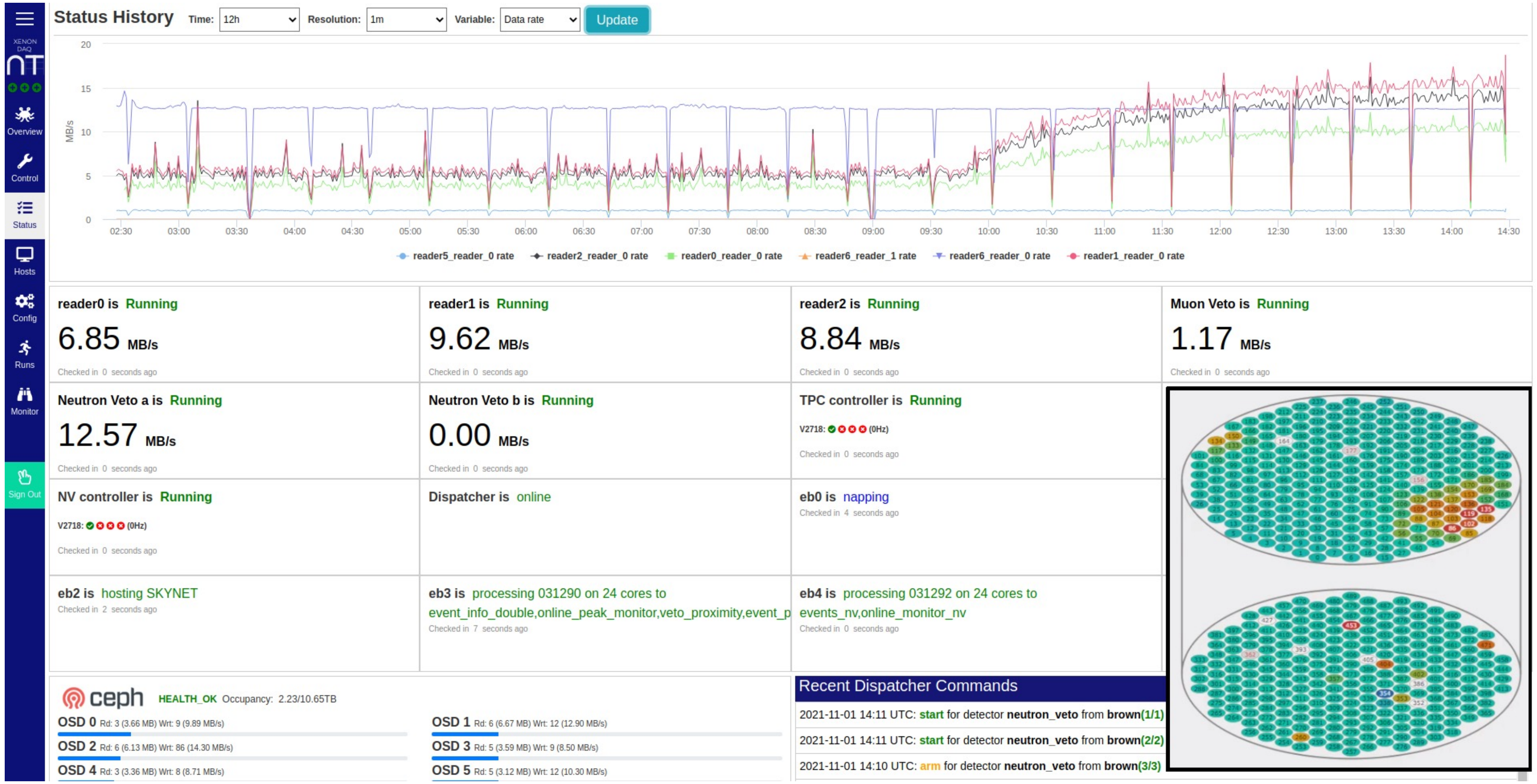


Each hour a plot is automatically produced and sent to the XENONnT-Slack

Control and monitor page

The status page displays instantaneous data rates for each readout process in the entire DAQ system, information about the current activity of each eventbuilder, and the current status of the Ceph high-speed buffer disk.

Front-end website developed using NodeJS



Summary

- A trigger system selects physics events of interest and suppresses background as efficiently as possible.
  - must match the event rate to the data acquisition rate.
- **Trigger-less DAQ** very attractive for underground experiments (i.e. neutrino telescope, direct dark matter detector, cosmic rays detector etc…) when events occur at arbitrary times
  - Typically no needs to have a full detector readout
  - background within random timing
  - Benefits:
    - No bias due to a trigger decision
    - More flexible and powerful trigger (online/offline) alghorithms
      - Software trigger can rely on a commercial hardware (switches/farms)
    - steaming DAQ able to read out many parallel continuous stream of data
    - calibration and monitoring without the need for special runs - deterministic time-ordered data transfer with corresponding strorage giving the opportunities for more streamlined and parallelization
  - Challenges:
    - Larger data rate to Event builder/CPU farm
      - A careful design to avoid bottlenecks
    - Stable and accurate timing is essential for time-stamping of each fragment
      - Common clock for each subdetectors
      - Time calibration
- The triggerless streaming readout for two underground experiments (KM3NeT and XENONnT) have been presented; DAQ constraints, construction design and performance are discussed.

Thanks for your attention!

Backup slides