TRIggerles Data acquiSition (TRIDAS) for the KM3NeT experiment

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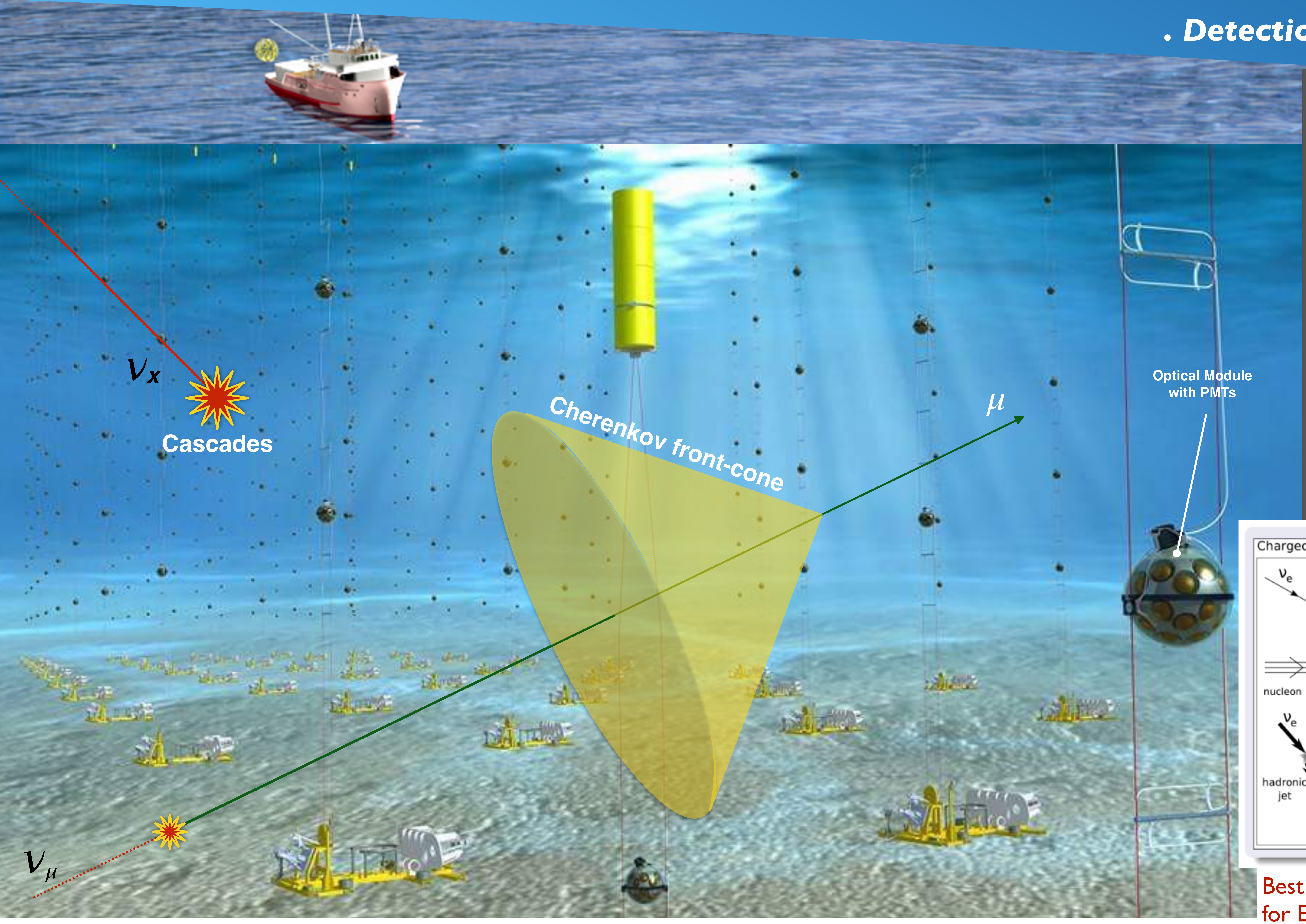
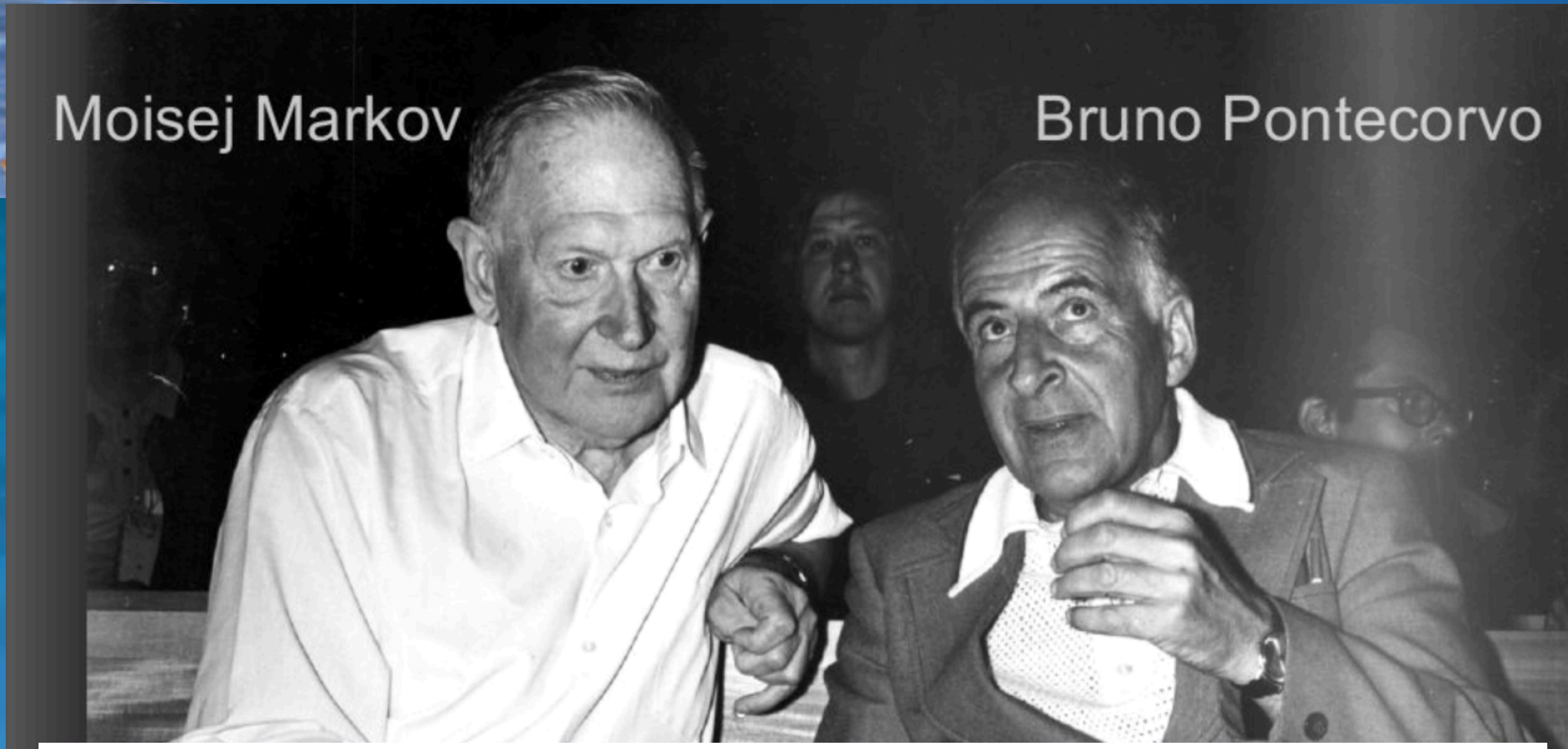
Talk's core business: the trigger-less data acquisition for underwater neutrino telescopes

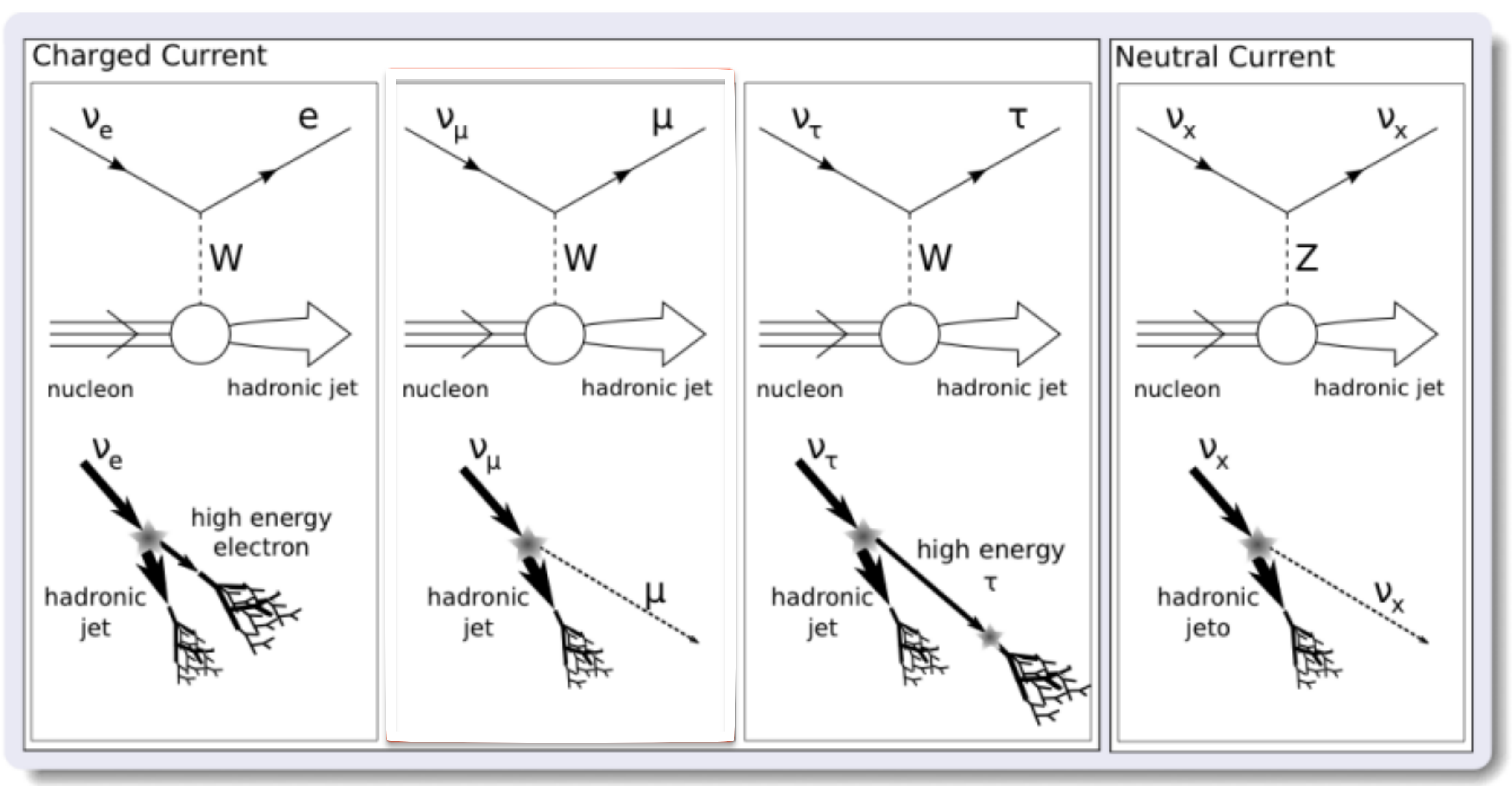
A prospection: porting the nu-tel DAQ to beam-dump experiments


χ
ν
GeV-TeV
TeV-PeV
Milky Way
?
Exotics :
Magnetic Monopoles
Nuclearites
>EeV
ν
Galactic
Extra Galactic
HE γ
(10 Mpc)
protons (50 Mpc)
neutrons
(unstables)
low energy particles
AGN
GRB
PeV-EeV





M. Markov:
"We propose to install detectors deep in a lake or in the sea and to determine the direction of the charged particles with the help of Cherenkov radiation"
1960, Rochester Conference



Best channel for Energy estimation

Golden channel for Astronomy (good angular res.)

"Double bang" resolved @ E>1PeV (τ range >50 m) rare events

Partial energy information

* Taking data and completed

** Taking data but still under construction

Very small neutrino cross-sections

$$\sigma_{\nu N} \sim 7.8 \times 10^{-36} \left(\frac{E}{GeV}\right)^{0.36} [cm^2] \quad \text{for } E_\nu > 1 \text{ TeV}$$

Very small expected fluxes

W.B. bound:

$$\frac{dN_\nu}{dE} \sim 9 \times 10^{-9} \left(\frac{E}{GeV}\right)^{-2} \left[GeV^{-1}\, cm^{-2}\, sr^{-1}\, s^{-1}\right]$$

⇒

- **O(km³) volume size detector**
- **many detector elements**
- **many years uptime**

Astrophysical source searches

with angular resolution < 1 deg over a km³ scale

⇒

- **Time resolution of O(1ns)**
- **Positioning resolution O(10 cm)**

No bunch-crossing time info

Abyssal sites

Undersea only: ^{40}K and bioluminescence

e.g.: > 50 kHz @ 10'' PMT (0.3 p.e. threshold)

Signal (atm. μ) to noise ratio $<10^{-4}$

⇒

- **Simple detector off-shore**
- **On-line Trigger on-shore**
- **Continuous data taking**

⇒

- ***All data to shore***
- **high throughput handling**
- **fast and effective background rejection**

. ANTARES – the first underwater nu-tel since 2006 .

- Running since 2007
- 885 10” PMTs
- 12 lines
- 25 storeys/line
- 3 PMTs / storey
- 0.05 km³ instr. vol.

STRINGS

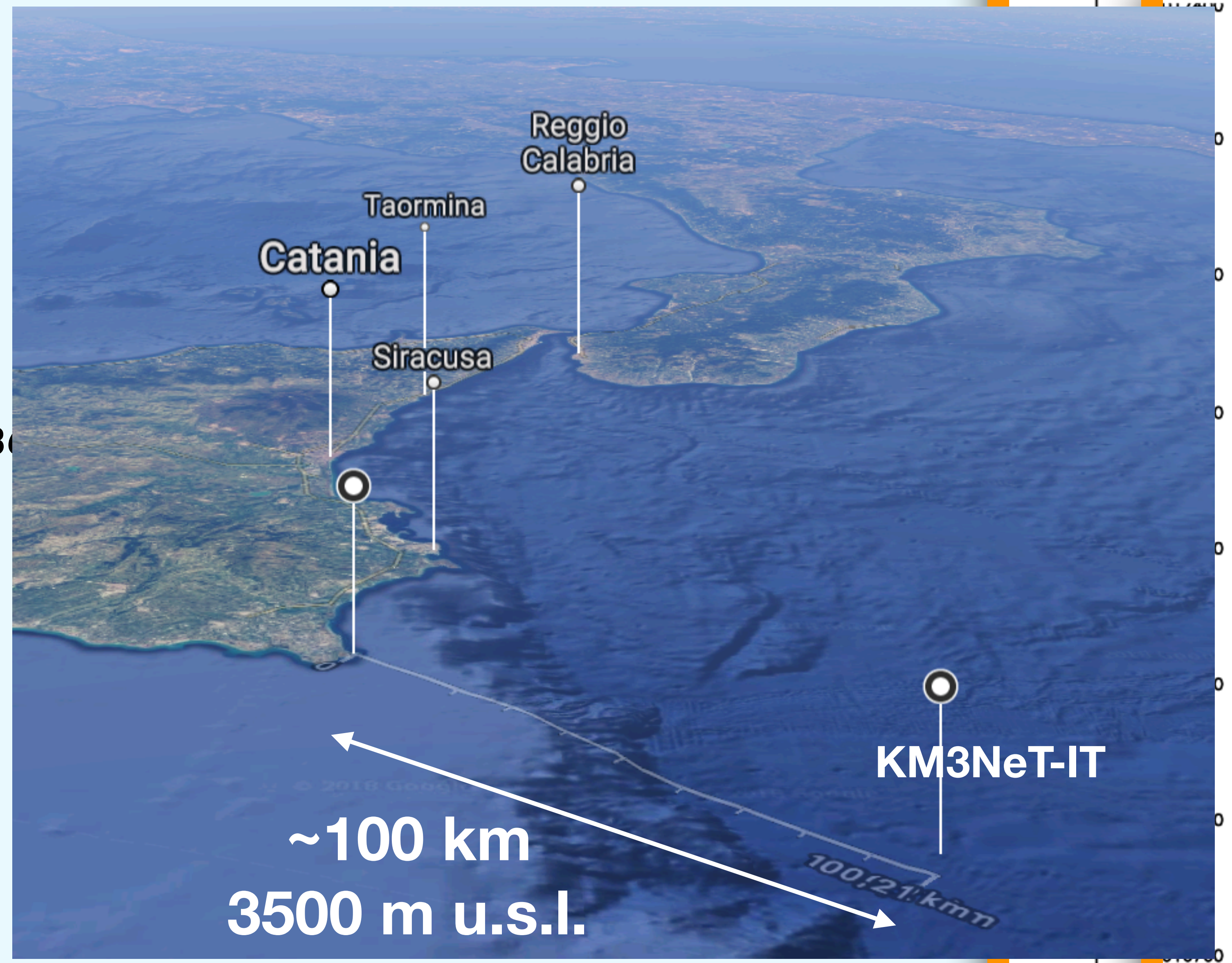
31 PMTs/DOM
18 DOMs/string
2 x 115 strings

558 PMTs/string
64170 PMTs/b.b.

TOWERS

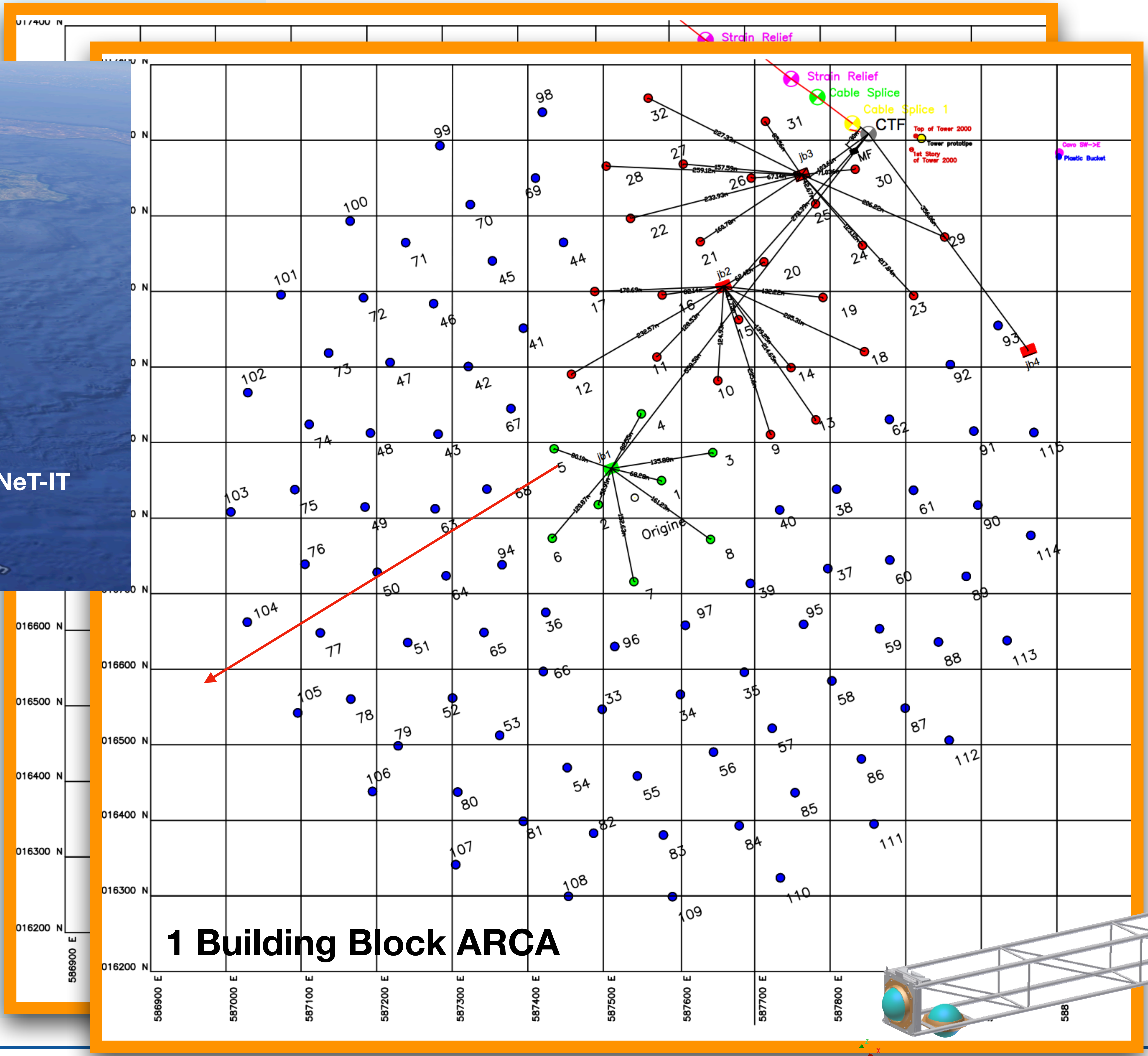
6 PMT-OM/Floor
14 Floors / Tower
8 Towers

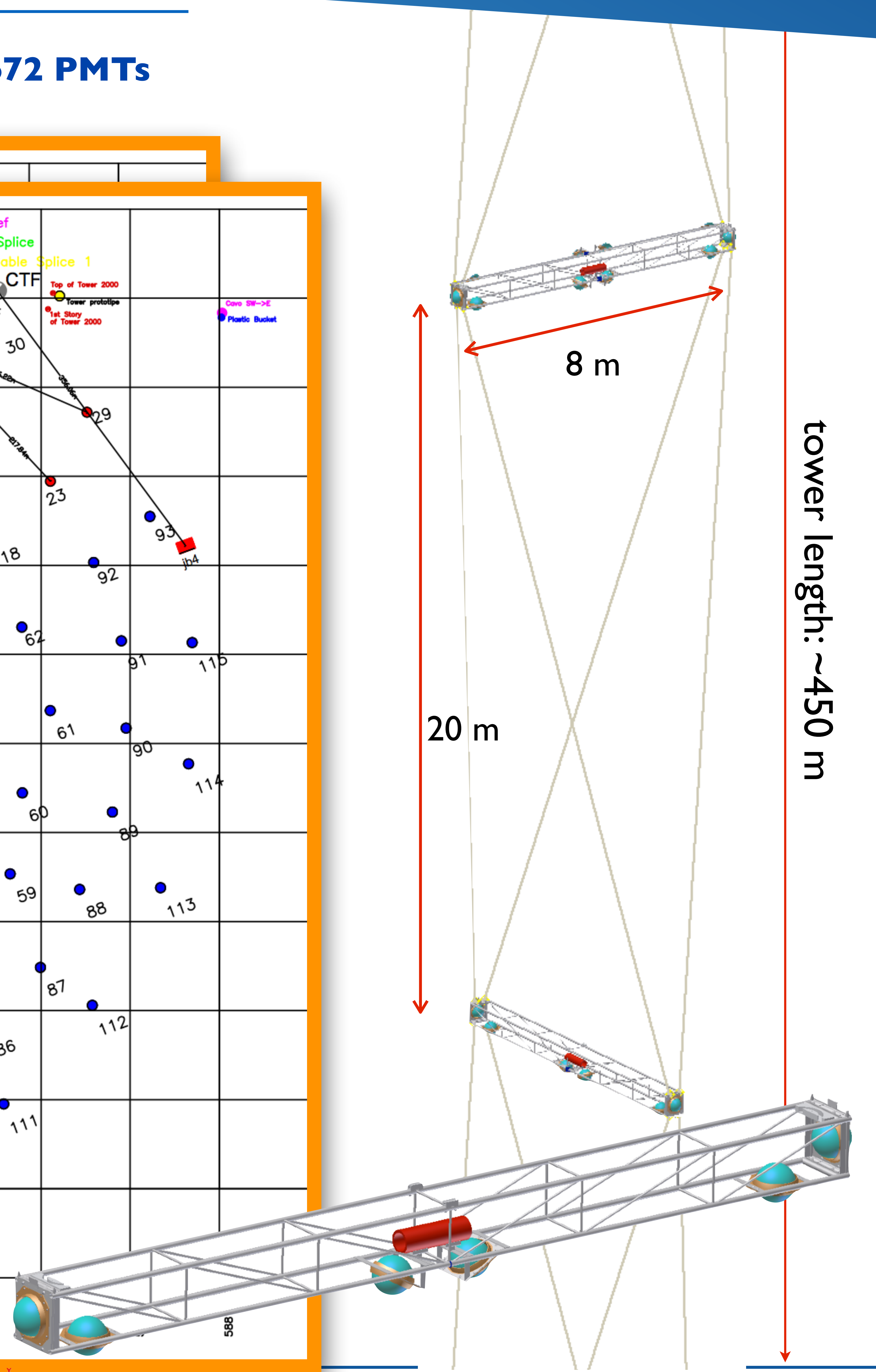
Tot: **672 PMTs**



Study of
astrophyisical neutrinos

2 *building block* in the
Italian site
vertical spacing: ~35 m
horizontal spacing: ~90 m



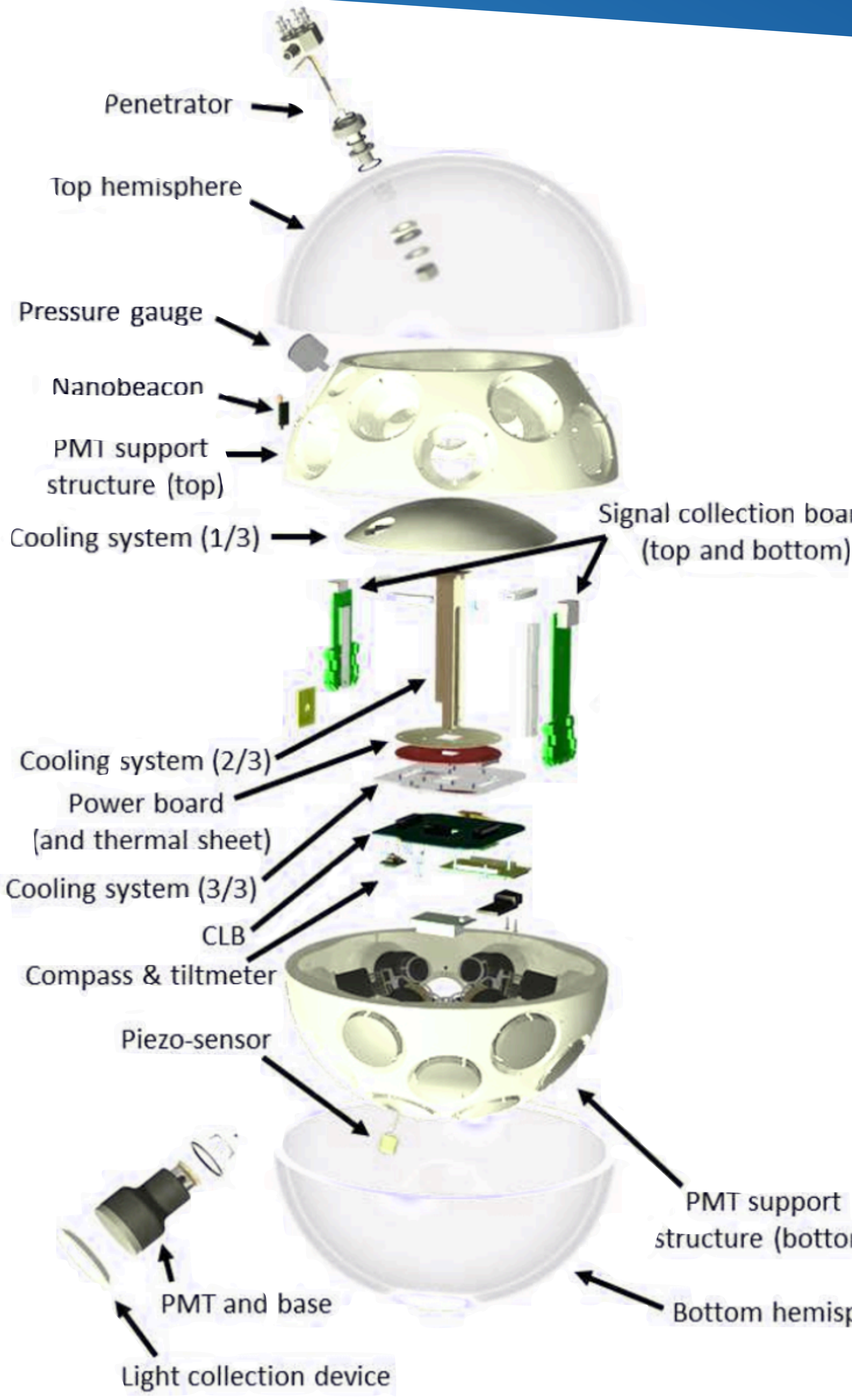


The OM: 10" Hamamatsu R7081, Front End Module, Time Calibration, LED beacons

- 31x3” PMTs (Hamamatsu R12199-02) in 17” glass sphere
- Front-end electronics, digitisation, optical signal → glass fibre
- Single penetrator

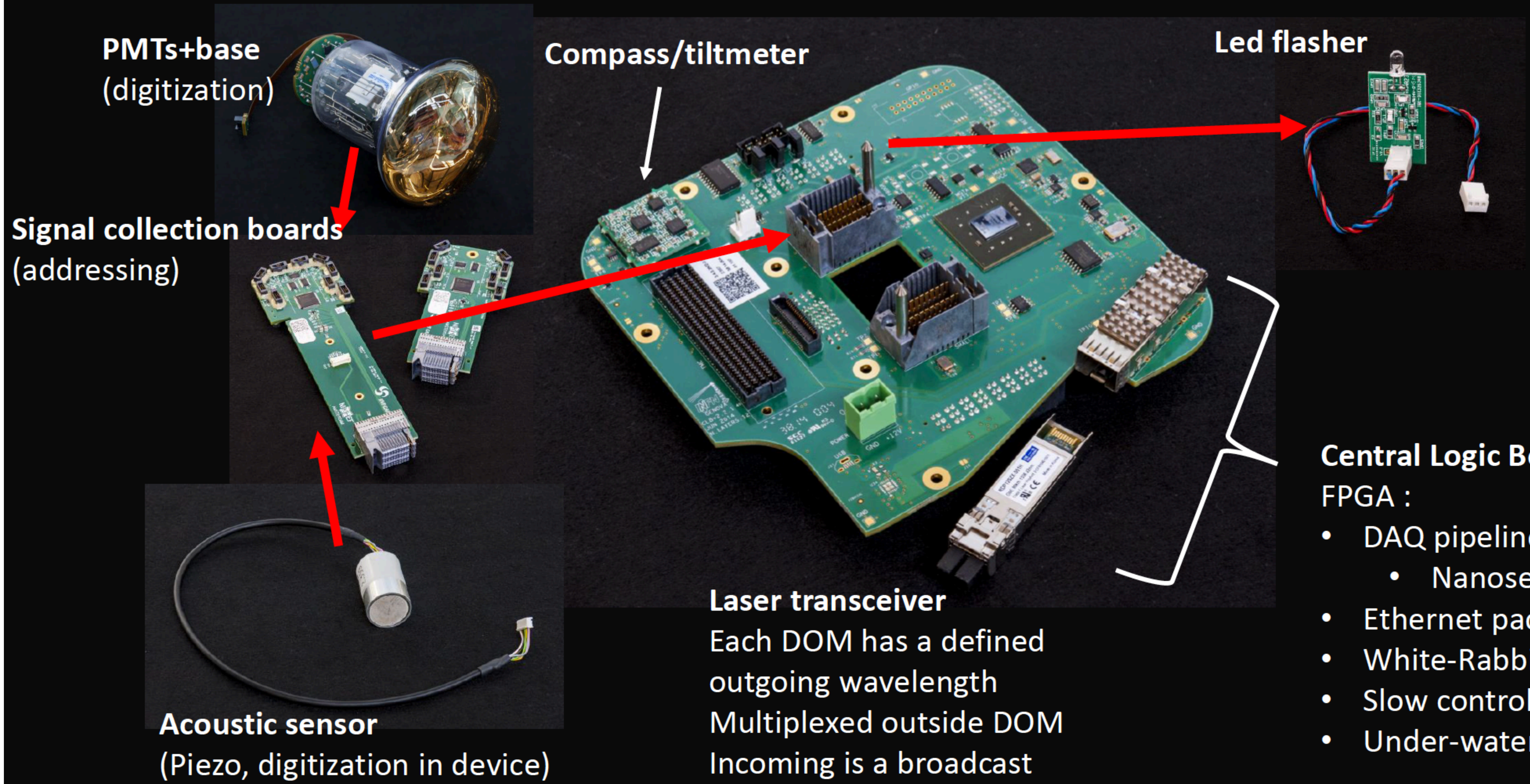
Advantages:

- Increased photocathode area
- 1-vs-2 photo-electron separation → better detection of coincidences
- Directionality
- Cost / photocathode area
- Minimal number of penetrations → reduced risk



Each **DOM** implements a dedicated FPGA firmware for DAQ with an embedded software for slow-control. Communication is set via **1Gbps ethernet** connection to shore. DOMs are the **submarine nodes** of the full DAQ LAN (>10 GbE on-shore).
Time synchronisation (better than 1 ns) is achieved exploiting the **White Rabbit** (CERN) technology.

DAQ/Electronics in DOM

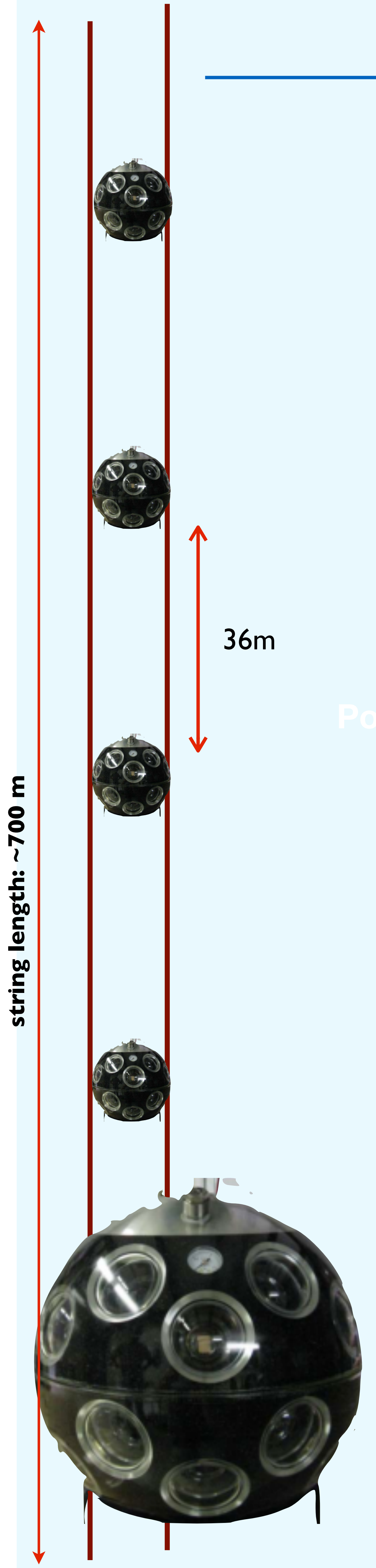


Central Logic Board (CLB)

FPGA :

- DAQ pipeline
  - Nanosecond timestamping
- Ethernet packet generation
- White-Rabbit timing
- Slow control CPU (LM32)
- Under-water reprogrammable

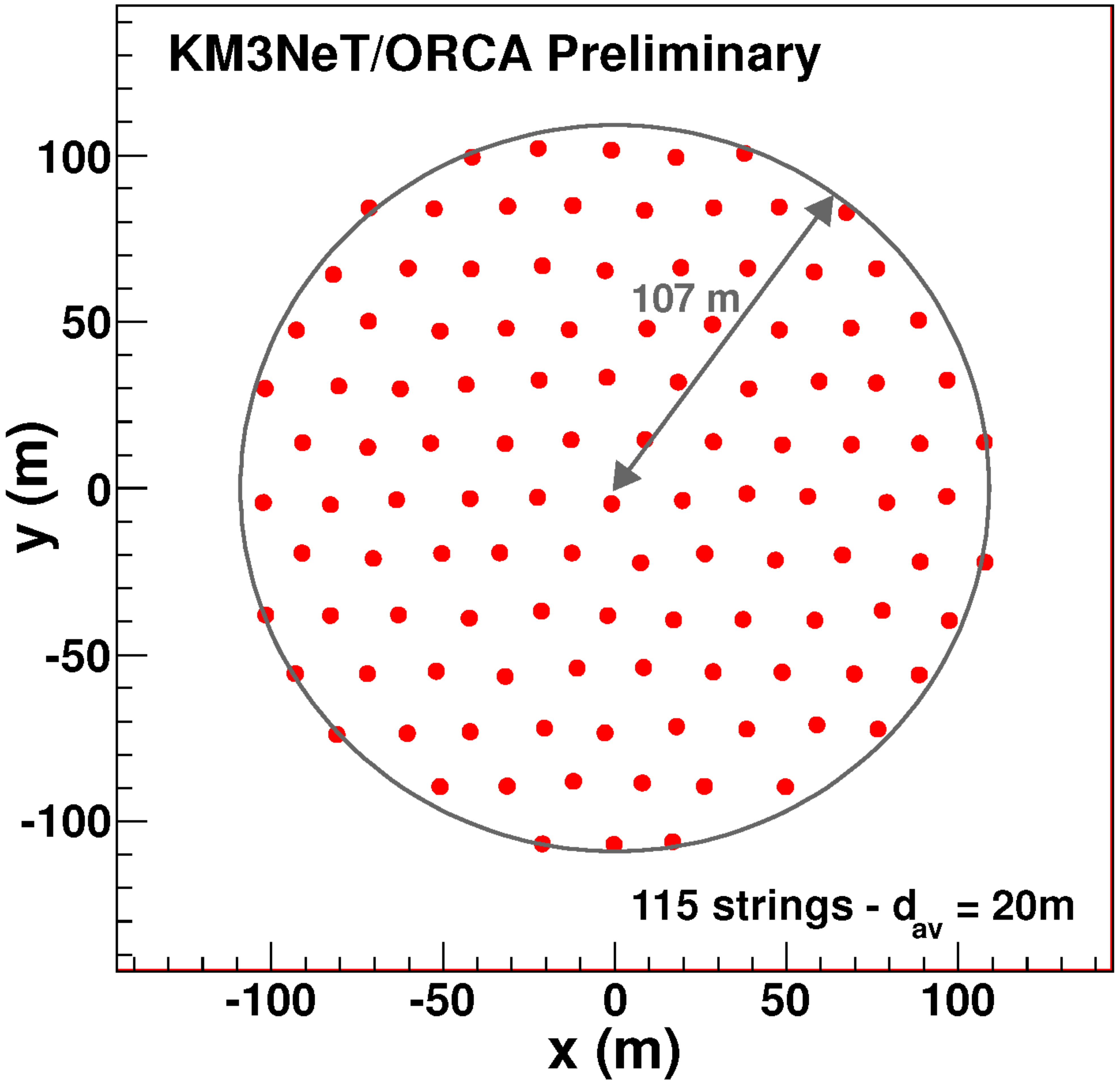
13



STRINGS

31 PMTs/DOM
18 DOMs/string
2 x 115 strings

558 PMTs/string
64170 PMTs/b.b.



1 Building Block ORCA

Study of
neutrino mass hierarchy

1 *building block* in the
French site
vertical spacing: **~6 m**
horizontal spacing: **~20 m**

The PMT hit as the basilar info seed

ANTARES / KM3NeT-Strings

Hit PMT-ID Info
Hit Timing
Hit Charge proxy (ToT)

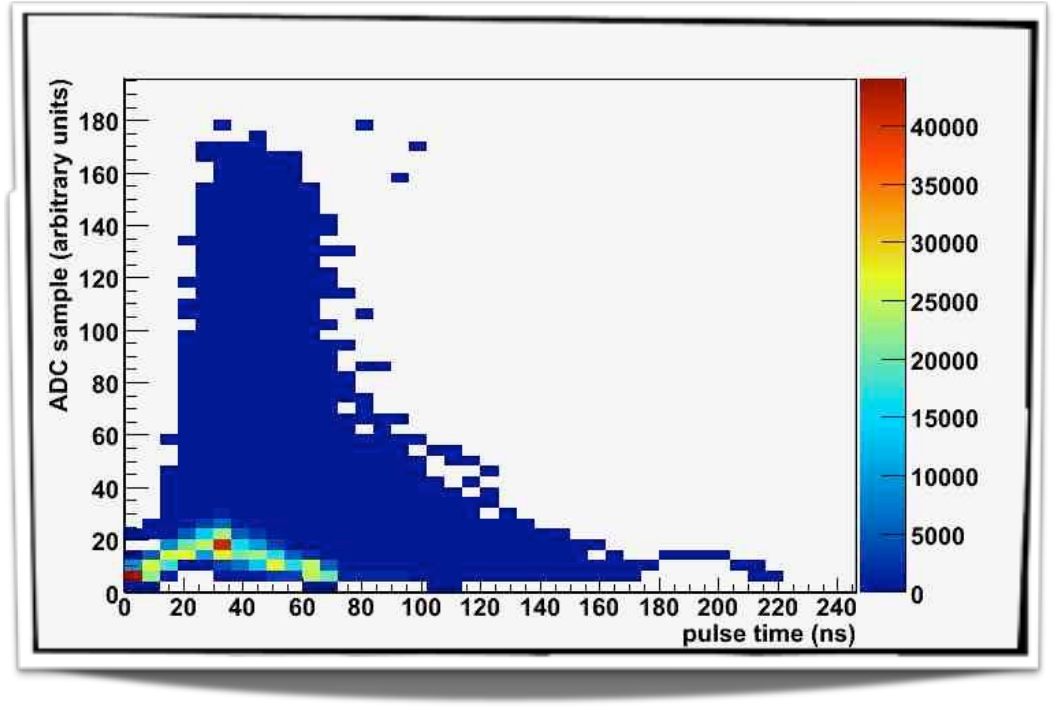
6 Bytes/hit

Single rate/PMT: > 6 kHz (0.3 p.e. thd)

KM3NeT-Towers

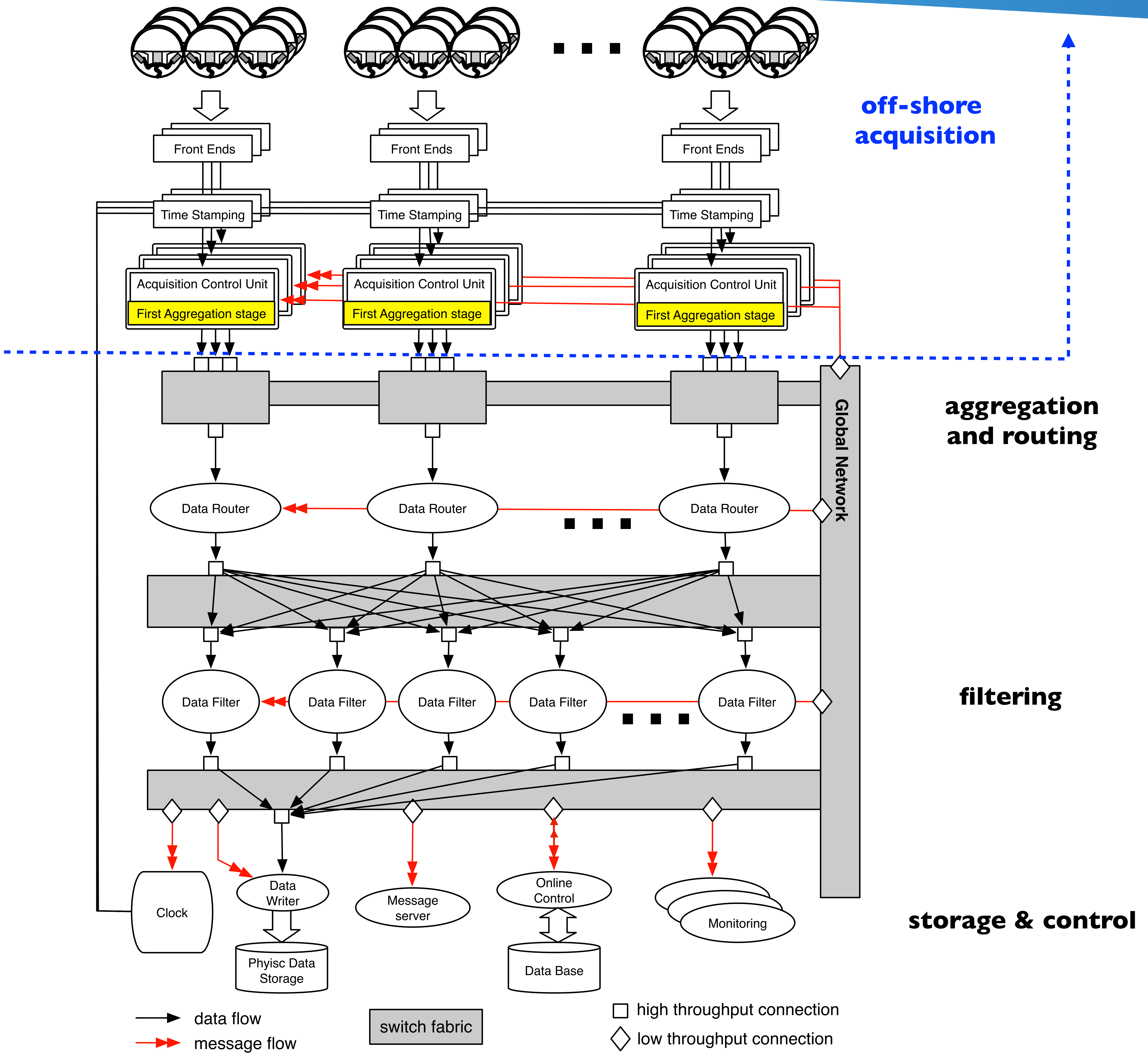
Hit PMT-ID Info
Hit Abs Time
Hit Charge
Hit Wave Form(samples) →

46 Bytes/hit



Single rate/PMT: > 50 kHz (0.3 p.e. thd)

Detector	N. PMTs, ø	Optical throughputs (Gbps)	Acoustic throughputs (Gbps)
ANTARES	885 , 10”	4 (max 15)	< 2
KM3NeT - ARCA	~140 k, 3”	50 (max 100)	~30
KM3NeT - ORCA	~64 k, 3”	22 (max 50)	~15
KM3NeT - Towers	672, 10”	12 (max 37)	~3



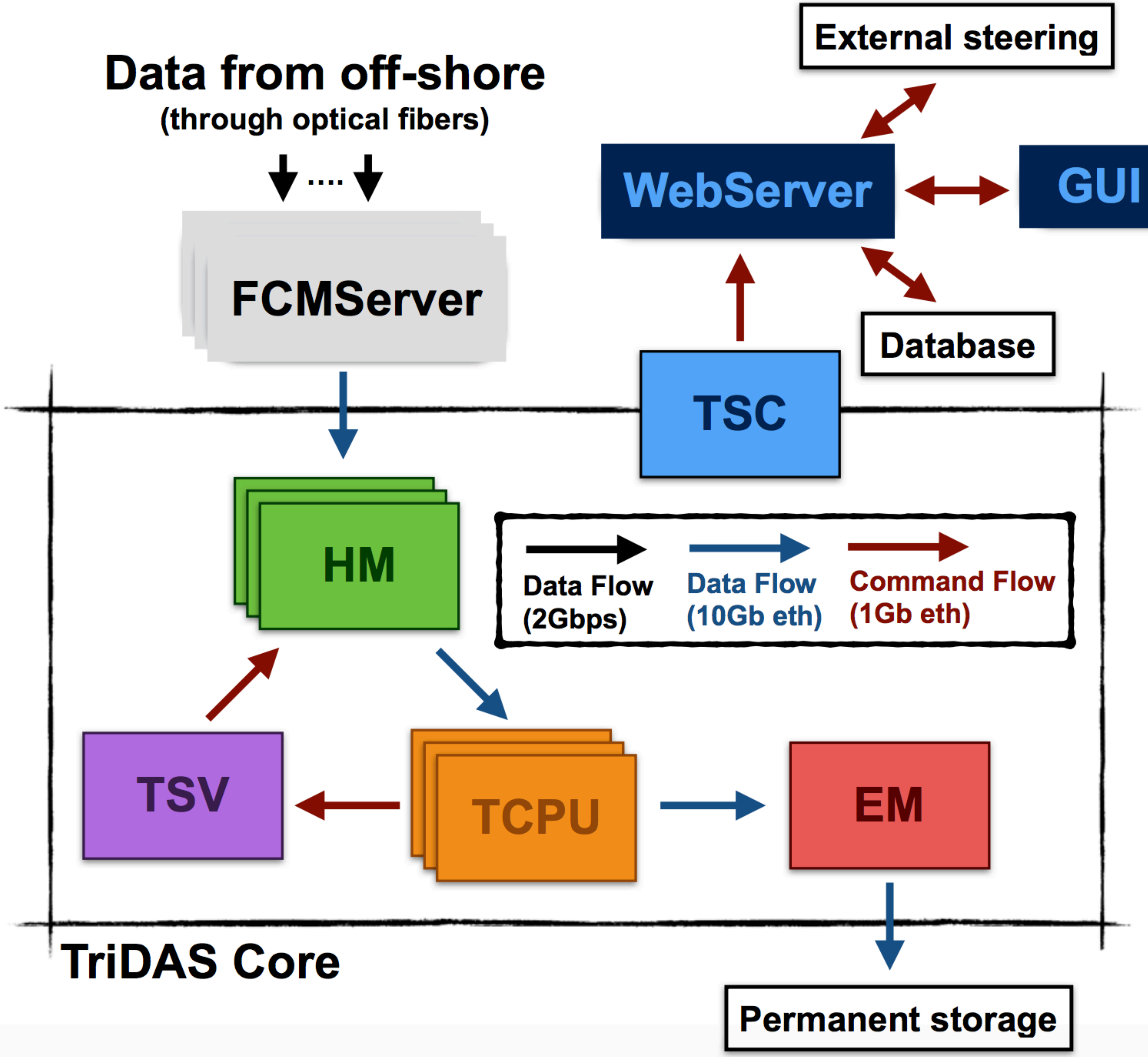
The DAQ model is applied to both strings and towers, **with due differences.**

For historical reasons, the readout electronics and the DAQ systems of strings and towers are different.

a) Both systems ***exploit fixed latency electronics*** for clock distribution but with due differences.

b) The recorded type and number of information per PMT hit are different.

c)The implementation of the computing resources on shore present some differences.

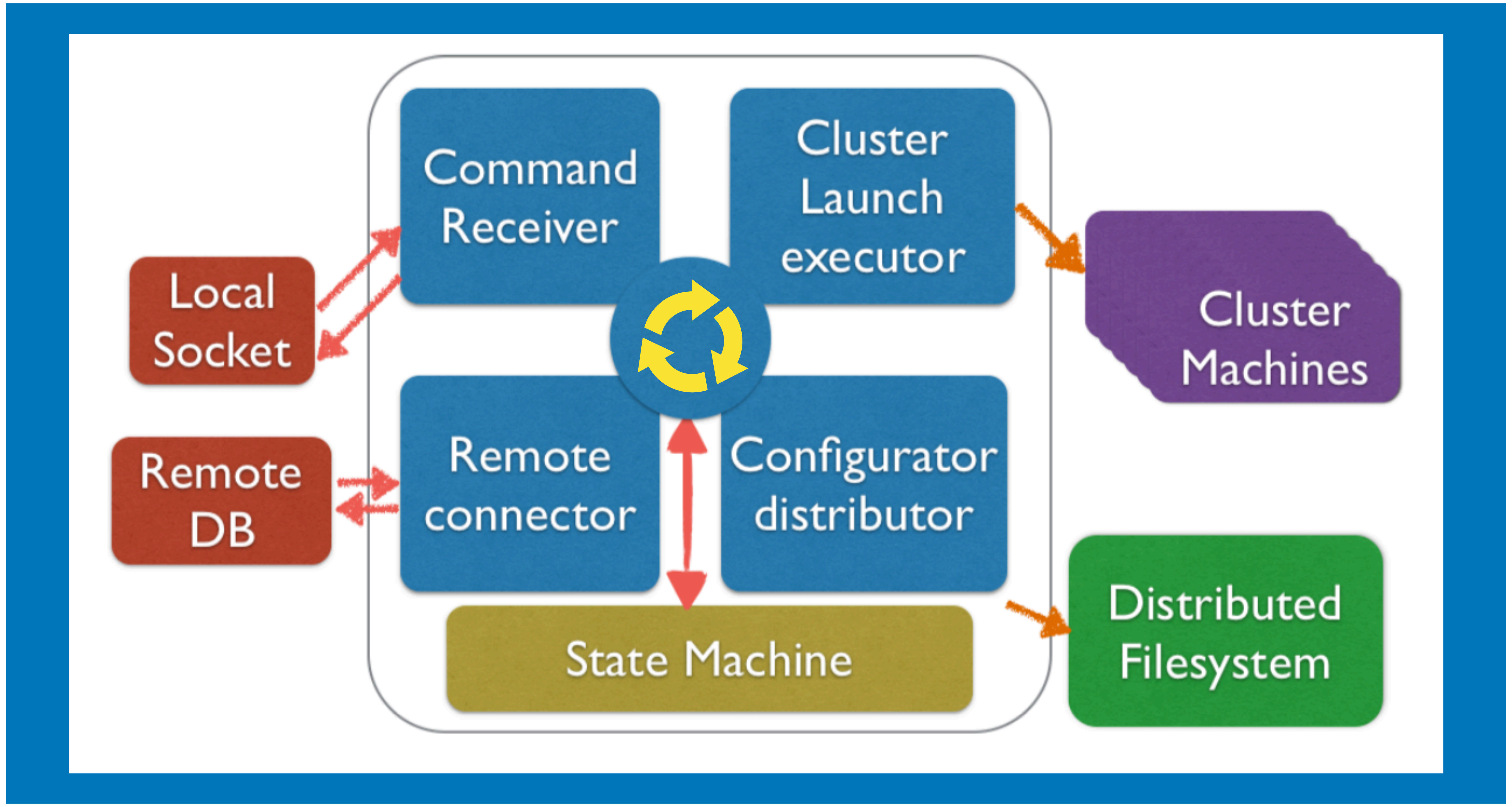


TriDAS core written in C++ 11

Auxiliary technologies

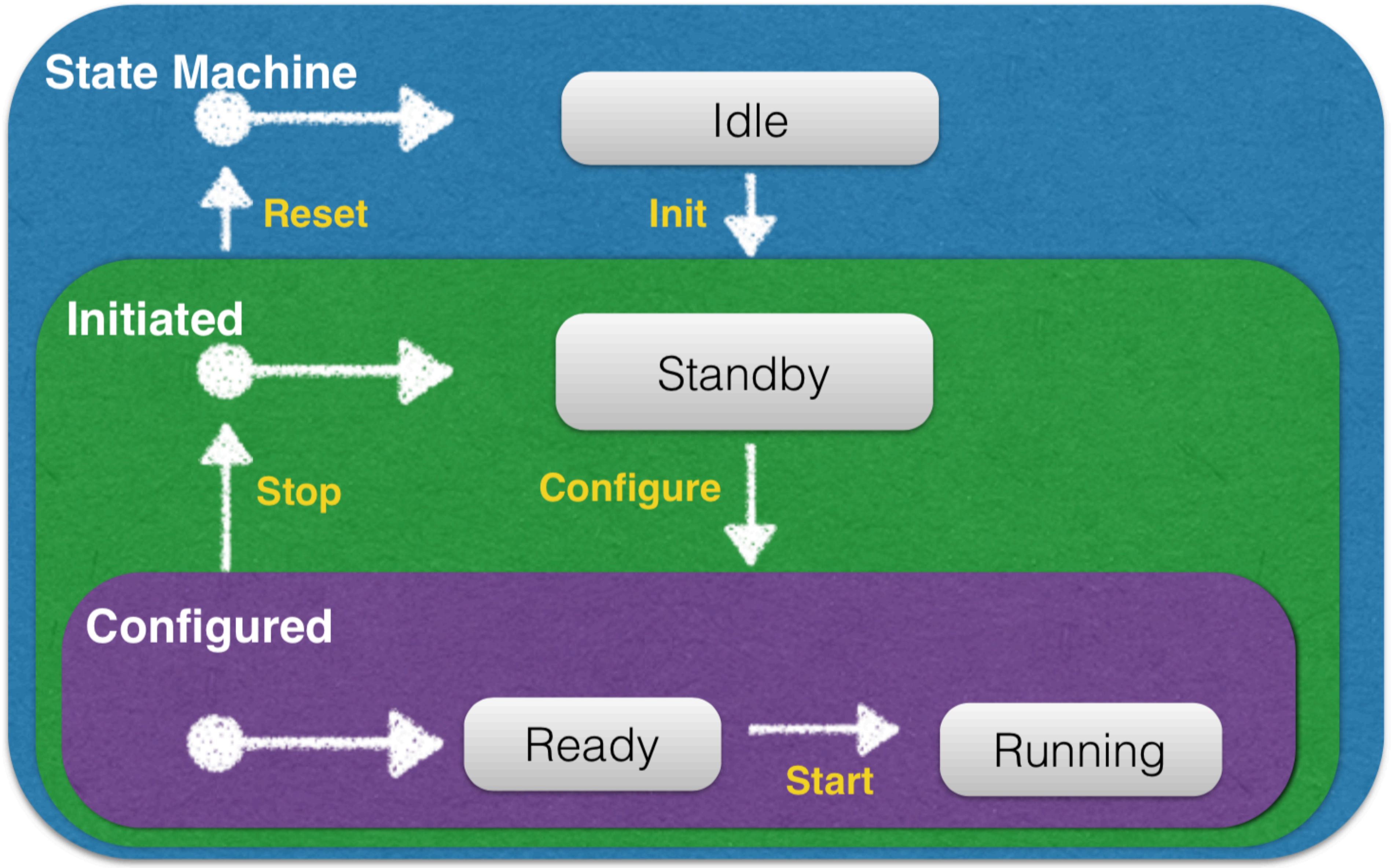
boost C++ LIBRARIES, Jenkins, git, ANGULARJS, Crossbar.io

Atlassian Bitbucket, CMake, ØMQ



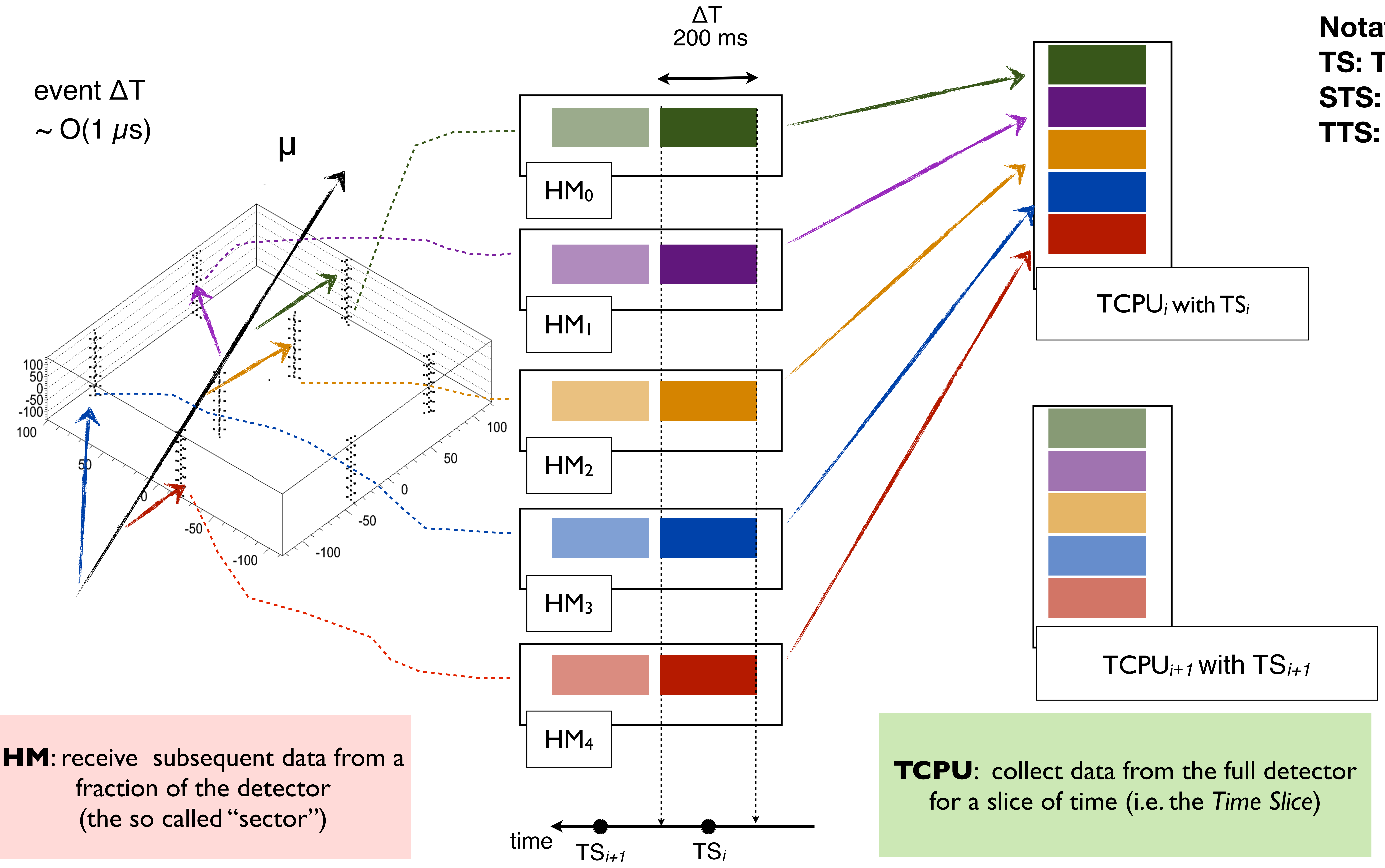
TSC Block Scheme

TriDAS
Hierarchical State Machine



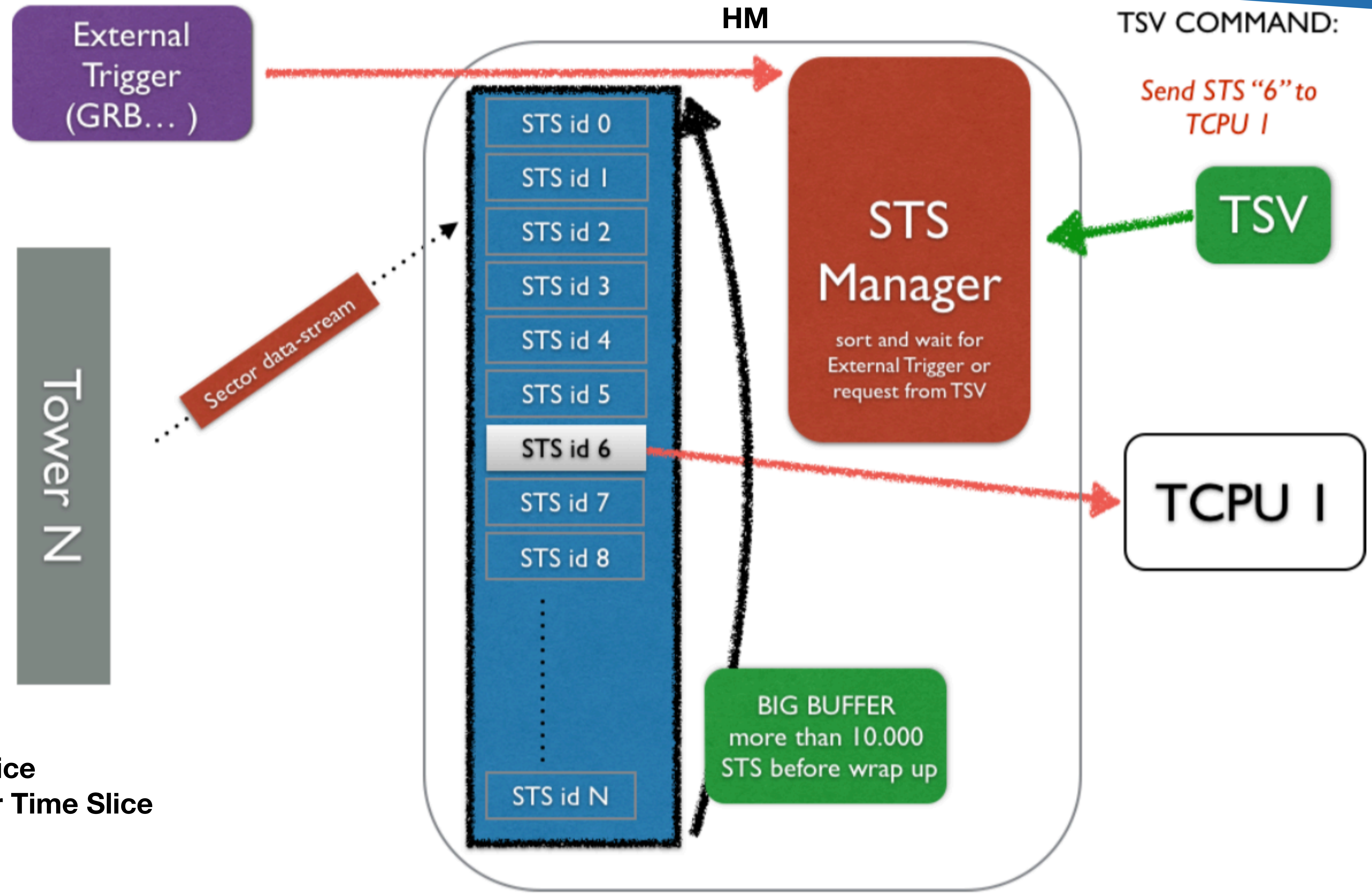
Online trigger applied to optical data contained in a full detector snapshot

Notation:
TS: Time Slice
STS: Sector Time Slice
TTS: Total Time Slice



HM: receive subsequent data from a fraction of the detector (the so called "sector")

TCPU: collect data from the full detector for a slice of time (i.e. the *Time Slice*)



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TS: Time Slice
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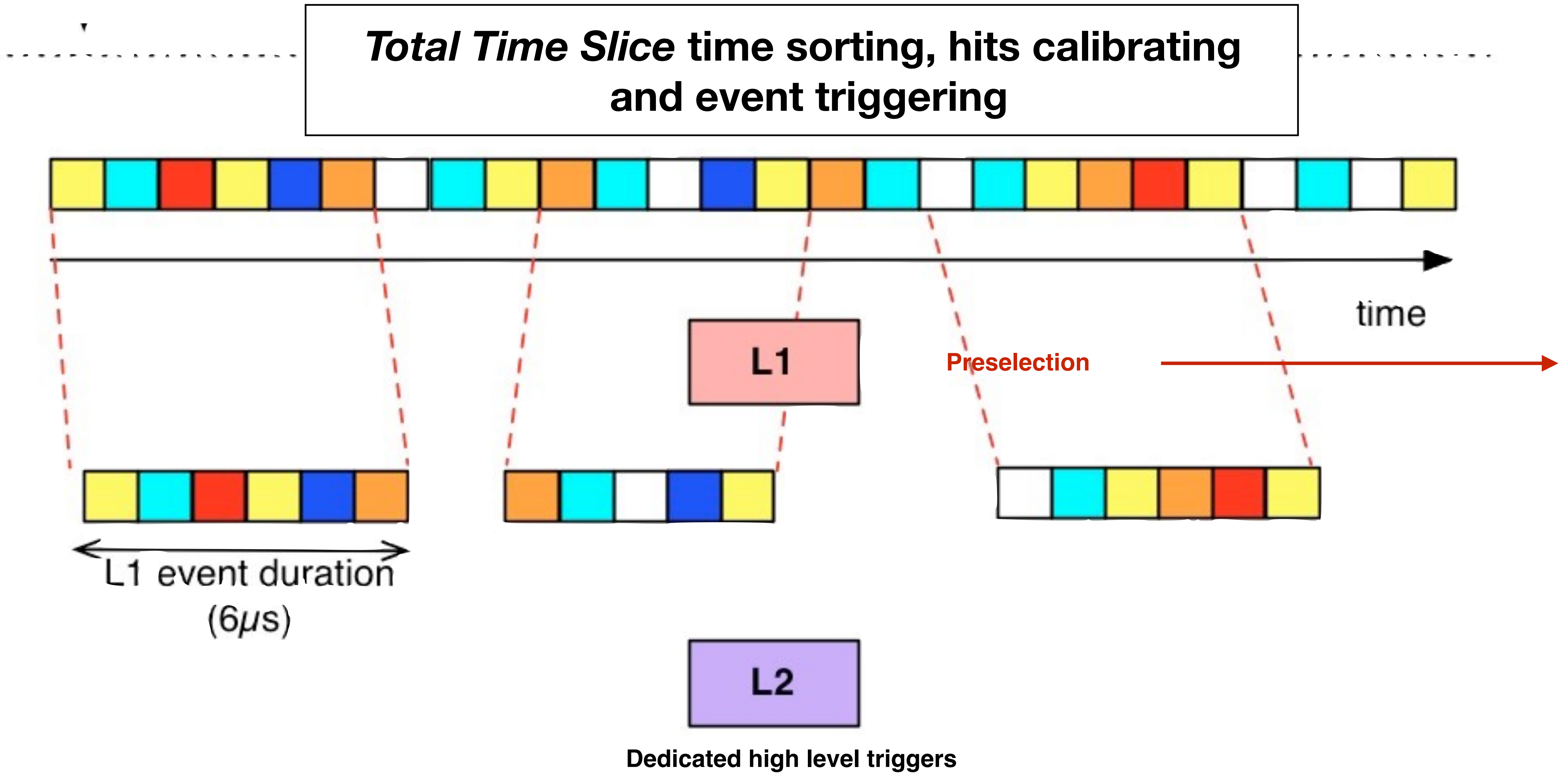
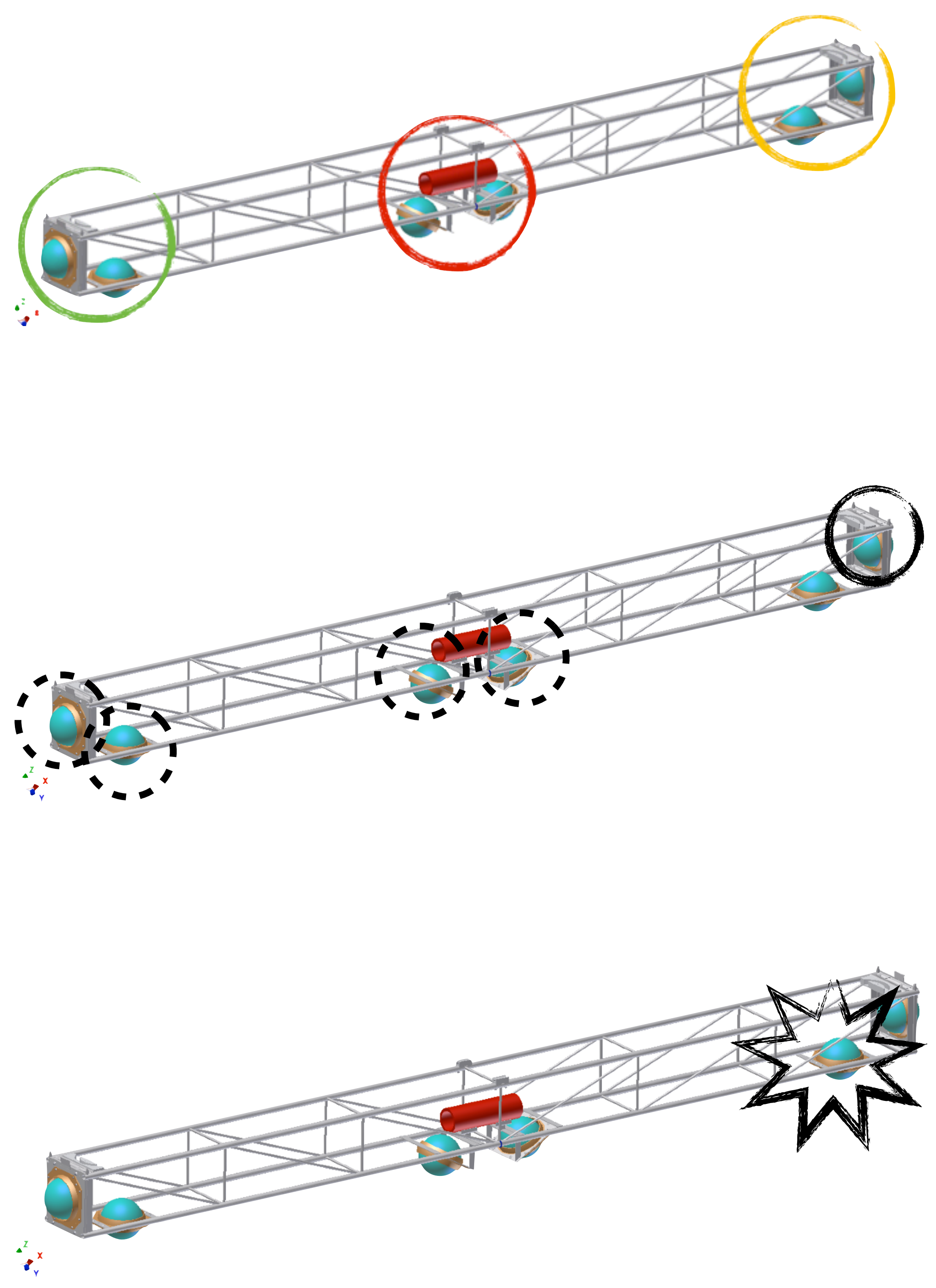


L1 Seeds



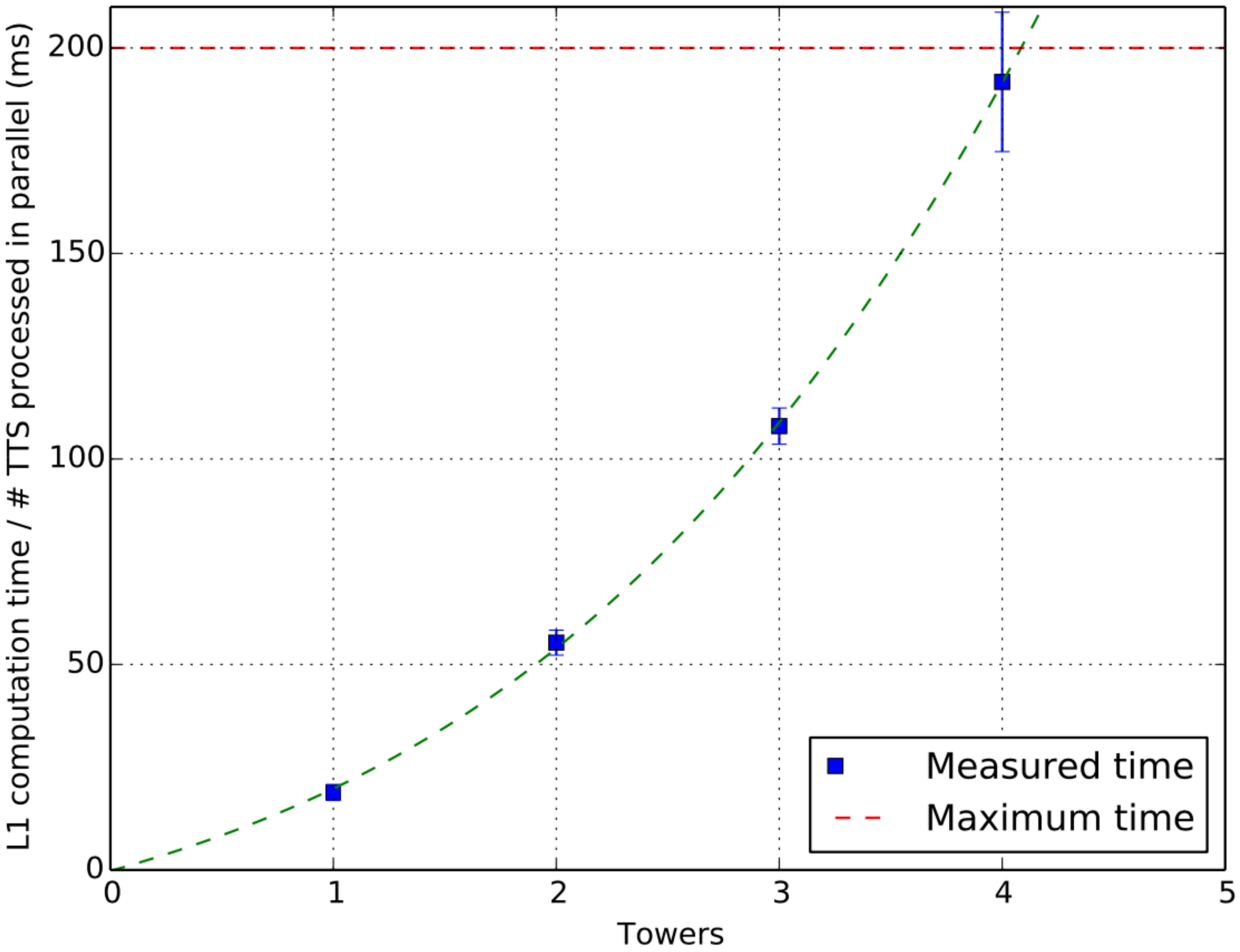
Simple Coincidences
$\Delta T \leq 20$ ns

Floor Coincidences
$\Delta T \leq 100$ ns

Shooting hit
$Q \geq Q_{threshold}$

- **Combinatorial/Causality**
  - minimum n. of sequential L1 seeds in a ΔT
- **Direction Scan**
  - causality tests for L1 seeds w.r.t. a grid of directions in the sky
- **Source tracking**
  - specific tests of L1 seeds + all hits of L1 event w.r.t. source directions vs time
- **Vertex and Inertia**
  - test on the topology of hits distribution

- Simulated Poissonian single rate per Optical Module: 100 kHz
- N. of TCPUs: 4 nodes (32 cores Intel(R) Xeon(R) CPU E5-2640 v2 @ 2.00GHz)
- Concurrent TimeSlice processing: 20 TS in parallel/node
- Time Slice duration : 200 ms
- L1 event length: 6 μs



It means that for N>4 Towers additional TCPU nodes are needed (or more trigger threads, if allowed by the computing resources).

Granny's recipe:

add TCPU as much as it suffices !!

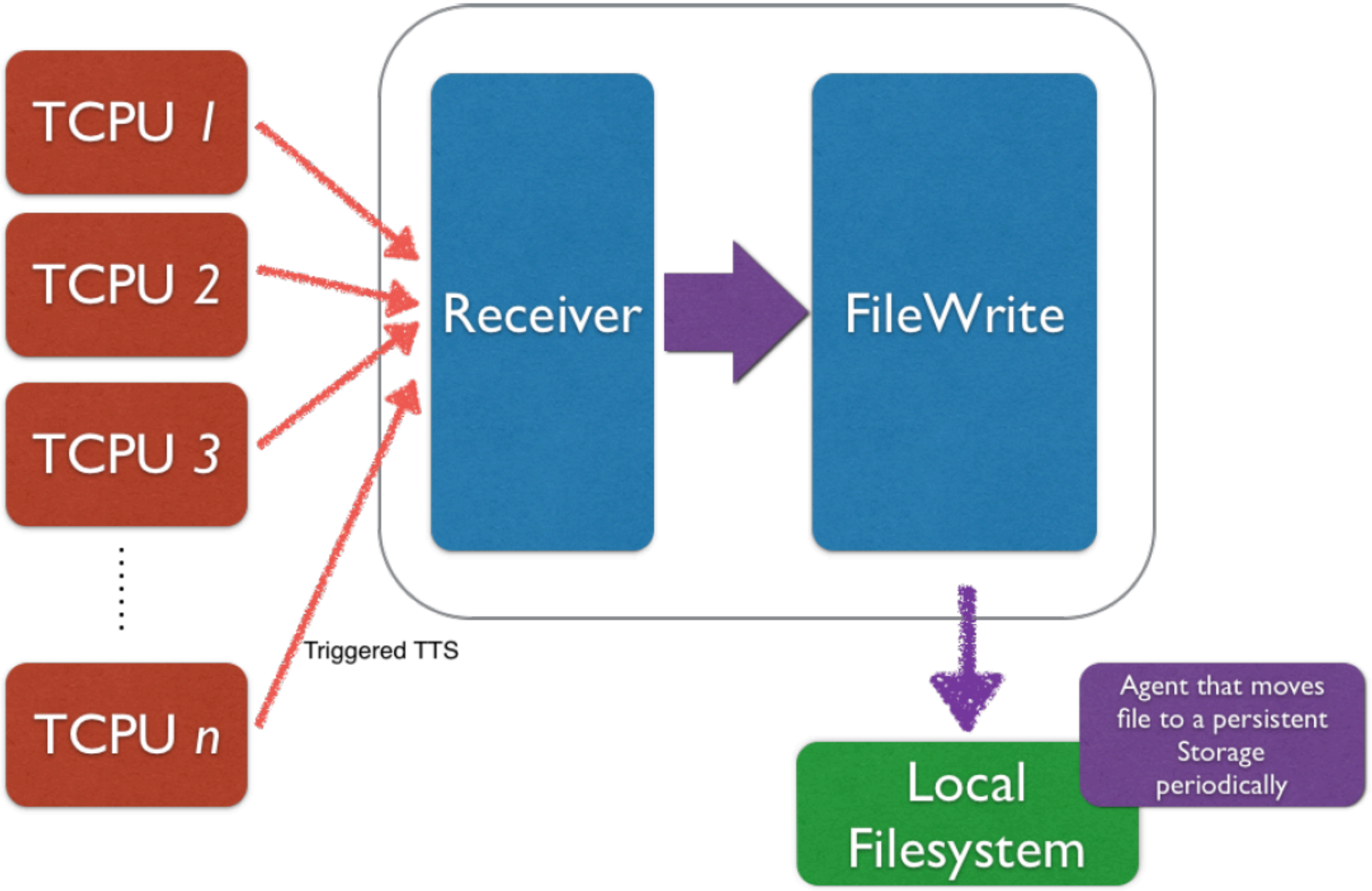
…without affecting the DAQ design.

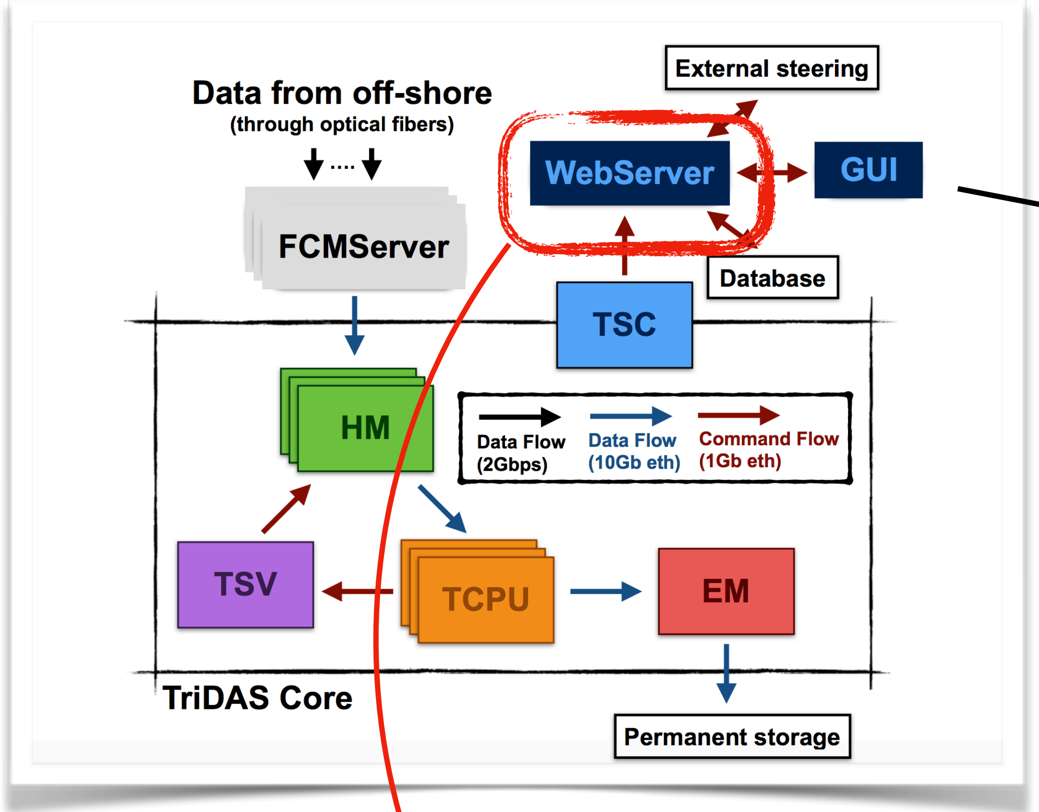
Scalability is granted!

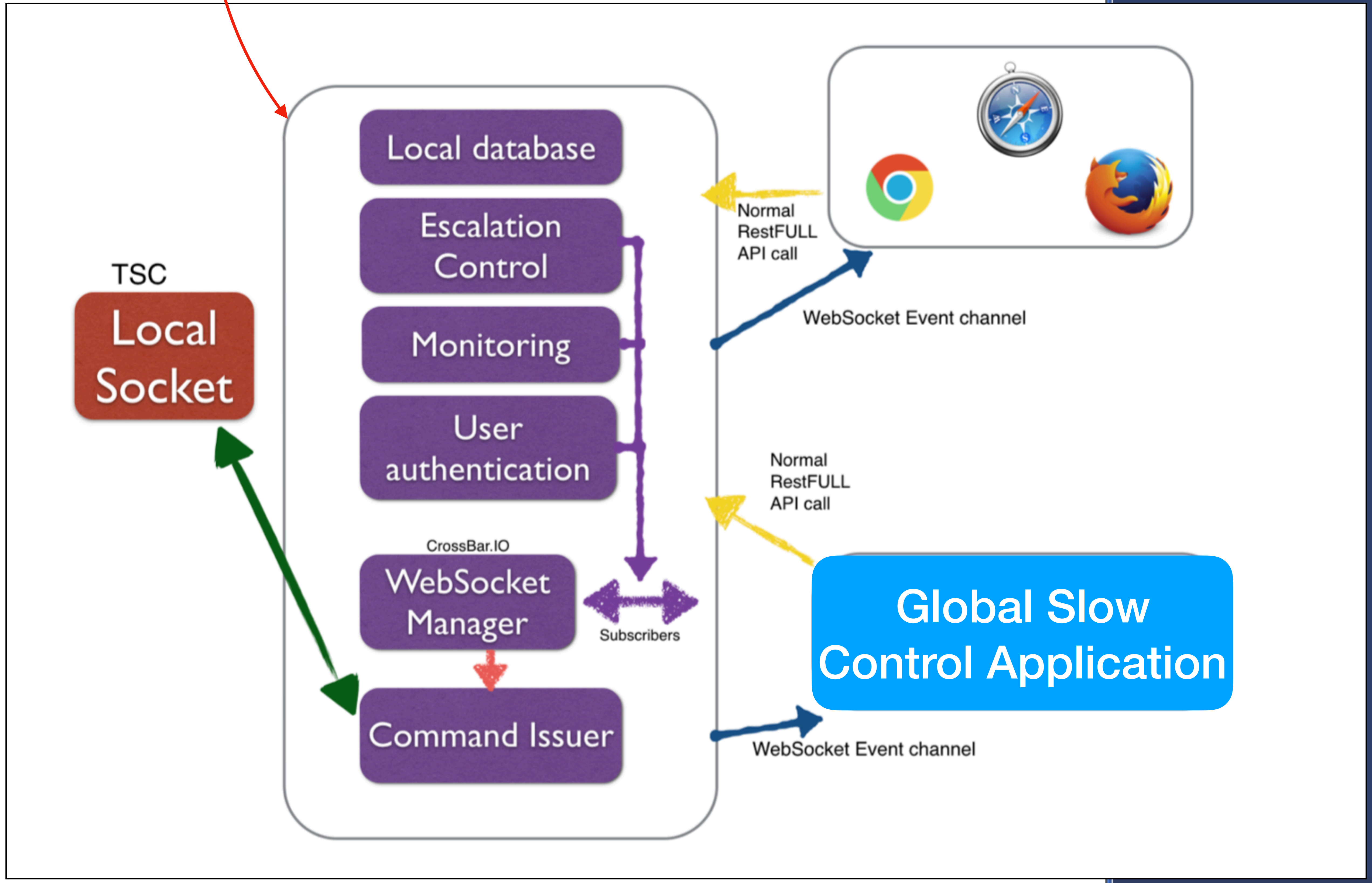
One **event is the collection of hits** which is supposed to describe the passage of neutrino induced muon or shower.

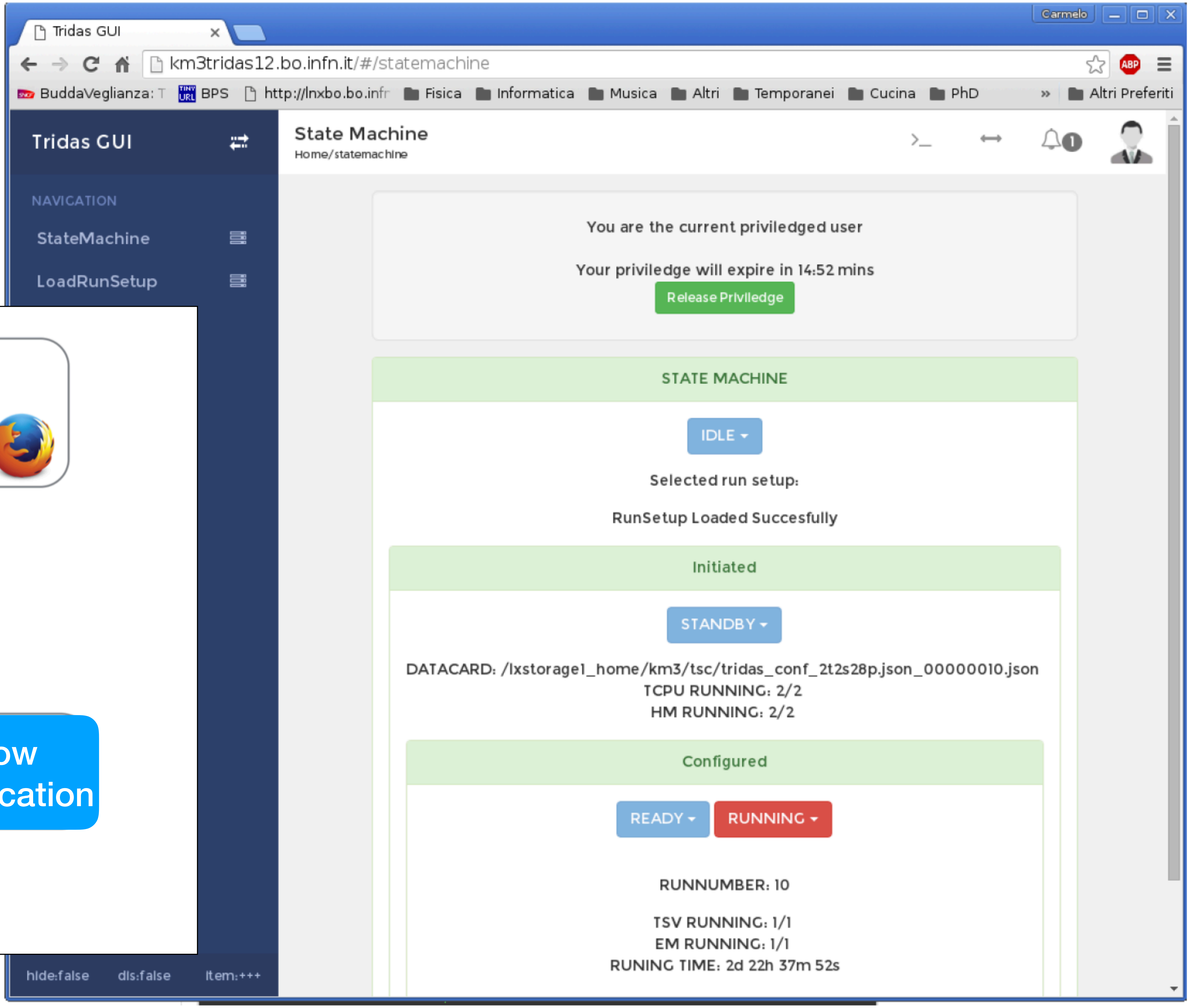
TCPUs **asynchronously process** independent Time Slices. The events are collected, but not time ordered, by the EM into a file.

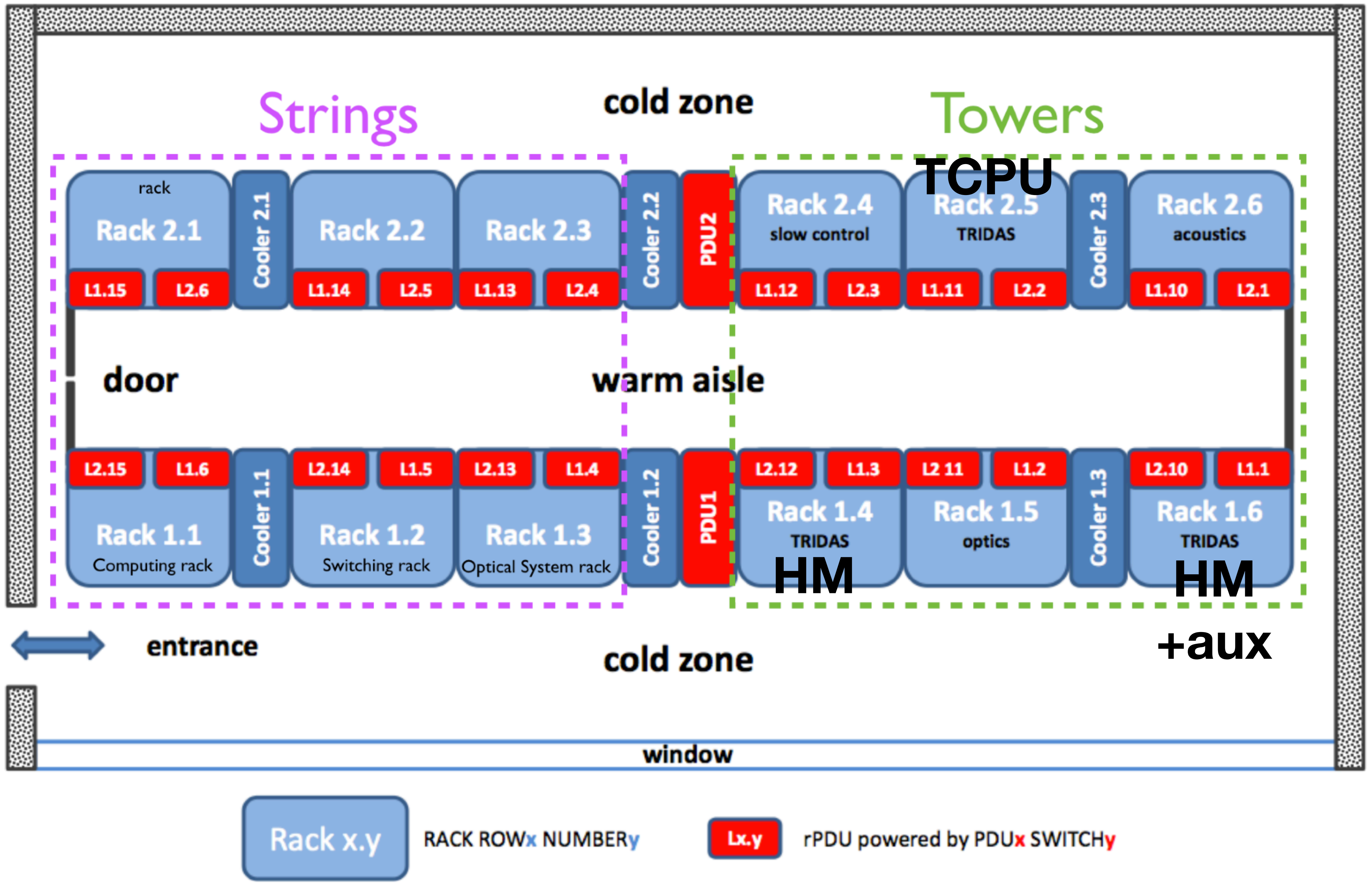
High-level readout classes are prepared to parse the recorded file.



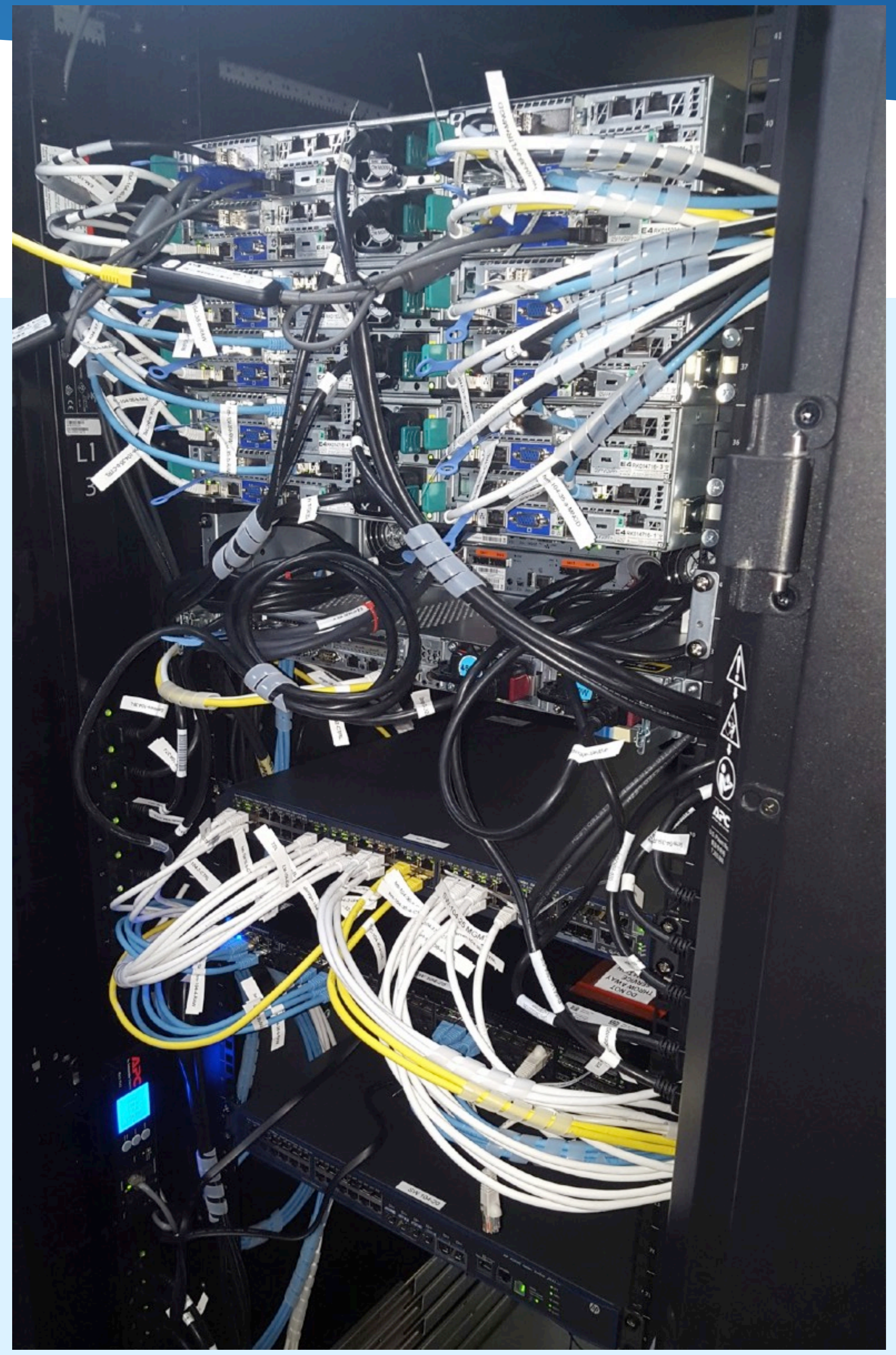

Data from off-shore
(through optical fibers)
External steering
WebServer
GUI
FCMServer
Database
TSC
HM
Data Flow (2Gbps)
Data Flow (10Gb eth)
Command Flow (1Gb eth)
TSV
TCPU
EM
TriDAS Core
Permanent storage


TSC
Local Socket
Local database
Escalation Control
Monitoring
User authentication
CrossBar.IO
WebSocket Manager
Subscribers
Command Issuer
Normal RestFULL API call
WebSocket Event channel
Normal RestFULL API call
Global Slow Control Application
WebSocket Event channel

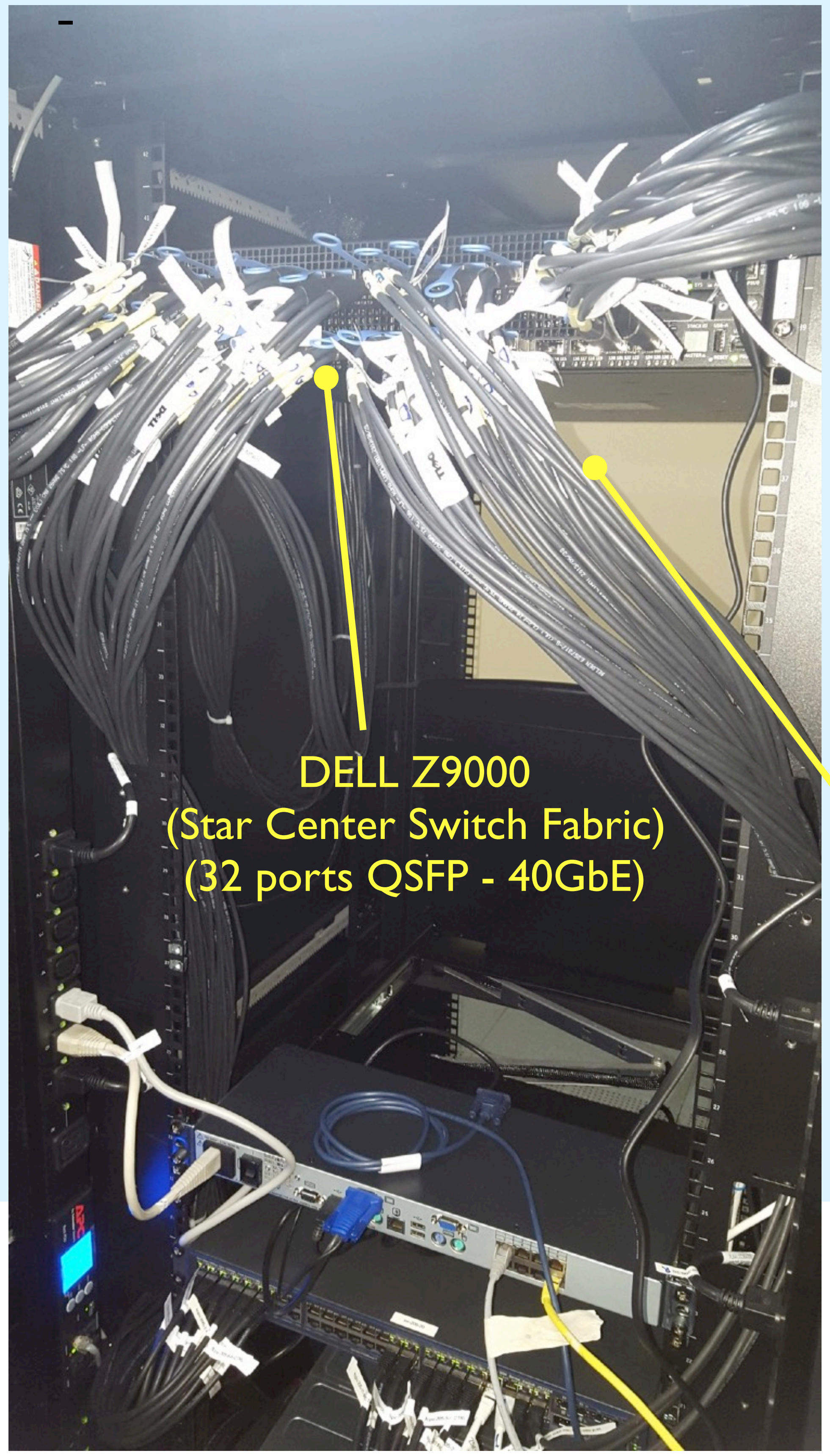

Tridas GUI
km3tridas12.bo.infn.it/#/statemachine
Tridas GUI
NAVIGATION
StateMachine
LoadRunSetup
State Machine
Home/statemachine
You are the current priviledged user
Your priviledge will expire in 14:52 mins
Release Priviledge
STATE MACHINE
IDLE
Selected run setup:
RunSetup Loaded Succesfully
Initiated
STANDBY
DATACARD: /lxstorage1_home/km3/tsc/tridas_conf_2t2s28p.json_00000010.json
TCPU RUNNING: 2/2
HM RUNNING: 2/2
Configured
READY
RUNNING
RUNNUMBER: 10
TSV RUNNING: 1/1
EM RUNNING: 1/1
RUNING TIME: 2d 22h 37m 52s
hide:false
dis:false
item:+++



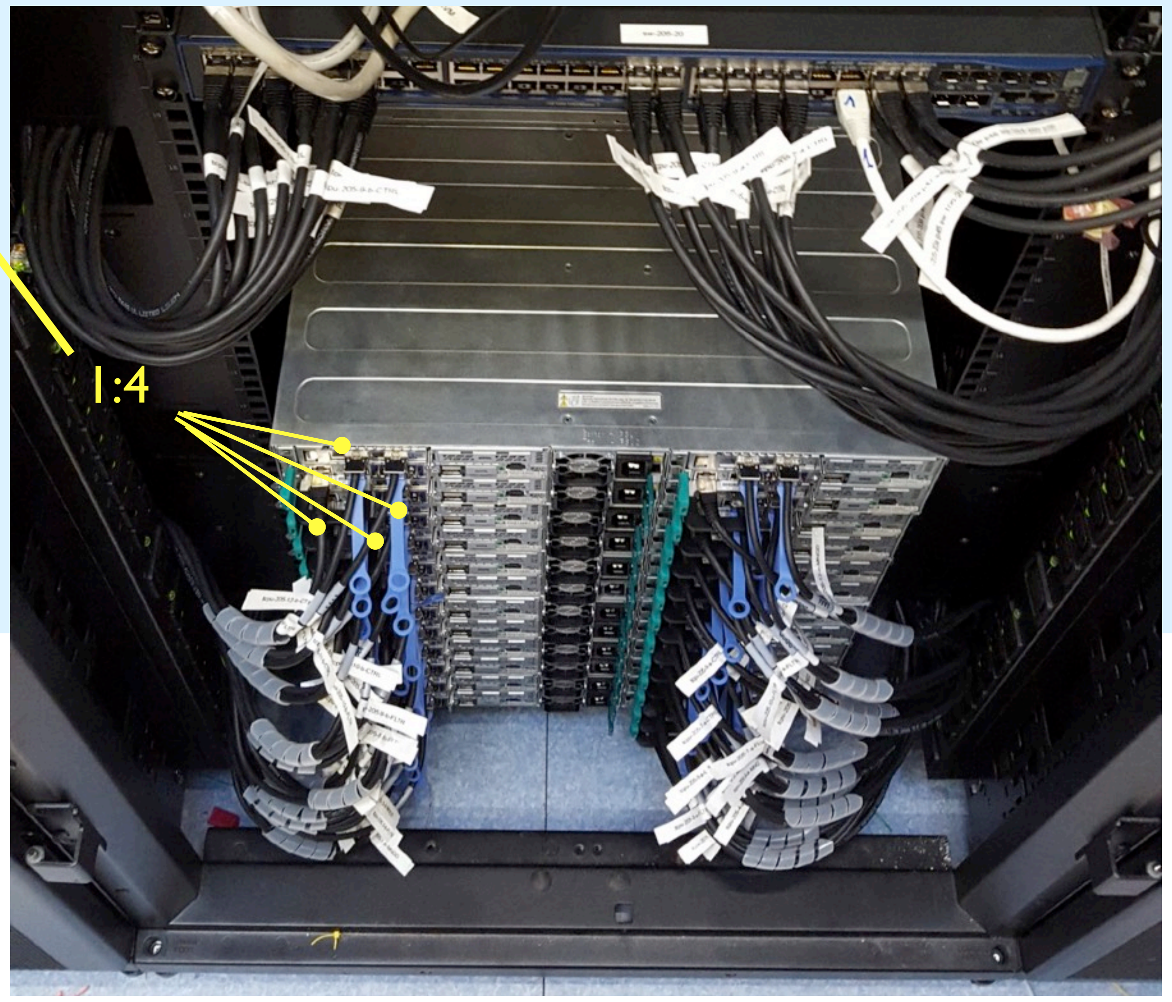
HMs and auxiliaries



(32 cores Intel(R) Xeon(R)
CPU E5-2640 v2 @ 2.00GHz)
64 or 128 GB RAM



Management switch



TCPUs

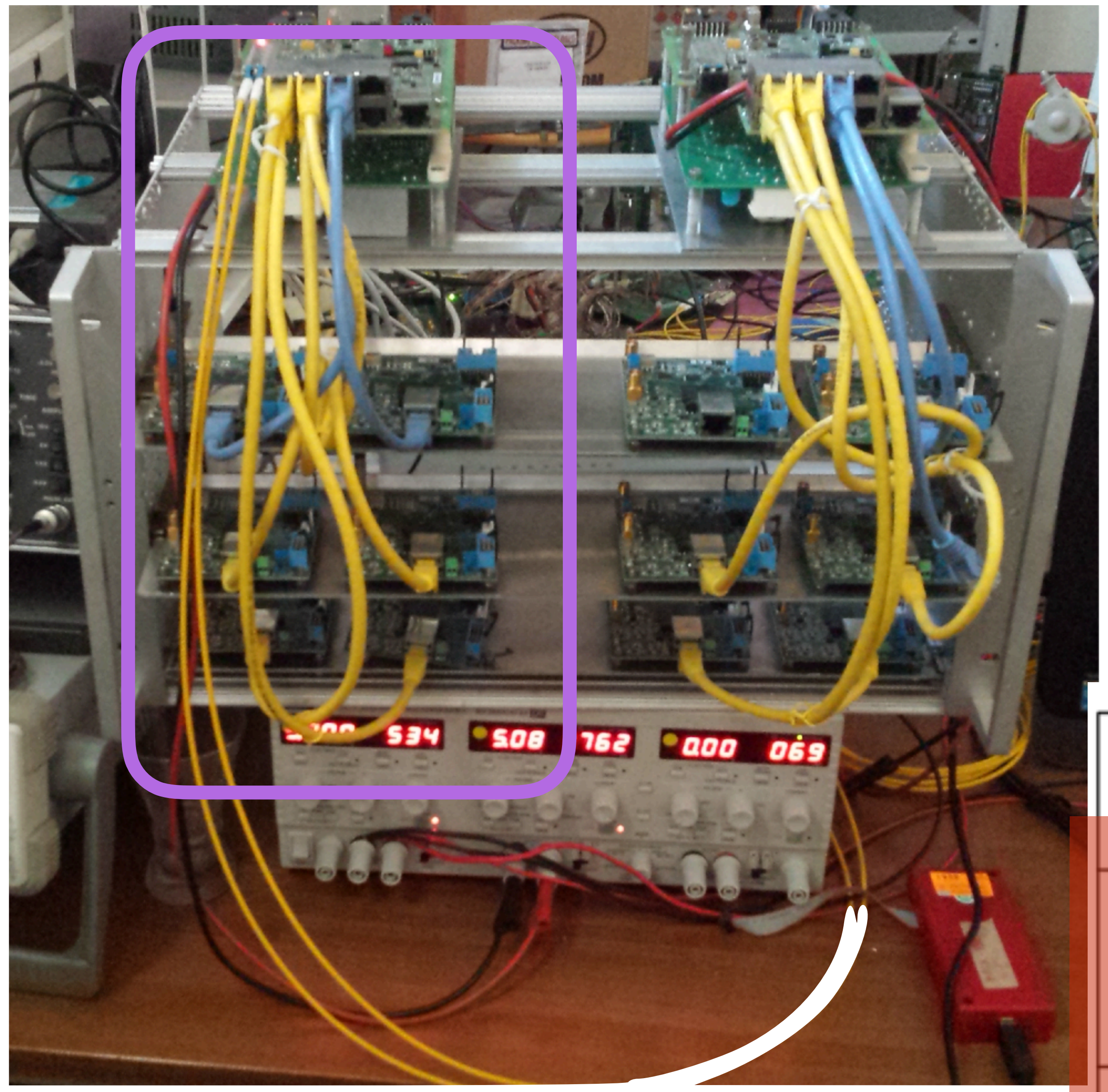
BDX DAQ will be based on fADCs
- CsI(Tl) decay time & low thresholds are incompatible with "traditional" (TDC+QDC)-based DAQ
- Full waveform recording: reduce backgrounds and allow detailed off-line analysis
- Expected 16 MB/s data rate (16MB/s = 5Hz x 1000 crystals x 2048samples x 12 bit)

Different options under investigation:

1) Triggered - commercial
trigger formed as *OR* of all crystals over thresholds (OVT)
- when trigger is released every channel with a signal in 10 μs window is recorded
- The simplest option (boards already available: e.g. CAENV1725 or JLAB-fa250) ***but expensive!***

2) Trigger-less - commercial
- trigger-less system, based on existing fADC + Trigger Boards (e.g. JLab fADCs and VTP boards)
- Pipe-line data transferred to a central trigger CPU and then moved to storage
- Requires ad-hoc firmware and software development
- ***Not clear if cheaper than*** 1) but may be more matched on BDX requirements

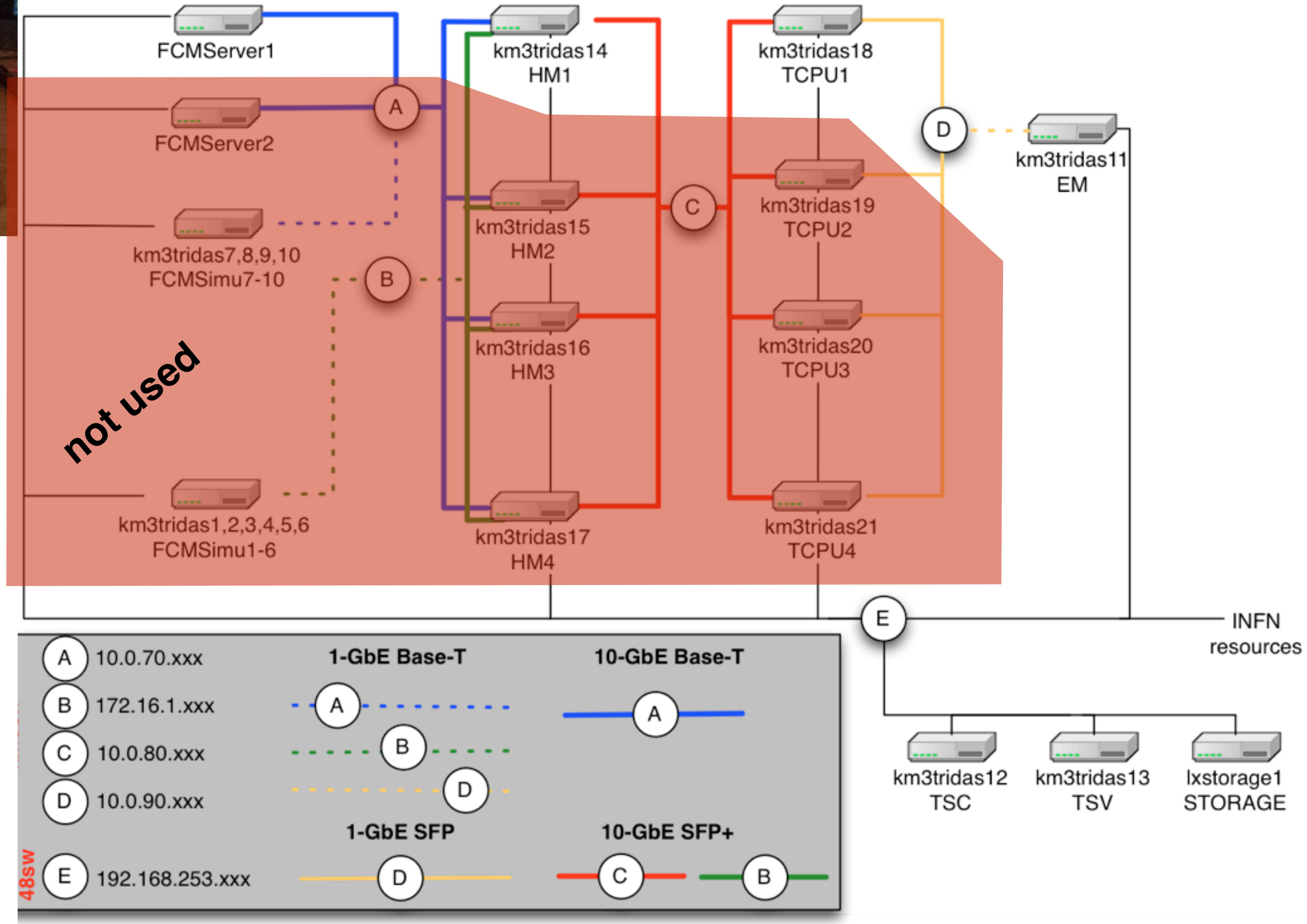
3) Trigger-less - custom
- trigger-less, based on a custom DAQ: single-channels digitisers, integrated in the front-end electronic
- Sophisticated solution matched to the experimental setup
- Requires ad-hoc hardware, firmware, and software development
- Similar approach used in other experiments(KM3NeT,PANDA)
- May benefit of technology/solutions sharing ***with reduced costs***



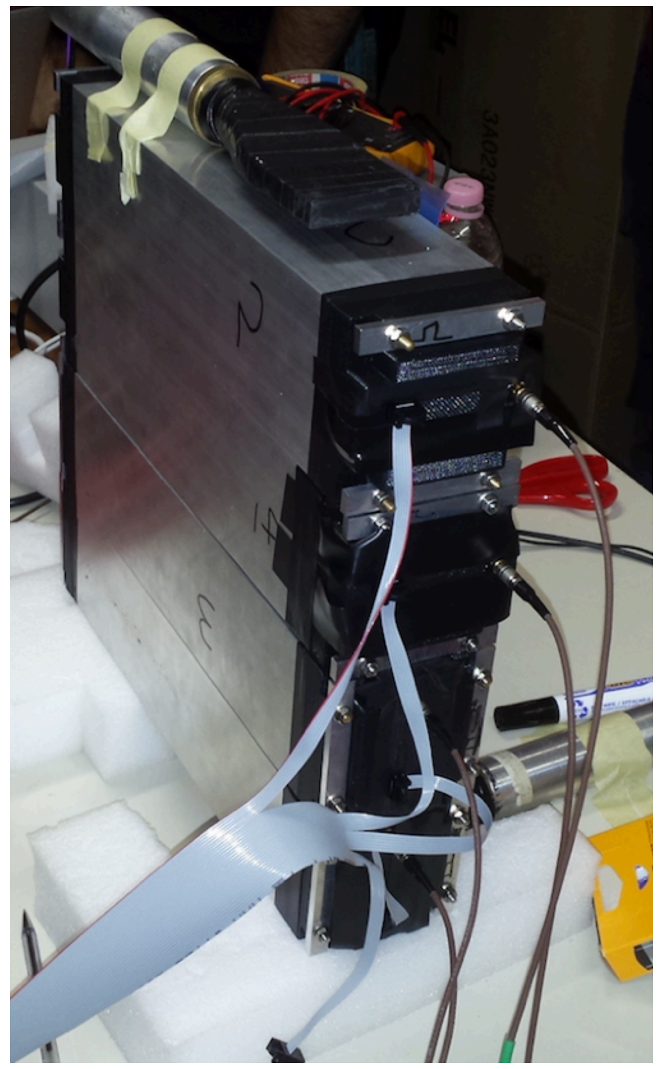
KM3NeT-Tower DAQ test-bench

Used gear:
- 1 FCM
- 6 FEM (1 per channel)
- a selection of the available computing resources

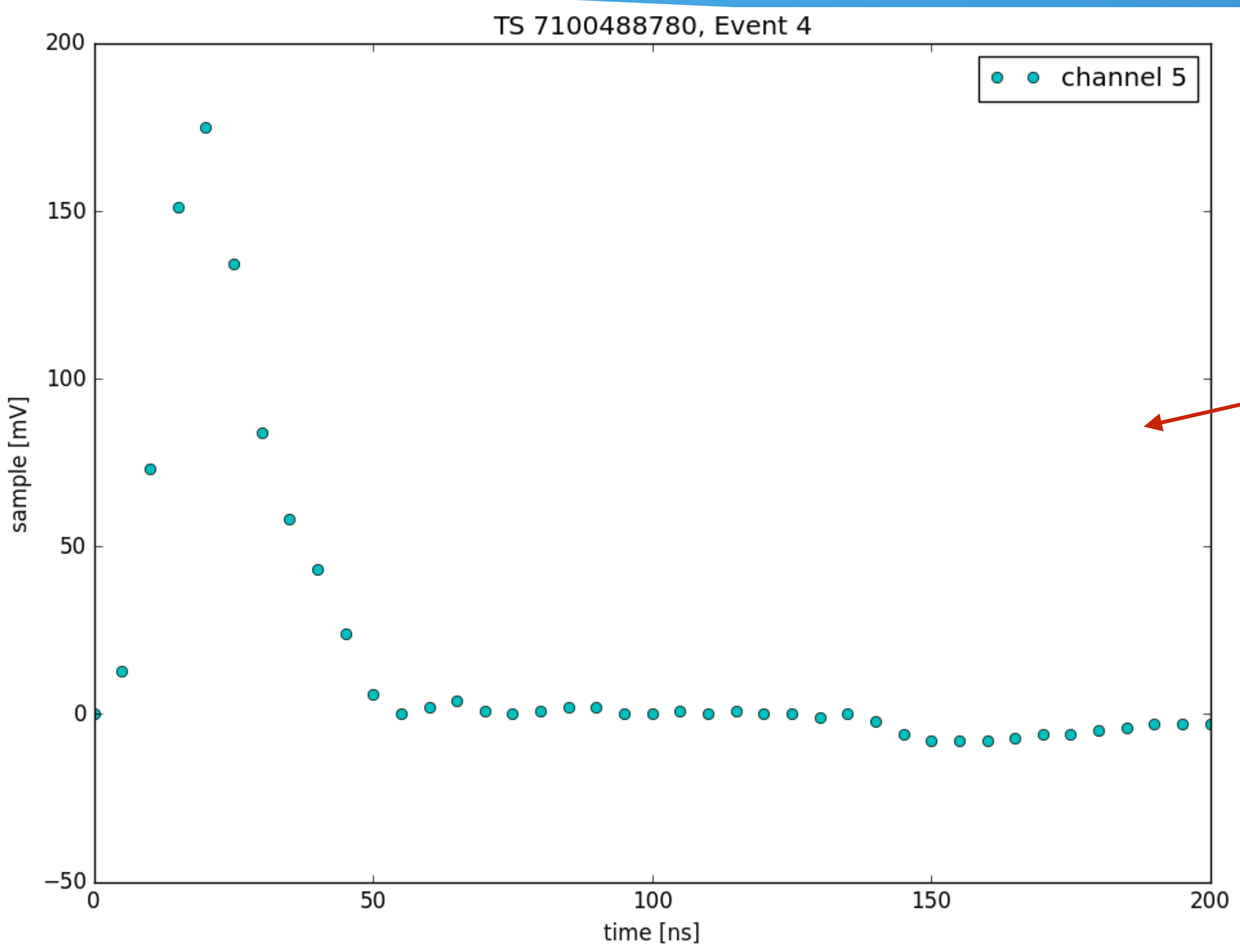
(*note: multi-servers use is here overkilling but remind this is a step 0 test!*)

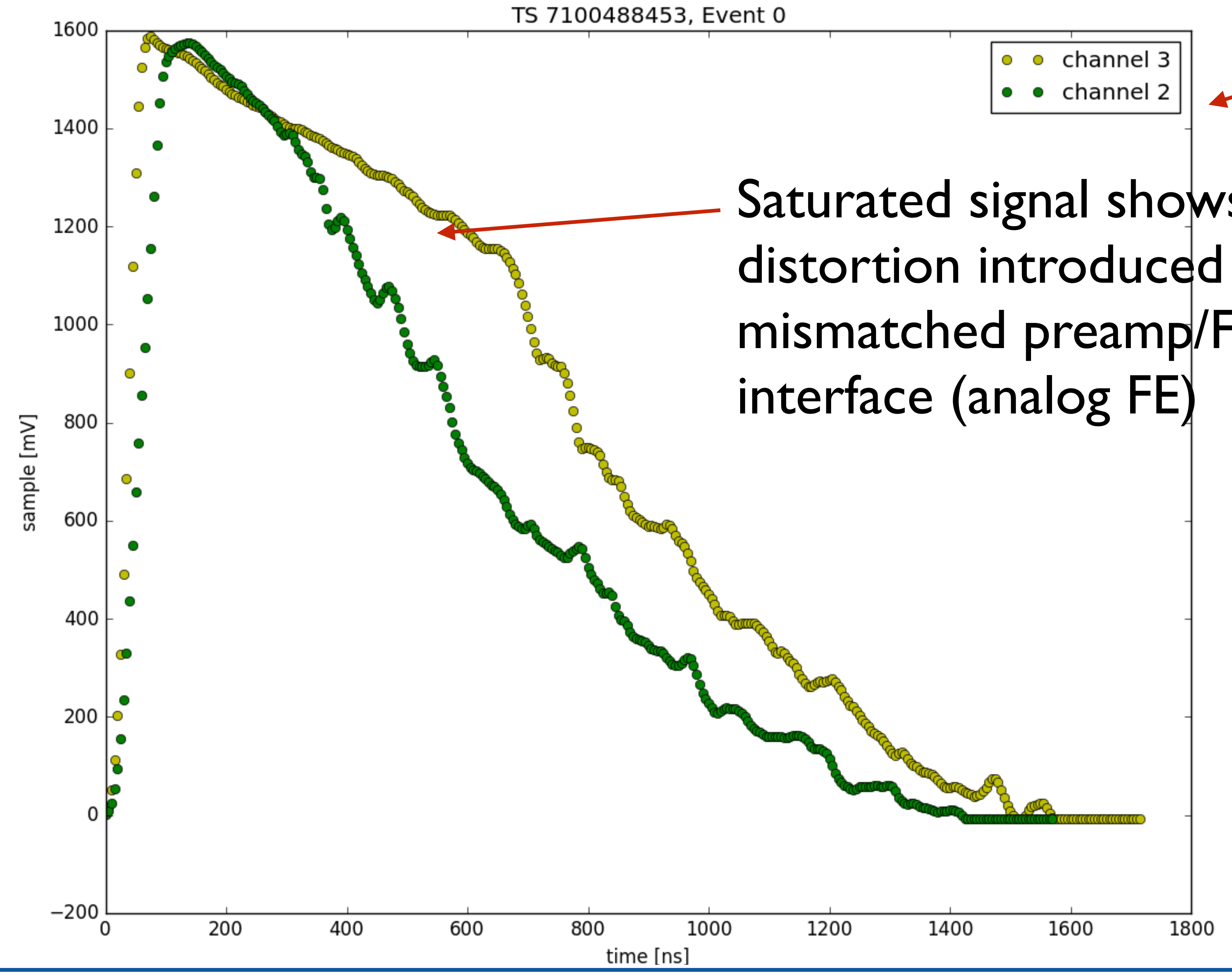


BDX gear

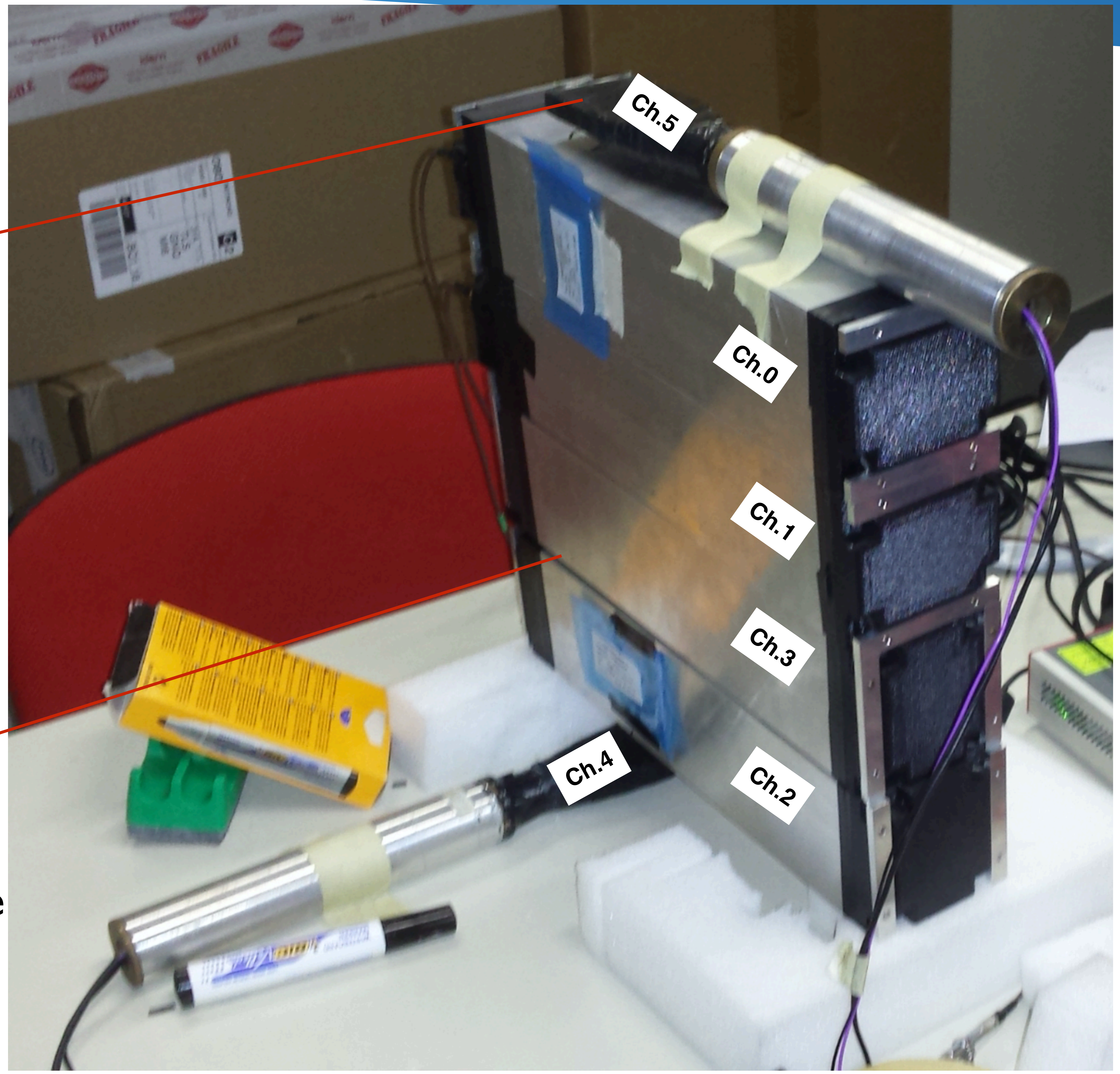


- 4 CsI(Tl) crystals
- 2 scintillators
- 6 SiPMs for readout





Saturated signal shows the distortion introduced by the mismatched preamp/FEM interface (analog FE)



L1 Trigger

★ Simple Coincidence (SC) in 20ns

★ Q>Q0 (300-400 pC)

L2 Trigger

★ &[all crystals Q]

★ Q(2)&SC(5,4)

★ Random Trigger (RT)

★ SC(4,5)

Redesign of electronics is almost completed: technology equivalent to 1 FCM + 12 x FEMs (=12 ch.) + ethernet integrated in one new single board (WaveBoard- refer to F. Ameli's talk, yesterday)

TriDAS can be immediately used "*as it is*"; planned some parameter fine tuning to optimise the data handling running with low single rate per channel.

Possibility to change the buffering at the level of HM.

The evolution of tests presented yesterday in A. Celentano's talk:
a full TriDAS setup running on one single server + a larger n. of sensors (plastic scintillators + CsI crystals) and the due n. of WaveBoards.

The BDX use-case has "triggered" the intention to improve the already **modular architecture (electronics + software)** in something more portable for trigger-less experiments.

Proposal to EU-ATTRACT call.

Thank you!

Further readings

T. Chiarusi, M. Spurio, High-energy astrophysics with neutrino telescopes, DOI: 10.1140/epjc/s10052-009- 1230-9, The European Physical Journal C (2010).

C. Pellegrino, et al., The trigger and data acquisition for the NEMO-Phase 2 tower, DOI 10.1063/1.4902796, AIP Conference Proceedings (2014).

M. Pellegriti et al., Long-term optical background measurements in the Capo Passero deep-sea site, DOI: 10.1063/1.4902780, AIP Conference Proceedings (2014).

TriDAS web site: https://bitbucket.org/chiarusi/tridas.

C. Pellegrino, T. Chiarusi , The TriDAS for KM3NeT neutrino telescope, DOI 10.1051/epjconf/201611605005, VLVNT 2015 Conference Proceedings (2015).

R. Ammendola et al., NaNet3: The on-shore readout and slow-control board for the KM3NeT-Italia underwater neutrino telescope, EPJ Web of Conferences 116, 05008 (2016).

M. Favaro, et al., The Trigger and Data Acquisition System for the KM3NeT-Italia towers EPJ Web of Conferences 116, 05009 (2016)

M. Manzali, et al., The Trigger and Data Acquisition System for the KM3NeT-Italy neutrino telescope , Proceedings of CHEP 2016

BDX proposal: https://arxiv.org/abs/1607.01390