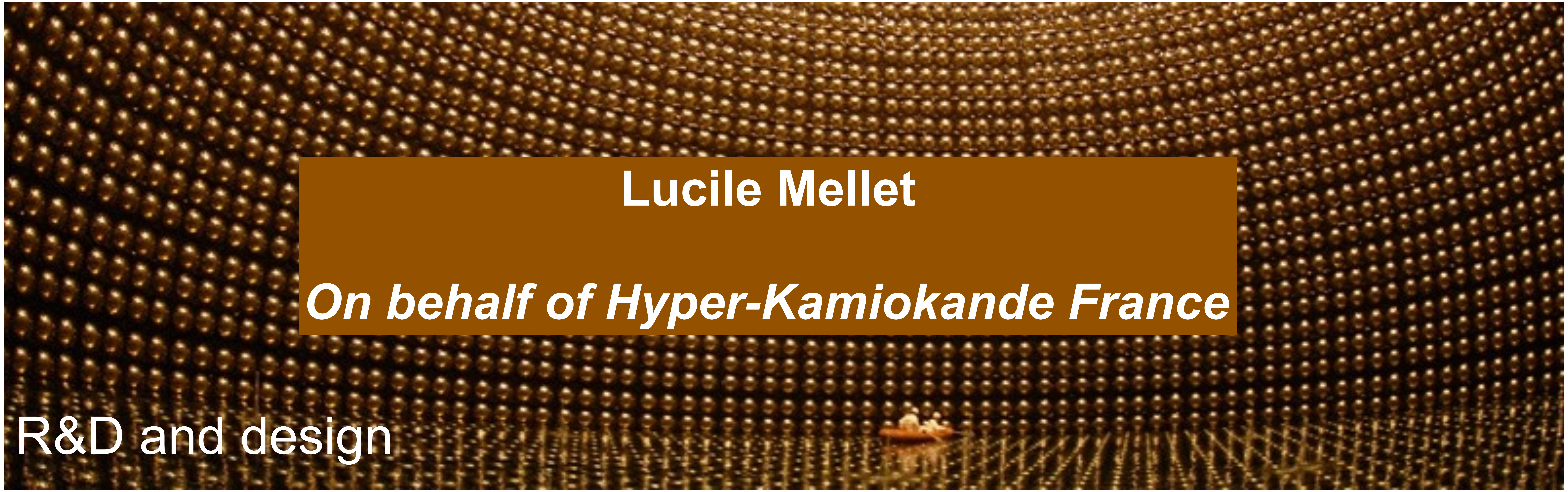
Precise time and charge digitization for the Hyper-Kamiokande experiment



Lucile Mellet

On behalf of Hyper-Kamiokande France

R&D and design

LPNHE Paris

ILANCE International Laboratory for Astrophysics, Neutrino and Cosmology Experiments

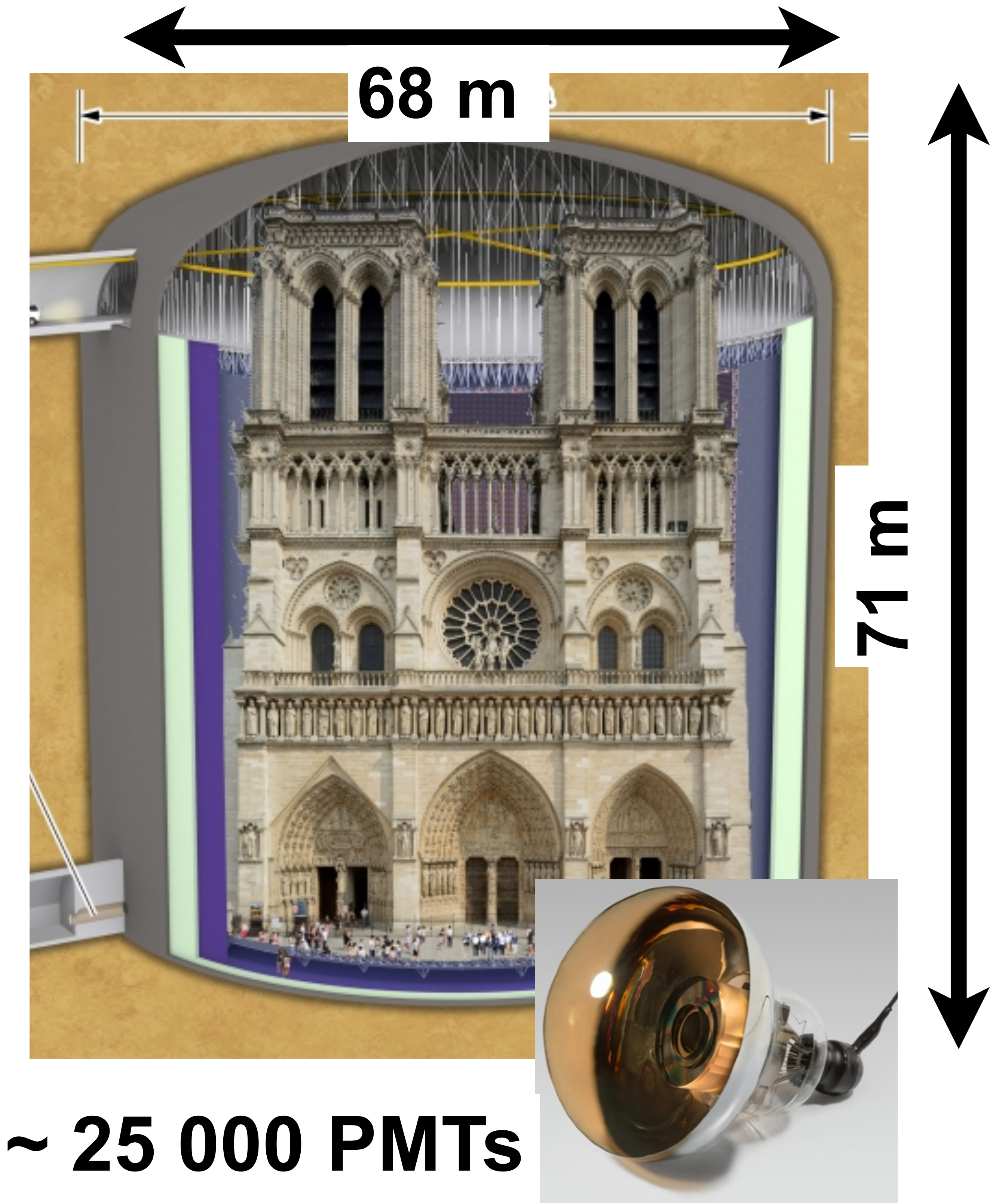
OMEGA Microelectronics

Laboratoire Leprince-Ringuet

cea

Hyper-Kamiokande

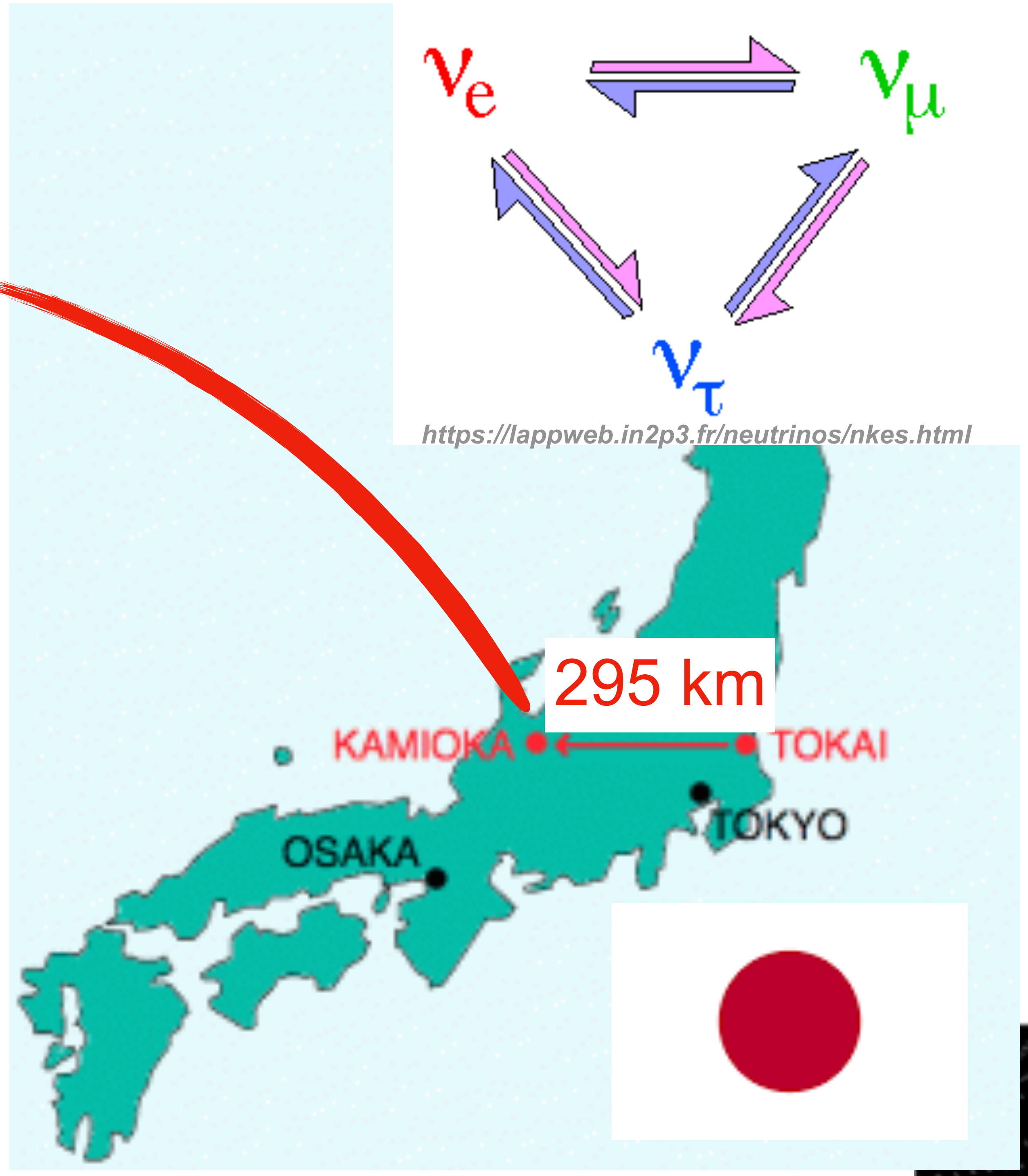
HK in a nutshell

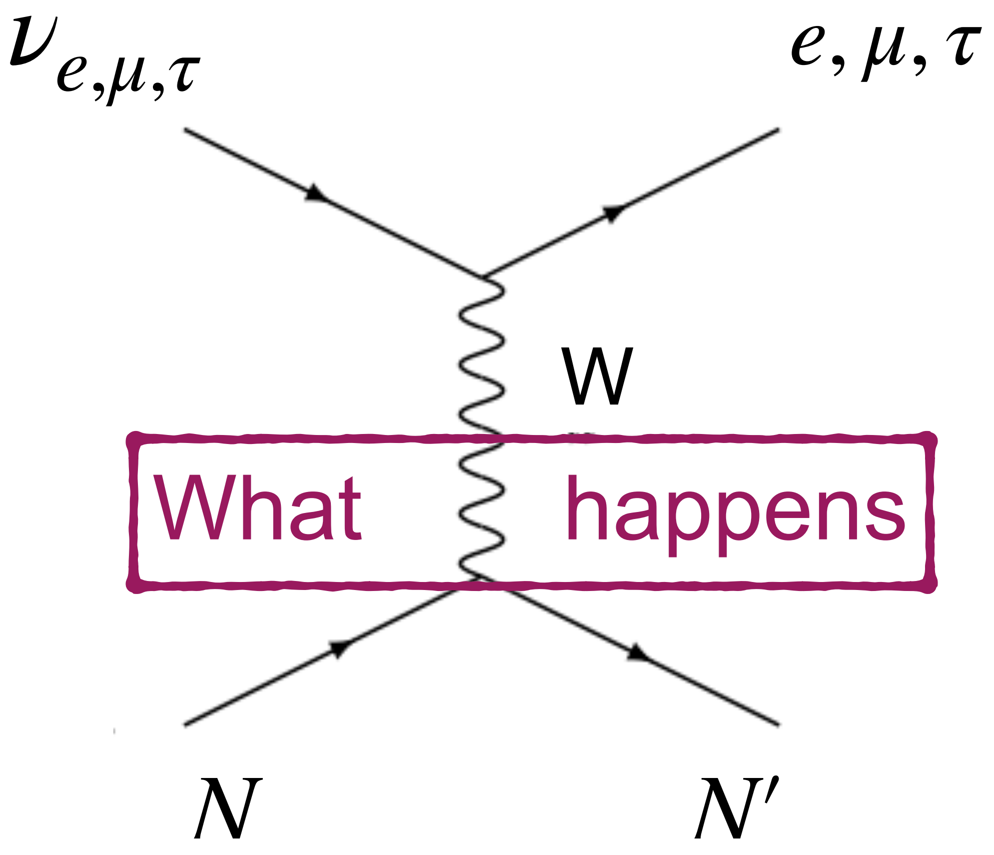


~ 25 000 PMTs

What we build

- Long baseline ν oscillation experiment
- Water Cerenkov detector

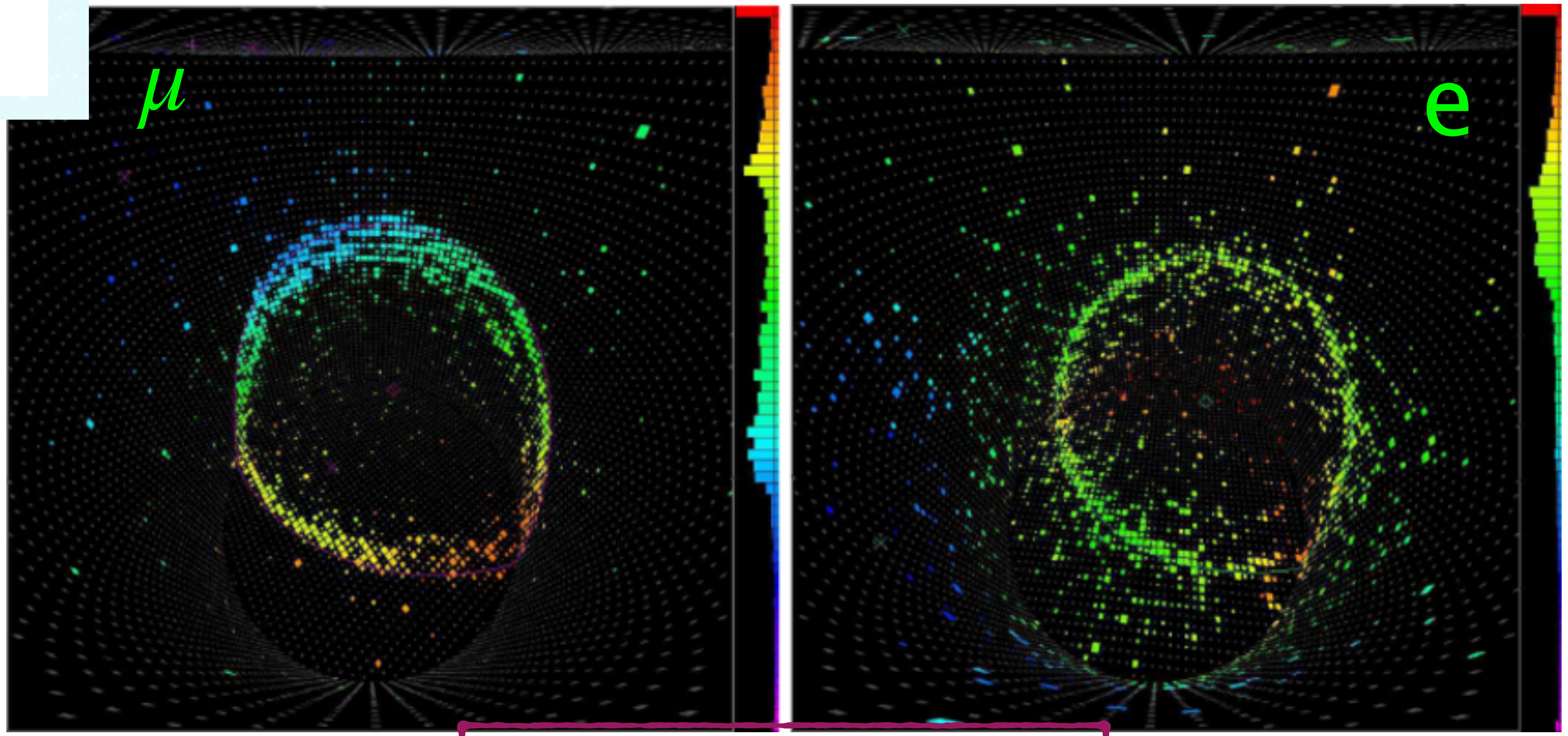




Main interaction : Charged current quasi elastic (CCQE)

- Beam ν physics
- Astrophysics ν observatory

Need for :
- Efficient **collection of the charge** output of the Photo-multipliers
- Precise **timing** for ring reconstruction



What we want to see

Global scheme of our participation to HK's electronics

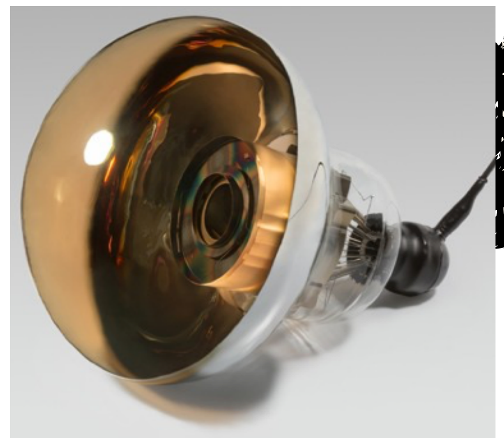
Link to UTC

III

Clock Generation

Time distribution

II



Photomultipliers

Charge digitization

Time digitization

I

Final signal

Need for :
- Efficient **collection of the charge** output of the Photo-multipliers
- Precise **timing** for signal coincidence

Charge and time digitization for HK

Some of the requirements

- Charge resolution :
  - Low energies : Solar ν
  - High energies : Atmospheric ν

➡ Large dynamic range

- Time resolution :
  - < 300 ps when > 1 p.e-
  - then < 200 ps above 10 p.e-

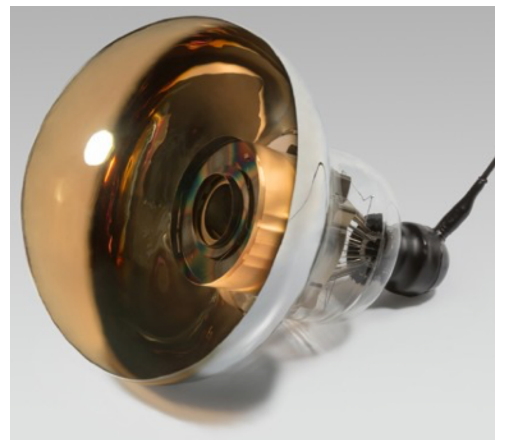
- Charge linearity : 1%

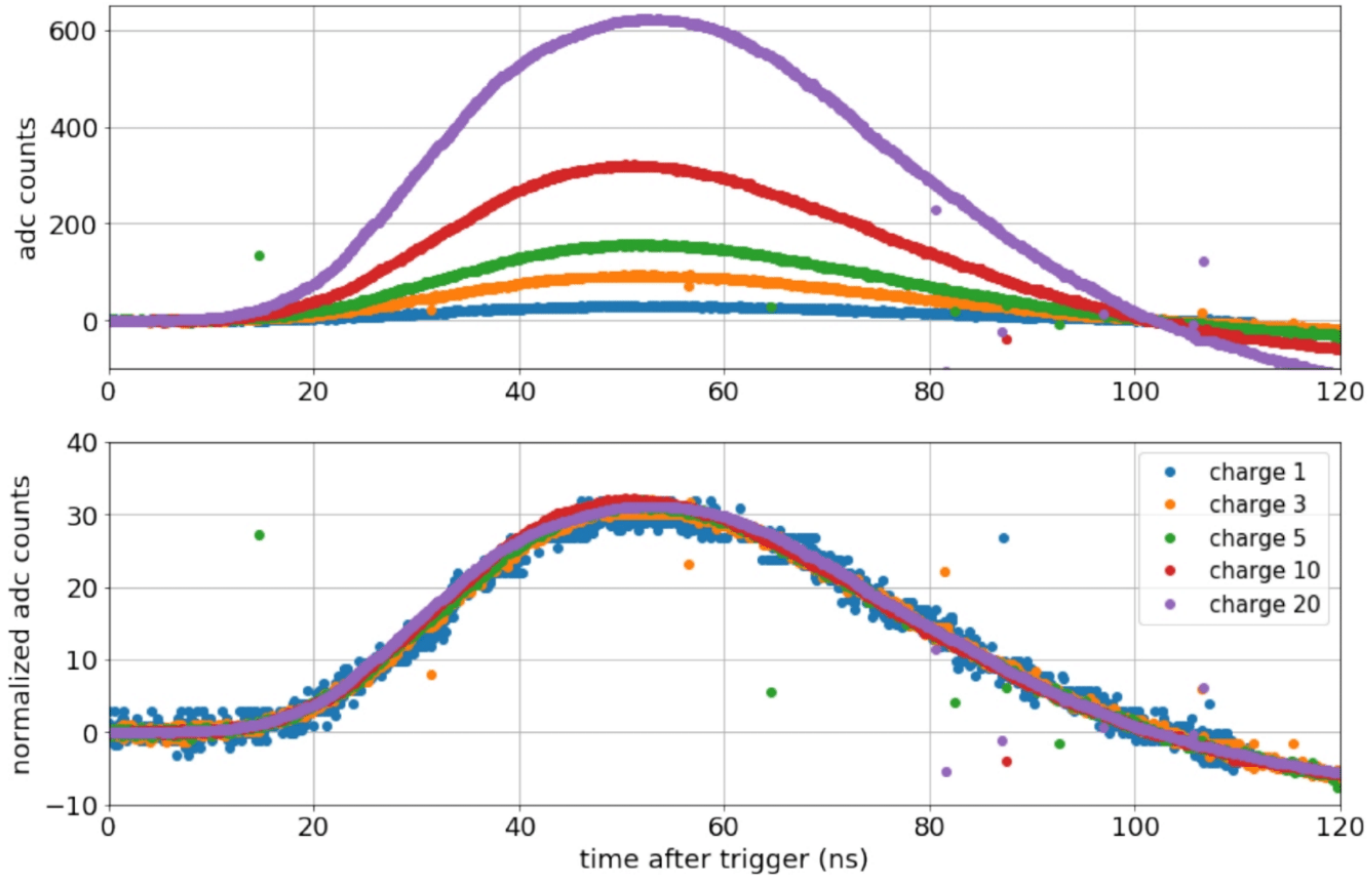
- Discriminator threshold : 1/6 p.e.

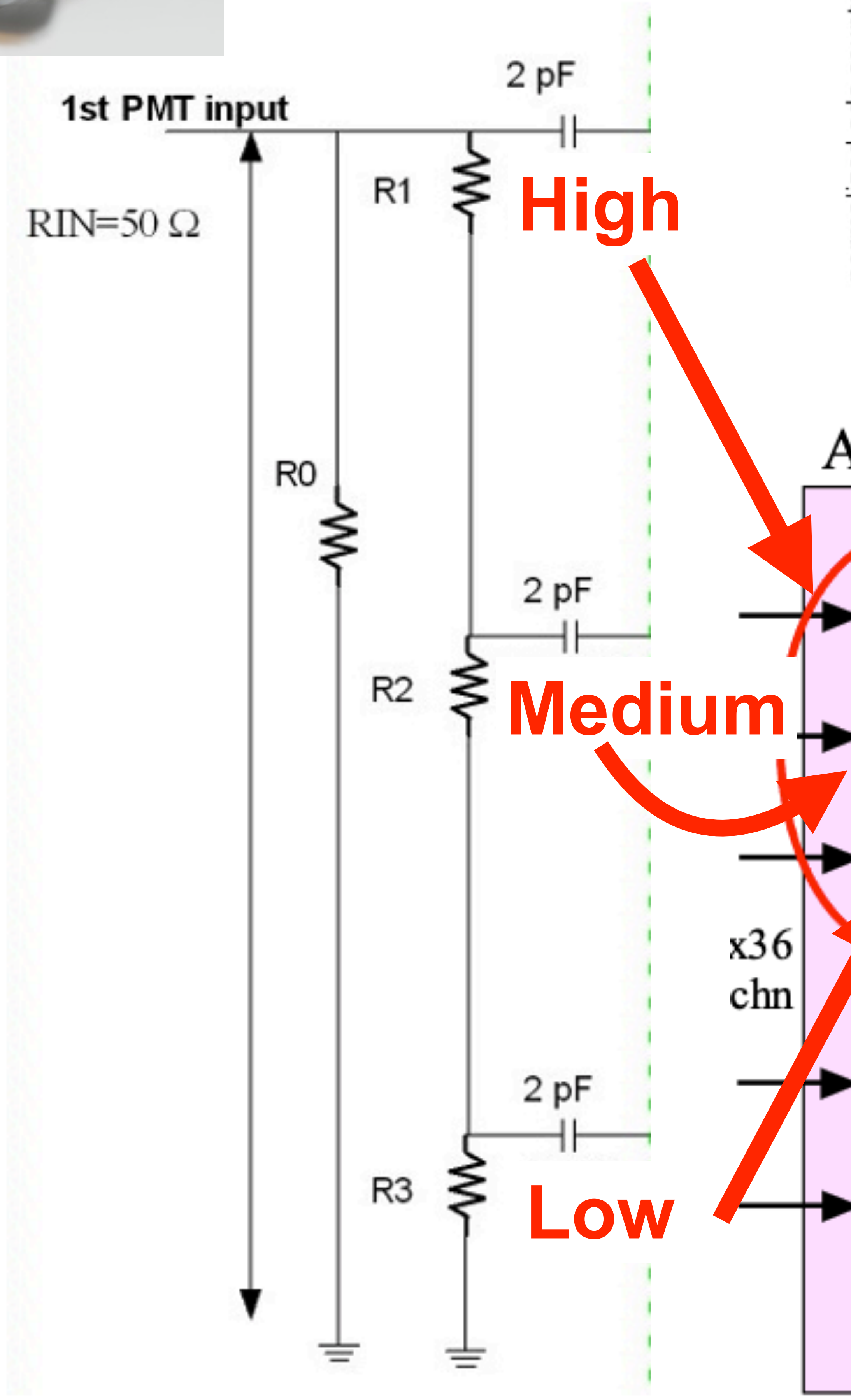
Charge and time digitization for HK

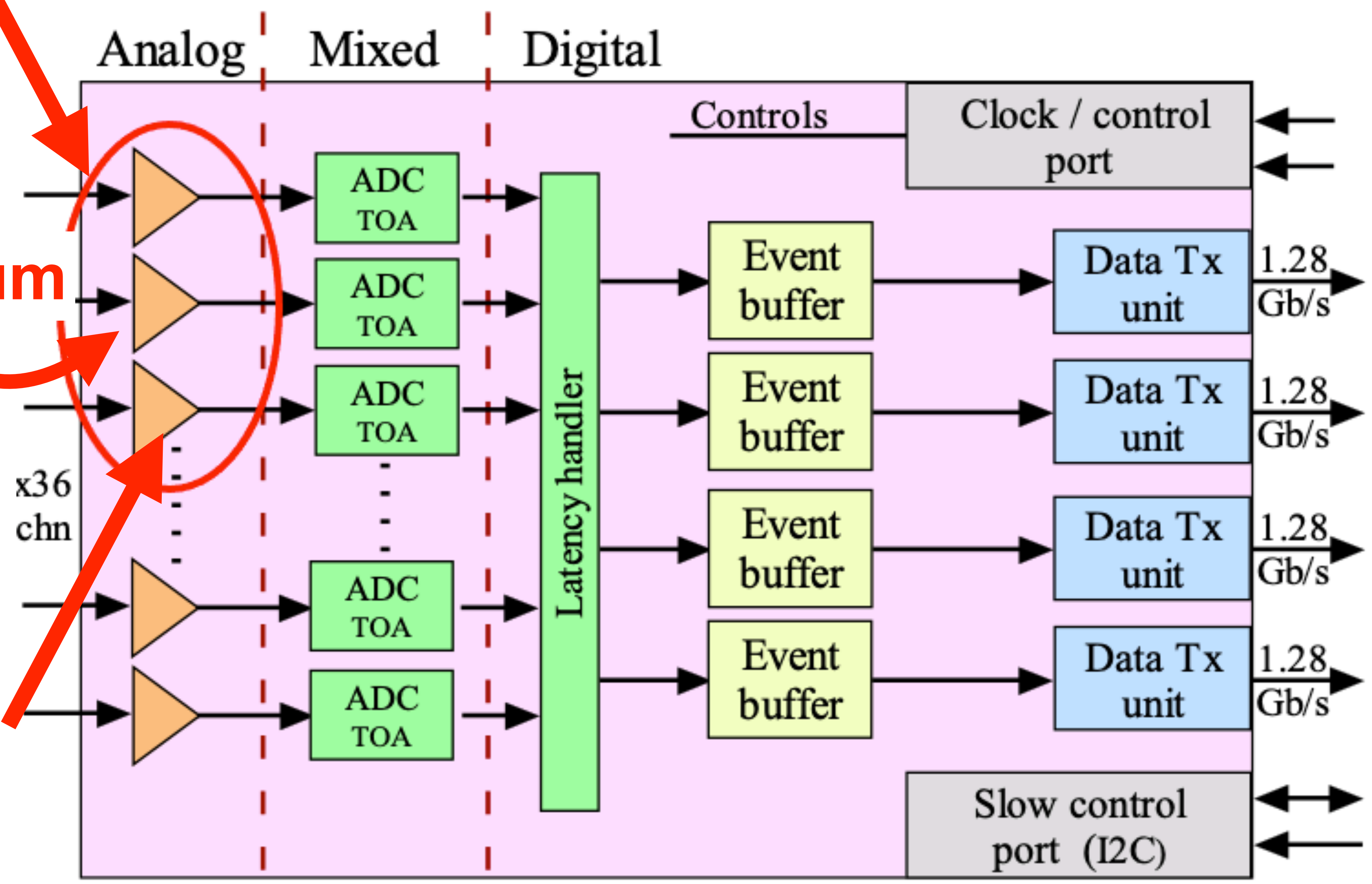
Proposed solution

- Based on HKROC chip
  - 3 gains per channel (low, medium, high)
  - Dynamic range from 0-2500 pC = 0-1250 p.e-
  - 1 readout for 3 PMTs → 1 trigger = read all 3 (hint for fake hit)

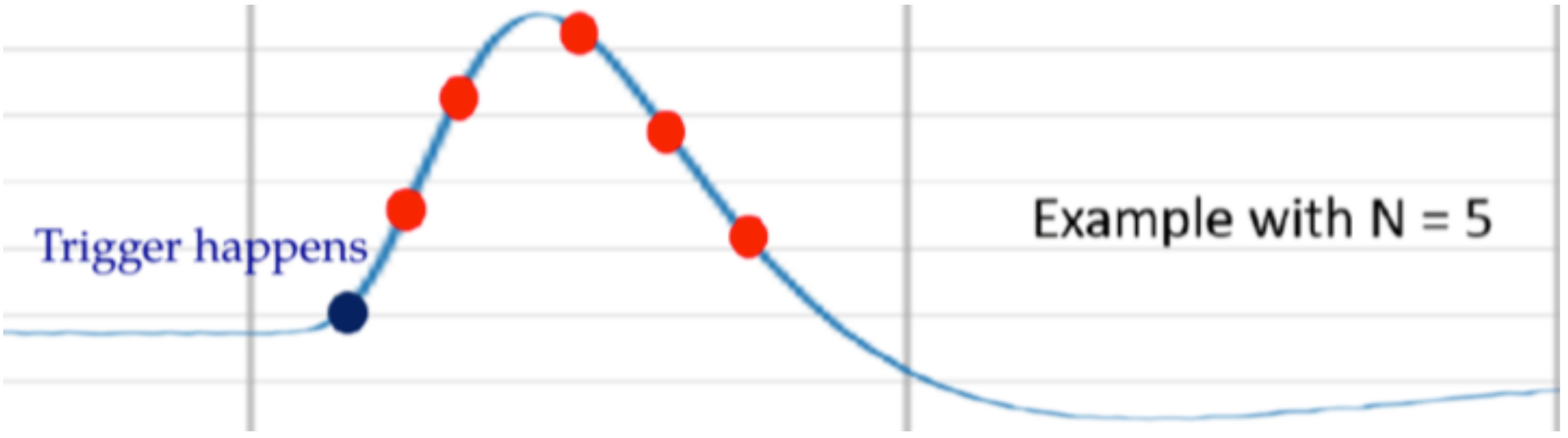








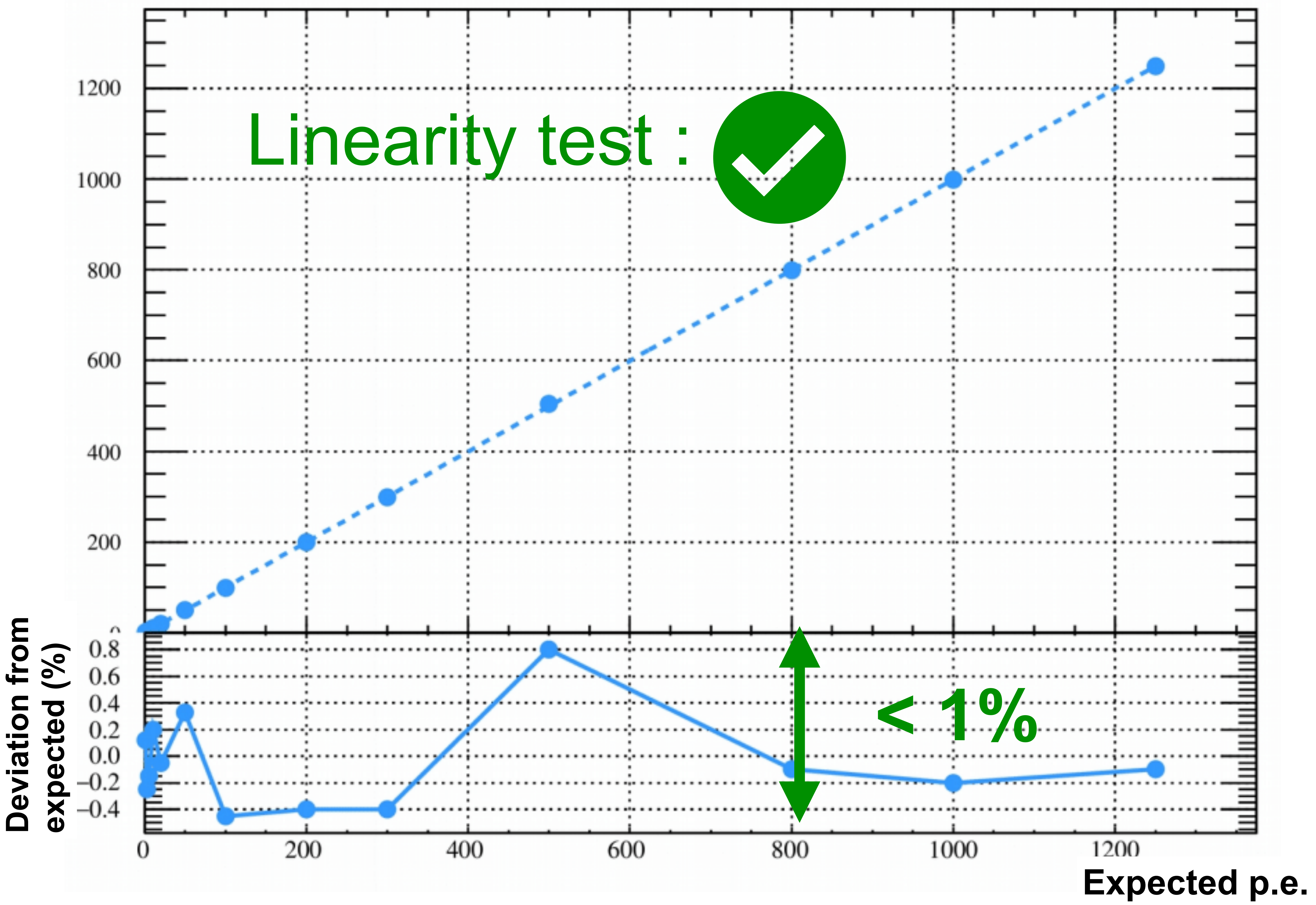
- Waveform-like digitizer @40MHz : 1 point/25 ns



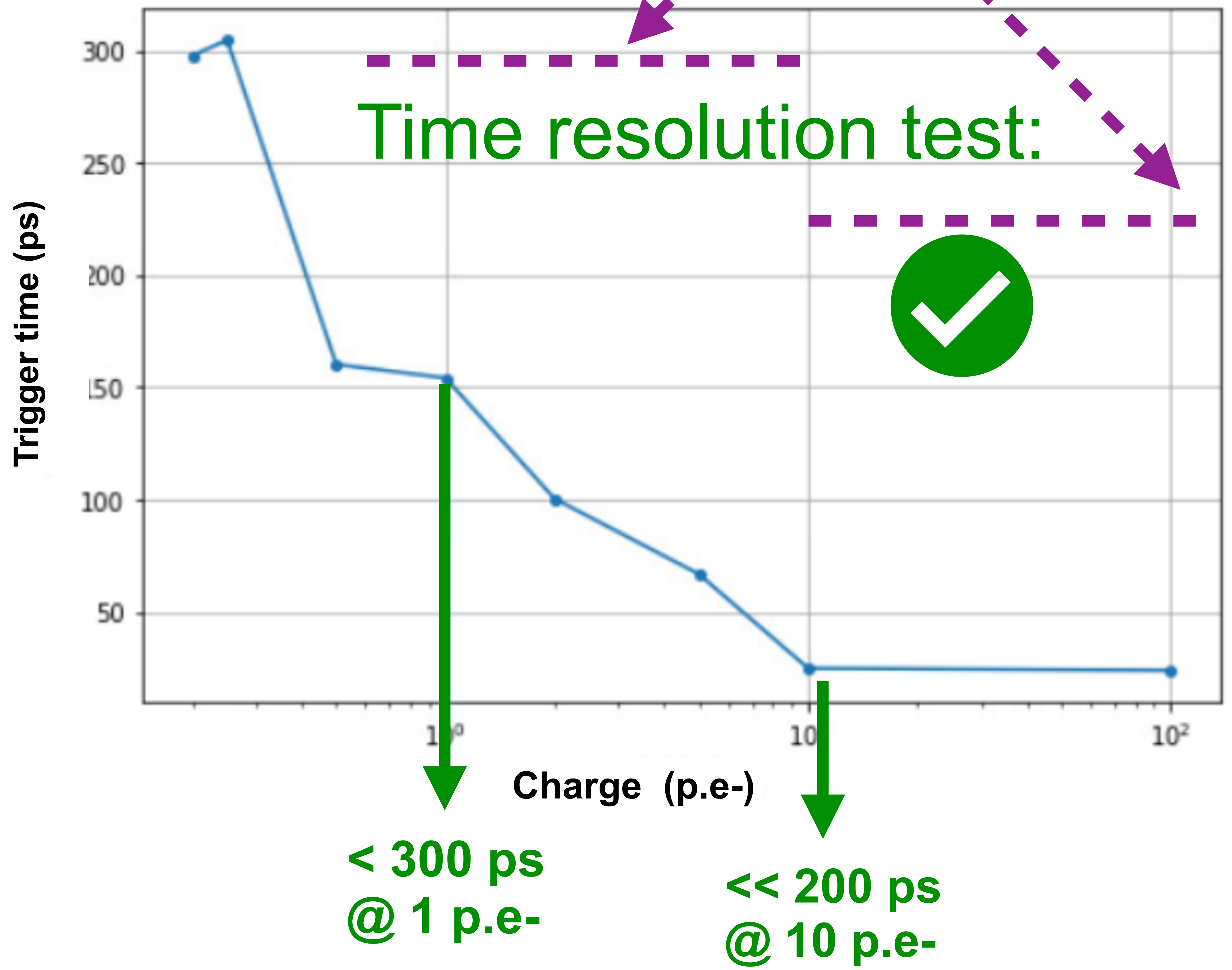
Charge and time digitization for HK

Some results

Mean p.e.

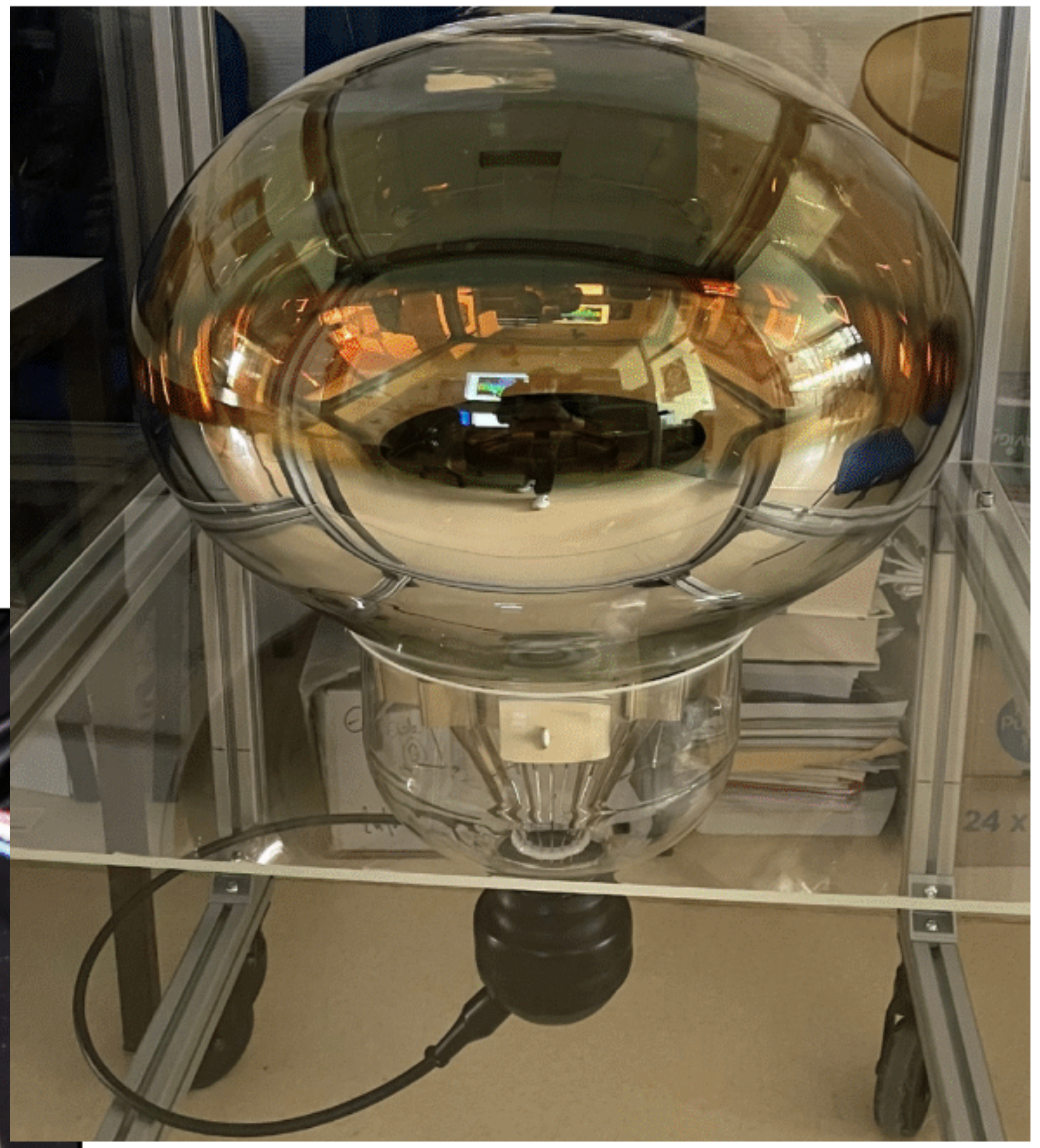


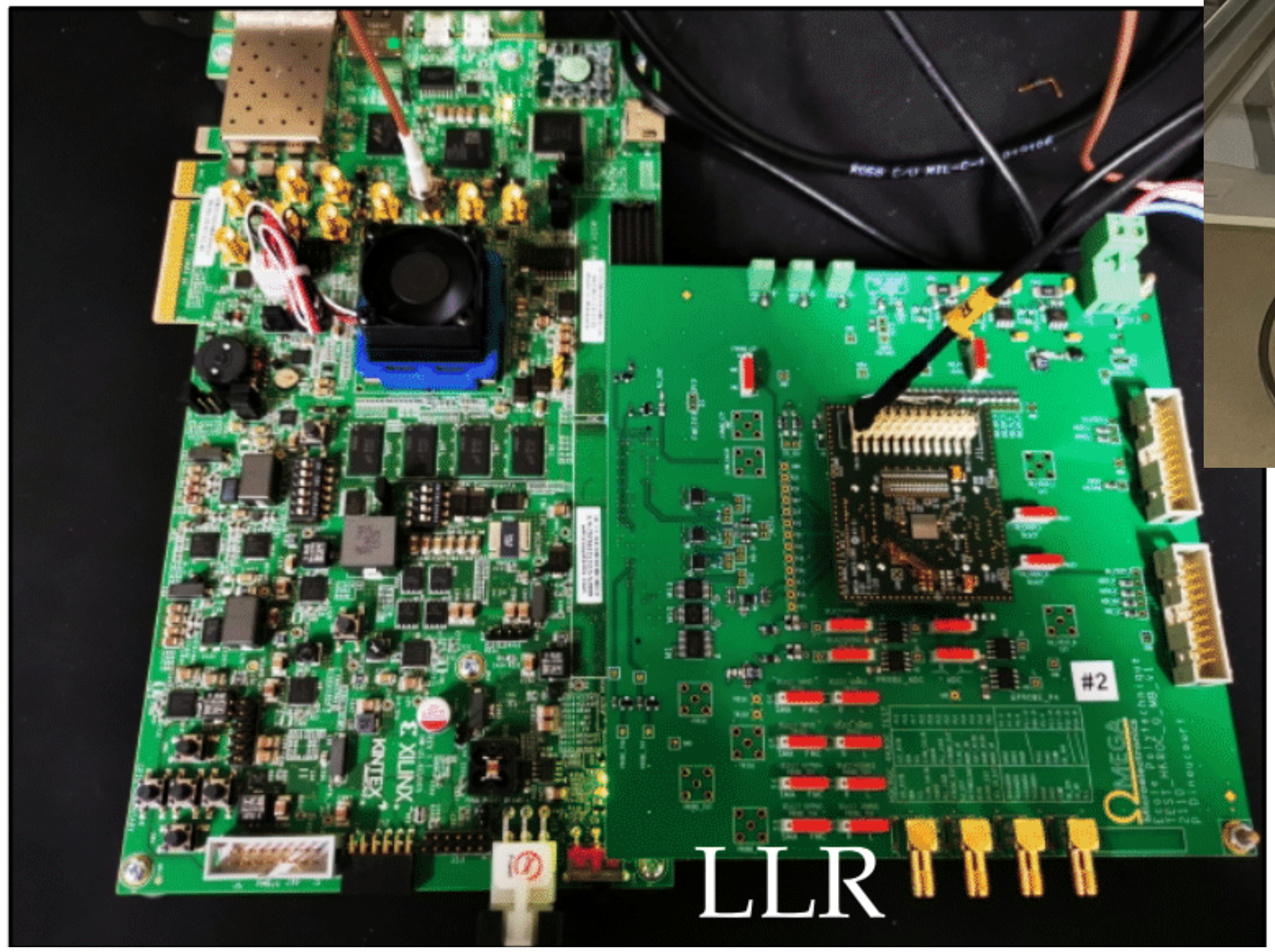
Requirements

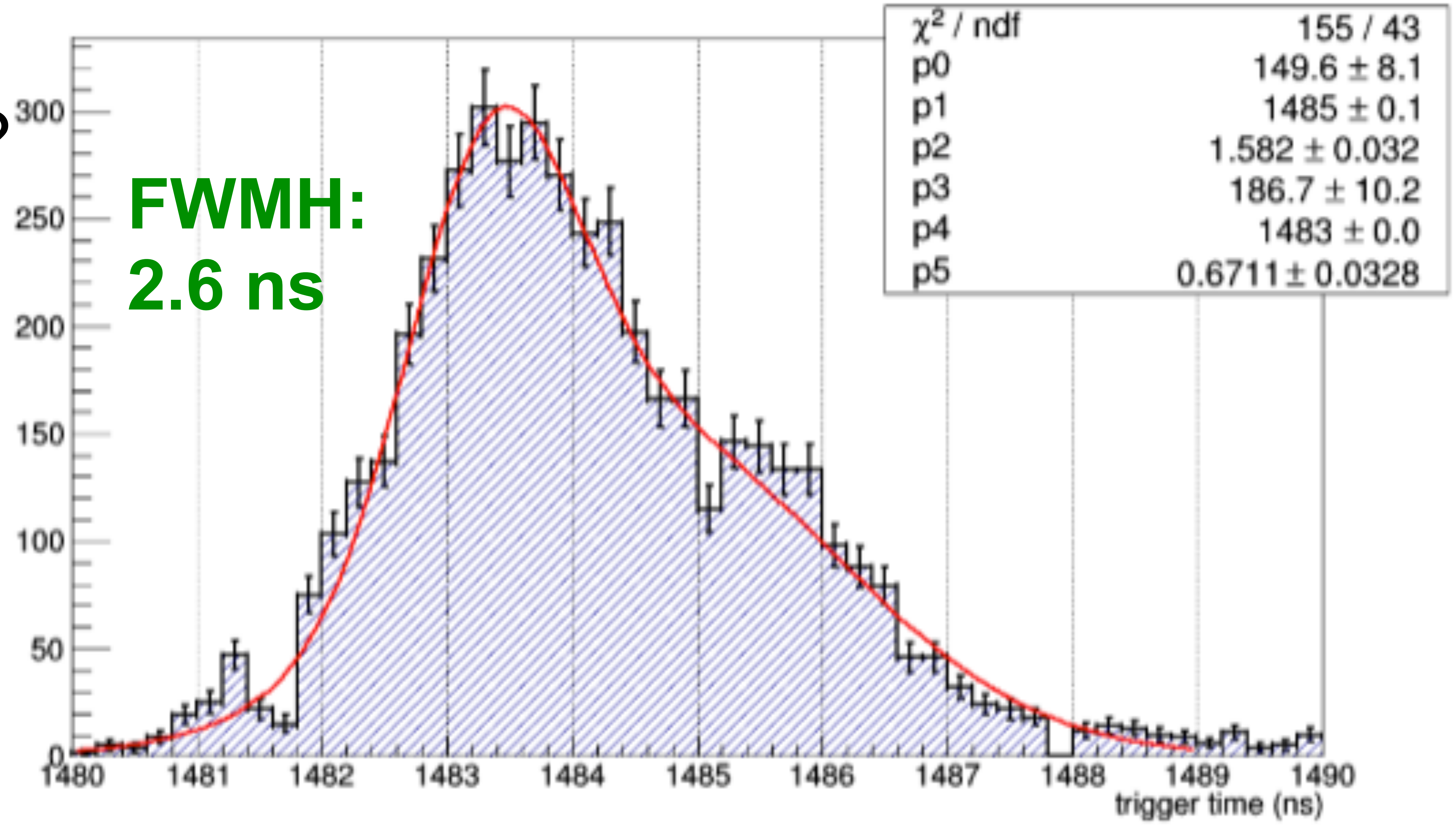


Charge and time digitization for HK

Time resolution of the PMT : ~2.8 ns
Does the digitizer degrade the PMT performance ?





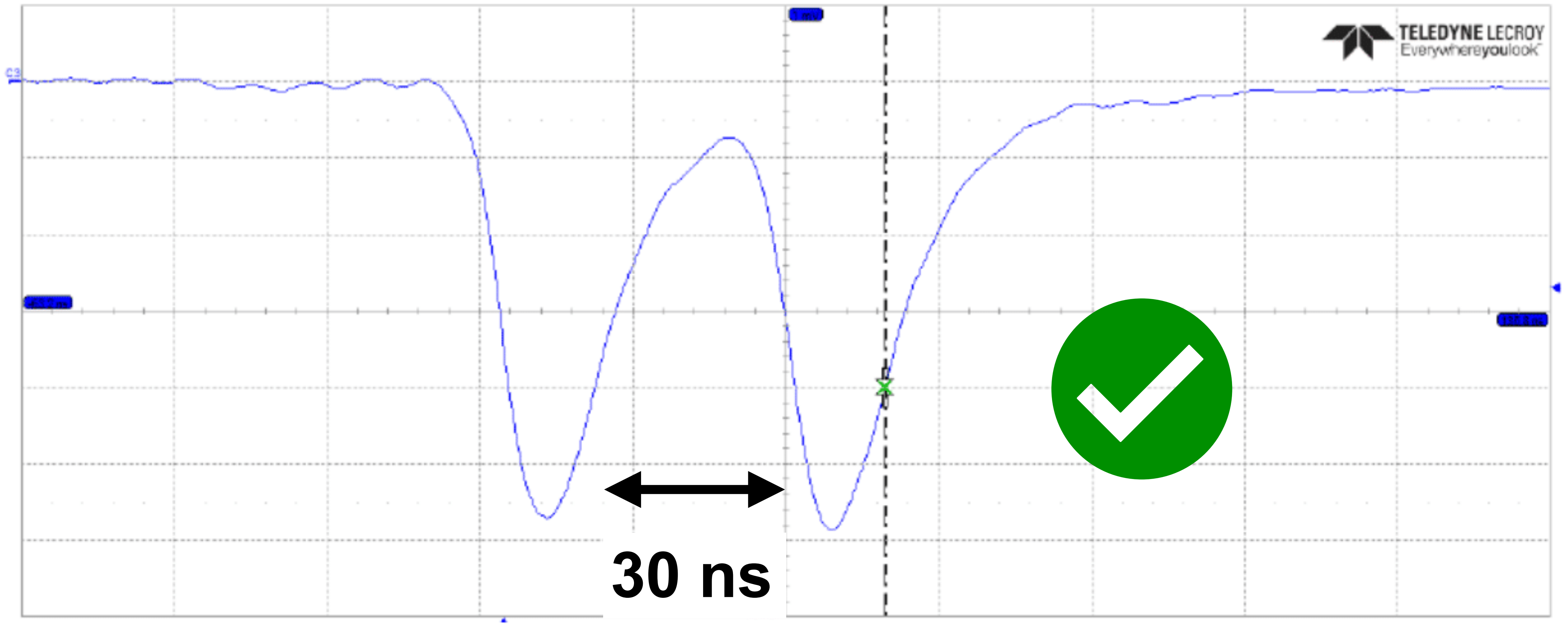


Time resolution with PMT : ✓

All tests on time and charge have been performed with PMT in real conditions

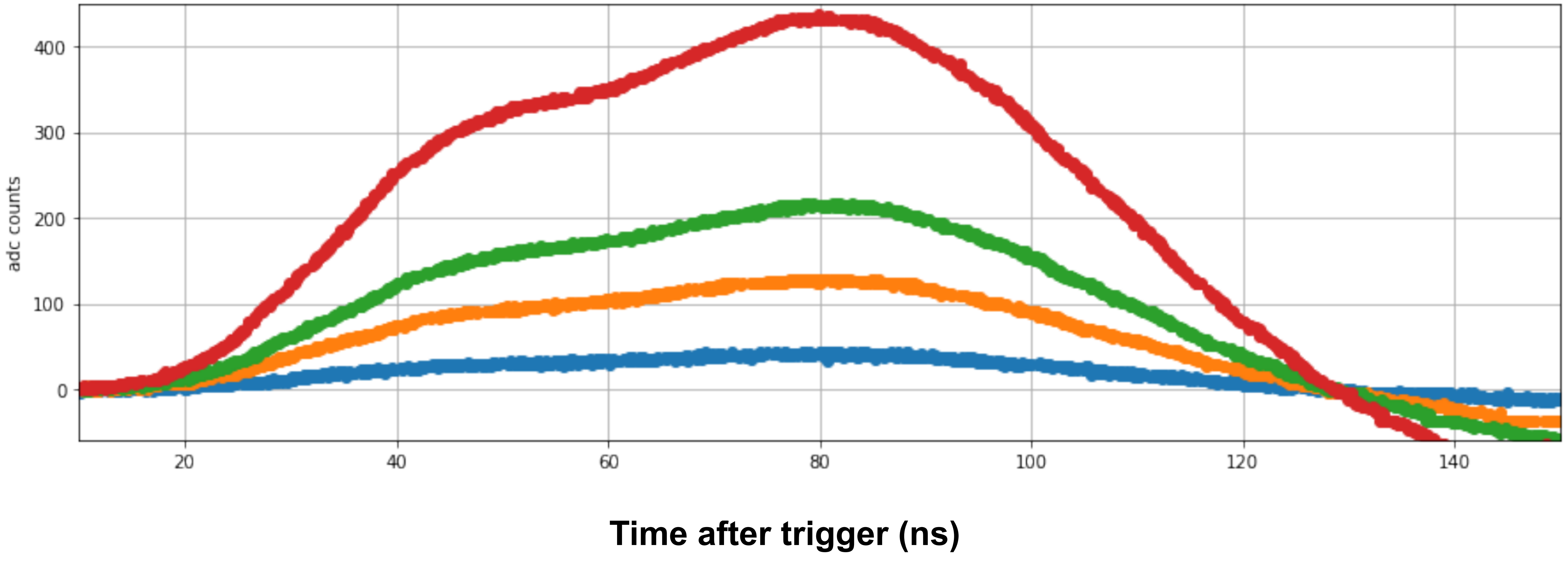
Charge and time digitization for HK

By the way, why a waveform digitizer ?

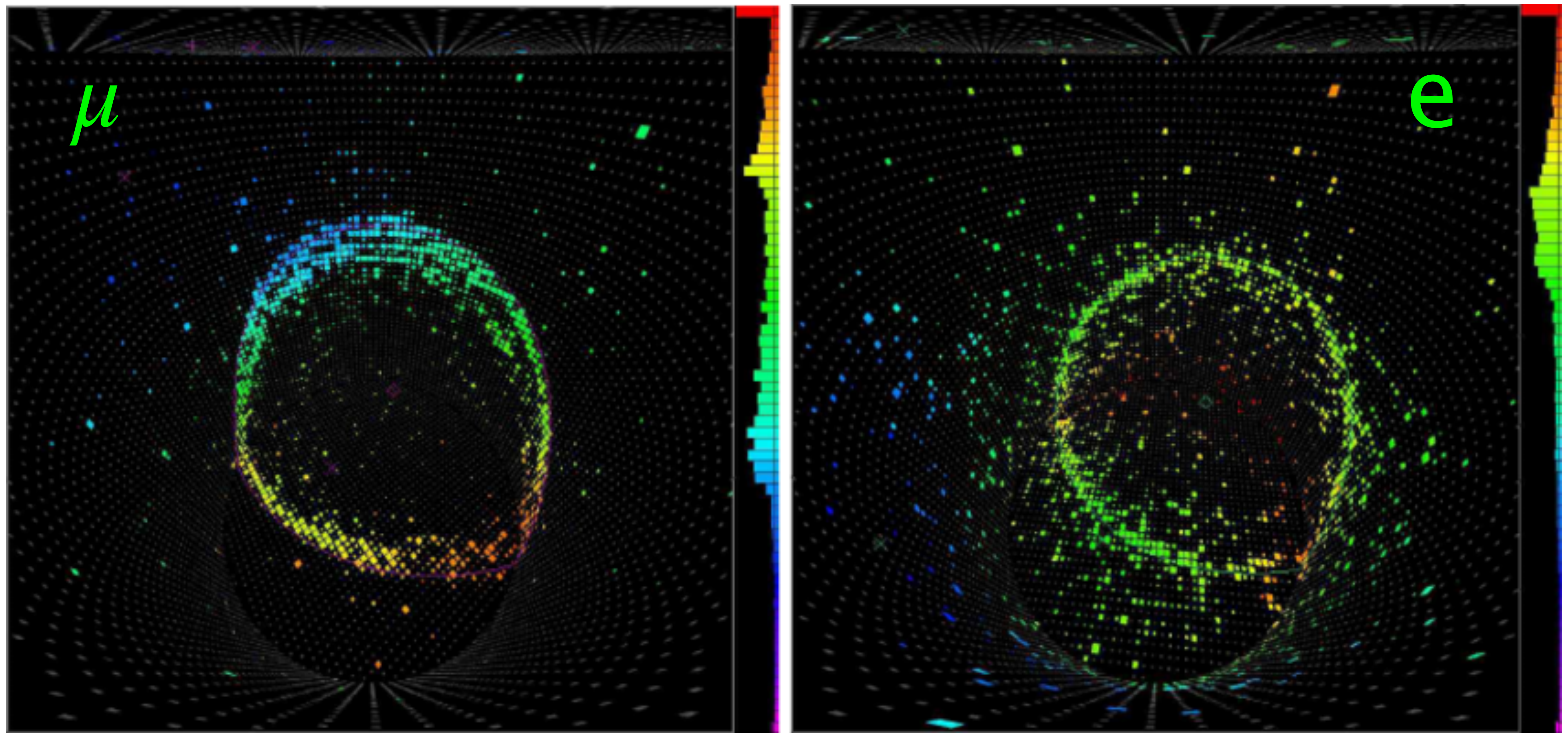


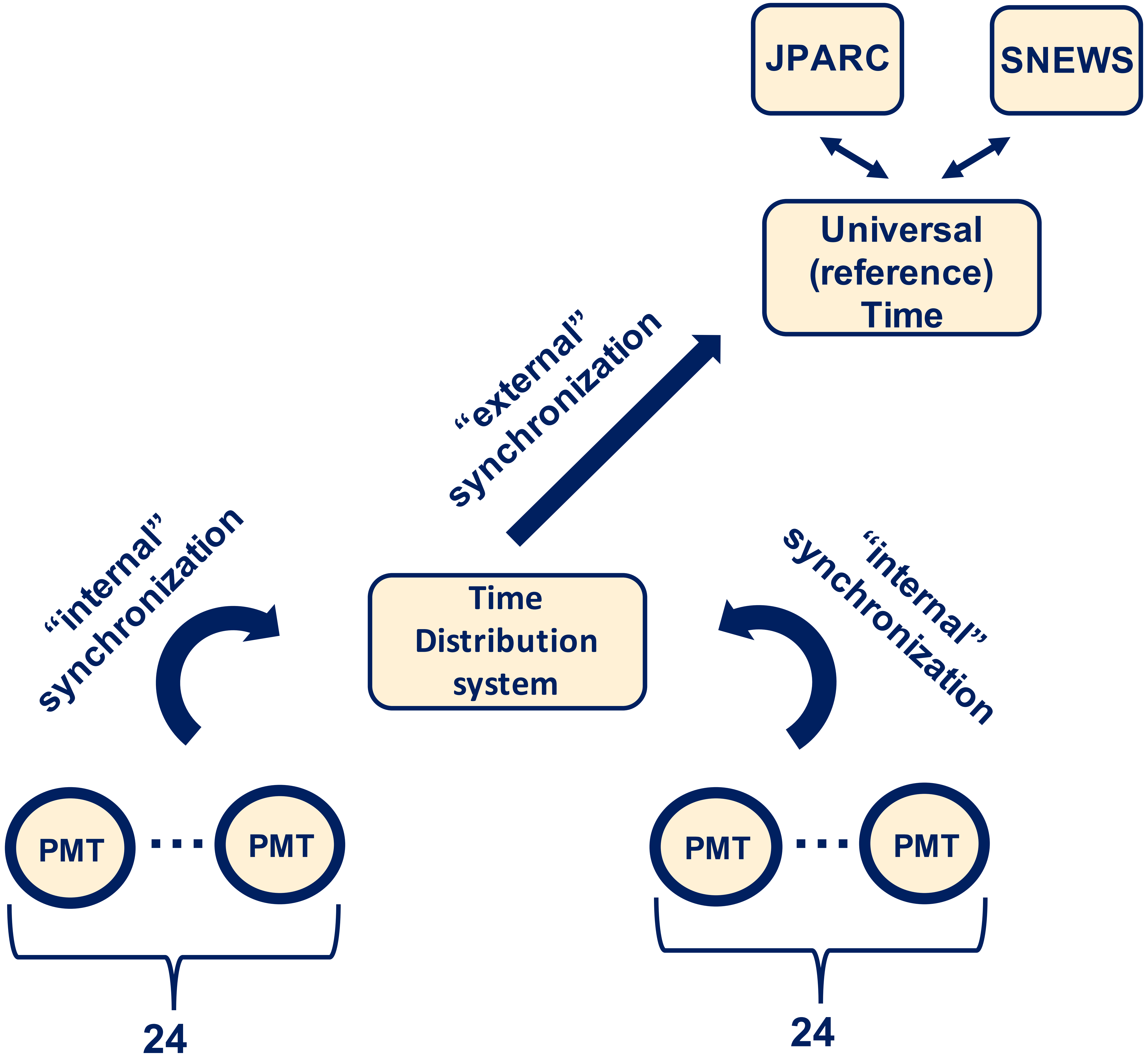
- Reduces dead time (requirement < 1 μs) up to 30ns

- Allows for separation between close events in time (pile-up) :
  - ➡ Software reconstruction
  - ➡ Delayed signals (decay e-, direct/indirect light, …)
  - ➡ High rate of SN explosion signal



Precise timing for Hyper-Kamiokande





- Internal sync : ring reconstruction by coincidence
  - Stability of less than 100 ps
- External sync : beam bunches + astrophysical observatory (SN) + other studies
  - At least 100 ns wrt UTC

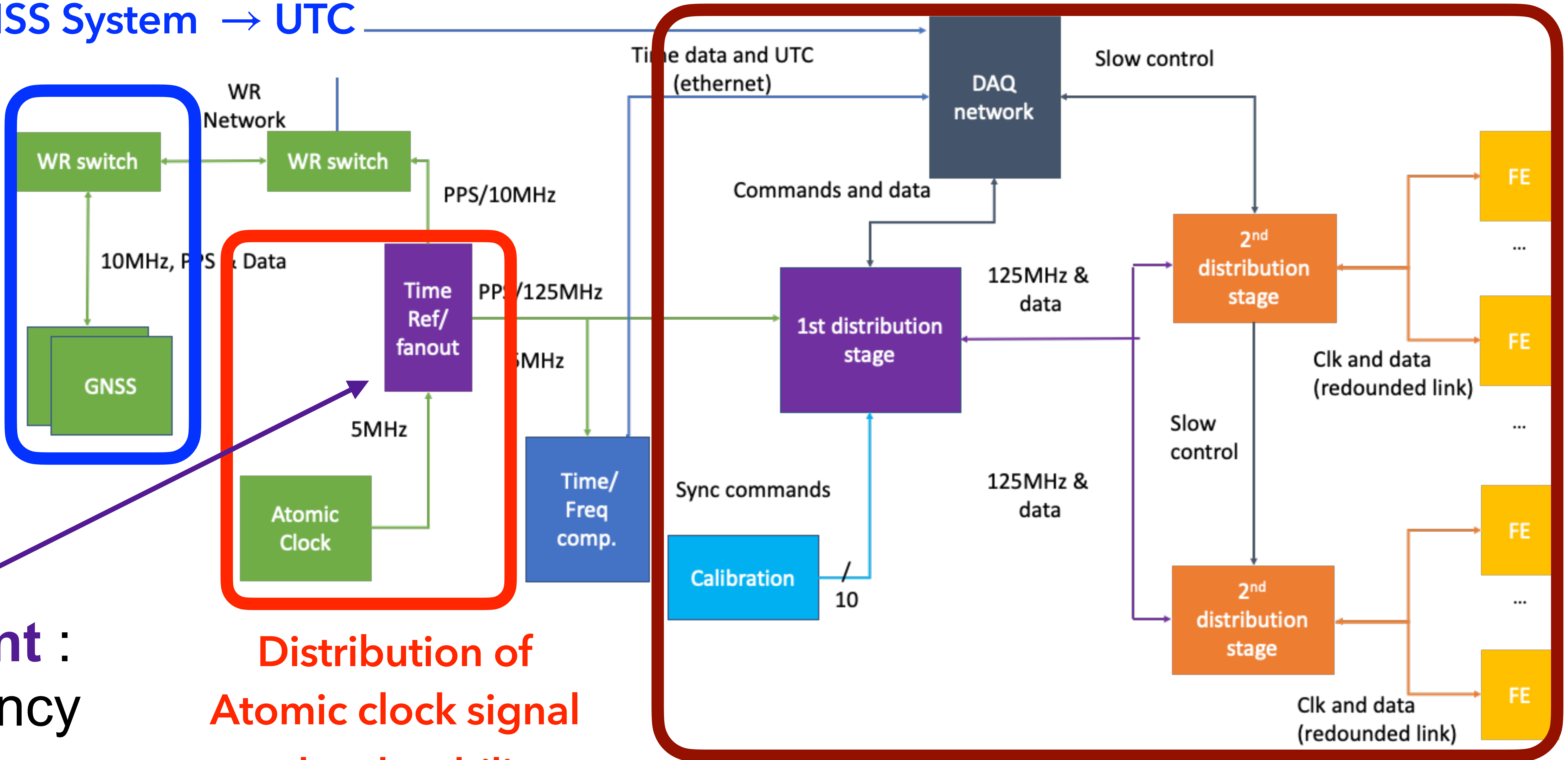
Detailed scheme of our solution

Currently in an R&D phase

Our proposed system :

What ?

GNSS System → UTC



Distribution of Atomic clock signal → local stability

Distribution to PMTs

- One local **time reference point** :
    - distributes a high-frequency clock signal
    - built from an **atomic clock**

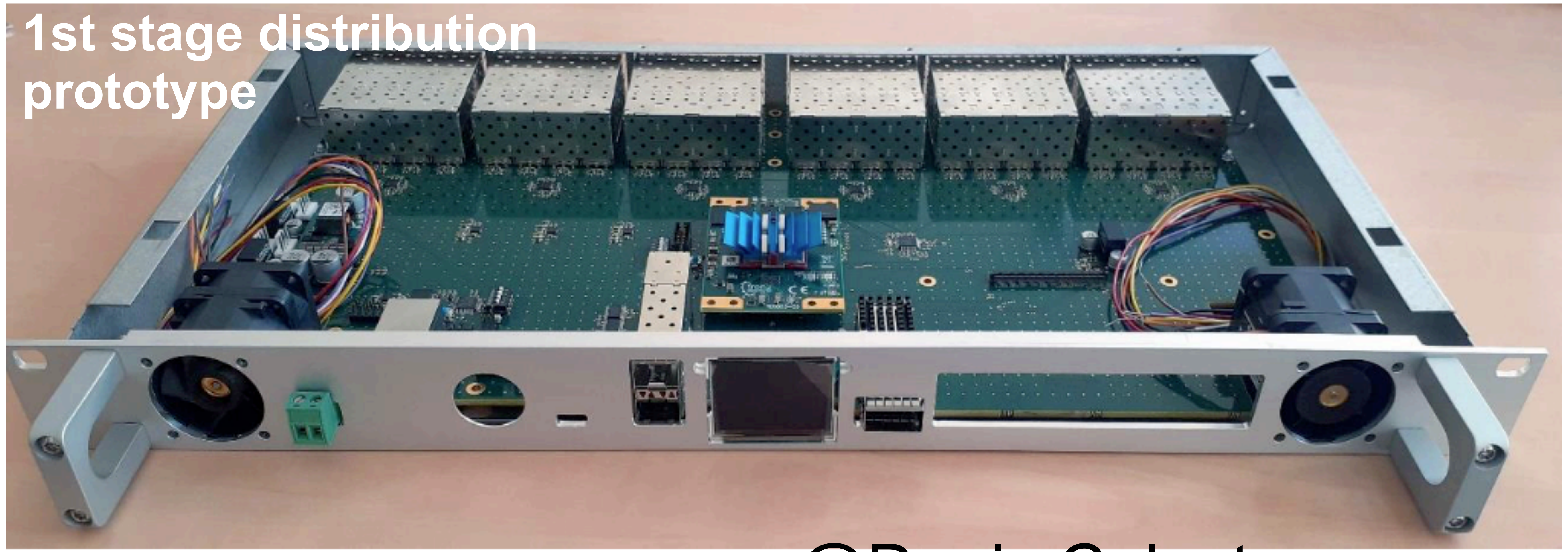
- A **GNSS** antenna + receiver : link to universal time (UTC)

- Two-stages distribution

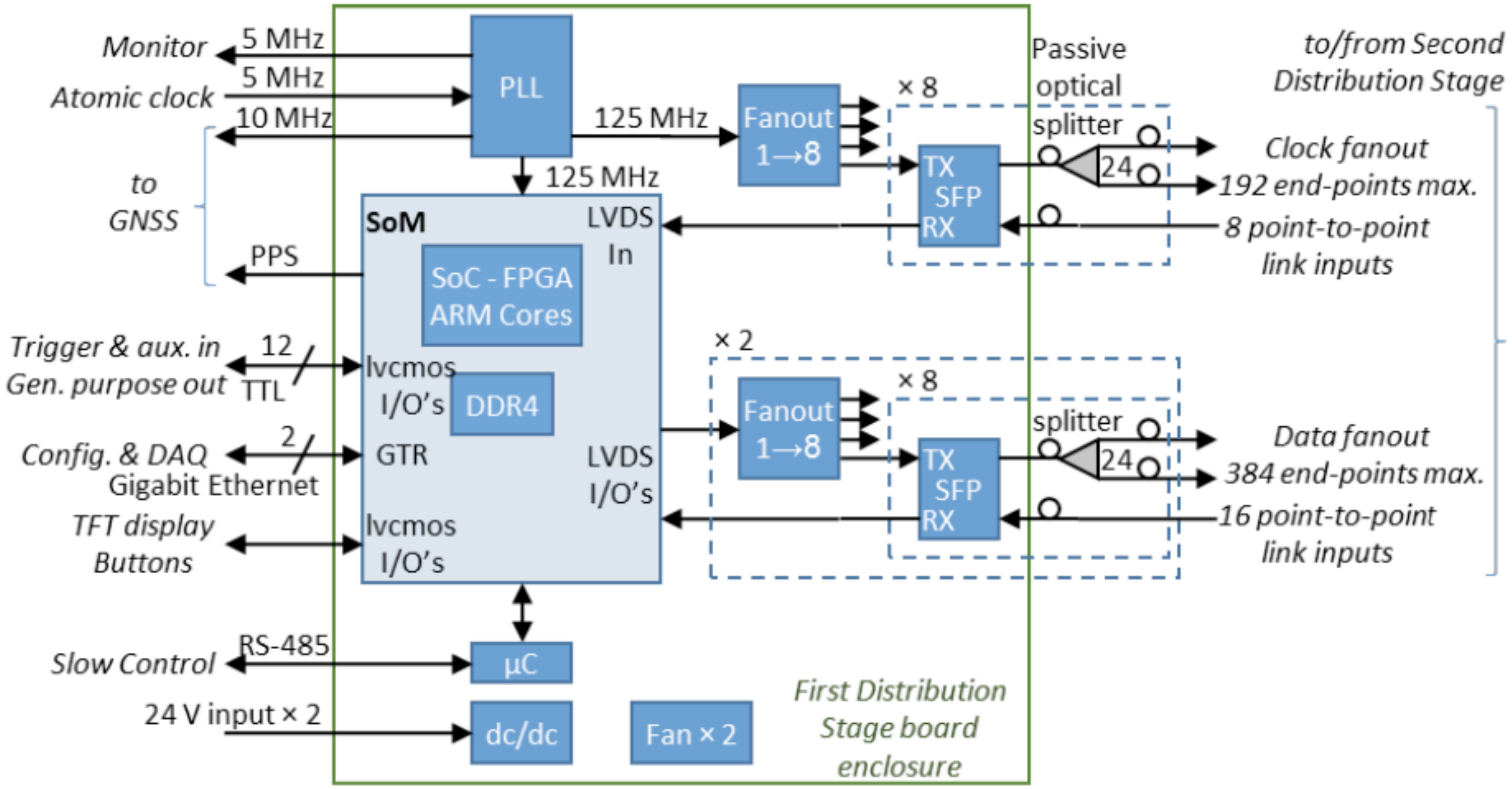
+ Redundancy

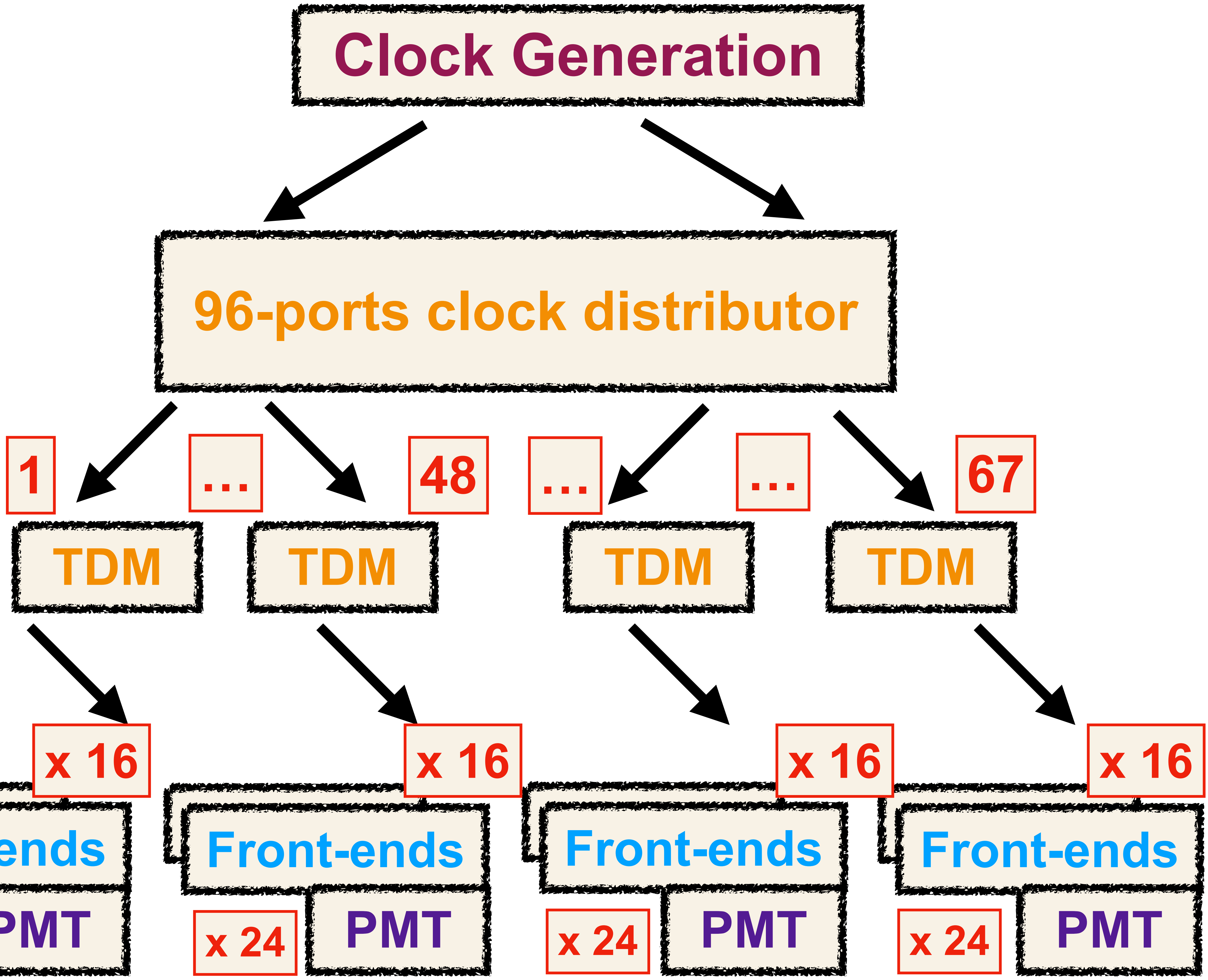
TDM = Time division multiplexer

Two-stages distribution



@Denis Calvet



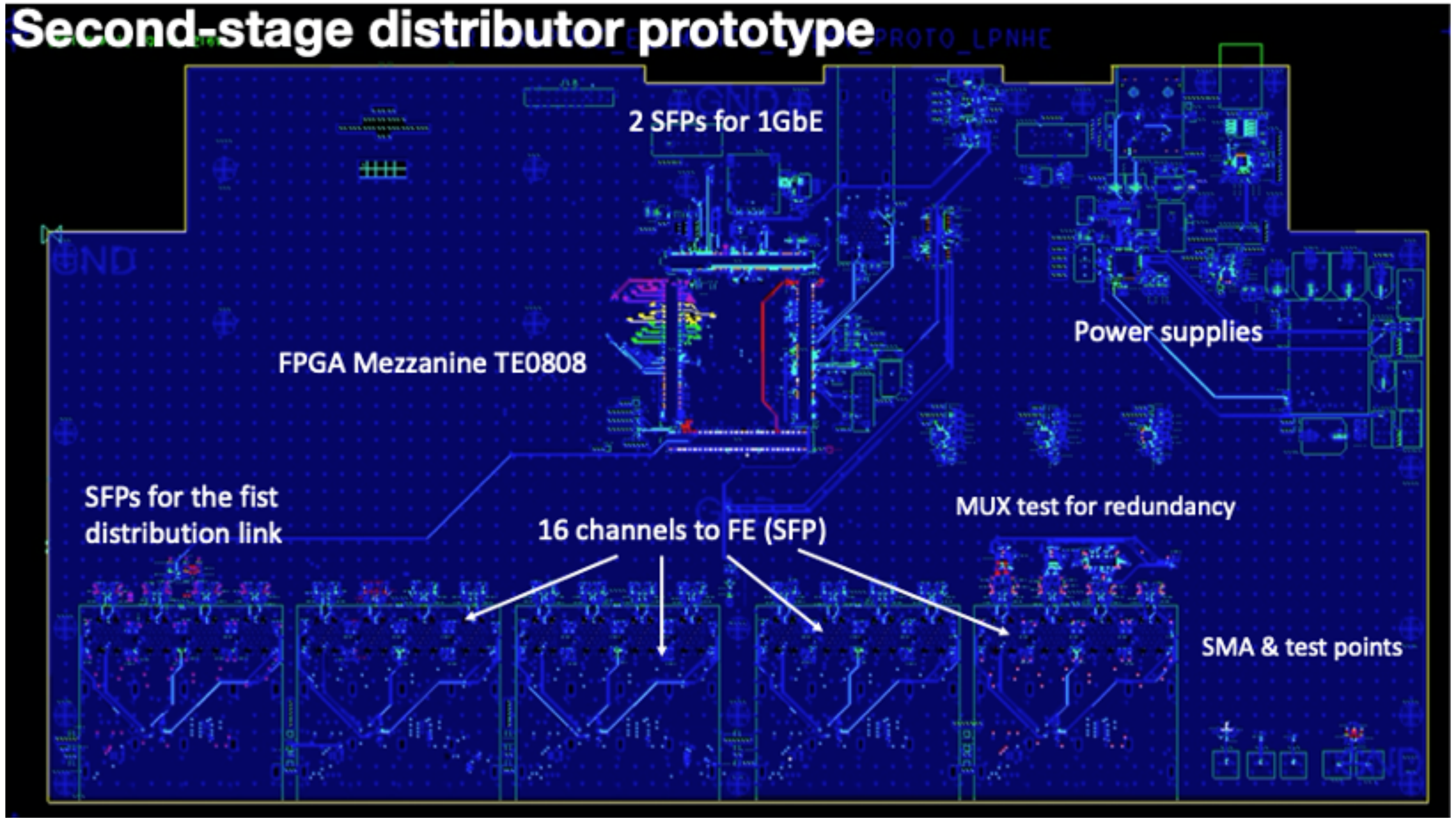


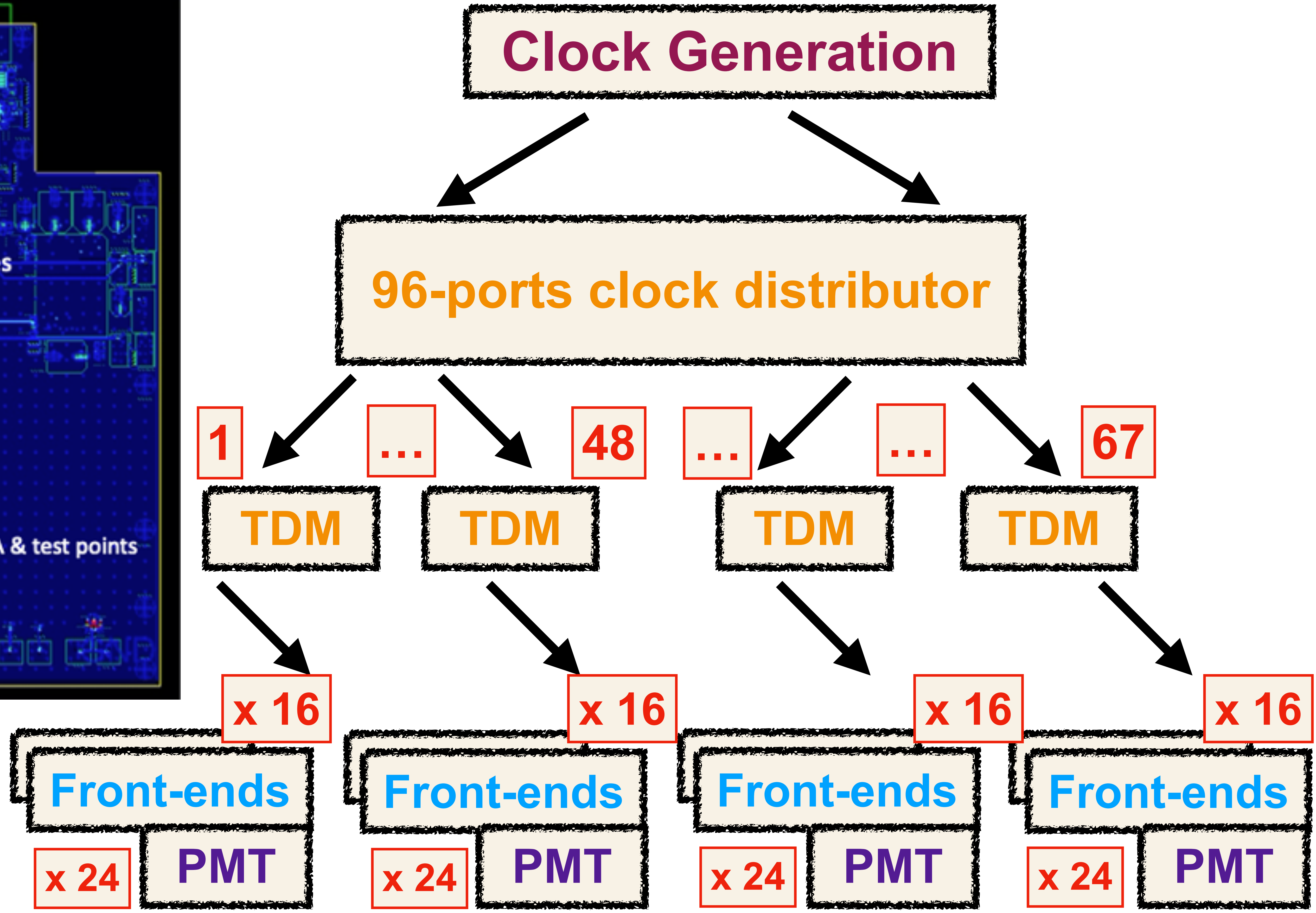
- 2 stages

- Electronic boards and cards are being designed and prototype

Two-stages distribution

TDM = Time division multiplexer





- 2 stages

- Electronic boards and cards are being designed and prototype

Undergoing tests in collaboration between French and Italian groups

Characterization of the proposed generation system

<u>Our proposed system</u> : **Why ?**

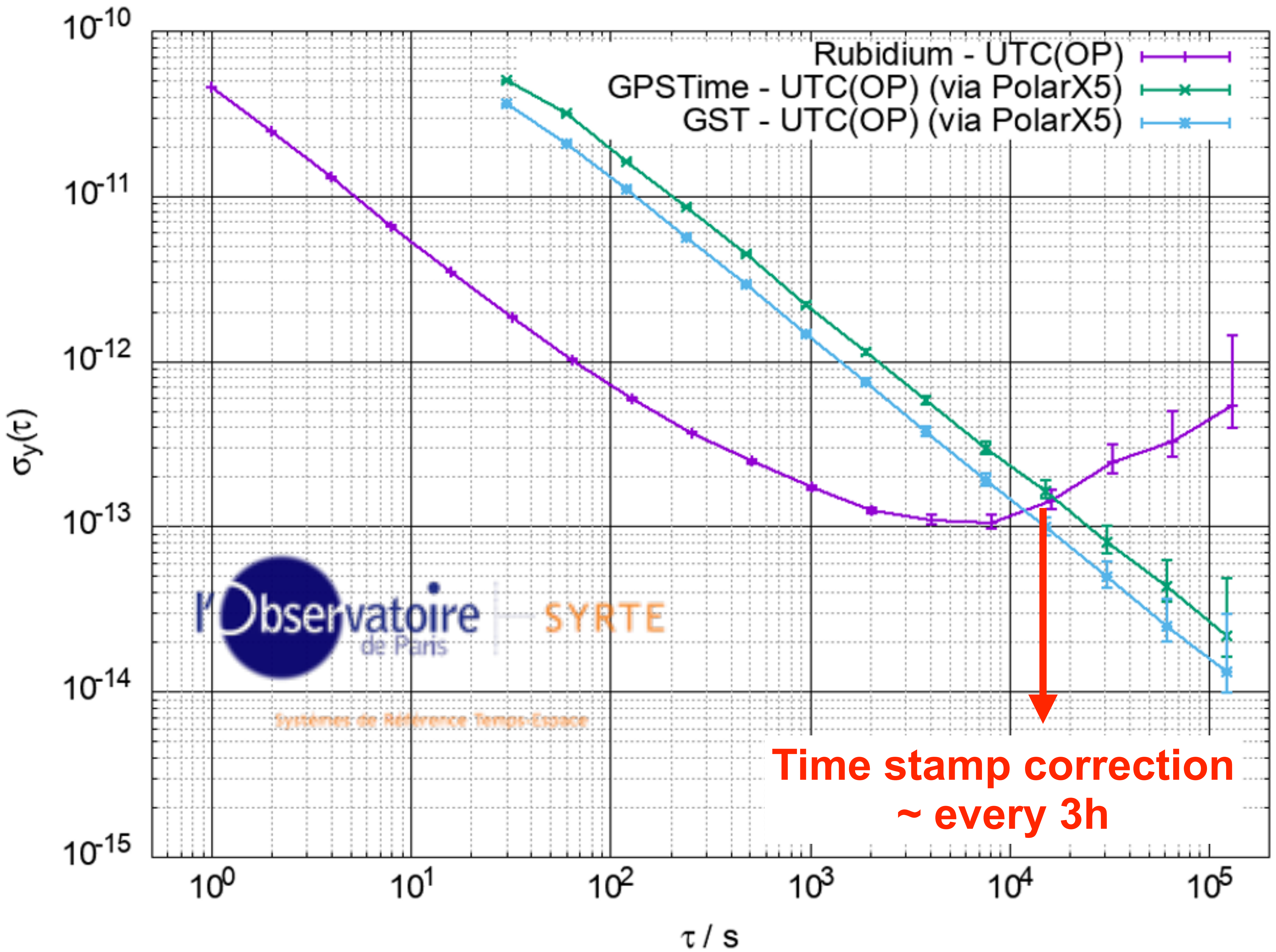
Atomic clock : the most stable at short term
- Tested a Rubidium clock
- Will test Passive Hydrogen Maser

GNSS signal : more stable at long term + link to UTC

Allan Standard Deviation (ASD) statistical tool :

$$\sigma_y^2(\tau) = \frac{1}{2} < (\bar{y}_{n+1} - \bar{y}_n)^2 >$$

Variance of Δt as a function of interval length : allows to separate noise types = visualize stability at various time scales



Purple curve : Rubidium clock stability (OP71 as reference)

Green curve : Received GPS time stability (OP71 as reference)

Blue curve : Received Galileo time stability (OP71 as reference)

Set-up for tests @ LPNHE

How to test the stability of a frequency ?

➡ Against a much more stable reference signal

➡Data : Δt between each signal at each pulse

Antenna output

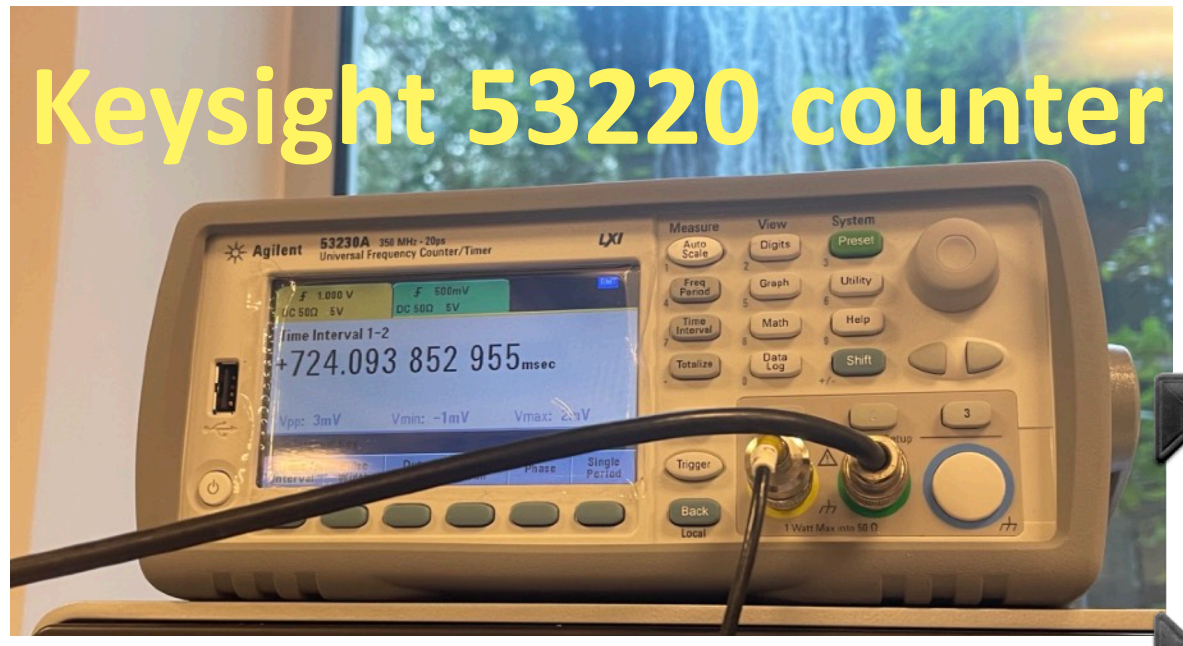
PPS

10 MHz

CGGTTS files :

- Infos on satellites
- All info on applied corrections
- …
- Time difference between input and GPS time in 0.1 ns

Δt



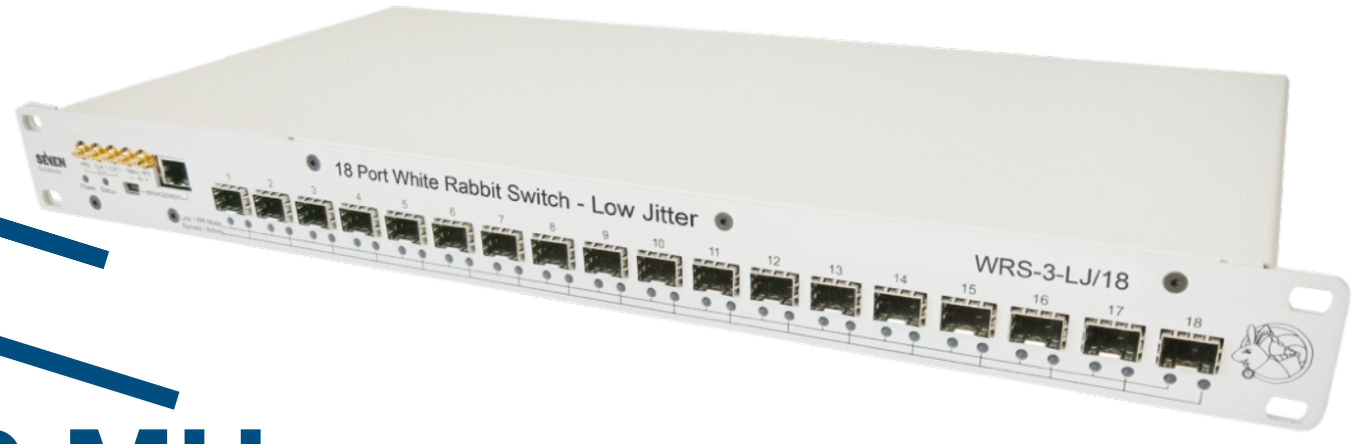
Δt

For other comparison

One or the other

PPS

10 MHz

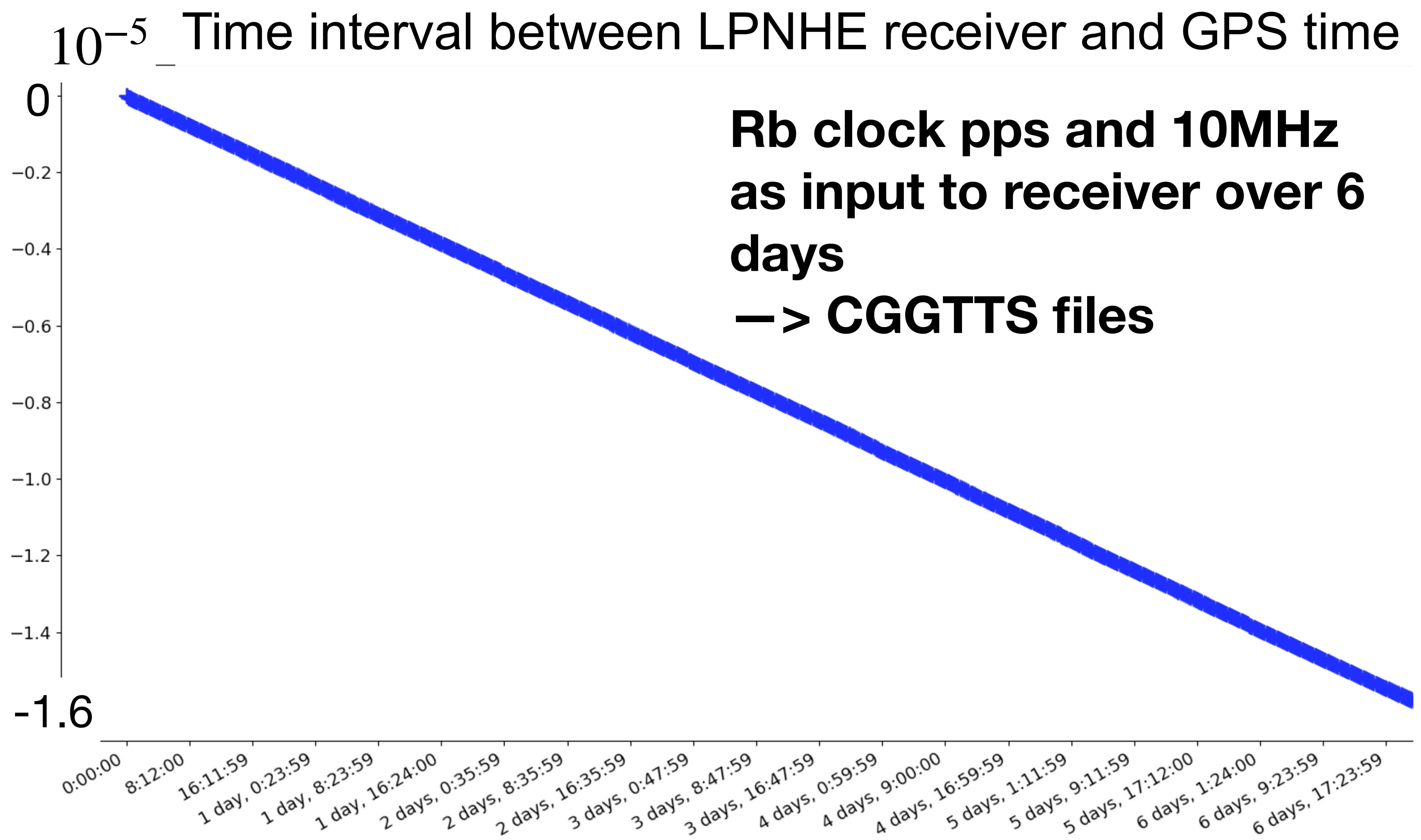


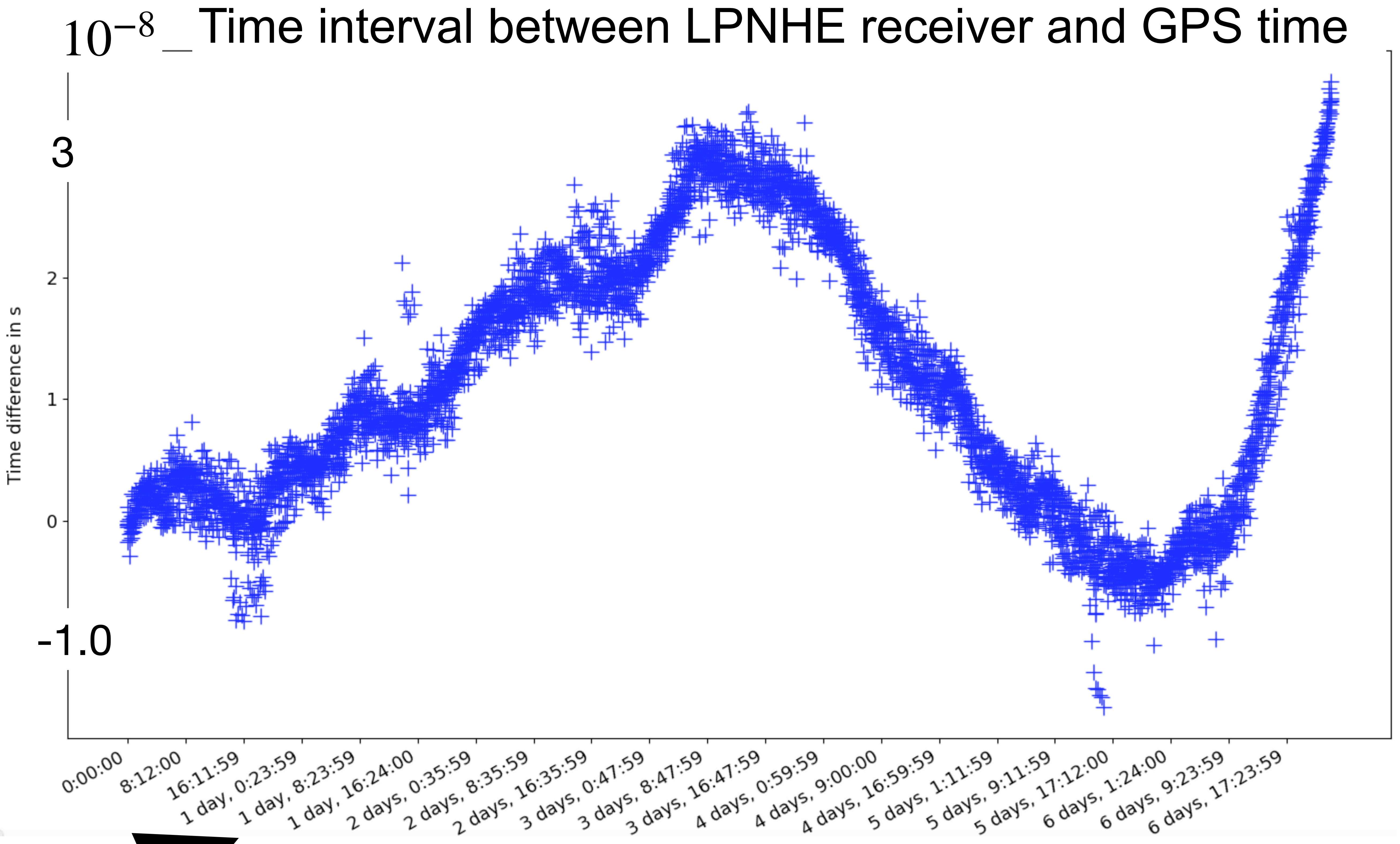
OP71 calibrated signal through optical fiber from :

l'Observatoire de Paris SYRTE Systèmes de Référence Temps-Espace

Characterization of our solution

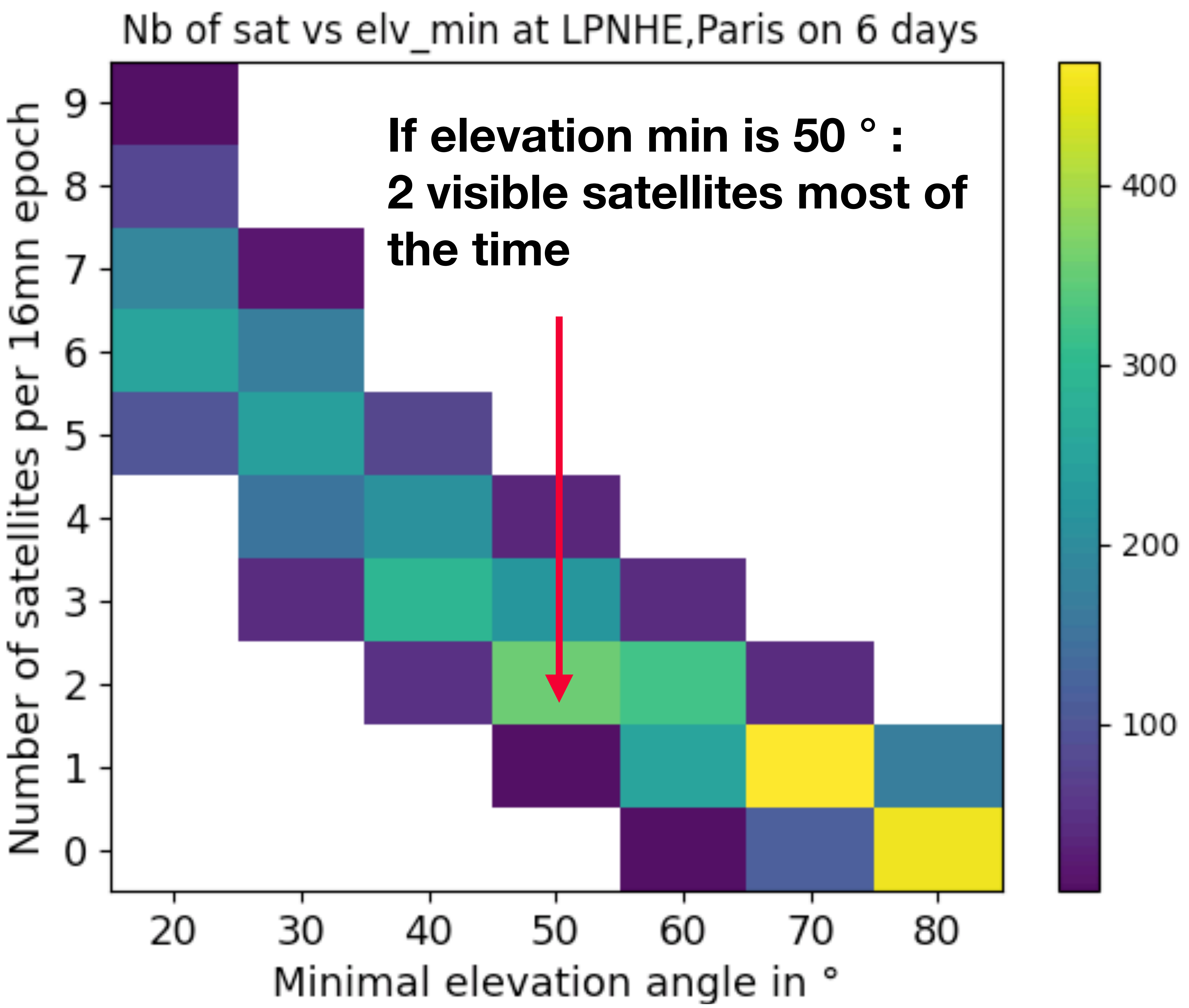
- Cross checks to find same performances as @ SYRTE
- Test of the proposed set-up : Rb clock as an input to the receiver

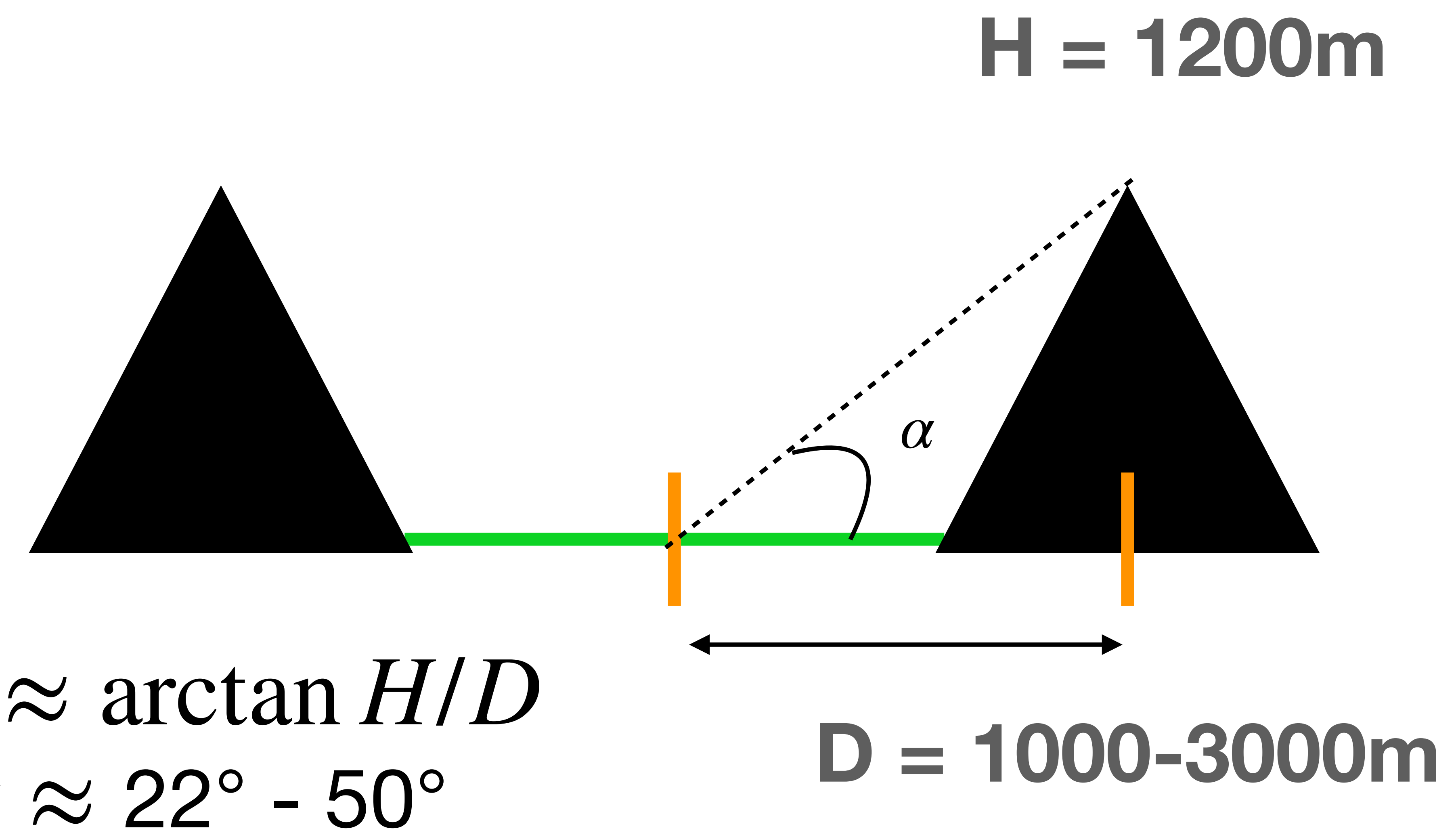




Remove linear drift over time = deterministic noise of the clock

Characterization of our solution





$\alpha \approx \arctan H/D$

$\alpha \approx 22° - 50°$

The system has to be robust against :

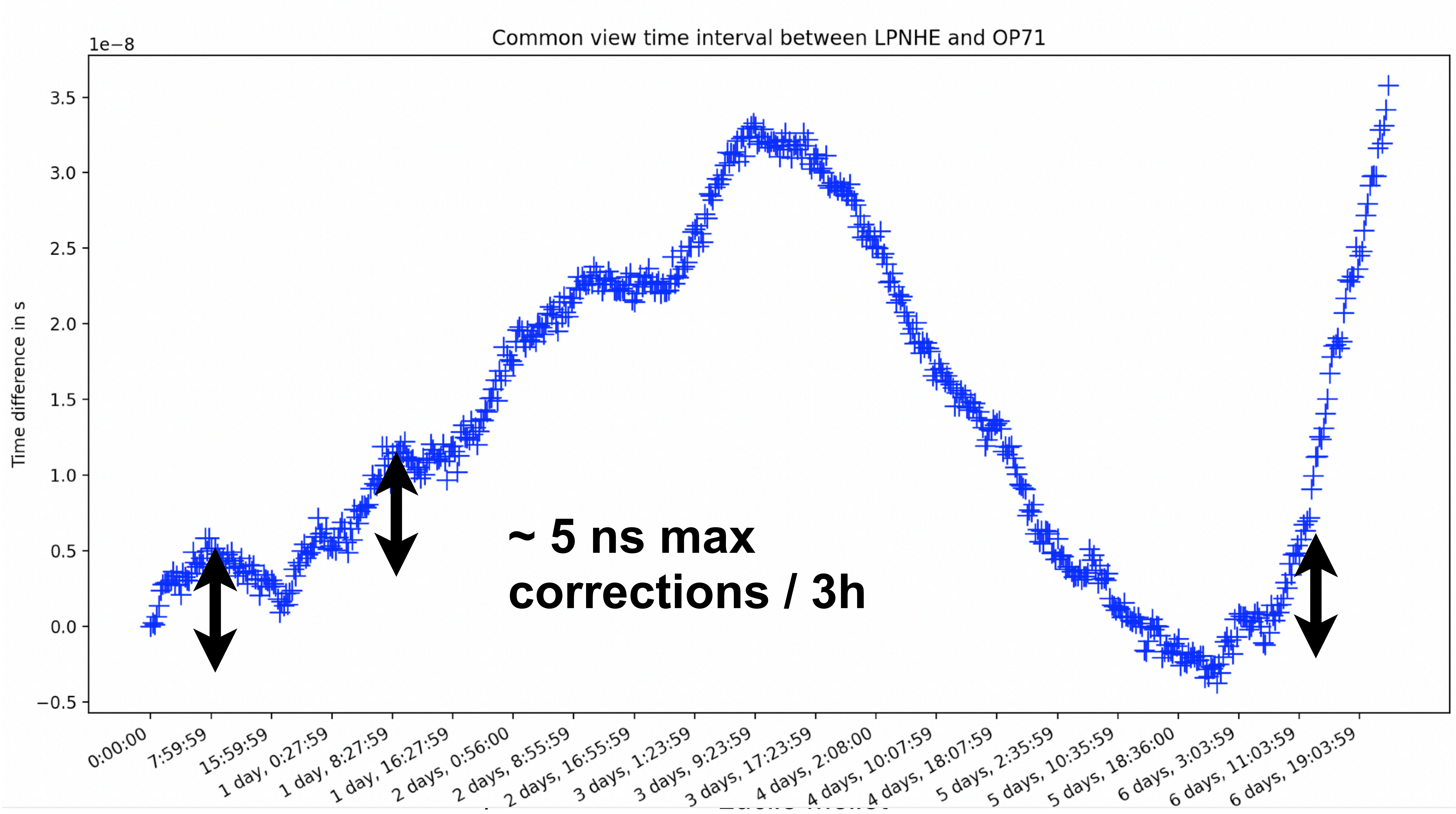
- Power outage → reboot procedure + calibration
- Limited nb of visible satellites (mountain area)

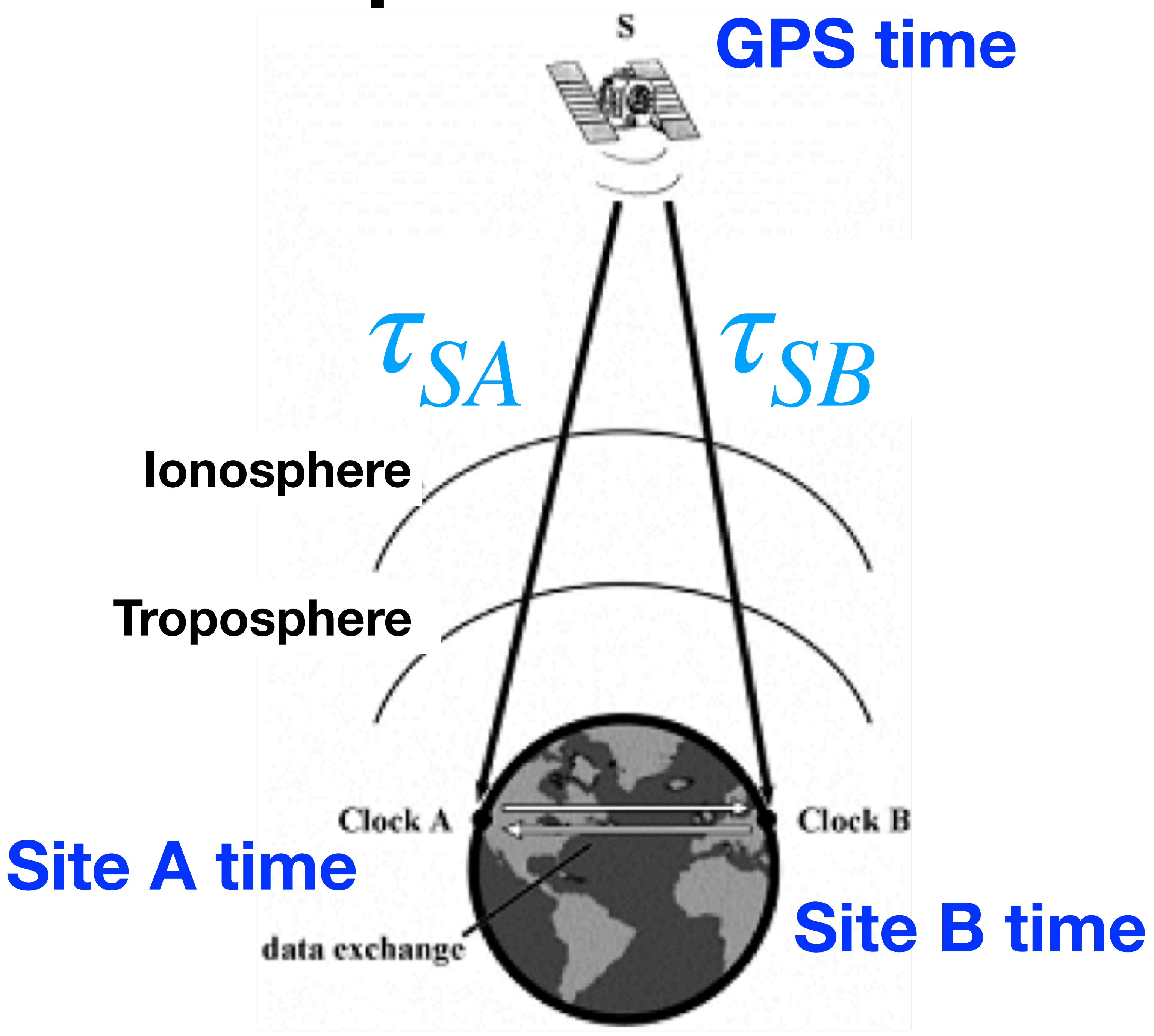
Common view Time transfer technique

How to obtain UTC time tags / corrections ?

Site A CGGTTS data : GPS Time – SiteA Time = $\Delta t_{GPS-A} = \tau_{SA}$
Site B CGGTTS data : GPS Time – SiteB Time = $\Delta t_{GPS-B} = \tau_{SB}$
Time transfer software computes $\tau_{SA} - \tau_{SB}$

If site B is the reference time keeper : → $\tau_{SA} - \tau_{SB} = \Delta t_{siteA}$ **wrt UTC (local)**





Last step of the process

Need tests and simulation to optimize the applied correction

Hyper-Kamiokande

Conclusion

- R&D has been happening for 2.5 years, almost final

- Internal HK reviews ongoing, choice this year

- Collaboration between at least 4 different groups
- Great synergy between the 2 items : digitizer and time distribution

- So far, everything seems to meet and exceed HK's requirements
    - Increase physics possibilities