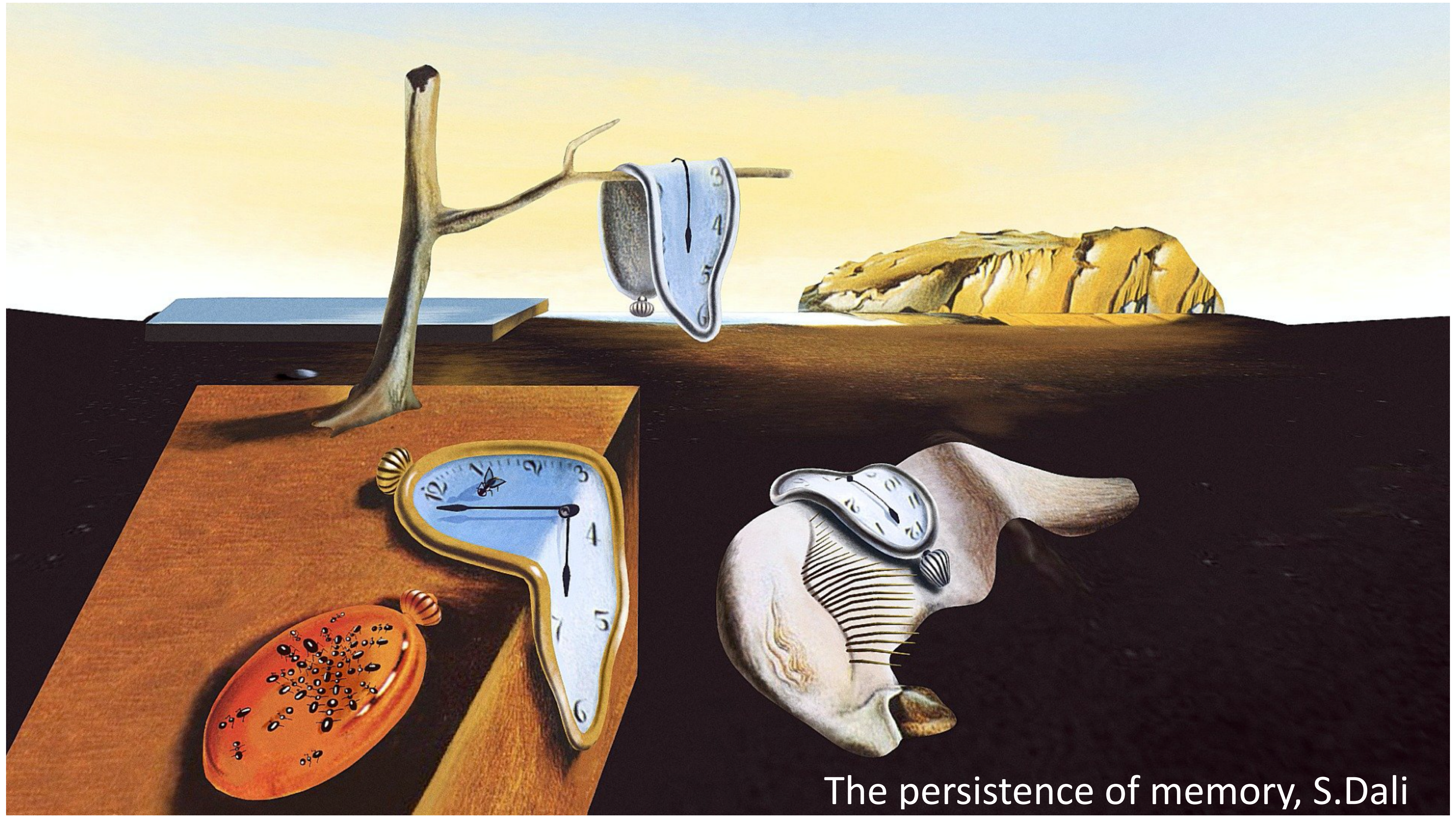
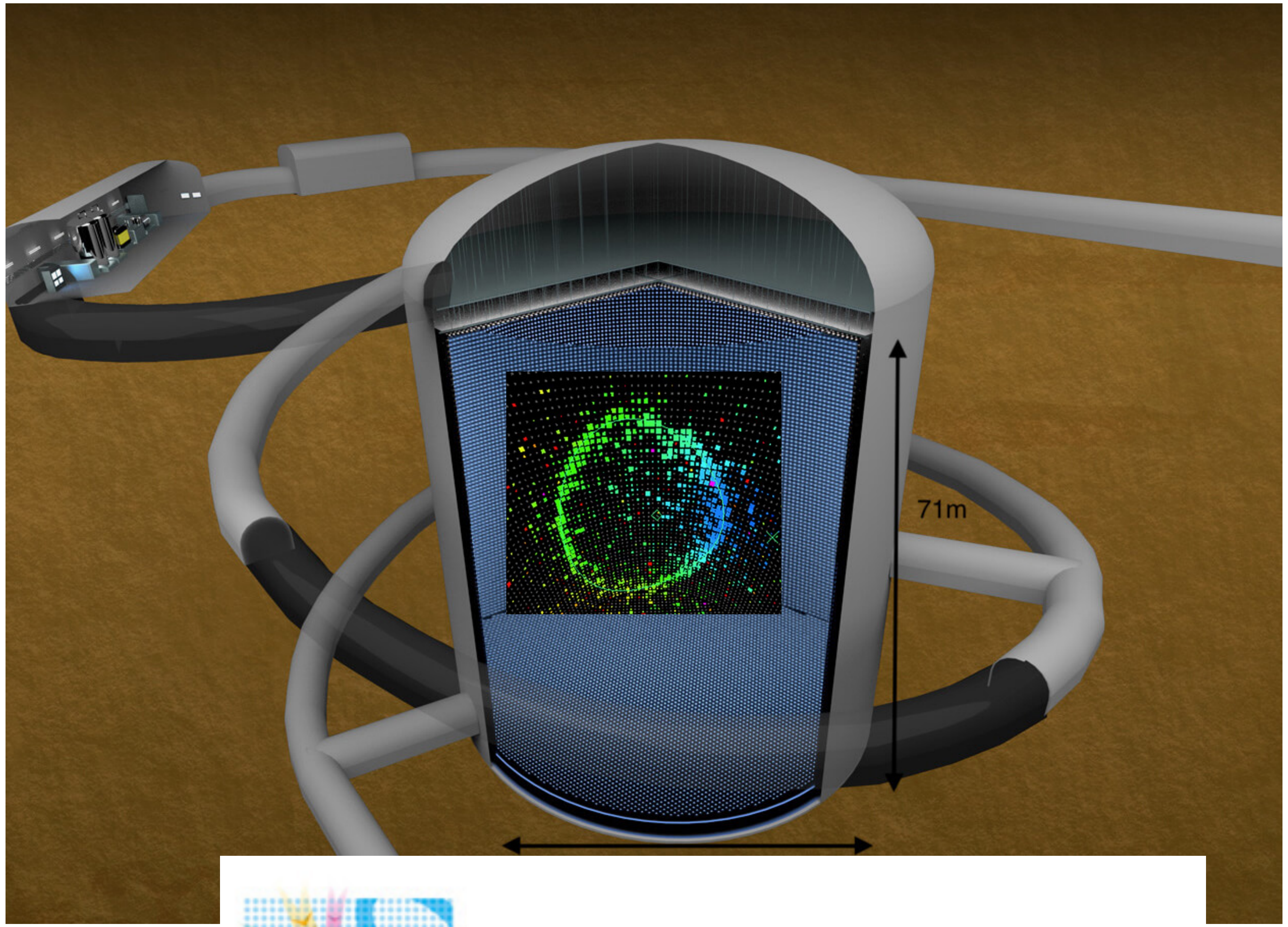
Time generation and clock distribution for Hyper-Kamiokande

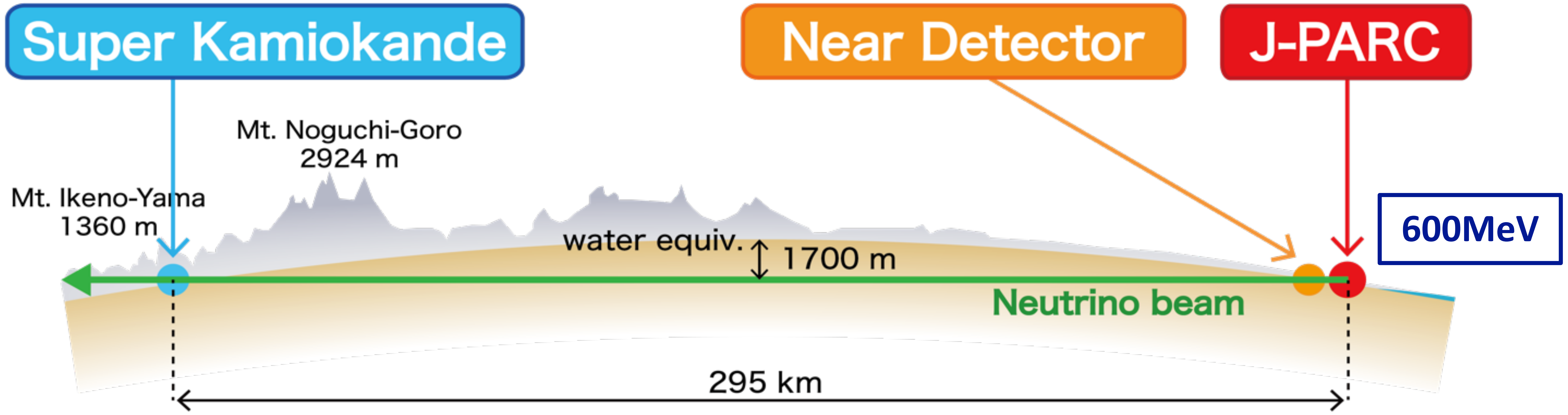

The persistence of memory, S.Dali

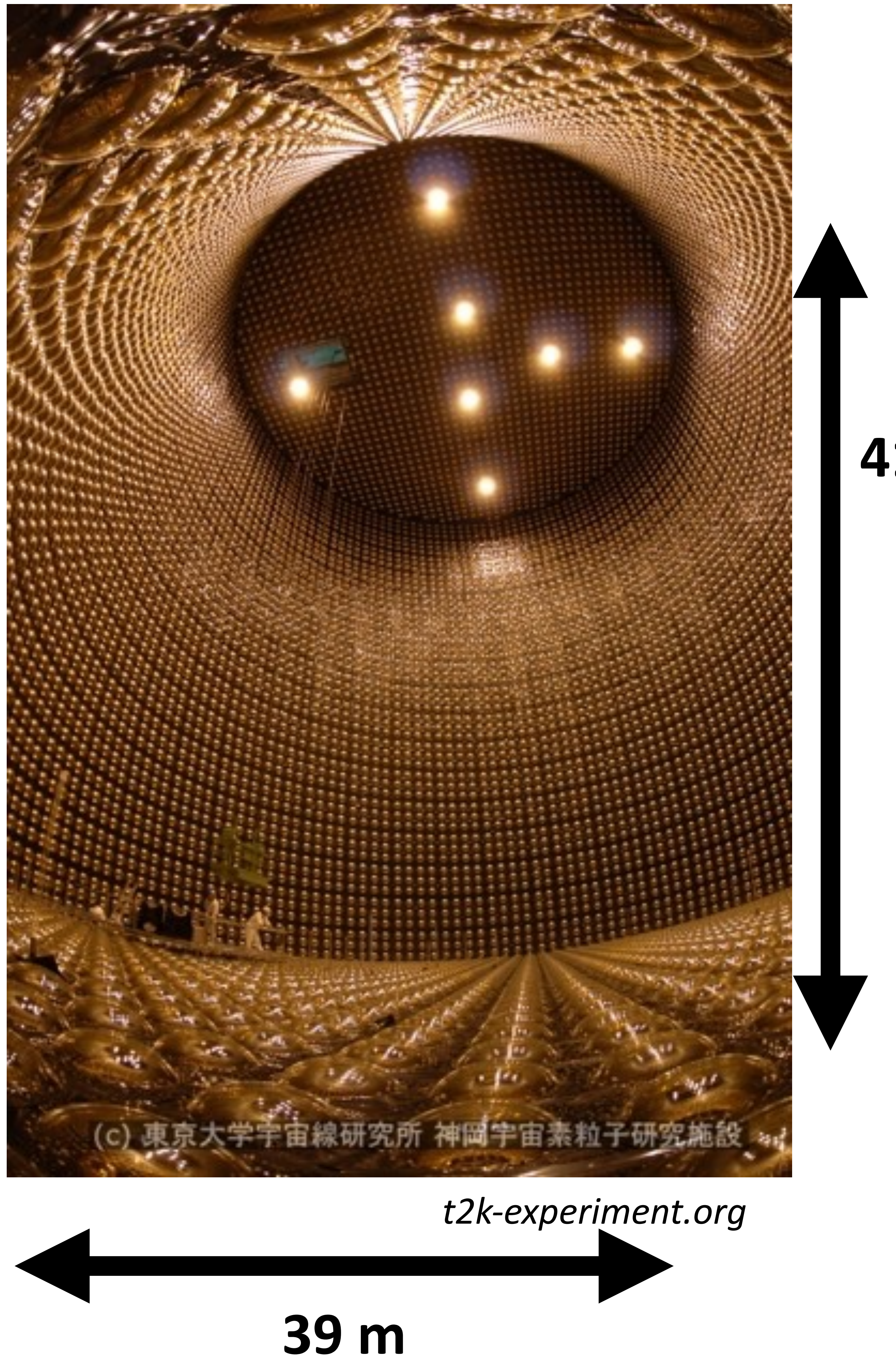


Lucile Mellet on behalf of electronics working group of the Hyper-Kamiokande collaboration

NuFact 2022

Japanese long baseline neutrino program : From T2K …

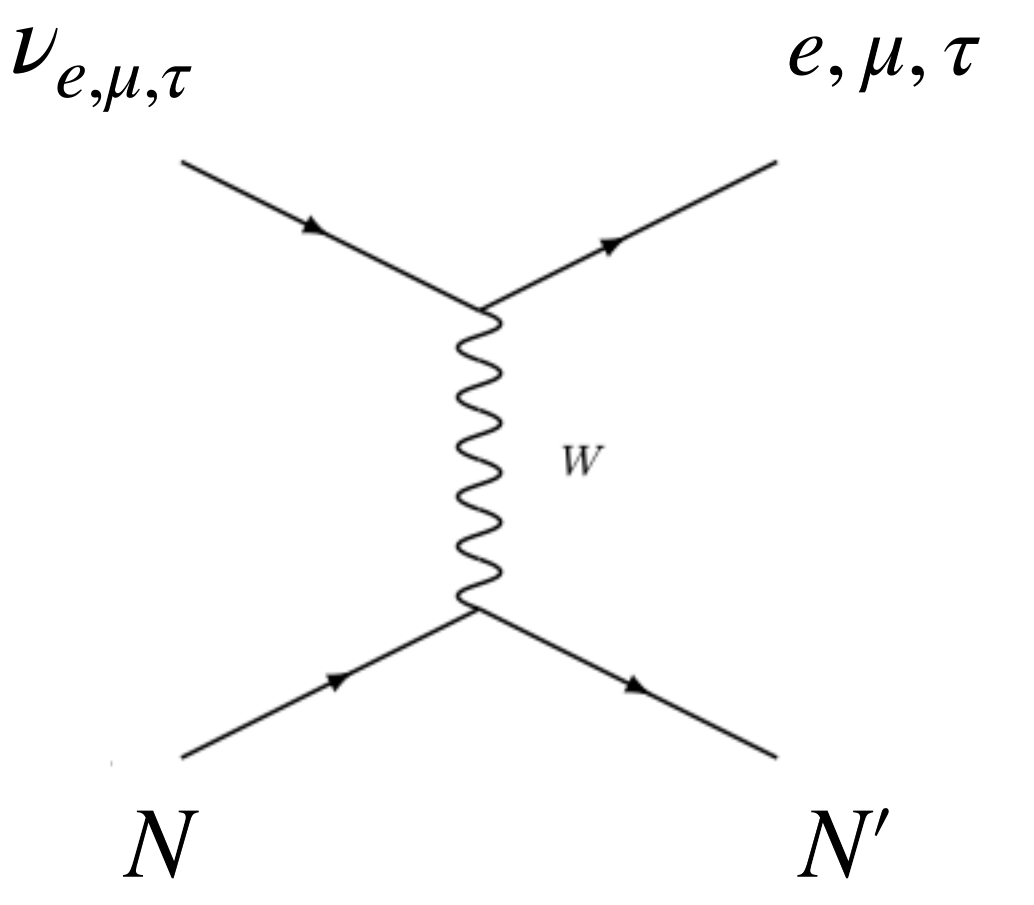




t2k-experiment.org

- Long baseline ν oscillation experiment
- Off-axis water Cherenkov detector
  - 50 kTons of ultra-pure water (+ Gd)
  - 11000 photo-multiplier tubes (PMT) (+ OD)

- Indirect detection : outgoing lepton
- Signal coincidence : ring reconstruction

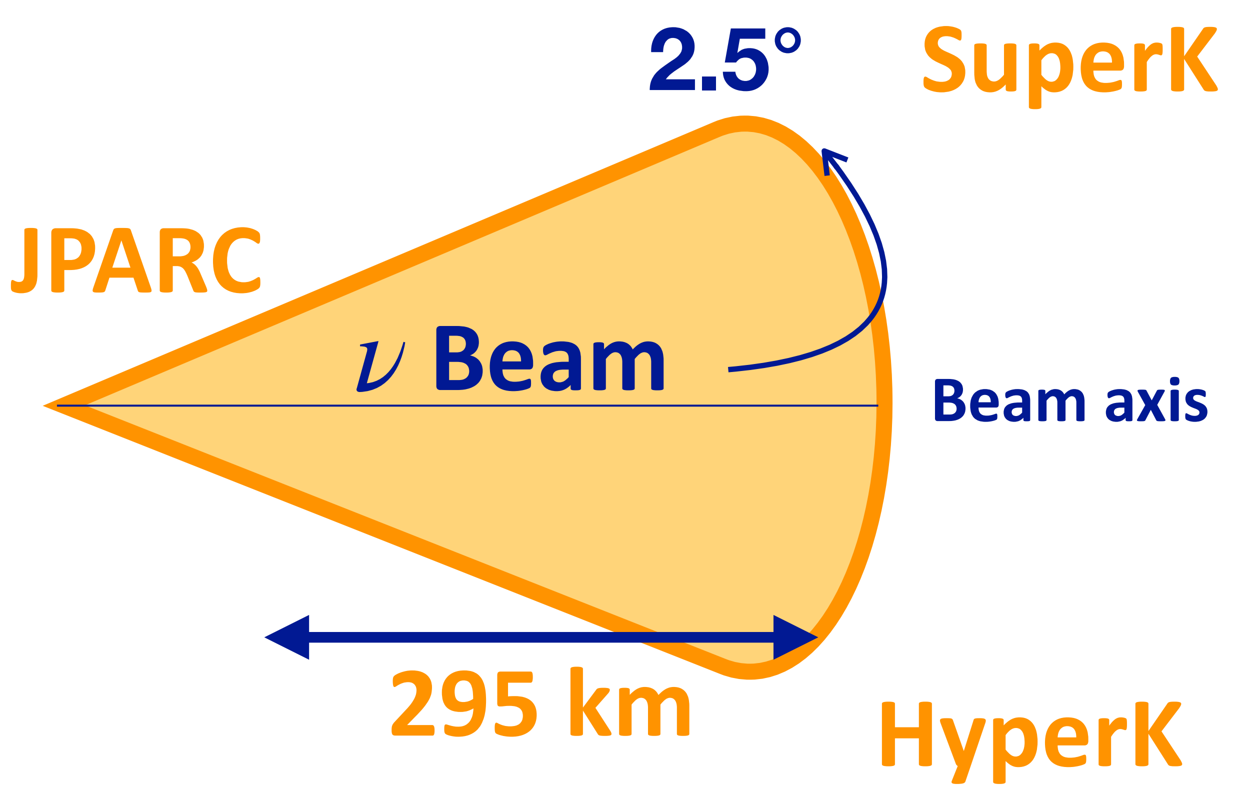


Main interaction : Charged current quasi elastic (CCQE)

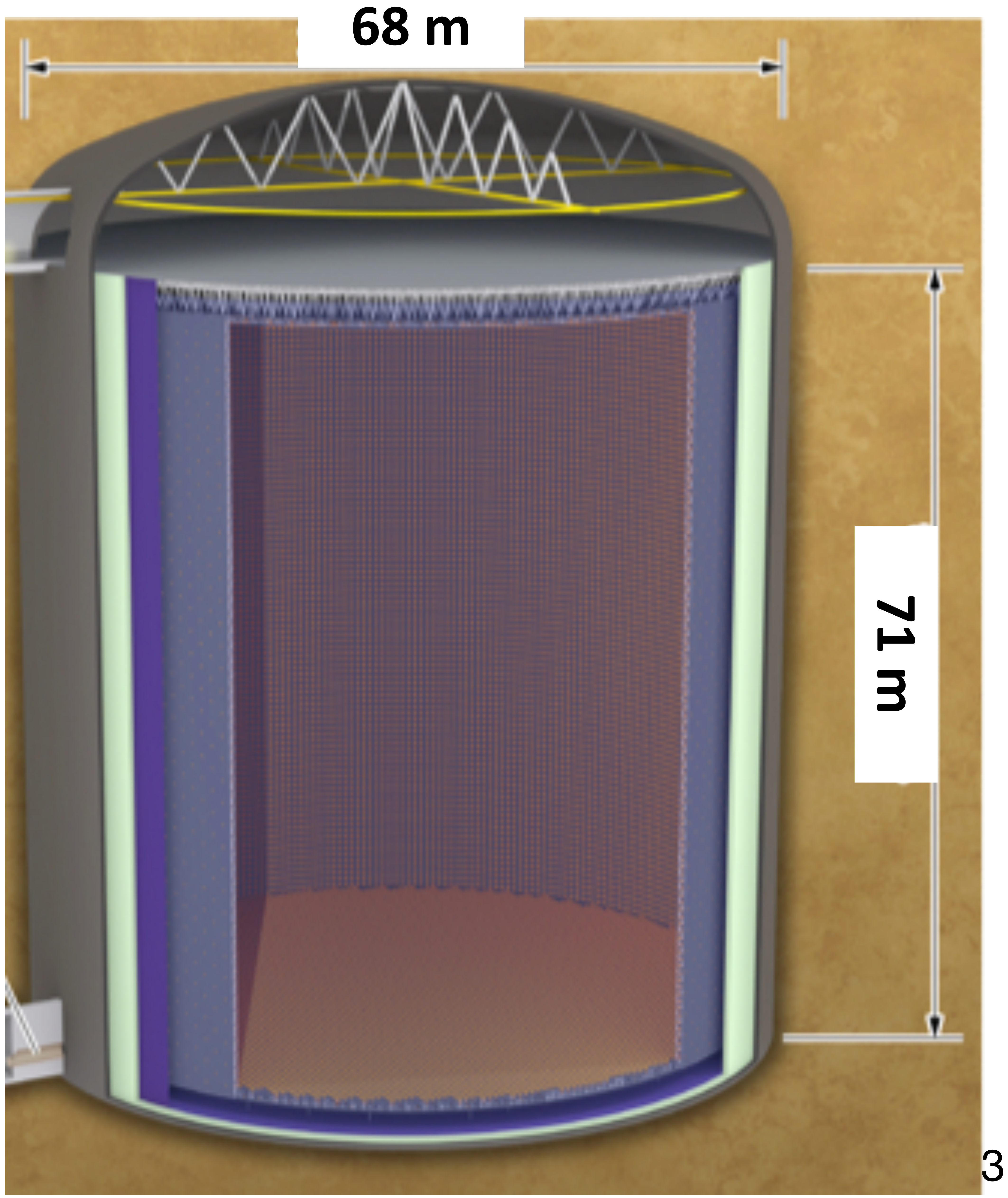
Hyper-Kamiokande

Japanese long baseline neutrino program : … to HK

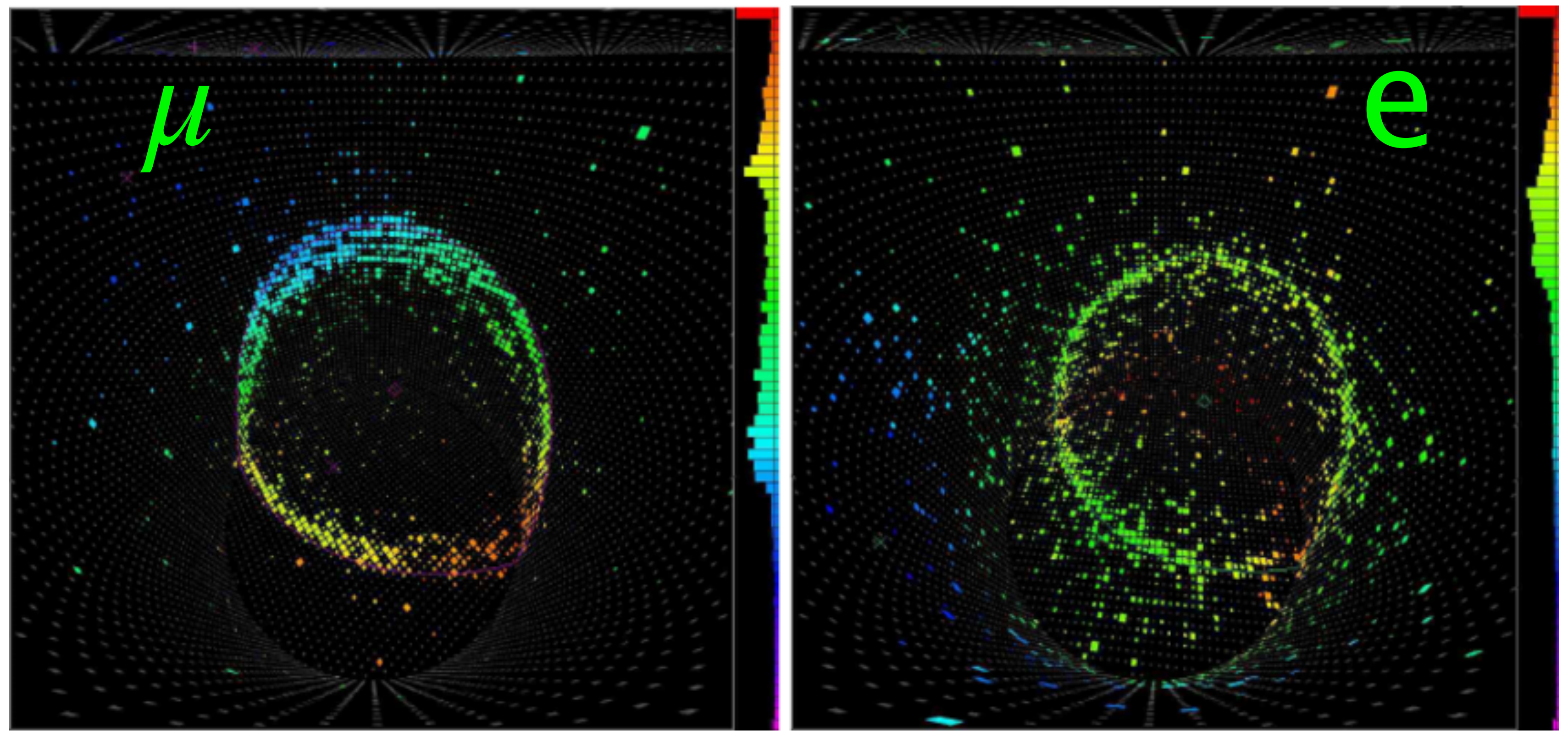
- Beam upgrade (500kW →1.3MW)
- Near detector upgrade
- **Hyper-Kamiokande new far detector**



- Data taking planned for 2027
- Tank ~ x5 larger (50ktons→ 260 ktons)
- Joint analysis with atmospheric ν
- New Photo-Multipliers (PMTs)
- New timing system

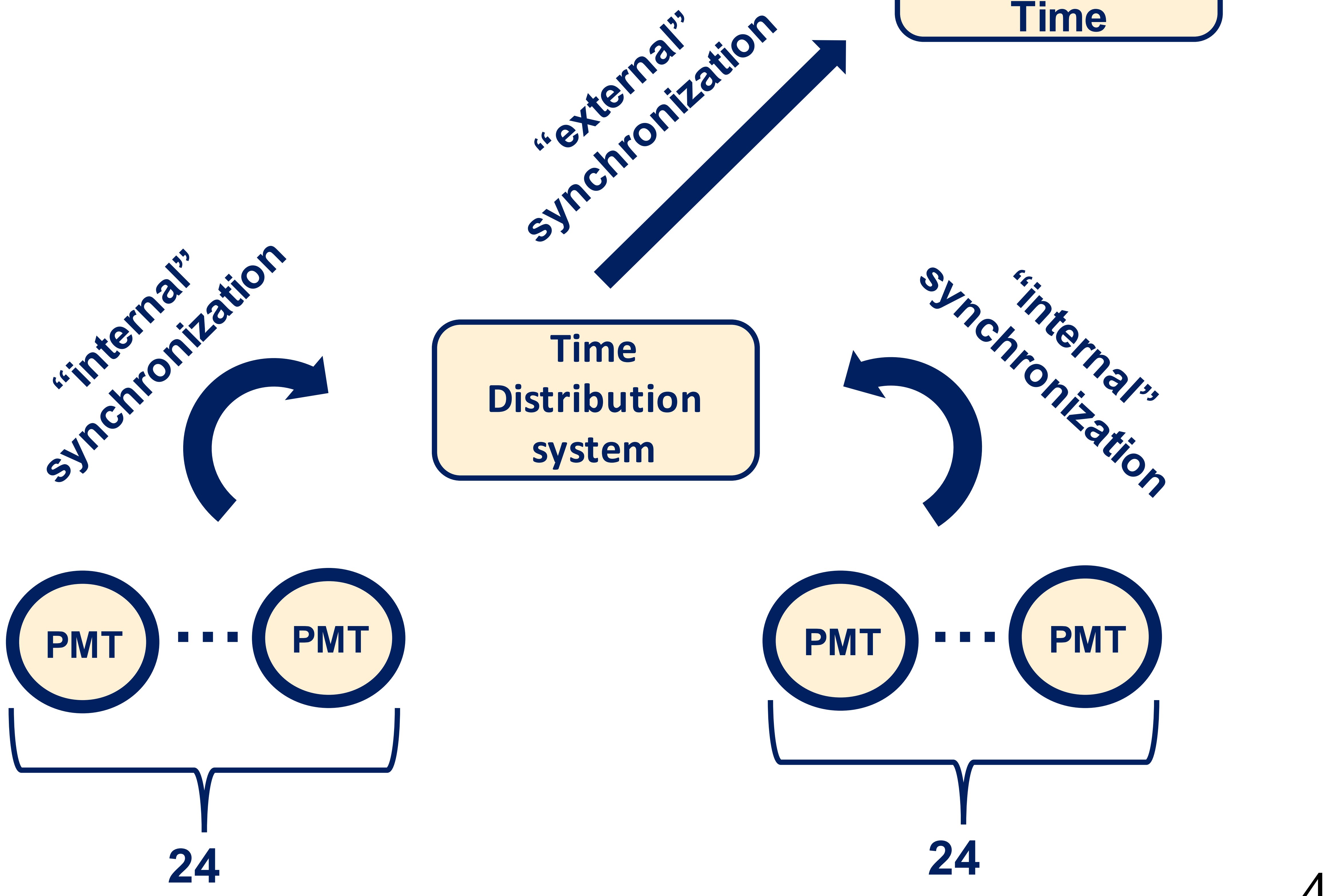


Needs and requirement in terms of timing



- Data : PMTs signal —> coincidence —> reconstruction and identification of Cherenkov ring patterns
  ➡ **Internal synchronization** with a stability < 100 ps. (Inter-channel)

- Beam bunches (+ astrophysical events)
  ➡ **External synchronization** with UTC monitored within 100 ns at least



Currently in an R&D phase

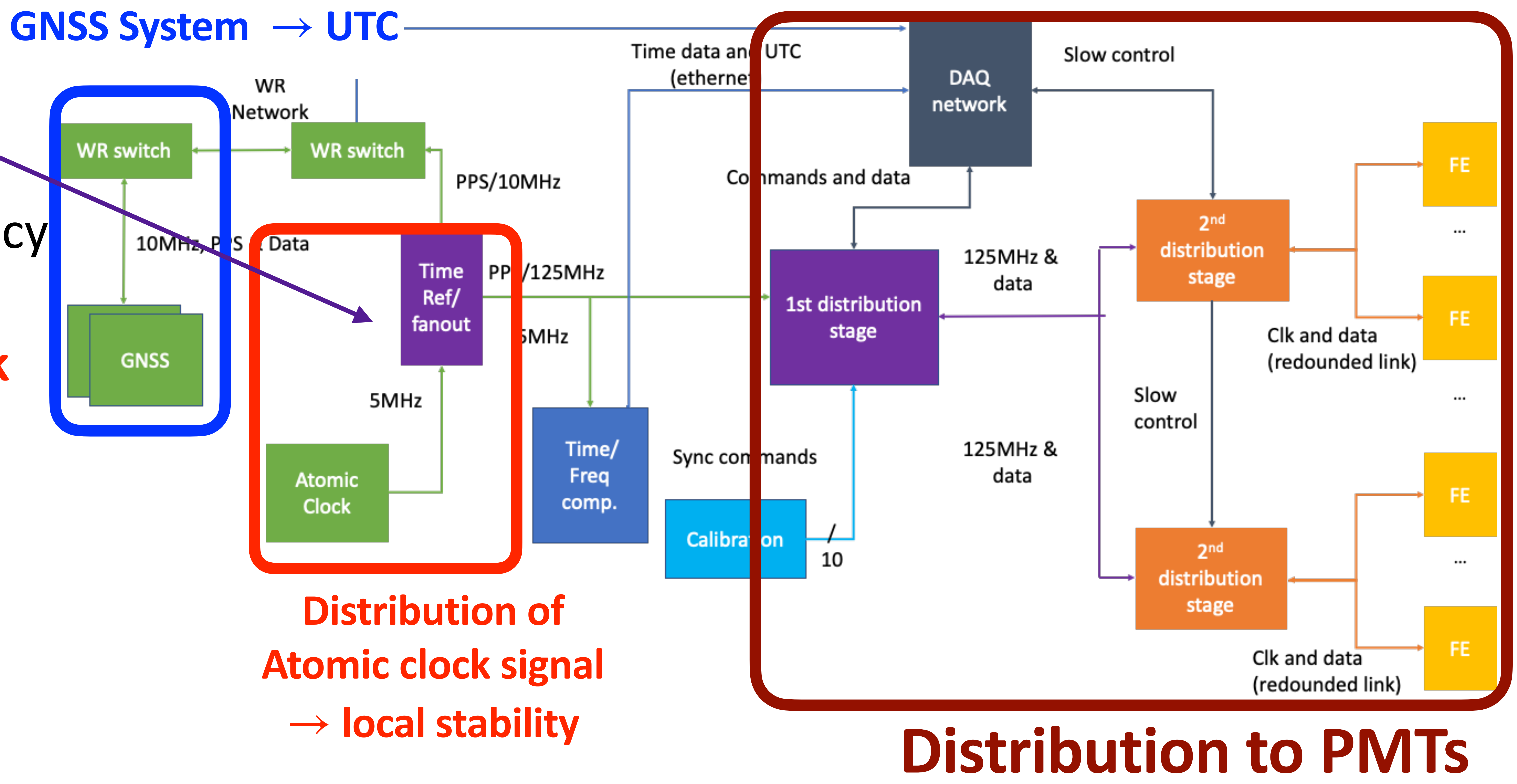
Our proposed solution

- 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

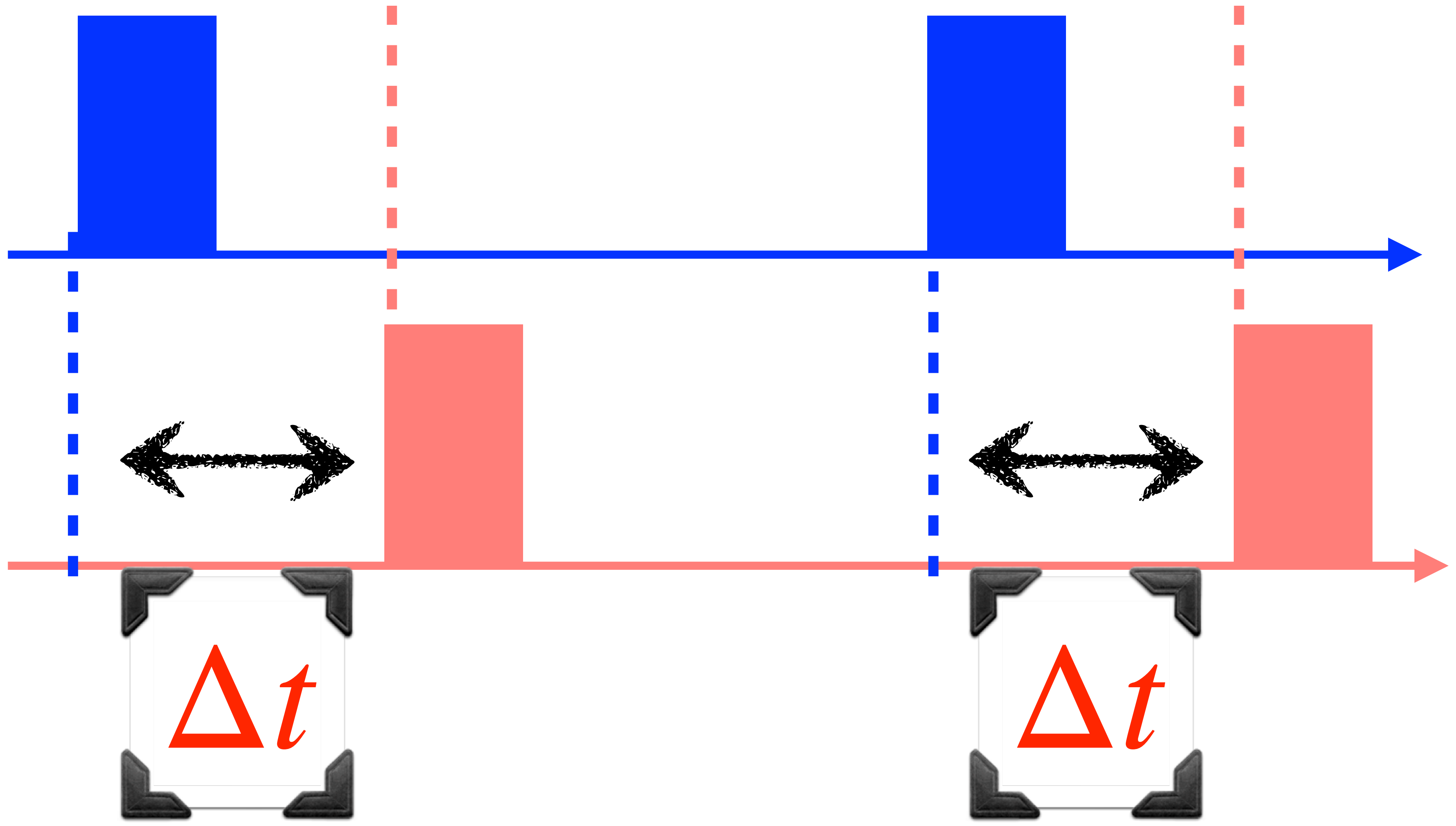
+ Redundancy



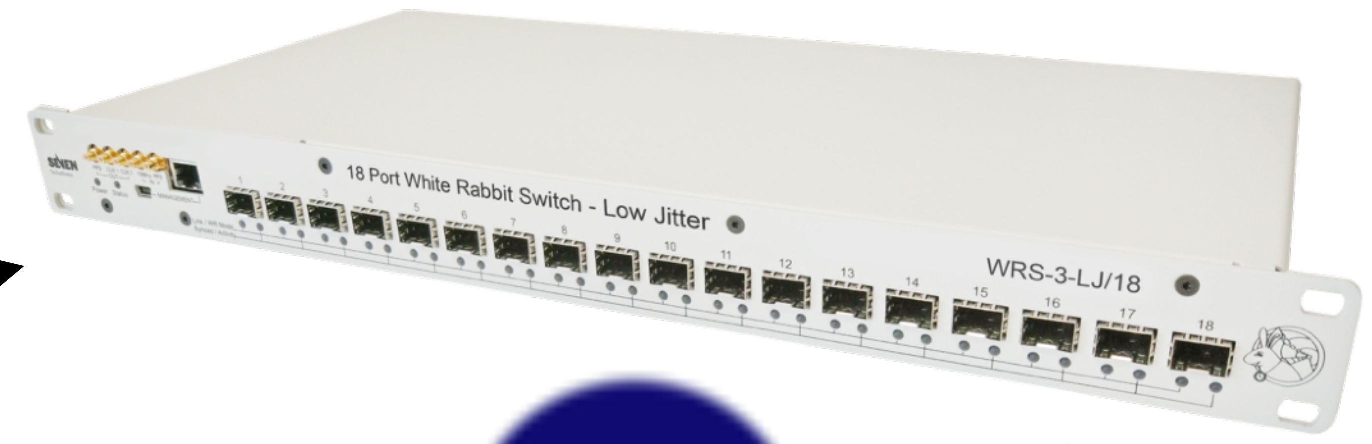
GNSS = GPS + other satellite constellations

How to measure a frequency stability ?

- Always against a more stable reference, no absolute independent measurement
- Data : Δt between ref pulse and *freq under test* pulse
- Stability = evolution of Δt over time



- What reference signal do we have ?
  - SYRTE : time keeping lab for France, very stable clock defining « UTC OP »
  - @LPNHE : UTC OP signal through optic link (White Rabbit protocol)
  - When using GNSS : GPS time, reference lab



l'Observatoire de Paris SYRTE

Systèmes de Référence Temps-Espace

Motivation for the proposed generation system

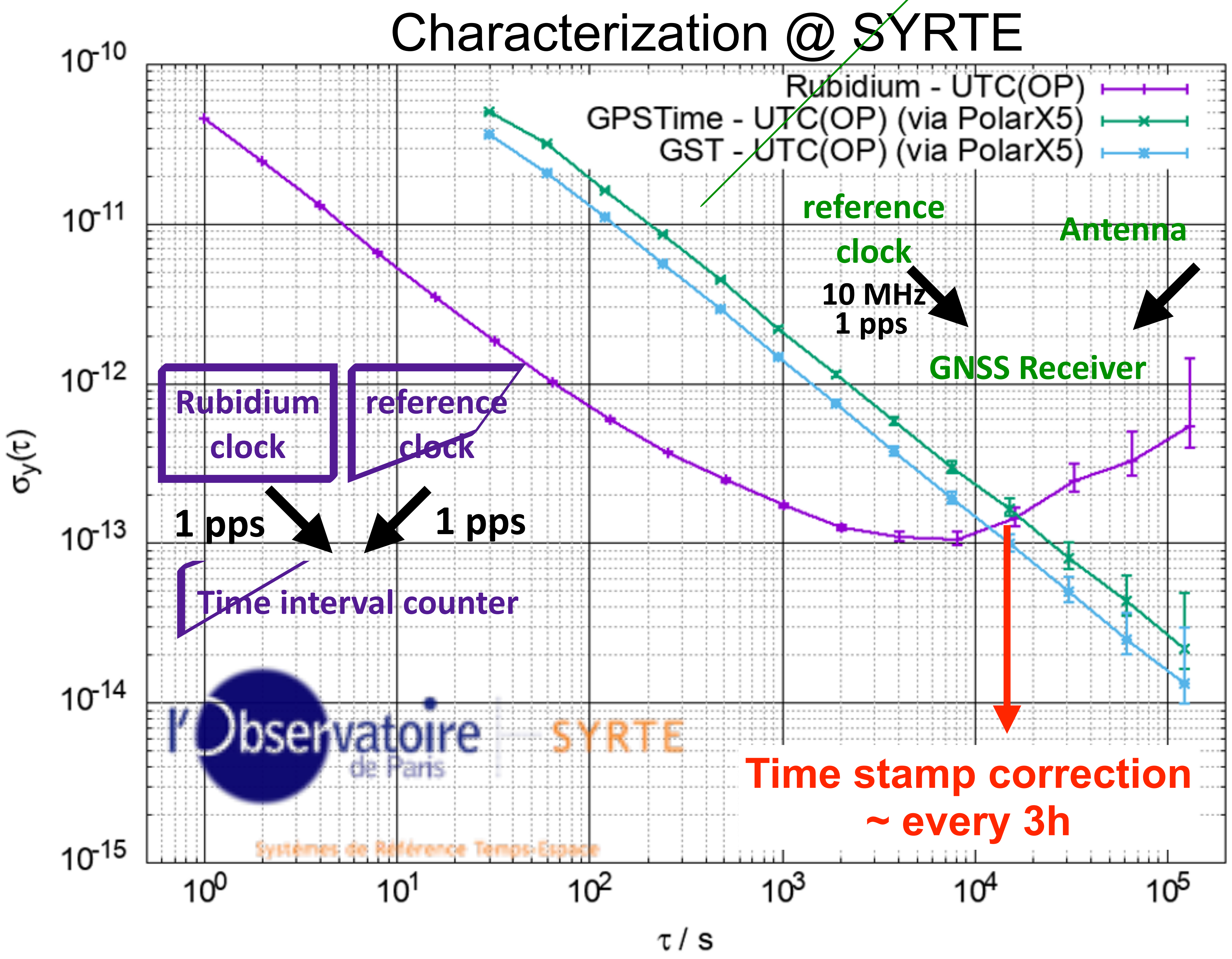
- Atomic clock : the most stable at short term
  - Tested a Rubidium clock (SRS FS725)
  - Will test Passive Hydrogen Maser (T4 Science pHM VCH-1008)

- 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 (UTC OP as reference)

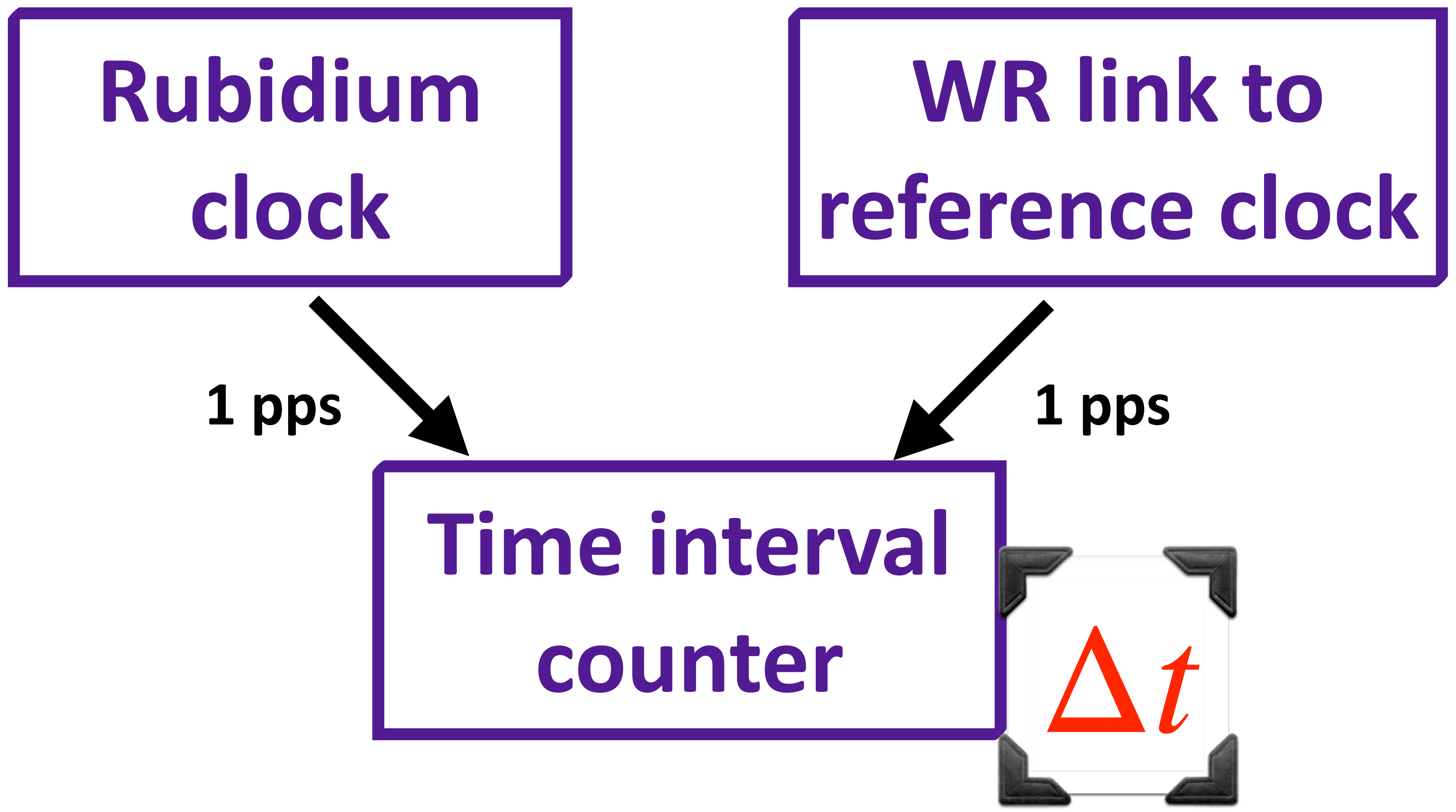
Green curve : Received GPS time stability (UTC OP as reference)

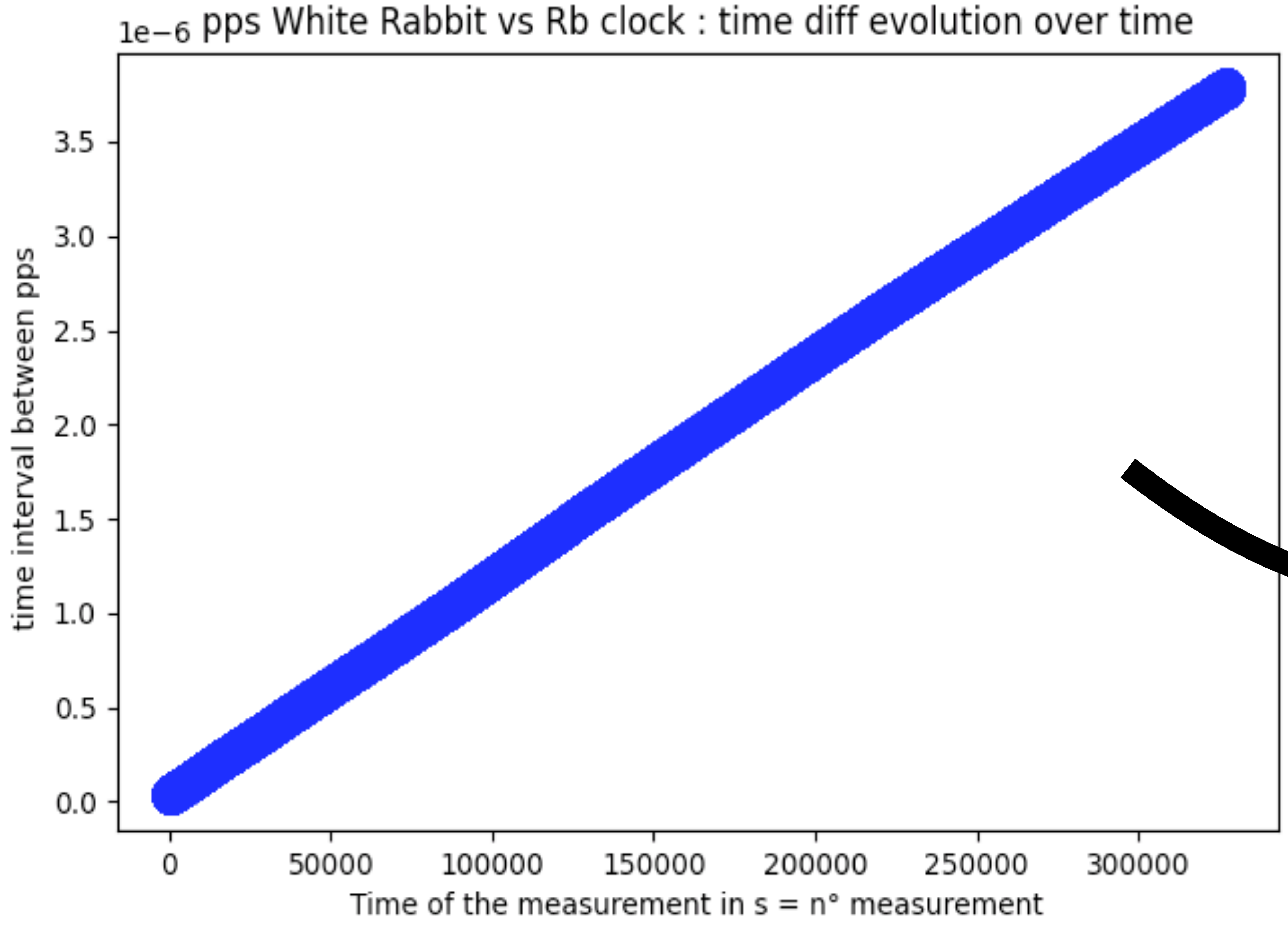
Blue curve : Received Galileo time stability (UTC OP as reference)

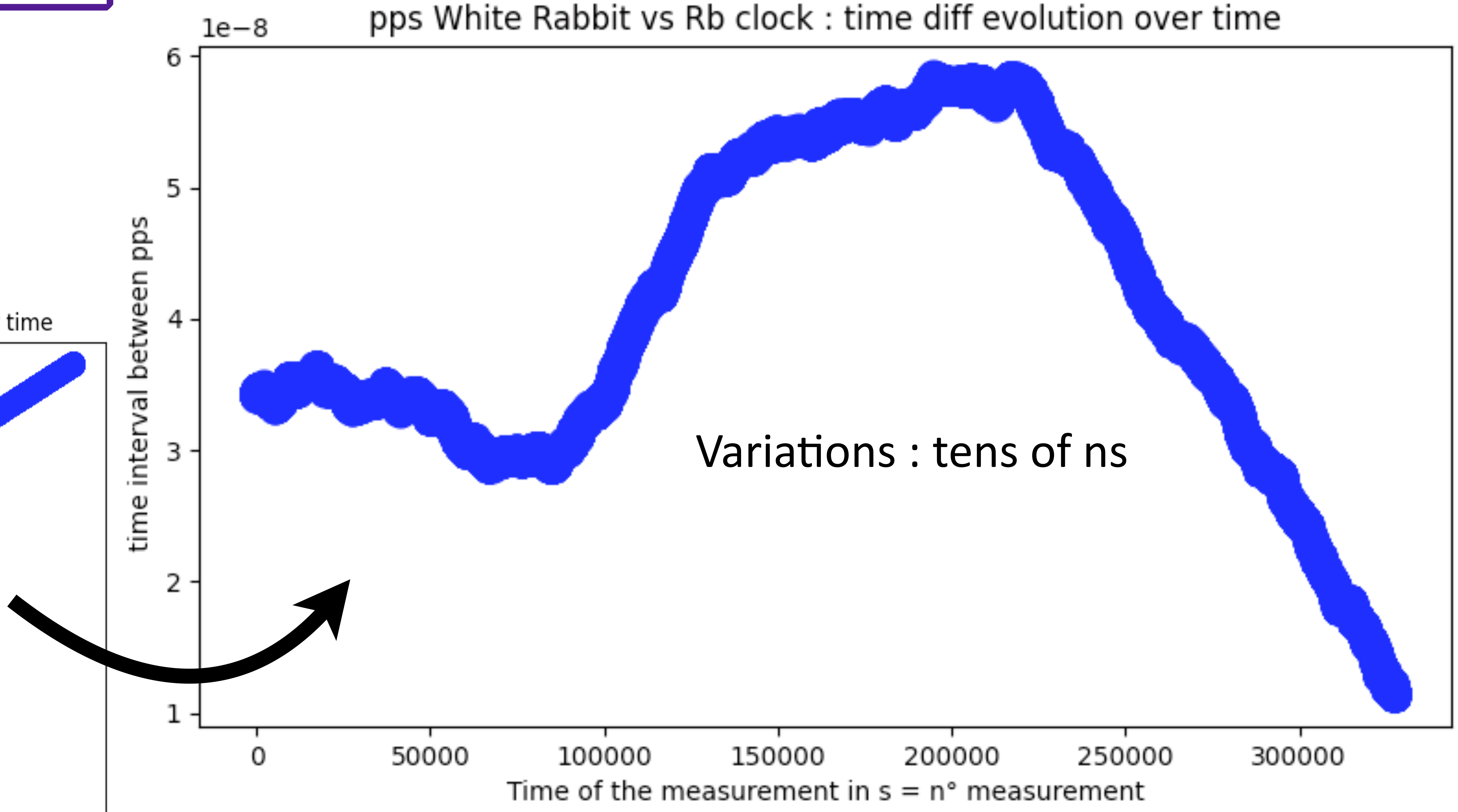
Characterization of the rubidium clock

1 pps : 1 pulse per second signal

Temperature stable over measurement







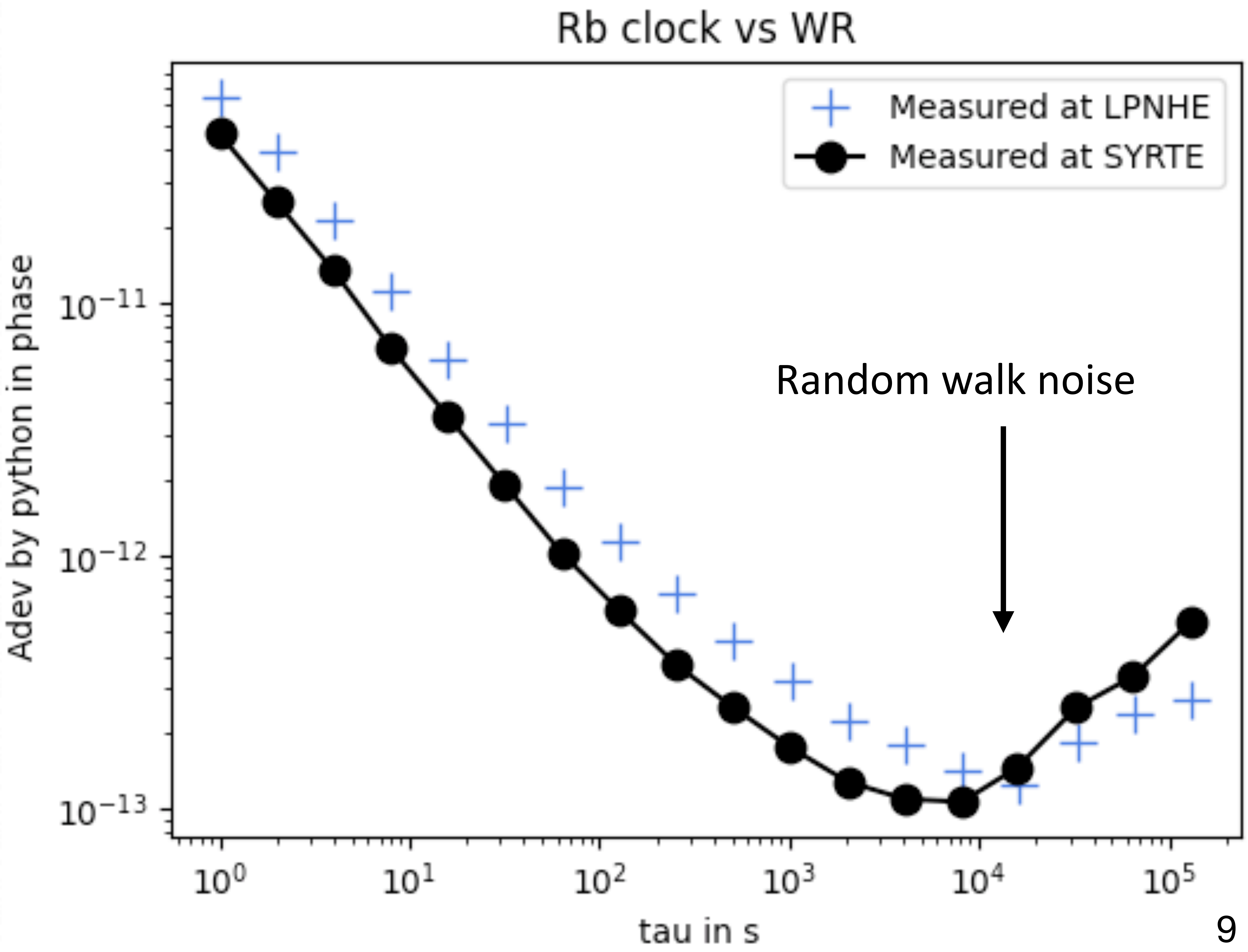
Remove linear drift = deterministic clock noise

Characterization of the rubidium clock

Rubidium clock → 1 pps → **Time interval counter** ← 1 pps ← **WR link to reference clock**

Δt

1 pps : 1 pulse per second signal



SRS FS725 clock

Input/Output of a GNSS receiver

Antenna output

CGGTTS files * :

- **Name of satellite**
- **Elevation of satellite**
- **Starting date and time of tracking**
- **All info on applied atmospheric delays**
- **Ephemeris used for correction**
- **Other receiver info band, channel, ...)**
- **Time difference between input and GPS time in 0.1 ns**

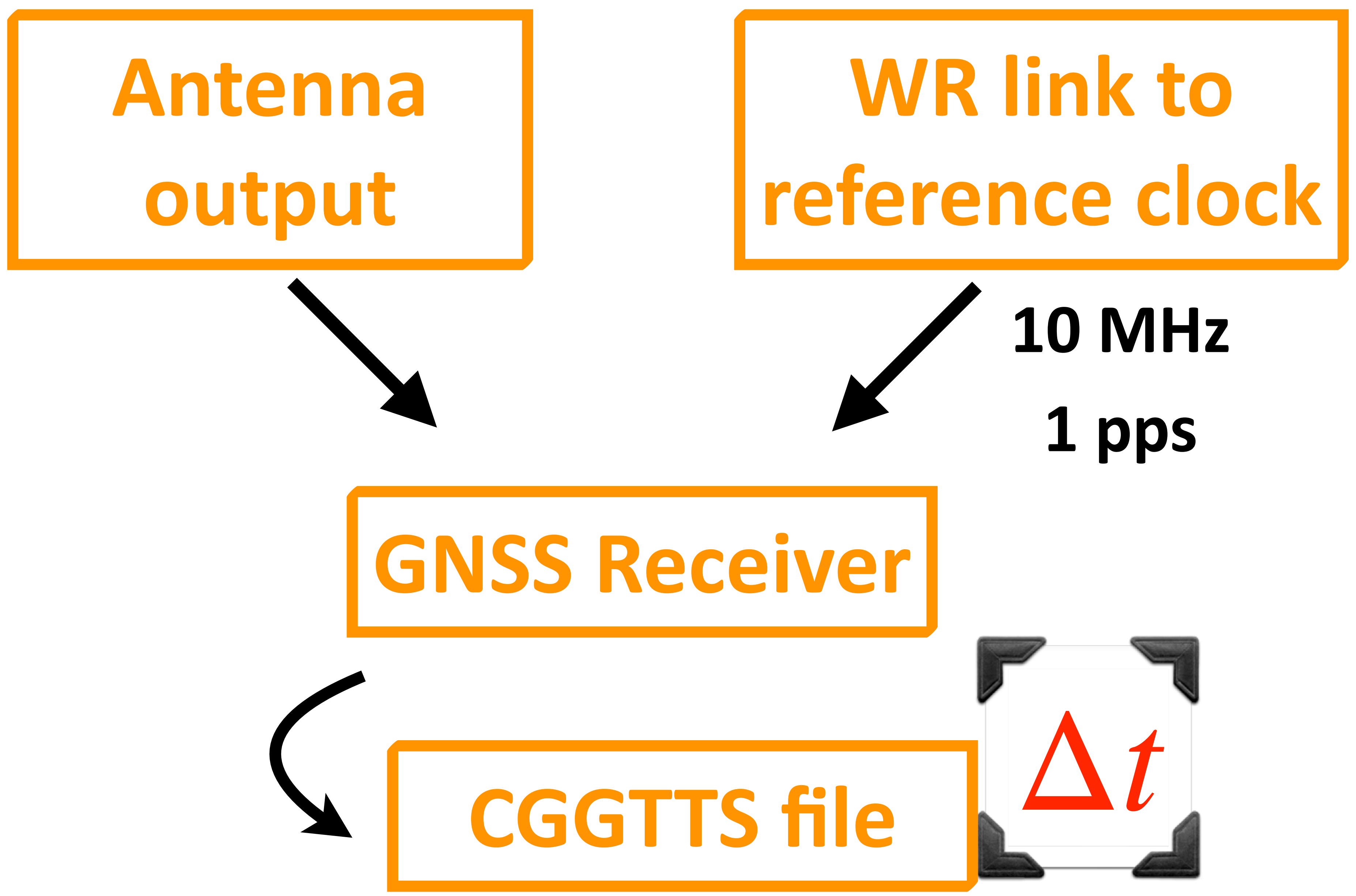
Δt

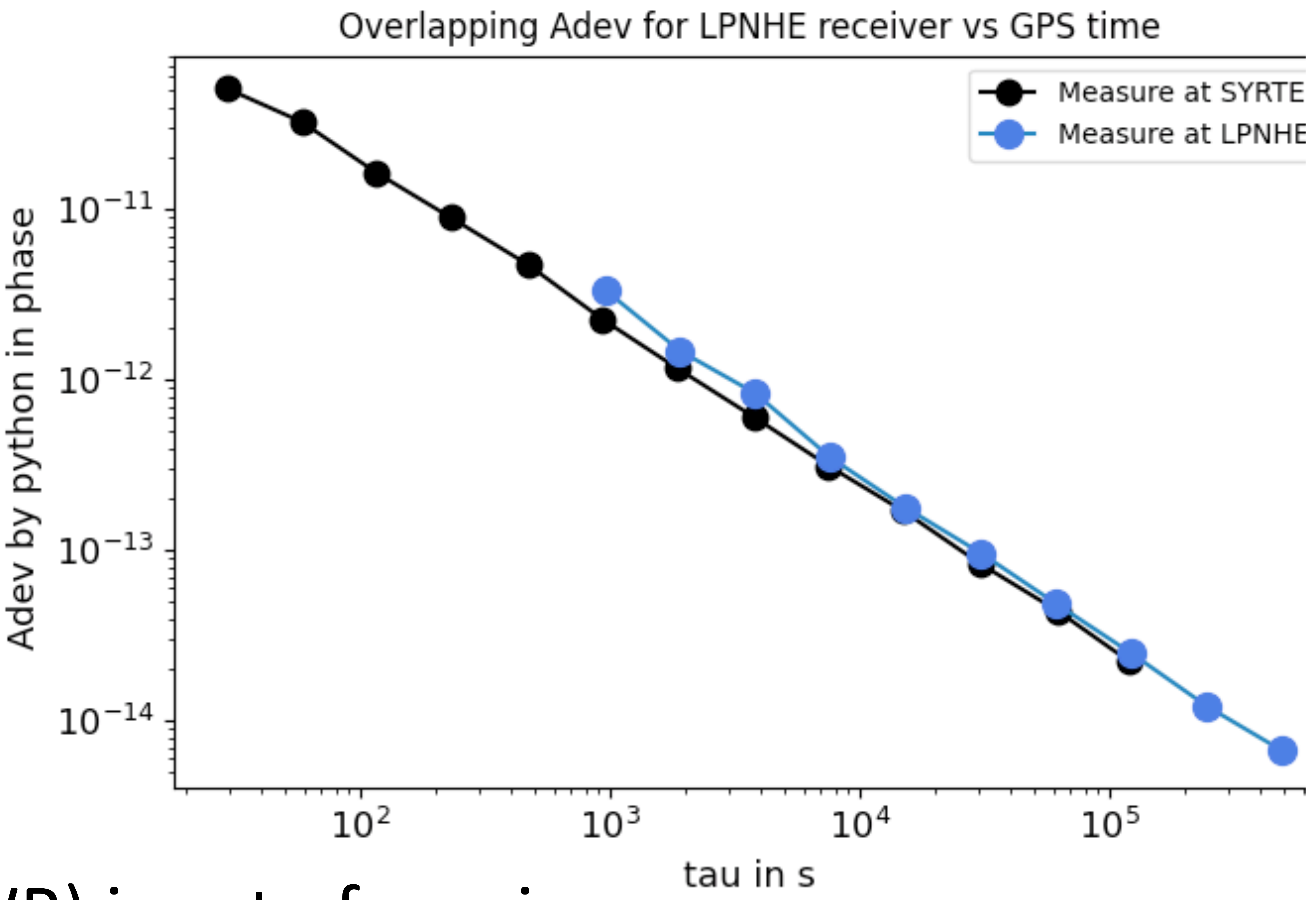
- Receiver in Timing mode after the exact position of the antenna is known
- Tracks each satellite then computes a Δt wrt GPS time per s every 16mn : Δt = GPS Time - receiver time
- Optional : input frequency Δt = GPS Time - input time

Septentrio PolaRx5TR antenna + receiver

* *P. Defraigne et G. Petit, CGGTTS-version 2e : an extended standard for GNSS time transfer, Metrologia 52 (6), 10.1088/0026-1394/52/6/g1, https://metrologia.bipm.org/ guides-stds-conventions/2015/G1.pdf (2015)*

Test of our set-up and analysis





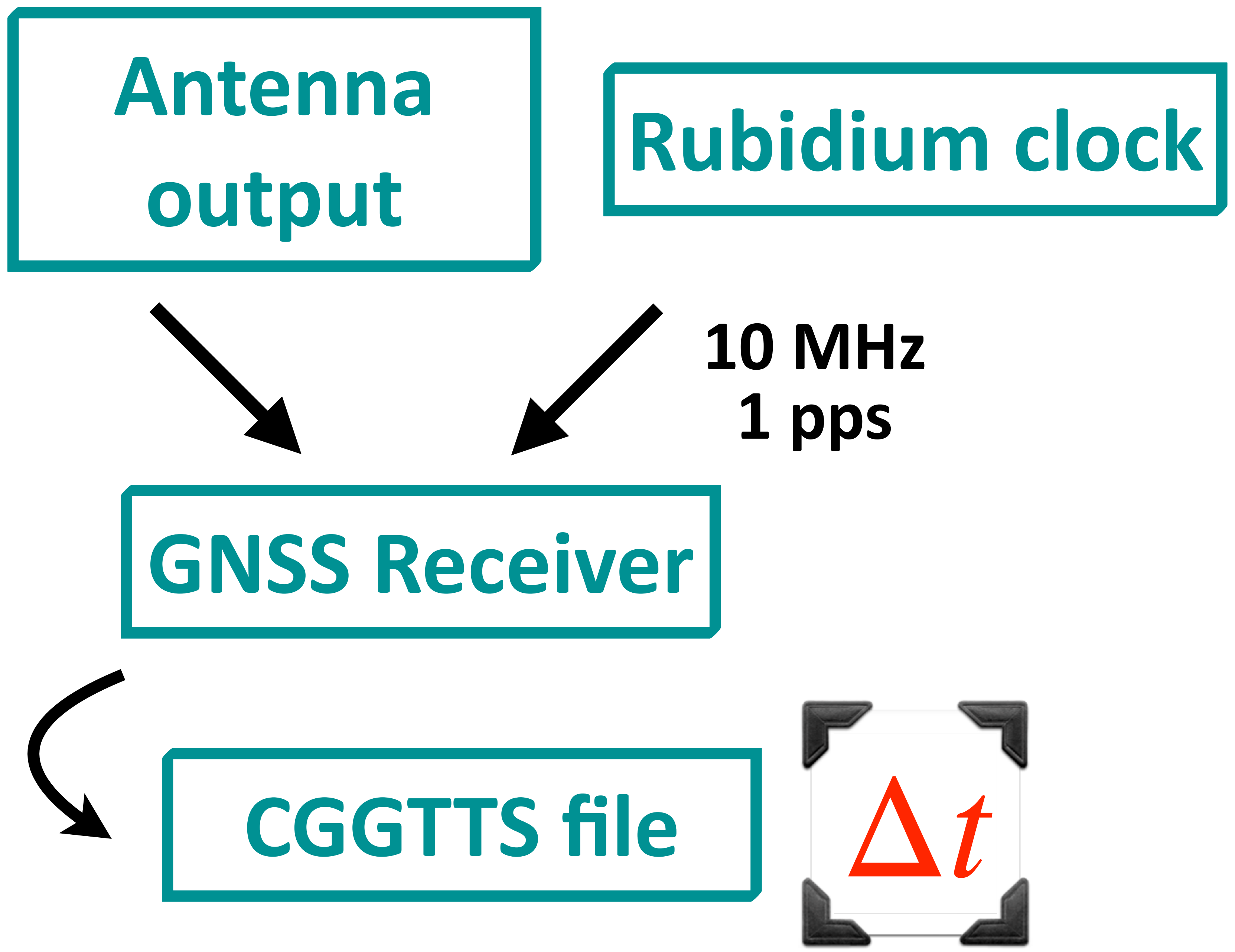
Results of reference frequency (via WR) input of receiver

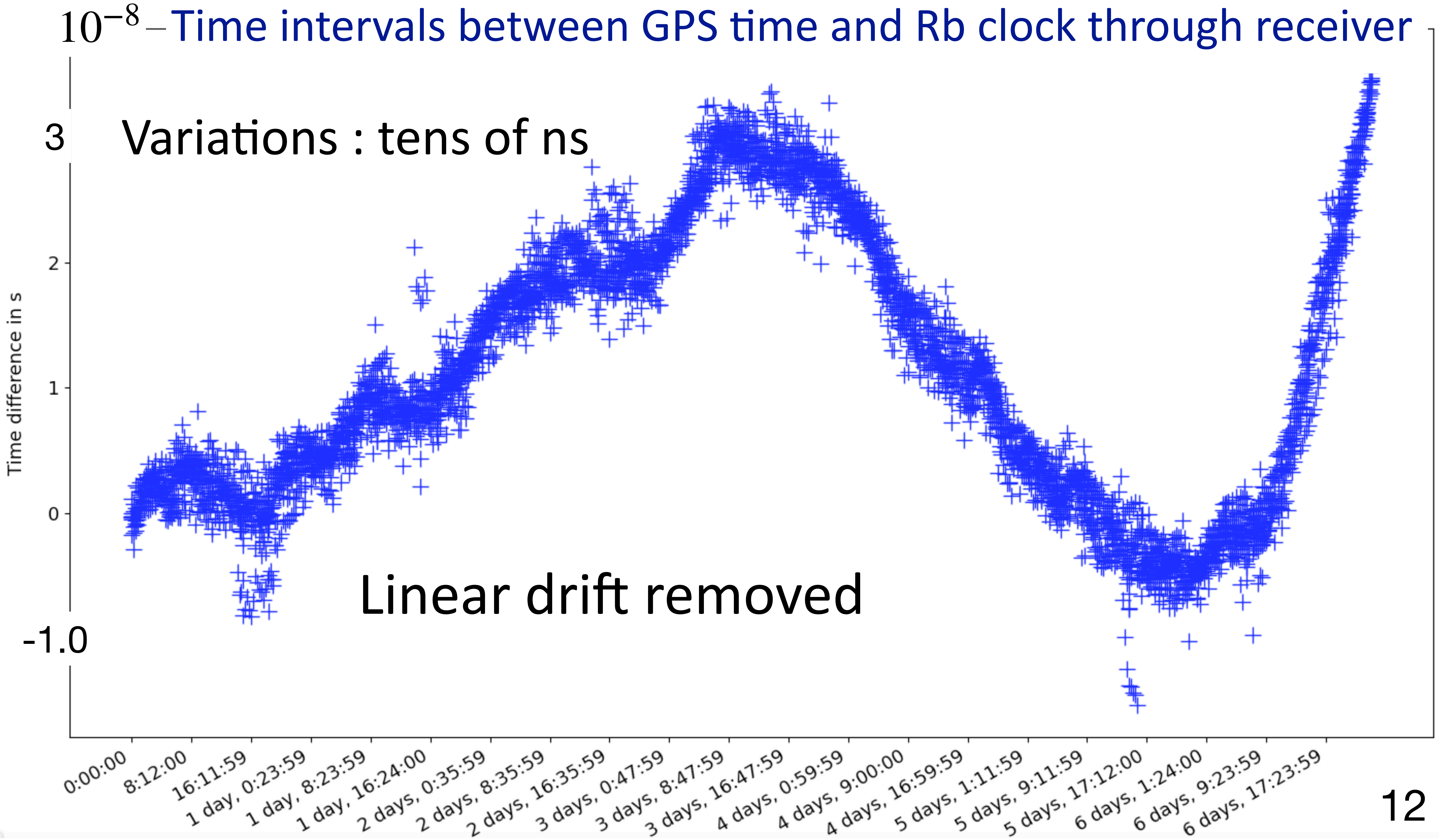
Set-up and analysis validated

Proposed solution : Rb as input to receiver

Why :

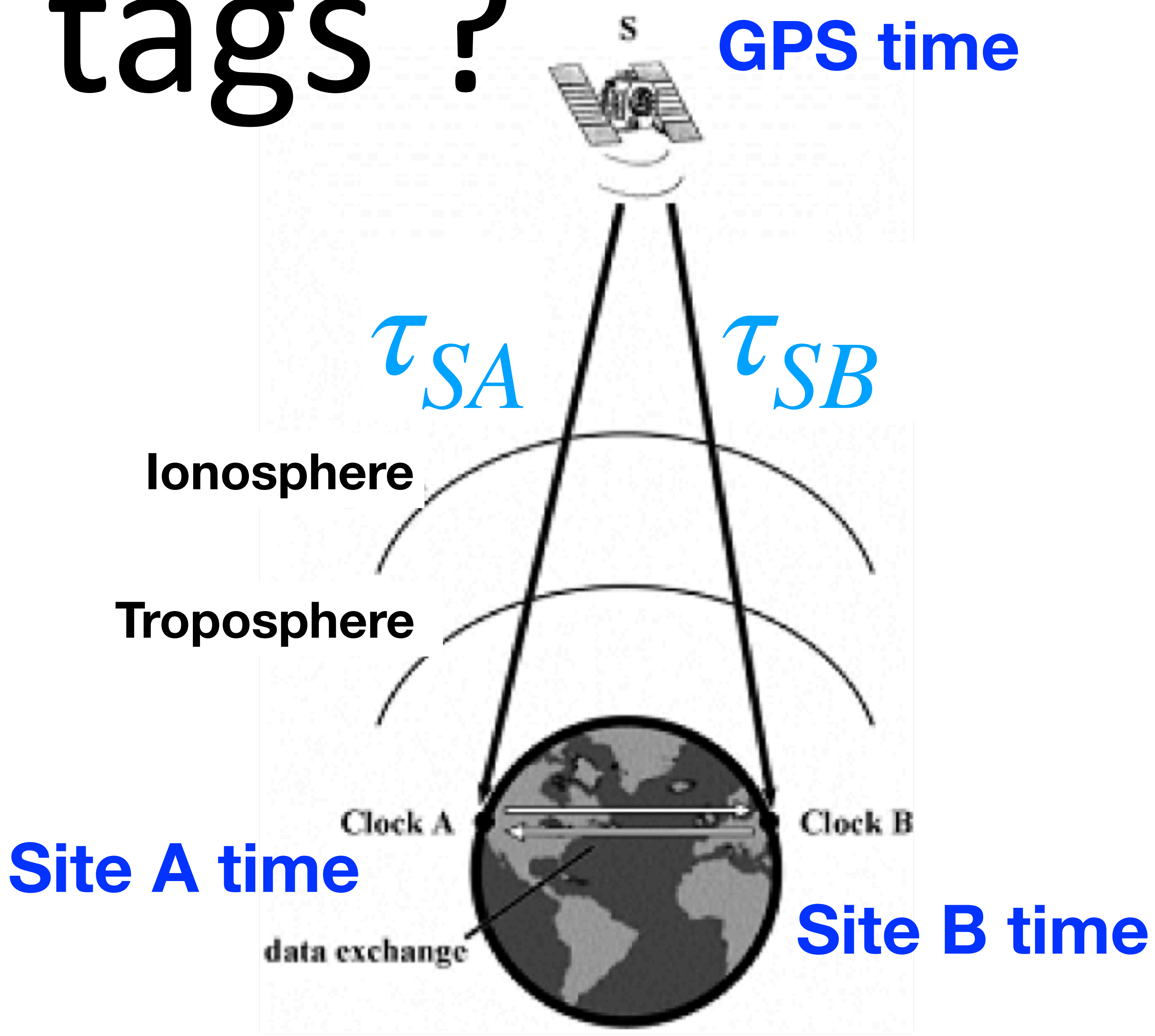
- Receiver monitors directly the Δt between the clock distributed to the system and the GPS time
- Clock in free-running : total control over applied corrections





Hyper-Kamiokande

How to obtain UTC time tags ?

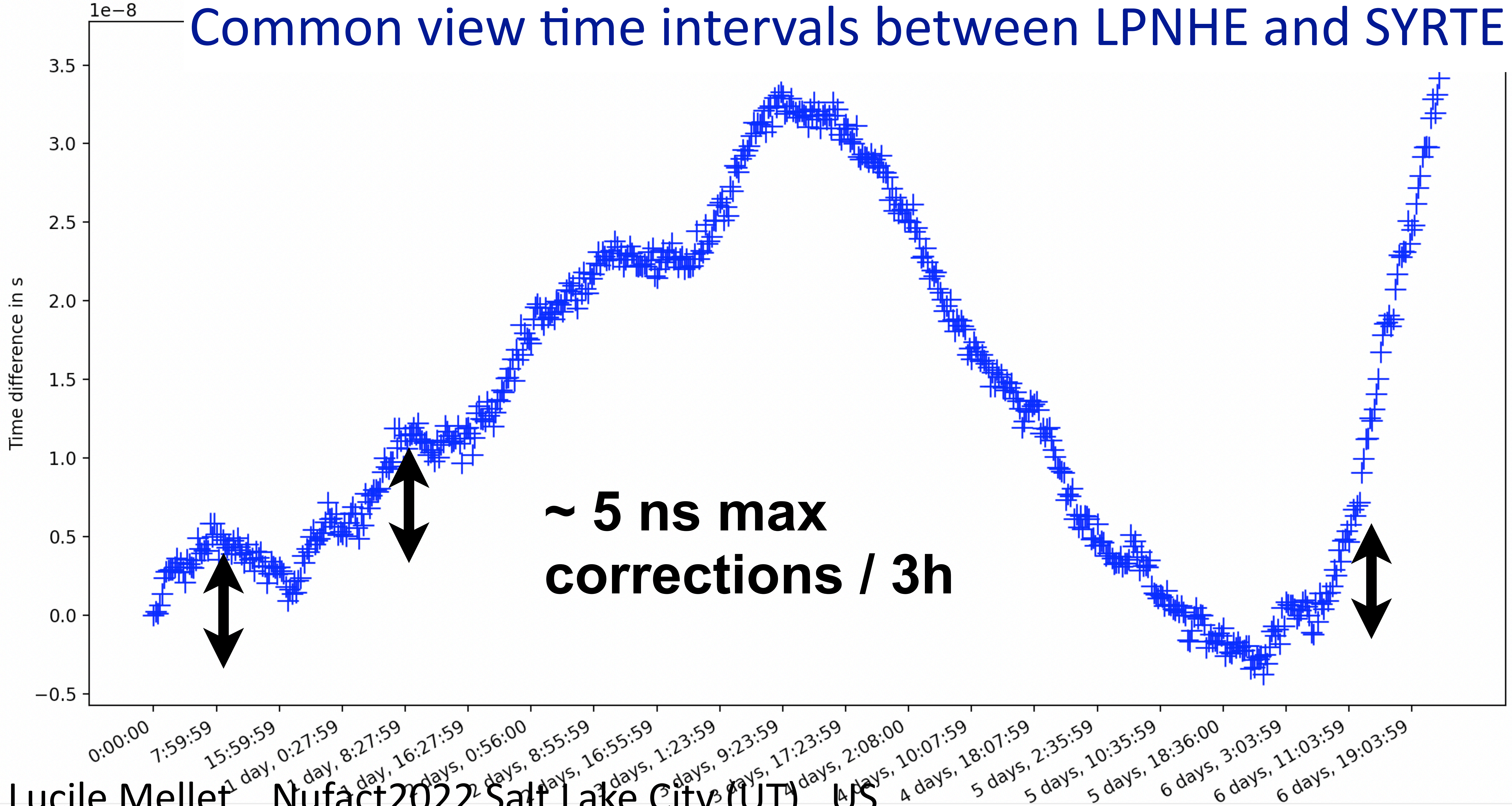


Time transfer by **common view technique**

Site A CGGTTS data : GPS Time – SiteA Time = Δt_{GPS-A} = τ_{SA}

Site B CGGTTS data : GPS Time – SiteB Time = Δt_{GPS-B} = τ_{SB}

Time transfer software computes $\tau_{SA} - \tau_{SB}$

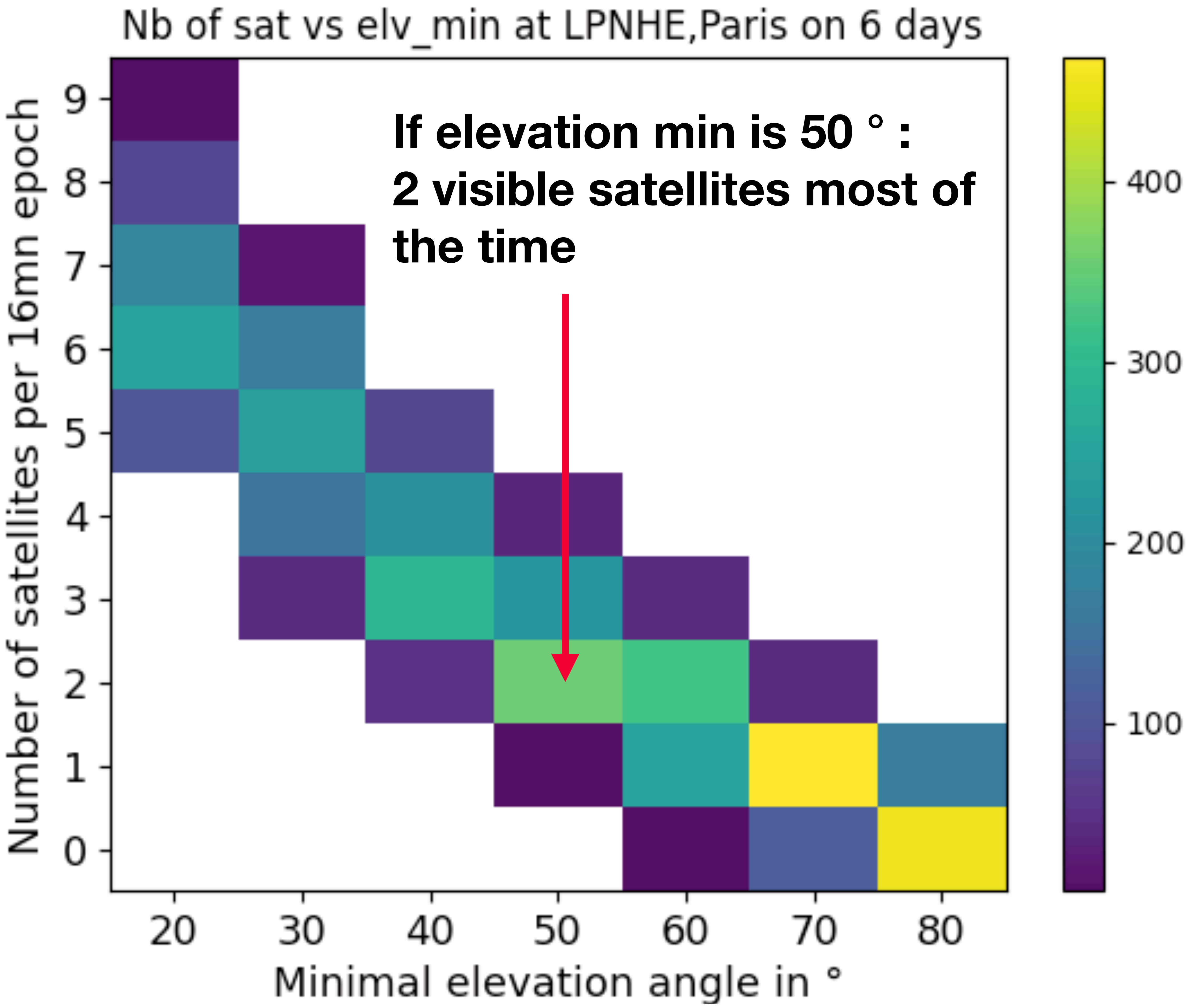


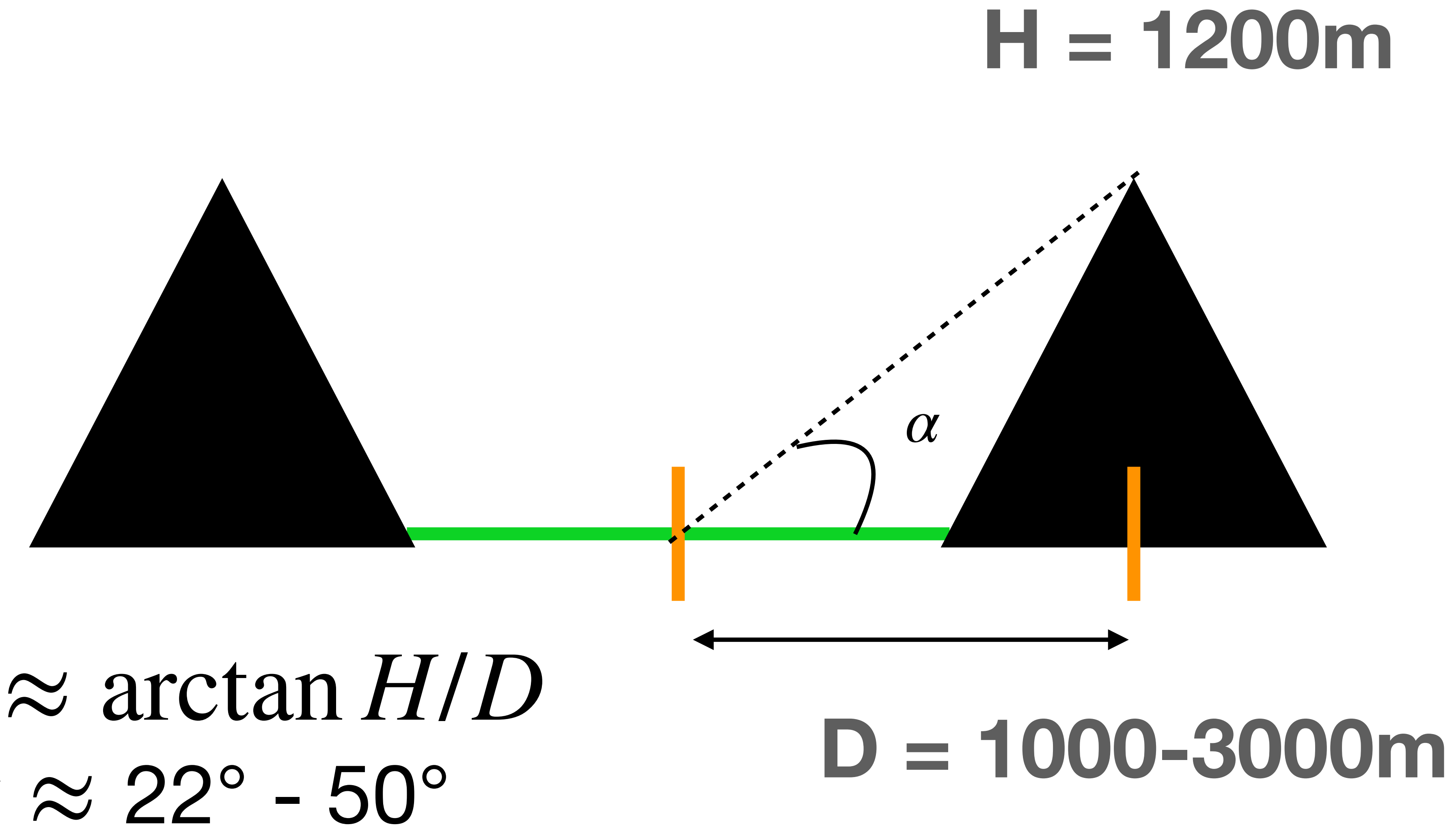
If site B is the reference time keeper : → $\tau_{SA} - \tau_{SB} = \Delta t_{siteA}$ wrt UTC (local)

Last step of the process

Need tests and simulation to optimize the applied correction

Elevation of satellites





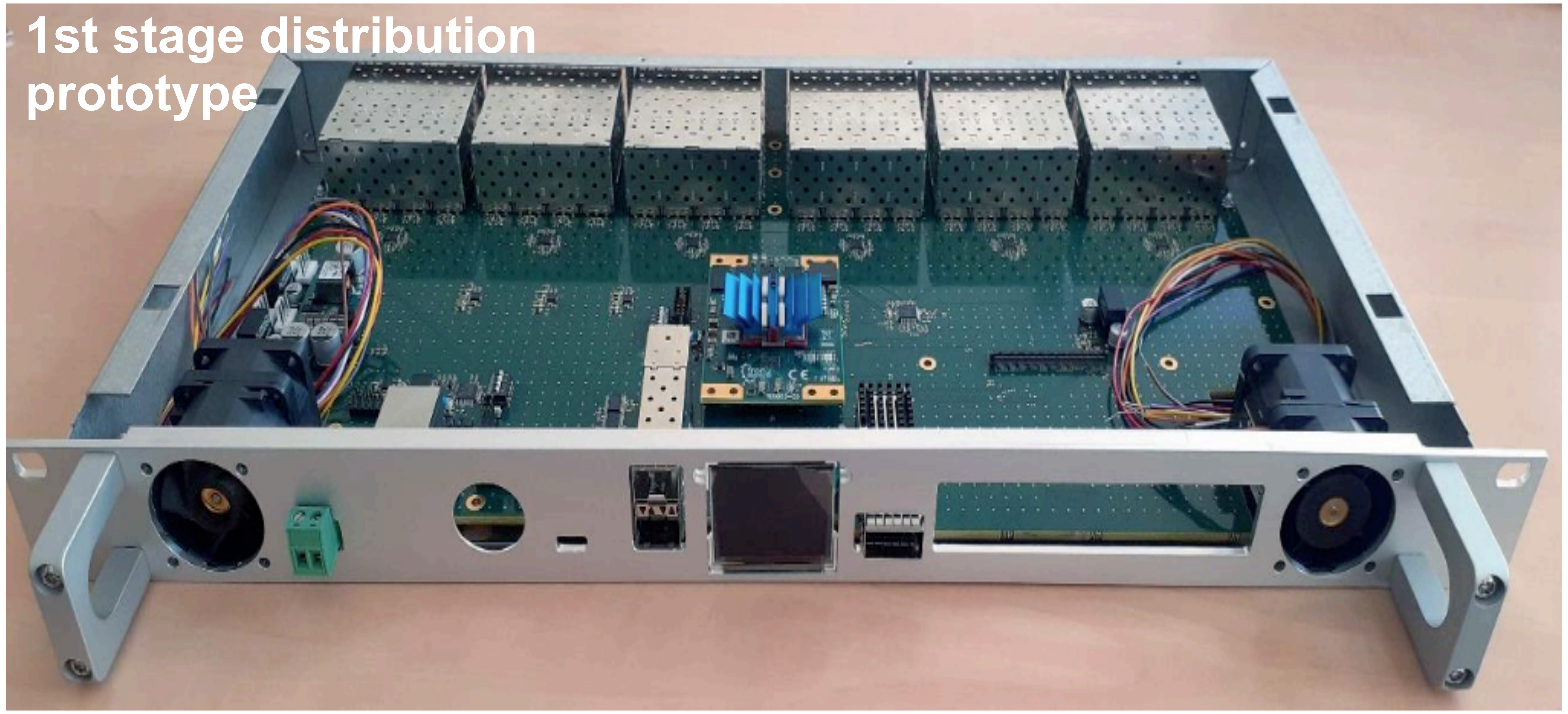
$\alpha \approx \arctan H/D$

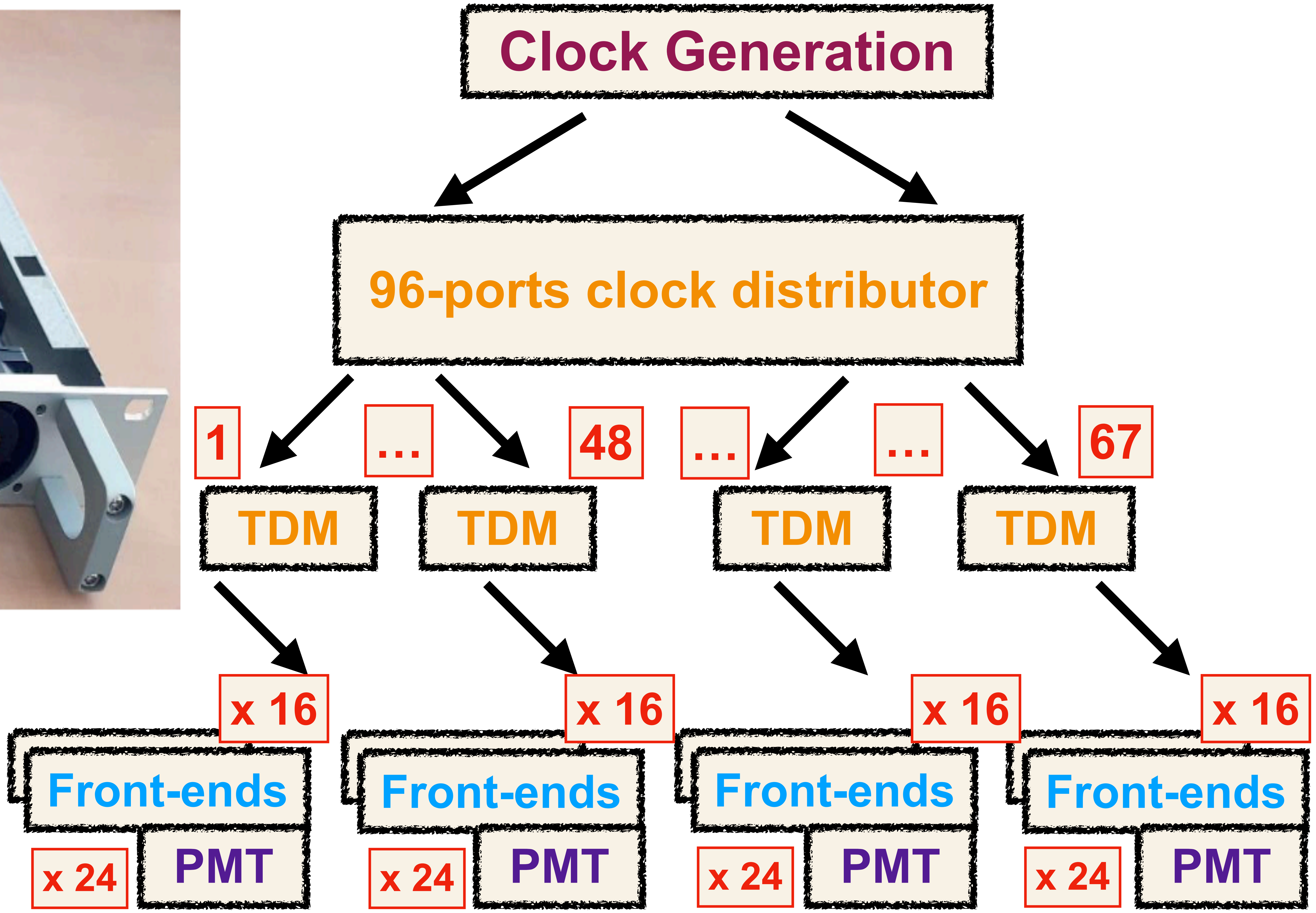
$\alpha \approx 22° - 50°$

The system has to be robust against :

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

Distribution of time to the PMTs





- 2 stages

- Electronic boards and cards are being designed and prototyped

Undergoing tests in collaboration between French (CEA, LPNHE) and Italian (INFN) groups

Conclusion

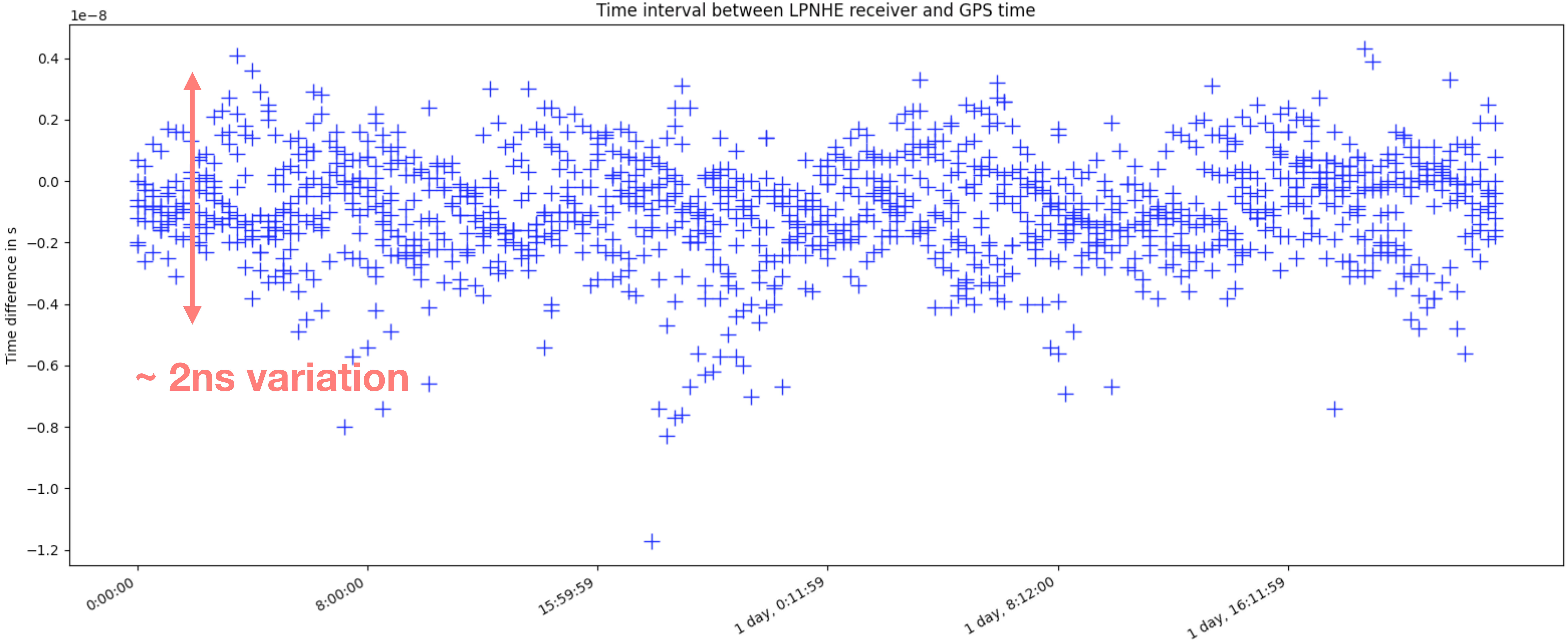
- R&D has been happening for about 2.5 years
- Internal HK reviews are ongoing
- Collaboration between several groups
- Good contacts with time keeping experts in France

- Great precision and stability over both clock generation and distribution will increase the physics reach (better ring reconstruction, SN explosion detection, neutrino time of flight studies, …)

Thank you for your attention

Back-up

Back up : WR as input to receiver : validation



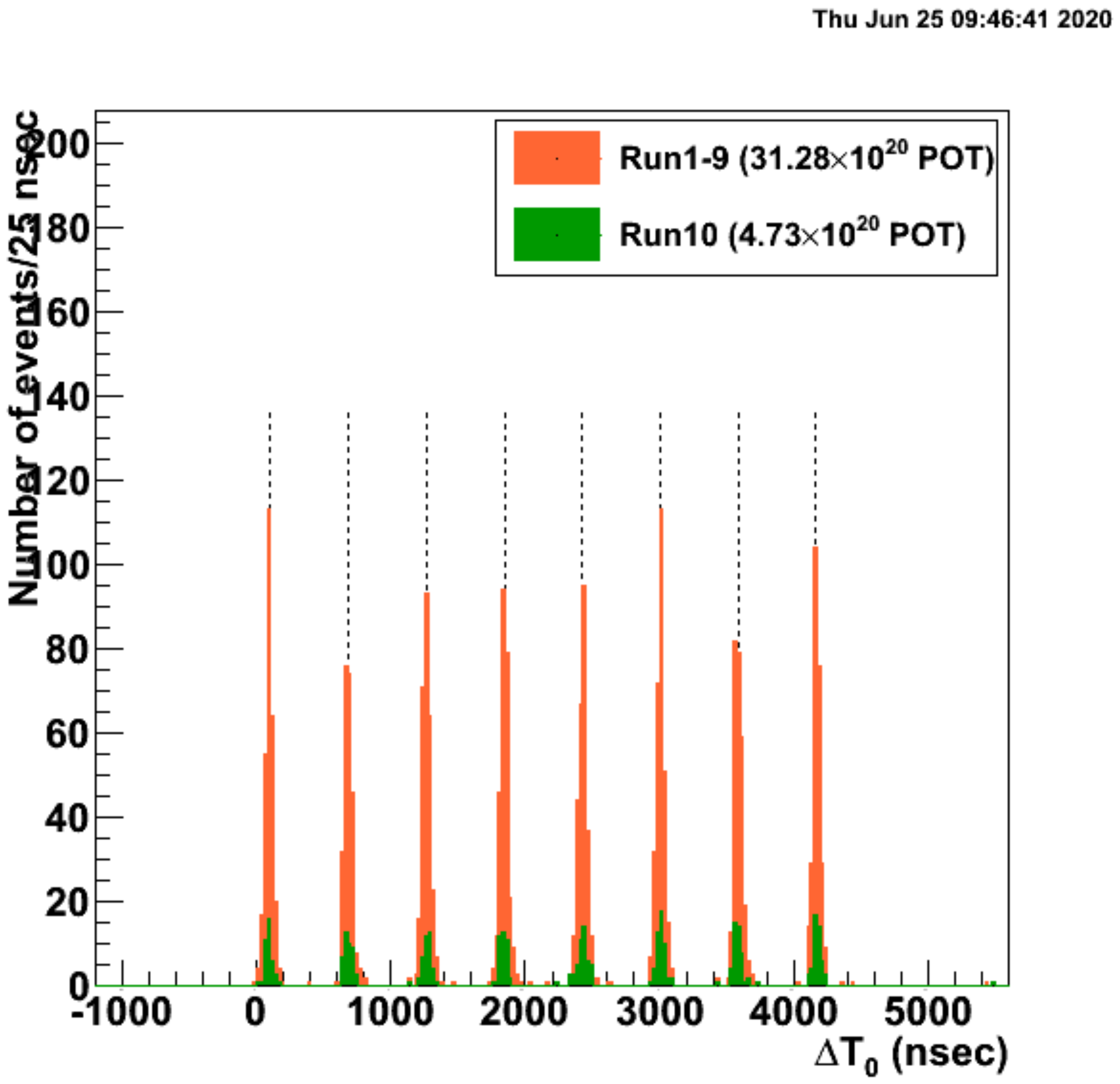
Back-up

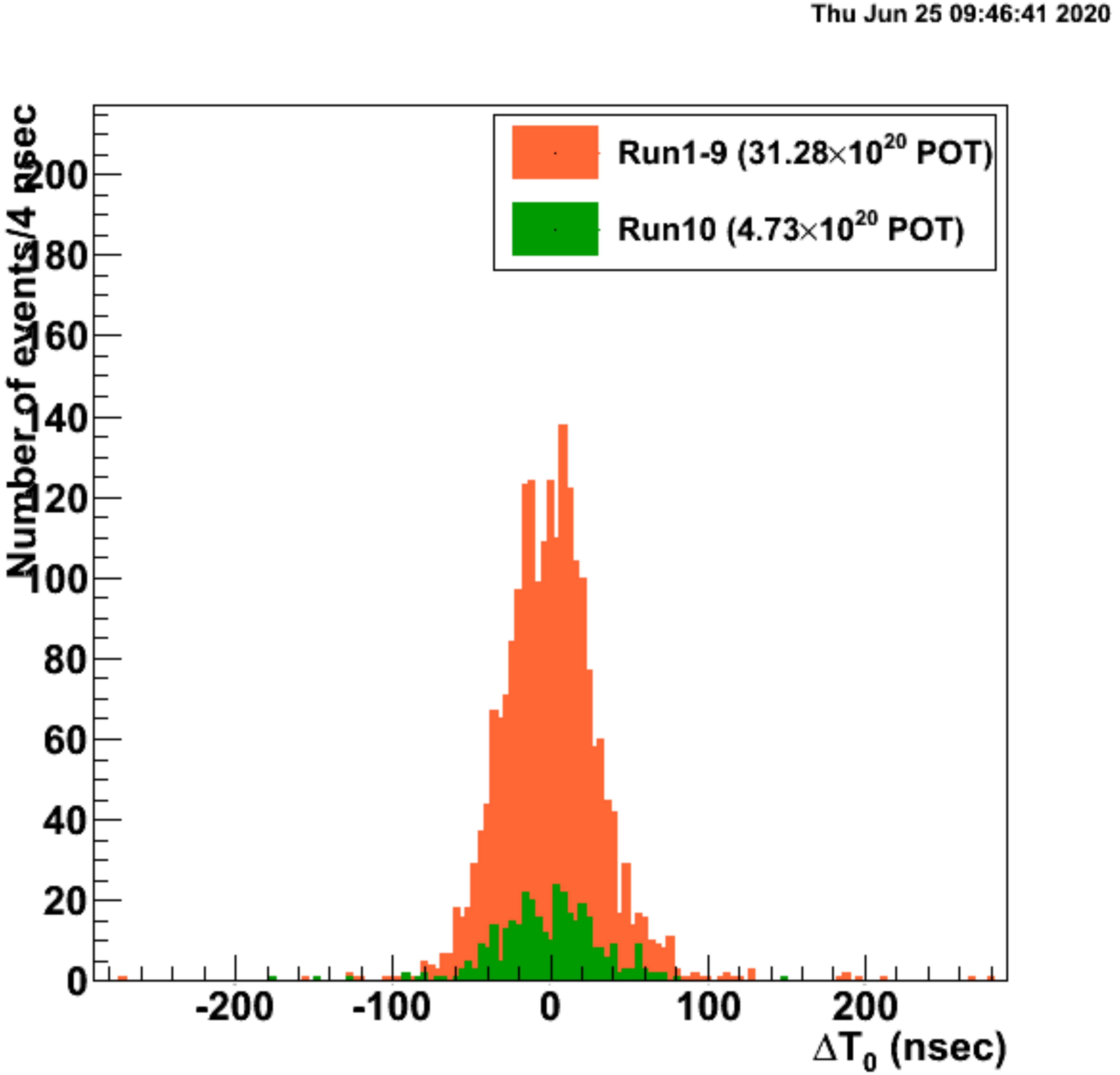
$$J = \frac{1}{2\pi f_0}\sqrt{\int_0^{\infty} S(f)\left(\frac{\sin(\pi\tau f)}{\pi\tau f}\right)^2 df}$$

This is a number quantifying the time-domain stability deviations from a pure signal and it can be computed over a period τ as a function of the power spectral density S(f), f being the fractional frequency offset with respect to the "ideal" frequency f_0

We aim at a Jitter lower than 100ps at τ = 1s.

Back-up


Thu Jun 25 09:46:41 2020
Run1-9 (31.28×10^20 POT)
Run10 (4.73×10^20 POT)
Number of events/25 nsec
ΔT0 (nsec)
-1000
0
1000
2000
3000
4000
5000


Thu Jun 25 09:46:41 2020
Run1-9 (31.28×10^20 POT)
Run10 (4.73×10^20 POT)
Number of events/4 nsec
ΔT0 (nsec)
-200
-100
0
100
200