Time synchronization and clock distribution for Hyper Kamiokande

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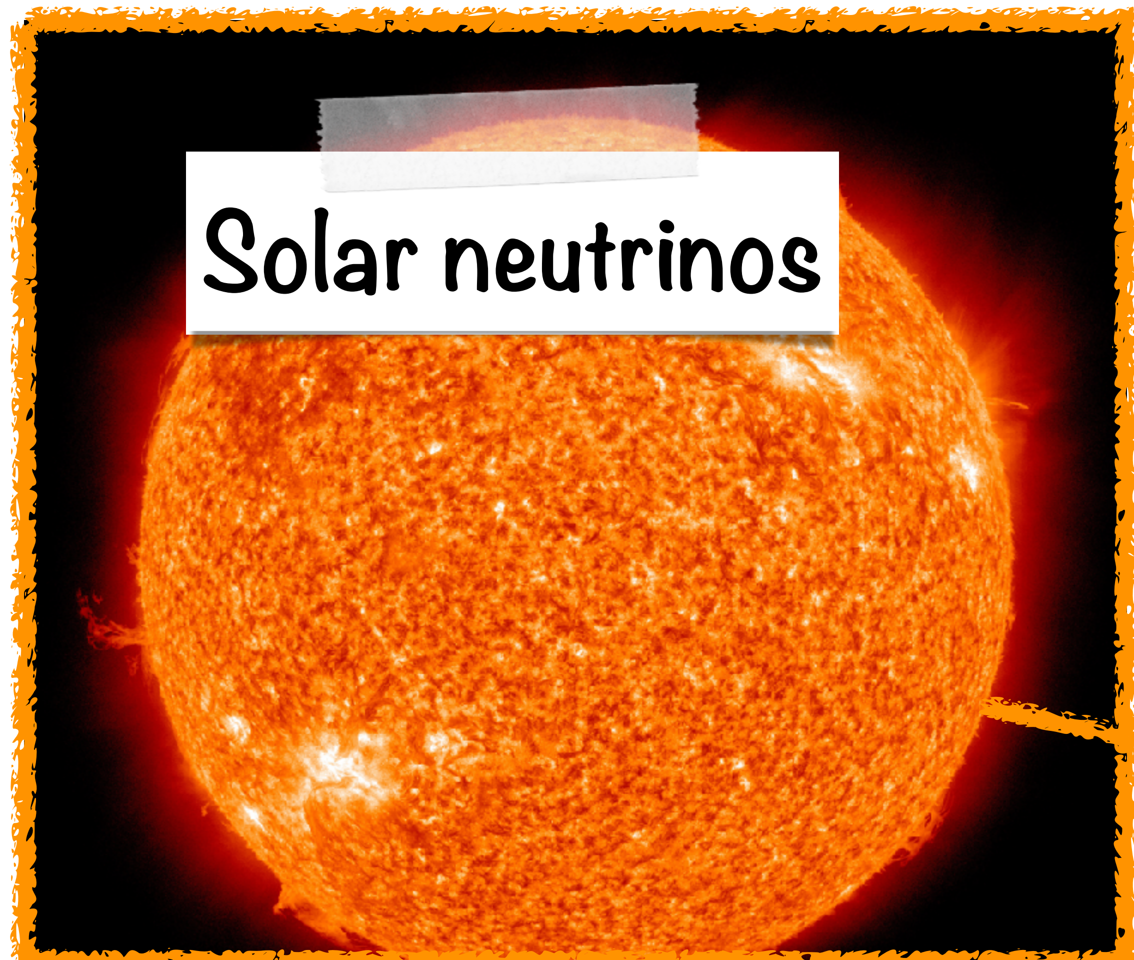
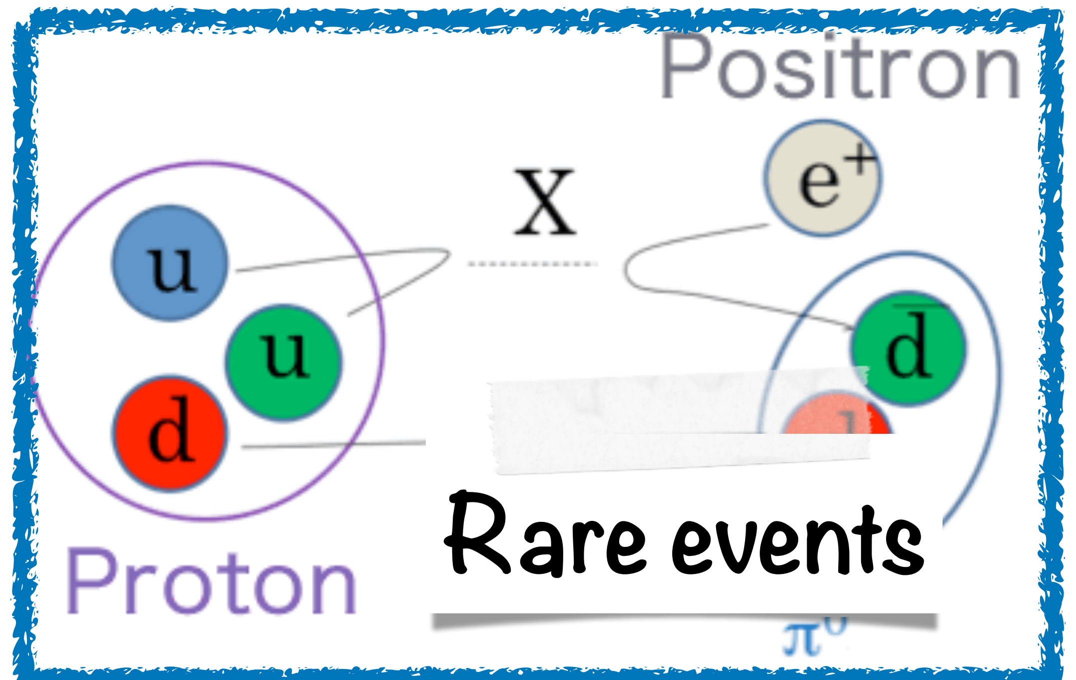
April 11th 2022

Hyper Kamiokande in a nutshell

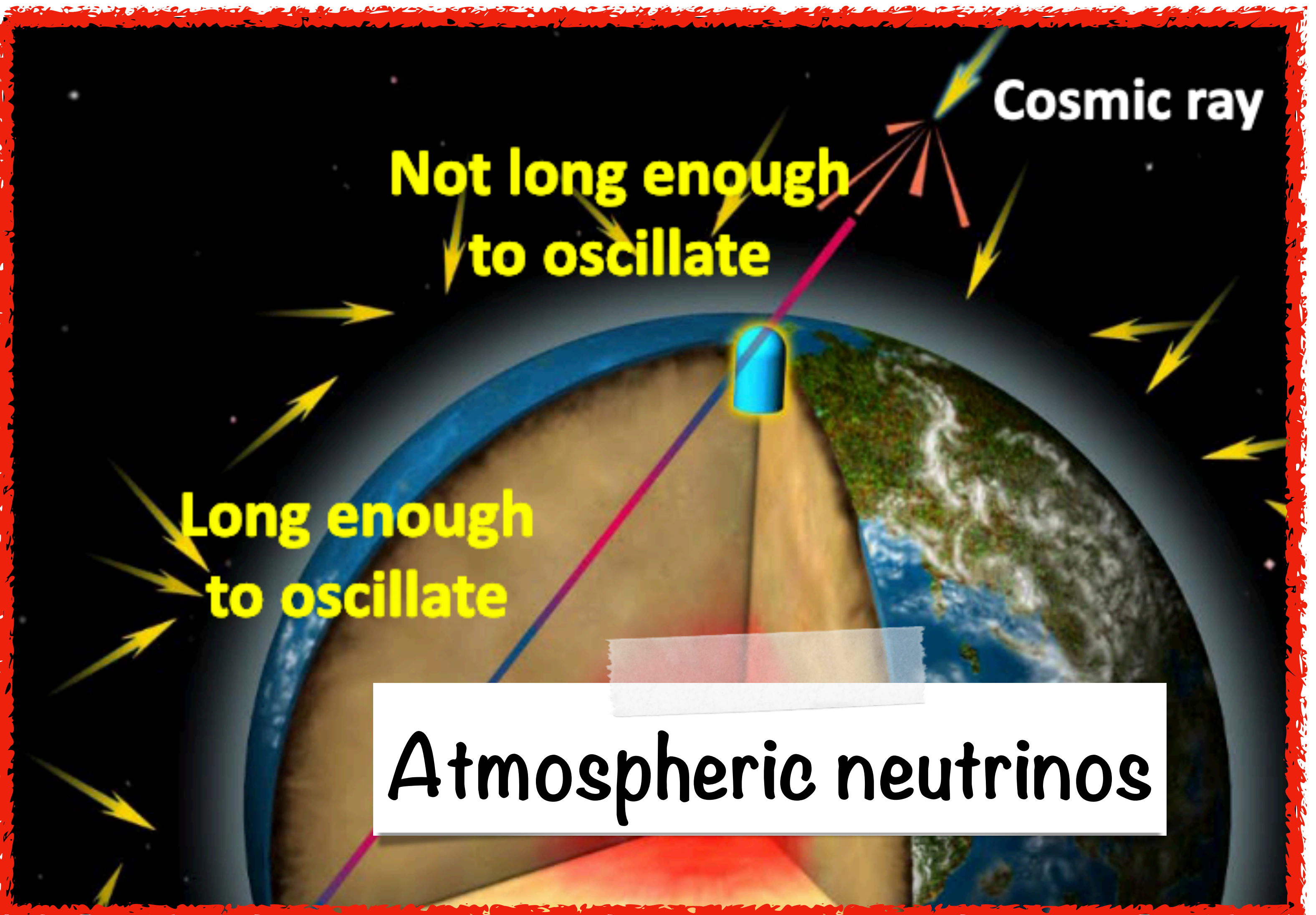


- MSW effect
- Non-standard interactions

ν_e

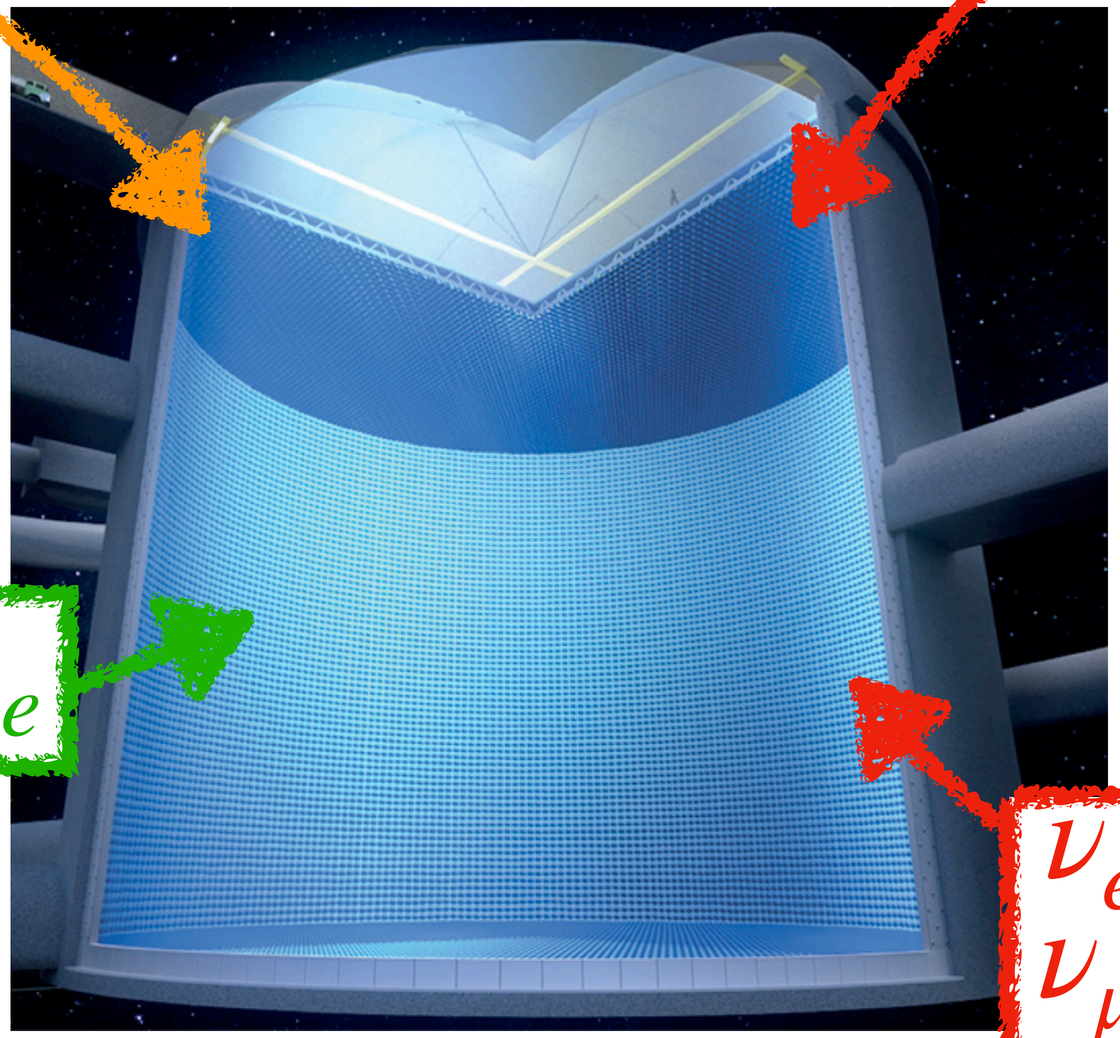


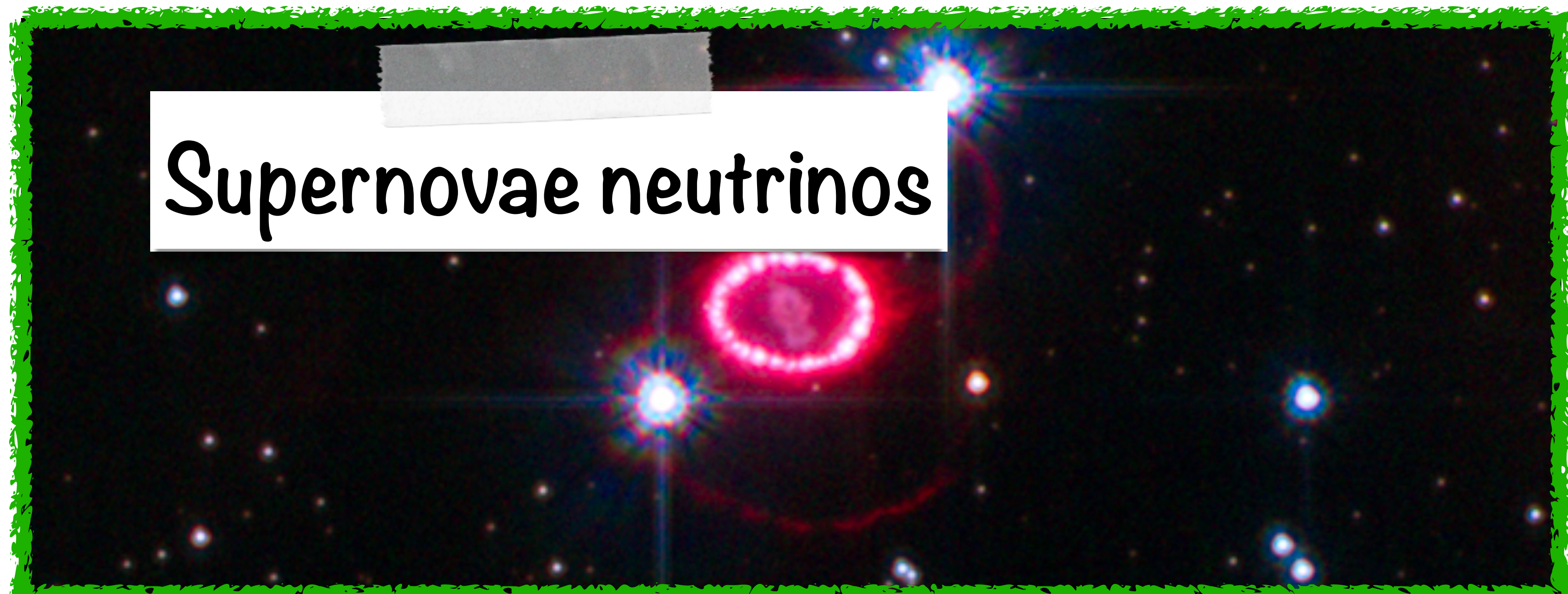
- Probe Grand Unified Theories via p-decay or $n - \bar{n}$ oscillation



ν_e $\bar{\nu}_e$ ν_μ $\bar{\nu}_\mu$

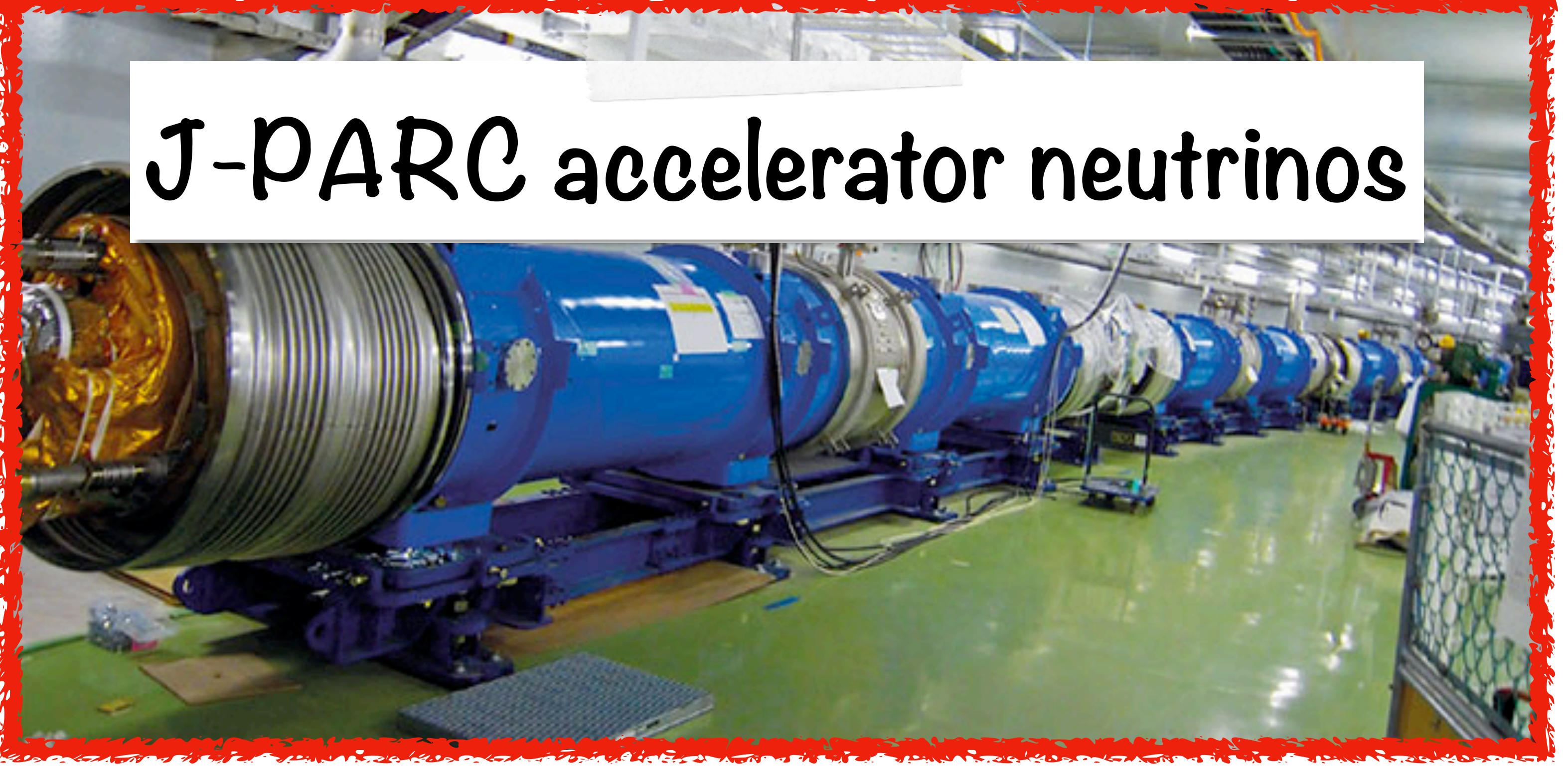
- Observe CP violation for leptons at 5σ
- Precise measurement of δ_{CP}
- High sensitivity to ν mass ordering





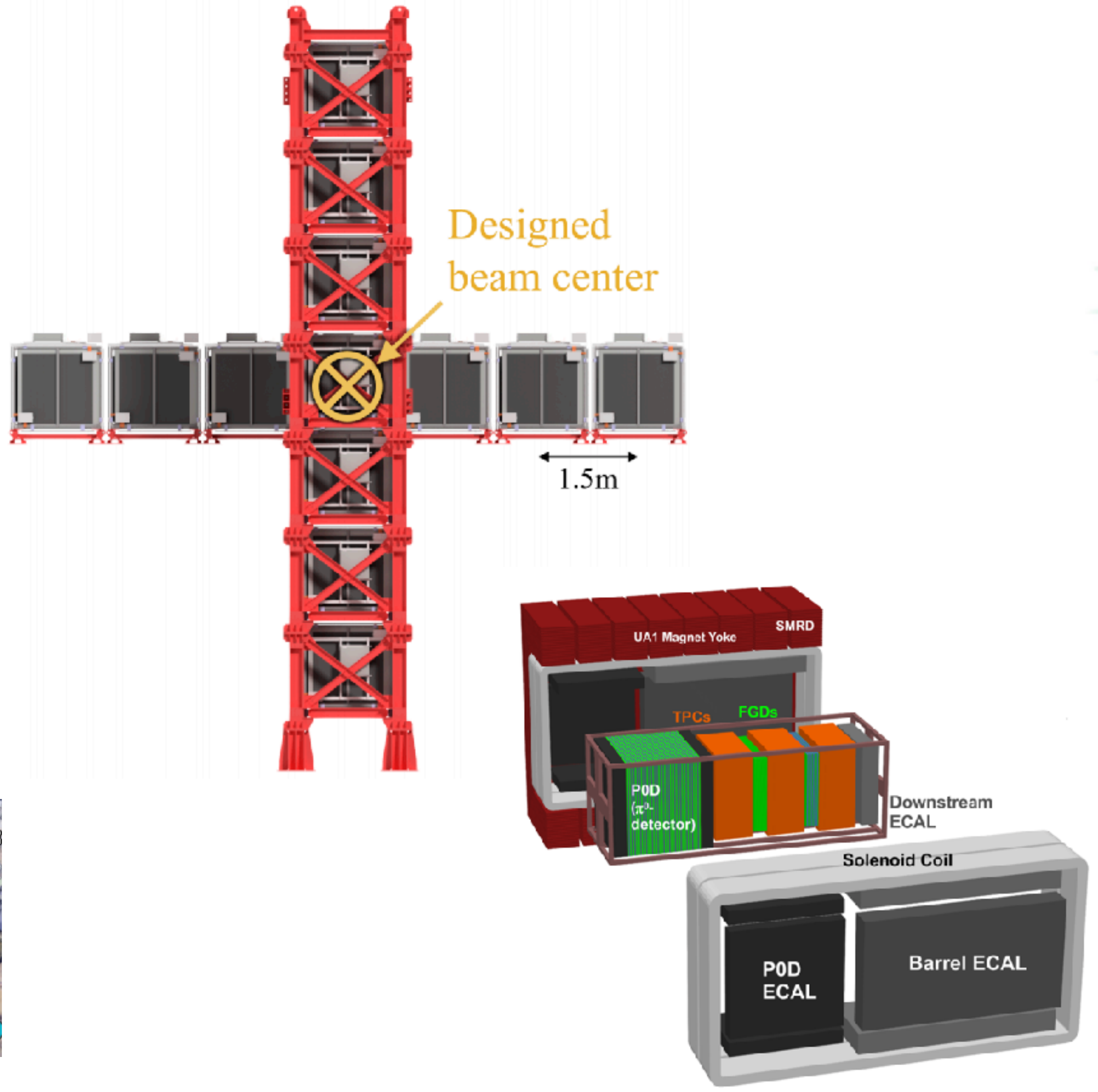
$\bar{\nu}_e$

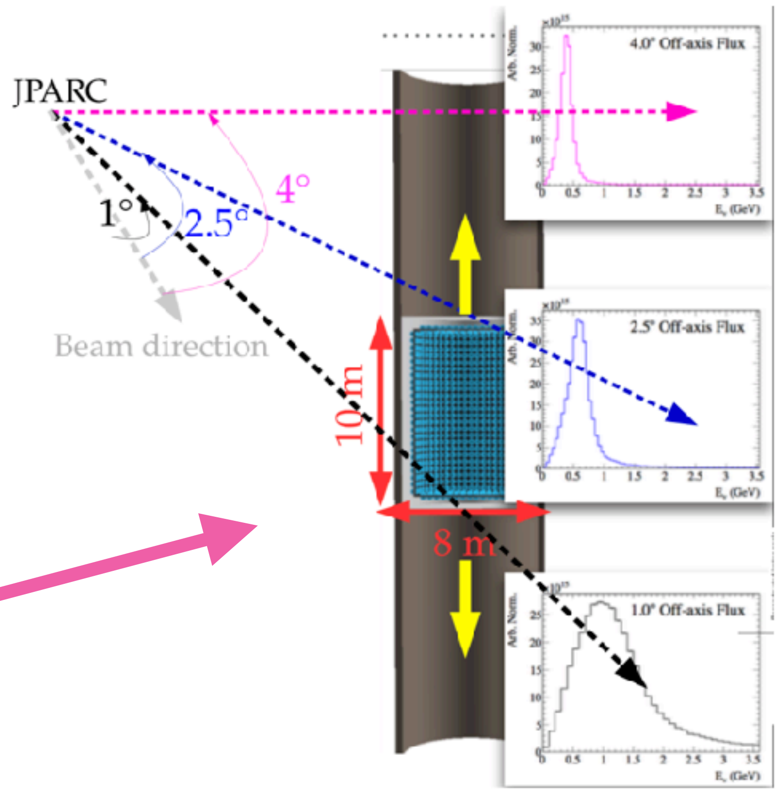
- Transient SN ν: constrain SN profile models
- Relic SN ν: constrain cosmic star formation

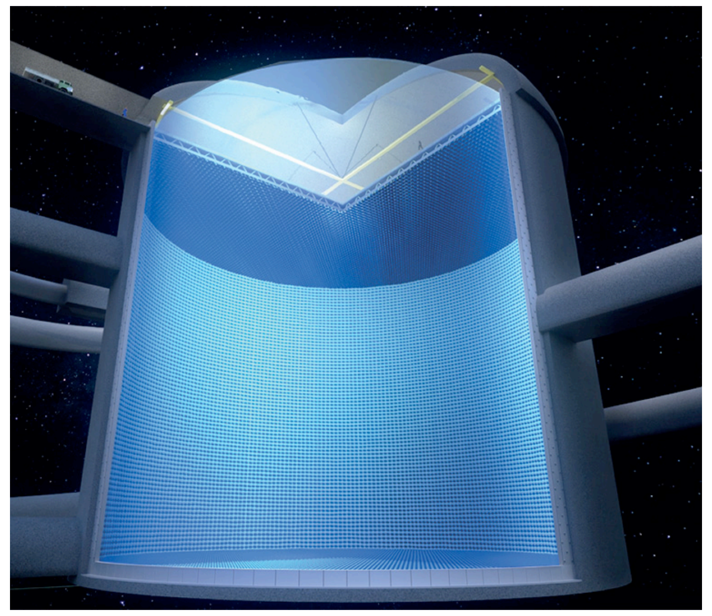


ν_e $\bar{\nu}_e$ ν_μ $\bar{\nu}_\mu$

From Tokai to Hyper KamiokaNDE





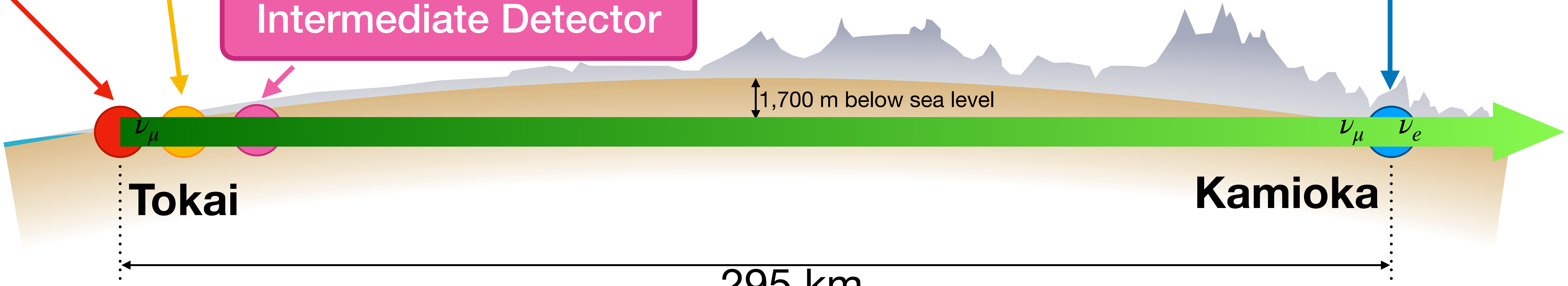


J-PARC

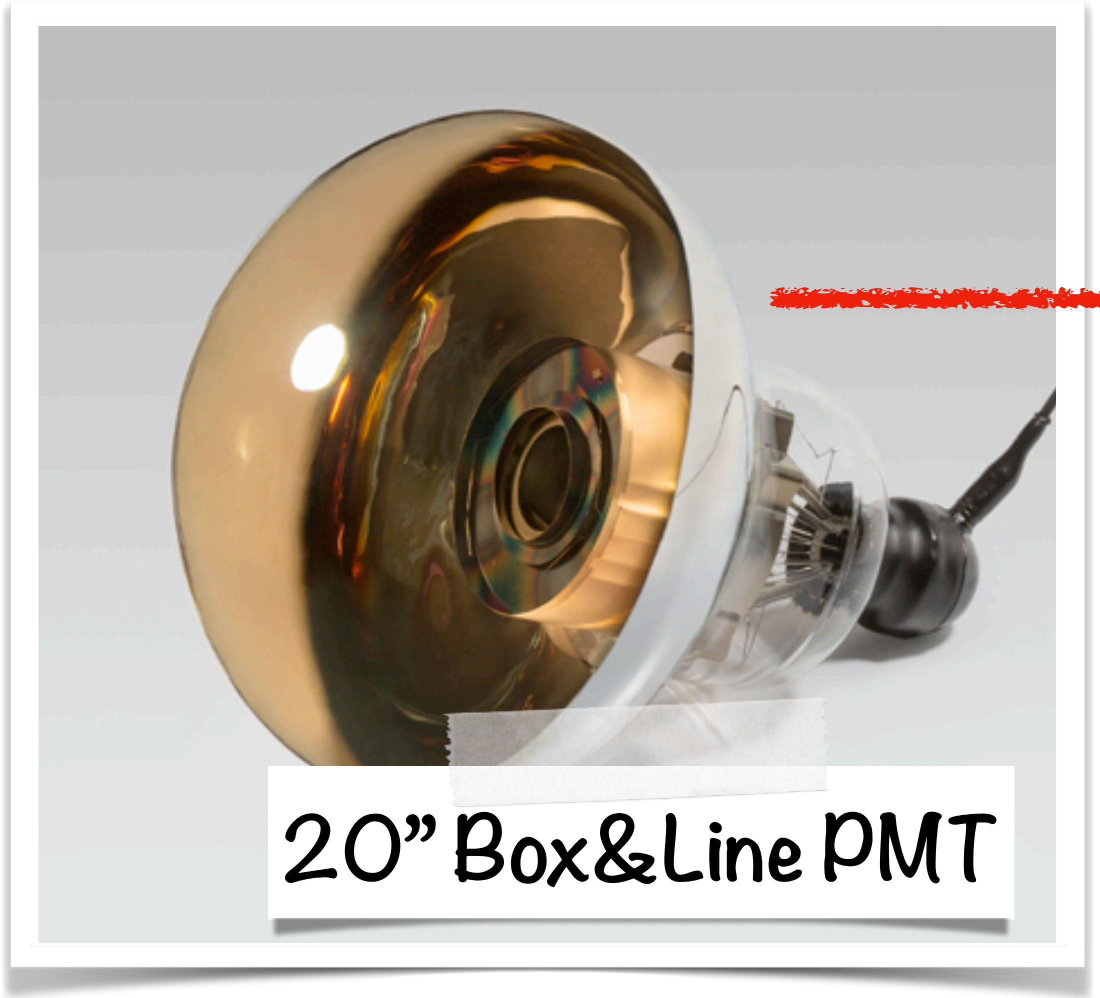
Near Detectors

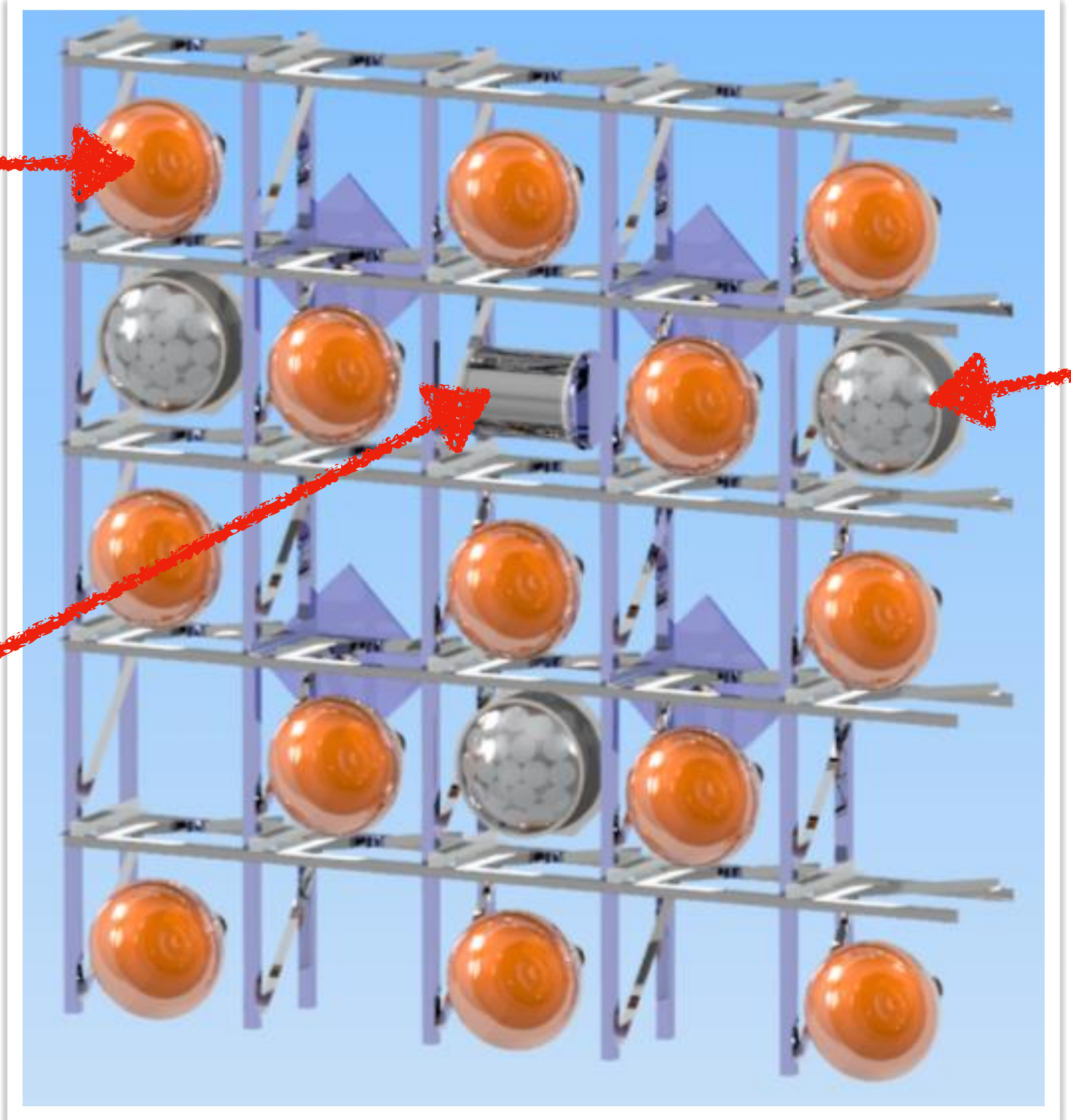
Intermediate Detector

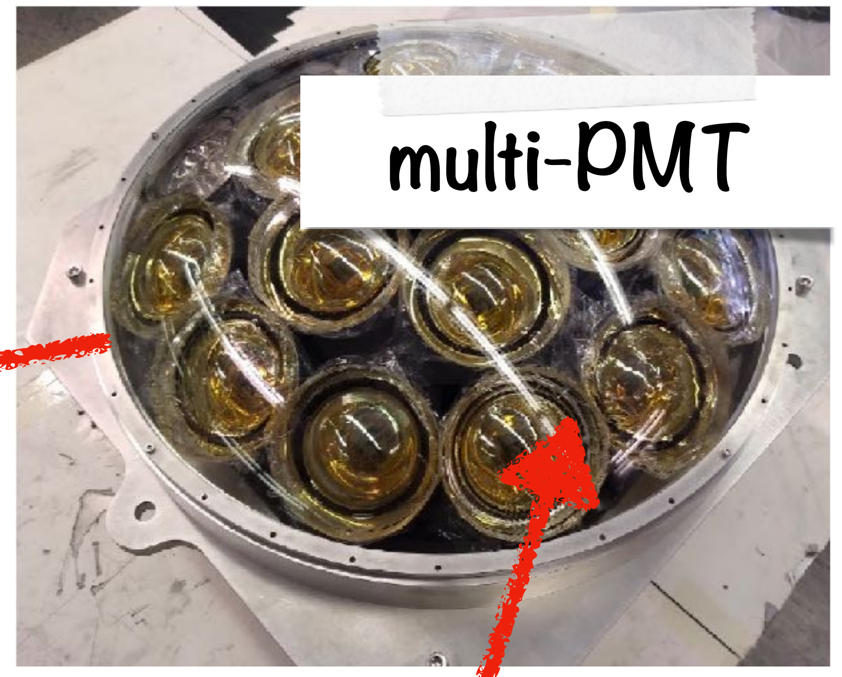
Hyper-Kamiokande



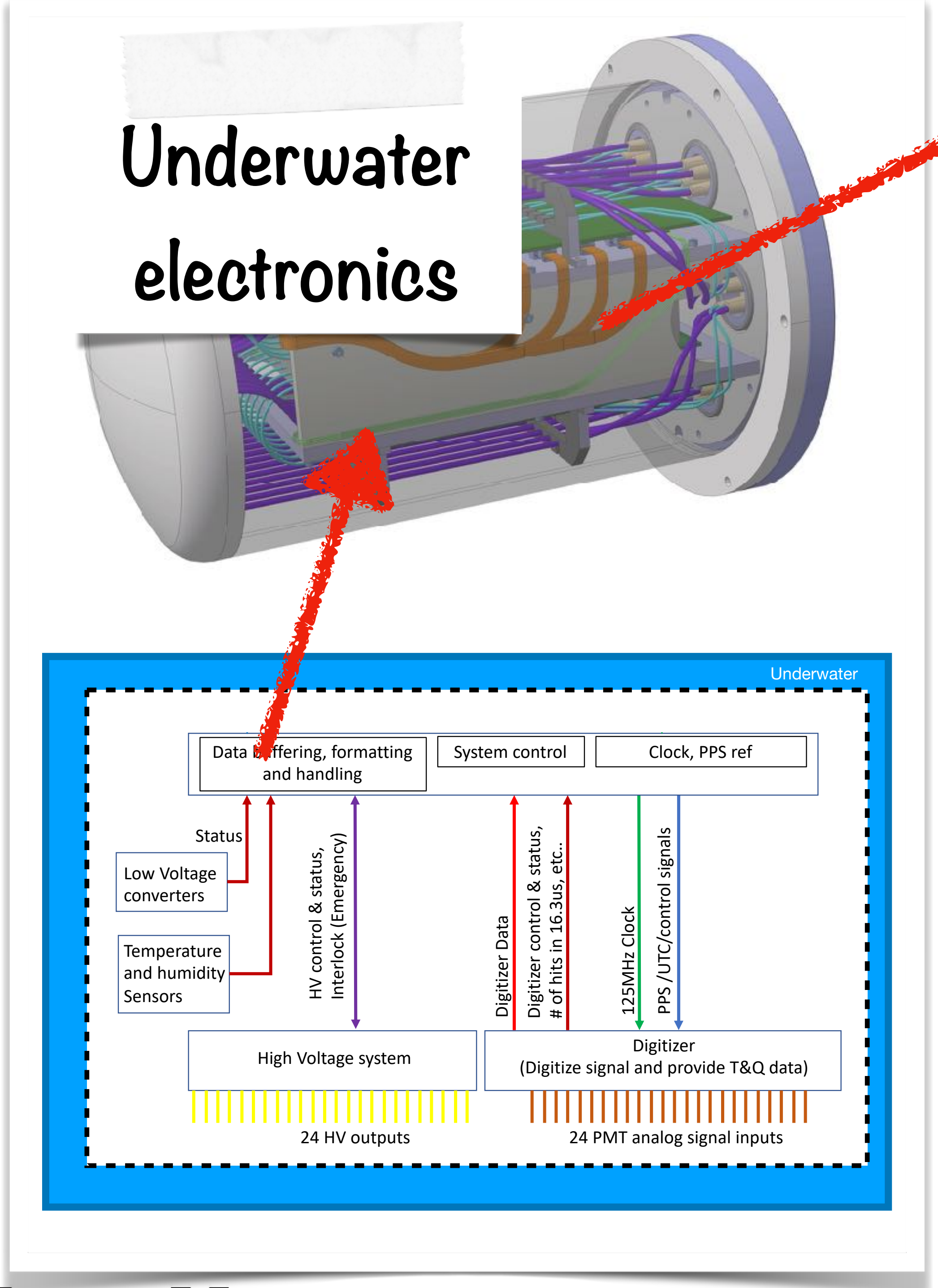
20” PMTs, mPMTs and readout







19 x 3” PMT



Inner detector composed of

- 20k+ 20” PMTs (Hamamatsu R12860)
- ~5k mPMTs (19 3” R12199-02 PMTs)

→ Better SNR, directionality, timing

Outer detector composed of a few thousands 3” PMTs

Clock and timing requirements

"External" synchronization

- SNEWS
- J-PARC
- Universal Time

Atomic clock (local reference)

"Internal" synchronization

Time distribution system

Front-end  X24

Front-end  X24

Front-end  X24

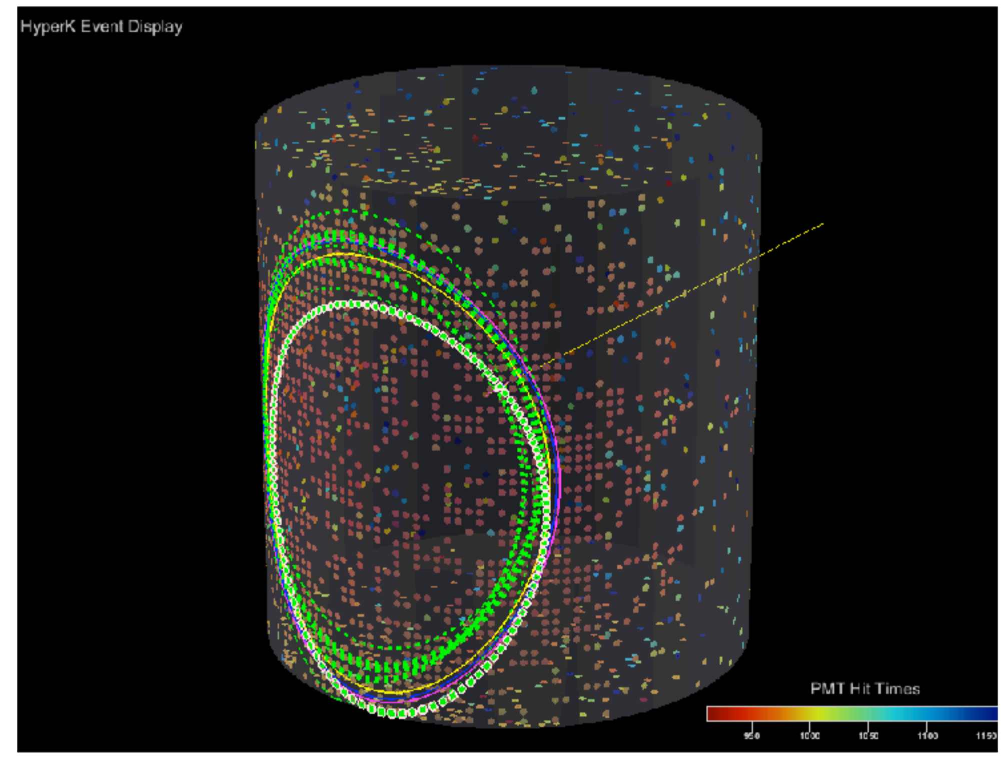
Correlation with external expts (J-PARC beam, TOF, SNs…)

→ event time-tagging < 100 ns using GNSS antennas

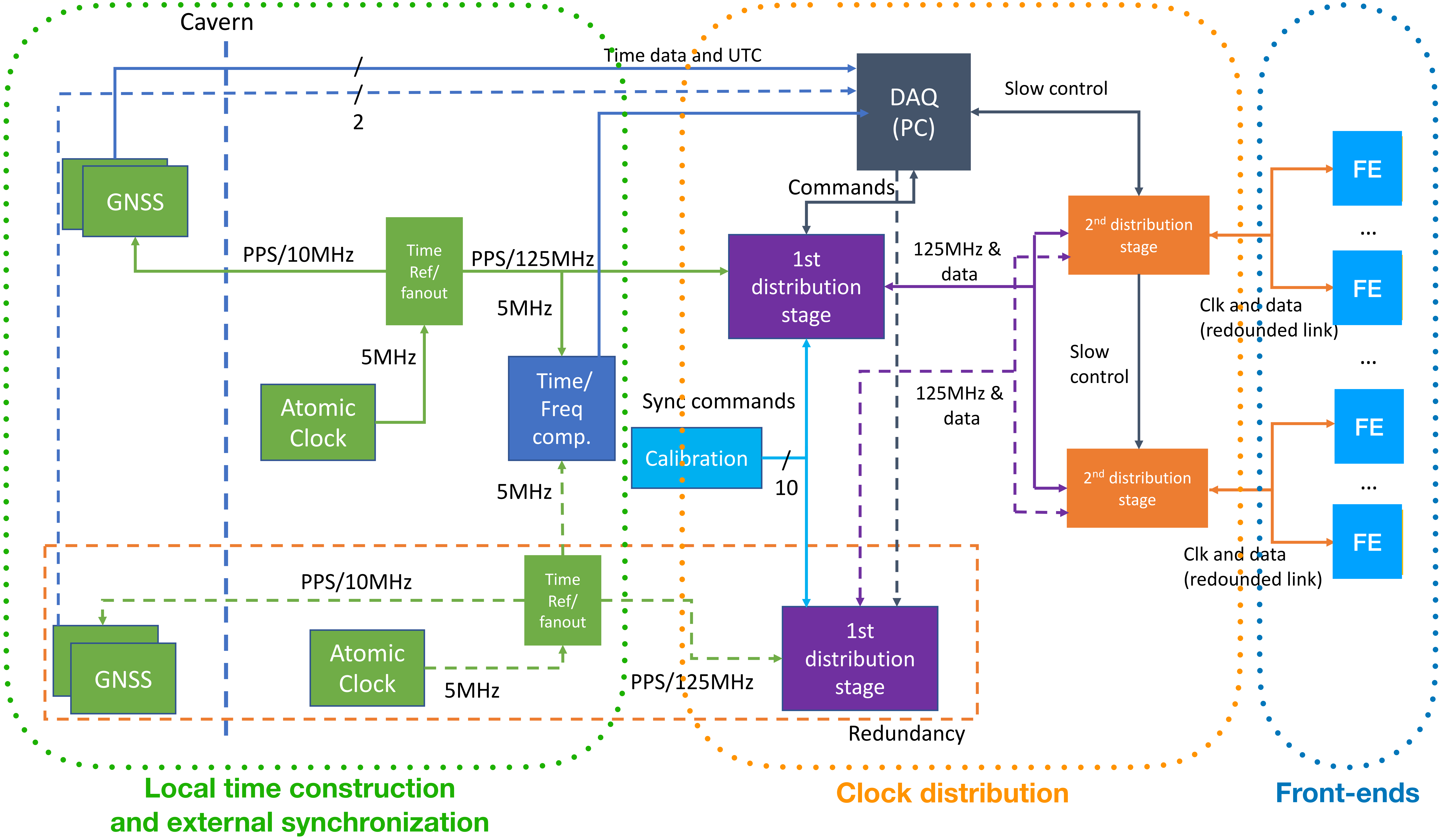
Rings reconstruction by coincidence

→ time difference between PMTs < 100 ps

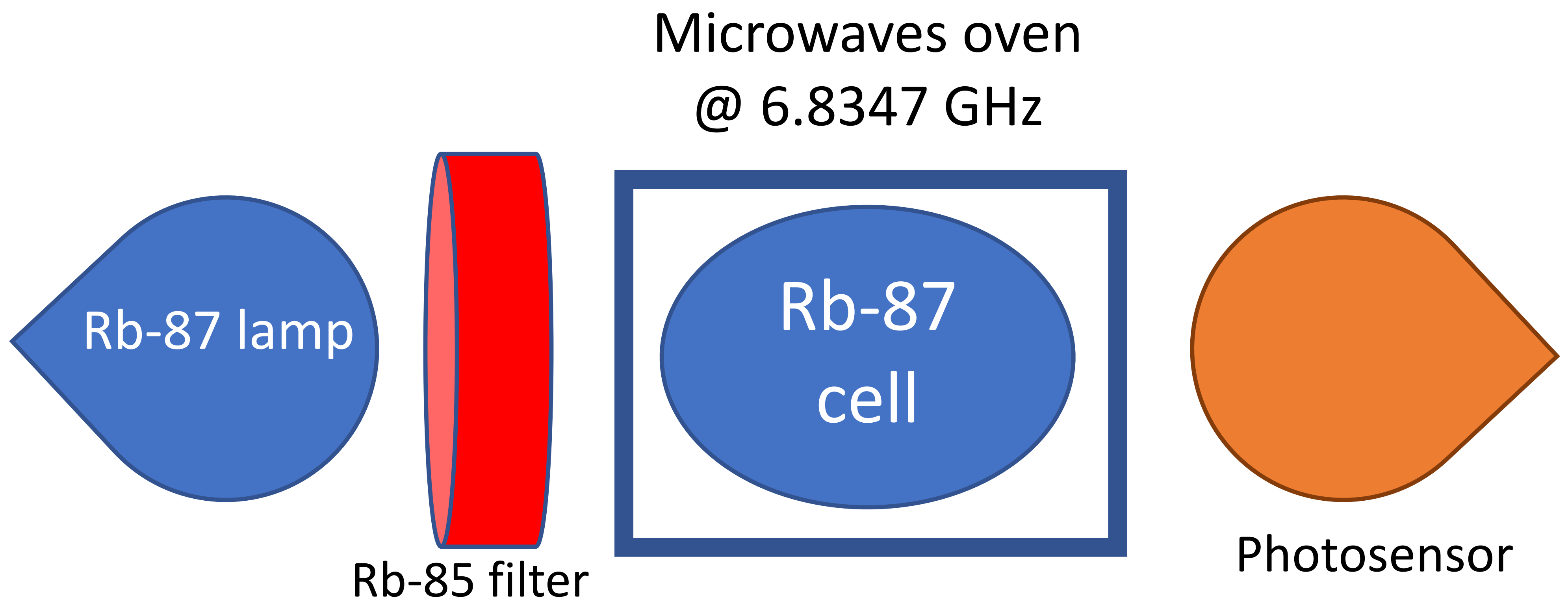
→ constant skew after reset

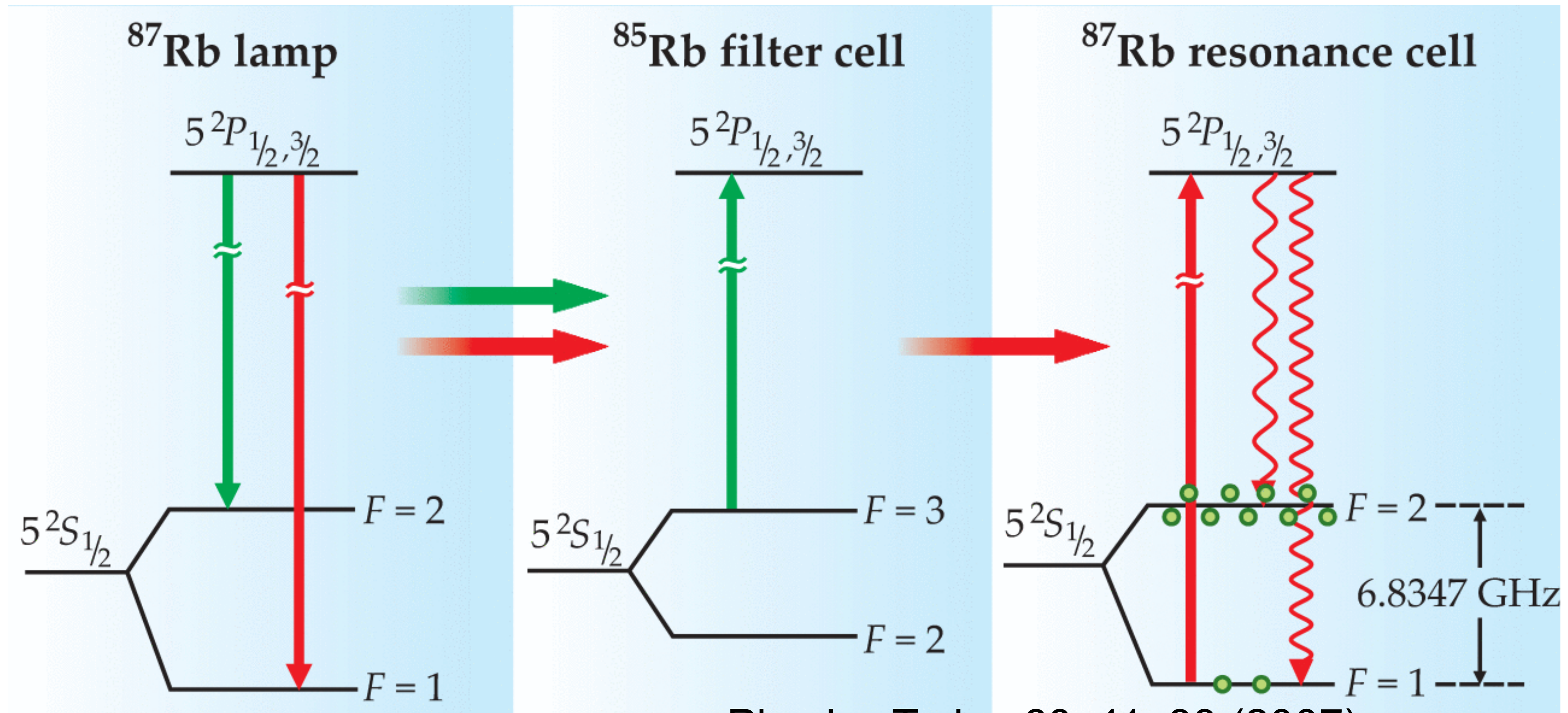


Overall scheme



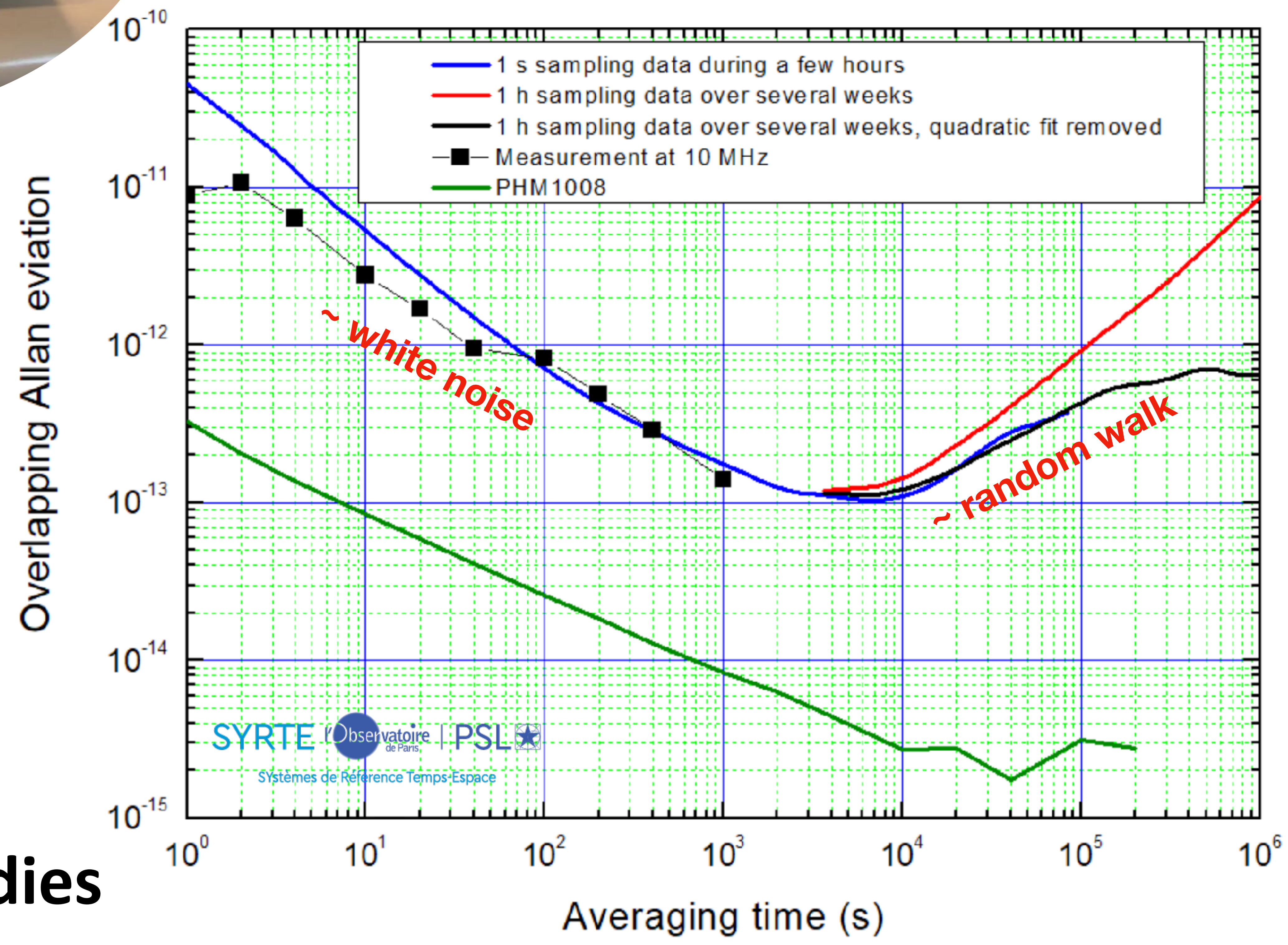
Time generation: atomic clock





Physics Today 60, 11, 33 (2007)

Intrinsic white noise
SRS FS7025: ~40 ps@1 s
PHM1008: 0.3 ps@1 s



Allan standard deviation: paper

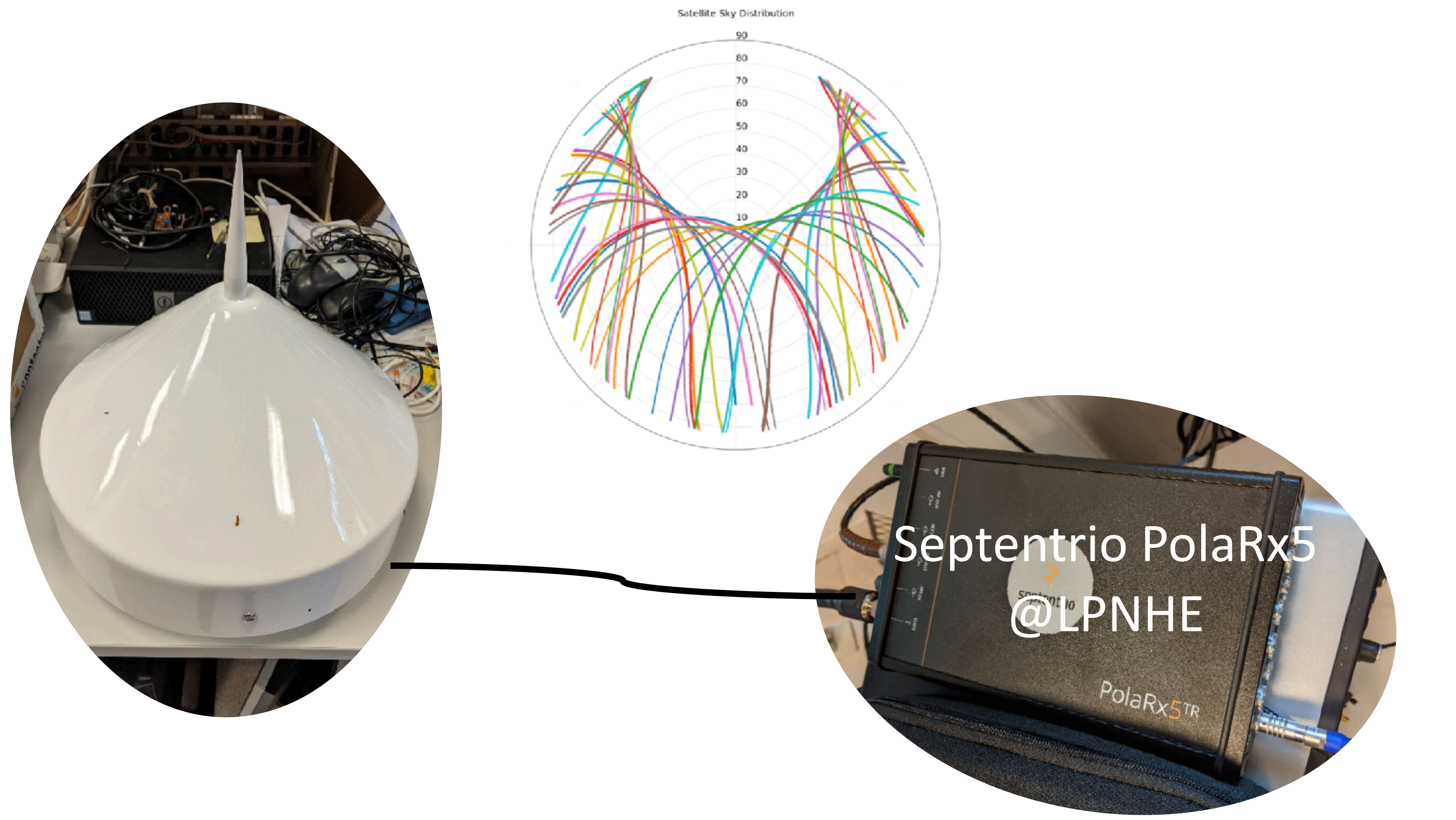
Comparison with time reference at SYRTE → **performances studies**
More stable clocks e.g. Passive Hydrogen Maser (PHM1008)

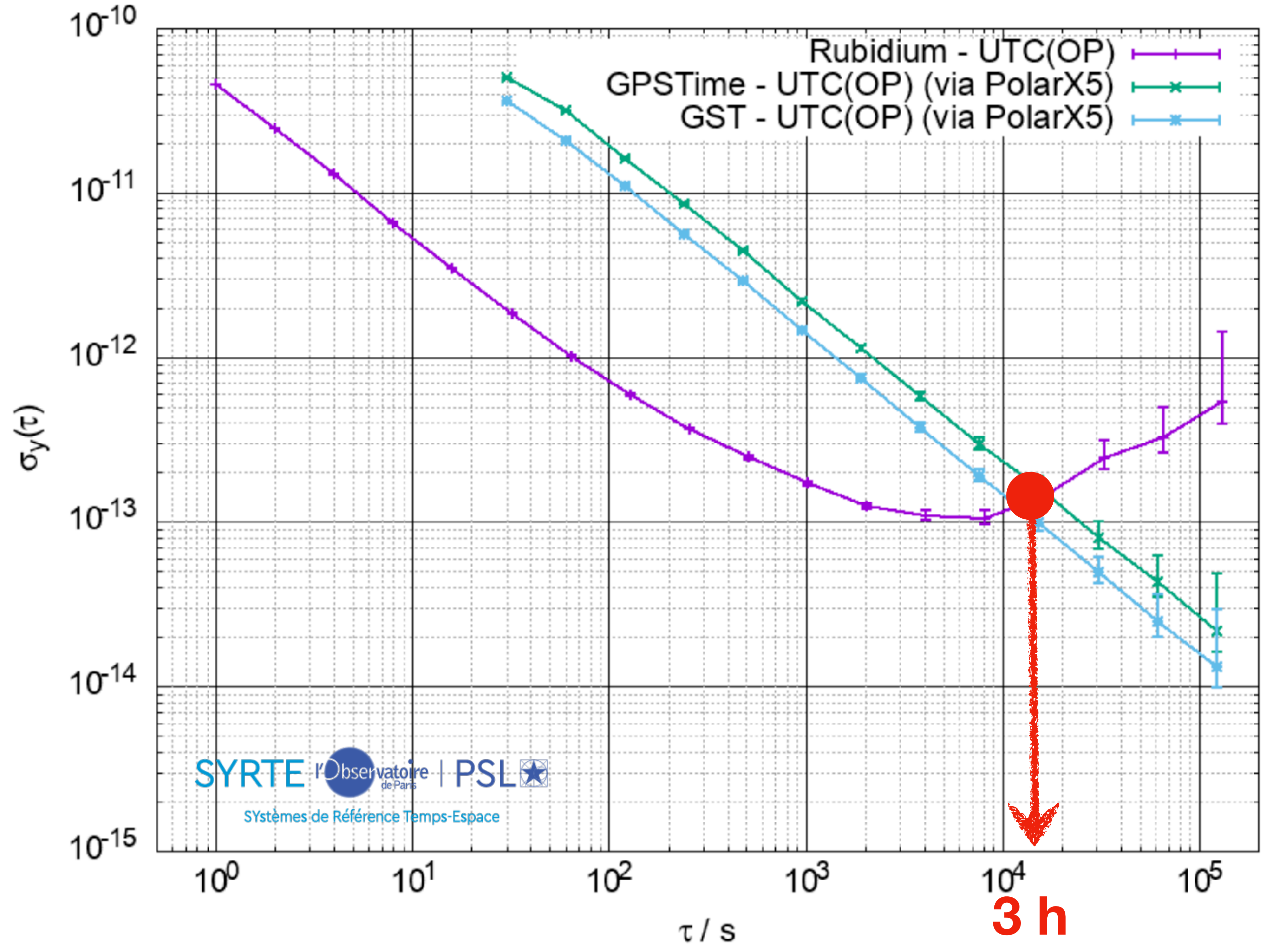
Time synchronization: GNSS

Correlation local time ↔ UTC using data stream coming from Global Navigation Satellite System (GNSS)

Short-term: Rb clock more stable than GNSS
Long-term: frequency of Rb clock changes (random walk) correctable using GNSS

→ Combine free-running atomic clock and offline time correction issued by GNSS receiver
→ Corrections every ~3 hours





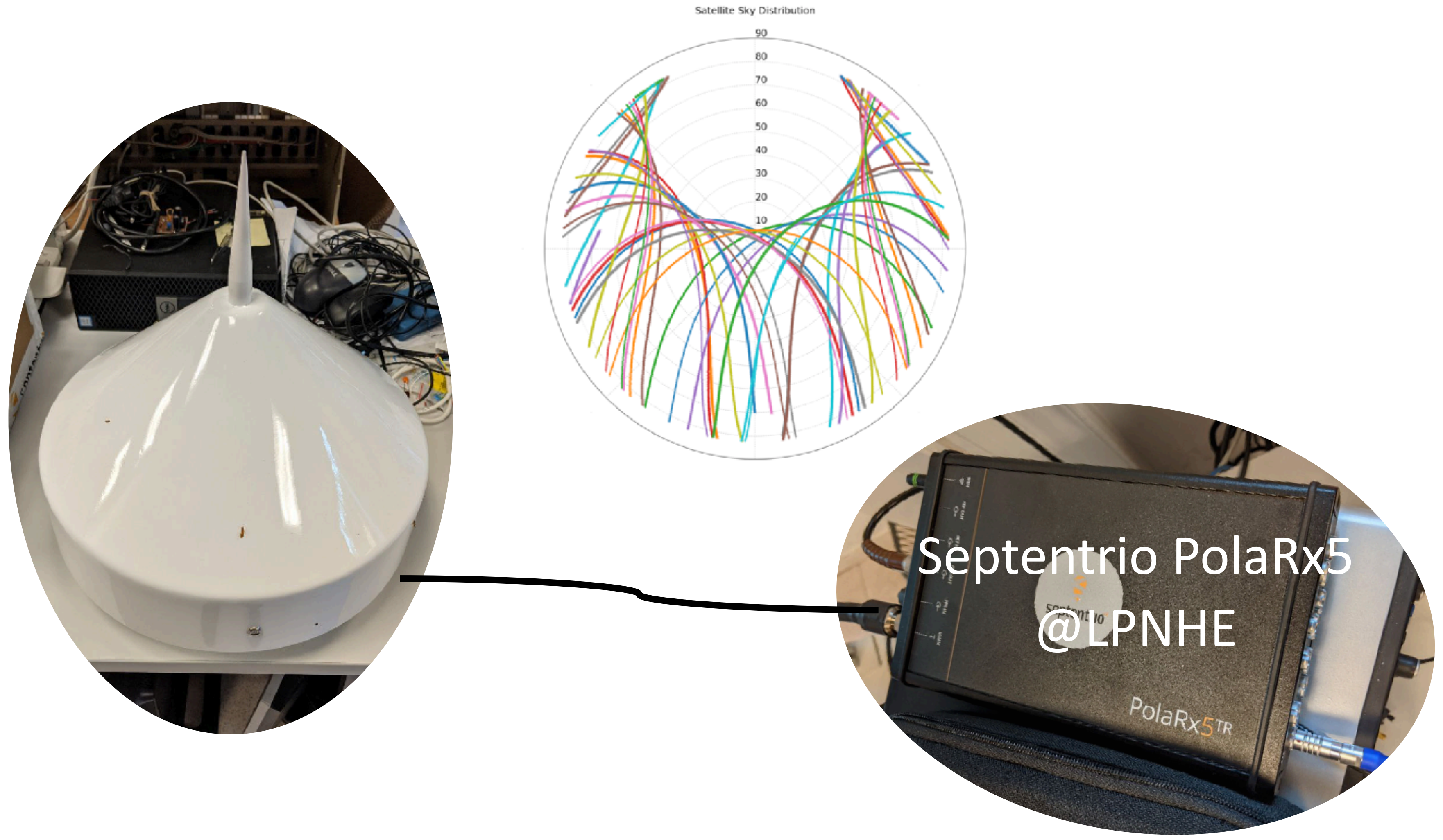
Time synchronization: GNSS

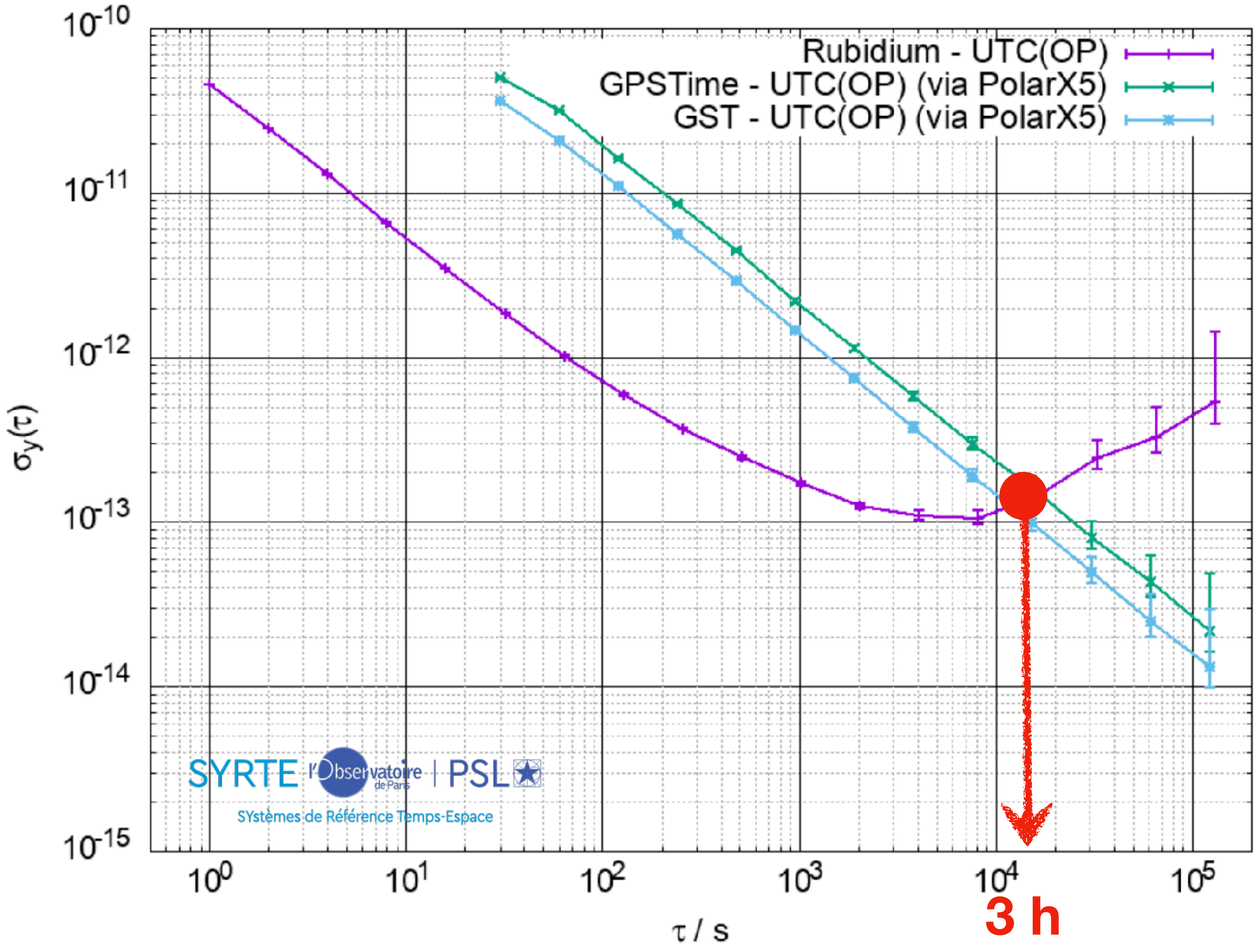
Correlation local time ↔ UTC using data stream coming from Global Navigation Satellite System (GNSS)

✓ Calibration of antenna, cables & electronics in collaboration with SYRTE (Obs. Paris) against time standard (precision sub-ns)

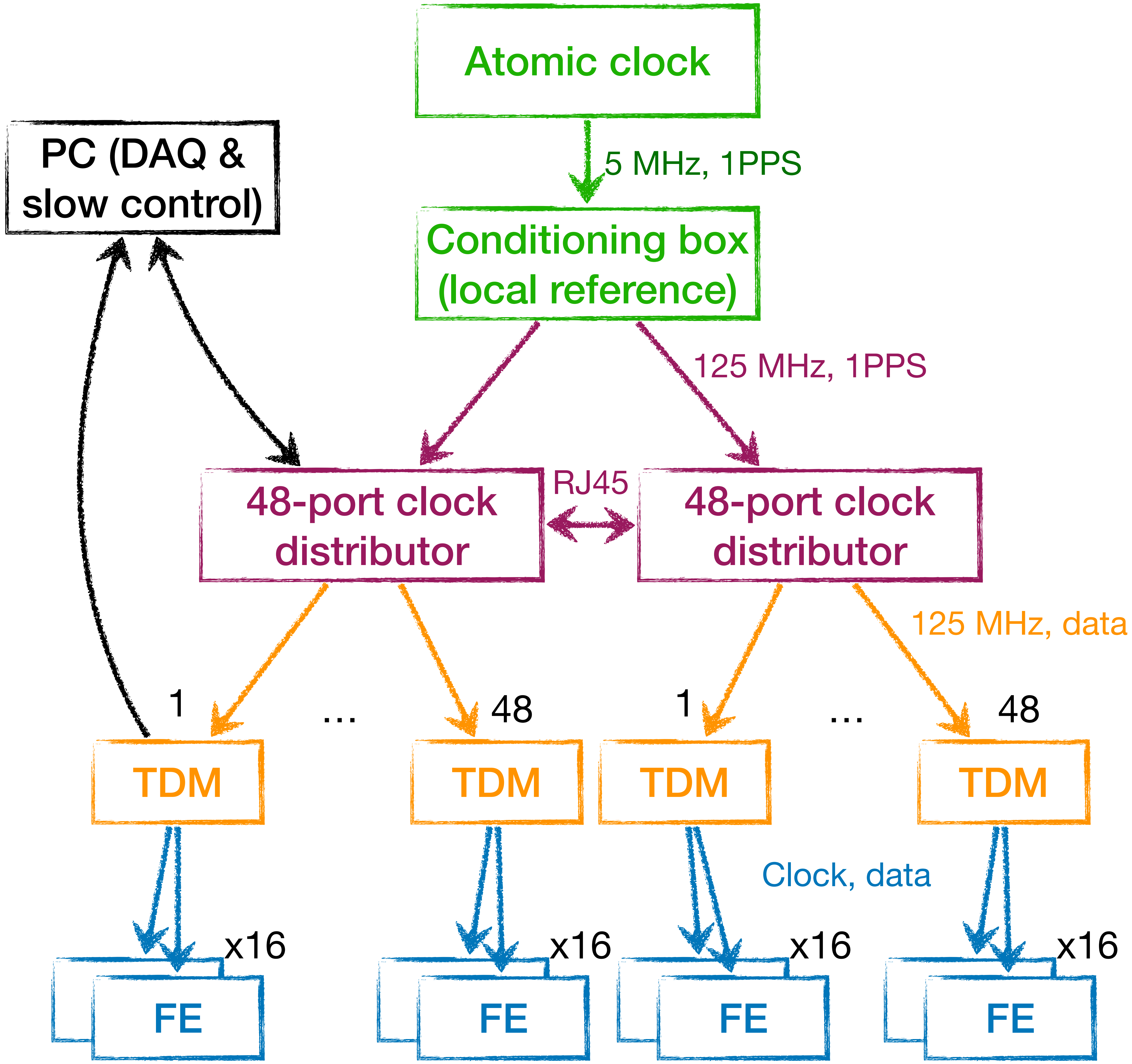
✓ Rb clock+GNSS measurements at LPNHE

- Impact of the number of visible satellites
- Synchronization GNNS-Rb clock via White-Rabbit
- Common view technique performances
- Usage of multi-constellations for better precision





Clock distribution scheme



Conditioning/fanout:
- serves as time reference point

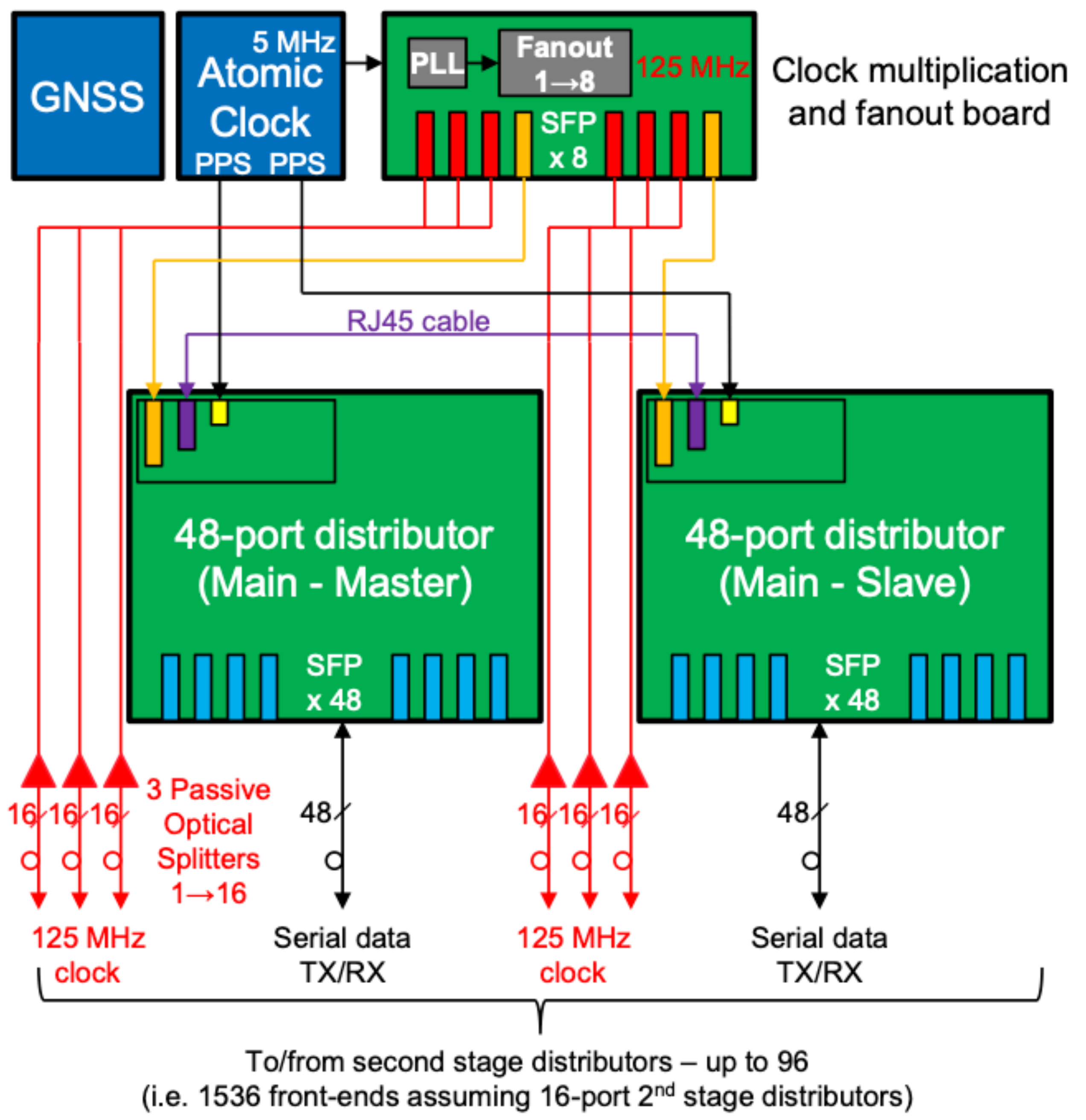
Based on Clock-in-Data-Recovery (CDR)

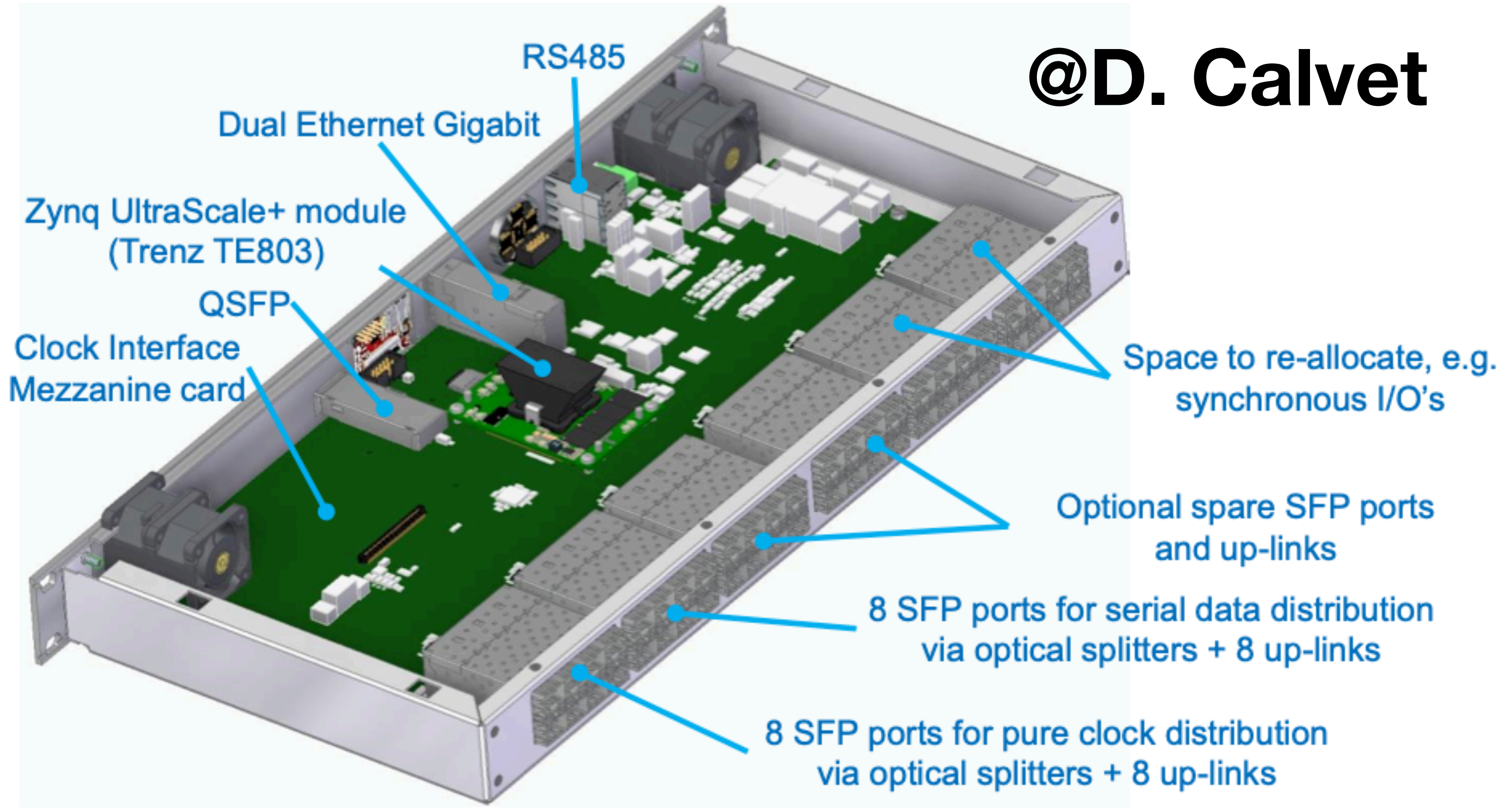
First-stage clock distributors (FSD):
- exchange control and status with DAQ PC
- receive synchronous signals
- send synchronous messages to second-stage distributors (TDM)

Second-stage clock distributors:
- receive and transmit clock/data from FSD to FE
- send slow control info to DAQ PC

Clock distribution prototypes

First-stage distributor prototype

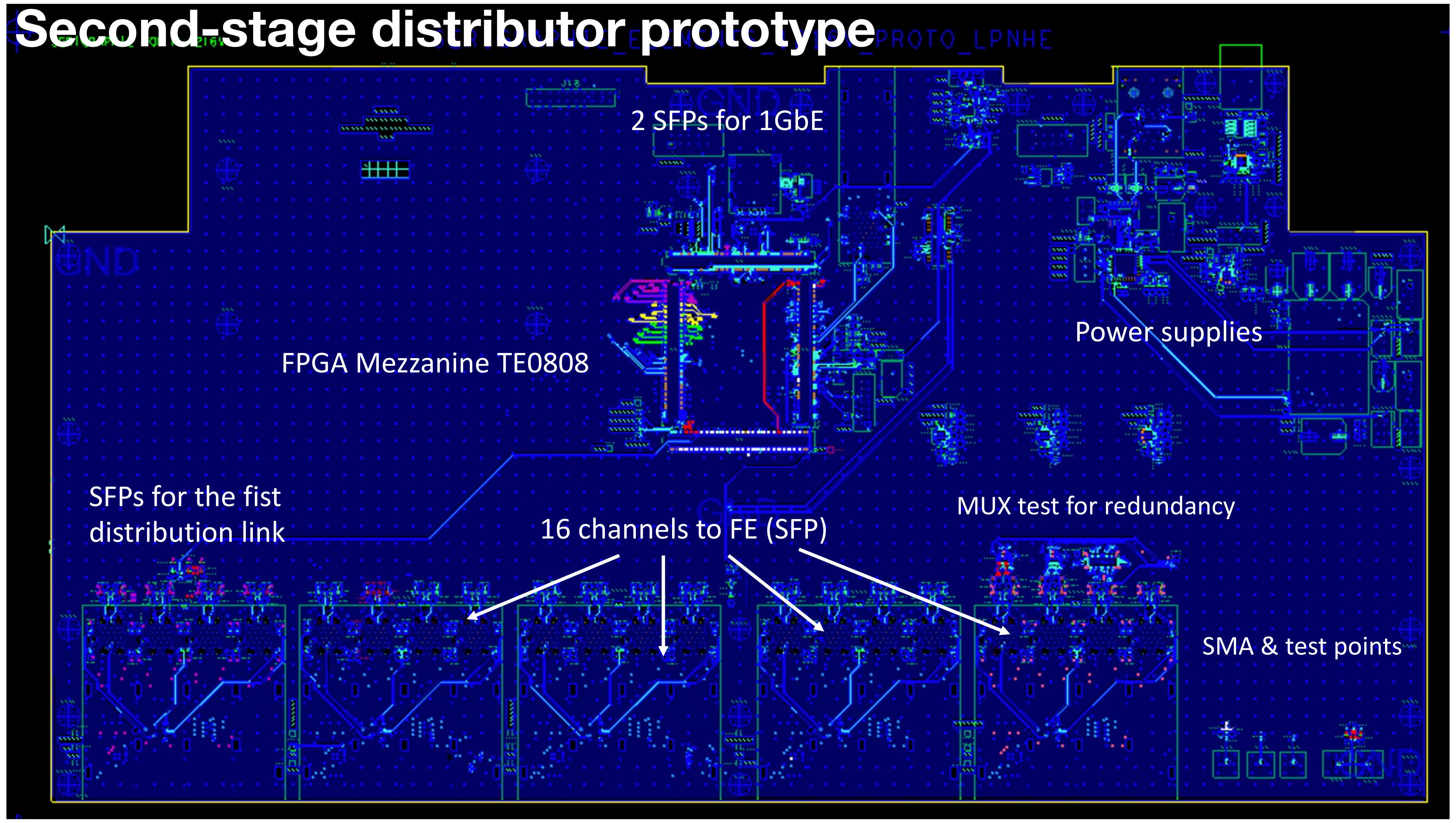




@D. Calvet

First- and second-stage distributors based on similar design
- Xilinx Zynq UltraScale+ (2 multi-core processors + FPGA)
- 48 or 32 SFP optical transceivers (half for redundancy)
- 2 GbEth links for external control and display

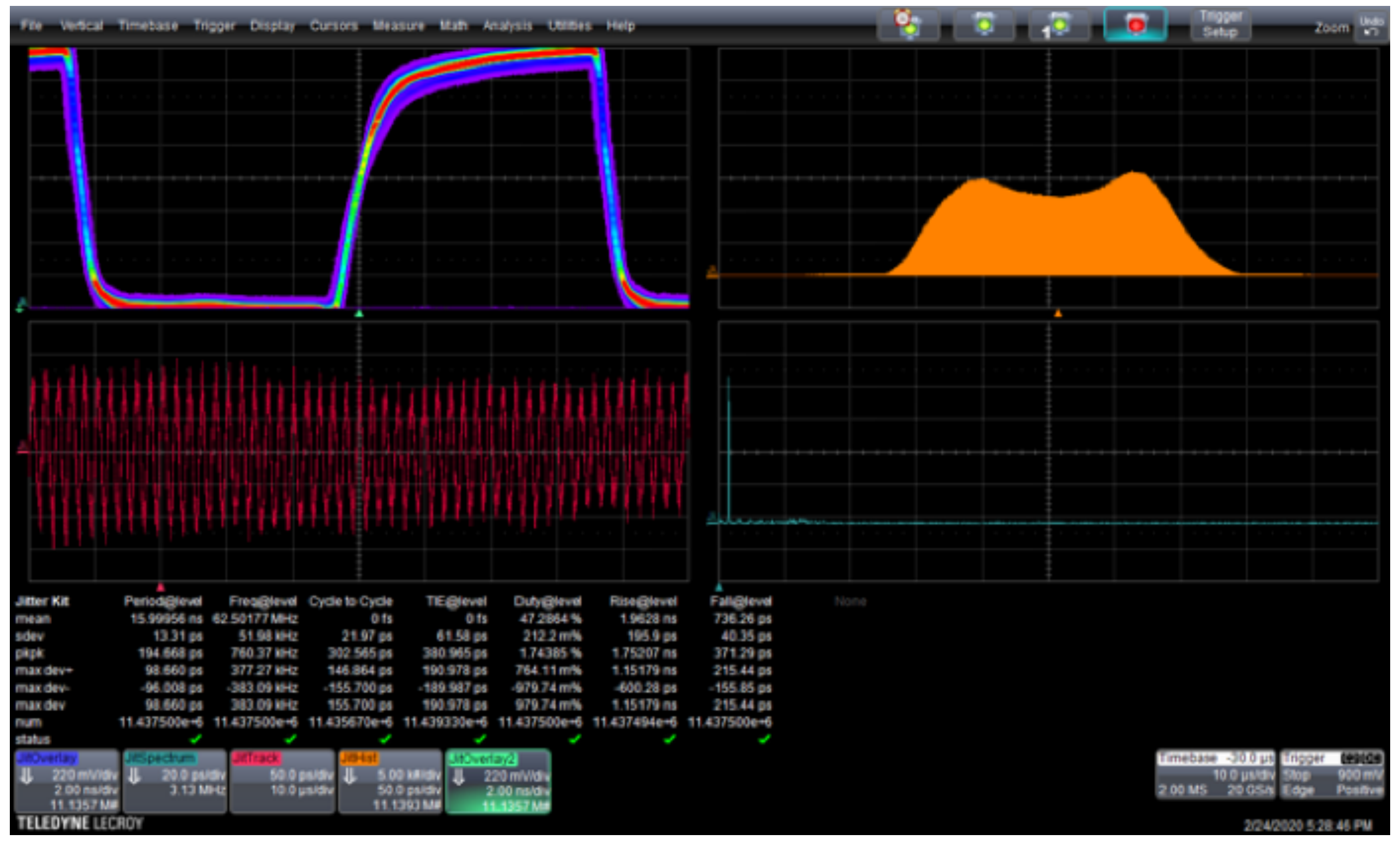
First prototypes being built/received and characterized



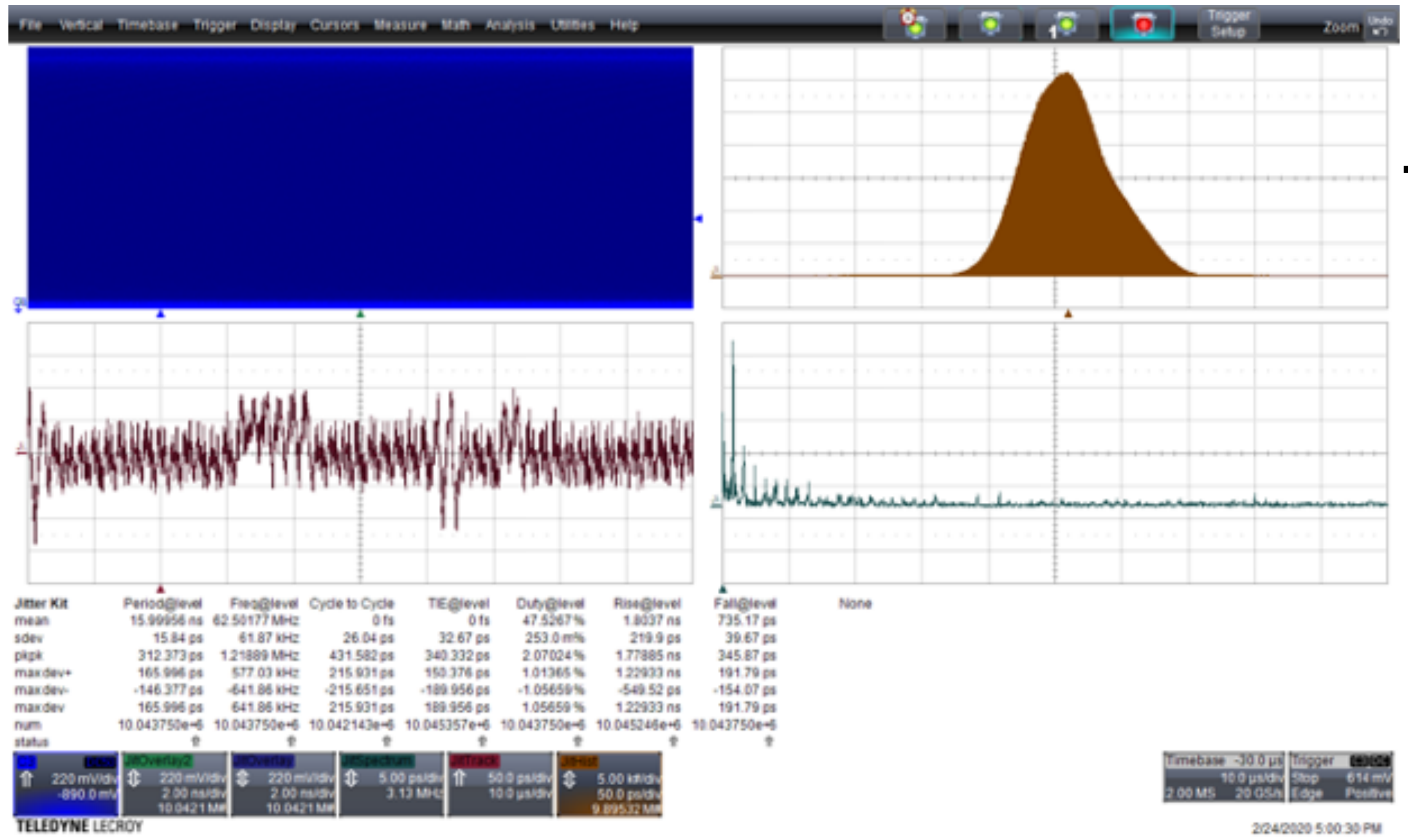
Clock distribution performances

Time domain

Received clock time
using oscilloscope (jitter 50 ps)

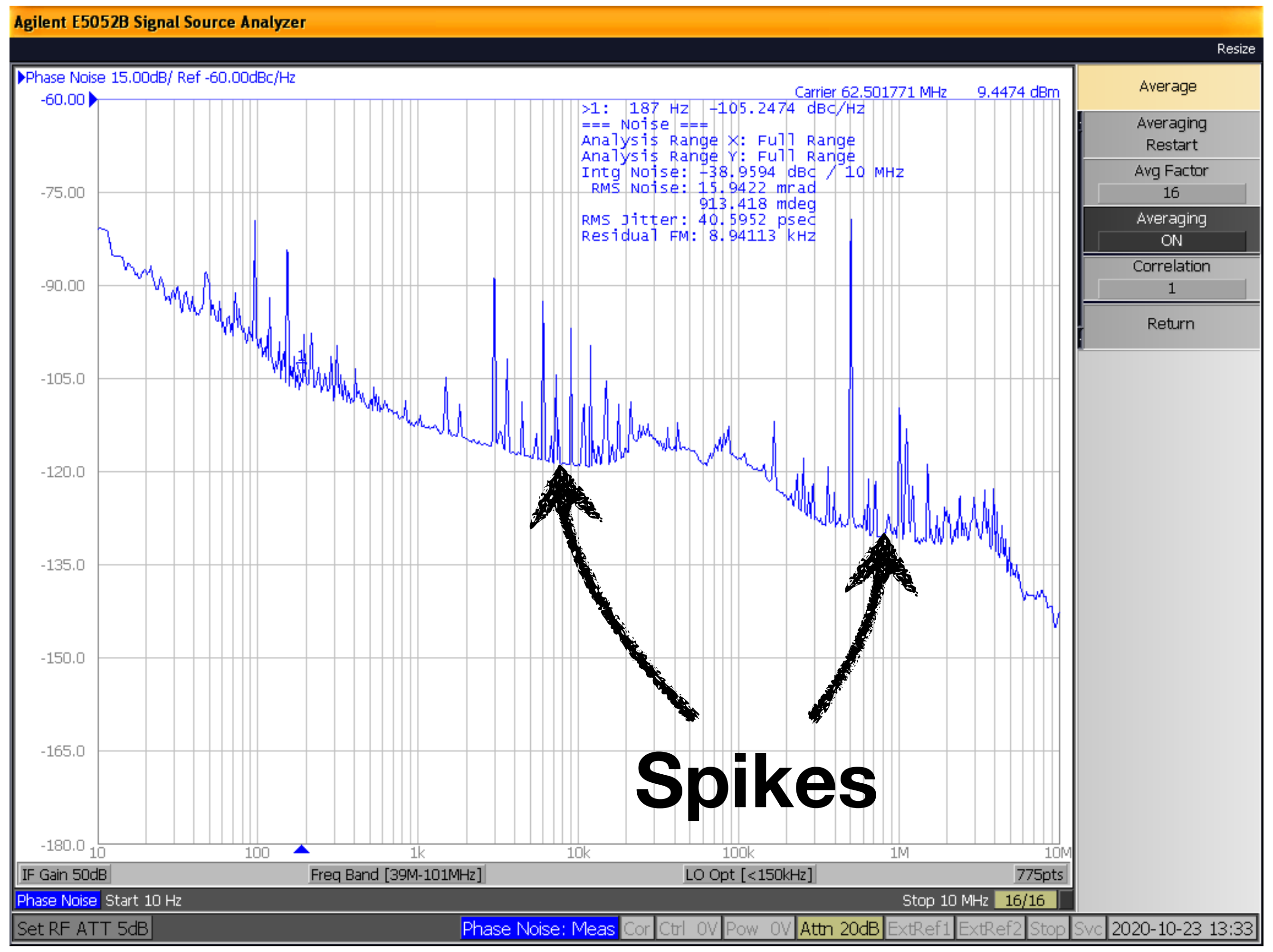


Transmitted clock time
using oscilloscope (jitter 32 ps)

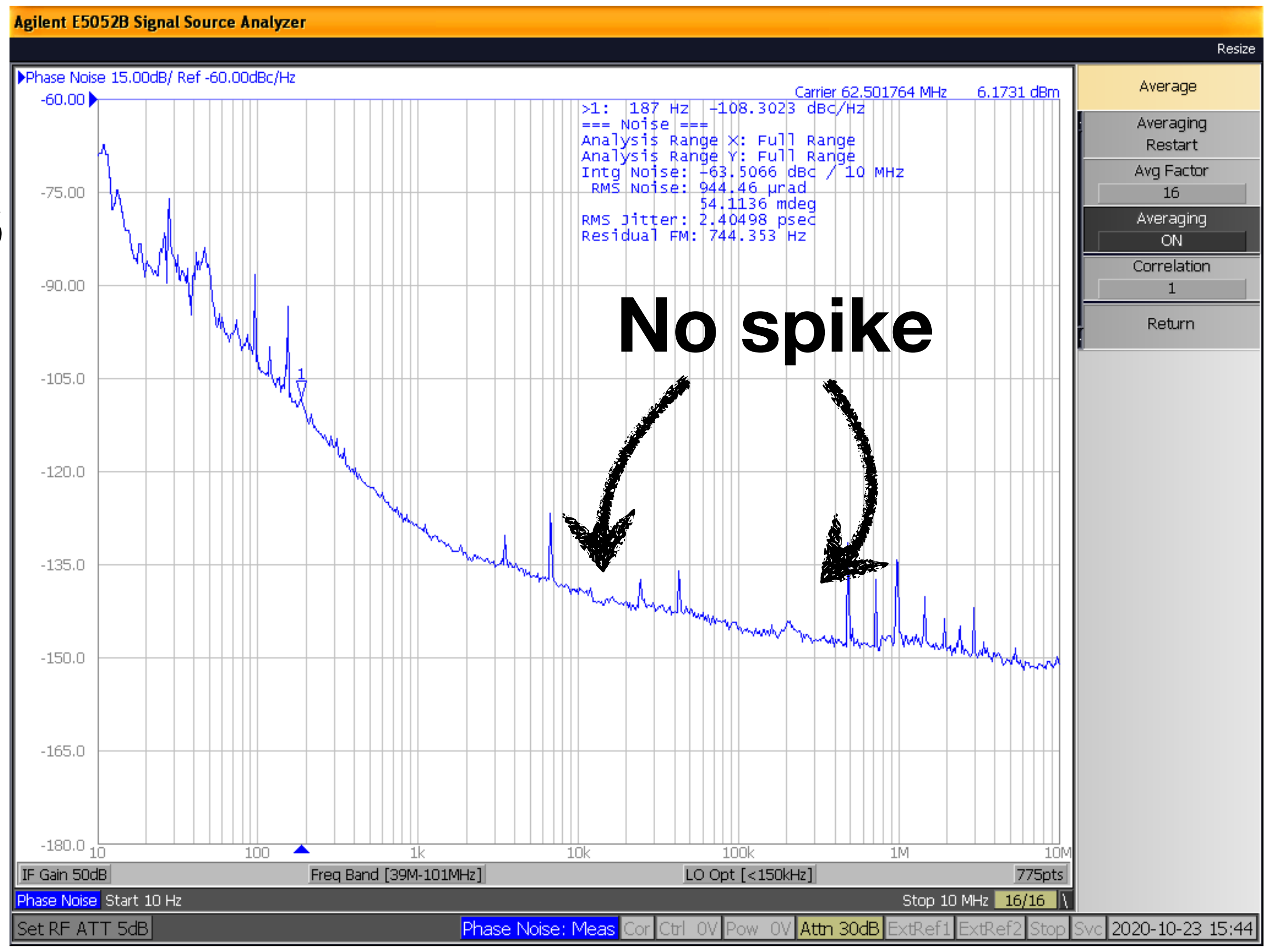


Frequency domain

Received clock (TX→RX) (jitter 40.6 ps)



Cleaned with Phase-Locked Loop (jitter 2.4 ps)



→ Required jitter below 100 ps is achievable with this technology !

Physics impact

Better precision for event time-tagging (~27 ns for T2K)
Better jitter (<100 ps)
Increased detector volume (x8 wrt SK)
More intense neutrino beam from J-PARC (x3 wrt T2K)

PRD 93, 012006 (2016)

Improved rings reconstruction

Time-Of-Flight measurements during J-PARC ν_μ beam
→ improvement by up to one order of magnitude (sub-MeV limit)

Time-Of-Flight using SuperNovae explosions
→ mostly improved by statistics
→ SN1987A with 20x stats → $m_\nu < 0.4$ eV (competitive with Katrin)

Conclusions

Hyper-Kamiokande has a vast and rich physics program including:

Long-baseline neutrino detection

Multi-messenger astrophysics (transient and diffuse SN detection)

→ **Need a precise timing determination of individual events**

→ **Need low jitter between PMTs all across the detector**

HK proposes:

- a time synchronisation system based on atomic clock and calibrated GNSS receivers
- a two-stage clock distribution system using CDR technology

Coordinated solution between France (IRFU & LPNHE) and Italy (INFN) with good synergies between boards

Excellent knowledge transfer between LPNHE and SYRTE