A Quick Introduction to White Rabbit and the White Rabbit Collaboration

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European Organisation for Nuclear Research
(CERN)

ENTSO-E Research, Development and Innovation Committee (RDIC) WG5 Meeting

12 September 2024

Outline

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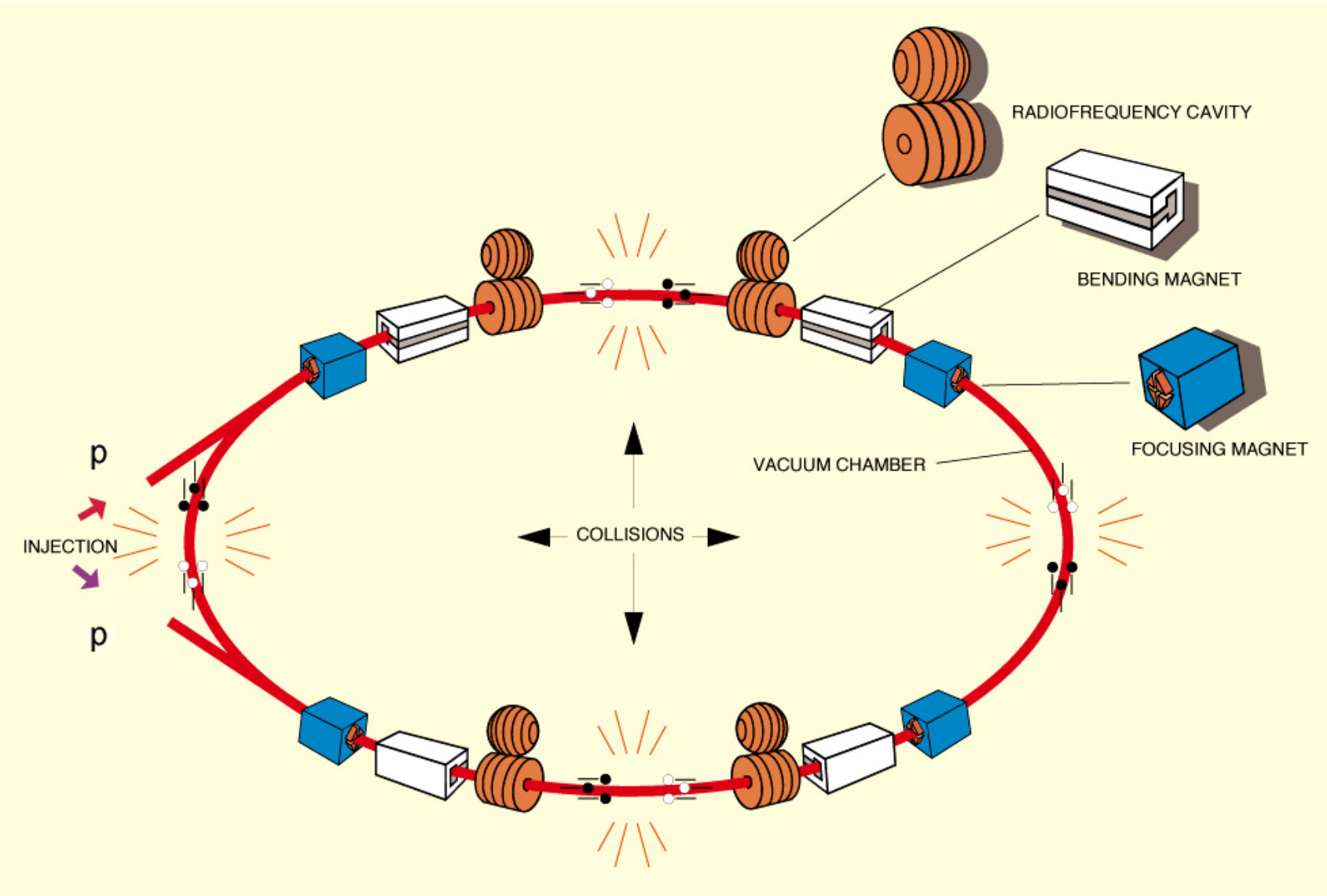
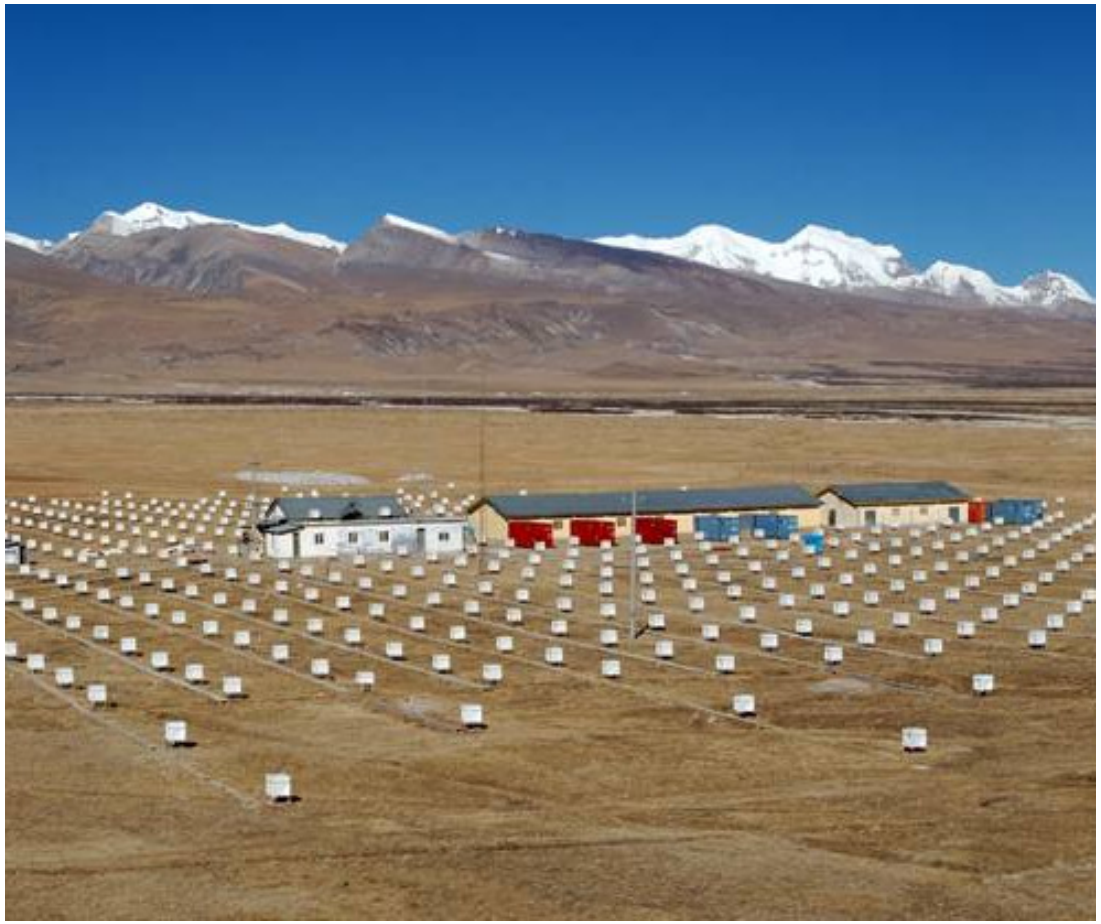
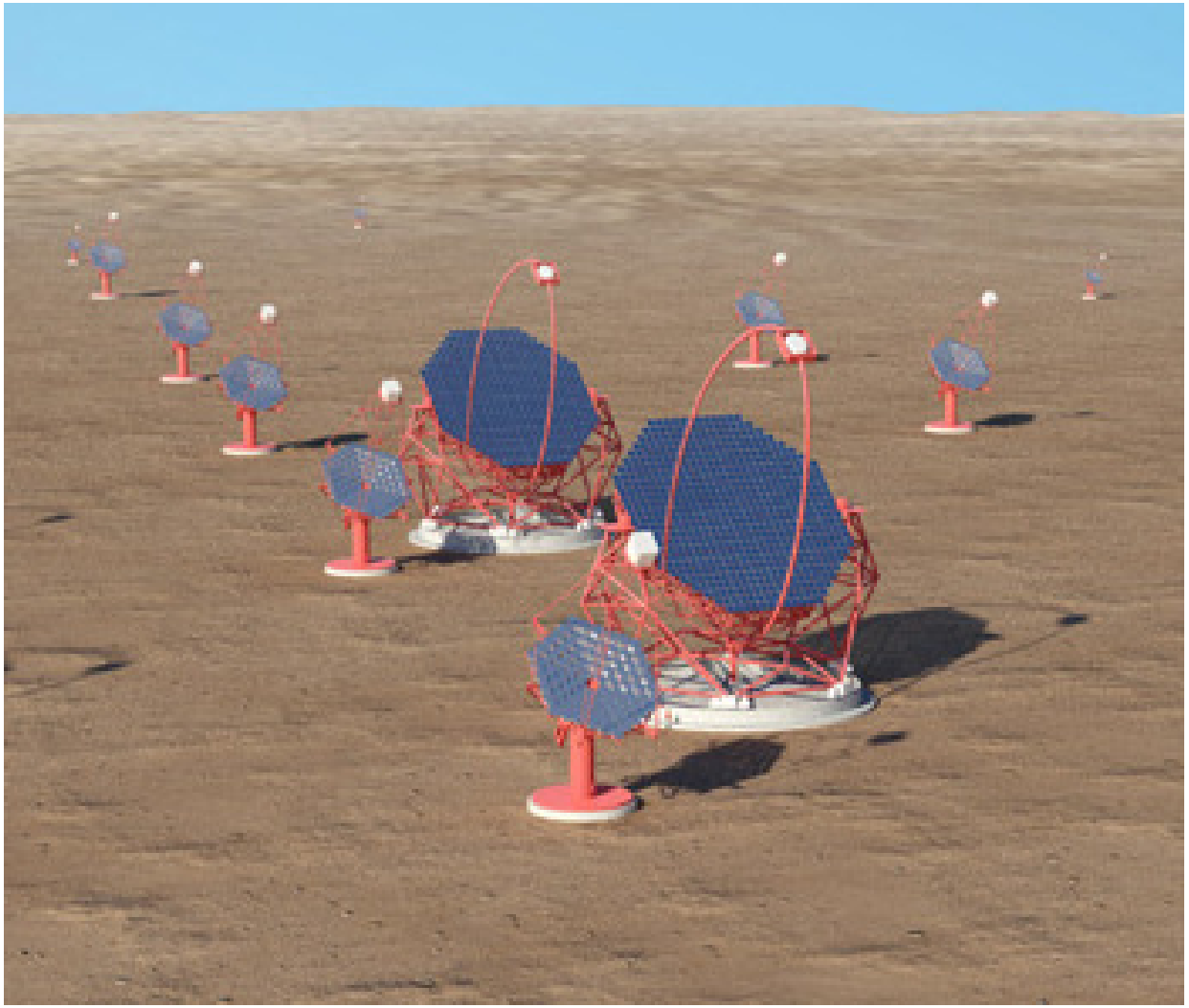
Why we need good synchronisation at CERN



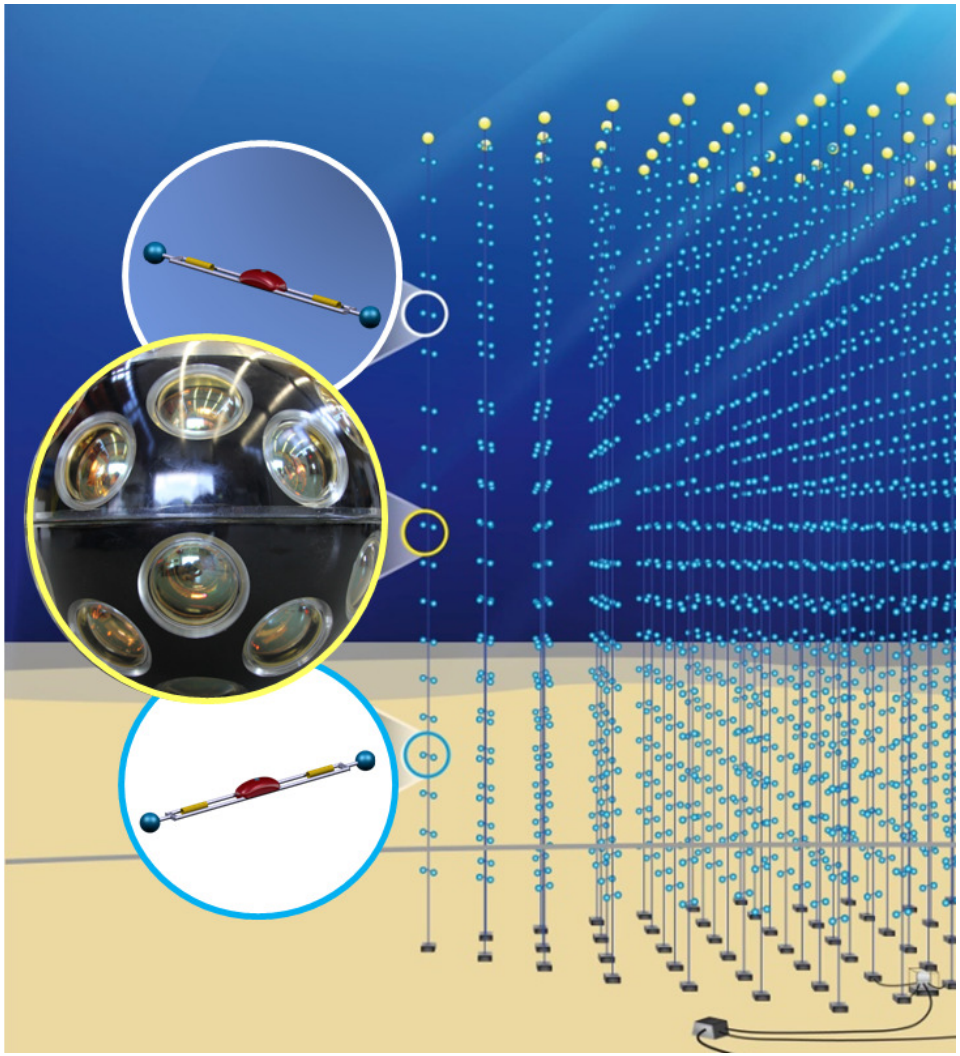
Large High Altitude Air Shower Observatory (LHAASO)



Cherenkov Telescope Array (CTA)



Cubic Kilometre Neutrino Telescope (KM3NeT)



And of course also outside Physics

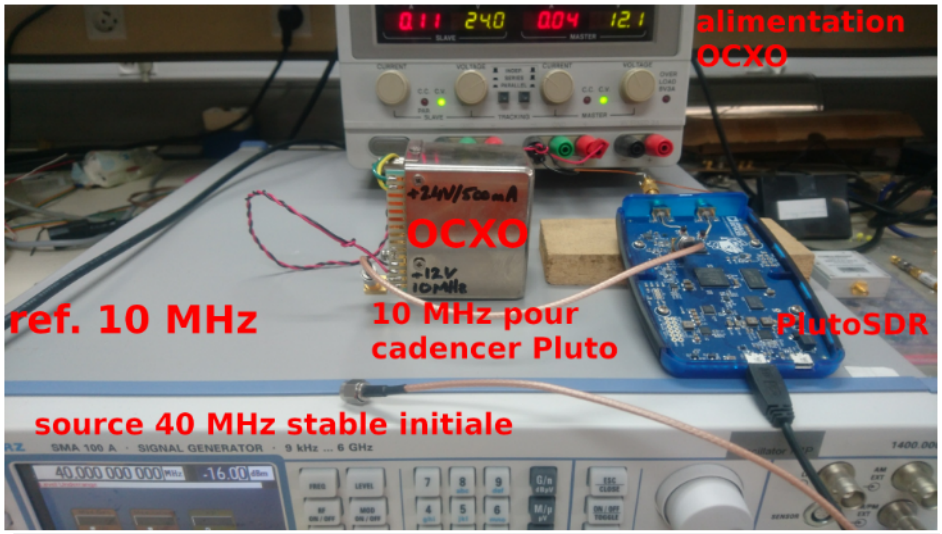
Some examples

- Electric power distribution
- Finance (time-stamping of transactions)
  - to comply with the law (MiFID II)
  - as a service to customers of e.g. a stock exchange
- Telecom

Outline

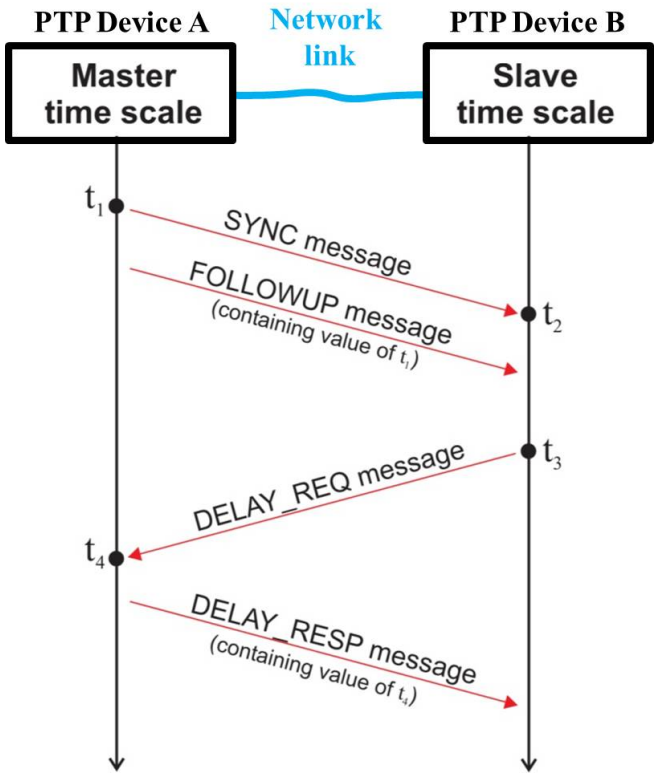
Global Navigation Satellite Systems (GNSS)

GNSS jamming and spoofing



Courtesy J.M. Friedt

Precision Time Protocol (IEEE 1588)



- Frame-based synchronisation protocol
- Simple calculations:
  - link delay: $\delta_{ms} = \frac{(t_4 - t_1) - (t_3 - t_2)}{2}$
  - offset from master: $OFM = t_2 - (t_1 + \delta_{ms})$

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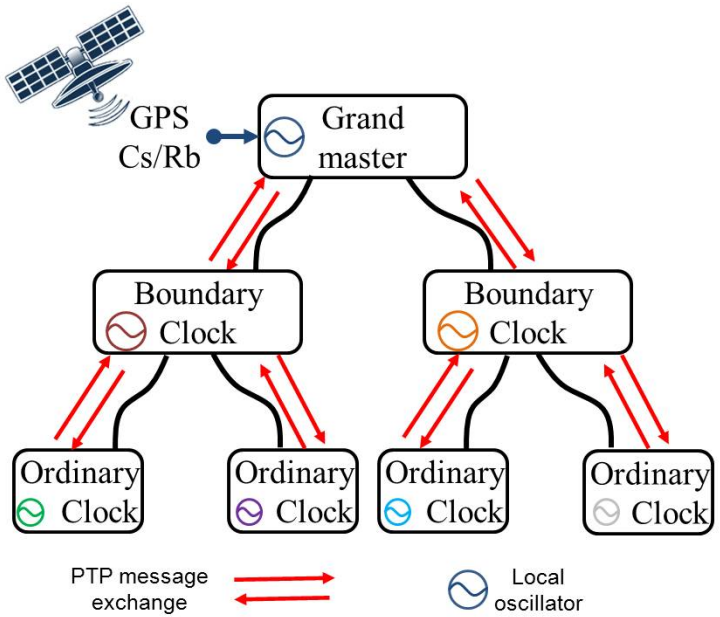

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- Hierarchical network

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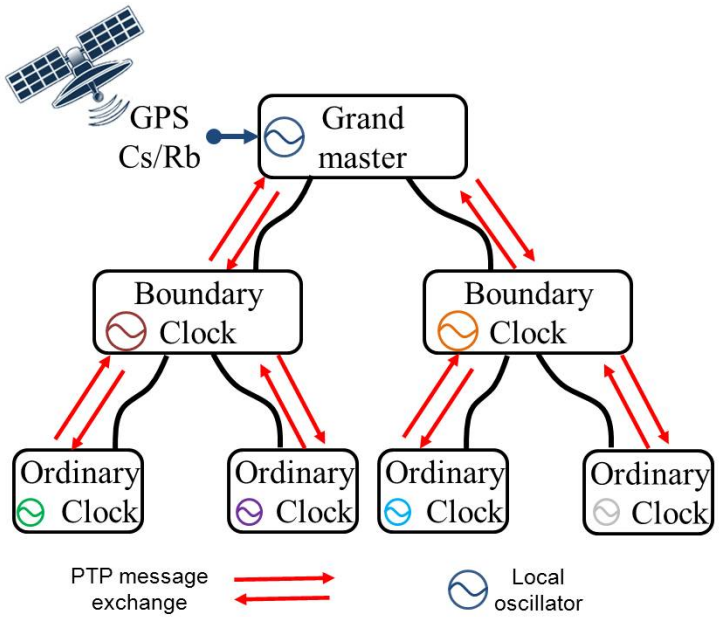

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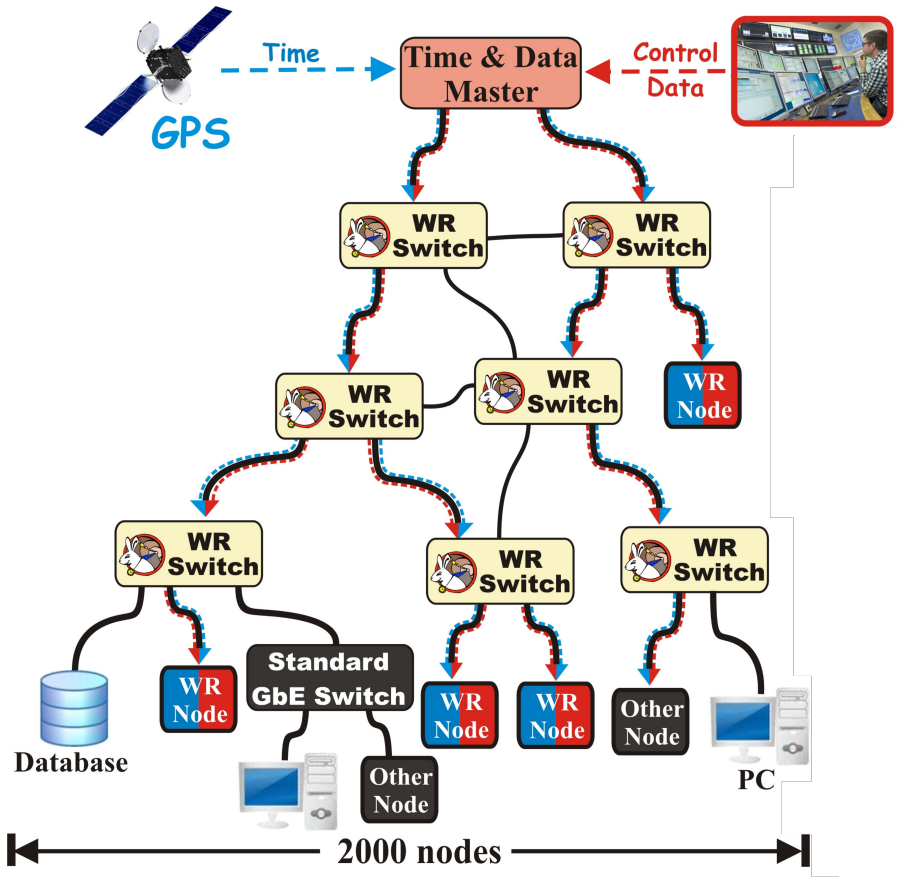
- Hierarchical network
- Shortcomings of traditional PTP:
  - devices have free-running oscillators
  - frequency drift compensation traffic can compromise determinism of other messages
  - assumes symmetry of medium
  - resolution of timestamps

Outline

What is White Rabbit?

- Initially meant for Big Physics facilities/projects: CERN, GSI, Nikhef...
- **Based on well-established standards**
  - Ethernet (IEEE 802.3)
  - Bridged Local Area Network (IEEE 802.1Q)
  - Precision Time Protocol (IEEE 1588)
- **Extends standards** to meet new requirements and provides
  - Sub-ns synchronisation
  - Deterministic data transfer
- Initial specs: links $\leq$10 km & $\leq$2000 nodes
- **Open Source and commercially available**



Open **and** commercially available off-the-shelf

WR Switch

Seven Sol, Spain
Creotech, Poland

OPNT, Netherlands
SyncTechnology, China

Simple VME FMC carrier (SVEC)
Janz Tec AG, Germany

Simple PCIe FMC carrier (SPEC)
Creotech, Poland
INCAA, Netherlands
Seven Solutions, Spain
ISD S.A., Greece

Compact Universal Timing Endpoint (Cute-WR-DP)
SyncTech, China

Digitizers
Struck, Germany
SP Devices, Sweden

GPS Disciplined Oscillator
Seven Solutions, Spain

ZEN TP-32 BNC
Seven Solutions, Spain

PXI module
Sundance, UK

Companies selling White Rabbit:

`www.ohwr.org/projects/white-rabbit/wiki/wrcompanies`

White Rabbit technology - sub-ns synchronisation

Based on

- IEEE 1588 Precision Time Protocol on Gigabit Ethernet over fibre

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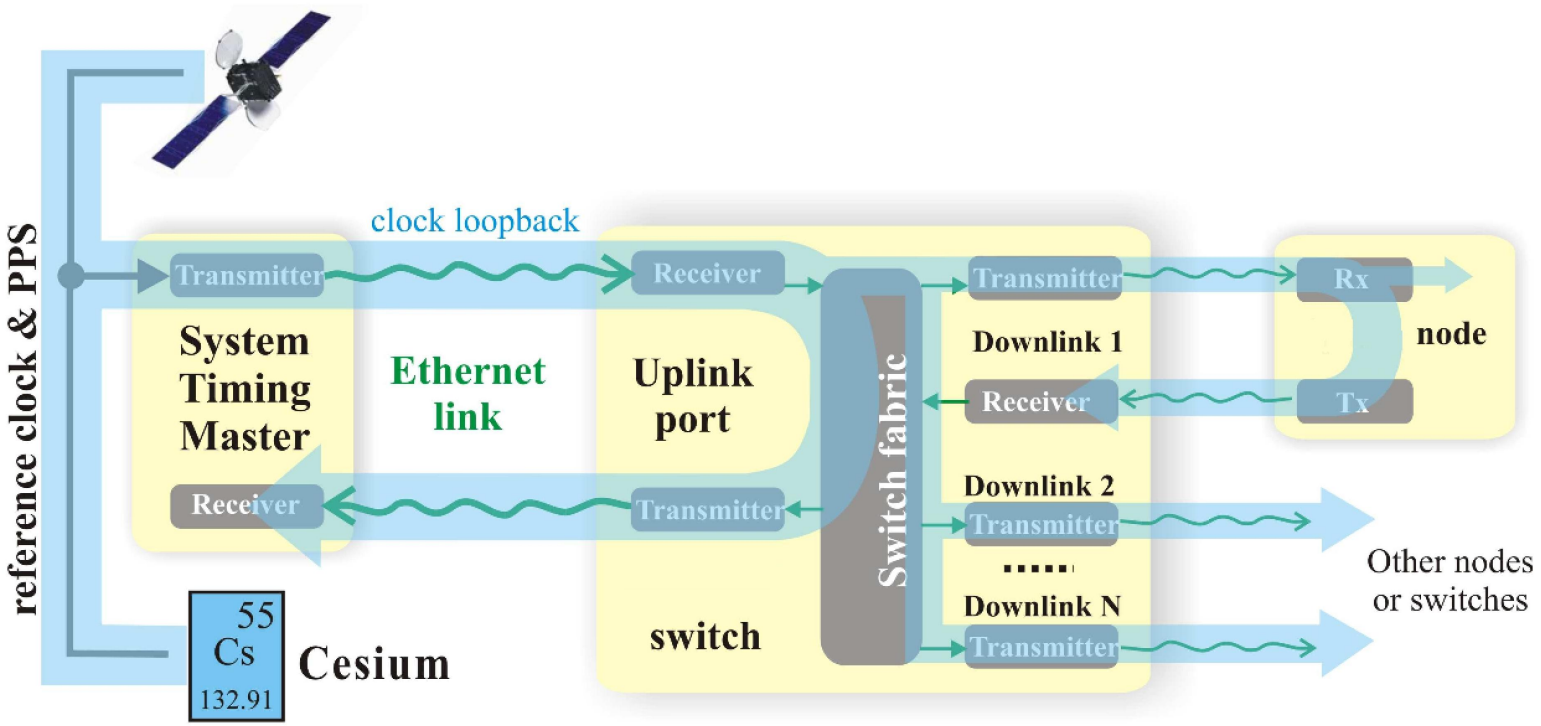
Enhanced with

- Layer 1 syntonisation
- Digital Dual Mixer Time Difference (DDMTD)
- Link delay model

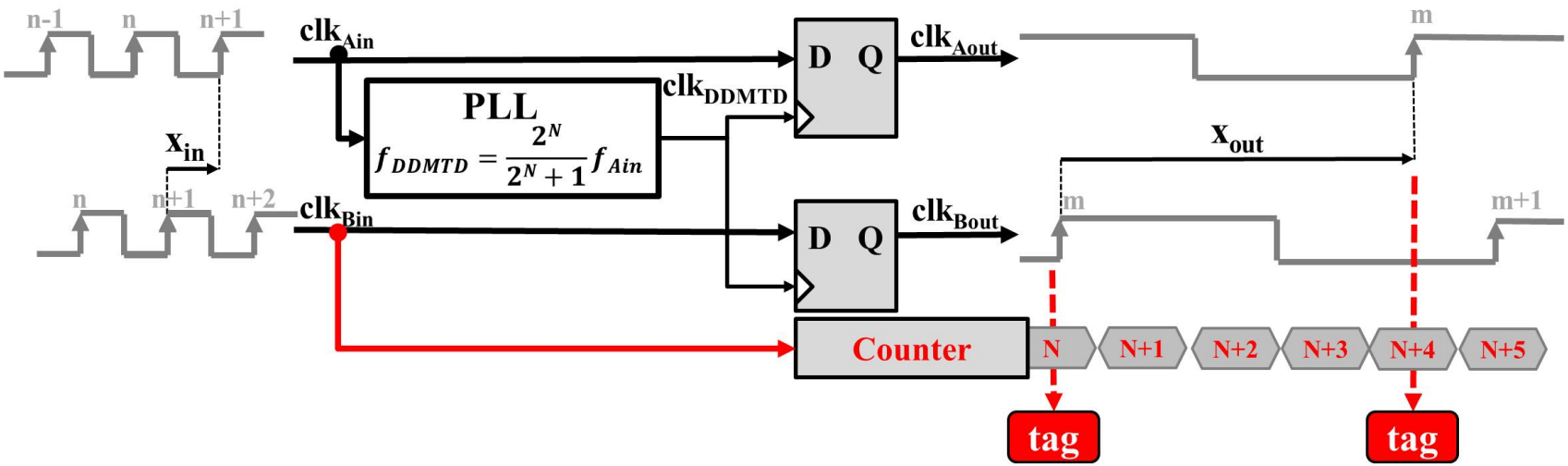
Layer 1 Syntonisation

- Clock is encoded in the Ethernet carrier and recovered by the receiver chip
- All network devices use the same physical layer clock
- Clock loopback allows phase detection to enhance precision of timestamps



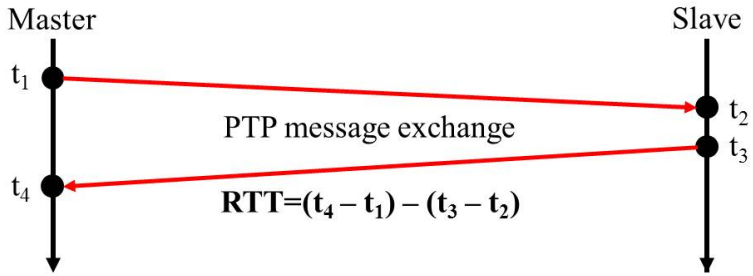
Digital Dual Mixer Time Difference (DDMTD)

- Precise phase measurements in FPGA
- WR parameters:
  - clk_{in} = 62.5 MHz
  - clk_{DDMTD} = 62.496185 MHz (N=14)
  - clk_{out} = 3.814 kHz
- Theoretical resolution of 0.977 ps



Link delay model

- Correction of Round Trip Time (RTT) for asymmetries



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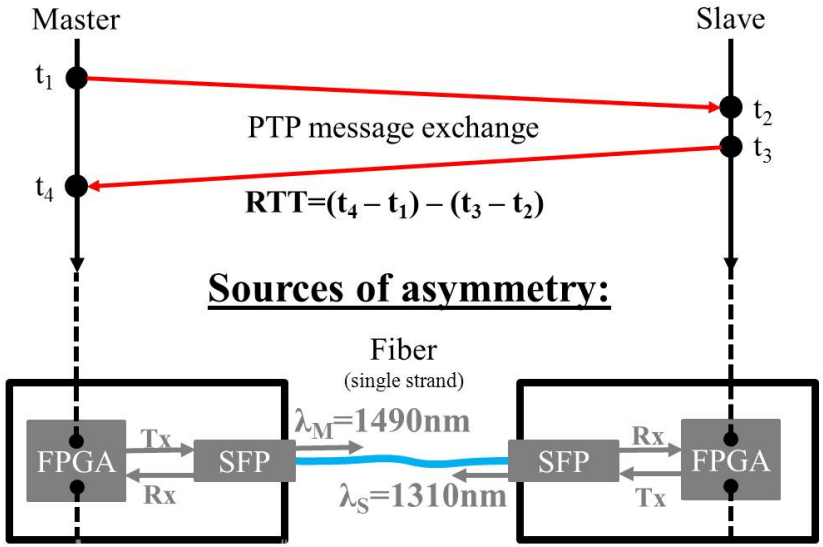
- Asymmetry sources: FPGA, PCB, electrical/optical conversion, chromatic dispersion



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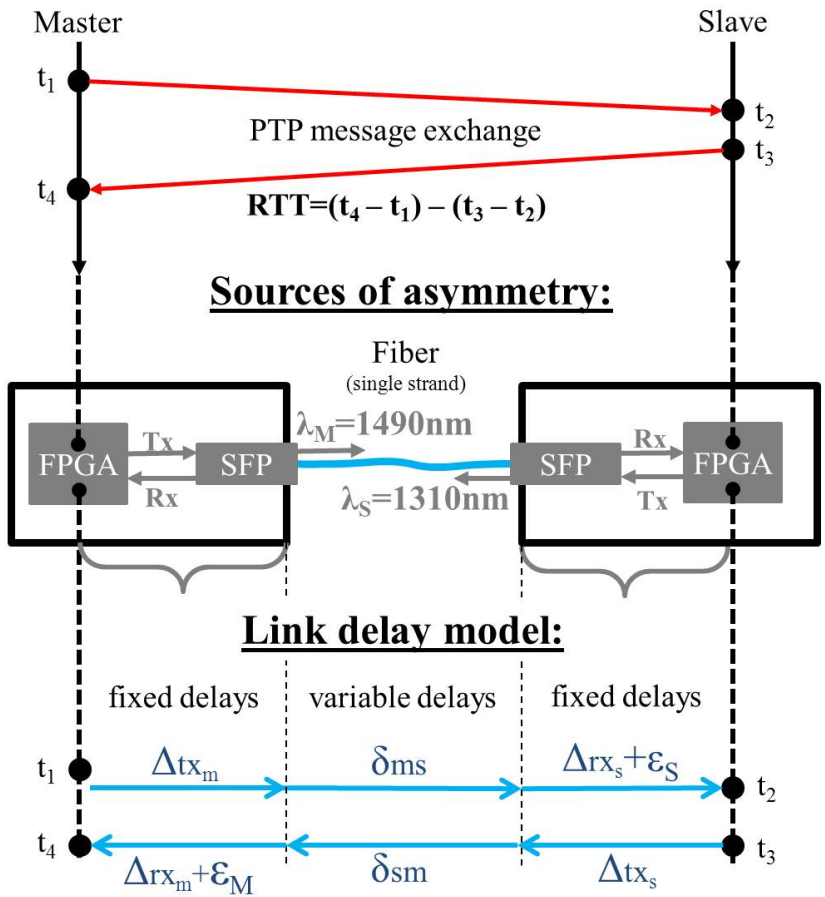
  - **Fixed delays** – calibrated/measured
  - **Variable delays** – evaluated online with:

$$\alpha = \frac{\nu_g(\lambda_s)}{\nu_g(\lambda_m)} - 1 = \frac{\delta_{ms} - \delta_{sm}}{\delta_{sm}}$$



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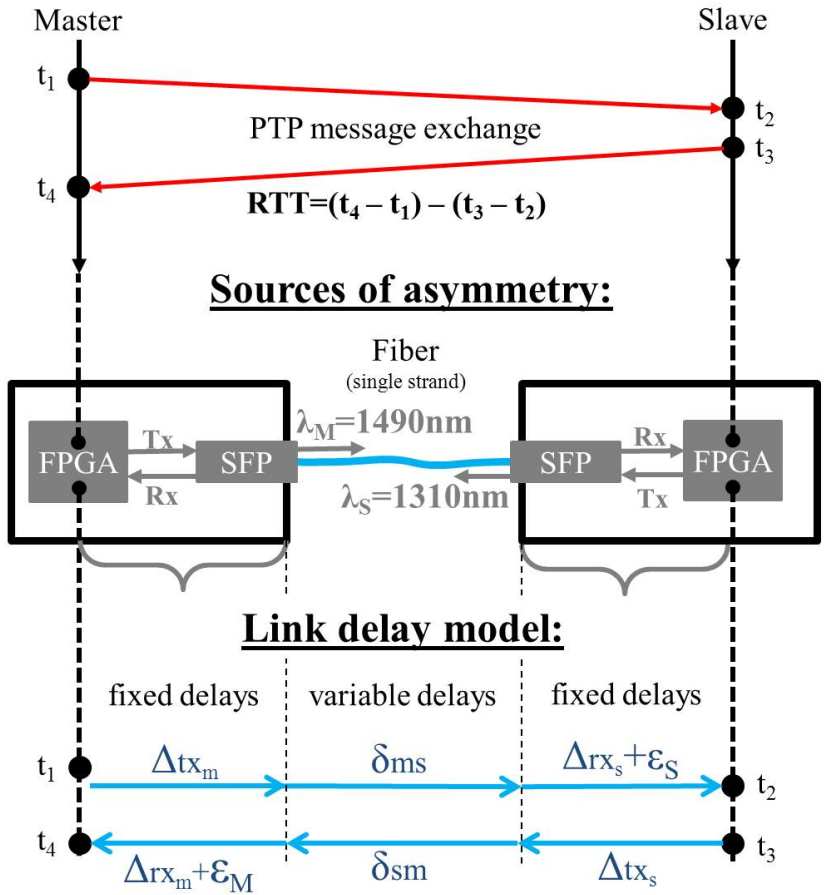
- Accurate offset from master (OFM):

$$\delta_{ms} = \frac{1+\alpha}{2+\alpha}\left(RTT - \sum \Delta - \sum \epsilon\right)$$

$$OFM = t_2 - (t_1 + \delta_{ms} + \Delta_{txm} + \Delta_{rxs} + \epsilon_S)$$



Outline

Short history of WR

- 2008: first meeting at CERN
- 2009: first switch prototype
- 2012: first COTS switch available (open-source hardware, gateware, firmware, software)
- 2012: first operational deployment of WR (Gran Sasso National Lab)
- 2013-2018: WR concepts standardised within IEEE 1588
- 2024: creation of the WR Collaboration (see launch event)

WR post-standardisation

A technology supported by a friendly community working on a fully open-source implementation of IEEE 1588-2019 High-Accuracy (HA) profile, with a guaranteed sub-nanosecond accuracy.

Outline

Entering a new phase

Post-standardisation issues

- How to maintain good support after the increase in uptake of the technology, both in industry and academia?
- How to ensure a high level of quality in the foundations of WR (switch and WR PTP core)?

The White Rabbit Collaboration in a nutshell

Ensuring sustainability

- Members pay a yearly fee and shape the future of the technology.
- Fees are used to pay the WR Collaboration Bureau, which offers support (including training) and ensures WRS and WRPC are always in good health.

The White Rabbit Collaboration in a nutshell

Letting information flow

- Collaboration with vendors ensures coherent growth of the WR ecosystem
- Keeping members well informed: online presentations, forum, regular meetings...
- Connecting people, institutes, companies (e.g. connecting NRENs with industry)

The White Rabbit Collaboration in a nutshell

Ensuring high-quality

- Making the evolution of WRS and WRPC the main task of the Bureau
- Teaming up with laboratories to establish a set of tests and qualification criteria
- Connecting the use of the WRC logo to the successful passing of those tests

The White Rabbit Collaboration in a nutshell

Projects! Some examples:

- Mobile (e.g. TDD on 5G)
- Quantum: see e.g. CERN's Quantum Tech Initiative at https://quantum.cern/
- Smart grids

An experiment in public-private partnerships

Getting the best of both worlds

- Dissemination according to our Open Science mandate
- Impact and sustainability

White Rabbit Collaboration

For more details, see
https://www.white-rabbit.tech/

Outline

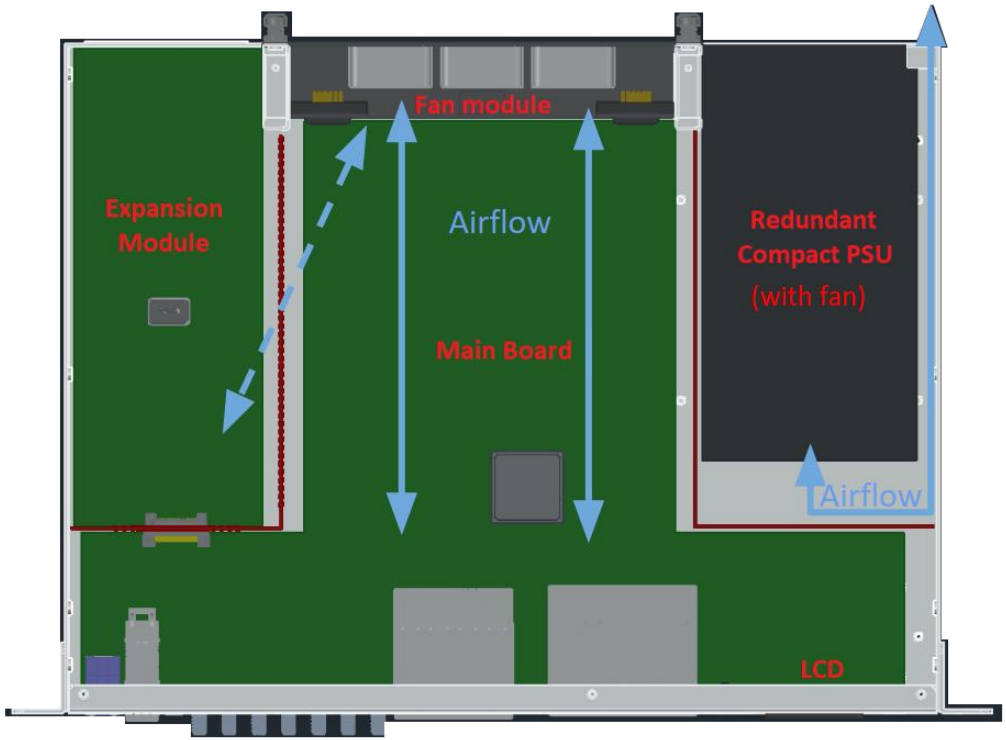
Plans

WR Switch v4

- GbE and 10GbE support
- Redundant and serviceable fans and power supplies
- Based on Xilinx/AMD Zynq UltraScale+ System-on-Chip (SoC)
- Expansion board slot for enhancements (low phase noise, hold-over...)

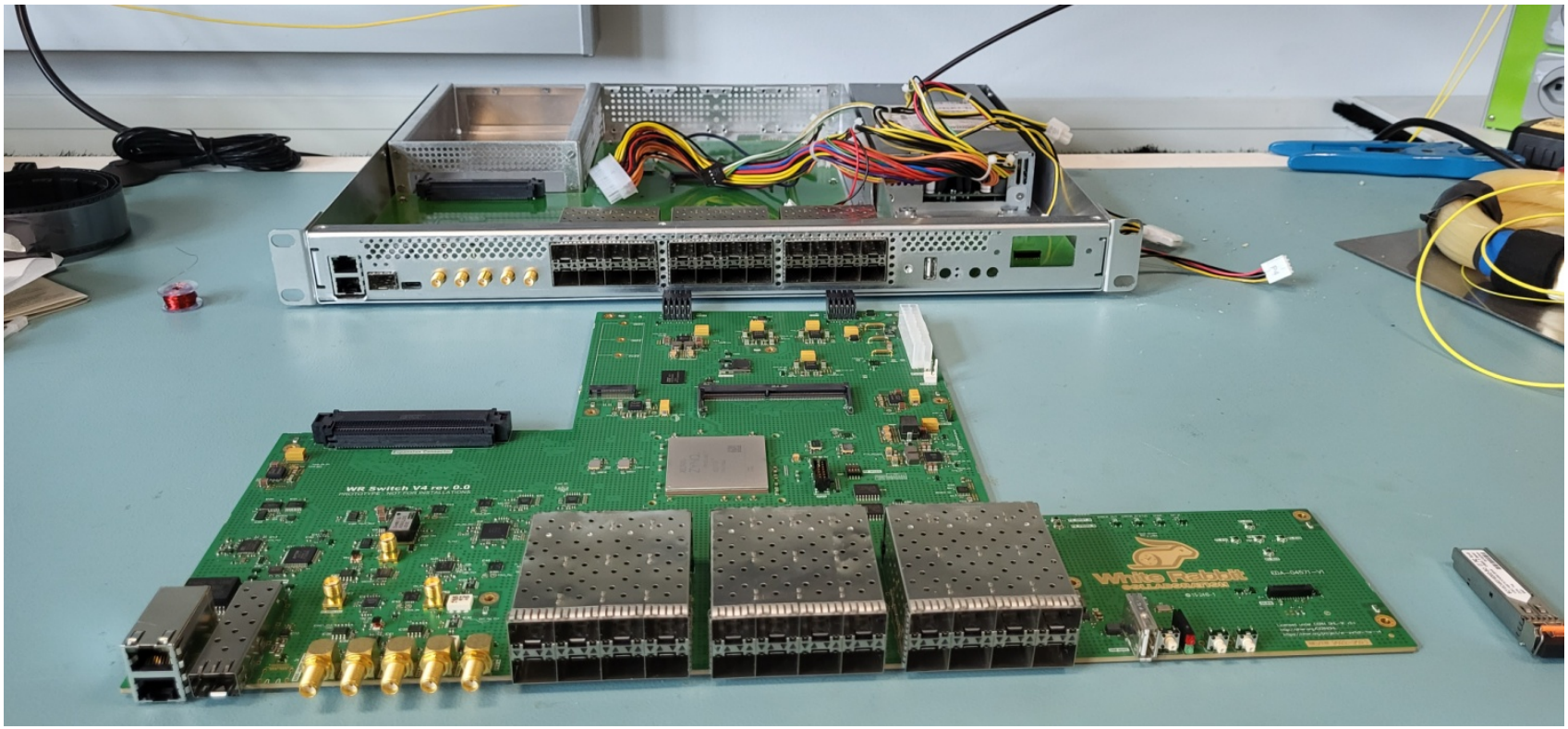
See https://ohwr.org/project/wr-switch-hw-v4/wikis for more details.

WR Switch v4

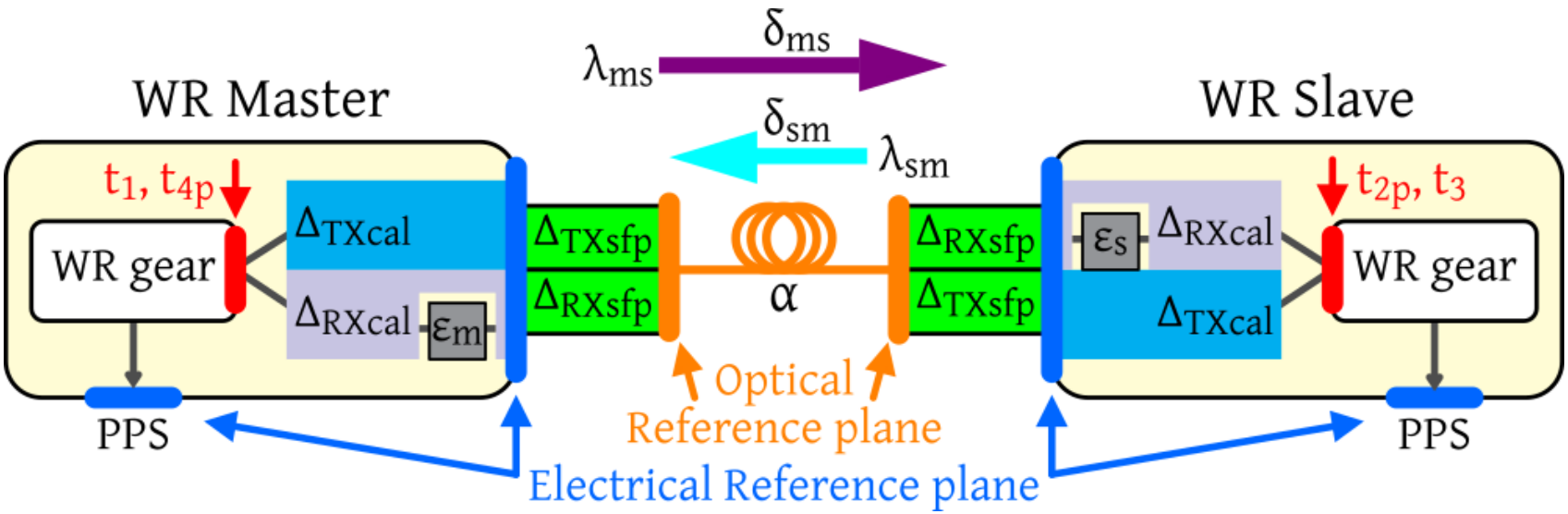


Prototyping stage, v3 functionality before the end of the year.

WR Switch v4



Standardisation++



Courtesy Henk Peek and Peter Jansweijer

Standardisation++ (P. Jansweijer, M. Lipiński)

Amendments to IEEE 1588-2019

- Absolute calibration
- In-situ calibration of asymmetry

Within the SNIA SFF working group

Storage of calibration parameters in SFP EEPROM

Possibilities for collaboration

For discussion:

- Monitoring and logging of important parameters and events with time stamps
- Automation of calibration of port delays and fibre asymmetry
- Robustness: hardware and system-wide (clock ensemble). Redundancy and seamless switch-over ($<$1ns jump). See work with GMV and IQD on hold-over.
- Best practices for long-distance WR
- Testing and qualification laboratory
- Other?