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Tutorial: White Rabbit Timing System

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CFEL,DESY, Hamburg

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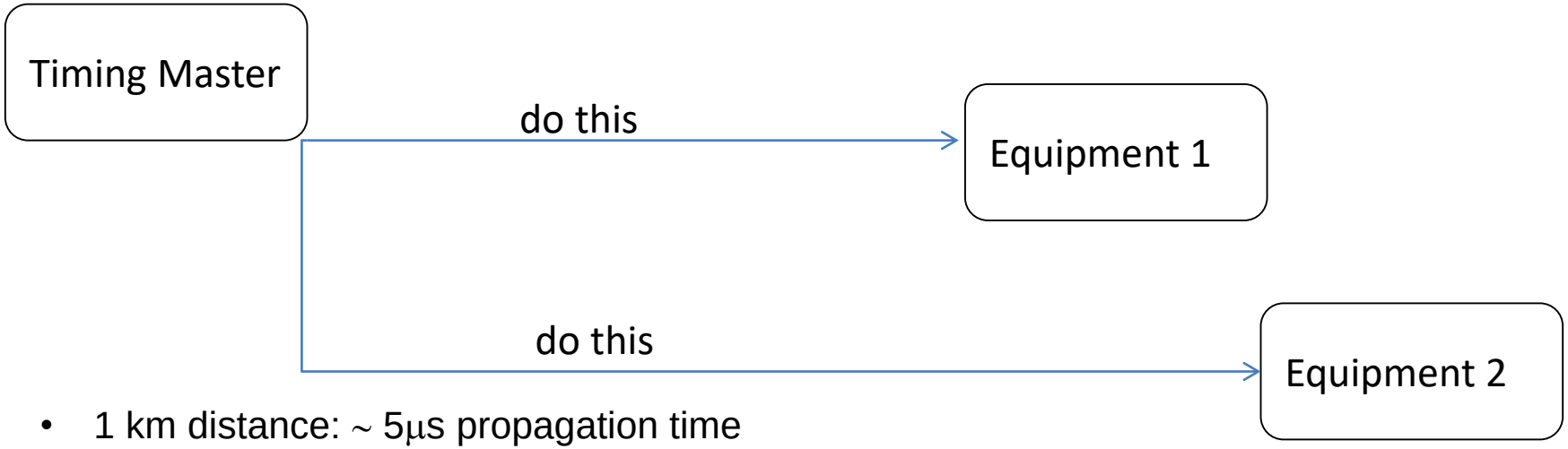
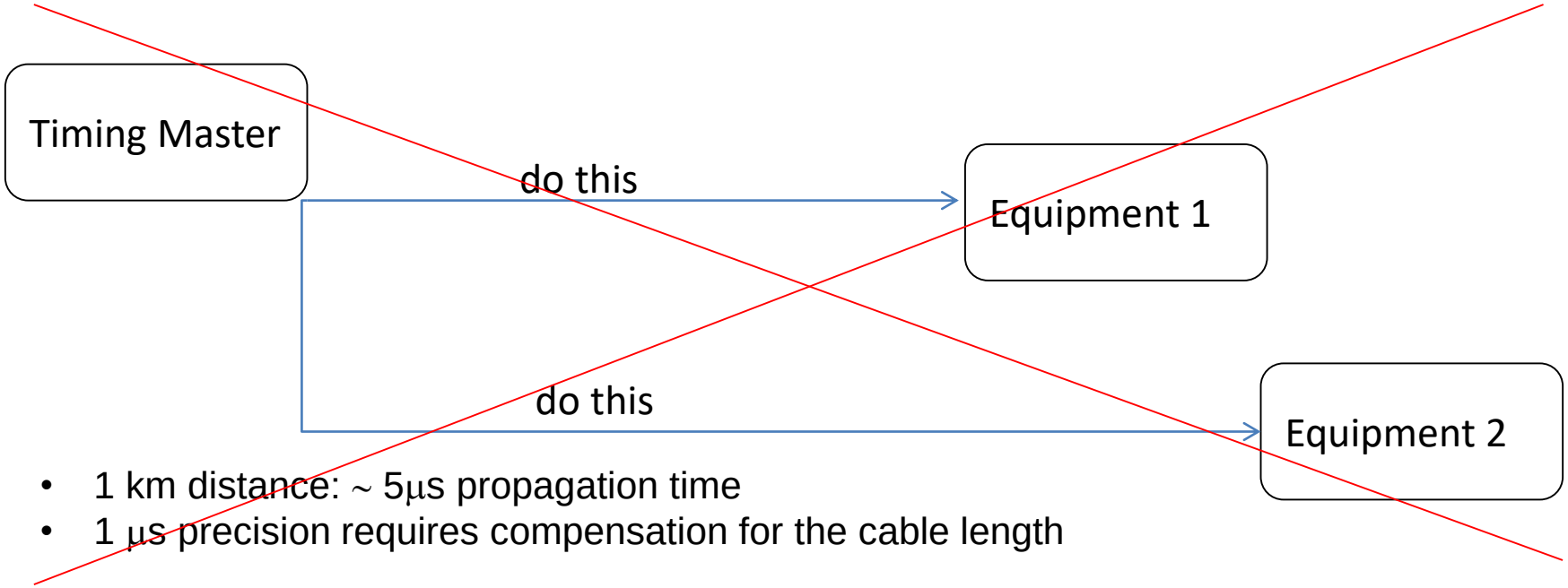
   brief introduction
2. White Rabbit technology
3. White Rabbit equipment
4. Use Cases

Timing System Based on Time



- 1 km distance: ~ 5μs propagation time
- 1 μs precision requires compensation for the cable length

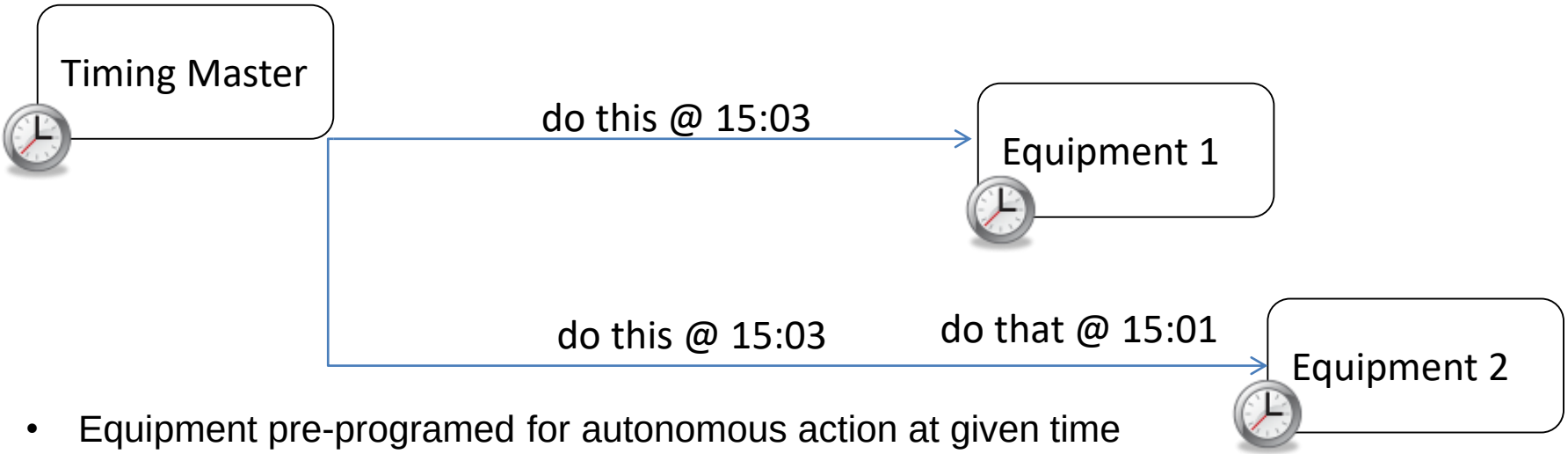
Timing System Based on Time



- 1 km distance: ~ 5μs propagation time
- 1 μs precision requires compensation for the cable length

Timing System concept

Instead...



- Equipment pre-programed for autonomous action at given time
- Pre-programing via **timing-events**
- Clock synchronization ~ns required
- Timing-events must be sent “early enough”
  - Need Upper bound latency for transmission (e.g. 100 μs) - **real-time!**
  - Need Lossless transmission - **robustness!**

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2. **White Rabbit technology:**
   - **What is White Rabbit?**
3. White Rabbit equipment
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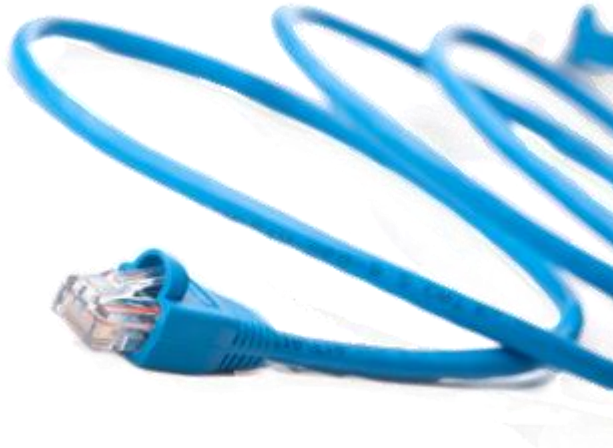
White Rabbit

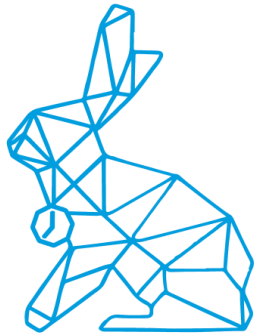
White Rabbit (WR) is the technology born at CERN and brought to industry by **Seven Solutions** for general purpose long-distance data transfer and sub-nanosecond accuracy synchronization.

An extension of Ethernet



- Synchronization: **Sync-E & PTP (IEEE-1588v2)**
  common notion of time!
- Accurate timestamps
  Subnanosecond synchronization!
- Thousand of nodes
  Data + Timing packet distribution!
- Distance range over 80 km

- Features for: Robustness & redundancy



Two main technologies/standards used:
Sync-E & PTP (IEEE-1588v2)

- **Synchronous Ethernet** (Sync-E).
- Enhanced PTP:

  Grand Master as a Timing Reference

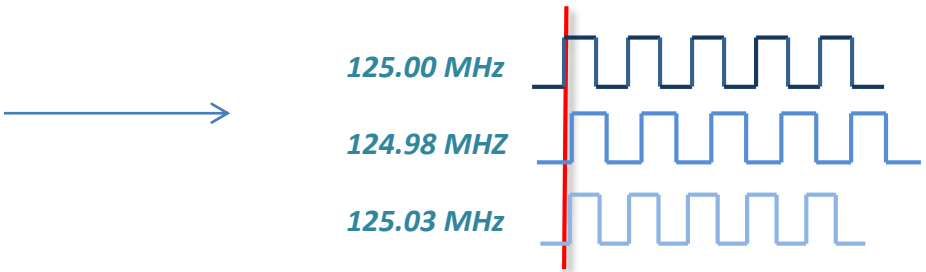
  Measure delay between master and slave (align nodes).

  Dynamic Calibration

Synchronization: **Sync-E & PTP (IEEE-1588v2)**

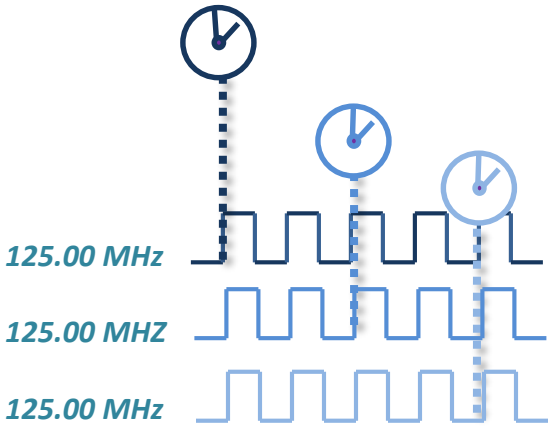
SYNTONIZATION VIA SYNC-E

Small differences in the node/switch individual clocks



Sync-E

Common notion of frequency!!

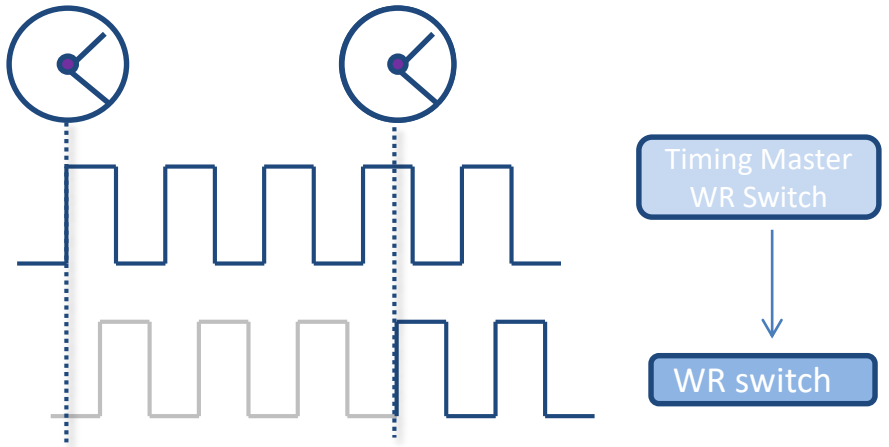


Synchronization: **Sync-E & PTP (IEEE-1588v2)**

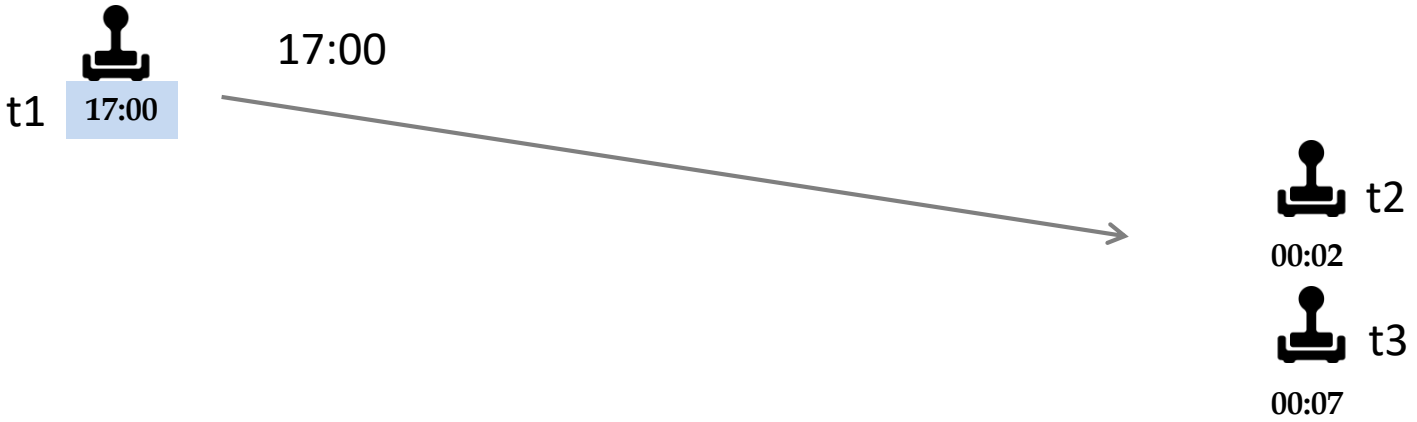
OFFSET ADJUSTEMENT WITH ENHANCED PTP

Temperature and distance affect!

DDMTD

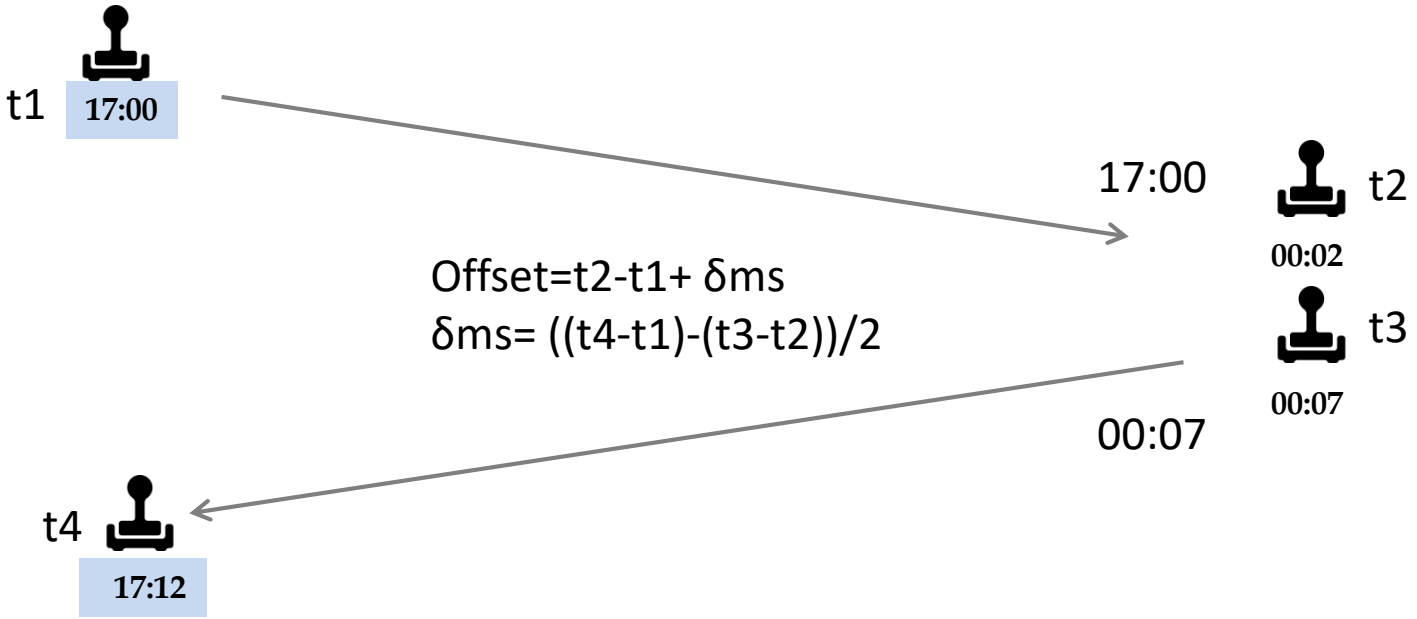


Capable of measuring time differences between two digital clock signals with very fine resolution (sub-picosecond)



OFFSET ADJUSTEMENT WITH ENHANCED PTP

Synchronization: **Sync-E & PTP (IEEE-1588v2)**

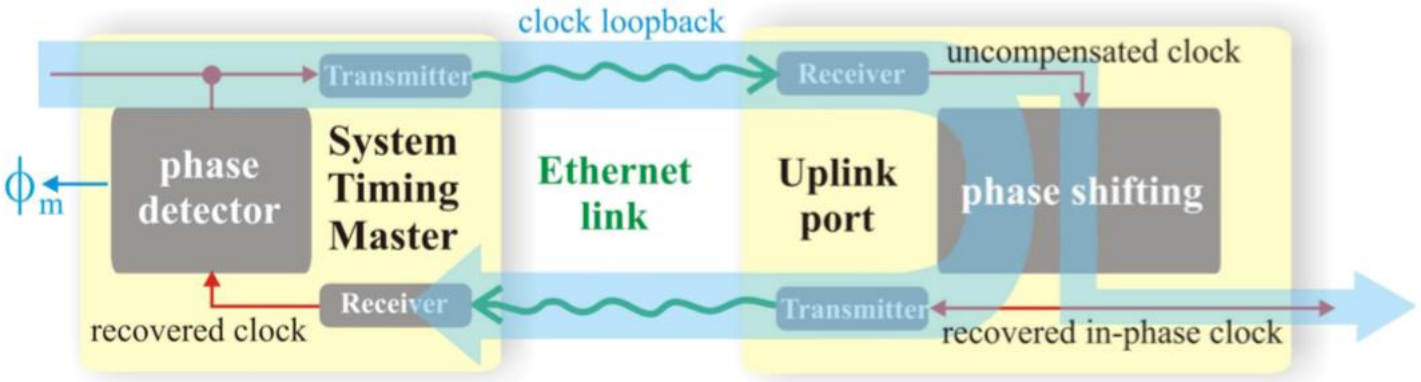


OFFSET ADJUSTEMENT WITH ENHANCED PTP

Synchronization: **Sync-E & PTP (IEEE-1588v2)**

White Rabbit mixed Hardware & Software

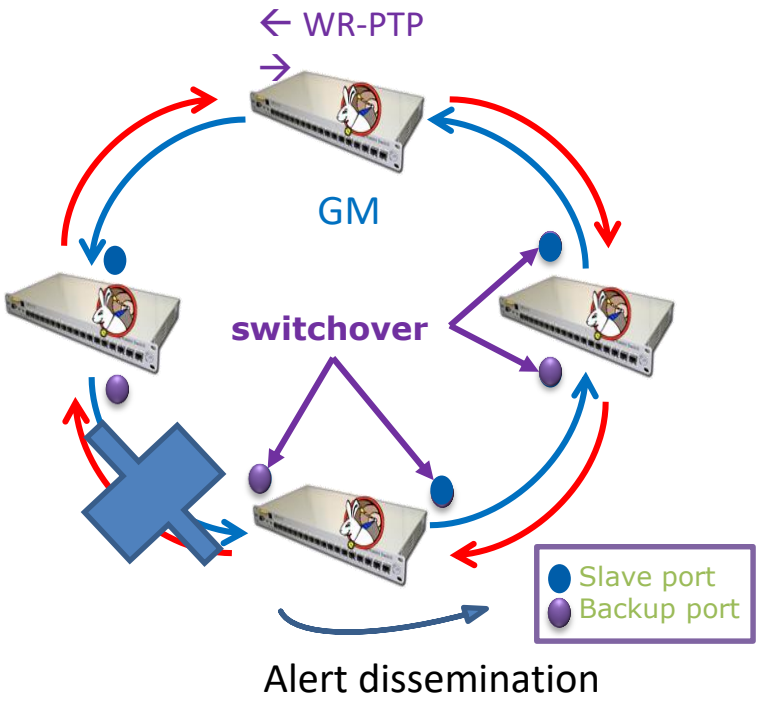
- DDMTD: Phase Measurement
- Enhanced Hardware timestamps
- Dynamic link asymmetry compensation
- Pre-calibration



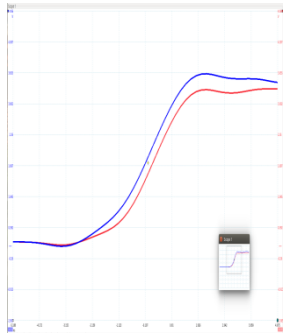
Advance Features: HSR Failover (Holdover + Switchover)

Objective:

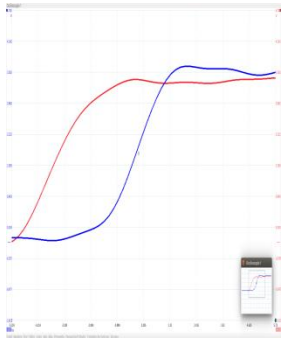
- Swap from primary to backup reference
- Disseminate alert



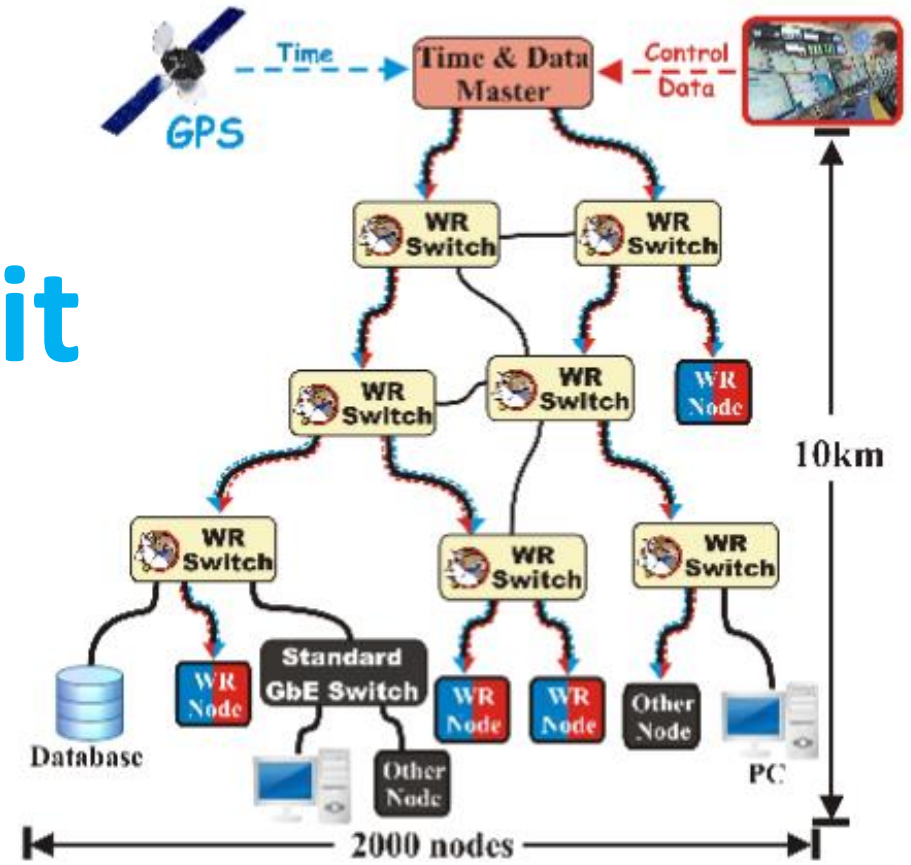
Normal Operation



Failure Detected



3. White Rabbit equipment



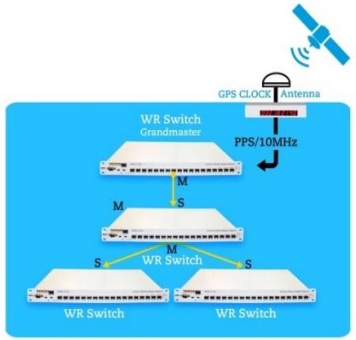
WR-Switch

The key element of a synchronized network

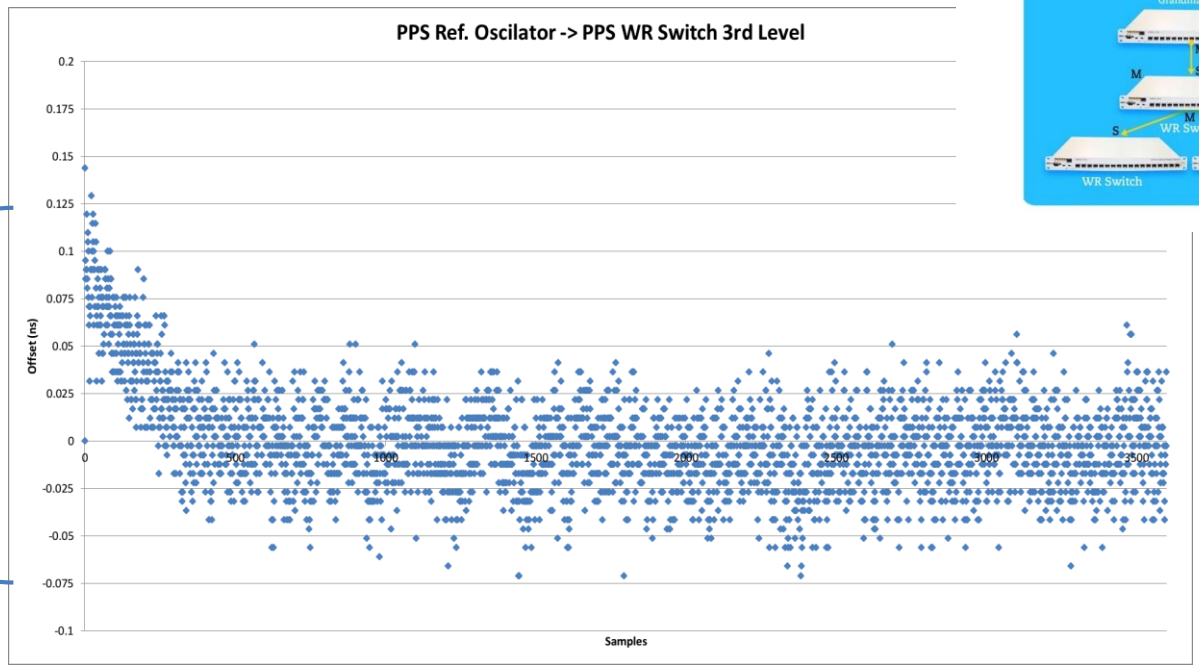
HIGHLIGHTS

- Sub-nanosecond deterministic time
- Thousands of nodes
- Distance range: over 80 km using fiber
- PTPv2, Sync-E supported
- Robustness & Redundancy
- Dynamic calibration
- Web and SNMP software interfaces

White Rabbit Switch Test



200 ps



Seven Solutions White Rabbit nodes

- Starting kits that will ease the first contact with the White Rabbit technology.
- Embedded nodes designed to be integrated into your product as OEM module.
- I/O, stand-alone and FMC cards

Starting Kid. FMC ADC/DAC, stand-alone, I/O cards

Dual FMC HPC cPCI serial carrier

White Rabbit Switch

White Rabbit LEN

The cost effective node to distribute synchronization

White Rabbit ZEN Time Provider

The ultra-precise standalone node with Redundancy & security features

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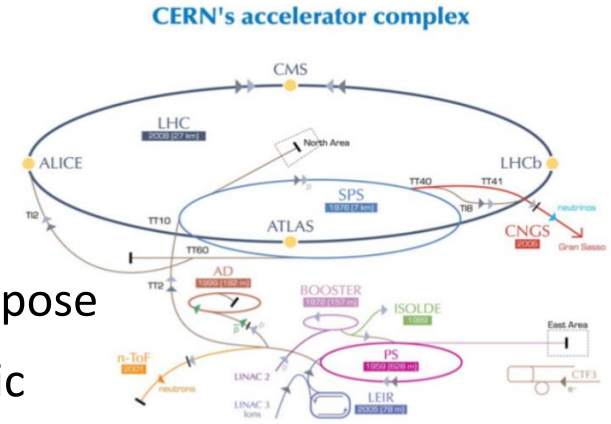
4. **Use Cases:**

CERN, GSI, ESRF, LIPAc

User Cases

Mayor contributor of White Rabbit technology



- "**Open Hardware**" approach and environment: https://www.ohwr.org/
- The **White Rabbit protocol** was articulated with the purpose of being the standard of the new generation of deterministic networks.

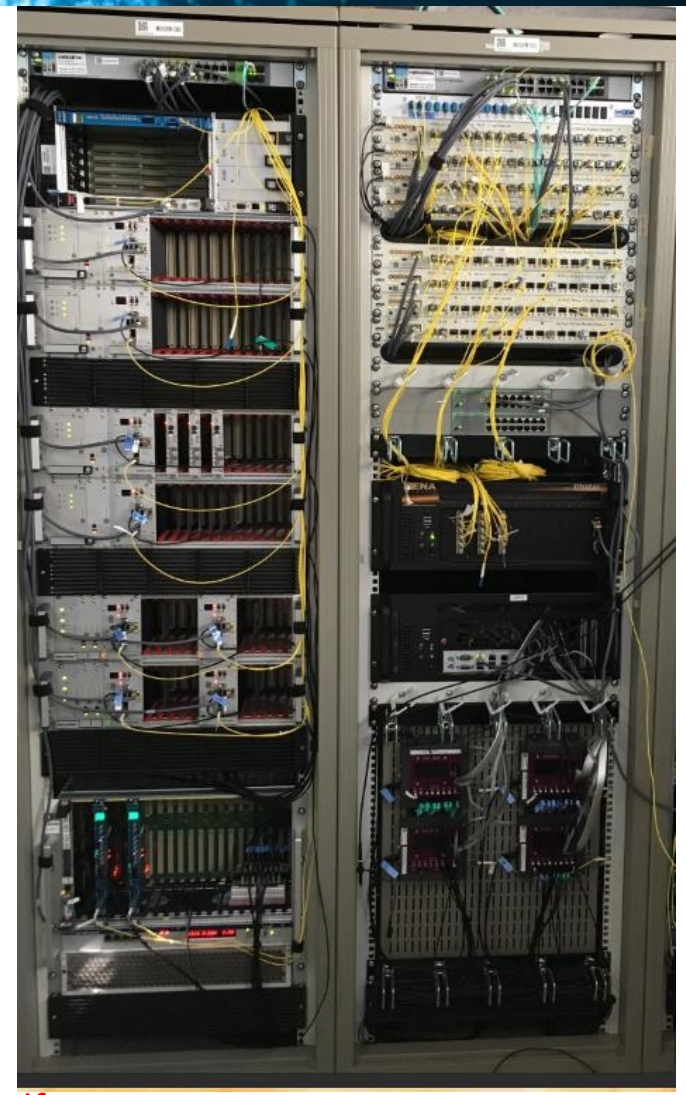
Main tasks:

- Requirements definition and formalization
- Reference designs and case studies
- Developer community management
- Dissemination activities

User Cases

GSI is using a White Rabbit based Timing System for all ring machines and high energy transfer lines:

- Currently: 32 WRS and 134 nodes (production system 8/2018).
- Timing System works reliable and stable
- lots of features for upcoming beam times still missing ('storage ring operation', 'therapy-like operation', ...)
- lots of features for FAIR still missing ('Forward Error Correction', 'Bunch-To-Bucket', ...)



* https://www.ohwr.org/attachments/5915/WR_2018_db_v0-13.pdf

User Cases

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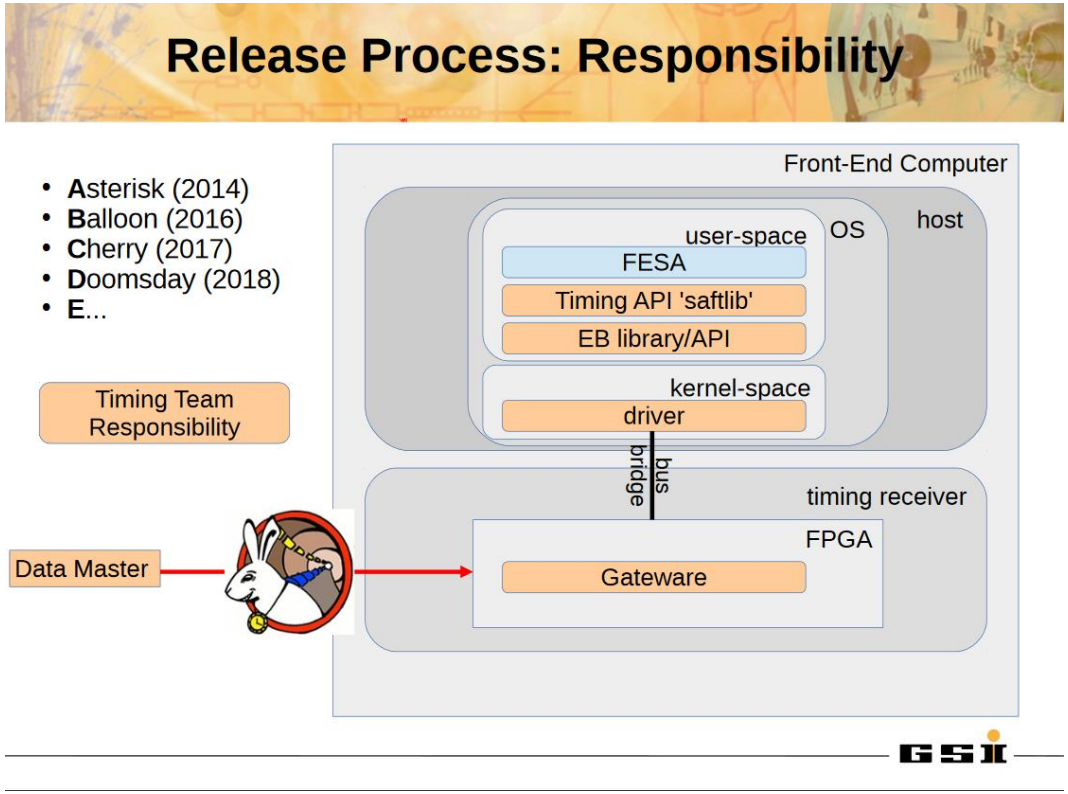
GSI Timing System:

- White Rabbit over Altera FPGAs
- Etherbone as a event distribution



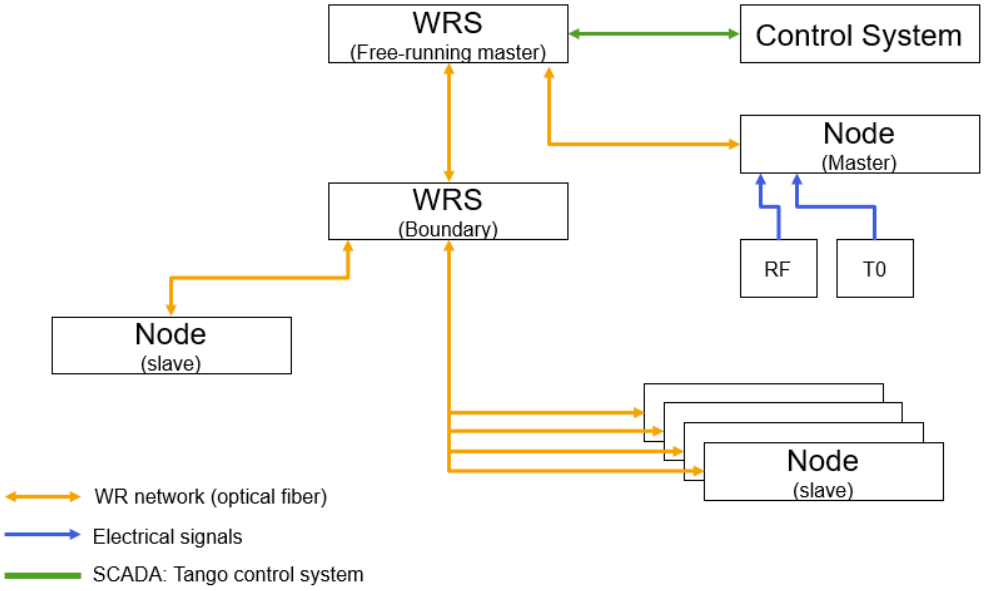
GSI Timing tests facility:

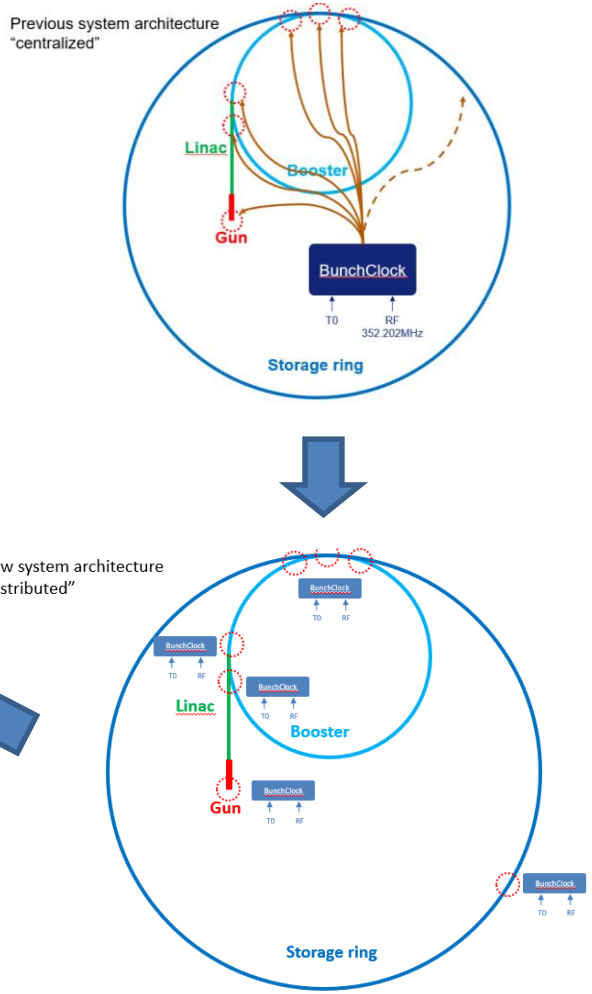
- Different timing receivers, OS, kernels, hosts, bitstream on FPGAs
- White Rabbit has to stay in track phase for weeks,PPS on IOs is measured constantly
- 10 layers of switches and an additional ethernet traffic generator for random,“ethernet noise“

* https://www.ohwr.org/attachments/5915/WR_2018_db_v0-13.pdf

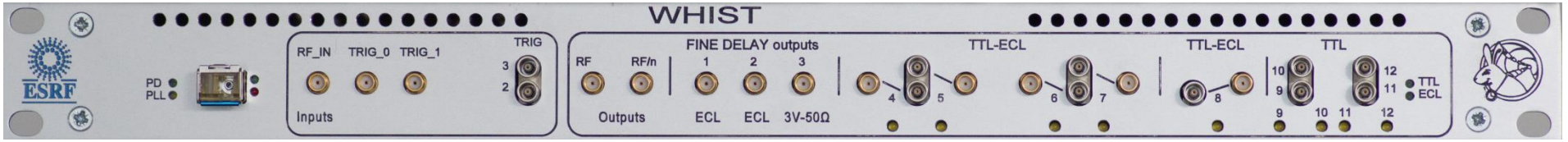
ESRF TIMING SYSTEM: WHITE RABBIT BASED

Network topology





- Complete installation phase 3: ***~40 modules***
- Implement event based ***triggers distribution***



* https://www.ohwr.org/attachments/5917/ESRF_Timing_10thWRworkshop.pptx

ESRF TIMING SYSTEM: WHITE RABBIT BASED

White Rabbit selected for ESRF refurbishment :

- Community support / low cost
- High flexibility
- Outstanding time stamping capabilities for ESRF needs
- Compatible optical fiber network already in place
- Available hardware allows “simple” in-house development -> WHIST module
- FPGA flexibility to add specific new features

White Rabbit solution building blocks / features :

“RF over White Rabbit” (Distributed Direct Digital Synthesis : D3S)
highly efficient CERN support

SPEC boards
large FPGA (SPARTAN-6 LX100T) available from 7 Solutions

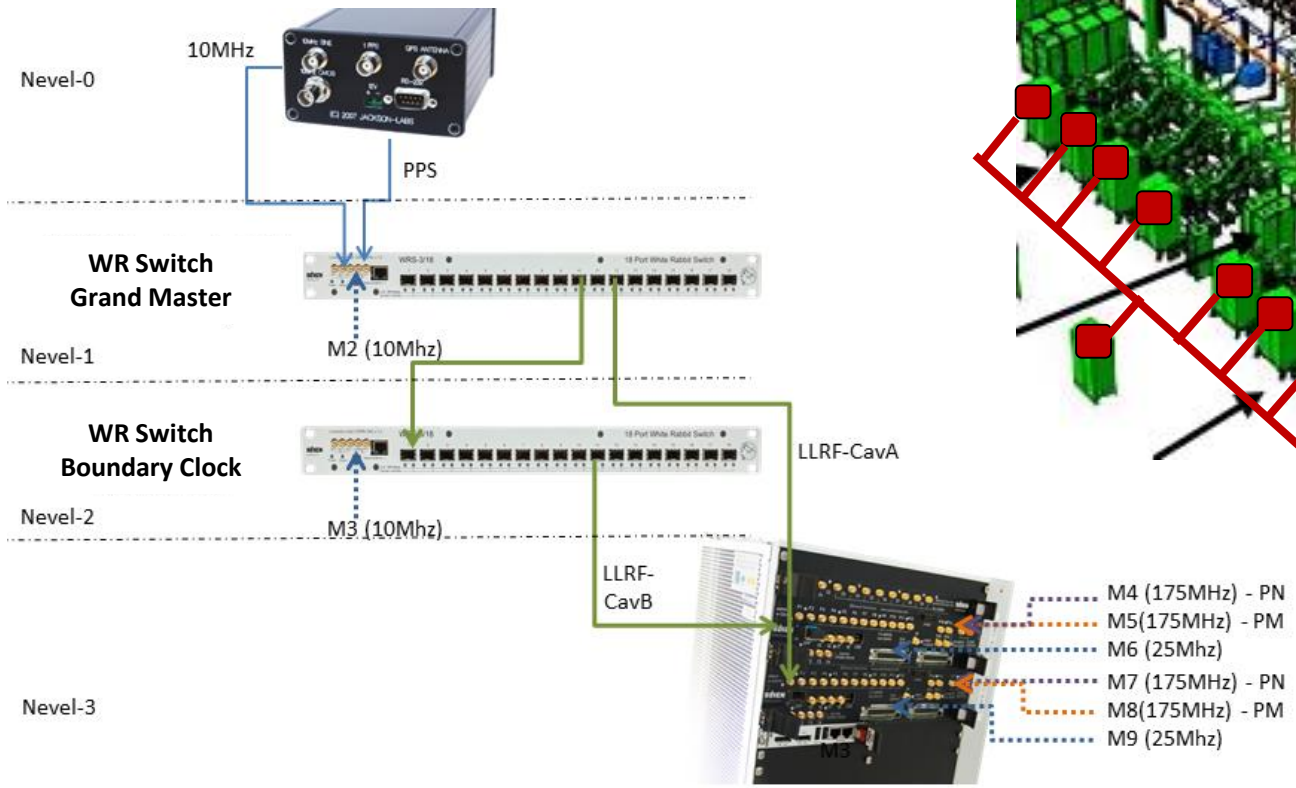
FMC-DDS mezzanine boards available for RF over Ethernet evaluation

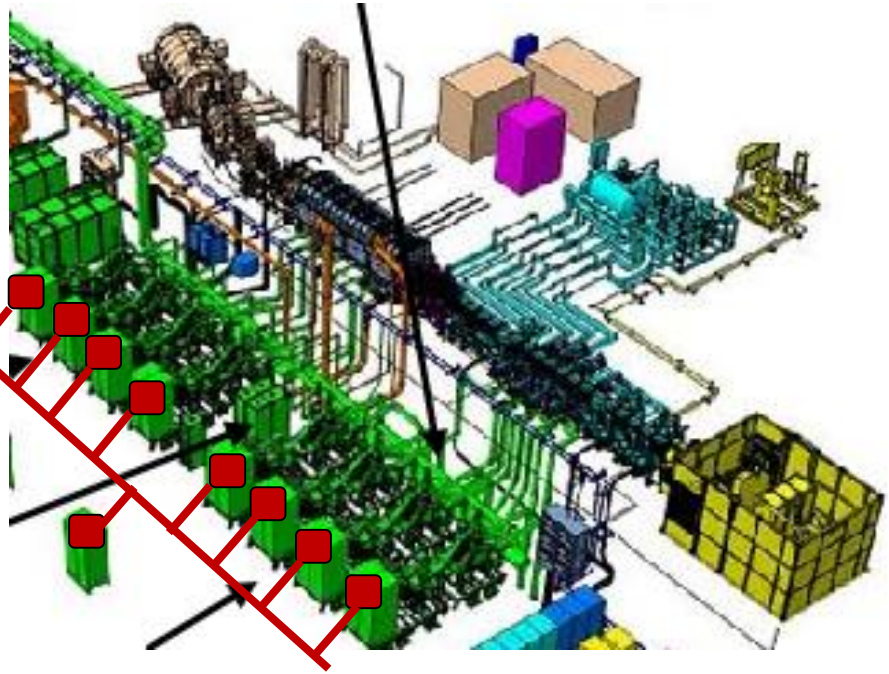
*** https://www.ohwr.org/attachments/5917/ESRF_Timing_10thWRworkshop.pptx**

LIPAc accelerator

RF distributions system:

Ciemat

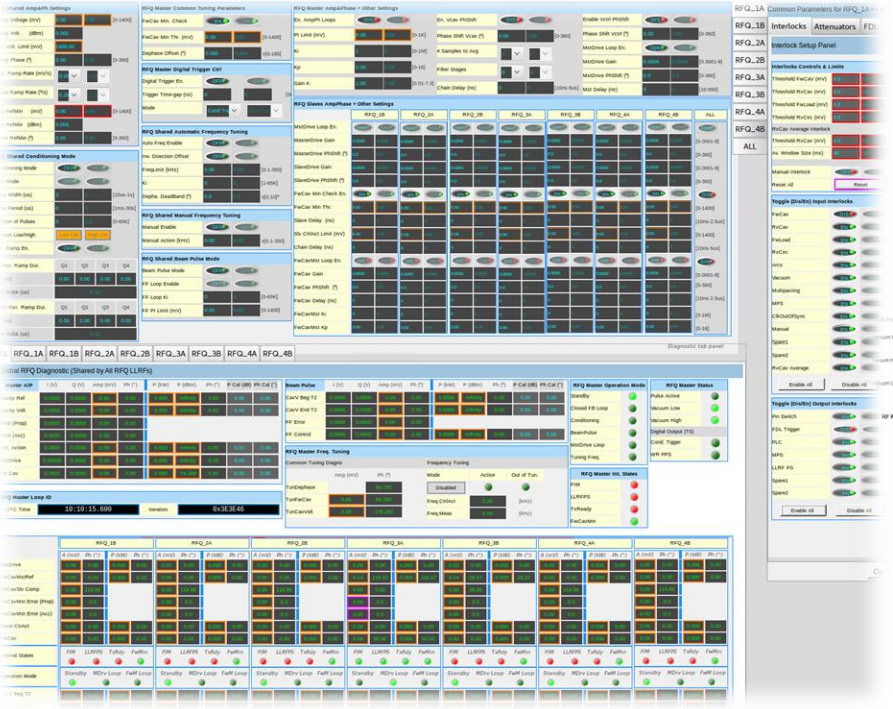




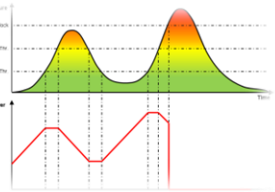
FUSION FOR ENERGY

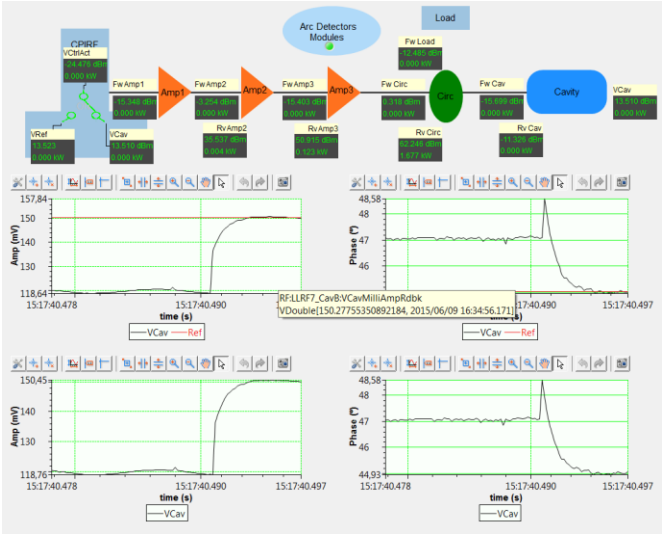
LIPAc accelerator

LLRF control system:



Diagnostic & Post mortem analysis:





EPICS remote control

LIPAc and current WR Solutions

1. LIPAc Control Systems include and beneficiate of White Rabbit technology

- **RF & Trigger distributions:** WR nodes and switches with low noise implementation, < 2 psec RMS jitter: ZEN, customized nodes, WR switch, Z-16,…
- **RF control system:** Low level RF (LLRF) control system.
  - Direct RF down-up conversion
  - White Rabbit node.
  - Feedback, Frequency and feedforward control loops
  - Conditioning, Beam pulse and continuous wave operation mode
- **Beam Position Monitor control system.**
  - CPCI serial rack
  - >12 ENOB bits, WR node with RMS jitter < 0,8 psec (1Hz-1MHz)

2. 7S On-going RF control compatible with WR technology:

- ***MicroTCA LLRF*** control system (White Rabbit compliant). **ACTECA**
- ***Digital and deterministic distribution*** of Fast interlocks and emergency stop signals

White Rabbit SUMMARY

- White-Rabbit technology, born as CERN, is **the most accurate IEEE-1588** implementation existing in the world. (sub-committee dedicated to White Rabbit)

- It is able to distribute in a **deterministic** way **timing and frequency**, achieving:
  - Sub-nanosecond time accuracy and trigger generation
  - Typical Clock RMS jitter < 10 ps
  - Deterministic Timing
  - Ethernet standard data delivery
  - Low-latency
  - Reliable

- **Many White Rabbit nodes** and network capabilities, topologies and flexibility.

- **Seven Solutions** is the **leading company** in White-Rabbit technology. We offer full turn-key solutions for research and industrial partners.

- Big particle accelerator facilities, neutrinos detectors, telescope arrays,… are already using **White Rabbit as a Timing system all over the world**.

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White Rabbit Around The World

When every nanosecond counts

1. **CERN:** General Machine Timing system.
2. **GSI:** General Machine Timing System at FAIR.
3. **CTA HiSCORE-EA:** Array Time Synchronization.
4. **KM3NET:** Deep-sea DOMS synchronization.
5. **LHAASO :** Timing system of Large High Altitude Air Shower Observation.
6. **MIKES:** Comparison and synchronization of geographically distant atomic clocks.
7. **IFMIF/EVEDA:** LLRF Timing system.
8. **SKA:** Array Time Synchronization.
9. **TIGRIS:** Detection and time tagging of events in the electrical grid.
10. **Sirius:** Fast orbit feedback and timing system.
11. **DLR:** Laser ranging to space-debris objects.
12. **Arkus:** Fixed latency trigger distribution system.
13. **CHIRON-IT:** Measurement system for high-voltage tests.
14. **Culham Centre for Fusion Energy:** Real-Time Protection System.
15. **DESY:** Array Time Synchronization.
16. **EISCAT:** High Performance Time-based Synchronization.
17. **ESS Bilbao:** Synchronization Network.
18. **JINR:** Main clock distribution.
19. **Universiteit van Amsterdam:** Central clock distribution system.
20. **Vrije Universiteit Amsterdam:** Time and Frequency.
21. **Allied Partners:** Deterministic ethernet solutions synchronization.
22. **ELI-BEAMS:** Facility level electronic timing system.
23. **ESRF:** RF transmission over WR.
24. **Hartnell College:** Time stamp information for triggers.
25. **Michigan State University:** Synchronization and trigger distribution system.
26. **University of Science and Technology of China:** Timing and control system.
27. **SPring-8:** Trigger and tag information distribution system.
28. **ELI-ALPS:** Timestamps for laser research facility.
29. **China Spallation Neutron Source Institute:** Target and instrument control.
30. **Gran Sasso Time Transfer:** Neutrino velocity measurement.
31. **NIST**
32. **Raytheon BBN**
33. **US Naval Observatory**
34. **Ohio University**
35. **Curtin University**
36. **Honeywell**
37. **Finnish Geospatial Research Institute**
38. **Beijin Ultrasync**
39. **Utah University**
40. **Rice University**

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When every nanosecond counts

Thanks for your attention!

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