White Rabbit: a next generation synchronization and control technology for large distributed systems

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Future Internet Engineering
Video-conference
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Outline

What is White Rabbit?

- Accelerator's control and timing
- International collaboration
- Based on well-known technologies
- Open Hardware and Open Software
- Main features:
  - transparent, **high-accuracy** synchronization
  - low-latency, **deterministic** data delivery
  - designed for **high reliability**

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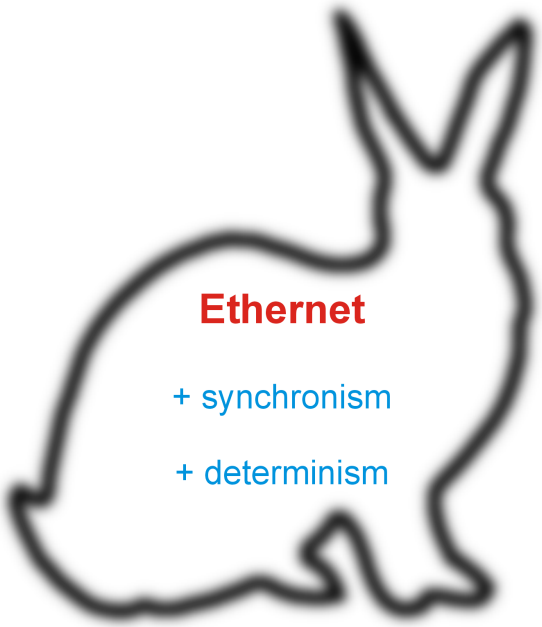
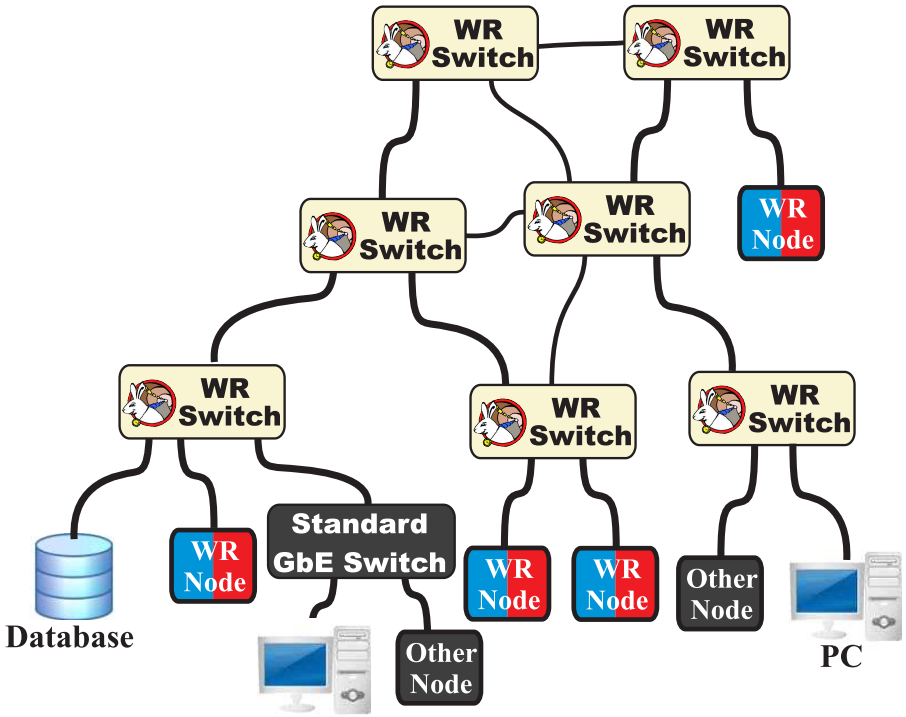


White Rabbit – enhanced Ethernet

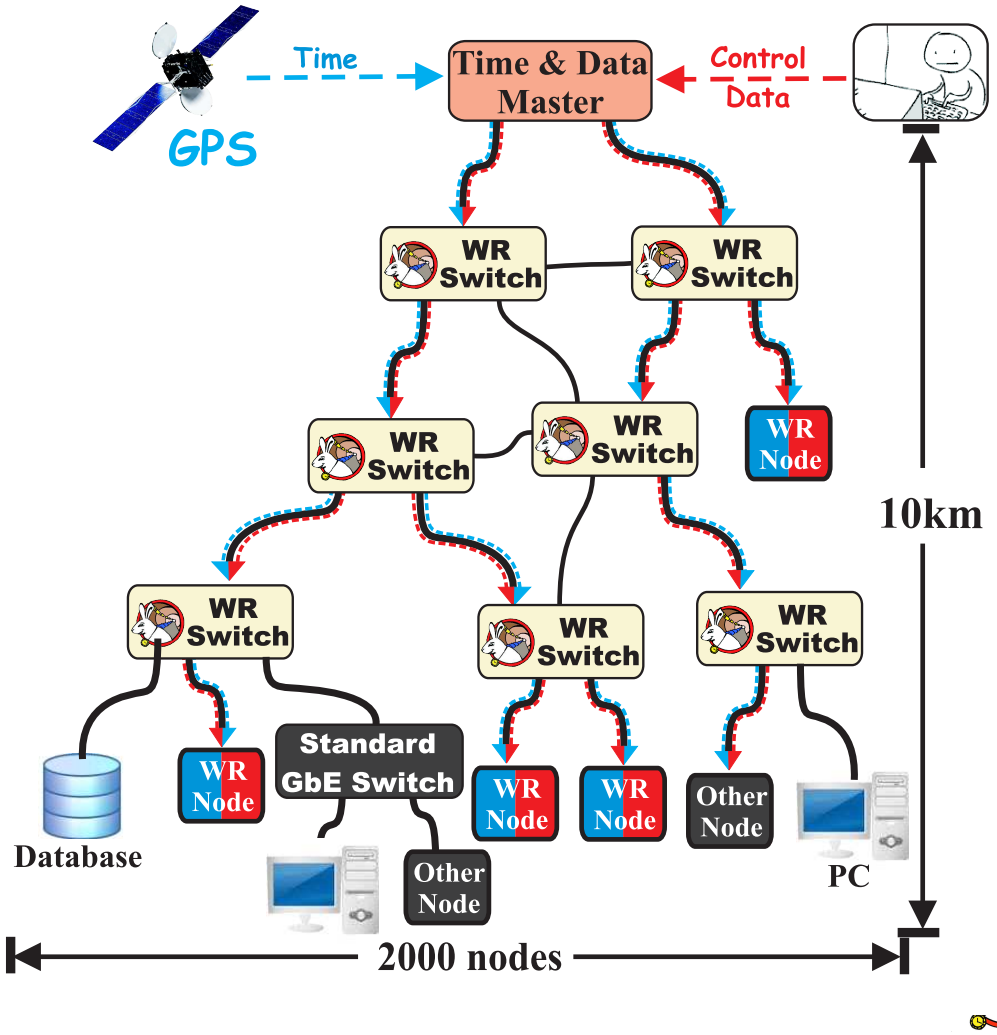
- Few thousands nodes
- Fiber medium
- Up to 10 km fiber links
- Bandwidth: 1 Gbps
- WR Switch: 18 ports
- Non-WR Devices
- Ethernet features (VLAN) & protocols (SNMP)



White Rabbit – enhanced Ethernet

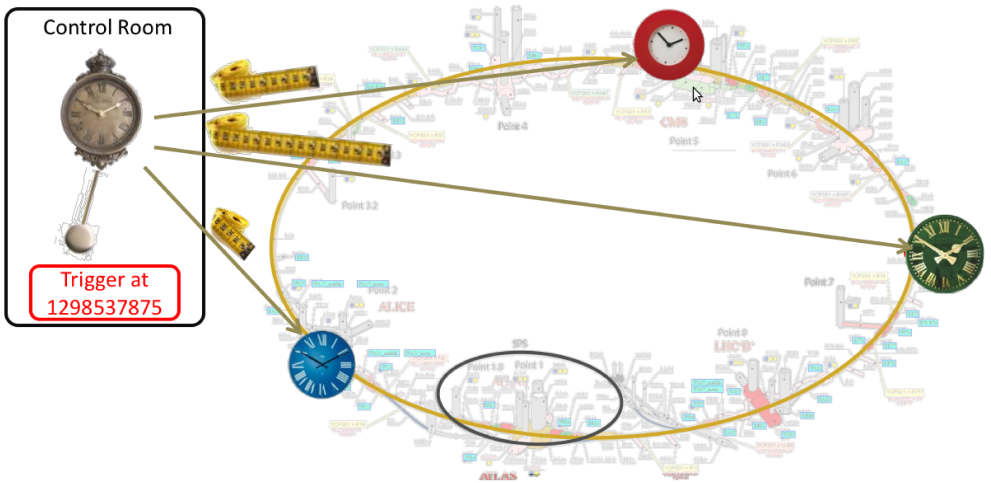
Two separate services (enhancements to Ethernet) provided by WR:

- High accuracy/precision synchronization
- Deterministic, reliable and low-latency Control Data delivery



Why White Rabbit ?

- Renovation of CERN General Machine Timing (GMT)
- GMT is great but...:
  - **RS-422**, 500kbps
  - **Unidirectional** communication
  - Separate network required
  - **Custom design, complicated maintenance**
- White Rabbit is meant to solve these problems



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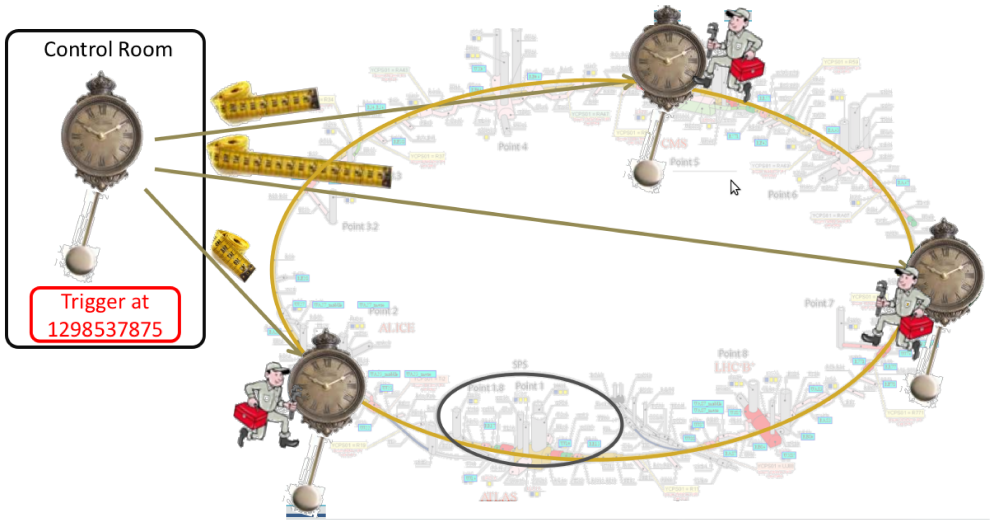

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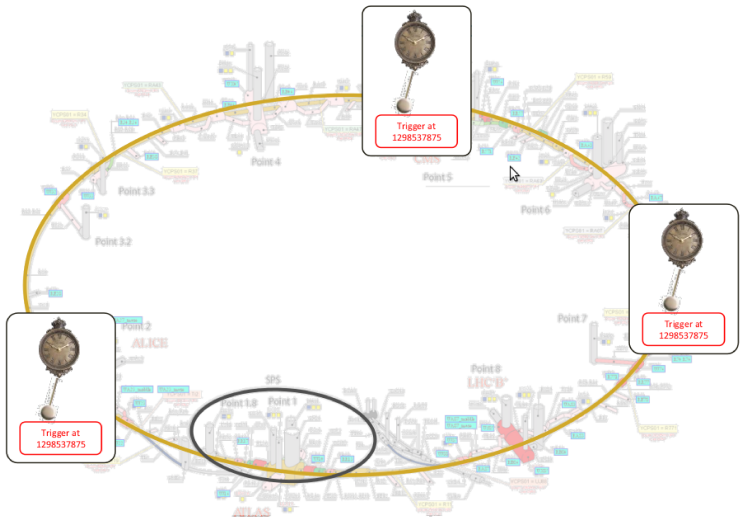
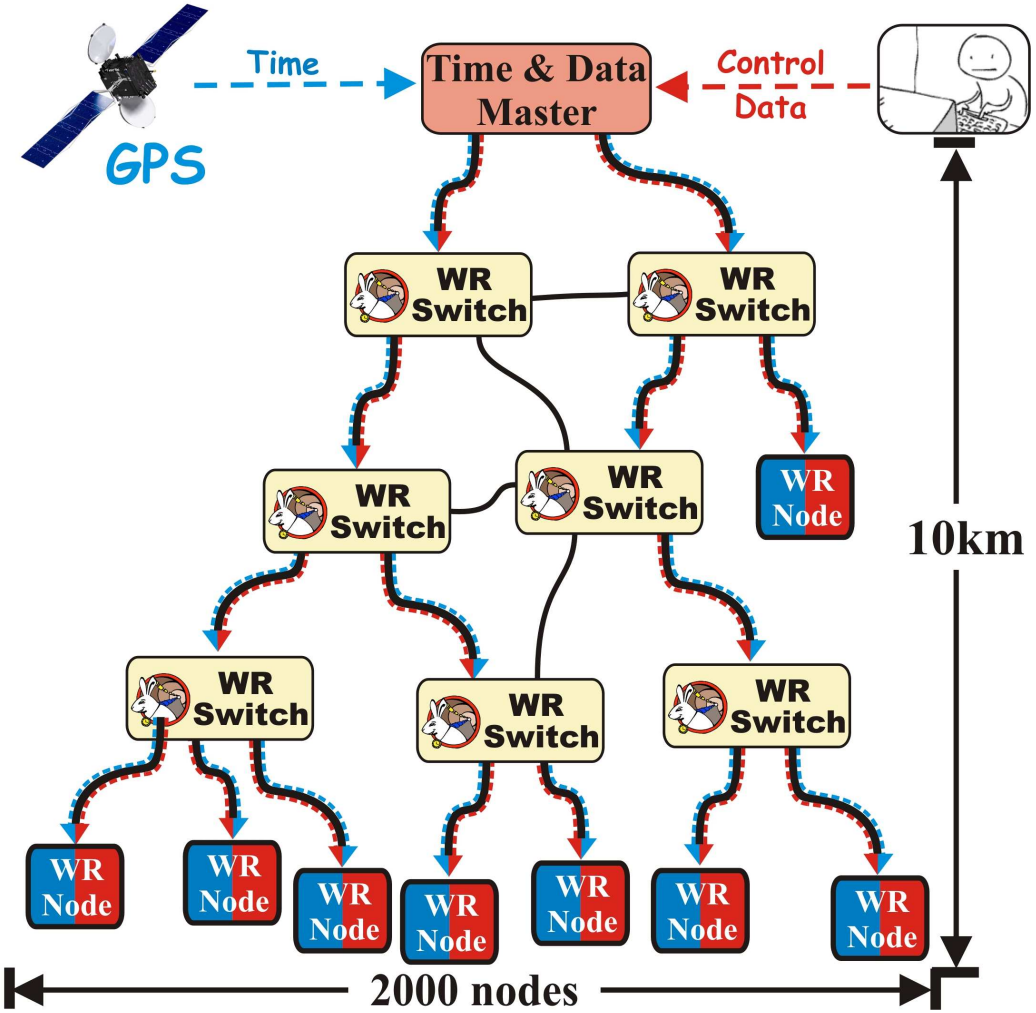


Time distribution in White Rabbit

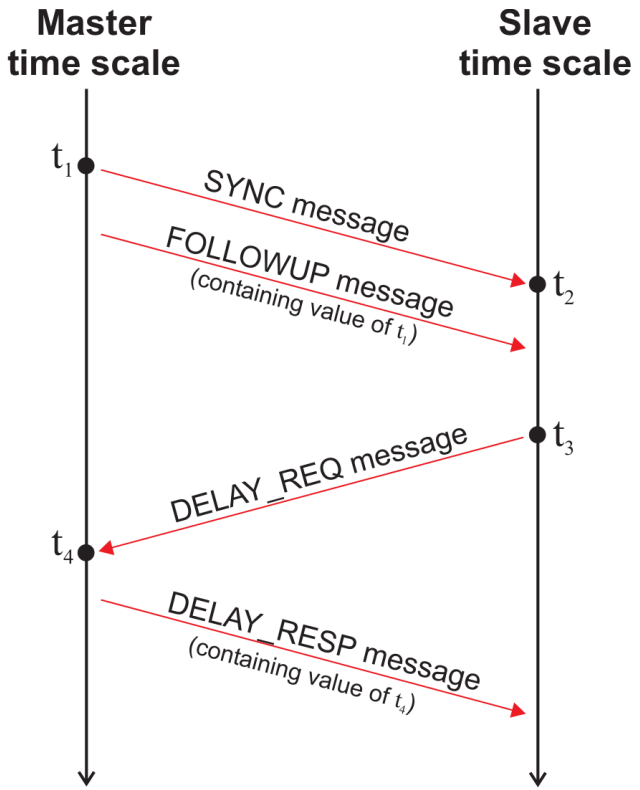
- **High accuracy/precision synchronization**
- Deterministic, reliable and low-latency Control Data delivery



Time Distribution in White Rabbit Network

- Synchronization with **sub-ns** accuracy and **ps** precision
- Combination of
  - Precision Time Protocol (**PTP**) synchronization
  - Synchronous Ethernet (**SyncE**) syntonization (L2)
  - Digital Dual-Mixer Time Difference (**DDMTD**) phase detection

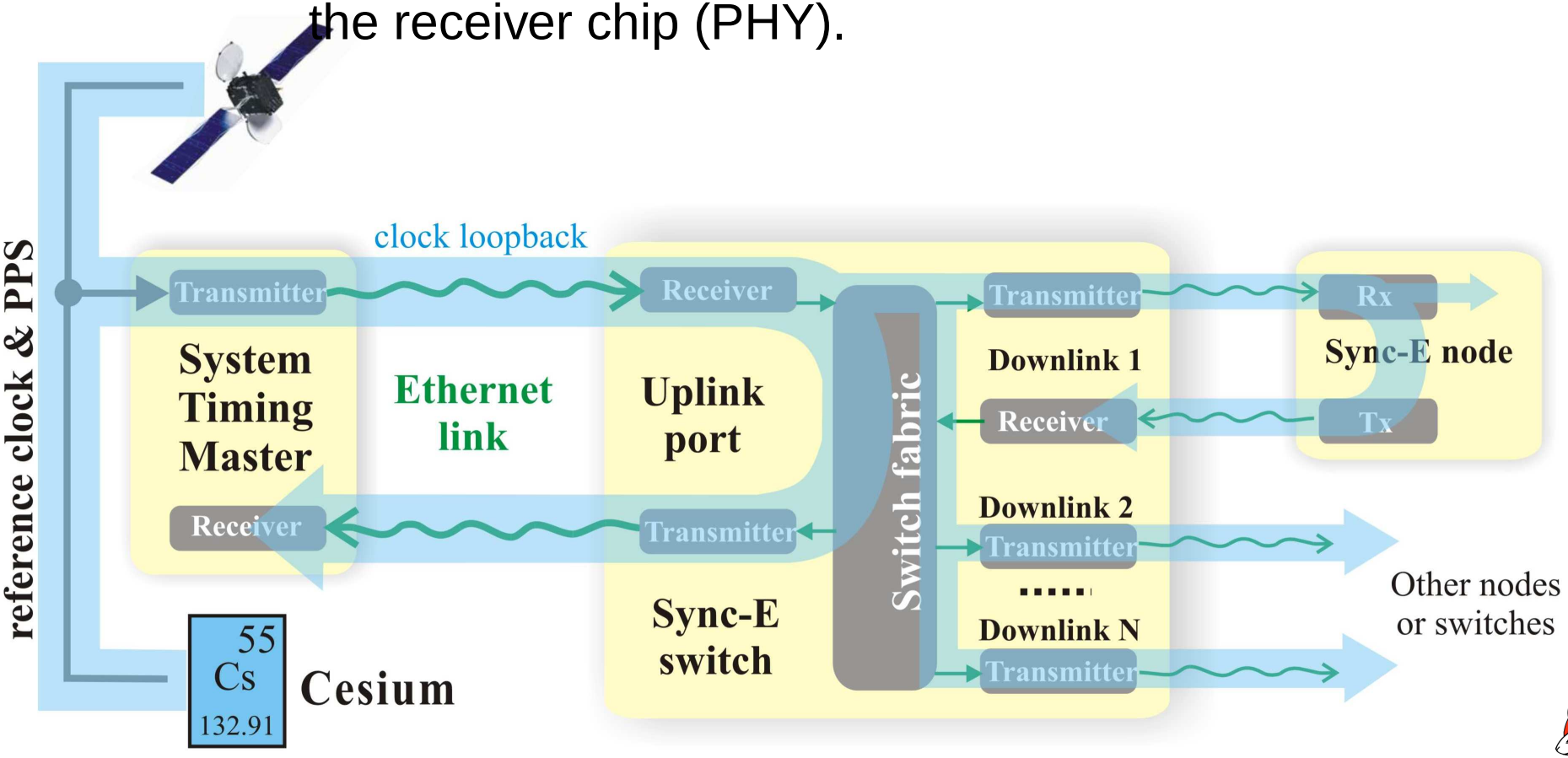
Precision Time Protocol (IEEE1588)



- Packet-based synchronization protocol (mapping over different physical medium)
- Synchronizes local clock with the master clock
- Link delay evaluated by measuring and exchanging packets tx/rx timestamps

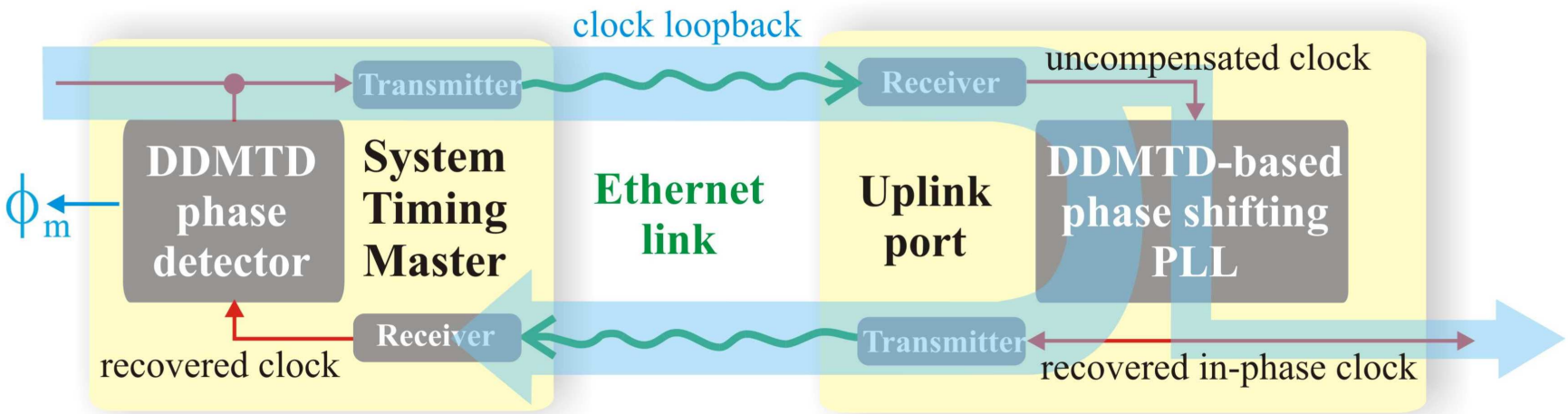
Synchronous Ethernet (SyncE)

- All network devices use the same physical layer clock
- Clock is encoded in the Ethernet carrier and recovered by the receiver chip (PHY).



DDMTD: Phase tracking

- PTP limitation: timestamping granularity
- Solution: take advantage of SyncE and measure phase shift



WR PTP

- Extension to PTP (IEEE1588) – defined as PTP Profile
- Addresses PTP's limitations (granularity, asymmetry, syntonization)
- Compatible with "standard" PTP gear
- Ongoing standardization effort
- Lab & field-tested for sub-ns synchronization

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According to ISPCS Plug Fest results ...

... White Rabbit is the most accurate PTP implementation in the world!

WR PTP Standardization effort

- **We want to standardize WR PTP**

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  - Profile (ITU-T, IEEE, ...)
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John Eidson:

“Why don’t you propose to include WR into PTPv3 ? You could do it in that way...”

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  - AVB gen 2
  - Consortium
- WR Standardization Group
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  - ITU-T/IEEE people
  - Companies
- ISPCS2012:
  - PTP will be openned for revision
  - WR PTP proposed to be included in PTPv3

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Standardization goal

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Data distribution in White Rabbit

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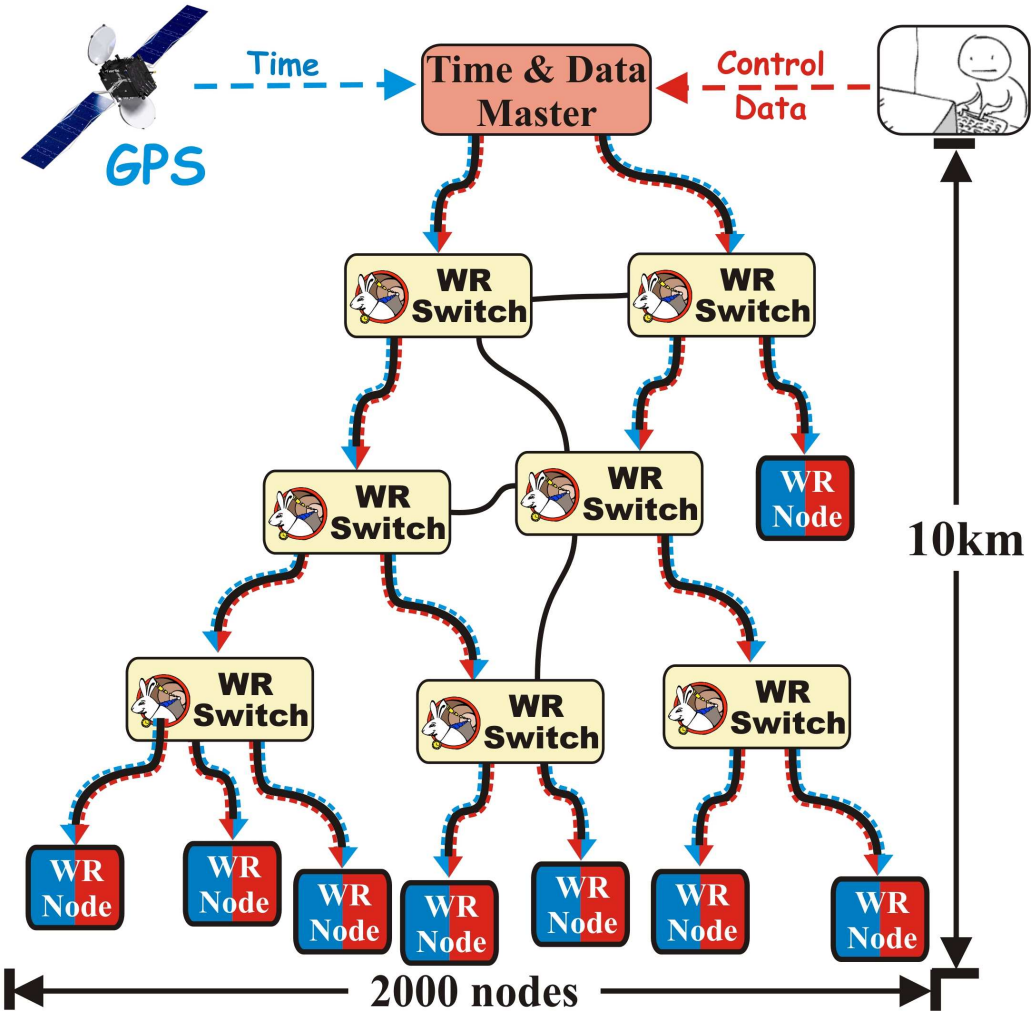
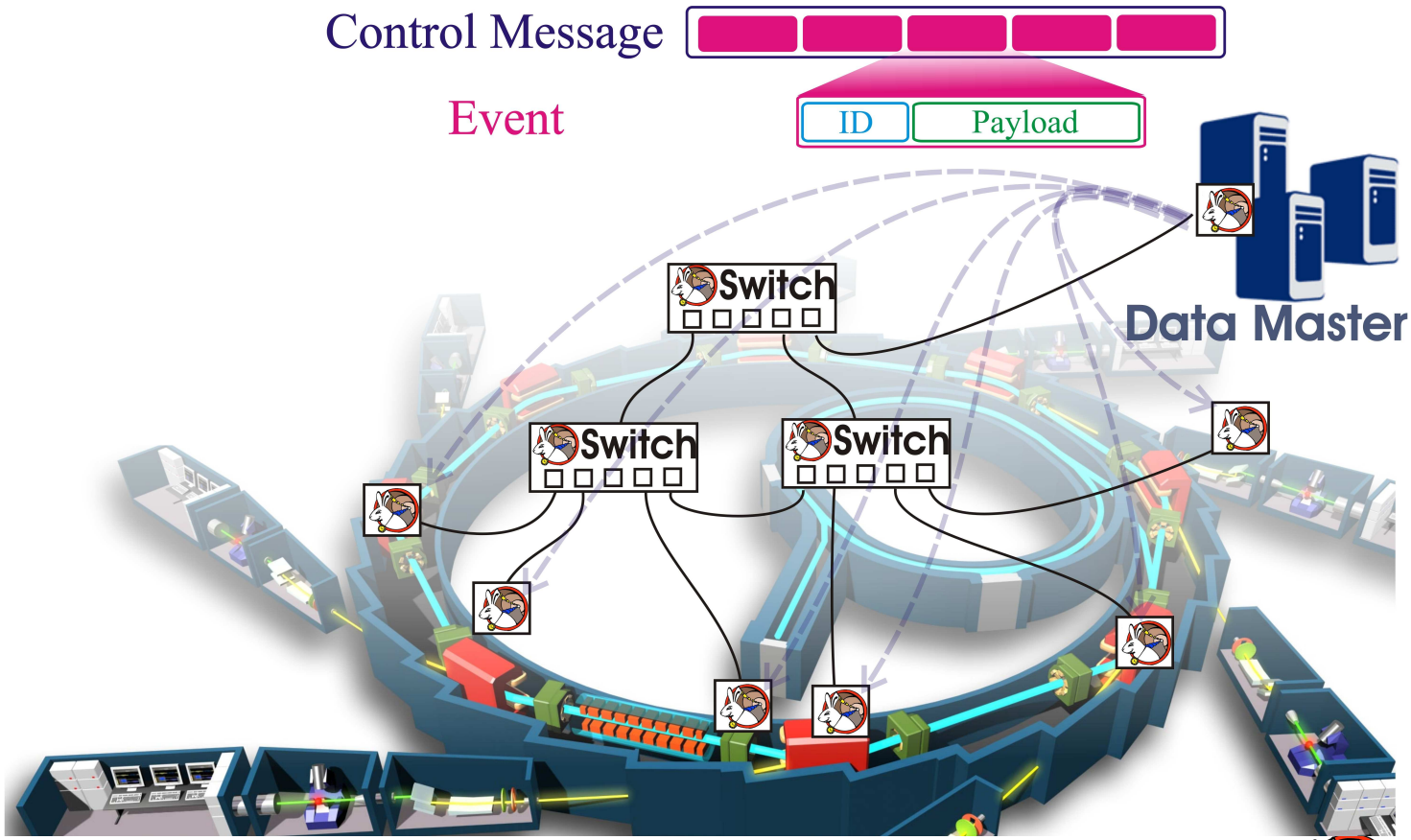
- **Deterministic, reliable and low-latency Control Data delivery**

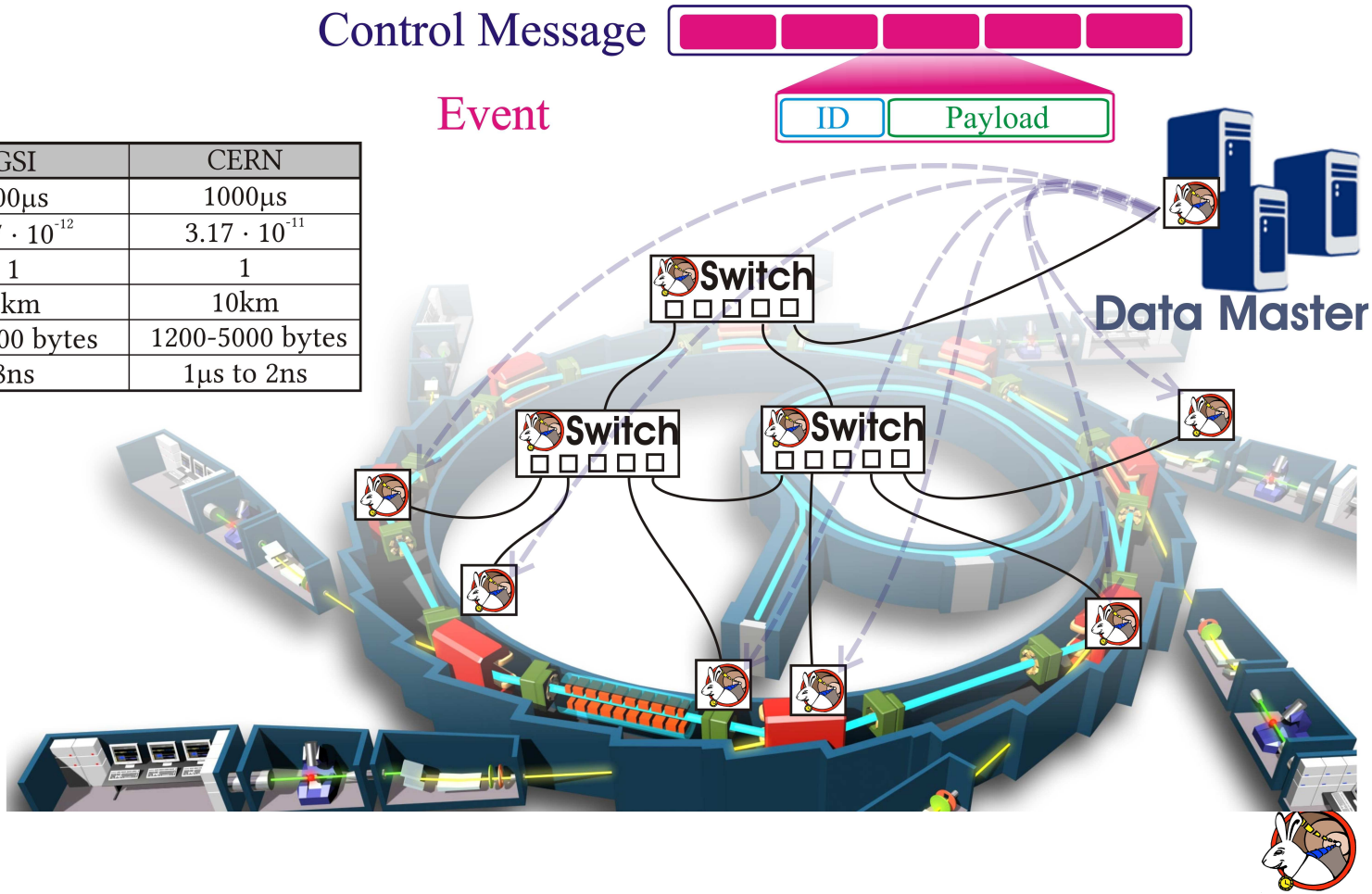


Data distribution in WR Control System



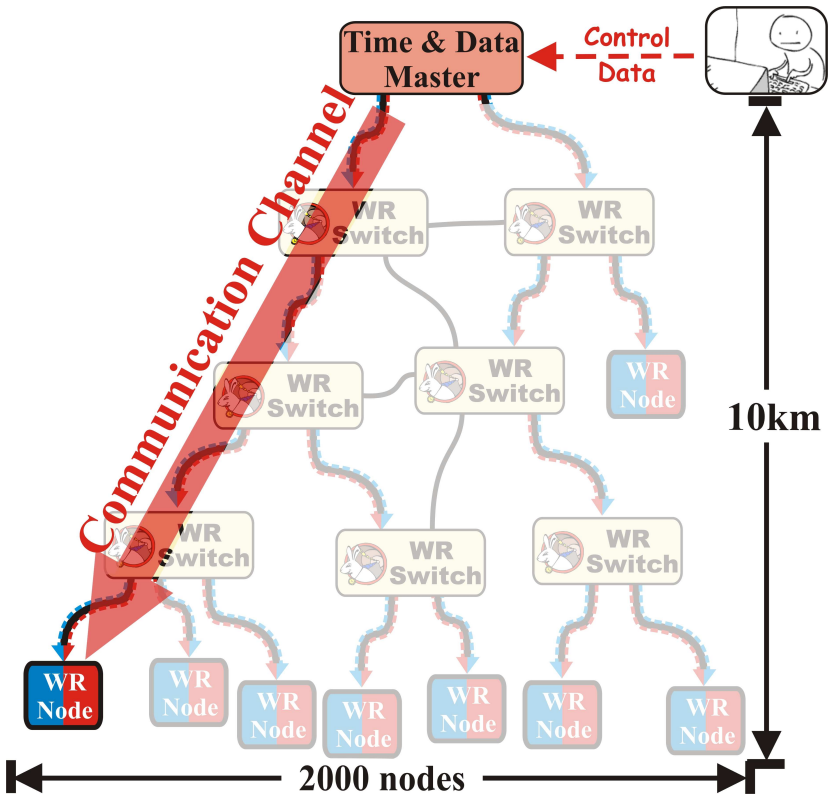
Data distribution in WR Control System

Requirement	GSI	CERN
Max latency	100µs	1000µs
CM failure rate	$3.17 \cdot 10^{-12}$	$3.17 \cdot 10^{-11}$
CMs lost per year	1	1
d_{max} from DM	2km	10km
CM size	200-500 bytes	1200-5000 bytes
Accuracy	8ns	1µs to 2ns



Control Data

- Two types of data:
  - **Control Data** (High Priority, HP)
  - Standard Data (Best Effort)
- Characteristics of **Control Data**
  - Sent in Control Messages
  - Sent by Data Master(s)
  - Broadcast (one-to-alot)
  - Deterministic and low latency
  - Reliable delivery

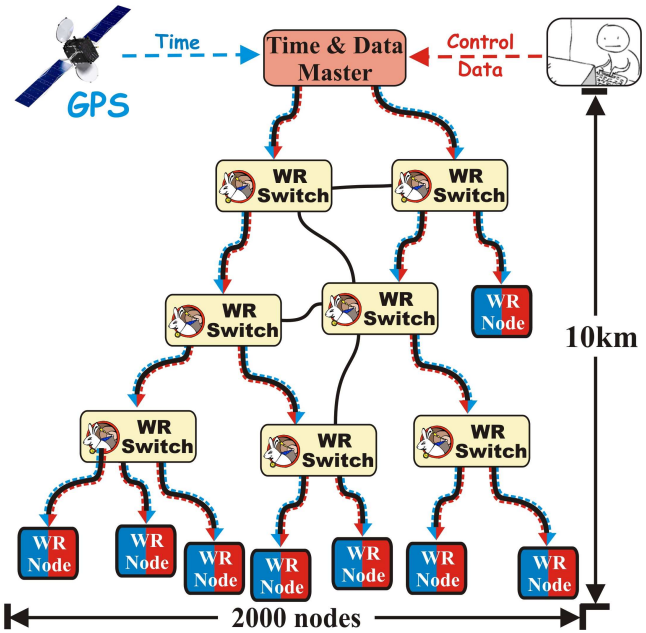


Data Redundancy

- Re-transmission of Control Data not possible
- **Forward Error Correction** – additional transparent layer:
  - One Control Message encoded into N Ethernet frames,
  - Recovery of Control Message from any M (M<N) frames
- FEC can prevent data loss due to:
  - **bit error**
  - **network reconfiguration**

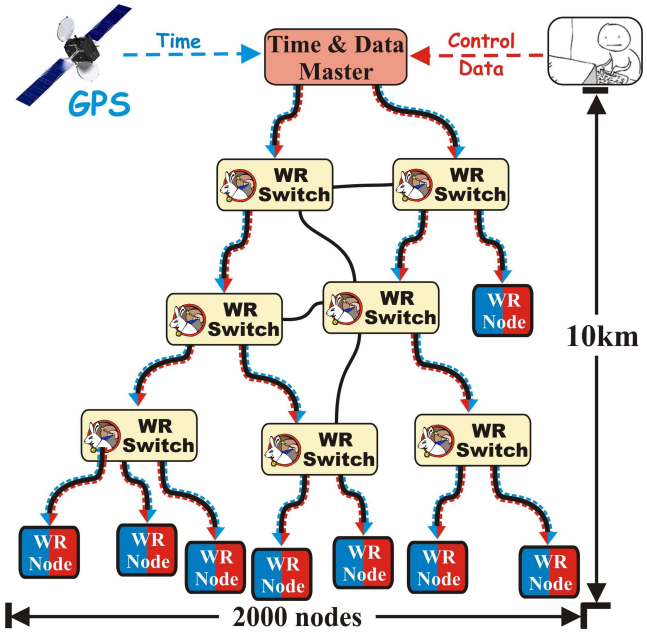
Topology Redundancy

- Standard Ethernet solution:
  Rapid/Multi Spanning Tree Protocol
- Reconfiguration time: $\approx$ **1s**
  (best: milliseconds)
- **1s =** $\approx$ **82 000** Ethernet Frames lost
- Solution:
  - take advantage of FEC
  - speed up (R/M)STP$->$**eRSTP** or
  - use multiple paths$->$**eLACP**



Determinism and low latency

- Control Data:
  7^{th} Class of Service (priority)
- WR Switch:
  - Quality of Service: resource reservation
  - Upper bound latency by design: $< 10us$
  - Cut-through
- Careful diagnostics



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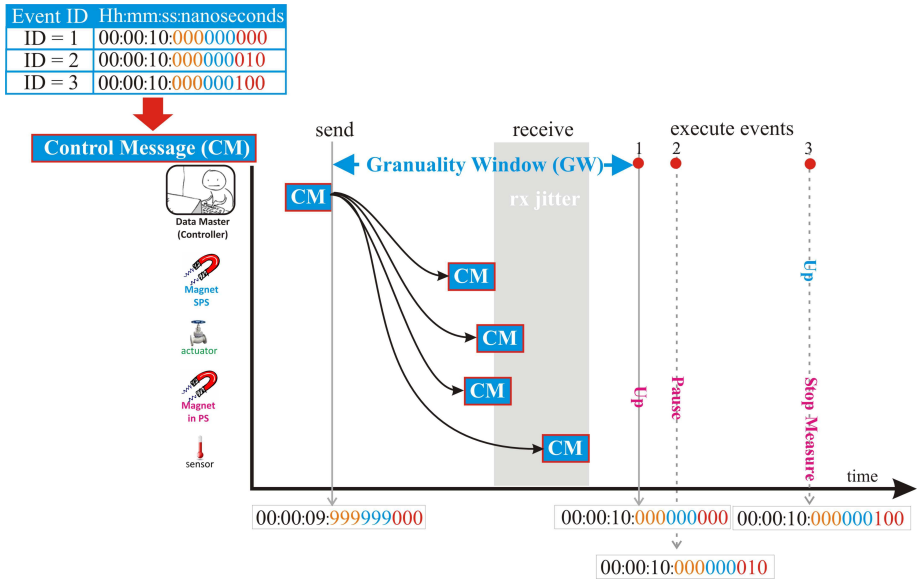
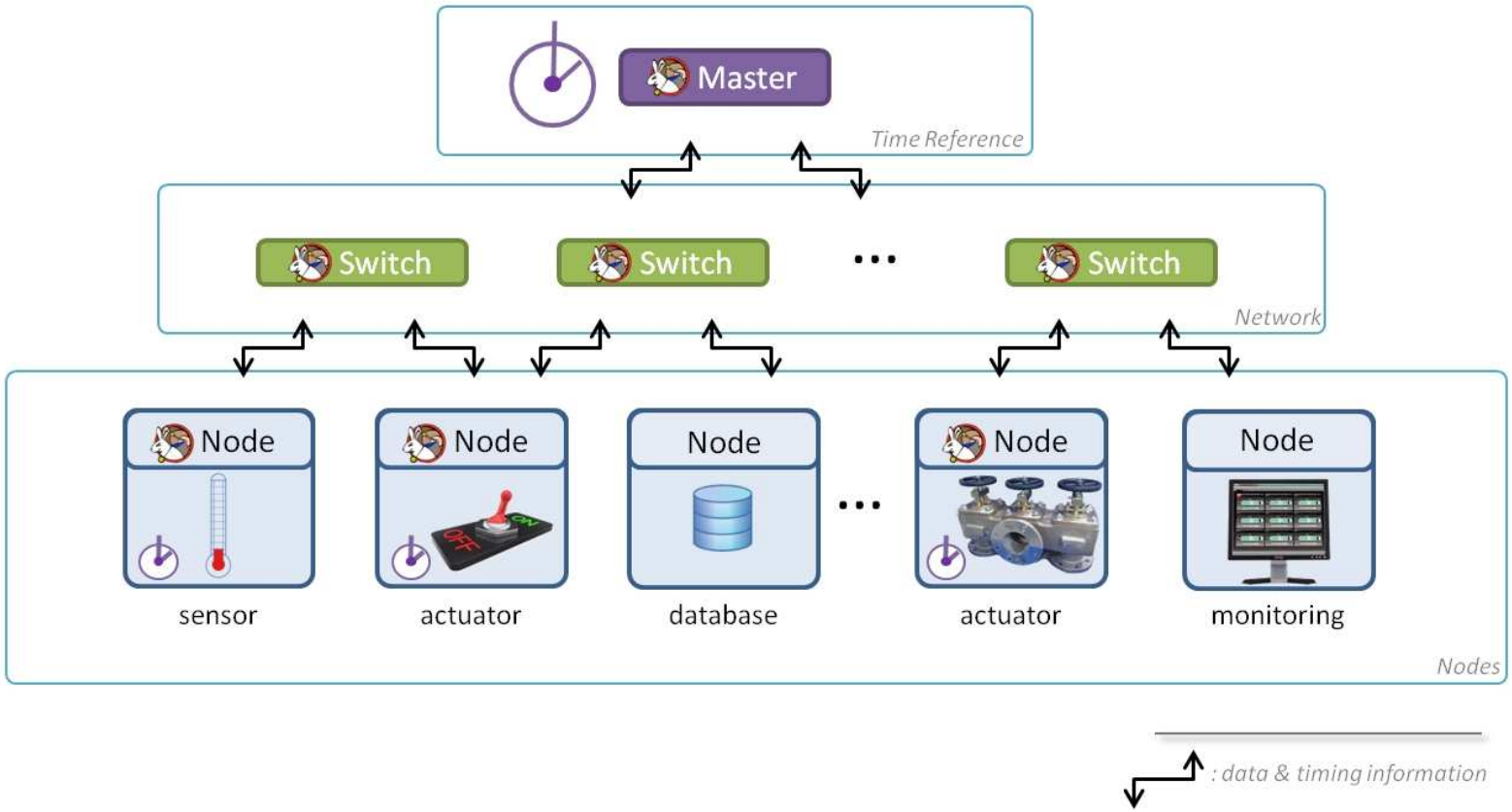


Data Distribution summary

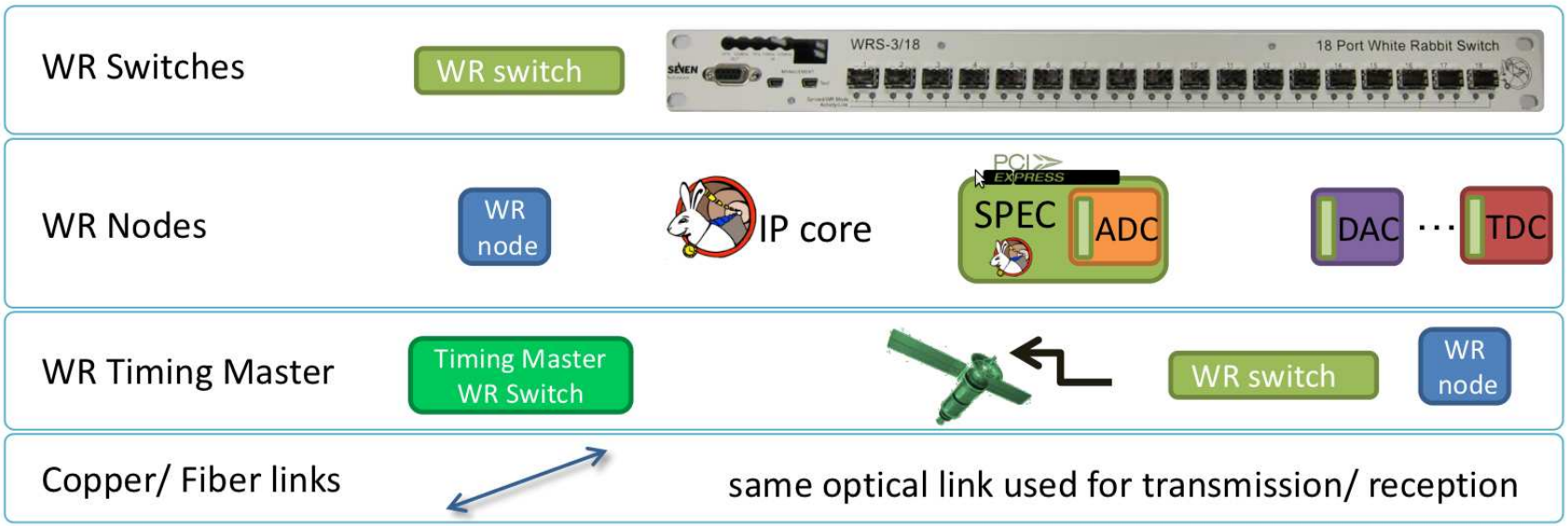
- Optional feature
- Openness enables everyone to verify the parameters
- Ongoing efforts (2012/2013)
- Commonalities with IEEE effort for 2^{nd} gen Audio Video Bridging

White Rabbit Network Components



White Rabbit Network Components

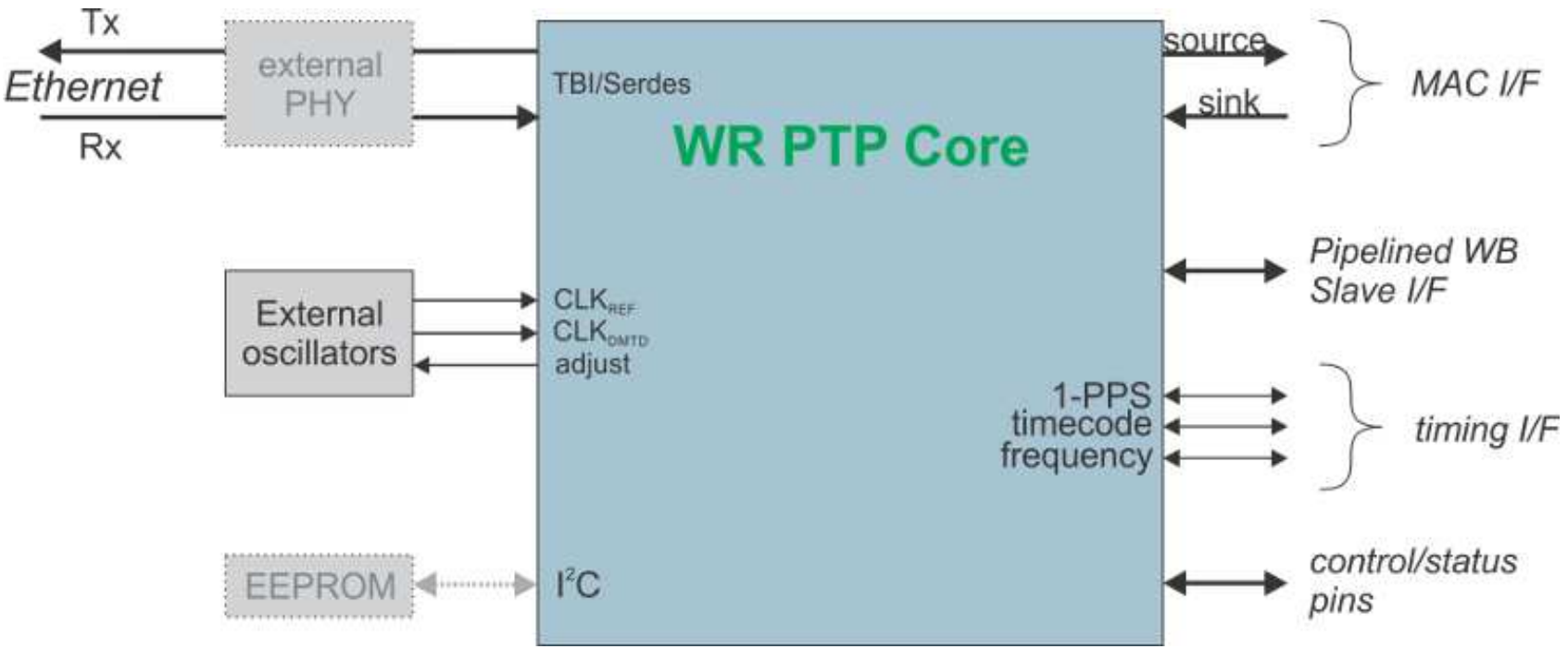
A White Rabbit network is composed of



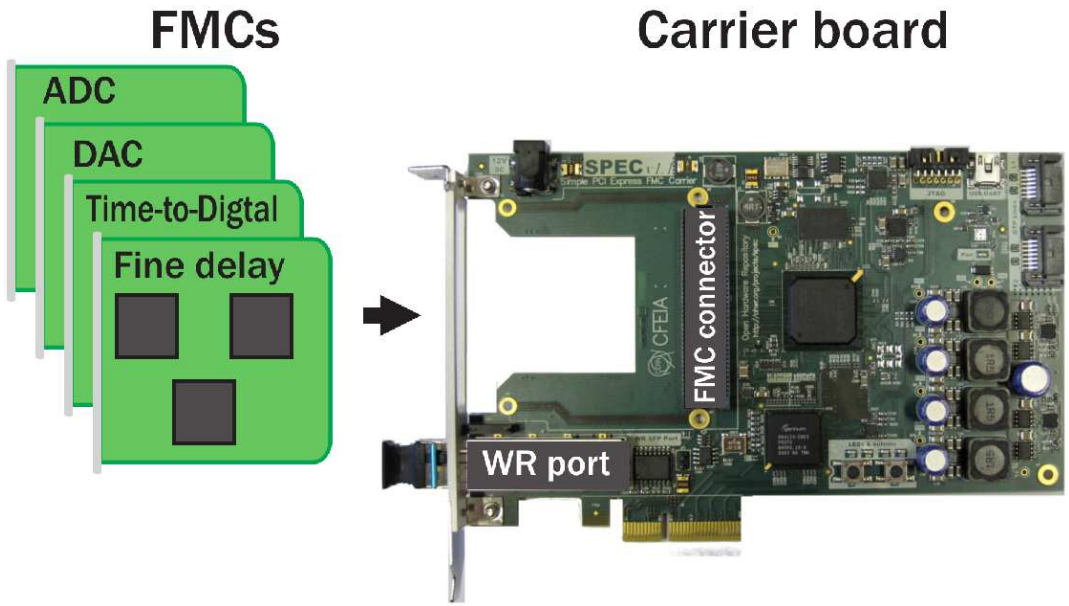
White Rabbit Switch (V3)

- Central element of WR network
- Original design optimized for timing, designed from scratch
- 18 1000BASE-BX10 ports
- Capable of driving 10 km of SM fiber
- Open design (H/W and S/W)

WR Node: WR PTP Core



WR Node: SPEC board



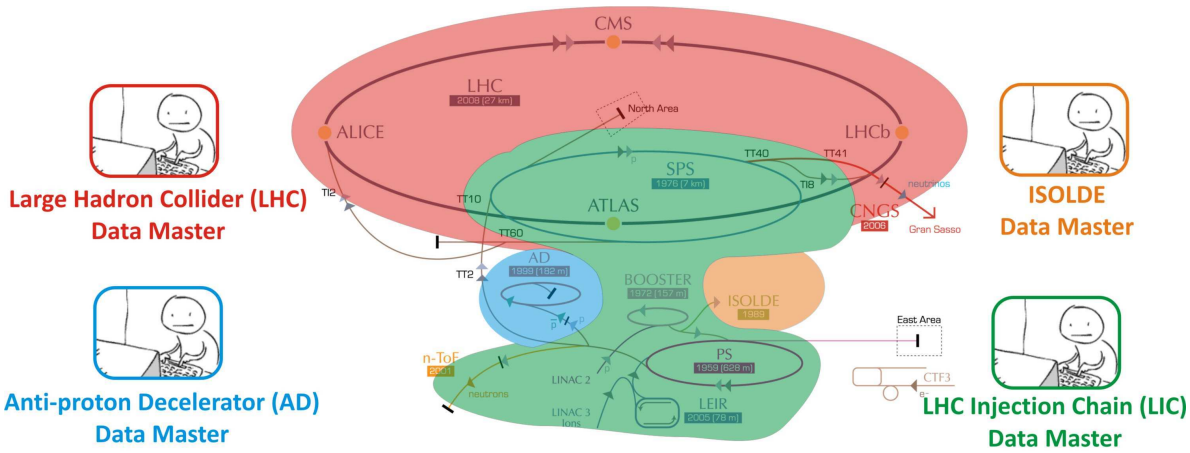
Co-HT FMC-based Hardware Kit:

- FMCs (FPGA Mezzanine Cards) with ADCs, DACs, TDCs, fine delays, digital I/O
- Carrier boards in PCI-Express, VME and uTCA formats
- All carriers are equipped with a White Rabbit port

White Rabbit applications

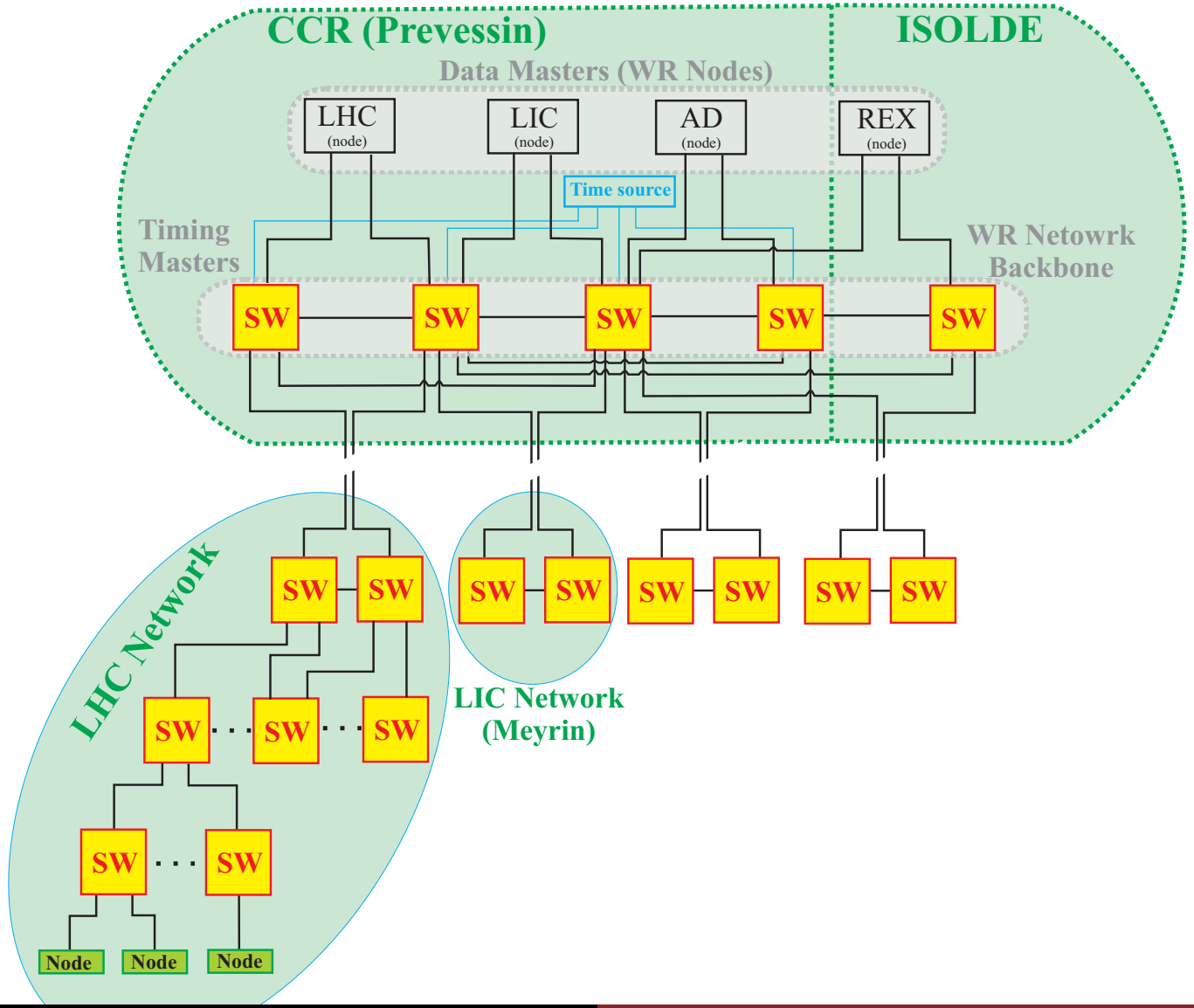
- Control and timing system
- Field bus recommended at CERN
- Time Transfer
- RF distribution
- Distributed oscilloscope
- ...

WR at CERN

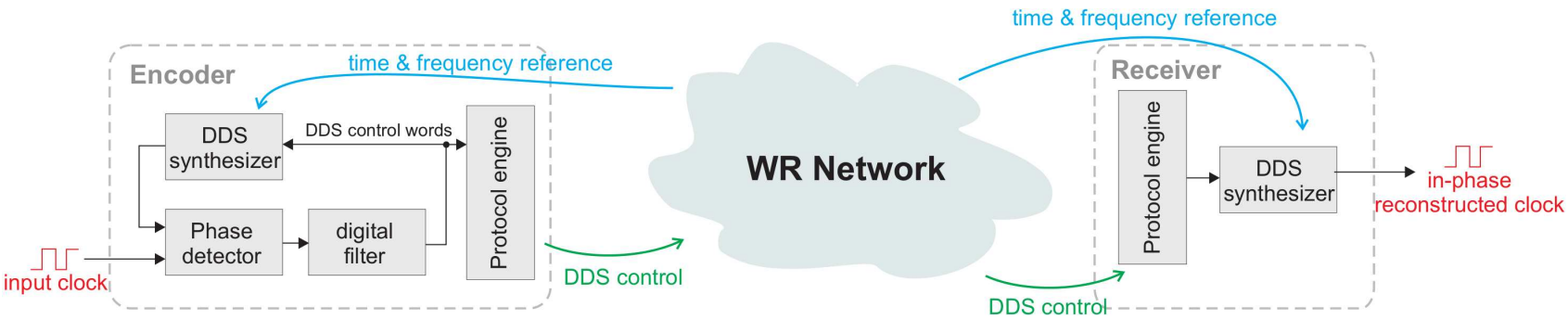


- 4 accelerator networks
- Separate **Data Master (DM)** for each network
- LIC Data Master communicates with other DMs and control devices in their networks
- Broadcast of **Control Messages** within network(s)

WR at CERN


CCR (Prevessin)
ISOLDE
Data Masters (WR Nodes)
LHC (node)
LIC (node)
AD (node)
REX (node)
Time source
Timing Masters
WR Netowrk Backbone
SW
LHC Network
LIC Network (Meyrin)
Node
Node
Node

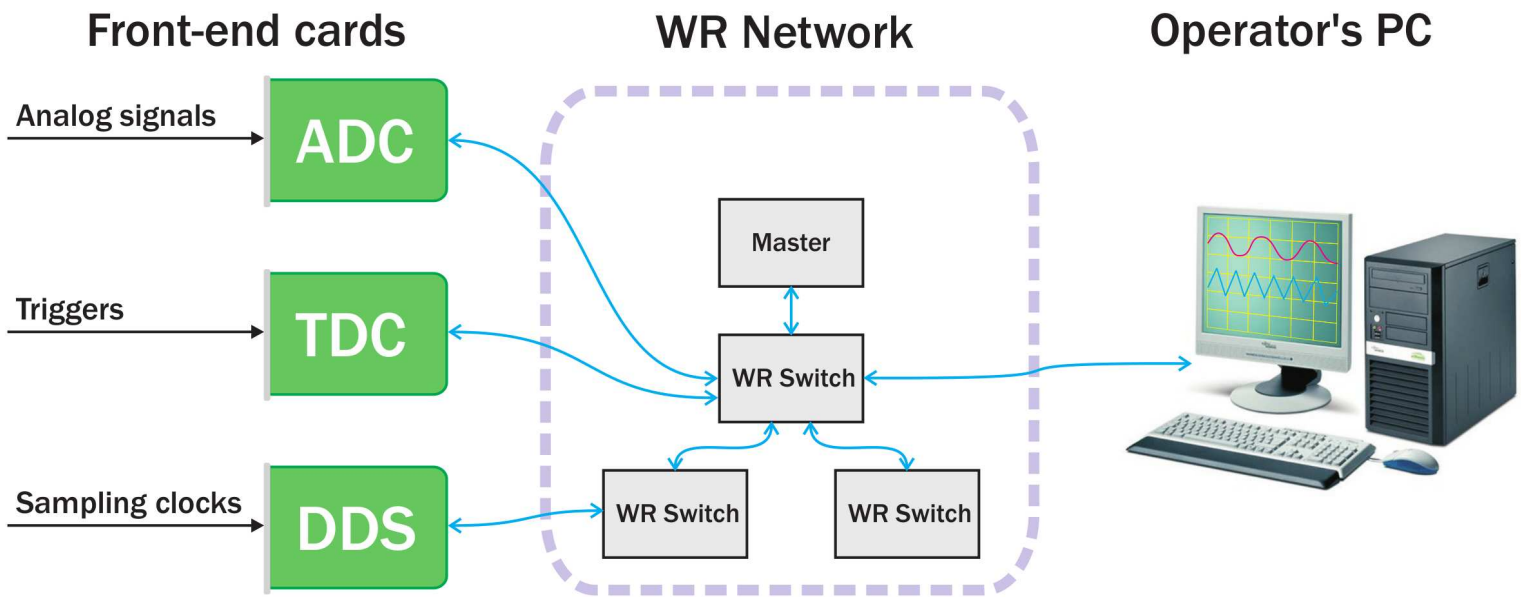
Ethernet Clock distribution a.k.a. Distributed DDS



Distributed Direct Digital Synthesis

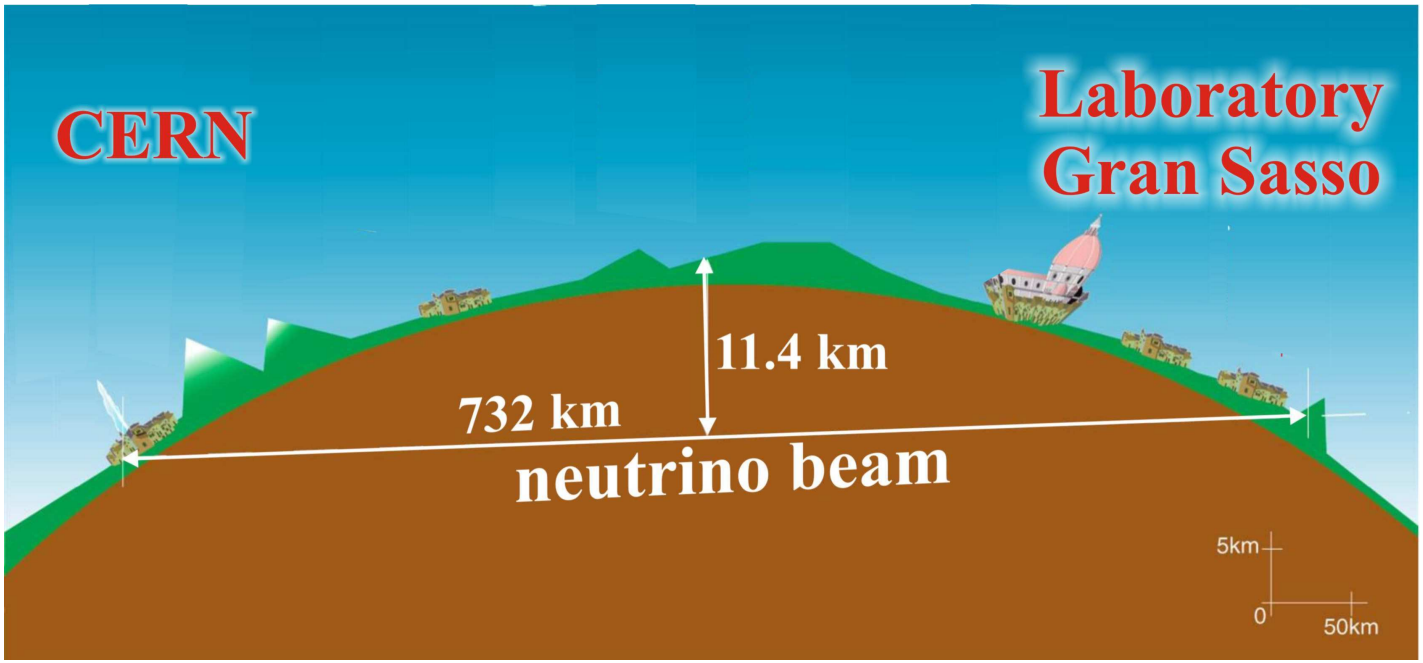
- Replaces dozens of cables with a single fiber.
- Works over big distances without degrading signal quality.
- Can provide various clocks (TTC, RF, bunch clock) with a single, standardized link.

Distributed oscilloscope



- Common clock in the entire network: no skew between ADCs.
- Ability to sample with different clocks via Distributed DDS.
- External triggers can be time tagged with a TDC and used to reconstruct the original time base in the operator's PC.

CERN Neutrinos to Gran Sasso (CNGS)



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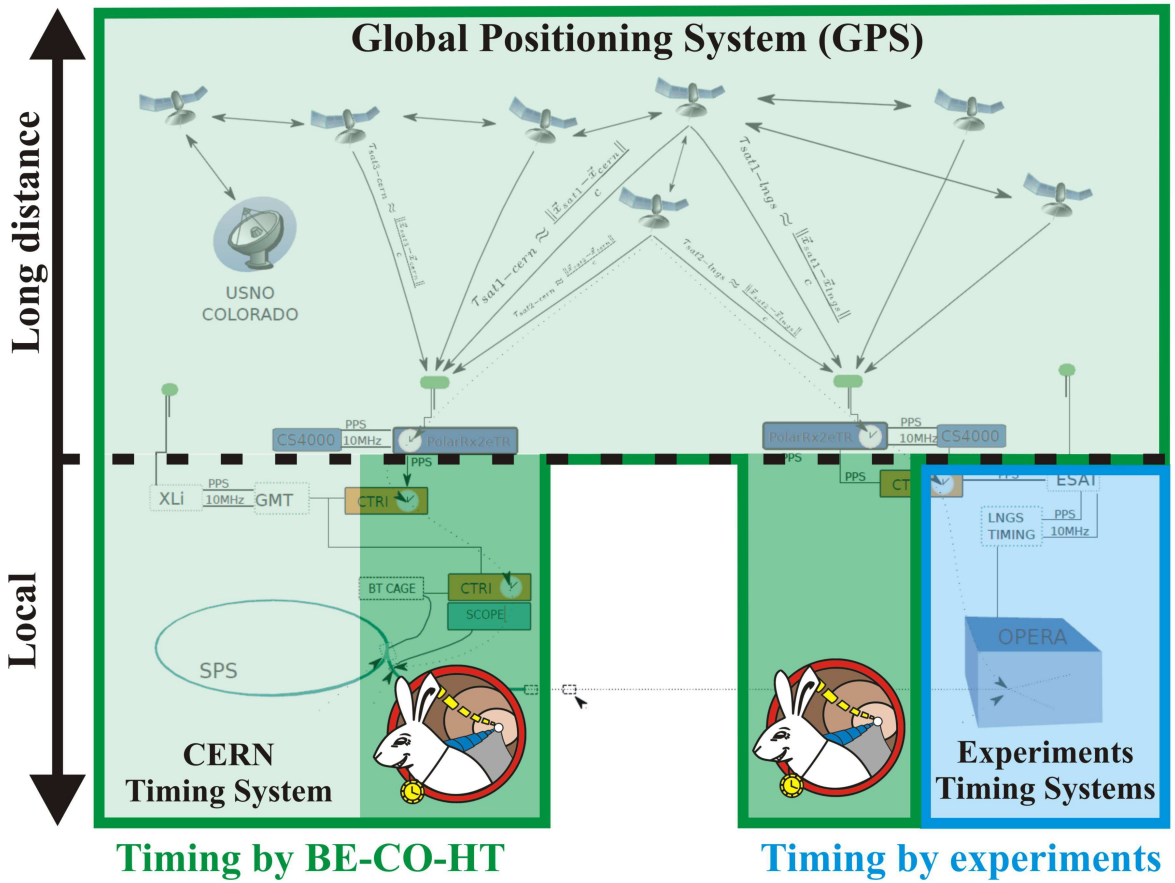
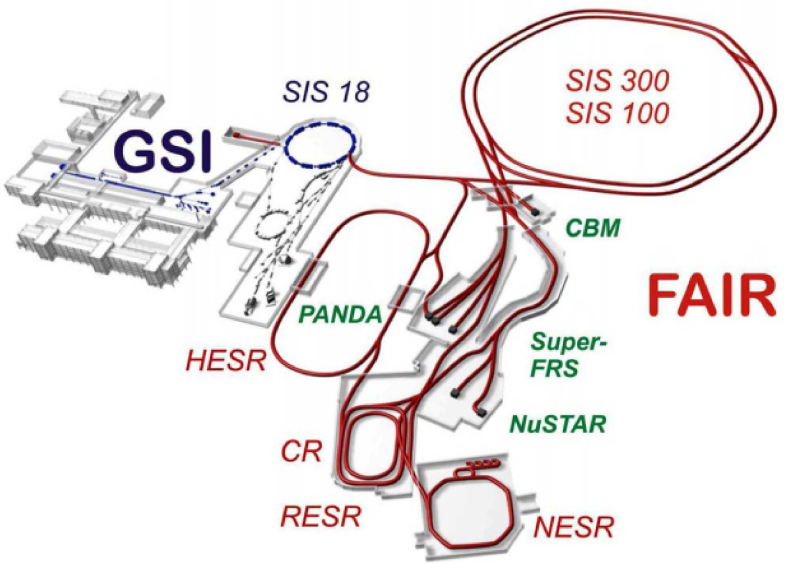


- Investigation of neutrino oscillation
- Time of Flight (ToF) measurement

Other White Rabbit applications

- Future applications:
  - **GSI**



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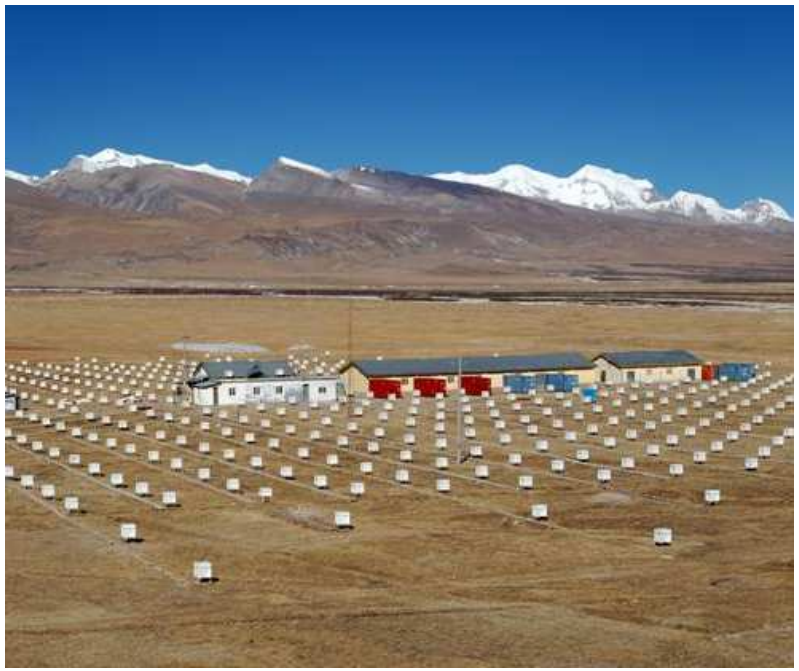
  - **The Large High Altitude Air Shower Observatory (China)**



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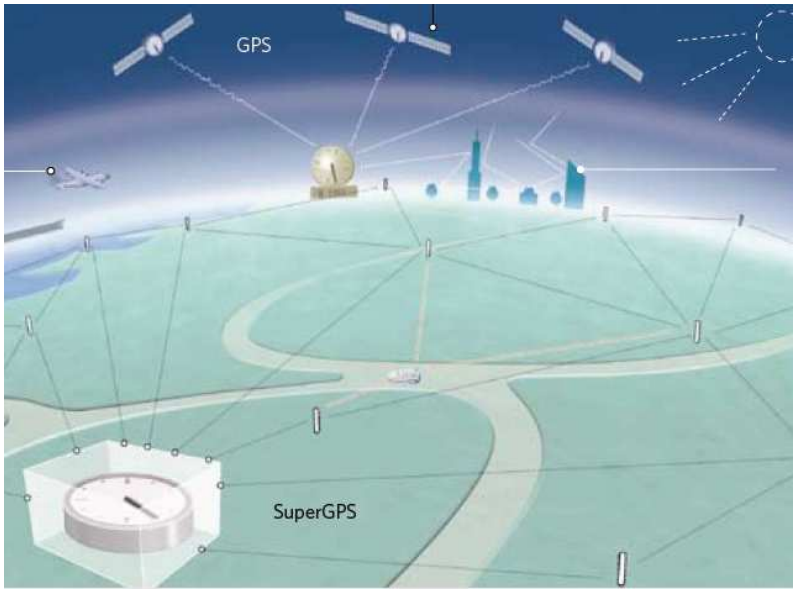
- Potential applications:
  - **SuperGPS through optical networks**



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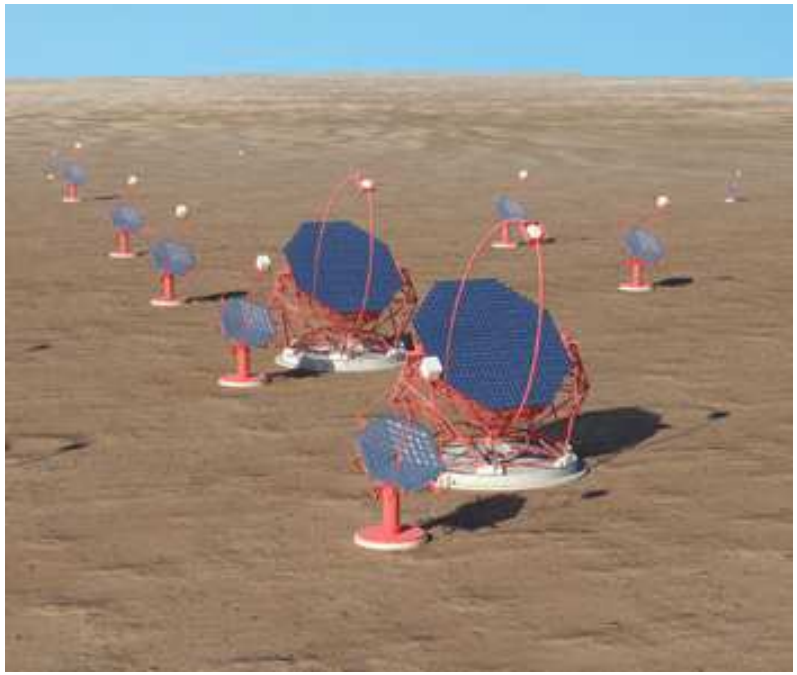

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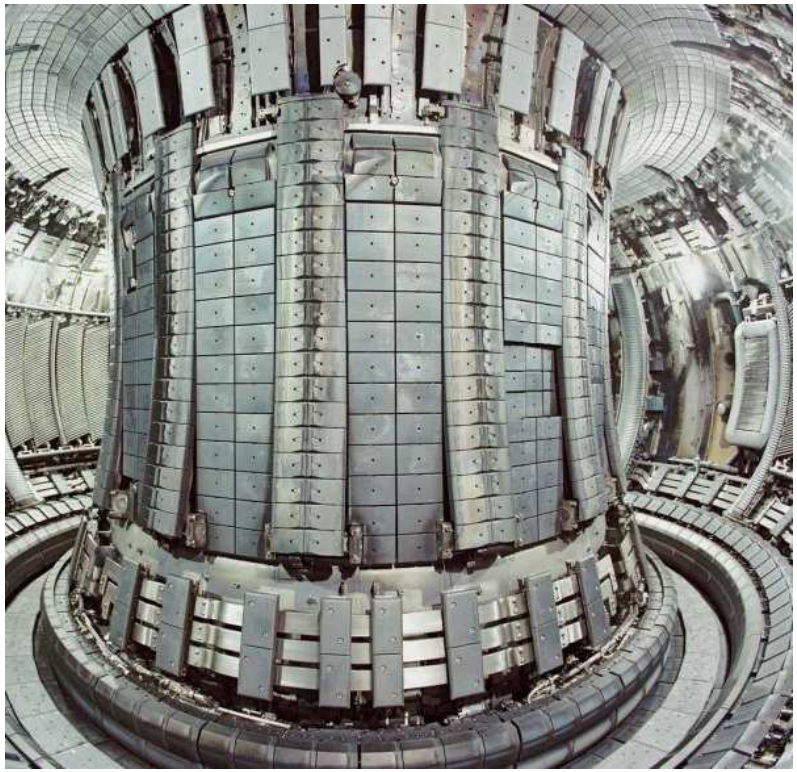
  - **ITER**



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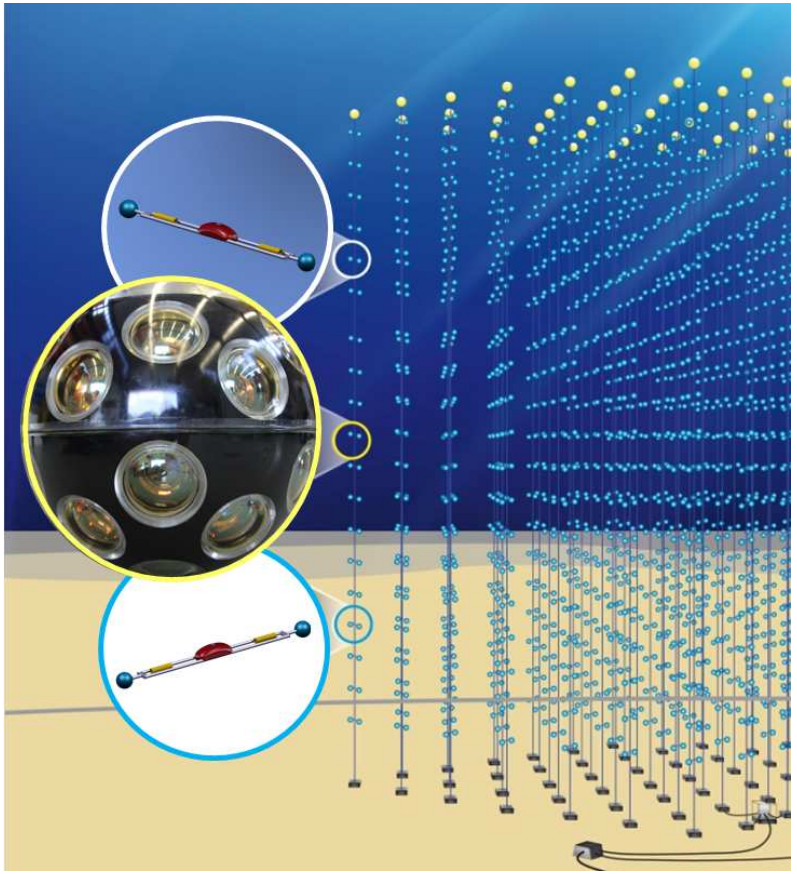
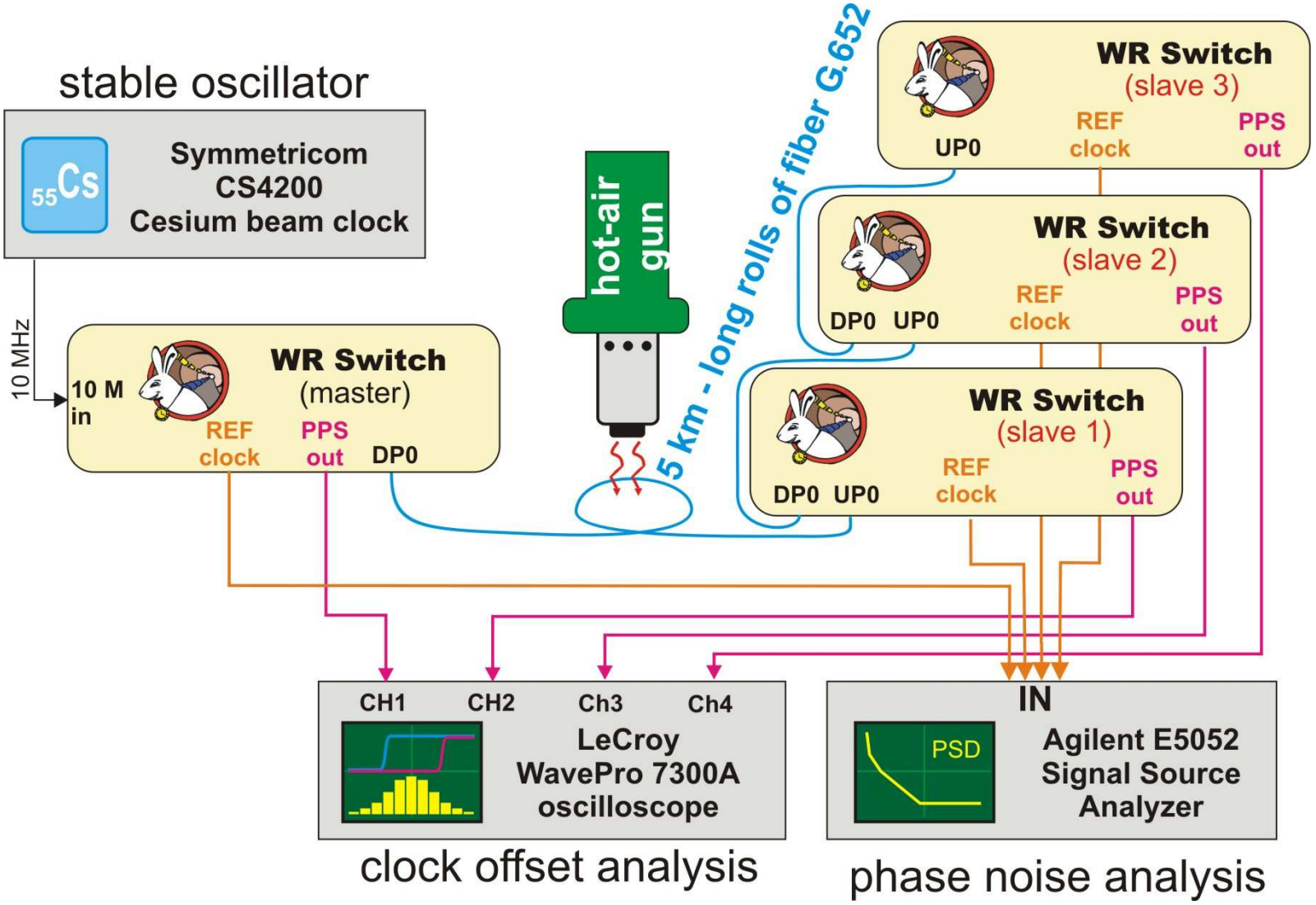
  - ITER
  - **European deep-sea research infrastructure (KM3NET)**



WR time transfer performance: lab tests



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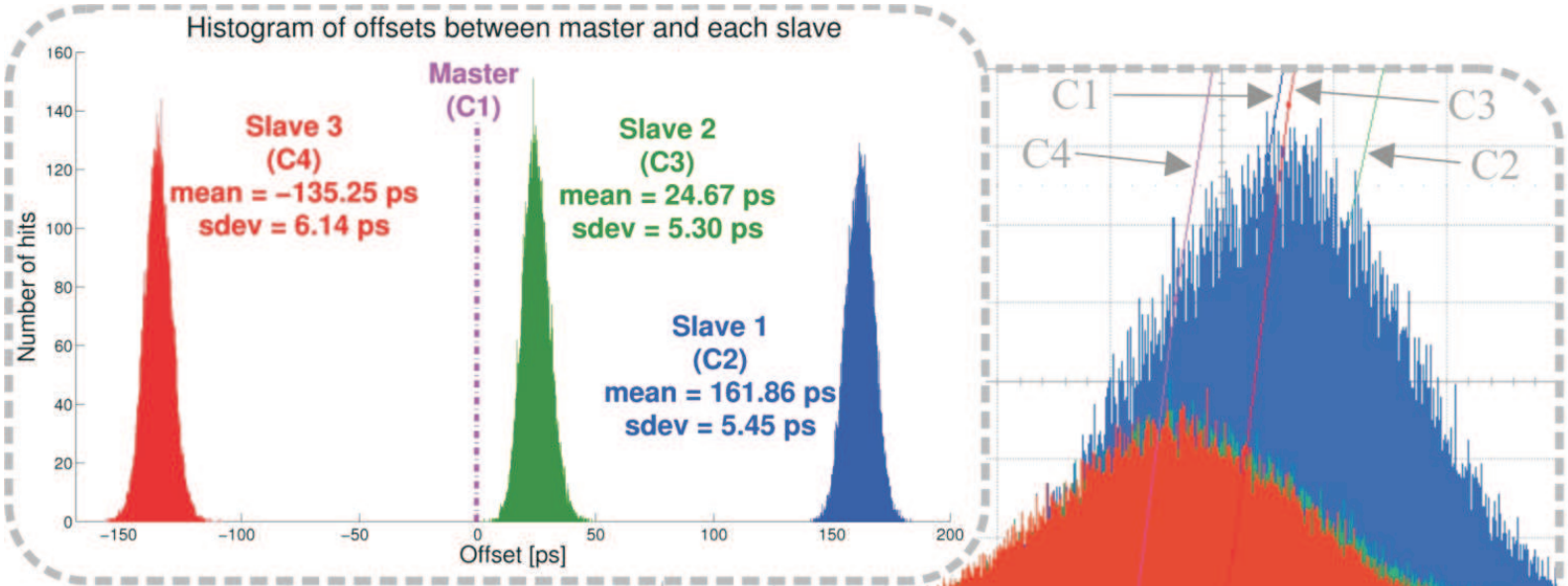
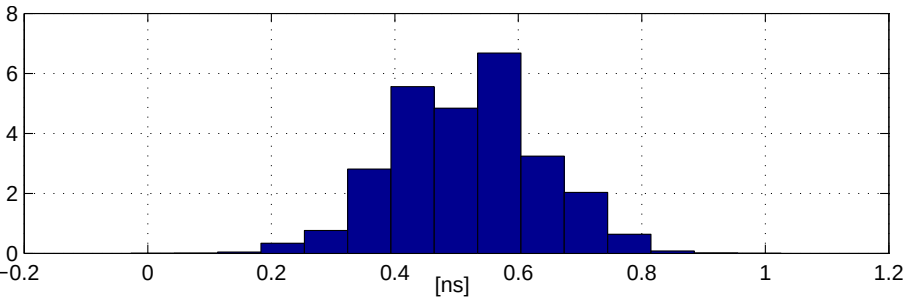


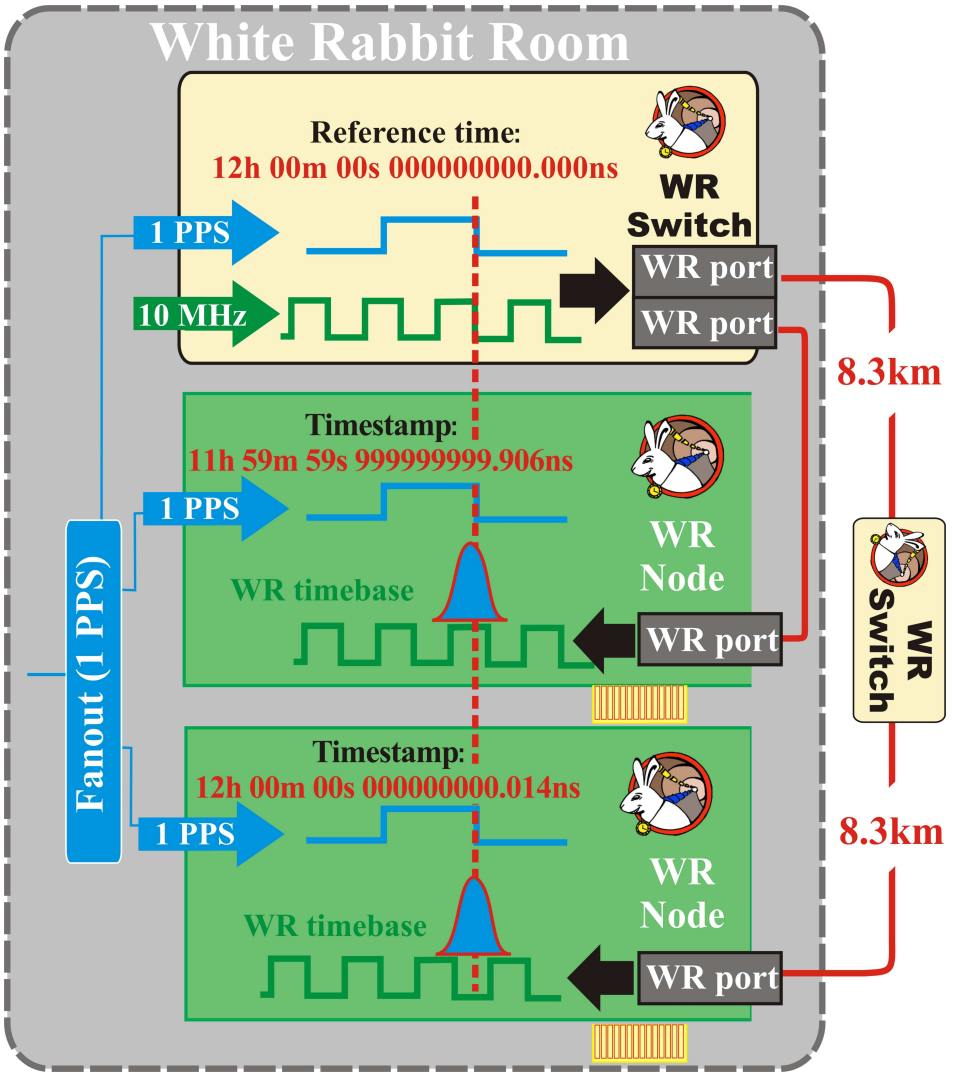
Matlab plot of collected data

Oscilloscope screenshot

WR time transfer performance: deployment for CNGS

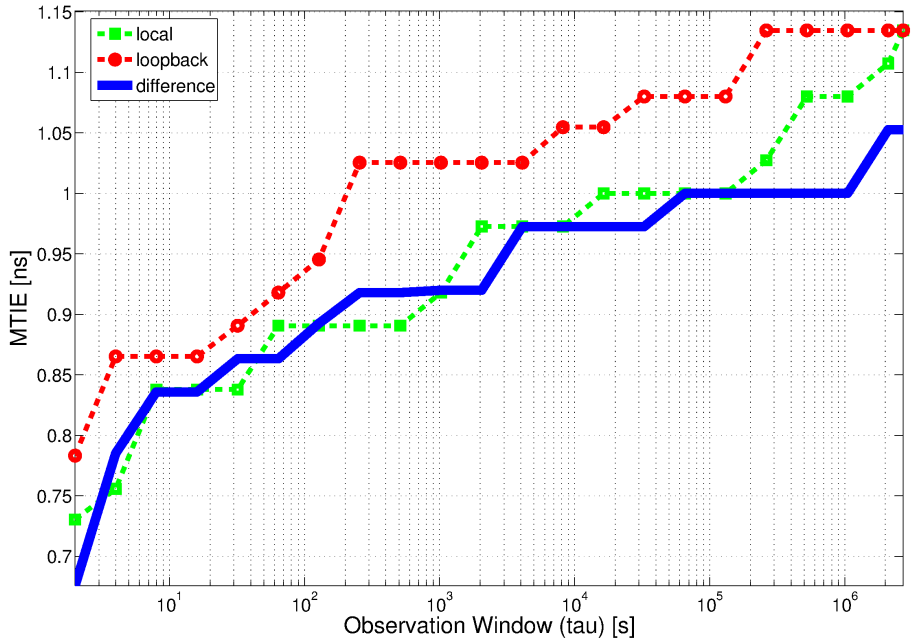


- Duration: 31 d, 7 h, 40 s ($2.7 * 10^6$ samples)
- WR Nodes with TDC used
- Measurement includes inaccuracy of TDC
- Timestamping reference PPS
- Accuracy: 0.517 ns
- Precision: 0.119 ns (std. dev)



WR time transfer performance: deployment for CNGS

Out of $2.7 * 10^6$ samples
9 values of x_{diff} [0.0003%]
exceeded MTIE=1ns



Future Internet Engineering and White Rabbit(1)

Future Internet Engineering

- redefines/improves 3-7 OSI Layers
- uses cutting edge 1-2 OSI Layers (Ethernet)
- virtualizes

White Rabbit

- improves 2 OSI Layer (i.e. GbE)
- brings into Ethernet Networks:
  - high accuracy synchronization
  - determinism
  - reliability
- provides hardware-support

Future Internet Engineering and White Rabbit(2)

Future Internet Engineering

- Uses cutting edge Layer 2 equipment (PIONIER)
- Large scale: used globally with millions of nodes
- Application: mass scale, public

White Rabbit

- Uses White Rabbit Layer 2 equipment
- Large scale: tens of km with thousands of nodes
- Application: dedicated, isloated, well-controlled

Summary

- White Rabbit
  - 2000 nodes
  - $<$ 1ns accuracy
  - determinism and reliability
  - tested up to 10km
- FIE and WR are complementary
- FIE is general-purpose and global-scale technology
- WR is specialized-purposed and large-scale technology
- WR improves the technology that FIE uses

Questions and answers