



White Rabbit
COLLABORATION

www.white-rabbit.tech

Towards a joint development of
high accuracy time transfer technology and best practices

Amanda Díez Fernández

Knowledge Transfer, CERN

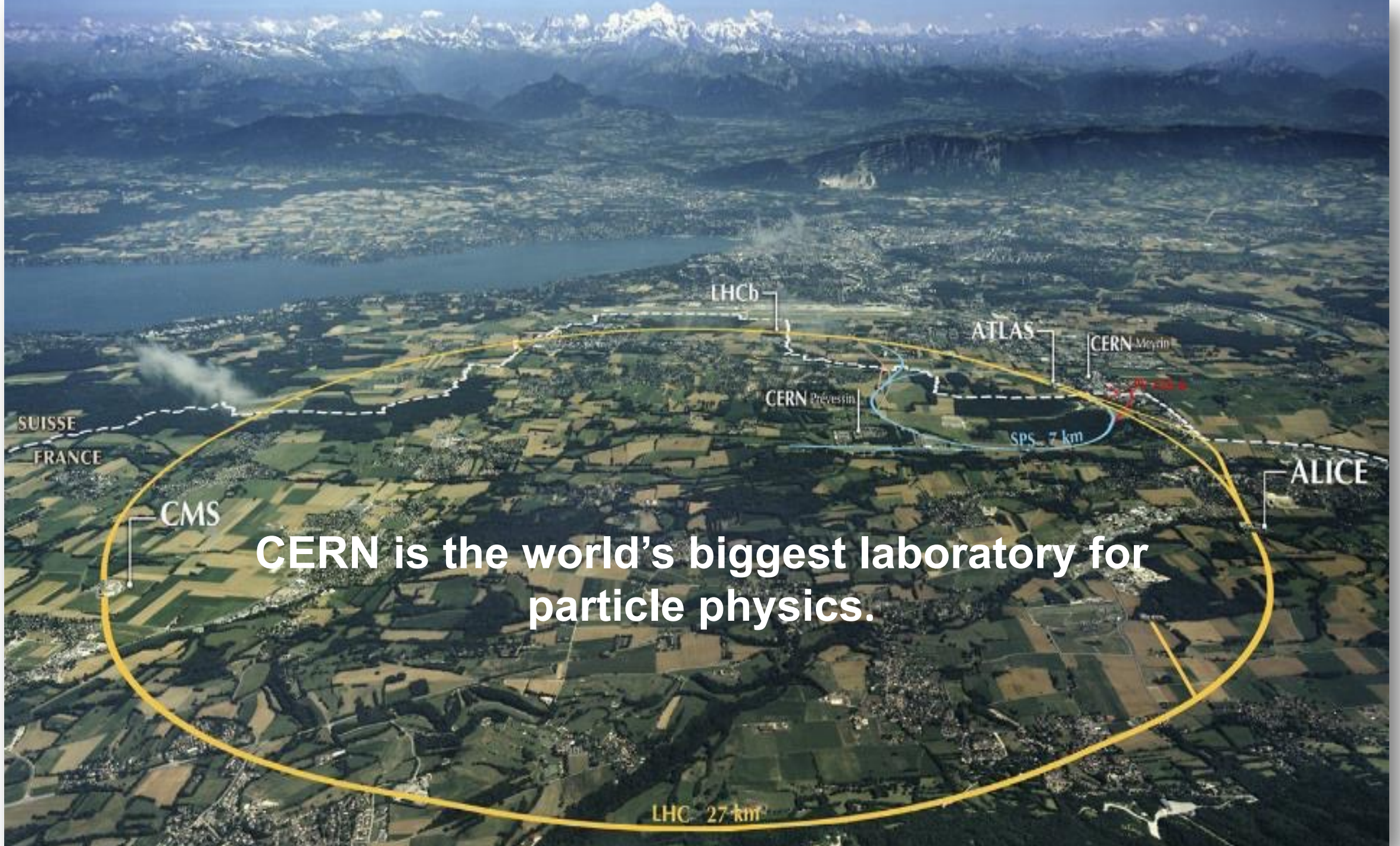
*Community Coordinator
of the WR Collaboration*



Outline

- A few words on CERN
- White Rabbit Technology
- Vendors and Applications
- The White Rabbit Collaboration
- 14th WR Workshop at CERN





SUISSE
FRANCE

CMS

LHCb

ATLAS

CERN Meyrin

CERN Prévessin

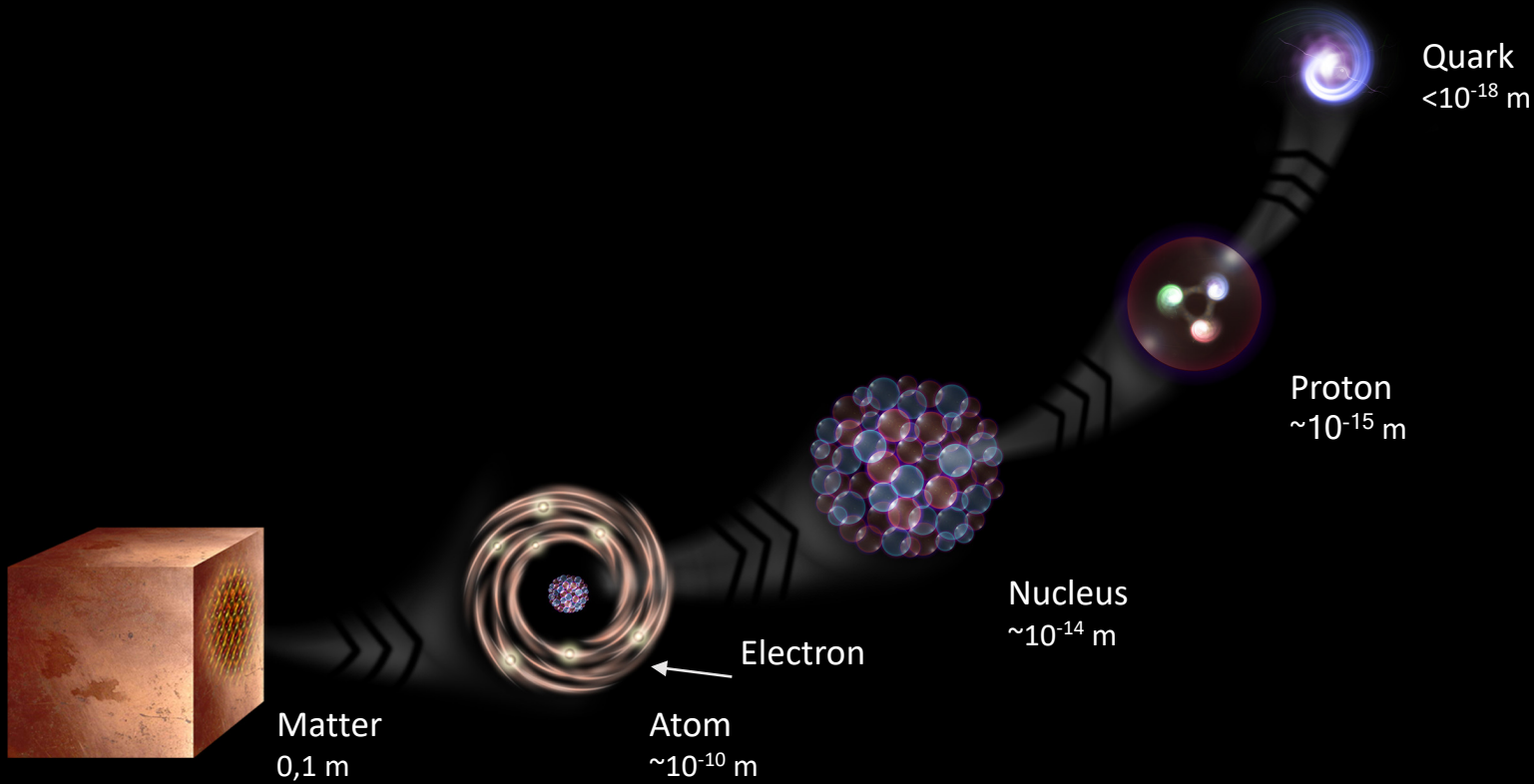
SPS 7 km

ALICE

CERN is the world's biggest laboratory for particle physics.

LHC 27 km

We study the elementary building blocks of matter and the forces that control their behaviour



CERN – a collaborative endeavour

24 Member States

Austria, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Israel, Italy, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovak Republic, Spain, Sweden, Switzerland and United Kingdom.

2 Associate Member States in the pre-stage to membership

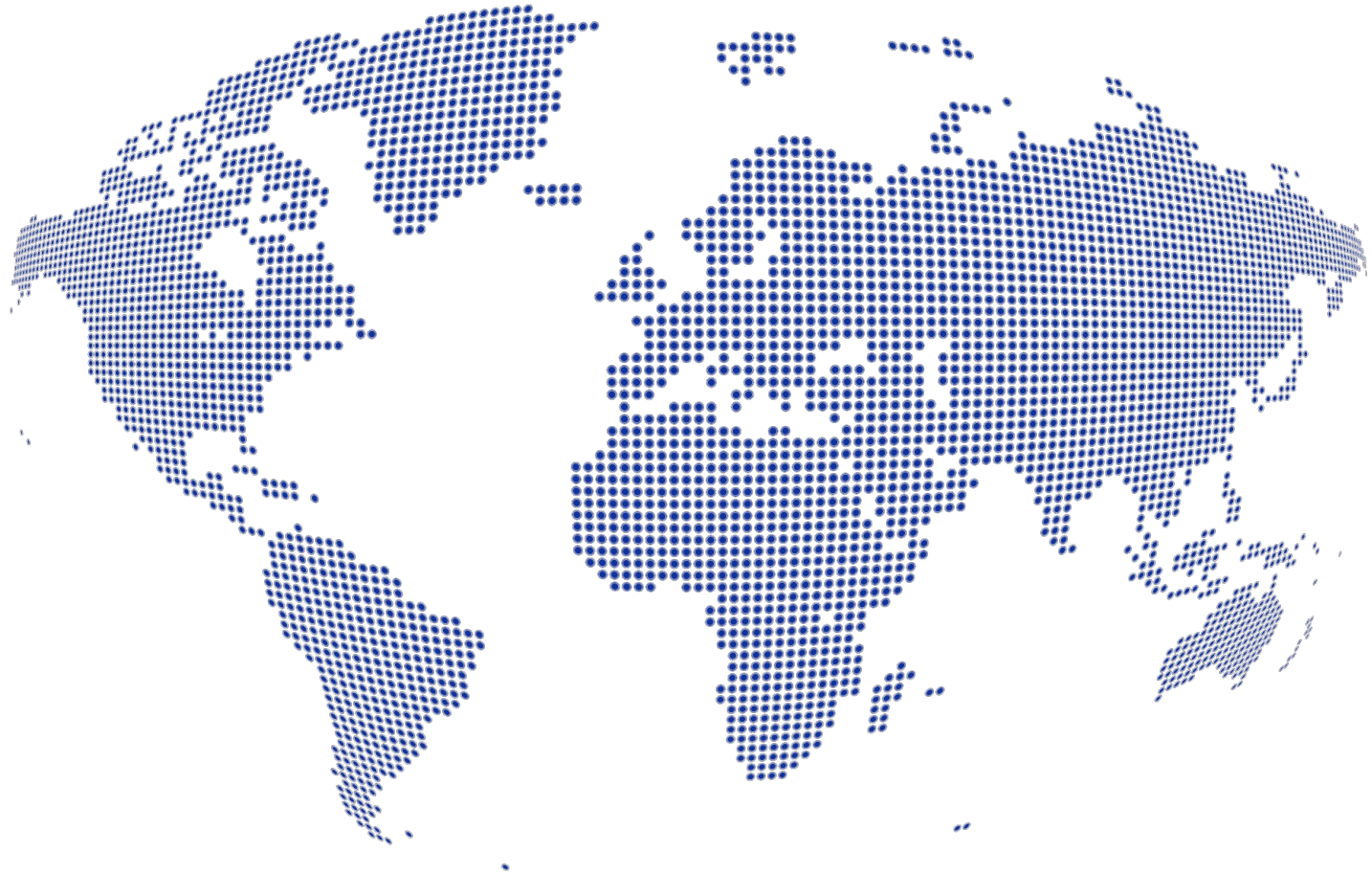
Cyprus – Estonia – Slovenia

8 Associate Member States

Croatia – India – Latvia – Lithuania – Pakistan
Turkey – Ukraine – Brazil

50 Cooperation Agreements
with non-Member States and Territories

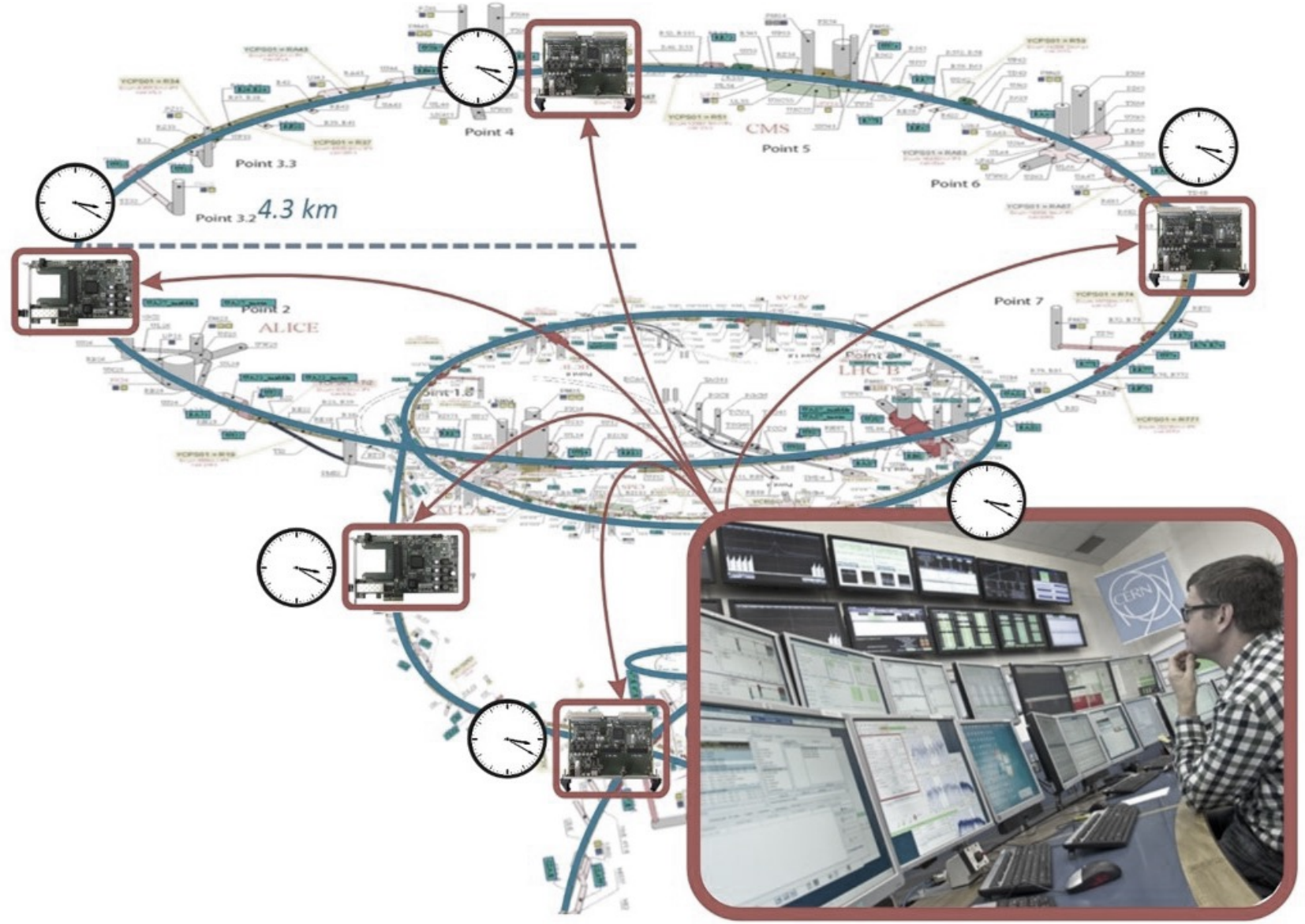
Over 600 institutes and universities
around the world use CERN's facilities.





We develop our own technologies and engineering capabilities to cover needs not addressed by industry

Developed
more than
10 years ago
to control the
accelerators at CERN



Fostering CERN's Impact beyond fundamental science



Maximise the technological and knowledge return to society, in particular through Member States industry



Promote CERN as a centre of excellence for technology and innovation



Demonstrate the importance and impact of fundamental research investments

CERN launches the White Rabbit Collaboration

White Rabbit, an open-source timing technology developed at CERN, has applications far beyond particle physics. To foster its uptake by industry, CERN has launched the White Rabbit Collaboration

22 MARCH, 2024

<https://home.cern/news/news/knowledge-sharing/cern-launches-white-rabbit-collaboration>

Listen to the talks of the event here:

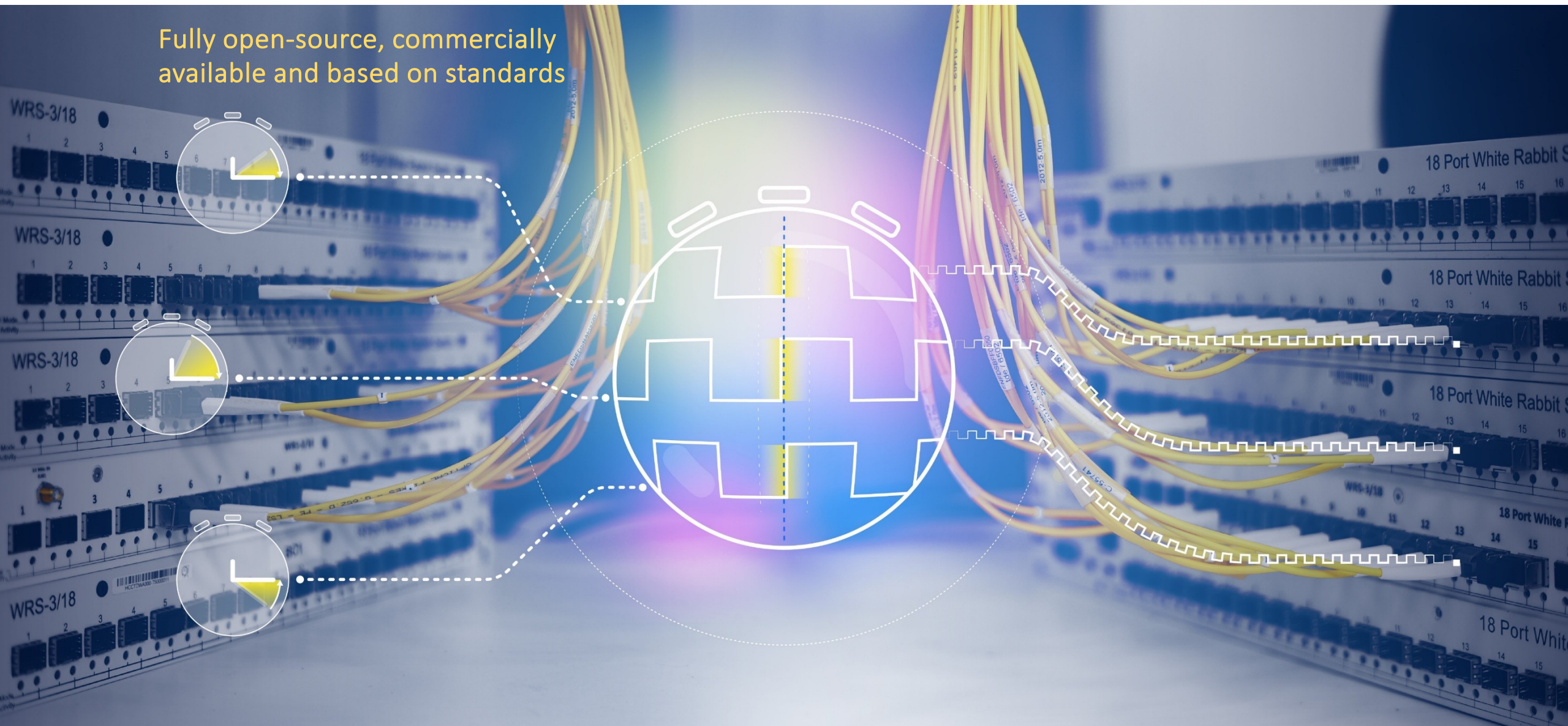
https://www.white-rabbit.tech/13th_WR_workshop/

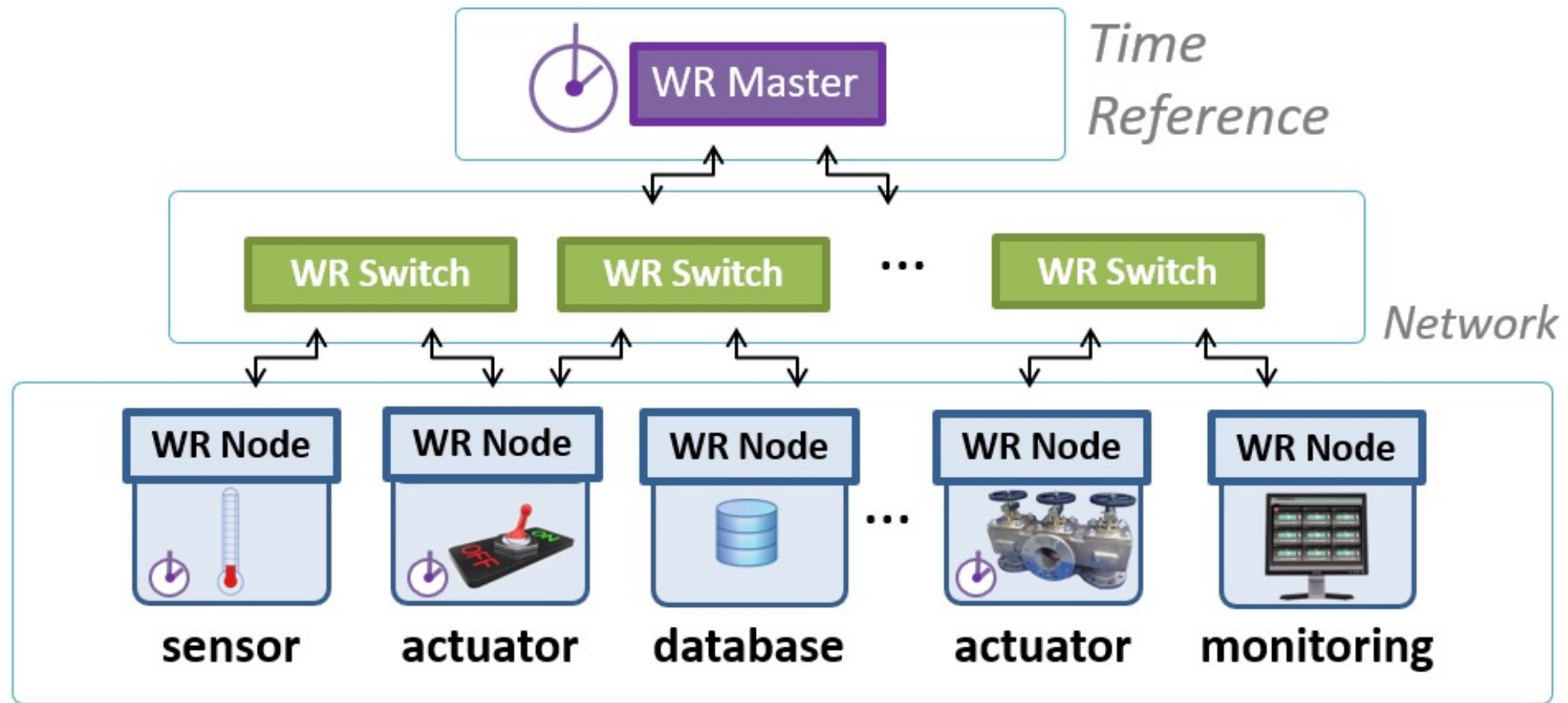


White Rabbit Technology

to synchronise devices on a fibre optic ethernet network to sub-nanosecond accuracy

Fully open-source, commercially available and based on standards





 : *data & timing information*

Calculating delays

11h50m00s000000000.000ns

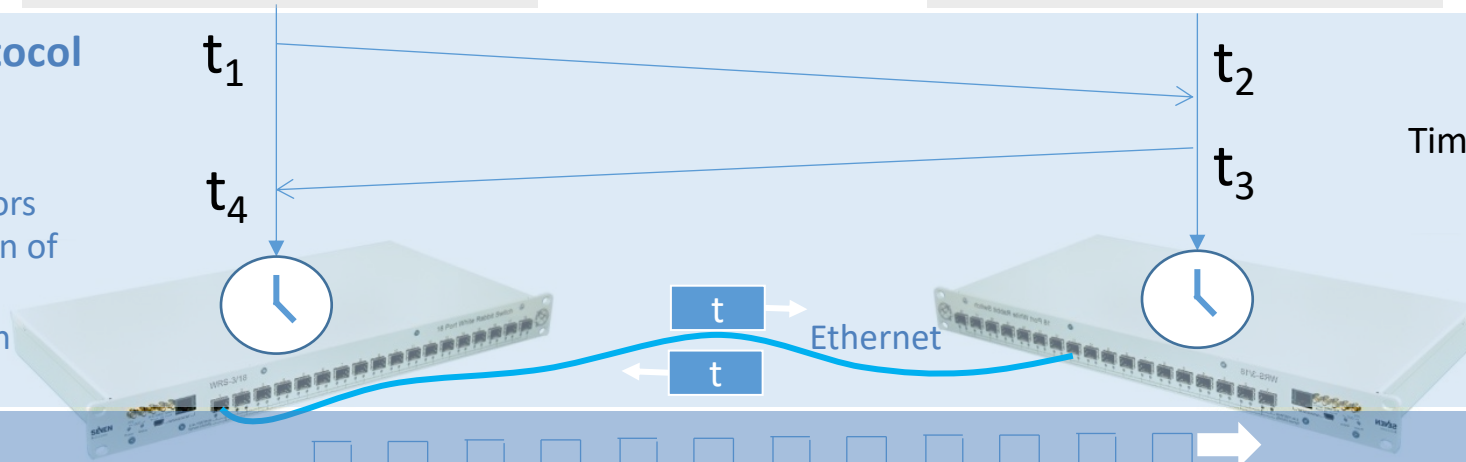
11h50m00s000000000.010ns

Precision Time Protocol (PTP, IEEE 1588)

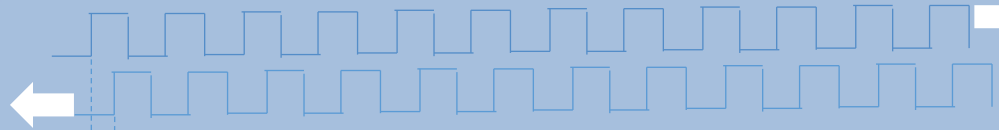
PTP limitations:

- Free-running oscillators
- Symmetry assumption of medium & hardware
- Timestamp resolution

$$\text{Time_cor} = \frac{(t_4 - t_1) - (t_3 - t_2)}{2} + \text{asym}$$



Frequency transfer



Enhance delay measurement thanks to common freq

Phase detection



Enhance timestamp precision to ps level by using phase detection techniques

Asymmetry corrections

- Single bidirectional fiber
- Link delay model
- Calibration

Enhance time corrections accuracy by automatic medium asymmetry calculation and calibration of hardware delays

IEEE SA
STANDARDS
ASSOCIATION

**IEEE Standard for a Precision
Clock Synchronization Protocol for
Networked Measurement and Control
Systems**

IEEE Instrumentation and Measurement Society

Developed by the
Technical Committee on Sensor Technology (TC-9)

IEEE Std 1588™-2019
(Revision of IEEE Std 1588-2008)



STANDARDS

White Rabbit, a CERN-born technology, sets a new global standard

The Institute of Electrical and Electronics Engineers has incorporated the White Rabbit technology into its industry standard, maximising its adoption by industry and other partners in their pursuit to build innovative solutions for world challenges

<https://home.cern/news/news/knowledge-sharing/white-rabbit-cern-born-technology-sets-new-global-standard>

www.white-rabbit.tech/ieee1588-standard/



WR Vendors

Safran

<https://safran-navigation-timing.com/solution/white-rabbit-solutions>

SyncTechnology

www.synctechonology.cn

Creotech

<https://creotech.pl/news/white-rabbit>

OPNT

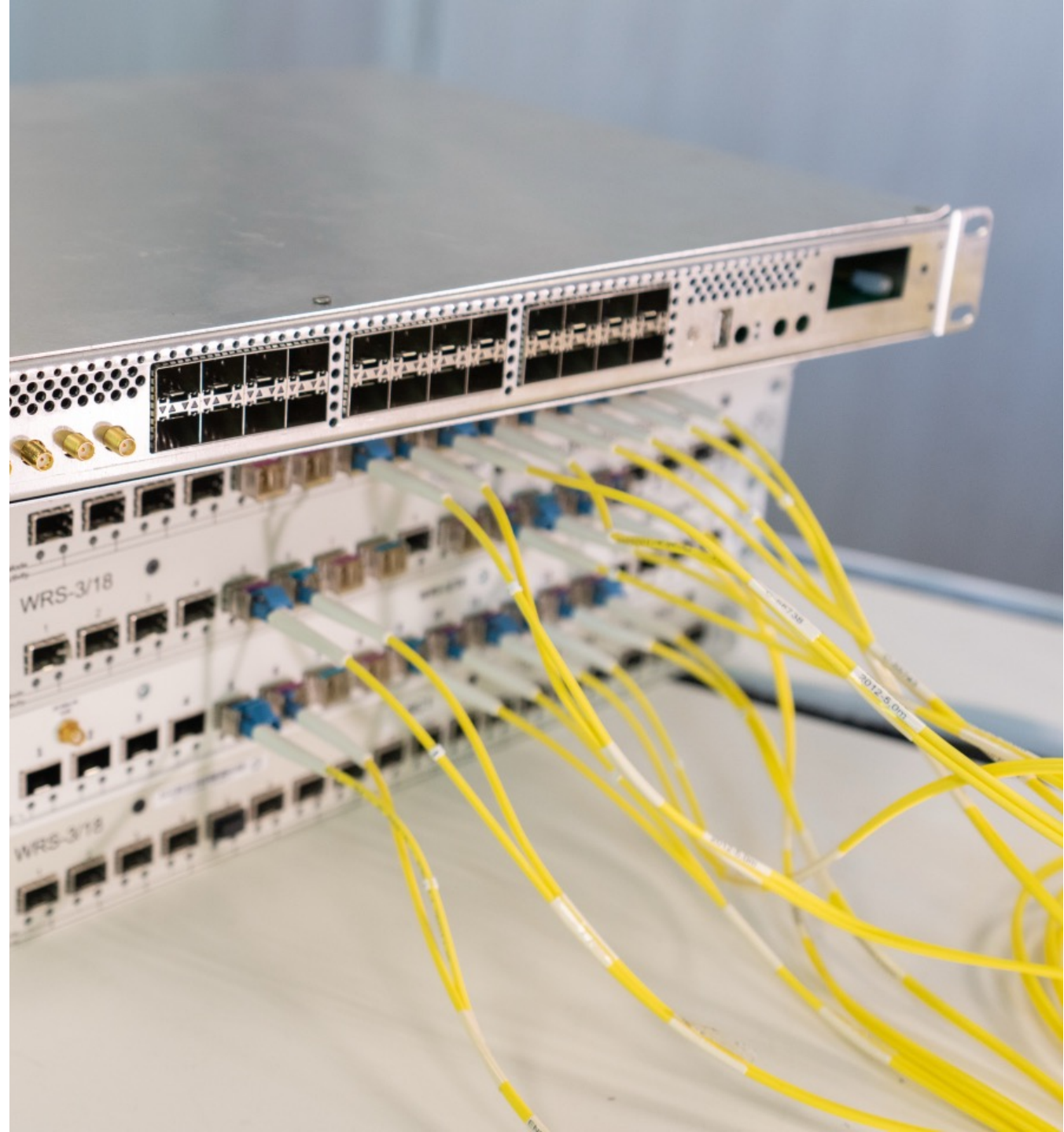
www.opnt.nl

GMV*

www.gmv.com

See talk of the WR Workshop this year:
<https://cds.cern.ch/record/2893521?ln=en>

*future vendor



*some examples of WR Nodes

D-tAcq

www.d-tacq.com



www.d-tacq.com/news.shtml

D-TACQ Solutions Ltd is a premier supplier of turnkey data acquisition products and services.

PicoQuant

www.picoquant.com



<https://www.picoquant.com/products/category/tcspc-and-time-tagging-modules/multiharp-150-high-throughput-multichannel-event-timer-tcspc-unit>
<https://www.picoquant.com/products/category/tcspc-and-time-tagging-modules/multiharp-160>

PicoQuant is known as a company leading in the field of pulsed diode lasers, time-resolved data acquisition, single photon counting, and fluorescence instrumentation.

CAENels

www.caenels.com



<https://www.caenels.com/product/damc-fmc2zup/>

We are a leading company in the design of power supplies and state-of-the-art complete electronic systems, having its main focus on dedicated solutions for the particle accelerator community and high-end industrial applications.

NAT

<https://nateurope.com>



<https://nateurope.com/product/native-r9-mtca4-chassis/>

<https://nateurope.com/product/native-r2-compact-mtca4-chassis/>

Creating sophisticated state-of-the-art solutions for wired and radio based applications in telecommunication and industrial automation.

iNCAA Computers

www.incaacomputers.com



cRIO-WR

CompactRIO White Rabbit Module

SPECIALIZED IN ADVANCED COMPUTER APPLICATIONS

www.incaacomputers.com/products/by-standard/general-by-standard/crio-wr/

janztec

www.janztec.com



Experts for the industrial Internet of Things. Design, implement and operate tailor-made IoT solutions for companies from a wide range of industries

www.janztec.com/wp-content/uploads/2020/03/datasheet_vme64-svec.pdf

Ettus Research

www.ettus.com

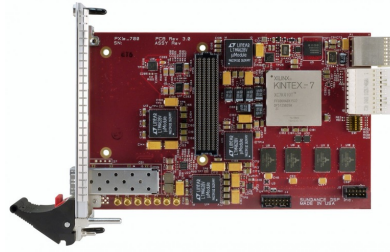


Ettus Research™, an NI brand since 2010, is the world's leading supplier of software-defined radio platforms, including the Universal Software Radio Peripheral (USRP™) family of products

www.ettus.com/all-products/usrp-n310/

sundance

www.sundance.technology



www.sundance.technology/som-carriers/pxi-boards/pxie700/

The Sundance company strategy is to produce a comprehensive range of products for the high-performance embedded processing market.

Teledyne

www.spdevices.com



www.spdevices.com/en-us/news/Pages/Newsletter-White-Rabbit-Application-Note.aspx

www.spdevices.com/en-us/Products_/Documents/ADQ7DC/17-2017-D%20ADQ7DC%20datasheet.pdf

Teledyne SP Devices designs, develops, and manufactures world-leading modular data acquisition and signal generation instruments

Struck

www.struck.de



www.struck.de/sis8160.html

www.struck.de/sis8300-ku.html

www.struck.de/sis1160.html

www.struck.de/conflyers17.pdf

Our core activity is the development, production and marketing of data acquisition board level electronics



DEUTSCHE BÖRSE
GROUP

Time services

State-of-the-art network time synchronisation with the T7 trading infrastructure

- ✓ Time Service (PTP)
- ✓ Time Service (White Rabbit)

<https://www.deutsche-boerse.com/dbg-en/products-services/ps-technology/ps-connectivity-services/ps-connectivity-services-time-services>

<https://cds.cern.ch/record/2895063?ln=en>

https://www.white-rabbit.tech/13th_WR_workshop/

White Rabbit – A perfect match

- White Rabbit synchronizes clocks with sub-nanosecond precision and accuracy
- When monitoring participants competing over single nanoseconds, this performance is required
- More and more devices support it natively

Equinix Precision Time®

Precise, Reliable, Secure Time as a Service

Introducing Equinix Precision Time

Equinix Precision Time on [Platform Equinix®](#) provides secure PTP and NTP Time as a Service for distributed enterprise applications. The service uses redundant and strategically located GNSS antennas with receivers (includes Rubidium holdover), grandmaster clocks and the high-performance network backbone of Equinix Fabric® to deliver secure, reliable and precise time synchronization.

<https://docs.equinix.com/en-us/Content/Edge-Services/EPT/EPT-faq.htm>



E Q U I N I X

Use cases

Key use cases for Equinix Precision Time include:

Regulatory compliance

Equinix Precision Time helps financial and audio/video broadcast sectors to meet FINRA, MiFID II and SMPTE-2110(PTP), respectively.

Network security and operations

Precise Time is required across the enterprise network infrastructure for Security Information and Event Management (SIEM/NMS) and improved log integrity.

Availability

Customers can use Equinix Precision Time throughout North America, Europe, Asia-Pacific and Latin America via Equinix Fabric.

Technical specifications

Protocols supported

- Network Time Protocol - NTPv4 (RFC 5905) and NTPv3 (including MD5 authentication supported) (RFC 1305)
- Precision Time Protocol - PTPv2 (IEEE 1588-2008)

Clock sources

- GNSS antennas and highly precise time servers with Rubidium oscillator and PTP/White-Rabbit technology

Technical documentation



WR for the Galileo Ground Segment

*“As a result of these efforts, ESA awarded the company (Thales Alenia Space) the contract to develop the **G2 Ground Mission Segment** - designed to keep the satellites synchronised with UTC. This segment, **as well as WR-PTP**, features a number of other major technological innovations. **This will deliver greater resilience to time and frequency dissemination in Europe** and provide the Galileo network with improved performance in terms of positioning, navigation and synchronisation”*

<https://www.euramet.org/casestudies/casestudiesdetails/news/default-d5f622bc71>

Towards Carrier Grade White Rabbit

Marek Brawanski, Orange

<https://mediastream.cern.ch/MediaArchive/Video/Public2/weblecture-player/index.html?year=2024&lecture=1379641c13&ftime=00:00:00#>

www.white-rabbit.tech/13th_WR_workshop/

Reliable & friendly time provider

- Familiar technology components: PTP & SyncE
- Best accuracy & precision for the price
- Open technology SW* and HW* (mostly)
- Customizable
- Field proven

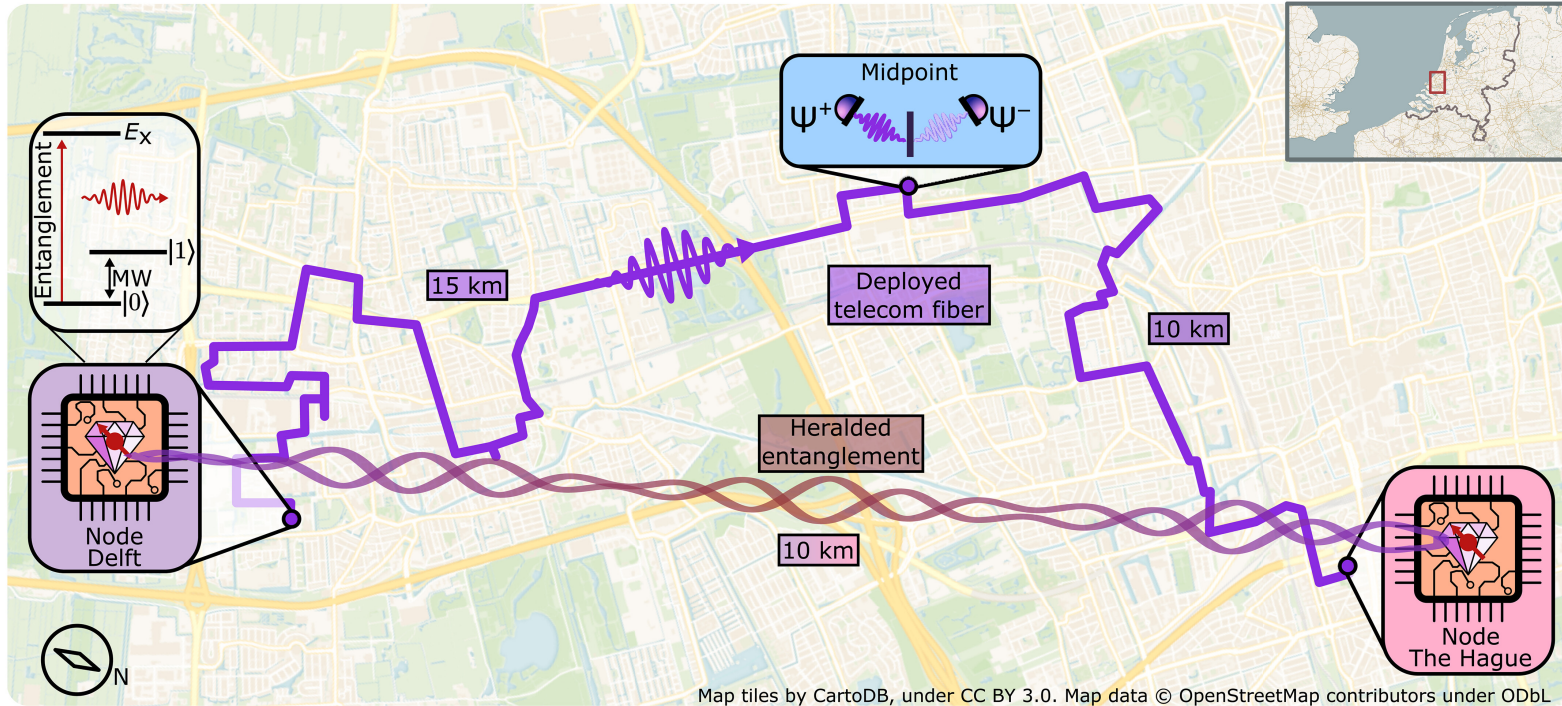
7 Orange Restricted



Metropolitan-scale heralded entanglement of solid-state qubits

ARIAN J. STOLK, KIAN L. VAN DER ENDEN, MARIE-CHRISTINE SLATER, INGMAR TE RAA-DERCKX, [...], AND RONALD HANSON +18 authors Authors Info & Affiliations

SCIENCE ADVANCES • 30 Oct 2024 • Vol 10, Issue 44 • DOI: 10.1126/sciadv.adp6442



White Rabbit facilitating entanglement distribution in the Netherlands

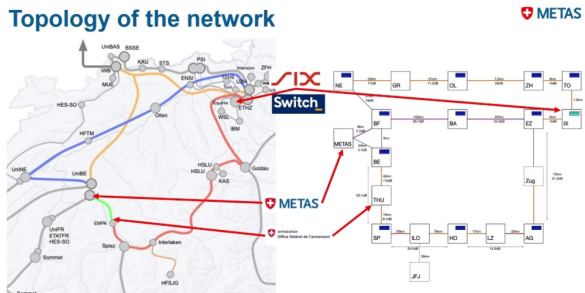
“The timing of the optical π -pulse is locally controlled and disciplined by an optically linked distributed clock that doubles as Ethernet connection (**White-Rabbit protocol**) (38) over a dedicated fiber.”

Listen to talk at CERN (January 2024): <https://cds.cern.ch/record/2922005>

www.science.org/doi/10.1126/sciadv.adp6442

An aerial night photograph of a city, showing a dense network of streets and buildings illuminated by warm orange and yellow lights, with some blue lights scattered throughout. The text is overlaid in the center of the image.

Long Distance WR
complementary PNT solution



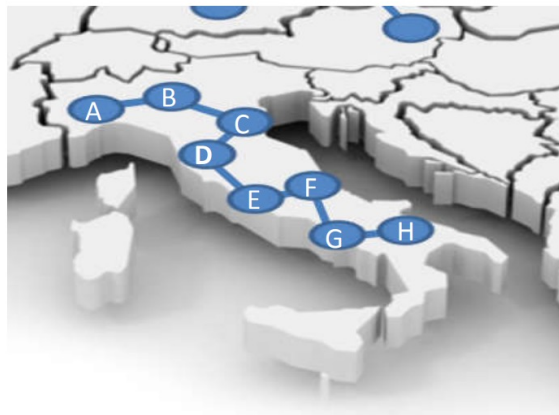
www.white-rabbit.tech/13th_WR_workshop/

We have also started developing a **BTFS (Belgian Time & Frequency) service in 2024** that builds on the BOOSTED project, namely the provision of a time signal based on the White Rabbit protocol.

<https://www.belnet.be/en/news-events/news/boosted-a-promising-project-paving-way-new-technologies>

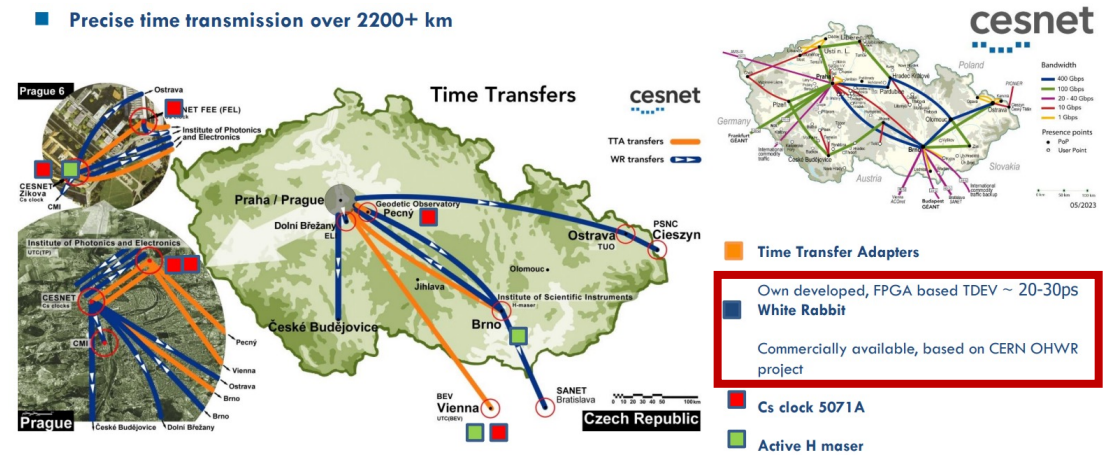
Sub-ns long-haul dissemination of UTC using WR in Switzerland

Antoine Jallageas, METAS



https://iris.inrim.it/retrieve/handle/11696/66134/dd2573c2-cbc5-e71c-e053-d805fe0ad5dc/ISPSC_Calonico.pdf

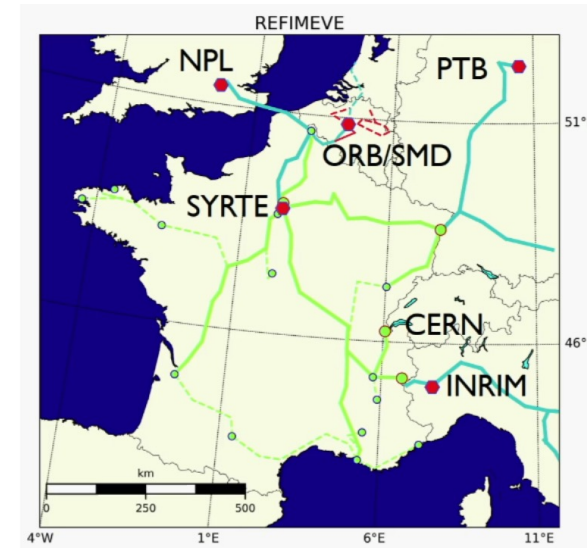
Precise time transmission over 2200+ km



https://events.geant.org/event/1581/sessions/770/attachments/940/1400/Cnr_wide_WR.pdf

Progressing Towards a **Nationwide White Rabbit Network** in DWDM Telecommunications for REFIMEVE, France's T/F Network for Education and Research

Paul-Éric Pottie, Syrte



www.white-rabbit.tech/13th_WR_workshop/

EU Science Hub

[Home](#) > [Scientific activities A-Z](#) > [Critical infrastructure protection](#) > [Alternative Position, Navigation and Timing \(AltPNT\)](#)

Alternative Position, Navigation and Timing (AltPNT)

JRC conducted testing campaigns of the mature technologies able to provide precise time and position, without use of navigation satellites. Aim is to strengthen EU economy and critical infrastructure resilience.

Read more:

Several solutions tested involved WR Technology

https://joint-research-centre.ec.europa.eu/scientific-activities-z/critical-infrastructure-protection/alternative-pnt_en

<https://publications.jrc.ec.europa.eu/repository/handle/JRC132737>



PROGRAMME OF THE
EUROPEAN UNION



EGNOS

NAVIGATION MADE IN EUROPE

EUROPEAN RADIO NAVIGATION PLAN 2023

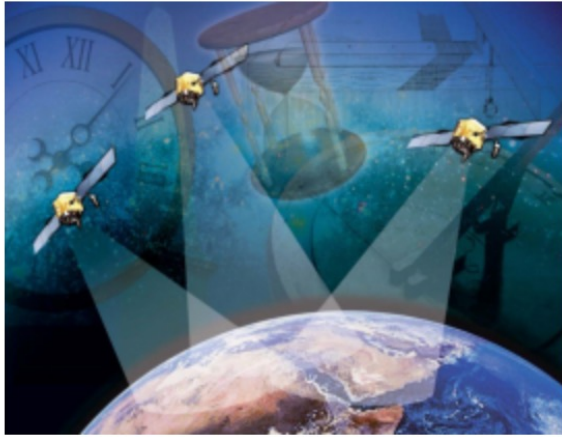
		Position & Navigation	Timing	Outdoors	Indoors & Underground	Safety of Life (aviation, maritime)	Critical Infrastructure (energy, telecom, finance)	Technology Readiness Level	
SYSTEMS		PNT System		ENVIRONMENT		APPLICATIONS		TRL	COMMENTS
GNSS	Global Coverage	High	High	High	Low	High	High	9	Four Global constellations available
	Regional Coverage	High	High	High	Low	High	High	9	Two Regional constellations available in Japan and India
	Satellite Augmentation (SBAS)	High	High	High	Low	High	High	9	Multiple SBAS systems in service or development worldwide No time integrity information is currently provided
CONVENTIONAL	Aviation NAVAIDS (VOR, DME, ILS, TACAN)	High	--	High	Low	High	--	9	Some will be part of the Minimum Operational Network (MON)
	Loran-C	Low	Medium	High	Low	Low	Medium	9	Apart from China and Russia, no longer in service
	eLoran & Differential eLoran	Low	High	High	Medium	Low	High	9	Already decommissioned in EU and US
	Longwave Time Distribution	--	Medium	High	Medium	--	High	9	Signal accuracy is limited and specific antennas are required
	Atomic Clocks	--	High	Low	High	--	High	9	Good timing accuracy for Critical Infrastructure
	White Rabbit	Low	High	Low	High	--	High	9	Requires uninterrupted fibre connection
EMERGING TECHNOLOGIES	Computer Network Time Distribution	--	High	Low	High	--	Medium	9	Timing accuracy from the dedicated networks.
	Pseudolites	High	High	High	High	Medium	High	9	Terrestrial only
	5G & Cellular Networks	High	Low	High	High	Low	Low	7	Communication technology which can provide also PNT
	R-Mode	High	Medium	High	Low	Low	--	5	Maritime, using slightly modified existing infrastructure
	Image based Navigation	High	--	High	High	Low	--	6	Multiple technologies, hardware dependent
	Mobile based Navigation	High	Low	High	High	--	--	9	Operating System based technology, requires internet connection
	Dead-reckoning & IMU	High	--	High	High	Medium	--	9	Passive system, prone to drift unless combined with other sensors
	Environmental maps	High	--	High	High	--	--	7	Passive system, require prior mapped information
	Low Earth Orbit (LEO)	Low	High	High	High	Low	High	8	Emerging space-borne broadband networks
	Quantum Technologies (Clock & IMU)	High	High	Low	High	Low	Low	4	New approach to navigation and timing hardware
Pulsars' PNT	Low	High	High	High	--	High	3	PN for deep space, proposed as a new time scale for Earth	

-- N/A Low suitability High suitability
 Medium suitability Potentially (under assessment/development)

Note: Technology Readiness Level (TRL) color indicates a range rising from the LOWEST readiness in red to the HIGHEST in green

Figure 2 – Overview of PNT systems classified as GNSS, Conventional and Emerging

https://joint-research-centre.ec.europa.eu/document/download/c4574d45-a940-406c-b6ba-a65ea9289317_en?filename=ERNP-2023_EN_101.pdf



108 - ASSESSMENT OF TIME TRANSFER TECHNIQUES FOR RESILIENT REGIONAL (TRANSNATIONAL) UTC INFRASTRUCTURE

Status: Intended

Activity ID: NAVISP-EL1-108

Planned Tender Issue: Q2

Price range: 650k€

An assessment of the feasibility of time transfer complementary to GNSS for comparison of UTC(k) clocks at geographically separate locations, ideally in different countries, will pave the way for a more resilient, certifiable timing infrastructure to protect CNI on a wider scale.

This activity may address the use of optical fibre-based time transfer techniques such as White Rabbit and Electronically Stabilised fibre optic system (ELSTAB), over long distance or transnational links, assessing technical and regulatory challenges.

<https://navisp.esa.int/opportunity/details/131/show>

CERN launches the White Rabbit Collaboration

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22 MARCH, 2024

<https://home.cern/news/news/knowledge-sharing/cern-launches-white-rabbit-collaboration>

Listen to the talks of the event here:

https://www.white-rabbit.tech/13th_WR_workshop/





a global

membership-based

community



Bringing of stakeholders of the technology together

- companies
 - end users
 - positioning, navigation and timing (PNT) providers
 - measurement instrumentation
- national metrology institutes
- universities
- research institutes/laboratories



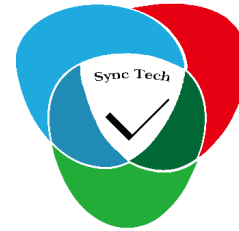
Pooling resources
& expertise

To maintain a
high-performance
open-source core
for the benefit of all





and together shape the
future of the technology



Collaboration Board Meeting December 2024, CERN



A short history of White Rabbit

- 2006: 1st meeting at CERN
- 2006: 1st system proposal
- 2012: 1st CDT's system available (open-source hardware, software, firmware)
- 2013: 1st operational deployment of WR (Open Access National Labs)
- 2014: WR connects components within ICSE, LSSE
- 2014: creation of the WR Collaboration
- 2024: creation of the WR Collaboration

See [WR's system architecture](#) for more details

A short history of White Rabbit

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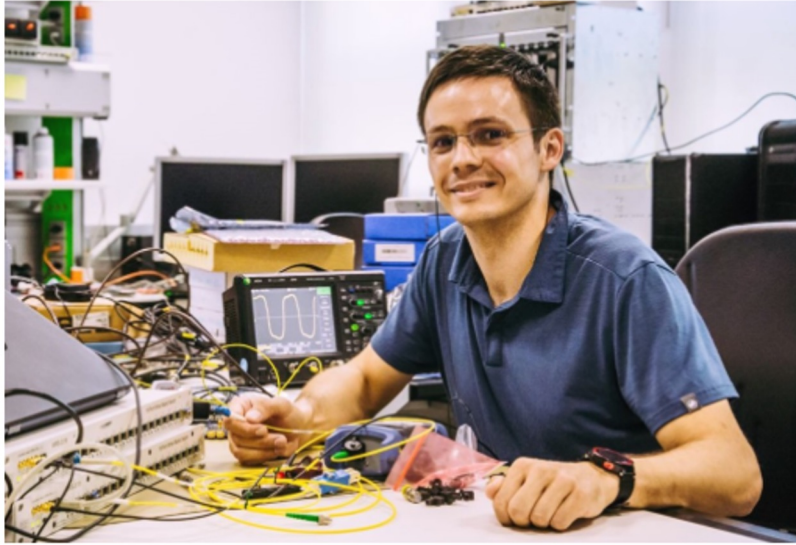
Collaboration Board Meeting December 2024, CERN

Members discuss:

- what they would like included in the annual development plan
- what R&D projects could be interesting to launch
- their insights on WR and the needs.



www.white-rabbit.tech/governance/



Maciej Lipinski

Collaboration Council Chair

Maciej Lipinski is an Electronics and Networking engineer at the European Organization for Nuclear Research (CERN), a specialist in control and timing for accelerators. He is a co-author of the White Rabbit extension to the Precision Time Protocol (IEEE1588) providing sub-nanosecond synchronization for scientific installations, co-chairs of the High Accuracy sub-committee in the P1588 Working Group and represents CERN in several standardization groups. Maciej holds a Ph.D., he graduated in Telecommunication, Electronics and Computer Engineering at Warsaw University of Technology (Poland) and Informatics at Coventry University (UK)

Council Members



Greg Daniluk

CERN

Greg is the leader of the Electronics Design and Low-Level Software section at CERN. He is an experienced electronics engineer, who developed the WR PTP Core and authored the WR Relative Calibration procedure. Actively involved in White Rabbit since 2011, he was one of the lead developers and the maintainer of WR Switch and WR PTP Core gateway/firmware releases.



Peter Jansweijer

Nikhef

Lead engineer at the electronics technology (ET) department of Nikhef that has been actively involved in WR since 2010. Main contributions are WR absolute calibration and various low phase noise hardware implementations. Peter is member of the New Features Committee in the P1588 Working Group



Bob Noseworthy

InterOperability Laboratory UNH

Collaboration Council

The mission of the Council is to ensure that the WR Technology remains vendor neutral and equally benefits to all Members and users of the WR Technology.

Composed of non-commercial members.

Amongst others, in charge of:

- Granting the status of Associated Labs
- Setting out the WR Technology Test requirements;
- Approving Project proposals;
- Approving the WR Technology future development plan.

*new members to be elected in the June 2025 Board Meeting

www.white-rabbit.tech/governance/

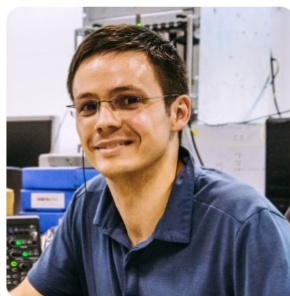
The Collaboration Bureau

Senior White Rabbit Engineers

Community Coordinator

Hosted at CERN, the Bureau is composed of senior engineers with extensive experience in the White Rabbit technology and a community coordinator.

The main task of the Bureau is to ensure a high-performance core technology through regular maintenance and upgrades. It is also there to support all collaboration activities and the day to day running of the Collaboration. The Bureau will provide support via the online forum, as well as direct, private, support to the members.



Maciej Lipinski

WR Engineer

graduated in telecommunications, electronics, and informatics; specialist in control and timing at CERN; co-author of the White Rabbit extension to PTP (IEEE1588-2008) and IEEE1588-2019; chair of the New Features Committee in the P1588 Working



Adam Wujek

WR Engineer

graduated in computer science and System-on-Chip design; member of White Rabbit core team since 2014; specialized in WR software; member of the New Features Committee in the P1588 Working Group



Amanda Díez Fernández

Community Coordinator

graduated in materials science and physics; works at the Business Development Section of the Knowledge Transfer Group at CERN, whose mission is to facilitate the uptake of CERN technologies and expertise by industry.

www.white-rabbit.tech/the-bureau



Development Plan

Implemented by the Bureau and
co-defined by the Members

First projects hosted in the Collaboration

Space

GMV awarded a £2 million contract to provide a White Rabbit Switch suited for protecting UK's infrastructure

07/08/2024



<https://www.gmv.com/en-es/communication/news/gmv-awarded-ps2-million-contract-provide-white-rabbit-switch-suited-protecting>

IQD joins the White Rabbit Collaboration, an initiative launched by CERN, to provide quantum-precision timing and synchronisation

Within the framework of the [WR Collaboration](#), IQD is working closely with [GMV](#) and [CERN](#): the latter are at advanced prototyping stages of the development of a new White Rabbit Switch Version 4, while IQD is adding [holdover](#) function to the switch by developing an expansion board product containing [IQD's ICPT-1](#) rubidium oscillator, a quantum atomic clock.

The ICPT-1 provides security and accuracy of signal continuity in case of temporary signal losses with its exceptional holdover ability, and can enable stability of accurate signals down to the picosecond level. This is the first time that holdover has been addressed in the open-source White Rabbit Switch device, and IQD is at the forefront of this technology.

<https://www.iqdfrequencyproducts.com/news/2024/06/14/iqd-joins-the-white-rabbit-collaboration/>



Final developments and prototyping of WRS v4



Developing an expansion board to provide holdover to the WRS v4



Dedicated and timely
support from the Bureau





Nu Quantum announces collaboration with CERN to adopt White Rabbit timing technology to enable data centre-scale quantum computing networks

07.11.2024

www.nu-quantum.com/news/nu-quantum-announces-collaboration-with-cern-to-adopt-white-rabbit-timing-technology-to-enable-data-centre-scale-quantum-computing-networks

Network Interface Card bringing sub nanosecond synchronization all the way to the host.

LMS ÜberNIC White Rabbit + PTM

ÜberNIC One Product - Multiple Use-Cases

- Network Adapter
- 1000 Mbit/s
- Precision Time Sync
- Host Time Sync
- ÜberNIC
- Sub-nanosecond I/O
- Packet Capture
- Time Synchronization

Red Hat Enterprise Linux



ÜberNIC Precision Time

Complete Front-to-Back Time Synchronization

- PTPV2.1 (Nanosecond Sync between ÜberNIC and GNSS RX)
- White Rabbit (Picosecond Sync between ÜberNIC and GNSS RX)
- PTM (Nanosecond Sync between ÜberNIC and Host RTC)
- TGPIO PPS (Picosecond Sync between ÜberNIC and Host RTC)

GNSS Antenna
GNSS RX
100-5A-100

Testing Committee



Defining testing procedures

to ensure performance and interoperability of products incorporating the open-source WR Technology

defined collectively by a subset of interested members and the Bureau, with complementary expertise and insights



Establish associate labs.

Trademark on tested products
which are also listed on
www.white-rabbit.tech

Provides trust to end-users on new products incorporating WR Technology
Serves to clearly identify open-source WR Technology





Training

A catalogue of trainings, including **free** trainings for members.

They will address fundamental aspects of the technology and its implementation

A way to coordinate efforts in different countries and sectors



14th

WR Workshop at CERN



Register
now:



25th & 26th June

Come and present your work!