Performance results of the first White Rabbit installation for CNGS time transfer

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Introduction
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Hardware & Timing Section:
- synchronization and control
- White Rabbit – PTP-based control and timing
- Time transfer for CNGS
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- **White Rabbit** – PTP-based control and timing
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CERN Neutrinos to Gran Sasso

732 km

Gran Sasso
Performance results of White Rabbit installation for CNGS time transfer
What is White Rabbit?

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

+ synchronism
+ determinism
Time Distribution with White Rabbit

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

![Diagram showing synchronization system](image)
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![Diagram of Time Distribution with White Rabbit](image-url)
Extension to PTP: WR PTP

- Addresses PTP’s limitations
- Compatible with "standard" PTP gear
- Ongoing standardization effort
CERN Neutrinos to Gran Sasso (CNGS)

- Investigation of neutrino oscillation
- Time of Flight (ToF) measurement
Old CNGS time transfer

Global Positioning System (GPS)

Long distance

Local

CERN Timing System

Timing by BE-CO-HT

Experiments Timing Systems

Timing by experiments
New time transfer with WR

Global Positioning System (GPS)

Long distance

Local

CERN Timing System

Timing by BE-CO-HT

Experiments Timing Systems

Timing by experiments
WR installation

- Grandmaster WR Switch
- 8 km of fiber between switches
- Boundary Clock WR Switch
- WR Node – includes Time-to-Digital Converter (TDC):
  - 55 ps precision (std. dev)
  - 300 ps accuracy
- Performance monitoring
WR installation

- Grandmaster WR Switch
- 8 km of fiber between switches
- Boundary Clock WR Switch
- WR Node – includes Time-to-Digital Converter (TDC):
  - 55 ps precision (std. dev)
  - 300 ps accuracy
- Performance monitoring
Duration: 31 d, 7 h, 40 s (2.7 \times 10^6 \text{ samples})

WR Nodes with TDC used

Timestamping reference PPS

Measurement includes inaccuracy of TDC
Time Errors:

\[ x_{lo} = 1\,000\,000\,000\,000 - 999\,999\,999.906 \]

\[ x_{lb} = 1\,000\,000\,000\,000 - 1\,000\,000\,000.014 \]

\[ x_{\text{diff}} = 999\,999\,999.906 - 1\,000\,000\,000.014 \]
Accuracy: 0.517 ns
Precision: 0.119 ns (std. dev)
CNGS performance results (2)

Overlapping Allan Deviation
(White or Flicker PM noise)

Maximum Time Interval Error
Out of $2.7 \times 10^6$ samples, 9 values of $x_{\text{diff}}$ [0.0003%] exceeded MTIE=1ns.
CNGS performance results (3)

- Stable temperature of performance measurement setup
- Time Error not correlated with temperature in WR Room
- Possibly varying temperature of deployed Nodes
Temperature tests setup (1)

- Measurement of WR Timebase (clock)
- Skew measurement with oscilloscope
Temperature tests setup (2)
Temperature tests results (1)

- Temperatures
  - measured in chamber
  - measured on SPEC

- Skew between Local SPEC and Master Switch (mean removed)

- Skew between Loopback SPEC and Master Switch (mean removed)

- Histogram of skew
  - loopback
  - local
  - sdev=36ps
  - sdev=55ps

Climatic Chamber

Single Mode Fiber (G.652.B type)

LeCroy WavePro 7300A oscilloscope

Maciej Lipiński
The change of time offset due to temperature changes

\[ \approx 4 \text{ ps per } 1^\circ \text{C} \]
Conclusions

- \( E = mc^2 \)
- **WR-based system**
  - deployed to verify the speed of neutrinos
  - provides nanosecond accuracy
- **WR-timebase**
  - sub-ns accuracy
  - tens of picoseconds precision
  - wide range of temperatures
- Possible compensation of WR Node’s temperature variation
- Important milestone in the White Rabbit Project
"I don’t answer faster-than-light-neutrinos questions" - said the presented
A neutrino walks into the room...