A_RD_24

Study of Laser – Beam arrival time synchronization towards sub-ps level

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The collaboration

- **IJCLab**
  - Daniel Charlet, Antoine Back, Cédric Esnault, Chafik Cheikali, Mathias Vecchio, Aurélien Martens, Christophe Joly, Nicolas Dosme, Bernard Genolini, Christelle Soulet, Olivier Perdereau, Sid Ali Cherrati, Gaetan Seuillot

- **Paris Observatory:** Astrophysics & cosmology, astroparticles, gravitational waves, theory
  - **Laboratoire Temps Espace:** Time and frequency metrology, time and frequency transfer, space-time reference frames
    - Paul-Eric Pottie, Michel Lours
  - **Observatoire Radio-astronomique de Nançay:** Radio-astronomy
    - Cédric Viou

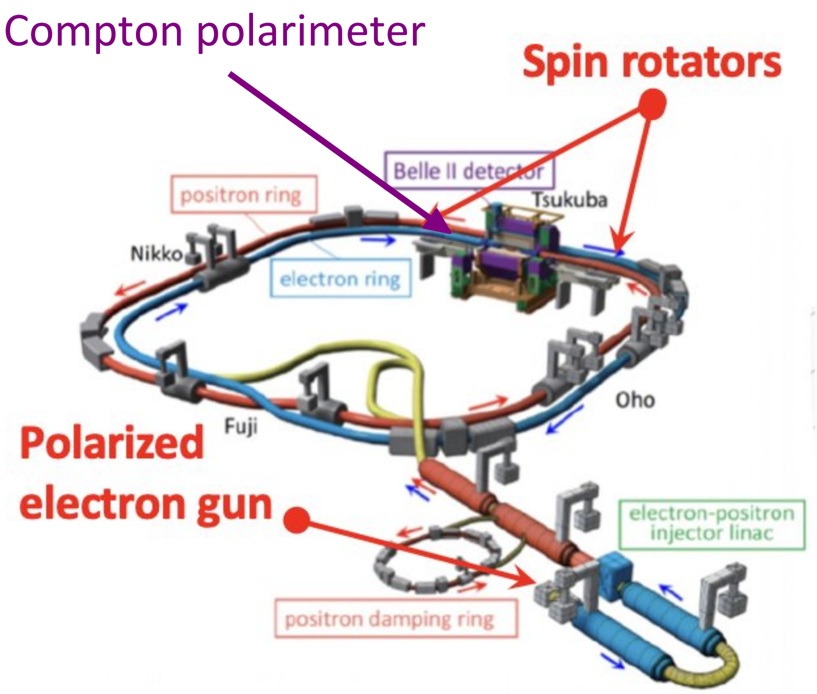
- **KEK**
  - Hiroshi Kaji, Alexander Aryshev, Tetsuya Kobayashi, Takaaki Yamaguchi

Context

Context

SuperKEKB polarization upgrade:

1. Compton polarimeter to measure e⁻ beam polarization in real-time in SuperKEKB;
2. Laser with picosecond pulse duration inside SuperKEKB ring;
3. Synchronization of laser on SuperKEKB clock with picosecond stability;
4. Use Idrogen system with White Rabbit protocol for synchronization.



IDROGEN system

IDROGEN system: Key concepts

- An architecture where all signals generated by the board are synchronous with the master clock synchronized by the White Rabbit (WR) protocol.
- High data rate acquisition system using standard protocols.
- Frequency generator.
- Fully re-configurable.

IDROGEN board

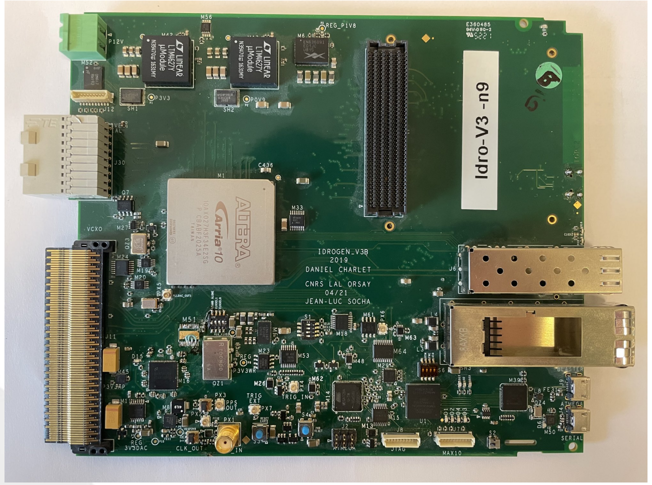
µTCA board, designed at IJCLab, based on Altera Arria10 FPGA with:

- White Rabbit protocol compliance for very high timing stability;
- High data rate transfer capabilities (PCIe, Ethernet, ...);
- Extension capabilities (RTM, FMC) for modularity.

Applications:

- ADC data acquisition (radio-astronomy, beam diagnostic, ...);
- Frequency generator (accelerators);
- Time and frequency transfer (metrology).

Closed collaboration with *Laboratoire Temps-Espace* (LTE) providing expertise in metrology.



Idrogen Board

IDROGEN: Gateware and Software

Gatewares:

- White Rabbit;
- PCIe Gen3 x4 (DMA);
- Ethernet:
  - Ipbus (slow control);
  - UDP streaming at 1G, 10G and 40G (ongoing development);
- JESD204B for 1GS, 500MS and 250MS ADCs.

Softwares:

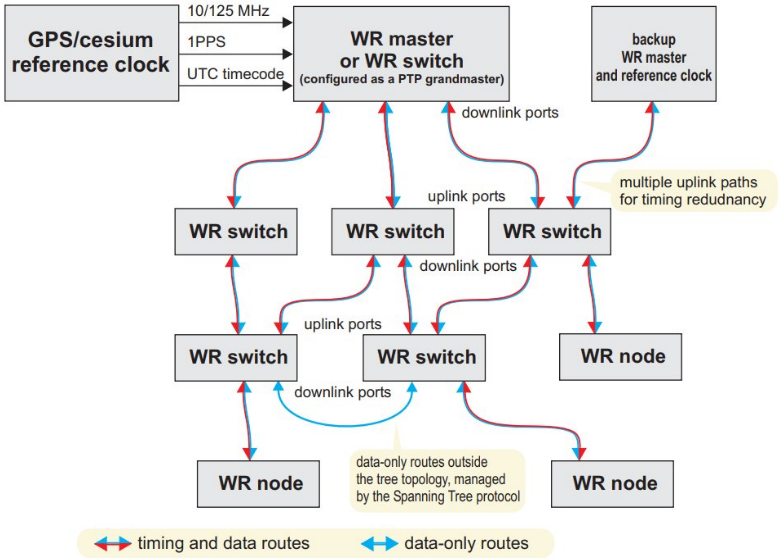
- Configuration GUI (Power, PLL, FMC) over USB and Ethernet;
- Slow control library and tools (I2C, SPI, WR diagnostic, …);
- Acquisition software.

White Rabbit protocol

Project initiated by CERN and GSI for sub-nanosecond accuracy time transfer.

- Gigabit Ethernet network based on:
  - Precision Time Protocol (IEEE1588);
  - L1 syntonisation (clock transmission);
  - DDMTD Phase tracking (Digital Dual Mixer Time Difference).
- Time propagation compensation.
- Large area and node number (+1000).
- Deterministic network.

Provides: Synchronization, Timestamp and Pulse-Per-Second (PPS) signal.



White Rabbit network topology [1]

(1) Precise time and frequency transfer in a White Rabbit network, *T. Wlostowski*

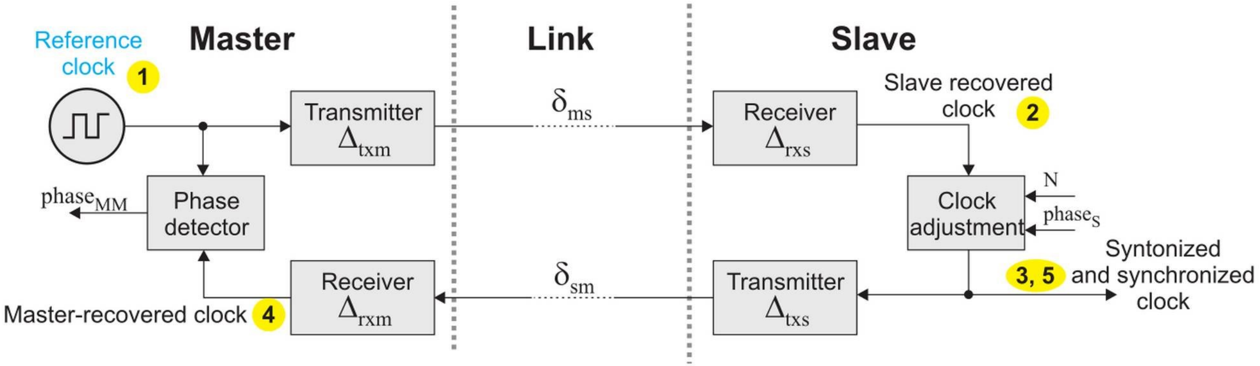
White Rabbit protocol

1) Reference clock transmitted by Master node and recovered on slave node (L1 syntonisation);

2) Measure Master – Slave and Master – Master delay (PTP);

3) Measure phase difference between recovered and local oscillator clocks (DDMTD);

4) Local clock phase adjustment (VCXO controlled with a DAC).



White Rabbit link model [1]

(1) Precise time and frequency transfer in a White Rabbit network, *T. Wlostowski*

Picosecond laser synchronization

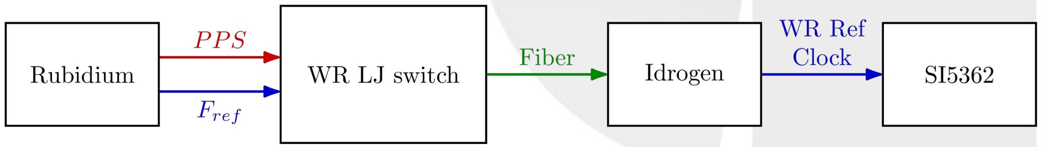
KEK

Fractional PLL (FPLL) for accelerator synchronization (SI5362)

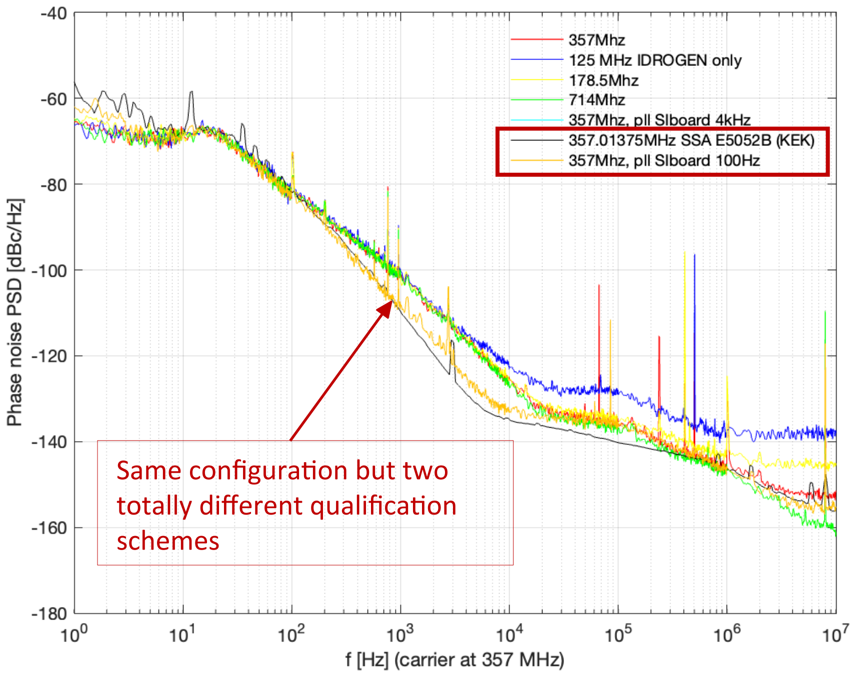
- Generate frequencies, disciplined by WR clock, from 10 kHz to 2.75 GHz, with 1 Hz resolution.

SI5362: Phase noise measurement

- Tests performed at IJCLab and KEK;
- Phase noise measured for various different output frequencies and input filters, re-scaled at 357 MHz: **1.7 ps RMS** jitter (357MHz SSA KEK);
- Consistency of KEK and IJCLab measurements.



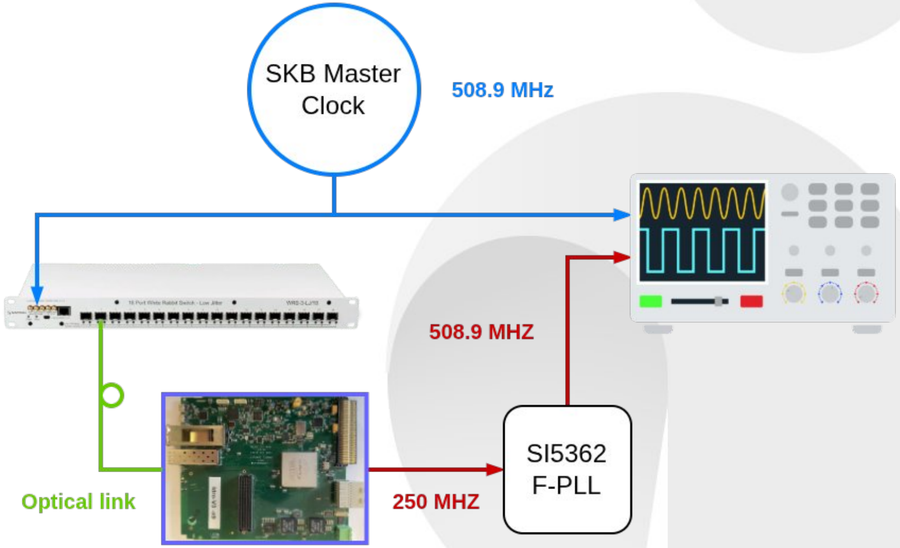
FPLL clock synthesis setup



D. Charlet (IJCLab) et al., H. Kaji (KEK SKB), K. Popov, A. Aryshev (KEK ATF)

Super KEK B clock synchronization with SI5362 FPLL (508.9 MHz).

→ Good synchronization between Master's clock and Idrogen / SI5362 clock.



Experimental setup at SKB

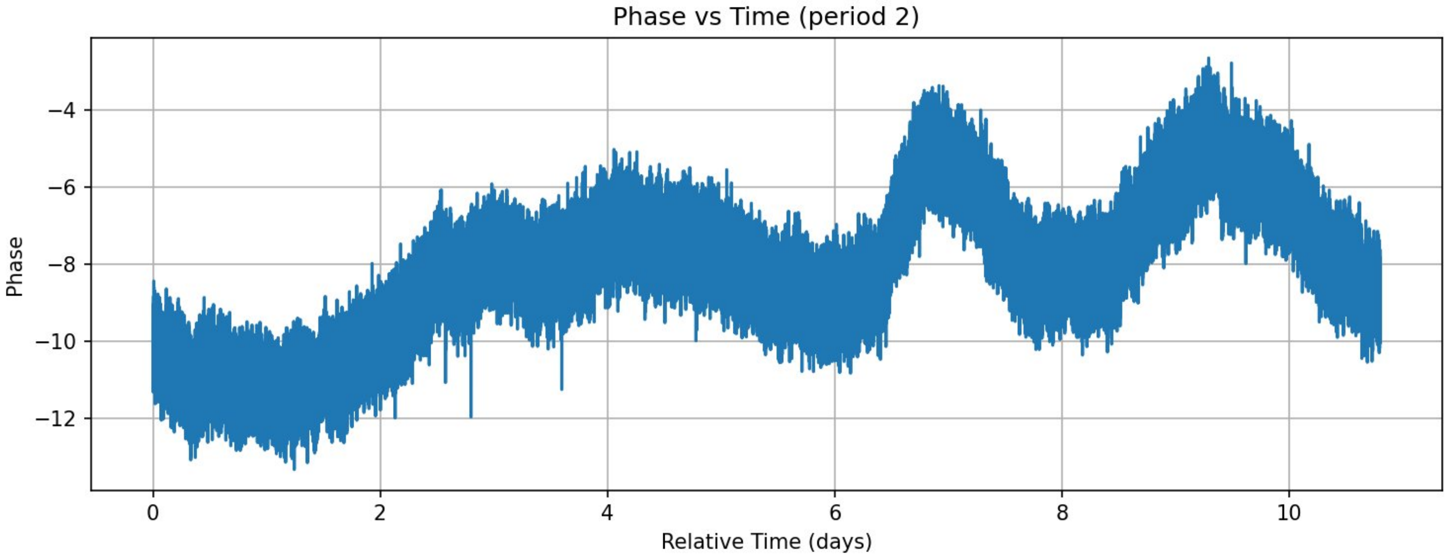
Comparison of SKB and Idrogen clocks
10h persistency, at scope resolution limit

D. Charlet (IJCLab) et al., H. Kaji (KEK SKB), K. Popov, A. Aryshev (KEK ATF)

IDROGEN + Fractional PLL phase drift

Long term phase difference (°) between SuperKEKB and Idrogen SI5362 clocks (508.9 MHz).

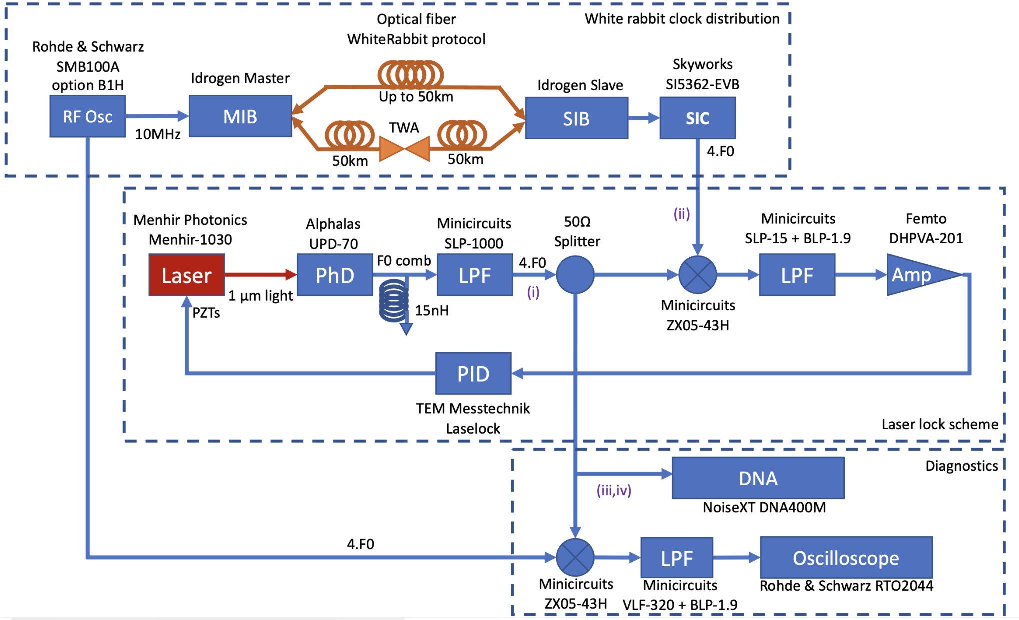
→ Variation ≈ 8° over 10 days



H. Kaji (KEK SKB) et al.

Laser synchronization

- SMB100A-B1H used as RF oscillator;
- Two Idrogen boards used as White Rabbit Grand Master and slave;
- Slave board generates a 250MHz signal provided to a SI5362 FPLL;
- FPLL generates a clock at the fourth harmonic of the laser frequency;
- Clock is mixed with the filtered signal from the laser, resulting an error signal for a PID driving the laser piezo transducer.

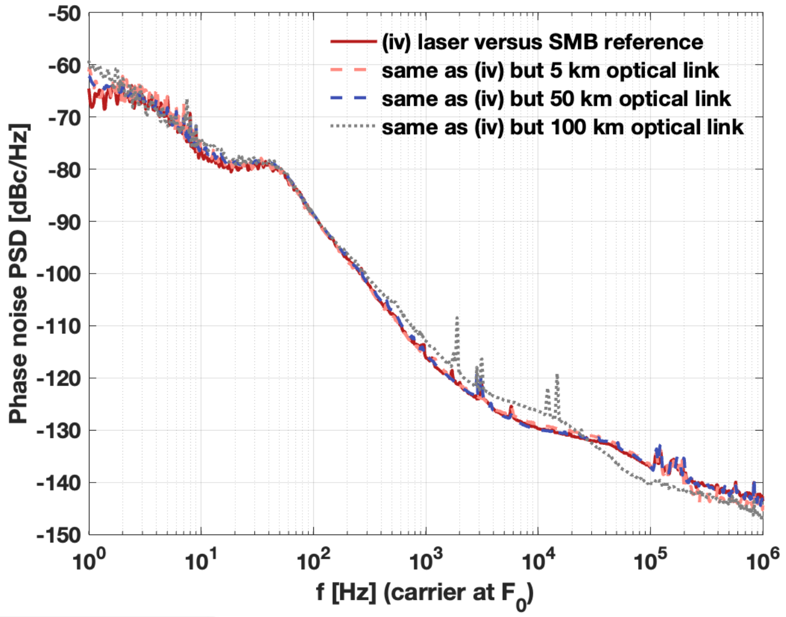


Laser synchronization setup

A. Renaux, R. Chiche, A. Martens et al. (IJCLab)

Phase noise power spectral density of the synchronized laser:

- Four difference optical fiber length: 10m, 5km, 50km and 100km;
- No modification of the phase noise when replacing it with a 5 km and 50 km fiber link;
- Significant difference with 100 km fiber link around 1Hz and above 300Hz.

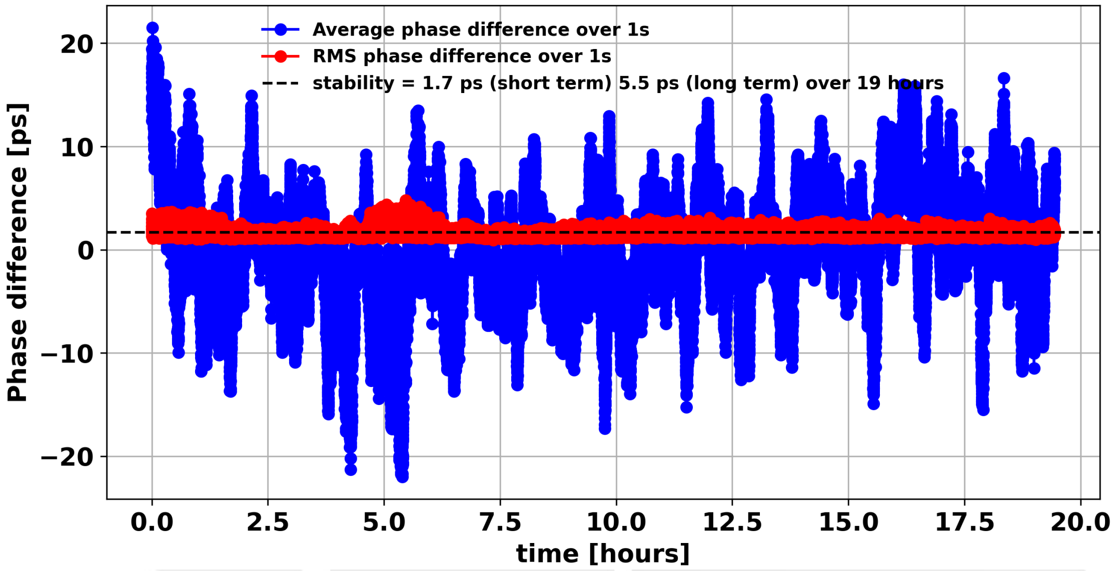


Power spectral density of phase noise

A. Renaux, R. Chiche, A. Martens et al. (IJCLab)

Long term phase drift

Phase difference between Photo Diode filtered signal and reference RF oscillator with 100km fiber.



A. Renaux, R. Chiche, A. Martens et al. (IJCLab)

Conclusion

Conclusion

- IDROGEN board achieve picosecond RMS jitter with arbitrary clock signal synthesizer;
- Picosecond RMS jitter of a laser synchronized with Idrogen boards;
- Ongoing work: Long term phase drift evolution;
- Planned travel to KEK in November for first test of synchronization with e^- beam;
- Version 4 of the Idrogen board is currently under development (outdated components).

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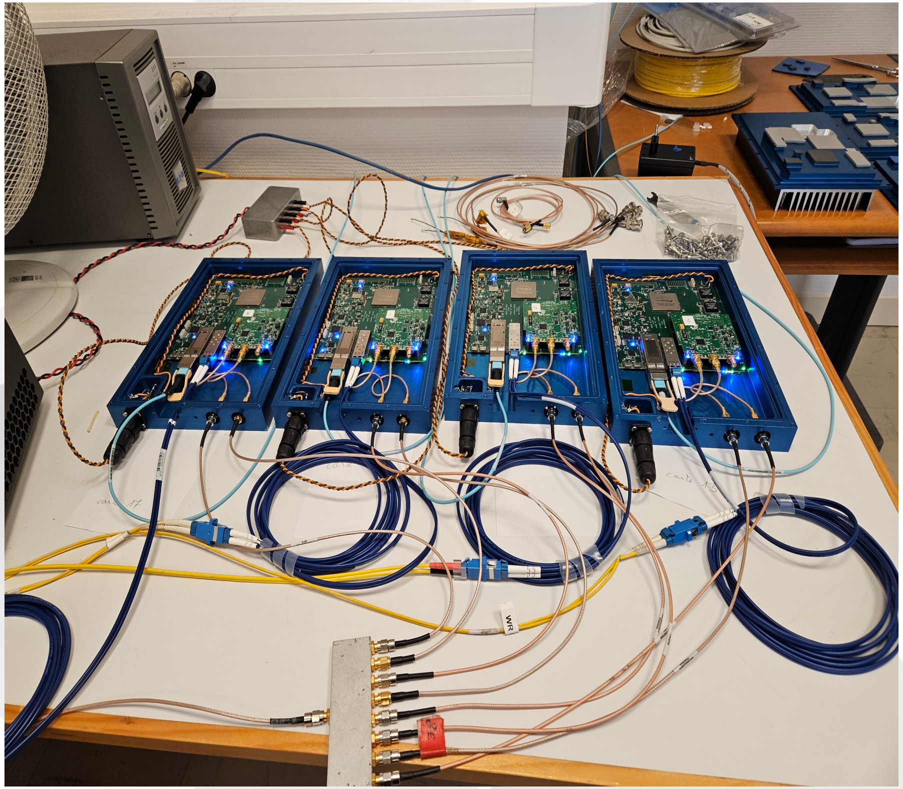
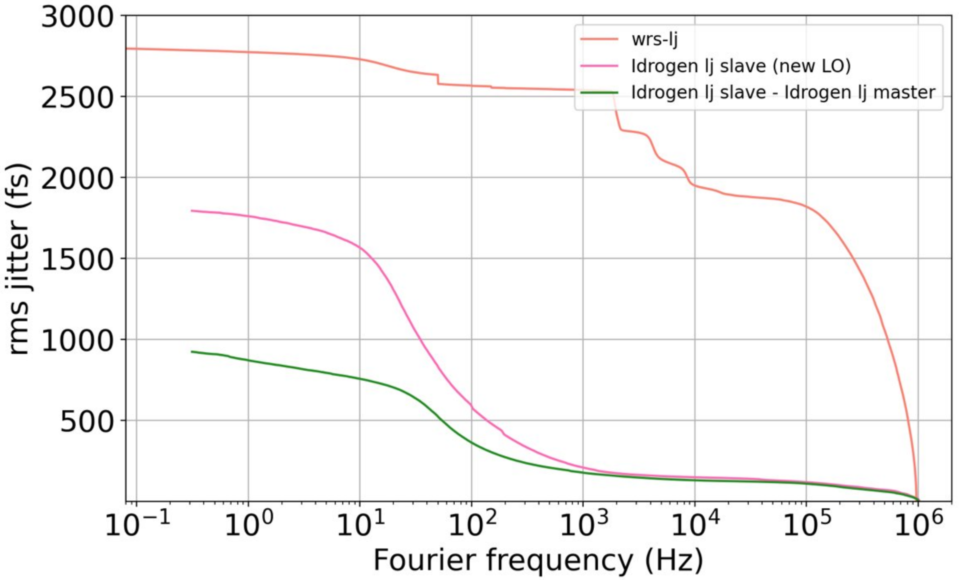
Backup

4 IDROGEN boards in a standalone mode

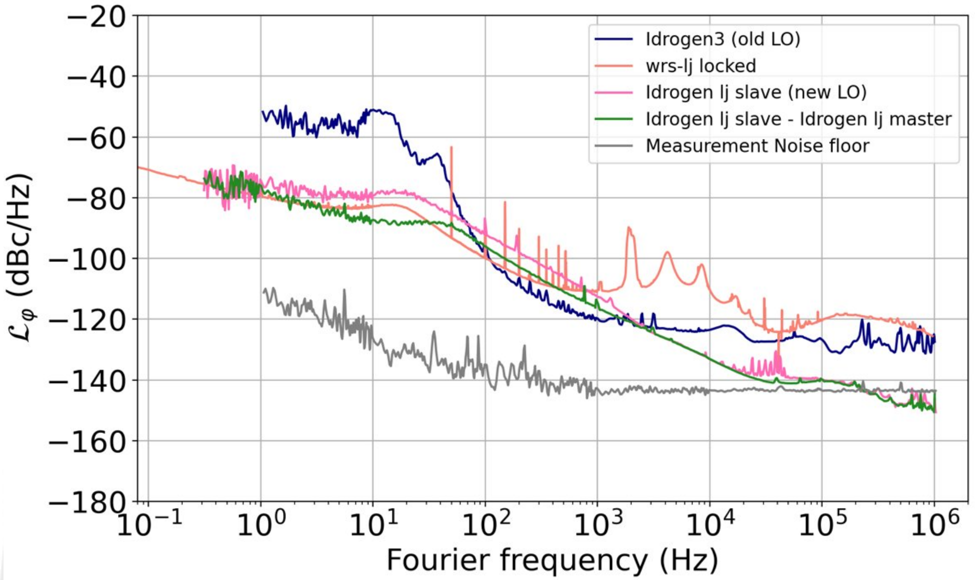


Phase noise measurement

RMS jitter according to integration range



Phase noise measurement (carrier at 100 MHz)



Variation of lower bound of integration range.
Upper bound fixed at 1 MHz

Phase noise improvement: 866 fs RMS (1 Hz, 1 MHz)