LLRF synchronization based on White-Rabbit. First results of the system in the IFMIF/EVEDA RFQ conditioning in Rokkasho

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LLRF Workshop 2017 - Barcelona
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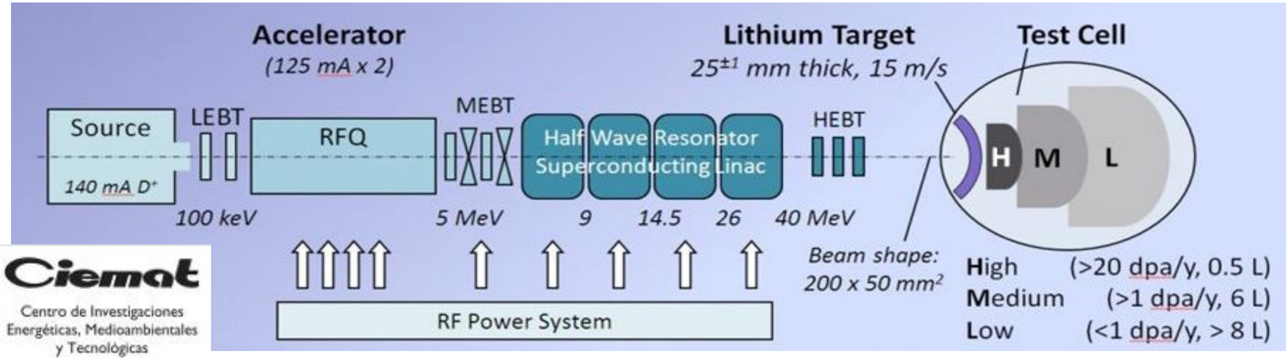
IFMIF/EVEDA project

The International Fusion Materials Irradiation Facility (**IFMIF**) has been designed to test the materials to be employed in future deuterium-lithium fusion reactors (2007).

IFMIF/EVEDA project (LIPAc facility): Is a linac with a total nominal power of 2.65 MW that will be injected in the Radiofrequency Quadrupole (RFQ), the Medium Energy Beam Transport (MEBT), and the Superconducting RF (SRF) cavities by means of 18 RF power chains:

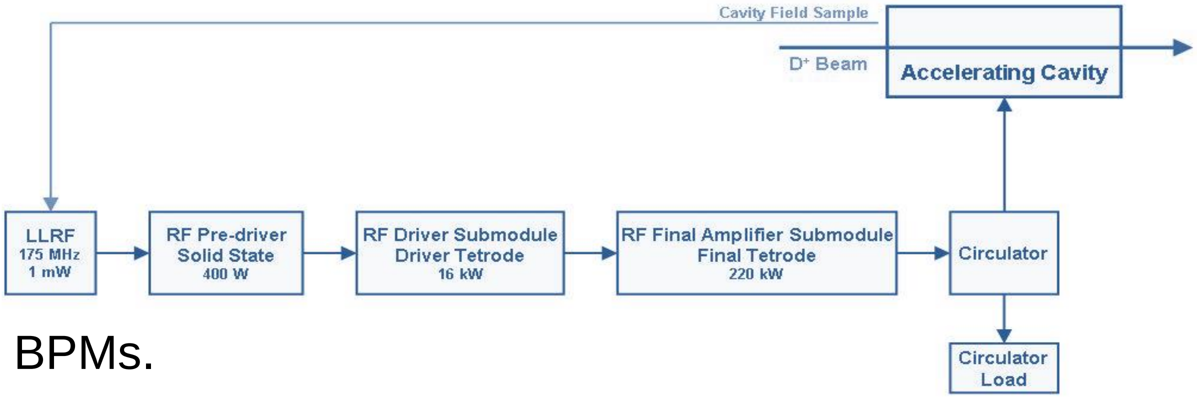
- 8 RFQ of 200kW
- 2 MEBT of 16kW
- 8 SRF of 105kW



IFMIF/EVEDA
7S involvement

CIEMAT is responsible of IFMIF-EVEDA RF System: 18 three-stage amplifiers chain working at 175 MHz. Seven Solutions was recruited to provide:

- The Low-Level Radio Frequency (**LLRF)**: responsible to control/tune the RF cavities in the accelerator. It also supports the synchronization, data logging and fast interlock system related to the RF cavities.



- And the **clock distribution** for BPMs.

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  - White Rabbit Technology
  - Clock & Timing distribution
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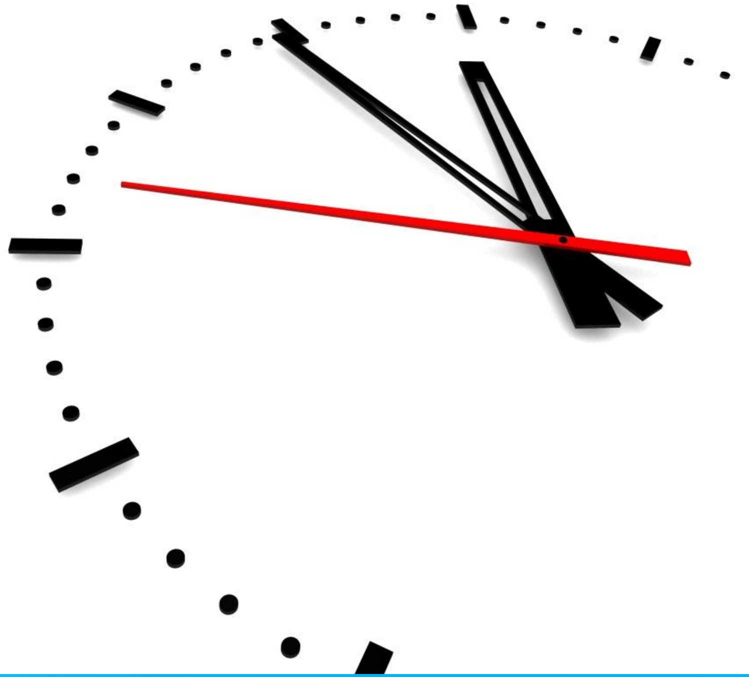
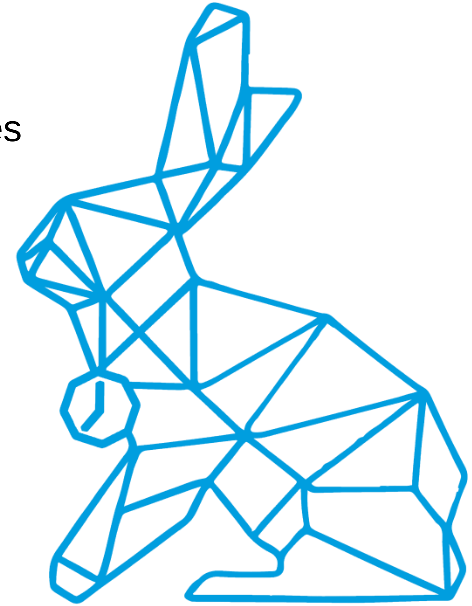


Seven Solutions

White Rabbit?…A*n extension of Ethernet.*

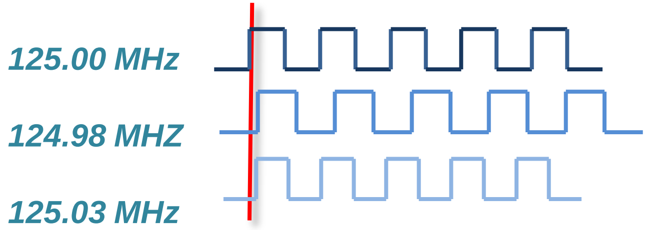
- It was born at CERN for time and frequency dissemination up to 1000 nodes
- Ultra-synchronization: **Sync-E & PTP (IEEE-1588v2)**
  - Sub-nanosecond time accuracy
  - Clock RMS jitter ~2 ps (1Hz – 1MHz)
- Accurate timestamps
- Thousand of nodes: compatible with standard Eth. nodes
- Distance range over 80 km
- Robustness & redundancy
- Self-calibration over long distances



How White Rabbit works

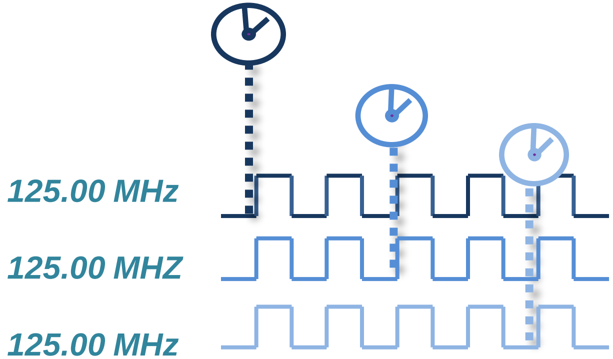
Synchronization: **Sync-E & PTP (IEEE-1588v2)**

Small differences in the node/switch individual clocks. →



Sync-E

Common notion of frequency!! →

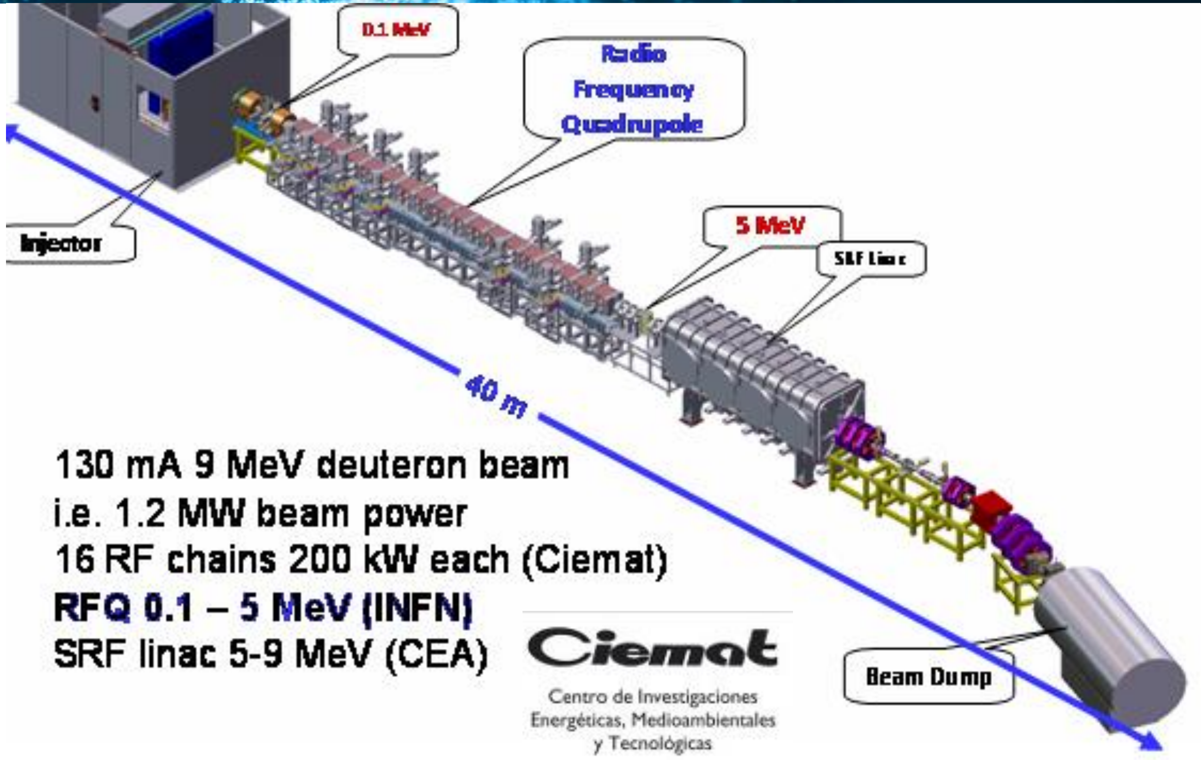


SYNTONIZATION VIA SYNC-E

IFMIF/EVEDA
Time needs

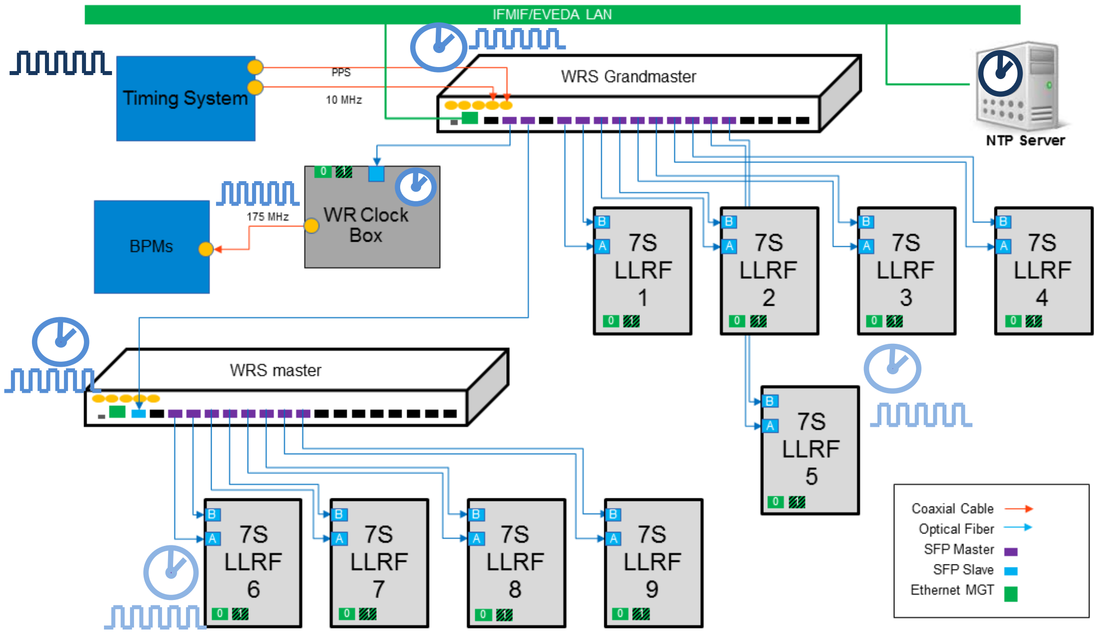
RF clock distribution:

Coaxial Fan-out	White Rabbit net
Analog and tested	**Digital**, new and tested
Ease to install	Ease to install
Need to characterize lines	**Auto-characterize**
Electromagnetic effect	Fiber optic
Temp. Derivation	**Self compensation** with temp. changes
Not scalable	**Scalable**
✘	✓



IFMIF/EVEDA WR network

Timing Distribution for IFMIF-EVEDA using White Rabbit



Timing and clock distribution thought the accelerator (WR):

- **Frequency distribution** through all WR node of the particle accelerator.
- **Common sense of time** in all the devices: Time and events are also distributed and used for triggering and time stamp the diagnostics.

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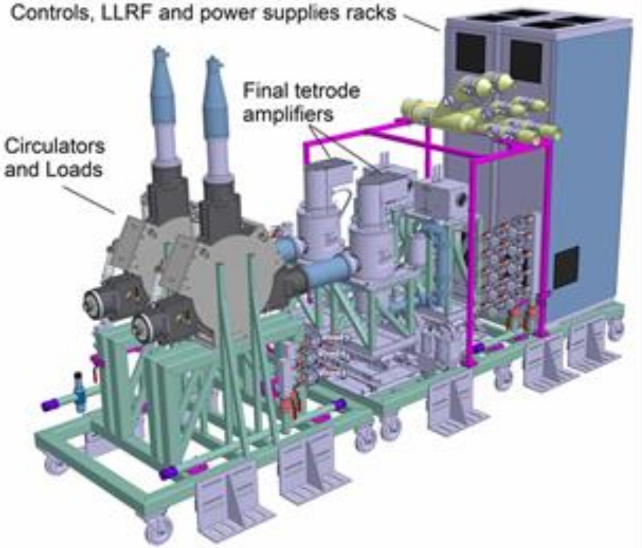
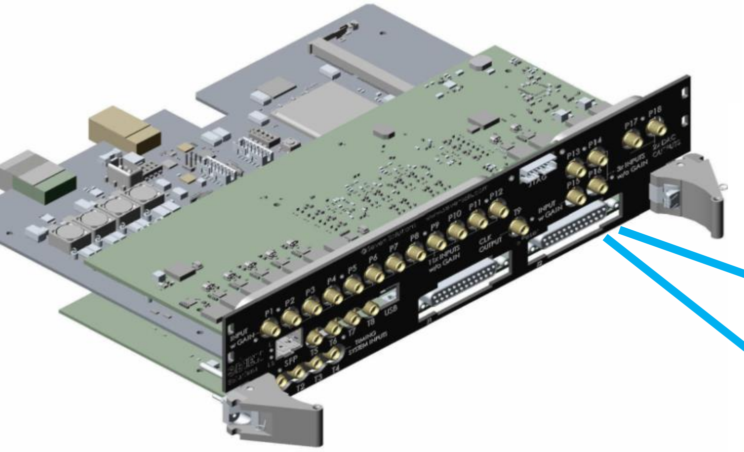


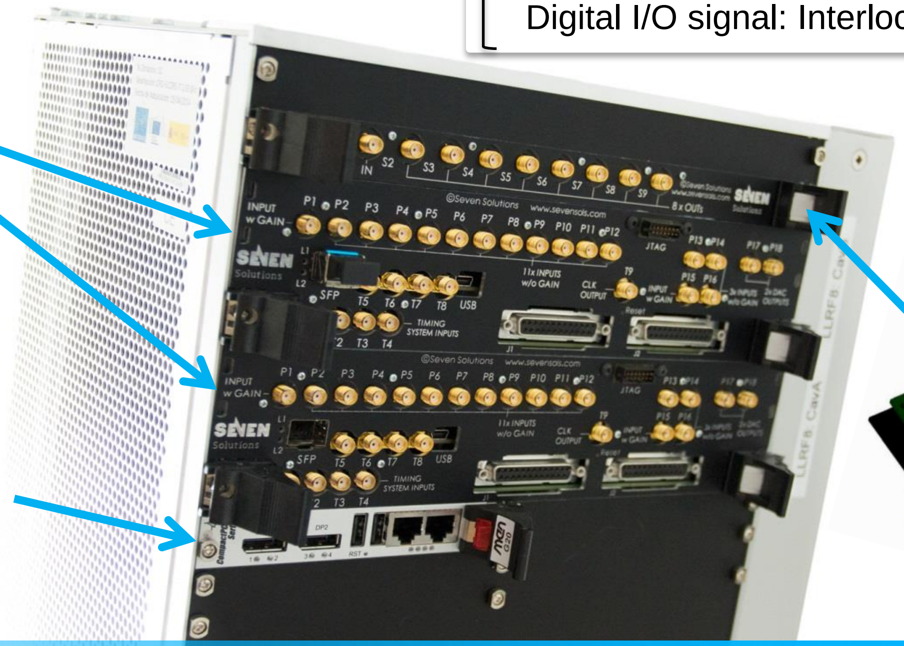
Digital LLRF HW Specs

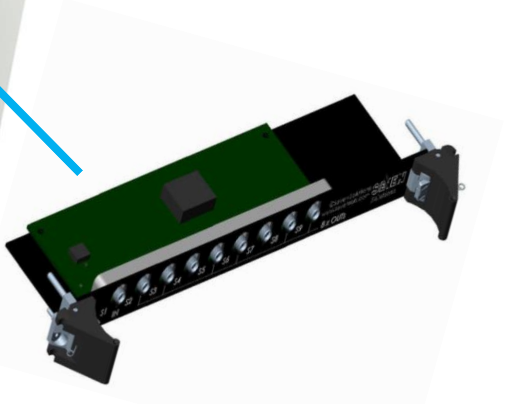
2x:
- 16 Analog-Digital converters (125Ms)
- 2 Digital-Analog converters (1.2Gs)
- GB Ethernet (SFP): White Rabbit compatible node.
- Digital I/O signal: Interlocks, Timing trigger system,…



Main Features

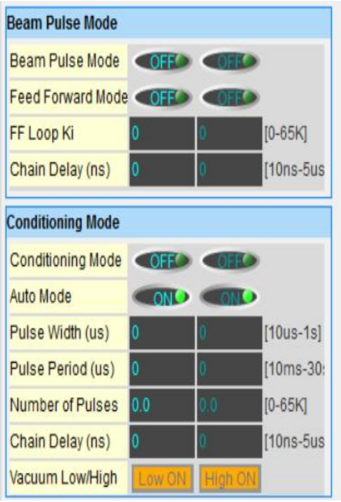
- Intel® Core™ i7, 2.53 GHz
- Dual-core 64-bit processor
- PICMG CPCI-S.0 CompactPCI® Serial
- Up to 4 GB DDR3 DRAM soldered, ECC
- mSATA and microSD™ card slots
- Standard front I/O: 2 DisplayPorts, 2 Gb Ethernet, 2 USB
- Standard rear I/O: 7 PCIe®, 8 USB, 6 SATA, DisplayPort®/HDMI
- Rear I/O via mezzanine board: up to 8 Gigabit Ethernet
- Intel® Turbo Boost 2.53..3.2 GHz, Hyper-Threading, Acti Management Technology
- Open CL 1.1 support





Digital LLRF SW Specs

- Control of acquisition, interlocks and data logger through **EPICS** platform & **CSS/BOY**.
- Integration of White Rabbit protocol to synchronize LLRF systems.
- Characterization and calibration of the ADC/DAC.
- Creation of a Python testing procedure to check the quality of the components (PLL, VCXO, ADC, Attenuators, etc).



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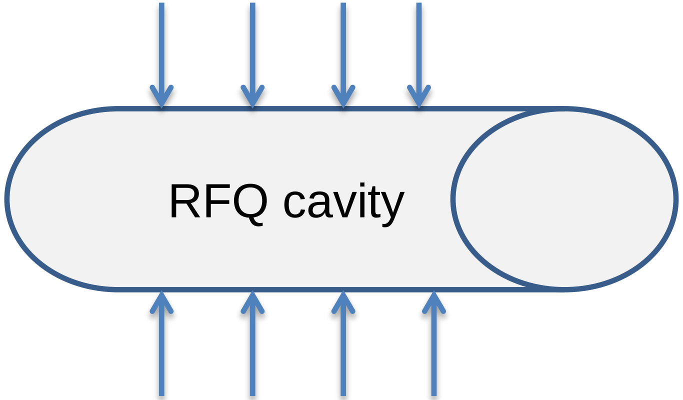
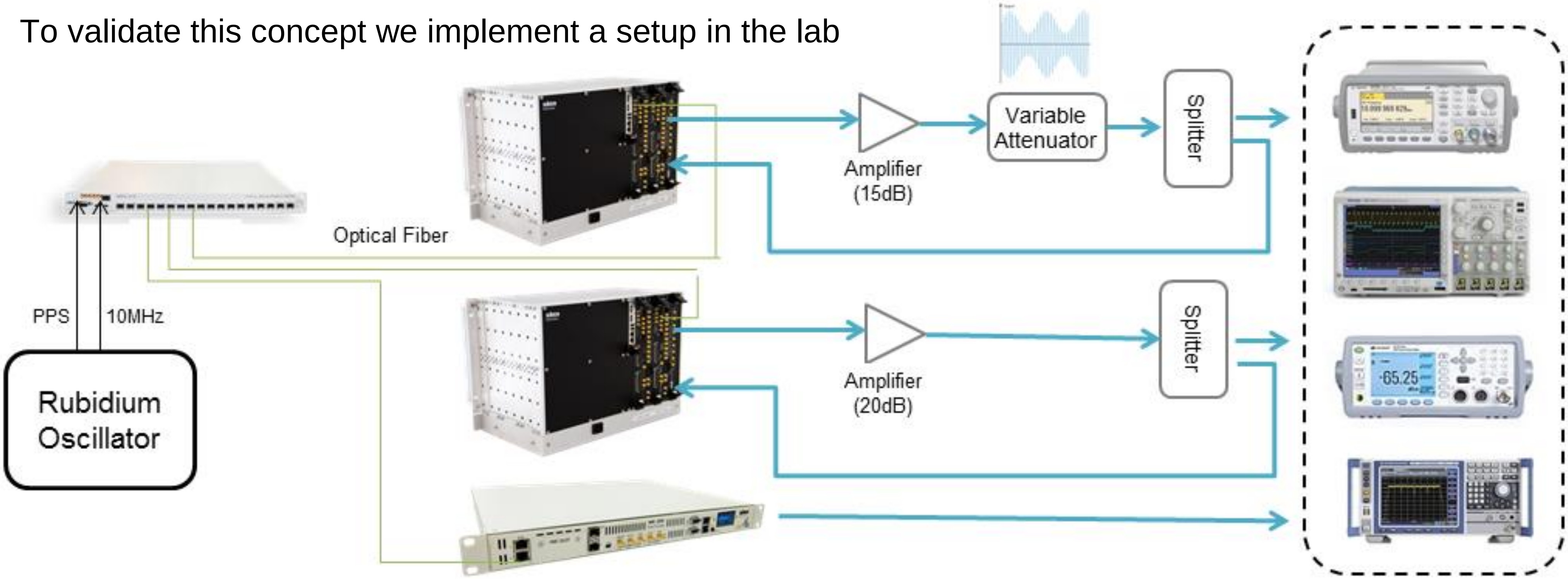
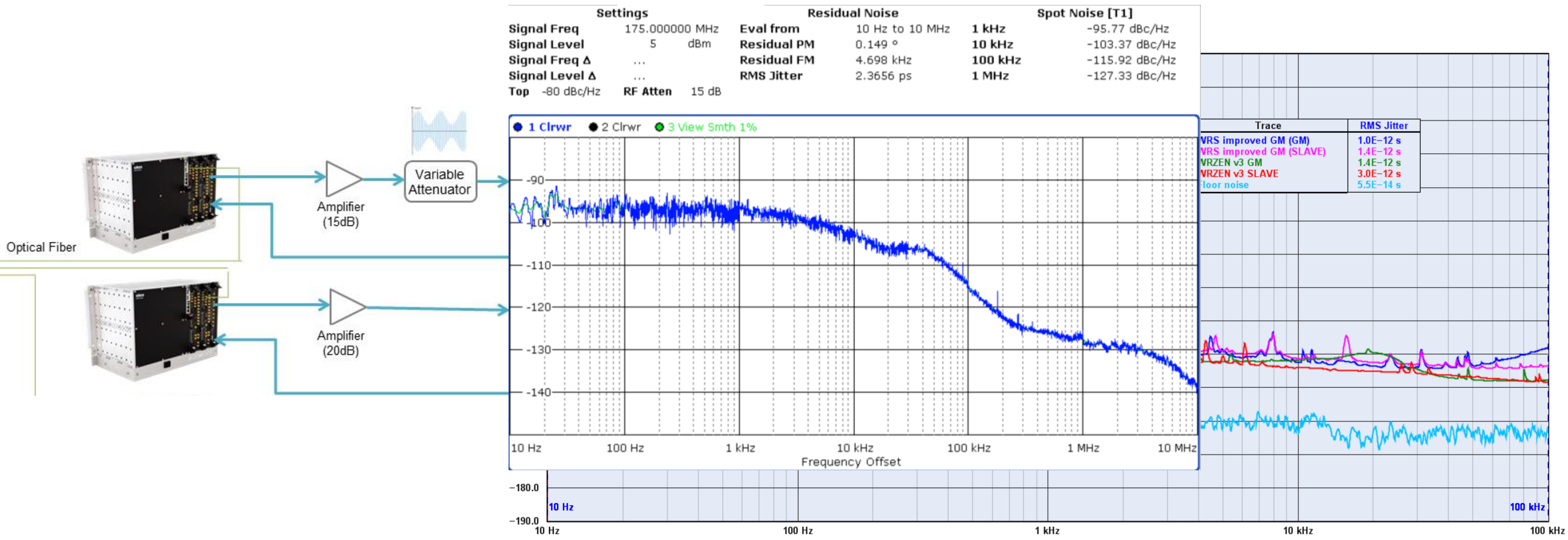


Lab. Setup Test

To validate this concept we implement a setup in the lab



Lab. setup
Results



Lab. setup
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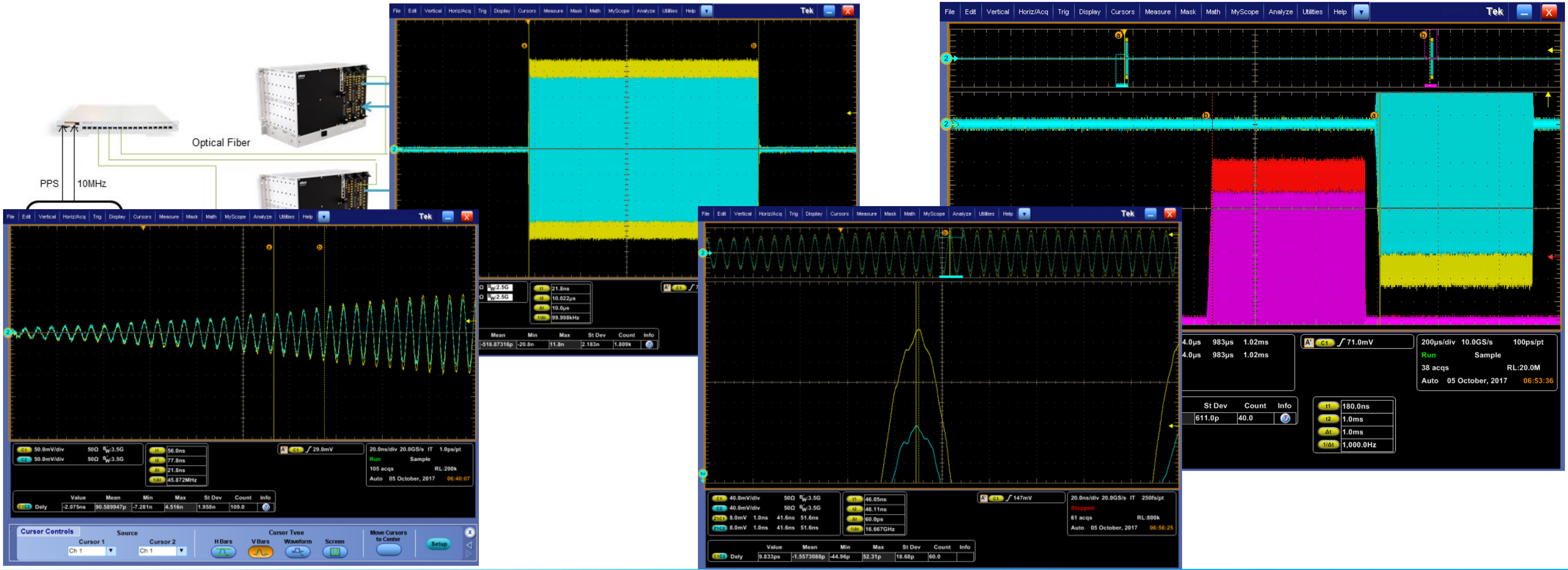


Lab. setup
Results

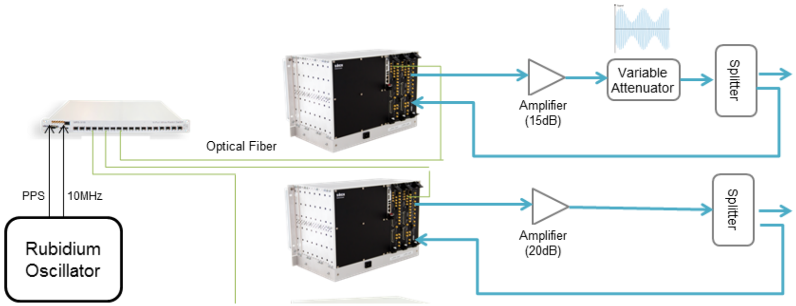
Lab Test: 56 hours(0,25SPS, 49KSP), 6º Temp. deviation

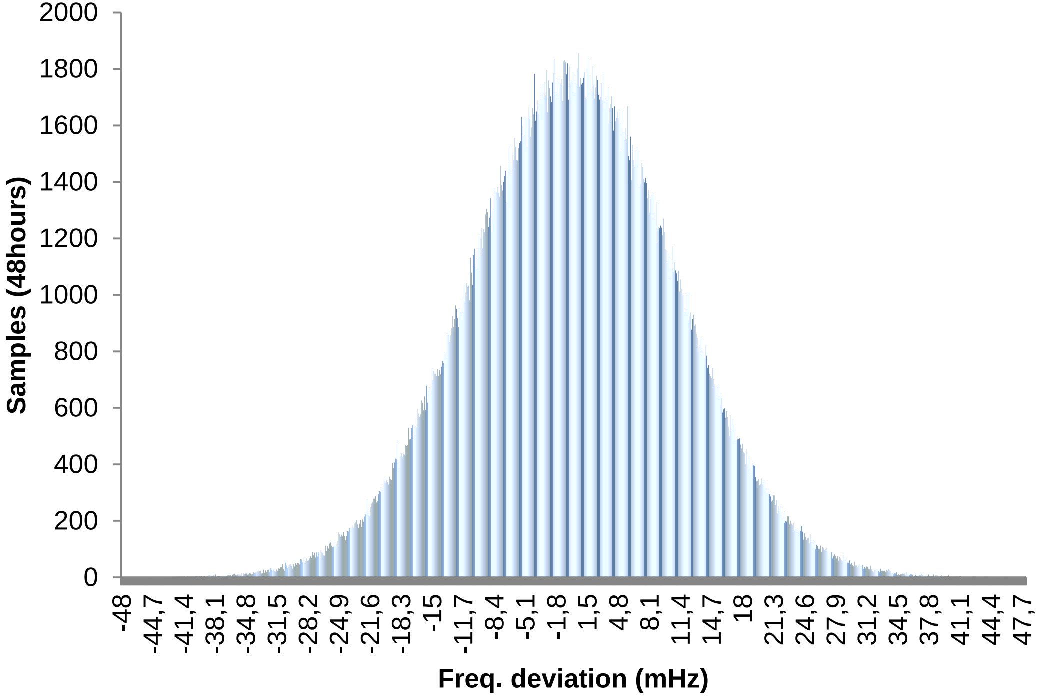
RF = 175000000Hz (StdDev = 0,0000006233)

Frequency deviation:

Min = -0,0002207% ; Max= 0,0002203%

RMS = 0,0000633 %





RFQ conditioning

Solutions

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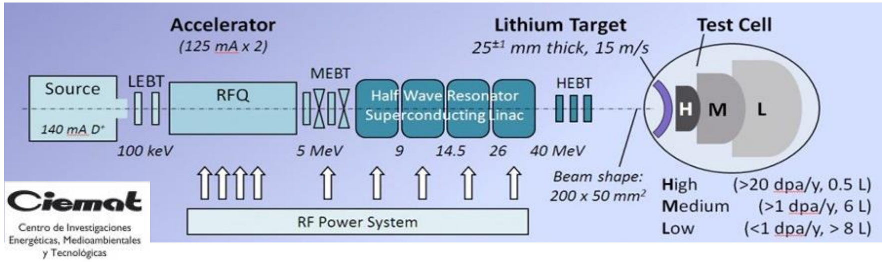

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RFQ conditioning
Rokkasho

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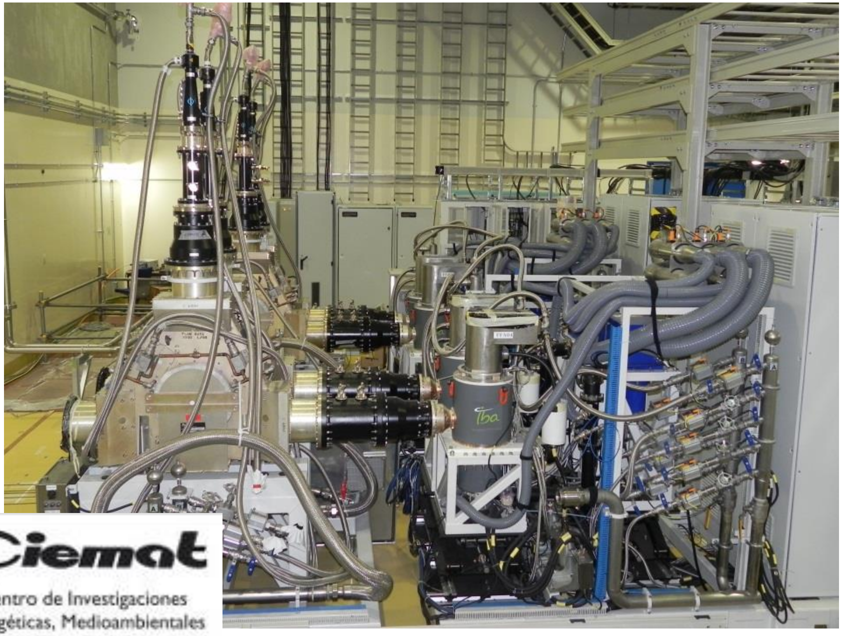
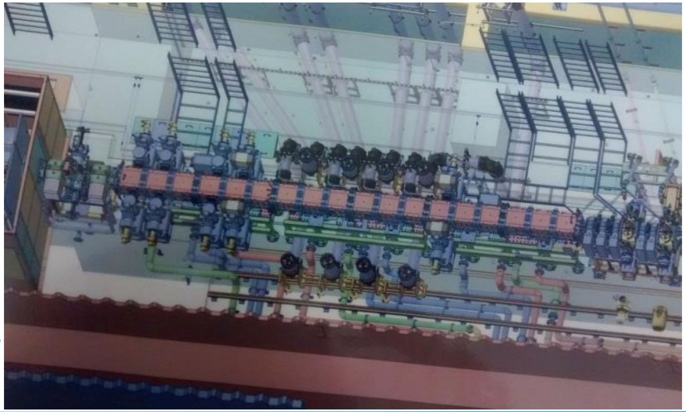
First results in the conditioning of IFMIF/EVEDA RFQ cavity

- RFQ cavity of 9.8 meters
- Conditioning of RFQ cavity
- 8 independent amplifier chain & RF control.





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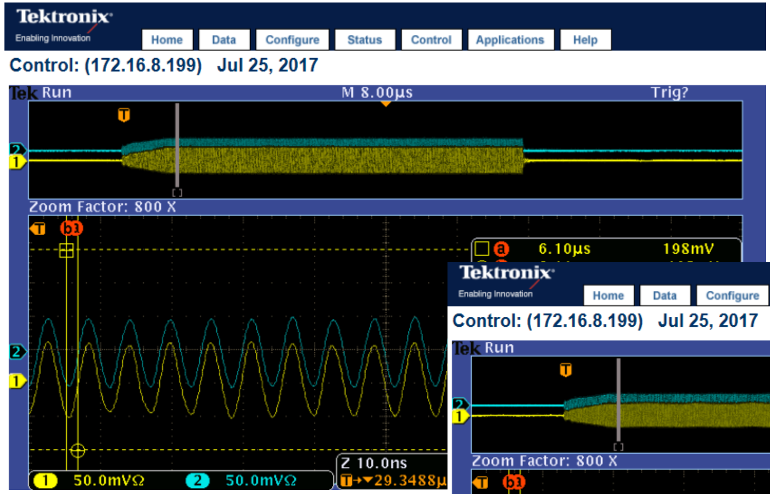
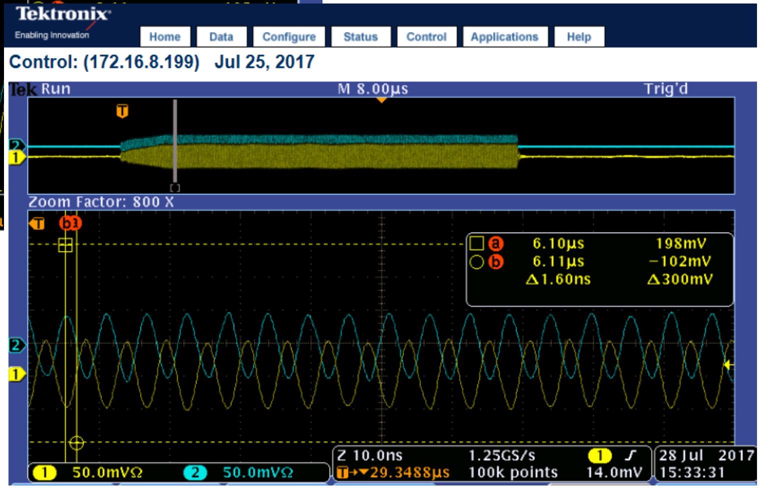
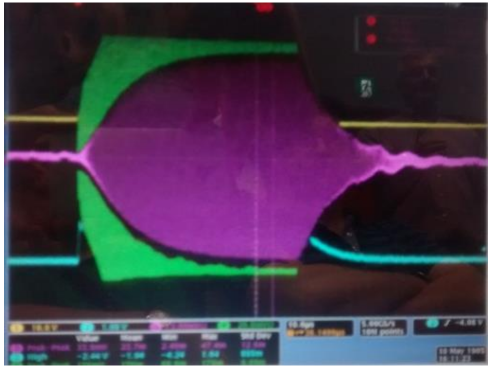
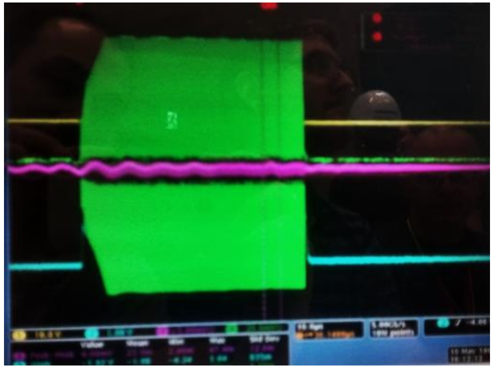
RFQ conditioning
First results









Thanks to CIEMAT and F4E/QST institutes in Rokkasho (Japan)

Conclusions

- We have developed a scalable, flexible and totally digital **LLRF** for IFMIF/EVEDA project and LIPAc facility in collaboration with CIEMAT.
- We use **White Rabbit Technology** to distribute clock and time through the accelerator RF controls (LLRF, BPMs) in a synchronized way.
- LLRF test results provide better accuracy and precision than expected:
  - Precision: 2,3psec (10Hz-10MHz without optimization)
  - Accuracy: 60/100psec (without specific calibration)
- Some characterization and optimization must be done.
- First results in Rokkasho were a grate successful and 8 independent amplifier chains for a RFQ cavity conditioning were synchronized.

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Thanks for your attention!

Many thanks to CIEMAT and F4E institutes in Rokkasho

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