

# New Digital LLRF System for CNAO Linear Accelerator

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## Abstract

CNAO is one of the six hadrontherapy centers able to treat cancer with proton beams and carbon ions. It is a synchrotron with a diameter of 77 meters, equipped with a LINAC as the injector. The stability of the RF in the LINAC being fundamental for the quality of the beam injected into the ring impelled CNAO to decide to upgrade the actual analogic LINAC LLRF to a digital one.

This proceeding describes the CNAO Linear Accelerator LLRF upgrade, and the Libera LLRF system modifications and extensions necessary to fulfill the CNAO requirements. The newly introduced features include: the ability of the LLRF system to process a dual-trigger source, the extension to additional interlock inputs, and the introduction of trigger output signals of configurable timing. It furthermore describes the upgrade of the CNAO LLRF with specific drive-power limitation functions, integrated within a non-linear high-power amplifier response calibration and the commissioning results of the CNAO Linear Accelerator Digital LLRF system.

## THE CNAO hadrontherapy facility introduction

The CNAO (National Center for Oncological Hadrontherapy) is a synchrotron based cancer therapy facility located in Pavia (Italy). A linear accelerator injects proton and carbon ions into the synchrotron, where the energy is ramped to the level required by the treatment.

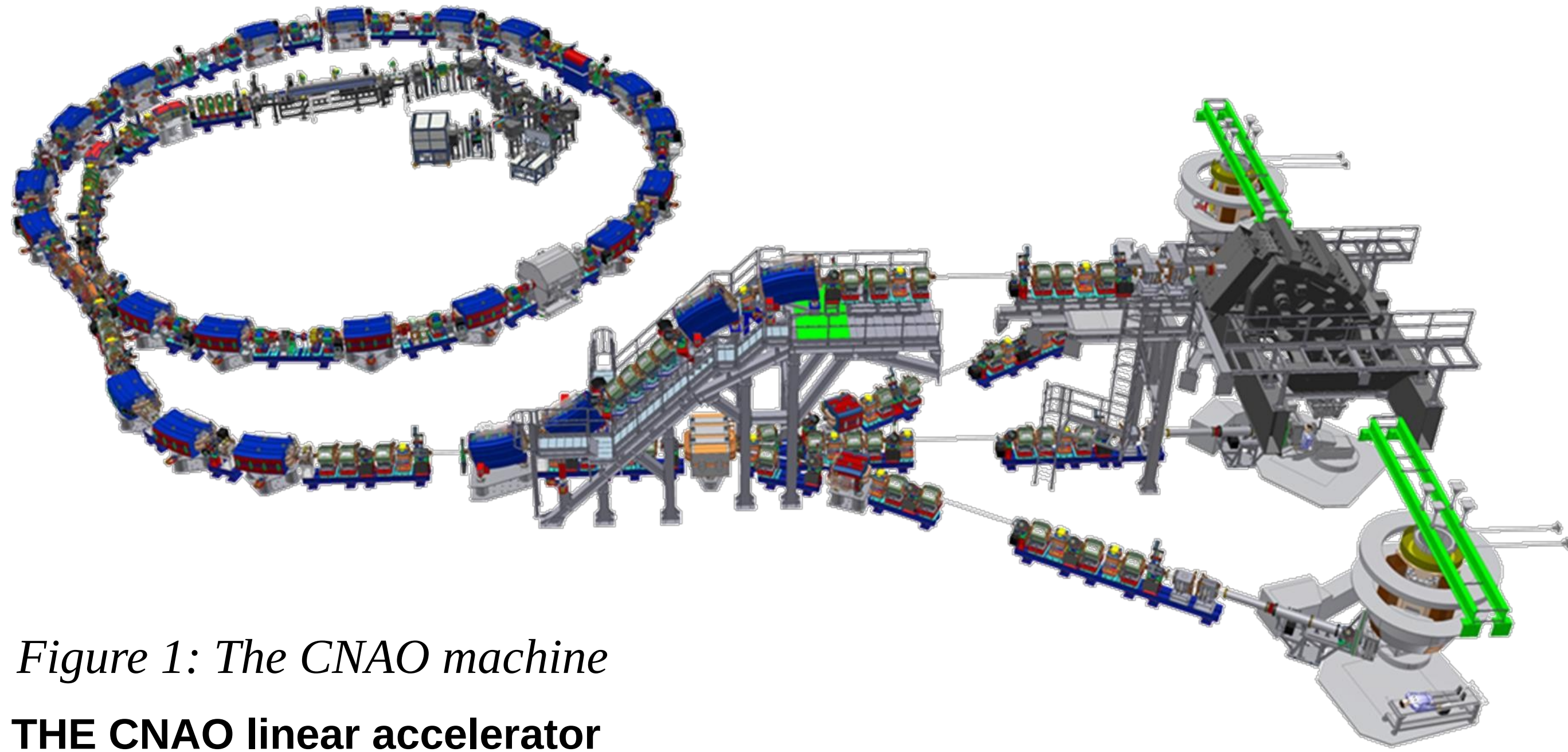


Figure 1: The CNAO machine

## THE CNAO linear accelerator

The CNAO LINAC is based on three RF stations: an RFQ, an IH and a Debuncher (RF frequency 218.816MHz, pulse Duration 500  $\mu$ sec, beam pulse duration 100  $\mu$ sec and pulse repetition rate 10Hz). The current RF system control is based on analog components. The main motivations of the upgrade is to have a more reliable and repeatable operation of the LINAC through a digital LLRF, to improve the control system interfaces and to have the possibility to acquire signal traces.

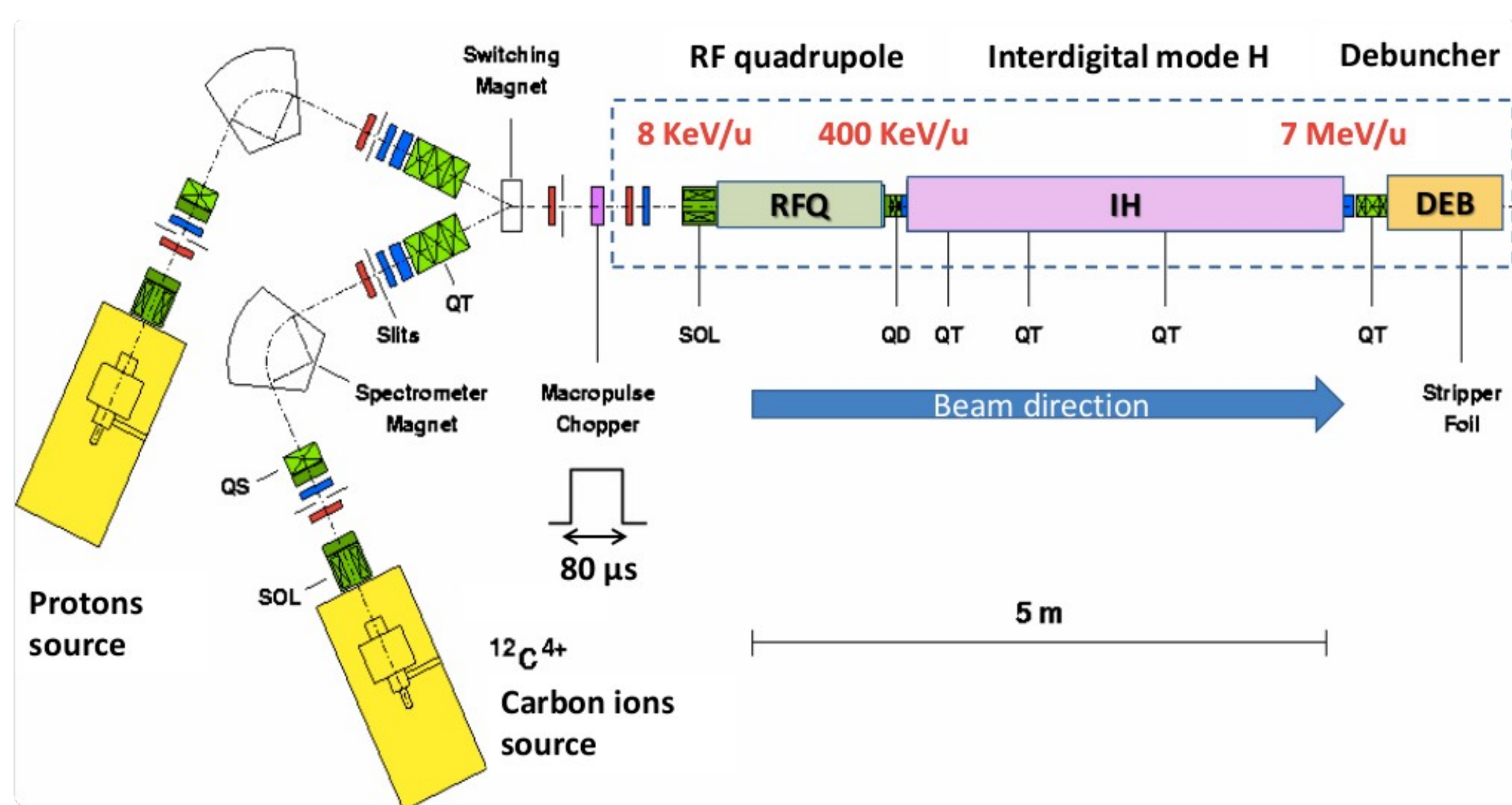


Figure 2: The CNAO LINAC

## THE CNAO LINAC LLRF upgrade requirements

- **Dual trigger** support (“beam pulse” for the particles being accelerated and “stability pulse” to keep the cavities warm). The LLRF system doesn’t know in advance which pulse is going to be triggered.
- Additional **external interlock sources**
- **Trigger outputs** to be enabled at specific user configurable time offset from the LLRF input triggers.
- **Polynomial correction** of the high power amplifier non linear amplitude response
- **Drive power limits** (coherent with the amplifier linearization and dependent from cavity tuning state).
- **Pulse shape control: rise and fall time**
- **Local and remote** user interface support

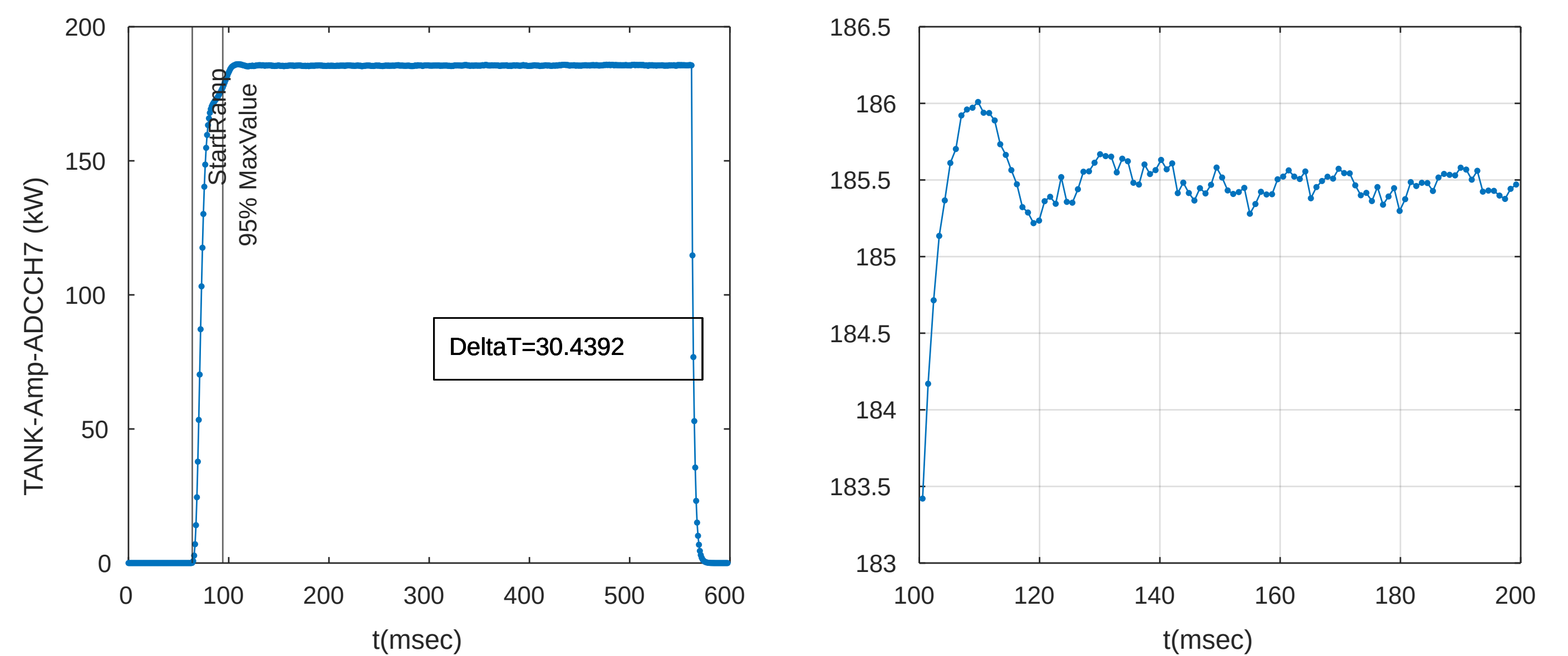


Figure 2: Output power of RFQ amplifier in carbon configuration. Rising time needed to achieve 95% of the desired value and overshoot are showed.

## THE CNAO LLRF upgrade



Figure 3: The CNAO Libera LLRF with the upgraded digital AMC module

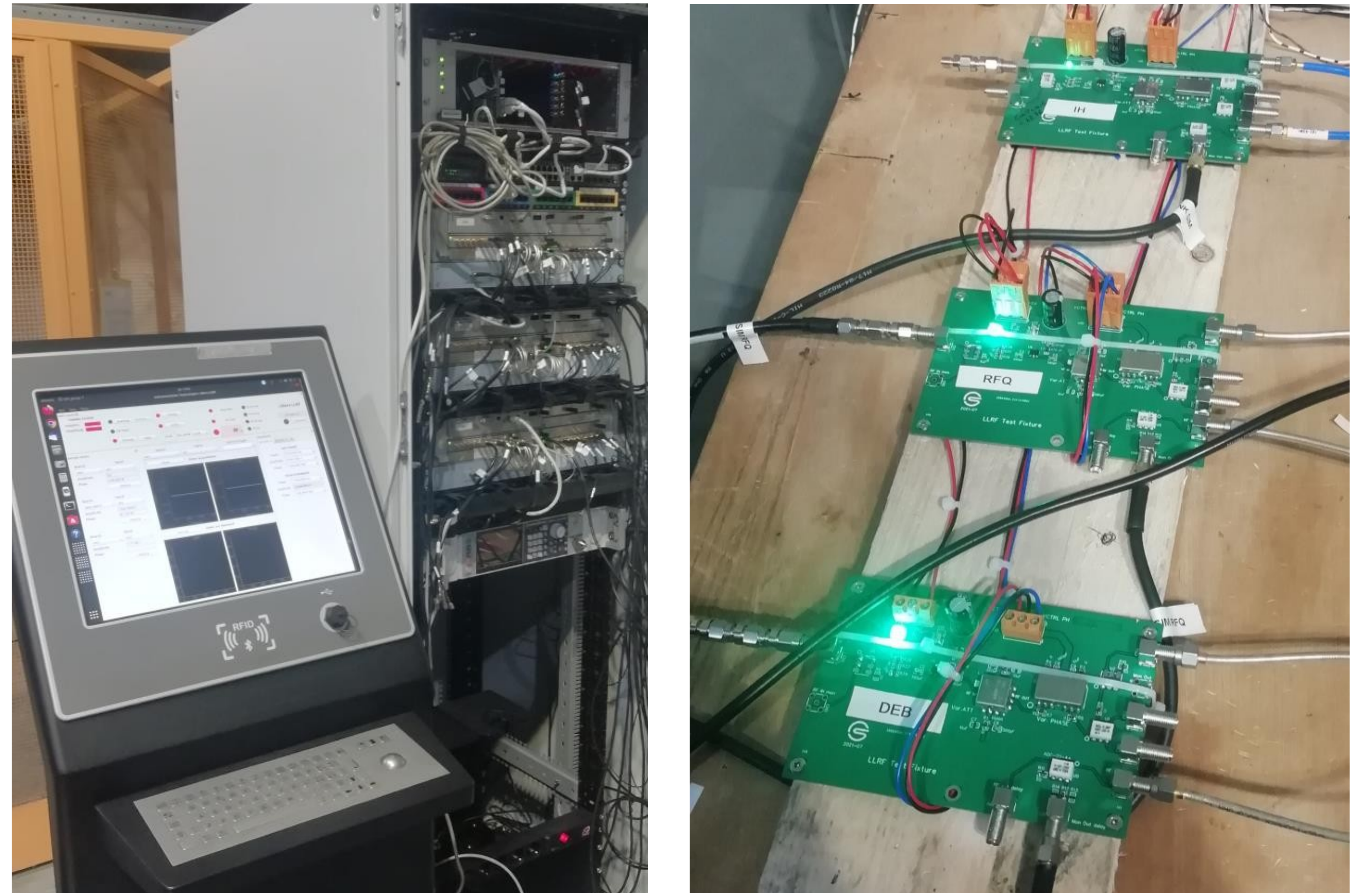


Figure 4: Installation and commissioning

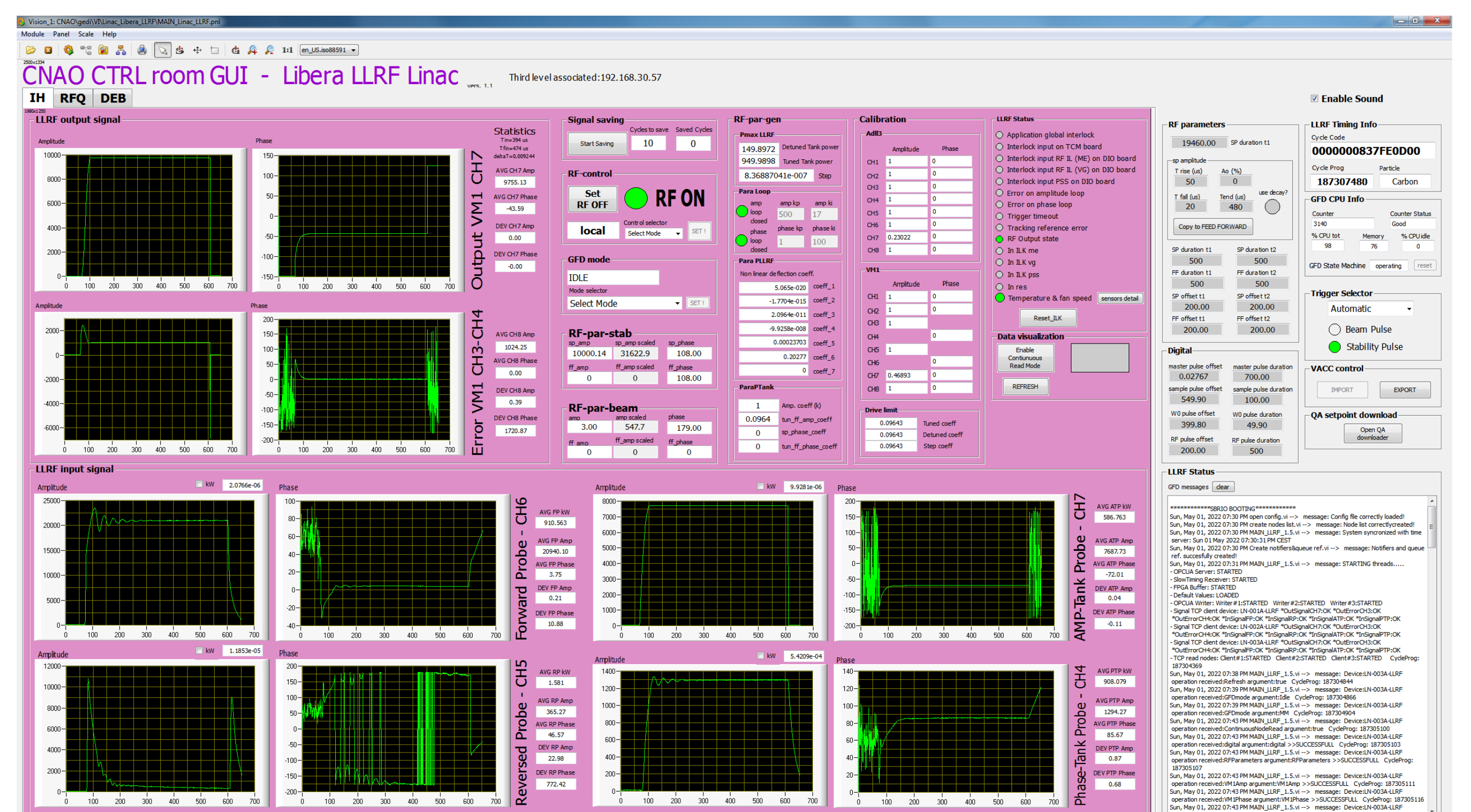


Figure 5: Libera LLRF integration into CNAO Control System

## Conclusion

The Libera LLRF system has been successfully upgraded with the functionality required by the CNAO LINAC upgrade project. Six Libera LLRF systems have been delivered to CNAO and successfully tested. After the extensive testing three Libera LLRF system have been installed in the CNAO LINAC. These results were possible thanks to the collaboration between the CNAO and Instrumentation technologies teams.

## References

- [1] CNAO LLRF upgrade requirements: <https://rb.gy/lS6bq7>
- [2] B. Baricevic et al. “LIGHT proton therapy LINAC LLRF system development”, LINAC18, Beijing, September 2018