

Advanced LLRF control and automatic RF conditioning for the SSRIP facility

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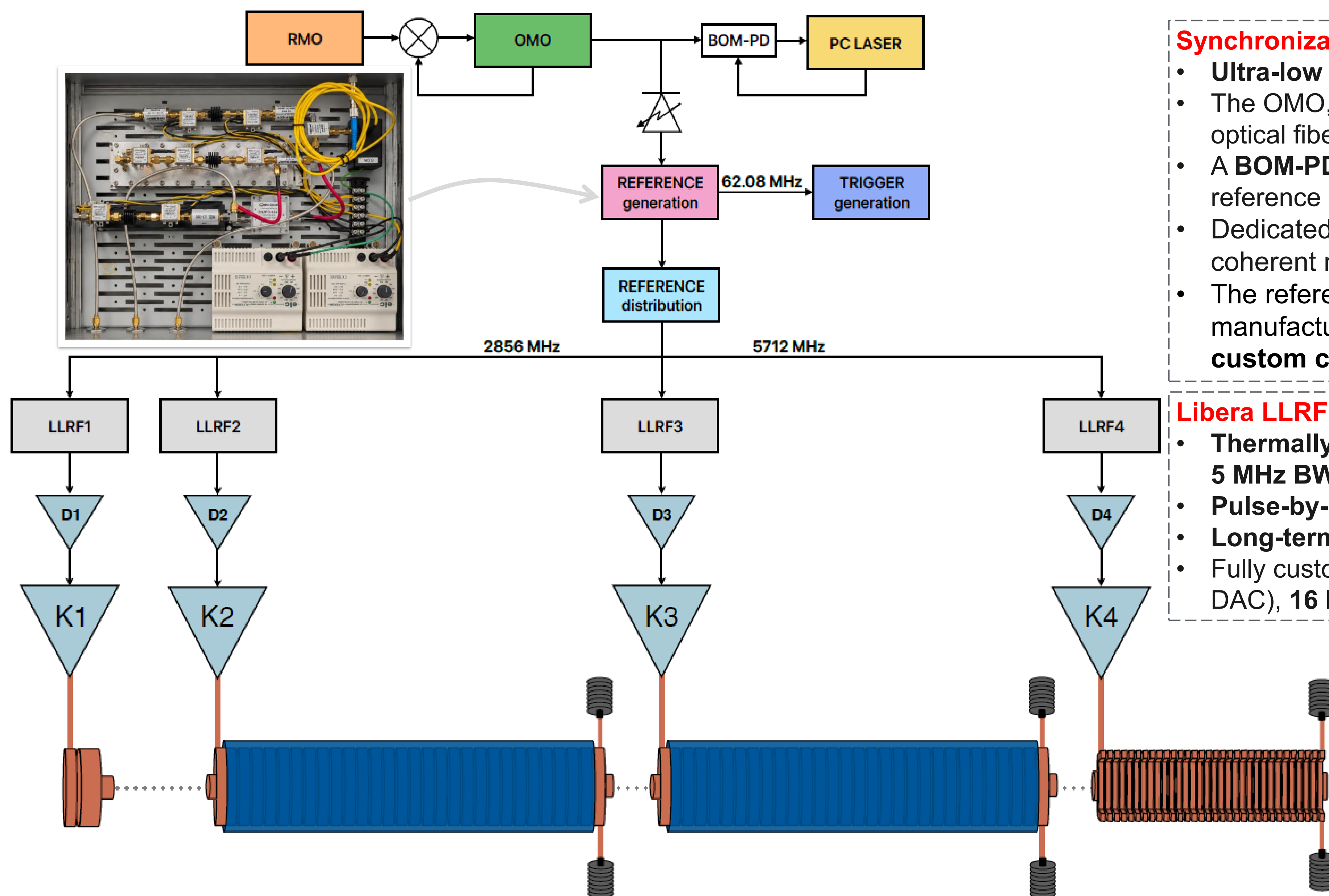
ABSTRACT

The **Scalable System for Radioisotope Production (SSRIP)** is a new compact **linear accelerator** developed at IFIN-HH (Măgurele, Romania), coordinated by INFN-LNF within the ELI-NP infrastructure. The accelerator is designed to produce high-brightness electron beams for radioisotope production applications. The SSRIP RF system consists of **four independent RF stations**, three operating at 2856 MHz (S-band) and one at 5712 MHz (C-band). Each station is equipped with a solid-state pulsed modulator and a high-power klystron amplifier. The RF control system is based on **digital, temperature-stabilized and FPGA-controlled Low Level RF (LLRF)** units, providing high-resolution amplitude and phase feedback for stable accelerator operation. An **automatic RF conditioning procedure** was developed to progressively increase the RF power up to the nominal operating level. The procedure continuously monitors vacuum levels and RF waveforms, automatically increasing or reducing the RF power according to the machine status, with minimal operator intervention. The subsequent beam commissioning, completed in July 2026, achieved an **electron beam energy of 109 MeV** with a **bunch charge of 100 pC**.

SSRIP



LAYOUT OF THE SSRIP RF SYSTEM

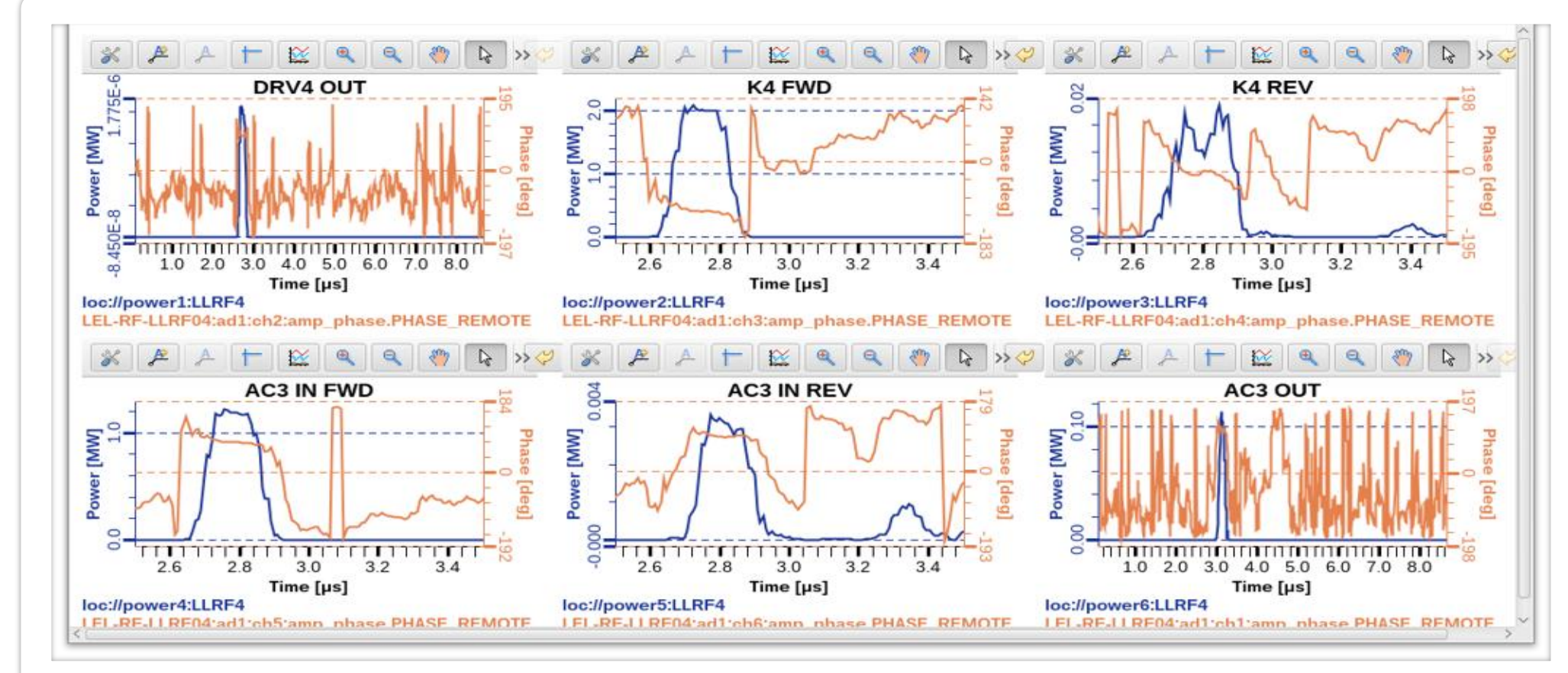


Synchronization system:

- Ultra-low phase noise RMO provides the 2856 MHz reference
- The OMO, phase locked with the RMO, distributes the reference through optical fiber
- A BOM-PD phase-locks the photocathode laser oscillator with the master reference
- Dedicated **optical-to-electrical conversion electronics** generate coherent references at **2856 MHz** and **5712 MHz**
- The reference generation and distribution hardware is designed and manufactured by the **LNF RF group** using commercial components and **custom cavity filters**

Libera LLRF features:

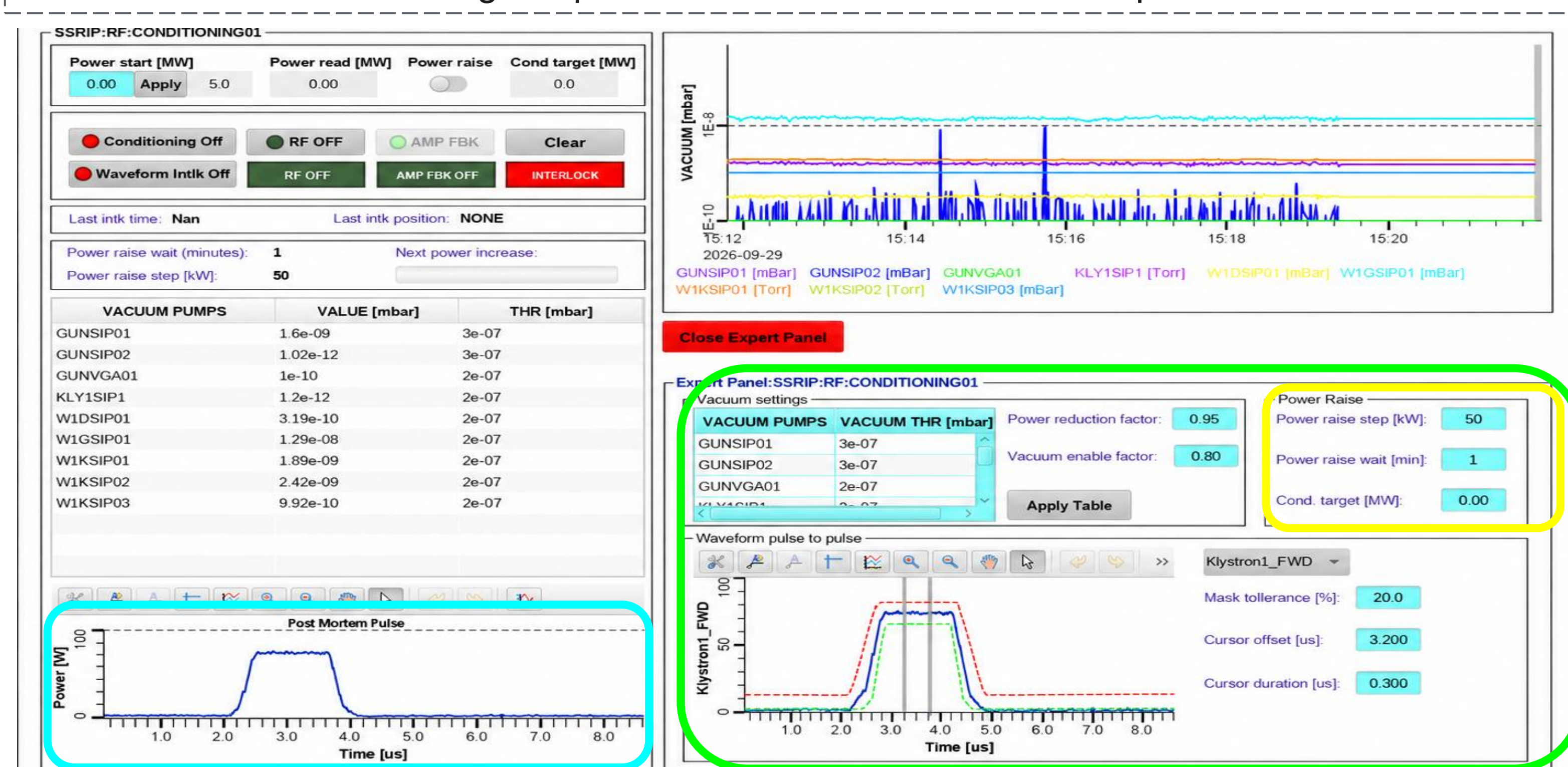
- Thermally stabilized front-end, IF=44.625 MHz, **16 bit ADC** at **119 MS/s**, **5 MHz BW**
- **Pulse-by-pulse** A, Φ independent **feedbacks**
- **Long-term (24h) stability** of RF station: **100 fs**
- Fully customizable pulse shape (A, Φ), analog VM driven by **FPGA** (14 bit DAC), **16 MHz BW**



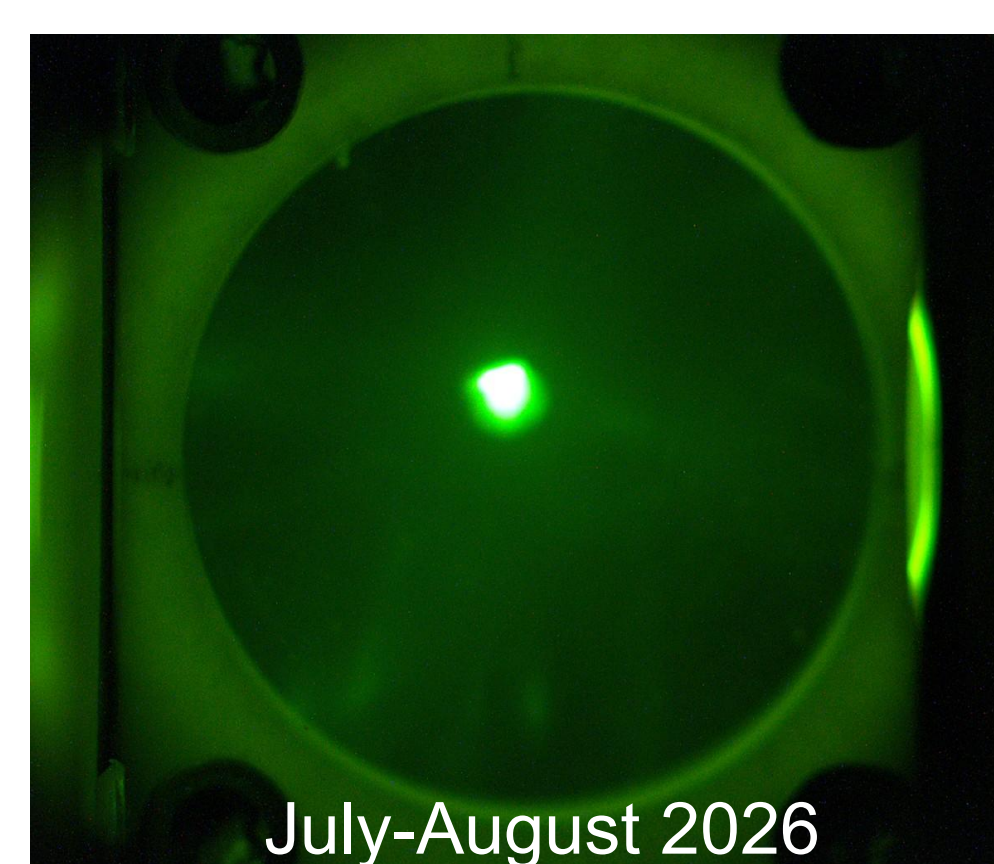
AUTOMATIC RF SYSTEM MANAGEMENT

Automatic conditioning:

- The **RF power** is progressively **increased** toward the **target value** using **configurable power steps** and **waiting times**
- During the ramp, the algorithm **continuously monitors** the **vacuum level** and a selected **RF pulse waveform**
- A configurable time window is selected on the RF waveform. Upper and lower limits are generated around the measured pulse by applying a predefined tolerance. The resulting **mask** is then **used to validate** the following **RF pulse**
- If the **vacuum** level exceeds its **threshold** or the RF waveform crosses the mask, the power ramp is stopped and the **RF is automatically switched off**
- The **interlock source** and timestamp are **recorded**. In the case of a waveform fault, the anomalous pulse is also stored for **post-mortem analysis**
- The algorithm waits until the vacuum level falls below a lower re-enable threshold, preventing repeated switching close to the interlock level
- The RF is restarted at a power level reduced by a configurable factor relative to the value reached before the fault
- The automatic conditioning ramp then resumes from the reduced power level



BEAM COMMISSIONING



- First electron beam extracted from the RF photoinjector in **June 2026**: approximately **5 MeV** and **50 pC**
- Successful beam capture, acceleration and transport through the complete LINAC
- Commissioning completed in **July-August 2026** with a final beam energy of **109 MeV**
- Nominal bunch charge of **100 pC** achieved at a repetition rate of **10 Hz**

Primo fascio di elettroni a SSRIP – INFN-LNF

Extreme Light Infrastructure - Nuclear Physics (ELI-NP)