Low Level RF System of the LIGHT Proton Therapy Linac

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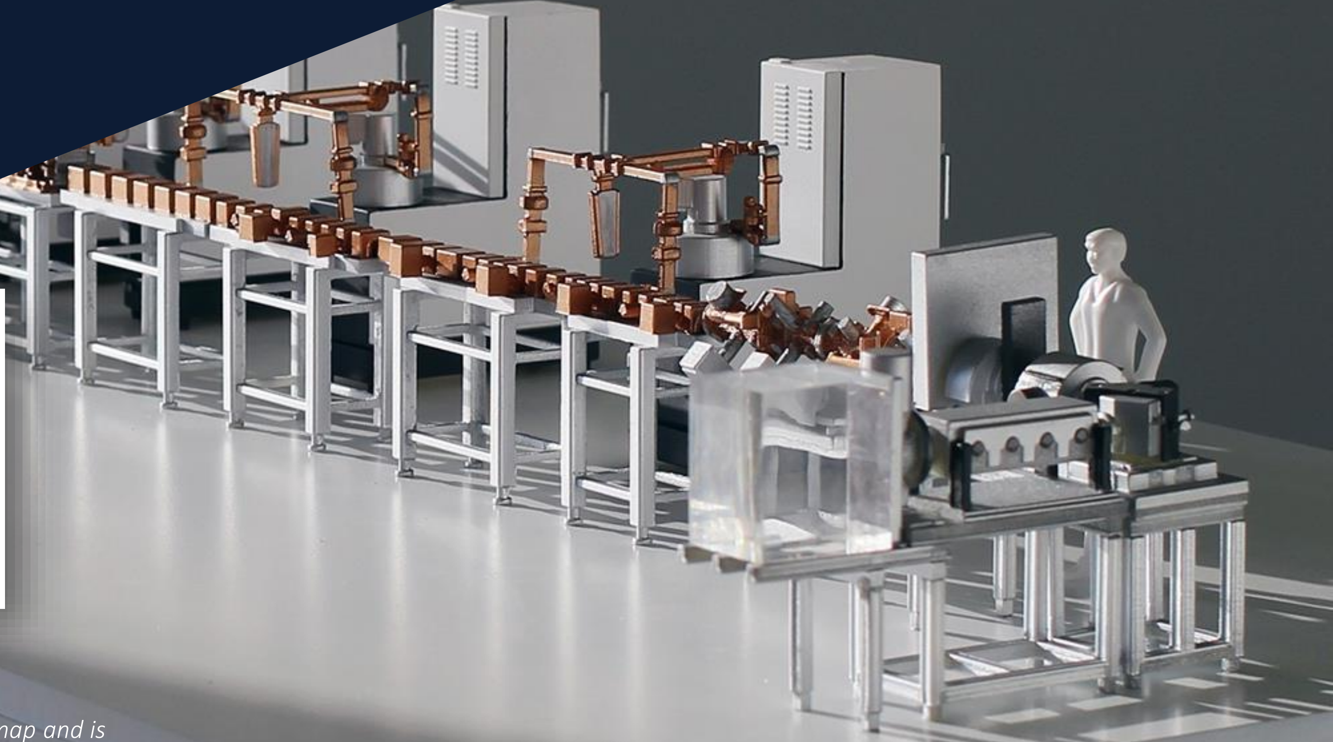

Democratising Proton Therapy

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Agenda

AVO-ADAM

2007 - Foundation of ADAM (Application of Detectors and Accelerators to Medicine), as a spin-off from CERN (the European Organisation for Nuclear Research).

2013 - Advanced Oncotherapy's acquire ADAM.

2018 – First LIGHT prototype in Geneva able to accelerate 52 MeV protons with energy modulation at 200 Hz.

2022 – LIGHT Beam Production System in UK: 230 MeV first beam milestone reached on the 26th September.

The LIGHT linear accelerator design by AVO-ADAM offers a modular compact solution for precise control of the treatment dose delivery, both position and energy wise. Proton energy can be modulated at up to 200 Hz in a range from 70 to 230 MeV by varying the gradient of the accelerating structures [*]

[*] B.B. Baricevic, A. Bardorfer, R. Cerne, G. De Michele, and Ye. Ivanisenko, "Light Proton Therapy Linac LLRF System Development", in *Proc. LINAC'18*, Beijing, China, Sep. 2018, pp. 171-173. doi:10.18429/JACoW-LINAC2018-MOPO081

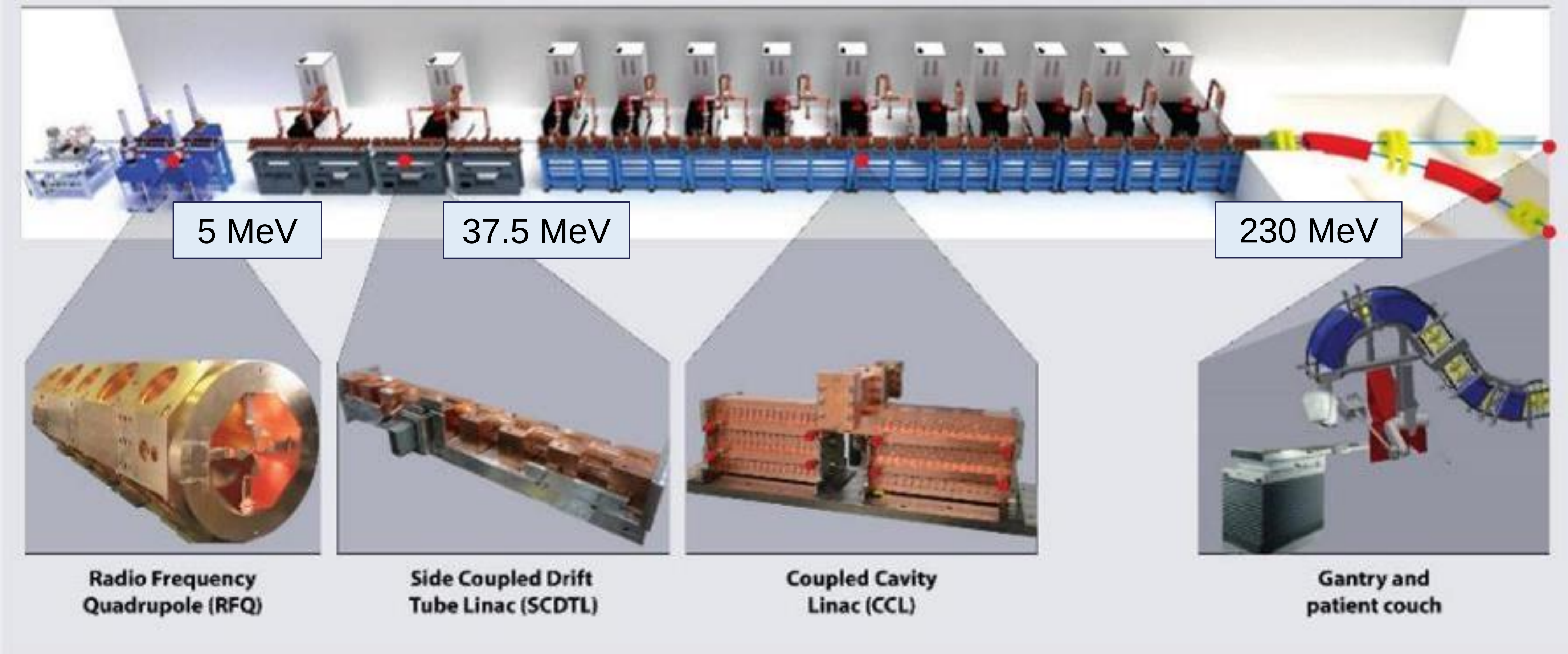
AVO-ADAM webpage link & QR

LIGHT - RF system

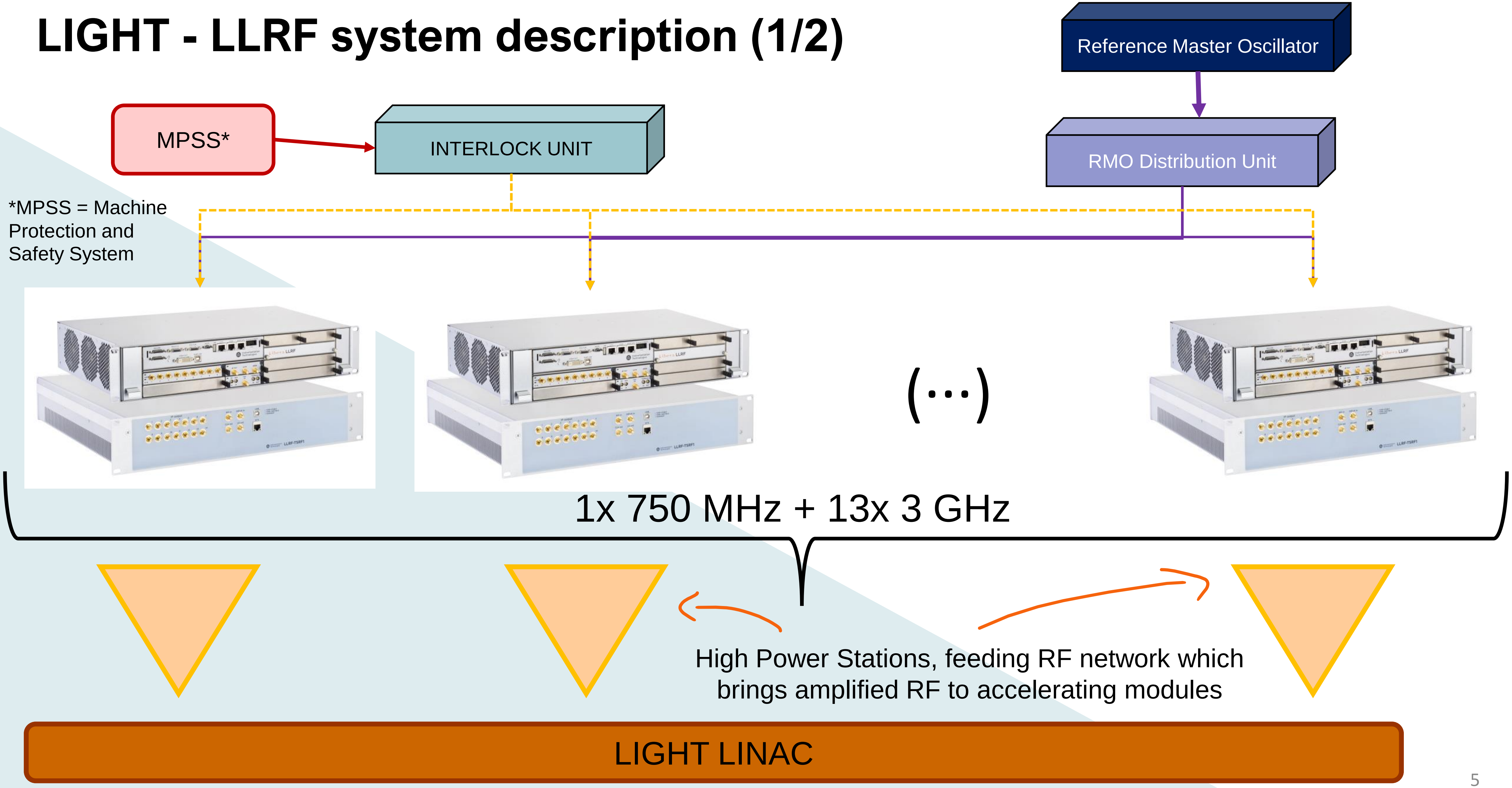
Recent advances at DIS, click on the link or scan QR:
https://www.youtube.com/watch?v=07TFUL5DzMU

LIGHT accelerating cavities:
- 1 RFQ (750 MHz)
- 4 SCDTLs (3 GHz)
- 15 CCLs (3 GHz)

RF generation & amplification
- 14 High Power Stations, providing 200 Hz, 5 us, RF pulses up to 7.5 MW
- 14 LLRF boxes - Libera LLRF by **Instrumentation Technologies**



LIGHT - LLRF system description (1/2)



LIGHT - LLRF system description (2/2)

2 types of LLRF boxes:

a. 749.48 MHz (RFQ)
   - Digital Processor + Splitter Unit

b. 2997.92 MHz with 1 or 2 ADC boards (SCDTL/CCLs)
   - Digital Processor: where the Intermediate Frequency (IF) signals are processed by the FPGAs and a drive signal is generated
   - Front End: temperature stabilization of the analog PCBs inside the LLRF analog front-end unit

Other LLRF modules

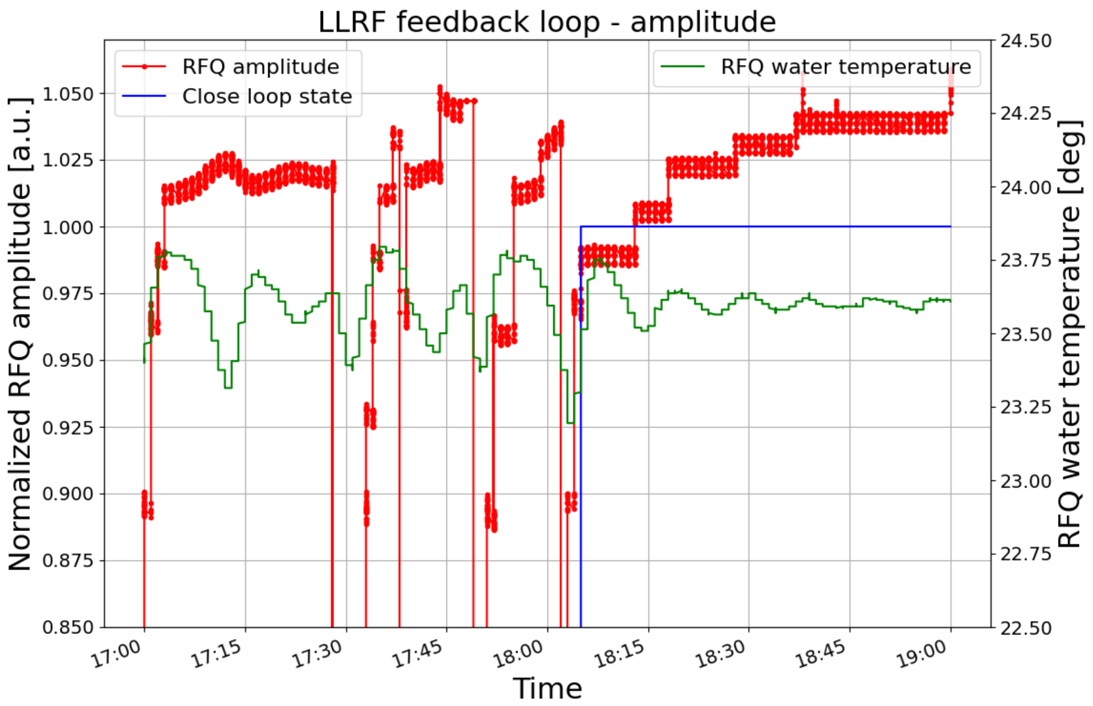
- Reference Master Oscillator + Distribution amplifier
  - CW reference at 2997.92 MHz to distribute the signal to each LLRF unit.
- Interlock unit
  - Distributes the interlock signals from the accelerator control system to each LLRF box.

One of the four LLRF racks in DIS during pre-installation SAT period

LIGHT - LLRF features (1/3)

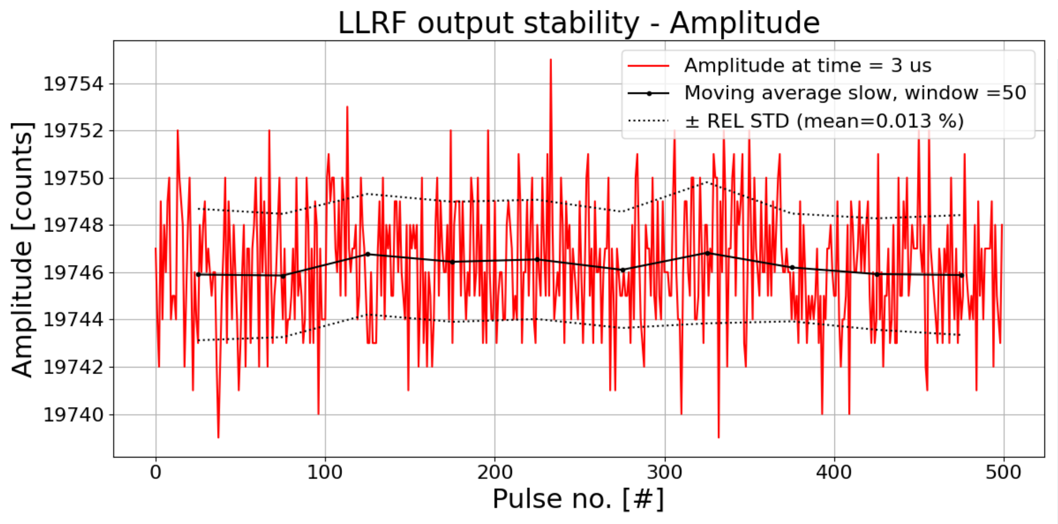
✓ **Feedback control** - Amplitude and phase regulation

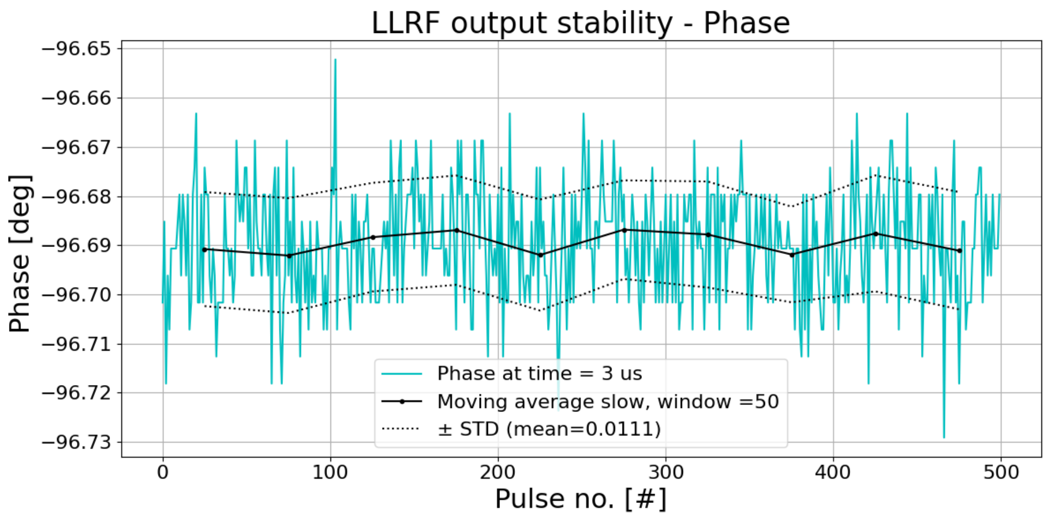
Example of the feedback loop behaviour from the RFQ commissioning tests and its counter effect to cooling oscillations.



✓ **RF output stability** - Amplitude and phase

- Requirement: better than 0.15 % in amplitude and 0.15 deg in phase (RMS).
- Tested, values ~ 0.01 % and 0.01 deg RMS at full range.





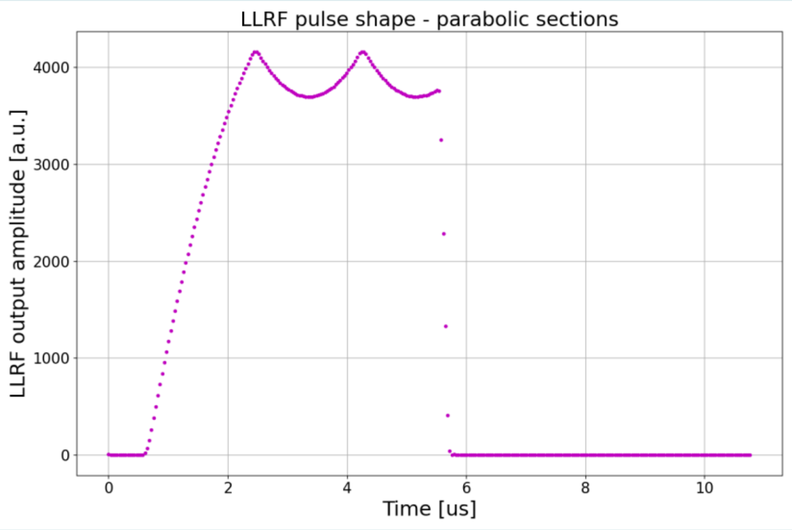
LIGHT - LLRF features (2/3)

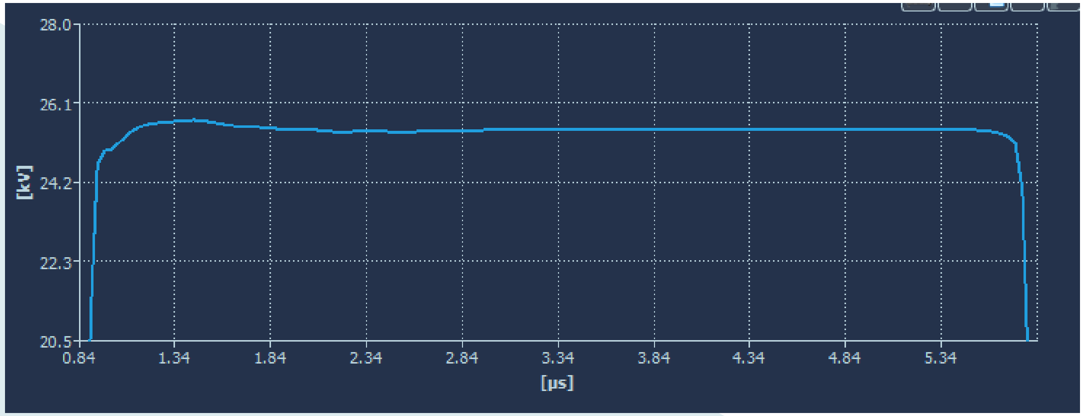
✓ Decay Analysis

- RF signal analyzed to provide a virtual frequency correction (frequency is fixed for beam acceleration).
- This can be translated into a temperature correction to keep resonance of the cavity by changing water temperature.
- Via Modbus RTU communication protocol
- Tested standalone, ongoing work to incorporate into the full LINAC.

✓ Pulse shapes

- Possibility to define second order polynomials to shape the output pulse.
- Flatten RF pulse after HPS amplification.



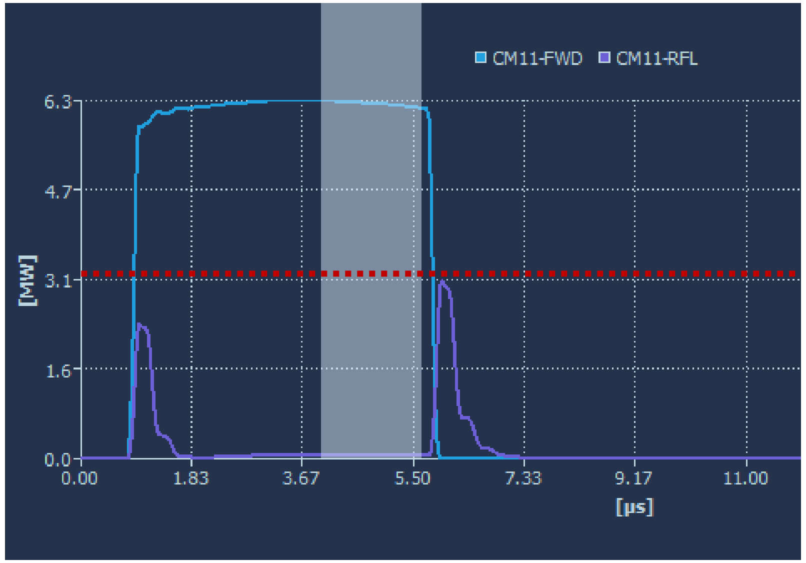


Uncompensated RF amplitude pulse from the Modulator Klystron system

LIGHT - LLRF features (3/3)

✓ **Breakdown detection**

- Detects when reflected RF power rises over a threshold.
- Counts number of events per unit time.
- Stops RF output if events are above allowed limit.
- Cavity protection from arcing discharges.



Forward (FWD) and reflected (RFL) RF power before CCL module 11. The breakdown detection checks within a time gate that RFL amplitude doesn't go above a percentage of the FWD amplitude (for example 50% as in red dotted line).

✓ **Front End Controller**

- Data Streaming Interface
  - Uni-directional interface to receive pulse related measurements..
- Slow Control Interface
  - Bi-directional interface to provide control, configuration and calibration settings to the system and to collect acquisition data that has update intervals in the 100 milliseconds.
- Real Time Interface
  - Bi-directional deterministic request-response interface to configure pulse-related settings.
  - All messages and responses within 5 ms.
- Trigger Interface
  - Uni-directional interface to send trigger signals to the LLRF Unit.

Installation description and status

✓ **Racks**

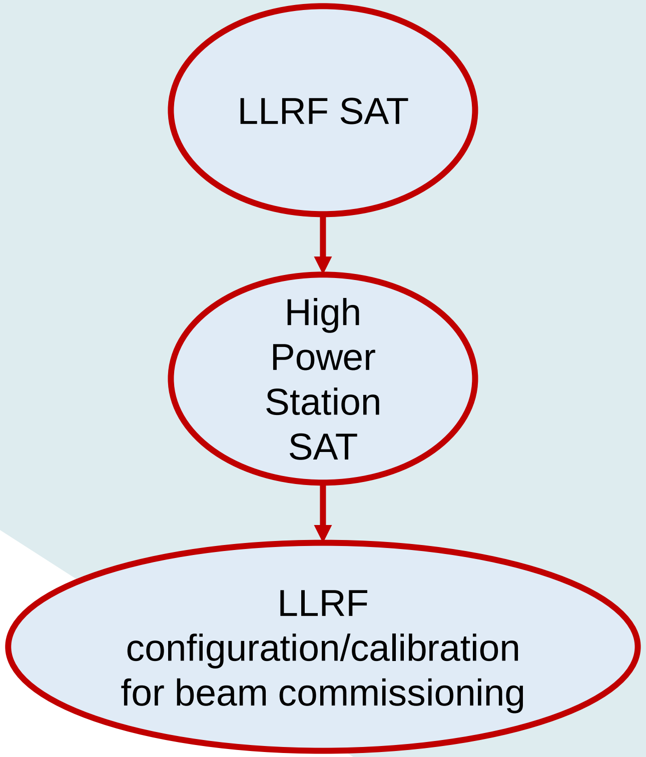
- 4 racks (42U) for the LLRF system on the Klystron gallery.

✓ **Site Acceptance Tests (SATs) and configuration**

- All 14 LLRF units passed their **LLRF SATs**.
  - Most tests are automatized thanks to the I-Tech Libera LLRF platform.

- Then, used for **High Power Stations SATs**:
  - RF unit working as a whole but not connected to the RF module.
  - Detect early potential problems, pre-configuration loaded.

- **Final configuration** for beam commissioning operation and **calibration**.
  - Piecewise: combining ADC response of the LLRF unit and RF line attenuation.
  - RF line attenuation considers cavity pickup couplings and cable losses up to the LLRF connection.



Final remarks

Summary

1. LIGHT LLRF system was produced and **delivered by Instrumentation Technologies to AVO-ADAM**.
2. **Fully SAT tested** in Geneva and Daresbury for the LIGHT proton therapy LINAC commissioning.
3. **Performance within the specifications** of the LIGHT requirements.
4. Successfully deployed for high RF power station SATs, cavity conditioning, and 230 MeV beam commissioning.

Experience / Lessons learnt

- High reliability during beam commissioning
    - **Very few associated incidents** due to LLRF (only at first boot up but solved with I-tech support)
- Graphical User Interface + Libera LLRF platform configurability
    - Important during initial development to understand the new device.

Next steps

- **Work ongoing** to implement Real Time features (every 5 miliseconds).
    - **Energy modulation** by changing LLRF amplitude.
    - Control feedback loop and breakdown detection.
- Health monitoring + purchase of spare units.

Thank you very much !

Happy to take questions

I´d like to acknowledge and thank sincerely Giovanni De Michele as RF group leader, Yevgeniy Ivanisenko as former LLRF component owner, Matevz Cerv as Control System LLRF Project leader and all my fellow colleagues from the RF department: Vasim, Luis, Stefano F., Giovanni, Stefano B., Joseph, Elliot and Abbey.