Low Level RF System of the LIGHT Proton Therapy Linac

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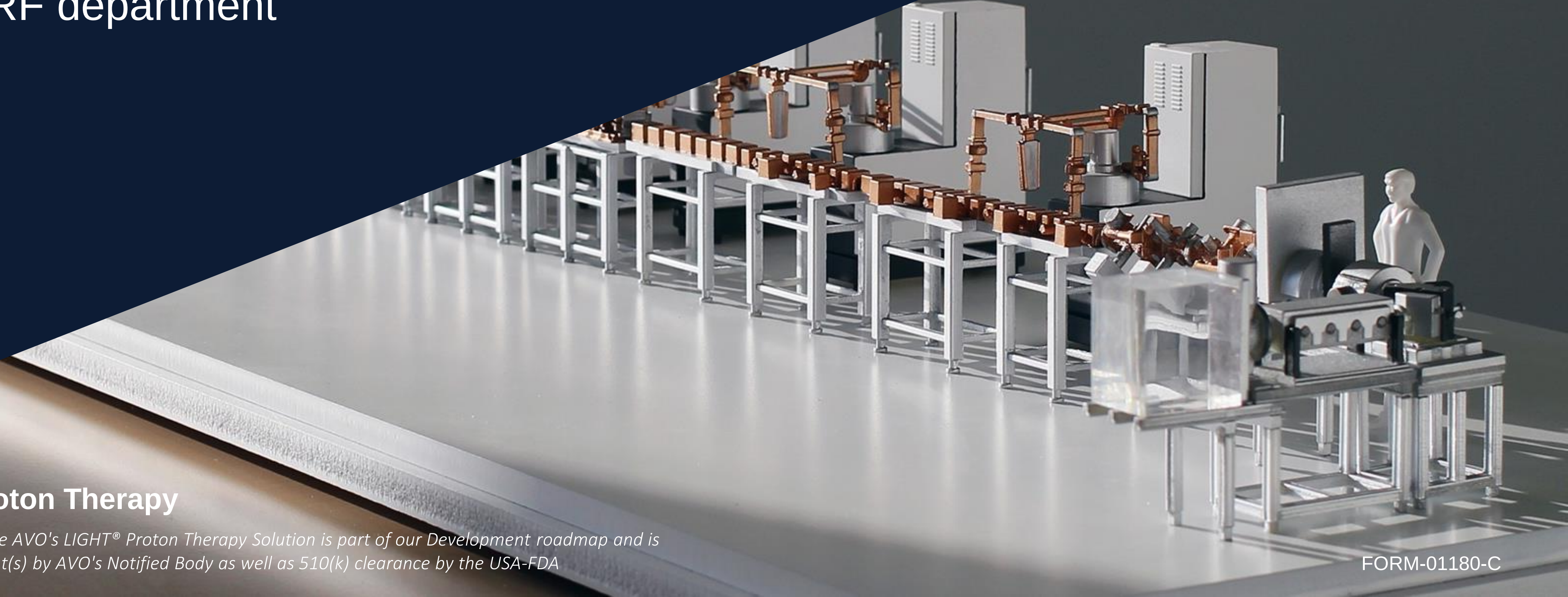

Democratising Proton Therapy

The following presentation of the AVO's LIGHT® Proton Therapy Solution is part of our Development roadmap and is subject to conformity assessment(s) by AVO's Notified Body as well as 510(k) clearance by the USA-FDA

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Agenda

- AVO-ADAM
- LIGHT - RF system
- LIGHT - LLRF system description
- LIGHT - LLRF features
- Highlights of Libera LLRF

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: 230 MeV beam commissioning at Daresbury Integration V&V Site (DIS) ongoing

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

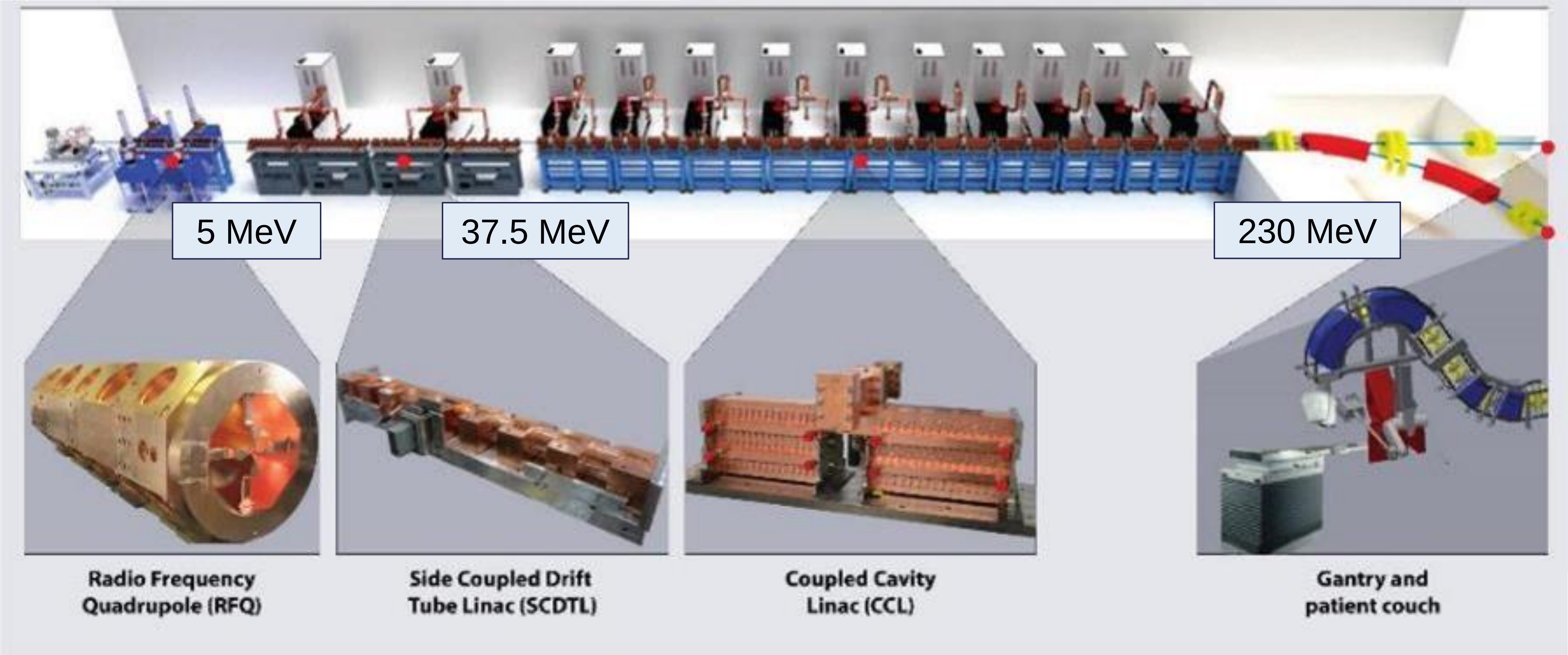
AVO-ADAM webpage link & QR

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 SCDLs (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

2 types of LLRF boxes:

a. 749.48 MHz
- Digital Processor + Splitter Unit

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

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.
- Trigger Synchronization unit

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

LIGHT - LLRF features (1/2)

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

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

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

✓ **Decay Analysis**

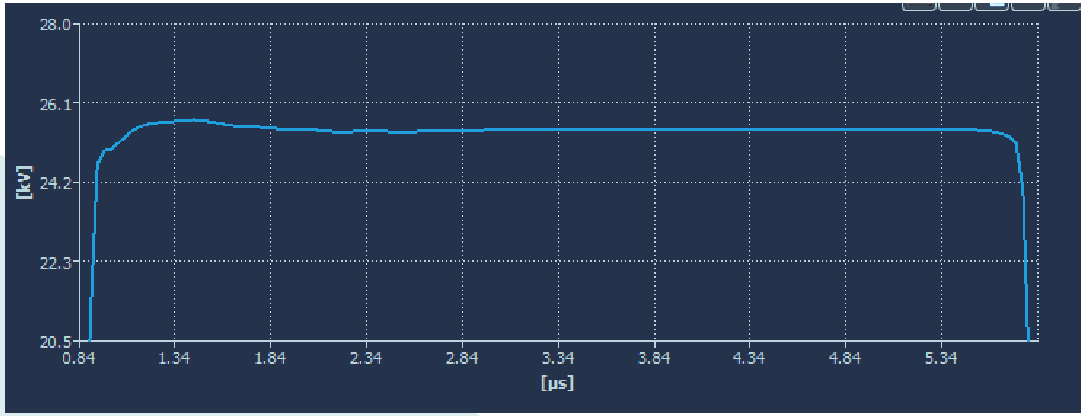
- RF signal analyzed to provide a virtual frequency correction (frequency is fixed for beam acceleration).
- This can be translated into a temperature correction to keep resonance of the cavity by changing water temperature.
- Via Modbus RTU communication protocol
- Tested standalone, ongoing work to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

✓ **Pulse shapes**

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

RFQ voltage (purple) during a test where cooling (white) was oscillating excessively. Once feedback control loop (cyan) was activated, stability improved.

Shape of the RF pulse in the RF network. Uncompensated.



LIGHT - LLRF features (2/2)

✓ **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.

✓ **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.

Highlights of Libera LLRF

- **Reliability**
  - Barely zero downtime related to LLRF units during beam commissioning in DIS

- **Configurability**
  - Many parameters and options to adjust the LLRF output / control. Possible to tailor it to the application needed.
  - Possibility to create routines easily and ease acceptance testing or calibration.

- **Graphical User Interface**
  - For testing purposes. It was quite handy before our control system was developed, allows to quickly see what you are doing and have the knobs one click away.

- **Support from I-tech**
  - Regular meetings > For updates on the project and purchases
  - Technical meetings > For specific questions, issues or ideas.
  - Email exchanges > Detailed descriptions supported by the LLRF documentation (>100 pages)

AVO-ADAM and I-tech collaboration continues for:

- Further improvement of the LLRF firmware
- Production spare-extra LLRF units

GIOVANNI DE MICHELE

HEAD OF RF GROUP & DEPUTY TECH. DIRECTOR (AVO-ADAM)

Instrumentation Technologies is a key supplier and an industrial partner providing the LLRF controls and BPM electronics for the LIGHT system. Via the Libera platforms, with ad-hoc features design, I-Tech has met the requirements of the LIGHT system. We are pleased to collaborate with such a professional, open and flexible team that has helped us enhance our customer experience.

Thank you very much !

Happy to take questions