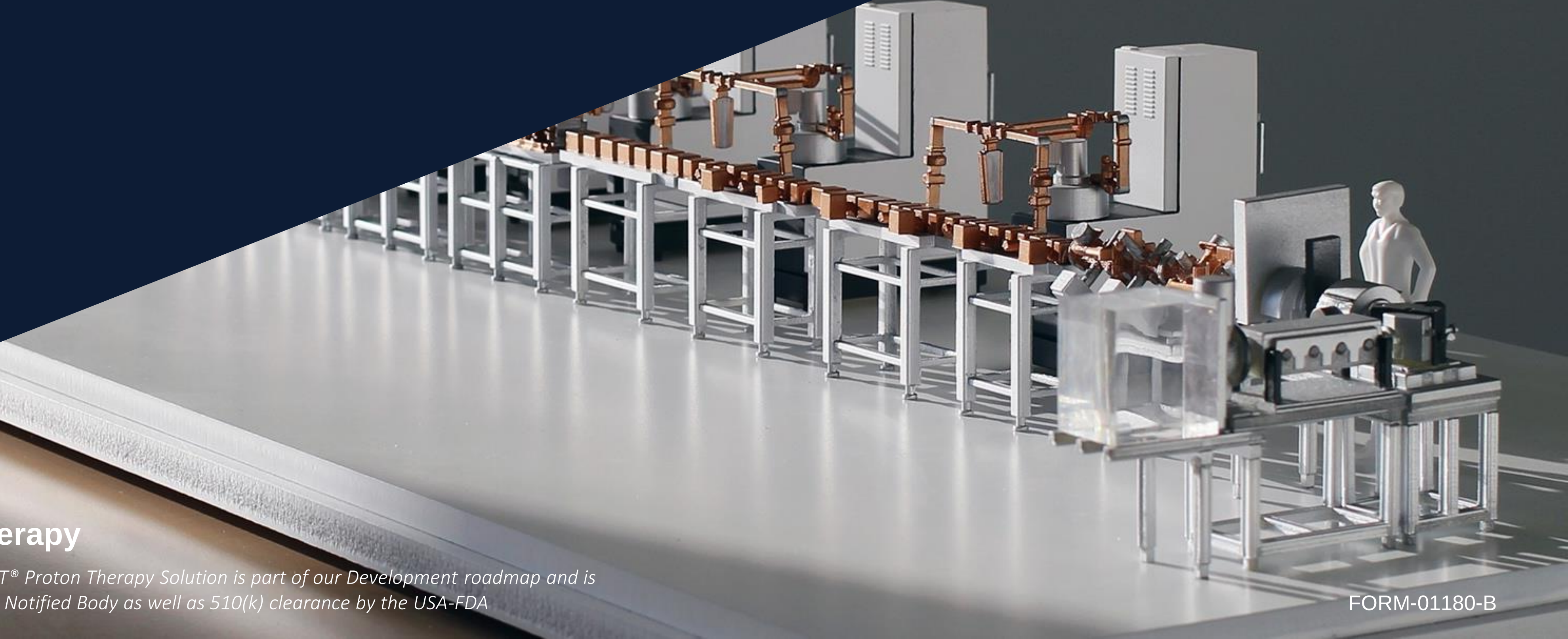
Operation and beam commissioning of LIGHT proton accelerator

Veliko Dimov

07/09/2022

Presented at UPHUK VIII

Bodrum, Turkey



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

Veliko Dimov = Veli Yildiz

CERN (2011-2016) Project associate, Fellow

- **Linac 4 project**
  - Beam dynamics
  - Linac4 beam commissioning
- **HF-RFQ project (750 MHz proton RFQ)**
  - Beam dynamics design

AVO-ADAM (2017 - present)

- **Physics group,** Deputy group leader
  - Leading 2 beam physicists, 6 accelerator operators
- **Accelerator run coordinator**
  - Coordinate operation activities
  - Lead beam commissioning of the linac

Source: uk-cpi.com

AVO-ADAM

1. Headquarters (Advanced Oncotherapy plc)

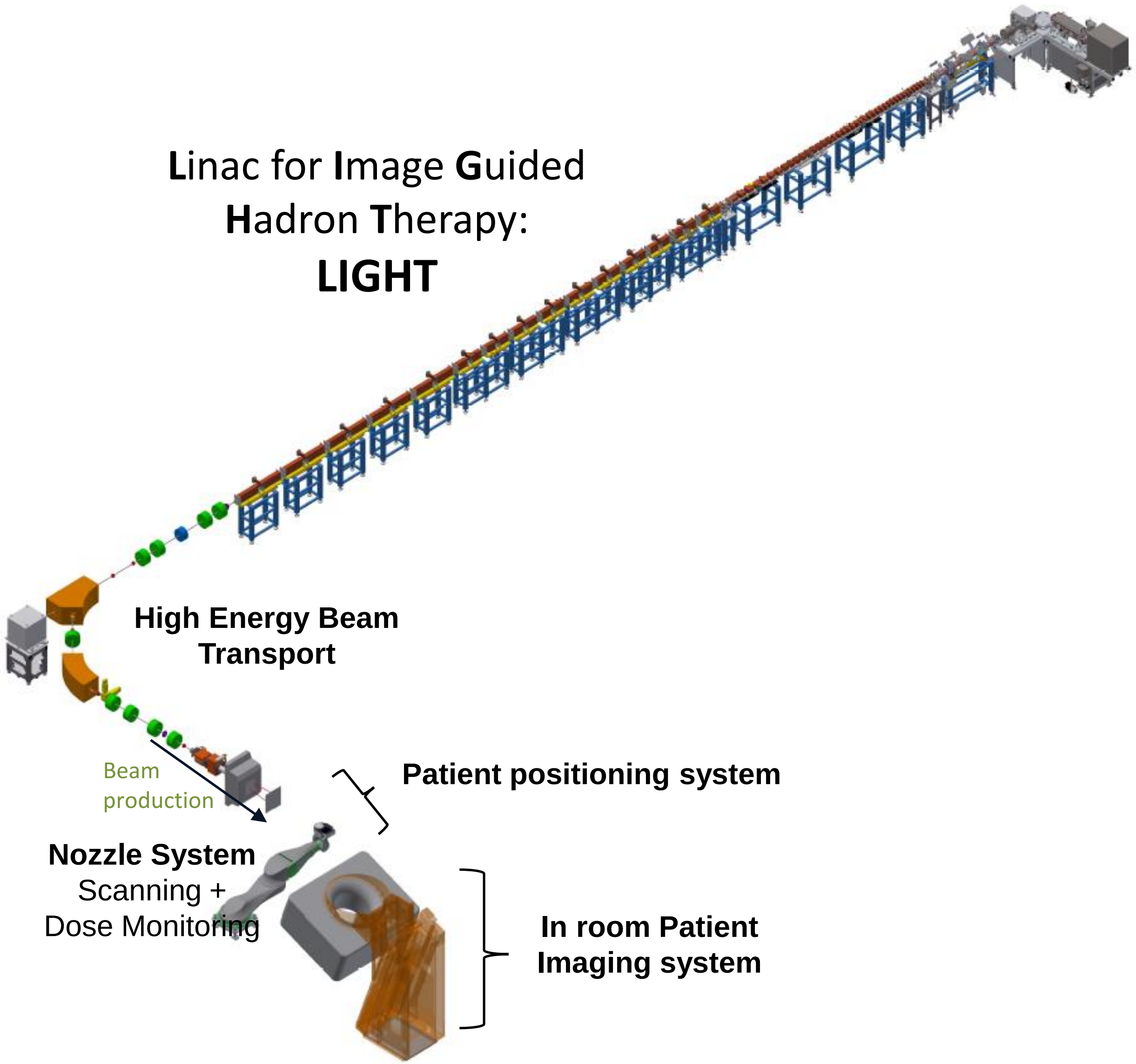
2. ADAM SA (R&D Facility)

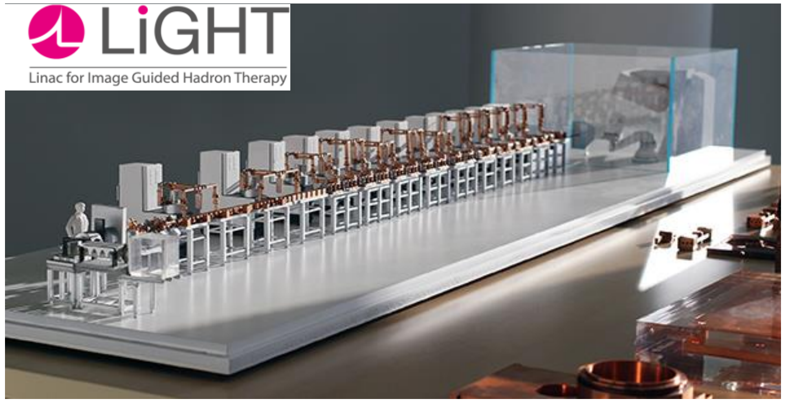
3. Testing and Assembly Site (STFC Daresbury Laboratory)

Other offices in Netherlands and USA.

https://www.avoplc.com/en-gb/

Proton therapy system based on linac technology



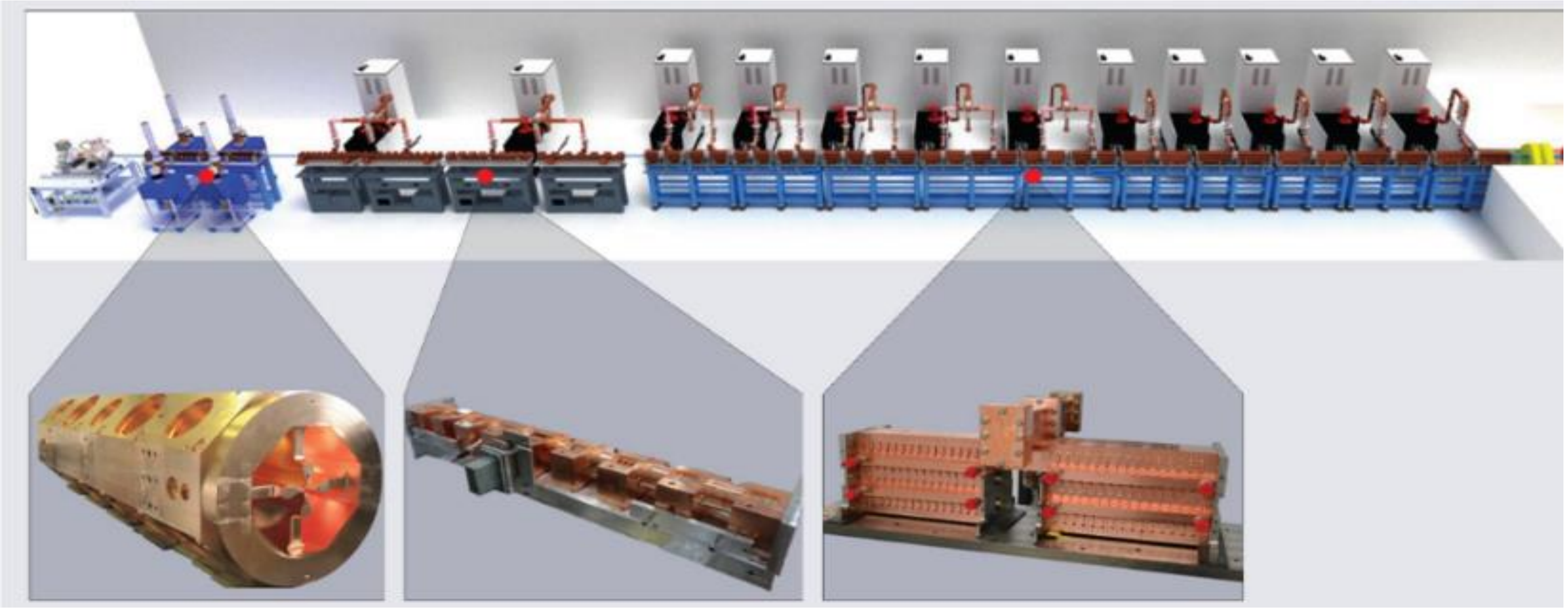


Parameter	Value	Unit
Length	~25	m
Max. Energy	230	MeV
Output Peak Current	40	µA
Pulse Length	0.5 - 2	µs
RF Frequency	2997.92	MHz
Max. Repetition Rate	200	Hz

Pulse to pulse intensity and energy modulation!
Only PMQs in the linac.

https://www.avoplc.com/en-gb/Technology/Overview-of-the-LIGHT-System

LIGHT accelerating structures



RFQ: Radio-Frequency Quadrupole

- **CERN-ADAM** (2013-2015)
- 1st prototype, world record highest frequency RFQ
- Industrialization: **AVO-ADAM**

SCDTL: Side Coupled Drift Tube Linac

- **ENEA** concept (Picardi et al. 1996)
- Tested with beam in ENEA Frascati (IMPLART project) since 2011
- Industrialization: **AVO-ADAM**
- Mass production: **AVO-ADAM**

CCL: Coupled Cavity Linac

- **TERA-CERN-INFN** concept (LIBO, 1998-2000)
- Tested **with beam** in Catania in 2002
- Industrial design: **ADAM** (first Unit, 2010)
- Mass production: **AVO-ADAM**

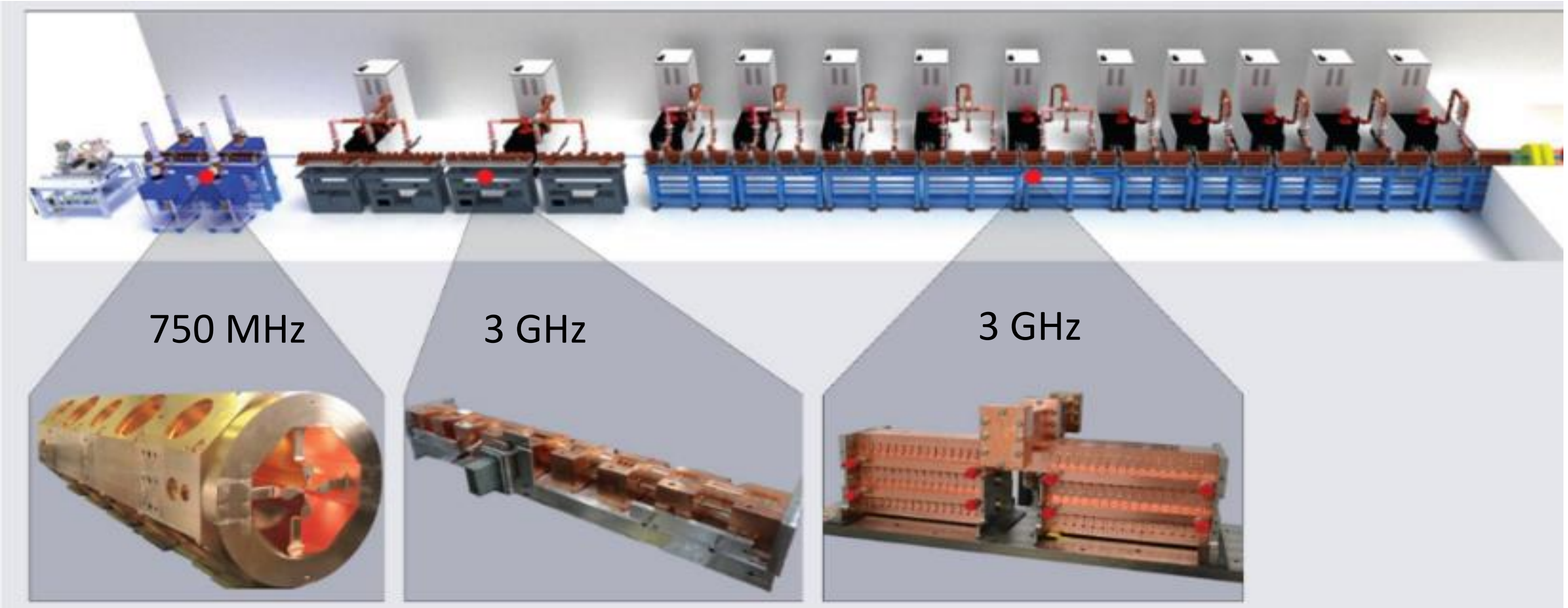
High frequency for protons: advantageous but challenging

High Frequency

- higher energy gain in a shorter distance
- Smaller size

- Smaller size→ smaller beam aperture
- Tighter production and alignment tolerances

Largest beam aperture in the linac (radius) < 3 mm



Industrial product satisfying medical standards. How?

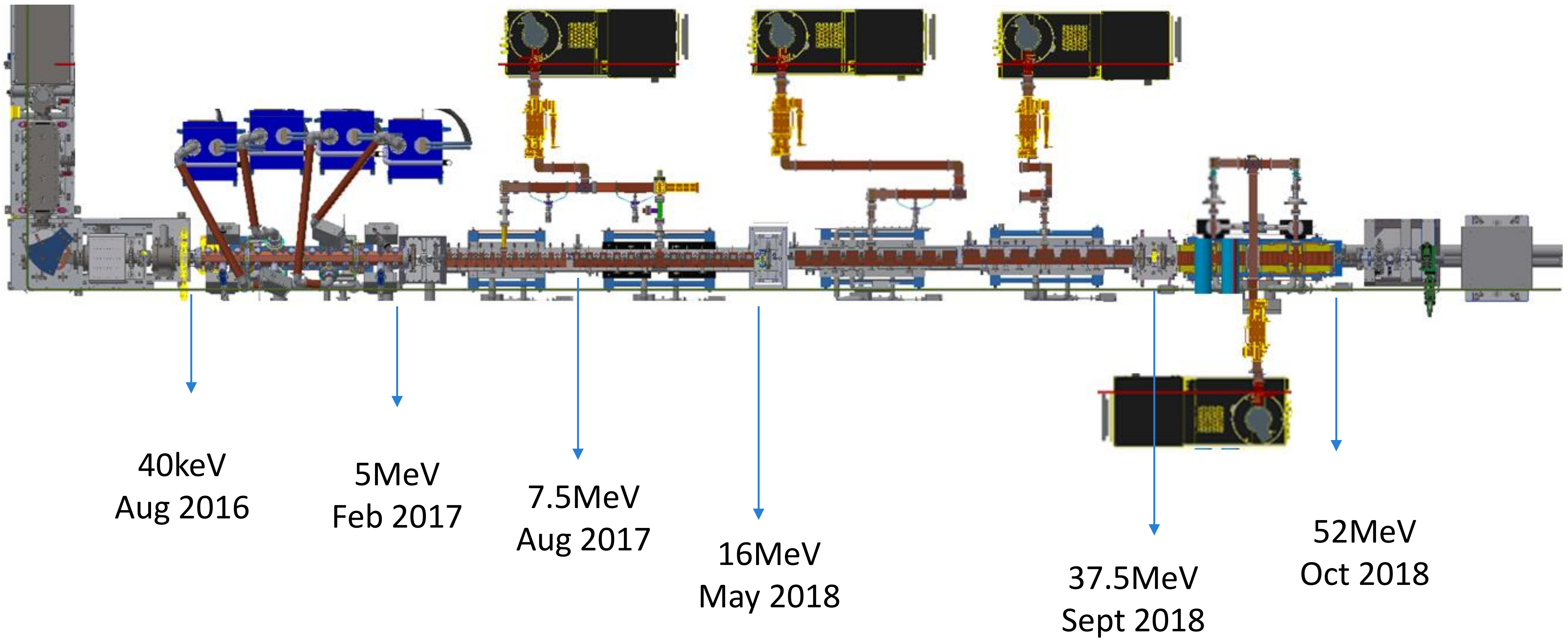
- **Few important steps:**
  - Technology Feasibility Studies (2016-2019 in Geneva, Switzerland))
  - Product Design & Development
  - Ongoing product Integration and V&V (2020-present in Daresbury, UK): Beam Production System + Medical Treatment area

- **Teamwork:**
  - Expertise in AVO-ADAM in accelerator related technologies:
    - Beam physics, RF, beam diagnostics, high power electronics, vacuum, cooling, mechanical engineering, control system and software engineering…

80+ people working on design, development, installation and testing

Feasibility study and demonstration of the technology

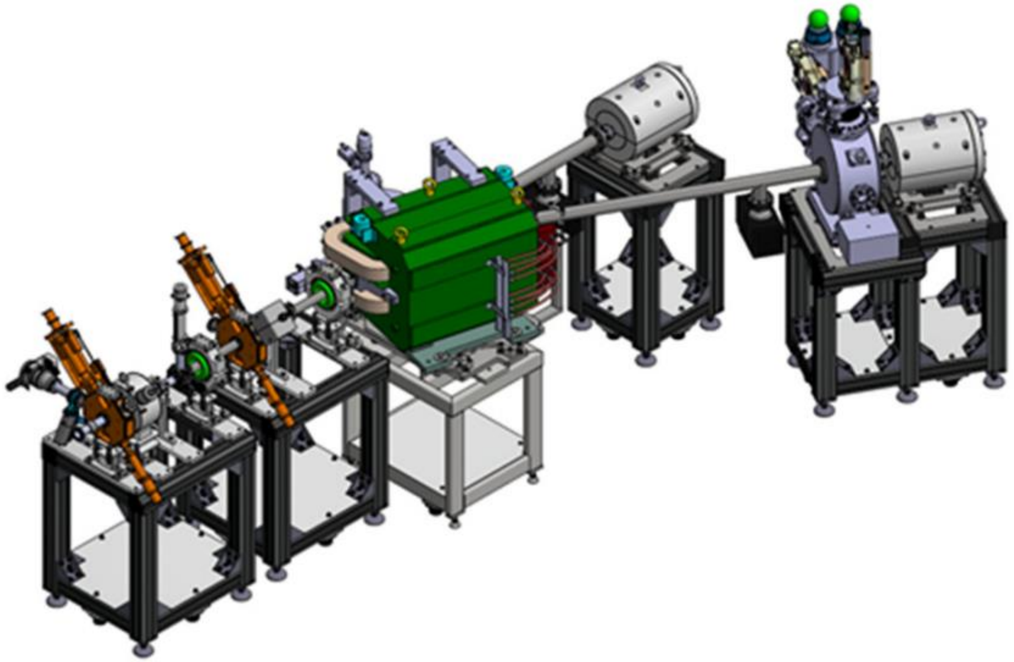
- Demonstration of proton beam acceleration with all three types of accelerating structures up to 52 MeV.
- In Geneva at a CERN site.



http://accelconf.web.cern.ch/AccelConf/ipac2018/papers/tupaf002.pdf

http://linac2018.vrws.de/papers/tupo013.pdf

Movable diagnostic test bench for beam commissioning



Movable diagnostics test bench used in Geneva
Above 5 MeV, a test bench similar to the one above was used.

Design might change as the energy increases.

- Direct emittance measurement vs. indirect emittance measurement
- With or without spectrometer.
- Type of measurement devices (ex: FC, ACT)

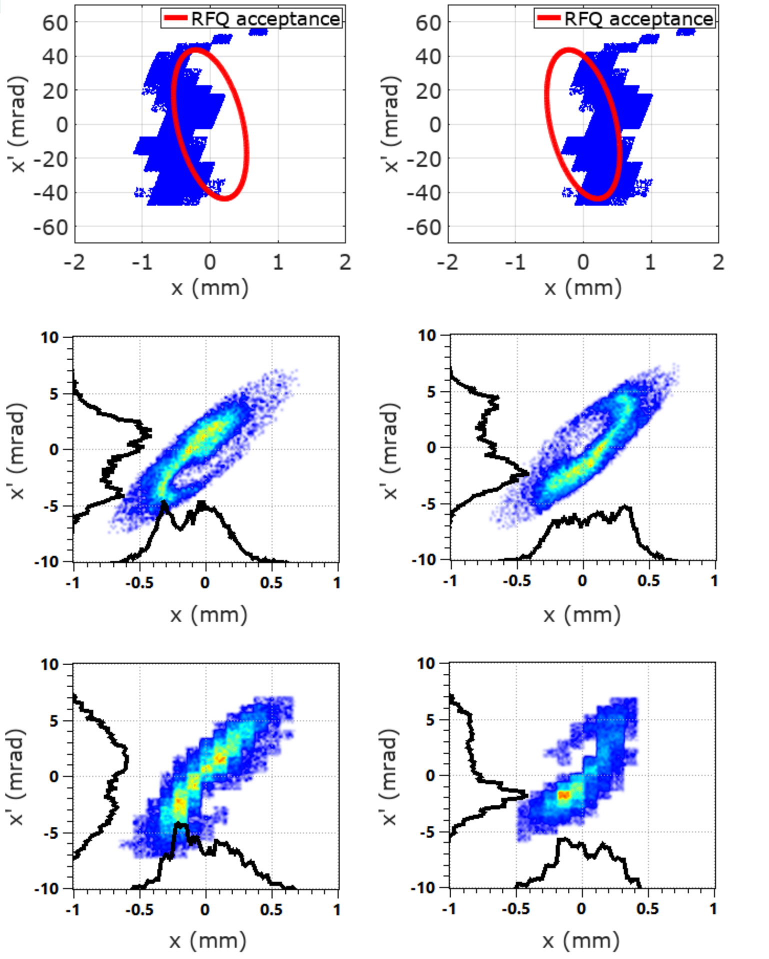
For the commissioning of the structures and characterization of the beam properties.

- Beam intensity (FC, ACT)
- Energy with Time of Flight (ToF) and spectrometer
- Transverse beam profile 1D, or 2D spot size
- Transverse beam emittance
- Beam position
- Energy spread

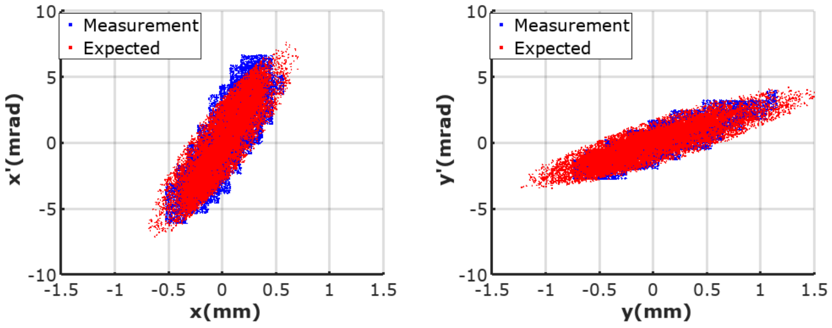
http://accelconf.web.cern.ch/AccelConf/ipac2018/papers/wepaf001.pdf

http://accelconf.web.cern.ch/AccelConf/ipac2018/papers/mopml014.pdf

Few example results from beam commissioning in Geneva

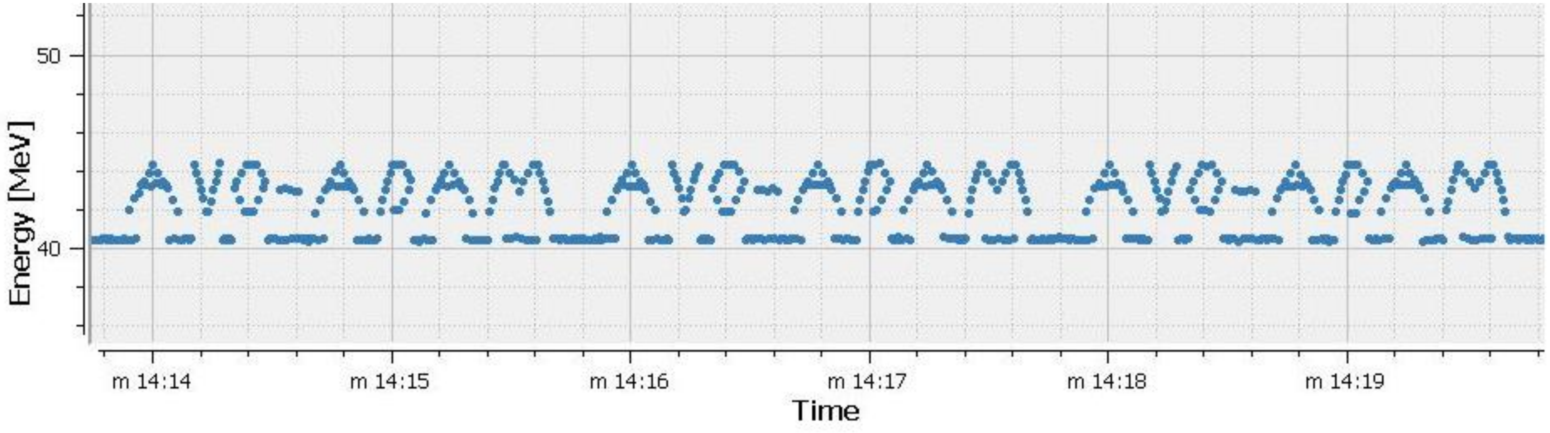


Horizontal phase space plots of the RFQ input beam when steered in the negative and positive x directions (first row), expected (second row) and the measured (third row) phase space plots after the RFQ for each case.



After RFQ Measured (blue) Simulated(red) transverse emittance (for a centered input beam)

Demonstration of pulse to pulse energy modulation (@100Hz rep. rate)

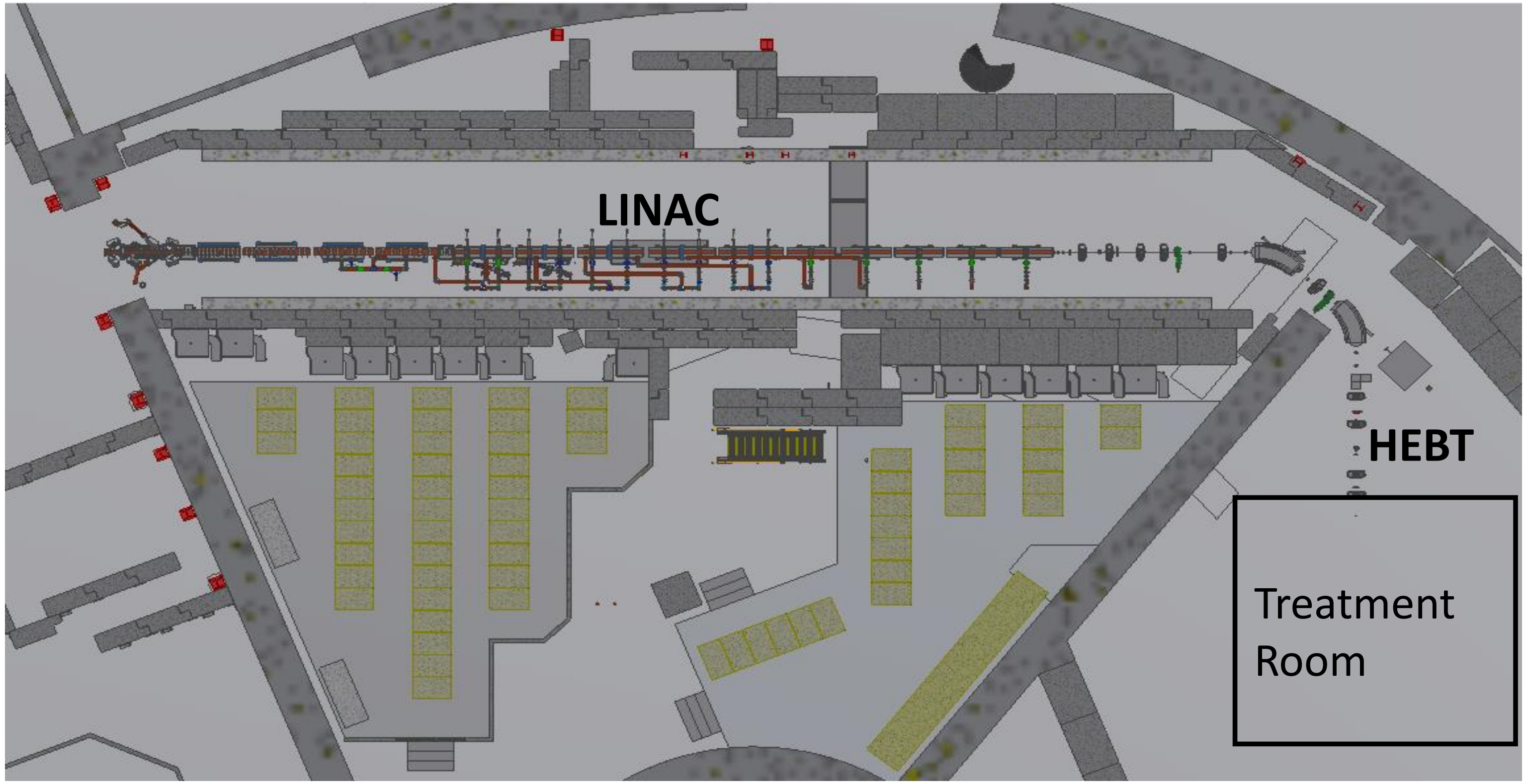


http://accelconf.web.cern.ch/AccelConf/ipac2018/papers/tupaf002.pdf

Integration and testing of the full system in Daresbury, UK

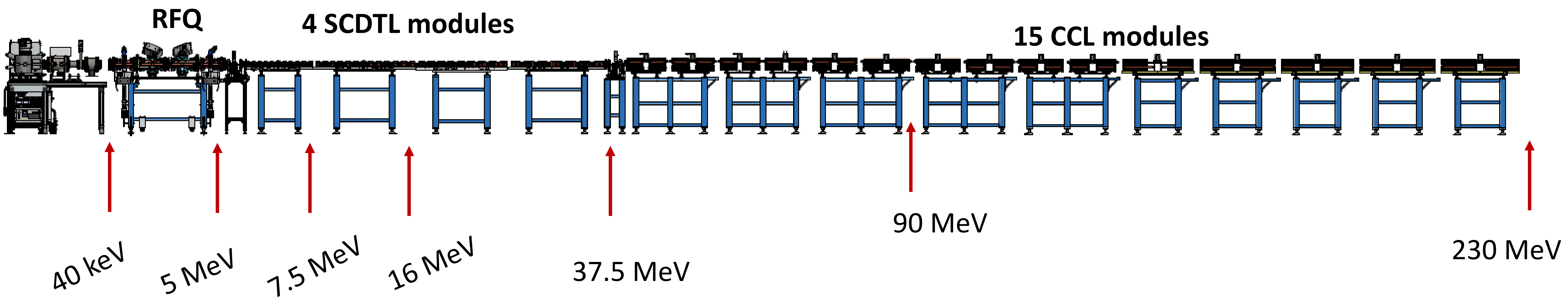
STFC Daresbury laboratory, Daresbury

Science & Technology Facilities Council



Status of the integration and testing in Daresbury, UK

As of today, all accelerating modules are installed.
Beam commissioning up to 90 MeV was completed in July 2022.
Beam commissioning of the complete linac will start beginning of October 2022.



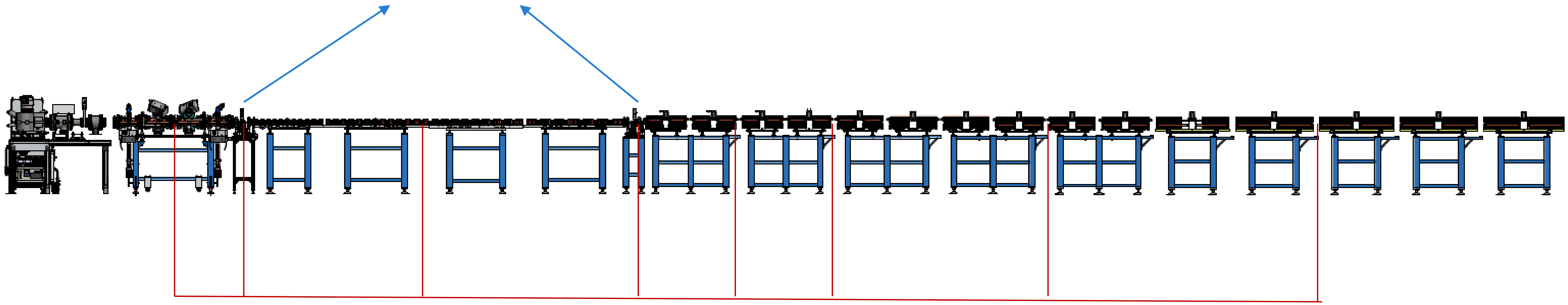
- Commissioning phases using movable test benches.
- Linac commissioning is being performed with a temporary version of the proton injector. It will be upgraded in 2023.

Permanent diagnostic devices

MEBT1 and MEBT2

- Steering magnets
- AC current transformer
- Beam position monitor

- Monitoring the beam for operation
- Reoptimization of the accelerator parameters



Phase measurement system using BPMs and Phase probes
Measures beam phase, energy (time of flight)

Main targets of Commissioning phases

- Machine optimization
  - RF cavity parameters, steering…
  - Scanning machine parameters to maximize beam performance.

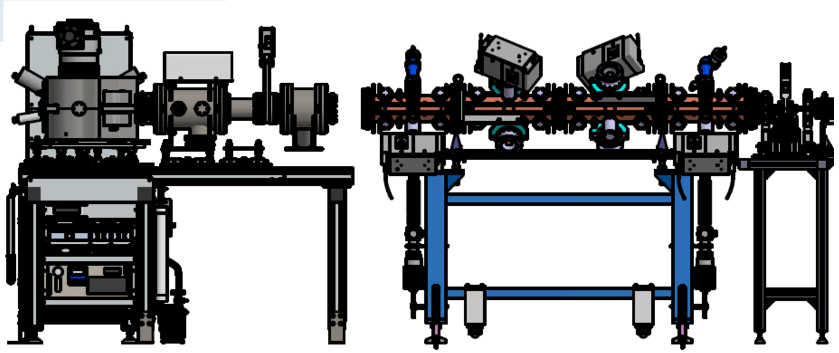
- Understanding the machine behavior (measurements + simulations)
  - Do the cavities work as designed?

- Validating the strategy for recommissioning (with minimal beam diagnostics)
  - How can we use permanent diagnostic devices to reoptimize the accelerator?

- Performing regular Machine QA.
  - Measuring and recording machine and beam parameters multiple times a day.

- Reference measurements
  - Characterizing the beam parameters before the end of operation

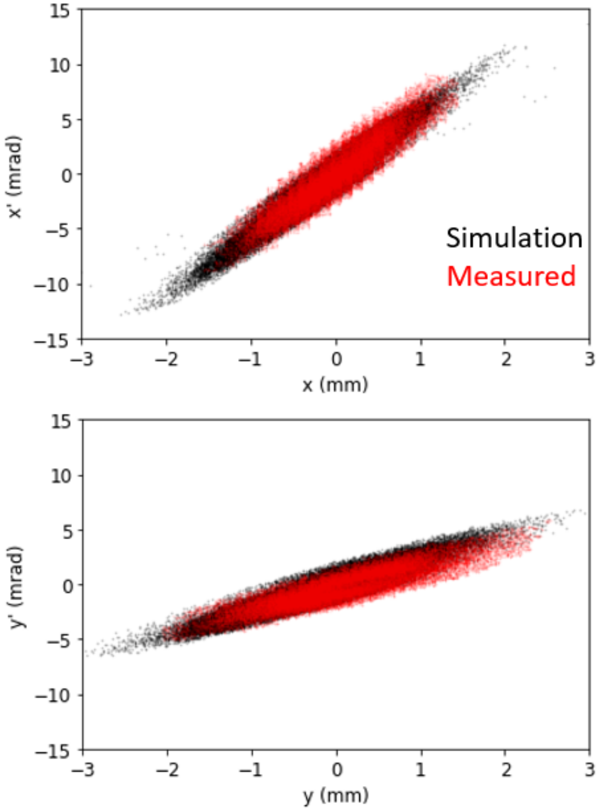
RFQ commissioning (Daresbury)



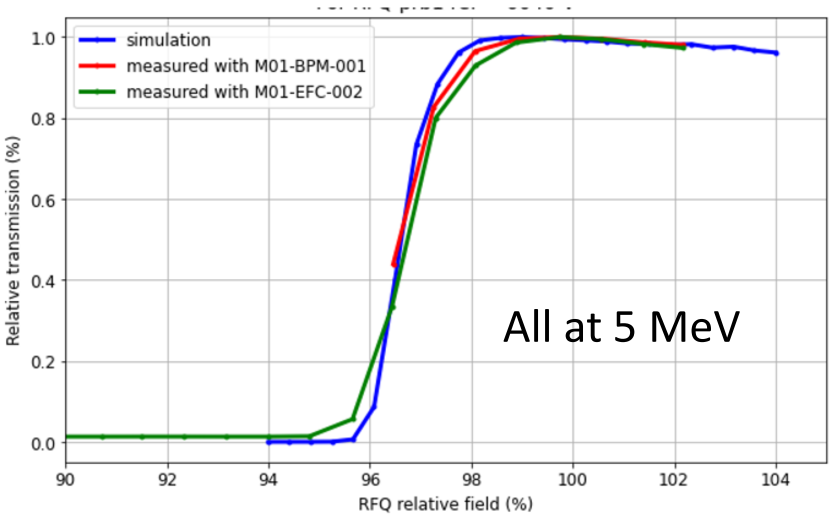
Proton injector RFQ MEBT1

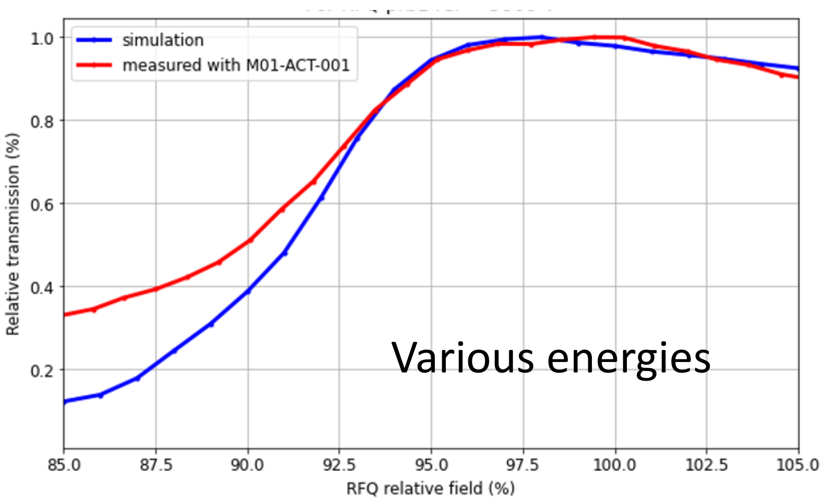
Test bench with spectrometer

Measured at the test bench
Direct transverse emittance using slit-slit-FC



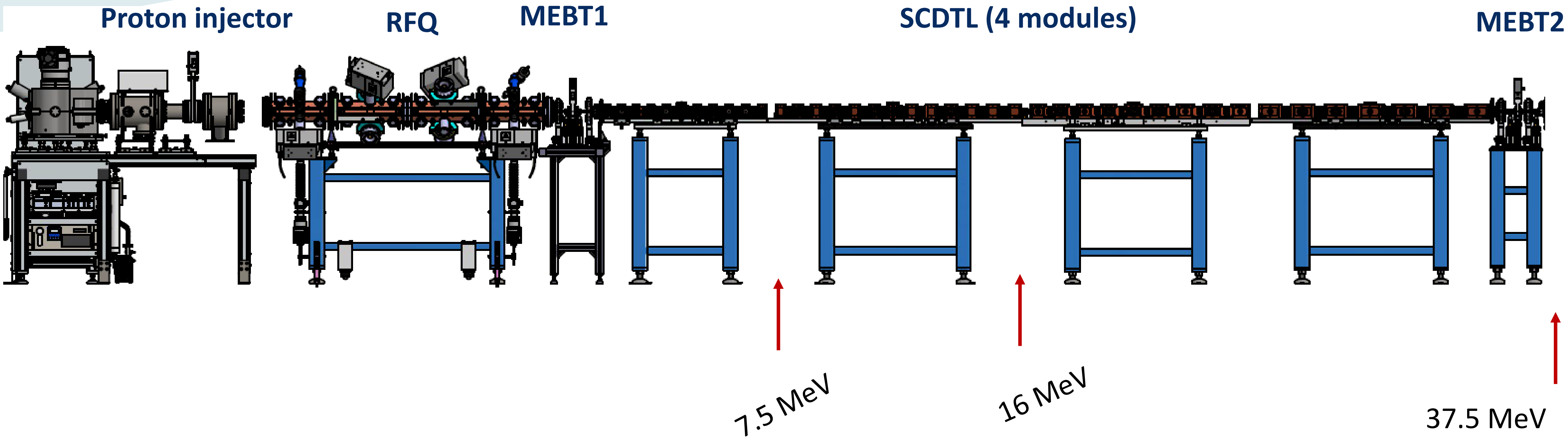
Characteristic curve of transmission measured at different locations





For future reoptimization: MEBT1 BPM.
(sensitive to only bunched beam, doesn't measure the unaccelerated particles)

SCDTL commissioning (Daresbury)



The same movable test bench was used for RFQ and SCDTL beam commissioning.

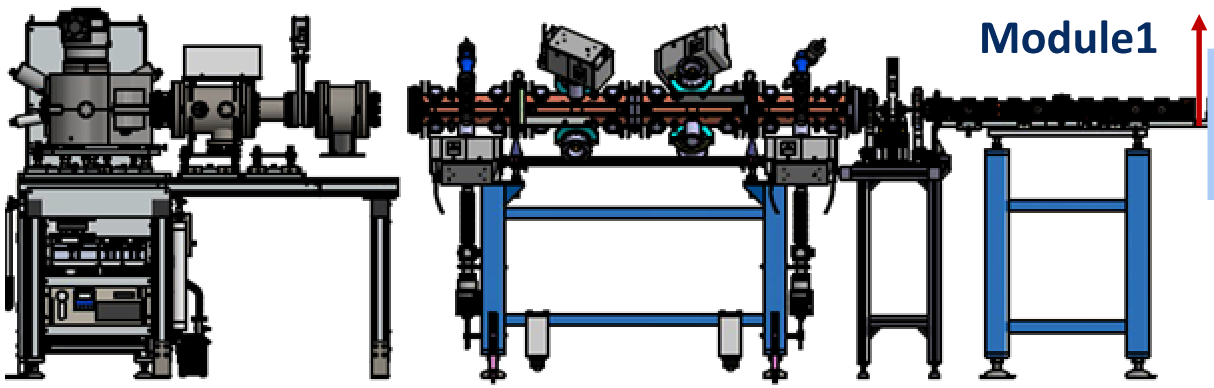
- Beam intensity (FC)
- Direct transverse emittance (Slit-Slit-FC)
- Energy with ToF and spectrometer
- Transverse beam profile
- Beam position

~ 40 PMQs for transverse focusing.

SCDTL commissioning (Daresbury)

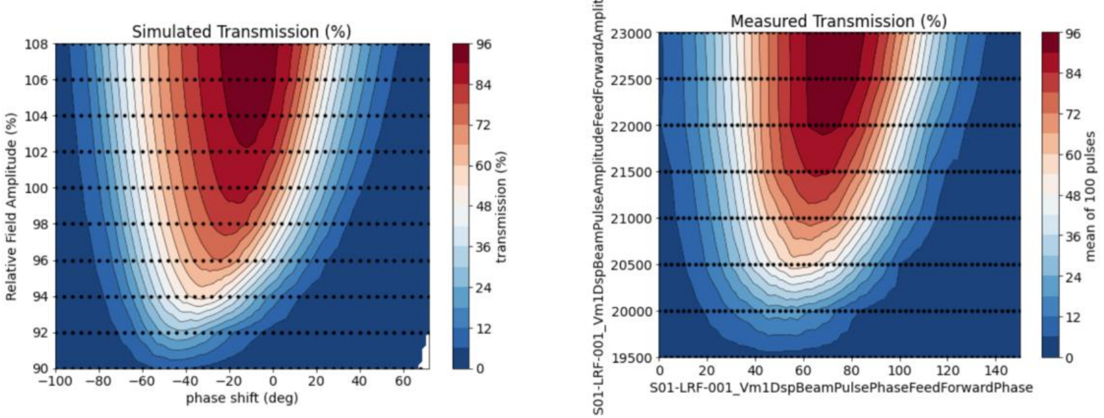
Proton injector **RFQ** **MEBT1** **SCDTL Module1**

7.5 MeV

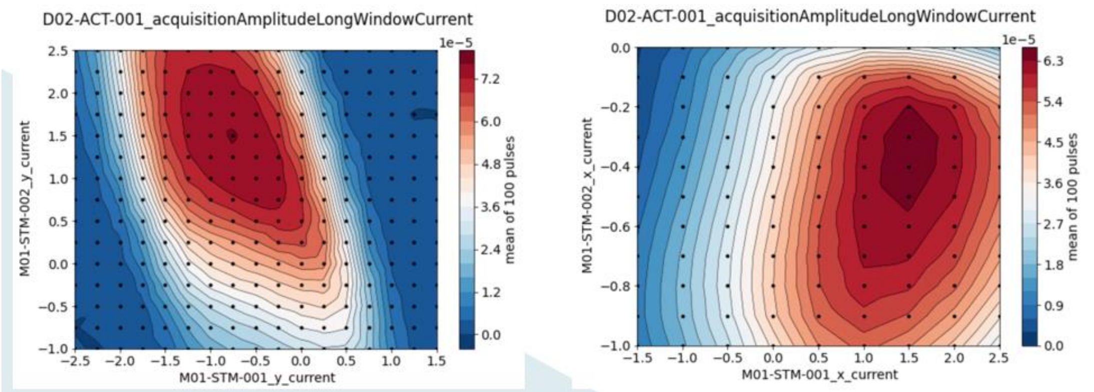


Test bench with spectrometer

Signature of the cavity on beam transmission

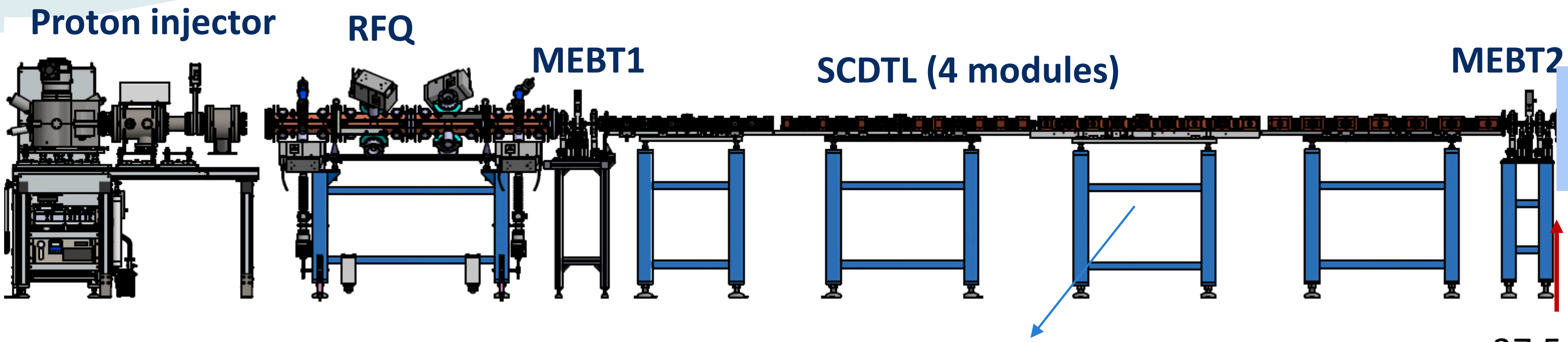


Scanning rf phase and amplitude to find the optimum setting for operation.



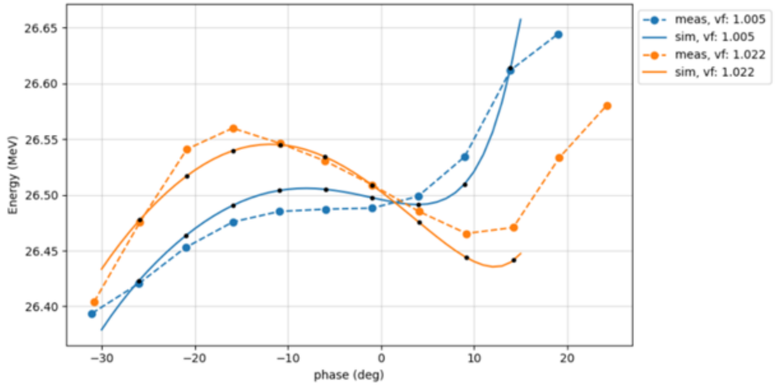
2D scan of the MEBT1 steering magnets to find the best setting.

SCDTL commissioning (Daresbury)

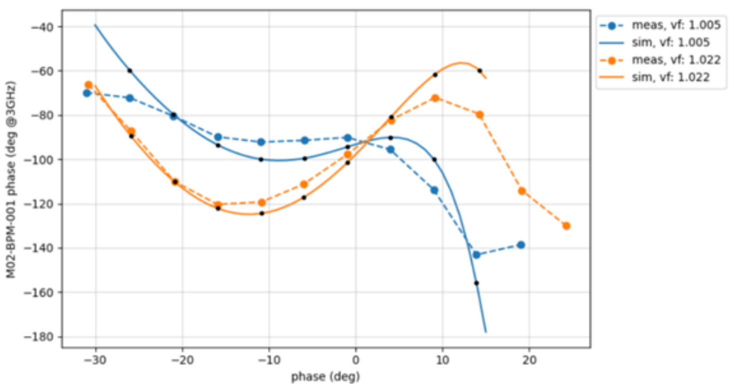


Test bench with spectrometer

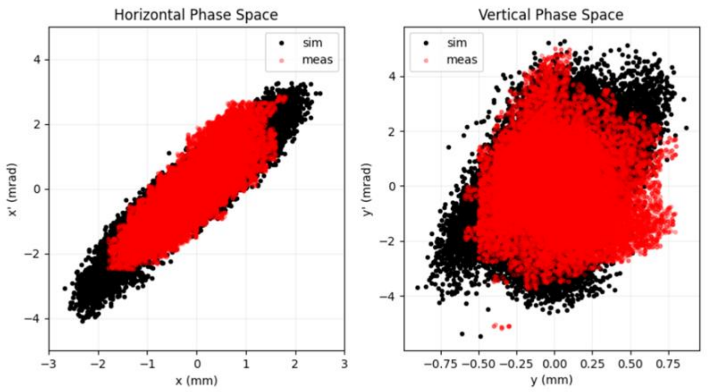
Can we use only phase measurement system for reoptimization?



Measured in testbench ToF

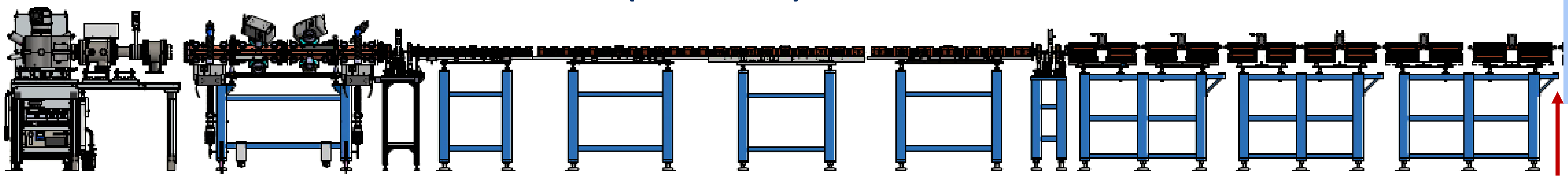


Measured at MEBT2



Direct transverse emittance at 37.5 MeV
Slit-slit-FC

CCL commissioning (Daresbury) (up to 90 MeV)

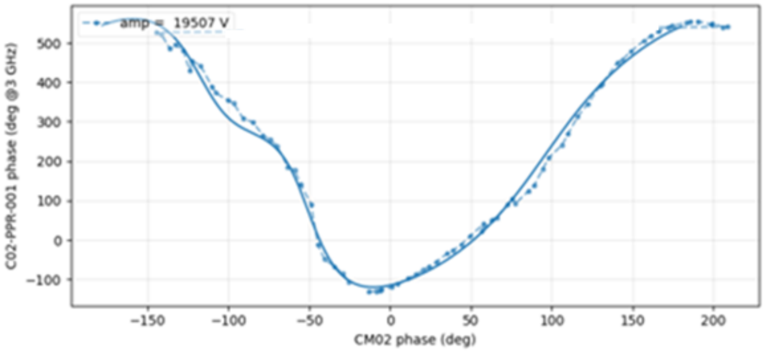


Test bench without spectrometer

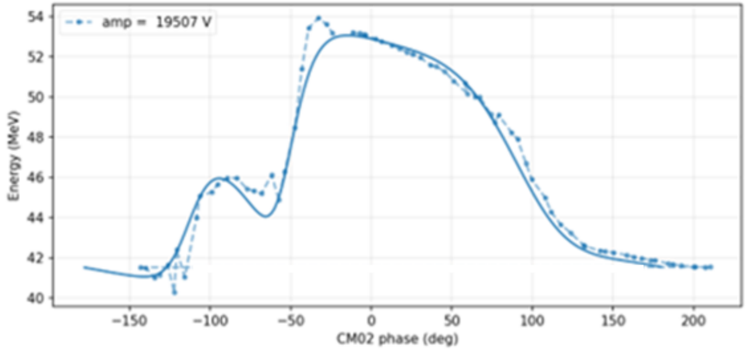
90 MeV
~ 45 uA beam

Switch on cavities one by one and use signature matching to find the operating phase and amplitude of the cavities

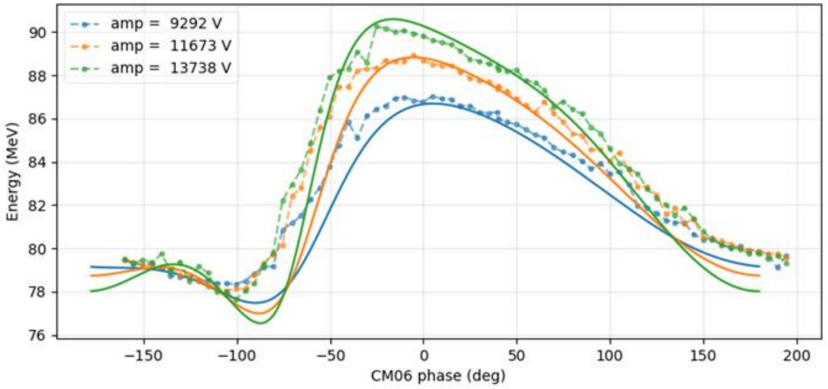
Signature matching with beam phase and beam energy.



Phase measurement system



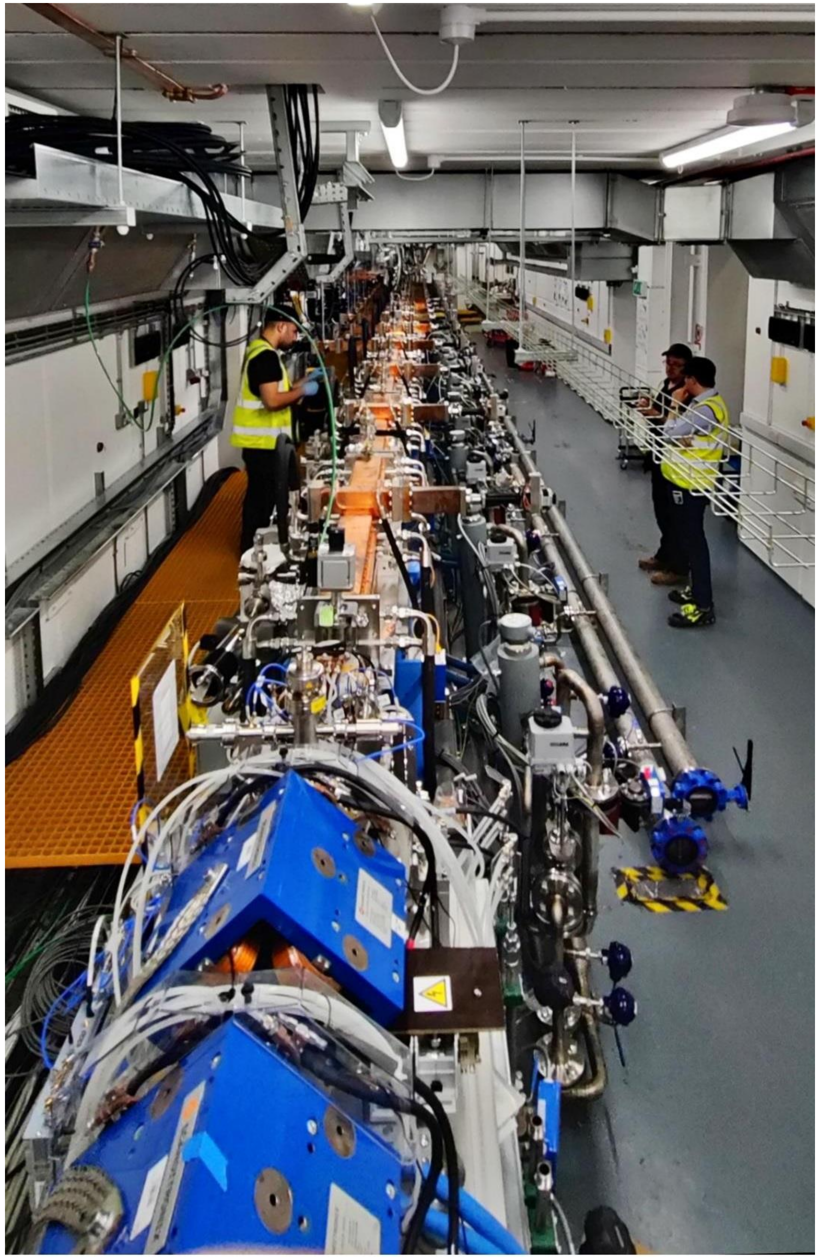
Time of flight



Scan of CCL module 6
Measuring the energy with ToF

Next steps

- All accelerating modules are installed.
- Component tests are ongoing, integration dry-run tests are about to start
- Beam commissioning of the full linac to reach 230 MeV will start soon after.
- In 2023, commissioning of the High Energy Beam Transfer line
- Medical tests in the treatment room.
- Patient treatment after certification.



Conclusion

- Back in 2018 AVO-ADAM demonstrated the acceleration of proton beam up to 52 MeV using a full linac (high frequency) solution in Geneva.
- First Beam Production System for medical purposes is being built and commissioned in the UK.
- 90 MeV commissioning was already successfully completed in July 2022.
- Beam commissioning of full beam (230 MeV) will follow the dry-run that is about to start.
- In 2023, commissioning of the High Energy Beam Transfer line will be performed.
- Patient treatment is foreseen in Daresbury after medical tests and certification.

Thank you!