ACCELERATOR CHALLENGES AT EUROPEAN SPALLATION SOURCE (ESS)

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for the ESS project

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HB2023, CERN

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ESS

Finding a home

- License:
  - Acquiring an environmental license
  - Acquiring radiation licenses for the facility

- Water:
  - How clean are the tap water pipes?

- Archeology
  - We created the largest ever archeological site in Sweden for a while

- Green field
  - Both an opportunity to make everything right and a challenge not to seek perfection

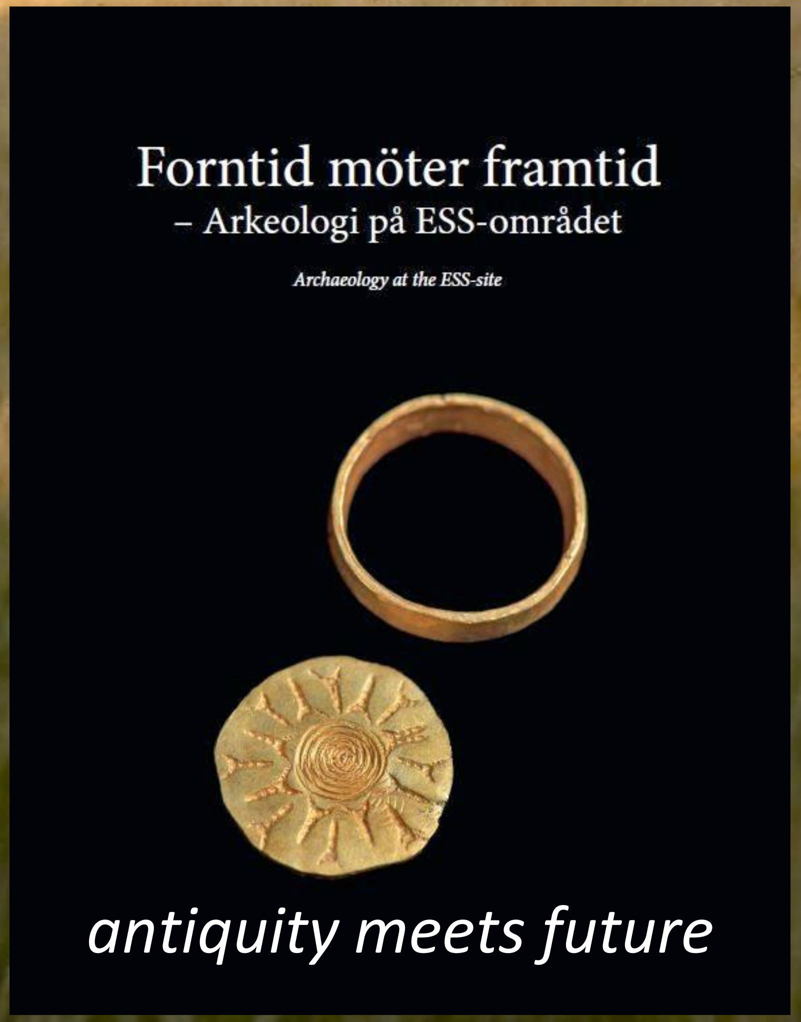


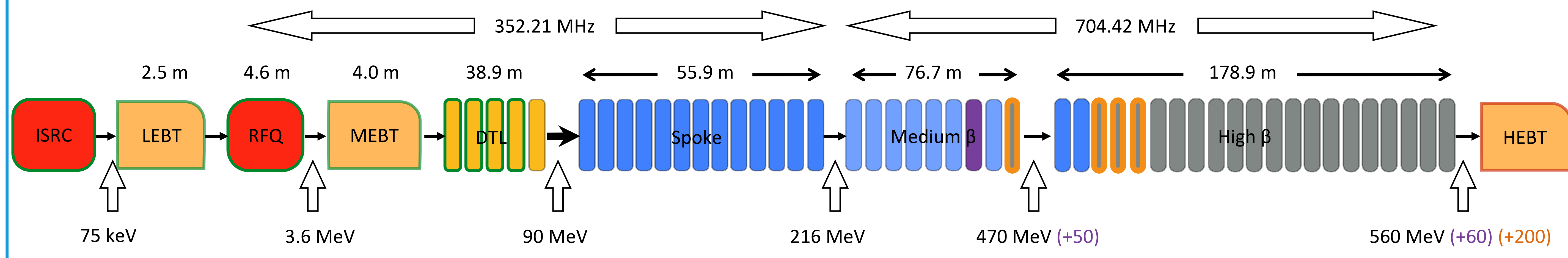
Photo: Caroline Prabert (2010 July)

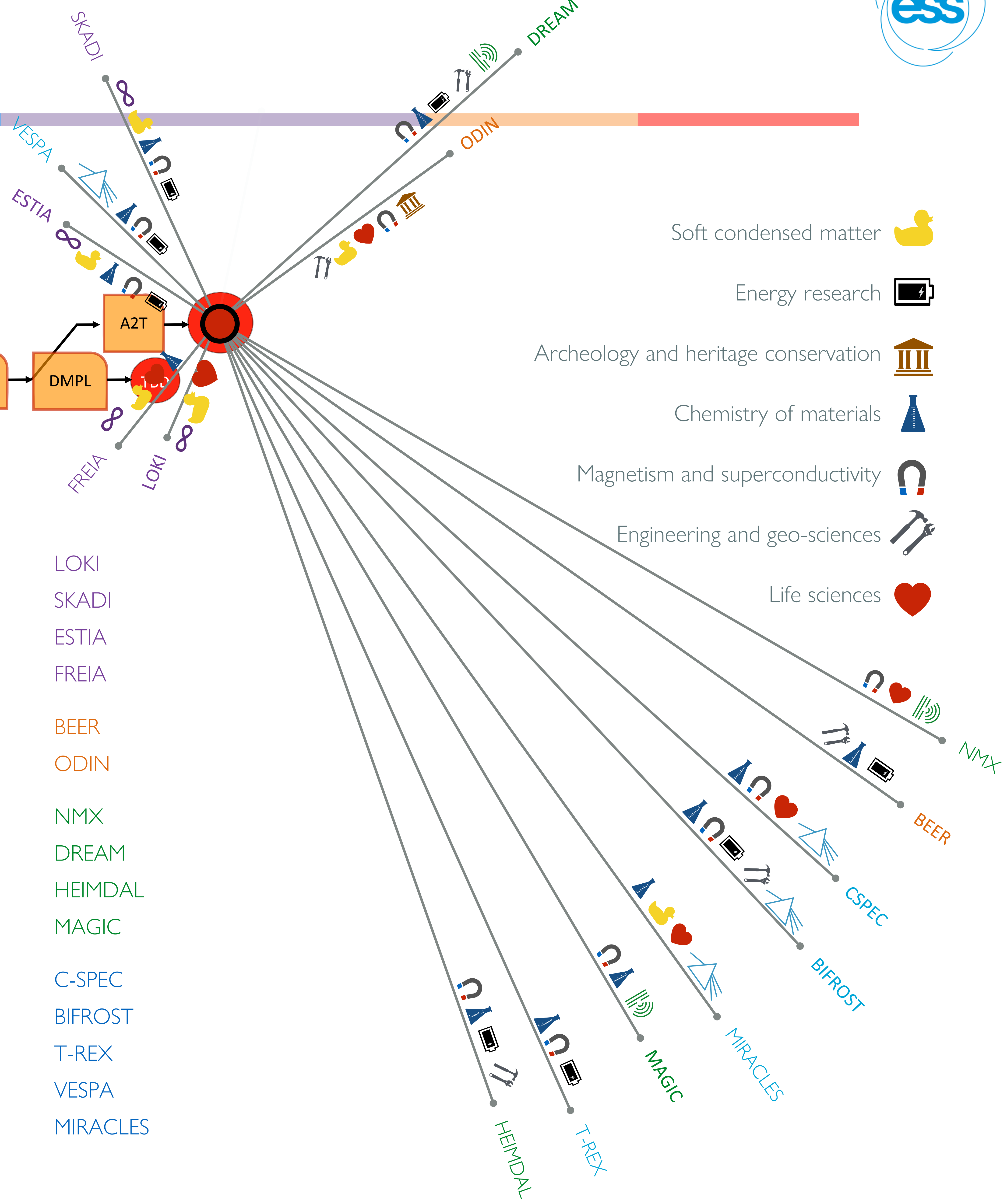
ESS

AND MAX IV IN ONE FRAME

ESS

Most of it in one slide





Linac

Energy	2.0 GeV
Current	62.5 mA
Repetition rate	14 Hz
Pulse length	2.86 ms
Losses	<1W/m
Ions	p

Flexible/Upgradable design

Minimize energy consumption

Controls

Control variables.	~1.6E6 PVs
MPS and PSS	
EPICS7	
µTCA.4	

Rotating tungsten target

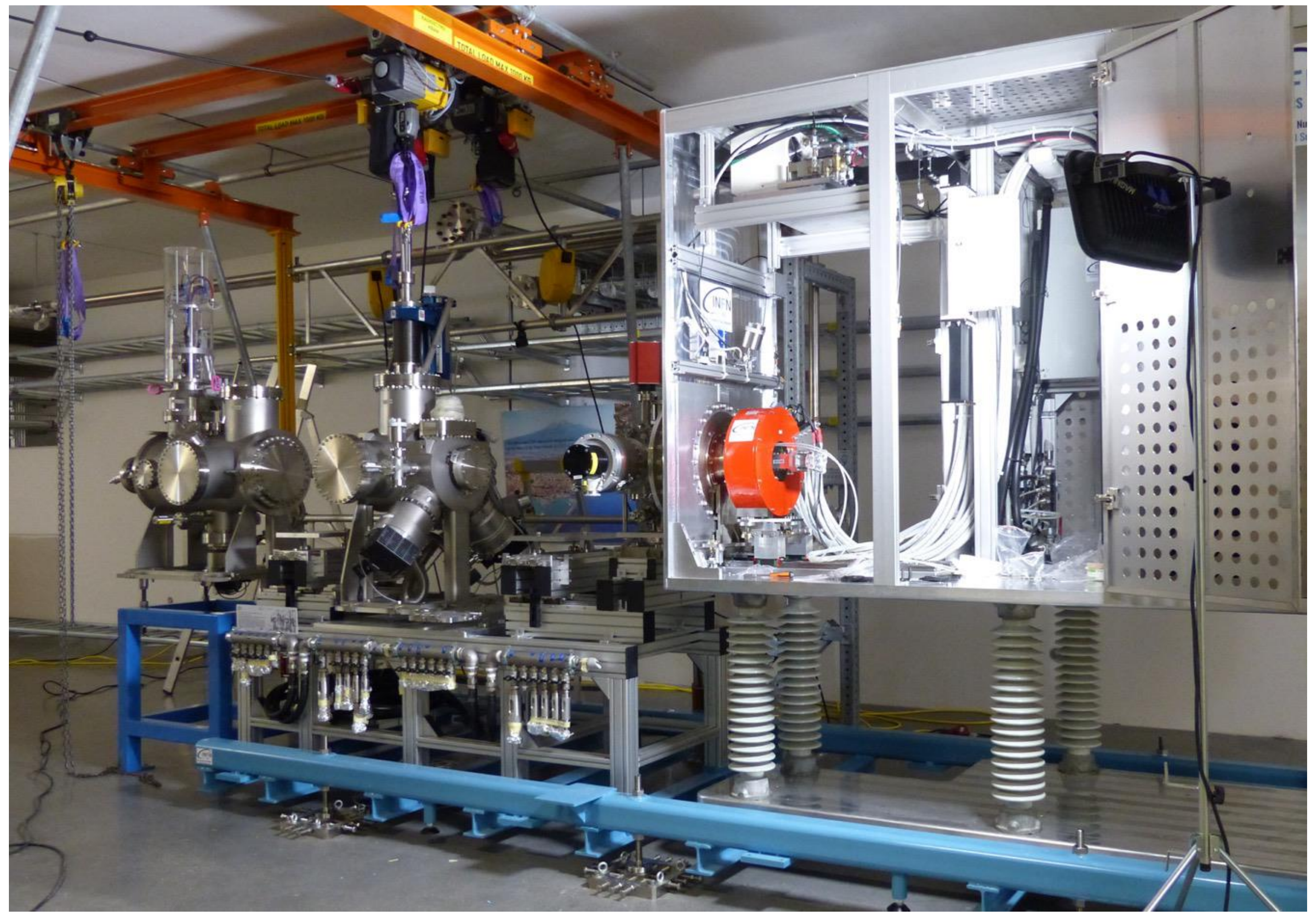
Target diameter	2.6 (0.45) m
Mass	11 (3) tons
	36 sectors
Rev. freq.	~0.4 Hz
Expected lifetime	5 years
Cooling	He gas
Beam ports	42
Peak flux	~30-100 x ILL
Cold moderator	Liquid H_2
	17 K
	30 mm
Thermal moderator	H_2O
	300 K
	30 mm

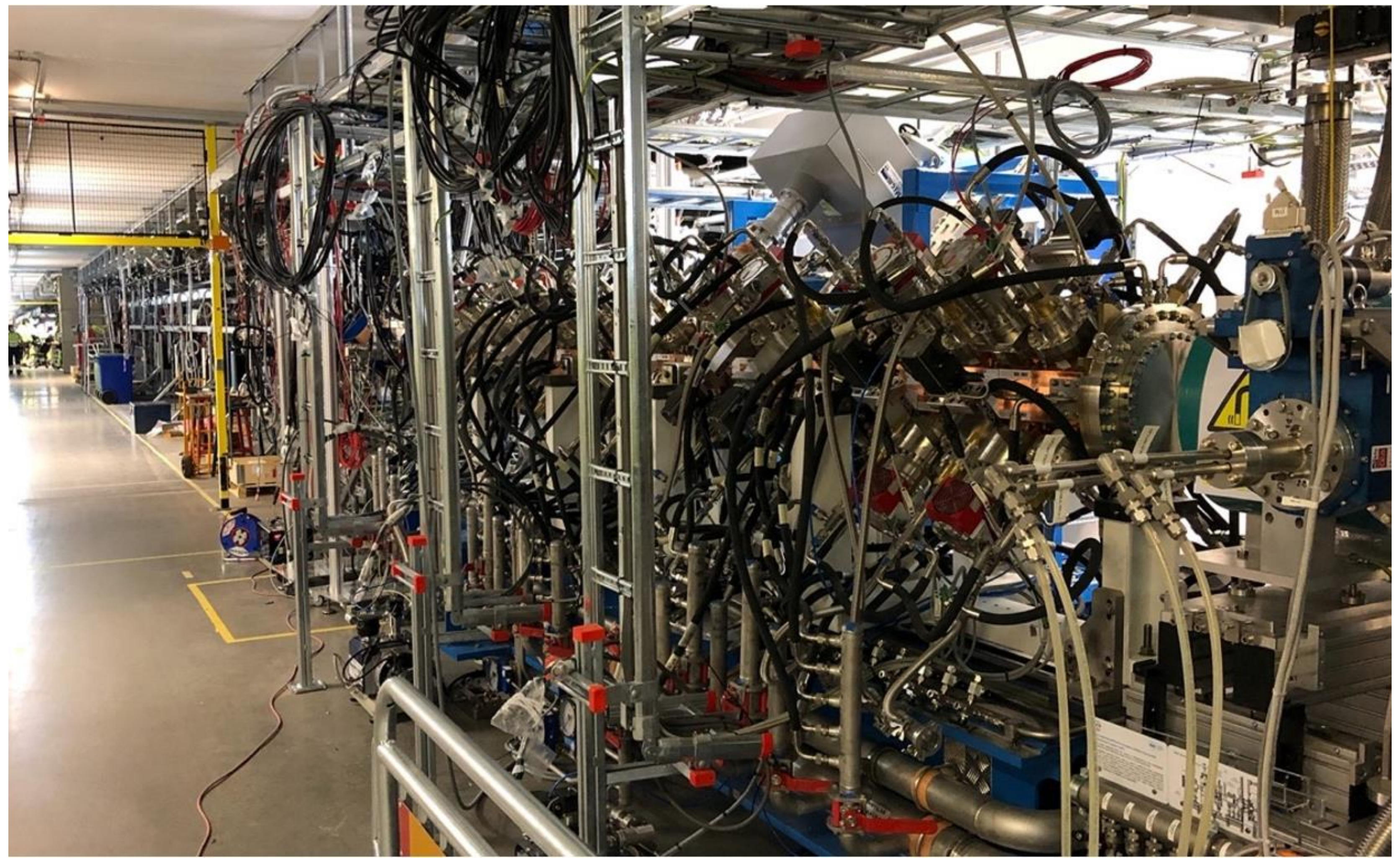
Instruments

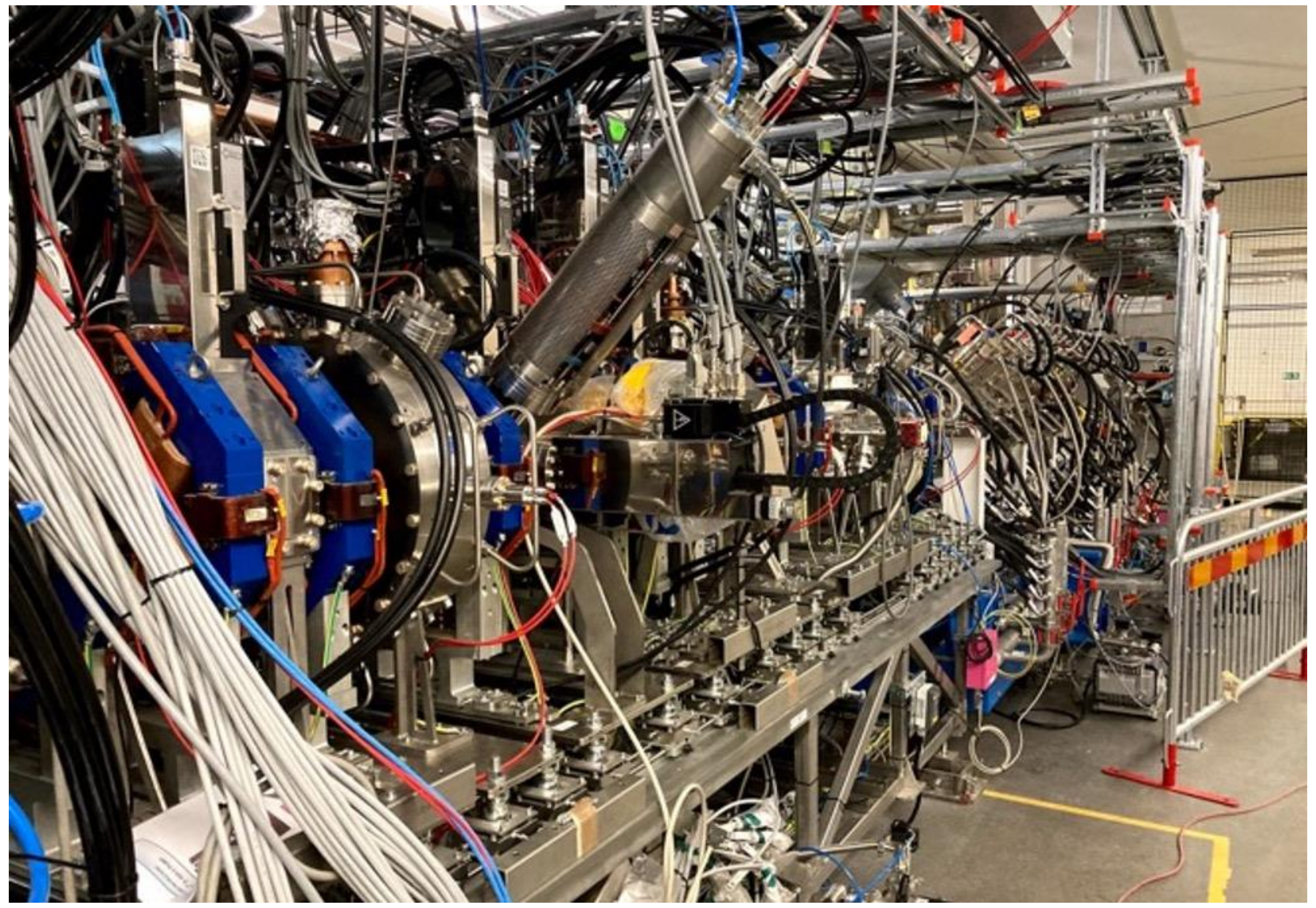
∞ Large Scale Structures	LOKI SKADI ESTIA FREIA
Engineering	BEER ODIN
Diffraction	NMX DREAM HEIMDAL MAGIC
Spectroscopy	C-SPEC BIFROST T-REX VESPA MIRACLES

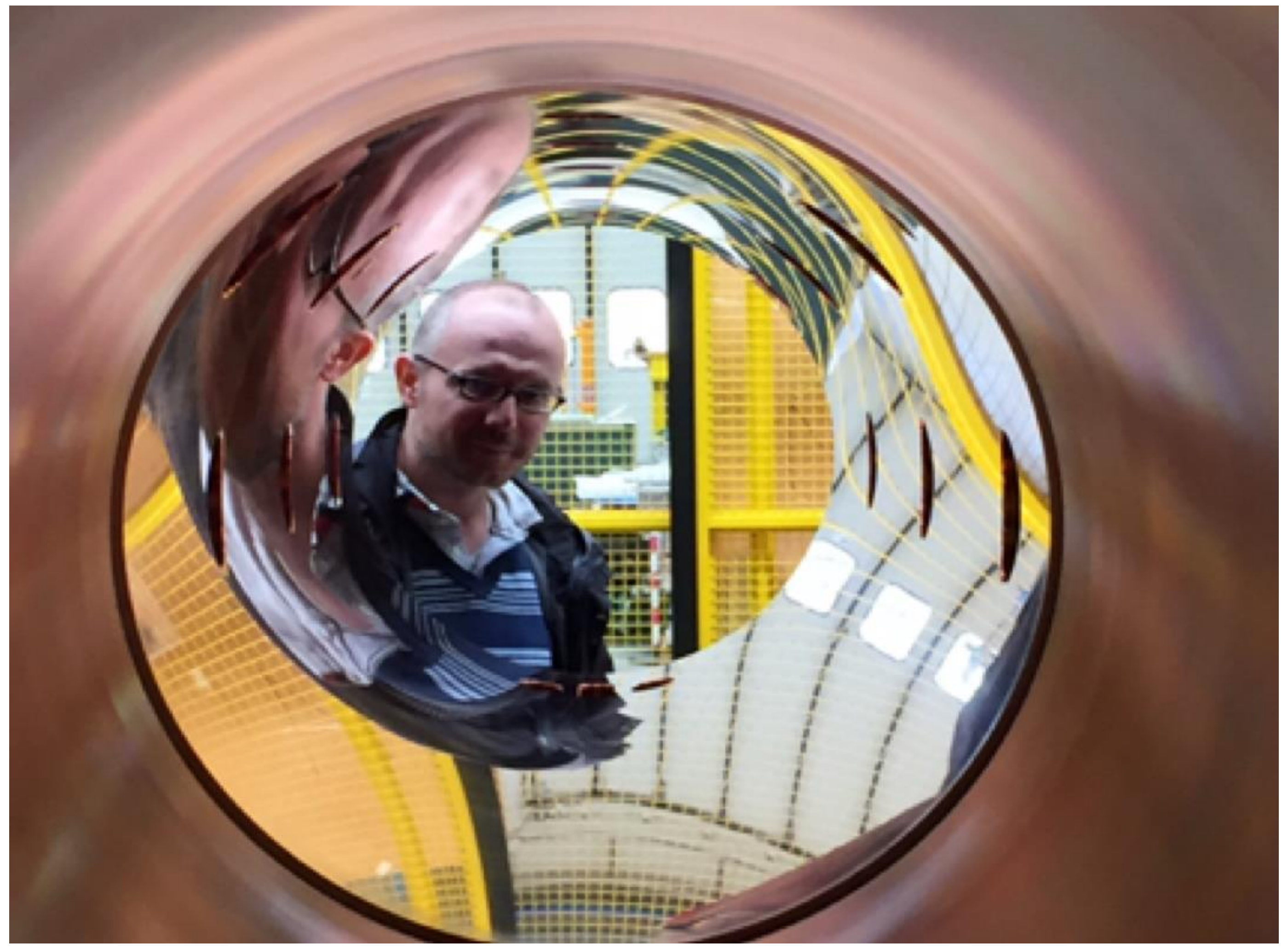
Front End

Ion Source, RFQ, MEBT and DTL









Drift tube linac

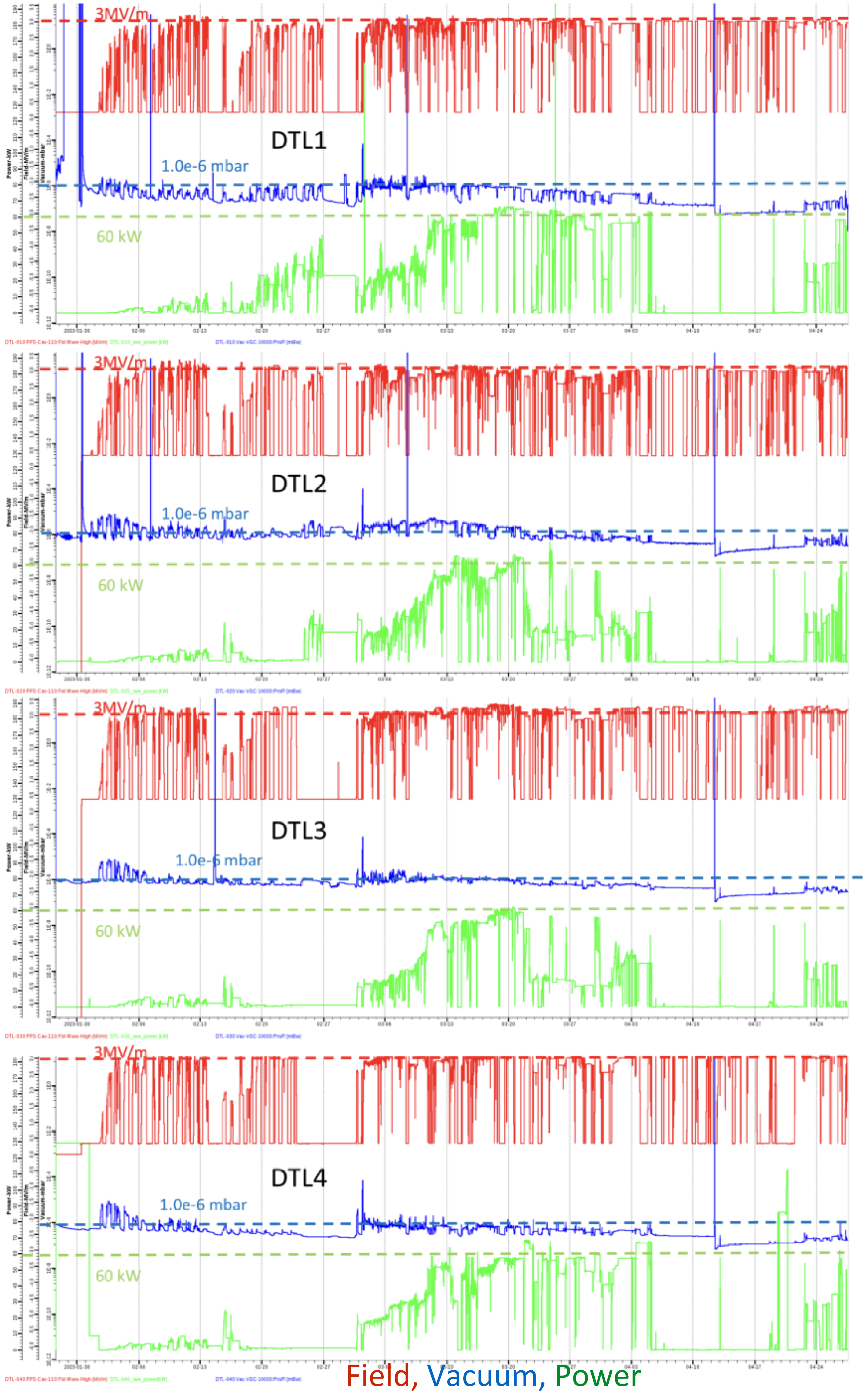
All the five tanks are in the tunnel now

Drift tube linac

All the five tanks are in the tunnel now

- Conditioning of the DTLs started on February 1st 2023, and it proceeded smoothly for some weeks:
  - On Feb-02 reached 2MW-14Hz-15us in all DTLs, equivalent to fields 2.8-3MV/m, depending on the cavity.
  - Feb-12: E0+5% goal reached for all cavities with 200-300 µs pulse
  - Feb-13: 14Hz-400us-3MV/m
- In the second half of March the DTL2 and DTL3 RF windows started arcing.

- High power operation gave us something to think about the pick up signals.



Francesco Grespan
HB 2023

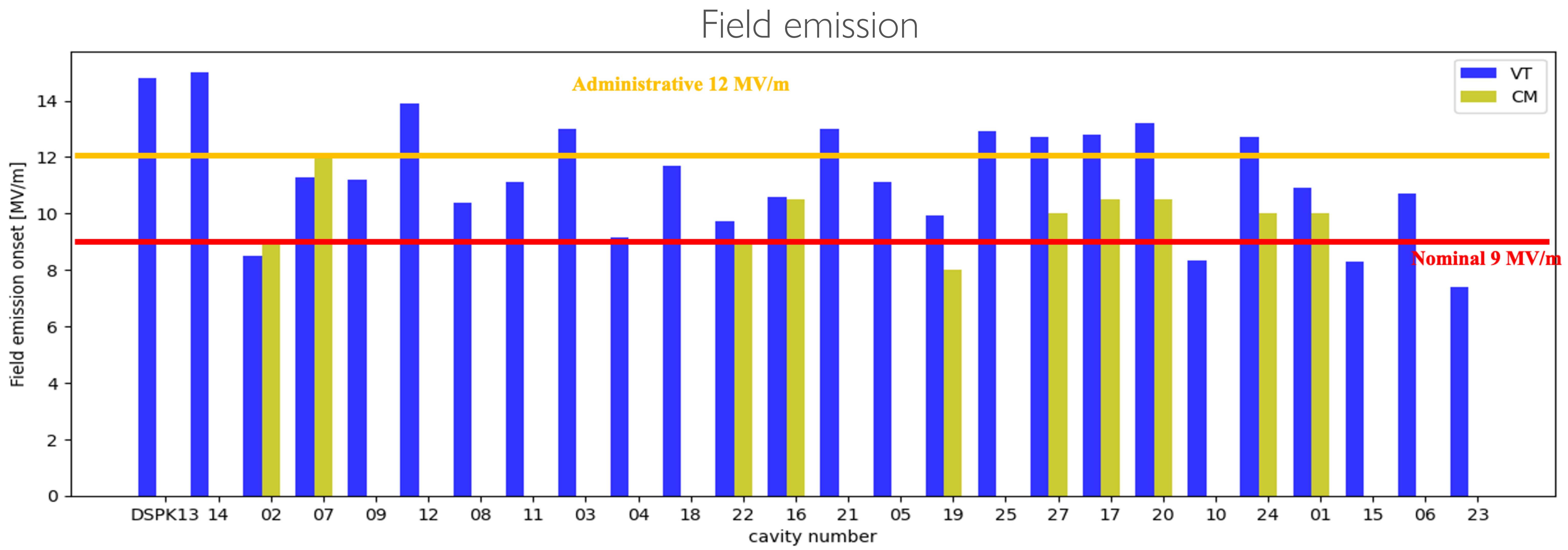
Spoke Linac

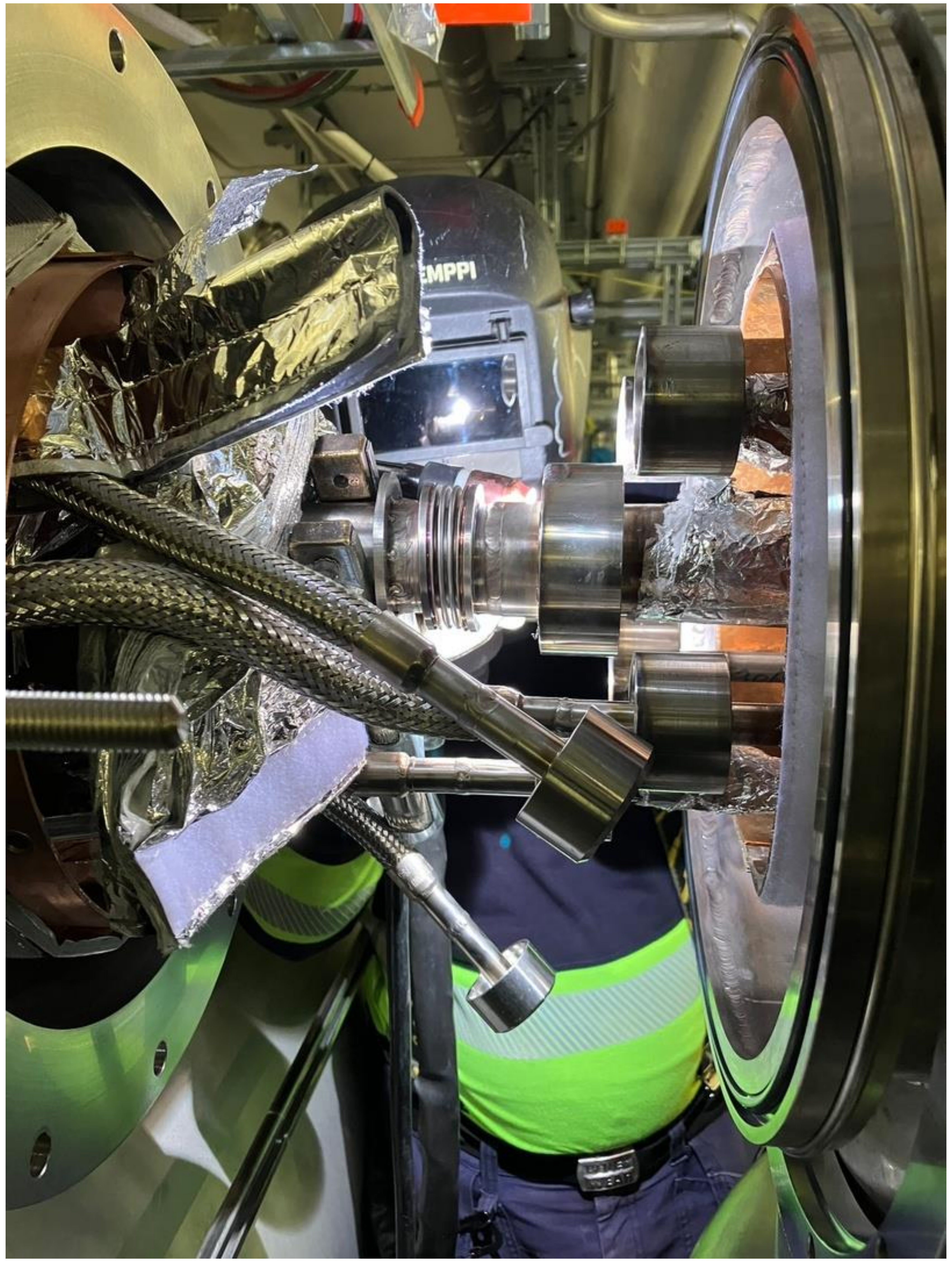
Cryomodule installation almost complete

Spoke Linac

Cryomodule installation almost complete

- All cavities reached the design gradient of 9 MV/m,
  - and typically operated to the max administrative limit of the test (12 MV/m).
  - Field emission below the nominal gradient very rare (1 cavity)



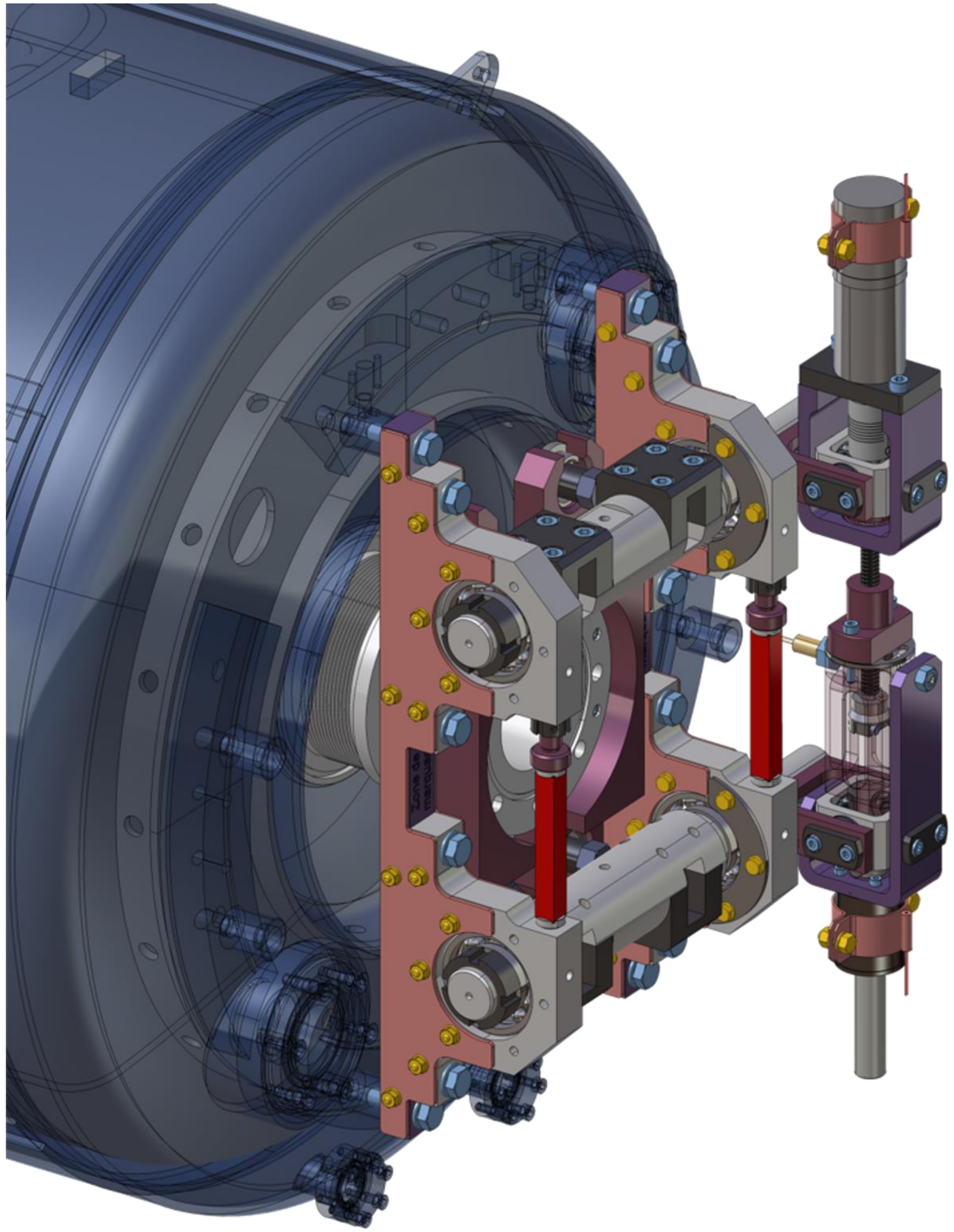


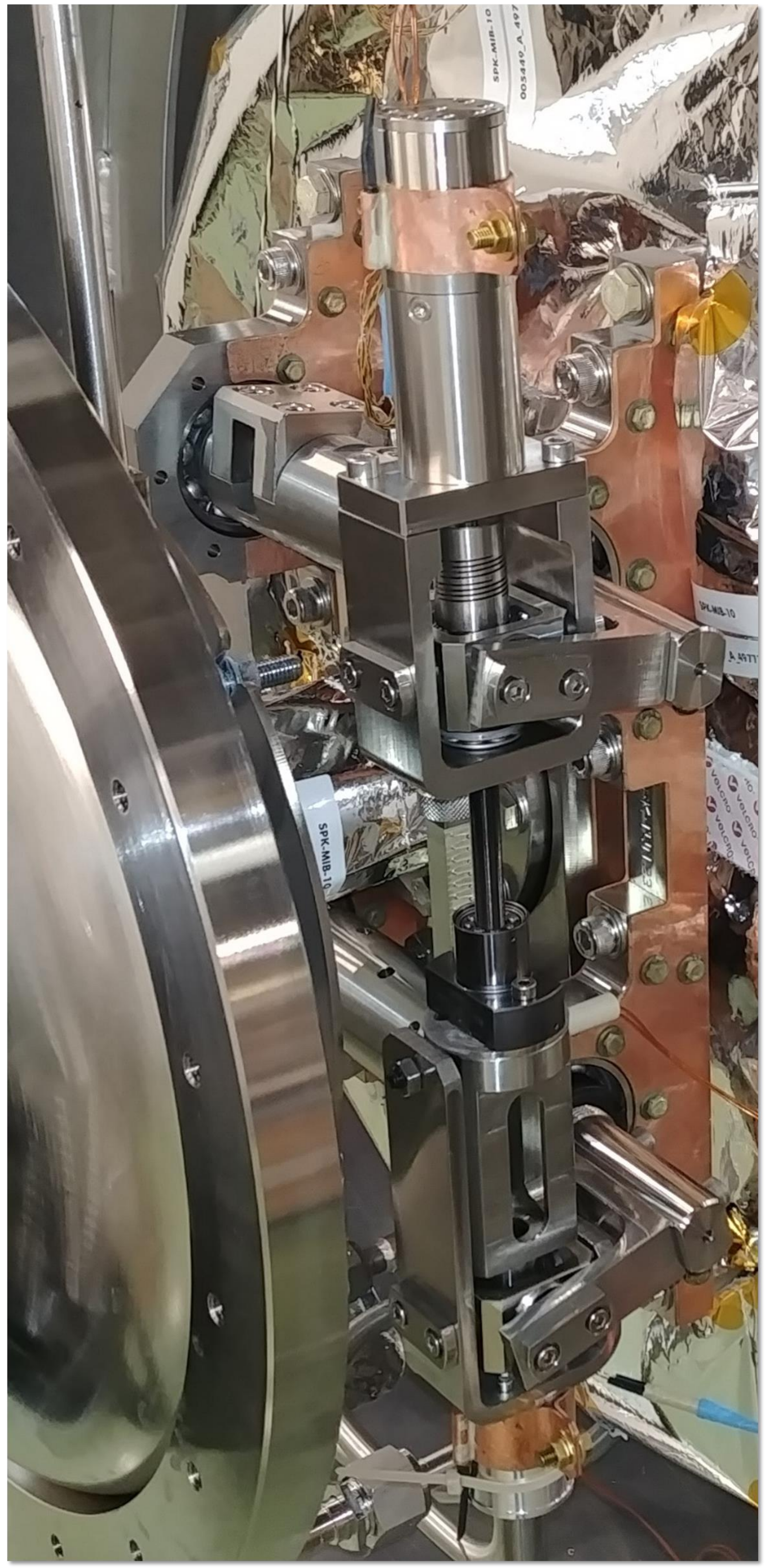
Paolo Pierini, R. Santiago Kern

ESS Challenges

Spoke cold tuning system

- Copper collar that was possibly squeezing the motor body at low temperature was removed
- Motor lifetime was challenged with accelerated life tests and gave unsatisfying results
  - Motivation to find alternative motor solution for cryomodule maintenance as a long term solution
  - Another motor actuator designed for particle accelerator will be tested on a modified tuner soon
    - More likely a plan B due to invasive part replacement
    - Tooling in-place for in-situ replacement
- Different coating was applied to the inside of the gearbox and gave satisfying durability results,





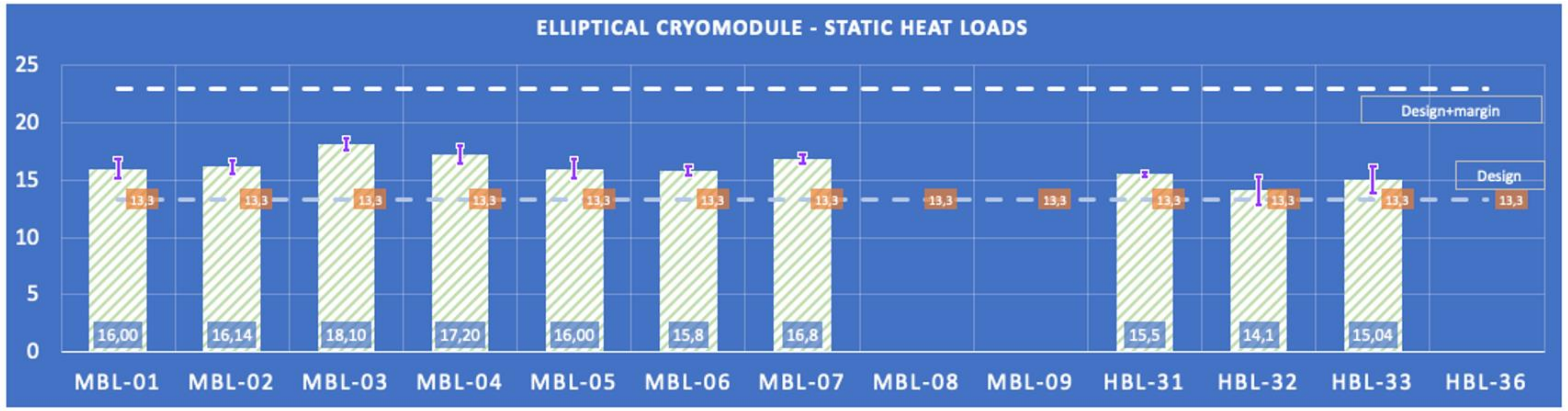
Nicolas Gandolfo et al.

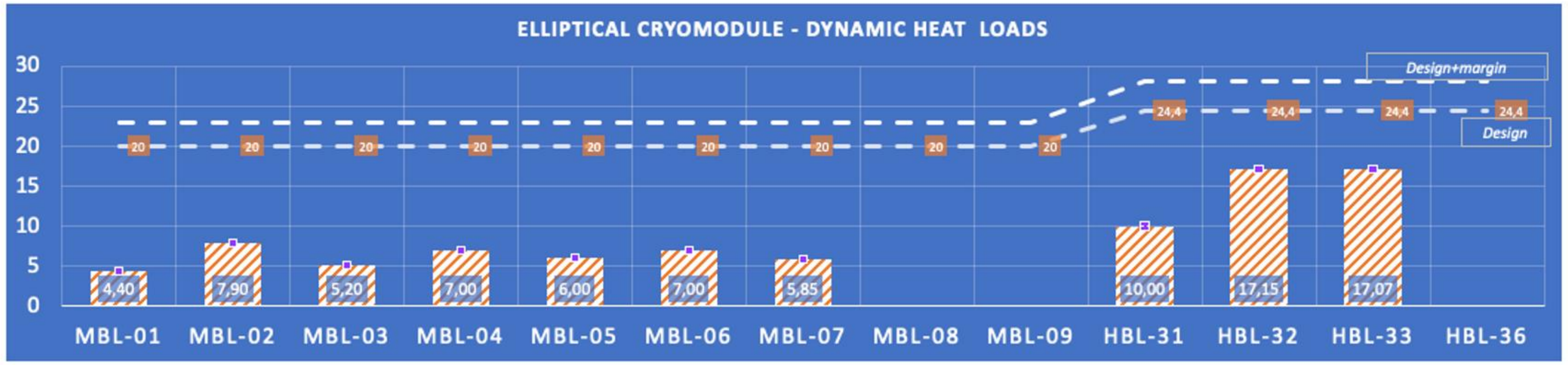
Elliptical

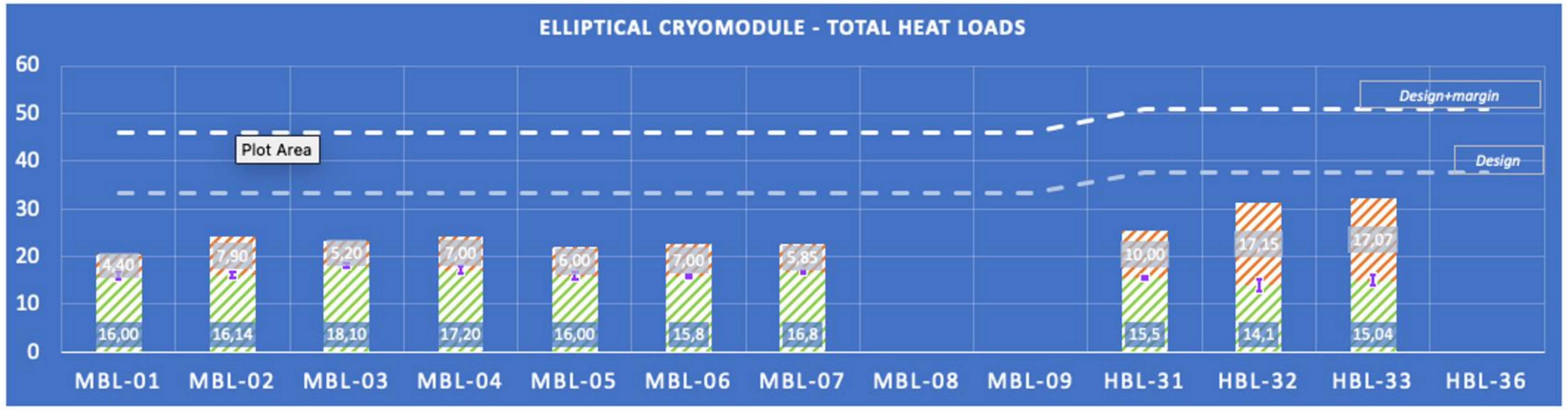
All CMs needed for Beam on target are ready for installation

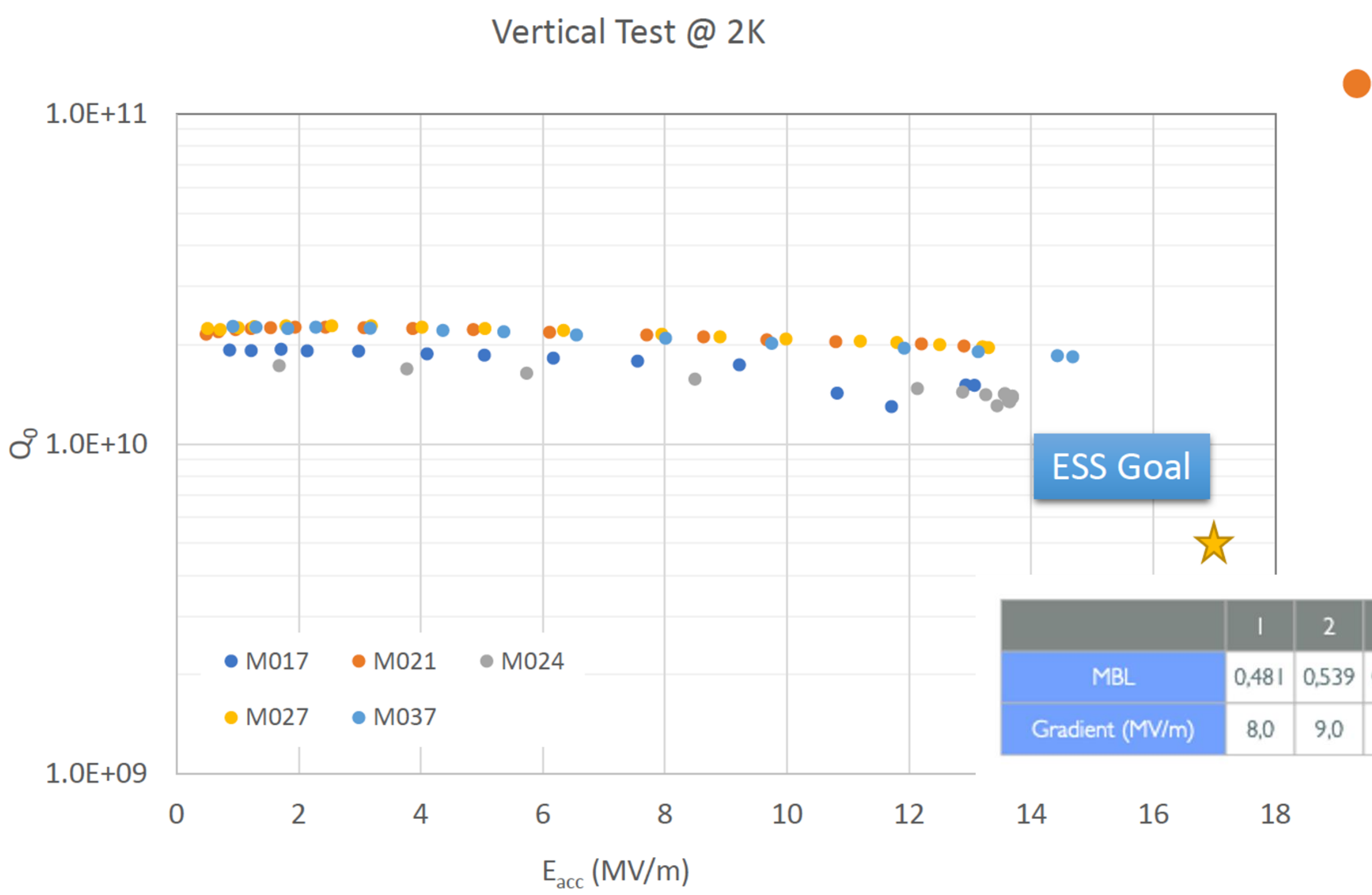
Elliptical

All CMs needed for Beam on Target are ready for installation









Cavity	Max E_{acc}	Q_0 at Max E_{acc}
M021	12.9	2.0E+10
M017	13.1	1.5E+10
M027	13.3	2.0E+10
M024	13.7	1.4E+10
M037	14.7	1.8E+10

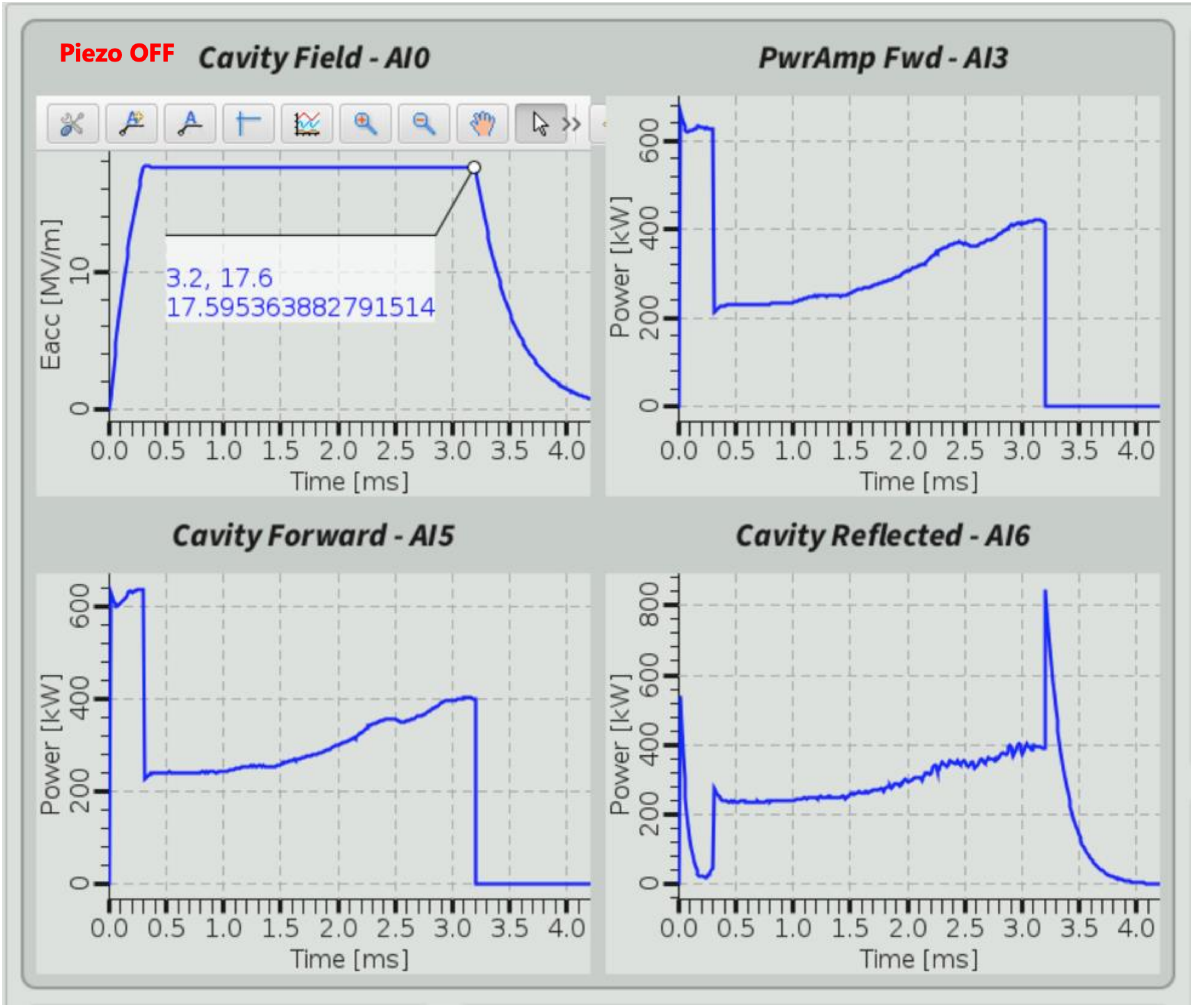
	1	2	3	4	5	6	7	8	9
MBL	0,481	0,539	0,641	0,745	0,853	1	1	1	1
Gradient (MV/m)	8,0	9,0	10,7	12,4	14,2	16,7	16,7	16,7	16,7

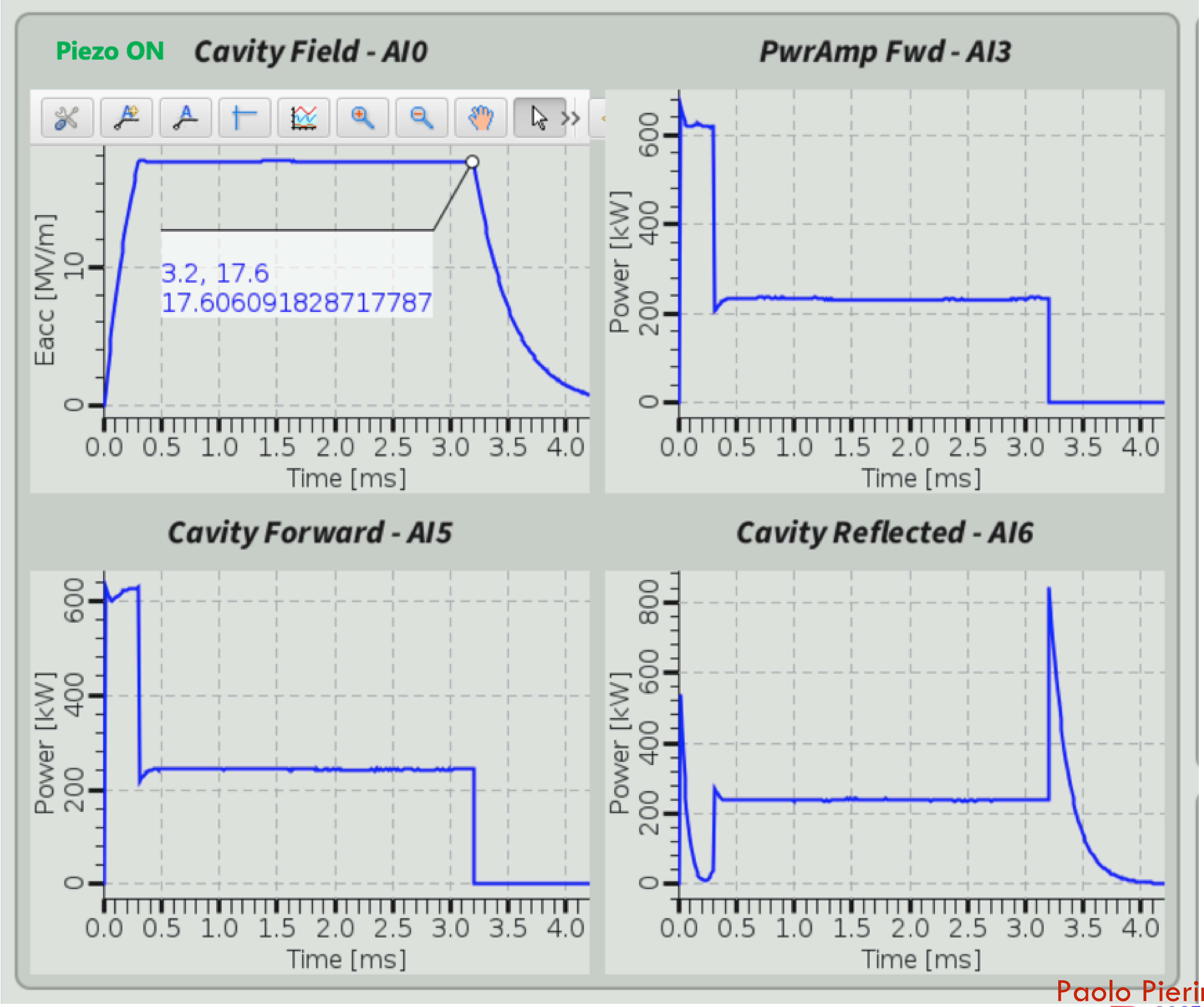
Paolo Pierini

ESS Challenges

Long pulse neutron source and Lorentz force detuning

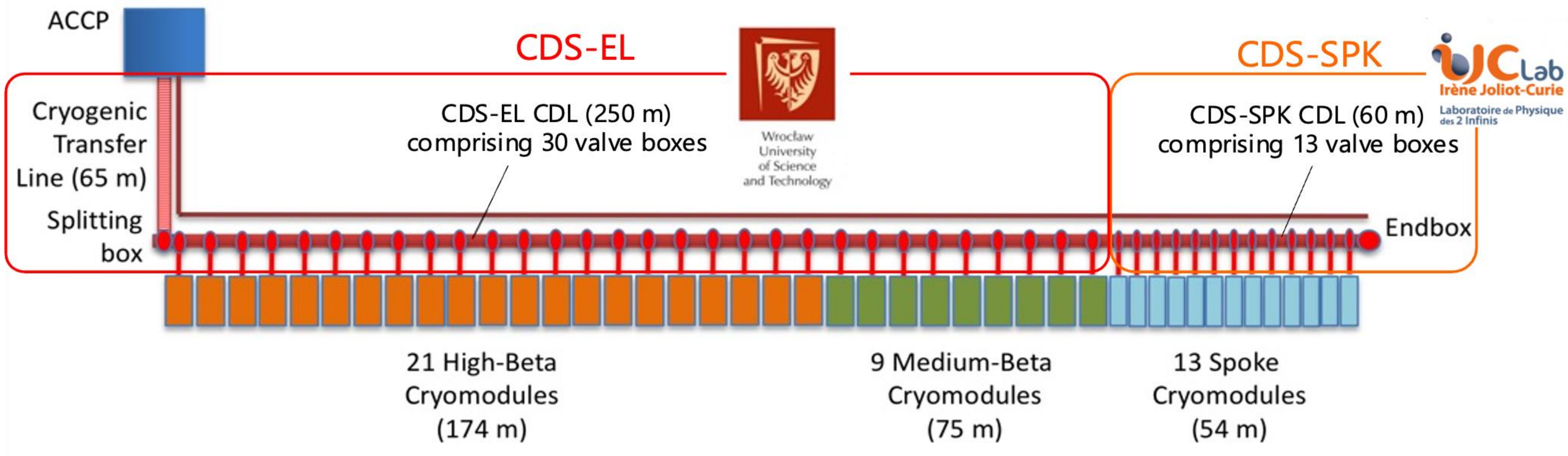
- We can now operate LLRF in closed loop reliably, which has improved cavity characterization uncertainties
  - All cavities are checked now individually in closed loop
  - Only 4-cavity operation in open loop
  - This is particularly important for HB, to highlight the challenges of high gradient long pulse operation under severe Lorenz Force Detuning

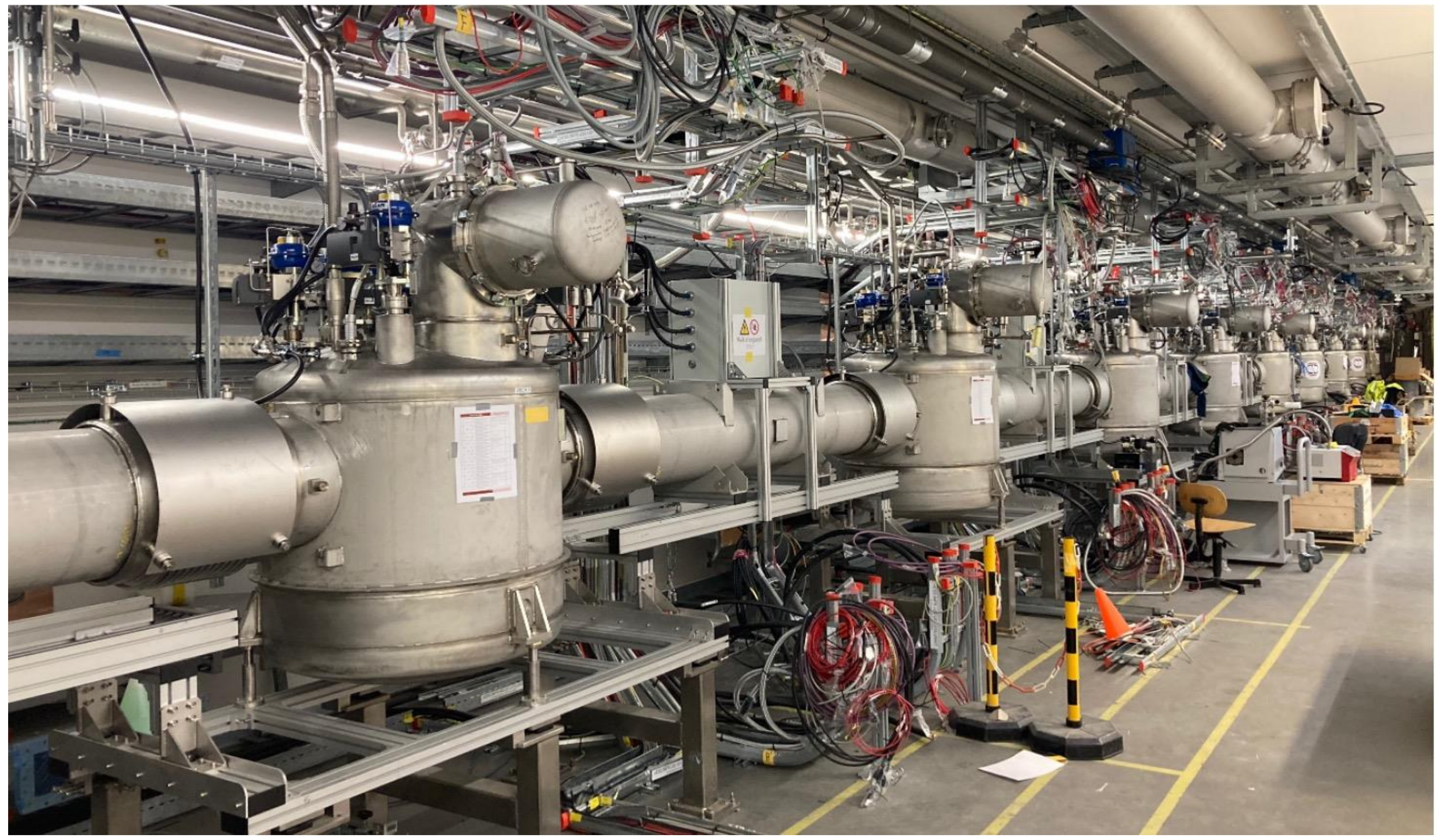




CDS

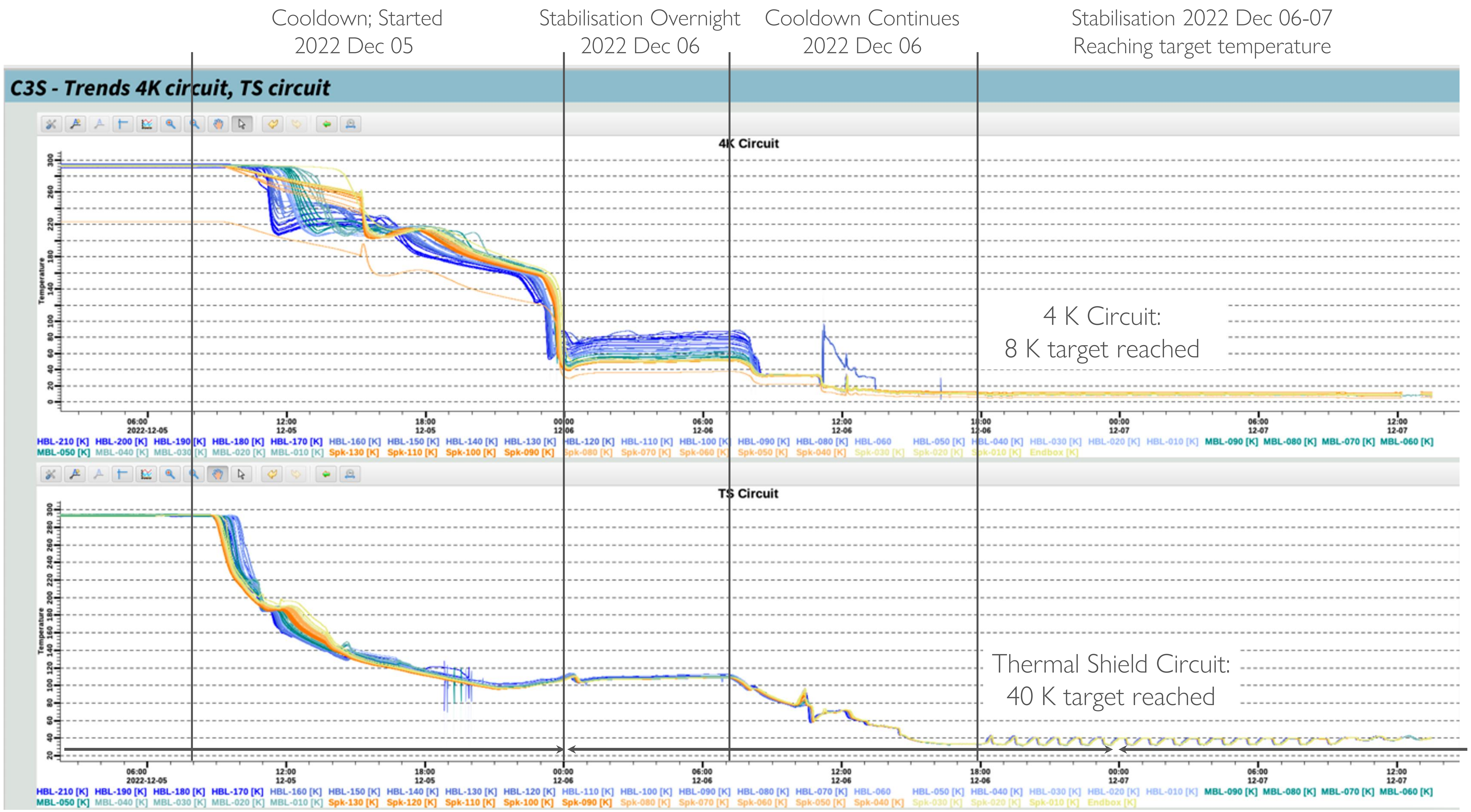
Cryo Distribution System, and Jumper connections





Cryogenics

First cooldown completed successfully in Week 49/2022



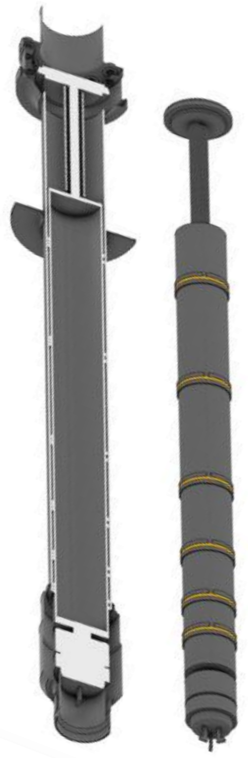
Philipp Arnold, Jaroslaw Fydrych

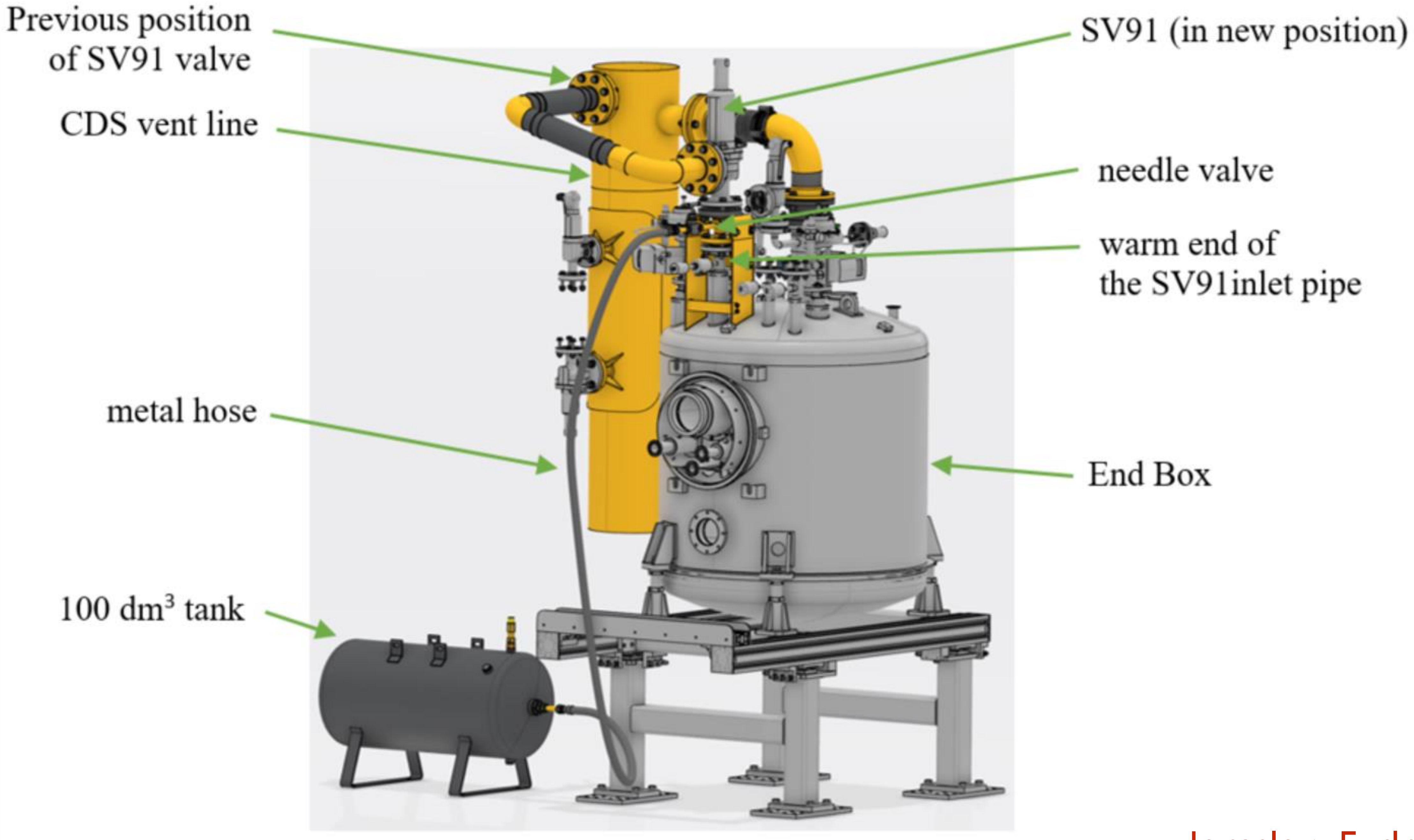
ESS Challenges

TAO Phenomena and mitigation

- Elimination of TAO on the CV04s in CDS-EL
  - No noise, vibration, or ice formation
- Repeat static heat load measurement of the CDS with the two connected CMs:
  - Measured heat load including 1 SPK and 1 MBL CM is ~458 W. Assuming CM static head load of ~40 W, the CDS head load is 418 W (design is 419 W)

- The TAO phenomenon in the End Box was analysed by ESS and in-kind partner IJCLab
  - SV91 moved close to the End Box connection pipe
  - A damper vessel connected via a needle valve to the connection pipe



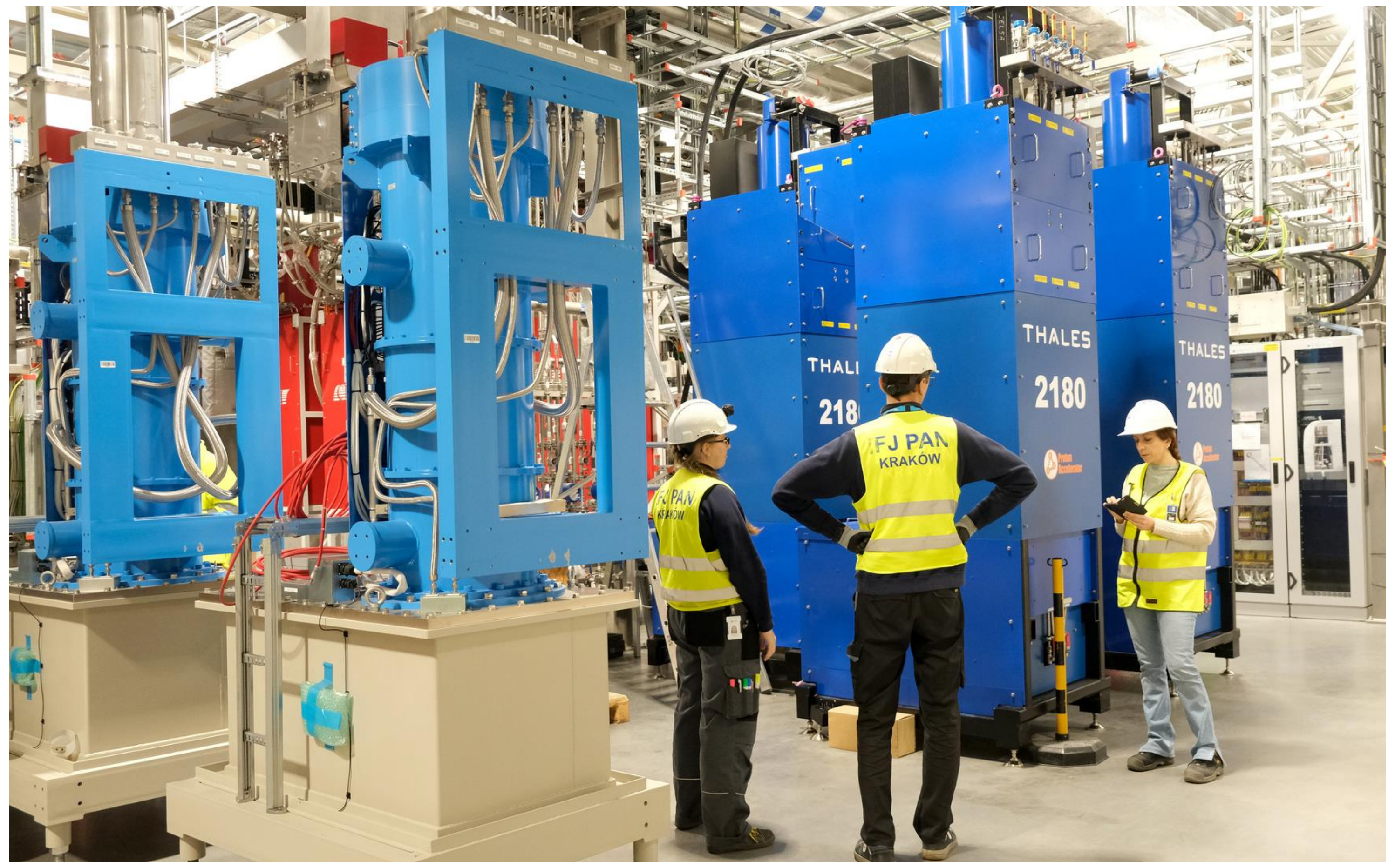


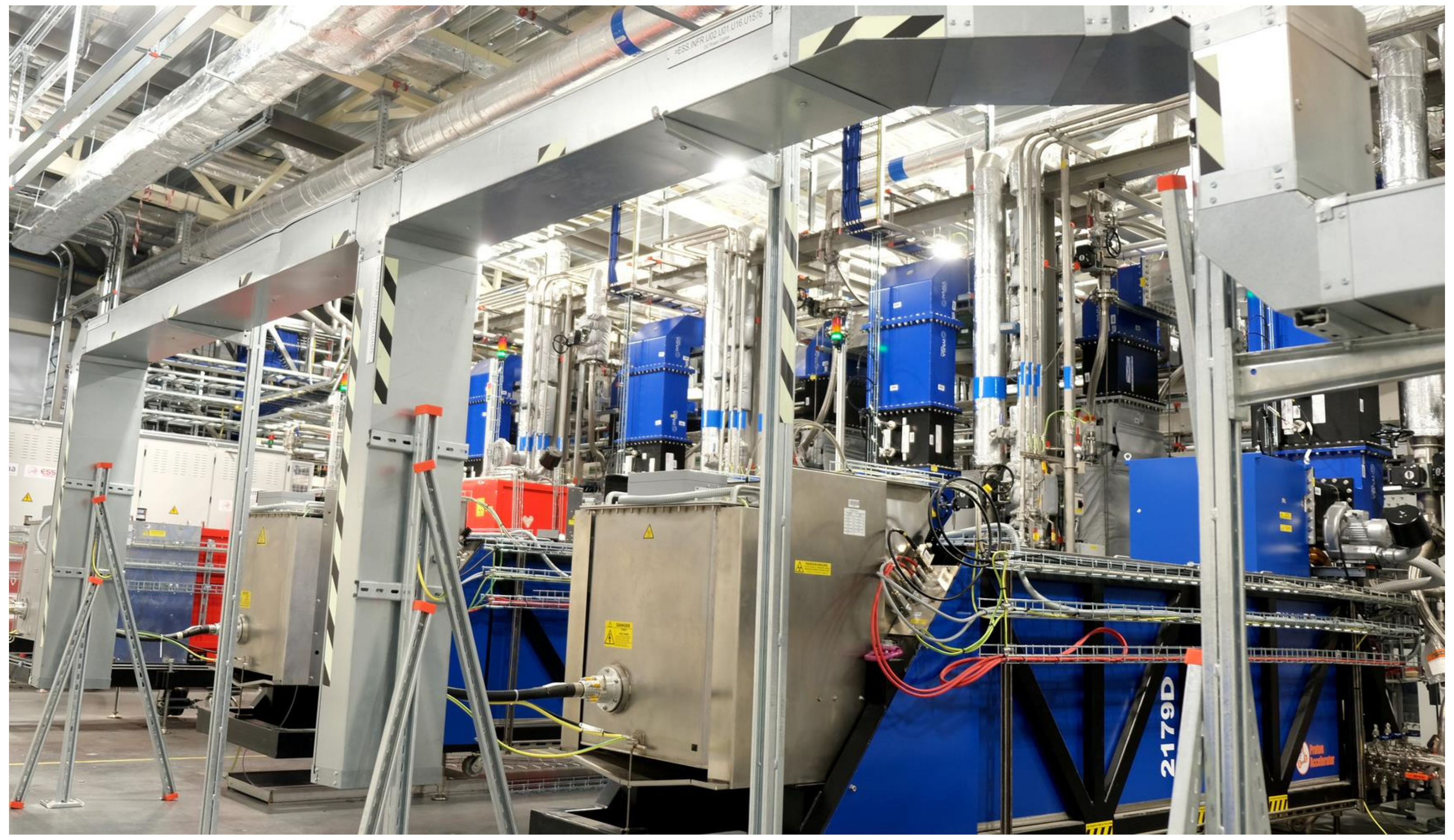
Jaroslaw Fydrych

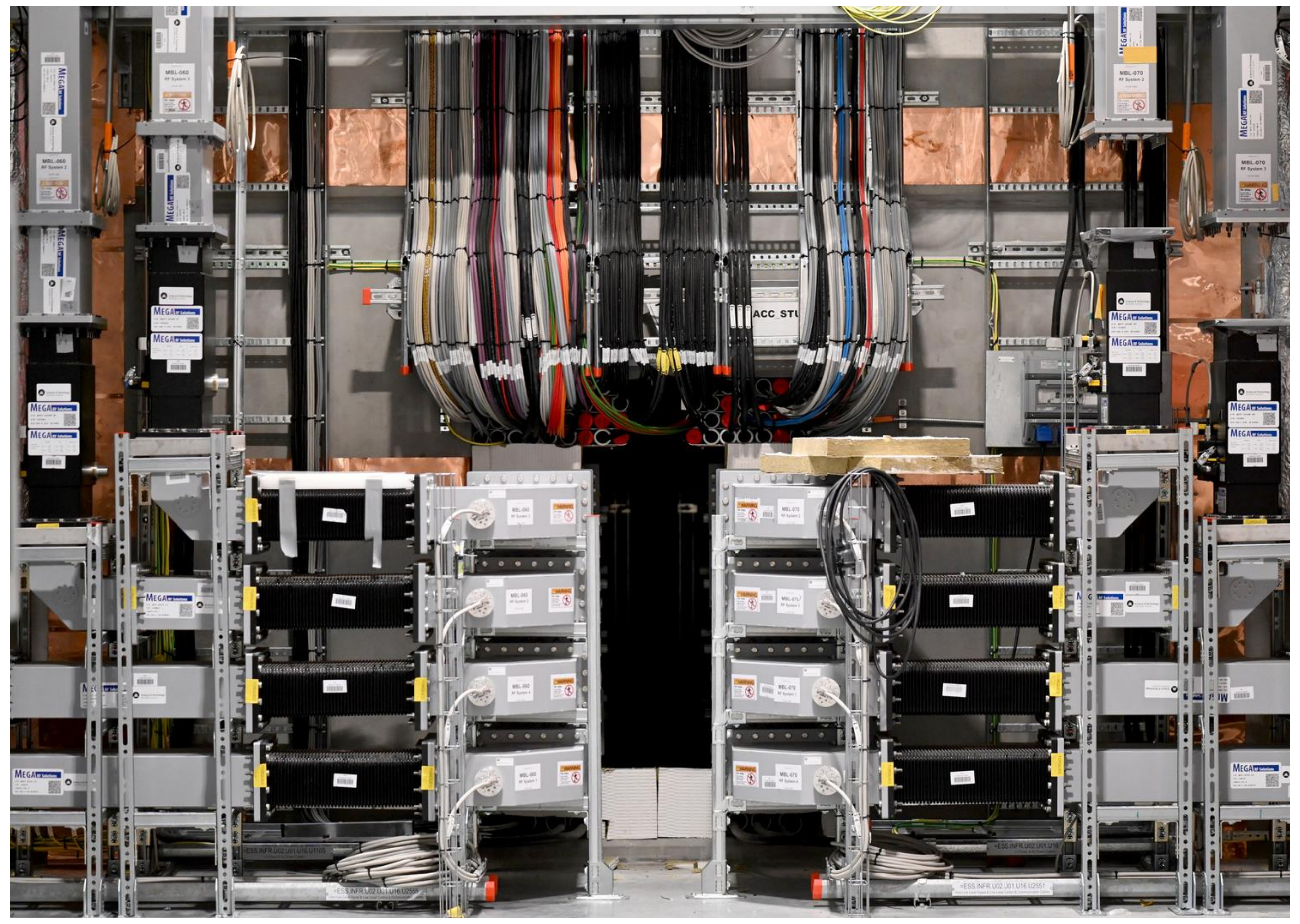
HB 2023

Klystron Gallery

High voltage moderators, RF, RFDS and Controls

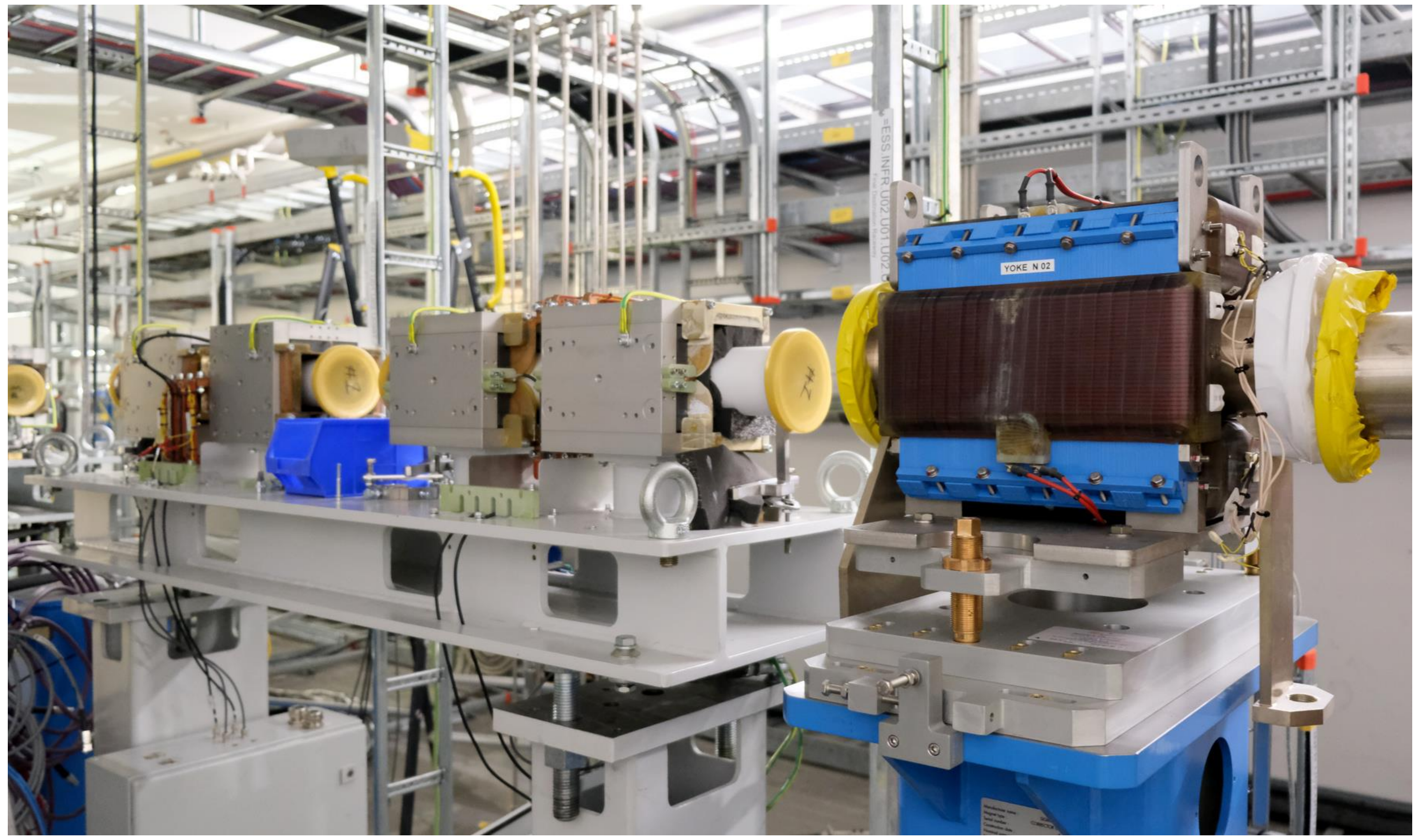


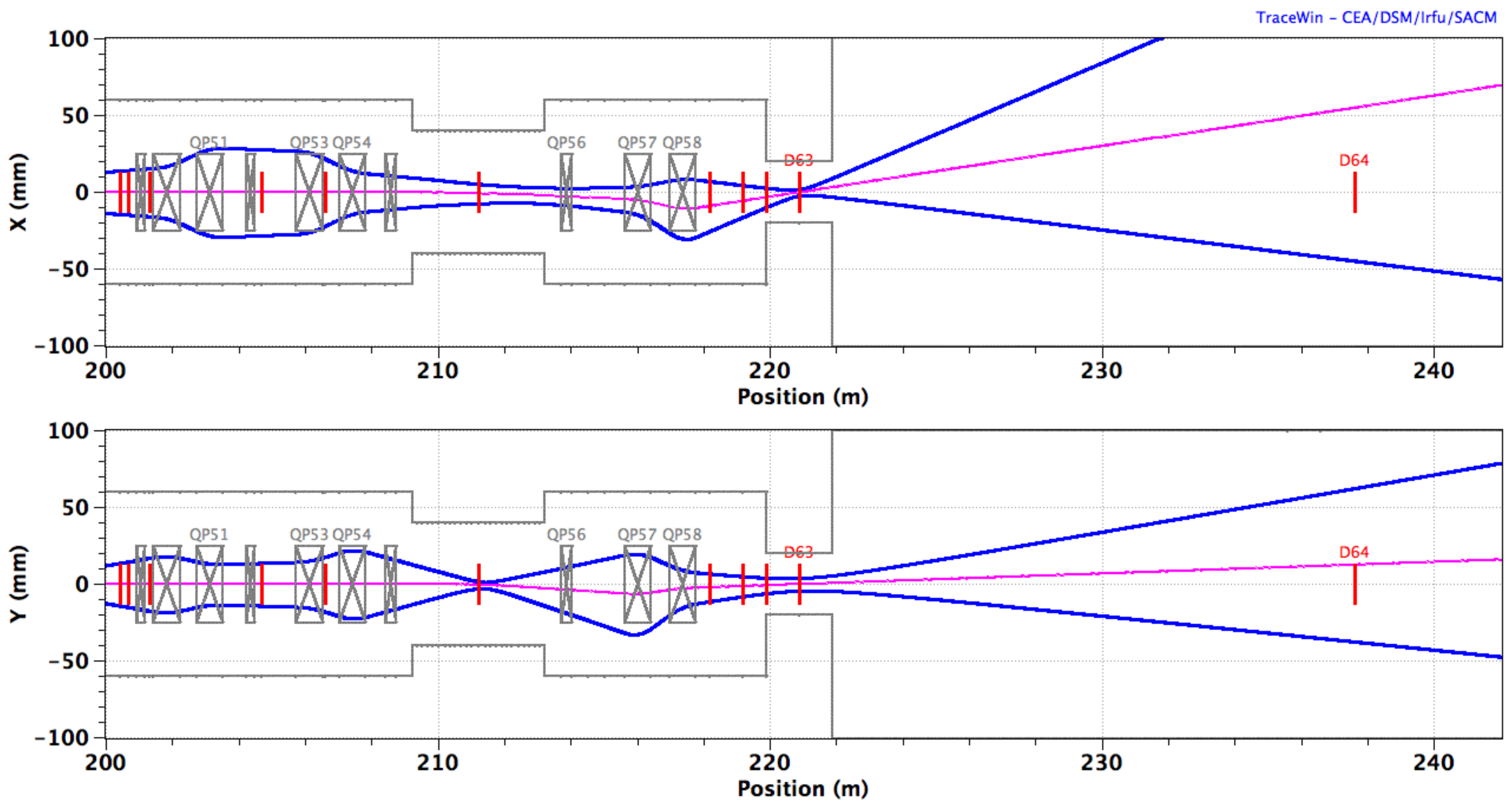


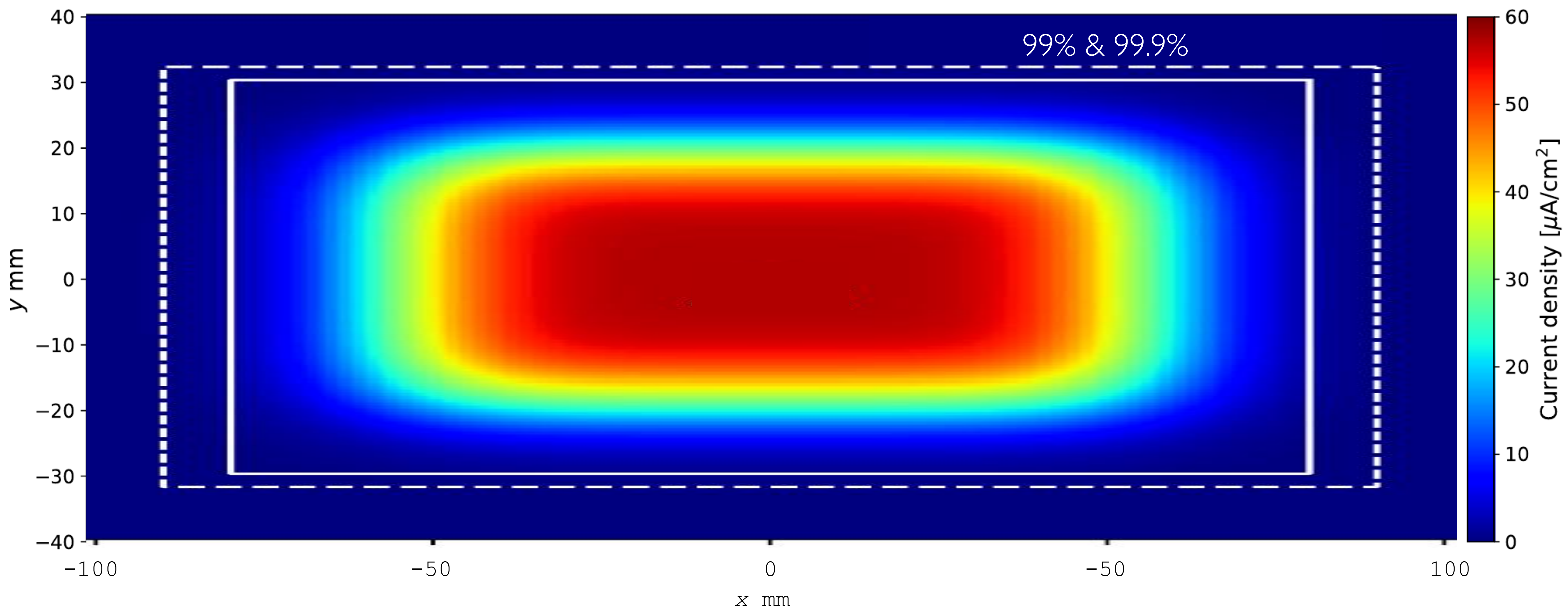


Accelerator to Target

How I learned to stop worrying and love the magnets



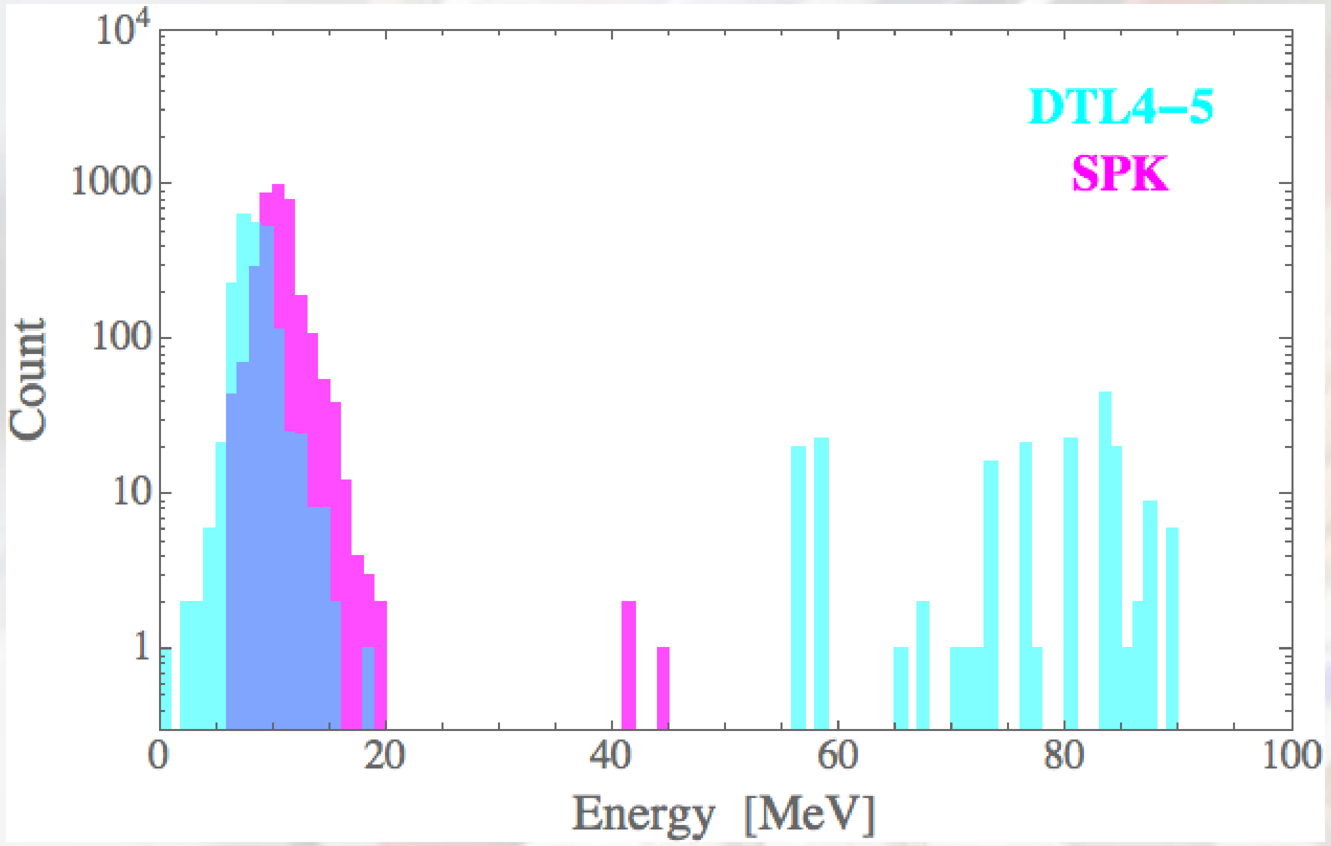


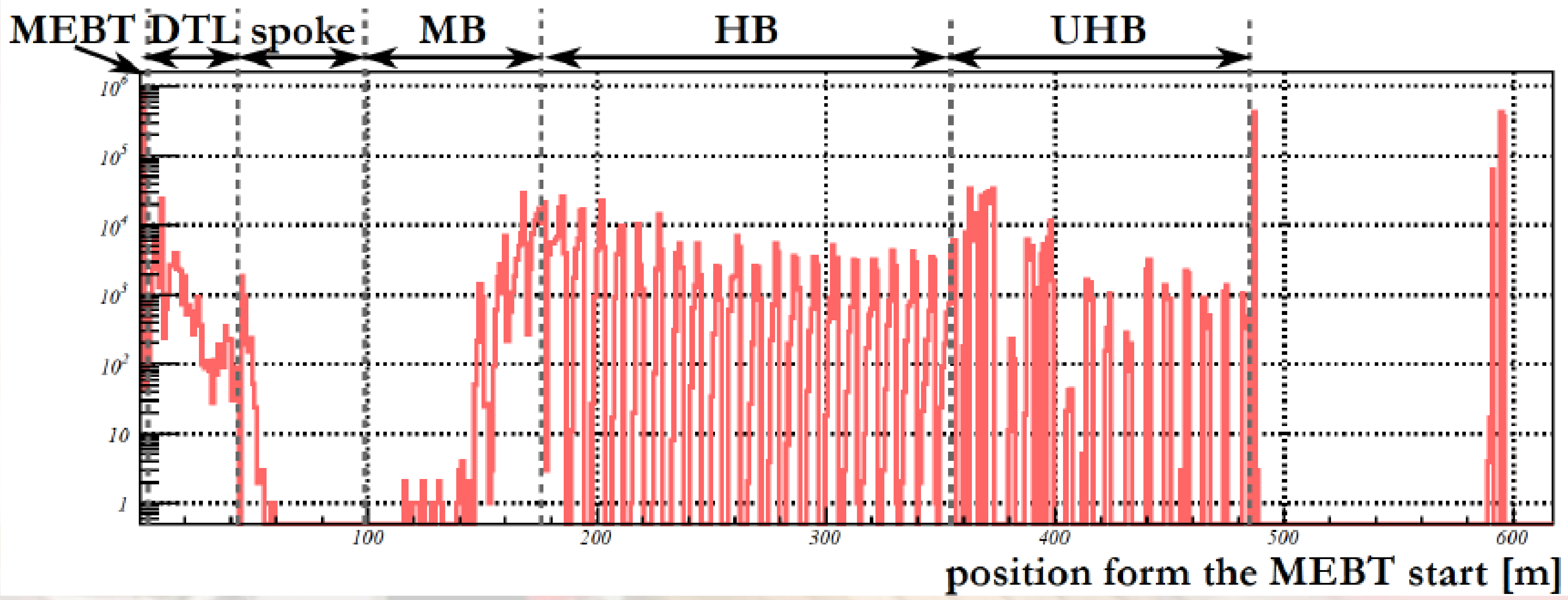


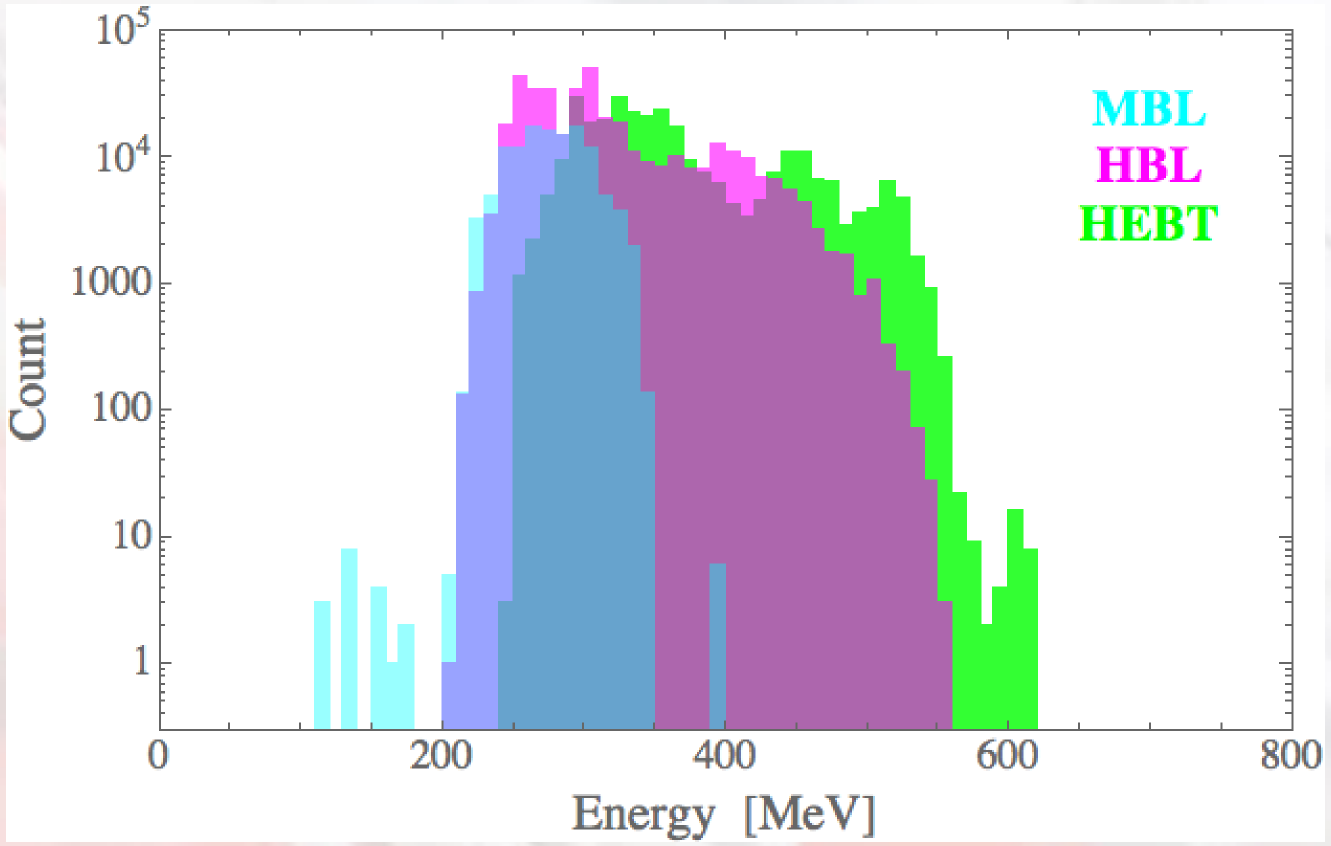
Raster motion: Heine Thomsen

Beam Dynamics Challenges

Beam loss



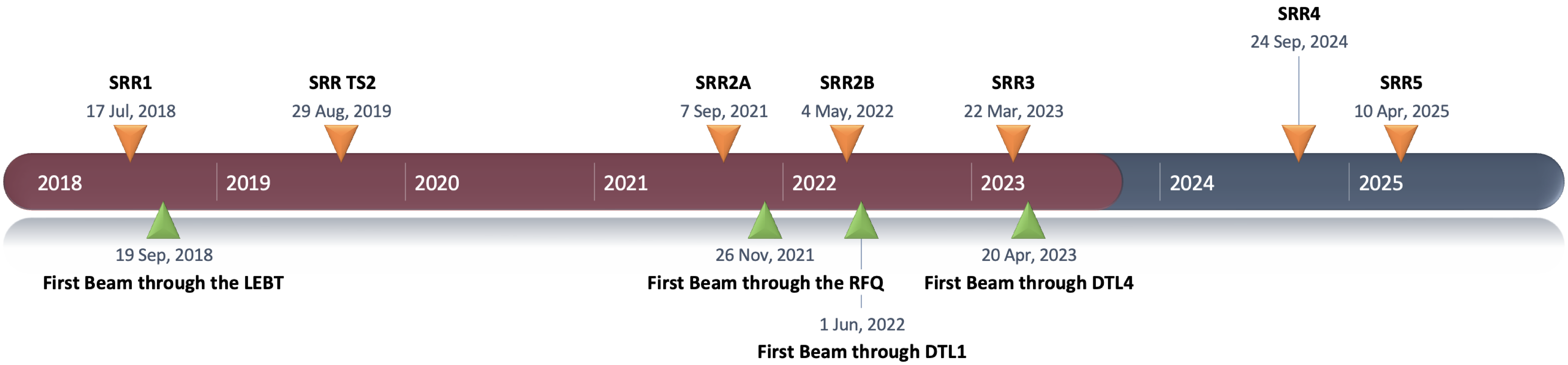


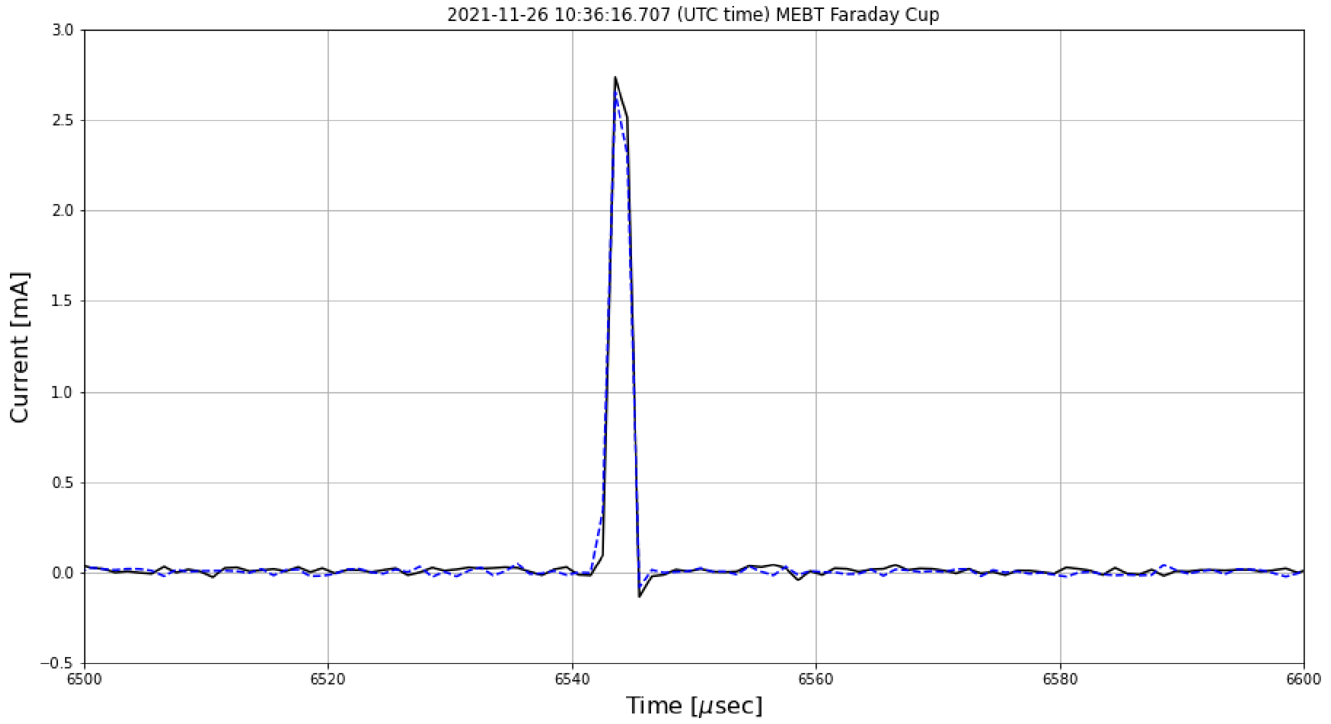


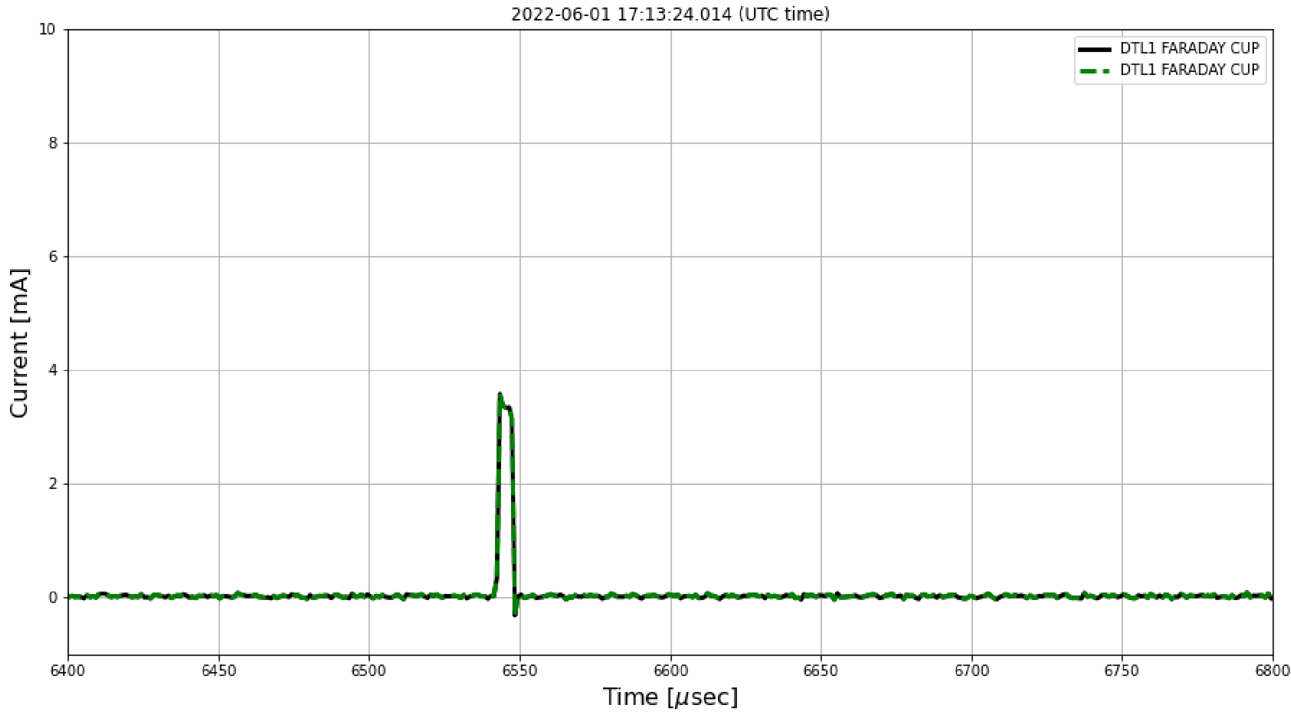
Device	ISRC	LEBT	RFQ	MEBT	DTL	SPK	MBL	HBL	HEBT	A2T	DmpL
Faraday cup		1		1	2						
BCM	1	1	1	2	5		1	1	2	3	2
Fast BCM				2							
Doppler		1									
BPM				7	15	14	9	21	16	12	4
Non-invasive profile		2		2		1	3	1		1	
Imaging										2	1
Grid										1	
Aperture										3	1
Emittance		1		1							
Bunch shape				1		1					
WS				3		3	3	1	3	1	
BLM				4	47	78	38	86	51	38	6

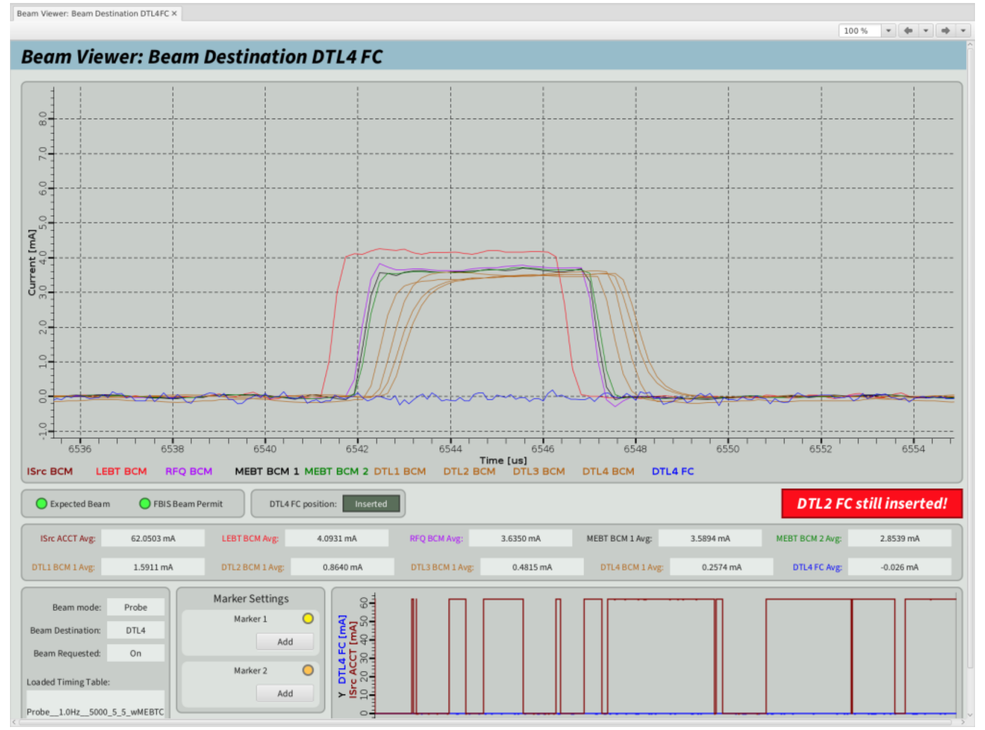
Beam commissioning

A Timeline







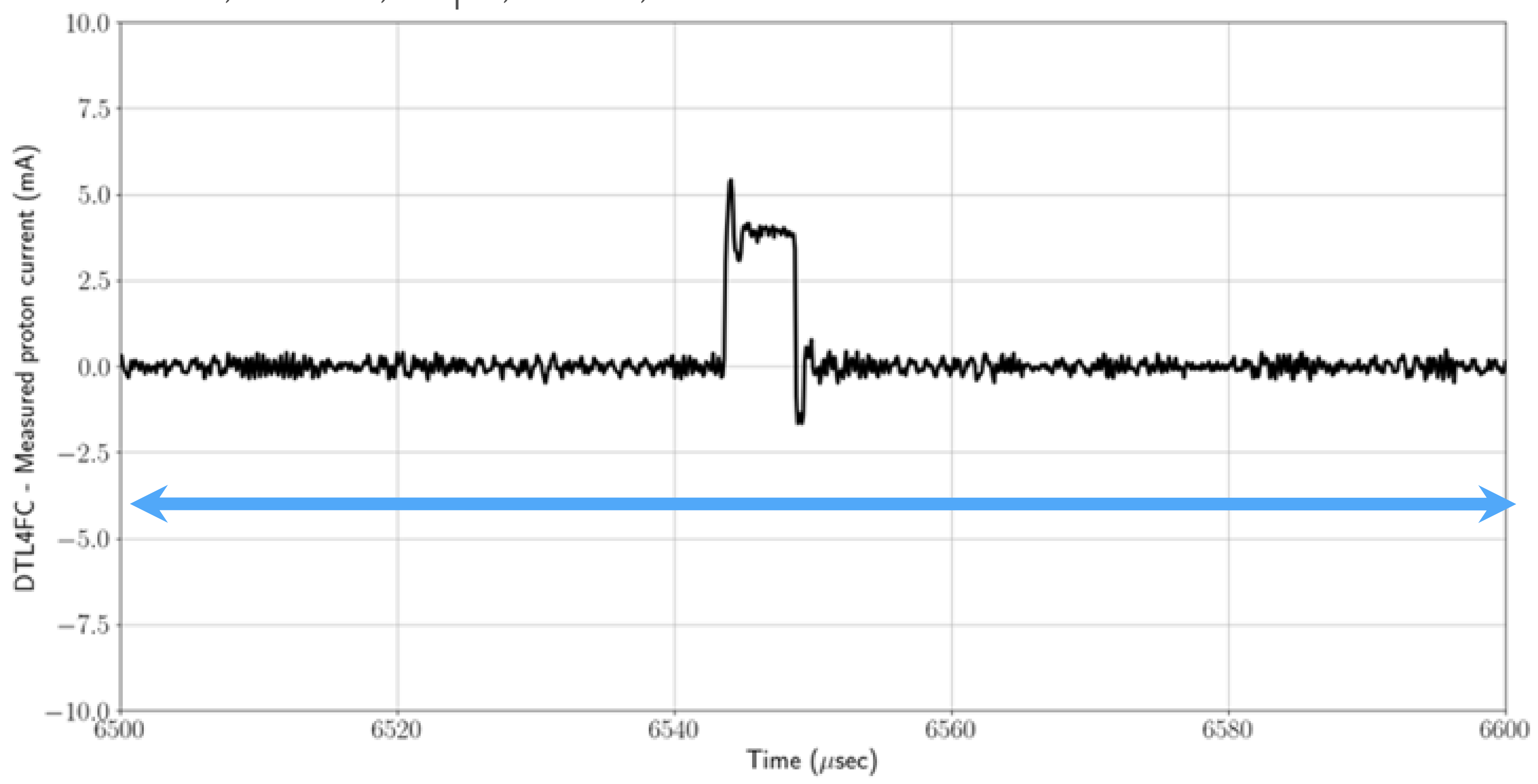


Commissioning team

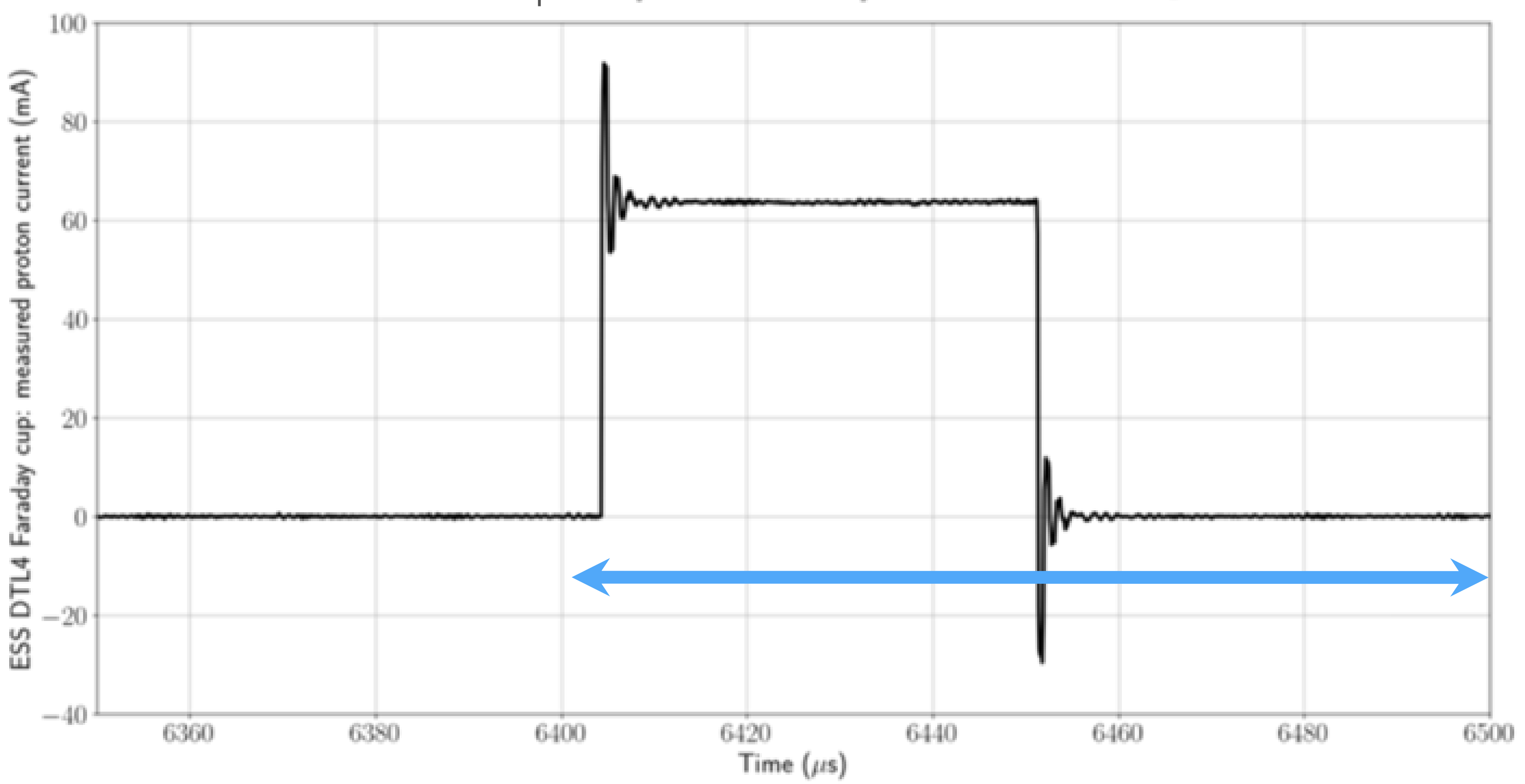
Beam commissioning

First and full current beam on DTL4's Faraday Cup

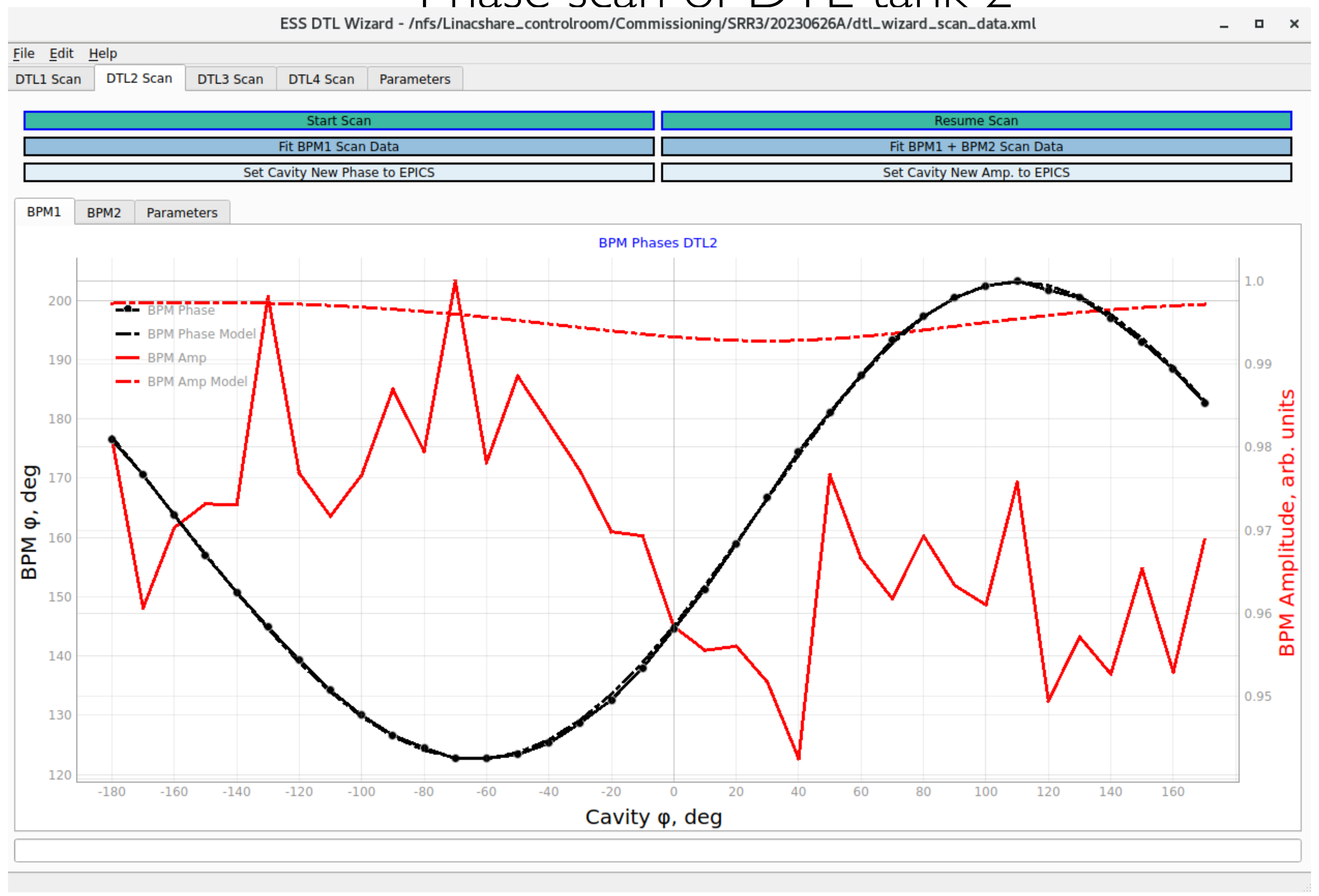
FC4, 4 mA, 5 µs, 1 Hz, 74 MeV



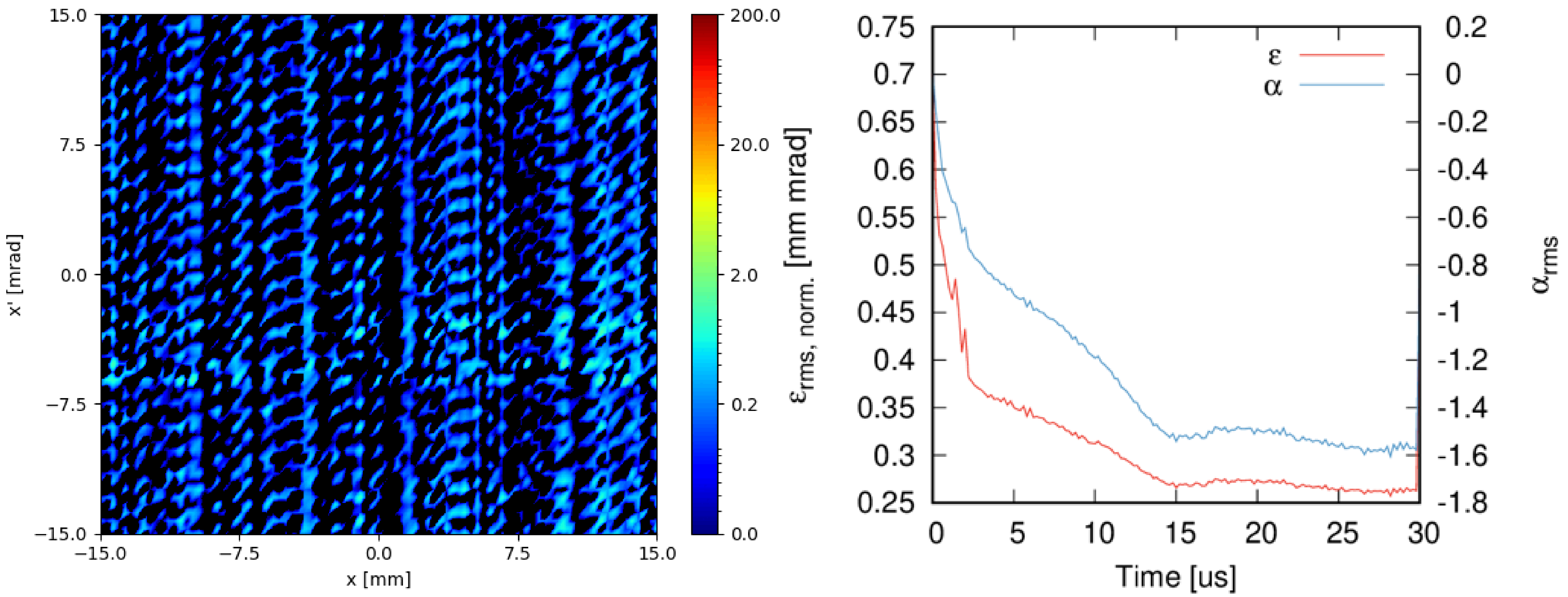
FC4, 62.5 mA, 50 µs, 0.2 Hz, 74 MeV



Phase scan of DTL tank 2



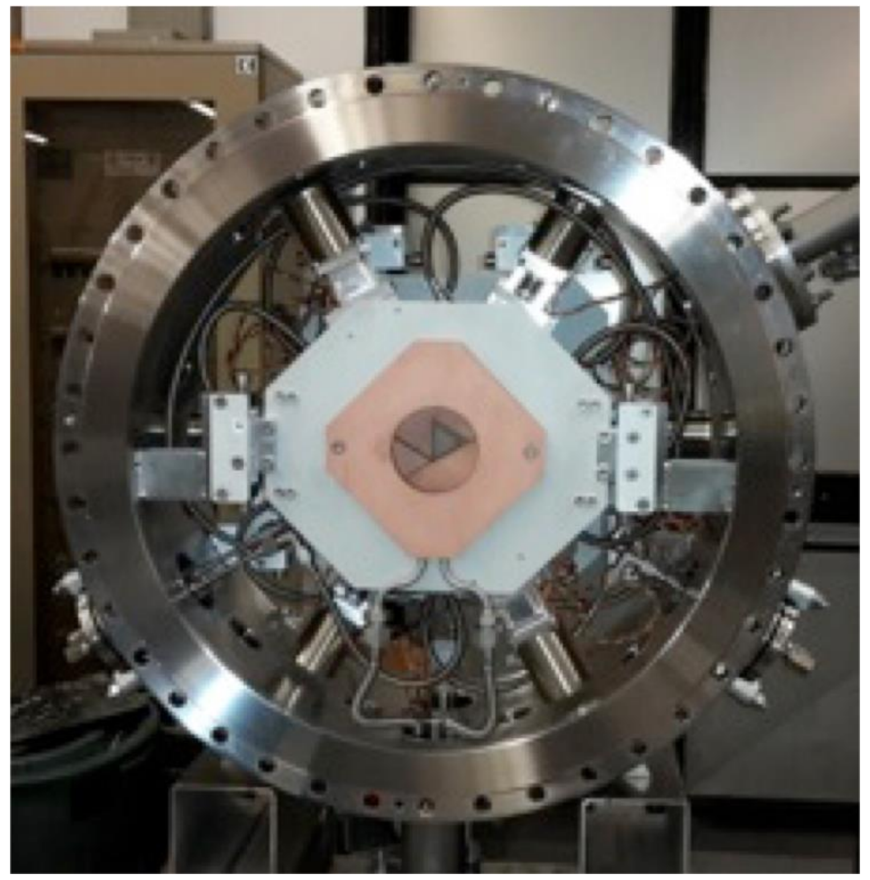
Emittance and its evolution within the pulse

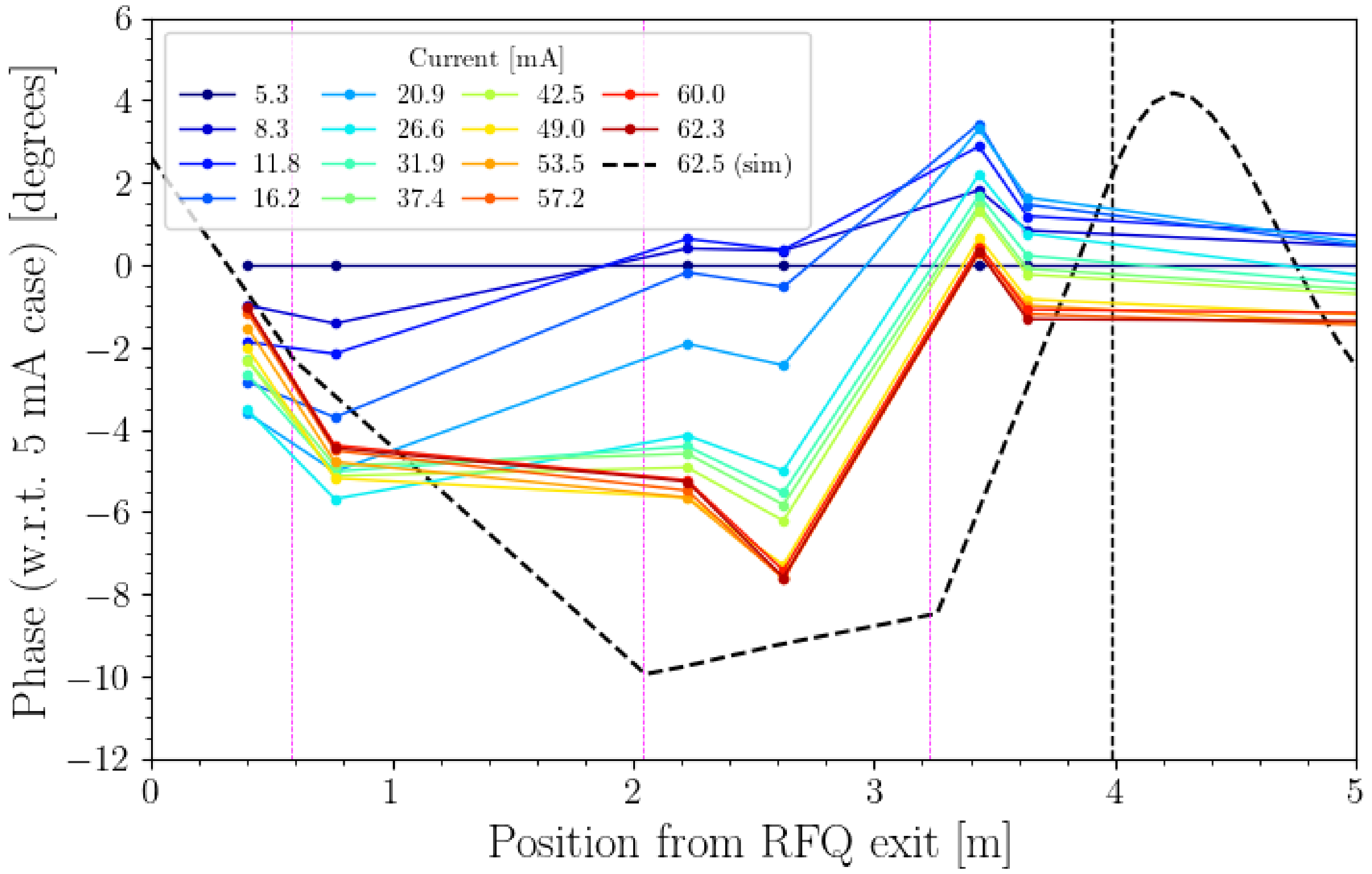


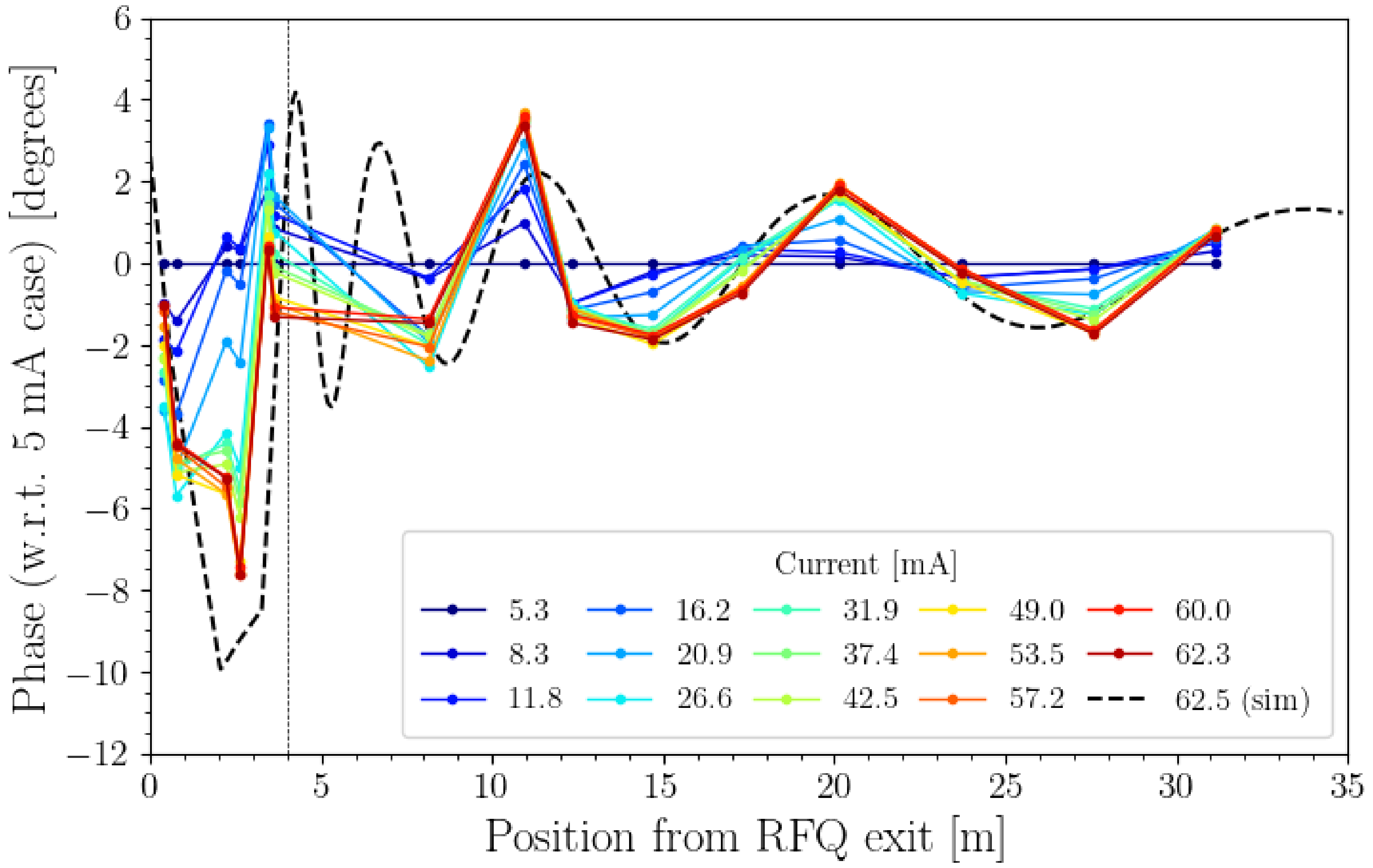
Ryoichi Miyamoto et al

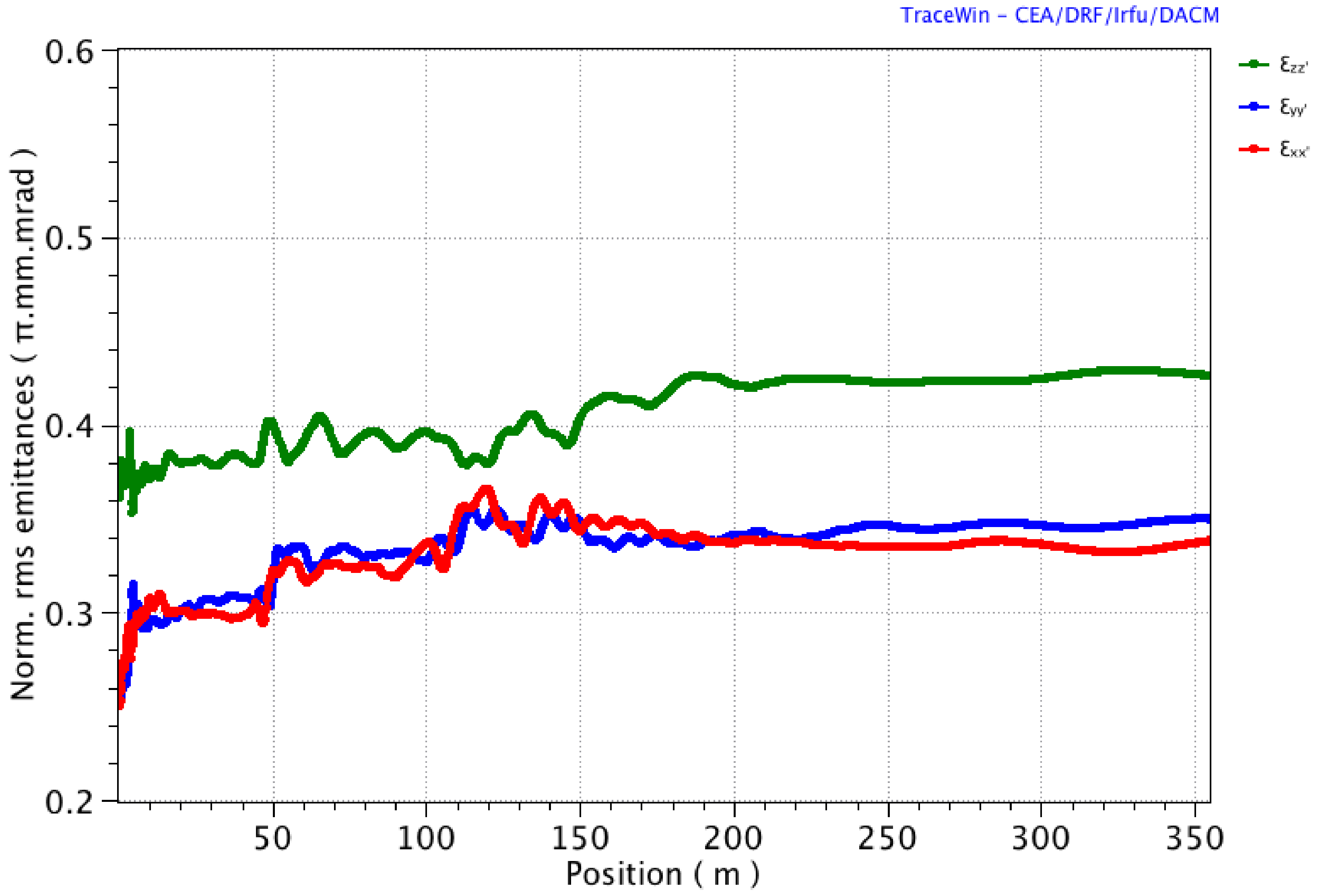
Beam commissioning

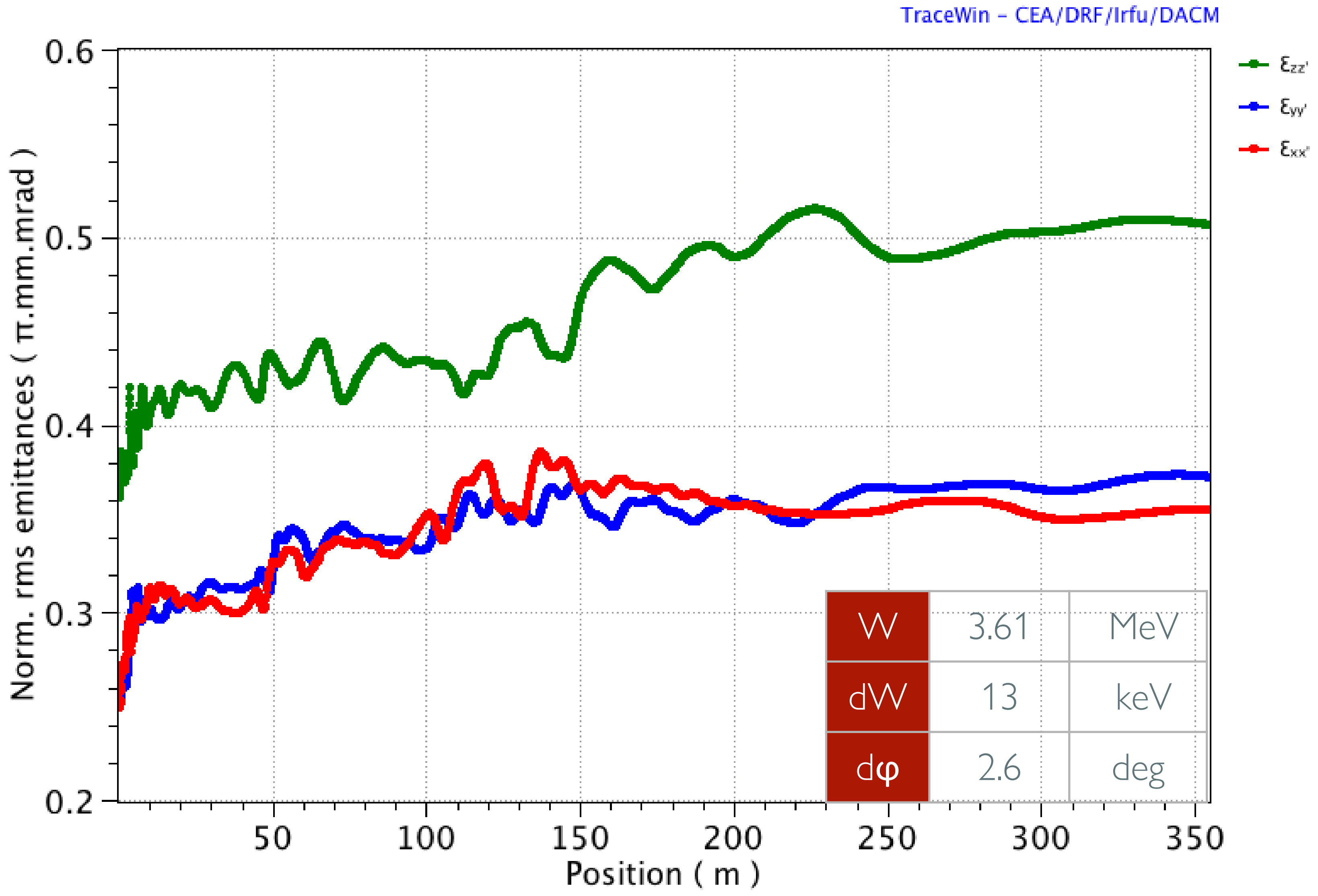
Phase shift vs. Beam current







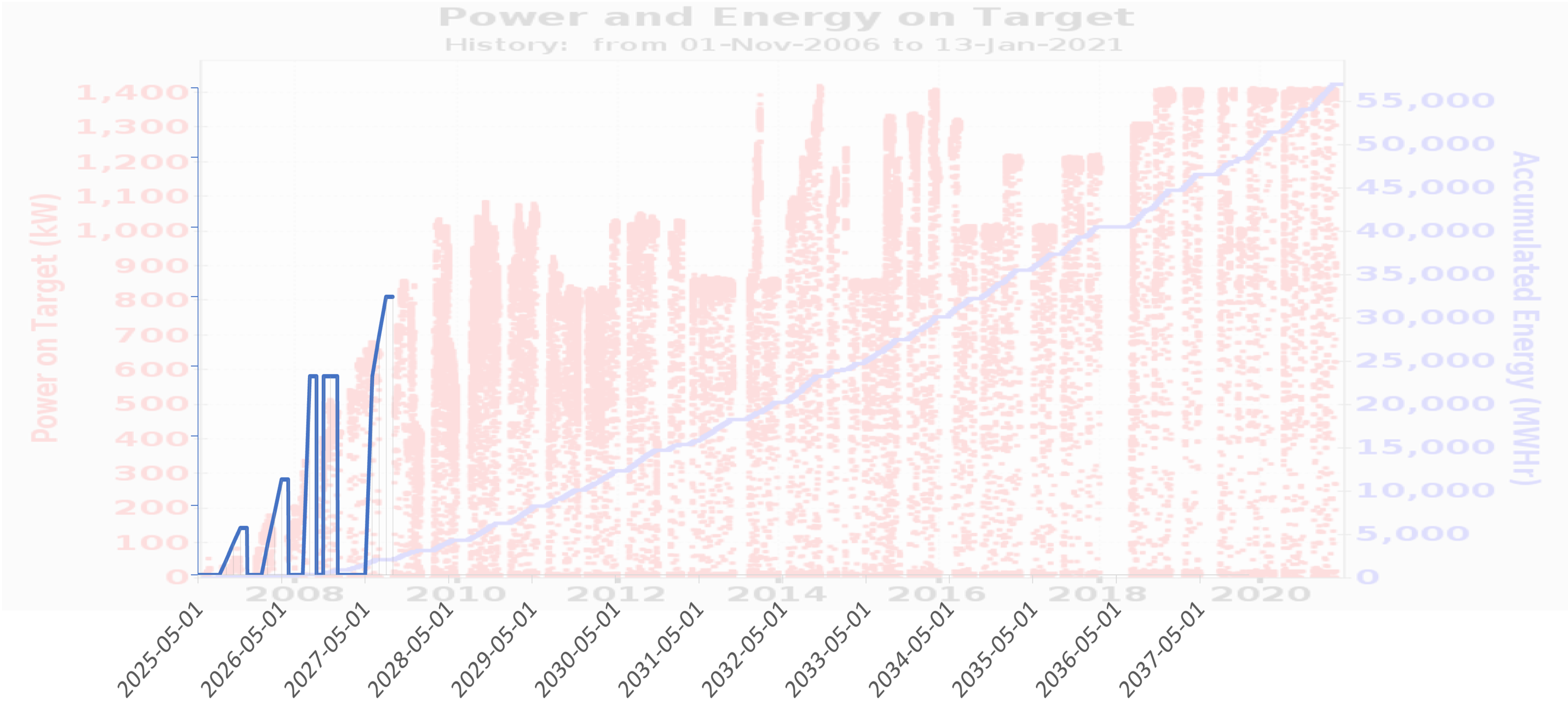




W	3.61	MeV
dW	13	keV
dφ	2.6	deg

Power ramp up

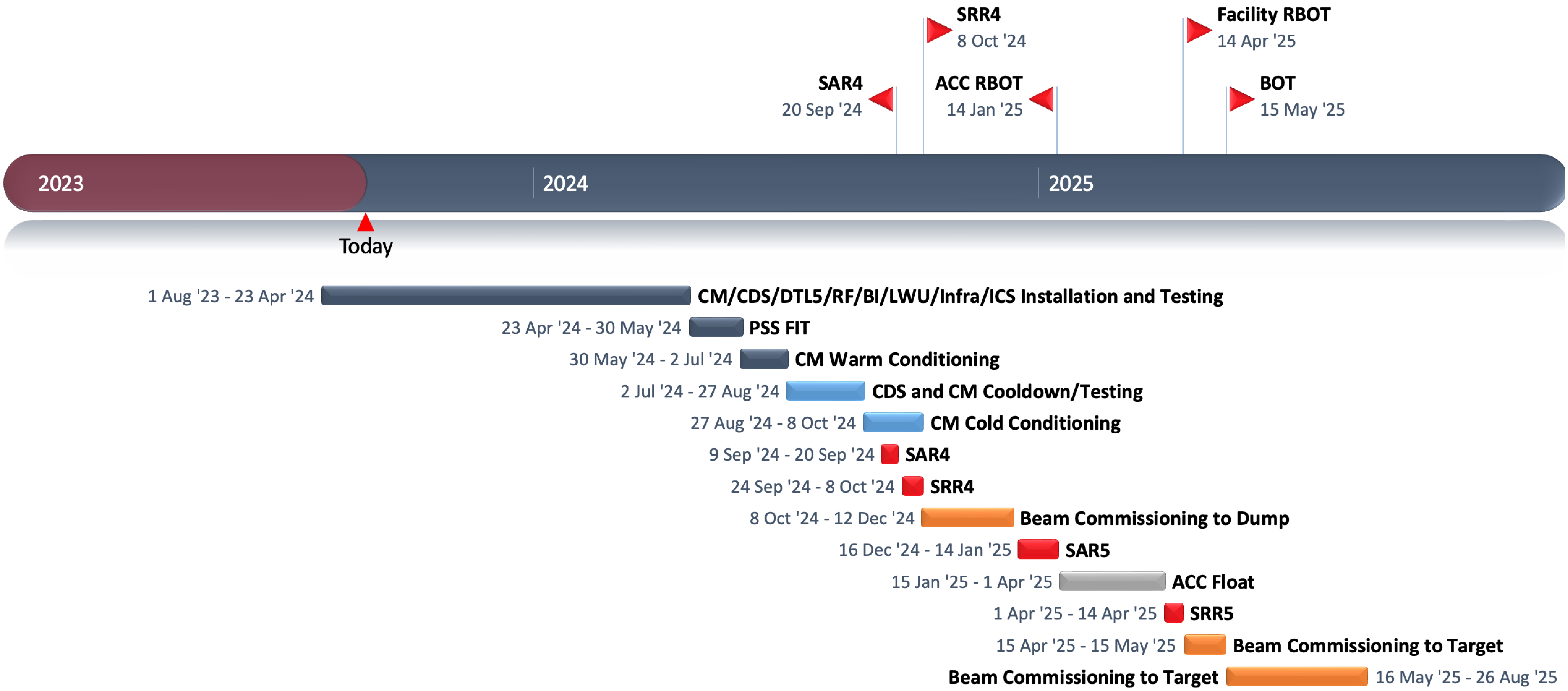
Before the Start of the user operation



SNS power ramp up: Andrei Shishlo, ESS: Andreas Jansson

ESS Challenges

Time



ESS

Energy Consumption per Discipline

2022 June

Energy

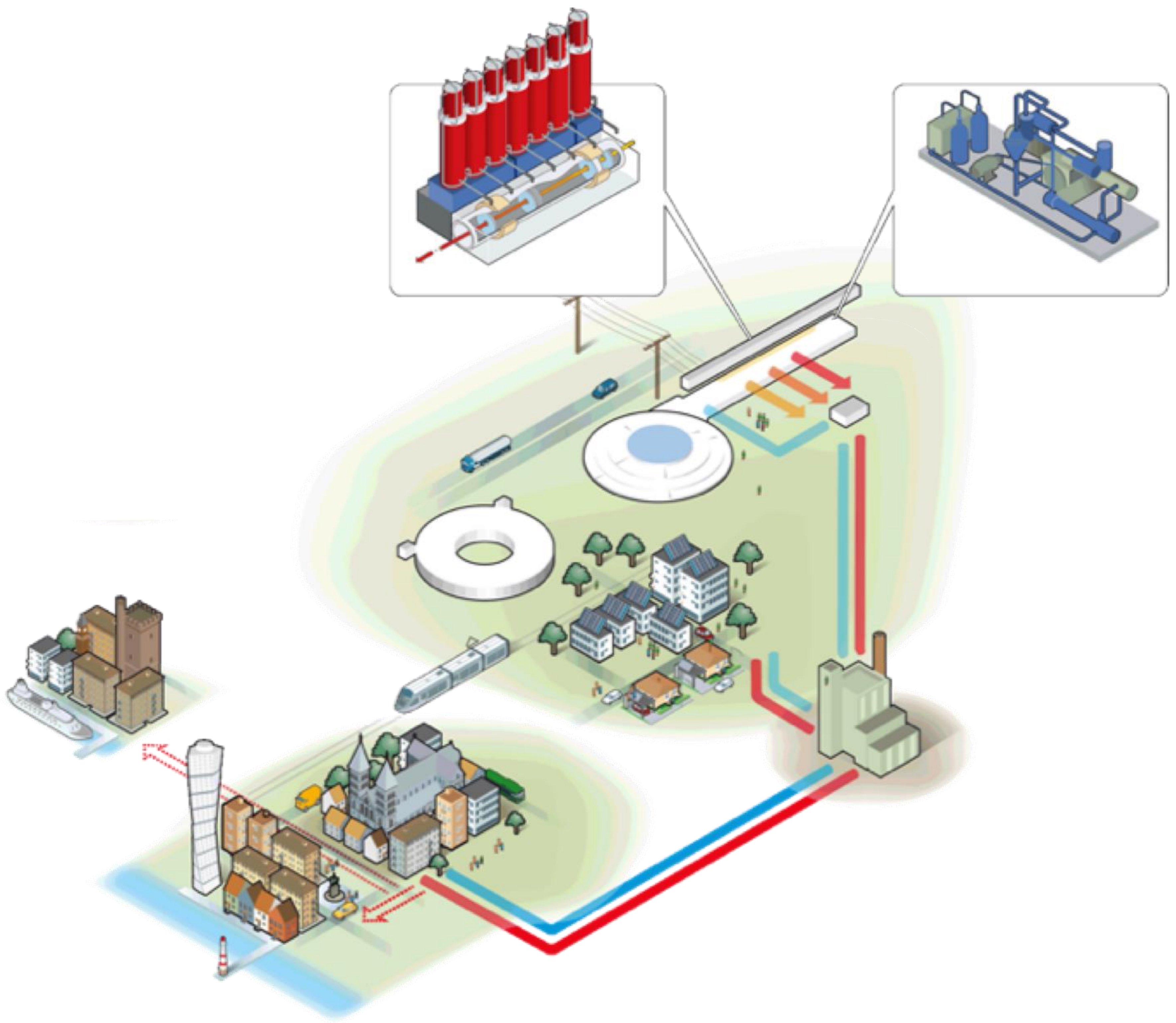
Responsible, Renewable, Recyclable (Reliable)

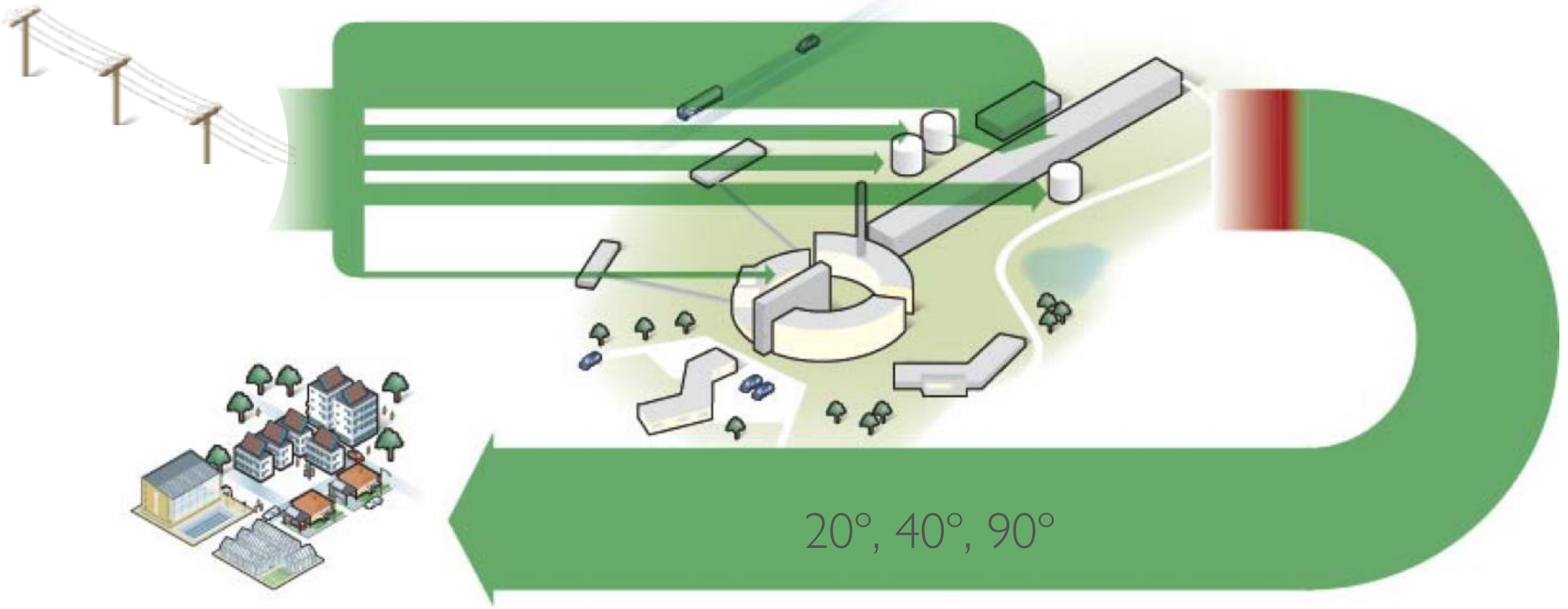

SVENSKA INNOVATIONSKLIMATET

Energikrisen kan stänga forskningsanläggning

Bild: Björn Lindgren/TT

Stigande elpriser och prisökningar riskerar leda till att forskningsanläggningen Max IV i Lund kan stängas tillfälligt, skriver Sydsvenskan.

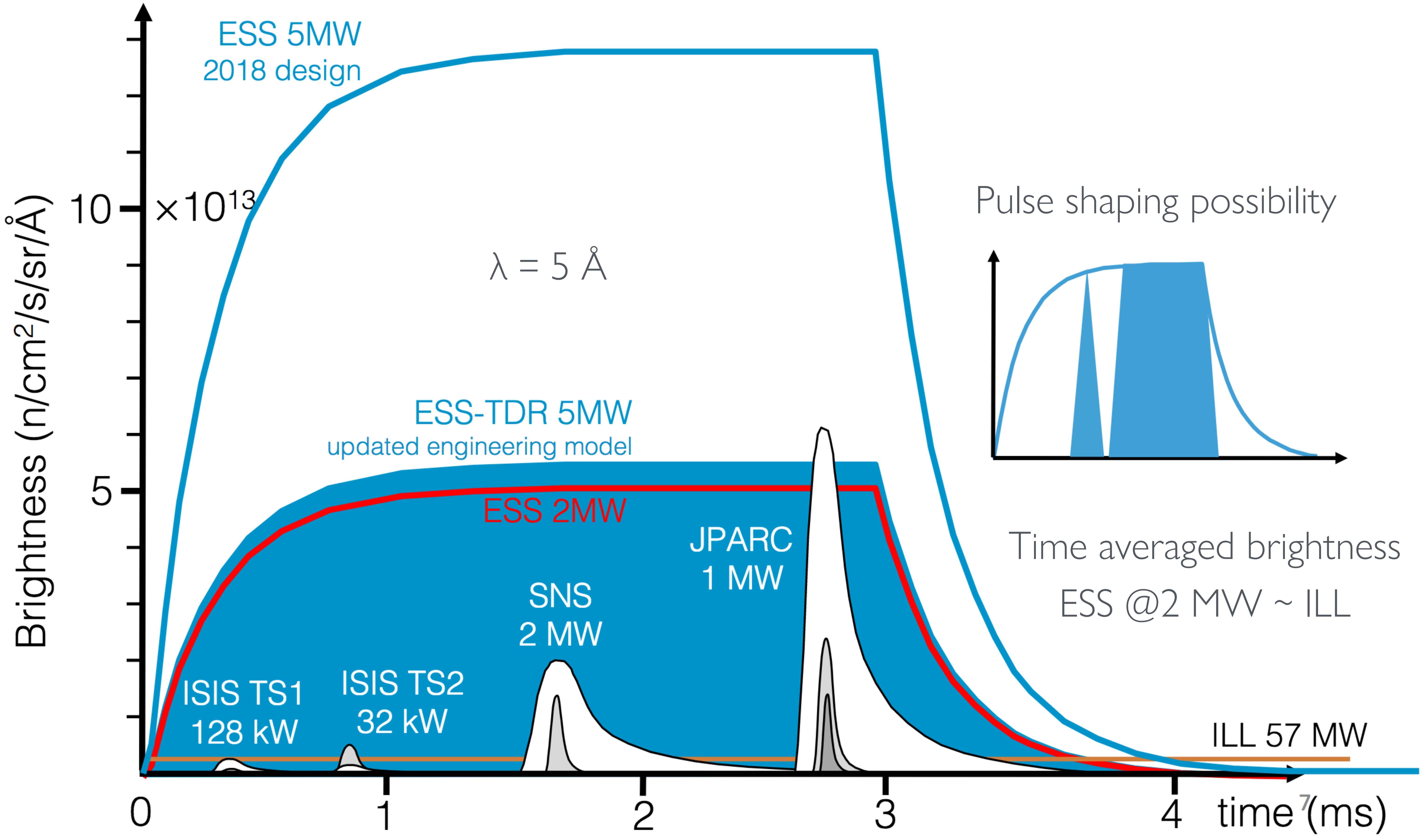




Colin Carlile, Thomas Parker

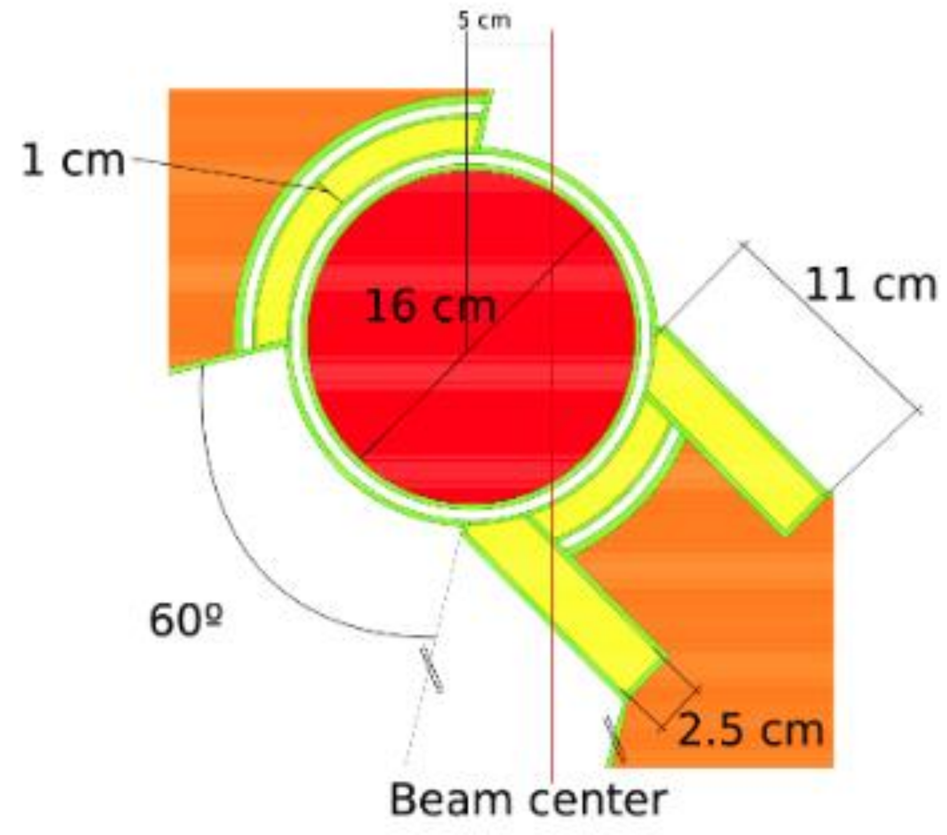
Long Pulse Source

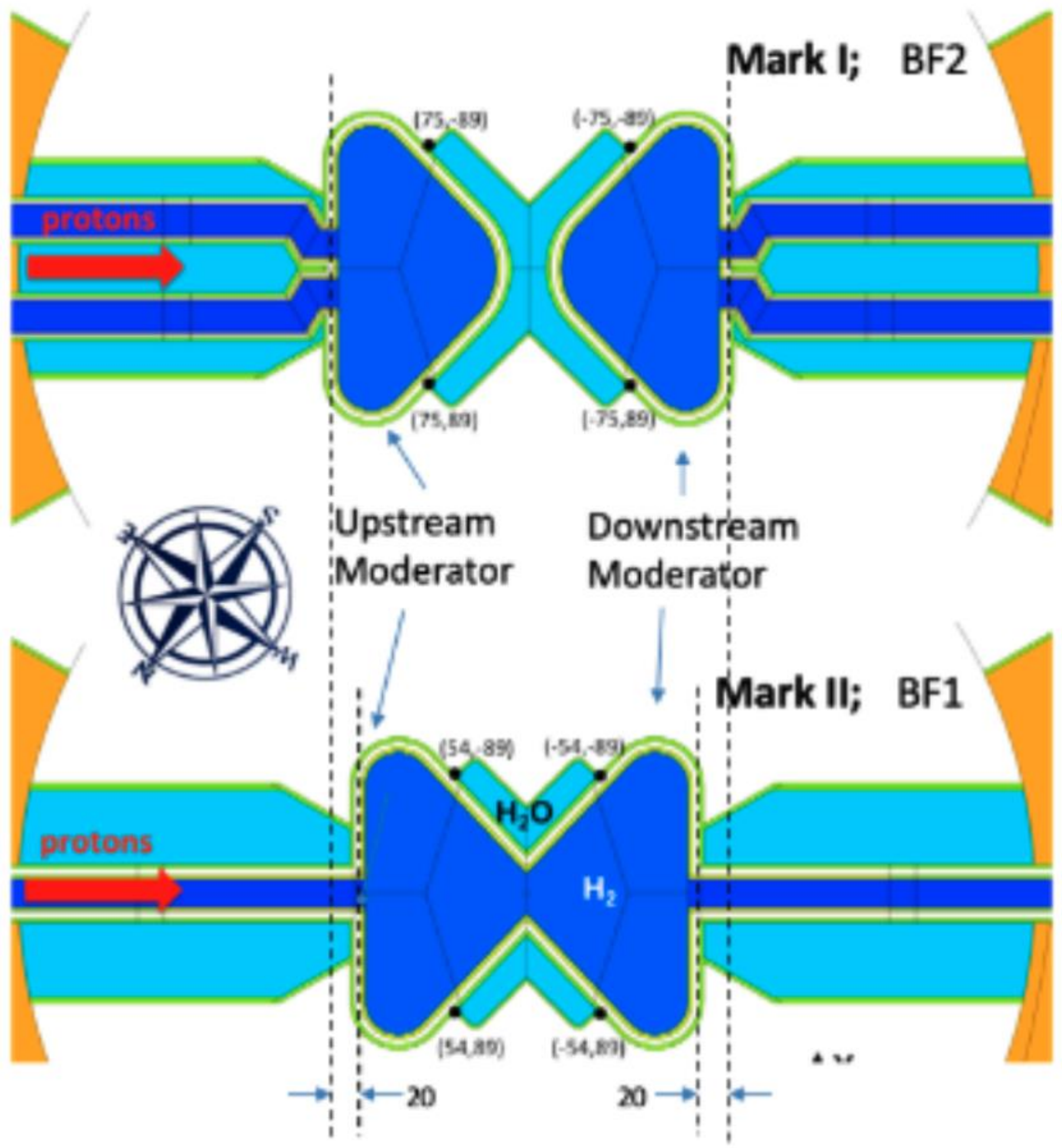
Moderator evolution



Pulse shaping possibility

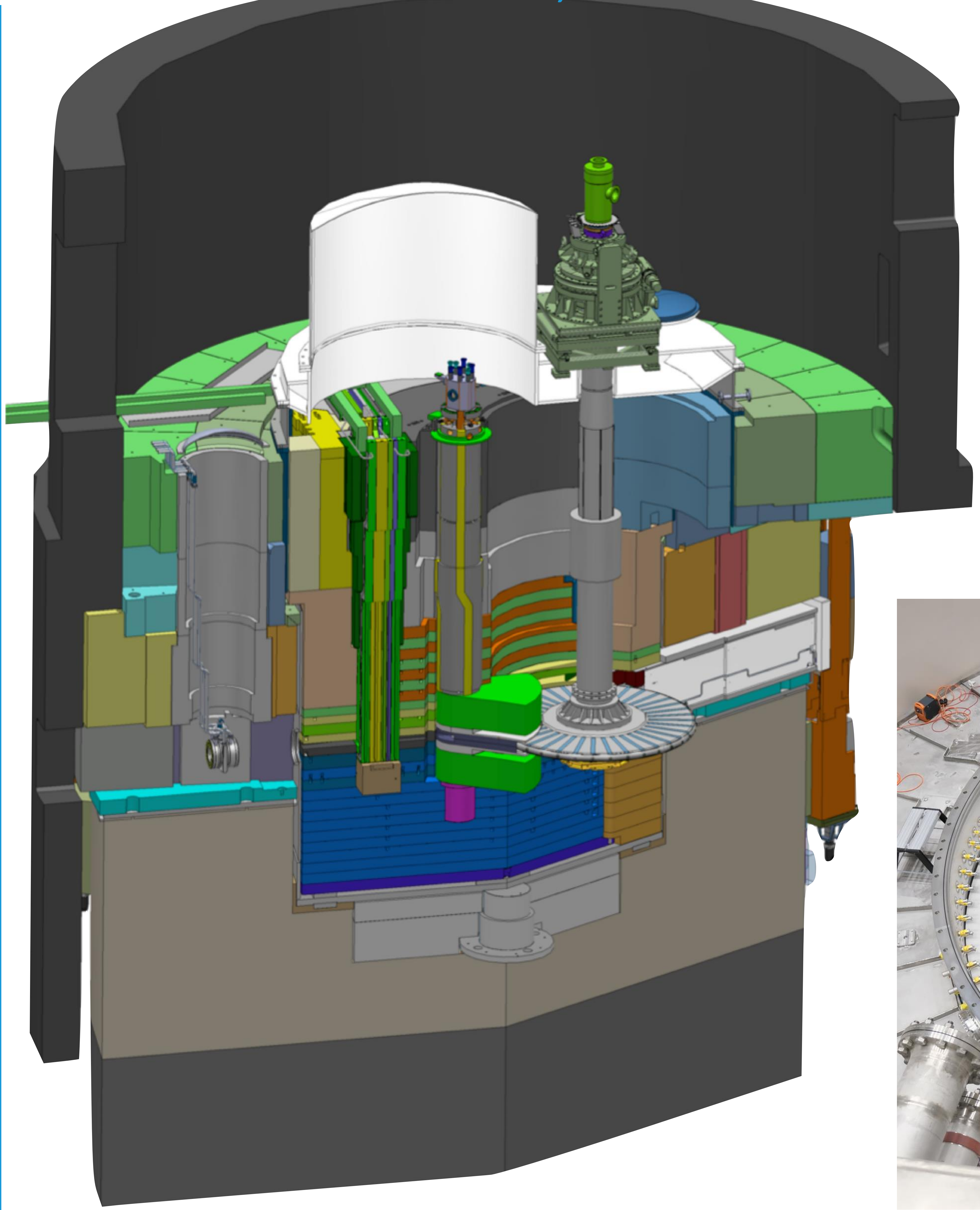
Time averaged brightness
ESS @2 MW ~ ILL

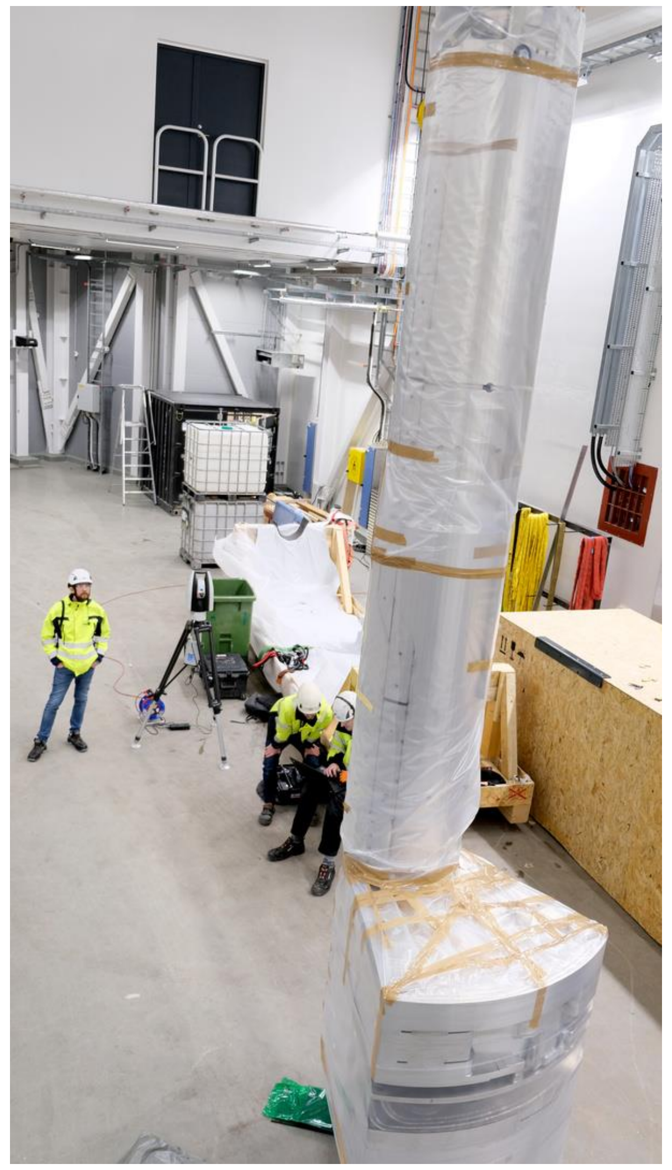


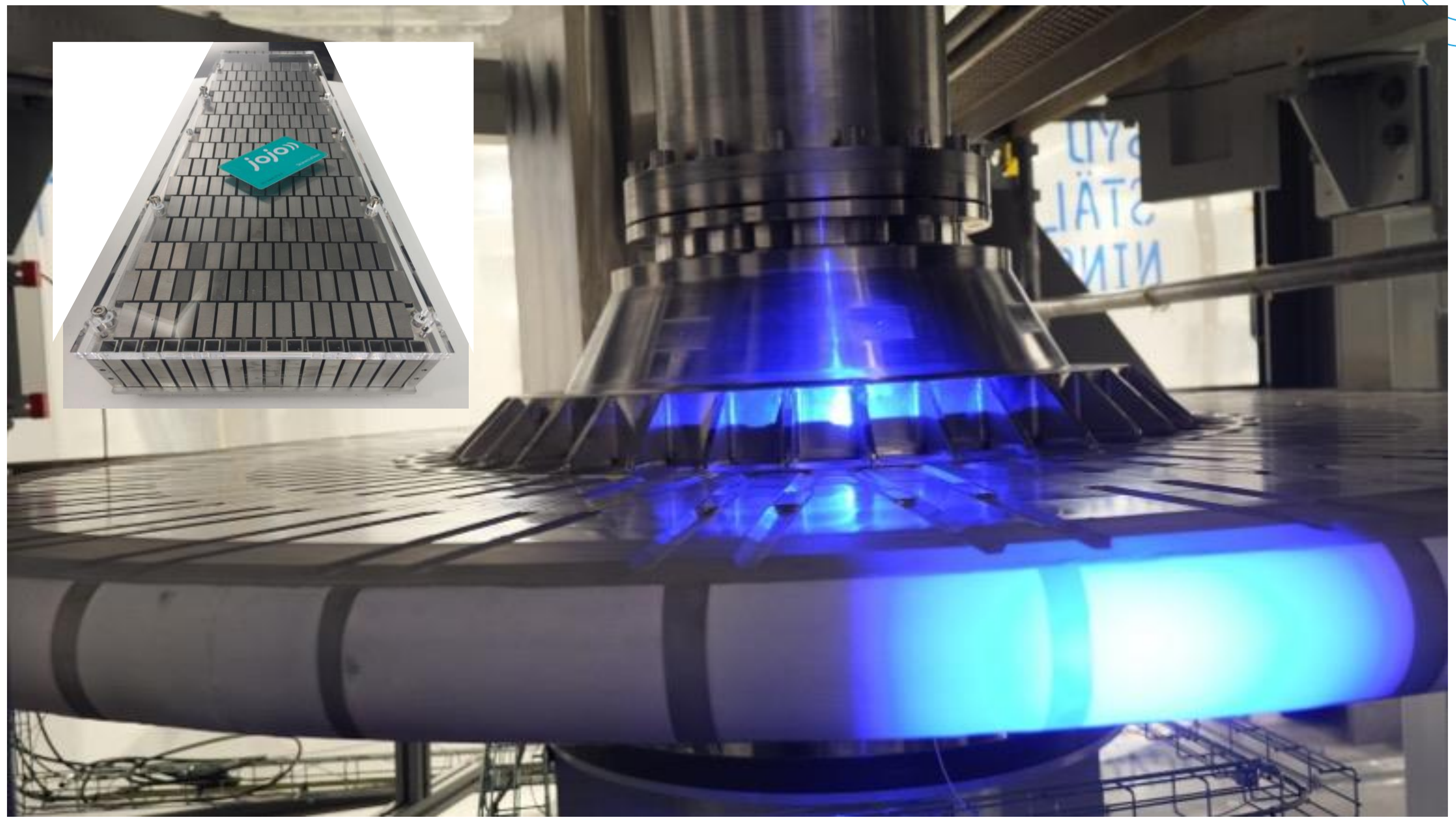


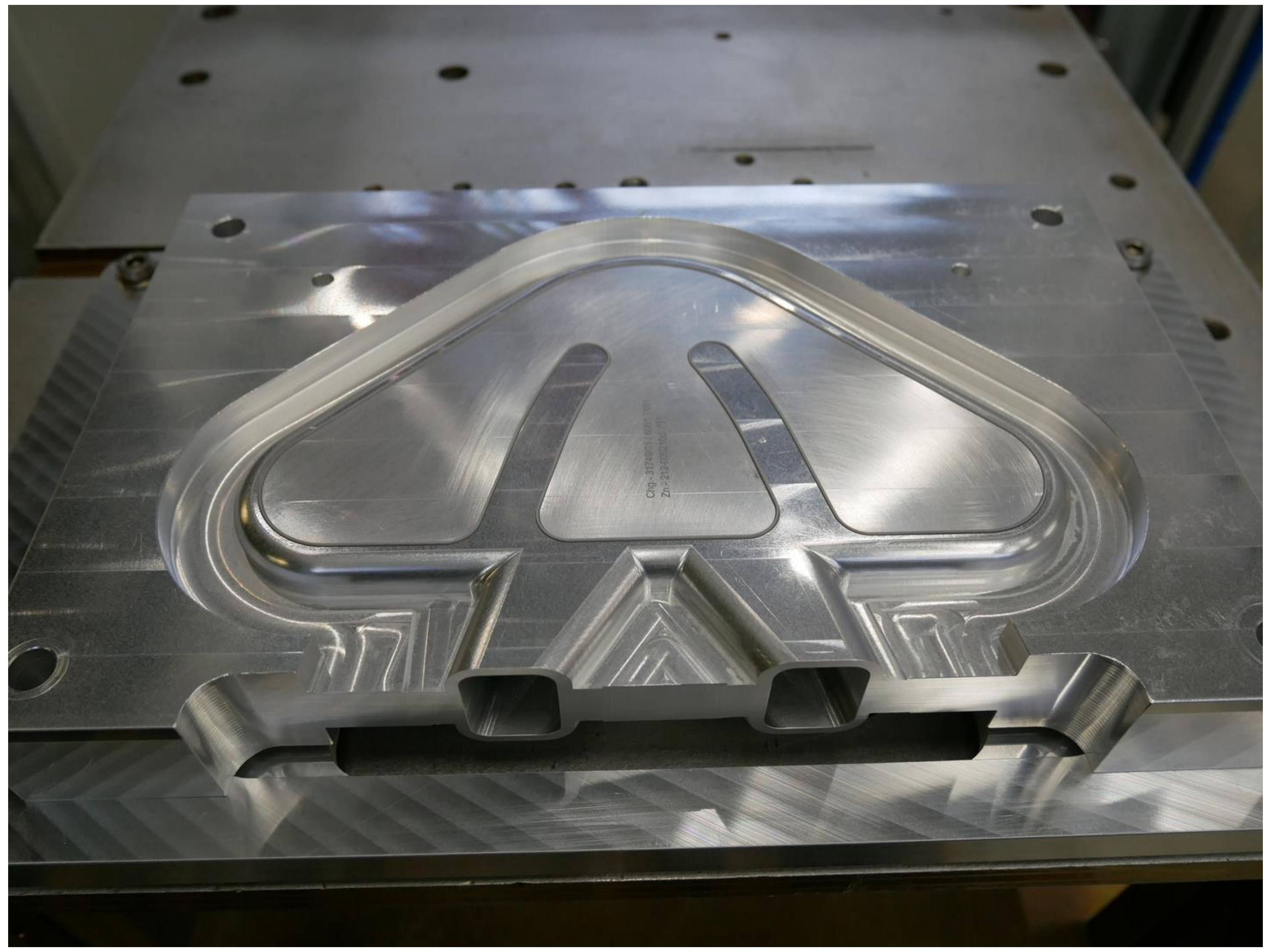
Target

Rotating tungsten wheel, moderator







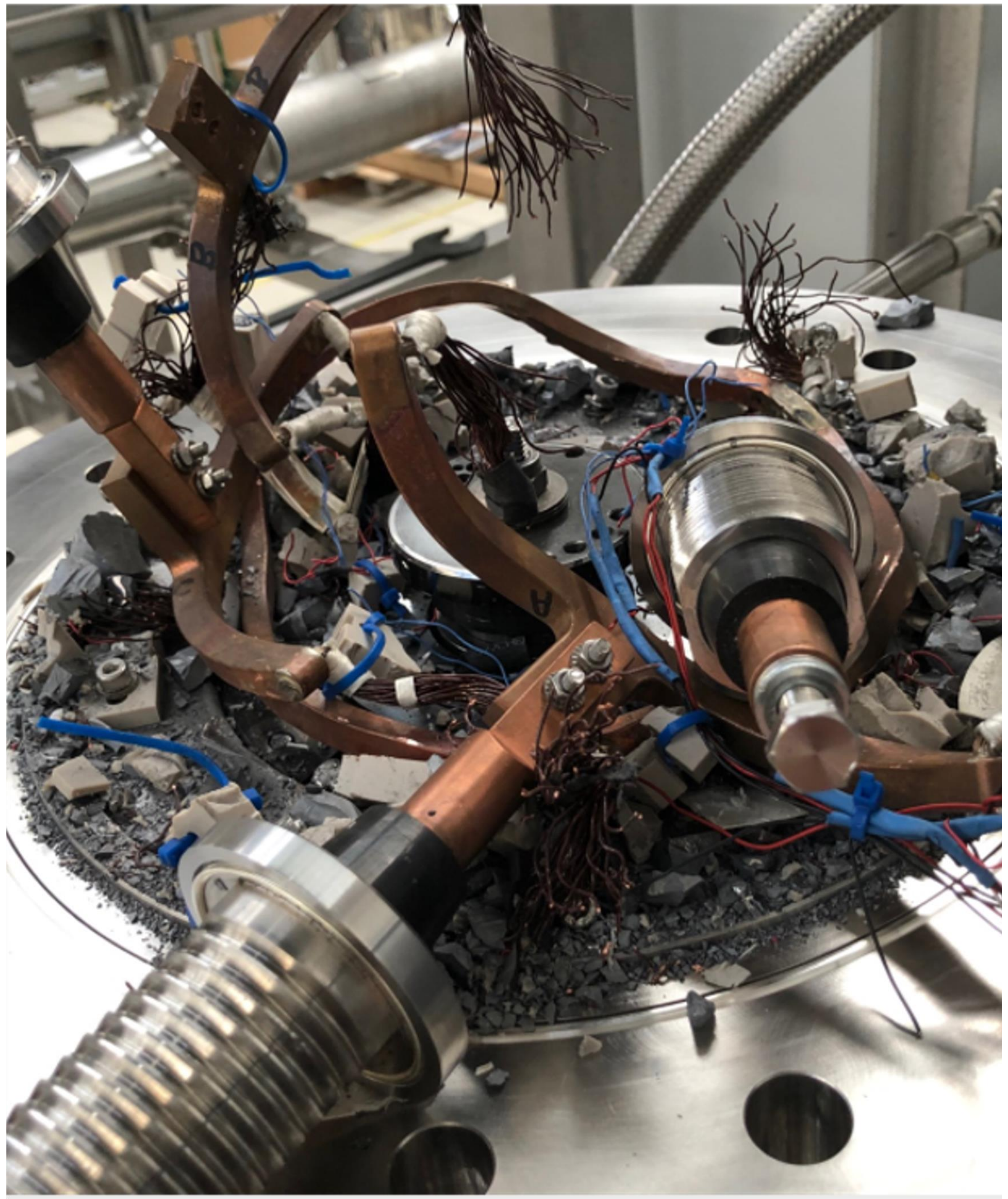


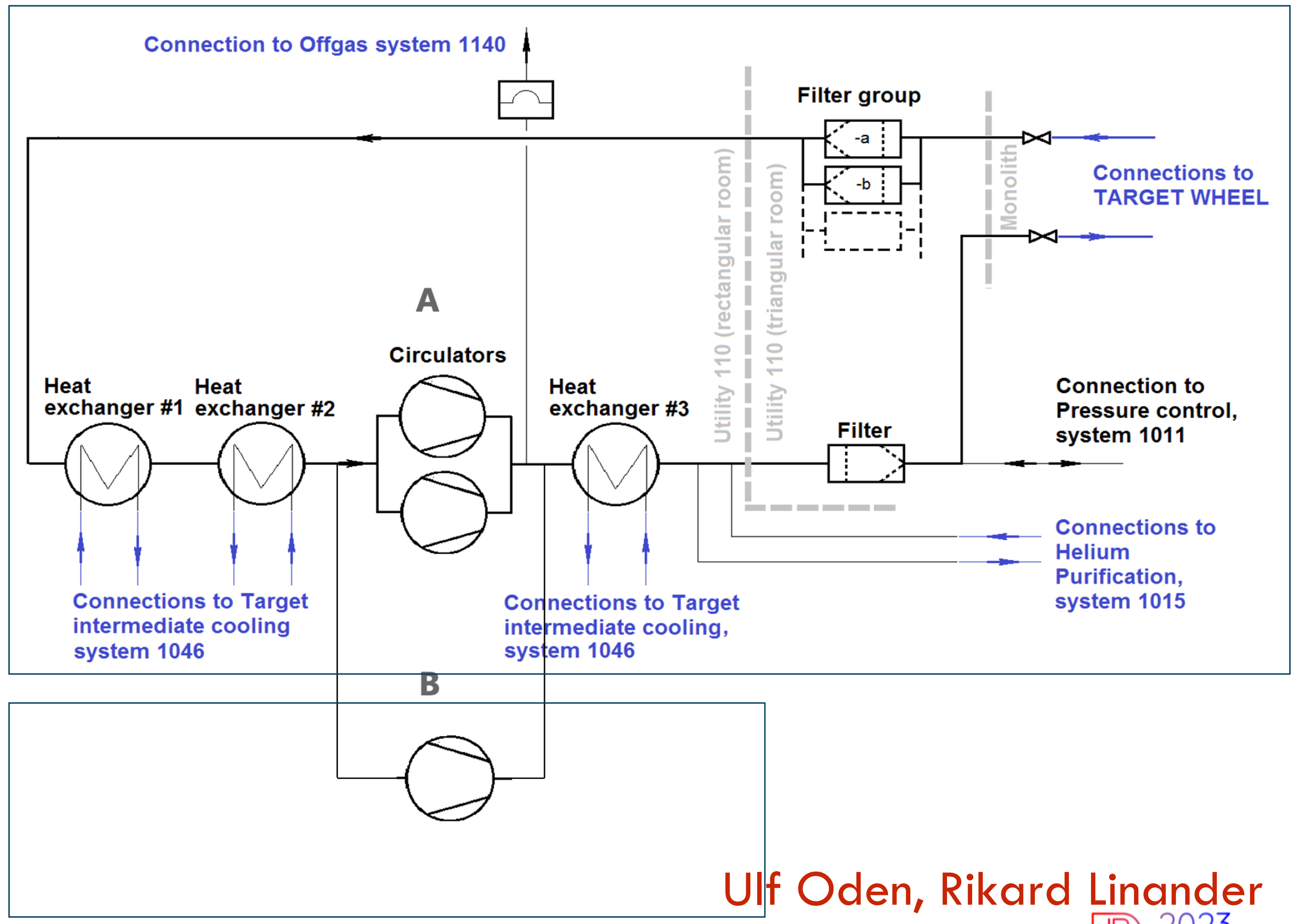
Target

Cooling a 5 MW target and its challenges

- Generated heat load (5 MW) 3 MW
- Helium Mass Flow 2.85 kg/s
  - Target Wheel requirement   2.7 kg/s
  - Trip limits (MPS 1.8 and TSS 1.75 kg/s)
- Outlet Pressure   1.1MPa
  - Pressure raise >140 kPa
- Target Shaft inlet temp 40°C
  - Temperature raise ~200 °C
- Radioactive particles 10g/y

- Two optional remedial solutions considered
  - Recovery of the failed machines (option A)
  - Acquisition of other machine(s), of different type of technology (option B)



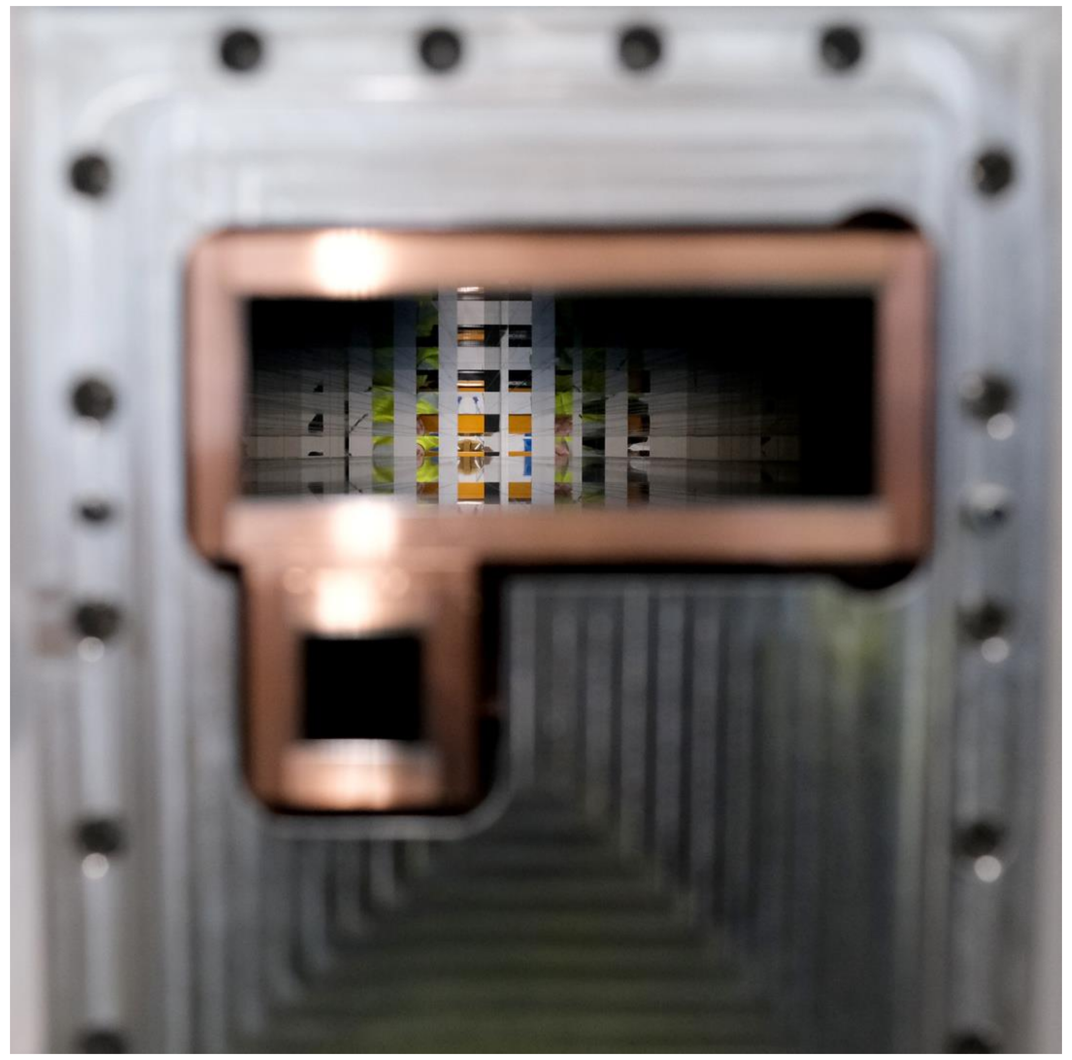


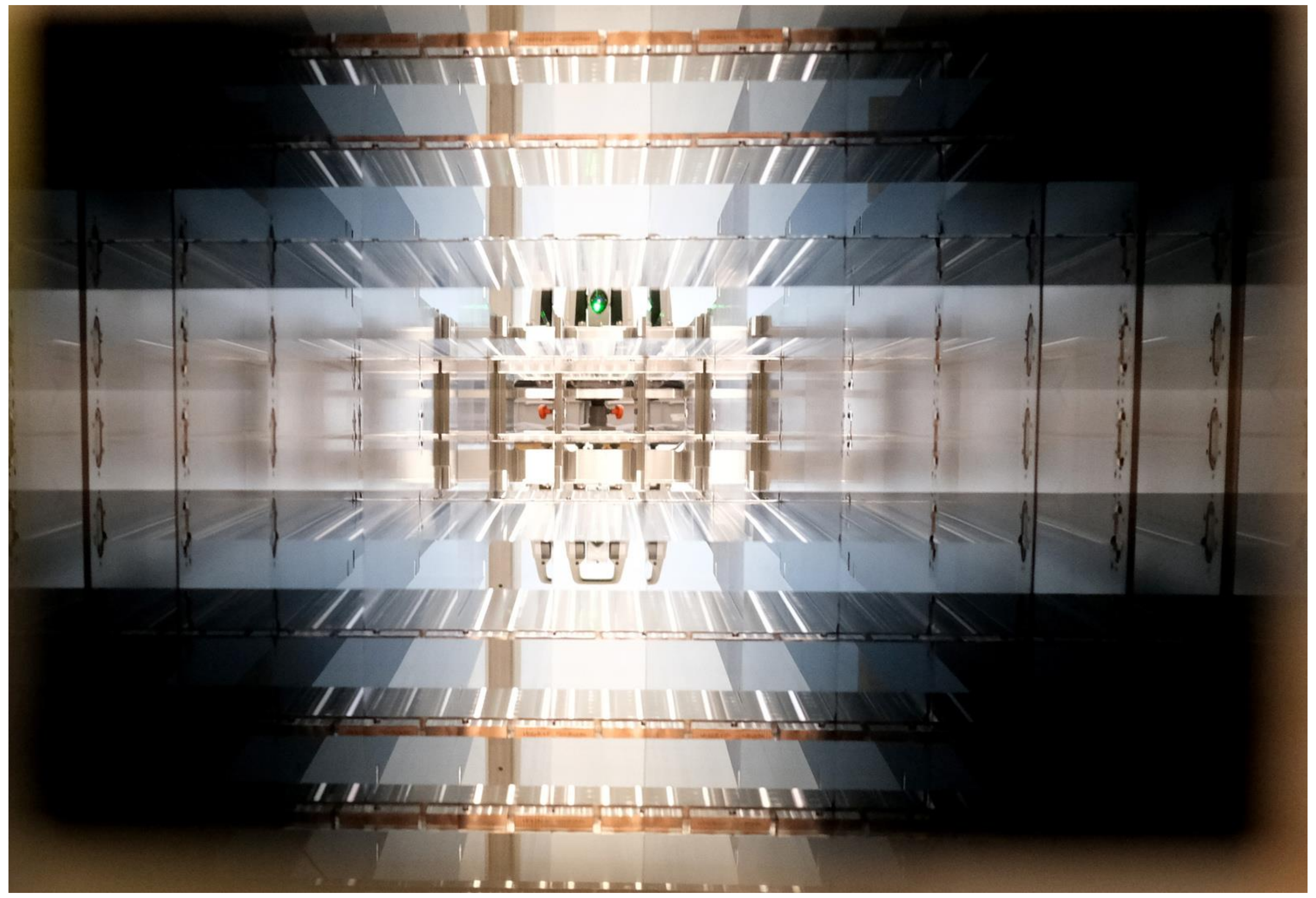
Ulf Oden, Rikard Linander

Delivering neutrons

From the neutron beam extraction port to the experiment





NMX

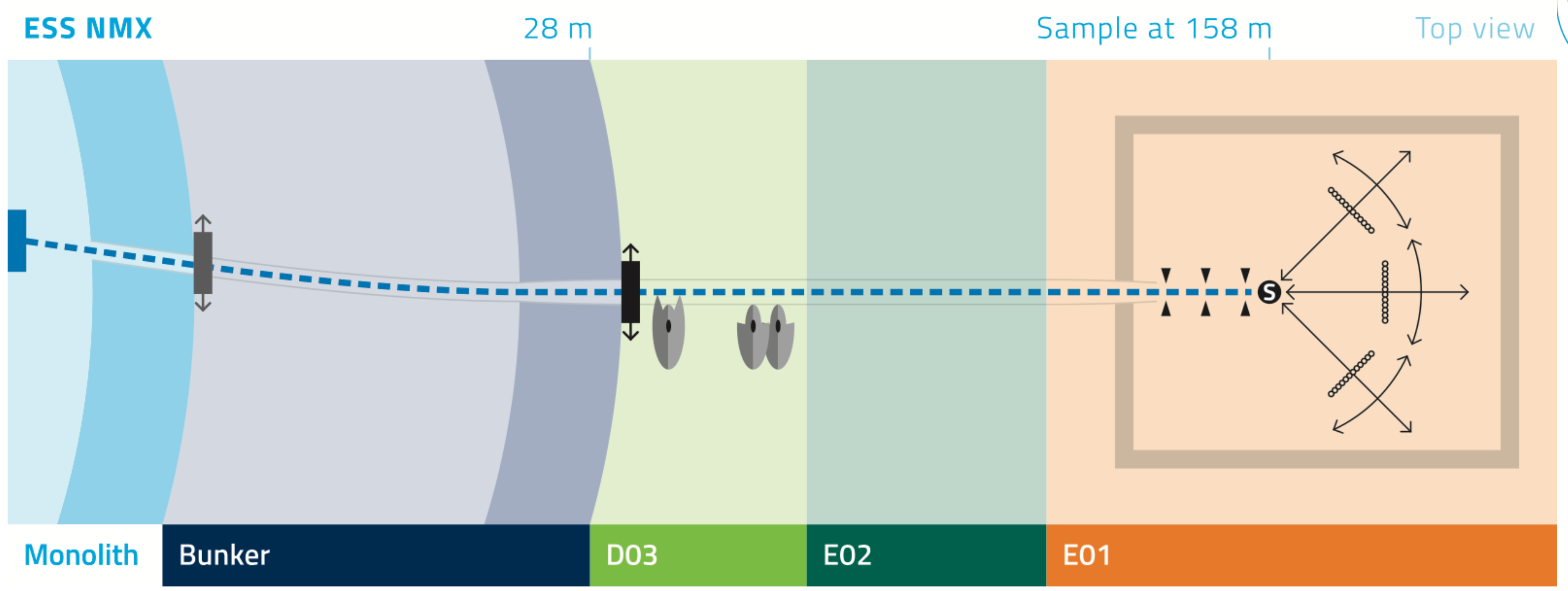
Macromolecular Diffractometer

- By Monte Carlo simulation 2 x 10^9 n/s/cm^2 at ±0.2° divergence
- LADI-III (ILL) 5 x 10^7 n/s/cm^2, divergence unclear (factor of 40)
- PCS (LANSCE) 9.7 x 10^6 n/s/cm^2 at ±0.1° divergence (factor of 200)

- NMX makes full use of the long pulse and high-brilliance moderators

- Should be realistic to collect 0.1 mm^3 crystal in < 1 day
  - The instrument should allow data collection from crystals of < 0.01 mm^3 volume

- NMX uses Gd detectors, several other instruments use ^{3}He



In-Kind

Accelerator collaboration

In-Kind

Accelerator collaboration

- It would've been impossible to build ESS without our in kind partners!
- Green field site and no existing organization.
- Very few labs*, read no one,* can build everything in house. For a green field site, this is not an option.
- In kind provides access to intellectual property, competence and qualified manpower (including procurement staff) at partner labs.
- For the member countries, it is a way to get local return on investment in a facility located in a different country.

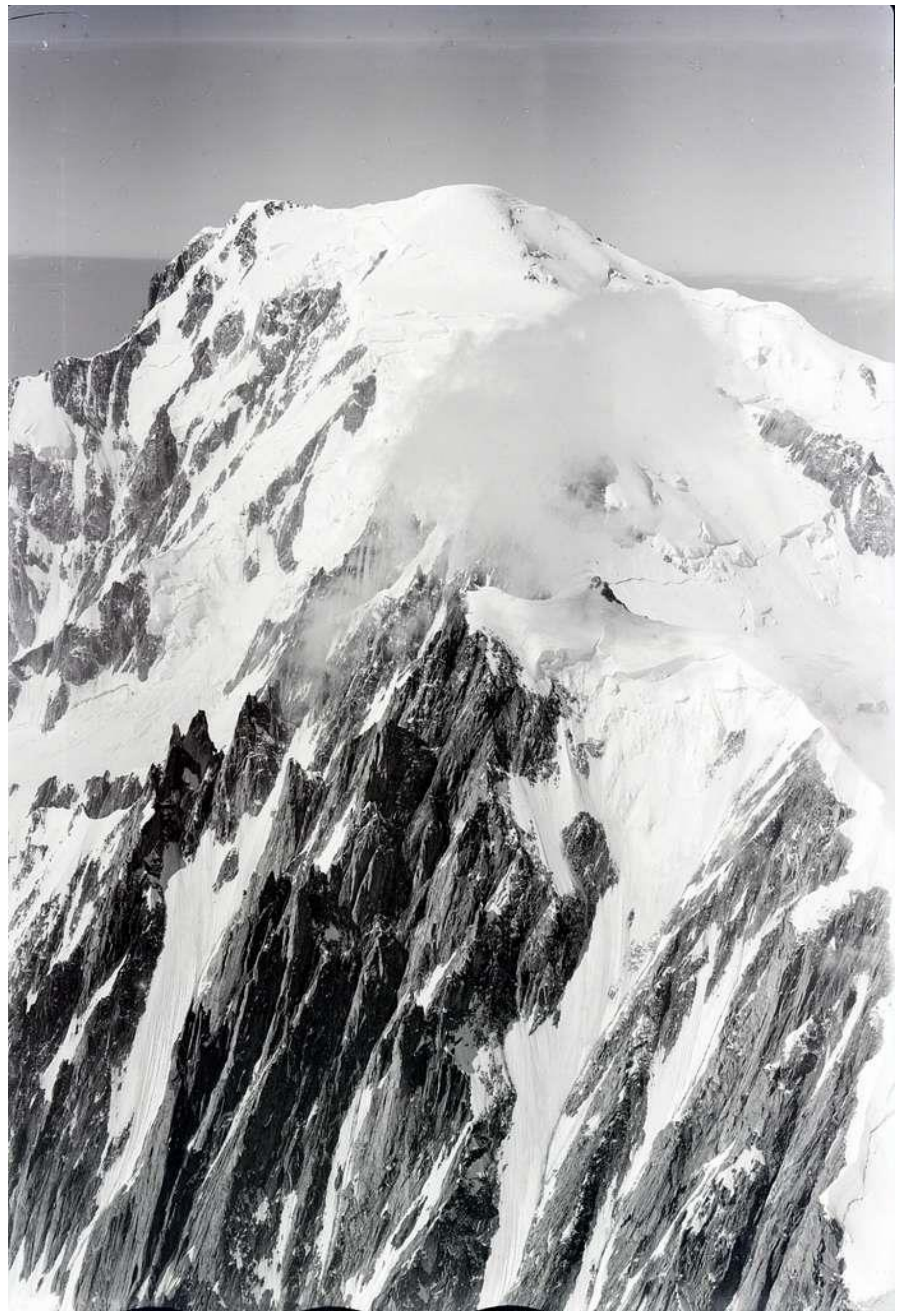
ESS Challenges
In-Kind

- Scope sometimes divided based on partner lab preferences and interest rather than according to functional breakdown.
  - Can lead to complicated interfaces
  - (and problems tend to happen at the interfaces)
- Partner lab priorities may change after agreements signed
- Partner labs may want to take on scope to expand their competence in areas where they have limited experience.
- Partner labs may lose critical competence, which may not be replaced in time.
- For scope that is procured from industry, adding another communication layer (can be challenging in case issues with vendor need to be resolved)

Summary

Who said we are doing it because it is easy!?

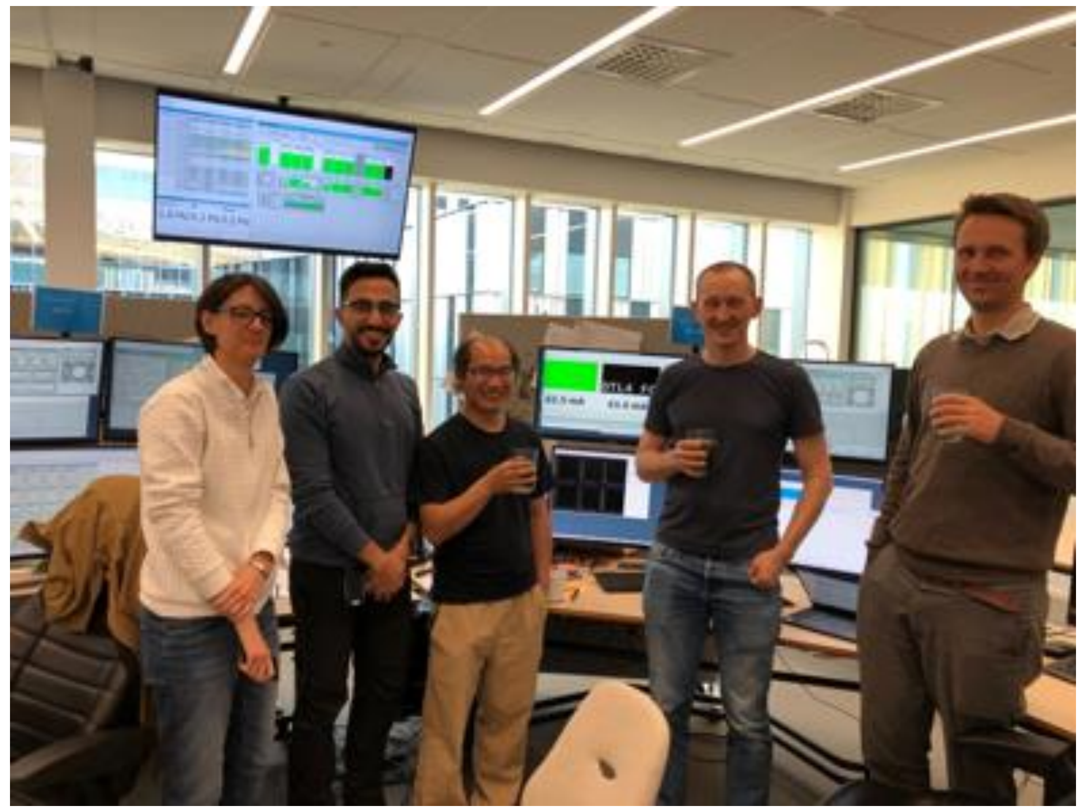
- Intense period at ESS with installation works on several sub-projects:
  - Accelerator installations will be done by Q1 2024 for beam on dump and beam on target
  - Target installations will be largely finalised by end-2023
  - Instruments are planned in three groups, the first group will have most of the installations done by late 2024
- Test and commissioning activities will be in focus for the coming year before beam commissioning in Q3 2024
- Highly innovative, first-of-a-kind technical solutions have been pursued, these impose challenges on both costs and schedule, and is associated with a certain level of risks.
- Building the ESS was made possible with the support of our in kind partners!



Mont citron: CERN, Mont Blanc: ETH-Bibliothek

One team, one dream

… and many more people



Thank you!

Other ESS contributions:

Juan F. Esteban Müller: Council Chamber, Tuesday 12:30
Evaluating PyORBIT as Unified Simulation Tool for Beam-Dynamics Modeling of the ESS Linac

Yngve Levinsen: Main Auditorium, Tuesday 15:20
ESS Normal Conducting Linac Commissioning Results

Elena M. Donegani: Council Chamber, Friday 9:00
The Beam Destinations for the commissioning of the ESS high power normal conducting linac

Cyrille Thomas, Poster area, Thursday (THBP46)
Simulation of the ESS proton beam window scattering

Photos courtesy of Ulrika Hammarlund