



Commissioning progress of the ESS linear accelerator

IPAC 2026

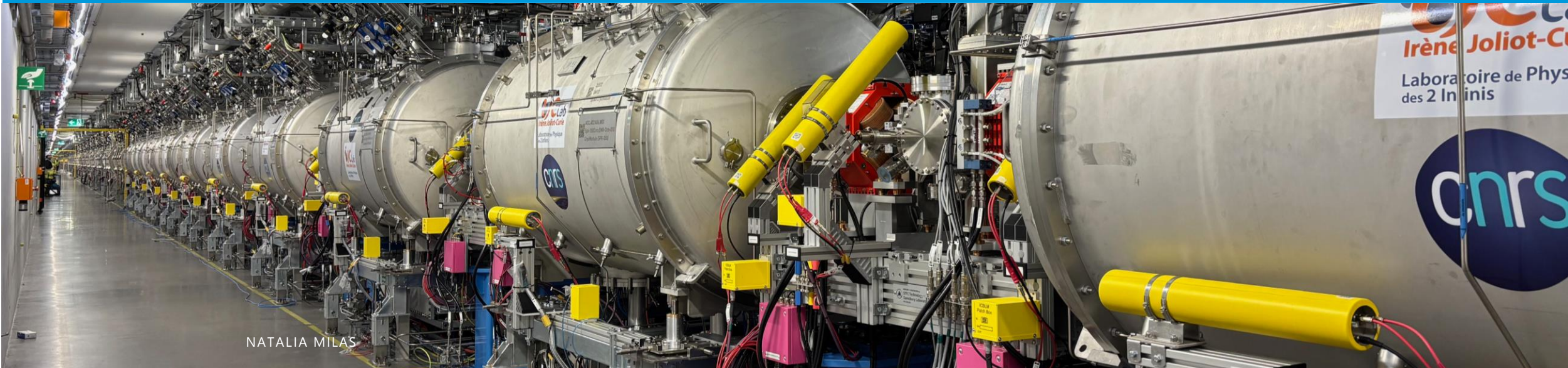
NATALIA MILAS, ON BEHALF OF THE COMMISSIONING TEAM

2026-05-13



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The European Spallation Source



ESS

Klystron gallery

Accelerator tunnel

Cryo-Compressor Bldg.

Cold box

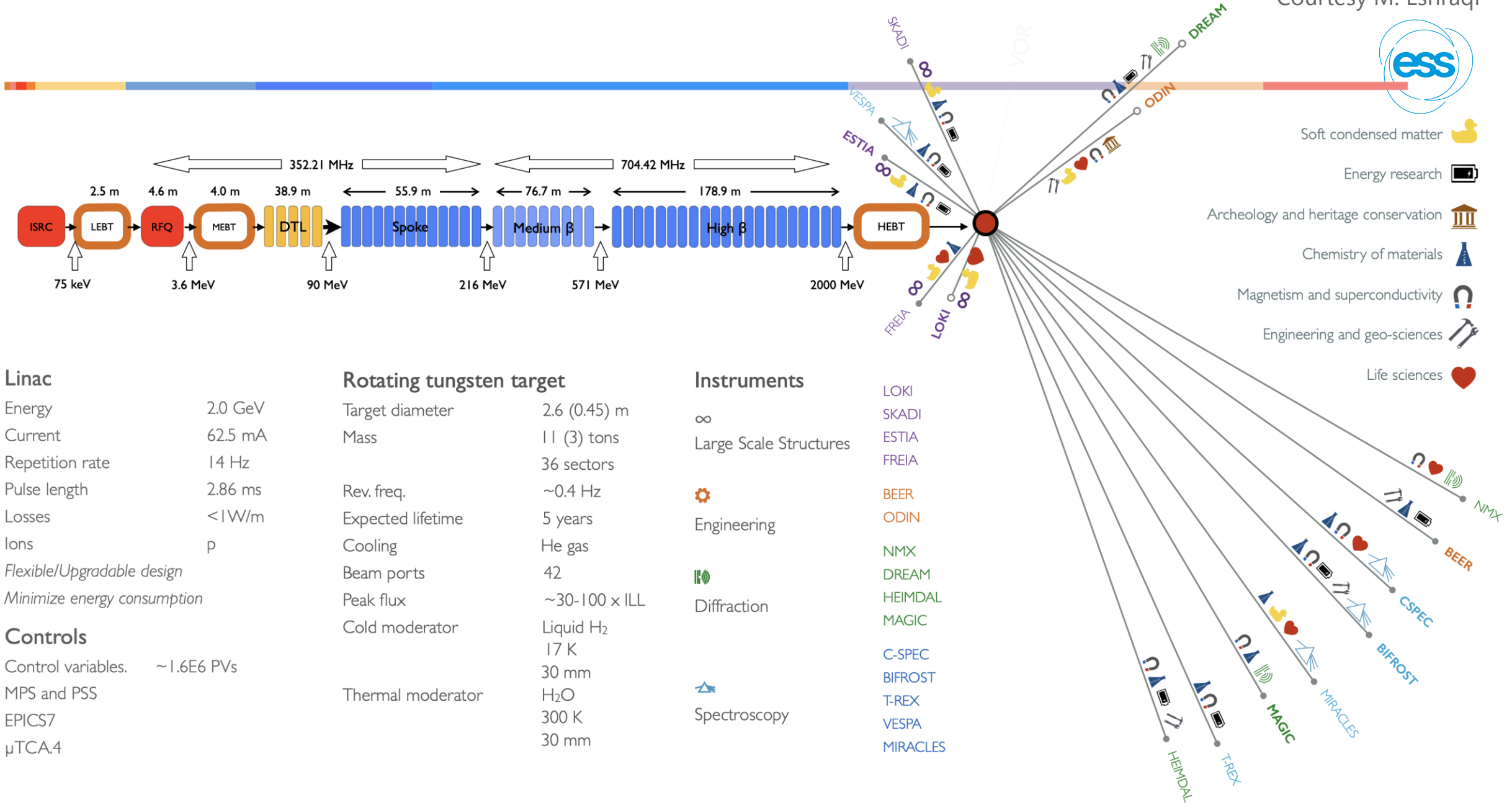
Target bldg.

Instruments

Offices

2022 June





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 ₂ O 300 K 30 mm

Instruments

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



In-Kind Partners



Czech Republic

- Nuclear Physics Institute of the CAS



Denmark

- Aarhus University
- Roskilde University
- Technical University of Denmark (DTU)
- University of Copenhagen



Estonia

- Tallinn University of Technology
- University of Tartu



France

- Laboratoire Léon Brillouin (LLB)
- National Center for Scientific Research (CNRS)
- French Alternative Energies and Atomic Energy Commission (CEA)



Germany

- Forschungszentrum Jülich
- Helmholtz-Zentrum Geesthacht
- Technical University of Munich



Hungary

- Hungarian Academy of Sciences - Centre for Energy Research
- Hungarian Academy of Sciences - Institute for Nuclear Research (ATOMKI)
- Wigner Research Centre for Physics



Italy

- National Institute for Nuclear Physics (INFN)
- Elettra Sincrotrone Trieste
- National Research Council of Italy (CNR)



Norway

- Institute for Energy Technology (IFE)
- University of Bergen
- University of Oslo



Poland

- Henryk Niewodni Institute of Nuclear Physics (IFJ PAN)
- National Center for Nuclear Research
- Polska Grupa Energetyczna
- Technical University of Lodz
- Warsaw University of Technology
- Wroclaw University of Science and Technology (WUST)



Spain

- ESS Bilbao Consortium



Sweden

- Lund University
- University West
- Uppsala University



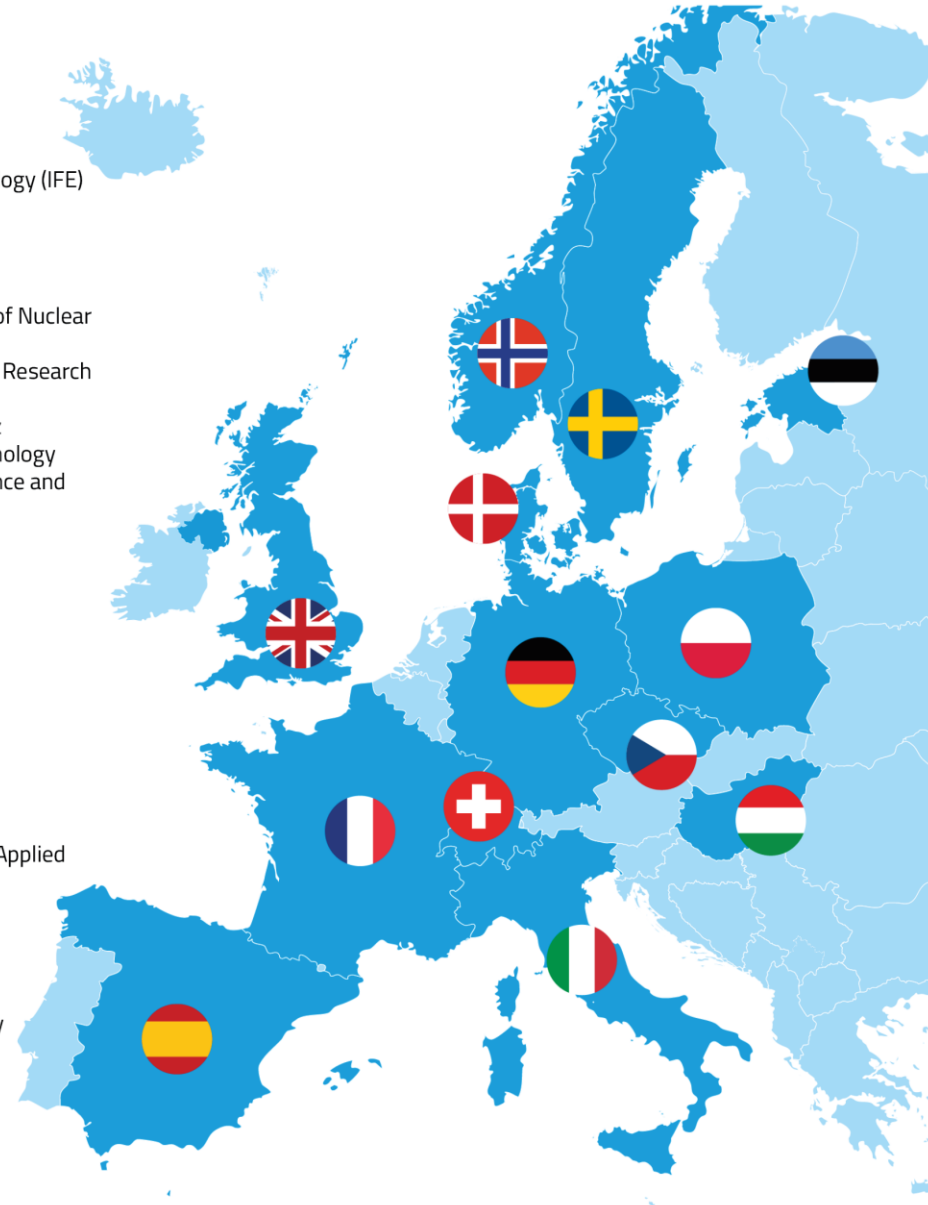
Switzerland

- Paul Scherrer Institute (PSI)
- ZHAW Zurich University of Applied Sciences



United Kingdom

- Science and Technology Facilities Council (STFC)
- UK Atomic Energy Authority (UKAEA)



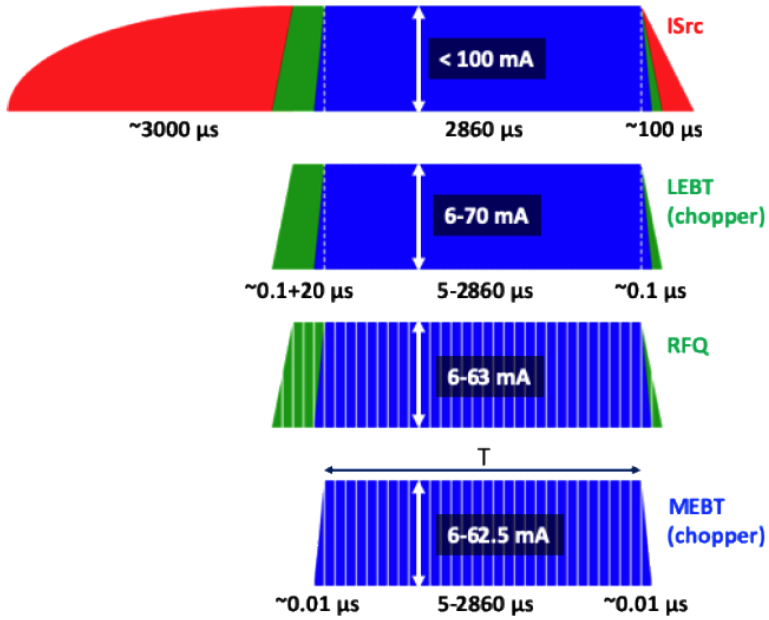
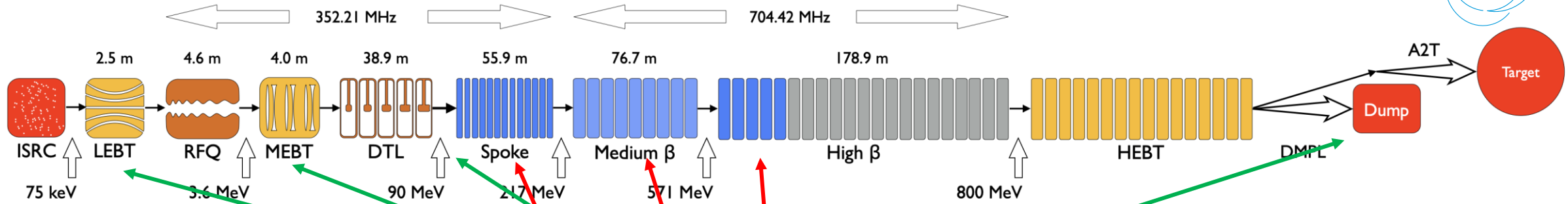
2

Commissioning Timeline

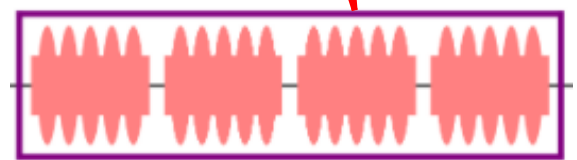


Beam Modes and Destinations

The beam stops for the ESS superconducting linac (MOP7098)

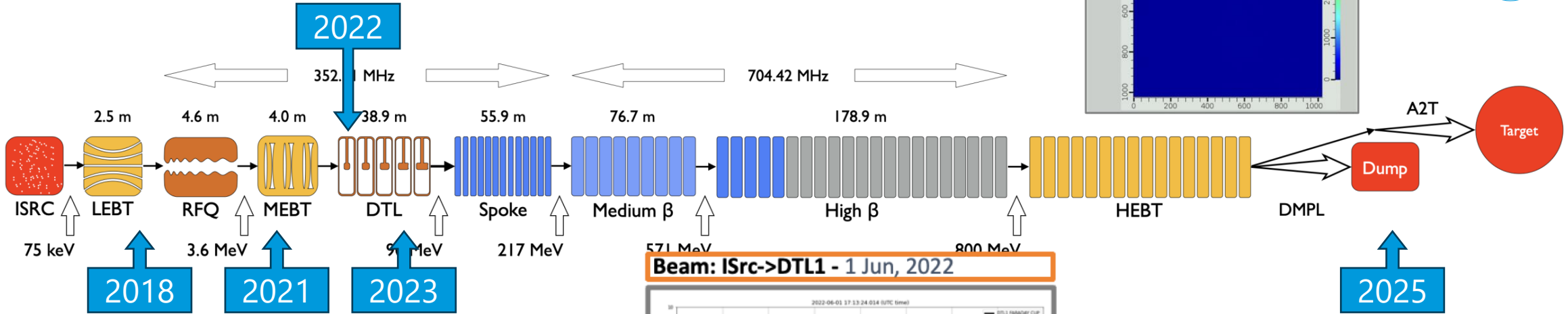


Multiple beam stops

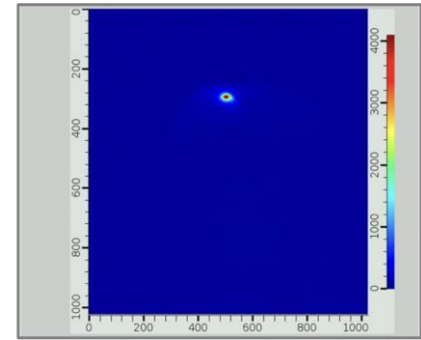


Parameter	Nominal	BOD 2026
Beam Power	5 MW (2 MW)	20 (200) W
Beam Energy	2 GeV (0.88 GeV)	0.8 GeV
Peak Beam current	62.5 mA	6 mA
Beam pulse length	2860 us	5 (50) us
Rep. rate	14 Hz	1 Hz
RF freq	351.21MHz/704MHz	

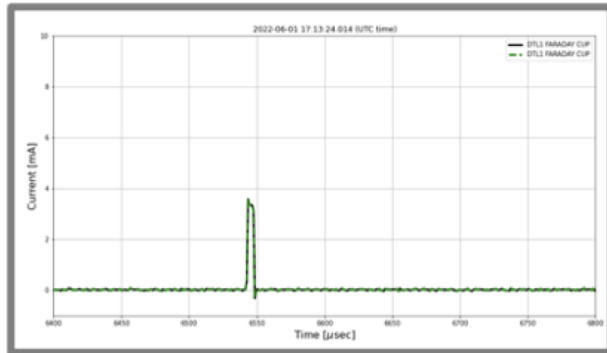
A history in commissioning



Beam: ISrc->TBD - 09 Apr, 2025



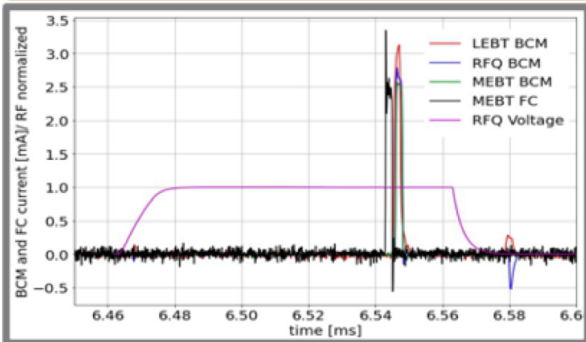
Beam: ISrc->DTL1 - 1 Jun, 2022



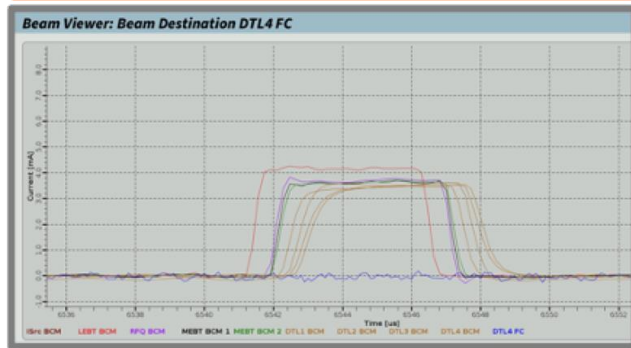
Beam: ISrc->LEBT - 19 Sep, 2018



Beam: ISrc->MEBT - 26 Nov, 2021



Beam: ISrc->DTL4 - 20 Apr, 2023



Commissioning timeline and goals



Beam on Dump part 1 and 2

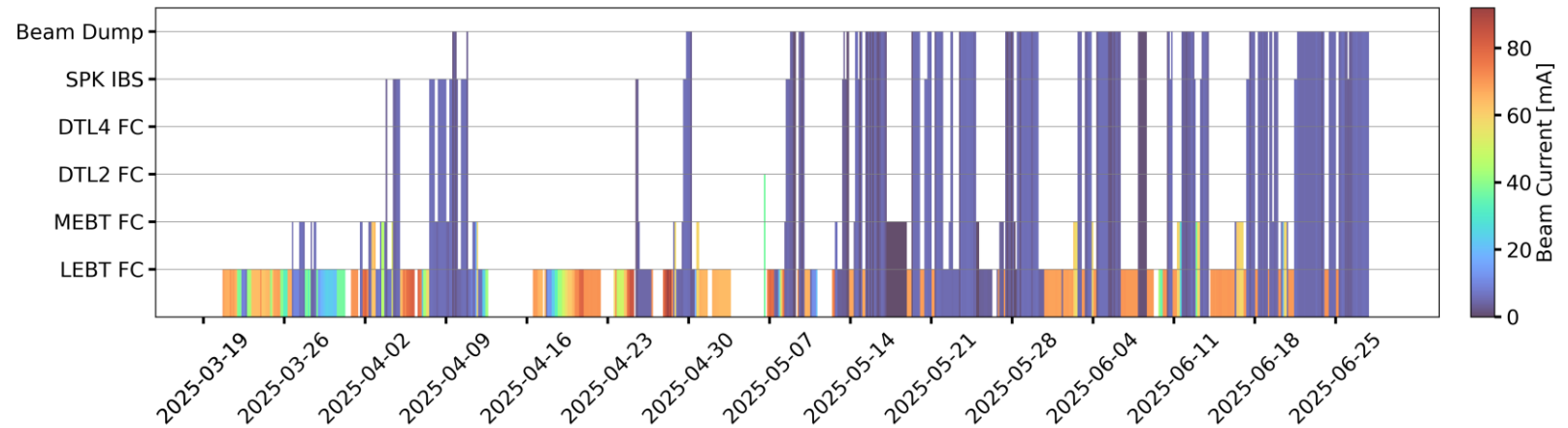
2025 (March to June)

Transport beam to dump

800 MeV

6 mA, 5 μ s

RF at 1 ms



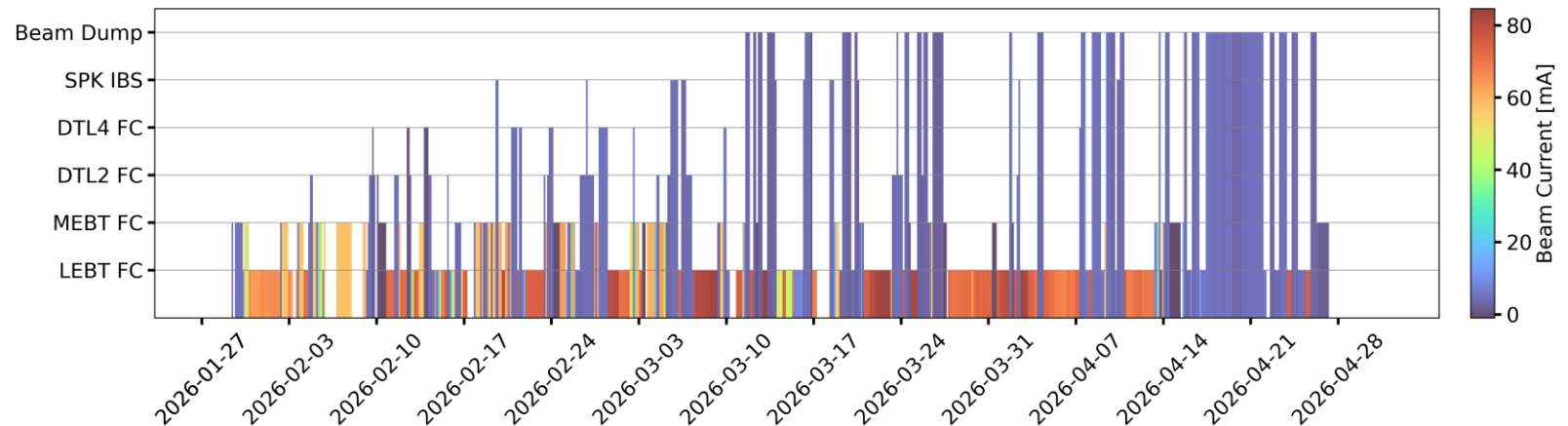
2026 (Jan. to July)

Beam to Target \rightarrow 2027

Increase beam pulse length and

Current ($> 5\mu$ s, > 6 mA)

RF at > 1 ms



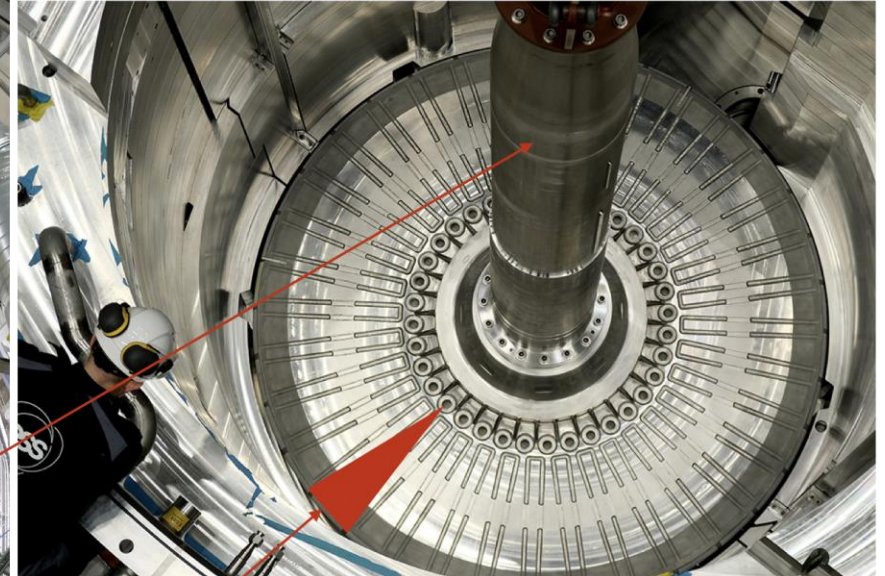
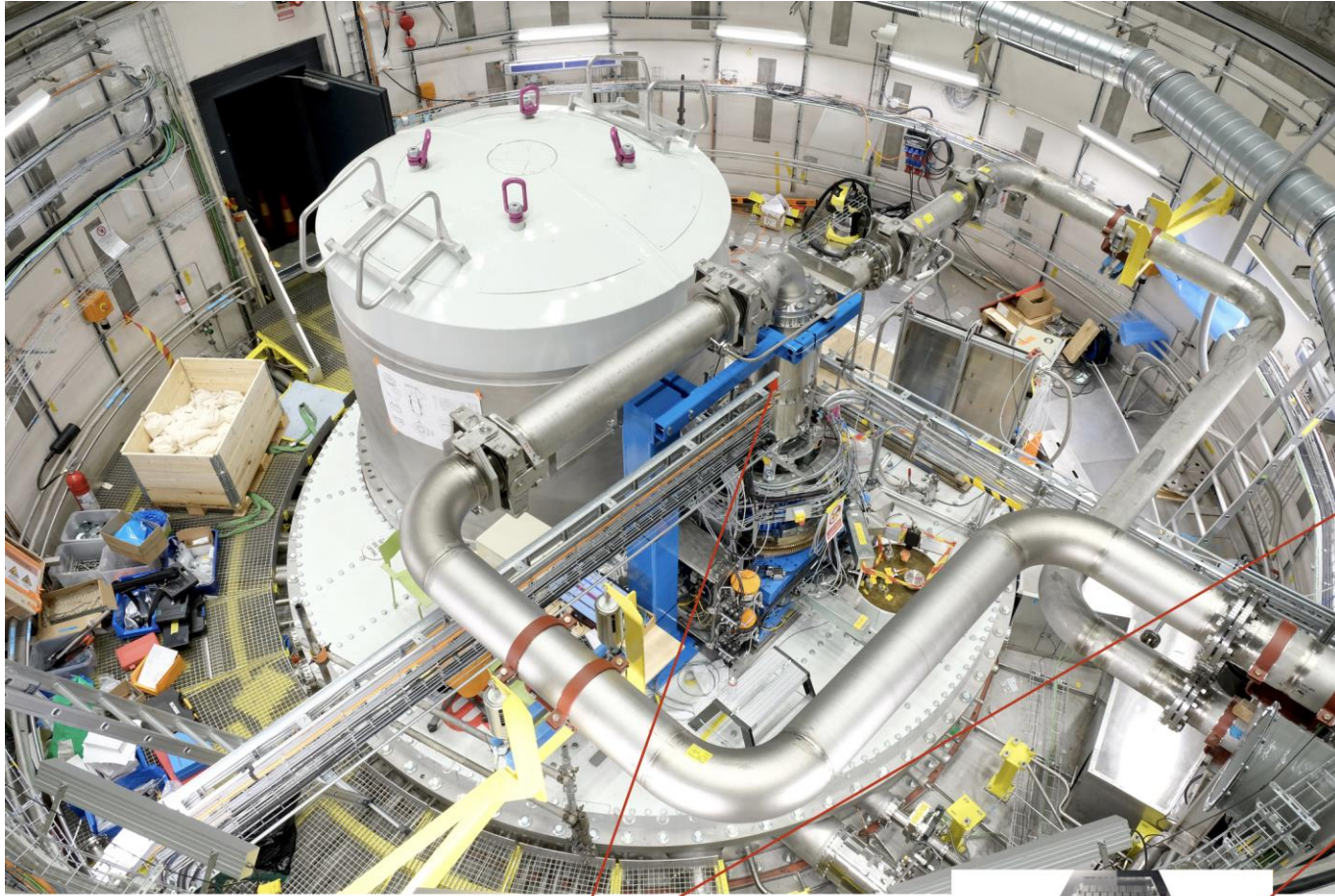


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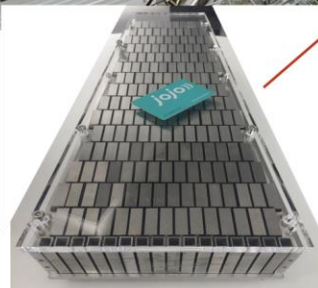
Systems Installations



Target and Moderator

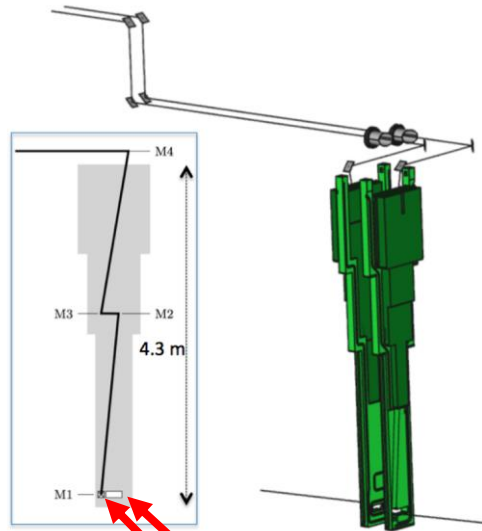


Target Shaft

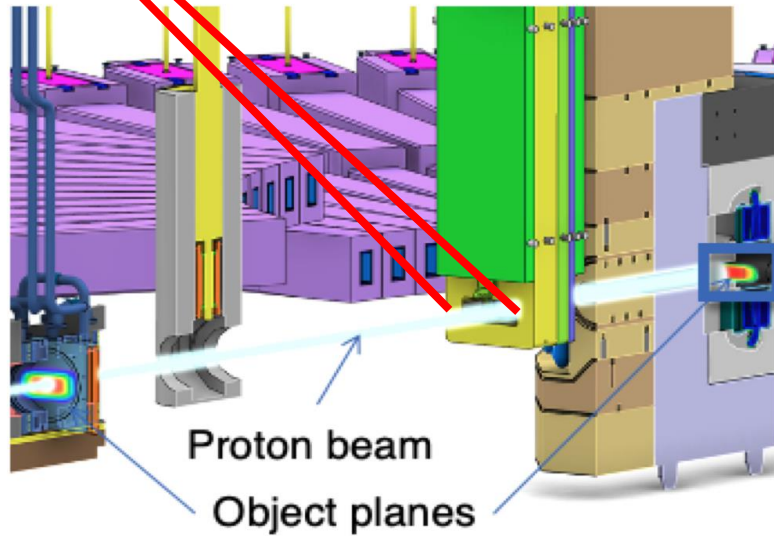
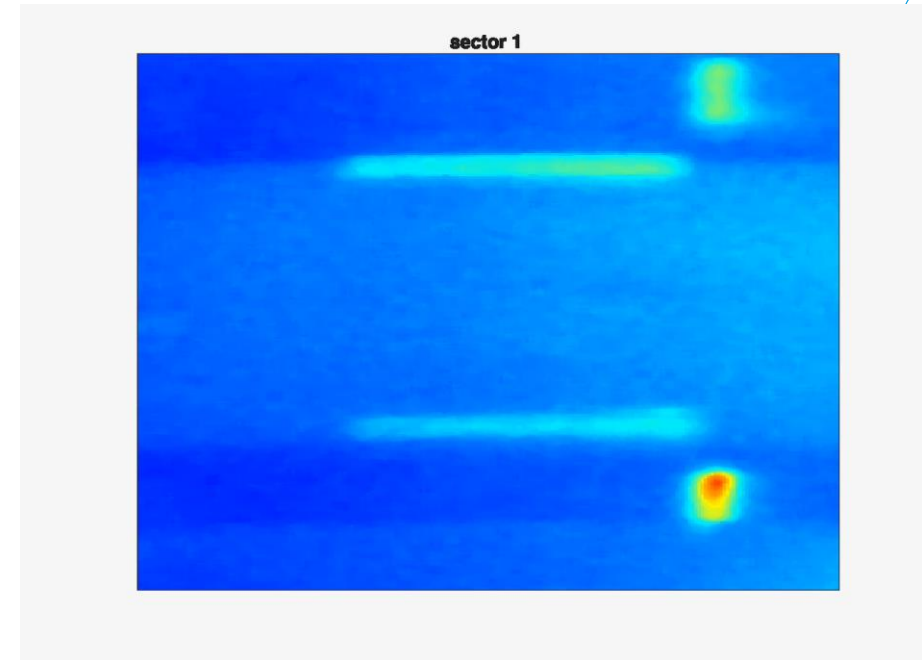


Target Imaging System

Courtesy C. Thomas



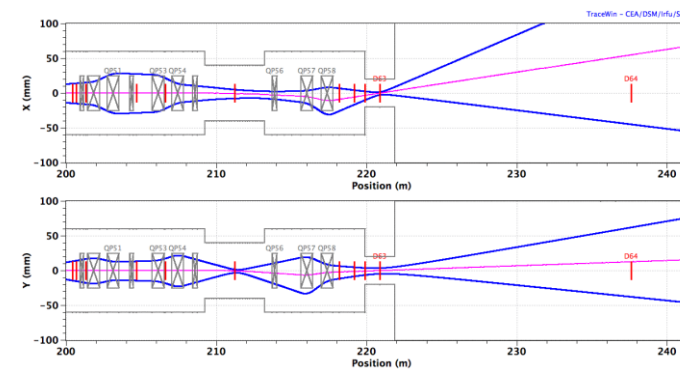
To monitor the beam on the target wheel we have a system that images the fluorescence a coating spread over the side when beam passes through



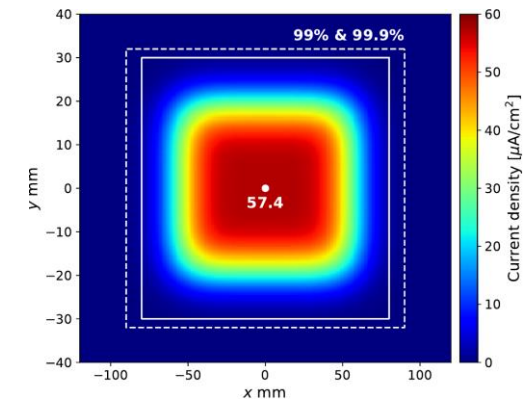
Rotating tungsten target

Proton beam

Object planes

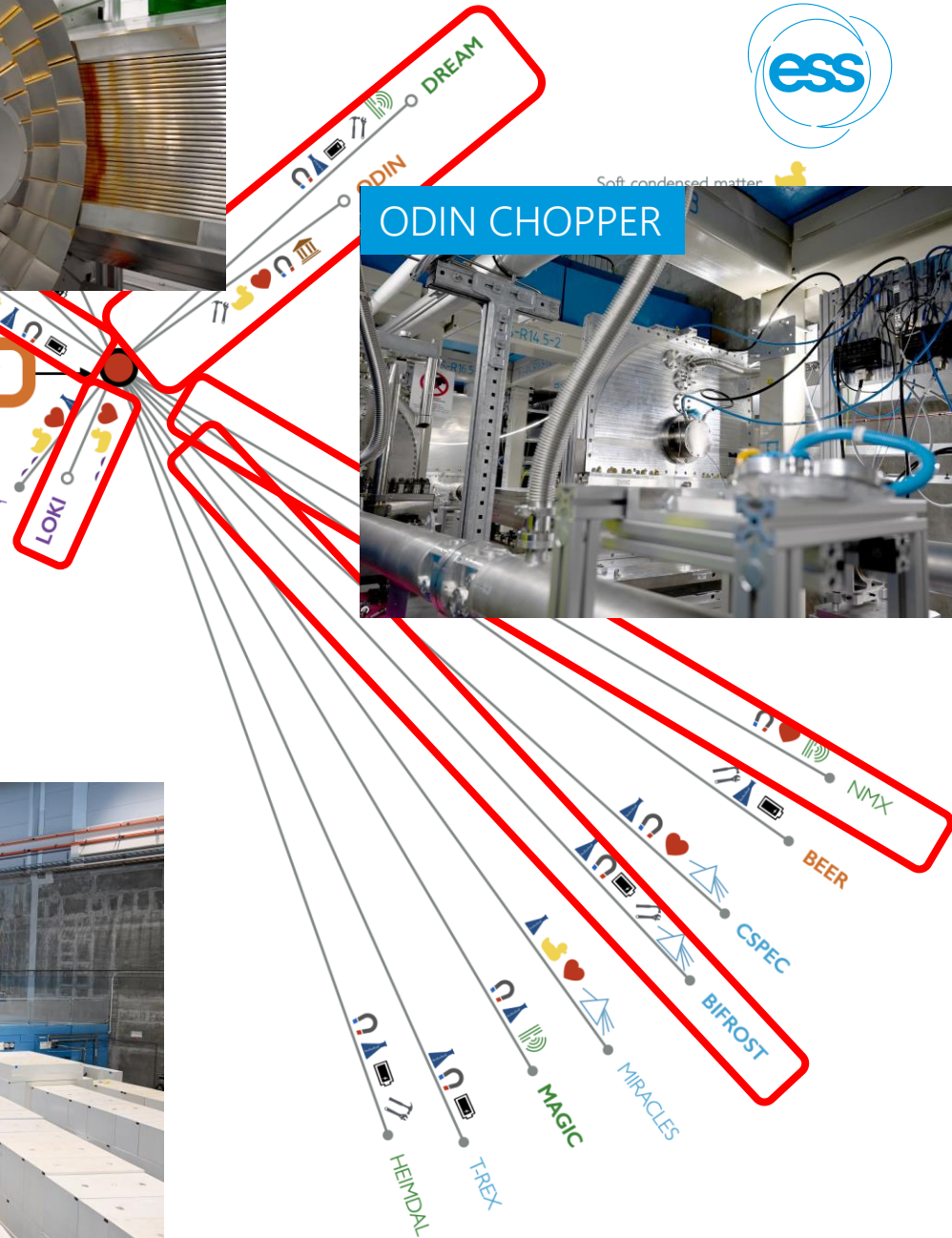
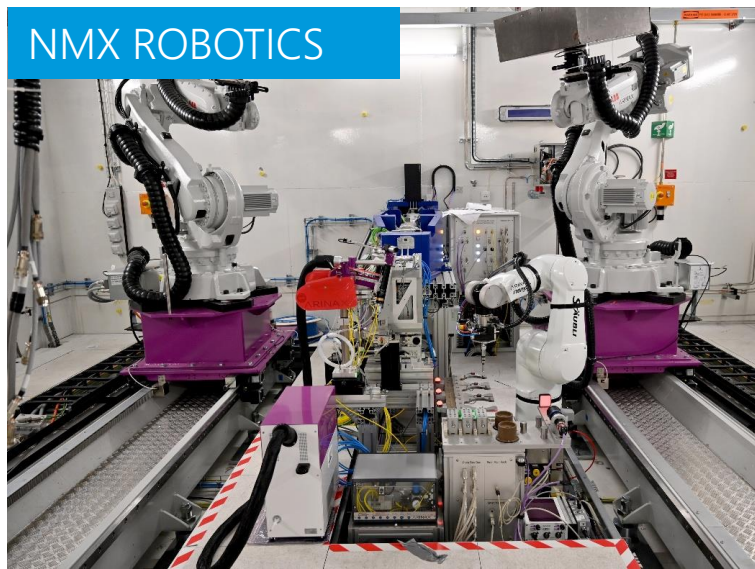
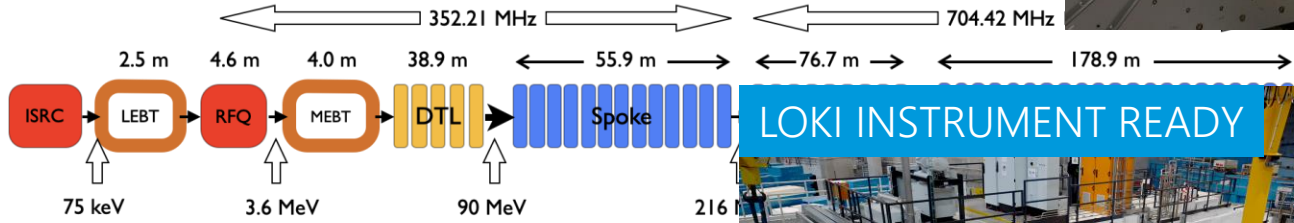
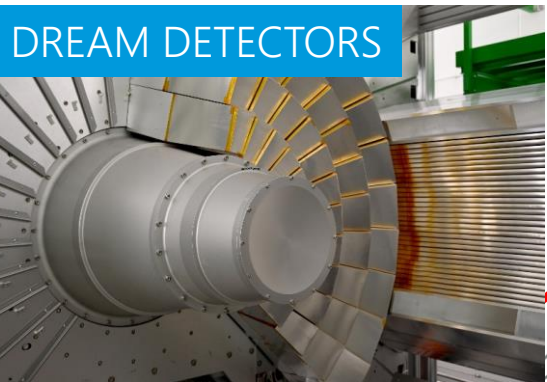


Raster motion
(Courtesy of H. Thomsen)



Beam-on-target footprint

Instruments



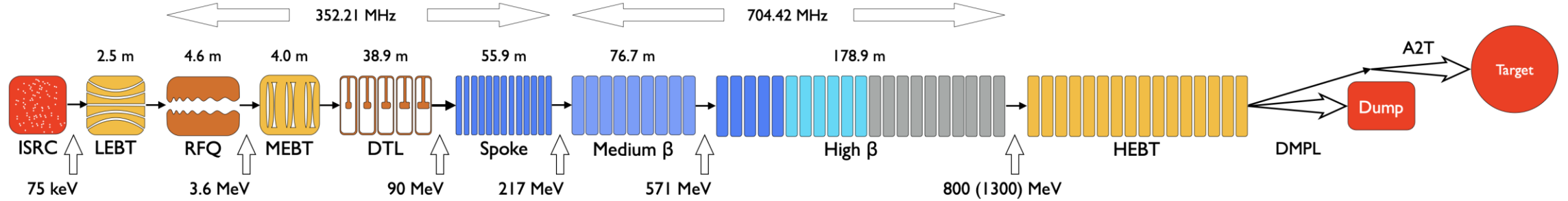
Soft condensed matter

Linac

Additional installation effort for the 3MW readiness at ESS (MOP7037)



Road to 3 MW capability



6 more cryomodules installed, summer 2025



Installation complete, ready for testing
CPI Klystron testing

4 modulators purchased as a risk mitigation for tetrodes

2 spare modulators available (not installed)

4

Some lessons we have learned



Power Disruption Incident

2025-11-25



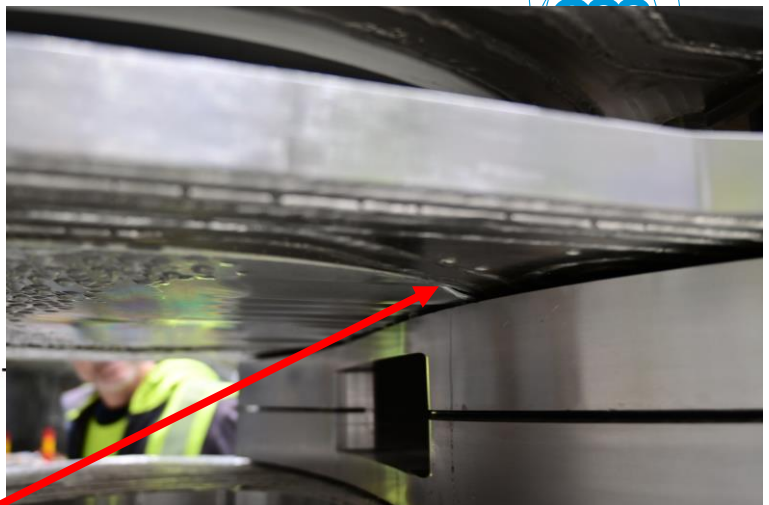
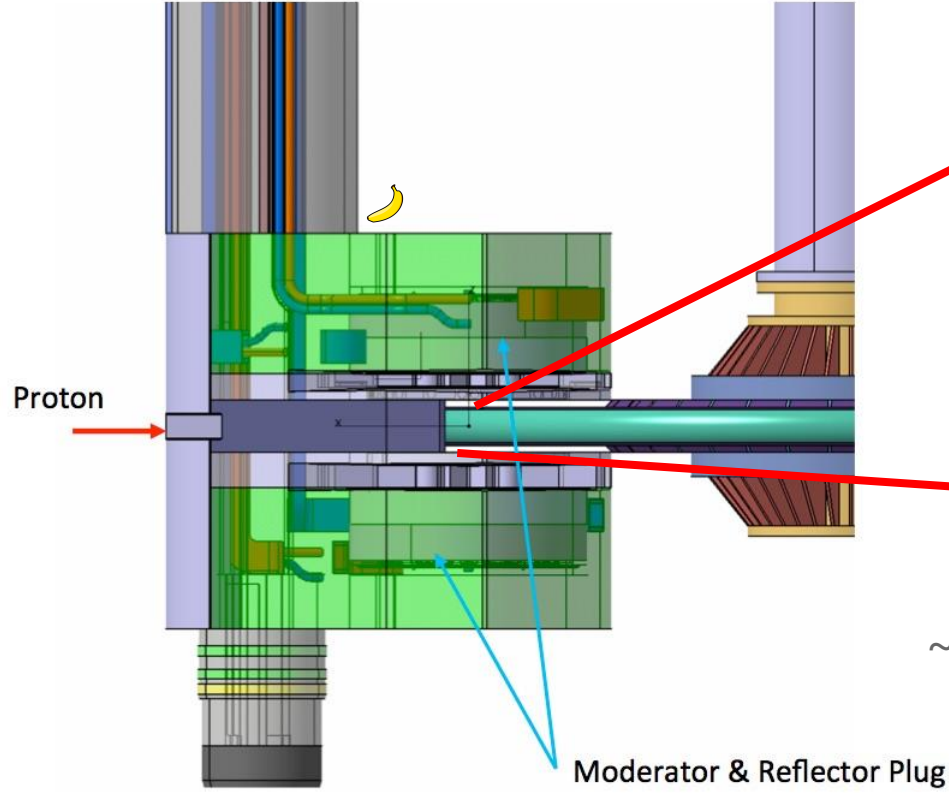
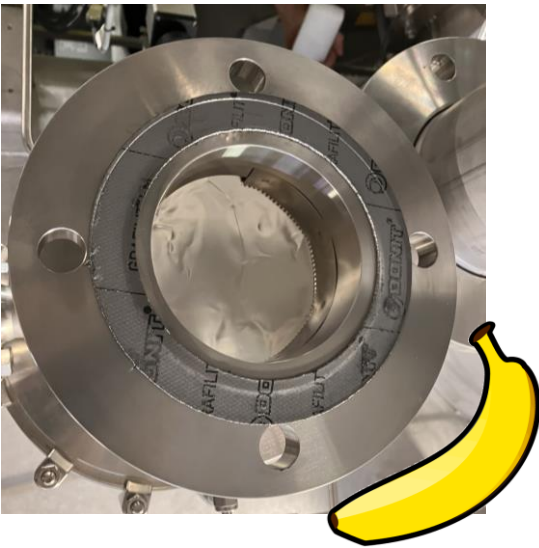
- ESS experienced a voltage dip from the incoming building 21 kV power to approx. 80% of nominal for approx. 127 ms
- Two immediate effects:
 - **ACC**: The ACCP Back-up Compressor (BCP, used as primary HP compressor) oil pump tripped, causing the BCP to trip and helium flow to the CMs to stop. Took ~10 days to reestablish 2K operation.
 - **TAR**: The pump in the 1041 Primary Water Cooling System tripped, causing water flow to stop and subsequently cooling water in the Moderator Reflector Plug (MRP) to freeze.
- Moderator Reflector Plug (MRP) Investigation
 - Water was present at several locations in the monolith and on MRP surfaces
 - Physical damage was evident on the pre-moderator structure
 - Internal damage assessment was not feasible
 - Moderator is not designed to be maintained. New moderator under construction
 - **Overall delay ~9 months.**



Moderator and Acc. Damage

2025: power glitch between 25/26 November

Burst disk from one of the SCL cavities

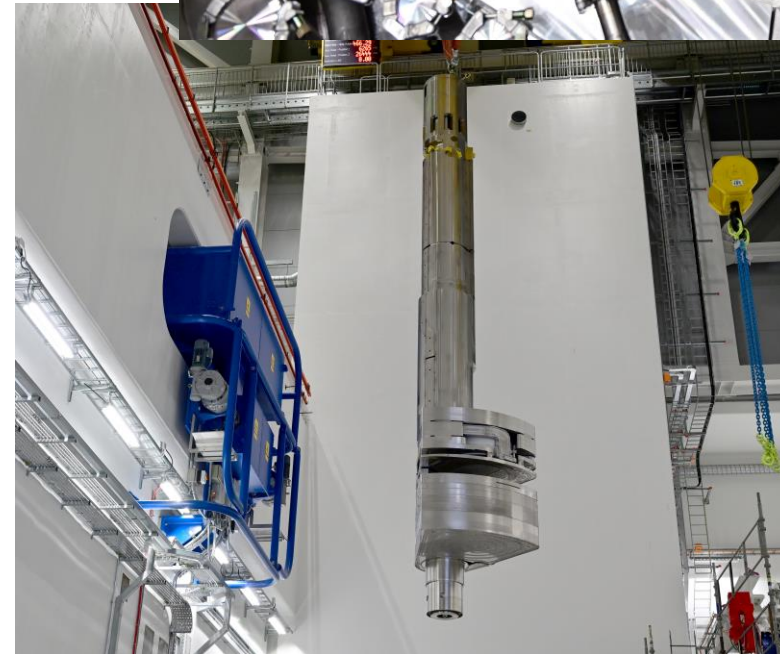
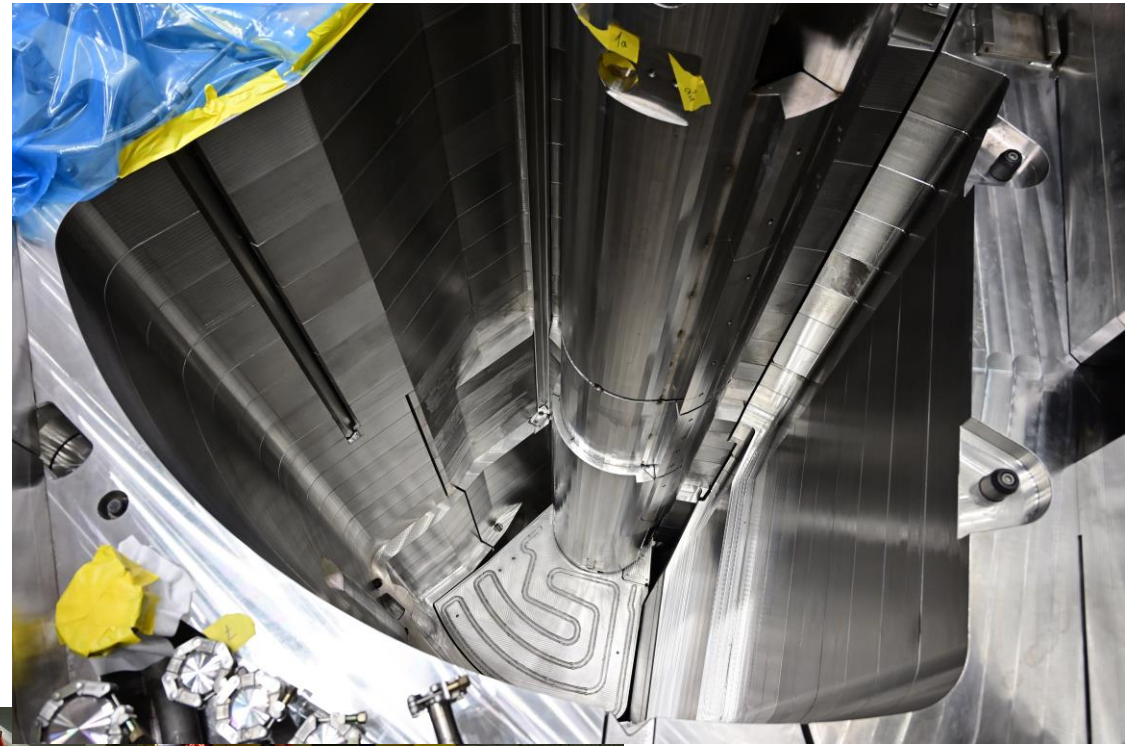


Moderator Damage

2025: power glitch between 25/26 November

Positive take-outs:

- A longer accelerator commissioning period.
- More instruments can be prepared and ready at BoT.
- The second moderator will provide an upgraded design → improved flux and higher neutron output.
- Further advancement on the Active Cells and cask installations reduces vulnerabilities.





Some Lessons Learned

Technical Challenges in Accelerator

SPK CM02 venting event during LWU installation 2024.

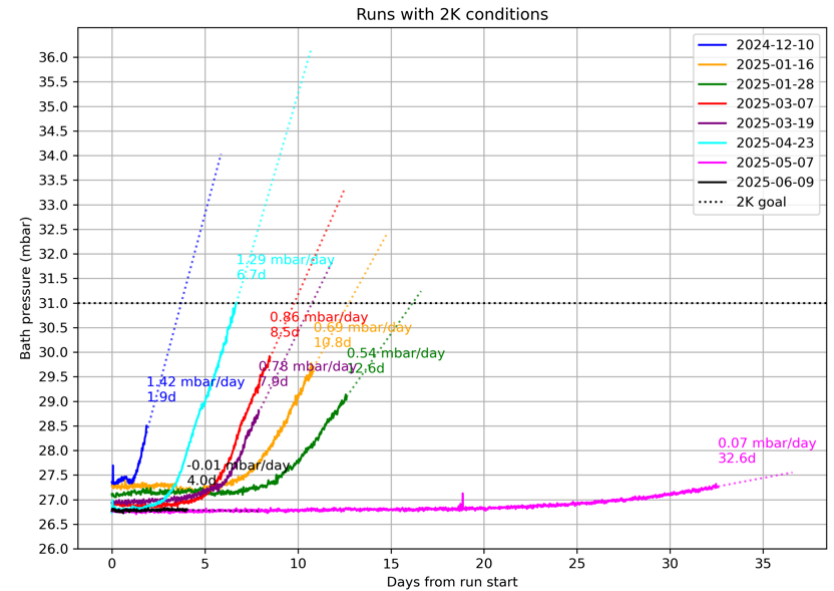
- “Race” to prepare the spare SPK CM14 for substitution.
- Significant installation effort.
- SPK CM02 repair

Water leak in the tunnel in the HEBT area over the weekend.

- Over 5000L of water spilled.
- Highlights improvements we need to make in preparation for operation.

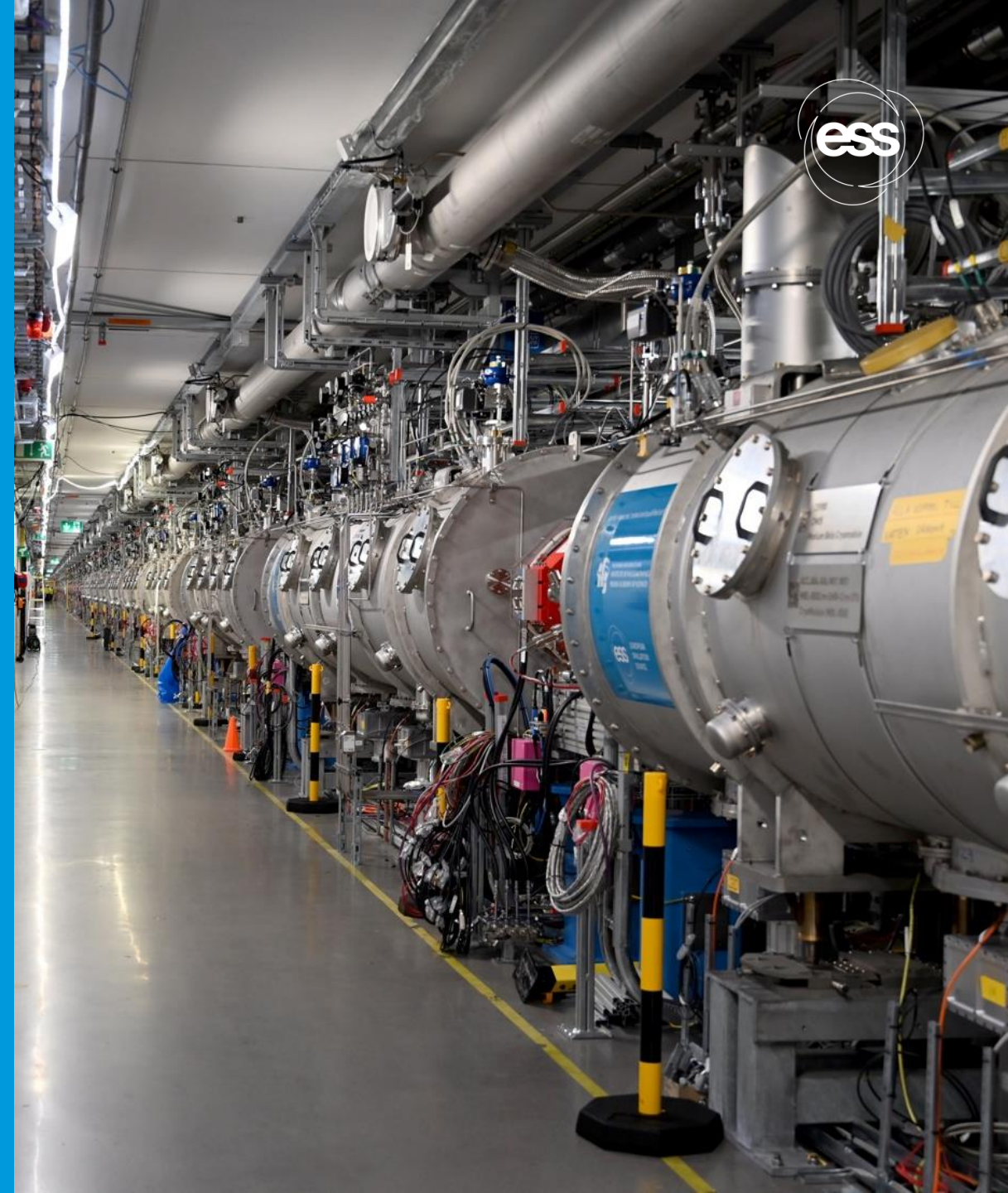
Cryogenic Operation

- Failed PLC update
- Power glitch
- Loss of water cooling
- Network issues, PLC network glitch
- Loss of instrument air
- Cold compressor inlet filter clogging



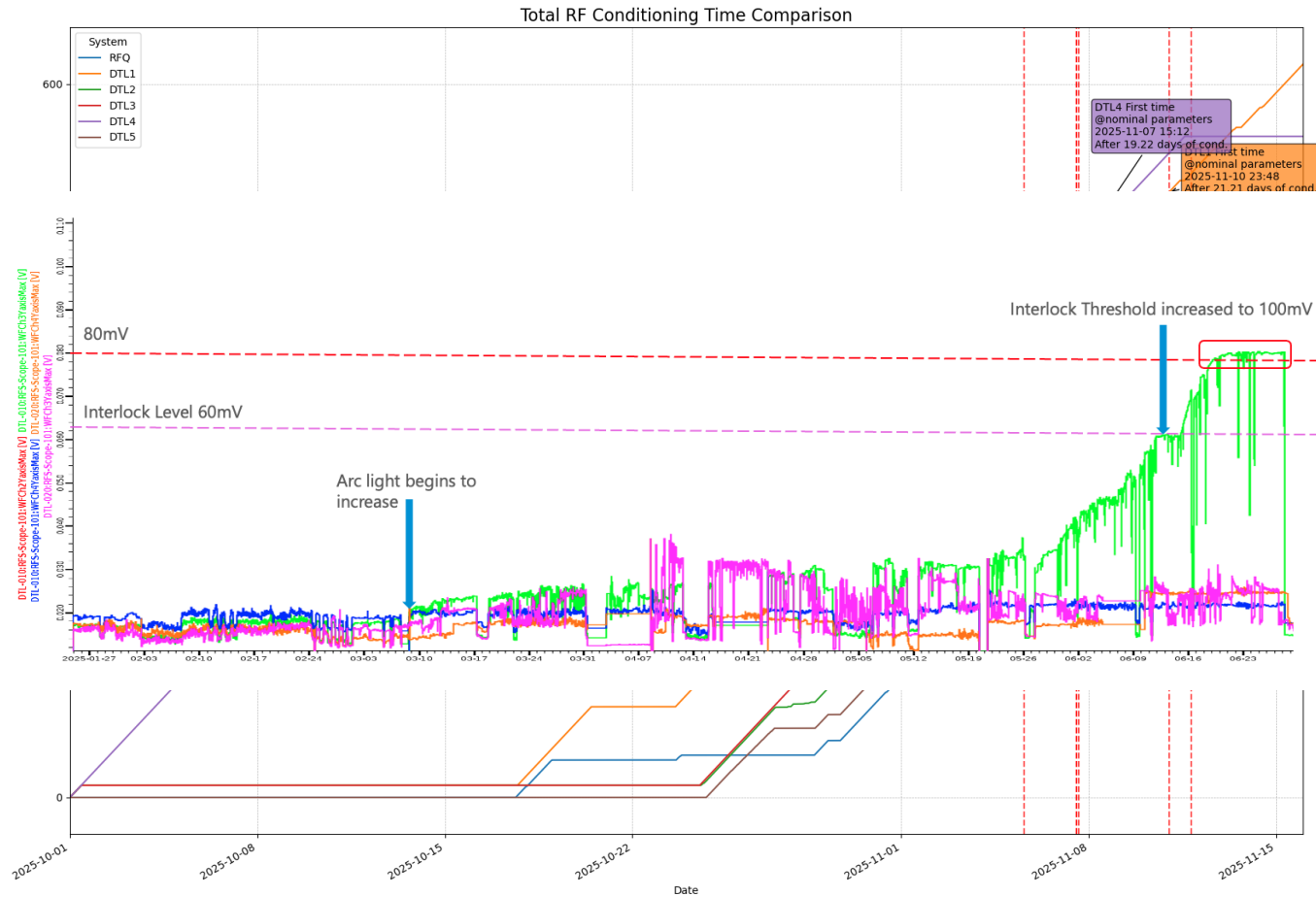
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RF Conditioning with long pulses

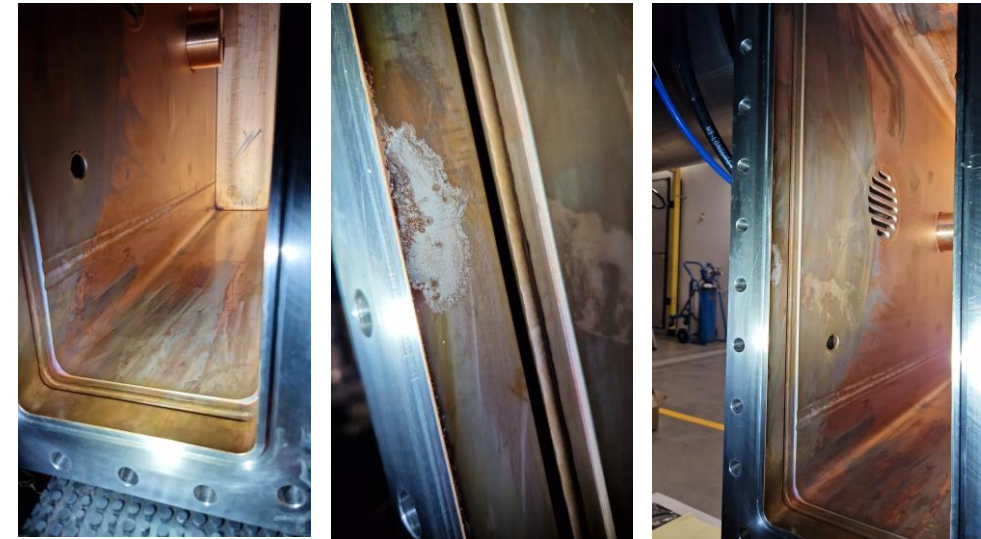


NCL Conditioning

3 ms pulses



Cavity	Time to condition to nominal	Total time spent in RF conditioning
DTL1	28 d	52 d
DTL2	38 d	81 d
DTL3	28 d	77 d
DTL4	22 d	67 d
DTL5	73 d	73 d
RFQ	44 d	56 d



DTL1 window arcing: insufficient (TiN) coating of the ceramic window.

Courtesy D. Nicosia

SCL Conditioning

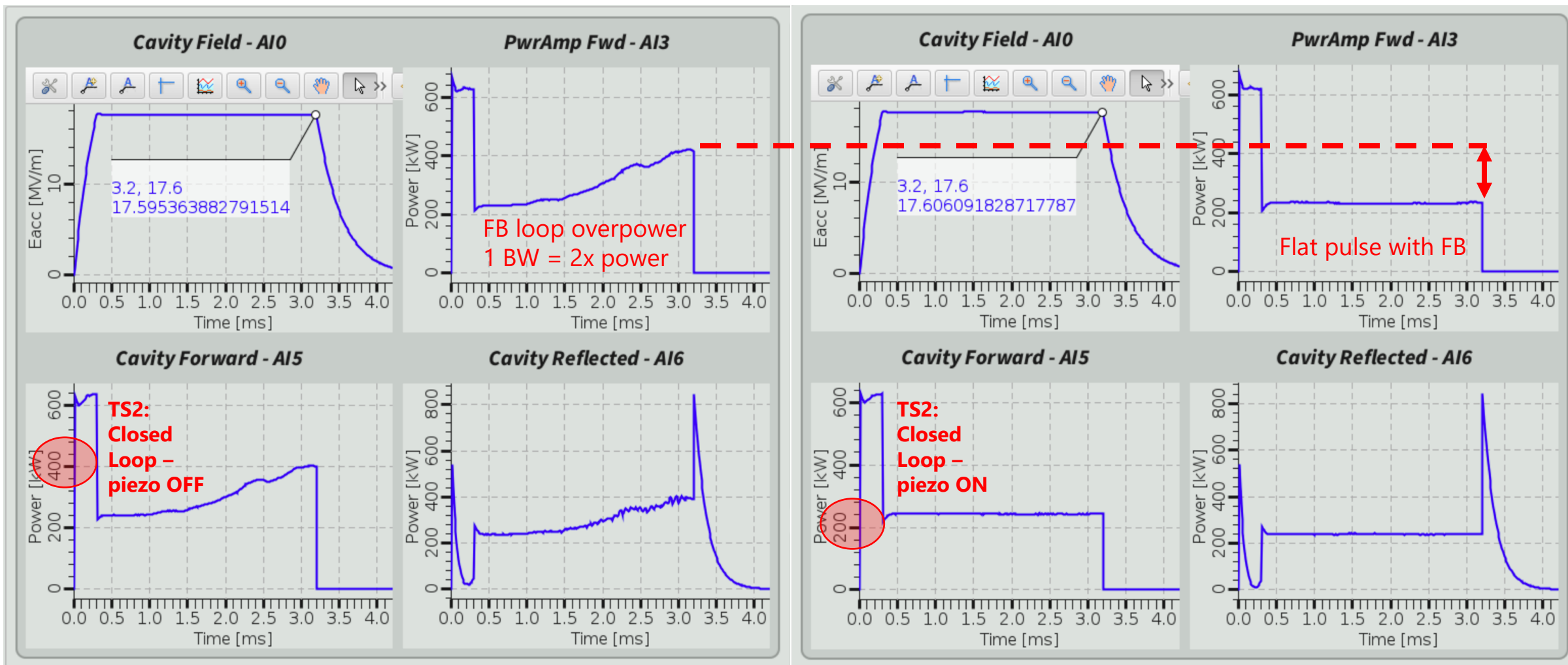
3 ms pulse + Piezos

Piezo OFF

Cavity detuning at high field (LFD) requires extra power at pulse end!



Piezo ON

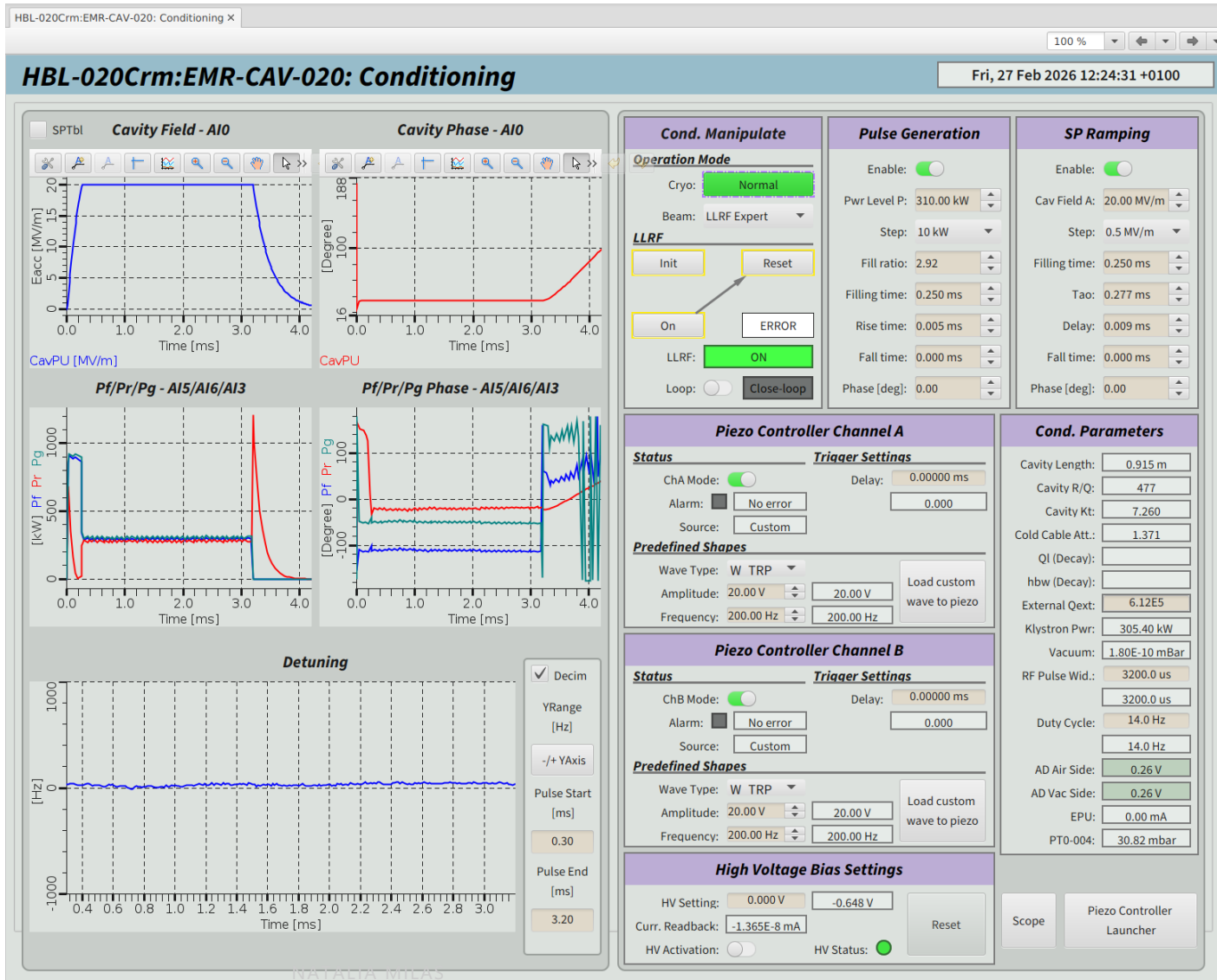


Proof of principle, now integrated in LLRF (semi-manual)

SCL Conditioning

3 ms pulse + Piezos

Cold Tuning System for ESS superconducting cavities (MOP7038)
SCL Preparation for Beam on Dump (MOP7039)
Piezo tuning (MOP7040)



On January we reached a milestone for RF:

- 3.2 ms long pulses
- 14 Hz repetition rate
- nominal filed in all cavities (both NCL and SCL)

We also managed to run RF at this parameters with closed loops and piezos engaged (for SCL)



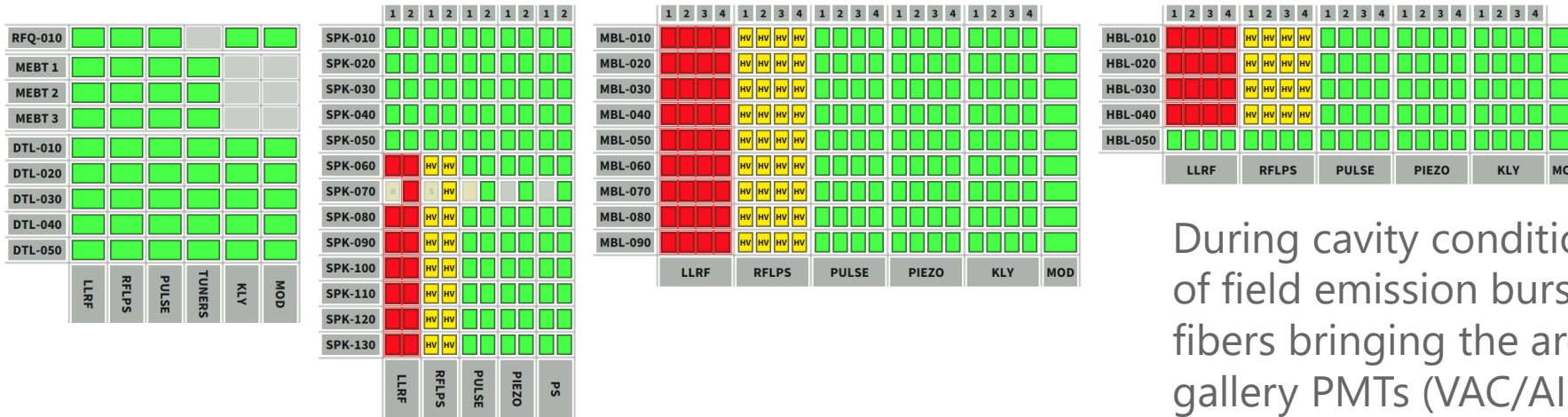
Much more on piezos MOP7040

SCL Conditioning

Field Emission

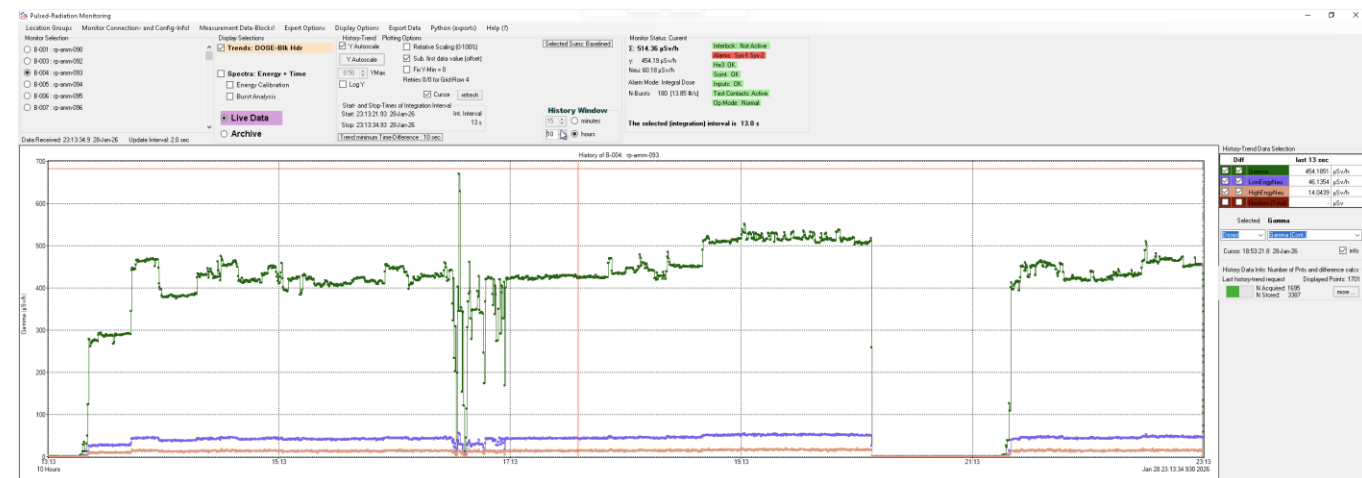
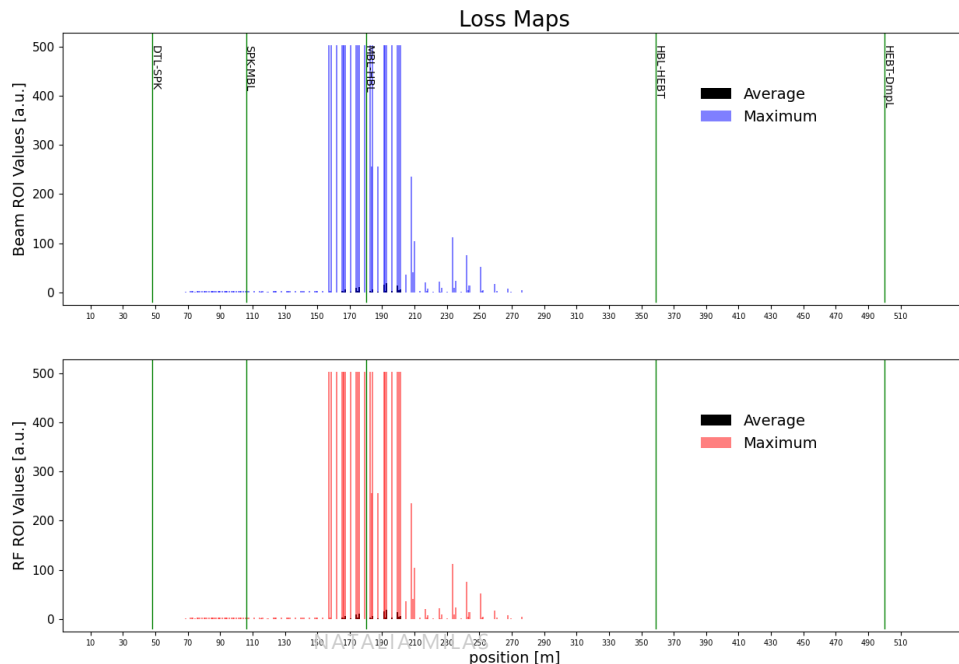


All data from 28.01.2026.



During cavity conditioning we had several events of field emission bursts which “lighted” all the fibers bringing the arc detector signals to the gallery PMTs (VAC/AIR side)

Still happening sporadically. Seen also by BLMs.

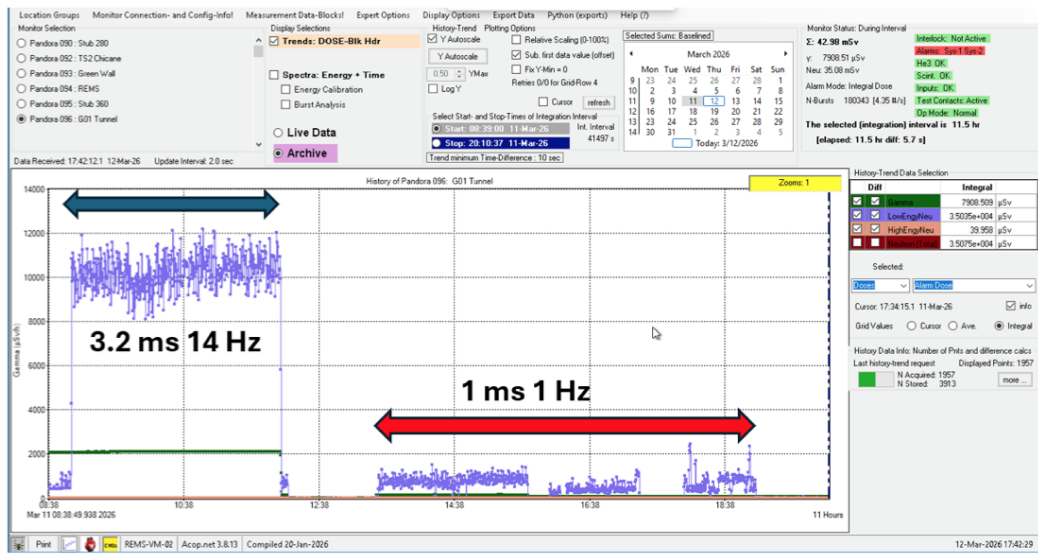


Courtesy A. Zwoznik and C. Maiano

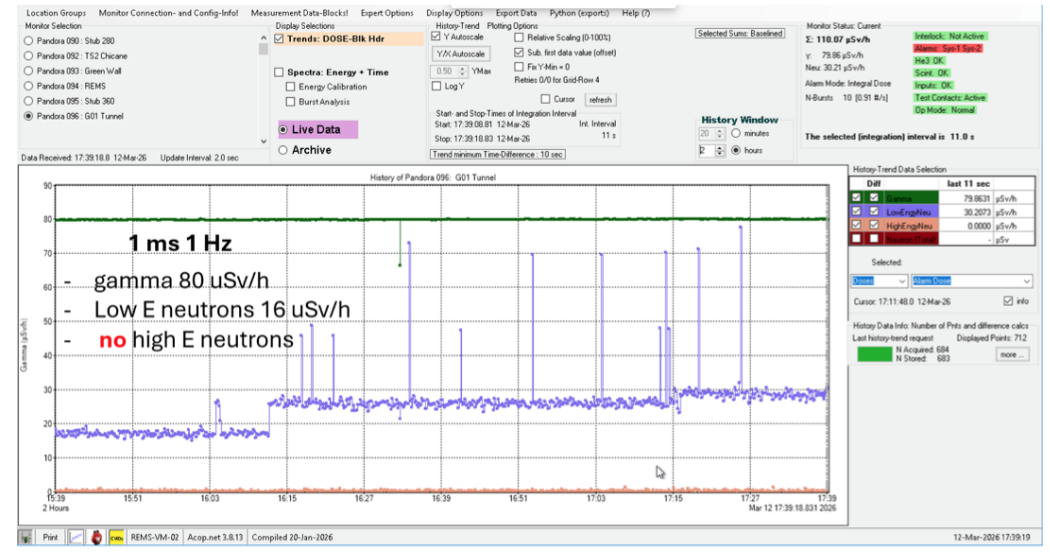
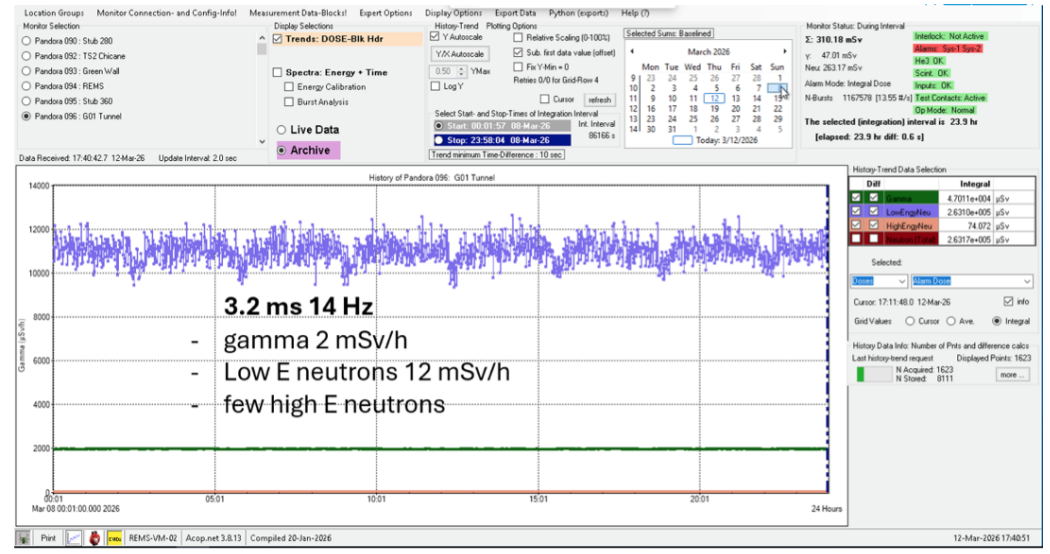


SCL Conditioning

Dose rate at 3.2 ms (14Hz) and 1ms (1 Hz)



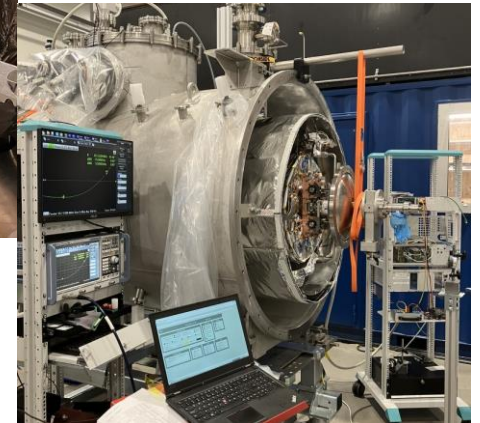
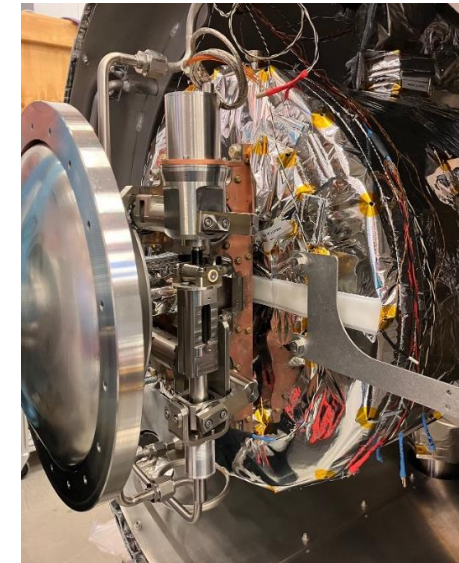
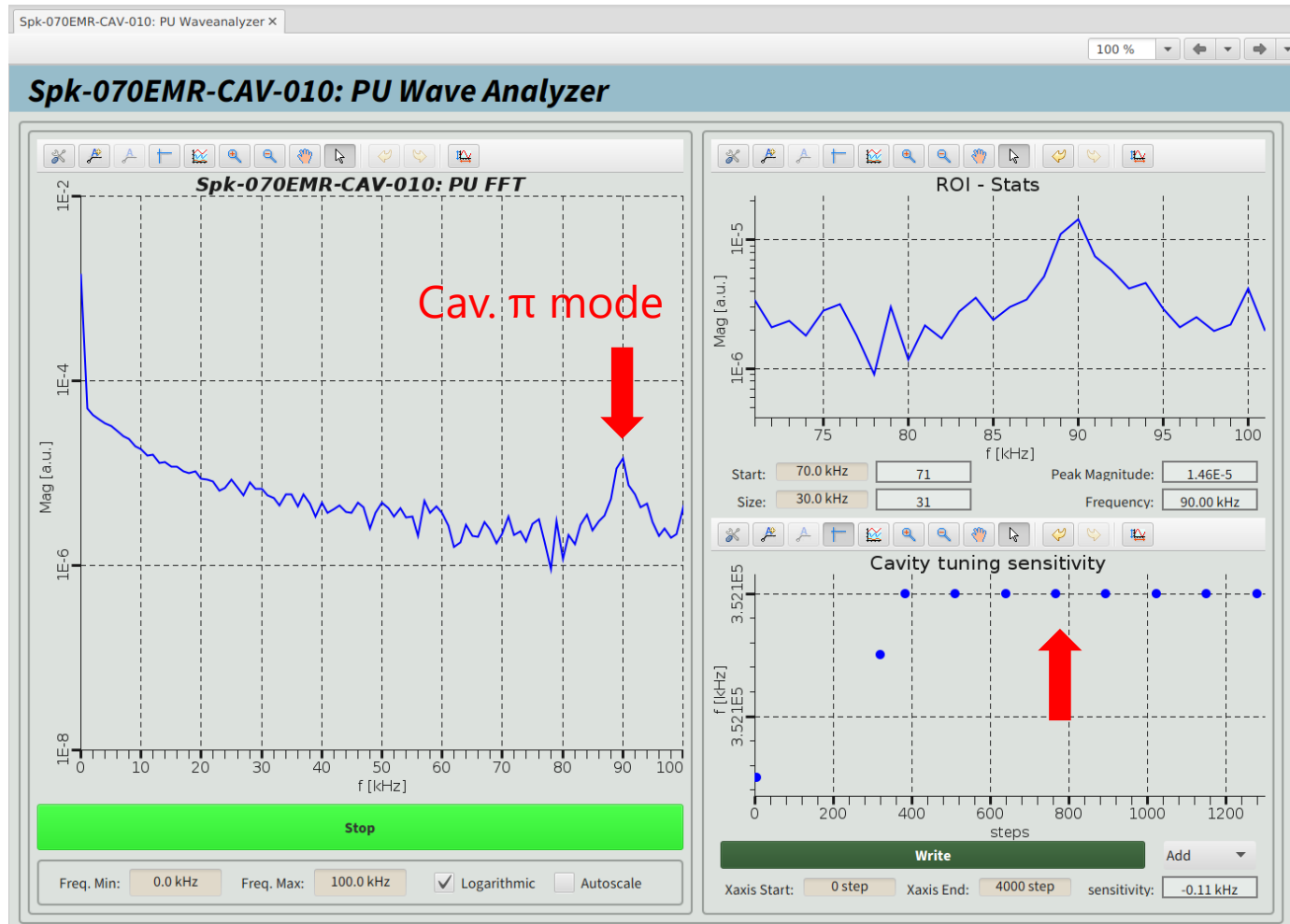
Courtesy A. Zwozniak





Spokes Tuning motors

Motor reaching end of life



This issue was known and we are working on a replacement for both motor and shaft.

For now, we avoid moving the Spokes tuners too much since we have a larger margin for power if compared with Ellipticals.

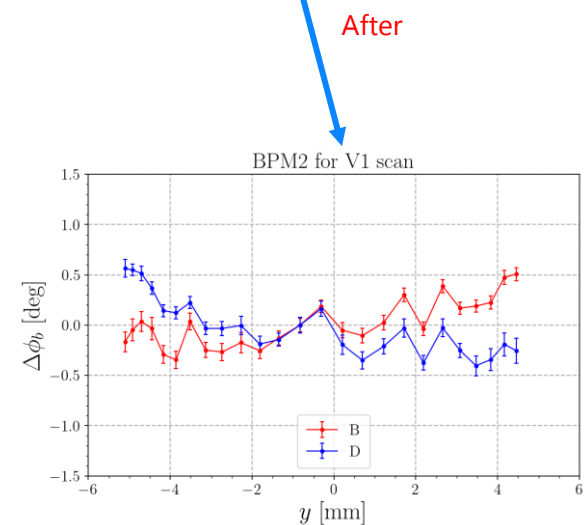
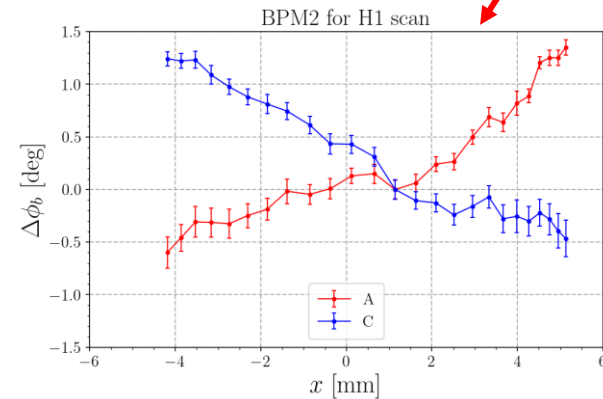
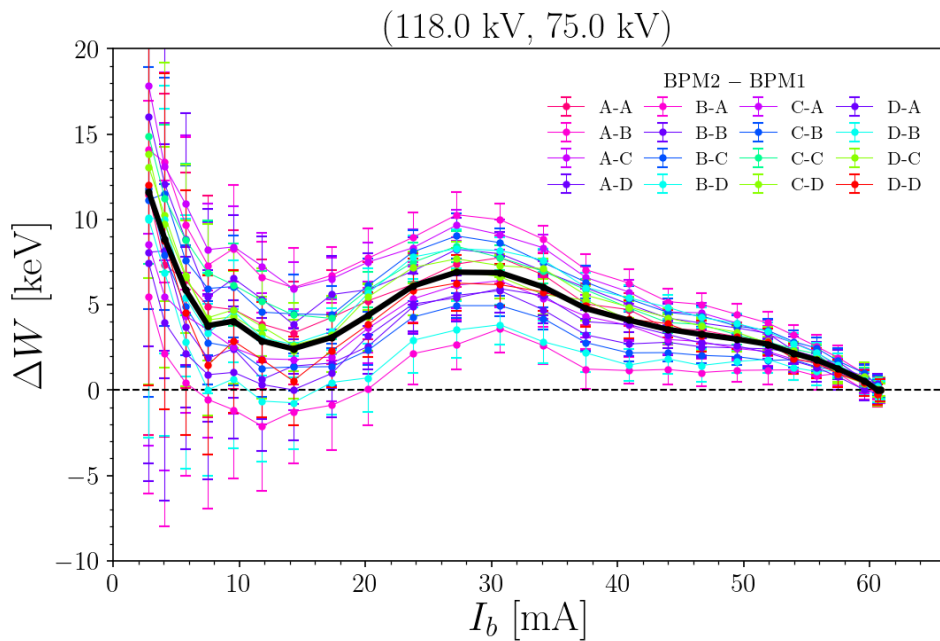
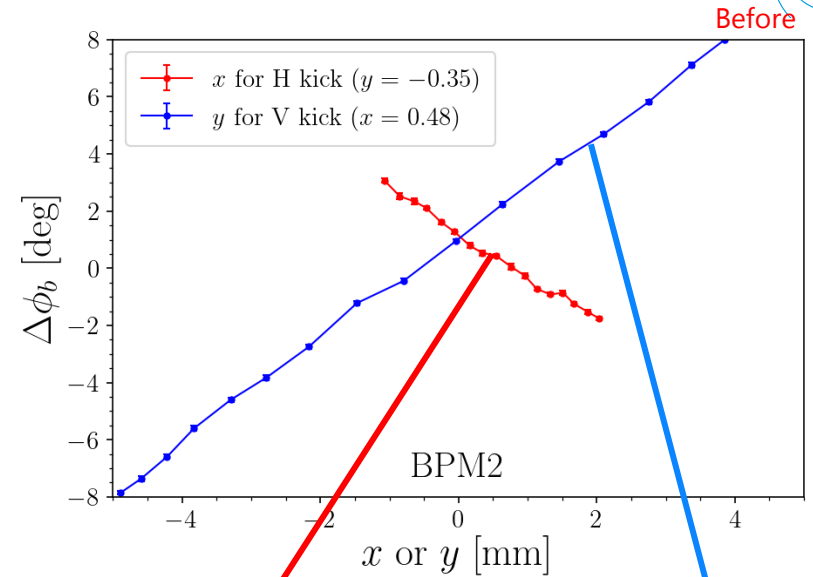
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Beam Commissioning Results



BPM phase-position dependence

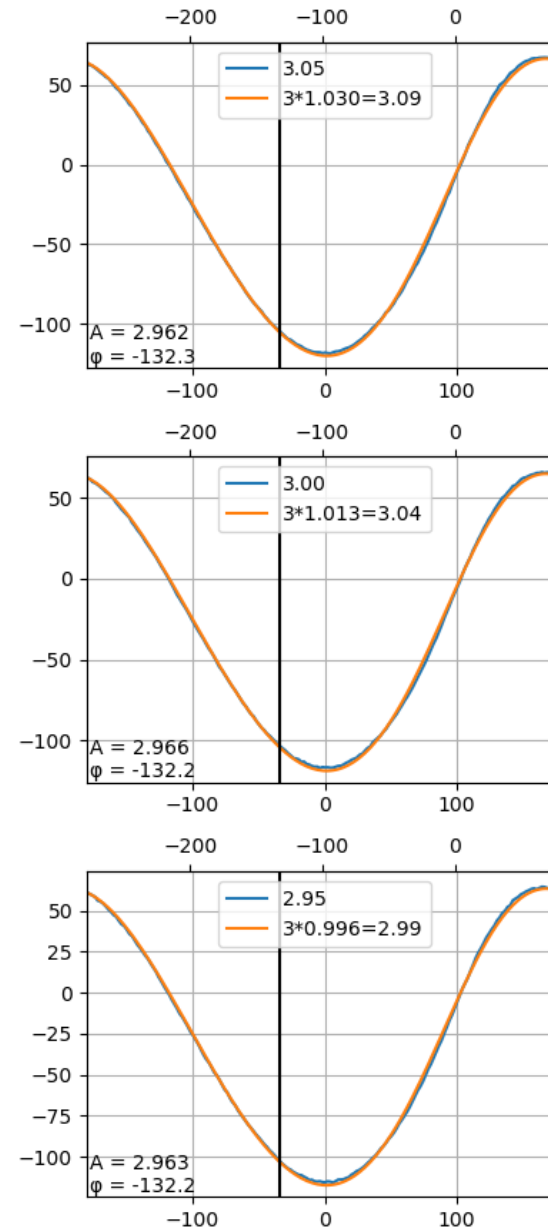
- Discovery of strong correlation between phase and position on the BPM in the NCL.
- The system expert immediately made an improvement (by enabling measurement from each channel for all the BPMs). Much better data now.
- Small systematics is remaining. (Further mitigation possible?)
- Even with this correction we still see an energy dependence on the beam out of the RFQ. How to compensate?



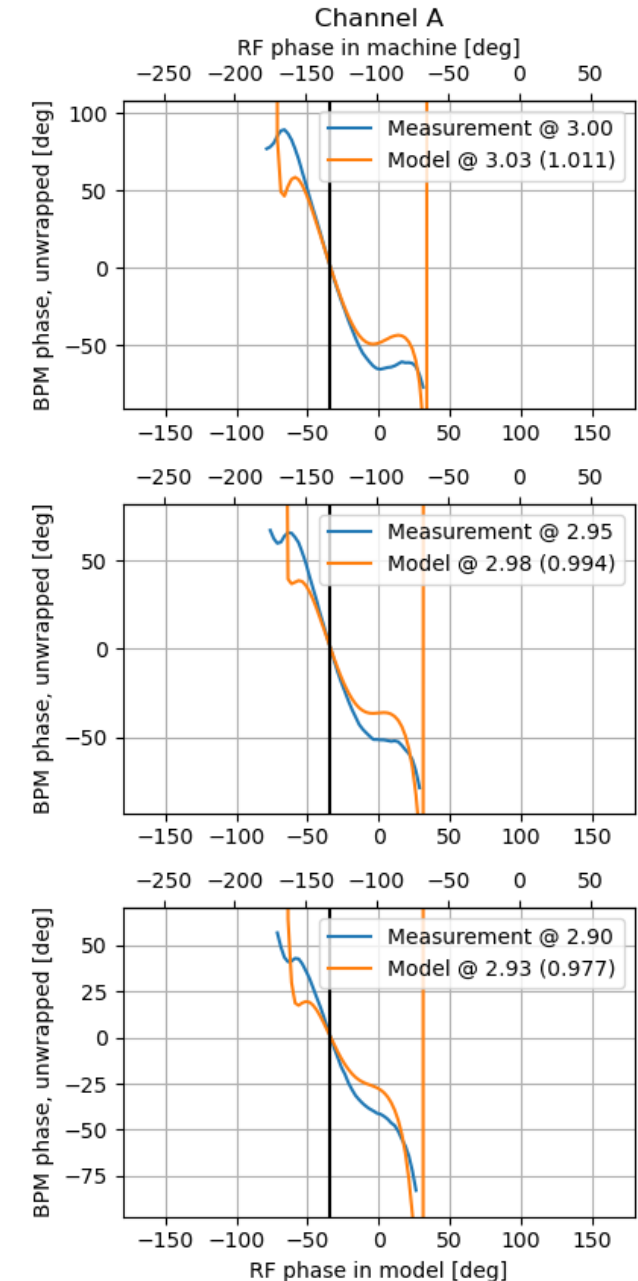
Phase Scan

- We are using a model independent script to run phase scans in the machine.
 - NCL remain slightly manual. With BPM position-phase dependence removed the results are much better than in previous commissioning's.
 - We fixed position of DTL BPMs in the model and now DTL phases scan use internal BPMs and the results match the model quite well. Before we had a systematic error of 10-12% in field amplitudes.
 - In the phase of testing an automatic scan script. Takes about 4 hours to scan all NCL+SCL (90 cavities). We require lattice changes along the way (also automatic). Trips due to beam loss and spurious radiation on RF arc detectors reduced significantly.

Internal BPM



External BPM

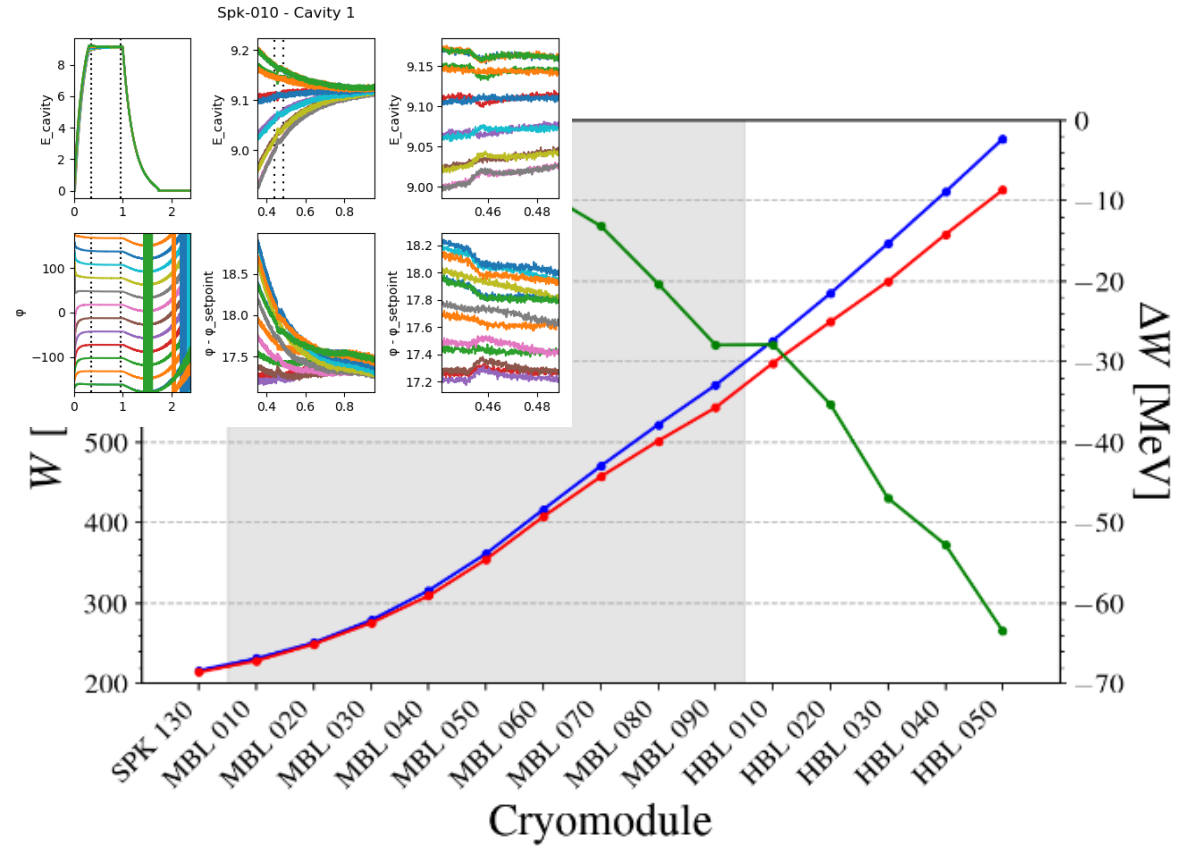




Phase Scan

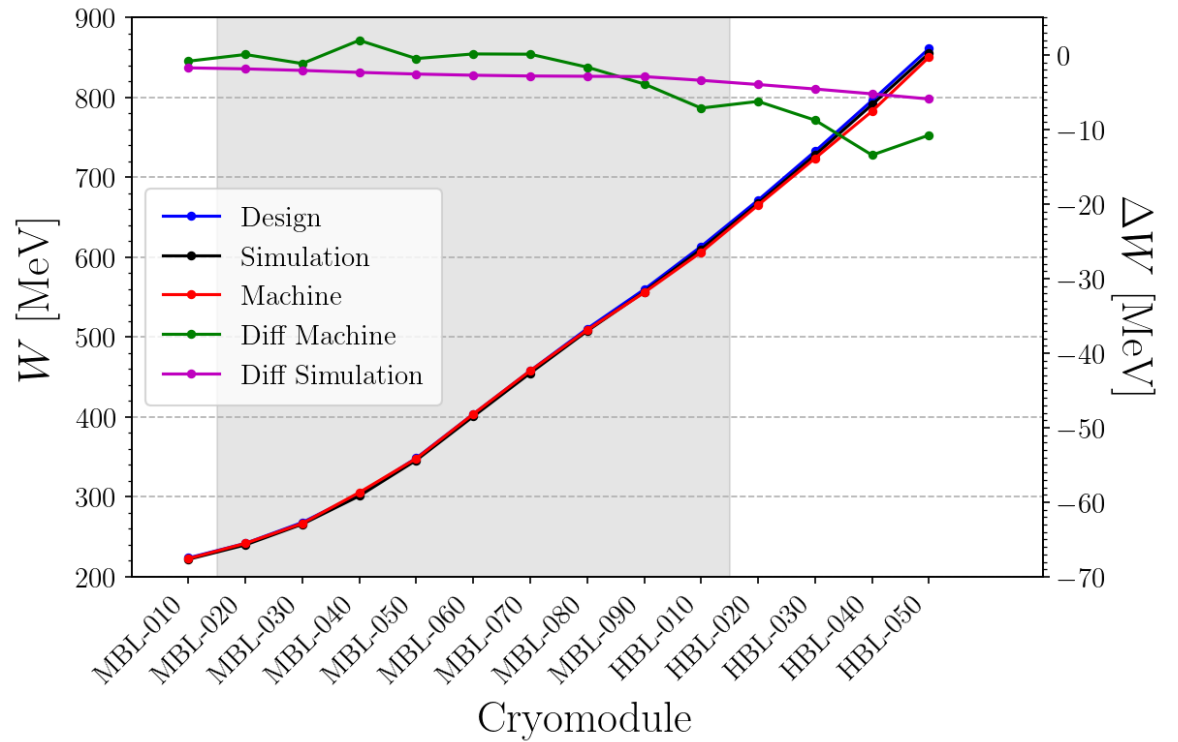
2025

- We did not take a lot of care with the flatness of the fields in SCL



2026

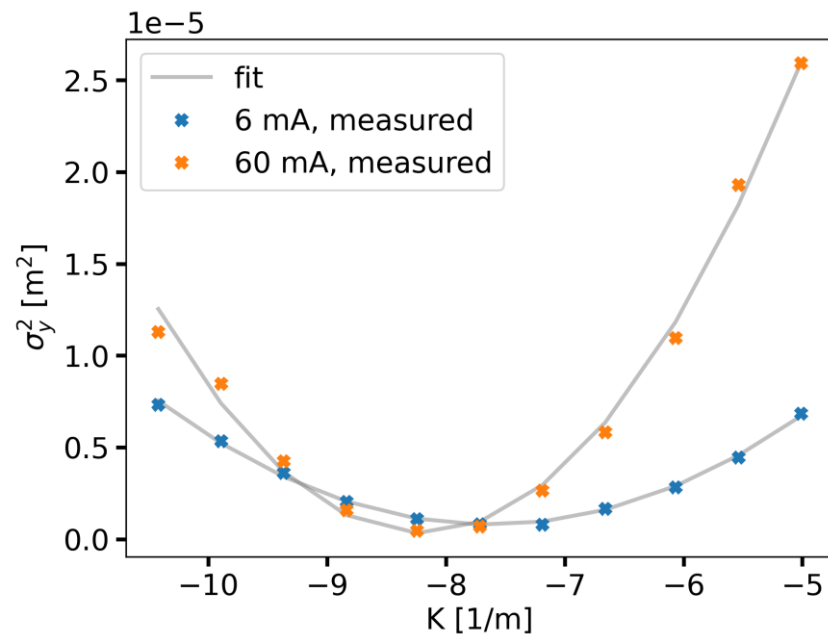
- Improved loops in LLRF
- Flatter Fields
- Improved Phase Scans of NCL
- We are trying to simulate and understand this energy drift



Transverse Dynamics

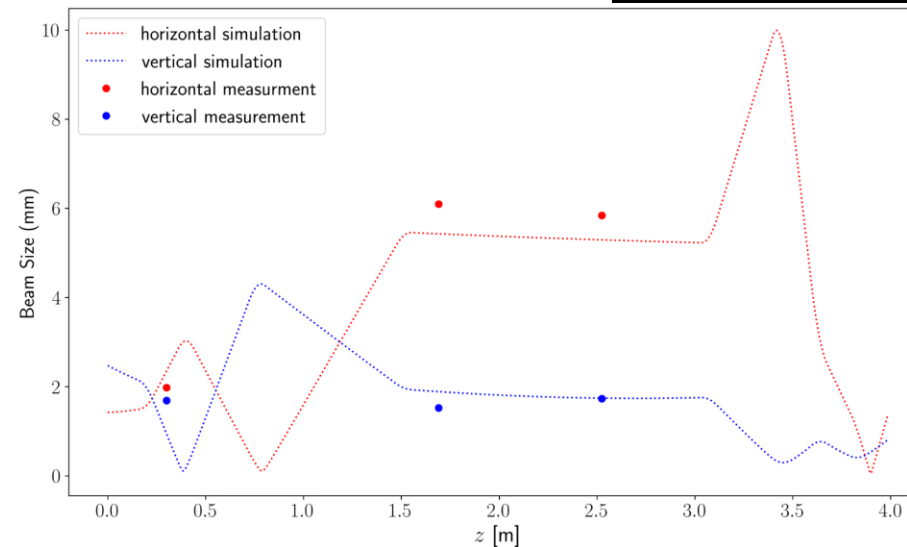
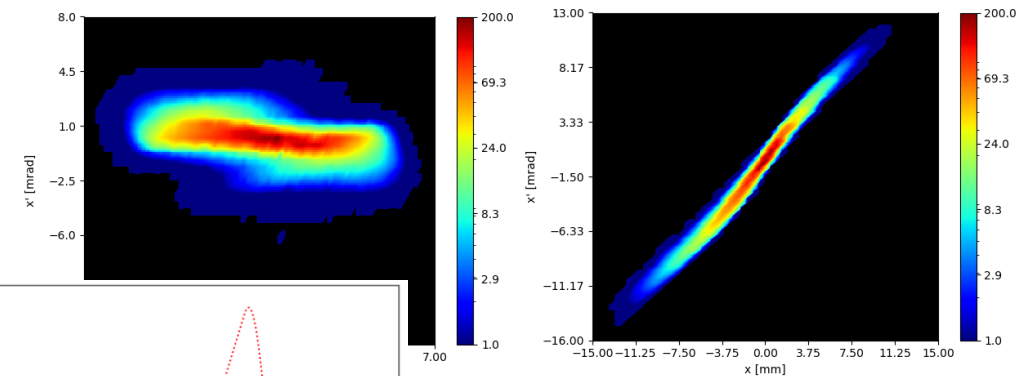
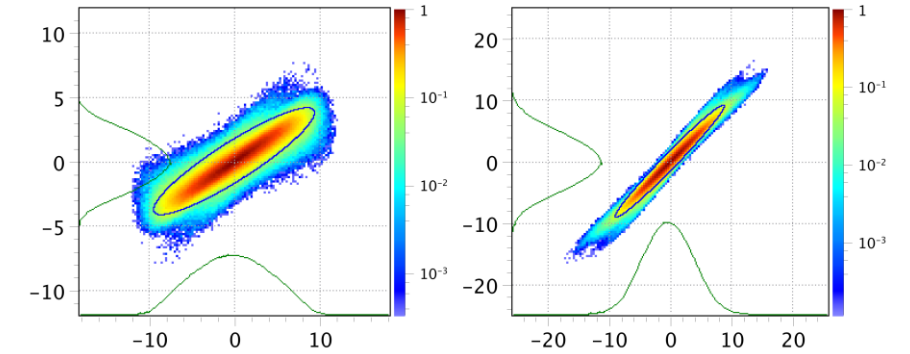
Method	6 mA (π mm mrad)		60 mA (π mm mrad)	
	ϵ_y	ϵ_x	ϵ_y	ϵ_x
Quad Scan	0.04	0.19	0.37	-
EMU	0.68	0.10	0.18	0.19
3 Wires	0.15	0.18	0.10	0.07
Design	0.09*	0.10*	0.25	0.25

*From backtracked dist. through RFQ



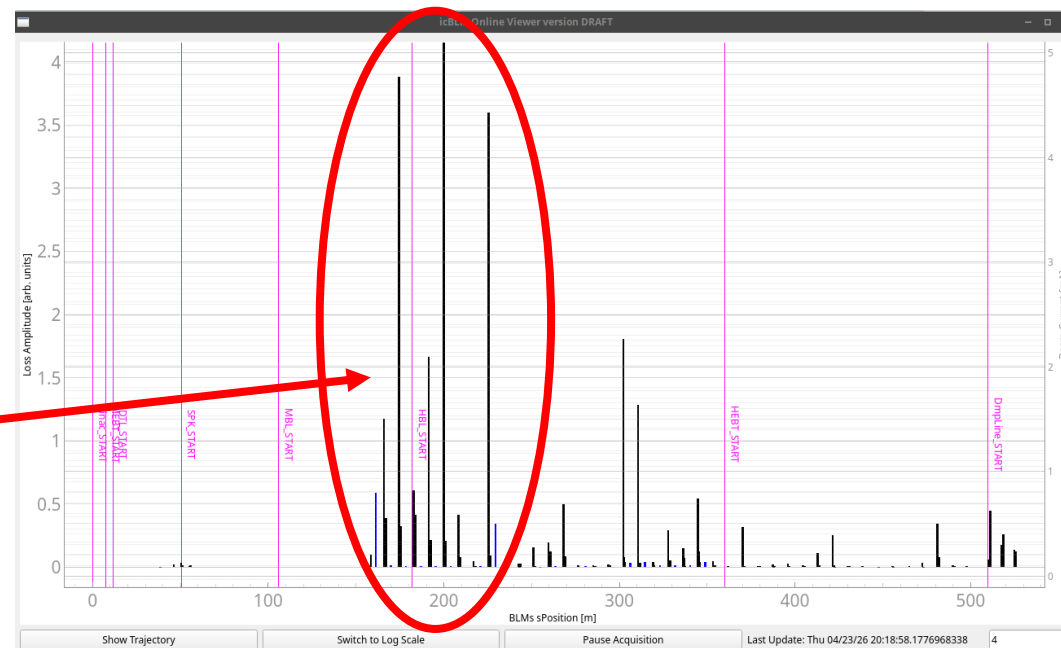
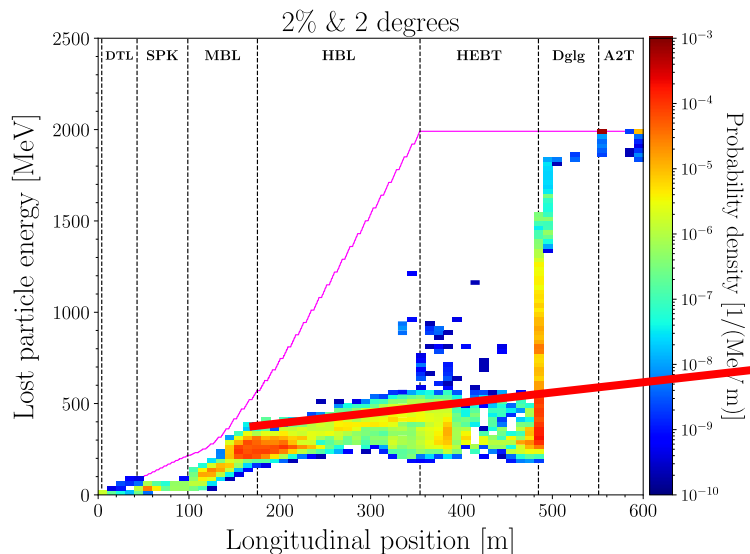
BPM Quadrupolar Component (WEP6075)

TraceWin - CEA/DRF/Irfu/DACM
MEBT-010_PBI-EMU-001 #90 [2.524 m] NGOOD : 975876 / 975924

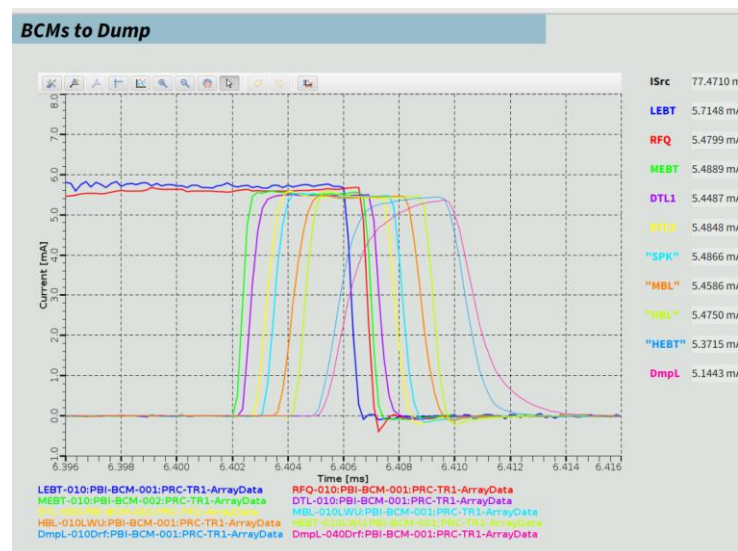




Beam Loss Tests



- For the beam loss, longitudinal dynamics is far more important than the transverse.
- (amp, phase) of each cavity is set one-by-one with time-of-flight measurements (w/ BPMs) and model fitting (*phase scan*).
- Tolerance: $(\sigma_{amp}, \sigma_{phase}) = (0.5\%, 0.5^\circ)$
 - Shared by the set-point error (from the beam-based measurement) and RF systematics.



BLMs and nBLMs installed and calibrated in the tunnel.



7

Outlook



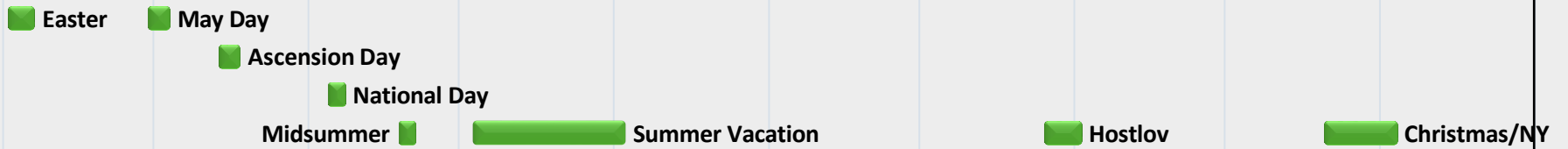
Next steps

Long pulses and beyond

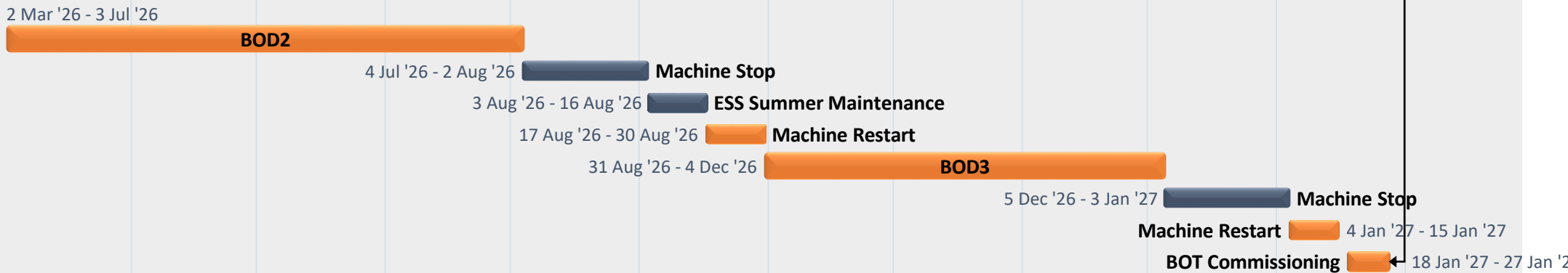


Today

Holidays



2026 ACC Operations (Jan 2026)



Spring Stop



Reviews



BOT System Permit 18 Jan '27 - 19 Jan '27
 BOT Beam Authorisation 20 Jan '27



Conclusions

We've built an accelerator!
Next: Beam on Target!





Thank you! Questions?

2026-05-13

