



# Commissioning progress of the ESS linear accelerator

IPAC 2026

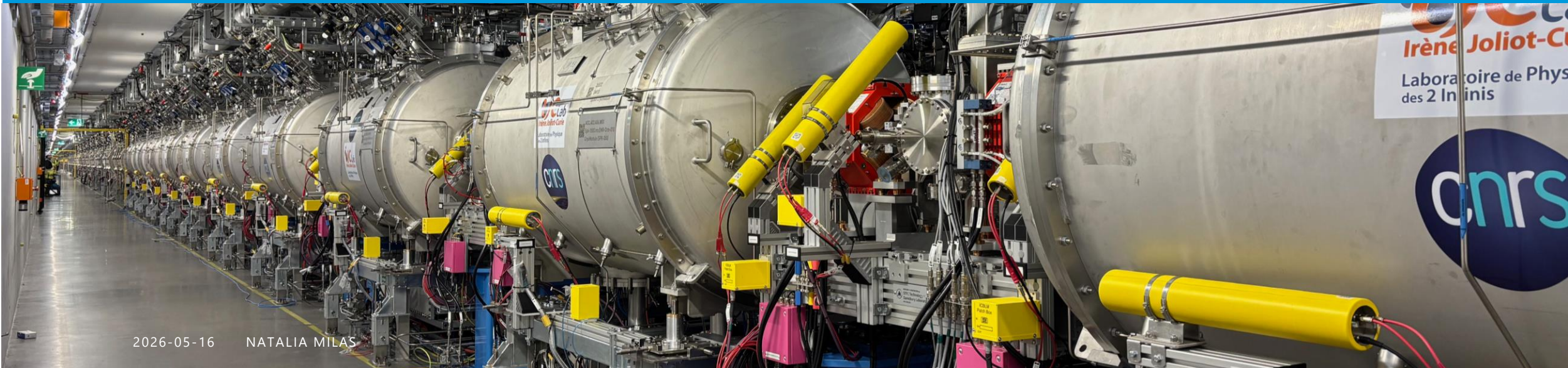
NATALIA MILAS, ON BEHALF OF THE COMMISSIONING TEAM

2026-05-16



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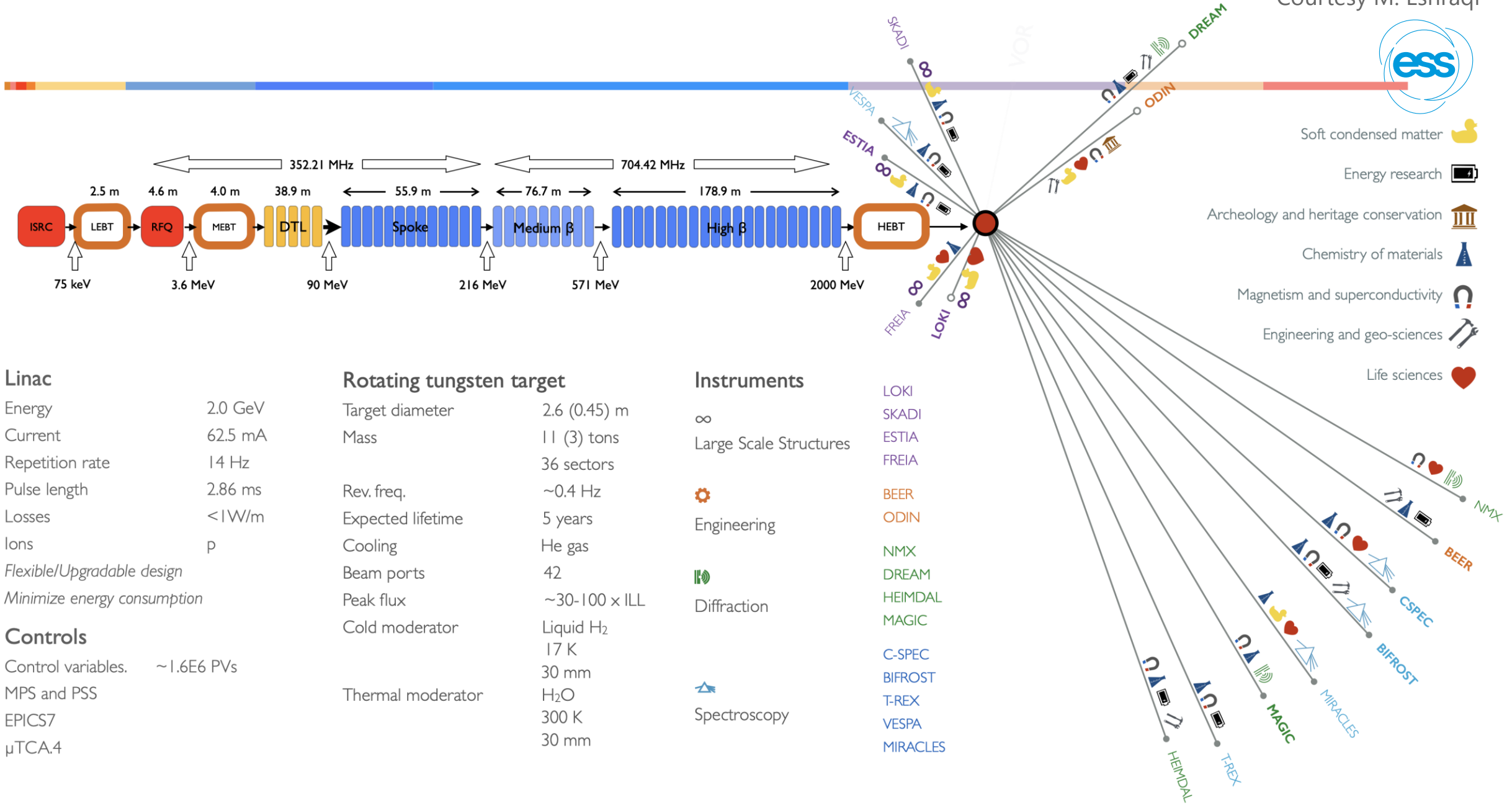
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# The European Spallation Source





- Soft condensed matter
- Energy research
- Archeology and heritage conservation
- Chemistry of materials
- Magnetism and superconductivity
- Engineering and geo-sciences
- Life sciences

### 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 <sub>2</sub> 17 K 30 mm
Thermal moderator	H <sub>2</sub> O 300 K 30 mm

### Instruments

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



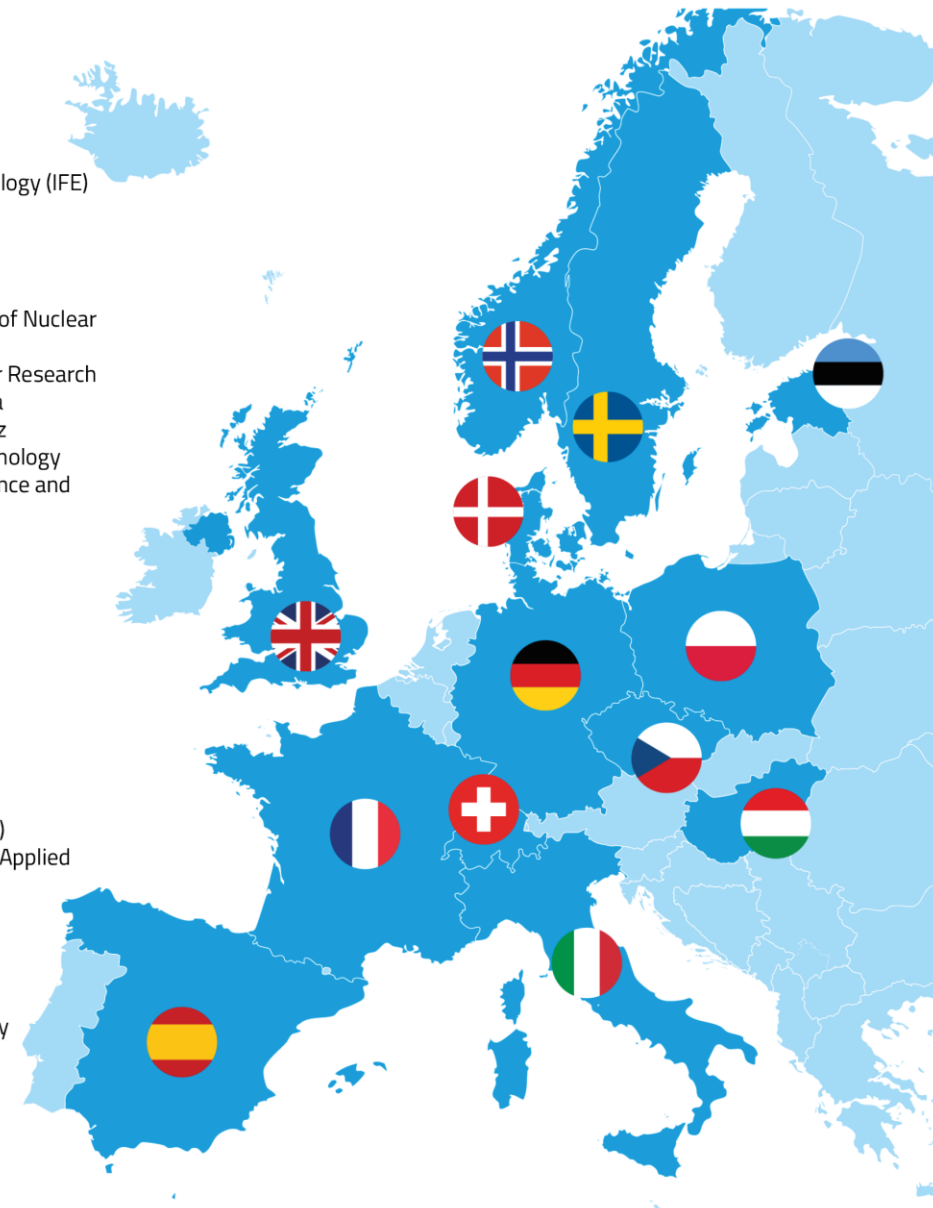
### Switzerland

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



### United Kingdom

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



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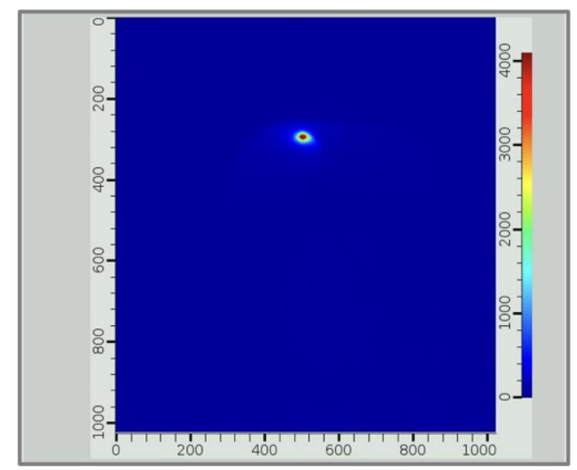
# Commissioning Timeline



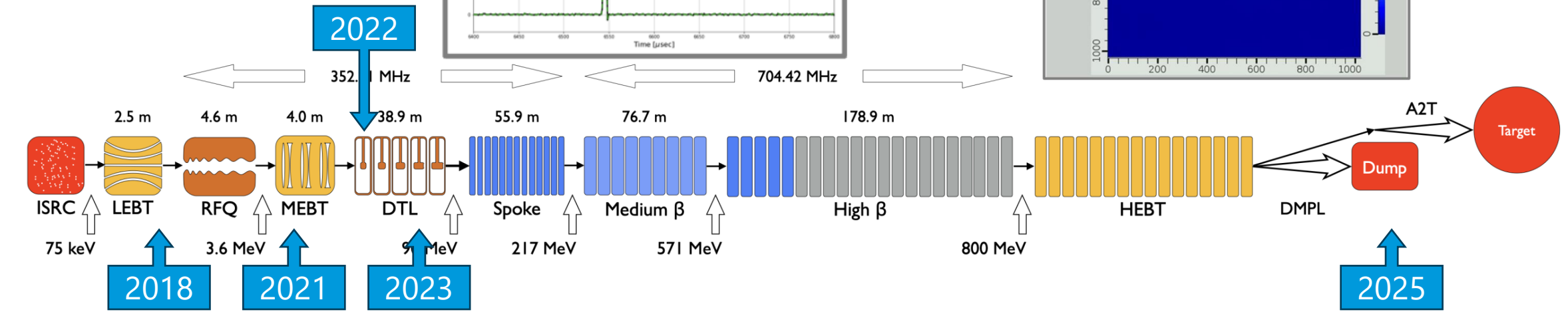
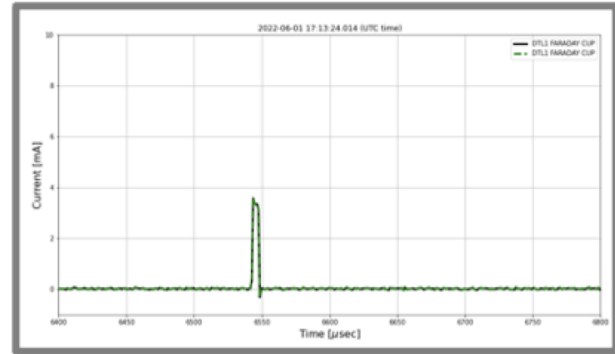


# A history in commissioning

Beam: ISrc->TBD - 09 Apr, 2025



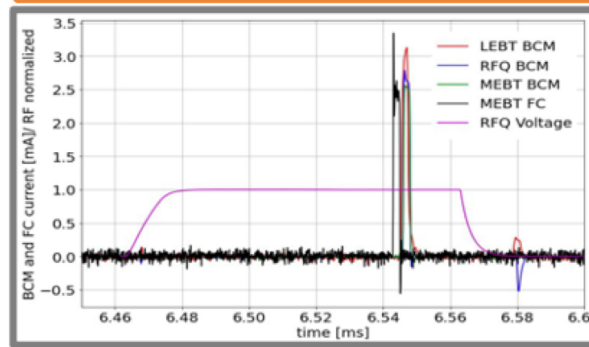
Beam: ISrc->DTL1 - 1 Jun, 2022



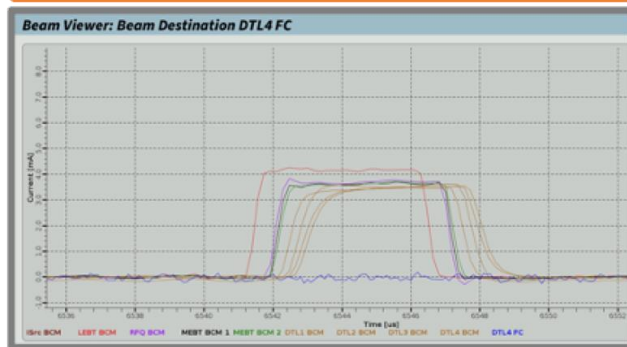
Beam: ISrc->LEBT - 19 Sep, 2018



Beam: ISrc->MEBT - 26 Nov, 2021



Beam: ISrc->DTL4 - 20 Apr, 2023



The beam stops for the ESS superconducting linac (MOP7098)

# Commissioning timeline and goals



## Beam on Dump part 1 and 2

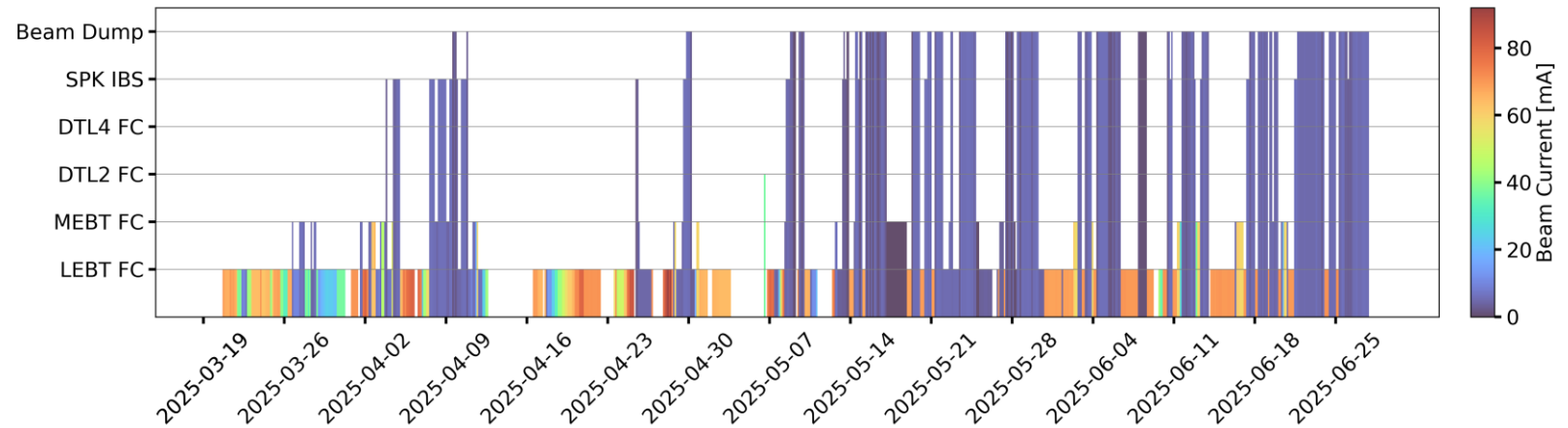
### 2025 (March to June)

Transport beam to dump

Final Energy: 800 MeV

Pulse: 6 mA, 5  $\mu$ s

RF pulse: 1 ms (max)

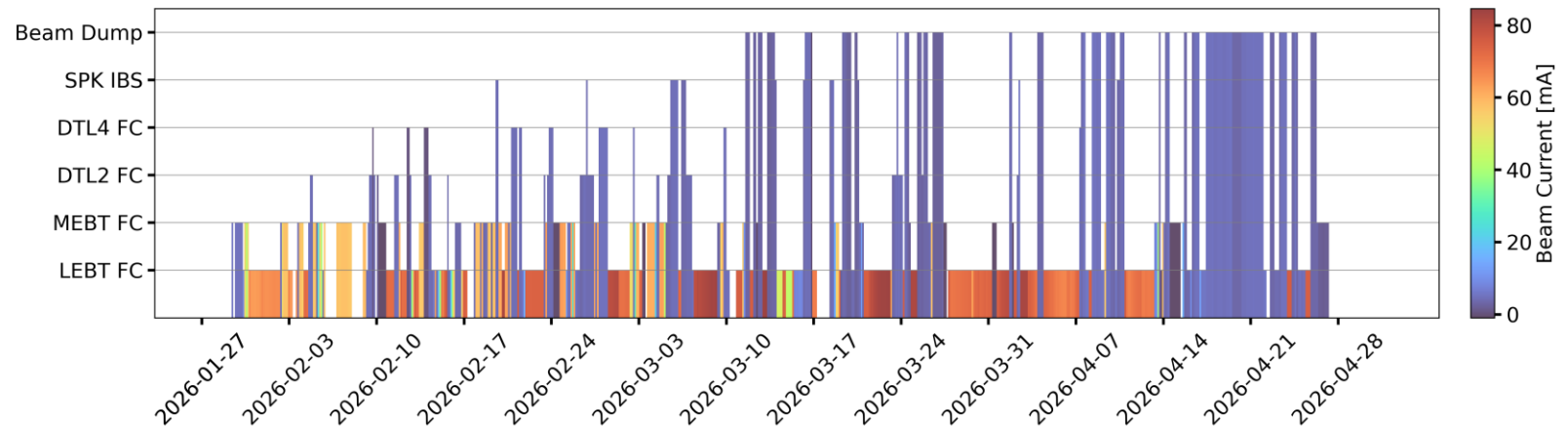


### 2026 (January to July)

Beam to Target  $\rightarrow$  2027

Increase beam pulse length and current ( $> 5\mu$ s and  $> 6$  mA)

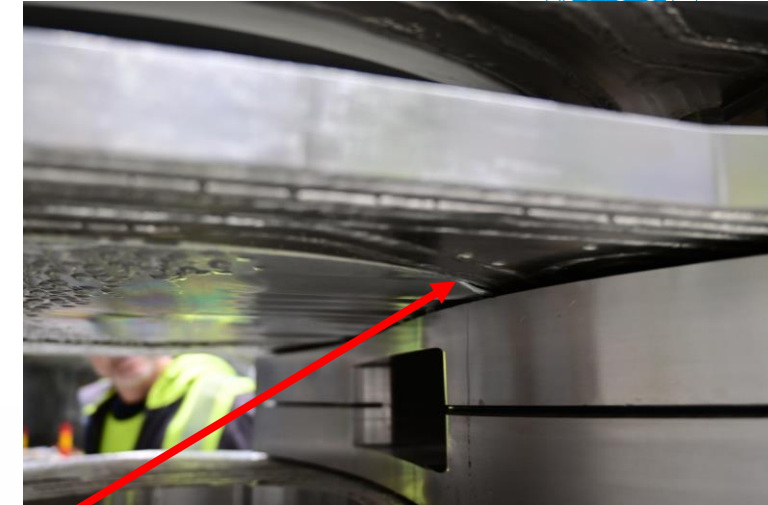
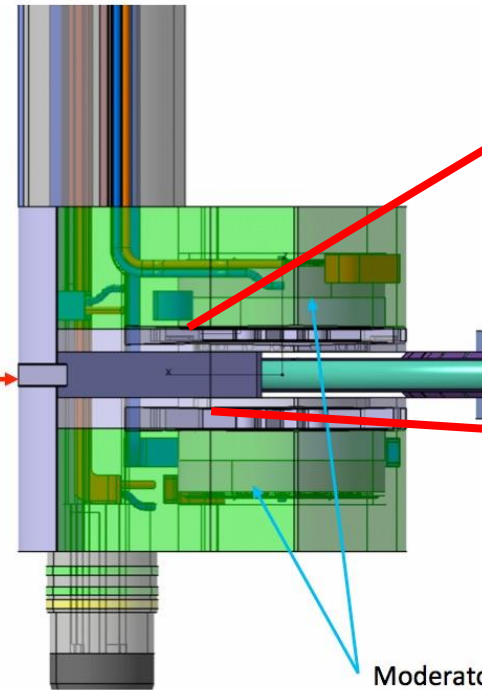
RF pulse: nominal



# 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 stopped, causing water flow to cease and subsequently cooling water in the Moderator Reflector Plug (MRP) to freeze. **Overall delay ~9 months.**

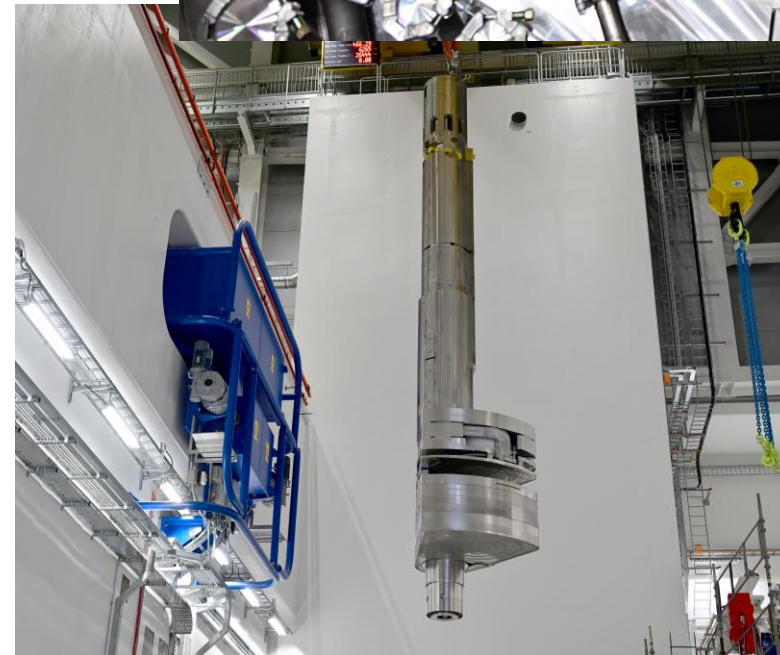


# Moderator Damage

2025: power glitch between 25/26 November

Positive take-outs:

- A longer accelerator commissioning period.
- More instruments (3 →6) 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.



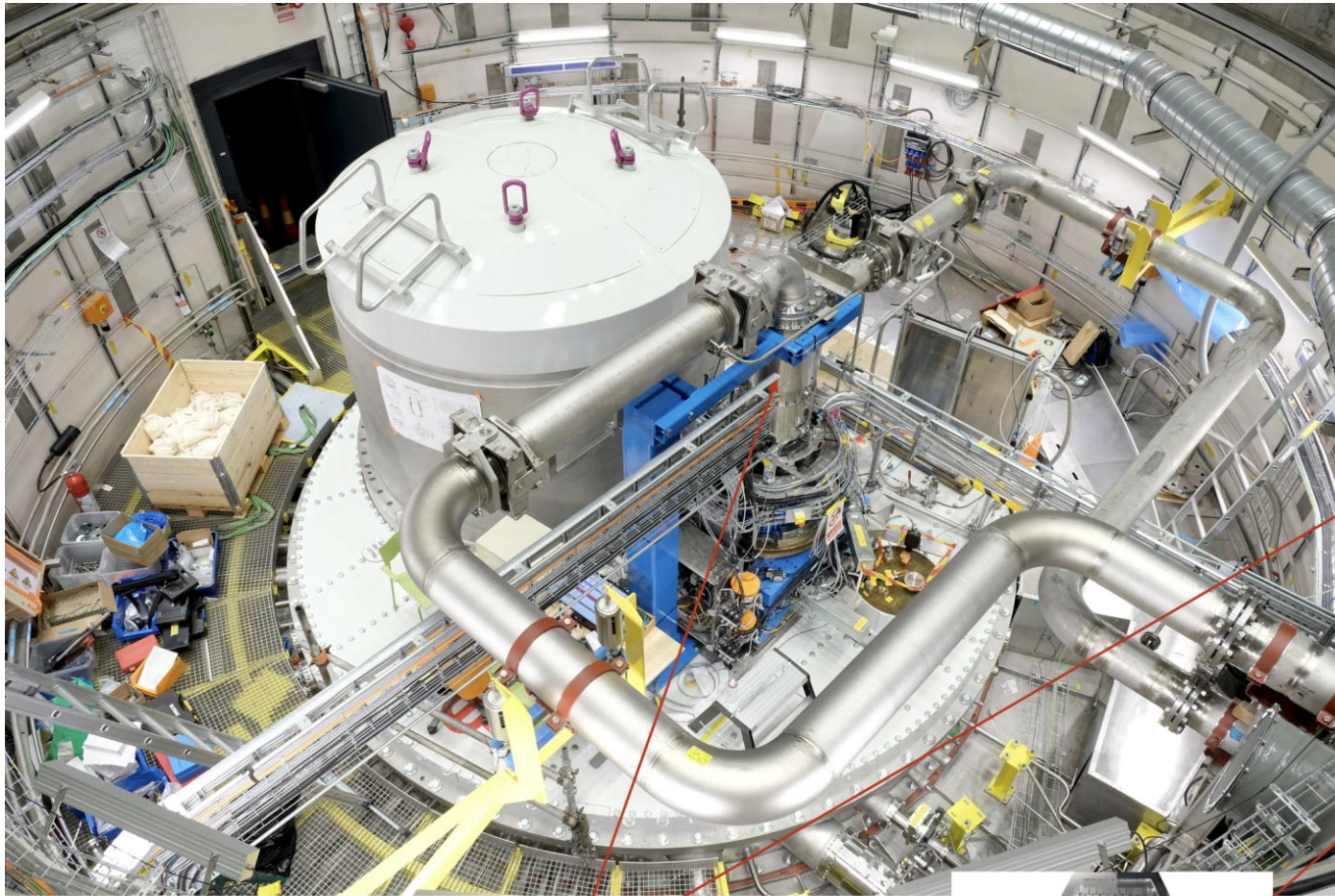


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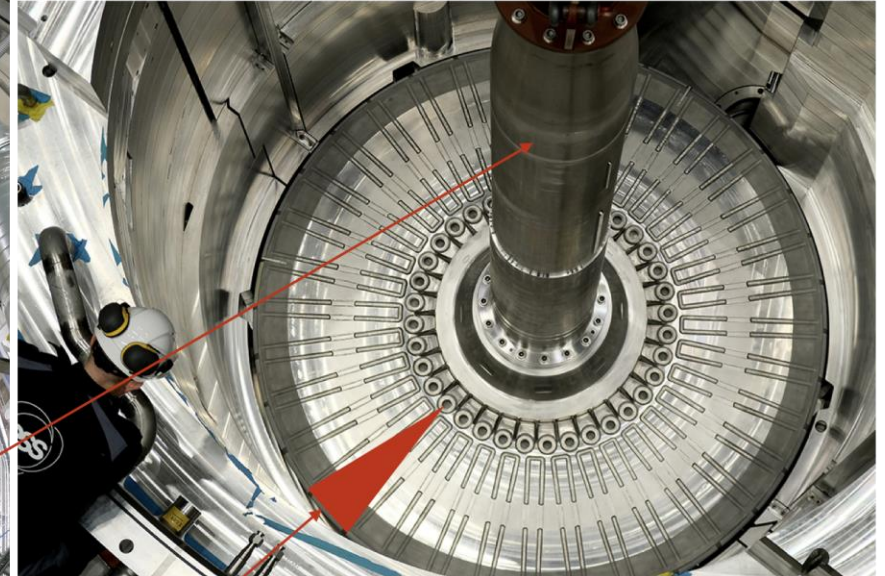
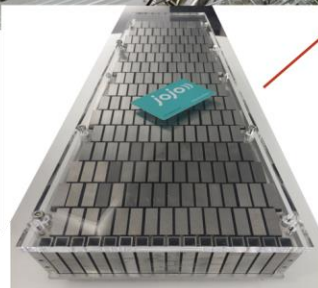
# Systems Installations



# Target and Moderator

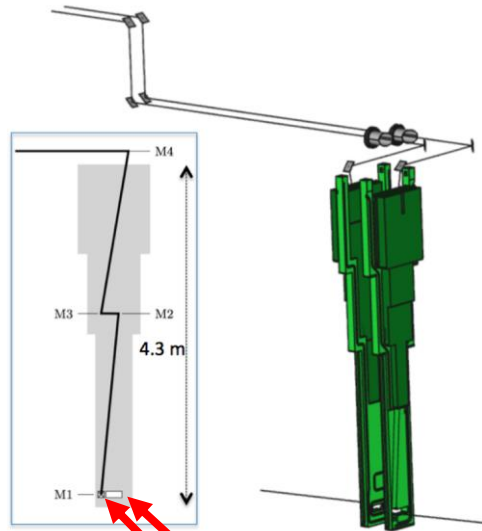


Target Shaft

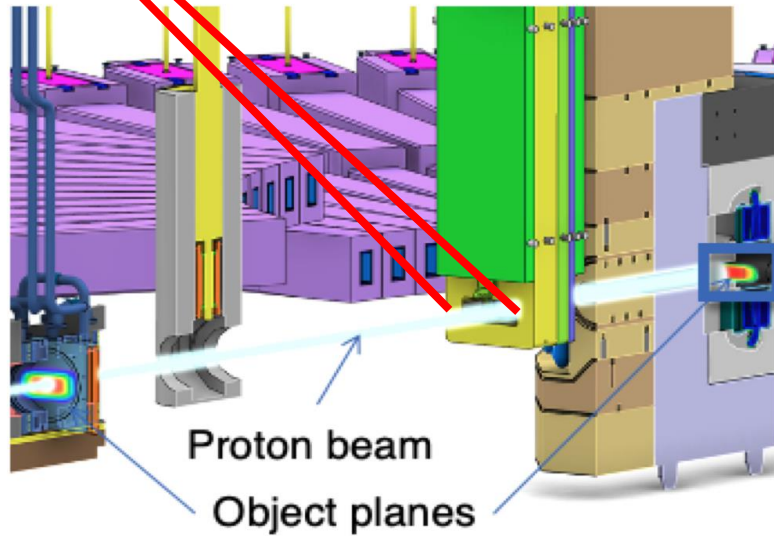
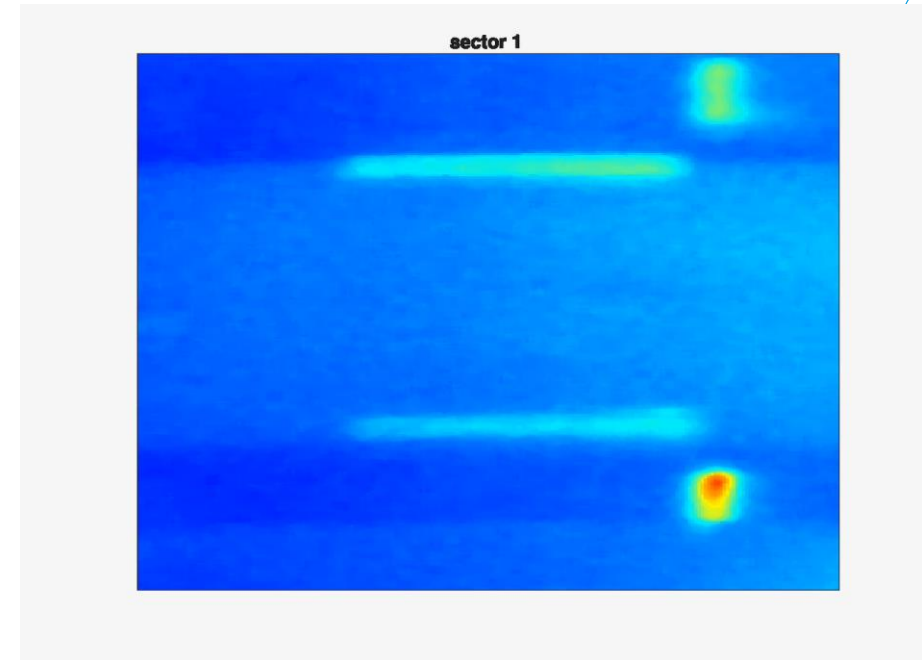


# Target Imaging System

Courtesy C. Thomas



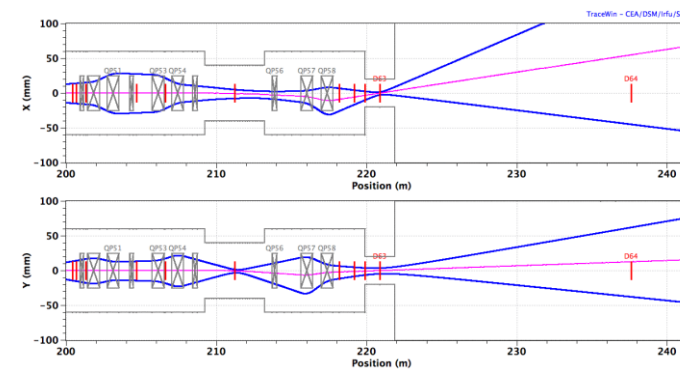
To monitor the beam on the target wheel we have a system that images the fluorescence a coating spread over the side when beam passes through



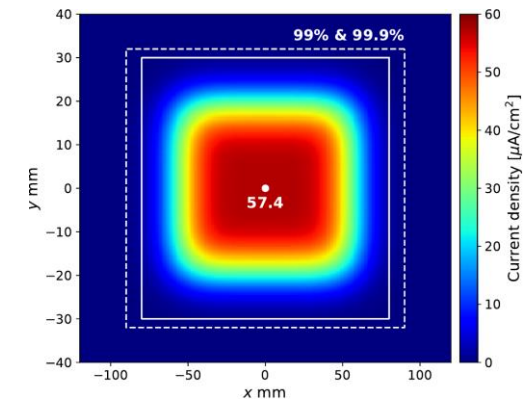
Rotating tungsten target

Proton beam

Object planes

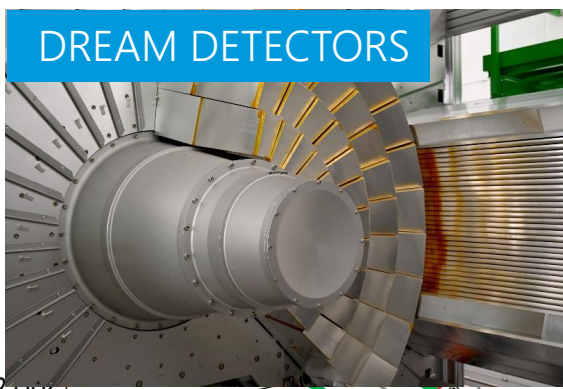


Raster motion  
(Courtesy of H. Thomsen)

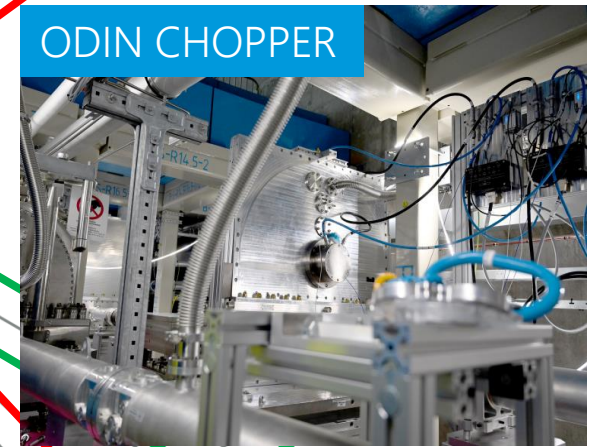
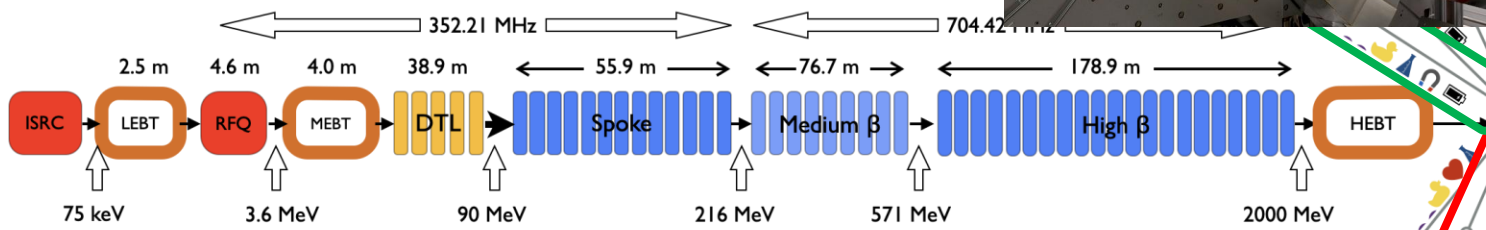


Beam-on-target footprint

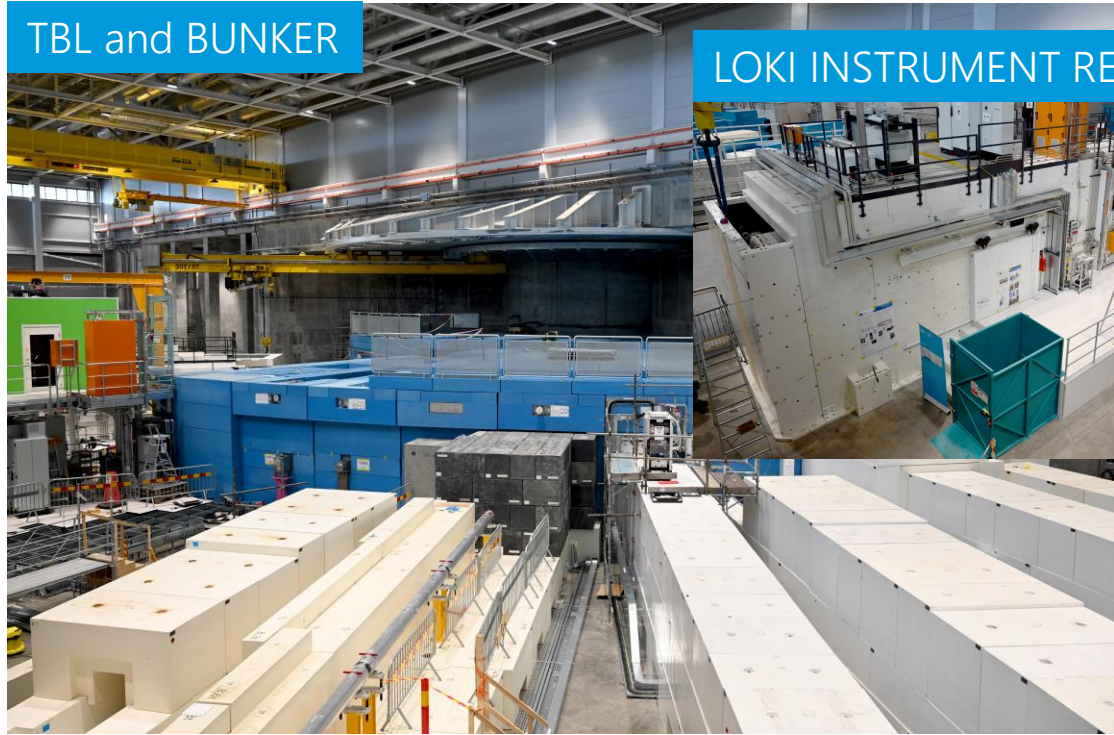
# Instruments



Soft condensed matter



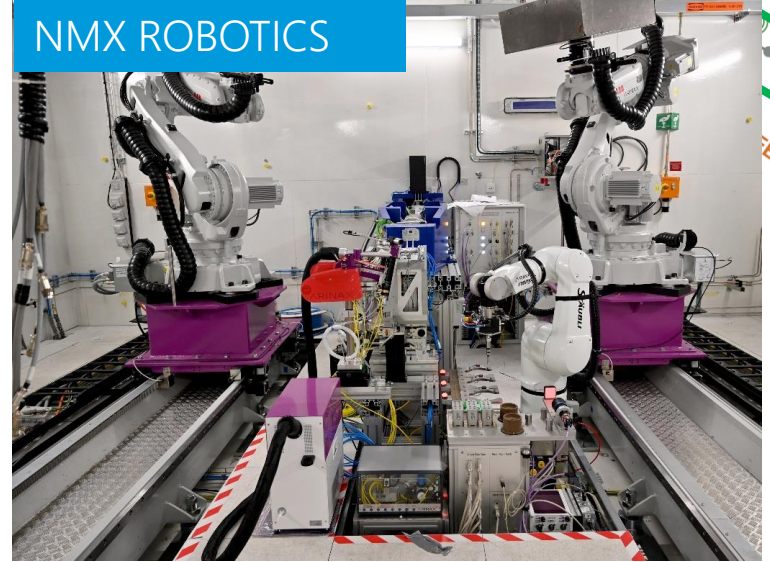
TBL and BUNKER



LOKI INSTRUMENT READY



NMX ROBOTICS

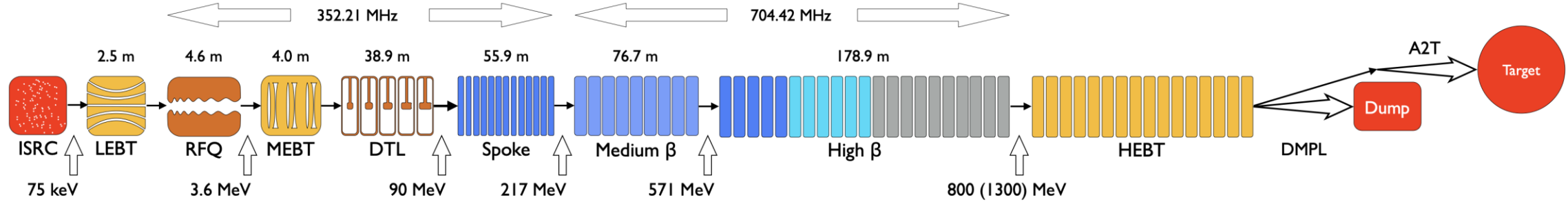


# Linac

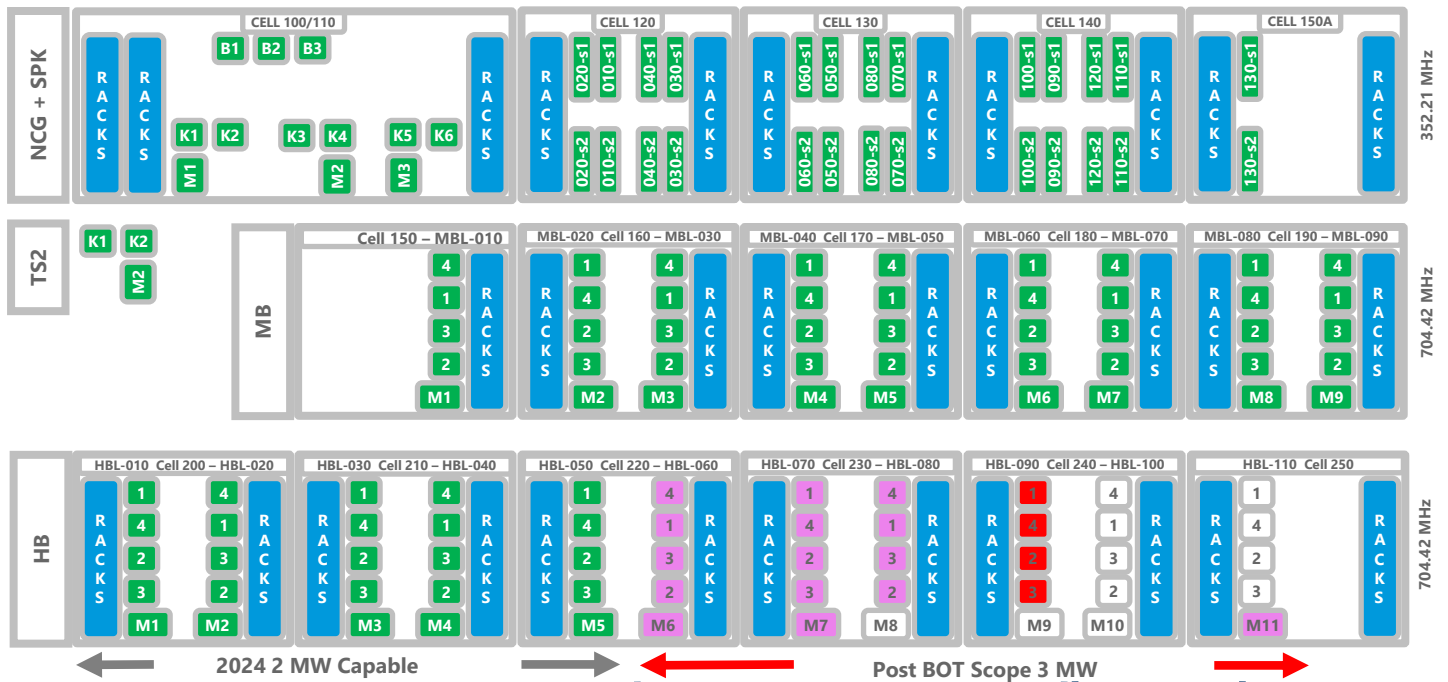
Additional installation effort for the 3MW readiness at ESS (MOP7037)



## Road to 3 MW capability



6 more cryomodules installed, summer 2025



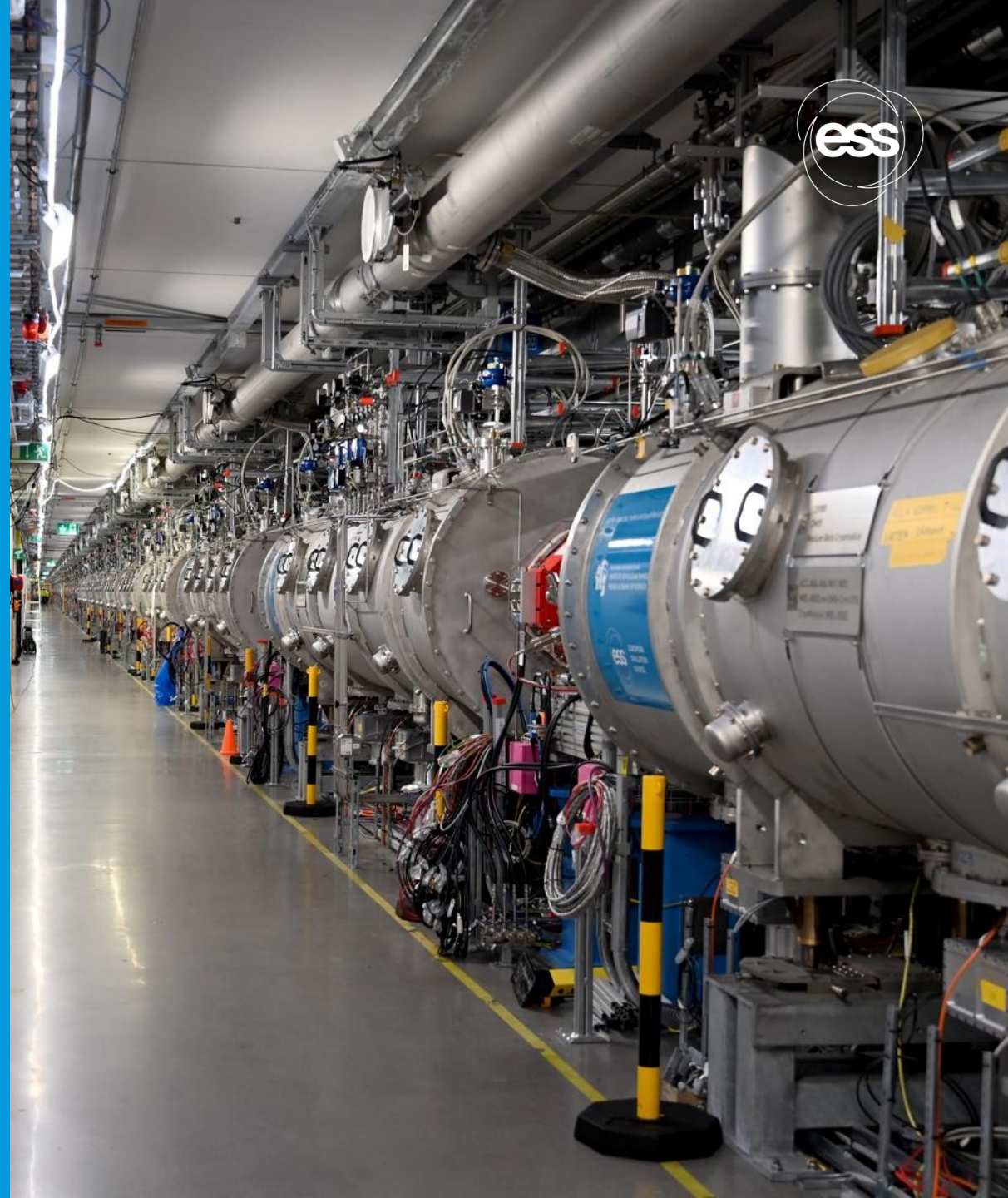
Installation complete, ready for testing  
CPI Klystron testing

4 modulators purchased as a risk mitigation for tetrodes

2 spare modulators available (not installed)

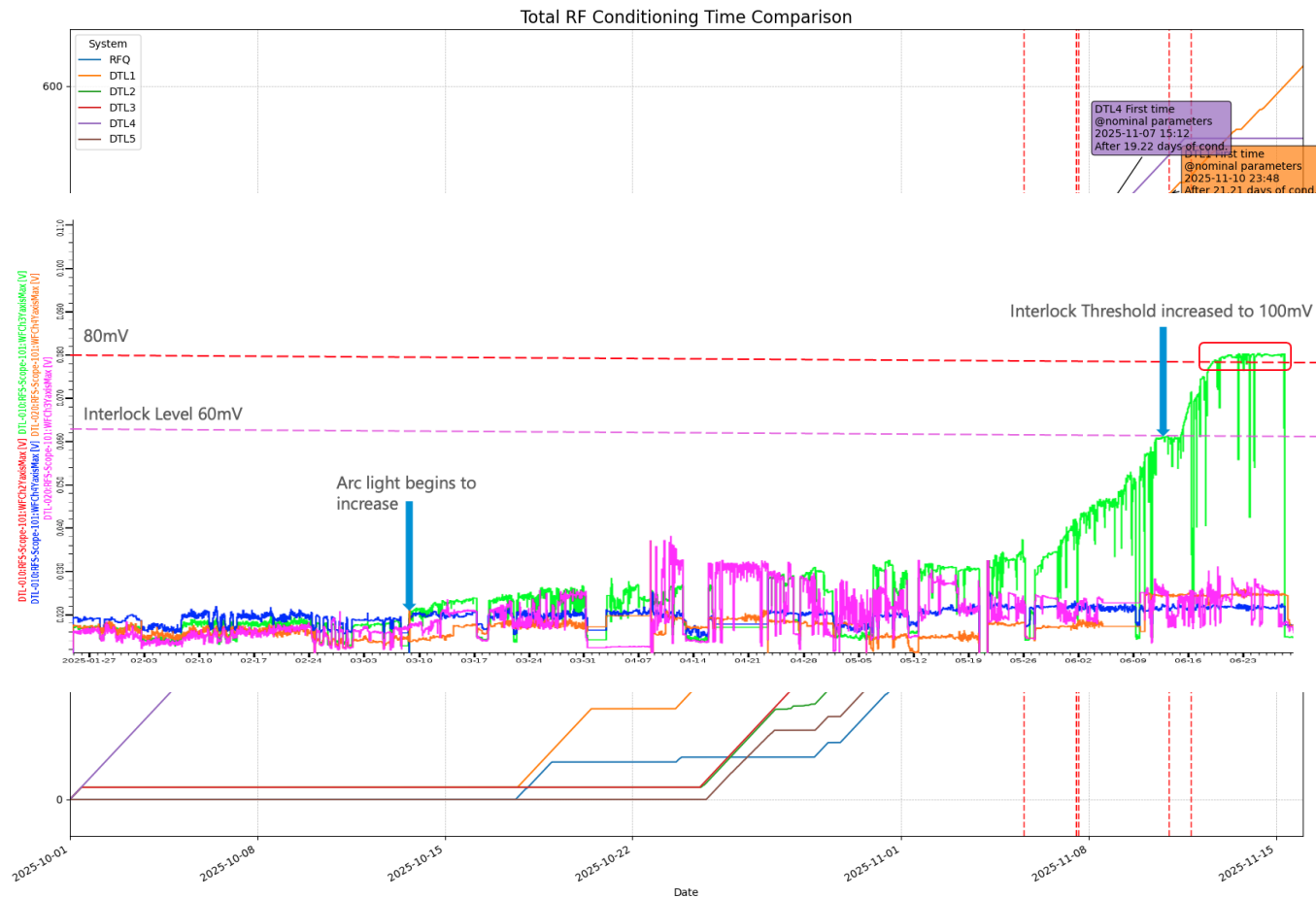
## 4

# RF Conditioning with long pulses

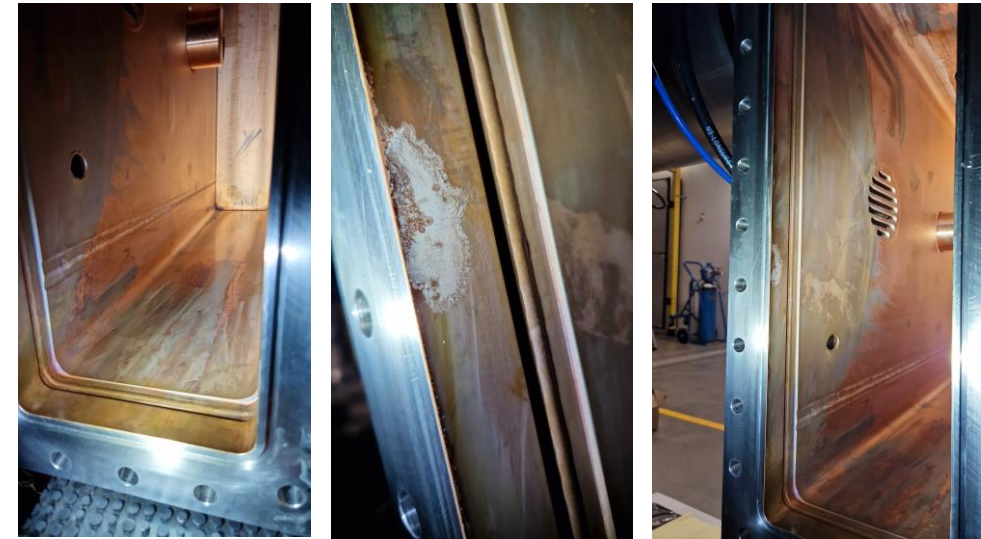


# NCL Conditioning

## 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



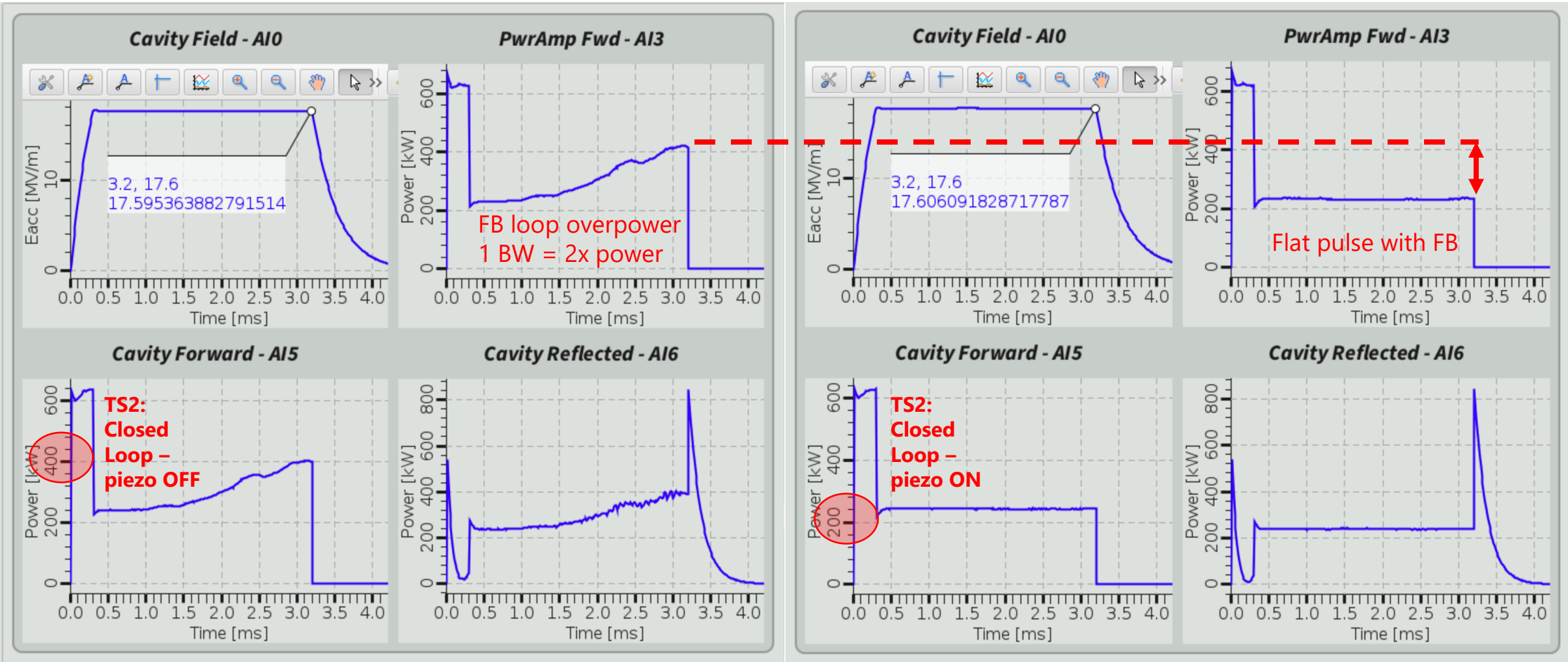
Piezo ON

# SCL Conditioning

3 ms pulse + Piezos

Piezo OFF

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

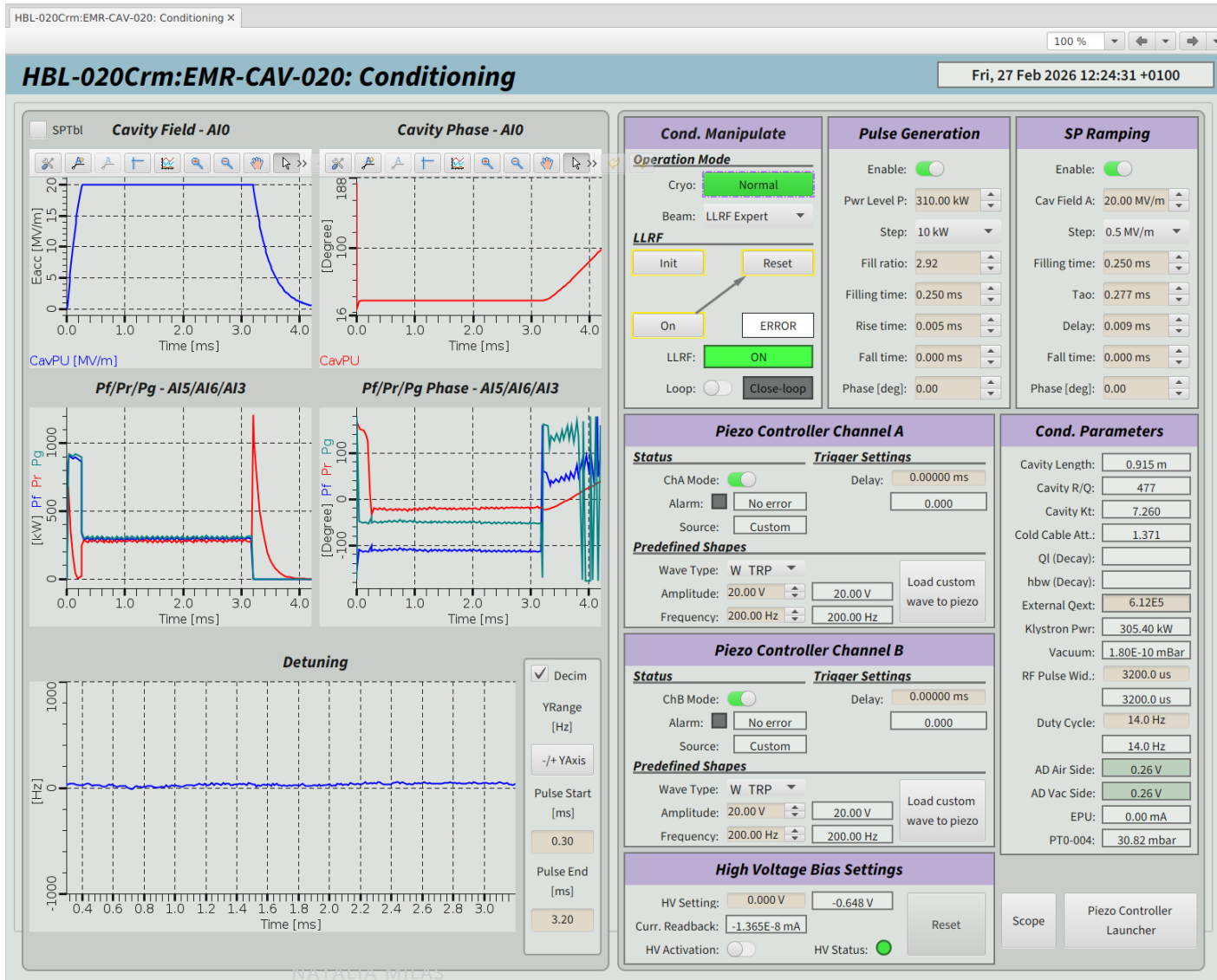


Proof of principle, now integrated in LLRF (semi-manual)

# 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)



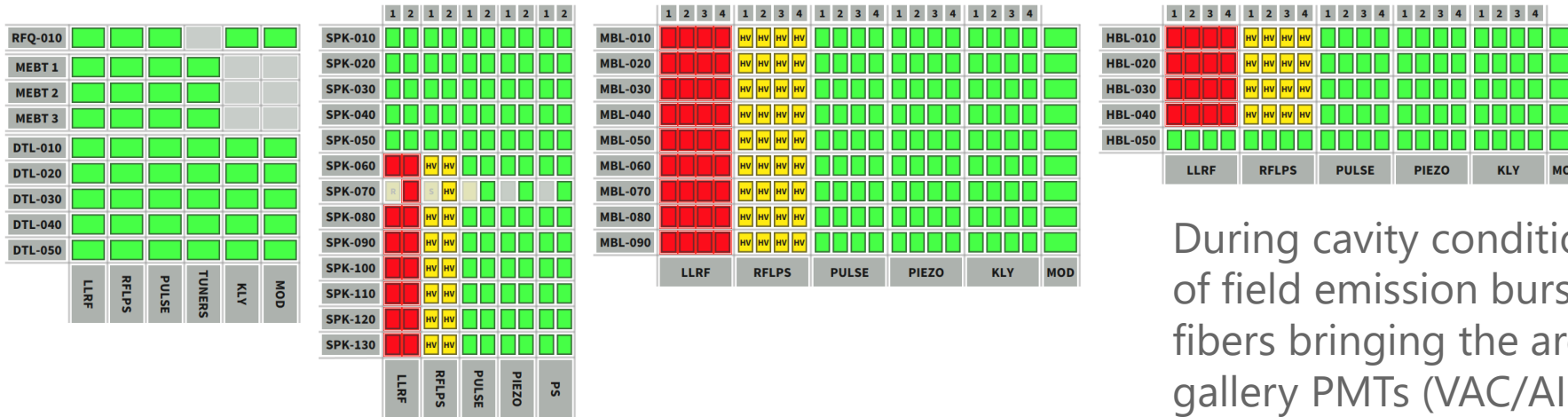
Much more on piezos MOP7040

# SCL Conditioning

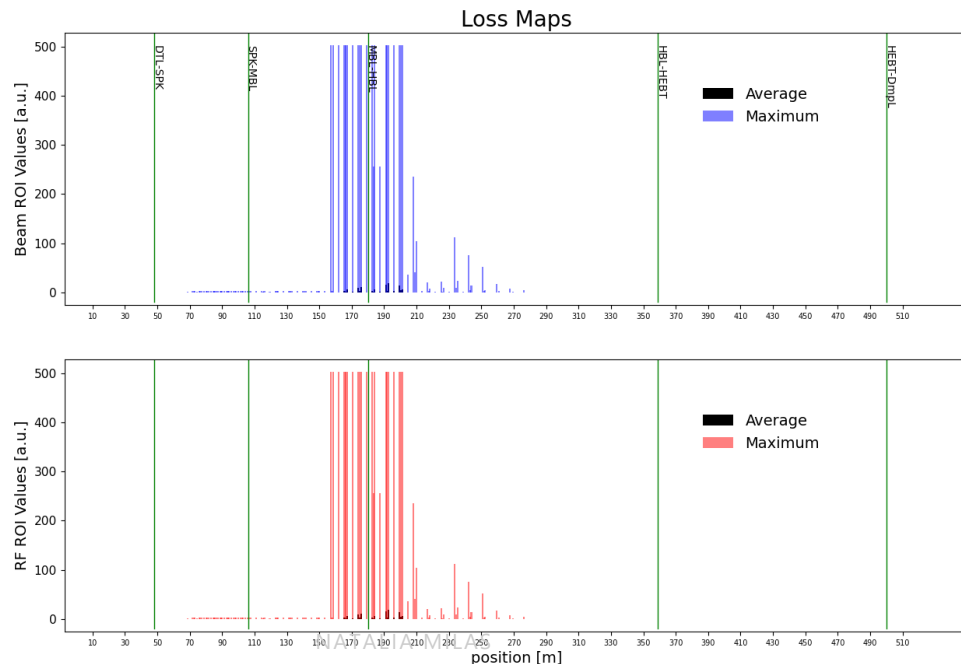
## Field Emission



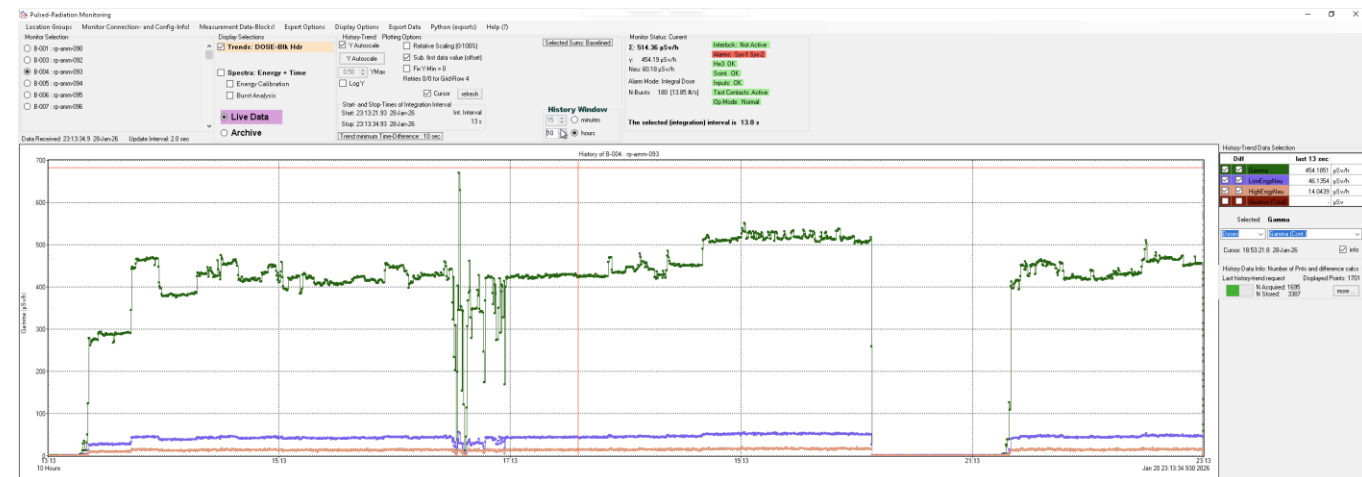
All data from 28.01.2026.



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.

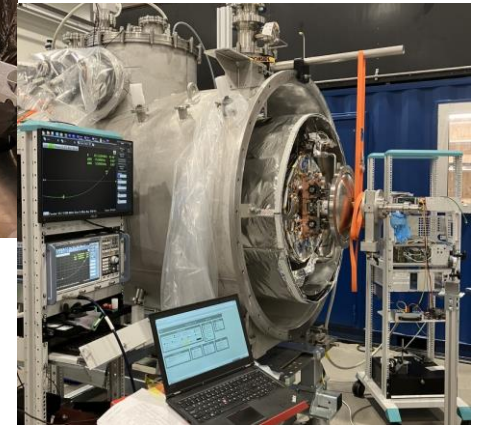
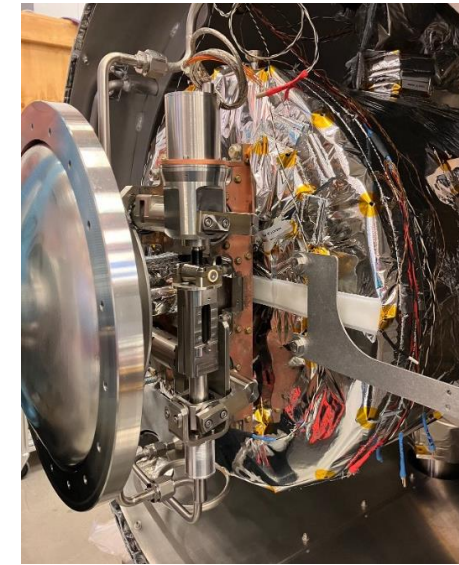
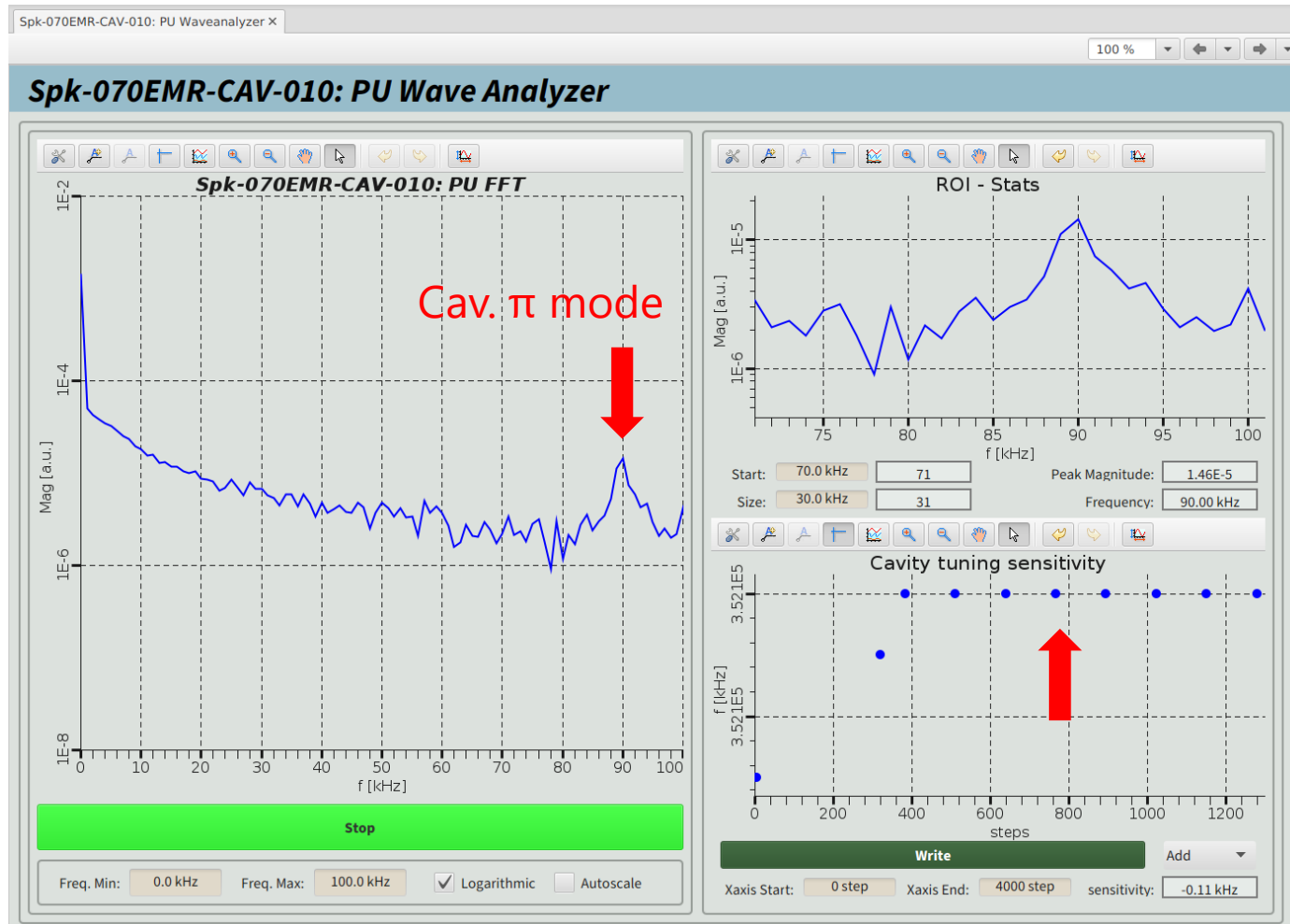


Courtesy A. Zwoznik and C. Maiano



# 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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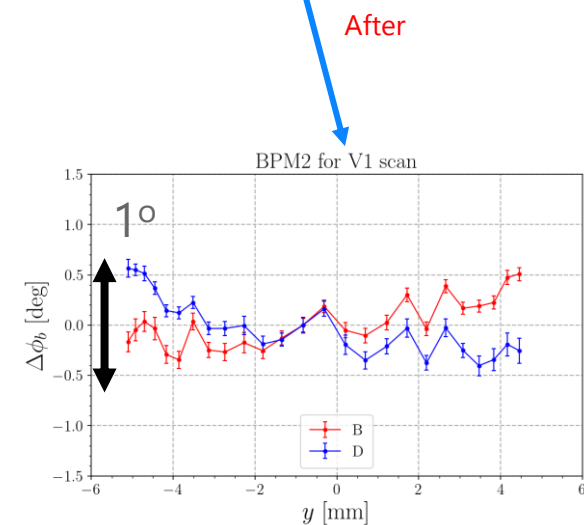
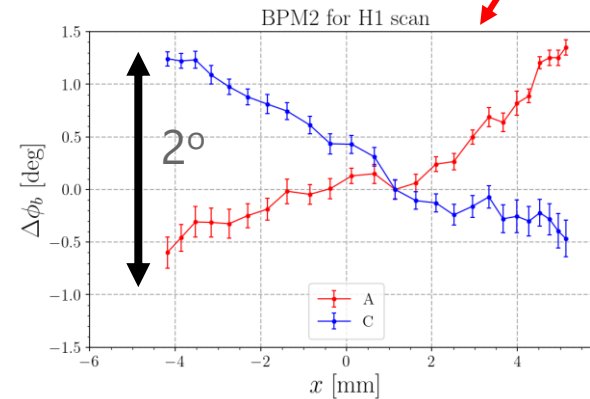
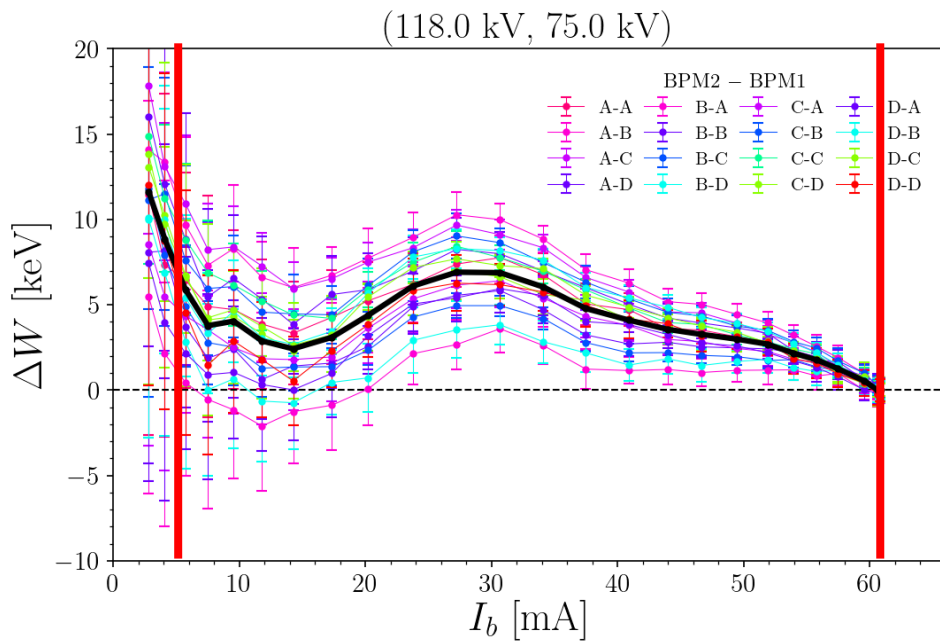
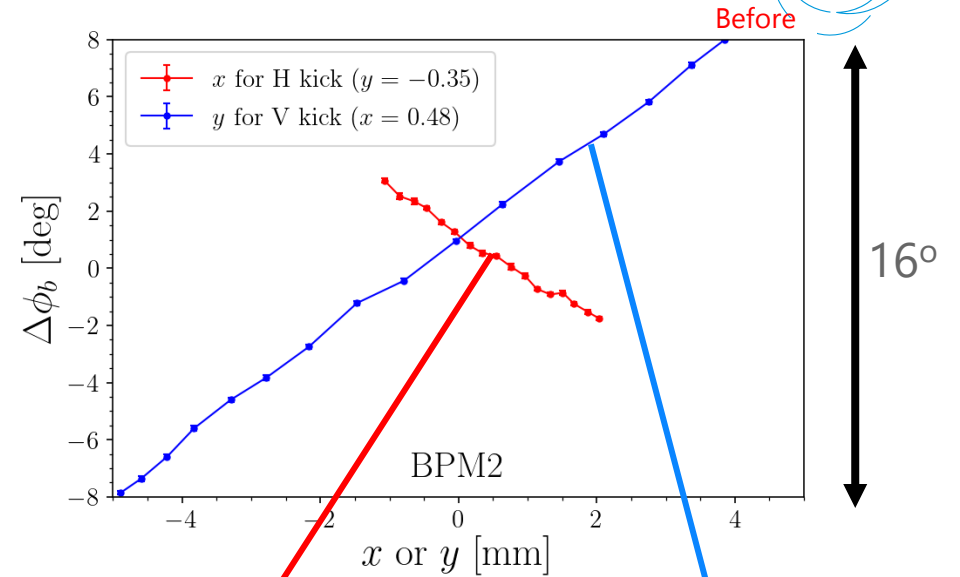
# Beam Commissioning Results





# BPM phase-position dependence

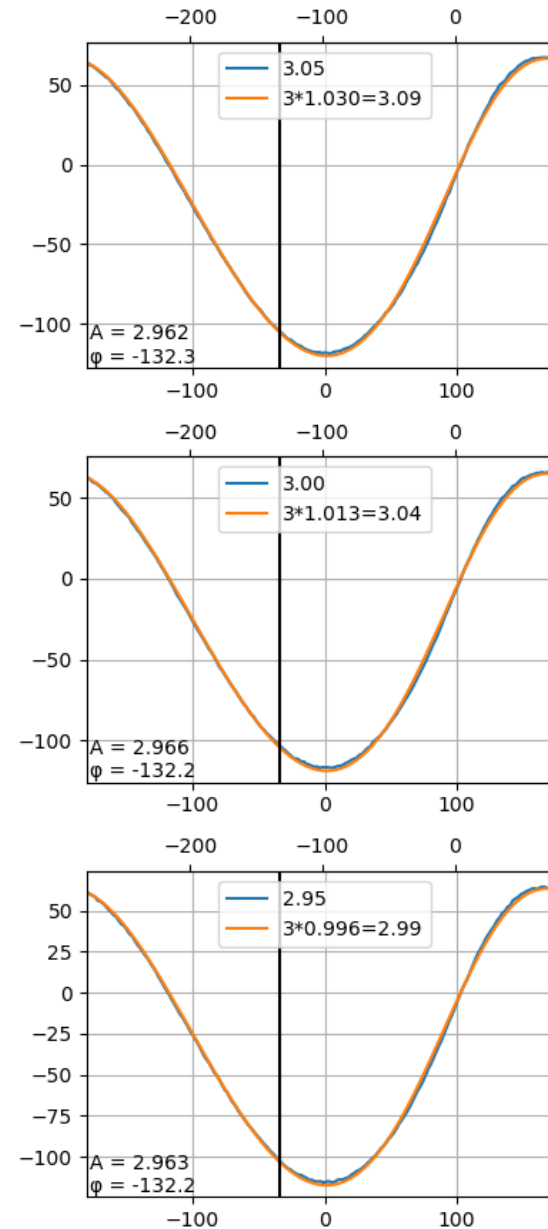
- Discovery of strong correlation between phase and position on the BPM in the NCL. This is now fixed
- Small systematics is remaining. (Further mitigation possible?)
- Even with this correction we still see an energy dependence on the beam out of the RFQ. How to compensate?



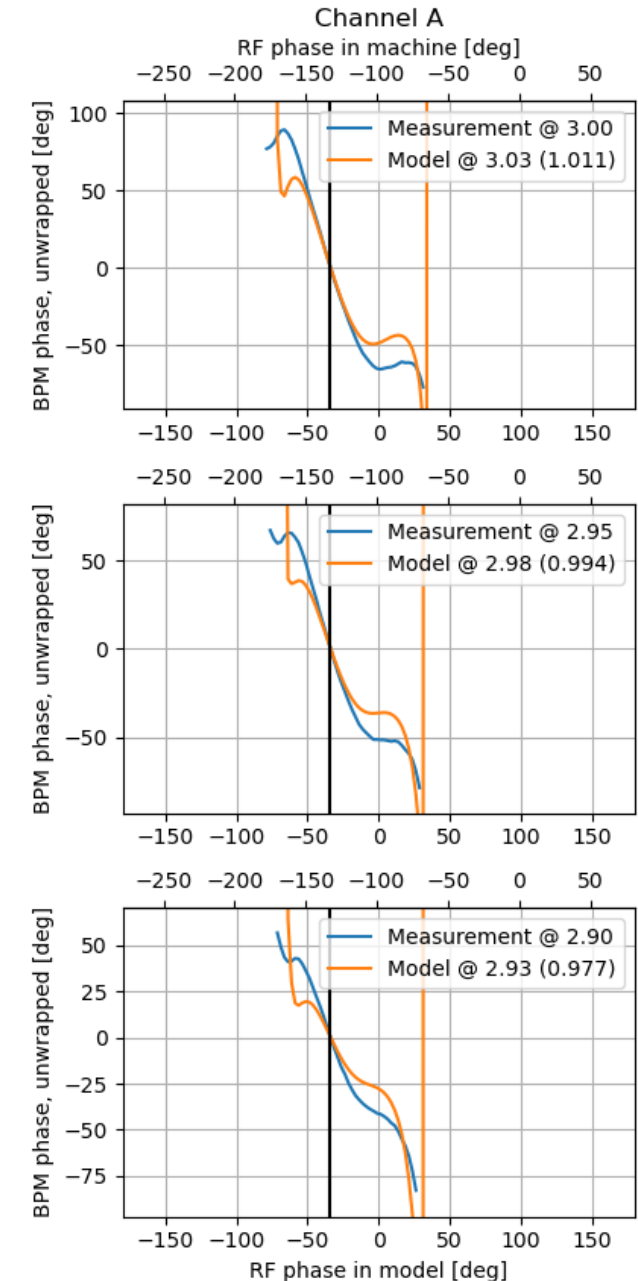
# Phase Scan

- Model independent script for phase scan, improvements in 2026:
  - NCL remain slightly manual. But results are much better (BPM phase-position fix)
  - Fixed position of DTL BPMs reduced systematic error of 10-12% in field amplitudes. Better fits to model
  - Automation: ~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

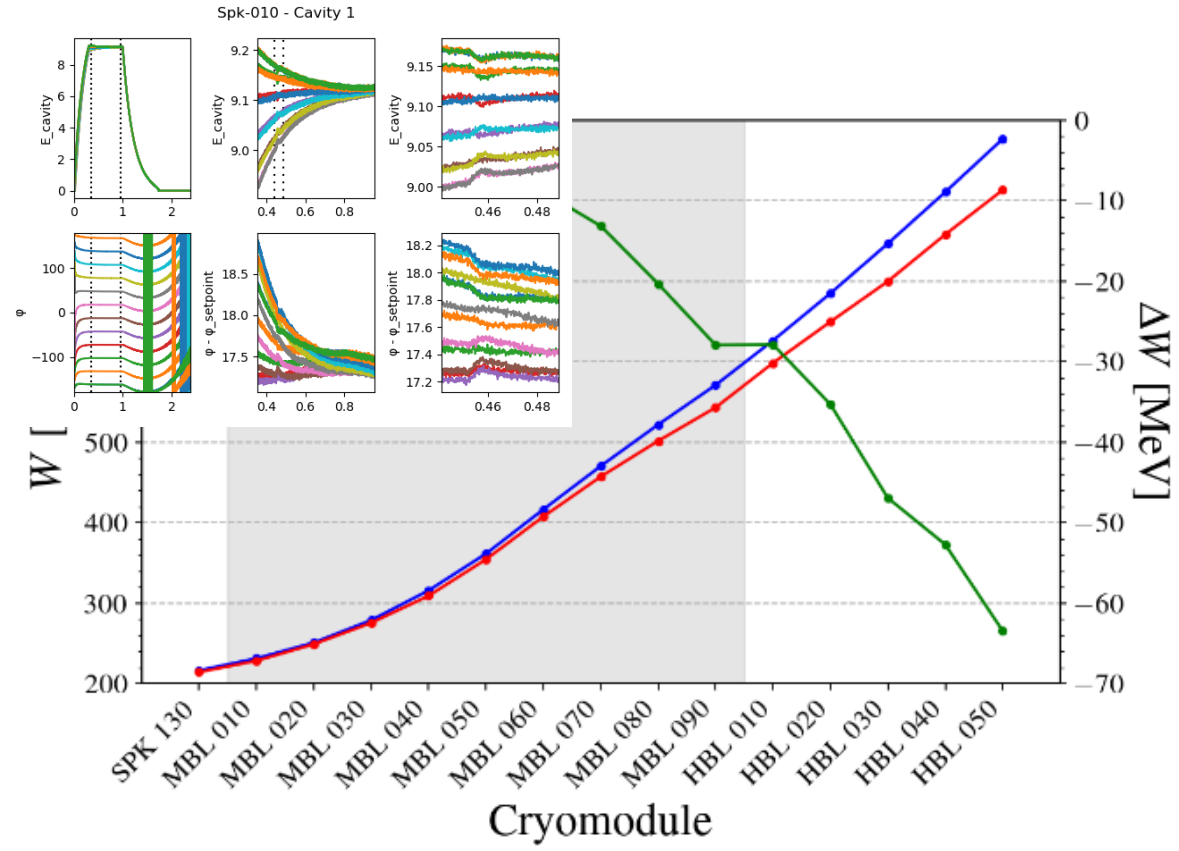




# Phase Scan

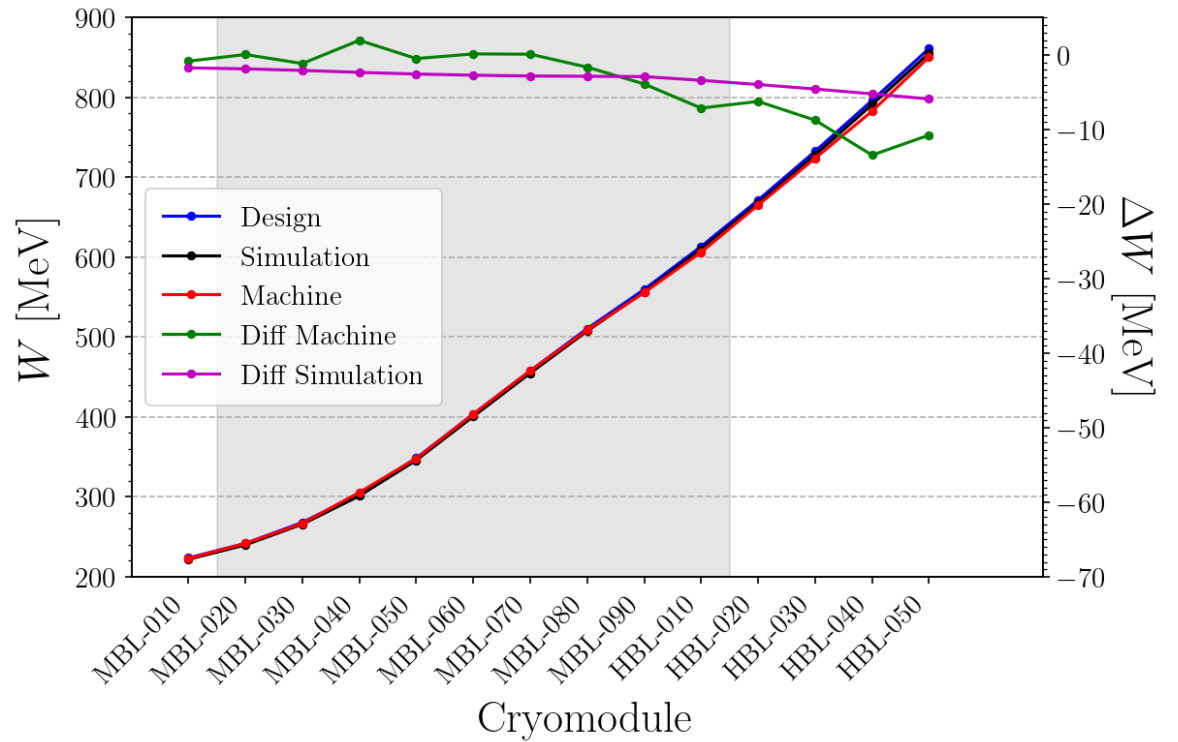
2025

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



2026

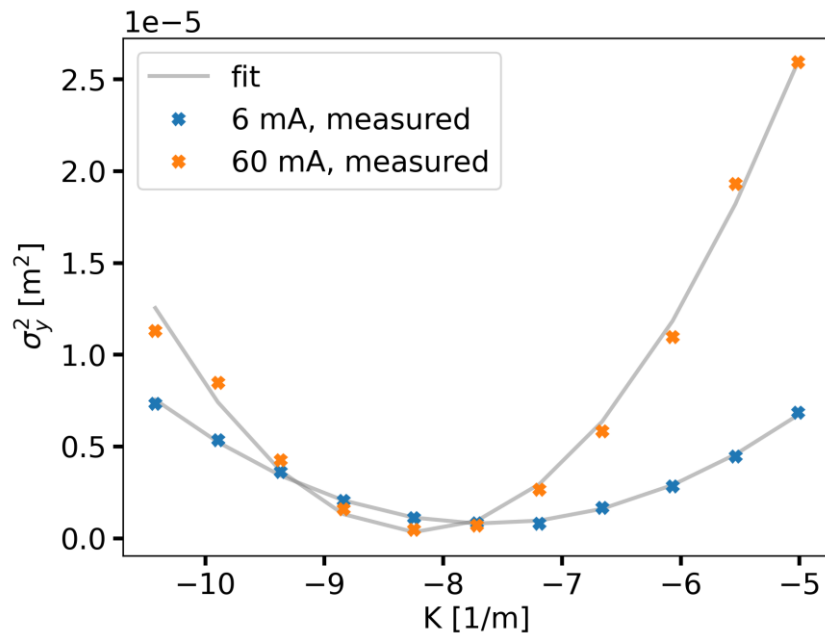
- Improved loops in LLRF
- Flatter Fields
- Improved Phase Scans of NCL
- We are trying to simulate and understand this energy drift



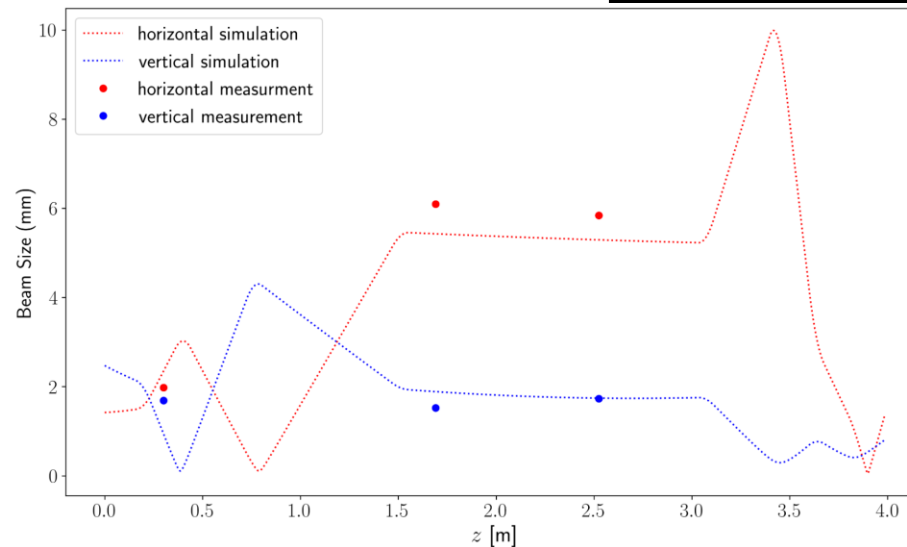
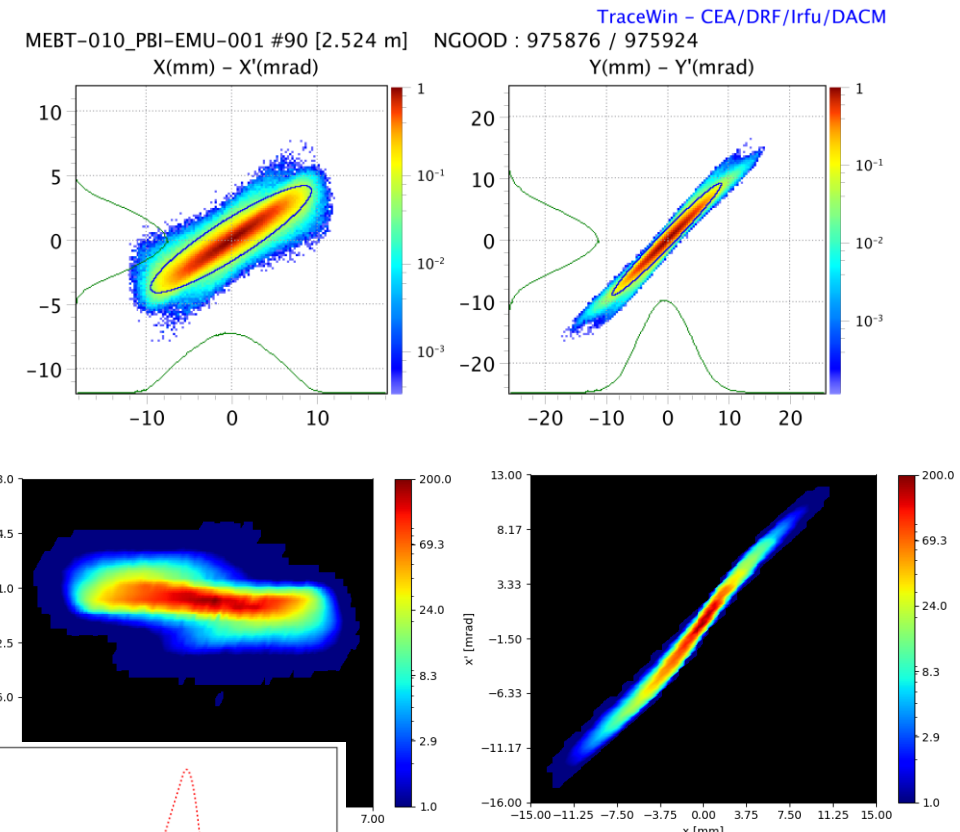
# Transverse Dynamics

Method	6 mA ( $\pi$ mm mrad)		60 mA ( $\pi$ mm mrad)	
	$\epsilon_y$	$\epsilon_x$	$\epsilon_y$	$\epsilon_x$
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

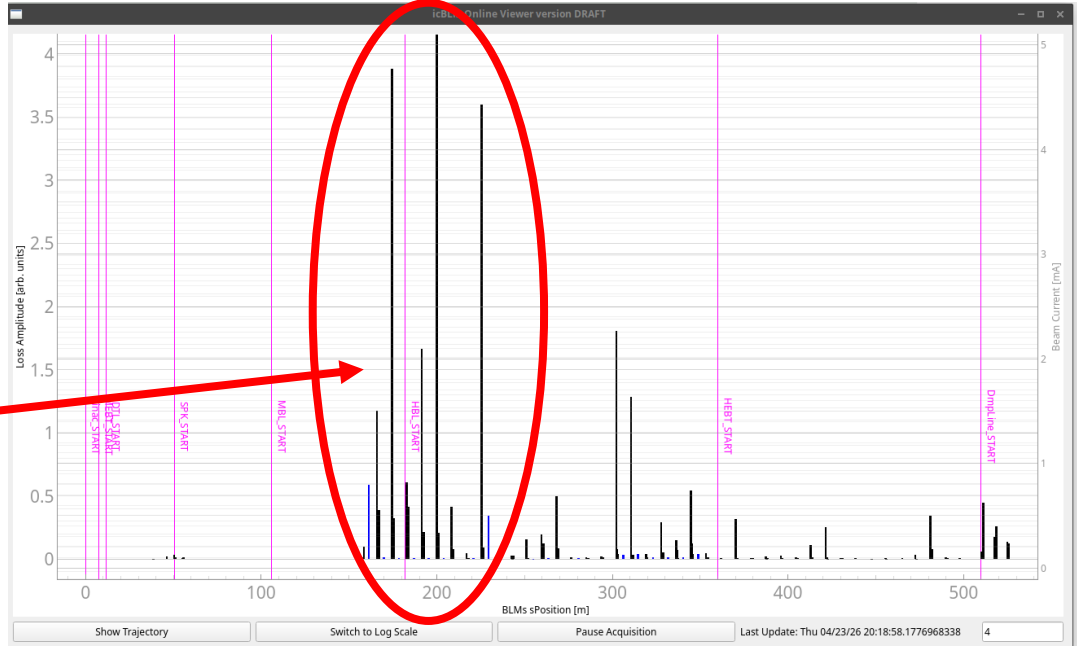
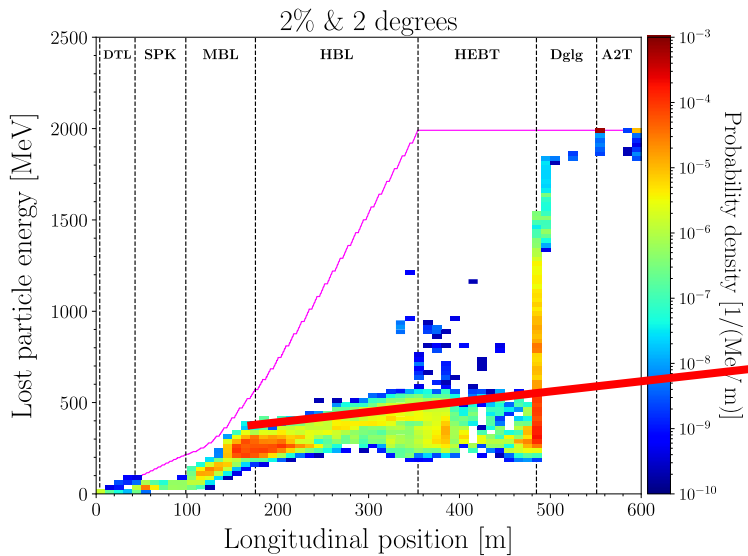


## BPM Quadrupolar Component (WEP6075)

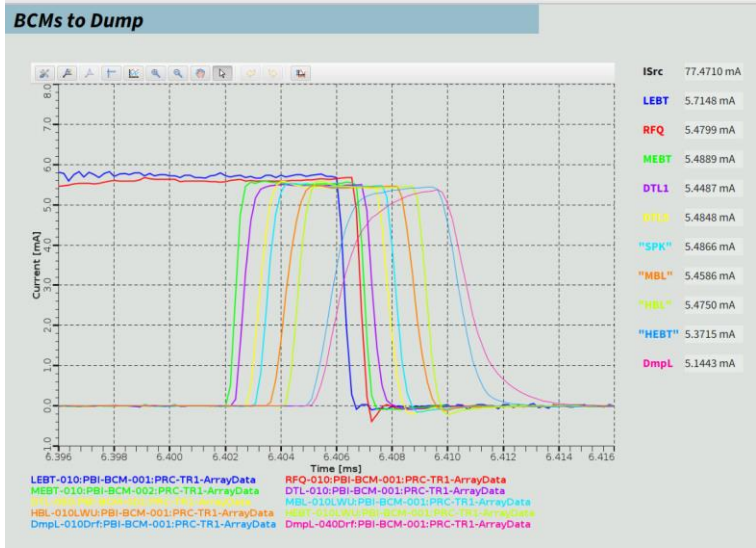




# Beam Loss Tests



- For the beam loss, longitudinal dynamics is far more important than the transverse.
- 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.



# 6

# Outlook

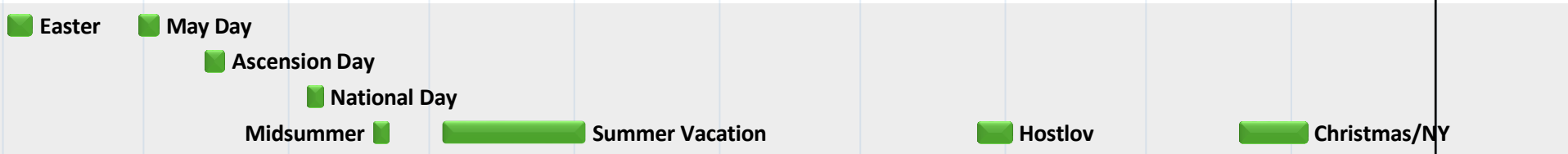


# Next steps

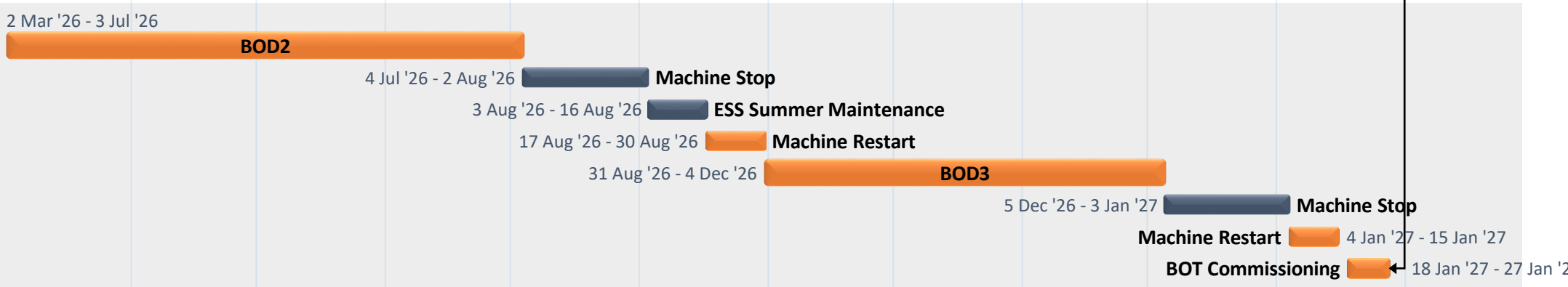
## Long pulses and beyond



### Holidays



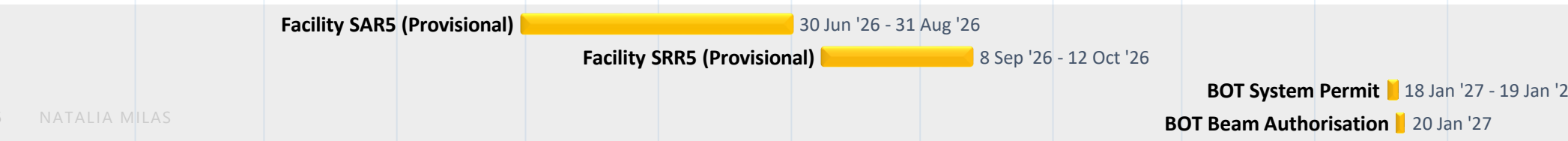
### 2026 ACC Operations (Jan 2026)



### Spring Stop



### Reviews





# Conclusions

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





Thank you! Questions?

2026-05-16



ESS

Klystron gallery

Accelerator tunnel

Cold box

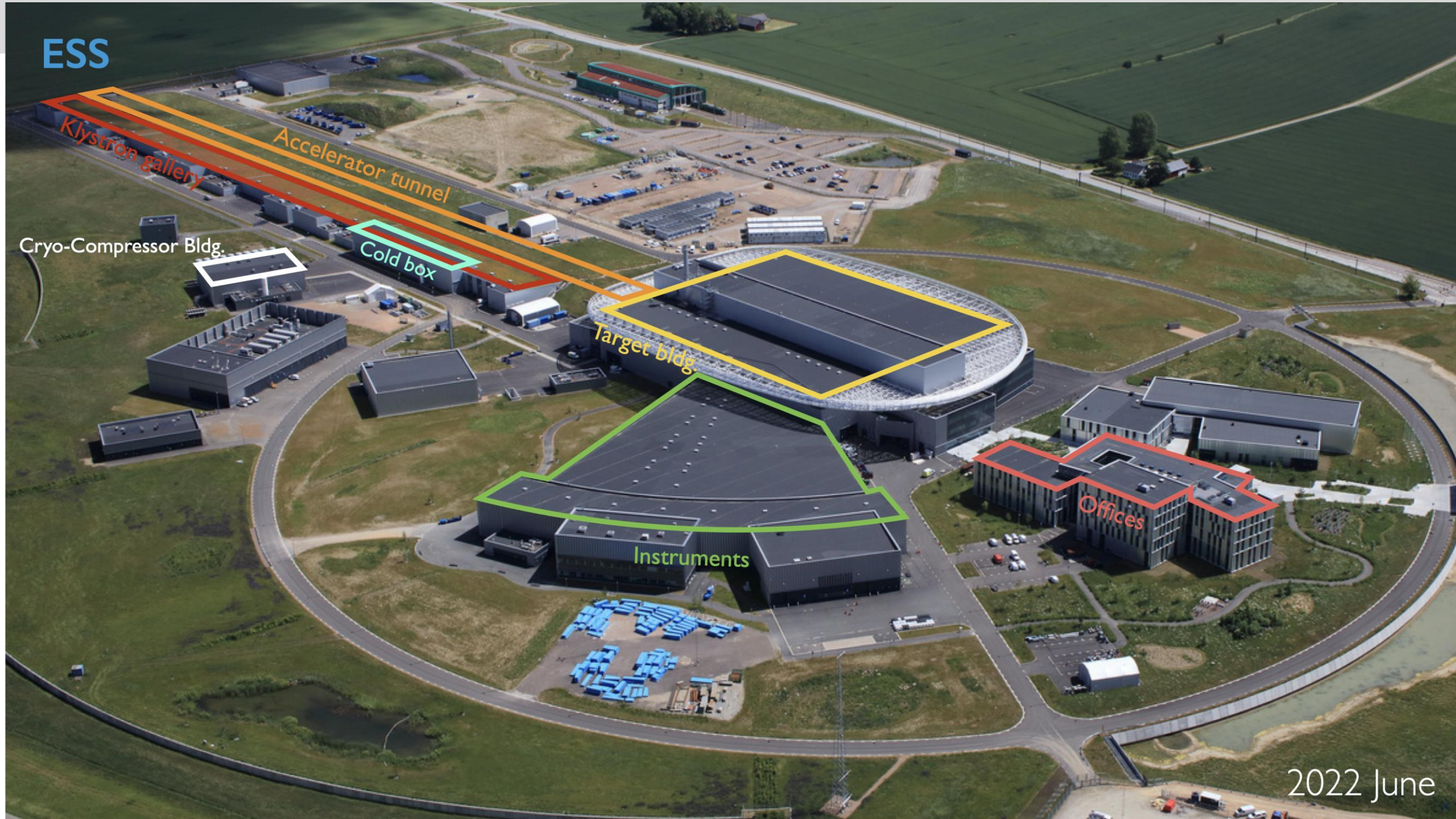
Cryo-Compressor Bldg.

Target bldg.

Instruments

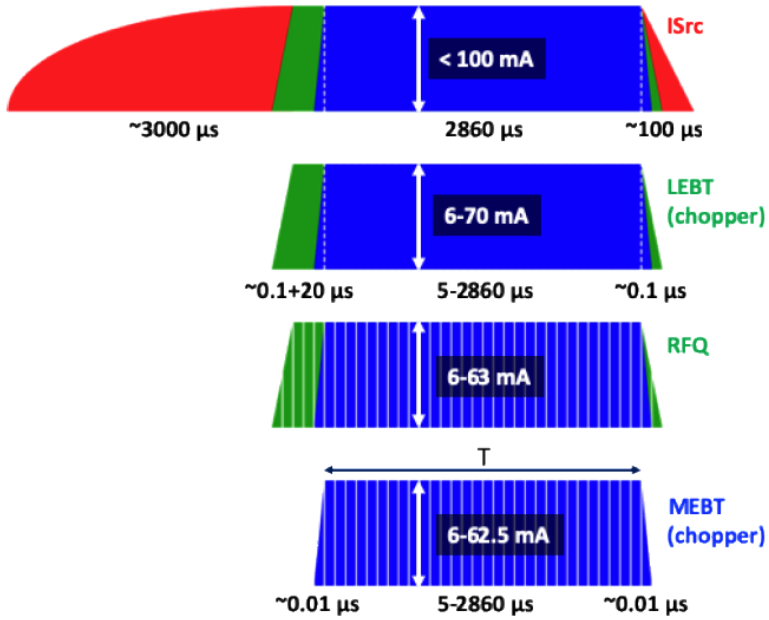
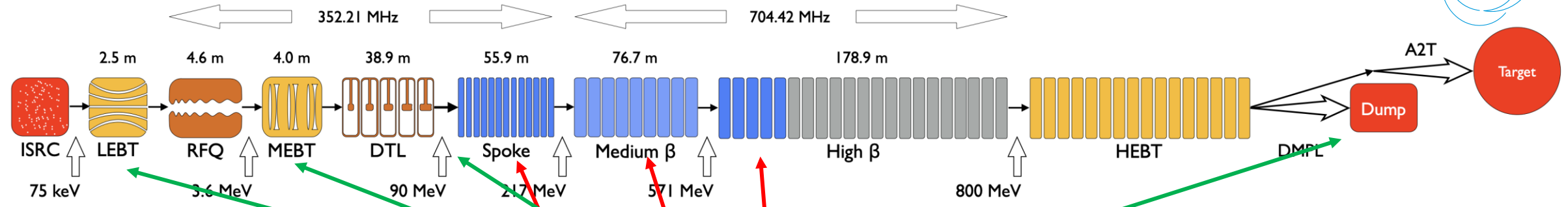
Offices

2022 June



# Beam Modes and Destinations

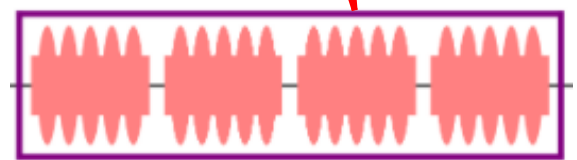
The beam stops for the ESS superconducting linac (MOP7098)



Multiple beam stops



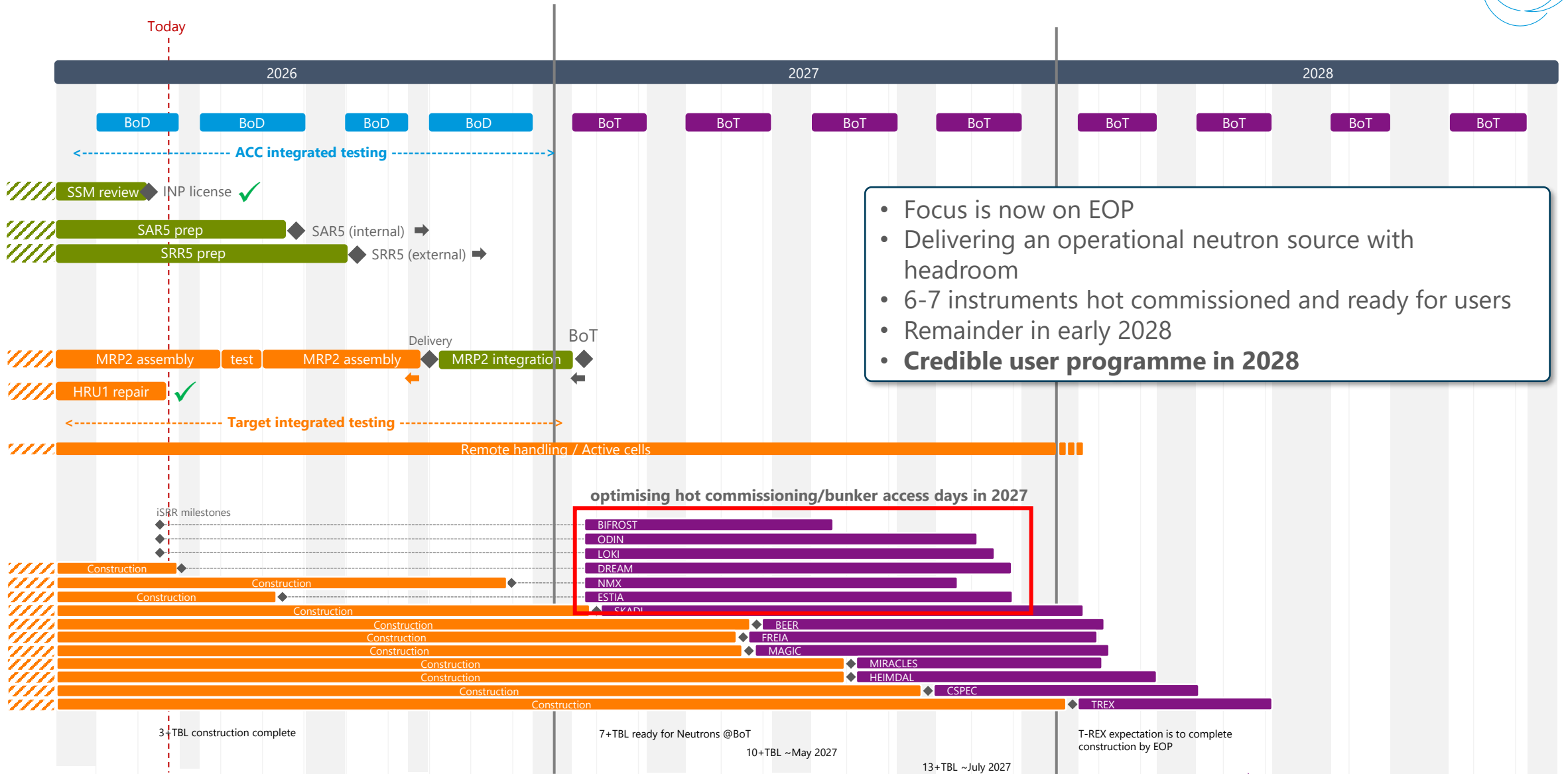
26 Double Spokes



56 Ellipticals

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	

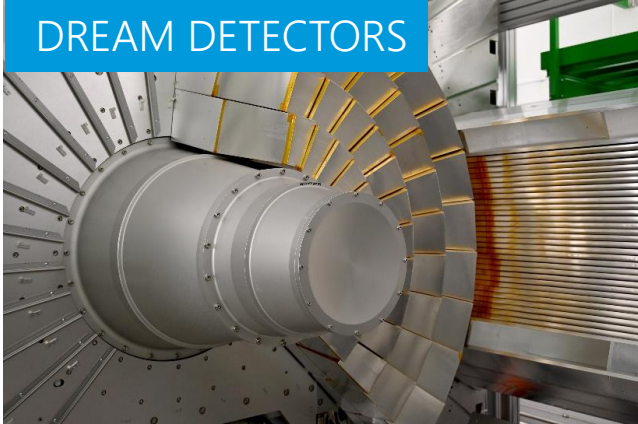
# Instruments



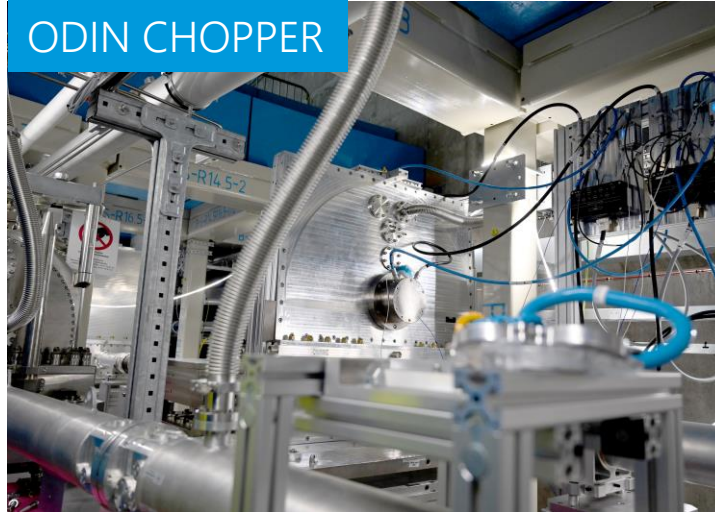
# Instruments

## Caves and instruments

DREAM DETECTORS



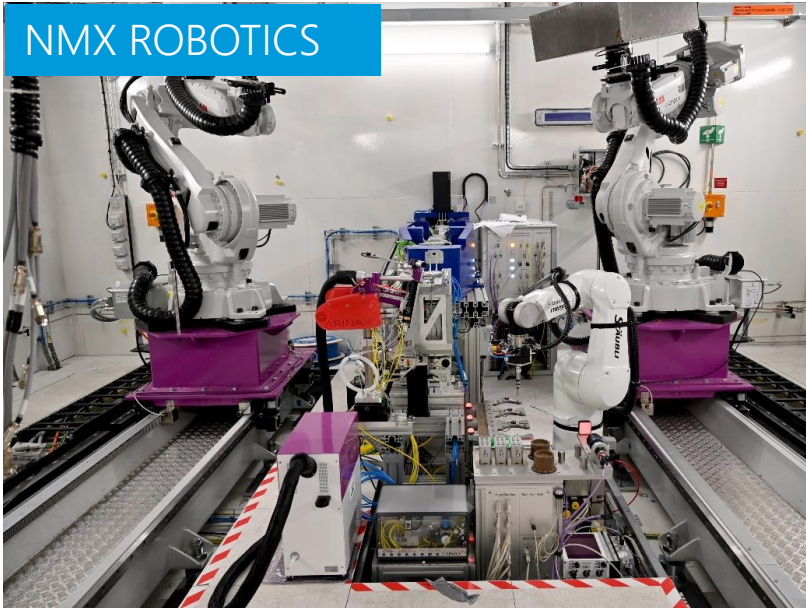
ODIN CHOPPER



LOKI INSTRUMENT READY



NMX ROBOTICS



E02 BEAMLINE GALLERY



TBL and BUNKER

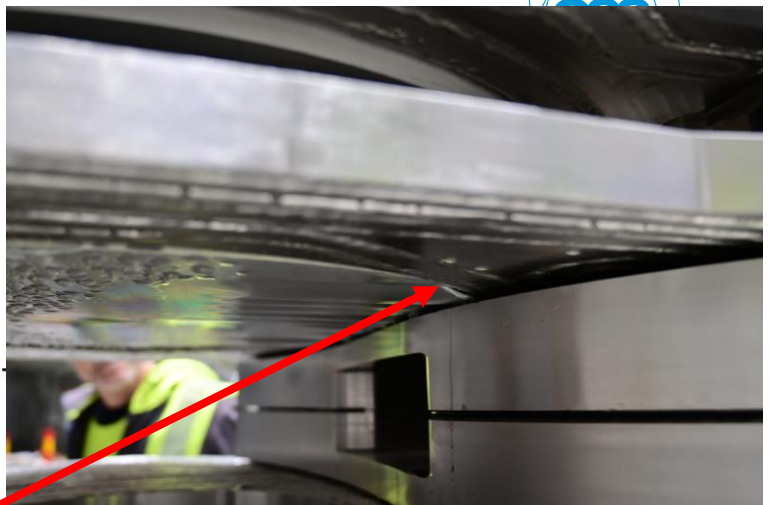
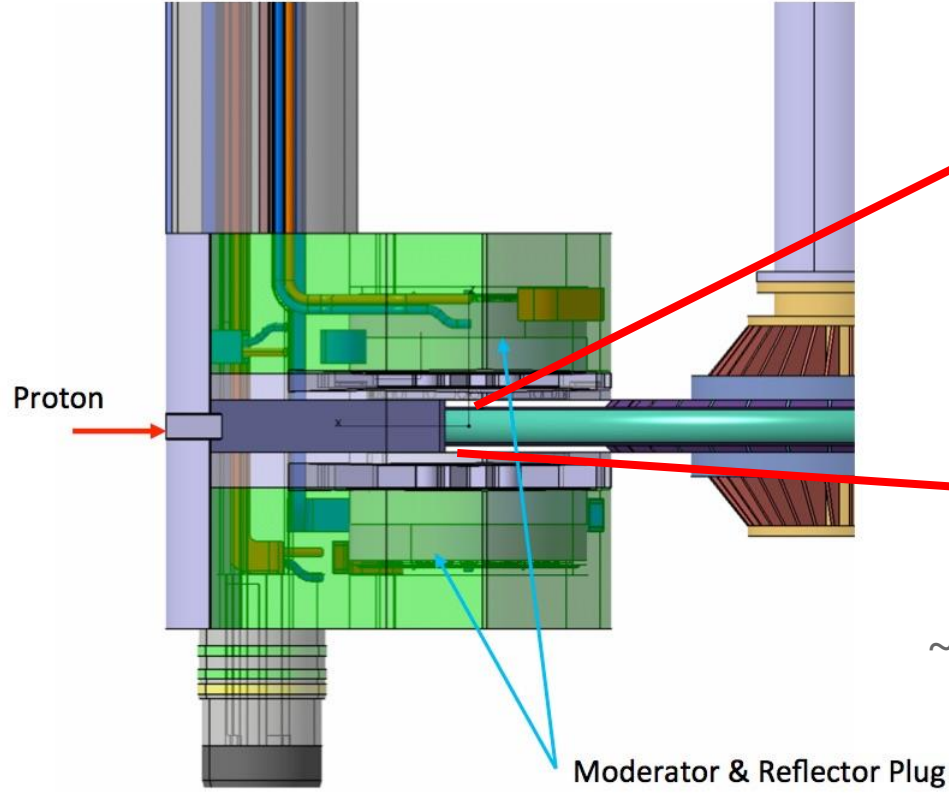
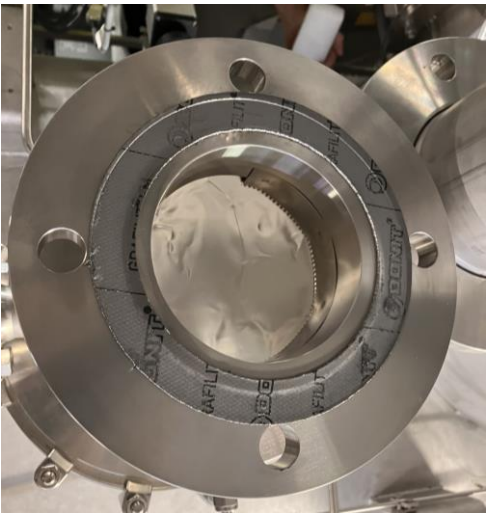




# Moderator and Acc. Damage

2025: power glitch between 25/26 November

Burst disk from one of the SCL cavities



# Some Lessons Learned



## Technical Challenges in Accelerator

### SPK CM02 venting event during LWU installation 2024.

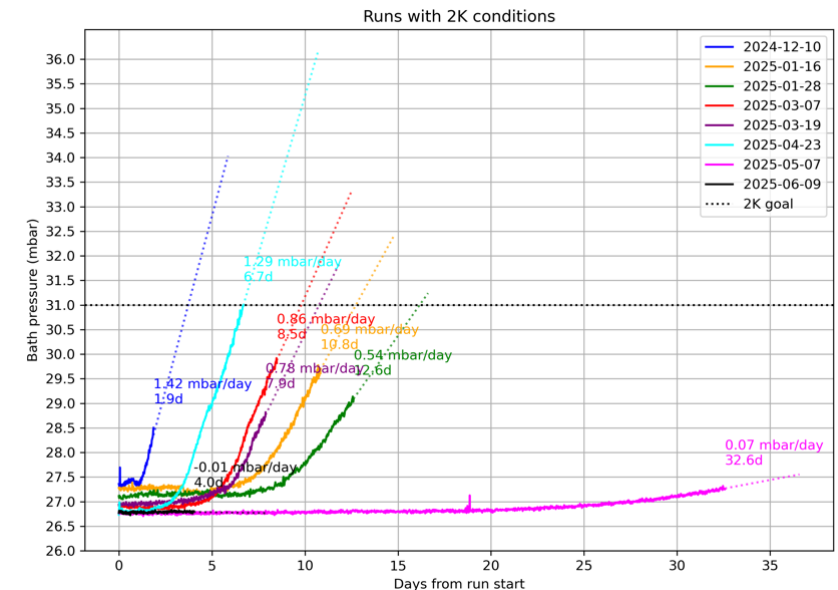
- “Race” to prepare the spare SPK CM14 for substitution.
- Significant installation effort.
- SPK CM02 repair

### 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

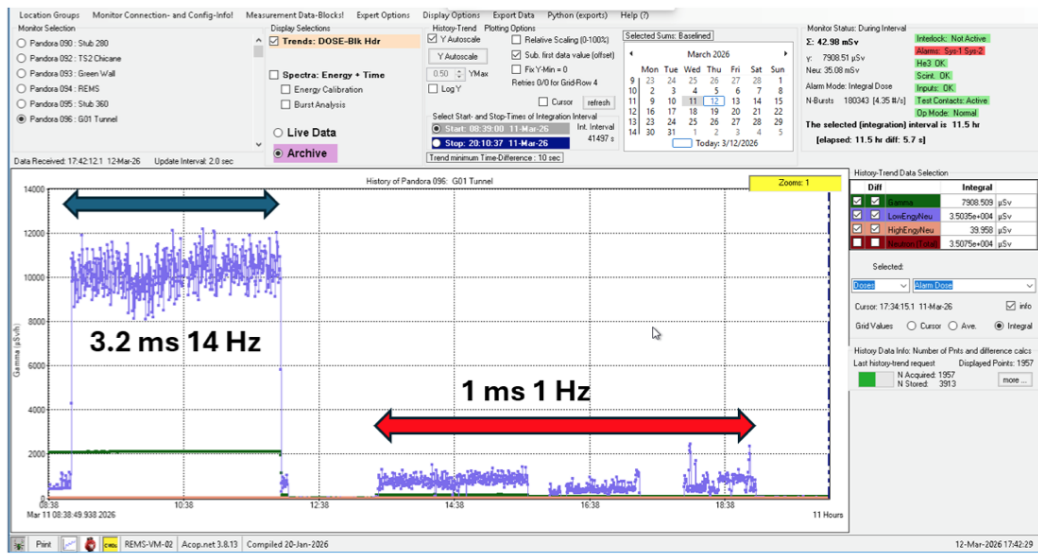
- Failed PLC update
- Power glitch
- Loss of water cooling
- Network issues, PLC network glitch
- Loss of instrument air
- Cold compressor inlet filter clogging



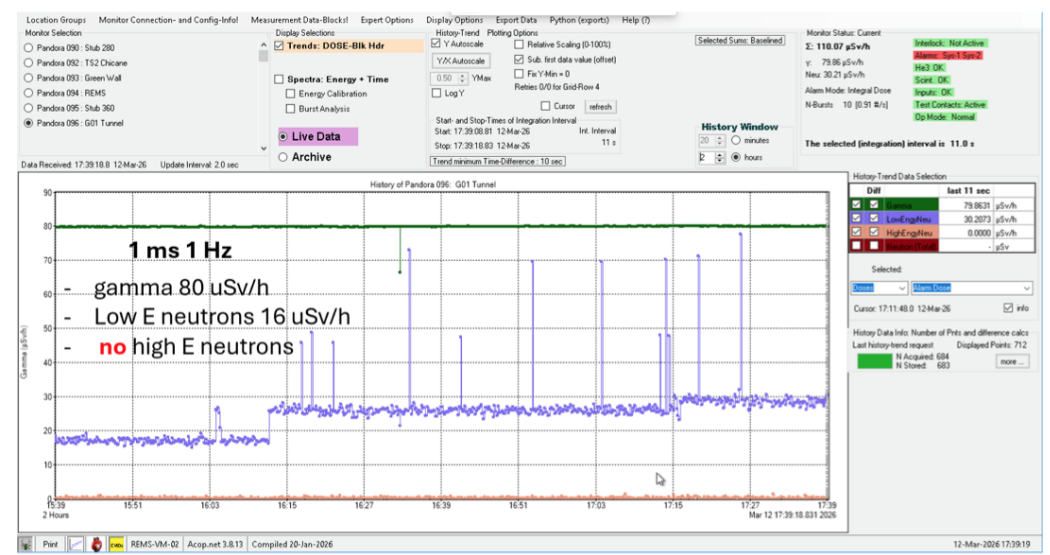
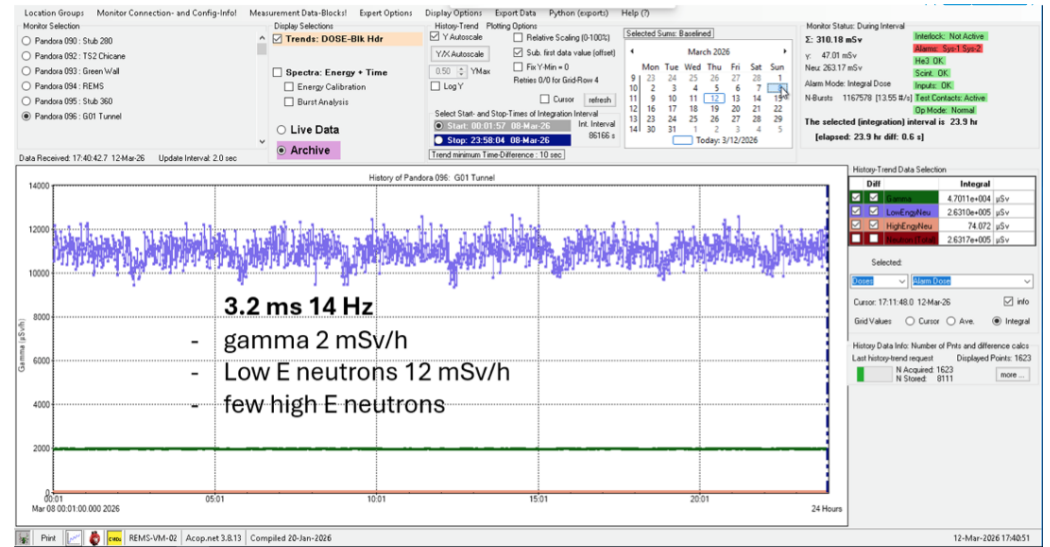


# SCL Conditioning

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



Courtesy A. Zwozniak



# Pulse position Scan

## Emulating long pulses (2025)

