The beam destinations for the commissioning of the ESS high power normal conducting linac

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CERN, European Organization for Nuclear Research
Geneva, Switzerland 9-13 October 2023

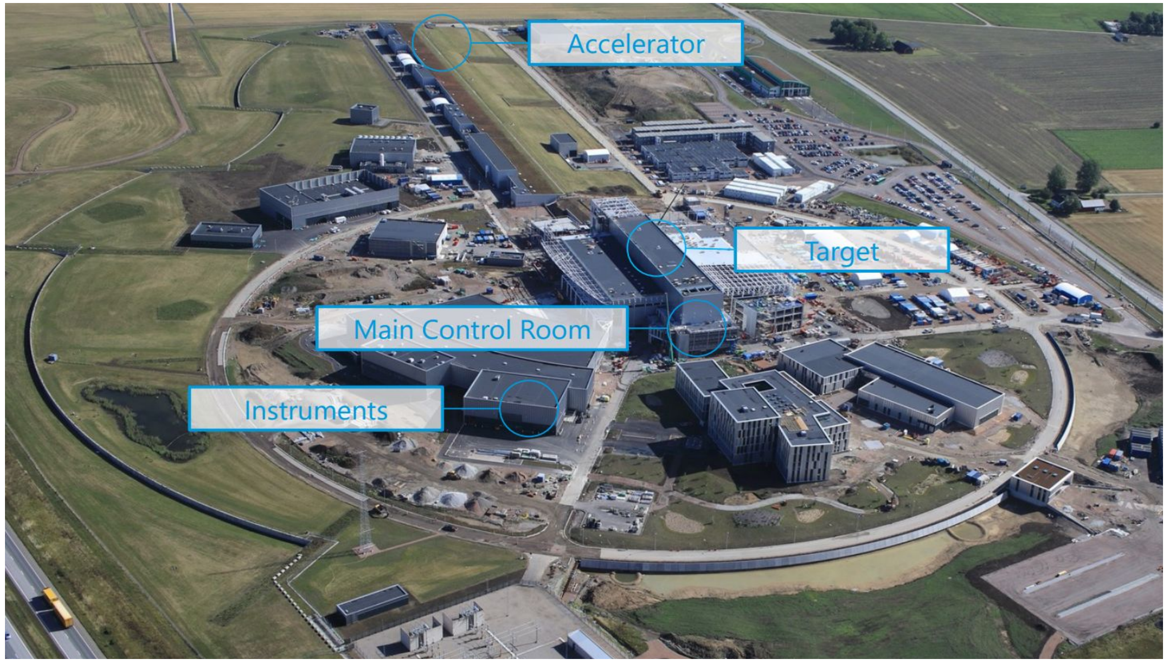
OUTLINE

Beam destinations for the ESS NCL
Workflow and challenges

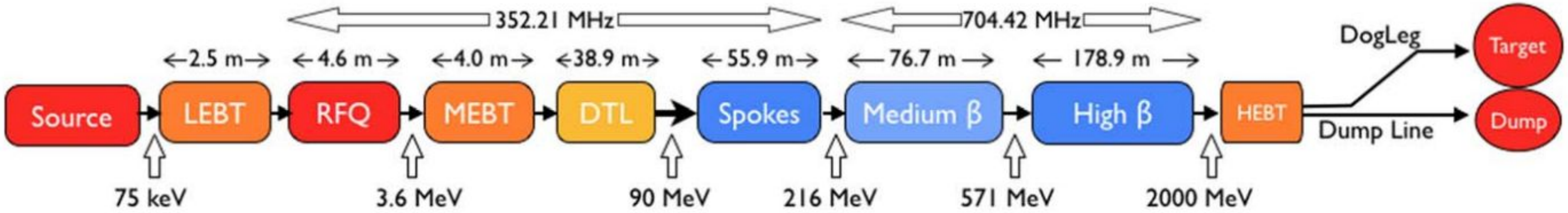
Commissioning results:
LEBT, MEBT, DTL1 – highlights
DTL4 – newest results

Conclusions and Outlook

ESS site in Lund (SWEDEN)



[R.GAROBY, Phys. Scr.93 (2018) 014001]



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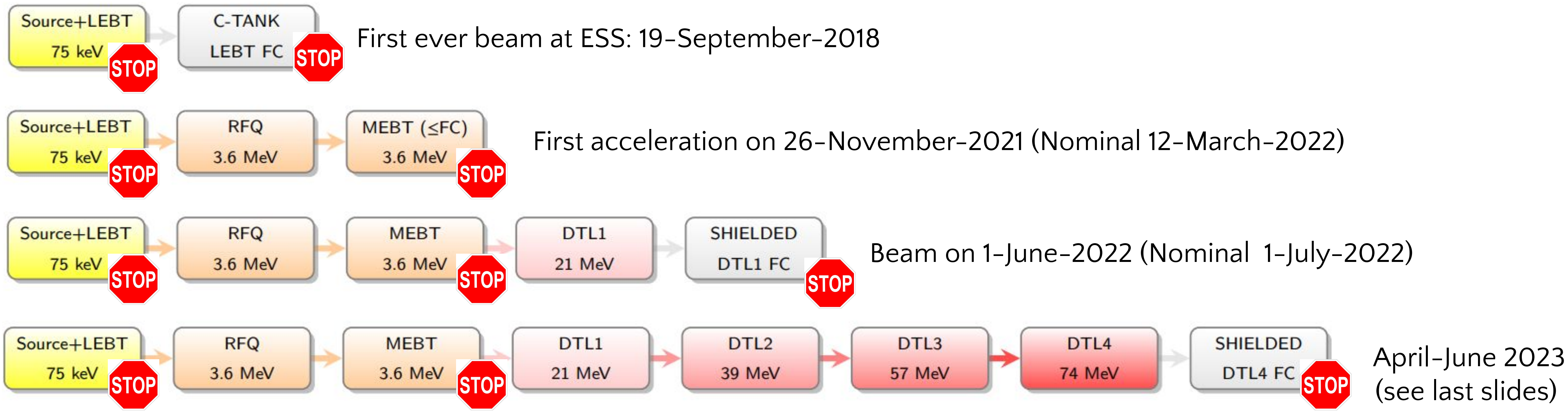
Beam Physics
Beam Diagnostics
Facility Management
Integrated Control System
Infrastructure
Linac
Mechanical Engineering
Operations
Procurement and Logistics
Project Management
Rigging
Radiation Protection
Survey, Alignment, Metrology
Vacuum
Workshop

BEAM DESTINATIONS

GOALS:
- To safely absorb and dissipate the **ESS beam power**
- To measure the **proton current** in real-time
- To measure the **pulse length** in real time
- NO expensive/bulky test-benches
- To minimize the activation and residual dose rates

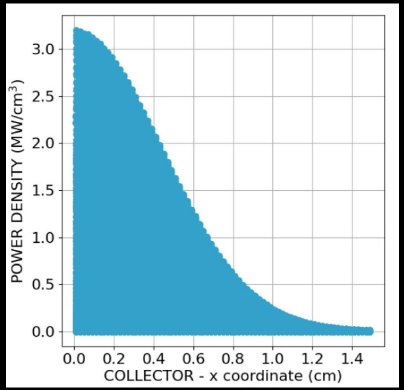
IN GENERAL:
- Designed for a specific proton energy (range)
- Water cooling system
- Pneumatic actuator for motion IN/OUT
- HV repeller bias (except the DTL4 FC)

→ EPICS for Timing, DAQ, HV, Motion, Cooling

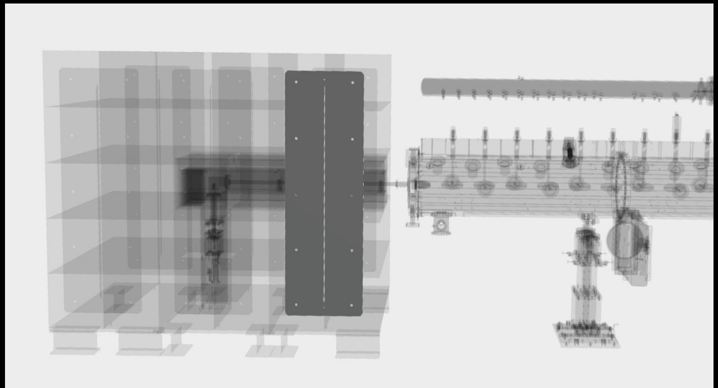


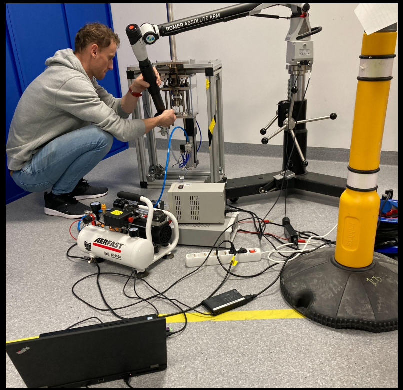
WORKFLOW

1. DESIGN →	2. PRODUCTION →	3. INSTALLATION →	4. DOCUMENTATION →	5. OPERATION
Simulations	Procurement	Acceptance tests	Simulations results	Operational limits
– Thermomechanical	Call of tenders	Cabling, connectors, pipes	Technical Reports	OPI verifications
– Activation	Design review	Electronics, rack	**Test Results**	**Verifications (with beam)**
– Dose	Manufacturing	DAQ calibration	Linac licensing	Control-room shifts
– Shielding	Assembly	**Survey and alignment**	Reviews' reports	Data analysis
CAD modelling	FAT	Control-system test	Proceedings	… *Debugging*
Linac integration	Spare components	Verifications (no beam)	Articles	
Control-system	Spare devices	… *Debugging*	….	**…. and dismantling**



Beam power density


CAD modelling, integration


Alignment preparation


Installation/Relocation

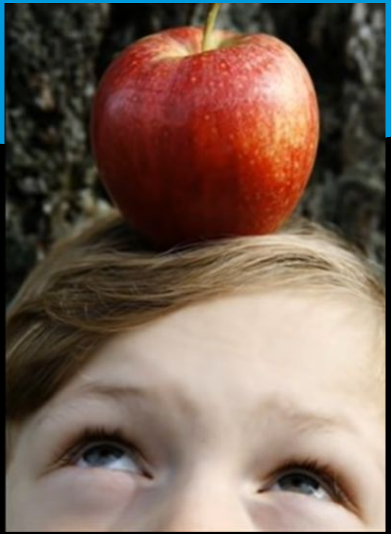
WORKFLOW

1. *DESIGN →*	2 …	… ON →	*5. OPERATION*
Simulations – Thermomechanical – Activation – Dose – Shielding CAD modelling **Linac integration** Control-system			Operational limits OPI verifications **Verifications (with beam)** Control-room shifts Data analysis … *Debugging* **…. and dismantling**

POINT OF VIEW OF THE FOUR BEAM DESTINATIONS

SELECTED TOPICS:

Monte Carlo simulations
EPICS-based control system
Proton current measurements



[Wilhelm Tell et son, 1307]

CHALLENGES

1. DESIGN →	2. PRODUCTION →	3. INSTALLATION →	4. DOCUMENTATION →	5. OPERATION
Very tight space Beam power density Radiation- and heat-resistant materials	Tight schedule Materials availability during COVID19 pandemic UHV requirements Ceramic parts ← → Oversea transportation		Beam size (?) Emittance (?) Energy (?) BCMs + BPMs + FCs → Scan / Simulations → Computing time	

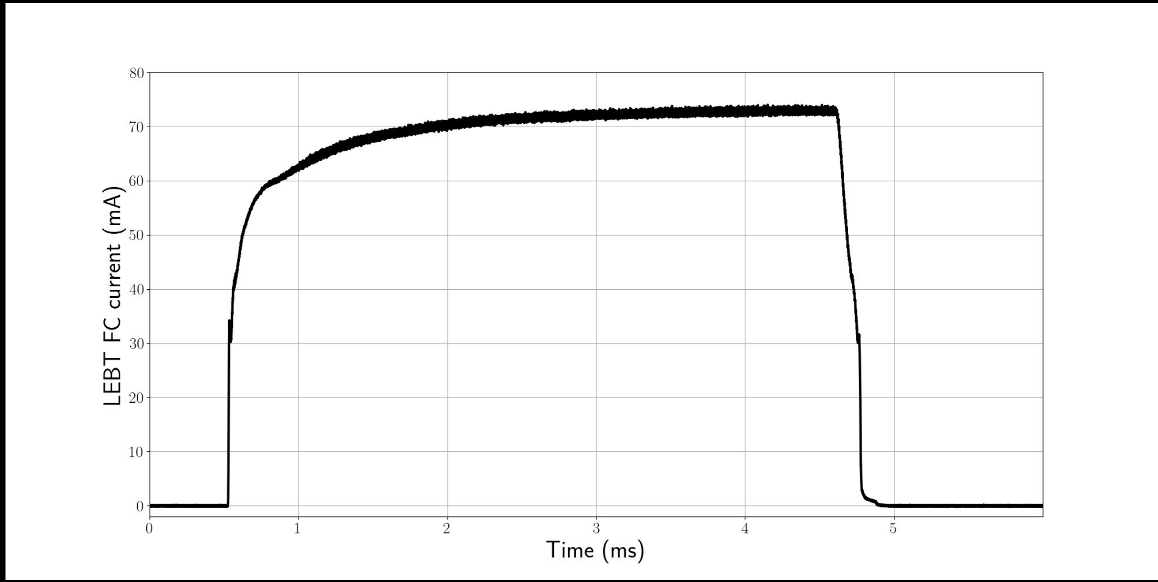
	I (mA)	Pulse (us)	Rate (Hz)
PROBE	6	5	1
FAST TUNING	62.5	5	14
SLOW TUNING (MEBT)	62.5	**50**	1
SLOW TUNING (DTL1)	62.5	**20**	**1**
SLOW TUNING (DTL4)	62.5	50	**0.2**

→

	E (MeV)	P (W)	T (°C)
LEBT FC	0.075	0.005	**800**
MEBT FC	3.6	16	**960**
DTL1 FC	21	170	**620**
DTL4 FC	[21, 74]	323	**1010**

LEBT – 9/2018

FC



MICROWAVE DISCHARGE ION SOURCE (INFN Catania)
[M.ESHRAQI et al., 2020, J. Surf. Investig. 14]

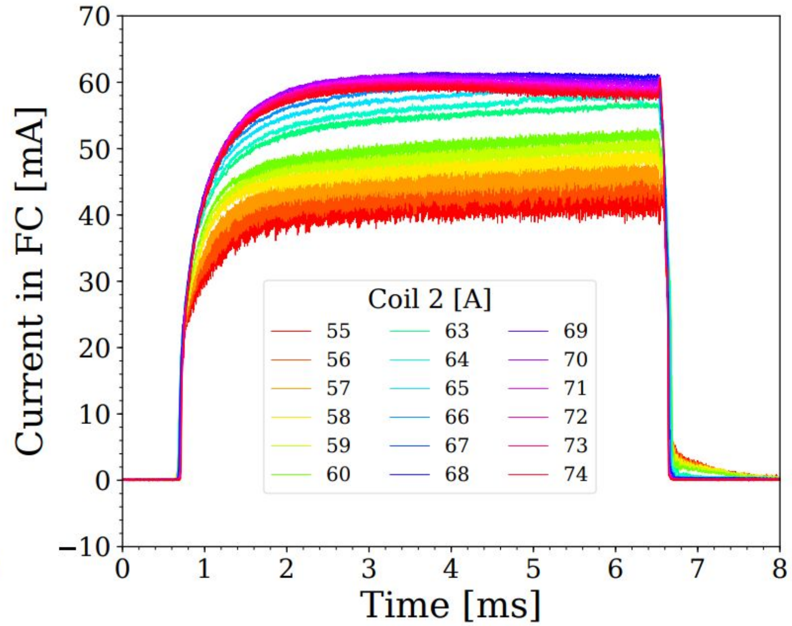
LEBT FARADAY CUP#1: Source tests in Catania
Commissioning at ESS in 2018 - 2019 (two tanks)
Several relocations during the commissioning
Facing soon the second ESS source

LEBT FARADAY CUP#2 installed on 14-Feb-2020
Designed at ESS, manufactured by Pantechnik
Copper body, two water cooling loops, HV (-900V)

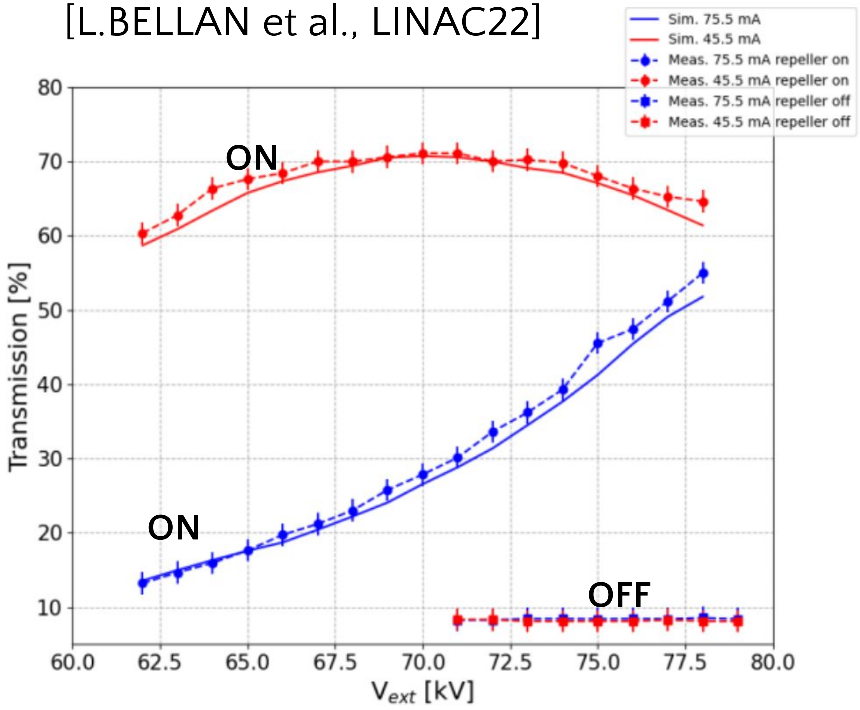
Paved the way for the first BD installations, tests and verifications procedures [C.DERREZ et al., IPAC19].
Operational during MEBT, DTL1, DTL4 commissioning

LEBT FC: measurements and simulations

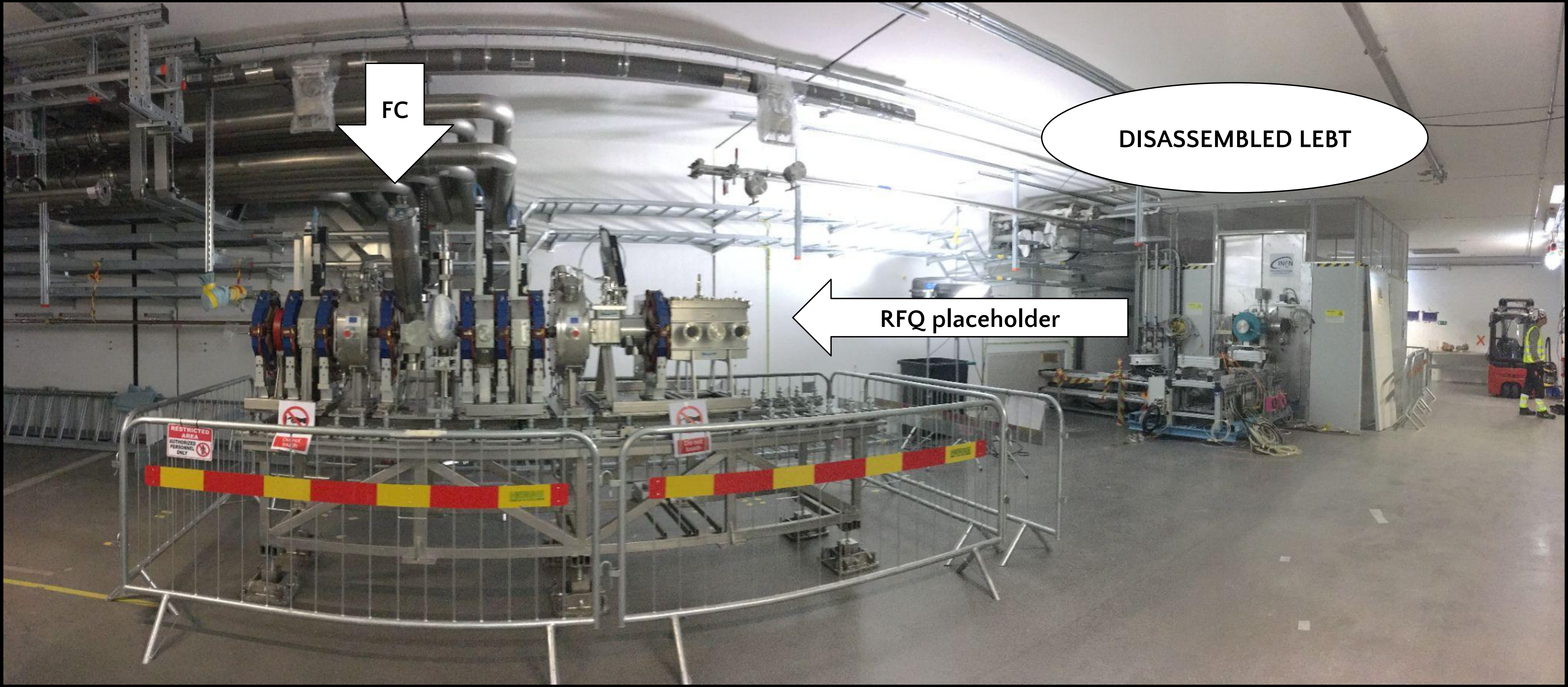
SOURCE TUNING (5 pars)
by scanning COIL2
→ optimal range in 67-68 A
RF power = 500 W
H2 flux = 3.5 sccm
COIL1 = 120 A, COIL3 = 217 A
FC in the Permanent Tank
[N. MILAS et al., HB2021]



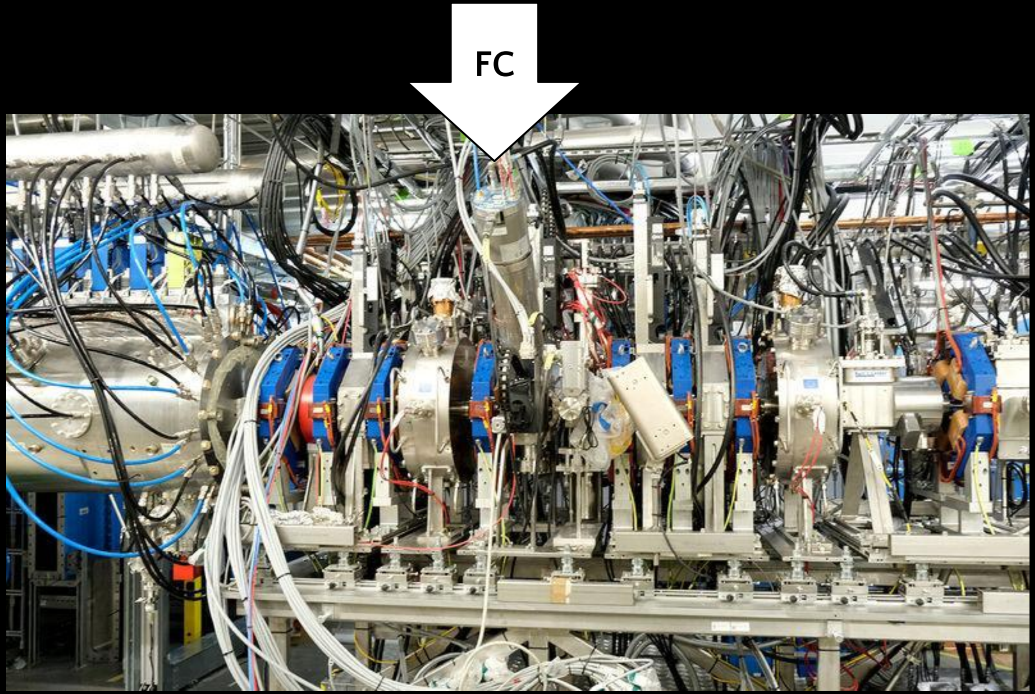
TRANSMISSION
vs. EXTRACTION VOLTAGE
Study of the beam divergence
Current 45.5 mA or 75.5 mA
Repeller OFF – no change
Repeller ON (-3.5 kV) → divergence
Amplification due to the e-flow
[L.BELLAN et al., LINAC22]

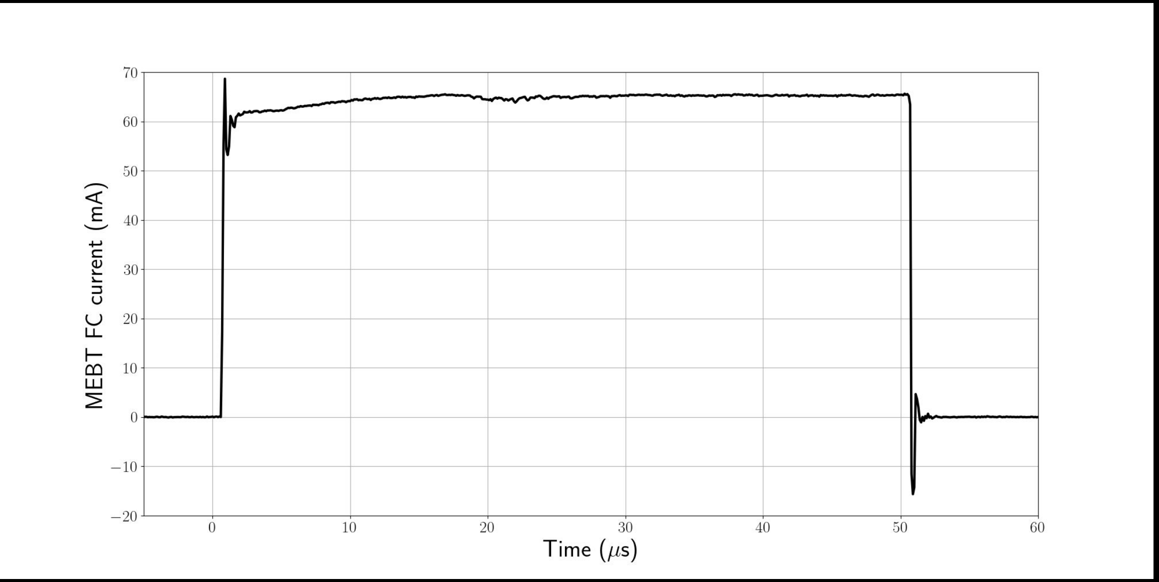


MEBT – 6/2019



MEBT – 11/2021





MEBT = Medium Energy Beam Transport

[I.BUSTINDUY et al., LINAC2014]
[A.SOSA et al., LINAC2022]
[N.MILAS et al., IBIC2022]

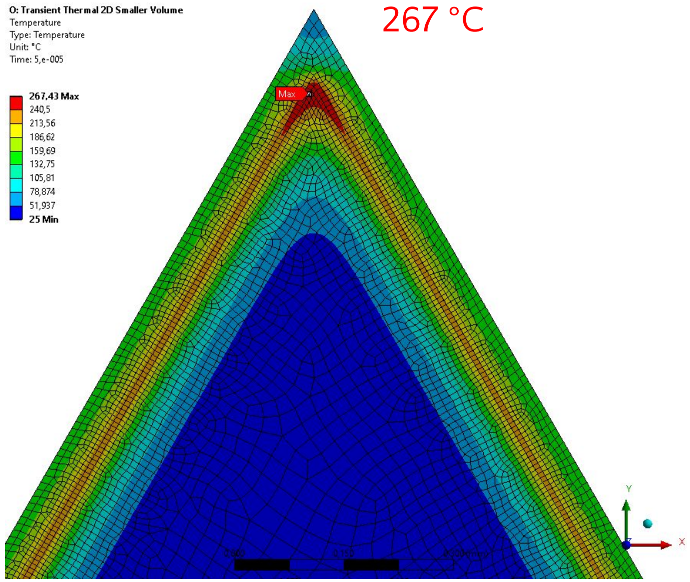
MEBT FARADAY CUP
Designed by ESS-Bilbao, manufactured by Pantechnik
11/2021 Probe beam successfully accelerated in RFQ

3/2022 Nominal current, 95% RFQ transmission (20 μs)
2023 Pulse cautiously increased up to 50 μs

MEBT FC: simulations and controls

SIMULATIONS
3.6 MeV protons in GRAPHITE

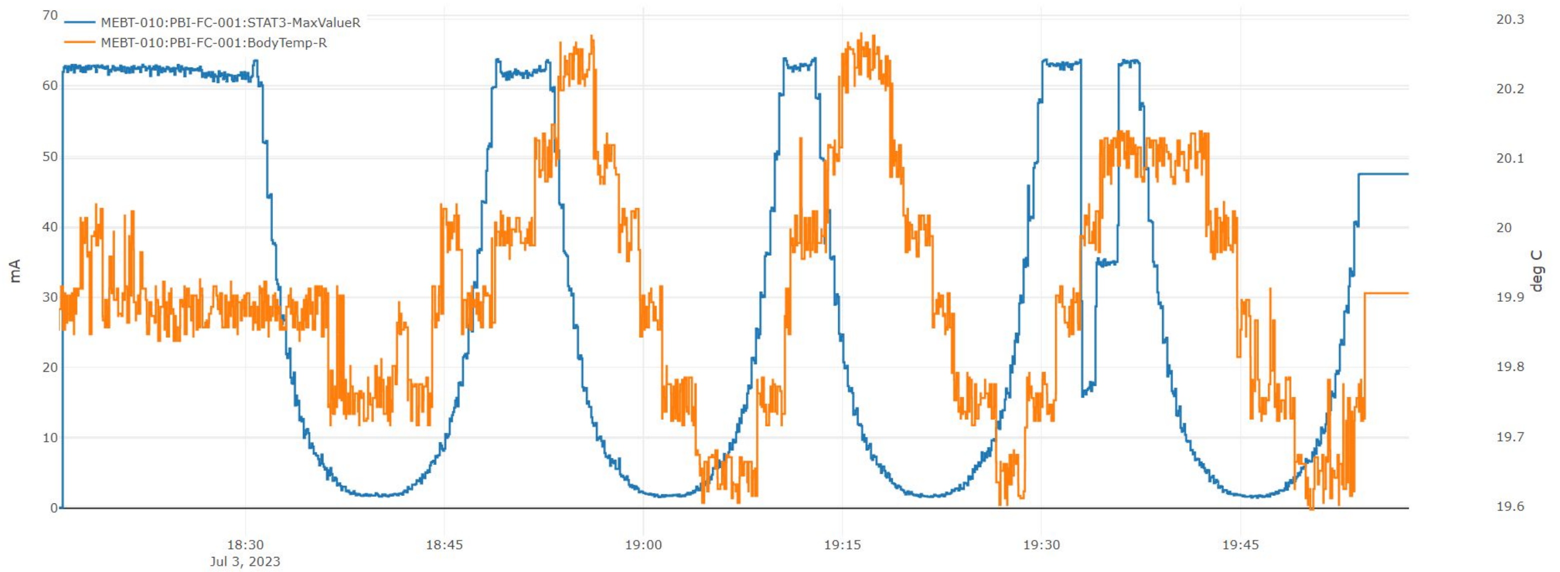
Peak after 130 μm in depth
→ surface erosion, blistering
→ replaceable collector



Courtesy of A. Olsson

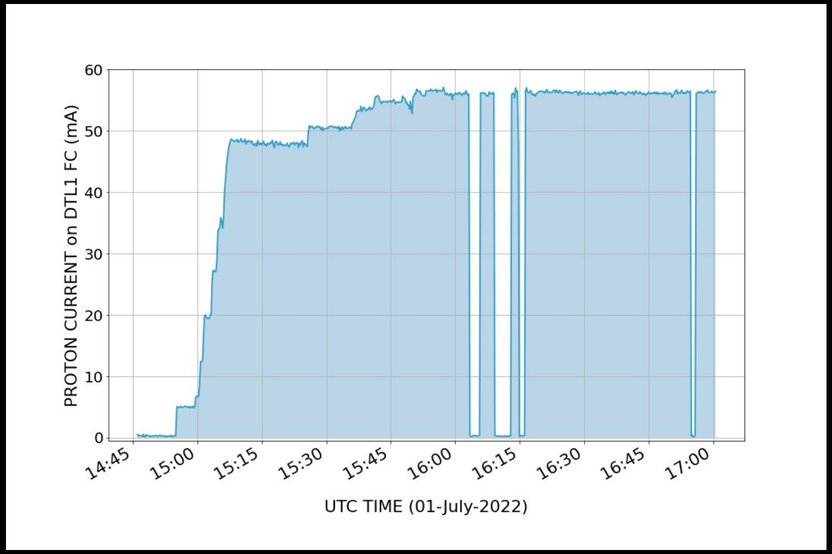
EPICS-BASED CONTROL SYSTEM (DAQ, Timing, HV, MOTION, COOLING)
Limited availability of diagnostics devices (only FC, BPMs and BCMs)
+ Need to validate critical HW and protection functions for the first time
= Lots of beam power density and thermo-mechanical calculations
= Administrative op. limits and a cautious approach in ramping up the beam power
[C.PLOSTINAR et al., IPAC2022]

PROTON CURRENT and **COOLING WATER TEMPERATURE**, as a function of time



From the EPICS archiver-appliance at ESS

DTL1 – 6/2022



DTL1 = Drift Tube Linac
[M.COMUNIAN et al., LINAC2016] Commissioning strategy
[F.GRESPAN et al., LINAC22] DTL1 conditioning
[Y.LEVINSEN et al., IBIC2022] First RF phase scans
[T.SHEA et al., IBIC2022] Diagnostics results
cfr. SNS DTL Faraday cups

DTL1 FARADAY CUP
Design by ESS, manufactured by RadiaBeam
6/2022 Probe beam
7/2022 Nominal current (max 20 μs)

[E.DONEGANI et al., NIMA, 2023 Vol. 1047]
Design and performance

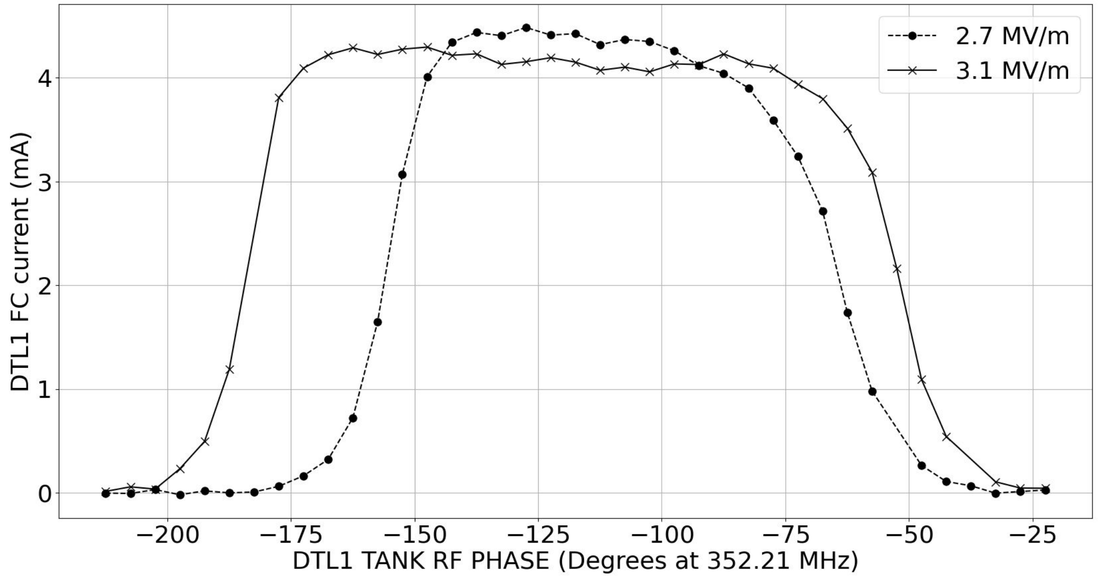
DTL1 FC: measurements and simulations

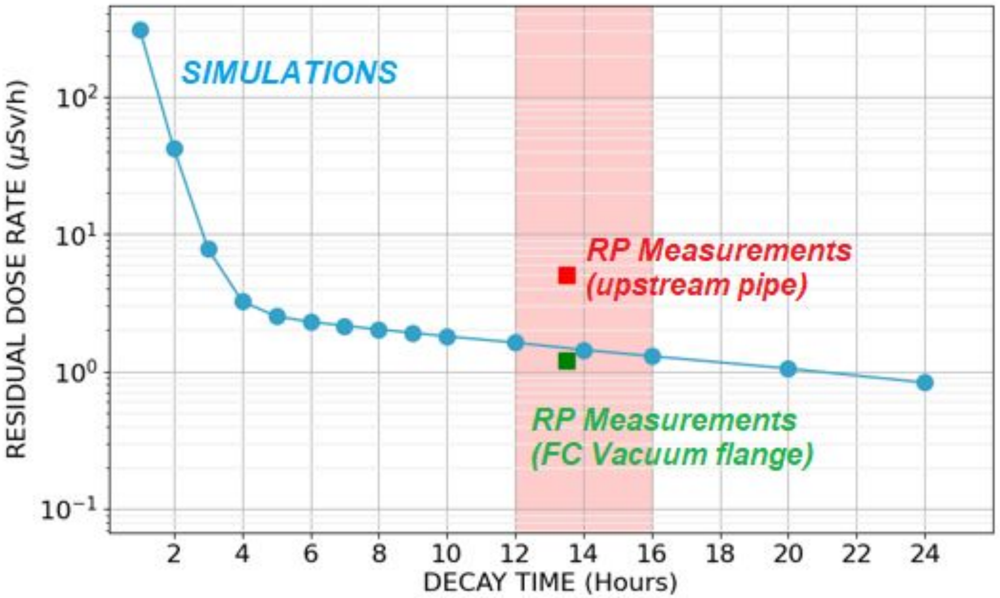
DTL1 FC MEASUREMENTS
Initial acceptance scan of the cavity phase
RF Amplitude with DTL1 accelerating field [2.7, 3.1] MV/m

DTL1 FC window to filter of protons E < 21 MeV
DTL1 FC window to reduce the thermal load on the collector

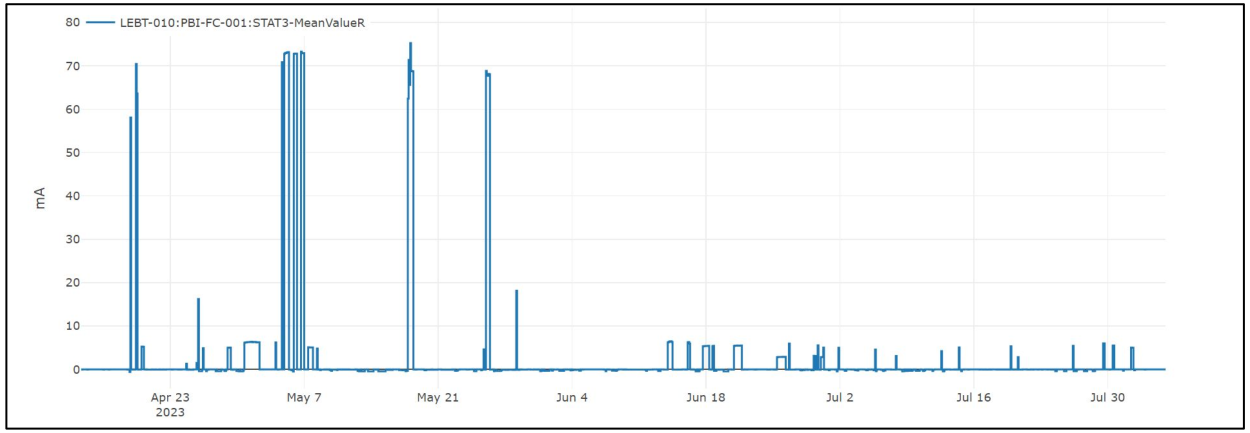
DTL1 FC ACTIVATION
Monte Carlo calculations to predict residual dose rates
RP measurements before dismantling < 2 μSv/h

Decay time = 10 hours
Dismantling the day after the end of the DTL1 commissioning

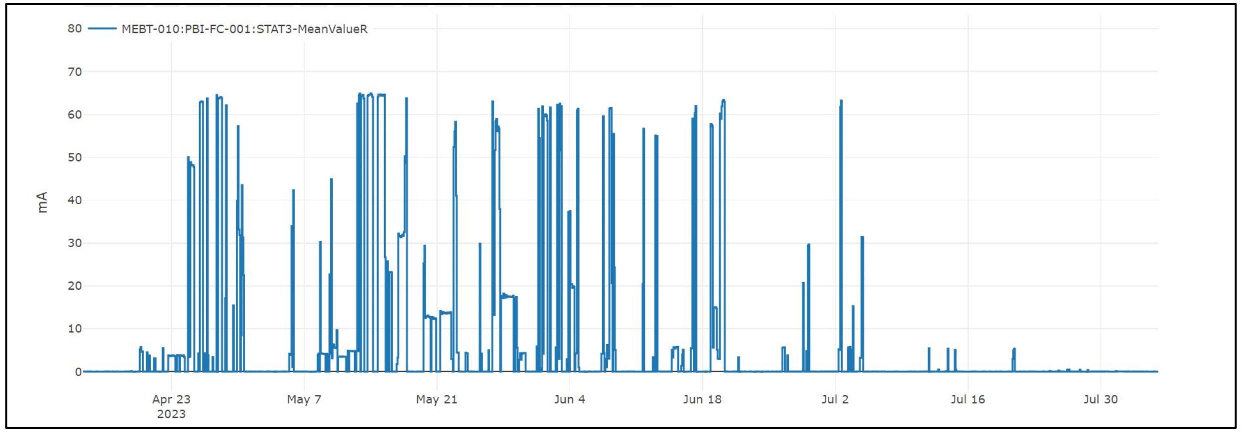




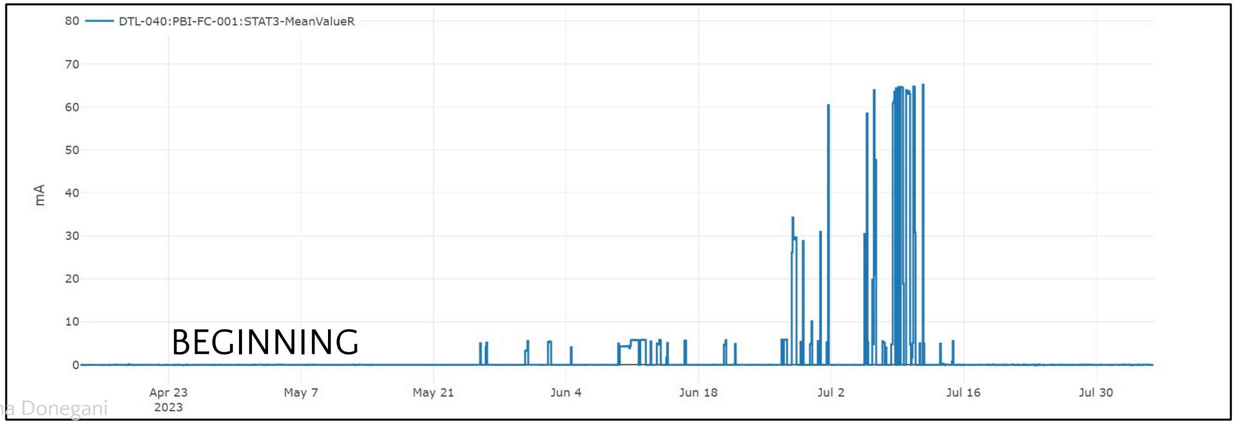
LEBT



MEBT

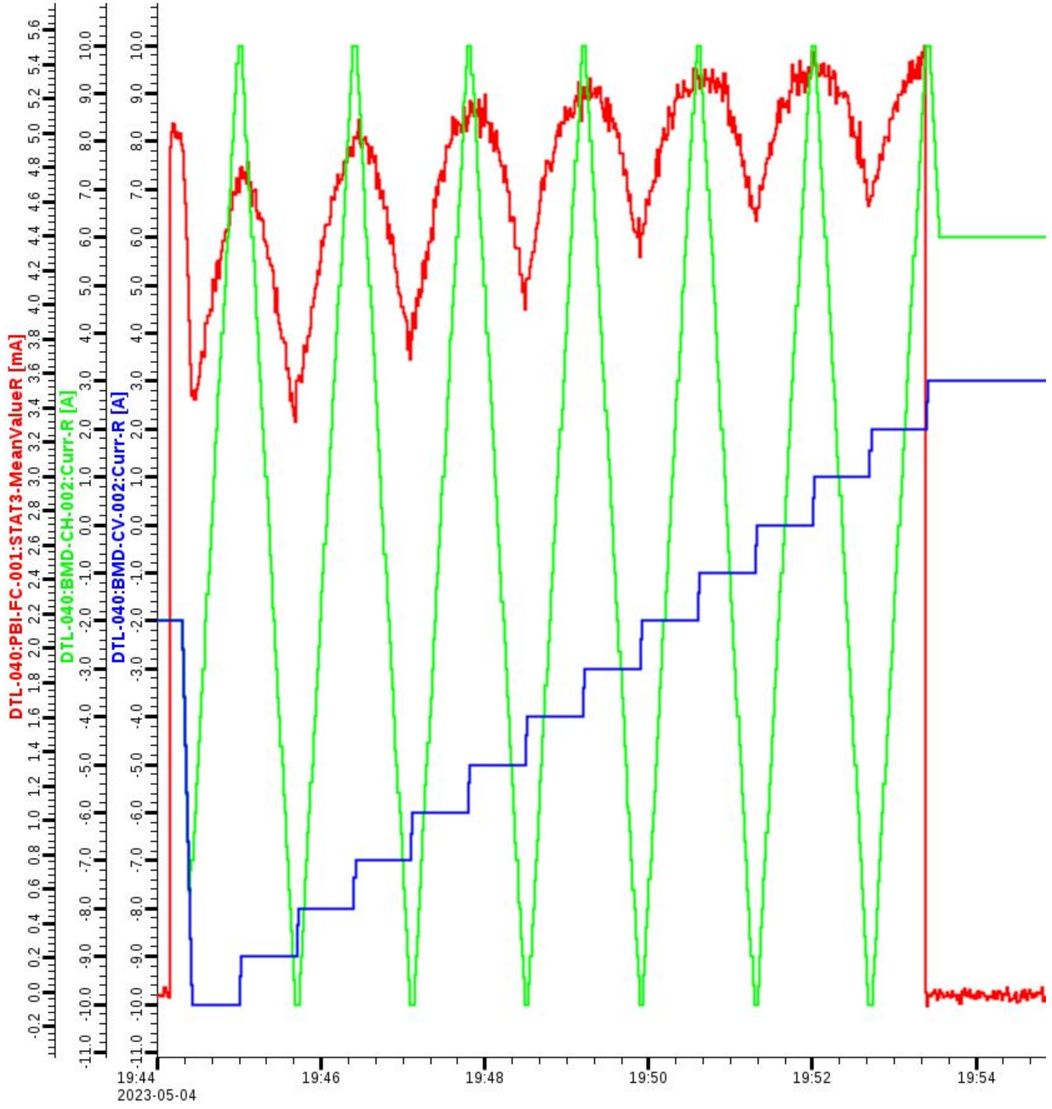


DTL4

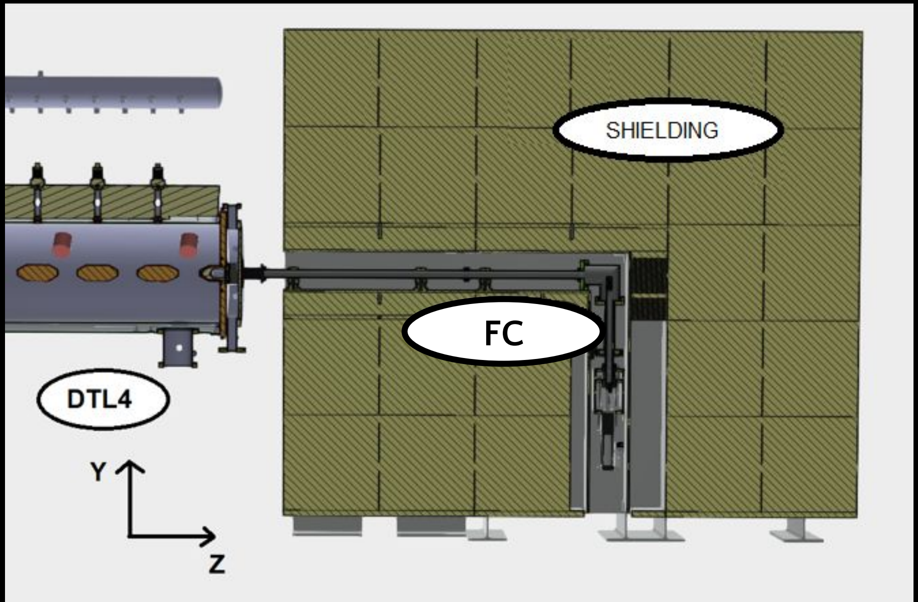


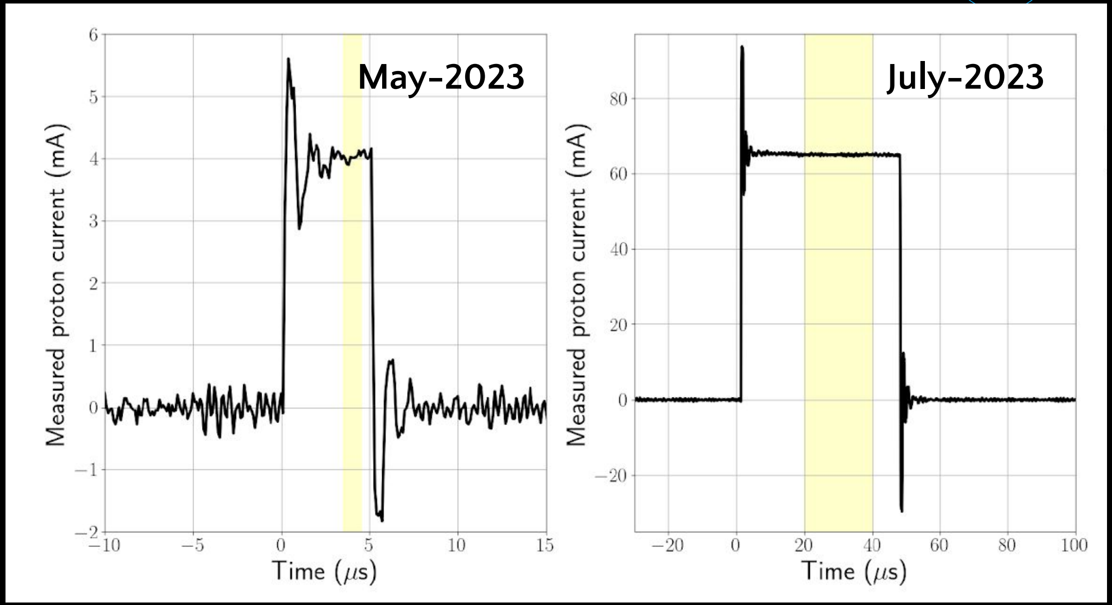
FCs trio – From April to July 2023

DTL4 FC: the beginning



DTL4 – 5/2023





To safely dump the proton beam (E = [57, 74] MeV)
To measure the beam current in real-time (I ≤ 62.5 mA)
To measure the pulse length in real-time (Δt ≤ 50 μs)

[R. MIYAMOTO et al., IPAC2023]
[Y. LEVINSEN et al., HB2023]
cfr. SNS DTL Faraday cups

DTL4 FARADAY CUP
Designed by ESS, manufactured by RadiaBeam
5/2022 Probe beam
7/2022 Nominal current (50 μs)

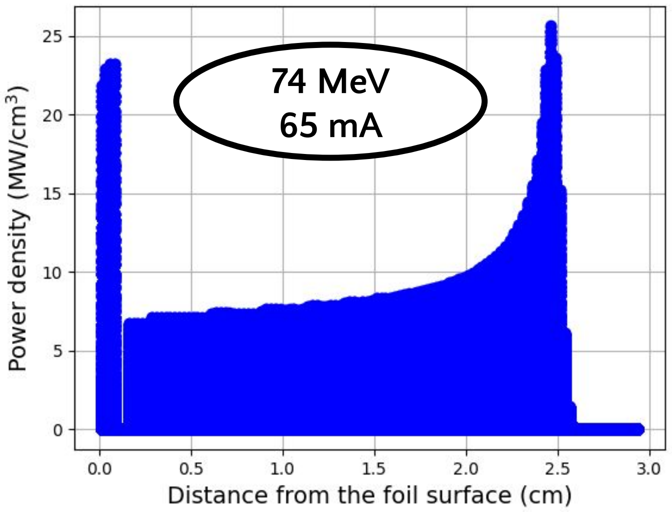
[E.DONEGANI et al., NIMA, 2023 Vol. 1057]
Design and performance

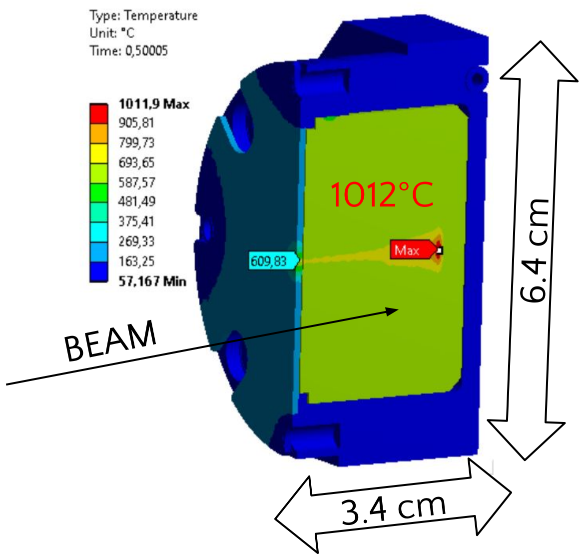
DTL4 FC: simulations

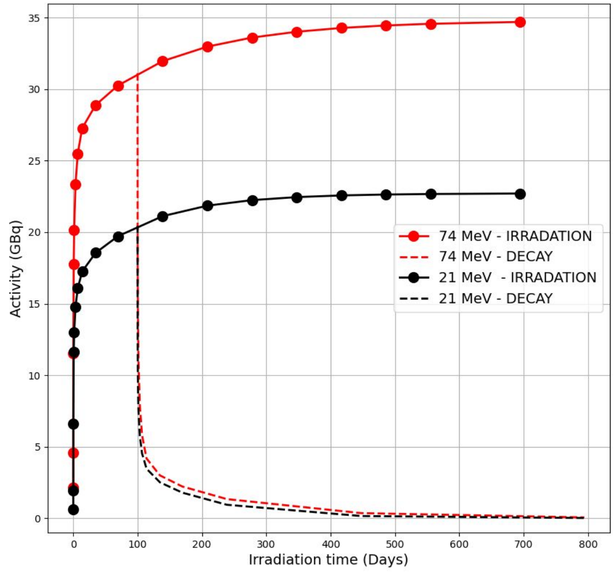
- **Very tight space** (< 35 mm along the beam direction)
- **Beam power density** 25 MW/cm^3 → 1000°C in the core
- **Shielding** → **no access** → EPICS-based control system
- **Low activation** (ongoing SCL installation, quick dismantling)

→ MCNPX [Los Alamos National Laboratory, LA-CP-11-00438]
→ CINDER90 [Gallmeier, ICANS XIX Conference, 2010]
Assuming 1 μA average current (*ESS Licensing)

Parameter	Value
Current (mA)	[0.1, 65]
Pulse (us)	1 – 2 – 5 – 50 – 100
Rate (Hz)	0.2, 1, 14
Energy (MeV)	74 – 57 – 39 – 21
FWHM_X (mm)	[1.8, 3.5]
FWHM_Y (mm)	[1.6, 3.5]



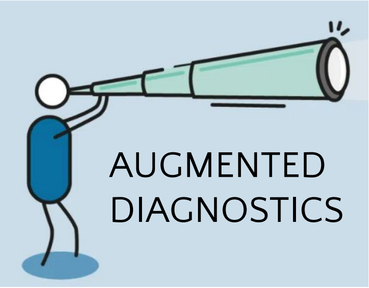




DTL4 FC: operational limits

- **Thermo-mechanical calculations** repeated for all the potential E, FWHM, current, pulse length, rates
- To identify safe conditions and to **avoid damaging** scenarios → Define accelerator settings
- No component of the beam-dump was damaged, no water leaks, no vacuum contamination

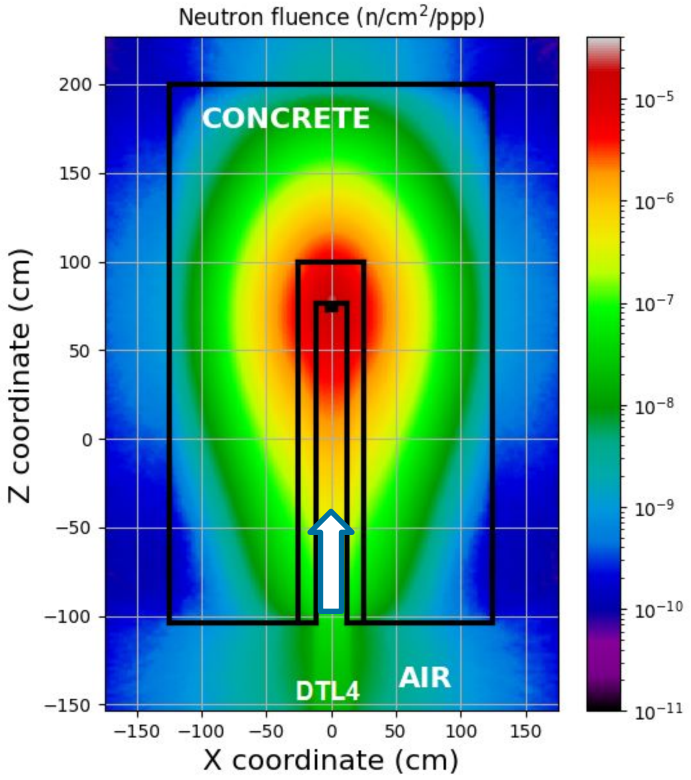
Beam parameters				Temperature		Mech. Stress		
Energy	Current	Pulse	Rate	T foil	T core	PS foil	PS core	
MeV	mA	us	Hz	°C	°C	MPa	MPa	
21	6	5	1	910	35	0.3	0	
21	65	5	14	1550	80	1.3	0	→ Foil to be damaged
39	65	5	14	400	530	0	9	
39	65	50	1	930	1150	0.1	35	→ Core to be damaged
74	65	50	1	610	1012	0	10	
74	65	100	1 pulse	920	900	0.3	25	→ OK but just once!

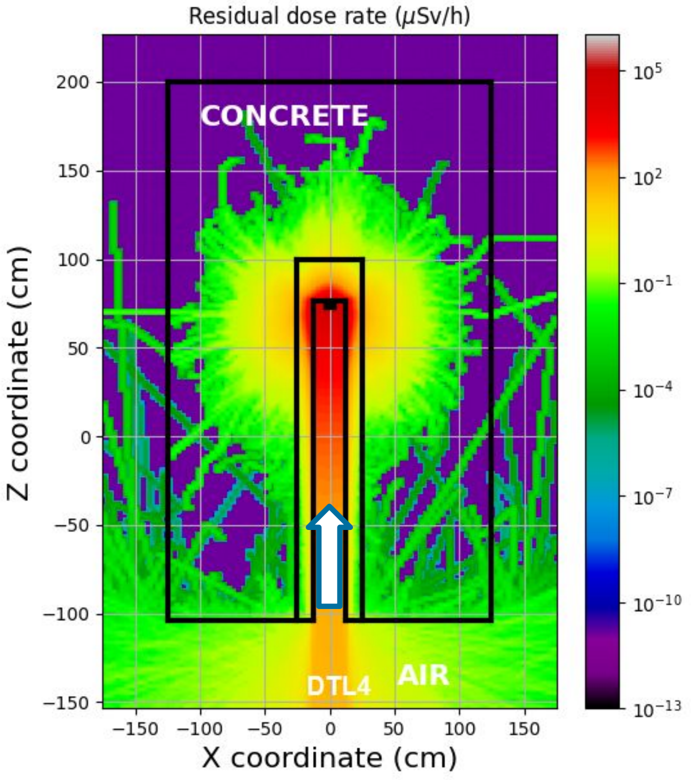


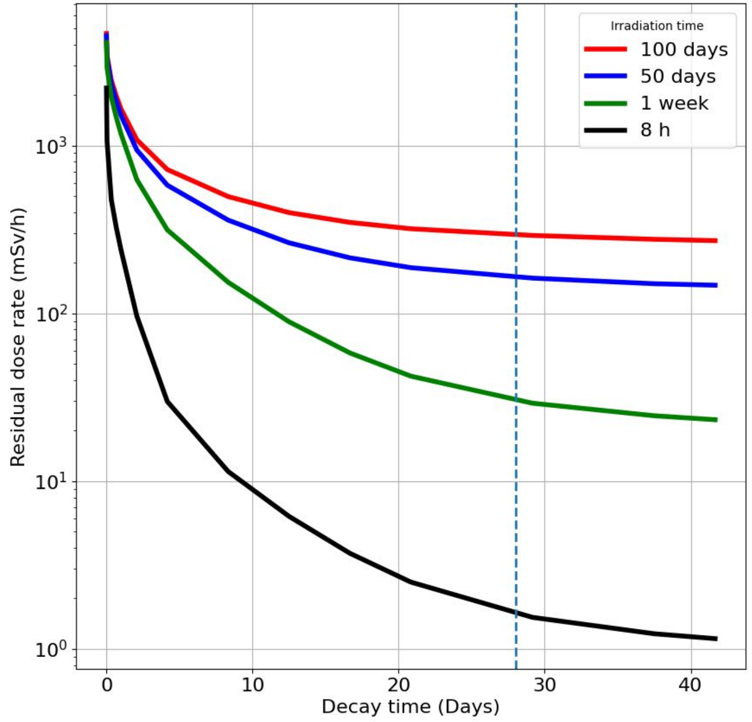
DTL4 FC: Residual dose rates

Shielding: prompt radiation, tunnel accessibility (e.g. maintenance), temporary storage of the beam dump
Central part (carbon steel) for shielding fast neutrons + concrete blocks (224 cm x 200 cm x 300 cm)

Calculations repeated at **potential irradiation times,** to determine the decay time before dismantling



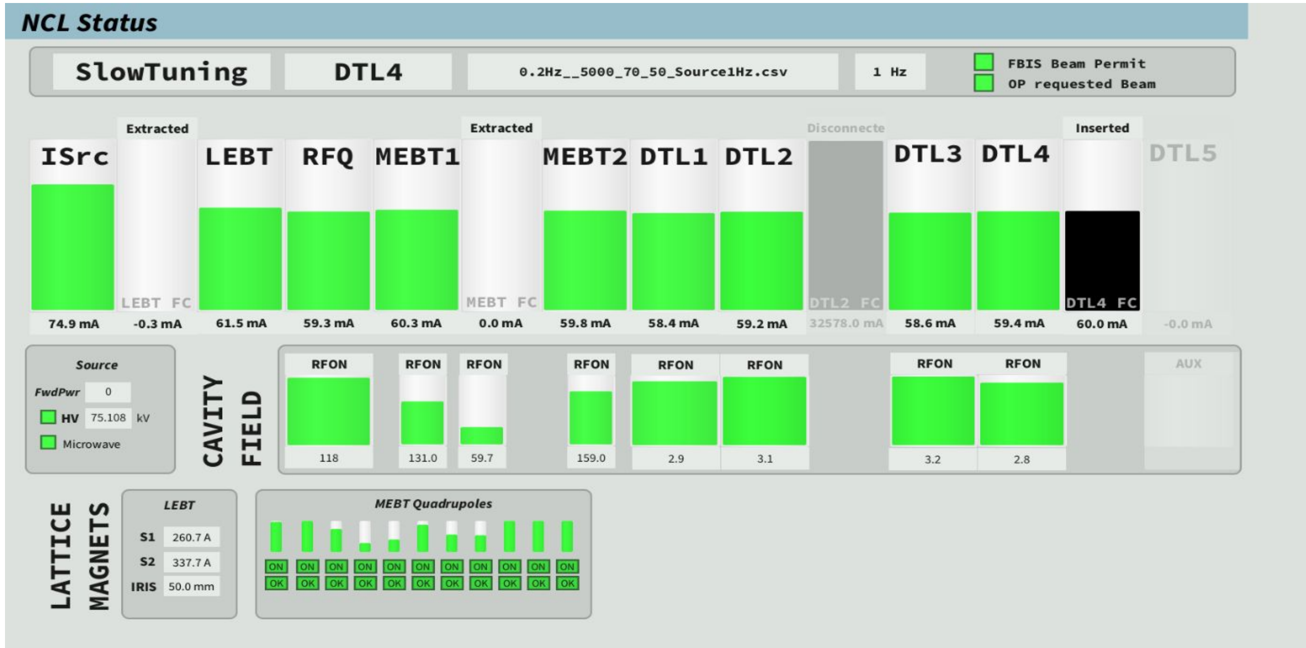




CONCLUSIONS

Summary of the ESS NCL commissioning results – point of view of the four beam destinations
Collaboration of many workers at ESS, ESS in-kinds, DMSC, Pantechnik, RadiaBeam – THANK YOU!

Key tools: **EPICS** – based controls and **MCNP/ANSYS** simulations, in particular:
Thermo-mechanical simulations for un/foreseen operational scenarios → NO DAMAGE
Monte Carlo simulations (before, during and after the commissioning)
→ Commissioning activities, beam studies, training of new operators, dismantling procedures, …



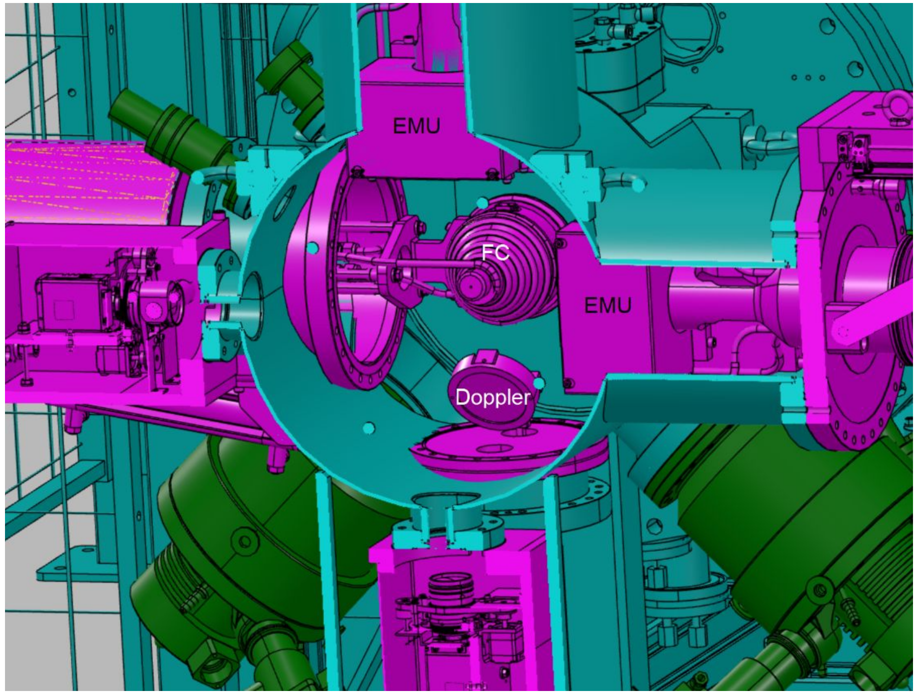
OUTLOOK

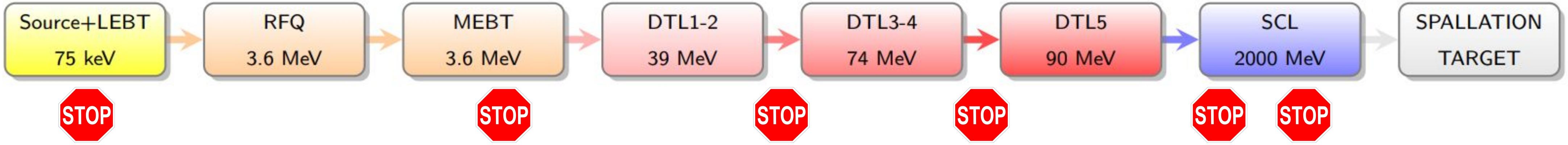
Next steps:
- Four Faraday cups permanently in the NCL (LEBT, MEBT, DTL2 IT, DTL4 IT)
- Procurement of the spare DTL4 FC (Spares already procured for LEBT, MEBT, DTL2)

Motion reliability tests for the DTL FCs (< 35 mm)
Collision avoidance wrt other insertable devices
Data analysis and comparison e.g. with BCMs

Preventive **maintenance**
Radiation damage for decades of operation
Simulations vs. RP measurements

Design/Controls/Operation of the ESS SCL beam stops

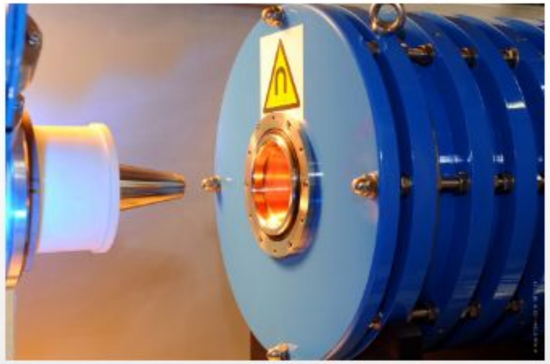




EUROPEAN
SPALLATION
SOURCE

About Pantechnik

PANTECHNIK
Boost Your Physics



ECR ION SOURCES

OTHER SOURCES

BEAM DIAGNOSTICS

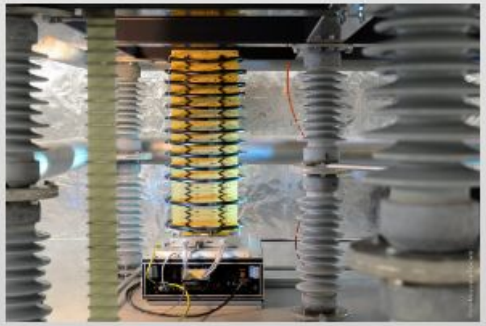
Faraday Cups

Beam Profilers

Emittance Scanners

Slits

TURNKEY SYSTEMS



SPECIAL DEVICES

About RadiaBeam

Twenty-year history in accelerator component design, engineering, fabrication, testing, and production

Wide range of products and capabilities

Bespoke beam instrumentation, including Bunch Shape and Charge monitors

Nb QWRs and 12 MHz solid state sources

Medical, Sterilization, and Application-focused systems

Inverse Compton scattering (ICS) X-ray sources

radiabeam TECHNOLOGIES