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


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HB 2023
**68th ICFA Advanced Beam Dynamics Workshop on High-Intensity and High-Brightness Hadron Beams**
CERN, European Organization for Nuclear Research
Geneva, Switzerland 9-13 October 2023

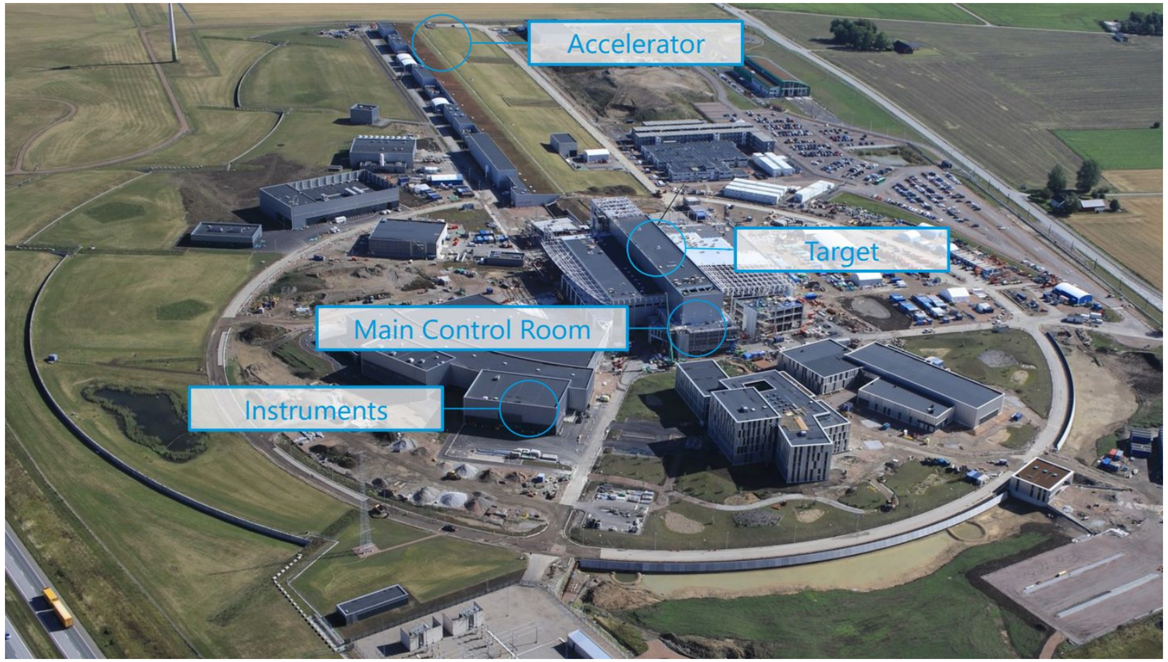
# OUTLINE

Beam destinations for the ESS NCL
Workflow and challenges

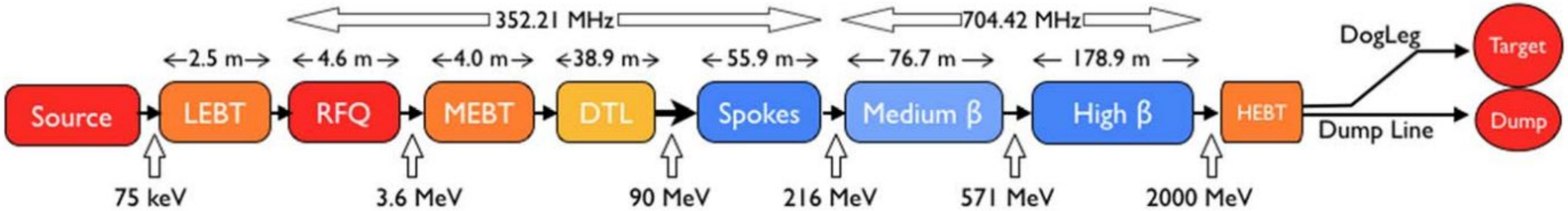
Commissioning results:
LEBT, MEBT, DTL1 – highlights
DTL4 – newest results

Conclusions and Outlook

ESS site in Lund (SWEDEN)




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



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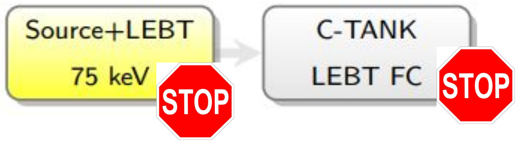
Beam Physics
Beam Diagnostics
Facility Management
Integrated Control System
Infrastructure
Linac
Mechanical Engineering
Operations
Procurement and Logistics
Project Management
Rigging
Radiation Protection
Survey, Alignment, Metrology
Vacuum
Workshop

# 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

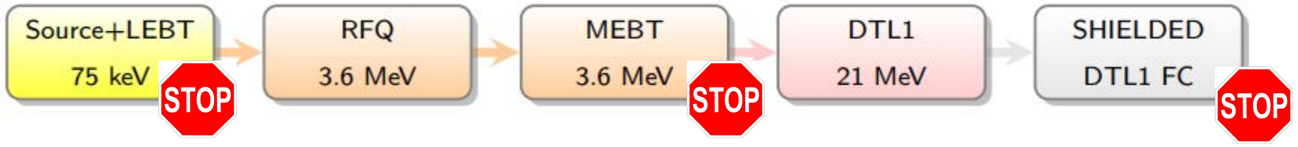
**IN GENERAL:**
- Designed for a specific proton energy (range)
- Water cooling system
- Pneumatic actuator for motion IN/OUT
- HV repeller bias (except the DTL4 FC)

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

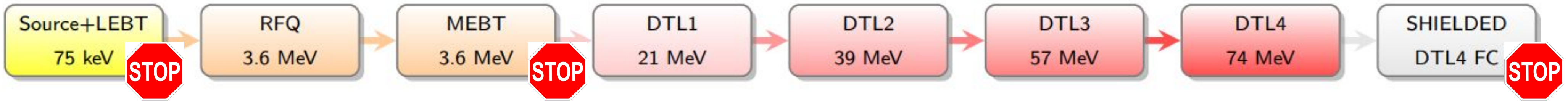



First ever beam at ESS: 19-September-2018


First acceleration on 26-November-2021 (Nominal 12-March-2022)



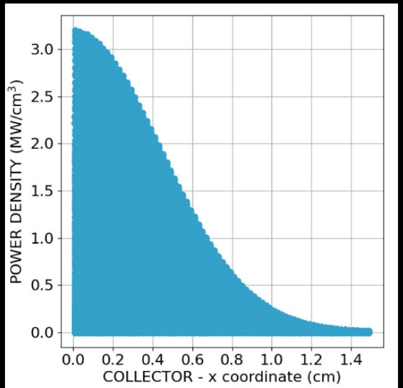

Beam on 1-June-2022 (Nominal 1-July-2022)



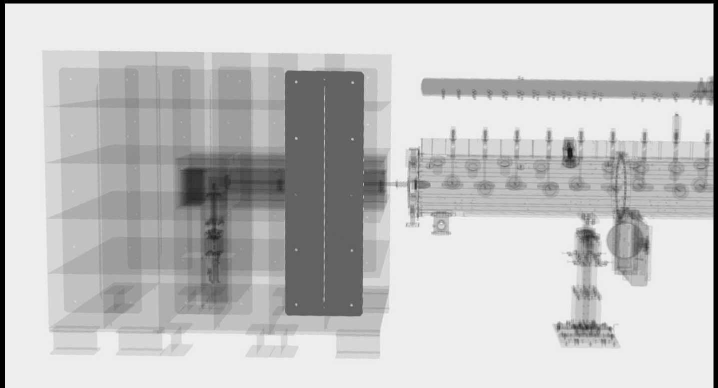

April-June 2023
(see last slides)

# WORKFLOW

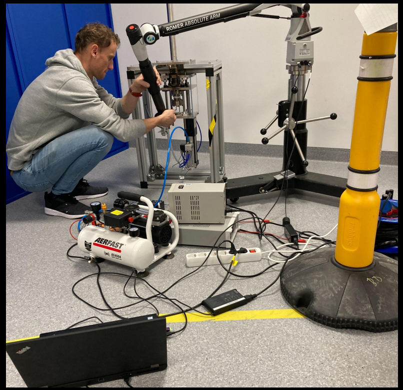
| 1. *DESIGN →* | *2. PRODUCTION →* | *3. INSTALLATION →* | *4. DOCUMENTATION →* | *5. OPERATION* |
|---|---|---|---|---|
| **Simulations** | Procurement | Acceptance tests | Simulations results | Operational limits |
| – Thermomechanical | Call of tenders | Cabling, connectors, pipes | Technical Reports | 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**<br>– Thermomechanical<br>– Activation<br>– Dose<br>– Shielding<br>CAD modelling<br>**Linac integration**<br>Control-system | | | Operational limits<br>OPI verifications<br>**Verifications (with beam)**<br>Control-room shifts<br>Data analysis<br>… *Debugging*<br><br>**…. 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<br>Beam power density<br>Radiation- and heat-resistant materials | Tight schedule<br>Materials availability during COVID19 pandemic<br>UHV requirements<br>Ceramic parts ←→ Oversea transportation | | Beam size (?) Emittance (?) Energy (?)<br>BCMs + BPMs + FCs<br>→ Scan / Simulations<br>→ Computing time | |

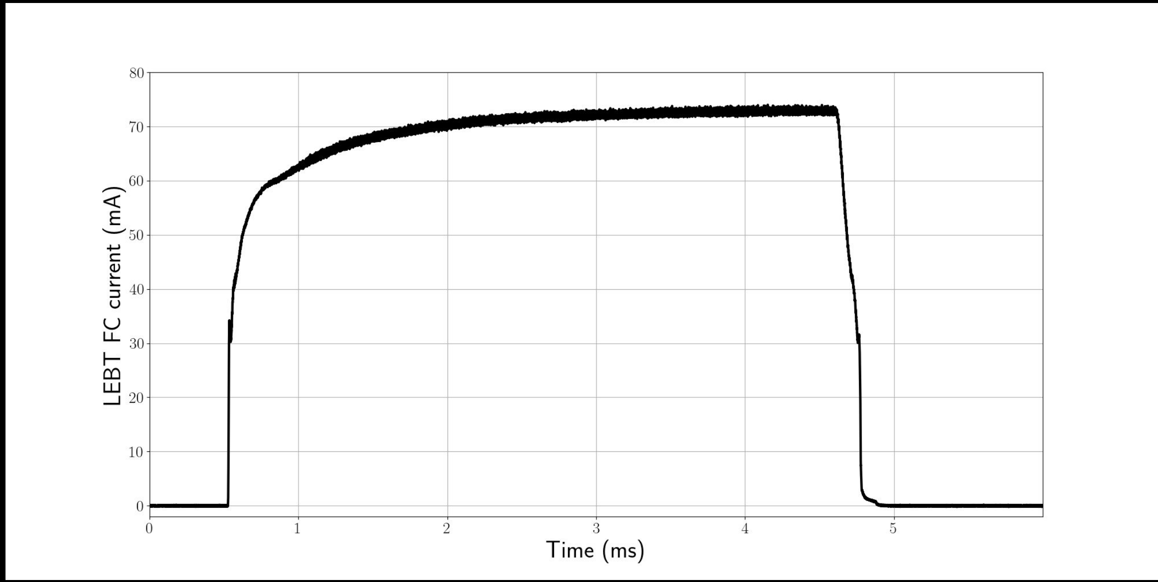
| | I (mA) | Pulse (us) | Rate (Hz) |
|---|---|---|---|
| **PROBE** | 6 | 5 | 1 |
| **FAST TUNING** | 62.5 | 5 | 14 |
| **SLOW TUNING (MEBT)** | 62.5 | **50** | 1 |
| **SLOW TUNING (DTL1)** | 62.5 | **20** | **1** |
| **SLOW TUNING (DTL4)** | 62.5 | 50 | **0.2** |

→

| | E (MeV) | P (W) | T (℃) |
|---|---|---|---|
| **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]

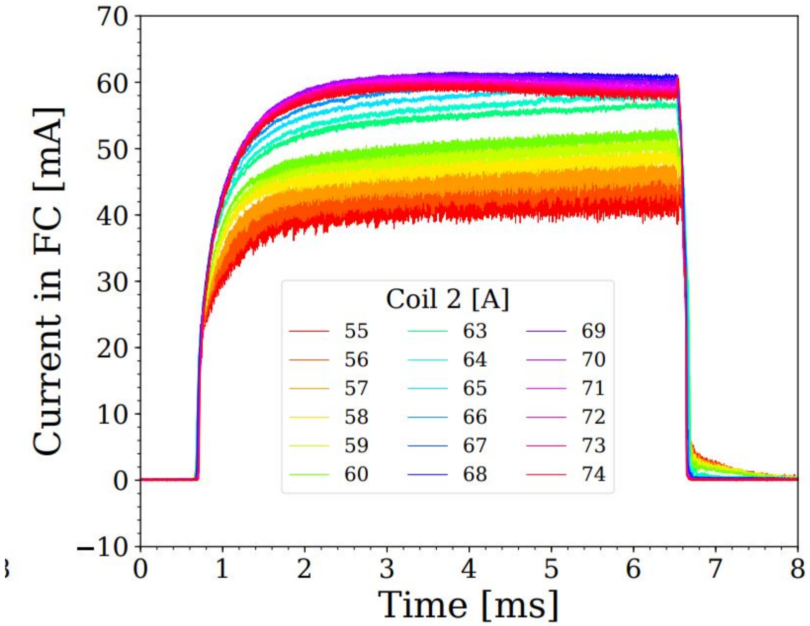
LEBT FARADAY CUP#1: Source tests in Catania
Commissioning at ESS in 2018 - 2019 (two tanks)
Several relocations during the commissioning
Facing soon the second ESS source

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

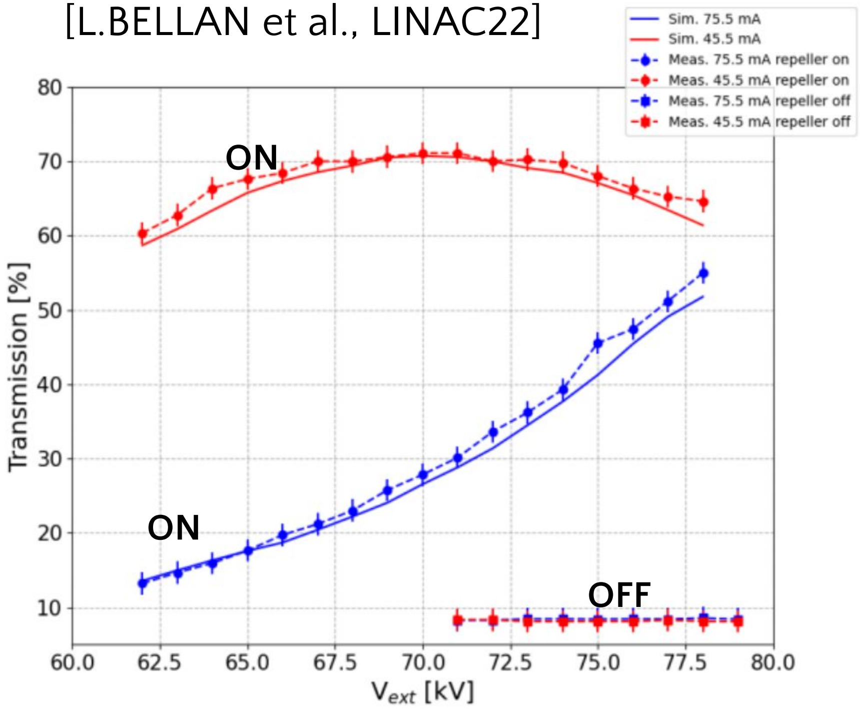
Paved the way for the first BD installations, tests and verifications procedures [C.DERREZ et al., IPAC19].
Operational during MEBT, DTL1, DTL4 commissioning

# LEBT FC: measurements and simulations

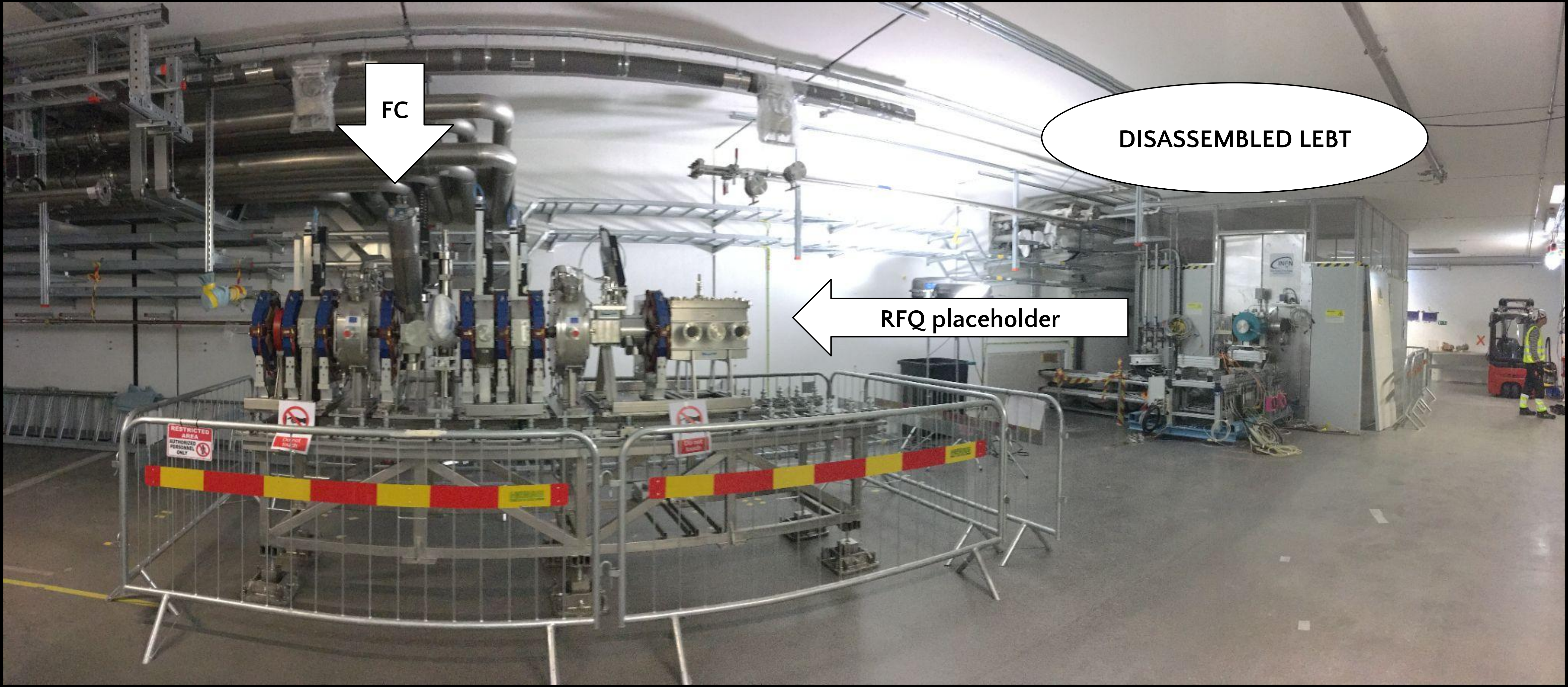
**SOURCE TUNING (5 pars)**
by scanning COIL2
→ optimal range in 67-68 A
RF power = 500 W
H2 flux = 3.5 sccm
COIL1 = 120 A, COIL3 = 217 A
FC in the Permanent Tank
[N. MILAS et al., HB2021]



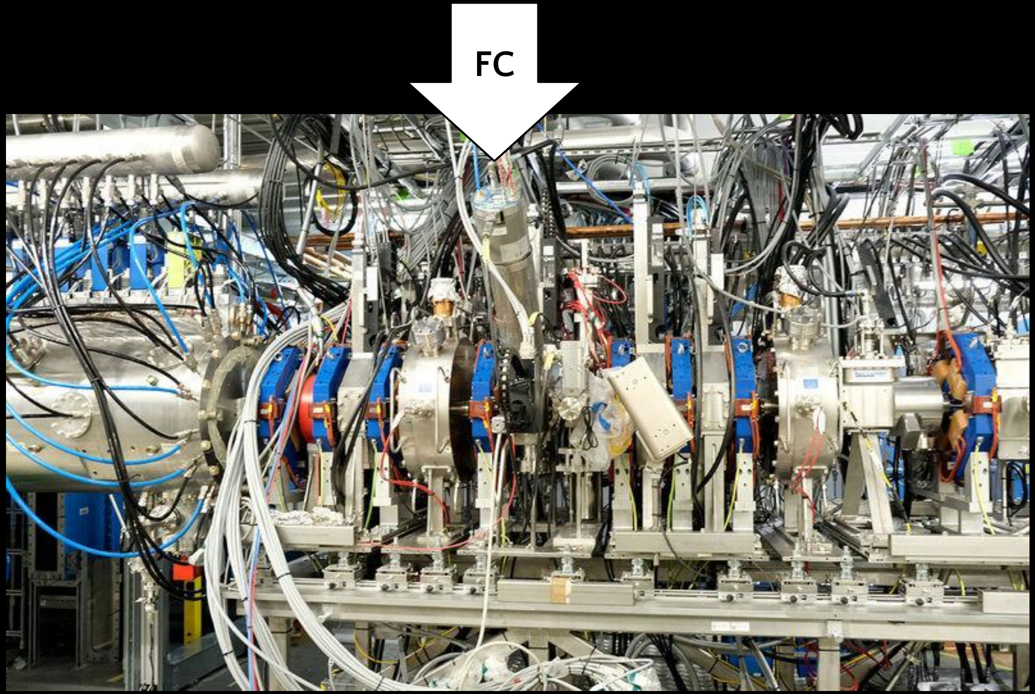

**TRANSMISSION**
**vs. EXTRACTION VOLTAGE**
Study of the beam divergence
Current 45.5 mA or 75.5 mA
Repeller OFF – no change
Repeller ON (-3.5 kV) → divergence
Amplification due to the e-flow
[L.BELLAN et al., LINAC22]

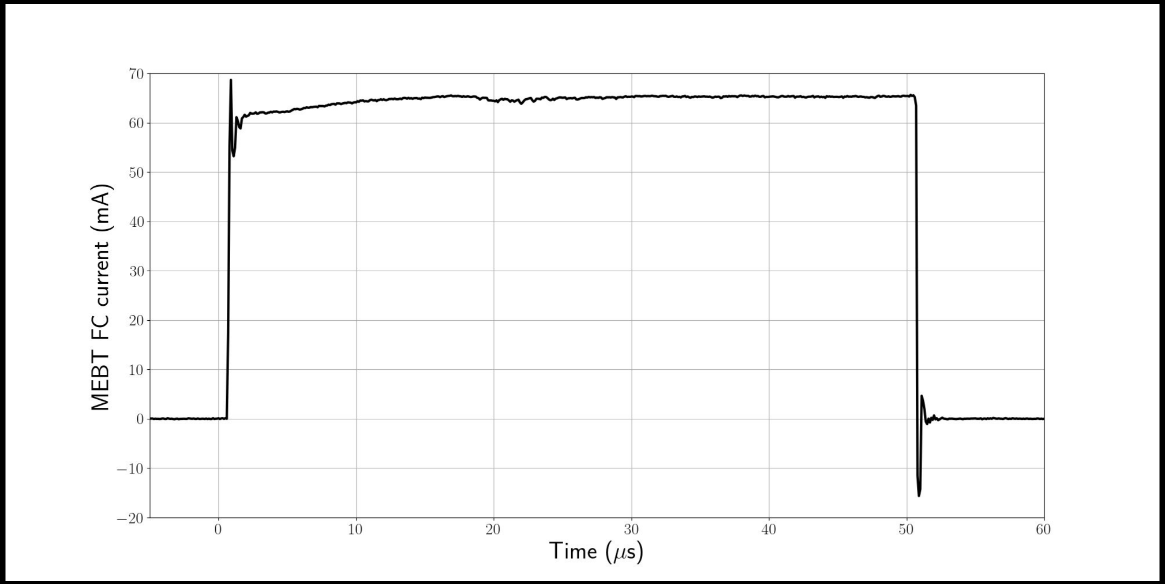


# MEBT – 6/2019



# MEBT – 11/2021




MEBT = Medium Energy Beam Transport

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

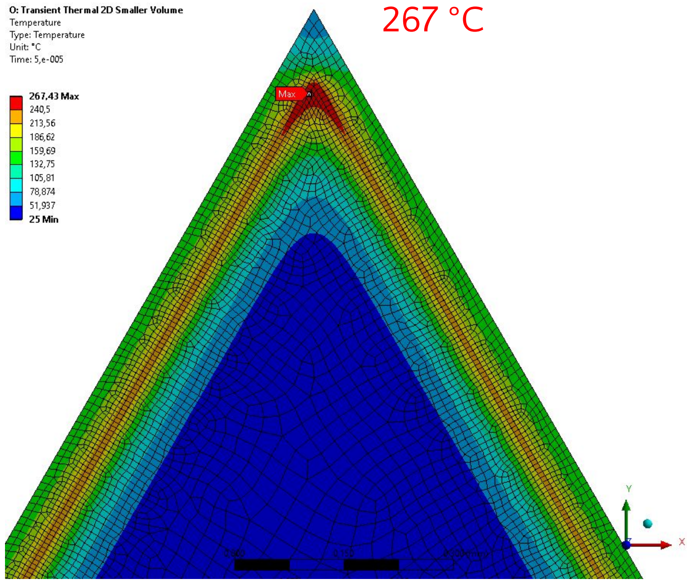
MEBT FARADAY CUP
Designed by ESS-Bilbao, manufactured by Pantechnik
11/2021 Probe beam successfully accelerated in RFQ

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**

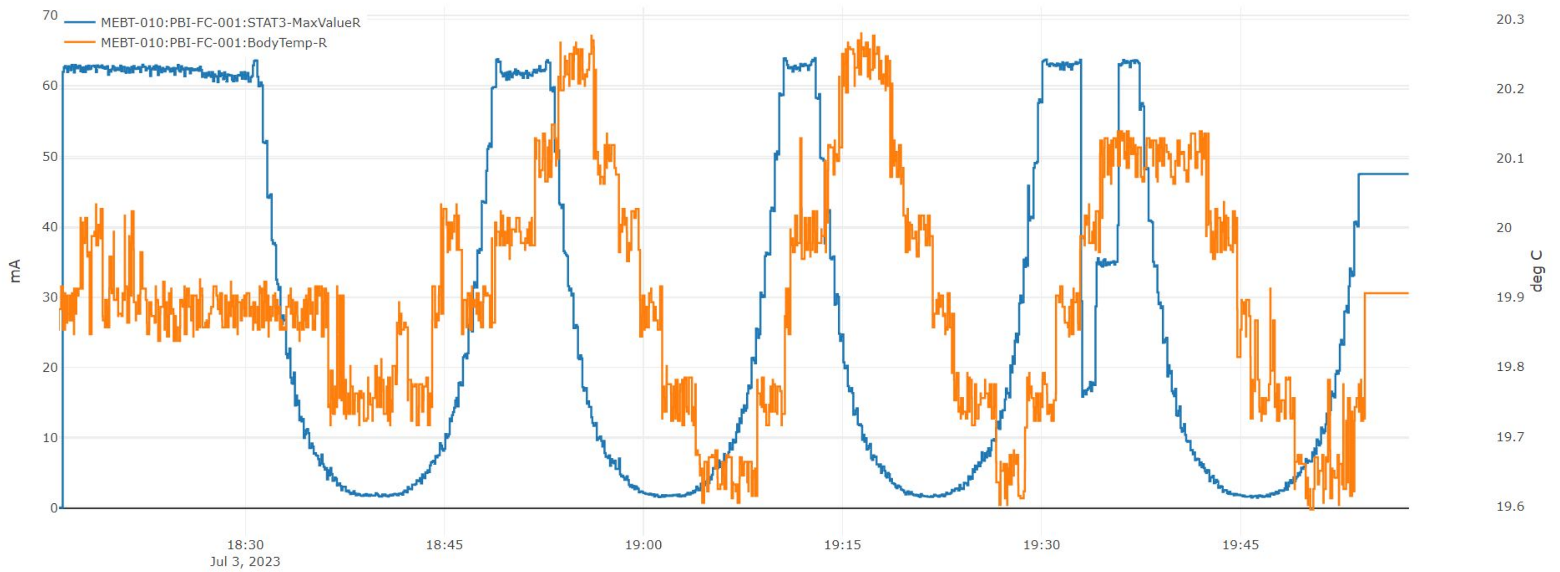
Peak after 130 µm in depth
→ surface erosion, blistering
→ replaceable collector




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]

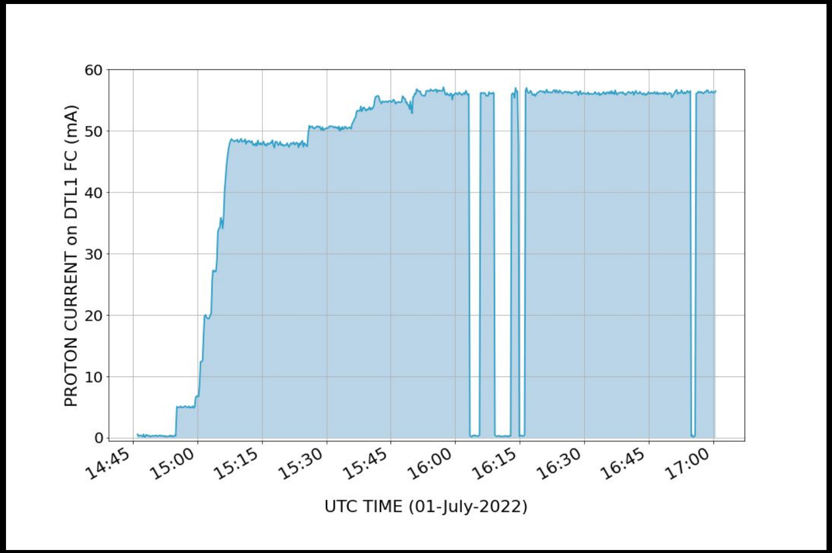
**PROTON CURRENT and COOLING WATER TEMPERATURE,** as a function of time




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

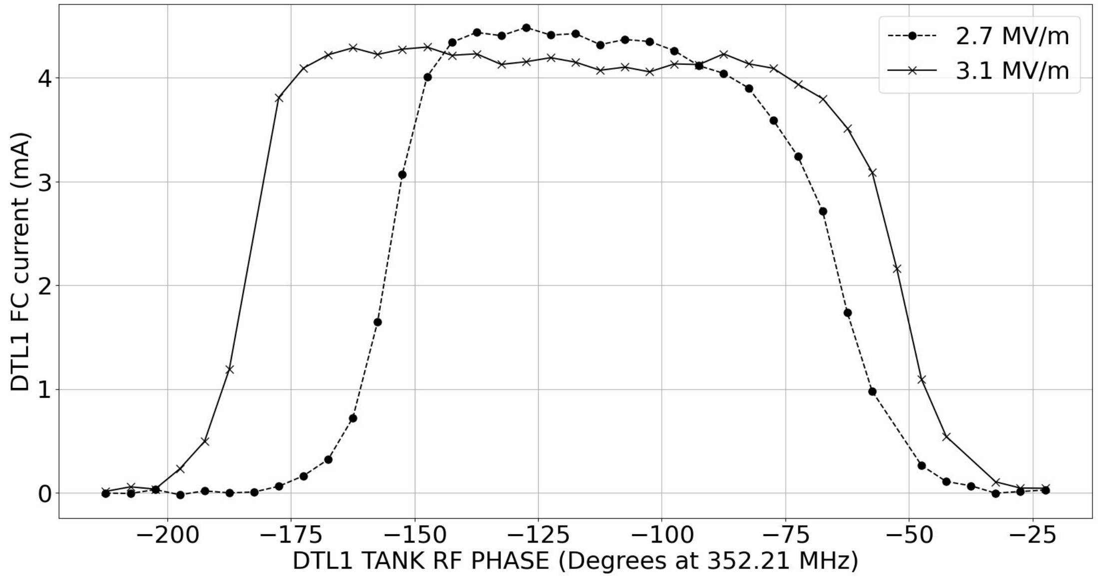
DTL1 FARADAY CUP
Design by ESS, manufactured by RadiaBeam
6/2022 Probe beam
7/2022 Nominal current (max 20 μs)

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

# DTL1 FC: measurements and simulations

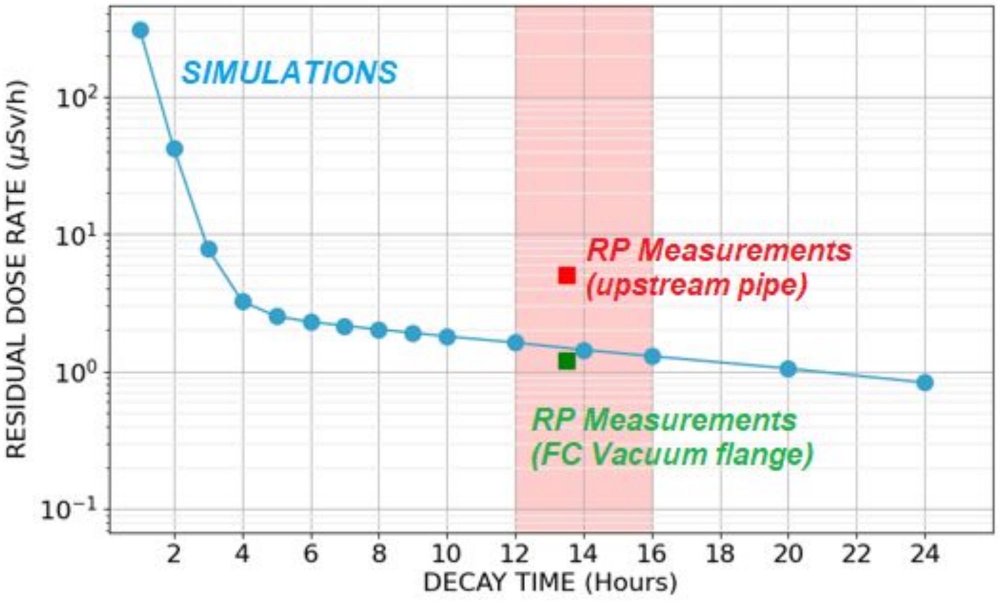
**DTL1 FC MEASUREMENTS**
Initial acceptance scan of the cavity phase
RF Amplitude with DTL1 accelerating field [2.7, 3.1] MV/m

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

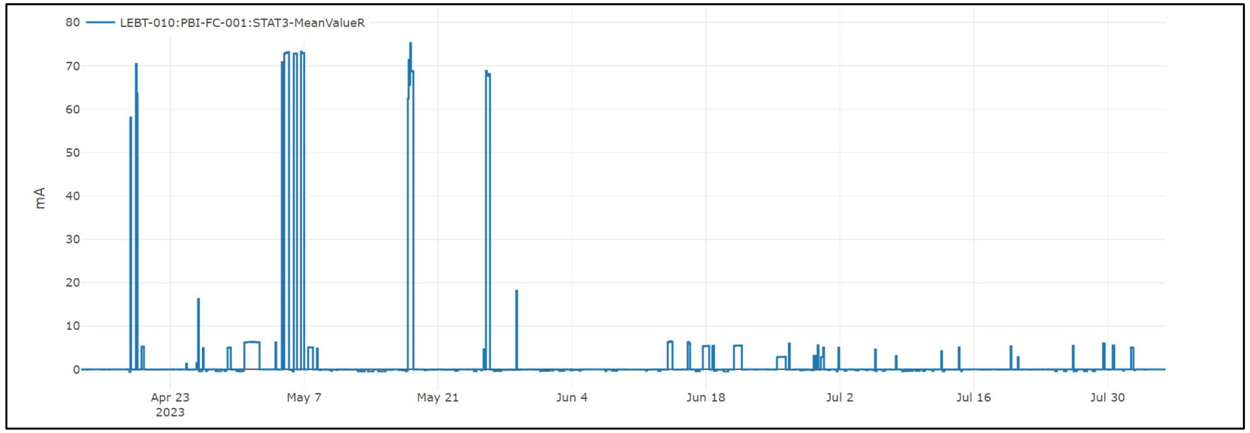



**DTL1 FC ACTIVATION**
Monte Carlo calculations to predict residual dose rates
RP measurements before dismantling < 2 μSv/h

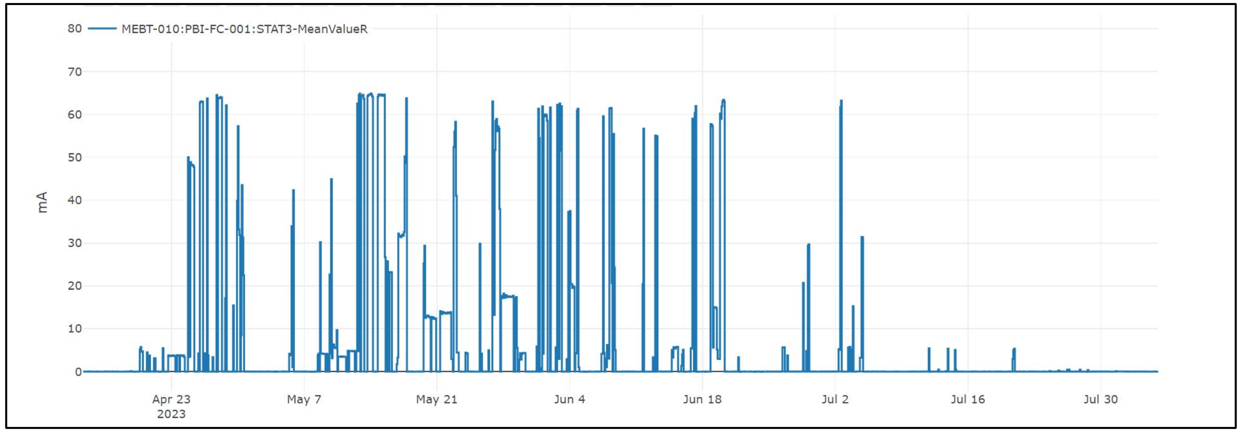
Decay time = 10 hours
Dismantling the day after the end of the DTL1 commissioning



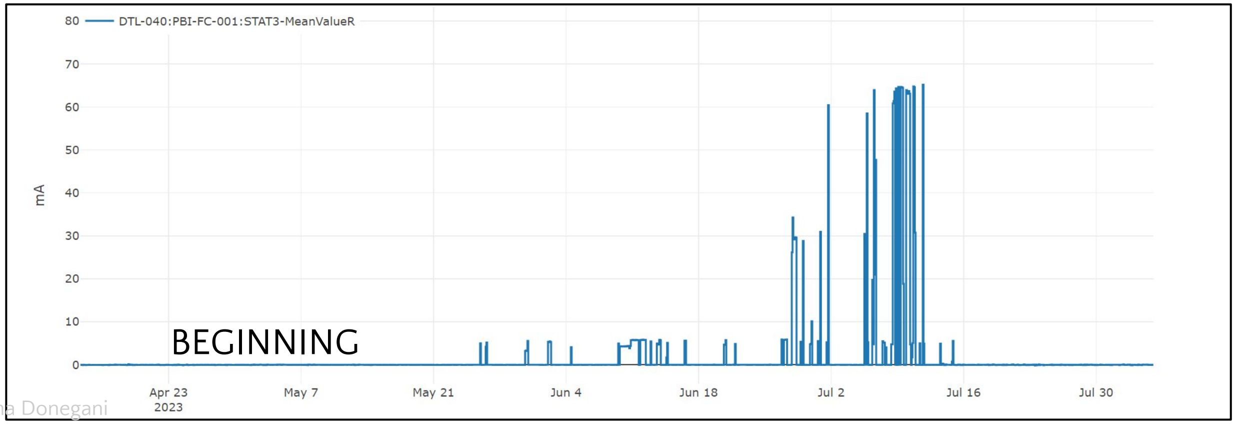
LEBT




MEBT

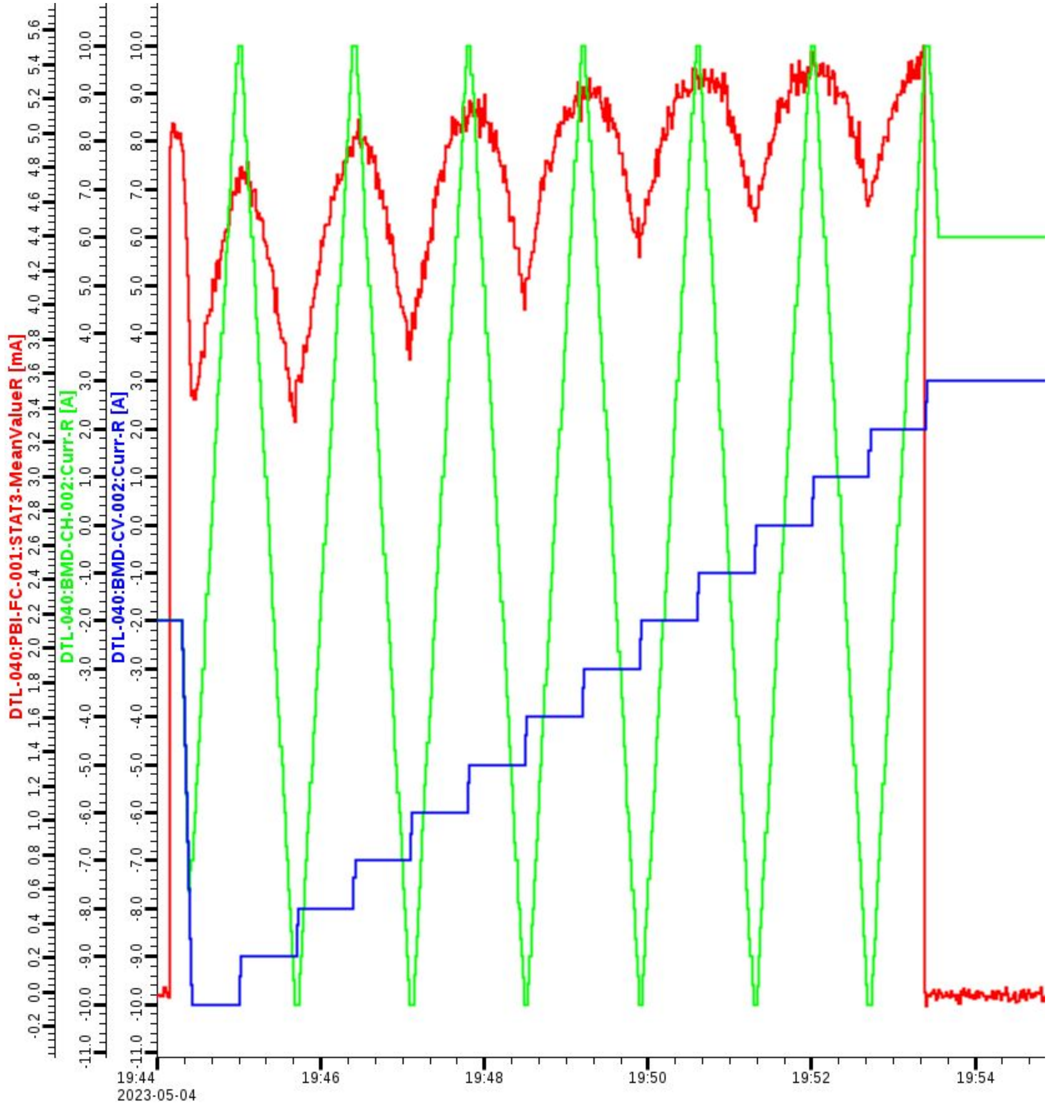



DTL4

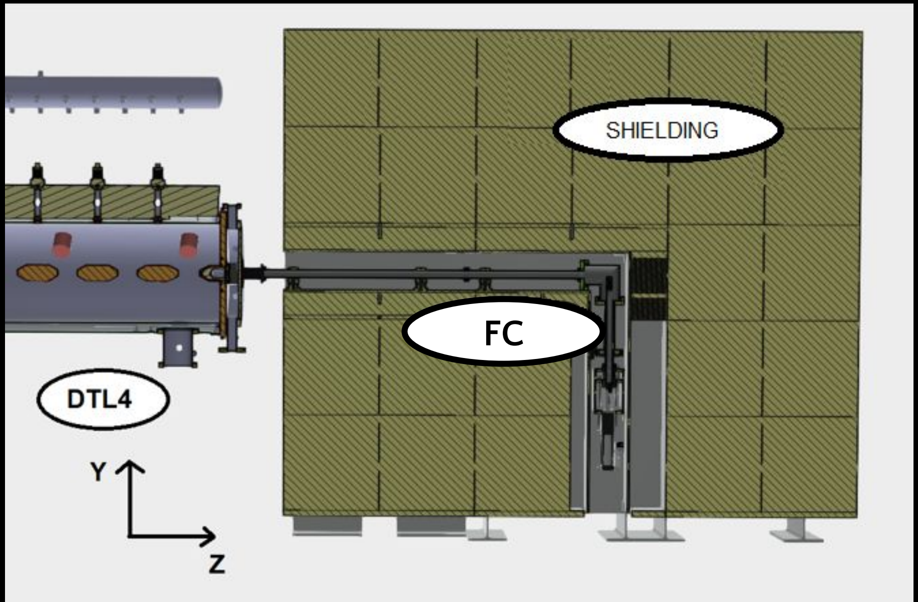


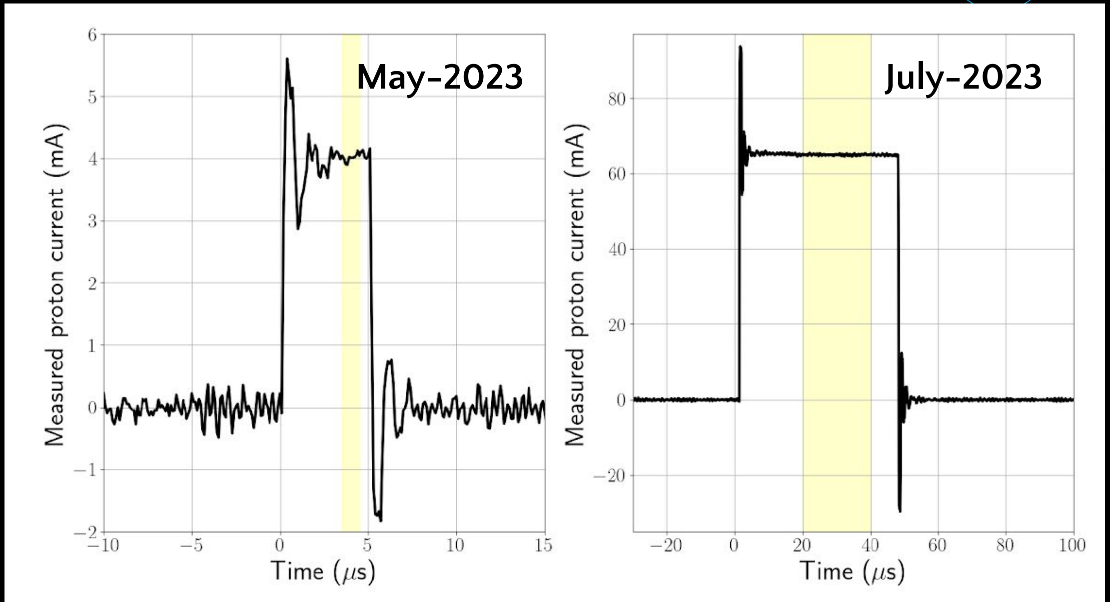

# FCs trio – From April to July 2023

# 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)

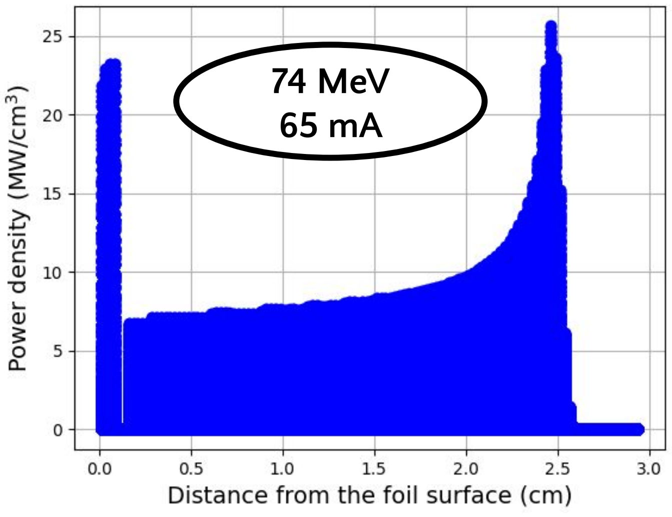
**[E.DONEGANI et al., NIMA, 2023 Vol. 1057]**
Design and performance

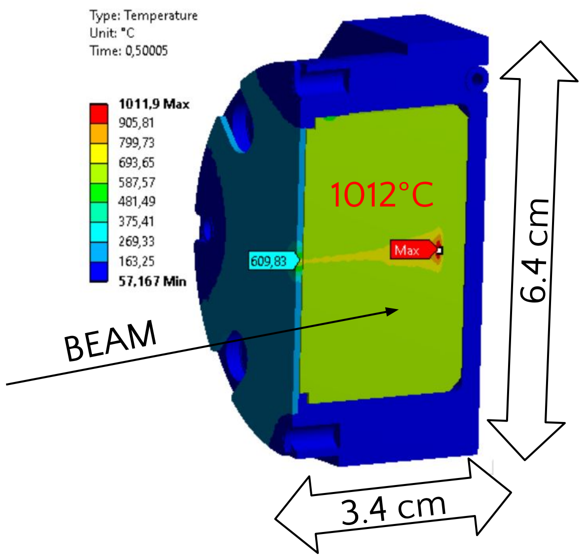
# DTL4 FC: simulations

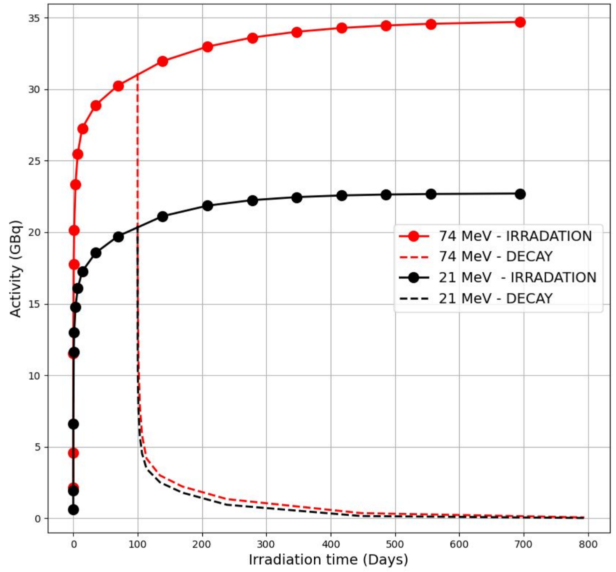
- **Very tight space** ( < 35 mm along the beam direction)
- **Beam power density** 25 MW/cm$^3$ → 1000°C in the core
- **Shielding** → **no access** → EPICS-based control system
- **Low activation** (ongoing SCL installation, quick dismantling)

→ 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] |



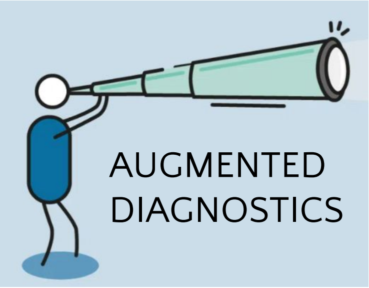



# DTL4 FC: operational limits

- **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

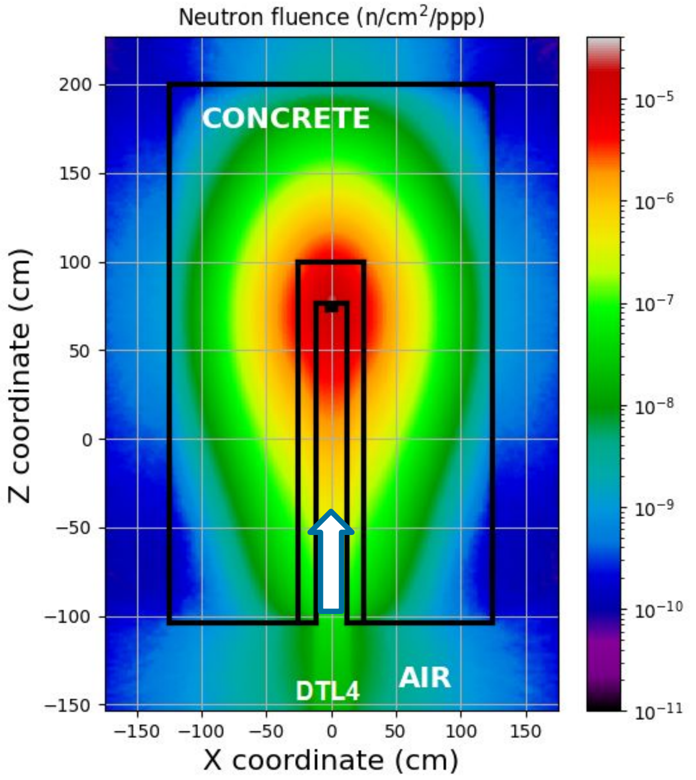
| Beam parameters | | | | Temperature | | Mech. Stress | | |
|---|---|---|---|---|---|---|---|---|
| **Energy** | **Current** | **Pulse** | **Rate** | **T foil** | **T core** | **PS foil** | **PS core** | |
| MeV | mA | us | Hz | °C | °C | MPa | MPa | |
| 21 | 6 | 5 | 1 | 910 | 35 | 0.3 | 0 | |
| 21 | 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! |

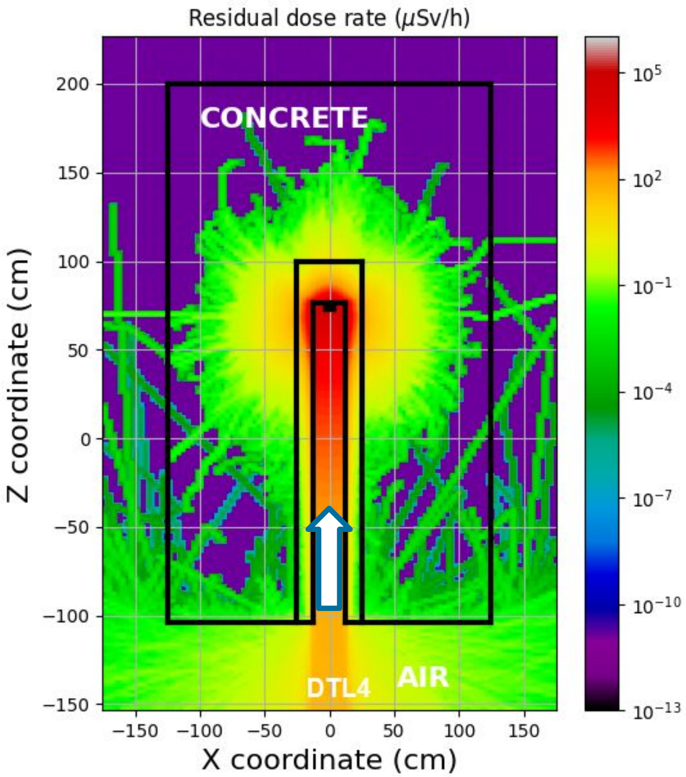


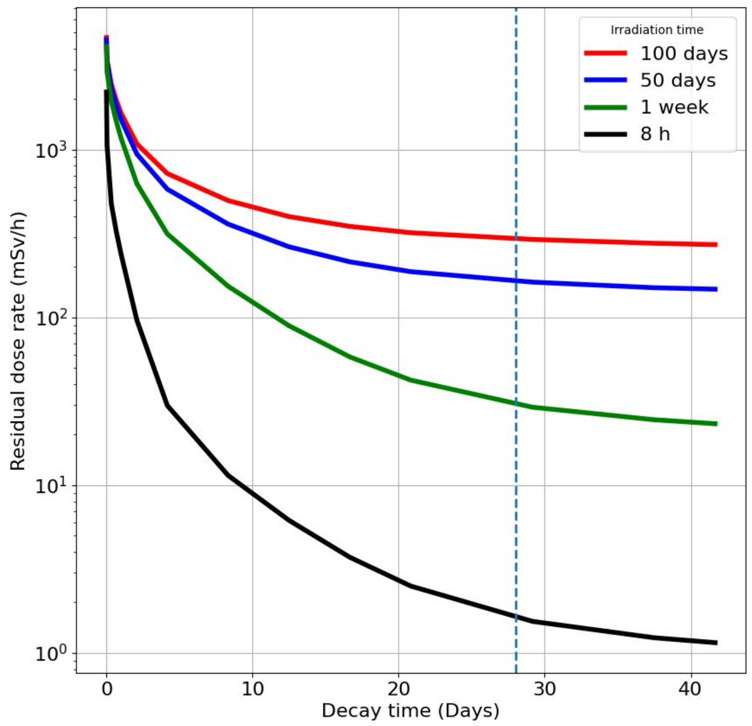
# DTL4 FC: Residual dose rates

**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



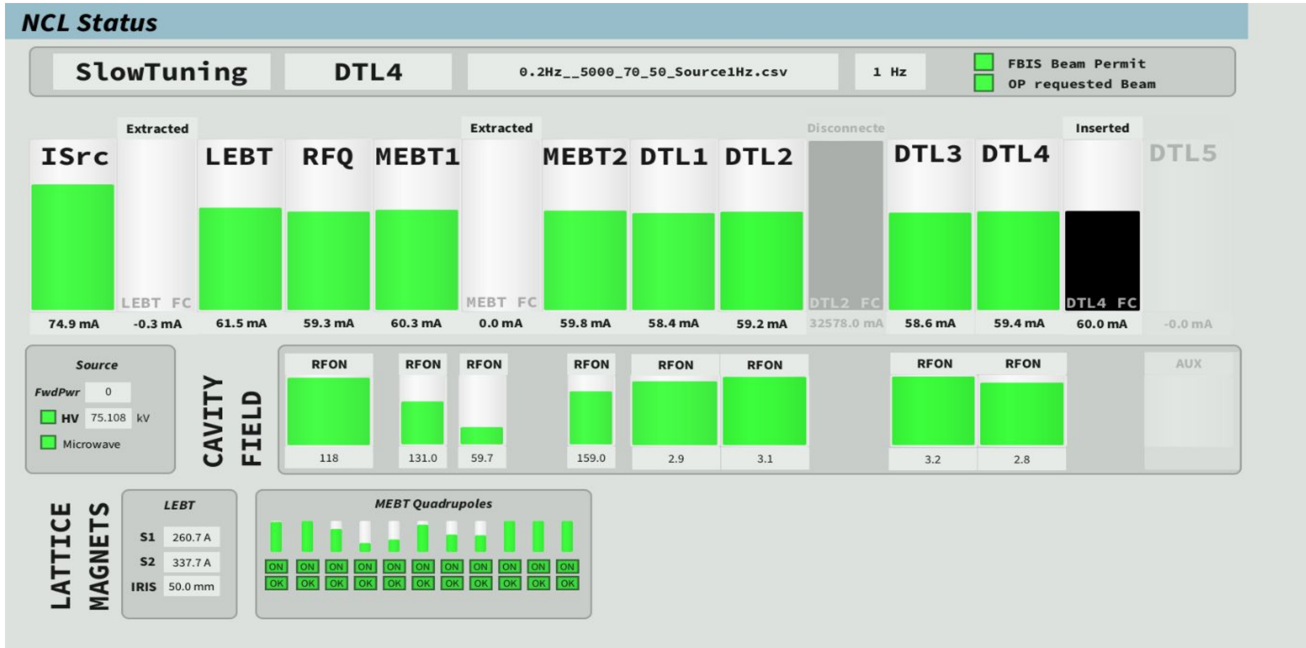



# CONCLUSIONS

**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, …



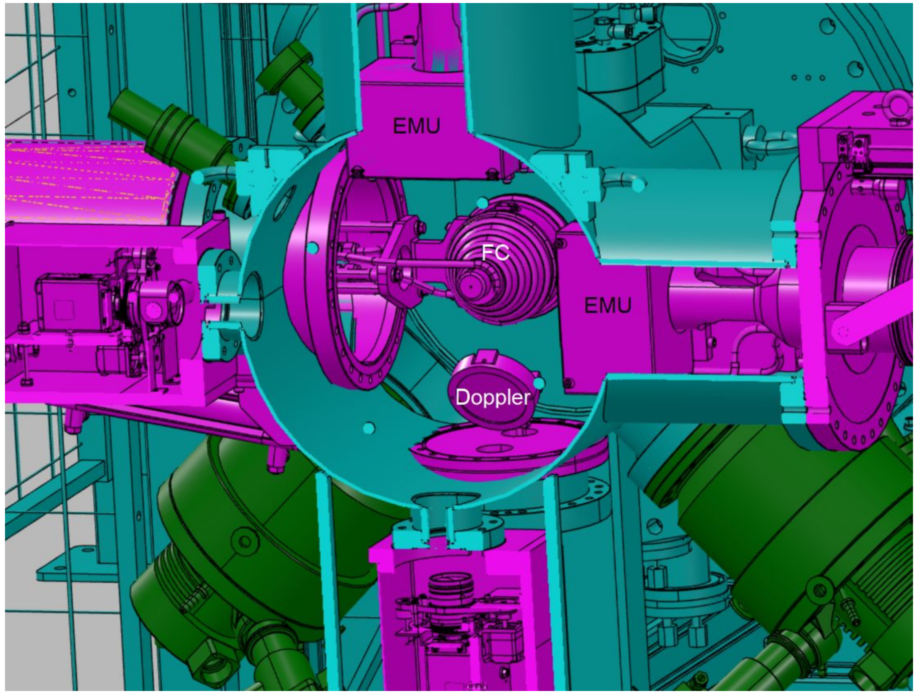

# OUTLOOK

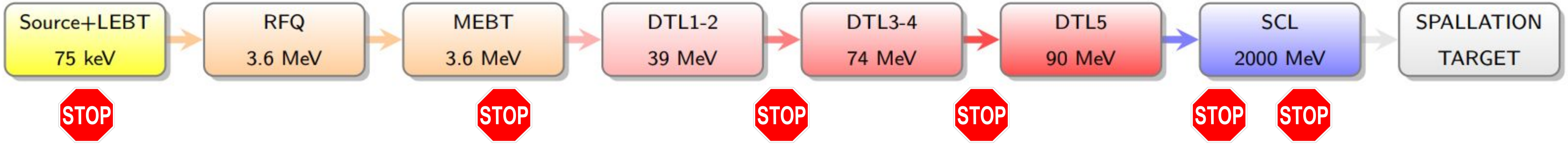
**Next steps:**
- Four Faraday cups permanently in the NCL (LEBT, MEBT, DTL2 IT, DTL4 IT)
- Procurement of the spare DTL4 FC (Spares already procured for LEBT, MEBT, DTL2)

**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

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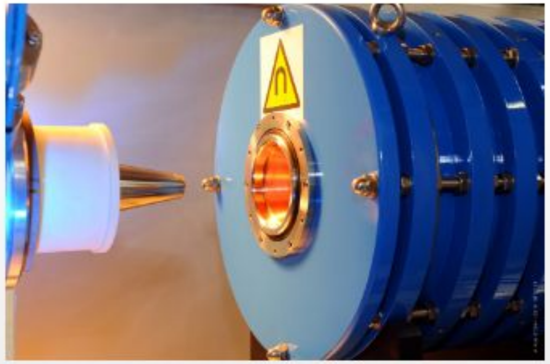


ECR ION SOURCES

OTHER SOURCES

BEAM DIAGNOSTICS

Faraday Cups

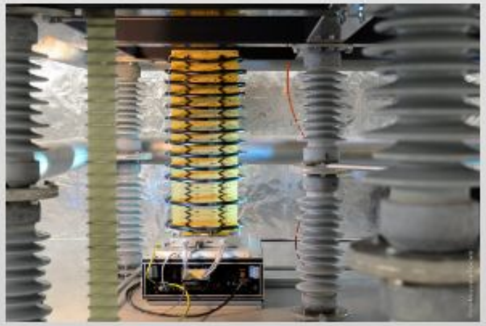
Beam Profilers

Emittance Scanners

Slits

TURNKEY SYSTEMS

Injectors



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