EUROPEAN SPALLATION SOURCE

Commissioning of Accelerators

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Contents – General points

- Definition of Commissioning
  - Adapting it to Accelerators
- Commissioning and Installation
  - System Commissioning
- Moving to Initial Operations
  - Commissioning of instruments
  - Personal and moving experience
- Optimizing Commissioning

What is commissioning

- Commissioning:
  - Process by which an equipment, facility, or plant (which is installed, or is complete or near completion) is tested to verify if it functions according to its design objectives or specifications.

Commissioning particle accelerators

- Unique systems in general. Most accelerators are based in individual design.
  - Makes predicting the commissioning proces challeging
  - Even ones based in previous design would be diferent enough to require specific commissioning
- In general is in multiple steps
  - Injector then storage ring
  - Different sections of the LINAC
- Could be in parallel to part of the installation

Beam Commissioning and Systems

- Commissionig could only start after installation is almost finish. Delays in the installation tend to reduce the avalaible time for commissioning
- Two main periods in the commissioning
  - System Commissioning: Each individual system is tested, optimized, and verify to reach the nominal parameters, WITHOUT producing beam
  - Beam Commissioning: Optimize the performance of the whole accelerator, detecting and mitigating the errors of the design, components and installating, and reaching the parameters required for Initial Operations.
  - And Dry Runs to link the two stages

User's Instruments commissioning

- In a user facility (light source, spallation source, collider) the corresponding instrument scientist's need to commission their systems
- That could require a different set of parameters than operation
- Pressure in the accelerator commissioning to switch to instrument commissioning
- Both could run in paralel for a while

Moving to Operations

- Knowledge acquired during commissioning needs to be carried overt to operations
  - Part of the commissioning is to document the information required for operations
  - Having continuity in the team between commissioning and operations

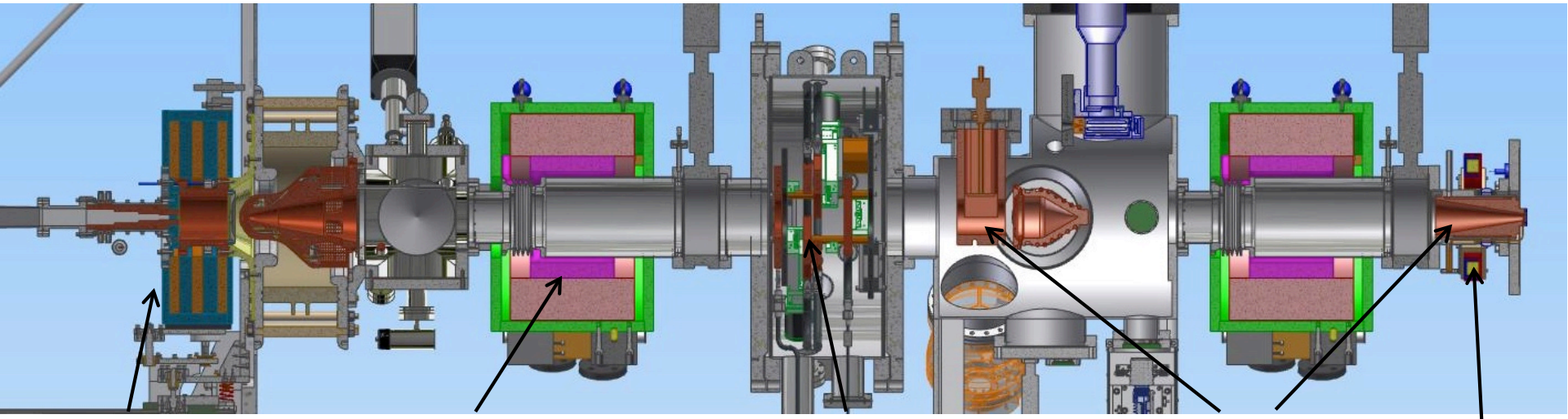
Preparing for commissioning

- Beam time is expensive, so try always to use the beam
- Have a plan for the commissioning (and be prepare to modify it often)
- Define clear procedures to perform the basic tasks of the commissioning
- Test the software using virtual accelerator
- Train the commissioning team in the use of the most common tools before hand
- Simulate at least some of the procedures using a virtual accelerator
- Use tools like OpenXAL or MML
  - Borrow, steal and copy from similar projects: reuse code, do not try to reinvent the wheel

Commissioning crew

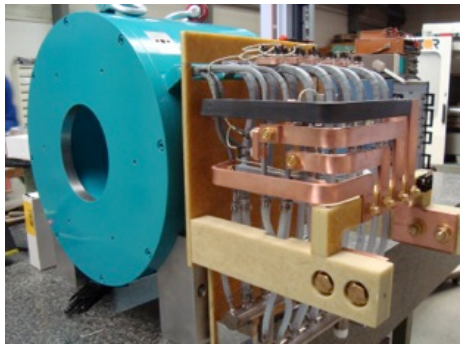
- Composition of the team
  - Try to involve the operators as soon as possible:
    - Experience carried over to operations
  - Operators vs experts
    - Operators are in general more careful and methodic
  - Experts should guide the commissioning
    - Accelerator physicist involved in the majority of the task of Beam Commissioning
- In-house team vs external experts
  - External experts could join for clear defined tasks

The Low Energy Beam Transport (LEBT) matches the beam to the RFQ input

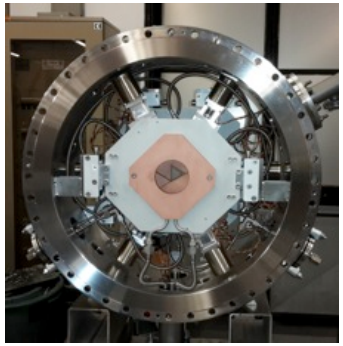


Proton source
– creates the beam

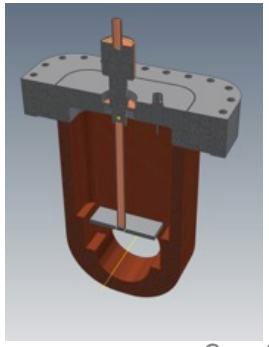
Solenoid
– focuses the beam



Iris
– controls the current



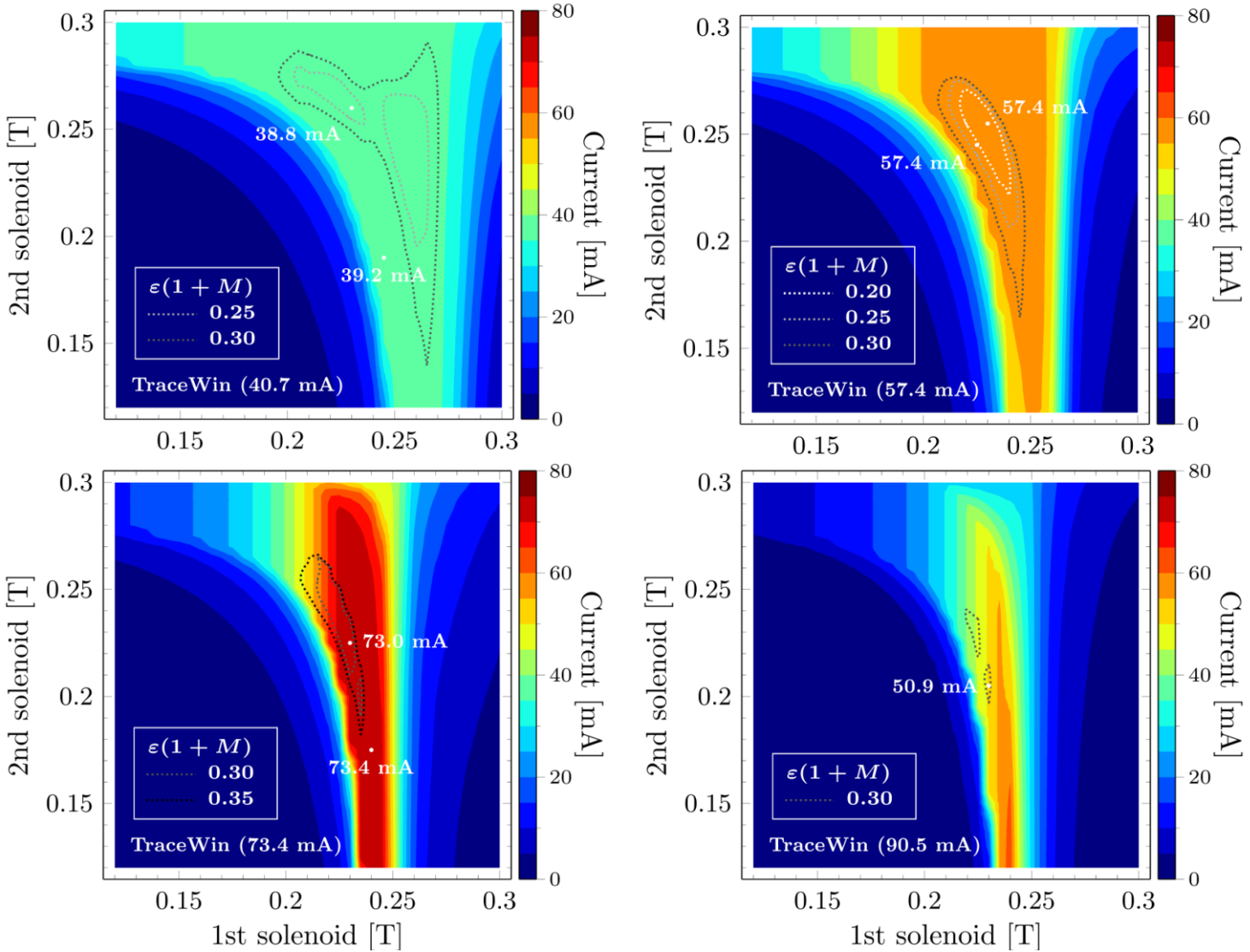
Chopper and collimator
– controls the pulse length



ACCT – measures current

Courtesy Oystein Midttun

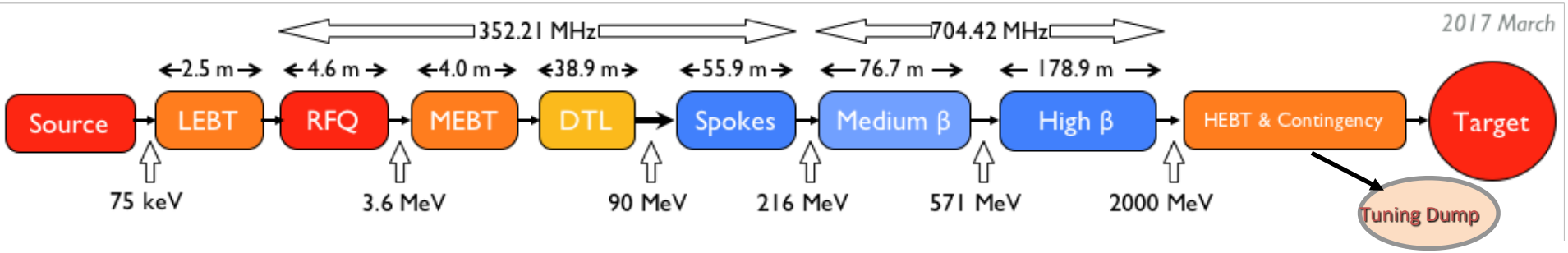
Solenoid scan in the LEBT



ESS Commissioning

- ESS Timetable
- Commissioning steps
- Defining the procedures
- Simulations

Accelerator overview



Parameter	Value	Units
Max energy	2	GeV
Peak current	62.5	mA
Repetition Rate	14	Hz
Pulse length	2.86	ms
Average Power	5	MW
RF Frequency	352/704	MHz
Maximum losses	1	W/m
Species	Proton	

Device	Total Number
RFQ	1
DTL tanks	5
Spokes Tanks	13
Spokes Cavities	26
Cryo tanks (M-β)	9
RF cavities (M-β)	36
Cryo tanks (H-β)	21
RF cavities (H-β)	84
Klystrons/IOTs	120
Modulators	30-60

Considerations about the commissioning

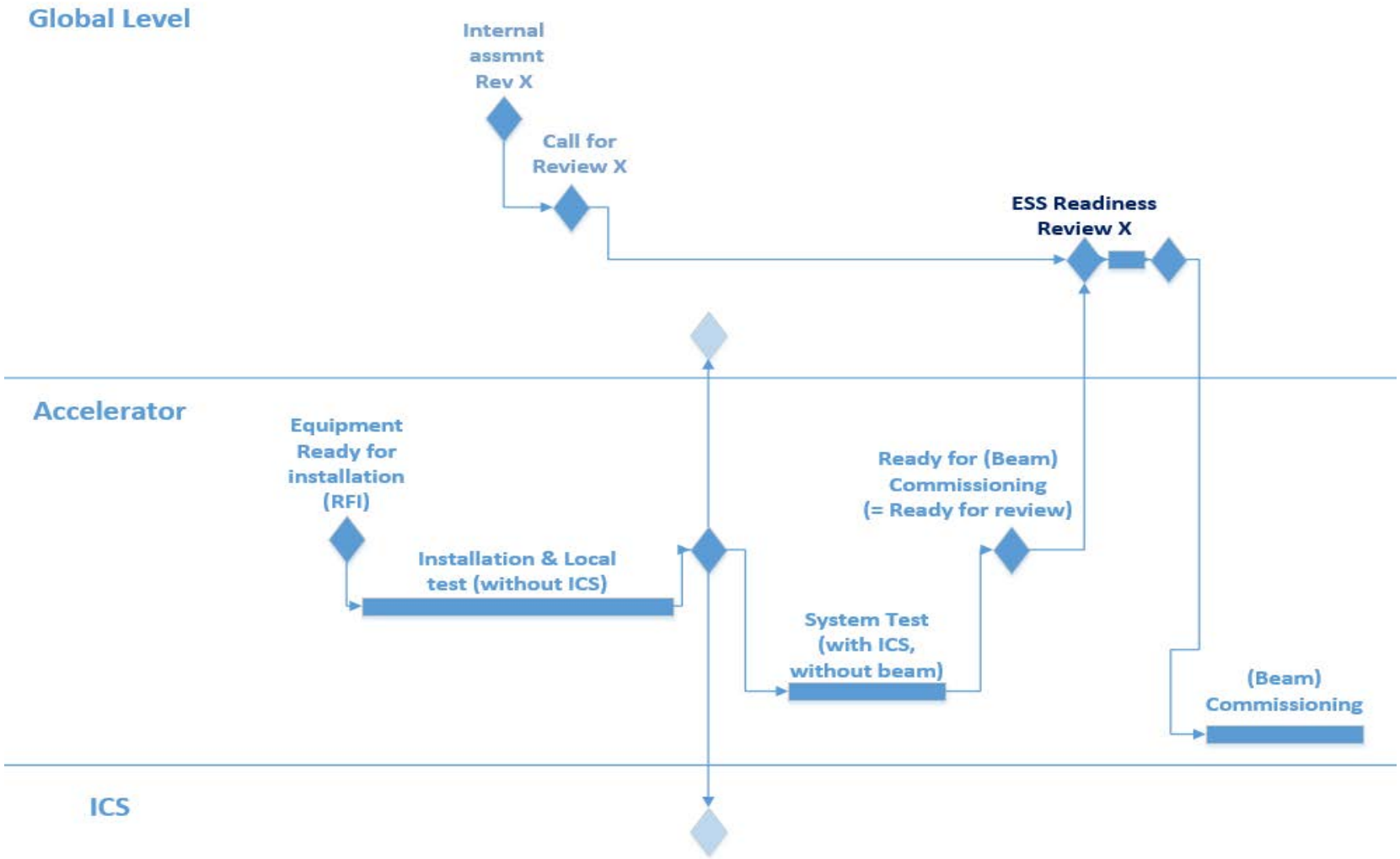
- ESS would operate with a long pulse (2.86 ms).
- High peak current: 62.5 mA-> space charge dominates at low energy
- Only 1.4 MW at end of commissioning
- Only beam stop to accept the nominal parameters is the Target
- The straight ahead tuning dump can take a full 2.86 ms pulse but only every ~30 s
- Most of the (invasive) diagnostic could not cope with the long pulse
- Large percentage of In-Kind contribution
- Start using a Local Control Room

- Systems should be fully tested and commissioned before start of Beam Commissioning (BC)
  - Beam diagnostic, Low level RF, would need the beam
- Staged Commissioning, in parallel to installation
  - Could require temporary dumps and diagnostic
  - Temporary shielding wall for parallel installation
  - Temporary beam stops (details under consideration)
- HBL cavities not installed, reduced power (0.57 GeV) at the end of commissioning

Staged Commissioning

- Warm Linac:
  - Mostly at 1 Hz, 5/50 µs beam (limited by the shielding wall)
- SC to Dump
  - Mostly at 1 Hz, 5/50 µs beam, some test with longer pulses at slow repetition rate (limited by tuning dump)
- Linac to Target
  - Starting with 1 Hz, 5 µs beam, ramping up to 2.86 ms

Logic and Milestones (P6)



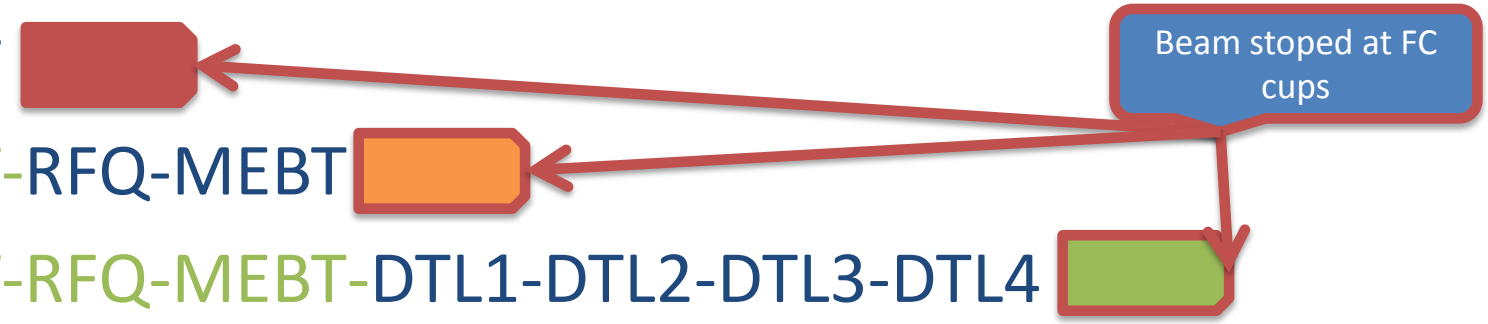
Linac Commissioning schedule

Step	Period	Max Energy
ISrc - LEBT	February-March 2018	75 keV
ISrc - MEBT	September-October 2018	3.7 MeV
ISrc - DTL4	January-March 2019	75 MeV
ISrc - DMPL	3rd quarter 2019	571 MeV
ISrc - Target	End 2019-Early 2020	571 MeV/ 1.3 GeV

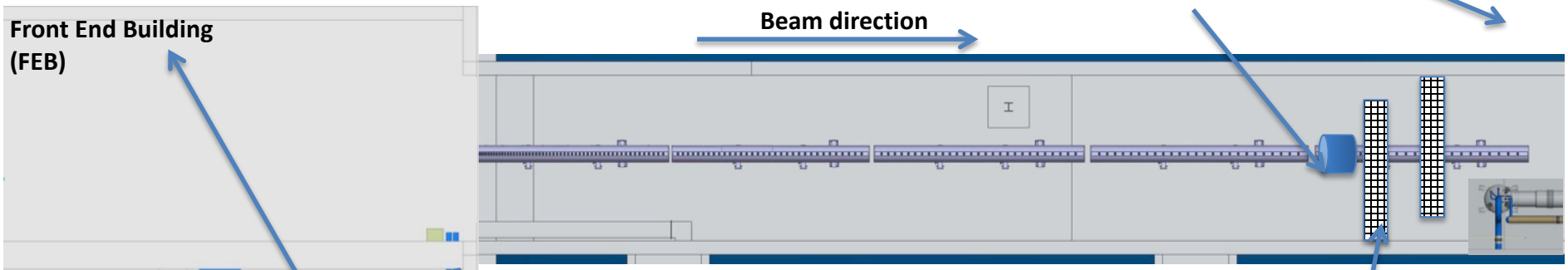
* Dates as 19 January 2017, but they are only a first aproximation

Sequence for commissioning to Target (no HBL cavities)

- Staged commissioning, in parallel to installation!
- IS-LEBT
- IS-LEBT-RFQ-MEBT
- IS-LEBT-RFQ-MEBT-DTL1-DTL2-DTL3-DTL4
- IS-LEBT-RFQ-MEBT-DTL1-DTL2-DTL3-DTL4-DTL5-SC Linac–HEBT-Dump
- IS-LEBT-RFQ-MEBT-DTL1-DTL2-DTL3-DTL4-DTL5-SC Linac–HEBT-A2T-Target



Temporary tunnel configuration for warm linac staged commissioning



Installation operations

FC with extra shielding

Temporary Front-end equipment access (with removable shield blocks)

Stubs and cable penetrations with final shielding configuration

Regular front end personnel access

Temporary shield wall separating warm and cold linac activities

Beam Modes (Operational Envelopes) used for early commissioning (NCL)

Name	Description	Characteristics	Notes
B0	No Beam	No beam	No beam
B1	Probe Beam	5 µs @ 1Hz	Used for initial tune up
B2	Fast Tuning	5 µs @ 14 Hz	limited beam loading; used for fast scans (e.g. RF and Wire scanners)
B3	Slow tuning	50 µs @ 1 Hz	Beam loading studies, limit of invasive diagnostics
B4	Long pulse	2.86 ms @ 1/20 Hz	Only use when tunes up.
B5	Production	2.86 ms @ 14 Hz	Normal operation with high power
B6	Mixed mode	2.86	running “pulse on demand”.
		50 µs @ 1 Hz	

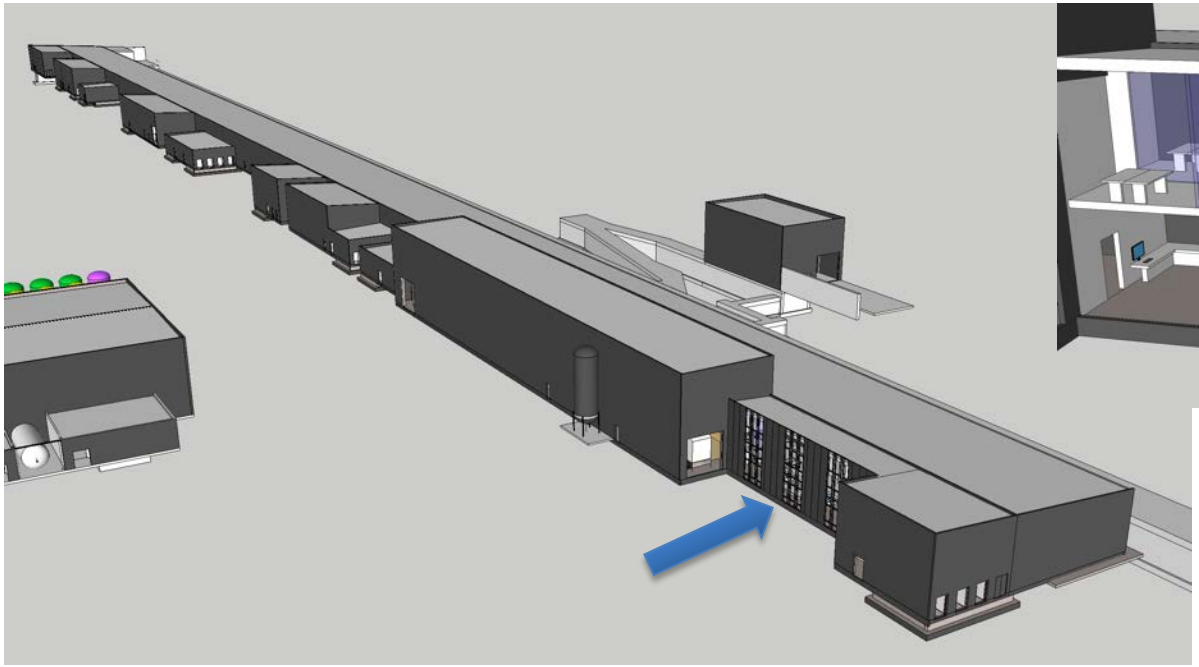
Ion source is capable of ~ 90mA * 6ms @ 14Hz. Investigating hardware methods to limit rate and pulse length for commissioning.

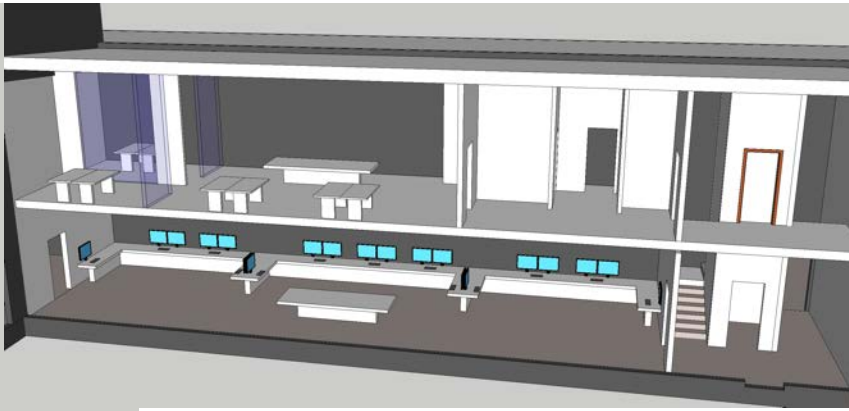
The temporary shielding wall will set the limit of the beam modes to use. IS limited to 1 Hz, 3 ms pulse

Supporting document: ESS-0038258

Local Control Room

- MCR will not be ready in time for BC
- We will use the Local Control Room, located at the end of the Gallery, in the Cryo Control Room





Courtesy R. Mudingay

SC BC Summary

1. Beam on tuning dump (demonstration?) in late 2019 at 571 MeV
2. Beam on target in late 2020 at 1.3 GeV

- Still needs to be confirmed

Stage 2: SC Linac to Dump

- Beam: Probe, Fast and Slow tuning, Long pulse verification(?), hybrid(?)
  - The tuning dump has a limited capability, it will mostly use in short (5 to 50 µs pulses)
- Max Energy: 571 MeV
- Beam destination: Tuning dump plus any beam stop in the Linac

Steps

- Step 1: NCL recommissioning and DTL5 commissioning:
  - Verify that the NCL up to DTL4 recovers to the previous configuration
  - Beam to the exit of DTL5 (measurements using the dump in the Spokes)
  - Optimize transmission
  - Corrected trajectory
  - Matched optics
  - Objectives:
    - Energy at the end of DTL5: nominal 89.6 MeV, minimum required 89 MeV
    - Transmission > 99±1%
    - Current > 30 mA
- Step 2: Spokes
  - Beam to the exit of Spokes (measurements using the dump in the MBL)
  - Optimize transmission
  - Corrected trajectory
  - Matched optics
  - Objectives:
    - Energy at the end of spokes: nominal 226 MeV, minimum required 200 MeV
    - Transmission > 98±1%
    - Current > 30 mA
- Step 3: Medium beta linac, MBL, MBL and beam transport to Tuning Dump
  - Beam to the exit of MBL
  - Beam transported to the Tuning Dump
  - Optimize transmission
  - Corrected trajectory
  - Matched optics
  - Objectives:
    - Energy at the end of MBL: nominal 570 MeV, minimum required 475 MeV
    - Transmission > 98±1%
    - Current > 30 mA
    - Beam Power: Objective 1 kW, minimum accepted 0.7 kW
- Step 4: 1/30 Hz, 2.86 ms beam to Tuning Dump

Stage 3 : SC Linac to Target - 1st neutrons

- Beam: Probe beam.
- First production of neutrons.
- Max Energy: 571 MeV or 1.3 GeV
- Two steps
  - Step 1: A2T/Dogleg commissioning
  - Step 2: ~570 MeV (or 1.3 GeV), <5 µs, <10mA, 1/10 Hz to Target, Raster system off, ~ 3 W of power on Target

Stage 4: Low Power in Target

The objectives of this stage are to commission the beam instrumentation systems in the Target and the rastering system, as well as to set the DC optics of the A2T. All the steps will have a small power in the target, under 1 kW in all cases.

- Step 1: Probe beam (5 µs, 30 mA, 1 Hz, 570 MeV) on Target, ~ 85 W of Power on Target
- Step 2: Commissioning of Target Beam Instrumentation: using as short pulse as possible
- Step 3: Commissioning Slow Tuning (50 µs beam, 30 mA, 1 Hz), ~850 W of Power in Target
- Step 4: Commissioning of 14 Hz rep rate, using the Fast Tuning beam
- Step 6: Commissioning of Raster system (6 mA, 2.86 ms, 570 MeV, 1/10 Hz) ~ 1 kW of power on target

Stage 5: 2.86 ms beam commissionig

The objectives of this stage are to commission the 2.86 ms beam, compare its parameters to the short pulse one and to verify the stability of the beam.

- Step 1: Increasing the pulse length to 2.86 ms, 1 Hz rep rate, <10 mA current, up to 16 kW of Power in Target
- Step 2: Verify parameters of the long pulse respect the short ones (trajectory, energy)
- Step 3: Medium term (8 h to 24 h) stability studies

Stage 6: SCL Power Ramp

The objectives of this stage are to ramp the beam to the parameters required for NSS instrument commissioning and operation.

- Step 1: Optimization of the Accelerator for long pulse
  - Objectives:
    - Energy > 500 MeV
    - Transmission: 99%±1
    - Rep Rate: 1 Hz
    - Current: 30 mA
    - Pulse length: 2.86 mA
    - Power ~ 50 kW
- Step 2: Increase of the repetition rate to 14 Hz
- Step 3: Increase of the current to the nominal one
  - Set the beam for instruments commissioning and operation