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Beam Commissioning at ESS

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(ESS/AD/BPOD/BP)

Workshop on Testing and Commissioning
16-17 October, 2018

Outline

- Beam commissioning overview
  - Planning
  - Configuration
  - Note on beam physics
- Summary

What I'm doing...

- Planning phase
  - Identify required activities with beam and their dependencies.
    - Primary focus is on beam physics related activities, e.g., RF cavity setting.
    - Also including hardware verifications with beam, e.g., diagnostics verifications.
  - Define a sequence of the activities based on the dependencies and priorities.
    - **Have no authority to change the term allocated to a beam commissioning stage.** (Only provide feedbacks to the integration, testing, and commissioning planner.)
  - Help to develop (or do develop) a procedure of each activity.
  - Maintain and update the plan.
- Execution phase
  - **When the beam is available**, determine conducted activities based on the plan and other conditions, e.g., availability of subsystems and personnel.
    - Availability of the beam itself is determined by the system owners and operations.
  - Help to conduct (or do conduct) each activity.
  - Is one of the primary stakeholders to permit (the shift leader) to use a new machine configuration and beam parameter envelope.
    - In the control room, the shift leader is in charge of these.
  - Maintain and update the plan.

Beam commissioning stages and schedule

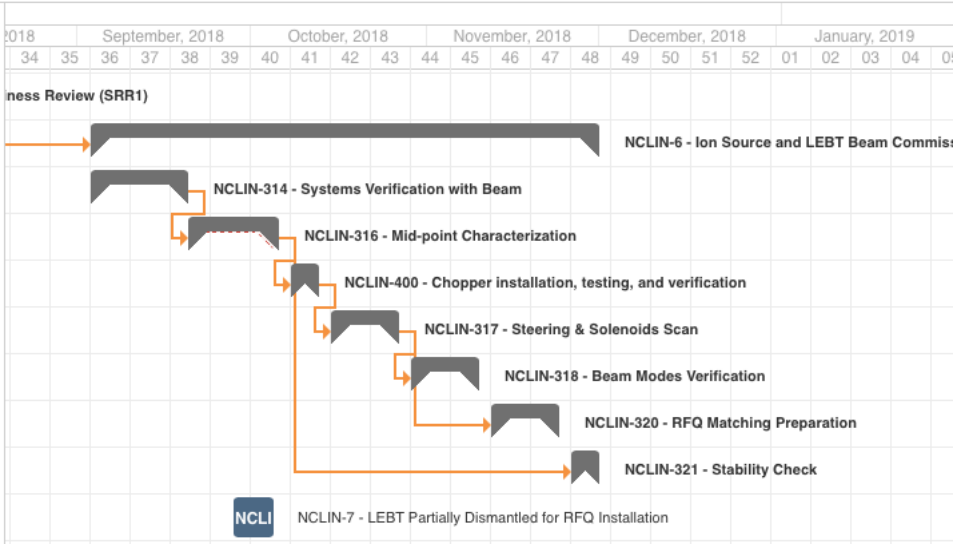
Stage	Energy [MeV]	Start date (old)	Start date (baseline)	Start date (update)	Duration [weeks]
ISrc - LEBT	0.075	2017-11-20	2018-06-28	2018-09-19	22
ISrc - DTL1	21	2018-11-05	2019-11-04	2019-11-11	14
ISrc - DTL4	74	2019-01-21	2020-04-27	2020-07-13	13
ISrc - dump (BOD)	~570	2019-05-13	2021-02-08	2021-04-26	13
ISrc - target (BOT)	~1370	2019-06-24	2022-06-08	2022-06-08	

- Focus now is on the ongoing ISrc-LEBT and the following NC linac stage.
- Schedule is driven by deliveries and installations of components. The sequence of beam commissioning activities is laid out to fit to the allocated time.
  - No contingency for unexpected interventions.
  - Every step has to be well prepared and executed as planned.
  - Possible to run out of time (e.g., before starting current ramp-up).
  - Doing better (e.g., including realistic contingency) is harder when the plan is not so stable.
- **Beyond the ISrc-LEBT stage, we use internal and permanent beam stops and diagnostics devices. This allows us to come back to a state of the preceding stages.**
  - The linac includes a thorough set of permanent diagnostics devices.

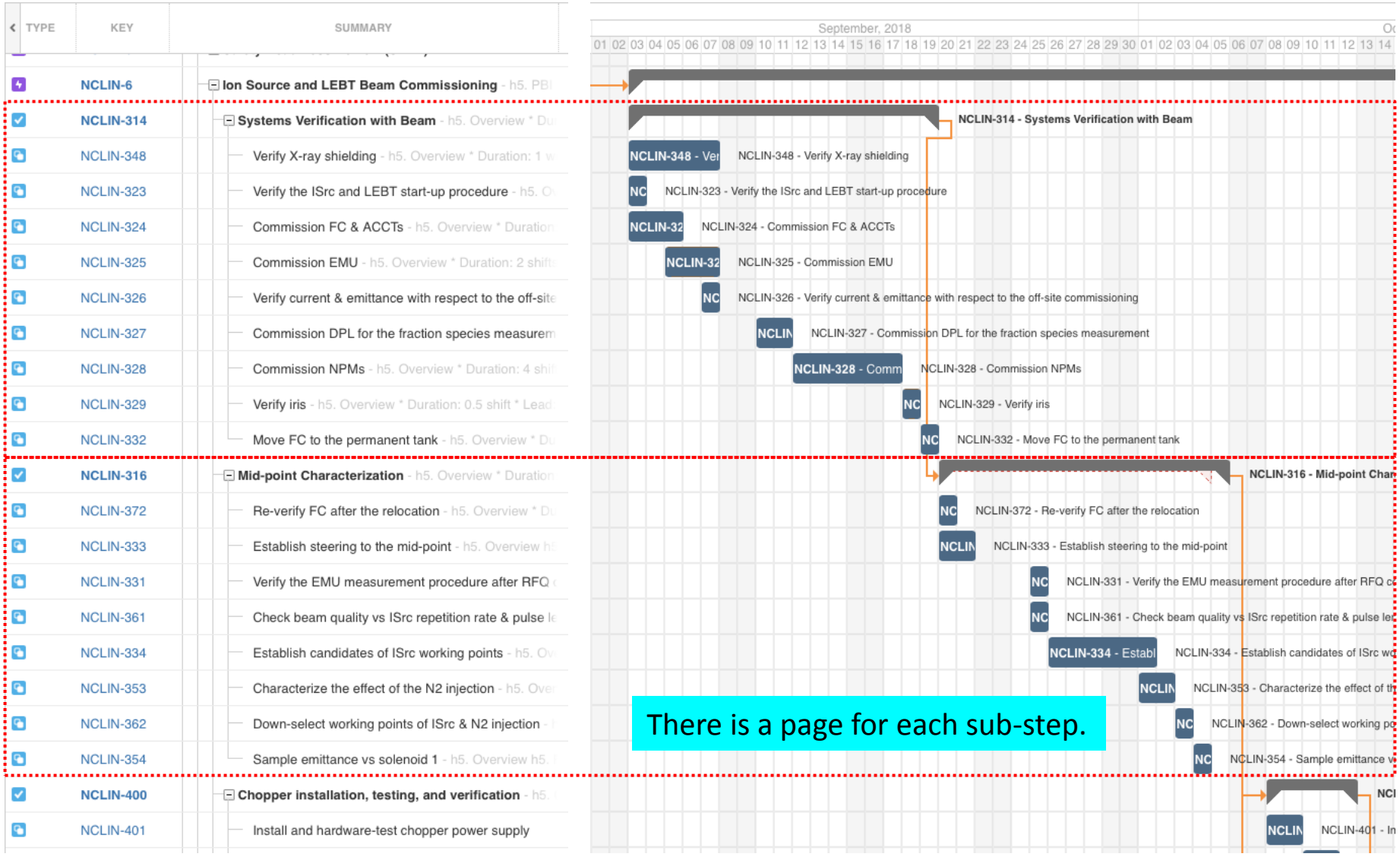
Planning example of commissioning steps: ISrc-LEBT

TYPE	KEY	SUMMARY	ASSIGNEE	STATUS	START DATE	END DATE	LABELS
	NCLIN-5	Safety Readiness Review (SRR1)	Edgar Sargsyan	IN PROGRESS	2018-Apr-17	2018-Jul-17	P6
	NCLIN-6	Ion Source and LEBT Beam Commissioning - h5. F	Ryoichi Miyamoto	TO DO	2018-Sep-03	2018-Nov-30	P6
	NCLIN-314	Systems Verification with Beam - h5. Overview *	Ryoichi Miyamoto	TO DO	2018-Sep-03	2018-Sep-19	BeamComm
	NCLIN-316	Mid-point Characterization - h5. Overview * Durat	Ryoichi Miyamoto	TO DO	2018-Sep-20	2018-Oct-05	BeamComm
	NCLIN-400	Chopper installation, testing, and verification - h	Ryoichi Miyamoto	TO DO	2018-Oct-08	2018-Oct-12	BeamComm
	NCLIN-317	Steering & Solenoids Scan - h5. Overview * Durat	Ryoichi Miyamoto	TO DO	2018-Oct-15	2018-Oct-26	BeamComm
	NCLIN-318	Beam Modes Verification - h5. Overview * Duratio	Ryoichi Miyamoto	TO DO	2018-Oct-29	2018-Nov-09	BeamComm
	NCLIN-320	RFQ Matching Preparation - h5. Overview * Durat	Ryoichi Miyamoto	TO DO	2018-Nov-12	2018-Nov-23	BeamComm
	NCLIN-321	Stability Check - h5. Overview * Duration: 1 week	Ryoichi Miyamoto	TO DO	2018-Nov-26	2018-Nov-30	BeamComm
	NCLIN-7	LEBT Partially Dismantled for RFQ Installation - Note t	Janet Schmidt	TO DO	2018-Sep-28	2018-Oct-04	P6

- High-level plan and strategy, in terms of beam physics, has been presented in internal documents (e.g., ESS-0149990 for NC linac) as well as in conferences and workshops.
- Steps and sub-steps of the ISrc-LEBT stage has been maintained and updated in Jira.
- Steps and sub-steps of the ISrc-DTL1 stage has been developed in Jira.
- How to prepare for each sub-step is up to the responsible person.

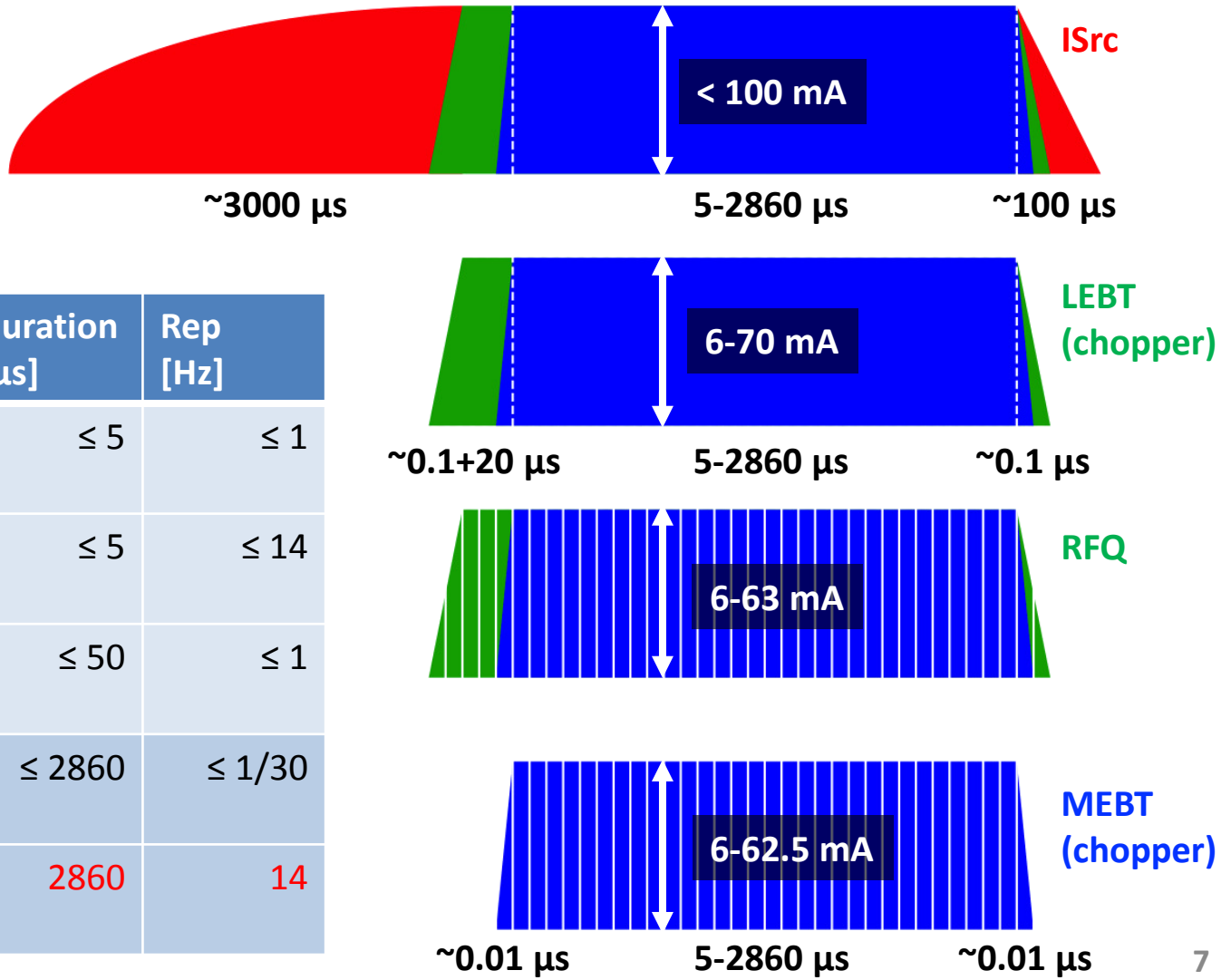


Planning example of commissioning sub-steps: ISrc-LEBT

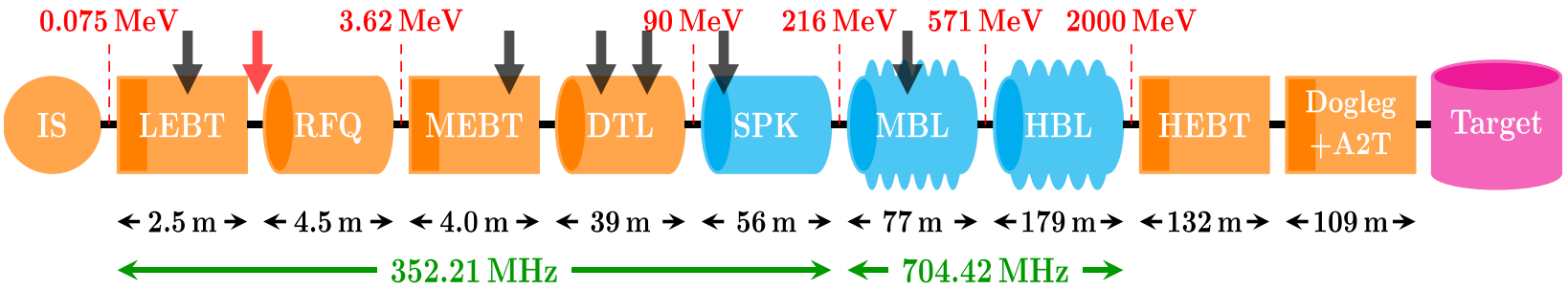


Beam modes

Mode	Current [mA]	Duration [µs]	Rep [Hz]
Probe	~6	≤ 5	≤ 1
Fast tuning	≤ 62.5	≤ 5	≤ 14
Slow tuning	≤ 62.5	≤ 50	≤ 1
Long pulse verification	≤ 62.5	≤ 2860	≤ 1/30
Production	≤ 62.5	2860	14



Beam stops



Location	Type	Availability	Tuning	Long-pulse	Production
LEBT (inside tank)	FC	Permanent*	Yes	Yes	Yes
LEBT (outside tank)	FC	**Temporary***	Yes	Yes	Yes
MEBT (inside tank)	FC	Permanent	Yes	--	--
DTL2 (intertank)	FC	Permanent	Yes	--	--
DTL4 (intertank)	FC	Permanent*	Yes	--	--
Spokes (doublet #1)	Stop	Permanent	Yes	--	--
Medium-β (doublet #6)	Stop	Permanent	Yes	--	--
Dump line	Dump	Permanent	Yes	**Yes**	--
Target	Target	Permanent	Yes	Yes	Yes

Full list of diagnostics devices (From the lattice synoptic viewer)

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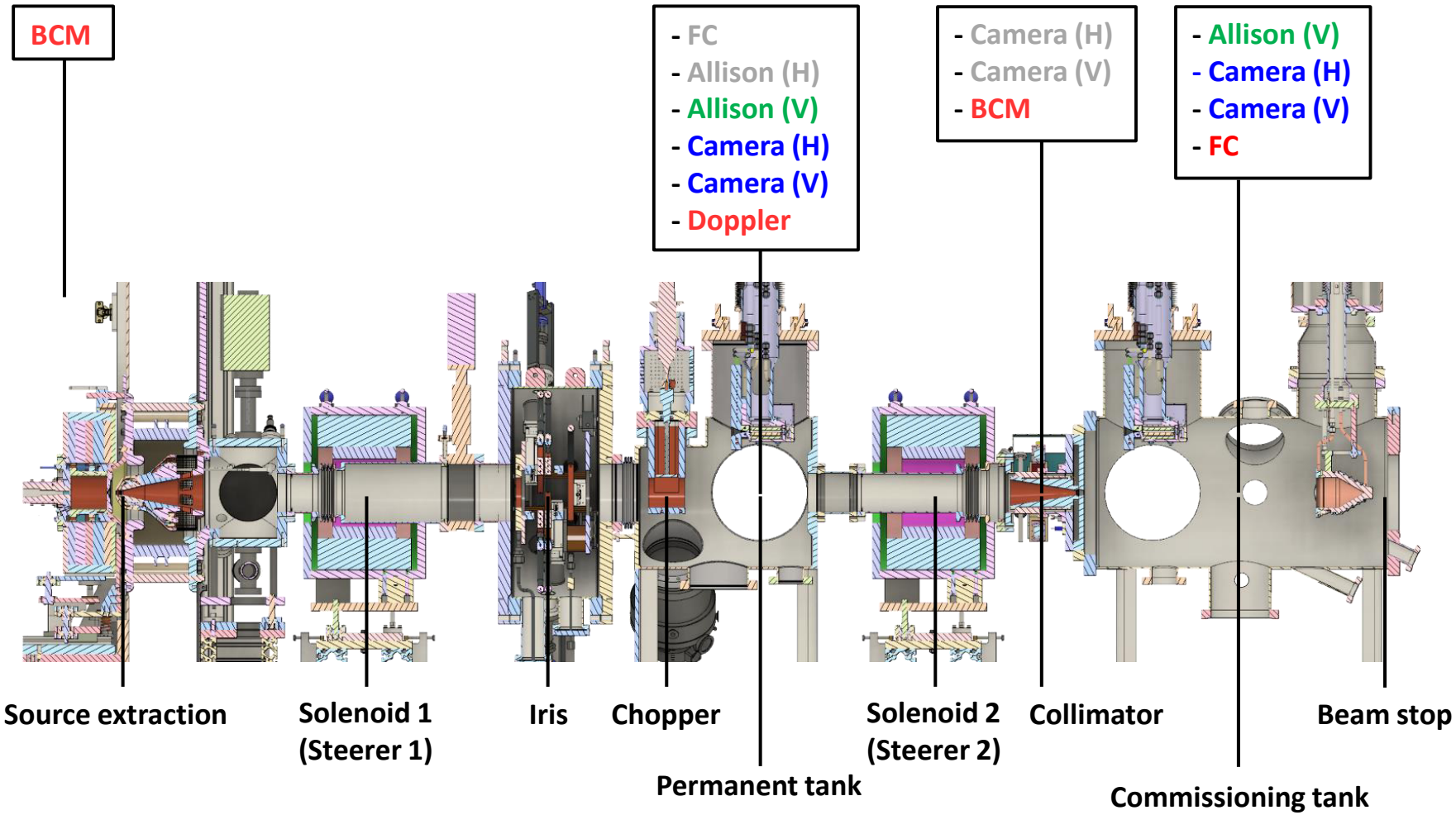
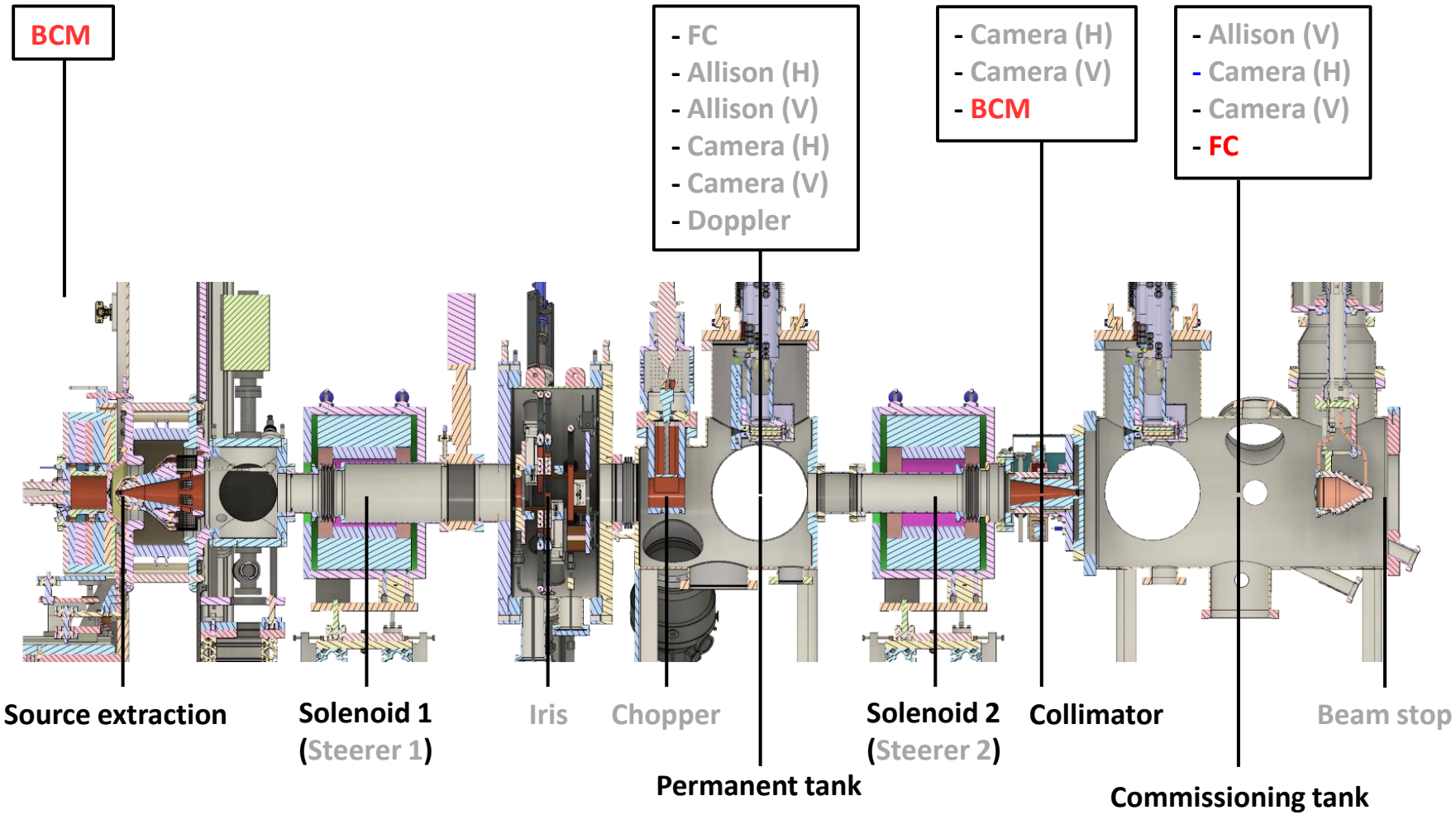
	ISrc	LEBT	RFQ	MEBT	DTL	SPK	MBL	HBL	HEBT	A2T	DmpL	Total
FC		1		1	2							4
IBS						1	1					2
BCM	1	1	1	2	5		1	1	2	3	2	19
FBCM				1								1
FBPM				1								1
Dpl		1										1
BPM				7	15	14	9	21	16	12	4	98
BIF		2		2						1		5
IPM						1	3	1				5
EMU		1		1								2
LBM				1		1	1					3
WS				3		3	3	1	3	1		14
AptM										3	1	4
Img										2	1	3
nBLM				4	42	26	2	2	2	4		82
icBLM					5	52	36	84	49	34	6	266

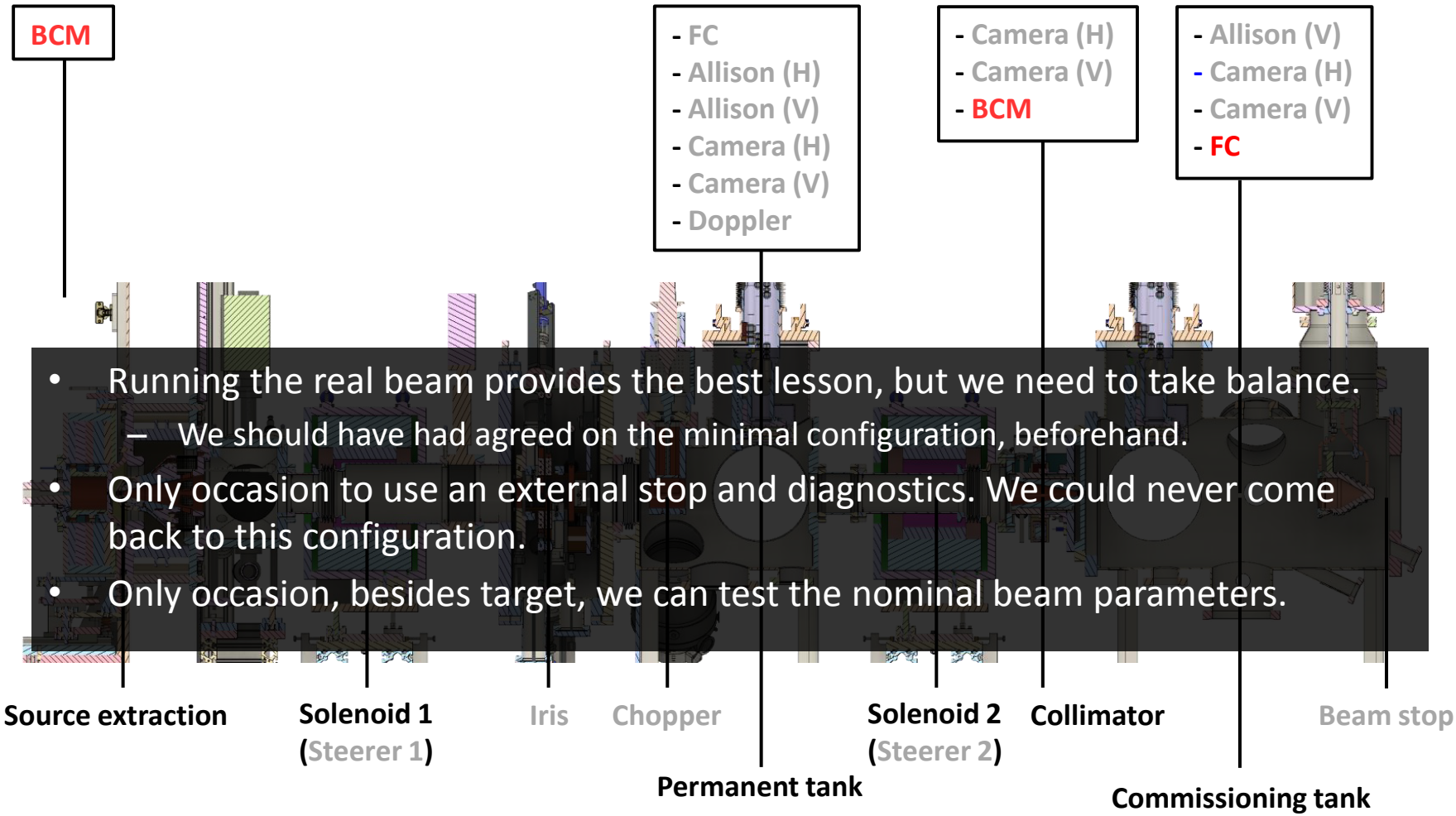
ISrc- LEBT commissioning configuration (Plan)



ISrc- LEBT commissioning configuration (How we started on 2018-09-19)



ISrc- LEBT commissioning configuration (How we started on 2018-09-19)



- Running the real beam provides the best lesson, but we need to take balance.
  - We should have had agreed on the minimal configuration, beforehand.
- Only occasion to use an external stop and diagnostics. We could never come back to this configuration.
- Only occasion, besides target, we can test the nominal beam parameters.

NC linac commissioning configuration (updated)

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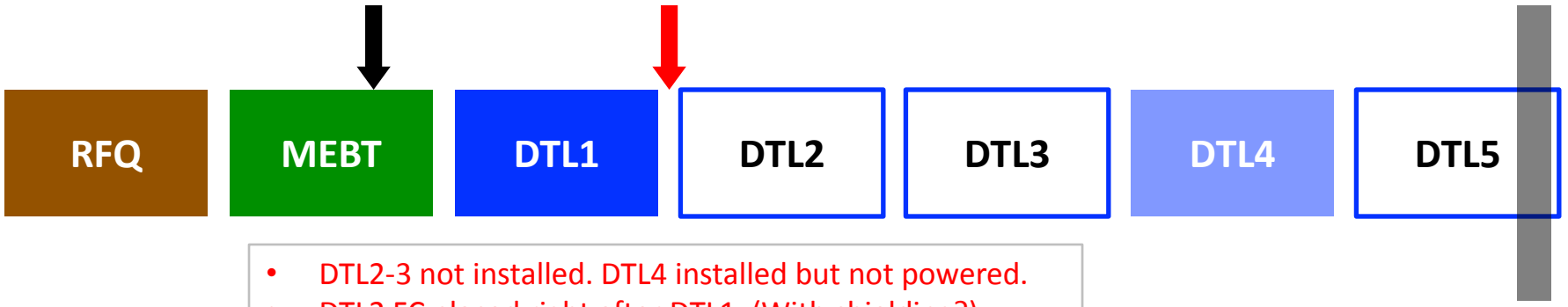
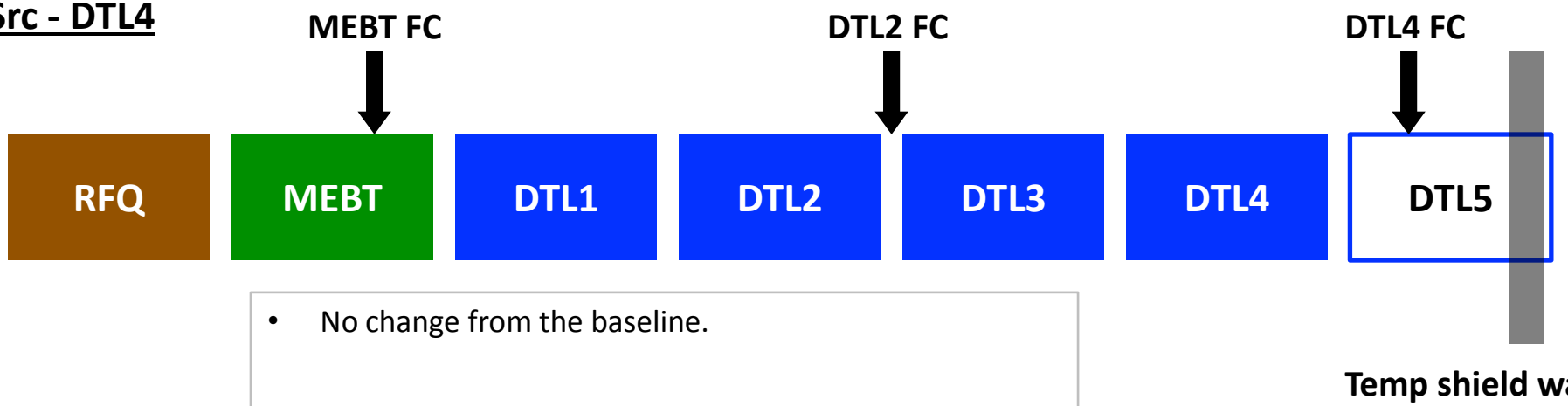
ISrc - MEBT, DTL1



- DTL2-3 not installed. DTL4 installed but not powered.
- DTL2 FC placed right after DTL1. (With shielding?)
- Temporary shield wall at DTL5.

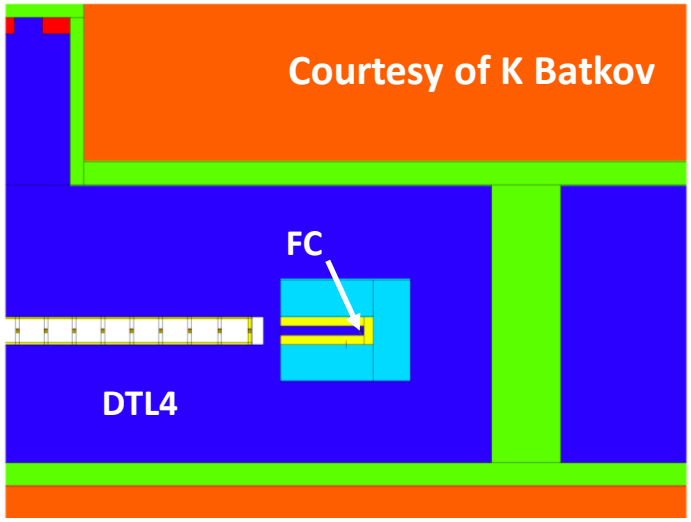
ISrc - DTL4



- No change from the baseline.

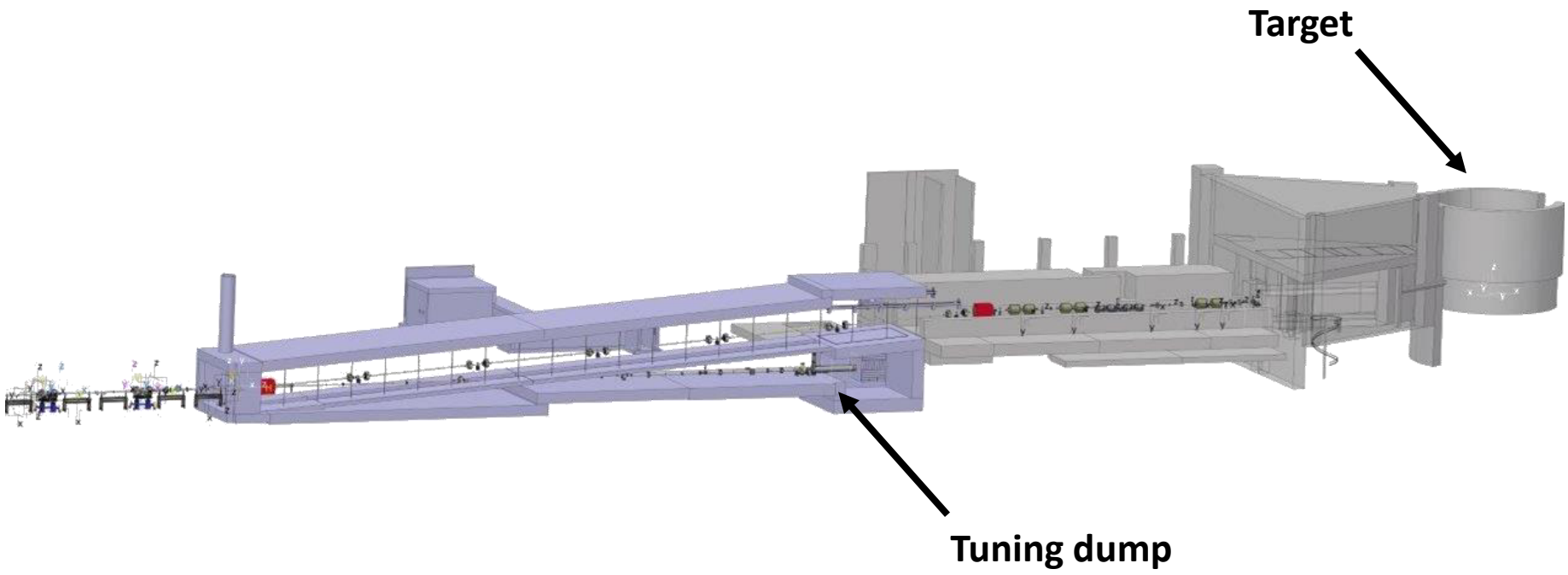
Limits during the NC linac commissioning (ESS-0118232 under revision)

- **This configuration (FC shielding + wall) allows the NC linac beam and SC linac installation in parallel.**
- Prompt dose limit:
  - 3 µSv/h (supervised area)
  - Averaged over 1 hour
- Limits in dose and FC itself are comparable. If either is missing, the beam very limited.



FC	Energy [MeV]	Ave curr lim [µA]	Probe lim [min/hour]	Slow-tuning lim [min/hour]	Fast-tuning lim [min/hour]
DTL4	22	8.8	--	--	--
	40	3.0	--	57	41
	57	1.4	--	26	19
	74	1.2	--	23	16
DTL2	22	8.8E-3	17	0.1	0.1
	40	3.0E-3	6	0.0	0.0

No special configuration after the NC linac commissioning



- The beam is stopped with internal beam stops, tuning dump, or target.
  - The tuning dump could bear with the 2.86 ms pulse but only at 1/30 Hz (12.5 kW).
- Only available number of cryomodules change over time.

Simple and or standard tuning

Standard linac/beamline tuning, requiring a dedicated application:

- Linear optics verification
  - Polarity check
  - Beam based alignment
  - Trajectory correction
- RF phase and amplitude setting
- Transverse matching with 3+ profile measurements

- Online beam physics application and diagnostics devices are keys to efficient beam commissioning.
- Further details on tuning were presented in the past conference, workshops, and reviews.

For beam transports and RFQ, many adjustments are done with a simple parameter(s) scan:

- LEBT
  - Iris verification
  - Chopper verification
- RFQ
  - Amplitude scan
  - Matching with LEBT solenoids scan
- MEBT
  - Chopper verification
  - Collimator positioning
- A2T (including dogleg)
  - Achromatic condition verification
  - Cross-over point verification
  - Raster verification

Could-be-challenging tuning
(Excluding operational challenges such as protection)

- ISrc optimization
  - Unlike H- machines, we need to balance the current and beam quality.
- Optics tuning of the non-periodic MEBT
- Twiss and emittance reconstruction with a quad or cavity scan
  - Space charge and beam loss require extra care.
- Matching at the frequency jump
  - Frequency jump at the SPK-MBL interface is the weakest point of our linac and requires a smooth matching. But, there is no nearly direct longitudinal measurement.
- Beam loss mitigation
  - We don't have the obvious beam loss cause of H- stripping.

Summary (and questions)

- Status of planning beam commissioning activities and their sequence:
  - For the ISrc-LEBT stage, the developed plan is being executed and also updated to adopt to situation.
  - For the NC linac stage, plan is being detailed.
  - For the SC linac stage (starting in ~2.5 years), due to a resource limitation, we only have very high-level plan (and studies).
  - **Is there a rule of thumb for contingency of the beam commissioning?**
  - **How detail we plan for each activity.**
    - Controlled document vs piece of code.
- The schedules of the stages beyond the ISrc-LEBT are aggressive but using internal and permanent beam stops and diagnostics allow to come back and repeat the process in any given point, later.
  - On the contrary, the ISrc-LEBT stage is unique.
  - **Comments/suggestions on this strategy?**

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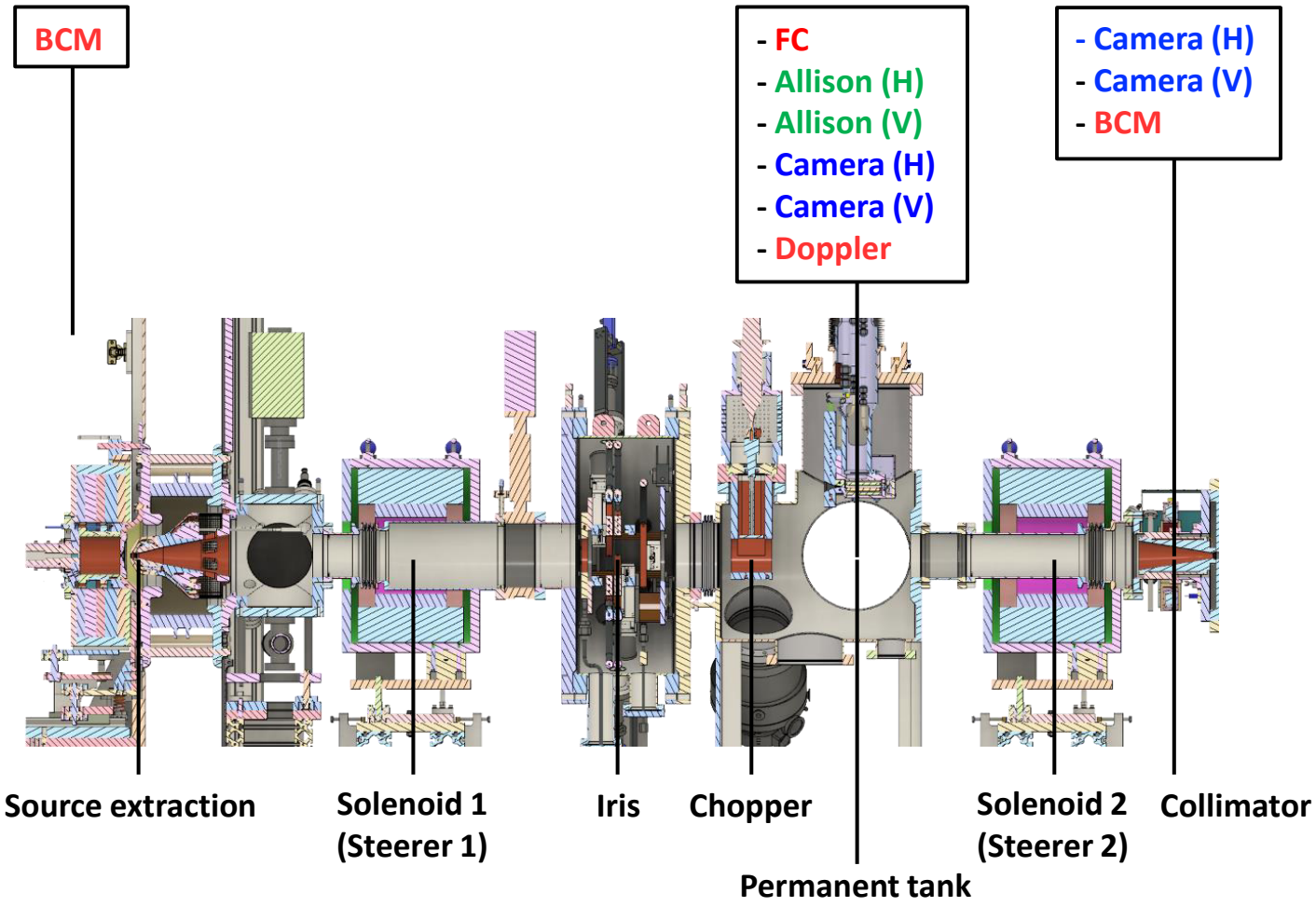
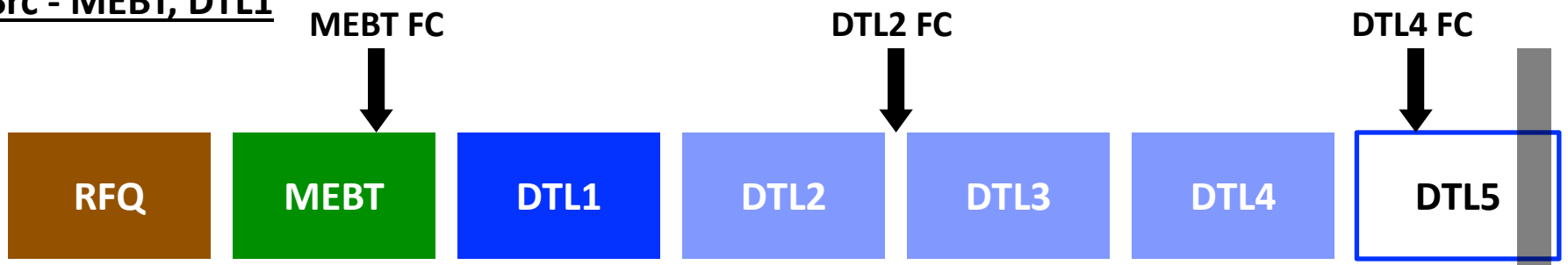
Backup

ISrc- LEBT operations configuration



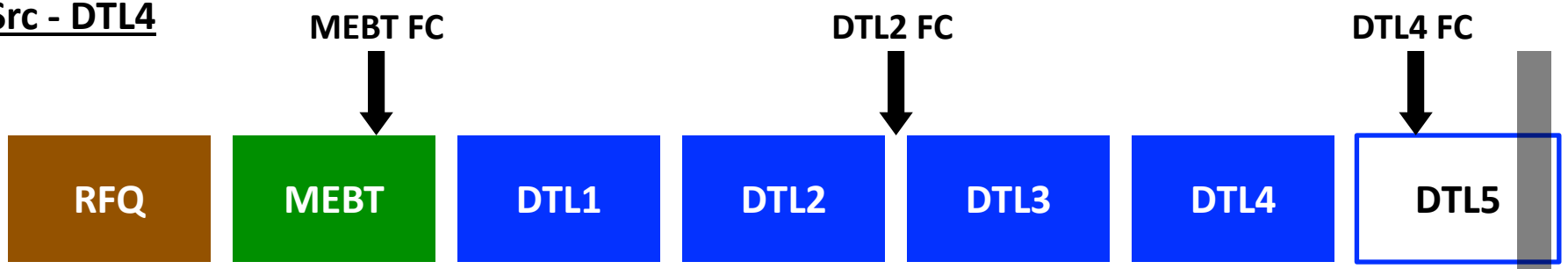
NC linac commissioning configuration (baseline)

ISrc - MEBT, DTL1



- DTL1-4 installed but only DTL1 powered.
- MEBT and DTL2 FCs at their nominal locations.
- Temporary shield wall + DTL4 FC with shielding at DTL5.

ISrc - DTL4



- DTL1-4 powered.
- MEBT and DTL2 FCs at their nominal locations.
- Temporary shield wall + DTL4 FC with shielding at DTL5.