ESS Linac Plans for Commissioning and Initial Operations

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HB2016 WG-D

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Opening remarks (1)

- Welcome to Malmö and Sweden!

- The beam commissioning of the ESS linac is planned to start in ~1.5 year from now.
- The linac design has been "stable" and now it's time for the beam physicists to ramp-up the preparation activities for the commissioning.
- A lot of efforts for the commissioning planning have been already made...
  - Last year had a task force to review the diagnostics devices, focusing on the need during the commissioning.
  - The commissioning steps for the initial stage (the normal conducting part) have been established, taking into account the radiation permit.
  - Planning for the control software
  - ...

Opening remarks (2)

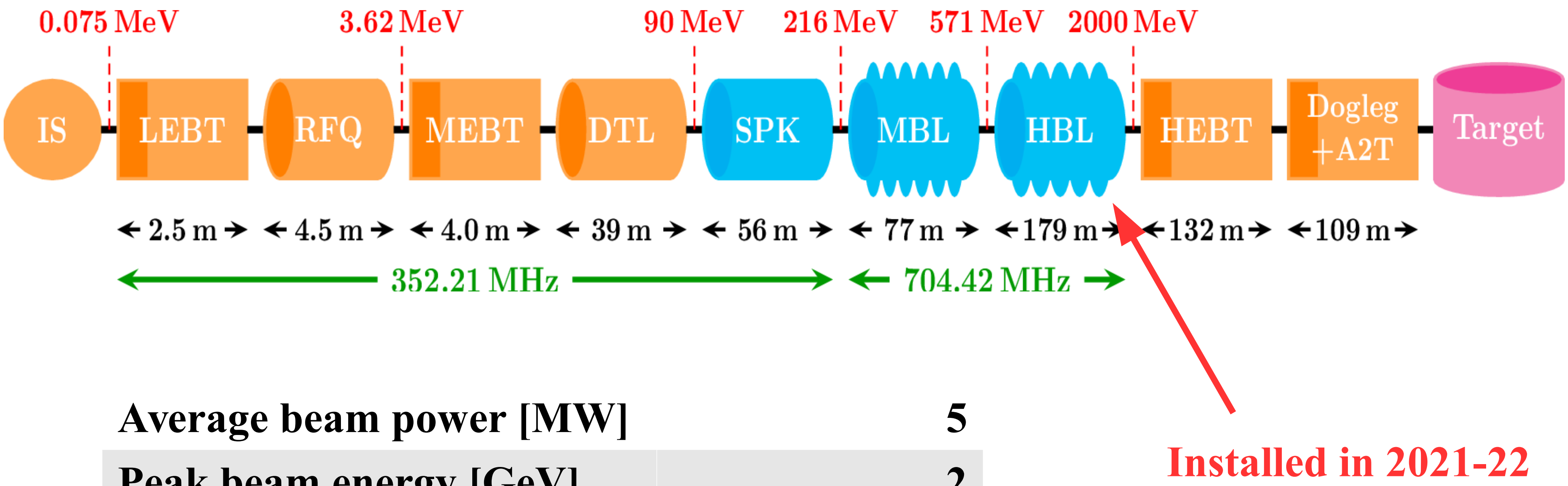
- We know which beam parameters we'd like to adjust and which components must be adjusted to achieve that. And, we think that we had necessary diagnostics devices are at the right places and are in the plan.
- But, since "**the devil lives in details**", we'd like to hear all the bad stories and experiences of the other facilities to prepare ourselves. That's why we proposed this working group.
- We are using this opportunity to think about the process of the beam commissioning from the 1st section to the last one-by-one, from the point of view of the lattice tuning.
- Comments, suggestions, criticisms are all welcome!

Outline

- Opening remarks
- Overview of the ESS linac and its commissioning
- Commissioning (types of tuning) for each section
  (Some examples of beam physics studies)
- Closing remarks

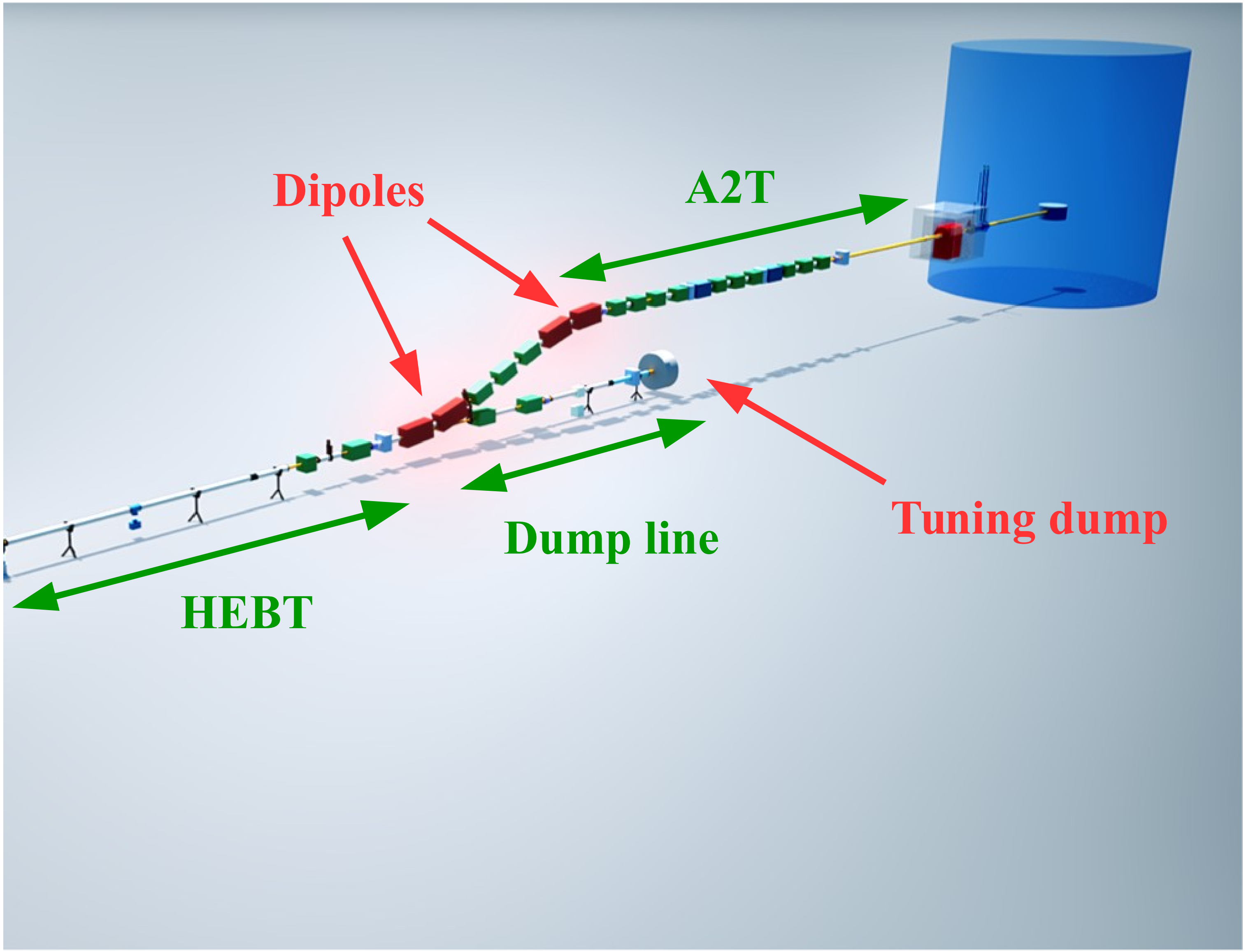
ESS Linac and Its Commissioning Overview

ESS linac overview



Average beam power [MW]	5
Peak beam energy [GeV]	2
Peak beam current [mA]	62.5
Pulse length [ms]	2.86
Repetition rate [Hz]	14
Duty cycle [%]	4
RF frequency [MHz]	352.21/704.42

Linac layout near the target

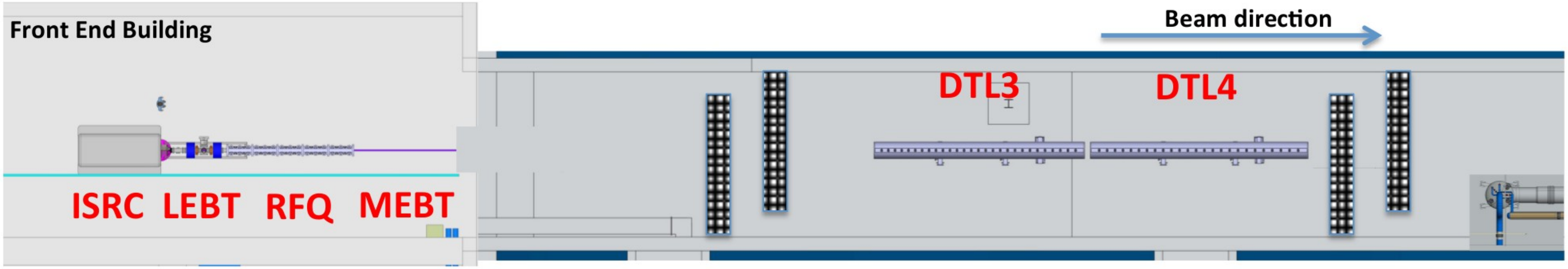


ESS linac selected milestones

~2017-Q4	**IS+LEBT delivered and commissioning started**
~2018-Q4	**IS ~ DTL tank 1 commissioned** **(In 2 steps: first IS ~ MEBT then IS ~ tank 1)**
~2019-Q1	**IS ~ DTL tank 4 commissioned**
~2019-Q2	**All components installed (except high-β cavities)**
~2019-Q4	**IS ~ target commissioned**
~2020	**1.4 MW beam power**
~2021-Q3	**~1/2 of high-β cavities installed**
~2021-Q4	**1370 MeV beam energy**
~2022-Q3	**All high-β cavities installed**
~2022-Q4	**2000 MeV beam energy**
~2025	**5 MW beam power**

- This presentation focuses on the initial part of the commissioning and operation.
- Note dates are not completely finalized yet.

Note on the 1st stage of commissioning

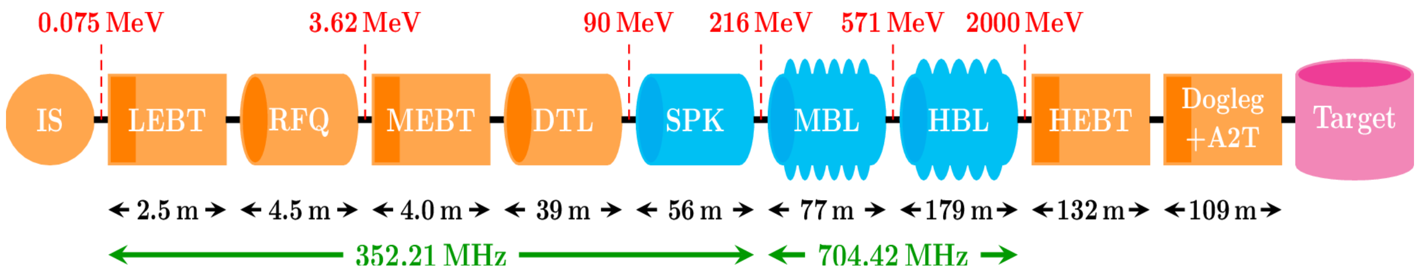


- To allow installation and beam commissioning in parallel, temporary shields will be used at this stage of commissioning.
- The beam commissioning will be done in 4 steps:
  - IS+LEBT
  - IS+LEBT+RFQ+MEBT
  - IS+LEBT+RFQ+MEBT+DTL1
  - IS+LEBT+RFQ+MEBT+DTL1+DTL2-4.
- Pulse length and repetition rate will be limited to (no limit in current)
  - To LEBT: (3 ms, 1 Hz)
  - To DTL1: (50 us, 1 Hz)
  - To DTL2-4: (5 us, 1 Hz)

Beam modes

Type	Current [mA]	Pulse length [us]	Rep rate [Hz]	Ave power (2 GeV) [kW]	Main usages
Probe	~6 - 62.5	≤ 5	≤ 1	≤ 0.6	- Initial check - Beam threading
Fast tuning	~6 - 62.5	≤ 5	≤ 14	≤ 9	- Cavity RF setting
Slow tuning	~6 - 62.5	≤ 50	≤ 1	≤ 6	- Invasive measurement - Matching - LLRF setting
Long pulse verification	~6 - 62.5	≤ 2860	≤ 1/30	≤ 12	- Beam loss check - Lorentz detuning check
Shielding verification	?	?	?	≤ 30	- Shielding verification
Production	? - 62.5	2860	≤ 14	≤ 5000	- Neutron production

Beam stops



Location	Mode	Limits
LEBT (exit)	Temporary	(3 ms, 1 Hz)
MEBT (exit)	Temporary	(50 us, 1 Hz)
DTL (tank 1 exit)	Temporary	(50 us, 1 Hz)
DTL (tank 4 exit)	Temporary	(5 us, 1 Hz)
LEBT (between the solenoids)	Permanent	N/A
MEBT (before the final quadruplet)	Permanent	(5 us, 14 Hz), (50 us, 1 Hz)
DTL (tank 2 exit)	Permanent	(5 us, 14 Hz), (50 us, 1 Hz)
DTL (tank 4 exit)	Permanent	(5 us, 14 Hz), (50 us, 1 Hz)
Spokes (doublet #1)	Permanent	(5 us, 14 Hz), (50 us, 1 Hz)
Spokes (doublet #6)	Permanent	(5 us, 14 Hz), (50 us, 1 Hz)
Medium-β (doublet #6)	Permanent	(5 us, 14 Hz), (50 us, 1 Hz)
Dump line	Permanent	(5 us, 14 Hz), (50 us, 1 Hz), 12 kW
Target	Permanent	N/A

Commissioning (Types of Tuning) for Each Section

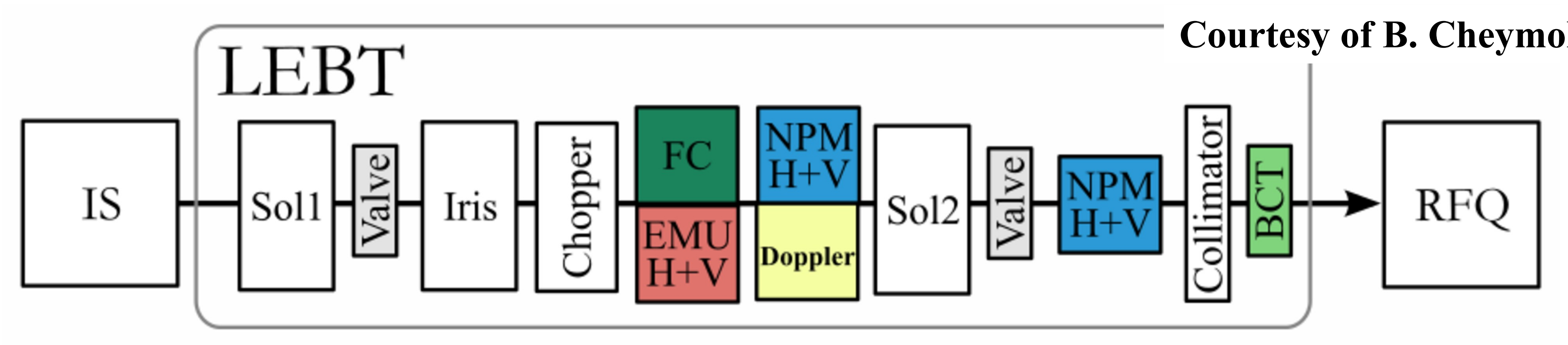
Super-simplistic template for beam commissioning

- Adjust the centroids.
  - Using the minimum current (~6 mA) **probe** or **fast-tuning** beam.
  - Thread the beam to the designated beam stop.
  - Set cavity phase and amplitude one-by-one.
- Verify/adjust the RMS parameters. (**Situation depends on a section.**)
  - Using the **slow-tuning** beam.
  - Check RMS sizes, Twiss, and emittances of 3 planes.
  - Transverse or and longitudinal matching, if needed.
  - Adjust beam sizes at selected locations, if needed. (Only for MEBT and A2T)
- Ramp-up the current, pulse length, and repetition rate.
  - Check the transmission and losses with the **slow-tuning** or **long-pulse-verification** beam.
  - Iterations may be needed for the previous steps if there is an issue.
  - **The full 2.86 ms pulse-length required when commissioning the neutron instrument.**
- Check long term stability.

Each step requires more careful planning

- We have to prepare more detailed plan and procedure for all the steps, taking into account the application, control system, interlock, and etc. Some steps also require detailed beam physics study.
- More detailed procedure of **beam threading** as an example.
  - Make sure to use the minimum current **probe beam**.
  - Make sure all the cavities are off (and detuned if needed).
  - Set the quads to the design strengths (for the given energy).
  - Check the polarities of BPMs and steerers by looking at difference trajectories. (**Also check the quad polarities at this stage?**)
  - Correct the trajectory. (One-to-one method should work for the BPM and steerer layout adopted in the ESS linac.)

IS+LEBT

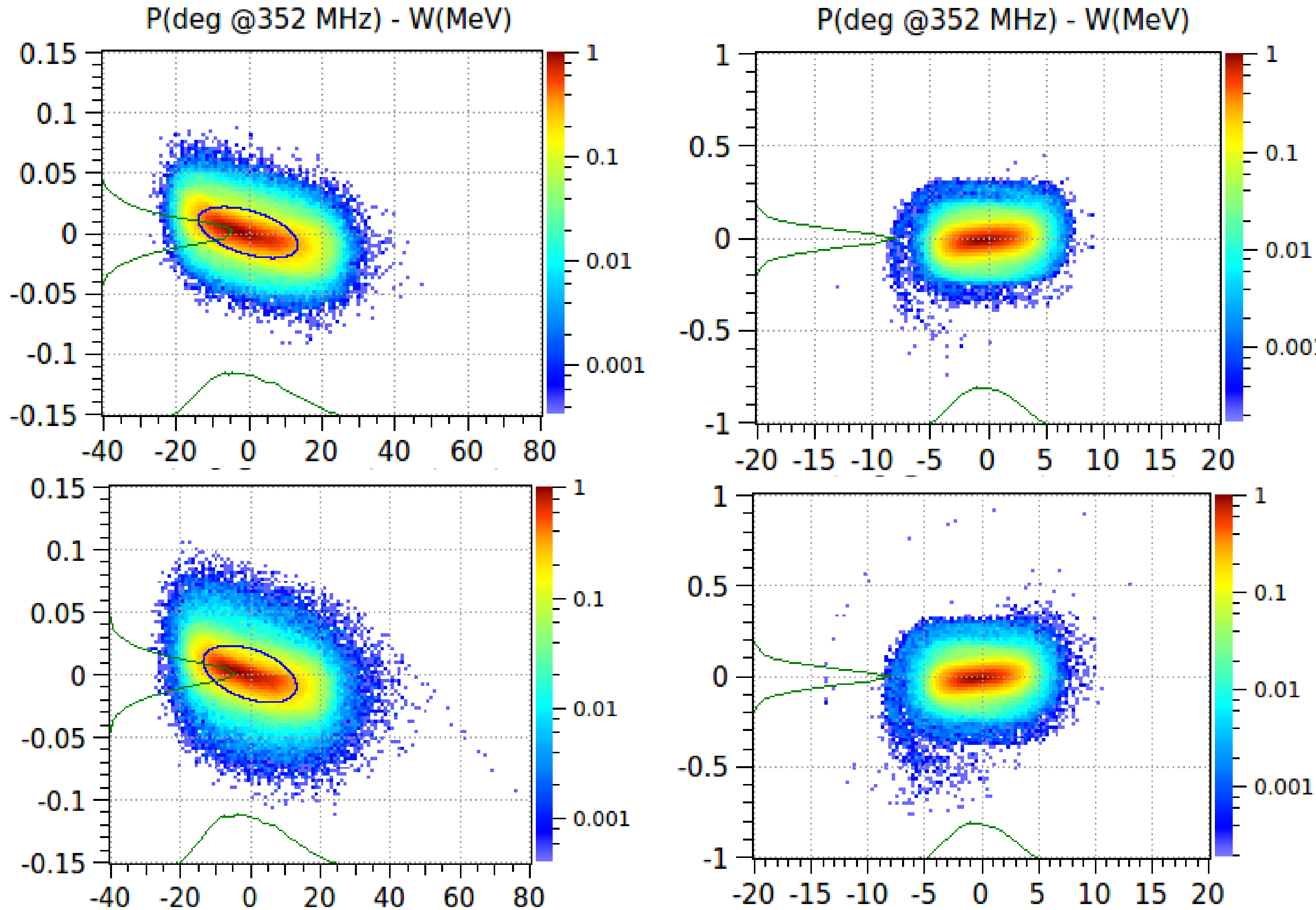


- Unbunched beam.
- 2 solenoids to focus the beam (each with windings of dipole correctors)
- The space-charge compensation anticipated ~95%. The level can be adjusted by gas injection.
- IS takes ~3 ms to get stabilized. ~6 ms out of the IS and the initial ~3 ms "chopped" to produce a 2.86 ms pulse. ~20 us "left over" removed by the MEBT chopper.
- The current adjusted with the iris (hexagonal cross section).
- Proton fraction ~75% or more.

Space-charge compensation 95% vs 90%

95% RFQ exit

90% RFQ exit

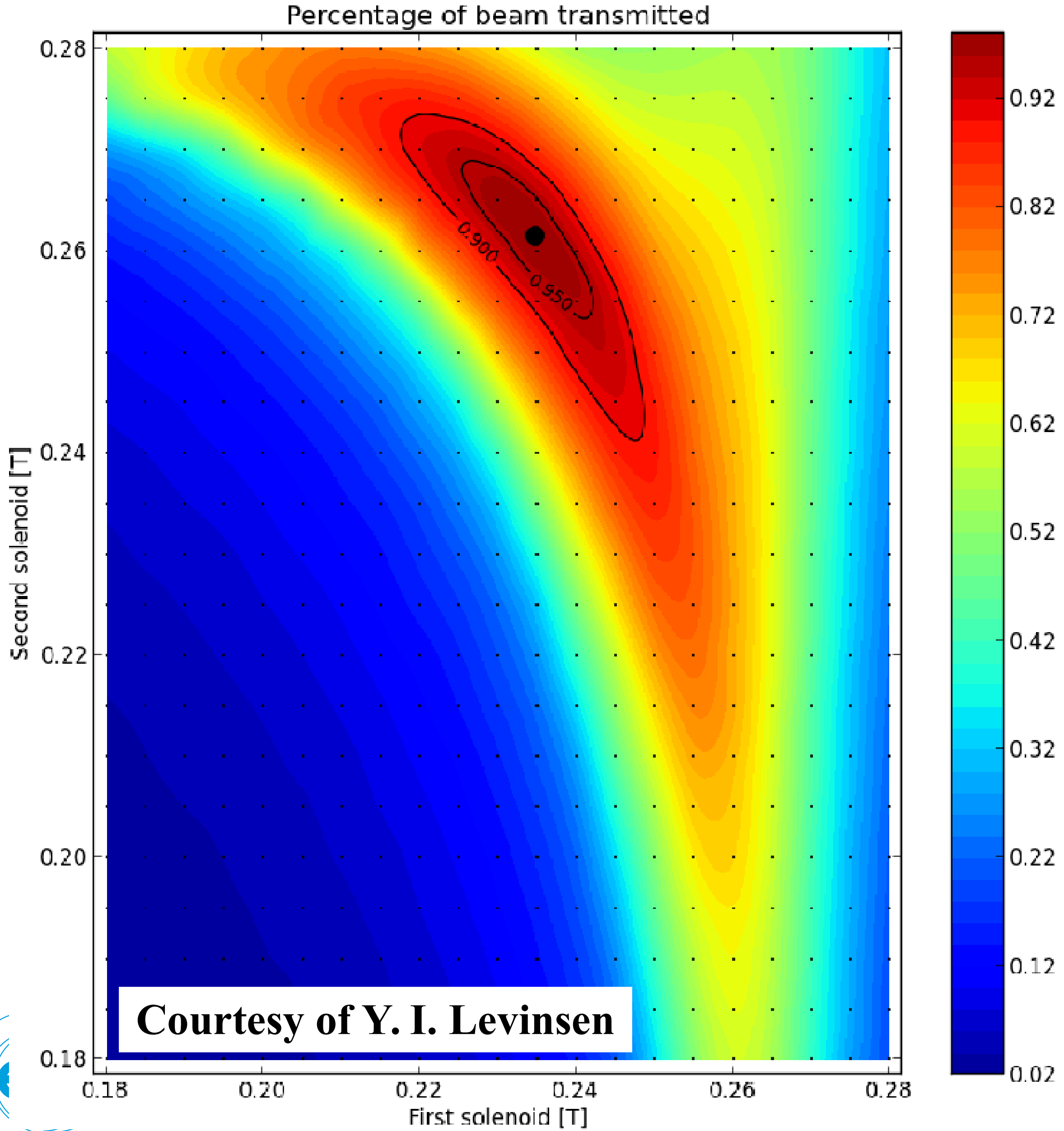


95%DTL exit

90%DTL exit

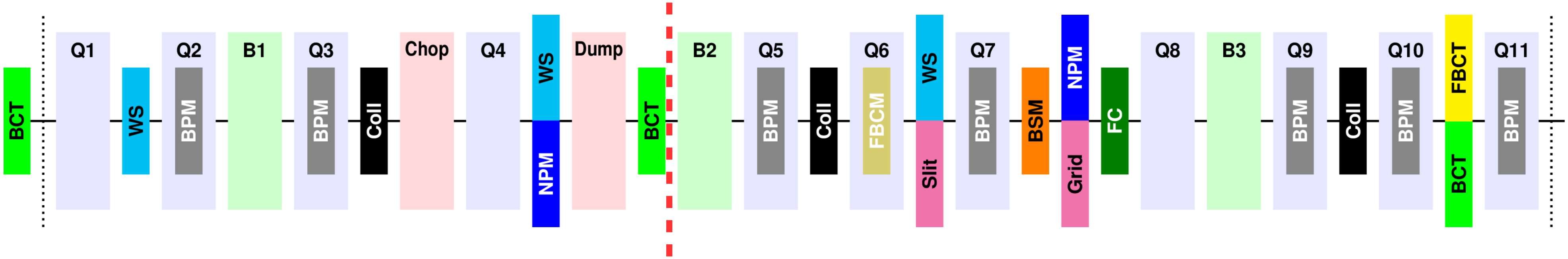
- Space-charge compensation has a large impact on the distribution downstream.
- When the level is lowered to 90%,
  - transmission at the RFQ exit lower by ~9%.
  - emittnances at the RFQ exit larger by ~4% for *x* and *y* and ~8% for *z*.
  - 0.01 - 0.1 W level losses within DTL with no error.

LEBT solenoids can



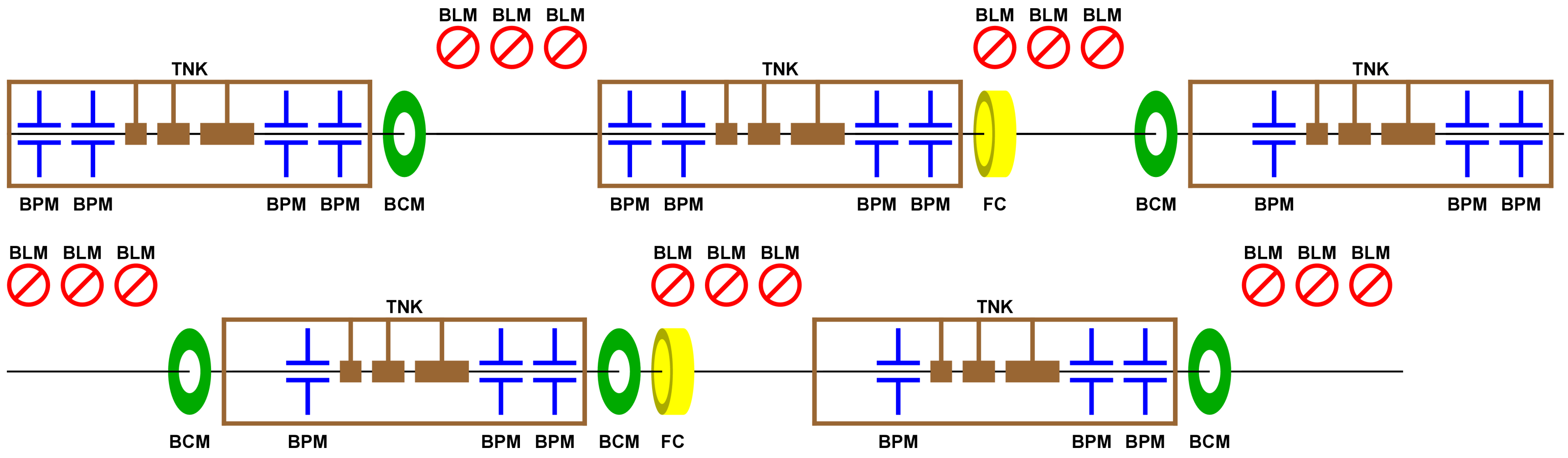
- Strengths of 2 LEBT solenoids are scanned and the transmission out of the RFQ is measured.
- When limiting the current with the iris, iterations may be needed to find the optimal settings.

RFQ+MEBT



- RFQ
  - The only degree of freedom is the field amplitude.
  - The transmission checked with the BCTs at the interfaces of the LEBT-RFQ and RFQ-MEBT and one in the middle of the MEBT.
- MEBT
  - Consisting of 3 buncher cavities, 11 quads, chopper, and chopper dump.
  - The initial part is for the chopping and the rest is for the matching to DTL.
  - Housing diagnostics devices to characterize the bunched beam (providing initial conditions for the simulation of the following part).
    - 3 WSs and one slit+grid emittance measurement unit should give enough info to adjust the transverse optics. (Nonlinear part of the space-charge not negligible.)
    - Only one longitudinal profile monitor (BSM) so “buncher scan” is needed to extract the emittance and longitudinal Twiss parameters.
  - Three collimators to remove the transverse halo.

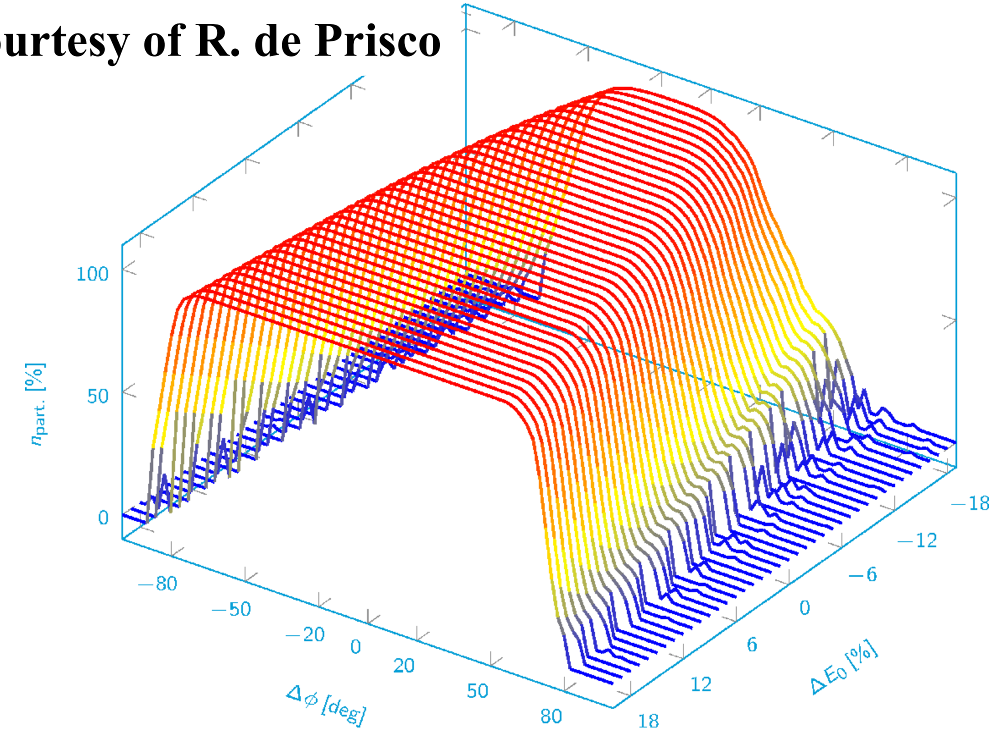
DTL

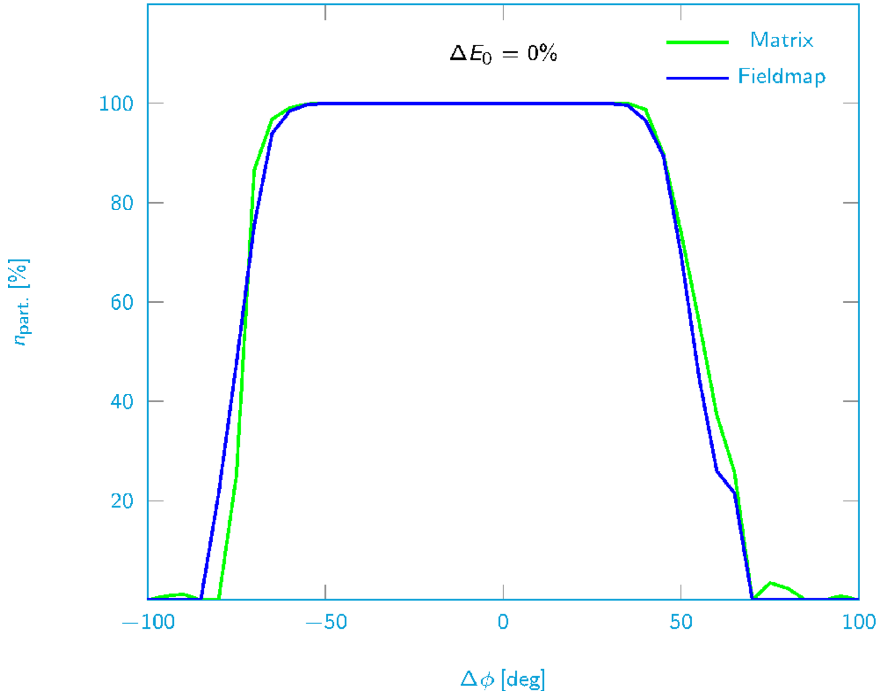


- 5 tanks.
- Every other drift tube houses a permanent quadrupole, forming a FODO lattice.
- BPMs and dipole correctors are in the drift tubes without the permanent quadruopole.
- The only degrees of freedom are the phase and amplitude of the field in each tank and dipole correctors.

DTL tank 1 phase scan

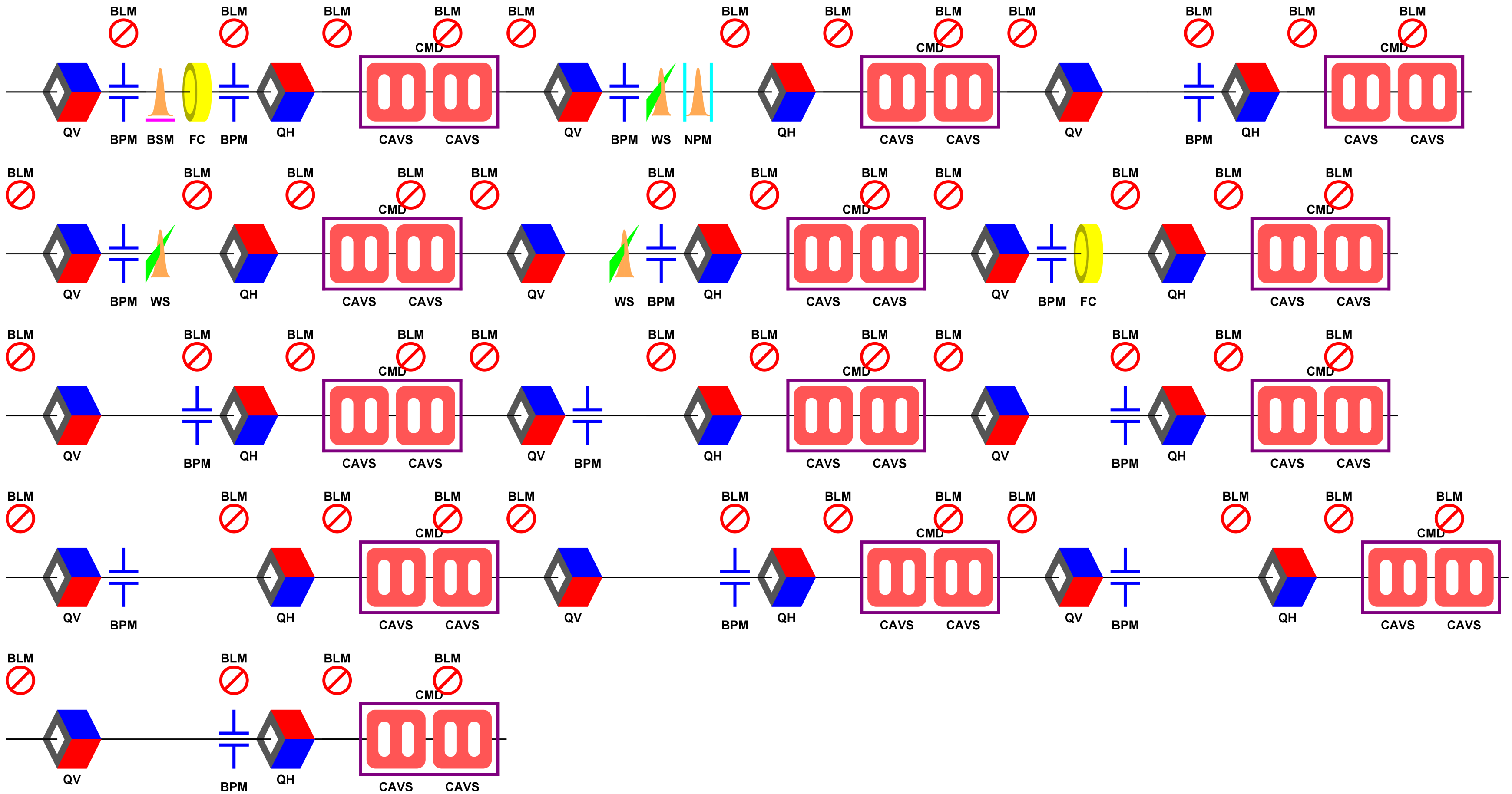
Courtesy of R. de Prisco





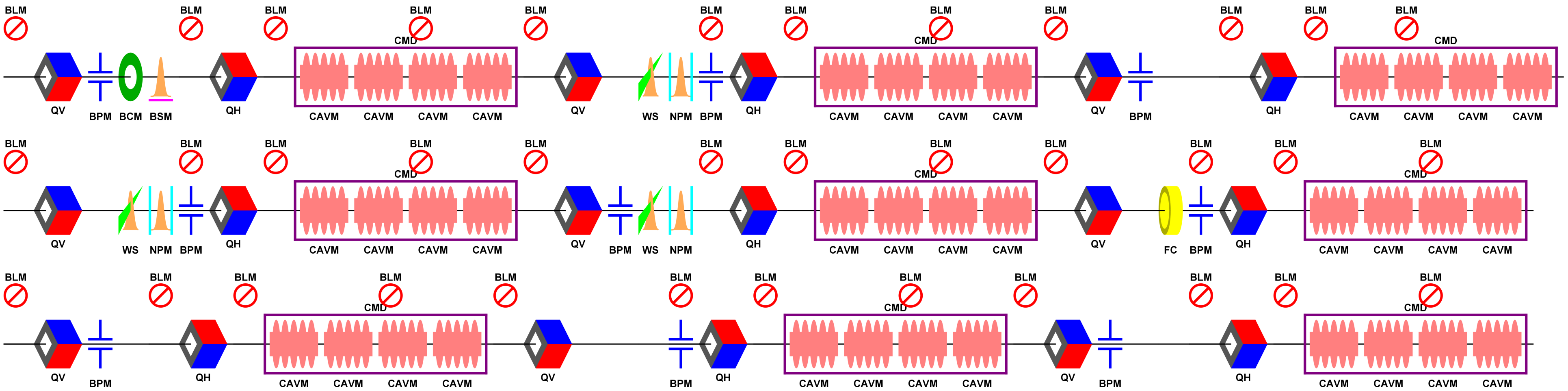
- The phase scan with the time-of-flight measurements is the significant of the DTL commissioning. (But, can't be done with just the tank 1.)
- For the DTL tank 1, transmission scanned over a wide-range of phase provides the initial guess of the right phase.
- Dynamics (transmission, signature curves, …) was compared in detail between the matrix model and field map and the difference was small around the ideal phase.

SCL (1): SPK



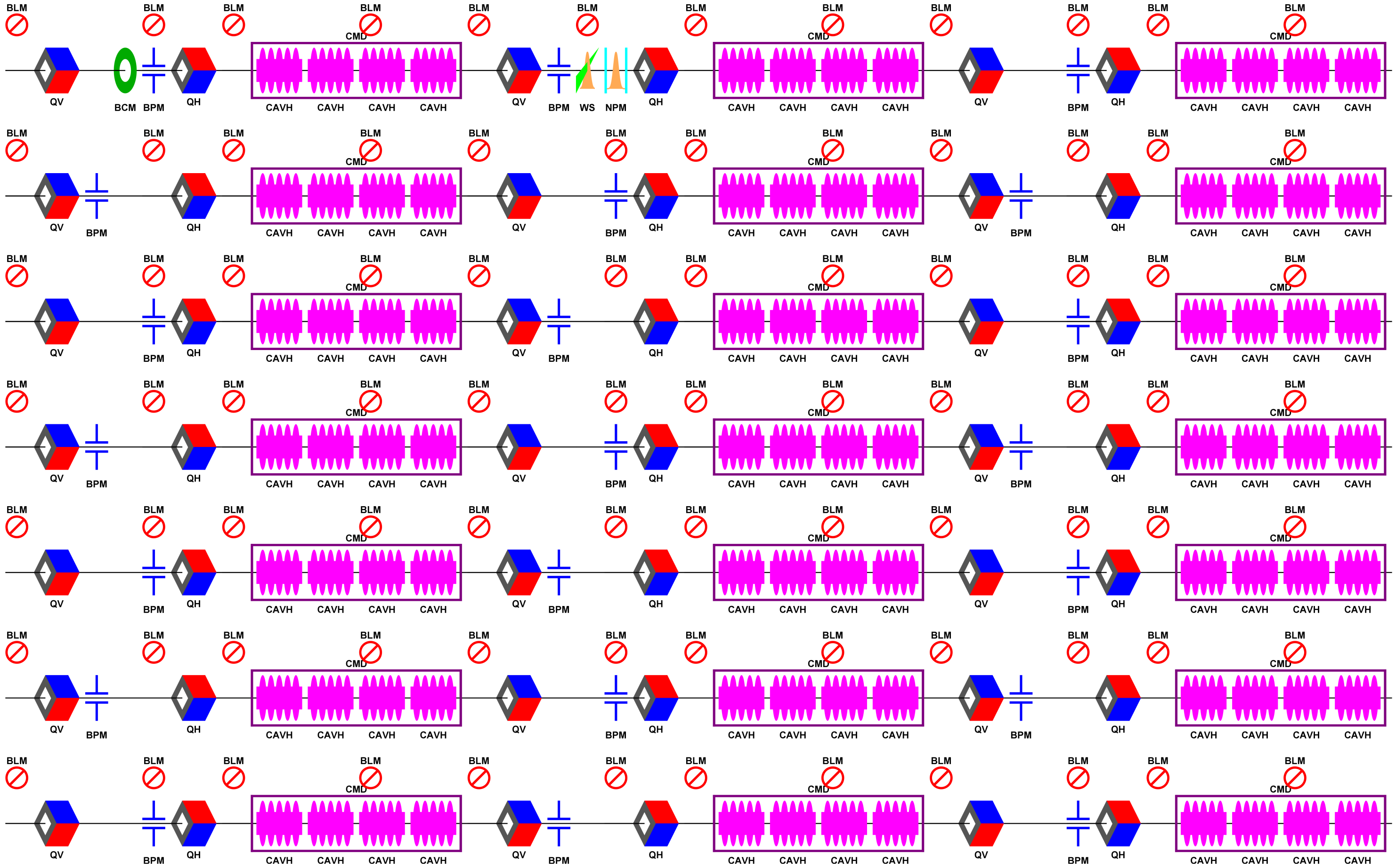
- The sections of the SCL have a structure of (LWU+cryomodule).
- 13 periods.
- 3 WSs and one BSM in the initial part for the matching.

SCL (2): MBL



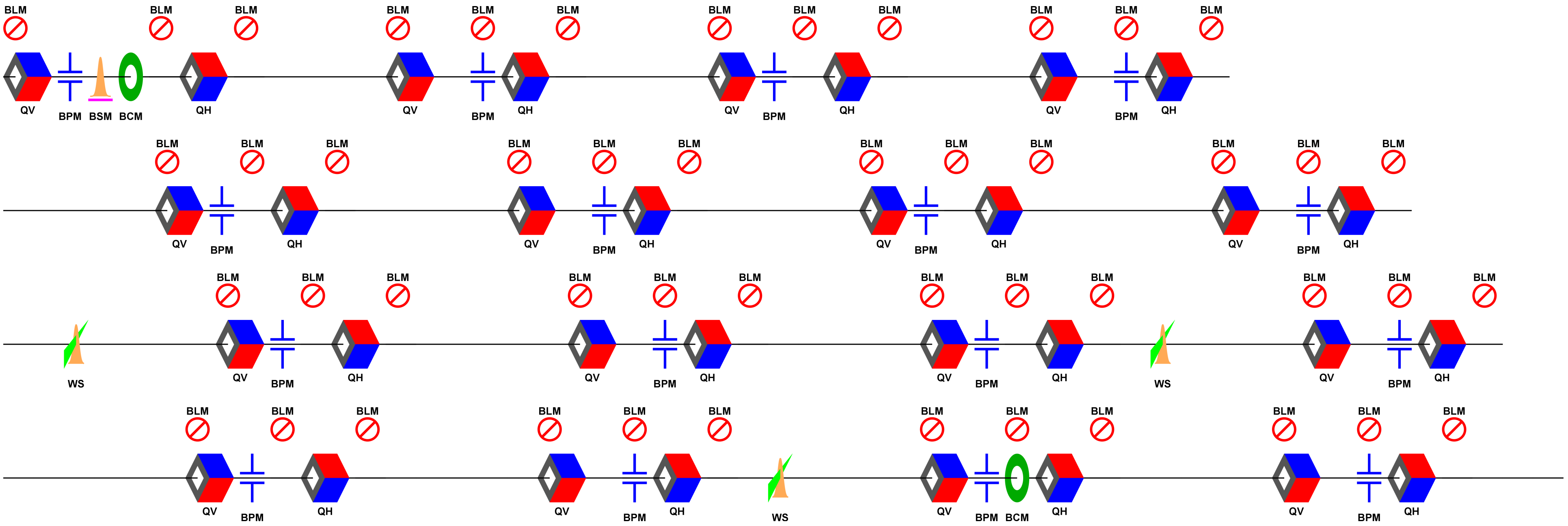
- 9 periods in MBL.
- As SPK, 3 WSs and one BSM in the initial part. (The energy may be too high at this location for BSM.)
- Longitudinal matching at the SPK-MBL may be crucial because of the frequency jump.

SCL (3): HBL



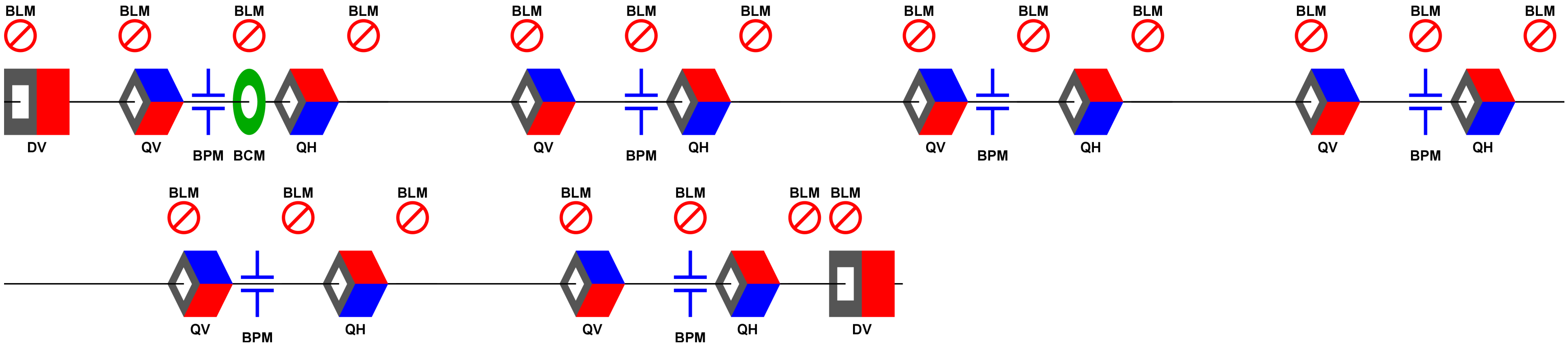
- 21 periods.
- No change in the lattice period and thus only one WS as a placeholder.
- Also note we commission HBL in 2021.

HEBT



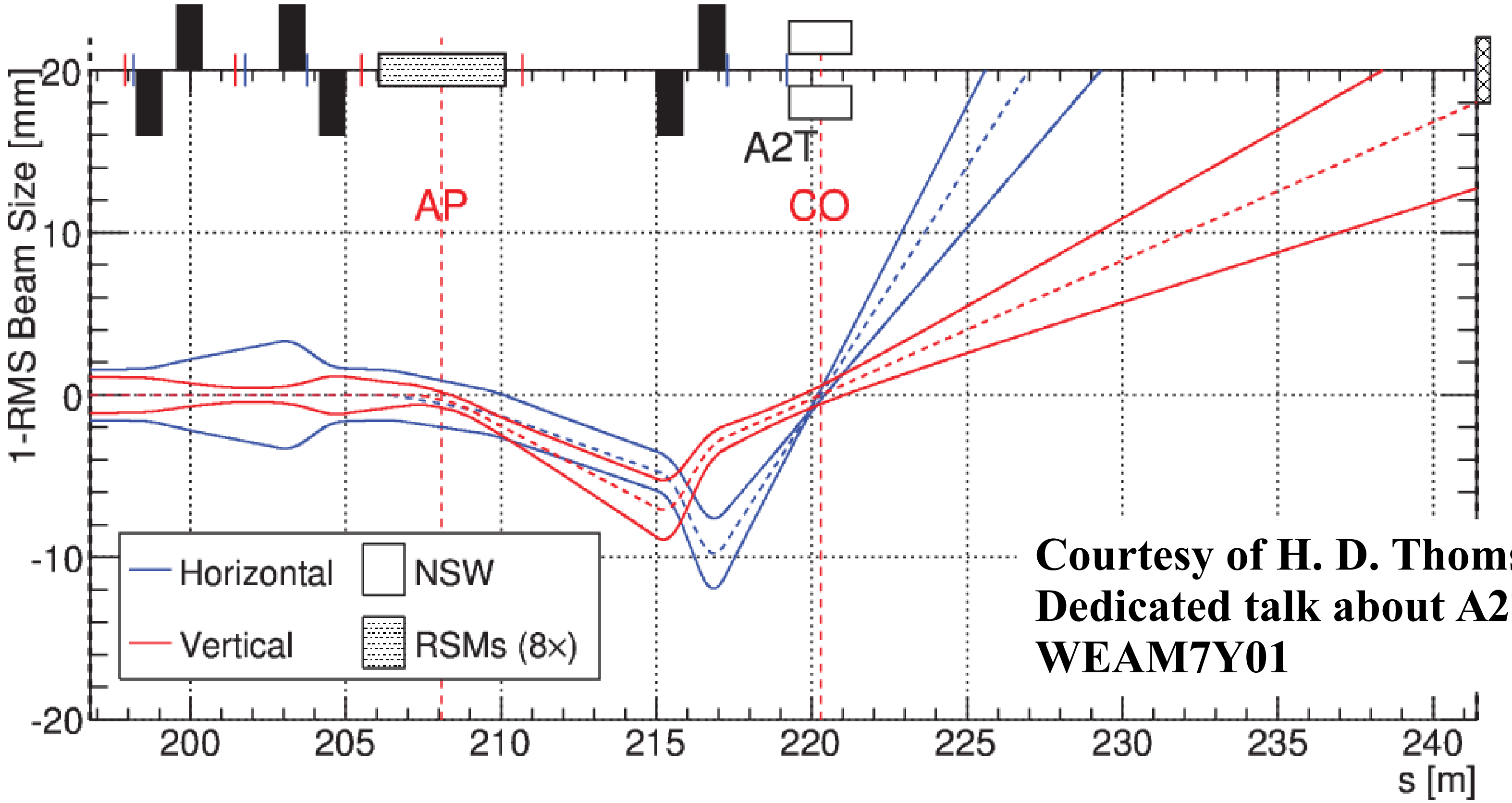
- The identical period length as HBL, allowing to add additional cryomodules for contingencies and or upgrade.
- 16 periods.
- 3 WSs to match the beam for the A2T, where the beam is manipulated for the target.

Dogleg



- Achromatic dogleg with 6 periods with ~60 deg phase advance per period.
- The first BPM in A2T is used to check the chromatic condition of the dogleg.

A2T



Courtesy of H. D. Thomsen
Dedicated talk about A2T on Wed WEAM7Y01

- The beam is painted with the raster system (4 fast oscillating dipole magnets per plane) on a rectangular region on the target surface to meet the requirements of 56 uA/cm^2 and 99% contained within 160 x 60 cm^2.
- The last two quads to make 180 deg phase advance between AP and CO.
- The first four quads to adjust the beam sizes at CO (the location of the neutron shield wall) and on the target.

Closing Remarks

Closing remarks

- Summary
  - Preparations of the ESS linac are ongoing for the beam commissioning planned to start in late 2017.
  - This presentation gave an overview of the beam commissioning, focusing on the types of beam tuning performed during the initial stage of the commissioning.
- Open questions
  - Linac4 like test bench has been discussed but not in the plan. Is it absolute necessary?
  - The beam seems sensitive to the level of the space-charge compensation. How well, we can adjust the level.
  - What can we do if have a loss issues besides fine-tuning the "centroids" and "RMS parameters".
  - Missing something?

Back-up slides

Platform of applications

- OpenXAL
  - Open source java-based platform for accelerator physics applications, originated from XAL developed for SNS.
  - World-wide collaboration including CSNS, ESS, FRIB, GANIL, SNS, TRIUMF.
  - Existing applications for general purposes and beam physics, allowing to save time to prepare necessary applications. (No development yet for the ESS linac tuning?)
  - Virtual accelerator with a virtual EPICS layer allows realistic tests of applications during the development phase.
  - ESS developed an extension to allow to write native python scripts, which was successfully tested at SNS.
- Online model
  - Online model allows to test change of settings, e.g., changes in quads and cavities, prior to application to the real machine.
  - A new model optimized for the ESS linac, ESS Linac Simulator, has been developed, benchmarked against TraceWin, as well as tested in SNS.