EUROPEAN SPALLATION SOURCE

How to stop beam operation? Actuation Systems

Benjamin Cheymol

On behalf of ESS Normal Conducting linac team

ESS INFN-LNS ESS-Bilbao

www.europeanspallationsource.se

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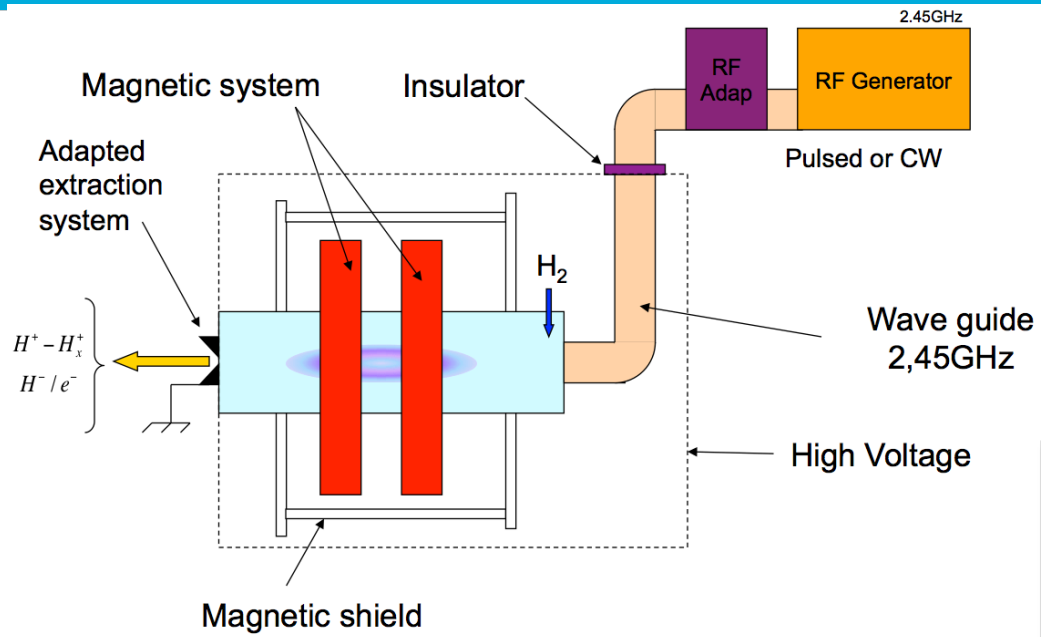
Outline

- How to generate beam ? Ion source principle
- Beam chopper : need for beam chopper in normal operation
- Beam chopper: LEBT chopper
- Beam chopper: MEBT chopper

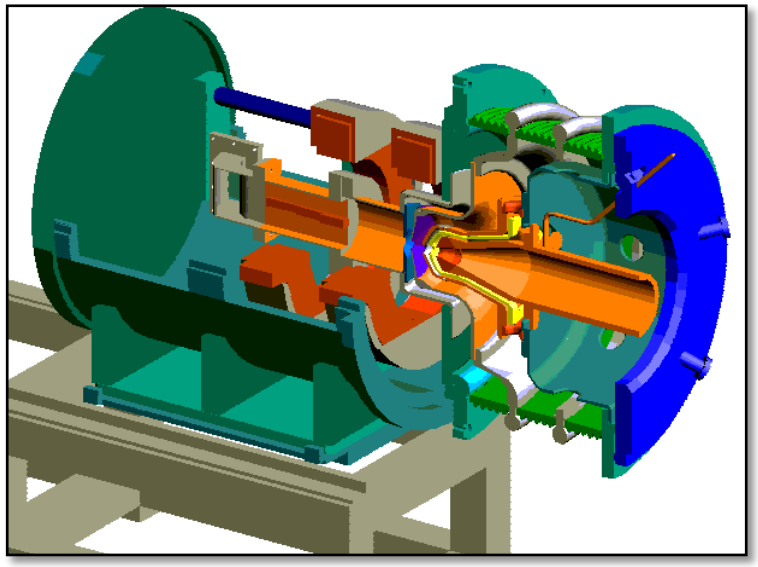
- How to stop the beam? Mitigation devices for MPS

Interfaces with Machine Protection System are not described in this presentation

How to generate beam ? Ion source principle



ECR ion source principle (courtesy of O. Tuske CEA)

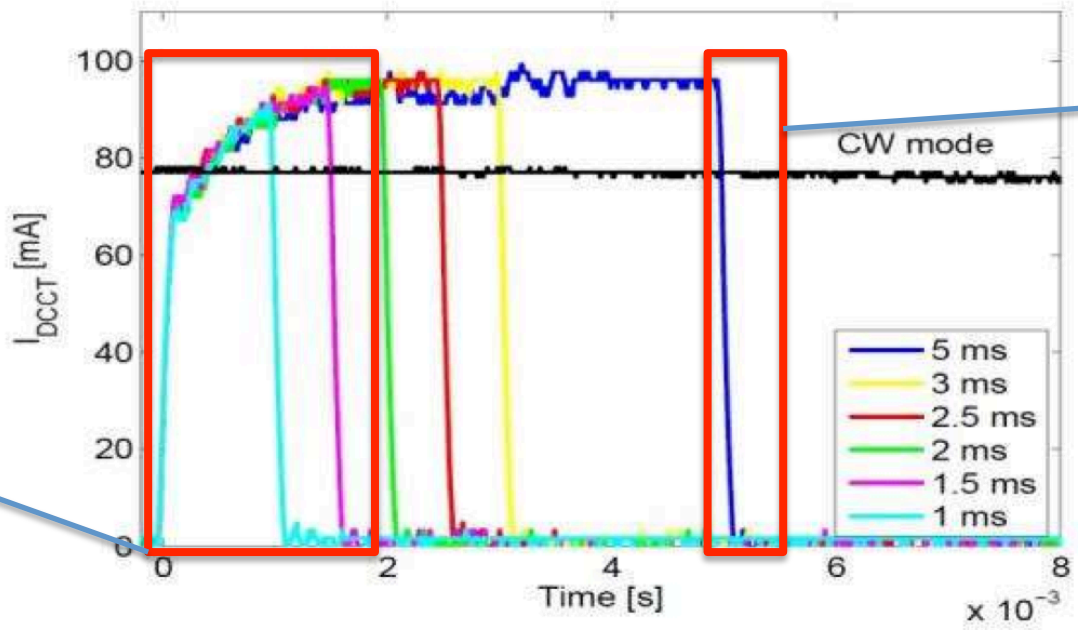


CEA SILHI ion source, 100 KeV, 100 mA CW

- ESS beam will be generated by an ECR ion source
- 75 kV extraction
- RF generator is a pulsed magnetron

Need for a chopper(s)

- At the target, the beam shall have these parameters:
  - 2.86 ms pulse length
  - 62.5 mA beam current
  - 14 Hz repetition rate
- But at the exit on the ion source the pulse shape is:



Fall time of the plasma up to 100 µs

Rise time of the plasma up to 3 ms

Beam current extracted at SILHI in pulsed mode (Courtesy of R. Gobin CEA)

Need for chopper(s)

- During rise time and fall time:
  - Beam parameters are not nominal, twiss parameters are not matched
  - Beam losses at high energy might occur if this part of the beam is transported/ accelerated to the target

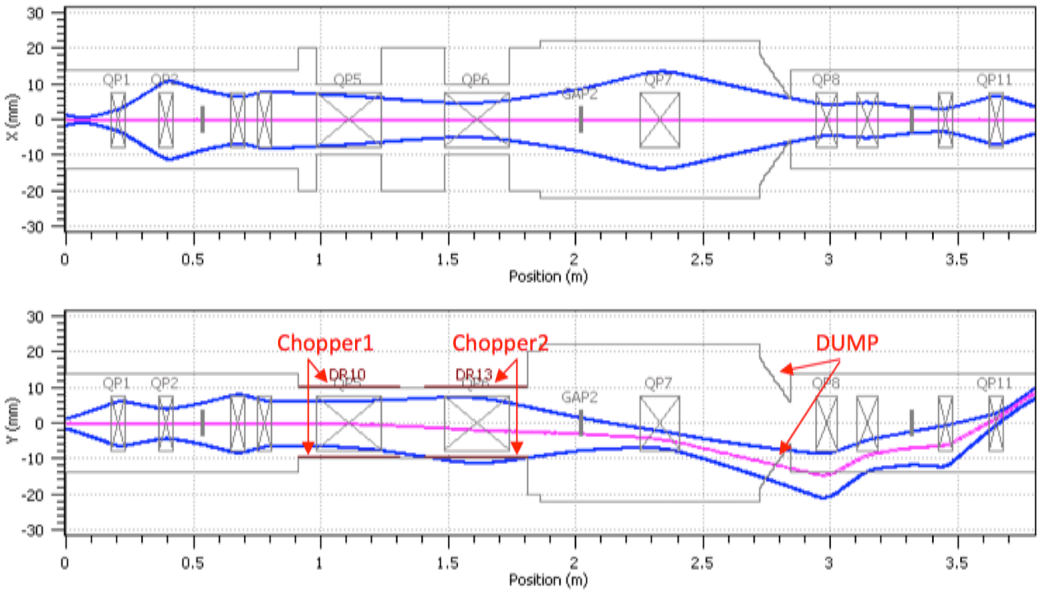
- Remove the unwanted part of the beam pulse with a pair of electrostatic choppers in the LEBT and MEBT
  - Reducing the risk of activation
    - Beam energy in the LEBT: 75 keV
    - Beam energy in the MEBT: 3.62 MeV
  - Reducing the problem of thermal load
  - Beam is less rigid

- In addition the choppers will be used to tune the pulse length and the repetition rate while the ion source is running at constant duty cycle
    - Pulse length from 5 μs to 2.86 ms at the target
    - Repetition rate from single pulse on demand to 14 Hz

Electrostatic chopper principle

- Electric field is generated between two parallel electrodes during a defined time period
- Beam to be removed ("chopped") see the field, its trajectory is affected by the field (an angular kick is given to the trajectory)
- A dump is positioned downstream the electrodes to absorb the chopped beam

- Note:
  - Rise time/fall time of the field from few ns to few hundred of ns
  - Dump geometry/material optimized to absorb the requested beam power (chopped beam) and avoid perturbation of the unchopped beam



Chopper off

Chopper on

Example of beam dynamics in the LINAC4 MEBT (Courtesy of J-B Lallement, CERN)

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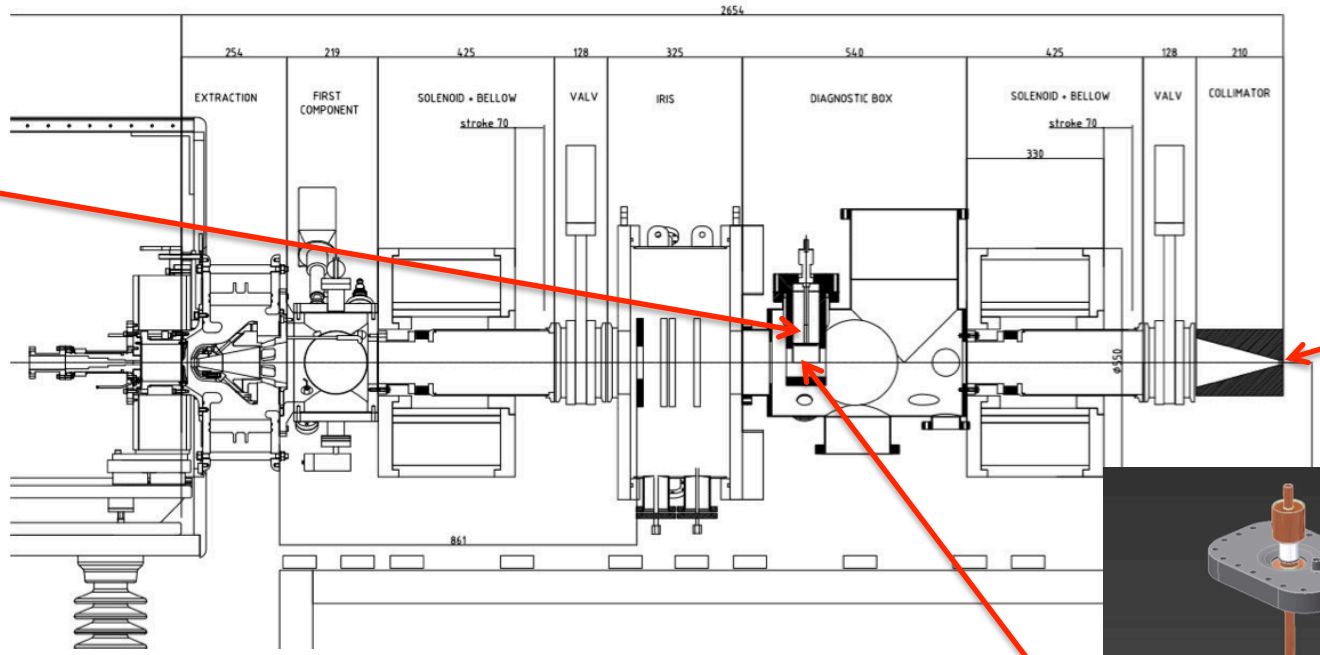
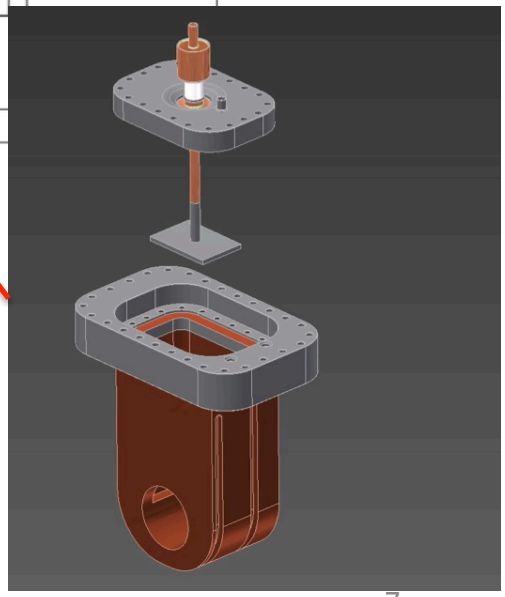
LEBT chopper



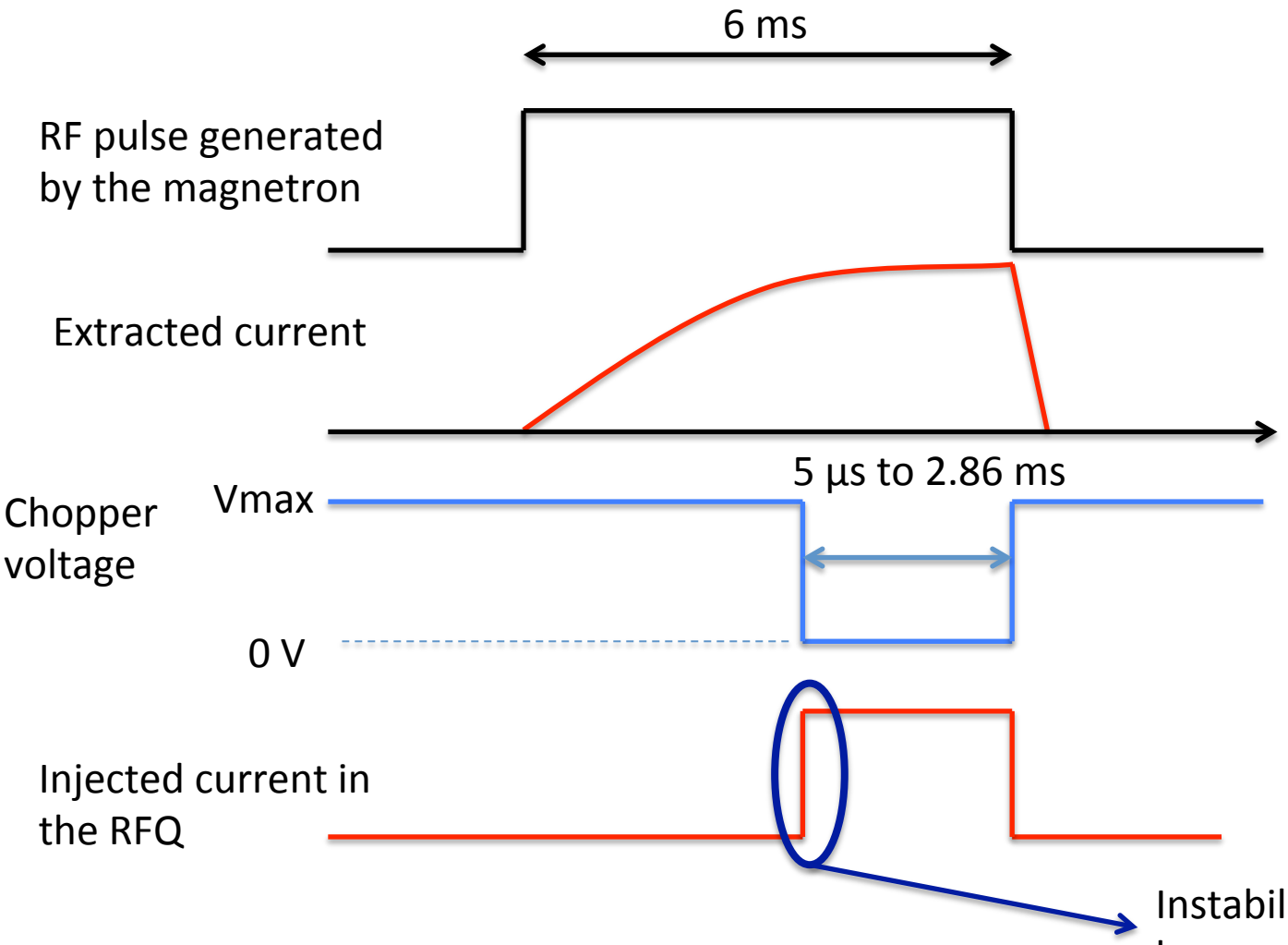
Chopper plates

Chopper dump



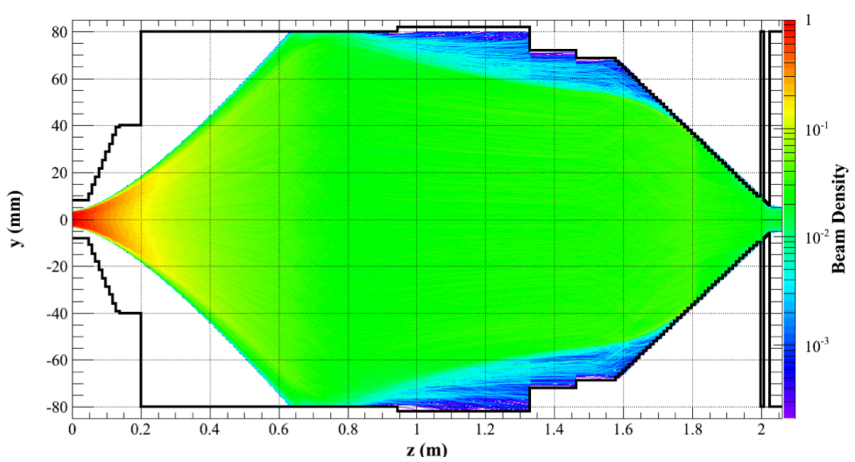
- Rise/fall time less than 100 ns
- Voltage up to 10 kV
- Electrodes:
  - Length equal to 100 mm
  - Gap equal to 70 mm
- Beam is deflected and defocused to the chopper dump at the exit of the LEBT
- Dump not designed yet

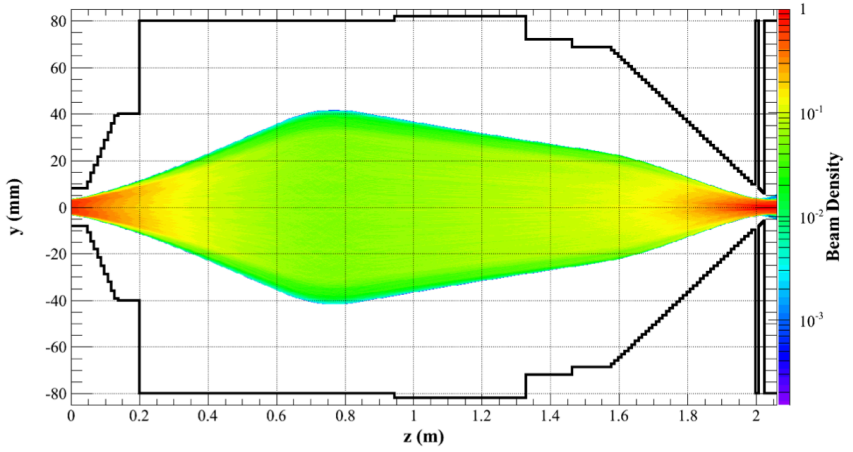
LEBT chopper operation



LEBT Chopper-space charge

- Beam dynamics in LEBT dominated by space charge
- Need to compensate the space charge to ensure beam transport





Beam dynamics in the IFMIF LEBT, in uncompensated regime (left) and fully compensated regime, time step between the two regimes is 20 us. (N. Chauvin CEA, “Space charge effects” CAS 2012 Ion sources)

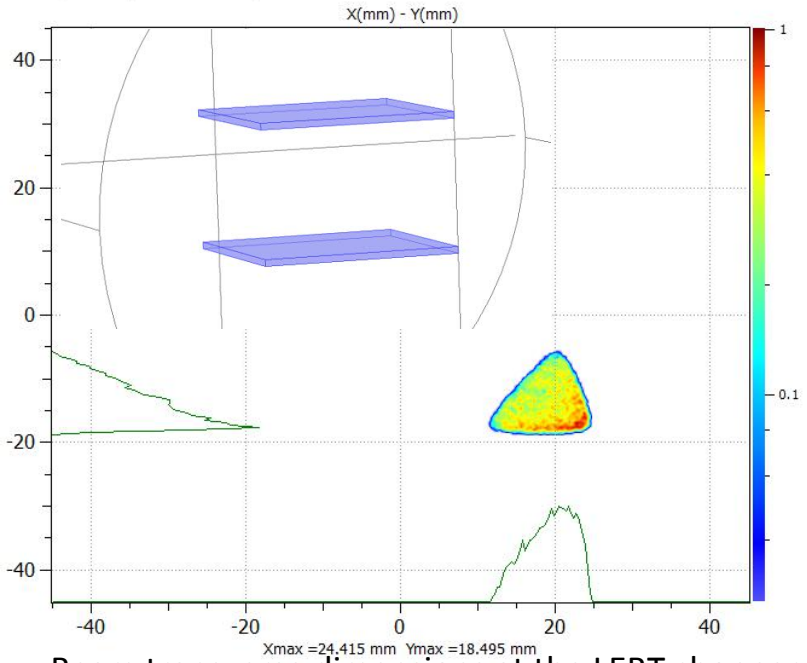
- Time recovery of space charge compensation is 1-20 µs
- Beam parameters are not nominal during this time
- Difficult to predict the time for a full compensation, will be measured during the commissioning
- A second chopper is needed to remove the head of the pulse
  - The second chopper shall be positioned at higher energy to avoid issue with space charge compensation
  - Need to change the LEBT chopper pulse length (5 µs to 2.86 ms => 25 µs to 2.88 ms)

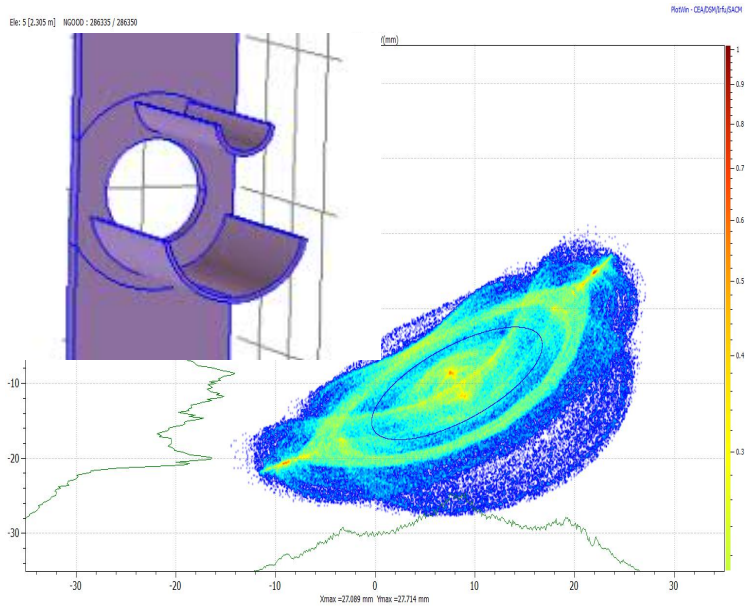
LEBT chopper dump

- To ensure safe operation of the LEBT chopper, the dump must absorb the full beam power.
- The design parameters of the dump are:
  - Peak current equal to 100 mA*
  - Pulse length equal to 6 ms
  - Repetition rate equal to 14 Hz
- Peak power equal to 7.5 kW, average power equal to 650 W
- Might be an issue if the beam is over focussed
  - Chopper plates redesign to give a defocusing effect
    - Plate geometry from parallel to cylindrical

*Note:

Not only protons will be extracted from the ion source, H3+ and H2 + ions will also be extracted. In the LEBT, few percent of the protons will be neutralized due to the interaction with the rest gas, a few percent will be also lost in the RFQ due to the bunching process. In order to have 62.5 mA at the target, and assuming all the phenomena described in this note, the total current extracted from the ion source shall be 90 mA. For the dump design, we assumed 10 % of engineering margin.



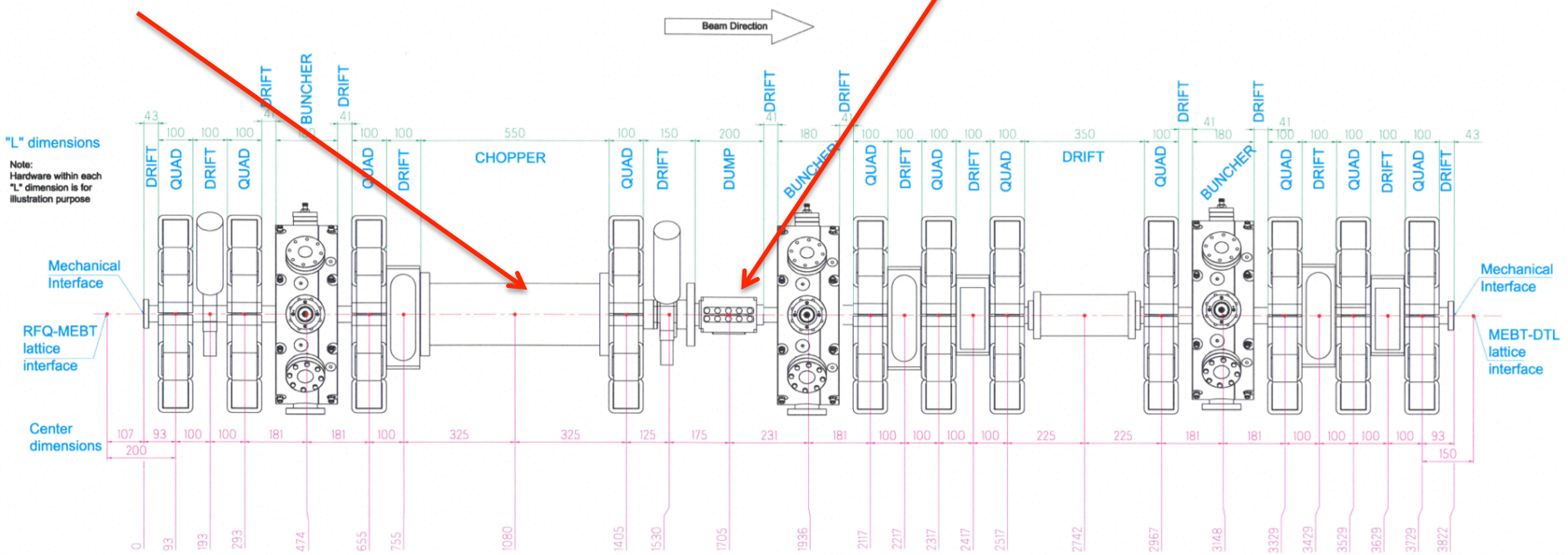


Beam transverse dimensions at the LEBT chopper dump, with and without defocusing effect

MEBT chopper

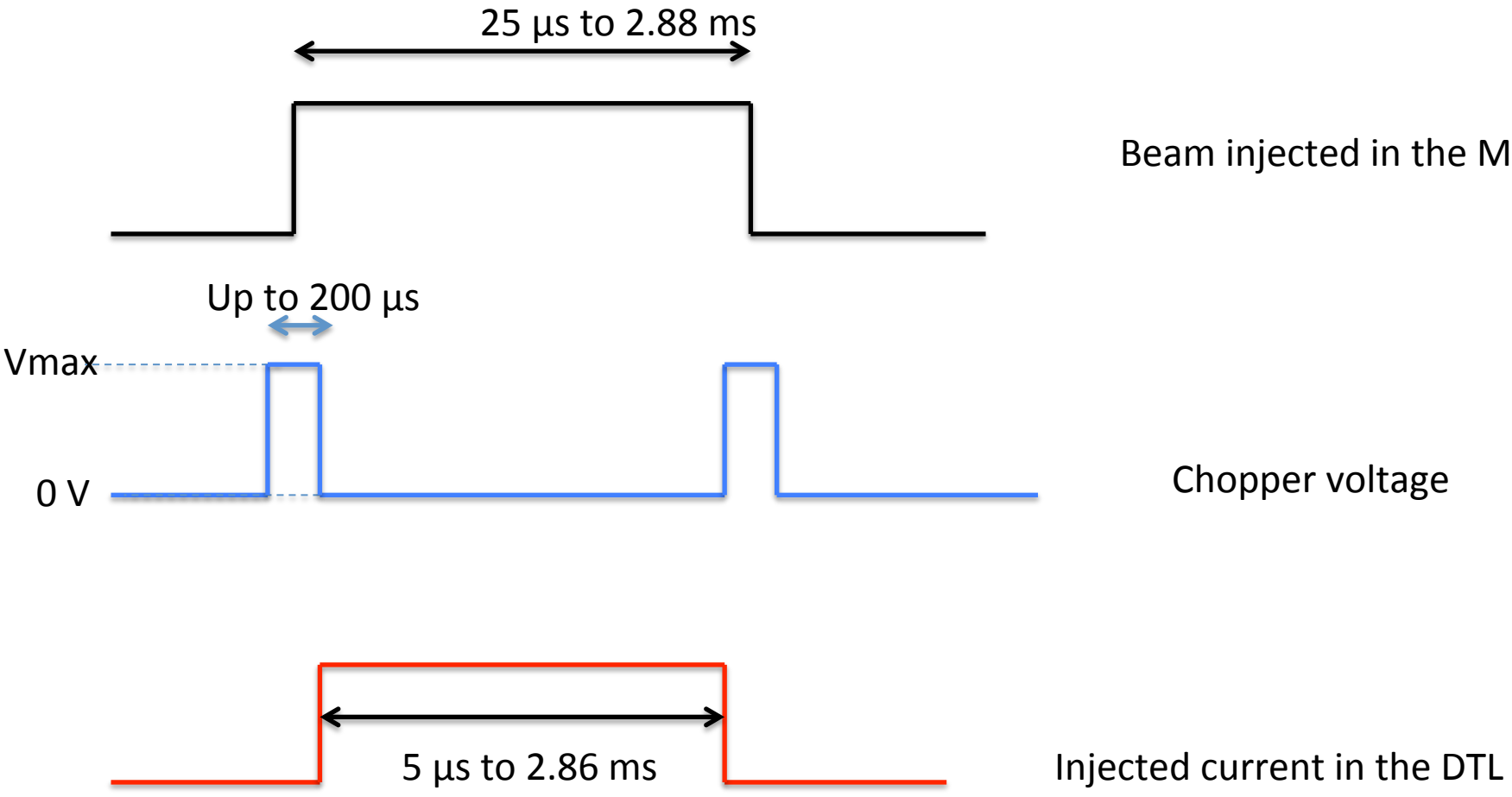
Chopper plates

Chopper dump



- Rise/fall time less than 10 ns
- Voltage up to 5.5 kV
- Electrodes:
  - Length equal to 450 mm
  - Gap equal to 20 mm
- No issue with space charge
- Currently under design

MEBT chopper operation



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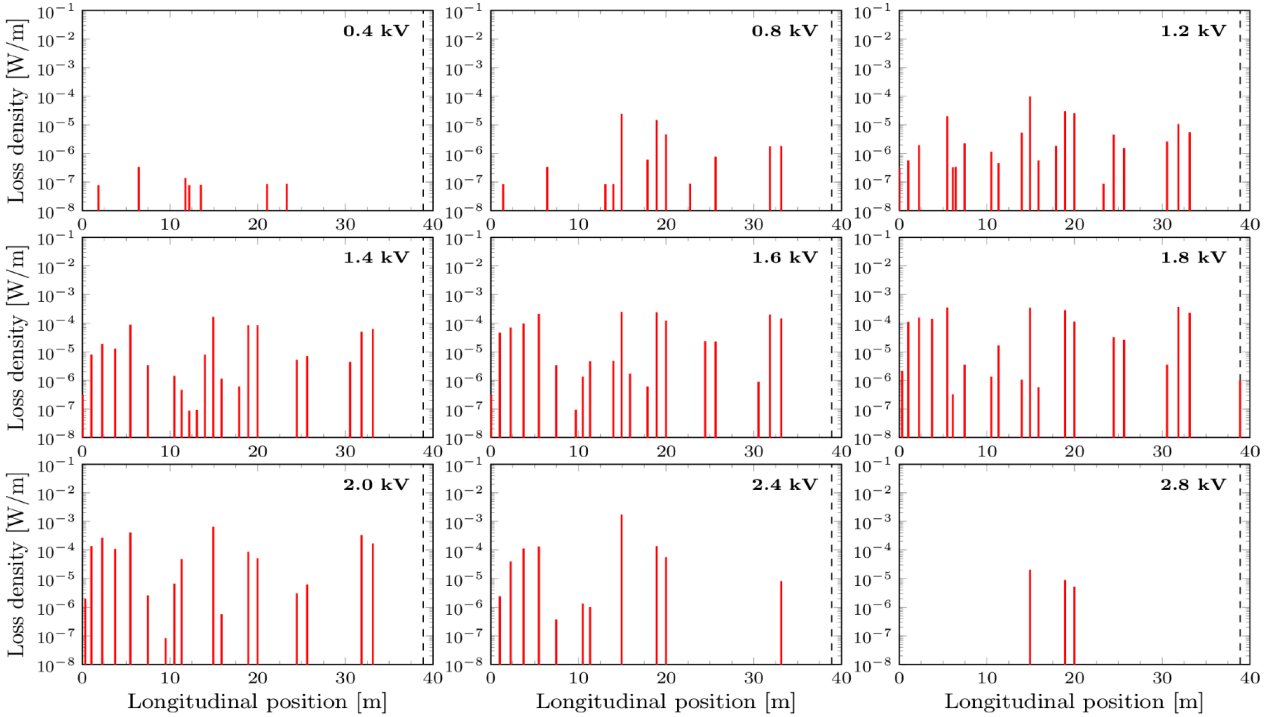
MEBT chopper-partially chopped bunch

- At ESS the bunch separation is 2.8 ns
- With 10 ns rise time, 3 bunches will feel an electrical field being too low to deflect them on the dump
- These bunches will start to oscillate and will be lost in the DTL tank
- No issue with activation, if the rise time is not longer than 10 ns



Beam loss maps in the ESS MEBT and DTL as function of the chopper voltage (R. Myamoto)

MEBT chopper dump

- In the MEBT, peak beam power is 230 kW.
- The dump is not able to absorb the full beam power

- Thermo mechanical simulations on going
- Limited power on the dump:
  - 40 us at each pulse (normal operation)
  - Single 200 us beam pulse

How to stop the beam?

- In the normal conducting linac, 3 systems can be used to stop the beam on MPS requests:
  - Ion source magnetron
    - Stop RF power generation
  - LEBT and MEBT chopper
    - Chopper voltage on

How to stop the beam?

- Magnetron:
  - Pros: no beam is generated
  - Cons:
    - Plasma fall time up to 100 us, need a second actuator
    - **Ion source can be stopped only for few seconds, a full restart of the ion source (16 hours) is needed after longer stop.**

- LEBT chopper
  - Pros:
    - Fast response
    - No need for a full restart of the ion source after long stop
  - Cons: chopper dump to be designed for high power and high duty cycle

- MEBT chopper
  - Pros: Fast response
  - Cons: Limited power to be used in parallel with the actuation on the magnetron

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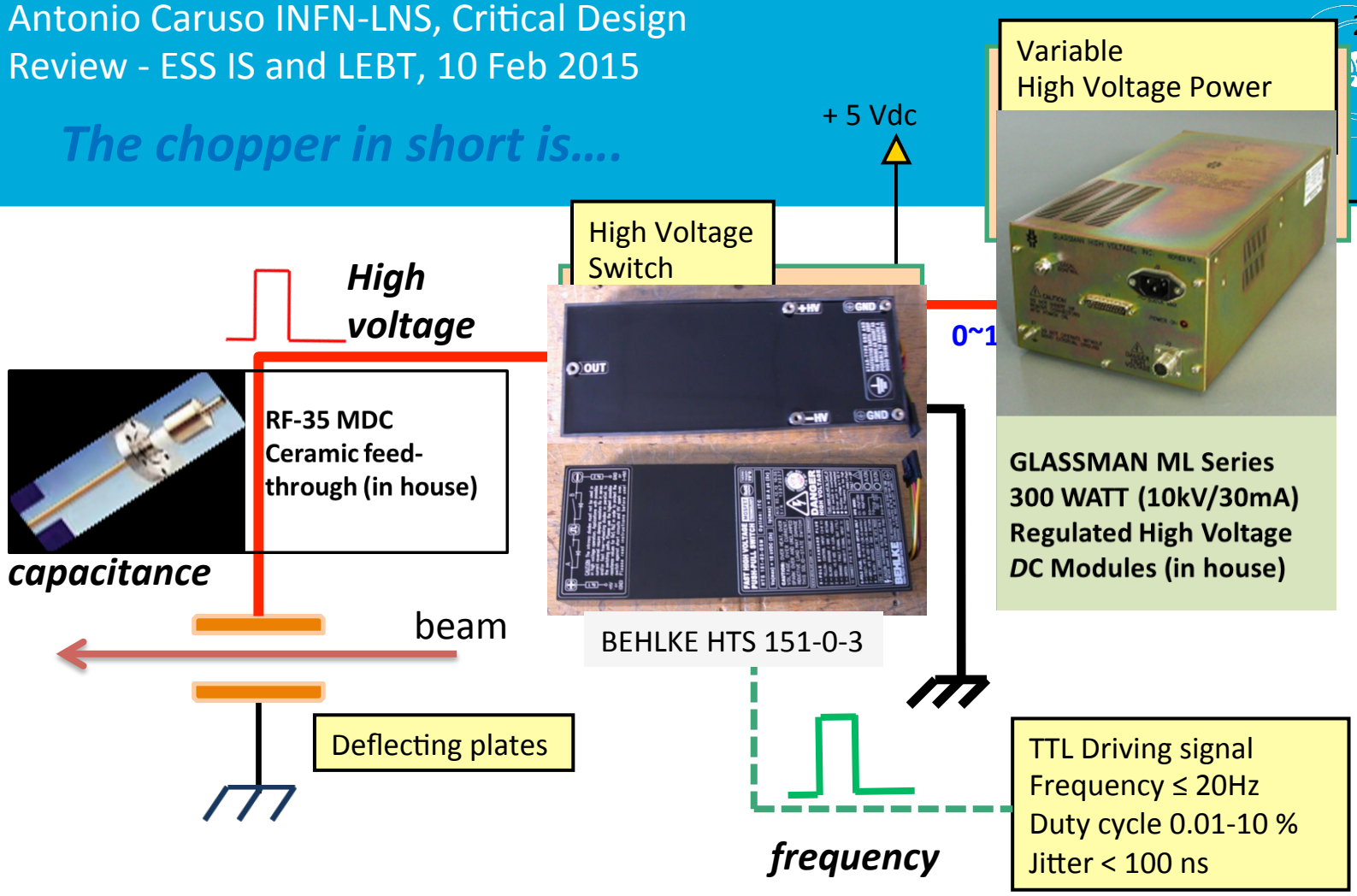
Back up slides

The chopper in short is….



The chopper electrode, the ceramic feed-through and the parasitic capacity of the switch correspond to a capacity *C* alternately (frequency *f*) charged and discharged from ground to the voltage *V* by the solid state switch. C about *50* pF (feed-through, output switch, electrodes).