Dynamics of the IFMIF very high-intensity beam

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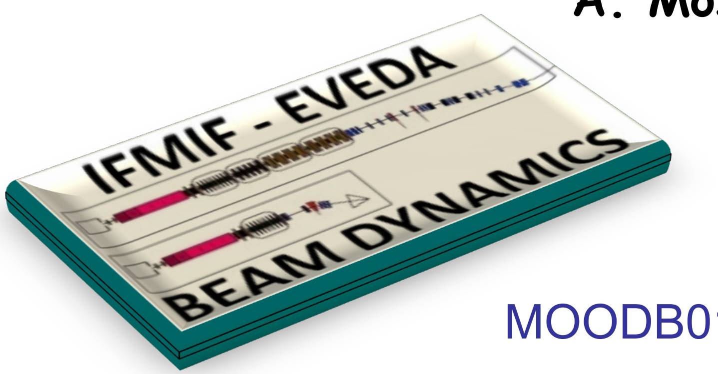


MOODB01

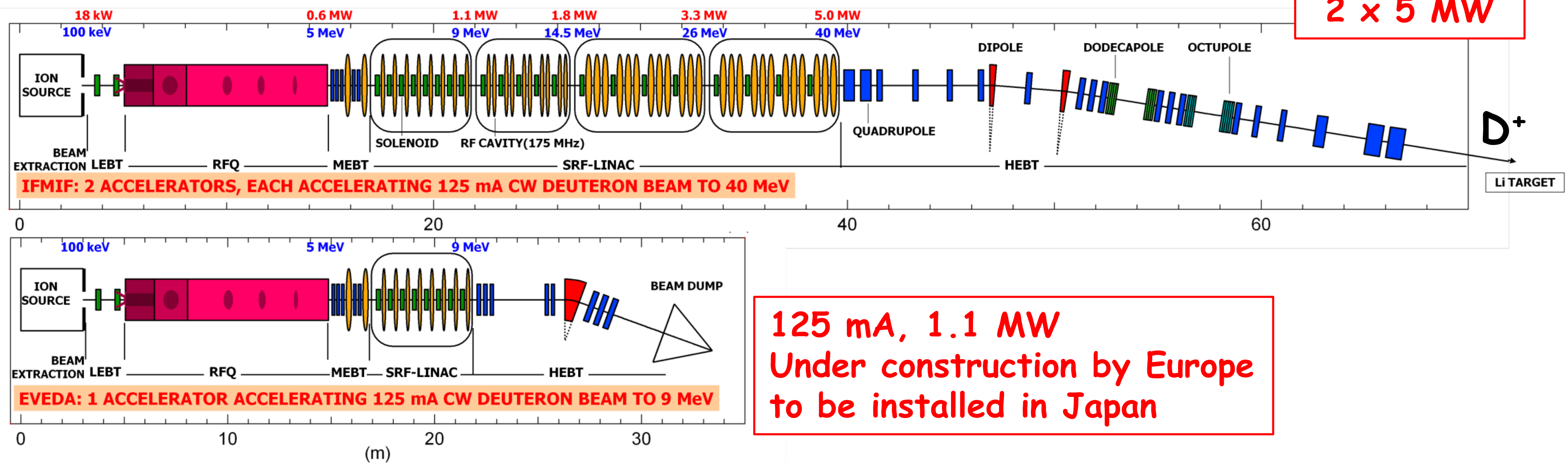
IPAC 2011, Sept 4th

Context

One of the three projects
Fusion Broader Approach between Japan & Europe

IFMIF: International Fusion Material Irradiation Facility

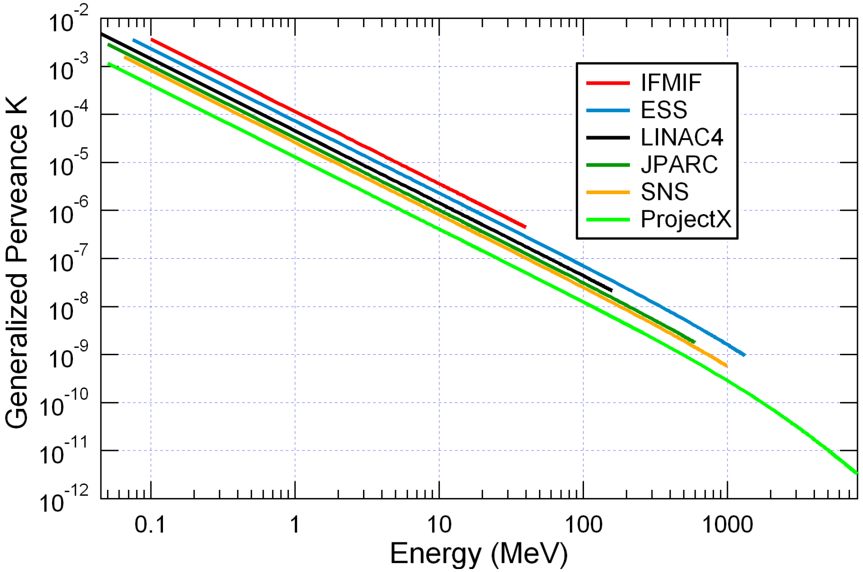
2 x 125 mA
2 x 5 MW

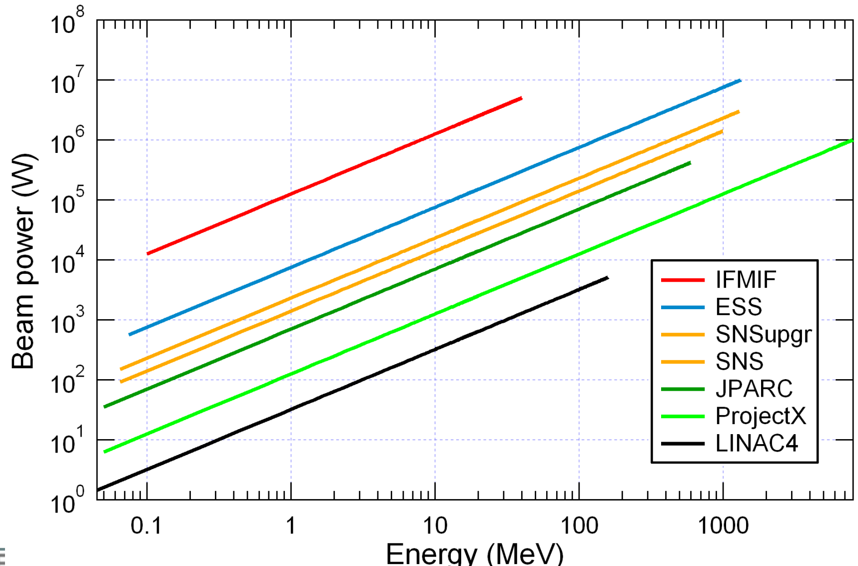


125 mA, 1.1 MW
Under construction by Europe
to be installed in Japan

EVEDA: Engineering Validation Engineering Design Activity

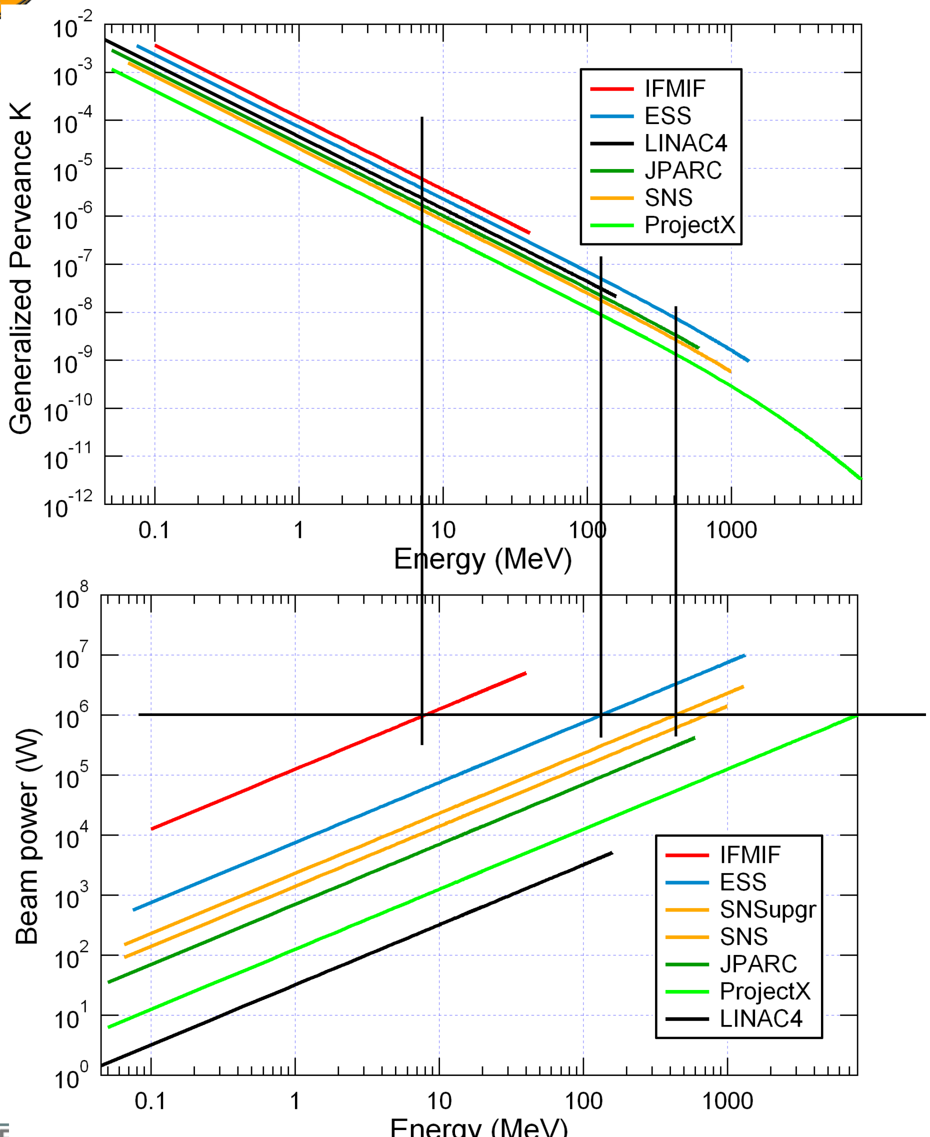
Global parameters (1)





The highest intensity
The highest beam power

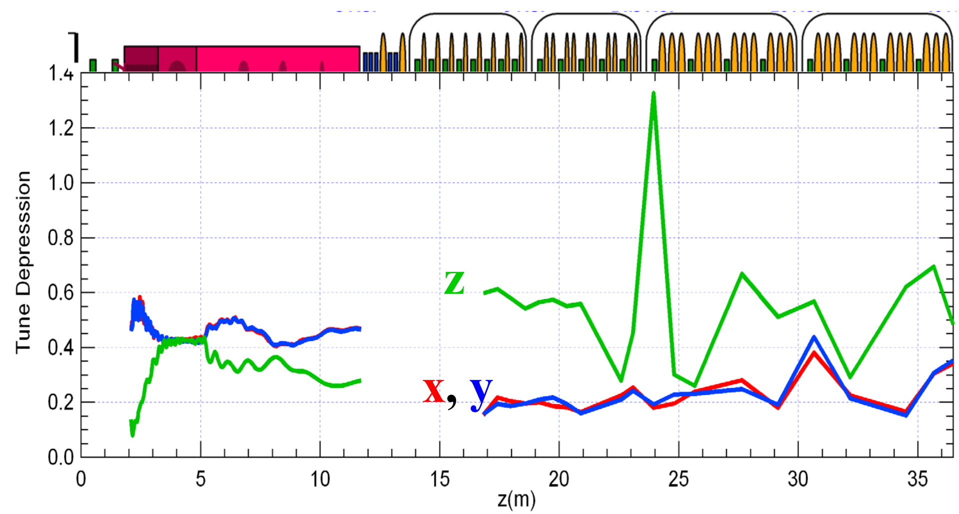
Global parameters (2)



Simultaneous combination

The highest intensity
The highest beam power
The highest space charge
The longest RFQ

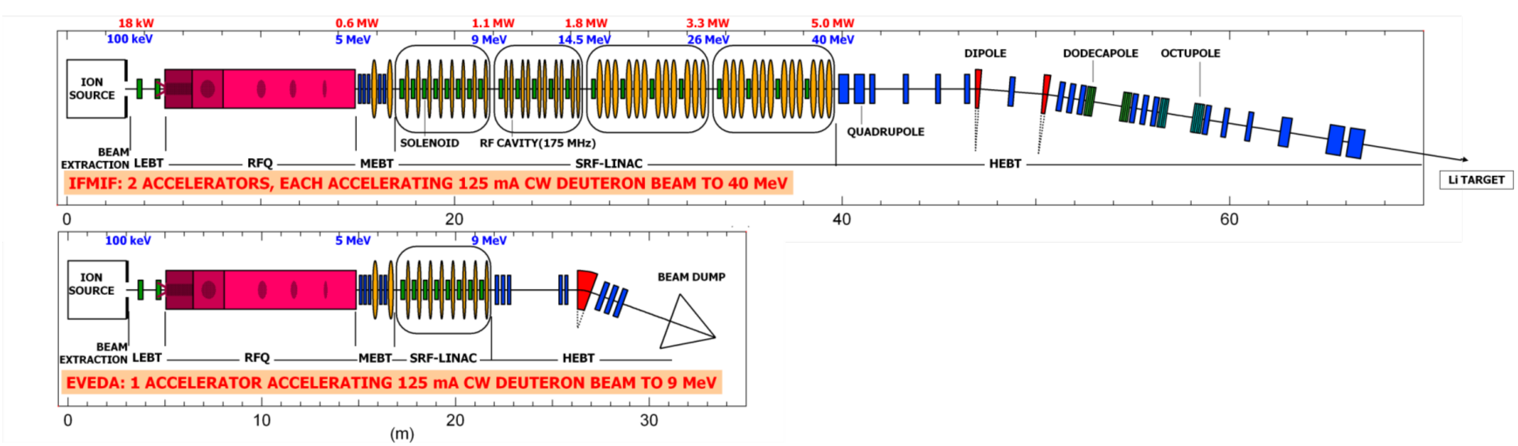
Unprecedented challenges



Main Issues

E < 5 MeV
Losses still significant (%)
→ Issue: To reach the required 125 mA

E > 5 MeV
Losses << 1W/m for material activation
→ Issue: To avoid micro-losses << 10^{-6} of the beam



Strong space charge → Distribution dependent
→ Issue: need of frequent on-line fine tuning

Issue: Emittance vs Halo growth

Issues and Strategy for E < 5 MeV (1)

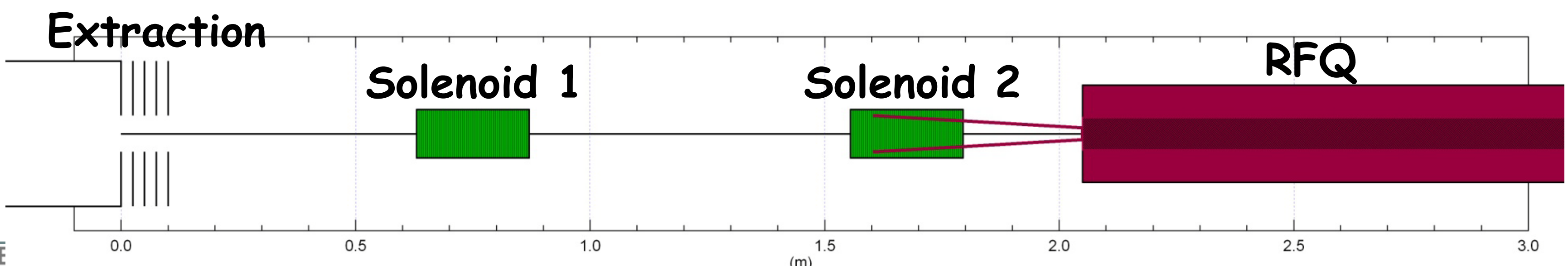
CW Current: 175 mA (ion source), 125 mA (RFQ)
Strong Space Charge → Emittance ↗

Optimum injection into RFQ
→ Emittance ↘

Conflicting issues !!

Strategy: Work around Space Charge effects

- **Enlarge extraction aperture**
- **Enhance SC compensation in the LEBT** (heavy gas and e⁻ repellers at each end)
- **Shorten lengths where no SC compensation**
  (reduce number of extraction electrodes, reduce injection path to the RFQ)
- **Increase accelerating field** (in extraction and RFQ, to the limit of el.breakdown)



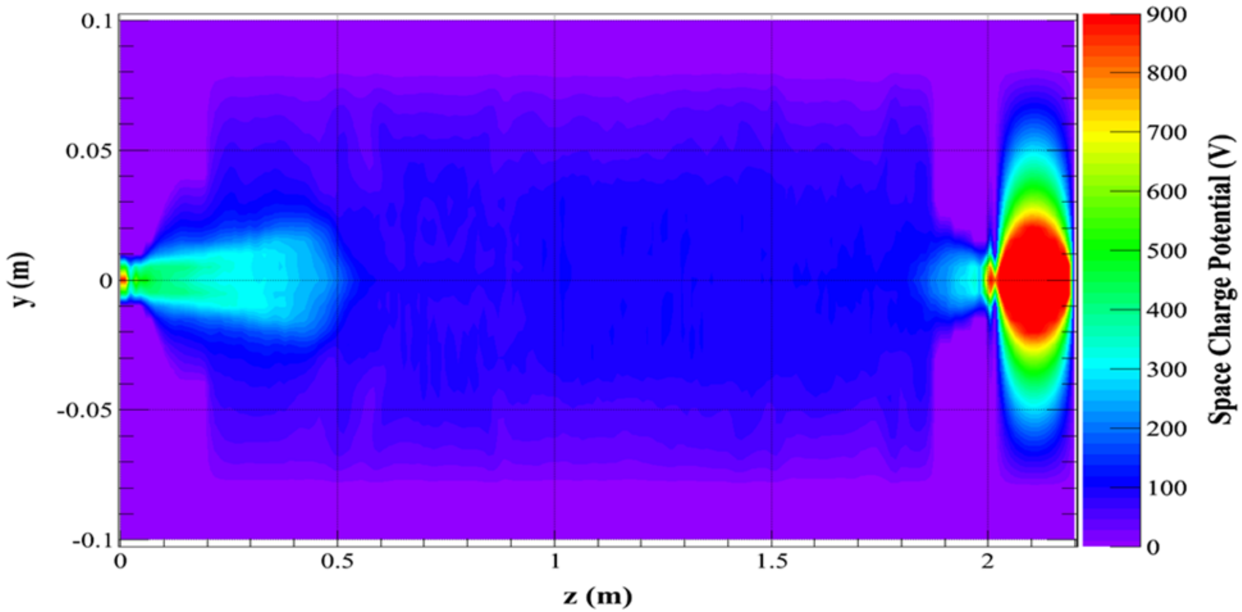
Issues and Strategy for E < 5 MeV (2)

High current → strong SC

Large σ_I → strong neutralisation

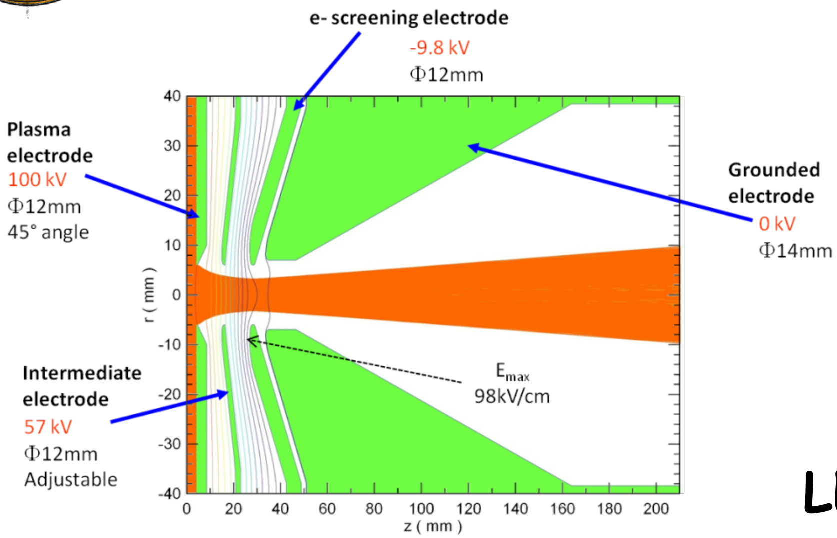
Competition must be finely studied
Which is the winner ? Where ?

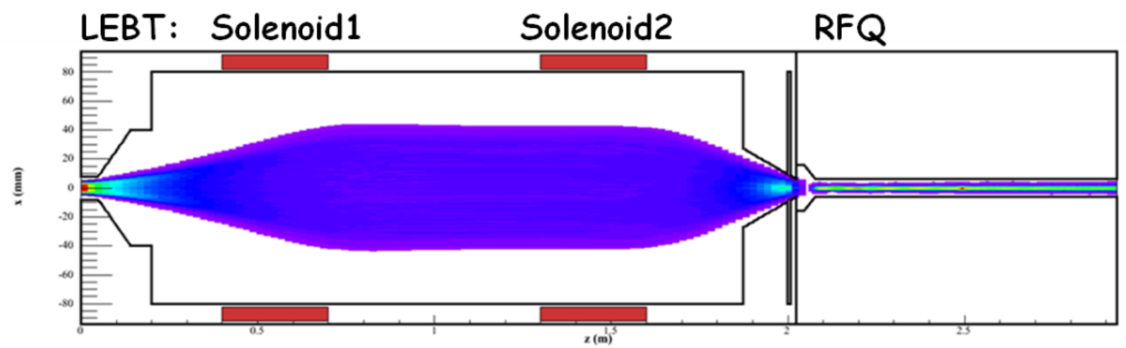
SolMAxP (CEA code): SC potential map
Main focusing field, Heavy ion gas (Kr), e^- repellers at entrance at exit



Resulting SC potential map is NOT uniform

Results for E < 5 MeV





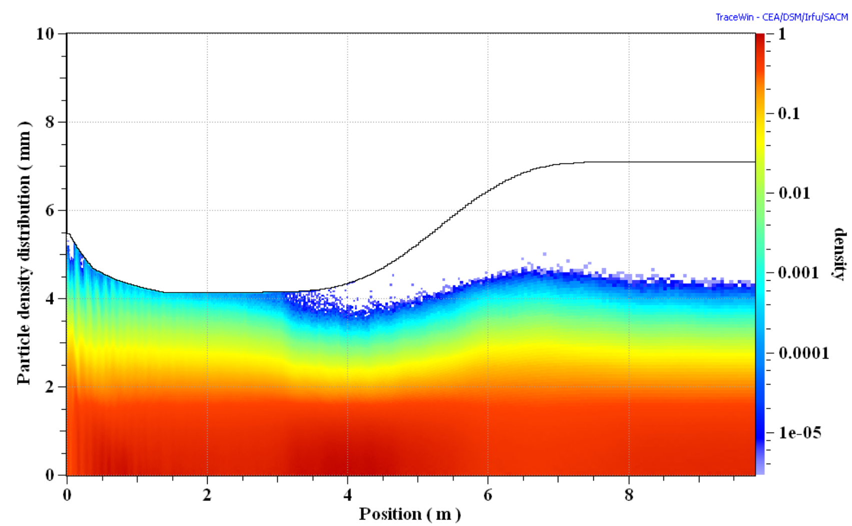
LEBT: no D^+ loss, optimum injection into RFQ

Extraction: 175 mA total

140 mA D^+, 26 mA D_2^+, 9 mA D_3^+

RFQ: 96 % current transmitted (134 mA)

Losses mainly in the first part, at low energy



Issues and Strategy for E > 5 MeV (1)

MEBT: transports and matches the beam into the SRF-Linac
SRF-Linac: channel with its well defined matched beam in terms of RMS
Tuning of MEBT and SRF-Linac are decoupled

- Strong SC →
any change in beam distribution
will change net forces,
will change particle trajectories
→ Distribution dependent

- E>5MeV →
harmful loss-induced activation
→ Loss << 1W/m
- High beam power (~MW)
→ Loss << 10^{-6} of he beam

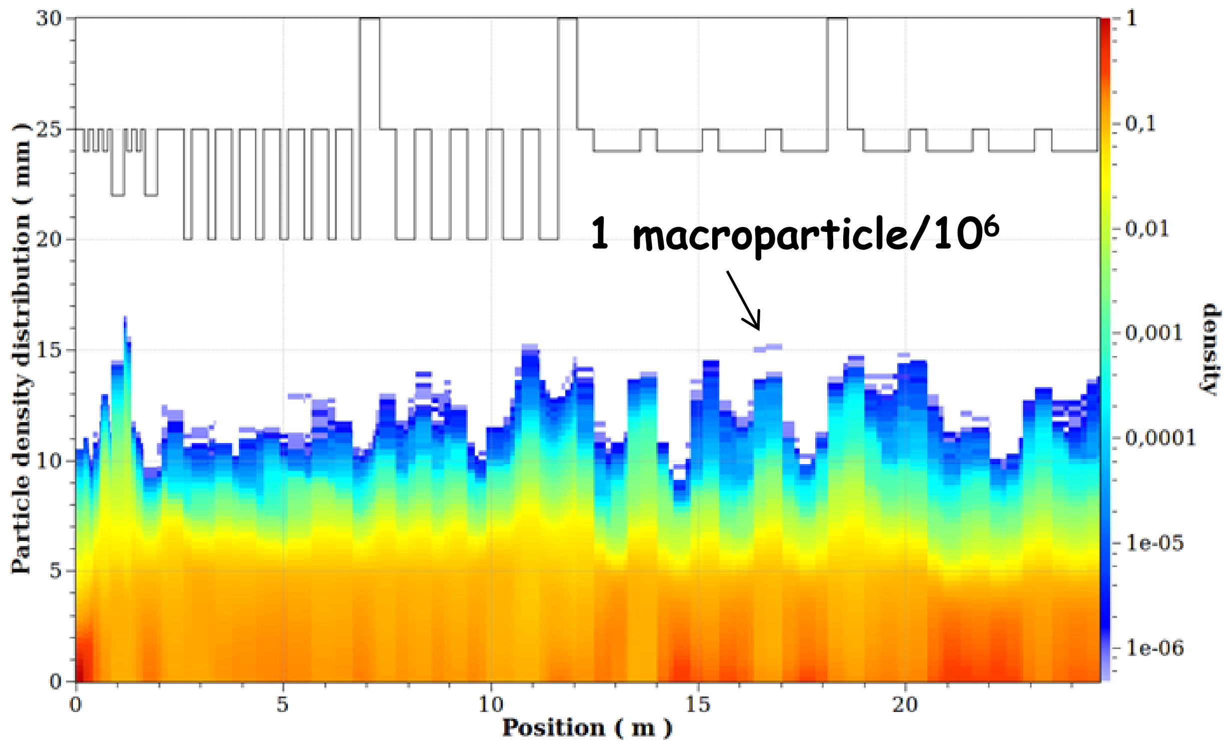
Multiparticle simulations with more than 10^6 macroparticles
For the MEBT and the SRF-Linac simultaneously
Each of the macroparticle at the external border must be scrutinised
→ Time consuming !

Issues and Strategy for E > 5 MeV (2)

Uncommon procedure:
- Match beam rms envelope, then
- Minimise extent of particles on the border

→ "Halo matching" instead of "Envelope matching"

MEBT + SRF-Linac



Issues and Strategy for E > 5 MeV (3)

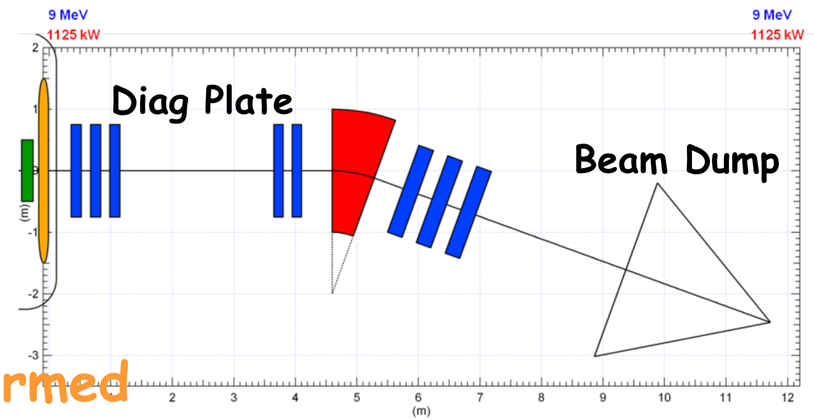
EVEDA HEBT:

- Adapt the beam size for measurements (Diag. Plate) → many tunings to foreseen
- Expand the beam at the Beam Dump

→Issues: for each tuning, simultaneously

- avoid micro-losses
- limit power density at the Beam Dump

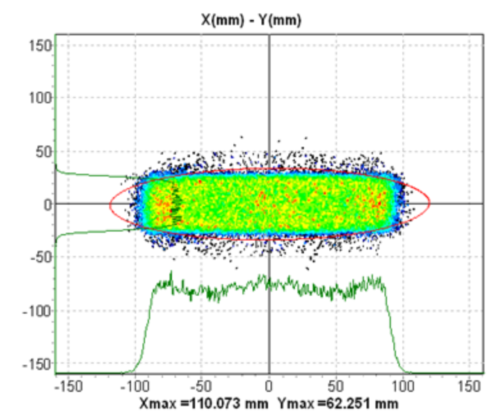
→ Many multiparticle simulations to performed



IFMIF HEBT:

Beam footprint at Lithium Target must be rectangular and uniform

→ Issues: Seen the beam power (2x5 MW) Pb of reliability, reproducibility and stability Remain to be studied



Issues and Strategy: on-line fine tuning (1)

Strong SC: settings depend on the beam distribution nature
But real beam ≠calculated beam, and changes with time

For E> 5 MeV,
Losses << 10^{-6} of the beam
But num.calc.not precised to 10^{-6},
machine not reproducible to 10^{-6}

On-line fine tuning ... with diagnostics should be mandatory and frequent.

Conflicting issues !!

Strong space charge →High compactness →Lack of room... for diagnostics

Issues and Strategy: on-line fine tuning (2)

Adopted rule: only carry out beam dynamics optimisations that can be later applied online with suitable diagnostics

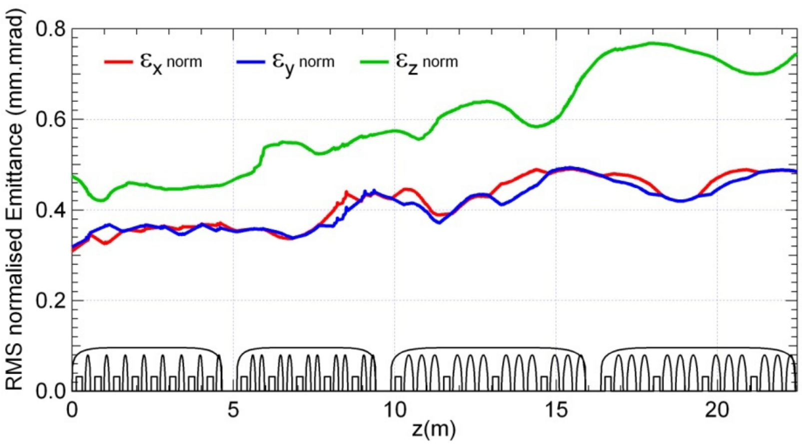
For the LEBT-RFQ,
- Optimisation method: highest transmission
- On-line: maximise current at RFQ exit

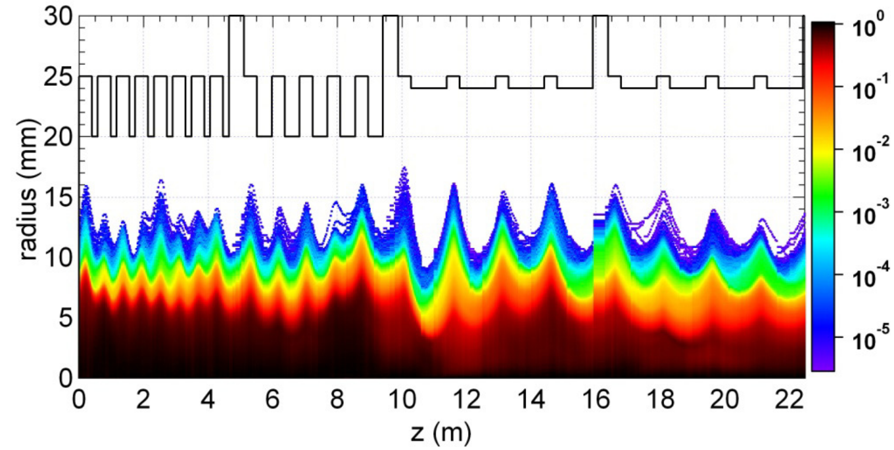
For the MEBT-SRF-Linac
- Optimisation method: halo matching
- On-line: minimise micro-losses

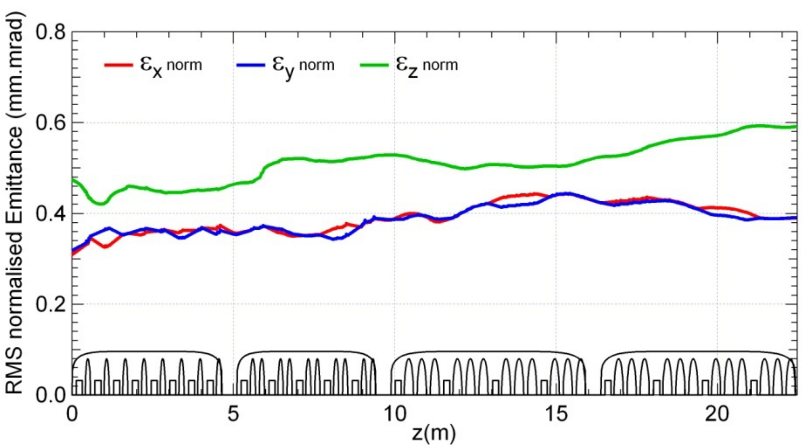
These beam current and micro-loss monitors should be used daily for fine tuning, should be considered as "essential" as the classical BPM

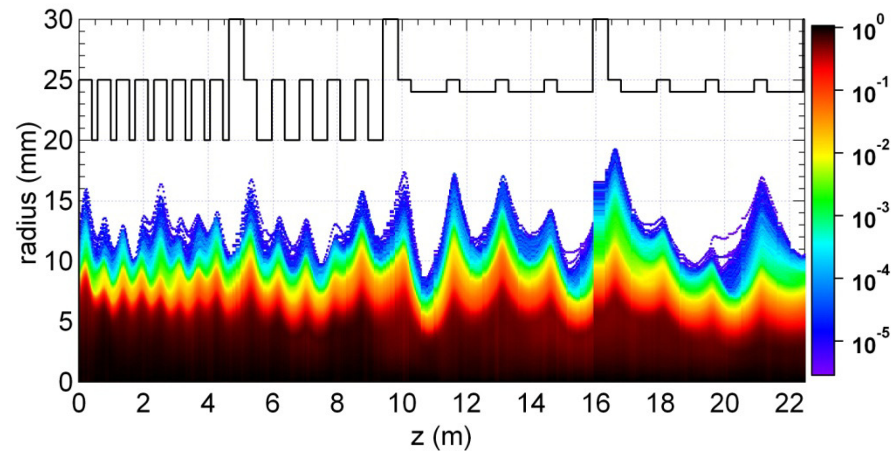
Emittance-growth issue (1)

Lower emittance ≡ More external halo (?)









Emittance-growth issue (2)

Once the external beam limit is perfectly minimised and regular, sometimes the emittance can literally blow up

→ Compromise between halo and emittance minimisations

Envelope equation: 2 competing terms

$$E_{x,y} = \frac{\varepsilon_{x,y}^2}{\sigma_{x,y}^3}$$ and $$SC = \frac{K}{2(\sigma_x + \sigma_y)}$$

K is generalised perveance, continuous beam independent of particle distribution type

or $$SC_3 = \frac{3K_3(1-f)}{(\sigma_x + \sigma_y)\sigma_z}$$

K_3 is generalised perveance, bunched beam dependent of particle distribution type (coef)

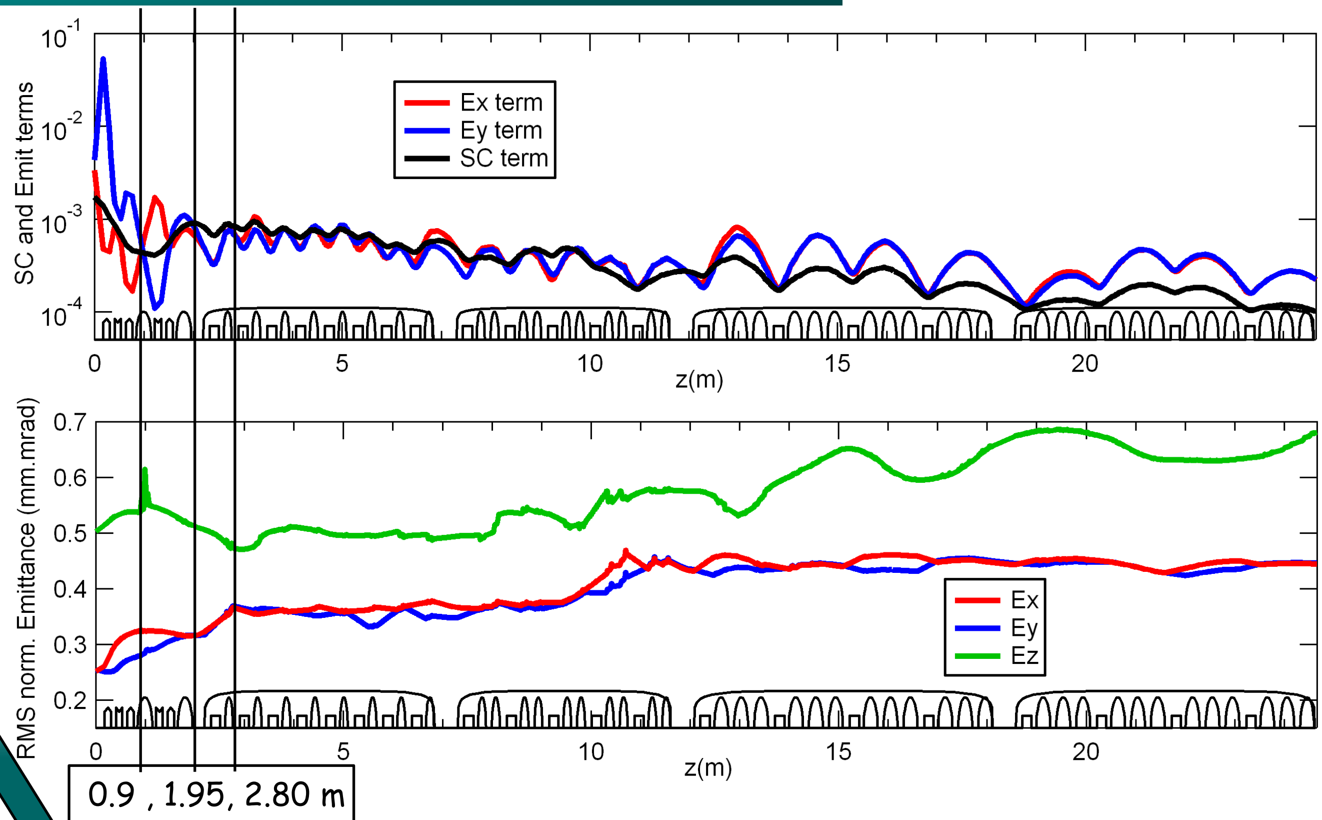
Coef is obtained by equalising SC and SC_3 at one position at MEBT entrance

Emittance-growth issue (3)

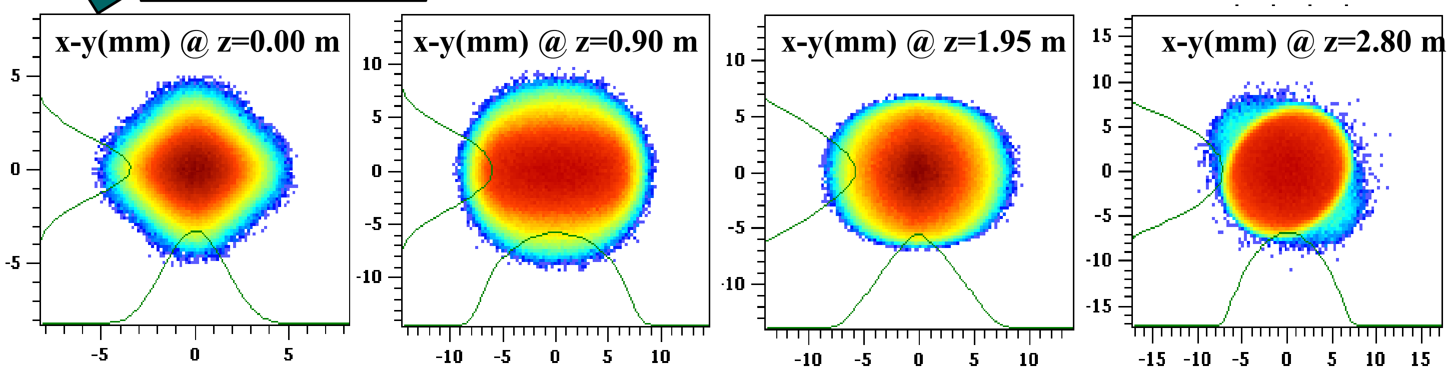
Growing distance

$\sim \beta c \tau_{pl}/4$

Charge redistribution

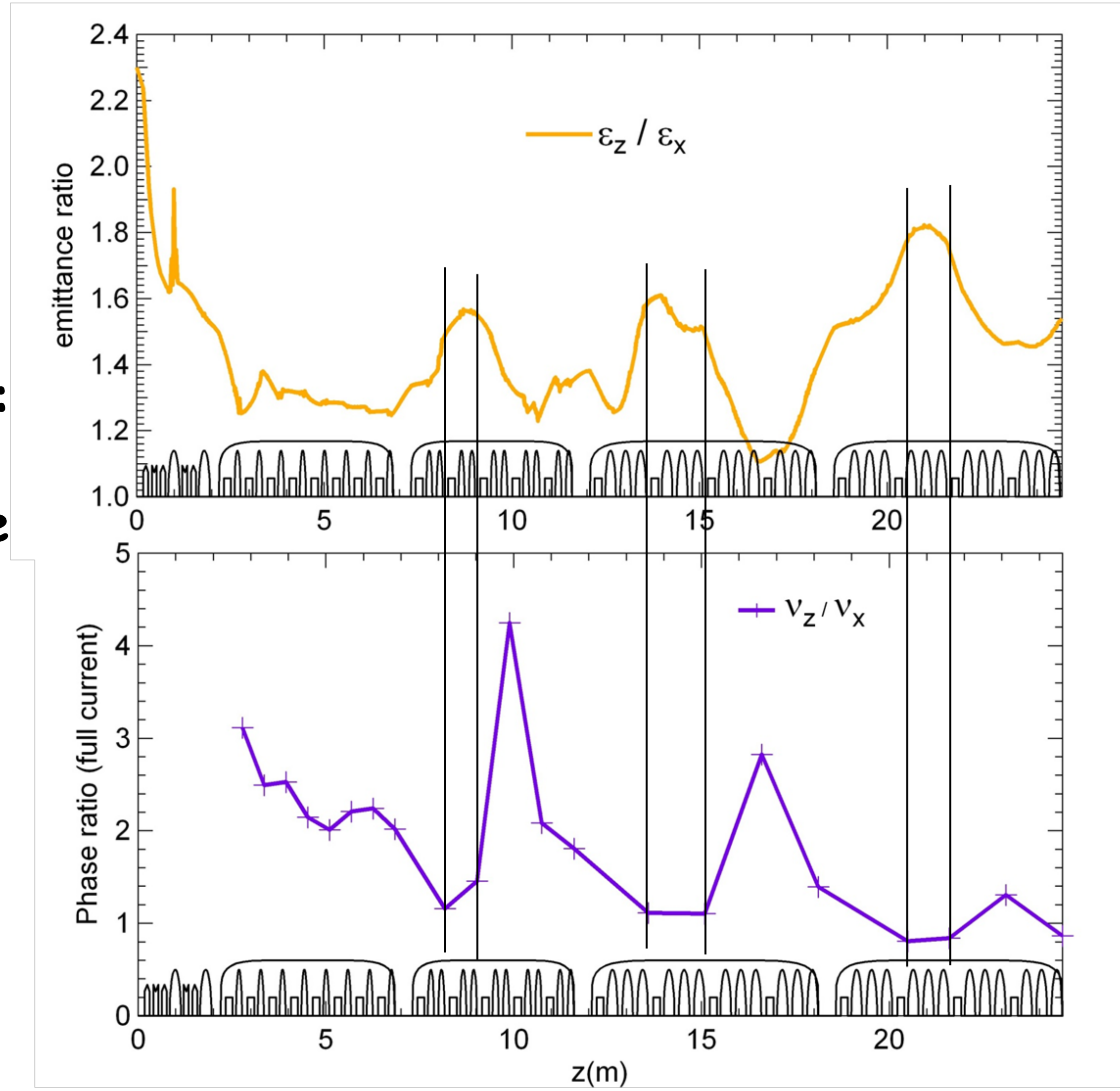


But that mechanism is not observed downstream, nor in longitudinal



Emittance-growth issue (4)

Transverse-Longitudinal coupling:
When $\nu_x \simeq \nu_z$,
Transfer of horizontal emittance to vertical one



This afternoon, 3 posters on IFMIF beam dynamics:

N. Chauvin et al: Start-to-end simulations

W. Simeoni et al: Stability charts

P.AP. Nghiem et al: Quad-Scan emittance measurement

Conclusion

Simultaneous combination of

The highest intensity
The highest power
The highest space charge
The longest RFQ
….

Unprecedented challenges
→new concepts: micro-losses, halo matching, essential diagnostic

True "Laboratory" for studying physics of High Intensity Beam (Halo formation, Core-halo interaction Emittance growth, sudden particle loss)

Improve beam dynamics
Improve tuning methods