Measurement of Momentum Halo Due To the Reduced RFQ Voltage During Beam Commissioning of LIPAc

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Linear IFMIF Prototype Accelerator (LIPAc)

Rokkasho Fusion Institute (BA Site)

TUA3I2

Outline

- LIPAc Overview
- Phase-B+ Beam commissioning
- Momentum Halo due to the reduced RFQ voltage
- Summary and Discussion

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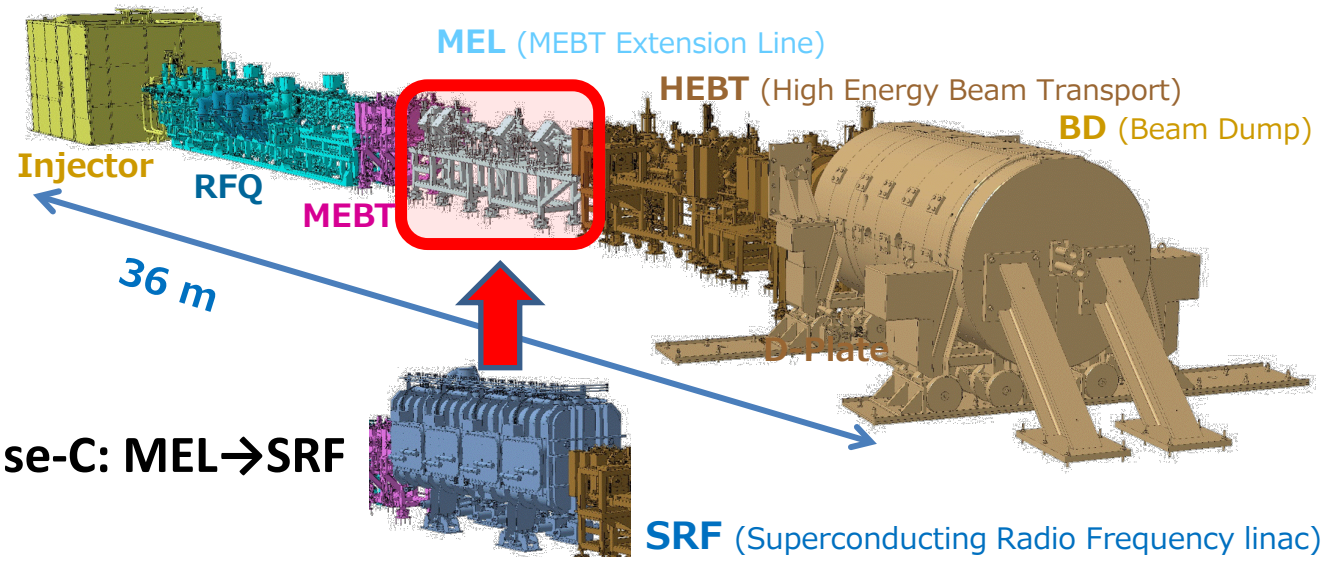
Linear IFMIF Prototype Accelerator (LIPAc)

To validate low energy part (≤ 9.0MeV) of the IFMIF accelerator for testing material for the fusion power plant.

Phase-B+ Layout

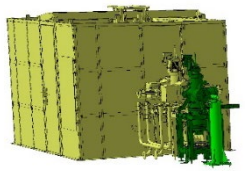


Phase-C: MEL→SRF

Ion species	D^+ (H^+ for start-up/tuning)
Peak current	Up to 125 mA
RFQ output energy	5 MeV
SRF output energy	9 MeV
RF frequency	175 MHz
Bunch width	0.1–0.7 ns (sim.)
Duty factor	10^{-2} – CW
Pulse length	10^2μs – CW
Beam power	Up to 1.125 MW

Previous Phases

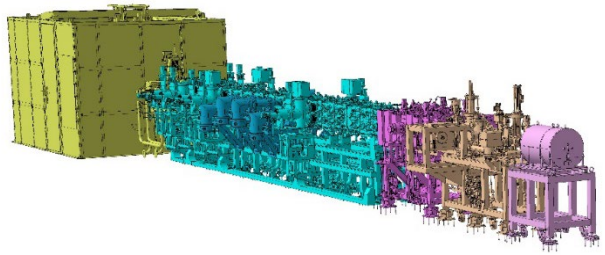
Phase-A (Apr. 2015 - Aug. 2017)



Injector + Diagnostic box

100keV, -125 mA, 12.5kW, CW beam

Phase-B (Jun. 2018 - Aug. 2019)

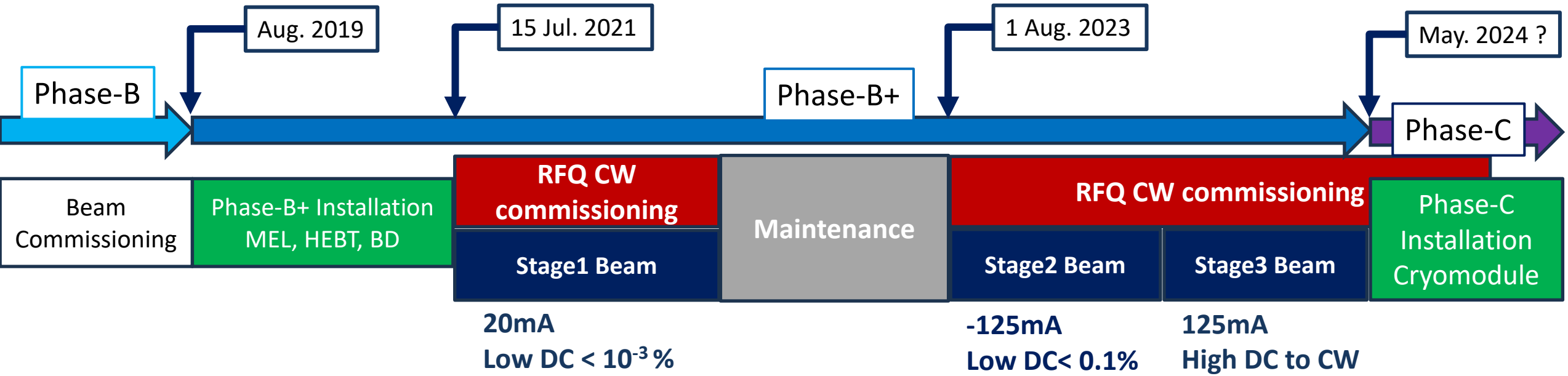


Injector + RFQ + MEBT + D-Plate + LPBD

5MeV, -125mA, 625kW, Pulsed beam

1. K. Kondo et al., Fusion Eng. Des. 153 (2020) 111503.
2. H. Dzitko et al., Fusion Eng. Des. 168 (2021) 112621.
3. K. Kondo et al., Nucl. Fusion 61 (2021) 116002.
4. L. Bellan et al., the Proc. of ICFA HB2021 (2021).

Strategy of the Phase-B+



Phase-B+ Mission

- Injector CW operation
- RFQ CW operation
- 125mA 5MeV D^+ beam in high DC

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- To Validate diagnostics
- Preparation for Phase-C

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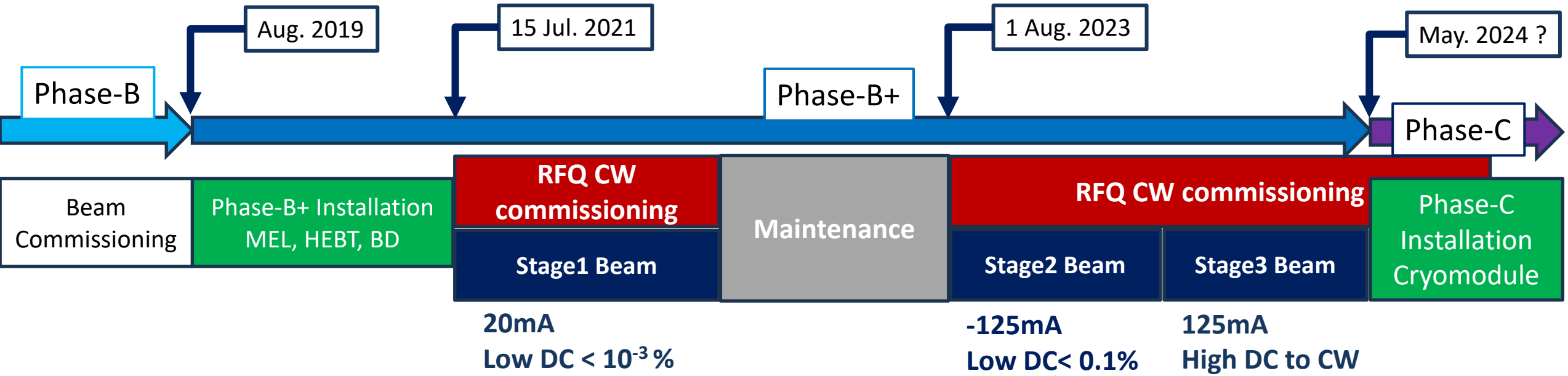

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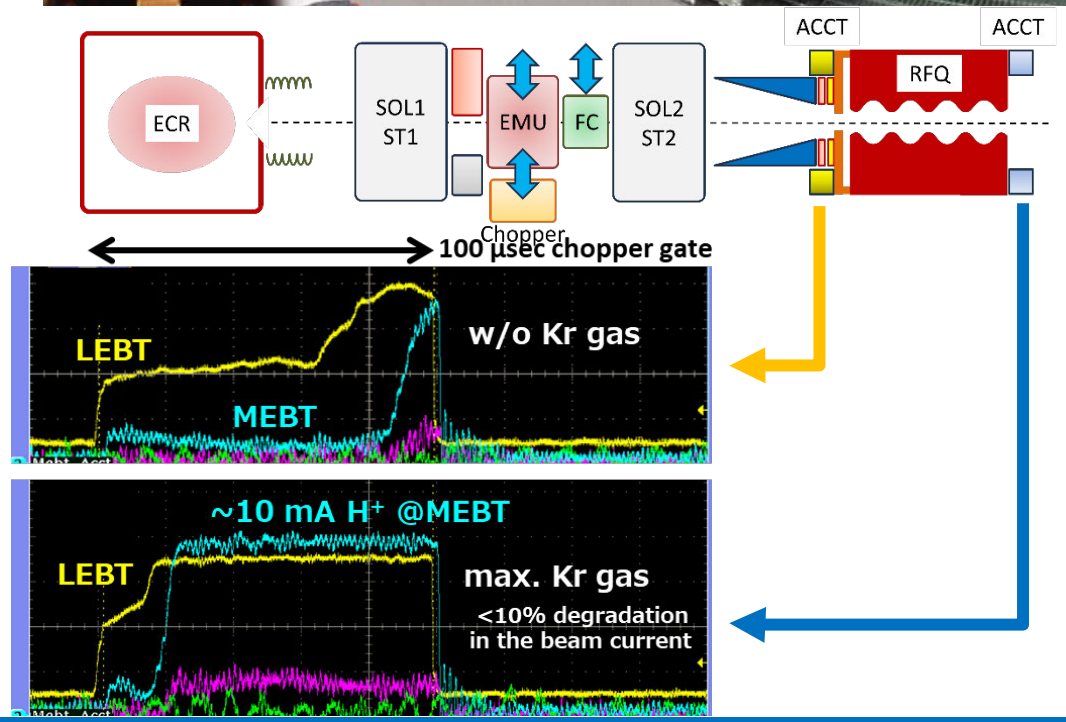
LIPAc Phase-B+ Stage-1



Stage-1 (Jul. 2021 – Dec. 2021)

- ✓ **The Pilot beam (10mA H^+ and 20mA D^+) were tested.**
- ✓ **Chopper pulsing has been confirmed.**
- ✓ **Alignment of full beam transport was check in beam-based method.**
- ✓ **Newly installed components were checked.**
  - ☐ Validation of diagnostics → Stage-2 and -3 in high current and DC.
- ✓ **Measured beam size could be reproduced by the simulation.**
- ✓ **Evaluation of space charge compensation degree.**

Interesting topics observed from this stage

- ☐ **Transient of chopper and space charge compensation.**

1. K. Masuda, the Proc. of LINAC2022 (2022).

LIPAc Phase-B+ Stage-2

Stage-2 (Aug. 2023 –)

Developed point – Learnt from Stage-1, Alignment corrected, Injector CW commissioning completed.

Objective and Results:

- ☐ **Recheck what we confirmed during stage-1, in the high current operation.**
  - ✓ **Chopper worked well.**
  - ✓ **Beam-based alignment was performed.**
- ☐ **Transport the 5MeV 125mA D^+ beam to the BD.**
  - ✓ **Beam transported to the BD (112mA D^+ 150us with 120us plateau, 1Hz).**
- ☐ **Validation of the Interceptive/non-interceptive diagnostics.**
  - ✓ **Interceptive devices worked well. Details → Oral session by S. Kwon (FRC1I2)**
  - ✓ **Visibility of all BPMs has been confirmed by steering scan.**
- ☐ **Study dynamics of space charge compensation degree.**
  - **Testing the effect of Kr gas flow rate to the transient**

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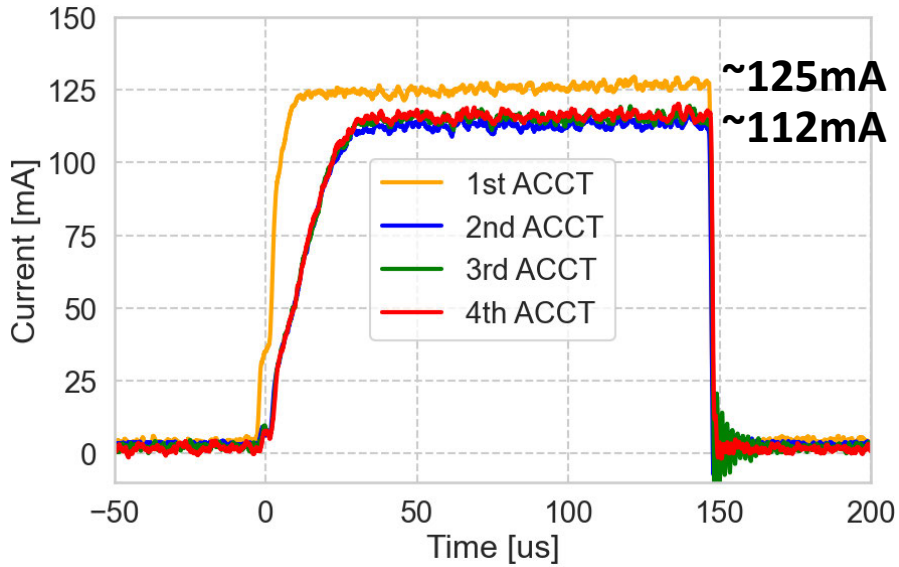
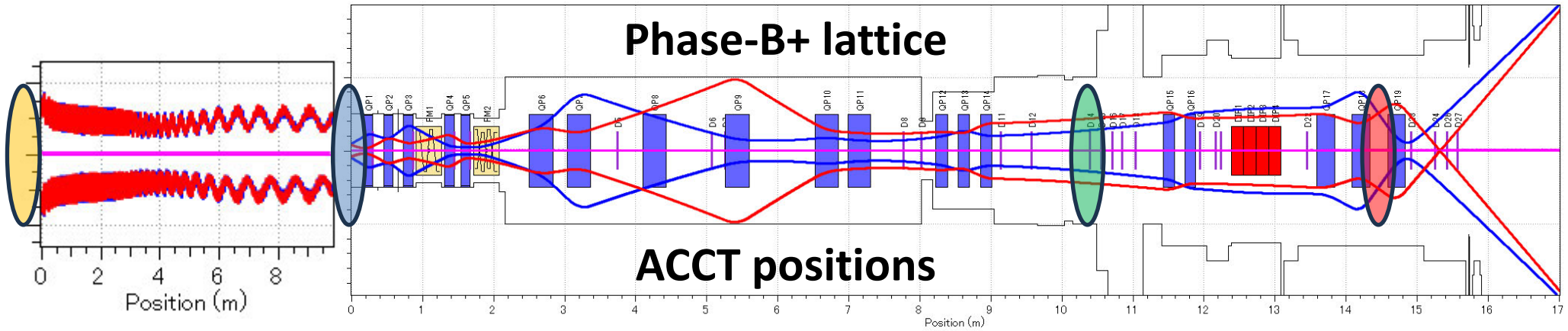
Measurement by ACCTs (7th / Sep. 2023)





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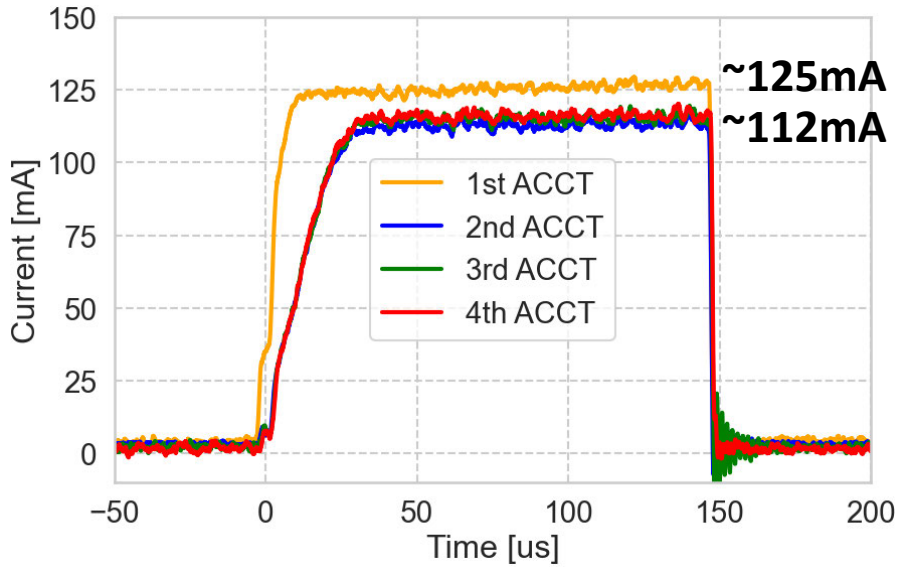

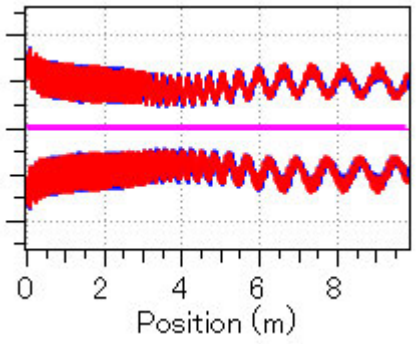

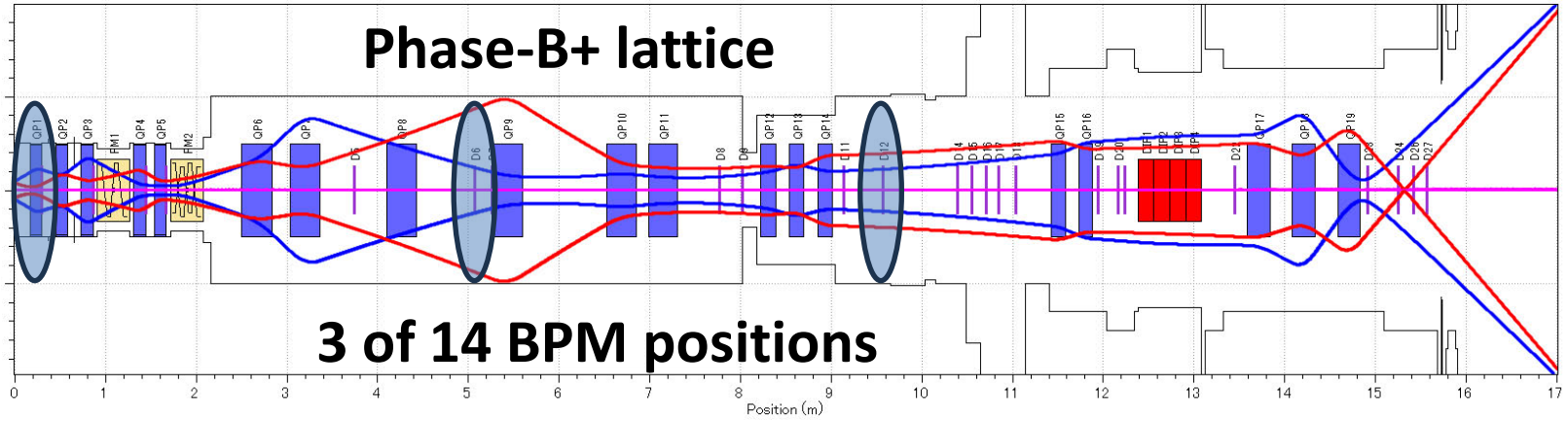

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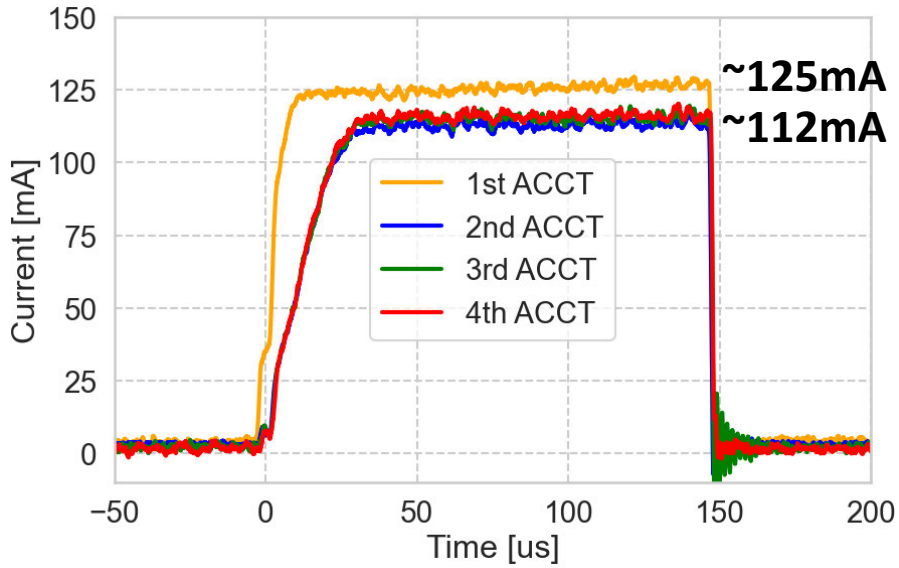
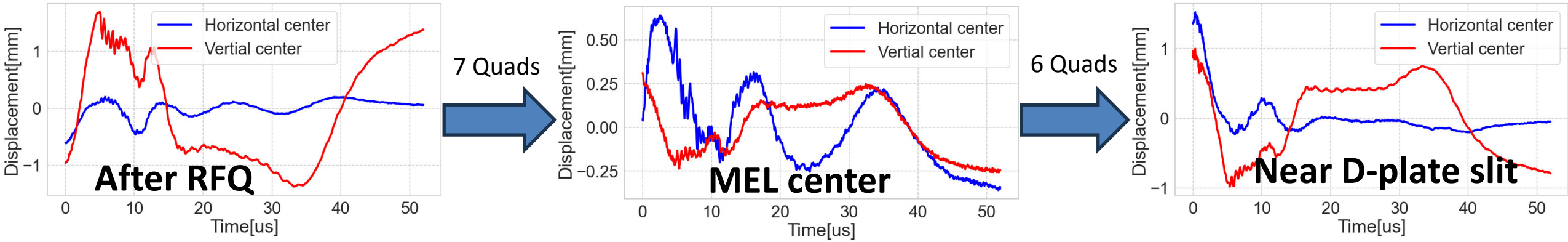
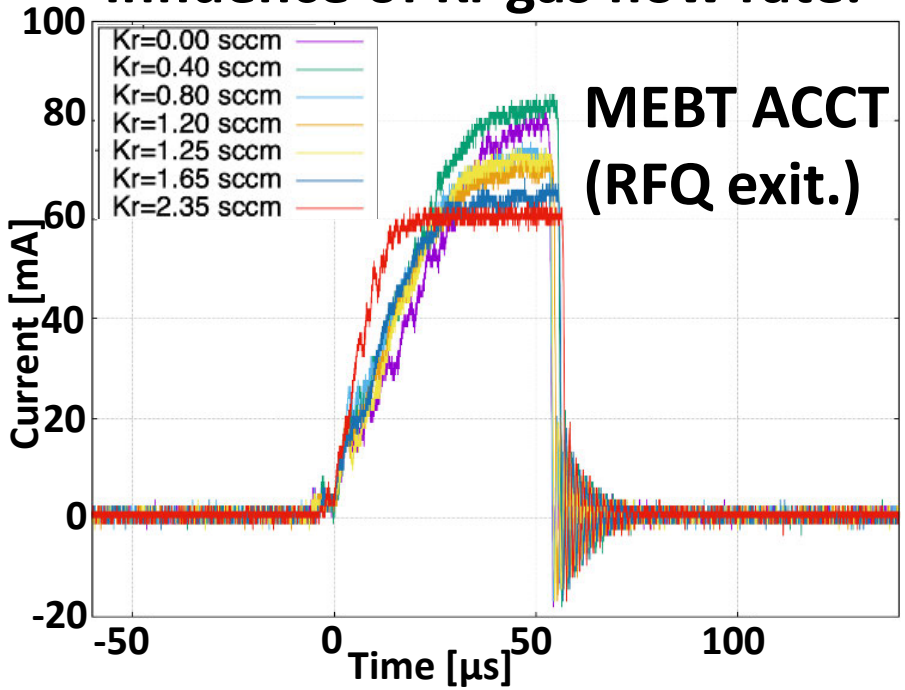




Centroid motion in a pulse measured by BPM.

LIPAc Phase-B+ Stage-2

Influence of Kr gas flow rate.

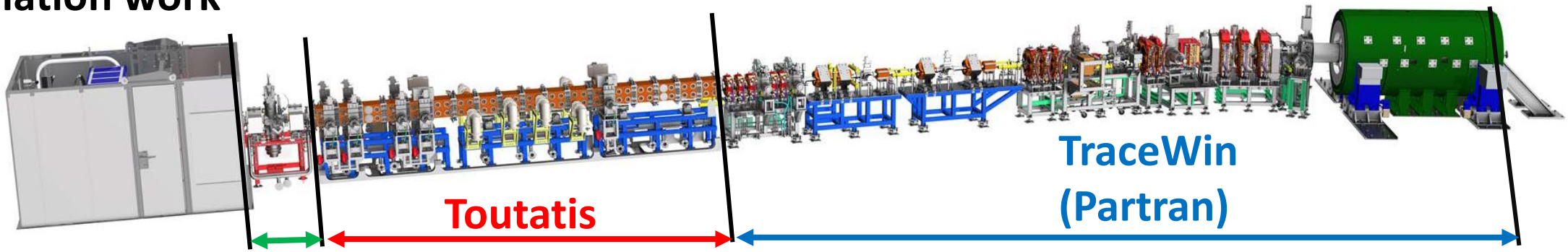


LIPAc RFQ (4 vanes type) spec.

- Length : 9.8m consists of 18 modules
- RF Frequency : 175MHz
- RFQ vane voltage : 132kV → 137kV (new nominal)
- Kilpatrick : 1.8
- RF source : 8 chains, 200kW / chain

Coming from Luca's work.
(L. Bellan, 2nd CBO workshop)

Simulation work



TraceWin (Partran)

Original source : TraceWin and Toutatis Input file designed by L.Bellan

LIPAc Phase-B+ Stage-2

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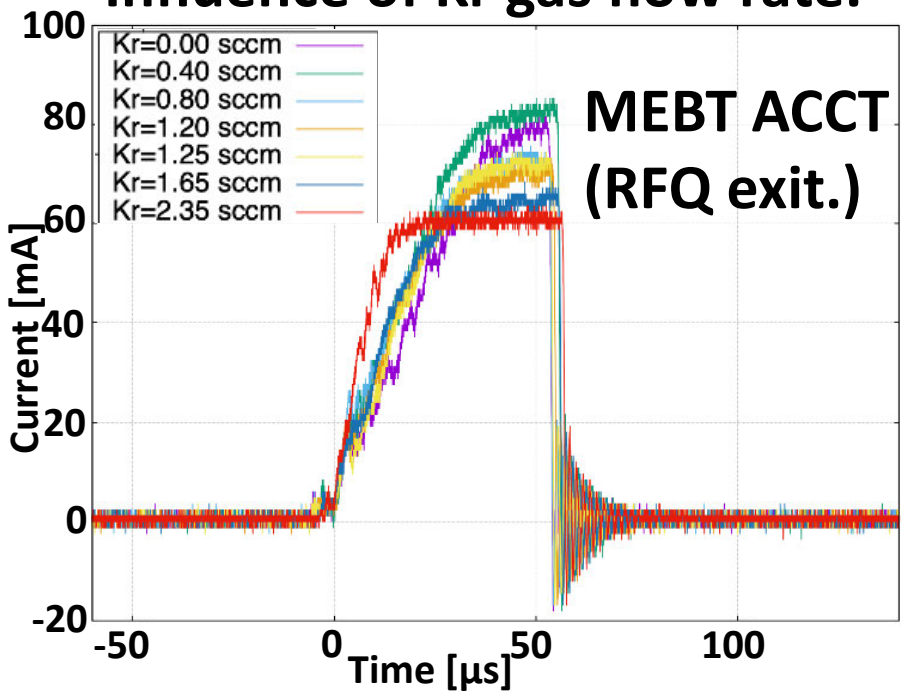

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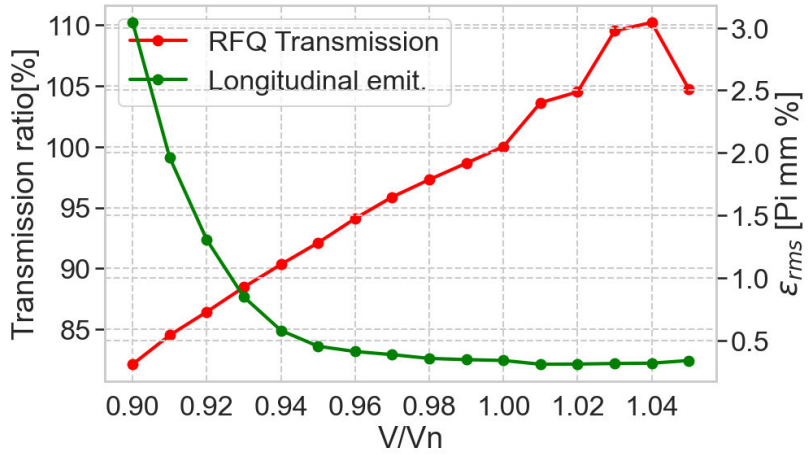
104% (137kV) is better.



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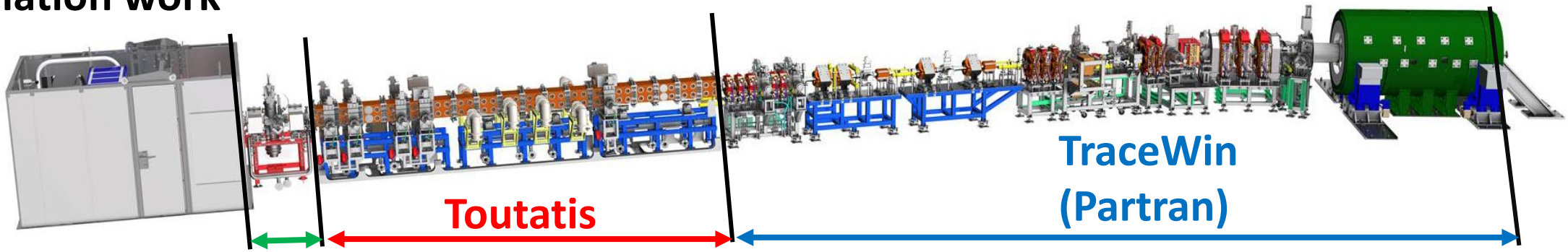

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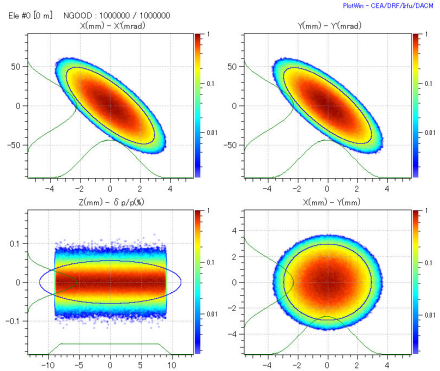
Motivation

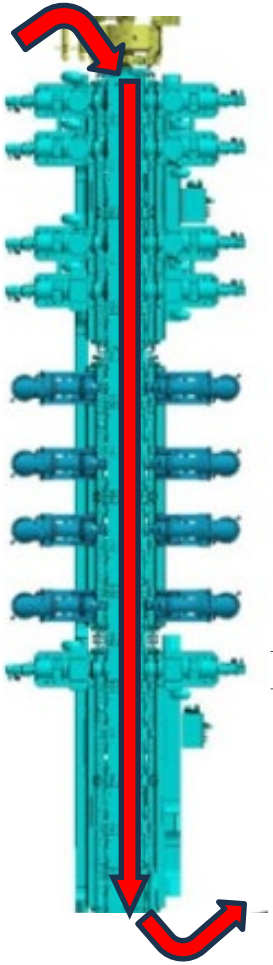
- Reduced RFQ voltage induces spreading distribution following discrete energy levels.
- Phase-C configuration has a cryomodule LINAC with 8 superconducting solenoids and cavities, which has 10W margin of the heat as the whole helium tank.
- Phase-B+ is a good chance to test beam dynamics depend on RFQ voltage, aggressively.
- By testing it in this phase, we are considering to prepare a kind of Interlock for losses in the cryomodule.

Momentum Halo due to the reduced voltage

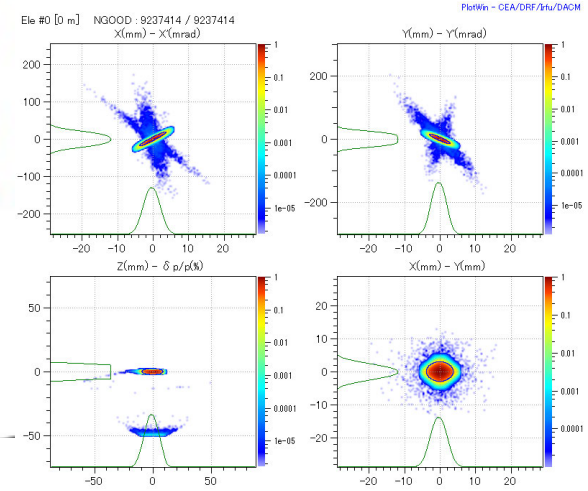
RFQ simulation: applied vane voltage = 90% (119kV) - 105% (138kV)



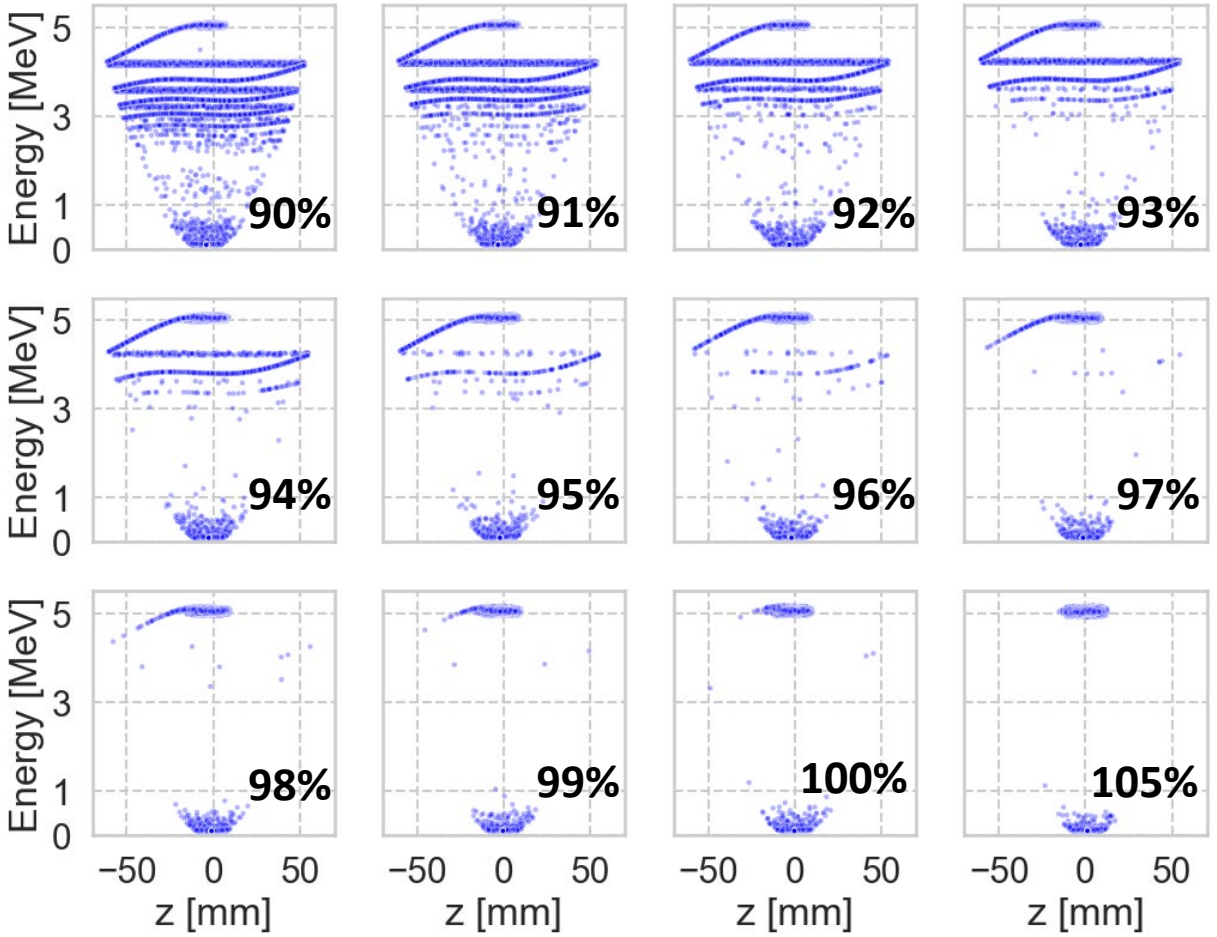
Initial distribution
(reproduced)



Output distribution
(10M particles for design voltage)



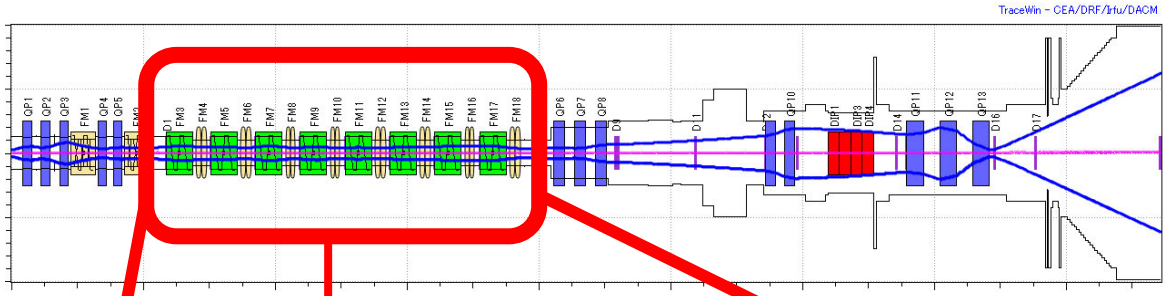
Particle distributions for longitudinal phase space



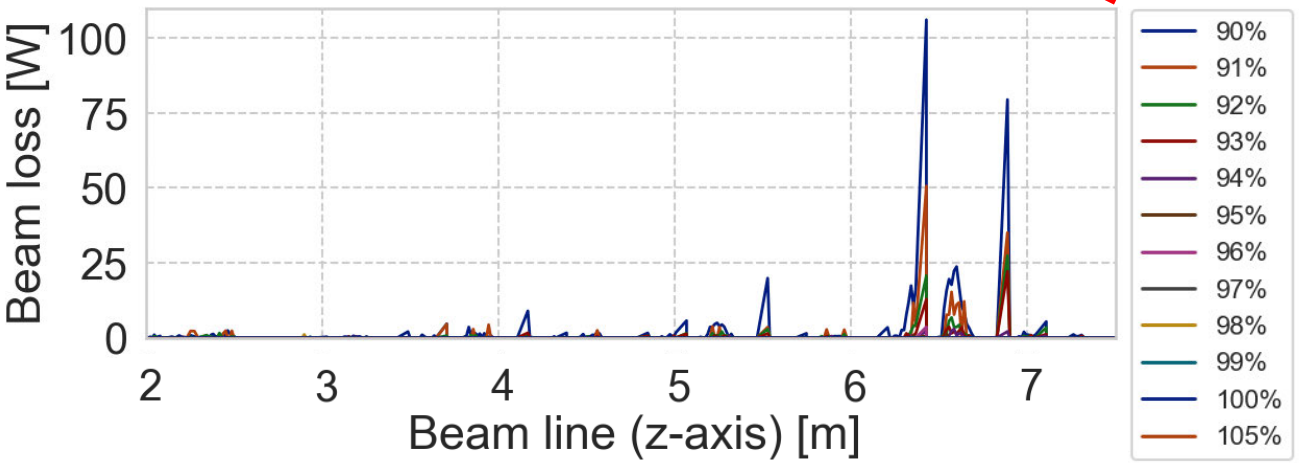
Not property accelerated particles, called “Momentum Halo”, are included in the same duration just after RFQ.

Downstream simulation for the cryomodule

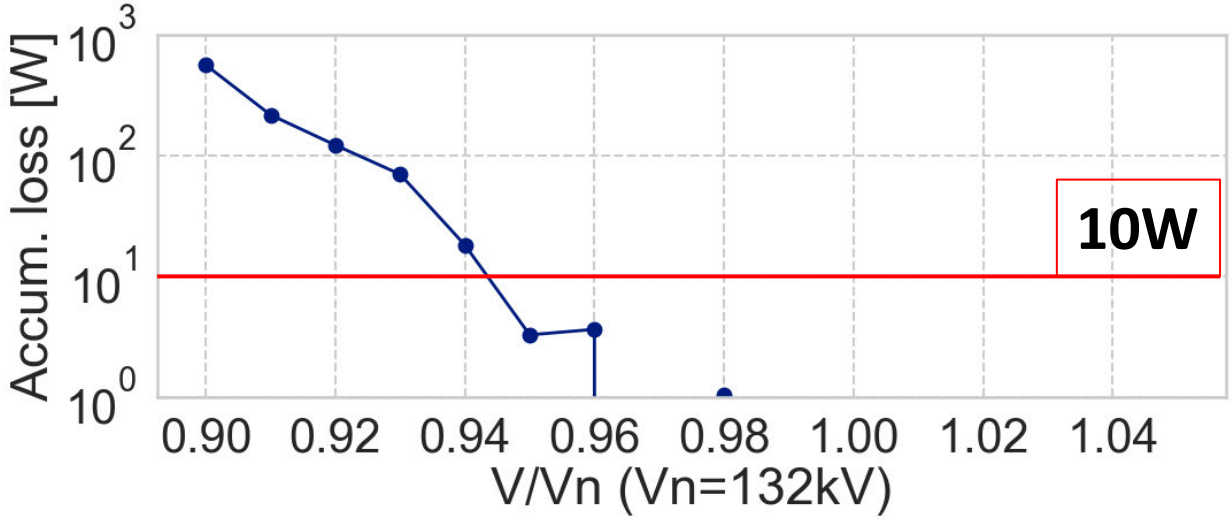
Beam loss in the cryomodule was checked by particle tracking simulation.



Z = 2m – 8m is the section of Cryomodule



RFQ volt. vs accumulated beam loss

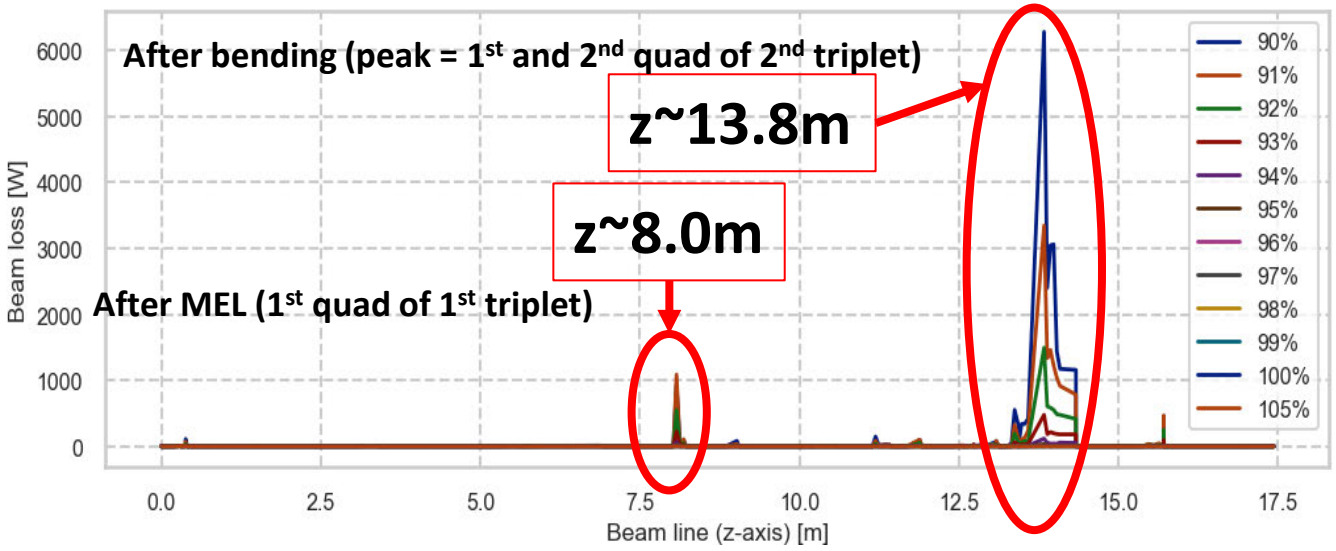


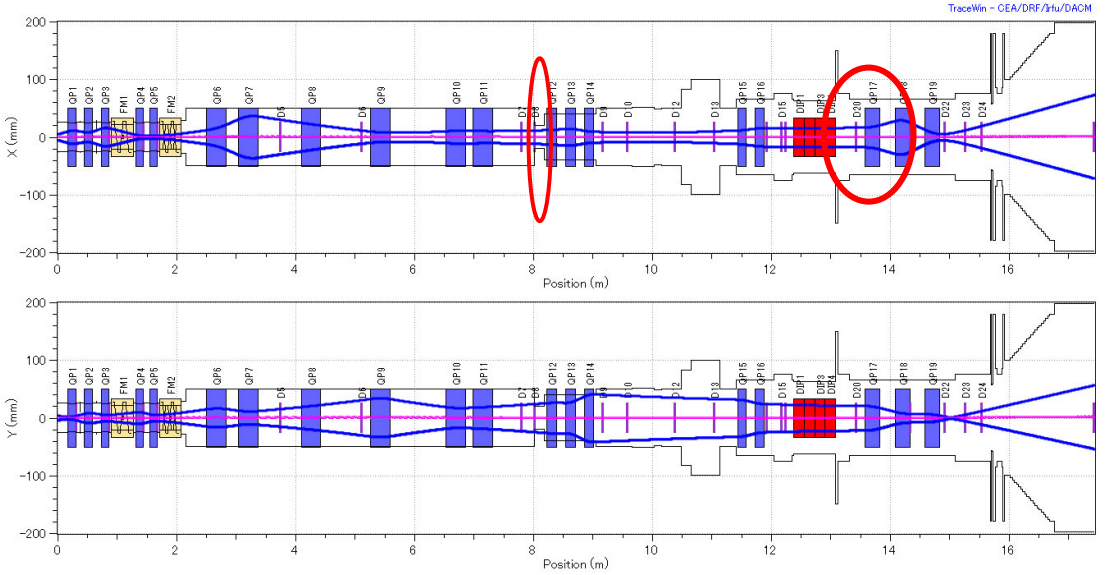
Less than 94% can produce beam loss > 10W in the simulation (1M pt.), without error study.

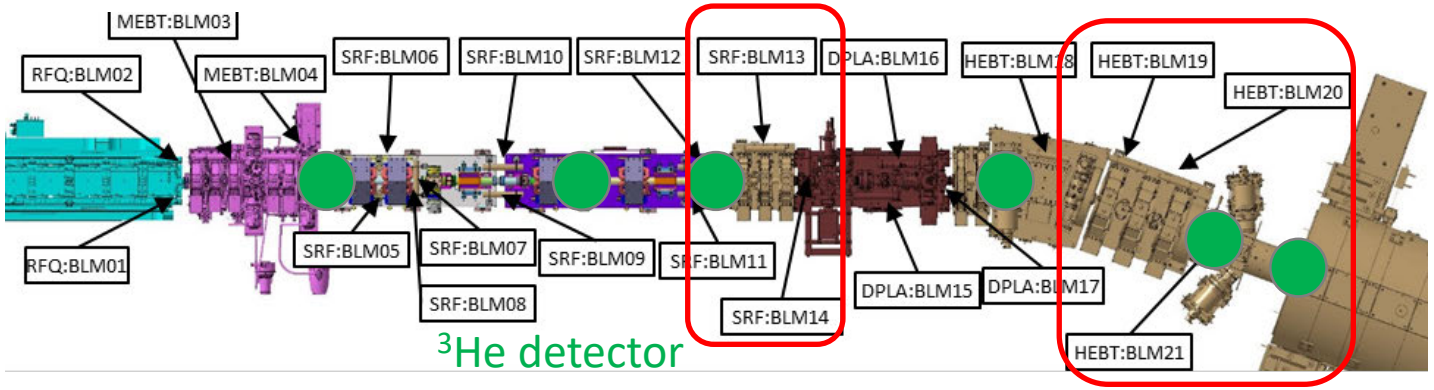
At least, 95% is one threshold.

Check Beam Loss in the Phase-B+

Estimation by tracking simulation was done to know good monitoring position if we can detect the effective beam loss along the downstream BT.







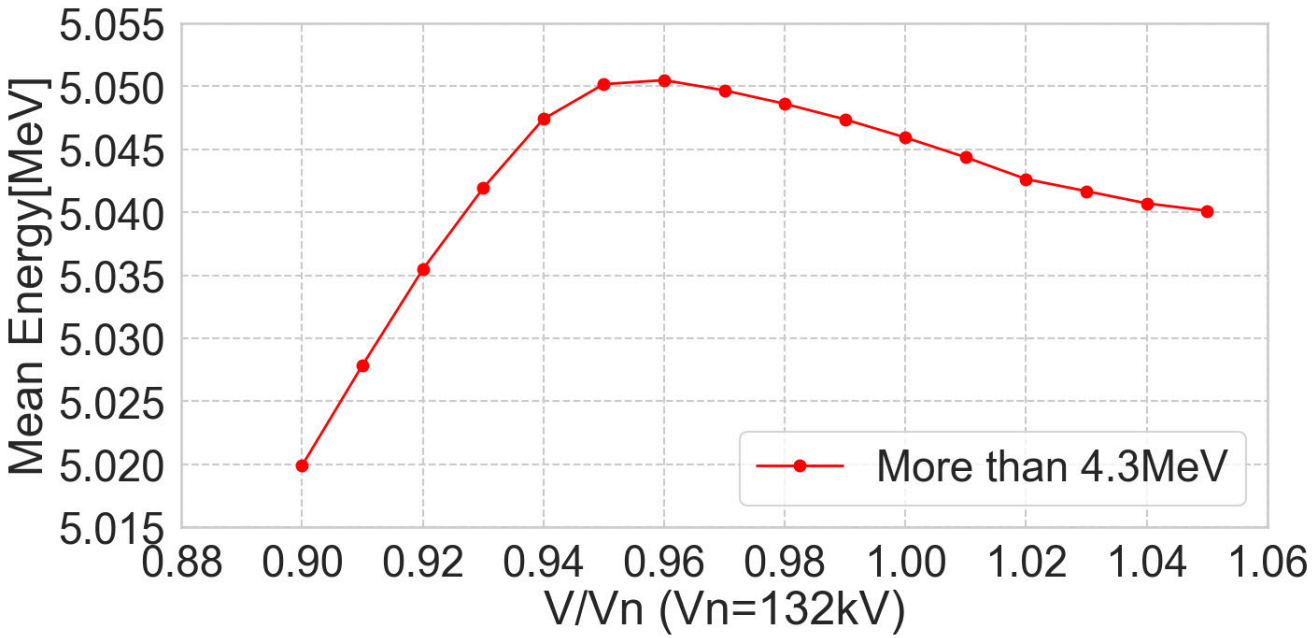
Effective beam loss can be detected by:

- **BLM13 and 14, and 3rd ^{3}He detector (Beam loss around z~8m)**
- **BLM 19, 20, and 21, an 5th and 6th ^{3}He detectors (Beam Loss around z~13.8m)**

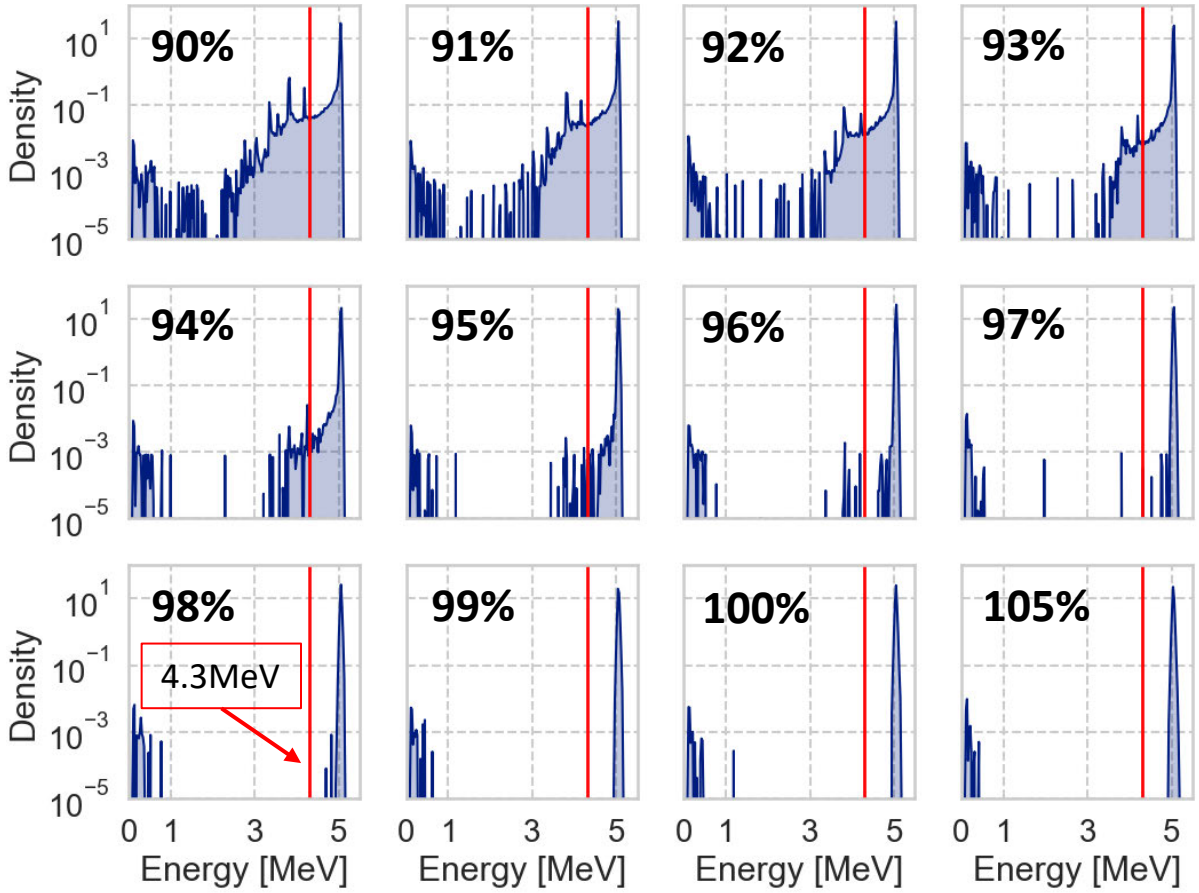
Mean Energy vs RFQ voltage

As a measurable value for our system, mean energy of each bunch is one candidate.

For the RFQ exit beam,
Not accelerated particles → Not detectable in BPM
Only core and its tail → Maybe measurable by ToF
(4.3MeV- particles)



Energy distribution (Logscale)



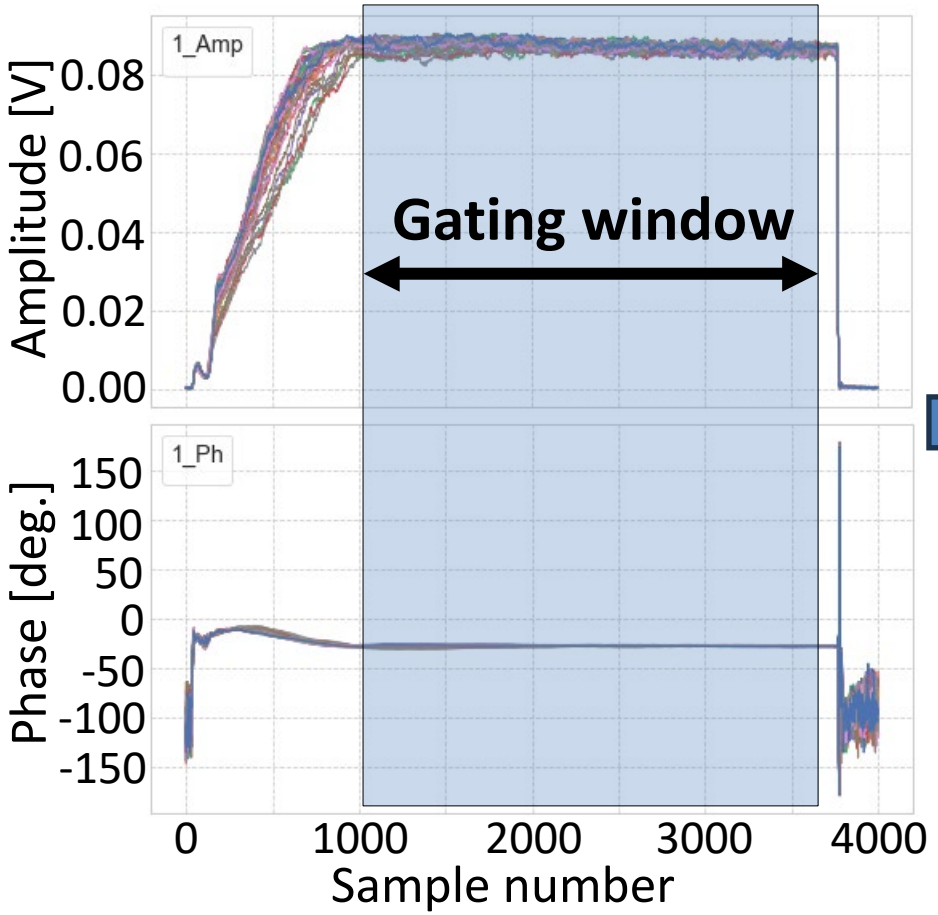
Less than 95%, ~ 5keV resolution is good to distinguish distributions of several RFQ voltages.
Upper region requires ~1keV resolution.

Previous results of BPM
1. I. Podadera, the Proc. of IBIC2019 (2019).

Preliminary test of BPM ToF

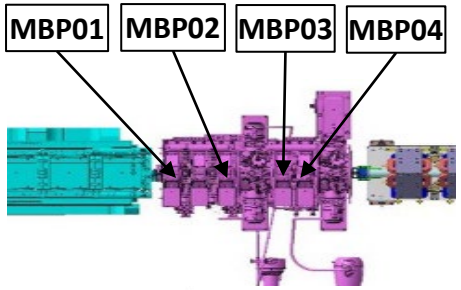
Evaluation of visibility of BPM phase measurement in a pulse.
150μs pulse, 1Hz, 112mA at RFQ exit ACCT

50 pulses raw data: BPM MBP01 electrode-L (+x)

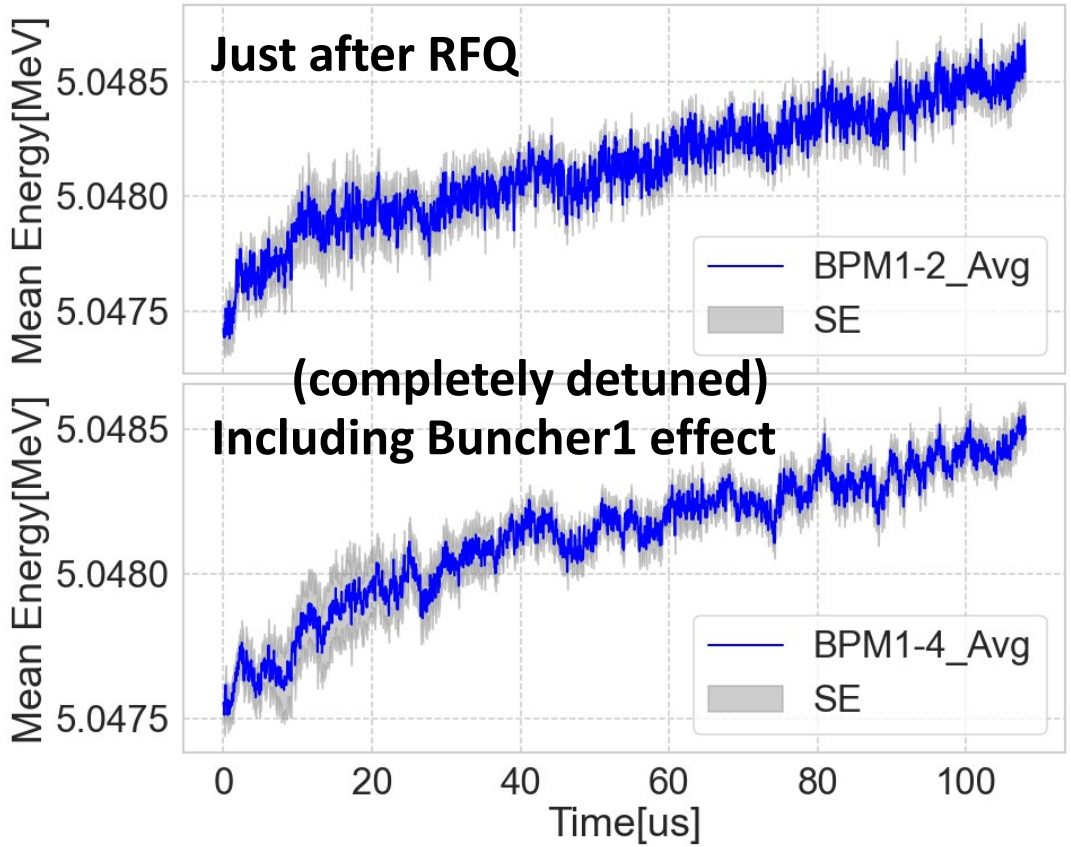


Analyzed (ToF)

Statistics : 50 pulses



Blue : average over 50 samples
Gray area : Standard error



As the mean energy resolution, < 0.5keV for 350MHz can be expected. → Enough to see 1% difference.

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Summary

- LIPAc is now in the beam commissioning Phase-B+.
  - Aims to High current, High DC
- Beam to the BD : 5MeV-112mA D^+ beam in 150us-1Hz DC.
- Good agreement between sim. and meas. for the pilot beam.
- Study of the space charge compensation is being proceeded.

- For momentum halo due to the reduced RFQ voltage,
  - Loss monitor approach near bend is planned in the Phase-B+.
  - Resolution of BPM-ToF looks enough (< 0.5keV) to draw the energy carve.

Thank you for your attention!