Accomplishment of high duty cycle beam commissioning of Linear IFMIF Prototype Accelerator (LIPAc) at 5 MeV, 125 mA D+

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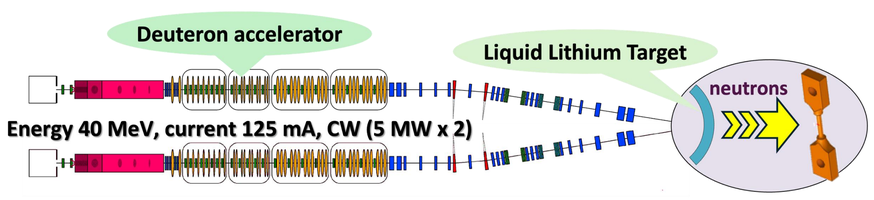
Abstract

The Linear IFMIF Prototype Accelerator (LIPAc) aims at validating the design of the low-energy section of the 40-MeV/125-mA IFMIF deuteron accelerator, thus up to 9 MeV in continuous-wave (CW) operation. While the Superconducting RF Linac (SRF Linac) has been assembled, the LIPAc beamline was operating in the intermediate configuration, namely the Phase B+ commissioning. The main objectives of this phase were to validate the 5-Mev/125-mA deuteron beam acceleration by the RFQ at a high-duty cycle and to characterize the beam properties in preparation for the final configuration with the SRF Linac. In June 2024, the Phase B+ commissioning was completed with the acceleration and transport of a 5 MeV/119 mA deuteron beam at 8.75% duty cycle up to the beam dump.

Introduction

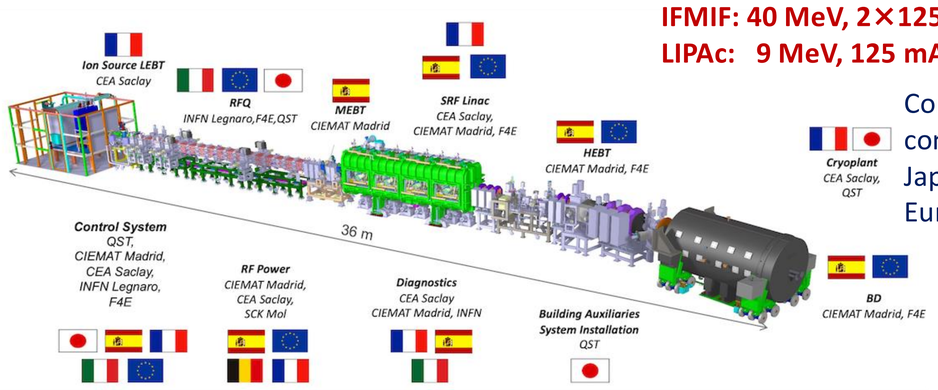
IFMIF (International Fusion Materials Irradiation Facility)



Equivalent to DEMO reactors neutron fluence (up to 20 dpa/y)

Long-term materials behavior verification for DEMO

LIPAc (Liner IFMIF Prototype Accelerator)



IFMIF: 40 MeV, 2×125 mA, CW
LIPAc: 9 MeV, 125 mA, CW

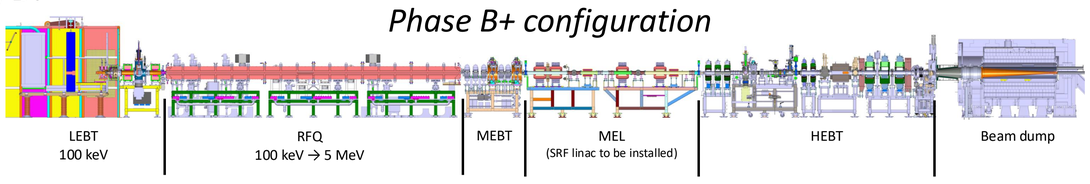
Commissioning is being conducted in Rokkasho, Japan, jointly between Europe and Japan.

High-duty deuteron beam test (Phase B+)

Objectives of Phase B+

- Demonstration of high duty cycle deuteron beam acceleration by RFQ (5 MeV, 125 mA, up to CW).
- Validation of the HEBT and the Beam dump (first time in operation).
- Characterization of beam to be injected into SRF in subsequent Phase C/D.

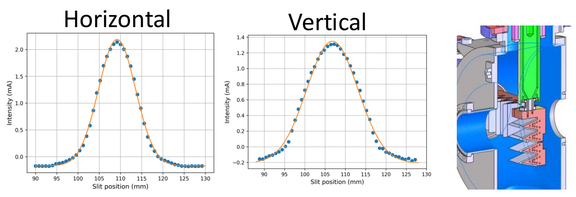
Phase B+ configuration



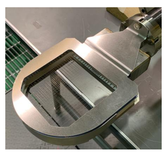
Diagnostics & Beam transport optimization

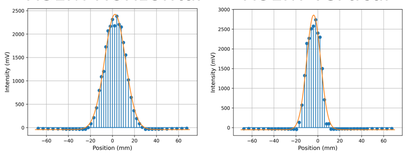
Transverse beam profiles measured by the interceptive diagnostics

DPlate SLITs (H/V) + CT



Secondary Emission Monitor (SEM) grid

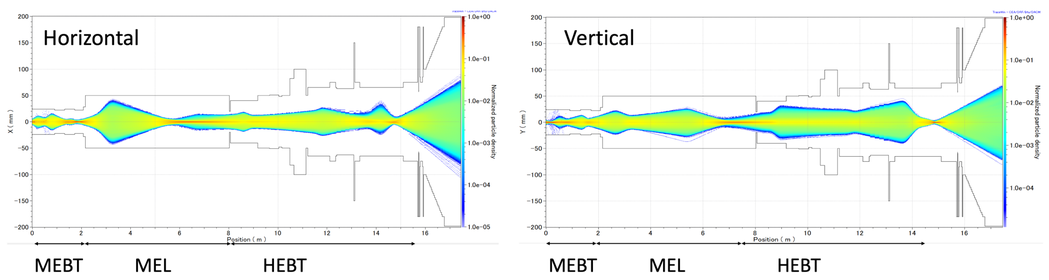




Following the observation of unexpected particle loss, the beam modeling was improved.

- Simulation using the exact quad field distribution, fully implementing fringing fields instead of the hard-edge model.
- Beam-based calibration of quadrupole magnet *g* (T/m) to *I* (A).

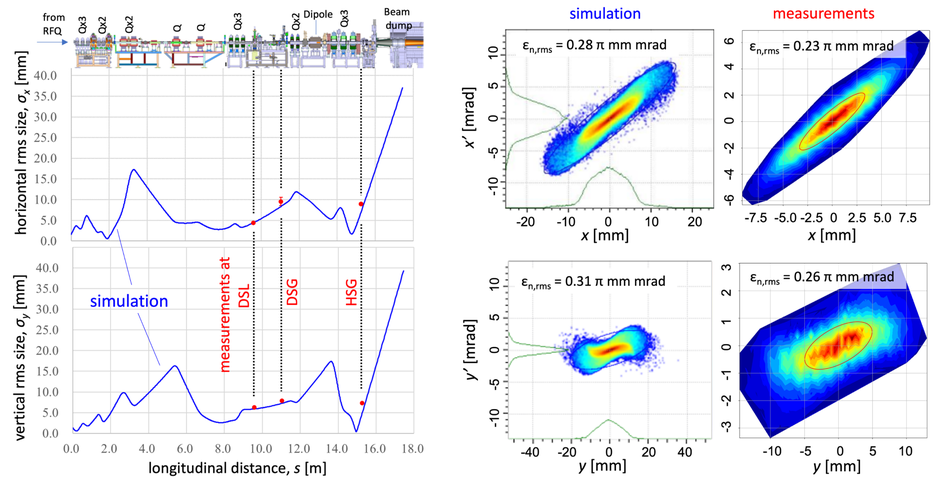
Updated beam optics with calibrated conversion factor and Fringe Field model



Outcome

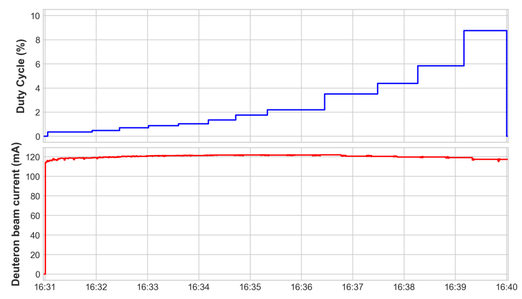
Validation of beam transport simulation

- Good agreement between measurement and simulation.
- Beam losses are significantly reduced.

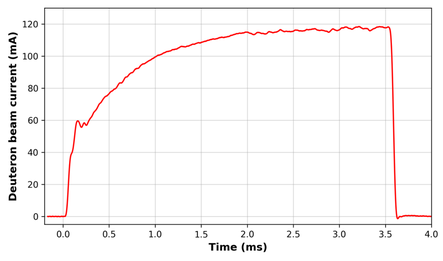


Maximum duty cycle of 8.75 % achieved

- 119 mA at HEBT, RFQ transmission is ~90% (consistent with RFQ design)
- RFQ average beam power: 40-45 kW



Beam current waveform at duty 8.75%



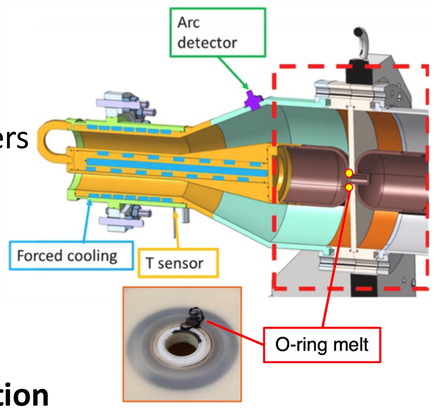
Challenges in high-duty operation

RFQ-RF: 175 MHz, 200 kW (design) x 8 chains
Nominal RFQ cavity voltage: 132 kV

Vacuum leak event occurred in March 2022
Viton O-rings were melted/deformed in 5/8 couplers

Identified multipacting as the cause of O-ring overheating.
Duty cycle was limited to 10% max in Phase B+ to avoid RFQ coupler damage.

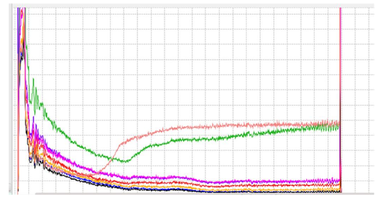
Present coupler (using EPDM O-ring)



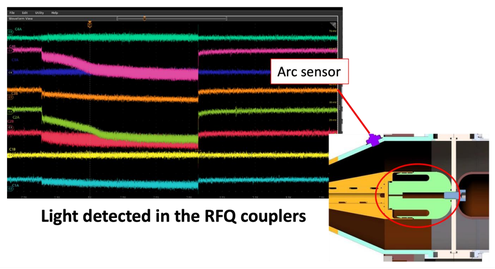
RFQ O-ring Coupler behavior at high-duty operation

- Confirmation that a duty increase of up to 10% is difficult with current RFQ O-ring couplers.

→ Preparation of brazed couplers for high-duty operation is ongoing.



Reflected power in the RFQ-RF chains



Light detected in the RFQ couplers

Conclusion

- Successfully demonstrated high-duty cycle operation of the LIPAc, achieving 8.75% duty cycle and 119 mA D+ beam current. HEBT and BD, were validated, and beam transport simulations were validated through experimental comparison.
- These achievements establish a solid foundation for future progress towards CW operation to demonstrate the IFMIF accelerator concept.
- A key challenge was RFQ RF couplers overheating due to multipacting; high-power tests of brazed couplers are ongoing.

Acknowledgements

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