The IFMIF/EVEDA Project

Hervé DZITKO – F4E

DONES Business Info Day

Embassy of Spain, Tokyo, Monday 4 December 2023

Target Facility

Accelerator Facility

Test Facility

IFMIF/EVEDA Project

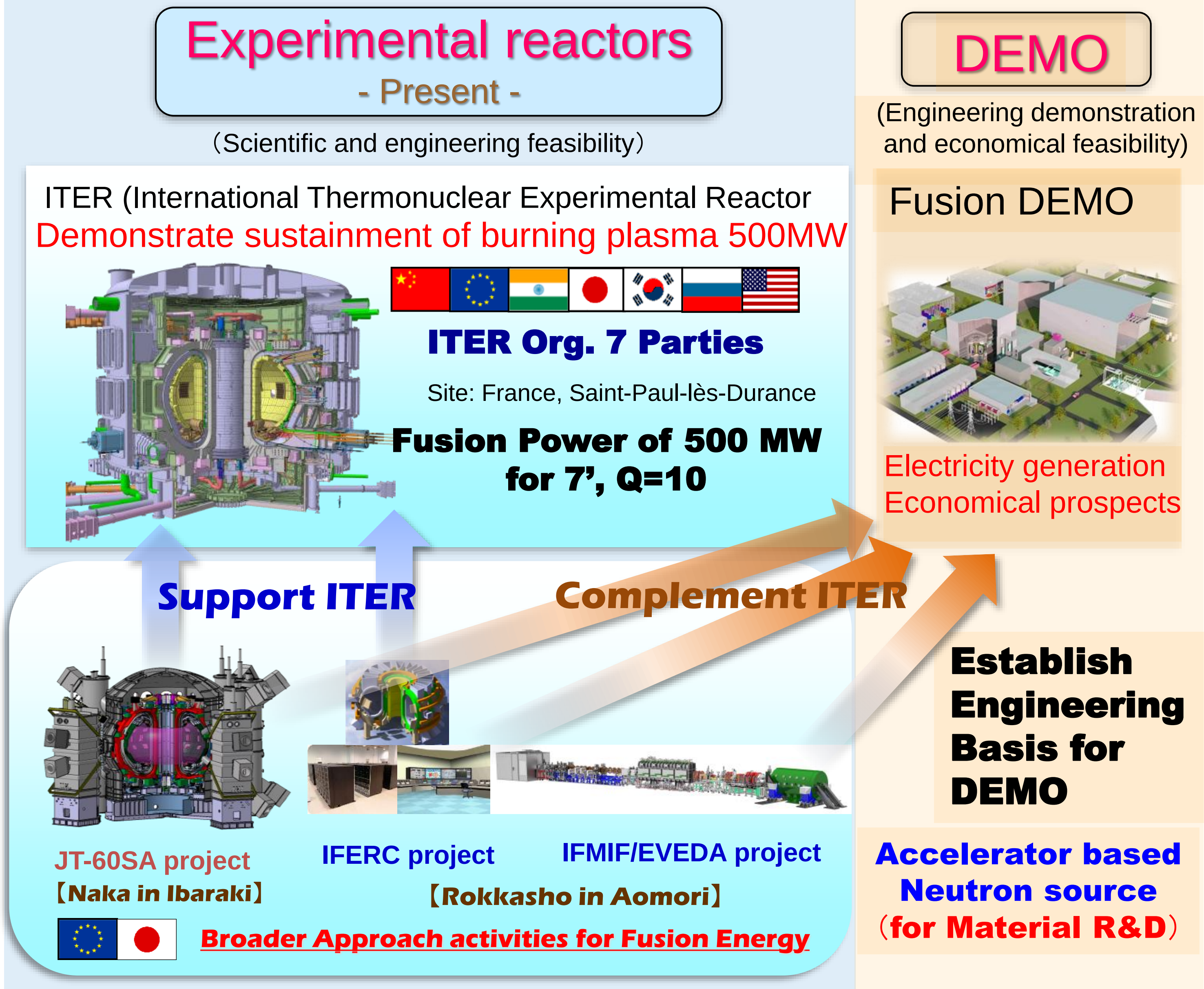
Outline

1. Broader Approach Initiative
2. Broader Approach Agreement
3. IFMIF/EVEDA
4. LIPAc concept and status
5. EU industry involved in the LIPAc project
6. Conclusion

The Broader Approach Initiative

Background

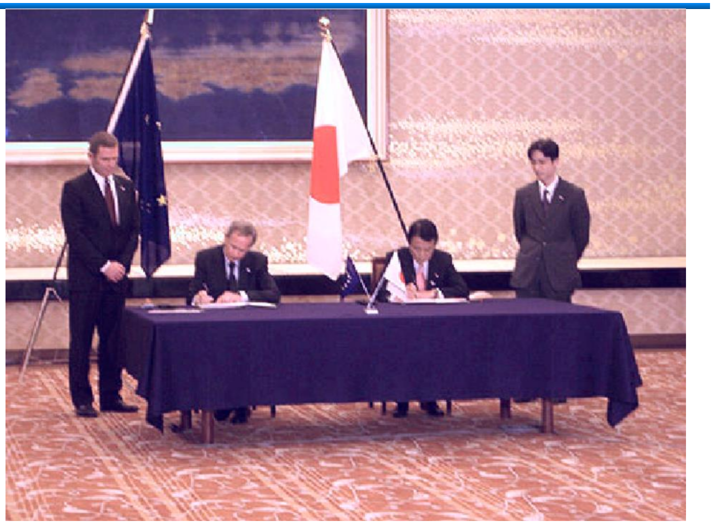
- Designed in 2005 during ITER negotiations as a “privileged partnership” between **Euratom,** represented by the **European Commission**, and **Japan**, represented by **MEXT** (Ministry of Education, Culture, Sports, Science and Technology)
- **Complementary of the ITER project** and **foster fusion energy research for early realization of commercial fusion power**
- **Activities to support to ITER and DEMO structured in 3 Projects**:
  - **STP**, the Satellite Tokamak Programme Project JT-60SA
  - **IFERC**, the International Fusion Energy Research Centre
  - **IFMIF/EVEDA**, the Engineering Validation and Engineering Design Activities for the International Fusion Materials Irradiation Facility
  - All located in Japan
- In practice ➔ Work carried out by **two Implementing Agencies**:
  - QST National Institutes for Quantum Science and Technology for JA
  - FUSION FOR ENERGY **F4E** for EU



The Broader Approach Agreement

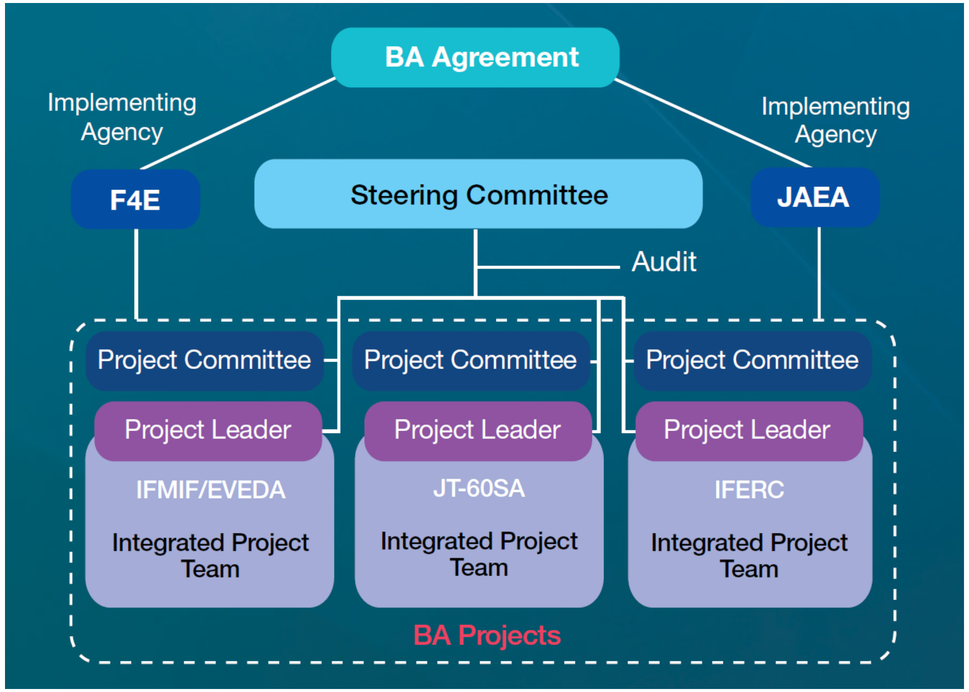
Agreement

- **Broader Approach Agreement signed on February 5, 2007 in Tokyo**
- Entered into force on June 1, 2007, for at least 10 years
- 2020, Europe and Japan took stock of the progress made, recognized this **highly successful collaboration** and reaffirmed their **commitment to continuing their joint activities**.
- March 2, 2020 Euratom and Japan **signed a joint declaration prolonging the duration of BA activities**
  - ➔ Start of a second phase **focused on exploiting the facilities that have already been built** and on **working closely with ITER**



BA governance

- **JA and EU equally represented in the SC**
- Main responsibilities: BASC
  - Steers the 3 Projects
  - Supervises activities
  - Appoints Project Leaders, and PT staff
  - Approves structure of the PT, Project Plans, Work Programs, annual reports
  - Decides on the participation of any other ITER parties



The Broader Approach Agreement

BA phase I key facts

- Japan and Europe contributed equally a fixed amount to the Broader Approach
- Nominal values: 339 M€ + 46 B¥ (June 2005 values) = 1000 kBAUA (BA Unit Account)
- 80% of the EU contribution came from Voluntary contributors
- Remaining 20% from Euratom via F4E
- **Phase I ➔ Mostly design and construction phase successfully implemented**
- The overall cost planned was maintained and **99.8 % of the planned credits in BA phase I** were released by its completion
- Scientific partnership between EU and JA hailed as a success to the extent that **policy-makers are using the same model for the establishment of DONES**

BA phase II novelties

- **Phase II focuses on operating, enhancing, and exploiting the facilities that have already been set up**, for the benefit of both parties
- Broader Approach teams work more closely with ITER ➔ **Trilateral agreement between IO, QST and F4E** signed on 20 Nov. 2019 followed by Cooperation Arrangements between BA and IO
- **No end date**, **objectives and financial contributions are set annually by both parties**
- A sliding 5-year Project Plan is submitted for approval to the BASC every year

FUSION FOR ENERGY

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GOBIERNO DE ESPAÑA, MINISTERIO DE ECONOMÍA, INDUSTRIA Y COMPETITIVIDAD, Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, EPFL

INFN, CONSORZIO RFX Ricerca Formazione Innovazione, ENEA ITALIAN NATIONAL AGENCY FOR NEW TECHNOLOGIES, ENERGY AND SUSTAINABLE ECONOMIC DEVELOPMENT

EUROfusion

QST

Nagoya University, Tohoku University, Tokyo University, Kyushu University, Hachinohe Institute of Technology, LHD NIFS, Hachinohe National College of technology, Osaka University

IFMIF/EVEDA


Li target
HFTM
HELOKA loop in Karlsruhe
ELTL in Oarai
Lipac phase B+
Clean Room in Rokkasho
RFQ

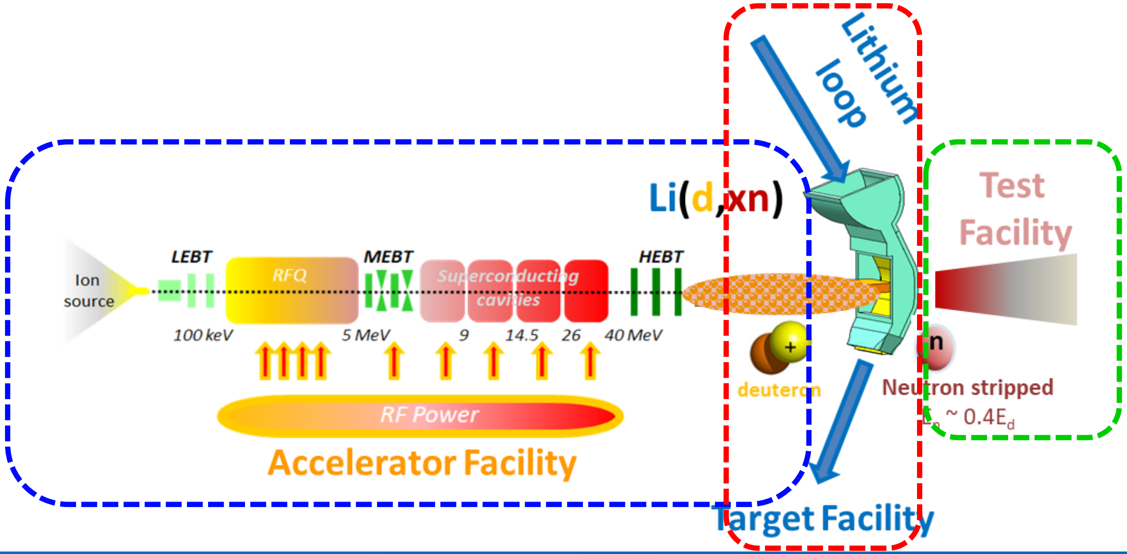
Why a Fusion Neutron Source?

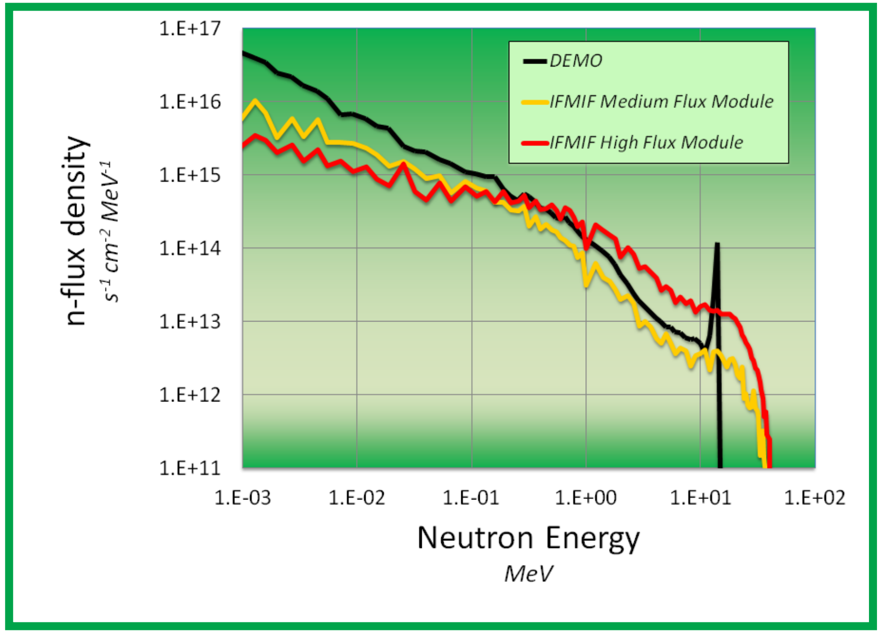
1. Selection and qualification of candidate materials for fusion reactors
2. Necessity to have a similar neutron energy spectra with suitable fluxes compatible with the fusion roadmap
3. Engineering data bases for design, licensing and safe operation of DEMO up to end-of-life

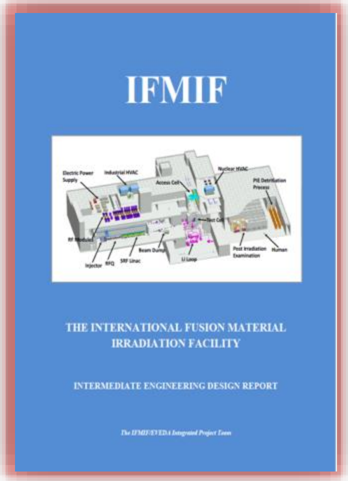
➔ Best option for satisfying the requirements of high neutron flux and Energy: **accelerator-driven neutron source using D-Li nuclear stripping reaction**

➔ IFMIF concept and the IFMIF EVEDA programme carried out by Japan Europe under the BA agreement

➔ **IFMIF/EVEDA concept retained for IFMIF/DONES**





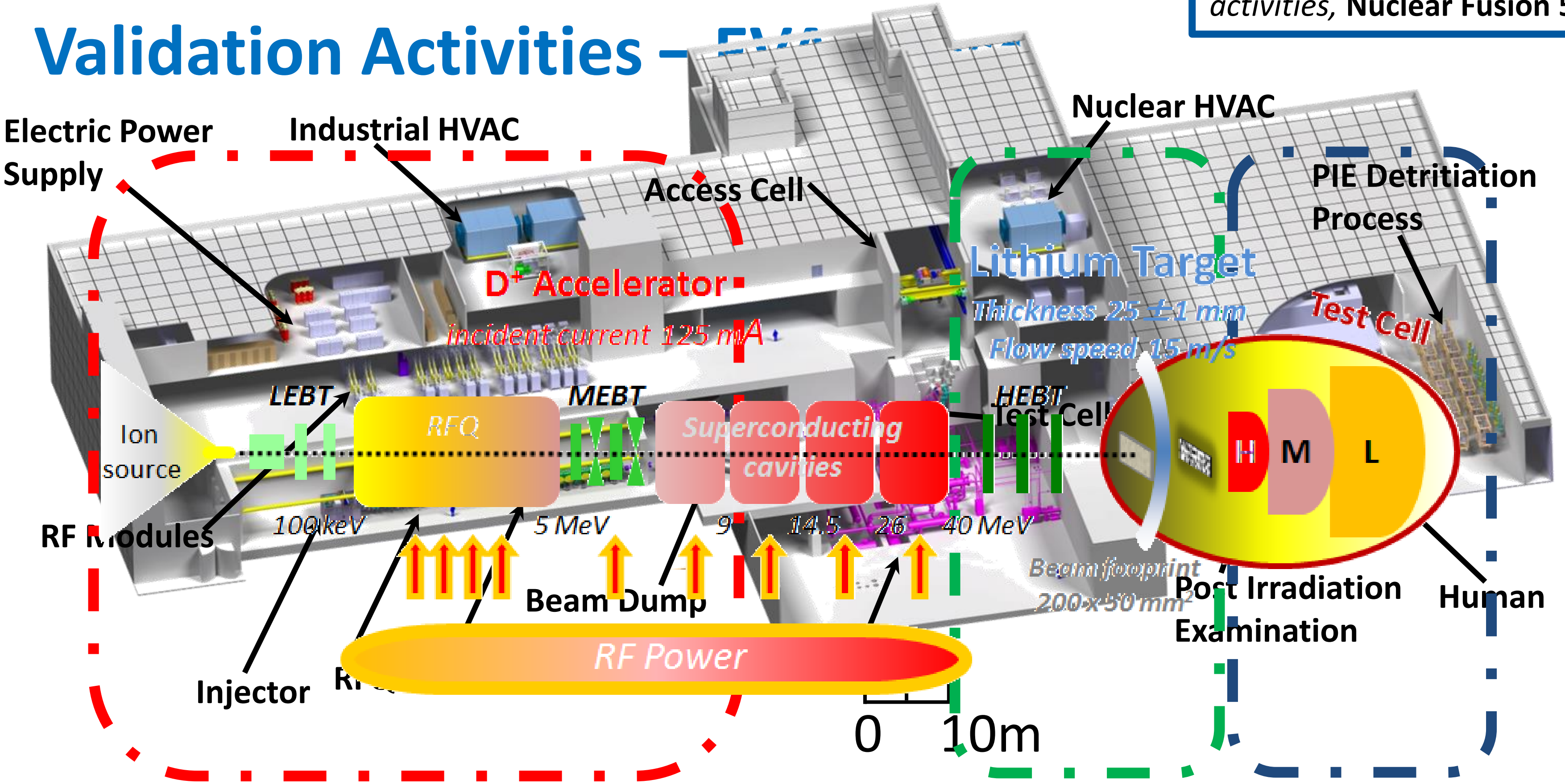


Engineering Design Activities – EDA phase

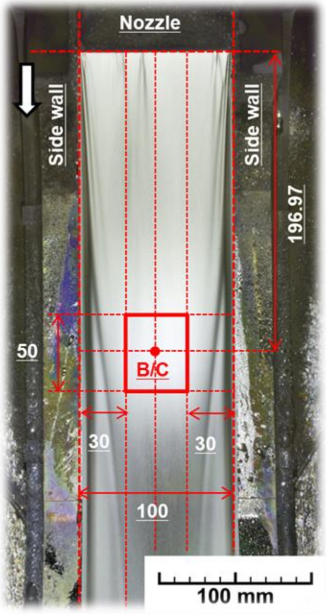
Successfully delivered on schedule in 2013

J. Knaster et al., *IFMIF: overview of the validation activities*, **Nuclear Fusion 53 (2013) 116001**

Validation Activities –



IFMIF/EVEDA Project – EVA Phase



Test Facility Completed in 2015

FNSD Activities restarted within BA II to complement the engineering design of the IFMIF FNS

Y. Carin et al, IFMIF/EVEDA Achievements Overview, ISNFT15
D. Jimenez et al, Overview of European Fusion Neutron Source activities within the IFMIF/EVEDA Project, ISNFT15

Target Facility

Li Test Loop operati
completed in 2015
Completion of Li er
corrosion tests in 2

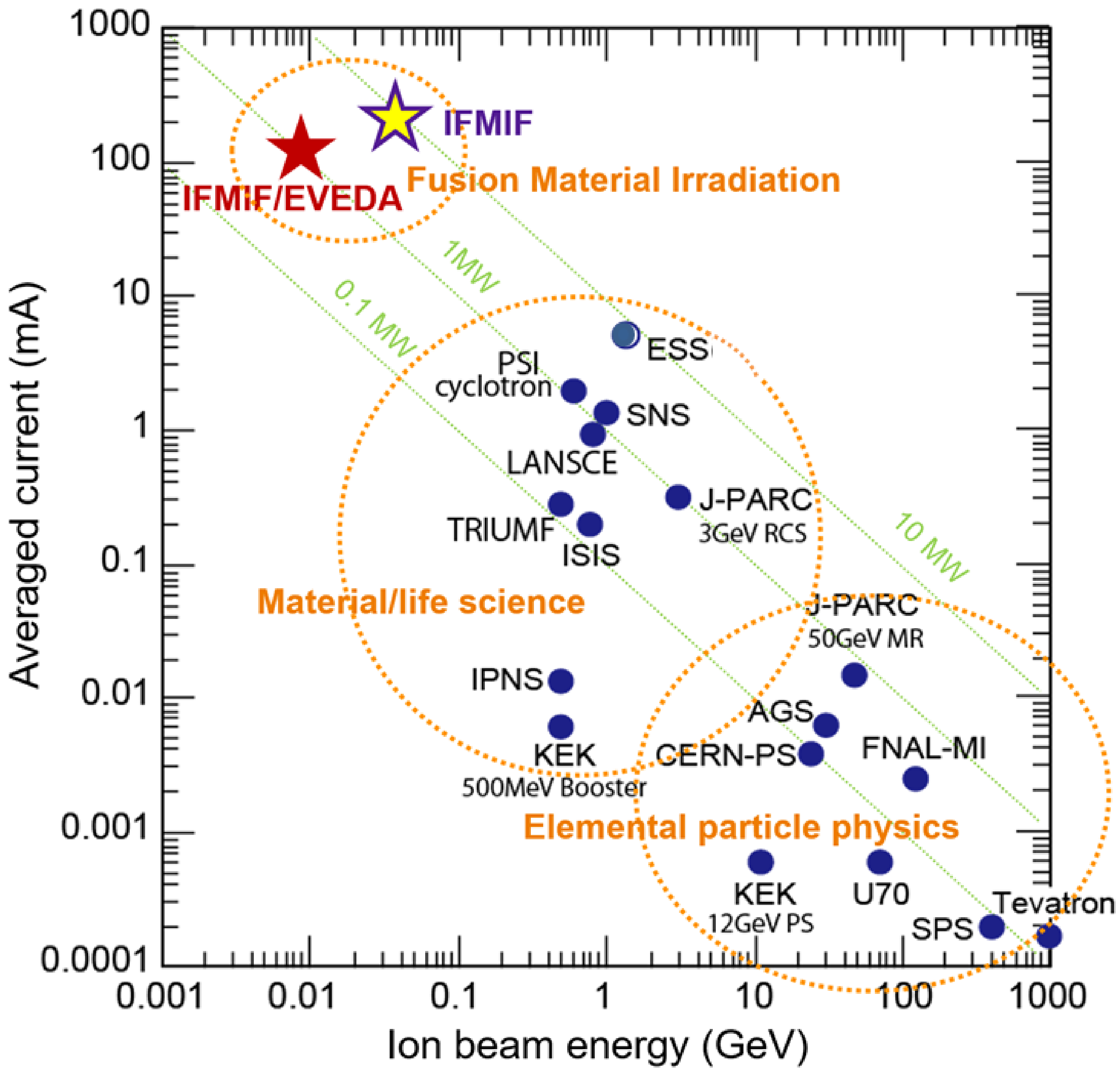
LIPAc: Demonstrator for DONES and A-FNS accelerator concepts

Commissioning on going

LIPAc: a compact but very challenging accelerator

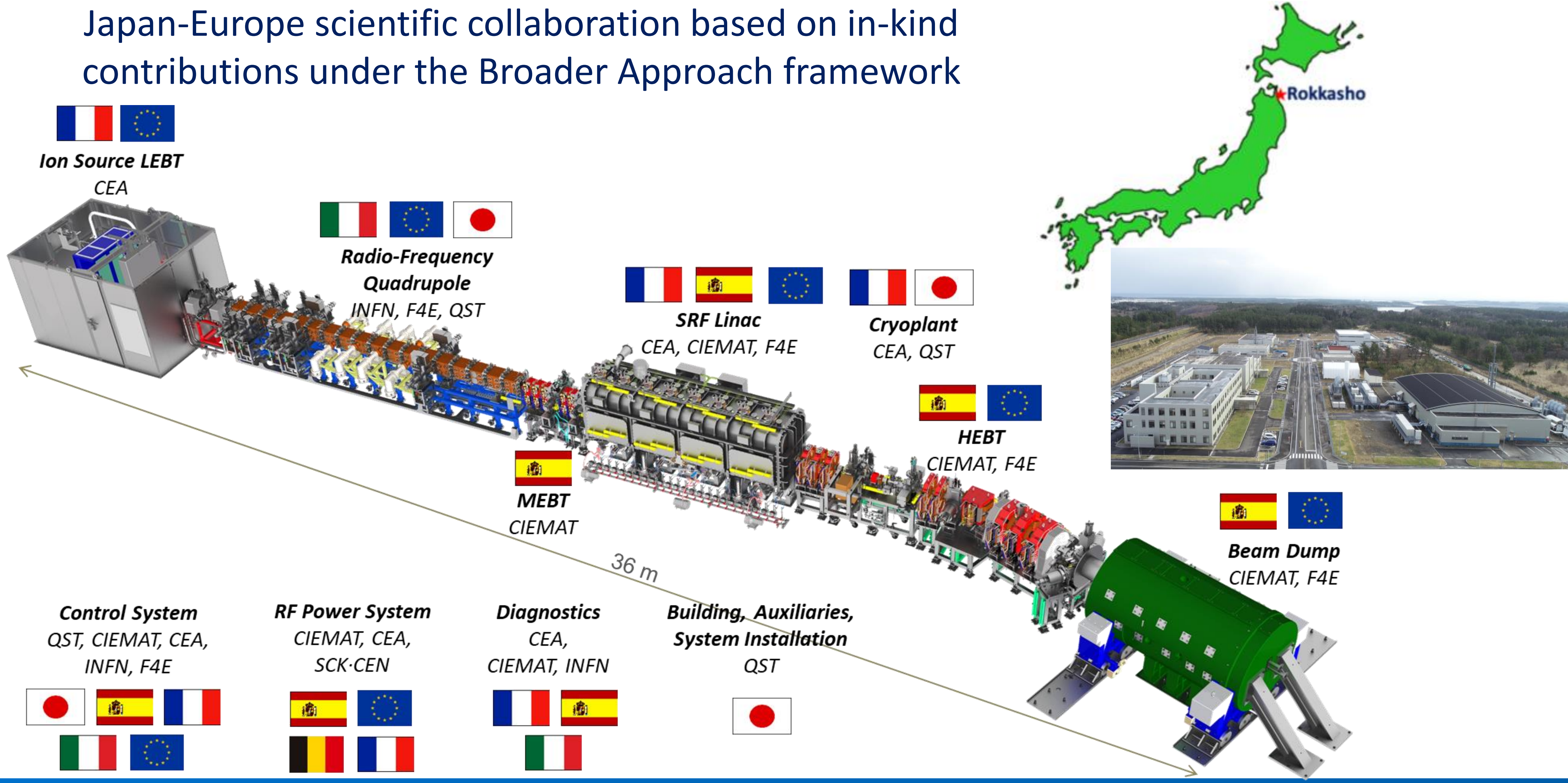
Main Challenges

- **High Current:** 125 mA, Deuteron
  - ➔ High space charge effects
- **High Duty Cycle:** 100 % (CW)
- World's highest current linac in CW
- Very high average beam power: 1.125 MW
- World's longest RFQ with highest beam current: 9.78 m
- World's highest light hadron current through SRF cavities
- High Beam loading in resonant cavities
- Highest Beam perveance



LIPAc Engineering Validation in Rokkasho

Japan-Europe scientific collaboration based on in-kind contributions under the Broader Approach framework

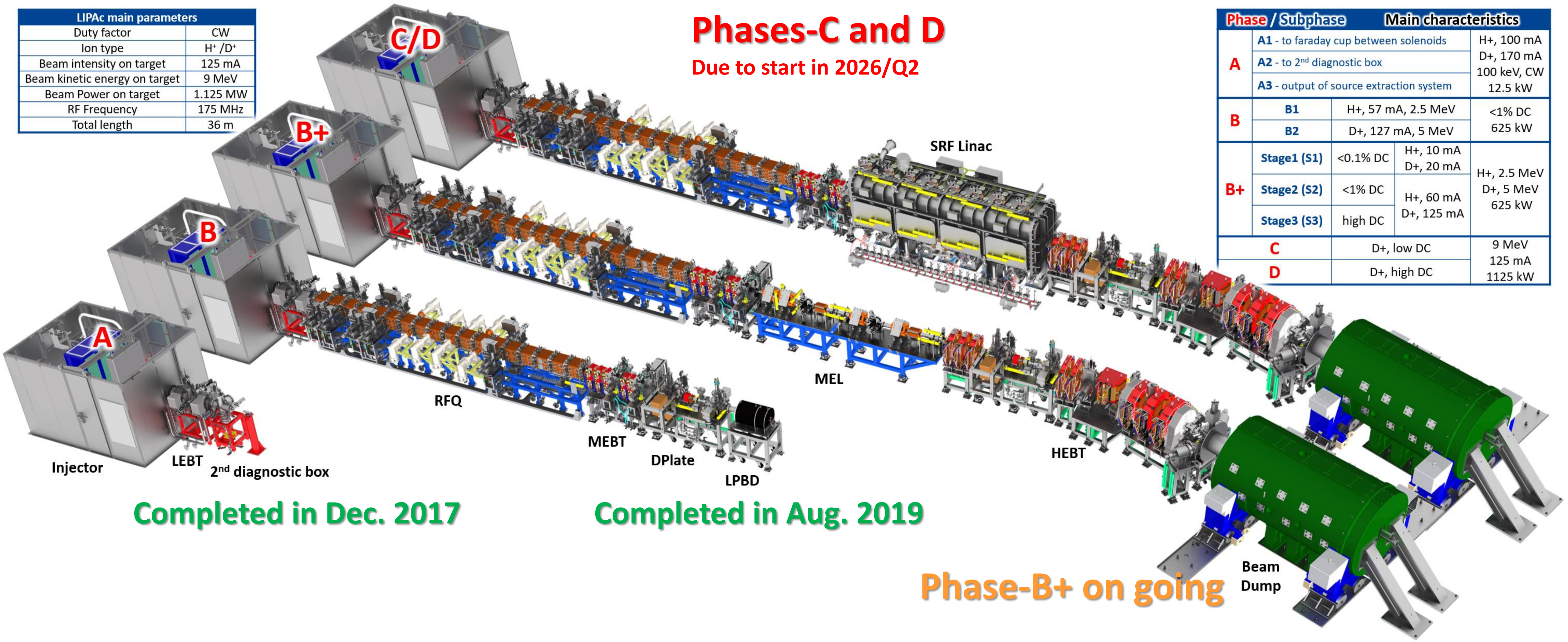


LIPAc commissioning with tiered approach

5 Phases and 4 configurations

LIPAc main parameters	
Duty factor	CW
Ion type	H^+ /D^+
Beam intensity on target	125 mA
Beam kinetic energy on target	9 MeV
Beam Power on target	1.125 MW
RF Frequency	175 MHz
Total length	36 m

Phase / Subphase				Main characteristics
A	A1 - to faraday cup between solenoids			H+, 100 mA D+, 170 mA 100 keV, CW 12.5 kW
	A2 - to 2nd diagnostic box			
	A3 - output of source extraction system			
B	B1	H+, 57 mA, 2.5 MeV		<1% DC 625 kW
	B2	D+, 127 mA, 5 MeV		
B+	Stage1 (S1)	<0.1% DC	H+, 10 mA D+, 20 mA	H+, 2.5 MeV D+, 5 MeV 625 kW
	Stage2 (S2)	<1% DC	H+, 60 mA D+, 125 mA	
	Stage3 (S3)	high DC		
C		D+, low DC		9 MeV 125 mA 1125 kW
D		D+, high DC		



LIPAc commissioning with tiered approach

Phase A completed in Dec. 2017

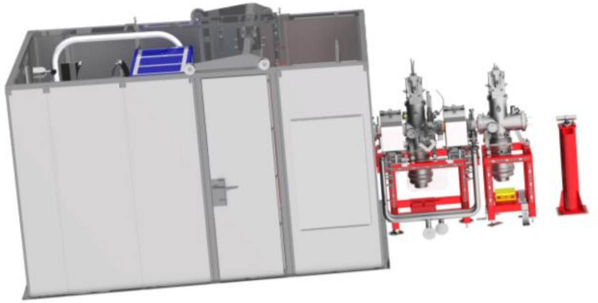
Validation of the injector concept

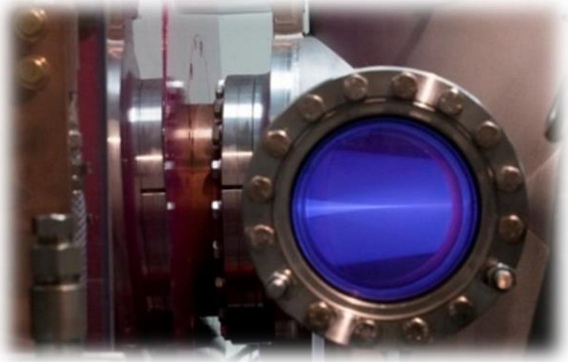
155-mA D+ Beam extracted with suitable characteristics

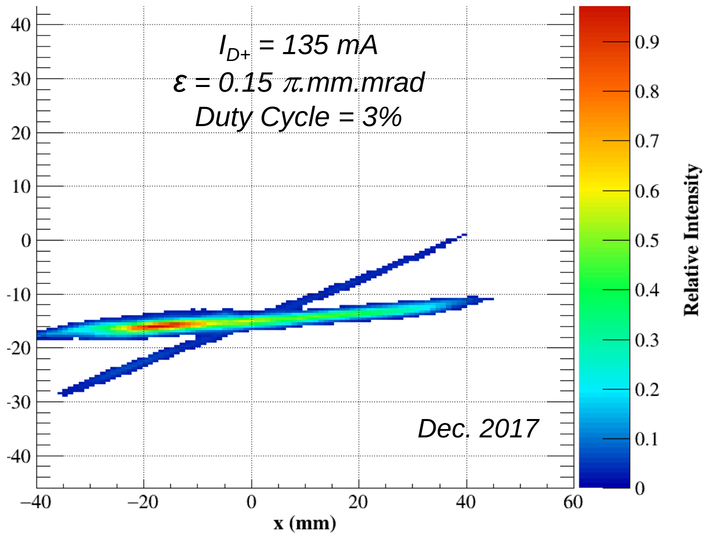
100 keV - 125 mA

12.5 kW CW

Injector







R. Gobin et al., IFMIF injector acceptance tests at CEA/Saclay: 140 mA/100 keV deuteron beam characterization, Rev. Sci. Instr. 85, 02A918 (2014)

Y. Okumura et al., Operation and commissioning of IFMIF LIPAc injector, Rev. Sci. Instr. 87, 02A739 (2016)

N. Chauvin et al., Deuteron beam commissioning of the linear IFMIF prototype accelerator ion source and low energy beam transport, 2019 Nucl. Fusion 59 106001

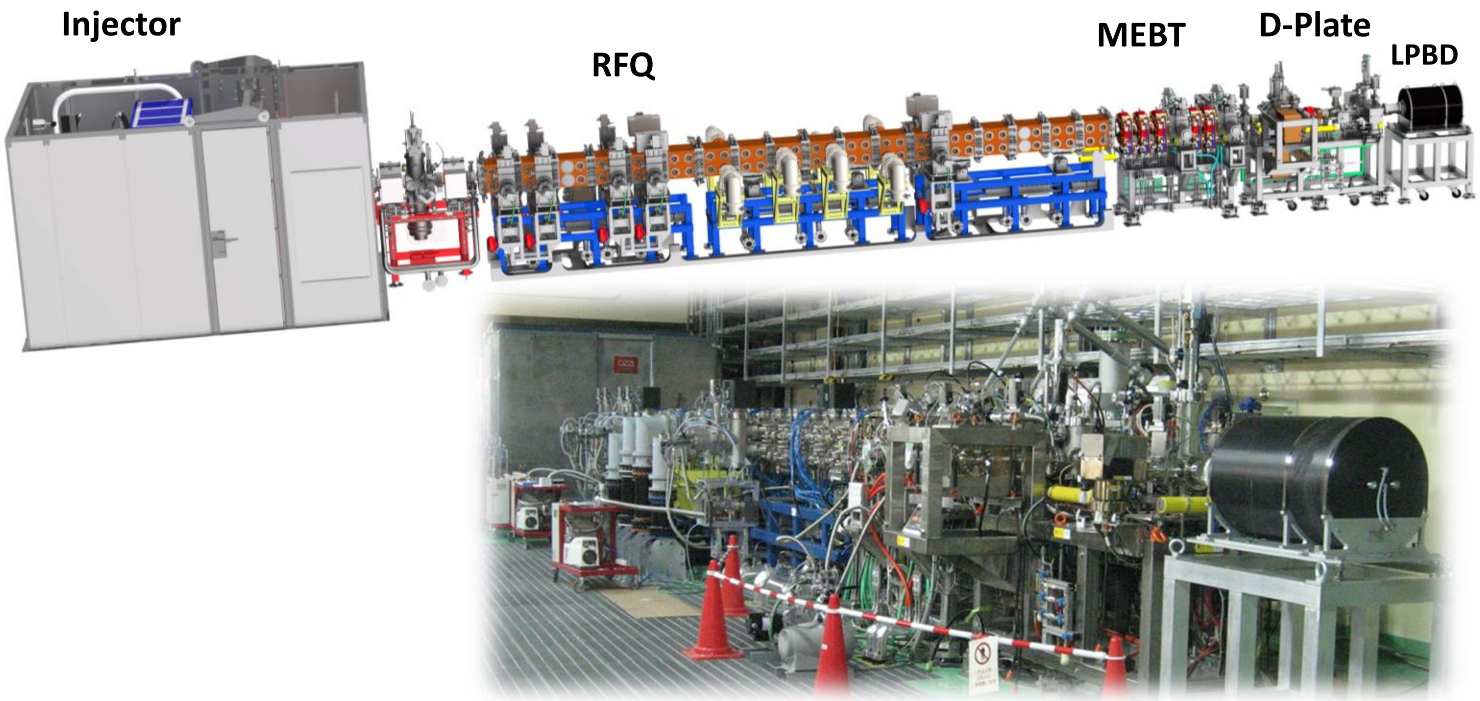
LIPAc commissioning with tiered approach

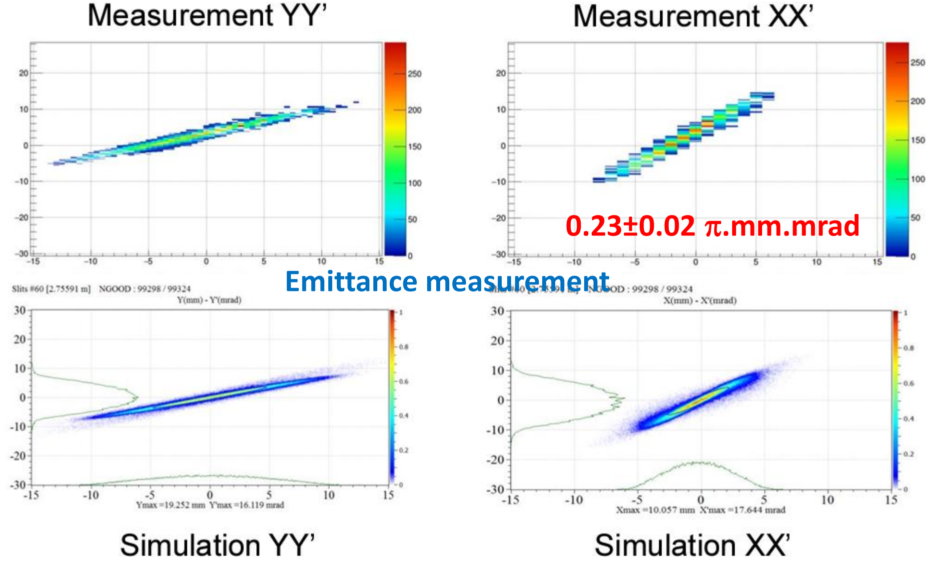
Phase B : completed in Aug. 2019

Validation of the RFQ from beam physics standpoint

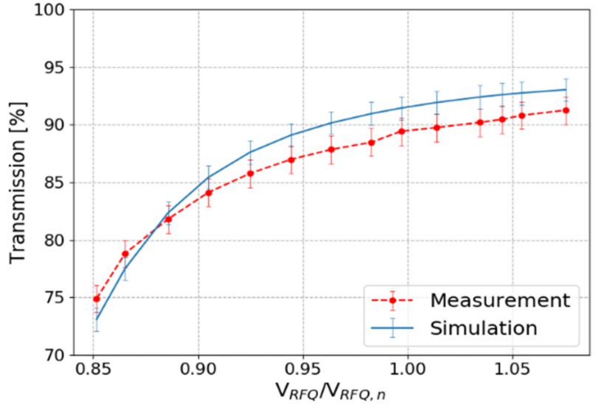
5 MeV - 125 mA

625 kW, pulsed up to 0.1 % DC





- **125 mA D^+** (macro-pulse peak) through RFQ reached on 9th Aug 2019 [1,2] ➔ World record broken



- **Confirmation of designed beam dynamics** in terms of beam transmission through RFQ [3].
- No significant trace of unexpected beam loss [4].

[1] H. Dzitko et al., Status and future developments of the Linear IFMIF Prototype Accelerator (LIPAc), Fusion Eng. Des. 168 (2021) 112621.
[2] K. Kondo et al., Validation of the Linear IFMIF Prototype Accelerator (LIPAc) in Rokkasho Fusion Eng. Des. 153 (2020) 111503.
[3] L. Bellan et al., Acceleration of the High Current Deuteron Beam Through the IFMIF-EVEDA RFQ: Confirmation of the Design Beam Dynamics Performances ,Proc. ICFA HB 2021 (2021).
[4] K. Kondo et al., Neutron production measurement in the 125 mA 5 MeV deuteron beam commissioning of Linear IFMIF Prototype Accelerator (LIPAc) RFQ, Nucl. Fusion 61 (2021) 116002.

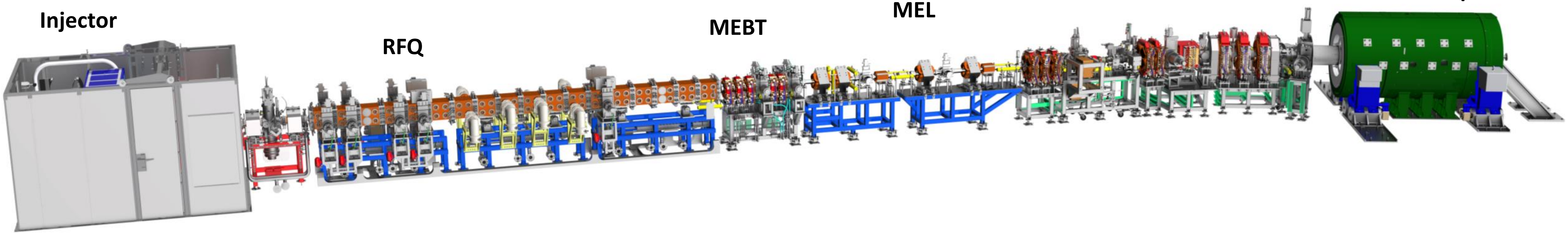
LIPAc commissioning with tiered approach

Phase B+: on-going

Validation of the RFQ and other LIPAc sub-systems except SRF-Linac at high DC

5 MeV - 125 mA

625 kW, pulsed up to 100 % DC

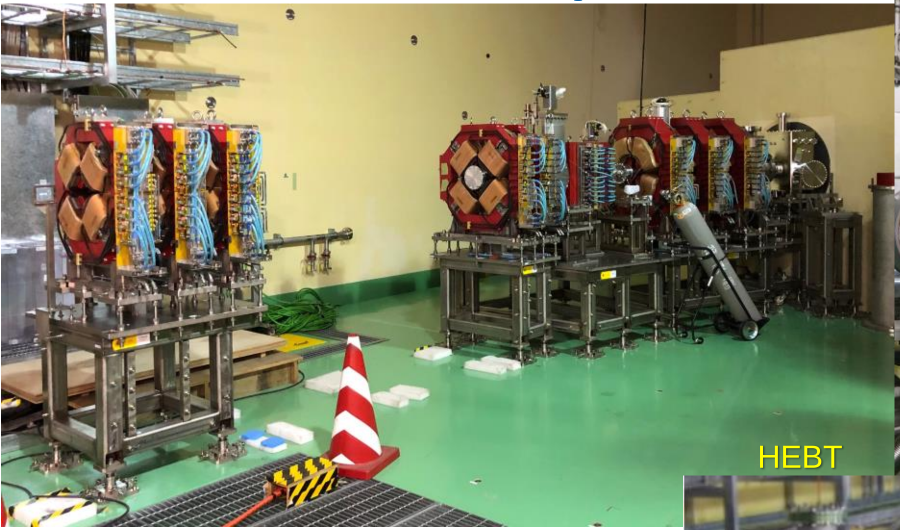


Main Goals of Phase B+

- Validate Injector, RFQ and MEBT, HEBT, BD up to CW with the nominal 125 mA, 5 MeV D+ beam
- Validate beam diagnostics for both low and high duty cycle operations
- Characterize the beam to be injected into SRF linac in the following Phase C
- **Phase B+ consists of 3 stages**
  - ➔ **Stage 1: Proton and deuteron probe beams at low duty cycle and low intensity**
  - ➔ **Stage 2: 125 mA D+ beam at low DC to validate the beam dynamics**
  - ➔ **Stage 3: 125 mA D+ beam to validate all the subsystems, except the SRF Linac, at high continuous power**

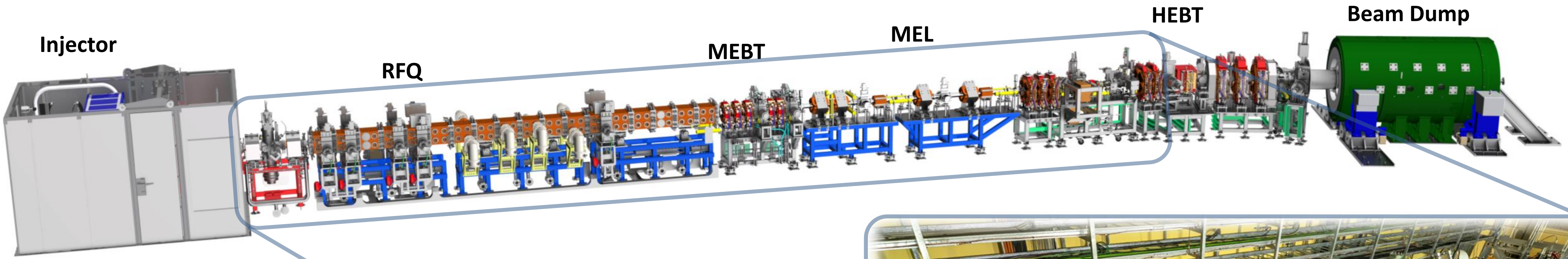
LIPAc commissioning with tiered approach

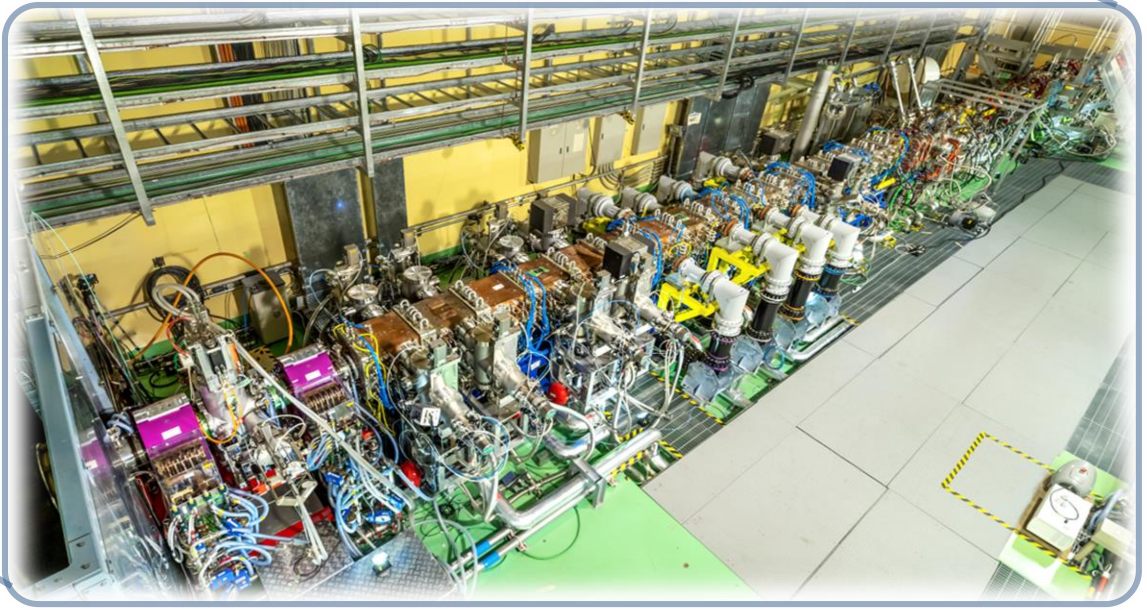
Phase B+ Preparation



Phase B+: Stage 1 completed, Stage 2 on-going

5 MeV - 125 mA
625 kW, pulsed up to 100 % DC





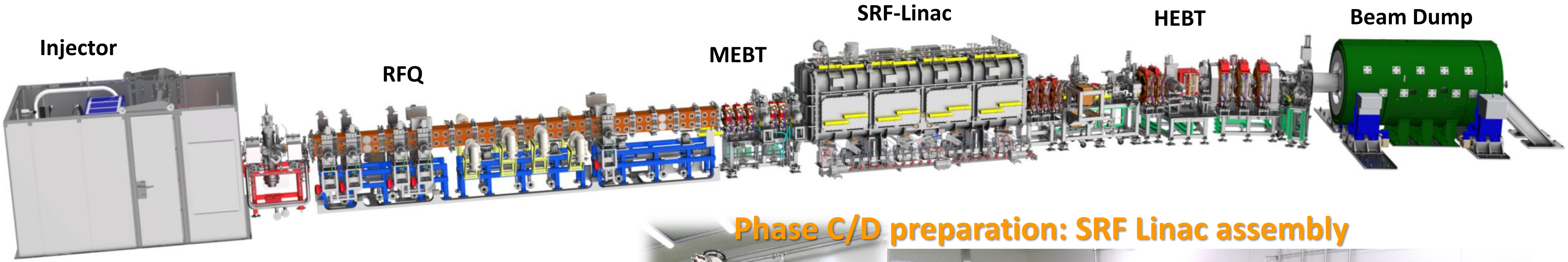
Beam operation restarted on August 1, 2023

- **Stage 1** was successfully completed in December 2021 ➔ Results obtained so far meet expectations (modelling vs experimental results)
- **Stage 2** is on going – nearly completed
- **Stage 3** due to start in the coming weeks and to be completed in **2024/Q2**

Y. Carin et al, IFMIF/EVEDA Achievements Overview, ISNFT15

Phase C/D: Preparation on going

9 MeV - 125 mA
1125 kW, pulsed (up to 100 % DC)



Phase C/D preparation: SRF Linac assembly

Main Goal of Phases C and D

- Validate the whole LIPAc accelerator at nominal 125 mA, 9 MeV D+ beam CW.

  ➔ **Demonstration of the IFMIF accelerator concept**

Enhancement Activities

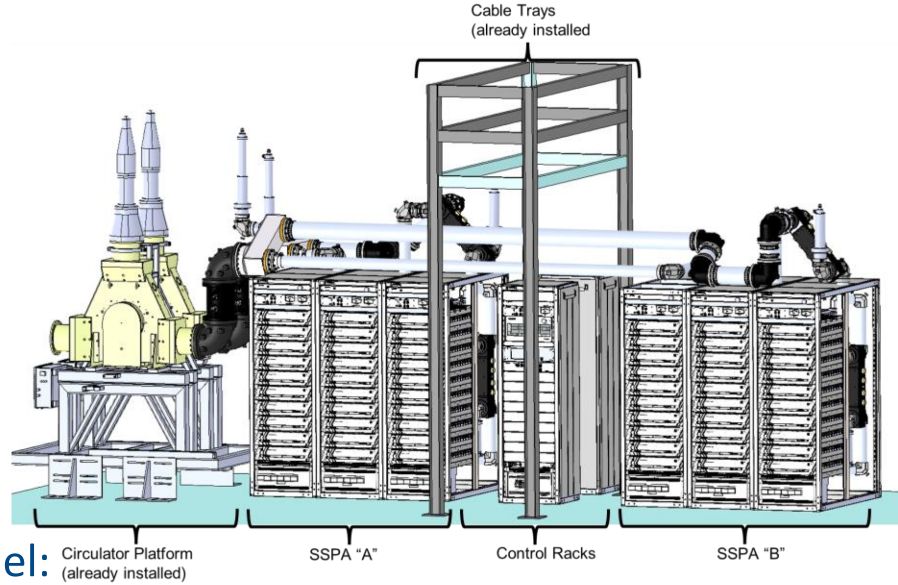
- **Enhancements activities** started with BA phase II and are ongoing
  ➔ Improvement the availability and reliability of LIPAc

- **RFQ Brazed couplers**
  ➔ For the existing brazed couplers: conditioning to be continued after phase B+ completion on an improved test bench
  ➔ New brazed couplers to be procured in the framework of DONES early procurements by F4E

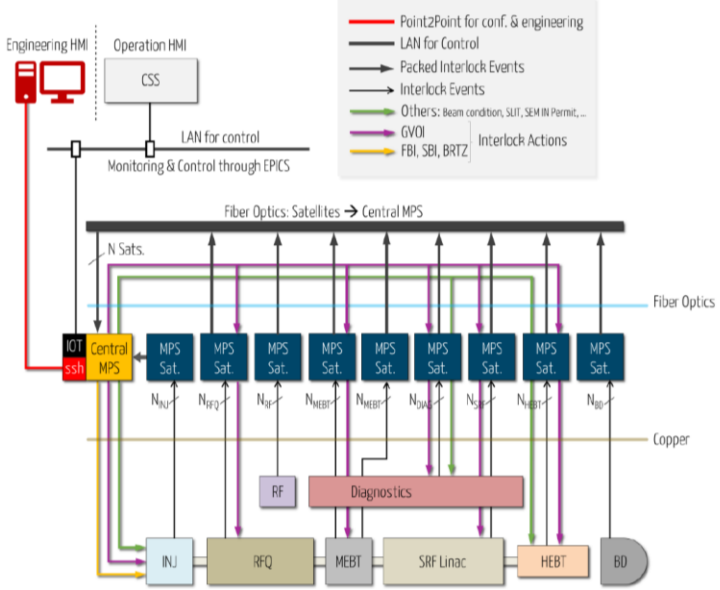
- **RFQ RFPS enhancement**
  ➔ Work plan for SSPA-based RFPS reviewed in June 2023 with JA/EU expert panel: No show stopper ➔ Proceed with prototyping until end-2024

- **Control System enhancement**
  ➔ Machine Protection System upgrade: Final Design Review took place July 2023 with JA/EU expert panel: no show-stopper ➔ Proceed with manufacturing. Other CS upgrades are planned in the coming years.

- **Injector enhancement:**
  ➔ Although the concept is validated, it is necessary to develop an upgraded injector meeting the reliability and availability requirements of DONES/A-FNS
  ➔ Phase B+ (CW) feedback is needed to finalize the tech specs and proceed with the procurement planned to start in 2024



RFQ RFPS SSPA layout



MPS upgrade design - architecture concept

EU companies involved in LIPAc

Manufacturing a particle accelerator like LIPAc (and DONES/A-FNS) involves a wide range of industries in conventional and high-tech sectors, including engineering, materials science, electronics, optics, SRF technologies, and specialized manufacturing

Injector

- SULLITRON – Power Supplies
- HAZEMEYER – HV Power Supplies
- FuG electronics – Power supplies
- OCEM – Power supplies
- CTM Laser – Plasma Electrode
- EXPLEO – RF-RFQ interface cone
- SOLCERA – acc. column tie rods
- CERAQUITAINE – acc. column alumina cylinders
- Mat-Tech BV – Emittance Meter Unit
- SAES getters – vacuum pumping train
- KYOCERA – ceramic insulators

Radio Frequency Quadrupole

- CINEL – RFQ Module
- DB SCIENCE – RF source test stand conditioning
- SIEMENS – RFQ temperature sensors

Medium Energy Beam Transport

- AVS – Scrapers
- ANTEC – Magnet
- Elytt Energy – Power Supplies
- Nortemecánica –Frame
- VACUUM PROJECTS –Vacuum Chamber & BPM
- Teratorr – MEBT Vacuum System
- LBA/CELLS – Magnet Magnetic measurements
- SIGMAPHI - steerers power supplies
- DMP – Buncher Cavities

Ancillaries

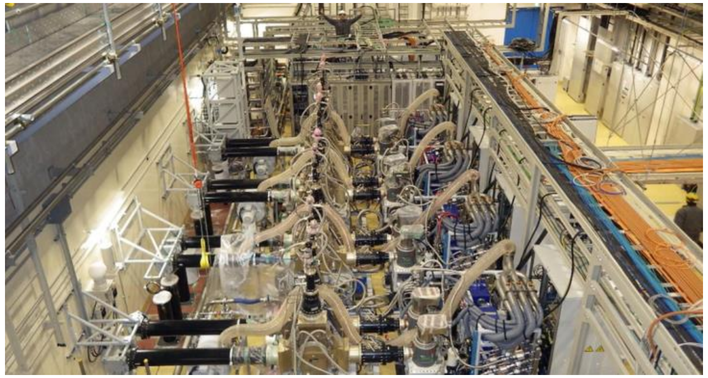
- AFARVI – HEBT-MEBT Cooling System
- ENGIE – RF and Beam Dump Cooling System
- ALAT – Cryoplant
- VAT – vacuum valves
- LEYBOLD – vacuum pumps
- SUMITOMO – vacuum pumps
- AGILENT – vacuum pumps
- Bertfelt – flow regulators
- KOBOLD – flow regulators
- Nieruf – flanges, gaskets, valves
- KALKI – Water filter and sleeves
- CINTROPUr – Water filters and sleeves

Control System

- SAFRAN ELECTRONICS & DEFENSE SPAIN
- GTD SCIENCE, INFRASTRUCTURES & ROBOTICS

EU companies involved in LIPAc

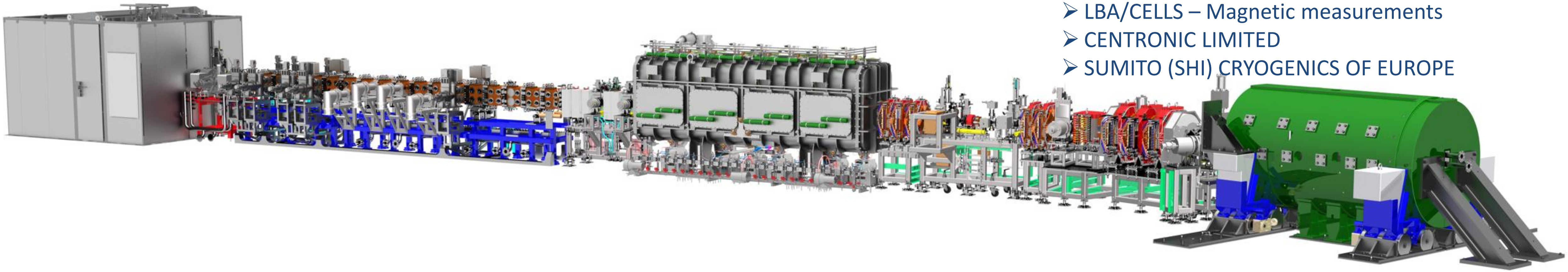
Radio Frequency Power Supplies
- INDRA – RFQ & SRF RF Modules
- JEMA – HV Power Supplies
- SAFRAN – LLRF
- IBA – RF Cavities
- BTESA – MEBT RF Module- New SSPA
- THALES – Tetrodes
- OCEM/AMPEGON – Tetrodes, maintenance
- EUROPÉENNE DE TÉLÉCOMMUNICATIONS SA



Superconducting Radio Frequency LINAC
- ZANON – Superconducting Cavities
- RI – Cryomodule Assembly
- Meca Magnetique
- SDMS
- RAVANAT
- GAVARD & CIE
- SODITECH
- CIMLEC INDUSTRIE
- SIGMAPHI – Solenoids coils power supplies
- SOPER – gaskets
- CIMLEC INDUSTRIE
- SIGMAPHI – Solenoids coils power supplies
- SOCIETE D'OUTILLAGE DE PRECISION

Diagnostics
- AVS – Diagnostics
- HEXA INGENIEROS – Diagnostics
- TECNOVAC – Vacuum System
- BERGOZ – MEBT FCT+ACCT
- CIVIDEC INSTRUMENTATION GMBH – Microloss detectors
- SAFRAN ELECTRONICS & DEFENSE SPAIN - Digitizers

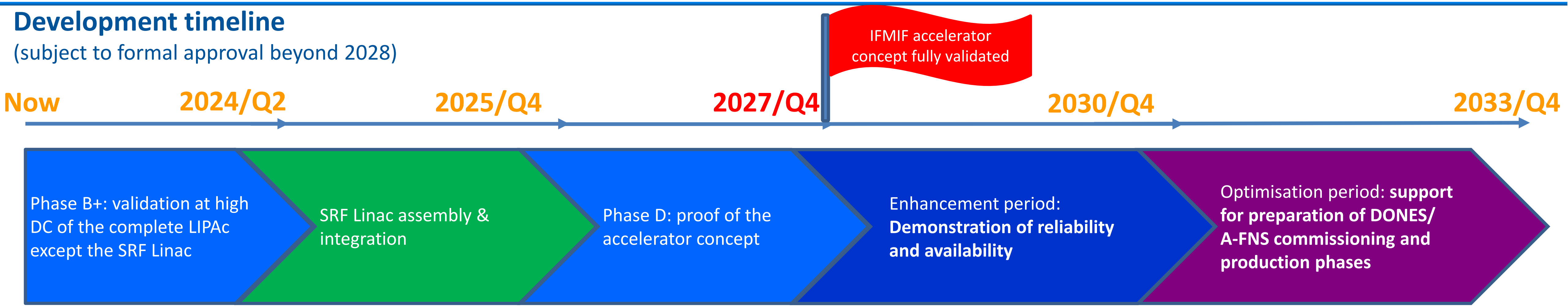
High Energy Beam Transport & Beam Dump
- ELYTT ENERGY – Magnet & Power Supply
- CADINOX – Beam Dump
- TVP – BD Cartridge disconnection system
- IREC
- Galvano-T – BD Cartridge
- Ramen – HEBT Vaccum chambers
- Sigmaphi – Magnets Power Supplies
- LBA/CELLS – Magnetic measurements
- CENTRONIC LIMITED
- SUMITO (SHI) CRYOGENICS OF EUROPE



LIPAc commissioning timeline and outlook

Development timeline

(subject to formal approval beyond 2028)



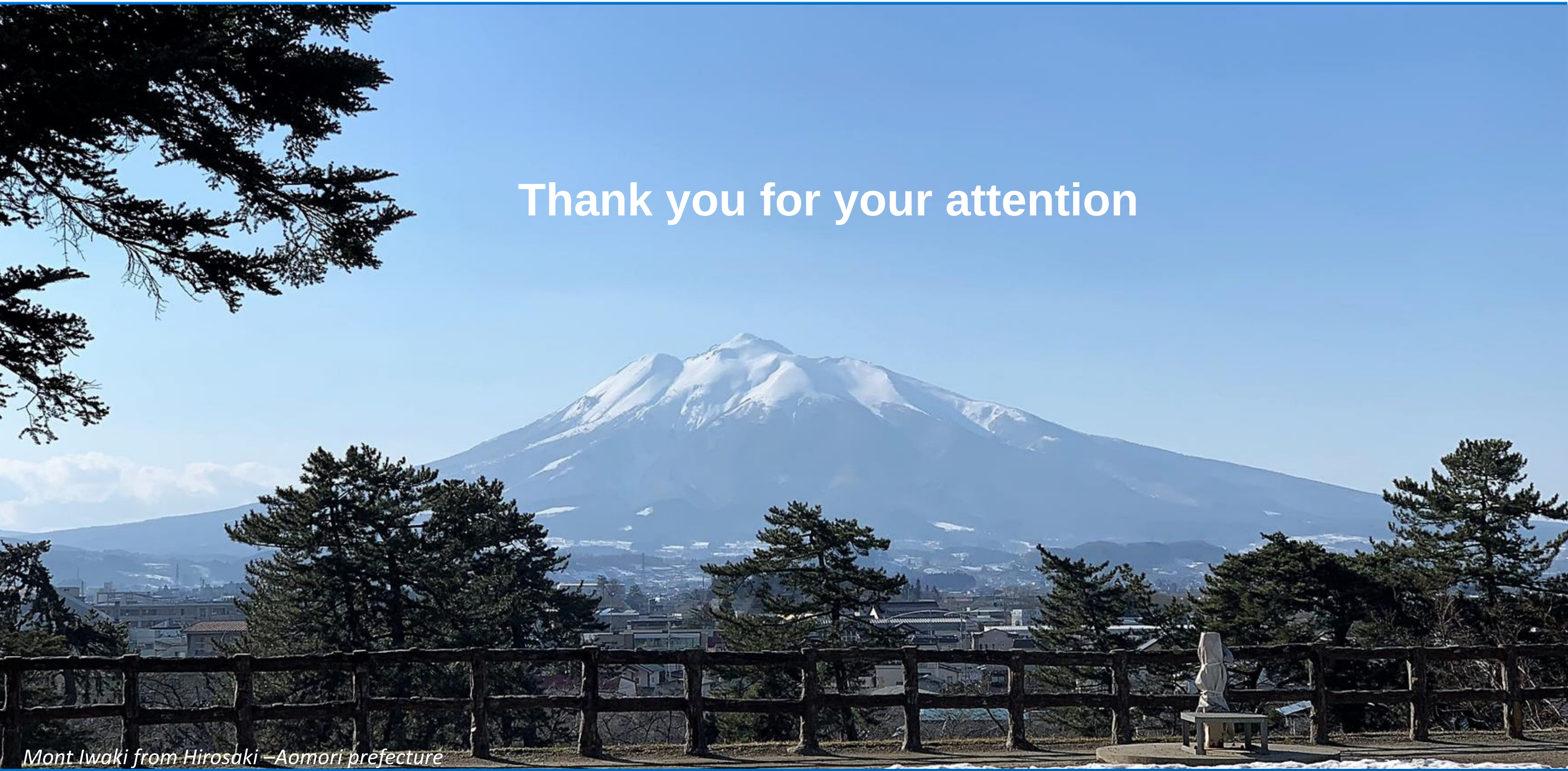
LIPAc not only the **demonstrator of the IFMIF accelerator concept (DONES and A-FNS)**, but also the **ideal platform** to:

- **Train** physicists, engineers, technicians, and students (4 young scientists from Granada University have already spent a year on Rokkasho site)
- **Test** new diagnostics, models, degraded modes, explore the limits of the working domains of the accelerator, etc.
- **Test and rehearse** operation and maintenance DONES/A-FNS scenarios
- Prepare and optimize the exploitation phase of DONES/A-FNS
- LIPAc will be used as a demonstrator for **safe early developments and real time tests** of ML/AI models for DONES/A-FNS
- **Develop and test models for ML and AI ➔** Streamline operations, improve maintenance efficiency, enhance performance, and support operators in maintaining the operability and safety. For an industrial accelerator like DONES it will be important to have AI tools to support the operators to run the accelerator 24/7, 45 weeks per year, and maintain its exceptional performance

Conclusion

- The IFMIF/EVEDA Project and more generally the Broader Approach represent a highly successful collaboration between Japan and Europe
- The Test cell and Liquid Lithium Target were fully validated respectively in 2015 and 2017
- IFMIF/EVEDA provided the bases for the DONES project
- LIPAc's validation is ongoing at QST Rokkasho Fusion Institute in collaboration with EU and Japan
- LIPAc RFQ demonstrated that 125 mA, 5 MeV deuteron acceleration with short pulses first time in the world in 2019
- First deuteron beam was injected into the beam dump in July 2021 (Full LIPAc except the SRF Linac)
- Phase B+ Stage 2 started 1-Aug 2023 targeting nominal current (125mA) and at high duty cycles up to CW
- The assembly of the superconducting Linac will resume in March/April 2024.
- LIPAc complete validation is expected in 2027/Q4, proving the IFMIF accelerator concept
- Upgrades and enhancements have started to improve availability and reliability, and new sub-systems (injector, RFPS, CS) will be deployed after reaching LIPAc primary goal (demonstration of the accelerator concept)
- LIPAc is an ideal training and test platform; it will contribute to prepare and optimize the commissioning and exploitation phases of the future Fusion Neutron Source (DONES and A-FNS)

Thank you for your attention



Mont Iwaki from Hirosaki –Aomori prefecture