FROM RESEARCH TO INDUSTRY

STATUS OF THE IFMIF/EVEDA SUPERCONDUCTING LINAC

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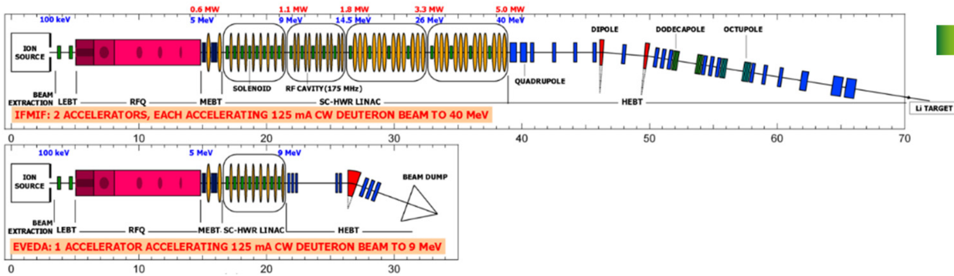
OUTLINE

- Introduction
- Qualification of the main components
    - Half-Wave Resonators
    - Power Couplers
    - Superconducting solenoids
    - High power test of accelerating units
- Assembly of the cryomodule in Japan
- Conclusion and outlook

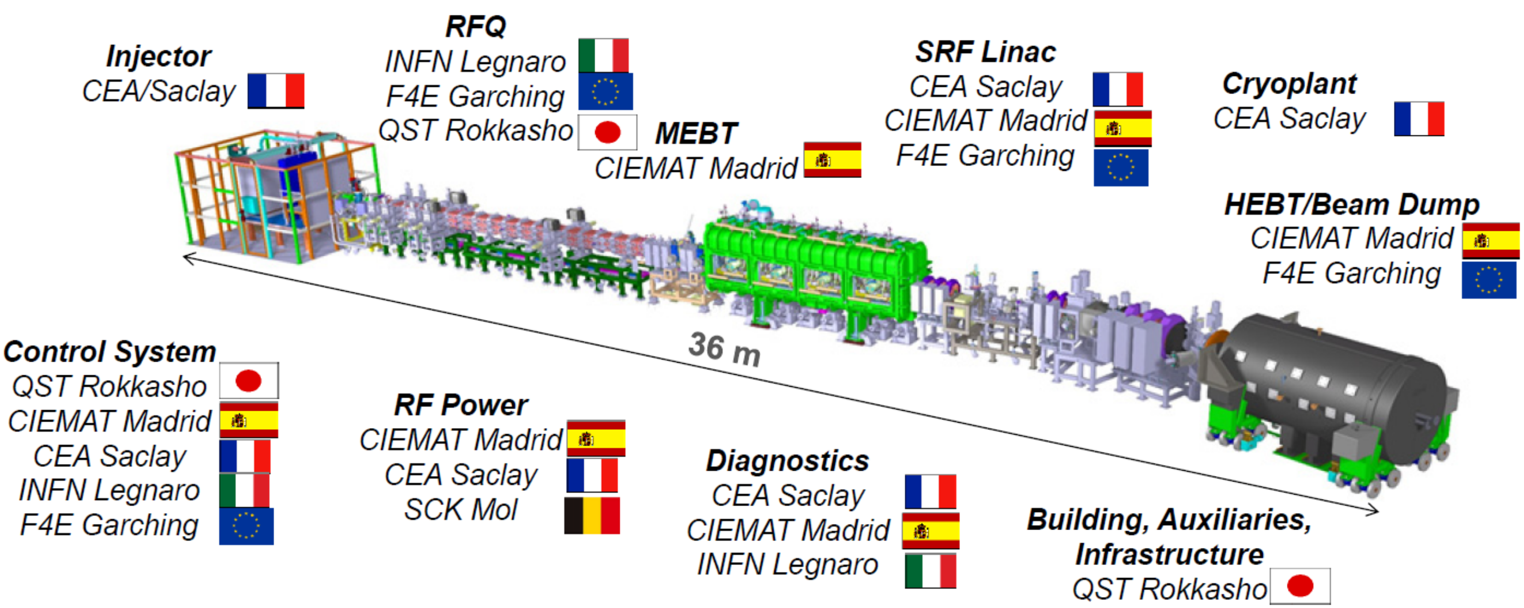
IFMIF/EVEDA - LIPAc



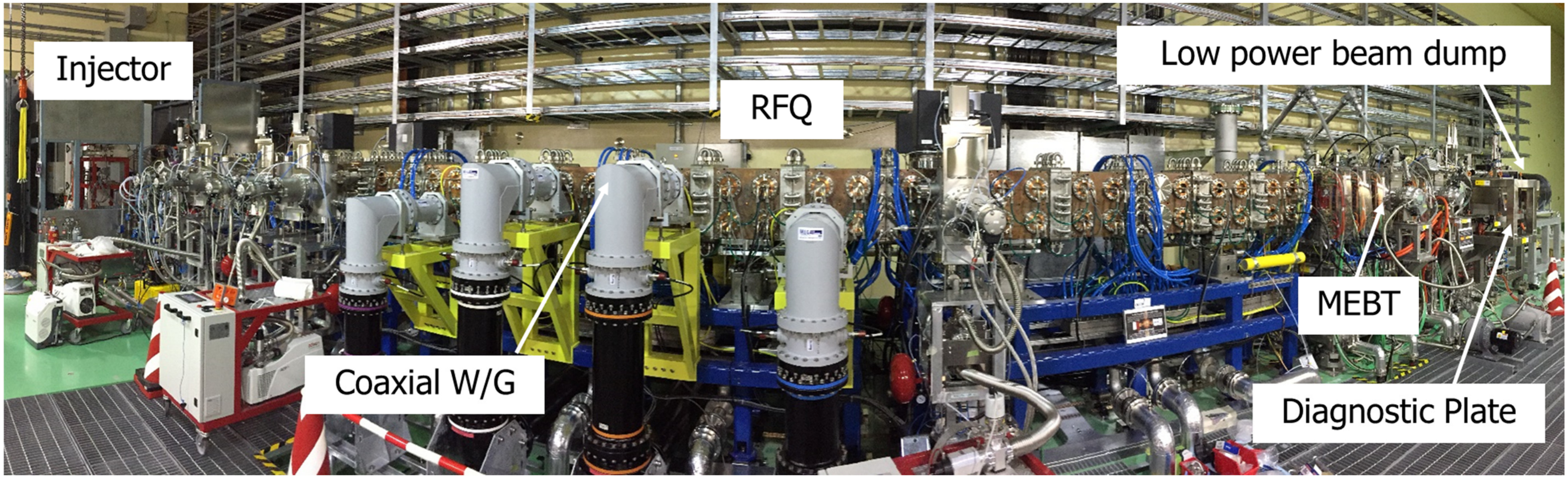
- IFMIF/EVEDA: validation phase of the IFMIF project which aims at characterizing the materials with intense neutrons flux for the future fusion reactors

- LIPAc (Linear IFMIF Prototype Accelerator) under construction in Japan, at Rokkasho Fusion Institute: 9 MeV, 125 mA deuteron beam CW

- Collaboration between Japan and Europe

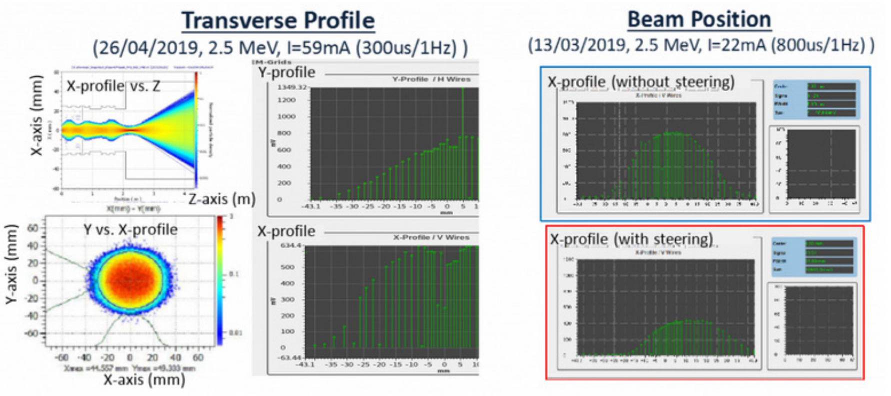


LIPAc: STATUS



- Proton Beam Commissioning @2.5 MeV
  - Extracted current of 88 mA and 300 µs maximum pulse length from the injector
  - 57 mA was accelerated in the Radio Frequency Quadrupole (RFQ) with a transmission of 93 %

More details : Poster MOP047

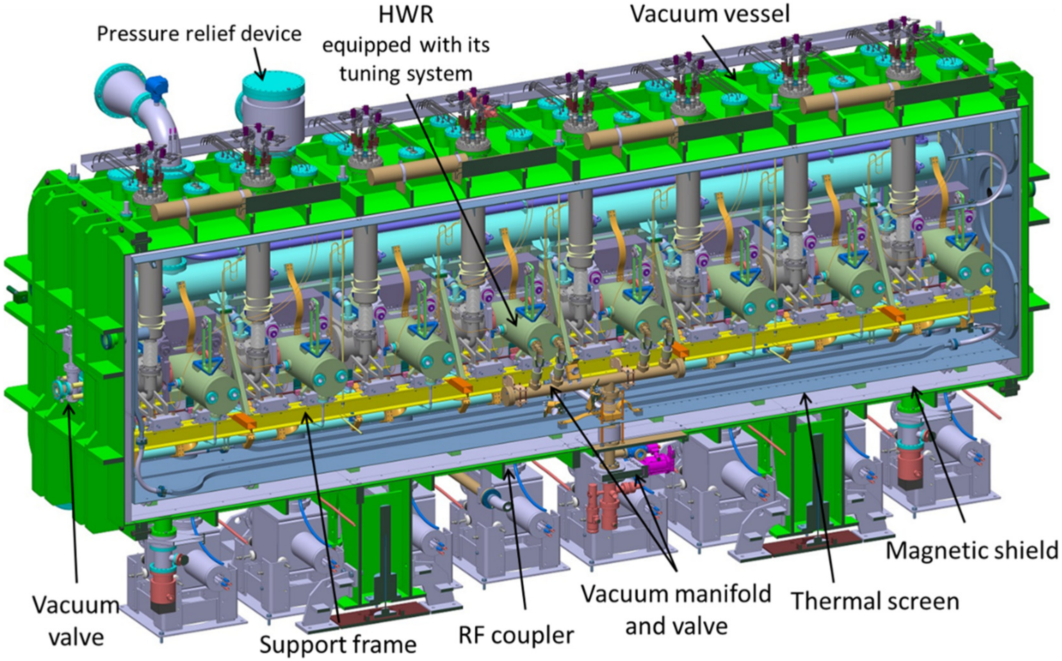


SLIT (Ciemat)/ SEM GRID (CEA) Interceptive diagnostic measurement

Left: measurement of beam profiles, providing the shape of the beam. Right: beam position.

LIPAc CRYOMODULE

- Eight half-wave resonators
  - 175 MHz, β=0.094
  - $E_{acc\text{-}nom}$ = 4.5 MV/m, $Q_0 \geq 5\times10^8$
  - Operating temperature: 4.4 K
- Power Couplers
  - Designed to handle 200 kW CW
  - 70 kW CW max on LIPAc

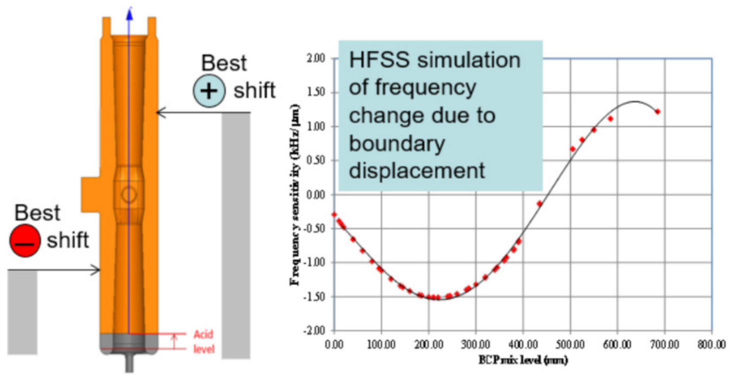


- Eight superconducting solenoids:
  - Two nested solenoids to focus the beam (6 T) with reduced fringe field (20 mT on cavity flange)
  - Two steerers for horizontal and vertical beam orbit correction (integrated field: 3.51 mT.m)
  - Beam position monitor (BPM)

CAVITIES: FREQUENCY TUNING

- For all HWRs, RF fundamental mode frequency has been adjusted between several steps of niobium resonator manufacturing
- However initial 50 kHz range for manufacturing target was not realistic

→ Differential etching for RF frequency correction



More details : Poster MOP087

- Each HWR BCP frequency tuning required its own calibration

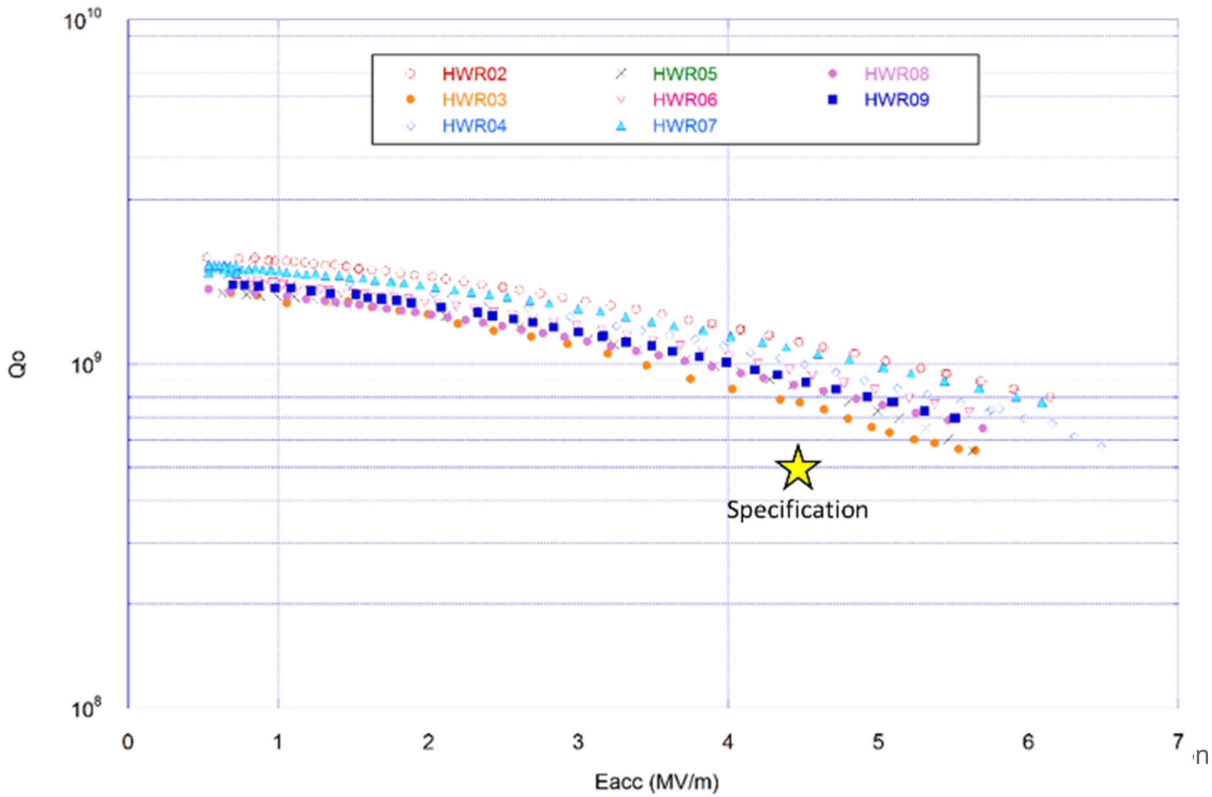
→ much more etching steps, frequency controls and thickness measurements needed than initially foreseen

- The initial frequency spread has been reduced by a factor 10
- All HWRs are within the cold tuning system range for 175 MHz operation

	Bare resonators as delivered at T=20°C	Qualification tests (T=4.2 K)
Minimum freq. (MHz)	174.736	175.018
Maximum freq. (MHz)	174.982	175.041
Spread (kHz)	246	23

CAVITIES: QUALIFICATION

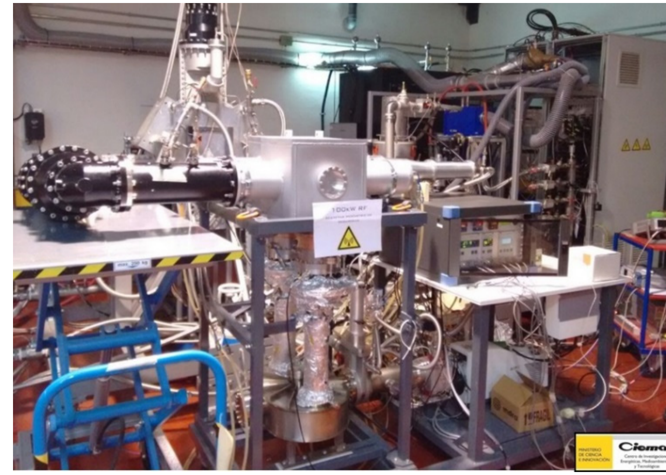
- All test are carried out up to at least E_{acc}=5.5 MV/m to be sure the 4.5 MV/m specification is reached with reasonable margin (including measurement error of 10%)
- All qualification tests are stopped below 6.5 MV/m in order to prevent firing field emission.
- No electron current nor X-ray measured at 5.5 MV on any of the HWRs
- X-ray onset only detected for HWR05 at 5.6 MV/m

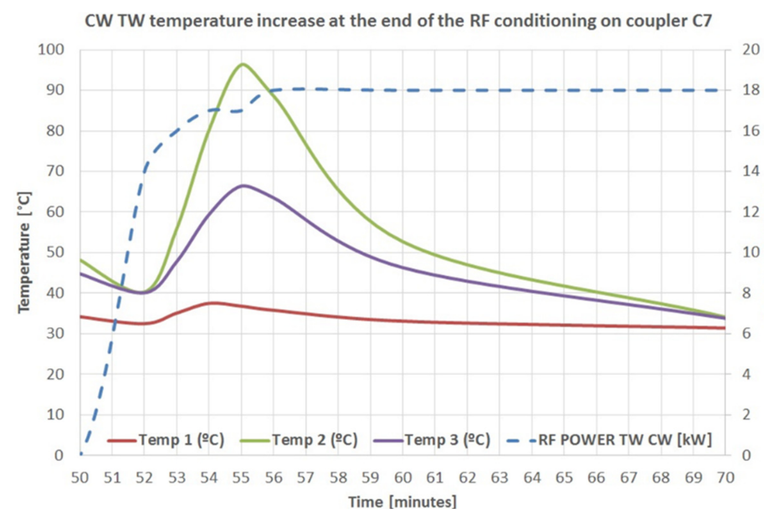


More details :
Poster MOP087

POWER COUPLERS: RF CONDITIONING

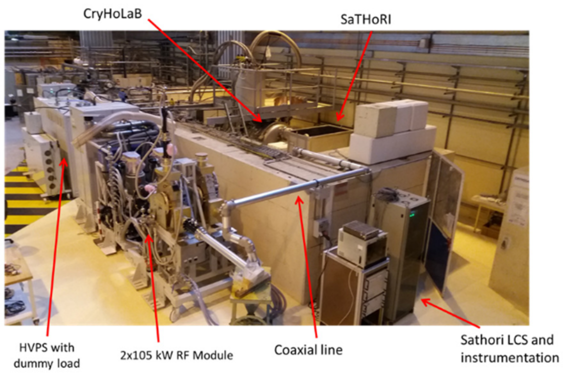
- All the power couplers reached the validation maximum power of 100 kW CW in TW and SW (full reflection) configurations
- The SW RF conditioning: 7 short circuit positions allowing to have maximum electrical fields on the ceramics and on intermediate positions.
- Some of the couplers (C5, C7) had important multipactor activity at a precise RF power levels (between 10 kW and 20 kW) generating heat increase for duty cycles higher than 10%.
  - Heating multipactor power ranges far below the nominal operating RF power of the coupler on the cryomodule
  - Multipacting level seems to be influenced by the RF configuration due to the assembly on the test box → behavior could be different on the cryomodule
- Good vacuum behavior : pressure below 10^{-7} mbar for power between 40 kW and 100 KW in CW at the end of the process.

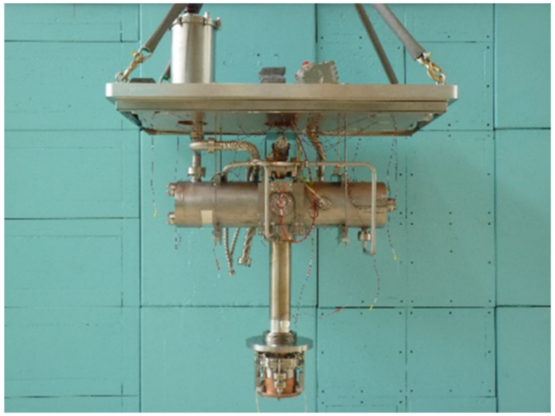


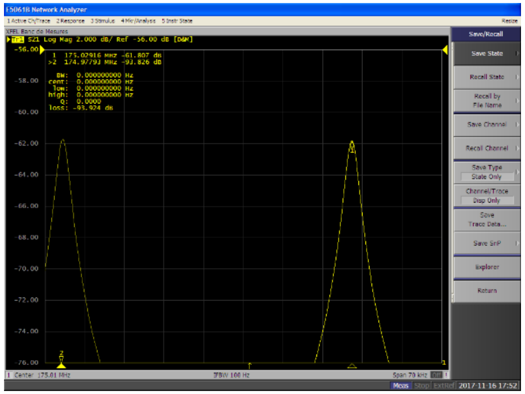


More details : IPAC2019, WEPRB009

HIGH POWER TESTS

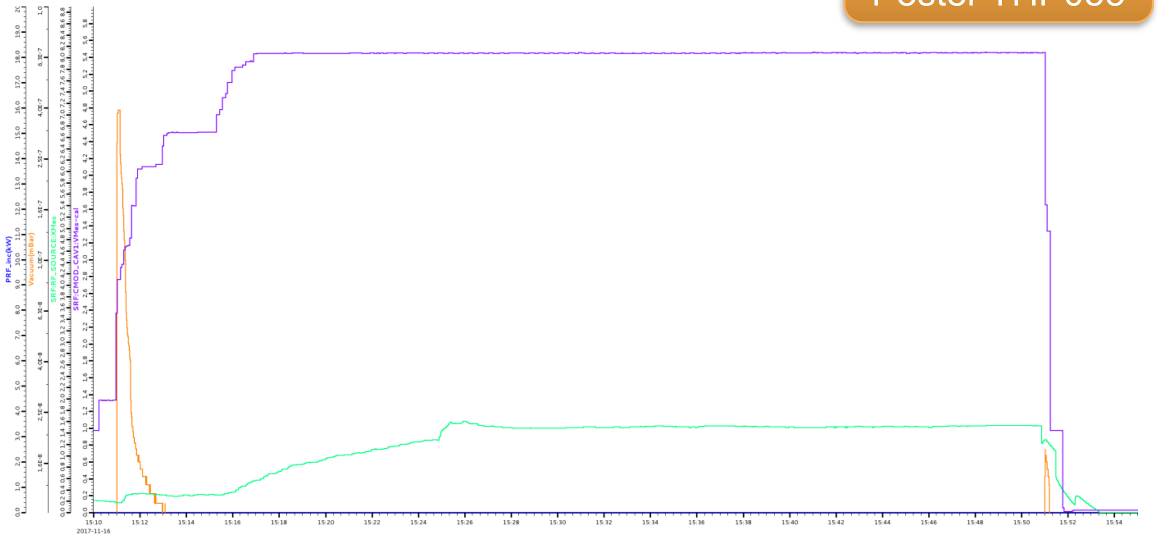






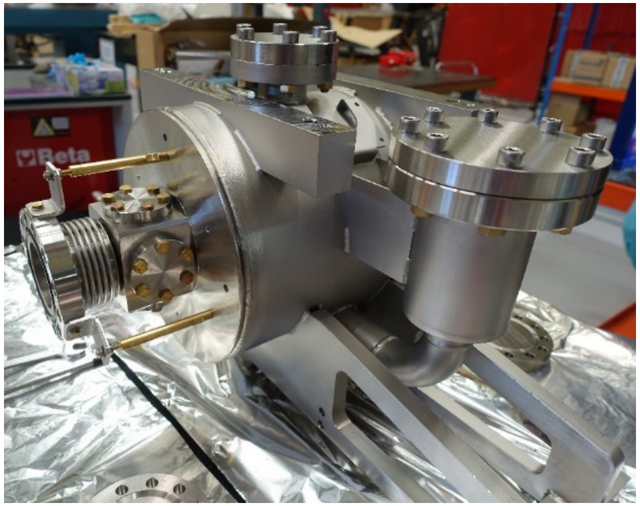
- Tests of two accelerating units - cavities equipped with its tuner and power coupler – in the dedicated test stand SaTHoRI
- Nominal accelerating field of 4.5 MV/m was achieved in the cavity with an injected power of 14 kW. Stable opertion of the cavity for 30 minutes at 5.4 MV/m (nominal accelerating filed Eacc + 20% margin) has also been demonstrated.
- Qualification of the tuning system: tuning range within the requirement of -50 kHZ

More details :
Poster THP053



SOLENOIDS AND CURRENT LEADS

- Electrical measurements at room temperature, both on coils and assembly: resistance, self-inductance, leakage current
- Cold tests of each magnet assembly in vertical cryostat
- Magnetic measurements at warm temperature after integration of the coils in the helium vessel: deviation of the magnetic axis.
- Qualification of the current leads: cold test in a vertical cryostat to regulate the position of the manual valves and measure the voltage drop at different currents with optimal cooling.

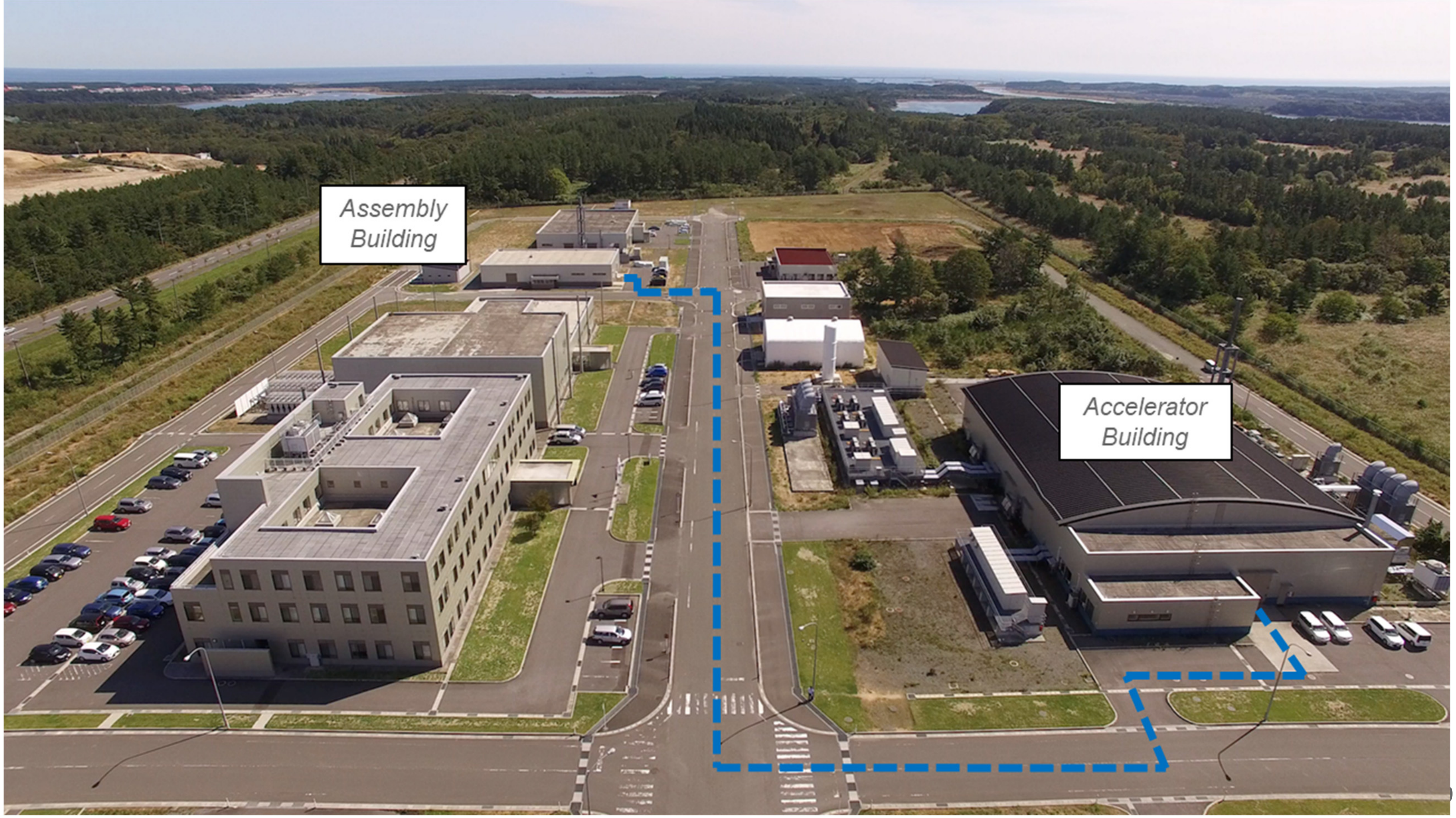


Qualification of the coils and integration in the helium vessel.

Current leads.

ASSEMBLY OF THE CRYOMODULE IN JAPAN

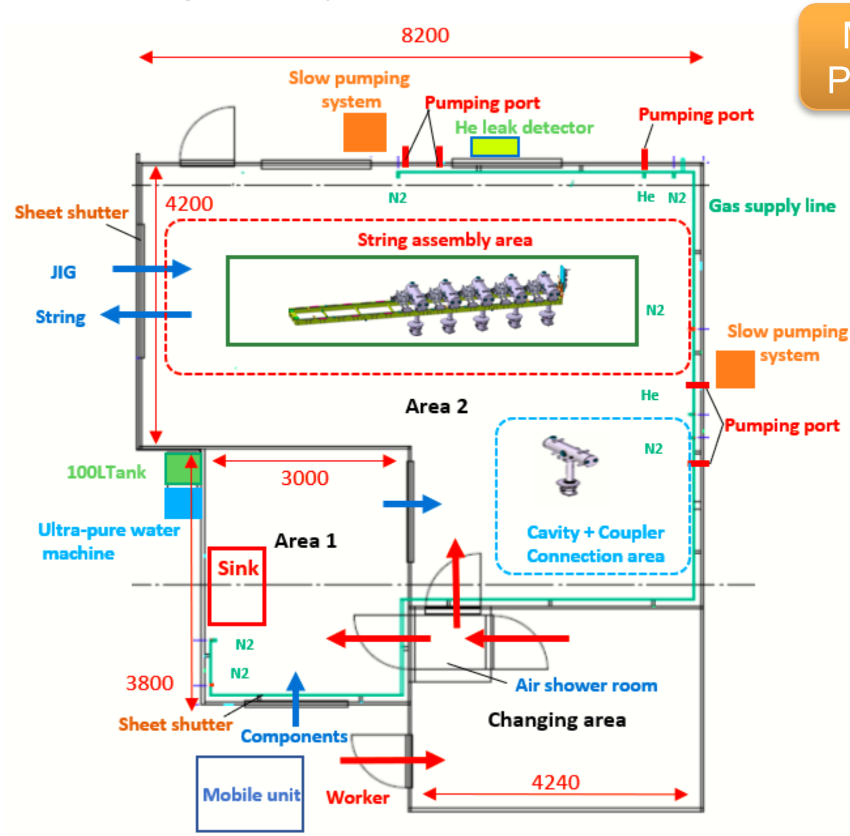
- Manufacturing and qualification of the components in Europe, then shipped to Japan
- Assembly of the cryomodule at Rokkasho Fusion Institute in a building close to the accelerator building
- Almost all the components were delivered at Rokkasho site in 2018

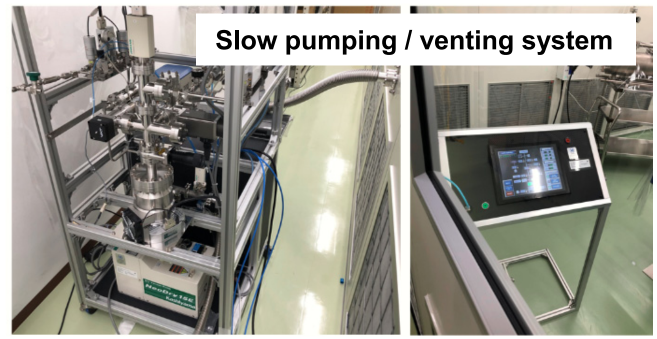


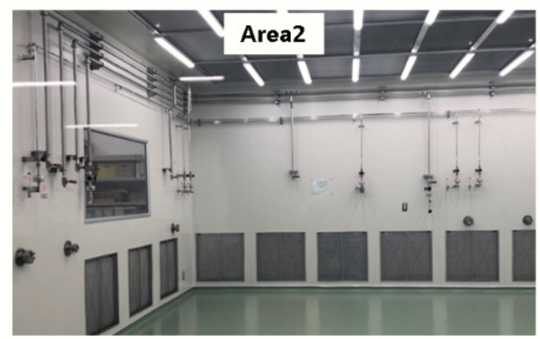
CLEAN ROOM

- ISO 14644-1 class 5 fully equipped clean room built at Rokkasho under the responsibility of QST
- Challenge: fit the clean room in an existing building with the space requirements based on CEA assembly preliminary scenario
- Slow pumping / venting system designed by KEK

More details : Poster TUP105





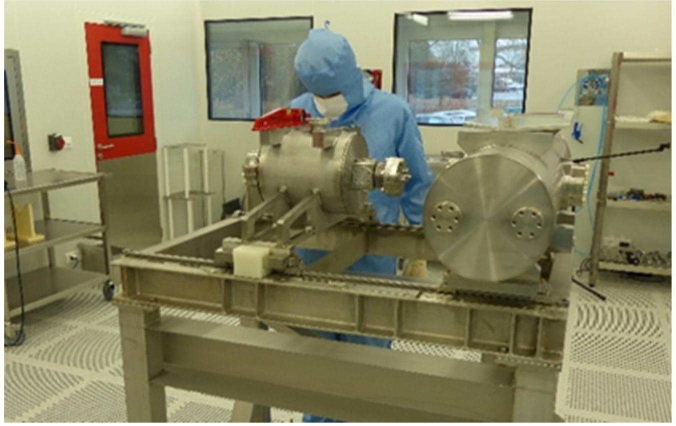


CRYOMODULE ASSEMBLY - 1

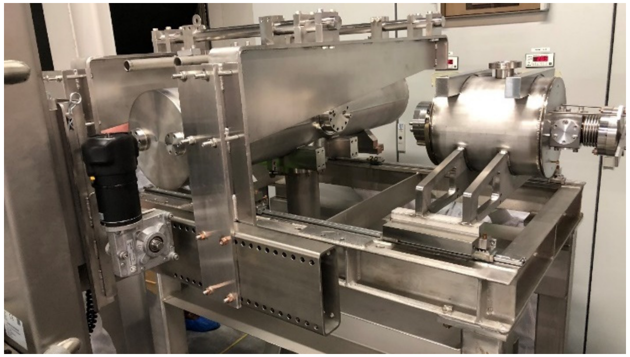
- Preparation work by CEA:
  - Development of a test bench by CEA and tests outside and in clean room at Saclay with mock-ups

More details : IPAC2017, MOPVA043

  - Tooling for coupler / cavity assembly: qualified with the results of the high power tests of two accelerating units



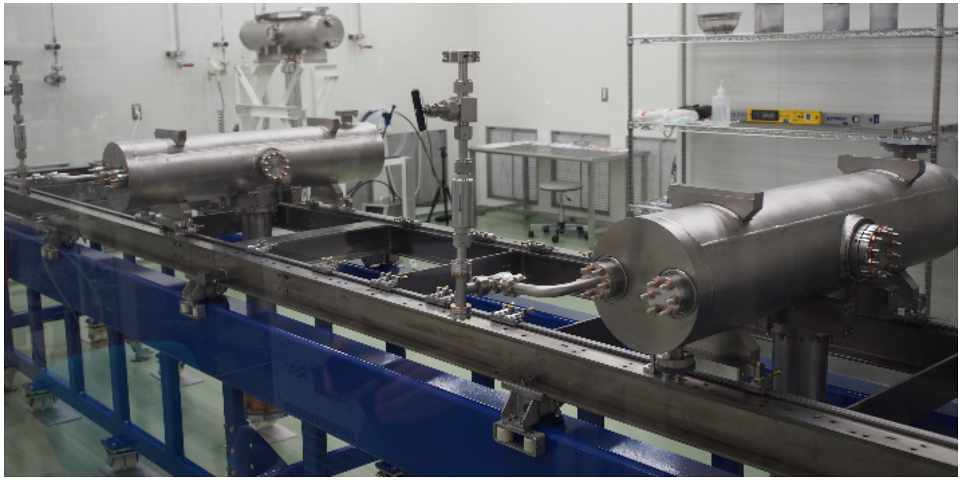
- Assembly contract: under the responsibility of F4E, awarded to Research Instrument GmBH after a worldwide call for tender

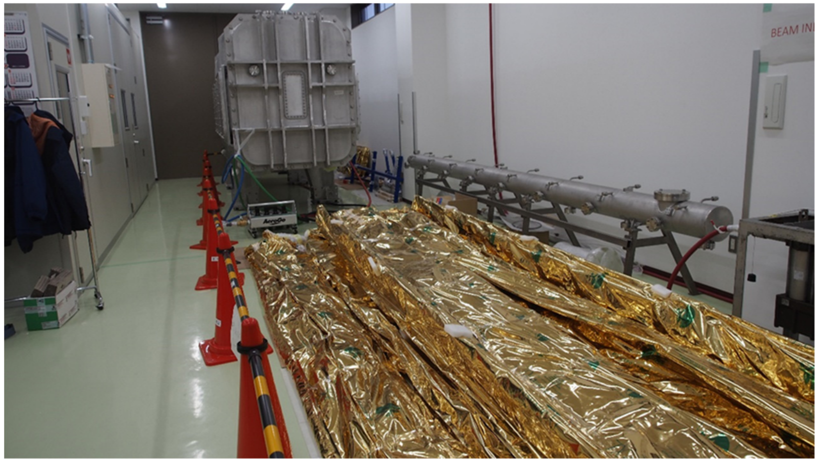


- Preparation work by RI:
  - Based on input from CEA, the assembly procedures were developed by RI
  - Trial assemblies using CEA mock-ups
  - The tooling was designed and manufactured, mostly by RI

CRYOMODULE ASSEMBLY - 2

- All tooling for clean room and post clean room operations is on site
- Vacuum vessel, thermal shield and phase separator are inside the JR building, ready for the cold mass assembly and its insertion in the cryostat
- First cavity-coupler assemblies were completed by RI in March
- Currently on hold, awaiting final beam line components. Solenoids but are expected to arrive on site in the second half of 2019





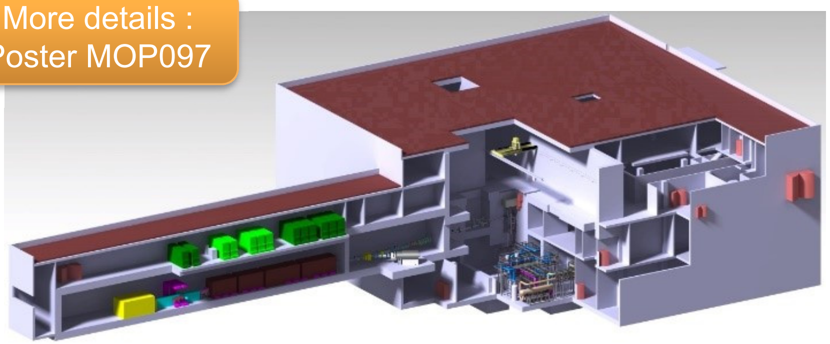
CONCLUSION

- Manufacturing of the components of the IFMIF cryomodule and qualification of the cavities, couplers and solenoids is now finished.
- Cavities performances are above the requirements.
- Two accelerating units have been successfully qualified in horizontal cryostat.
- Most of the components are now delivered in Japan, where the assembly of the cavity string has started.
- The cryomodule shall be complete during the first quarter of 2020 and then installed on the beam line of the LIPAc accelerator for the conditioning and the commissioning with beam.

OUTLOOK

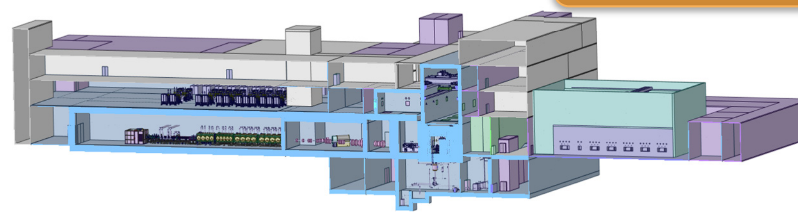
- The need of a neutron source for the qualification of materials to be used in future fusion power reactors have been recognized in fusion programs since many years
- Two projects based on a staged approach (one 40 MeV /125 mA deuteron beam linac coupled to a lithium target – with the possibility to upgrade to 10 MW by addition of a second linac) are under study
  - IFMIF-DONES (DEMO Oriented Neutron Source) in Europe
  - A-FNS (Advanced Fusion Neutron Source) in Japan

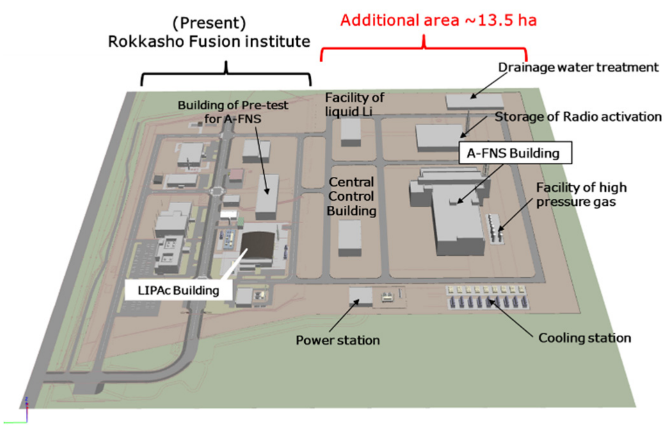
More details : Poster MOP097



Conceptual design of the DONES Plant in Grenada, Spain

More details : Poster MOP047





Conceptual design of the A-FNS Facility at Rokkasho, Japan