

DE LA RECHERCHE À L'INDUSTRIE



CEA EXPERIENCE ON SUPERCONDUCTING LINAC

With a particular focus on standardization

N. BAZIN

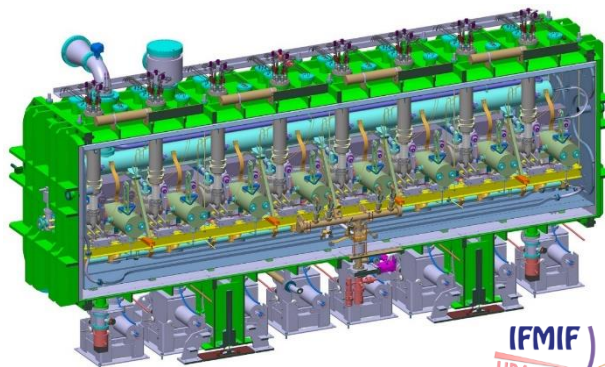
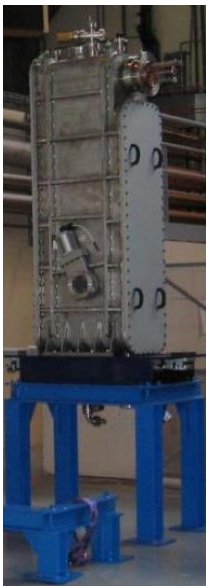
PIP-II Workshop on cryomodule
standardization

BARC, Mumbai – September 2018

CEA EXPERIENCE ON SUPERCONDUCTING LINAC



SPIRAL2: design and assembly of 12 cryomodules



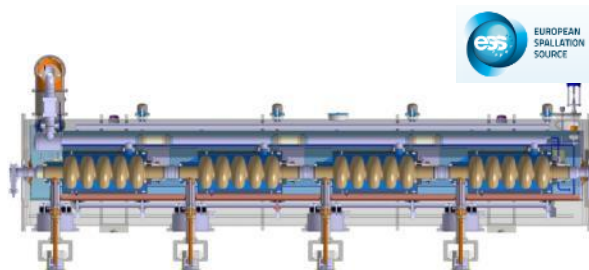
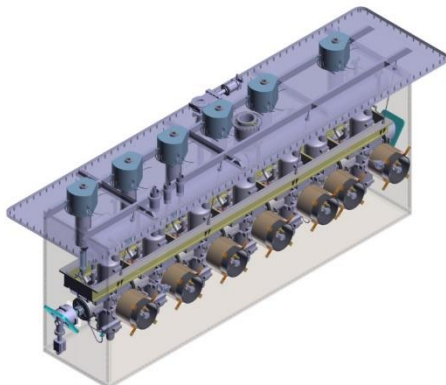
IFMIF LIPAc: 1 cryomodule



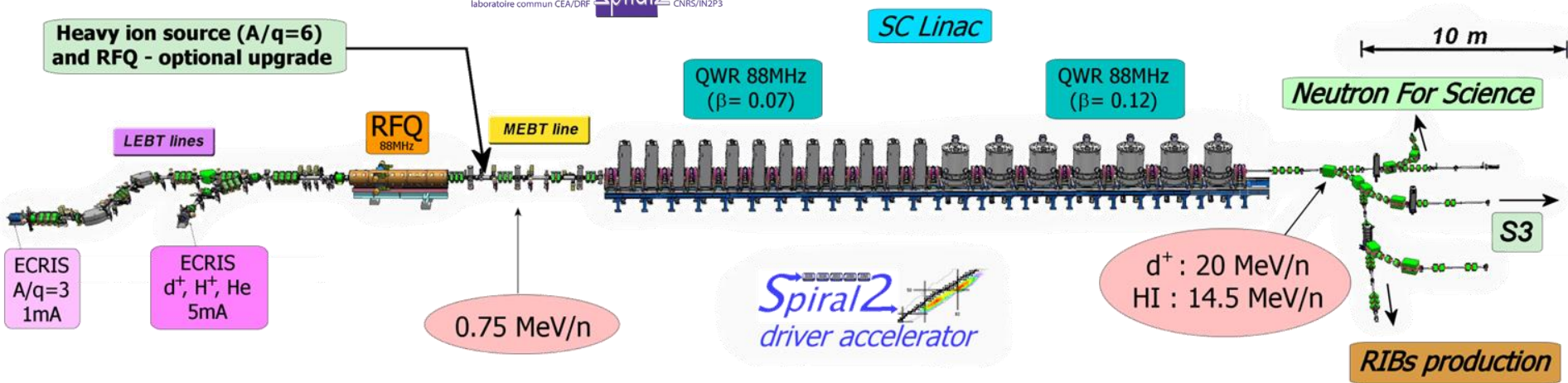
XFEL: assembly of 103 cryomodules (1 CM/wk)

ESS: cavities and couplers design, 2 demonstrators (MECCTD, HEDDTD), integration of 30 cryomodules

SARAF Phase2: 4 cryomodules



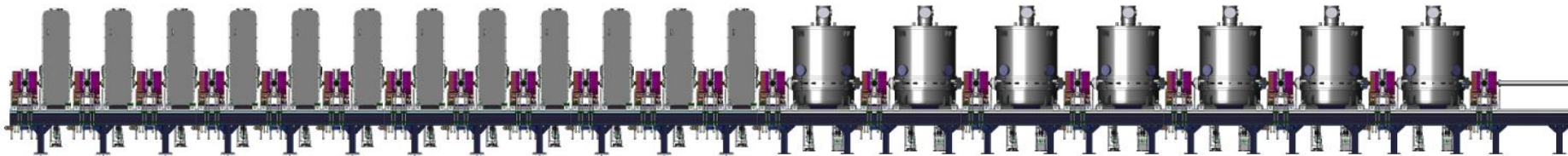
SPIRAL2 LINAC



Total length: 65 m
Slow (LEBT) and Fast Chopper (MEBT) RFQ (1/1, 1/2, 1/3) & 3 re-bunchers
12 QWR beta 0.07 (12 cryomodules)
14 QWR beta 0.12 (7 cryomodules)
1.1 kW helium liquefier (4.5 K)
Ambient temperature Qpoles
Solid state RF amplifiers (10 & 20 KW)
6.5 MV/m cavity gradient

Particles	H ⁺	³ He ²⁺	D ⁺	Ions	
Q/A	1	2/3	1/2	1/3	1/6 (opt.)
I (mA) max.	5	5	5	1	1
W ₀ max. (MeV/A)	33	24	20	15	9
CW max. beam power (KW)	165	180	200	44	48

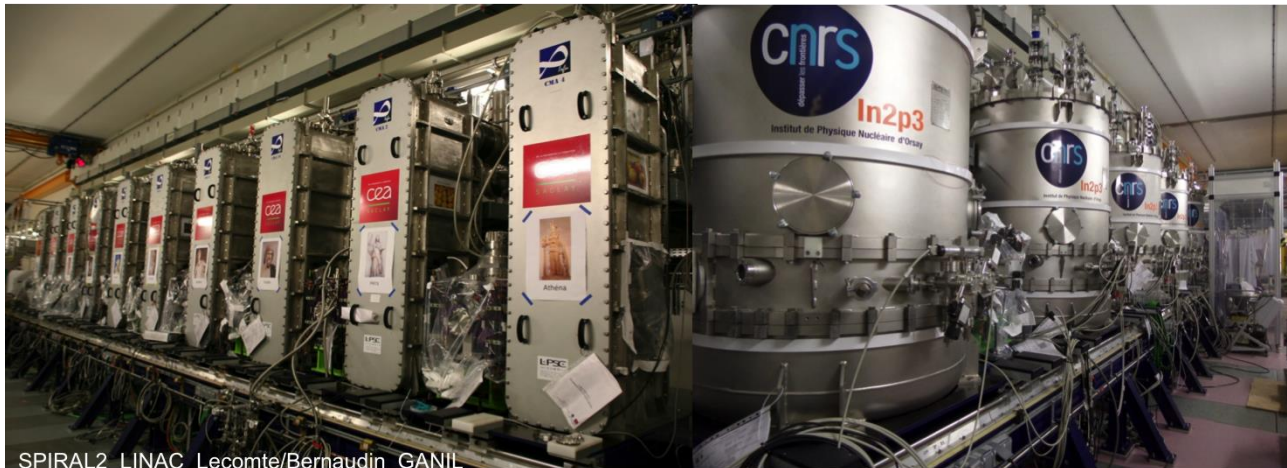
SPIRAL2 SUPERCONDUCTING LINAC



12 $\beta_0=0.07$ cavities

$L \approx 32$ m

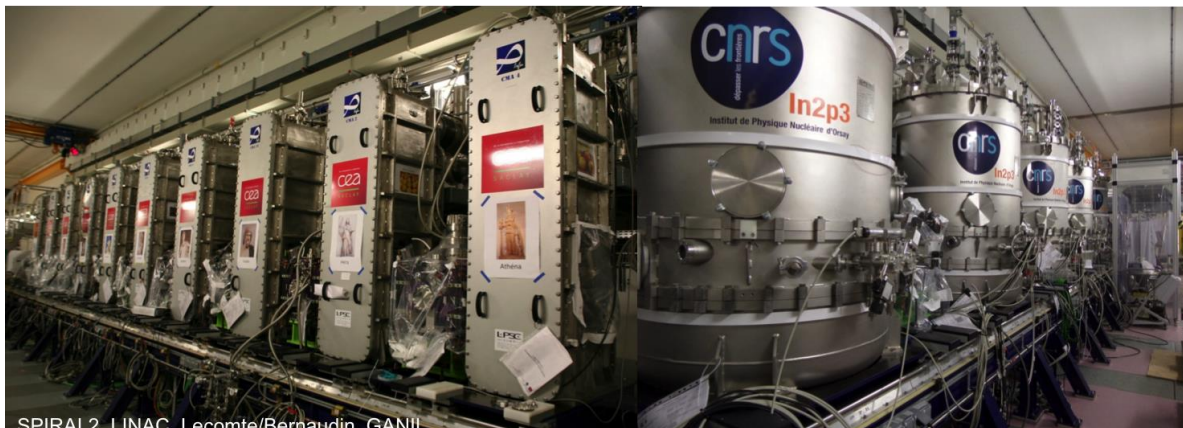
14 $\beta_0=0.12$ cavities



SPIRAL2 LINAC Lecomte/Bernaudin_GANIL

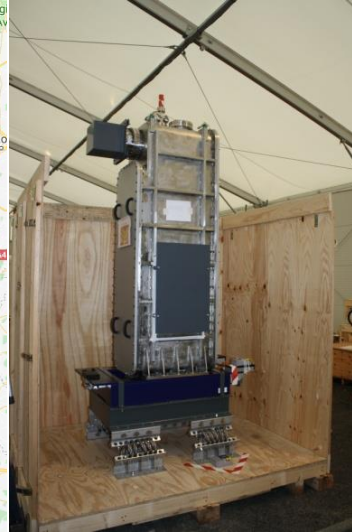
- Warm section at the end of every cryomodule: two quadrupoles, two steering magnets (one horizontal and one vertical), one BPM for beam position, information on beam size (transverse matching) and phase measurements, one longitudinal beam extension monitor, and pumping and vacuum diagnostics system
- CEA: cryomodule A with one QWR cavity
- IPN Orsay: cryomodule B with two QWR cavities
- LPSC Grenoble: 12.8 kW CW couplers similar for both cavities, one ceramic window

- Mechanical components of CMA and CMB: nothing in common
- Assembly tooling: nothing in common.
 - Cryomodules assembled at CEA / IPNO and shipped to Ganil
 - Tooling shipped to Ganil. Cryomodules could be repaired there.
- Instrumentation: similar for both cryomodules:
 - Same temperature sensors, same vendors for the cables and electrical feedthroughs
 - Internal cabling and instrumentation flanges different
- Vacuum components: same vendors for valves, gauges and controllers
- Vacuum pumping group provided by Ganil
- Cryogenic valve box: general design in common, valves adapted to each type of cryomodules
- Cryomodule support (interface with ground): in common
- Alignment in the accelerator vault: same supports for targets on the vacuum vessel



SPIRAL2 LINAC Lecomte/Bernaudin GANIL

SPIRAL2: SHIPMENT



- 250 km (~150 miles) between CEA and Ganil (Caen - Normandy)
- Cryomodule installed on a transport frame with dampers
- Transport test on a cryomodule type A
 - Shipped from Saclay to GANIL, unloaded in GANIL, then loaded again on the truck and shipped back to CEA Saclay
 - Alignment measurement before and after the shipment: no change
 - Cold test at CEA Saclay at the end of the round trip: performances were not altered

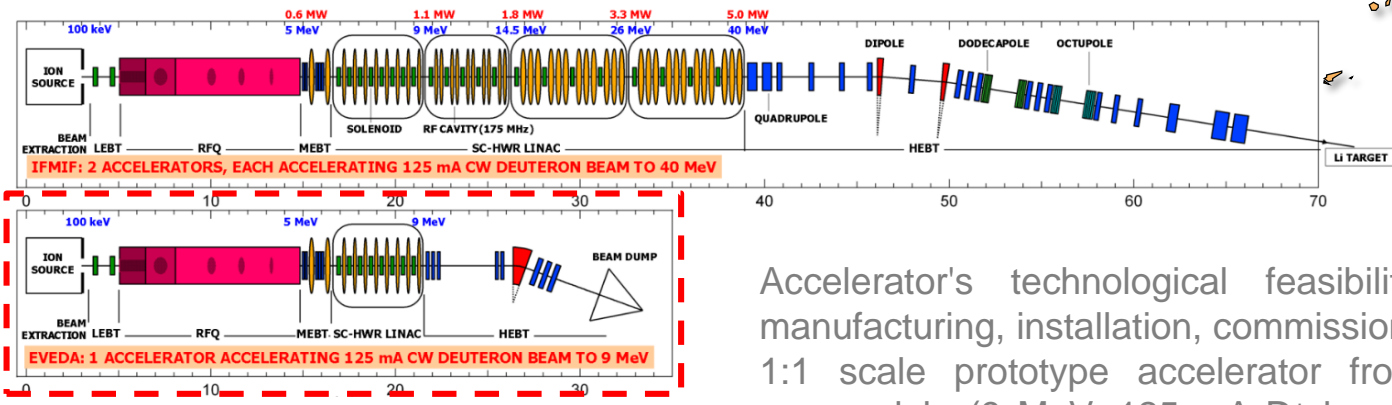
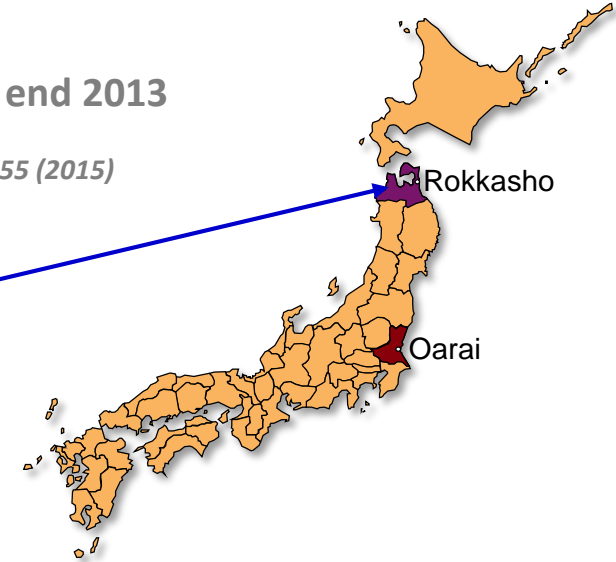
The Engineering Validation and Engineering Design Activities (EVEDA), conducted in the framework of the Broader Approach aim at:

– **Providing the Engineering Design of IFMIF** → IIEDR released by end 2013

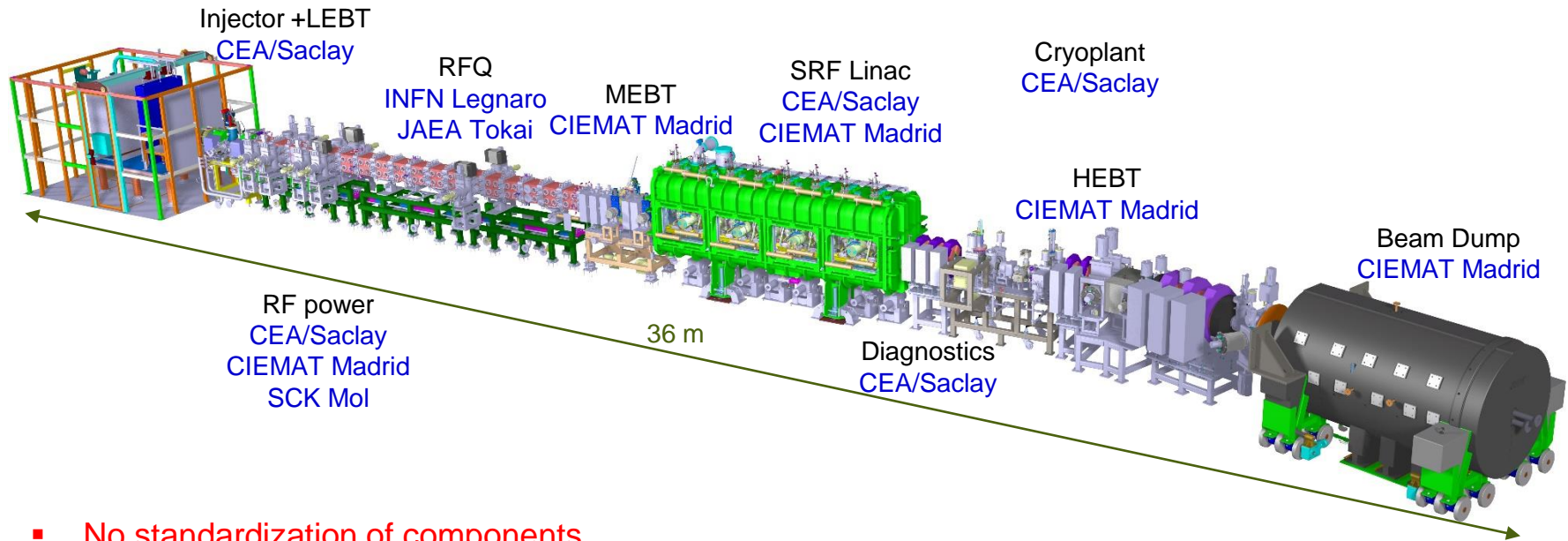
Cf. J. Knaster et al, "The accomplishment of the Engineering Design Activities of IFMIF/EVEDA: The European–Japanese project towards a Li(d,xn) fusion relevant neutron source", Nucl. Fusion 55 (2015)

– **Validating the key technologies (high priority)**

- The lithium target facility
- The high flux modules
- The low energy part of accelerator



Accelerator's technological feasibility tested through design, manufacturing, installation, commissioning and testing activities of a 1:1 scale prototype accelerator from the injector to the first cryomodule (9 MeV, 125 mA D⁺ beam CW): LIPAc (Linear IFMIF Prototype Accelerator)

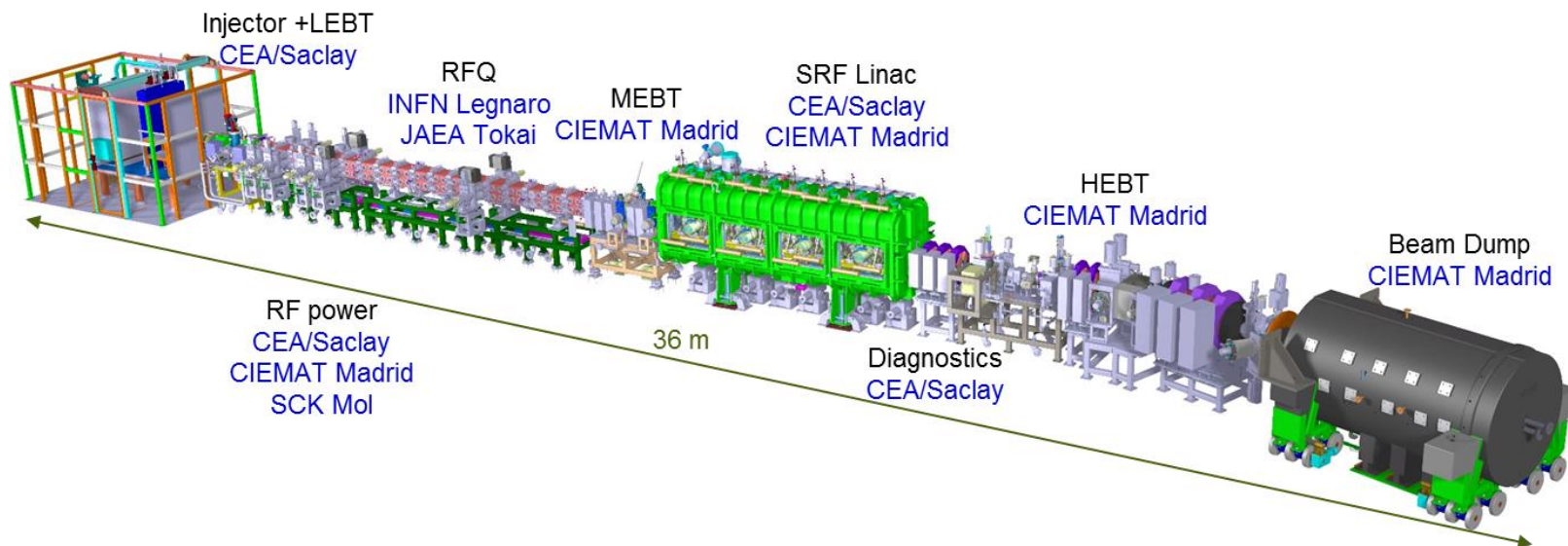


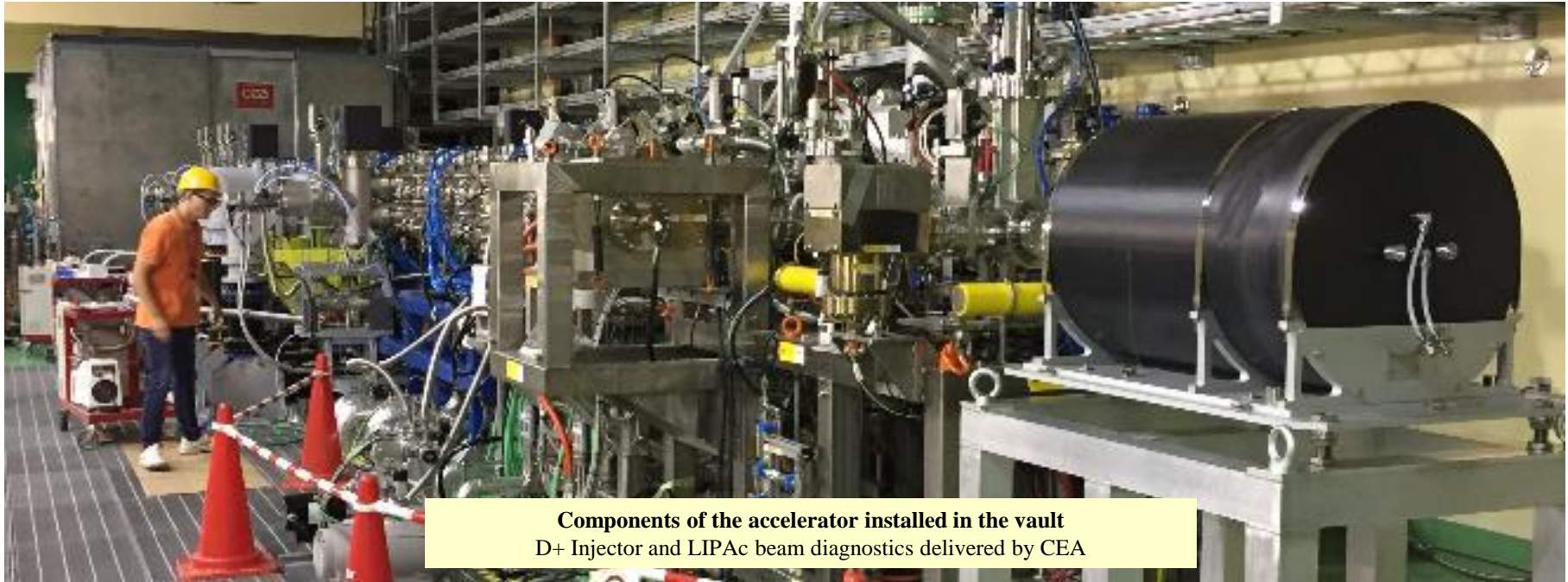
■ **No standardization of components**

- Instrumentation, electrical feedthroughs, connectors, cables
- Vacuum components: pumps, valves, gauges ...
- Water cooling system: valves, flow meters ...
- Interface with the ground (ex: type and size of rawplugs)
- Alignment: supports and targets

Defined and supplied by each system

LIPAC: STATUS INSTALLATION





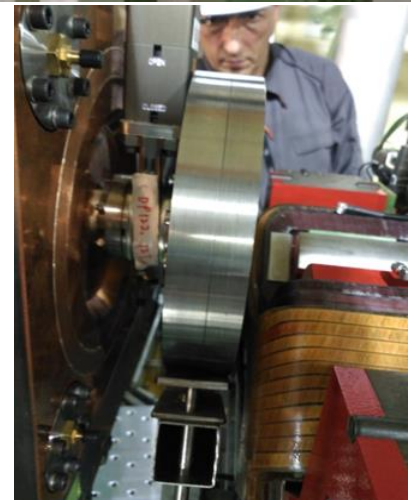
Components of the accelerator installed in the vault
D+ Injector and LIPAc beam diagnostics delivered by CEA



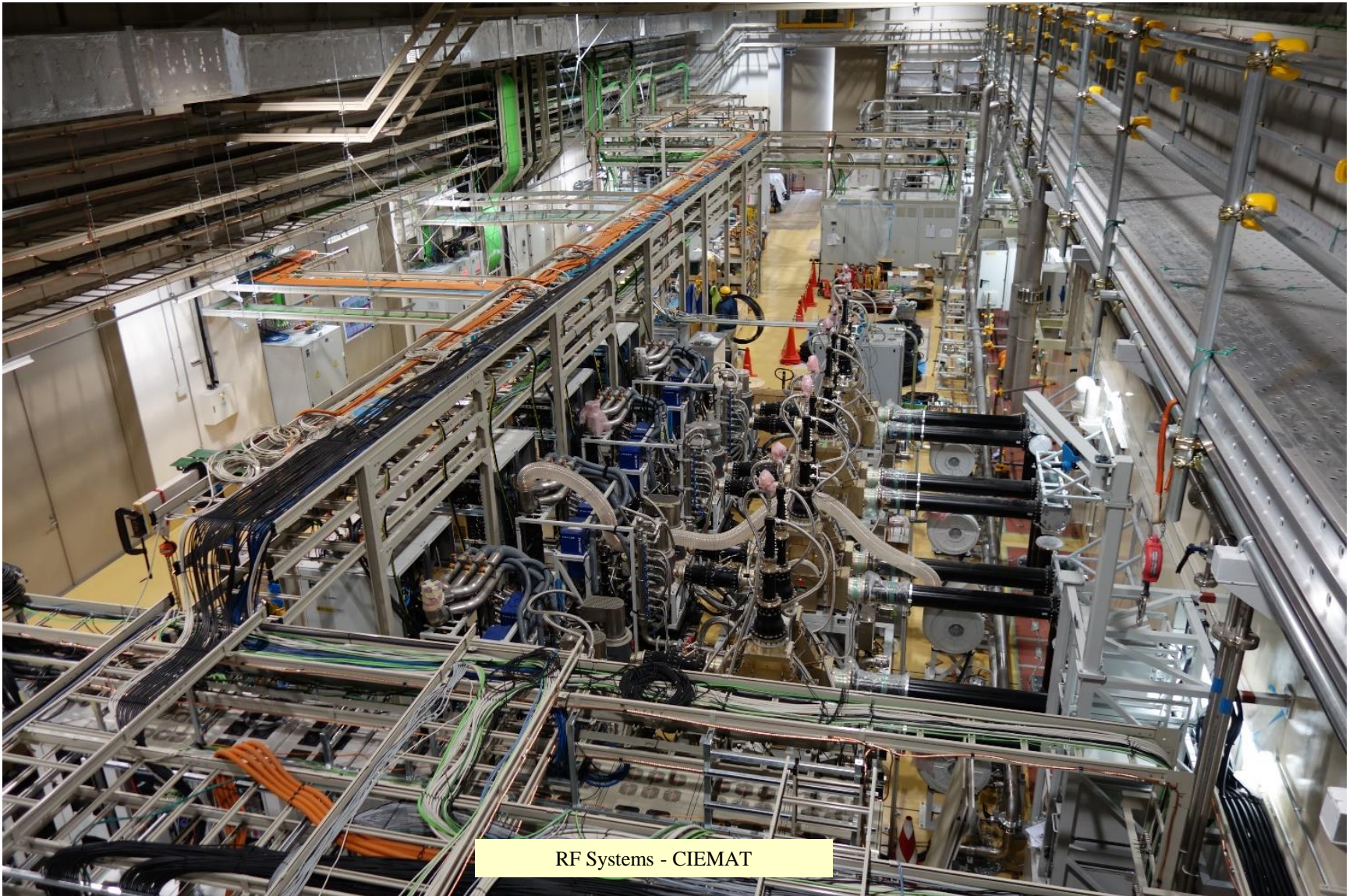
Phase B : Installation du système de refroidissement



D-Plate (CIEMAT & CEA)

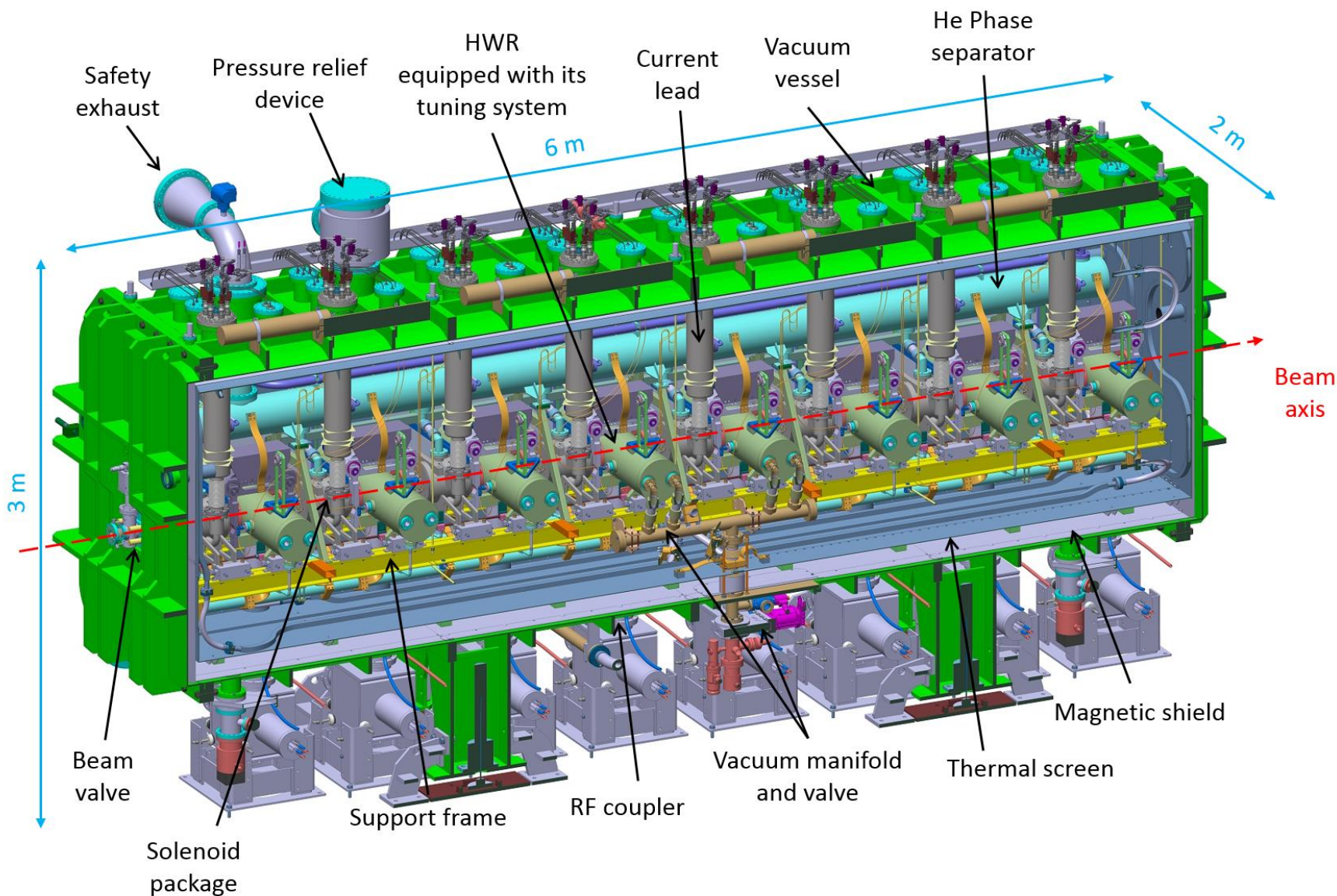


interface MEFT & RFQ



RF Systems - CIEMAT

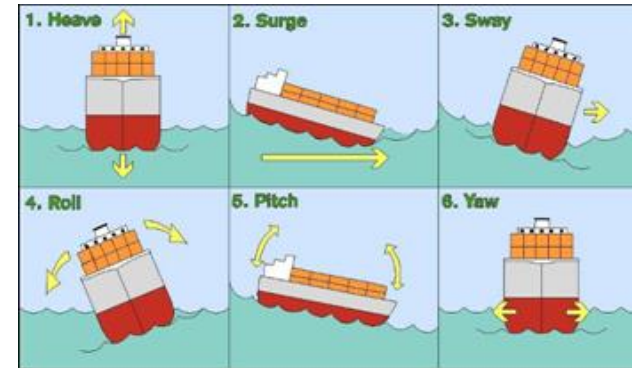
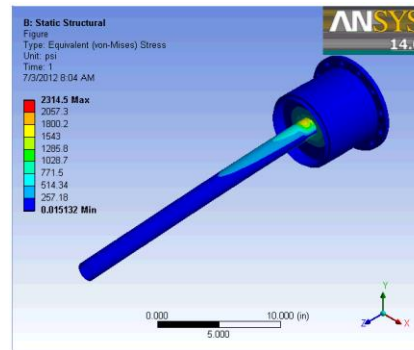
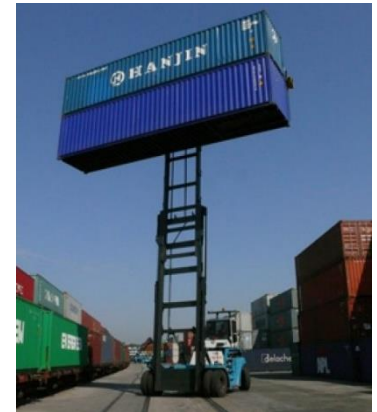
CRYOMODULE DESIGN



Original plan

Transportation by sea. Cheapest solution but:

- ❑ Several loadings/unloadings → heavy shocks possible during transshipment
- ❑ Coupler window failure or weakening due to fatigue (resulting from ocean swell)
- ❑ Risk of contamination of the beam vacuum during shipment (long journey)
- ❑ Additional transport studies (fatigue, shock and vibration levels, frame, container, etc.)



Mitigation

- ❑ Transportation by plane
- ❑ Assembly in Japan



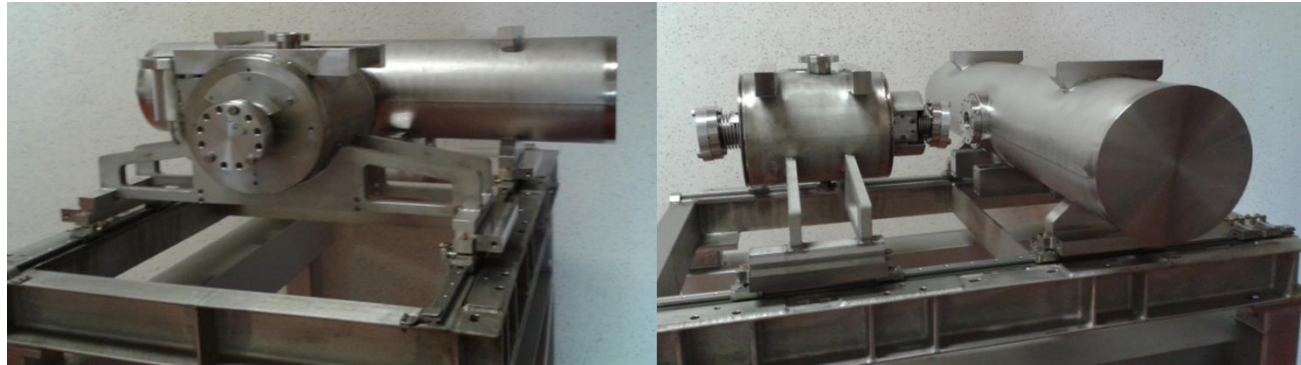
N. Bazin – PIP-II workshop on cryomodule

JT60 coils shipped by Antonov-124

- ❑ CEA send separately all the components of the cryomodule to QST Rokkasho Fusion Institute
- ❑ The cryomodule is assembled there under the responsibility of F4E (Fusion for Energy) with CEA assistance
- ❑ To fulfill the assembly of the cavity string, a cleanroom is being built at Rokkasho Fusion Institute under the responsibility of QST

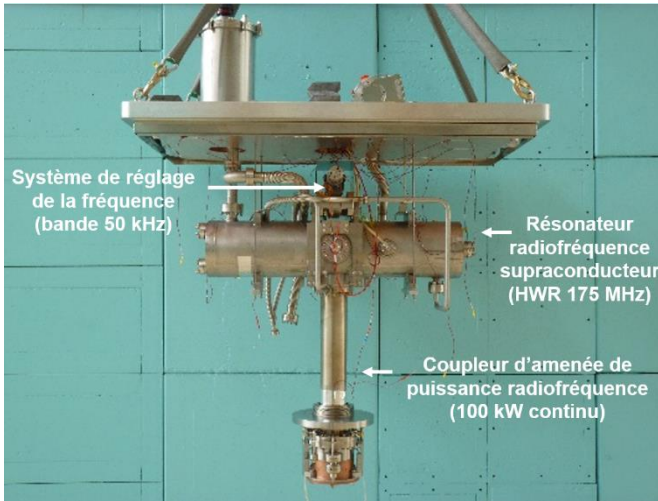
➔ Early testing before cryomodule assembly

- Important mitigation measure to prevent a critical event during the assembly of the cavity string.
- A dummy cavity, solenoid, coupler and part of the support frame manufactured and used to perform tests outside and inside the clean room to validate and optimize the assembly procedure and the tools.

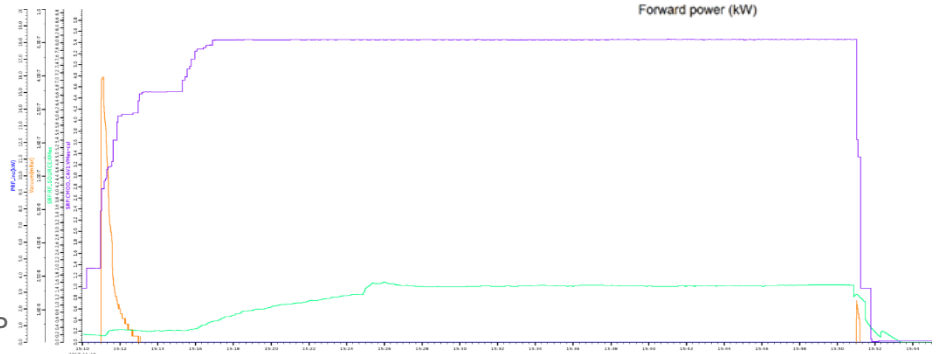
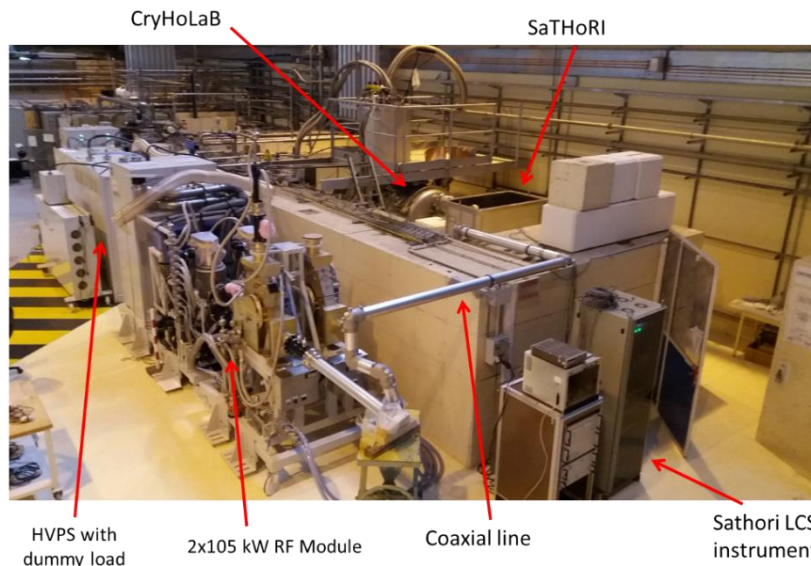
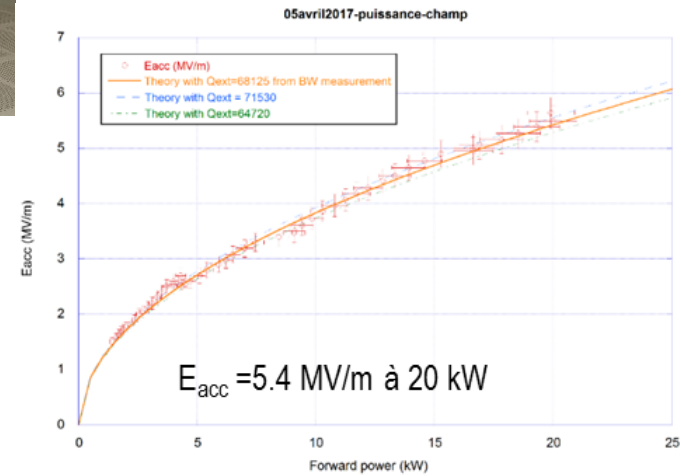


- Dummy element welds are leak tight → check of the leak tightness of the gaskets between the dummy cavity, solenoid and coupler.
- Mock-ups intended are used to train the operators for the assembly of the whole cavity string.

SaTHoRI: operational equivalent tests and tuning of HWRs at Saclay of two accelerating units



Tooling for the assembly of a power coupler on a cavity: qualified during the SaTHoRI tests, will be used for the assembly of the cavity string



Since 2014 SNRC and CEA collaborate to the upgrade of the SARAF accelerator to 5 mA CW 40 MeV deuteron and proton beams (Phase 2)

Top Level Requirements :

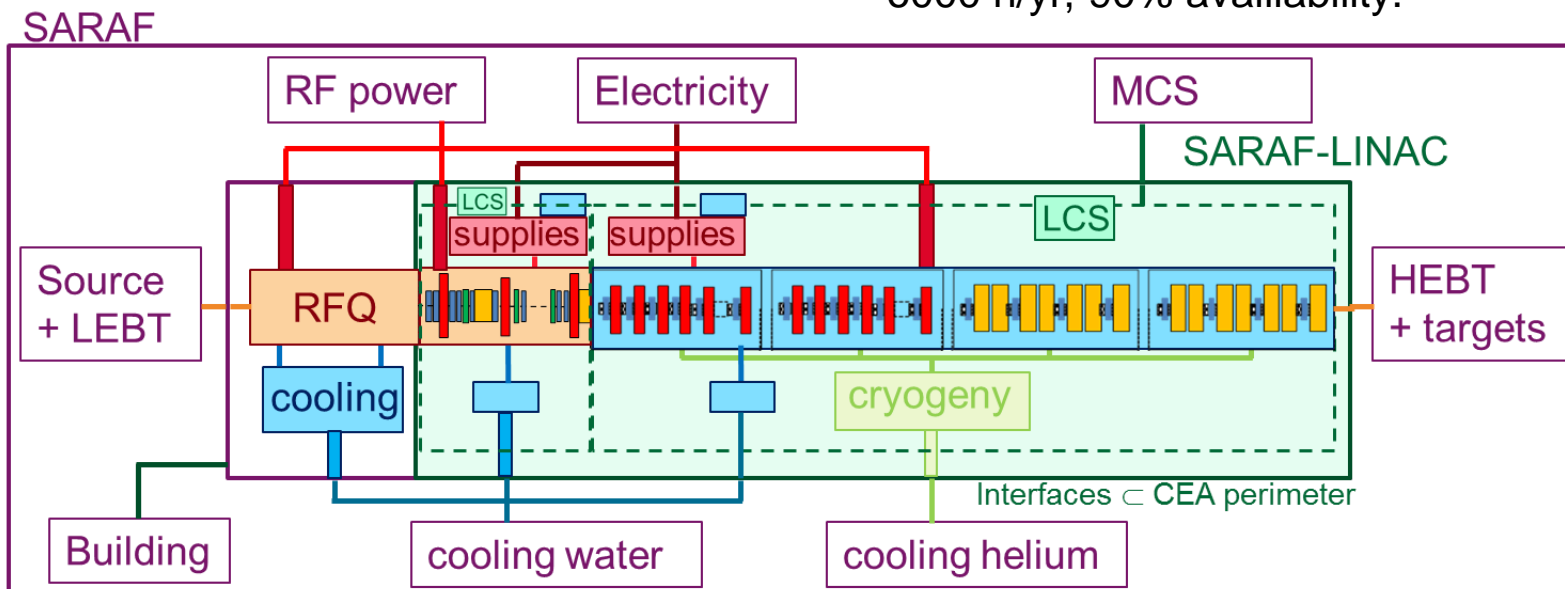
- Beam:

- Deuterons/protons,
- pulsed/cw,
- 0.04 - 5 mA,
- 2.6-40 MeV (protons 35 MeV).

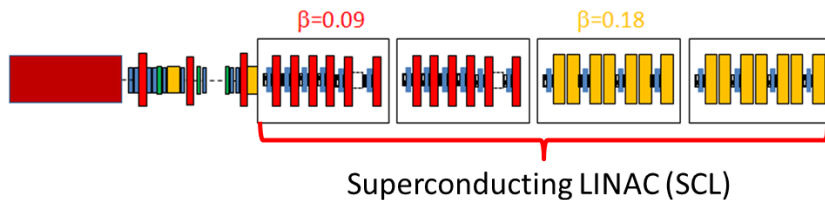
- Losses: in order to allow hands-on maintenance, level of losses much lower than 1 W/m are aimed

- <150 nA/m @ <5 MeV,
- <40 nA/m @ <10 MeV,
- <5 nA/m @ <20 MeV,
- <1 nA/m @ <40 MeV.

- 6000 h/yr, 90% availability.

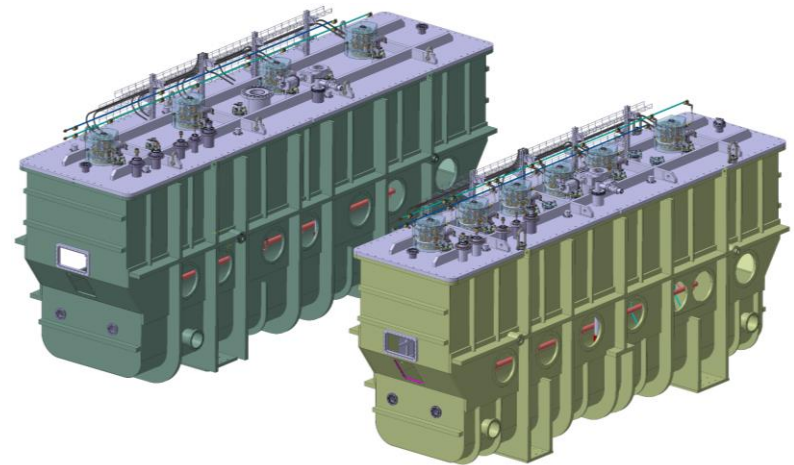
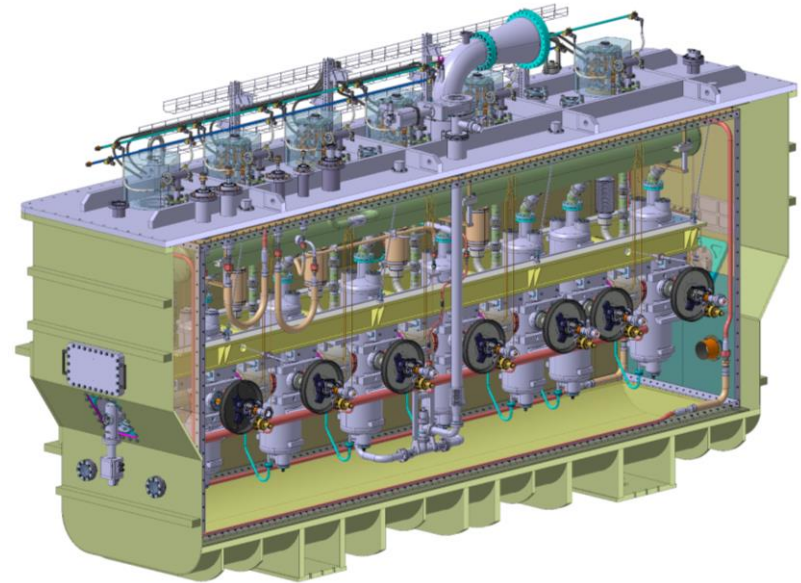


SARAF –LINAC Project
April 2014 Reference Design



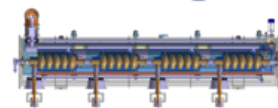
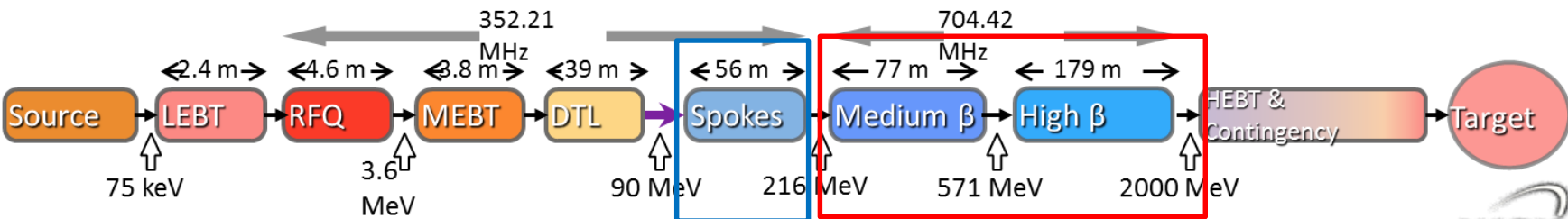
- ❑ The SCL is made of:
 - 4 cryomodules including 176 MHz superconducting HWR cavities and superconducting solenoids
 - 4 warm diagnostic boxes at the end of each cryomodule, housing beam instrumentation
- ❑ The two first cryomodules (CM1 and CM2) are (almost) identical:
 - They house $\beta_{opt} = 0.091$, 176 MHz half-wave resonators and 6 focusing superconducting solenoids with steerers.
 - A 360 mm free space between the fifth cavity and the sixth solenoid package is left in CM1 to facilitate the matching with next cryomodule.
 - Space occupied by a seventh cavity in CM2.
- ❑ The last two cryomodules (CM3 and CM4) are identical: they house 6 $\beta_{opt} = 0.181$, 176 MHz half-wave resonators and 4 focusing superconducting solenoids with steerers.

- ❑ Similar design principles for both types of cryomodule
- ❑ Design efforts to make components of low and high beta cryomodules as similar as possible
 - Same components for low beta cryomodules (CM1 and CM2): ports for the seventh cavity on the helium distribution closed with blank flanges
 - Same tooling for the assembly
 - Same instrumentation flanges and cabling
 - Raw materials similar for a same low and high beta component
 - Support frame: same cross section beam
 - Thermal shield: same sheet thickness and cooling tube section
 - Vacuum vessel: same sheet thickness and strengthening bar sections
 - Cryogenic valve box: general design in common, valves adapted to each type of cryomodules
- ❑ Vacuum: standardization on CEA systems: vacuum systems defined by the same person for MEBT and SCL





- ❑ European Spallation Source is under construction in the city of Lund, in southern Sweden
- ❑ ESS will offer neutron beams of unparalleled brightness for cold neutrons, delivering more neutrons than the world's most powerful reactor-based neutron sources today, and with higher peak intensity than any other spallation source
- ❑ ESS Cold Linac: a collaborative project



M-β

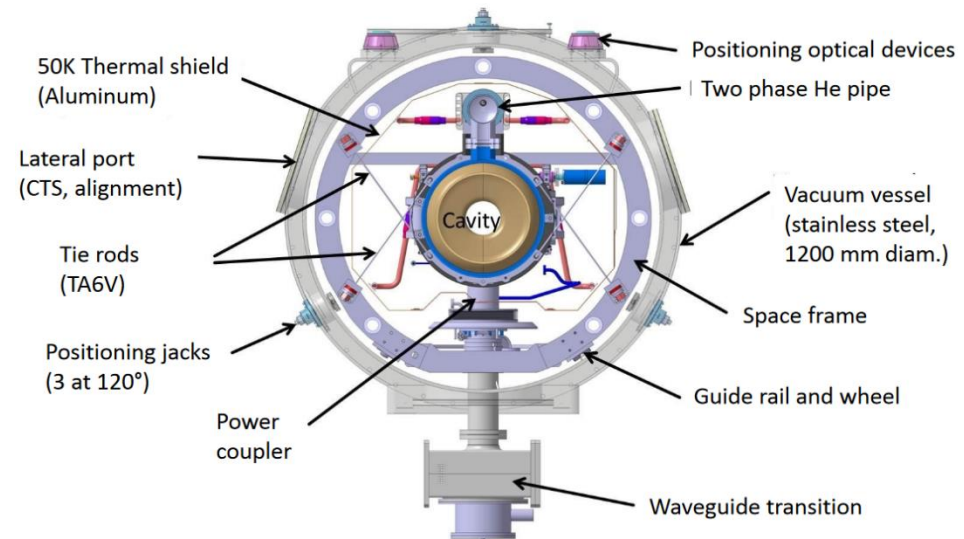
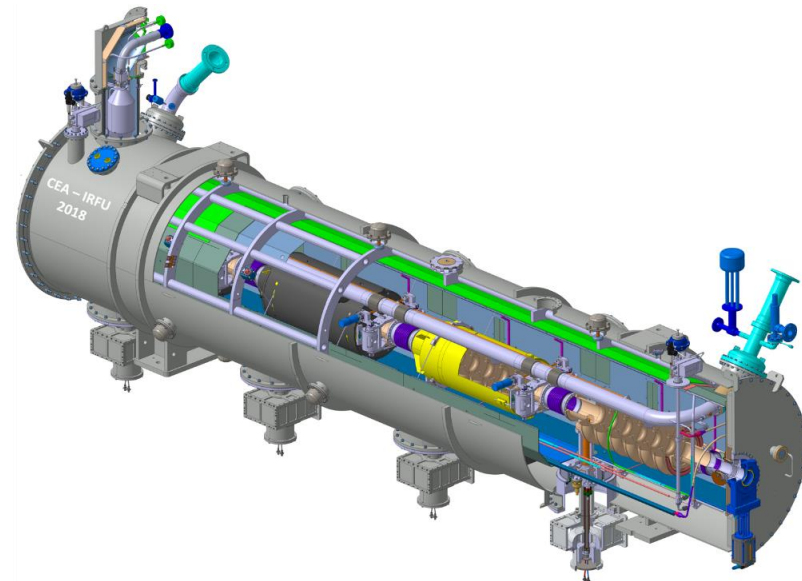
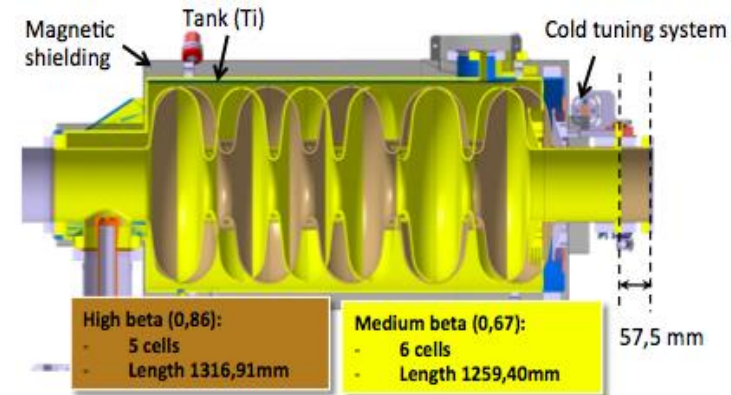


H-β



ELLIPTICAL CRYOMODULES

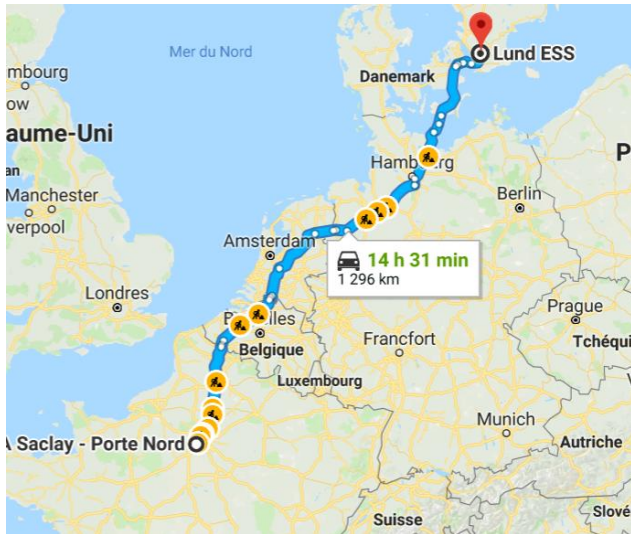
- ❑ 30 Cryomodules (9 medium-beta and 21 high-beta) are required to accelerate protons from an energy of 216 MeV up to an energy of 2 GeV.
- ❑ Common design for medium and high beta cryomodules:
 - Made sensible thanks to the small length difference between 6-cell medium and 5-cell high beta cavities
 - Main components are identical: vacuum vessels, thermal shields, supports, spaceframes, alignment system ...
 - Only few elements differ: details in cryo piping, beam pipe bellows
 - Same assembly tooling



- ❑ Collaboration between ESS / IPNO / CEA to standardize some components on the superconducting linac
 - Instrumentation: same type of multipin and RF connectors, same temperature sensors, same pressure transmitter
 - Tuning system motor: same vendor, references are different
 - ESS is making an effort of standardization for vacuum components:
 - Insulation vacuum: the interface between the vacuum vessel and the pumping system is defined by ESS, vacuum system, valve and gauges provided by ESS
 - Beam vacuum: same vendor for the beam valves, references are not the same due to the difference in beam pipe diameter between spoke and elliptical cavities

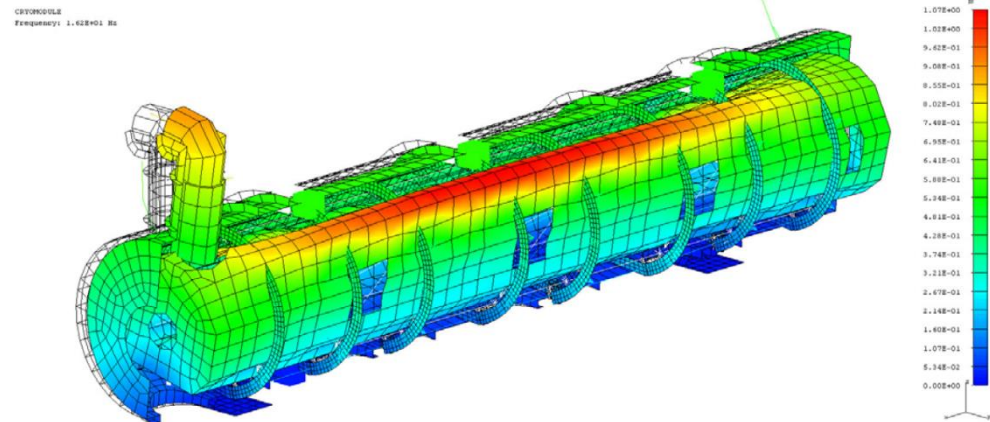
- ❑ Interface with the cryogenic system: defined by ESS
 - Spoke cryomodules: cryogenic valves in the cryogenic distribution
 - Elliptical cryomodules: cryogenic valves in the module

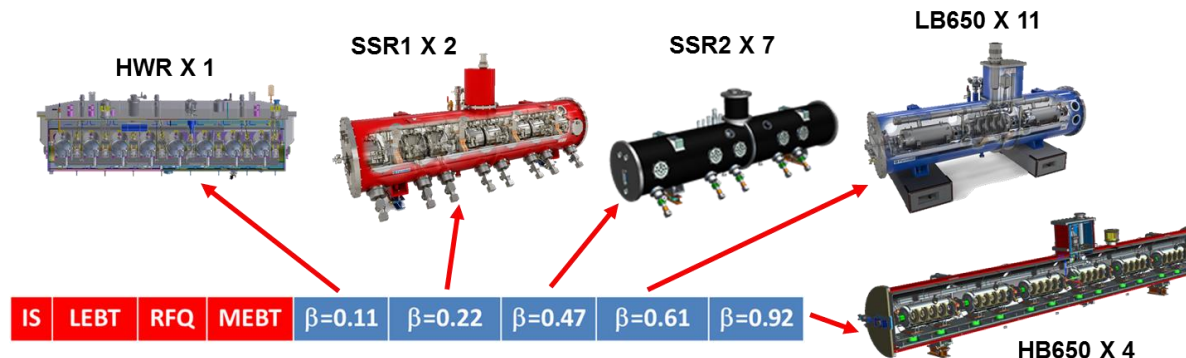
- ❑ Cryomodule supports: no standardization on the anchoring and the positioning system (unlike Spiral 2)



- ❑ Road transport between CEA Saclay and ESS Lund (1300 km – 800 miles)
- ❑ A damping frame similar to the XFEL one will be used
- ❑ Mechanical simulations have been performed on a high level model to assess the behavior of the cryomodule during the road transport between Saclay and Lund

- ❑ Some components have to be clamped for the transport (ex: thermal shield)
- ❑ A transport test is planned on one of the demonstrator cryomodules (MECCTD or HECCTD): RF tests at CEA Saclay, transport, RF tests at ESS Lund





❑ Standardization: why?

- ❑ Ease the maintenance and repair operations, and the supply / storage of consumables (less suppliers, less references)

❑ Standardization: what?

- ❑ Common design rules: it has been agreed in June to use metric system, but which Geometric Dimensioning and Tolerancing norms: ISO 2768 or ASME Y14.5-2009?
- ❑ Common CAD software
- ❑ Identical components: off the shelf products, consumables, specially designed parts (C clamps, alignment supports, piping ...) → see next slide
- ❑ Assembly tooling (depending on the design concept of the different cryomodules) → good definition of the interfaces and assembly steps at the beginning of the detailed design phase
- ❑ Specific requirements on the components: vacuum compatibility, criteria for the use in clean room, magnetic hygiene, hard-rad materials ...

❑ Standardization: how?

- ❑ To be discussed during this workshop

- Piping: material and diameter
- Cryogenic valves
- Vacuum components: vacuum valves, vacuum gauges, pressure transmitter ...
- Safety devices: safety valve, burst disk ...
- Instrumentation flanges with electrical feedthroughs
- RF cryogenic cables
- Type of gaskets / seals: beam vacuum, insulation vacuum, cryogenic circuits
- Instrumentation: temperature sensors, heaters, tuning system motors
- Fasteners: type, material, size, length, specific requirements (electropolishing , magnetic permeability, silver plating ...)
- MLI: how to attach the parts: aluminum tape or Velcro?
- Alignment targets
- Cryomodule supports