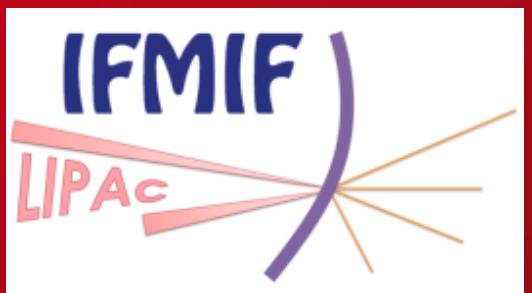


FROM RESEARCH TO INDUSTRY



# ACCÉLÉRATEUR PROTOTYPE IFMIF/EVEDA: STATUS



[www.cea.fr](http://www.cea.fr)

N. Bazin

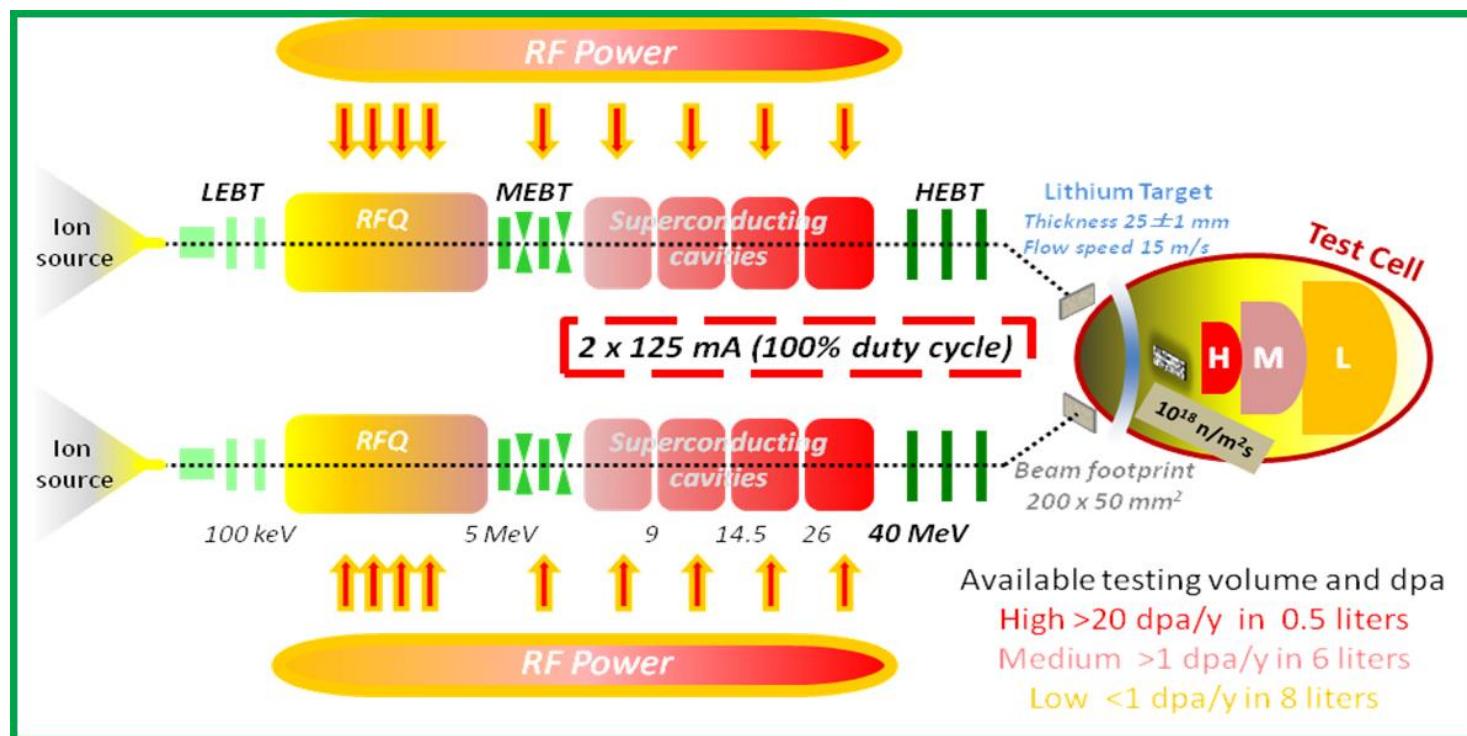
Journées accélérateurs 2019 de la SFP

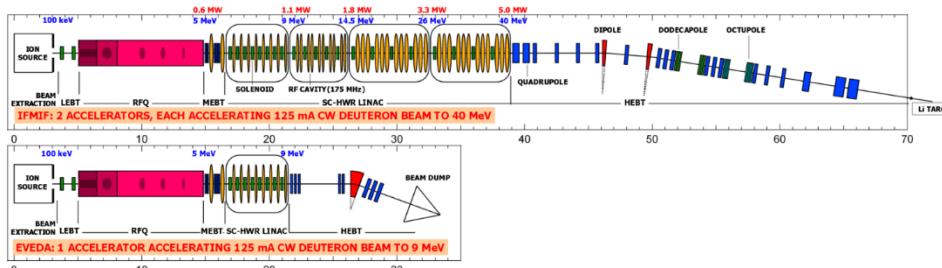
- Introduction
- LIPAc: statut des activités à Rokkasho
- Cryomodule: statut
- Perspectives: DONES et A-FNS

## International Fusion Materials Irradiation Facility

**Objectif:** produire un flux de neutrons ( $10^{18} \text{ n.m}^{-2}.\text{s}^{-1}$ ) à 14 MeV afin de tester les matériaux des futurs réacteurs à fusion

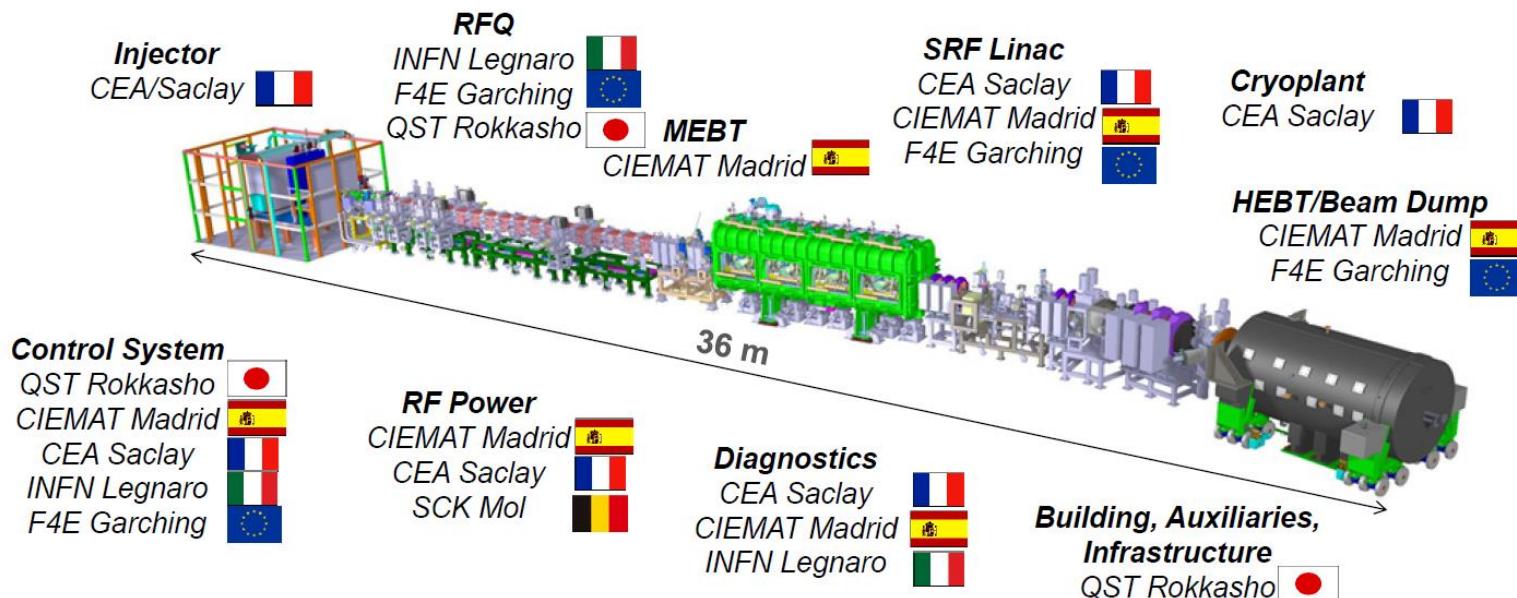
**Principe:** deux faisceaux de deutons à 125 mA CW de 40 MeV bombardant une cible de lithium liquide circulant à 15 m/s



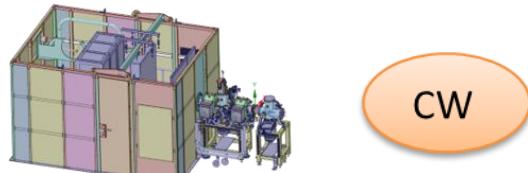


■ IFMIF/EVEDA: validation phase of the IFMIF project

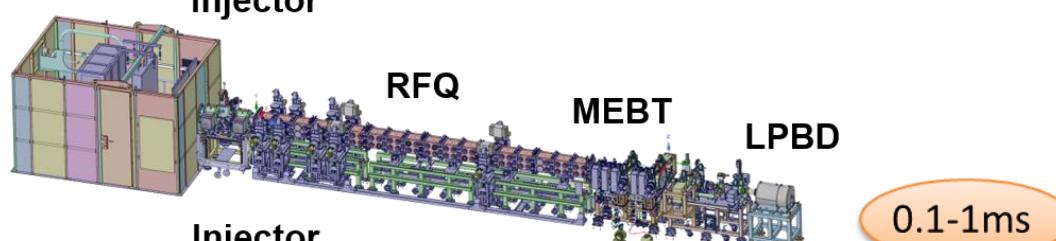
- LIPAc (Linear IFMIF Prototype Accelerator) under construction in Japan, at Rokkasho Fusion Institute: 9 MeV, 125 mA deuteron beam CW
- Collaboration between Japan and Europe



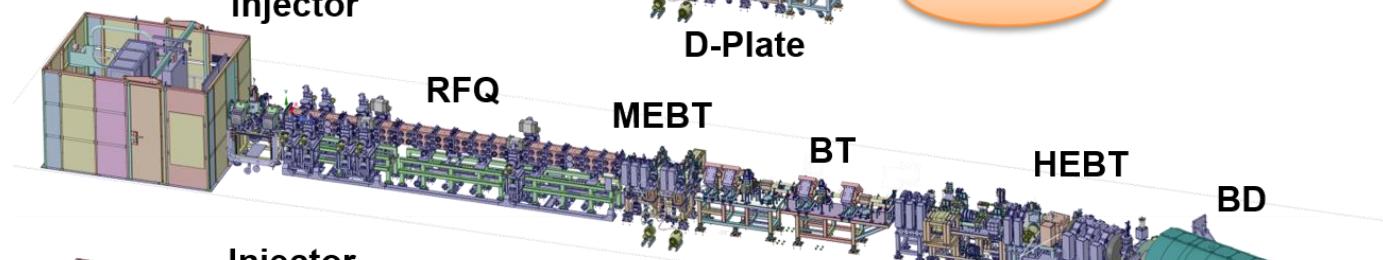
Phase A



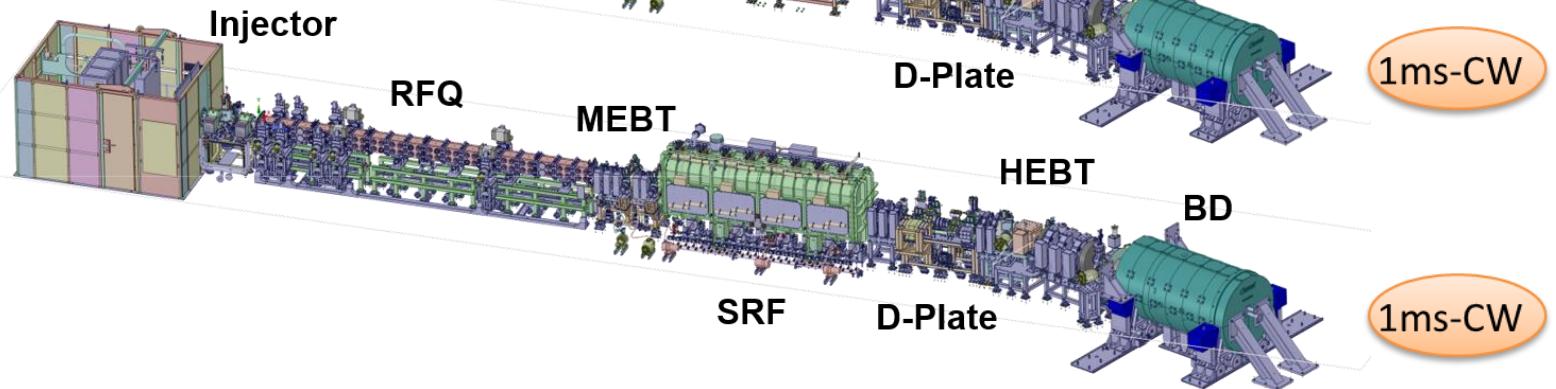
Phase B

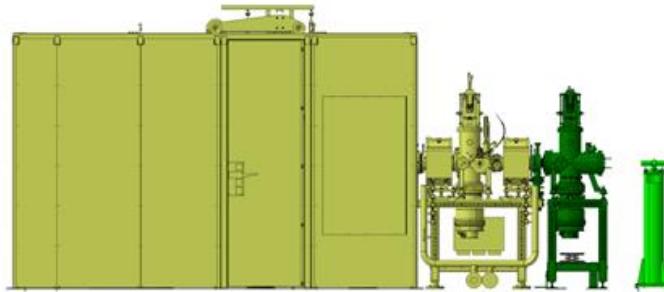


Phase B+



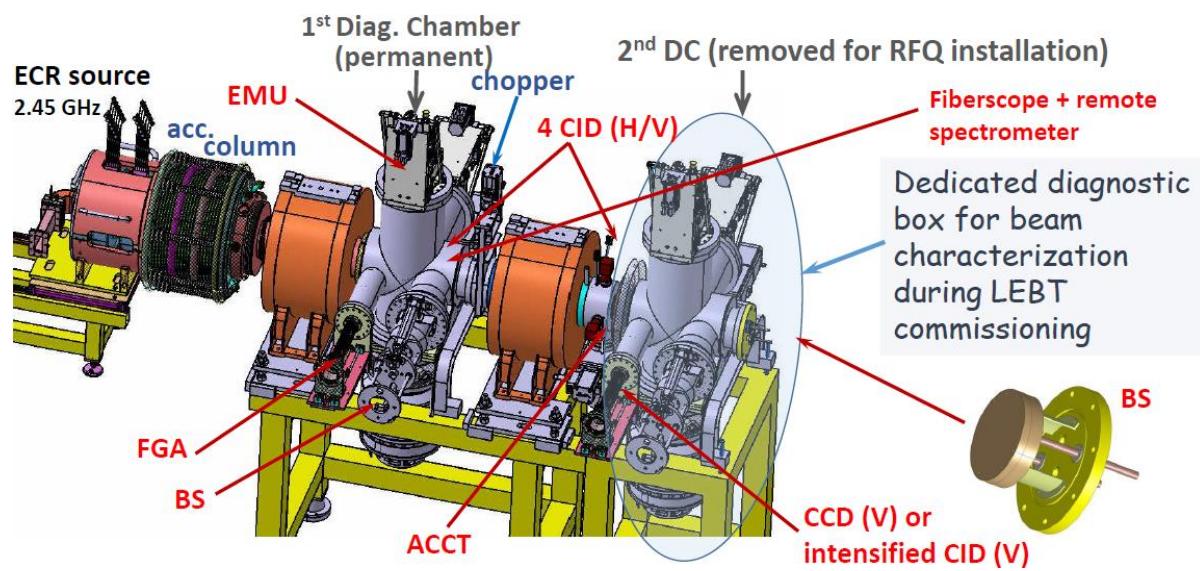
Phase C/D



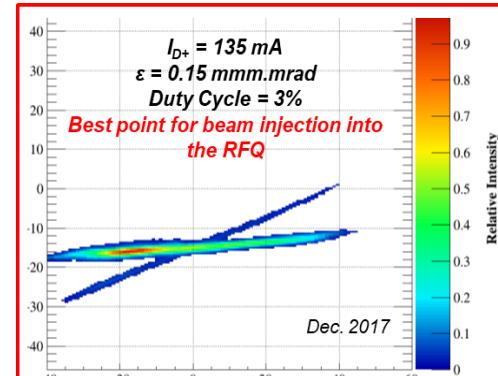
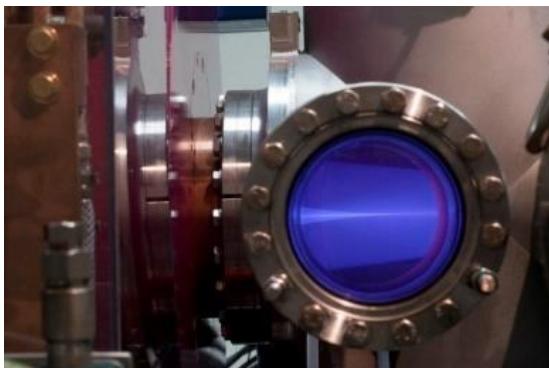
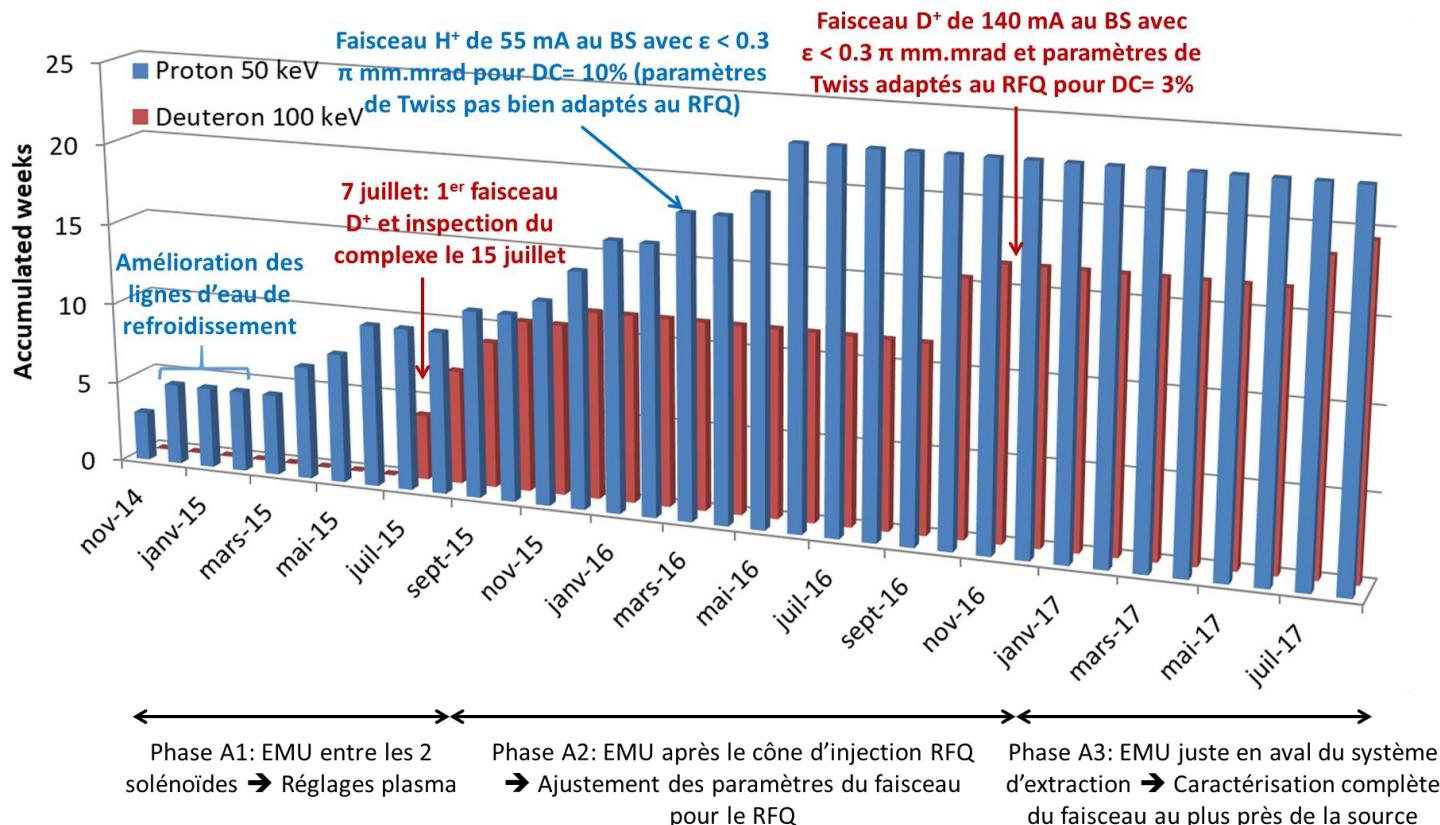


### Objectifs:

- Commissioning de l'injecteur (en proton pour limiter l'activation, puis en deutons)
  - Réglages et caractérisation du faisceau avant injection dans le RFQ
- Implantation de multiples diagnostics faisceau

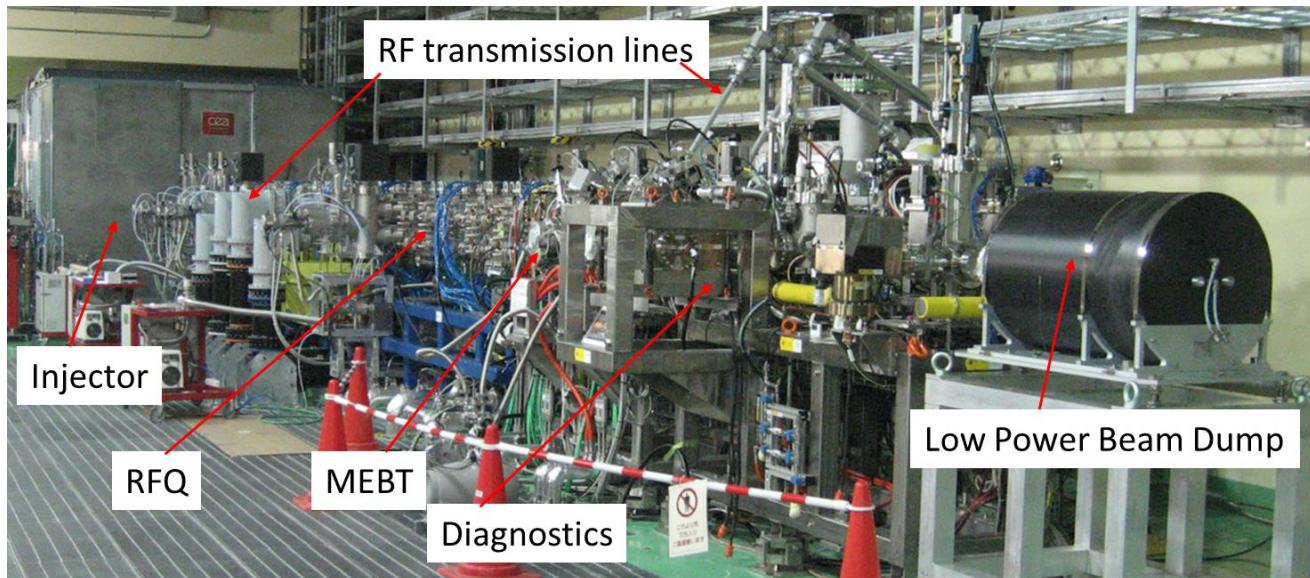
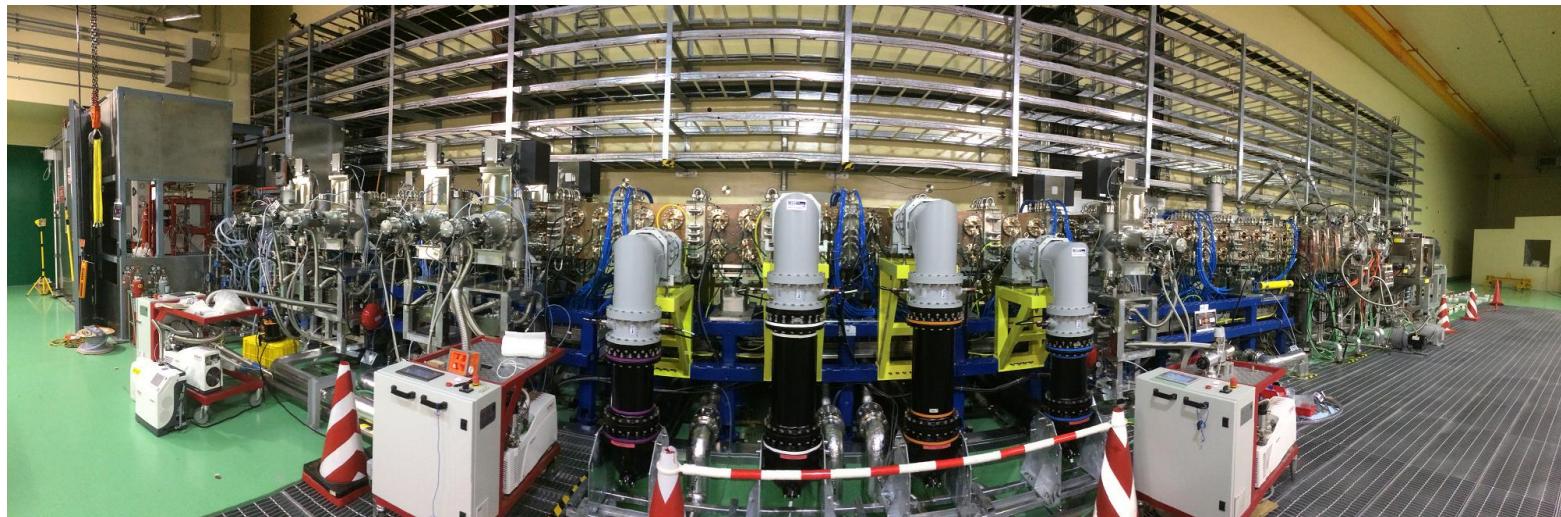


## PHASE A

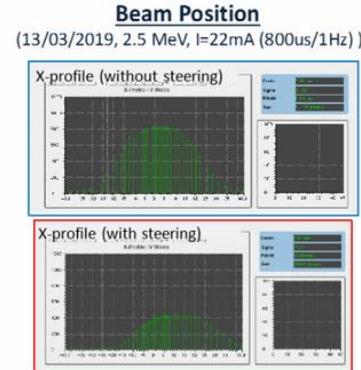
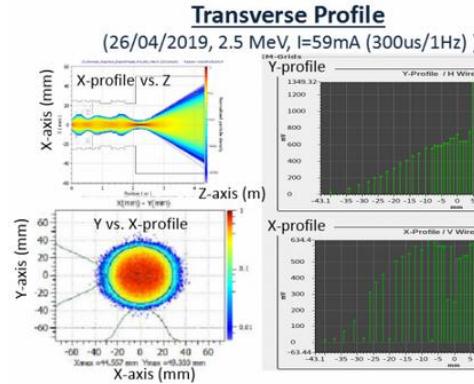
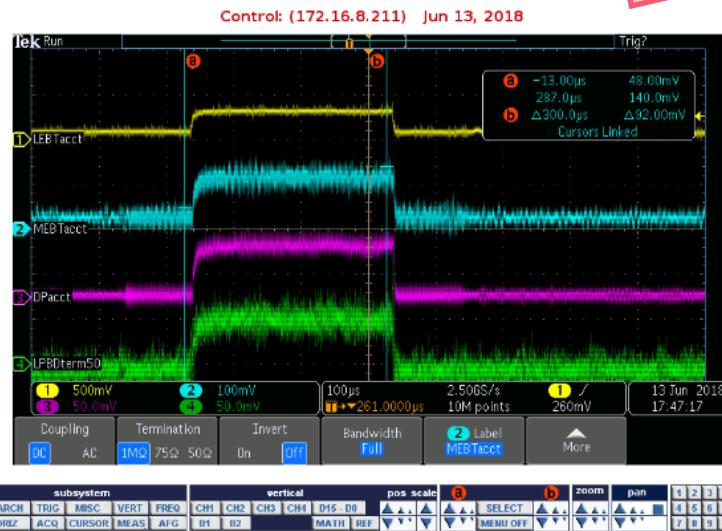


Plus d'informations:  
*Deuteron beam commissioning of the linear IFMIF prototype accelerator ion source and low energy beam transport*  
N. Chauvin et al 2019 *Nucl. Fusion* **59** 106001

# PHASE B



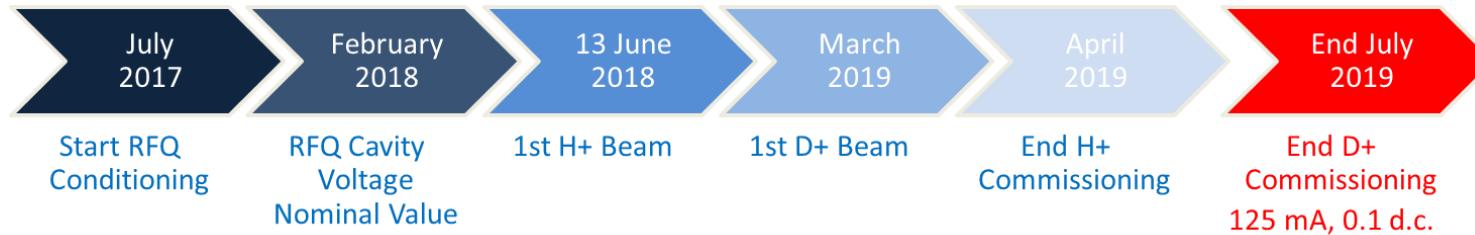
# PHASE B: CAMPAGNE EXPÉRIMENTALE



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

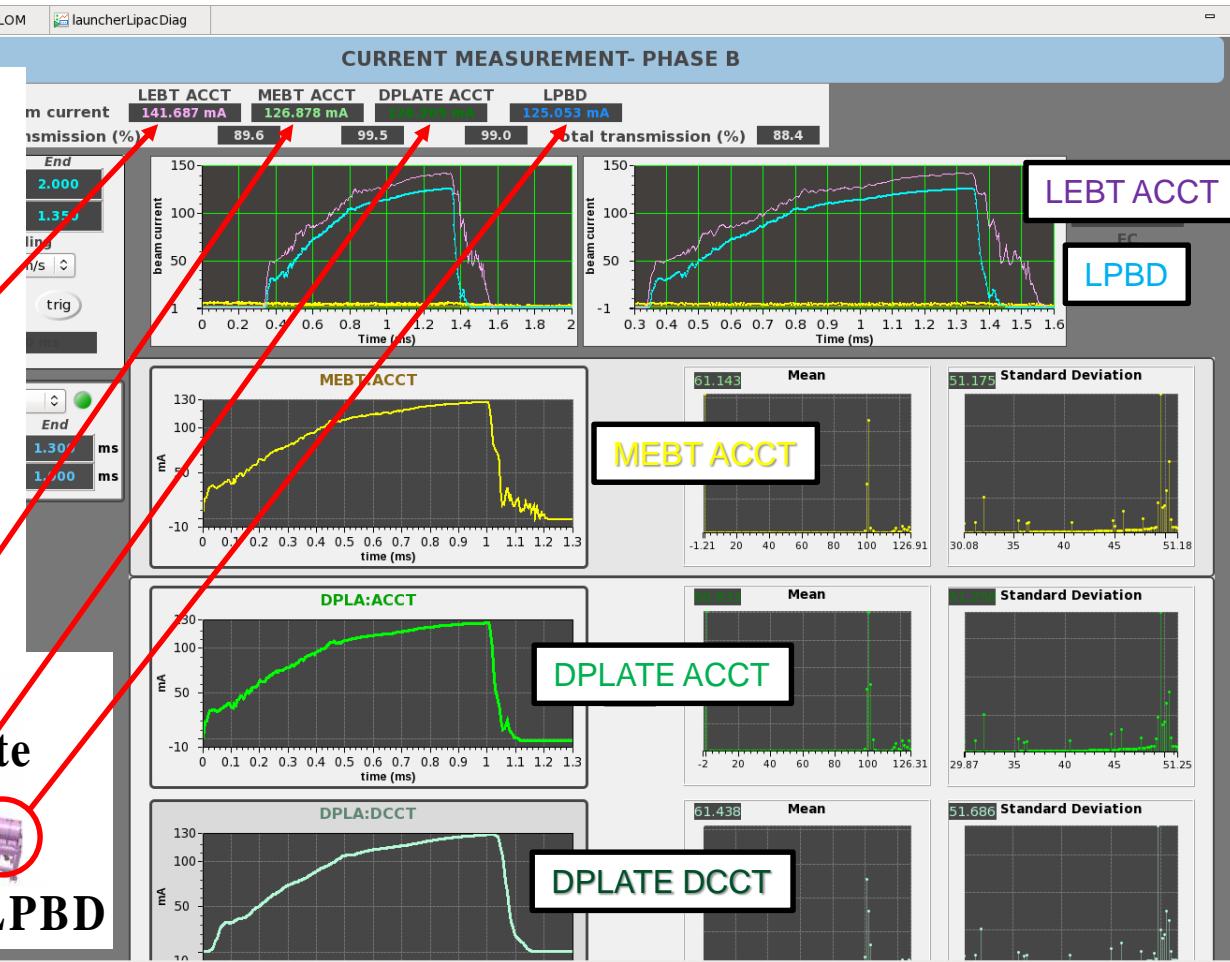
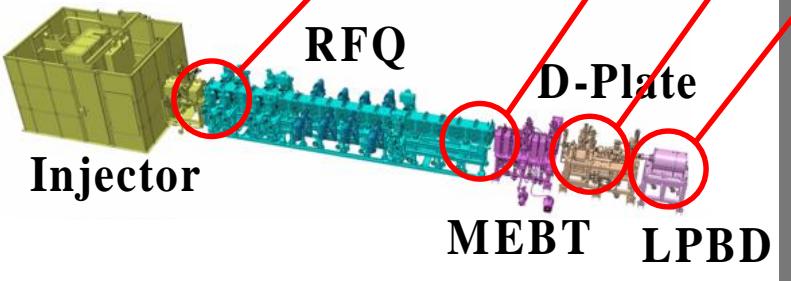
- Premier faisceau (protons) en sortie du RFQ le 13 juin 2018 avec 80% de transmission
- Low duty cycle, courant jusqu'à 65 mA en sortie de l'injecteur
- Faisceau de protons à 2.5 MeV
- Validation des diagnostiques faisceau
- 88 mA en sortie de l'injecteur, pulse de 300 μs
- 57 mA accéléré dans le RFQ avec une transmission de 93%

## PHASE B: CAMPAGNE EXPÉRIMENTALE



24 juillet 2019, 19h13

- **166 mA** extrait de la source ( $\varepsilon_{n,rms} \sim 0.2\pi \text{ mm mrad}$ )
- **142 mA** injecté dans le RFQ
- Tension RFQ **~132 kV** (valeur nominale de design)
- Pulse RF  $\sim 1 \text{ ms}, 1 \text{ Hz}$
- **127 mA** en sortie de RFQ (transmission  $\sim 90\%$ )
- **125 mA** envoyé dans le beam dump
- Energie du faisceau  $\sim 5 \text{ MeV}$

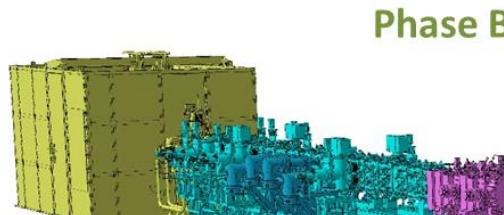


- Phase expérimentale en parallèle de l'assemblage du cryomodule

## Objectifs:

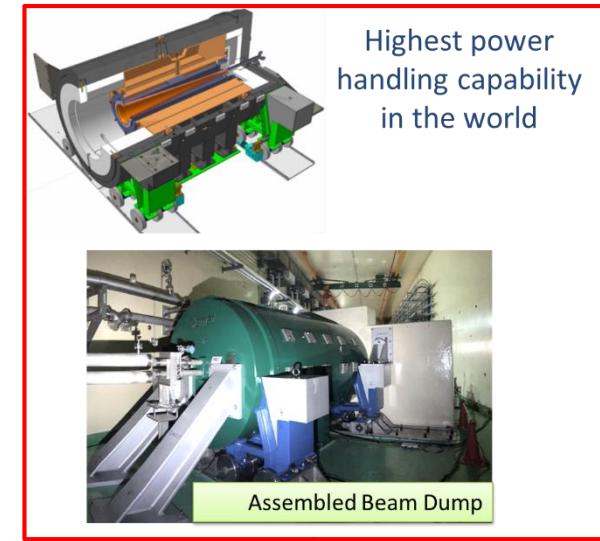
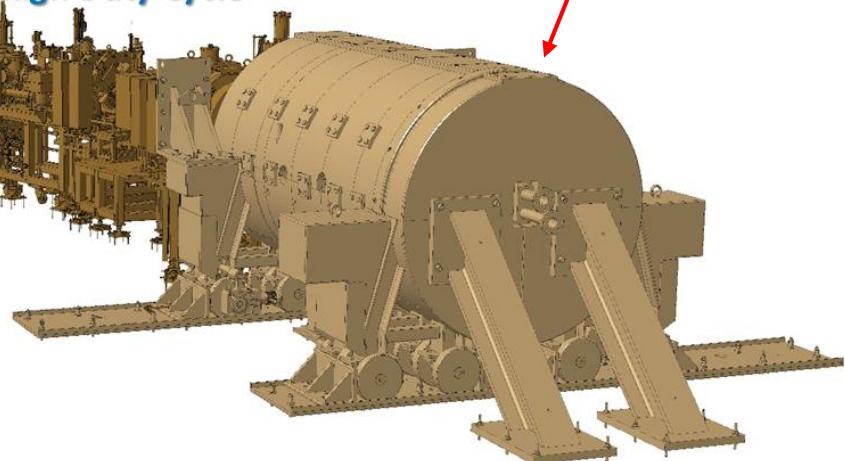
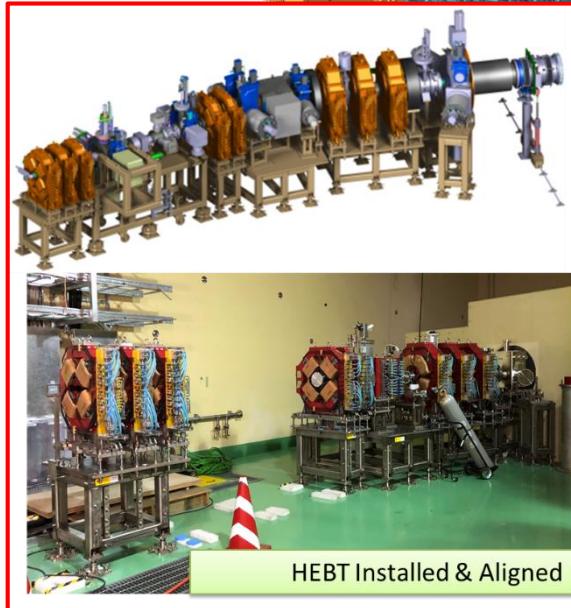
- Valider le fonctionnement du RFQ en continu
- Commissioning de la HEBT et du Beam Dump

### Phase A



### Phase B

**Phase B+**  
**5 MeV - 125 mA**  
**625 kW – high Duty Cycle**



Highest power handling capability in the world

### Statut:

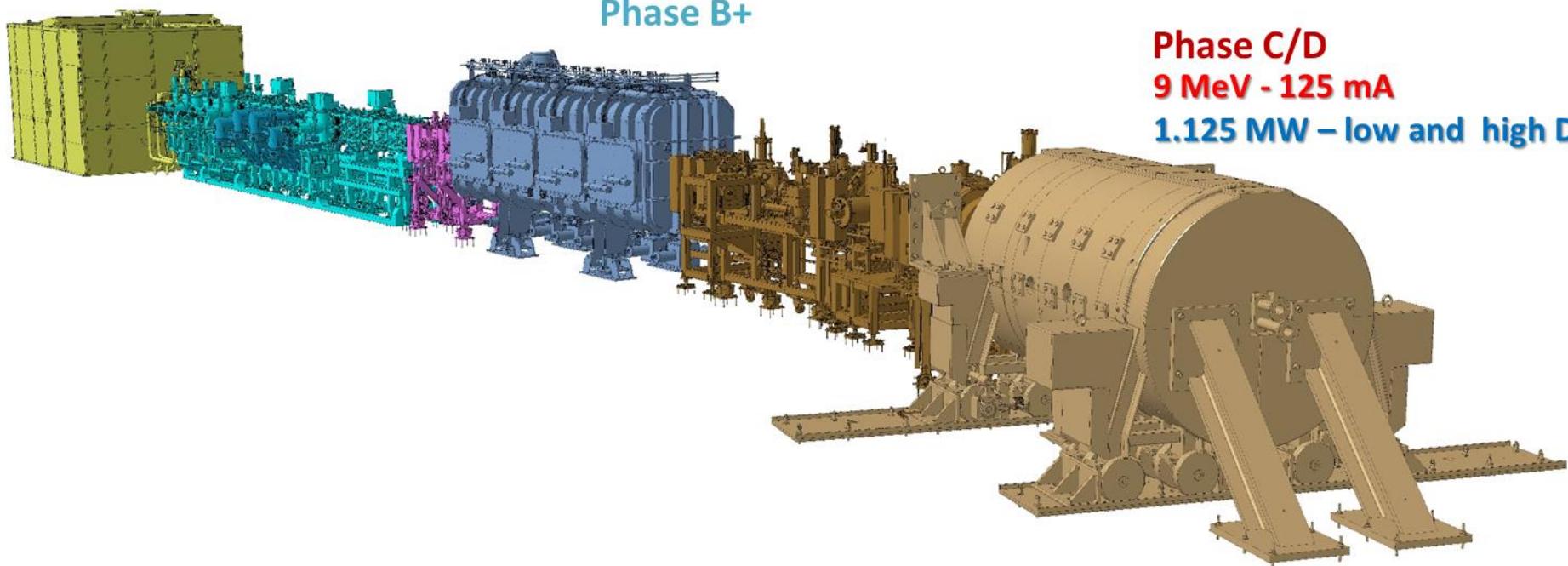
- Installation du Beam Dump réalisée, finalisation de l'installation de la HEBT
- Réalisation de la Drift Line en cours

Phase A

Phase B

Phase B+

**Phase C/D**  
**9 MeV - 125 mA**  
**1.125 MW – low and high DC**



## ■ Eight half-wave resonators

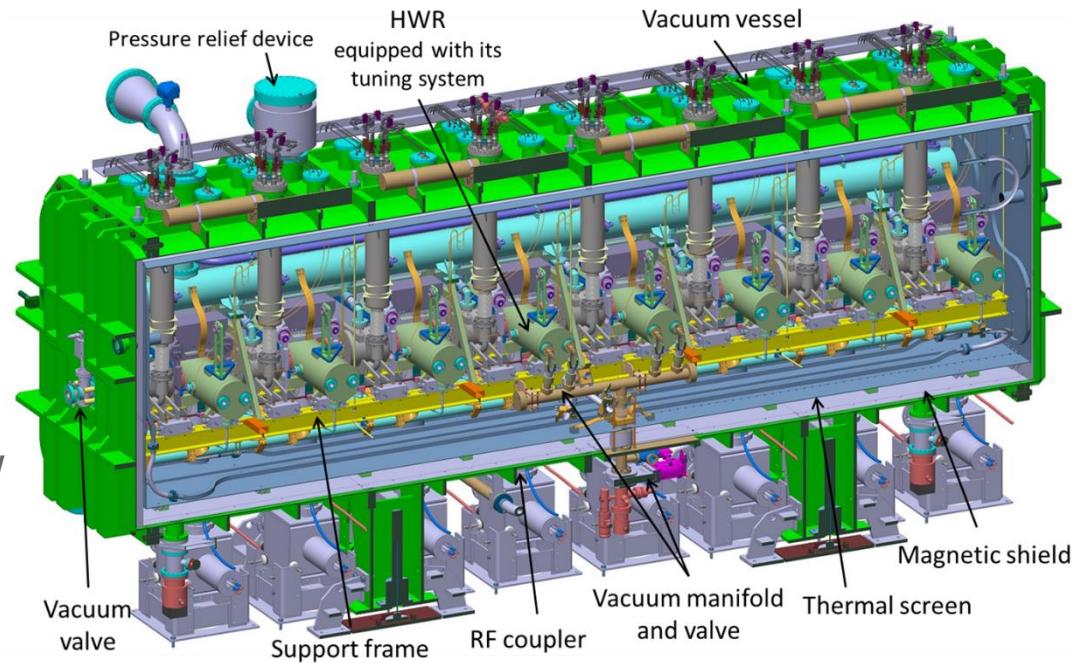
- 175 MHz,  $\beta=0.094$
- $E_{acc-nom} = 4.5 \text{ MV/m}$ ,  $Q_0 \geq 5 \times 10^8$
- Operating temperature: 4.4 K

## ■ Power Couplers

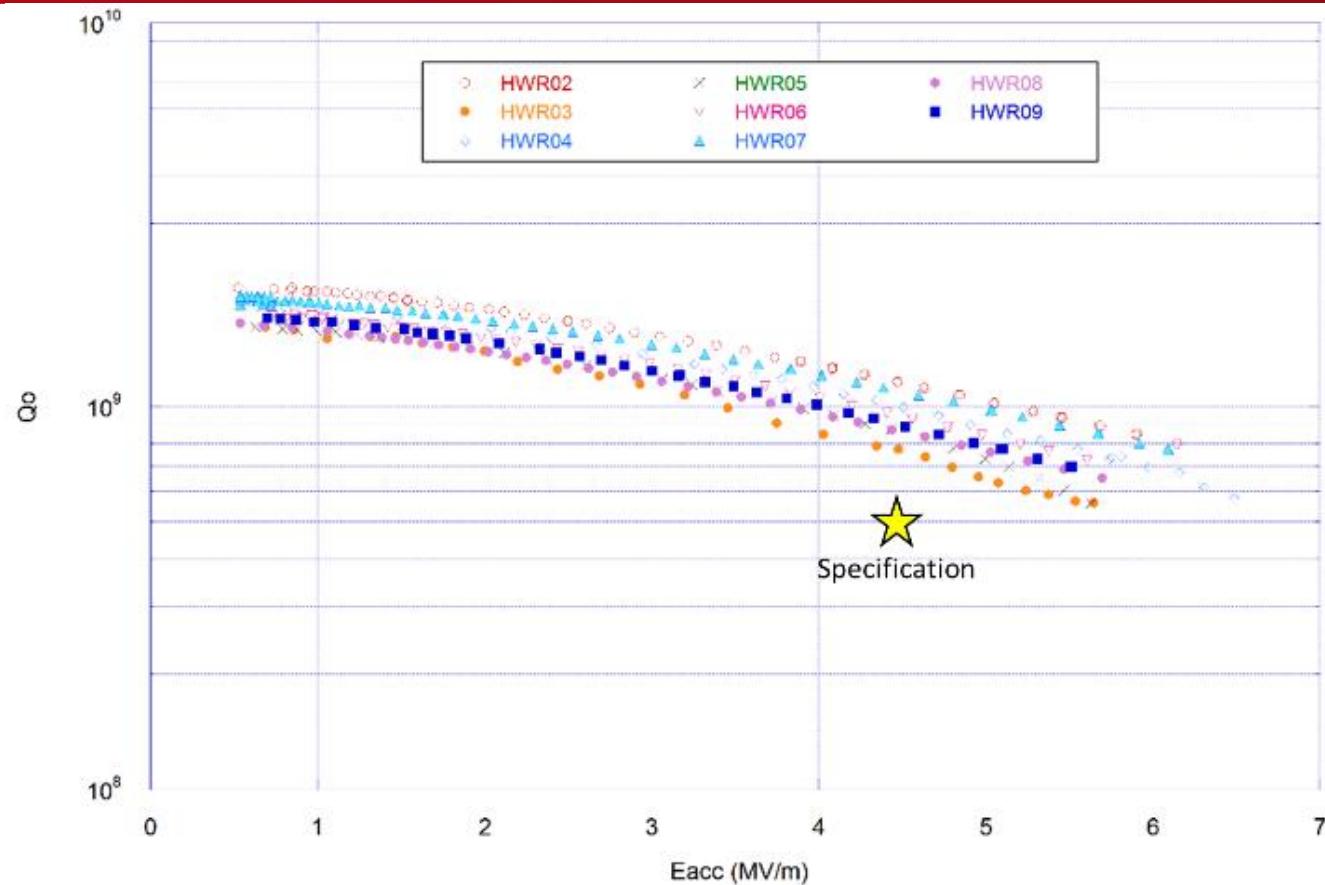
- Designed to handle 200 kW CW
- 70 kW CW max on LIPAc

## ■ 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)



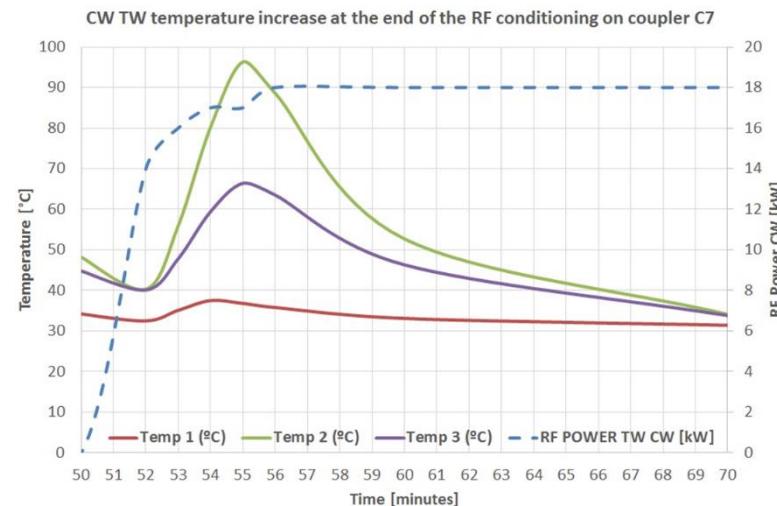
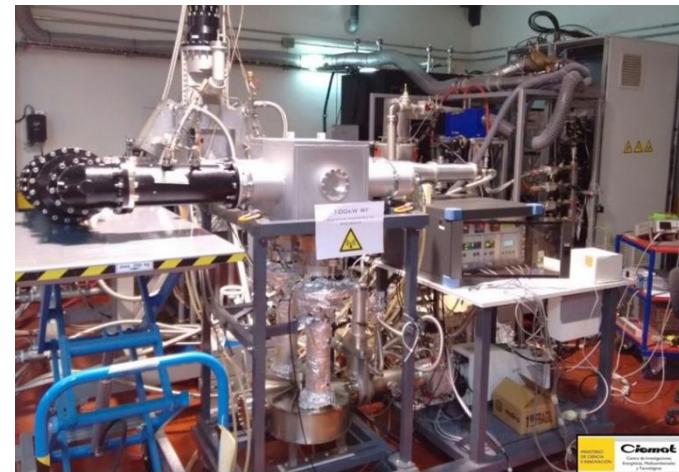
# CAVITÉS: QUALIFICATION



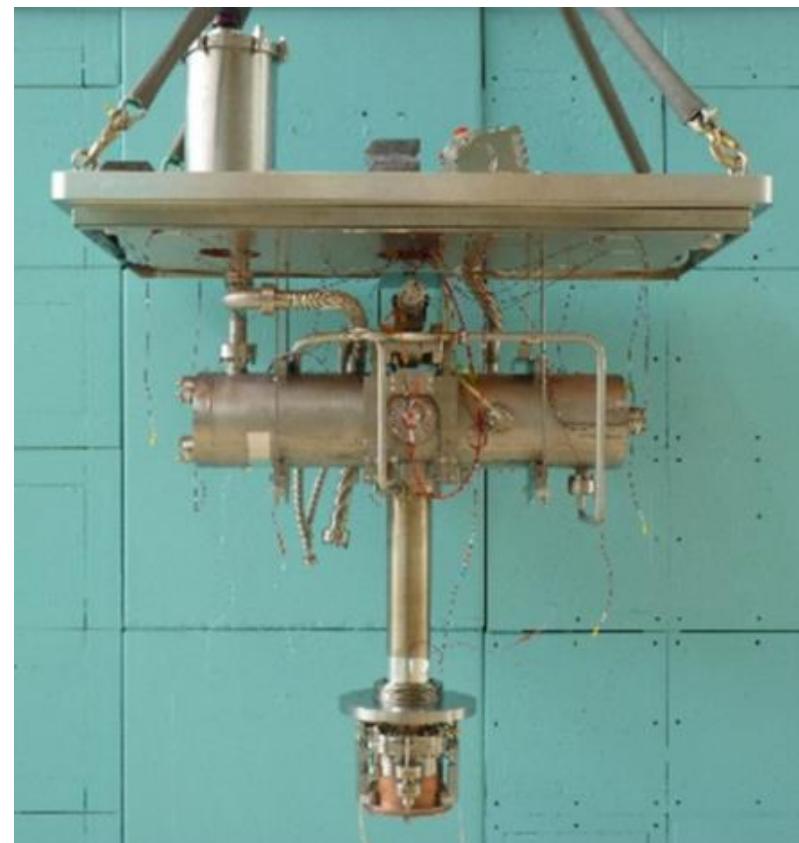
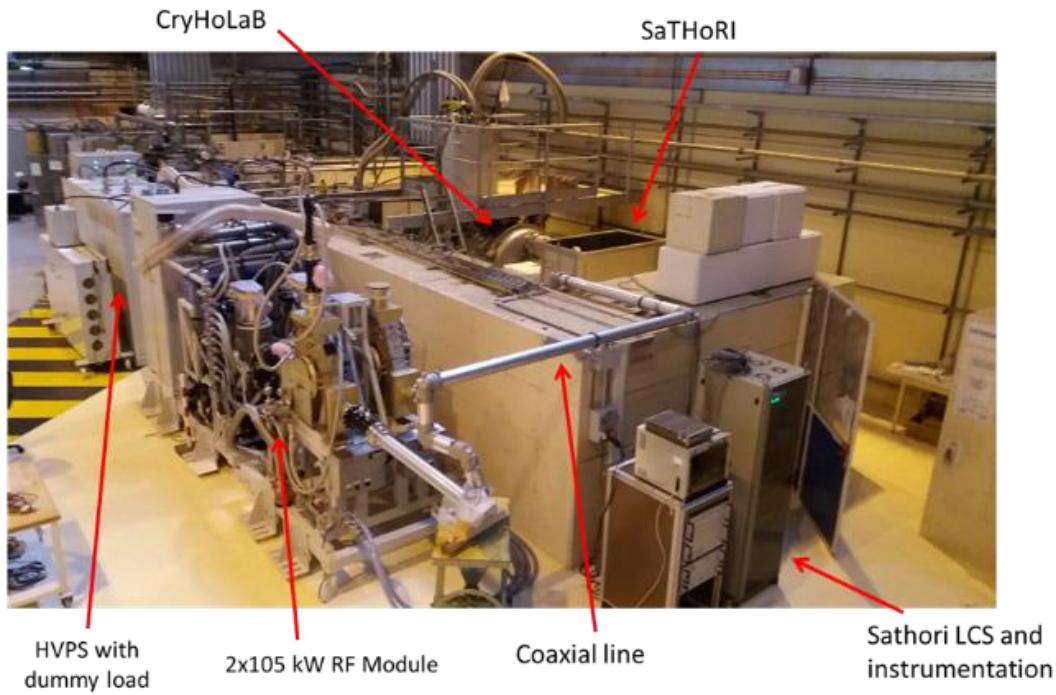
- All test are carried out up to at least  $E_{\text{acc}}=5.5 \text{ MV/m}$  to be sure the  $4.5 \text{ MV/m}$  specification is reached with reasonable margin (including measurement error of 10%)
- All qualification tests are stopped below  $6.5 \text{ MV/m}$  in order to prevent firing field emission.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

# COUPLEURS DE PUISSANCE

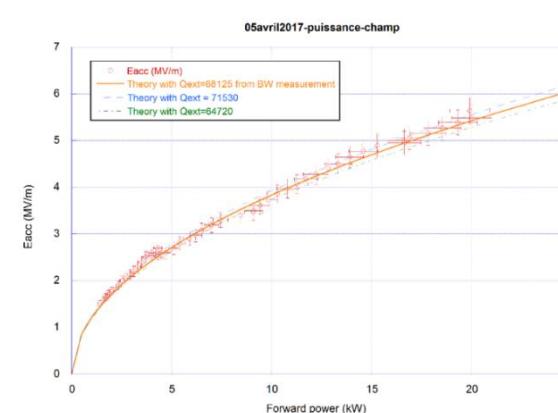
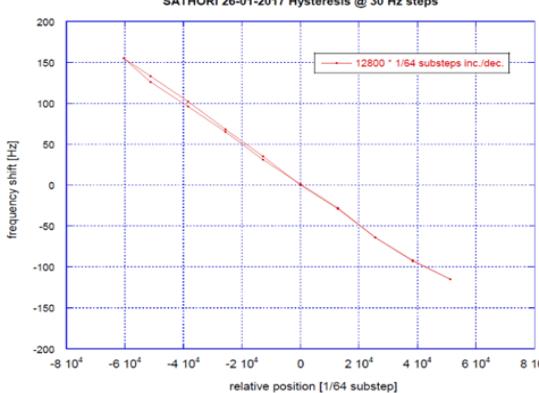
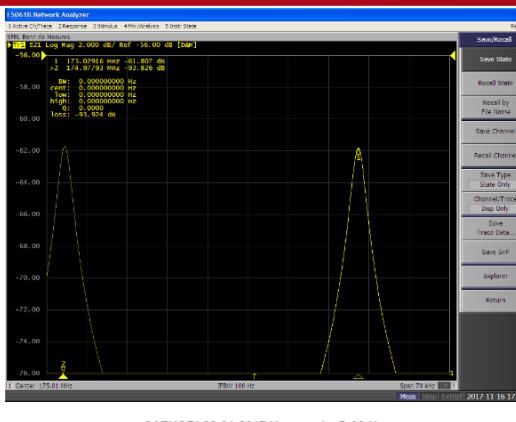
- All the power couplers reached the validation maximum power of 100 kW CW in TW and SW (full reflection) configurations
- The SW RF conditioning: 7 short circuit positions allowing to have maximum electrical fields on the ceramics and on intermediate positions.
- Some of the couplers (C5, C7) had important 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.



- Tests de deux mailles accélératrices (cavité + coupleur de puissance + système d'accord en fréquence à froid) au CEA Saclay
- Mise en place d'un test stand dédié: SaTHoRI = **S**atellite de **T**est **H**orizontal des **R**ésonateurs **IFMIF**



# MAILLE ACCÉLÉRATRICE: RÉSULTATS

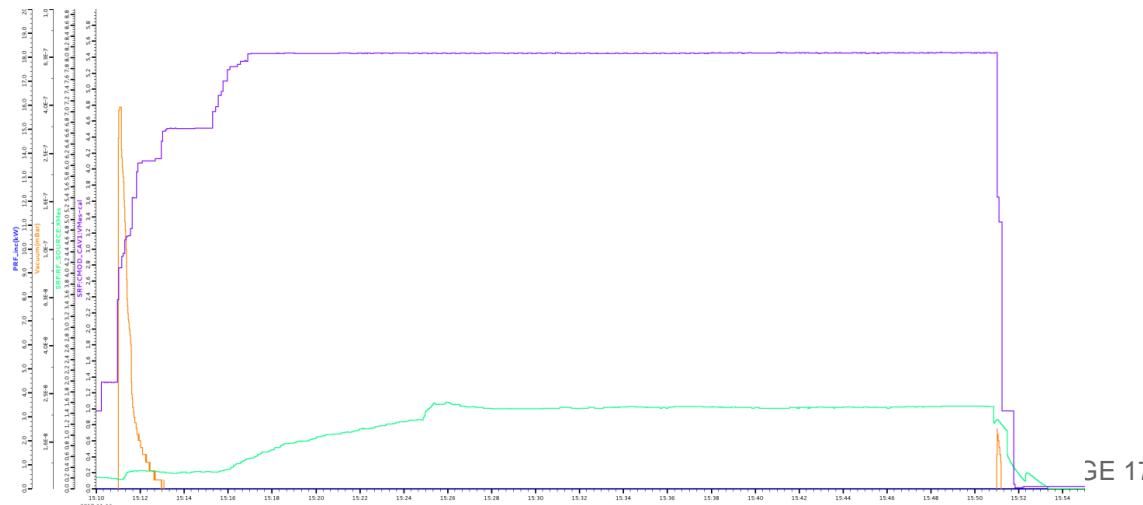


■ Performances du système d'accord à froid conformes aux spécifications

- Plage de réglage en fréquence ~50 kHz
- Hystérésis ~ 6Hz
- Procédure d'urgence: moins de 30 minutes pour parcourir toute la plage, conforme aux performances de l'alimentation de secours (onduleur – 45 minutes)

■ Couplage cavité / coupleur proche de la valeur théorique

- 4.5 MV/m dans la cavité avec une puissance injectée de 14 kW
- Système stable à 5.4 MV/ m (champ accélérateur nominal + 20% de marge) pendant 30 minutes

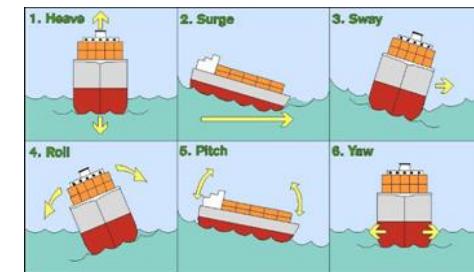


# TRANSPORT DU CRYOMODULE ENTRE L'EUROPE ET LE JAPON



- Plan initial: assemblage et test du cryomodule en Europe, transport par bateau jusqu'au Japon

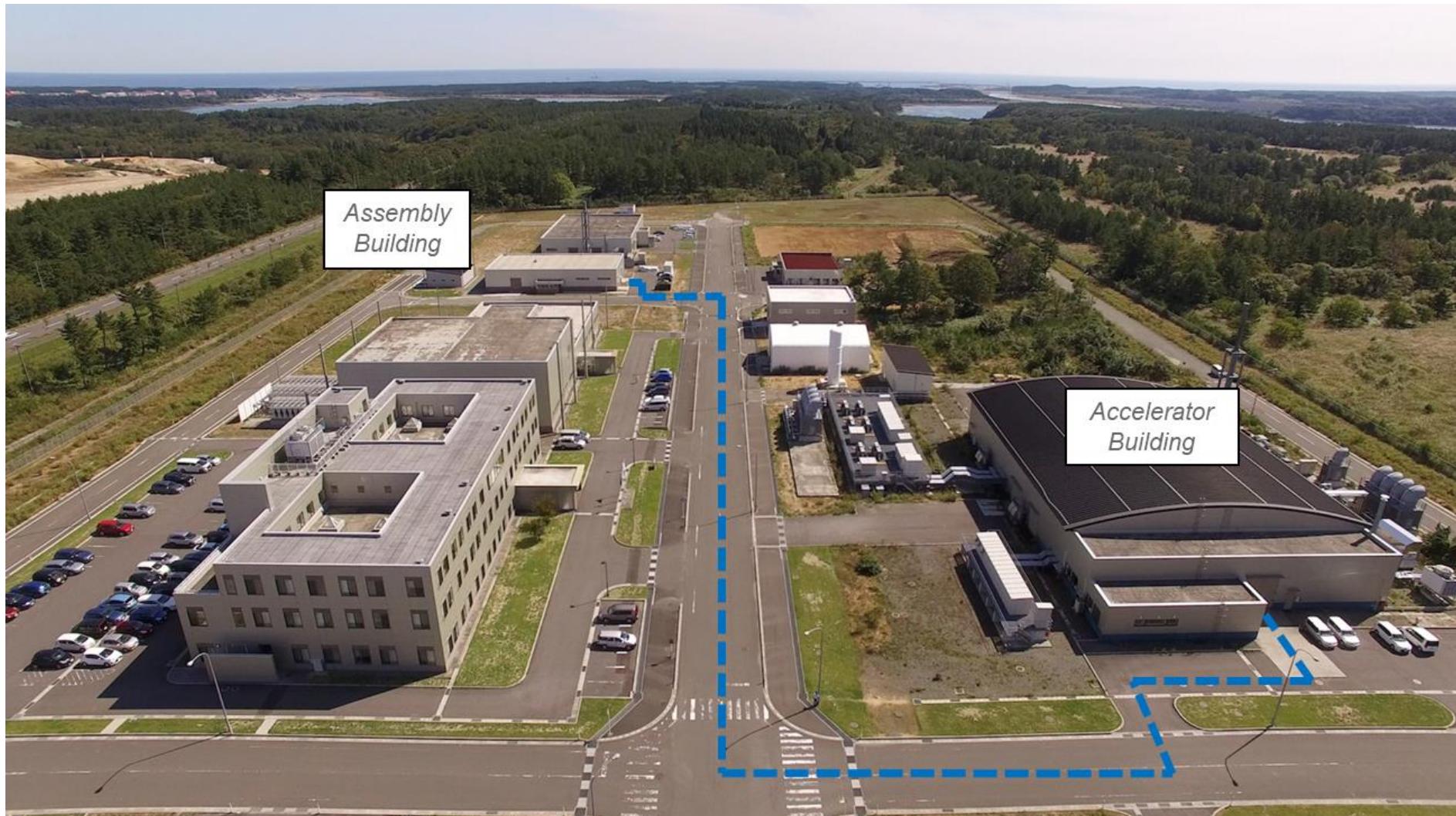
Risque d'endommager un composant du vide faisceau lors des chargements / déchargements ou à cause de la fatigue (céramique du coupleur de puissance par exemple)



- Mitigation du risque transport

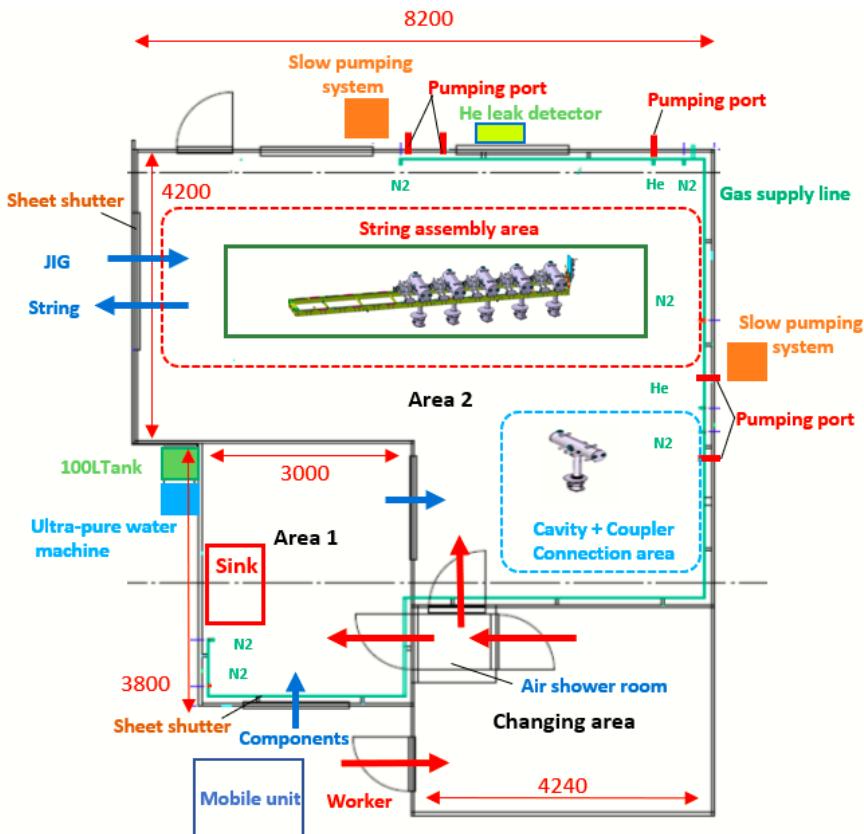
- Transport aérien → Antonov 124 du fait des dimensions du cryomodule
- Assemblage sur site à Rokkasho → nécessité de construire une salle blanche

# ASSEMBLAGE DU CRYOMODULE



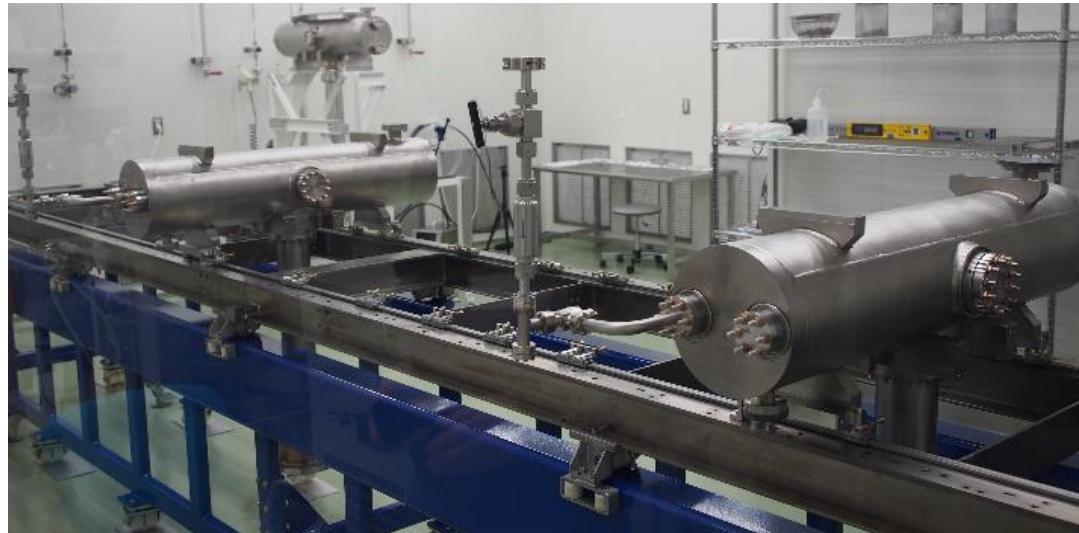
# SALLE BLANCHE À ROKKASHO

- Construction de la salle blanche ISO 5 et achat des équipements sous la responsabilité des Japonais (QST)
- Système de pompage lent et de remise à la pression atmosphérique développé en collaboration avec KEK
- Challenge: s'adapter aux contraintes du bâtiment déjà existant tout en respectant les besoins du projet



# ASSEMBLAGE DU CRYOMODULE

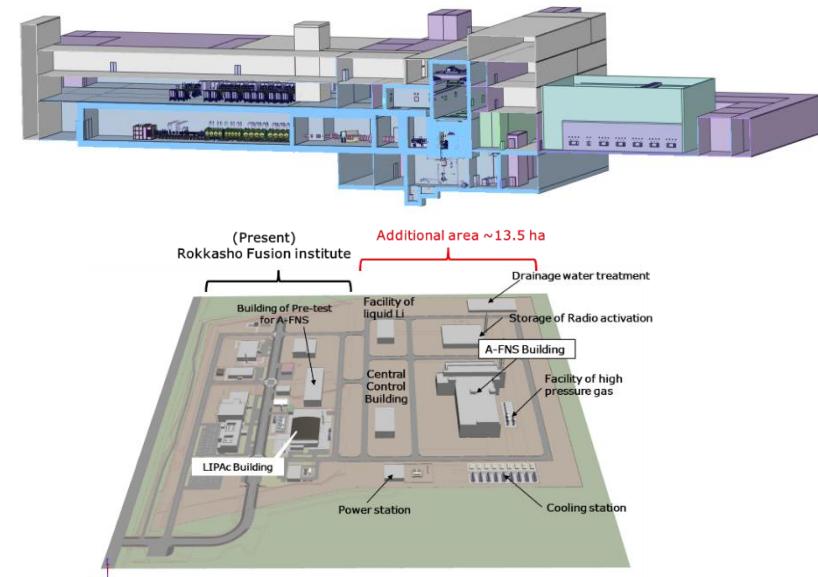
- Responsabilité de F4E, activité sous-traitée à Research Instrument GmbH (RI)
- Travail préparatoire du CEA: rédaction de scénarios avec les grandes lignes de m'assemblage en et hors salle blanche, tests d'outillage salle blanche et d'opérations à l'aide de maquettes
- Les activités ont commencé à Rokkasho premier semestre 2019 avec l'assemblage de trois ensembles cavité / coupleur
- En stand-by du fait du retard des solénoïdes



- 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, on the ESFRI roadmap (European Strategy Forum on Research Infrastructures)
  - A-FNS (Advanced Fusion Neutron Source) in Japan



Conceptual design of the DONES Plant in Grenada, Spain



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