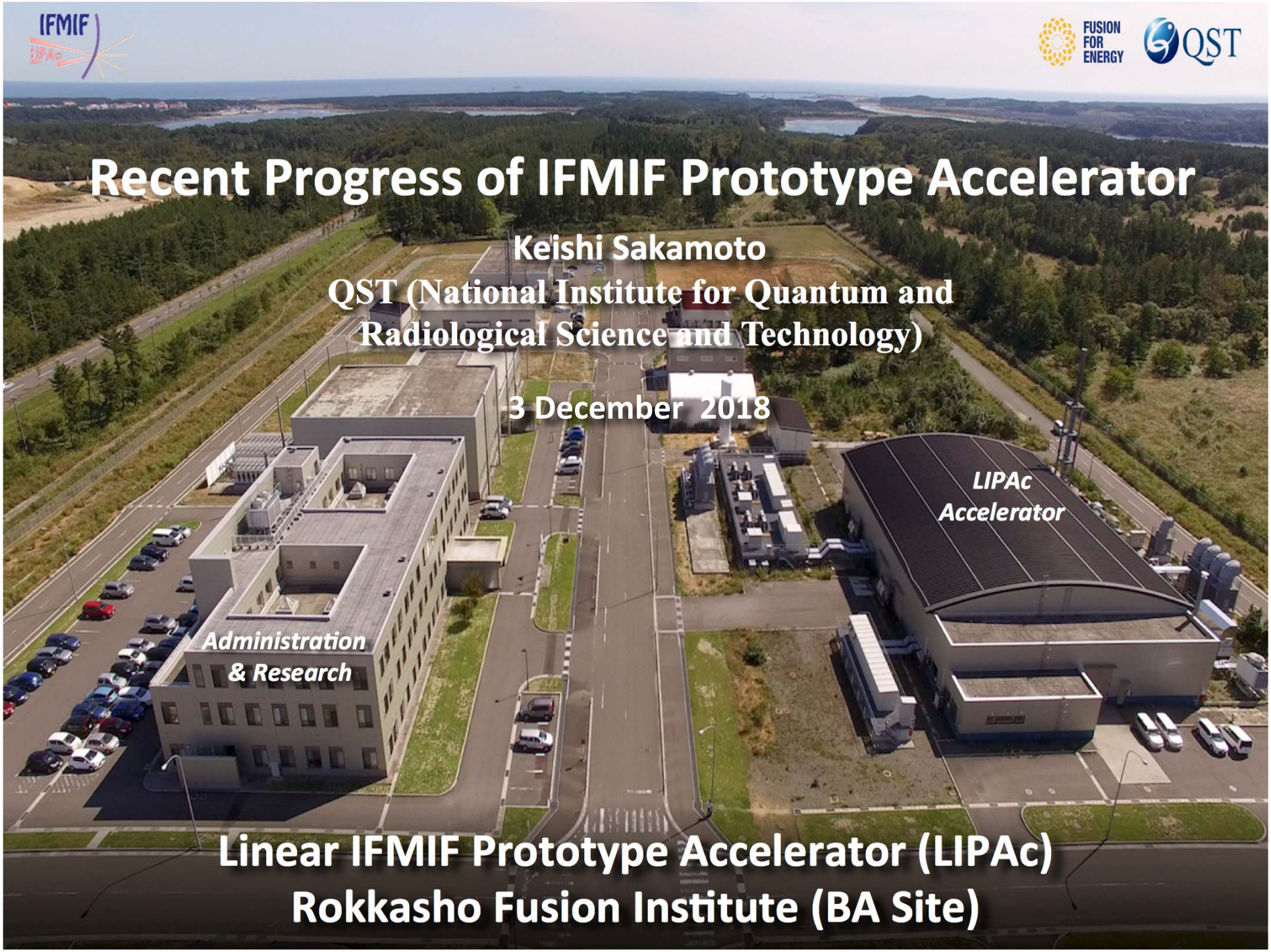
IFMIF
LIPAc
FUSION FOR ENERGY
QST
Recent Progress of IFMIF Prototype Accelerator
Keishi Sakamoto
QST (National Institute for Quantum and Radiological Science and Technology)
3 December 2018
LIPAc Accelerator
Administration & Research
Linear IFMIF Prototype Accelerator (LIPAc)
Rokkasho Fusion Institute (BA Site)

Staff for IFMIF Prototype Accelerator Development

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(Red: EU staffs living in Rokkasho/Aomori, Blue: EU staffs of short-term visits)

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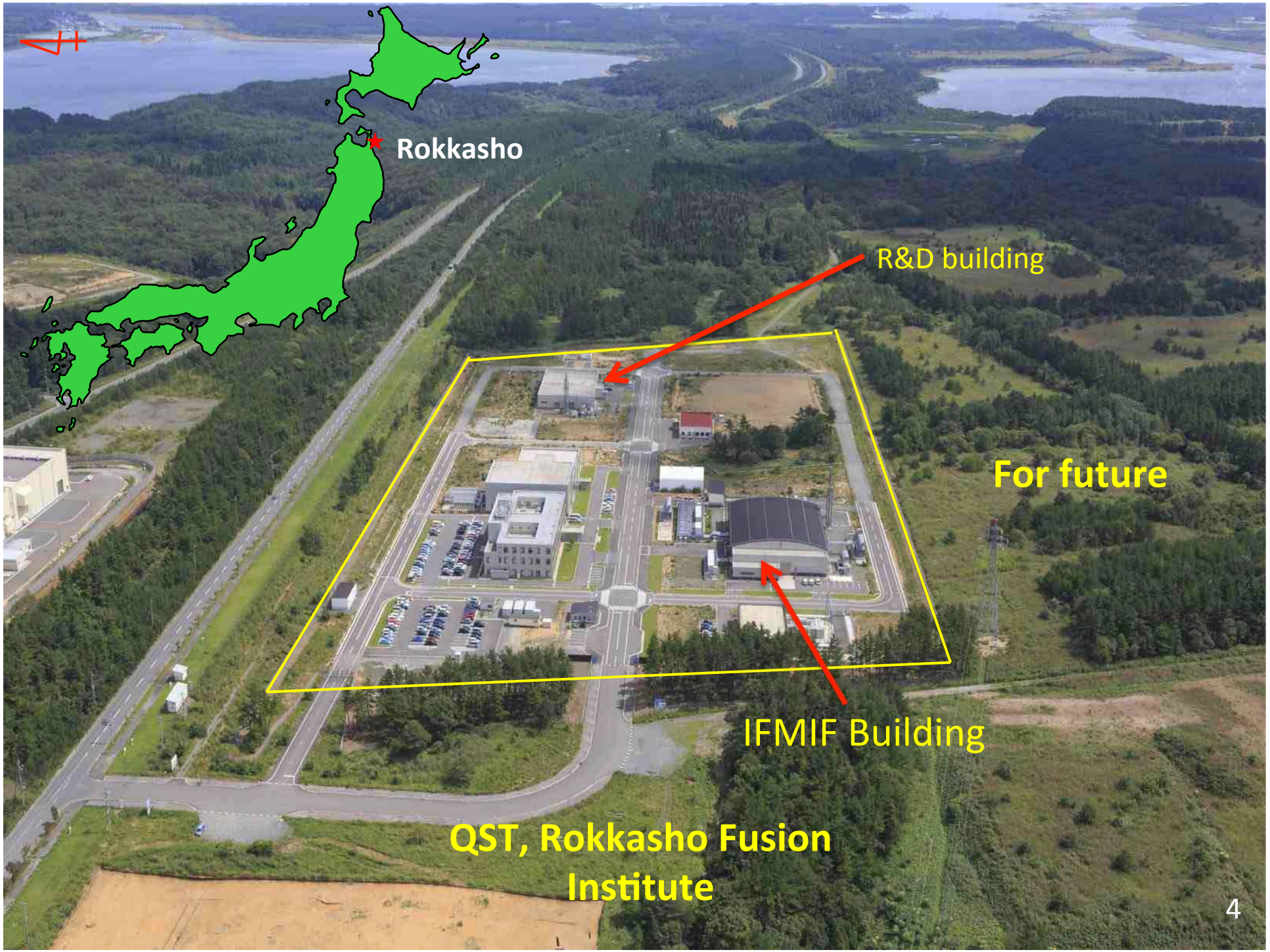
写真提供：新むつ小川原株式会社

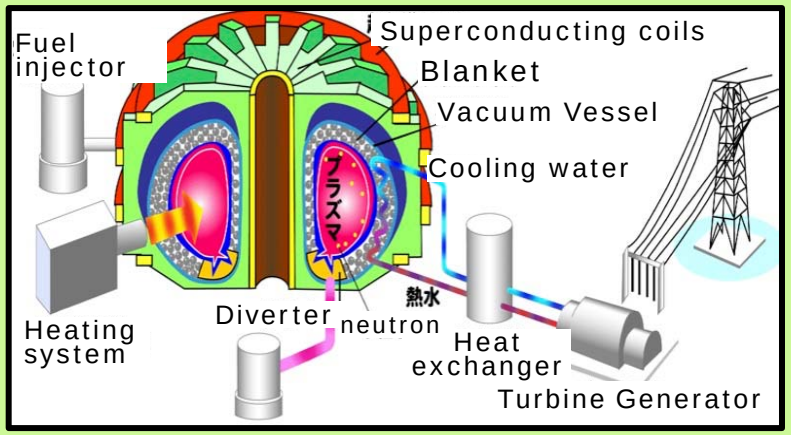

Rokkasho
R&D building
For future
IFMIF Building
QST, Rokkasho Fusion Institute

Key R&Ds for Fusion DEMO Reactor

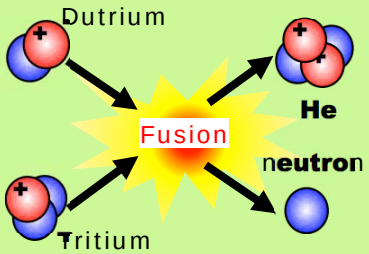
The first wall of the reactor vessel shall absorb neutrons energy

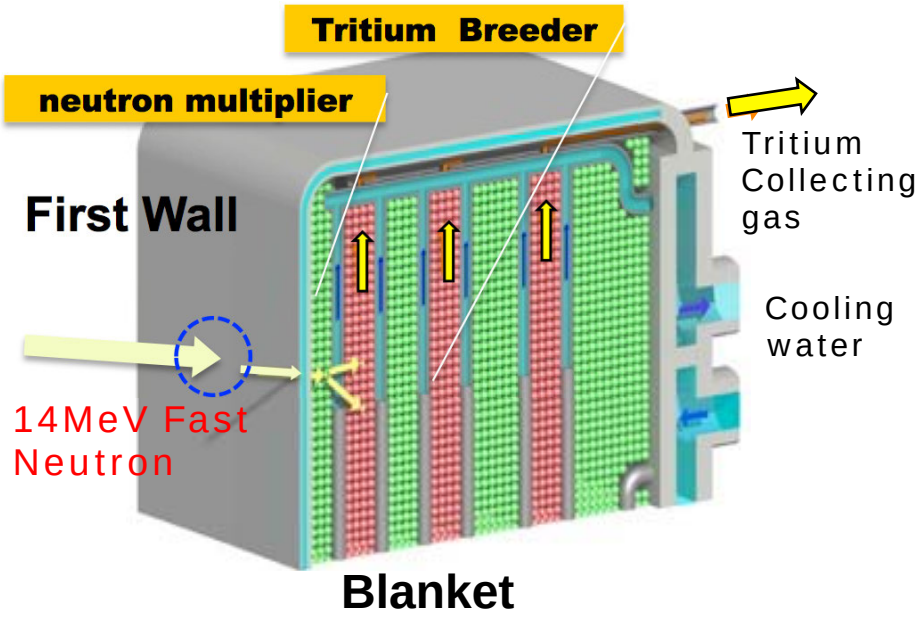
In the material development for fusion reactor (DEMO), it is important to investigate the influence of the high energy high flux neutron caused by D-T burning on the material. (Swelling, Blistering, Boiding, etc)

Fusion DEMO Reactor



Robust Material against high heat flux and neutron irradiation,

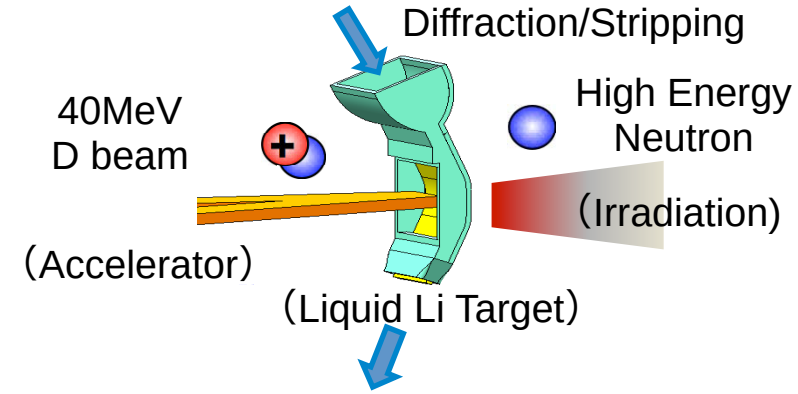


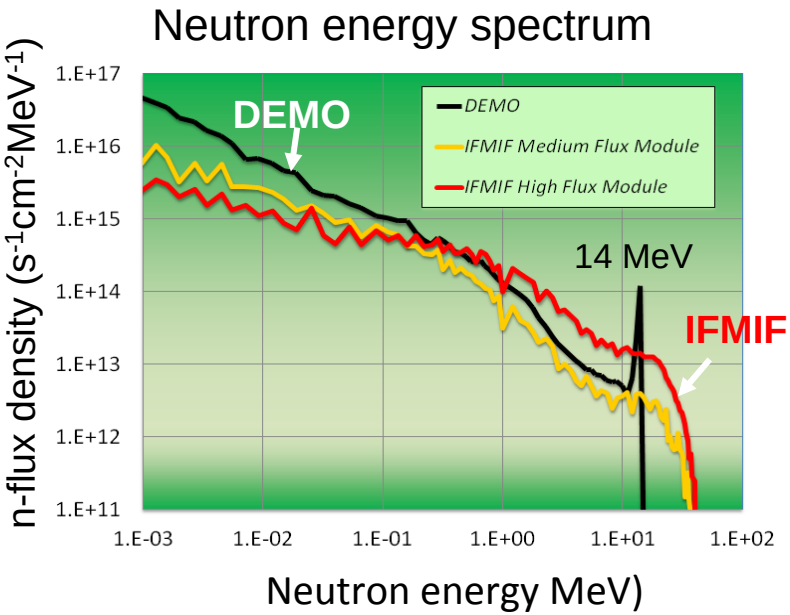


Neutron Irradiation Facility is necessary !

Fusion Material Irradiation Facility with Accelerator

- **40 MeV D-Beam on Li-target produces the high energy neutron of ~14 MeV, which allows the Fusion Material Irradiation test for DEMO.**



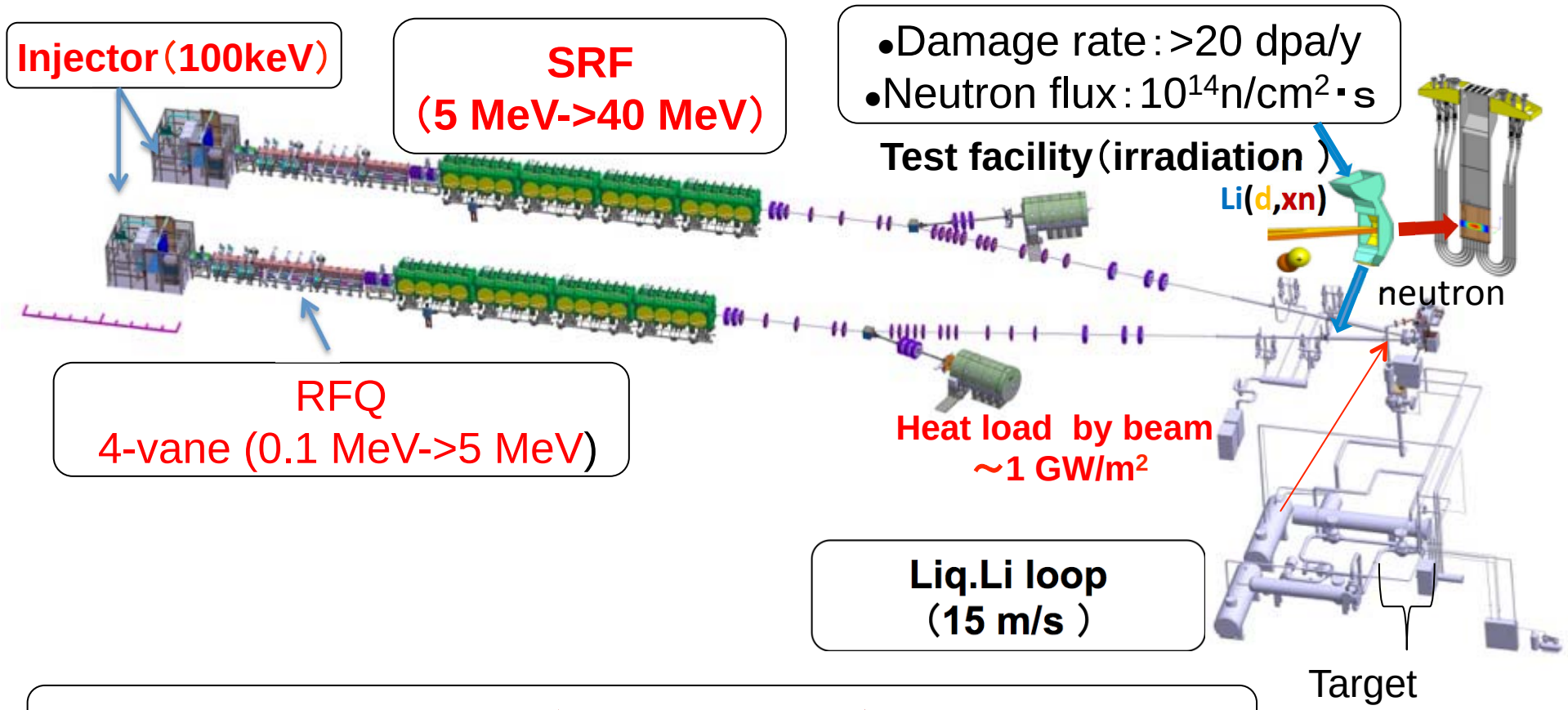


IFMIF : **(International Fusion Materials Irradiation Facility)**

By the D+beam radiation of 40MeV-250mA to Liquid Lithium, 14 MeV neutron generates, which is used for irradiation test of fusion reactor materials.

International Fusion Material Irradiation Facility（IFMIF）

Accelerator Based High Intensity Neutron Source for Fusion Material Irradiation



International Fusion Material Irradiation Facility（IFMIF）

High Intensity neutron source for fusion material irradiation

Injector（100keV）

SRF
（5 MeV->40 MeV）

Damage ratio：>20 dpa/y
•N-flux：10^{14}n/cm^2・s

Irradiation Test facility

Li(d,xn)

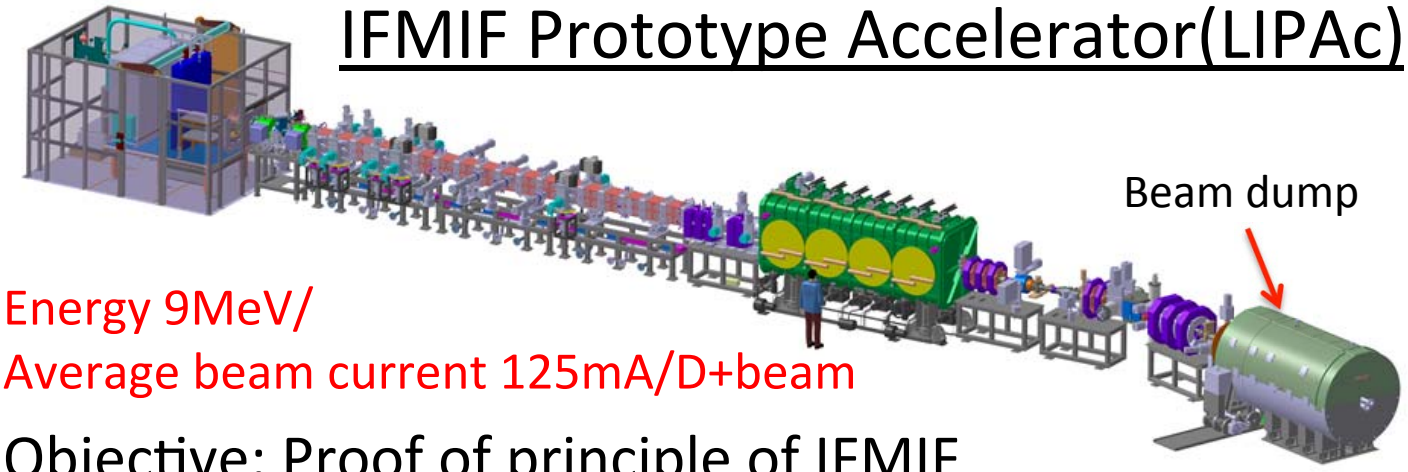
Neutron

Heat load～1 GW/m^2

RFQ
4 vane type (0.1 MeV->5 MeV)

Target

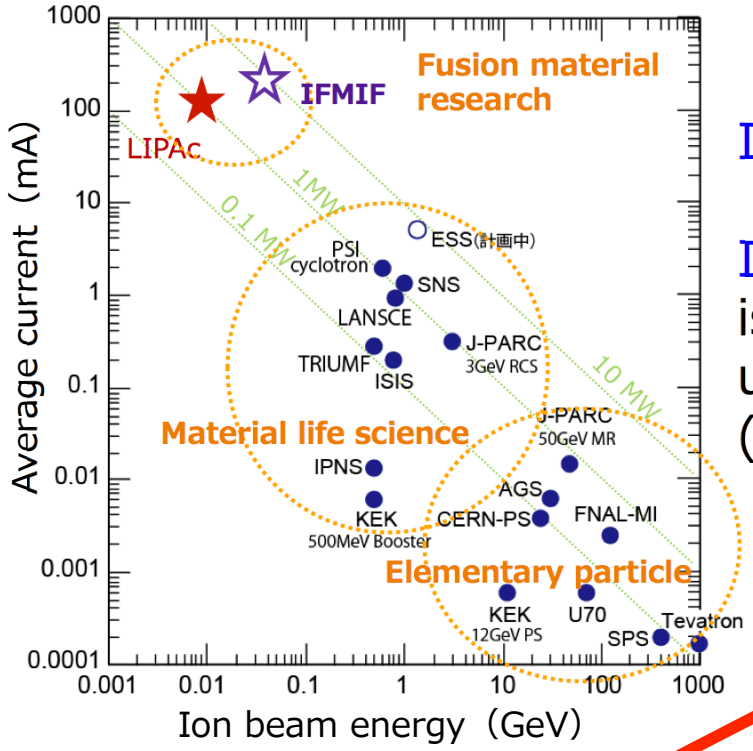
IFMIF Prototype Accelerator(LIPAc)



Energy 9MeV/
Average beam current 125mA/D+beam

Objective: Proof of principle of IFMIF

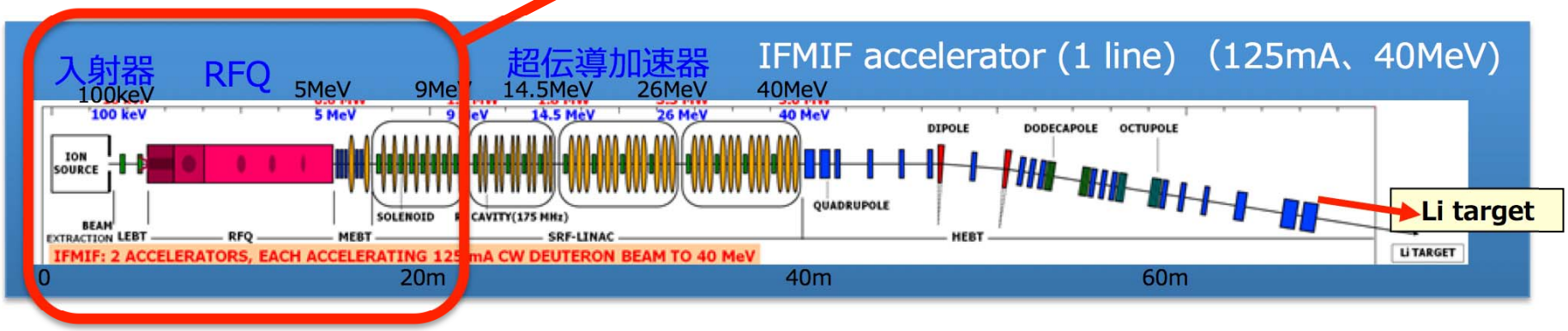
Development of high current accelerator



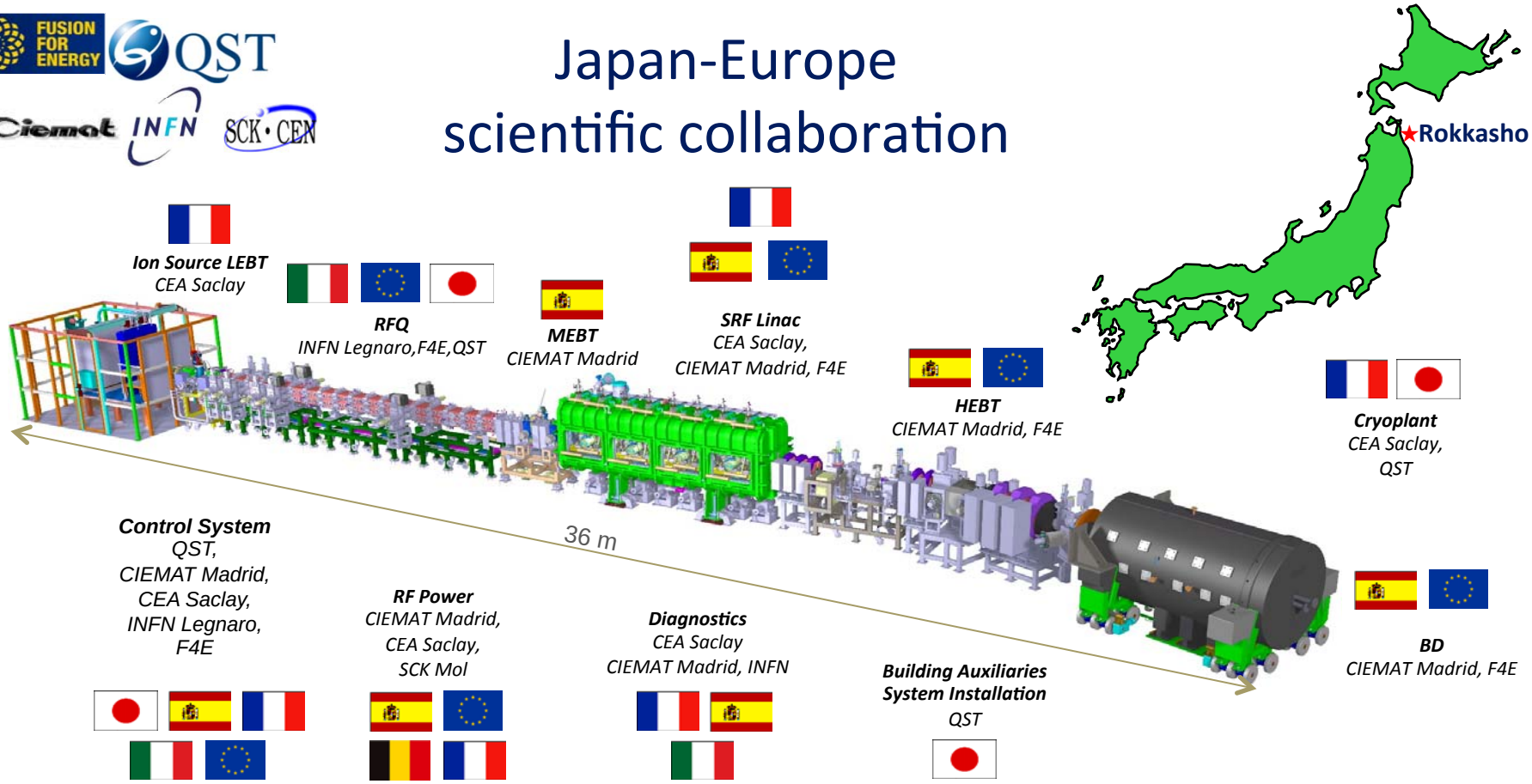
IFMIF:（125m A ×2 lines、40MeV）

IFMIF/EVEDA Prototype accelerator (LIPAc)
is under development in Rokkasho village
under EU-Japan collaboration
(Broader approach in fusion research)

IFMIF/EVEDA Prototype accelerator（125mA、9MeV）



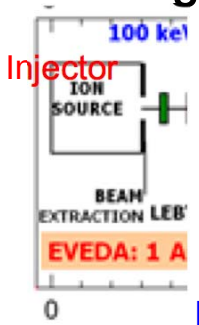
Japan-Europe scientific collaboration



JA-EU Contribution

Three stages in LIPAc R&D operation

1st stage (Injector)

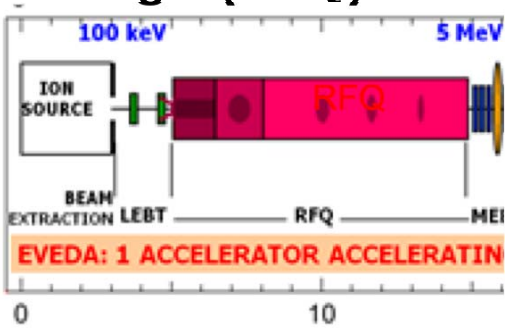


Acceleration : 0.1 MeV
Current : 140mA
Beam power: 12.5kW
From 2014
Beam emittance < 0.3 π.mm mrad

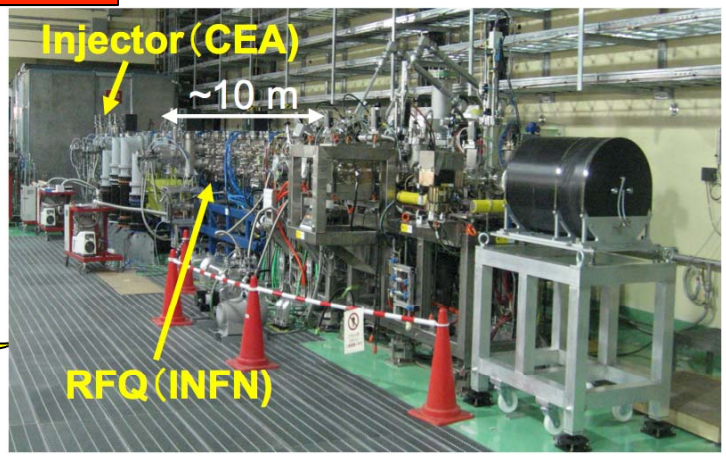
Energy: x 50
Power: x 50

Now!

2nd Stage (RFQ)

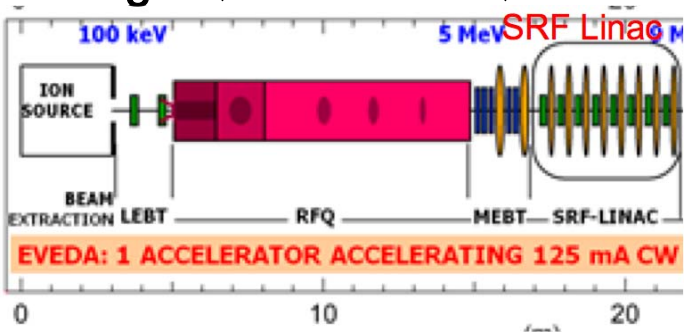


Acceleration : 5MeV
Current : 125mA
Beam enegy:625 kW
From ~2017
beam transmission ratio >~ 95 %
World's longest RFQ



Energy: x 1.8

3rd stage (SRF Linac)



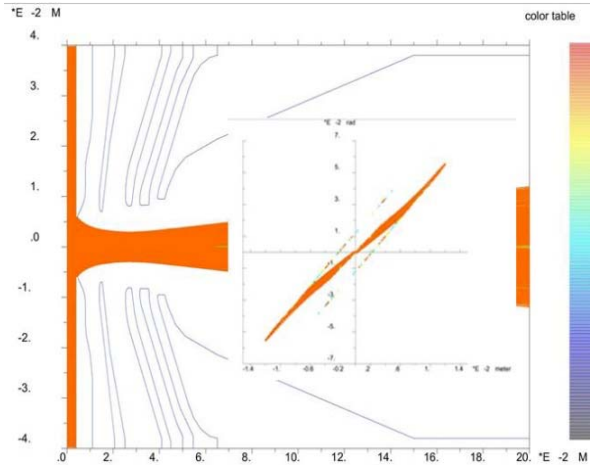
Acceleration : 9MeV
Current : 125mA
Beam energy: 1.125 kW
From ~2020
Superconducting cavity
Low beam loss < ~1 w/m

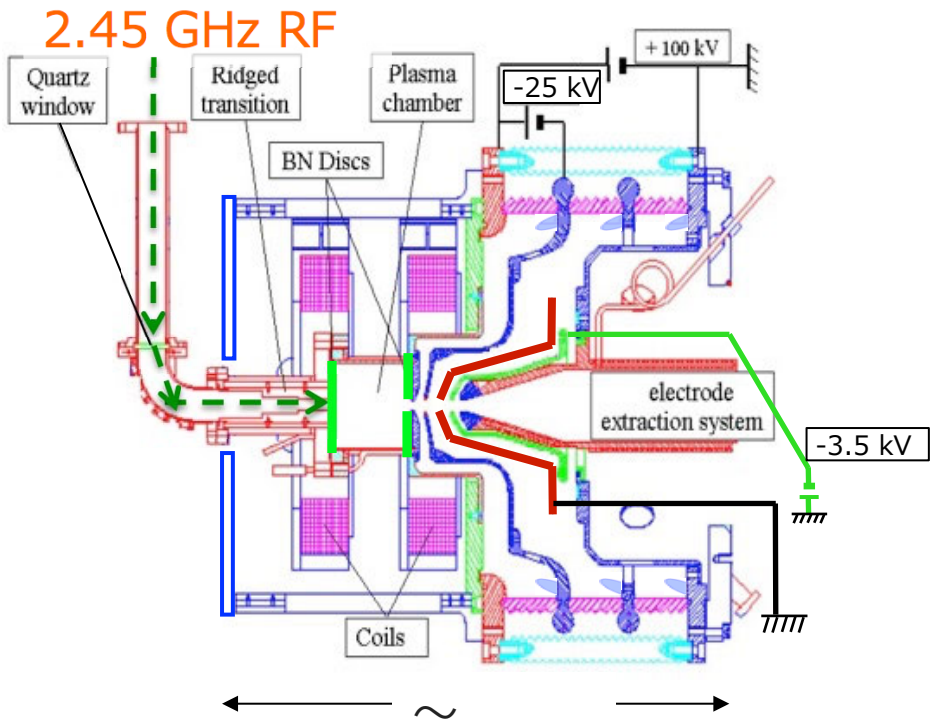
Injector

Based on “SILHI” (CEA)

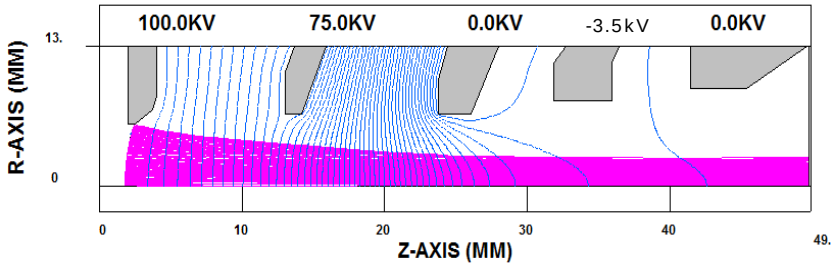
5 electrodes

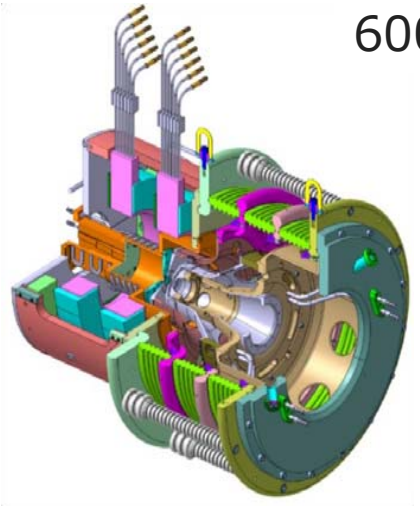
Beam Simulation (CEA)





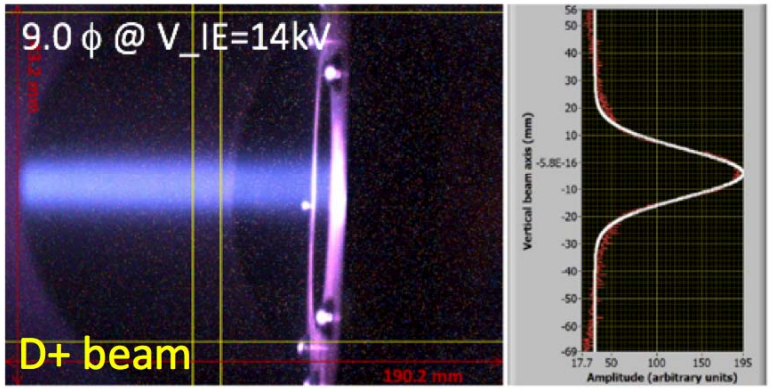
Beam simulation (QST)

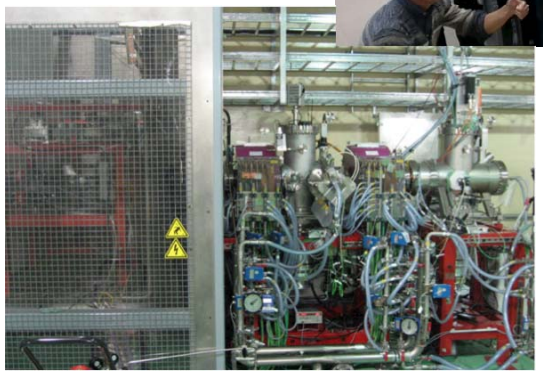




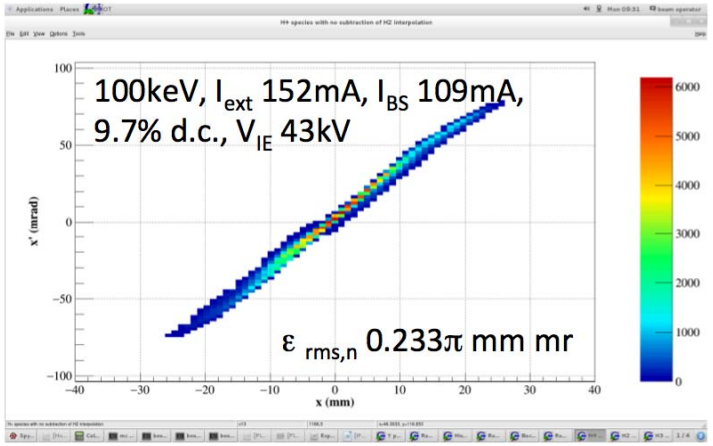
(CEA Saclay)

First Experiment of Injector





Emittance meter



Emittance@2015

（target: < 0.3π）

ε = 0.233π mm·mrad

@ beam current=109 mA

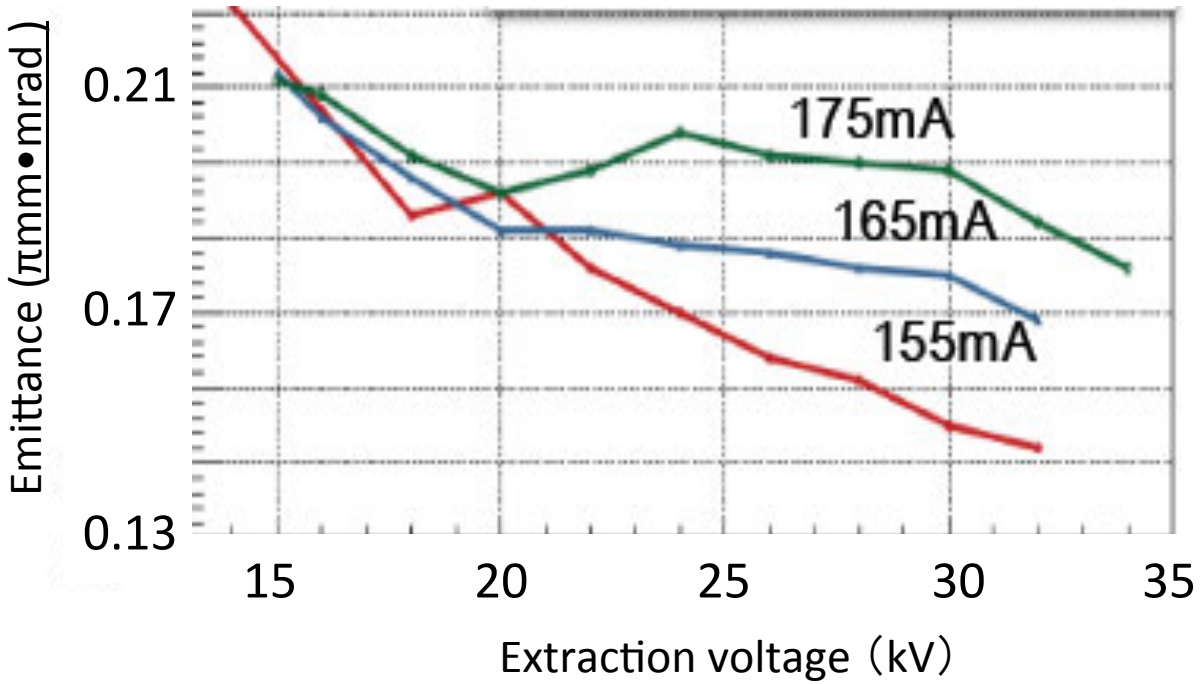
Beam voltage: 100 keV

10% duty

First D+ beam was obtained at July 2015.

Beam Emittance measurement

Injector Experiment (Oct. 2017)

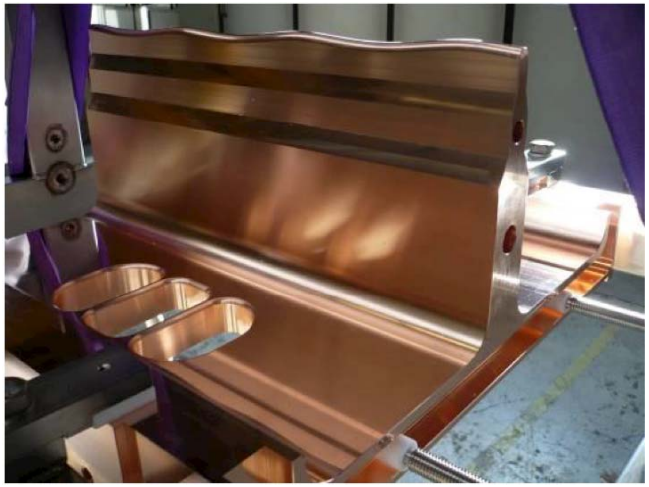


D+ beam／100kV: Good Emittance of <0.20πmm•mrad was achieved.

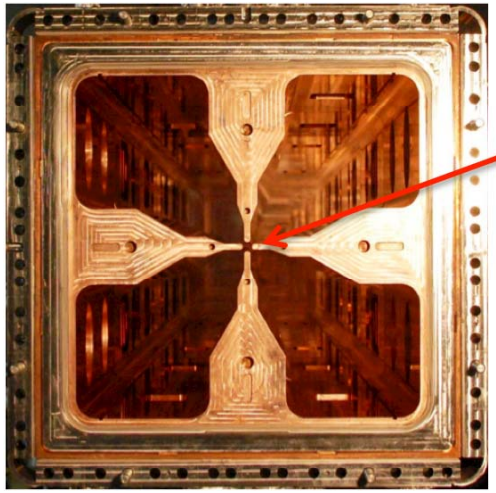
(Target value: <0.3πmm•mrad)

World Largest RFQ

RFQ（Length 9.8m ：0.55mx18 module）



Vane before assembly



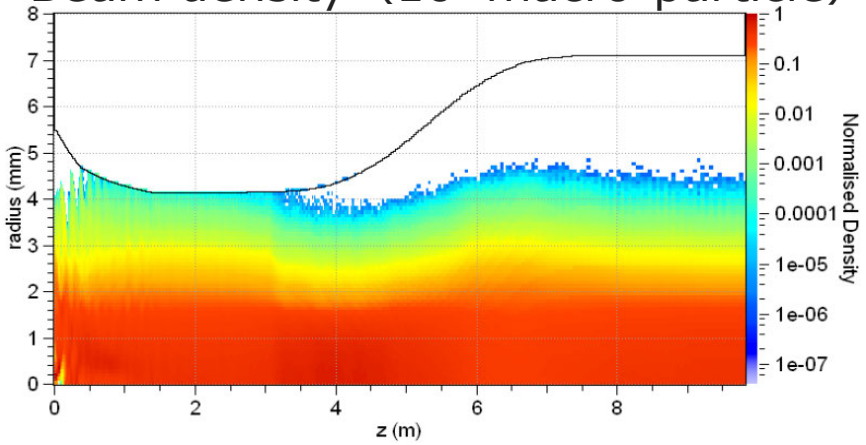
RFQ cross section
（430x430mm）

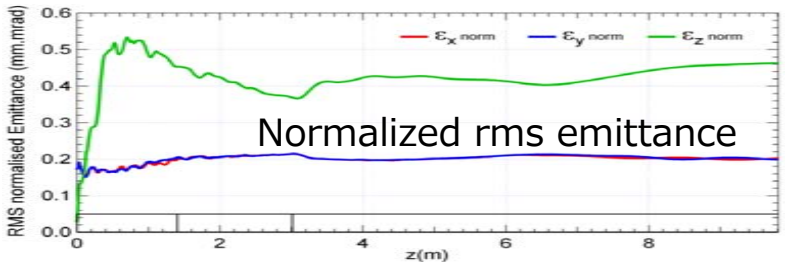
D+ beam
- acceleration
- focusing
- bunching

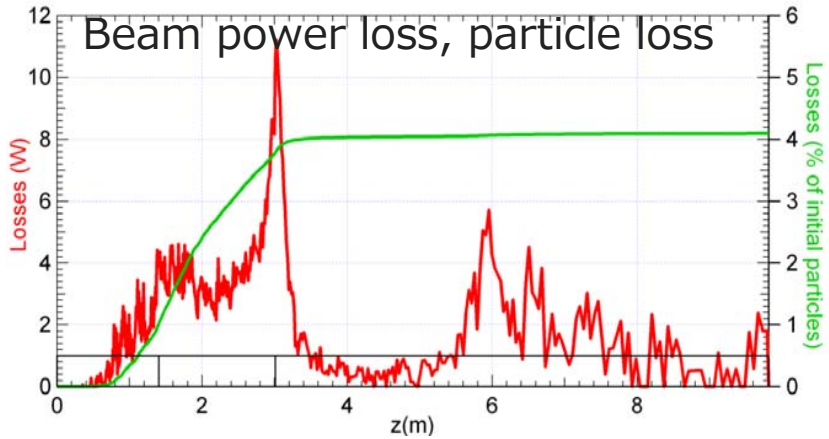
Design of RFQ

Beam Simulation（PARMTEQM、Toutatis）

Beam density（10^6 macro-particle）

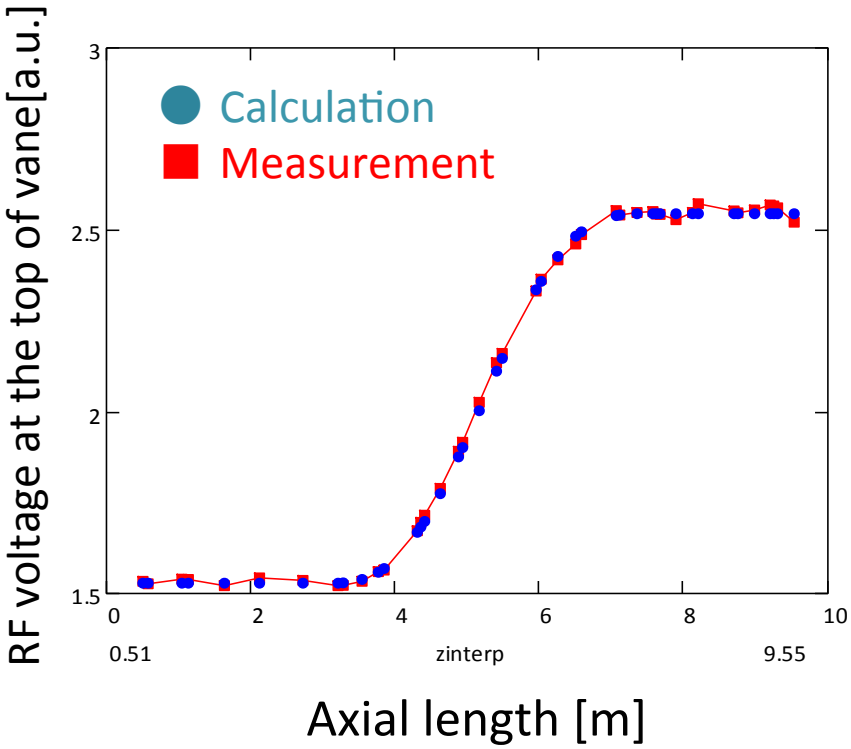


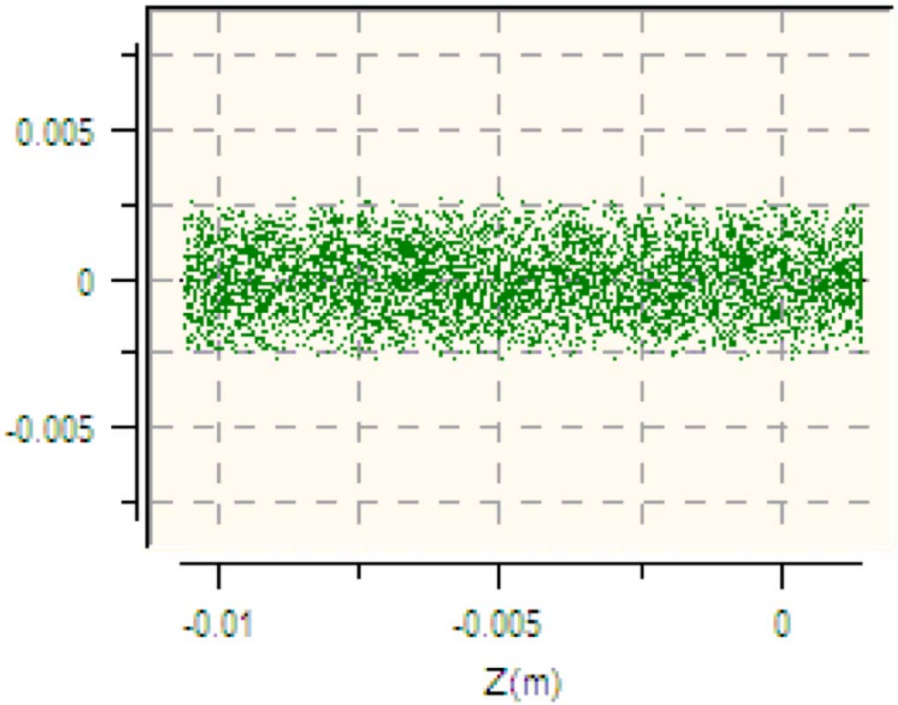




- Emittance at RFQ output：
  0.20 πmm.mrad
- Transport ratio of particles：95.9%
- Loss occurs at the first 3m.
- Local loss：~12W
- Loss at high energy section：~6W
- At 140mA input, output current will be 133 mA.
  (Target is 125mA. 5% margin)

RFQ RF field adjustment at low power

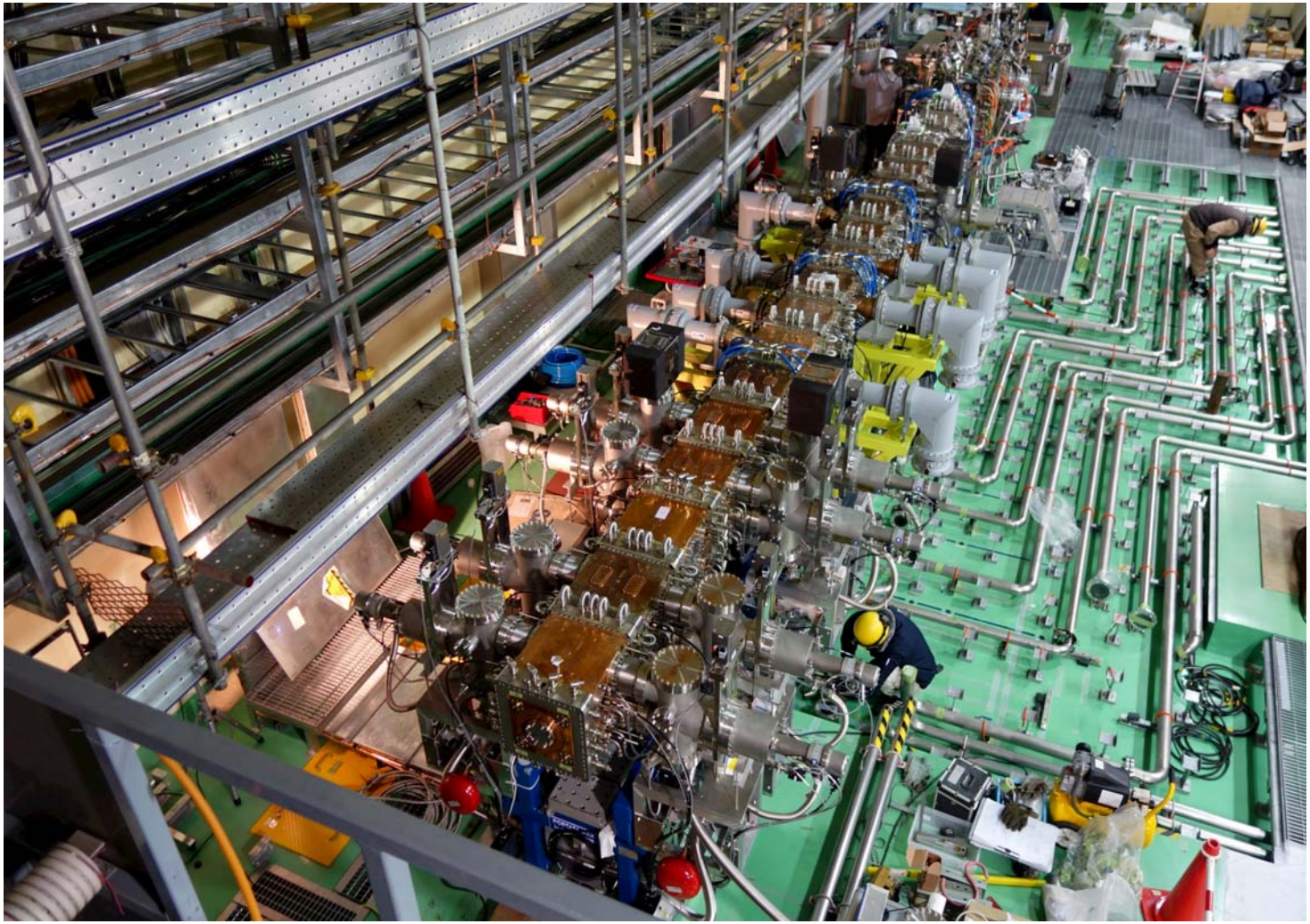




98 tuners are adjusted.

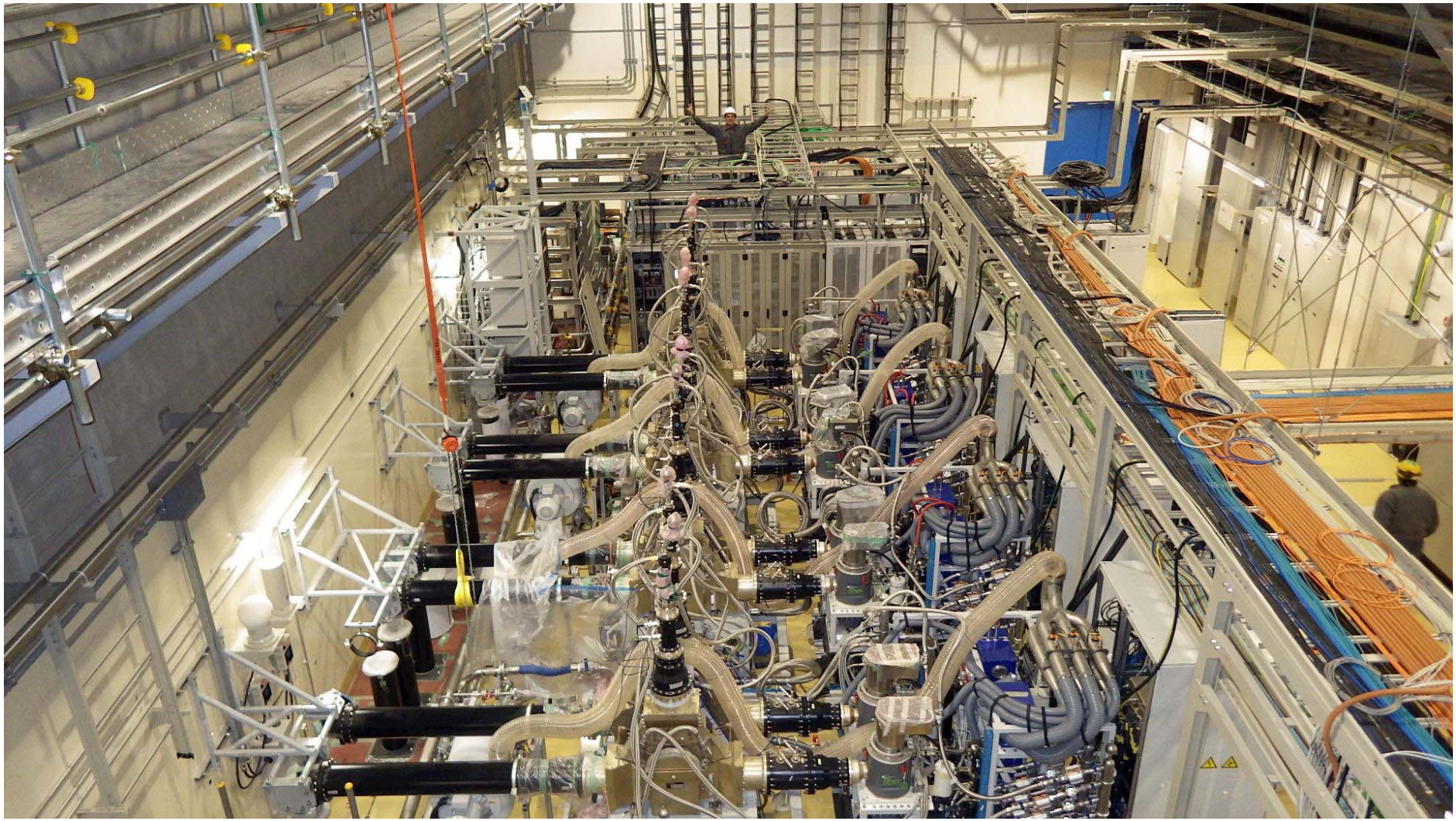
Required resonant frequency and electric field distribution as designed were obtained

RFQ and Cooling Pipes

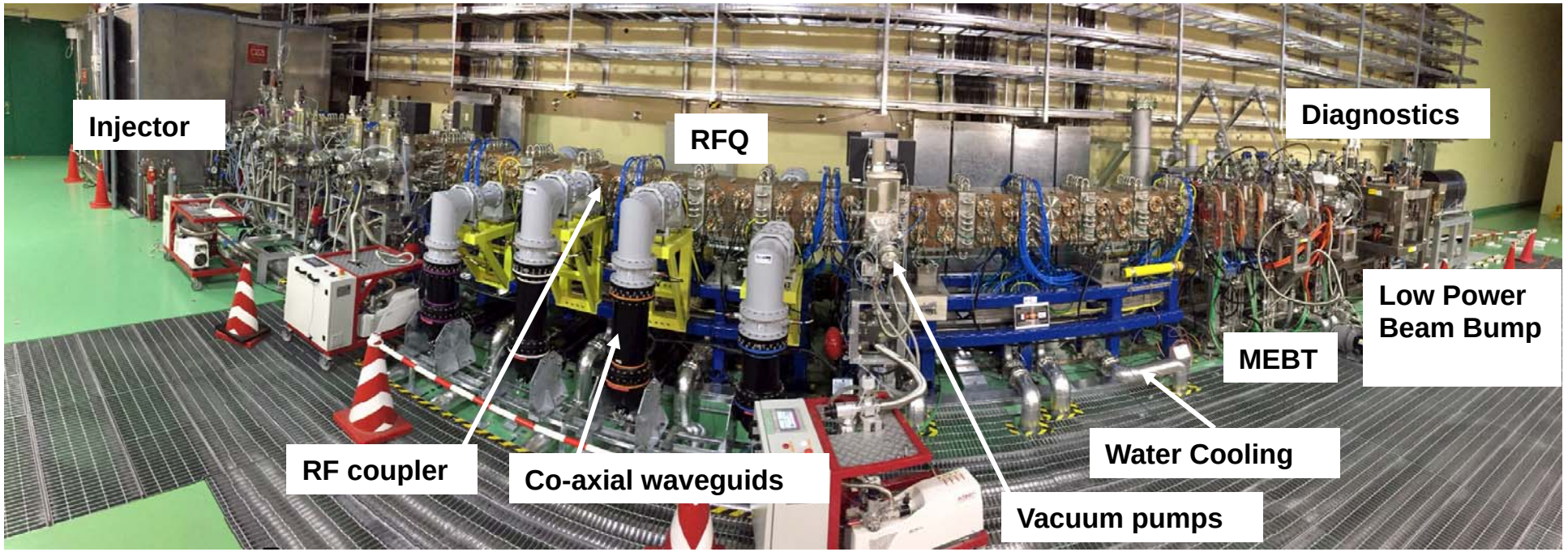


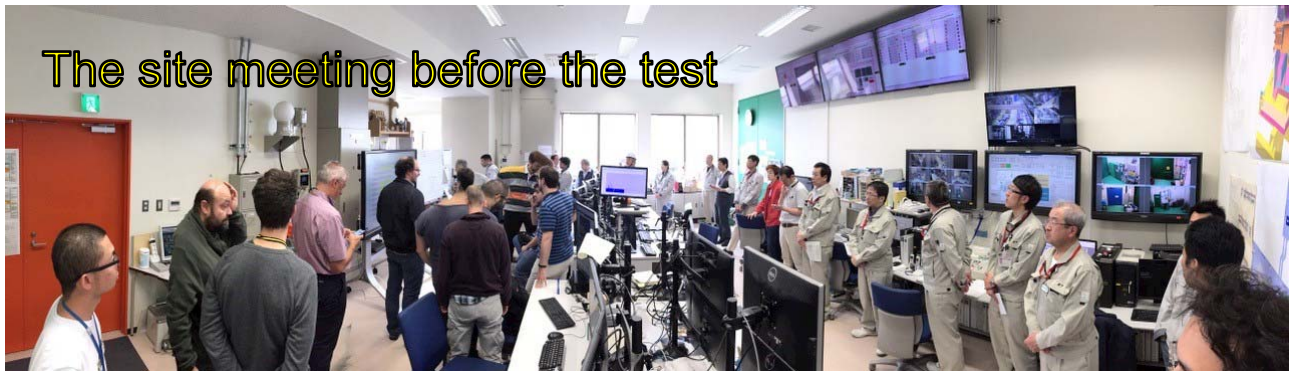
High Power RF system

175 MHz 200 kW (tetrode) x8 sets、
Power supply , Control System（LLRF+White Rabbit)



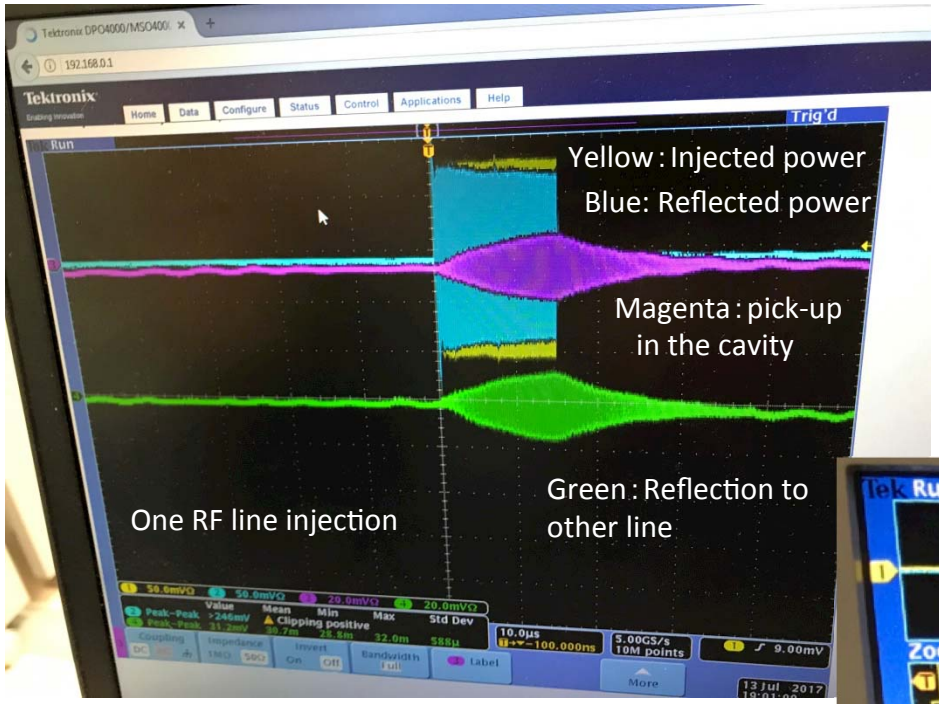
Commissioning &operation by Japan-EU joint team





Good International Collaborative Work

First RF injection to RFQ (July 2017)



(1) First step

Using 1 RF line

- low power（several kW）、short pulse 15μs、low duty（2Hz）
- ～10% power injection into the RFQ
- ～70% reflection from injected line、
- ～20% reflection to other lines (total)

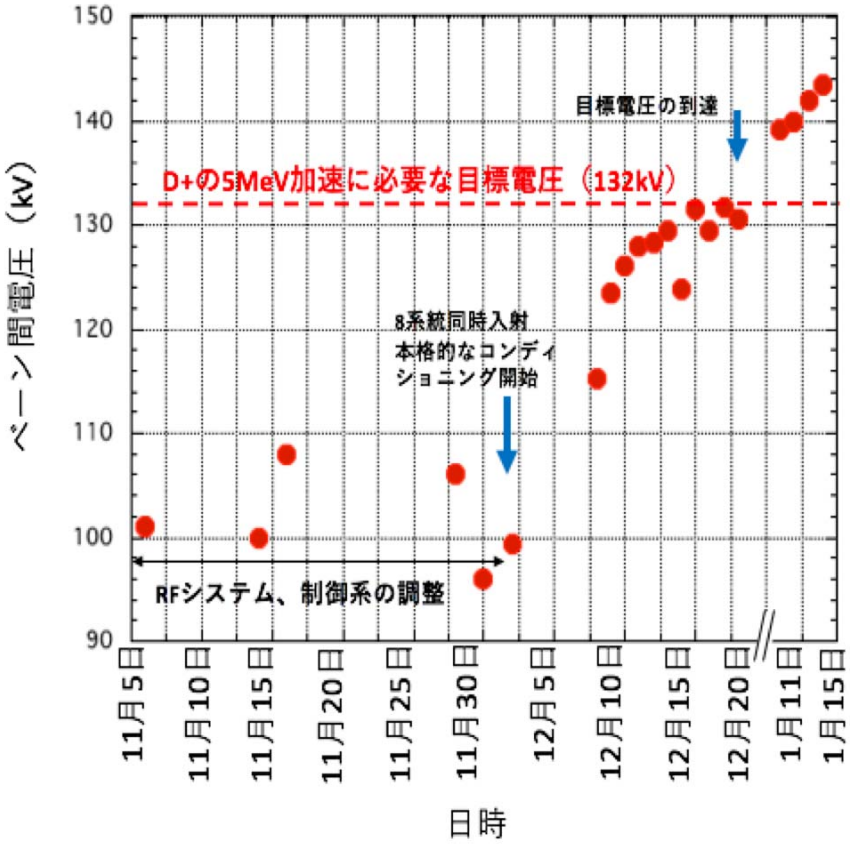
(2) Second step

- Simultaneous injection from 8 RF lines（31 July 2017）
- White Rabbit

(3) Third Step

From October, RFQ conditioning has started.

Status of RFQ Conditioning



<- Required Vane Voltage
for D+ beam acceleration

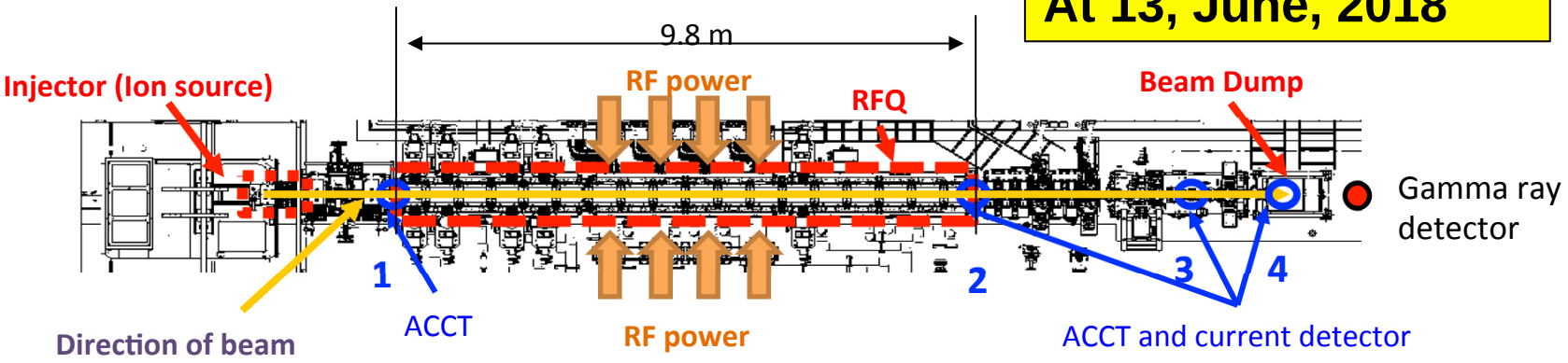
Short pulse (~20 microseconds)

RFQ Conditioning

- Simultaneous Injection using 8 RF modules
- Voltage between the vanes : 143 kV was achieved
  (enough for D+ beam acceleration)

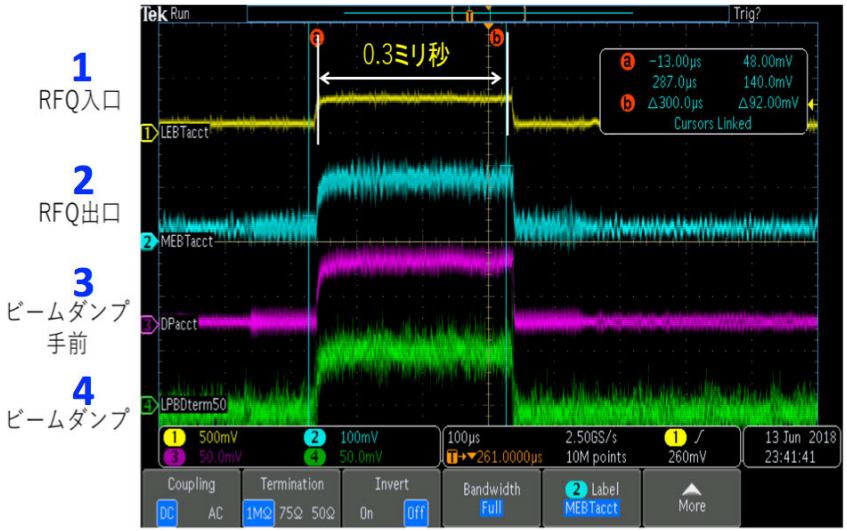
First Acceleration of H+ beam by RFQ

At 13, June, 2018



8-RF power source

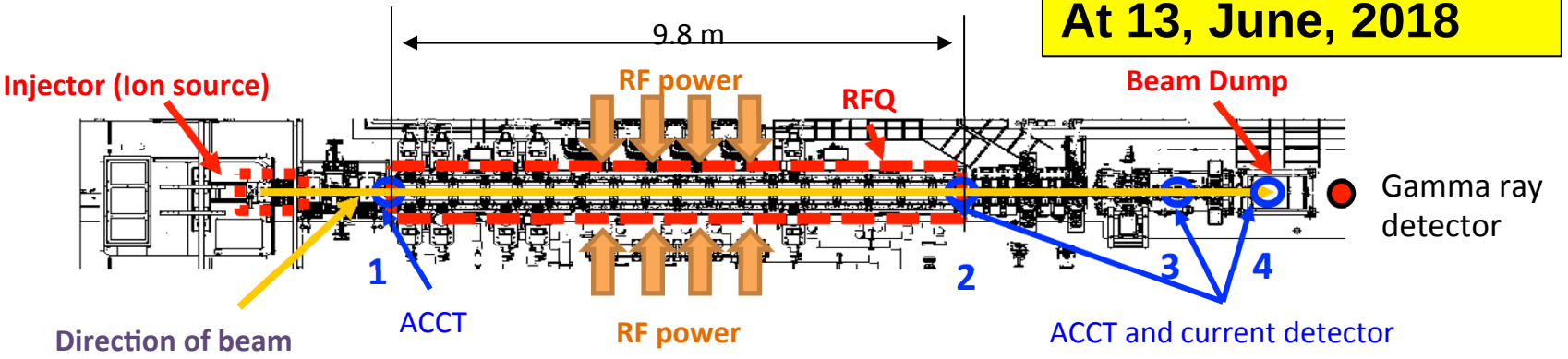
Waveform of each current



The first beam wave observed in the IFM
prototype accelerator RFQ

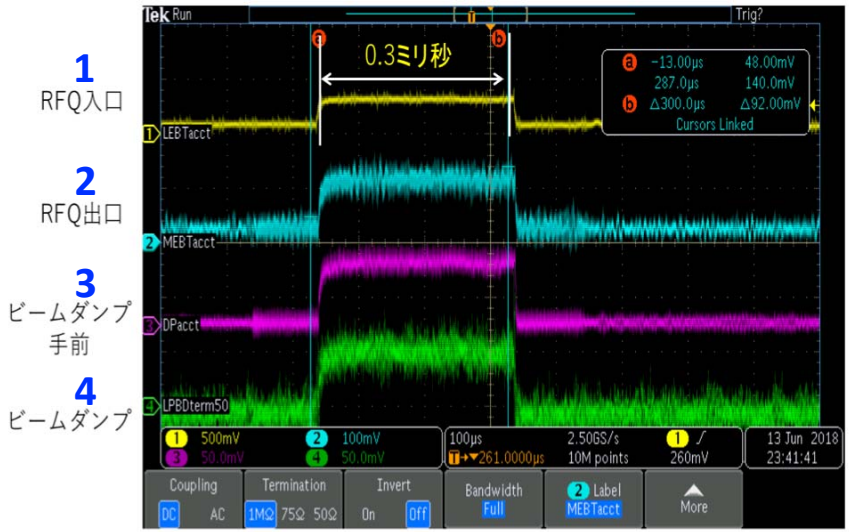
First Acceleration of H+ beam by RFQ

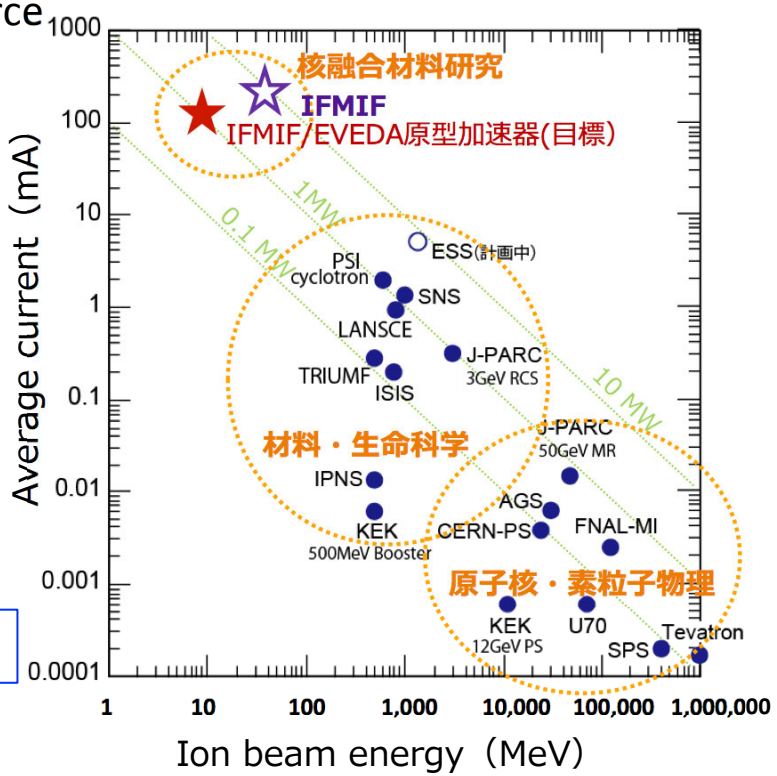
At 13, June, 2018



8-RF power source

Waveform of each current





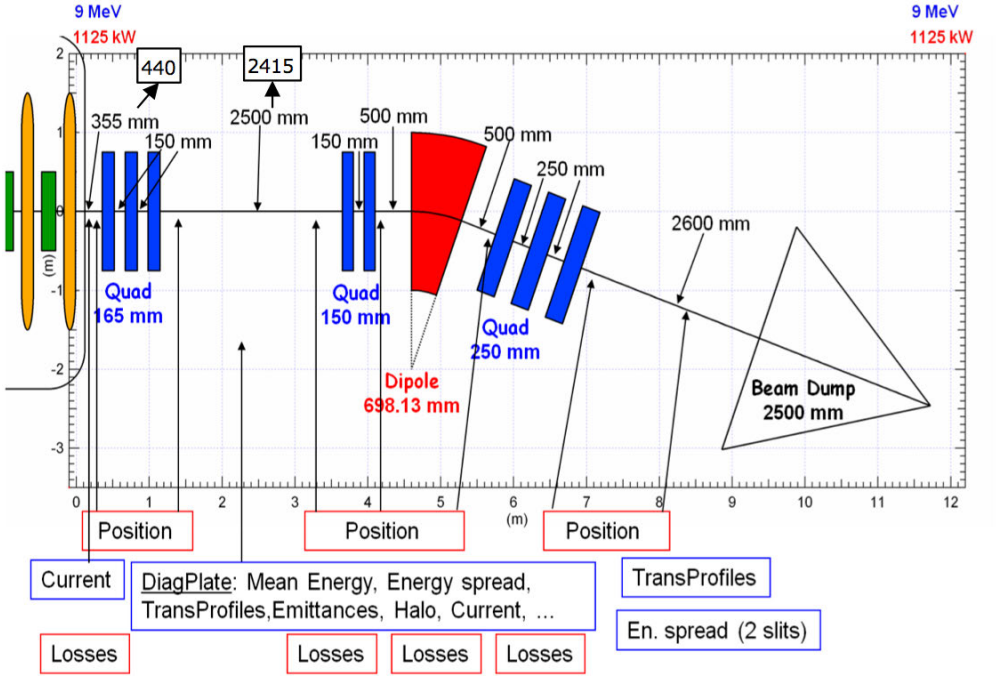
25mA, ~95% proton beam transmission（duty3/10000）

- RFQ conditioning will be re-started in Jan. 2019.
- D-beam RFQ experiment will be started from March 2019.

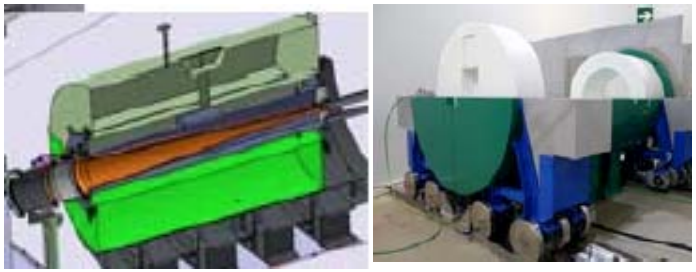
HEBT (High Energy Beam Transport)

- **Design**
  - 1.1MW High Power beam Dump: Power density<300W/cm^2
  - Loss except the beam dump: <1W / m (beam loss <10^{-6})

- **Code**
  - TraceWin

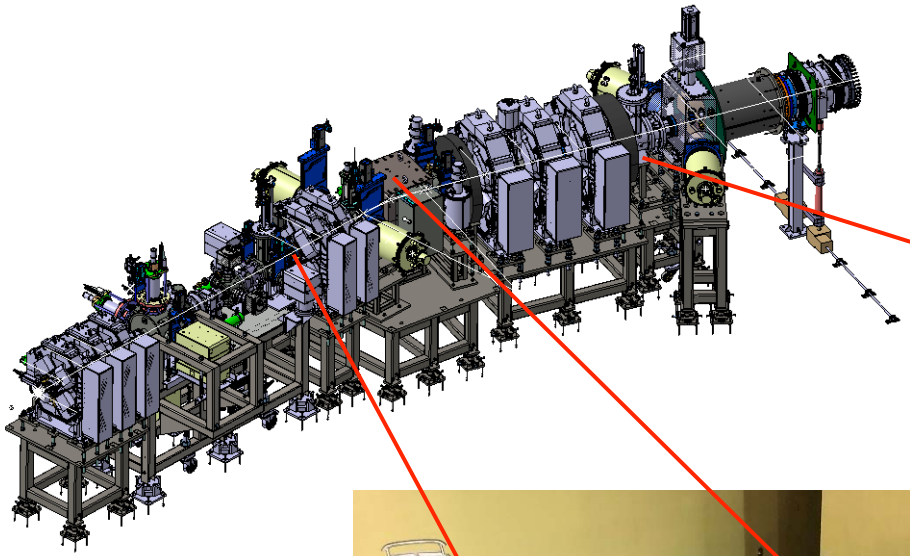


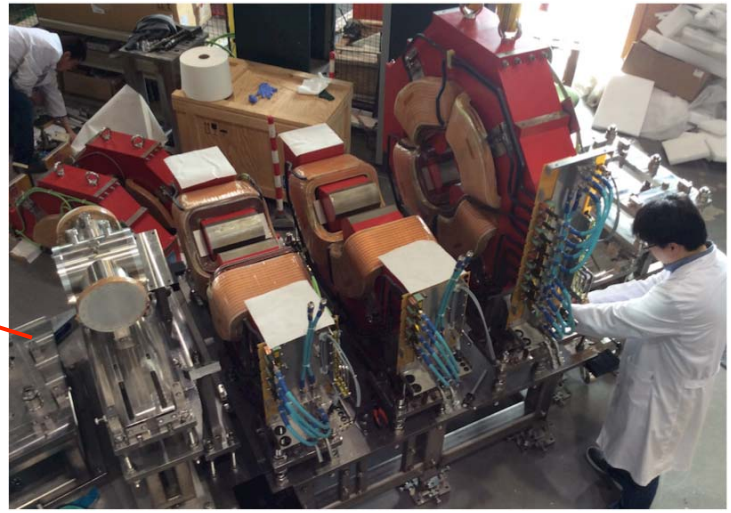
HEBT



Beam dump (1.15MW CW)

High Energy Beam Transport



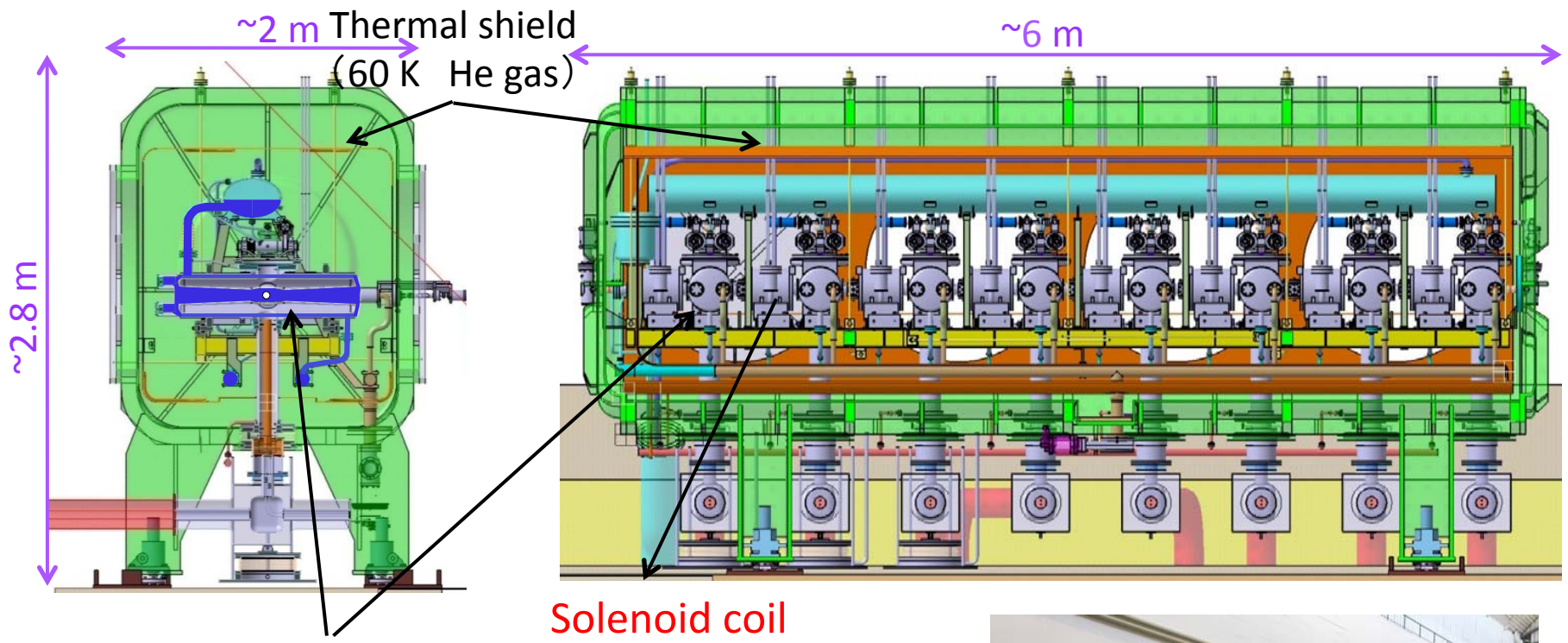


2nd Triplet of Q-Magnet

Doublet and Dipole
(assembled in Rokkasho)

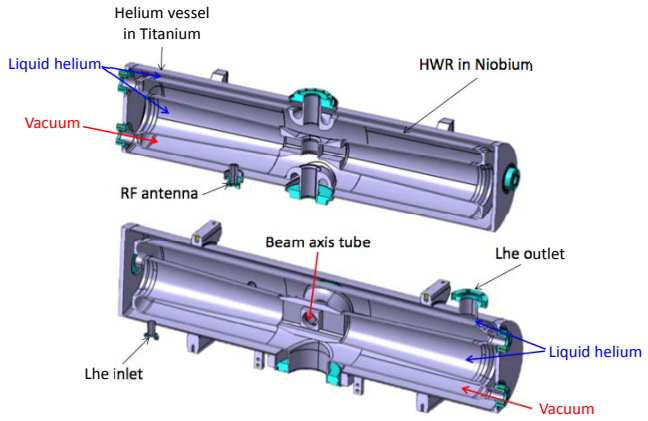
High Power Beam Dump

SRF linac

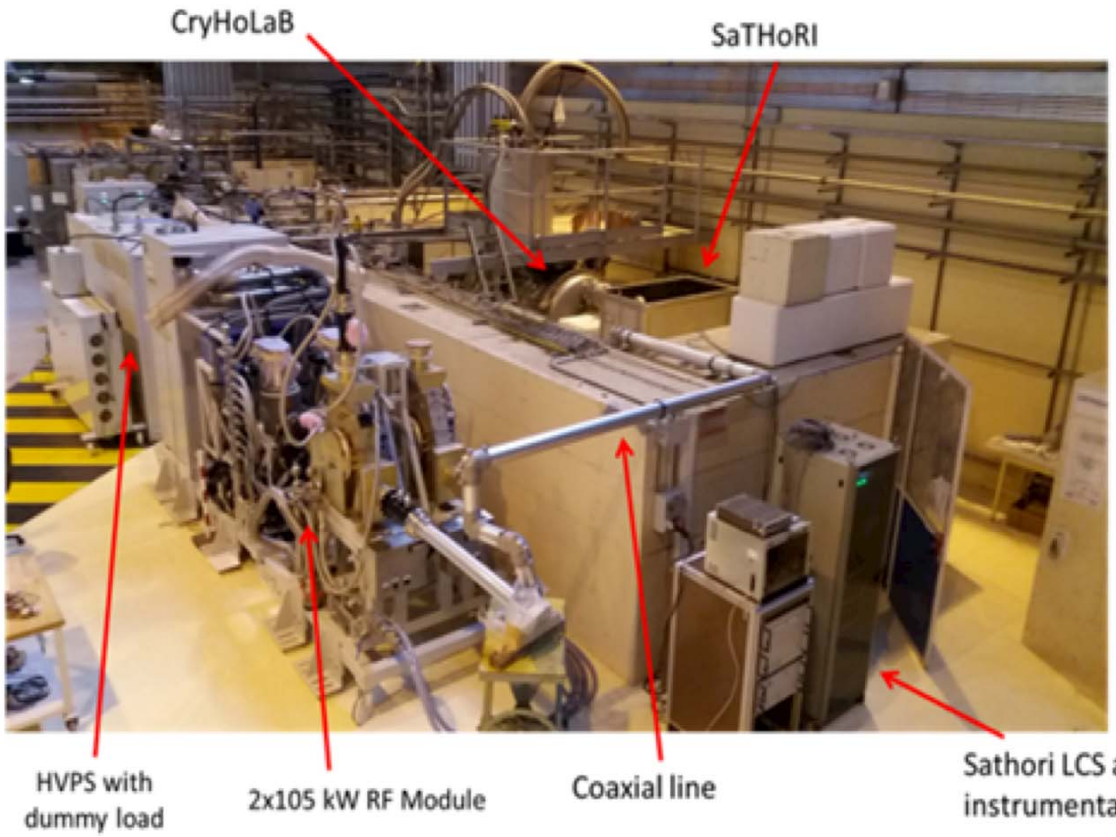


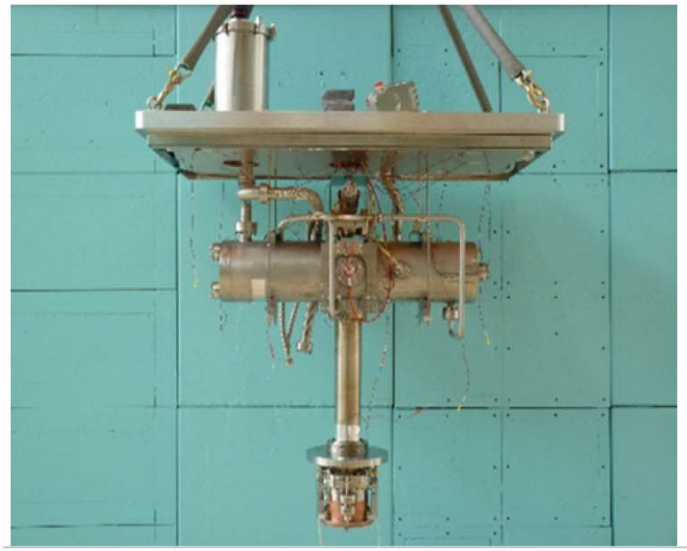
Solenoid coil

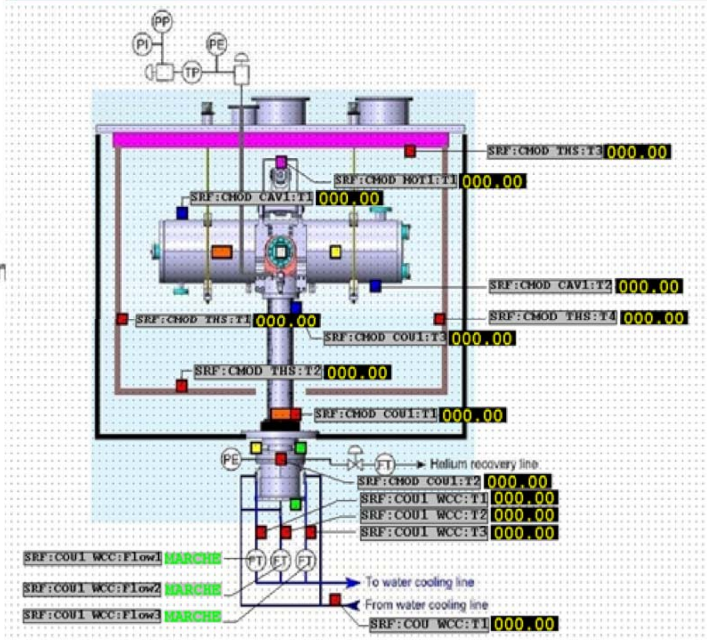
Half-wave length cavity



Test-stand of SaTHoRI cryostat (CEA-Saclay)

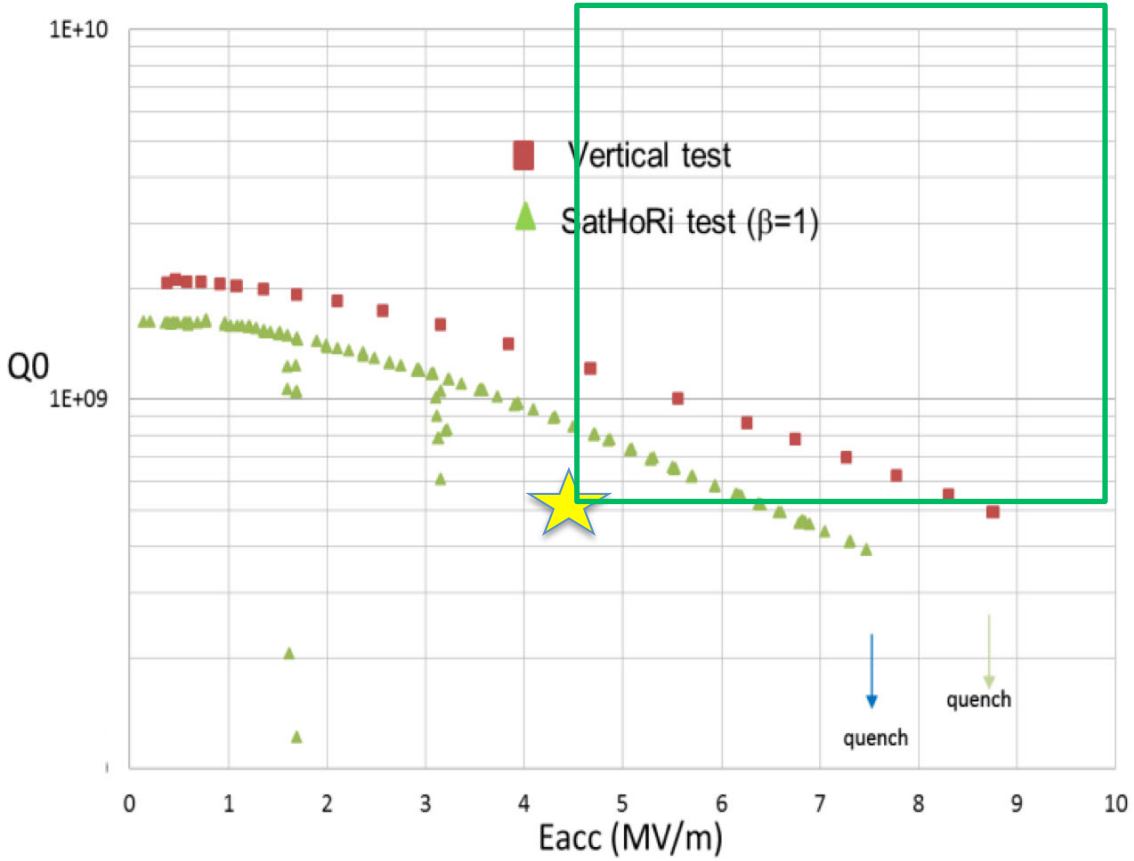






RF Module (175MHz, 200kW)

Q_0 vs. E_{acc} curve

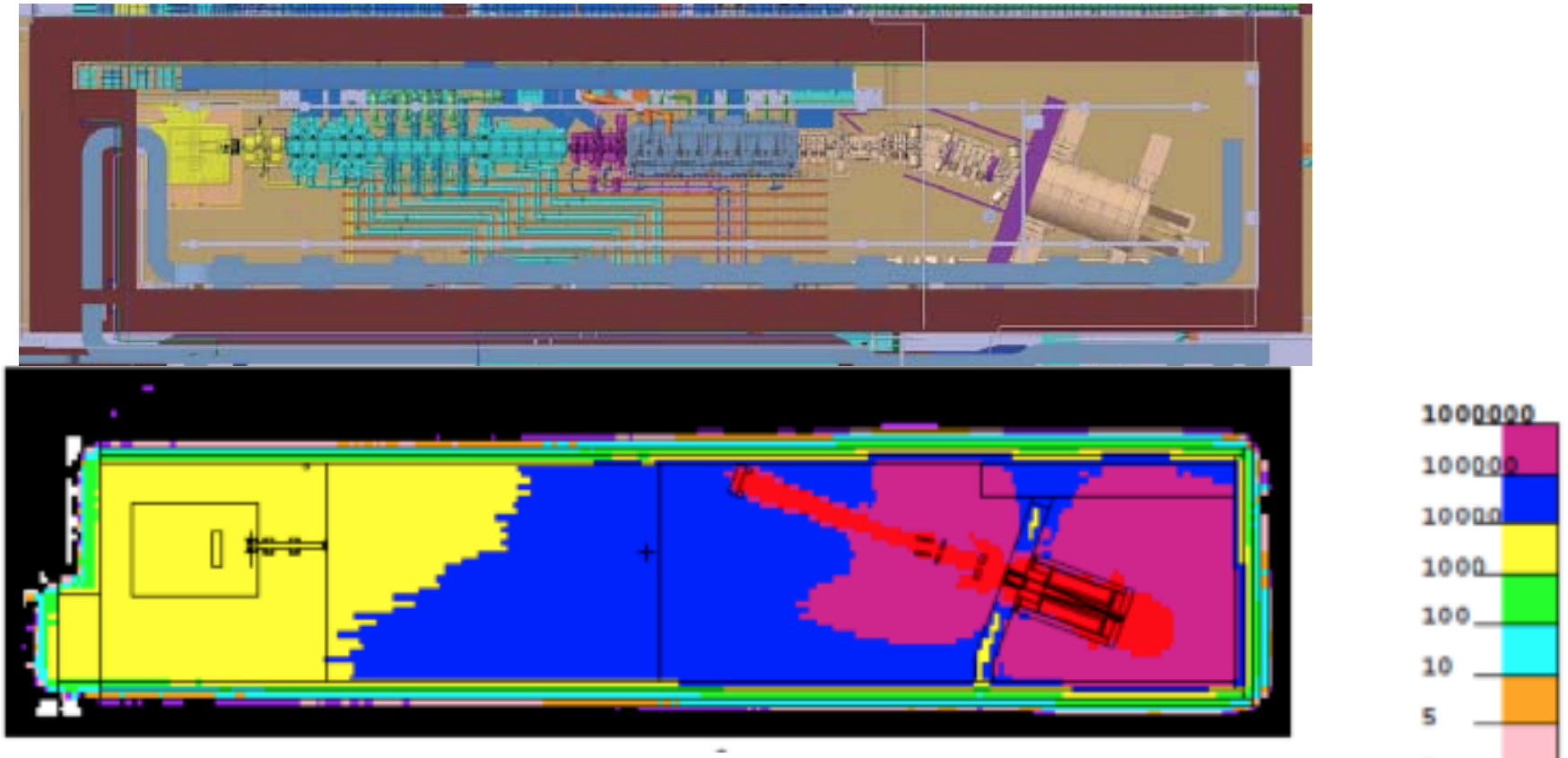


@The maximum accelerating field in horizontal test is 7.5 MV/m.
@The measured Q_0 at nominal field (4.5 MV/m) is $8x10^8$
which is above the specifications ($5x10^8$).

Good performance has been achieved with stable operation at first cavity.
All cavity will be delivered to Rokkasho soon.

Installation of Cryoplant at Rokkasho site

Radiation (Neutron) during operation



Neutron yield when D^+ hit Cu of the HPBD
During operation at 9MeV/125mA.

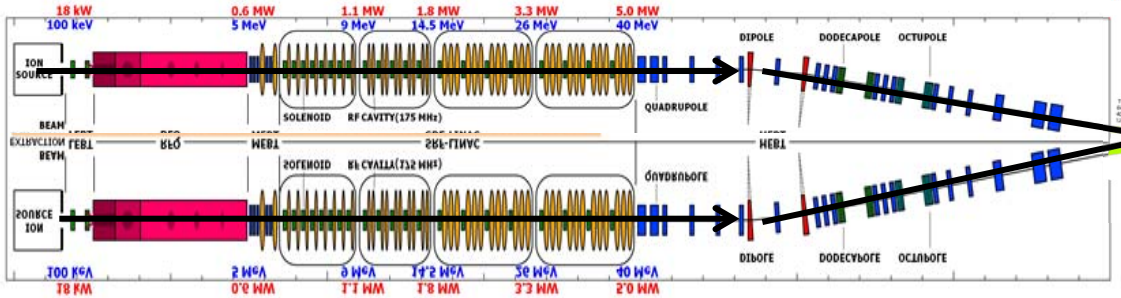
A-FNS
(Advanced Fusion Neutron Source)

- Domestic plan of the neutron source development for nuclear fusion

A.Kasugai, K.Ochiai, S.Satoh, H.Kondo, M.Ohta, M.Oyaizu,
M.Nakamura, S.Kwon, C.Park,H.Tanigawa, T.Nozawa, M.Teduka, H.Suzuki, S.Ishida
K.Sakamoto

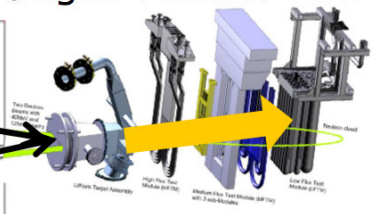
IFMIF and A-FNS

IFMIF: 40 MeVx125mAx2 lines



Injector RFQ SRF D-beam transport

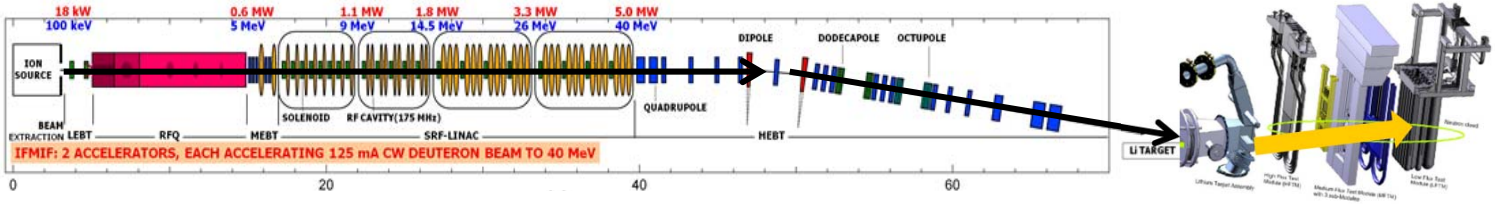
Irradiation module
(High、Middle、Low flux)



Liq. Li target

Neutron source for fusion

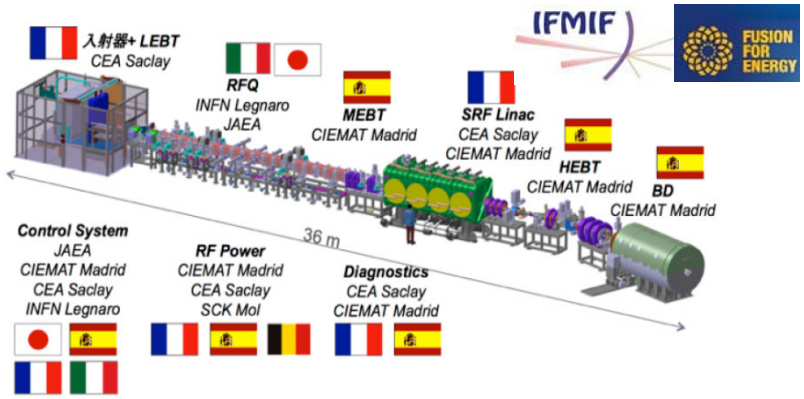
A-FNS: 40 MeVx125mAx1 line



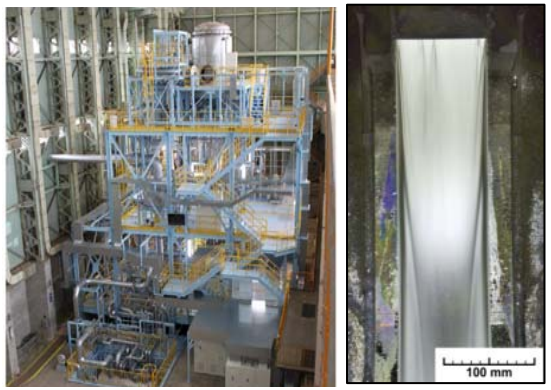
Neutron source for Fusion + application

A-FNS conceptual design based on IFMIF/EVEDA

- Target: Prototype of Liquid Li target loop was constructed and tested.
- R&D of Accelerator : Underway on IFMIF prototype accelerator
- Conceptual design is underway. Will be shifted to Engineering phase.

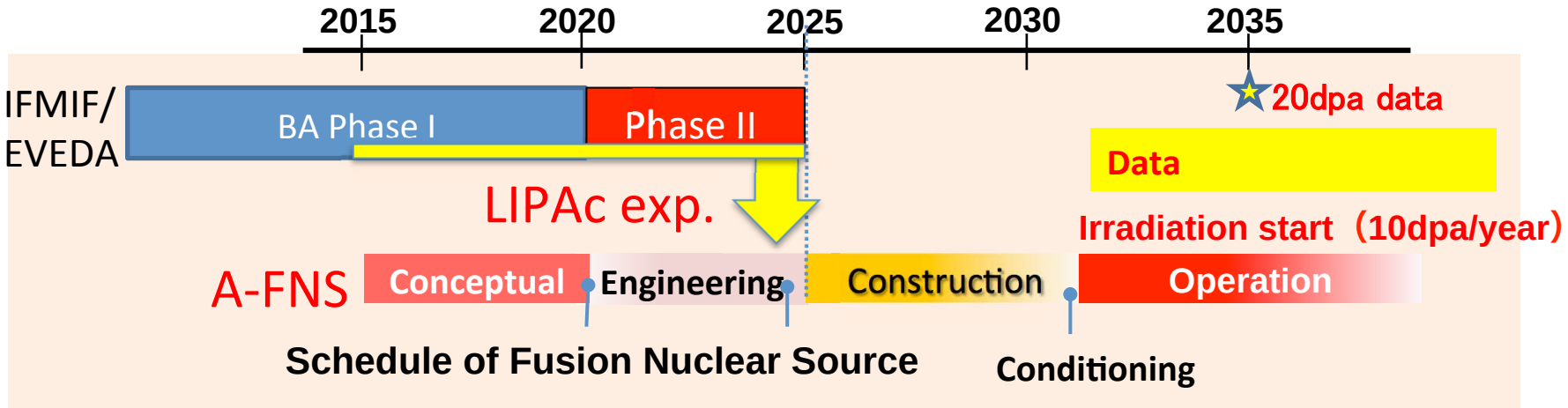


IFMIF/EVEDA Prototype accelerator

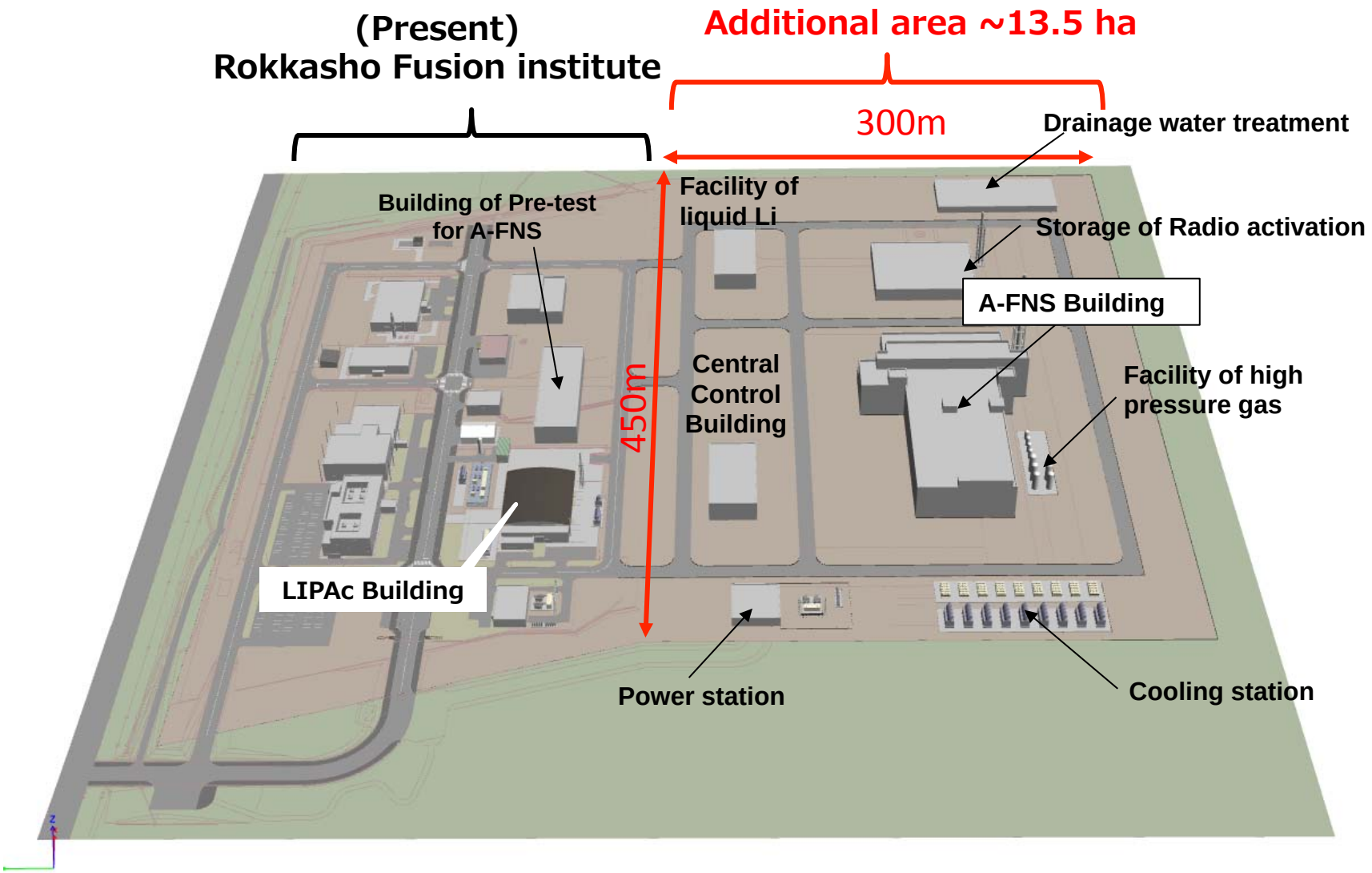


IFMIF/EVEDA Li target loop

Demonstrated
Stability : 25±1㎜
Flow speed : 15m/s
Operation time : >1500hr

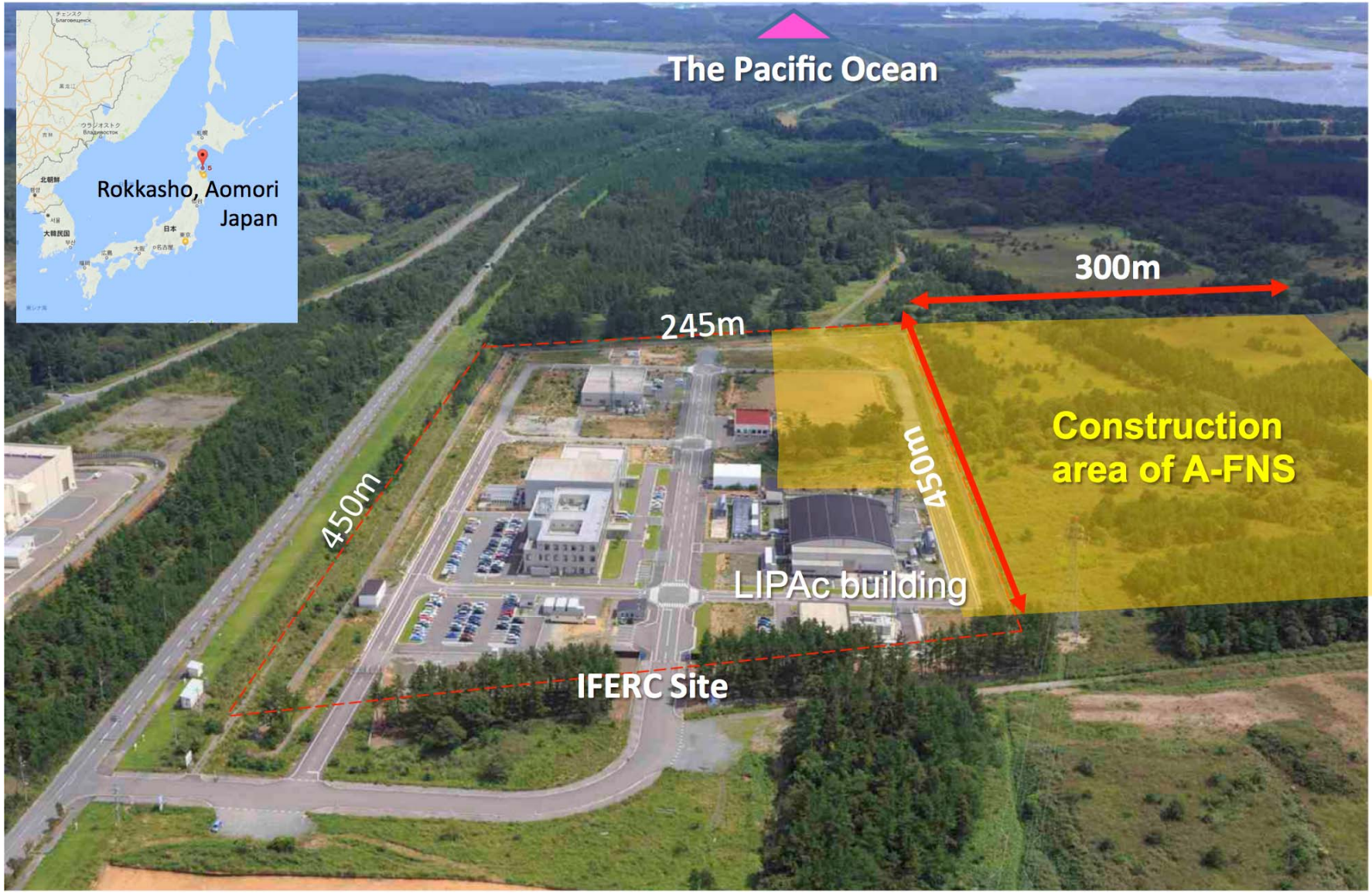


Layout of A-FNS in Rokkasho



Consideration of Site Utilities is just started for A-FNS

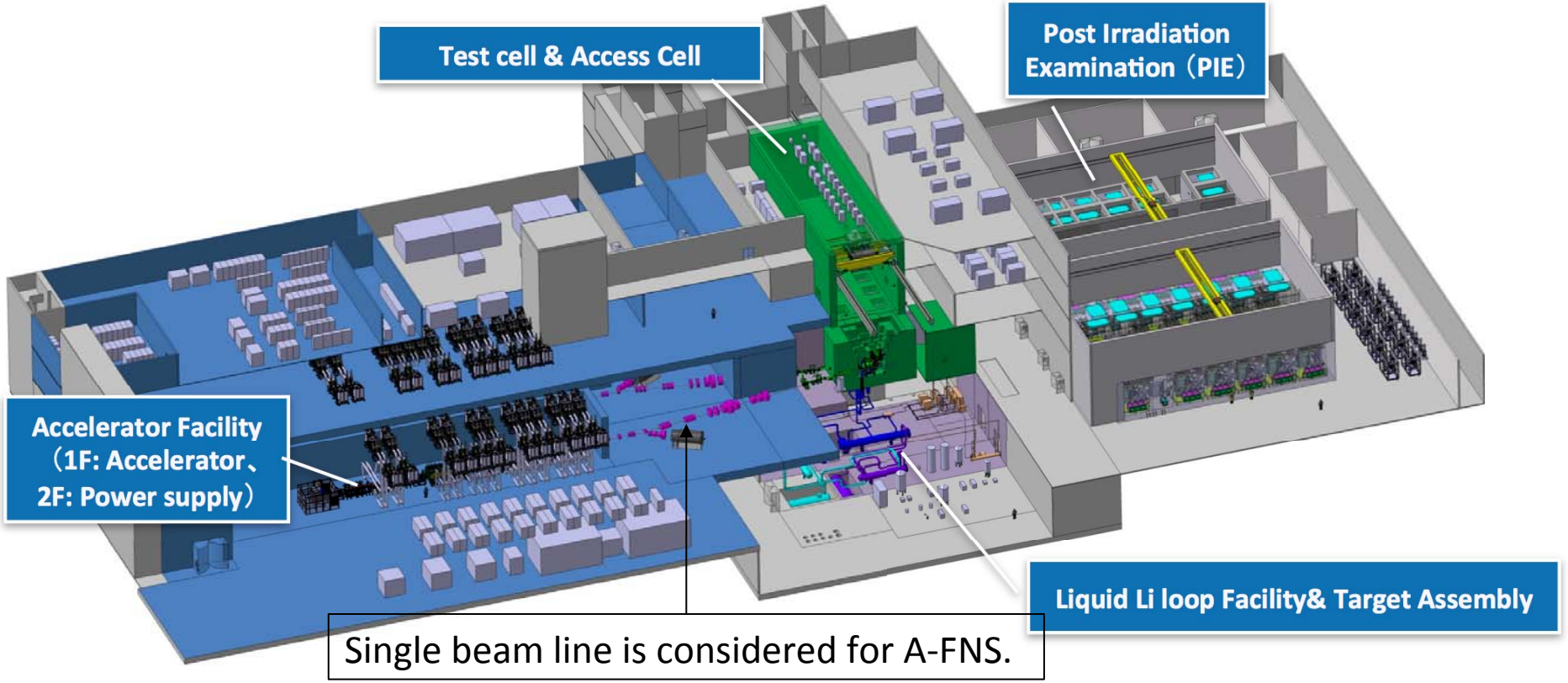
Site of A-FNS


The Pacific Ocean
Rokkasho, Aomori
Japan
300m
245m
450m
450m
Construction
area of A-FNS
LIPAc building
IFERC Site

Conceptual Design of A-FNS

Dimension of A-FNS building

- Length : 187 m
- Width : 100 m
- Hight 3F up : 21 m
- 2F under : 15 m

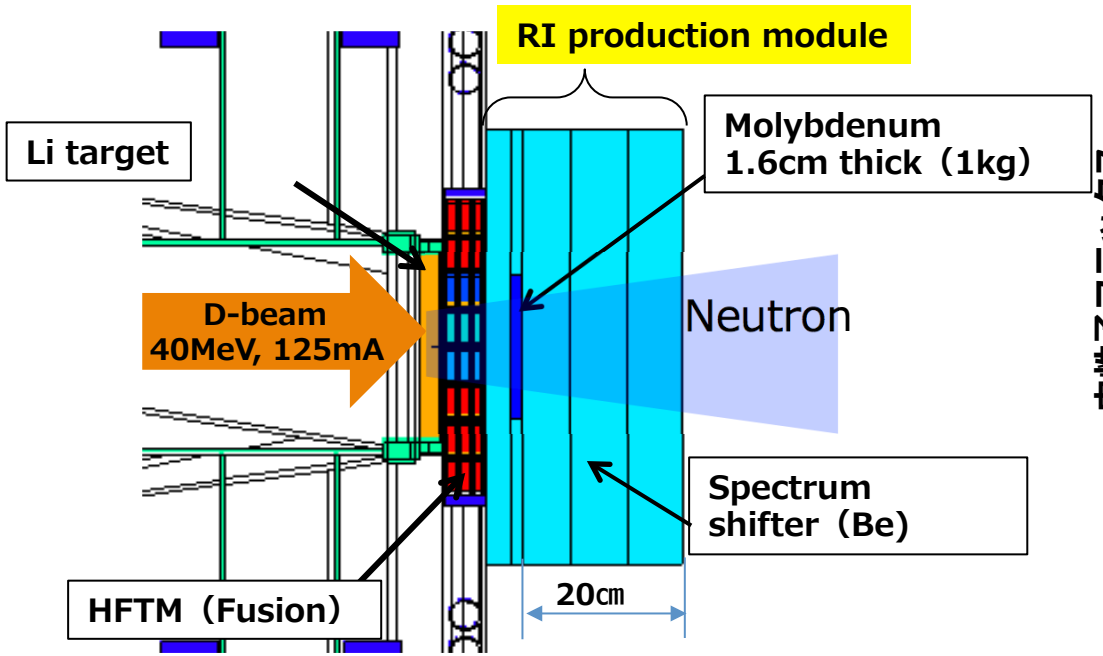


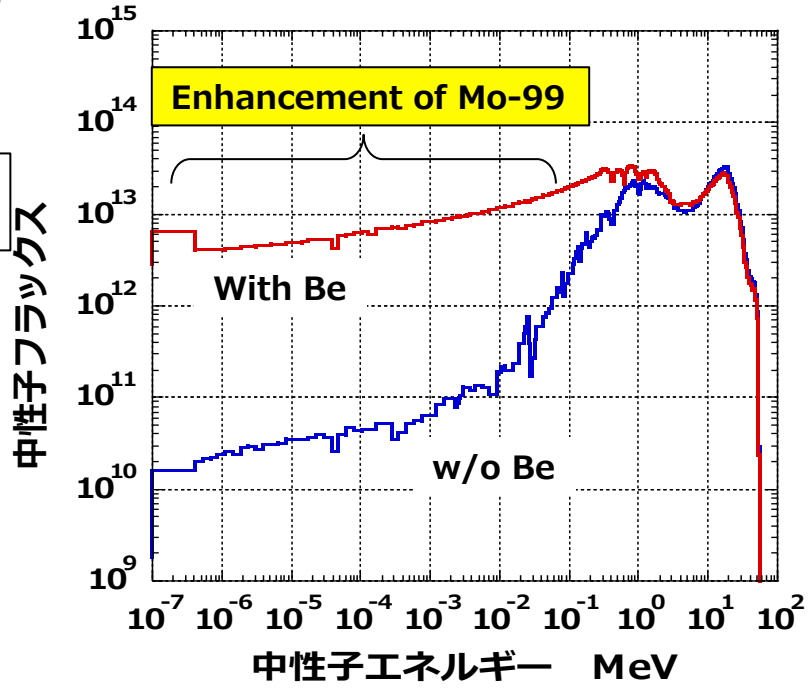
Conceptual Design of A-FNS based on Engineering design of IFMIF

A-FNS application (Isotope production)

Mo-99 Production (Medical application) :

- Utilize the backward of the fusion material irradiation area
- Improve RI production speed with neutron spectral shifter and reflector





Simultaneous radiation: fusion material irradiation+isotope production

Supply 100% of the domestic demand amount of Mo－99

Application of neutron source to other field

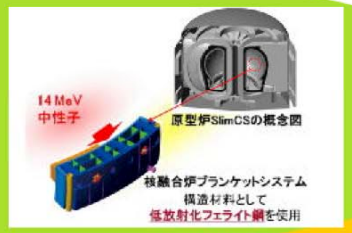
•Data base of fusion material

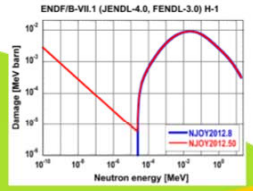
Fusion component

Neutronics

Medical, RI production

Liq. Li target





核設計データ研究

A-FNS
40MeV D beam
125mA（CW）

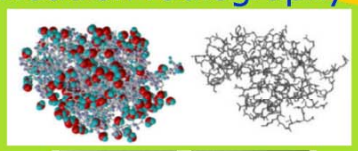
Material test

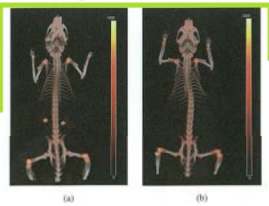
Fusion component test

Application (Industry, Medical)

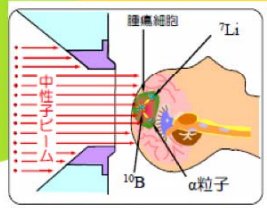
6.8×10^{16}/s

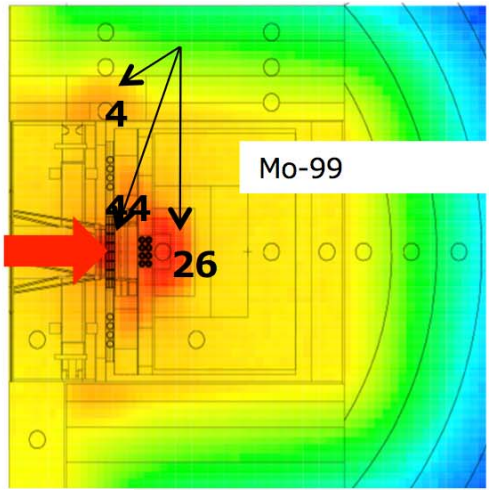
Neutron radiography



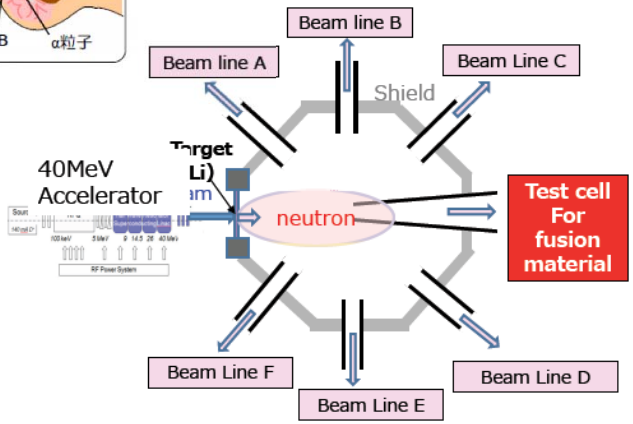


BNCT





Simulation of Mo-99 production



Material Science, Material development

Summary & Future Plan

- Proton beam acceleration in the RFQ section of the LIPAc have started at June 2018.
- D-beam experiment will be started form March 2019.
- SRF linac will be assembled in 2019 at Rokkasho, and beam experiment will be started by March 2020.
- Five years extension of BA activities, so called BA phase II, is under discussion to demonstrate the feasibility of 125 mA, 9MeV for long pulse operation with SRF linac.
- After the BA phase II, QST plans the construction of the *Advanced Fusion Neutron Source* (*A-FNS*) with 40 MeV SRF linac in Japan, which is one beam line system of the IFMIF, to satisfy the Japanese Action Plan towards DEMO.

Tentative schedule of IFMIF/EVEDA and A-FNS