# Status of FFA accelerator in Kyushu University

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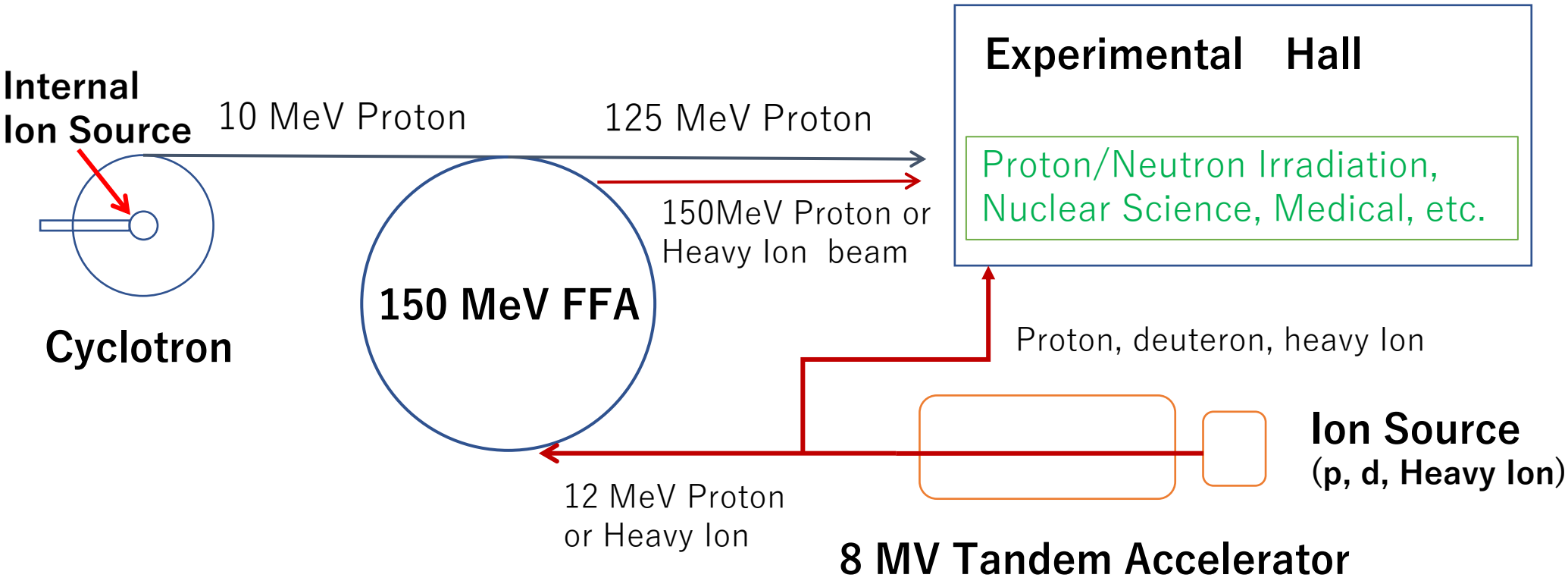
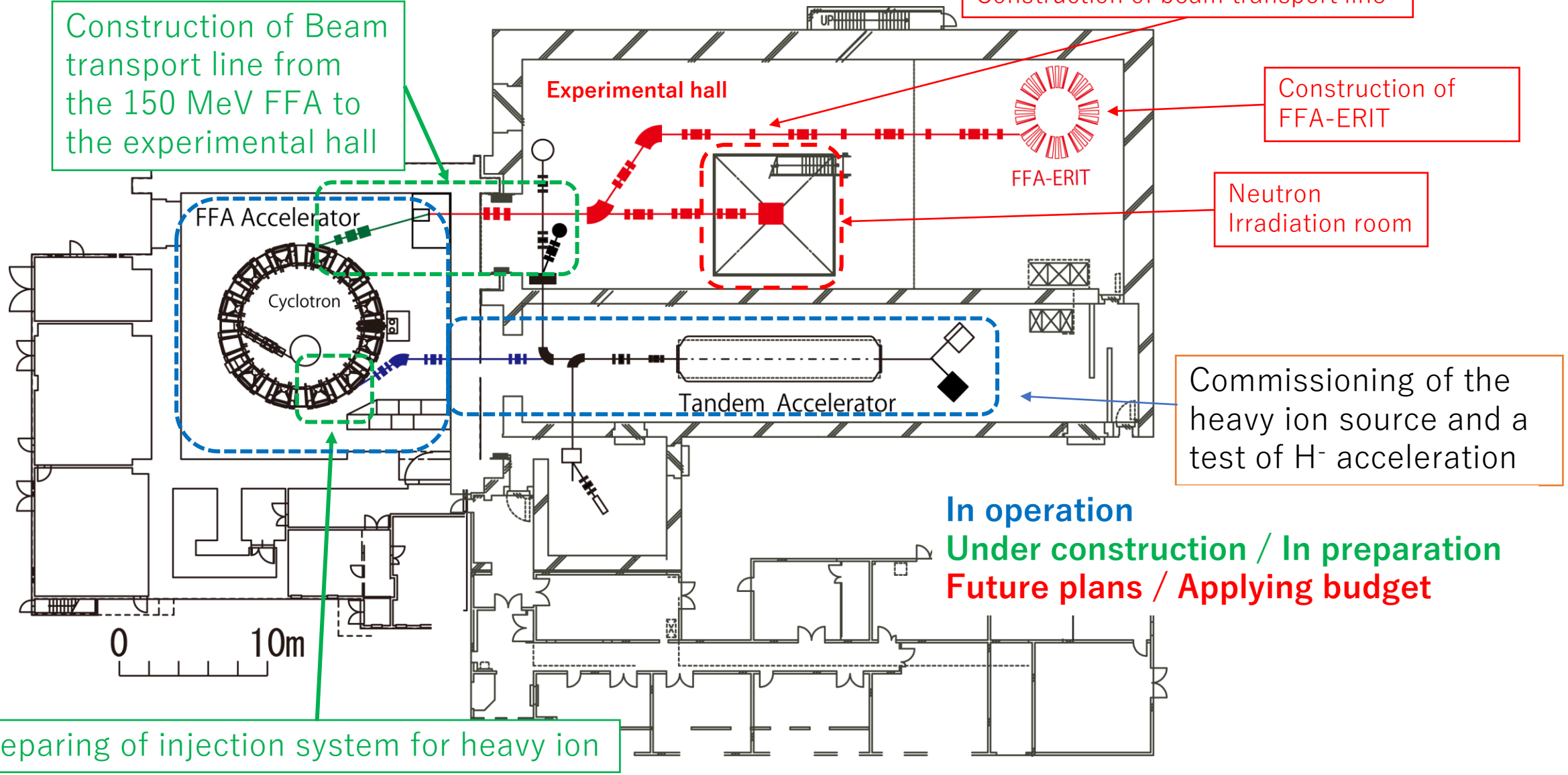
- Summary

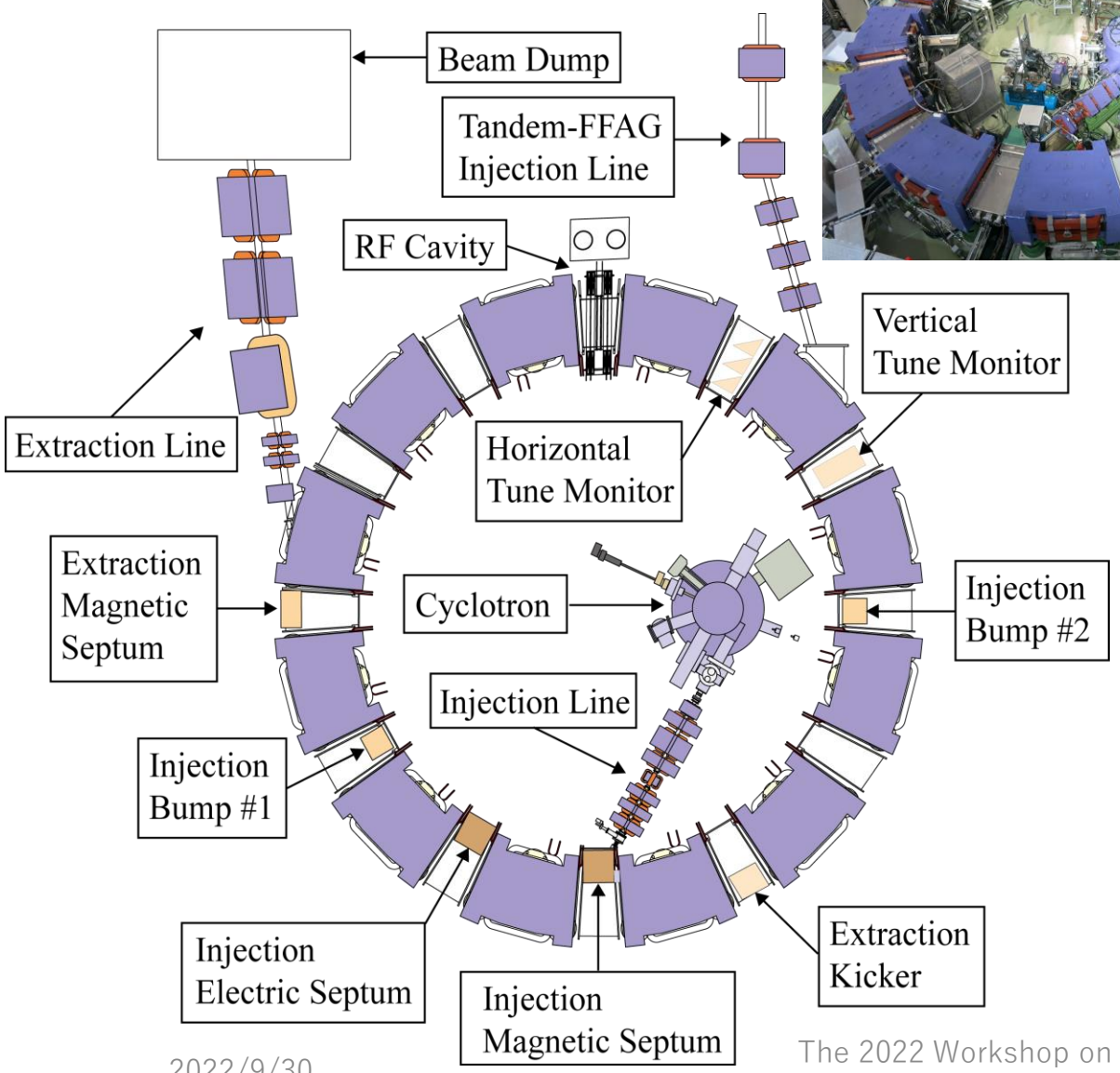
# Overview of the accelerator facility of Kyushu University

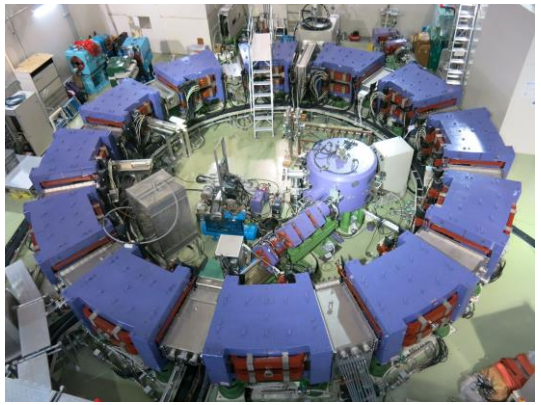


# Status of the accelerator facility in 2022



# 150 MeV FFA



Design parameters of 150 MeV FFA

| | |
|---|---|
| Magnet Type | Radial Sector (DFD Triplet) |
| Number of Cell | 12 |
| Proton Energy | 10 – 125 MeV (12 – 150 MeV) |
| Average radius | 4.47 – 5.20 m |
| Repetition | 100 Hz (2 Cavity) |
| Beam Current | 1.5 nA |
| Betatron Tune (Injection Energy) | 3.61 (Horizontal)<br>1.46 (Vertical) |

Design parameters of injector cyclotron

| | |
|---|---|
| Type | AVF Cyclotron |
| Extraction Energy | 10 MeV (Proton) |
| RF Frequency | 47 MHz ($2^{nd}$ Harmonics) |
| Beam extraction radius | 0.3 m |
| Beam Current | 2 $\mu$A |

# Tandem accelerator

| | |
|---|---|
| Accelerator Type | Horizontal Tandem Van de Graaff |
| Model | NEC Pelletron (8UDH) |
| Terminal Voltage | 7 MV (max. 8 MV) |
| Accelerator Tank | Diameter 3.0 m<br>Length 13.6 m |
| Insulation Gas | $SF_6$ (pressure 0.6 MPa) |
| Ion Source | Sputter Ion Source (NEC MC-SNICS)<br>RF Ion Source (NEC Alphatross) |
| Injection Voltage | -70 kV |
| Beam | p, d, H.I. |
| Current | 1 nA |
| Terminal Stripper | C Foil and Ar Gass |
| Charging Device | Double Pellet Chains<br>(Current 150 $\mu$A×2) |

8 MeV tandem accelerator

Sputter Ion Source (NEC MC-SNICS)

RF Ion Source (NEC Alphatross)

# Ongoing and planned projects of FFA in Kyushu University

Three projects are ongoing, one project is planned.

**Ongoing projects**

1. Construction of the experimental hall to utilize beam of the 150 MeV FFA

2. Injection and acceleration of heavy ion with the 150 MeV FFA

3. Development of a prototype machine of vertical FFA for Harmonytron

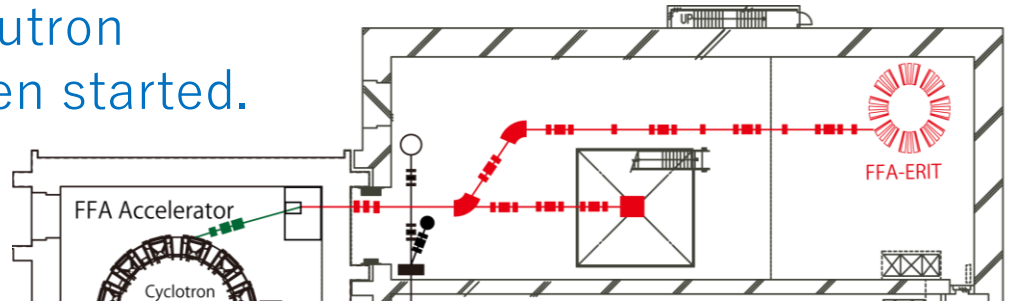
**Planned project**

4. Production of neutron and unstable nuclei with FFA-ERIT ring

Details will be reported later in my presentation.

# 1. Construction of experimental hall to utilize beam of the 150 MeV FFA

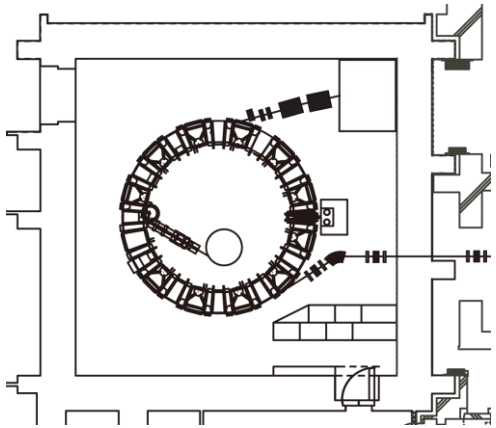
To promote study of nuclear physics, material and neutron science, construction of the experimental hall has been started.



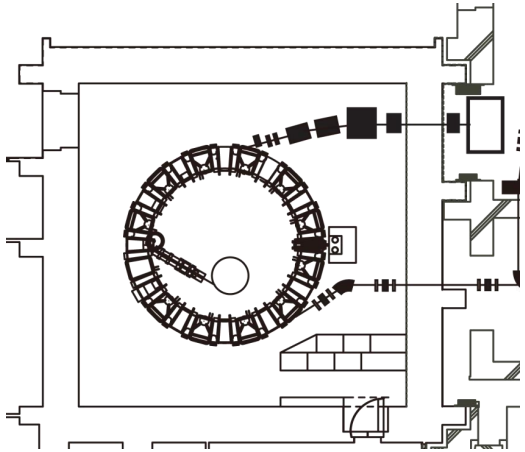

## 1-1. construction of beam transport line

Part of the construction budget was approved in 2022.

The 3rd stage of the construction facility has been started.
The beam transport line from the FFA to the experimental hall is under construction.

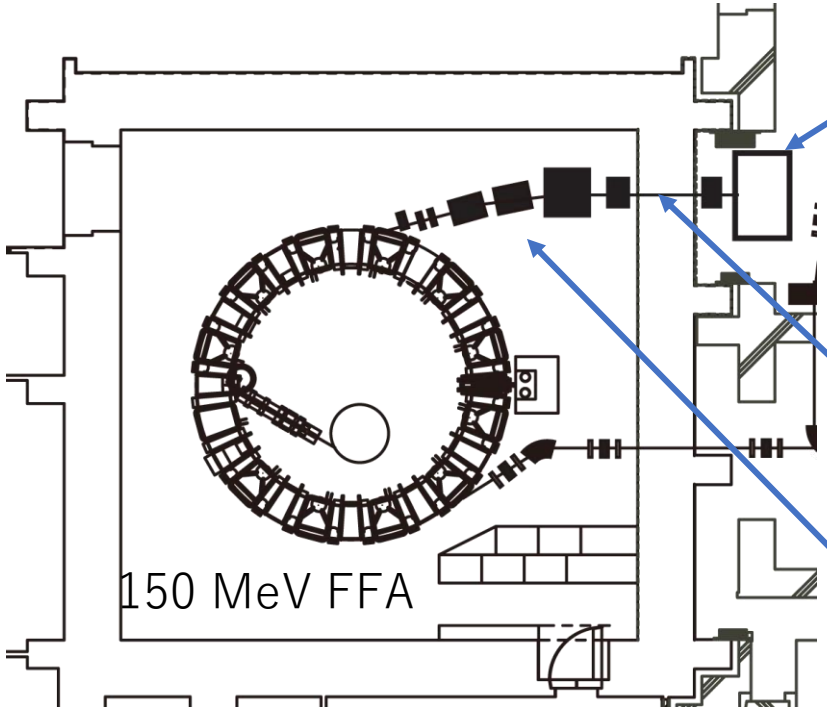


Present condition

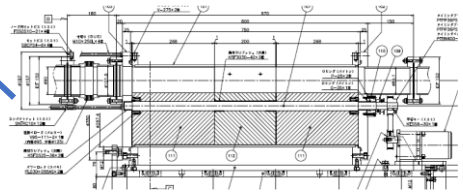


2023~2024 ?

# 1-1. Status of construction of beam transport line

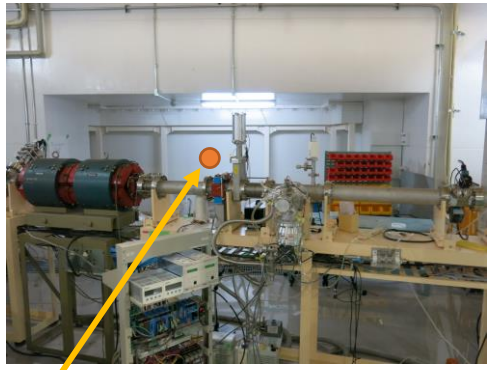



**Disassemble and relocate beam dump**
Preparing inspection of radiation safety



**Rotary shutter (movable radiation shield in vacuum)**
Manufacturing completed
Ready for installation

**Magnets**
Relocated from KEK
Ready for installation



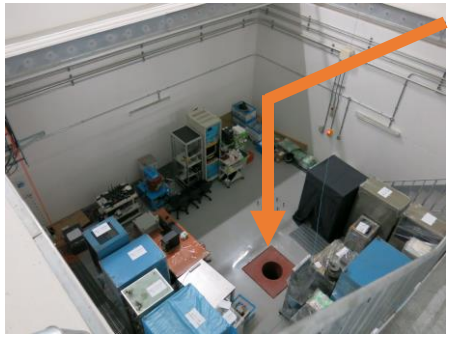
**Making hole in the radiation shield to install the rotary shutter**
Preparing inspection of radiation safety

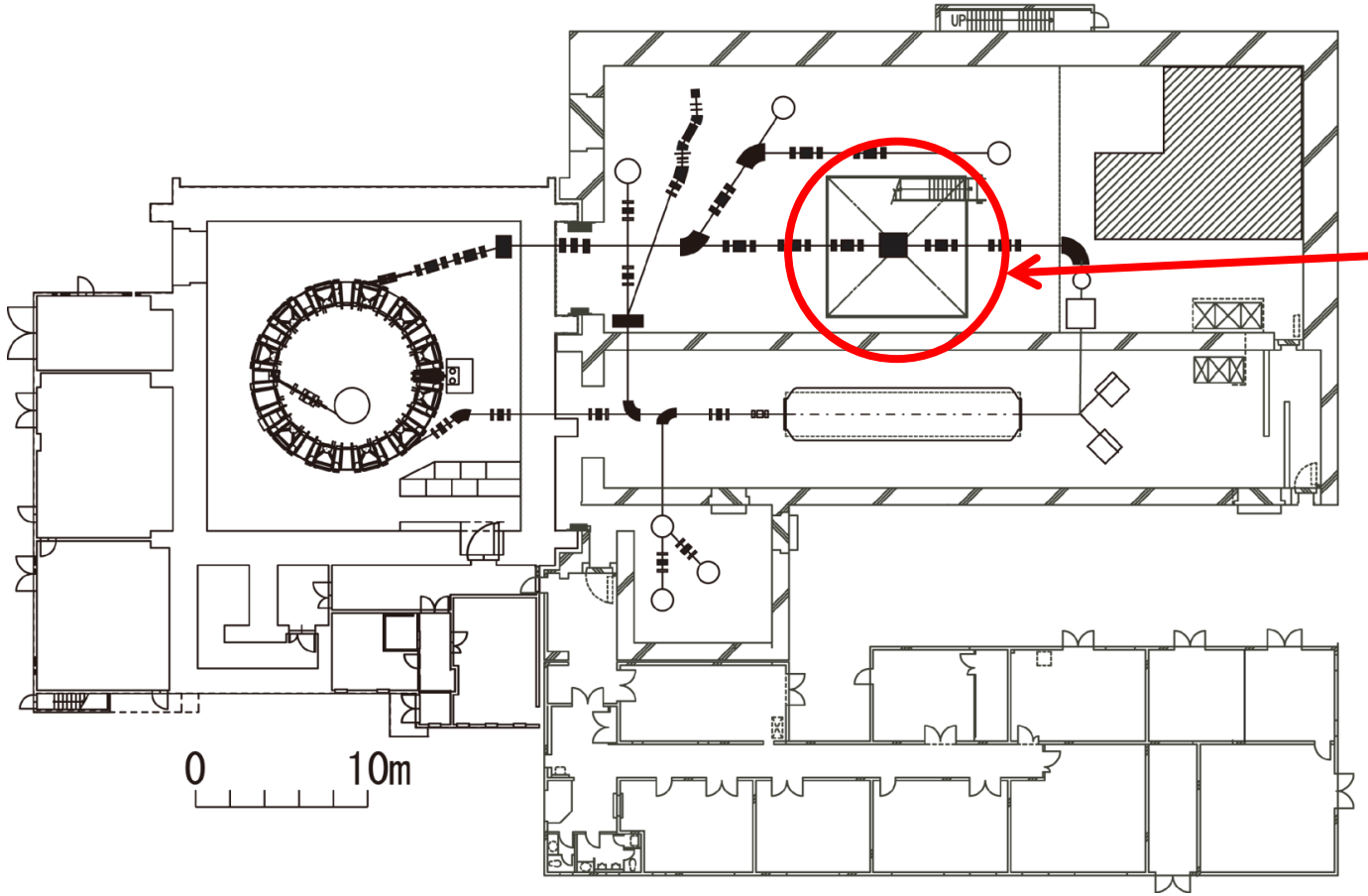
The construction of the beam transport line is expected to be delayed by more than a year due to delays in the review of the application for a radiation safety.

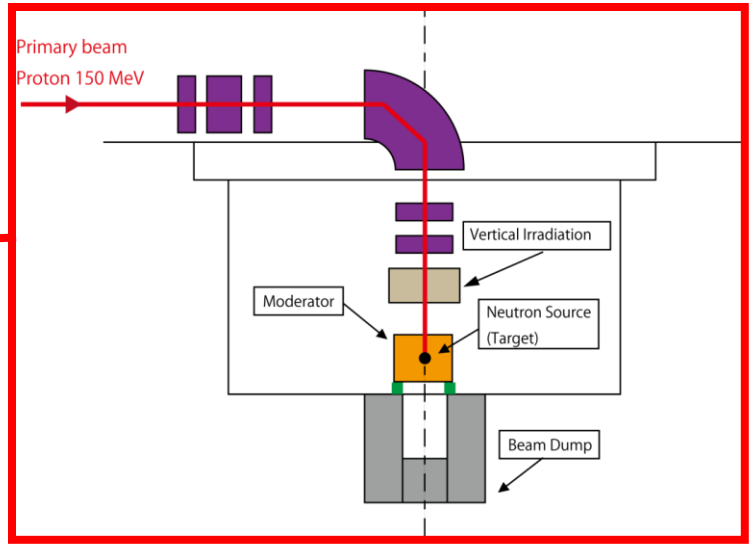
Because many applications have been submitted for the restart of nuclear power plants?

# 1-2. Construction of proton and neutron Irradiation room

To promote study of life science, material physics and neutron science, the construction of the vertical beam line and the proton and neutron irradiation room is planned in the future.





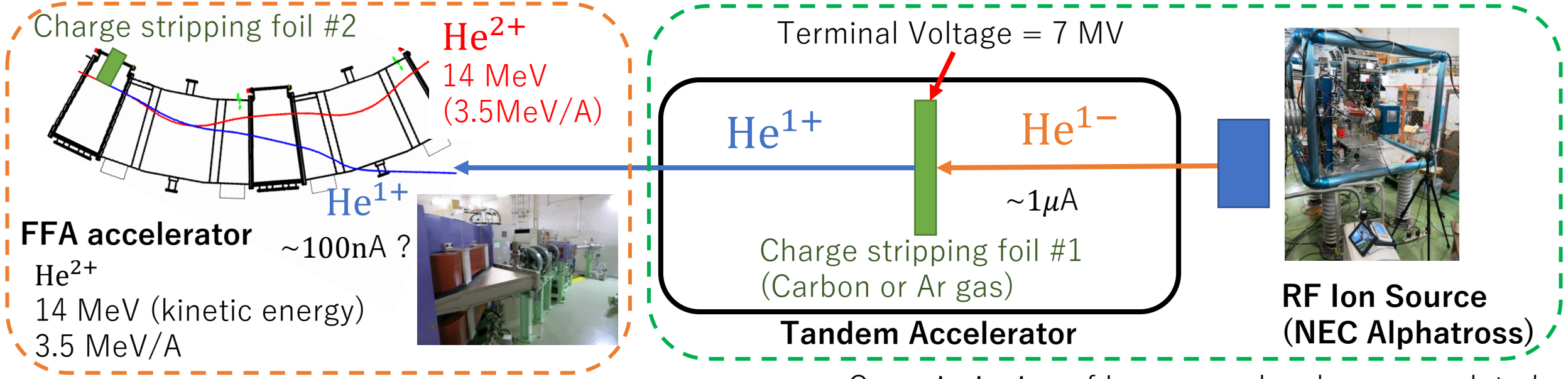

**A budget for construction has been applied for.**

# 2. Charge exchange injection of heavy ion to the 150 MeV FFA

The purpose of the experiment is to demonstrate a charge exchange injection of heavy ion to the FFA.

In preparing

In commissioning




Commissioning of Ion source has been completed.

**2-1. Charge exchange injection system**

Preparing charge converting foil
(10 $\mu g/cm^2$ of Carbon foil is employed.)

**2-2. Test of the charge stripping foil**

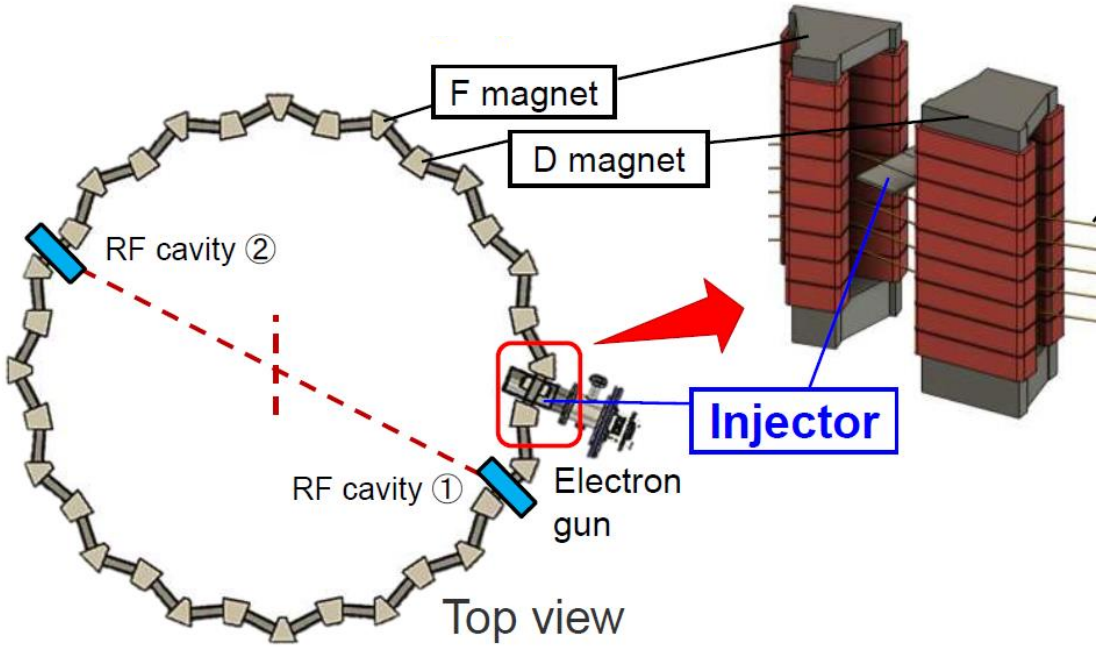
Beam experiment of charge conversion has been carried out.
Test of the Carbon foil is in progress.
The Argon gas stripper is being prepared.

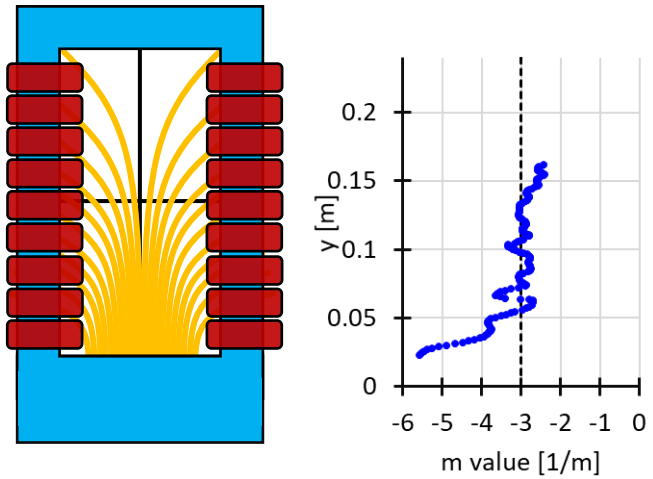
**$He^{1+}$ ion beam will be injected to the FFA in 2023.**

# 3. Development of a prototype machine of vertical FFA for Harmonytron[1]

- Field optimization of magnets
- Simulation of beam injection and acceleration
- Commissioning of electron gun

have been carried out.




Details will be reported in Mr. Adachi's presentation

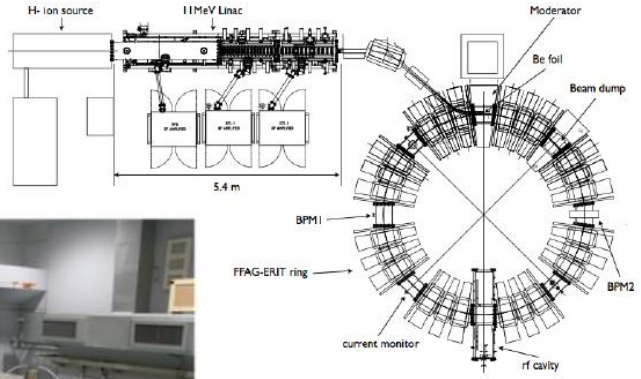
[1] Y. Mori, Y. Yonemura and H. Arima : "A Proposal of Harmonictron", Mem. Fac. Eng. Kyushu Univ., Vol. 77, No. 2, pp. 1-13 (2017).

# 4. Production of neutron and unstable nuclei with FFA-ERIT

FFA-ERIT is an accelerator-based neutron source with ERIT(Energy Recovery Internal Target[2] ) scheme developed in Kyoto University.

Design parameters of FFA-ERIT[3]

| | | |
|---|---|---|
| ERIT system | Expected turn number | ~ 1000 turn |
| | Be target thickness | ~ 5 μs |
| Injector Linac | Ion spices | $H^-$ |
| | Kinetic energy | 11 MeV |
| | Average beam current | ~ 70 μA |
| FFAG storage ring | Injection scheme | $H^-$ Injection |
| RF cavity | RF voltage | 200 kV |
| | Harmonic number | 6 |




The FFA-ERIT has been decommissioned and disassembled in 2021.
Experiments on nuclear physics and neutron science with FFA-ERIT are planned in Kyushu University.

**[2] Y. Mori, "Development of FFAG accelerators and their applications for intense secondary particle," Nuclear Instruments and Methods in Physics Research Section A, Volume 562, Issue 2, pp. 591-595, 2006.**

[3] K. Okabe, et al., "DEVELOPMENT OF FFAGERIT SYSTEM FOR BNCT", Proc. Cyclotrons and Their Applications 2007, Eighteenth International Conference (2007). pp. 210-212.

# 4. Production of neutron and unstable nuclei with FFA-ERIT ring

- **Low-energy and medium-energy neutron source**
  - Boron Neutron Capture Therapy (BNCT), Material Irradiation
  - To obtain the cross sections of interaction of neutron in medium energy

Details of medium-energy neutron source with the remodeled ERIT ring will be reported in Mr. Takamatsu's presentation

- **Production of unstable nuclei with ERIT scheme**

To find the island of stability in the region of super-heavy elements is one of the largest challenges in nuclear physics.

Interactions of neutron-rich nuclei and stable nuclei are employed for production unstable nuclei.

For example, $^{70}_{30}\mathrm{Zn} + {}^{209}_{83}\mathrm{Bi} \rightarrow {}^{278}_{113}\mathrm{Nh} + 1\mathrm{n}$

Neutron-rich Stable Unstable nucleus

$^{64}_{30}\mathrm{Zn}(48.6\%)$, $^{66}_{30}\mathrm{Zn}(27.9\%)$, $^{67}_{30}\mathrm{Zn}(4.1\%)$, $^{68}_{30}\mathrm{Zn}(18.8\%)$, $^{70}_{30}\mathrm{Zn}(0.6\%)$
$^{209}_{83}\mathrm{Bi}(100\%)$

However, the production efficiency of unstable nuclei is very low.

The purpose of this study is to demonstrate a new method to produce unstable nuclei with ERIT scheme.

Final goal: $^{56\sim60}_{20}\mathrm{Ca}$ +actinide target (Z~94) ➔ $_{114\sim120}$New nucleus (stable?)

# Construction plan of facility for production of neutron and unstable nuclei with FFA-ERIT

The application of the construction budget has already been submitted and it will be reviewed by the end of this year.

## In the 1st stage (2023~?)

1. **Neutron production using 11 MeV of proton beam from the tandem accelerator.**

   11 MeV proton beam + Be target

2. **Preliminary research for a new method with ERIT scheme for production of unstable nuclei**

- To examine the separation method of produced nuclei
- To measure production efficiency

**Stable nuclei Beam:**

5~6 MeV/A of $^{7}_{3}\mathrm{Li}$ (charge state: +1)

$3 \leq Z(Atomic\ number) \leq 20$

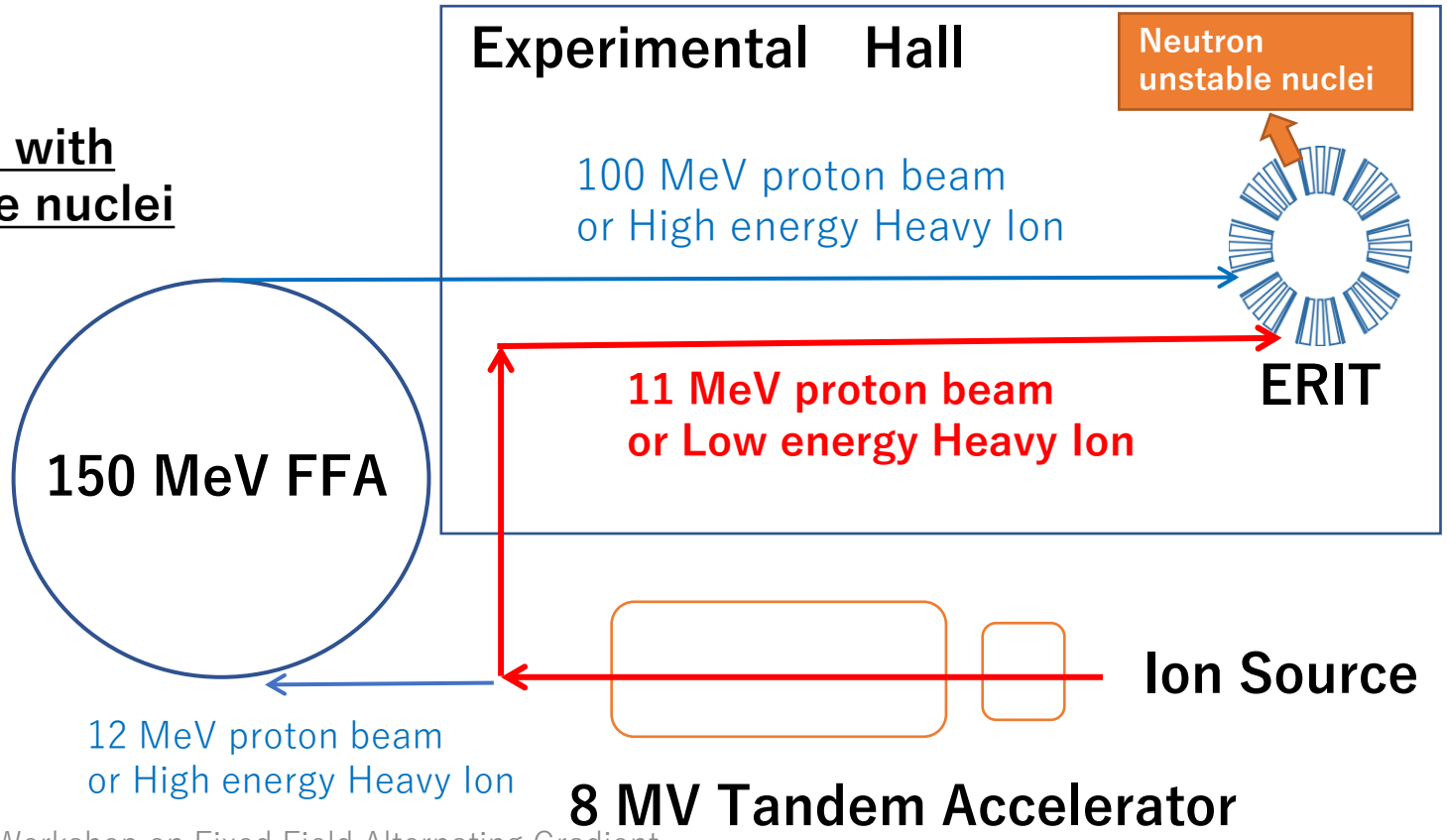
**Stable nuclei Target:**

Heavy nuclei target (Bi ?)

## In the 2nd stage (undecided)

Remodeled ERIT for medium-energy beam

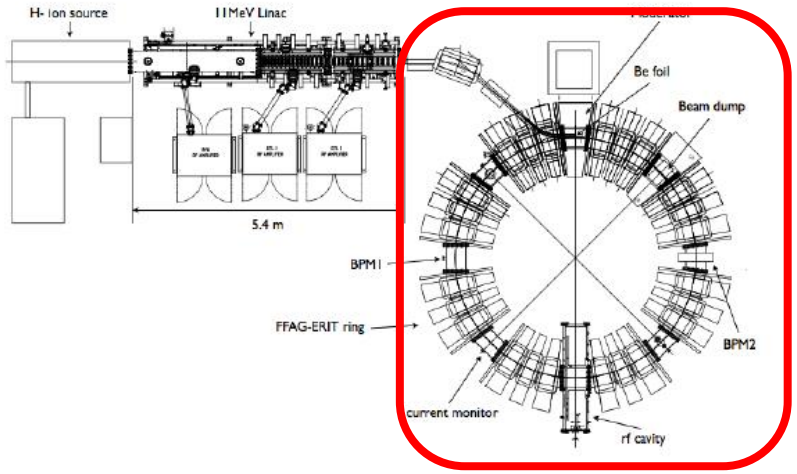
➔ Mr. Takamatsu's presentation



# Disassemble and relocation of FFA-ERIT ring

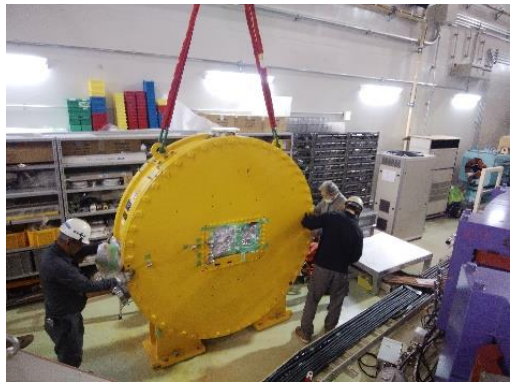
The budget for the relocation of FFA-ERIT ring was approved in last year.
The relocation of the FFA-ERIT ring from Institute for **Integrated Radiation and Nuclear Science of Kyoto University** to **Kyushu University** has been carried out successfully.

**Linac** **FFA-ERIT ring**




relocated

Oct. 2021 Disassemble of ERIT was started



Nov. 2021 RF cavity has been transported to Kyushu University

Mar. 2022 Magnets and vacuum chambers have been transported to Kyushu University

We appreciate all the support of Mori-sensei, Ishi-sensei and all staff of Kyoto University.

# Summary

The present status of the accelerator facility in Kyushu University is reported.

- The constructions of the beam transport line from the FFA to the experimental hall are in progress.
- The test of the beam acceleration of $\mathrm{He}^{1+}$ with the tandem accelerator has been started.
- The relocation of components of the FFA-ERIT ring has been completed.
- The development of a prototype machine of the vertical FFA is in progress.