Galactic Cosmic-Ray SEE Testing in Japan

[RADNEXT] A Guide to Japan for SEE Travelers

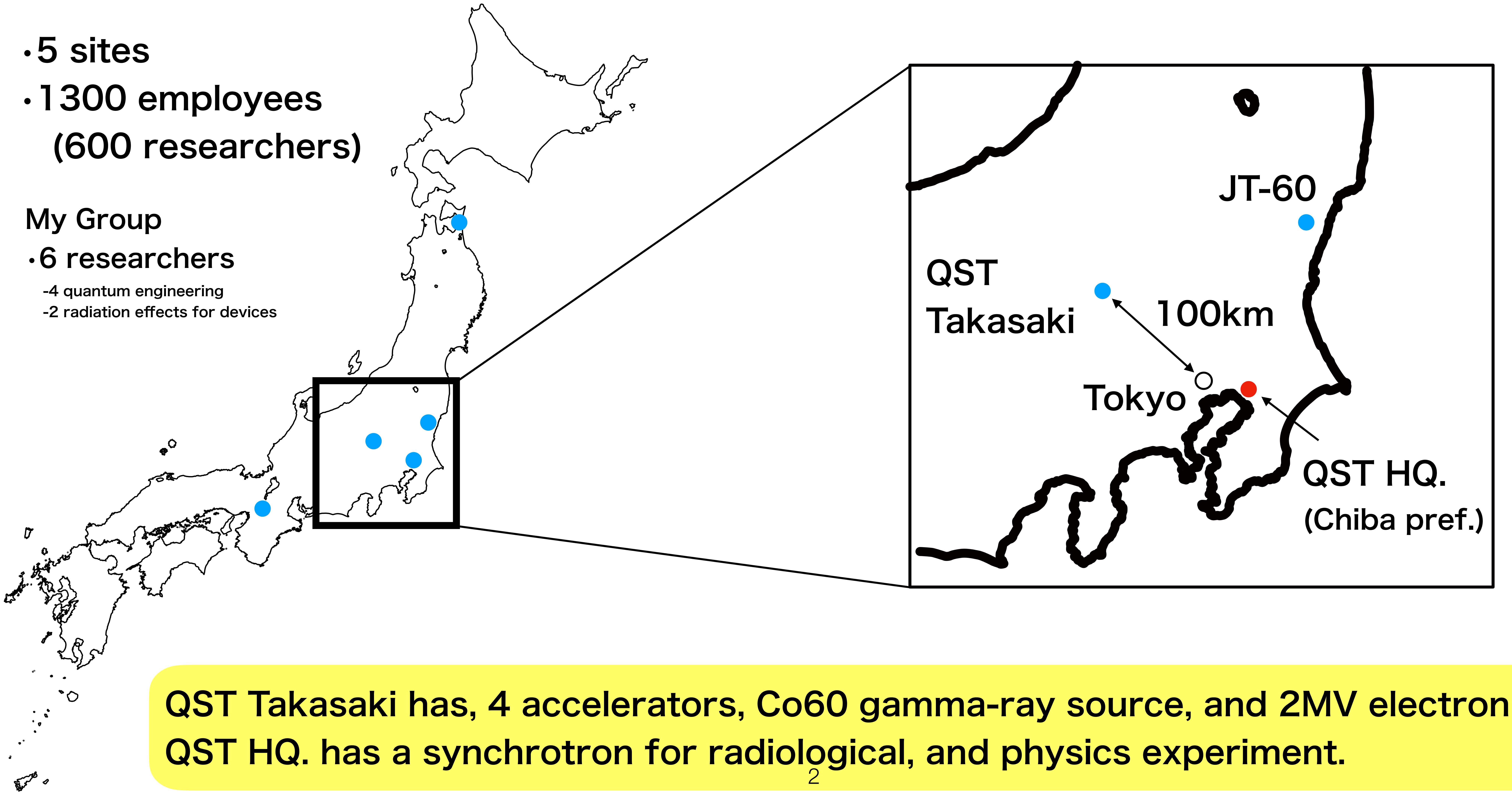
Takahiro MAKINO, QST, JAPAN.   13, Dec. 2022

QST

National Institutes for Quantum Science and Technology

- 5 sites
- 1300 employees
  (600 researchers)

My Group
- 6 researchers
  - -4 quantum engineering
  - -2 radiation effects for devices

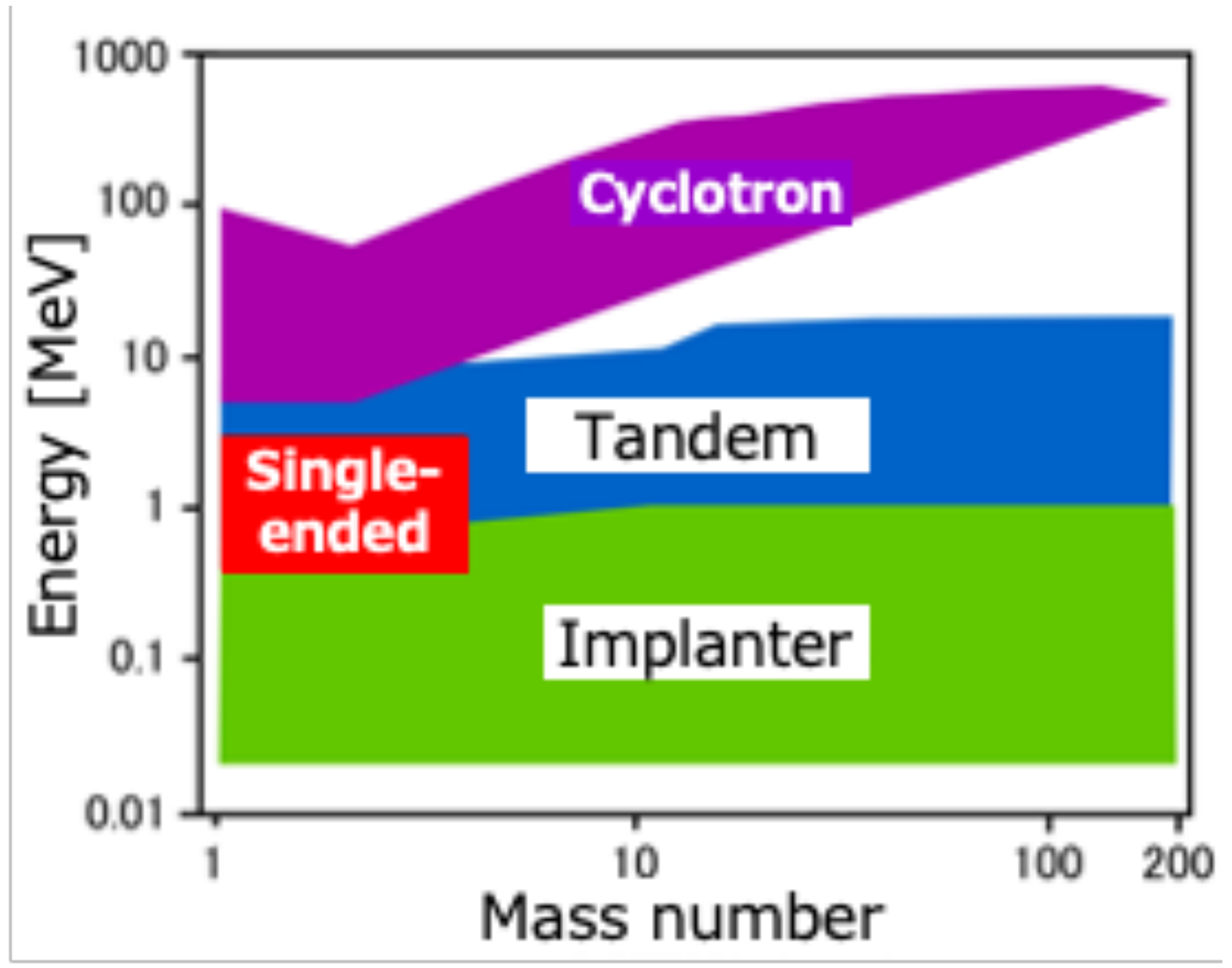


QST Takasaki has, 4 accelerators, Co60 gamma-ray source, and 2MV electron accelerator.
QST HQ. has a synchrotron for radiological, and physics experiment.

Ion Accelerators for SEE testing in QST

at Takasaki site. (**TIARA**: Takasaki Ion Accelerator for Advanced Radiation Application)

- **AVF Cyclotron**
- **3MV Tandem**
- 3MV Single-ended: Micro PIXE*, Proton beam writing**.
- 400kV Ion implanter:
  ion doping for semiconductor wafer, Fusion materials.



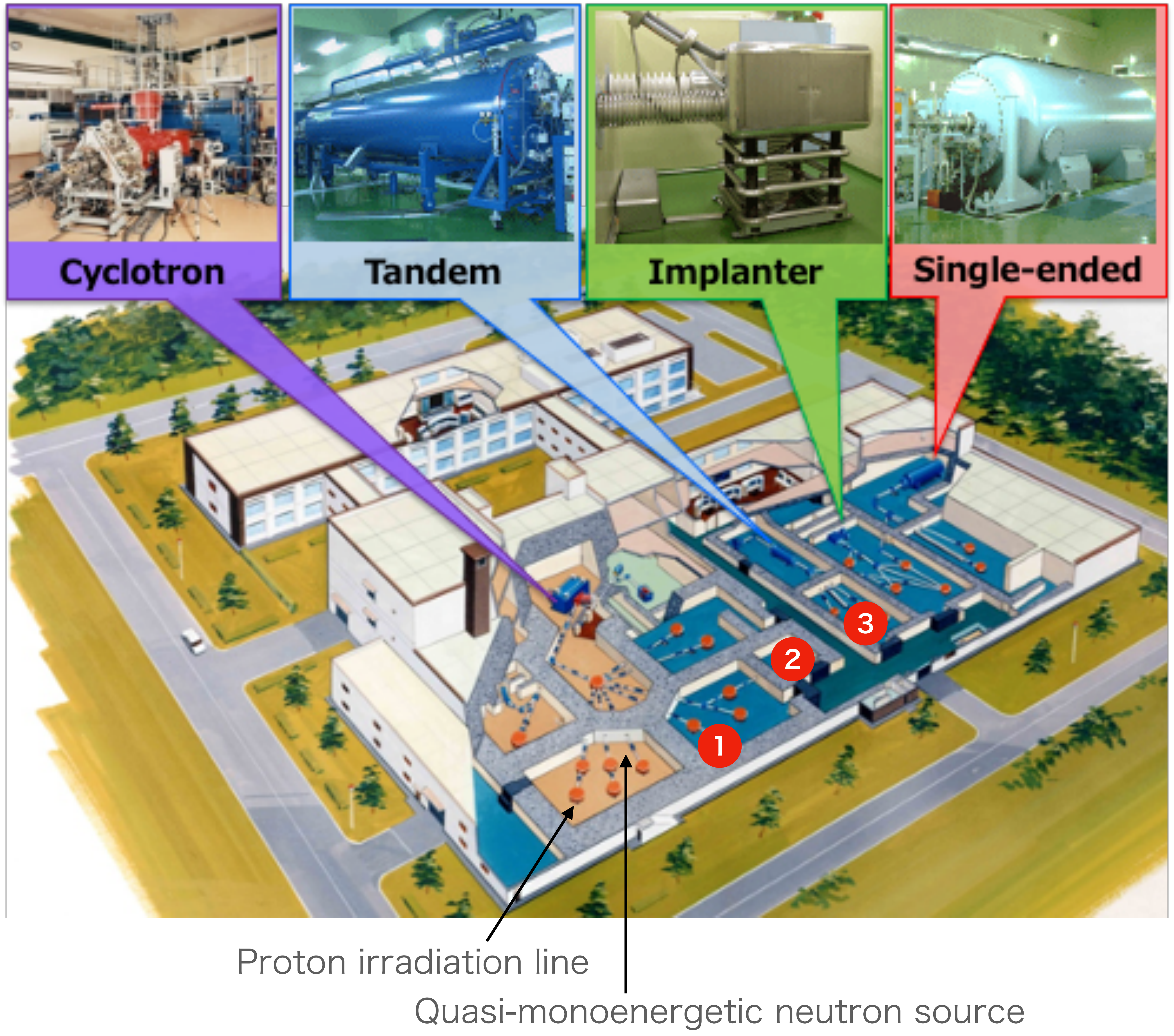
Ion species and energy ranges of TIARA

at HQ. (**HIMAC**: Heavy Ion Medical Accelerator in Chiba)

- **Synchrotron for heavy ion cancer therapy**

Micro PIXE*: Particle Induced X-ray Emission.
Proton beam writing**: Micro area doping by proton micro beam.

Layout of TIARA



Wide variety of beam lines

Cyclotron

1. LSIs and wide area devices & Systems (Commercial device testing)
2. Discrete devices

Tandem

3. Micro Beam Testing

AVF cyclotron (TIARA)

AVF Cyclotron

Available Ions: p^+~Os

Ion	Energy(MeV)
p+	10~65
He	50~107
B	60
C	75~320
N	56~190
O	60~335
Ne	75~350
Si	75~390
Ar	195~520
Fe	200~400
Ni	388
Kr	322~520
Ru	320~505
Xe	450~560
Os	490

Frequently used for SEE test.

Cocktail beam*(M/Q=5)

Ion	Energy (MeV)	LET in Si (MeV·cm²/mg)	Range in Si (μm)
$^{10}B^{2+}$	37		
$^{15}N^{3+}$	56	3.45	52.7
$^{20}Ne^{4+}$	75	6.33	42.5
$^{40}Ar^{8+}$	150	15.3	39.6
$^{84}Kr^{17+}$	322	39.9	40.9
$^{129}Xe^{25+}$	454	69.2	38.7

and

$^{192}Os^{30+}$	490	90	..

Wide LET Range!

*Cocktail beam

A technique to quickly change ion species extracted from the cyclotron. It takes only 10min. to change the ions.

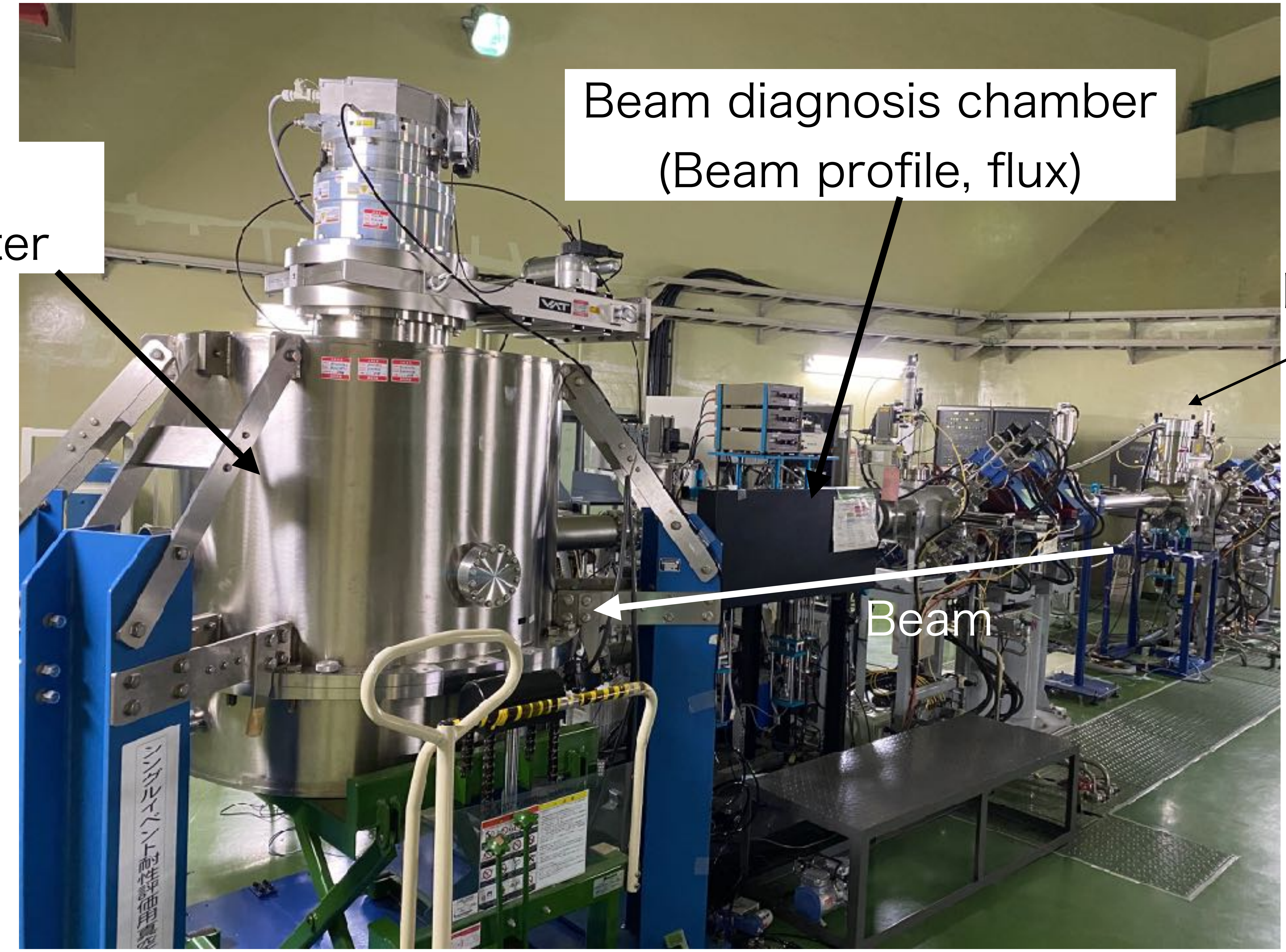
Ions with the same M/Q and velocity can be transferred from an ion source and then injected into a cyclotron.

Actual M/Q is slightly different depending on ion species. Therefore, the cyclotron frequency is also different. So…

Irradiation chamber for

LSIs and wide area devices & Systems (Commercial device testing)

Target Chamber
1m hight x 1m diameter



Beam Scatterer
(Au foil)

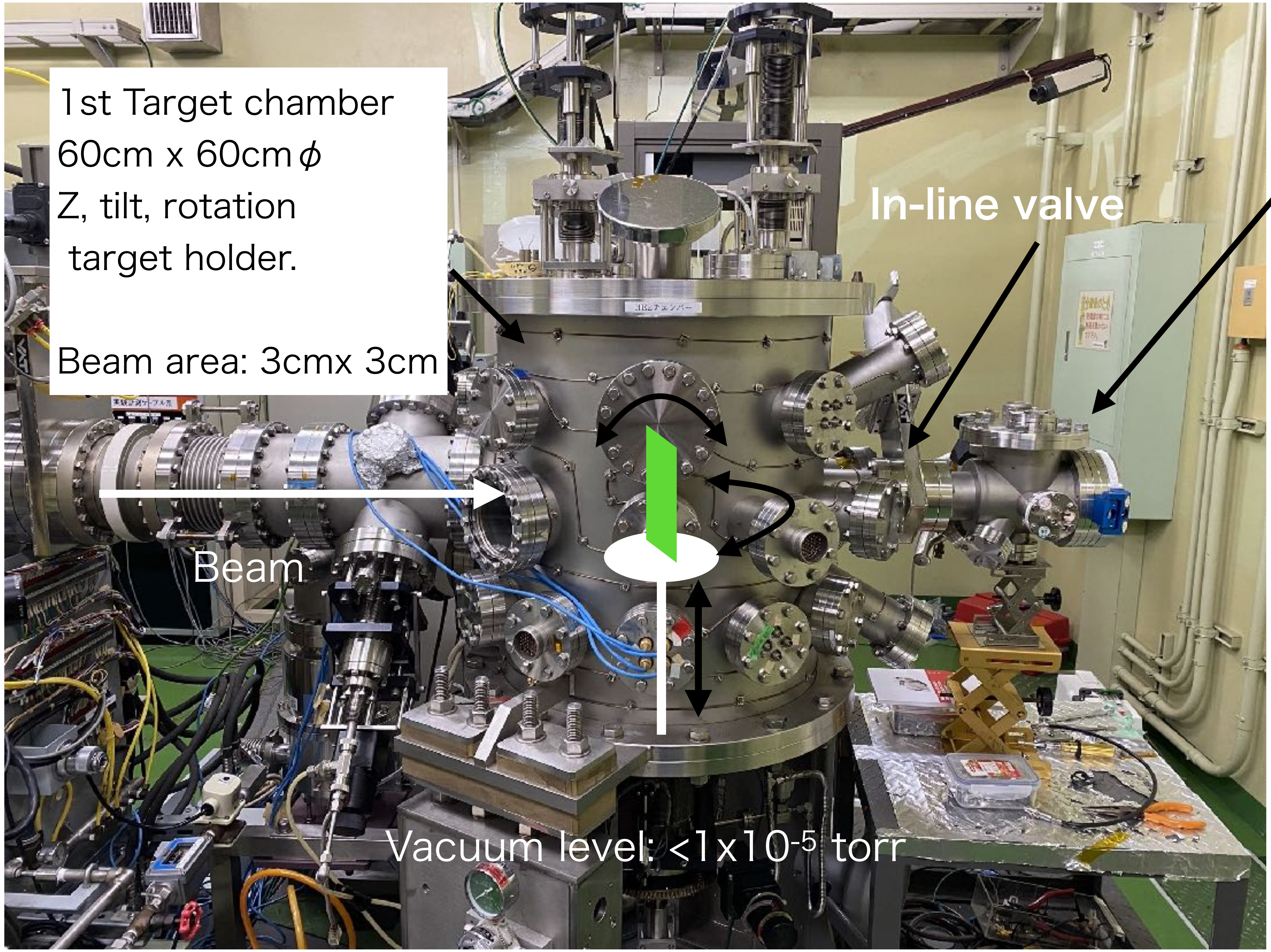
X-Y-Z, tilt, rotation
target holder

Vacuum level:
$<1 \times 10^{-5}$ torr (Interlock of the accelerator)

Beam flux and profile is checked by scintillator+PMT. The profile is controlled to be flat in the 5cm diameter.

Irradiation Chamber for

Discrete devices



2nd Target chamber
15cm x 15cmx 15cm
Beam area: 1cmx1cm

Easy to access to samples, and to vacuum down!

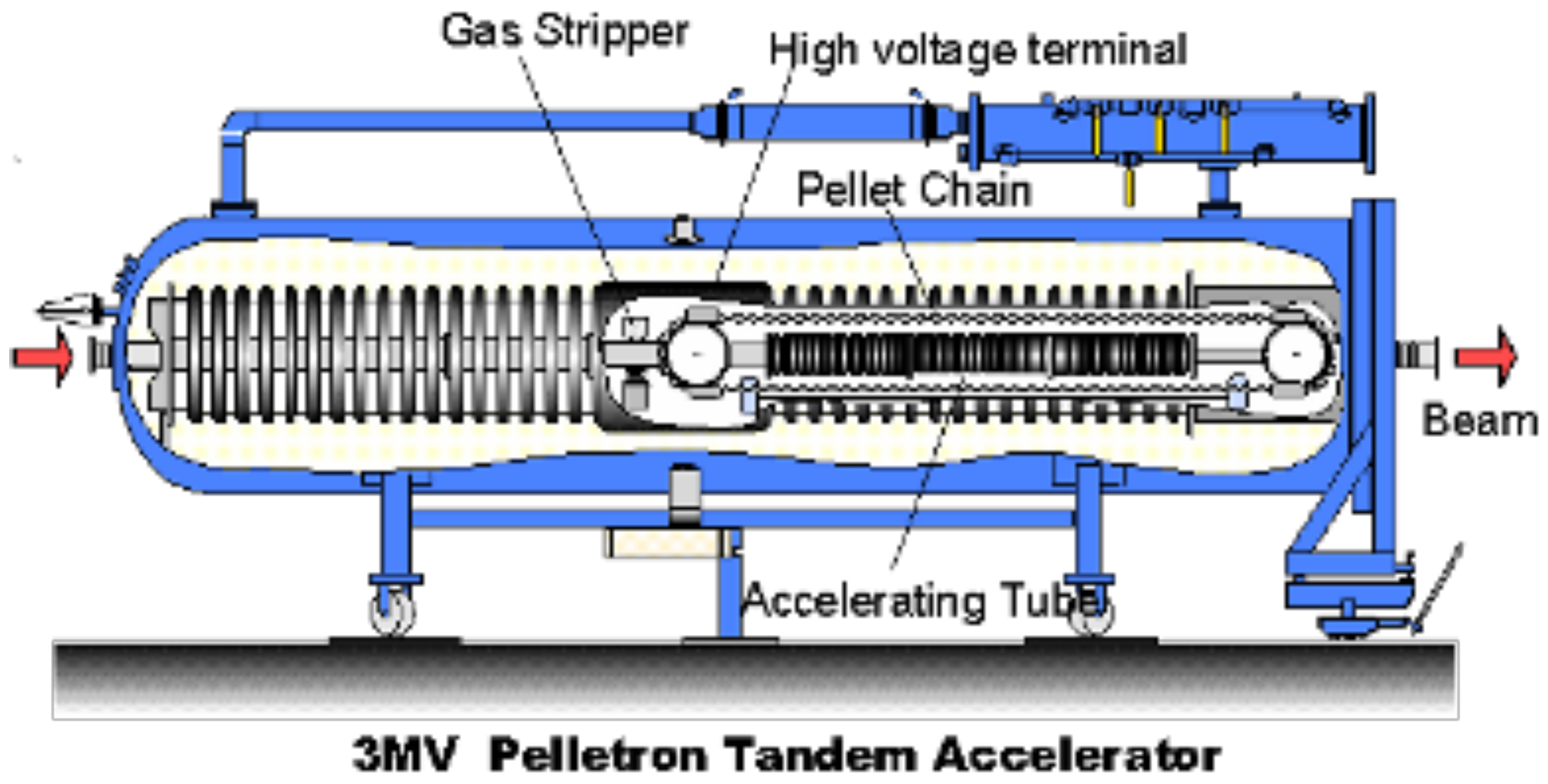
IO:

27pin connector, BNC-Coaxial, USB, SMA coaxial, SHV Coaxial, and 2.92mm-Connector* are available.

Beam flux: 10~5x10^4 ion/cm^2/s
(Limited by SSD measurement)

*2.92mm-Connector: 50Ω, DC~40GHz
for High frequency wave measurement as SETs.

3MV Tandem Accelerator (TIARA)



Available Ions: p^+~Au

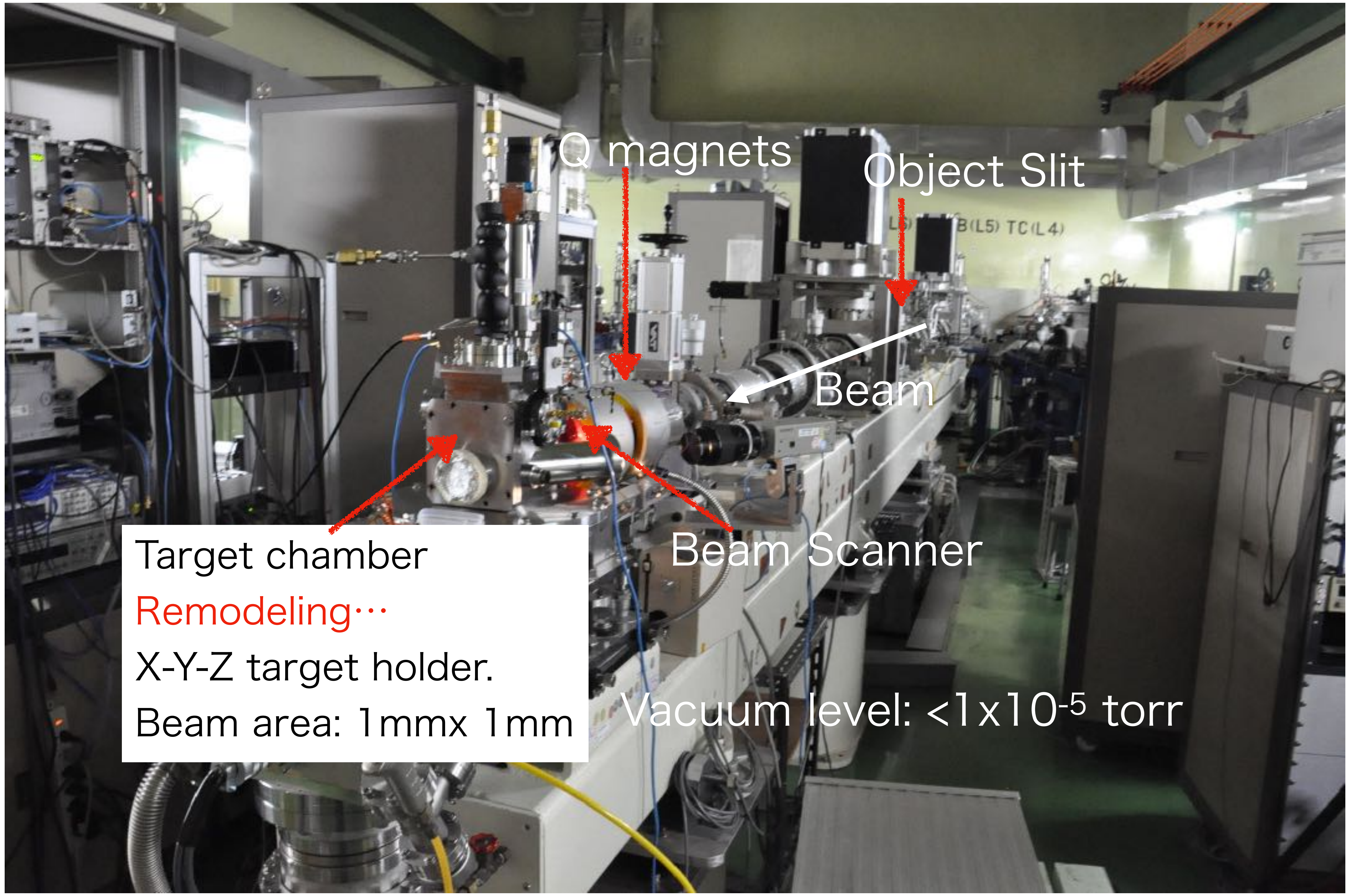
Typically used for SEE testing, due to easy to make Micro-beam.

Ion	Energy(MeV)
He	0.8~9
C	0.8~18
O	0.8~18
Ni	0.8~18

Negative charged ion accelerated by the first accelerating tube.
The accelerated particles to the HV terminal are positive charged by a gas stripper, and accelerated again by the second accelerating tube.

Irradiation Chamber for

Micro Beam Testing



Under renewal ~FY. 2022

- Focusing time will be short
- Beam diameter: <1μm

- IO:

  BNC-Coaxial, USB, SMA coaxial, SHV Coaxial, and 2.92mm-Connector* will be available.

- Beam: 1~ count at a point.

Measurement, and irradiation system specification is not fixed yet.

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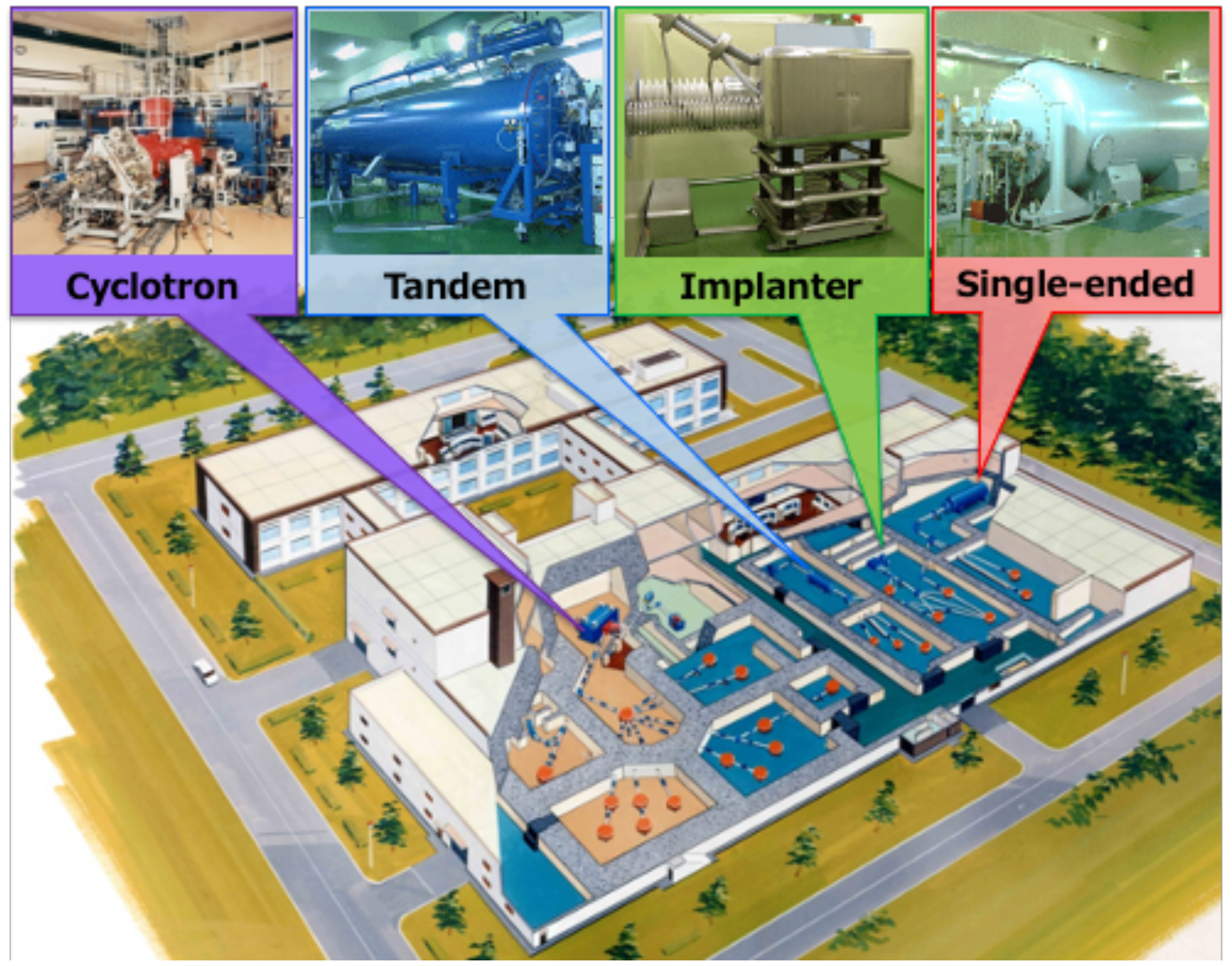
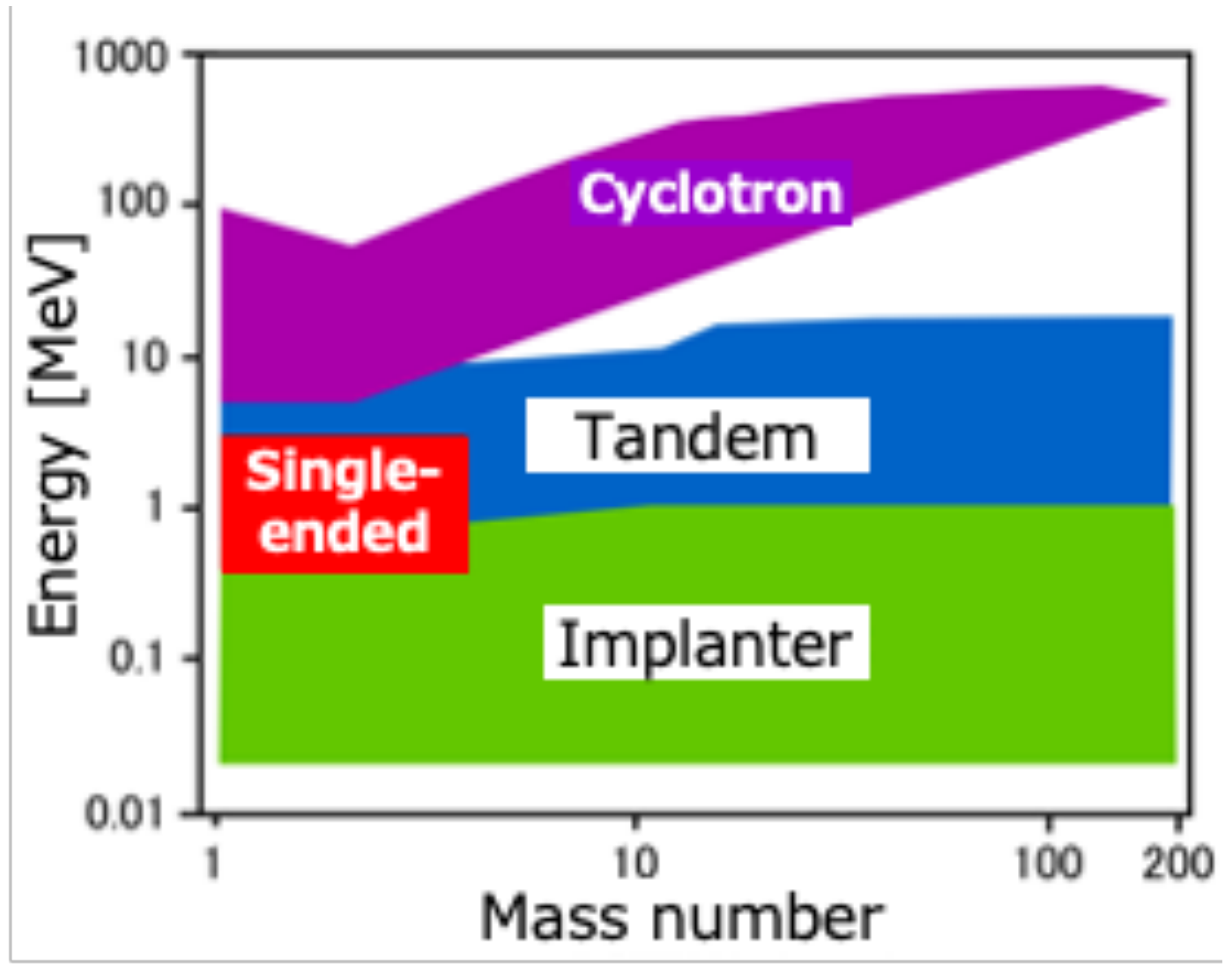
- 400kV Ion implanter



Design of TIARA



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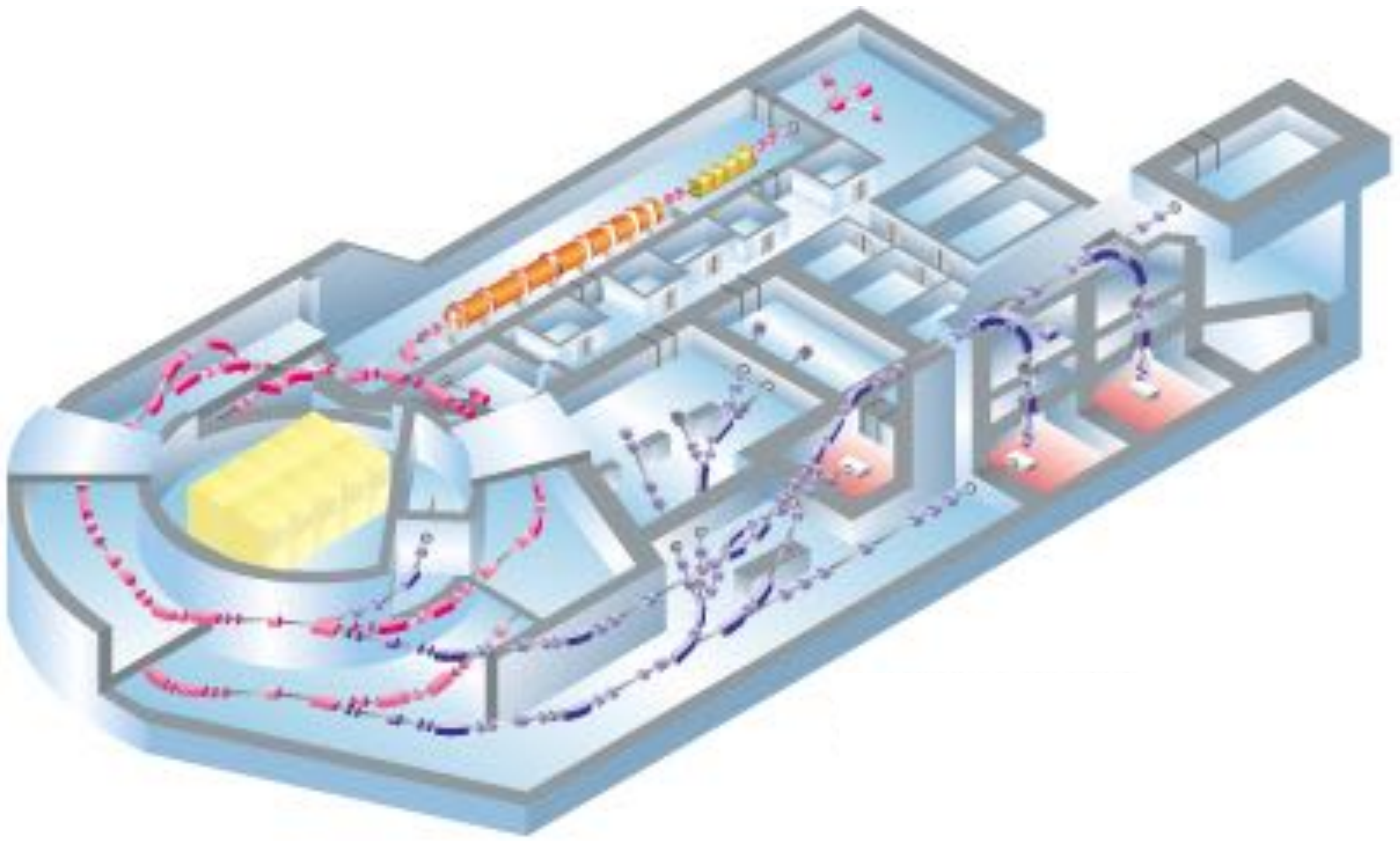
Synchrotron in Chiba (HIMAC)



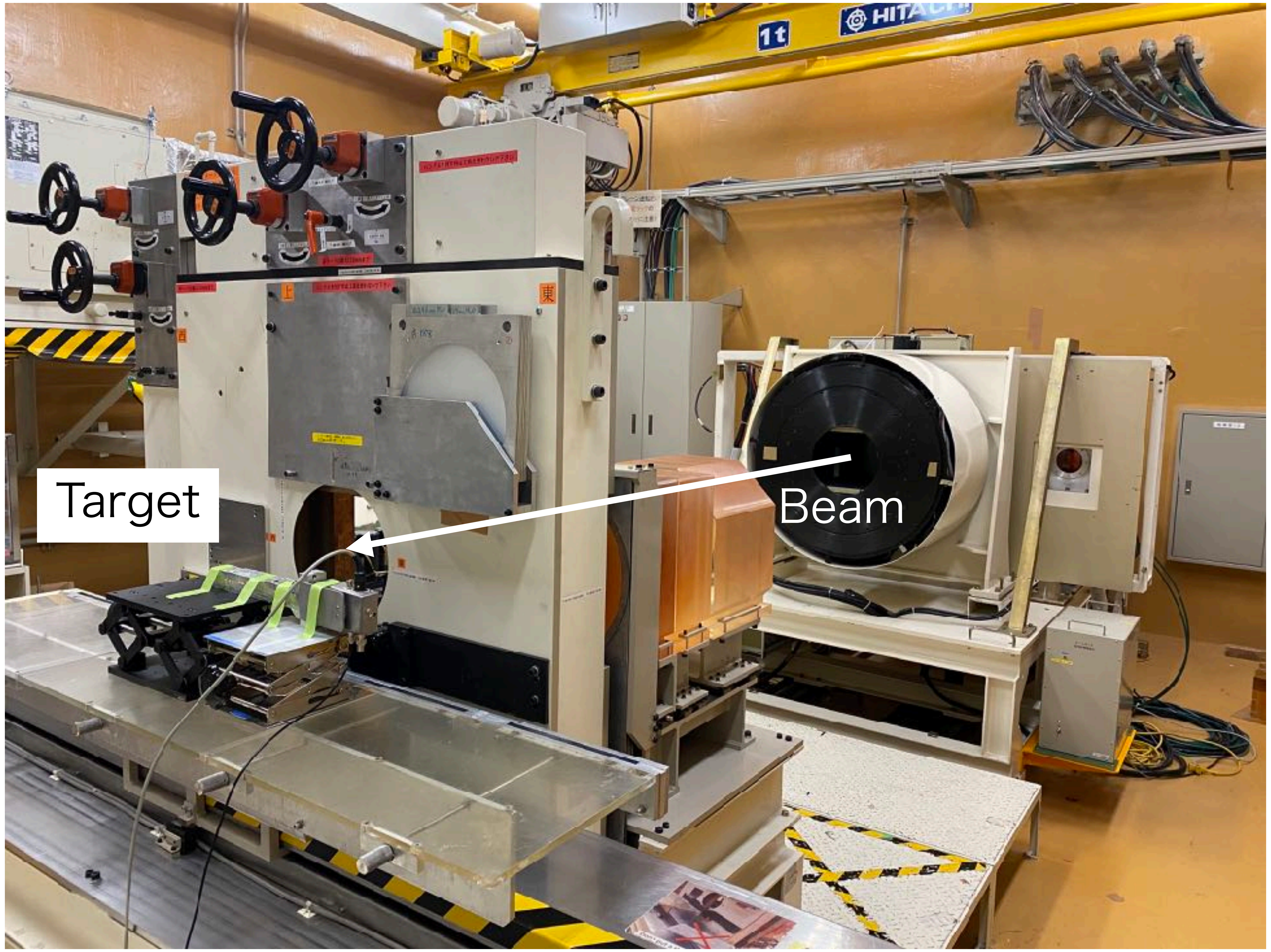
Operating for cancer therapy in the daytime.

Ion	Energy(MeV/u)
He	100~230
C	100~430
N	100~430
O	100~430
Ne	100~600
Si	100~800
Ar	290~650
Kr	400 (33GeV total)
Xe	290 (38GeV total)

LET in SiC	Energy at DUT	Range in SiC
8	27.4 GeV	~10mm
10	25.9 GeV	

after the therapy, the beam is provided to biological, and physics experiments.

Irradiation area



Irradiation in the air. Easy to setup.

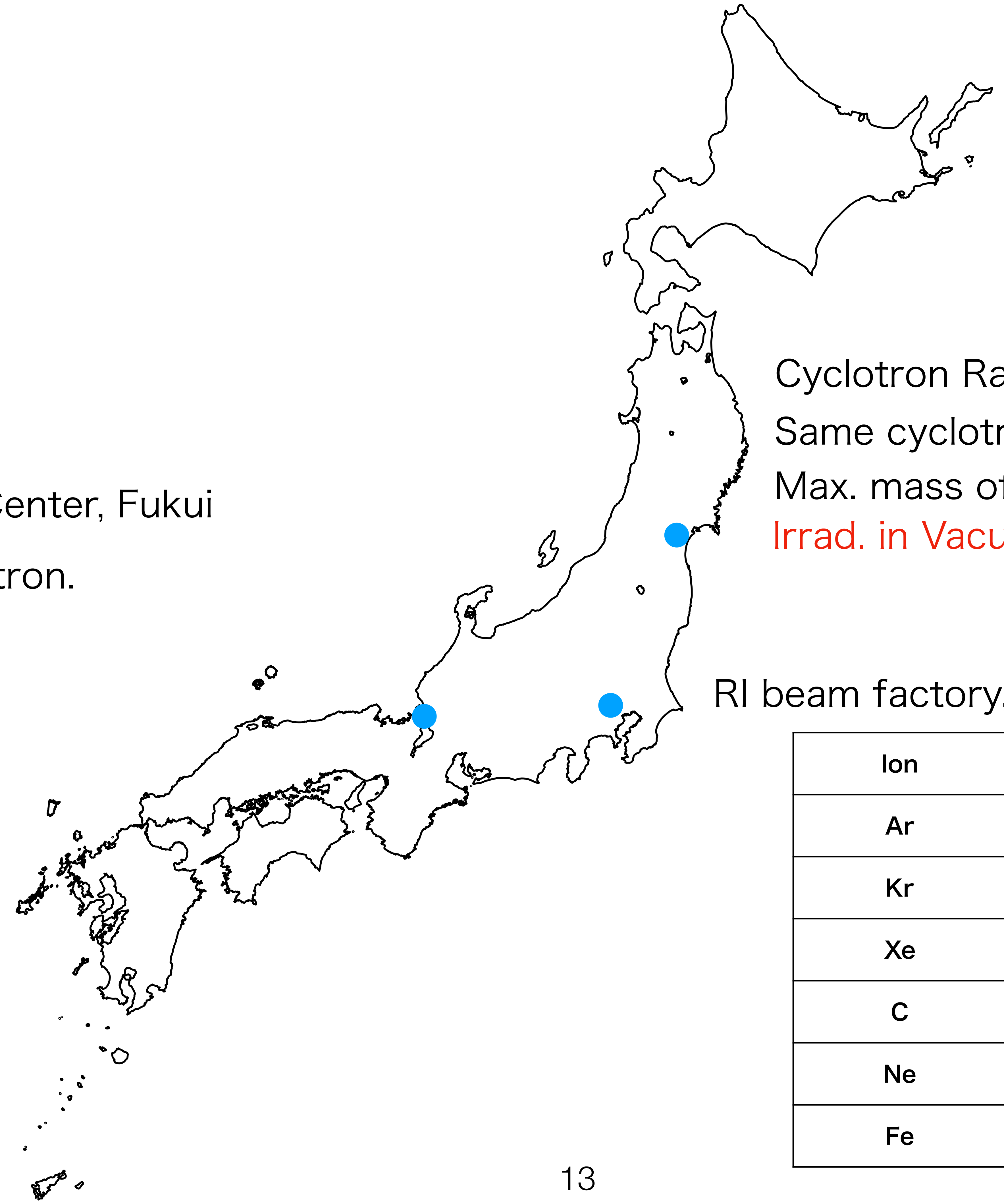
Beam diameter is 6 cm.

Si-SSD or Scintillator+PMT
are used for beam measurement.

Beam flux*: 10~5x10^7 ion/cm^2/s.

*The beam of synchrotrons are extracted and provided cyclic. e.g., 1s beam every 5s.
Flux is estimated as a average flux in few min.

Other heavy ion irradiation facilities for SEE testing



The Wakasa-Wan Energy Research Center, Fukui

5MV Tandem, and 200MeV Synchrotron.
Heaviest ion is Carbon.
Irrad. in Vacuum.

Cyclotron Radio-isotope Center, Tohoku Univ., Sendai
Same cyclotron as TIARA,
Max. mass of ion and energy are Kr 400MeV.
Irrad. in Vacuum.

RI beam factory, RIKEN, Saitama

Ion	Energy(MeV/u)
Ar	95
Kr	70
Xe	10.75 or 39
C	135
Ne	135
Fe	90

Irrad. in the Air.

SEE researches in QST

- **Single Event Effects**

Ion induced temporary function error, and/or malfunction of semiconductor devices.

- Single Event Upset (SEU)
  - Onoda et al., IEEE TNS, vol. 59, no. 4, (2012) 4H-SiC, Microbeam
  - + many collaboration works with prof. Daisuke KOBAYASHI.
- Single Event Transient (SET)
  - Makino et al., IEEE TNS, (2009) Si SOI CMOS, Cyclotron
  - Onoda et al., IEEE TNS, (2009) 4H-SiC MESFET, Microbeam
  - Onoda et al., IEEE TNS (2013) GaN HEMT, Microbeam
  - Makino et al., QuBS (2019). 0.2μm FD-SOI, Cyclotron
  - + many collaboration works with prof. Daisuke KOBAYASHI.
- Single Event Burnout (SEB)
  - Makino et al., IEEE TNS, vol. 60, no. 4, (2013) 4H-SiC SBD, Cyclotron
  - Makino et al., presented in conferences, 4H-SiC MOSFET, Synchrotron
- Single Event Gate Rupture (SEGR)
  - Deki et al., NIM B, 319, (2014), , Cyclotron & Microbeam

and More.

Conclusion

- QST has many accelerator and beam lines specialized for SEE testing.
- These accelerators cover wide LET range, and ion projectile range.
- Irradiation area: Micro ~6cm diameter.
- QST works for all SEE mode by using own accelerators.
- QST has many collaboration works with Daisuke.

We welcome you all to visit Japan and QST.