

Current status of proton and neutron irradiation beamlines at the RFT-30 H⁻ cyclotron facility

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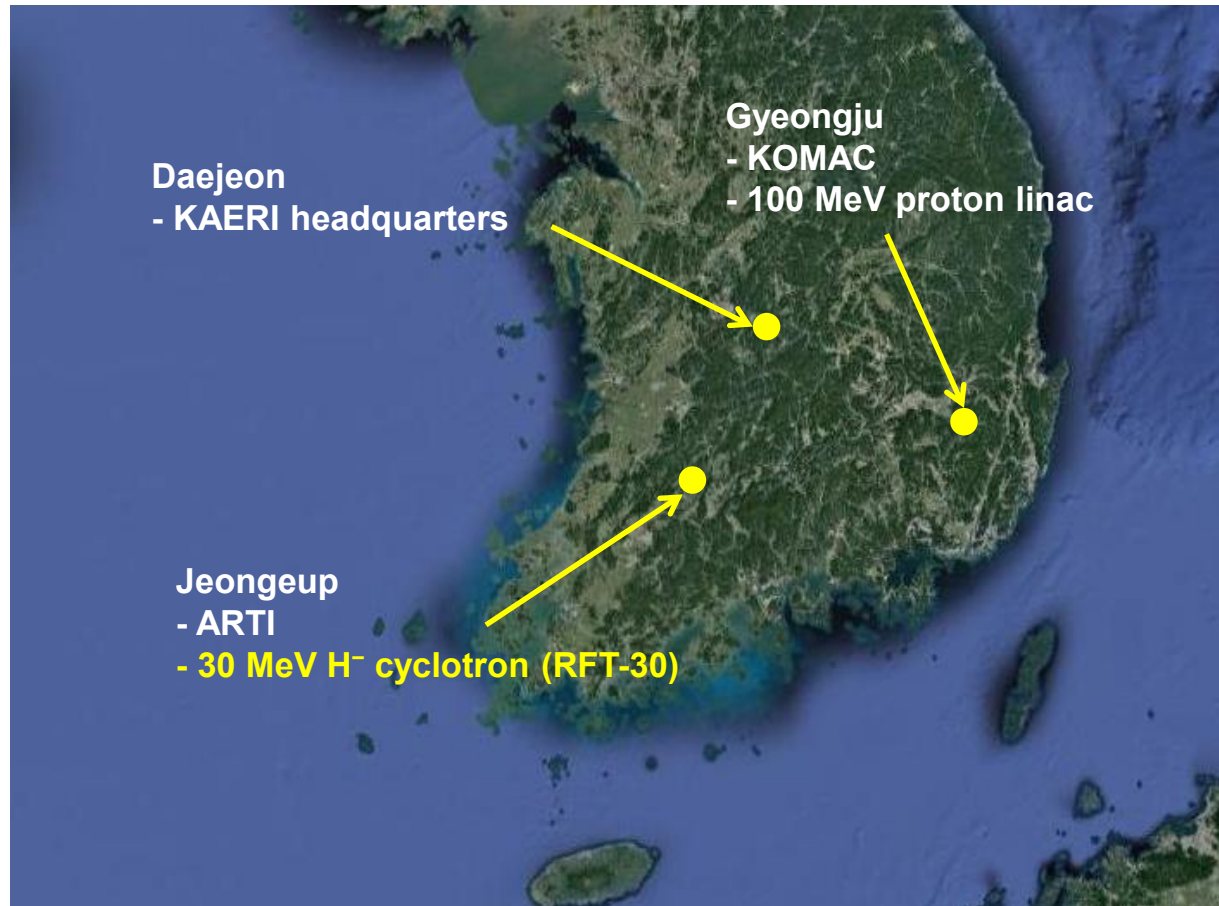
Advanced Radiation Technology Institute, Korea Atomic Energy Research Institute

Outline

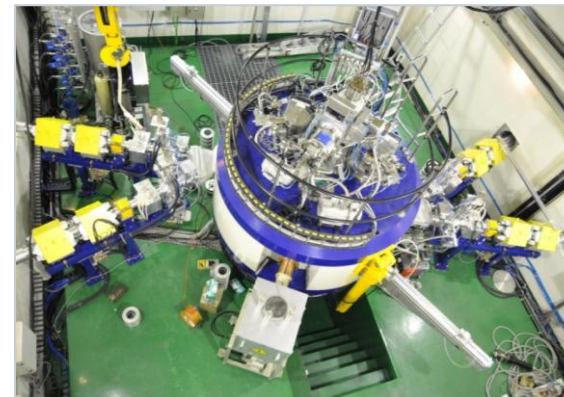
- 1. The machine – accelerate negative hydrogen**
2. Beam delivery – one beamline at a time
3. Proton irradiation – from high-current spots to low-current areas
4. Neutron irradiation – beryllium targets and imaging
5. Summary and outlook

RFT-30 facility

Two proton accelerators – a 30 MeV RFT-30 cyclotron at ARTI and the 100 MeV linac at KOMAC



ARTI, KAERI (Jeongeup)



RFT-30 cyclotron, installed in 2012

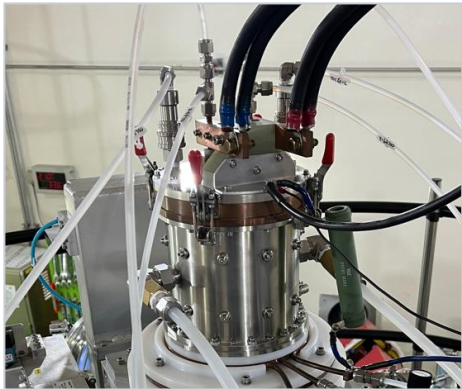
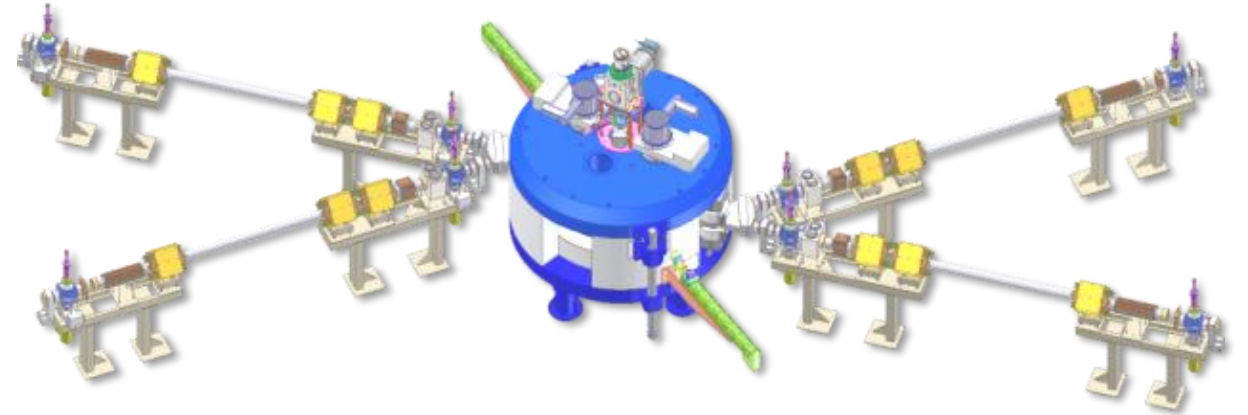


Target station for RI production

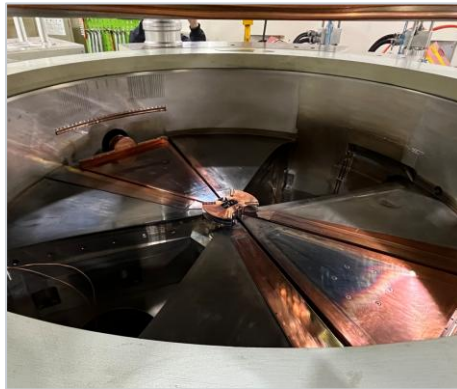
The machine

An H^- beam is accelerated, stripped to protons, and sent to one of four beamlines

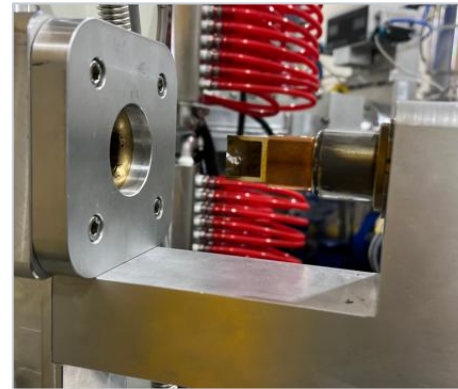
Proton energy	15–30 MeV
Extracted current	up to 200 μA
Beamlines	4 (3 isotope production, 1 irradiation)
Vacuum	2 cryopumps
Magnet	Isochronous AVF type
RF system	4th harmonics, two dees
LEBT system	External ion source and spiral inflector



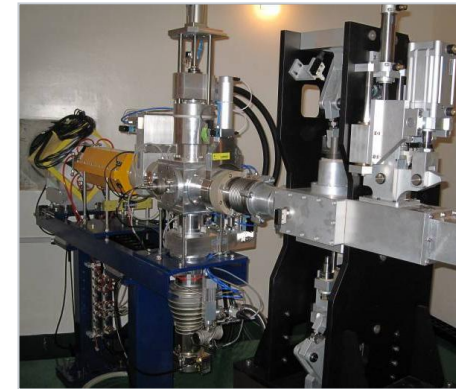
H^- ion source



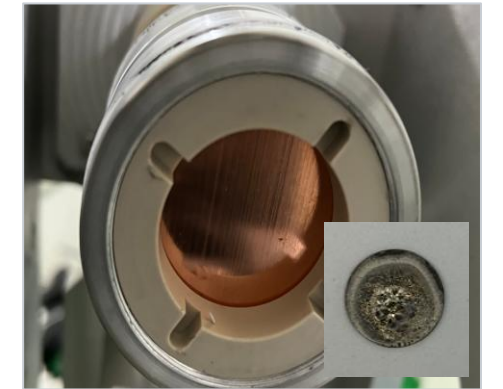
AVF acceleration



Stripping extraction



Beamline



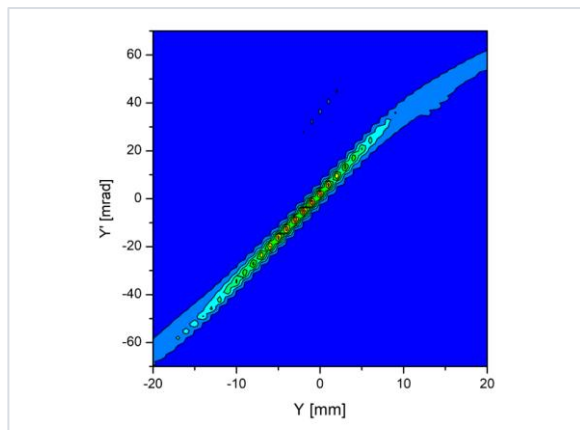
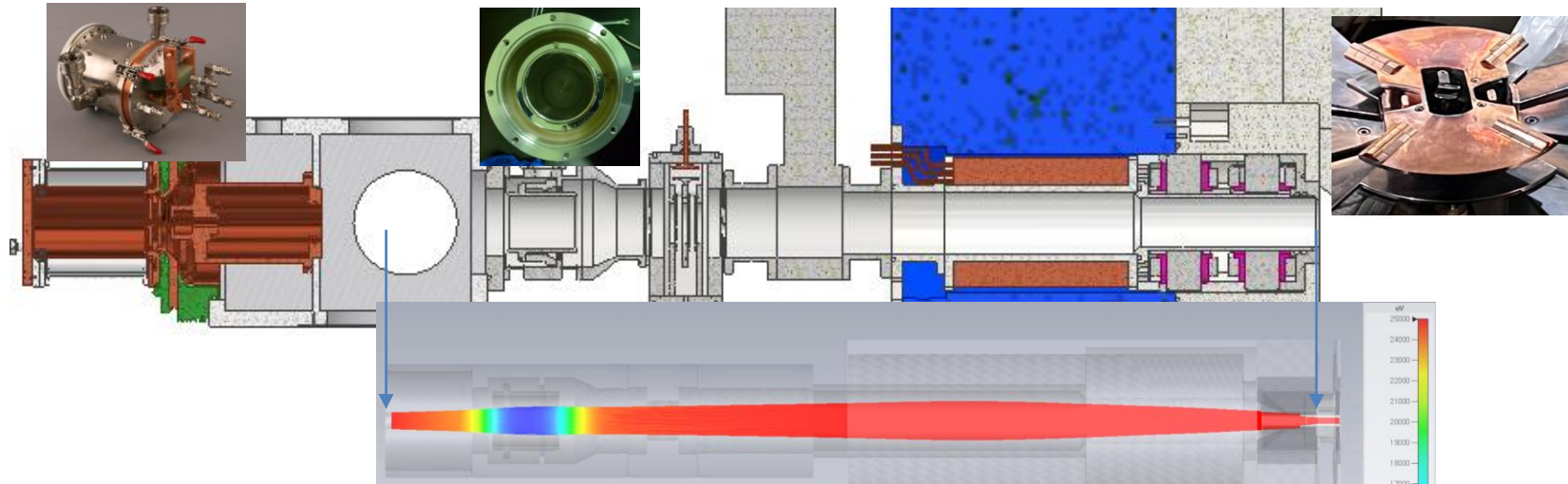
Target



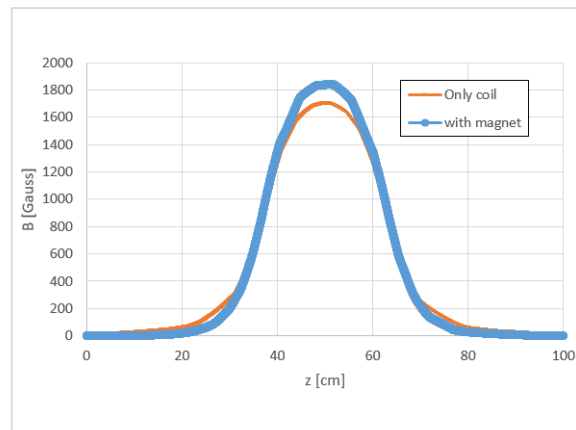
H⁻ ion source and injection

An external H⁻ source injects beam into the cyclotron through a solenoid LEBT and a spiral inflector

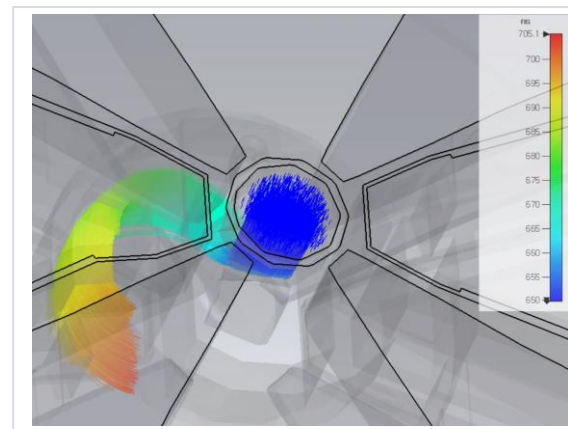
Multicusp H ⁻ source	25 keV, 0–3 mA
RMS emittance	~ 24 mm mrad
Einzel lens electrode	one-cylinder, –11 kV
Solenoid lens	142 A, up to 1.8 kGauss
Spiral inflector	12.5 / –7.8 kV
RF buncher gain	~ 1.8 (for beam current)
Extraction slot	8 × 16 mm
Inflected beam size	5 × 10 mm



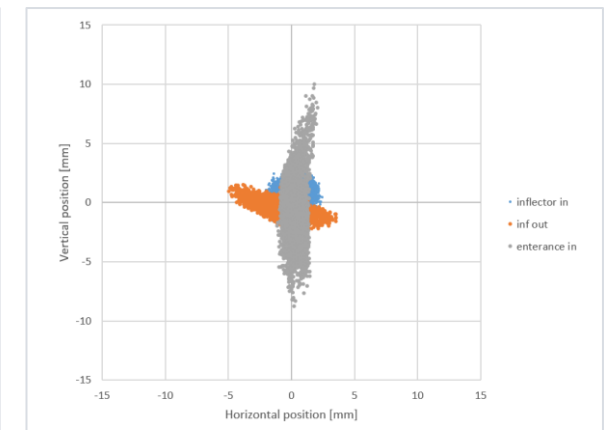
Vertical phase space at the ion source exit



Solenoid field along the beam axis



Beam trajectory through the spiral inflector

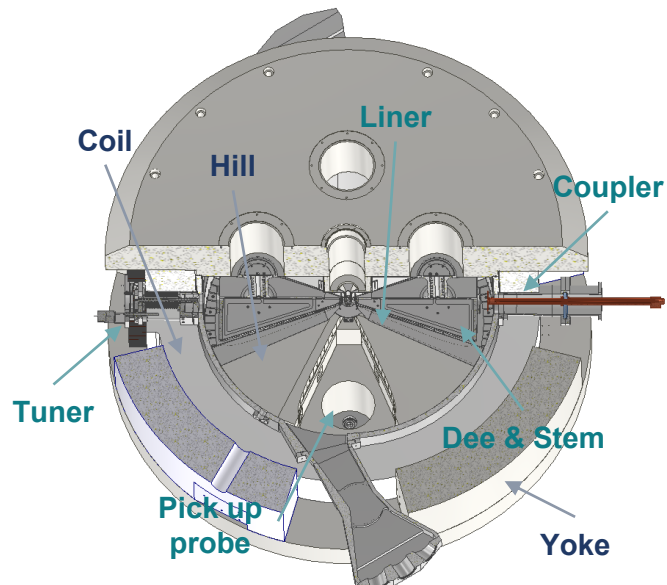


Beam distribution at the inflector entrance and exit

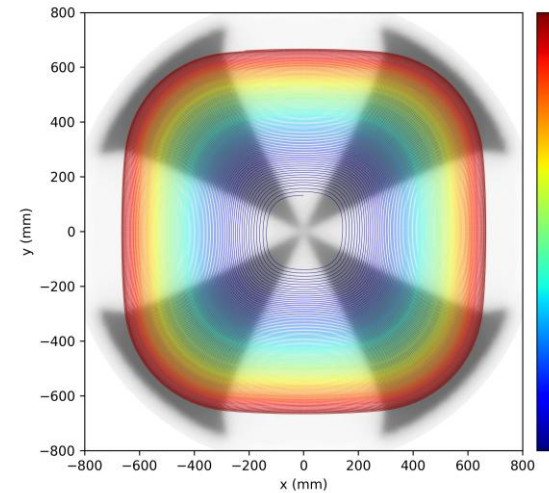
Acceleration

An AVF magnet and a fixed-frequency cavity accelerate the beam on the fourth harmonic

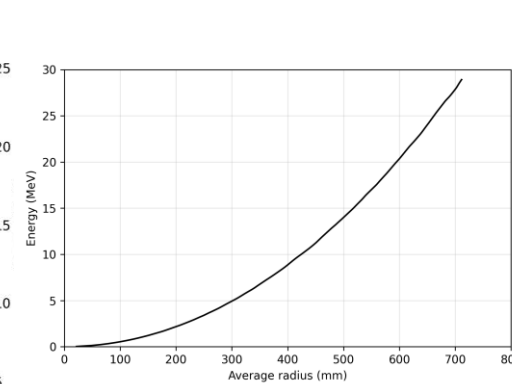
Pole / yoke radius	810 / 1350 mm
Hill / valley gap	30 / 620 mm
Field, hill / valley	19 / 2 kG
RF frequency	63.96 MHz
Harmonic	4 th
Dee voltage	~ 58 kV



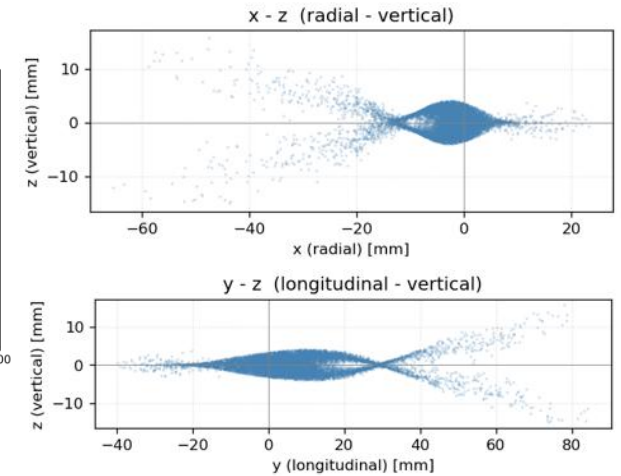
Magnet and cavity structure



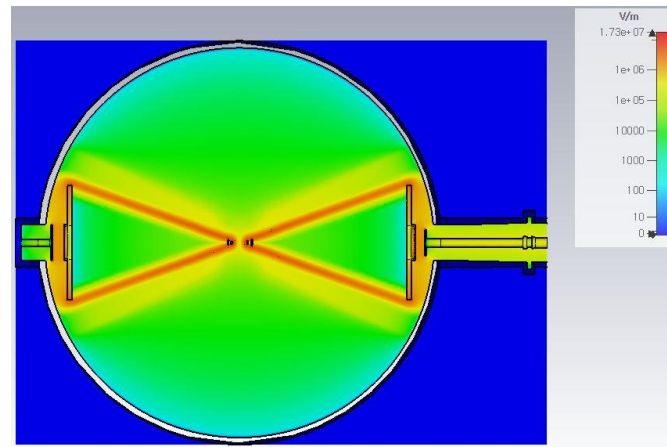
Single-particle trajectory in the magnetic field



Simulated beam energy vs. radius



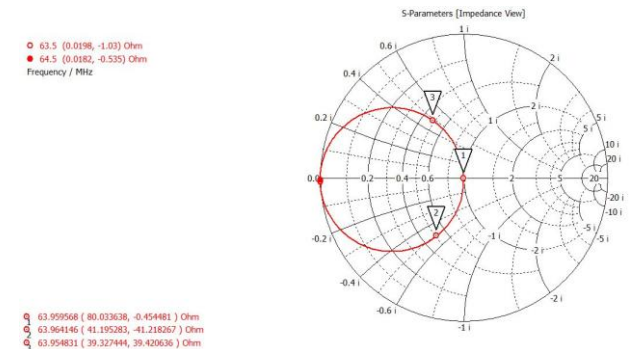
Beam distribution at the final turn



Electric field in the cavity



Power coupler

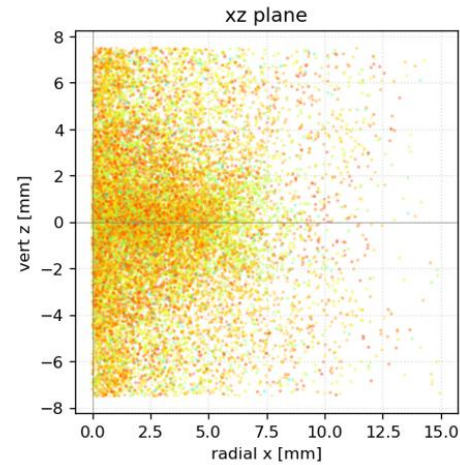


Coupling measured on a Smith chart

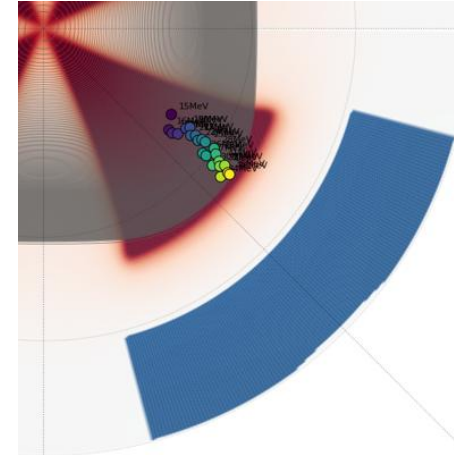
Extraction

The foil radius determines the beam energy and a 30° switching magnet selects one beamline

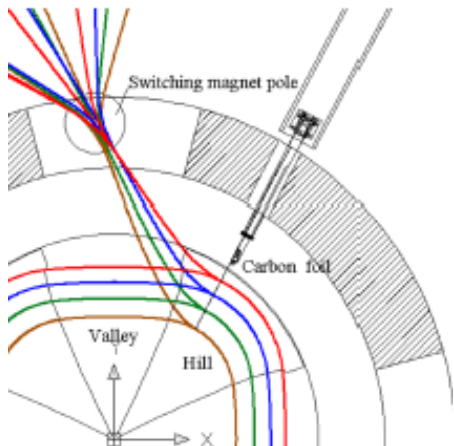
Stripping foil	carbon, 100 $\mu\text{g}/\text{cm}^2$
Foil thickness	$\approx 0.5 \mu\text{m}$
Conversion	$\text{H}^- \rightarrow \text{proton}$
Energy	15–30 MeV (foil radius)
Stripping area	15 × 15 mm
Foil motion	insert / tilting
Switching magnet	30°, ~ 15 kGauss



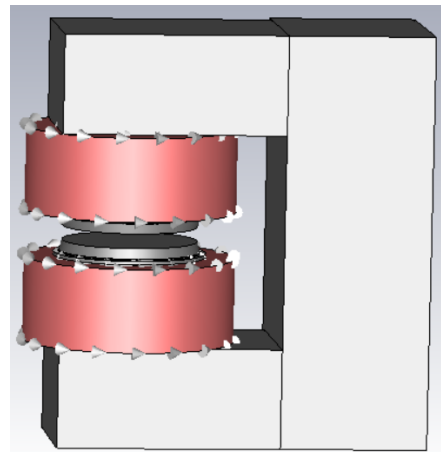
Simulated stripping distribution



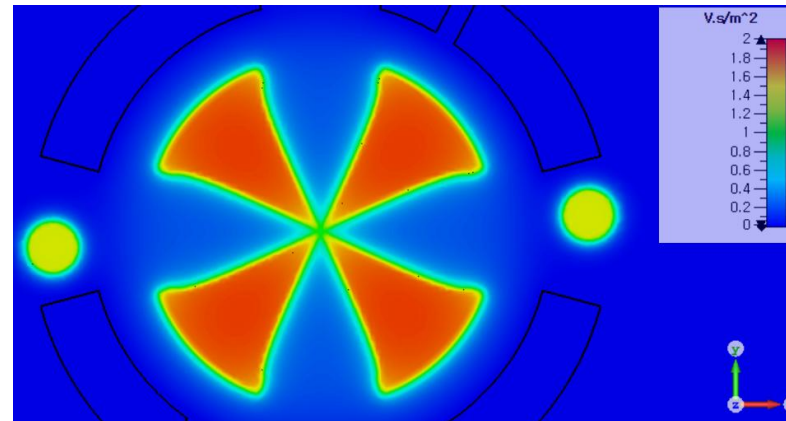
Simulated foil position



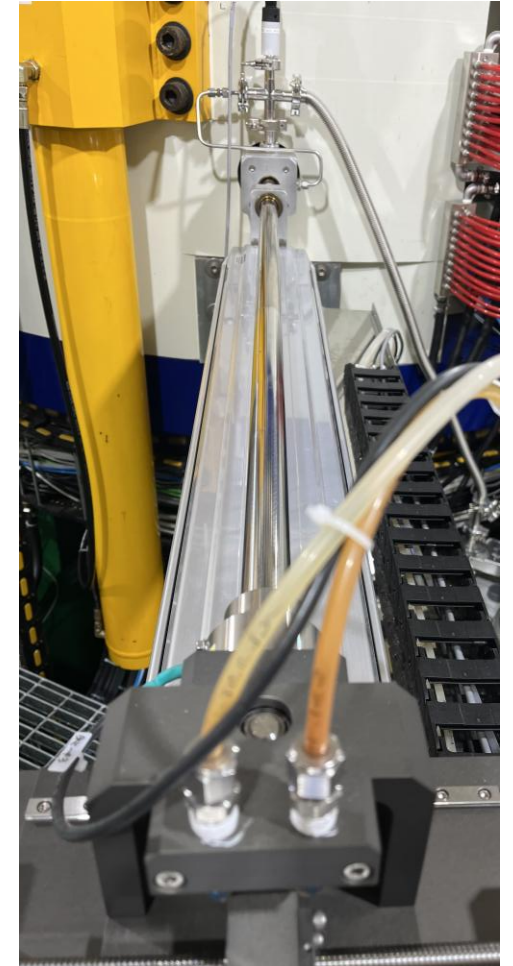
Stripper foil and switching magnet



Switching magnet model



Field distribution in the switching magnet

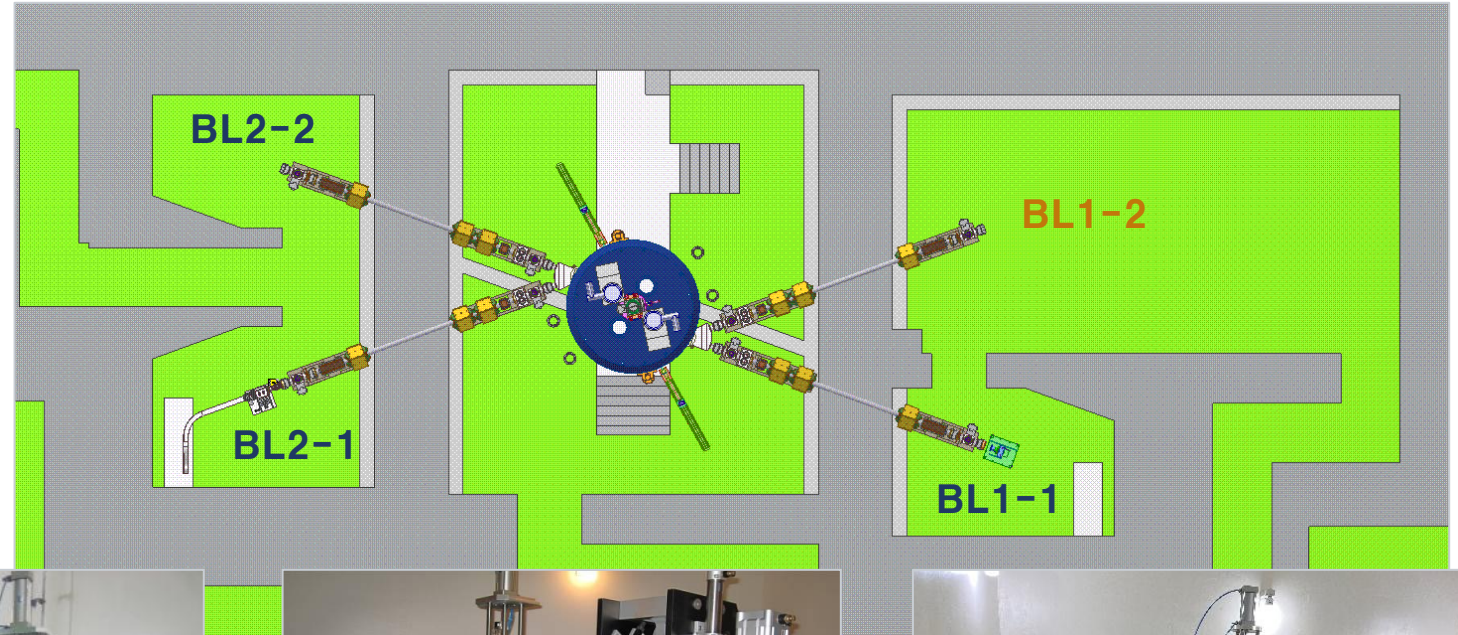


Stripper foil system

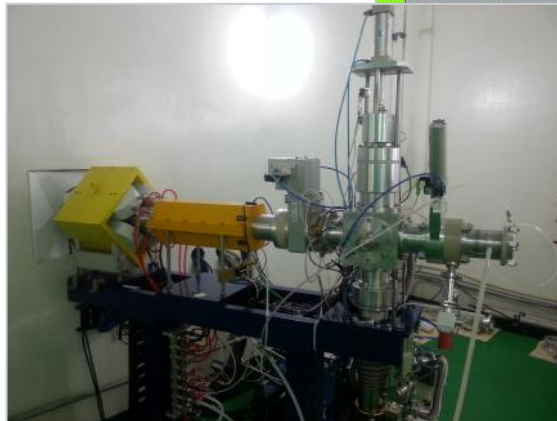
Four beamlines

Three lines produce isotopes, one is dedicated to proton and neutron irradiation

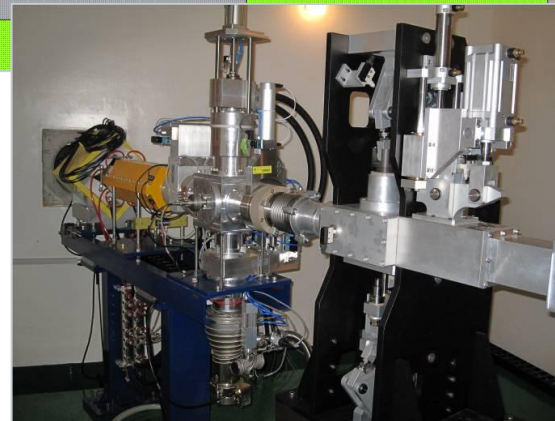
BL 1-1	RI target multi-loading (Zr-89)
BL 1-2	proton and neutron irradiation
BL 2-1	electroplating (Co-57, Cu-64, Cu-67)
BL 2-2	coin target, He cooling (Ge-68)
Operation	one beamline at a time



BL 1-1



BL 1-2



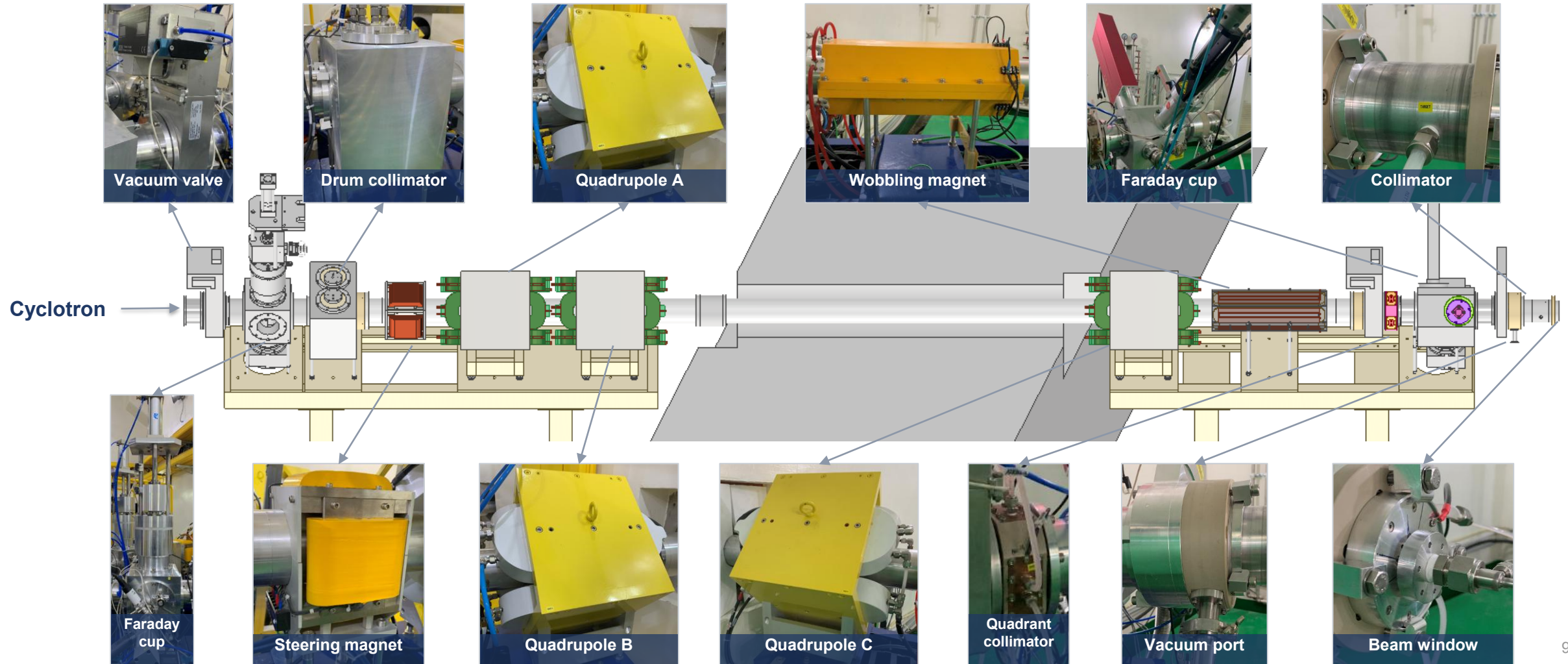
BL 2-1



BL 2-2

The irradiation beamline

Focusing, steering and diagnostics all within six meters



Radioisotope production

Three target stations in routine operation

Focus

Ge-68 production

Routine

Zr-89

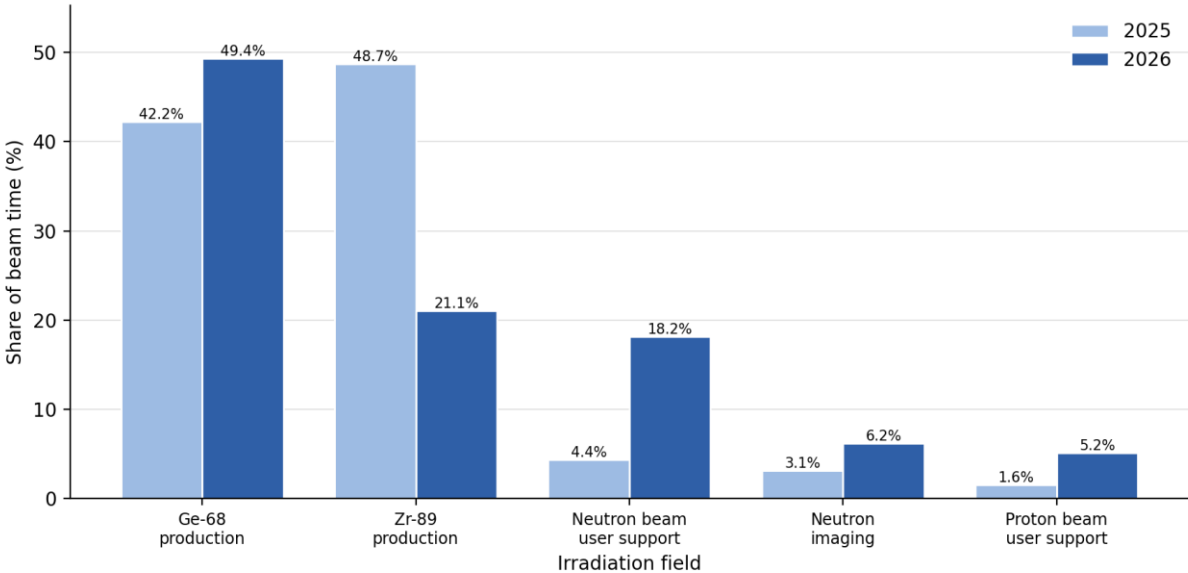
Target handling

remote control

Purification

automatic system

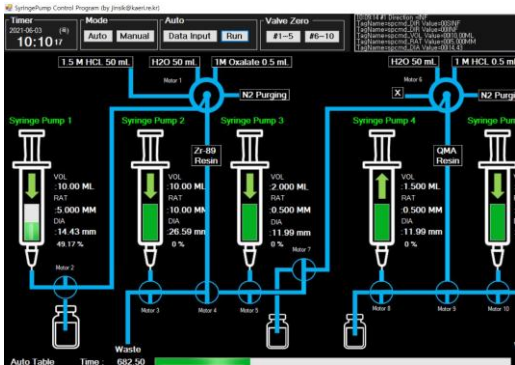
Nuclide	Nuclear Reactions	Yield (mCi/batch)	Application
Zr-89	$^{89}\text{Y} (p, n) ^{89}\text{Zr}$	200	PET Imaging
Sc-44	$^{44}\text{Ca} (p, n) ^{44}\text{Sc}$	210	PET Imaging
Ge-68	$\text{natGa} (p, \alpha) ^{68}\text{Ge}$	80	$^{68}\text{Ge}/^{68}\text{Ga}$ generator Calibration source
Cu-67	$^{70}\text{Zn} (p, \alpha) ^{67}\text{Cu}$	50	SPECT, Therapy
Co-57	$^{60}\text{Ni} (p, \alpha) ^{57}\text{Co}$	10	Calibration source, SPECT Imaging



Hot cell for RI handling



Automatic purification system

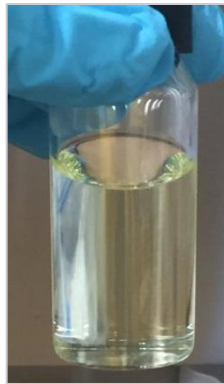


Purification control program

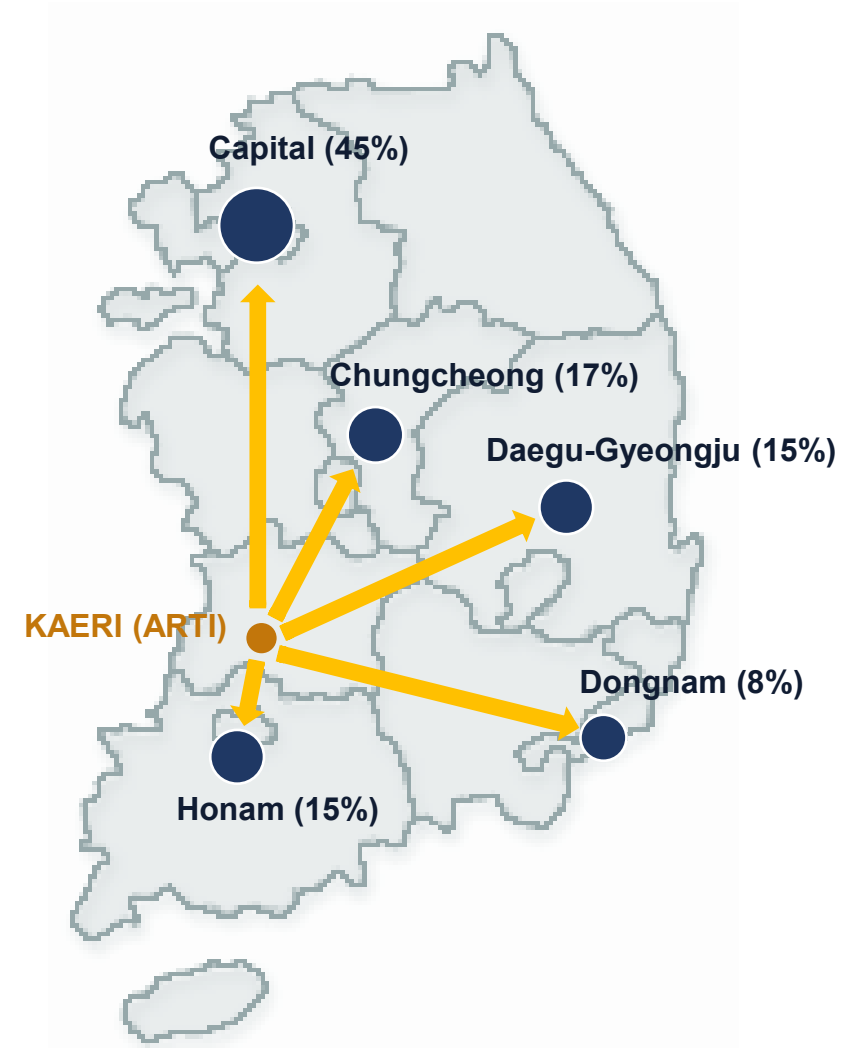
Isotope supply

Isotopes from RFT-30 reach domestic hospitals and overseas users

Zr-89	routine production, domestic supply
Zr-89 export	China, South Africa, Pakistan
Ge-68 export	United States, China
Internal use	application research



RI	Zr-89
Activity	5~10 mCi
Volume	100 ~ 200 μ L
Purity	99.9 %

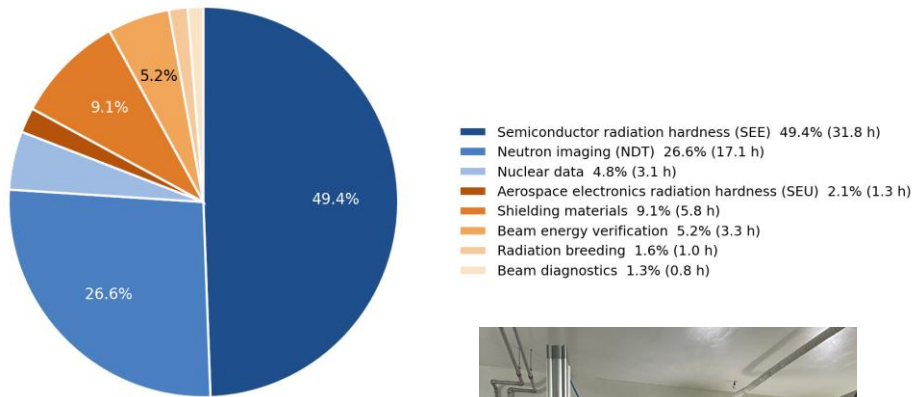


What irradiation users ask for

Irradiation users ask for the opposite of production – large area, low dose

High current
Low current

triplet quadrupoles focused
quadrupoles defocused



Sample loading system



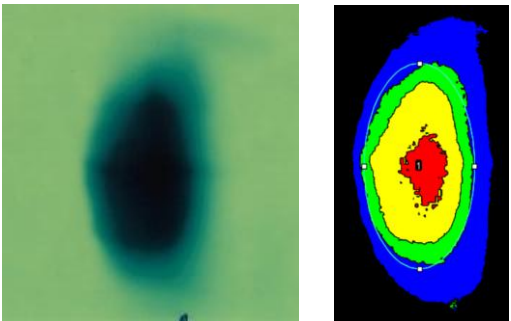
Neutron beamline

Irradiation particle	Beam current	Proton area	Research field
Neutron	~ 10 μ A	Focusing	Semiconductor radiation hardness (SEE)
Neutron	7.5 μ A	Focusing	Neutron imaging (NDT)
Neutron	1 μ A	Focusing	Nuclear physics data
Proton	1 nA	Defocusing	Space radiation electronics hardness (SEU)
Proton	10 ~ 50 nA	Defocusing	Shielding materials
Proton	50 nA	Defocusing	Beam energy verification
Proton	1 nA	Defocusing	Radiation seed breeding
Proton	1 μ A	Focusing	Beam diagnostics

Beam windows

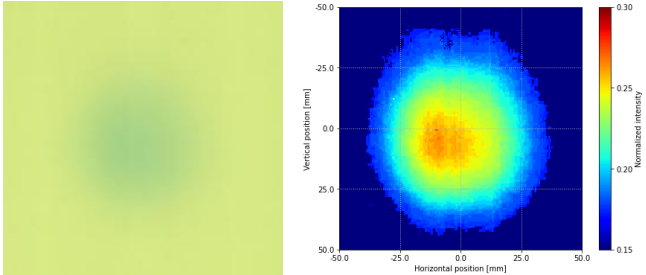
Two window configurations – different energy loss, different current

Al window **1 mm, 4.1 MeV loss (est.)**
Aperture **13 mm**
Current **~ 10 μ A**

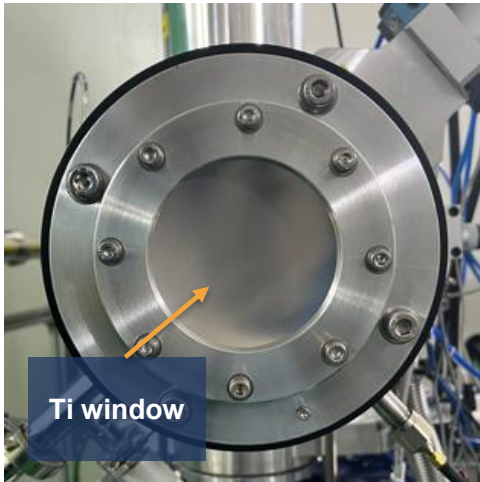
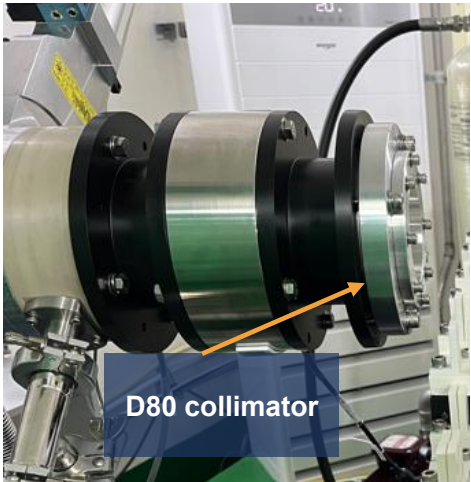
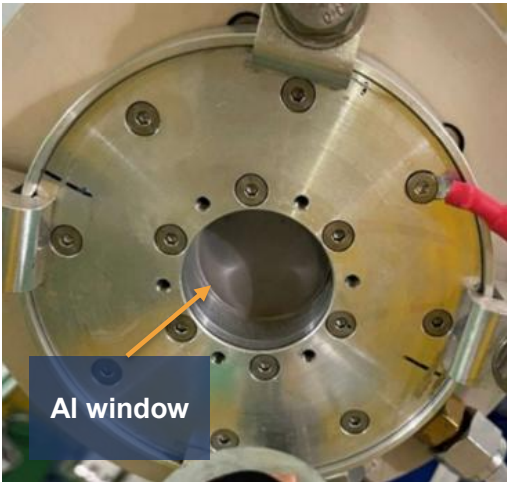
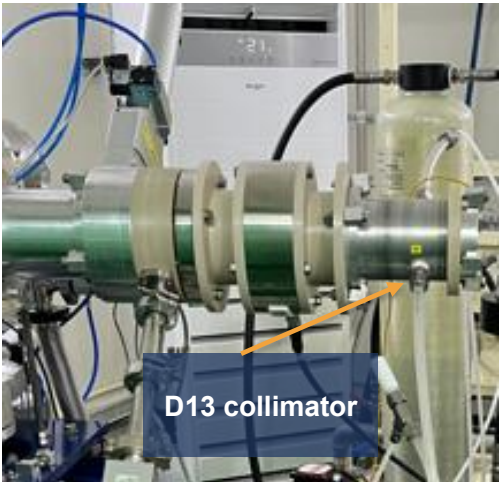


Para.	Value
Energy	30 MeV
Width	11 mm
Height	20 mm
Current	50 nA

Ti window **50 μ m, 0.4 MeV loss (est.)**
Aperture **80 mm**
Current **~ 100 nA**



Para.	Value
Energy	30 MeV
Width	69 mm
Height	80 mm
Area	10 nA

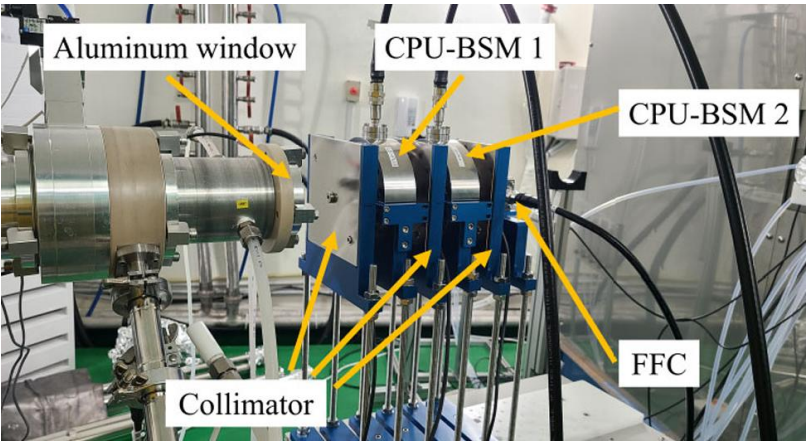


High current, small area

A pulsed beam on a small spot is used for single-event-effect testing and diagnostics device

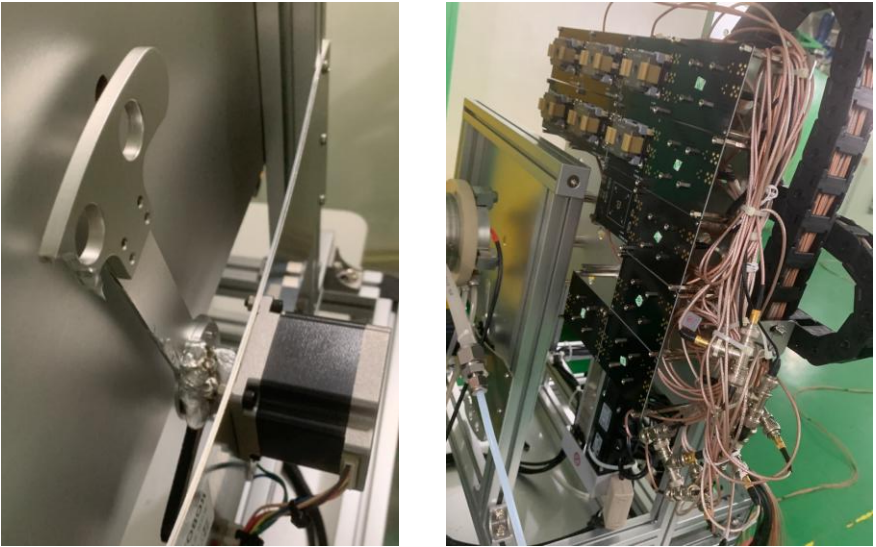
Mode	pulsed proton
Test	single event effect single bunch meas.
Devices	CPU / memory / flash
Diagnostics	phase probe, fast FC

D.Kwak et al., PTEP, 2025, 073G01

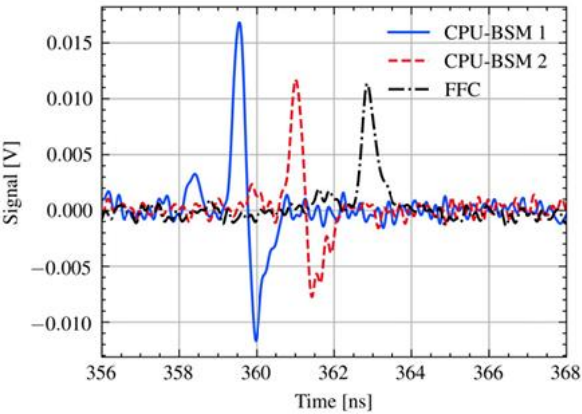


Beam diagnostics test setup

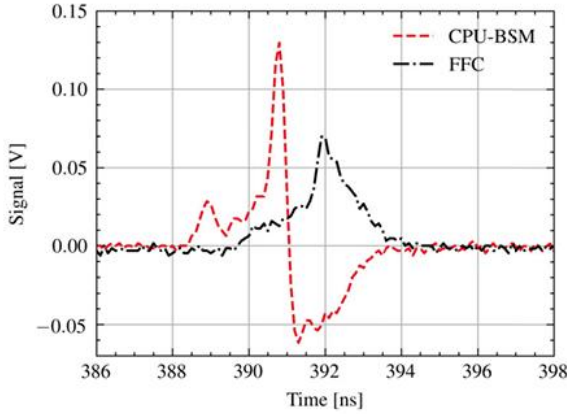
Minwoong Lee, IEEE Elec. Dev., 70, 1, 2024



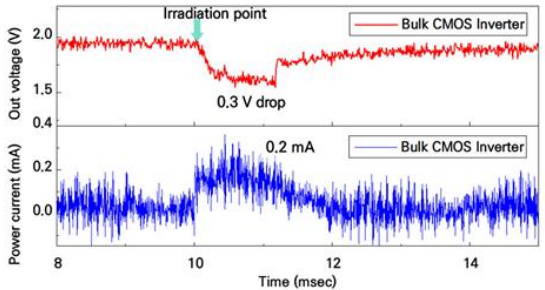
Mechanical chopper and device holder



Time difference between two phase probes



Bunch length measurement

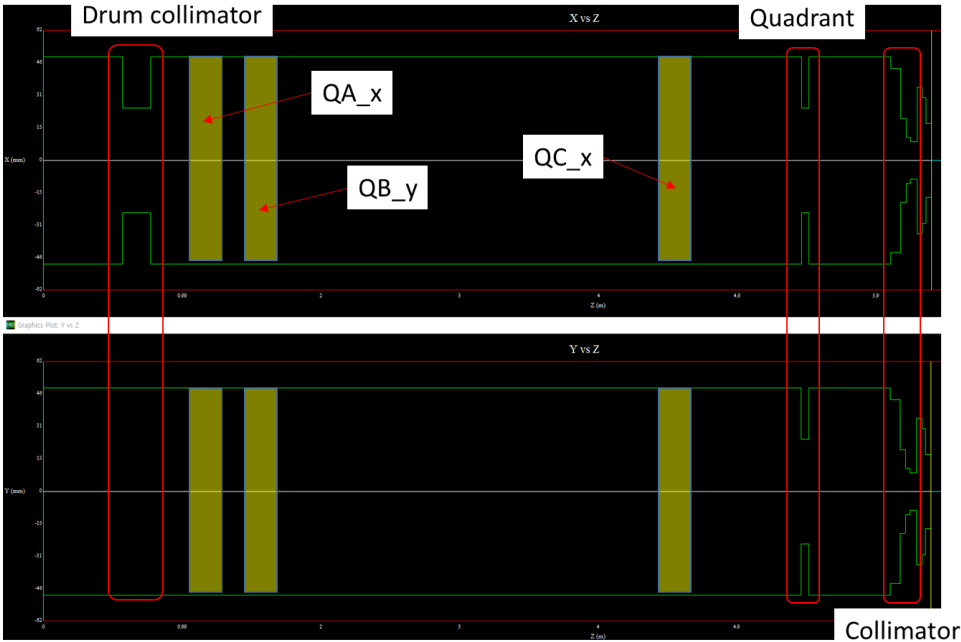


Beam spot and SEE test area

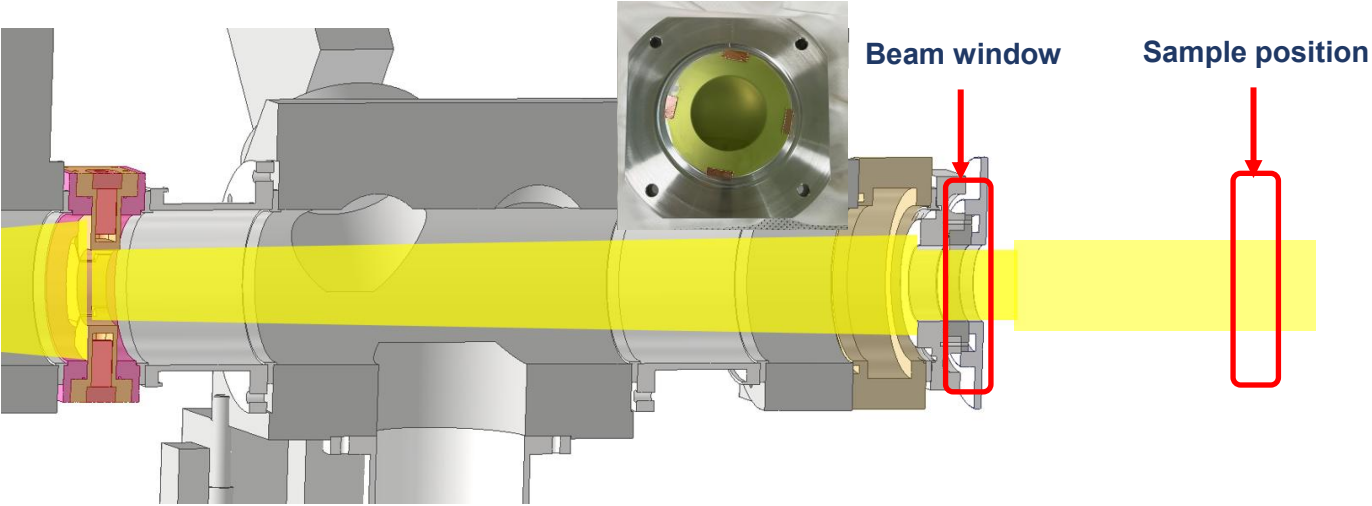
Low current, large area

A defocused beam spreads low current over a large area

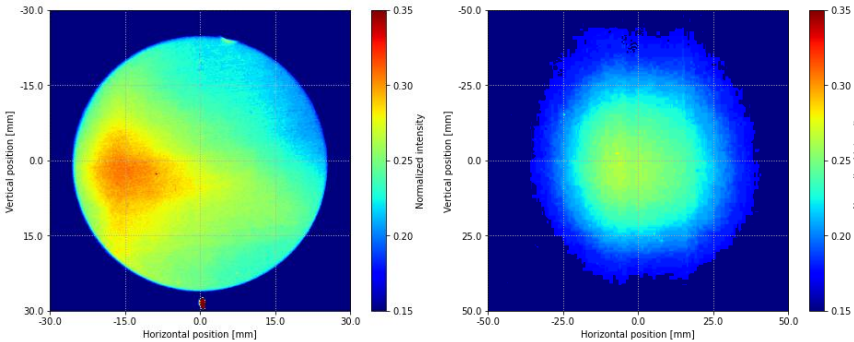
- Application: mutation breeding (seeds)
- Application: single event upset at low current
- Spreading: quadrupole current reduced → defocusing
- Protection: quadrant collimator current monitored



Beamline cross-section with the triplet quadrupoles



Beam distribution measurement setup



Beam window position

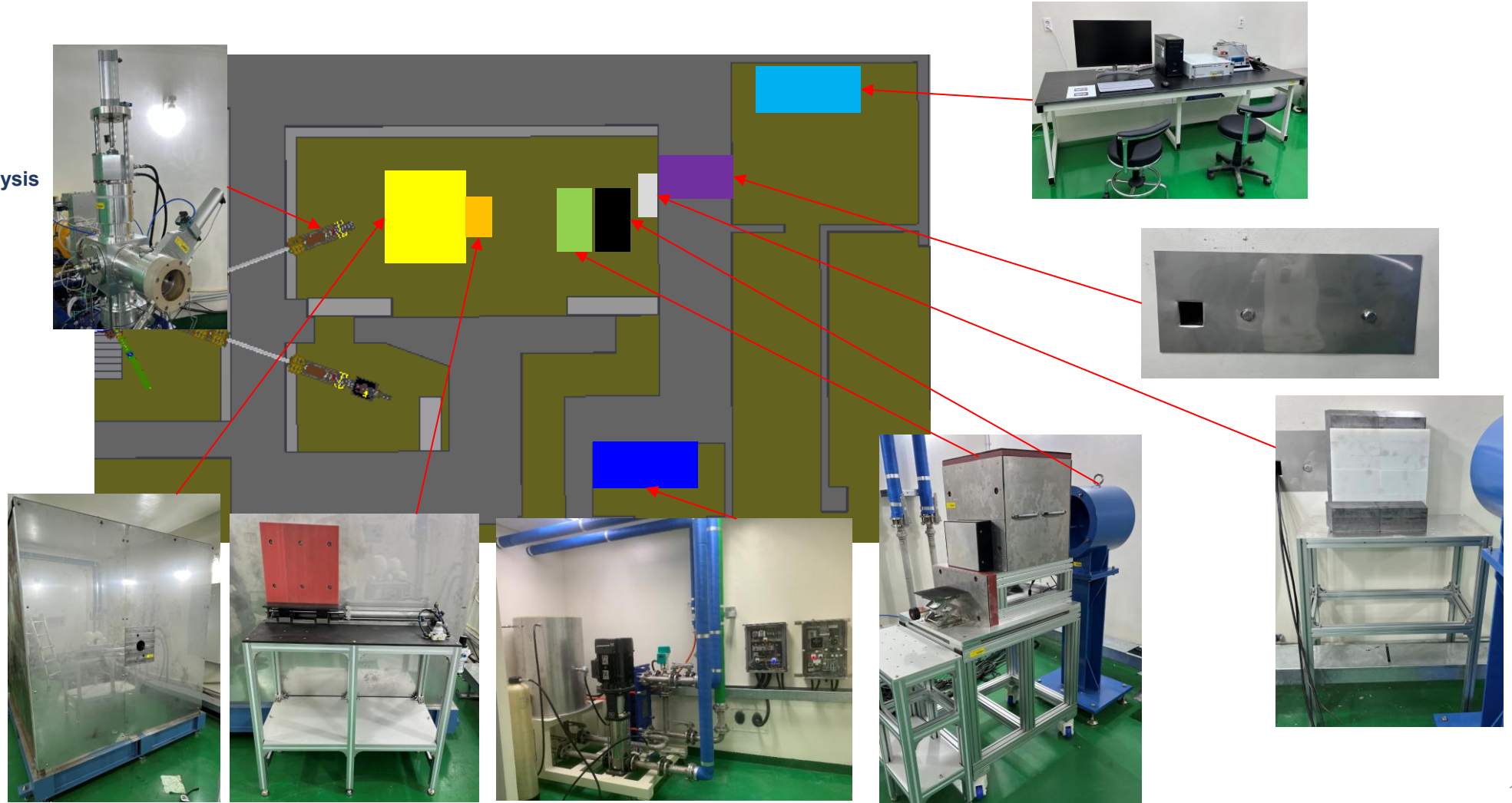
Sample position

Neutron irradiation facility

A neutron irradiation station on the same beamline – imaging, nuclear data, materials

Target
Application
Shielding

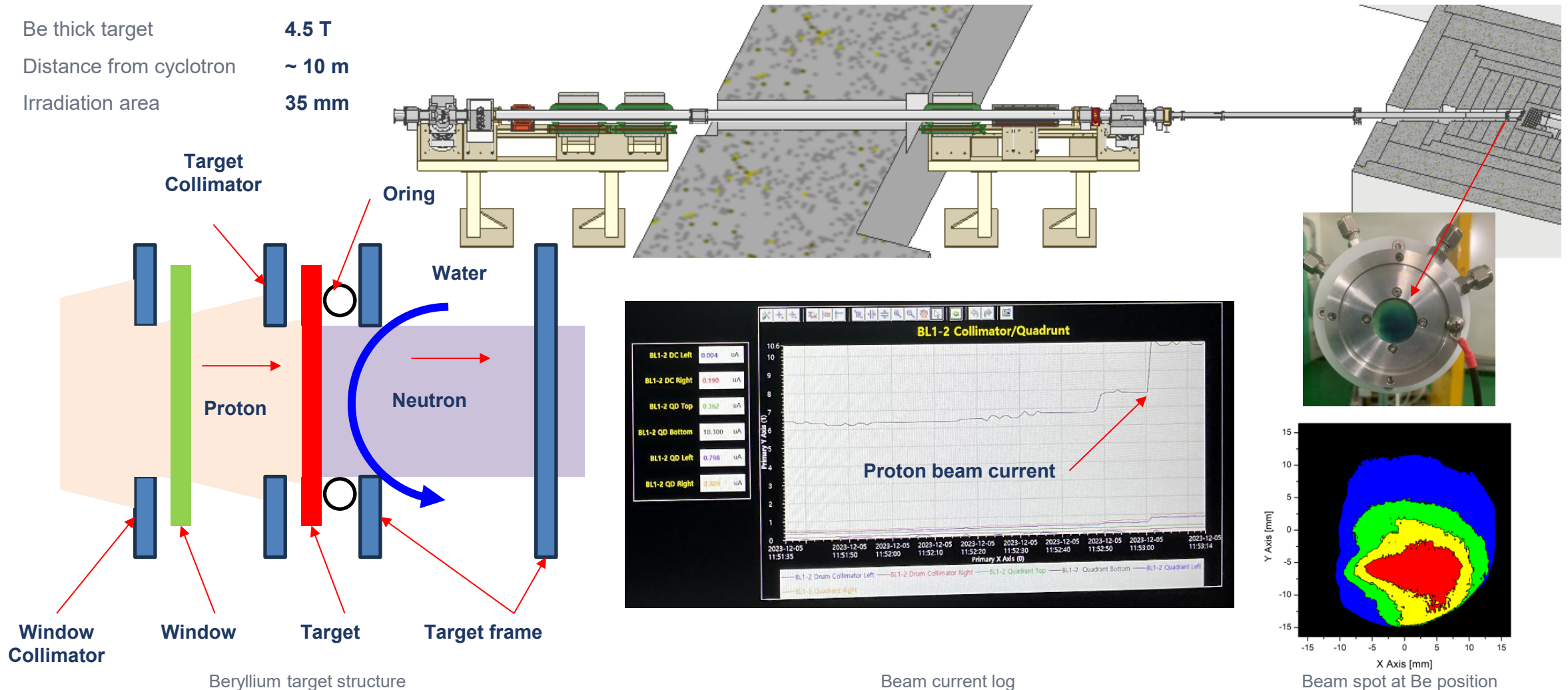
beryllium
radiography
nuclear data
material analysis
internal



Thick target

A thick beryllium target gives a broad neutron energy spectrum

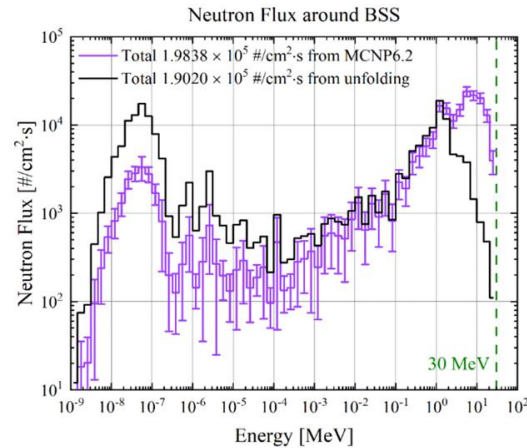
Be thick target 4.5 T
Distance from cyclotron ~ 10 m
Irradiation area 35 mm



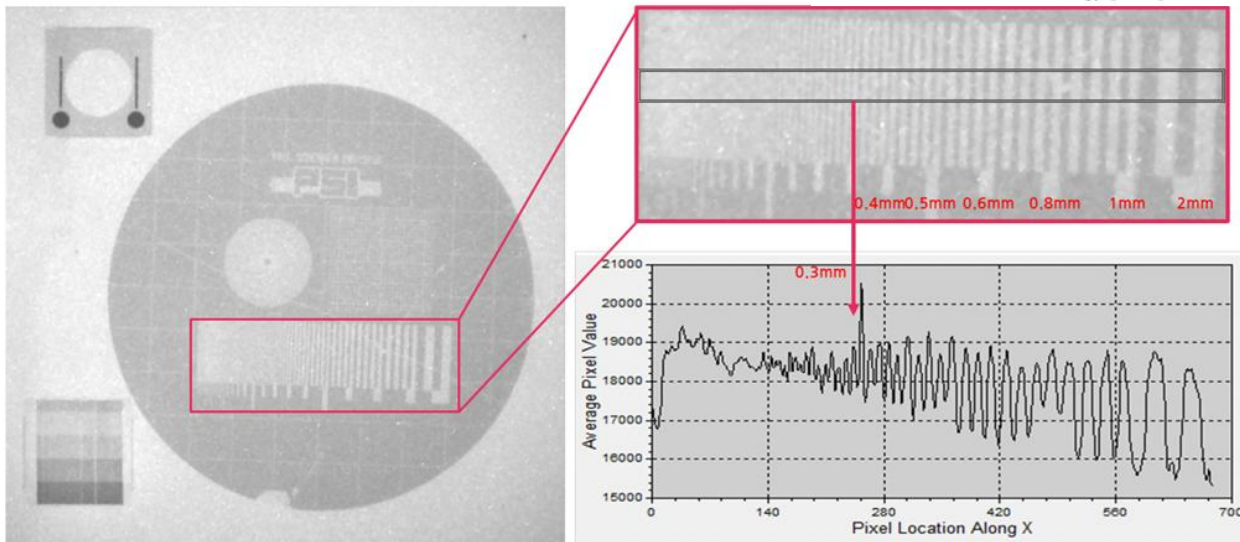
Neutron imaging

The images were analyzed for spatial resolution about 300 μm

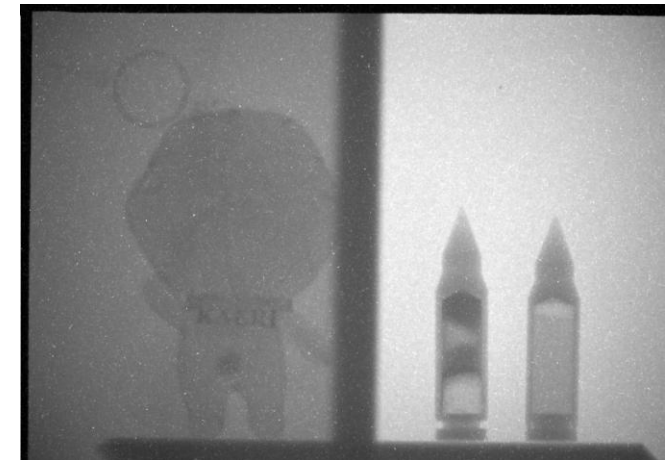
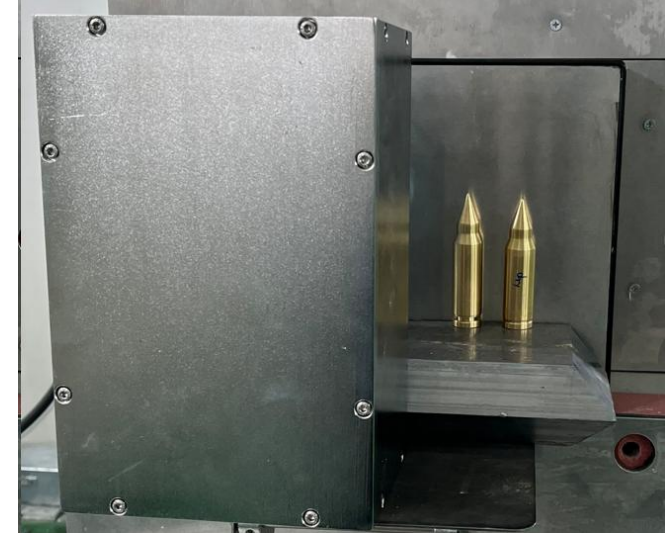
Flux at sample	$\sim 10^4 \text{ n/cm}^2/\text{s}$
Source strength	$\sim 10^{12} \text{ n/s at the Be target (est.)}$
Spatial resolution	$\sim 0.3 \text{ mm}$
Samples	various irradiation tests



Kihyun Lee et al., Can. Jour. Phy., 103, 1213-1224, 2025



Wafer image for spatial resolution



KAERI doll and bullet samples (wet / dry)

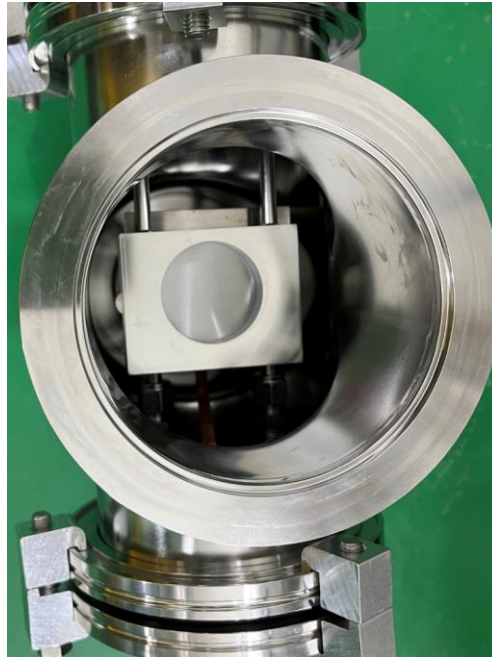
Thin target

A thin beryllium target with a carbon proton stopper runs air-cooled up to 1 μ A

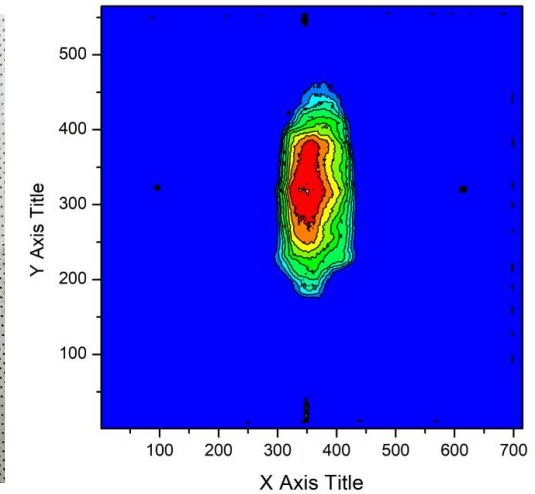
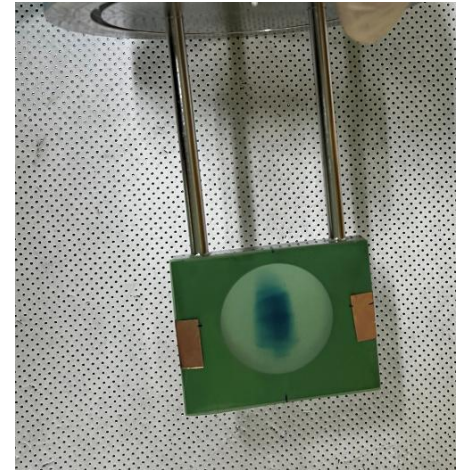
Be thin target	2 T
Proton stopper	carbon, 6 mm
Max current	1 μA (air-cooled)



Thin Be target chamber



Be target



Proton distribution at the thin Be target

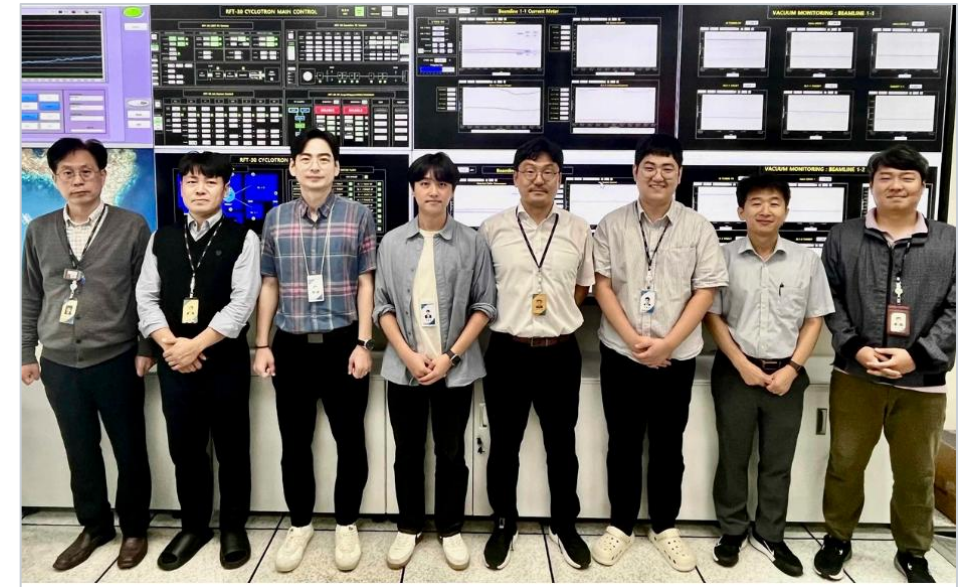


Metal samples and HPGe detector for nuclear data

Summary and outlook

Extending the flexibility of an H^- machine toward irradiation research

- The foil radius determines the beam energy (15–30 MeV) and a switching magnet selects the beamline
- Three lines produce isotopes; BL 1-2 is dedicated to proton and neutron irradiation
- Proton irradiation spans high-current small spots and low-current large areas
- A beryllium target converts the same beam into neutrons for imaging and nuclear data
- Next : state the irradiation condition in numbers – in-beam energy, current and profile



Team member Dr. Jeong Hoon Park, Dr. Min Goo Hur, Dr. Young Bae Kong · Dr. Jun Young Lee, Mr. Jinsik Ju · Dr. Byeongchan Lee · Dr. Donghyun Kwak



Thank you

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