Commissioning of a 70 MeV proton cyclotron system of IBS, Korea

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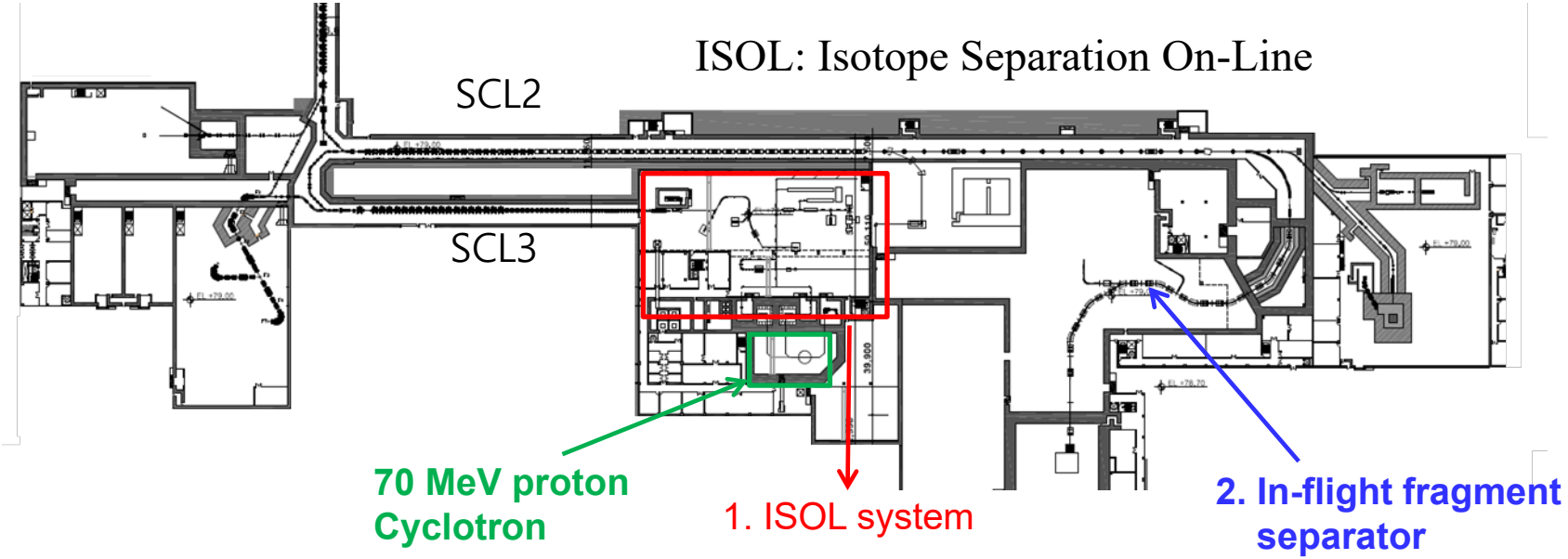
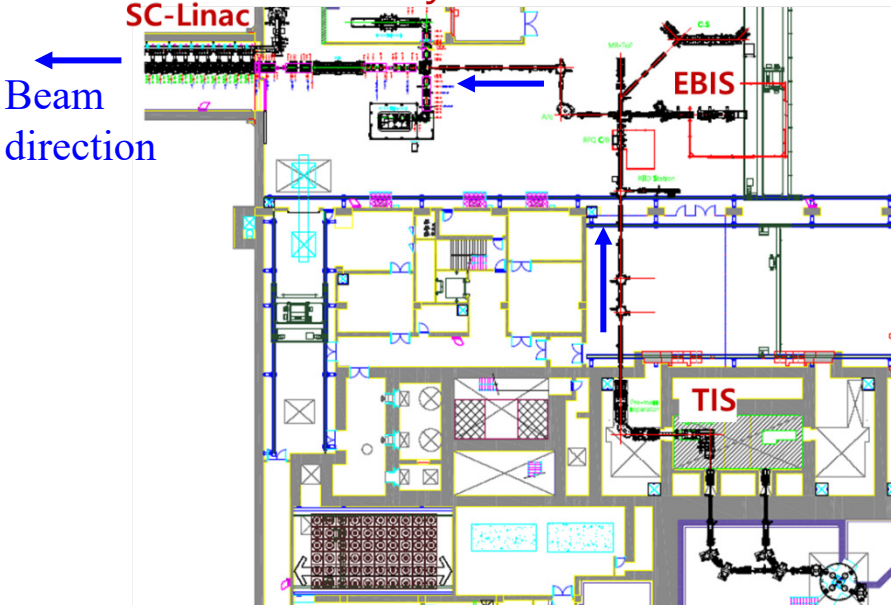
Layout of Rare Isotope Science Project (RISP)

Period: 2011.12~ 2022.12
Budget: ~1.3 billion USD (~0.9 billion for building and land)
Total area: ~0.95 km^2

RI beam production by **ISOL method for RISP**



Layout of ISOL



Charge breeding by EBIS

	TIS	EBIS
Ion	$^{132}Sn^{1+}$	$^{132}Sn^{33+}$
E	60 keV	10 keV/u

Chronology of cyclotron system installation and beam tests

2019 June**:** Contract with IBA of Belgium

2020 Jan.: Finalizing the beam line design
Oct.: Field mapping and shimming completed

2021 July~Aug.: Factory Acceptance Tests and shipping
Nov.: Cyclotron rigging and start installation

2022 June: Internal beam test
Sep.: Start of Site Acceptance Tests
Oct.: Max. beam power test (70 MeV, 50 kW) for ~6 hrs

Specifications of the cyclotron (C70p)

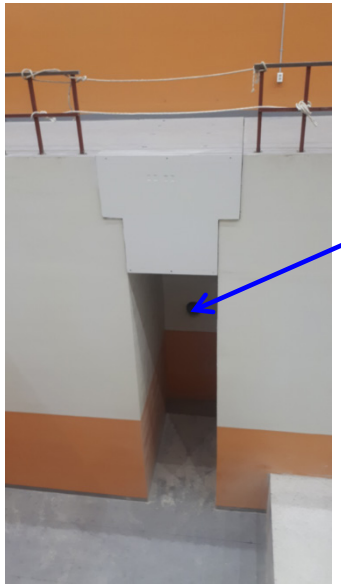
Energy	30-70 MeV
Maximum proton intensity	750 μA
Simultaneous extracted beams	2
Number of sectors	4
Hill field	1.6 Tesla
Harmonic mode	4
Frequency (fixed)	62MHz
Injected H-current	10 mA (H-)
Total weight	140 tons
Cyclotron dia.	3.8 m

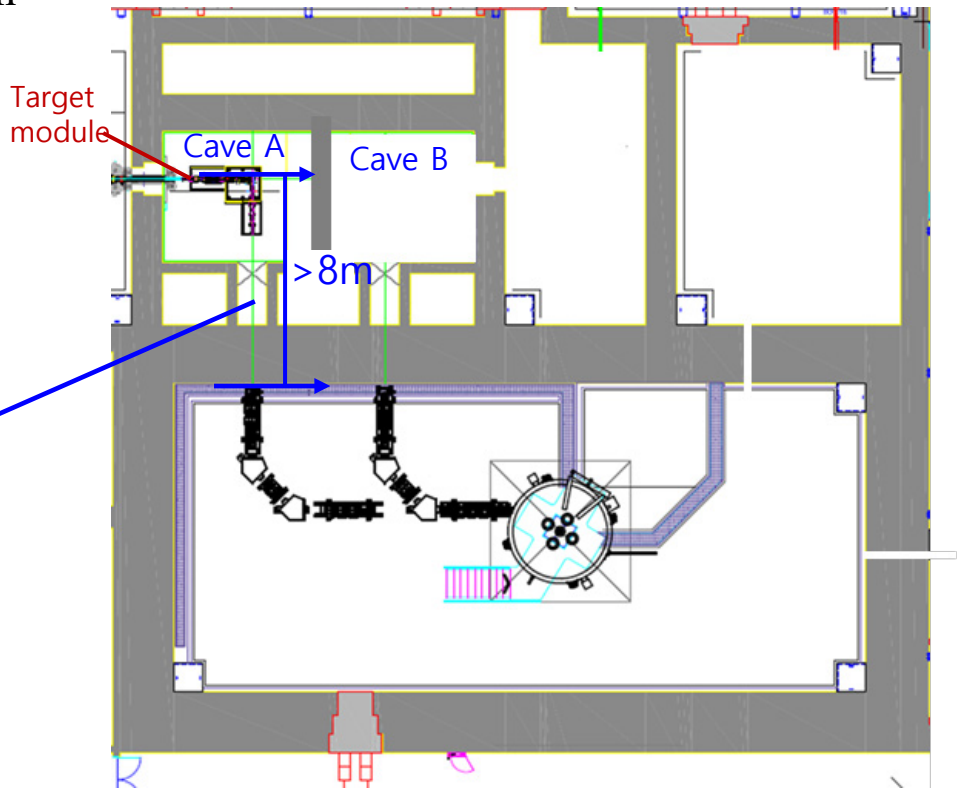
Beam line design finalized in Jan. 2020

An issue: a long distance (>8m) from the last quadrupole doublet to the ISOL target
if a quadrupole doublet is located in cyclotron room

Building was designed based on the previous contract with **Best Cyclotron Inc. (2017)**

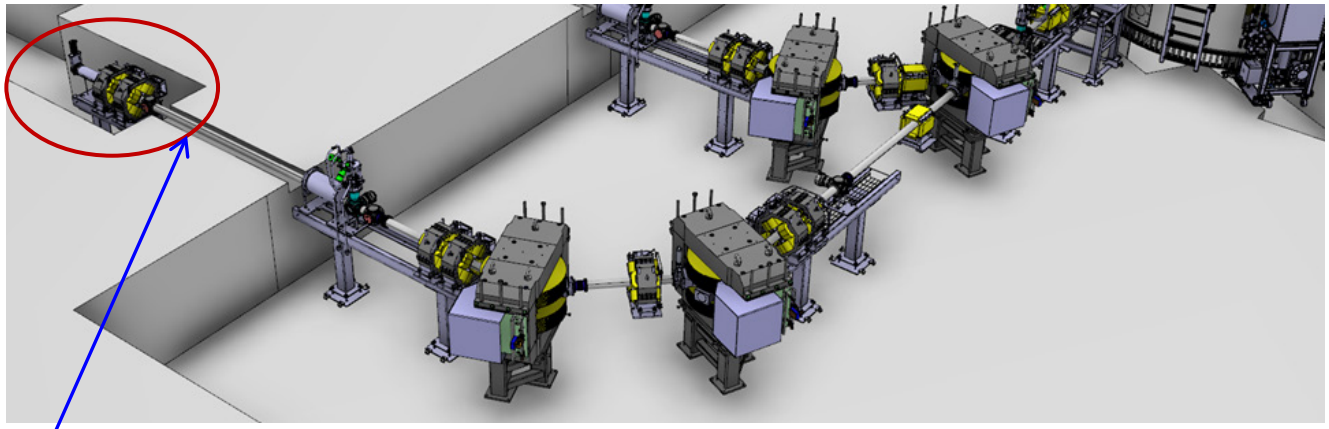
ISOL tunnel





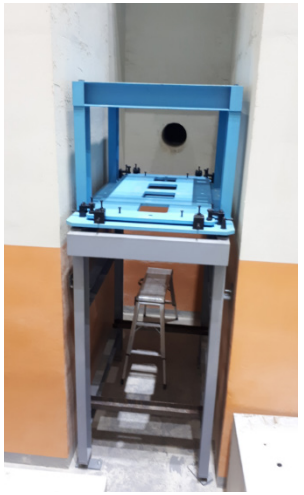
Beam line configuration chosen with beam optics study

Configure 1: Quadrupole doublet in ISOL tunnel (chosen)

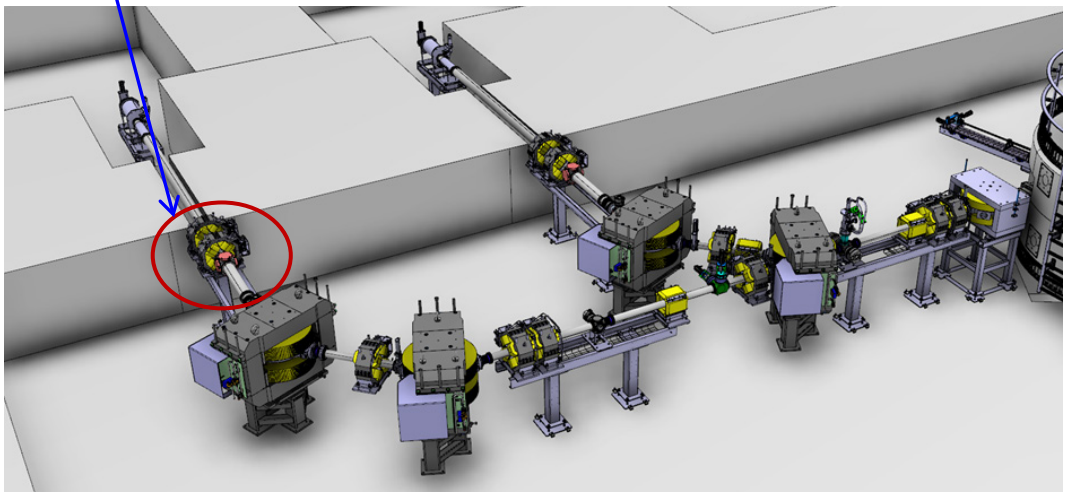


Quadrupole doublet

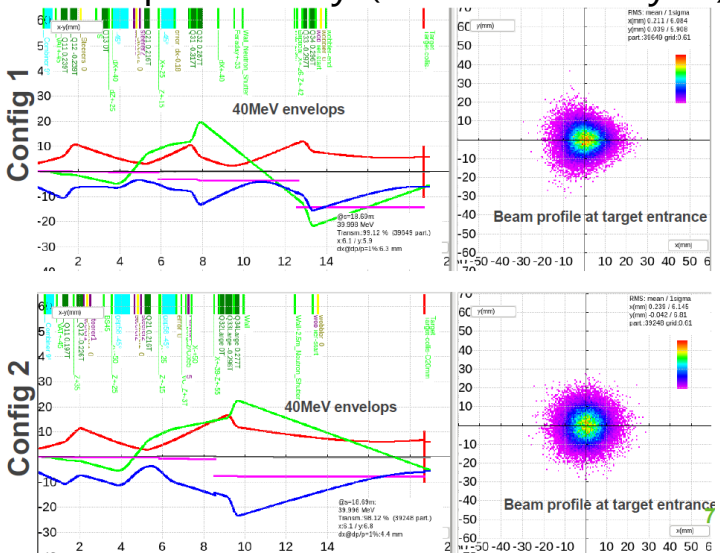
ISOL tunnel



Configure 2: No quadrupole magnets in ISOL tunnel



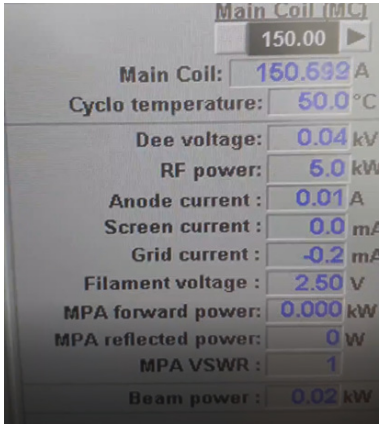
Beam optics study (inc. error analysis)



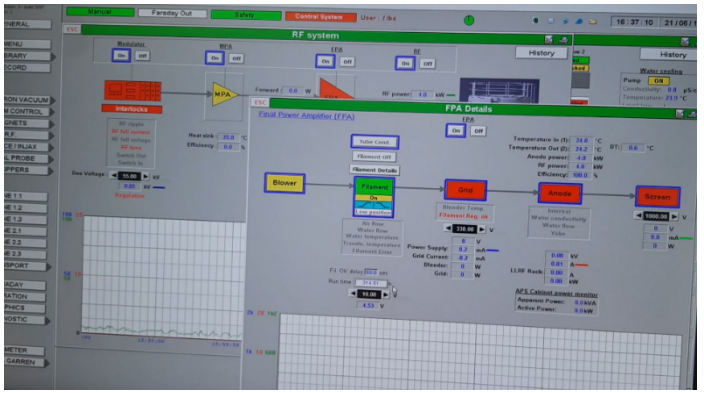
Factory Acceptance Tests remotely (June 2021)

C70 cyclotron at IBA

Magnet current ramping

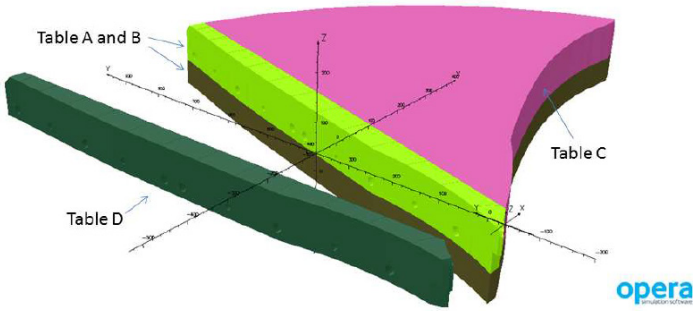


RF power test



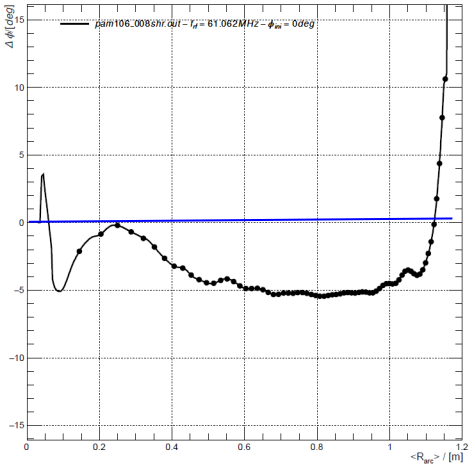
Isochronization of magnetic field

Removable pole edge



$$\phi(E_f) = \int_0^{E_f} \frac{2\pi h}{f} \frac{\Delta f(E)}{\Delta E_n \cos\phi(E)} dE,$$

Phase excursion



Cyclotron System Rigging (Nov. 2021)

Crane
(1200 tons)

Installation of all components and utilities (April 2022)

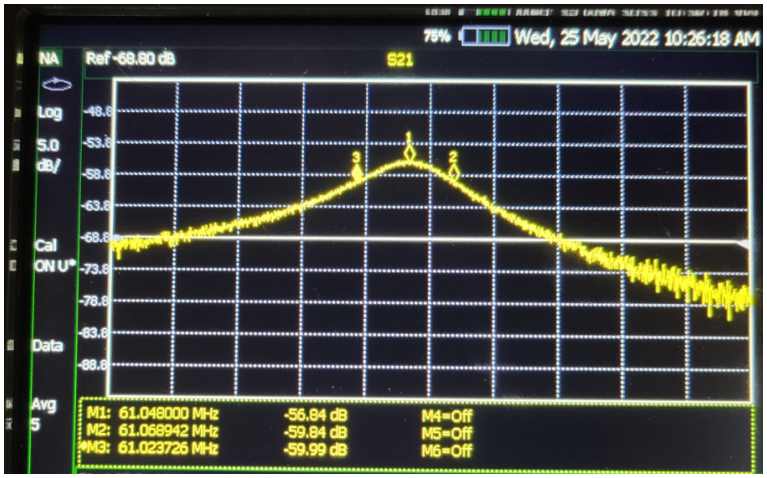
Cyclotron vault

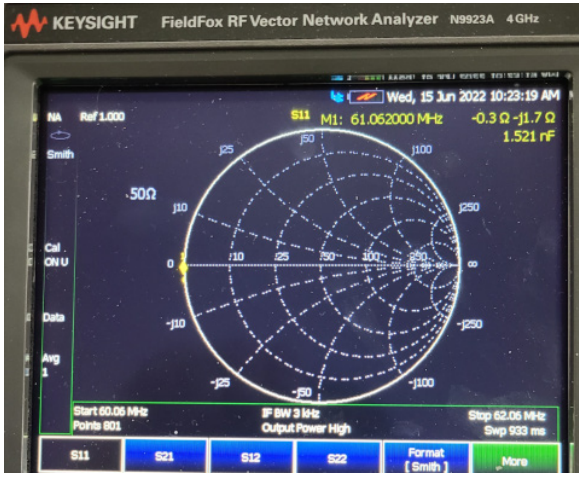
Cyclotron cooling room

Power Supply room

Final focusing & wobbler module in ISOL bunker

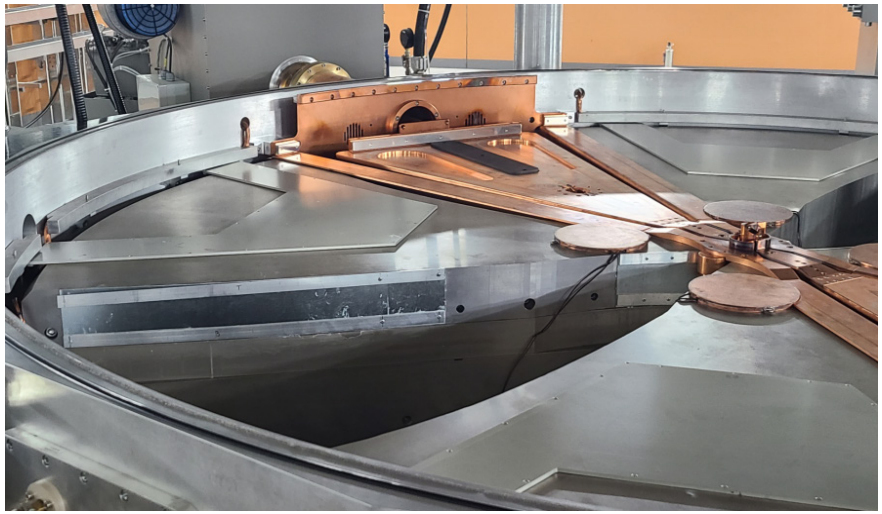
RF system test (May 2022)



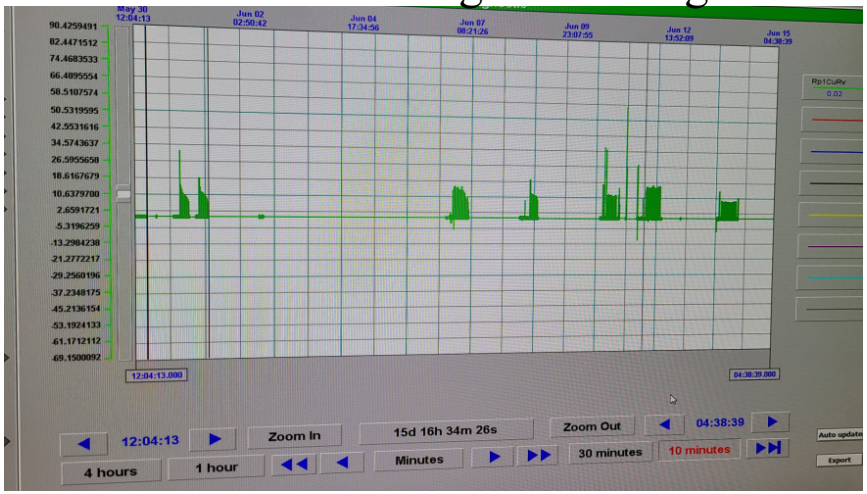


LLRF → Solid State Amp. (5 kW) → Final Power Amp. (100 kW)

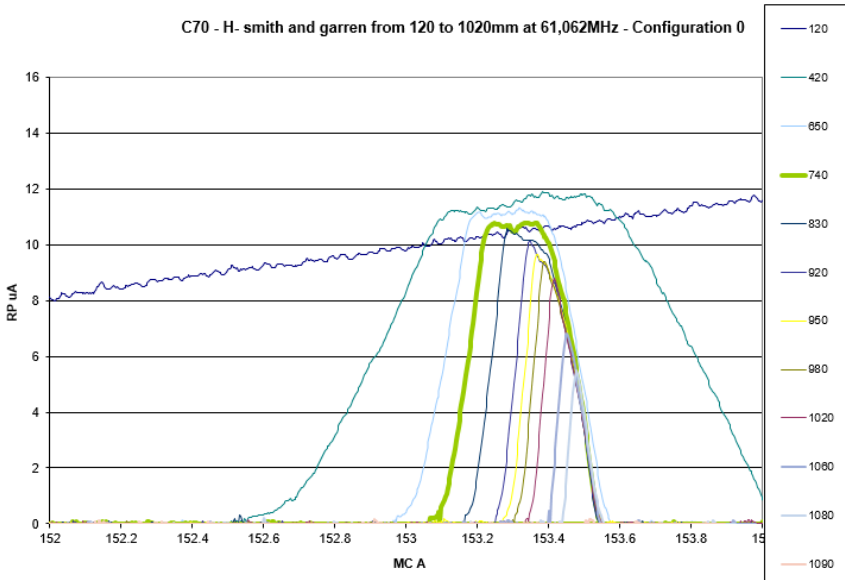
Optimization of magnet field using Smith-Garren method (June, 2022)



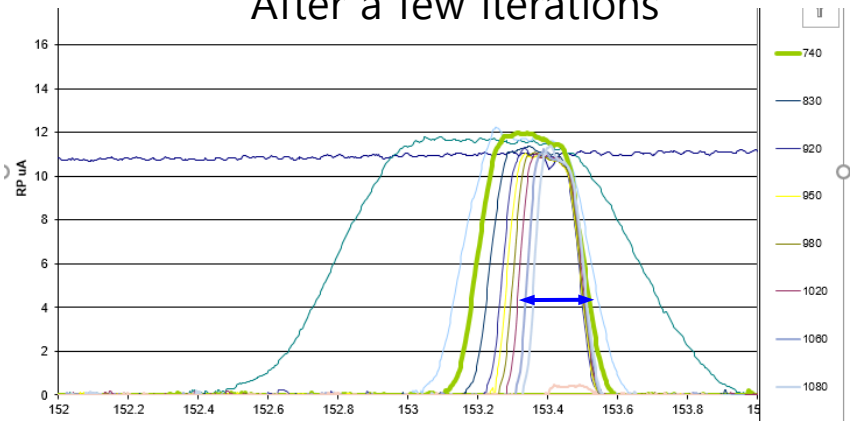
Beam current scanning at differing radii



Before Smith-Garren



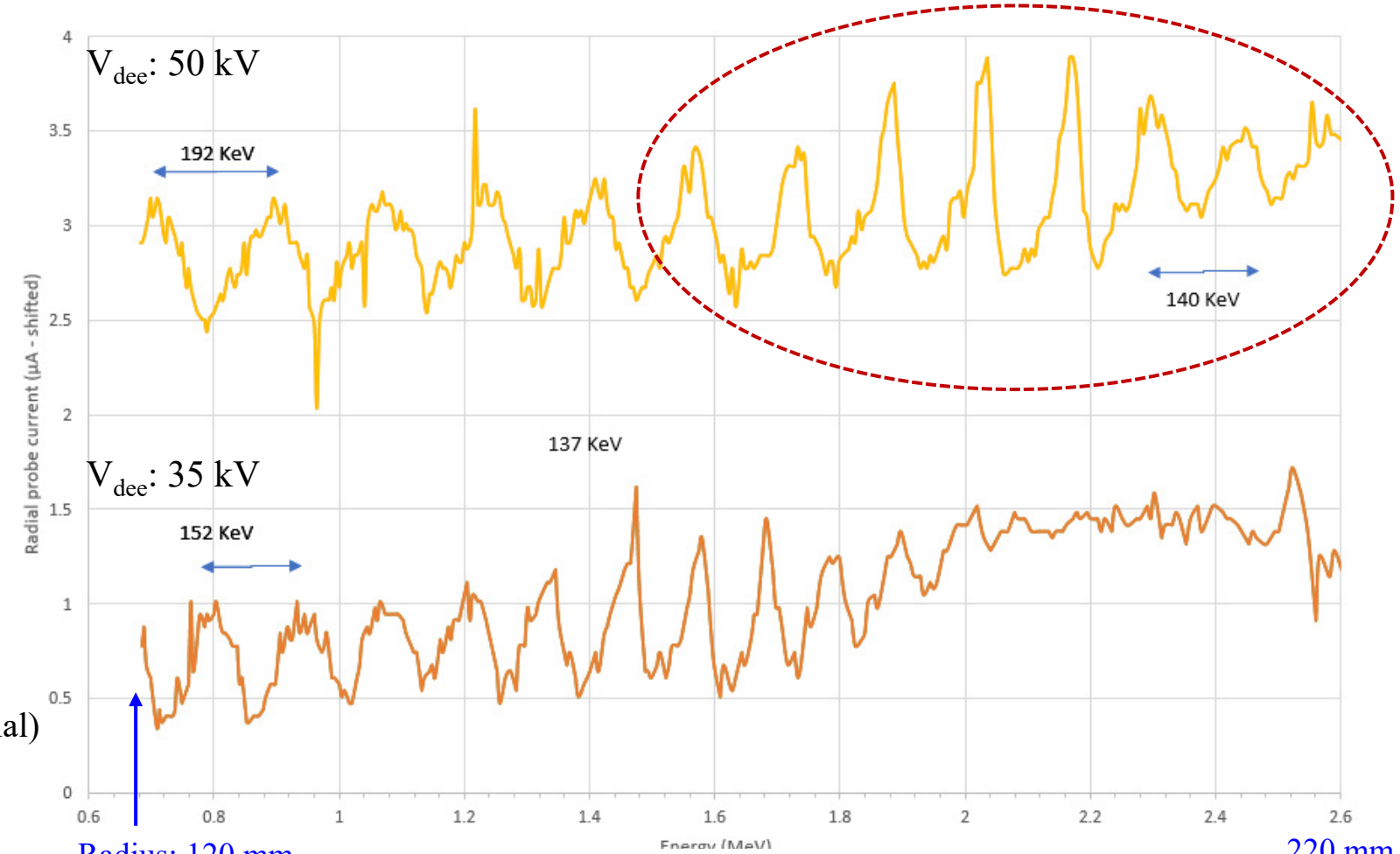
After a few iterations



Main coil current (A)

Turn separations in the cyclotron center region

Radial (differential) probe

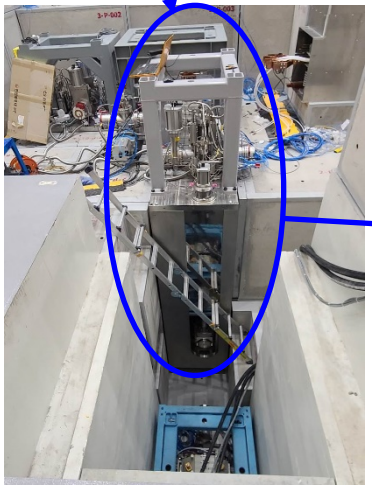


Radius: 120 mm

220 mm

Preparation for Site Acceptance Test (Aug. 2022)

ISOL module



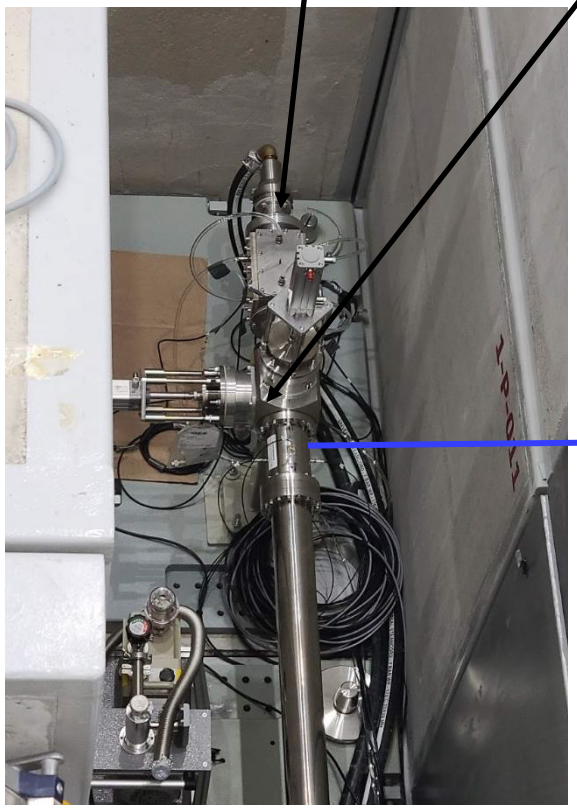
Cave A (beamline setup for SAT)

Cave B (radiation shielding for 50 kW)

First beam operation in Cave A

Beam dump at ISOL target location

Beam Profile Monitor (IBA)



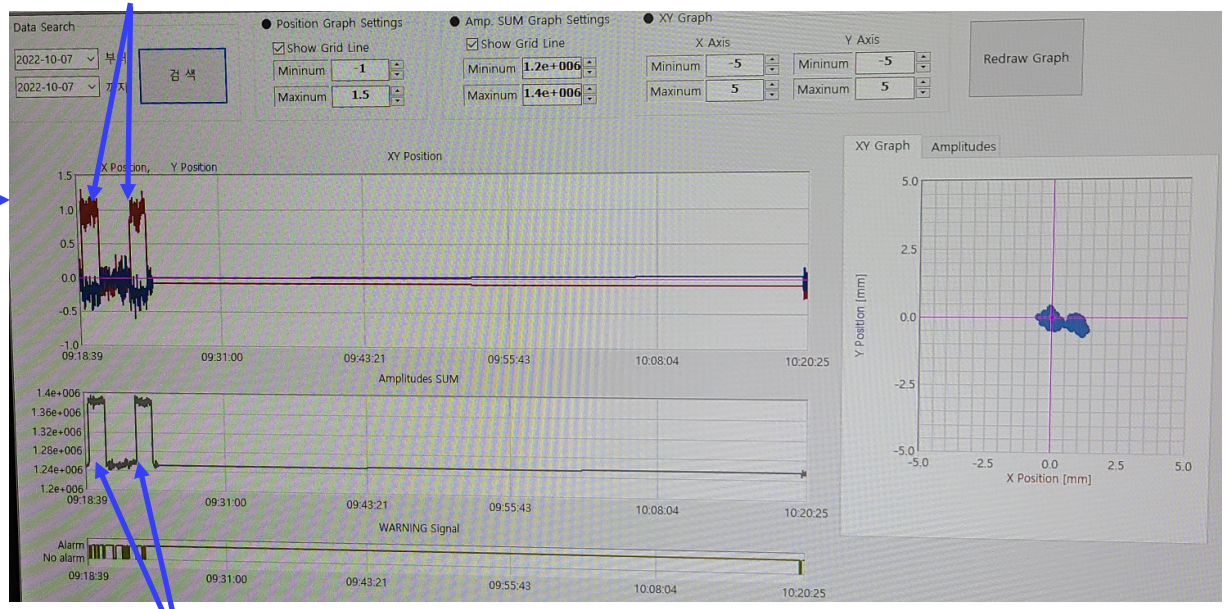
Cave A

Measuring beam off-center

ΔX: ~1 mm

ΔY: <0.5 mm

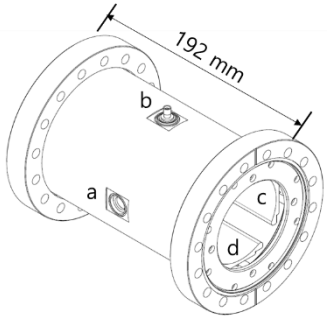
Beam Position Monitor (IBS)



I: ~10 μA

Oct. 7 2022

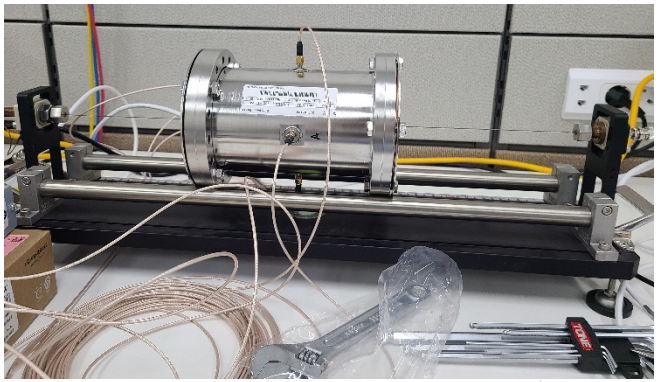
BPM to monitor beam off-center and beam current

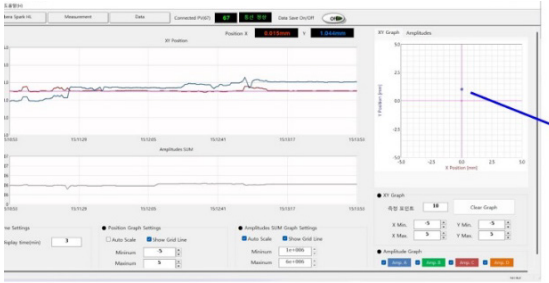


Setup for BPM test using a moving wire (61 MHz)

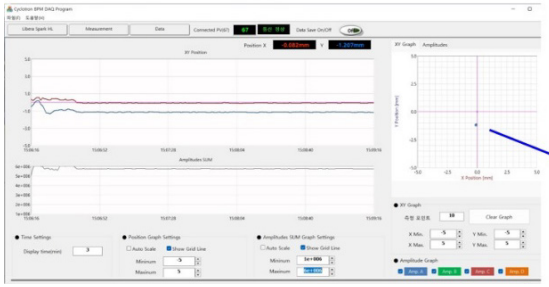
Pohang Light Source (July 2022)

1. Calibration of position by moving wire





Wire shifted by 1 mm



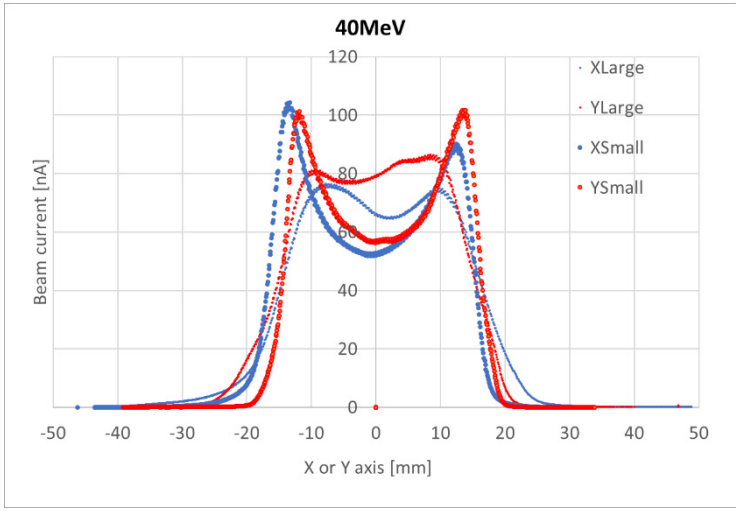
Wire shifted by -1 mm

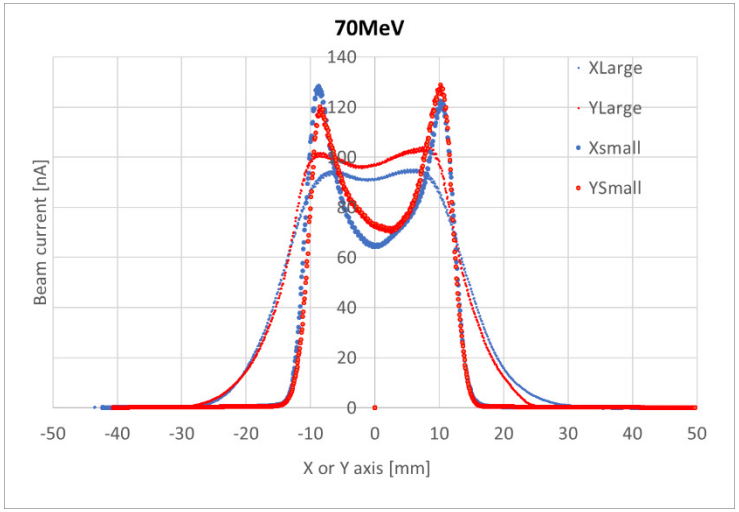
2. Calibration of beam current using current readings at beam dump

Beam wobbling tests for ISOL operation

Two collimators (15 kW) with apertures of ø2~5cm (target diameter)

· Tune the beam envelope to be at a waist at target location (Beam Profile Measure)
· Adjust ø of beam shape and wobble the beam (60 Hz) to produce beam shapes required

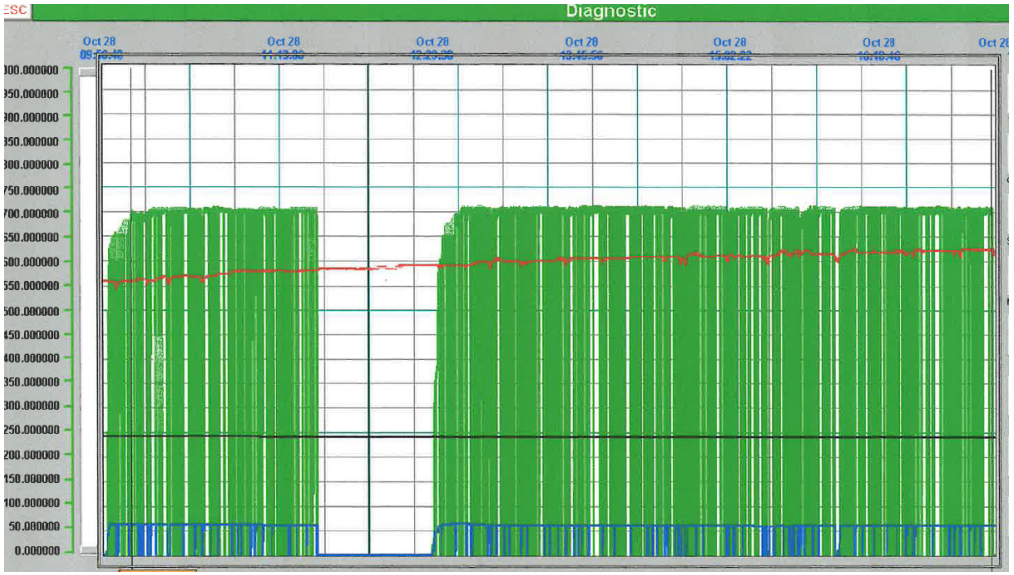


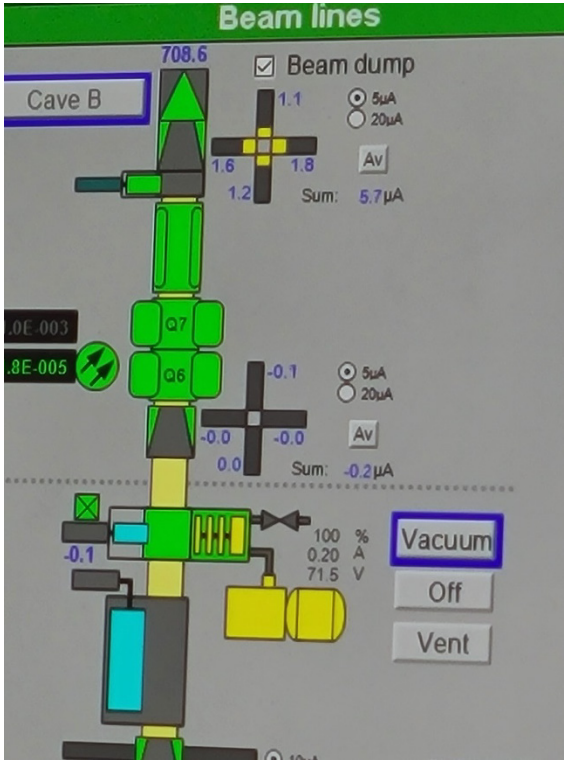


□: 1.5 - 6 mm

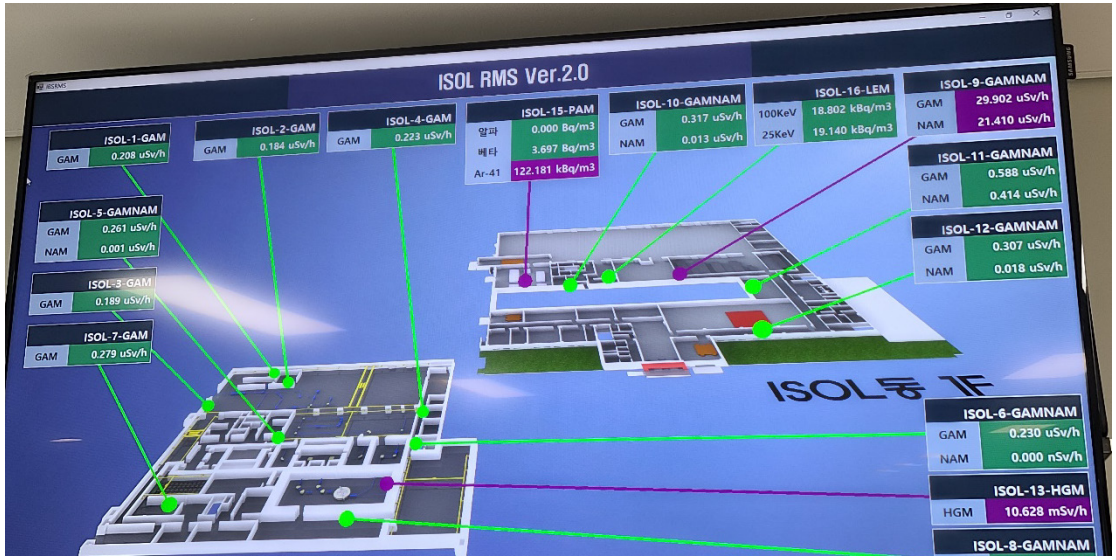
High power beam test at 70 MeV, 50 kW (Oct 28, 2022)

SAT: 70 MeV, 50 kW for 6 hrs (Oct. 28, 2022)



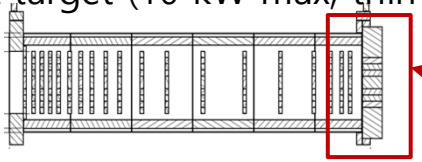


First beam tuning to 700 μA
(Oct. 27, 2022)



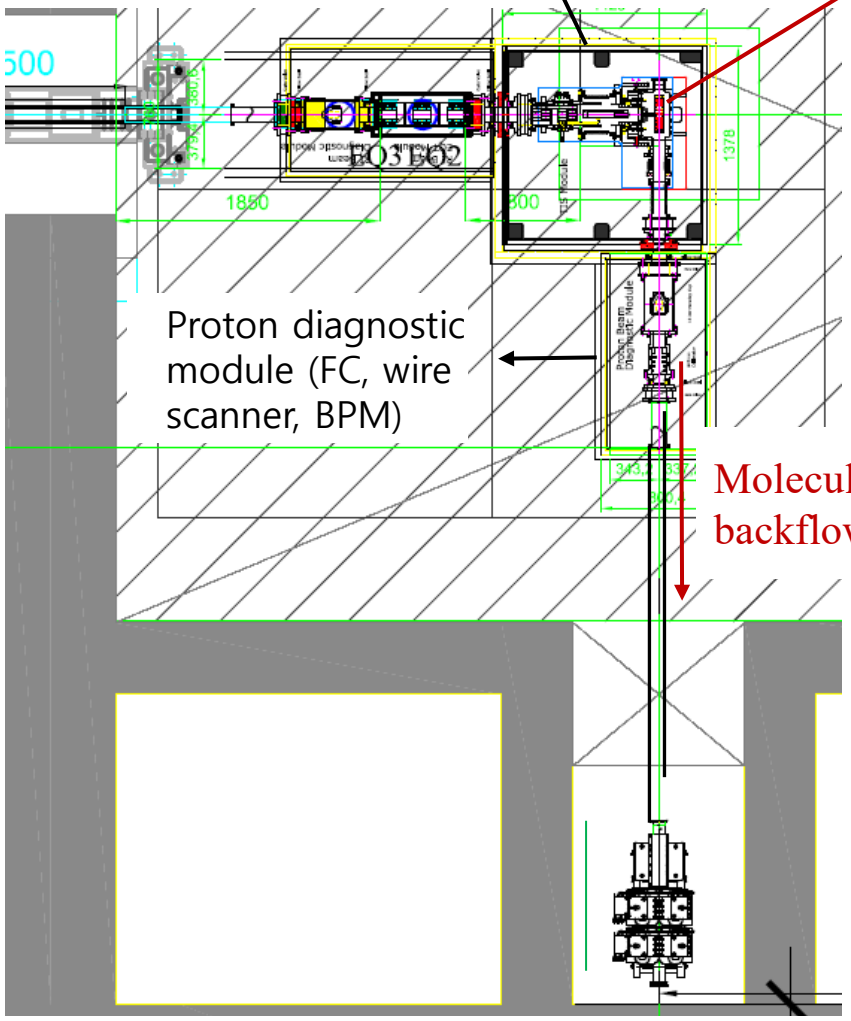
Preparation for ISOL target operation (Dec, 2022)

ISOL target (10 kW max, thin slice, UC_x,..) → 2000 °C

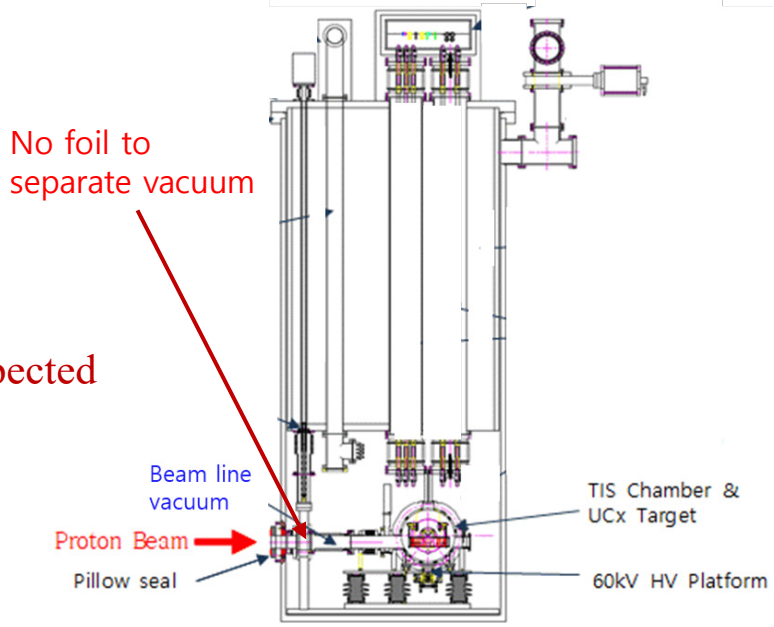


Not hermetically sealed

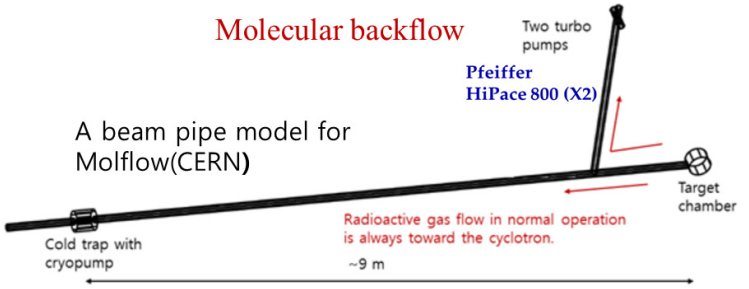
ISOL target module



Sectional view of TIS module

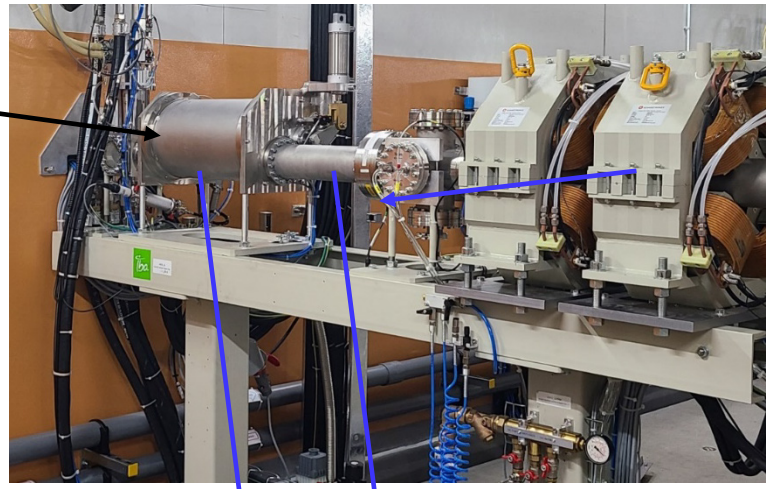


Molecular backflow

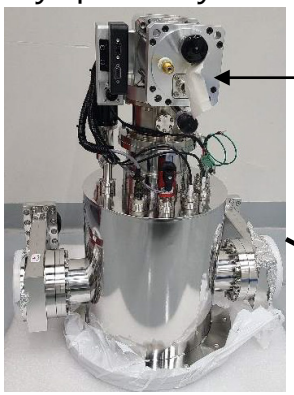


Fast closing valve and Cryopanel system for safety of ISOL operation

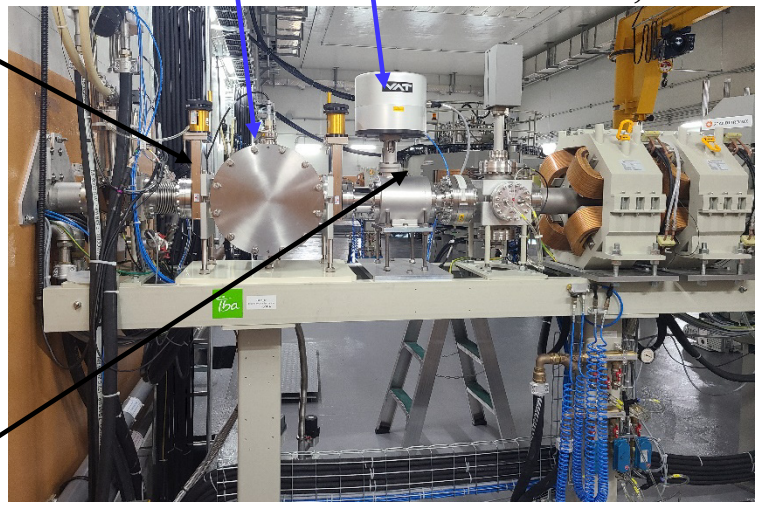
Neutron shutter is replaced by
Cryopanel system (20~30 K)



Cryopanel system

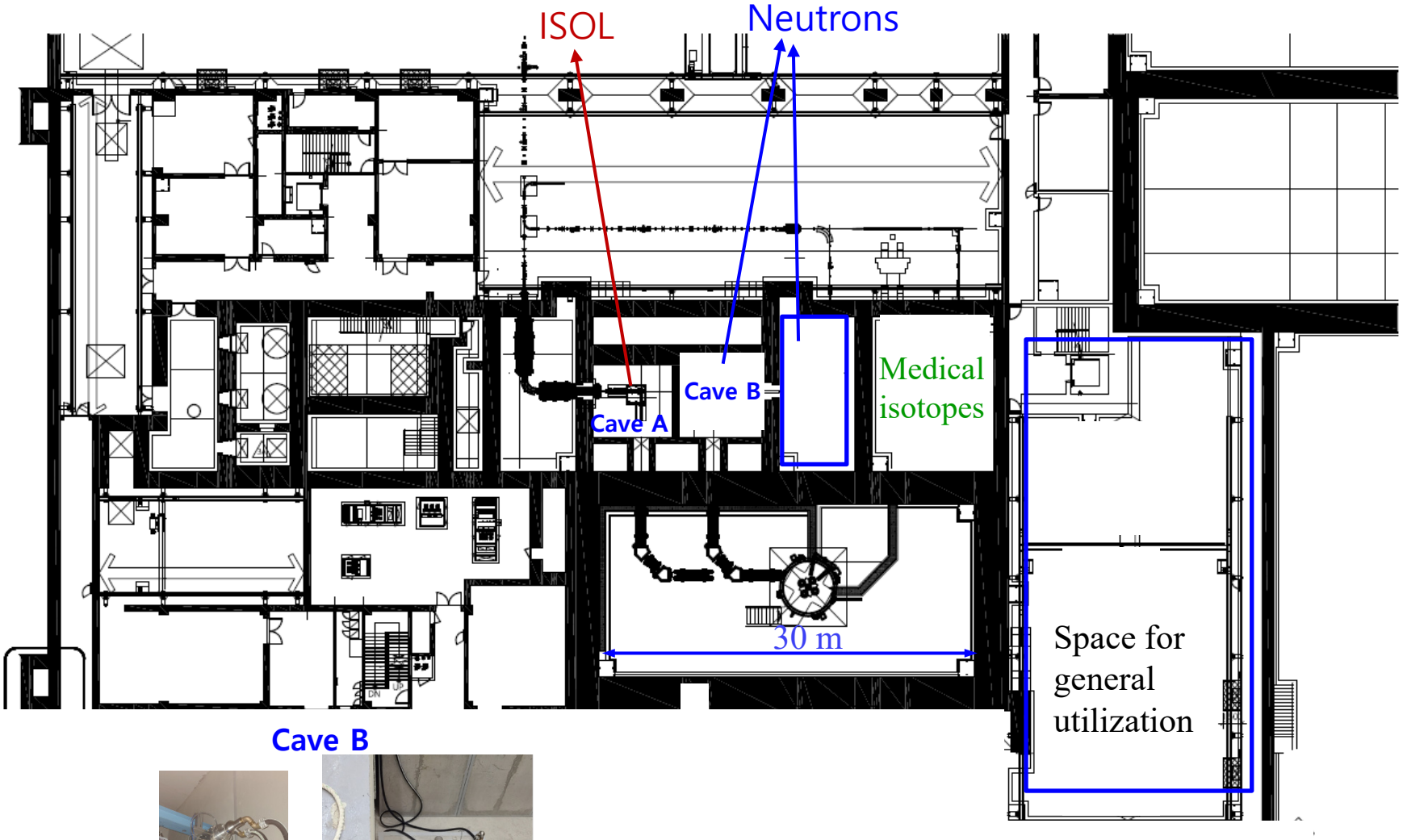


Dec. 2, 2022

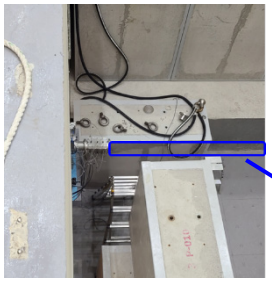


Fast closing valve (< 20 ms, VAT)

Utilizations of C70 (ISOL, neutron, medical isotopes)

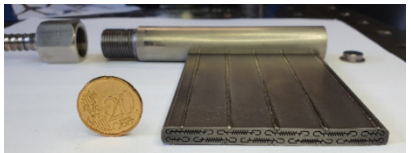


Cave B



Beam line extension needed for **target**, modulator, reflector

Ta target for 70 MeV proton (Julich)



Conclusions

- The cyclotron was successfully tested at 70 MeV, 50 kW for ~6 hrs.
- The beam line in Cave A is being prepared for ISOL operation to provide a test beam this year.
- The cyclotron facility has spare areas in Cave B and a bunker for neutron science and medical isotope production, respectively.