RAON Rare isotope Accelerator complex for ON-line experiments

Status of RAON

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Outline

I. Introduction to RAON

II. Current Status of the Facility
(Accelerator systems and Experimental systems)

III. Summary

라온 -> RAON -> Rare isotope Accelerator complex for ON-line experiments

Goal	**To build a heavy ion accelerator complex, RAON, for rare isotope science research**
Period	**1st Phase: 2011.12 - 2022.12** **R&D for the 2nd Phase: 2022.12 - 2025.12**
Budget	**~$ 1.4 B (Facilities ~ $ 0.5 B; Land, Bldgs & Utilities ~ $ 0.9 B)** * includes initial experimental apparatus

RAON

Accelerator complex
ISOL + In-Flight Fragmentation

Origin of Matter

- Nuclear Astrophysics
- Nuclear Matter
- Super Heavy Element Search
- High-precision Mass Measurement

Properties of Exotic Nuclei

- Nuclear Structure
- Electric Dipole Moment and Symmetry
- Hyperfine Structure Study

Applied Science

- Bio-Medical Sciences
- Material Sciences
- Neutron Science

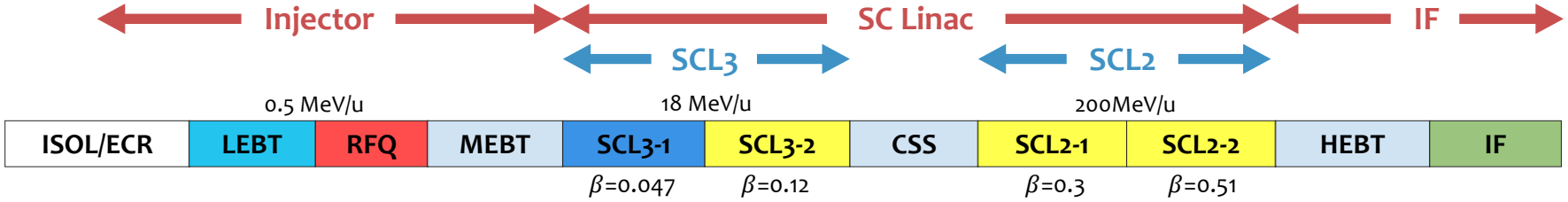
Where is RAON?

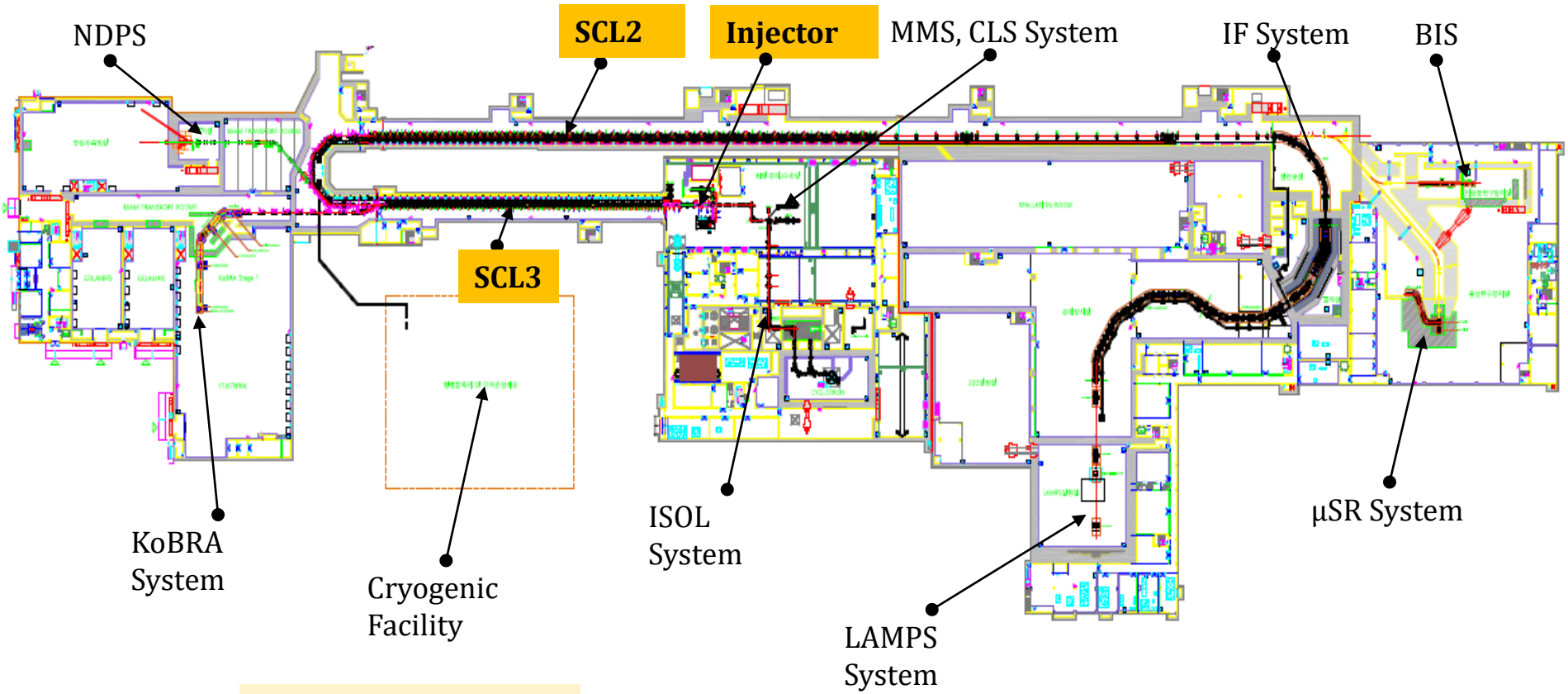
Bird's-eye-view of RAON

- Accelerator System
- RI production System
- Conventional Utilities
- Experimental System

Area of the land ~ 1M m²

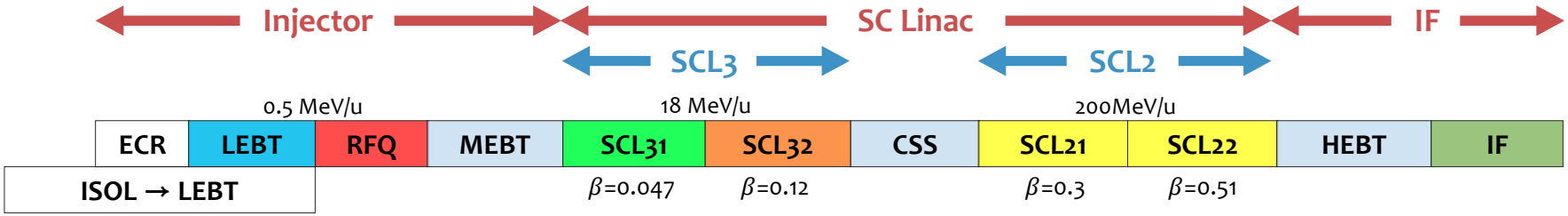
Accelerator System





※ SCL1 is postponed.

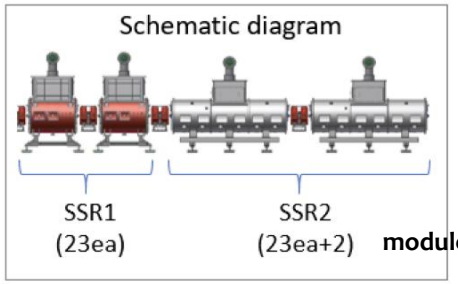
Accelerator System



SCL3

22 26 76 **Cavities (124)**

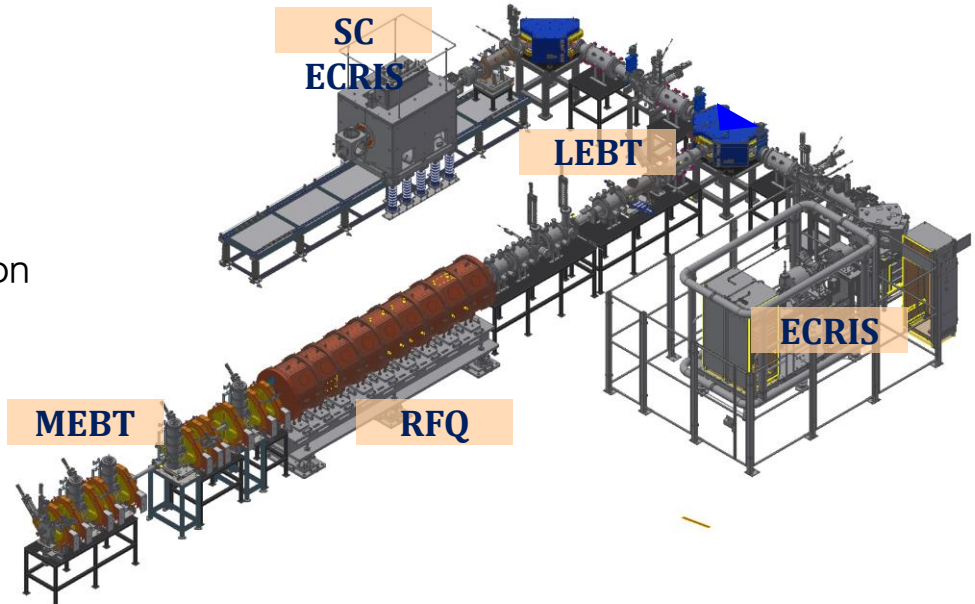
SCL2

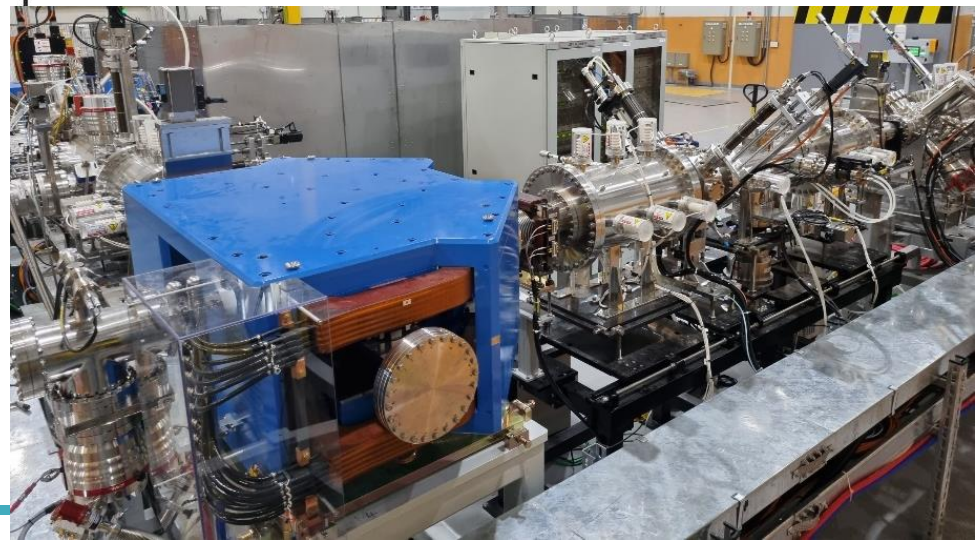


69 138+12 **Cavities (219)**

Injector System

- **Two ECR-IS on high voltage platforms**
  - 14.5 GHz ECR ion source
  - 28 GHz superconducting ECR ion source
- **LEBT (E = 10 keV/u)**
  - 10 keV/u, Dual bending magnet
  - Chopper & Electrostatic quads, Instrumentation
- **RFQ (E = 500 keV/u)**
  - 81.25 MHz, Transmission Eff. ~98%
  - CW RF Power 94 kW (SSPA: 150 kW)
- **MEBT (E = 500 keV/u)**
  - Four RF bunchers (SSPA: 20, 15, 2×4 kW)
  - Simple quadrupole magnets, Instrumentation





Cryogenic System

- SCL3 cryoplant (4.2 kW @ 4.5 K)

Compressors and Oil Removal System (WCS)

Cold Box(CB)

- SCL2 cryoplant (13.5 kW @ 4.5 K)

Compressors and Oil Removal System (WCS)

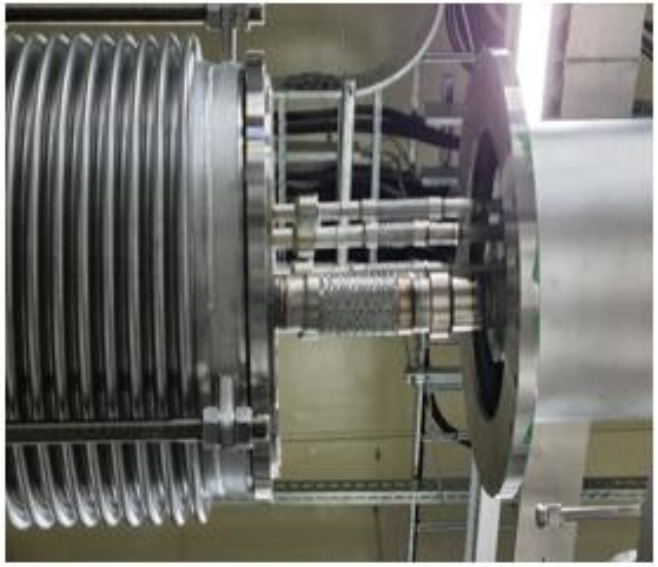
Cold Box (CB)

(Left warm side, right – cold side)

SCL3 Cryoplant was commissioned in Aug 2022

Cryogenic System

- Cryogenic Distribution System
  - All QWR VBx are installed and assembled (VBx-VBx, VBx-CM).
  - All HWR VBx are installed and assembled @ SCL3.
  - Cryogenic transfer Lines are installed
  - SSR1 VBx : 23 ea, SSR2 VBx : installed

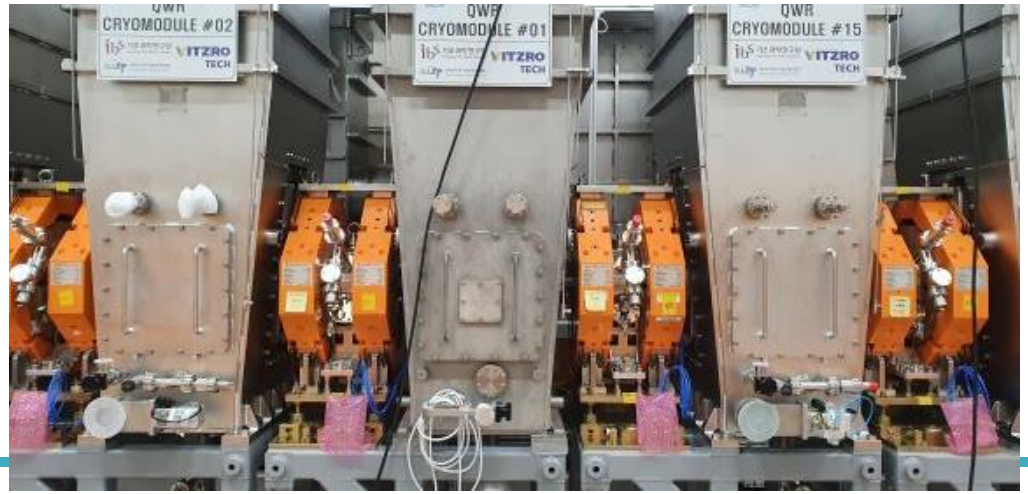


SCL3 Cryoplant and CDS were commissioned in Aug 2022

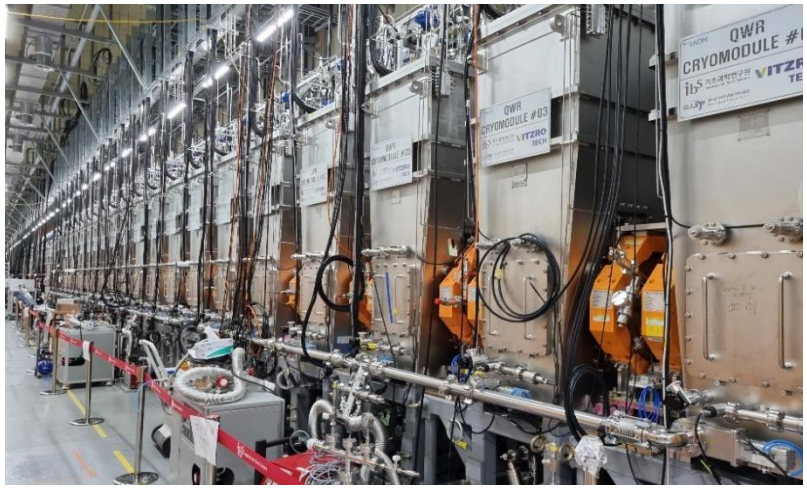
Assembly of SCL3 linac in the tunnel

(Cryomodule + Warm section) + (Cryomodule + Warm section)

- Cryomodule & Warm section is clean-assembled in the clean booth in the tunnel
- Total particle counts(size=0.5um above/10 mins) were less than 30 counts

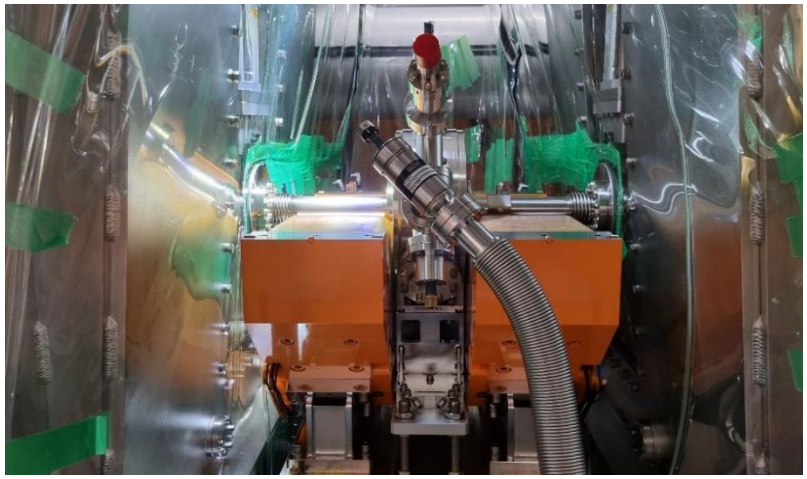


Superconducting linac SCL3 (tunnel and gallery)



QWR & HWR Cryomodules

Cryogenic Distribution to Cryomodules

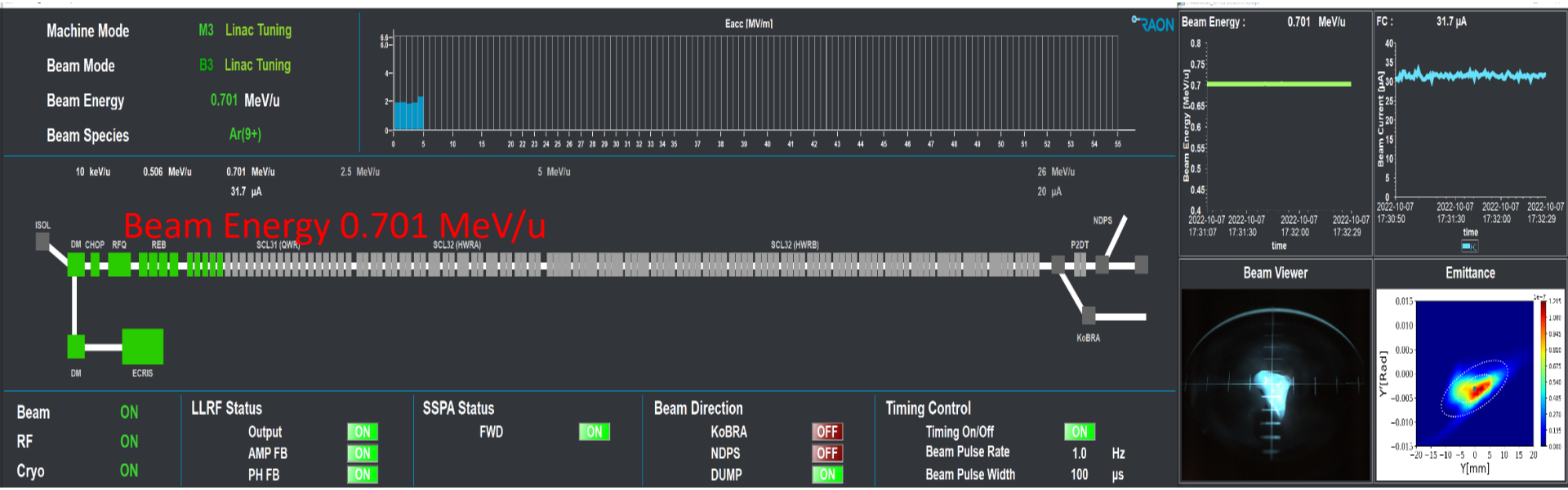


Clean beam line assembly

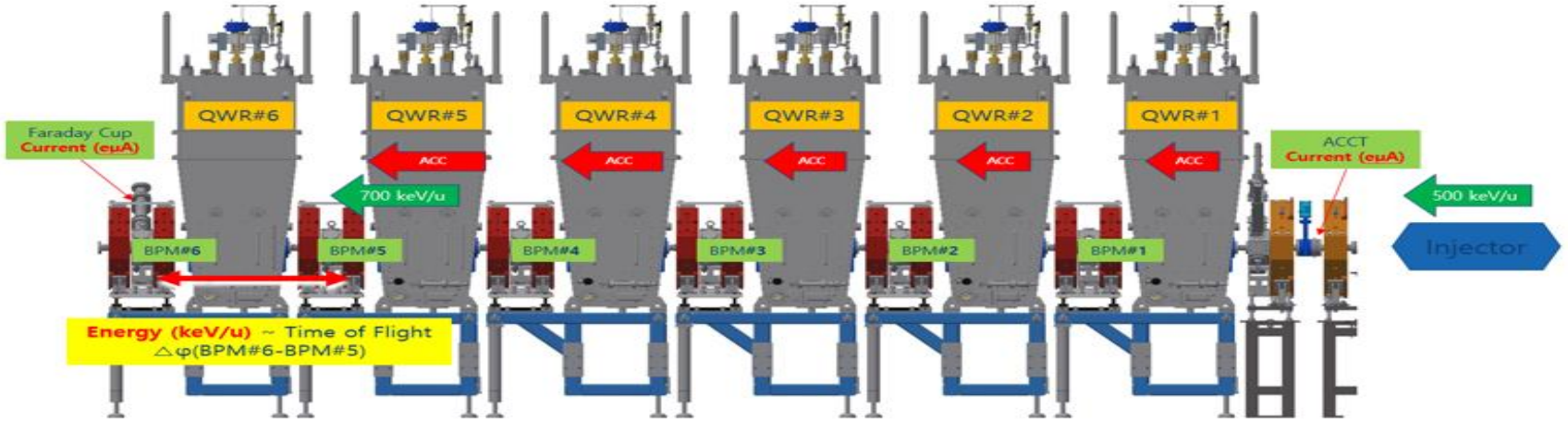
CM/Cryogenic Control Rack and SSPA

Installation completed in 2021 and beam commissioning finished in May 2023

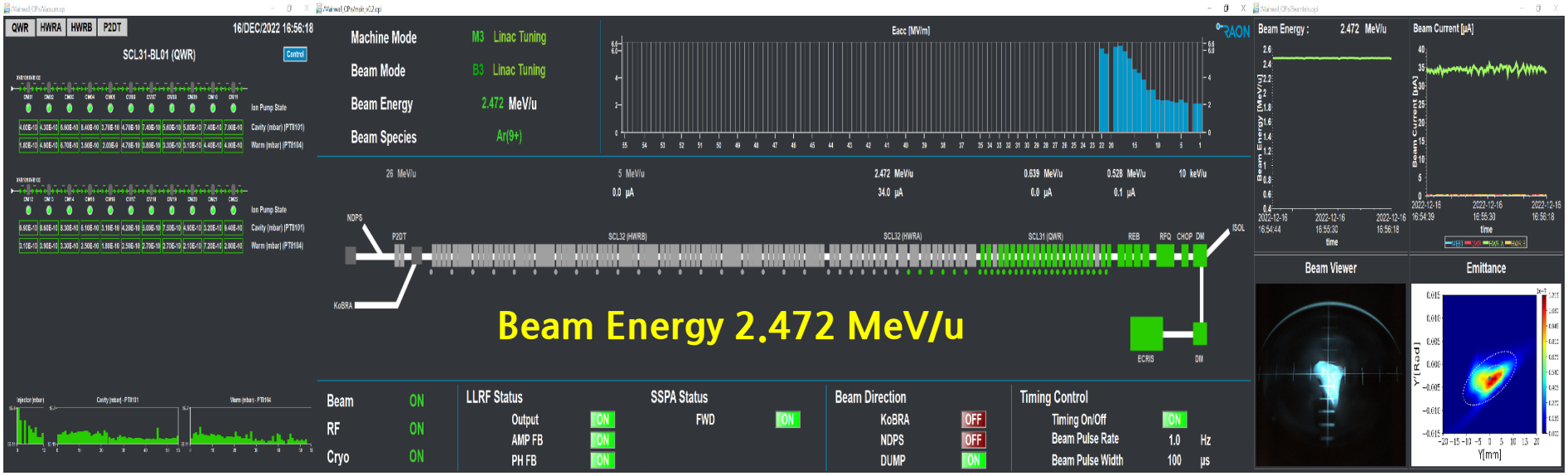
The 1st SCL3 Beam Commissioning (Oct. 7, 2022)



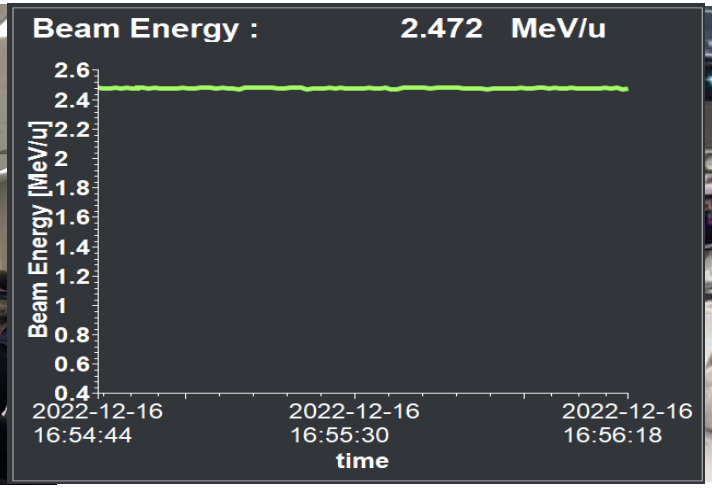
Ar^{9+} beams accelerated by QWR #1~#5 on Oct 7, 2022



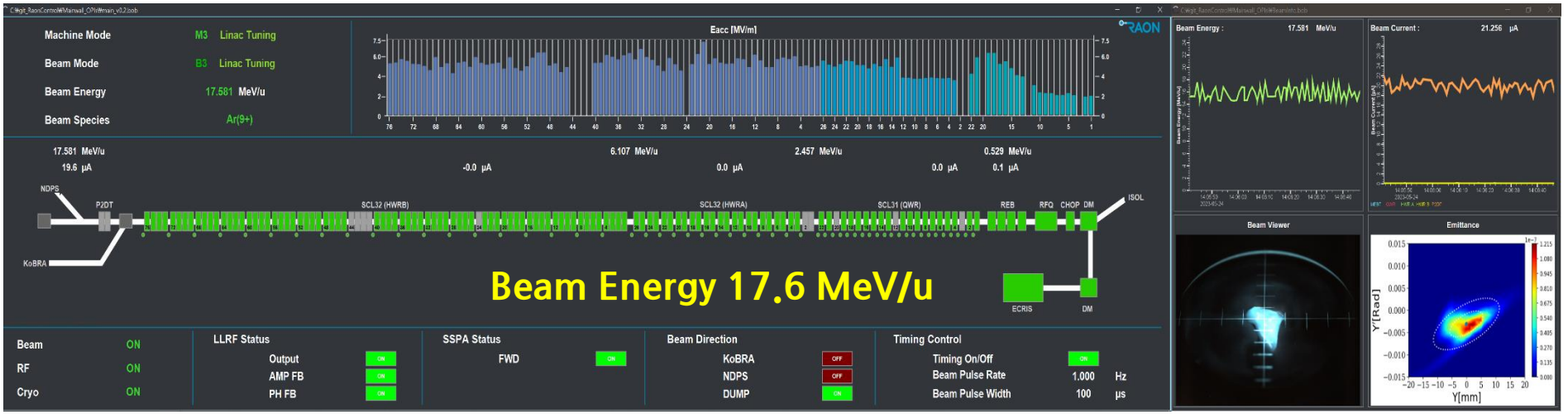
The 2nd SCL3 Beam Commissioning (Dec. 16, 2022)



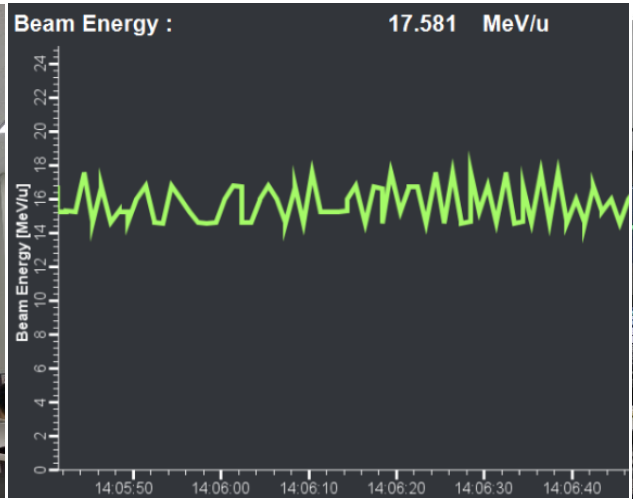
Ar^{9+} beams accelerated by QWR #1~#22 on Dec 16, 2022



The 3rd SCL3 Beam Commissioning (May 23, 2022)



Ar^{9+} beams accelerated by entire SCL3(QWR/HWR) on May 23, 2022

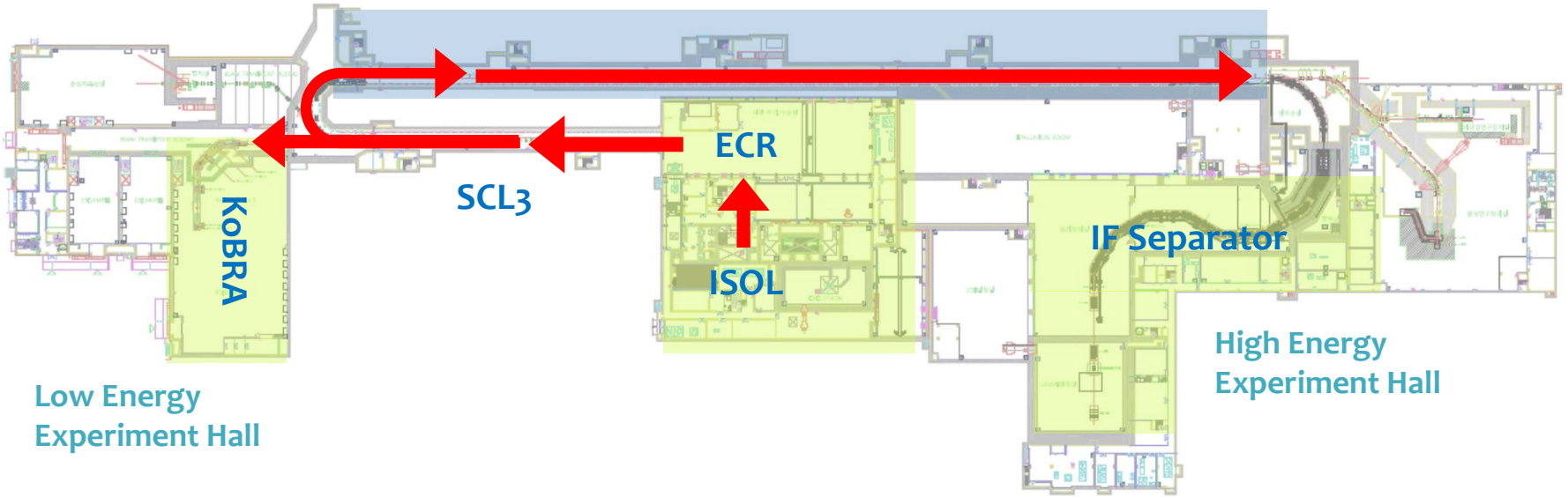


Status of Accelerator Commissioning

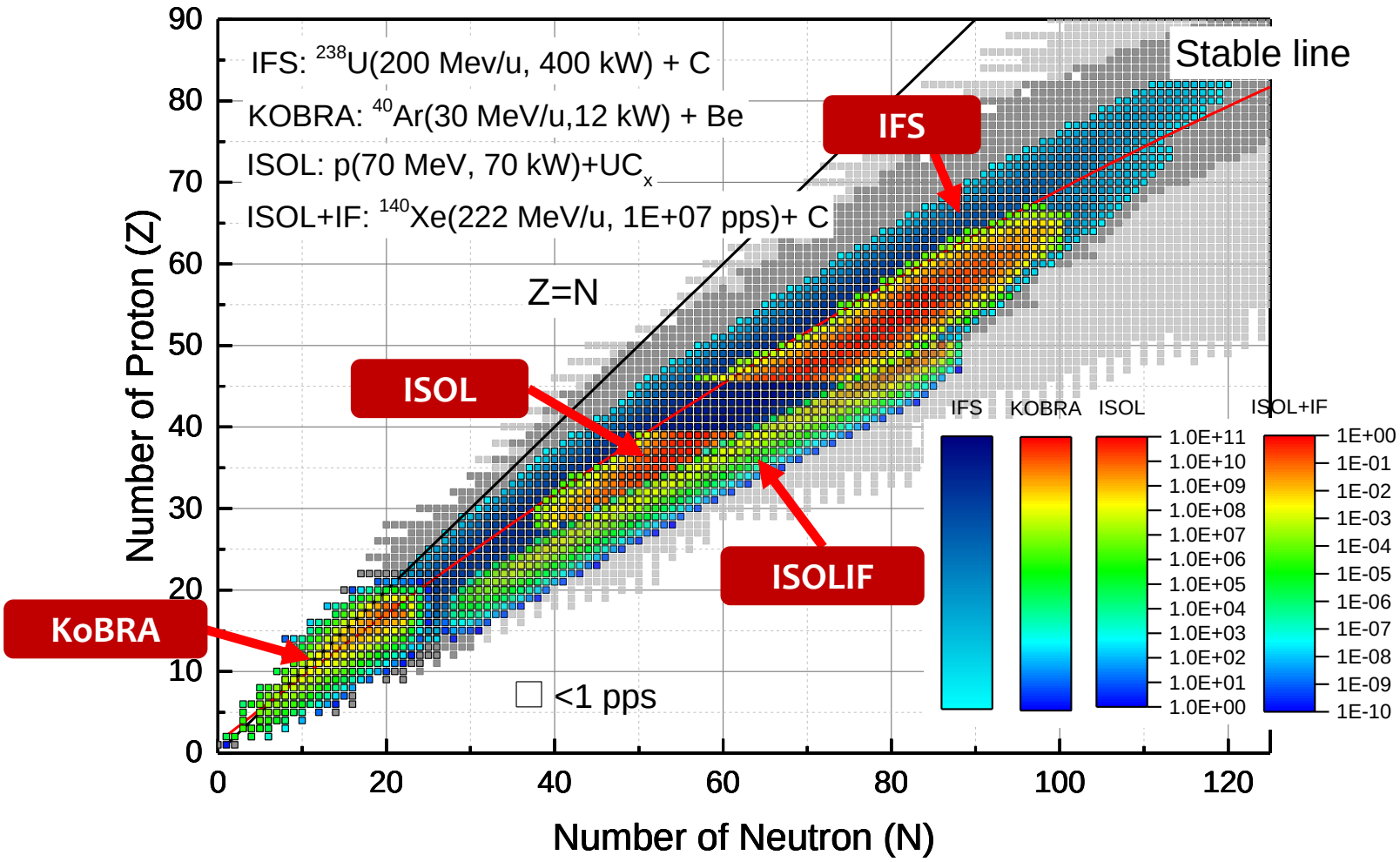
- **Injector beam commissioning completed, achieving machine setting and key measurements :**
  - measured beam parameters (emittance, Twiss parameters, beam sizes, etc.)
  - capable of controlling LEBT and MEBT beam optics freely as needed
  - achieved beam transmission of 95% max (routinely > 90%)
  - machine verification including diagnostics devices
- **As soon as the cryoplants started operation, it took just one month to cool the linac and transmit the RF.**
- **Linac (SCL3) beam commissioning was successfully done**
  - beam commissioning of QWR section in Dec. 2022
  - beam commissioning of HWR section in May 23, 2023
  - **Ar^{9+} delivered to KoBRA target in May 31, 2023**
- **SCL3 warm-up and maintenance from June, 2023**
- **Beam delivery to experiments (KoBRA) in early 2024**

Uniqueness of RAON : RIB Production

	KoBRA	ISOL	IF Separator
RIB Production & Acceleration Mode	ECR (SIB) → SCL3 → KoBRA production target	Cyclotron (p) → TIS (RIB) → SCL3	ECR (SIB) or ISOL (RIB) → SCL3 → SCL2 → IF (RIB)
Production Mechanism	Direct reactions & Multi Nucleon Transfer	p induced fission of U	Projectile Fragmentation (U fission)
RIB Energy	< a few tens of MeV/u	> a few keV/u	< hundreds of MeV/u
	(Under commissioning)	(Under commissioning)	(Not ready)



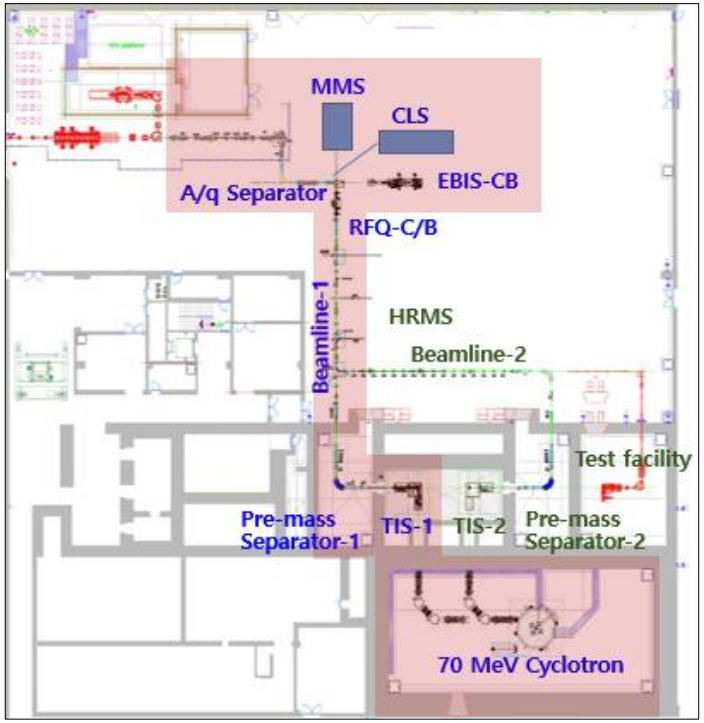
Expected RIs from RAON



RAON is expected to access more neutron-rich regions of the nuclear chart

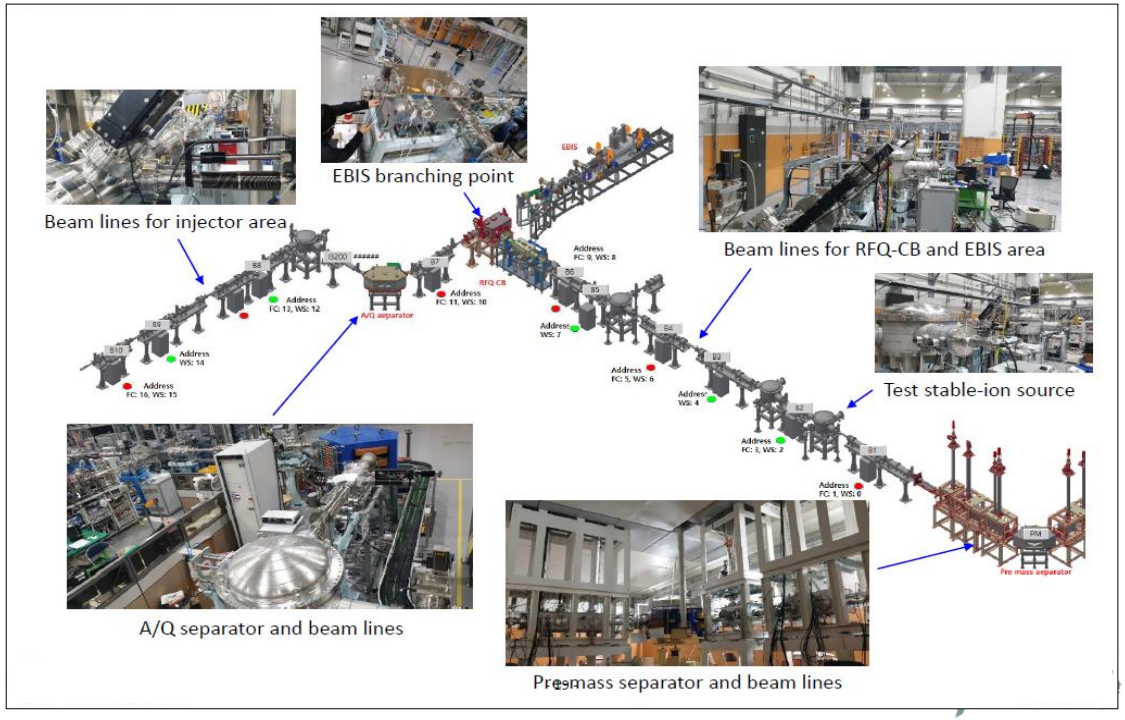
ISOL System

Target ion Source	Pre - Separator	RFQ Cooler	EBIS	Post linac
20 keV, $^{132}Sn^{1+}$	m/δm = 400	3πmm mrad, < 5ev	10 keV, $^{132}Sn^{33+}$	Charge state n+



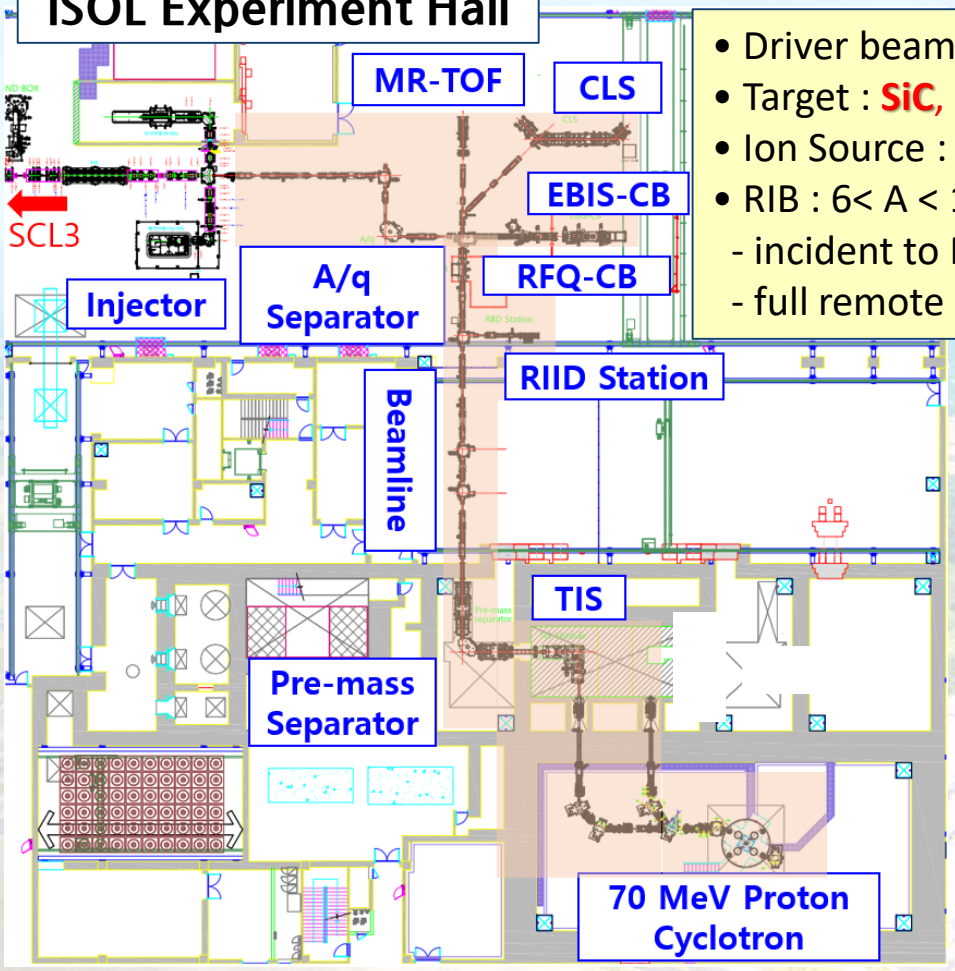
- In 2021, ISOL beam lines were commissioned with a Cs souce
- In 2023, ISOL system was commissioned with SiC target

- **Driver beam :** proton 35<K<70 MeV, up to 70 kW
- **Target :** SiC, BN, MgO, LaC_2, UC_x, CaO, BeO, etc
- **Ion Source :** Surface, RILIS, Plasma
- **RIB :** 6< A < 160, 10<K< 80 keV, 10^8 pps(Sn), >90% purity @Exp.
  - incident to RFQ with 10 keV/u for post acceleration
  - fully remote handling maintenance system with TIS modularization

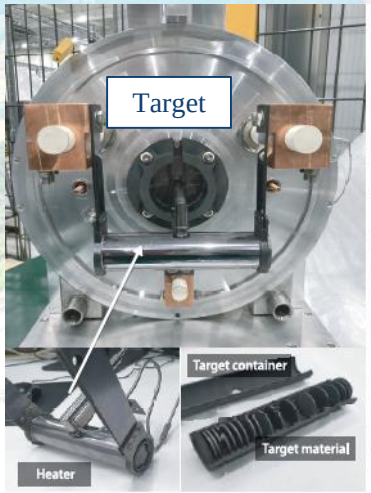


ISOL System

ISOL Experiment Hall



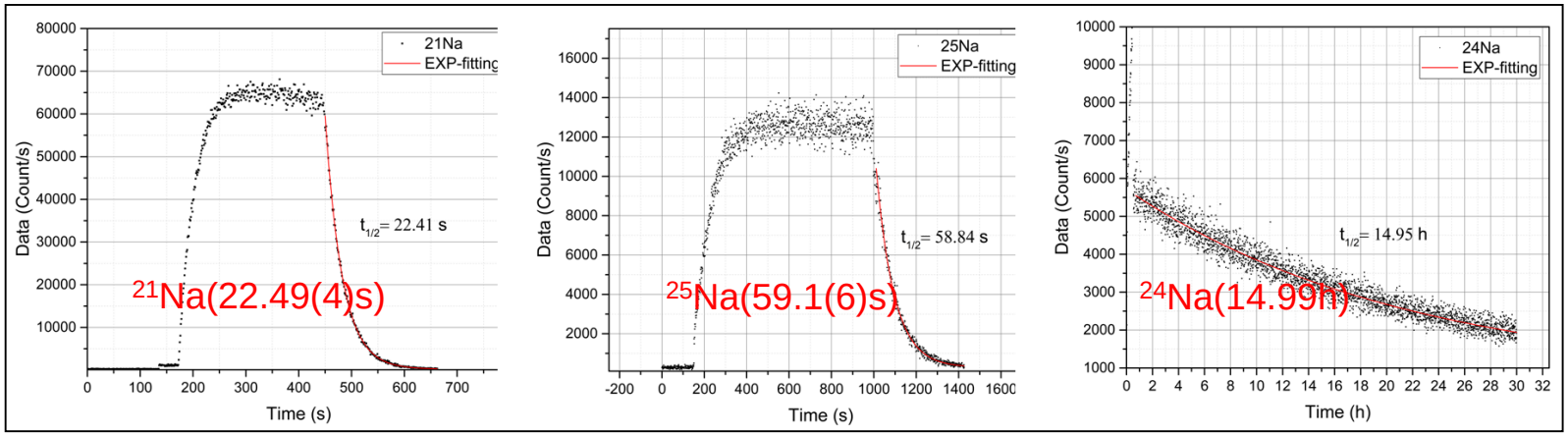
- Driver beam : proton 35 ~ 70 MeV, up to 70 kW
- Target : **SiC**, BN, MgO, LaC_2, UCx, CaO, BeO, etc
- Ion Source : **Surface, RILIS**, Plasma
- RIB : 6< A < 160, 10<K< 80 keV, 10^8 pps(Sn), >90% purity @Exp.
  - incident to RFQ of post accelerator 10 keV/u
  - full remote maintenance system with TIS modularization



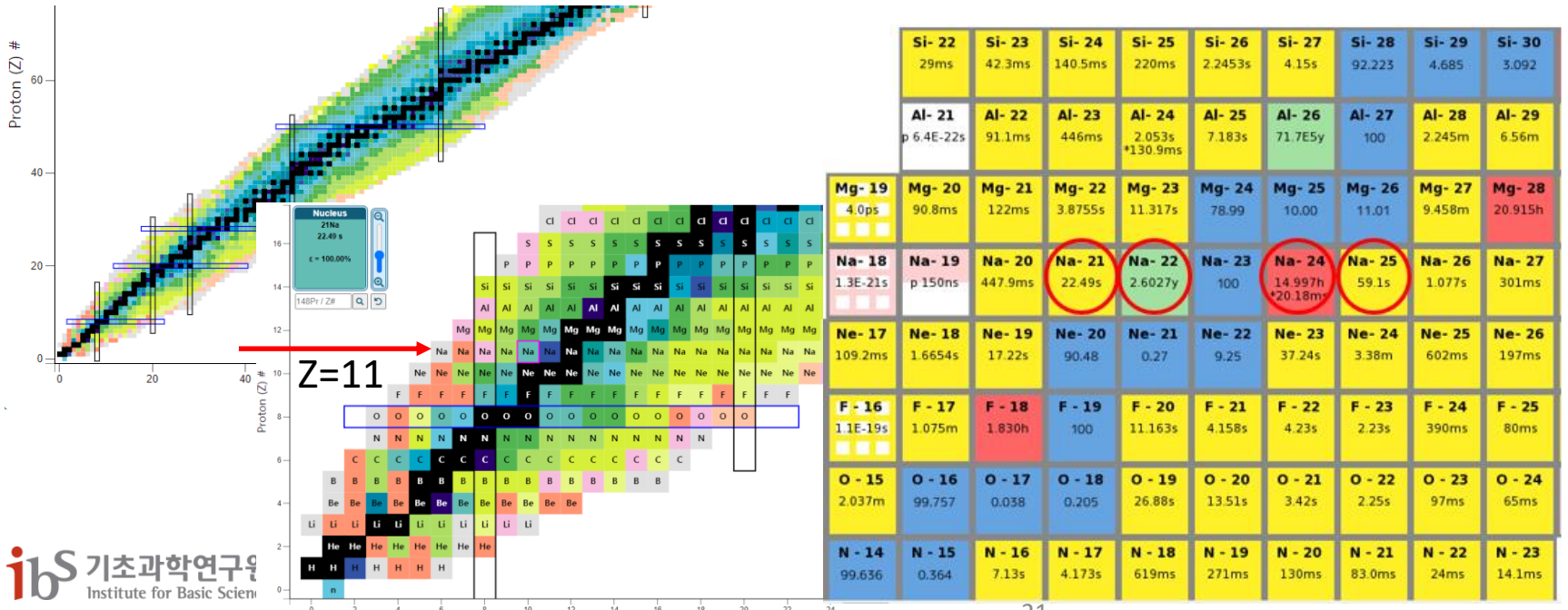
- ISOL beam lines including sub-systems were commissioned with a Cs ion source in Dec 2021
- **RI beam commissioning using SiC target (March 2023)**

First ISOL Beam Commissioning with RIB ($^{21, 22, 24, 25}$Na)

The first RI Production and transport at ISOL on March 3, 2023



The measured half-lives of Na isotopes by using PMT & Scintillators

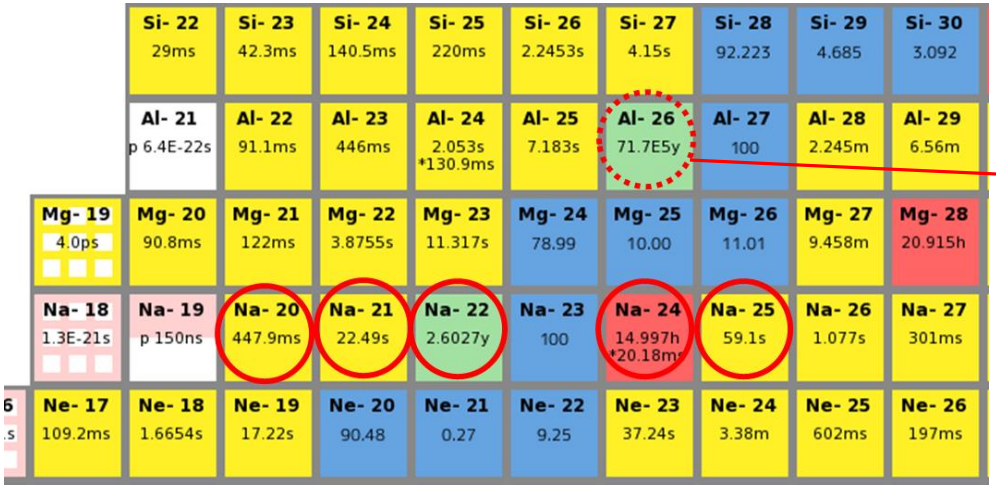


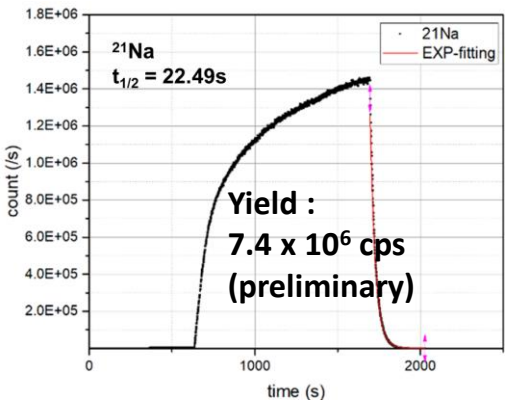
Second ISOL Beam Commissioning with RIB (^{26m}Al)

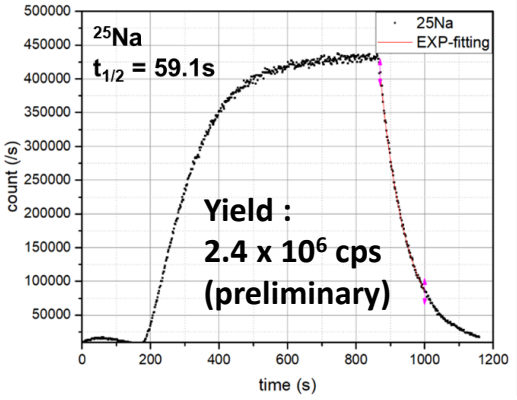
- **Experimental results**

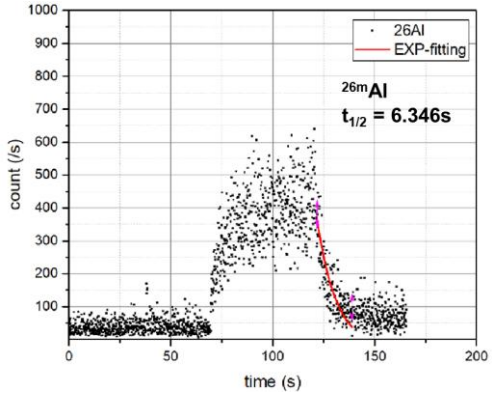
The second RI Production on May 23, 2023

  - Proton beam 70 MeV, 1.2 μ A
  - SiC target temperature ~1,400℃ (Ta heater ohmic heating 1.8 kW)
  - Measured RIs (so far June 1)





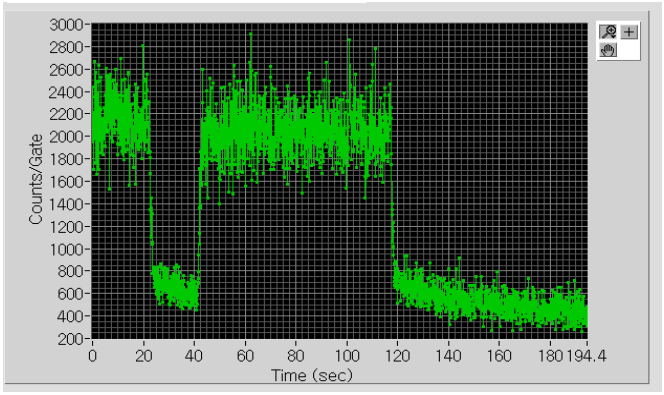


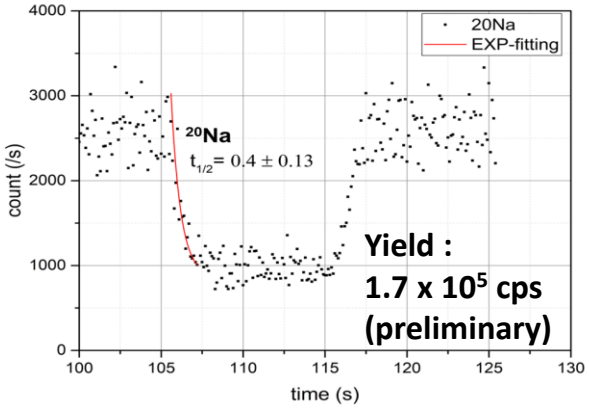


< Measurement results using scintillator + PMT >

Second ISOL Beam Commissioning with RIB (^{20}Na)

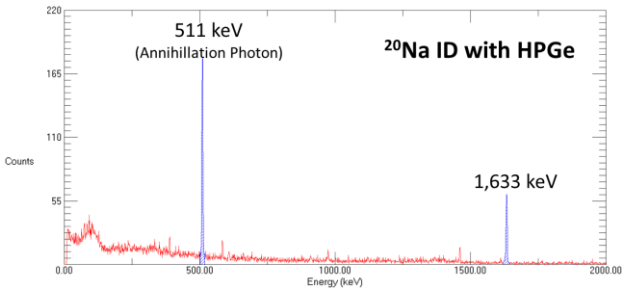
- **Measured results of ^{20}Na (half-life : 0.4479 s)**

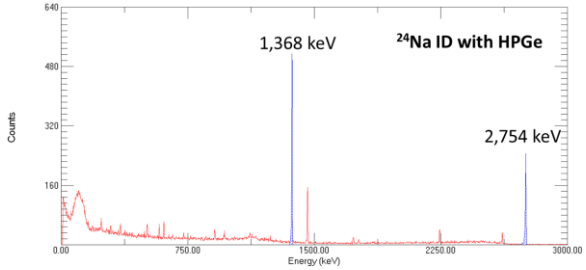


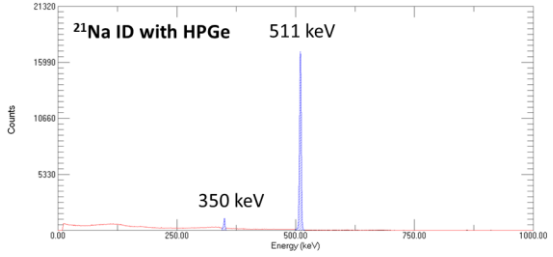


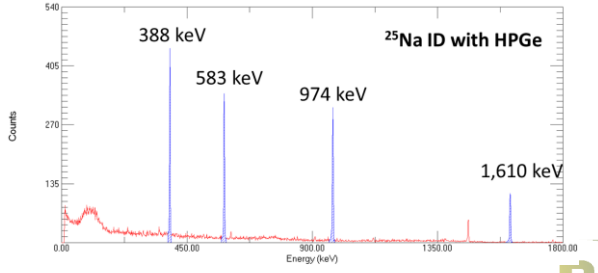
< Measurement result of ^{20}Na using scintillator + PMT >

- **Na RIs detected by HPGe at RIID**







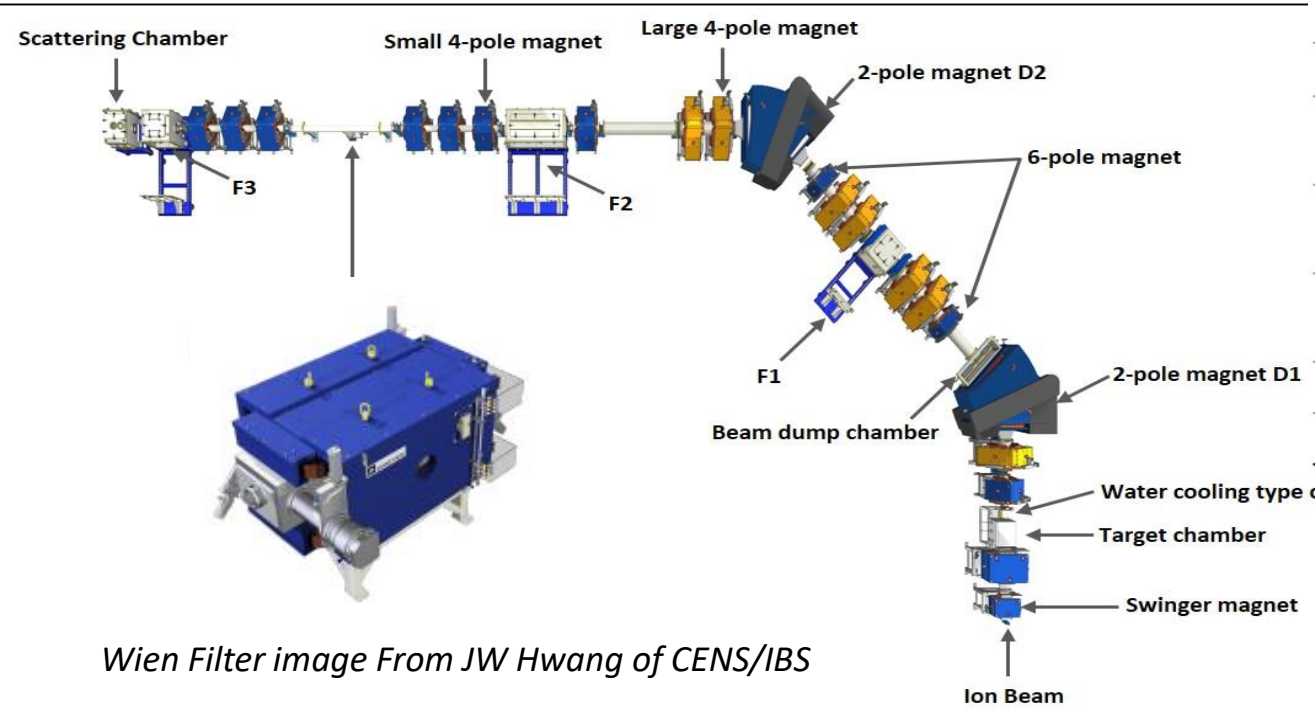


KoBRA spectrometer

KoBRA(**Ko**rea **B**road acceptance **R**ecoil spectrometer and **A**pparatus)

Multipurpose spectrometer for nuclear structure and nuclear astrophysics using stable or RI beams in the energy range of 1~40 MeV/u

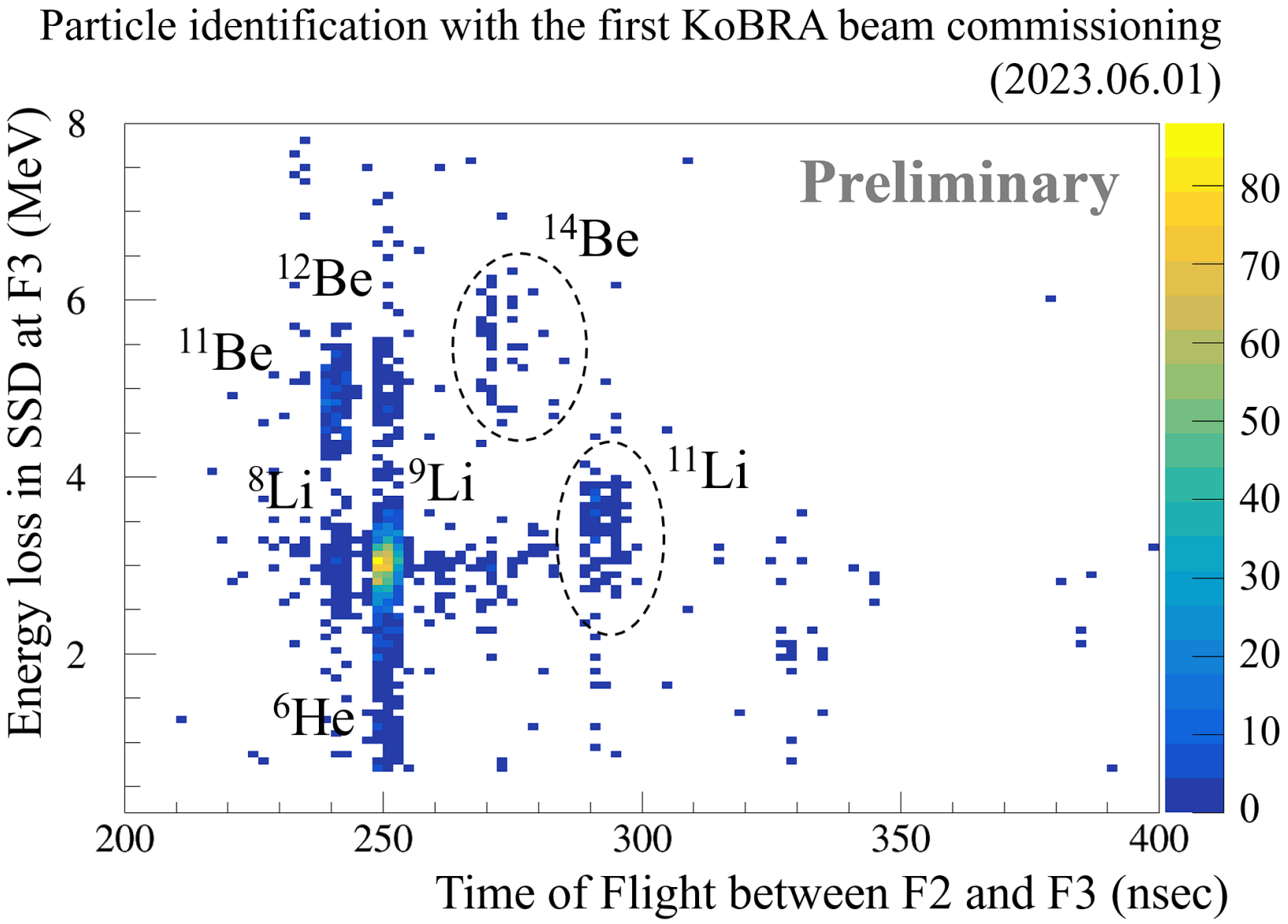
- RI production at a few MeV/u and 20 ~ 40 MeV/u using a stable beam from ECR-IS
- Recoil mass spectrometer (<a few MeV/u) for direct measurement of the radiative capture process, using RI beams from ISOL



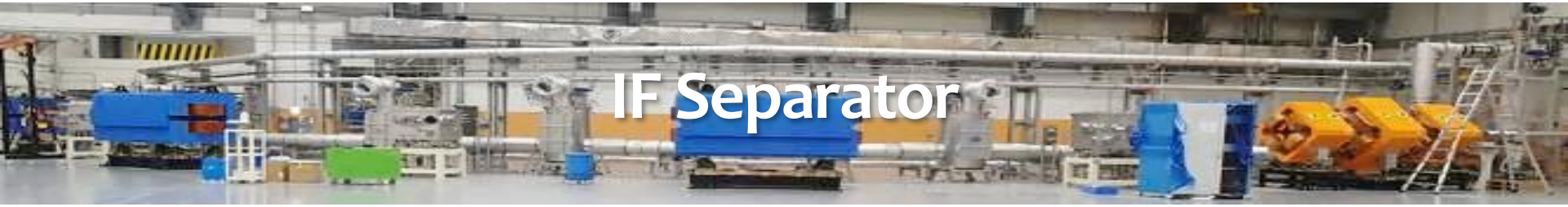
Wien Filter image From JW Hwang of CENS/IBS

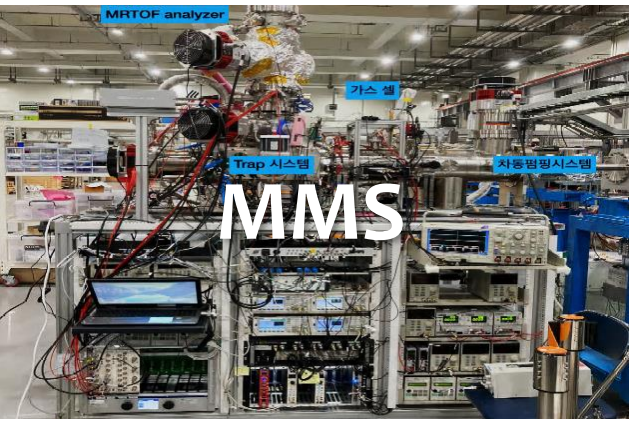
Magnetic rigidity	0.25 – 3.0 Tm
Angular acceptance	80 mrad (H) 200 mrad (V)
Momentum acceptance	8%
Momentum resolving power at F1	2100 at 2 mm beam size
Mass resolving power (with Wien filter)	750 at 2 mm beam size
Beam swinger	up to 12 degree for 3 Tm
High order correction	up to 4th order
Degrader at F1	Homogeneous

First production of RIs at F3 of KoBRA spectrometer (Ar + C)



Other Experimental Systems





All exp. systems are installed and machine-commissioned by 2022

MOUs with 17 International Institutes

Summary

- The beam commissioning of accelerator systems is done.
- Initial beam commissioning of the KoBRA spectrometer is done.
- NDPS is expected to be prepared for use in 2024
  Fission experiments are planned.
- Candidates of early stage experiments are under discussion with users.
- Beams will be provided to domestic users first in early 2024.
- The first PAC may be held in late 2024.
- RAON will provide new opportunities not only in nuclear physics, but also in nuclear data and other applications.
- International collaboration has been essential.
- Hope to provide beams to the international users soon.

- The 17th international symposium on Nuclei in the Cosmos
  - **September 17(Sun) - 22(Fri), 2023**
  - **IBS, Daejeon, Korea**
  - **https://indico.ibs.re.kr/event/nic2023**
- There will be an “NIC school” from Sep. 11 to 15.