November 26, 2021
IWM-EC 2021
via zoom (GANIL)

Status of the RI accelerator in Korea and experimental preparations

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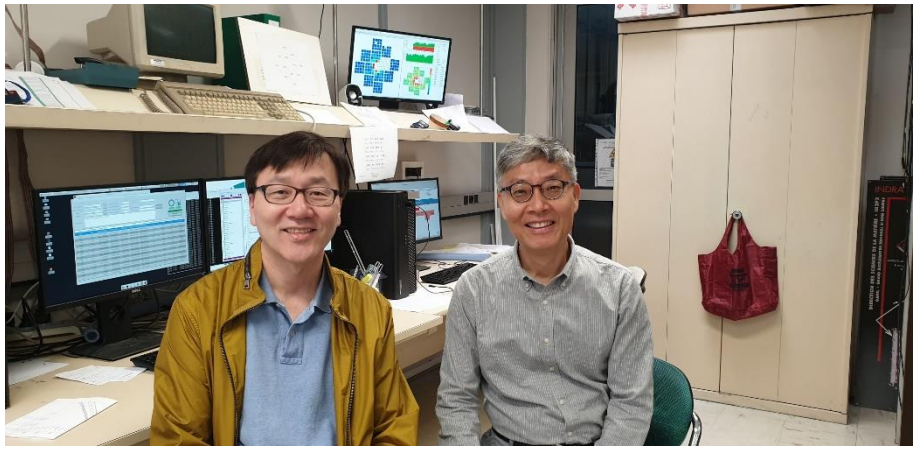
Most of the slides are from Taeksu Shin from RISP and Tony Ahn from CENS

Visited GANIL three times in 2019



1. Overview Rare Isotope Science Project (RISP)

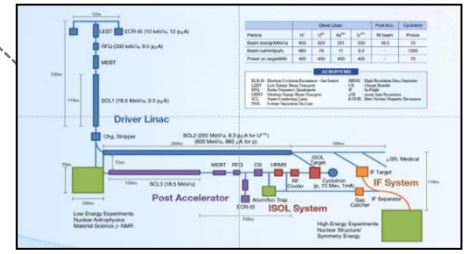
- **Goal:** To build **a heavy ion accelerator complex RAON,** for **rare isotope science** research in Korea.

  * RAON - Rare isotope Accelerator complex for ON-line experiments

- **Budget: KRW 1,518 billion (US$ 1.32 billion, 1$=1,146krw)**
  - accelerators and experimental apparatus : 522.8 billion won
  - civil engineering & conventional facilities : 996 billion won (incl. site 357 billion won)
- **Period: 2011.12 ~ 2021.21 (1st Phase)**

System Installation Project

Development, installation, and commissioning of the accelerator systems that provides high-energy (200MeV/u) and high-power (400kW) heavy-ion beam



- **Providing high intensity RI beams by ISOL and IF**
  ISOL: direct fission of ^{238}U by 70 MeV proton
  IF: 200 MeV/u ^{238}U (intensity: 8.3 pμA)
- **Providing high quality neutron-rich beams**
  e.g., ^{132}Sn with up to 250 MeV/u,
  up to 10^9 particles per second

Facility Construction Project

Construction of research and support facility to ensure the stable operation of the heavy-ion accelerator, experiment systems, and to establish a comfortable research environment

※ Accelerator and experiment buildings, support facility, administrative buildings, and guest house, etc.

- **Providing More exotic RI beam production by combination of ISOL and IF**

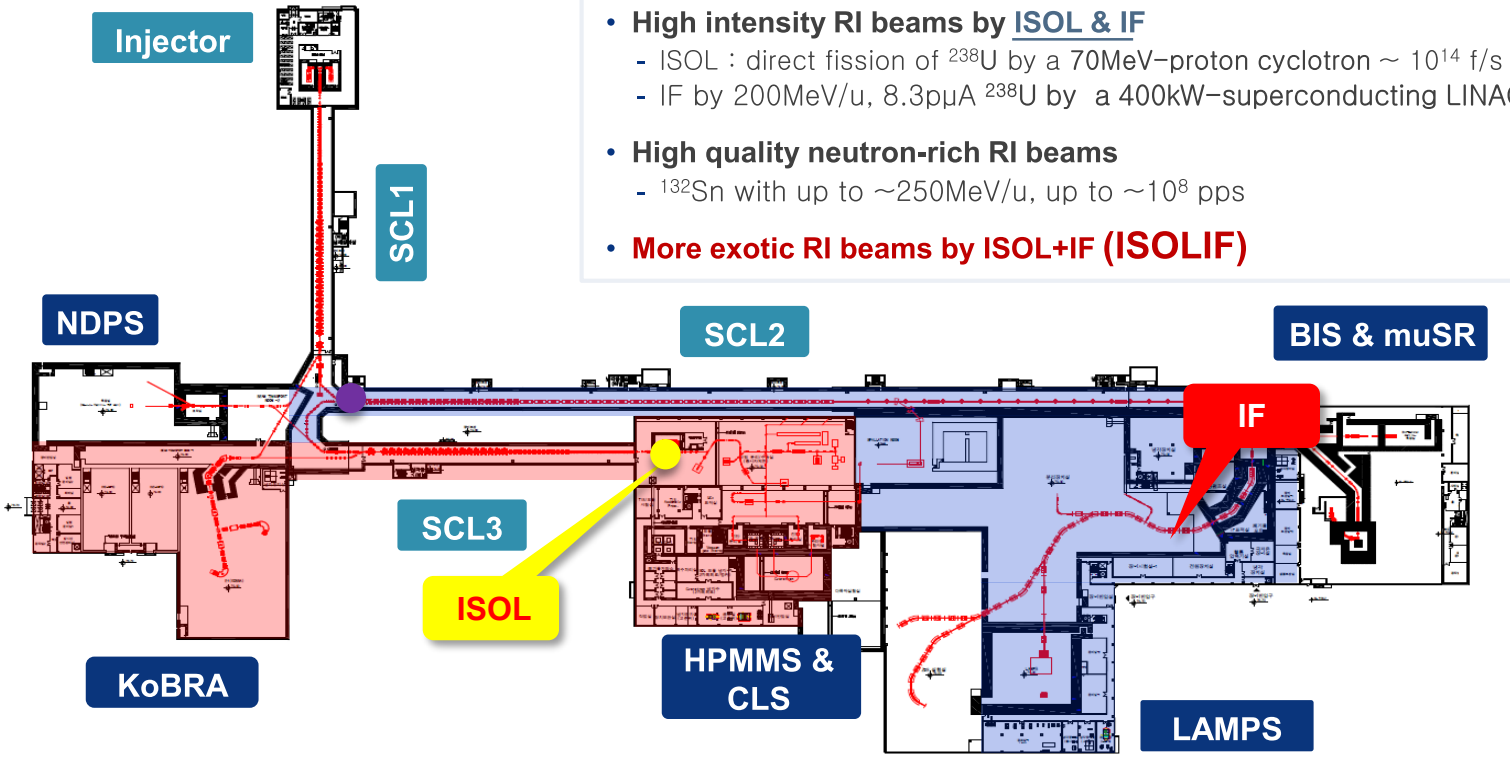
RAON Layout

Accelerator System · Conventional Utilities
RI producing System · Experimental System

- Campus Area : **952,066**㎡ (including the reservation area of **144,640**㎡)
- Building Area : **76,259**㎡(**11** bldgs) with total bldgs. Area of **116,252**㎡

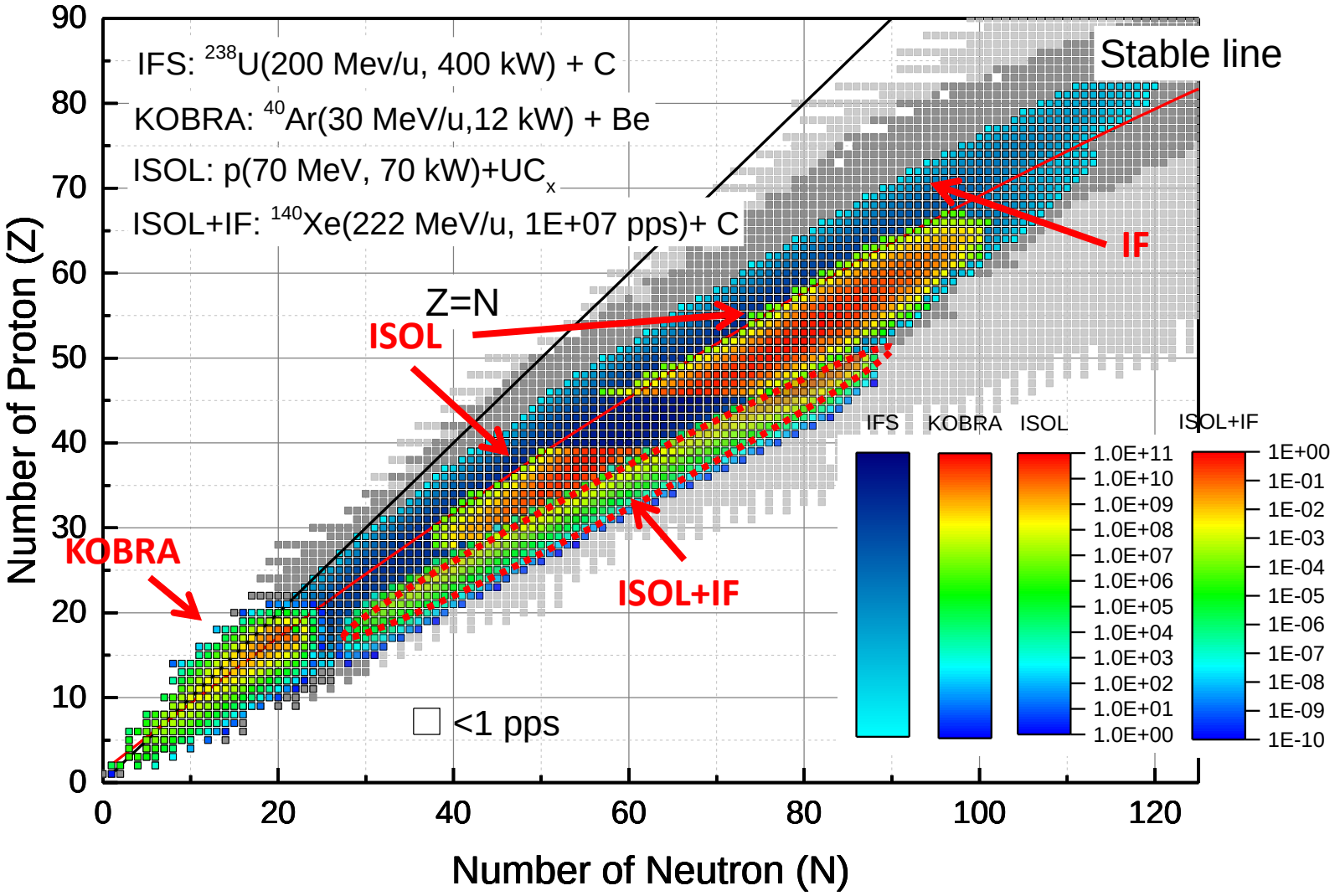
RAON Concept (ISOLIF)

Accelerator complex for producing rare isotope beams



- **High intensity RI beams by ISOL & IF**
  - ISOL : direct fission of ^{238}U by a 70MeV-proton cyclotron ~ 10^{14} f/s
  - IF by 200MeV/u, 8.3pμA ^{238}U by a 400kW-superconducting LINAC
- **High quality neutron-rich RI beams**
  - ^{132}Sn with up to ~250MeV/u, up to ~10^{8} pps
- **More exotic RI beams by ISOL+IF (ISOLIF)**

SCL1 has been decided to be pended
SCL3 is going to be taking a role of SCL1 in the early operation



- **RAON will provide access to unexplored regions of the nuclear chart**

1. Overview Project Milestone

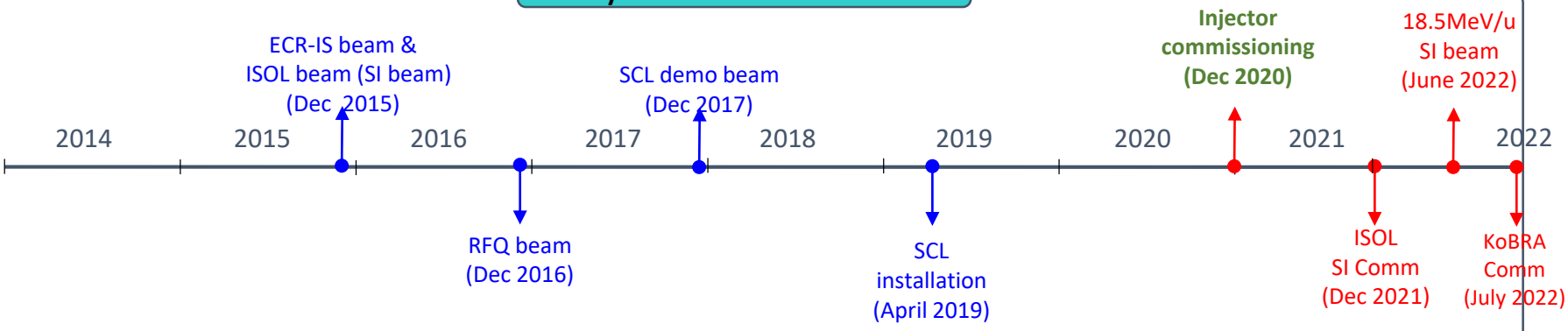
(2018) SCL3 manufacturing, SCL2 Prototype

(2019) SCL3 Installation, SCL2 manufacturing

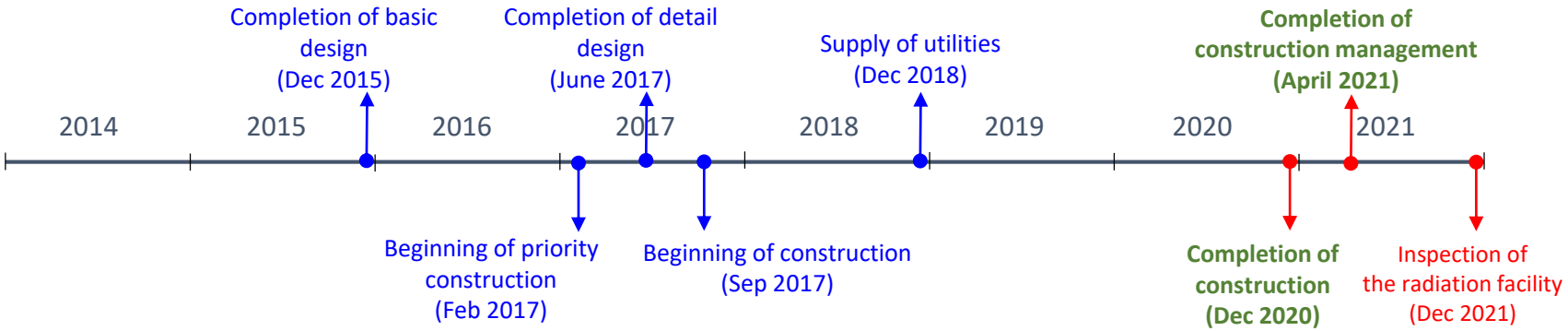
(2021~22) SCL3 Beam Commissioning/ Const. Completion

(2022) KOBRA operation/ Project Completion

System Installation



Facility Construction

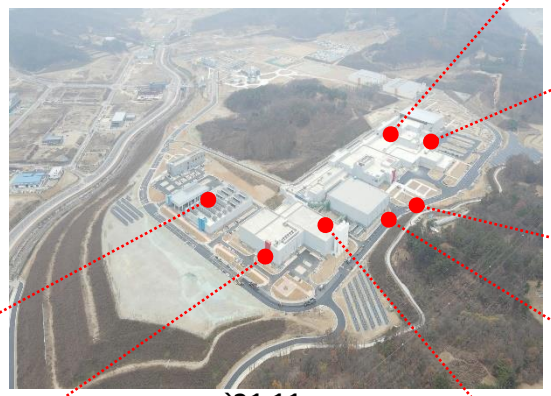


● View of Construction Place (`21.11)


<`17.01>


<`18.01>


<`19.01>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<Assembly Bd.>


<SRF Test Bd.>


<High Energy Exps.>


<Main Control Center>

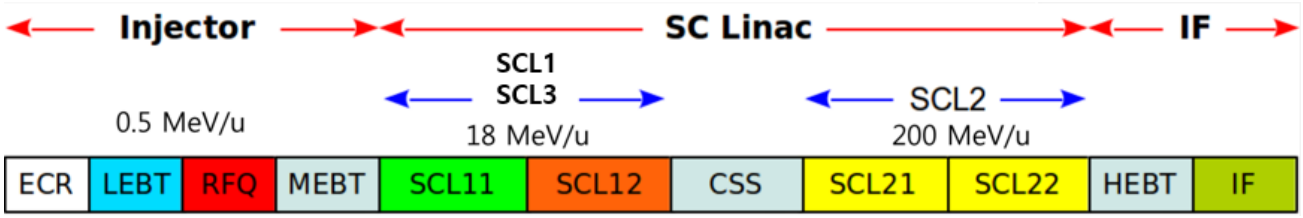

<Low Energy Exps.>

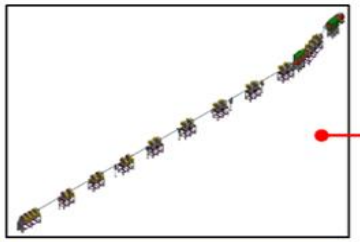

<SCL3>


<ISOL & Cryoplant>

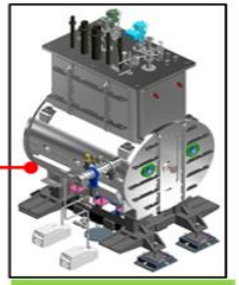
Part 2.

Accelerator Systems

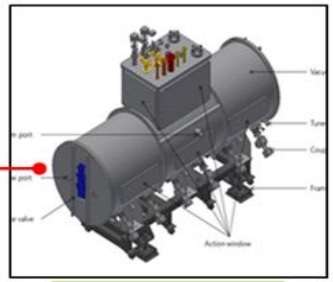




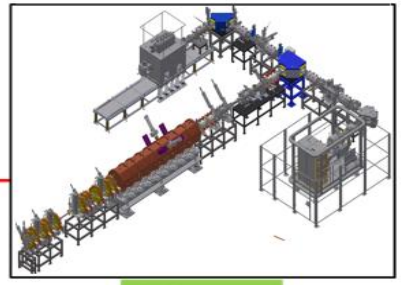
SCL3-KoBRA beam line



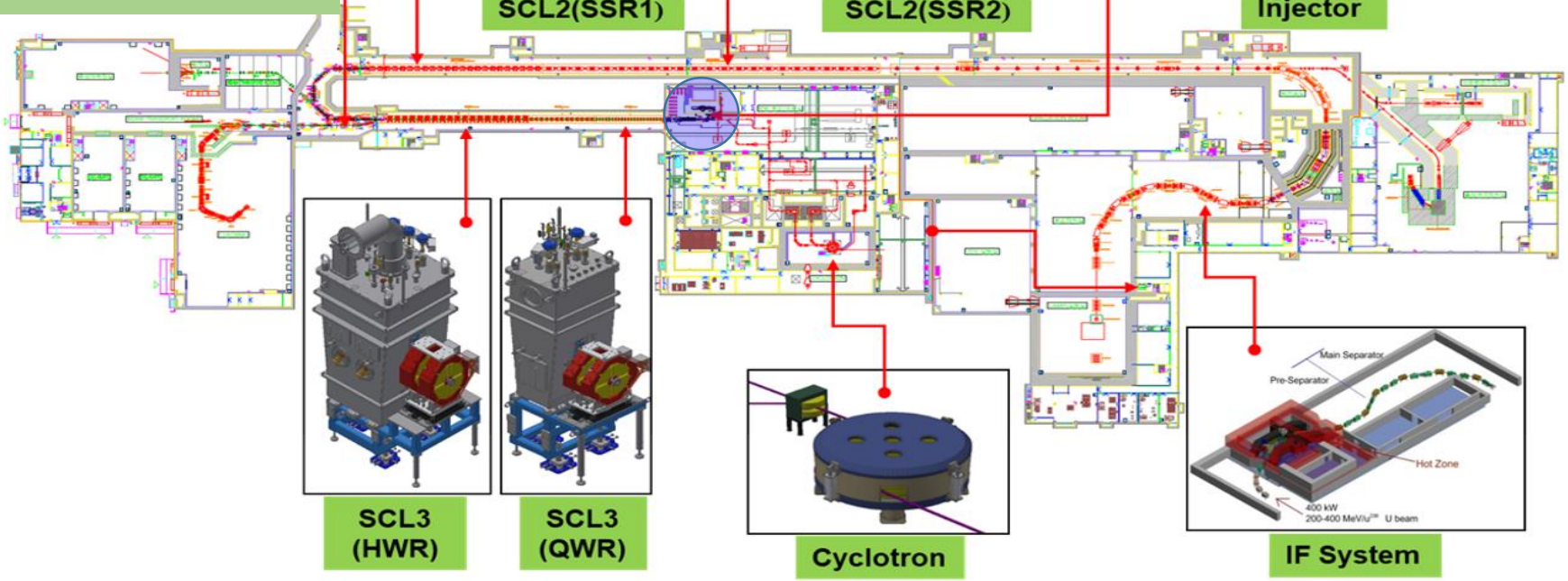
SCL2(SSR1)



SCL2(SSR2)



Injector



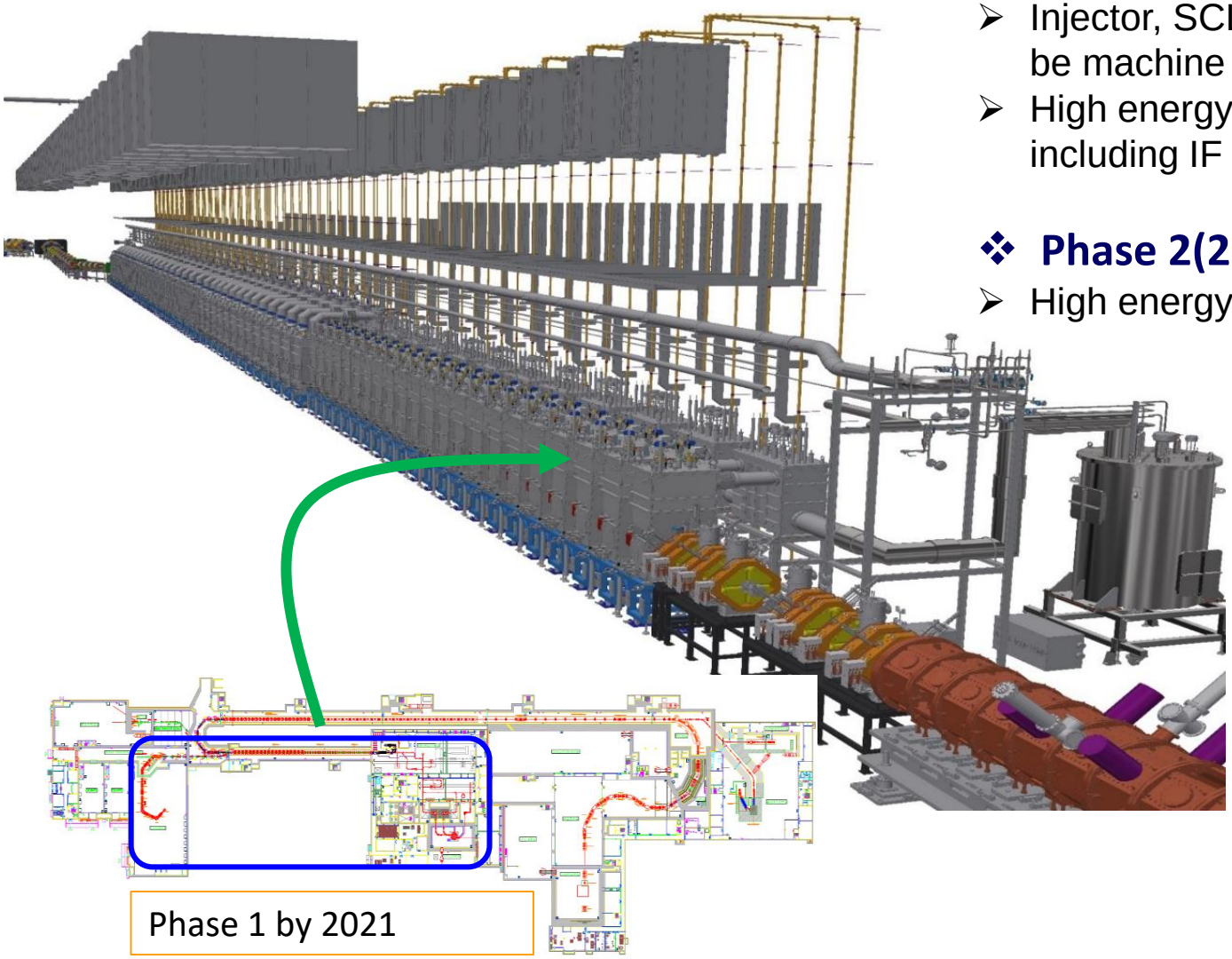
SCL3 (HWR)

SCL3 (QWR)

Cyclotron

IF System

Accelerator System



Phase 1 by 2021

❖ Phase 1(~2021)

- Injector, SCL3 including ISOL to be machine commissioning
- High energy experimental system including IF system to be installed

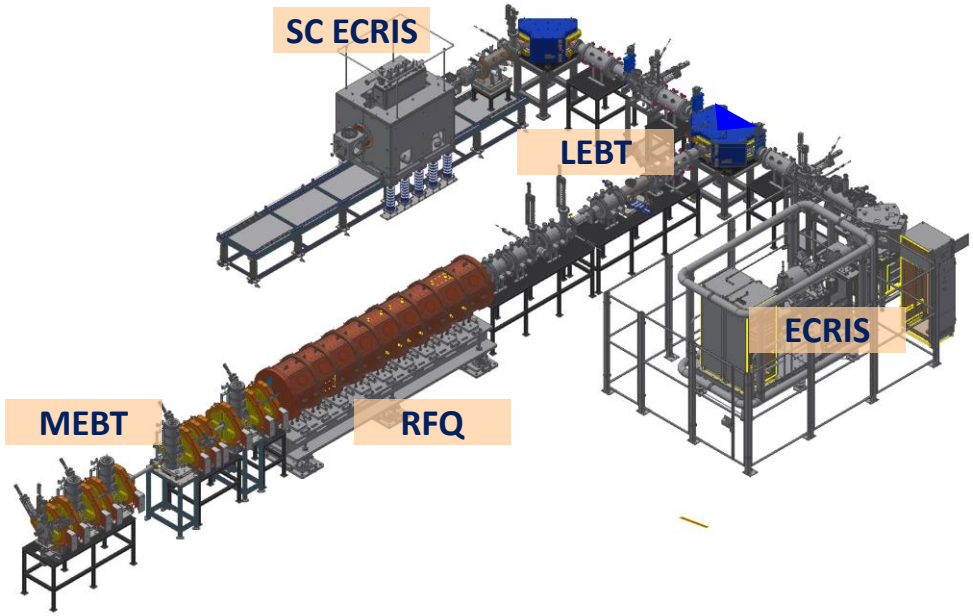
❖ Phase 2(2022~)

- High energy Linac, SCL2

SCL3 → installation by 2021 & commissioning on 2022

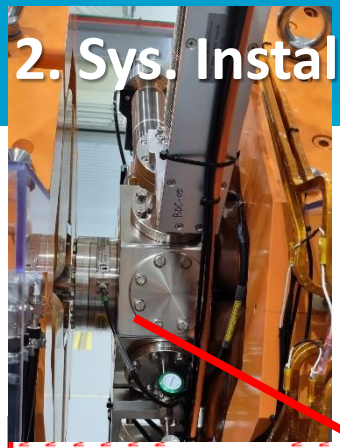
2. Sys. Install. RAON Injector System

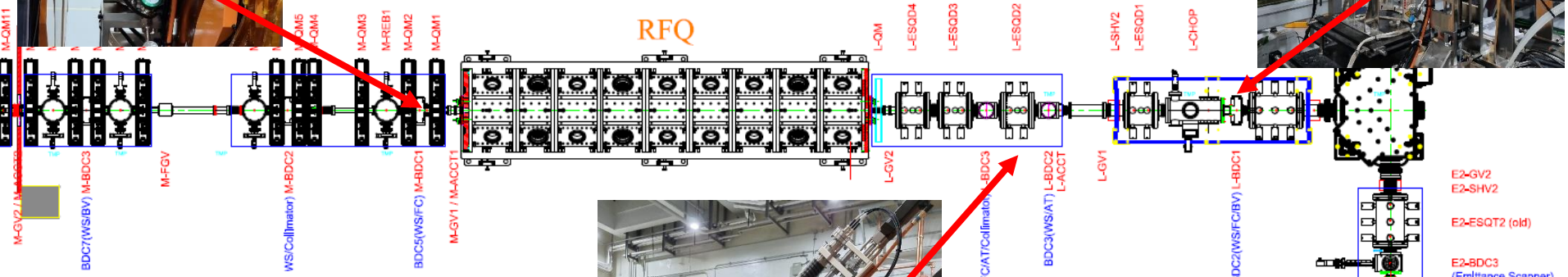
- **Two ECR-IS on high voltage platforms**
  - 14.5 GHz ECR ion source
  - 28 GHz superconducting ECR ion source
- **LEBT (E = 10 keV/u)**
  - 10 keV/u, Dual bending magnet
  - Chopper & Electrostatic quads, Instrumentation
- **RFQ (E = 500 keV/u)**
  - 81.25 MHz, Transmission Eff. ~98%
  - CW RF Power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

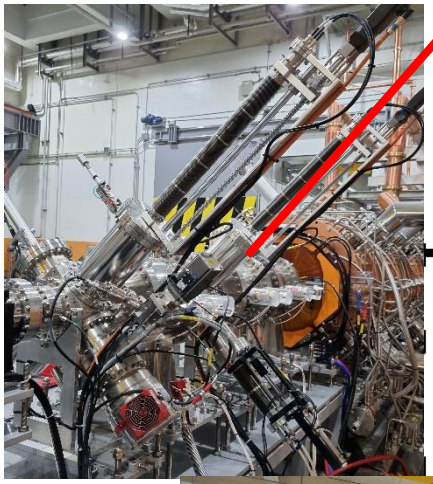


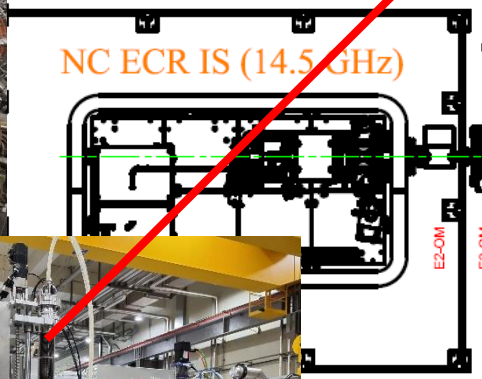
Installation completed and beam commissioning from October, 2020

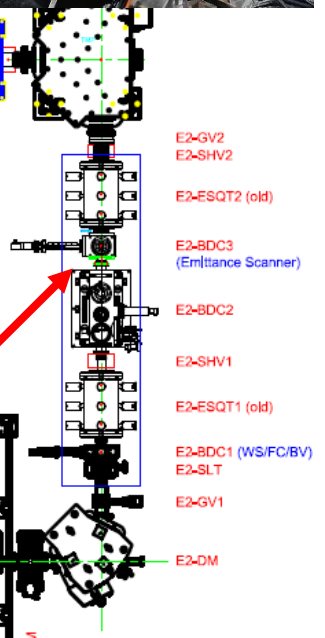
2. Sys. Install. RAON Injector Instrumentation







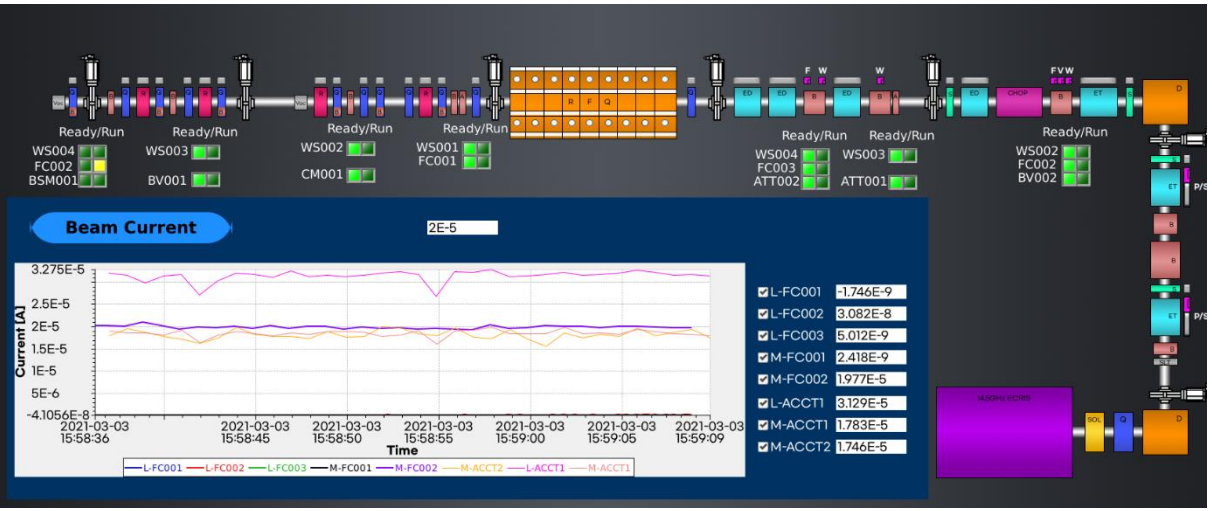


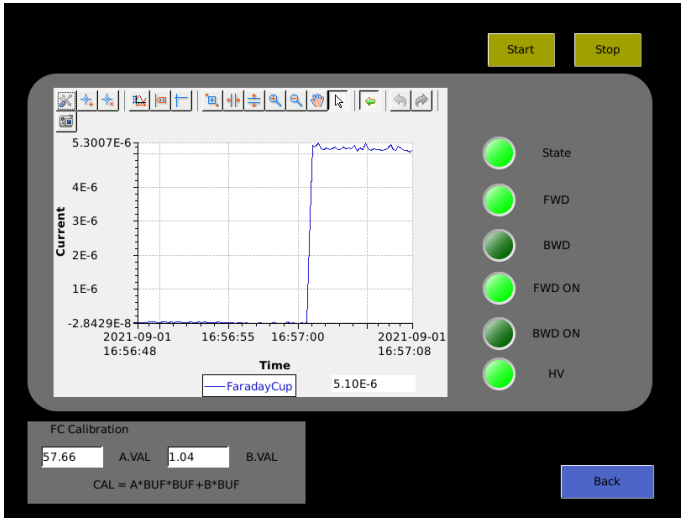


- **LEBT**
  - Wire scanner - 5 sets (4 installed)
  - Beam Viewer – 3 sets (2 installed)
  - Bergoz ACCT – 1 set
  - Faraday Cup – 5 sets (4 installed)
  - beam Attenuator – 2 sets
  - 2-D Allison Scanner – 2sets (1 installed)
- **MEBT (Installed)**
  - Wire scanner - 4 sets
  - Beam Viewer – 1 set
  - Bergoz ACCT – 2 sets
  - Faraday Cup – 2 sets
  - Stripline FFC – 1 set
  - BPM – 6 sets

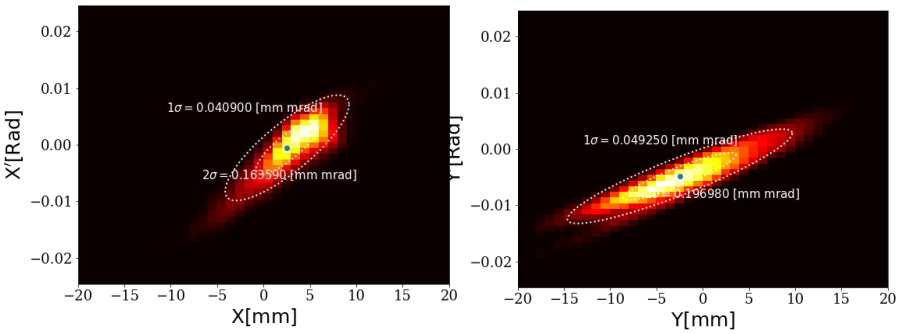
◈ Injector beam commissioning

- ✓ EPICS basis control system
- ✓ Reference beam: $^{40}Ar^{9+}$ (100 μs pulse beam, 1Hz repetition rate)



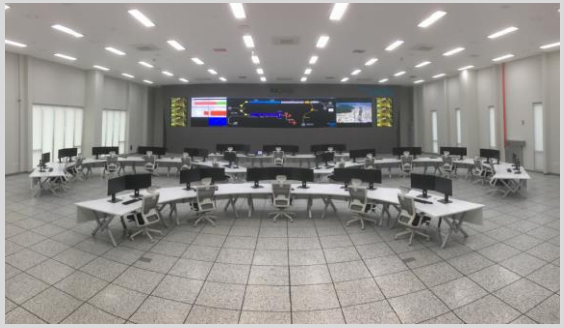


- WS/FC/BV operation GUI(Sequence, Interlock)
- WS/FC – DAQ calibration and auto setting/saving
- Analysis(fitting) WS measurements using py-epics
- Energy measurements with BPM pairs(TOF)



2. Sys. Install. Control System

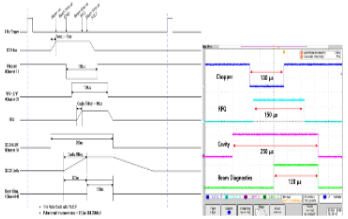
Control Center



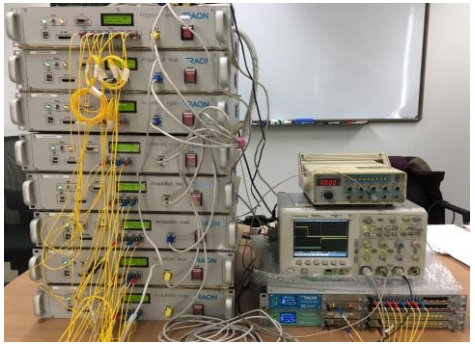
Main Control Room

Data Storage System

Integrated Control System



Timing System

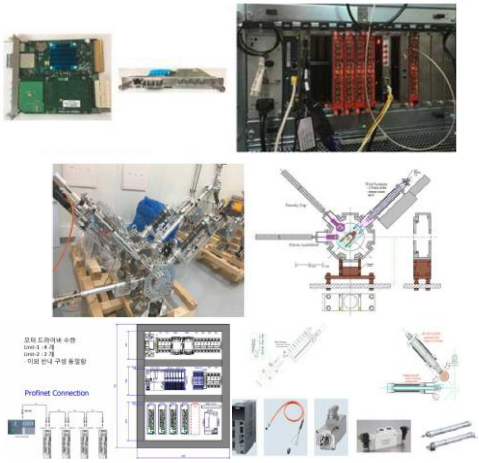


Fast Protection System

Local Control System

EPICS IOC Controllers

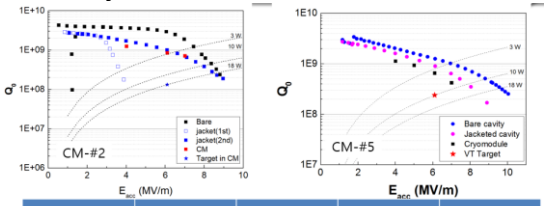
SCL3 Control System(43)



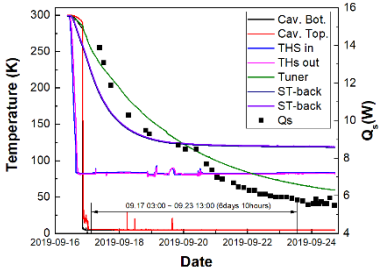
Beam Diagnostics Control System

SCL31(QWR)

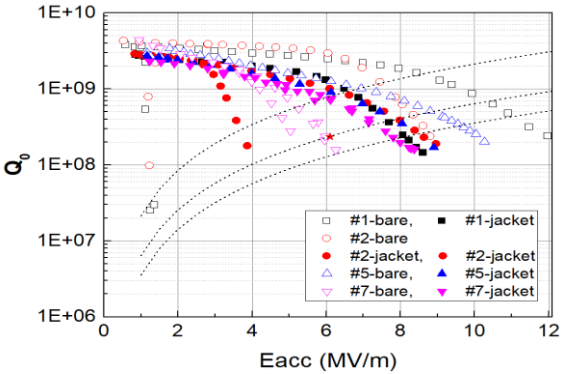
- **Design performance was achieved with prototypes(2017.5)**
- **Oxygen beam was accelerated with injector and one QWR module(2017.10)**
  500 keV/u → ~700 keV/u, Successful long-tem operation of cryomdoule
- **Mass production was contracted with domestic vendor(2017.12)**
  Pre-production cavities and cryomodules passed qualification, mass production is on-going
  Total thermal load <20W@6.1MV/m, 4.2 K
- **QWR Cryomodule installation done at SCL3 tunnel(2020.5)**



	Total (W)	Static (W)	Dynamic (W)	Q_0 of cavity
QWR-CM-#1	11.7	7.7	4.0	6.0e+8
QWR-CM-#2	10.8	8.0	2.8	8.5e+8
QWR-CM-#3	13.1	8.4	4.7	5.1e+8
QWR-CM-#5	14.4	9.5	3.5	6.6e+8



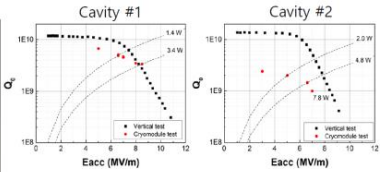
Static thermal load: 5.8 W
(Target: max. 7.5 W)



VT target: 2.4e+8@6.1MV/m

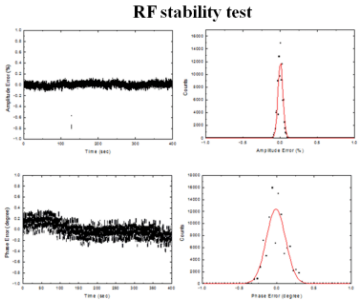
SCL32(HWR)

- **Design performance was achieved with prototypes(2017.10)**
  Thermal load <14.1W@6.6MV/m, 2.1 K (HWR type A)
- **Mass production was contracted with domestic vendor(2018.5)**
- **HWR Cryomodule installation to be done(2021.12)**



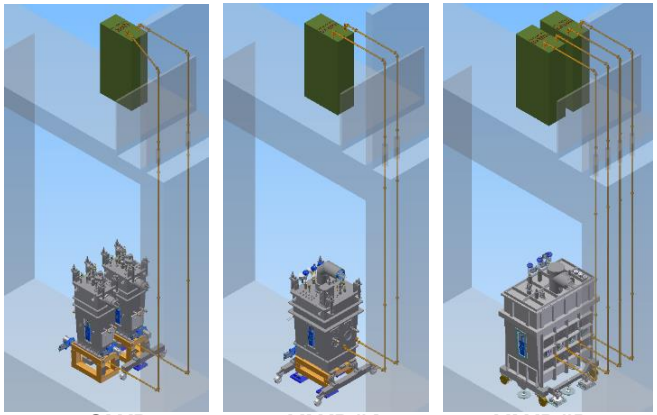
Static thermal load	Dynamic thermal load	Total thermal load
6.6 W	1.4 W (cavity#1)	12.8 W
	4.8 W (cavity#2)	

Target total thermal load @ 2.92 MV, 2K: <14.1 W



RF System

- **SSPA (4kW) : 2018.07~2020.05**
  Pre-production performance test(2019.11)
- **HPRF transmission line (1-5/8")**
  Installation vertical parts (2019.10)
- **LLRF control system (2019.07~2020.06)**
- **RF reference line (81.25MHz) : ~2019.12**



QWR HWR#A HWR#B

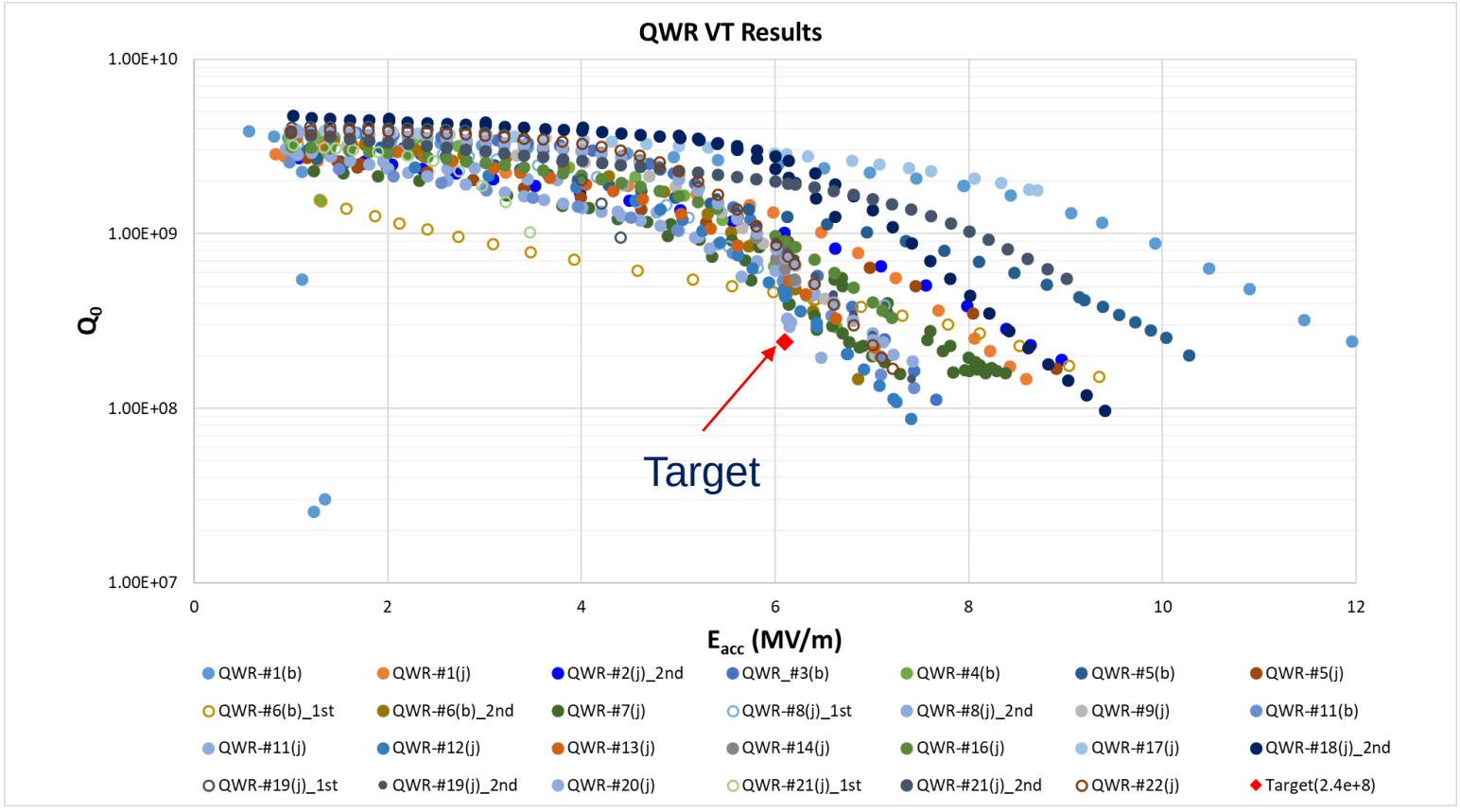
Accelerator System – Test facility

On-site (Shin-Dong) test facility

- 1 onsite - 3 VT pits and 3 cavities per pit, 3 HT bunkers
- 1 offsite (15 Km from site) - 2 VT pits and 2 cavities per pit
- Cover all RAON cavities - QWR (82.125 MHz), HWR (162.5 MHz) and SSR1 & 2 (325 MHz)

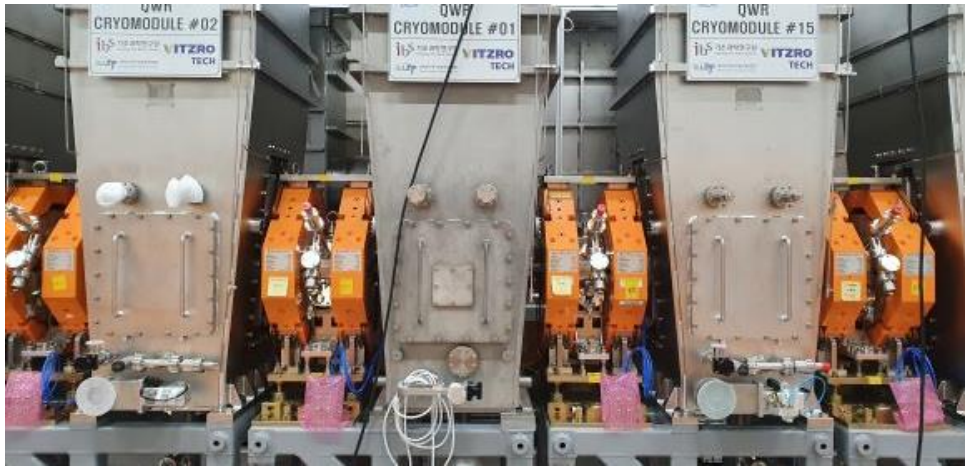
Accelerator System – QWR test results

Frequency (MHz)	Optimum β	Eacc (MV/m)	Vacc (MV)	Q0	# of cavity	# of module	Op. temp (K)
81.25	0.047	6.1	1.06	1.3e+8	22	22	4.5



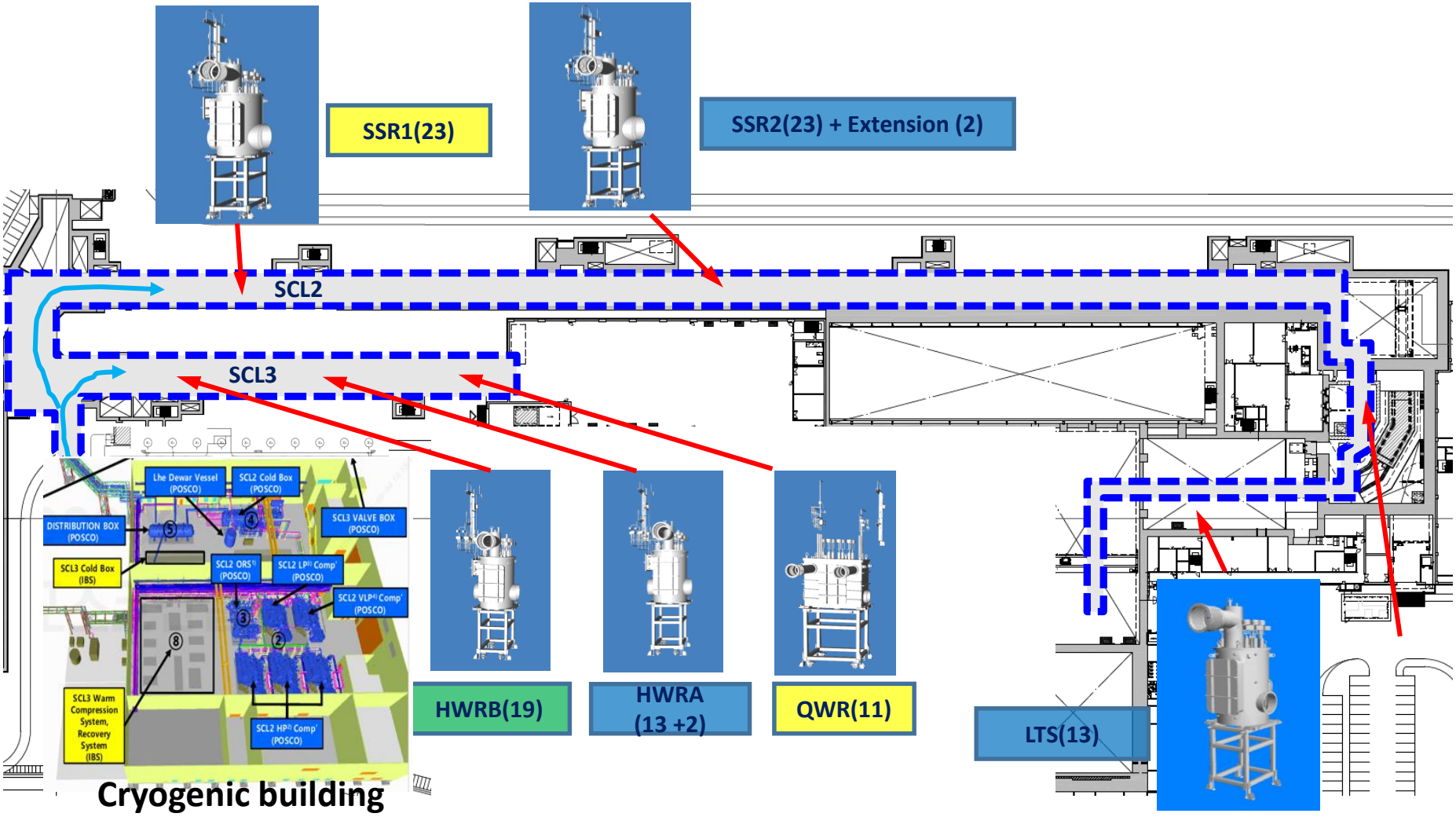
(Cryomodule + Warm section) + (Cryomodule + Warm section)

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



Layout Cryogenic Distribution Systems

- Layout of cryogenic distribution system @ SCL3 and SCL2



2. Sys. Install. Cryoplant

- 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)

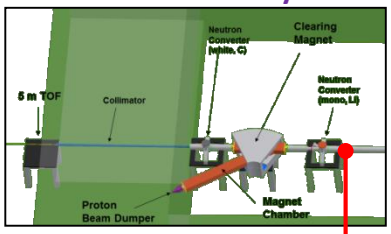
SCL3 & SCL2 cryoplant are underway pre-commissioning, cool down ready by Feb 2022

Part 3.

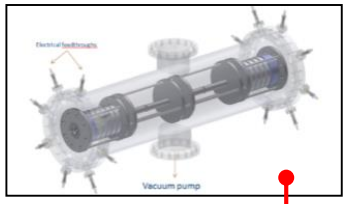
RI & Experimental Systems

RI & Experimental System

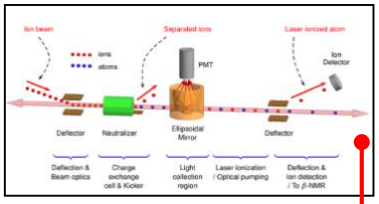
Neutron Facility



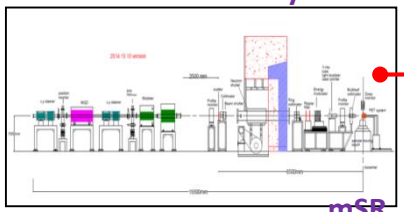
HPMMS



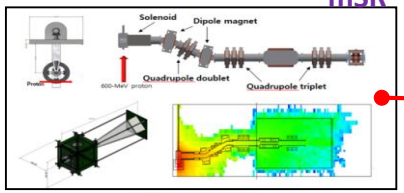
CLS



Bio-medical facility

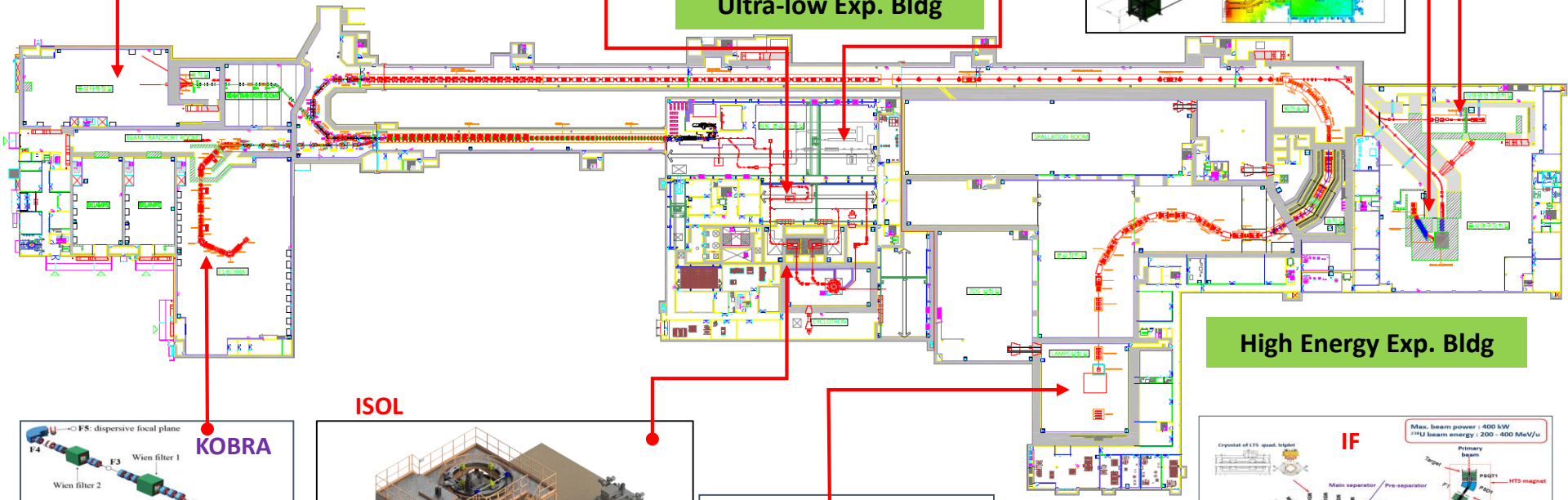


mSR



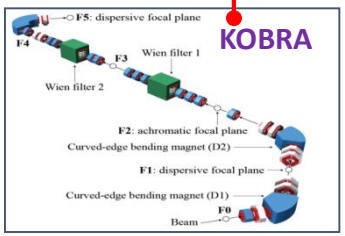
Low Energy Exp. Bldg

Ultra-low Exp. Bldg

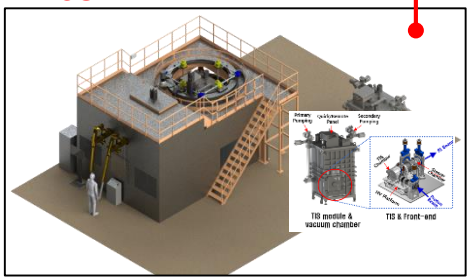


High Energy Exp. Bldg

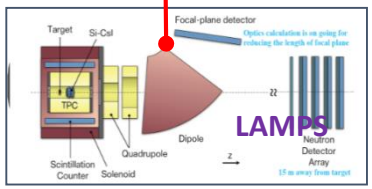
KOBRA



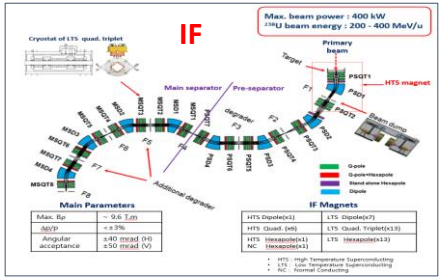
ISOL



LAMPS

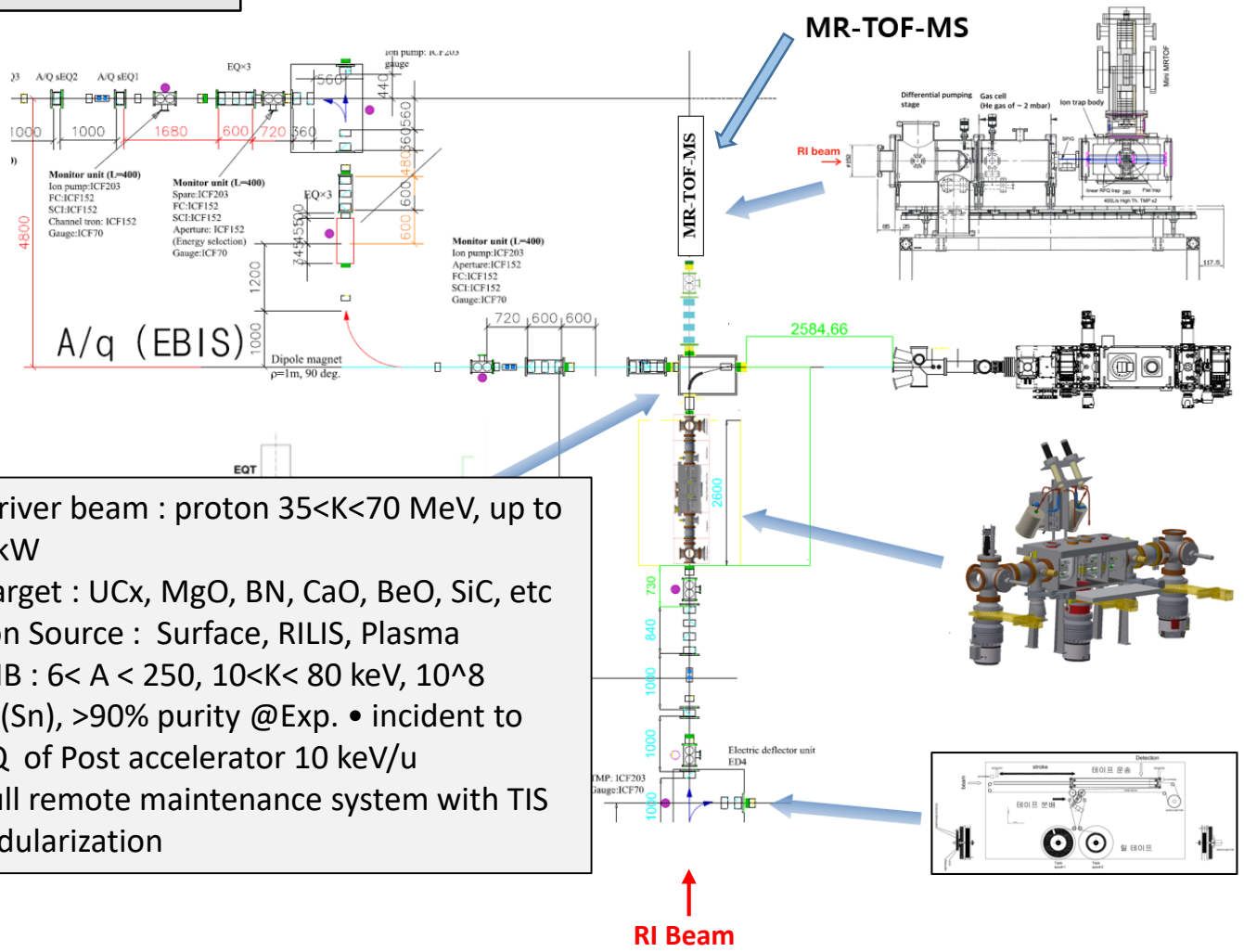


IF



3. Sys. Install. ISOL system

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

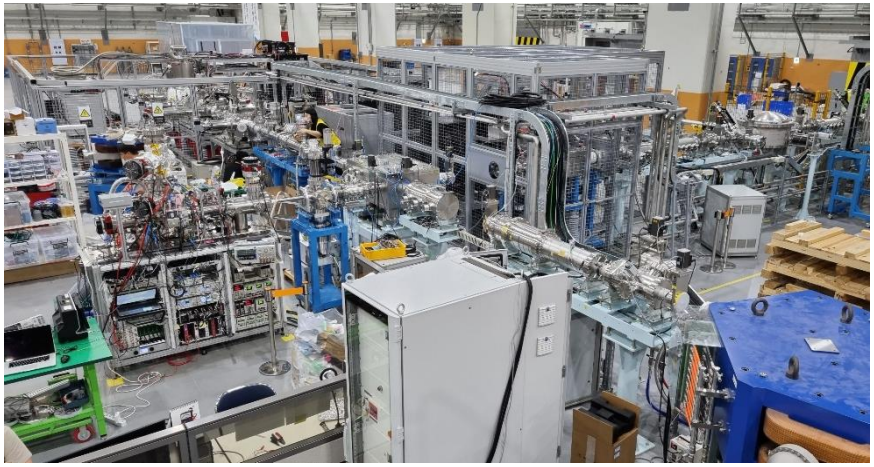


- Driver beam : proton 35<K<70 MeV, up to 70 kW
- Target : UCx, MgO, BN, CaO, BeO, SiC, etc
- Ion Source : Surface, RILIS, Plasma
- RIB : 6< A < 250, 10<K< 80 keV, 10^8 pps(Sn), >90% purity @Exp. • incident to RFQ of Post accelerator 10 keV/u
- full remote maintenance system with TIS modularization

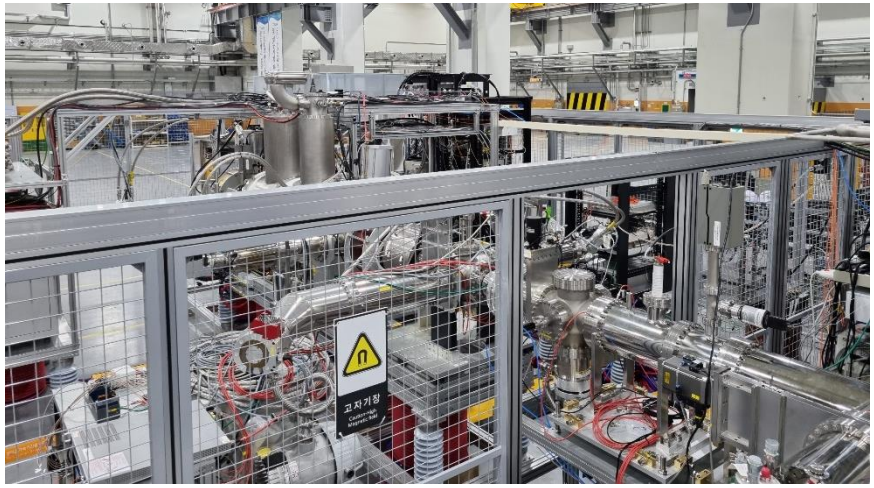
3. Sys. Install.

ISOL System

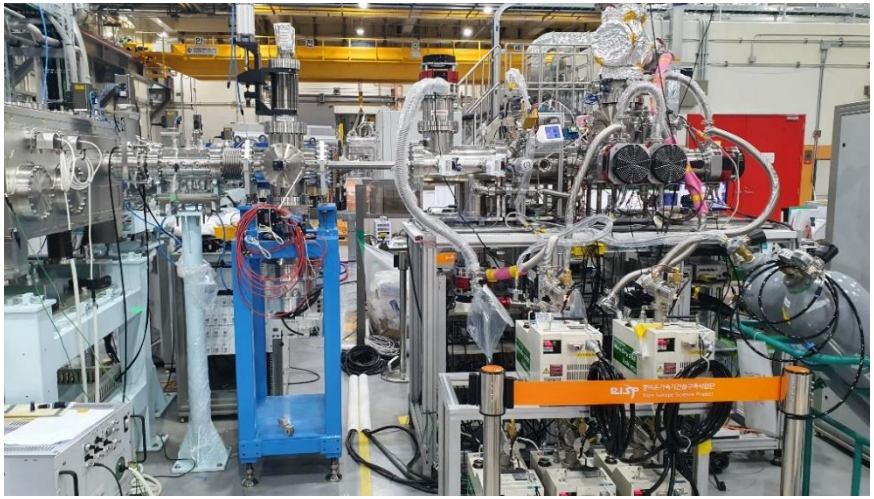
ISOL Target Room



ISOL Beam Line



EBIS Charge Breeder

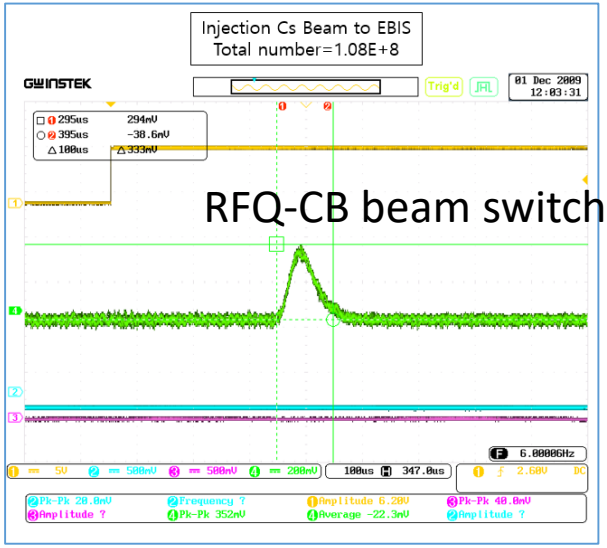


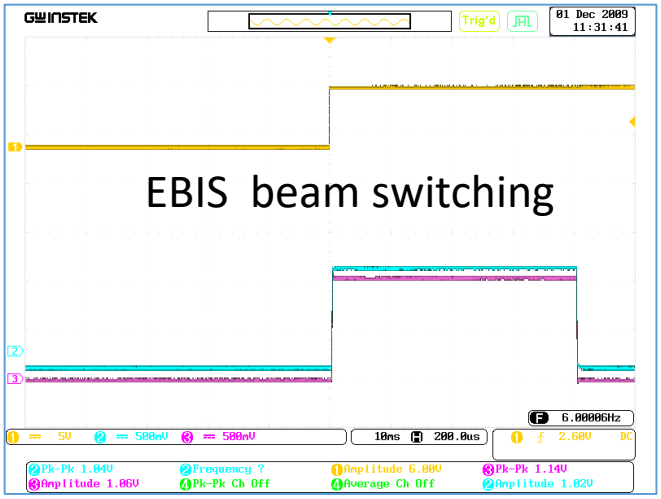
MMS/MR-TOF

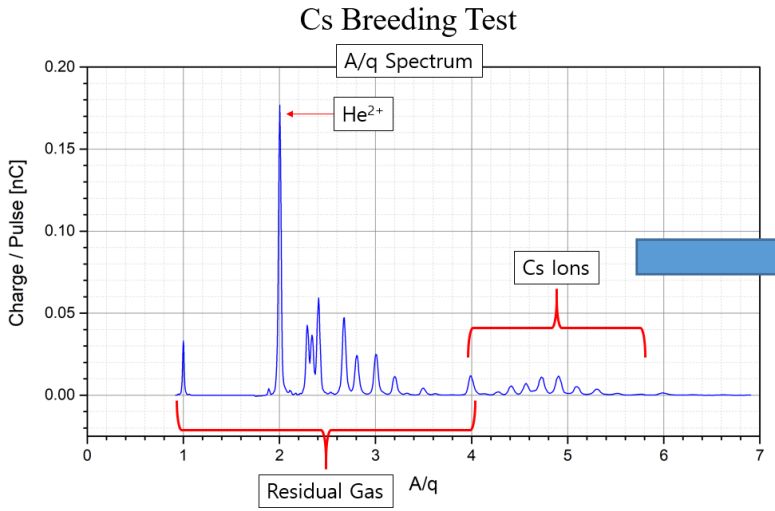
TIS, EBIS, RFQ-CB, beam line is being tested with SI(Cs) beam, completed in 2021

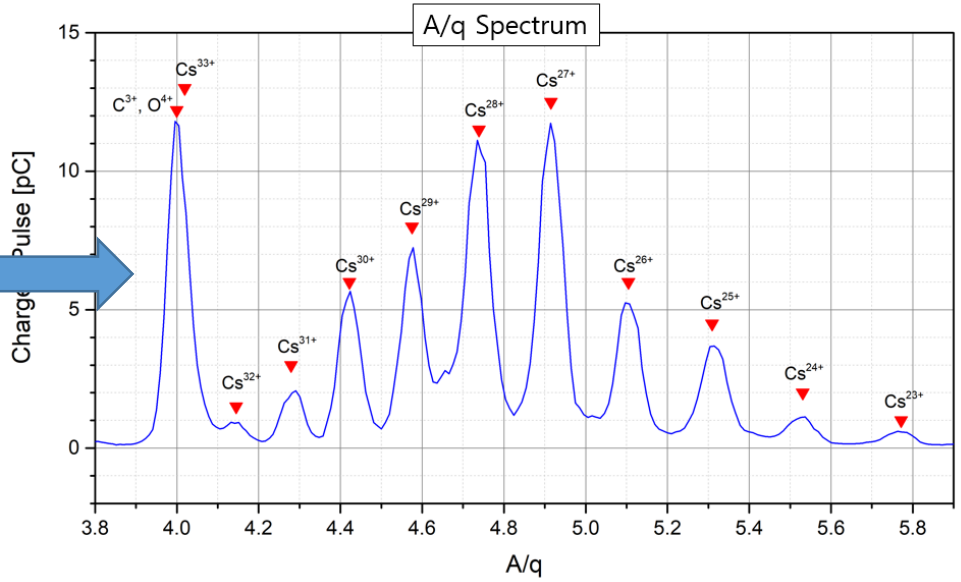
ISOL System

Success for charge breeding from RFQ-CB → pathway to RI SCL3 reacceleration to be ready on 2021





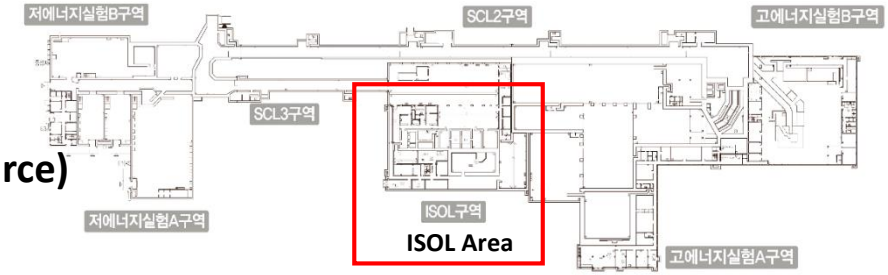




3. Sys. Install. Cyclotron

◆ **Specs**

: 35~70 MeV proton, 0.75mA max with two beam lines connecting to ISOL TIS bunker(Target Ion Source)



◆ **Schedule**

: Contract('19.6), pre-survey('19.11) , Design finalized('20.4) , FAT ('21.6) , Shipping('21.8), Installation('21.11.11~22.4.28)

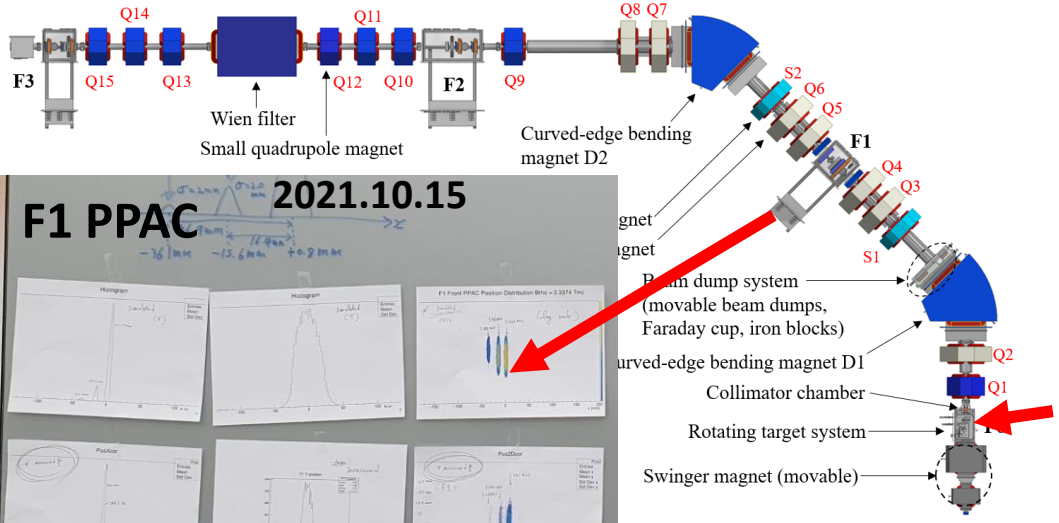
Rigging will be done on Nov. of 2021, Installation/SAT on July of 2022

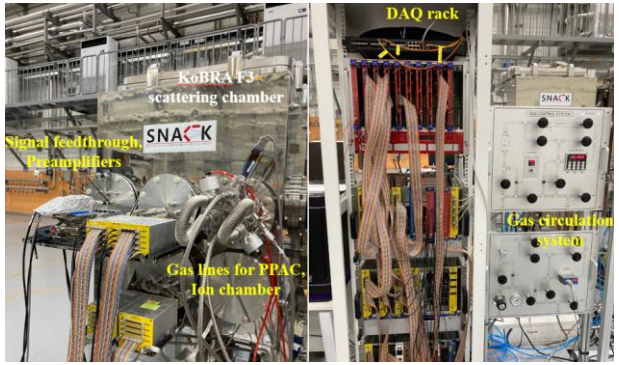
Korea Broad acceptance Recoil spectrometer and Apparatus

Goal: Construction of **multi-purpose experimental instrument** using stable or RI beams for studies of the nuclear structure and nuclear astrophysics, in the energy range of about 1 – 30 MeV/u

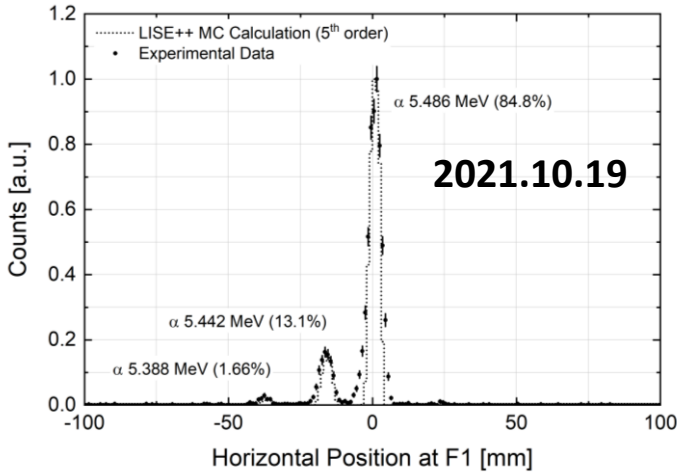
- RI beam productions at a few MeV/u and at about 20 – 40 MeV/u using a stable beams from ECR ion source
- Recoil mass separator at less than few MeV/u for direct measurements of radiative-capture cross, using a RI beams from ISOL facility

KoBRA machine commissioning completed on 2021.10

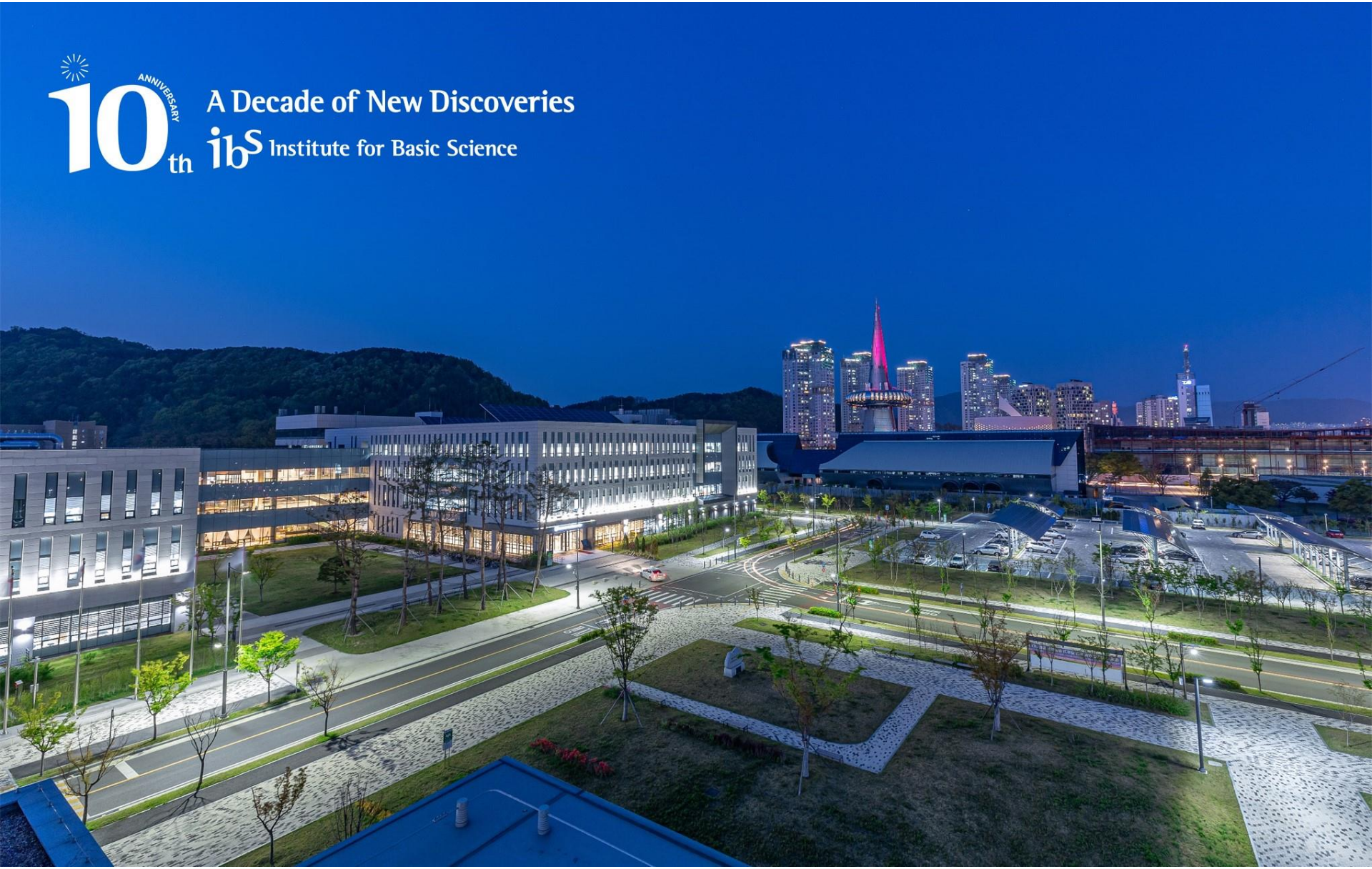




Alpha source (^{241}Am)



Momentum dispersion and resolving power at F1/F2/F3 were confirmed!


10th ANNIVERSARY
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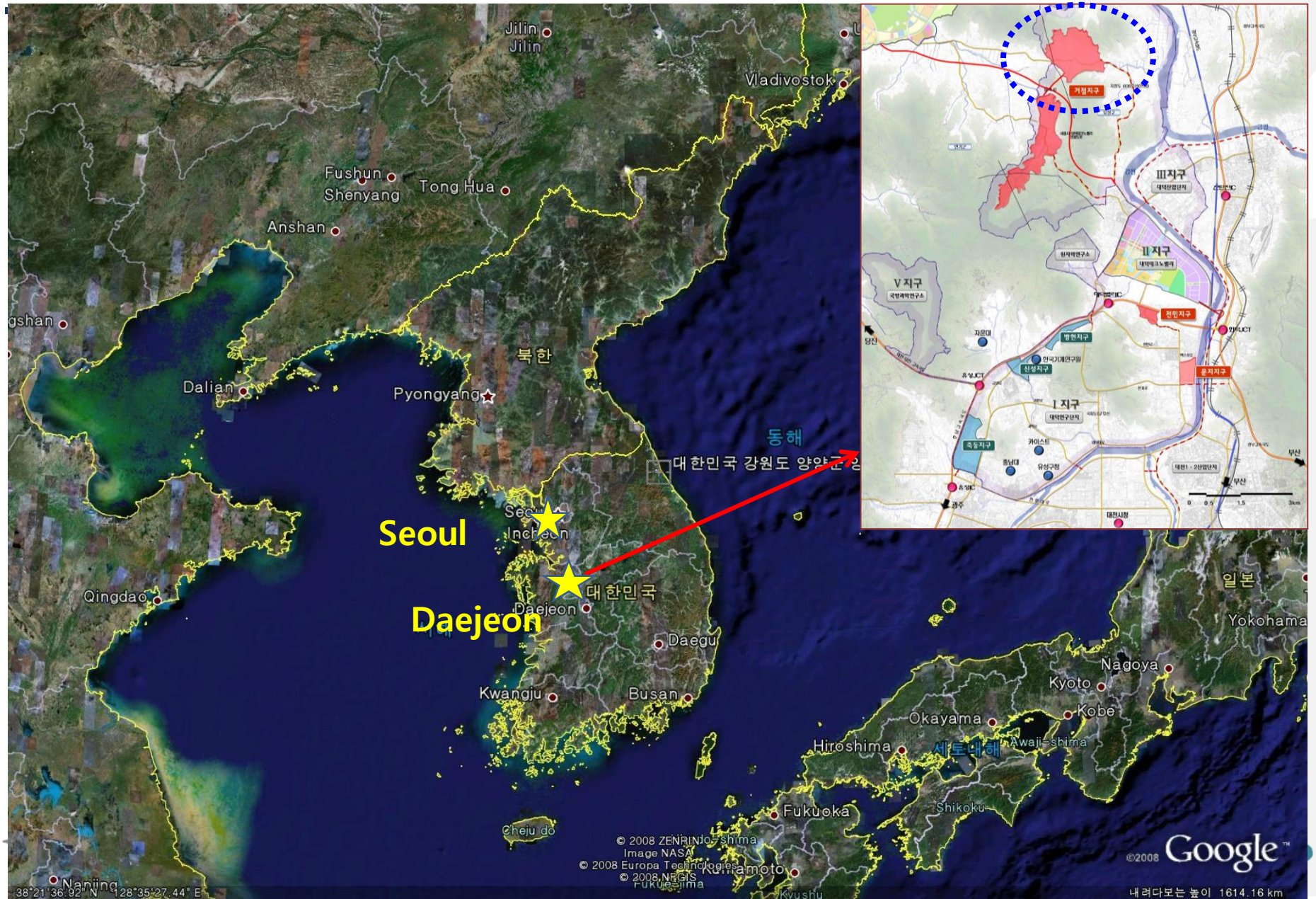
ibs Institute for Basic Science

RAON Site


Jilin
Jilin
Vladivostok
Fushun
Shenyang
Tong Hua
Anshan
Dalian
북한
Pyongyang
동해
대한민국 강원도 양양군
Seoul
Incheon
대한민국
Daejeon
Daejeon
Qingdao
Daegu
Kwangju
Busan
일본
Yokohama
Nagoya
Kyoto
Kobe
Okayama
Hiroshima
Awaji-shima
서토내해
Fukuoka
Shikoku
Kumamoto
Kyushu
Cheju do
Nanjing
거점지구
III지구
II지구
V지구
I지구
천인지구
방현지구
신성지구
죽동지구
문지지구
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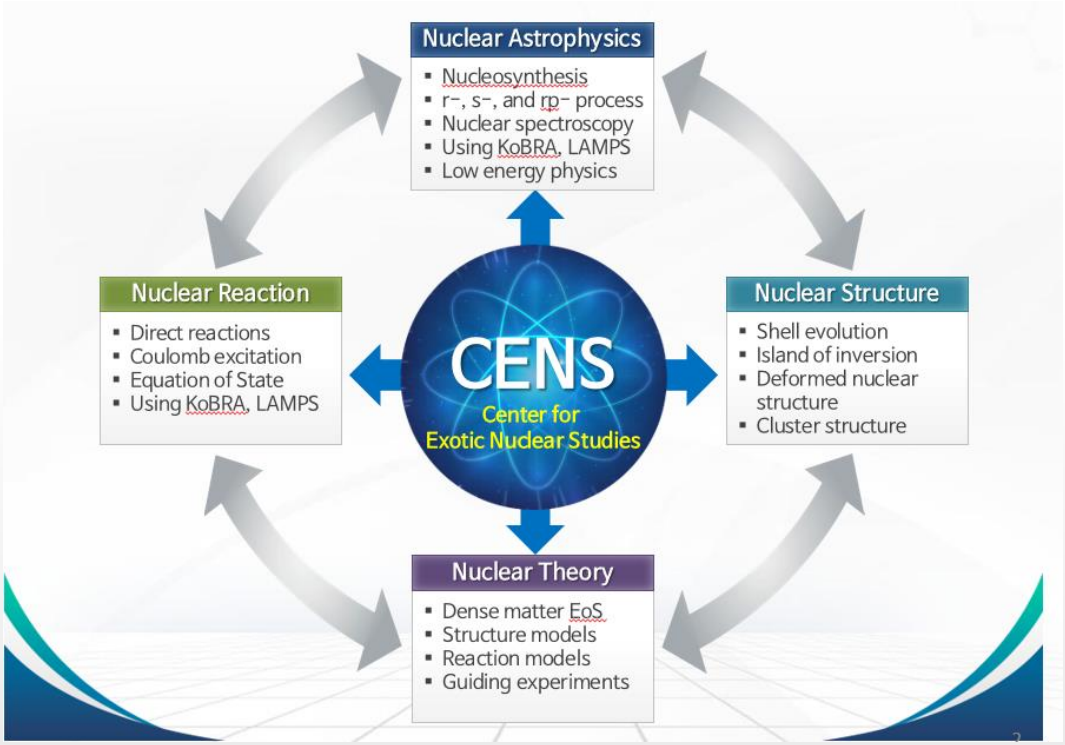
©2008 Google
38°21'36.92" N 128°35'27.44" E
내려다보는 높이 1614.16 km

Introduction of IBS CENS

Origin of elements in the universe and properties of exotic nuclei

- The Center for Exotic Nuclear Studies (CENS) was launched in December 2019.
- It is located at the IBS HQ building in Daejeon, ~20 minutes to the RAON site by car.
- We currently have 18 researchers as of November 21, 2021.



Organization of CENS

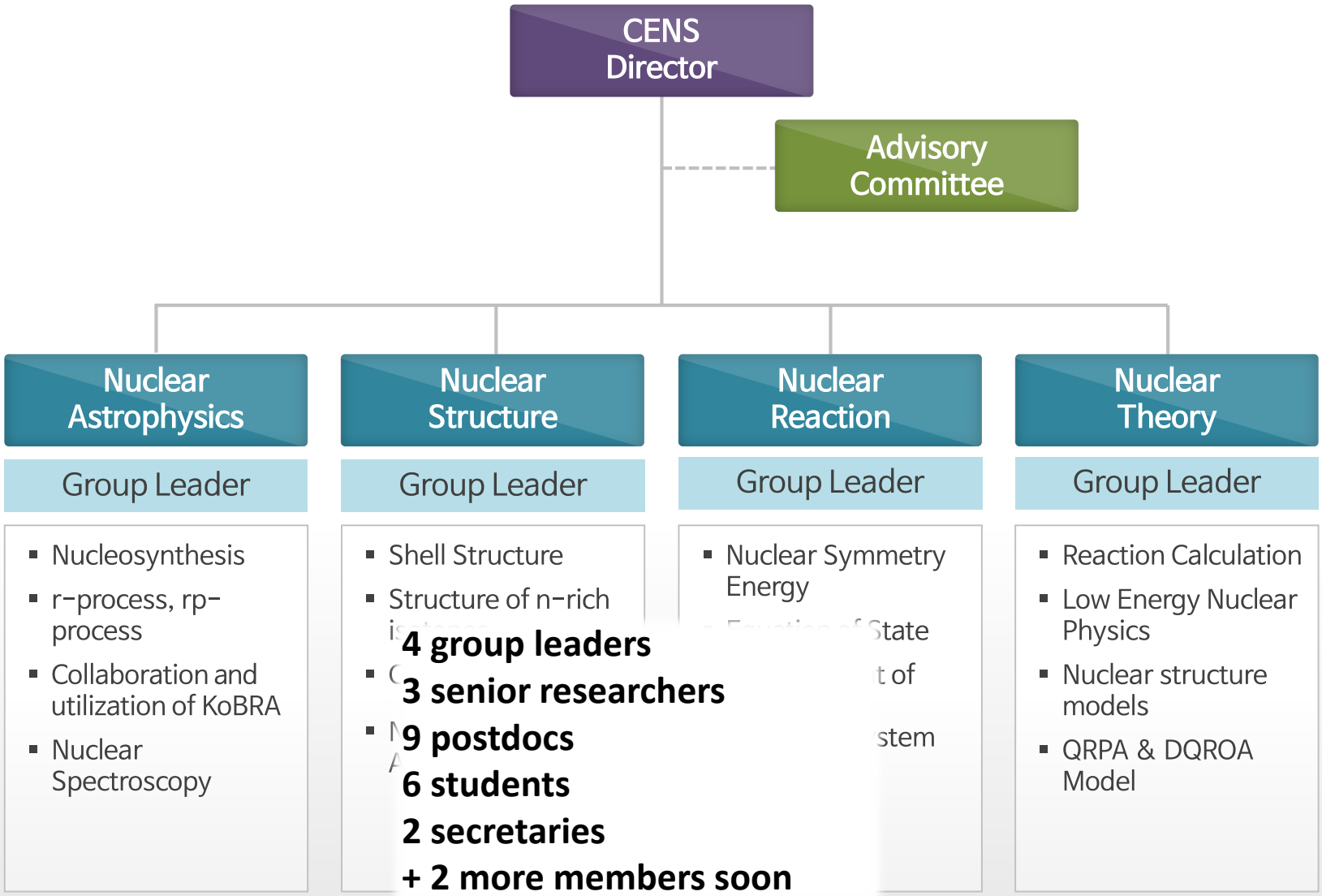
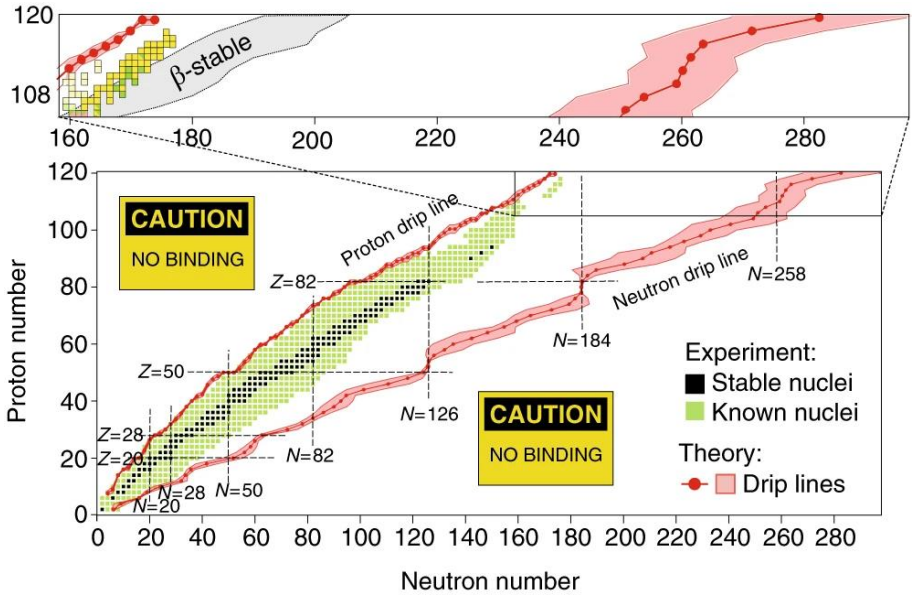
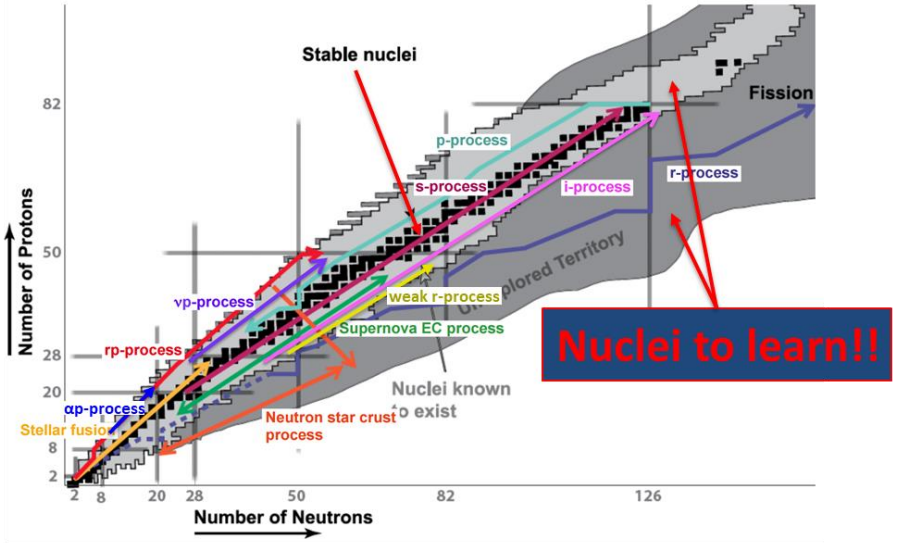


Chart of Nuclei

- **Properties of Nuclei: mass, Q-value, $T_{1/2}$, P_n, level densities, reaction rates, level structure, magic number and drip line**



Landscape of nucleon-bound nuclei as a function of Z and N.
W. Nazarewicz, 2018

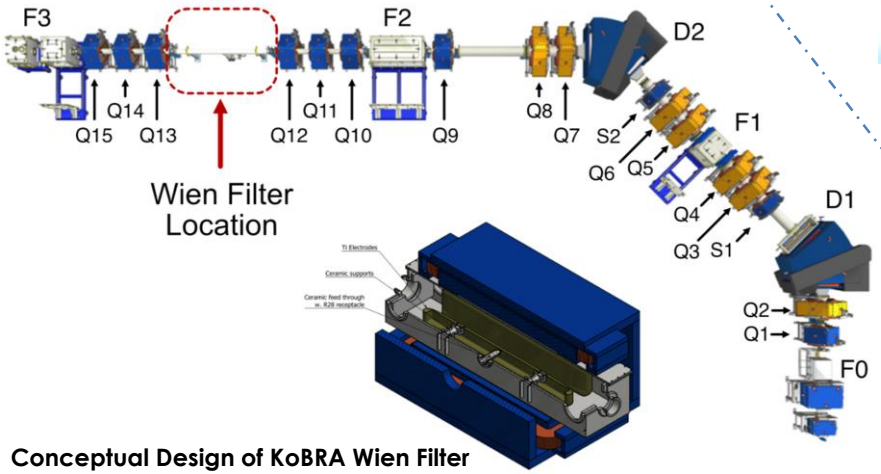


Schematic overview of the nuclear processes on nuclear chart
H. Schatz, 2016

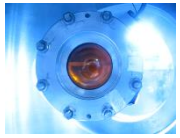
New Major Apparatus Developments

Devices for Rare Isotope Science!

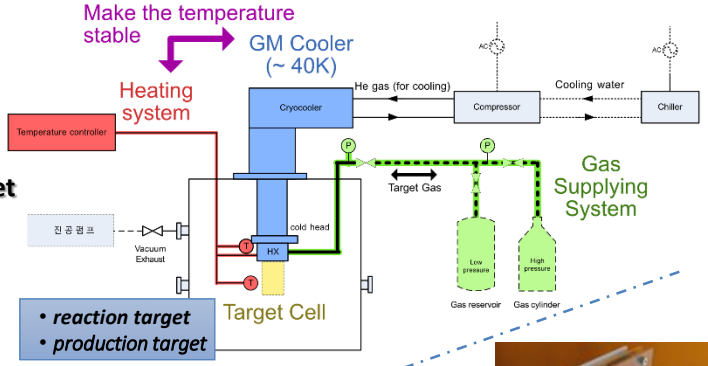
Low Beam Intensity, Efficiency, Energy/Angle Resolution, Fast Timing, Low Threshold and so on..



Conceptual Design of KoBRA Wien Filter



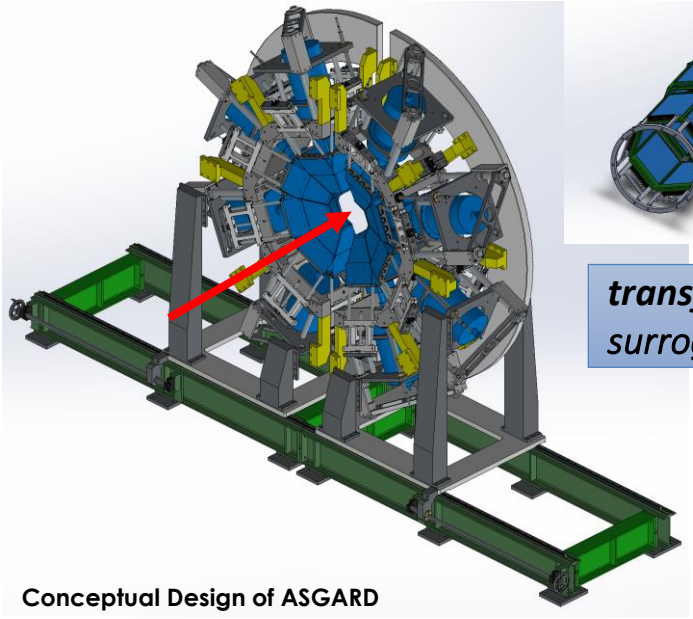
Gas Cell Target



Layout of CryoSTAR

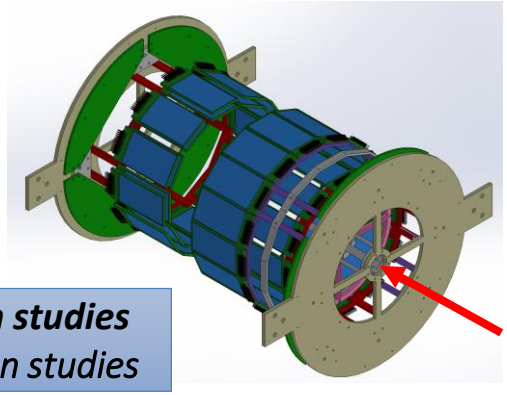
Photo of DL-MCP

New Major Apparatus Developments



Conceptual Design of ASGARD

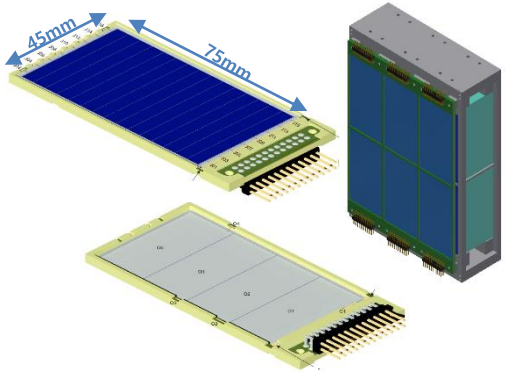
STARK Jr.



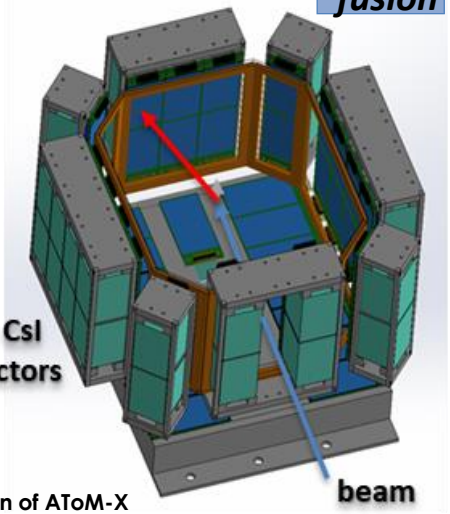
Conceptual Design of STARK

transfer reaction studies
surrogate reaction studies

(*p*,*p*)
(*d*,*d*)
(α,α)
(α,*p*)
(α,*n*)
fusion



Newly designed silicon detector : X6



Conceptual Design of AToM-X

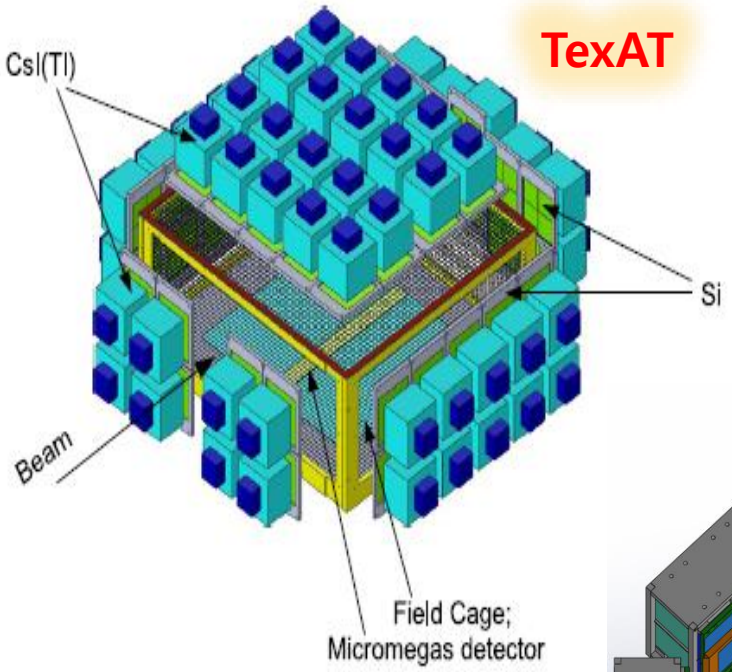
Plan for the future experiment

$^{22}Mg(\alpha,p)^{25}Al$

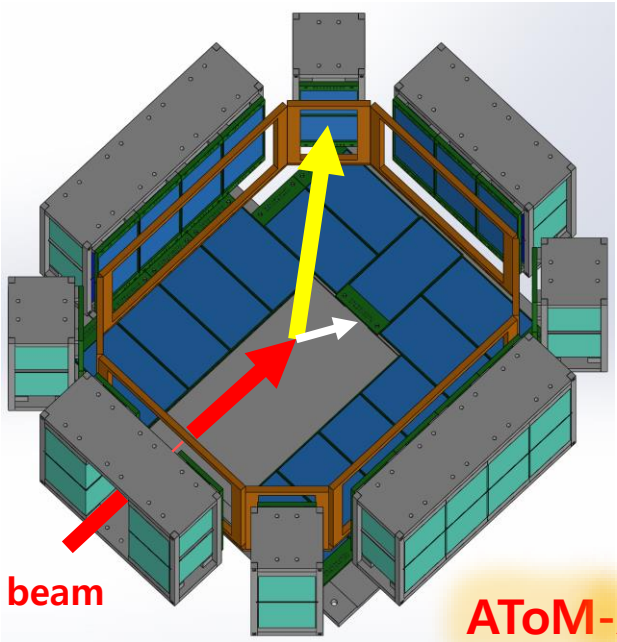
$^{18}Ne(\alpha,p)^{21}Na$

$^{21}Na(\alpha,p)^{24}Mg$

$^{17}F(\alpha,p)^{20}Ne$



TexAT



AToM-X

CENS Project Timeline

	2020	2021	2022	2023	2024	2025
Wien Filter		KWF Purchase & installation at RAON		Test & Commissioning	Operation	
HPGe Detector Array	HPGe detector R&D Part 1 Purchase & installation			Test & Commissioning	Operation	
Silicon Detector Array	Silicon detector R&D Purchase & installation		Test	Purchase & installation	Test	Operation
CENS AT-TPC		AT-TPC R&D Purchase & installation		Test	Operation	
CENS Cryo Gas Cell Target		Cryo Gas Cell R&D Purchase & installation		Test	Operation	
RAON Schedule	SCL3 Commissioning			SCL3 Test		
FRIB@MSU Schedule	Completion by 2022					
FAIR@GSI Schedule	Completion by 2025 (Phase 0 for R&D and core detector test experiments: 2018, 2019)					

plus

- ✓ **Beam PID and Diagnostics System**
- ✓ **Detector System for Internal Conversion Electrons**
- ✓ **A New Plunger Device**

and more……

Summary & Outlook

- **Accelerator & RI, Exp systems**
  - Beam commissioning for the injector is a success and continued to the end of 2021.
  - Installation for SCL3 will be completed by at the end of 2021, followed by cool down and beam commissioning on 2022
  - ISOL will finish SI beam commissioning by 2021 and KoBRA is ready for beam commissioning on 2022
- **By the end of 2022, we will achieve**
  - **SI beams:** Stable ion beams (^{16}O, ^{40}Ar) from ECRIS → SCL3 → KoBRA low E exp hall
  - **RI beams:** RIBs extraction from ISOL → re-acceleration through SLC3 → low E exp hall
  - Stable / RI beams will be delivered to low-E experimental hall
  - **Early phase experiments are going to be performed using KOBRA**
    → RIBs production at KOBRA (A<~50, beam energy < 20 MeV/u) using SI beams from SCL3
  - Preparation for the 2nd stage of construction begins for SCL2
  - Installation and independent commissioning for IF, LAMPS, Neutron, bio-medical and μSR
    → Collaborative works with RUA (RAON Users Association) via RULC (RAON Users Liason Center)
- **Beyond 2022,**
  - Beam commissioning for ISOL → SCL3 → SCL2 → IF
  - Stable operation with 200MeV/u beams up to 80kW
  - Science program starts with both ISOL and IF systems
  - UCx target and U-beam operation

Thank you!