RAON
Rare isotope Accelerator complex for ON-line experiments

Status of RAON

Young Kwan KWON

NTSE2018
Oct 30th, 2018

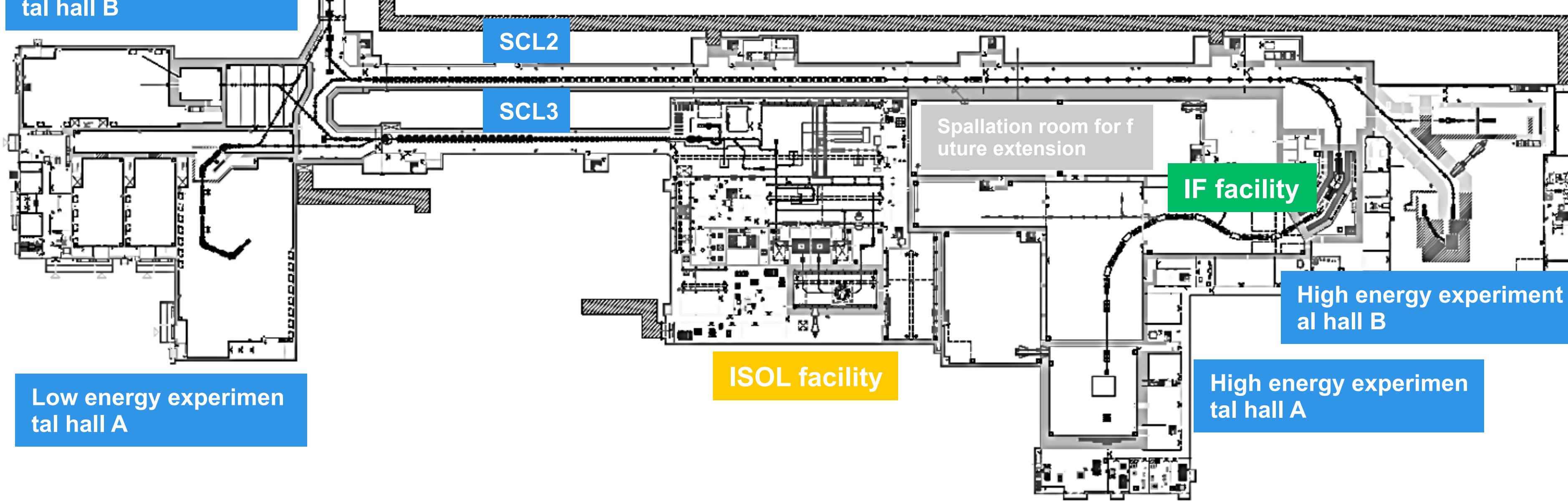
RAON: Rare Isotope accelerator complex for ON-line experiment

Goal: To build a heavy ion accelerator complex RAON for RI science researches

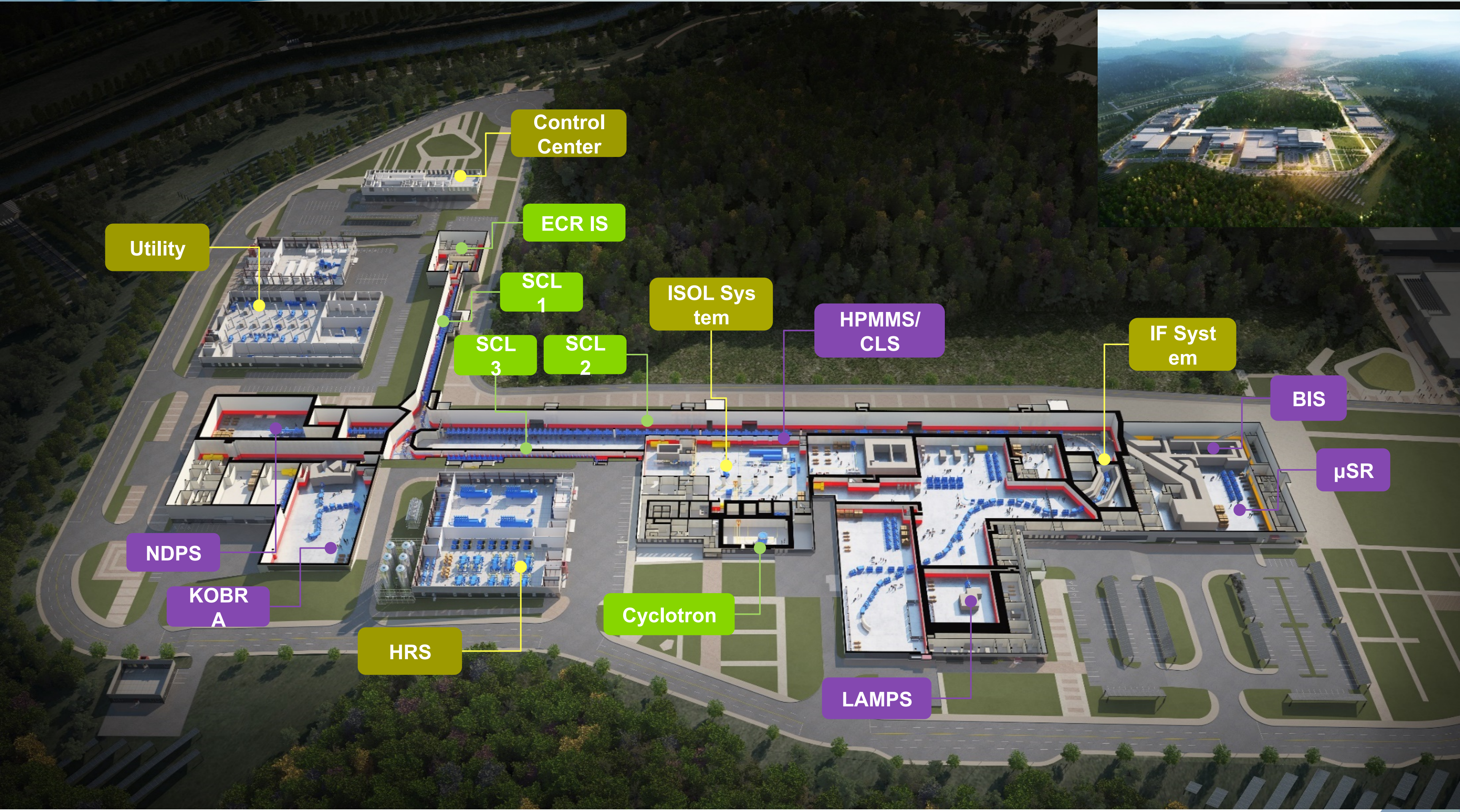
- ❖ **Providing high intensity RI beams by ISOL and IF**
  - ISOL: direct fission of ^{238}U by 70 MeV proton
  - IF: 200 MeV/u ^{238}U (intensity: 8.3 pμA)
- ❖ **Providing high quality neutron-rich beams**
  - e.g., ^{132}Sn with up to 250 MeV/u, up to 10^9 particles per second
- ❖ **Providing More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

○ **Project period : 2011.12 - 2021.12**

○ **Total Budget : ~$ 1.43 billion**
(Facilities ~ $ 0.46 bill., Bldgs & Utilities ~ $ 0.97 bill.) (include initial experimental apparatus)



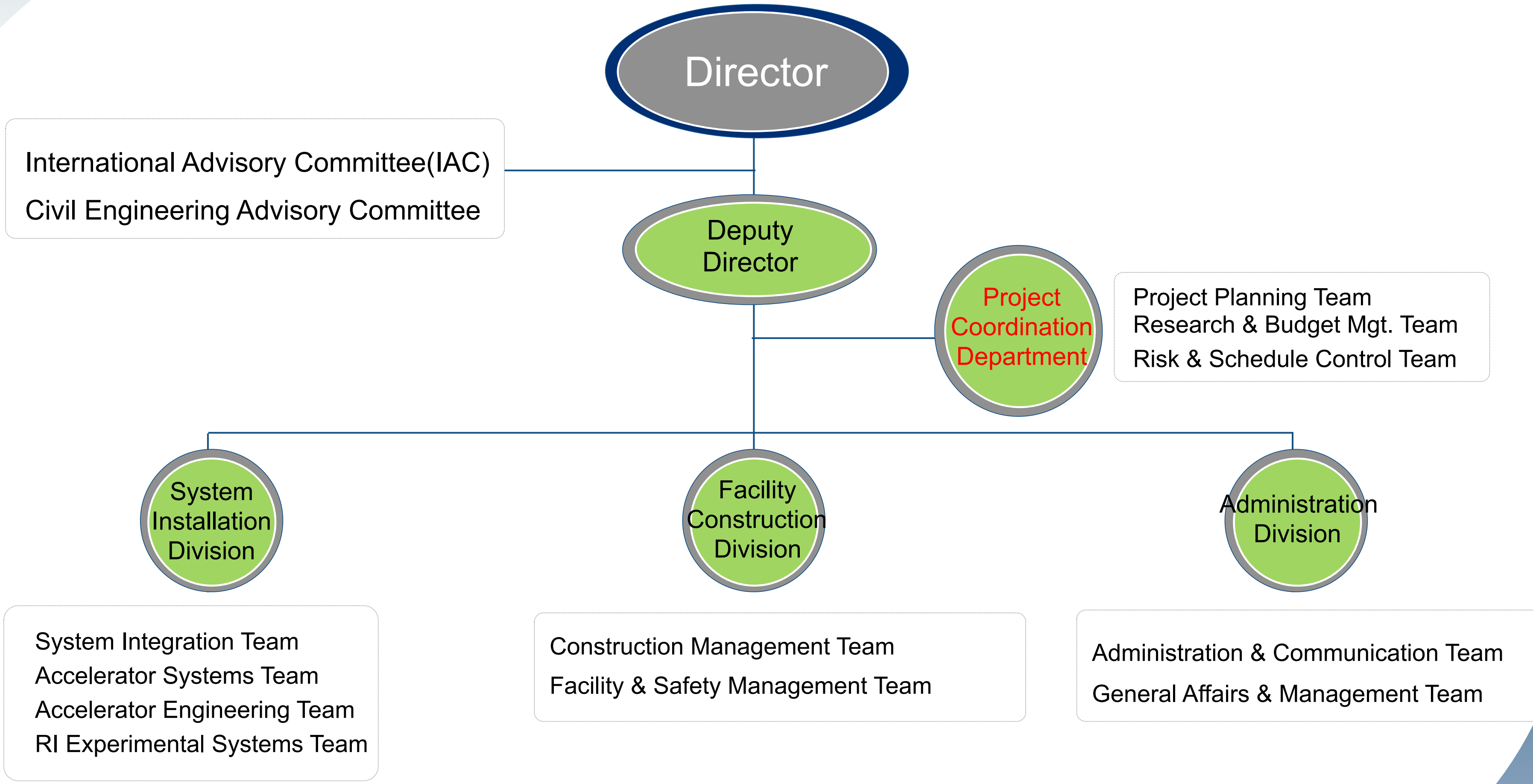
RAON Layout



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

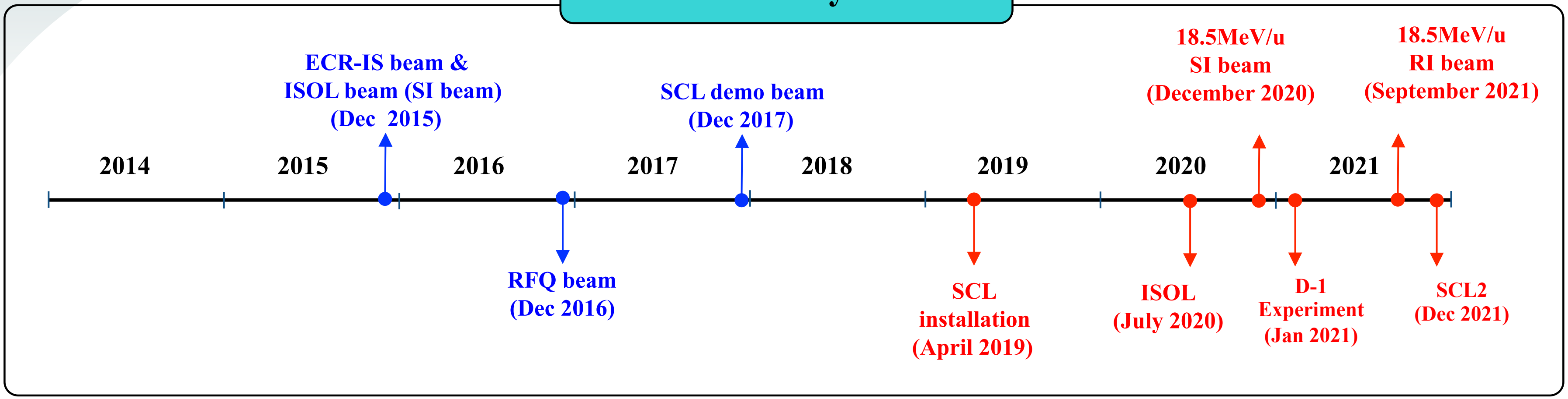
RISP Organization

1 department, 3 divisions, and 11 teams

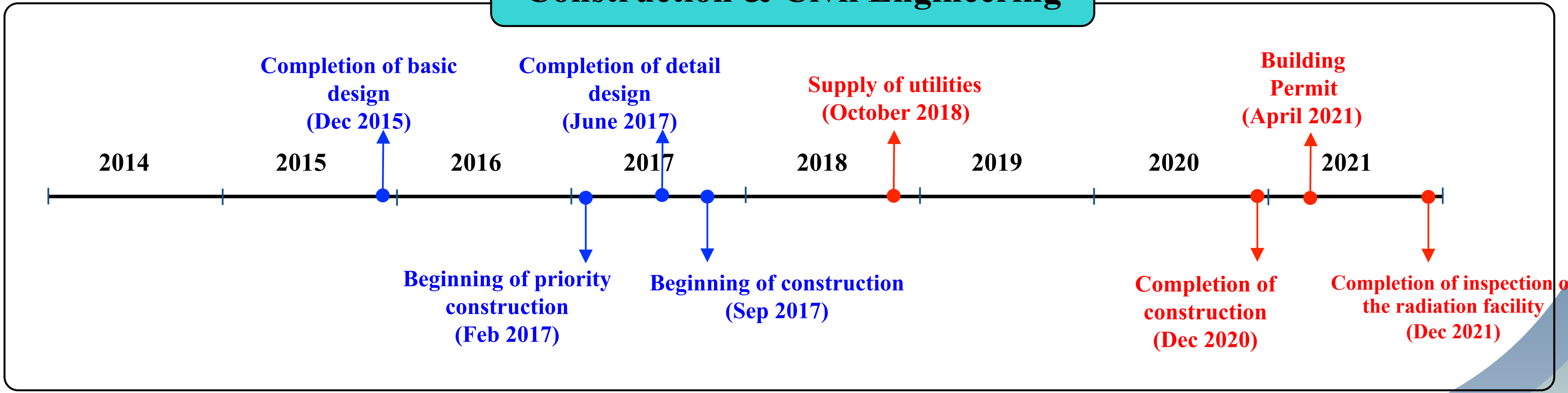


Project Major Milestones

Facility



Construction & Civil Engineering



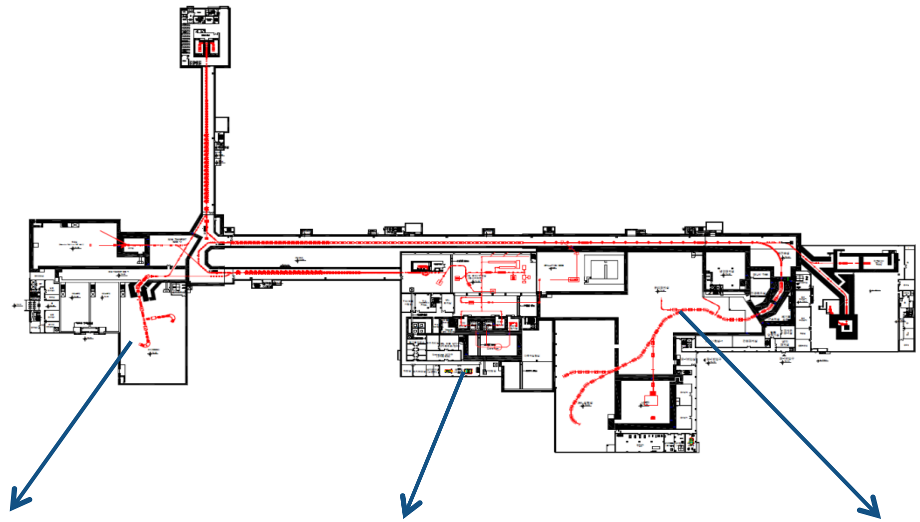
Construction

중이온가속기 시설건설사업 건립공사 시공 현황 (건물/구역별)	(`18.9.12, 현재)
	
SCL2구역 (터널 벽체 철근배근 및 Conc 타설)	SCL3구역 (갤러리 벽체 철근배근)
	
저에너지AB구역 (B1F 벽체 철근배근 및 Conc 타설)	ISOL구역 (B1F 벽체 철근배근 및 Conc 타설)
	
IF/고에너지A구역 (B1F 벽체 철근배근 및 Conc 타설)	고에너지B구역 (B1F 벽체 철근배근 및 Conc 타설)

	
SRF시험동 (내부 마감 공사)	초전도조립동 (내부 마감 공사)
	
수전설비동 (하지철물 설치)	중앙제어센터 (2F 벽체 철근배근)
	
유틸리티동 (1F 벽체 철근배근 및 Conc 타설)	본부동 (터파기)

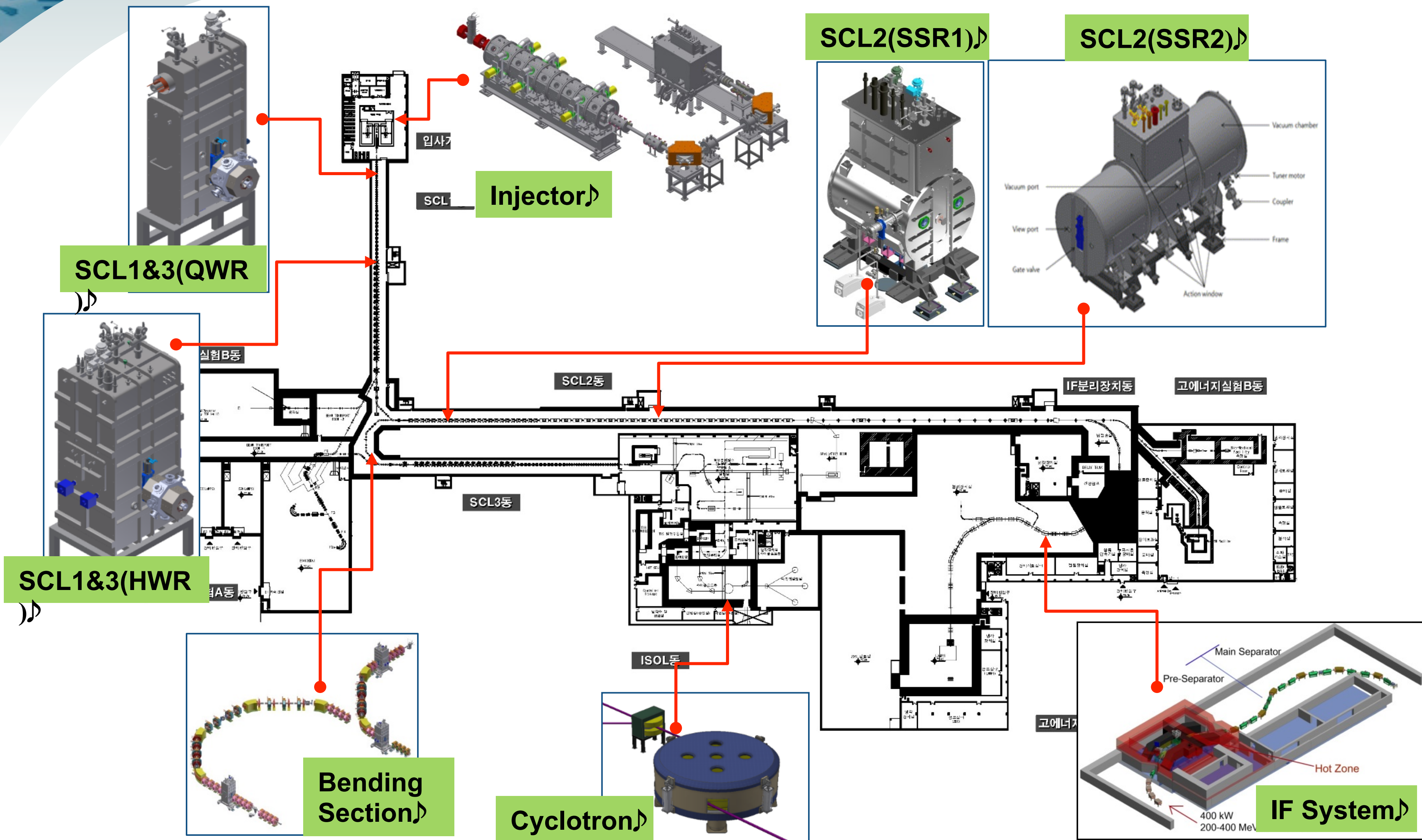
Lineup of RIB production & Separation

- ISOL→IF
  : ISOL→SCL3→SCL2→IF
  : ISOL→SCL3→KOBRA
- IF→Re-Acc (future upgrade)
  : IF→stopped beam→SCL



	KOBRA (low E IF)	ISOL	IF (high E)
Driver	SCL3 or SCL1	Cyclotron	SCL3→2 or SCL1→2
Post acc		SCL3 or SCL3→2	
Production mechanism	Direct reactions - (p,d), (^{3}He,n) etc , MNT	p induced U fission	PF, U fission
Available RIB energy	< a tens of MeV/u	> a few of keV/u	< a hundreds of MeV/u

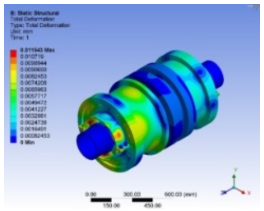
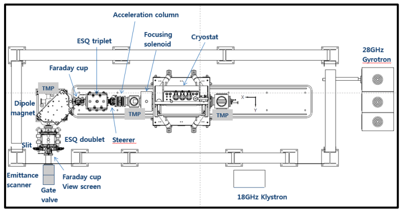
RAON Layout : Accelerator System

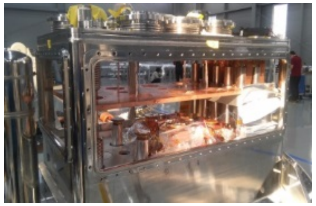


ECR Ion Source(28GHz, 14.5GHz)

28GHz

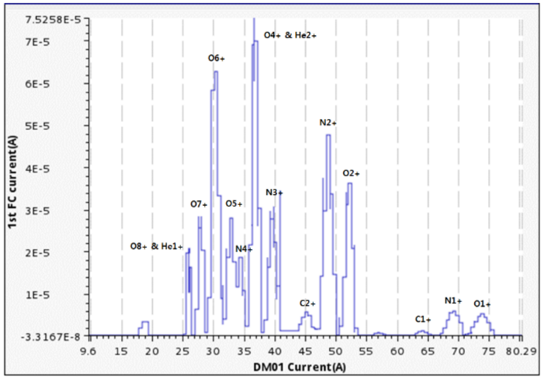
Design & Fabrication	Installation & **Test (Munji Campus)**	Transfer to main site	Commissioning	Operation
2011 ~ 2014	**~ 2019.06**	~ 2019.12	2020	2021

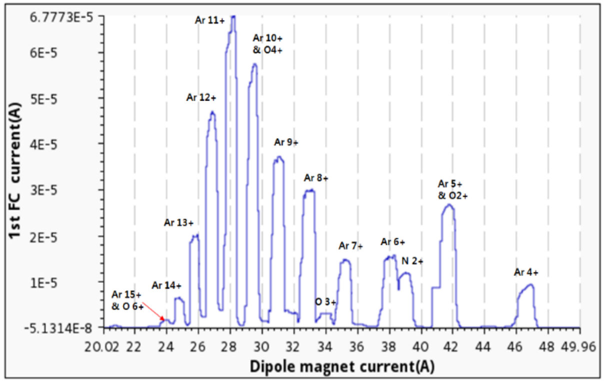



28GHz ECR test results

- As an early test stage,
  - O^{7+} of 30euA was extracted
  - Ar^{11+} of about 70euA was extracted.
- After cryo-cooler maintenance, cooling capacity margin is improved.





14.5GHz

Purchasing process	Manufacturing	Installation & Commissioning	Operation
2018	~ 2019	~ 2020.5	2020.6~

- 14.5GHz ECRIS for a secondary ion source.
- 14.5GHz ECRIS and 28GHz ECRIS will supply a stable isotope beam to SCL3 alternately
- 14.5GHz ECRIS will be a main ion source when 28GHz ECRIS moves to SCL1

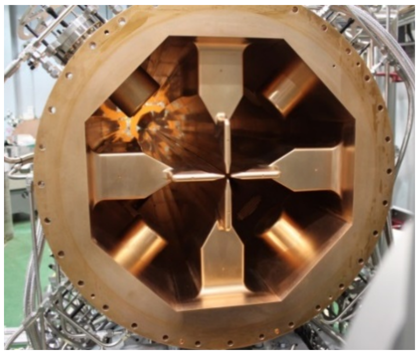
Injector

RAON

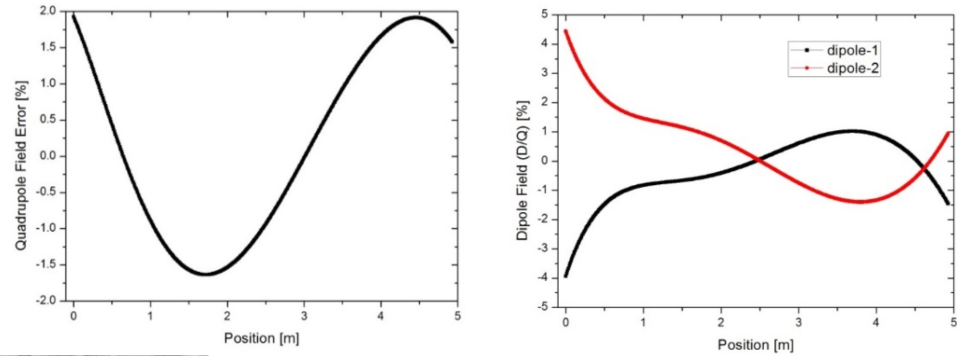
Conceptual design	Prototype	**Test & Upgrade**	Installation	Commissioning	Operation
2011 ~ 2012	~ 2015	**~ 2018**	2019	2020	2021

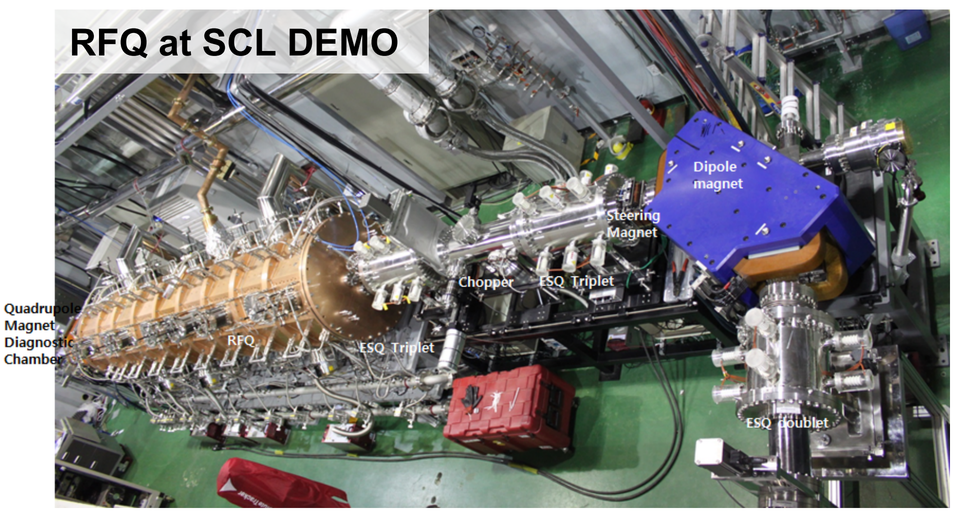
Installation & Test of injector @ SCL demo

- Completion of RFQ manufacturing and tuning (Quad. Field < ±2%, Dipole Field < ±5% of Q.)
- Installation of injector and test for beam acc. Performance of RFQ (>500keV/u)

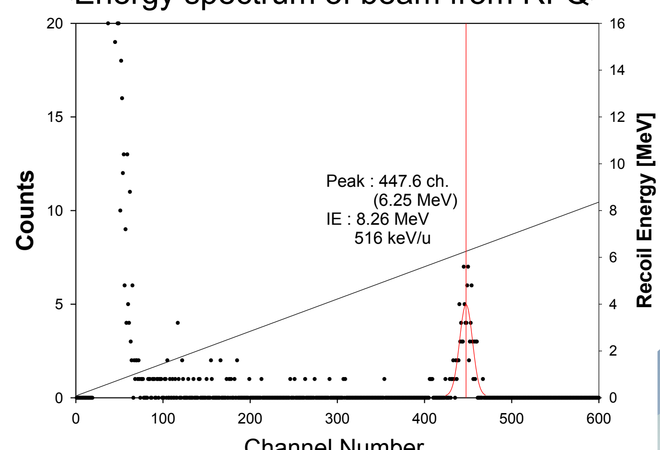


<RFQ tuning result>





<Energy spectrum of beam from RFQ>

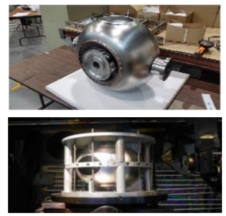


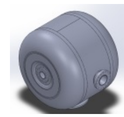
SuperConducting Linear accelerators (SCL3, SCL2)

SCL3 (QWR, HWR)	Conceptual design: 2011 ~ 2012	Prototype: ~ 2016	**Test and Manufacturing: ~ 2018**	Installation: 2019	Commissioning: 2020	Operation: 2021
SCL2 (SSR1, SSR2)	Conceptual design: 2011 ~ 2012	**Prototype: ~ 2018**	Test and Manufacturing: ~ 2019	Installation & Commissioning: ~ 2021		Operation: 2022

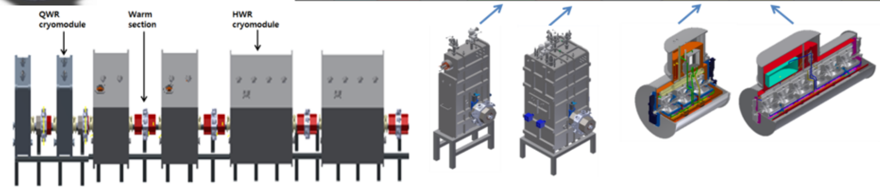
QWR

HWR



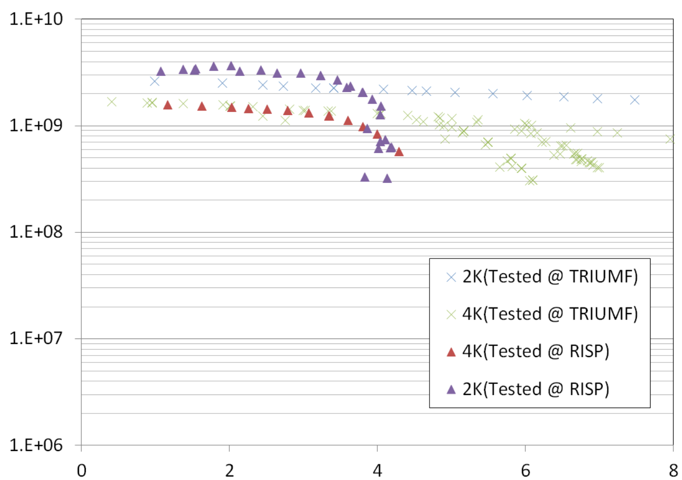


SSR2



Superconducting cavity test

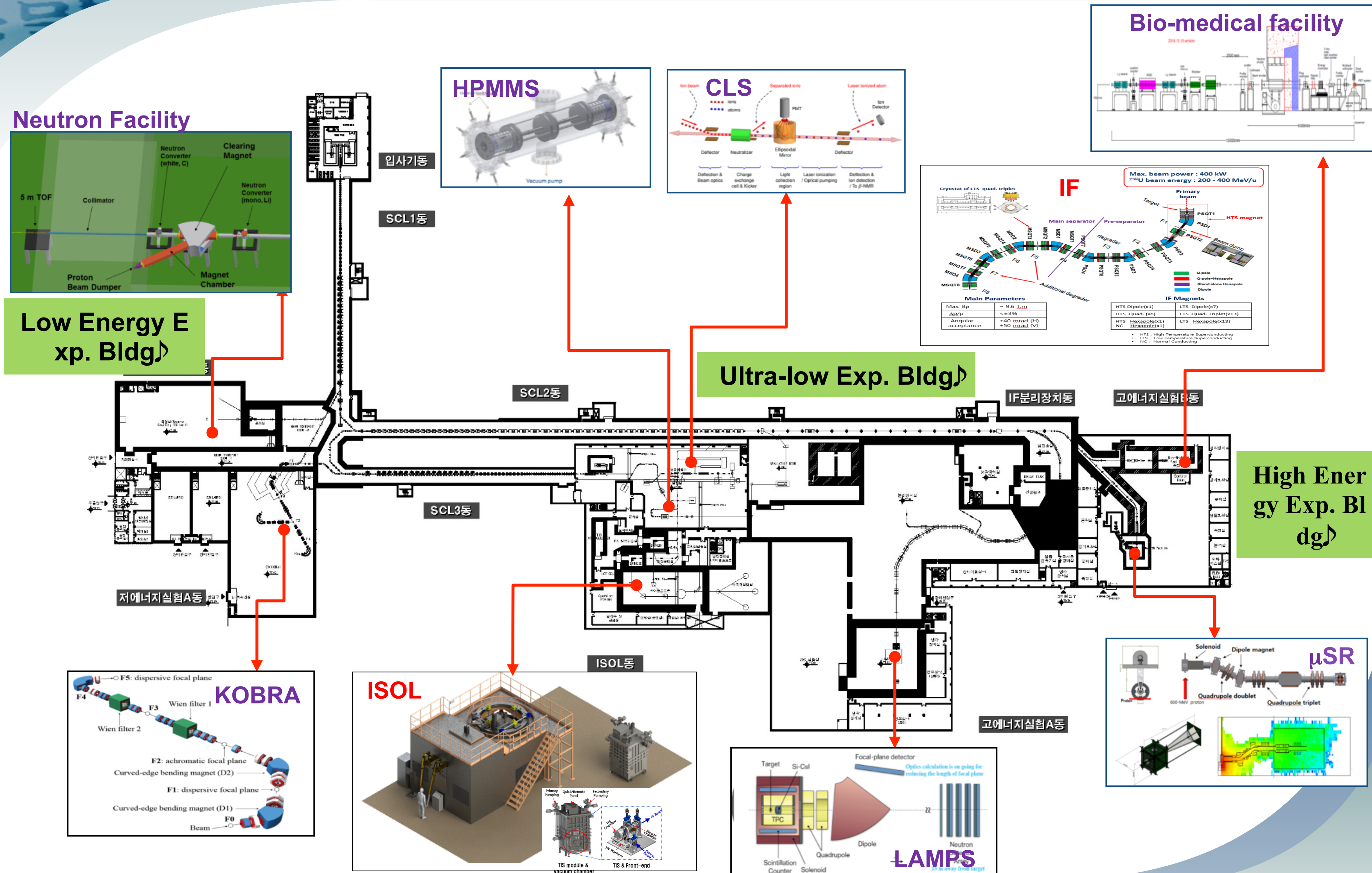
- SRF test facility @ KAIST Munji Campus
- Manufacturing and Performance test for QWR x 4, HWR x 6, SSR1 x 1 is under way ('18)



<Result of HWR cavity performance test>

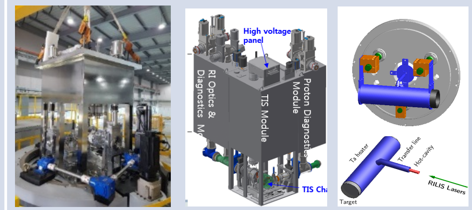
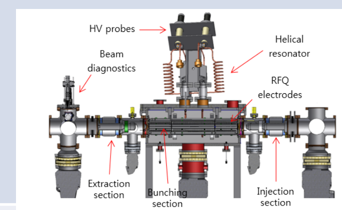
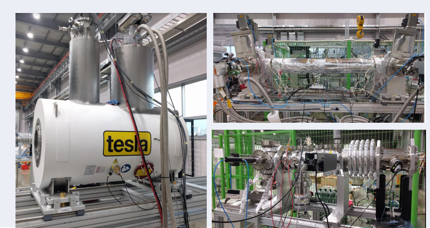
<Cavity test pit, Cryostat, Control room>

RAON Layout : RI & Experimental System



ISOL System

Conceptual design	Prototype	**Manufacturing**	Installation	Commissioning	Operation
2011 ~ 2012	~ 2017	**~ 2019.3**	~ 2020.7	2021.6	2021

System	Specification	Current Status	
Target Ion Source	· UCx Fission Target 10kW · SIS, RILIS, FEBIAD	· Manufacturing(partly)	
Beamline, Remote handling, Hot cell System (incl. A/q Separator)	· $R_{A/q}$: ~200 (for EBIS) · E + B Combination	· Purchasing process	
RFQ cooler & Buncher	· Cooling time : <100 ms · Transmi. Effi. : >50%(Sn) · Output emittance: <3 · Capacity: <10^8 ions/bunch	· Under design	
EBIS-Charge Breeder	· E/A : 10 keV/u · A/q : 10 keV/u · Effi. : 15%($^{133}Cs^{27+}$) · Breeding time: 50~100 ms · Capacity: <10^8 /bunch	· Start integrate assembling - E-gun/collector - SC solenoid - Drift tube · Breeding test ('18.12~)	

IF System

Conceptual design	Prototype & Test	Manufacturing	Installation	Commissioning	Operation
2011 ~ 2012	~ 2018	~ 2020.11	~ 2021.7	2021.12	2022~

Max. beam power : 400 kW
^{238}U beam energy : 200 - 400 MeV/u

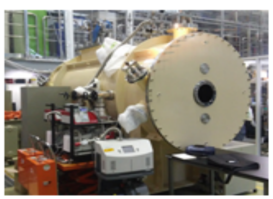
Target/dump: Staged 80 kW → 400 kW

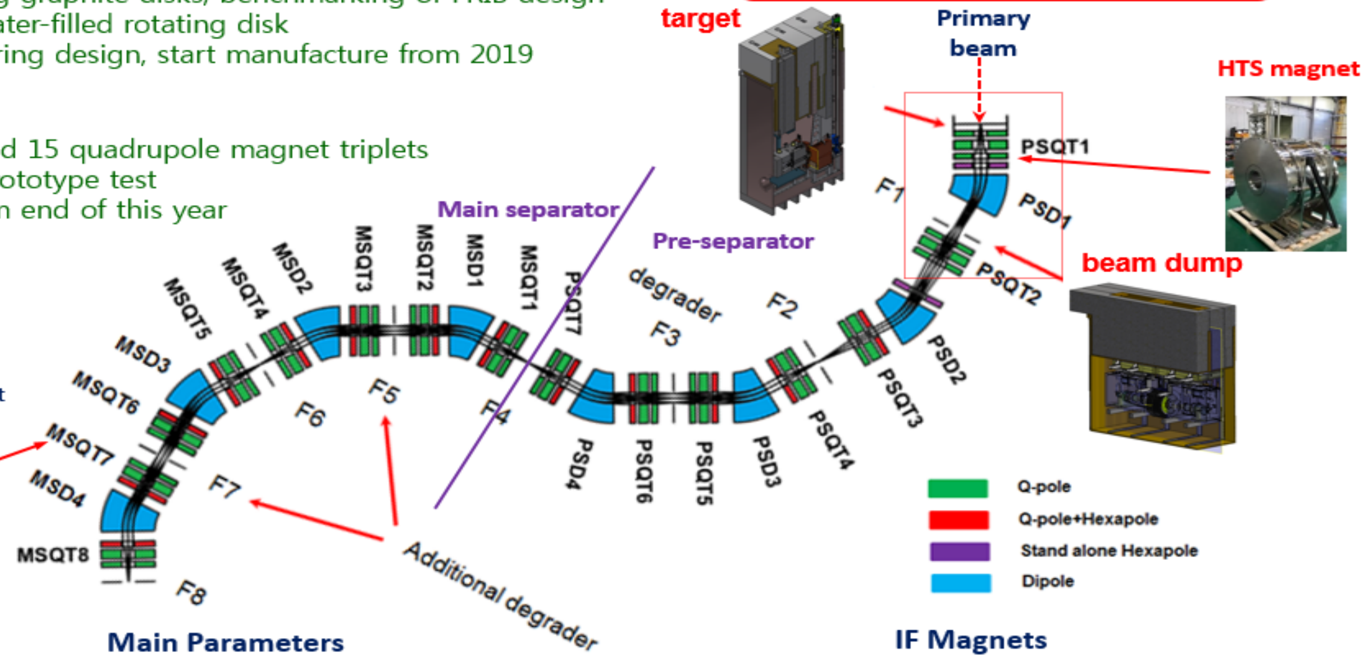
- **Target**: multi rotating graphite disks, benchmarking of FRIB design
- **beam dump**: two water-filled rotating disk
- finalizing manufacturing design, start manufacture from 2019

Magnet

- 8 dipole magnets and 15 quadrupole magnet triplets
- HTS, LTS: finish of prototype test
- Production start from end of this year

Prototype LTS quad. triplet





Main Parameters

Max. Bρ	~ 9.6 T.m
Δp/p	< ±3%
Angular acceptance	±40 mrad (H) ±50 mrad (V)

IF Magnets

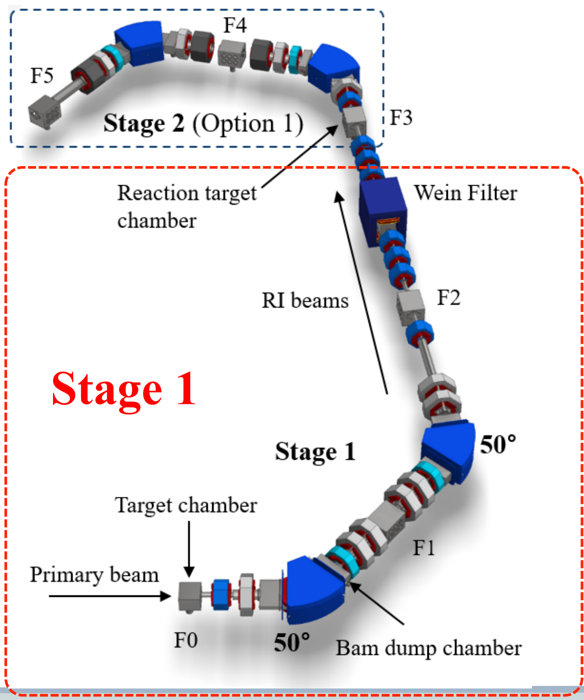
MIC Dipole(x1)	LTS Dipole(x7)
HTS Quad. (x6)	LTS Quad. Triplet(x13)
HTS Hexapole(x1) NC Hexapole(x1)	LTS Hexapole(x13)

- HTS : High Temperature Superconducting
- LTS : Low Temperature Superconducting
- NC : Normal Conducting

KoBRA (KOrea Broad acceptance Recoil spectrometer and Apparatus)

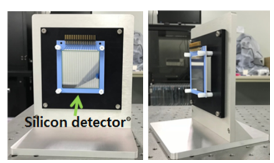
Conceptual design	Prototype & Test	**Manufacturing**	Installation & Commissioning	Operation
2011 ~ 2012	~ 2017.9	**~ 2019.4**	~ 2020.12	2021.1~

- A first part of stage1 (stage1 part1) has been contracted with foreign and domestic companies in April 2018, and production is ongoing.
- The present design of second part of stage1 (stage1 part2) was finally decided among the various design options in June 2018 by consultation with domestic potential users, and is scheduled to bid in August 2018.
- Stage1 will be installed in Low Energy Experimental room (E1) until the end of June 2020.
- The commissioning of Stage1 will be started from beginning of 2021 with stable ion beam.



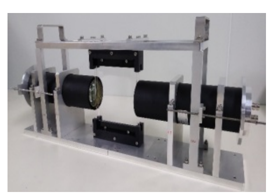
PPAC

- We have 2 10 x 10 cm^2, 2 20 x 20 cm^2, 1 40 x 20 cm^2 active area PPACs
- 4 10 x 10 cm^2 and 1 40 x 20 cm^2 PPACs will be produced



SSD

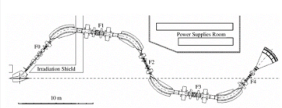
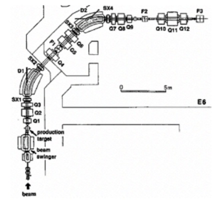
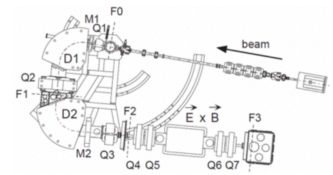
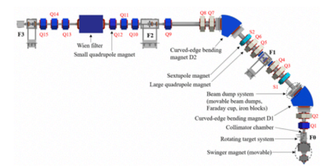
- We have 2 5 x 5 cm^2 active area, 50 μm thick, 16 channel SSD
- Energy resolution ~ 0.7%, S/N ~ 272 for 5.486 MeV α inside vacuum



Plastic scintillator detector

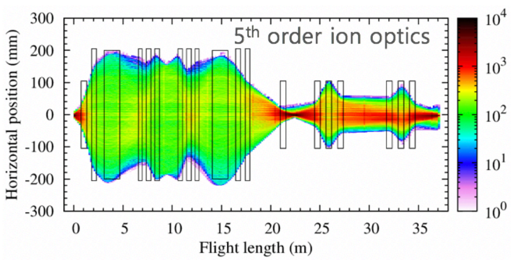
- We have 2 10 x 10 cm^2 active area, 100 μm thick both side readout plastic detector
- Time resolution < 42 ps for 5.486 MeV α inside vacuum

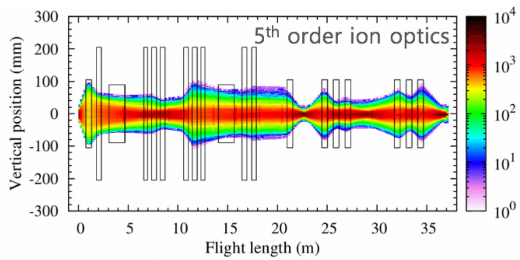
Specification comparison chart of RI beam Separators

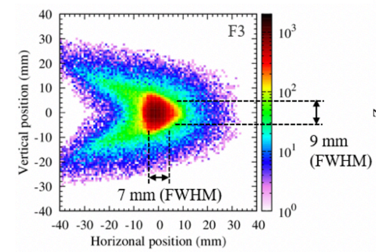
	RIBLL (HIRFL)	RIPS (RIKEN)	CRIB (CNS, University of Tokyo)	KoBRA stage1 (RAON)
Layout				
Magnetic Rigidity	≤ 4.2 Tm	≤ 5.8 Tm	≤ 1.3 Tm	0.25 – 3.0 Tm
Separator Length	35 m	28 m	About 13 m	38 m
Energy Acceptance	20%	12%	30%	16%
Angular Acceptance	50 mrad	80 mrad	75 mrad	80 mrad (H), 200 mrad (V)
Incl. Wien Filter	No	No	1.5 m (50 kV/cm)	2.5 m (27 kV/cm)
Beam Swinger	Up to 5°	Up to 15°	Rotatable separator (-5°–60°)	Up to 12°

Z. Sun et al., NIM A 503 (2003) 496, T. Kubo et al., NIM B 70 (1992) 309, Y. Yanagisawa et al., NIM A 539 (2005) 74, K. Tshoo et al., NIM B 376 (2016) 188.

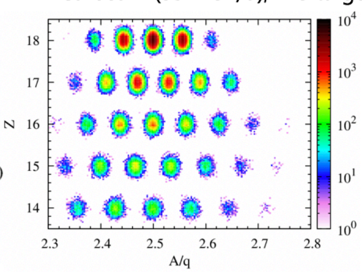
❖ **Secondary beam envelope of KoBRA stage1 & PID simulated**





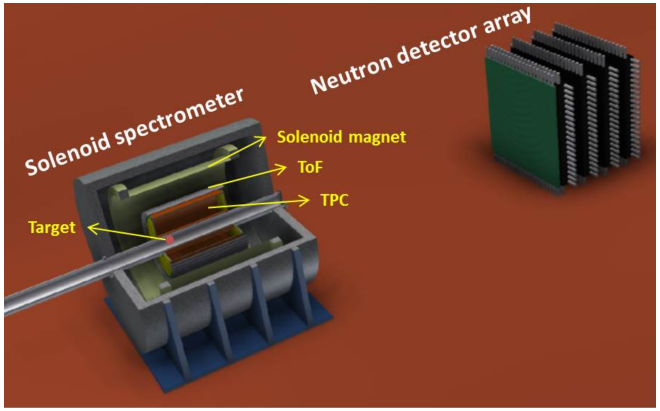


^{48}Ca beam (35 MeV/u), ^{9}Be target



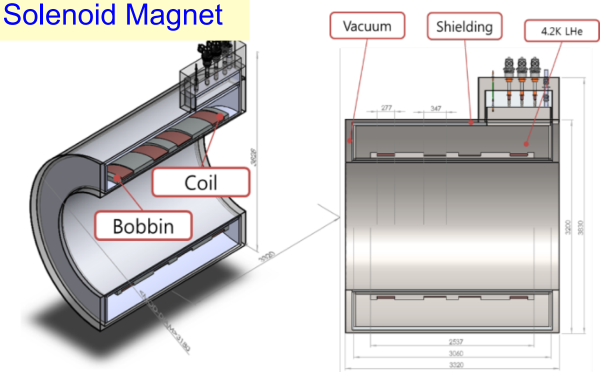
LAMPS (Large Acceptance Multi-Purpose Spectrometer)

Conceptual design	**Prototype & Test**	Manufacturing	Installation	Commissioning	Operation
2011 ~ 2012	**~ 2018.12**	~ 2020.12	~ 2021.7	2021.12	2022~



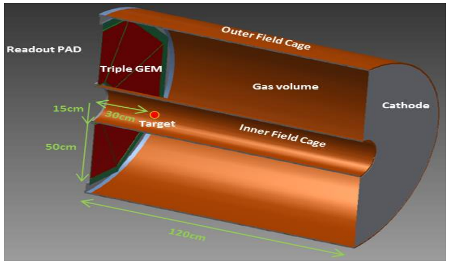
- Beam Energy: up to 250 MeV/u
- Solenoid Spectrometer
  - Max. 1T solenoid magnet
  - TPC (~ 3π sr acceptance, charged particle tracking)
  - Scintillation counter (trigger & ToF)
- Neutron Wall (neutron tracking)

Solenoid Magnet



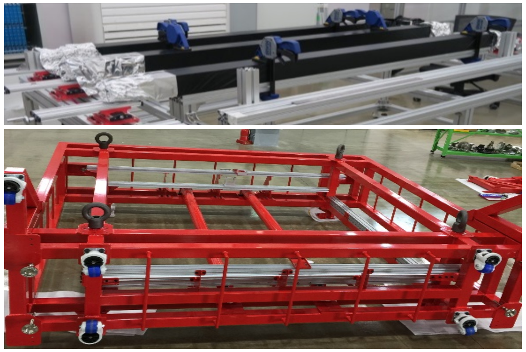
Design change
- Normal to superconducting magnet
- Coil radius: 1 m → 0.8 m
- Fulfill requirement
  - operation B-field: 0.5 T
  - maximum B-field: 1 T, ΔB/B < ±1% at Time Projection Chamber region

Time Projection Chamber (TPC)



- Test with prototype of TPC completed
- Fulfill the requirement of TPC
- Based on test results, change TPC design
  - Both side readout → one side readout
  - P-10 gas → P-20 gas

Forward Neutron Detector Array



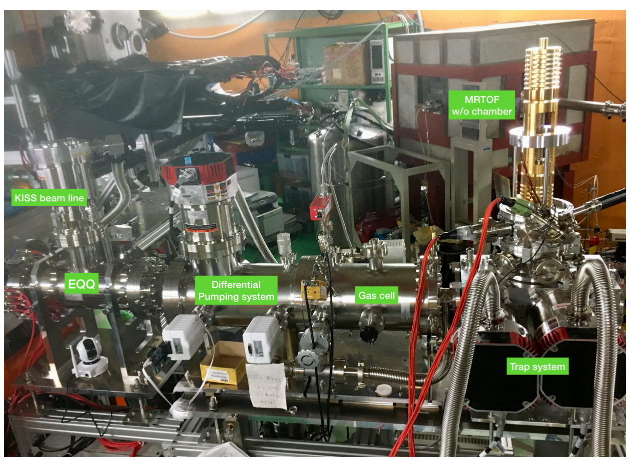
- Completed all R&D processes
- Finalized Array frame design
- Detector production in progress
  - 2 veto detectors (total: 20)
  - 10 neutron detectors (total: 160)
- Complete integration & test by the middle of 20

High Precision Mass Measurement System (MR-TOF)

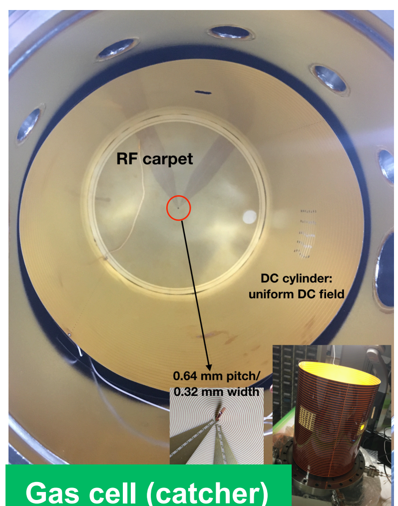
Conceptual design	Manufacturing & Test	Installation	Commissioning	Operation
2011 ~ 2012	**~ 2020.1**	~ 2020.10	~ 2021.12	2022~

▪ MRTOF-MS construction under the collaboration

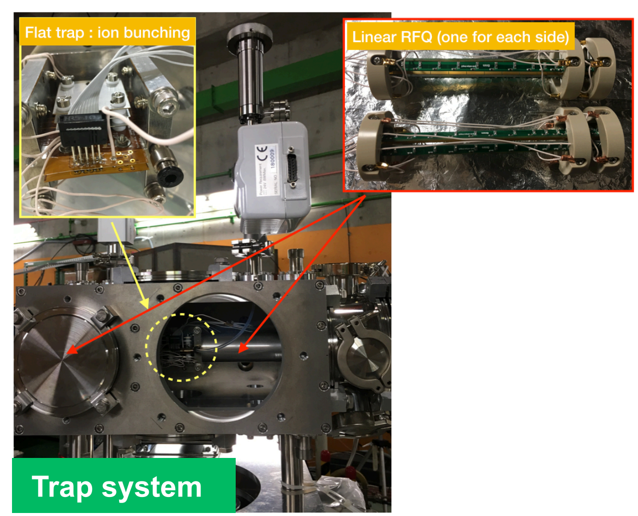
- R&D work, led by WNSC MRTOF group (Leader : Prof. Wada)
- Additional beam line to the MRTOF-MS, already constructed (2017)
- Differential pumping system, gas cell (or catcher), Trap system, and MRTOF analyzer have been ass embled, waiting for offline ion source test.
- Test of the differential pumping system with the gas cell filled with 1 mbar helium gas, performed : 3. 4×10^{-4} Pa upstream side (acceptable)
- Optimizing the beam transmission through the φ 2-mm gas cell hole, performed : 72% efficiency, b ut will be improved by additional beam steerer.



A picture of MRTOF-MS system and others at RISP-KEK/WNSC



Gas cell (catcher)



Trap system

Summary & Outlook

- Accelerator
  - Mass production for SCL3 is under way
  - SCL2 is under pre-production phase
  - **From April, 2019, installation for SCL will start from SCL3**
  - Test facility for cavities and cryomodules will operate from next Jan.

- By the end of 2021, we will achieve
  - **SI beams:** Stable ion beams (^{16}O, ^{40}Ar) from ECRIS → SCL3 → 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 (with low intense RI beams)**
    → RIBs production at KOBRA (A<~50, beam energy < 20 MeV/u) using SI beams from SCL3
  - Beam commissioning starts for SCL2
  - Installation and commissioning for IF, LAMPS, Neutron, bio-medical and muSR
    → Collaborative works with RUA (RAON Users Association) via RULC (RAON Users Liason Center)

- Post RISP (2021 ~)
  - Beam acceleration for ISOL → SCL3 → SCL2 → IF **(ISOL+IF)**
  - Beam commissioning and experiments for IF, LAMPS, Neutron, bio-medical and muSR
  - **Ramping-up to get the 400kW beams (more 5 yrs)**
  - Energy upgrade to 400MeV/u (require budget)


노벨상 향한 대장정 스타트
중이온가속기 라온
가속기는 '노벨상의 산실'로 불린다. 기초과학 연구에는 필수 실험시설이자, 산업계에는 새로운 기술 개발의 터전이다. 머리카락 한 올 두께보다 작은 나노미터(nm·1nm는 10억 분의 1m)와, 이보다 100만 배 더 작은 펨토미터(fm·1fm는 1000조 분의 1m)의 세계를 보여주는 최첨단 '현미경'이기도 하다. 한국형 중이온가속기 '라온(RAON)'이 2021년 완공을 목표로 구축에 들어갔다. 빅뱅 3분 뒤의 우주를 재현하고, 한국의 이름을 붙인 새로운 원소 '코리아늄'을 발견해 주기율표에 등재하겠다는 포부도 세웠다.
Thank you