RAON Rare isotope Accelerator complex for ON-line experiments

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Overview of The Rare Isotope Science Project (RISP)

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RISP 중이온가속기건설구축사업단 Rare Isotope Science Project

CONTENTS

Part 1. Project Overview

Rare Isotope Science Project (RISP)

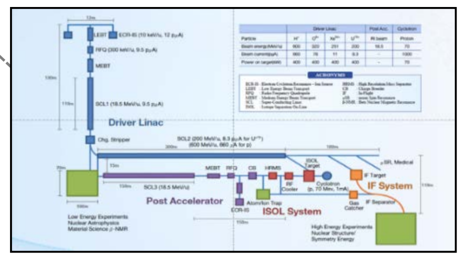
- **Goal:** To build **a heavy ion accelerator complex RAON,** for **rare isotope science** research in Korea.

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

- **Budget: KRW 1,432 billion (US$ 1.26 billion, 1$=1,135krw)**
  - accelerators and experimental apparatus : 460.2 billion won
  - civil engineering & conventional facilities : 972 billion won (incl. site 357 billion won)
- **Period: 2011.12 ~ 2021.12**

System Installation Project

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



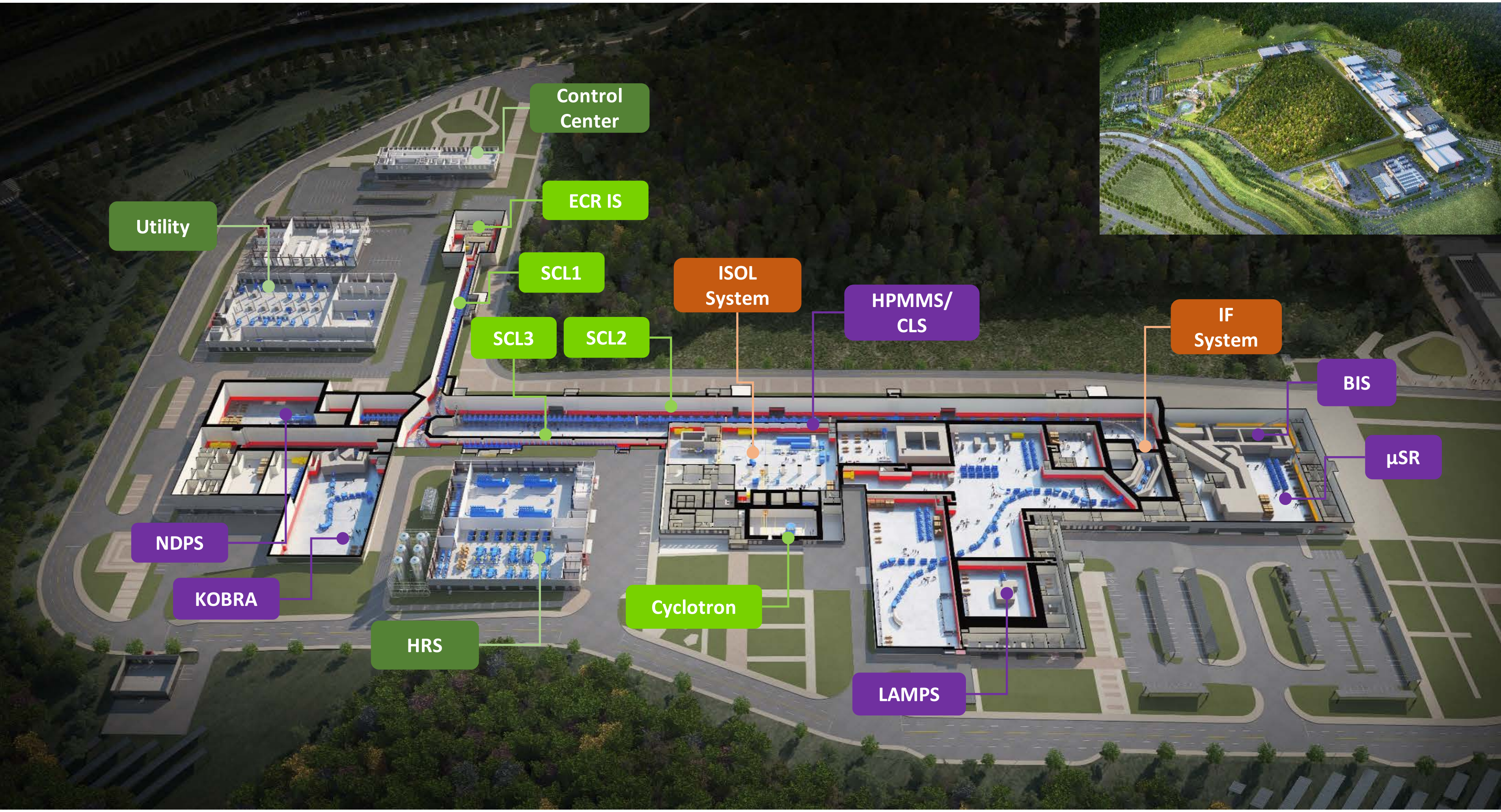
Facility Construction Project

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 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**

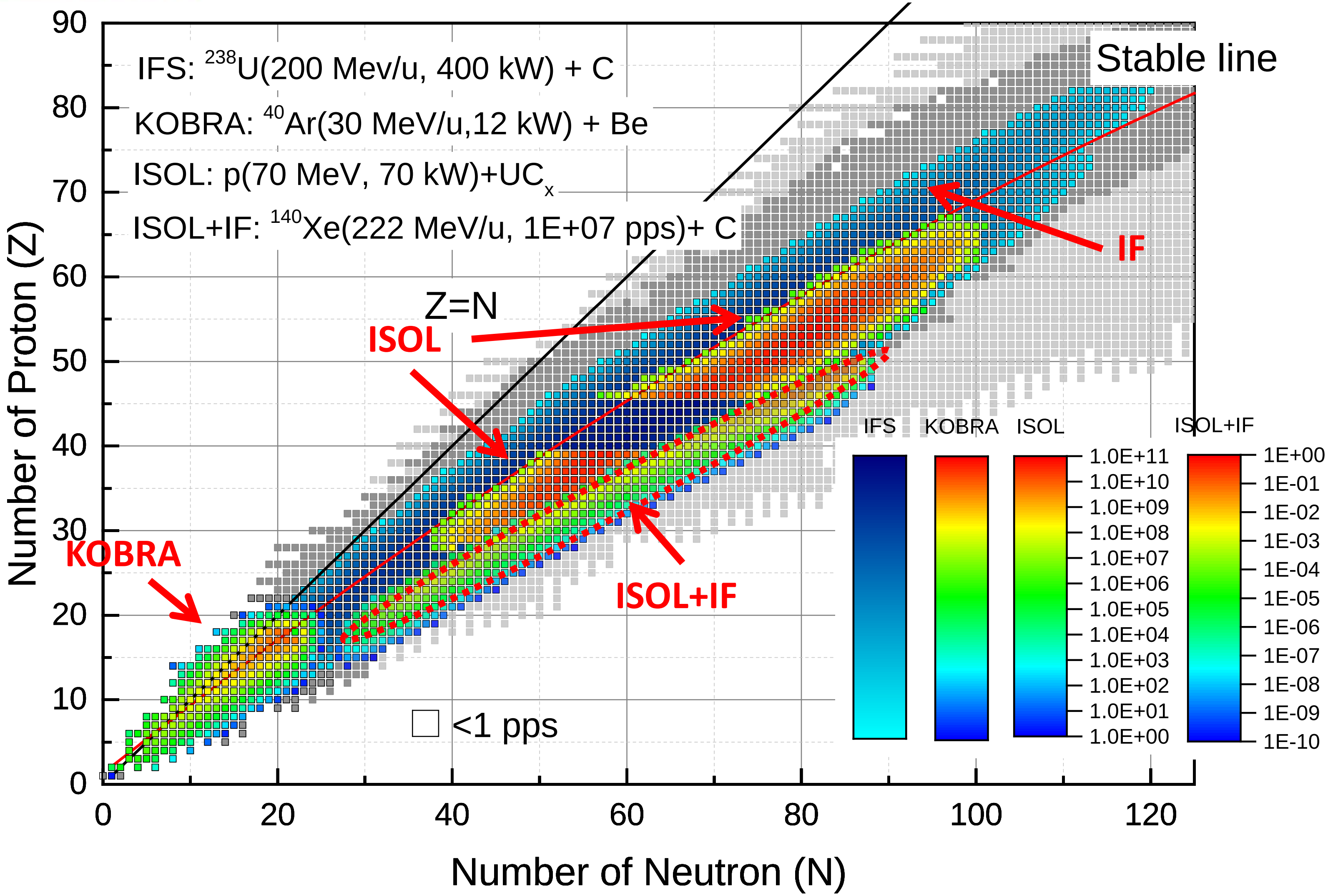
RAON Layout



- **SCL1 has been decided to postpone**

  : SCL3 is going to be taking a role of SCL1 in the early operation

RIBs at RAON



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

Project History

System Installation | Facility Construction | Project General

2012

Jan 2012 Established Master Plan for RISP

June 2012 Submitted Basic Design Summary (BDS)

Jan 2009 Finalized the Comprehensive Belt Plan (National Science & Technology Commission)

June 2010 Completed the research to establish the Heavy-ion Accelerator Construction Plan

Feb 2011 Completed the Heavy-ion Accelerator Conceptual Design

Dec 2011 Launched the Heavy-in Accelerator Project

2013

June 2013 Completed Technical Design Report (TDR)

Sep 2013 Revised the Master Plan (1st) (period extension (~2019), implementation schedule change, etc.)

2014

May 2014 Finalized the Master Plan for the Establishment of the IBS (Heavy-ion Accelerator)

July 2014 Finalized the Implementation Plan for the Construction of the Heavy-ion Accelerator Facility

Dec 2014 Began the basic design of facility construction

2015

April 2015 Revised the Master Plan (2nd) (period extension (~2021), implementation strategy change, etc.)

Dec 2015 Completed the basic design of facility construction

2016

June 2016 Constructed the SRF test facility at Munji

Sep 2016 Started detail design of facility construction

2017

Feb 2017 Began the priority work of facility construction

May 2017 Successfully completed the performance test of the SCL3 QWR module

June 2017 Completed the detail design of facility construction

Sep 2017 Began the facility construction

Oct 2017 Successfully completed the SCL demo runs

Dec 2017 Project review by TF

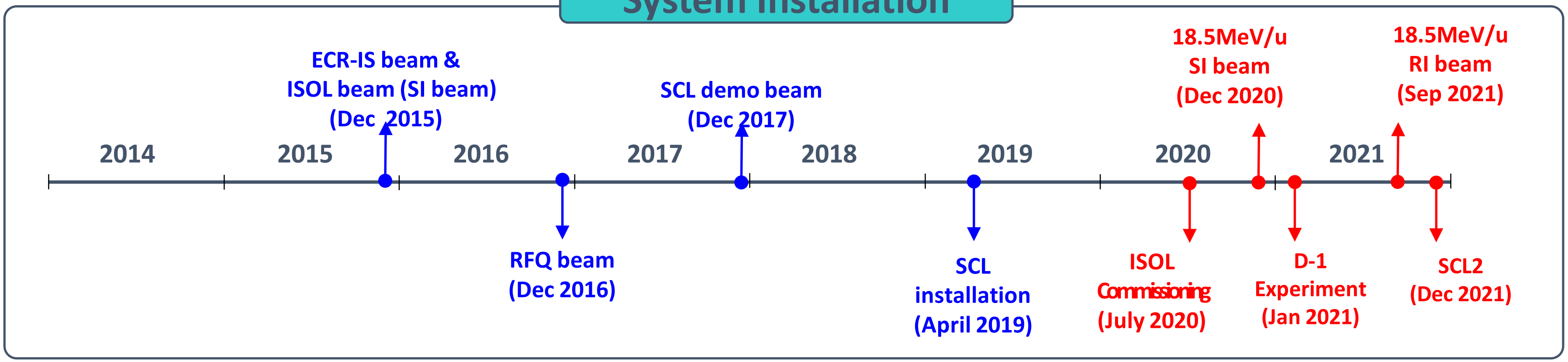
2018

March 2018 Completed the SCL3 HWR prototype module performance test

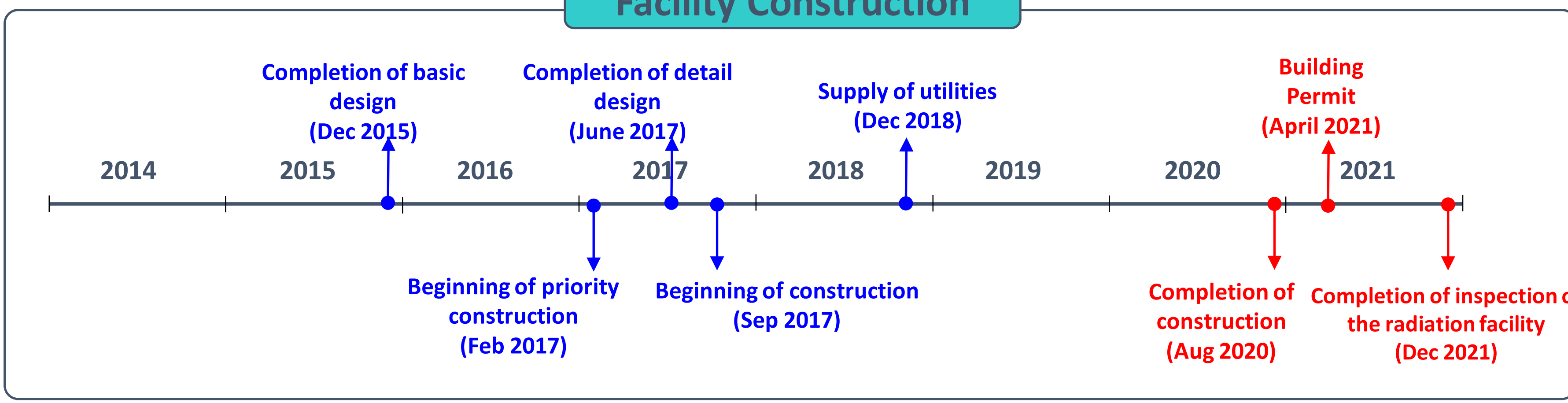
Project Milestone

- (2018) SCL3 manufacturing SCL2 Prototype
- (2019) SCL3 Installation SCL2 manufacturing
- (2020) SCL3 Beam Commissioning/ Const. Completion
- (2021) SCL3 Beam Commissioning/ Project Completion

System Installation

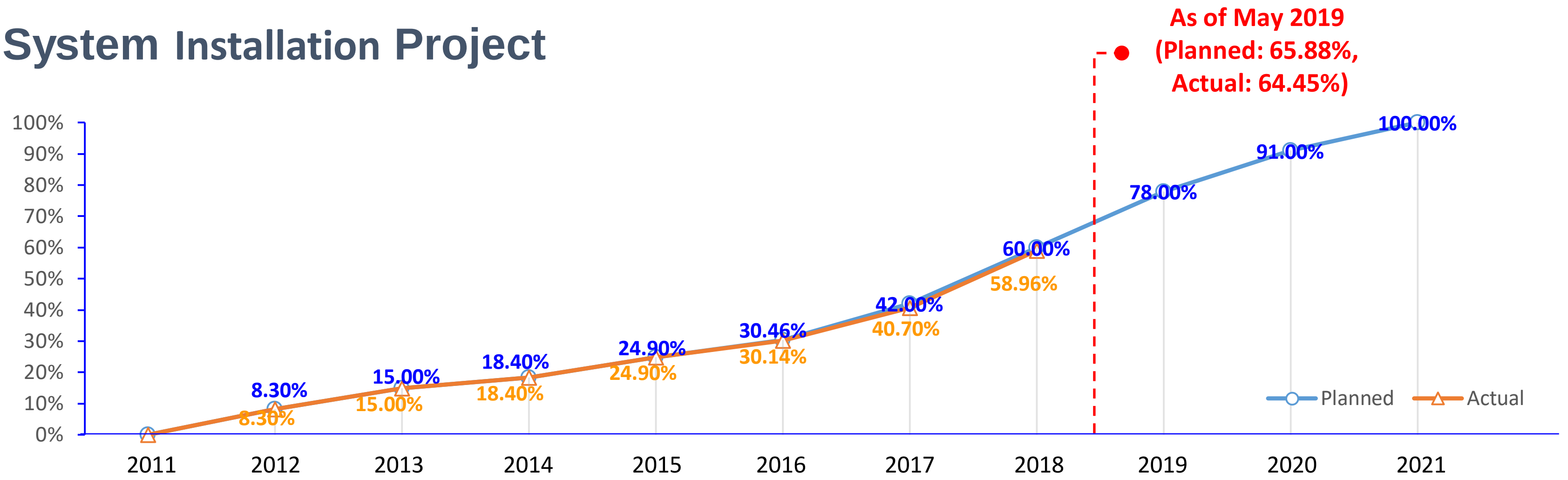


Facility Construction

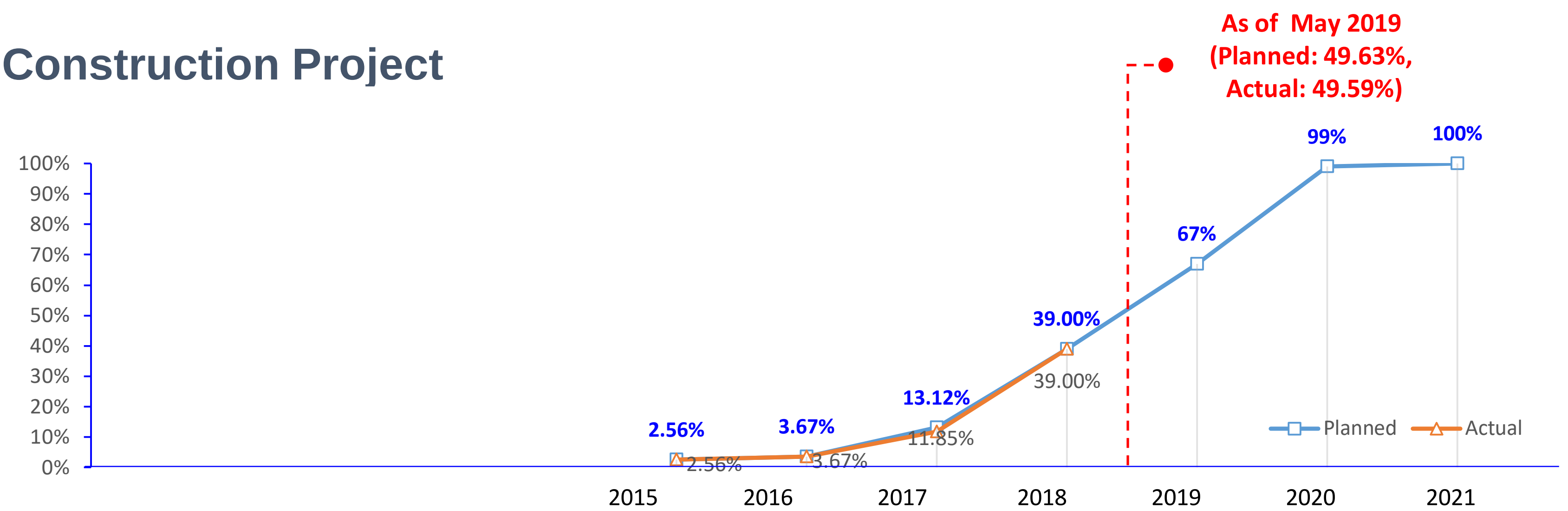


Progress Rate

System Installation Project



Construction Project



Part 2. Construction

Building Layout

Building Layout

- Campus Area : **952,066**㎡ (including the reservation area of **144,640**㎡)
- Period : **2014** ~ **2021**(8 years)
- Cost : 972 billion won (incl. 357 billion won for land)
- Building Area : **76,259**㎡ (**11** Bds)
- Total Bd. Area : **116,252**㎡
- Constructor : POSCO Consortium(11 companies)

View of Construction Place

View of Construction Place (`19. 6)

<`17.01>

<`17.12>

<Assembly Bd.>

<SRF Test Bd.>

<`18.6>

<`19.6>

<High Energy Exps.>

<Control Center>

<Low Energy Exps.>

<SCL3>

<ISOL>

Conventional Facilities


SCL2


SCL3


Low Energy A/B


ISOL


IF/ High Energy A


High Energy B


SCL3


Bending Section


SCL3-gallery

Accelerator Bd.

Conventional Facilities

SRF Test Bd.

Assembly Bd.

Control Center

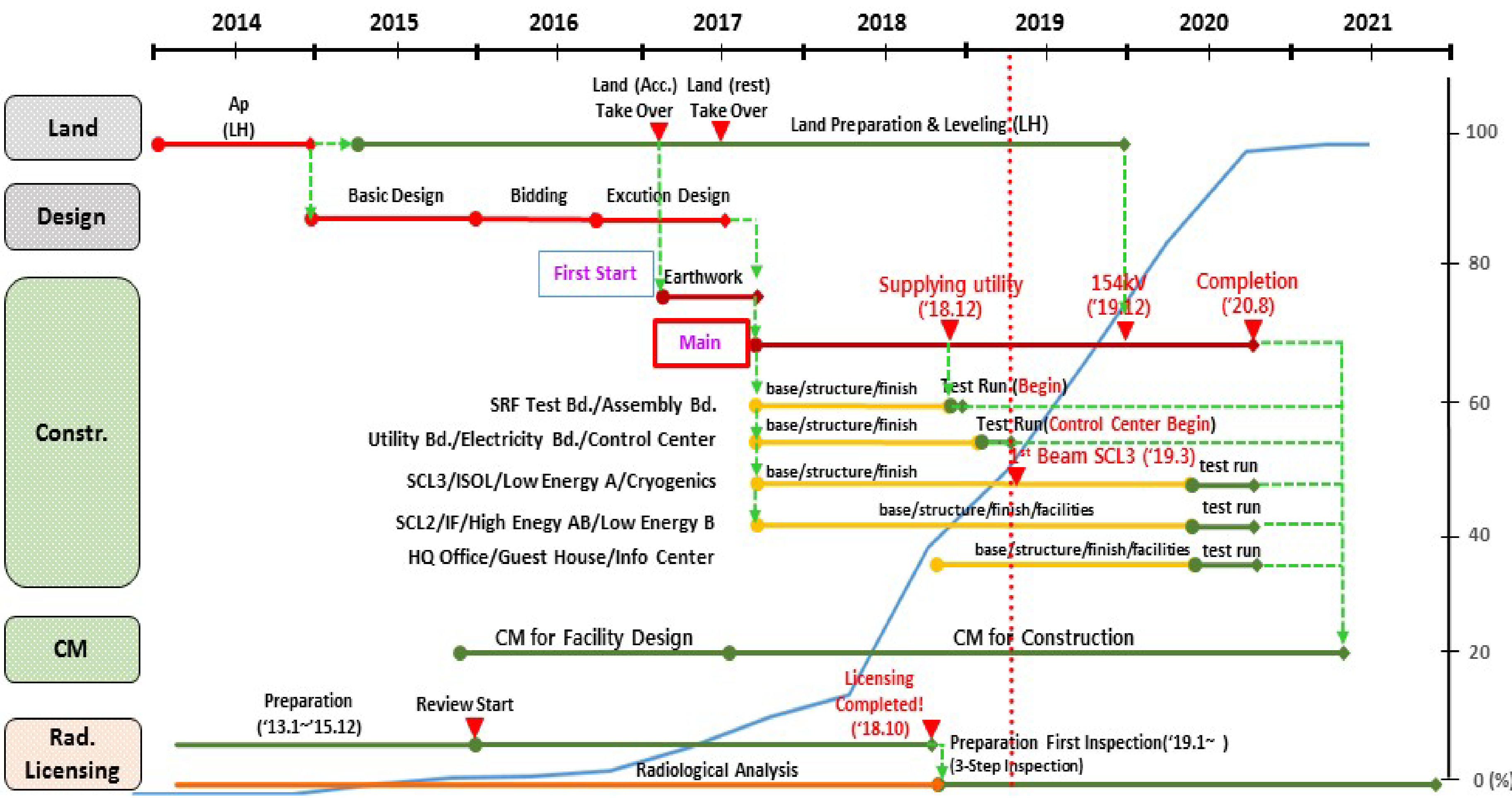
HQ Office

Utility Bd.

Electricity Bd.

Construction Schedule

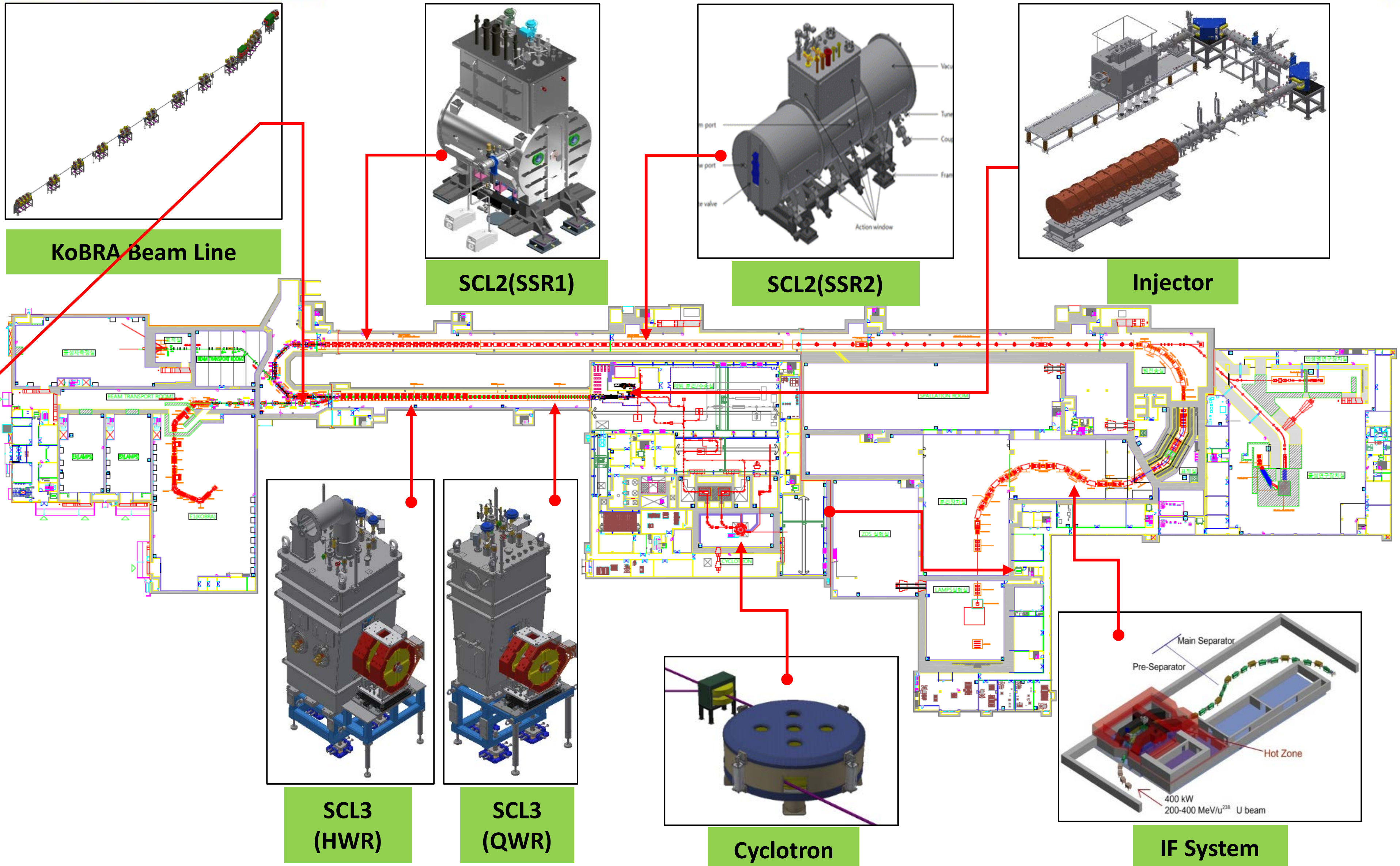
Construction Schedule



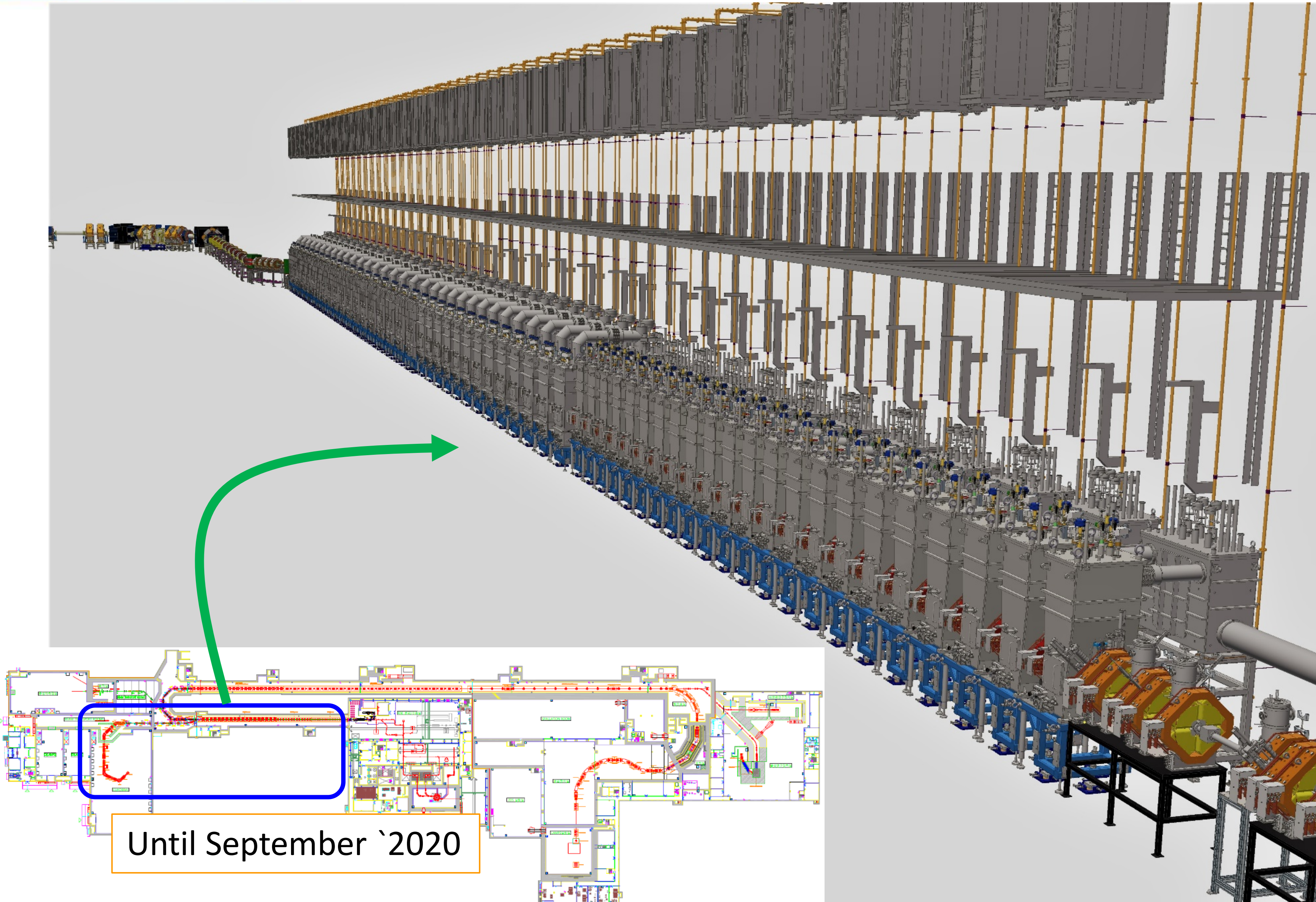
Part 3. System Installation

Accelerator System

TRIUMF Fermilab IMP IHEP RIKEN



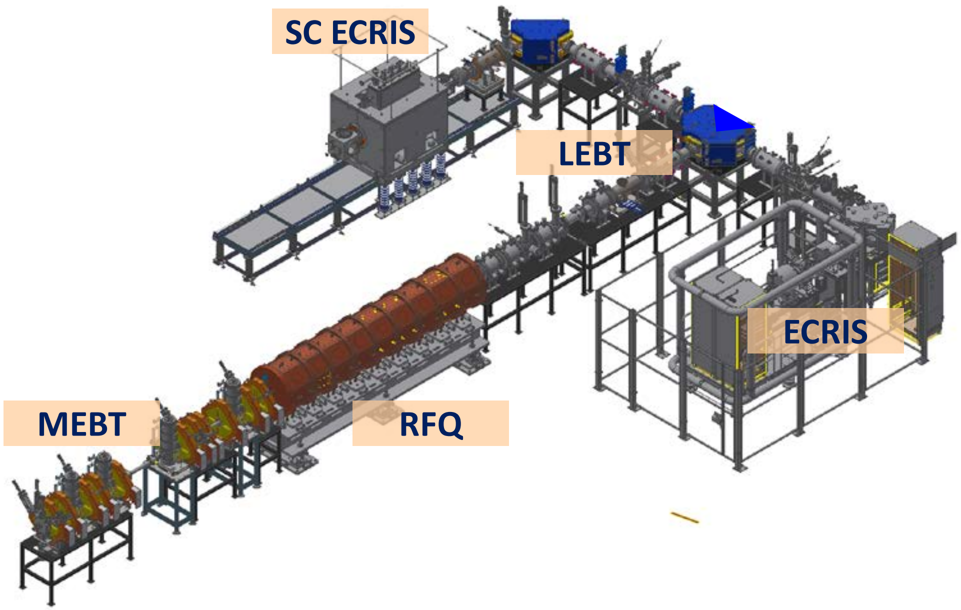
Accelerator System



Accelerator System - Injector

◆ Injector

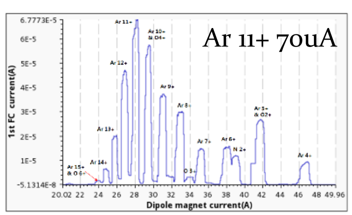
- **Two ECR ion sources on high voltage platforms**
  14.5 GHz ECR ion source
  28 GHz superconducting ECR ion source
- **LEBT (E = 10 keV/u)**
  Beam energy – 10 keV/u, Dual bending magnet
  Chopper & Electrostatic quads, Instrumentation
- **RFQ (E = 500 keV/u)**
  Frequency 81.25 MHz, Transmission 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



◆ SC ECRIS commissioning

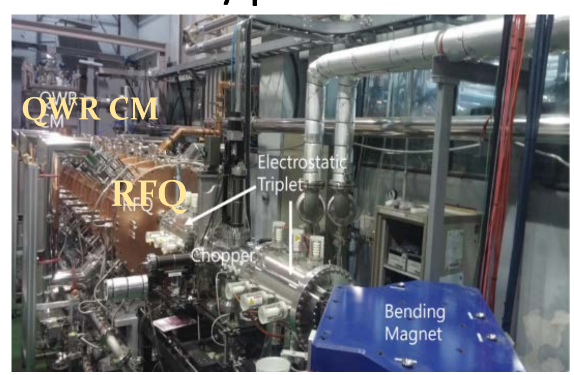
- **Beam experiment for the performance enhancement**
- **Basic metal beam experiment**

Ar beam experiment
Charge distribution

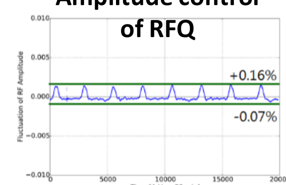


◆ RFQ commissioning

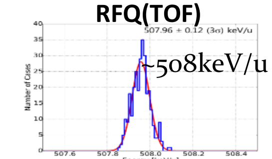
- **RFQ has been conditioned to 40kW, sufficient to accelerate A/q=4.5 beams**



Amplitude control of RFQ



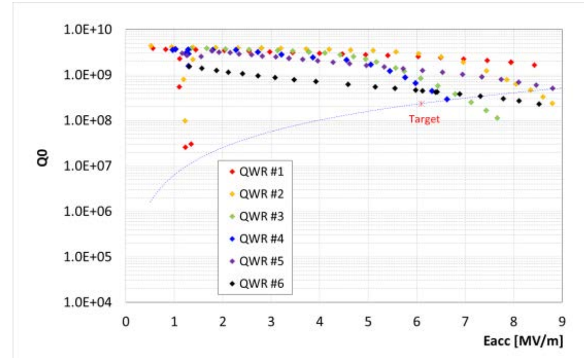
Output Energy of RFQ(TOF)

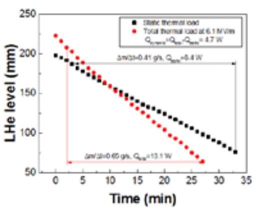


Accelerator System – SCL3

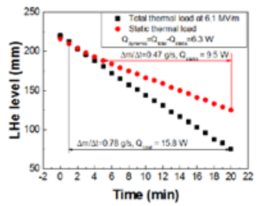
◆ SCL31(QWR)

- **Designed 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
  Thermal load <20W@6.1MV/m, 4.2 K

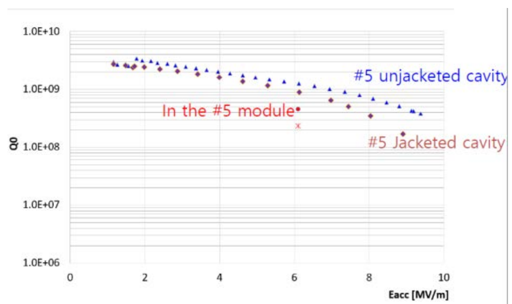




QWR-CM-#3



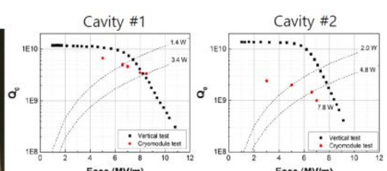
QWR-CM-#5



	Total (W)	Static (W)	Dynamic (W)	Cavity Q_0 (10^9)
QWR-CM-#1	11.7	7.7	4.0	7.7
QWR-CM-#3	13.1	8.4	4.7	6.5
QWR-CM-#5	15.8	9.5	6.3	4.6

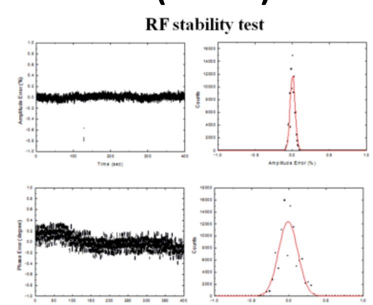
◆ SCL32(HWR)

- **Designed 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)**



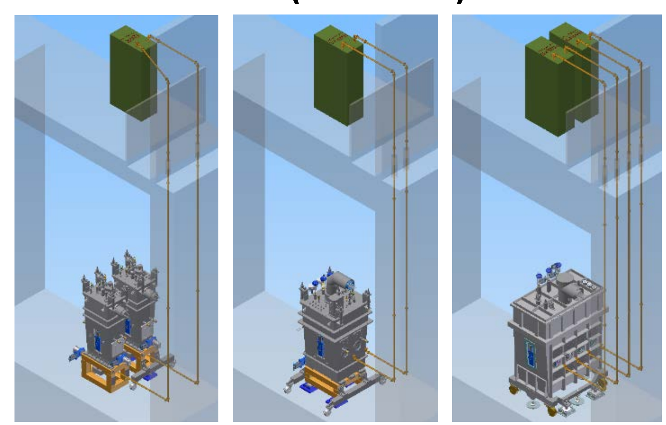
Static thermal load	Dynamic thermal load	Total thermal load
6.6 W	1.4 W (cavity#1)	12.8 W
	4.8 W (cavity#2)	

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



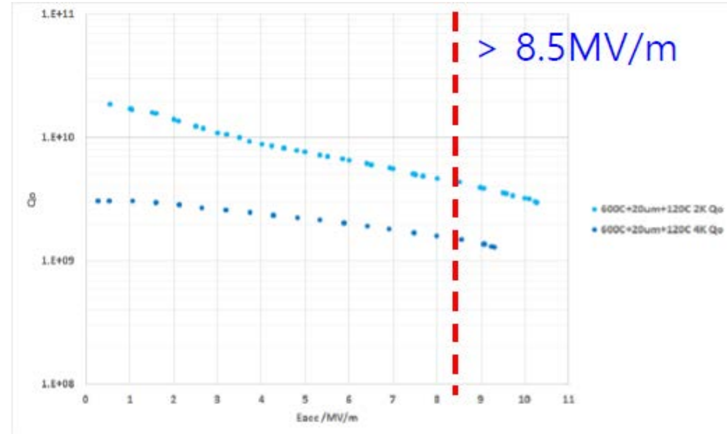
◆ RF System

- **SSPA (4kW) : 2018.07~2020.04**
  Prototype performance test
- **HPRF transmission line (1-5/8")**
  Installation start (2019.08)
- **LLRF control system (2019.07~2020.06)**
- **RF reference line (81.25MHz) : ~2019.12**



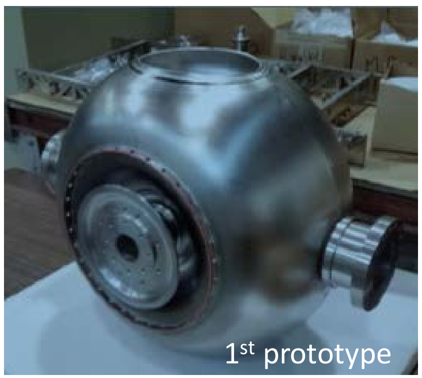
QWR HWR#A HWR#B

Accelerator System – SCL2



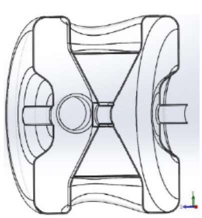
◆ SCL21(SSR1)

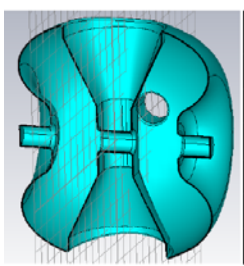
- **1st prototype was manufactured by TRIUMF(2019.6)**
  Balloon type(less multipacting, better mechanical characteristics)
  Accelerating gradient over 8.7MV/m, Multipacting below 2MV/m
- **2nd prototype with domestic vendor is under fabrication**



◆ SCL22(SSR2)

- **1st prototype of cavity is under fabrication**
  Designed by RISP, being fabricated by domestic vendor
  Balloon type, Deep drawing (depth ~280mm)
- **2nd prototype with IHEP is in design stage**
  Cylindrical type



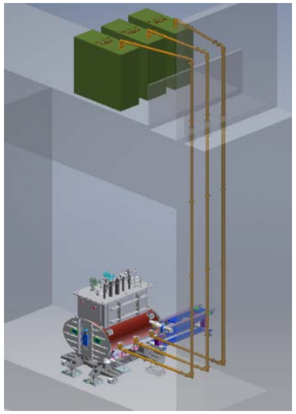


Parameters	Value
β	0.51
f [MHz]	325
$L_{eff}(=\beta_o\lambda)$[mm]	~470
Beam tube diameter [mm]	50
E_{acc} [MV/m]	8.7
V_{acc} [MV]	4.1

RISP design(balloon type)

◆ RF System

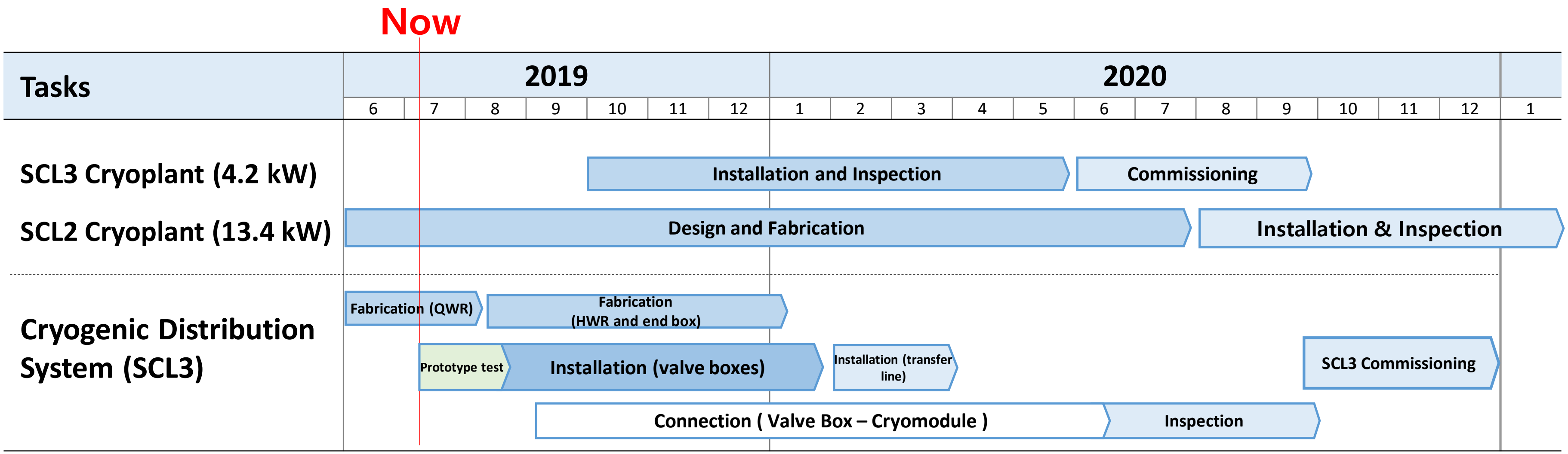
- **SSPA (8, 20 kW): 2020.01~2021.06**
  Requirement for RF power being optimized
- **HPRF transmission line**
  3-1/8", 4-1/16" rigid coaxial
- **LLRF control system (2020.04~2021.06)**
- **RF reference line (81.25MHz) : ~2020.12**

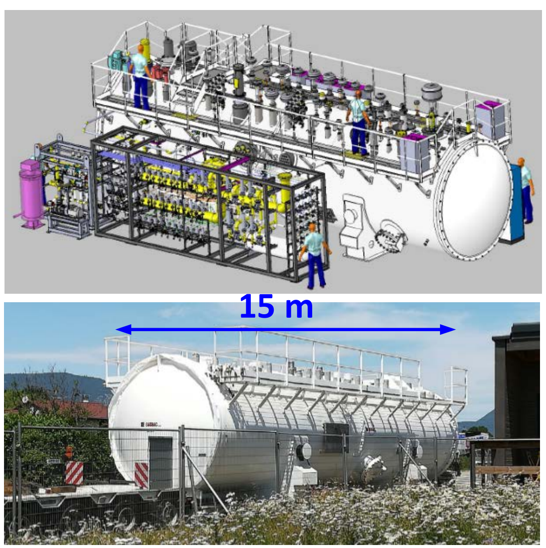


SSR1

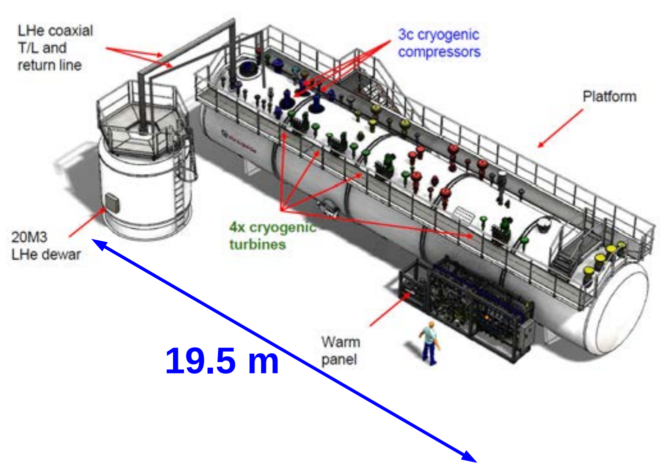
SSPA Prototype

Cryogenic System





SCL3 Cold Box (95 ton)



SCL2 Cold Box (130 ton)

QWR Valve Box

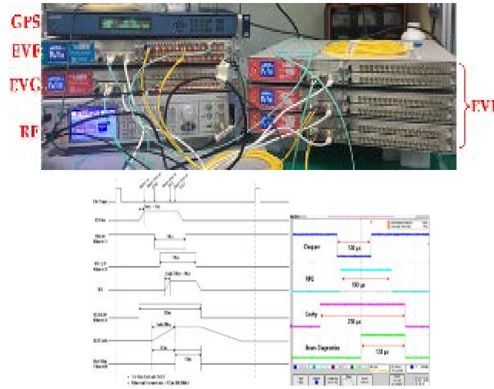
3. Sys. Install. Control System

Control Center

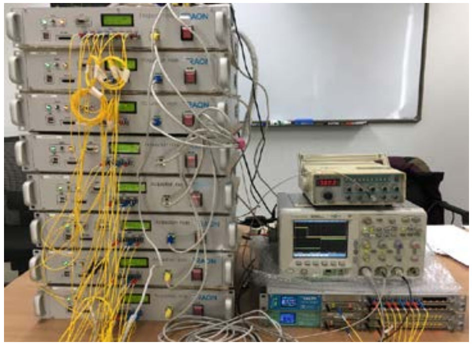
Display Wall


Data Storage System

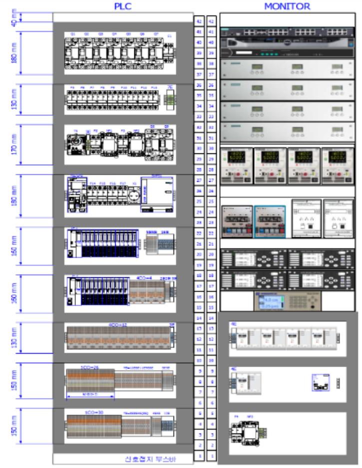
Integrated Control System



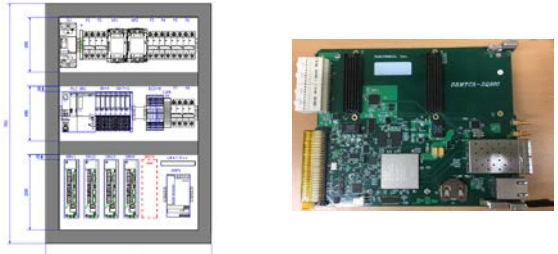
Timing System


Fast Protection System

Local Control System

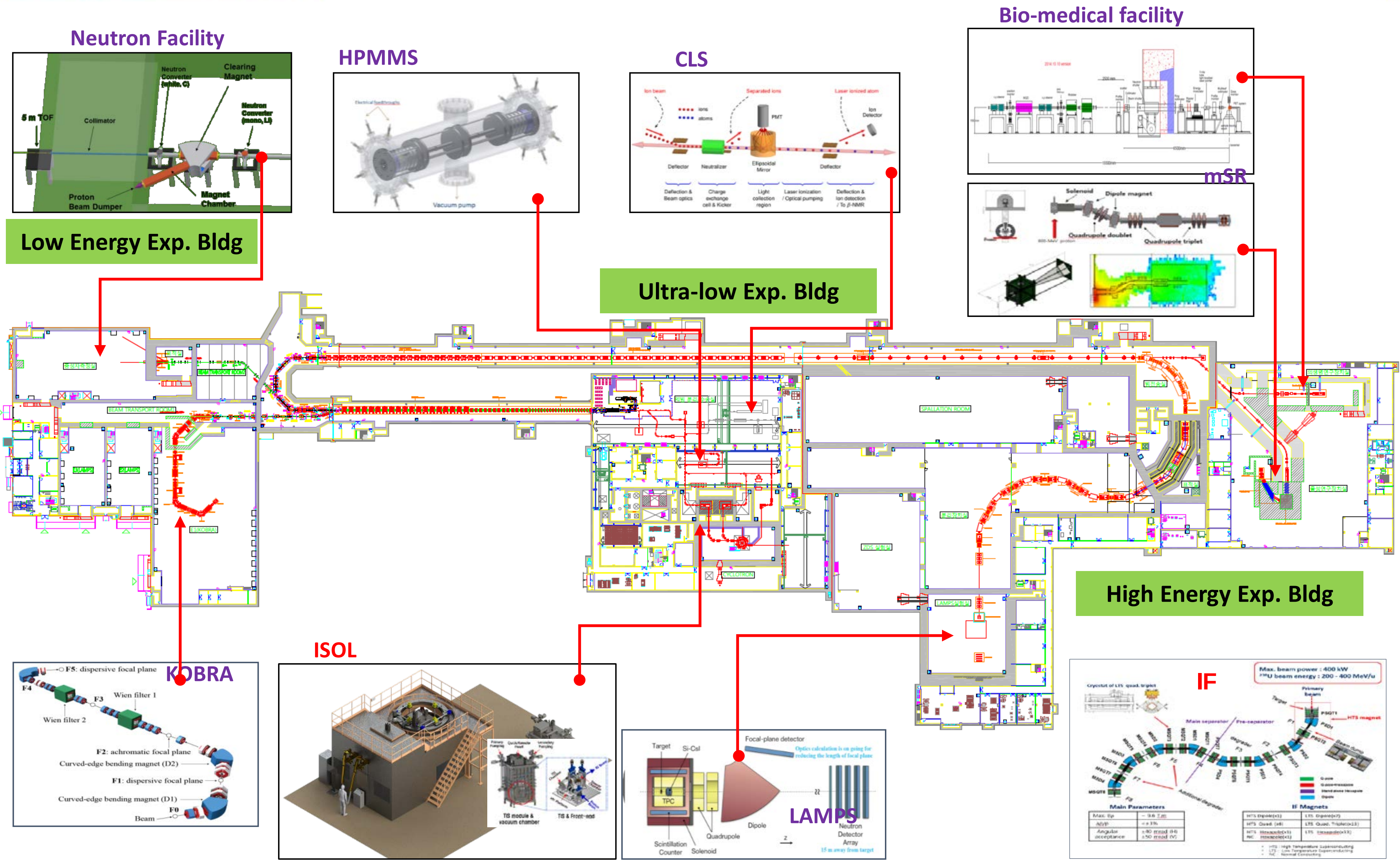


SCL3 Control System


Beam Diagnostics Control System

Embedded EPICS IOC Controller

RI & Experimental System



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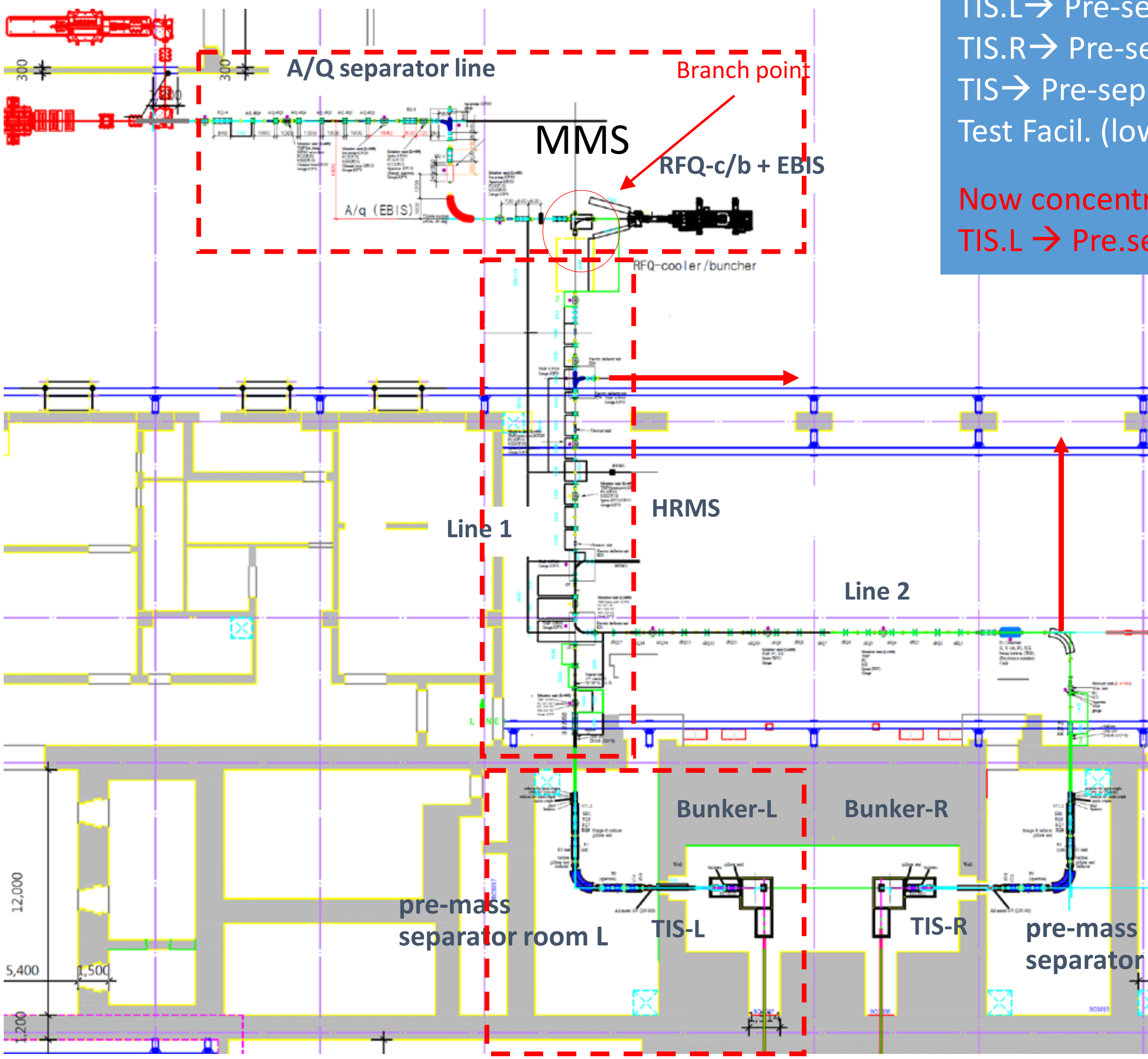
Rare Isotope Science Project

ISOL system



TIS.L→ Pre-sep → HRMS → user
TIS.R→ Pre-sep. → Mass sep. → HRMS → user
TIS→ Pre-sep. → HRMS → EBIS → a/q→post acc.
Test Facil. (low pow., non U) → Pre-sep → user

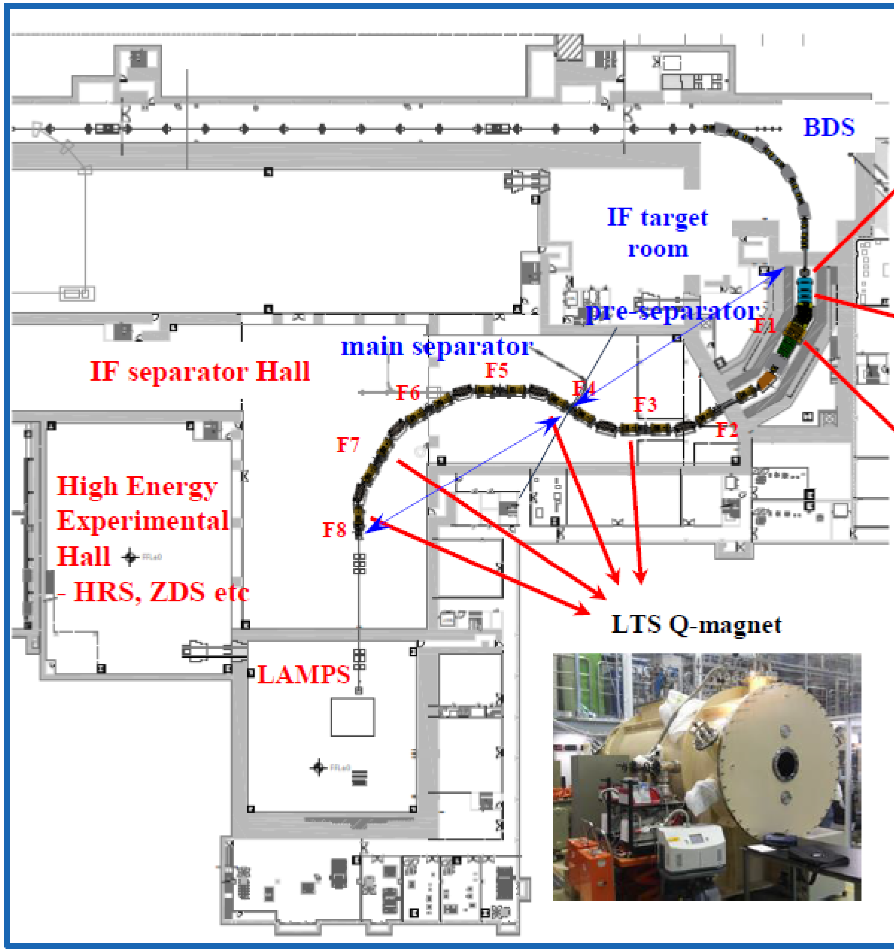
Now concentrating on the shortest line
TIS.L → Pre.sep → EBIS → A/q → Post.acc

ISOL building ready by '19.12
- Ground floor: TIS, beamline, experimental hall
- 1st floor: experimental hall, Laboratory, utilities
- 2nd floor: Control room, Analysis room

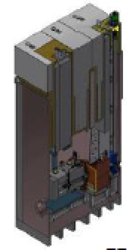
Early stage operation

RIB	Yield (pps)	Target material	1 kW proton
$^{8-9}$Li	10^{6-7}	BN	SI
$^{20-22, 24}$Na	10^{6-7}	MgO, SiC	SI
$^{22-23}$Mg	10^{6-7}	SiC	SI+LIS
$^{24-26}$AL	10^{4-5}	SiC	SI+LIS
^{126}I	10^{6-7}	LaC_2	FEBIAD
^{131}Cs	10^{5-6}	LaC_2	SI
^{132}Cs	10^{5-6}	LaC_2	SI
^{131}Ba	10^{0-1}	LaC_2	SI
^{135}Ce	10^{0-1}	LaC_2	SI

In-Flight separator layout

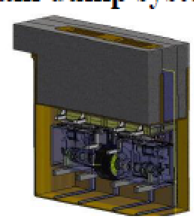


target system

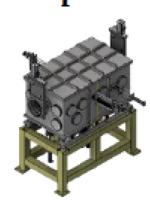


HTS Q-magnet

beam dump system



Focal plane chamber



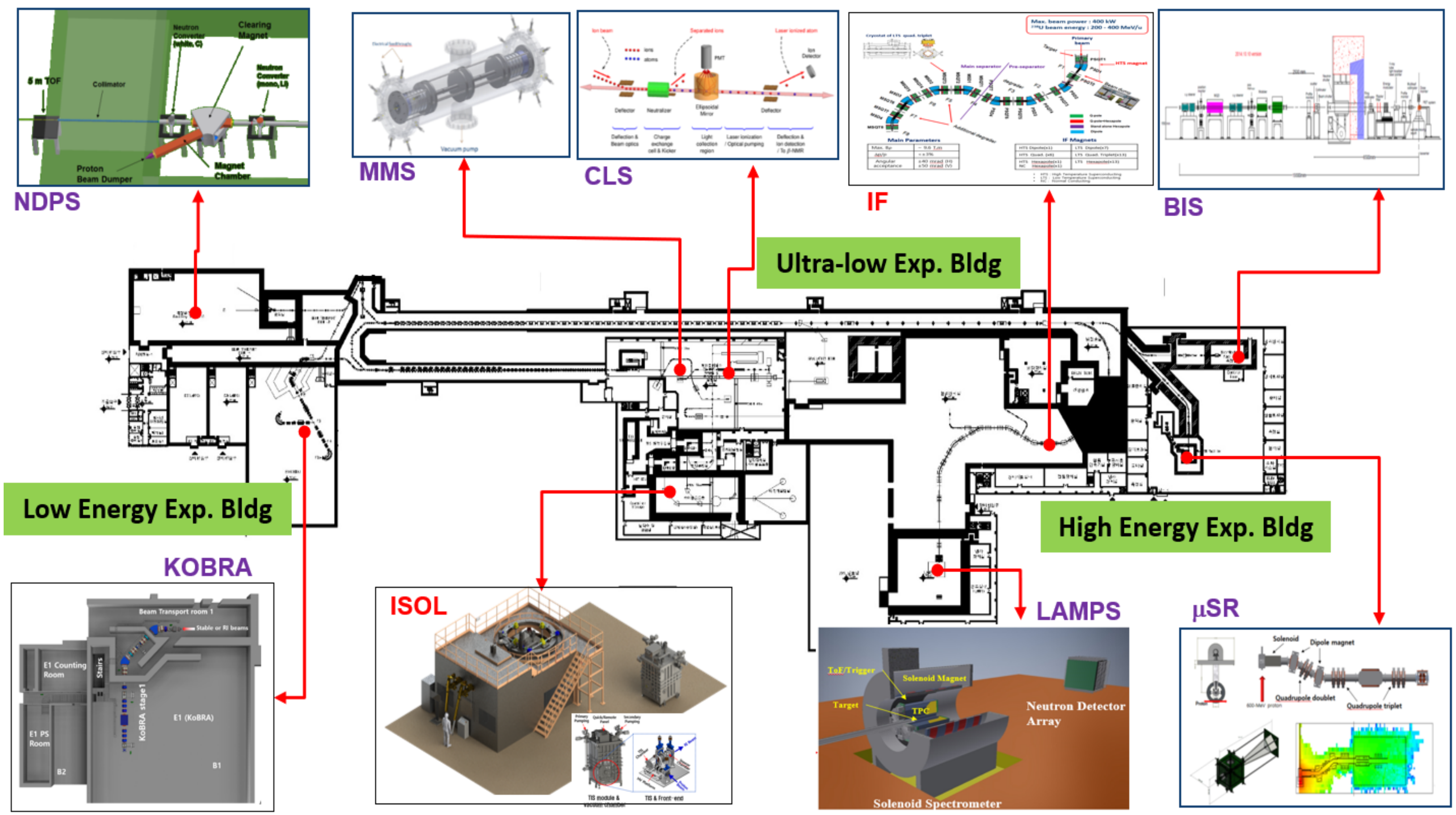
Configuring device list

- Target system
- Beam dump system
- Collimator
- Q-pole magnet(HTS) 6 ea
- Dipole(MIC, NC) 8 ea
- Q-pole triplet(LTS) 13 ea
- Vacuum chamber
- Vacuum pump
- Valve, pipe, tube etc.
- Radiation shielding block

Total length~ 120 m

Layout of Experimental System at RAON

- **Nuclear science** - KOBRA, LAMPS, NDPS, MMS, CLS (based on atomic physics)
- **Applied science** - μSR (Material science), BIS (Bio & Medical application)
- ➡ **7** (at the beginning of RAON operation) + upgrade + ?? (in the future, space reserved)

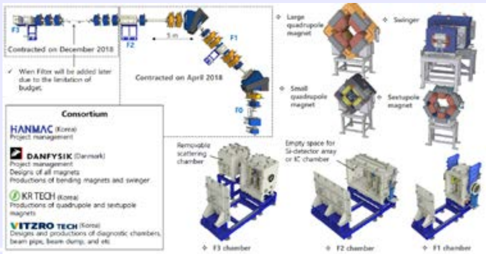


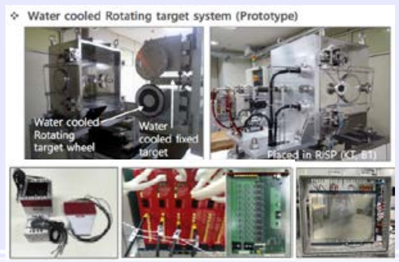
Current Status of Experimental System

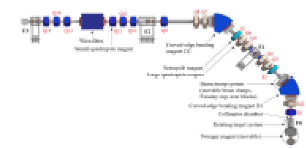
1. KOBRA

(KOrea Broad acceptance Recoil spectrometer & Apparatus)

- **Research** Studies of nuclear structure and nuclear astrophysics in the energy range of < a few tens of MeV/u
- **Current status** Under fabrication (start installation from Sep. 2019)



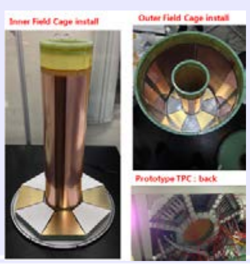


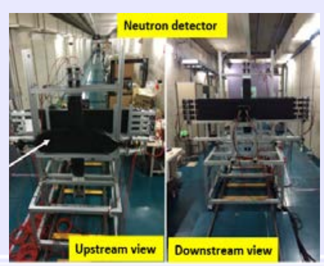
	KoBRA stage1 (RAON)	KoBRA stage1 + stage2 (RAON)
Layout		Improve a mass resolution & primary beam rejection with cleanup section (Under Discussion)
Magnetic Rigidity	0.25 – 3.0 Tm	
Max. Electric Rigidity	2.0 – 18.5 MV	
Spectrometer Length	38 m	
Angular Acceptance	80 mrad (H), 200 mrad (V)	
Energy Acceptance	16%	
Mass Resolution	≈ 650	
Primary Beam Rejection	> ~10^{-13}	

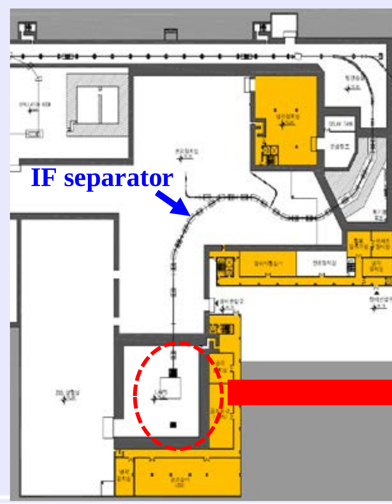
2. LAMPS

(Large Acceptance Multi-Purpose Spectrometer)

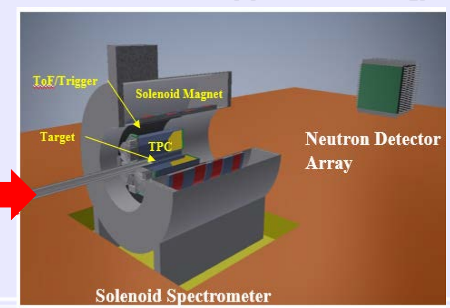
- **Research** Studies of nuclear matter and nuclear reactions with stable and RI beams at intermediate energy regime
- **Current status** Under fabrication (start installation from Jan. 2021)







- **Solenoid Spectrometer**
  - Max. 1T solenoid magnet
  - TPC (~ 3π sr acceptance, charged particle tracking)
  - ToF & Trigger
- **Neutron Detector Array (neutron tracking)**

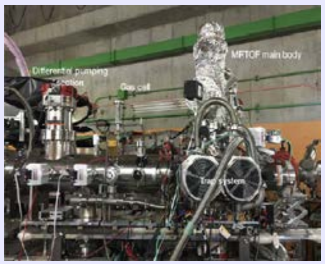


Current Status of Experimental System

3. MMS (Mass Measurement System)

· **Research** High precision mass measurement of short lived rare isotopes

· **Current status** Under assembly and test (start installation from Feb. 2020)



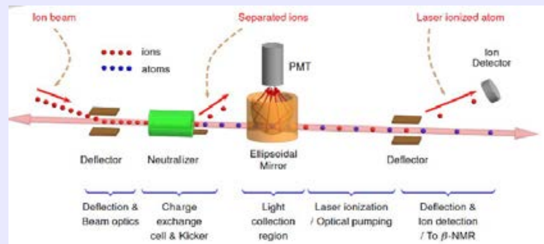
MR-TOF-MS

$$\frac{\delta m}{m} = \frac{1}{R_m\sqrt{N}} \quad \sim 6.67\times10^{-7}$$

4. CLS (Collinear Laser Spectrometer)

· **Research** Model independent Studies of nuclear ground and isomeric state properties

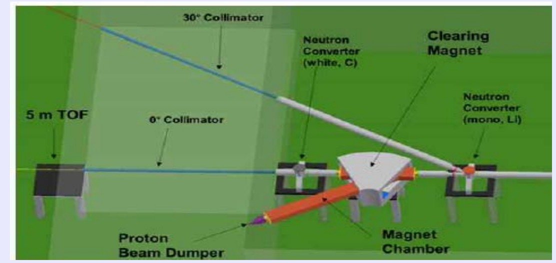
· **Current status** Restart development (start installation from Jan. 2020)



5. NDPS (Neutron Data Production System)

· **Research** Measurement of neutron induced reaction data for nuclear science

· **Current status** Restart development (start installation from Jan. 2021)



6. µSR (Muon Spin Rotation/Relaxation/Resonance)

· **Research** Studies of local electromagnetic structures and exotic properties of material by using polarized muons

· **Current status** Restart development (start installation from Nov. 2020)

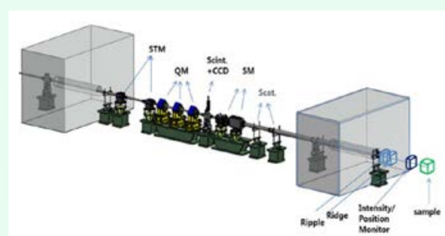
Contents	Requirement
Species and polaization	μ^+, ~100%
Yield on Sample	> 10^5 pps
Beam energy (muon)	< 4,000 keV
Beam energy (primary beam)	> 500 MeV
Beam current (primary beam)	> 0.06 mA
Transport efficiency (surface muon beamline)*	> 1.5%

* system specification

7. BIS (Beam Irradiation System)

· **Research** Biomedical studies such as cancer treatment, human body effect by space radiation and cell mutation

· **Current status** Restart development (start installation from Feb. 2021)

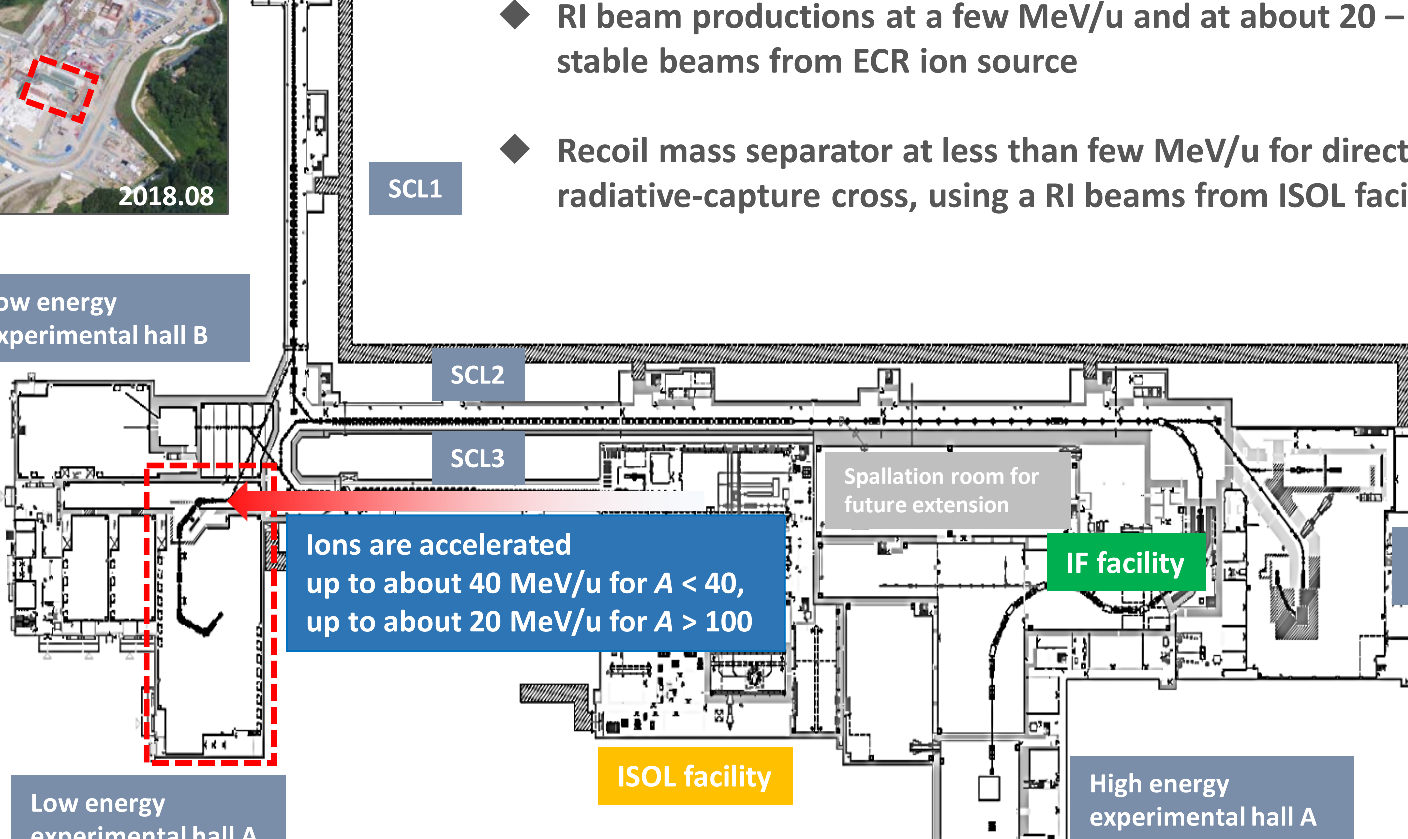


Uniformity on sample	< 3%
Dose rate on sample	2Gy/min ~ 2000Gy/min
Irradiation area on sample	< 20 cm × 20 cm
Primary Beam energy	310 MeV/u for 12C6+
Primary Beam current	1 nA for early BIS, increased up to several pµA

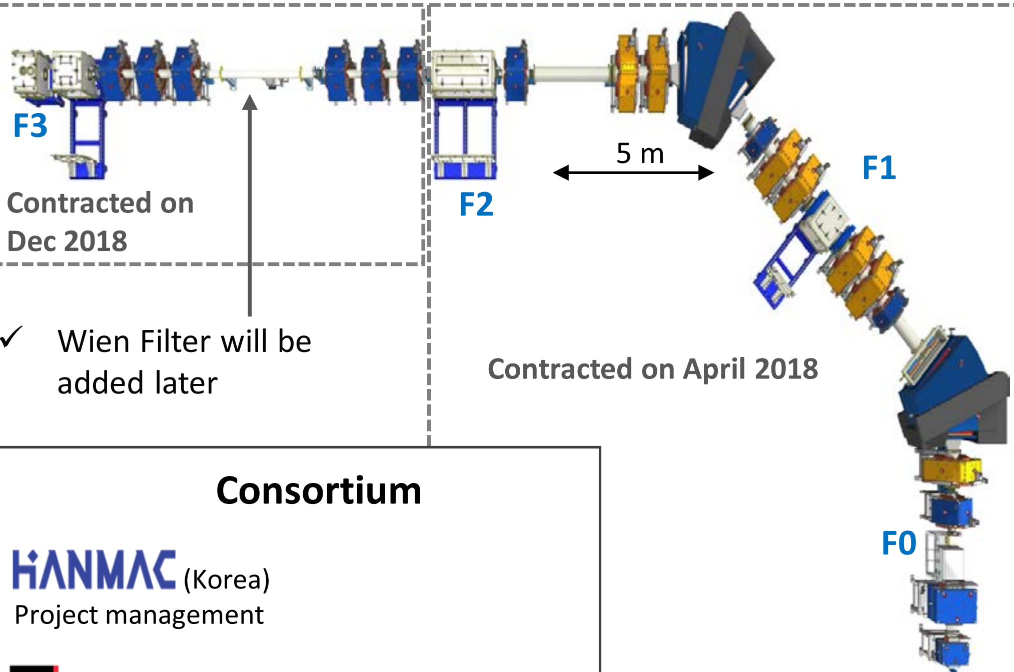
KOBRA

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**



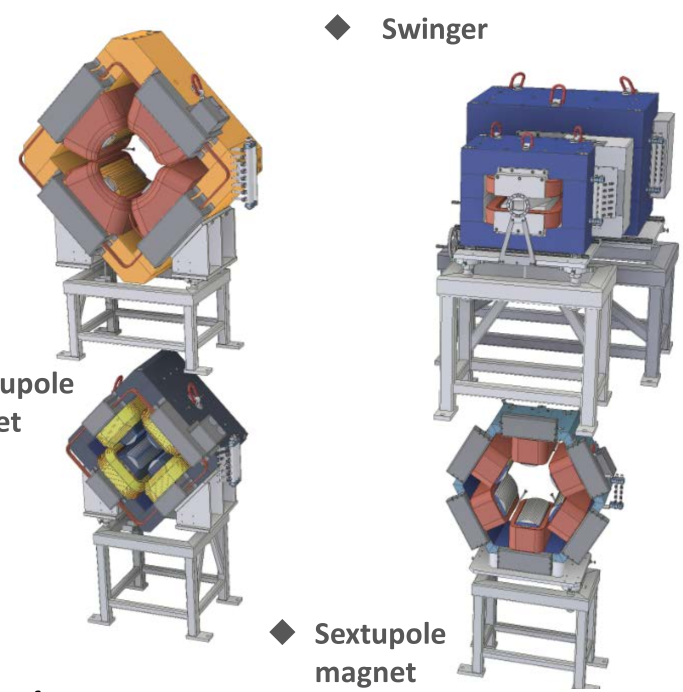
KOBRA



Contracted on Dec 2018

Contracted on April 2018

✓ Wien Filter will be added later



- Swinger
- Small quadrupole magnet
- Sextupole magnet

Consortium

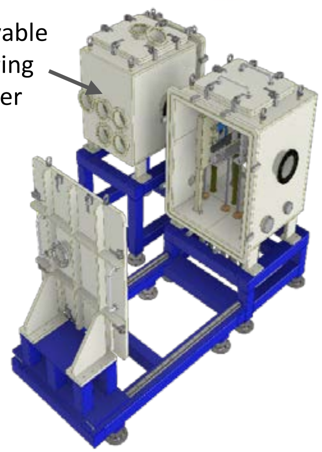
HANMAC (Korea)
Project management

DANFYSIK (Denmark)
Project management
Designs of all magnets
Productions of bending magnets and swinger

KR TECH (Korea)
Productions of quadrupole and sextupole magnets

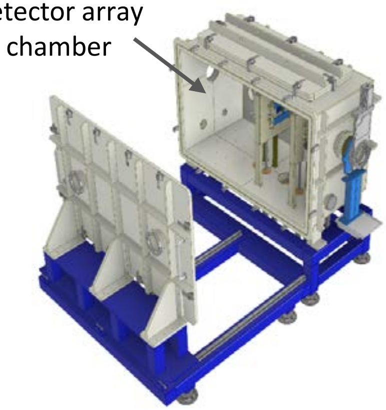
VITZRO TECH (Korea)
Designs and productions of diagnostic chambers, beam pipe, beam dump, and etc.

Removable scattering chamber



- F3 chamber

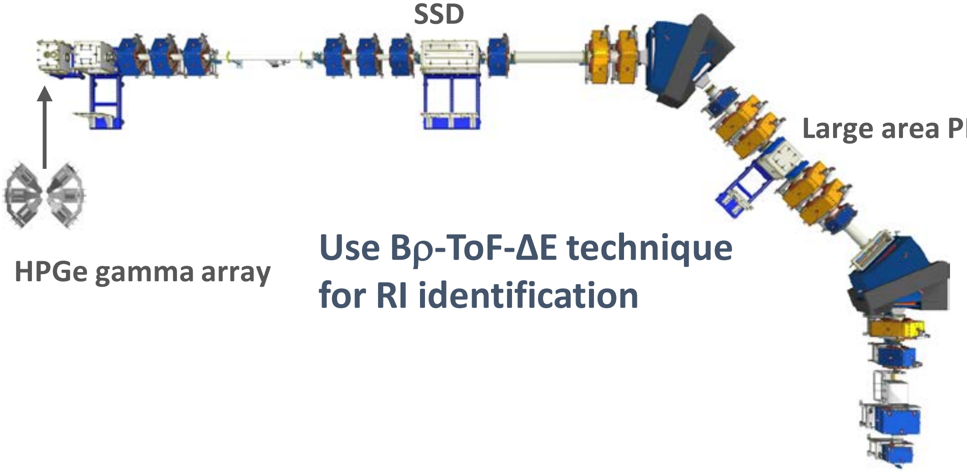
Empty space for Si-detector array or IC chamber



- F2 chamber

- F1 chamber

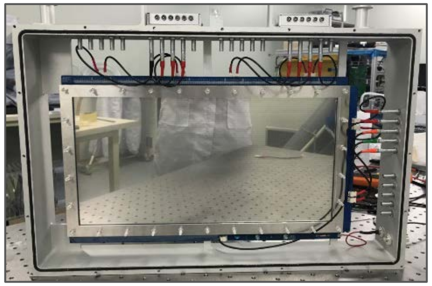
KOBRA



Use Bρ-ToF-ΔE technique for RI identification

PPACs

- Six 10 x 10 cm^2, two 20 x 20 cm^2, two 40 x 20 cm^2 active area PPACs
- Position resolution: < 1 mm in FWHM, (C_4H_{10} gas, ^{16}O beam at $2x10^6$ pps)

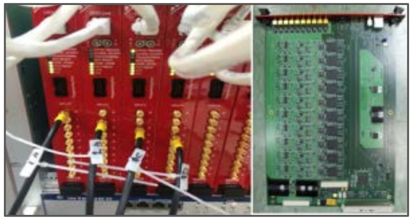



Plastic scintillator detectors

- One 10 x 10 cm^2 active area, 100 μm thick both side readout plastic detector
- One 10 x 10 cm2 active area, 100 μm thick one side readout plastic detector
- Time resolution < 42 ps for 5.486 MeV α in vacuum

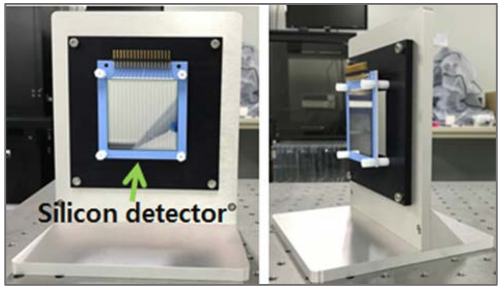
HPGe gamma ray detectors

- 32 segmented HPGe detectors (6set)
- Compton suppressor BGO crystals (6set)
- Complete set of TIGRESS electronics


SSD

- Two 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 in vacuum



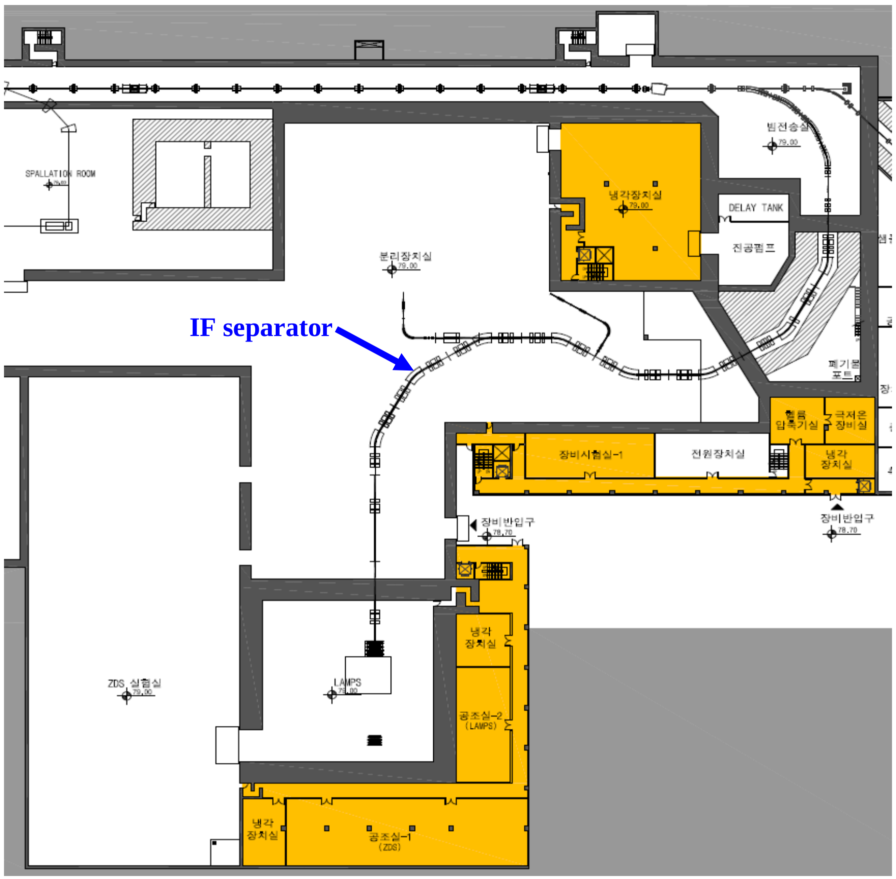
- All of detectors are fulfilled KoBRA detection system requirements
- Complete KOBRA detection system including spare detectors, Ion Chamber, HPGe gamma array and DAQ system will be ready by the middle of 2019

LAMPS

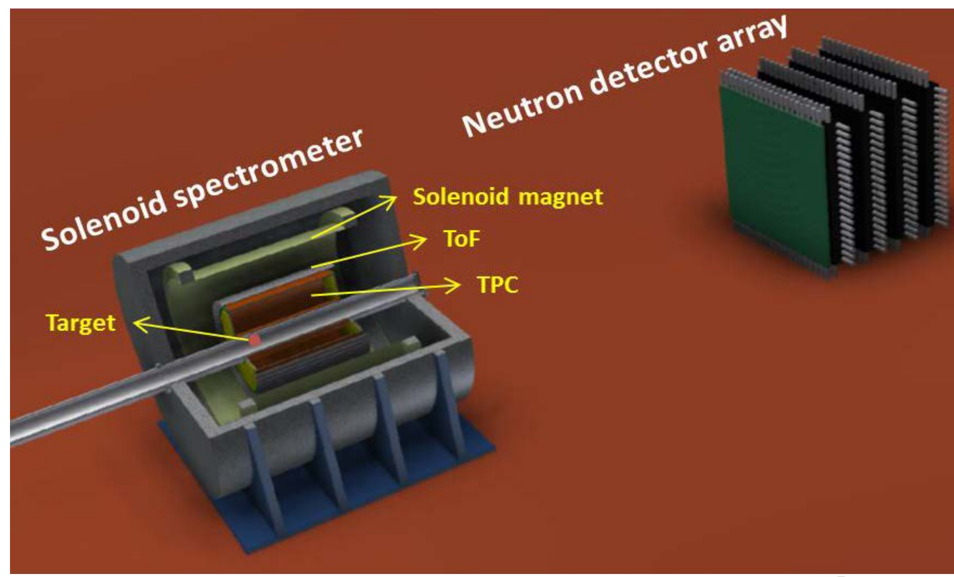
Main facility for nuclear matter and nuclear reaction studies with stable and rare isotope beams at intermediate energy

- Main Research Subject

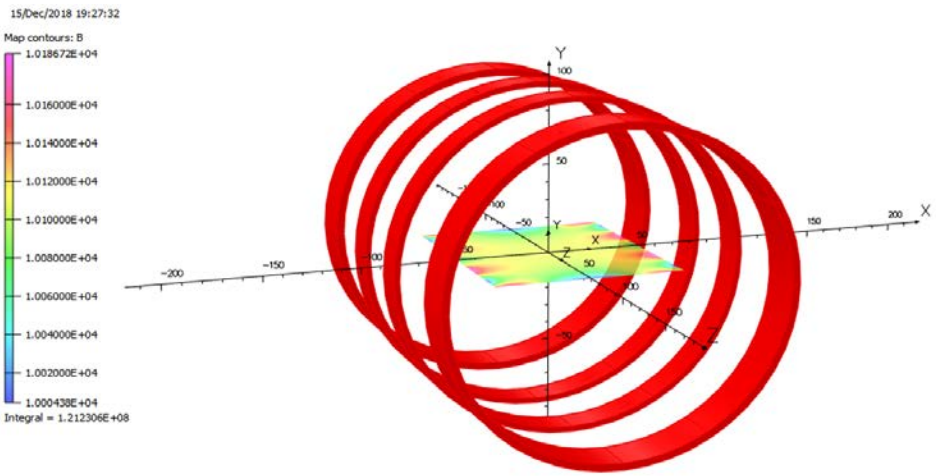
Study of nuclear symmetry energy at supra-saturation density via heavy-ion collision experiment using rare isotope beam with varying beam energies and collision systems
(e.g. measure *n/p* ratio & collective flow at the same time in the combination of $^{50,54}Ca+^{40}Ca$, $^{68,70,72}Ni + ^{58}Ni$, $^{106,112,124,130,132}Sn + ^{112,118,124}Sn$)



- **Beam Energy: up to 250 MeV/u for ^{132}Sn ($\leq 10^8$ pps)**
- **Solenoid Spectrometer**
  - **Max. 1T solenoid magnet**
  - **TPC (~ 3π sr acceptance, charged particle tracking)**
  - **Scintillation counter (trigger & ToF)**
- **Neutron Wall (neutron tracking)**

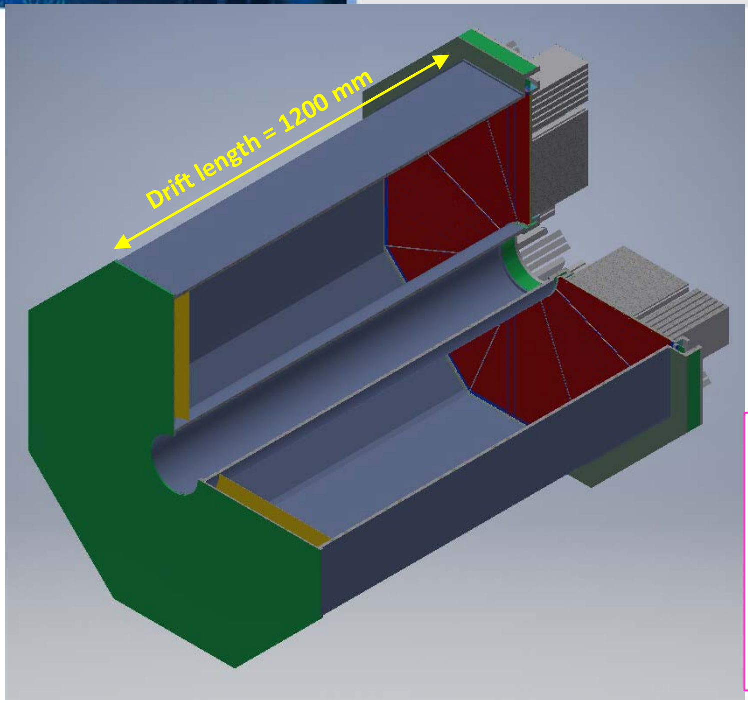


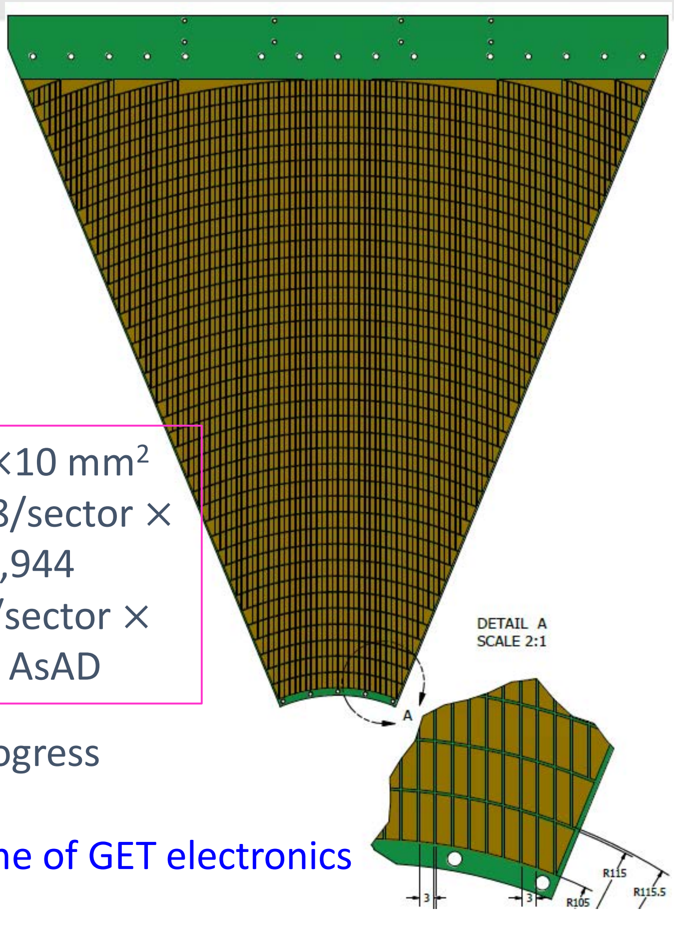
LAMPS



- Fine tuning on the design parameters by experts
  - Cylindrical SC magnet
  - Dim.: 3300 mm (L) × 2200 (W) × 2600 mm (H)
  - Fit into the pit
  - Diameter of bore = 1600 mm
  - Max. B-field > 1 T
  - Variation of B-field over TPC volume = ±0.94%
  - Passive quench protection
  - Conduction cooled with 4K vessel thermal shield and vacuum vessel
- Contracted with Tesla Engineering Ltd. UK by RISP magnet-vacuum R&D group in Feb. 27, 2019
- Production design is ongoing

LAMPS





- Pad dim.: ~ 3×10 mm^2
- # of Ch.: 2,618/sector × 8 sectors = 20,944
- FEE: 11 AsAD/sector × 8 sectors = 88 AsAD

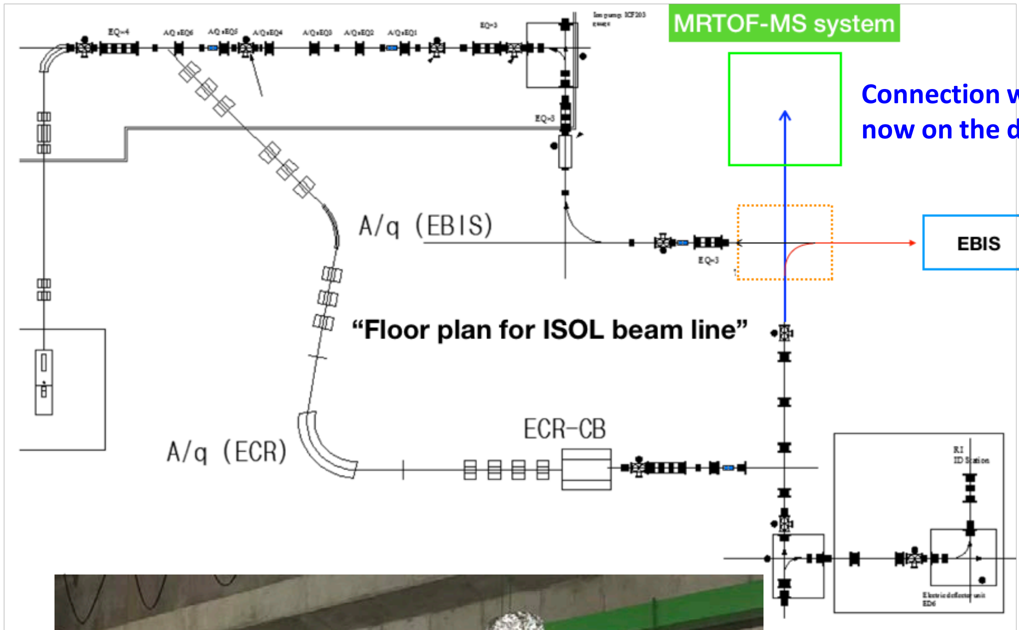
- Final design of readout, gas vessel, and field cage is in progress
  - Readout will be only at the upstream end
  - P20 gas with v_{drift} > 6 cm/µs meets entire readout time of GET electronics over full drift length (120 cm)
  - Octagonal outer barrel and circular inner barrel
  - Inner radius: 150→100 mm, Outer radius: 500→535 mm
  - Maximize the active region for R = 105 ~ 503.5 mm
- Test of the real-size GEM foil is underway
  - If gain is too small, an option for quadruple GEMs may be explored
- LAMPS TPC will be constructed in 2019 and tested by 2020

LAMPS

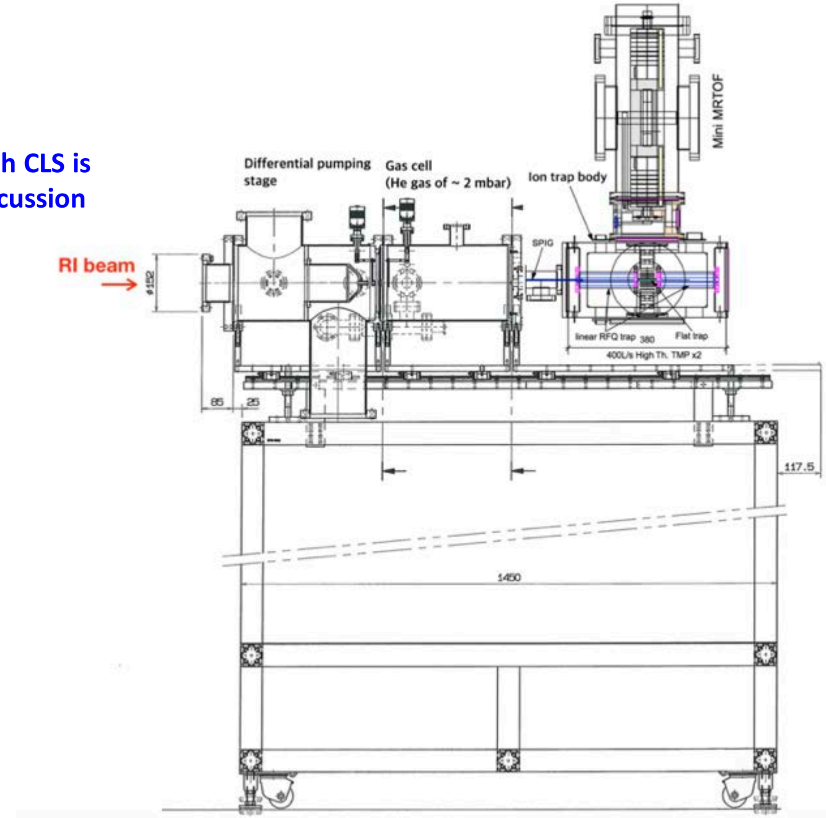
- **Installation of all modules (160 neutron detectors + 20 veto detectors) in the frame were completed in December, 2018**
- Preparation of cosmic muon test is almost ready
- Detector operation will be done remotely at Korea University Lab. in Seoul

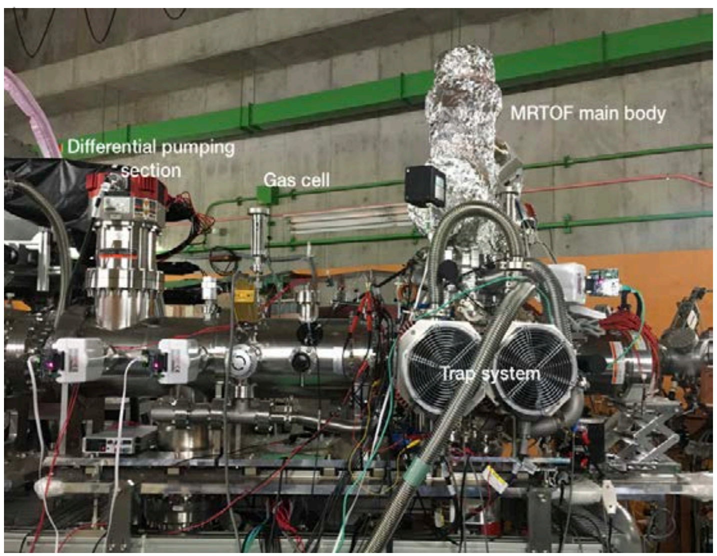
MR-TOF

RI beam of A < 150 and E = 40 ~ 60 keV requires windowless Gas catcher/Differential pumping system (similar beam condition to KISS).



Connection with CLS is now on the discussion





- Low energy beam of < 60 keV
- Differential pumping stage
- Windowless helium gas catcher
- Trap and bunching system
- MRTOF reflection chamber

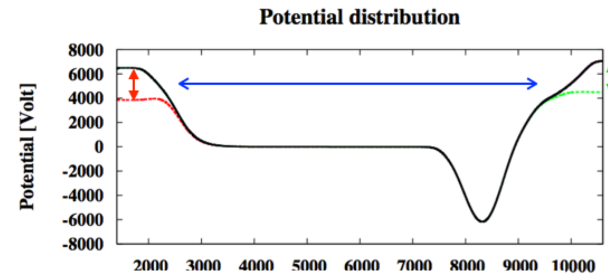
3. Sys. Install. MR-TOF

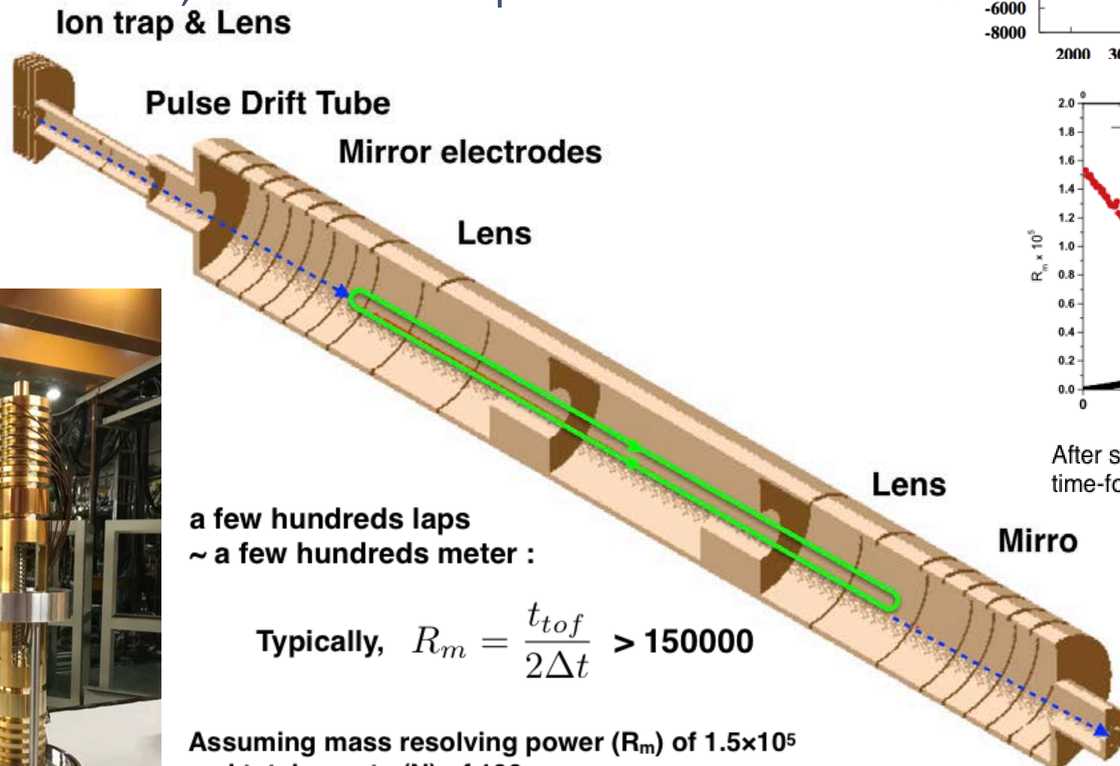
MR-ToF-MS can provide a high mass resolving power of > 10^5 even with short measurement time of 10 ~ 30 msec

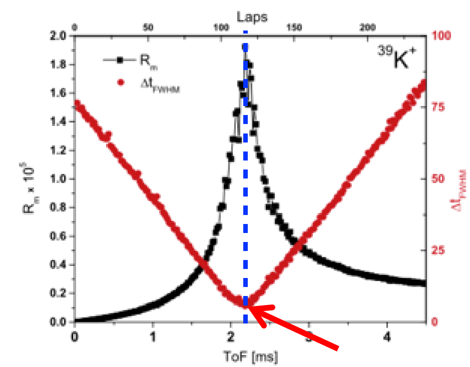
It is more suitable for the short-lived nuclei region

"Fast and Precise"

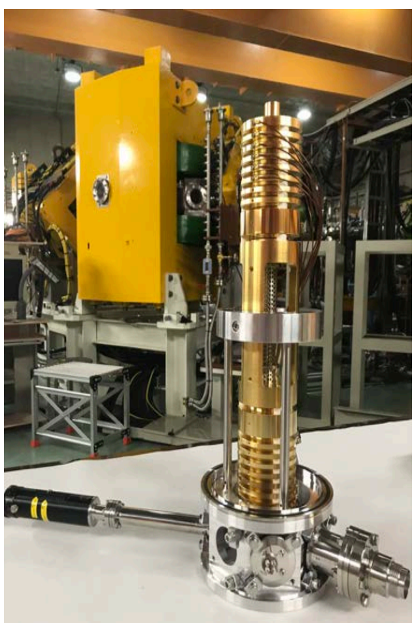
Mass measurement, but also Beam purification







After some laps, the ions become time-focused. (P. Schury et al, NIM B 335 (2014) 39)



a few hundreds laps
~ a few hundreds meter :

Typically, $R_m = \dfrac{t_{tof}}{2\Delta t}$ > 150000

Assuming mass resolving power (R_m) of 1.5×10^5 and total counts (N) of 100 :

$$\longrightarrow \frac{\delta m}{m} = \frac{1}{R_m\sqrt{N}} \sim 6.67\times10^{-7}$$

$$m_1 = m_2\left(\frac{t_1 - t_0}{t_2 - t_0}\right)^2 = m_2\rho,$$

$$\rho = \left(\frac{t_1}{t_2}\right)^2 + 2\frac{t_1(t_1 - t_2)}{t_2^3}t_0 + O\left(\frac{t_0}{t_2}\right)^2.$$

1: mass of interest
2: mass of reference

Scientific program at early phase operation(candidate)

Facility	Subject for early phase operation
KOBRA	· **Transfer reaction measurements in inverse kinematics** ($^{29}P(d,p)^{30}P$, $^{26}Al(\alpha,p)^{24}Si$) · **Radiative capture reactions using batch mode RI beams** ($^{26g}Al(p,\gamma)^{27}Si$) · **RI beam production via quasi-projectile-like fragmentation** for ^{16}O or ^{40}Ar
LAMPS	· **Ar+KCl or Xe+CsI** in case of IF separator commissioning not completed
MMS	· **Isomer separation** with using **$^{26g.s.}Al$** and **^{26m}Al** beams
CLS	· **Laser ionization** and **measurement of isomeric property** for **^{26}Al**
NDPS	· **Activation experiments with a quasi mono energy neutrons** for light and heavy nuclei · **Surrogate reactions** for fission
μSR	· One of research areas of **superconductivity** and **quantum magnetism** with their scientific significance at the time of the μSR instrument completion
BIS	· **Physical dose distribution** and **linear energy transfer** measurements with a **$^{12}C^{+6}$ beam (310 MeV/u)**

3. Sys. Install. International Cooperation (MOUs with 17 Intl Institutes)

Part 4. Radiation Safety

Radiological Features of the Facility

High Power Targets

- IF : 400 kW, ISOL : 30 ~ 70 kW
- induce high activation in concrete, air, cooling water, machine parts
- need robust remote handling in target areas

Use of Uranium Material

- fission products contaminate ISOL target system, IF beam dump, etc.
- generation of radioactive waste containing actinides-> need a long-term storage space of the waste until ready to transfer to the national site

Various Reactions to analyse

- various beam and target combination
- wide energy range (low 18~40MeV/u, high 200~320 MeV/u, 600 MeV p)
- need to find correct simulation codes and conditions

Experiments	Beams	Targets
IF	O, Ca, …, Kr, .., Sn, Xe, U, ~20 species	C
ISOL	p	UC
KOBRA	He, B, O, Ar, U	Be, Cu
Bio-medical	C	Fe
muSR	P	C
LAMPS	Ca, Ni, Zr, Sn	Ca,….
Neutron Exp.	p, d	C

Radiation Safety Licensing : Completed!! (18.10)

Preparation

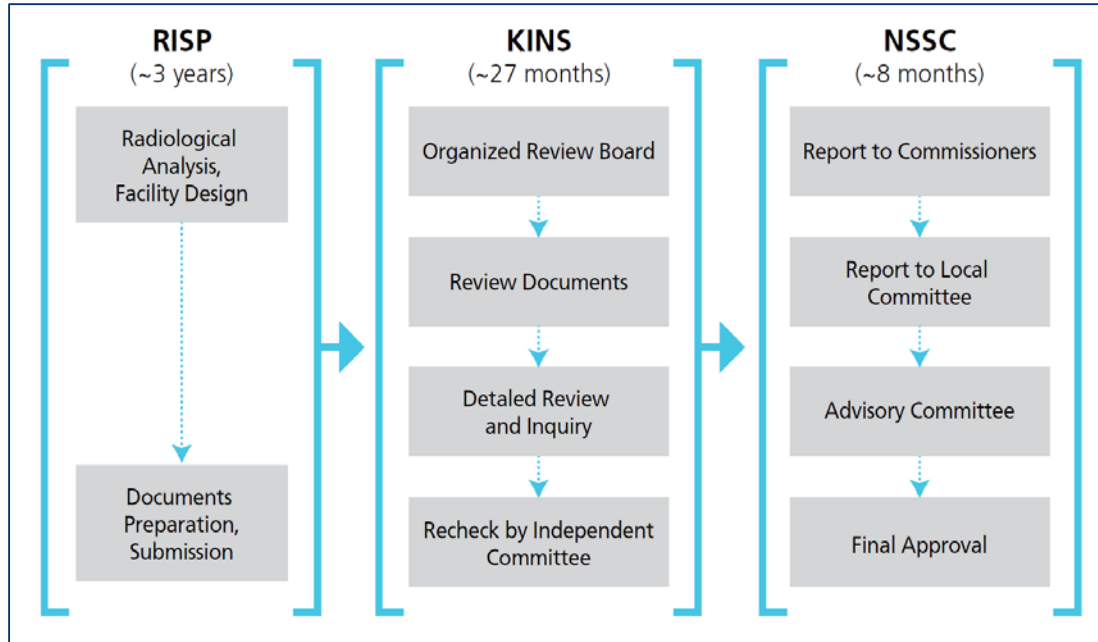
- many domestic experts joined radiological analysis
- facility basic design by a experienced company

Documents for Review

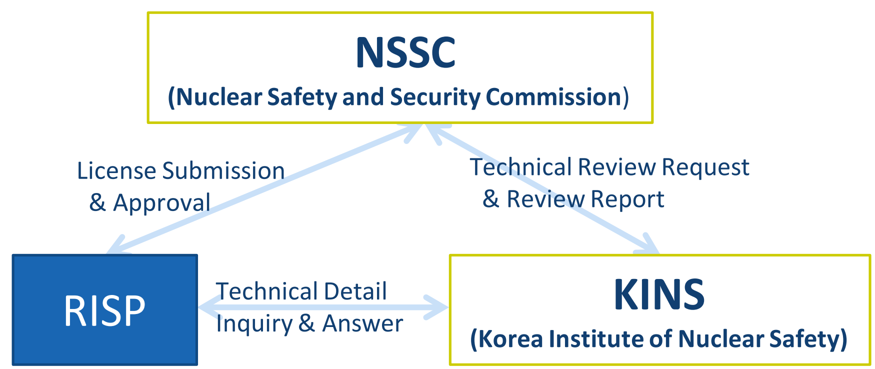
- **radiation safety report**
  (shielding, activation, env. Influence, RMS/PSIS, exhaust, accident analysis, radioactive waste, etc..)
- description of accelerators and experiments
- details in radiological analysis (codes, input/output)
- geological survey report
- stability assessment of building and ground
- quality assurance plan/procedures
- fire hazard analysis

Extensive Reviews

- by more than 30 KINS reviewers
- 382 cases of answers/further assessment/correction/design improve and changes
- multilevel review(KINS, NSSC, Advs..)



History of efforts to obtain the permit, from the preparation to the final approval



4. Rad. Safety

Plan – First Facility Inspection

- **mandatory step before operation (every year after the first inpection)**

'19				'20				'21			
1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q

Arranged with KINS to make 3-steps inspection → Ion Source (end of '20 4Q) / SCL3, KOBRA, ISOL ('21, between 1Q and 2Q) / SCL2+IF, h.e.Exps (end of '21 4Q)

- **check items**
  - safety organization / manpower
  - record of quality assurance activity
  - performance of all RMS & PSIS systems
  - implementation of fire protection
  - performance of exhaust/draining/remote system
  - readiness of preventive and mitigative measures for possible accidents of more once in 30 years
  - procedures to handle radioactive wastes
  - etc..

RMS Equipments in the site	
Environment Monitor	12
Area Monitor	94
Area Air Monitor	11
Stack Monitor	6
Hand & Foot Monitor	11
Nuclide Analyser	6
Paging Phone	88
CCTV camera	101
Emergency Stop & Alarm	174
Vehicle Radiation Monitor	2

Safe Facility for workers & vistors & citizens !

Part 5. Summary & Outlook

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**.

▪ 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**
  → 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 than 5 yrs)**
- Energy upgrade to 400MeV/u (requires 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