Progress of The Rare Isotope Science Project In Korea

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Rare Isotope Science Project (RISP)

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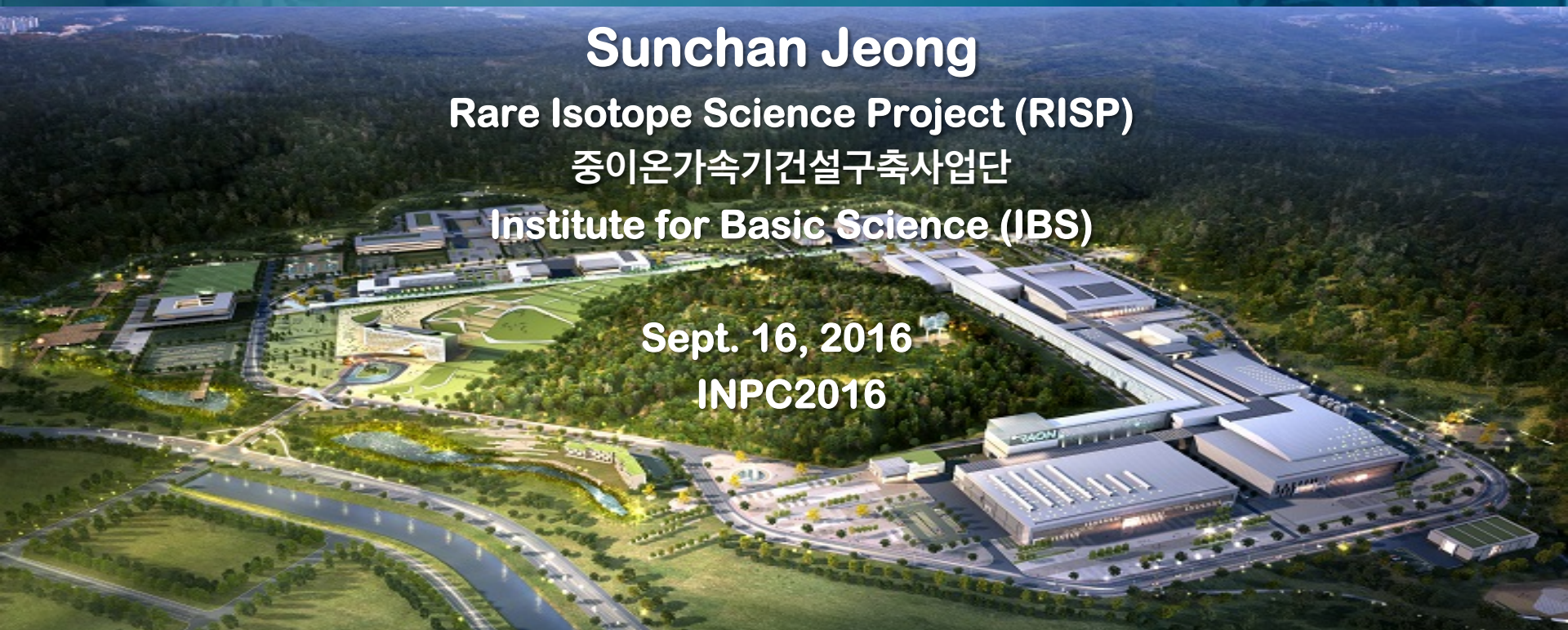
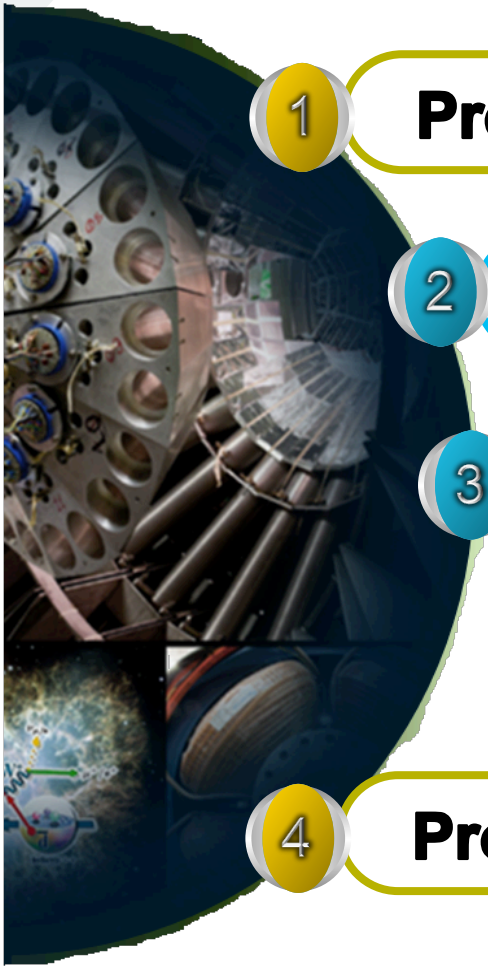
Institute for Basic Science (IBS)

Sept. 16, 2016

INPC2016



Contents



RISP Overview

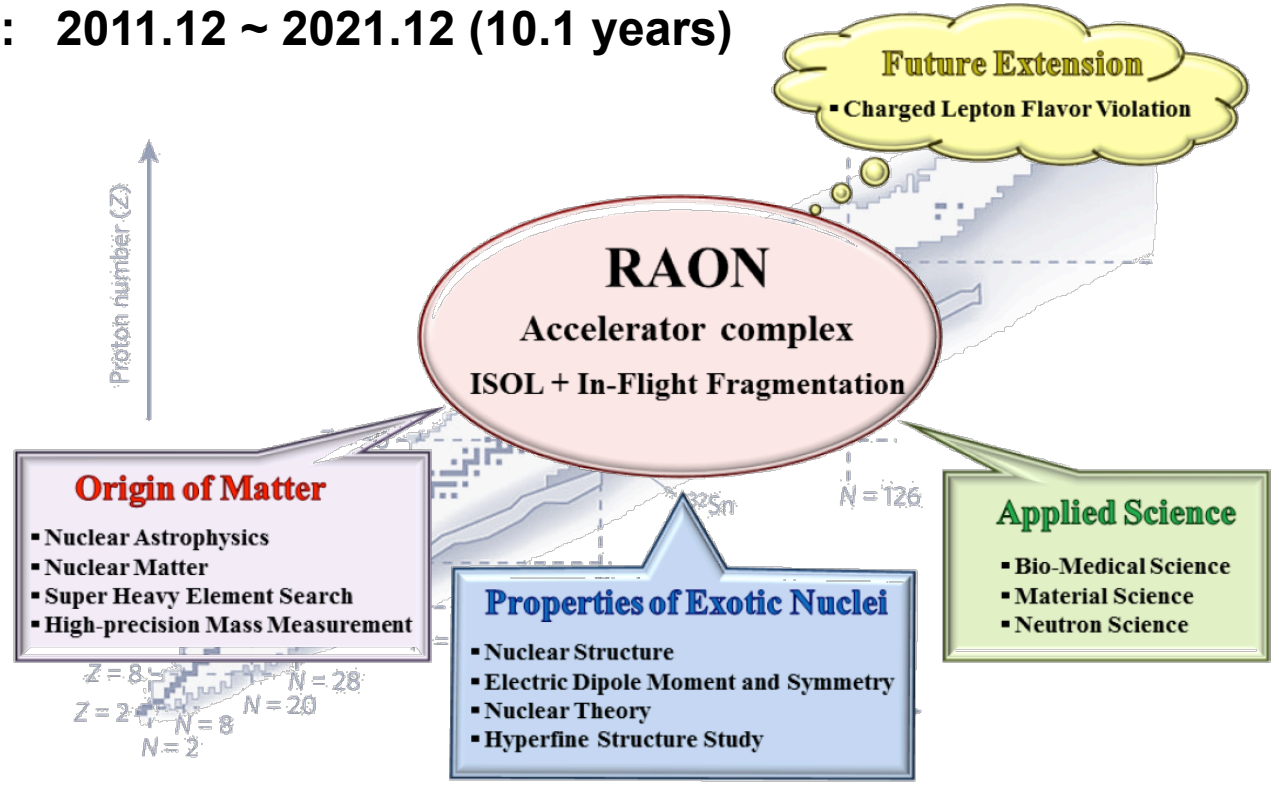
Rare Isotope Science Project (RISP)

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

  * RAON Pure Korean word meaning Delightful, Joyful, Happy

- **Budget: US$ 1.44 B** (1 B$~1T Won)
  - accelerators and experimental apparatus : 0.46 B$
  - civil engineering & conventional facilities : 0.98 B$ (incl. construction site purchase)
    (recently approved in June 2014)

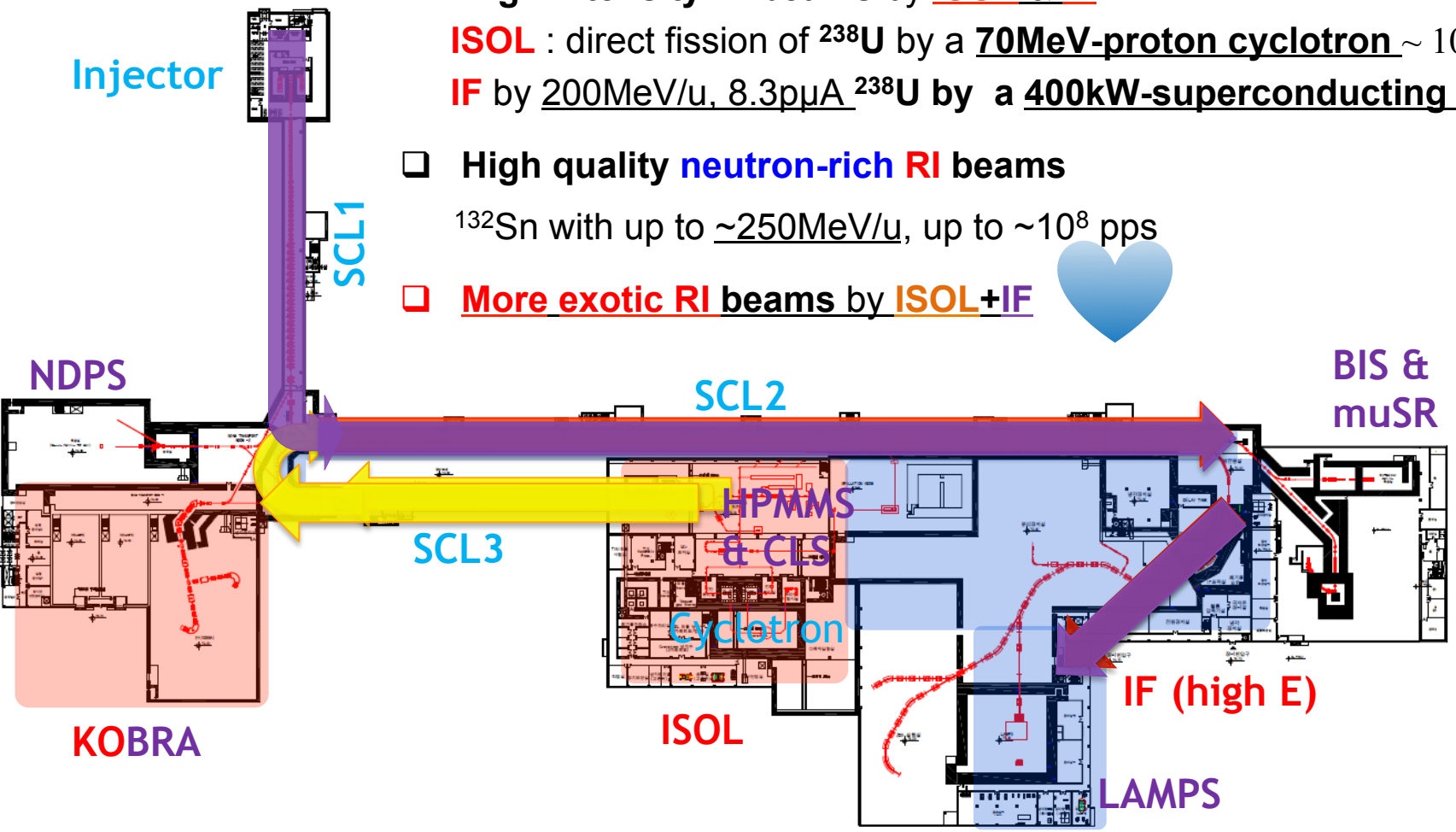
- **Period: 2011.12 ~ 2021.12 (10.1 years)**



RAON Concept

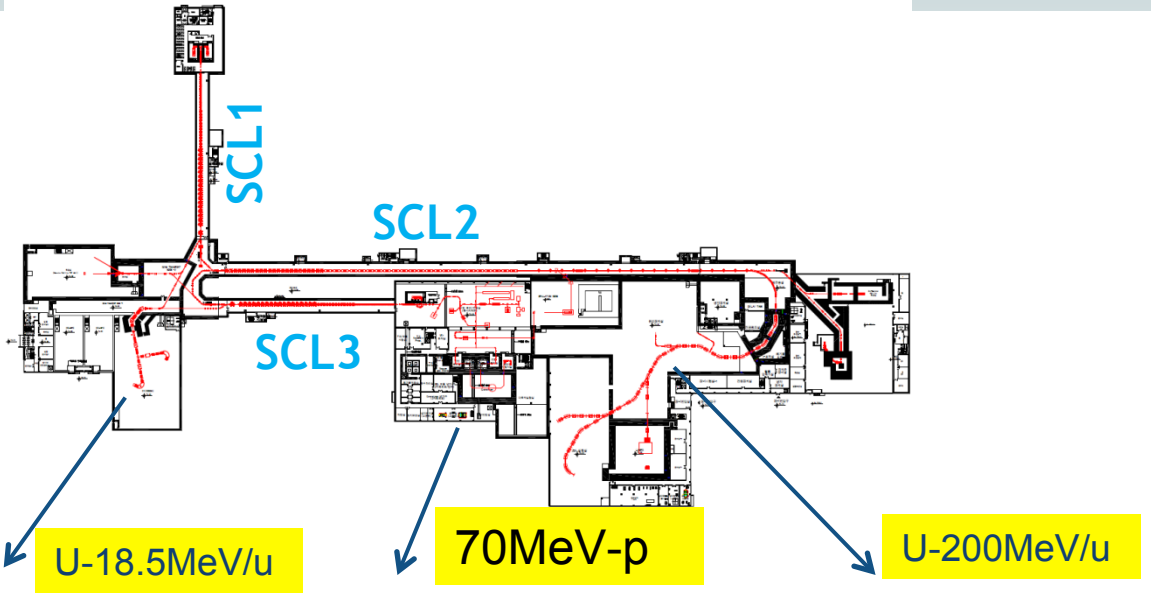
: Accelerator complex for producing rare isotope beams

- **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**



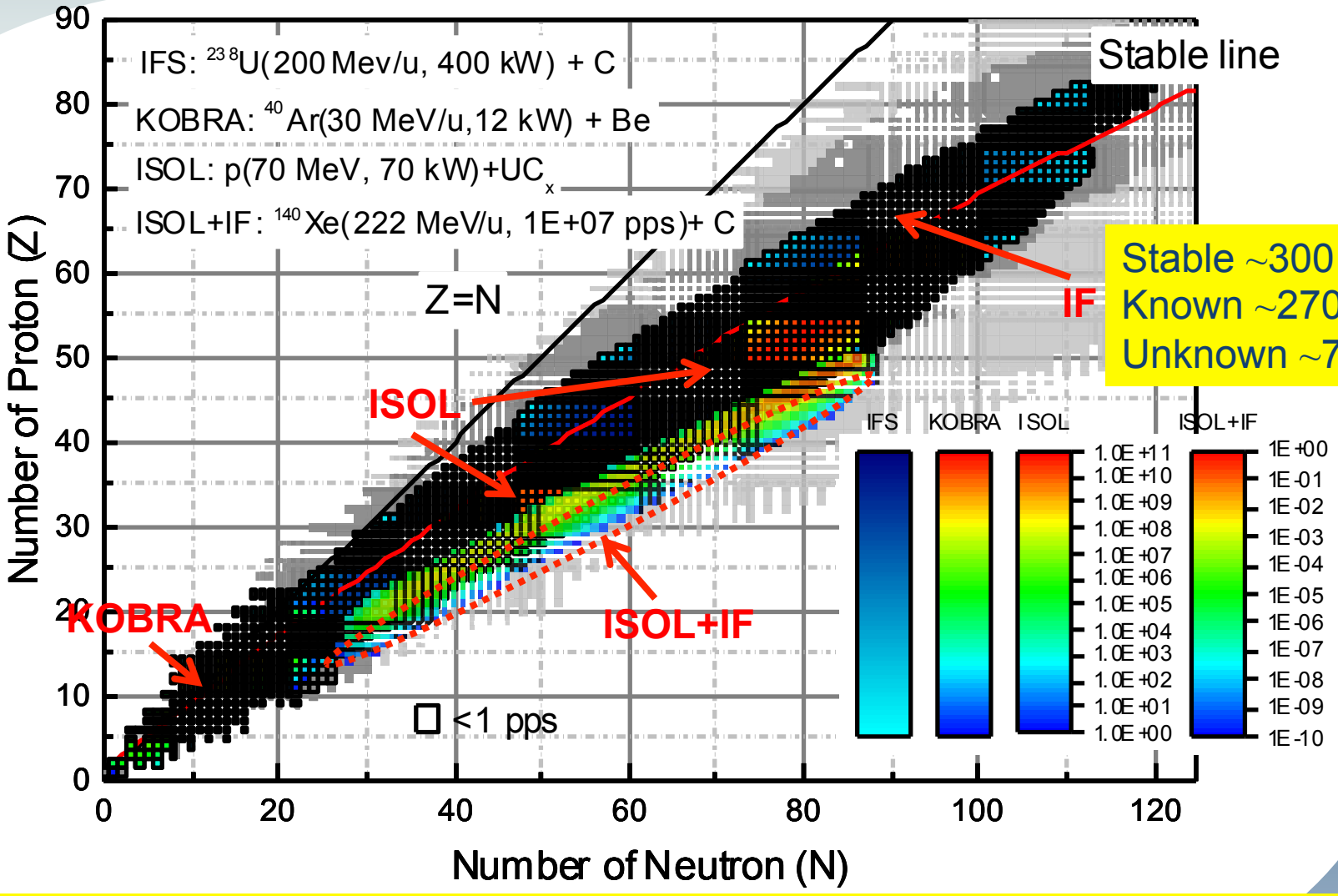
Lineup of RIB production & separation

- 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

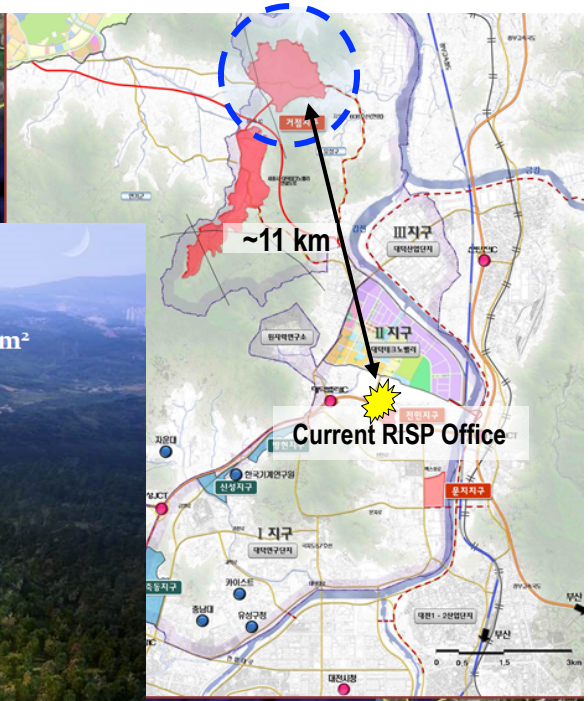
Expected RIBs at RAON in nuclear landscape



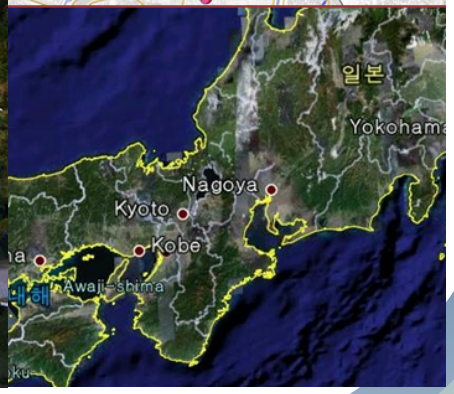
- **RAON will provide access to unexplored regions of the nuclear chart !**
- **RAON will be a powerful RIBs' supplier to users globally**

→ More exotic, More intense, and More various RIBs

RAON Site : Sindong in Daejeong

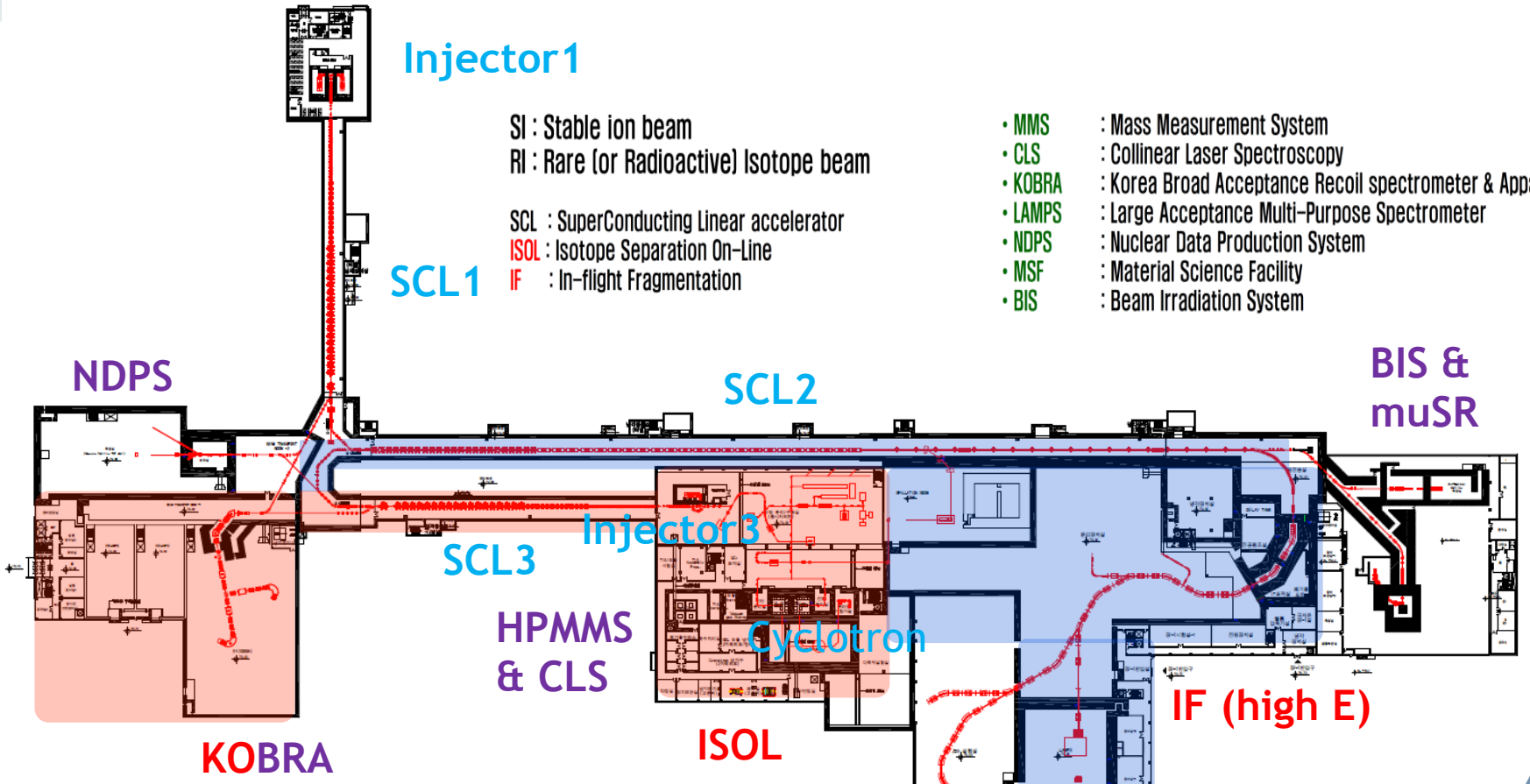


Basic design was finished in Dec. 2015
A construction company was selected in Sept. 6, 2016.



RAON Overview

Layout of RAON

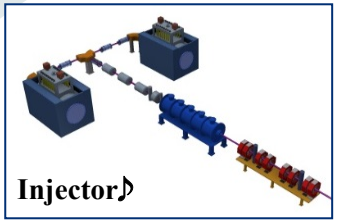


1순위: Cyclotron, ISOL, SCL3, KOBRA, MMS, CLS

2순위: SCL2, IF, LAMPS

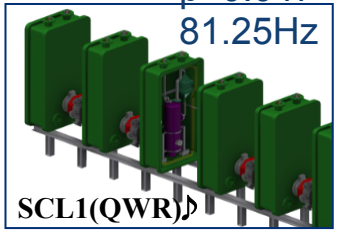
3순위: SCL1, NDPS, MSF, BIS

Accelerator systems (Layout & Specs.)



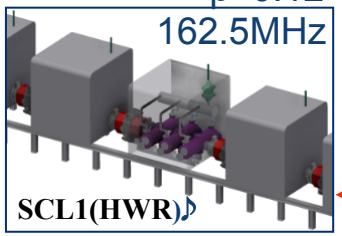
28-GHz ECRIS
(A/q<7 10keV/u)
81.25MHz 4-vane RFQ
(500keV/u)

β=0.047
81.25Hz



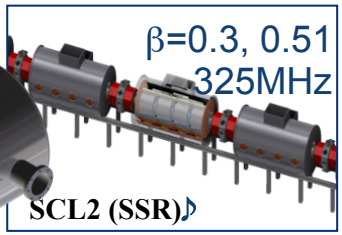
1/22
(2.7MeV/u)

β=0.12
162.5MHz

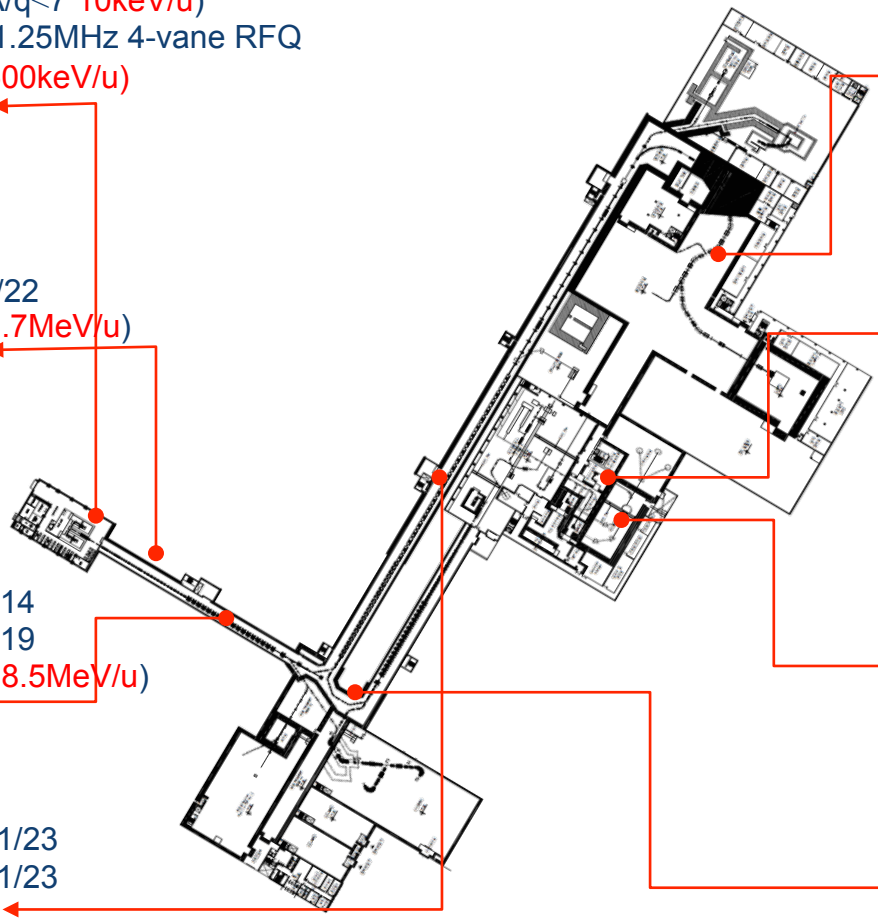


2/14
4/19
(18.5MeV/u)

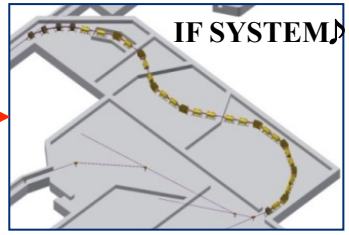
β=0.3, 0.51
325MHz



3/1/23
6/1/23
(200MeV/u)

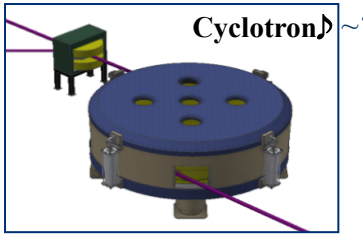


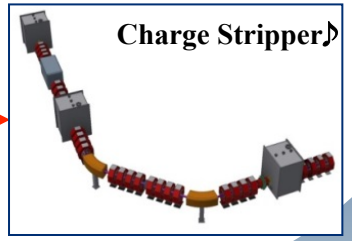
10Tm
F8



RILIS/SI
EBIS
MR-TOF

70-MeV H⁻ cyclotron
~10^{14} fis/s





Liq. Li
20μm
A/q
~7➔~3

Warm sections for focusing components betw. CMs

Experimental Systems

HI >200MeV/u

P-600MeV

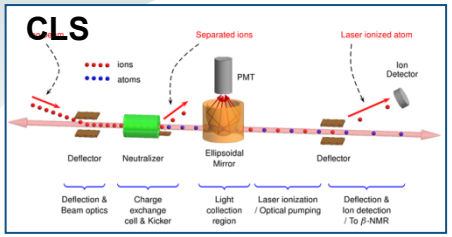
~keV/u

p, d, Li <P-88MeV/u

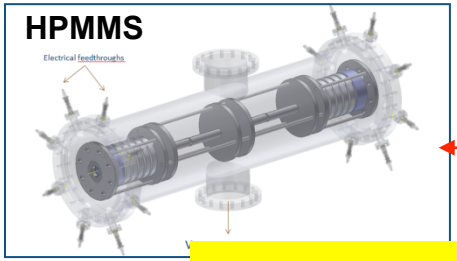
> U-200 MeV/u

> U-18.5MeV/u

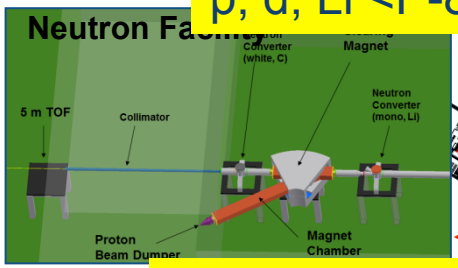
CLS



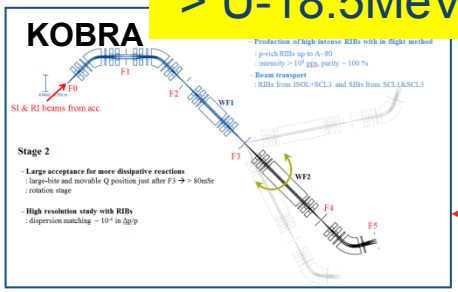
HPMMS

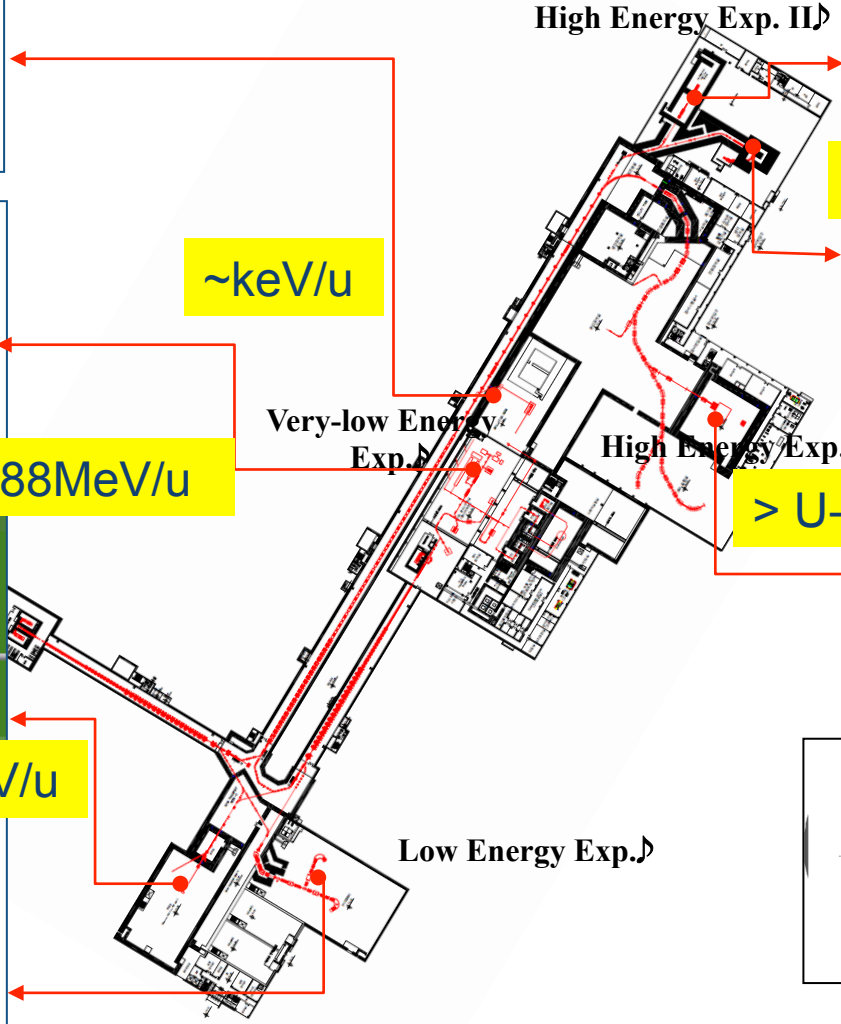


Neutron Facility

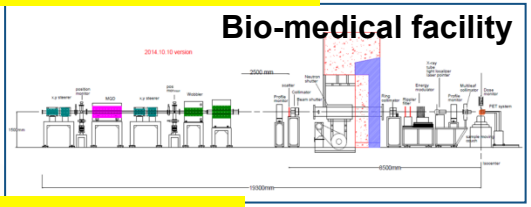


KOBRA

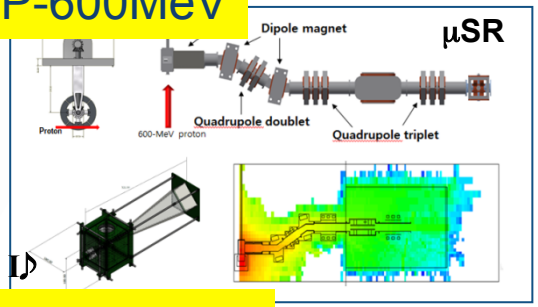




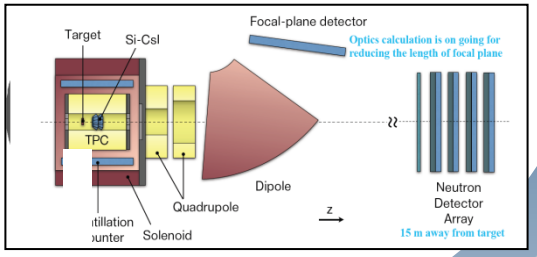
Bio-medical facility



μSR



LAMPS

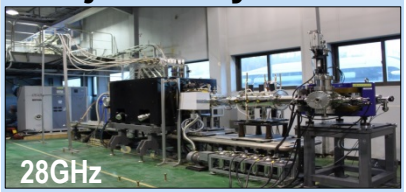


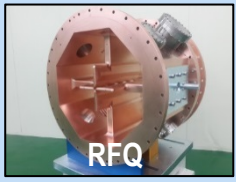
Project Status

Prototyping & test… under progress

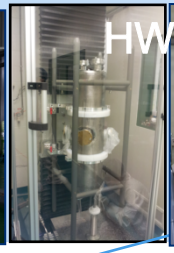
RAON

Injector System

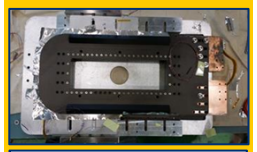


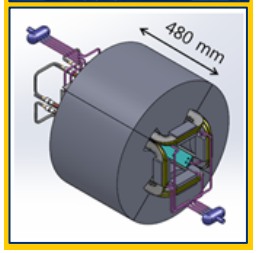


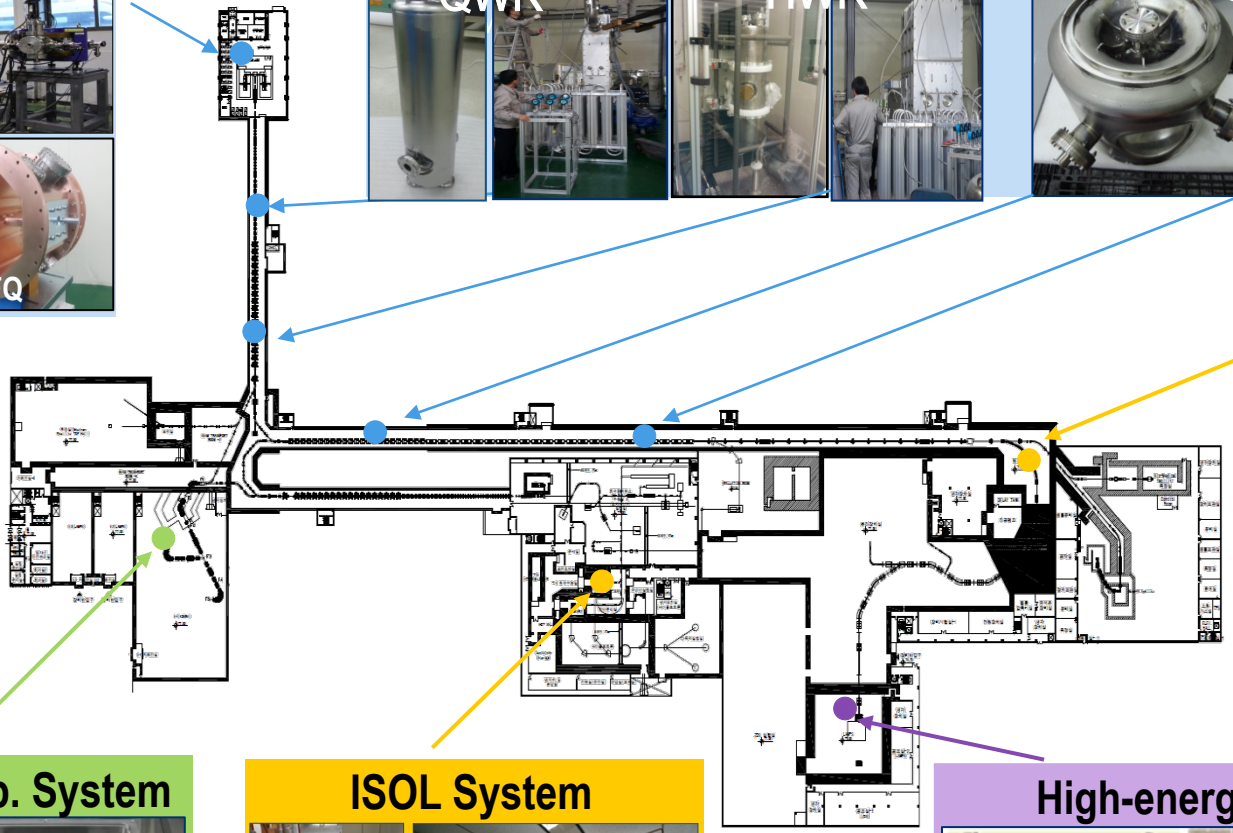
SC LINAC System



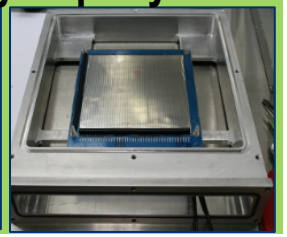
IF System





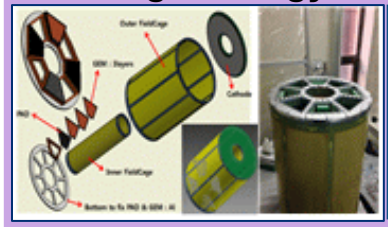


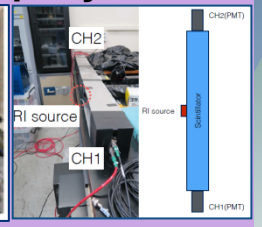
Low-energy Exp. System



ISOL System

High-energy Exp. System





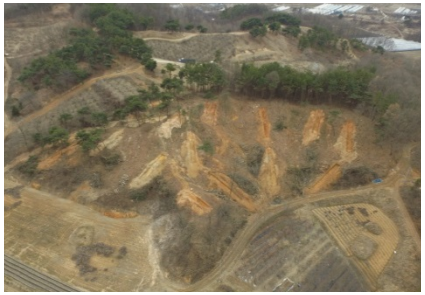
Construction & Civil Eng.

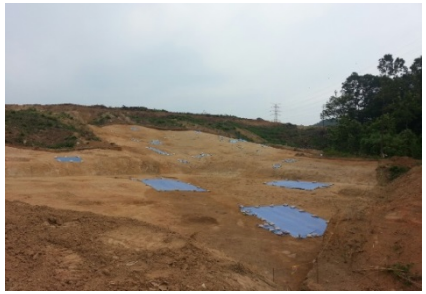
Status of Site (Cultural assets & Site preparation)

Sales contract (`14.12.26.)	➡	Land compensation (`15.10.01.)	➡	Expropriation decision (`16.06.14.)	➡	Site preparation (`16.06.15.)

- **Excavation of cultural assets**

  Acc. & Exp. bldg site('15.12.~'16.09.), Support bldg site('16.06.~'16.11.)



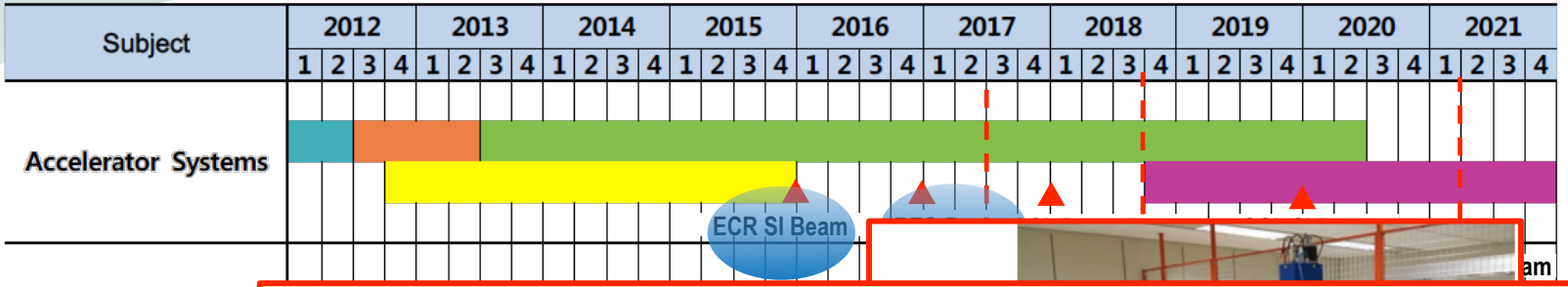
- **Site preparation :**

  Acc. & Exp. bldg site ('16.07.~'17.01.), Support bldg site('16.08.~'17.06.)



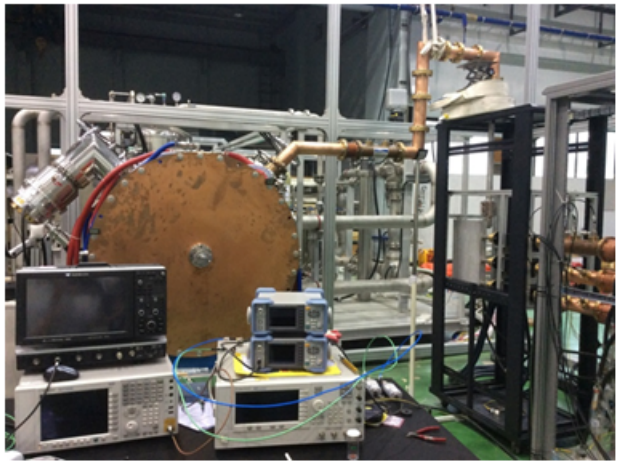
RISP Milestone Schedule

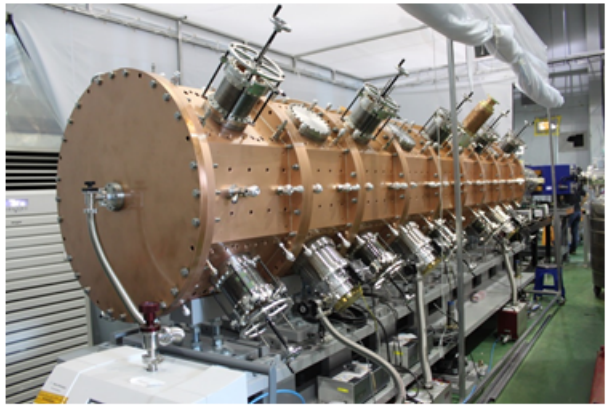
RAON



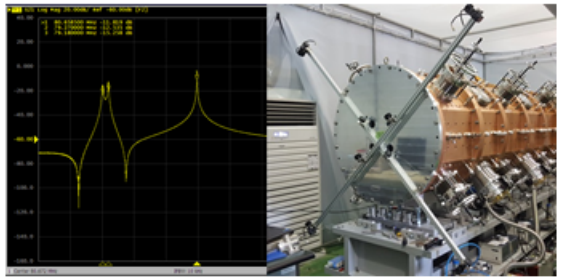
Parameter	Value
f	81.25 MHz
E_{in}	10 keV/u
E_{out}	0.507 MeV/u
ε_{out}	0.0125 .cm. mrad ~26 keV/u-degree
Transmission	~98 %
P_{loss}	94 kW
Duty factor	100%

Prototype test: ~15 kW CW





Nine segments of the RFQ aligned

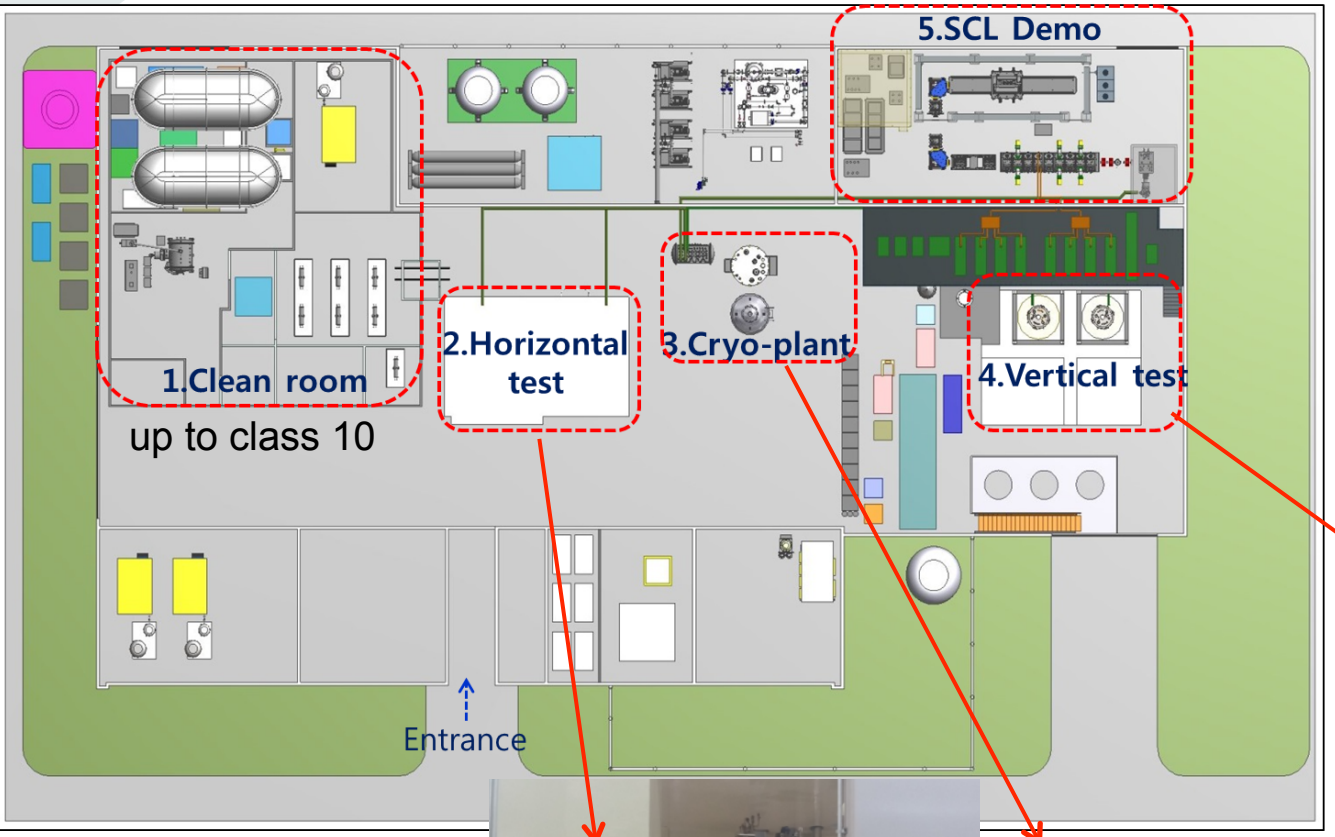


Field tuning underway with a bead-pull method (Aug. 2016)

Demonstration system @ off-site test facility

SRF Test Infrastructure (off-site test facility)

Performance test of SC cavities and cryomodules
Quality control of SC cavities and CMs delivered by vendors in mass production

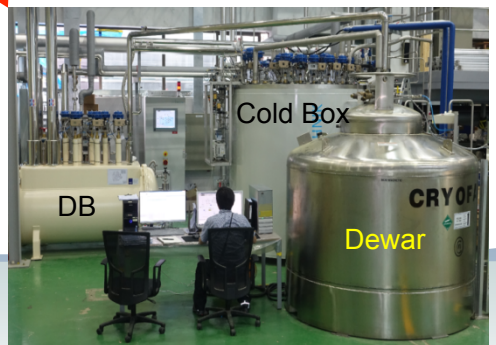


Test schedule in 2016

	July	Aug	Sep	Oct	Nov	Dec
Cavity						
- SSR2 (SFA) 1st prototype		■	■			
- HWR (VitzroTech) 1st prototype			■	■		
- QWR (VitzroTech) 3rd prototype					■	■
Cryomodule						
- HWR1 prototype(heat leak test)	■					
- QWR 1st prototype				■	■	
- HWR1 1st prototype					■	■

Start operating from June, 2016.

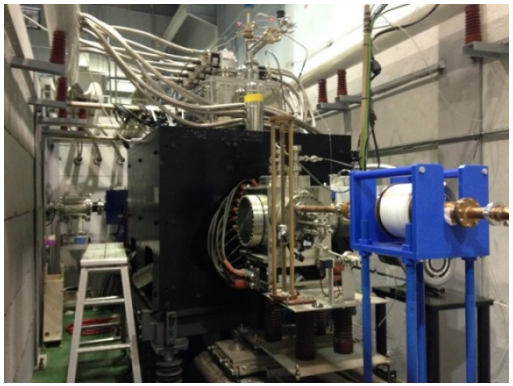
Cryomodule test



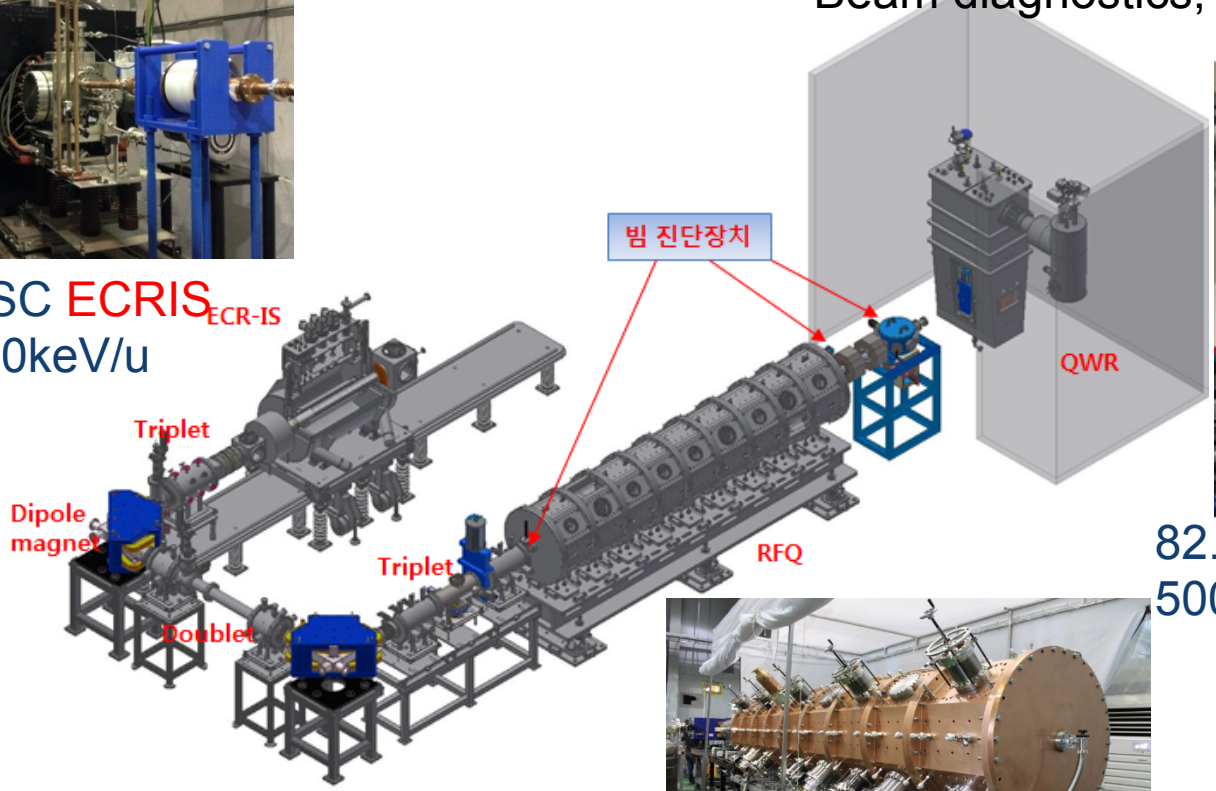
Vertical cavity test

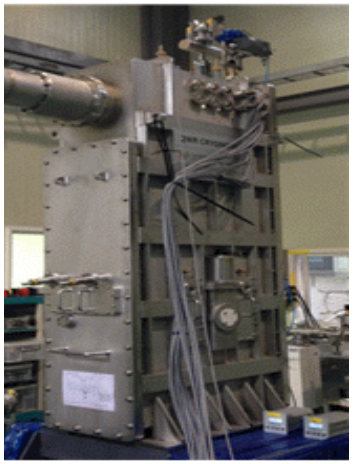
Demonstration System

- For integral test of key accelerator systems
- Sub-systems to be installed by the end of 2016
  - ECR-IS, LEBT, RFQ, MEBT, QWR
  - Aux systems: Cryogenic system,RF system,
    Beam diagnostics, Beam dump, etc.

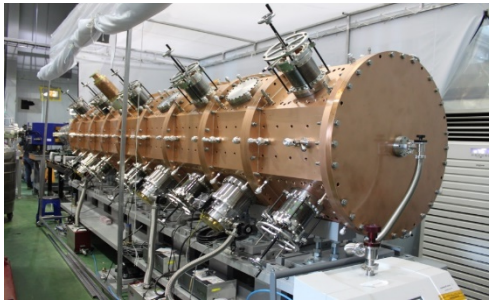


28GHz SC ECRIS
A/q~7, 10keV/u





82.25MHz QWR
500keV/u➔ 530KeV/u



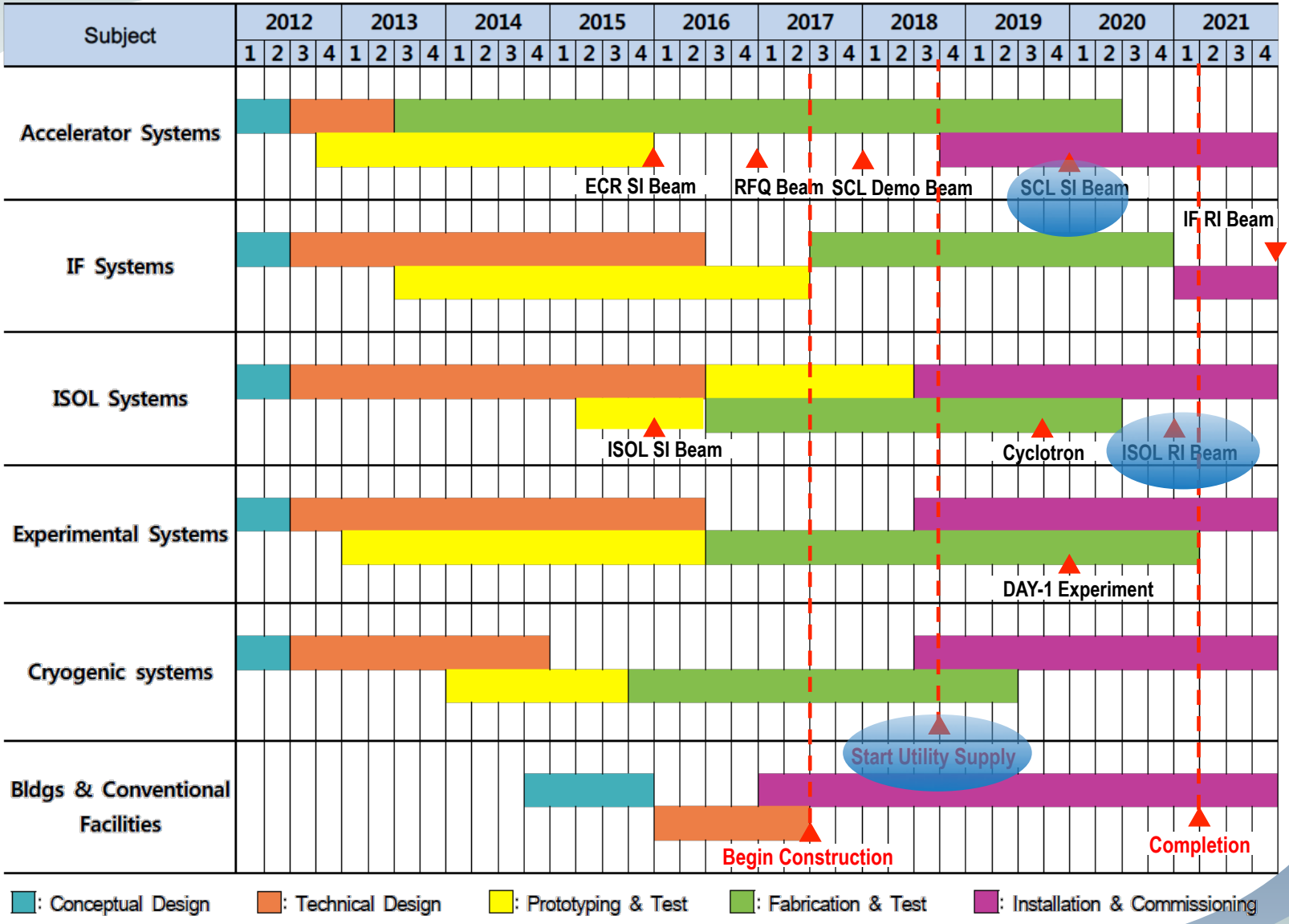
82.25MHz 100kW RFQ
10keV/u➔500keV/u

Project prospects (short-term)

Early operation for LE-Exp.

SIB @ 2020
RIB @ 2021

RISP Milestone Schedule

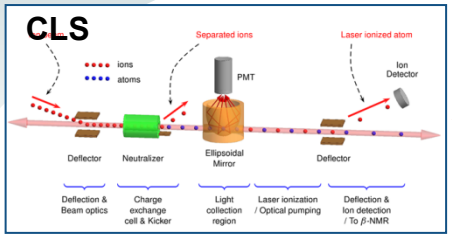


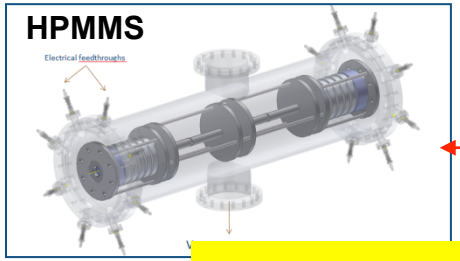
Cyclotron+ISOL+SCL3 for LE-Exp.

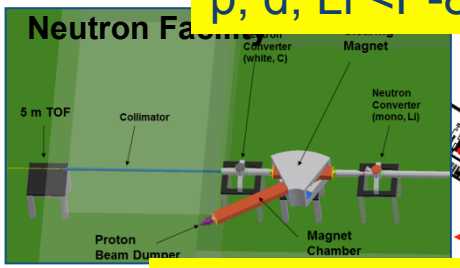
SIB @ 2020
RIB @ 2021

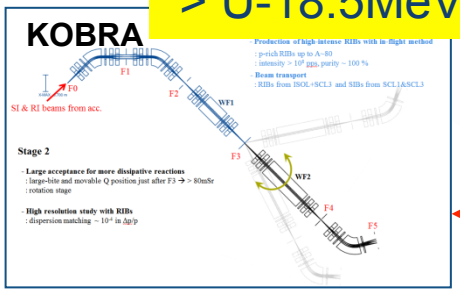
RAON

Uniqueness
in terms of beam energy
(SIB, RIB)
➔Variable
from ~500keV/u
to U-18.5MeV/u
& p-88MeV/u





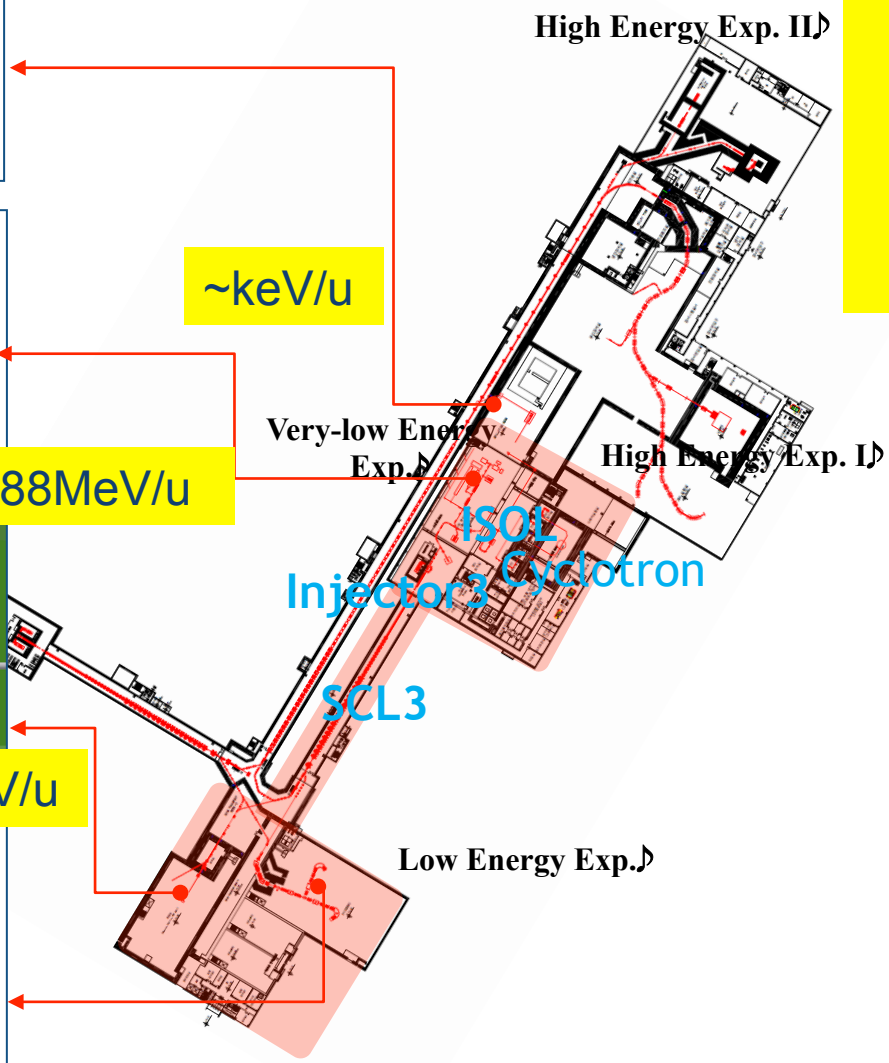




~keV/u

p, d, Li <P-88MeV/u

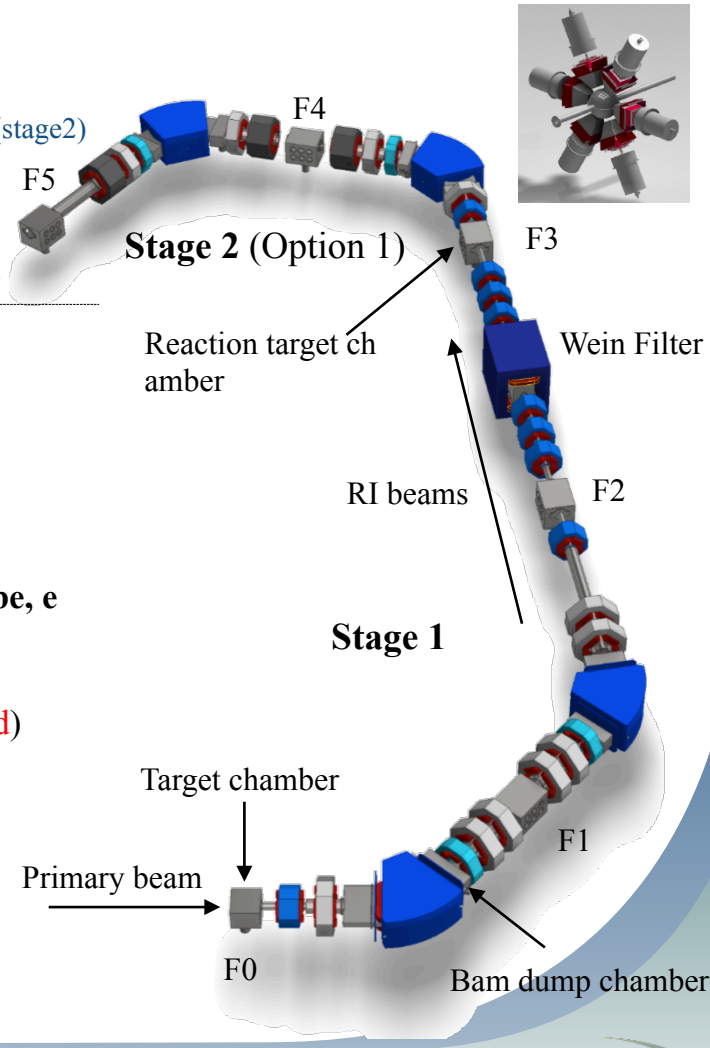
> U-18.5MeV/u



Science at KOBRA

Competitivenes

- **Secondary beam energy : < a few tens of MeV/u**
- **Versatile two-stage device for multi-purpose**
- **RIB production** (stage1) **+ high performance spectrometer** (stage2)
  : high resolution by dispersion matching
  : high intense RIBs can be produced **(A<50)**
- **More exotic RIBs with ISOL→post acc→KOBRA stage1**



- Nuclear Structure
  - **Study of shell evolution in proton- and neutron-rich nuclei:**
    Measurements of excitation energy and angular distribution
    Determination of nucleon occupancy in single particle orbit
    (inelastic scattering, (d,p) reaction, nucleon removal reaction, etc)
  - **Study of soft dipole and Pygmy dipole resonances using nuclear probe, e .g., α, Ca and Pb:**
    Measurements of excitation energy and angular distribution
    (bound state: ϒ ray spectroscopy, unbound state: missing mass method)
- Nuclear Astrophysics
  - **Direct measurement of charged-particle capture cross section**, e.g. , for $^{15}O(\alpha, \Upsilon)$ reactions at < ~1 MeV/nucleon
  - **Indirect measurement of radiative capture cross section**, e.g., for (d,p) reaction at a few MeV/nucleon

As closing (1)… *(As project development)*

Development of accelerator and experimental systems o f the RISP is on track with civil constructions

- Prototyping of major accelerator parts has been in progress since 2013 (after TDR)
- Some prototypes are in testing stage.

- SRF test facility is operating from June 2016.

- Under progress for the procurement of cavities, cryomodules etc… of SCL3 in 2016.4Q (for mass-production) ➔Vendor(s) for SCL3 will be selected in 2016

As closing (2)… scientific opportunity

- RAON- Rare isotope Accelerator complex for ON-line experiments
- Stable and Rare Isotope HI beams (accelerated properly) can open a new era in Korea for the research of basic science.
- Strong connections to applications and training

- Early operation of Low-Energy Facility from the end of 2019
- Efforts on collaboration:

-IBS research centers, international and domestic users communities

- Call for LoIs in 2016, especially for low-energy facility

-Welcome suggestion for new instruments: space available in experimental halls

Thank for your attention.

Case study 1: Direct measurement of $^{15}O(\alpha,\gamma)^{19}Ne$

✧ Motivation

- $^{15}O(\alpha,\gamma)^{19}Ne$ reaction

  : breakout path from hot-CNO to rp-process

  : key reaction to understand nucleosynthesis under explosive stellar environments

✧ Experimental Challenges

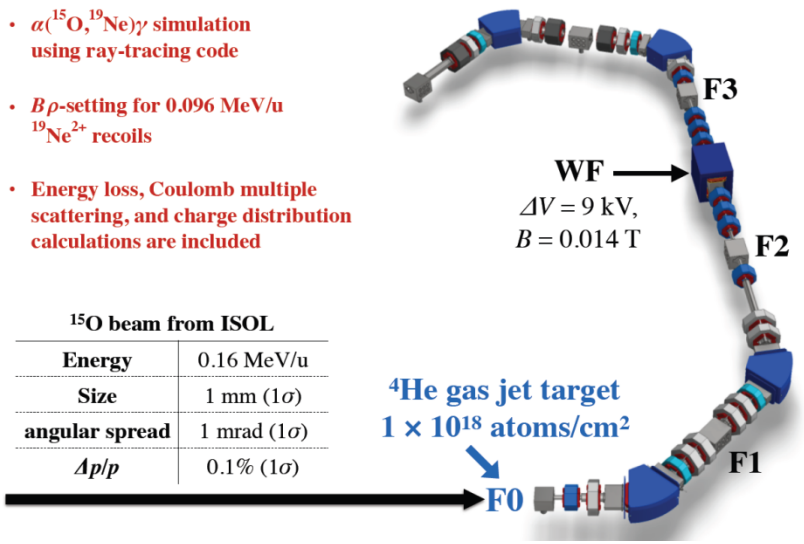
- For direct measurement of cross section we need

  : ^{15}O RI beam intensity > 10^{10}pps , Helium-4 target density > 10^{18} atoms/cm^2,

  recoil detection efficiency > 40% → **then ~1 counts/hr**

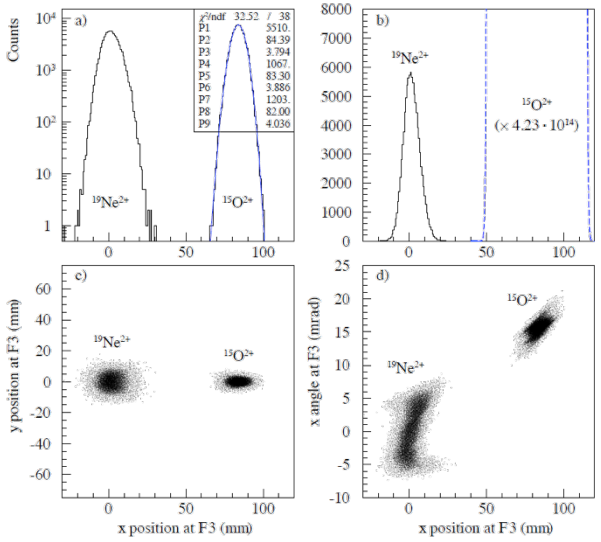
✧ Simulation to check the performance of KOBRA

- **$\alpha(^{15}O,^{19}Ne)\gamma$ simulation using ray-tracing code**
- **$B\rho$-setting for 0.096 MeV/u $^{19}Ne^{2+}$ recoils**
- **Energy loss, Coulomb multiple scattering, and charge distribution calculations are included**



^{15}O beam from ISOL

Energy	0.16 MeV/u
Size	1 mm (1σ)
angular spread	1 mrad (1σ)
$\Delta p/p$	0.1% (1σ)

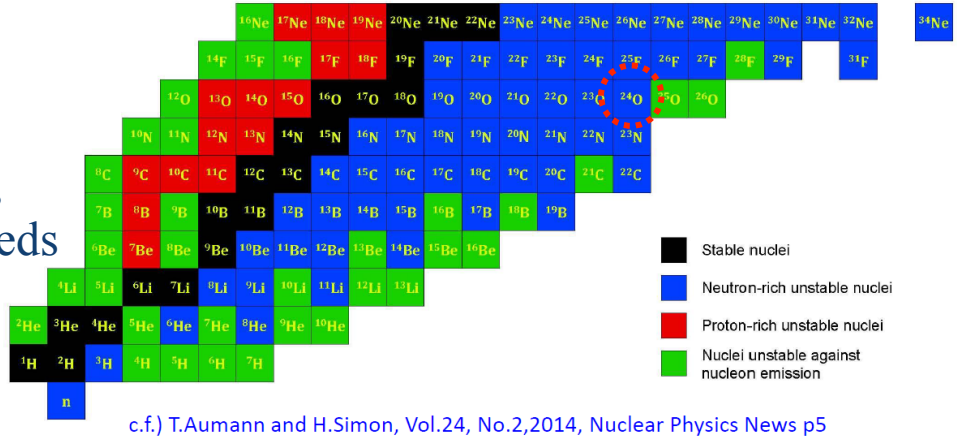


- Width of single Gaussian fitting (1σ)
  - $^{19}Ne^{2+}$: 5 mm
  - $^{15}O^{2+}$: 4 mm
- Fitting for tail of $^{15}O^{2+}$
  - linear combination of 3 Gaussian functions
- Fitted function for position distribution of $^{15}O^{2+}$
  - multiplied by factor of 4.23×10^{14} (N_{beam}/N_{recoil})
- **$^{15}O^{2+}$ beams are clearly separated from $^{19}Ne^{2+}$ recoils** (background effects are not included)

Case study 2: Production of ^{24}O

✧ Motivation

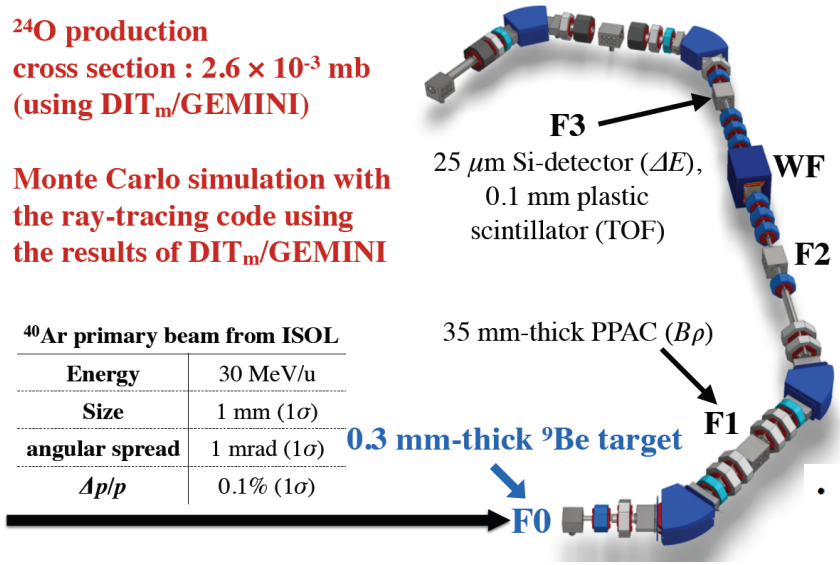
- ^{24}O
  : the most n-rich of bound Oxygen isotopes
- RIBs' production capability of KOBRA, especially RIBs near p- or n-drip line needs to be checked
  : comparison with other facilities



c.f.) T.Aumann and H.Simon, Vol.24, No.2,2014, Nuclear Physics News p5

✧ Simulation to check the performance of KOBRA

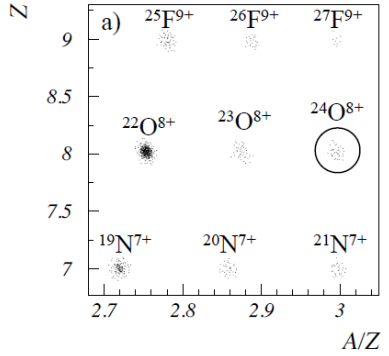
- **^{24}O production cross section : 2.6 × 10^{-3} mb (using DIT$_m$/GEMINI)**
- **Monte Carlo simulation with the ray-tracing code using the results of DIT$_m$/GEMINI**

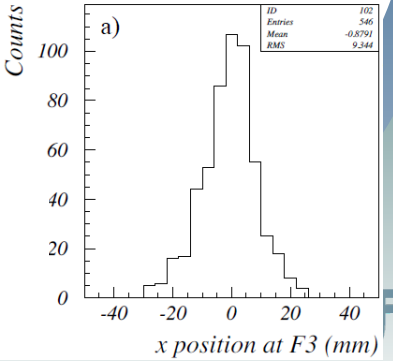


^{40}Ar primary beam from ISOL	
Energy	30 MeV/u
Size	1 mm (1σ)
angular spread	1 mrad (1σ)
Δp/p	0.1% (1σ)

Kinetic energy of ^{24}O after F3 plastic scintillator	23.6 ± 1.2 MeV/u (in RMS)
Horizontal (vertical) width of ^{24}O	9.3 (12) mm (in RMS)
Acceptance of ^{24}O	17%
Intensity of cocktail beam at F1 for 10 pnA of ^{40}Ar	1.0 × 10^6 pps

- **^{24}O beam intensity = 100 pps** for **10 pnA of the ^{40}Ar** primary beam



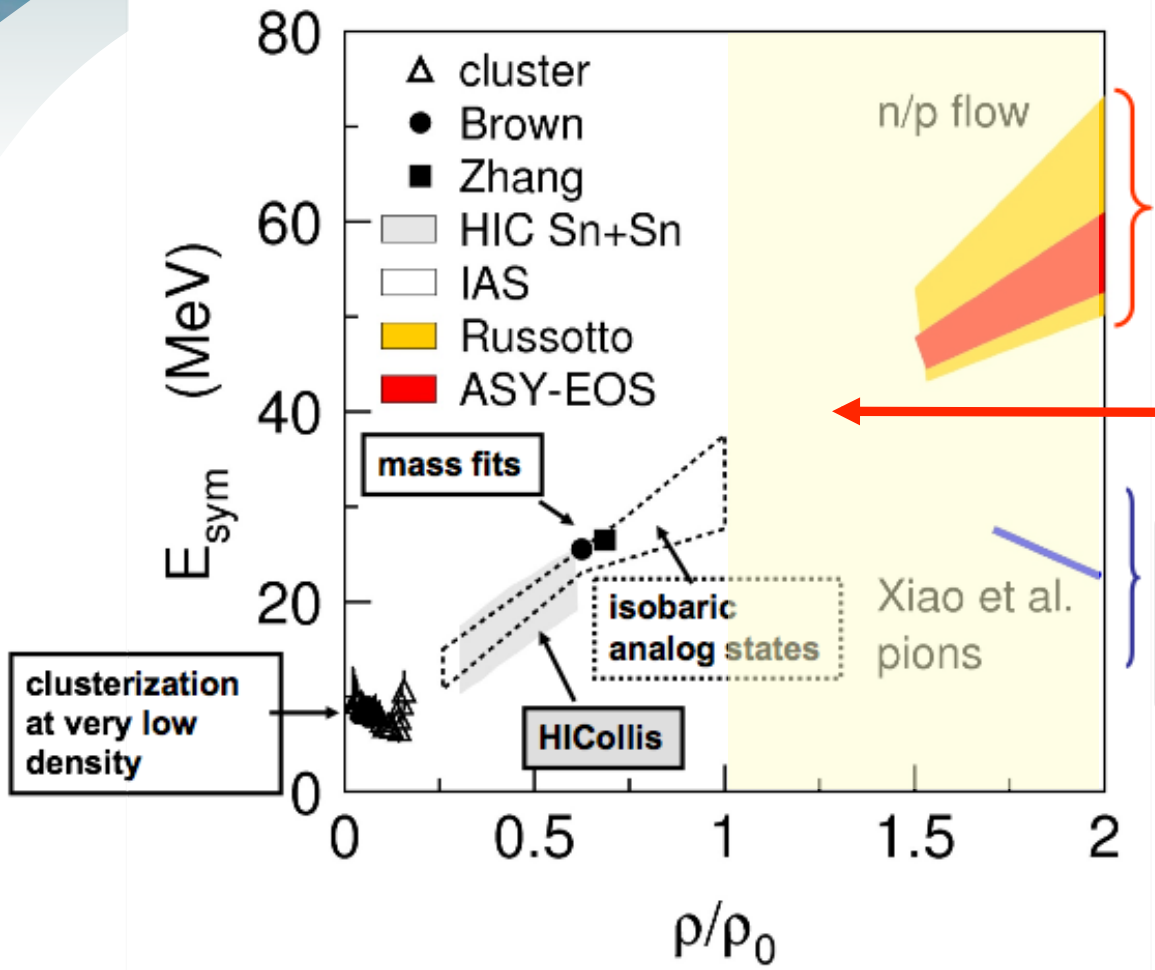


Science at LAMPS

RAON

Present Constraints on the Symmetry Energy (shown as $E_{sym}(\rho/\rho_0)$)

Competitivenes



n/p flow at 400 – 800 MeV/A → symmetry energy rather stiff

LAMPS will provide experimental data using rare isotope beam
e.g. ^{132}Sn + ^{124}Sn
→ measure n/p ratio & proton/neutron flow at same time

π^-/π^+ ratio, but also other results. still a difficulty!

- **Experimental data are measured with stable beams**
- **Data of pion ratio and data of n/p flow are from different experiments**
- **Models in the market show different results even within same observable**