EMIS2012, Matsue, Japan

Current Status of RISP (Rare Isotope Science Project)

7th December 2012

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on behalf of RISP

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ibS 기초과학연구원 Institute for Basic Science

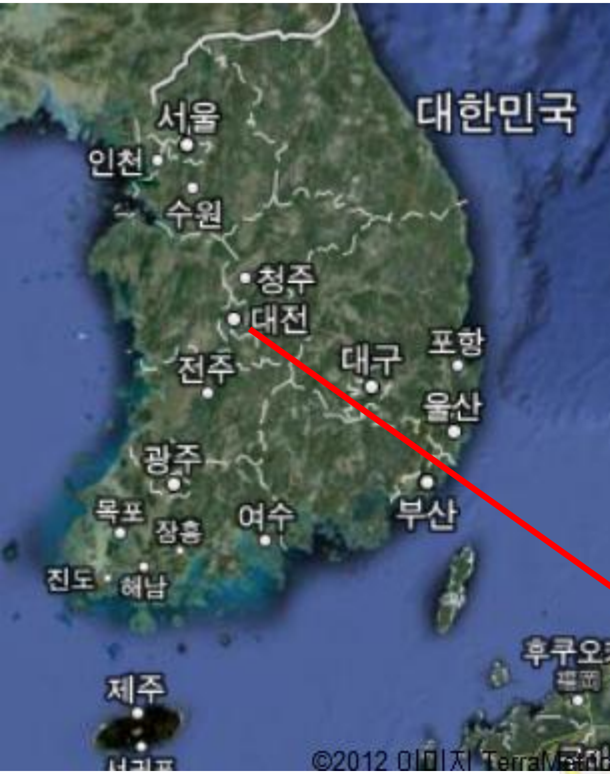
Brief History

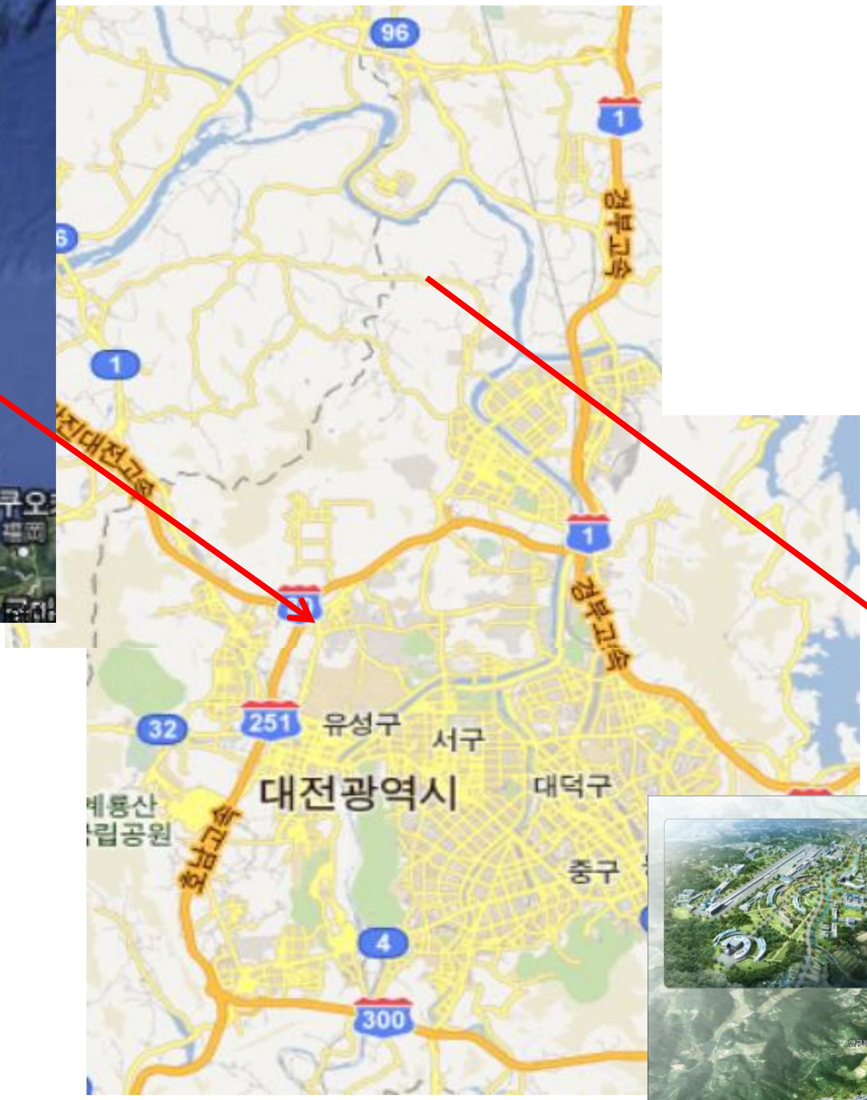
- **ISBB plan** (2009.1) : New Science Initiative in Korea

- Preliminary Design Study (2009.3-2010.2)
- Conceptual Design study (2010.3-2011.2)
- International Advisory Committee(2011.7)

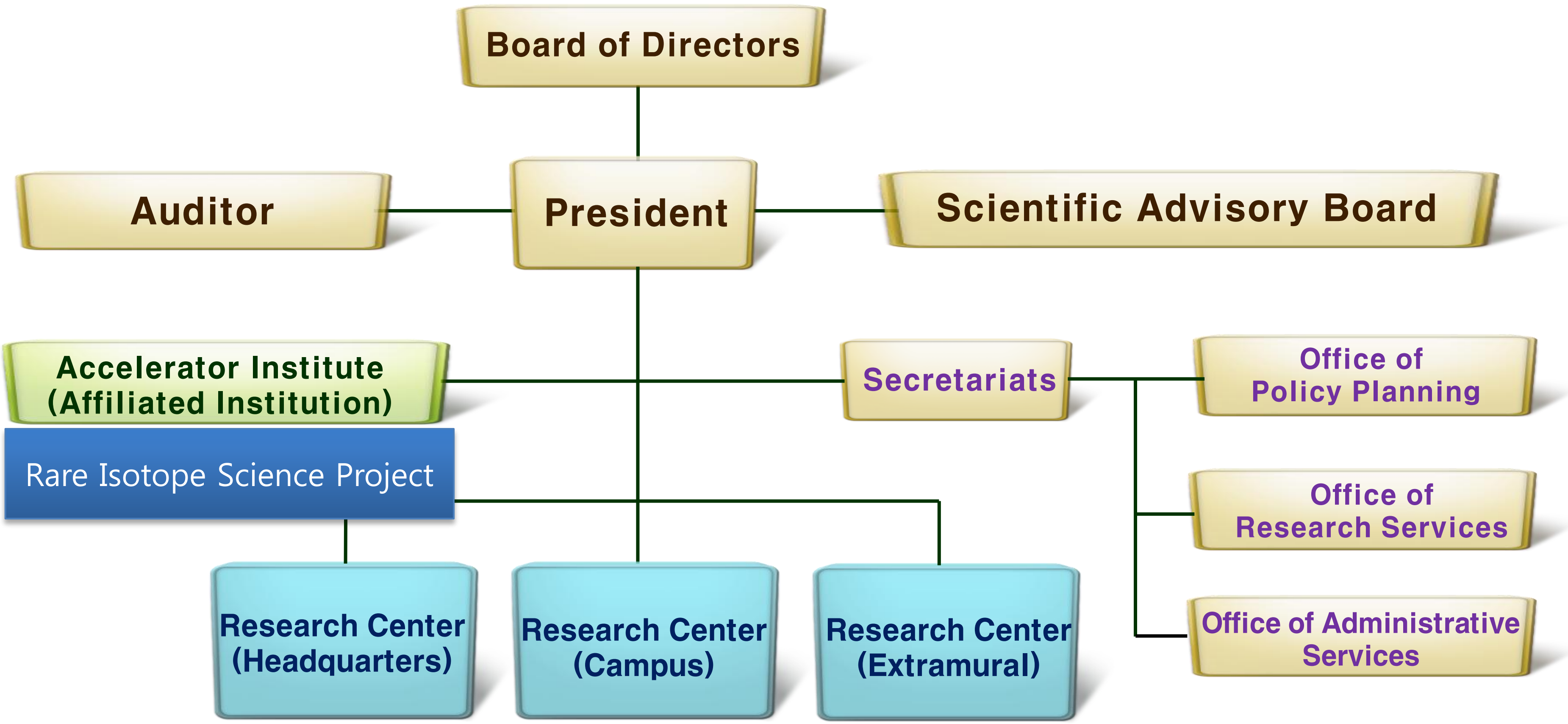
- **Institute for Basic Science(IBS)** established(2011.11)
- **Rare Isotope Science Project(RISP)** launched(2011.12)

Location : Daejeon





Organization of IBS (Institute for Basic Science)

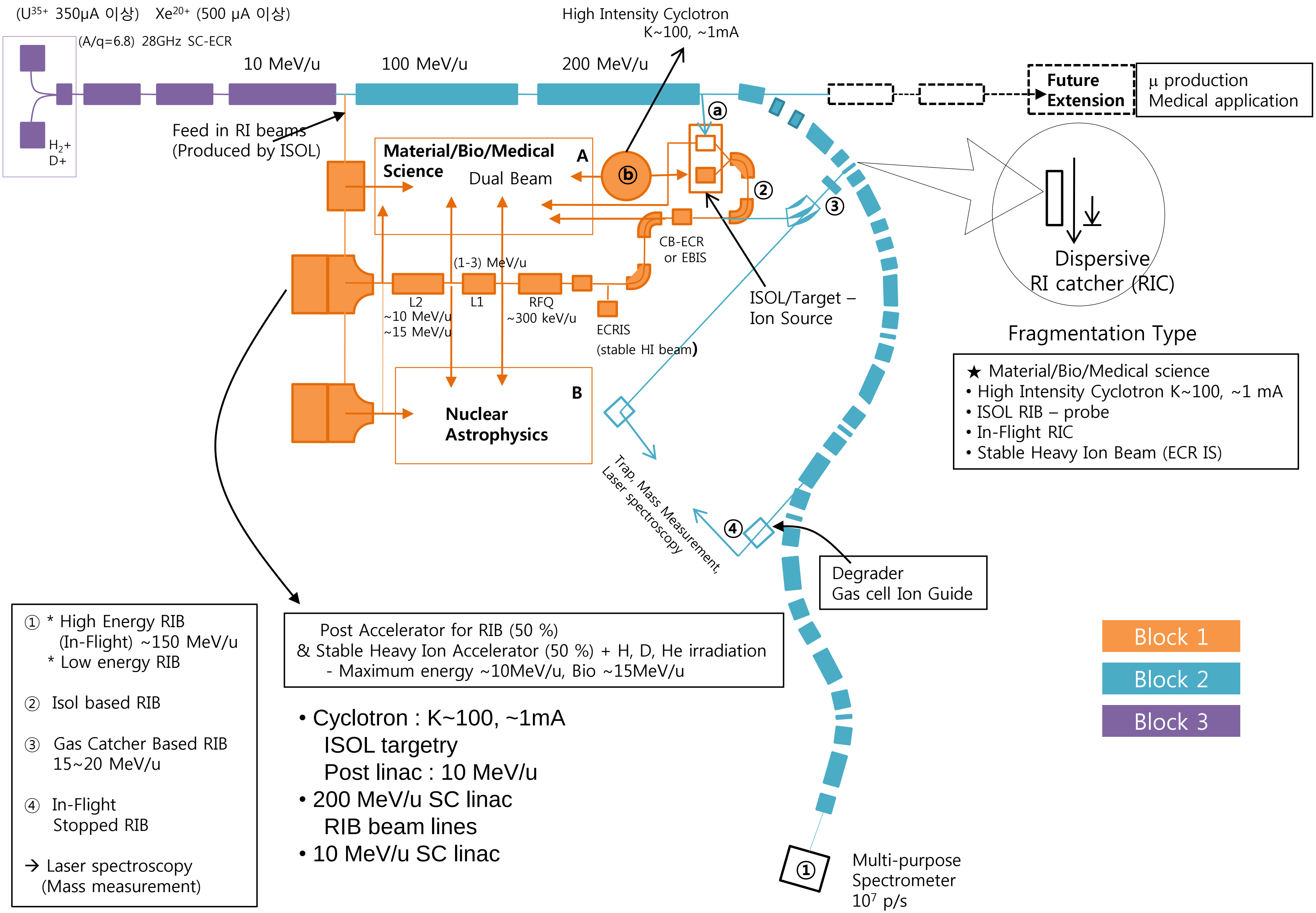


- IBS consists of 50 research centers, supporting organizations, and affiliated research institutes
- Each Research Center : ~50 staff, average annual budget ~ 9 M USD
- The number of staff: 3,000 (2017, including visiting scientists and students)
- Annual Budget: USD 610 million (2017, including operational cost for the Accelerator Institute)

RISP Status and Plan

- Conceptual Design report (Mar. 2010 - Feb. 2011)
- IAC review (Jul. 2011 – Oct. 2011)
- Rare Isotope Science Project started in IBS (Dec. 2011)
  Director Prof. Sunkee Kim
  Full budget for facility R&D approved by MEST
- Conceptual Design of the Building and Conventional Facilities (May 2012)
- Baseline Design Summary (by July 2012)
- Technical Design Report (by Jun. 2013)
- Ground Breaking (2014)

Birth of RISP : KoRIA (April, 2009)



Key Science Drivers of RISP

- **Highest priority research subjects**
  - Nuclear reaction experiments important to nuclear-astrophysics : e.g. $^{15}O(a,\gamma)^{19}Ne$, $^{45}V(p,\gamma)^{46}Cr$
  - Search for super heavy elements : $Z > 113$
  - Nuclear structure of n-rich RI near N=126, 80<A<140
  - Nuclear symmetry energy at sub-saturation density
  - Precision mass measurement & Laser spectroscopy

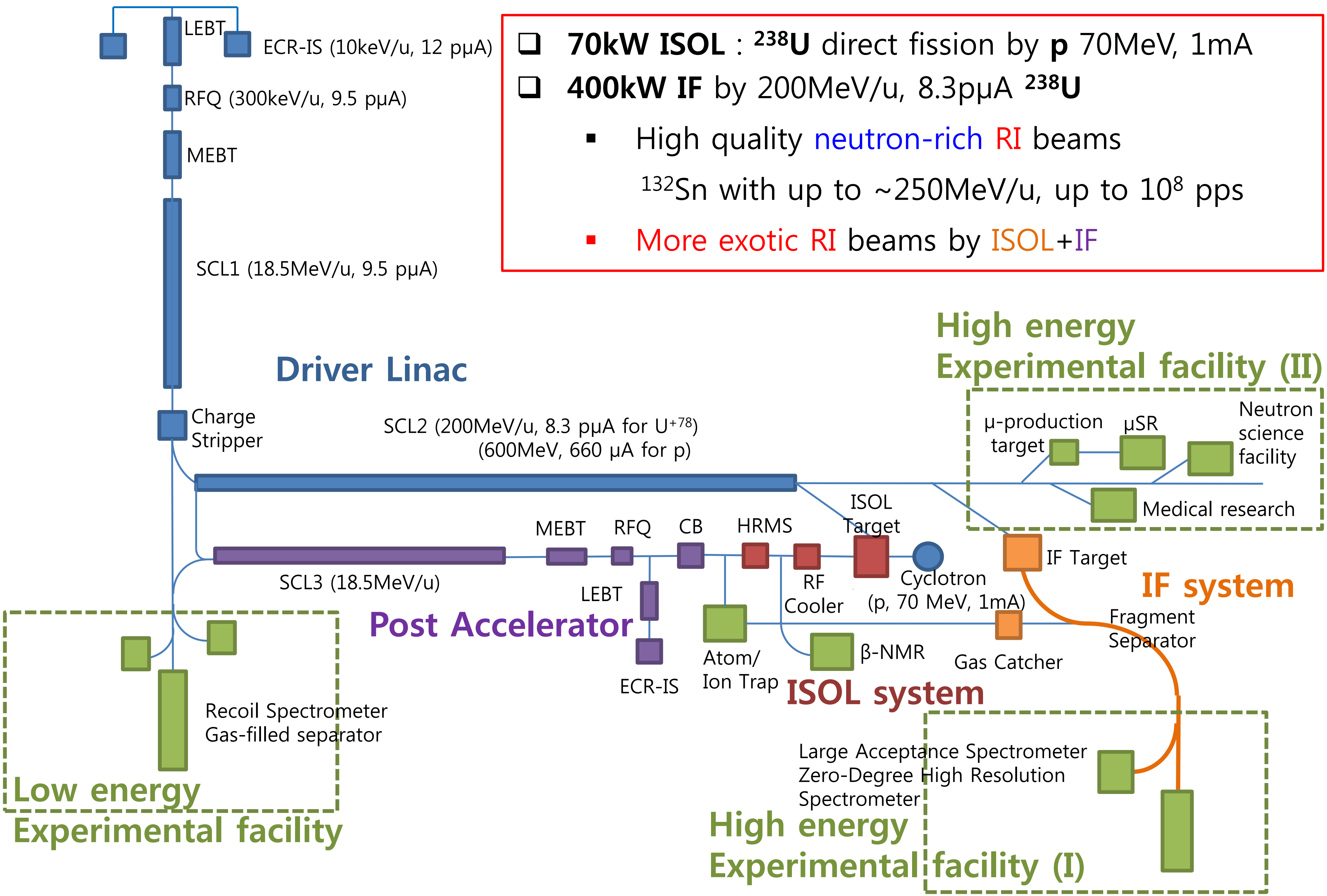
- **Important scientific applications**
  - Material science : β-NMR, μSR
  - Medical and bio-science
  - Nuclear data for Gen-IV NPP and nuclear waste transmutation

Selected RI beams for Design

RI Beam species	Energy Range	Desired Intensity [pps]	Research fields
^{132}Sn, ^{144}Xe	> 100 A MeV	10^8, 10^6	Nuclear structure
^{15}O	< 10 A MeV < 30 keV	10^{10} 10^8	Nuclear astrophysics Material Science
^{26m}Al	< 15 A MeV	10^7	Nuclear astrophysics
^{45}V	0.6-2.25 A MeV	10^7 – 10^9	Nuclear astrophysics
^{68}Ni, ^{106}Sn, ^{132}Sn, $^{140, 142}$Xe	10-250 A MeV	10^9	Symmetry energy
^{6,8}He, ^{12}Be, $^{24-30}$O	50-100 A MeV	10^9	Nuclear Study with Polarized target
^{17}N, ^{17}B, ^{12}B, $^{14-15}$B, $^{31-32}$Al, ^{34}K	50-100 A MeV	10^9	Nuclear Study with Polarized RI beam
^{64}Ni, ^{58}Fe (stable)	A few A MeV	10^{12}	SHE
^{8}Li, ^{11}Be, ^{17}Ne	< 30 keV	10^8	Material science
$^{133-140}$Sn	< 60 keV	1	Atomic physics
^{8}B, $^{9-11}$C, ^{15}O	≥ 200 A MeV	10^7 – 10^9	Medical and Bio science

RAON : RISP Accelerator Complex

- **70kW ISOL** : ^{238}**U** direct fission by **p** 70MeV, 1mA
- **400kW IF** by 200MeV/u, 8.3pμA ^{238}**U**
  - 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



Development Plan

2009

LoIs from domestic users
- **Science program** with RI beams up to 200 AMeV
- **83 LoI's**
  (nuclear/astrophysics, nuclear data, standard model, biomedical, mass measurement, material science, ERD analysis)

2010 ~ 2011

Science classification
- Nuclear science
- Atomic & Molecular science
- Material science
- Medical & Bio science

2011 ~ 2013

Facility specifications
- Beam specifications
  (energy, intensity, pulse width …)
- Specifications of experimental facilities

We are here!!!

2013 ~ 2017

R&D and Installation
- Spectrometer
- Detection system
- Beam line
- Apparatus for applied sciences

2017

Day-1 experiments

Upgrade and extension

2012 ~ 2013

Refinement
- Based on Realistic modification of specifications
- **LoIs for specified experiments (domestic + foreign)**

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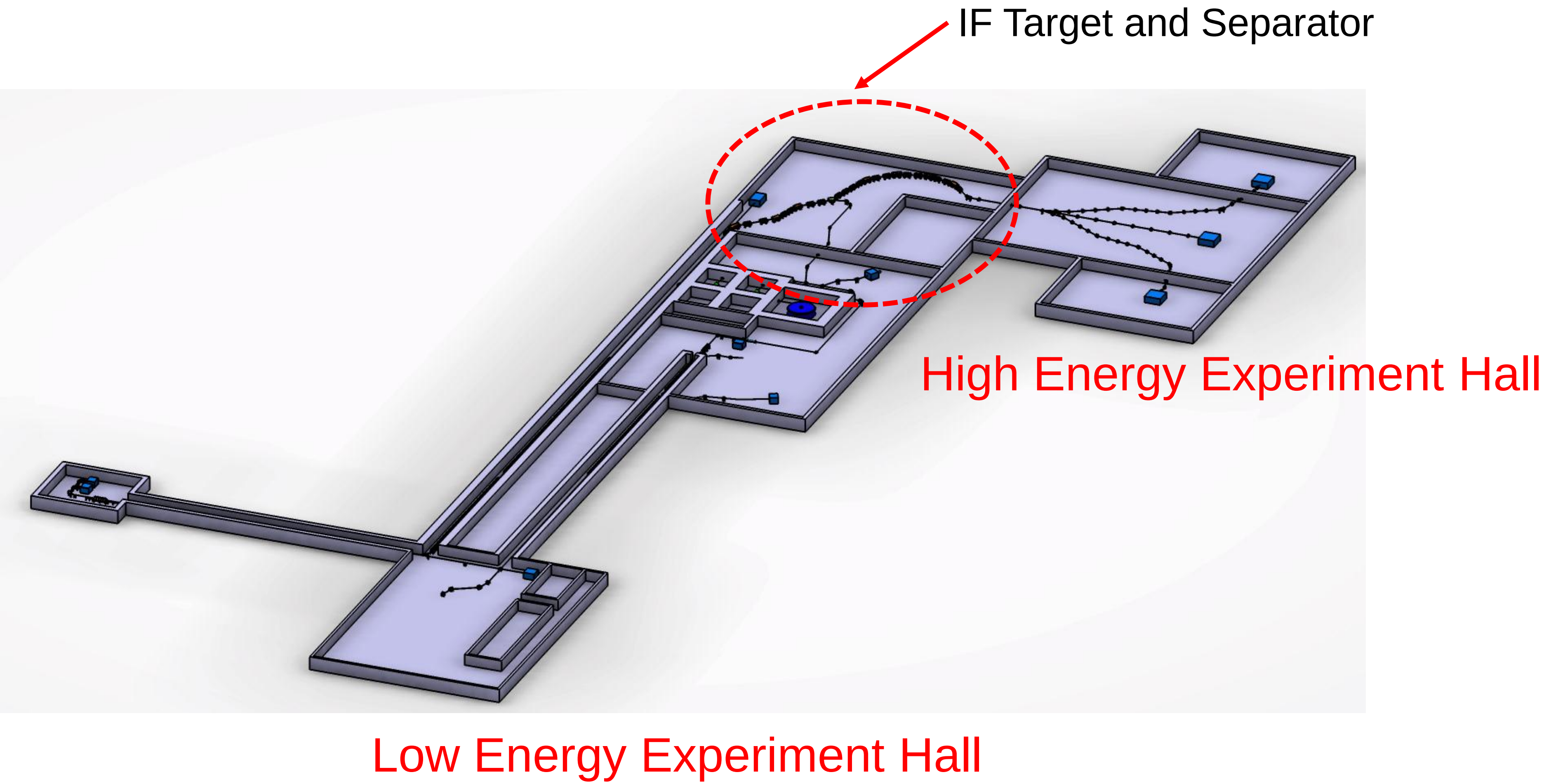
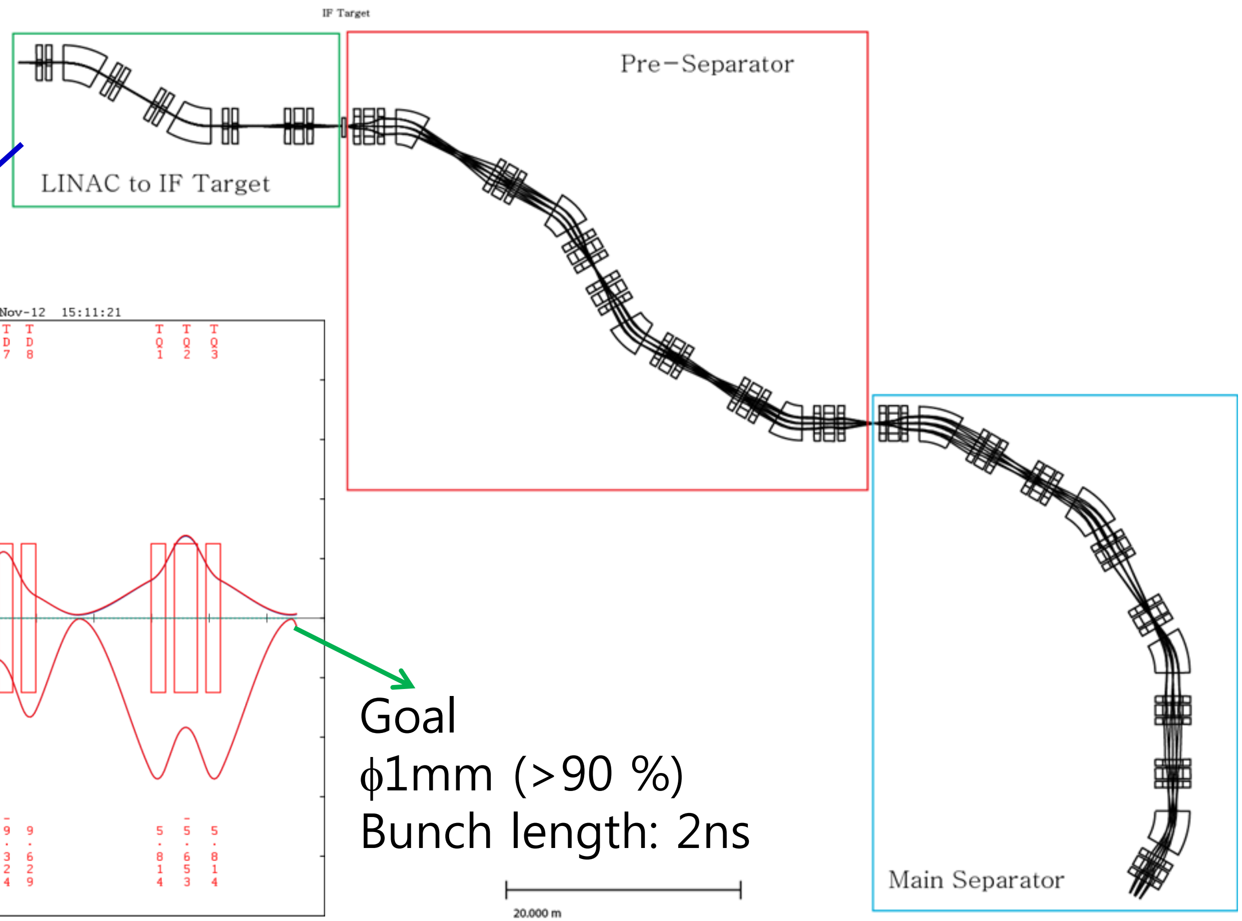
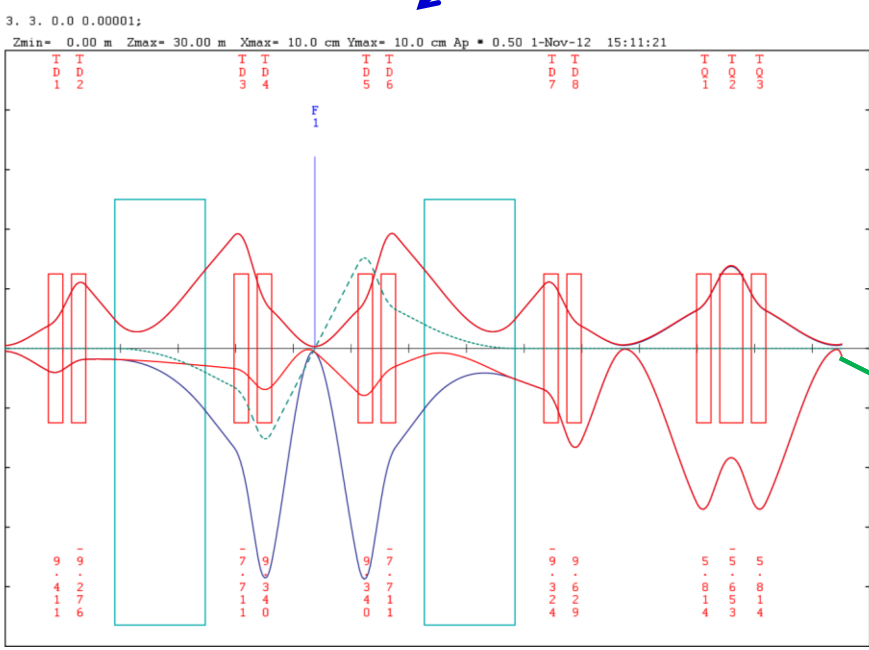
IF System


IF Target and Separator
High Energy Experiment Hall
Low Energy Experiment Hall

Configuration of Fragment Separator

Design of beam transport line between the linac and target





Goal
ϕ1mm (>90 %)
Bunch length: 2ns

TRANSPORT, $^{238}U^{79+}$: $\Delta P = \pm$ 2.5 %
→ Calculation with DYNAC underway for multi-charge beam

RISP ISOL

Rare Isotope Science Project

Necessity

- Diverse experiments
- Need of neutron enrich isotope

Objective

- Design of 10 kW ISOL
  - Rare isotope ion source with high purity and high intensity

  * Especially our goal : 70 kw ISOL

1900

Becquerel discovers radioactivity

The Curies discover polonium

Isotopic tracer technique by von Hevesy

1930

First therapeutic application of artificial radionuclide

6-He produced in Copenhagen

Neutron-induced fission

Fermi builds controlled fission reactor

Radiochemistry used to monitor nuclear weapons tests

Explanation of magic numbers

Explanation of magic numbers

Z=100 (Fm) discovered

First ISOL experiment in Copenhagen

Parity violation in beta decay

First in-flight separator at Oak Ridge

beta-NMR demonstrated at ANL

BBHF theory of nucleosynthesis

1960

Nobel Prize for magic numbers

Beta-delayed proton radioactivity discovered at Dubna and McGill

Z=105 (Db) discovered in Dubna

ISOLDE

First mass measurement of short-lived nuclei at PS in CERN

Invention of PET scanner

Island of inversion at N=20 and shape coexistence in proton-rich Hg at iSOLDE

Nobel Prize for unified model

First in-flight fragmentation experiments at Berkeley

First application of radiochemistry to inertial fusion target diagnosis

Nobel Prize for nucleosynthesis

GANIL

Measurement of half-life of r-process nucleus at Studsvik

Neutron halos discovered at Berkeley

Measurement of half-life of r-process nucleus at TRISTAN

Momentum distribution of halo at RIKEN

IGISOL at Jyväskylä

RIKEN

GSI

NSCL

First accelerated beam experiment (13-N) at LLN

100-Sn discovered at GSI and GANIL

Relativistic Coulomb excitation of 32-Mg at RIKEN

Laser ion source at ISOLDE

Trapped francium at Stony Brook

Shell structure of exotic nuclei with knockout reactions at NSCL

HRIBF

SPIRAL1

ISAC-I

2000

REX-ISOLDE

KEK-JAERI

Targeted alpha therapy at ISOLDE

Direct radiative capture with 21-Na at ISAC-I

38m-K β-ν correlations at TRINAT

Two-proton emitters discovered at GSI and GANIL

Shell structure changes in exotic nuclei at ATLAS/HRIBF/NSCL

6-He enhanced reaction cross sections at TwinSol

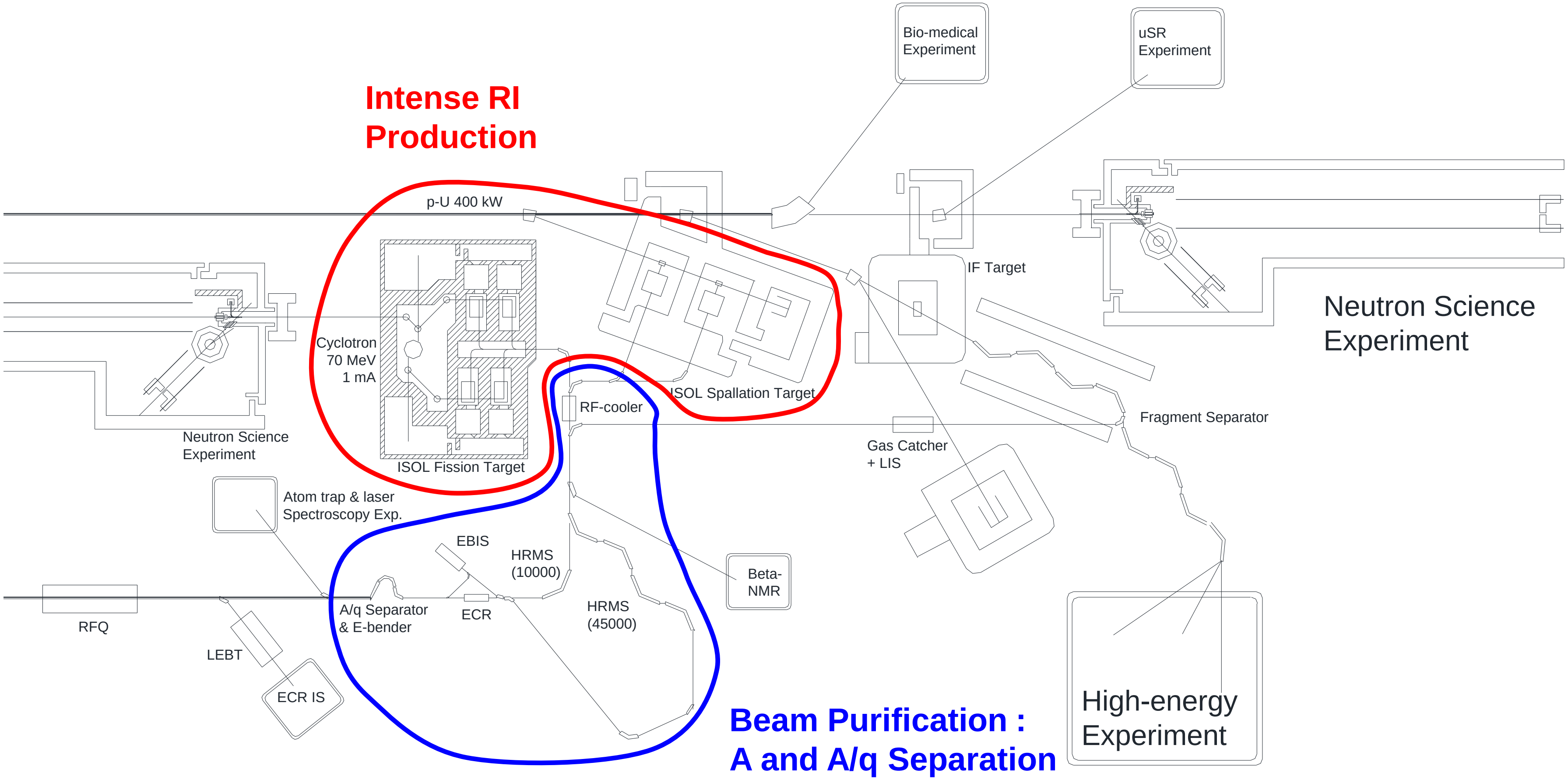
Studies with accelerated 132-Sn and 82-Ge at HRIBF

21-Na β-ν correlations at Berkeley

Charge radius of 6-He at ATLAS

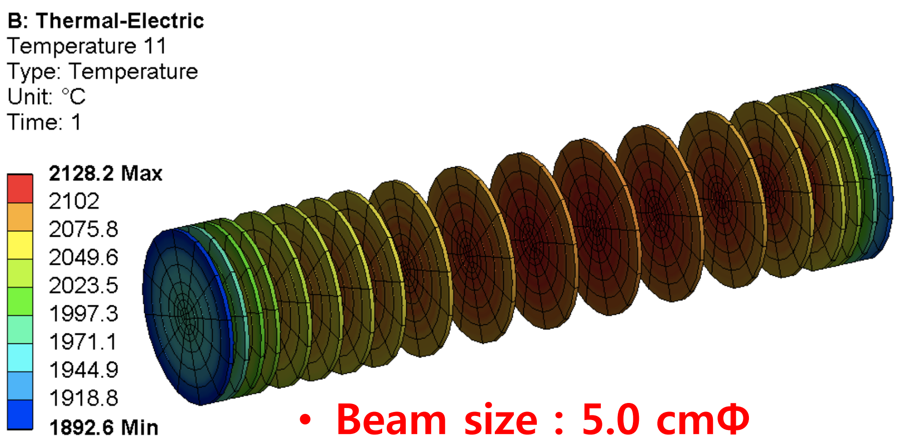
78-Ni lifetime at NSCL

Layout of ISOL facility

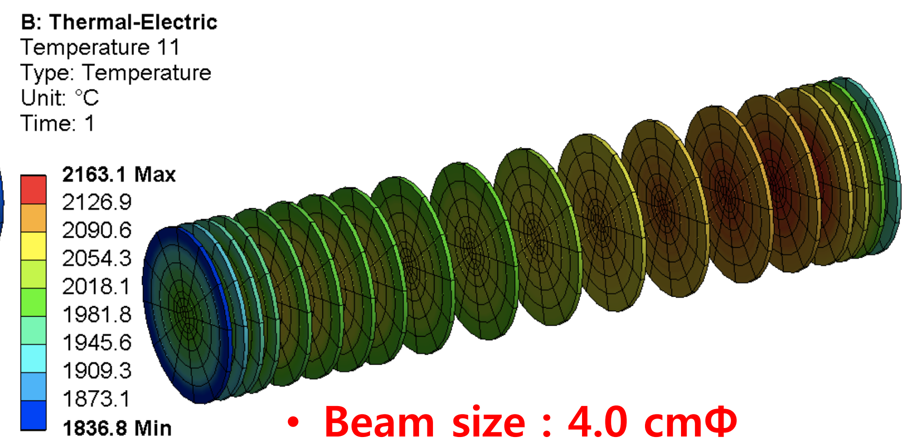


Target Assembly	ISOL Target / RI Ion Source / TIS Front-End
RI separation	Pre-separator / RF cooler / HRMS / Charge Breeder / A/q Separator
Conventional System	Utilities / Radiation Safety System / Beam Diagnostics

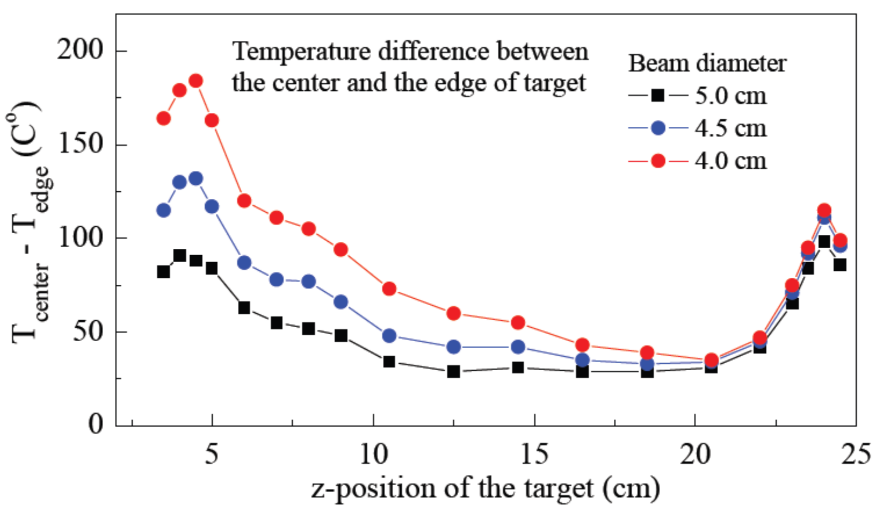
Thermal analysis of 10 kW ISOL Target

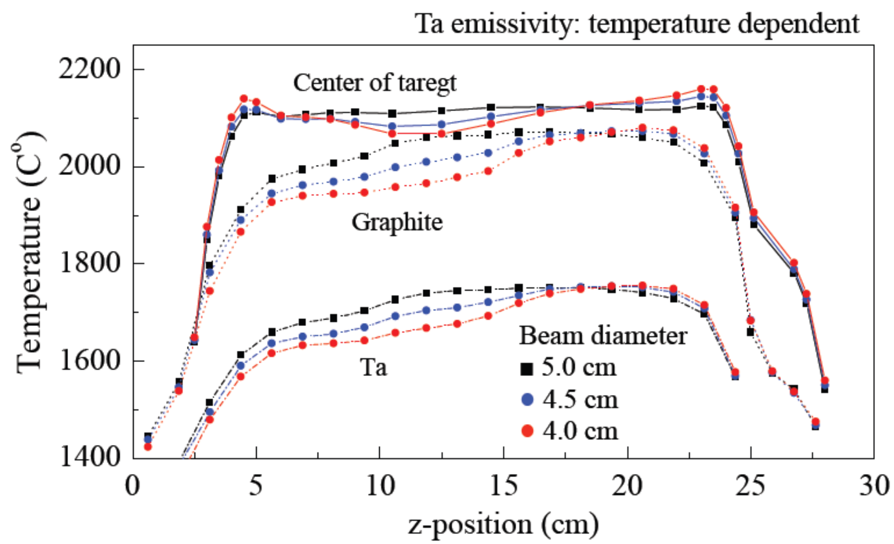


- Beam size : 5.0 cmΦ
- Fission rate : $1.49 \times 10^{13}\ s^{-1}$



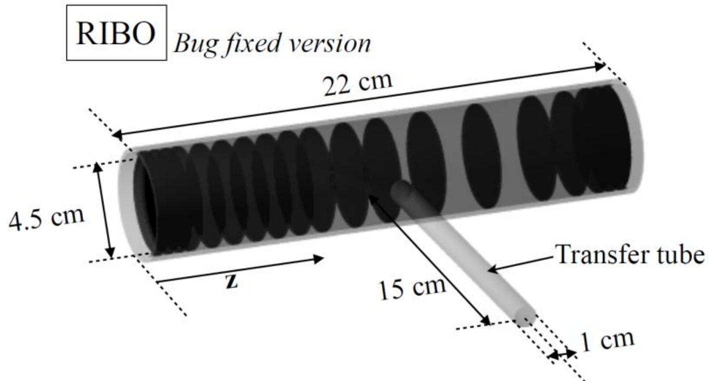
- Beam size : 4.0 cmΦ
- Fission rate : $1.63 \times 10^{13}\ s^{-1}$

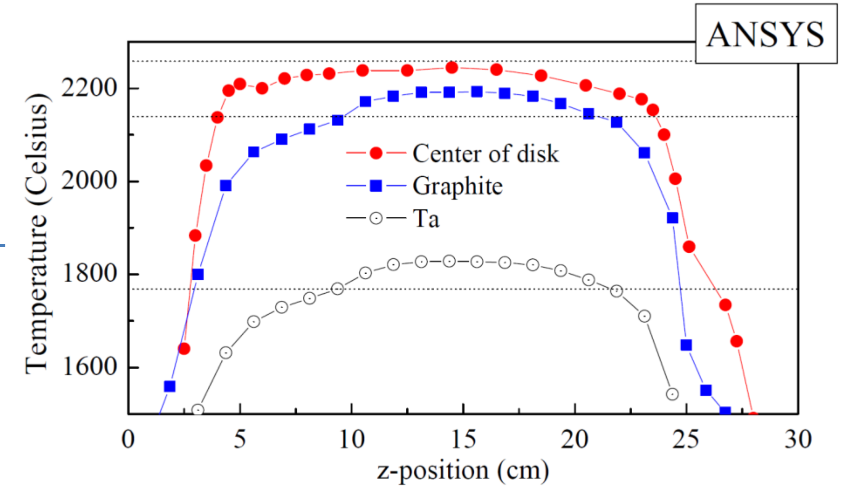




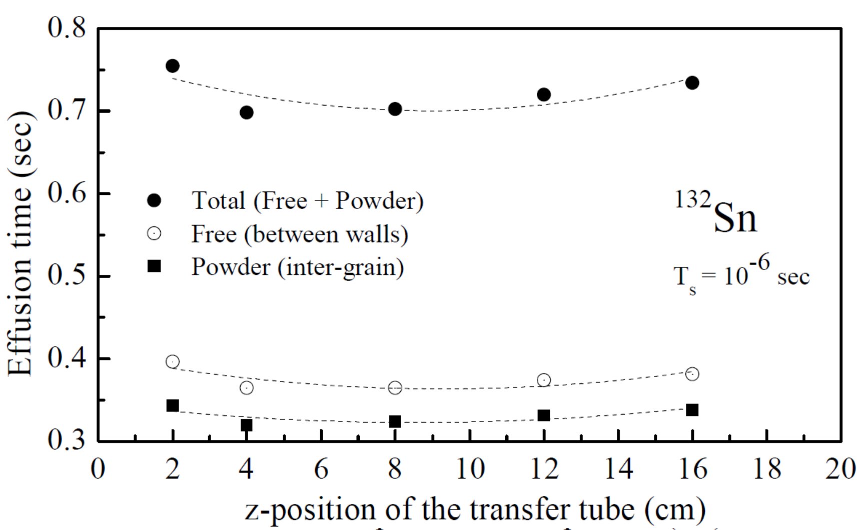
*UCx melting point : 2300~2400℃

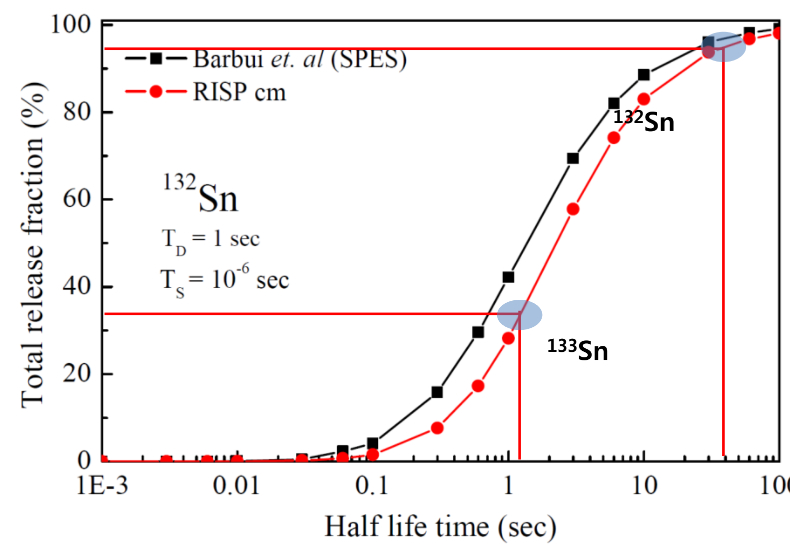
Release efficiency of 10 kW ISOL Target





Transfer tube temperature : 2000 °C
Graphite temperature : 2061 °C (calculated from ANSYS)





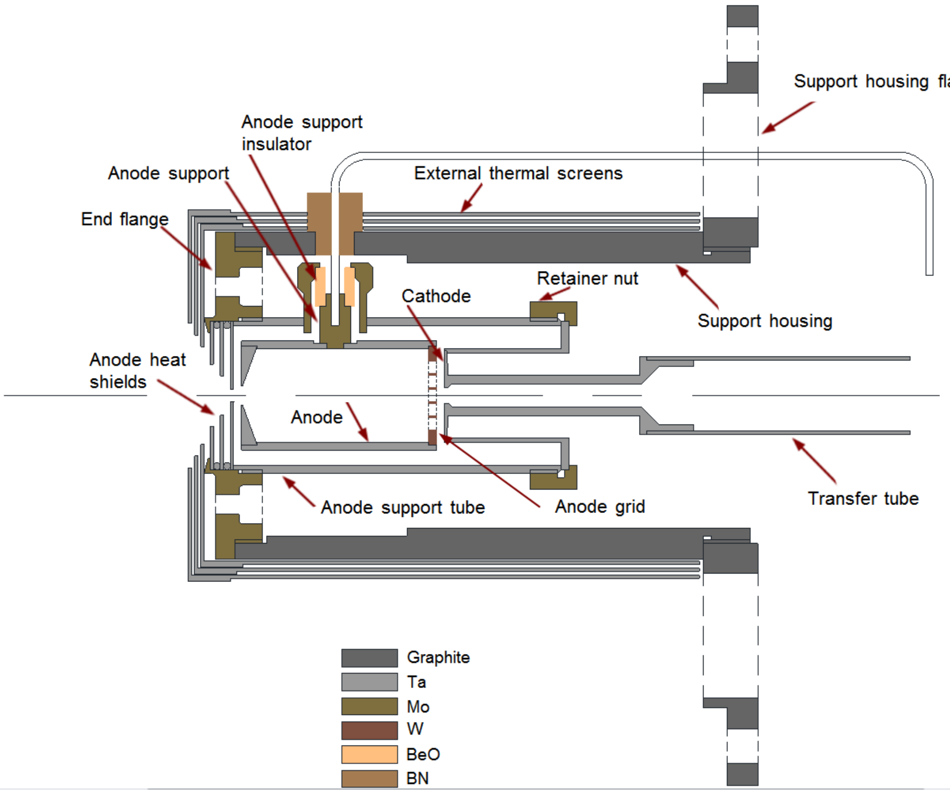
ε_r = 95 % for ^{132}Sn
= 32 % for ^{133}Sn
assuming the diffusion is 1sec

Technical design of FEBIAD Ion Source

Purpose : To produce gaseous neutron-rich RI beams
Design Goals

- Must be compact
- Must withstand high radiation field (~1 MGy)
- Compatible with standard connections/interfaces
- Compatibility with Front End interfaces
- Maximal efficiencies for the desired beams
- Minimize Transverse emittance, energy spread

Design Sketch of the RAON FEBIAD ION source



Temperature	1500 - 2300°C
Cavity	L = 2-3 cm Φ = 1-2 cm extr.: 0.5-3 mm
Anode, Cathode, etc Materials	C, Ta, Mo, W
Insulator	BN, BeO, Al_2O_3
Cathode Heating	Ohmic heat, 100-1000 W
Plasma density	10^7-10^{10} /cm^3
Plasma potential	70% of Anode V (50-100 V)
E_{e-}	10-300 eV
$\varepsilon_{95\%}$@30kV	15-25 π mm mrad
Extraction Potential	30 kV

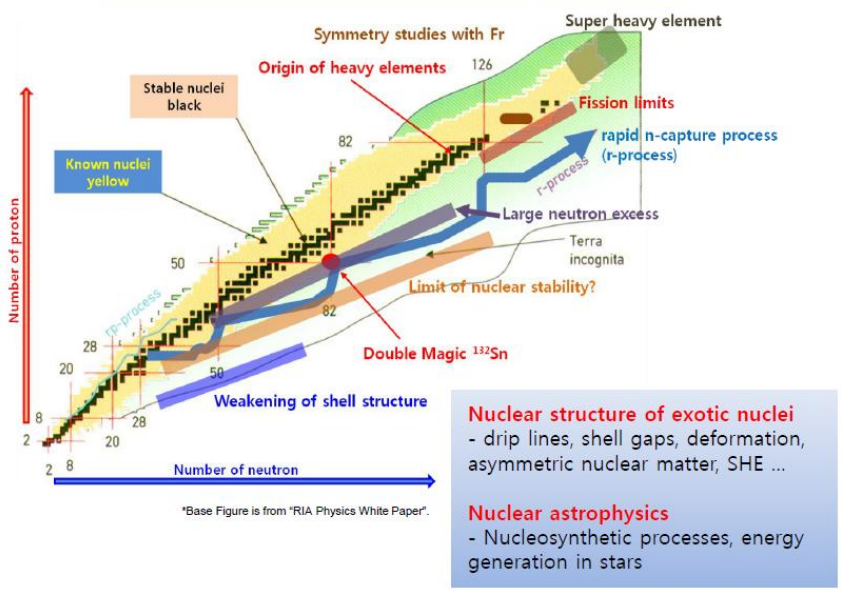
RISP Recoil Spectrometer

Objective

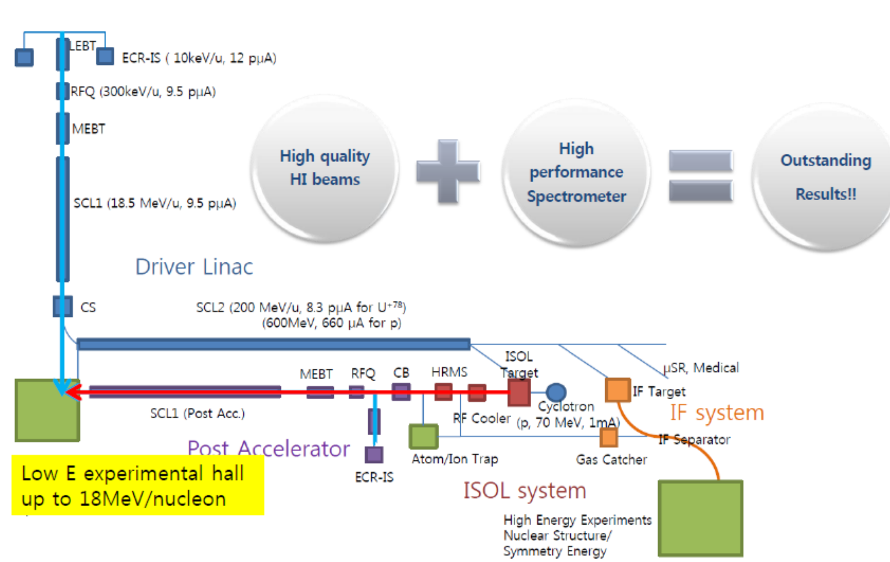
- Design of Recoil Spectrometer for low energy (<18.5 MeV/nucleon) nuclear and nuclear astrophysics study
  - * Cancellation of velocity dispersion with two Wien filters
  - * Large angular acceptance of < ±100mrad for more dissipative reactions

Necessity

Nuclear science program



Low energy beam scheme



- Main experimental facility for nuclear physics with SI (stable isotope) and RI (rare isotope) beams up to 18.5 MeV/nucleon

Preliminary result

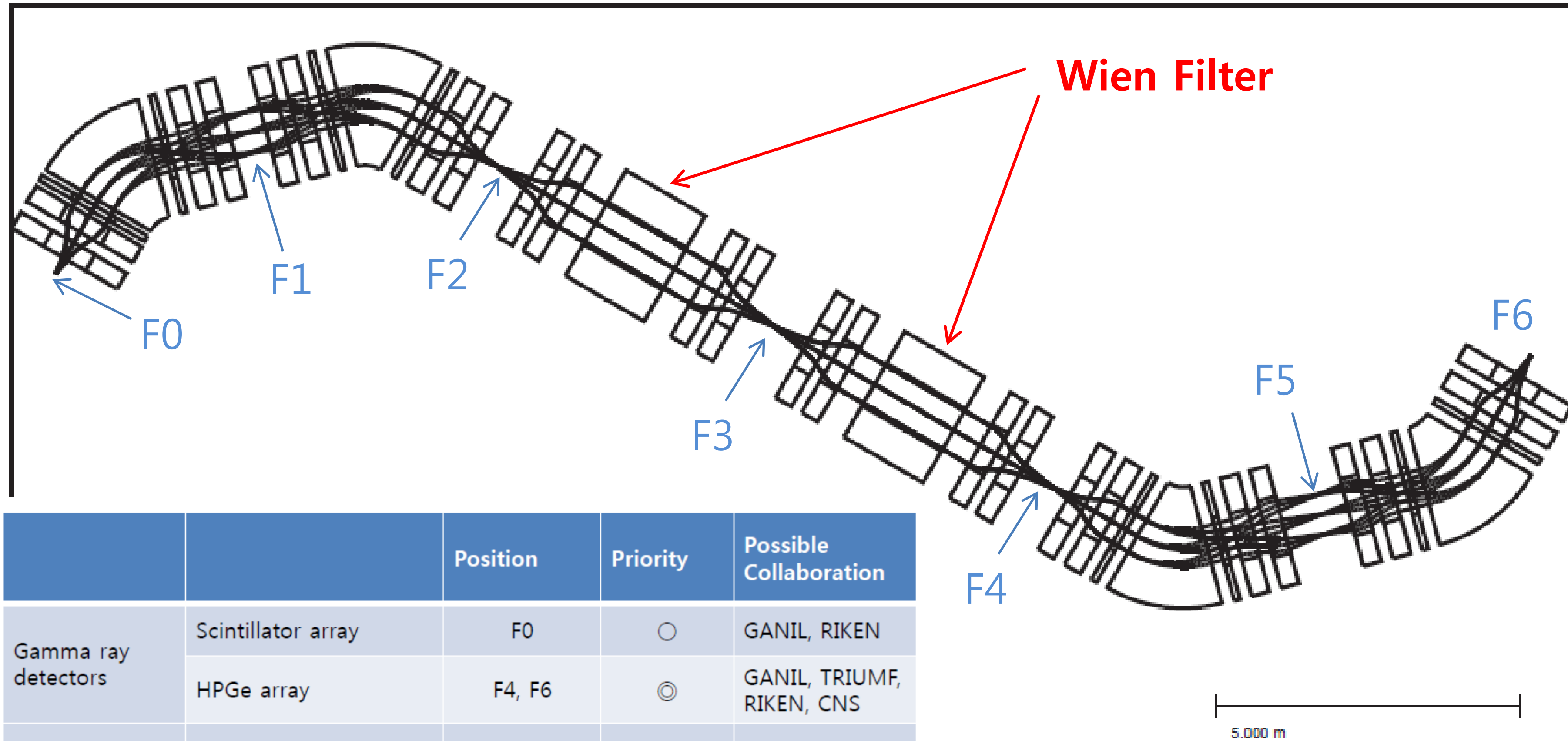
- Design goal for recoil spectrometer

Maximum magnetic rigidity (T·m)	~ 1.5
Mass resolution ($\Delta M/M$)	< 0.5 %
Momentum resolution ($\Delta p/p$)	~ 0.05 %
Angular acceptance (mrad)	< ± 100
Background reduction	< 10^{-12}

- Available experiments at the RISP Recoil Spectrometer

Physics topics	Measurements
rp-process	radiative capture, transfer reaction, elastic/inelastic scattering
s- & r-process	transfer reaction (d,p), decay measurement
neutron drip line studies, halo nuclei	transfer reaction, scattering
proton drip line studies	transfer reaction, fusion-evaporation reaction
Super heavy elements search	fusion-evaporation reaction

- Double achromatic focusing system using two electrostatic components – Wien Filter
- Four dipoles + Twenty four quadruples + Eight multi-poles + Two Wien Filters
- Total length ~ 36 m



		Position	Priority	Possible Collaboration
Gamma ray detectors	Scintillator array	F0	○	GANIL, RIKEN
	HPGe array	F4, F6	◎	GANIL, TRIUMF, RIKEN, CNS
Charged particle detectors	DSSSD	F0, F4	◎	
	IC+Plastic scintillator	F6	○	
	Active-target	F4	○	KEK, MSU
Beam tracking detectors	PPAC, MCP	F0, F2, F4, F6	◎	
	Thin scintillator		○	

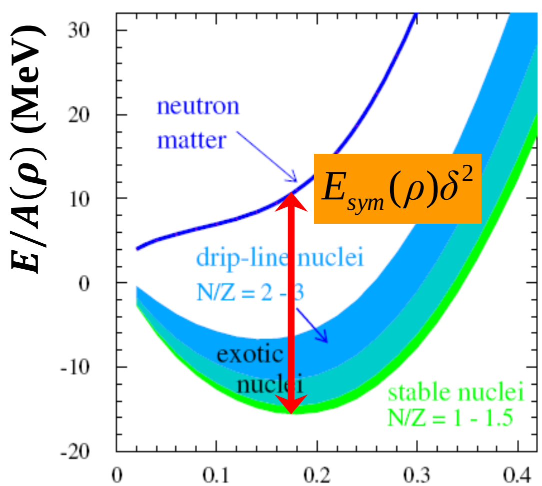
RISP Heavy-ion Collision Experiment

Rare Isotope Science Project

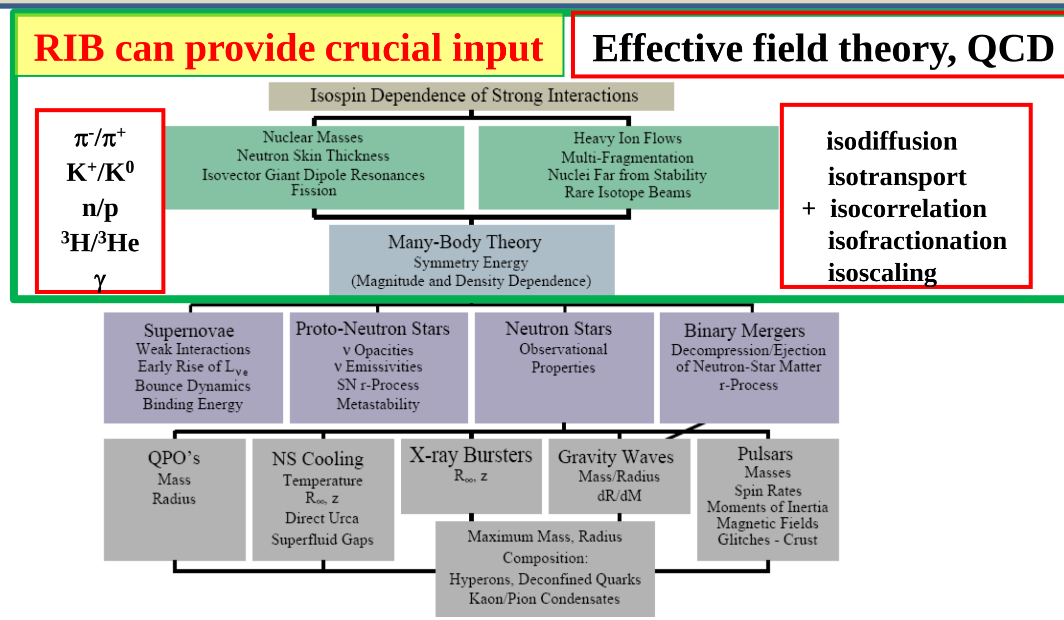
Objective

- Design of Heavy-ion Collision Experiment using RI beam
  - Study of Nuclear symmetry energy
  - * To cover entire energy range at RISP with complete event reconstruction within large acceptance (3πSr TPC & ±50mSr Dipole Spectrometer)

Necessity



CDR, FAIR (2001) ρ (fm^{-3})

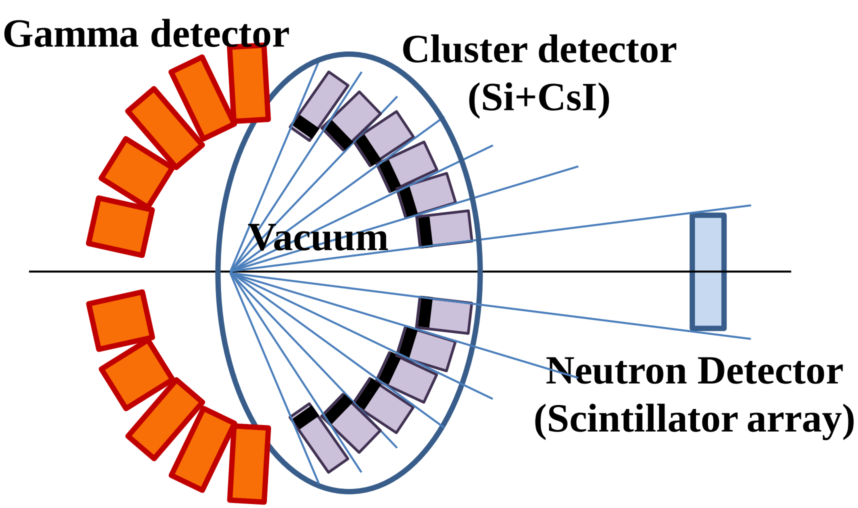


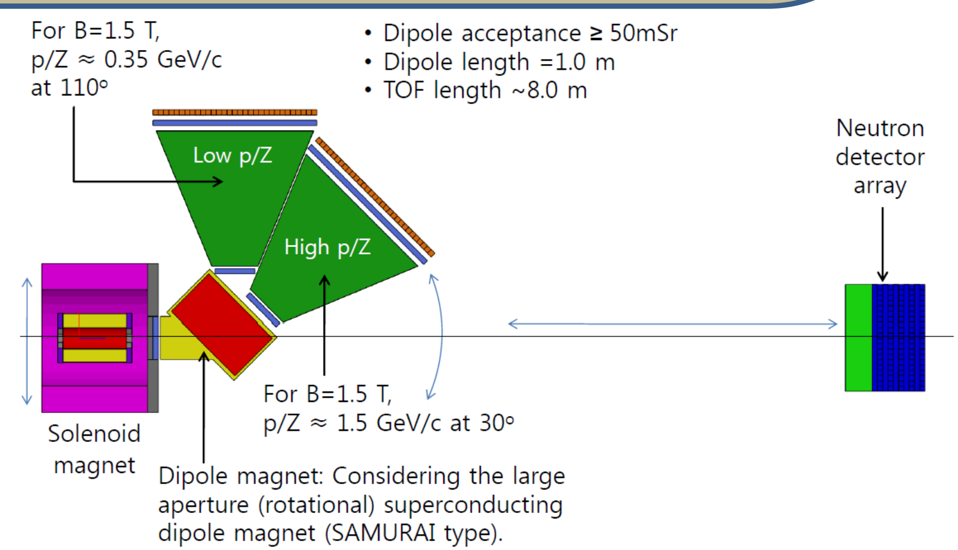
- **A.W. Steiner, M. Prakash, J.M. Lattimer and P.J. Ellis, Physics Report 411, 325 (2005)**
- **Red boxes: added by B.-A. Li**

- System size (e.g. Ca, Ni, Ru, Zr, Sn, Xe, Au, U), energy (e.g. lowest to top energies), centrality, rapidity and transverse momentum dependence studies of Pigmy/Giant dipole resonance, Particle spectrum, yield, ratio, Collective flow, and more

Performance at RISP

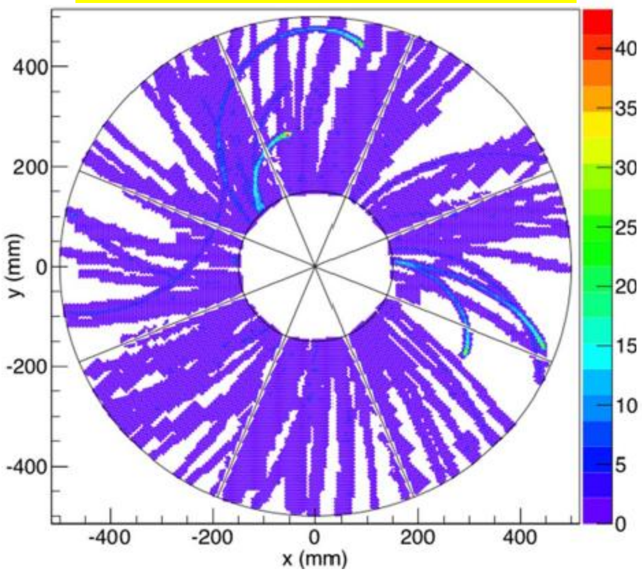
1. Design of experimental setup
    - For low energy (E_{beam} = 0 - 20 MeV/u)
    - For high energy (E_{beam} = 20 - 250 MeV/u)
2. Optics calculation for high resolution spectroscopy
    - Rotatable dipole magnet (~2T) and focal plane
3. Detector simulation and R&D
    - TPC (~ 3π Sr acceptance)
    - ΔE-E (Si+CsI)
    - MWDC (3 tracking stations)
    - ToF (σ_t < 100 ps for $\Delta p/p < 10^{-3}$ at $\beta = 0.5$)
    - Neutron Wall (capable for neutron tracking)
    - Gamma Array (for measurement of Pigmy/Giant dipole resonance)





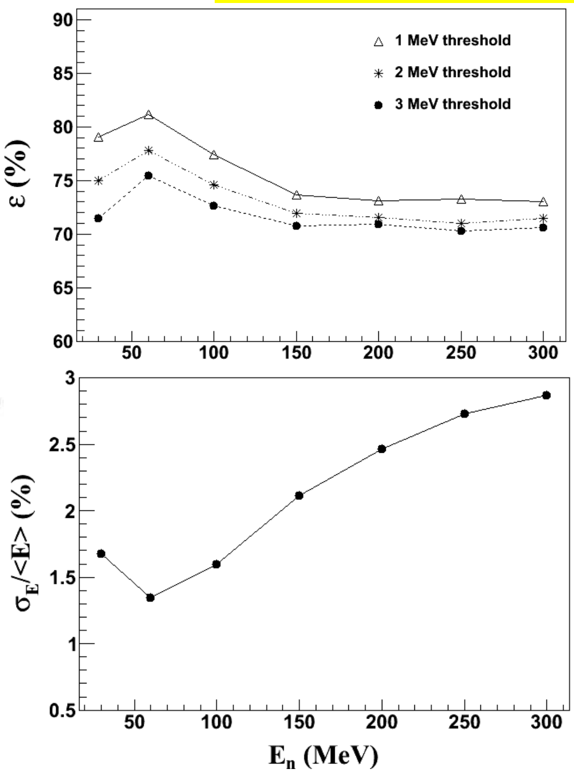
Preliminary result

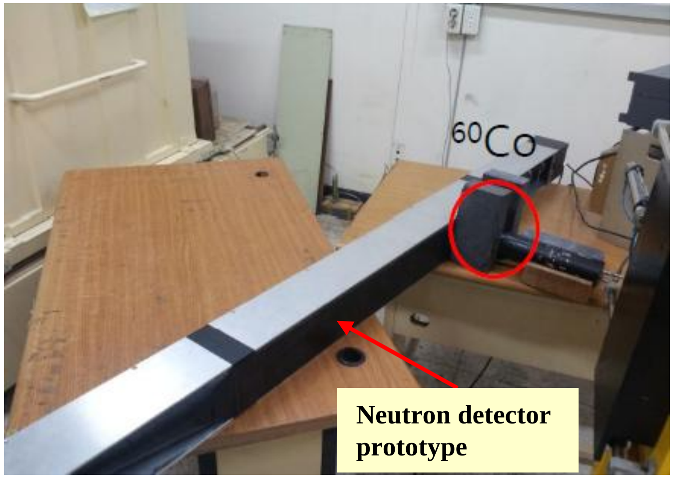
TPC Geant4 simulation



After digitalization including the detailed detector response
Input: IQMD Au+Au @ 250*A* MeV

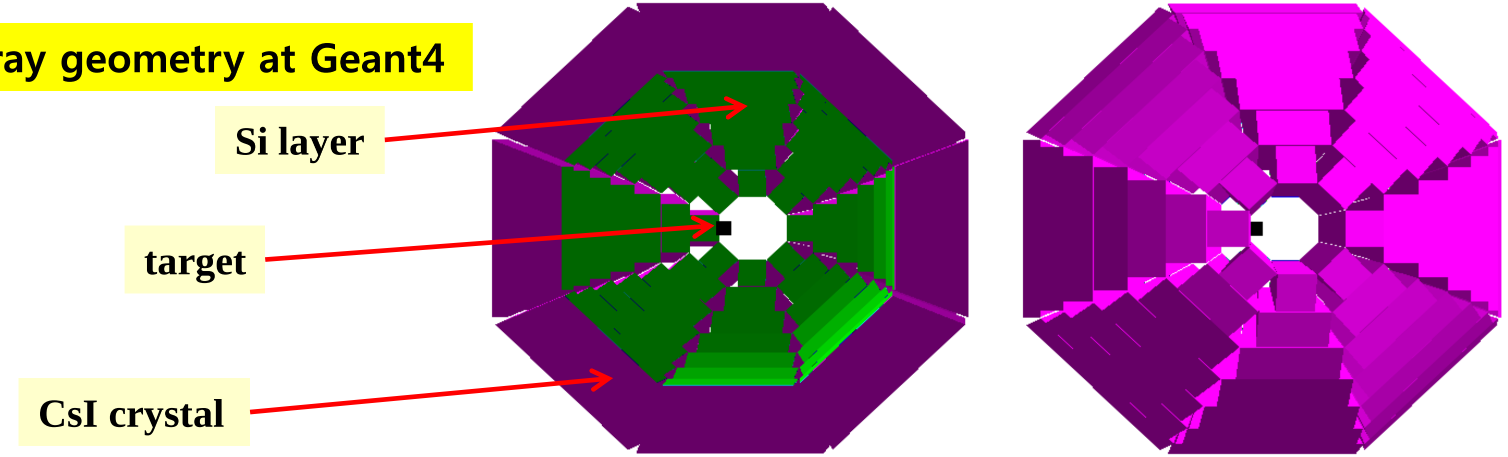
Neutron detector Geant4 simulation and R&D





Test of neutron detector prototype with ^{252}Cf and ^{60}Co

ΔE-E (Si+CsI) array geometry at Geant4



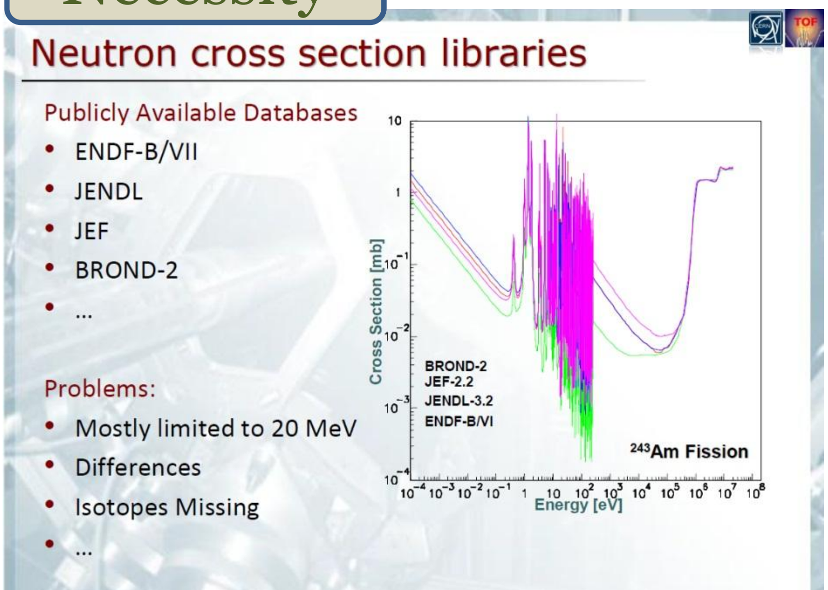
RISP Neutron Science Facility

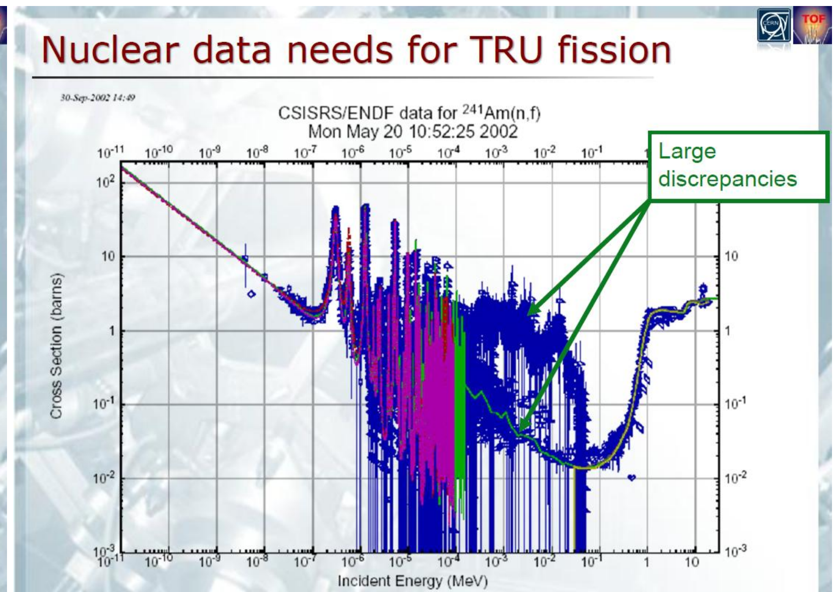
Rare Isotope Science Project

Objective

- Design of Nuclear Data Production Facility
  -Nuclear data : Total, Capture, Fission cross section(FC) etc.
  * Especially within the uncertainty of 1 % for FC

Necessity





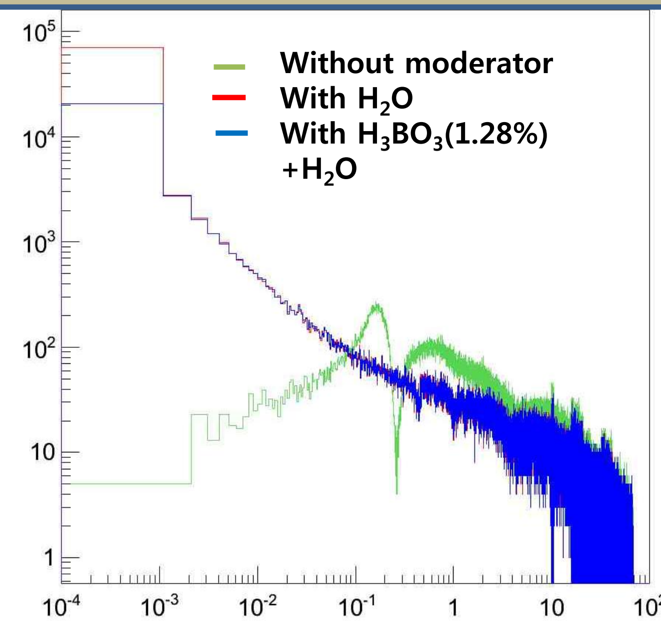
- OECD/NEA high priority & General request : 36 species
  - E_n <20 MeV, Fission 13 species, Capture 10 species, Total 3 species

Performance at RISP

1. Simulation of neutron source
   - 70 MeV, 1mA proton(Cyclotron), Li target ± Moderator
2. Design of n-TOF system
   - Simulation for optimum condition of n-TOF by MCNP
3. Design of vacuum line and collimator
4. Design of detection system
   - Capture cross section : C_6D_6 detector
   - Fission cross section : TPC

Preliminary result

● Neutron spectrum for Li target with thickness of 17 cm for 70 MeV p beam, distance of 1 m from target , and radius of 1 m



Rare Isotope Science Project

RISP Precise Mass Measurement Facility

Rare Isotope Science Project

Objective

- Design of High Precision Mass Measurement Facility
  - Multi-Reflection Time-of-Flight for Isobaric Mass Separation
  - Highly Charged Ions for Accuracy Improvement
  - Sympathetic Laser Cooling Technique for Reducing Energy Spread
  : Mass resolution better : ~ 10^{-8} –> 10^{-9}

Necessity

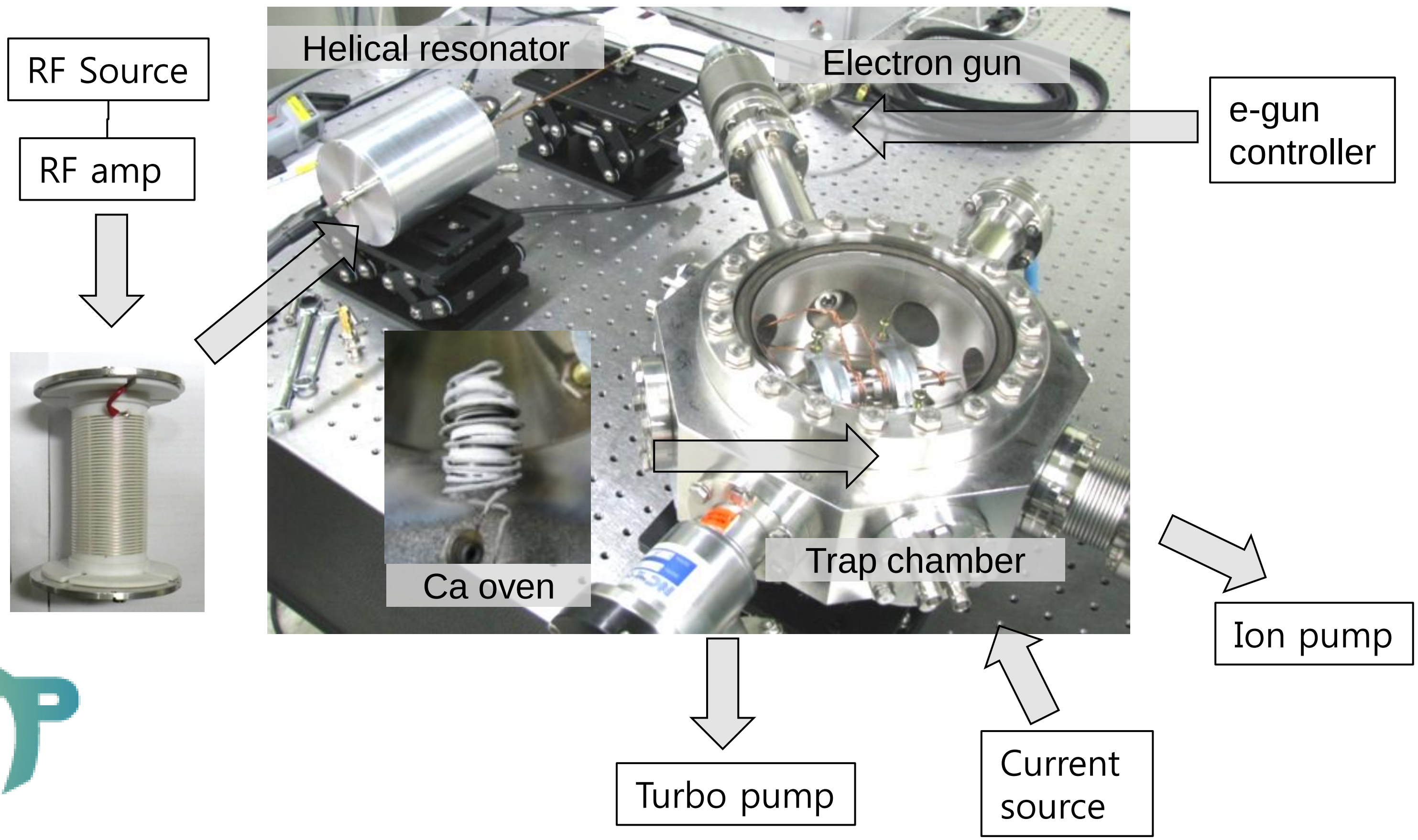
- Test of the conserved vector current hypothesis and the unitarity of the CKM matrix
- Nuclear masses far from stability to test new mass models
- Proton-neutron interactions and the new masses
- Understanding nuclear structure
- Probing and resolving isomer states of nuclides

Target Specification

- Relative mass accuracy: ~10^{-8} for short lived rare isotopes
  ~10^{-9} for stable nuclides

Performance at RISP

1. Simulation for ion motion in Penning trap
2. Analyzing the statistical and systematic uncertainty in mass measurement system
3. Building laser system for sympathetic cooling of Ca^+ ions



Rare Isotope Science Project

RISP Laser Ion Source

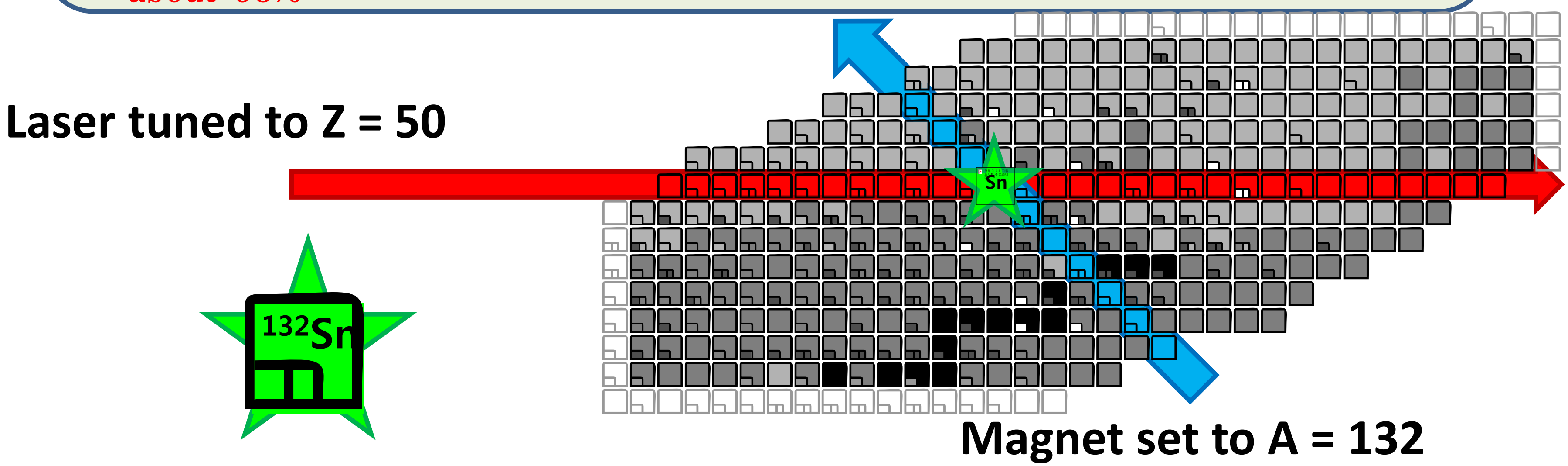
Rare Isotope Science Project

Objective

- For the production of **isobarically pure** & **highly efficient** beams of radioactive ions

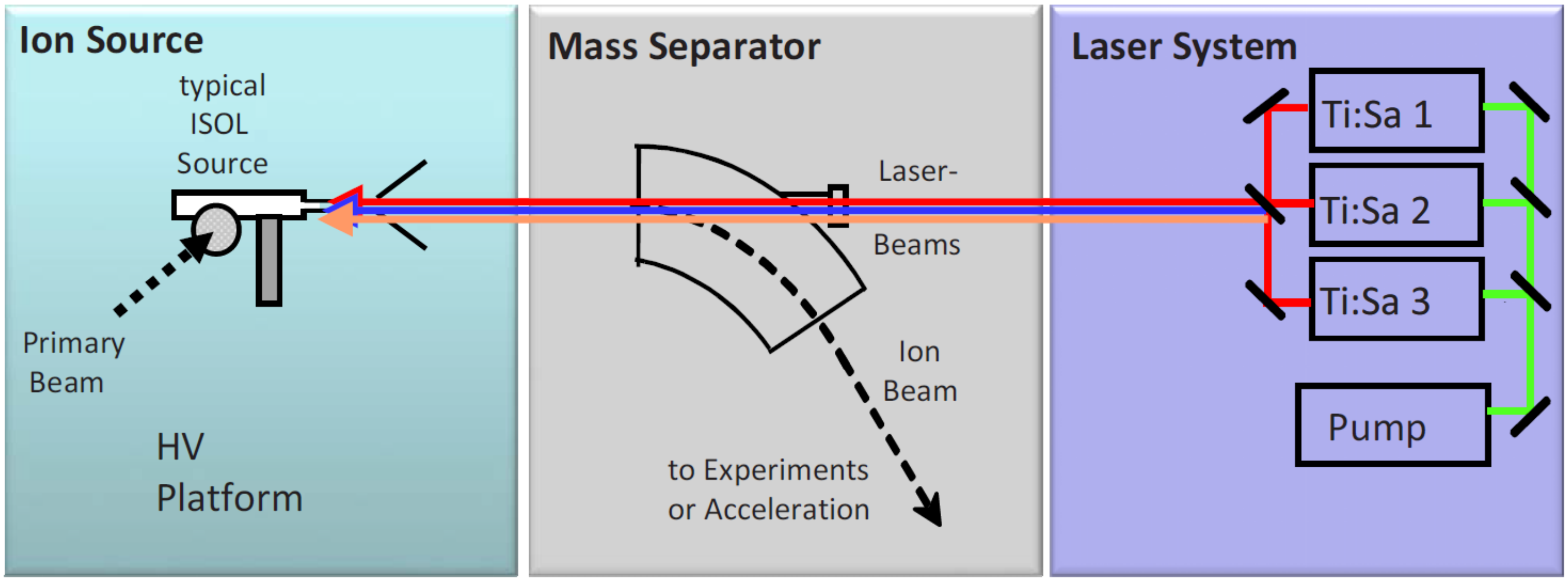
Necessity

- Due to unwanted **isobars** (same mass number A, but different proton number Z) emerging from the target, additional separation between nuclides with different proton number Z is required.
- **Laser Ion Source** based on resonant excitation is known to be the most efficient way to remove the isobaric contamination.
- Using two hyperfine ground level s : efficiency will be increasing (about 30% -> about 60%

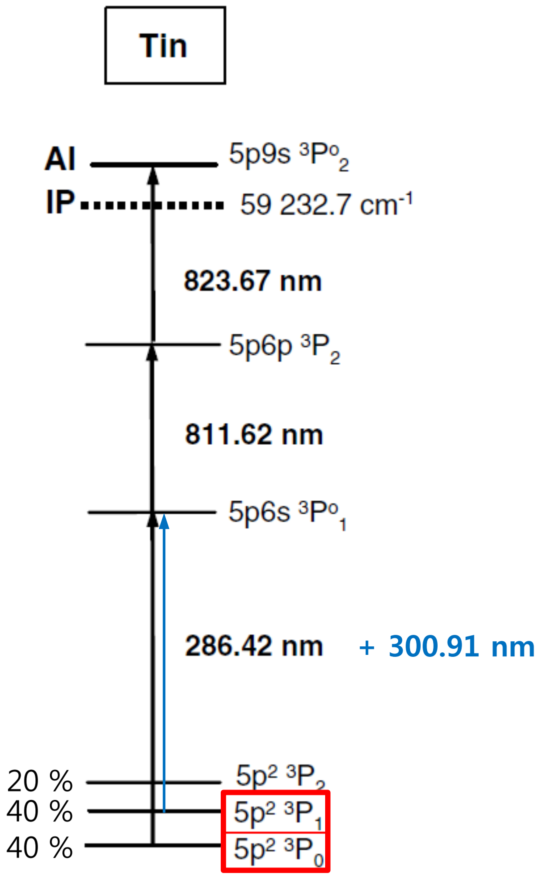


Performance at RISP

1. Laser System Design (in progress)
   - High repetition tunable Ti:Sapphire lasers (3 ea)
   - Repetition rate: >10 kHz
   - Tuning range: 700-1000 nm
   - Line width: <5 GHz
   - Power: ~5 W
2. Ion Source Design (in progress)
   - Hot metal cavity (T>2000 K)



Preliminary result

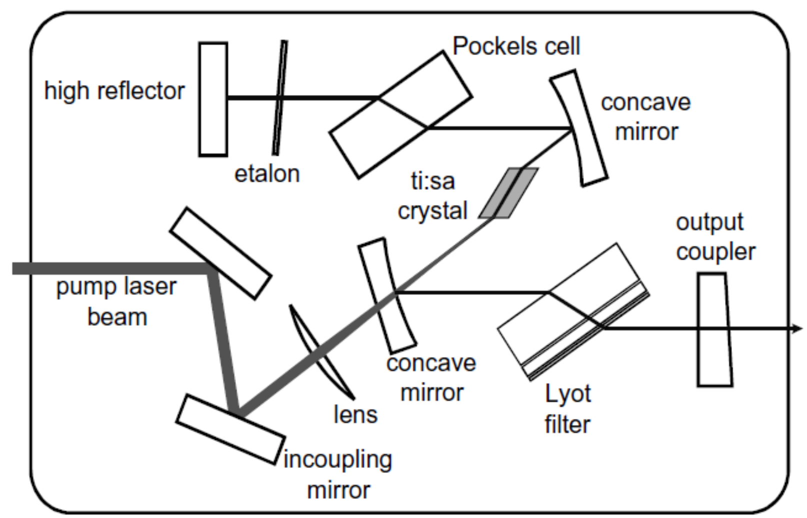


[Ionization scheme for Sn]

- Ionization efficiency of Sn: **~22 %** (Oak Ridge National Laboratory)
  - Ionizer tube length: 30 mm
  - Initial state: $5p^2\ ^3P_0$
- Improving the ionization efficiency
  1) Optimization of the tube geometry : ~**80 mm** in length
  2) Using **one more laser** (300.91 nm) to excite the atoms in two ground states

→ Estimated efficiency of Sn: **~60 %**

- High repetition & tunable Ti:Sa laser design



[Layout of the Ti:Sa laser]

RISP Material Science Facility

Rare Isotope Science Project

Objective

- Design of β-NMR and μSR facilities

- $10\sim10^3$ times higher sensitivity than those of conventional analysis methods.

Necessity

- Lack of usable facilities and difficulties in securing beam time from the existing facilities
- Rapid increase in the number of user around the world

❖ Applicable research topics of β-NMR and μSR

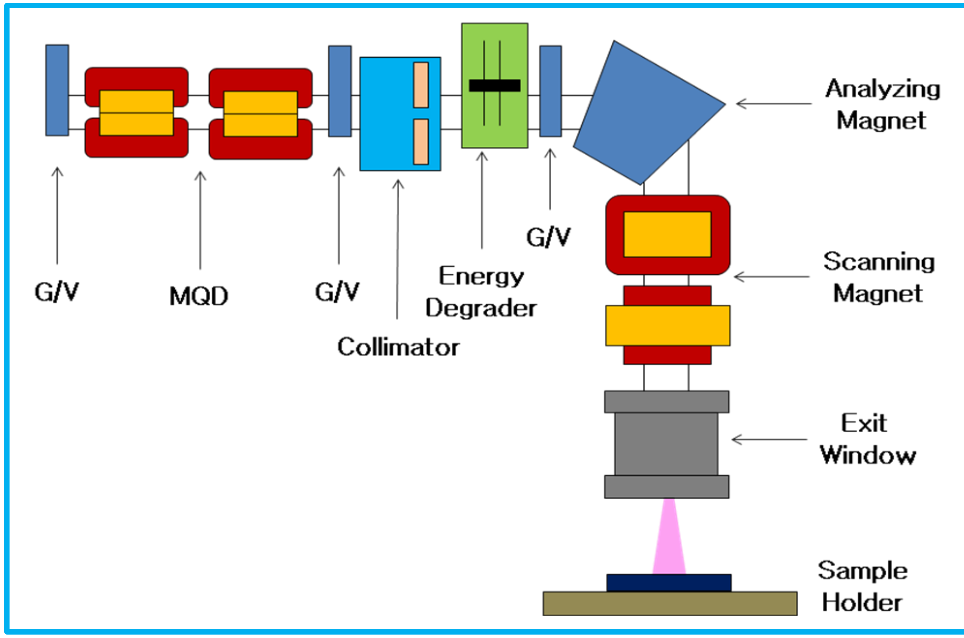
Using muon and Li as probe	Using muonium as probe
• Magnetic materials and devices • Colossal magnetoresistance • Secondary batteries • Thermoelectric Oxides • Photo-induced magnetism • Organic/Inorganic hybrid materials • Heavy fermions • Magnetic vortices • Exotic superconductors • Charged particle transport • Frustrated magnetic system • Charge dynamics at interfaces	• Molecular structure and conformational motion of organic free radicals • Hydrogen atom kinetics • Green chemistry in supercritical CO_2 • Catalysis • Mass effects in chemical processes • Reaction kinetics as probes of potential energy surfaces • Electron spin exchange phenomena in glass • Hydrogen in semiconductors

❖ β-NMR and μSR facilities operating in the world

β-NMR	μSR
• TRIUMF (Canada) - the only facility operating for material science in the world - using a ^{8}Li beam - about 1 month per year beam time	• PSI (Germany) - CW muon beam - Ultra low-energy (0.5~30 keV) muon beam - total 6 ports • TRIUMF (Canada) - CW muon beam - total 4 ports • ISIS (UK) - Pulse muon beam - Ultra low-energy muon beam • J-PARC (Japan) - Pulse muon beam

RISP Bio-Medical Science Facility

Applied beam line

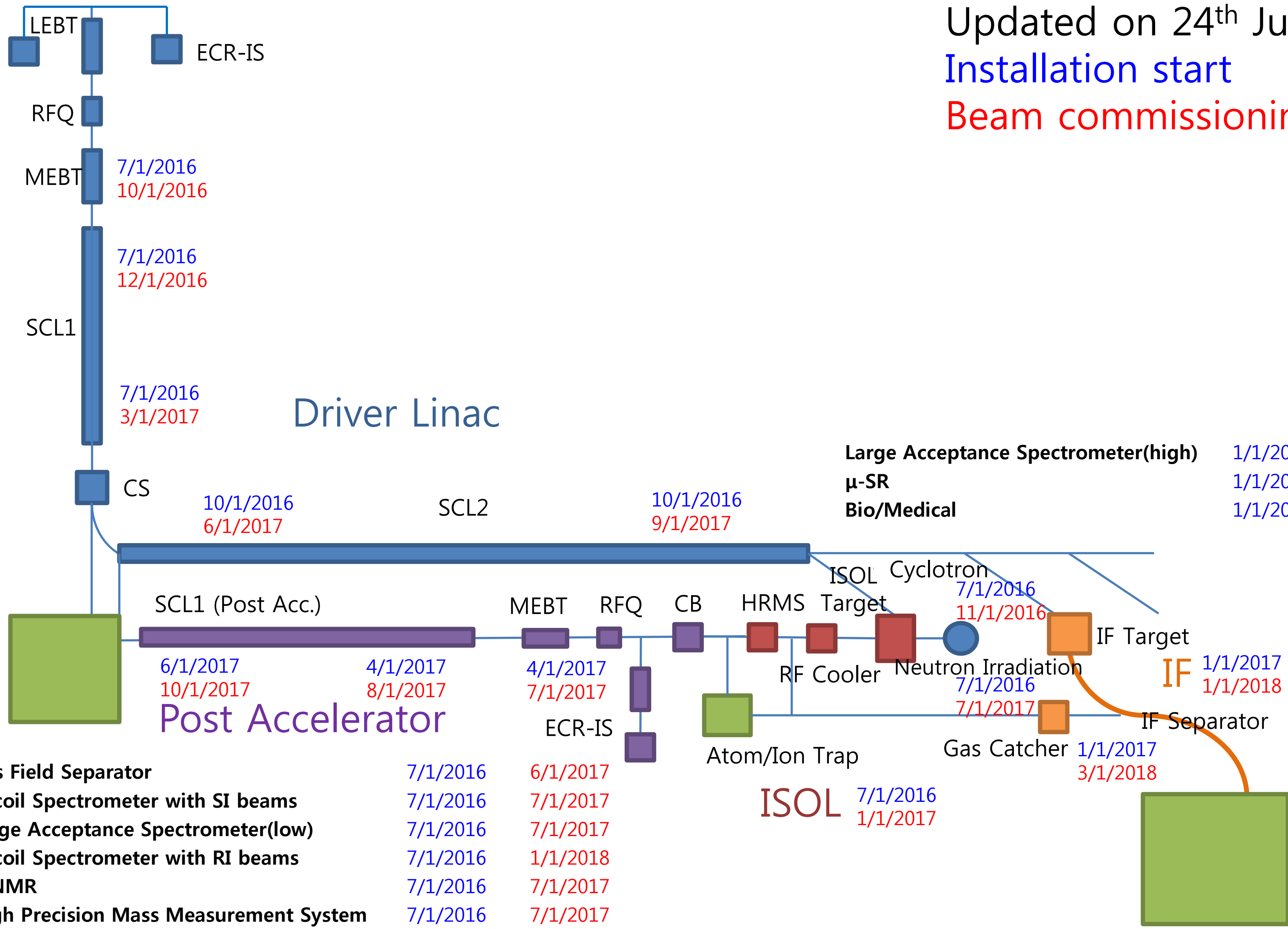


Beam line design
- Electromagnet and power supply system
- Beam diagnostics system
- Vacuum system
- Cooling system
- Sample target system
- Control system

Specification
- Irradiation from perpendicular beam line
- Beam irradiation size : 5~20 cm
- Beam window for atmosphere irradiation
- Cooling system to prevent heat
- Beam energy degrader for control

Schedule

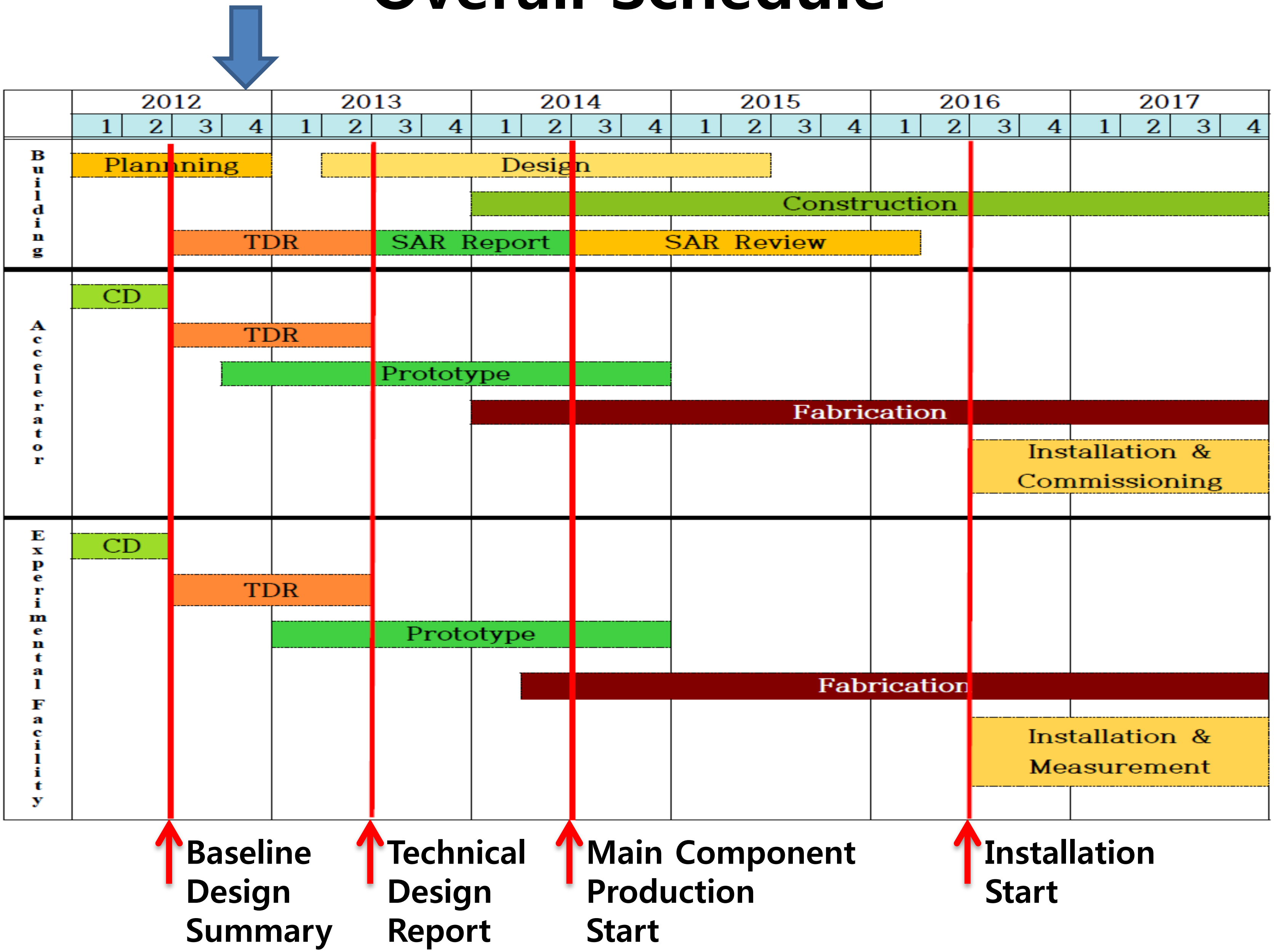
Updated on 24th July 2012
Installation start
Beam commissioning start



Large Acceptance Spectrometer(high)	1/1/2017	3/1/2018
μ-SR	1/1/2017	1/1/2018
Bio/Medical	1/1/2017	1/1/2018

Gas Field Separator	7/1/2016	6/1/2017
Recoil Spectrometer with SI beams	7/1/2016	7/1/2017
Large Acceptance Spectrometer(low)	7/1/2016	7/1/2017
Recoil Spectrometer with RI beams	7/1/2016	1/1/2018
β-NMR	7/1/2016	7/1/2017
High Precision Mass Measurement System	7/1/2016	7/1/2017
High Precision Laser Spectrometer	7/1/2016	7/1/2017

Overall Schedule



RAON [ra'on] **is the new name of RISP (Rare Isotope Science Project) Accelerator Complex.**

RAON [ra′on] is the new name of RISP (Rare Isotope Science Project) Accelerator Complex.

Thank you for attention !