Science opportunities with RAON

Seung-Woo Hong

RAON User Liaison Center

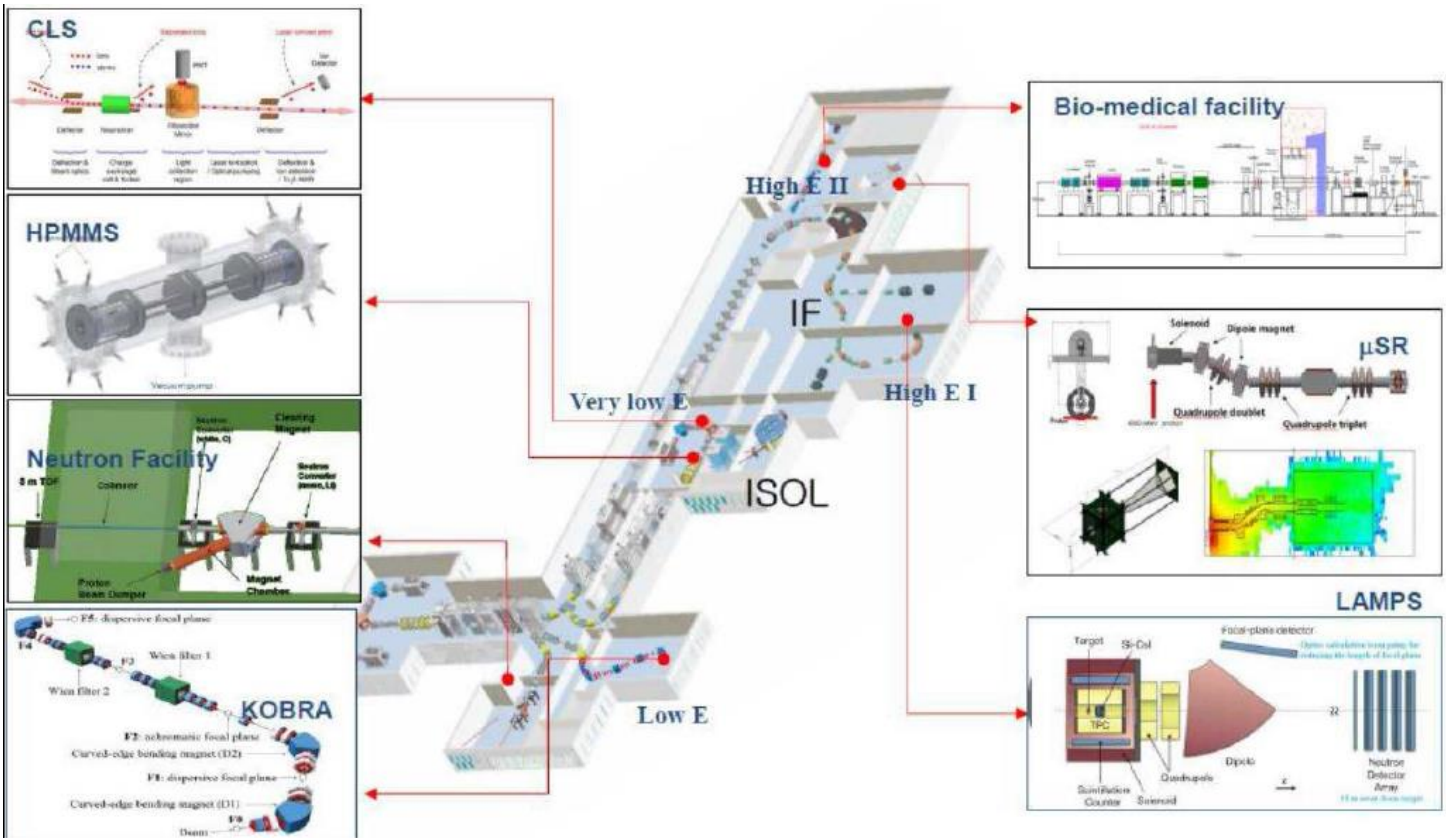
Contents

- Experimental systems of RAON
- Brief overview of RAON science
- RAON Users
- Summary

Bird’s eye view of RAON


RAON under construction

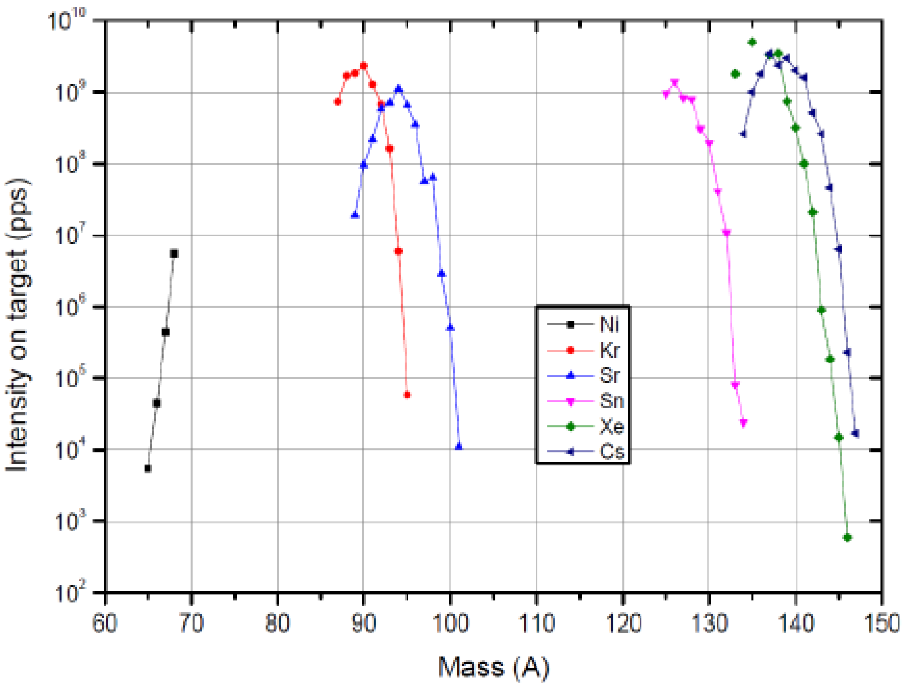
Experimental systems of RAON



Yields of RI from ISOL

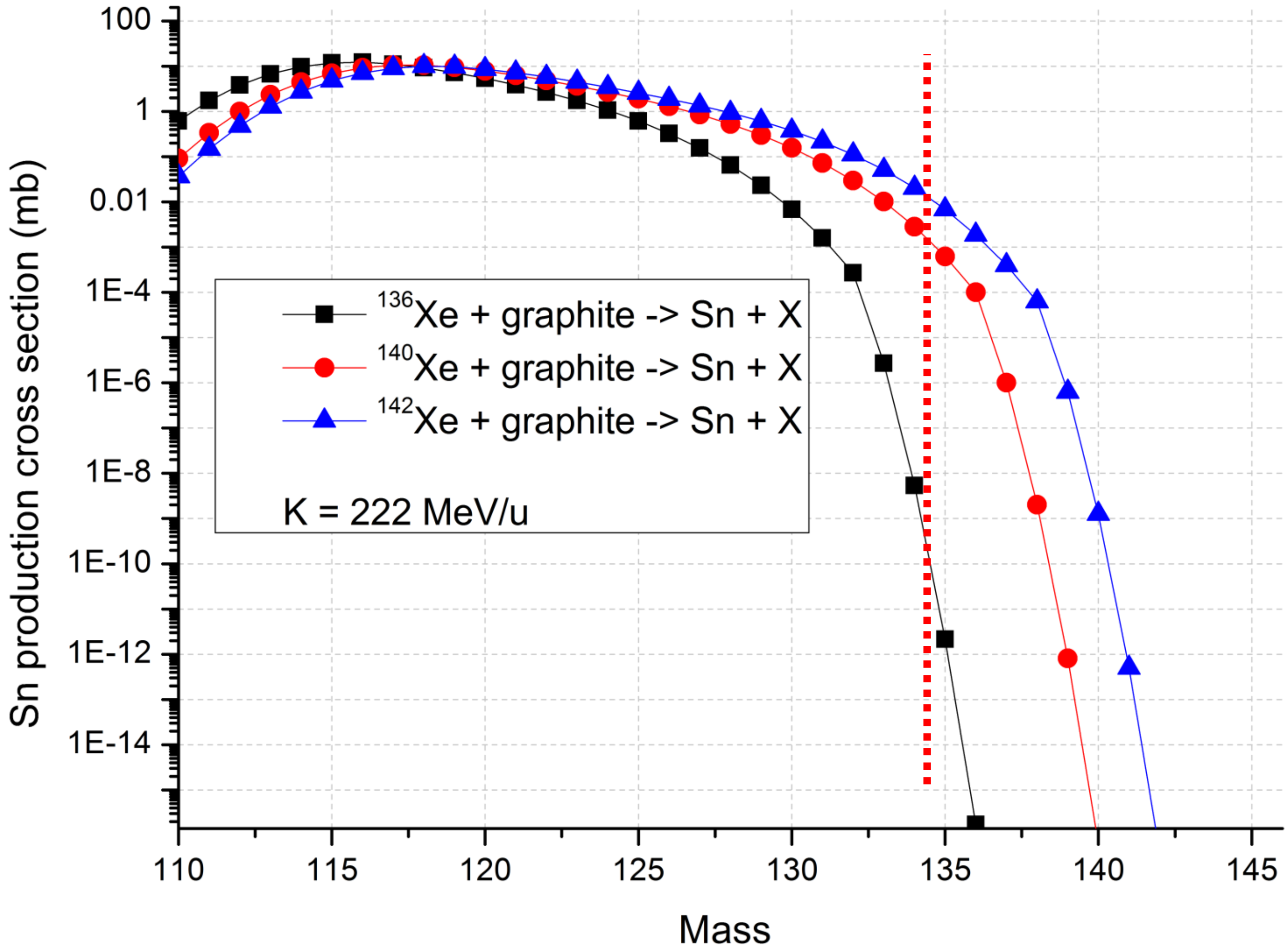
- p + UCx → n-rich isotopes (80 < A< 160) by fission reaction
- Fission rate (10 kW) : 1.6×10^{13} f/s

Expected lab. intensities (10 kW target)



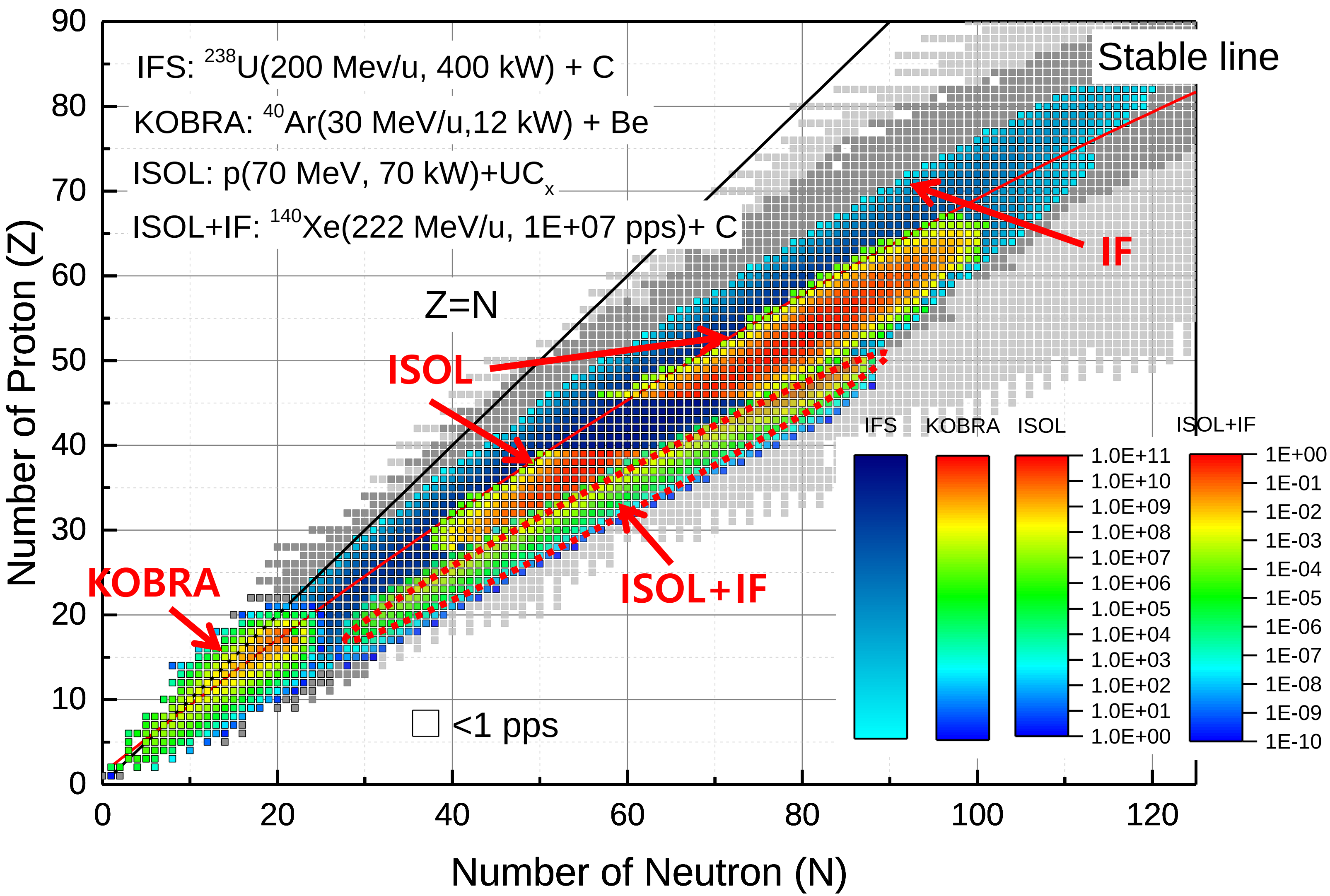
Isotope	Half-life	Science	Lab. Yield (pps)
^{66}Ni	2.28 d	pigmy	4×10^5
^{68}Ni	21 s	symmetry	5×10^6
^{132}Sn	39.7 s	r-process, pigmy	1×10^7
$^{130-135}$Sn	0.5 s ~ 3.7 min	Fine structure, precision mass	10^4~10^8
^{140}Xe	13.6 s	Symmetry	3×10^8
^{144}Xe	0.4 s	Symmetry	1×10^5

ISOLIF (ISOL+IF) at RAON



slide from C. C. Yun

ISOLIF: Unique RI productions at RAON



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

RAON Science

Nuclear science

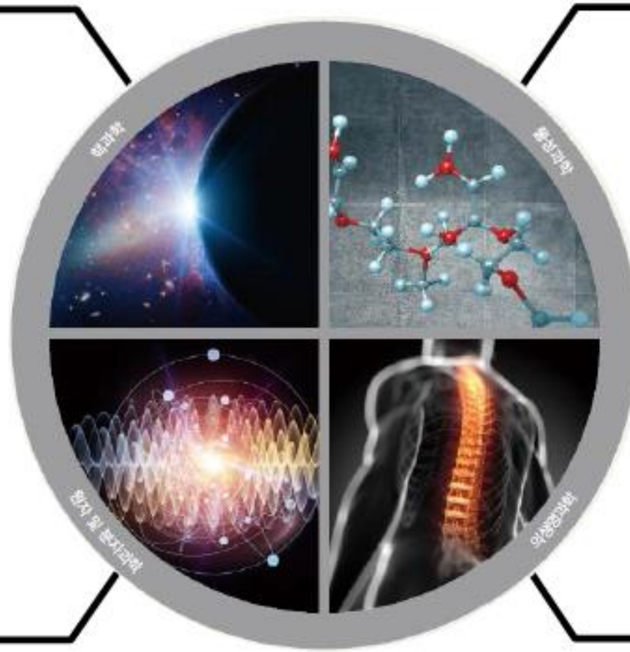
Origin of elements
Systematic search of new rare isotopes

- Chemical history of the universe
- Nuclear structure/reaction
- Nuclear data
- Nuclear theory

Material science

Microscopic structure and process study of various materials.

- Experimental technique with extreme sensitivity to probe deep inside materials
- New materials: nanostructured conductors, high T_c superconductor, etc



Atomic & Molecular science

Precision mass and radius measurements of rare isotopes

- Fundamental properties of nuclei: masses, moments, spins and radii
- Measurement of fundamental constants

Medical & Bio science

Paradigm shift in medical/bio science with rare isotopes

- New cancer treatment
- New biotechnology in plant breeding

8 User Groups

RAON-1	**KOBRA**	**K**orea **B**road **A**cceptance **R**ecoil spectrometer & **A**pparatus	Kevin I. Hahn
RAON-2	**LAMPS**	**L**arge **A**cceptance **M**ulti-**P**urpose **S**pectrometer	E. J. Kim
RAON-3	**MMS**	**M**ass **M**easurement **S**ystem/ Multi-Reflection Time-of-Flight	Andy K. Chae
RAON-4	**CLS**	**C**ollinear **L**aser **S**pectroscopy	J. B. Kim
RAON-5	**μSR**	**Mu**on **S**pin **R**elaxation/Resonance	K. Choi
RAON-6	**NDPS**	**N**uclear **D**ata **P**roduction **S**ystem	S. W. Hong
RAON-7	**BIS**	**B**eam **I**rradiation **S**ystem	W. Y. Park
RAON-8	**Theory**	Nuclear Theory	M. K. Cheoun

1. KOBRA

▪ KoBRA system at RAON

Design Goals: Construction of multi-purpose experimental instrument using stable or rare isotope (RI) beams for less than 30 Me/u

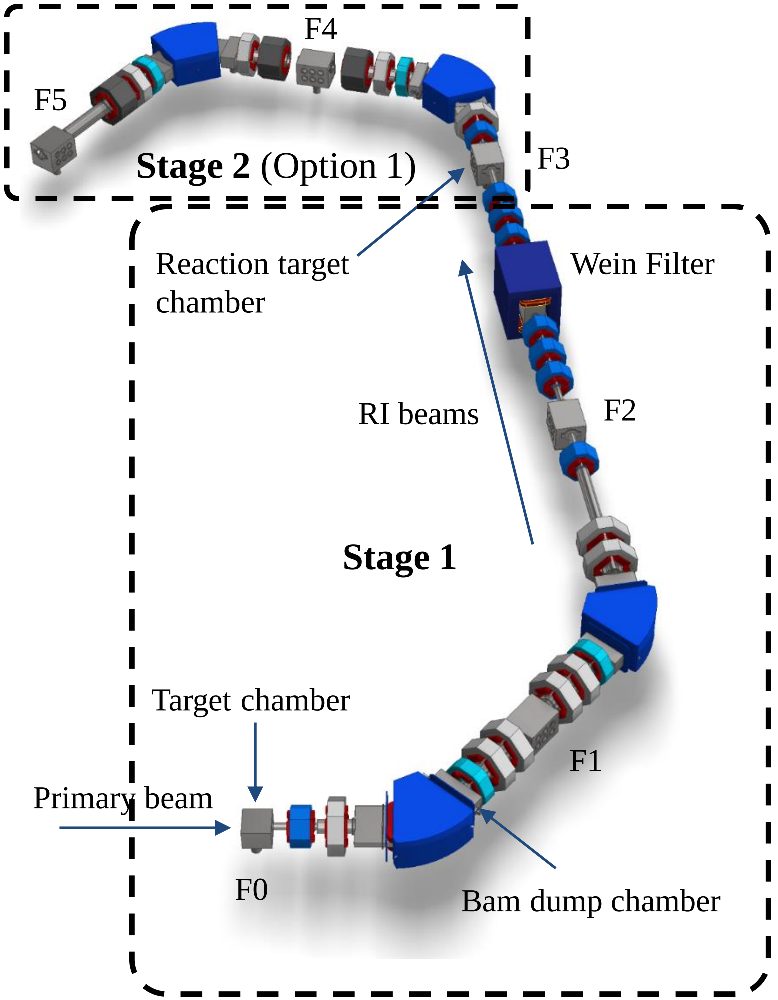
- RI beam productions using stable or rare isotope (RI) beams
- Recoil mass separator
- High-resolution spectrometer, and so on

Stage 1

- RI beam production at a few MeV/u and about 25 MeV/u: **production mode**
  - Reaction: (p,n), (d,p), (d,n), and (^{3}He,n) at a few MeV/u
  - Multi-nucleon transfer reactions at about 25 MeV/u
- Recoil mass separator at about 1 MeV/u: **radiative capture mode**

Stage 1 + Stage 2

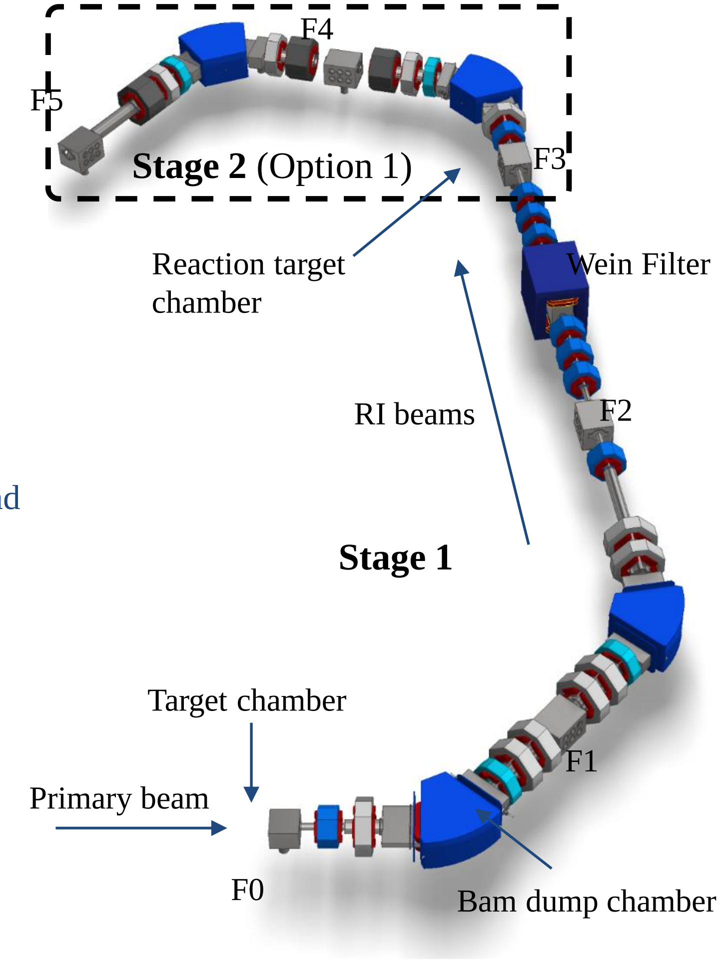
- High-resolution separator at few -25 MeV/u: **primary beam dispersion matching of stage 1**
- Recoil mass separator at about 1 MeV/u: **radiative capture mode** (under discussion)
- RI beam production and dispersion matching: **secondary beam dispersion matching mode** (under discussion)



slide from K. H. Tshoo

1. KOBRA

- 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, and so on)
  - **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 ^{65}As(p, ϒ) and ^{15}O(α, ϒ) reactions at < ~1 MeV/nucleon
  - **Indirect measurement of radiative capture cross section**, e.g., for (d,p) reaction at a few MeV/nucleon



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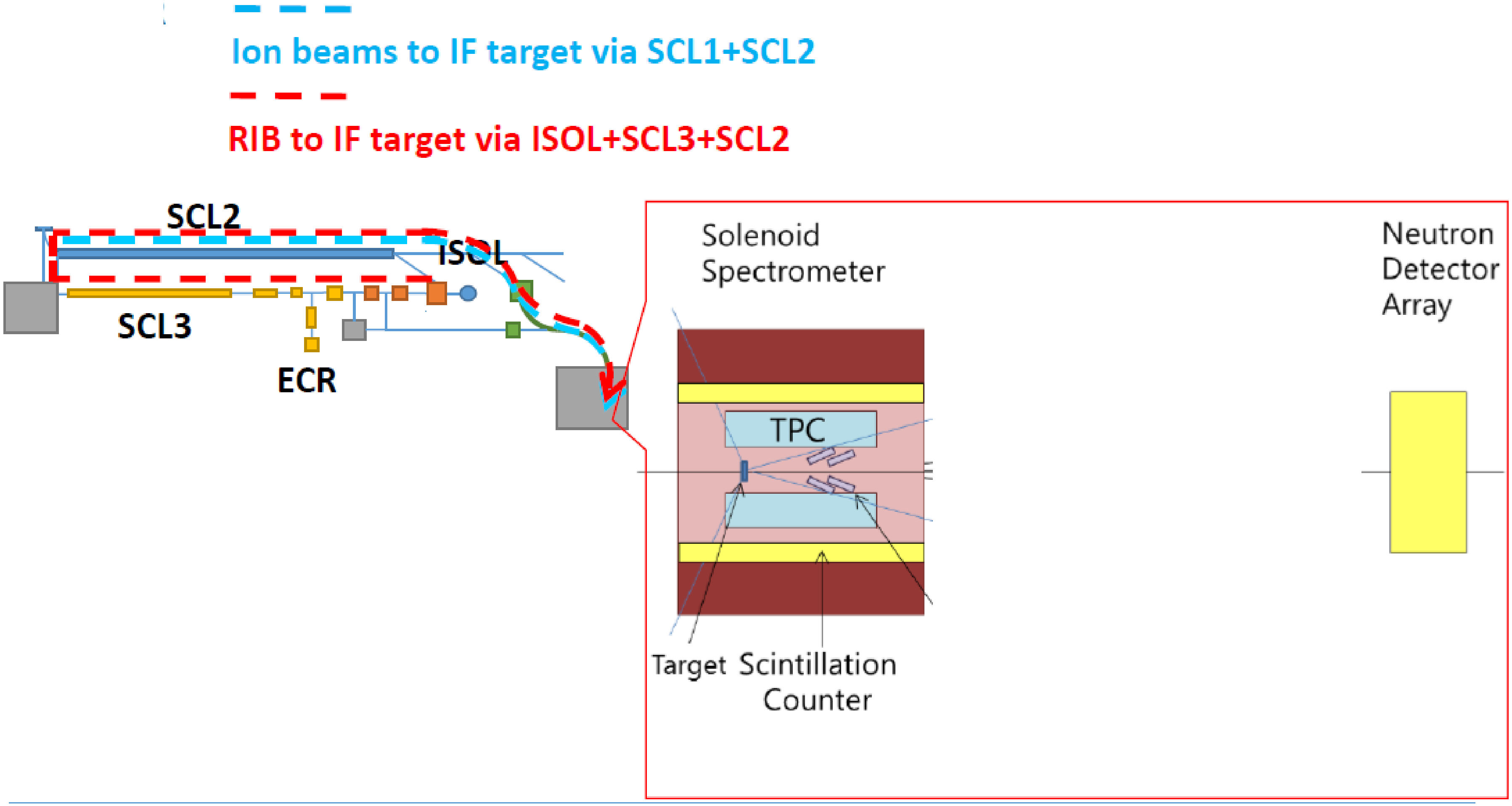
2. LAMPS

- **LAMPS at RAON**

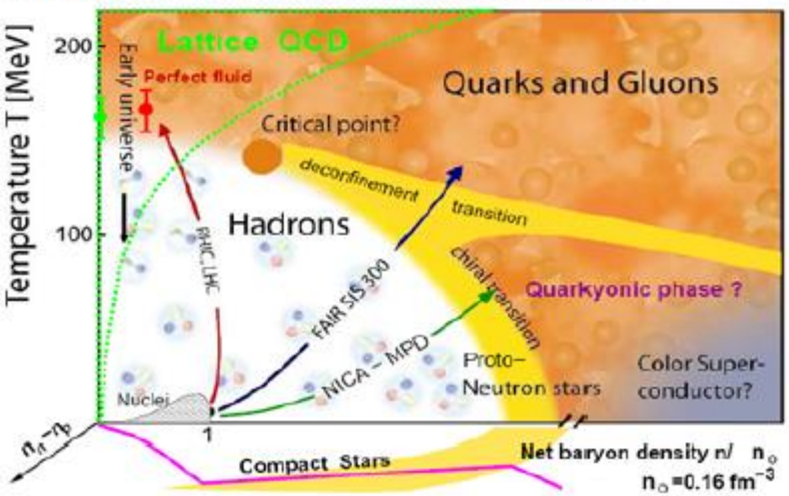


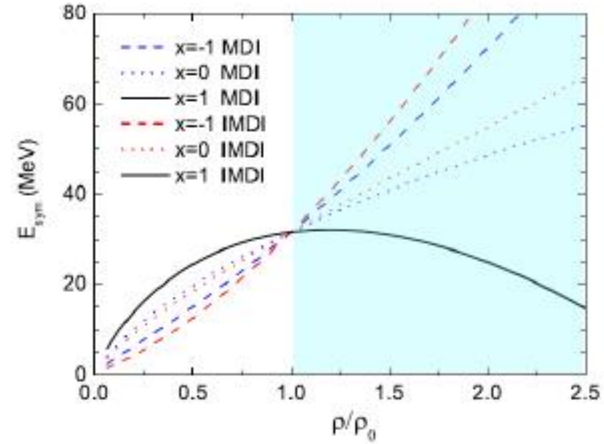
slide from B. Hong

2. LAMPS

Symmetry Energy Study at RAON

- **Exploring the nuclear phase diagram via heady-ion collisions including the isospin axis using RI beams**
- **Role of isospin degree of freedom in strong interaction**
  - **- Nuclear symmetry energy from sub- to supra-saturation densities**
  - **- Characterization of the core of neutron stars**





C. Xu and B. A. Li, PRC 81, 044603(2010)

LAMPS(Large Acceptance Multi-Purpose Spectrometer) is going to study of nuclear symmetry energy at sub- & supra-saturation densities via heavy-ion collision experiment at RAON

slide from Y. J. Kim

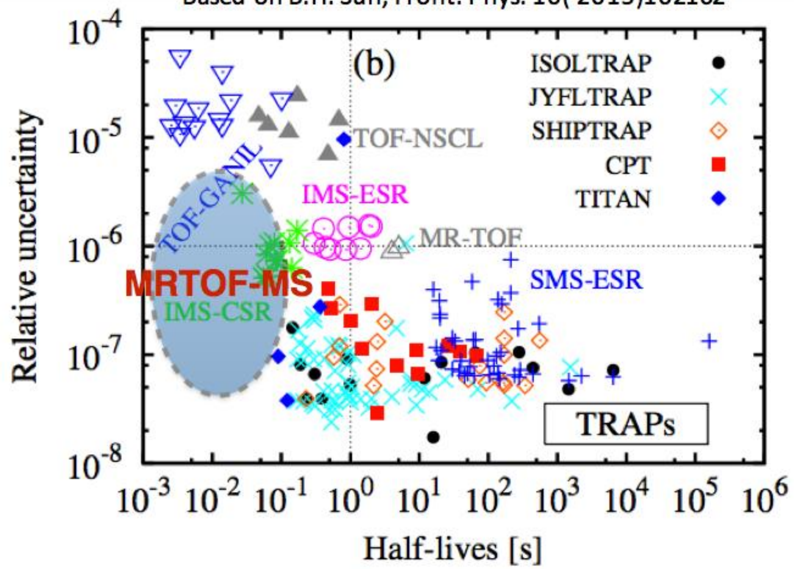
3. MMS

- For nuclei participating in astrophysical rp-process, masses can be measured with very sufficient precision mostly by using Penning Trap technique since the lifetimes are rather long (a few hundreds ms ~ a few seconds)

- For r-process nuclei, precision of ΔM < 100 keV (**$\Delta M/M < 10^{-6}$**) is needed since lifetimes are short (< 100 ms)

- **MRTOF-MS** is more suitable for quicker and sufficiently precise measurements!

Based on B.H. Sun, Front. Phys. 10('2015)102102



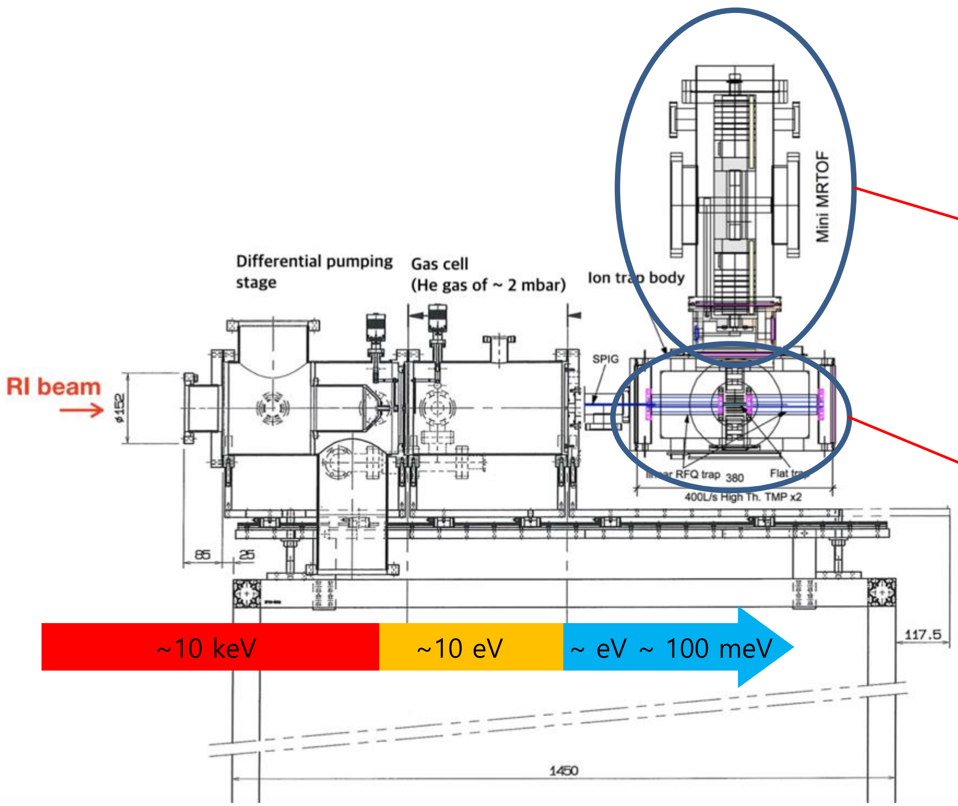
J. Y. Moon & Y.-H. Park

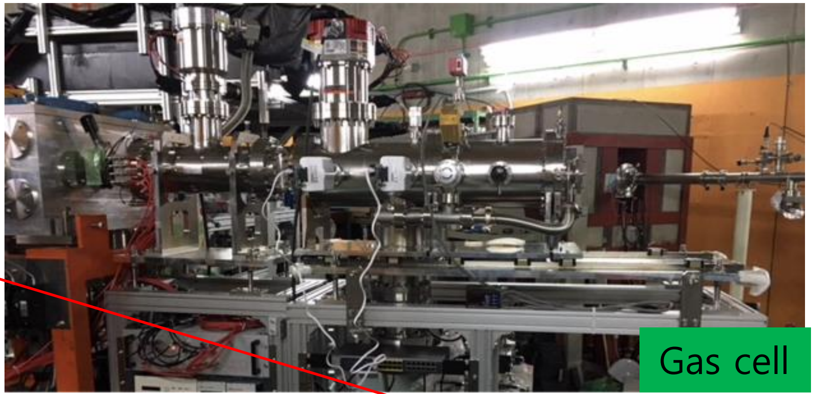
- MRTOF for RAON is constructed and commissioned at KEK

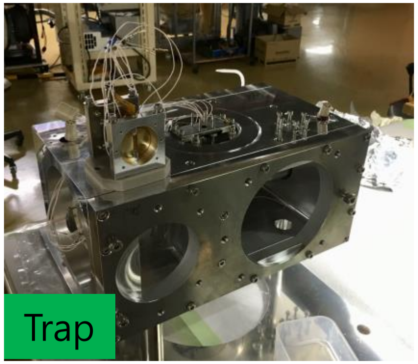
- Will be used to measure the masses of Ir and Os isotopes (^{198}Ir, ^{197}Os, ^{198}Os, and more) for r-process study

High Precision Mass Measurement System (MR-TOF)

- Multiple Reflection TOF Mass spectrograph, chosen for mass measurement of unstable nuclei with short life time of < 100 ms and with sufficient precision of better than 10^{-6}.
- RISP-KEK/IPNS has made a MOU supplement for the collaboration in R&D of RISP MRTOF-MS system. And based on that, additional collaborative agreement is made, valid for 4 years (2016 ~ 2019).





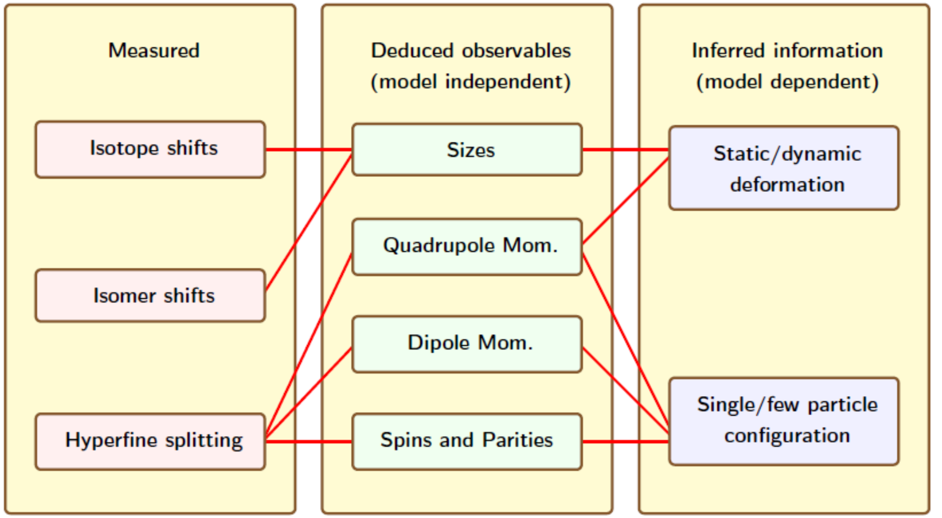


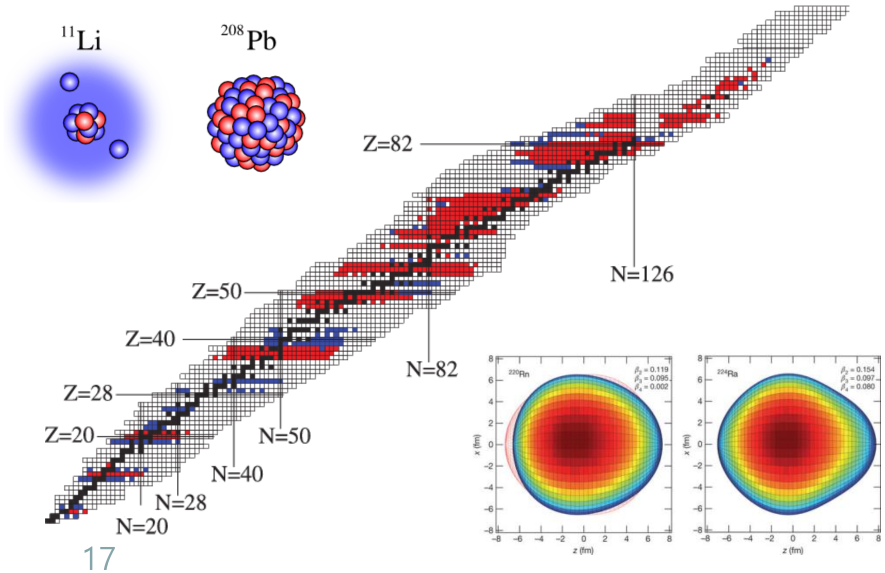
4. CLS

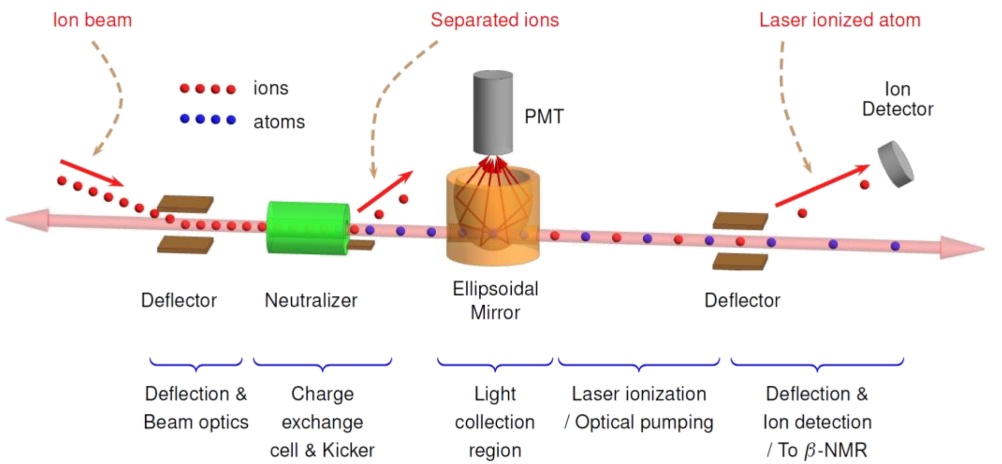
- **CLS at RAON**

Laser spectroscopy of radioactive isotopes and isomers is an efficient and model-independent approach for the determination of nuclear ground and isomeric state properties.

- **Physics using CLS**
  - **Nuclear structure:**
    - Isotope shifts: charge radii, halo nuclei
    - Hyperfine splitting: spin, magnetic and electric moments
  - **Nuclear spin polarization using optical pumping technique → β-NMR**





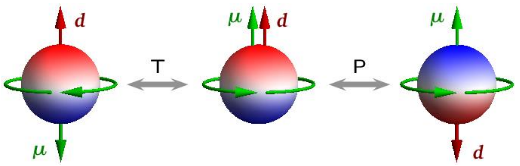


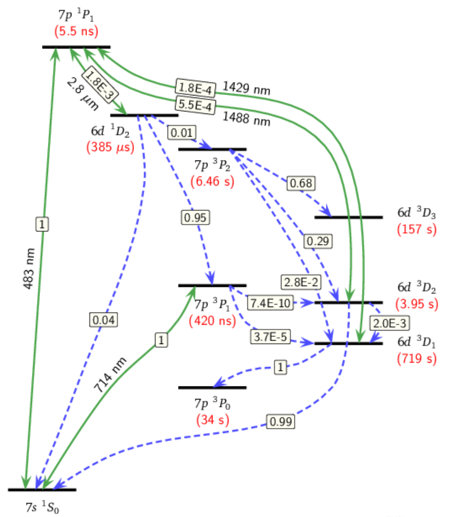
4. CLS

- **Applications using laser spectroscopic technique**

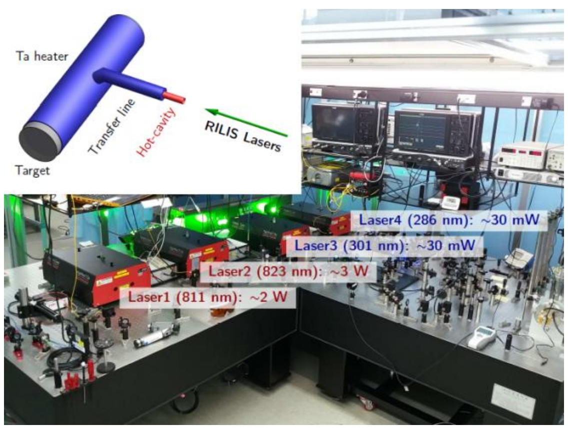
  - **ISOL laser ion source (Resonant Ionization Laser Ion Source)**
  - **Optical nuclear clock** using the nuclear transition between an excited state (isomer) of thorium-229 and the nuclear ground state
  - **Atomic EDM search of** of Ra-225 using the laser cooling and trapping technique

EDM search

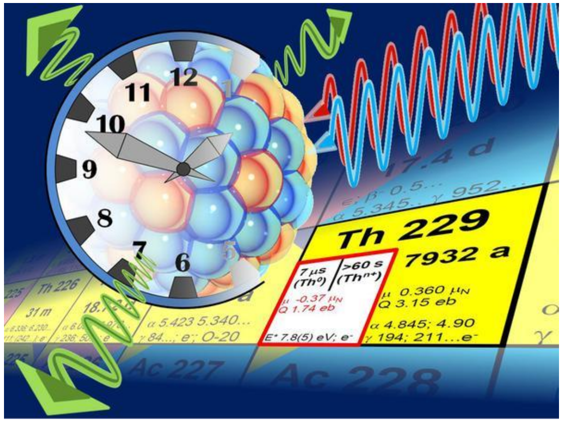


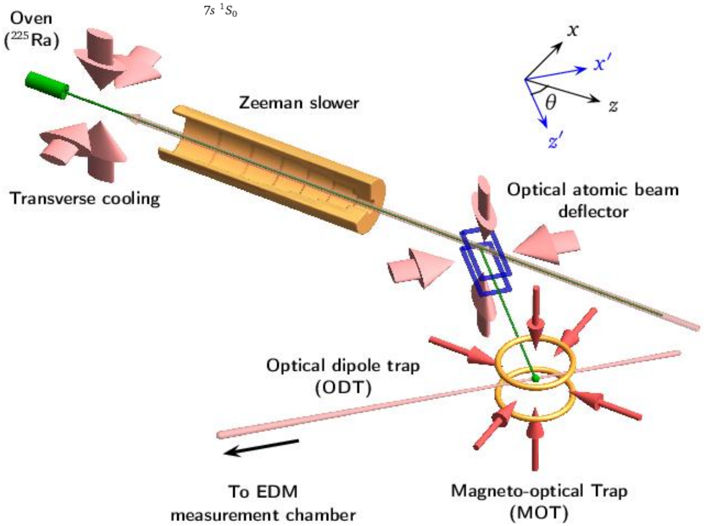


Laser ion source



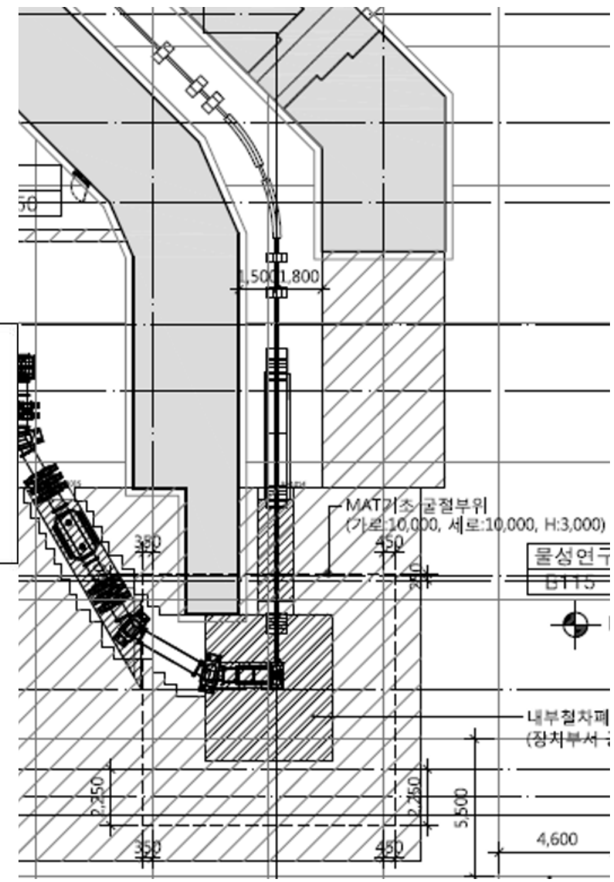
Optical nuclear clock





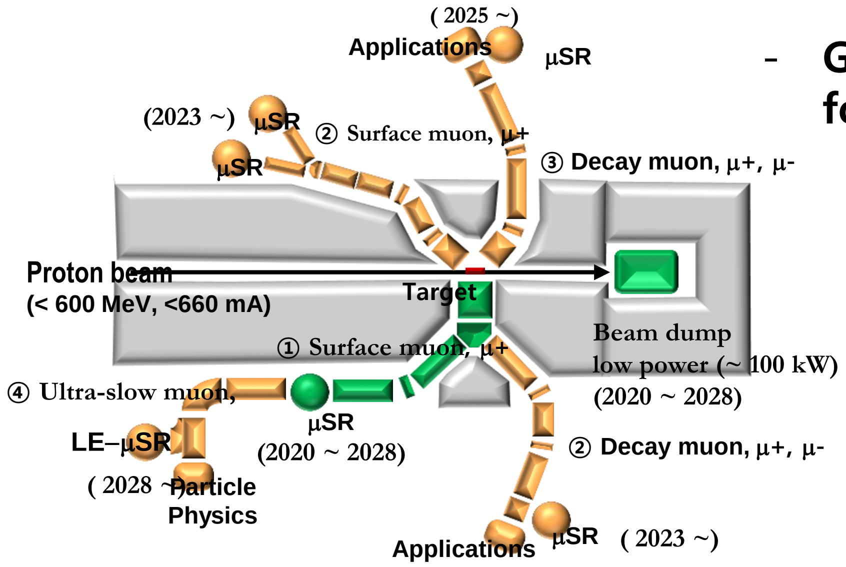
5. μSR

• Charge Radius 측정
CLS
BIS
• 암 치료 연구
• 새로운 육종 연구
• 물성 연구
Solenoid
Dipole magnet
Quadrupole doublet
Quadrupole triplet
μSR
LAMPS
• 핵 물질 연구
• 중성자별 연구
Target
Si-CsI
Focal-plane detector
TPC
Dipole
Quadrupole
Scintillation Counter
Solenoid
Neutron Detector Array
KOBRA
• Astrophysics
• 핵 구조 연구
F5: dispersive focal plane
F4
F3
Wien filter 1
Wien filter 2
F2: achromatic focal plane
Curved-edge bending magnet (D2)
F1: dispersive focal plane
Curved-edge bending magnet (D1)
F0
Beam

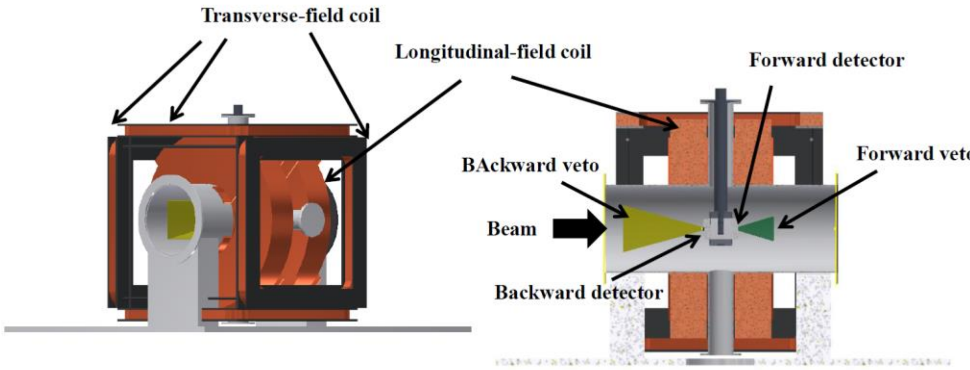


1,500
1,800
MAT기초 굴절부위
(가로:10,000, 세로:10,000, H:3,000)
450
380
물성연구
2,250
5,500
4,600
350

GEneral Use Spectrometer (GEUS) for μSR

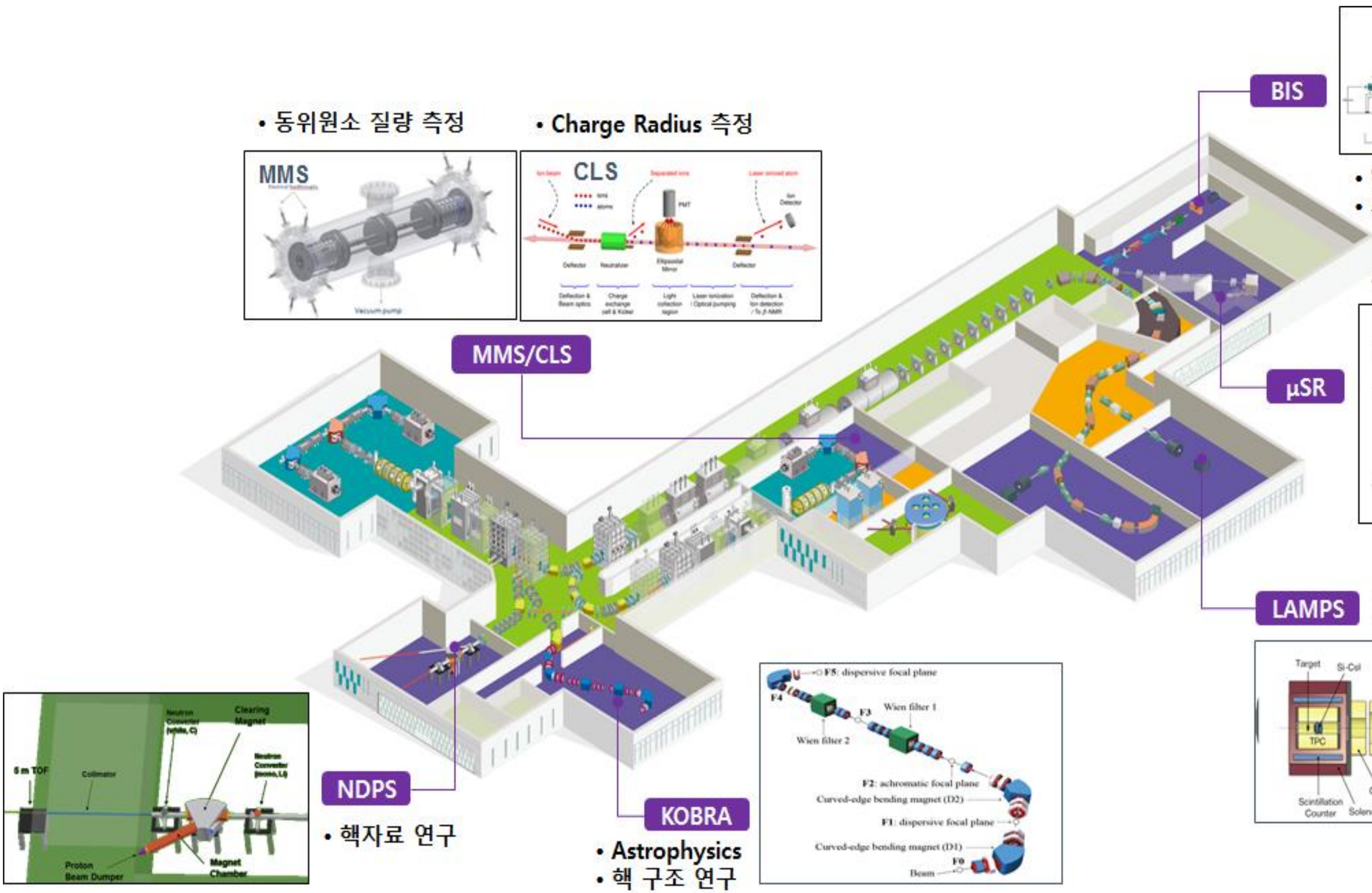


- GPS (PSI) and LAMPF(TRIUMF) type spectrometer for material research

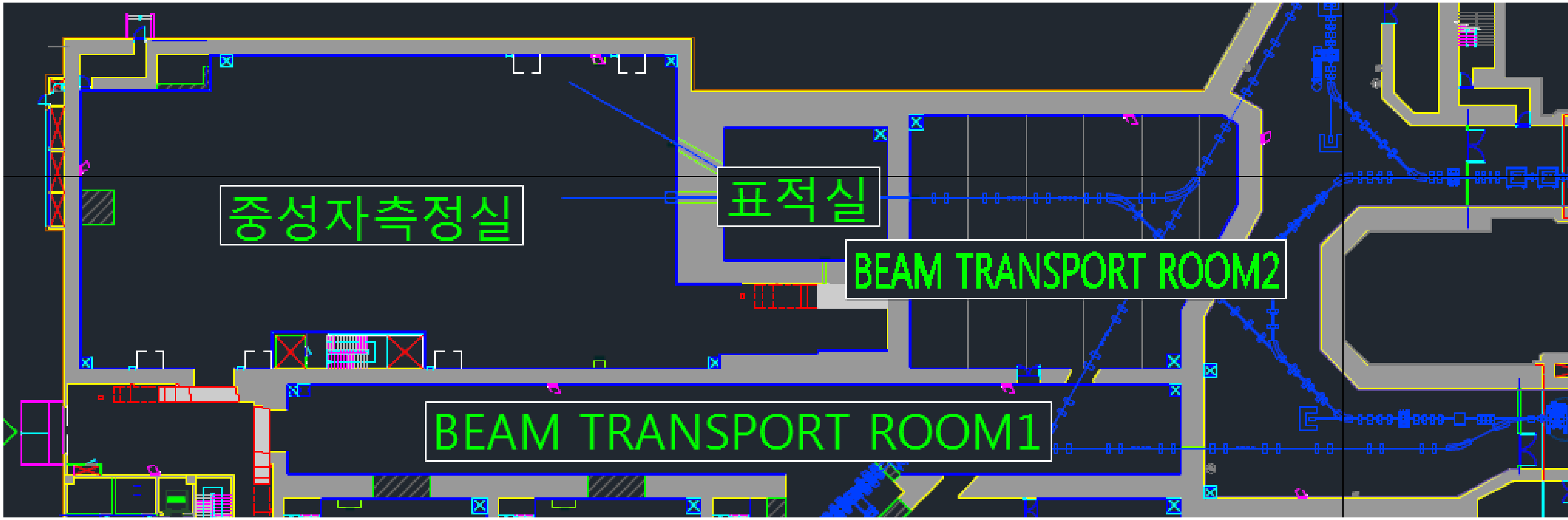


General specifications	
Primary beam	Proton (E_p ~ 600 MeV, I_p < 660 μA)
Secondary beam	Positive muons μ^+, standard momentum: 28 MeV/c, I_μ > 10^7 pps
Beam line	Transmission efficiency > 1.5% - Capture magnet > 30%, Beam transport > 5%
Temperature range	1.6 – 400 K
Longitudinal field (Helmholtz magnet)	< 0.5 T
Transverse field	~ 30 mT

6. NDPS



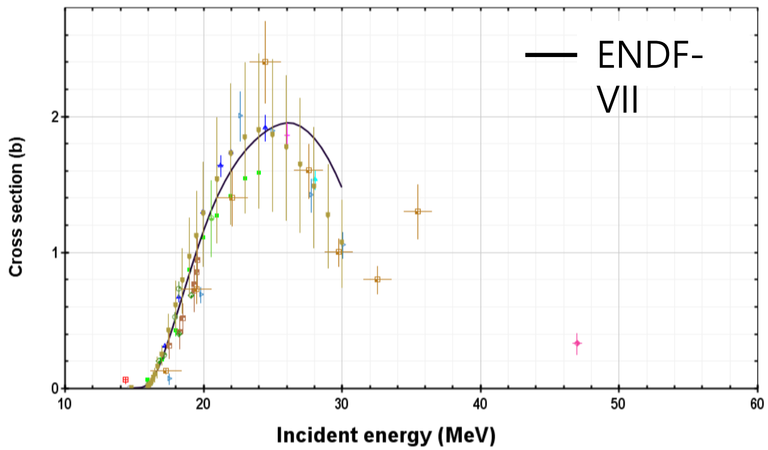
• 동위원소 질량 측정
• Charge Radius 측정
MMS
Vacuum pump
CLS
Deflector
Neutralizer
Ellipsoidal Mirror
Deflector
BIS
MMS/CLS
μSR
LAMPS
Target
Si-CsI
TPC
Scintillation Counter
5 m TOF
Collimator
Neutron Converter (white, C)
Clearing Magnet
Neutron Converter (mono, Li)
Proton Beam Dumper
Magnet Chamber
NDPS
• 핵자료 연구
KOBRA
• Astrophysics
• 핵 구조 연구
F5: dispersive focal plane
F4
F3
Wien filter 1
Wien filter 2
F2: achromatic focal plane
Curved-edge bending magnet (D2)
F1: dispersive focal plane
Curved-edge bending magnet (D1)
F0
Beam



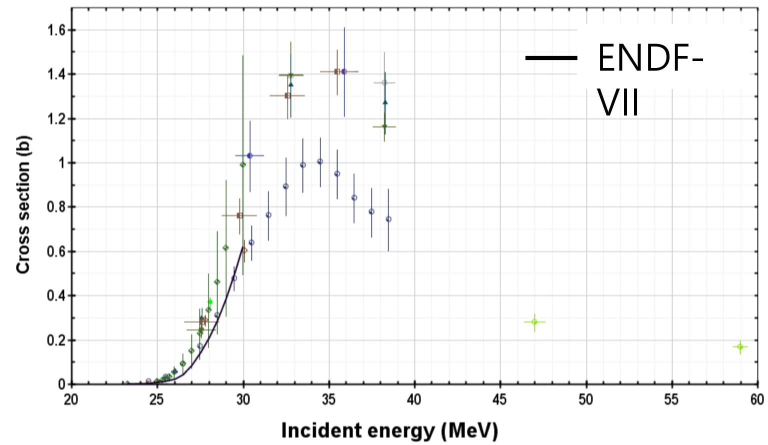
중성자 발생장치	
중성자 에너지	< ~53 MeV (white), <~75 MeV (mono-energetic)
중성자빔 세기	2 x10^{12} neutrons/sr/μC (white)
펄스빔의 반복률	300 kHz ~1 MHz
펄스빔의 폭	< 1~2 ns
표적 두께	Li : < 5 mm, C : < 10 mm
검출 장치	
n-TOF system	plastic detector with ~20 m and 5 m
fission 반응 단면적 측정용 검출기	불확도 : < 10 %

Current ^{197}Au(n,xn) cross-section data

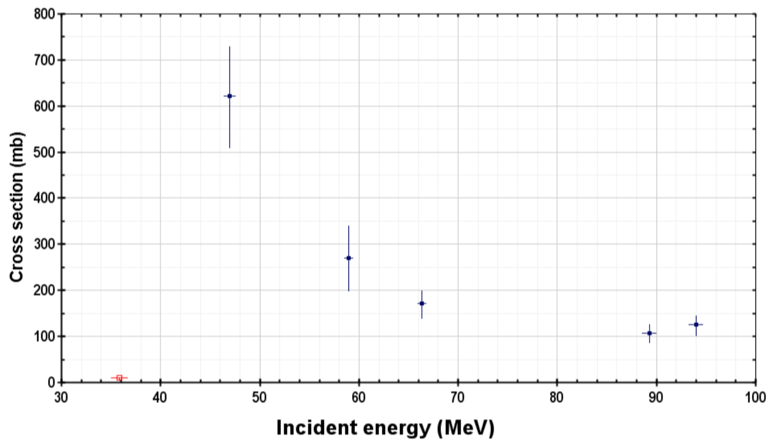
- ^{197}Au(n,3n) ^{195}Au



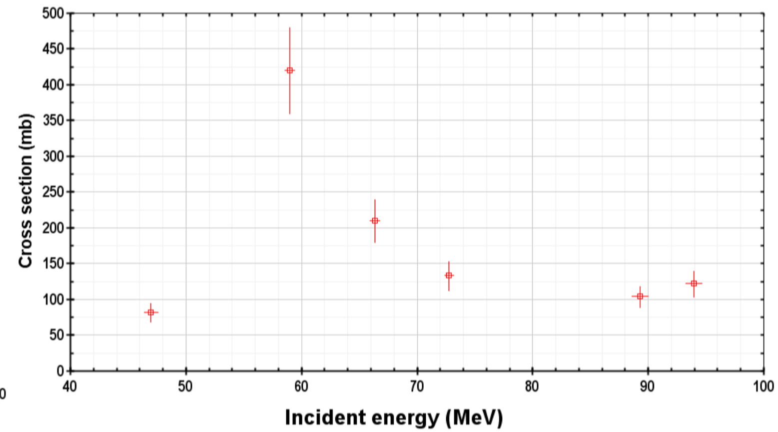
- ^{197}Au(n,4n) ^{194}Au



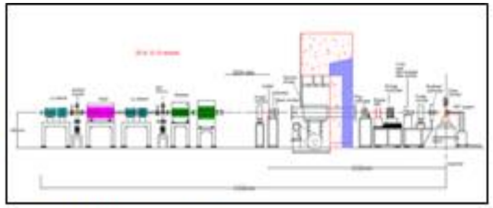
- ^{197}Au(n,5n) ^{193}Au



- ^{197}Au(n,6n) ^{192}Au

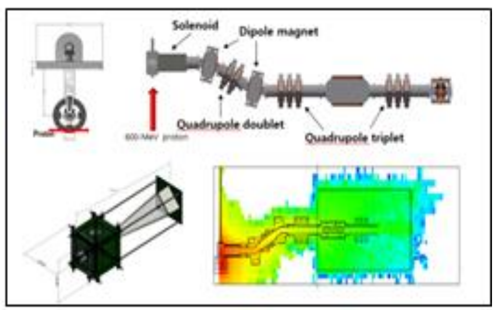


7. BIS

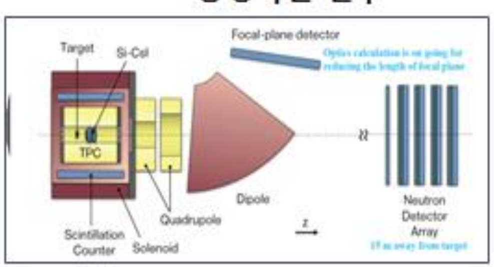


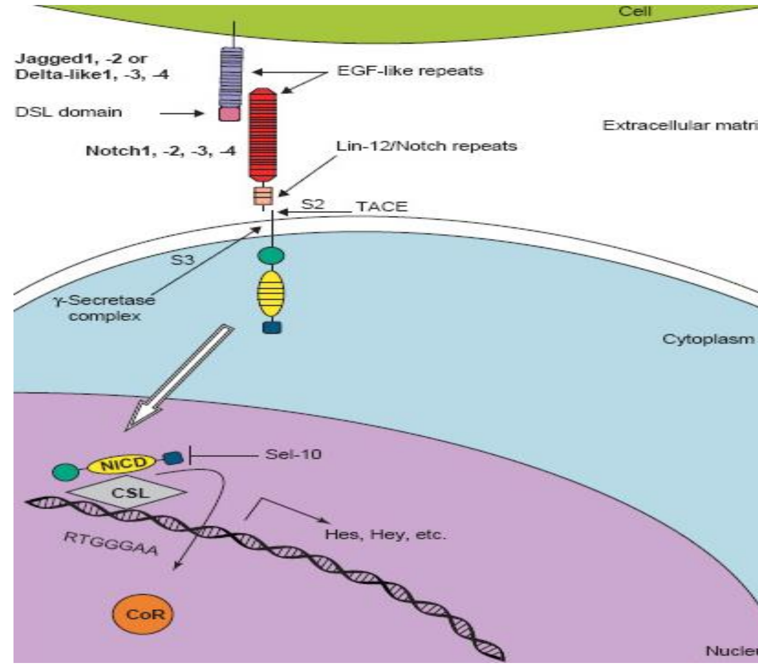
- 암 치료 연구
- 새로운 육종 연구

- 물성 연구

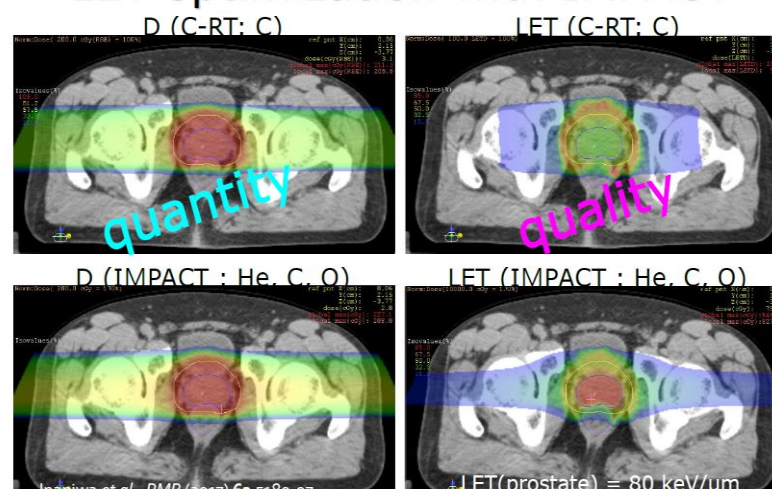


- 핵 물질 연구
- 중성자별 연구





LET optimization with IMPACT



8. Theory

Low Energy Nuclear Science (LENS)	Dense Matter Physics (DMP)	Nuclear Astrophysics (NAP)
1. Nuclear Structure	**1. Heavy Ion Collision**	**1. Nucleosynthesis**
Shell Model (No-Core SM) QRPA (Deformation & Unlike Pairing, Isospin Condensation) RMF (Deformation & N-rich Nuclei) QMC (Coupling Constant inside Nuclear Medium) DFT (Chiral EFT) …	Simulation of HIC (QMD Model, AMD Model and Classical Model)	BBN S- ,R- and P-processes Neutrino process Nucleosynthesis Sites
2. Nuclear Reaction	**2. Equation of State**	**2. Neutrino Physics**
Low Energy Ion Collision (Halo Nuclei) Nuclear Fusion (Super-heavy Nuclei) Nuclear Reactions based on Chiral EFT	Symmetry Energy (Isospin d.o.f, Hyperon Puzzle, Other Constraints) EOS for Exotic Compact Objects (Quark Star and Quark Cluster Star)	Supernova neutrino Neutrino Detection WIMPS Sterile Neutrino Dark Matter (Interaction and Search)
3. Neutrino-Induced Reaction		
Nuclear Weak Structure (Axial Currents Study) WIMP Interactions		
4. Nuclear Astrophysics Reaction		
Capture Reactions (Neutron, Proton and Alpha) Statistical Model for Compound Nuclei		

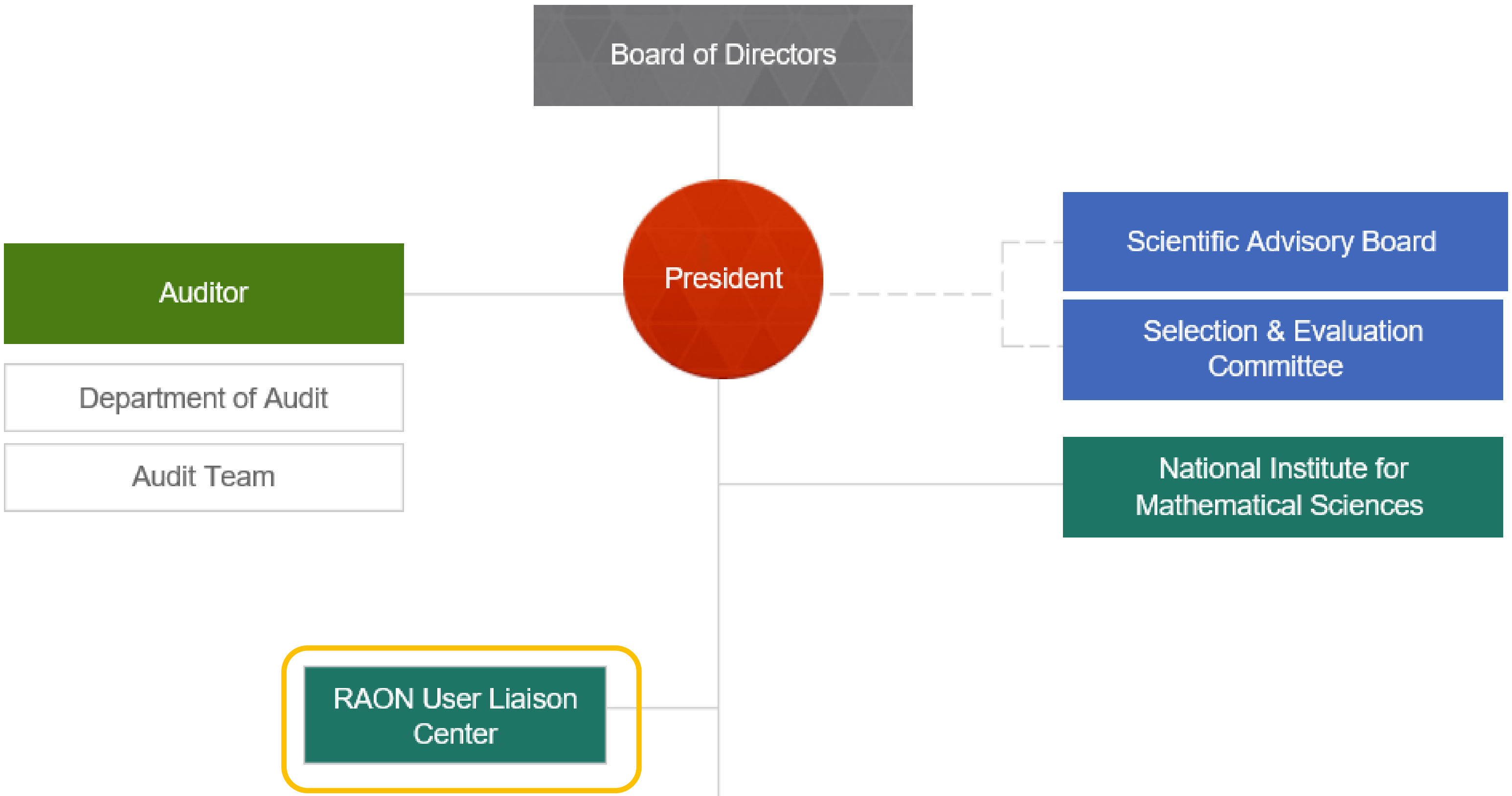
RAONUsers Association

- RAON Users Association was formed in 2012.
- RAON Users Association is registered as a NPO under the Ministry in 2018.
- ~ 180 Members: ~120 Ph.D.'s & ~ 60 students

RAON User Liaison Center

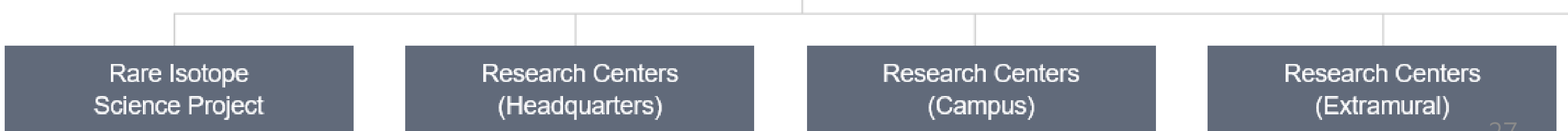
- Train manpower
- Collaborate with RISP to construct 7 experimental facilities
- Form international collaboration groups for 7 experimental facilities
- Develop research topics

RAON User Liaison Center



1. **Facilitating and supporting exchanges and cooperation with RAON user groups**

2. **Planning and operating events/committees to promote the use of RAON**



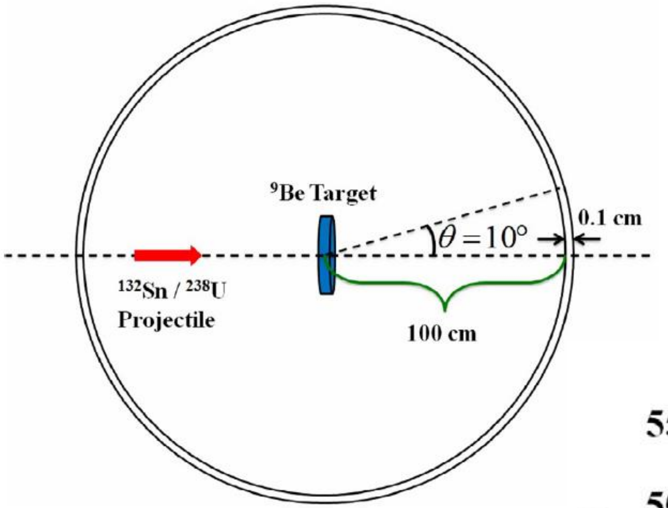
Summary

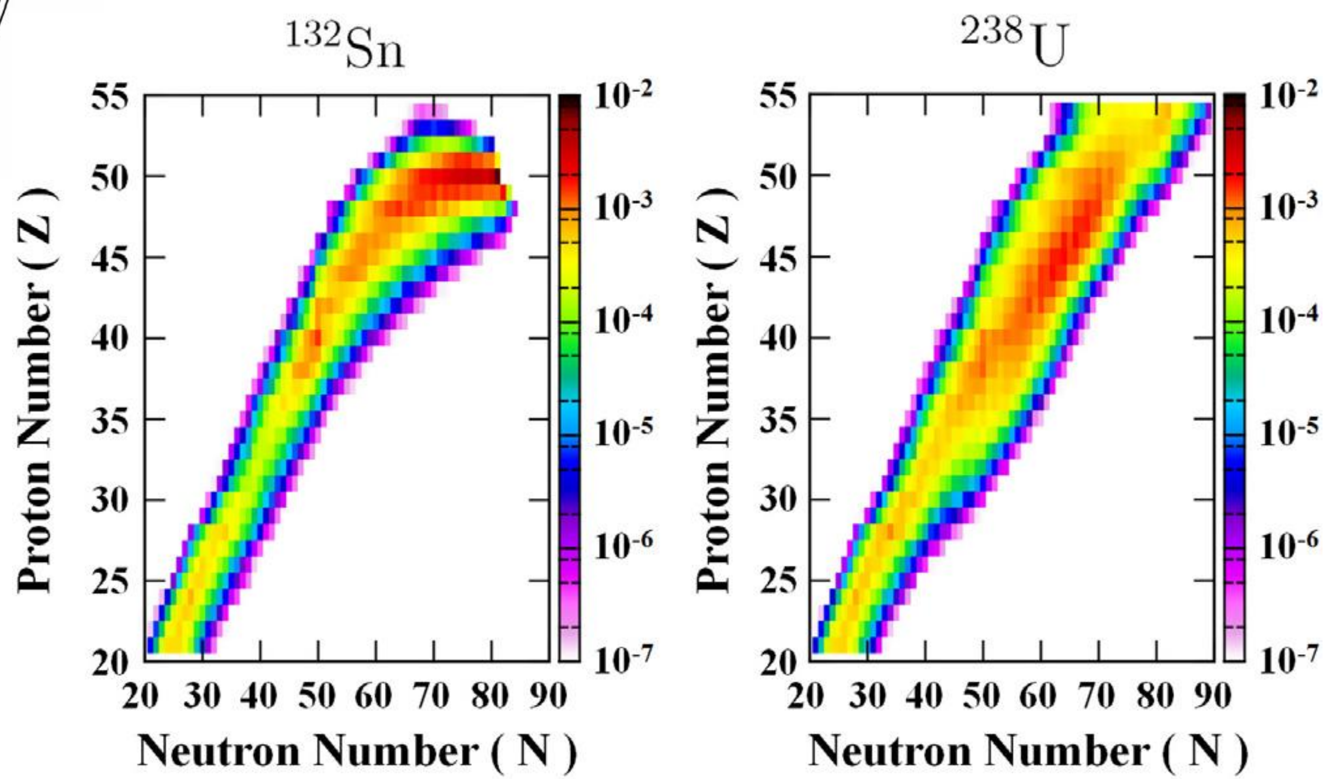
- RAON will provide great research opportunities not only in nuclear physics, but also in applied sciences such as material and bio-medical sciences.

- RAON Users Association, RAON User Liaison Center, and RISP are closely working together for successful utilization and application of RAON.

- We need international collaborations to make the best use of
the facility. Please join us.

ISOLIF = ISOL + IF





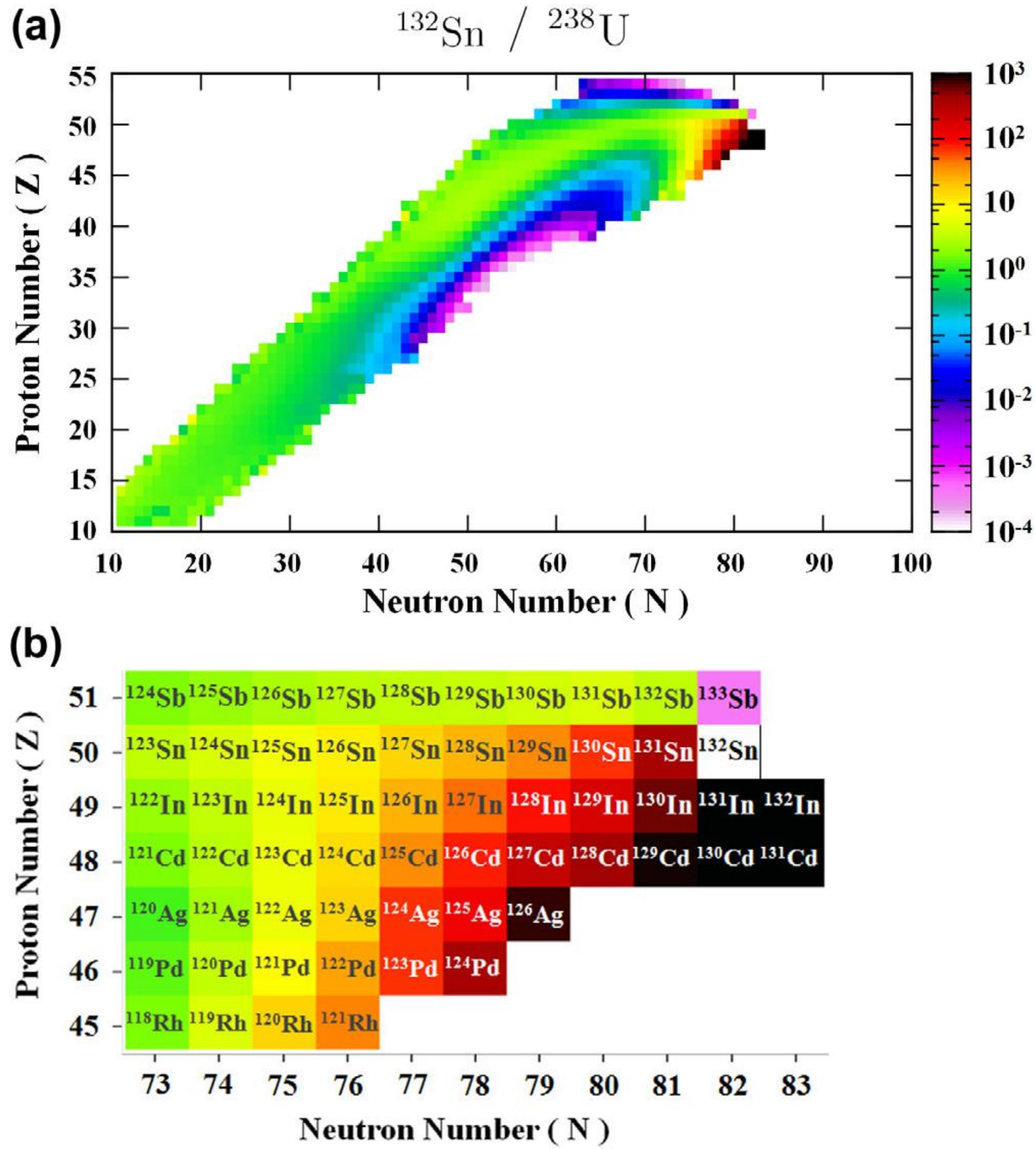
J.W. Shin et al. / NIM B 349 (2015) 221–229

The isotopic production yields plotted in the N–Z plane,
for 200 MeV/u 132Sn (left) and 238U (right) beams on the 9Be target.

ISOLIF = ISOL + IF

The ratios of
the yields due to 132Sn beams
to the yields due to 238U beams.

The region where the ratio is greater than 10^3 is denoted by black.



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