The Japan-Korea PHENIX collaboration Workshop

R&D of RAON Experimental Systems at IBS/RISP

27th November 2012

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Institute for Basic Science
& Hanyang University

ibs 기초과학연구원 Institute for Basic Science

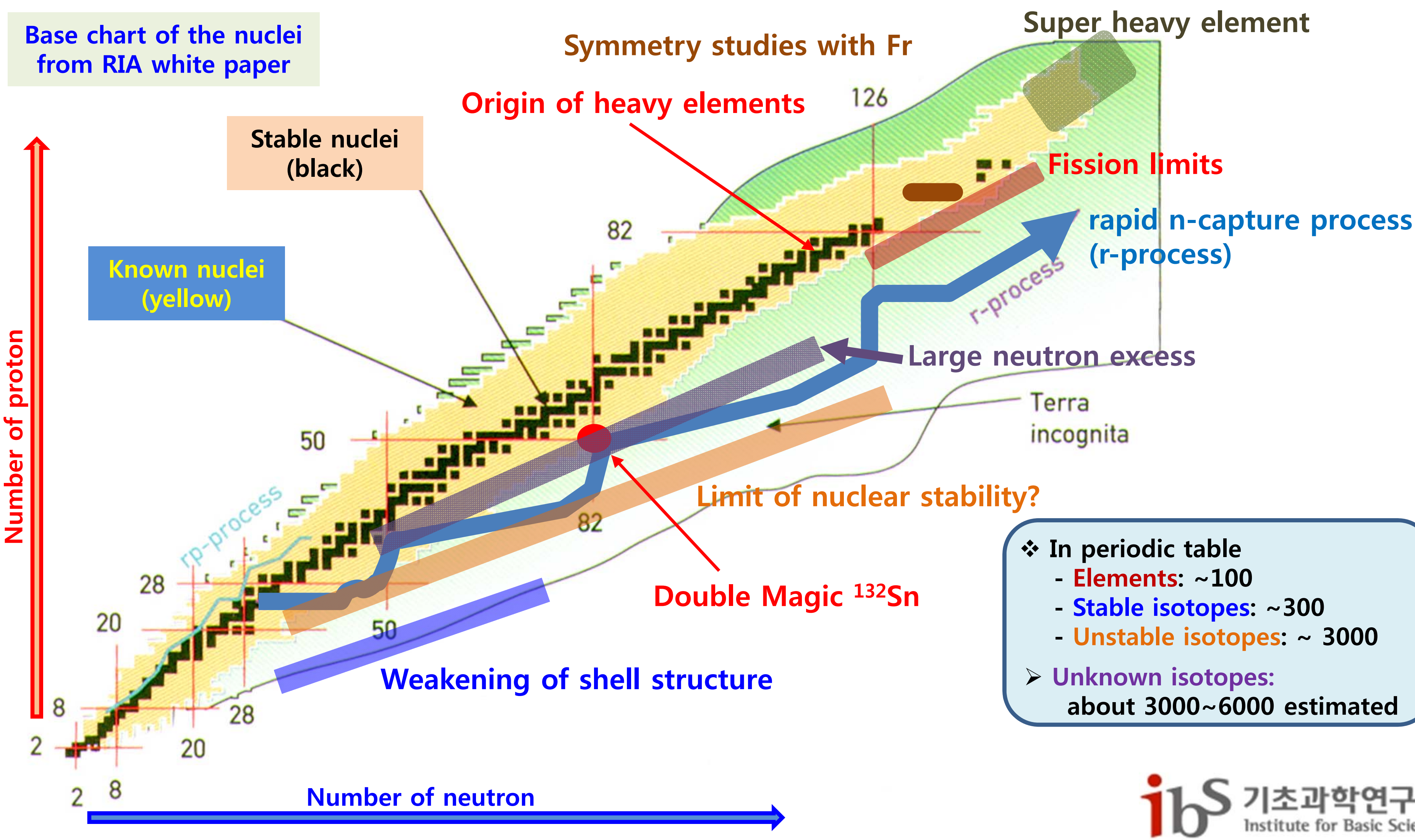

RAON [raon]
new name of RISP (Rare Isotope Science Project)
Accelerator Complex

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
- RISP Workshop on accelerator systems (May 6 – 9, 2012)
- TAC (May 10, 2012)
- Conceptual Design of the Building and Conventional Facilities (May 2012)
- Baseline Design Summary (by July 2012) – Base line parameters
- RISP Workshop on Advanced Experimental Techniques using RI Beams – (16, July, 2012)
- IAC (July 26-27, 2012)
- Technical Design Report (by Jun. 2013)
- Ground Breaking (2014)

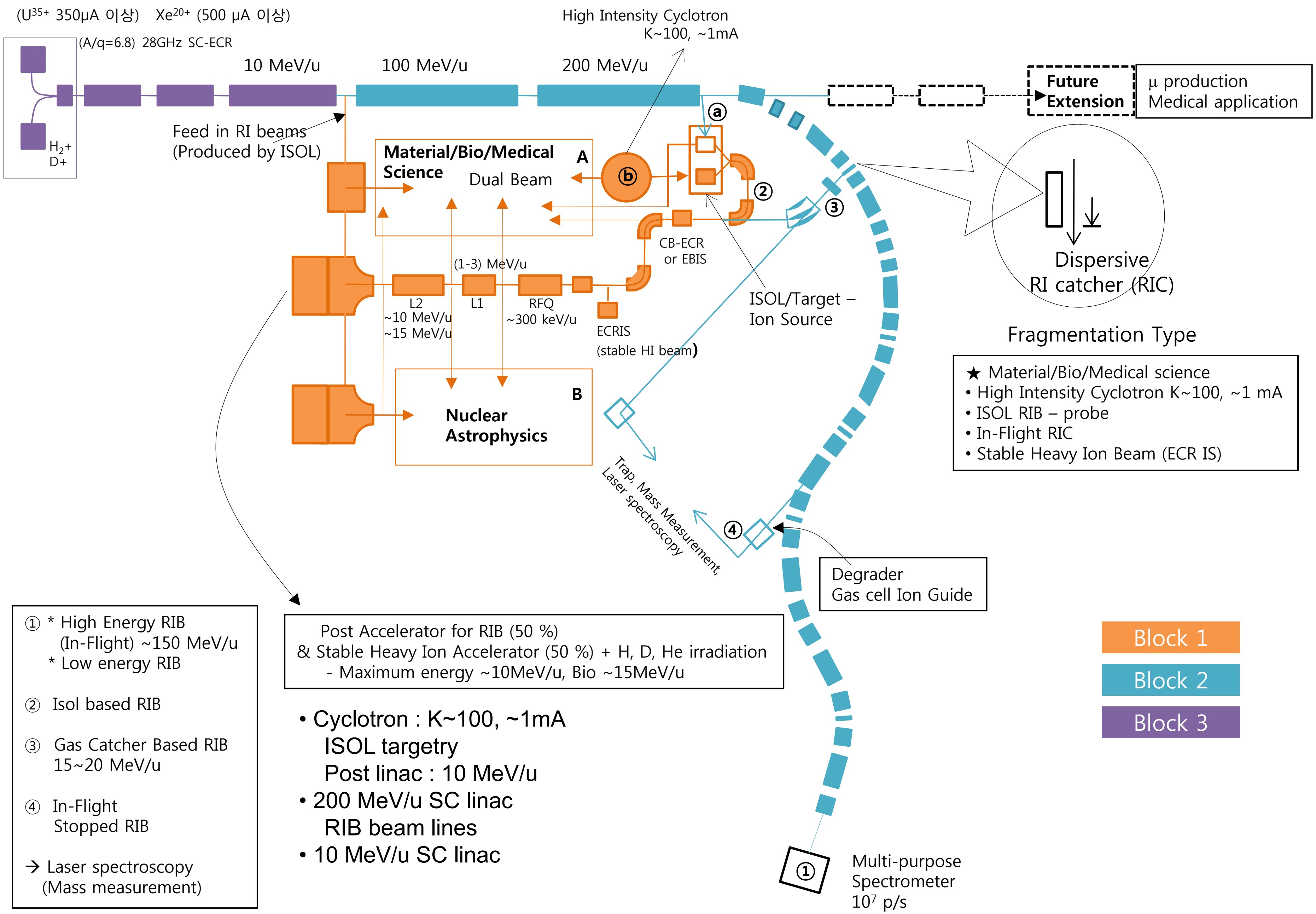
Rare Isotope Nuclear Science

"Nuclear science is entering a new era of discovery in understanding how nature works at the most basic level and in applying that knowledge in useful ways". - National Academy 2007 RISAC Report -



- ❖ In periodic table
  - Elements: ~100
  - Stable isotopes: ~300
  - Unstable isotopes: ~ 3000
- ➢ Unknown isotopes: about 3000~6000 estimated

Birth of RISP : KoRIA (April, 2009)



- Cyclotron : K~100, ~1mA
  ISOL targetry
  Post linac : 10 MeV/u
- 200 MeV/u SC linac
  RIB beam lines
- 10 MeV/u SC linac

User Community (Domestic, 2010)

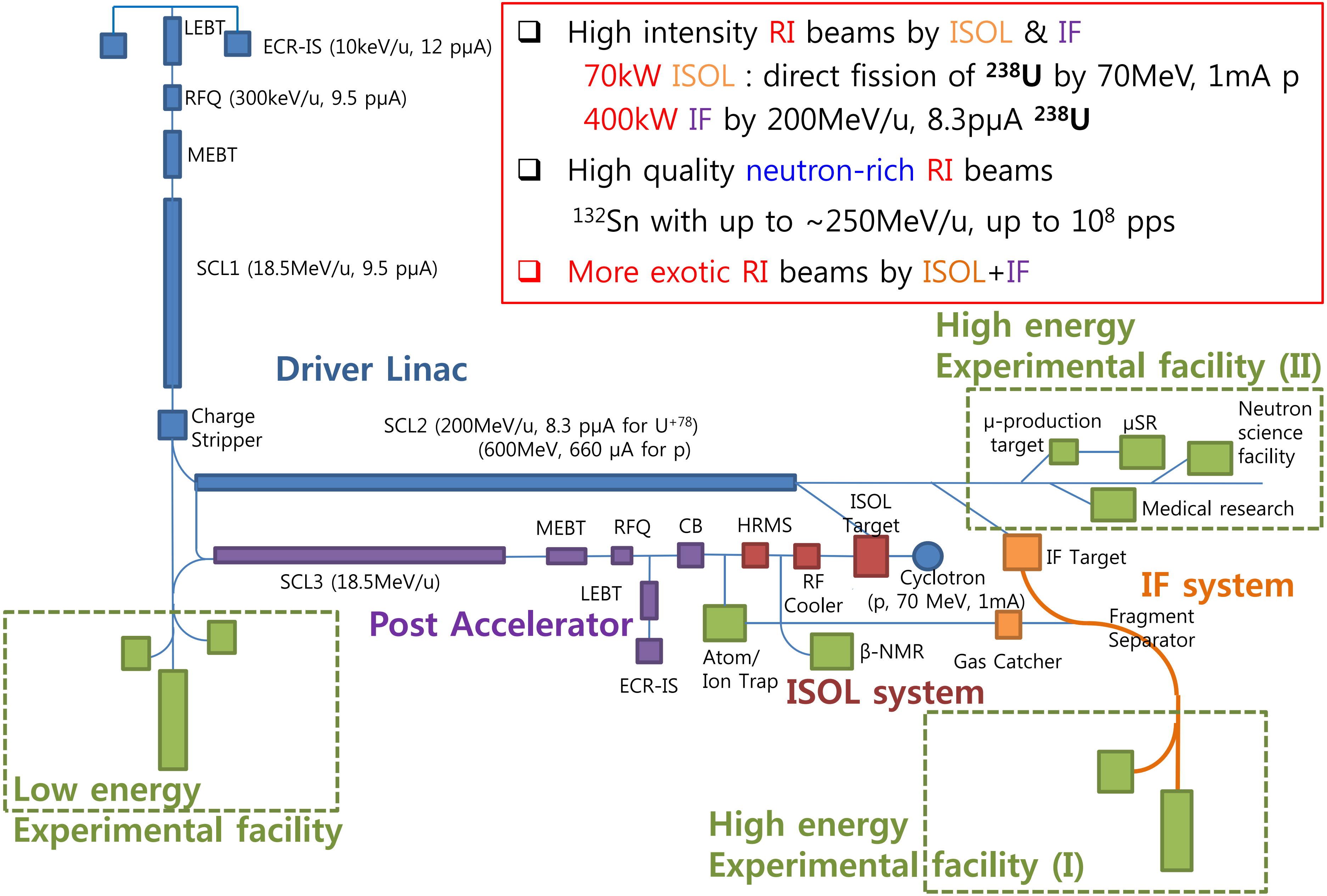
76 Ph.D.s and 43 graduate students in 8 working groups

PI of conceptual design	Y. K. Kim (Hanyang Univ.)	B. G. Cheoun, B. H. Kang, M. S. Ryu, S. M. Kang, D. Y. Jang, B. H. Park, T. Schaarschmidt, S. K. Lee, J. S. Kang, K. H. Jo, B. K. Shin, S. H. Kim, I. S. Lee (4/10)

Working Group	Nuclear Structure	Nuclear Astrophysics & Nucleosynthesis	Nuclear Matter	Nuclear Theory	Medical & Bio Application	RI Material Research	Nuclear Data	Atom traps for RI research
Leader (Institution)	S. H. Choi (Seoul National Univ.)	C. B. Moon (Hoseo Univ.)	C. H. Hyun (Daegu Univ.)	M. K. Cheoun (Soongsil Univ.)	W. Y. Park (Chungbuk National Univ.)	S. H. Park (KAERI)	Y.O. Lee (KAERI)	D. H. Yu (KRISS)
Group members	W. Kim I. K. Yoo S. Stepanian Sato H. S. Lee #K. S. Lee #E. J. Ha M. Evgeniy H. S. Do J. K. Lee C. W. Son K. S. Oh K. E. Choi J. H. Song H. K. Kim J. S. Song (6+2/9)	I. S. Hahn J. H. Lee Y. K. Kwon J. Y. Moon C. C. Yun J. S. Yoo A. Kim E. H. Kim J. S. Park (8/2)	S. H. Lee H. C. Kim E. J. Kim J. K. Ahn Y. S. Oh K. S. Lee C. H. Lee H. J. Lee B. Hong #K. S. Lee H. J. Jeong, J. H. Jeong K. B. Kim, S. H. Kim J. Y. Park, J. H. Jeong S. Y. Yu, H. S. Jo S. J. Kim, K. H. Lee M. E. Baek, B. H. Choi E. A. Joo, K. Y. Baek J. H. Jang, S. H. Hwang H. H. Shim, J. K. Lee Y. M. Kim (11/19)	C. Ryu #E. J. Ha K. Kim B. G. Yu T. Choi W. Y. So (7/0)	Y. C. Ahn I. G. Kim K. C. Kim I. L. Jeong T. R. Kim U. Jung H. J. Song J. R. No J. C. Ahn *J. W. Gwak *D. H. Shin *S. J. Ye *Join research not project member (7+3/3)	J. K. Kim W. Hong B. Y. Han S. K. Ahn H. S. Shin N. Y. Kim H. S. Kim B. J. Seo H. Im #Y. J. Rhee #J. M. Han #H. M. Park #K. H. Ko #G. Lim (15/0) # Joining 2 working groups	G. D. Kim J. G. Yoo H.-W. Choi H. J. Woo T. Y. Song H. I. Kim C. W. Lee #Y. J. Rhee #J. M. Han #H. M. Park #K. H. Ko #G. Lim (8+5/0)	Y. K. Lee C. Y. Park J. C. Moon T. Y. Kwon S. E. Park S. B. Lee H. S. Kang M. K. Oh Y. H. Park (10/0)

RAON : RISP Accelerator Complex

- High intensity RI beams by ISOL & IF
  - 70kW ISOL : direct fission of ^{238}U by 70MeV, 1mA p
  - 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



Main Research Subjects

Nuclear Science	Nuclear Astrophysics & Nucleosynthesis	- Direct measurements of proton and alpha capture reactions - Search for Super Heavy Elements beyond Z=113
	Nuclear Structure & Matter	- RI nuclear structure of neutron rich nuclei near N=126, $80<A<140$ - Symmetry energies at sub-saturation density
	Nuclear Data	- Neutron capture cross section measurements by using n-TOF
	Nuclear Theory	- Development of RI nuclear theories
Atomic & Molecular Science	Precision Mass Measurement & Laser Spectroscopy	- Hyperfine structure and characteristics of element and nuclei
Material Science	RI Material Research	- Search for new material and its properties with β-NMR/μSR and RI beam
Medical & Bio Science	Medical & Bio application	- Development of new cancer therapy - Biological effect of tissue and DNA by RI beam

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

- **Important scientific applications**
  - Precision mass measurement & Laser spectroscopy
  - **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, $^{24\text{-}30}$O	50-100 A MeV	10^9	Nuclear Study with Polarized target
^{17}N, ^{17}B, ^{12}B, $^{14\text{-}15}$B, $^{31\text{-}32}$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
$^{133\text{-}140}$Sn	< 60 keV	1	Atomic physics
^{8}B, $^{9\text{-}11}$C, ^{15}O	≥ 200 A MeV	10^7 – 10^9	Medical and Bio science

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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Essential experimental systems

- Study the preliminary researches
- Develop the experimental systems in parallel with the accelerator
- Make user program with the international collaboration

Nuclear Physics	Large Acceptance Spectrometer
Nuclear Astrophysics	Korea Recoil Spectrometer (KRS) Gas filled Separator for SHE
Atomic physics	Atom & Ion Trap System
Nuclear data by fast neutrons	neutron Time-of-Flight (n-ToF)
Material science	β-NMR/NQR, mu-SR Laser Selective Ionizer
Medical and Bio sciences	Heavy Ion Therapy research Irradiation Facility

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Institute for Basic Science

RISP ISOL

Rare Isotope Science Project

Necessity

- Diverse experiments
- Need of neutron enrich isotope

Becquerel discovers radioactivity

The Curies discover polonium

1900

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

Explanation of magnetic numbers

Radiochemistry used to monitor nuclear weapons tests

First ISOL experiment in Copenhagen

Explanation of magic numbers

Parity violation in beta decay

Explanation of magic numbers

Z=100 (Fm) discovered

First in-flight separator at Oak Ridge

1960

Beta-delayed proton radioactivity discovered at Dubna and McGill

Z=105 (Db) discovered in Dubna

Nobel Prize for magic numbers

beta-NMR demonstrated at ANL

BBHF theory of nucleosynthesis

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

Neutron halos discovered at Berkeley

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

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

GANIL

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

REX-ISOLDE

KEK-JAERI

2000

Direct radiative capture with 21-Na at ISAC-I

38m-K β-ν correlations at TRINAT

Two-proton emitters discovered at GSI and GANIL

Targeted alpha therapy at ISOLDE

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

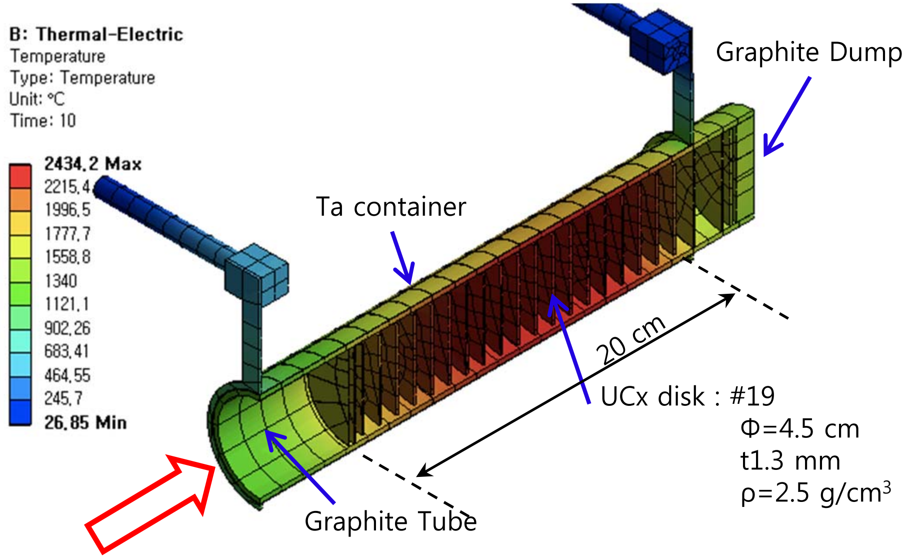
78-Ni lifetime at NSCL

Objective

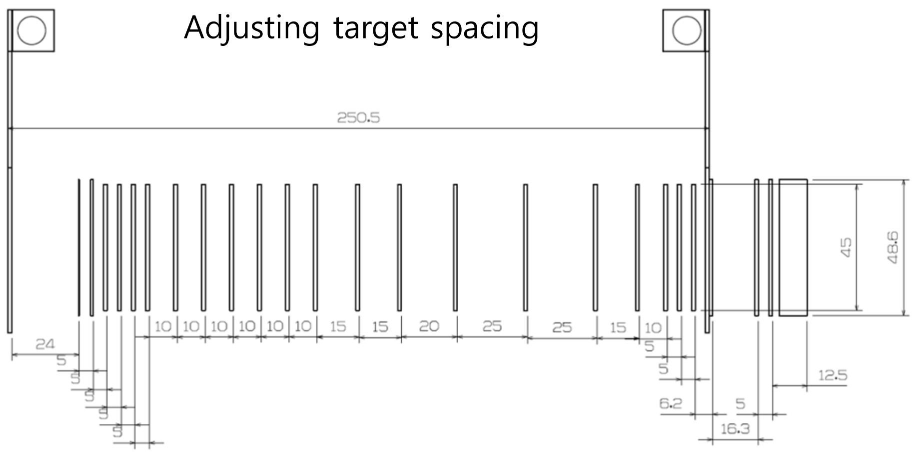
- Design of 10 kW ISOL
  - Rare isotope ion source with high purity and high intensity

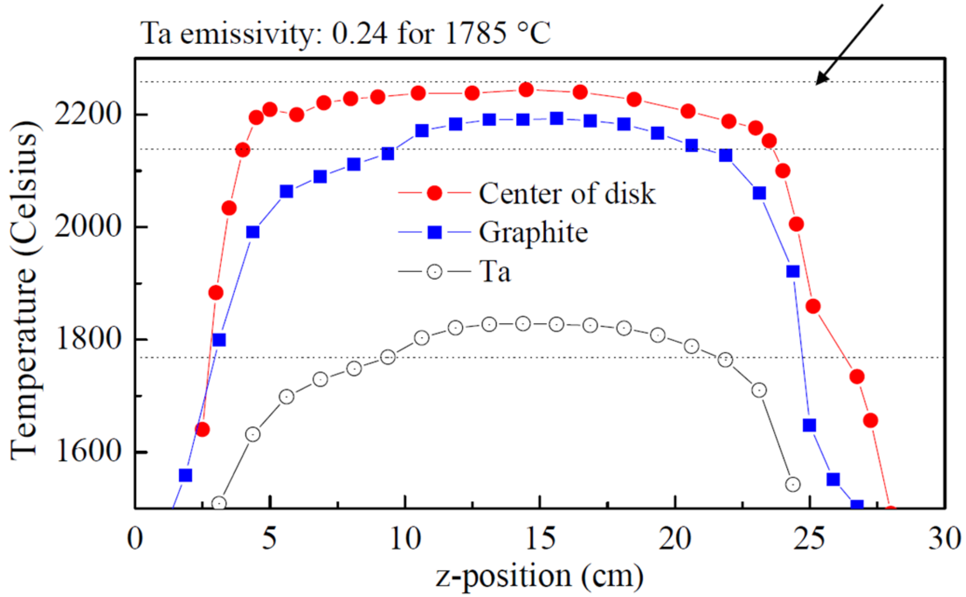
  * Especially our goal : 70 kw ISOL

Thermal Analysis of 10 kW ISOL Target



Proton : 70 MeV, 10 kW, Φ = 4.5 cm (uniform)

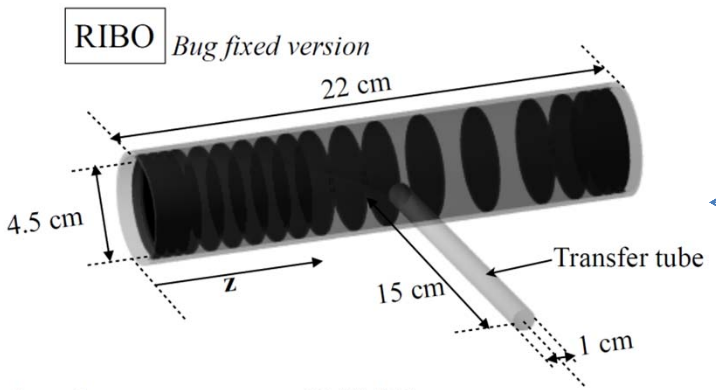


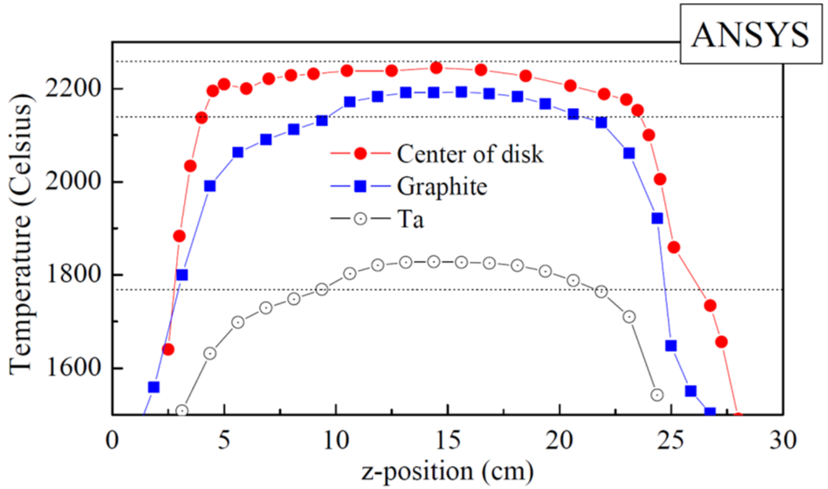


	Power deposited (KW)
Target disk	**5.1**
graphite disk	1.7
Graphite dump	0.4
Graphite tube	2.7
Ta Container	0.3

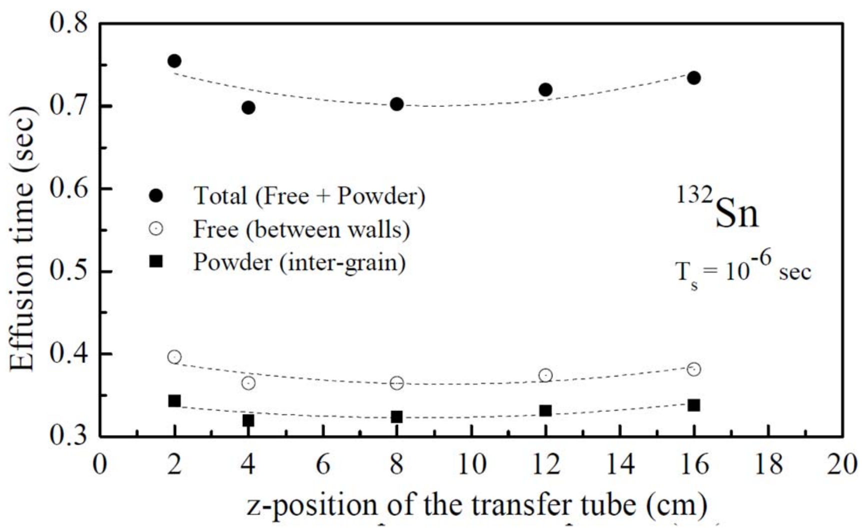
- **Under analysis to achieve the uniformity of temperature by adjusting the target gap spacing, size, thickness and etc.**

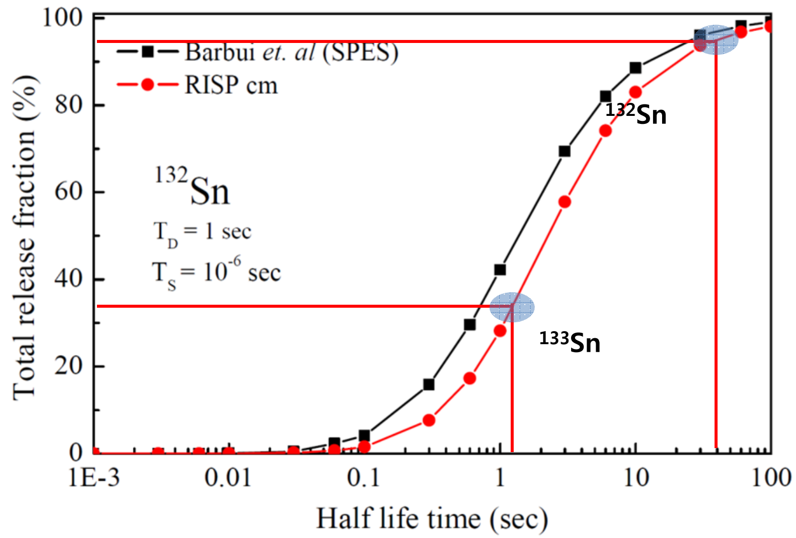
Release efficiency of 10 kW ISOL Target





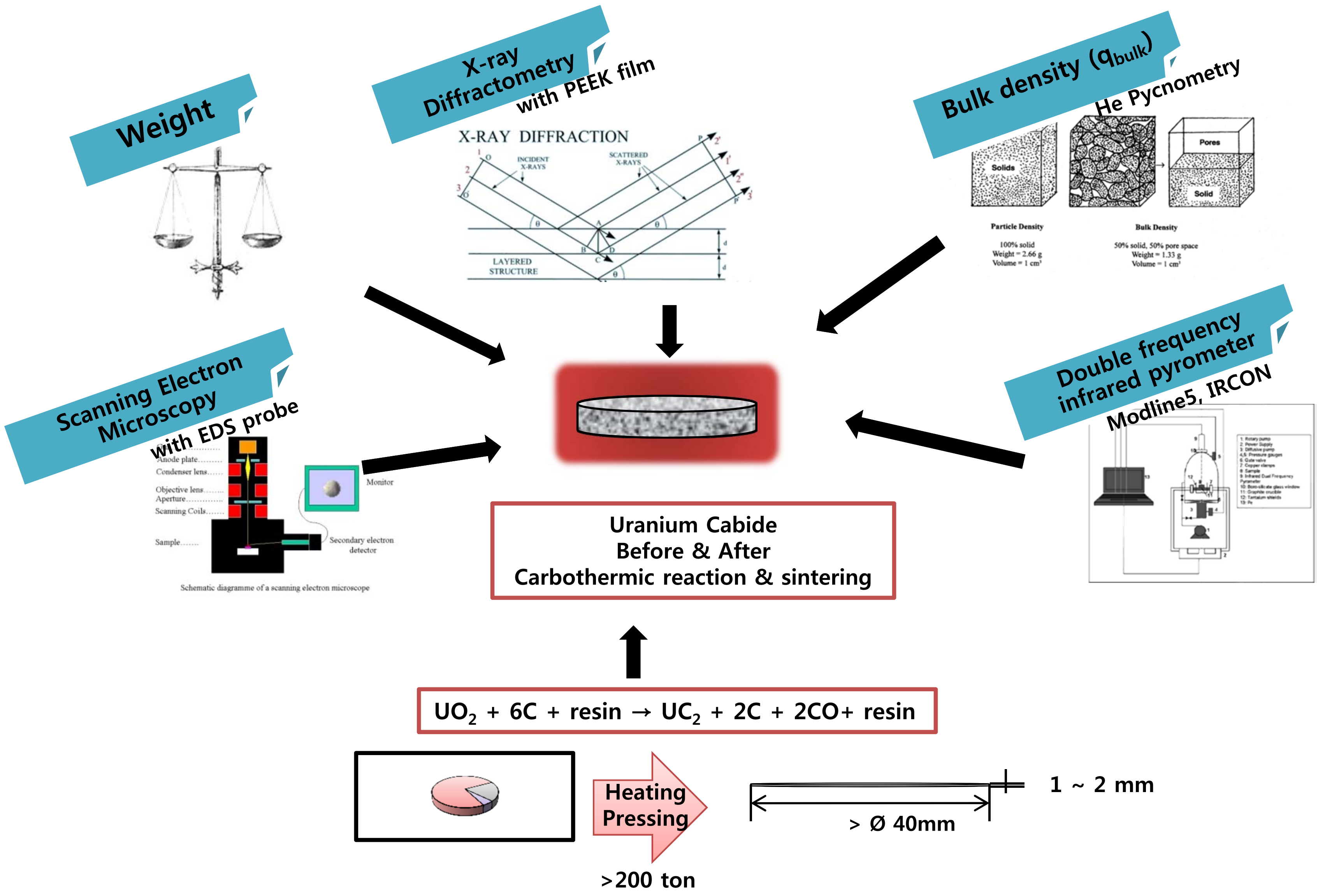
Transfer tube temperature : 2000 °C
Graphite temperature : 2061 °C (calculated from ANSYS)





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

Preparation of UCx disk development

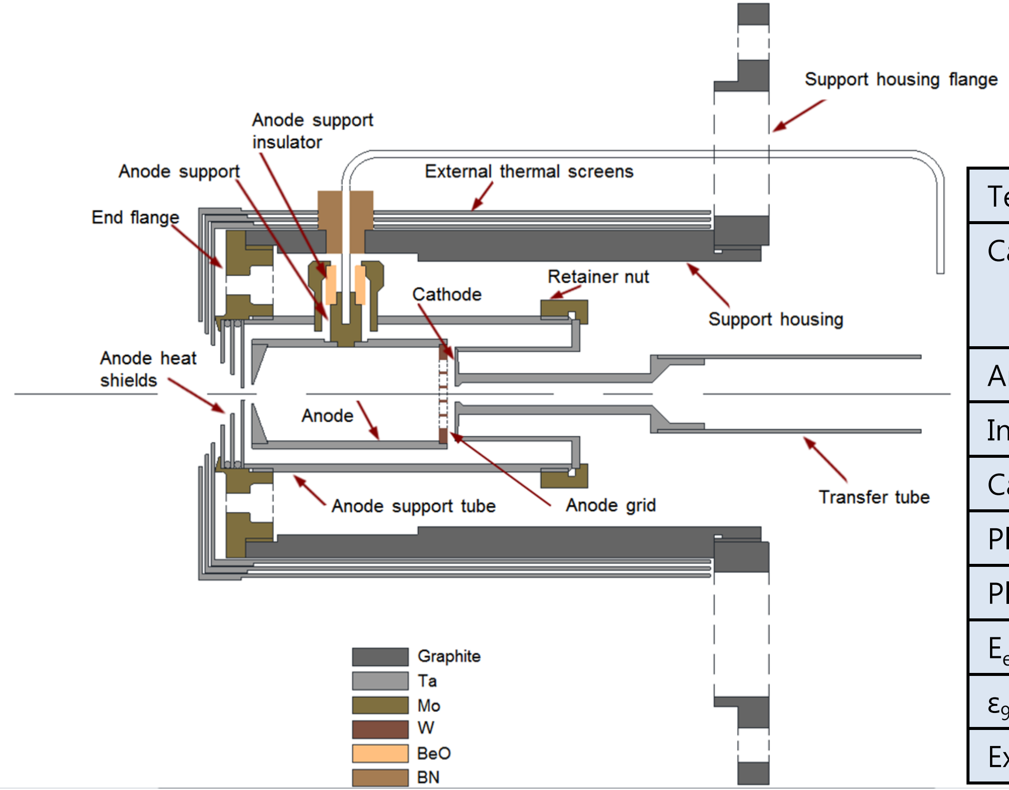


Technical design of FEBIAD Ion Source

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

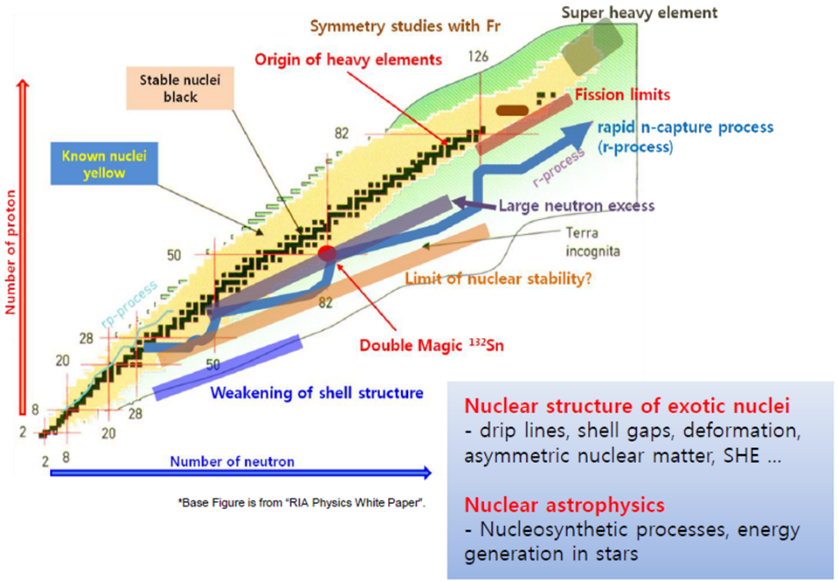
- Design of Recoil Spectrometer for low energy (<18.5 MeV/nucleon) nuclear and nuclear astrophysics study

  * Cancellation of velocity dispersion with two Wien filters

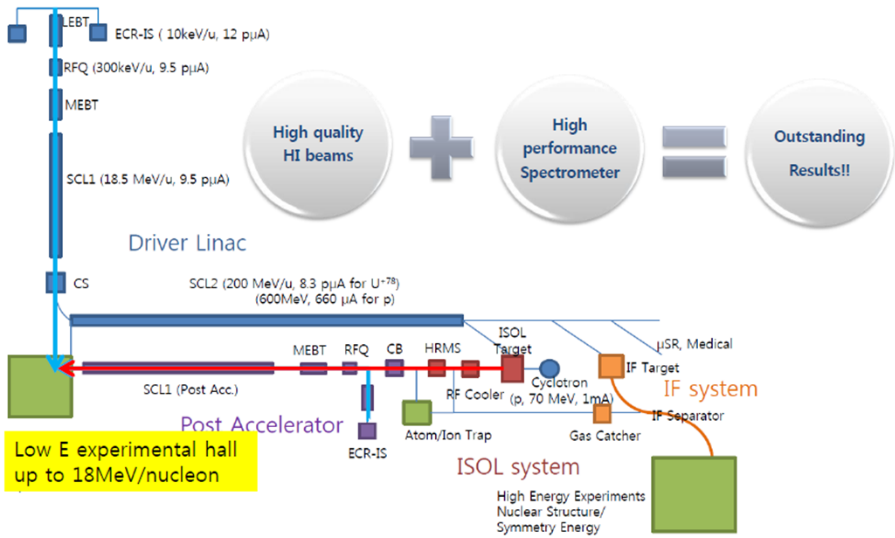
  * Large angular acceptance of < ±100mrad for more dissipative reactions

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

Performance at RISP

1. First-order beam optics calculation
   - In-flight separation (IF) mode with SI beams from LINAC
   - Recoil tagging (RT) mode with n-rich RI beams from ISOL
   - Recoil separation (RS) mode with p-rich RI beams from ISOL
2. Case study
   - $^{44}Ti(\alpha,p)^{47}V$: ^{44}Ti yield in SN II. IF mode
   - $^{15}O(\alpha,\gamma)^{19}Ne$: breakout to rp-process. RS mode
3. Design of detection system
   - Beam tracking: PPAC, MCP
   - Particle detection: ΔE-E telescope array
   - Gamma-ray detection: HPGe and Scintillator array
4. Design of gas target system
   - Supersonic gas jet target

Rare Isotope Science Project

Preliminary result

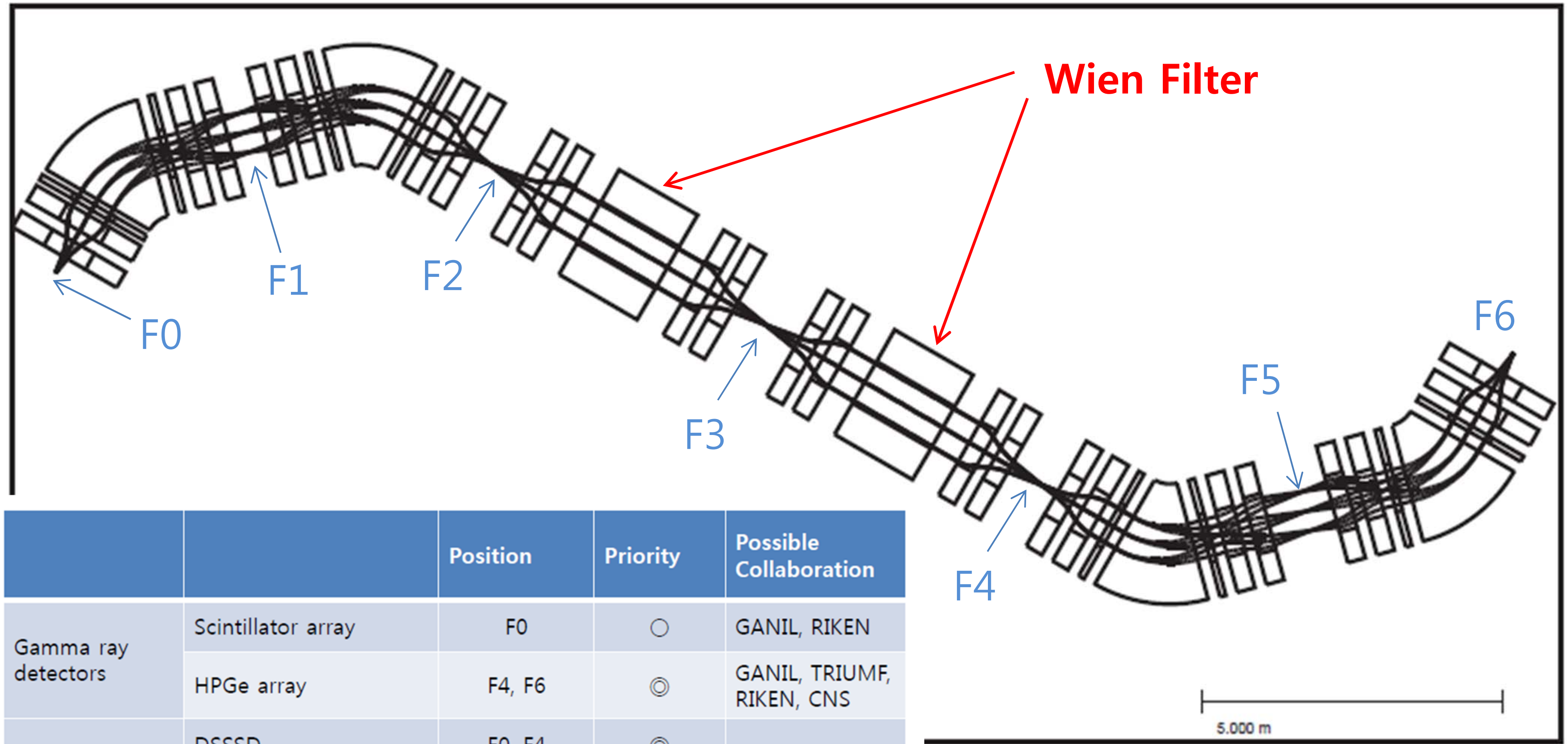
- Design goal for recoil spectrometer

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		○	

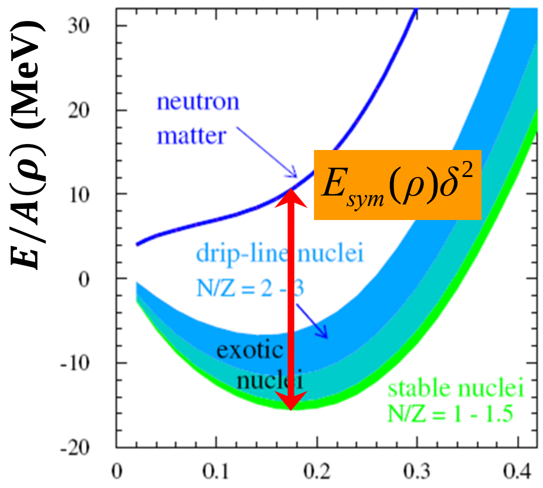
RISP Heavy-ion Collision Experiment

Objective

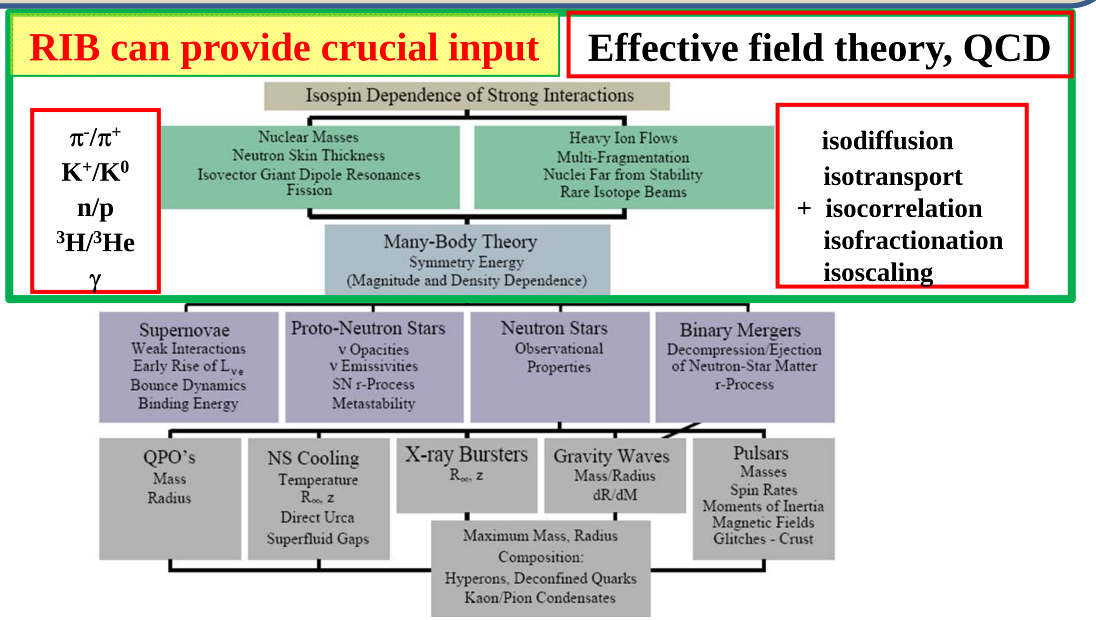
- Design of Heavy-ion Collision Experiment using RI beam
  - Study of Nuclear symmetry energy

  * 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})

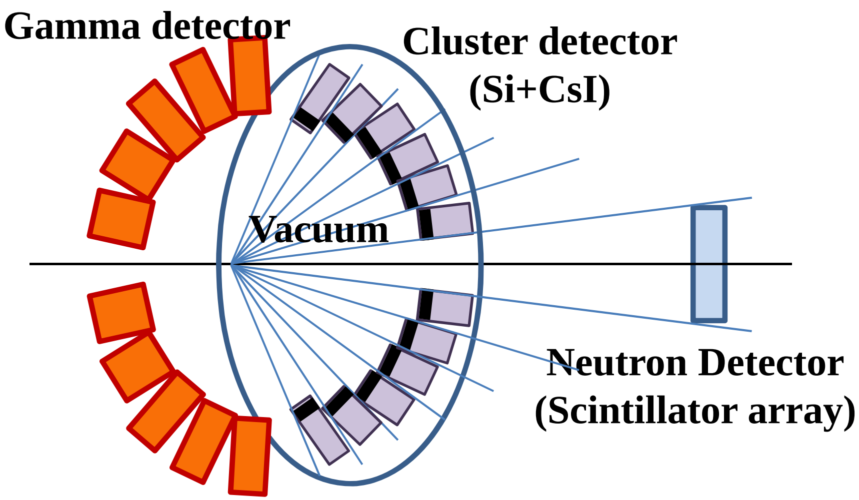


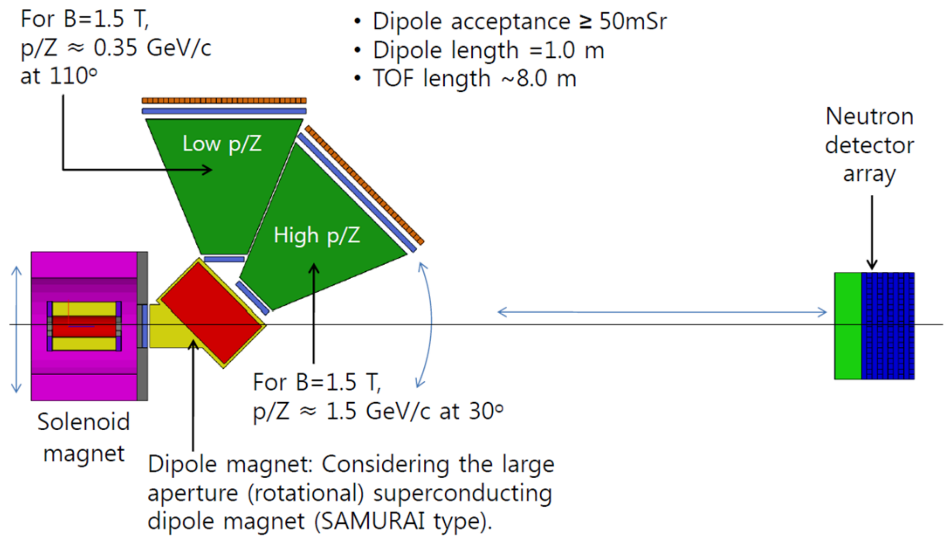
- **A.W. Steiner, M. Prakash, J.M. Lattimer and P.J. Ellis, Physics Report 411, 325 (2005)**
- **Red boxes: added by B.-A. Li**

- 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

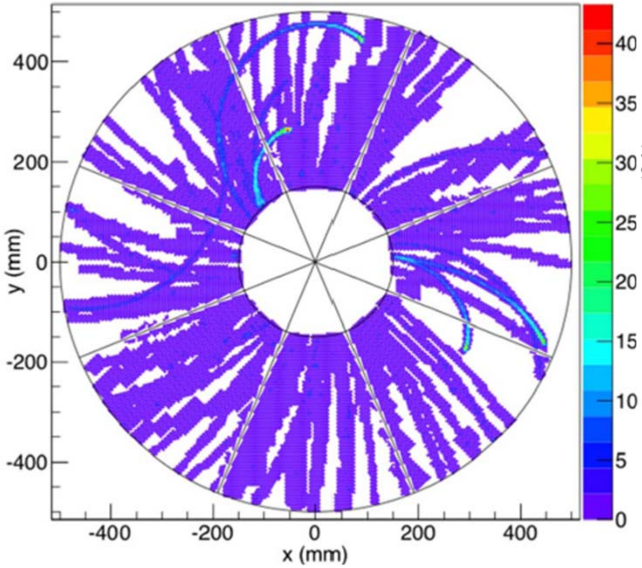
1. Design of experimental setup
   - For low energy (E_{beam} = 0 - 20 MeV/u)
   - For high energy (E_{beam} = 20 - 250 MeV/u)
2. Optics calculation for high resolution spectroscopy
   - Rotatable dipole magnet (~2T) and focal plane
3. Detector simulation and R&D
   - TPC (~ 3π Sr acceptance)
   - ΔE-E (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)





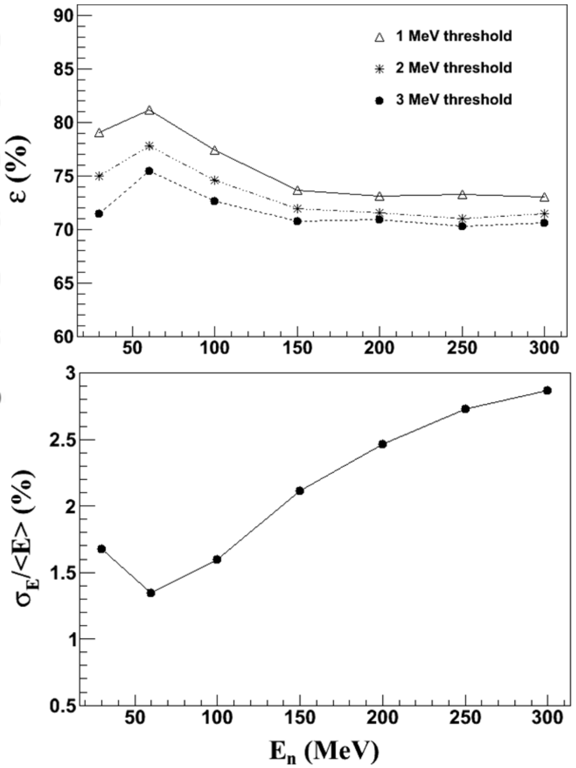
Preliminary result

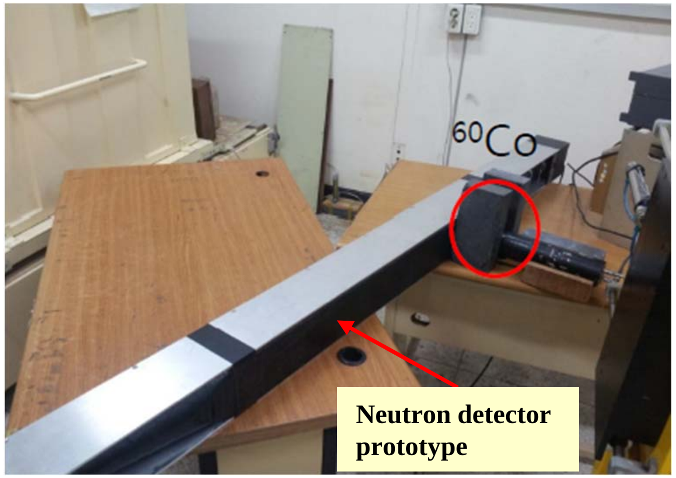
TPC Geant4 simulation



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

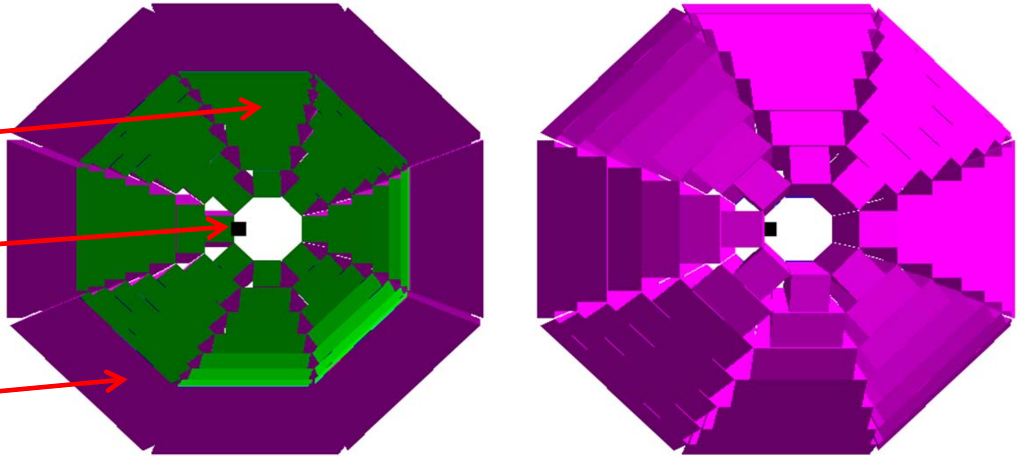
Neutron detector Geant4 simulation and R&D





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

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

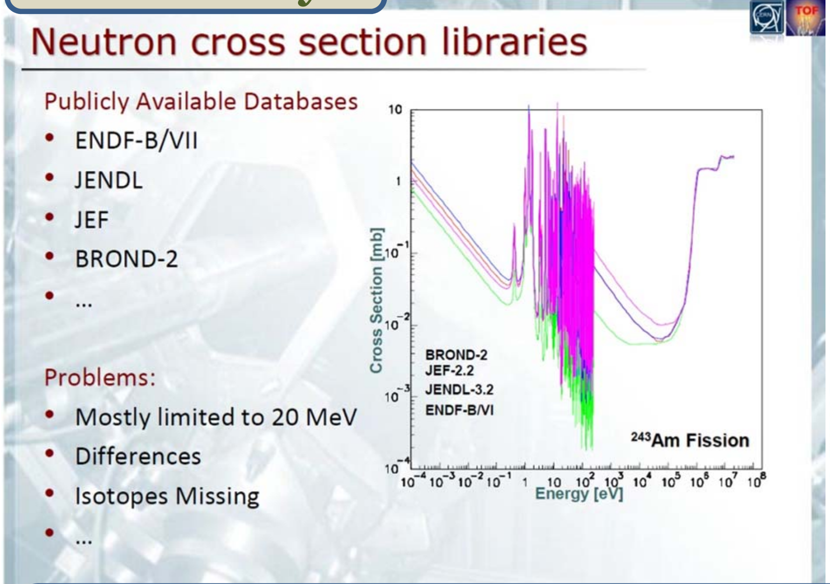


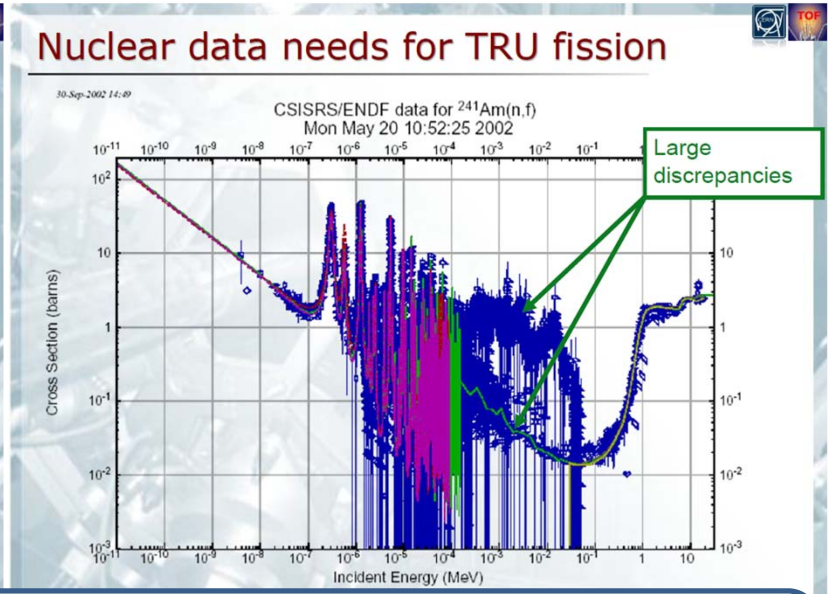
RISP Neutron Science Facility

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





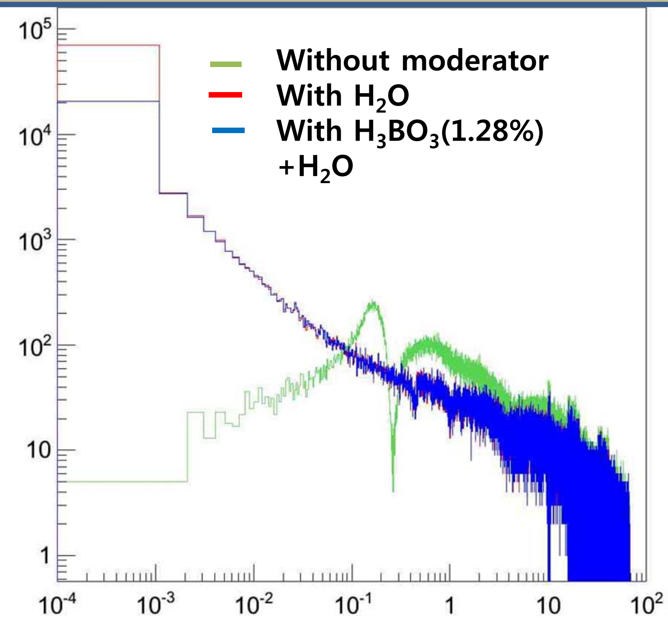
- OECD/NEA high priority & General request : 36 species
  - E_n <20 MeV, Fission 13 species, Capture 10 species, Total 3 species

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

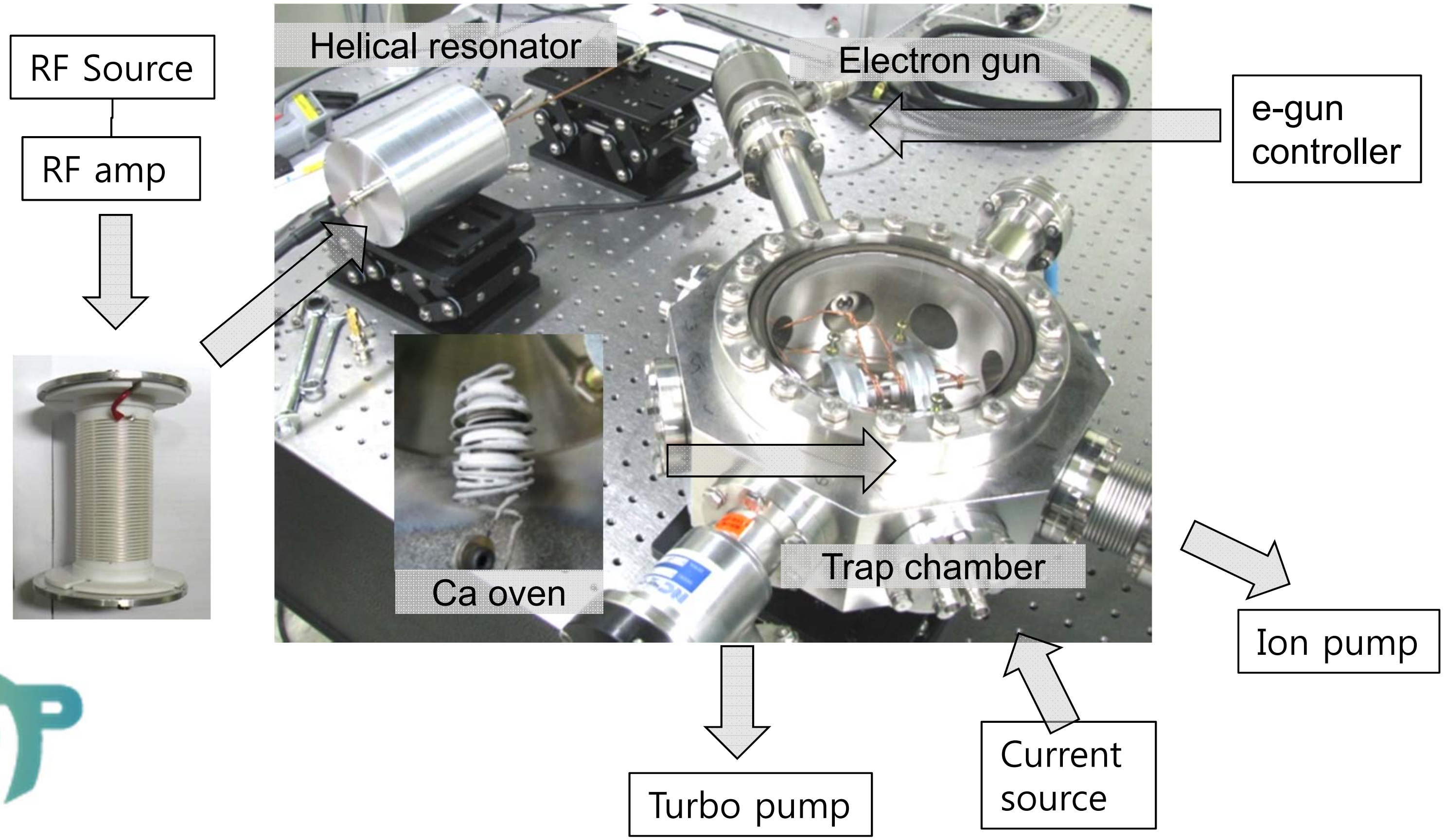
- Test of the conserved vector current hypothesis and the unitarity of the CKM matrix
- Nuclear masses far from stability to test new mass models
- Proton-neutron interactions and the new masses
- Understanding nuclear structure
- Probing and resolving isomer states of nuclides

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



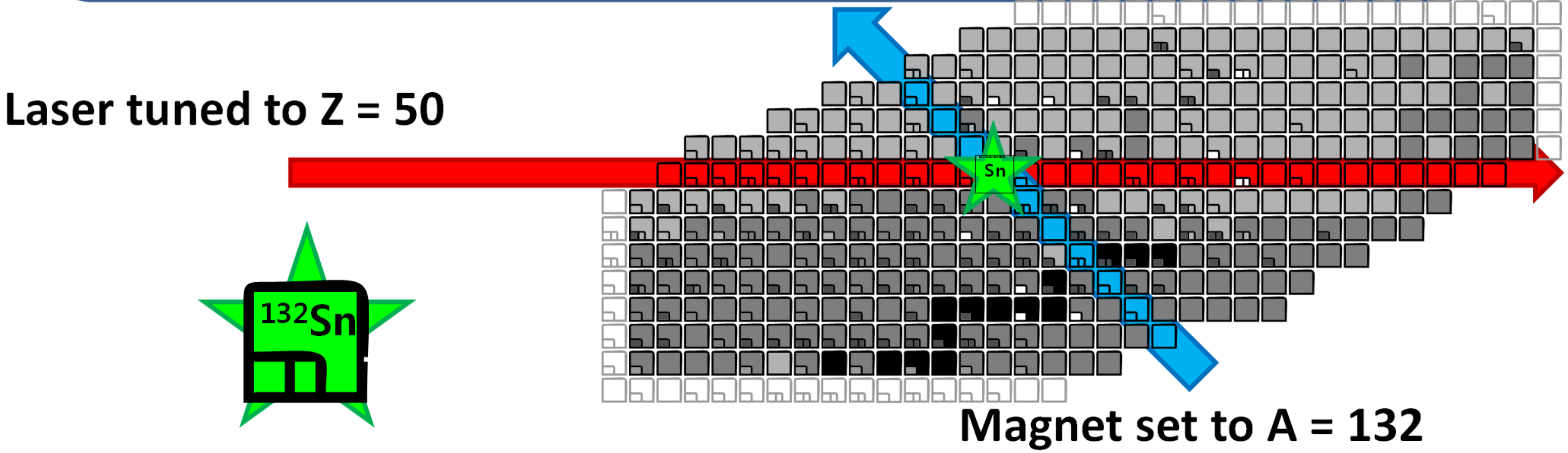
RISP Laser Ion Source

Objective

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

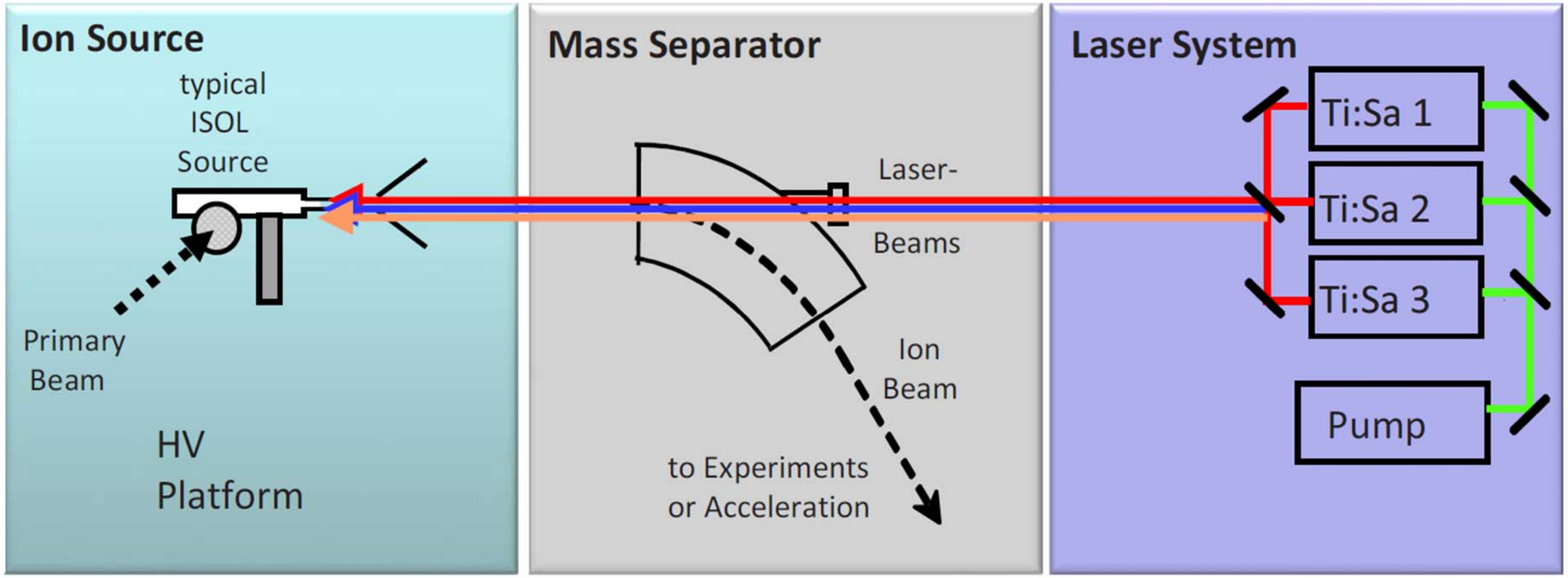
Necessity

- 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 70%

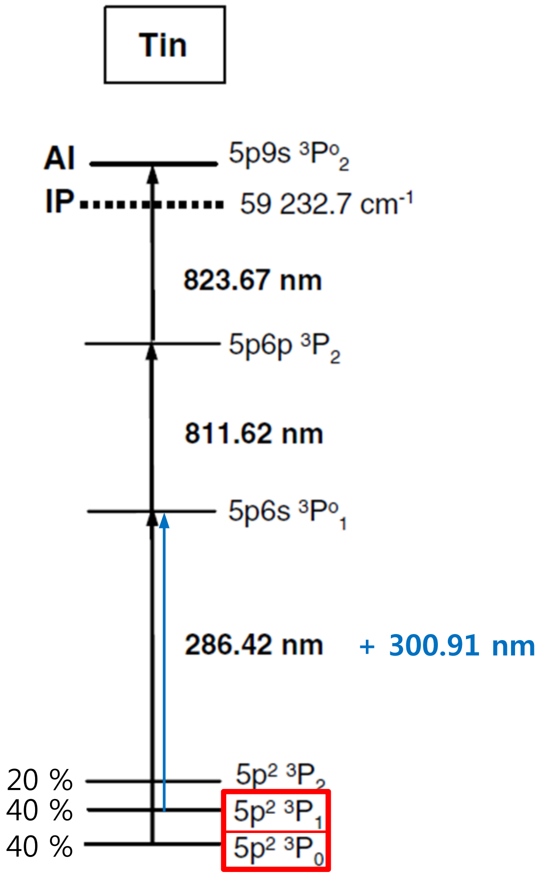


Performance at RISP

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



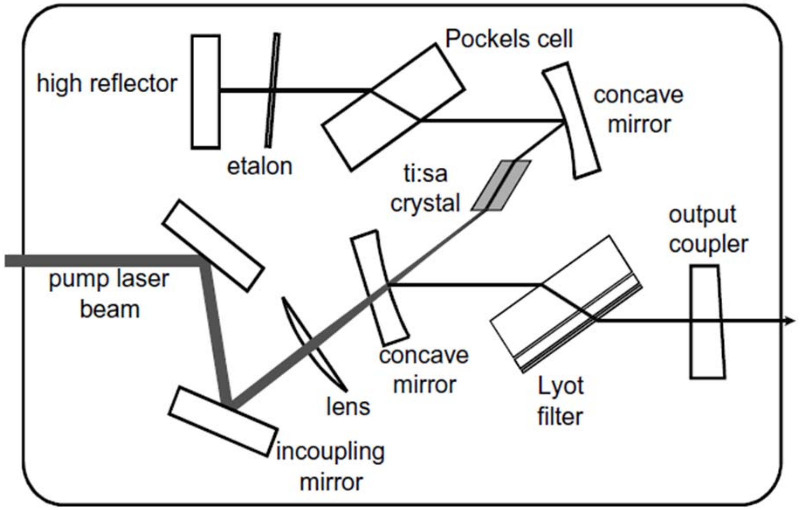
[Ionization scheme for Sn]

- 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: **~70 %**

- High repetition & tunable Ti:Sa laser design



[Layout of the Ti:Sa laser]

RISP Material Science Facility

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

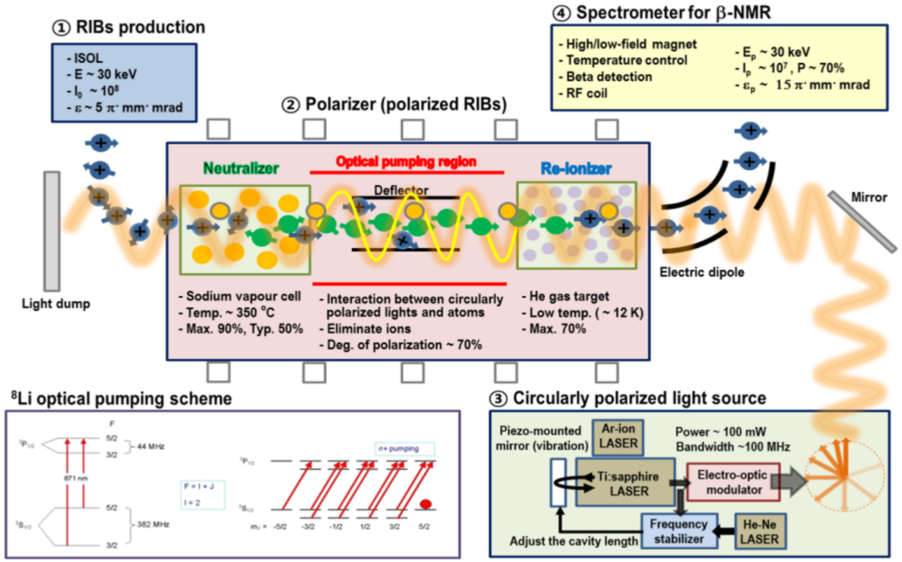
❖ β-NMR and μSR facilities operating in the world

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

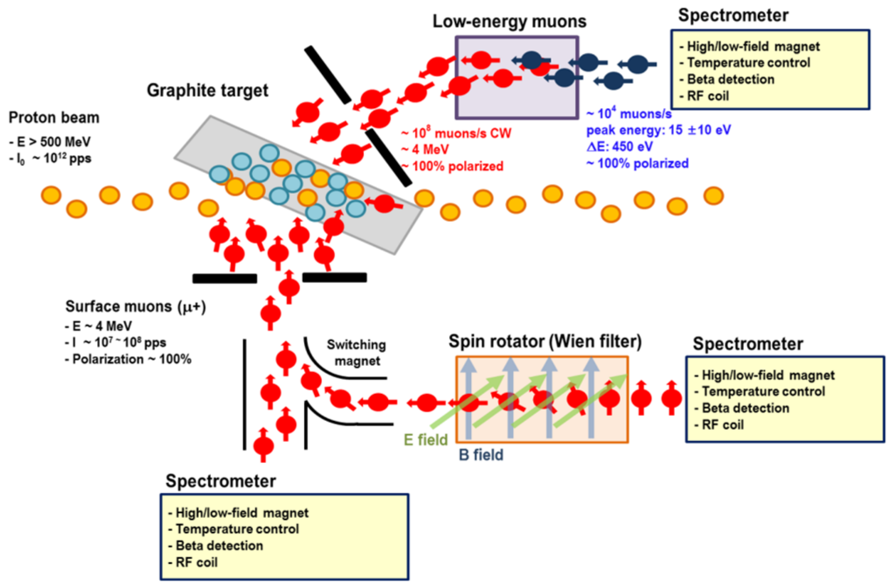
Characteristics of β–NMR and μ–SR facilities at RISP

β-NMR	• ^{8}Li, ^{15}O, ^{17}Ne beams (E ~ 30 keV, Intensity ~ 10^8 pps, polarizability ~ 70%) • Total 3 ports (2 exclusive ports for a ^{8}Li beam and 1 port for searching new beams) • Collinear optical pumping method for highly polarized beams • Temperature controllable HF and LF spectrometers (0.3 K < T < 500 K)
μSR	• CW and ultra-low energy muon beams • Minimum 4 ports (2 ports for a surface muon, 1 port for low-energy muon and 1 port high-energy muon) • Using a Wien filter for rotating a spin axis of muon • Temperature controllable HF and LF spectrometers (0.3 K < T < 500 K)

❖ Conceptual layout of β-NMR facility



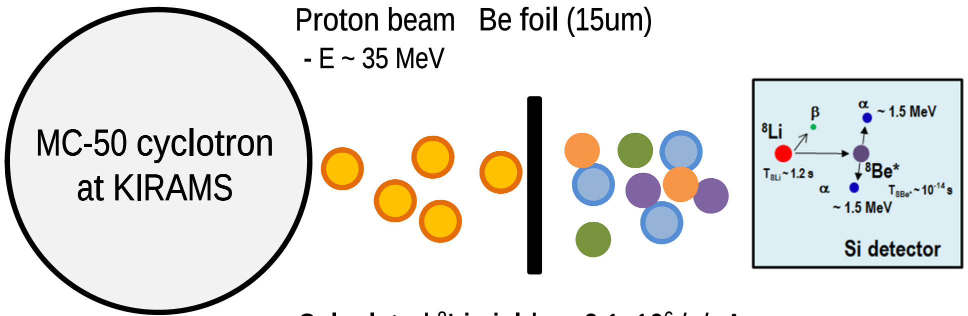
❖ Conceptual layout of μSR facility



Preliminary Results

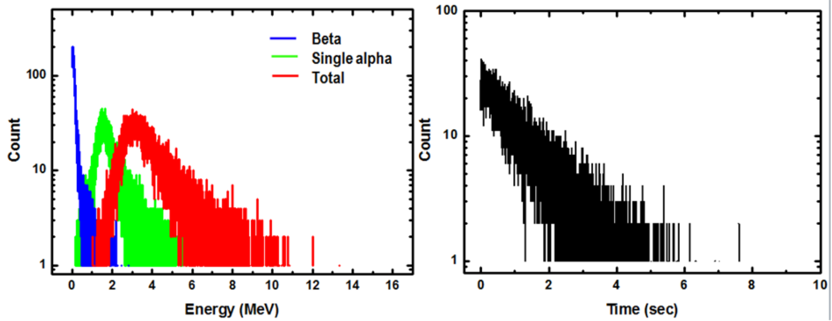
Rare Isotope Science Project

1. Feasibility study for ^{8}Li beam production using a $^{9}Be(p, 2p)^{8}Li$ reaction



- Calculated ^{8}Li yield : > 2.1×10^{6} /s/uA
- Decay measurement

- Energy and time spectra for ^{8}Li decay (Monte Carlo simulations)



Without ISOL ion source : Patents Pending

2. Optimization for Neutralizer

- Key parameters for achieving the maximum neutralization efficiency

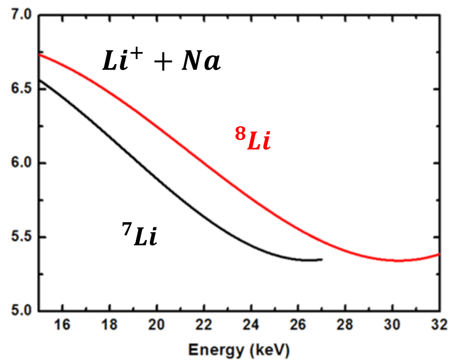
$$A^{+} + B \rightarrow A + B^{+} + \Delta E$$

$$\sigma \sim \exp(-|\Delta E|)^{*}$$

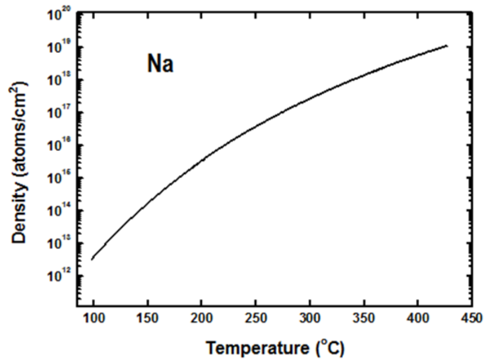
$$P \sim \exp(-\sigma n l)^{**}$$

- σ : Charge exchange cross section
- ΔE : Energy defect, depends on the species of an ion and atom
- n : Density of target vapor, depends on vapor temperature T_v
- l : Effective length of an ion in vapor, depends on a geometry of chamber

- Charge exchange cross section



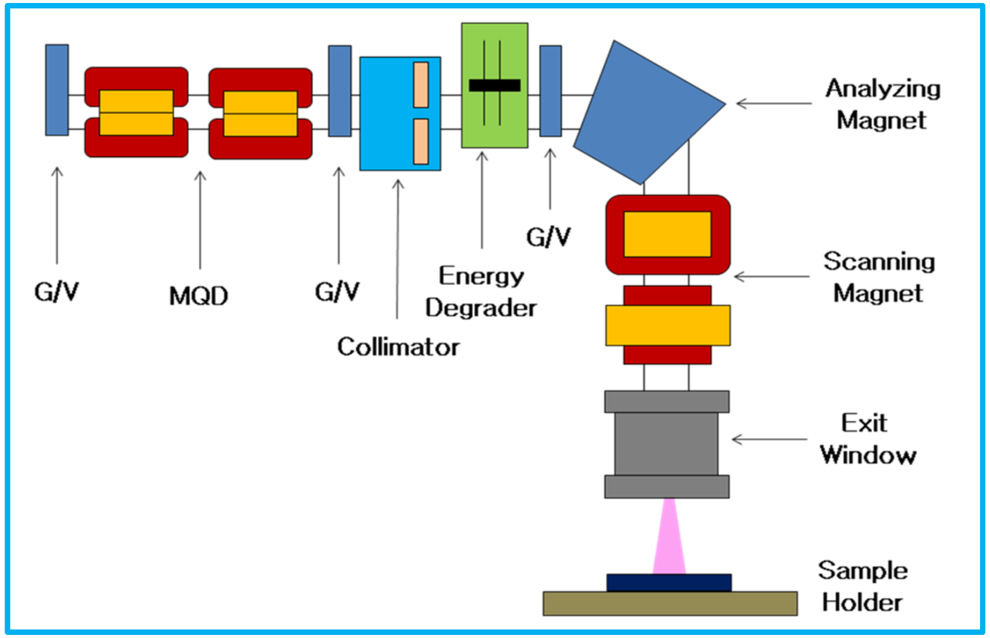
- Temperature dependency of vapor density



RISP Bio-Medical Science Facility

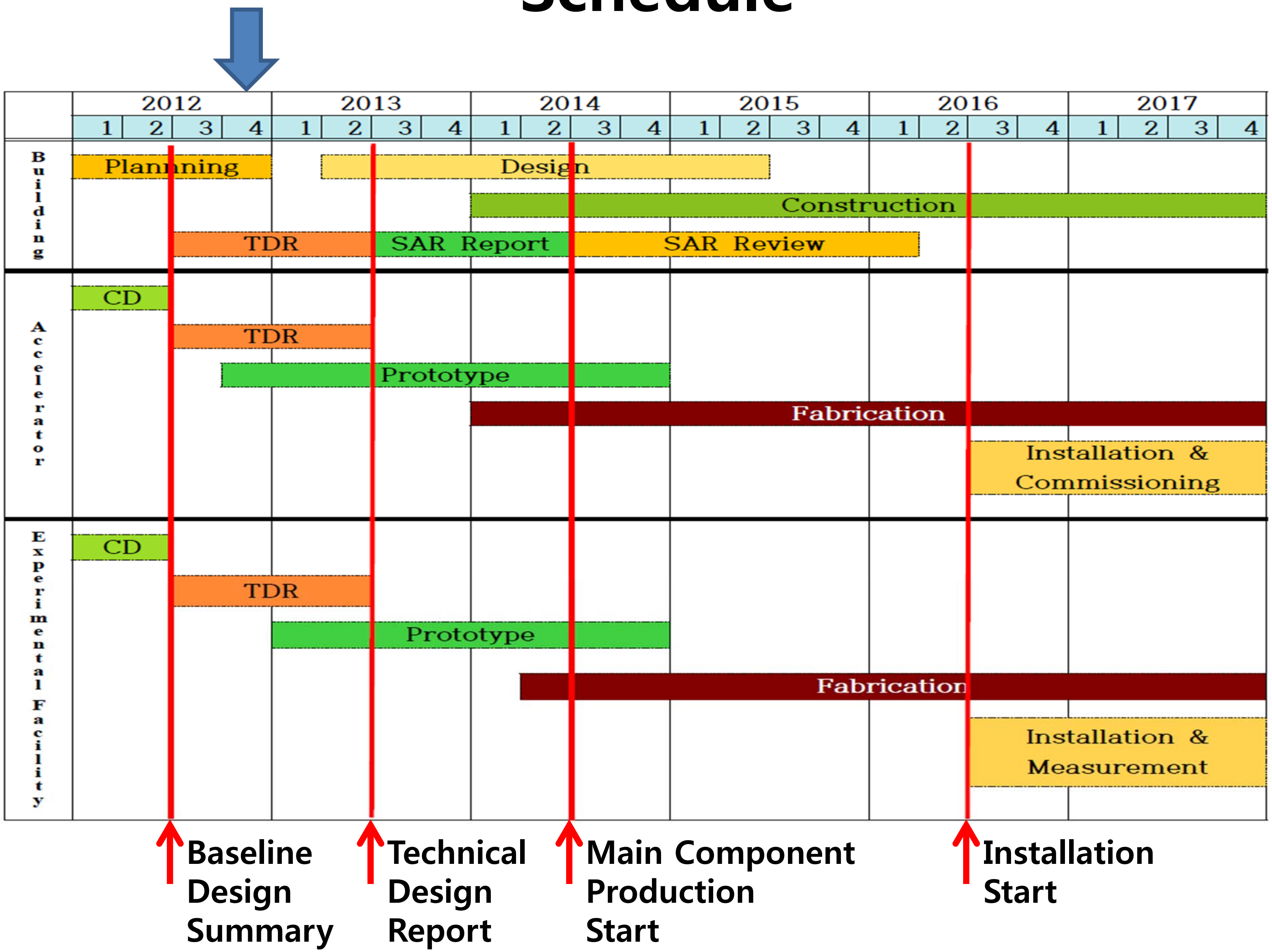
Applied beam line

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



2012
2013
2014
2015
2016
2017
1 2 3 4
Building
Planning
Design
Construction
TDR
SAR Report
SAR Review
Accelerator
CD
TDR
Prototype
Fabrication
Installation & Commissioning
Experimental Facility
CD
TDR
Prototype
Fabrication
Installation & Measurement
Baseline Design Summary
Technical Design Report
Main Component Production Start
Installation Start

Thank you for attention !

Question or comment ?