# Overview on the Rare Isotope Science Project in Korea

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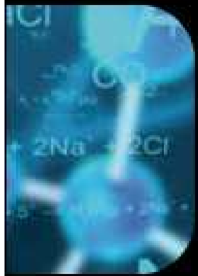
(Asia Pacific Center for Theoretical Physics)

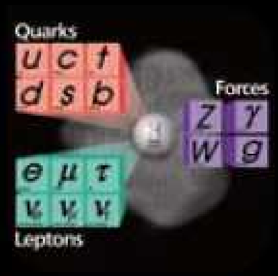
- IBS (Institute for Basic Science)

- RISP (Rare Isotope Science Project)

www.ibs.re.kr

# Institute for Basic Science






Excellence


Autonomy

Openness

Creativity

# History of IBS

## 2008

- Oct, 2008: ISBB Support Office kicks off.
- Feb, 2008: "Science Belt Development Plan" is established by the Science and Business Belt Task Force of the Presidential Transition Committee.

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## 2011

- Nov, 25th 2011: Dr. Se-Jung Oh is appointed as President of IBS.
- Nov, 2th 2011: IBS is registered as a legal entity.
- Sep, 22th 2011:"Basic Plan for IBS Establishment and Operation" is confirmed.
- June, 10th 2011: Administrative HQ of IBS opens.
- May, 16th 2011: The site for International Science and Business Belt (ISBB) is announced. "Fundamental Principles of IBS Establishment and Operation" is confirmed.
- April, 7th 2011: The Committee on ISBB kicks off with the selection of its founding members.
- April, 5th 2011: ISBB Planning Group kicks off.

## Vision and Purpose

### Vision

top-10 research institute in the basic sciences

### Purpose

world's top 10 institutes in terms of how frequently its academic papers are cited.

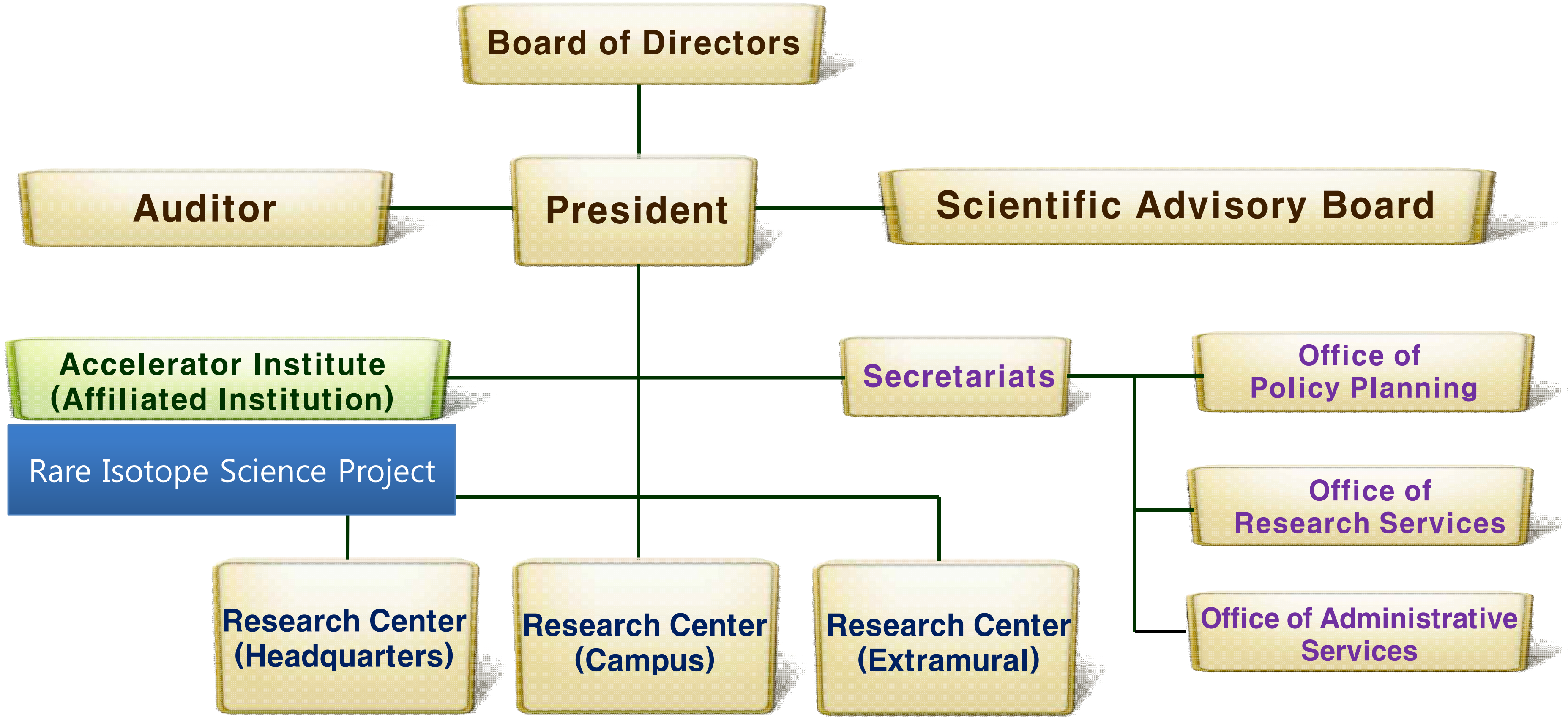
### Purpose

workplace for the world's leading scientists.

### Purpose

To become a hub to attract and train young scientists.

# Organization




- 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)

About IBS | Core Project | Information | News & Events

Research Group Configuration | Rare Isotope Accelerator


ABOUT IBS

## Location

## IBS's Organization

- IBS plans to develop into an institute with 3,000 researchers and staff based at 50 newly established research centers by 2017.
- Research centers will be located not only at the headquarters in Daejeon, but also in three of the leading campuses in Korea.
- Moreover, extramural research centers will be established at other universities and institutes in Korea and abroad that meet high standards of scientific excellence.

## Operation of Research Centers

- Directors (principal investigators) of IBS Research Centers are recruited through an open invitation process and recommendations from SAB (Scientific Advisory Board) based on the criteria of scientific excellence and future research proposals.
- Directors are given autonomy in researcher recruitment, budget administration and in how they operate their research centers.
- IBS research centers welcome enthusiastic and committed young scientists and researchers from other institutes to collaborate on IBS research projects.

# 10 IBS Research Center Directors Appointed

IBS Directors to Lead Innovation with Full Autonomy in Research Center Operation

*Press Release on May 8, 2012*

*Public Relations Division, MEST*

*Public Relations & Cooperation Team, IBS*

# Where?

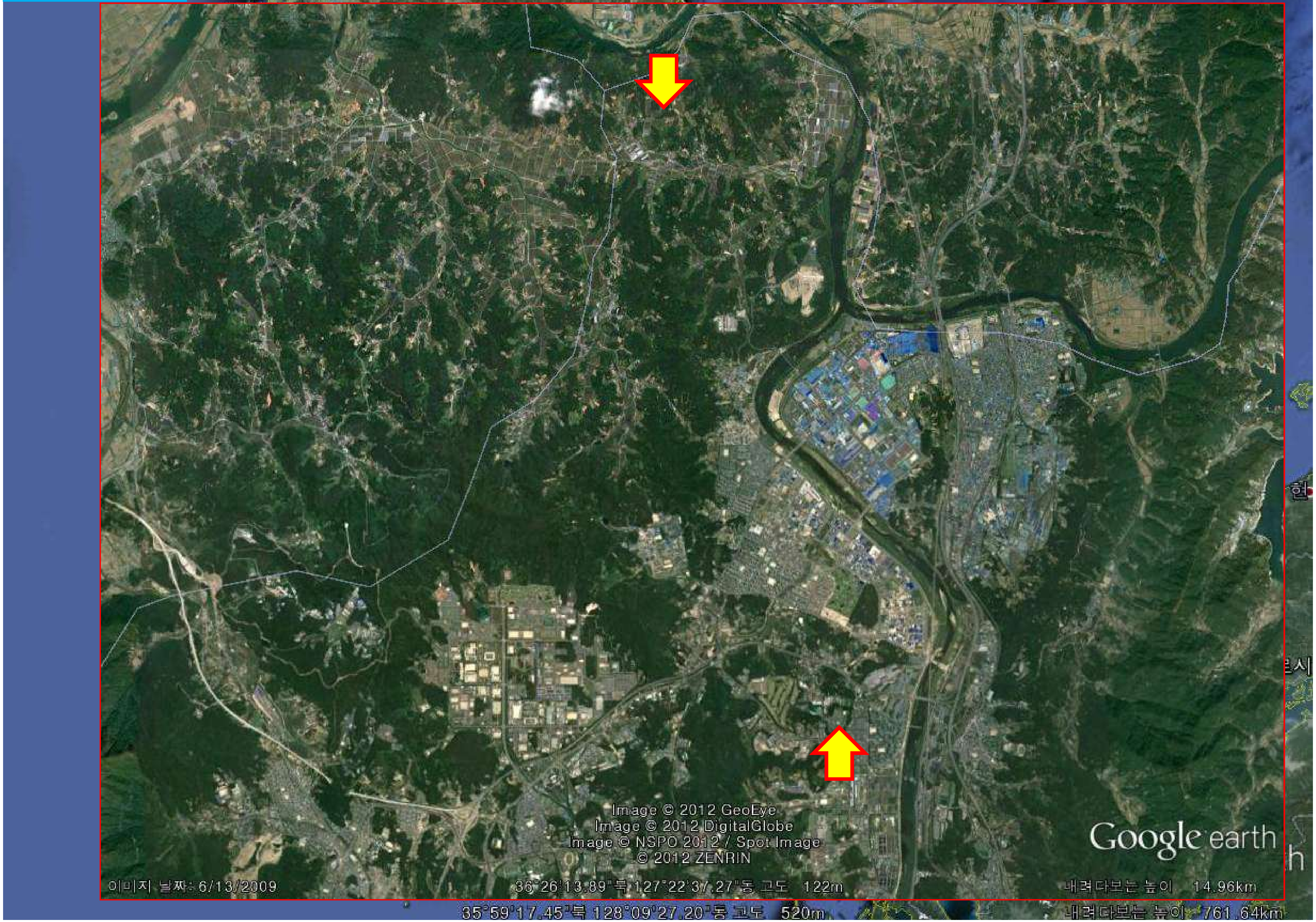


Image © 2012 GeoEye
Image © 2012 DigitalGlobe
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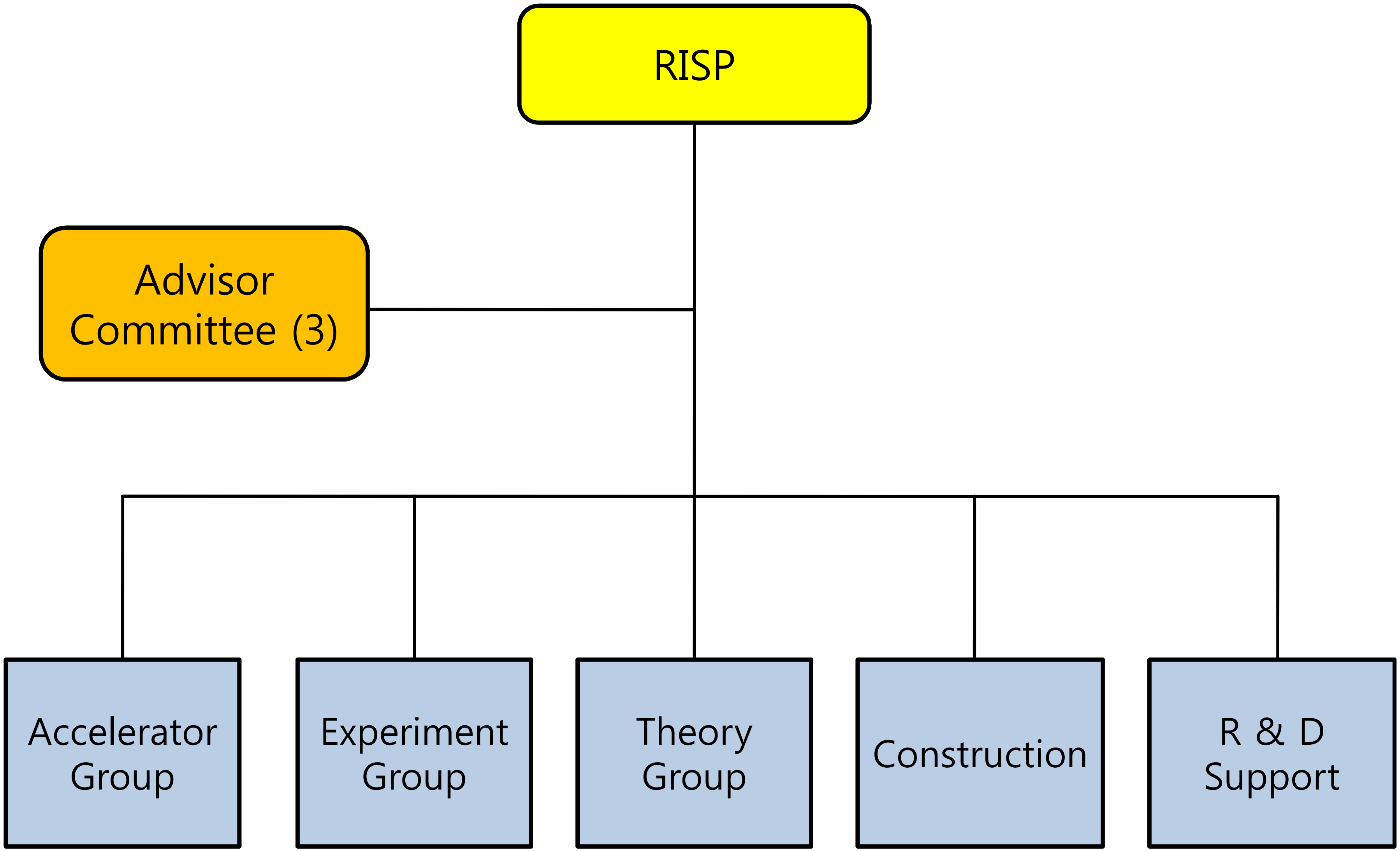
© 2012 ZENRIN
Google earth
이미지 날짜: 6/13/2009
36°26'13.89"북 127°22'37.27"동 고도 122m
내려다보는 높이 14.96km
35°59'17.45"북 128°09'27.20"동 고도 520m
내려다보는 높이 761.64km

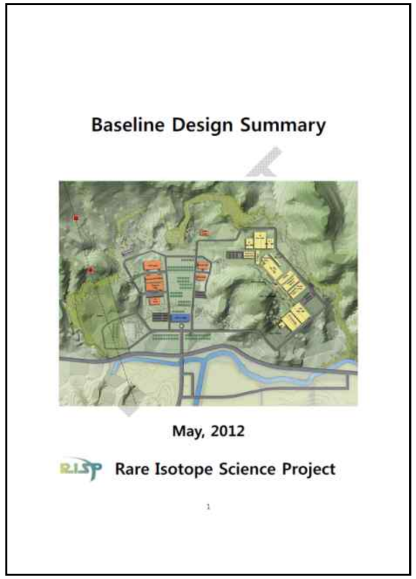
# Rare Isotope Science Project



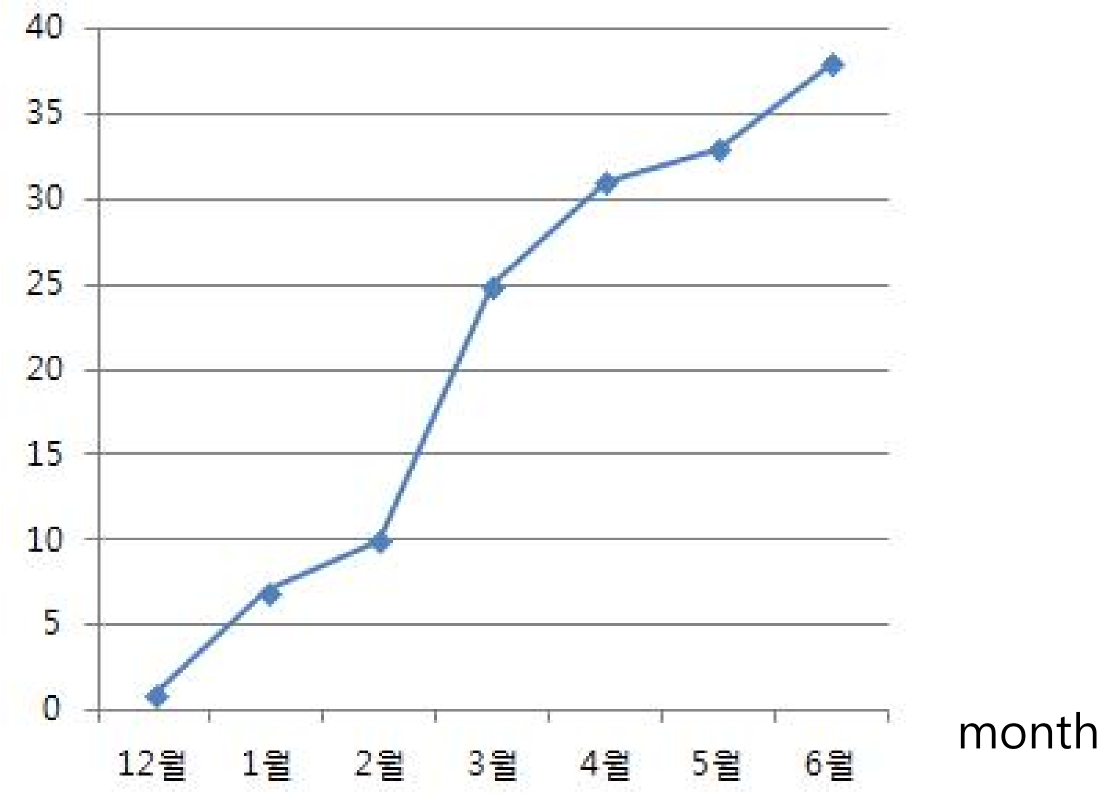

**As of June 7, 2012**

# 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)**
- RISP Workshop on accelerator systems (May 6 – 9, 2012)
- RISP Workshop on RI Physics Theory (May 11 – 12, 2012)
- TAC ( May 10, 2012)
- **Baseline Design Summary (by Jun 2012)**
- School on Nuclear Transport (July 3 – 8, 2012)
- RISP Workshop on Advanced Experimental Technology (July 16-18, 2012)
- IAC( July 26-7, 2012)
- **RISP School: Nuclear Structure (Oct. 19 – 20, 2012)**
- **Technical Design Report (by Jun. 2013)**

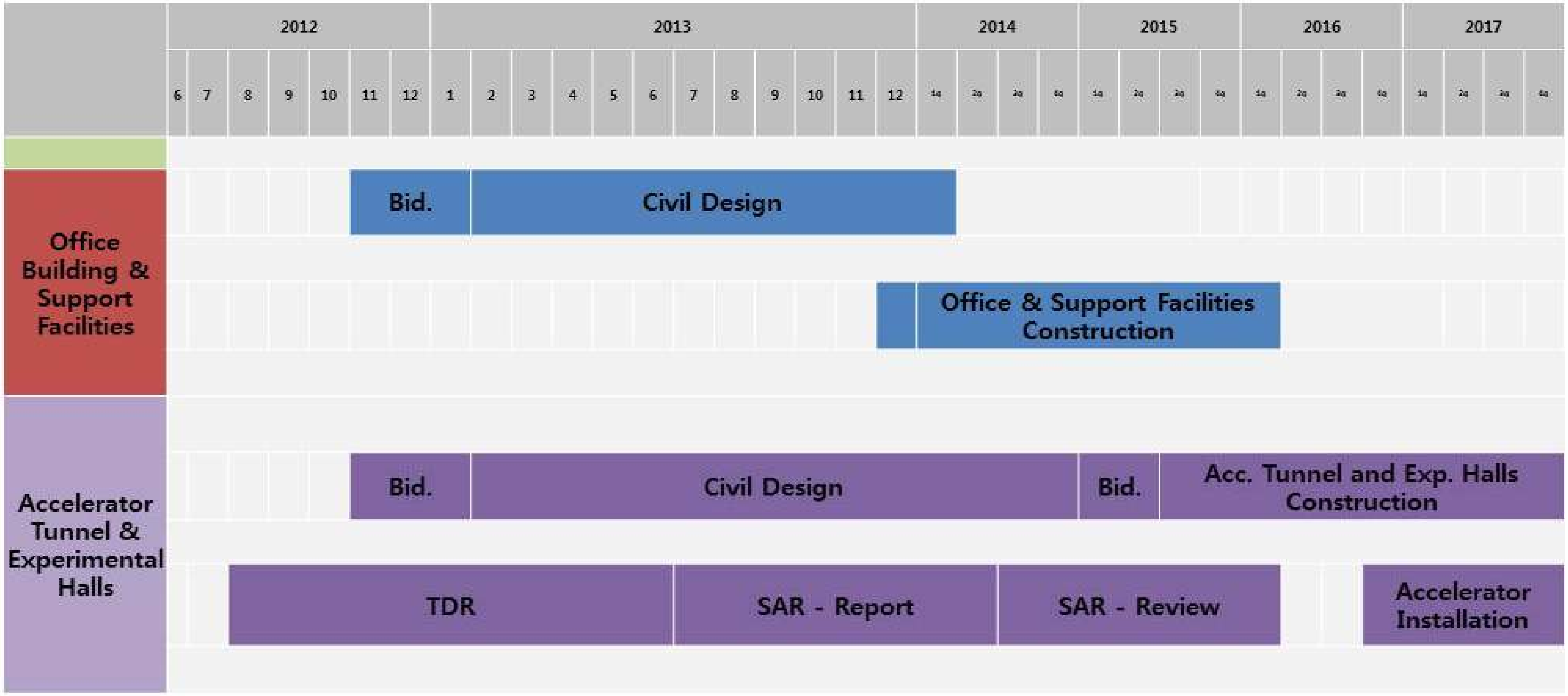


Number of people at RISP since last December




No theorists yet, but some from September 1, 2012

# Preliminary Schedule



# Rare Isotope Factory

- High intensity RI beam … ISOL & IF
  - 70kW ISOL from dir… …ission of $^{238}$U ind… …by 70MeV, 1mA p
  - 400kW IF by 200M… …/u, 8pμA $^{238}$U
- High energy, hi… intensity &… quality neutron-rich RI beams
  - $^{132}$Sn with … …o ~250M… …, up to 9x10$^{8}$ pps
- More exo… …RI be… …by ISOL+IF+ISOL(t…
- Simulta… …peration … …the maximum use of the facility

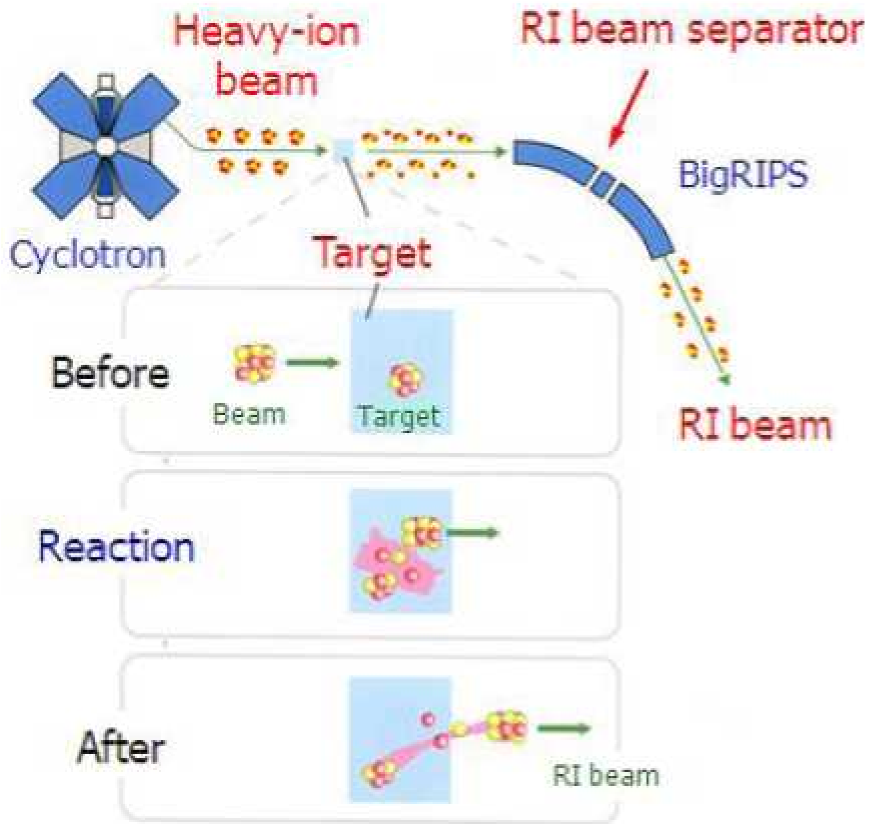
Varity of isotopes with high intensity

Upgradable to higher energy, higher current !

World leading RI science facility for next 20~30 years

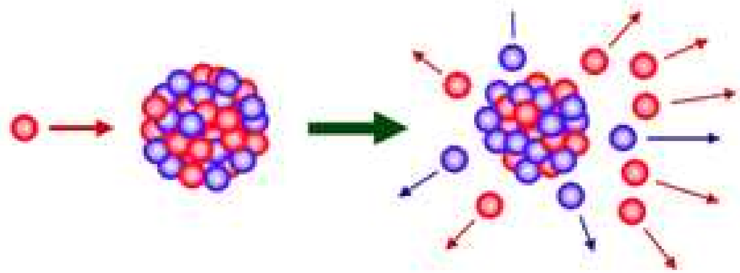
| Accelerator | Beam specification | Components |
|---|---|---|
| Driver Linac | p, 600 MeV,<br>$^{238}U^{+78}$, 200 MeV, 8 pμA | ECR-IS, LEBT, RFQ, MEBT, QWR, HWR, Charge Stripper, SSR1, SSR2 |
| Post Linac | RI, ~ 18 MeV/u | Charge Breeder, ECL-IS, LEBT RFQ, MEBT, QWR, HWR |
| Cyclotron | p, 70 MeV, 1mA | Cyclotron, Pulsed ion source, Charge Stripper, Beam line |

1. In-flight (IF) facilities: a high energy ion beam is fragmented in a suitable thin target and the reaction products are selected according to their A/q and momentum values and then transported to the secondary target.

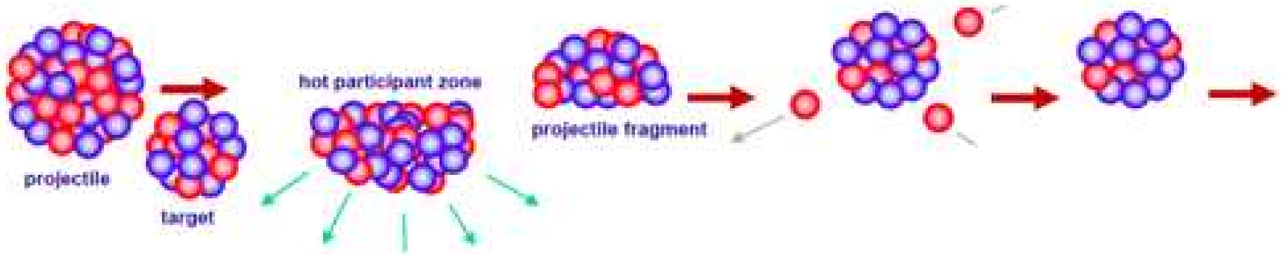


2. ISOL-type facilities: radioactive ions are produced at rest in a thick target either by direct bombardment with particles from a driver accelerator or via fission induced both by fast and thermal secondary neutrons.

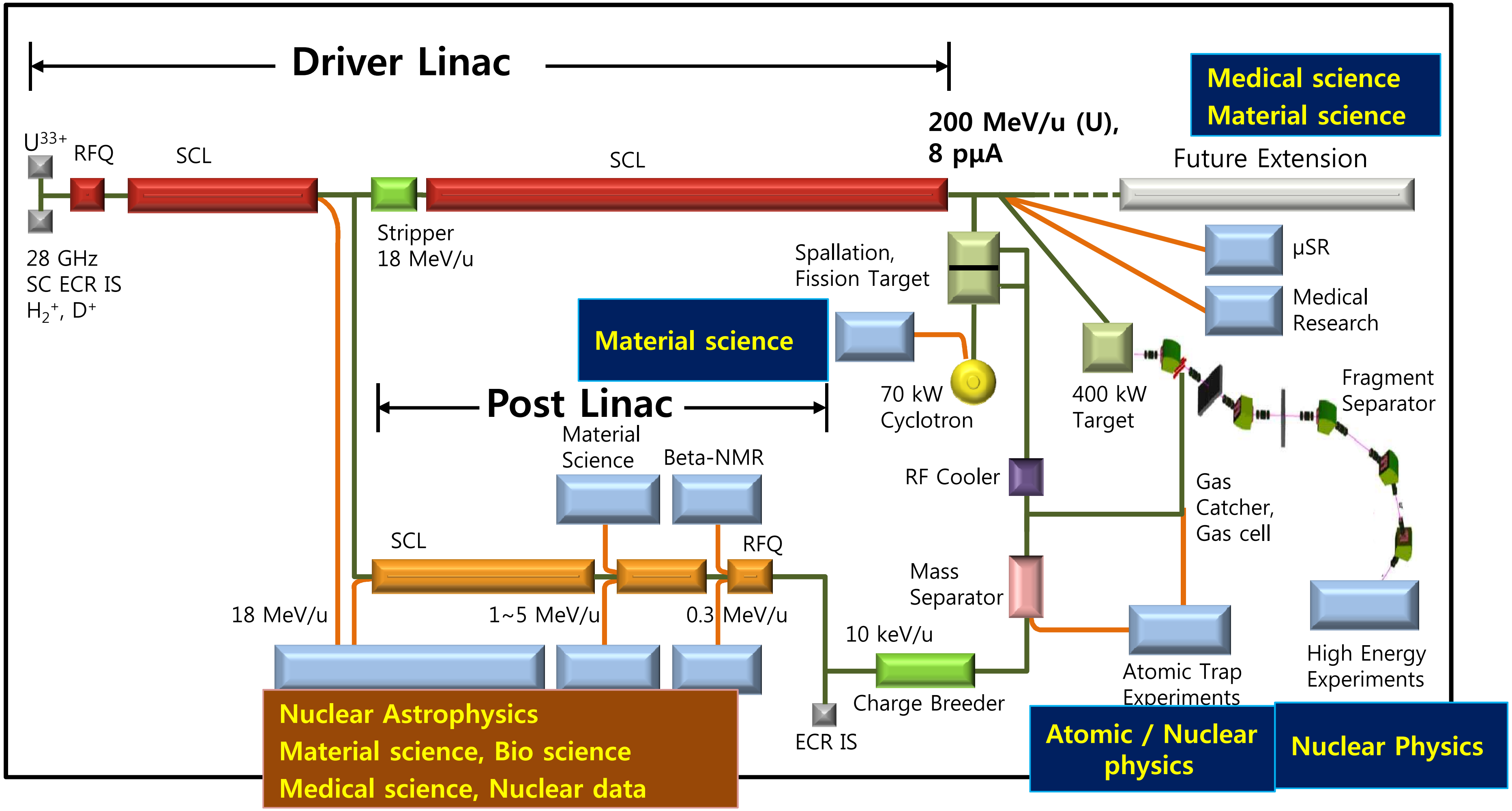
ISOL



IFF



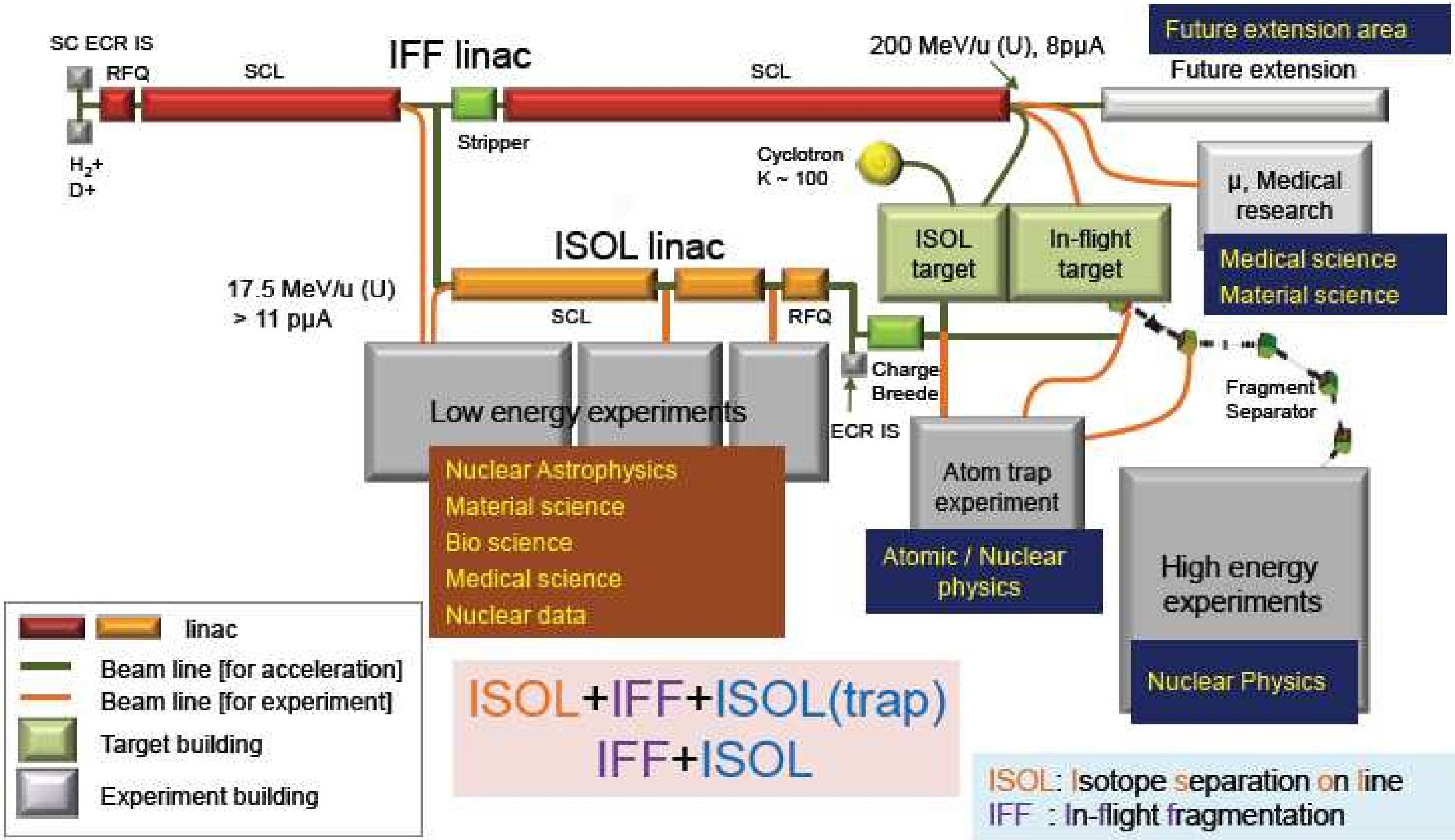
# Concept of the Accelerator Complex




SC Linac 200MeV/u for 238U, 600 MeV for p → IF driver, high power ISOL driver
Cyclotron 70 MeV for p → ISOL driver
SC Linac ISOL post accelerator 18 MeV/u

# Layout of KoRIA

For the basic and applied science with stable and unstable isotopes




ISOL+IFF+ISOL(trap)
IFF+ISOL

ISOL: Isotope separation on line
IFF : In-flight fragmentation

# 2011.12.26 – 2012.06.25

## Selected RI beam requirements for RISP

| RI Beam species | Energy Range | Desired Intensities [ particles / sec ] | Research fields |
|---|---|---|---|
| $^{80}$Ni, $^{76}$Fe, $^{132}$Sn, $^{144}$Xe | > 100 A MeV<br>5-20 A MeV | $> 10^{9}$<br>$> 10^{8}$ | Nuclear structure |
| $^{15}$O, $^{14}$O | < 10 A MeV<br>< 30 keV | **$> 10^{10-11}$**<br>$> 10^{8}$ | Nuclear astrophysics<br>Material Science |
| $^{26m}$Al | 5-20 A MeV | $> 10^{7-8}$ | Nuclear astrophysics |
| $^{45}$V | 0.613-2.25 A MeV | **$> 10^{7-9}$** | Nuclear astrophysics |
| $^{39}$Si, $^{36}$Mg | 5-10 A MeV | $> 10^{7-9}$ | Nuclear structure |
| $^{68}$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 |
| $^{8}$Li, $^{11}$Be, $^{17}$Ne | < 30 keV | $> 10^{8}$ | Material science |
| $^{133-140}$Sn | < 60 keV | > 1 | Atomic physics |
| $^{8}$B, $^{8}$Li, $^{9}$C, $^{11}$C, $^{15}$O | ≥ 400 A MeV | $>10^{7-9}$ | Medical and Bio science |

# 2011.12.26 – 2012.06.25

## Requests on beam characteristics for experiments

| Characteristic of beam | requirement | comments |
|---|---|---|
| Maximum Beam Energy | 250 AMeV for $^{132}Sn$ | - Symmetry energy |
| Minimum Beam Energy | ≤0.3 AMeV<br>(Min E from RFQ~0.5 AMeV) | - Nuclear astrophysics<br>- 0~1 AMeV is possible? |
| Energy Variability | 0.5% at <18 AMeV<br>(ex. 50 AkeV @ 10 AMeV)<br>1MeV at >18 MeV/nucleon | - Fast and precise beam energy changes for low energy beams (<5 AMeV) |
| Beam Energy Definition | 0.1% or better | - Beam-energy analysis spectrometer |
| Time Resolution | 0.5 ns/bunch (FWHM)<br>upper limit ~ 1 ns | - TOF measurement<br>- How about energy spread of the beam? |
| Time Structure:<br>pulse rate and chopping | - 100~200 ns (5~10 MHz)<br>- chopping 12 ns ~ 1 ms | - TOF measurement, 81.25 MHz (~12.3 ns) is high<br>- for LAMPS experiment<br>- for Beam ID, ~12.3 ns is OK. |
| Beam Sharing | - 5 ports for muSR<br>- 2 ports for beta-NMR<br>- low E nucl. Phys.+material sci. | - to use the beam time efficiently |
| Stable Beam Operation<br>at post-accelerator | - $10^{11-12}$ pps | - Setting up and calibrating instruments<br>- Reference points for studies with RIBs<br>- by-pass BT line for high E is required? |
| Beam Purity | single-isotope beams | |
| Beam Emittance and<br>Spot Size | 1~2 $\pi$ mm mrad<br>$2mm^2$ | - for RI beams from ISOL<br>- Is technically feasible? |

# Research subjects by using KoRIA

KoRIA User Community

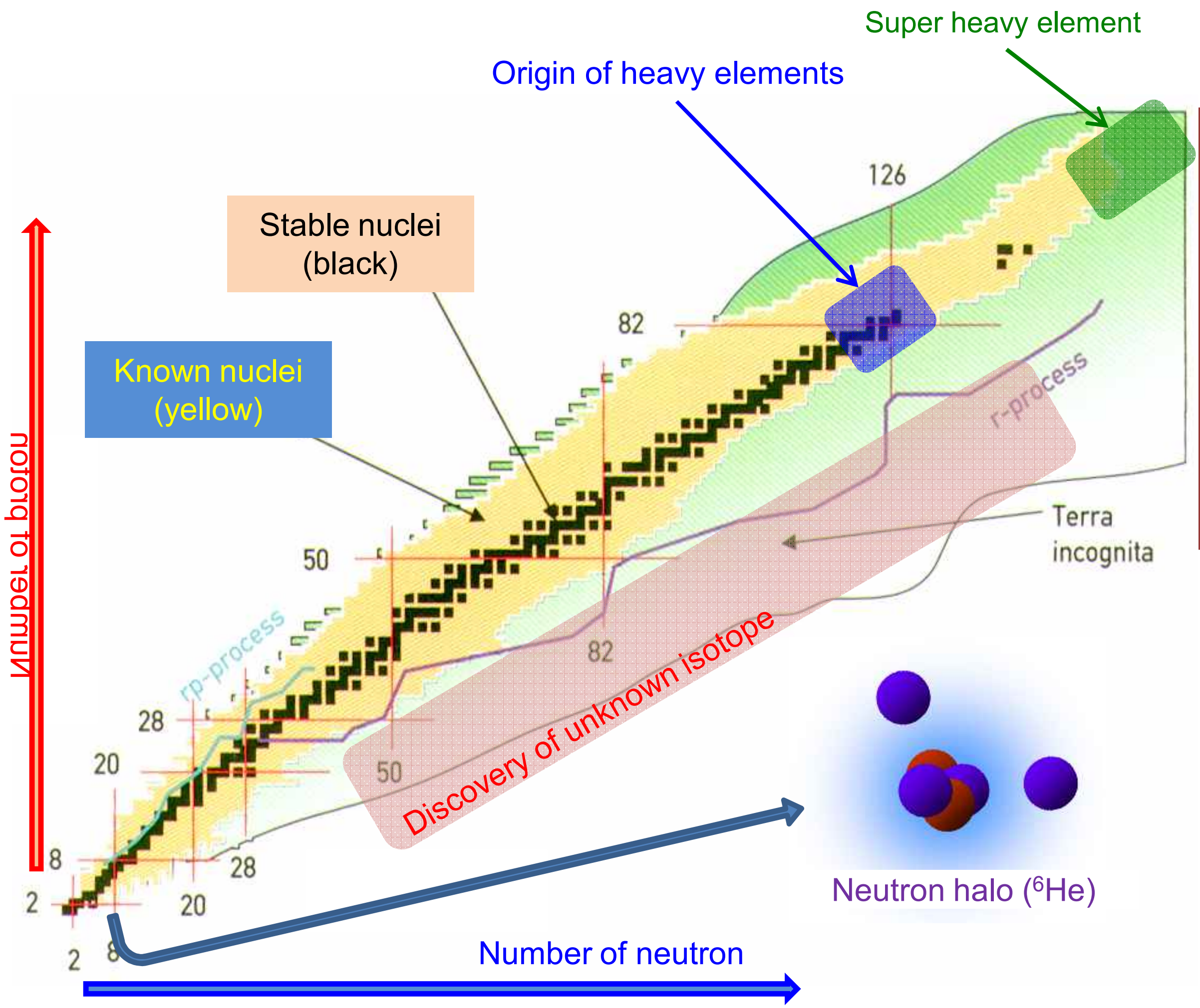
8 Working group

| | |
|---|---|
| Nuclear Structure | - Better understanding of system of nucleons at wide variation in the chart of nuclei |
| Nuclear Astrophysics & Nucleosynthesis | - To understand the role of unstable nuclei in the nucleosynthesis<br>- To understand the life cycle of a star and origin of elements |
| Nuclear Matter | - To understand symmetry energy, EOS of hot and dense nuclear matter and property of hadron at dense neutron region |
| Nuclear Theory | - To understand origin of matter to describe the history of the Universe<br>- To understand the matter by describing nuclear structure and reaction |
| Medical & Bio application | - Development of new cancer therapy using radioactive heavy ion beam<br>- To understand biological effect of tissue and DNA by RI beam |
| RI Material Research | - Development and utilization of new material<br>- To understand property of material by RI |
| Nuclear Data | - Nuclear data construction to develop future nuclear power technology<br>- Research for the radioactive waste transmutation |
| Atom traps for RI research | - To understand basic property of atom and nuclei<br>- Study of structure and characteristics of element and nuclei |

Research

# Nuclear structure

- To discover unknown isotopes
- Better understanding of system of nucleons at wide variation in the chart of nuclei




- ❖ To discover unknown isotope and study their properties
- ❖ To understand origin of heavy element
- ❖ Superheavy element (ex. Koreanium?)
- ❖ To study unknown nuclear structure (ex. neutron halo)

❖ In periodic table
- Elements: ~100
- Stable isotopes: ~300
- Unstable isotopes: ~ 3000

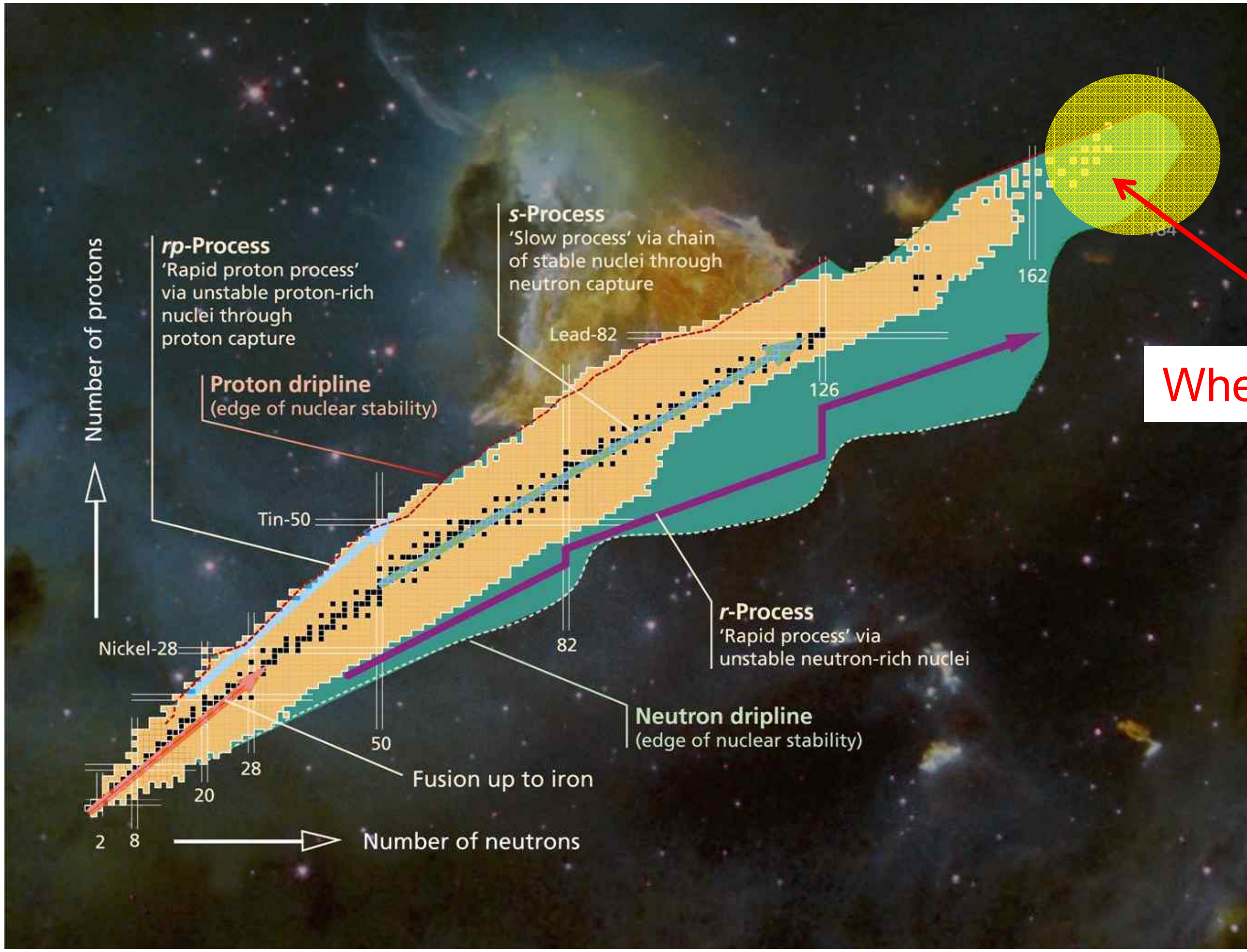
➢ Unknown isotopes: about 3000~6000 estimated

KoRIA user community

# Synthesis of the superheavy elements

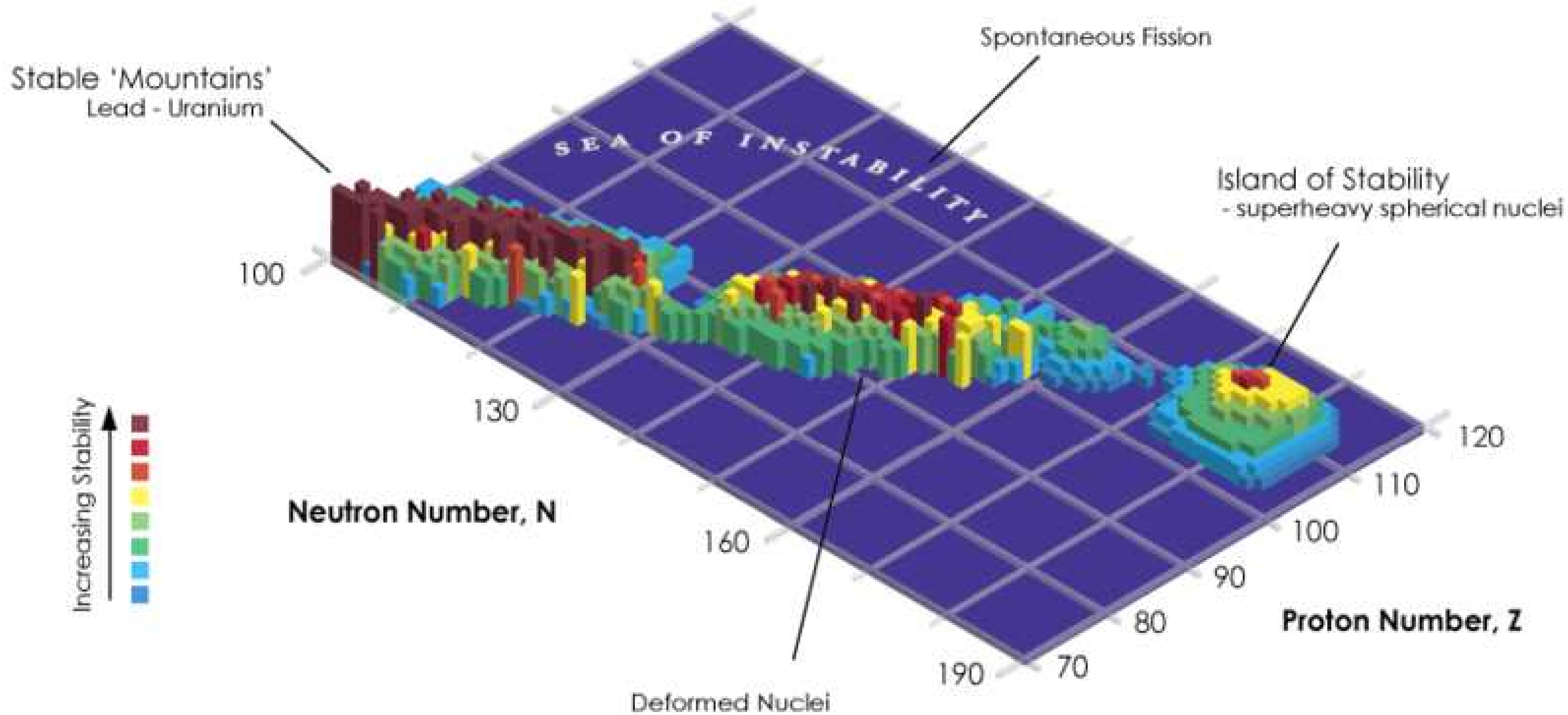
proves

- long-held nuclear theories regarding the existence of the "island of stability",
- the ultimate limits of the periodic table of the elements and
- how nuclei are held together and how they resist the fission process.



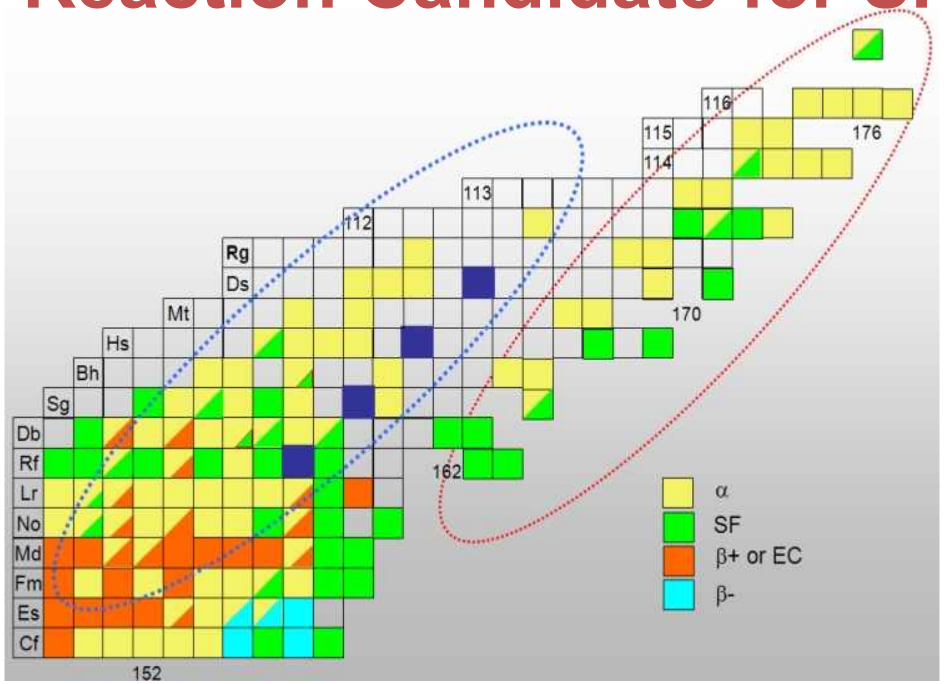

Where is the ultimate limit ?

KoRIA user community




WIKIPEDIA
The Free Encyclopedia

# Reaction Candidate for SHE synthesis




5~20 events were observed

**Blue : by cold fusion reaction : GSI, RIKEN**
(~350MeV, ~0.5 pμA)

$^{209}Bi + ^{64}Ni \rightarrow ^{272}111 + n$
$^{209}Bi + ^{70}Zn \rightarrow ^{278}113 + n$
*J. Phys. Soc. Jpn 76 043201 (2007)
$^{208}Pb + ^{76}Ge \rightarrow ^{283}114 + n$
$^{209}Bi + ^{76}Ge \rightarrow ^{284}115 + n$

$\sigma \sim 1$ pb

**Red: by hot fusion reaction : Dubna**
(actinide target) + $^{48}Ca$ (~250 MeV, 1 pμA)→ 111 ~ 118

$^{238}U + ^{48}Ca \rightarrow 112 + xn$
$^{242}Pu + ^{48}Ca \rightarrow ^{287}114 + xn$
$^{248}Cm + ^{48}Ca \rightarrow ^{292}116 + xn$
*PRC 74, 044602 (2006)

**Reaction Candidate for SHE @ KoRIA**

candidates of hot fusion reactions (using actinide target) grater than 115 are better to produce because of its high cross sections rather than cold fusion.

**(Actinide target) + (Intense Fe, Ni beam)**
**→ 116 ~ 122**

$^{232}Th + ^{58}Fe \rightarrow ^{290-x}\mathbf{116} + xn$
$^{232}Th + ^{64}Ni \rightarrow ^{296-x}\mathbf{118} + xn$
$^{244}Pu + ^{58}Fe \rightarrow ^{299}\mathbf{120} + 3n$
$^{238}U + ^{64}Ni \rightarrow ^{299}\mathbf{120} + 3n$

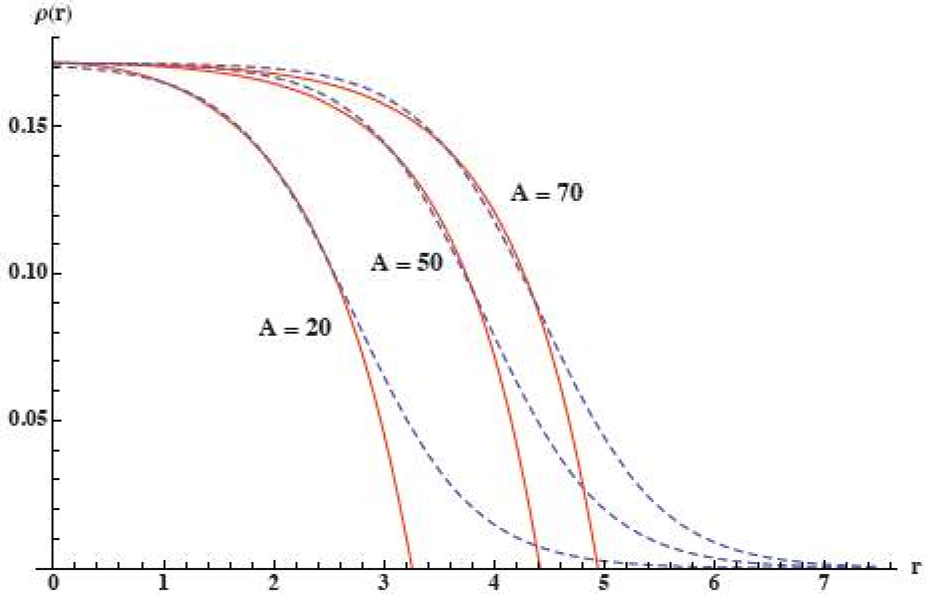
**Yield Estimation (rough)** $^{232}Th + ^{64}Ni \longrightarrow ^{296-x}118 + xn$

- Cross Section (σ): 1 pb (assumed)
- Target Thickness (T): **0.4**mg/cm$^2$
- Beam intensity(I): ~ **20** pμA
- Total efficiency(ε): **0.8**

**-> Y/s = ε x σ x T x I ~** **1 event / day**

KoRIA user community

Baryon number density profile in a stringy model




$$\sqrt{\frac{1}{r_0}\int_0^{r_0} |\rho_1(r) - \rho_2(r)|^2 dr}$$

| $A$ | $1/z_m$ |
|---|---|
| 20 | 72.8 MeV |
| 30 | 77.5 MeV |
| 50 | 79.0 MeV |
| 70 | 78.5 MeV |
| 100 | 77.0 MeV |

Note that in the hard wall model $1/z_m$ is about 300 MeV.
So, confinement scale in free space and inside nuclei are different.

Kyung Kiu Kim, Yumi Ko, YK, JHEP 1010 (2010) 039

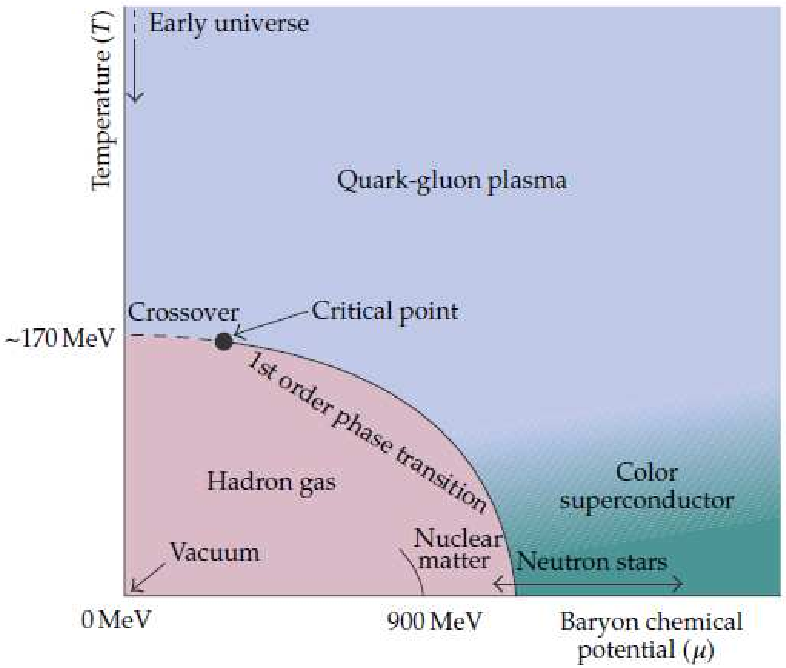
Research

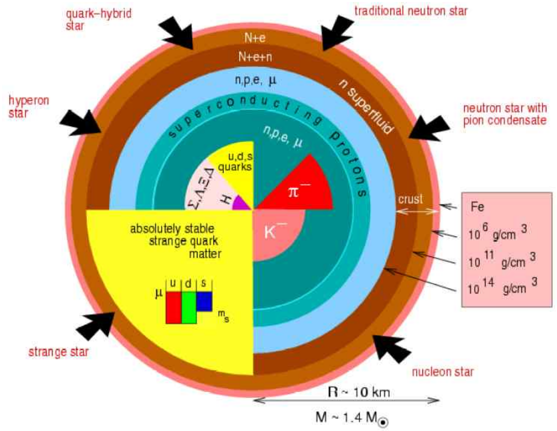

# Nuclear matter

➢ To understand the origin of matter, its evolution and overall structure of the universe

- Symmetry Energy of nuclei far from stability
  - Neutron skin thickness, isovector giant dipole resonance,...
  - Phenomena of symmetry violation (ex, parity)
  - The explosion of supernovae and formation of neutron star
  - Inner structure of neutron star

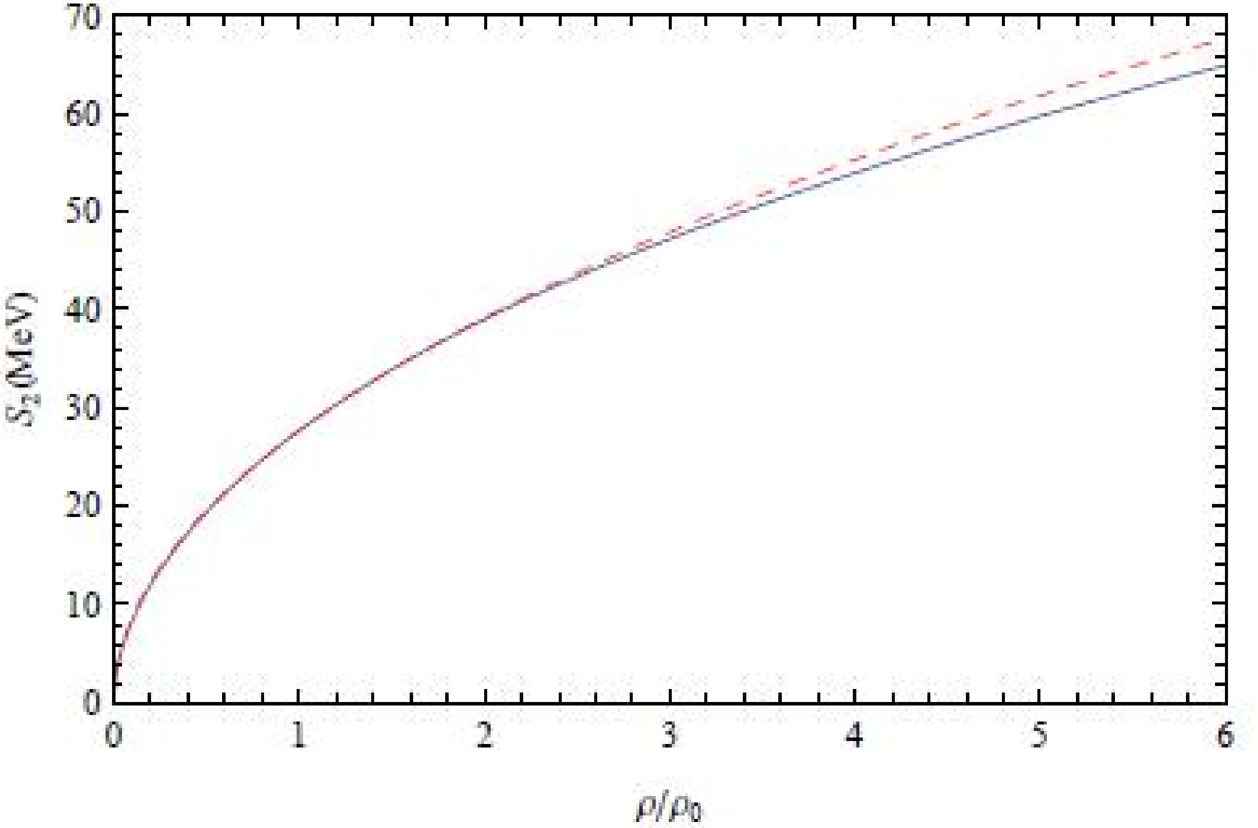
  …
- Heavy ion flows
- Property of hadron at dense neutron region
- Equation of state (EOS) for hot and dense nuclear matter



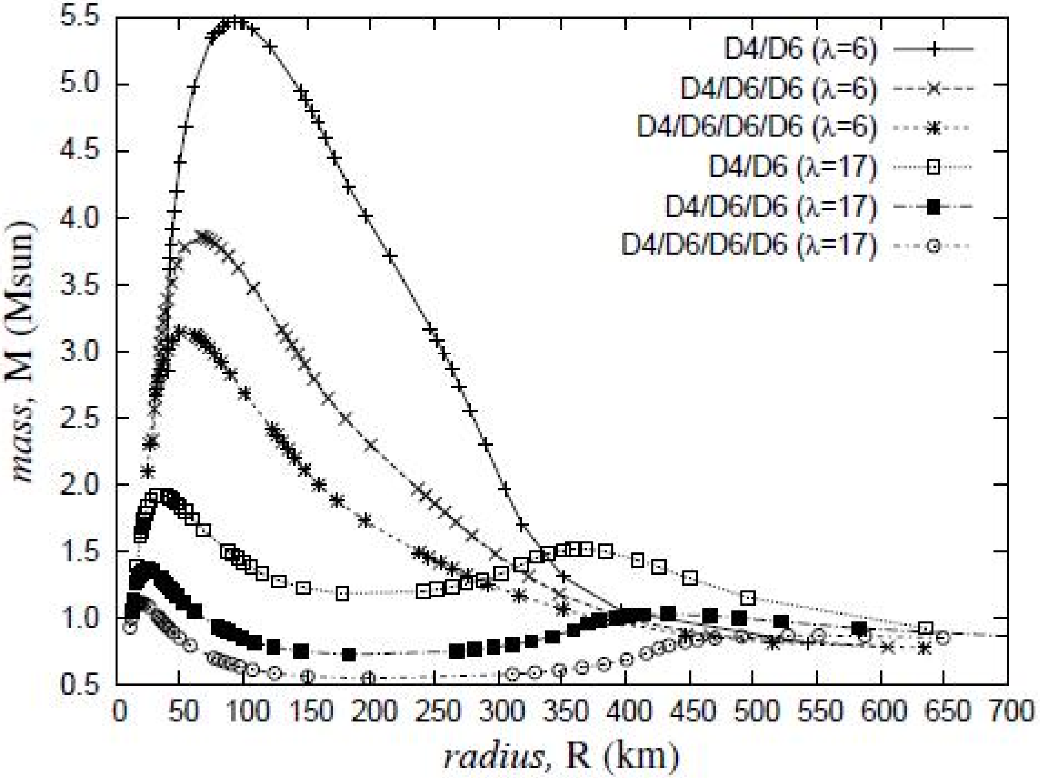

KoRIA user community

Symmetry energy in D4/D6 model




YK, Y. Seo, I. J. Shin, and S.-J. Sin, JHEP 1106:011,2011

Holographic EOS and compact stars




YK, Chang-Hwan Lee, Ik Jae Shin, Mew-Bing Wan, JHEP 1110 (2011) 111

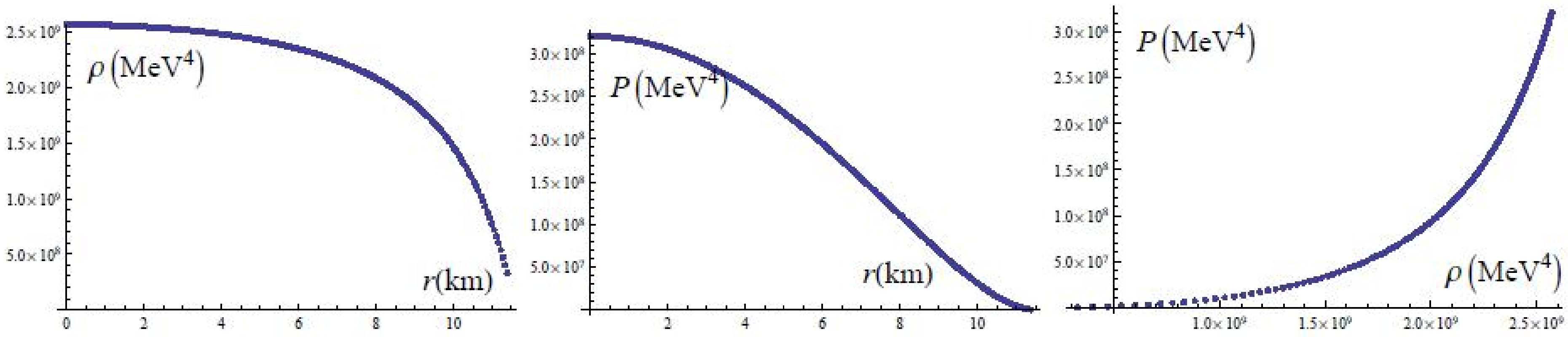


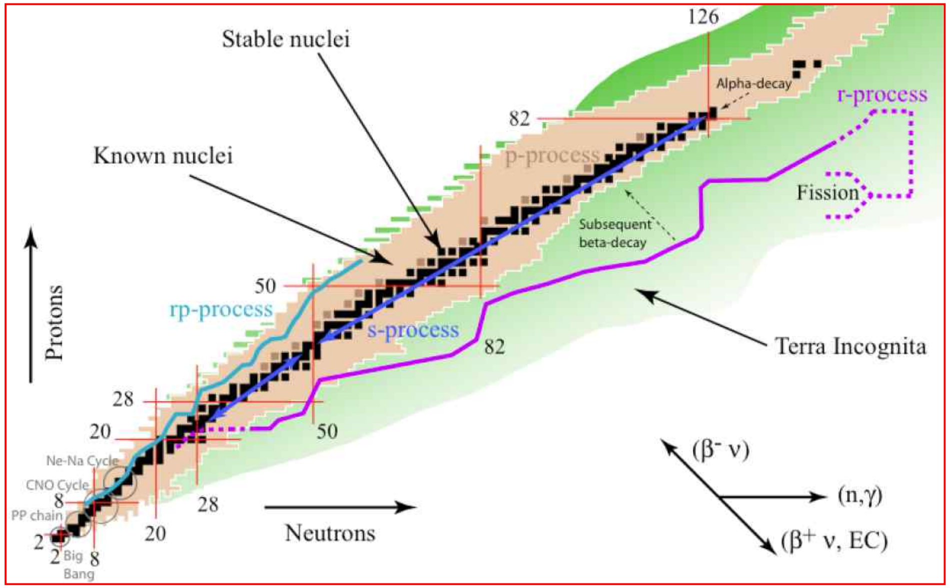

**Figure 3:** Energy density, pressure and equation of state for $\rho_c = 2.5713 \times 10^9\,\mathrm{MeV}^4$ and $P_c = 3.2141 \times 10^8\,\mathrm{MeV}^4$ with surface energy density $3.26 \times 10^8\,\mathrm{MeV}^4$. This configuration provides a star of the radius $11.45\,\mathrm{km}$ and the mass $1.26\,M_\odot$.

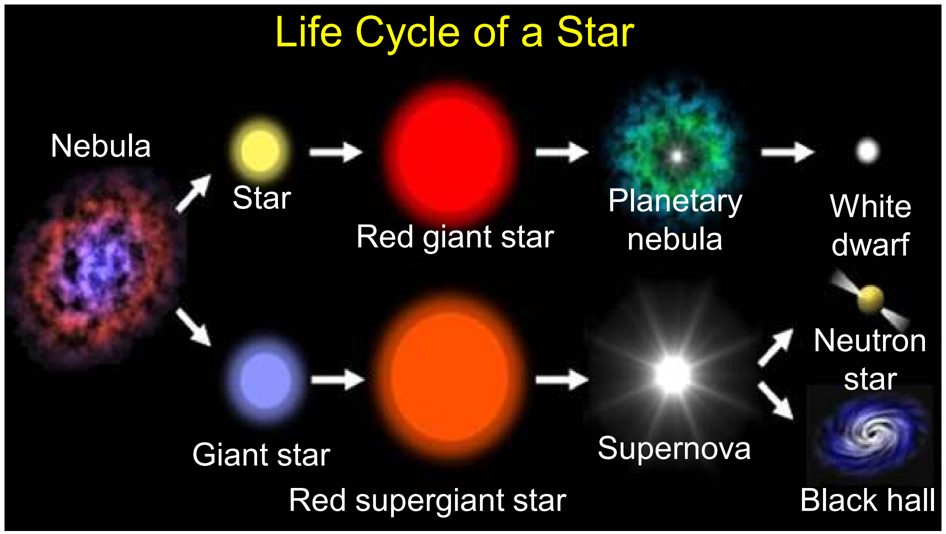

Kyung Kiu Kim, YK, Ik Jae Shin,
"Equations of state and compact stars in gauge/gravity duality," arXiv:1206.4421[hep-ph].

Research

# Nuclear astrophysics

➢ To understand the role of unstable nuclei in the nucleosynthesis




1) Study of the abundances and formation processes of elements in the stars

2) Identifying the formation process of energy generated in the stars

3) Identifying the structure of extreme neutron rich nuclides regarded as existing in the neutron star or super giant stars and their properties

Synthesis of light nuclei

Synthesis of heavy nuclei

KoRIA user community

# Study of the nucleosynthesis of the n-rich nuclides by r-process around 50<N<82

The r-process is very important to explain the nucleosynthesis mechanism, abundance of the chemical elements, and nuclear structure, and it happens in a region of very exotic nuclei.

- <u>Basic parameters for r-process</u>

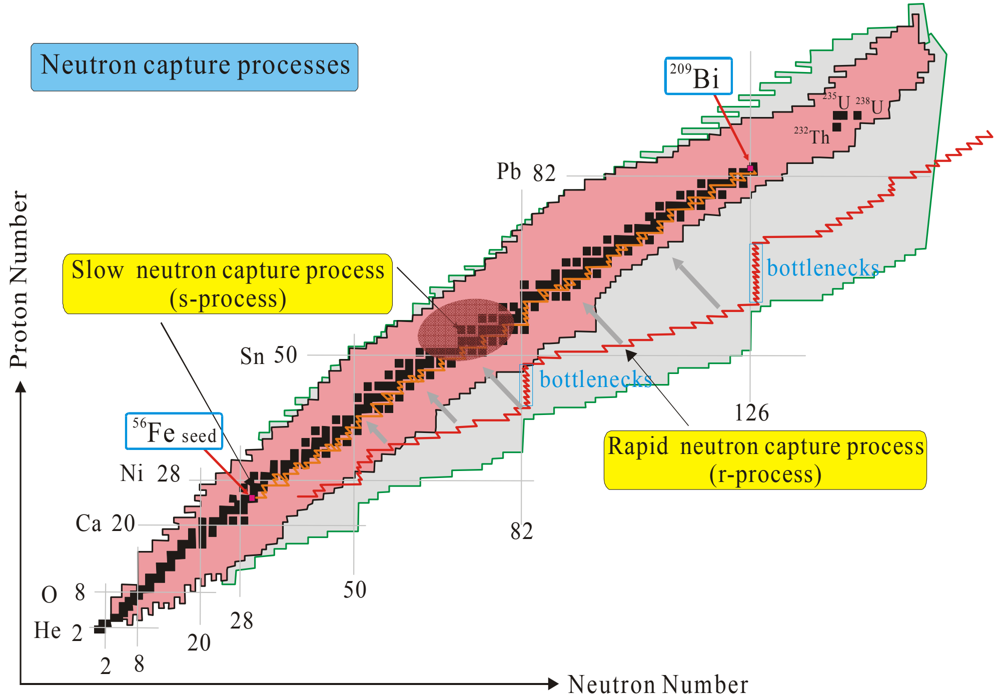
Half-lives（$T_{1/2}$）
→ abundance
→ process speed

Cross sections
→ location of the path
Masses ($A$, $Q_\beta$)
Resonances
Continuum

beta-delayed neutron（$P_n$）
→ final abundances

- Why 50<N<82

→ The model underestimate the abundance by one order in A~100
→ corrected under assumption of a reduction of shell gap in n-rich nuclide
→ Introduce new double magic nucleus $^{110}$Zr (p=40, n=70) which is theoretically expected in n-rich region
* NPA 693, 282(2001)

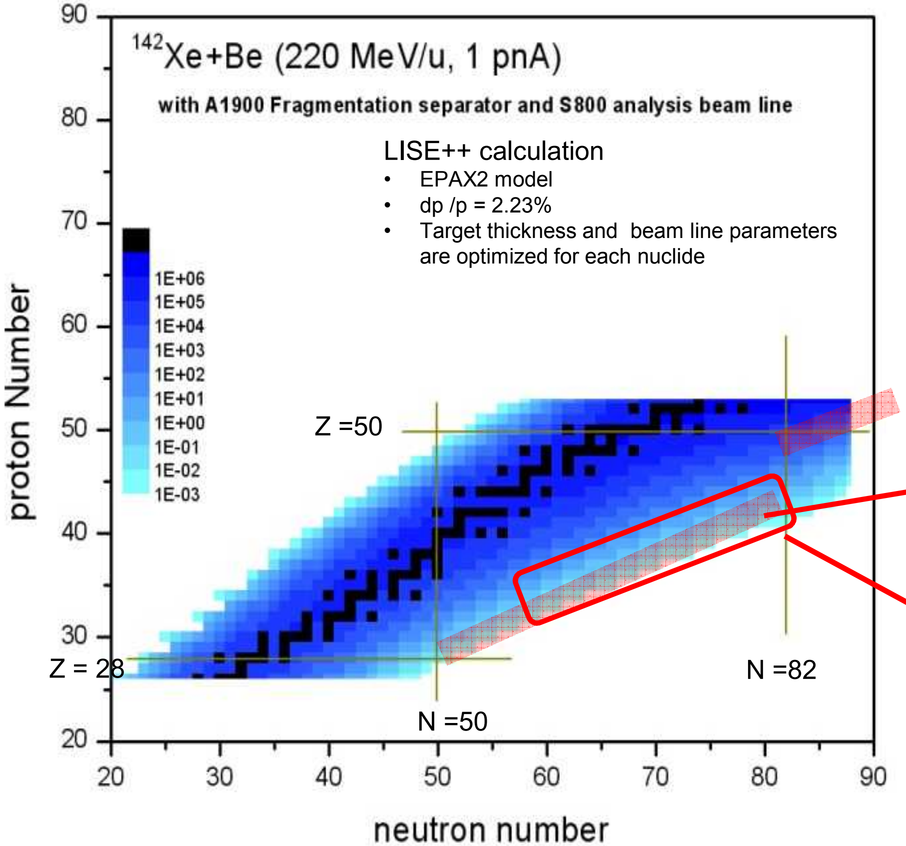


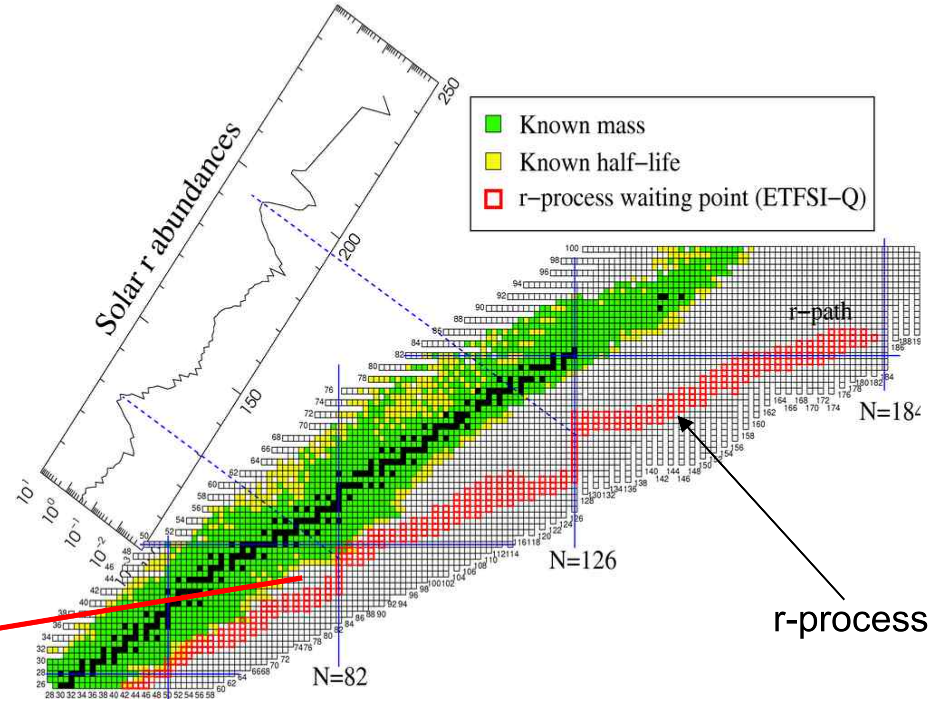

The first experiment will be to measure β-decay properties of nuclei in the neighbourhood of $^{110}$Zr to investigate its possible spherical character arising from new semi-magic numbers : Half-lives, $P_n$ of neutron-rich of Y, Zr, Nb, Mo, Tc, etc.

✓ NSCL reported the measurement of $T_{1/2}$ and $P_n$ of $^{100\text{-}105}$Y, $^{103\text{-}107}$Zr, $^{106\text{-}109}$Nb, $^{108\text{-}111}$Mo and $^{109\text{-}113}$Tc with $^{136}$Xe (120 MeV/u, 1.5 pnA)+ Be– PRC 79, 035806 (2009)

We will investigate the more neutron-rich isotope near to r-process waiting point $^{110}$Y, $^{110}$Zr, $^{114}$Nb, $^{116}$Mo, $^{118}$Tc with $^{142}$Xe (220 MeV/u, 1pnA).

# Production of more-exotic medium mass n-rich RI




Korea RI Accelerator could reach new n-rich isotope with rates of $10^{-3}$-10 pps.

$^{142}$Xe (ISOL) → post-accelerator → re-accelerator → In-flight target → Fragmentation separator → experiments

| nuclide | Estimated Intensity (pps) |
|---|---|
| $^{110}$Y | 1.8 |
| $^{110}$Zr | 1.8 |
| $^{114}$Nb | 1.1 |
| $^{116}$Mo | 3.8 |
| $^{118}$Tc | 1.4 |

Note that ~$10^3$ times higher than $^{136}$Xe (350 MeV/u, 10 pnA)+Be.

# Facilities for the scientific researches

- Design of the experimental facilities in conceptual level
- User training program with the international collaboration

| | |
|---|---|
| Nuclear Structure → | Multi-Purpose Spectrometer |
| Nuclear Matter → | Large Acceptance Multi-Purpose Spectrometer (LAMPS) |
| Nuclear Astrophysics → | KoRIA Recoil Spectrometer (KRS) |
| Atomic physics → | Atom & Ion Trap System |
| Nuclear data by fast neutrons → | neutron Time-of-Flight (n-ToF) |
| Material science → | B-NMR/NQR<br>Elastic Recoil Detection (ERD)<br>Laser Selective Ionizer |
| Medical and Bio sciences → | Heavy Ion Therapy<br>Irradiation Facility |

KoRIA user community

Facility

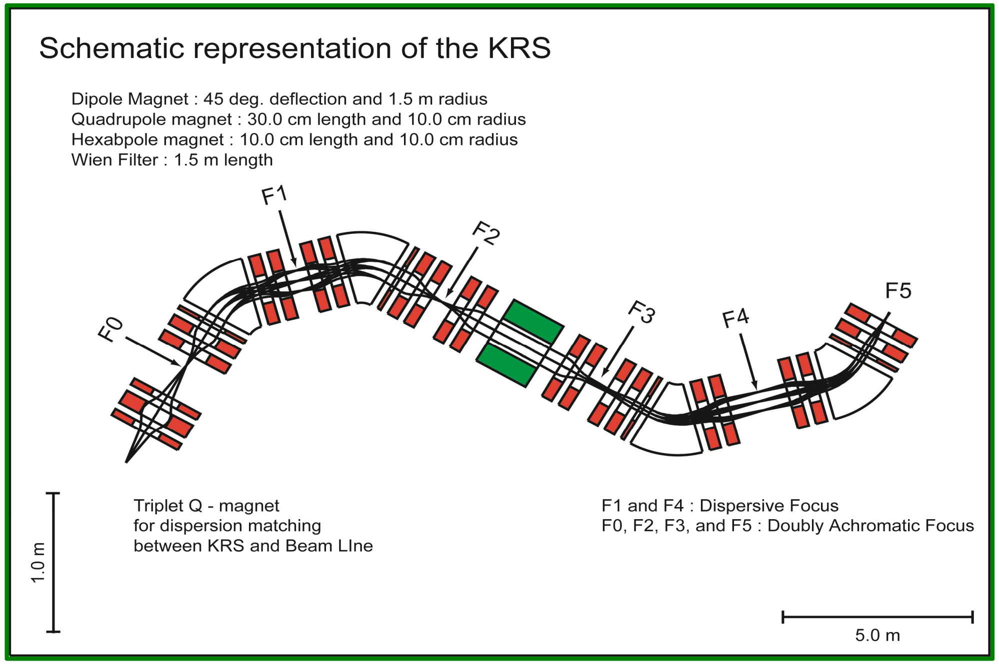
# Nuclear astrophysics

## KoRIA Recoil Spectrometer (KRS)

Beam transport system
with performance of high efficient, high selective and high resolution spectrometer

**Configuration**
Length: ~25 m
Space : 20 X 5 $m^2$

1) 4 dipole magnets
2) 20 quadruple magnets
3) 4 hexapole magnets
4) velocity filter (Wien filter)




| | RMS mode (recoil mass separator) | IRIS mode (In-flight RI separator) | BT mode (beam transport) |
|---|---|---|---|
| Main purpose | • **direct measurements of capture reaction (p,γ) and (α,γ)** | • in-flight RI beam separation using stable or RI beam from KoRIA + spectrometer<br>• **production of more exotic beams** | • **beam transport from KoRIA to the focal plane of KRS** |
| Requirements | • background reduction<br>• high mass resolution (M/ΔM)<br>• large angular acceptance<br>• highly efficient detection system | • large angular acceptance<br>• high-density production target system<br>• high-quality beam (high purity, low emittance, high intensity) | • 100% transport efficiency |

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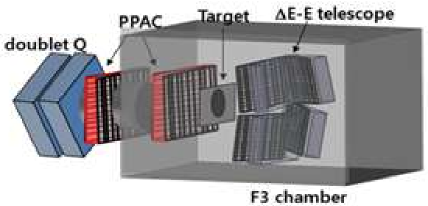
## Target System


Supersonic jet gas target developed in GSI

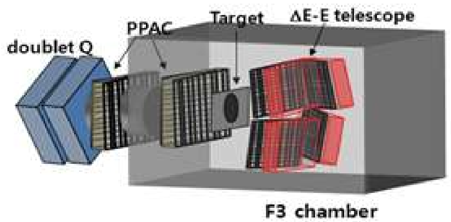
## Beam Tracking at F0 & F3


| | MCP | PPAC & MWPC |
|---|---|---|
| Multiple scattering | ~0.1 mrad | ~0.05 mrad |
| Counting rate | > 1 MHz | > 2MHz |

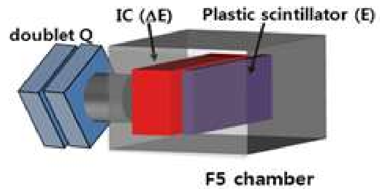



Energy loss: < 1 MeV

## Particle Detection at F3 & F5



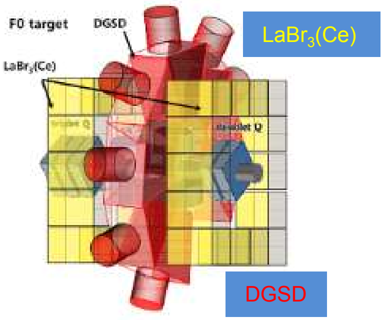

50 keV (FWHM) @ 5 MeV α-particle

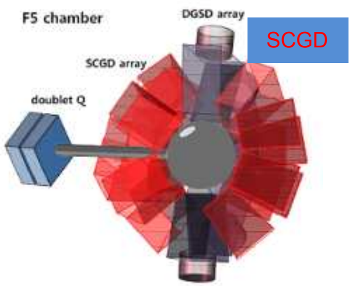



PID for low-energy recoil particle

## Gamma-ray Detection at F0 & F5

ε~ 20 % @ 2 MeV γ-ray

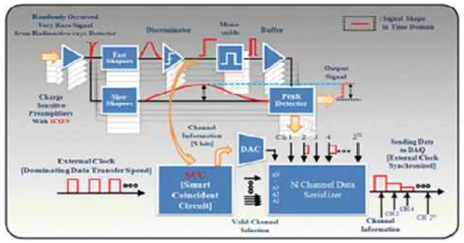



Position resolution : < 1 mm

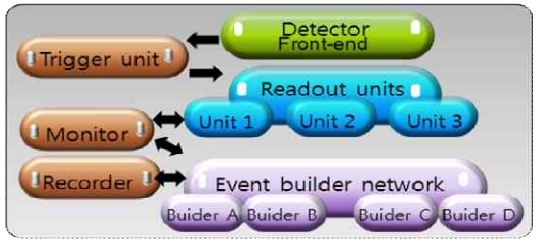
## Front-end electronics

$10^5$ Channels



## DAQ

> 2 GHz high frequency

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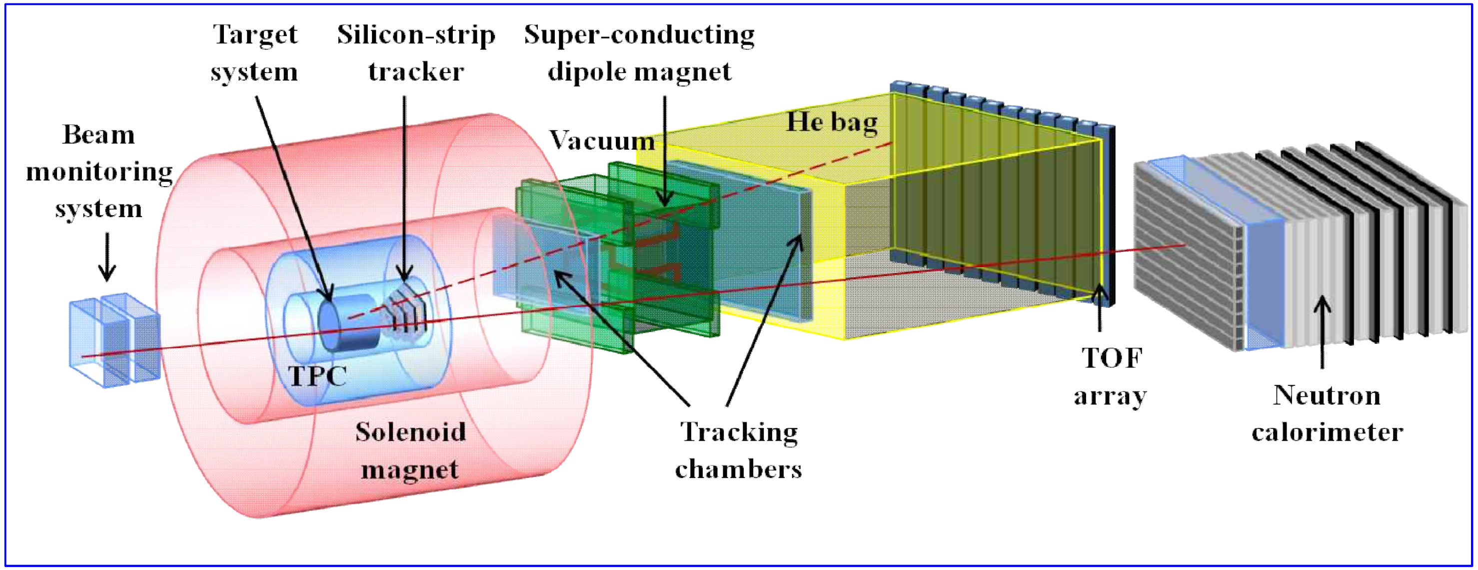
# Nuclear matter



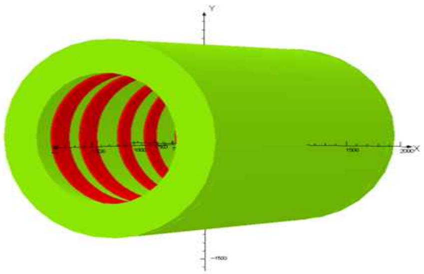

Large acceptance:
> 3π Sr

Multipurpose:
Charged & neutral particle detection

High detection efficiency of particle

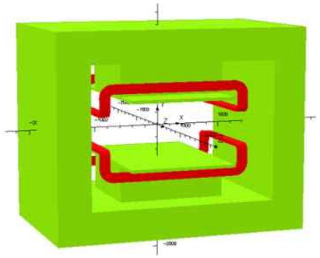
## Large Acceptance Multi-Purpose Spectrometer (LAMPS)

### Solenoid



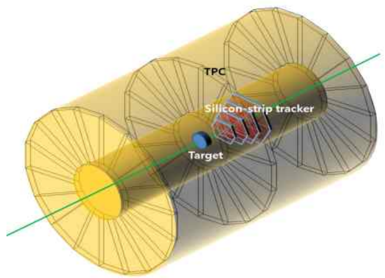
R = 1.0 m
$L_z$ = 2.0 m
$B_z$ = 1.0 T

### Dipole magnet



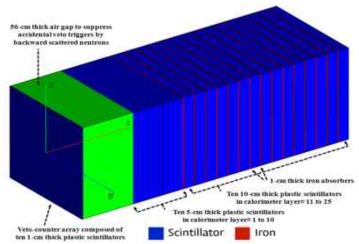
- Central pole-gap = 1 m
- Width = 1.5 m
- Field gradient = 1.5 T·m

### TPC & SST




TPC acceptance ~ 3π Sr
SST acceptance ~ 1 Sr

### Neutron array




Energy resolution
~ 1.8% @ 30 MeV
~ 2.7% @ 100 MeV
~ 3.4% @ 300 MeV

ε ~ 90 % from 30~300 MeV

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# International collaboration plan

Instruments:

- Recoil Spectrometer
- Target: for Experiments, Neutron Production, etc
- Detector system
  - Gamma-ray Array, Charged particle detector
  - TPC, Focal plane detector, Neutron detector
- Trap, Laser related system
- Polarization system
- Irradiation system
- ISOL related system

Facilities/Institutes:

RIBF/RIKEN, CNS, FRIB/MSU, SPIRAL-II/GANIL, TRIAC/KEK, SPES/LNL, ISOLDE/CERN, TRIUMF, FAIR/GSI, etc.

Collaborations to participate in:

SAMURAI, SHOGUN, ISLA, Theory, S3, ISOLDE, etc.

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## A few key words of theory group (not official, very personal)

- From quarks to neutron stars
- QCD vacuum ←→ quarks and gluons ←→ hadrons ←→ (light/heavy, stable/unstable) nuclei ←→ neutron stars
- Strong tie with experiment group
- Ab Initio, Interdisciplinary, …


Thank you very much!