KIAS Workshop
Nuclear and Particle Physics in KoRIA and BSI

Utilization of Intense Rare Isotope Beam at KoRIA

2011. 9. 17

Yong-Kyun Kim
(Hanyang University)

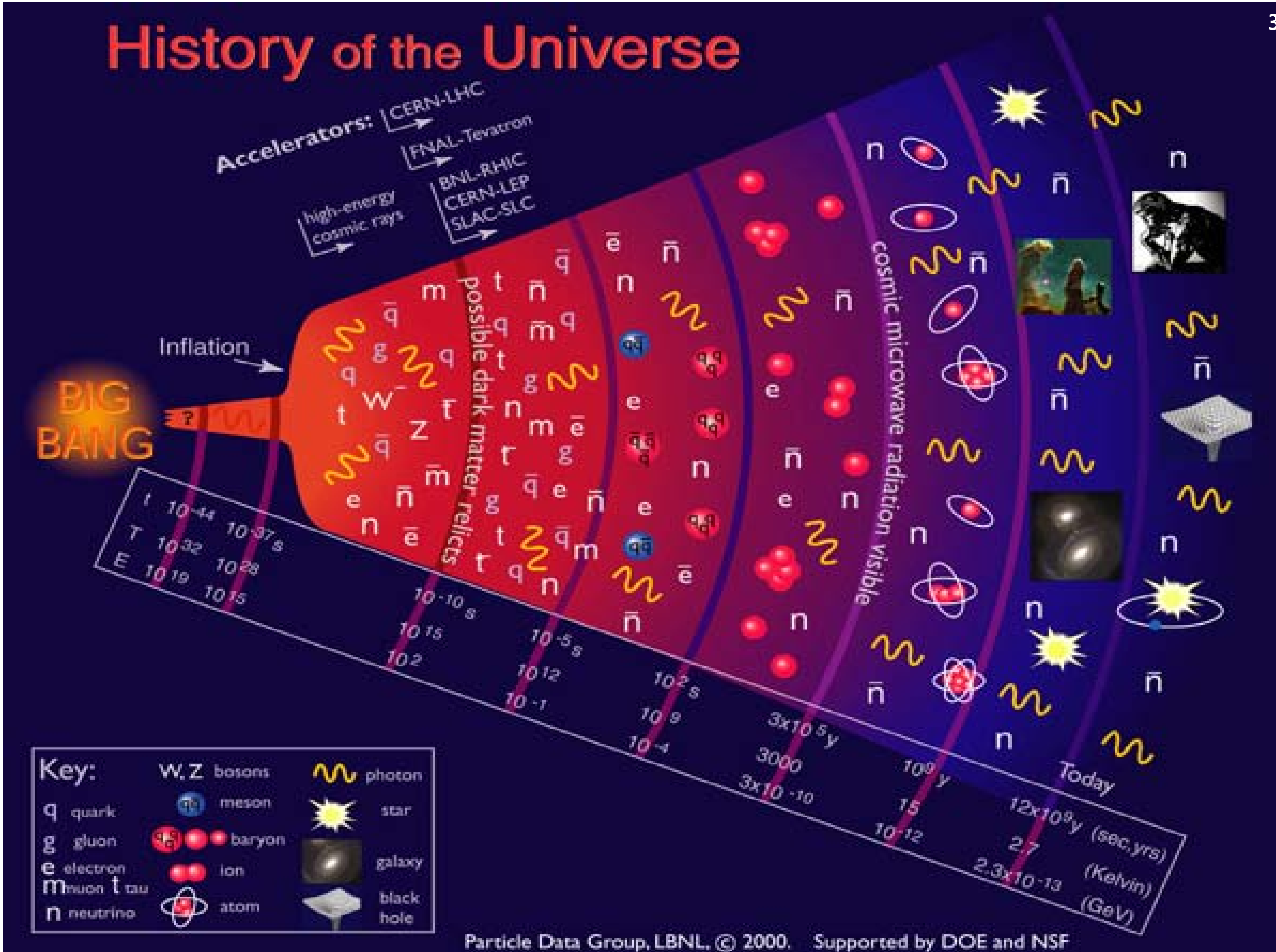
On behalf of KoRIA User Community

초신성의 관측

M101 PTF11kly

초신성의 관측

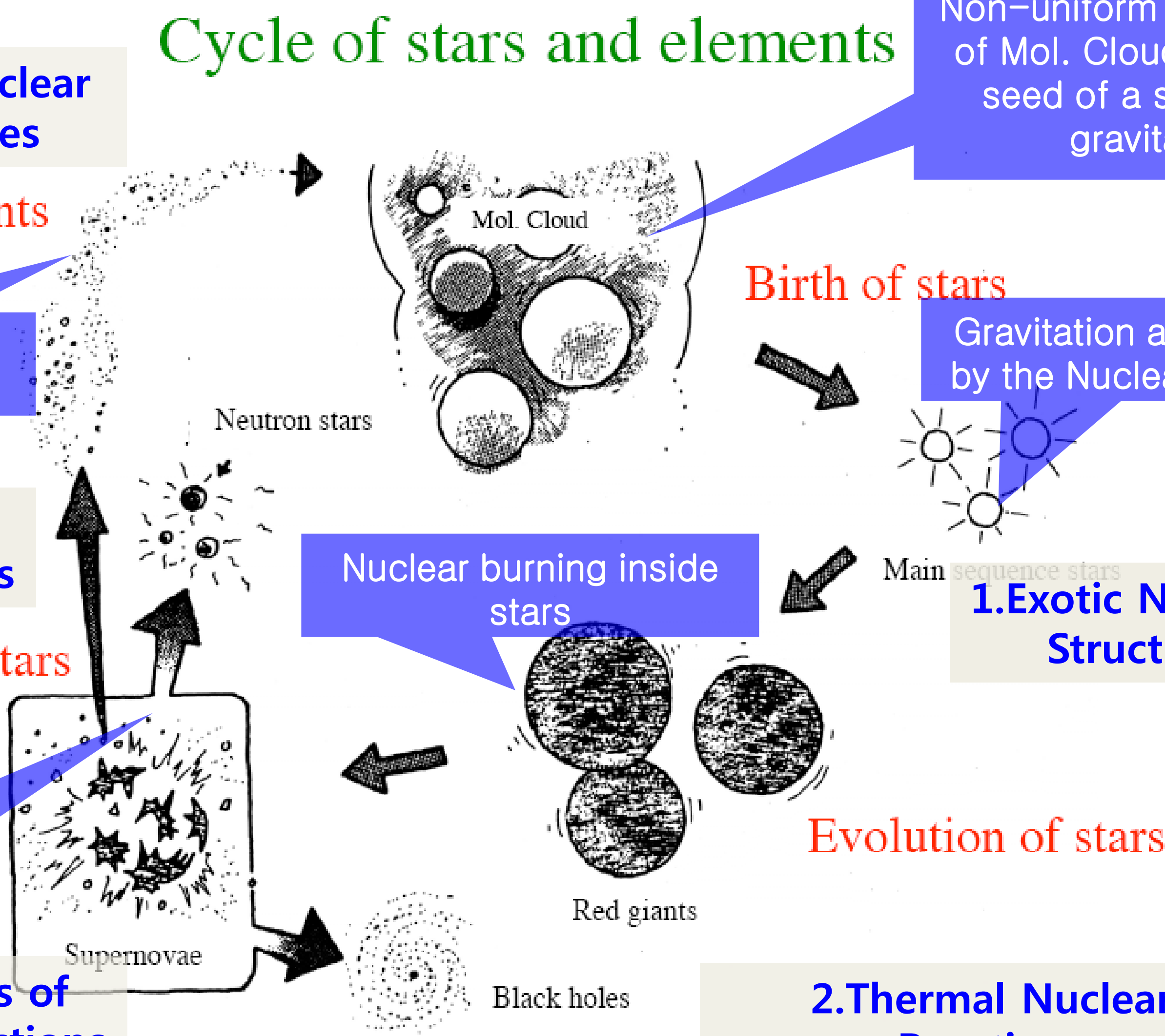
M101 PTF11kly


History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relics
cosmic microwave radiation visible
t 10-44 10-37 s
T 1032 1028
E 1019 1015
10-10 s
1015
102
10-5 s
1012
10-1
102 s
109
10-4
3x105 y
3000
3x10-10
109 y
15
10-12
Today
12x109 y (sec, yrs)
2.7 (Kelvin)
2.3x10-13 (GeV)
Key:
q quark
g gluon
e electron
m muon t tau
n neutrino
W, Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

Stellar Evolution and Nuclear Astrophysics

5. **Atomic/Nuclear Abundances**

Non-uniform distributions of Mol. Cloud become a seed of a star by the gravitation



Seeds for the next generation stars

Gravitation and Pressure by the Nuclear Reactions

4. **Sites for Nuclear Processes**

Nuclear burning inside stars

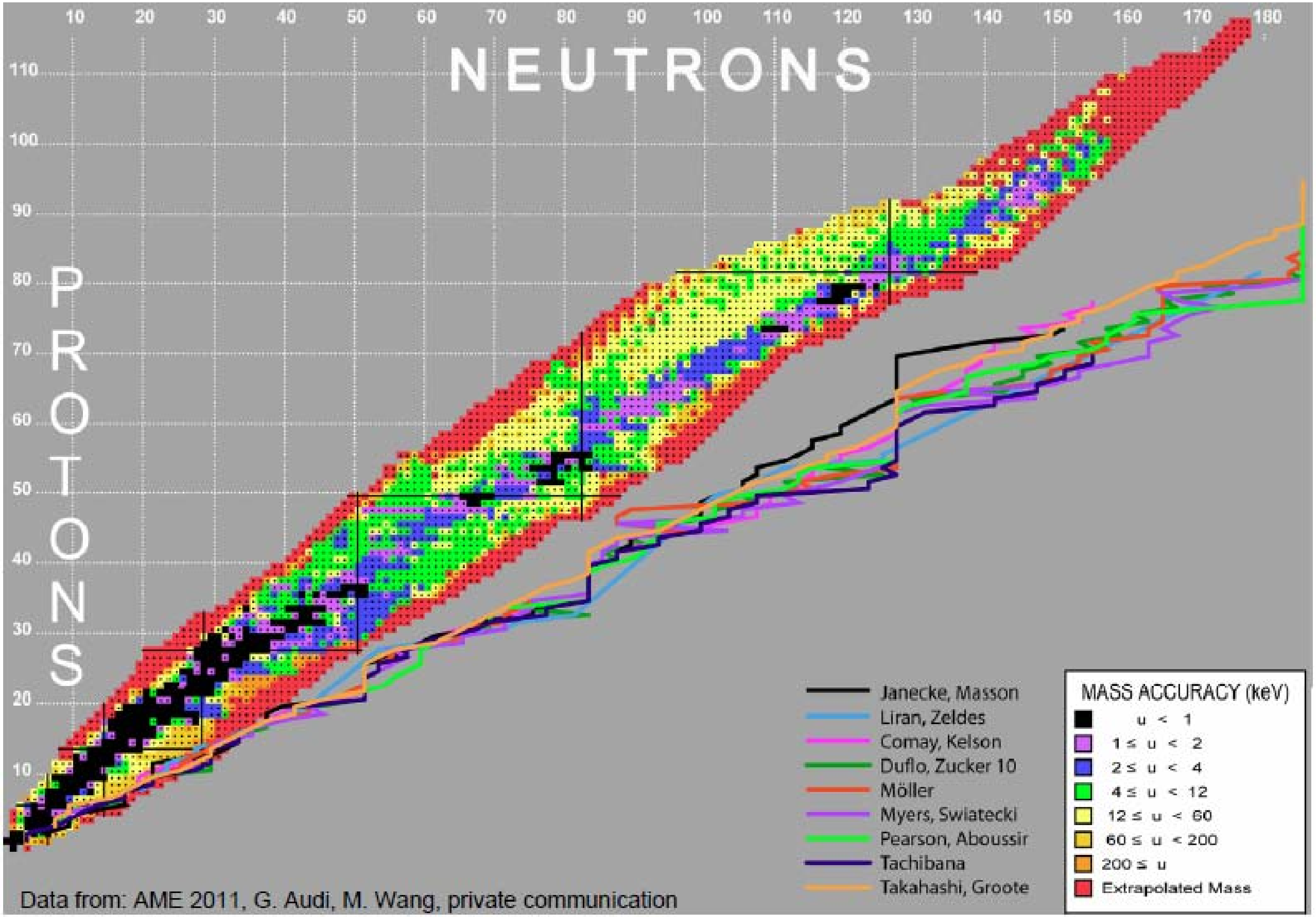
1.Exotic Nuclear Structure

Shock wave by gravitational collapse and neutrino wind

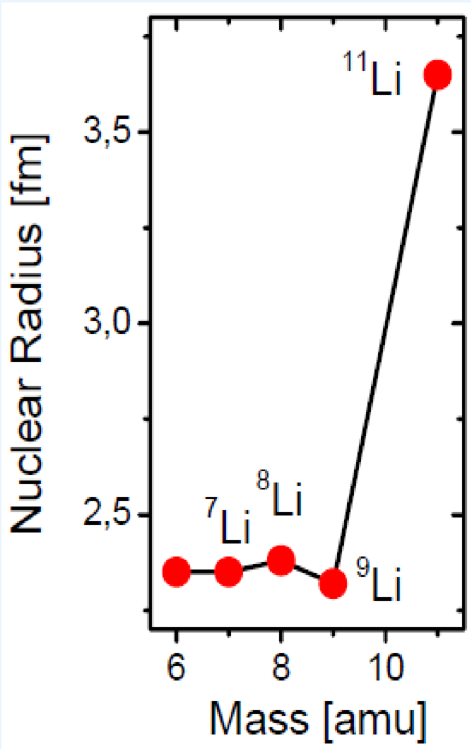
3. **Processes of Nuclear Reactions**

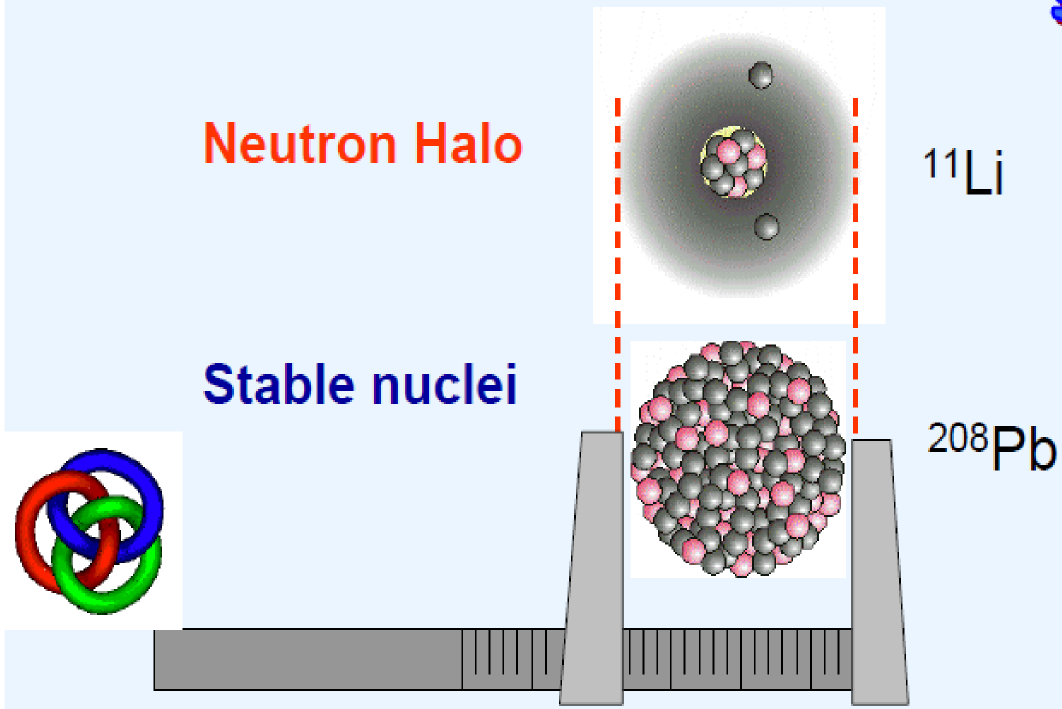
2.Thermal Nuclear Reactions in the Universe

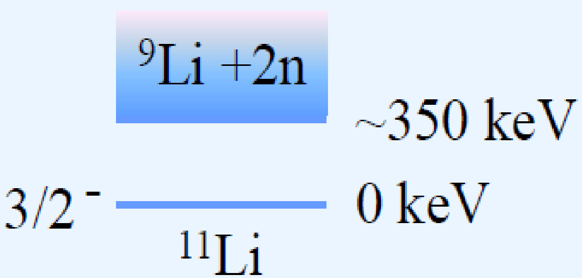
Limit of nuclear existence: n drip-line



New structure: ^{11}Li – A Neutron Halo







How to probe that ^{11}Li is a neutron halo?

Mass measurements
→ Two-neutron separation energy

Laser spectroscopy
→ Nuclear charge radii

I. Tanihata, J. Phys. G 22, 157 (1996).

Worldwide Rare Isotope Beam Facility

Basic Concept of KoRIA

- High intensity RI beams by ISOL & IFF
  - 70kW ISOL from direct fission of ^{238}U induced by 70MeV, 1mA protons → ~MW ISOL upgrade
  - 400kW IFF by 200MeV/u, 8pμA ^{238}U

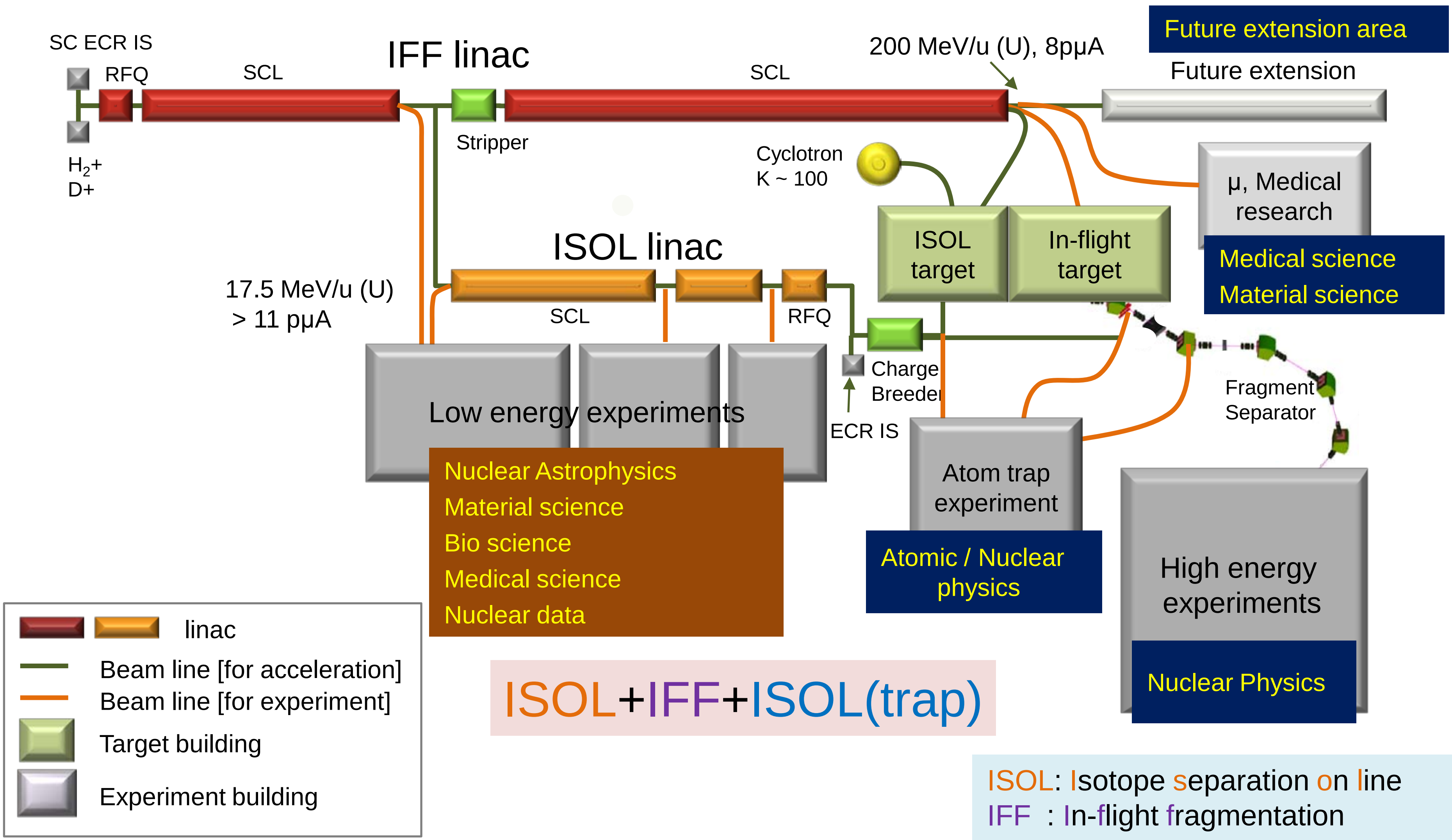
- High energy, high intensity & high quality neutron-rich RI beams
  - ^{132}Sn with ~250MeV/u, up to $9x10^8$ pps

- More exotic RI beams by ISOL+IFF+ISOL(trap)

- Simultaneous operation of ISOL and IFF for the maximum use of the facility

Layout of KoRIA

For the basic and applied science with stable and unstable isotopes



ISOL+IFF+ISOL(trap)

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

IFF Linac Beam Specification

Ion Species	Z/ A	Ion source output		SC linac output			
		Charge	Current (pμA)	Charge	Current (pμA)	Energy (MeV/u)	Power (kW)
Proton	1/ 1	1	660	1	660	610	400
Ar	18/ 40	8	42.1	18	33.7	300	400
Kr	36/ 86	14	22.1	34-36	17.5	265	400
Xe	54/ 136	18	18.6	47-51	12.5	235	400
U	92/ 238	33-34	11.7	77-81	7.9	210	400

Estimated RIBs based on ISOL

Isotope	Half-life	Yield at target (pps)	Overall eff. (%)	Expected Intensity (pps)
^{78}Zn	1.5 s	2.75×10^{10}	0.0384	1.1×10^{7}
^{94}Kr	0.2 s	7.44×10^{11}	0.512	3.8×10^{9}
^{97}Rb	170 ms	7.00×10^{11}	0.88	6.2×10^{9}
^{124}Cd	1.24 s	1.40×10^{12}	0.02	2.8×10^{8}
^{132}Sn	40 s	4.68×10^{11}	0.192	9.0×10^{8}
^{133}In	180 ms	1.15×10^{10}	0.184	2.1×10^{7}
^{142}Xe	1.22 s	5.11×10^{11}	2.08	1.1×10^{10}

ISOL Calculation by Dr. B. H. Kang (Hanyang Univ.)
- Beam: proton of 70 MeV and 1 mA
- Target: UC_2 of 2.5 g/cm^3 and 3 cm thickness

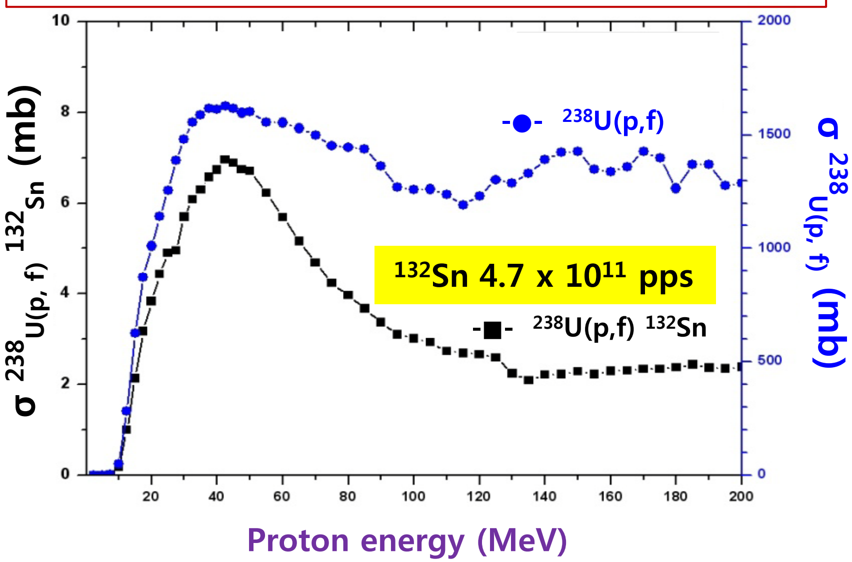
Intense RIB Production

GOAL: High intensity-high quality RI beam using relatively low beam power and direct fission target

Simulation of $^{238}U(p, f)$

- Model: MCNPX and ETFSI fission model
- Beam: 70 MeV, 1mA proton
- Target: UC_2 of 2.5 g/cm^3 and 3 cm thickness

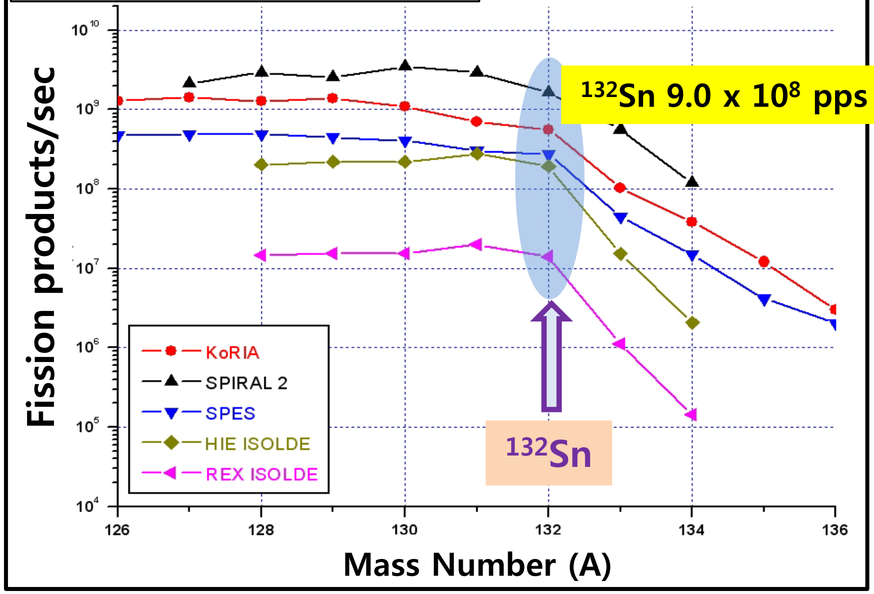
^{132}Sn cross-section from fission production



on target

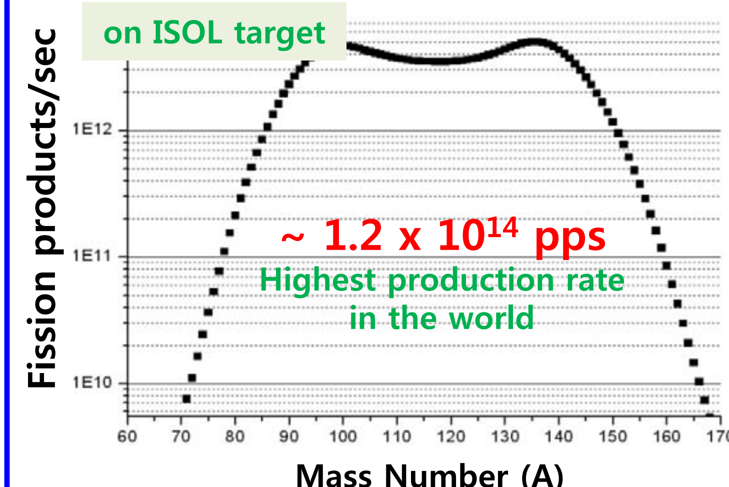
Intensity of Sn isotopes

At experimental hall



Mass Distribution from fission of ^{238}U

on ISOL target

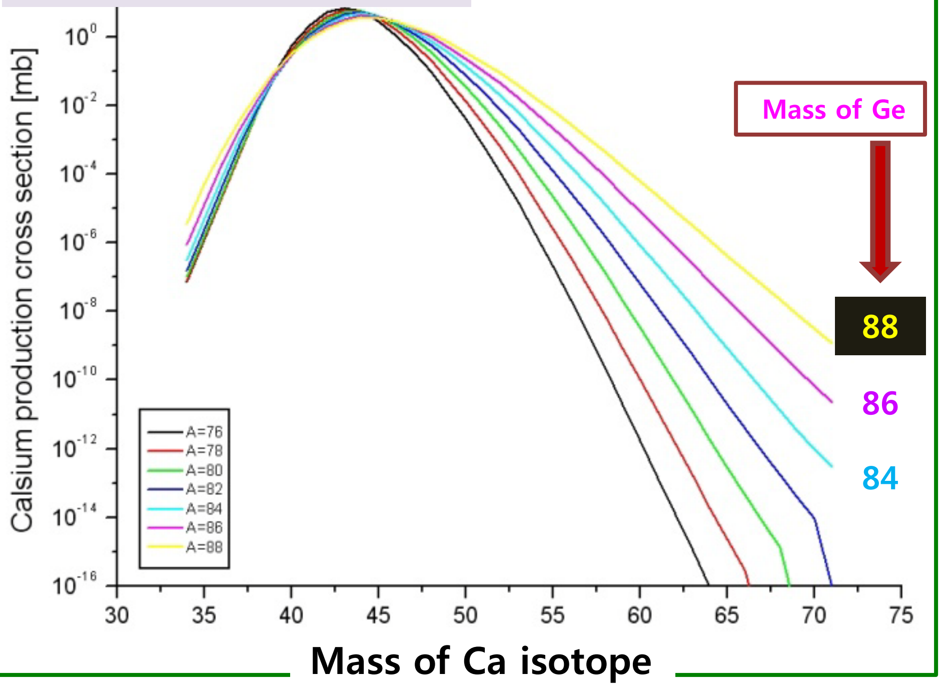


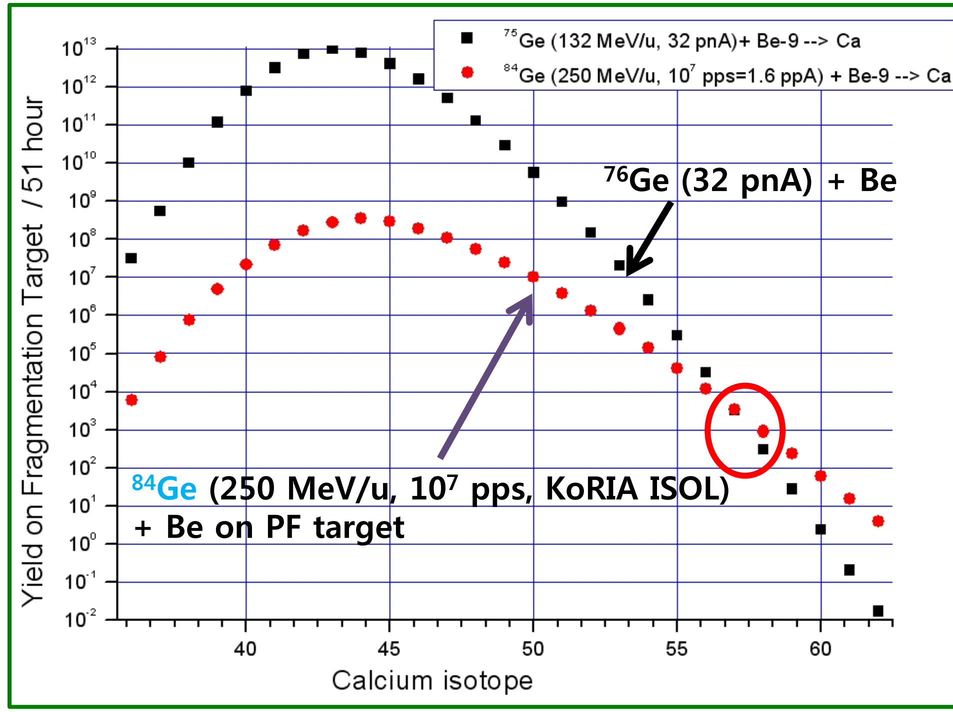
Sn

KoRIA user community

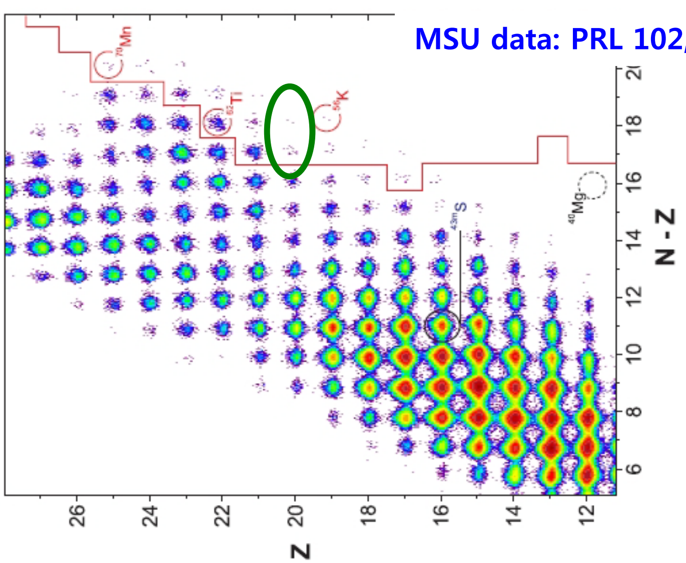
Merit of Intense RIB

Ge (250 A MeV) +^{9}Be → Ca
computed by LISE++





MSU data: PRL 102,142501 (2009)



^{57,58}Ca discovery
^{76}Ge(132 A MeV, 32pnA) + ^{9}Be
- 51 hour irradiation
- projectile fragmentation reactions
- A1900 fragment separator+ S800 analysis beam line
- NSCL at MSU 2009

Yield expectation of Calcium after A1900

Ca isotope	MSU (measured) ^{76}Ge beam	KoRIA (predicted) ^{84}Ge beam
57	~15	~15
58	3	7
59	0	3

Research subjects by using KoRIA

KoRIA User Community

8 Working groups

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 - 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 - To understand the matter by describing nuclear structure and reaction
Medical & Bio application	- Development of new cancer therapy using radioactive heavy ion beam - To understand biological effect of tissue and DNA by RI beam
RI Material Research	- Development and utilization of new material - To understand property of material by RI
Nuclear Data	- Nuclear data construction to develop future nuclear power technology - Research for the radioactive waste transmutation
Atom traps for RI research	- To understand basic property of atom and nuclei - Study of structure and characteristics of element and nuclei

Research topics and RI beams (I)

Research group	Research topics	Energy & current of RIs
Nuclear Structure	• exotic nuclei near the neutron & proton drip line • Isomer research • Super heavy element	• Unstable: $_{20}$Ca, $^{84}_{32}$Ge, $_{36}$Kr, $^{132}_{50}$Sn,$_{54}$Xe • Stable: $^{76}_{32}$Ge, $^{86}_{36}$Kr, $^{136}_{54}$Xe, $^{238}_{92}$U 0 ~ 200 MeV/u, > 0.1 nA (10^9 pps)
Nuclear Astrophysics & Nucleosynthesis	• Breakout reaction from Hot-CNO cycle to rp-process • Nucleonsynthesis contribution of isomers • Important constraint on core-collapse supernova model	•Unstable: $^{15}_{8}$O, $^{26m}_{13}$Al, $^{45}_{23}$V, $^{62-66}_{32}$Ge, $^{46-52}_{12}$Mg, $^{132}_{50}$Sn, $^{134}_{52}$Te, $^{140,144}_{54}$Xe, $^{194-196}_{75}$Re, $^{198,202}_{77}$Ir, $^{195}_{69}$Tm • Stable: $^{23}_{11}$Na, $^{134-135}_{55}$Cs • 0~10 MeV/u and few hundreds MeV/u 0.1 nA ~ 1 μA (10^6 ~ 10^{13} pps)
Nuclear Matter	• Symmetry energy in astro- & nuclear physics - Neutron skin thickness - Isovector giant dipole resonance - Collective flows in HI collisions, and etc.	• All ions from H to U, (H, $^{132}_{50}$Sn, $^{140}_{54}$Xe, $^{238}_{92}$U) 0 ~ 200 MeV/u, > 10^9 pps
Nuclear Theory	• Nuclear reactions by neutrinos in supernovae • Nucleosynthesis of proton capture in stars • Superburst in neutron star • Study for the crust of neutron star	• ^{180}Ta (beta decay of ^{180}Ta) • ^{13}N (^{13}N(p, γ)^{14}O reaction) • ^{23}Mg or ^{23}Na (^{23}Mg + n reaction) • ^{208}Pb (Reaction by ^{208}Pb beam)

Notation: Stable, neutron-deficient, neutron rich RIs, and μ

KoRIA user community

Research topics and RI beams (II)

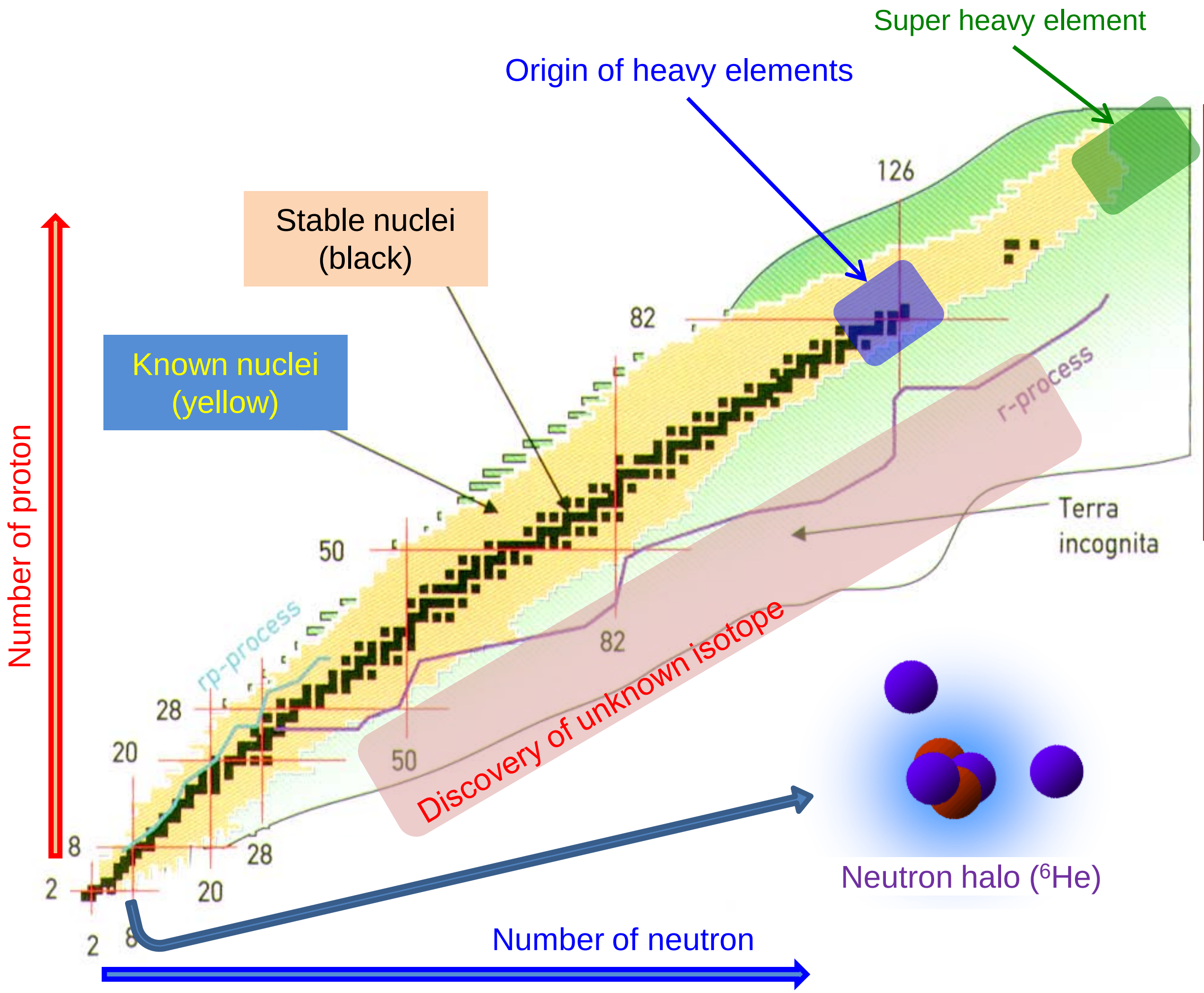
Research group	Research topics	Energy & current of RIs
Medical & Bio application	• Effect on human body by HI • Radiobiology research with HI beams • Radiation therapy with HI beams • Industrial applications with HI beams	• Unstable: μ, $^{11}_{6}C$ • Stable: p, $^{4}_{2}He$, $^{12}_{6}C$, $^{16}_{8}O$, $^{20}_{10}Ne$, $^{28}_{14}Si$, $^{35}_{17}Cl$, , $^{40}_{18}Ar$, $^{48}_{22}Ti$, $^{56}_{26}Fe$, $^{131}_{54}Xe$, 10 ~ few hundreds MeV, 0.1 nA ~ 1 uA
RI Material Research	• New material and its properties with - β-NMR - Elastic Recoil Detection (ERD) system - μSR • Radio isotope ions production by using laser	• Unstable: μ, ^{8}Li, ^{11}Be, $^{15,19}_{8}O$, $^{17}_{10}Ne$, $^{62}_{30}Zn$, $^{77}_{33}As$, $^{99}_{41}Nb$, $^{99}_{43}Tc$, $^{100}_{46}Pd$, $^{117}_{48}Cd$, $^{111,117}_{49}In$, $^{131}_{52}Te$, $^{140}_{59}Pr$, $^{172}_{71}Lu$, $^{181}_{72}Hf$, $^{187}_{74}W$, $^{199}_{81}Tl$, $^{204}_{83}Bi$ few tens keV ~ 10 MeV, 15~30 nA • Stable: p 50 and 600 MeV, >30 μA
Nuclear Data	• Nuclear data with fast neutron • Nuclear data with neutron from nuclear fragmentation • Nuclear data with charged particles	• Stable: p, d, $^{3,4}_{2}He$ 10 ~ few hundreds MeV/u > few mA • Actinide (Z=89~103) ion beams, 2~10 MeV/u, > few mA • Nuclear fragments (W, Ta, Pb, etc), few hundreds MeV, > few mA
Atom traps for RI research	• Precision mass measurement • Precision laser spectroscopy	• Unstable: $^{11}_{3}Li$, $^{11,14}_{4}Be$, $^{8}_{5}B$, $^{10,19}_{6}C$, $^{17}_{10}Ne$, $^{34}_{17}Cl$, $^{62}_{31}Ga$, $^{74}_{37}Rb$, nuclei (Z=82) near n-rich drip line 40 ~ 100 keV/u, 20,000 pps

Notation: Stable, neutron-deficient, neutron rich RIs, and μ

KoRIA user community

Nuclear structure

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



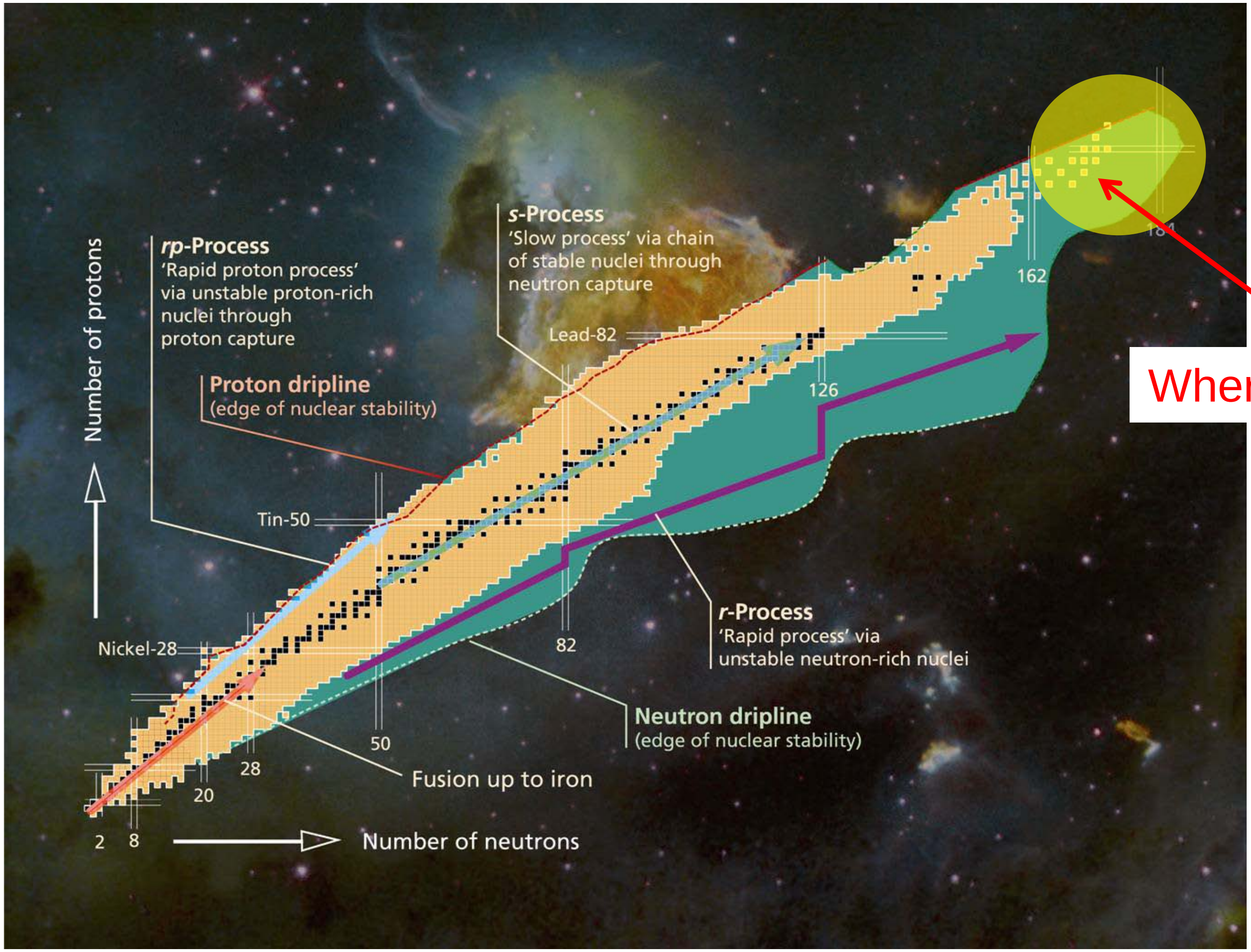
- To discover unknown isotope and study their properties
- To understand origin of heavy element
- Superheavy element (ex. Koreanium?)
- To study unknown nuclear structure (ex. neutron halo)

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

Synthesis of the superheavy elements

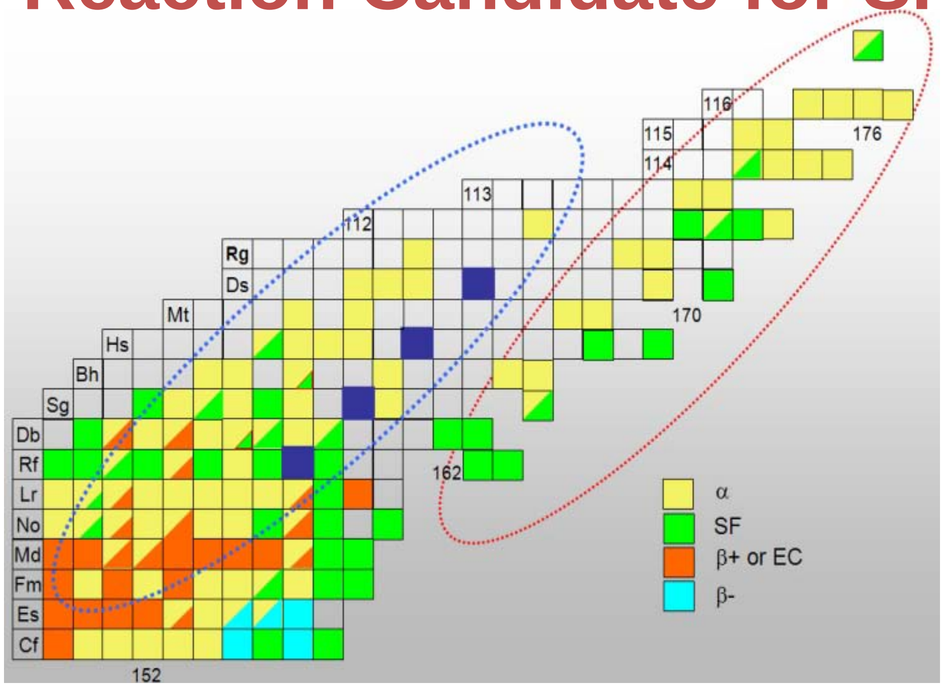
proves

- 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 ?

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

σ ~ 1 pb

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

^{238}U + ^{48}Ca → 112 + xn
^{242}Pu+^{48}Ca → ^{287}114 + xn
^{248}Cm + ^{48}Ca → ^{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 → $^{290-x}$**116** + xn
^{232}Th + ^{64}Ni → $^{296-x}$**118** + xn
^{244}Pu + ^{58}Fe → ^{299}**120** + 3n
^{238}U + ^{64}Ni → ^{299}**120** + 3n

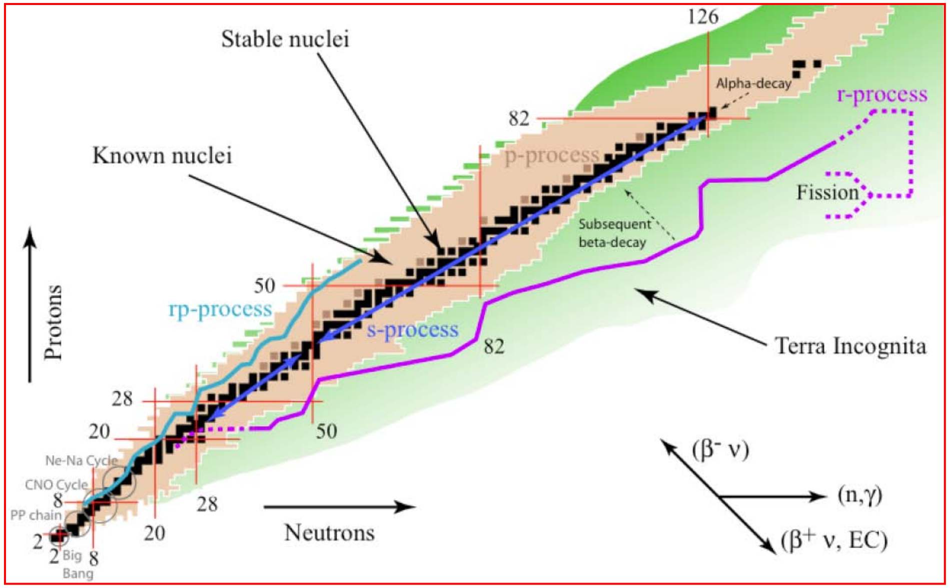
Yield Estimation (rough) **^{232}Th + ^{64}Ni → $^{296-x}$118 + xn**

- 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

Nuclear astrophysics

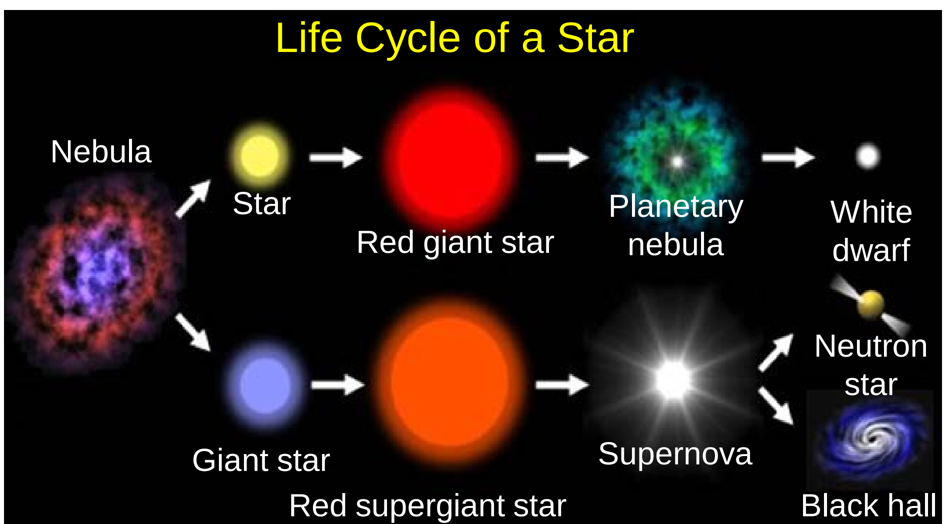
➢ To understand the role of unstable nuclei in the nucleosynthesis



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.

- Basic parameters for r-process

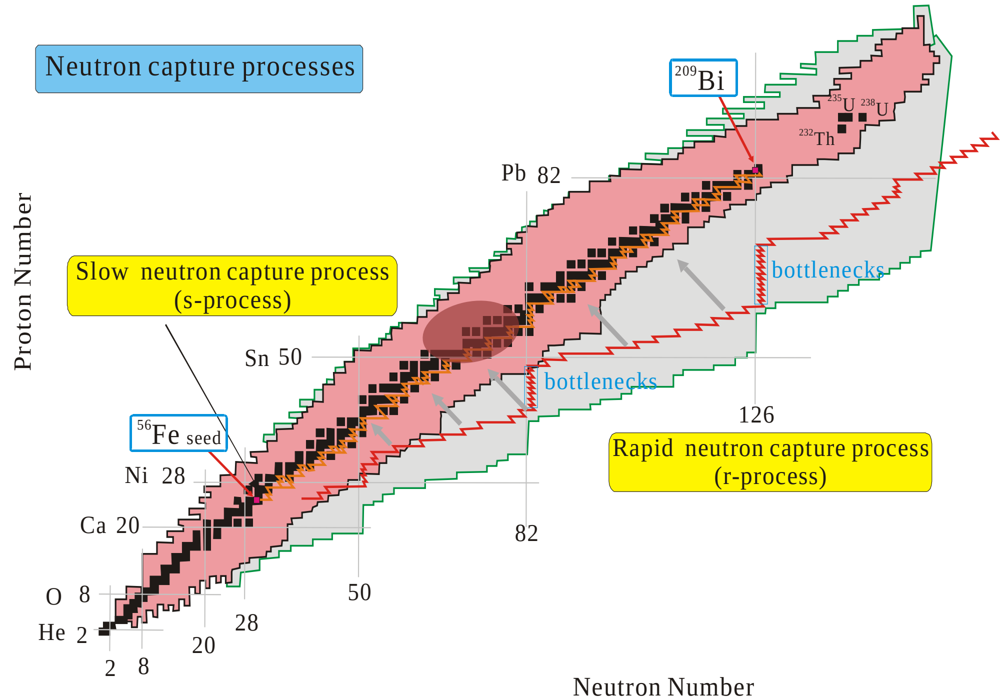
Half-lives ($T_{1/2}$)
→ abundance
→ process speed

Cross sections
→ location of the path
Masses (A, Q_β)
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)

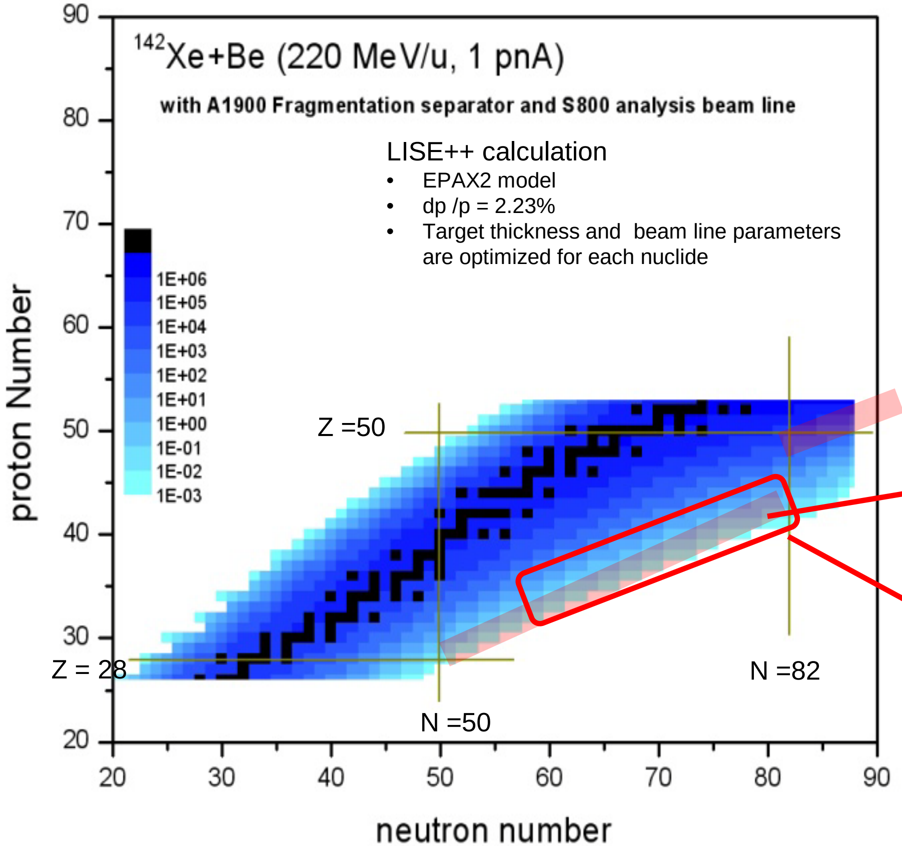


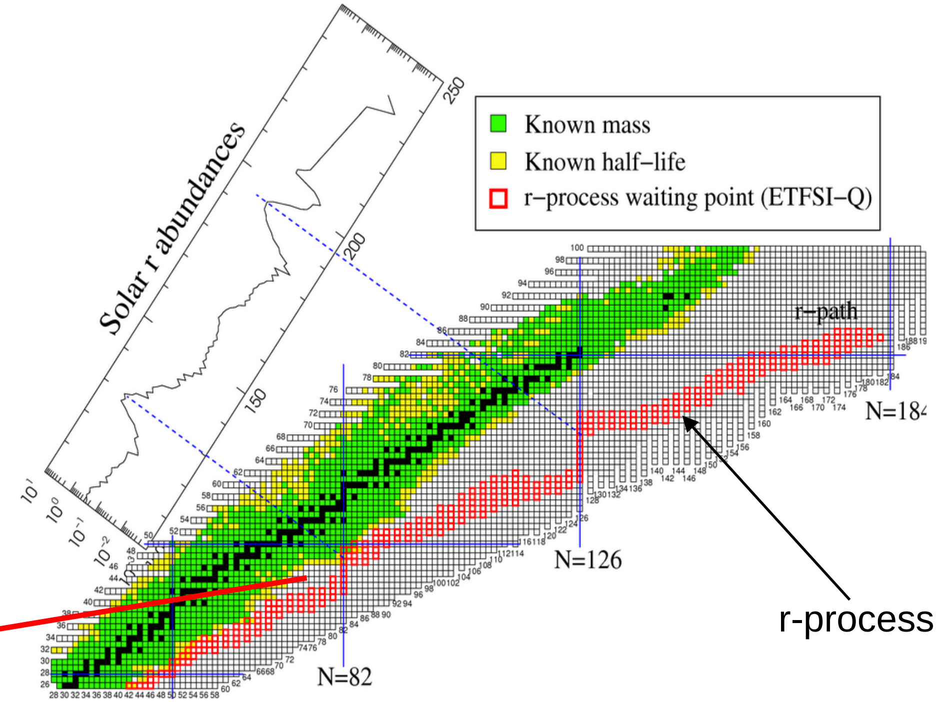
The first experiment will be to measure β-decay properties of nuclei in the neighbourhood of ^{110}Zr to investigate its possible spherical character arising from new semi-magic numbers : Half-lives, P_n of neutron-rich of Y, Zr, Nb, Mo, Tc, etc.

- ✓ NSCL reported the measurement of $T_{1/2}$ and P_n of $^{100-105}$Y, $^{103-107}$Zr, $^{106-109}$Nb, $^{108-111}$Mo and $^{109-113}$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.

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

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

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

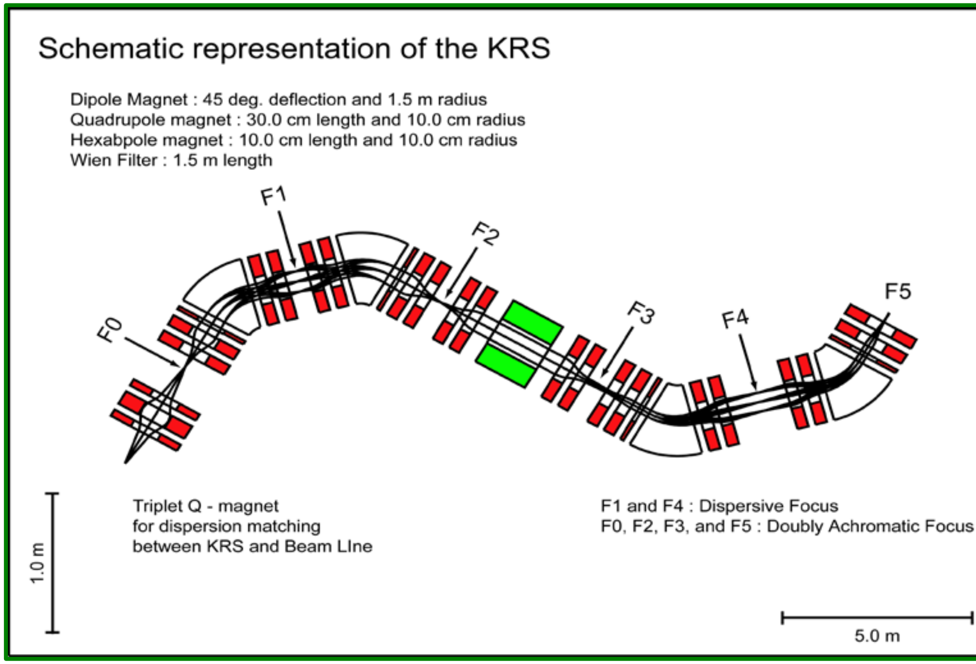
Nuclear astrophysics

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 • **production of more exotic beams**	• **beam transport from KoRIA to the focal plane of KRS**
Requirements	• background reduction • high mass resolution (M/ΔM) • large angular acceptance • highly efficient detection system	• large angular acceptance • high-density production target system • high-quality beam (high purity, low emittance, high intensity)	• 100% transport efficiency

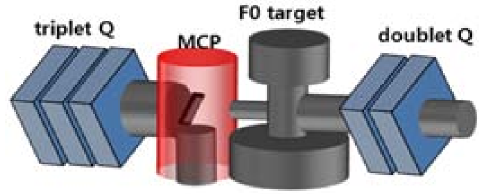
Facility

Nuclear astrophysics

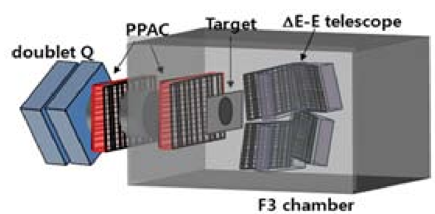
Target System

Supersonic jet gas target developed in GSI

Beam Tracking at F0 & F3

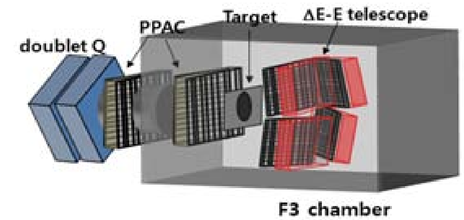


	MCP	PPAC & MWPC
Multiple scattering	~0.1 mrad	~0.05 mrad
Counting rate	> 1 MHz	> 2MHz

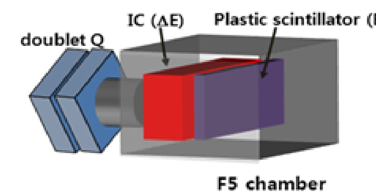


Energy loss: < 1 MeV

Particle Detection at F3 & F5



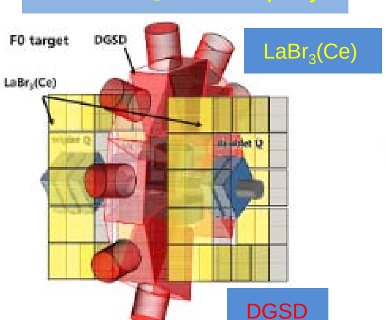
50 keV (FWHM) @ 5 MeV α-particle

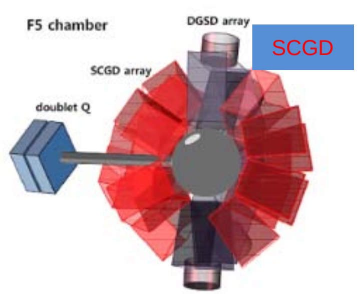


PID for low-energy recoil particle

Gamma-ray Detection at F0 & F5

ε~ 20 % @ 2 MeV γ-ray

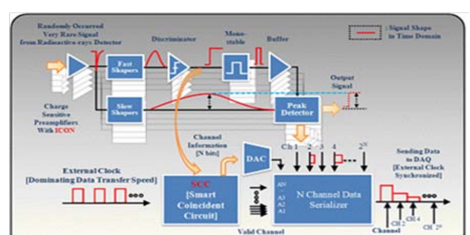




Position resolution : < 1 mm

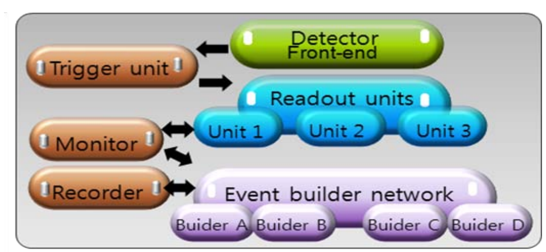
Front-end electronics

10^5 Channels



DAQ

> 2 GHz high frequency



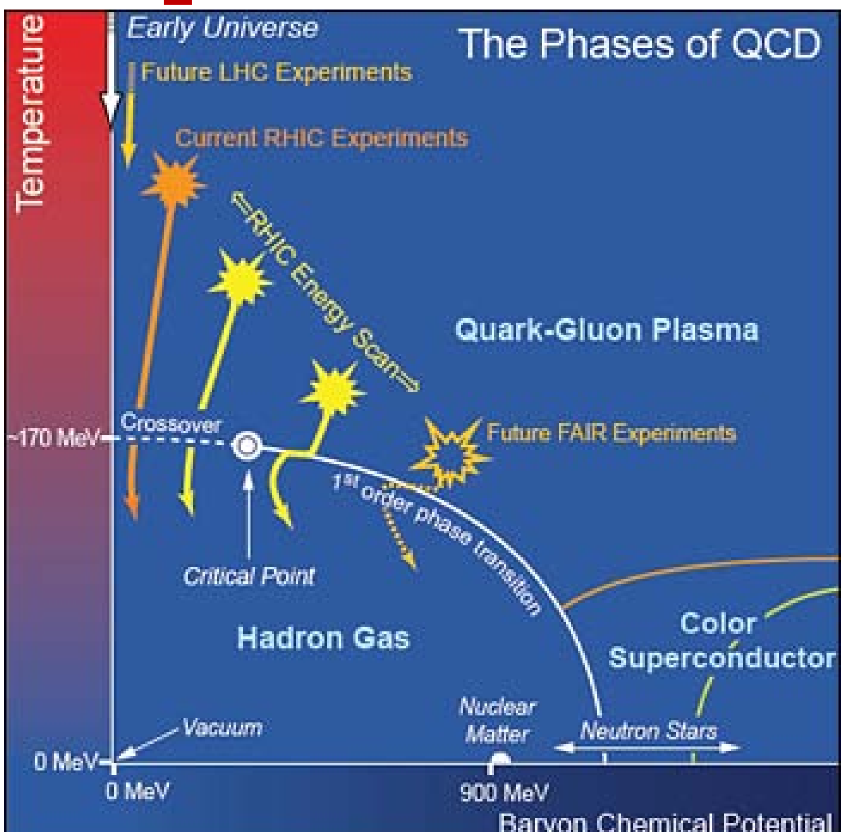
KoRIA user community

Research

Nuclear matter

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

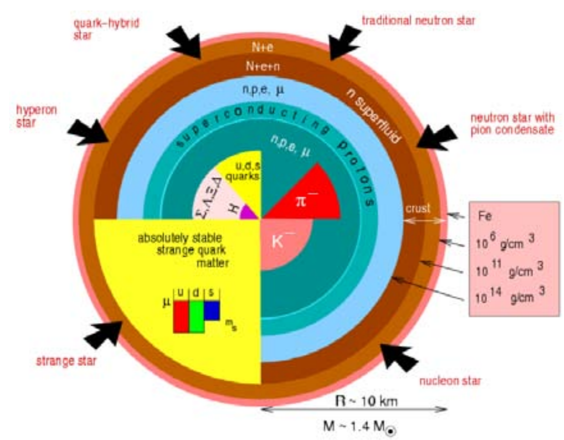
Hot nuclear matter
(Bigbang, early of universe)



- ❖ 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

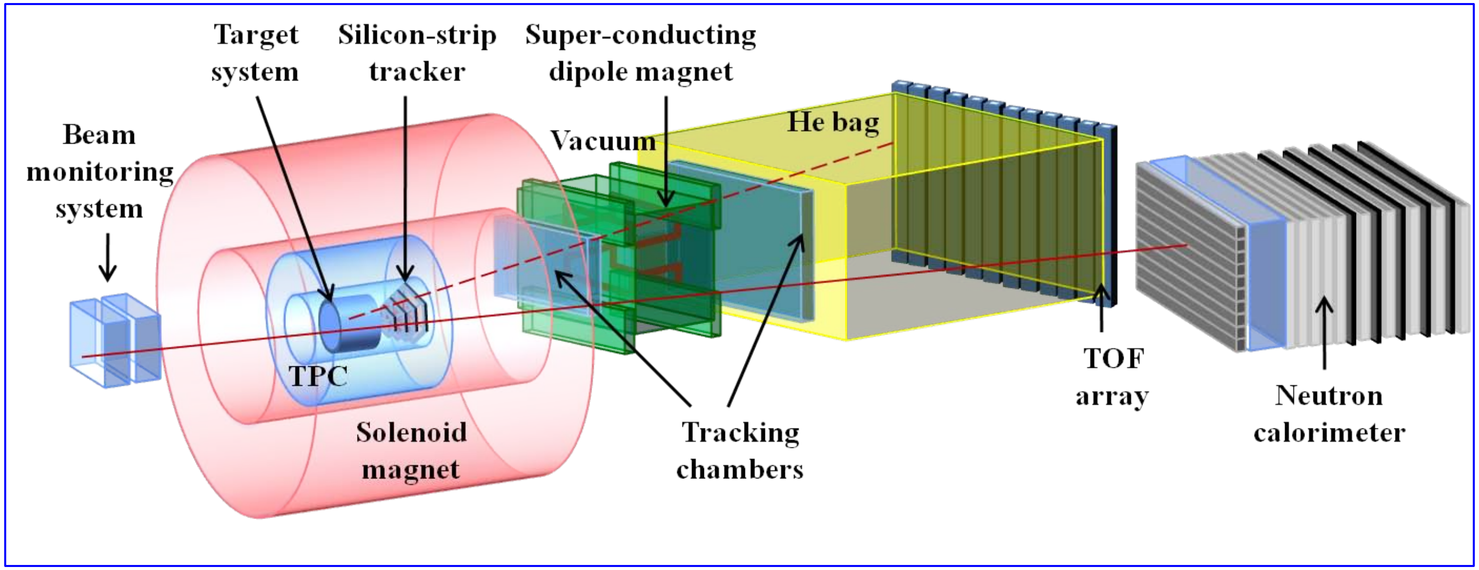
  …
- ❖ Heavy ion flows
- ❖ Property of hadron at dense neutron region
- ❖ Equation of state (EOS) for hot and dense nuclear matter

Dense nuclear matter
(Neutron star)



KoRIA user community

Nuclear matter



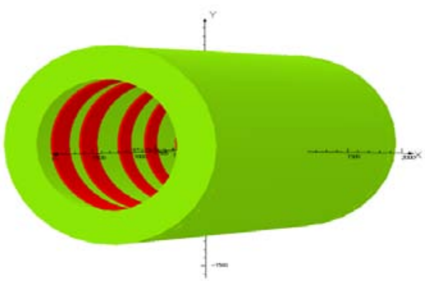
Large acceptance:
> 3π Sr

Multipurpose:
Charged & neutral particle detection

High detection efficiency of particle

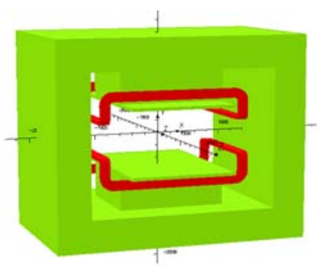
Large Acceptance Multi-Purpose Spectrometer (LAMPS)

Solenoid



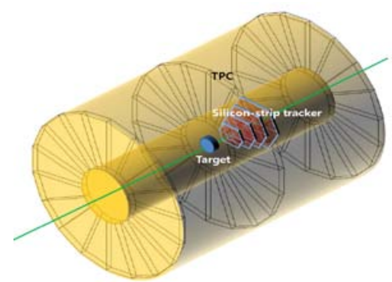
R = 1.0 m
L_z = 2.0 m
B_z = 1.0 T

Dipole magnet



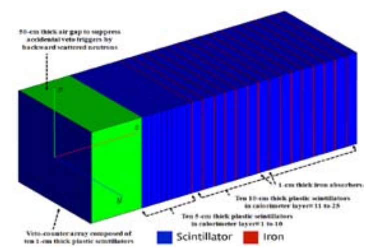
- Central pole-gap = 1 m
- Width = 1.5 m
- Field gradient = 1.5 T·m

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

Atomic & nuclear physics

Precision Mass Measurements

High-accuracy mass measurements and mass comparisons of stable or radioactive nuclides on the level of 10^{-8}

Key questions

Fundamental prope
Test of nuclear models and for

Nuclear Structure
Shell closures, pairing, deform

Reaction and decay
Q-values, Boundaries on exoti

Limits and Islands
Drip lines and Superheavies

Nuclear Astrophysics
r- and rp-process

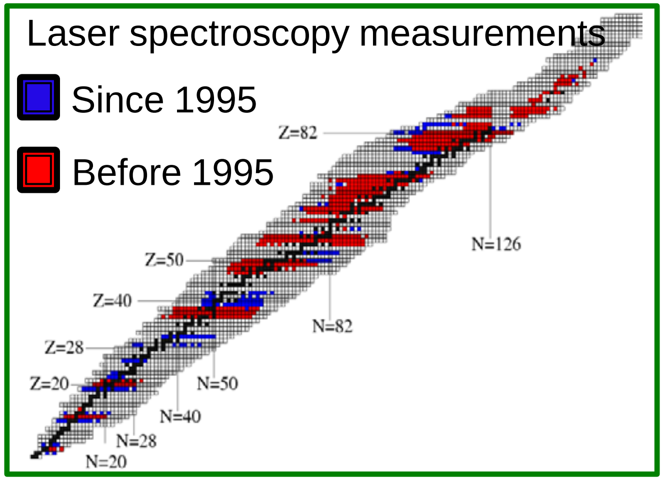
Fundamental tests
Symmetries
Weak interaction: CVC hypothesis, search for scalar and tensor currents

Precision Laser Spectroscopy

Magnetic & electrostatic hyperfine structure
spin, magnetic moment, and quadrupole moment

Key questions

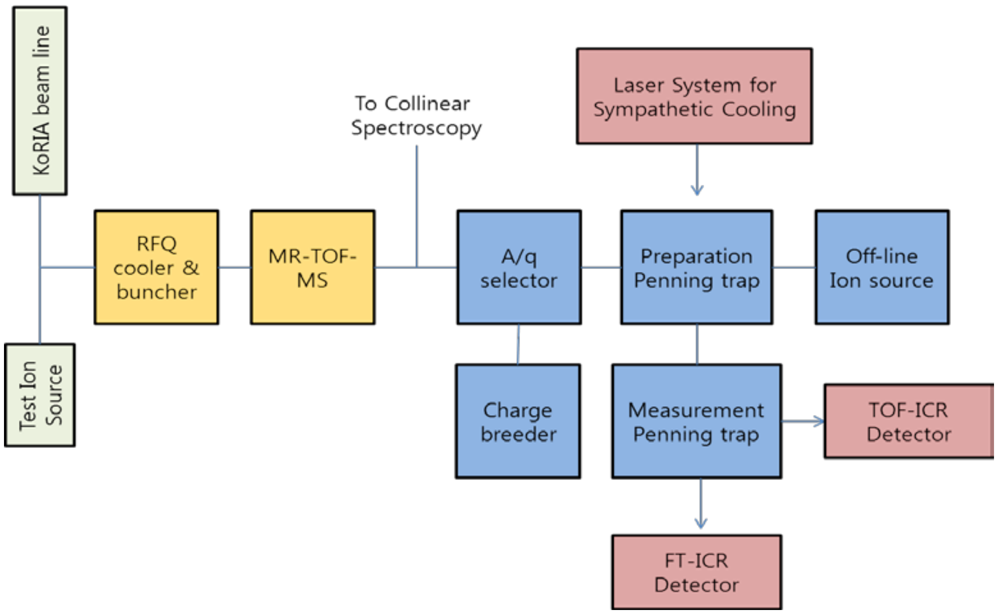
- Limits of nuclear existence
- New formation type of nuclear matter
- New collective motion
- Change of the ordering of quantum states



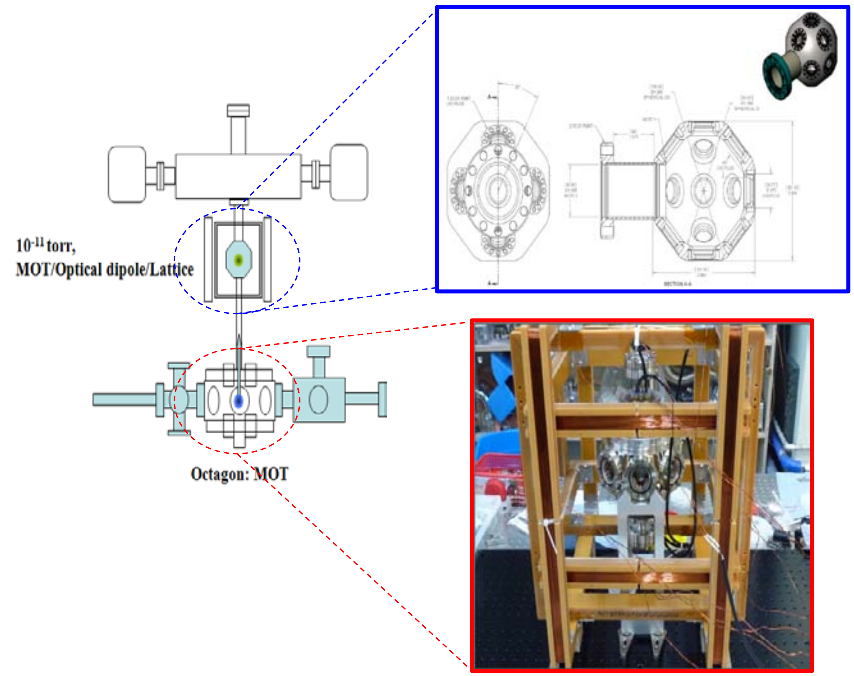
KoRIA user community

Atomic and nuclear physics

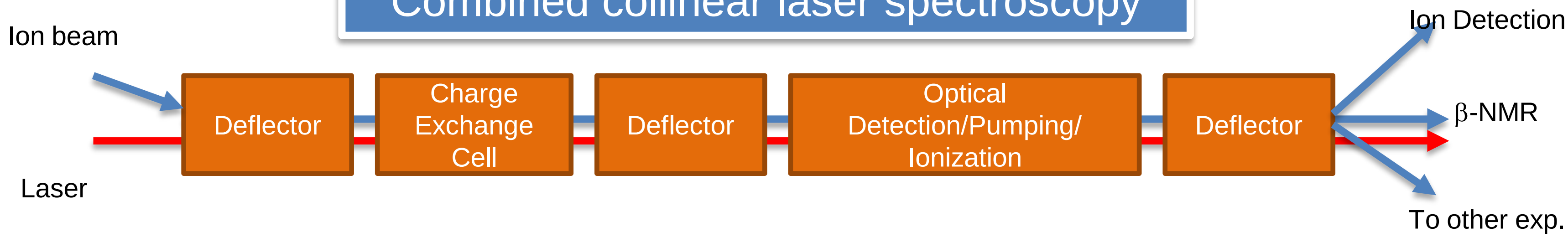
Precision mass measurement



Double MOT system for Standard Model test



Combined collinear laser spectroscopy



KoRIA user community

International collaboration plan

Instruments:

- Recoil Spectrometer
- Target: for Experiment, 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:

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

Collaborations to participate in:

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

Research Program

- Conceptual Design of the experimental facilities
- 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 →	β-NMR/NQR Elastic Recoil Detection (ERD) Laser Selective Ionizer
Medical and Bio sciences →	Heavy Ion Therapy Irradiation Facility

KoRIA user community

Thank you for attention !