

Nuclear Physics

Sakura-i Hiro-yoshi
櫻 井 博 儀

Fundamental interactions

Elementary particles

Composite particles

Nuclear Physics is not Particle Physics,
not Condensed Matter Physics

Interaction?

Effective interaction ?

Correlations ?

Isospin, Density, temperature dependences ?

Surface boundary, non-linear, finite system

Collective motions

Q. 1 Life time of neutron ?

Q. 2 Age of universe is 13.7B Years after BigBang.
At present, there are neutrons in materials. Why?

Q. 3 Spin-parity for ground state of deuteron ?

Q. 4 Limits of existence of nuclei ?

Q. 5 Magic numbers of nuclei ?

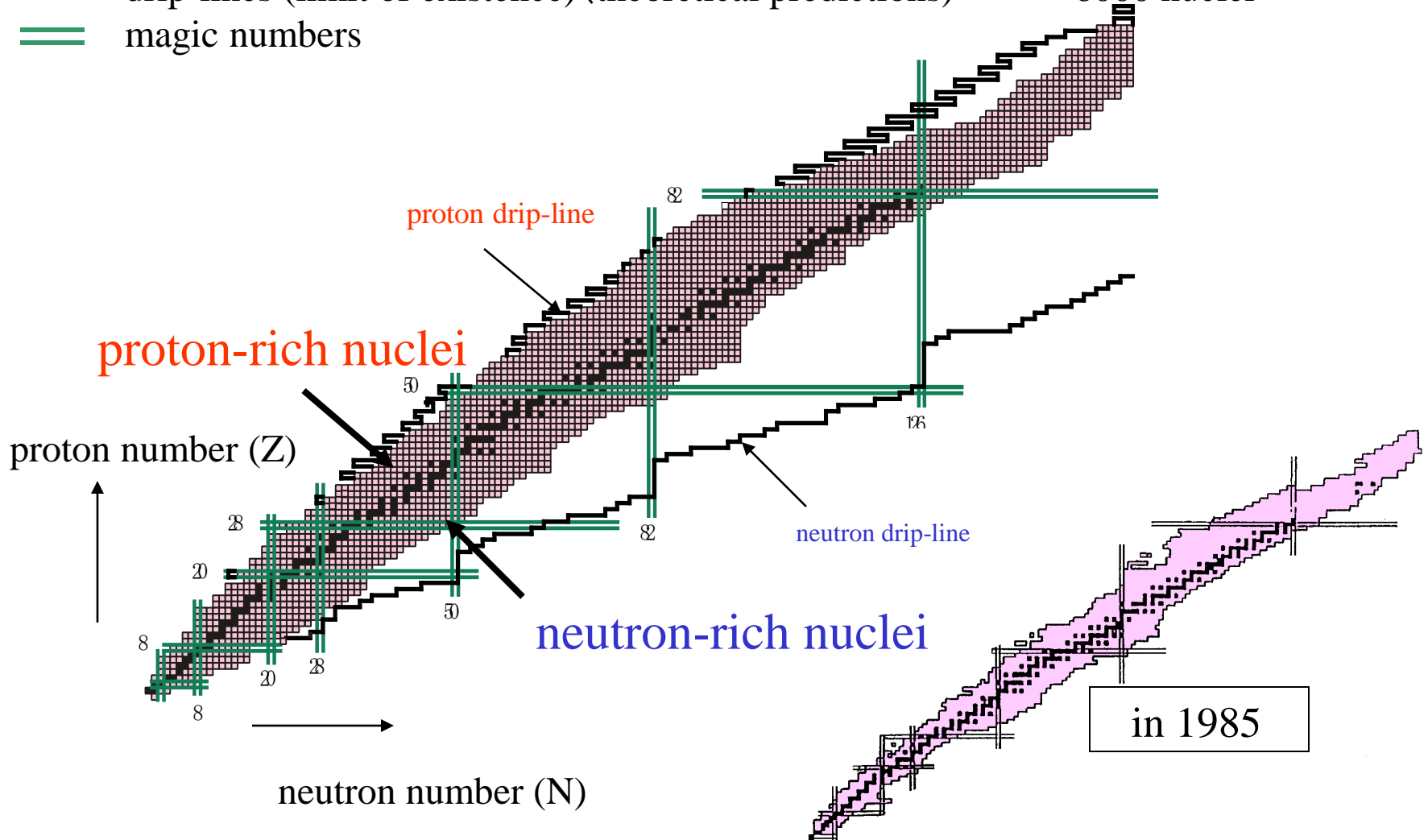
Q. 6 Size of nuclei ?

Q. 7 Collective motions of nuclei ?

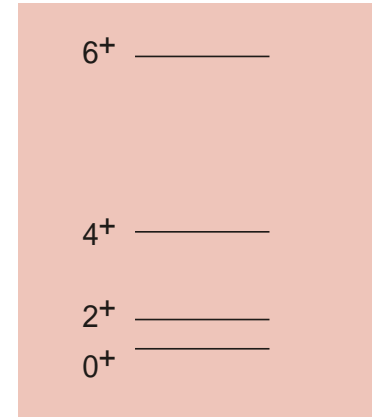
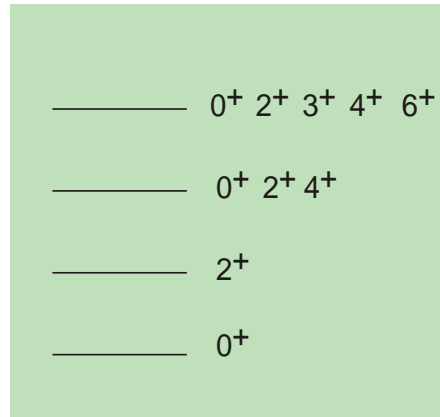
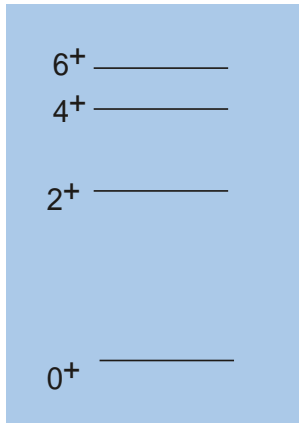
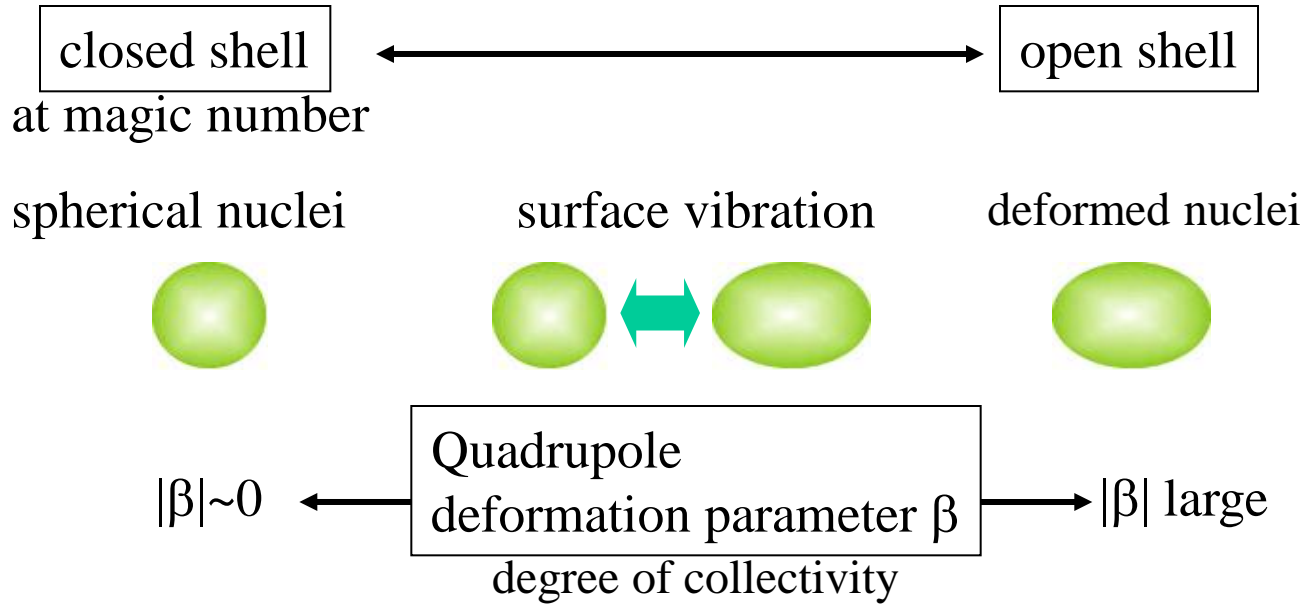
Q. 8 How and where elements around us have been created ?

Exploration of the Limit of Existence

- stable nuclei ~300 nuclei
- unstable nuclei observed so far ~2700 nuclei
- drip-lines (limit of existence) (theoretical predictions) ~6000 nuclei
- == magic numbers



Nuclear Collective Motion



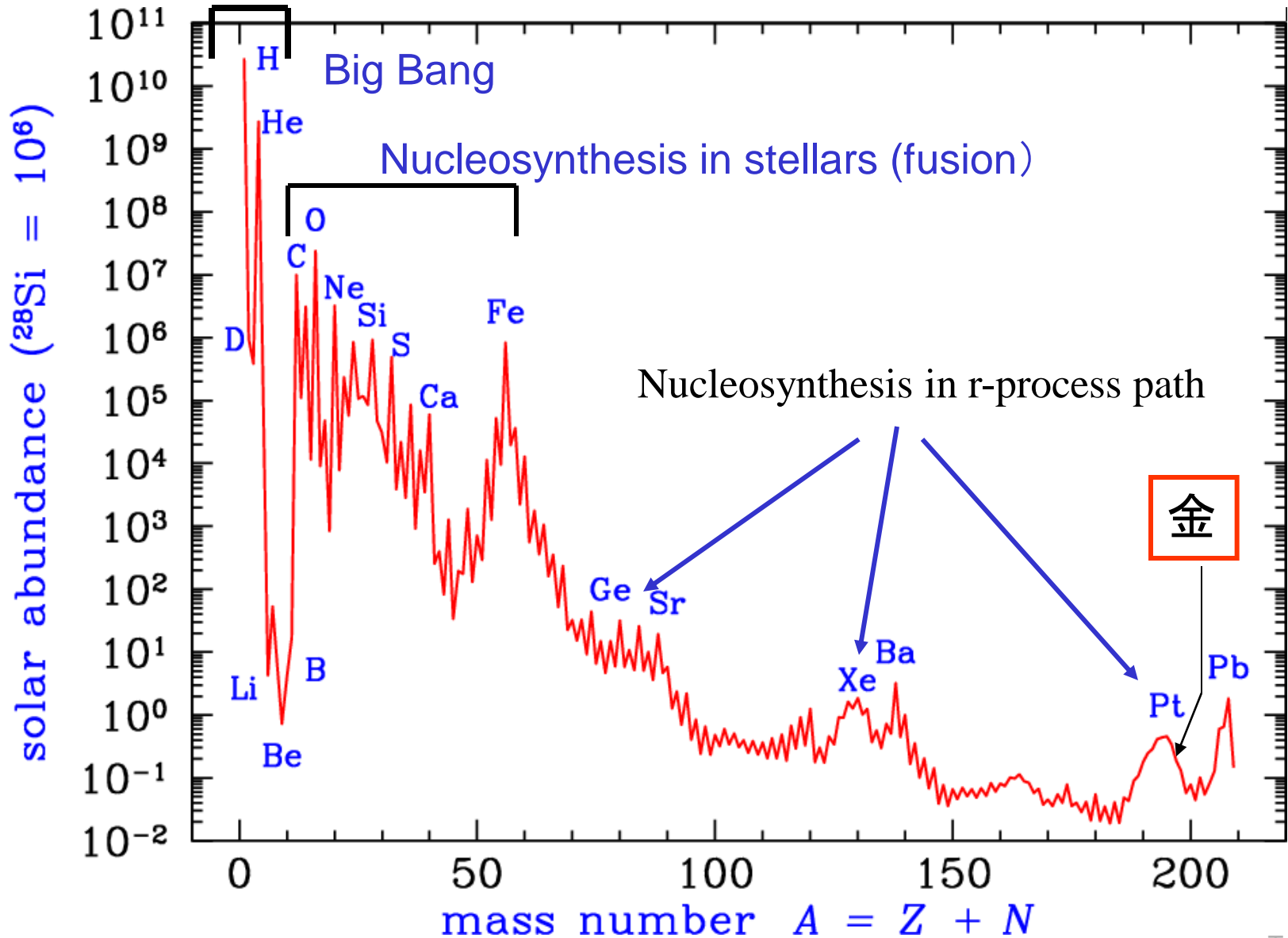
$E(4+)/E(2+)$

~ 1.8

~ 2.2

~ 3.3

Solar Abundance of Elements



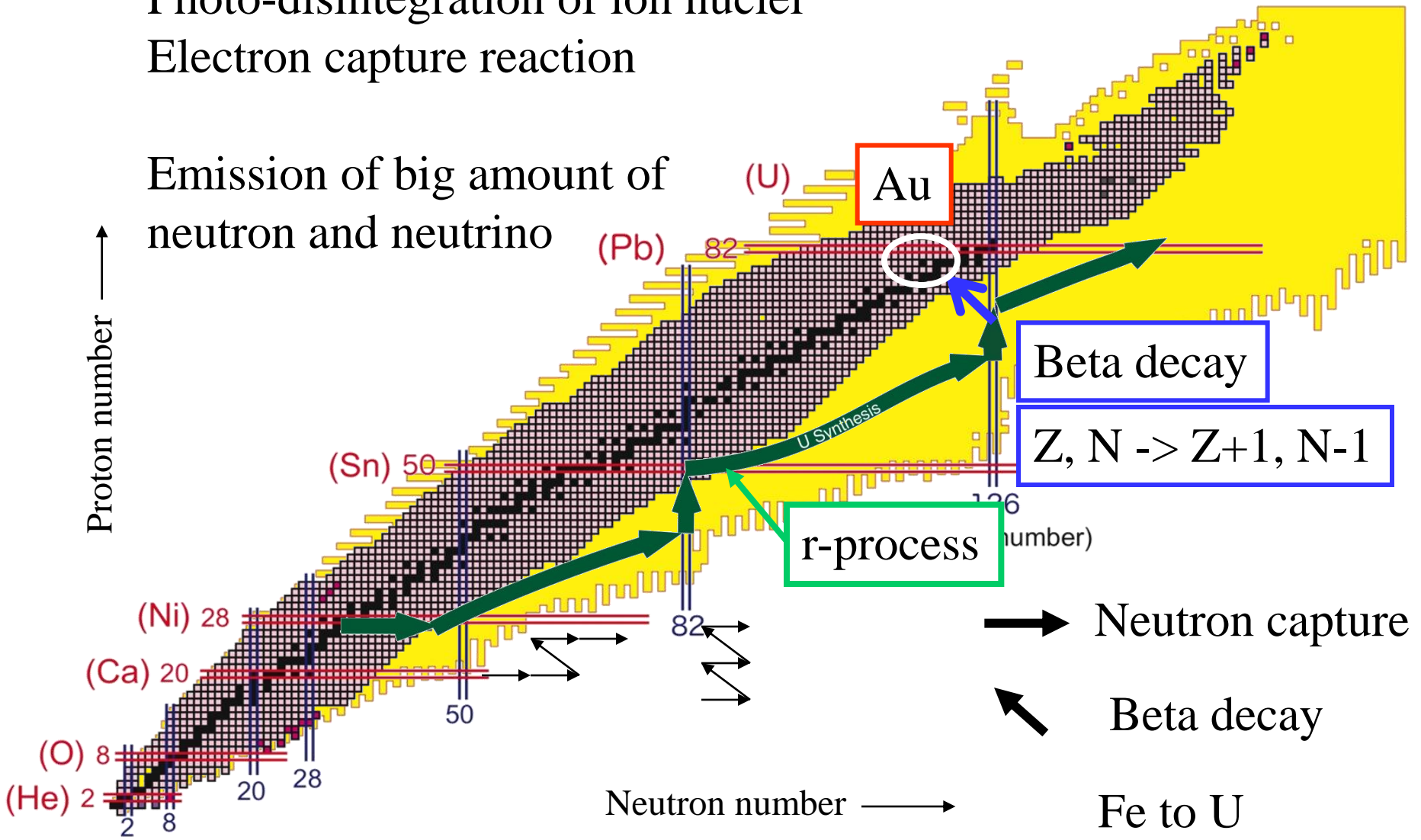
Gold . . .



r-process path in supernova explosion

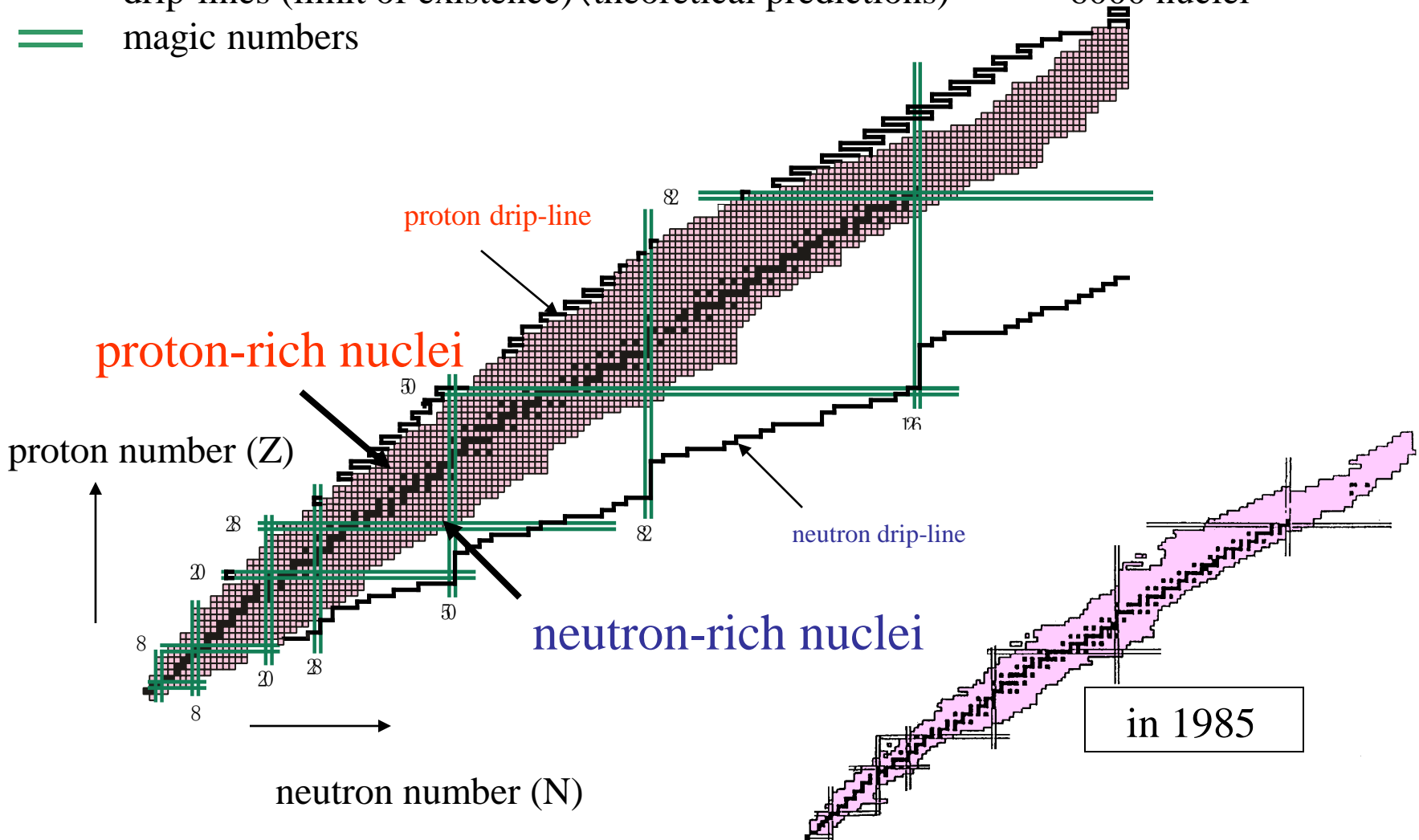
Photo-disintegration of ion nuclei
 Electron capture reaction

Emission of big amount of
 neutron and neutrino



Exploration of the Limit of Existence

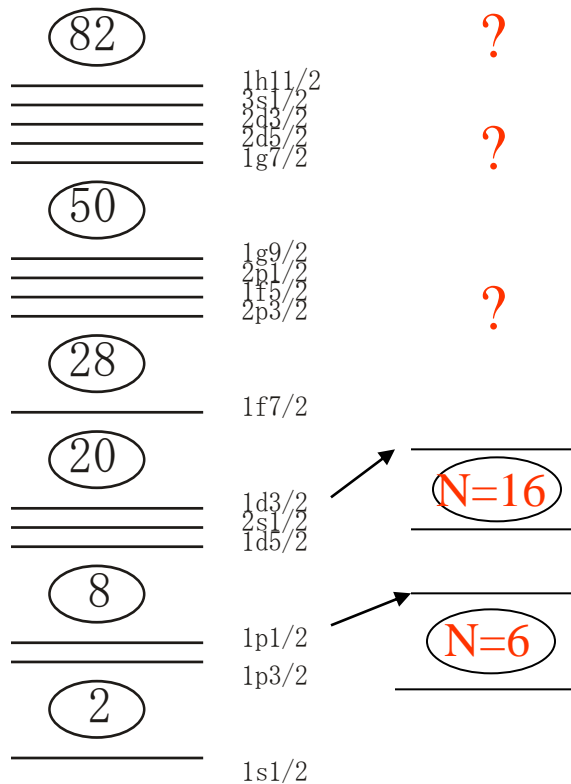
- stable nuclei ~300 nuclei
- unstable nuclei observed so far ~2700 nuclei
- drip-lines (limit of existence) (theoretical predictions) ~6000 nuclei
- == magic numbers



New frameworks for the new region of nuclear chart

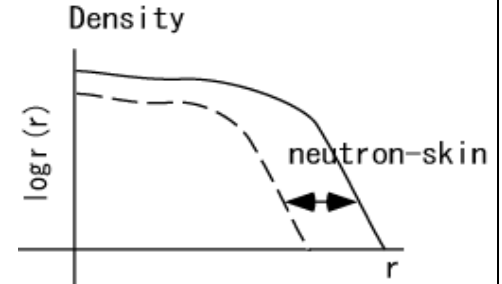
Nuclear Structure: Shell evolution

Stable Nuclei Neutron-rich Nuclei

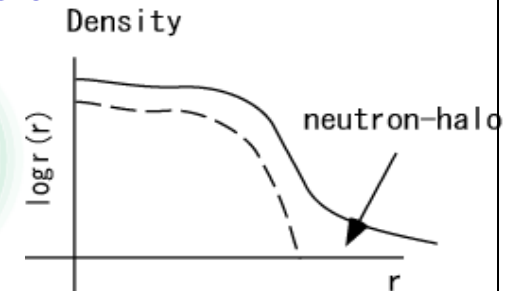
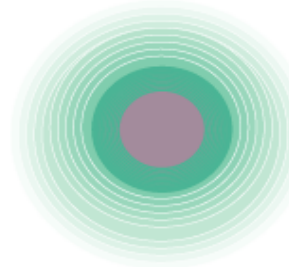


Nuclear Matter: New forms

neutron-skin nuclei



neutron-halo nuclei



¹¹Be, ¹¹Li, ¹⁹C...

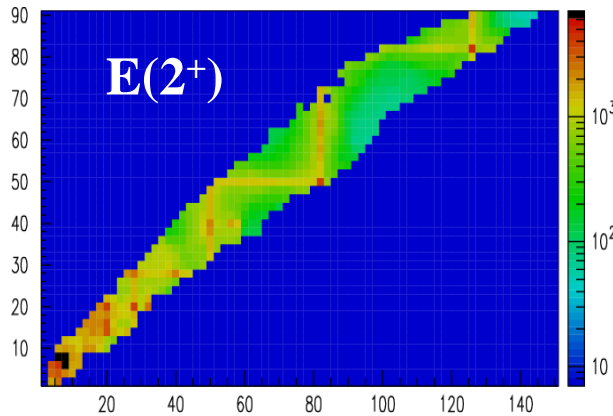
To write up new text book: Exotic phenomena, Systematics, etc.

Isospin-, density-dependences of effective interactions, nucleon-corrections

Microscopic system (nuclei) to Macroscopic system (neutron stars)

Liberation from Stable Region and Exotic Nuclei

Shell Evolution : magicity loss and new magicity



- Shape ?
- Shell gap ?
- Single particle level ?
- Cluster formation ?
- Role of 3NF ?
- Magicity loss ?

50, 82, 126, 184

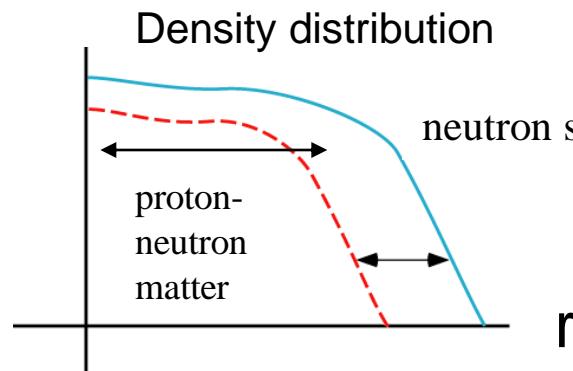
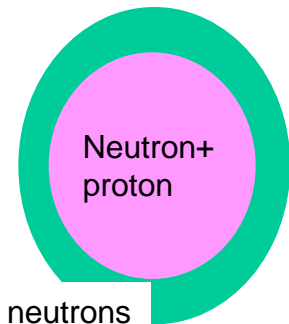
Spherical



Deformed



Dynamics of new “material” : Neutron-skin (halo)



- New quantum objects with two surfaces
- Skin thickness ? Density distribution ?
- Role of skin in reactions ?
- Pairing in skin ? di-neutrons ?
- Exotic modes of skin ?

RIBF provides data for nuclei far from the stability line

Challenges in establishing new frame work of nuclear physics

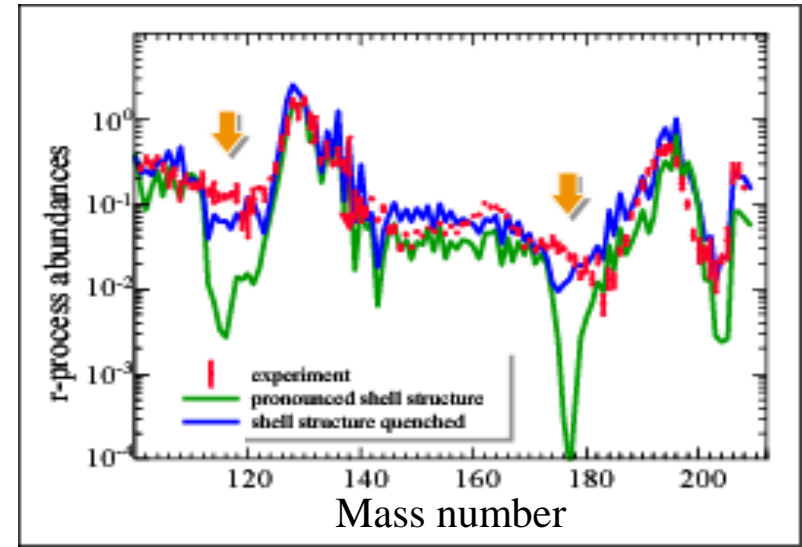
Challenge for r-process path and explosion in supernovae

Synthesis up to U (r-process)

unknown neutron-rich nuclei
theoretical predictions only

Necessary of experimental investigation
for nuclear properties of heavy and
neutron-rich nuclei

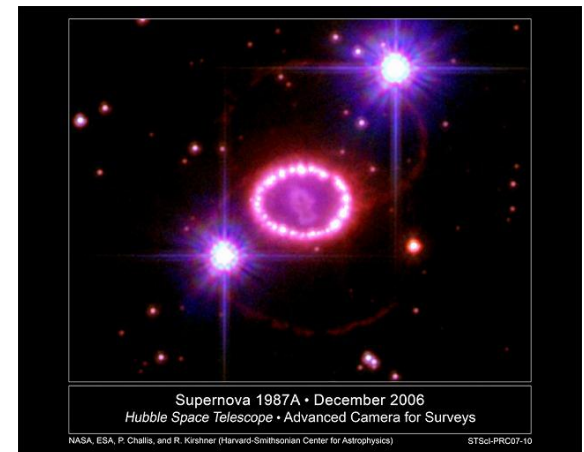
Mass, life-time, decay mode



Explosion mechanism of supernova

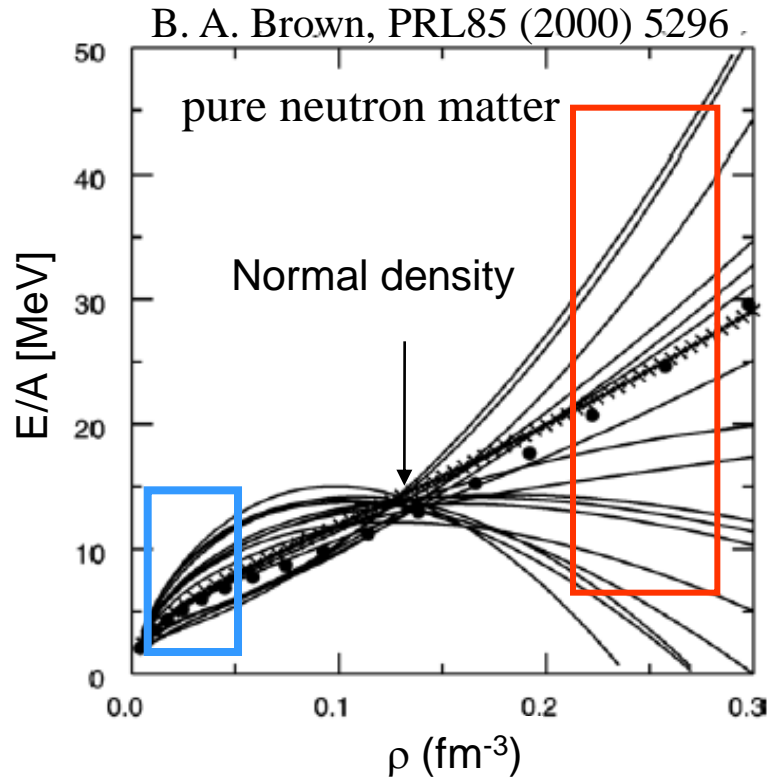
No explosion in theoretical works
Outer clast of neutron star

Necessary of experimental study for
Equation-of-State for nuclear matter



1987A

Challenge to investigate EOS of neutron matter from nuclei to neutron stars



1S correlation

BCS-BEC crossover
in dilute system ($\rho \sim 0.1\rho_0$) ?

3P_2

$T=3/2$ channels?
density dependence?

Elastic $d+p$ for $T=1/2$

Nuclear structure in

very neutron-rich nuclei for $T=3/2$?

Heavy-ion Collisions to achieve $\rho \sim 2-3\rho_0$?

3P_2 correlation

pairing gap?

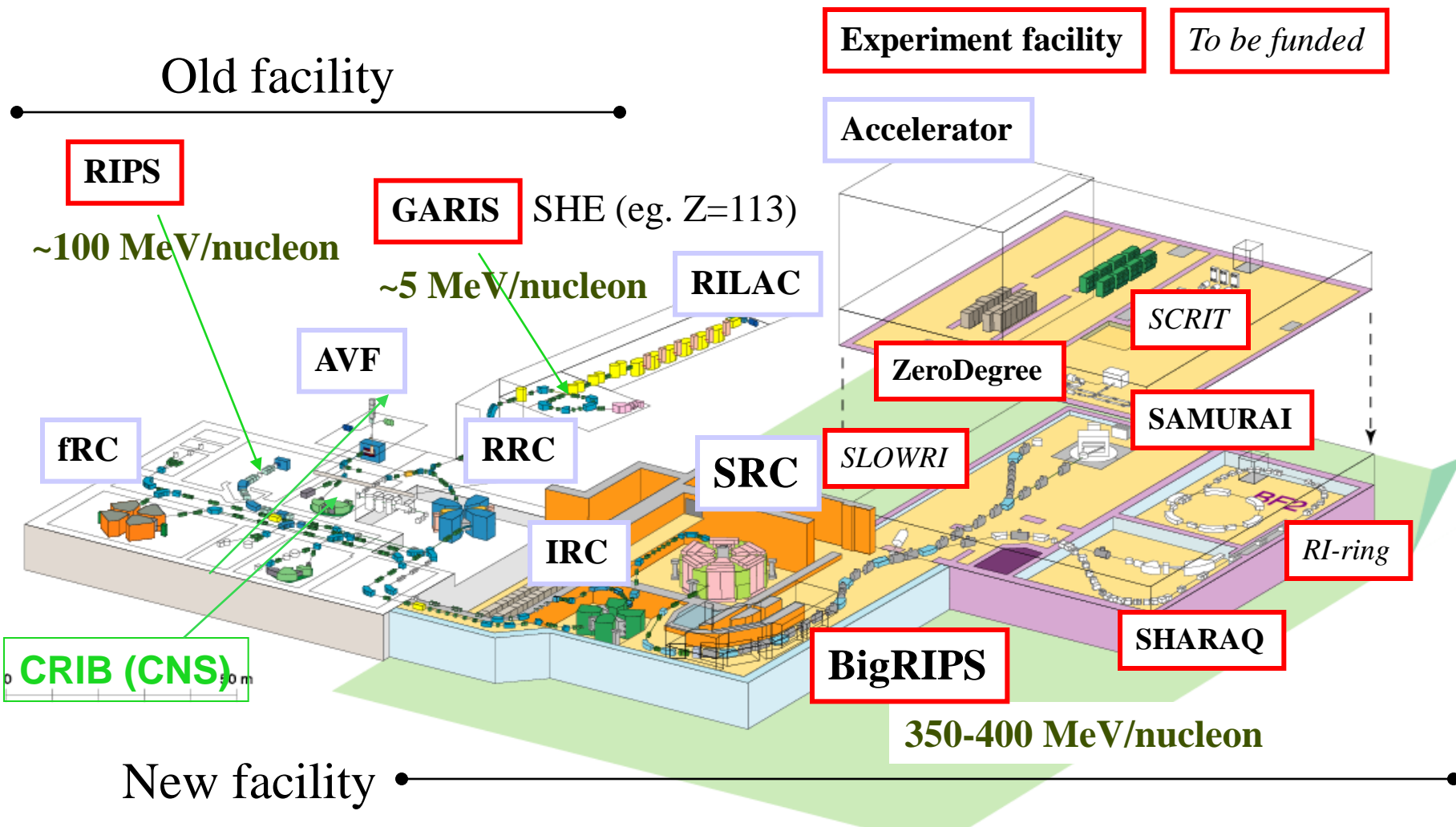
Density dependence?

????

Role of di-neutron in skin? : collectivity, transfer reactions

RIKEN RI Beam Factory (RIBF)

Old facility



New facility

Intense (80 kW max.) H.I. beams (up to U) of 345A MeV at SRC
Fast RI beams by projectile fragmentation and U-fission at BigRIPS
Operation since 2007

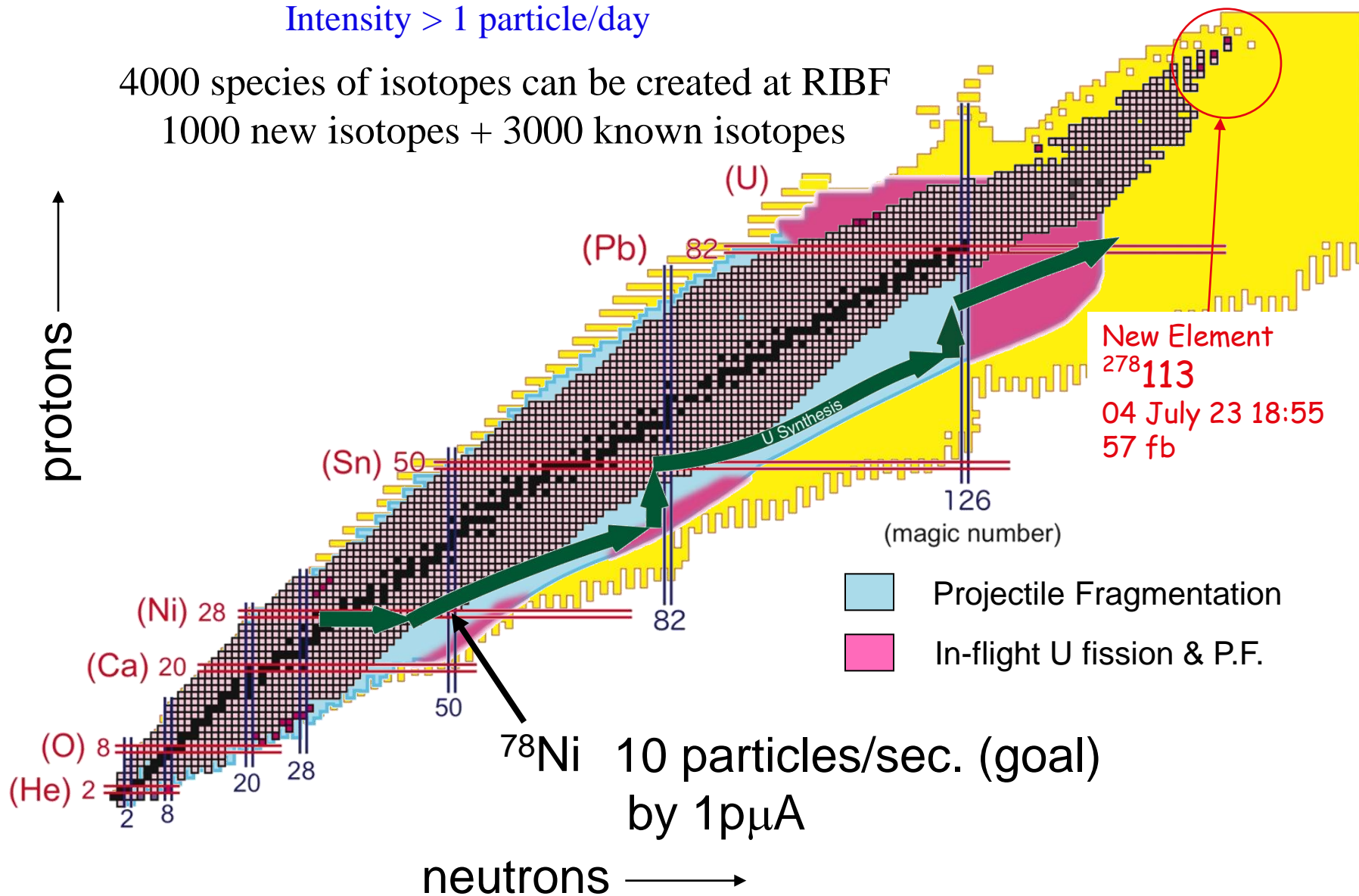
Exploration of the Limit of Existence

Great expansion of nuclear world by RIBF

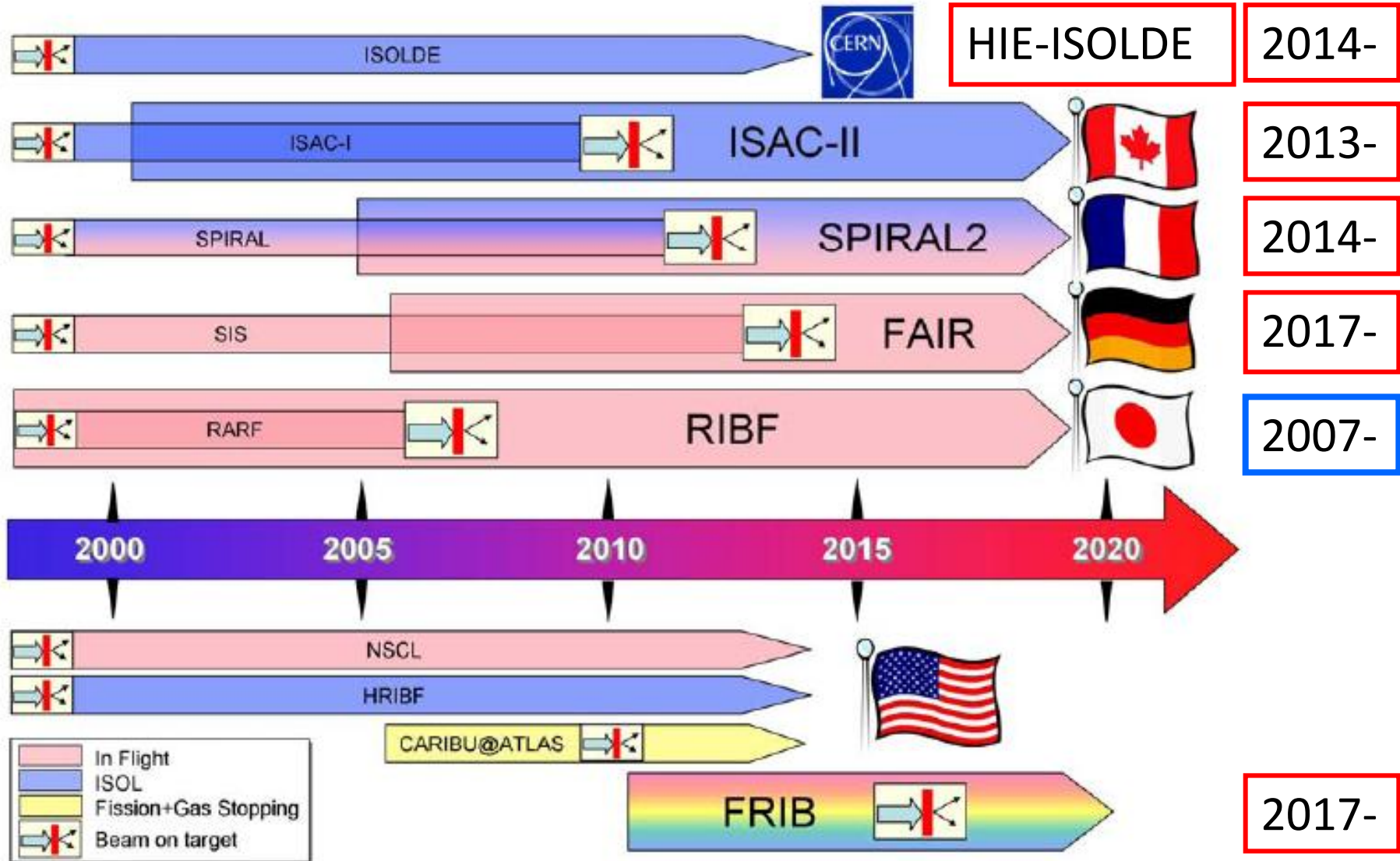
Intensity > 1 particle/day

4000 species of isotopes can be created at RIBF

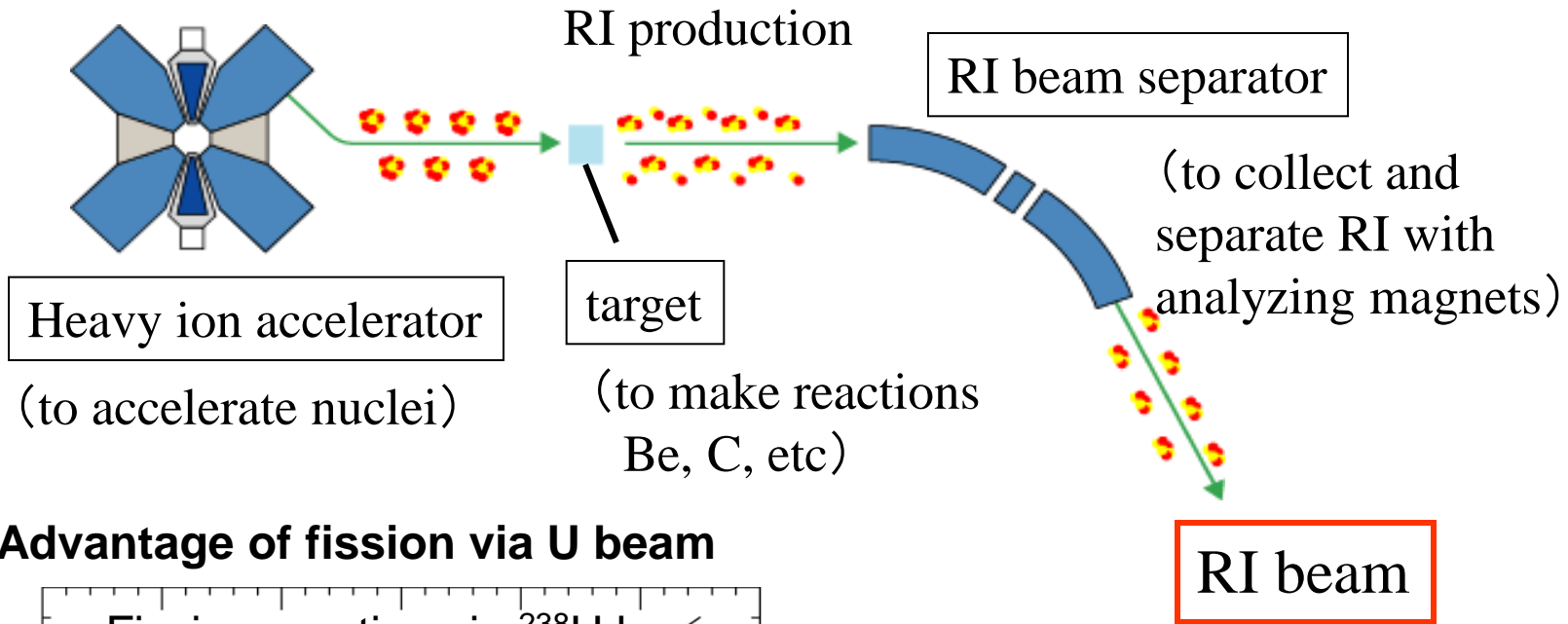
1000 new isotopes + 3000 known isotopes



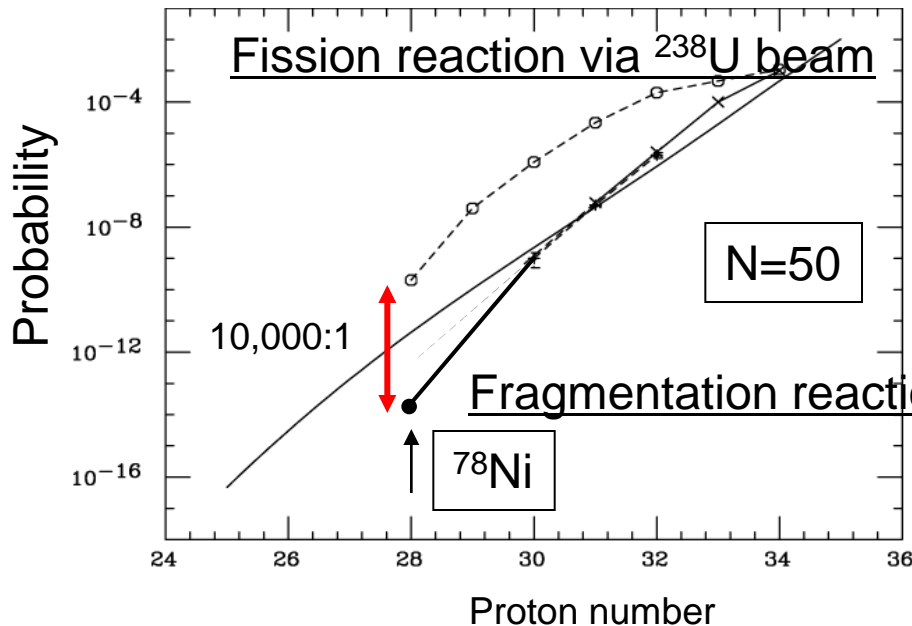
Large-scaled Facilities in the world



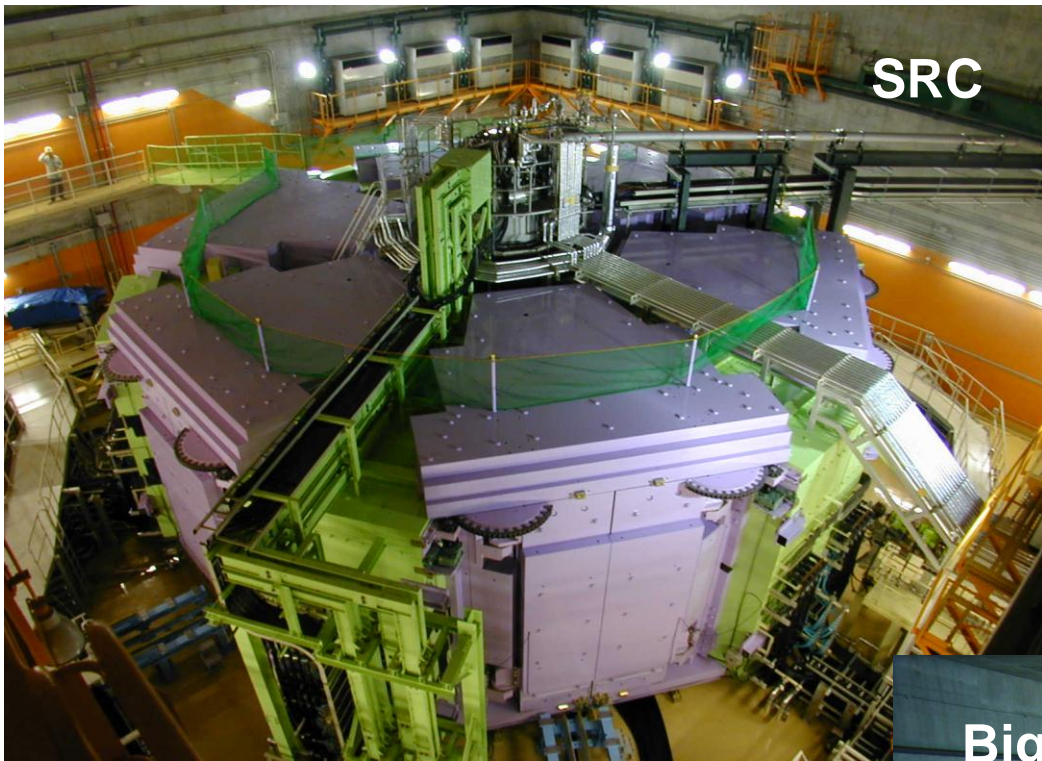
RI beam production via in-flight method



Advantage of fission via U beam



Yield rate of ^{78}Ni via fission is **about 1,000** times higher than via fragmentation.



SRC

**World's First and Strongest
K2600MeV
Superconducting Ring Cyclotron**

400 MeV/u Light-ion beam
345 MeV/u Uranium beam

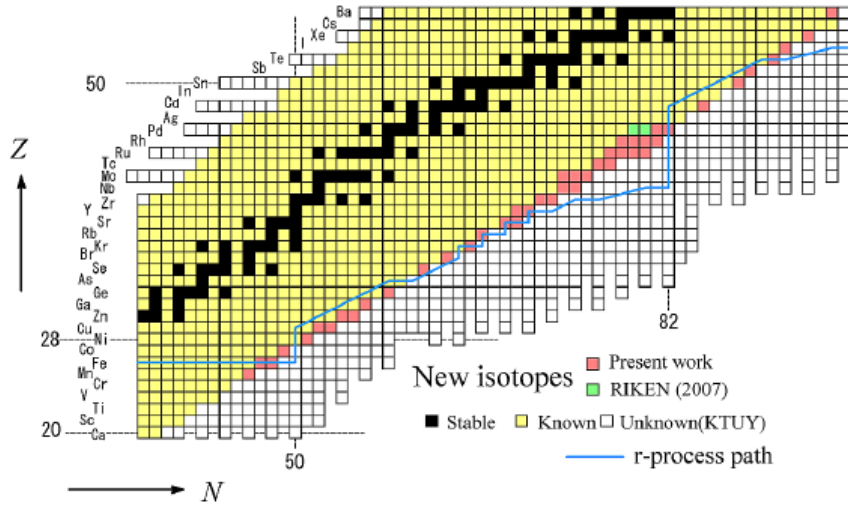
**World's Largest Acceptance
9 Tm
Superconducting RI beam Separator**

~250-300 MeV/nucleon RIB



BigRIPS

Identification of 45 New Neutron-Rich Isotopes Produced by In-Flight Fission of a ^{238}U Beam at 345 MeV/nucleon



T. Ohnishi, et al., JPSJ 79, 073201 (2010).

Nov., 2008

Averaged beam intensity ~0.2 p nA

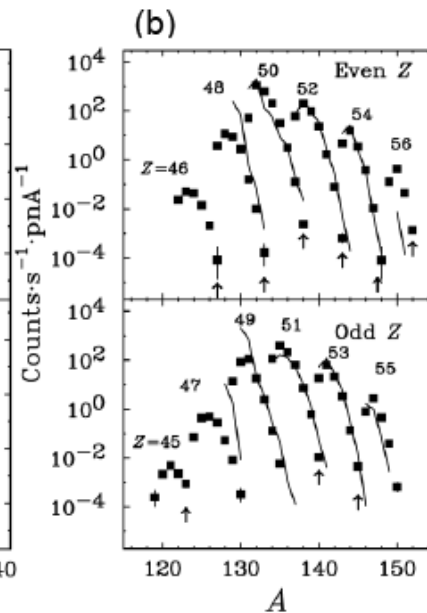
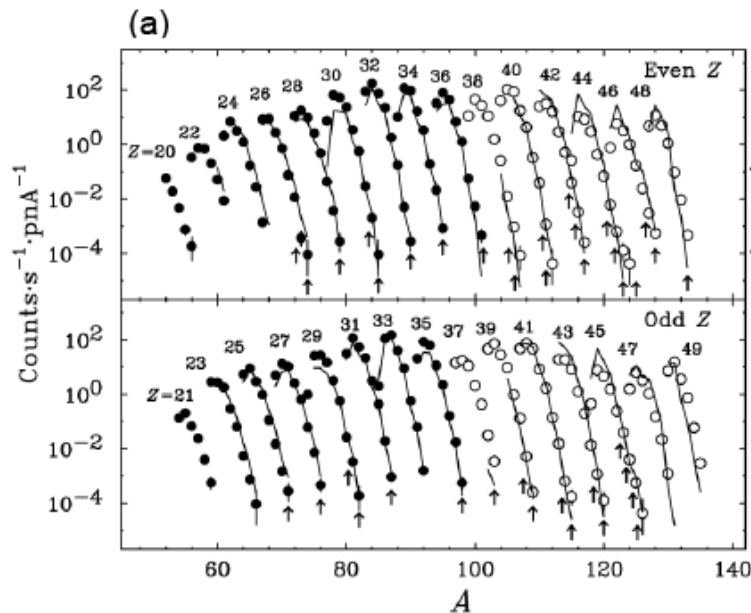
Maximum intensity 0.4 p nA

Mn (Z=25) to Ba (Z=56)

Covered by three Brho settings

Be and Pb targets

Total dose $1-2 \times 10^{14}$ for each Brho setting



Yield rates reasonably reproduced by LISE++

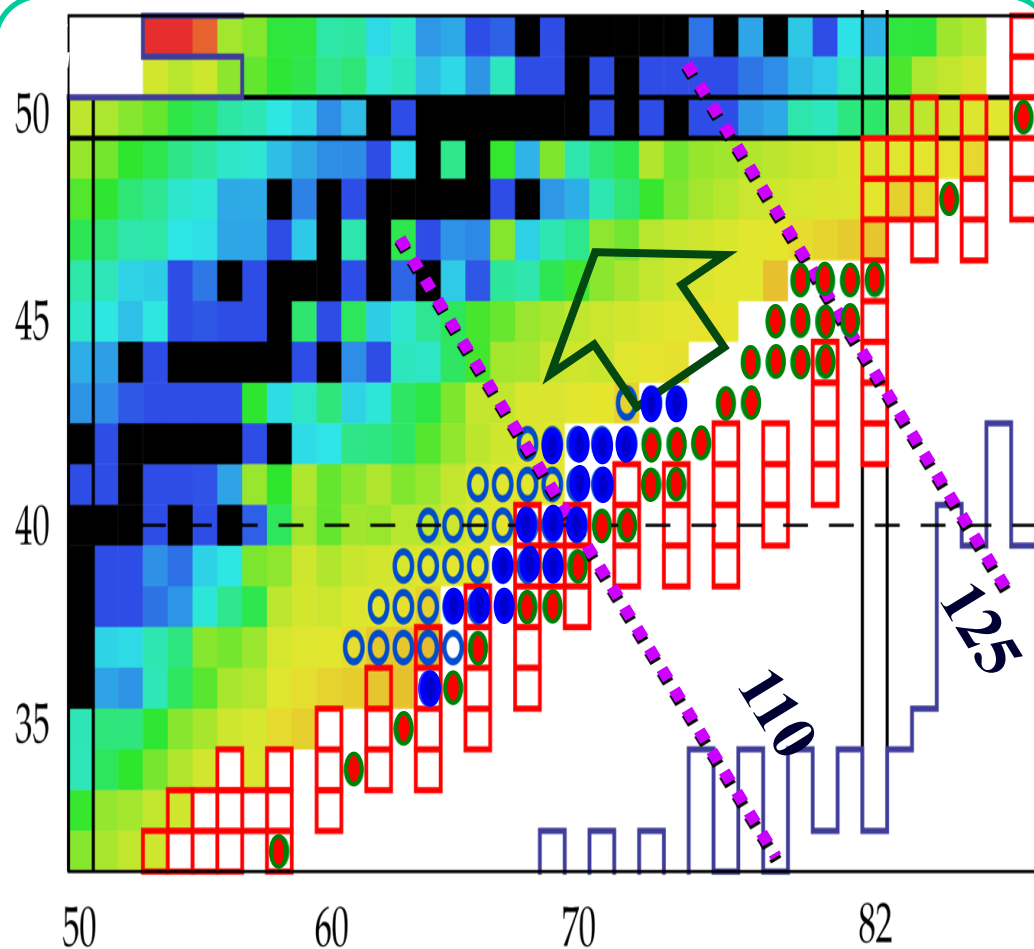
Half-Lives of Very Neutron-Rich Nuclei

S. Nishimura et al.

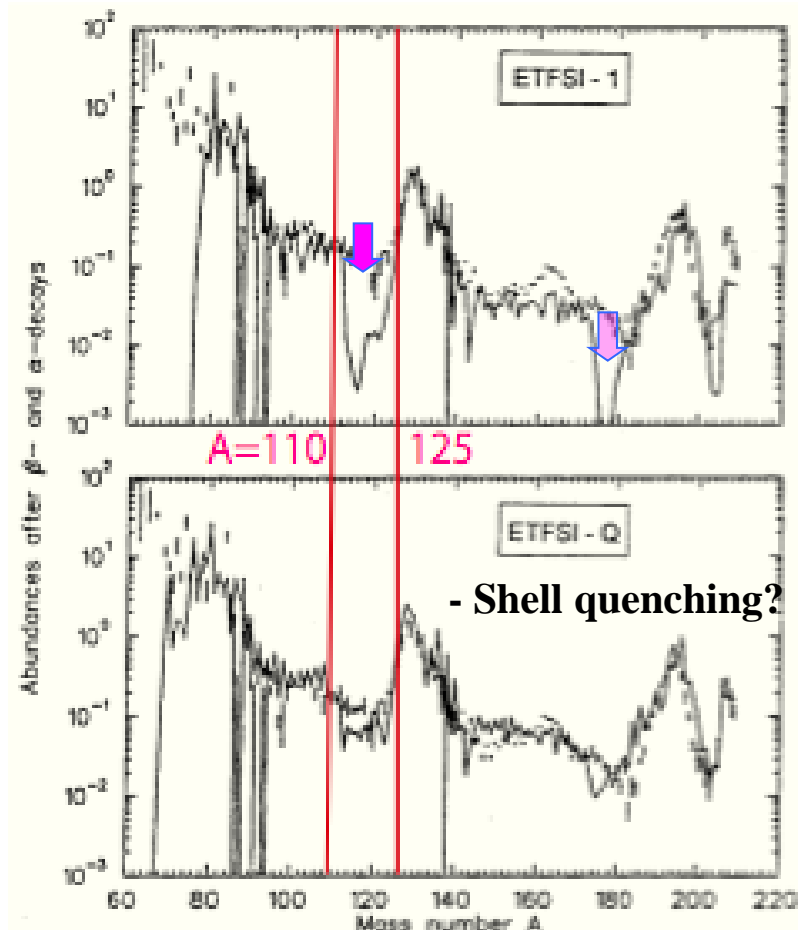
(Kr,Rb,Sr,Y,Zr,Nb,Mo,Tc) around 2nd R-Process Peak

T. Ohnishi, JPSJ 79 (2010).. 45 new isotopes

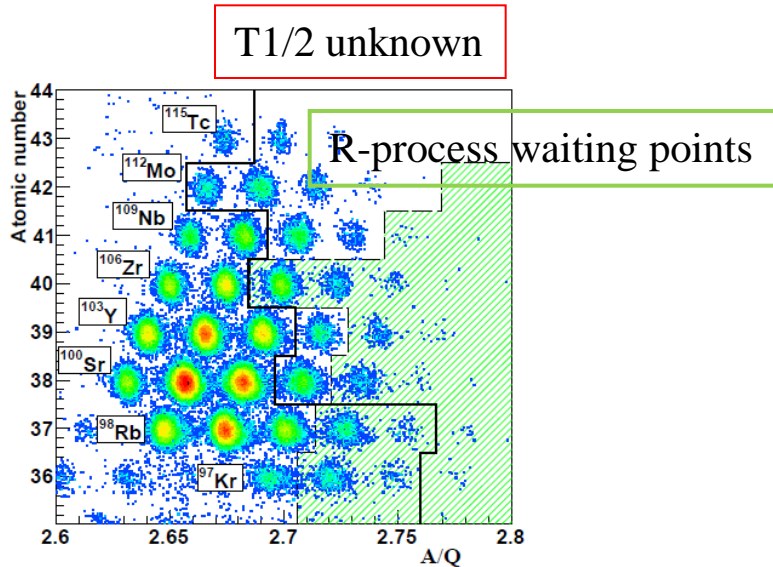
New half-lives (18 nuclei) are measured !



B. Pfeiffer et al. Z. Phys. A357 (1997)



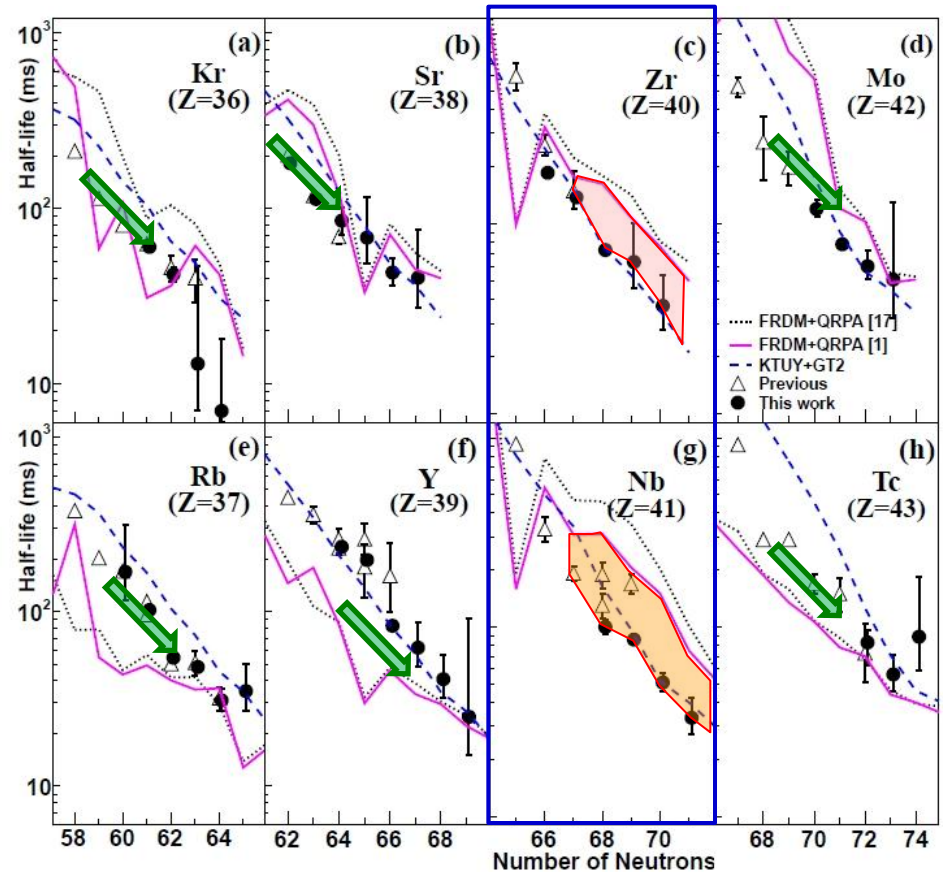
Brand-new half-life data for 18 isotopes



S. Nishimura et al., PRL 106 (11) 052502

1/3 ~ 1/2 Shorter Half-lives of Zr and Nb (A~110)

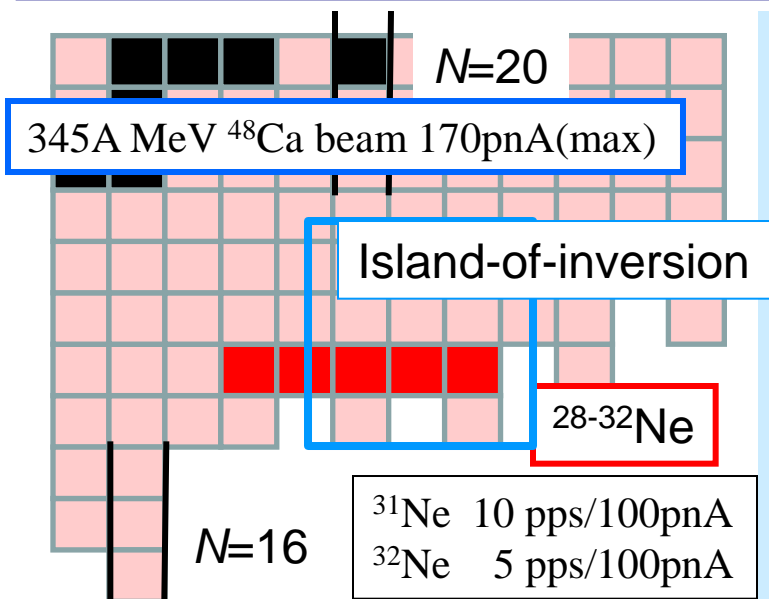
8 hour data acquisition
 T1/2 data of 38 isotopes including
 first data for 18 isotopes
 FRDM may underestimate Q-value
 for Zr and Nb by 1 MeV at A~110
 More rapid flow in the rapid
 neutron-capture process
 than expected



DayOne Experiments in Dec., 2008

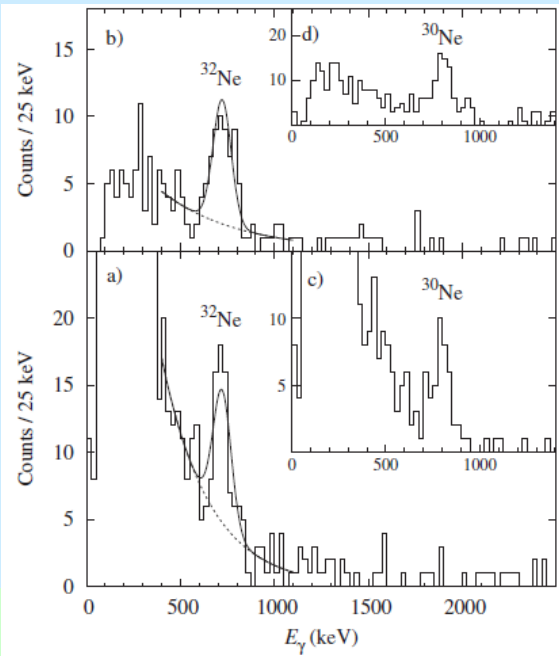
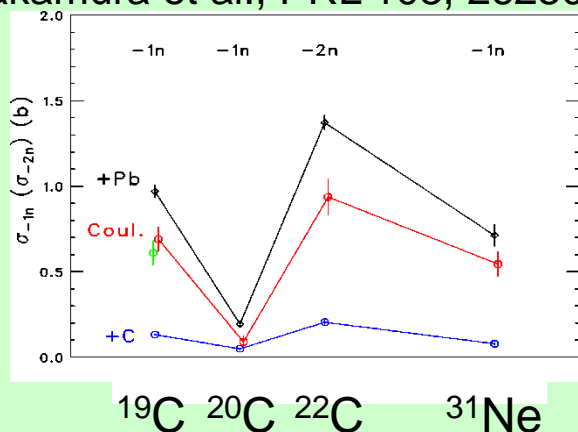
-The first data in the “island-of-inversion” -

Coordinated by Aoi



A new candidate of halo nuclei ^{31}Ne via Coulomb breakup

Nakamura et al., PRL 103, 262501(2009)



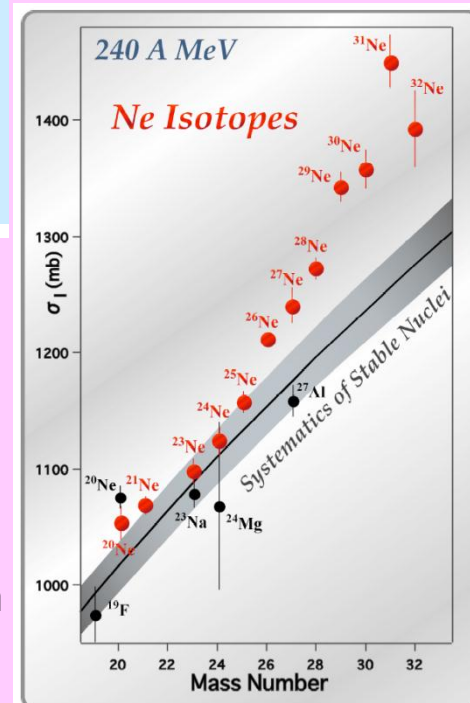
Spectroscopy of ^{32}Ne and the “island-of-inversion”

$$E(2+) = 722 \text{ keV}$$

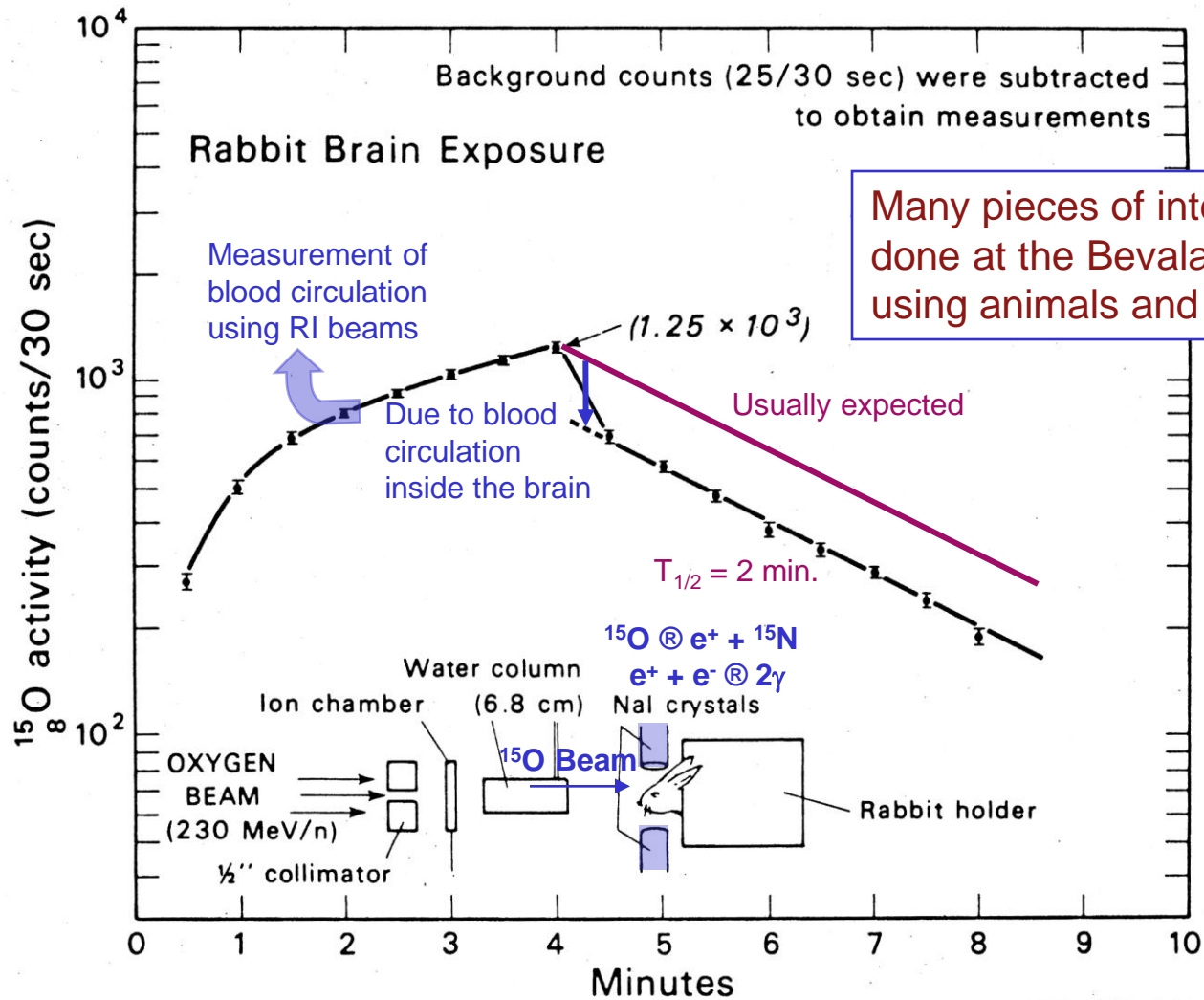
Doornenbal, Scheit et al. PRL 103, 032501 (2009)
New states in $^{31,32,33}\text{Na}$ PRC 81, 041305R (2010)

Total interaction cross sections for the neutron-rich Ne isotopes

Takechi, Otsubo et al., Niigata 2010 symposium

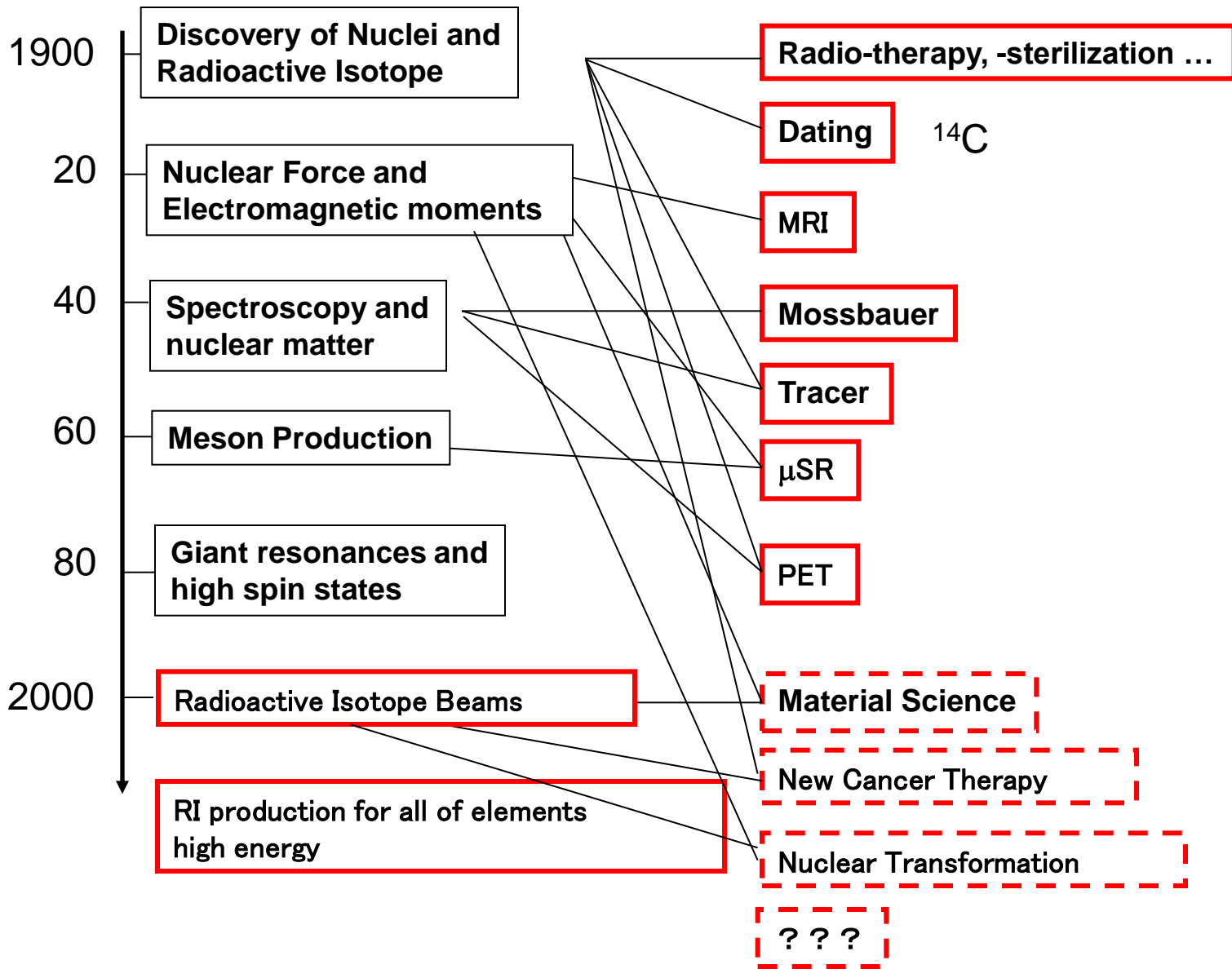


The First RI Beam Experiment (1974)



Many pieces of interesting work done at the Bevalac in biology using animals and plants

Development of Nuclear Physics and Applications

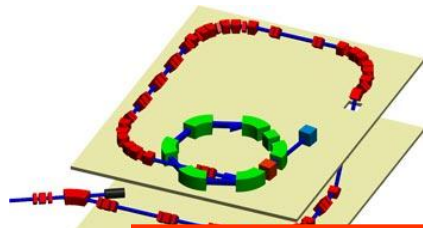


New Devices of RIBF

To maximize the potentials of intense RI beams available at RIBF

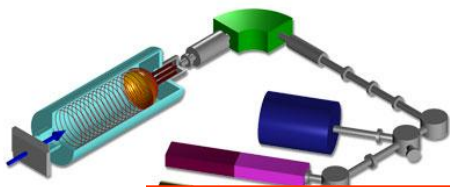
for several 100 – 1000 species

Rare RI ring



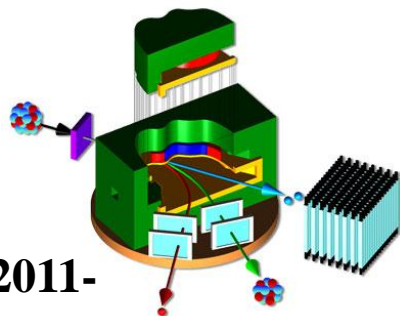
to be funded

SLOWRI



to be funded

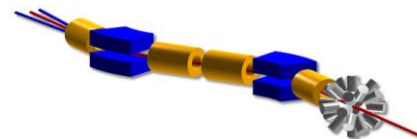
SAMURAI



2011-

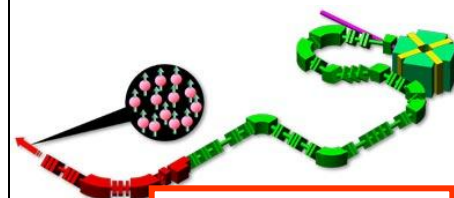
mass
half-life
excited states
deformation
charge radii
matter radii
charge distribution
matter distribution
EM moments
single particle states
astrophysical reactions
giant resonances
exotic modes
HI collisions (EOS)

ZeroDegree



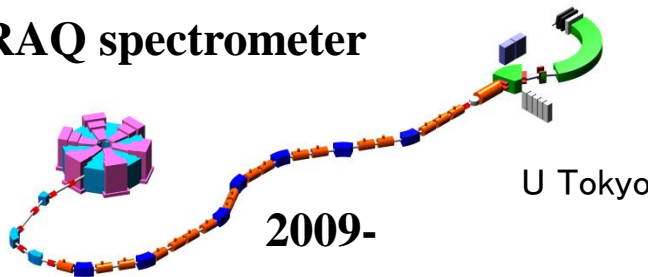
2008-

IRC-to-RIPS BT



to be funded

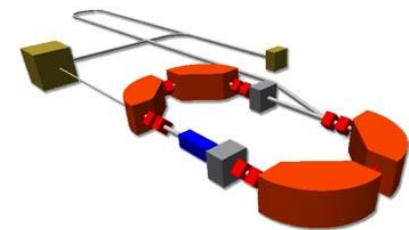
SHARAQ spectrometer



2009-

U Tokyo

SCRIT

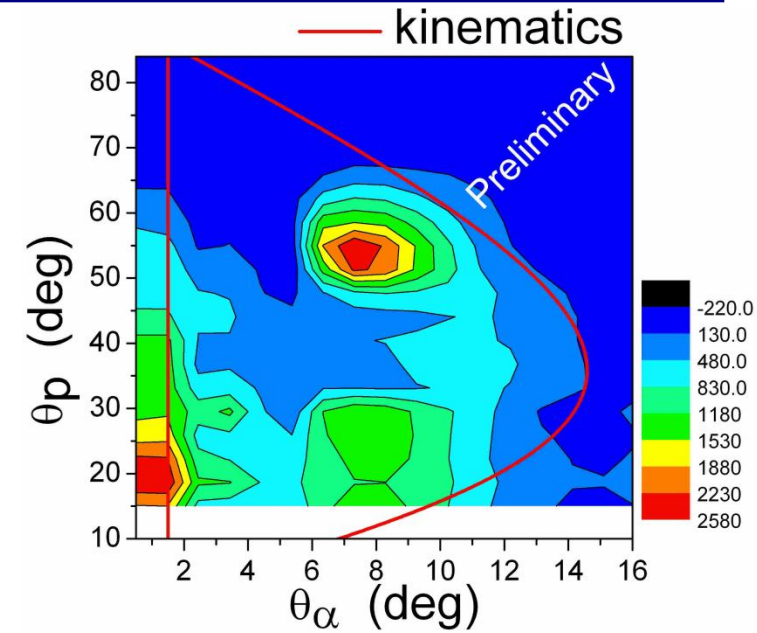
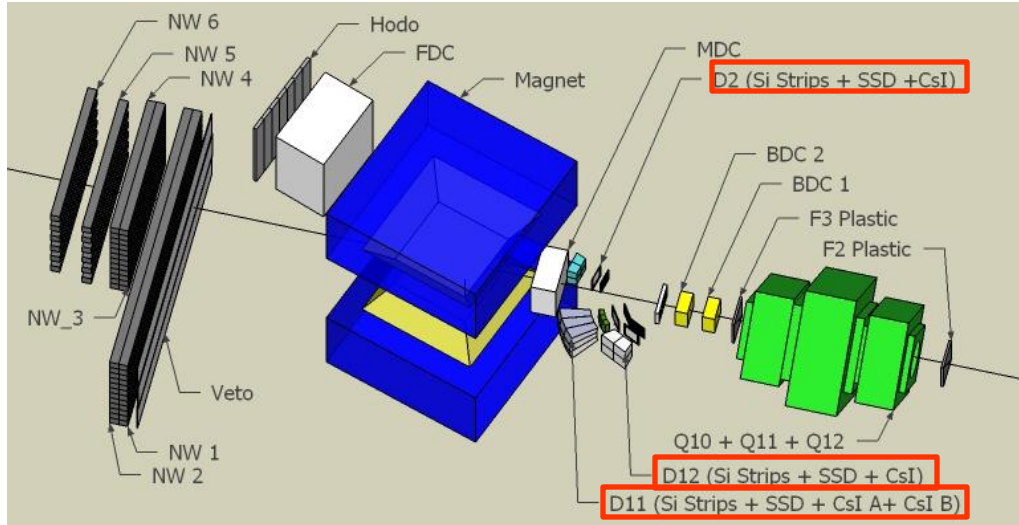


2010-

Recoiled proton tagged knockout reaction for He-8 at RIPS

PKU-RIKEN-IMP-TITech-Seoul

Ye et al., July 2009



“Quasi-elastic scattering of He-6 from C-12”
Lou and Ye et al., PRC 83, 034612 (2011)

Cao and Ye et al., in preparation

Challenge

Action

Discussion

Enjoy