Simulation study of RI-beam circulation in FFAG-ERIT toward synthesis of long-lived superheavy nuclei

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Collaborators

Kyushu University

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Kyoto University

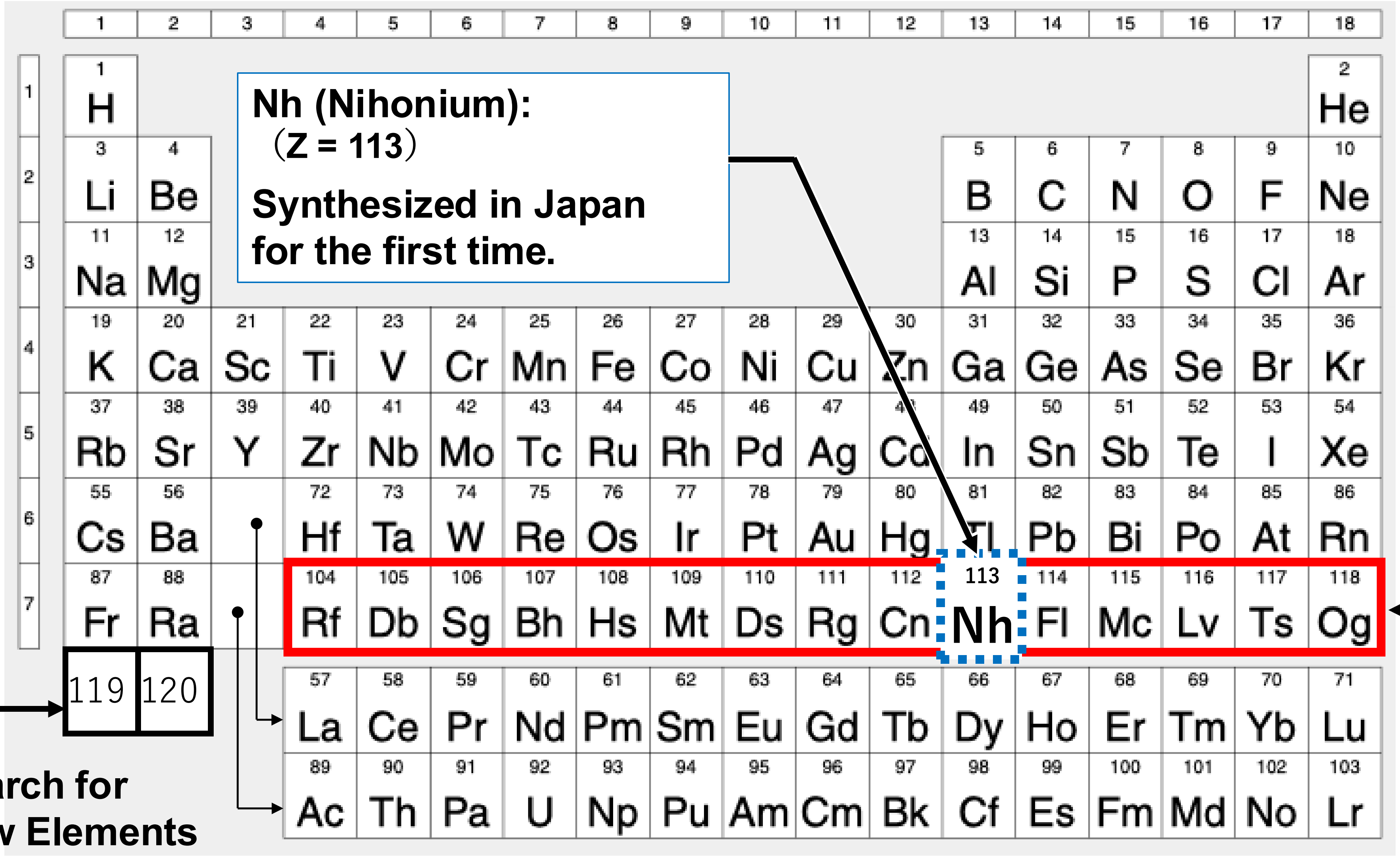
- Y. Ishi
- Y. Mori

JAEA

- K. Nishio

Outline

Expansion of the periodic table

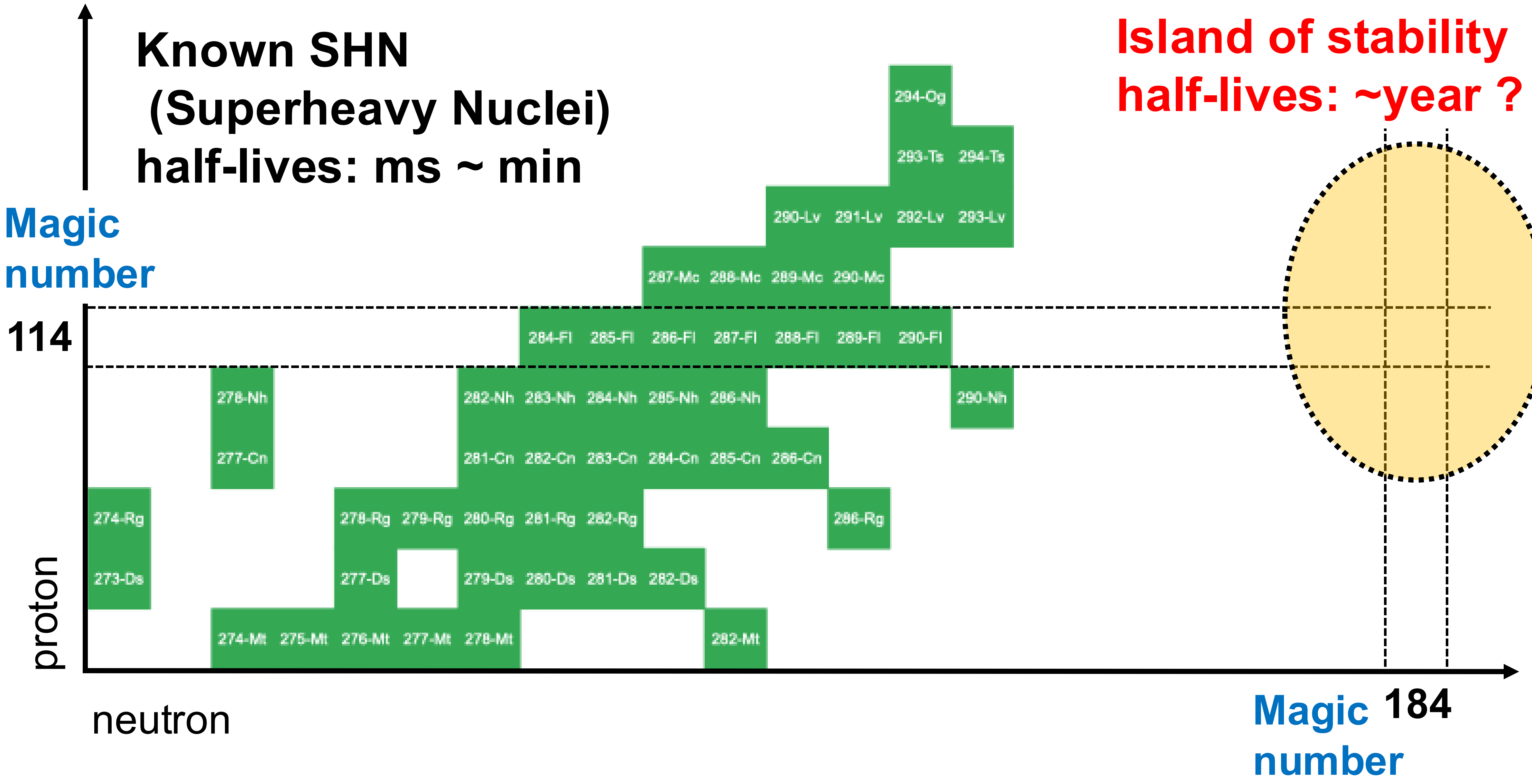


Superheavy Element (SHE)
(Z ≧ 104)

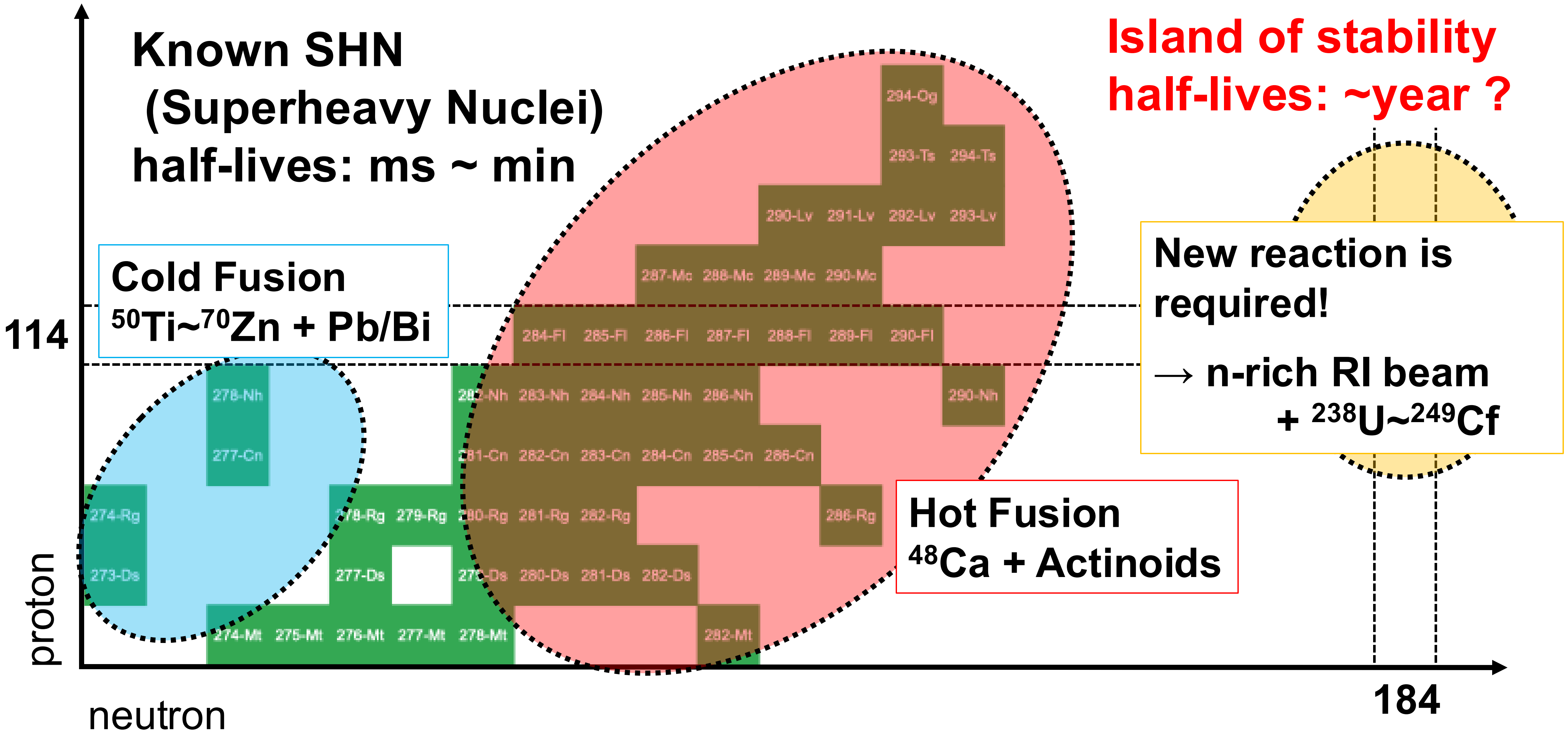
Short-lived

Search for New Elements @RIKEN and ...

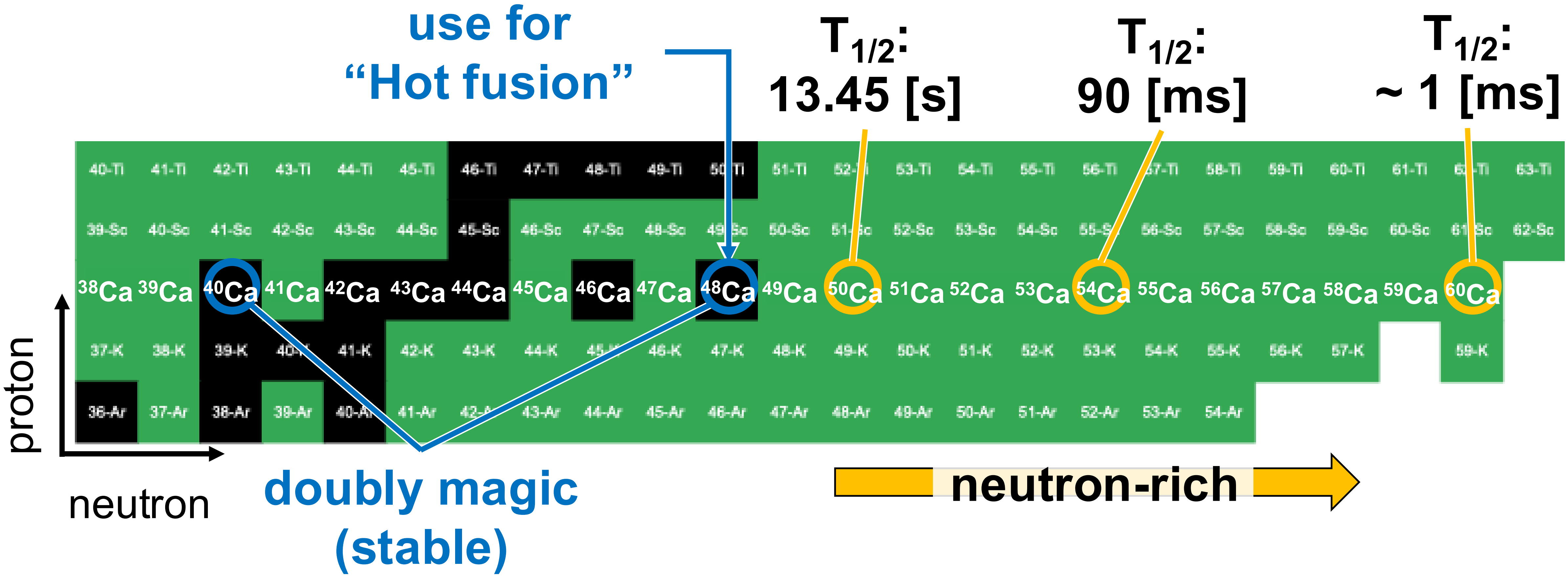
Expansion of the nuclear chart



Expansion of the nuclear chart



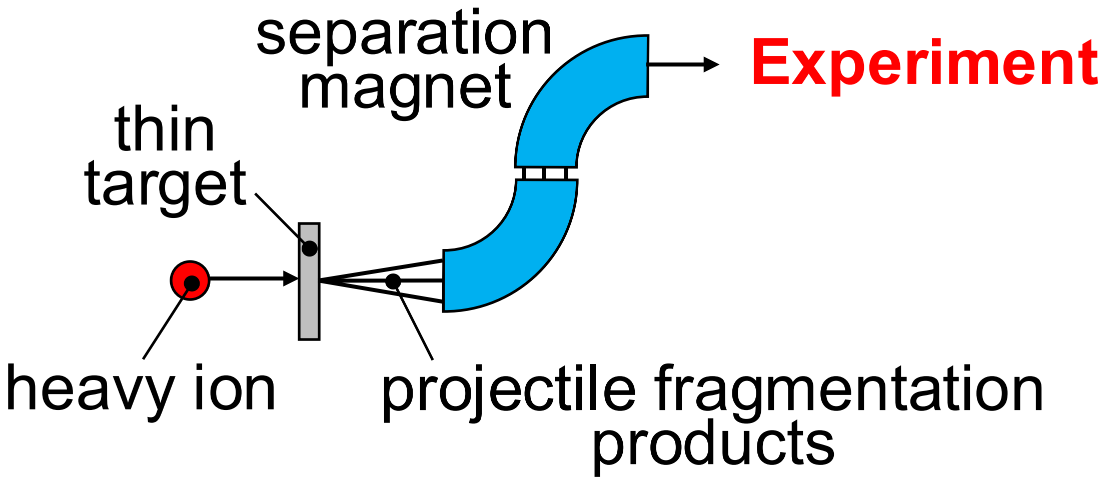
Neutron-rich RI beam



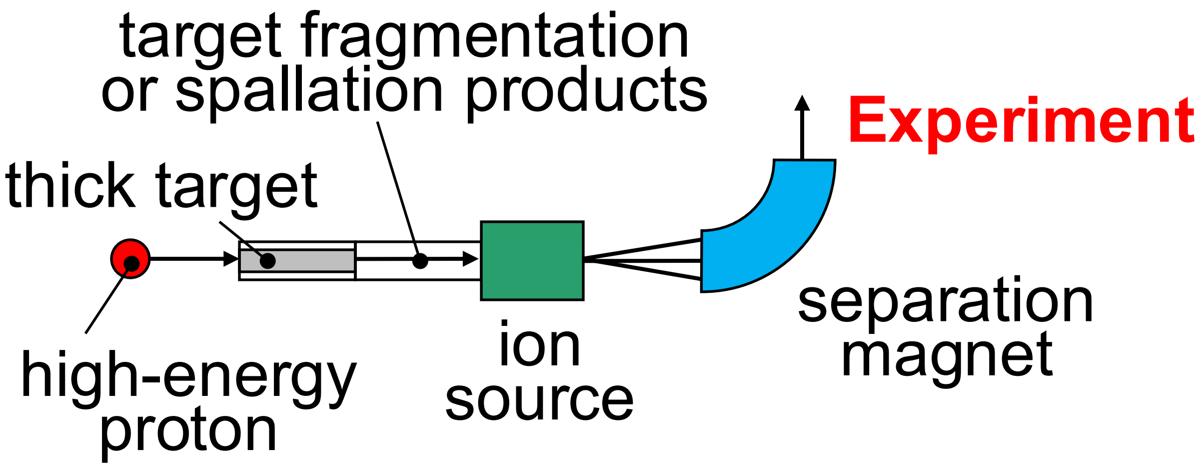
How to produce such neutron-rich RI beams? (next slide)

Neutron-rich RI beam

In-Flight Method



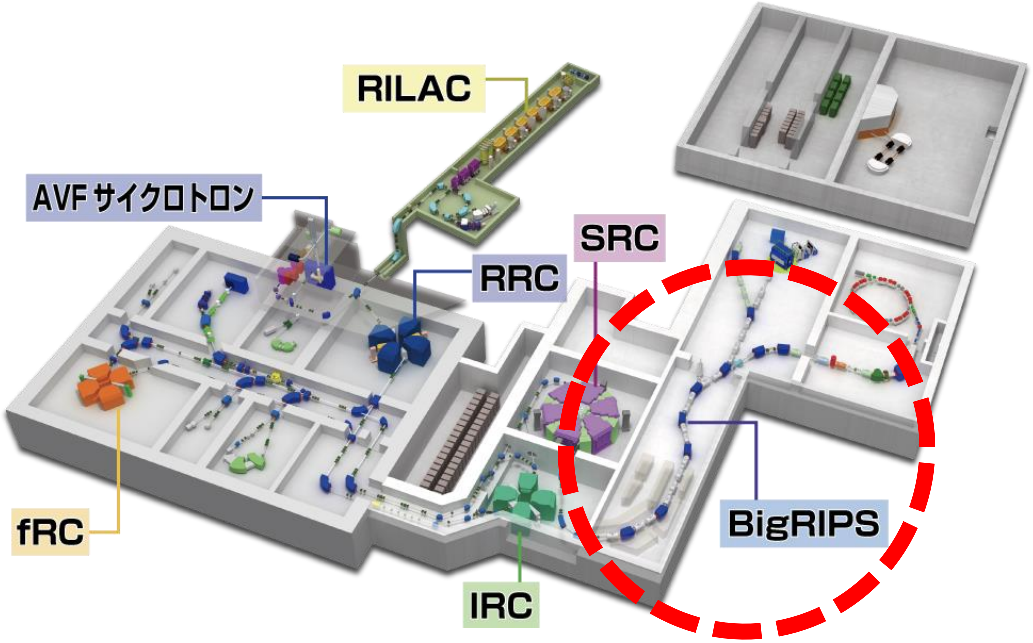
ISOL Method
(Isotope Separation Online)



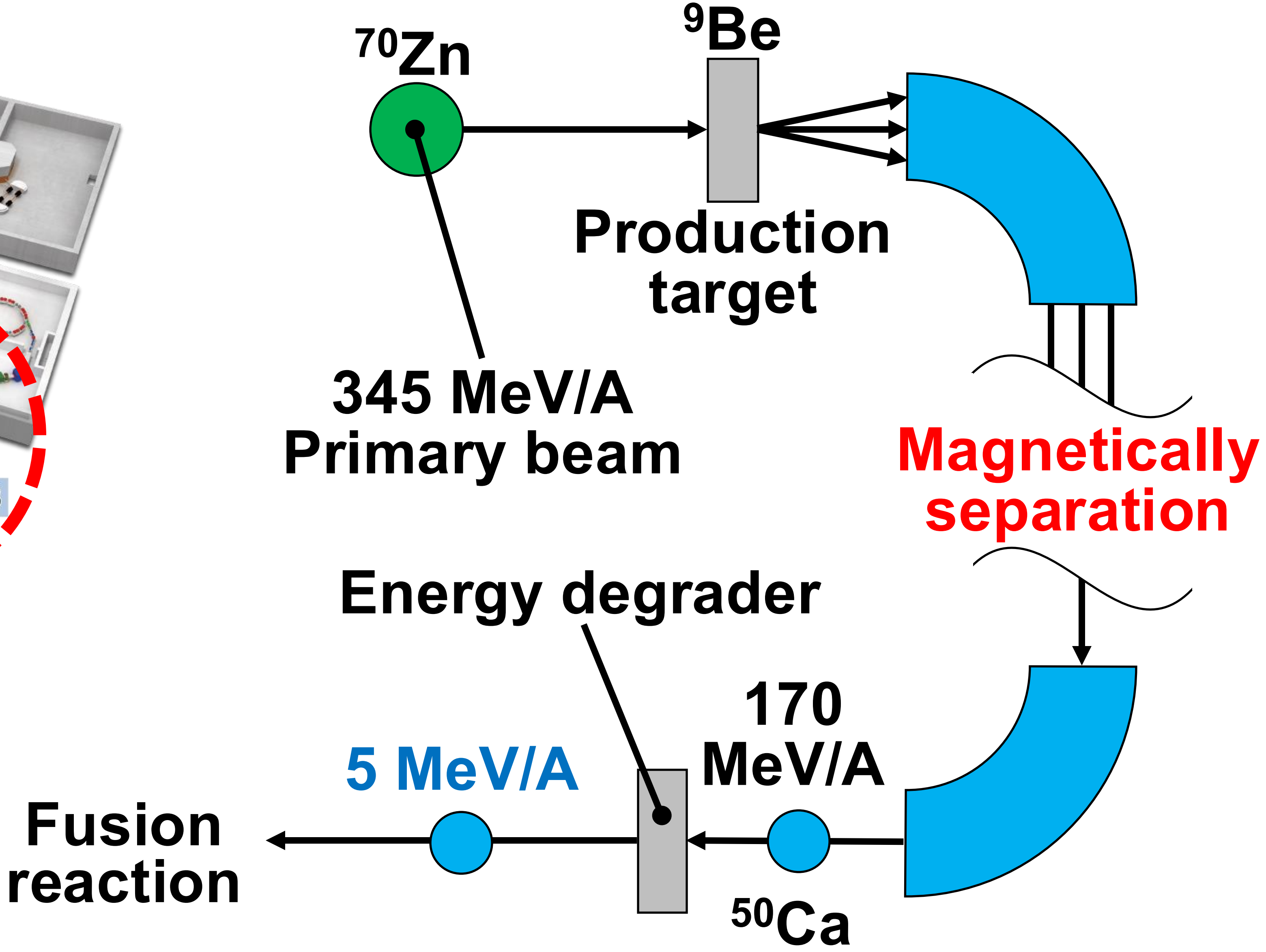
	In-Flight		ISOL	
	Low	**Intensity**	High	
for fast RI beam	High	**Energy**	Low	**for slow RI beam**
for short-lived nuclei	~100 ns	**Separation Time**	100 ms ~ 1 s	
	Large	**Emittance**	small (same as primary beam)	

RI-beam production by in-flight method

RIBF, RIKEN



https://www.nishina.riken.jp/facility/RIBFfacility.html



Difficulties in SHN production with RI-beams

Difficulties in superheavy element synthesis

- **Extremely small cross sections**

Difficulties in Fusion Reactions with RI Beams

- **Low intensity**
  - Many orders of magnitude lower than stable nuclear beams

→ Need for **beam recycling scheme** to achieve higher luminosity

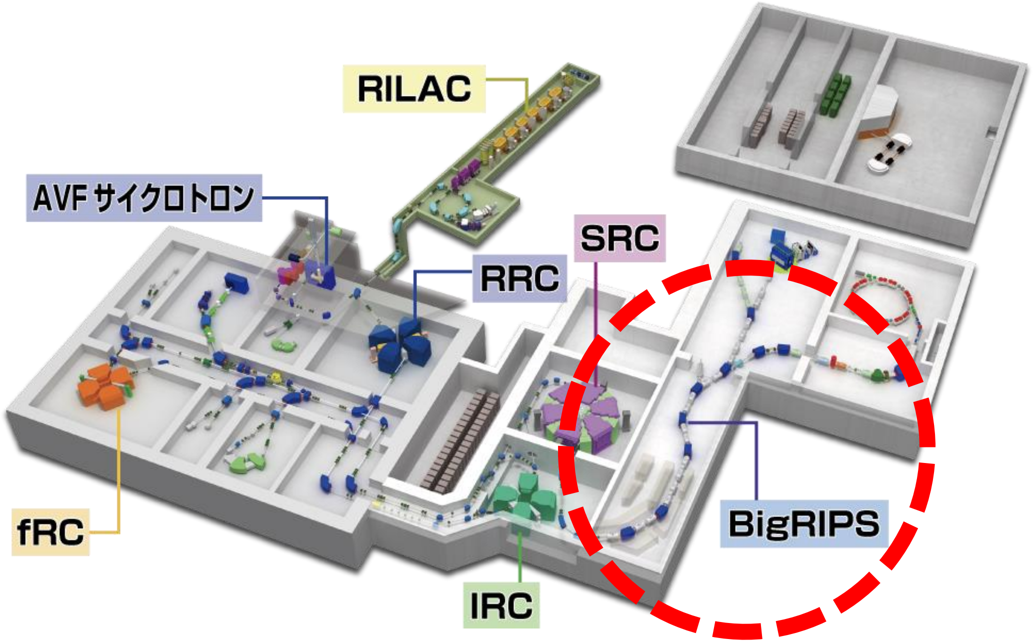
- **short-lived**
- **large emittance**

Can the RI beam be efficiently recycled?

Small cross section × Low beam intensity makes experiments very difficult

RI-beam production by in-flight method

RIBF, RIKEN



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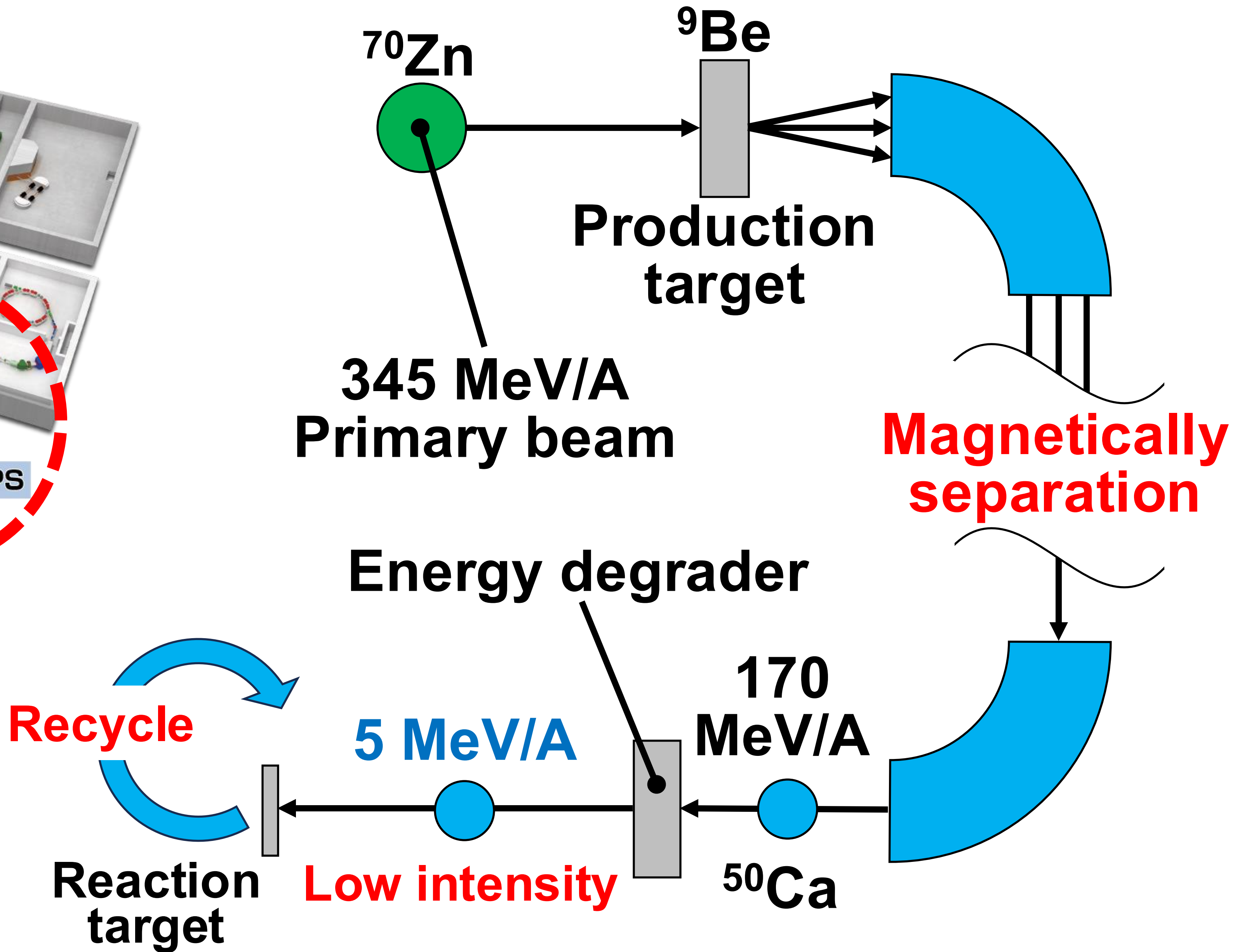
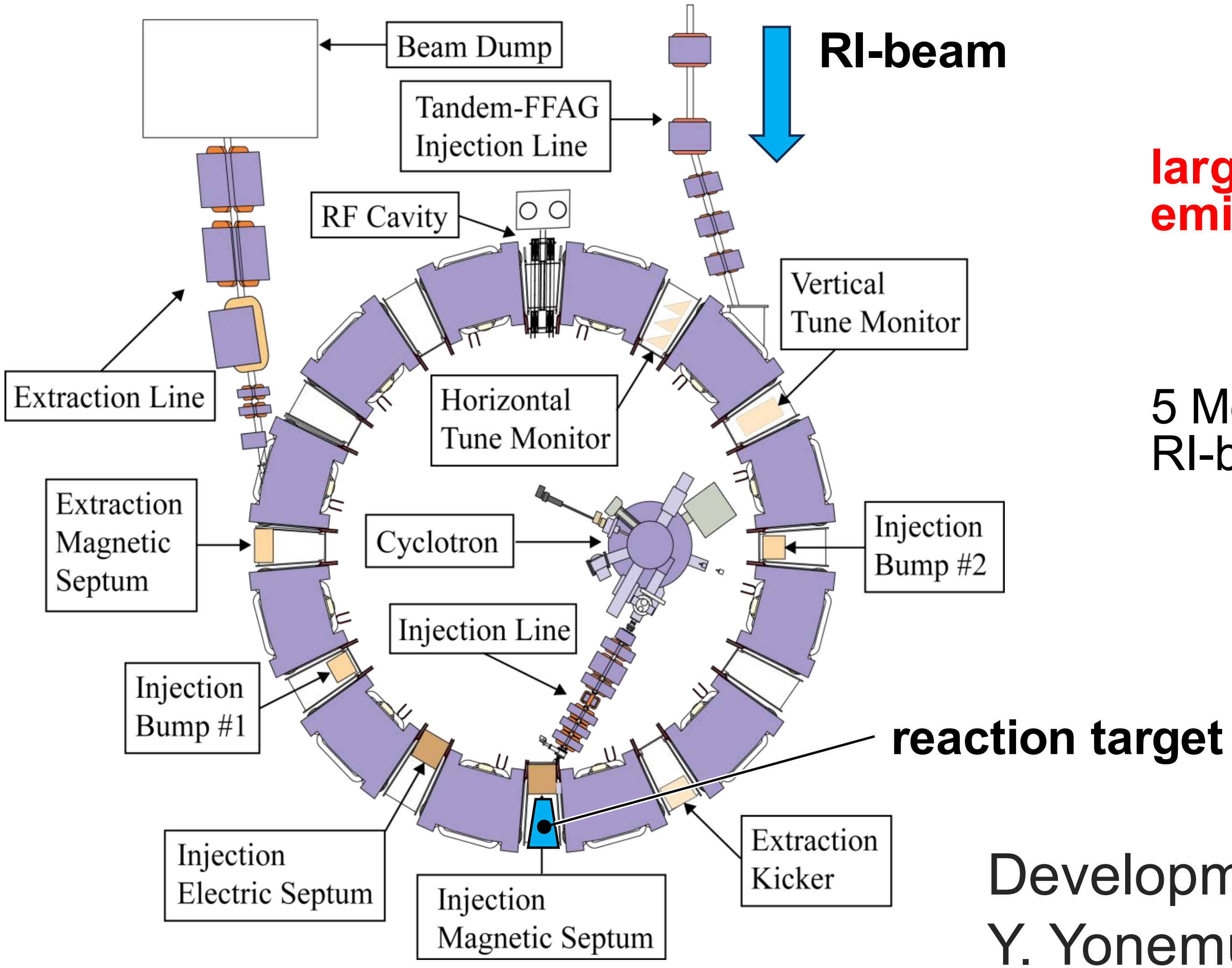
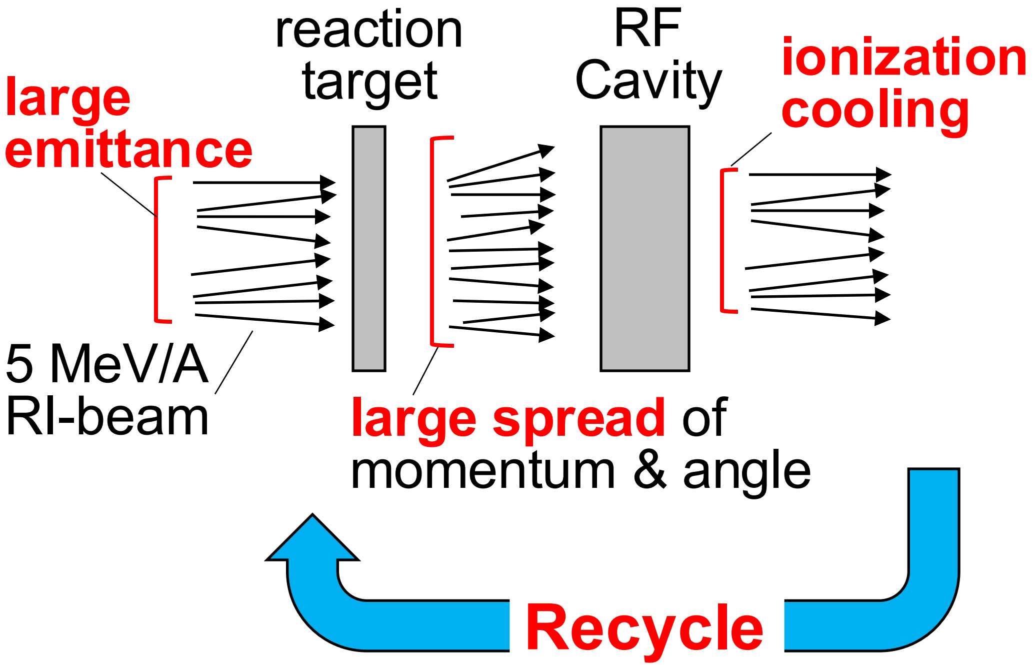


Beam recycling scheme

FFAG-ERIT (FFAG-Energy Recovery with Internal Target)





Development of FFAG at Kyushu:
Y. Yonemura, N. Ikeda

Motivation of this study

Motivation

Is it possible to efficiently recycle the RI-beams with **low energy** and **large emittance**?

Things to consider

・Beam energy is as low as 5 MeV/A,
leading to **significant energy loss** and **emittance growth**

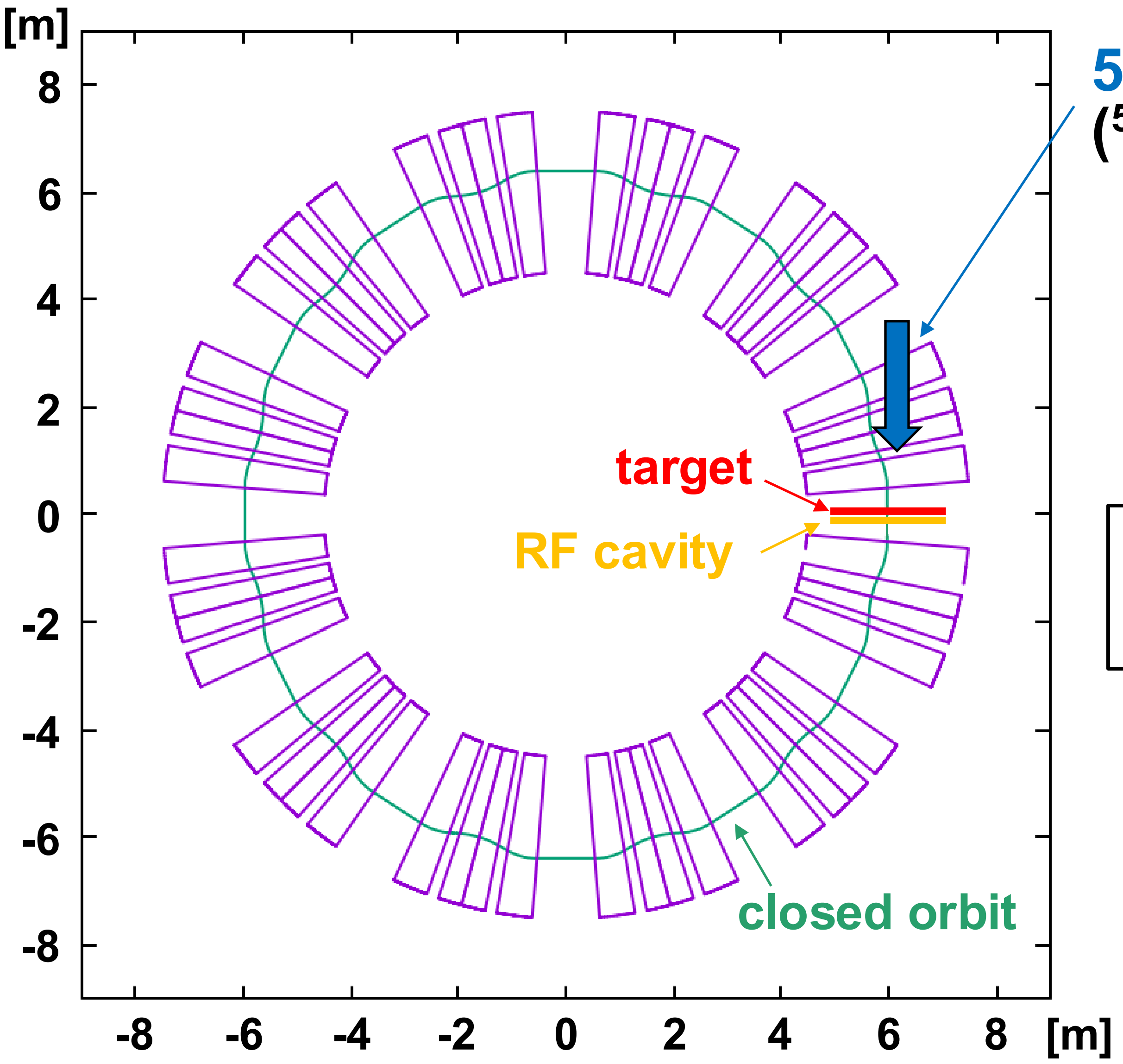
・Original RI-beam has **large emittance** (in-flight method)

・Beam loss due to **radioactive decay**

・Beam loss due to **nuclear reactions** (not evaluated in this study)

⇨ **Simulation study to calculate the average number of circulations of RI beams with the FFAG-ERIT schem.**

Simulation study of RI-beam circulation



5 MeV/A RI-beam
(^{50}Ca, ^{54}Ca, ^{60}Ca)

initial emittance
x: 818 [mm•mrad]
y: 1496 [mm•mrad]

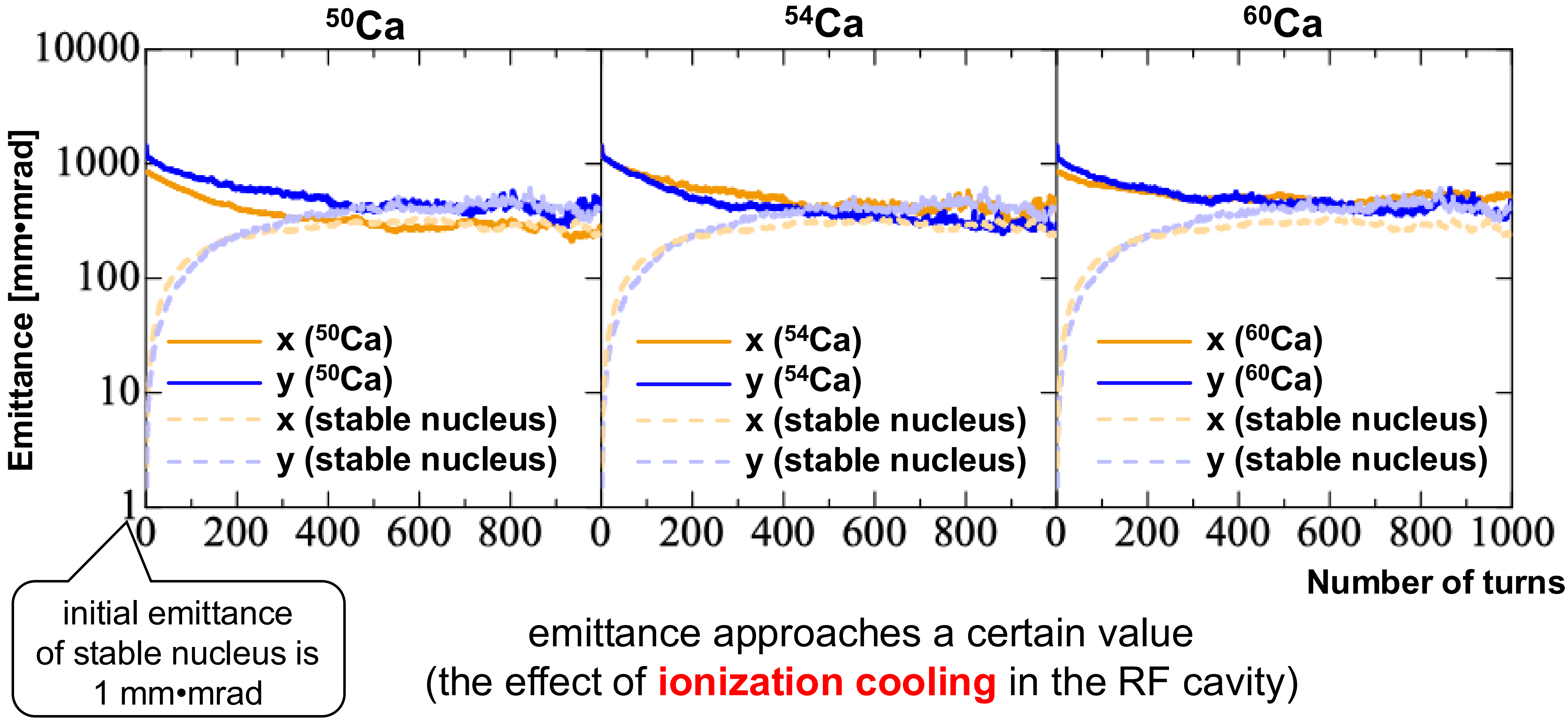
In the case of a 5 MeV/A RI beam produced at RIKEN

Can the RI beam be efficiently recycled?

- Emittance evolution and beam loss turn by turn
  → Average number of circulations
- Beam loss due to the radioactive decay

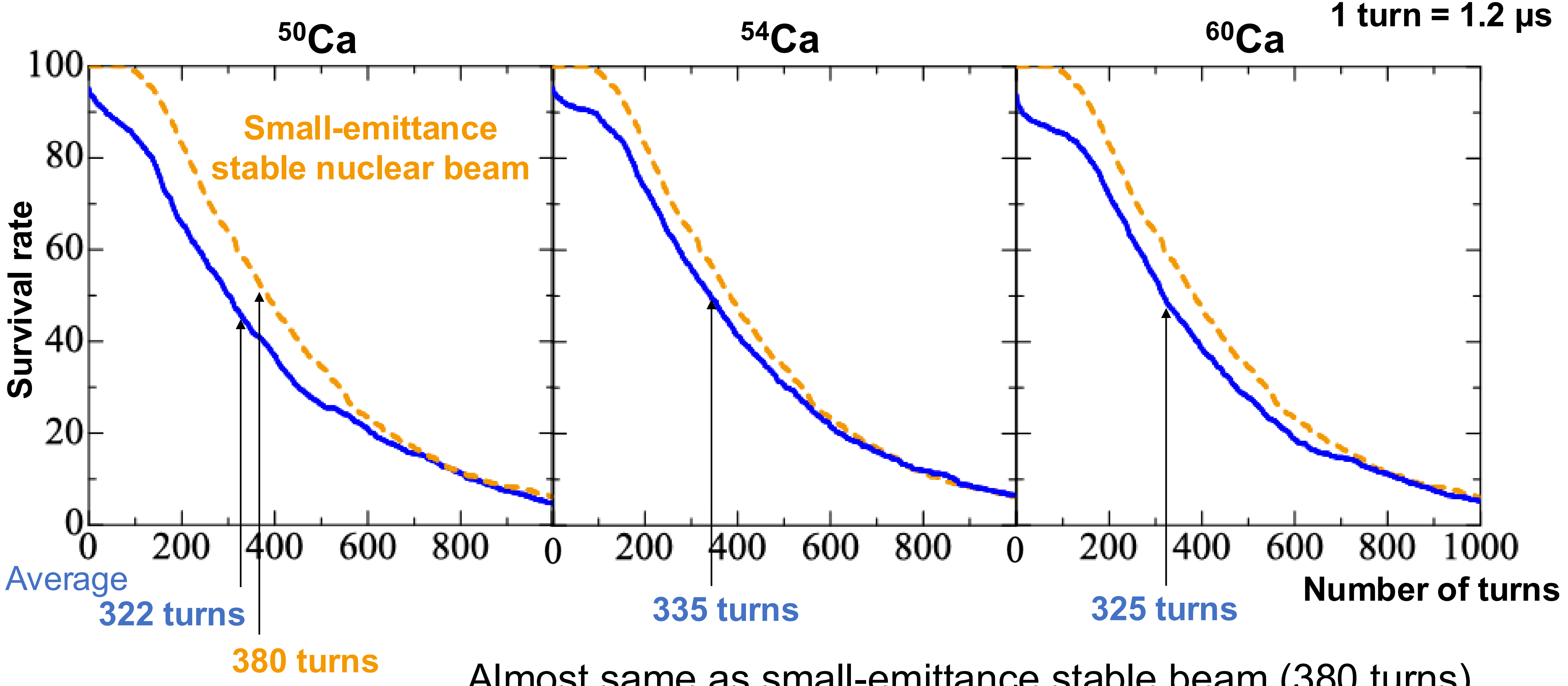
Simulation code by Ishi-san

Emittance evolution



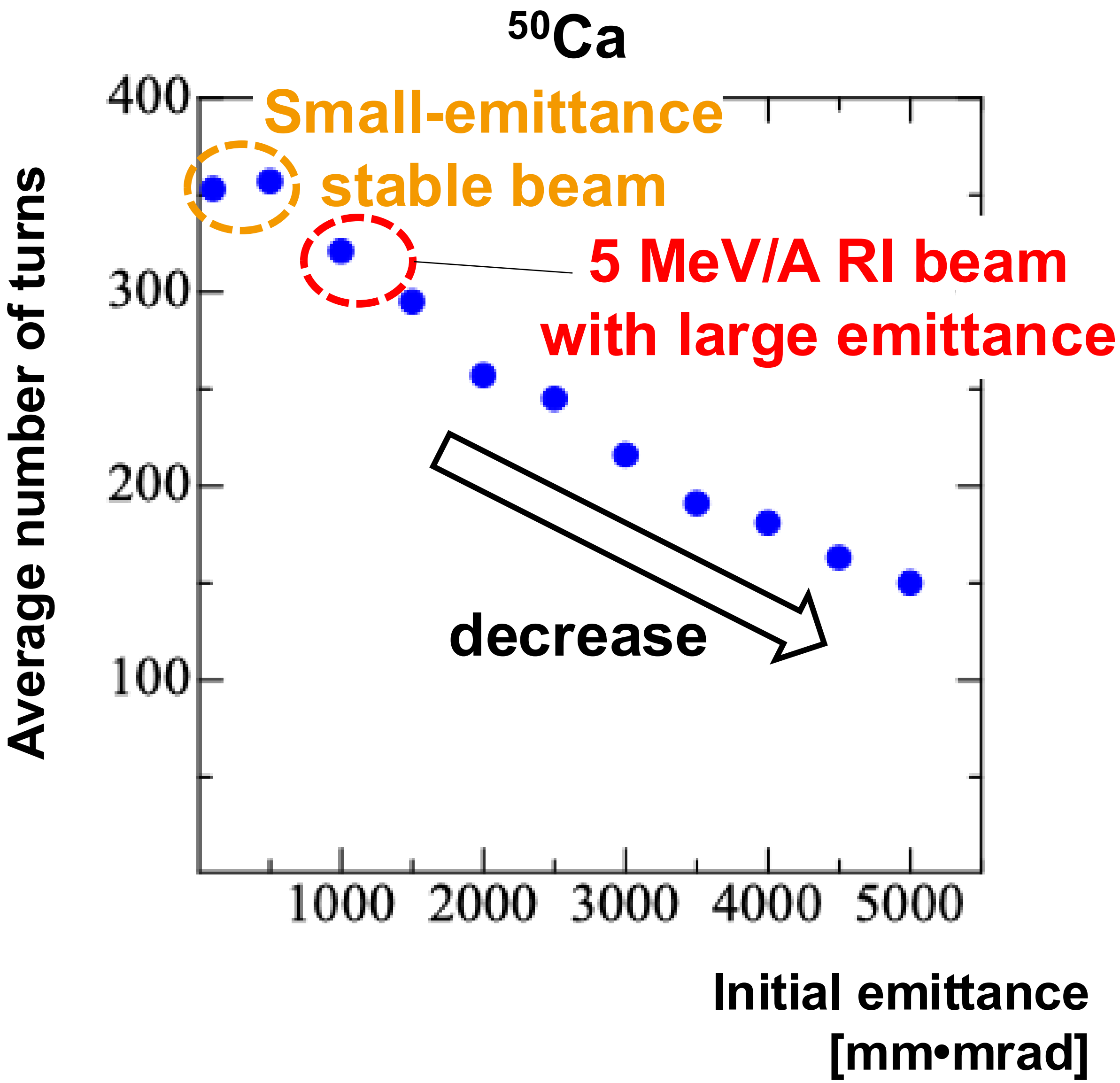
emittance approaches a certain value
(the effect of **ionization cooling** in the RF cavity)

Average number of turns (effect of large emittance)



Almost same as small-emittance stable beam (380 turns),
thanks to **large acceptance** of the FFA ring

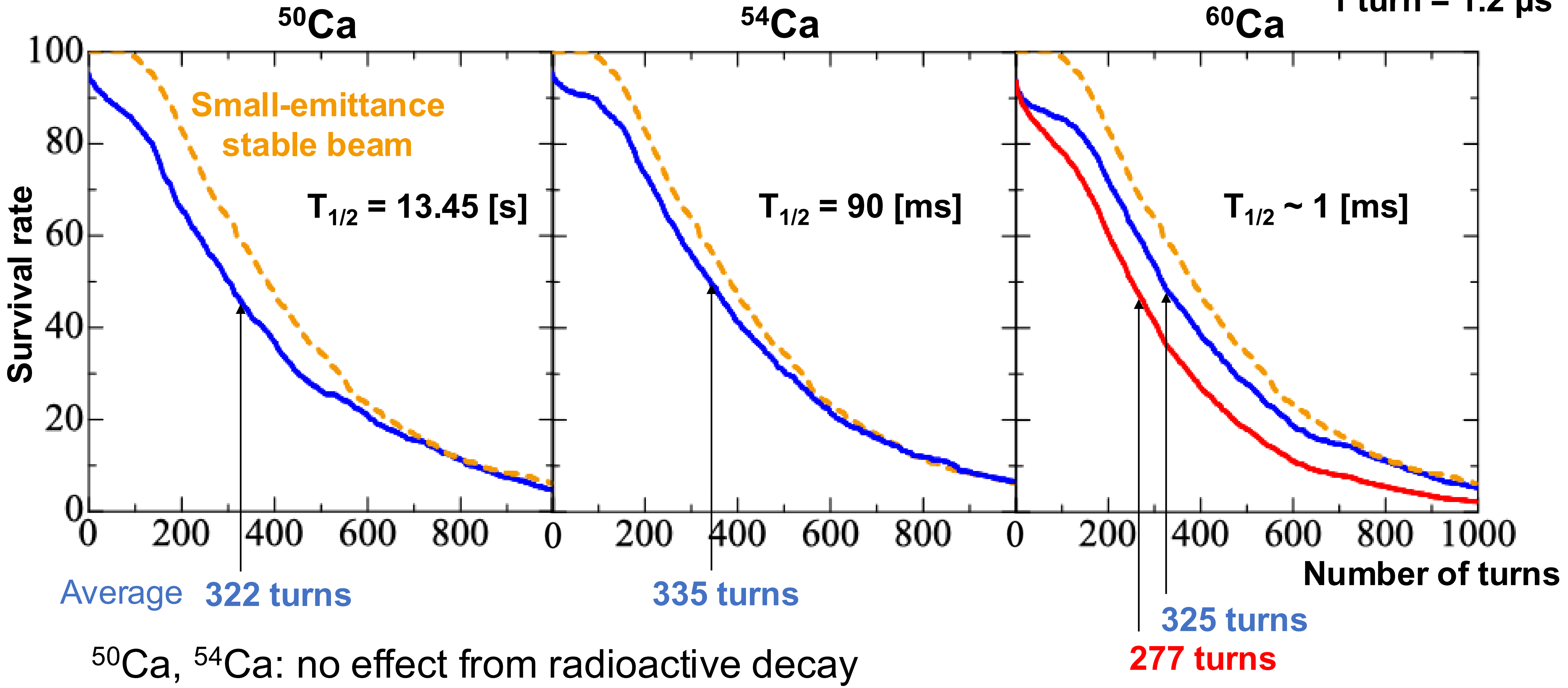
Initial emittance v.s. Average number of turns



x and y directions
is the same for simplicity

Beam loss due to radioactive decay

1 turn = 1.2 μs



^{50}Ca, ^{54}Ca: no effect from radioactive decay

^{60}Ca: reduced number of circulations due to decay (-15%)

Summary and perspective

Key question:

Can the RI beam be efficiently recycled using FFAG-ERIT?

→ **Yes!**

- Almost same as small-emittance stable beam, thanks to **large acceptance** of the FFA ring
- Effect of radioactive decay
  - ^{50}Ca, ^{54}Ca: no effect
  - ^{60}Ca: reduced number of circulations (-15%)

Next stage:

- Analysis of the evolution of energy distribution
- Yield estimation
- Super-large-acceptance ERIT ring for 5 MeV/A beam?