Two-Step RI beam @ TRIUMF

A look beyond first step of ARIEL

R. Kanungo

TRIUMF

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Open scientific questions with neutron-rich nuclei

Nuclei with large N/Z bring different environment than found in stable nuclei

- weak binding
- extended neutron surface ; low-density
- low level density
- di-neutron cluster

❖ Discovering new features in heavy nuclei with large neutron-proton asymmetry

~ Do traditional shell closures vanish and new ones appear beyond $N = 28$?

~ Search for exotic nuclear forms - giant neutron halos, shape coexistence, clustering

❖ How do heavy neutron-rich nuclei drive heavy element synthesis in the Universe?

~ What are the astrophysical sites of the *r*-process?

❖ Neutron-rich nuclei shed light on neutron star properties

Neutron skin -> symmetry energy of EOS

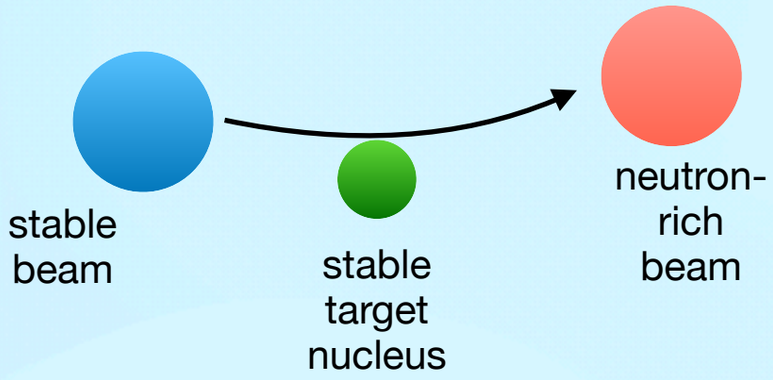
Heavy ion collisions -> high density EOS

❖ Tests of fundamental symmetries in nature CP violation

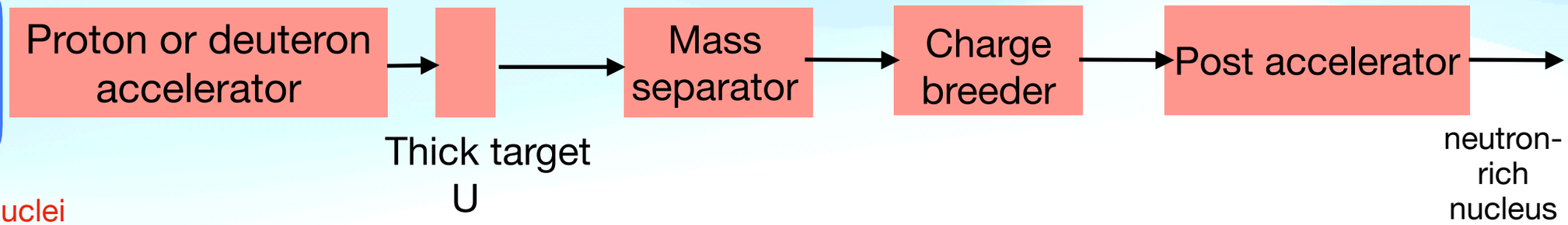
Electric dipole moment of octupole deformed nuclei

Radioactive Molecules

What is two-step RI beam?



ISOL RIB
TRIUMF, Canada
ISOLDE, Switzerland
GANIL, France
RAON, Korea

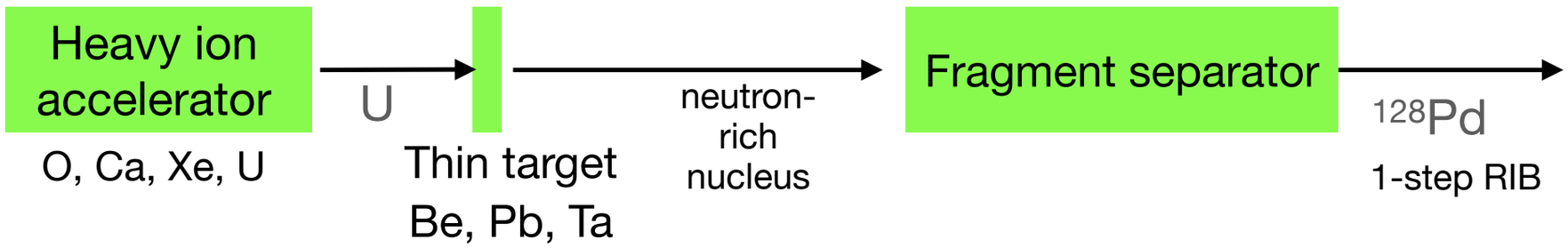


Merit : Some neutron-rich nuclei produced with high intensity

Limitation : Refractory elements cannot be produced.

Yield drops rapidly for very neutron-rich nuclei

In-flight RIB
FRIB, USA
RIBF, Japan
FAIR, Germany



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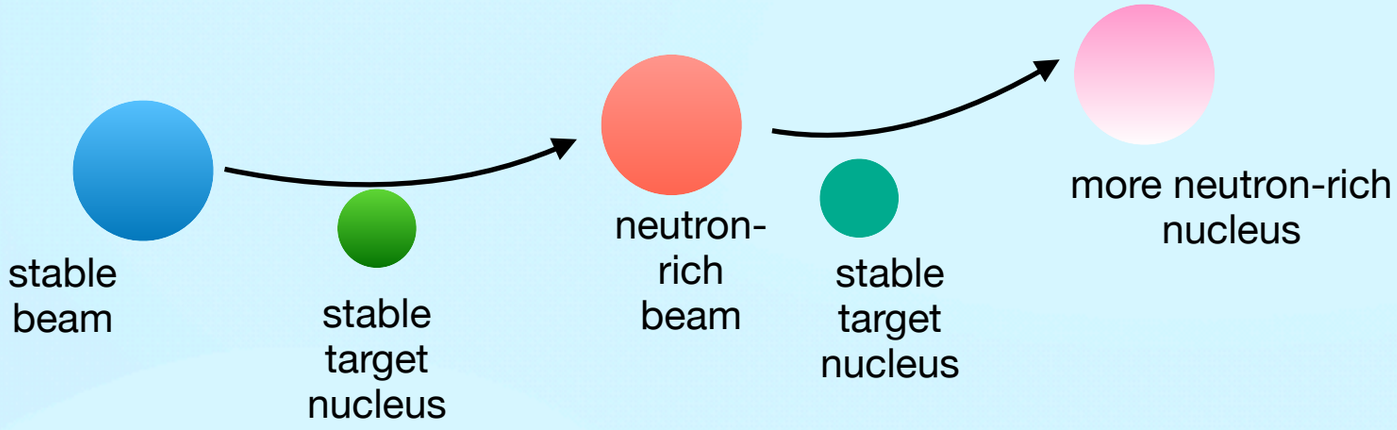

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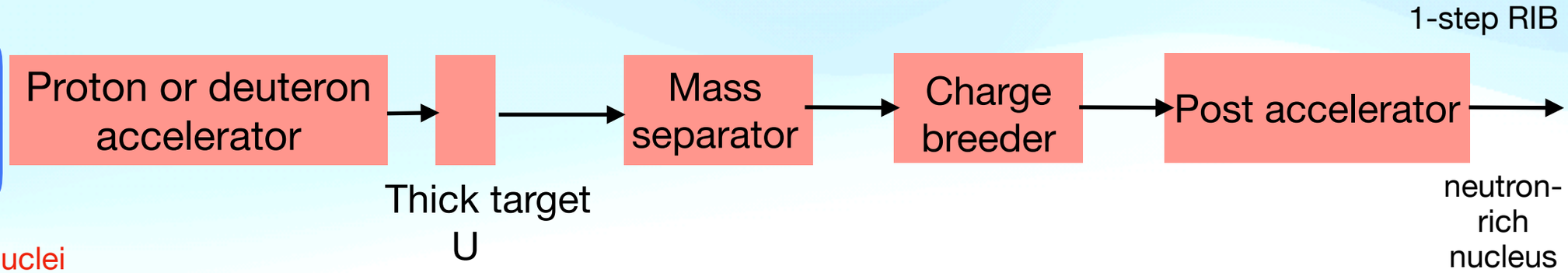

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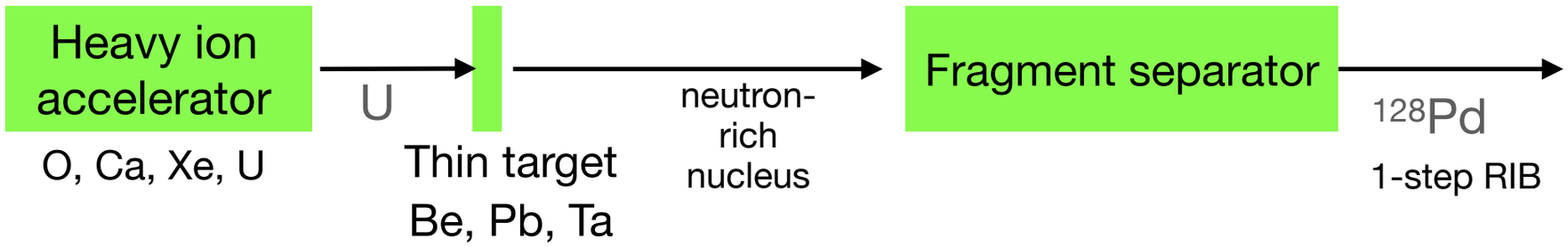

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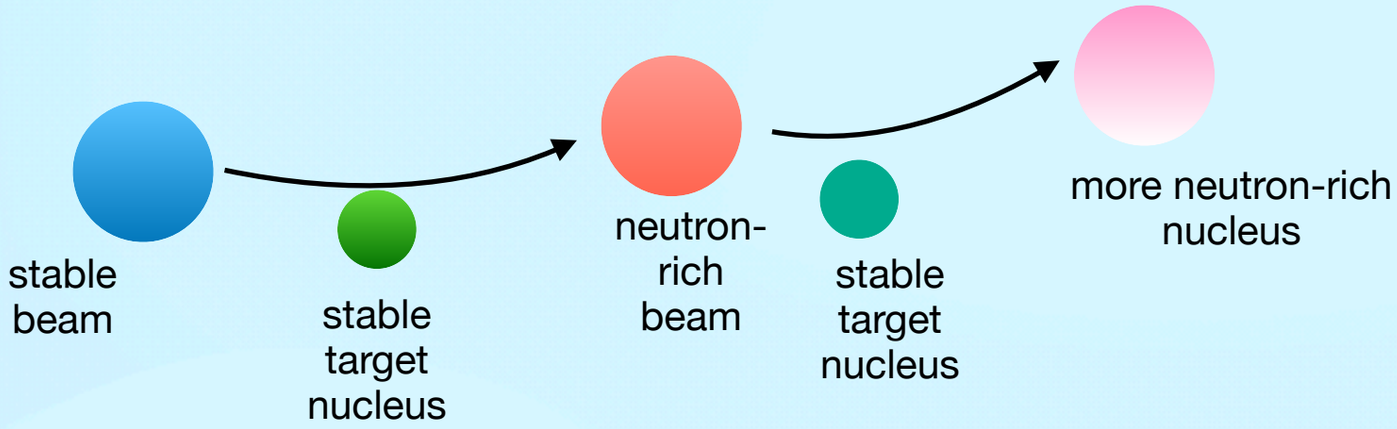

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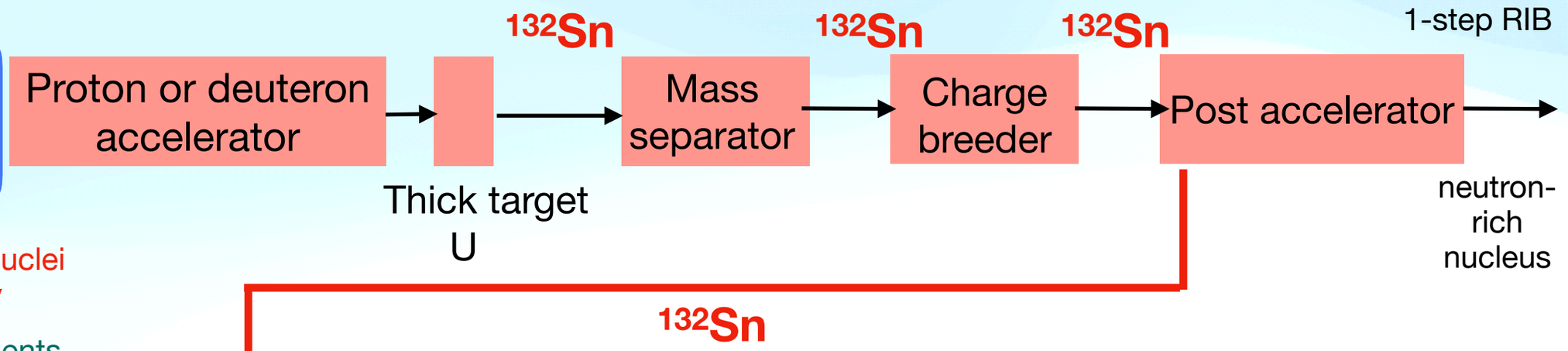

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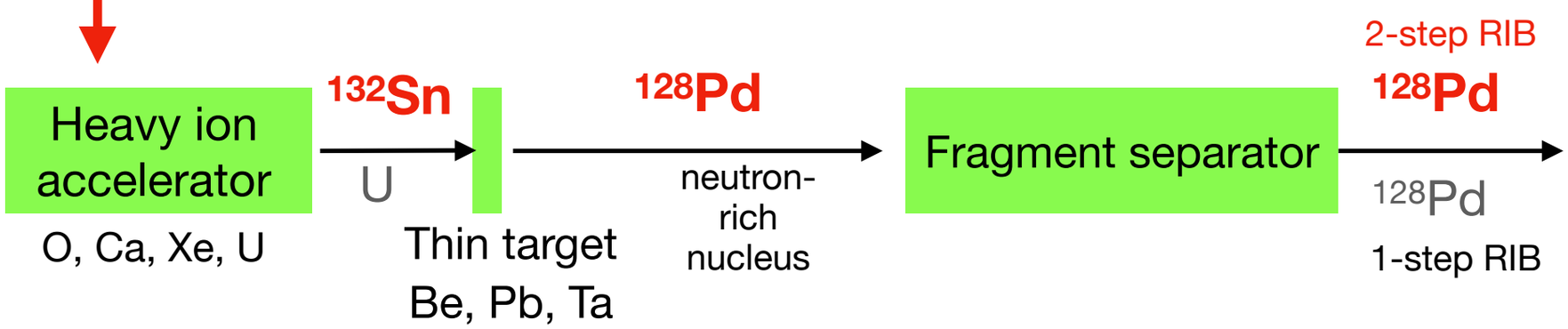

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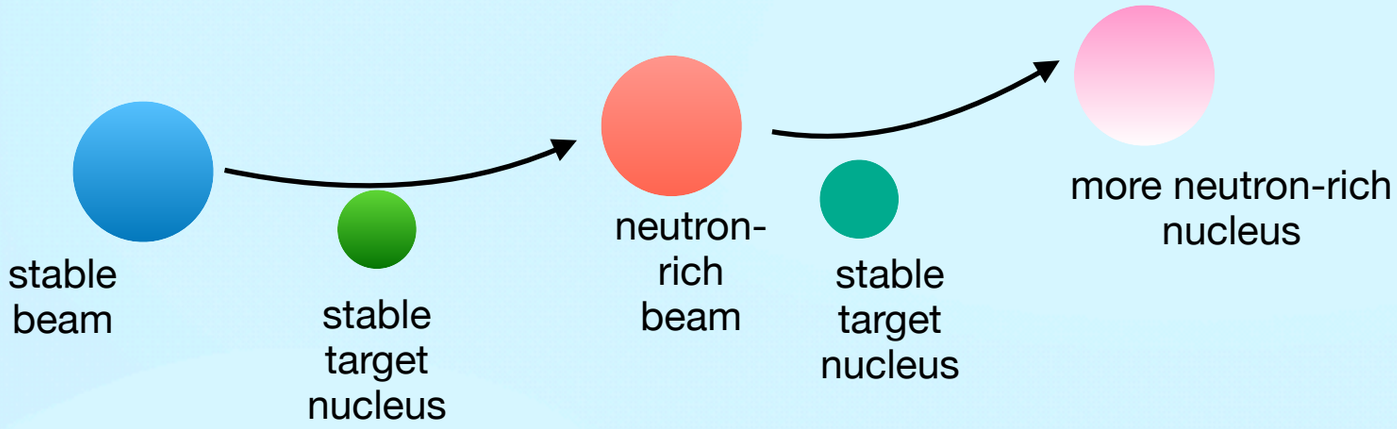

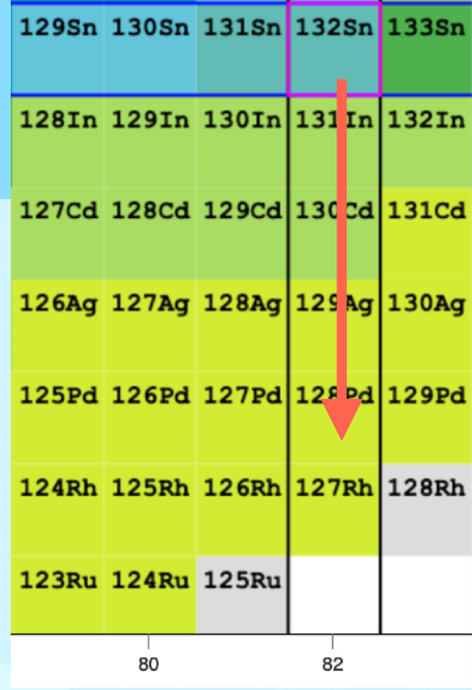

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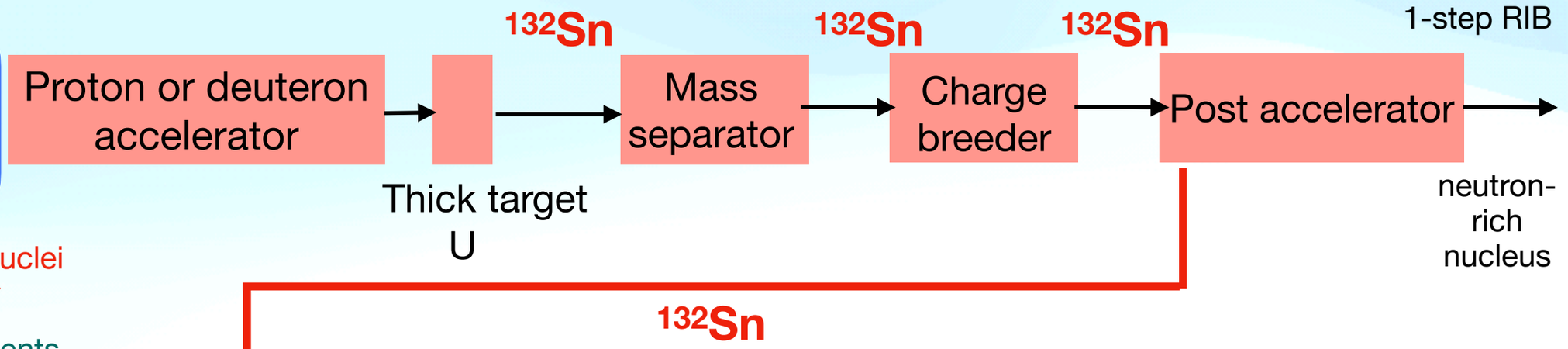

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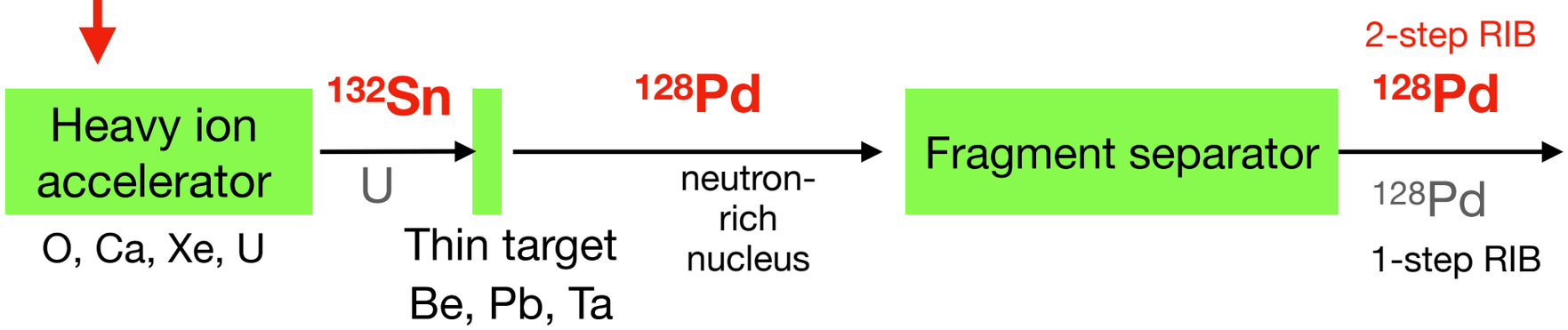

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Why two-step RI beam @ ARIEL

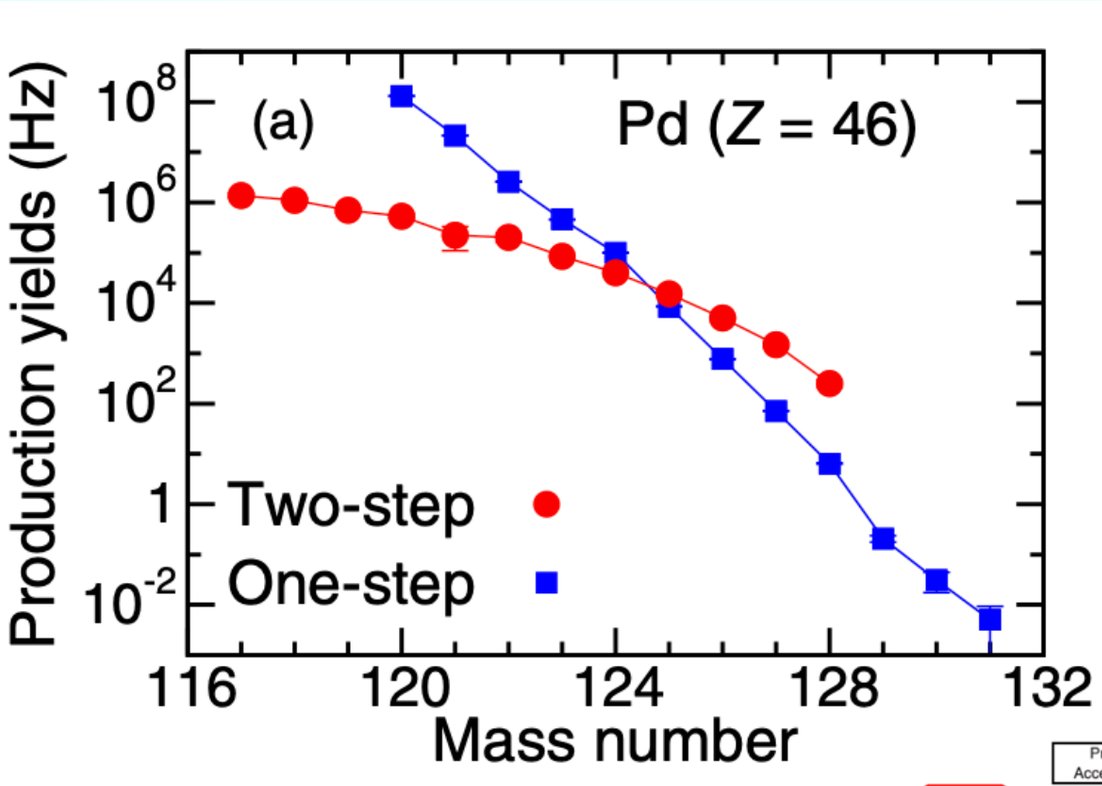
Access to more neutron-rich nuclei -> higher production yield

Access to refractory elements -> production from 2nd step in-flight

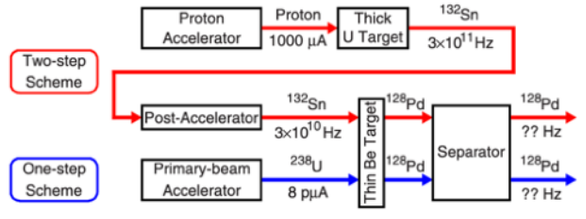
Access to EOS studies, in-beam γ spectroscopy, fission studies, reaction studies -> relativistic energies

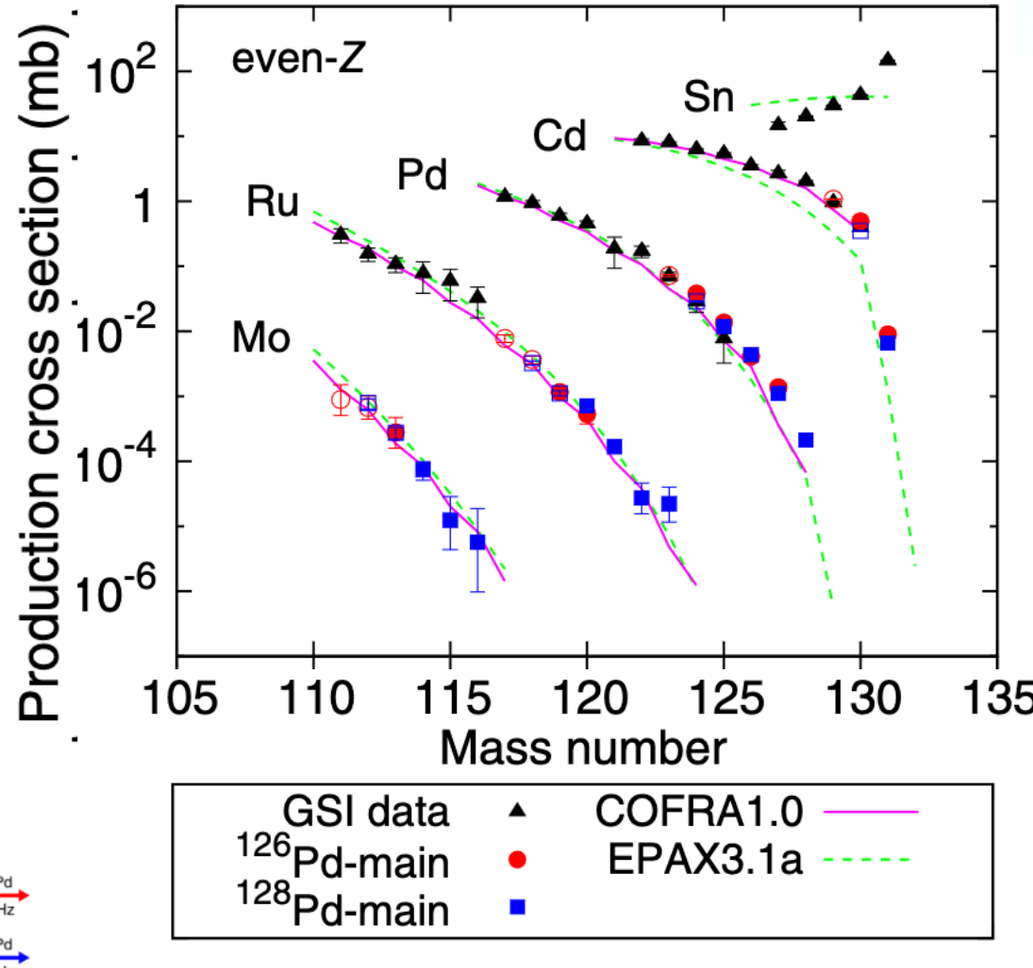
Photofission @ ARIEL will provide world's most intense beam of some neutron-rich nuclei, ^{132}Sn

ARIEL is the ideal facility in the world for two-step RIB production & access to the most neutron-rich nuclei

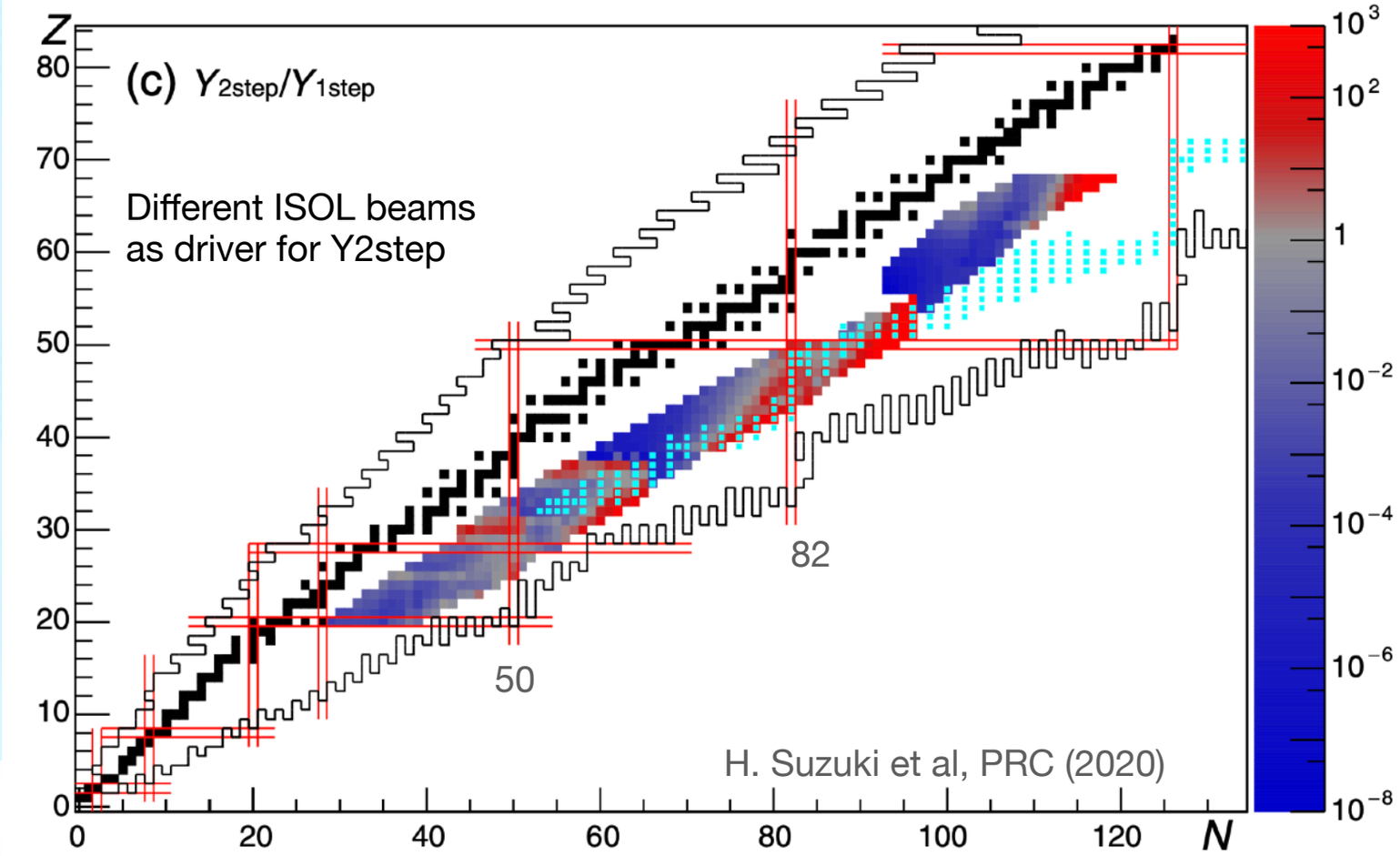


H. Suzuki et al, PRC (2020)





Accessing neutron-rich nuclei in r-process path



Assumed conditions for the yields

Y1step : **1 MW U beam**

Y2 step : 1 MW on target
3x10¹⁰ pps ^{132}Sn
2nd step driver beam

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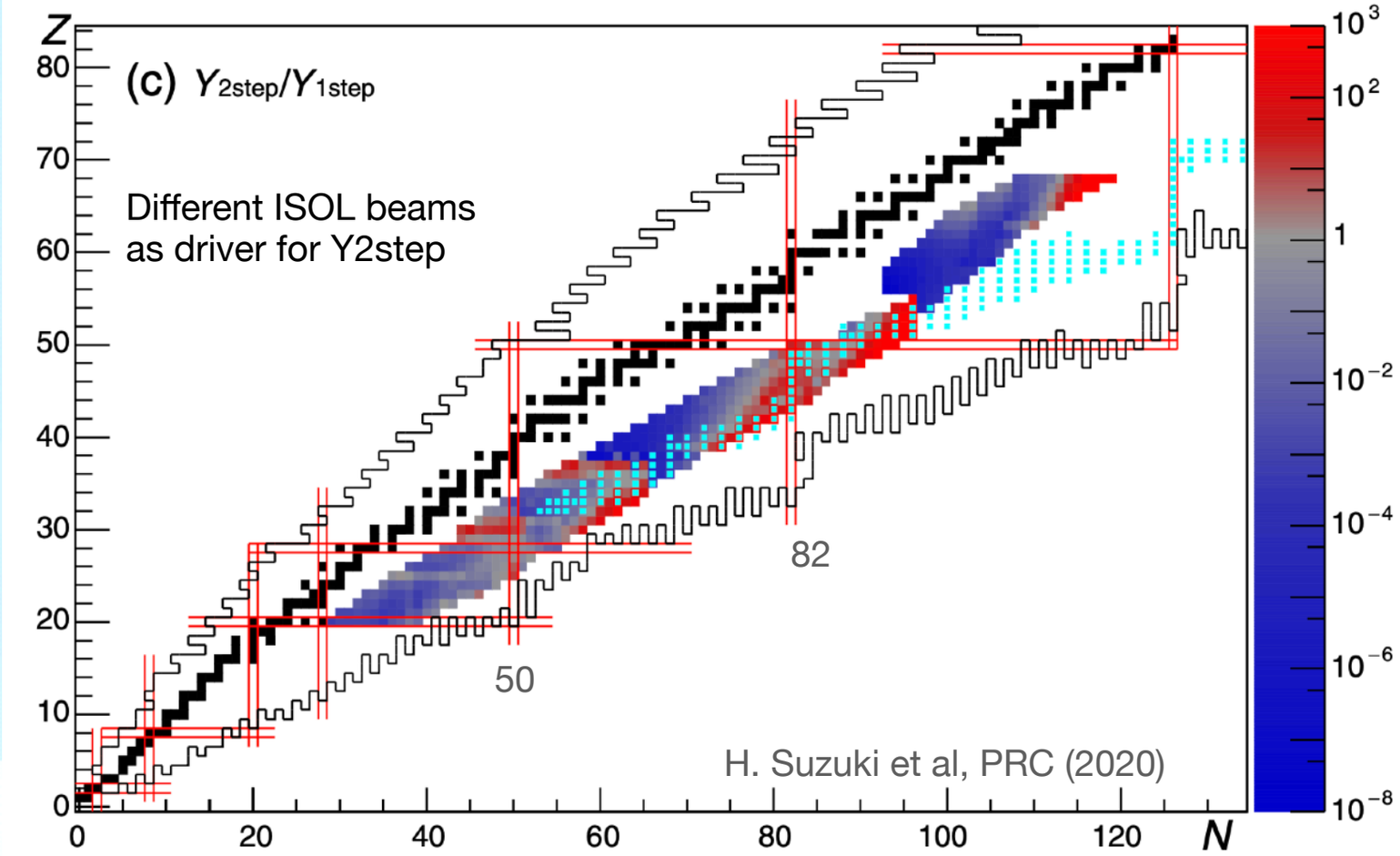

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Y1step
Current FRIB : 20 kW U beam

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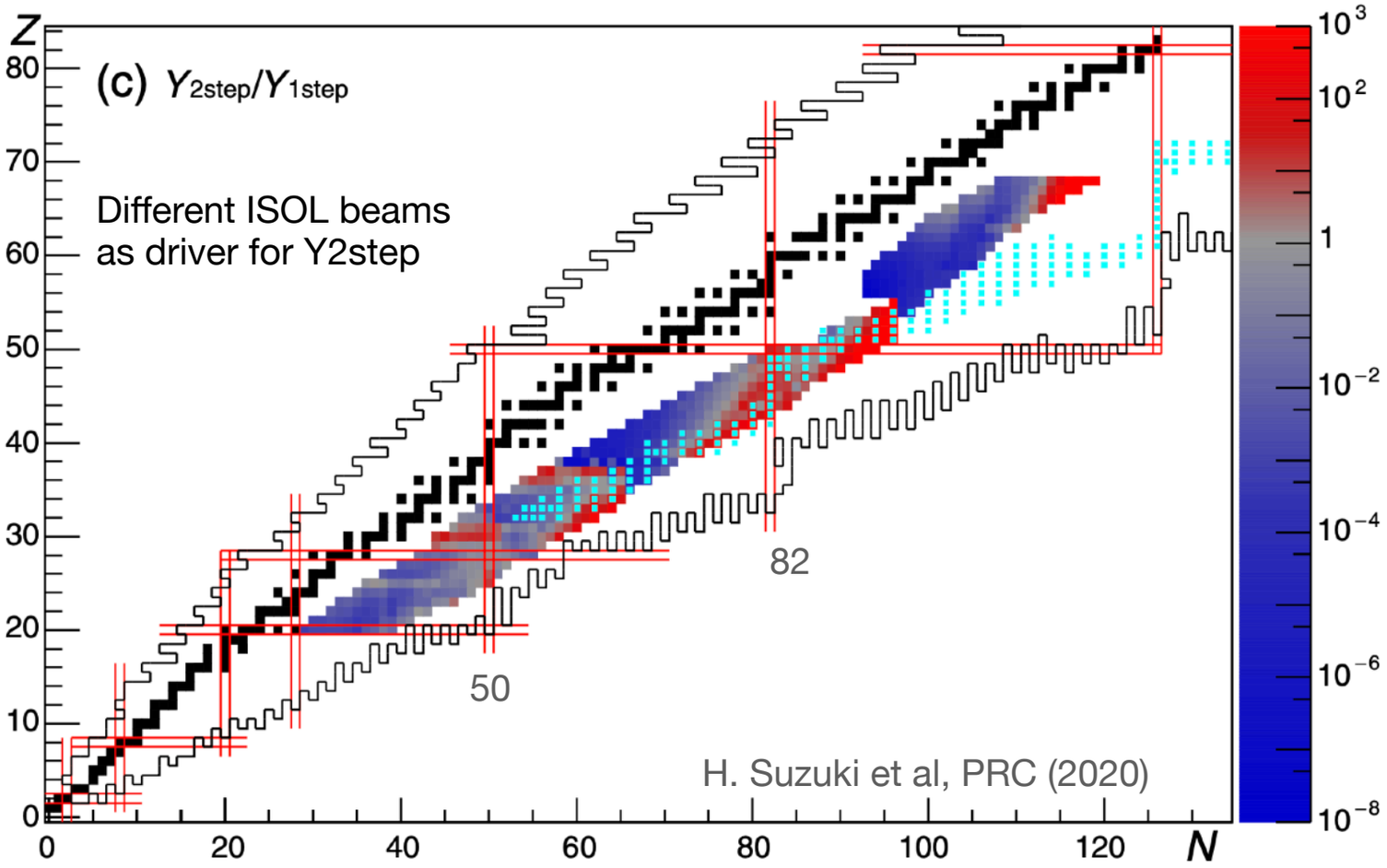

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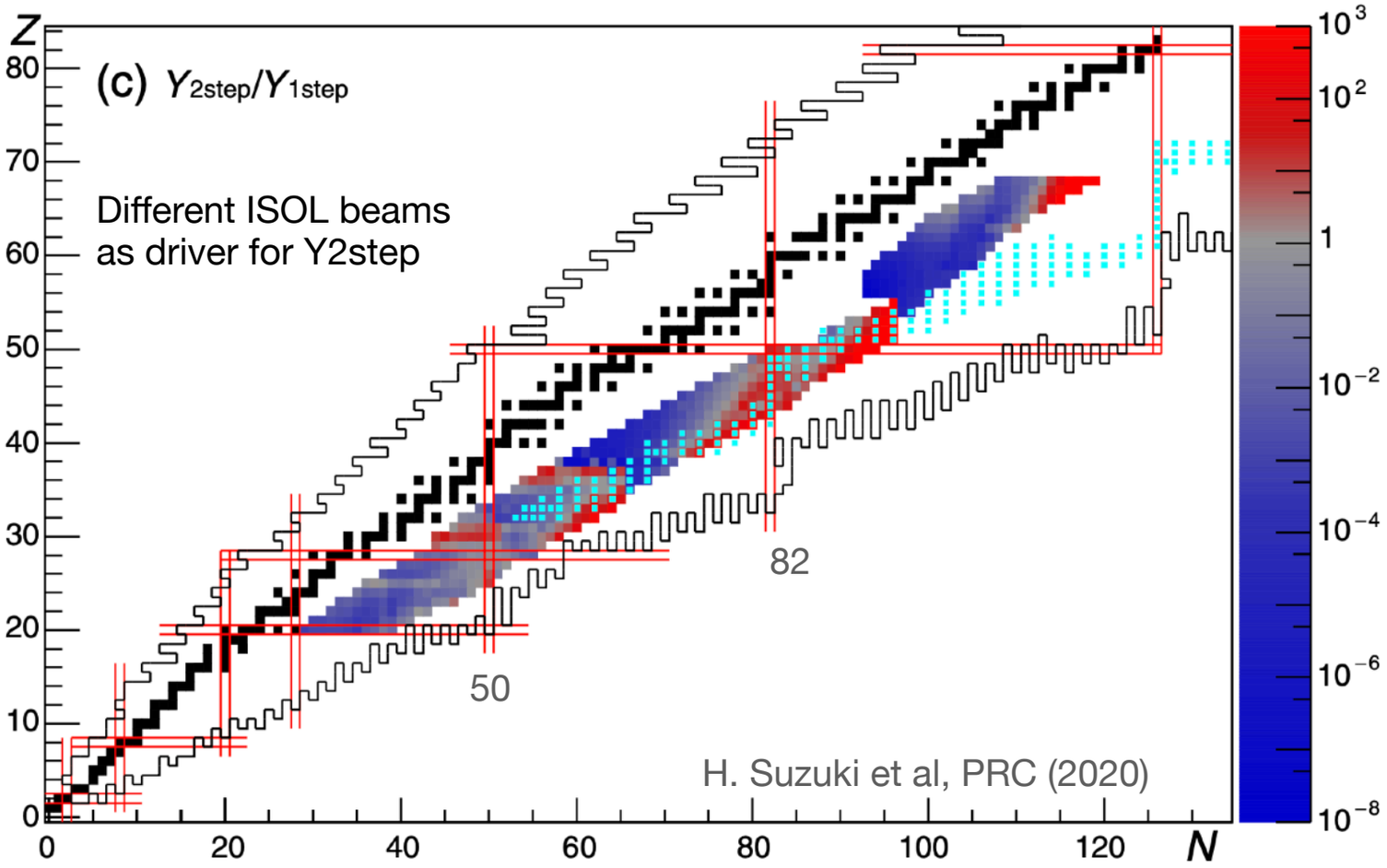
Y1step
Current FRIB : 20 kW U beam

Y2 step
Current ^{132}Sn TRIUMF
p + UCx ~ 7.5 kW
measured @ yields
1x10⁸ pps ; A/Q = 132
6 x10⁶ pps ; A/Q = 6.29

Accessing neutron-rich nuclei in r-process path



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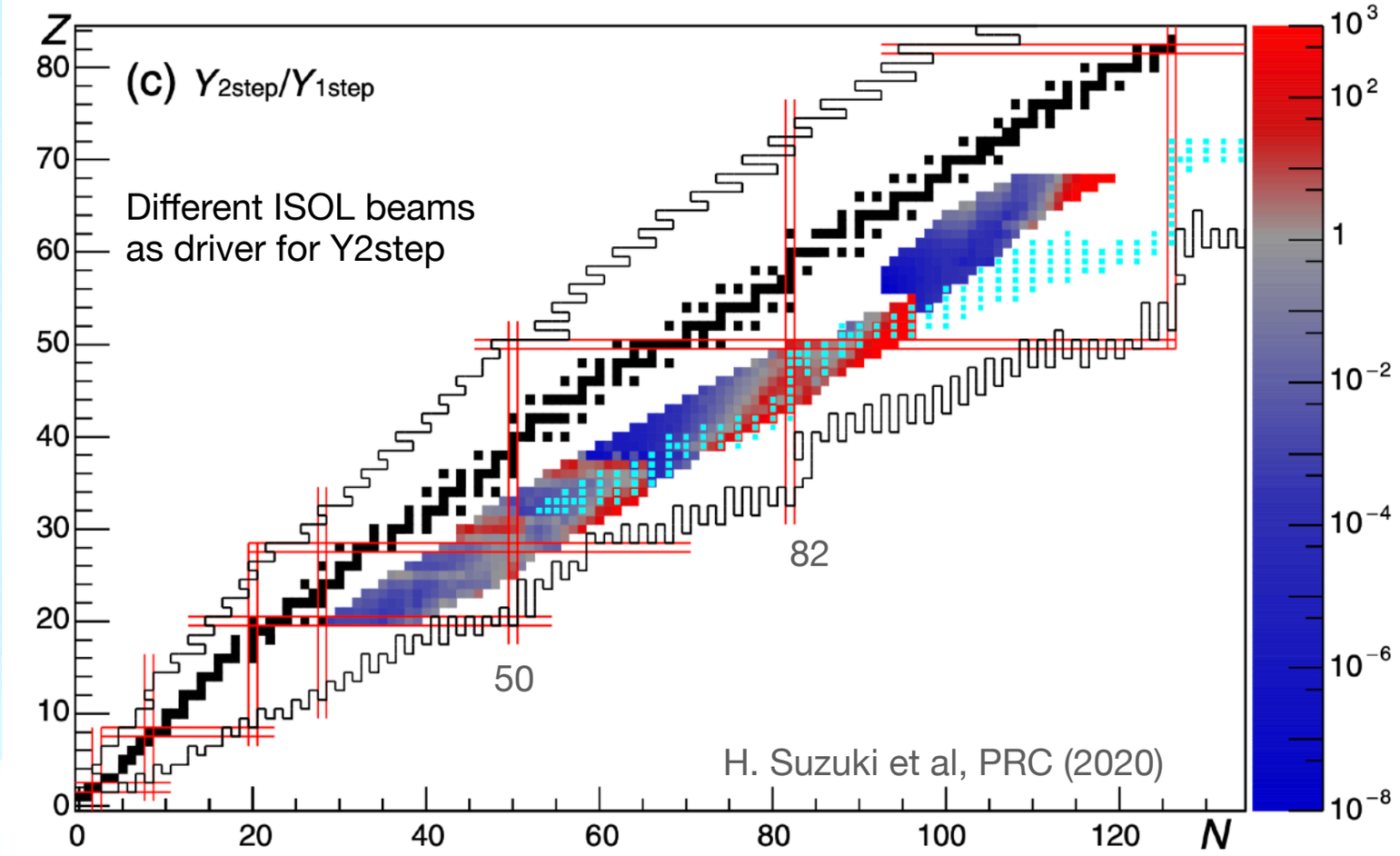
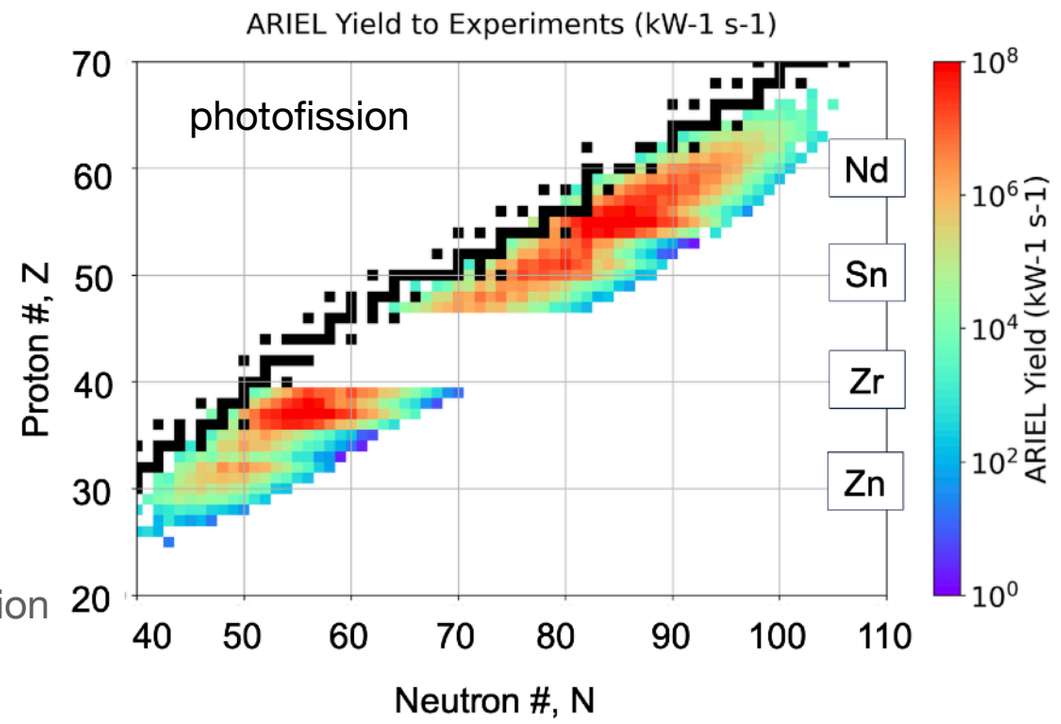
^{132}Sn photofission @ ARIEL
prediction
in-target yield ~ 4x10⁷ pps /kW

Accessing neutron-rich nuclei in r-process path





Courtesy :
TRIUMF Accelerator Division

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3x10¹⁰ pps ^{132}Sn
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Y1step
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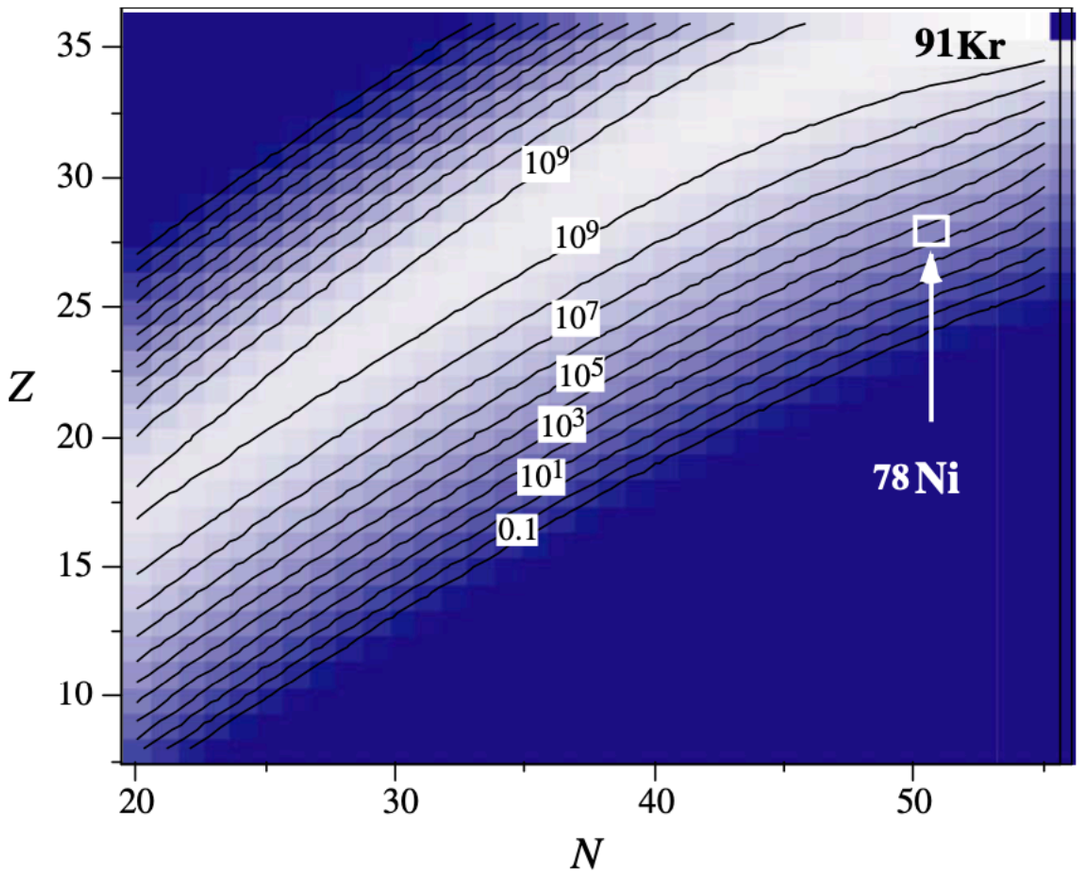
prediction
in-target yield ~ 4x10⁷ pps /kW

Accessing medium mass neutron-rich nuclei

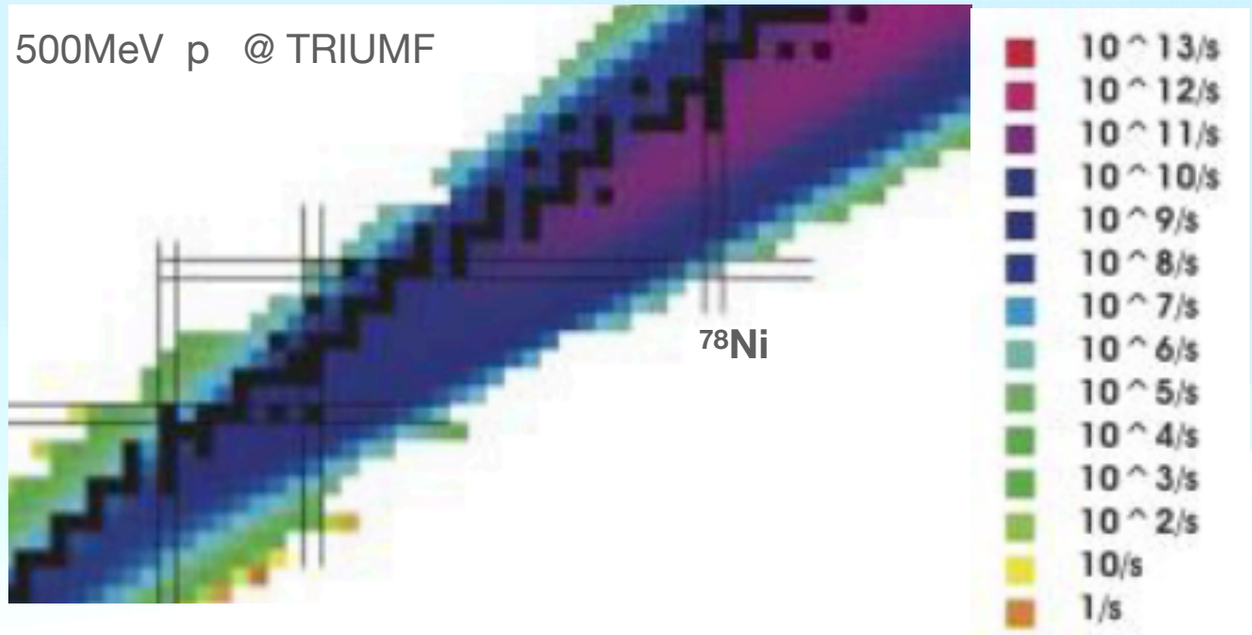


I. Tanihata NIM B (2008)

Two-step RIB yields with

^{91}Kr 7x10^{10} pps

in-target production yield



Capabilities with two-step in-flight beams

1 per day - New Isotope Discovery
> 0.001 per sec - Masses
> 0.1 per sec - Beta decay (half lives, beta delayed neutrons)
> 1 per sec - Radii (Interaction & charge-changing cross section)
> 5 per sec - Inelastic scattering eg. (p,p'γ), knockout reactions
> 100 per sec - In beam gamma spectroscopy, Coulomb dissociation

Possible to study reactions with low intensity by using thick targets

Summary

High intensity RI Beam from ARIEL has a potential to expand the rare isotope production capability at TRIUMF by 2-step RIB method (ISOL + In-flight)

Gains :

- **Access to refractory elements.**
- **Access to isotopes with larger N/Z than can be produced by ISOL or in-flight.**
- **High energy accelerator opens new suite of experiments at TRIUMF, even by accelerating the ISOL beams.**

Why TRIUMF?

Highest beam power ISOL facility in the world - essential condition for success

2-step RIB production

RAON (South Korea) : ISOL + In-flight in construction in stages.
ISOL not yet reached the power comparable to TRIUMF.