Mass measurements of rare-radioactive isotopes with a unique storage ring

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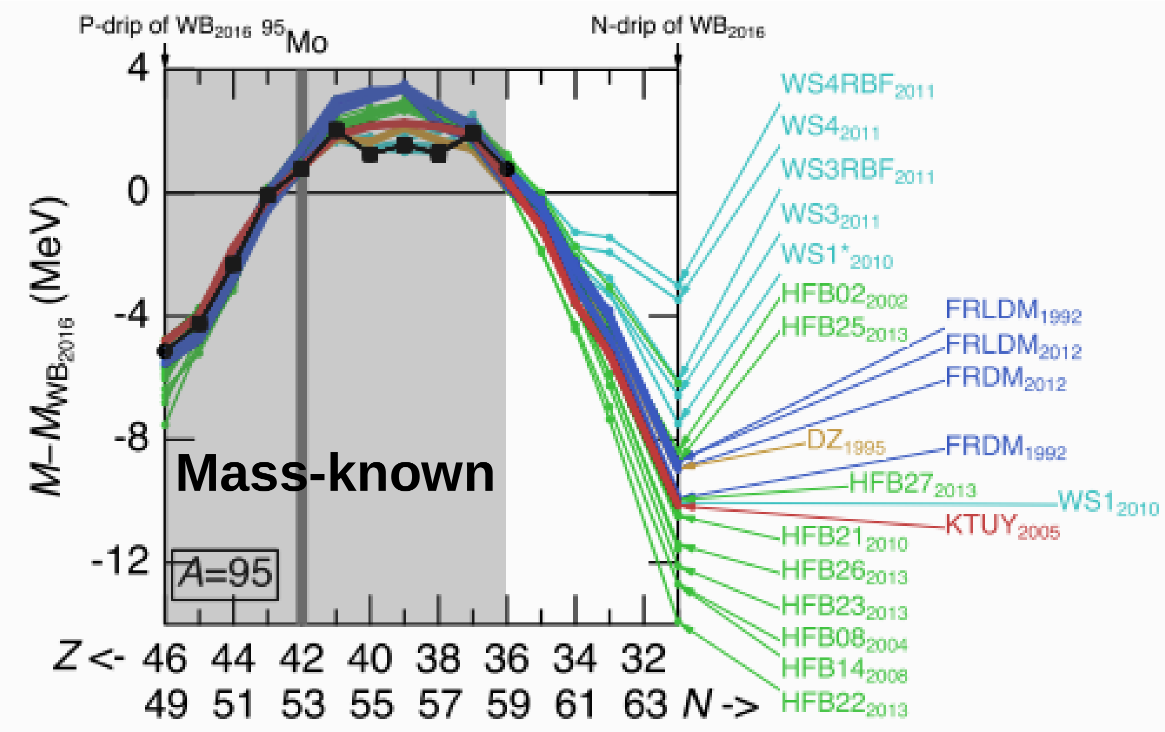
Contents

The importance of nuclear masses

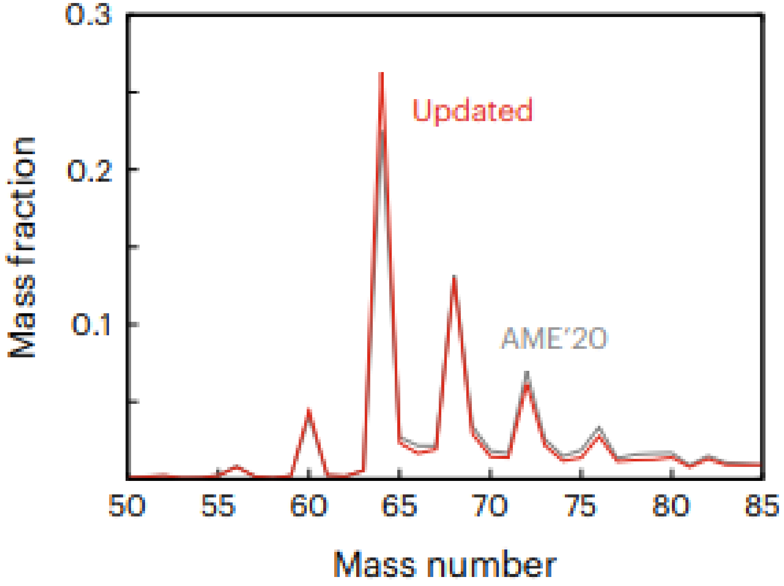
Validation of mass models



T. Yamaguchi *et. al*, PPNP **120** (2021) 103882

Solar abundance

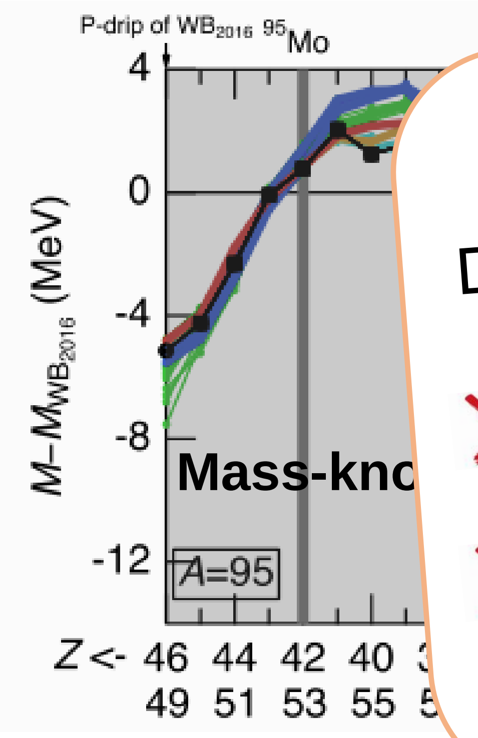
The mass of ^{64}Ge was measured
→ S_p of ^{65}As decreased by ~0.1 MeV
→ rp-process slowed down



X. Zhou *et. al*, Nature **19** (2023) 1091-1097

The importance of nuclear masses

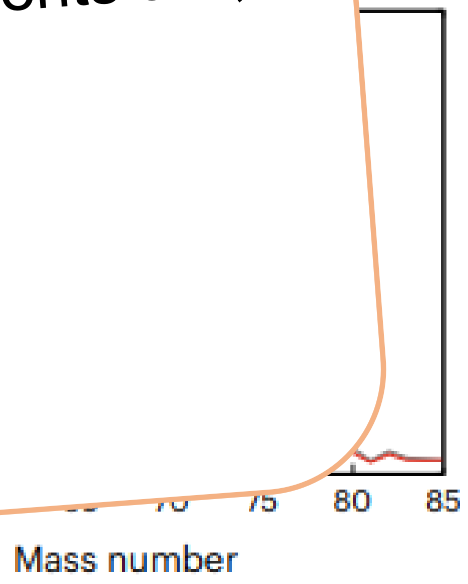
Validation of mass formulae



T. Ya… **120** (2021) 103882

Solar abundance

sured
~0.1 MeV



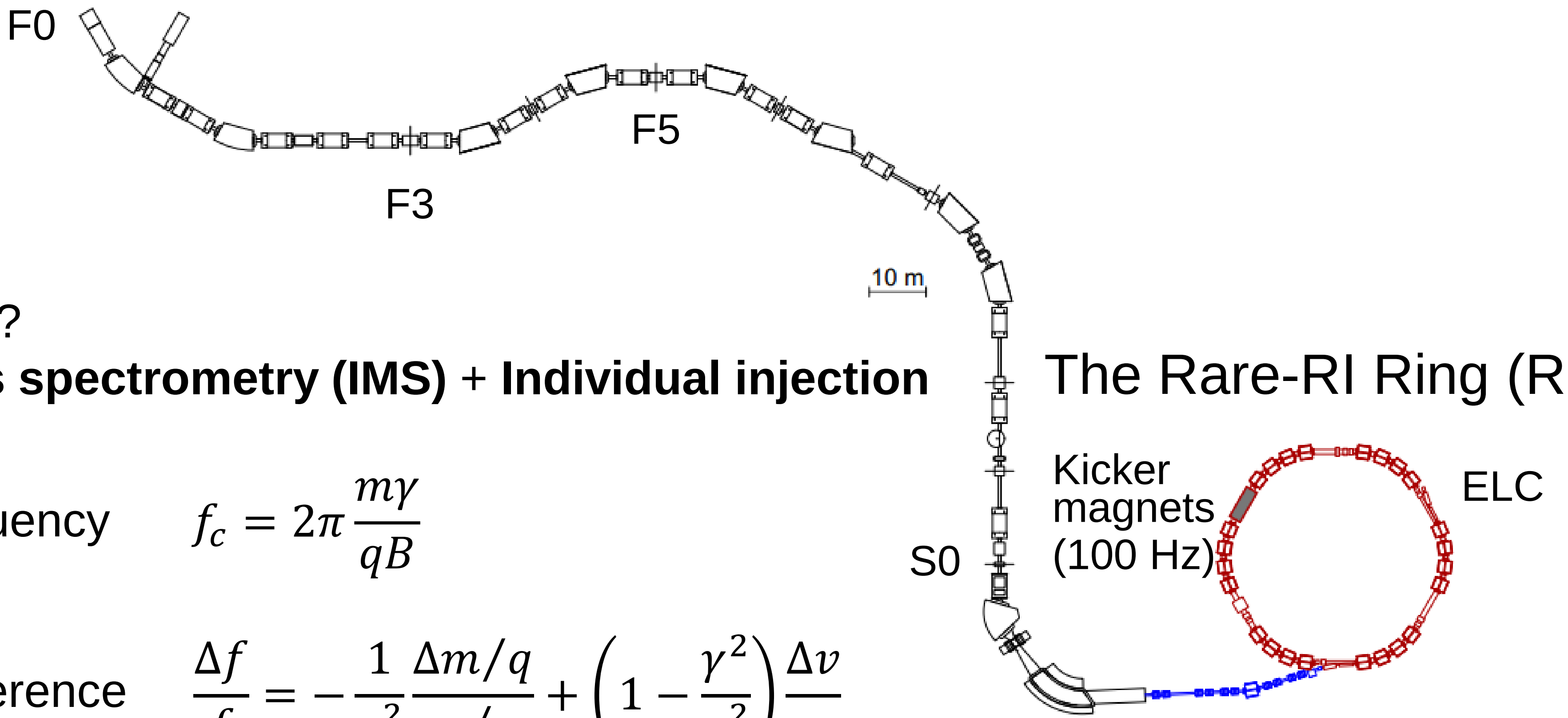
X. Zhou *et. al*, Nature **19** (2023) 1091-1097

Difficulties in unstable nuclear measurements are;

- ✗ short half-lives (~10 ms)
- ✗ low yield (few events/day)

Contents

A unique storage ring optimized for rare RIs



The Rare-RI Ring (R3)

What makes it unique?
→**Isochronous mass spectrometry (IMS)** + **Individual injection**

<u>IMS</u>

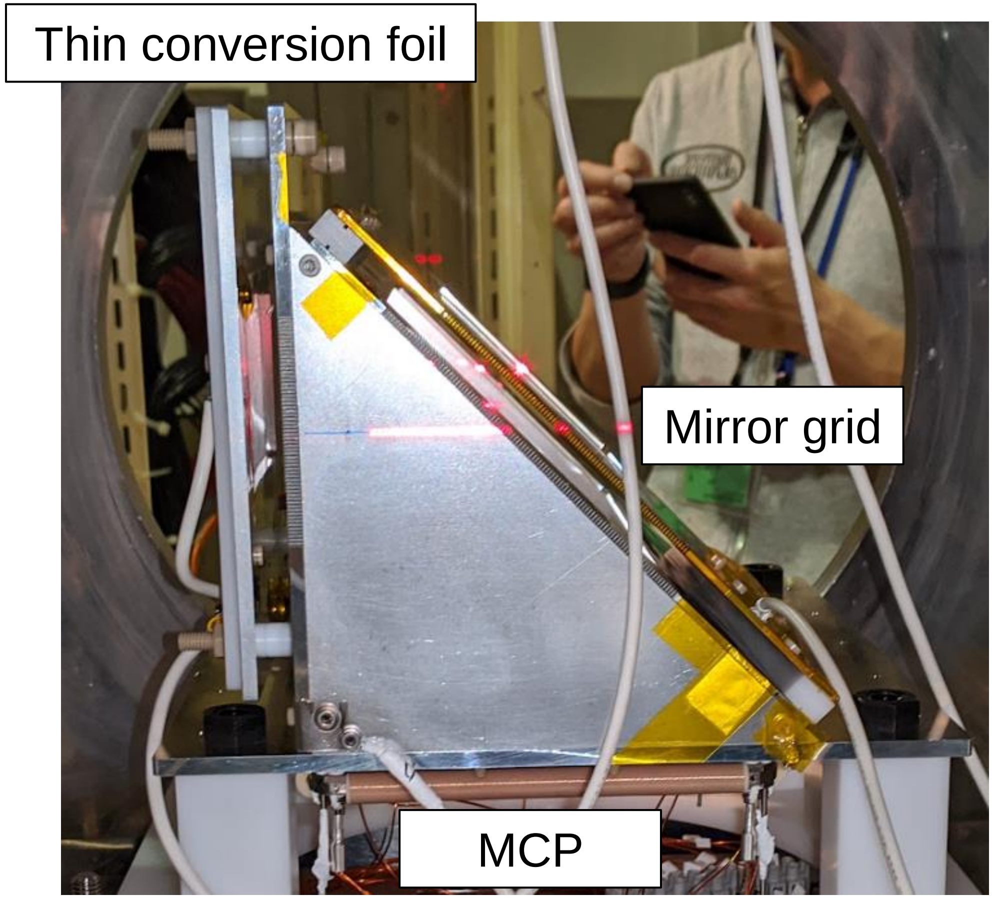
✓ The cyclotron frequency $$f_c = 2\pi \frac{m\gamma}{qB}$$

✓ The frequency difference $$\frac{\Delta f}{f} = -\frac{1}{\gamma_t^2}\frac{\Delta m/q}{m/q} + \left(1 - \frac{\gamma^2}{\gamma_t^2}\right)\frac{\Delta v}{v}$$

if $\gamma_t = \gamma$ $$\frac{\Delta f}{f} = -\frac{1}{\gamma^2}\frac{\Delta m/q}{m/q}$$

Circumference	60.35 m
Max. Bρ	6.4 Tm
Momentum acceptance	dp/p=1%

Frequency measurements inside R3

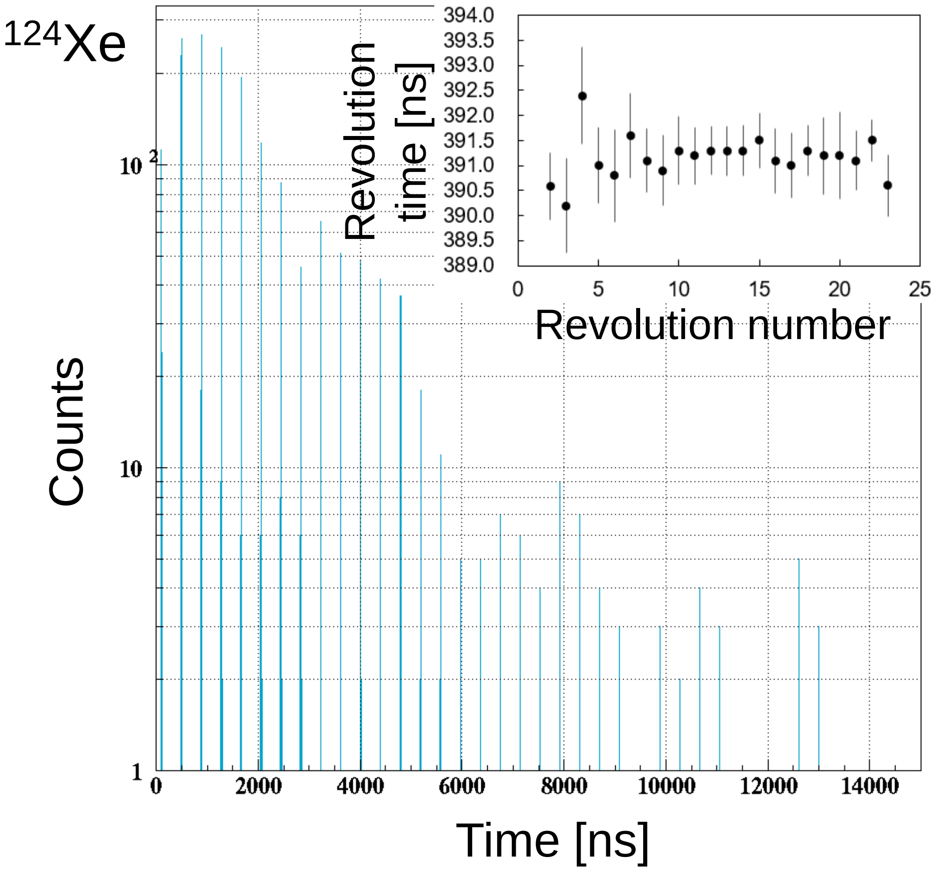


Size:
100×50 mm

Foil:
Carbon 4 μm

σ:
69(1) ps

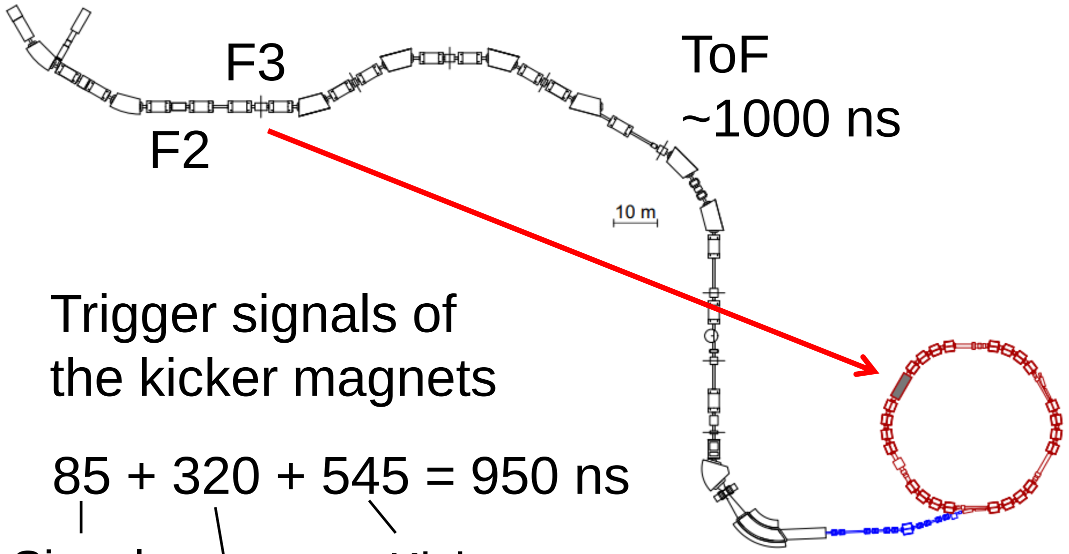
Efficiency:
88(1)%



Revolution time: 391.195(72) ns
Number of revolutions: ~2000 turns

Individual injection with ToF selection

A indispensable method for R3



Trigger signals of
the kicker magnets

85 + 320 + 545 = 950 ns

Signal generation

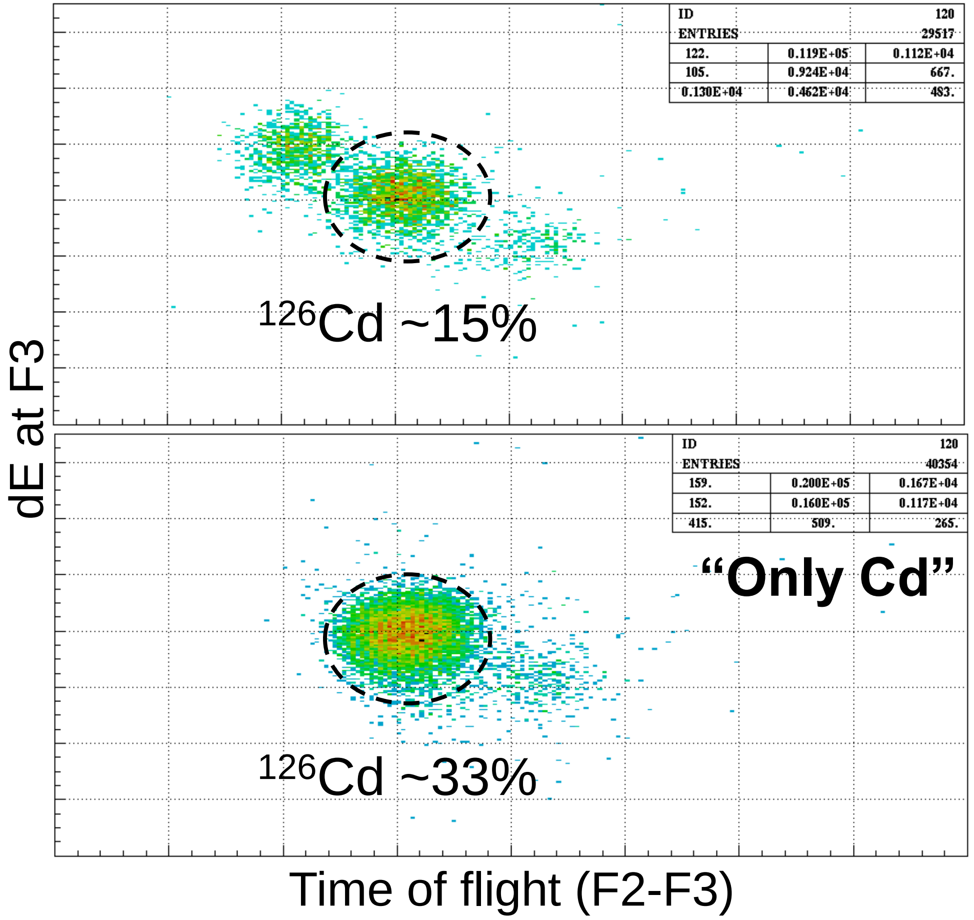
Transmission

Kicker excitation

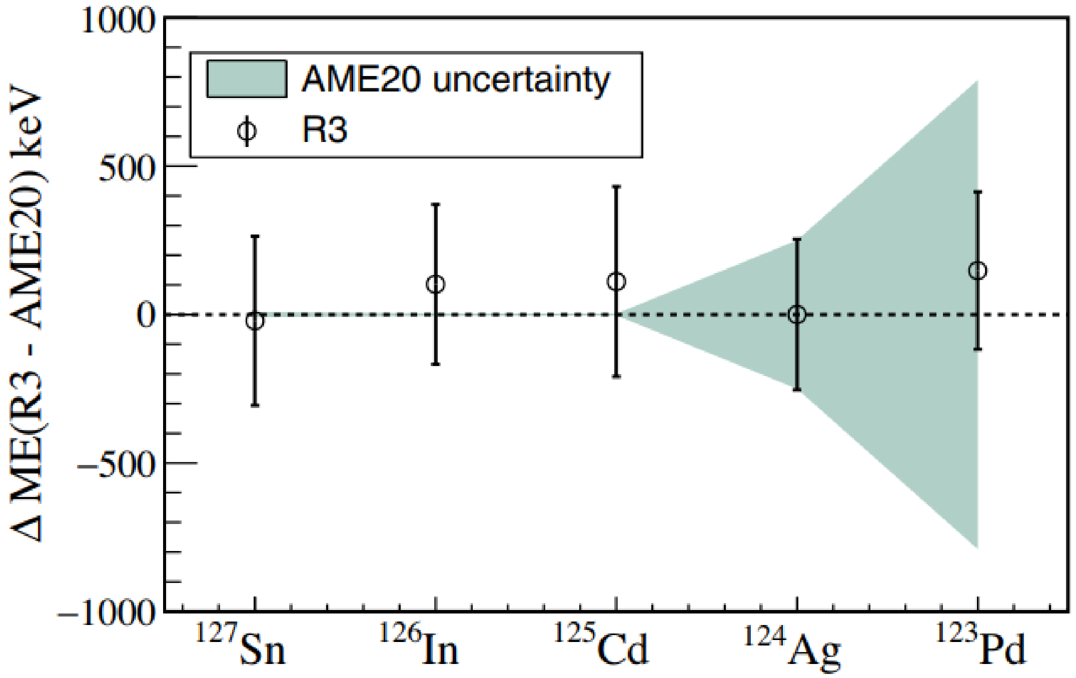
Adjusting the excitation timing of kicker magnets

→Efficient injection

Also we can control **the purity of the trigger**.



A highlight of R3



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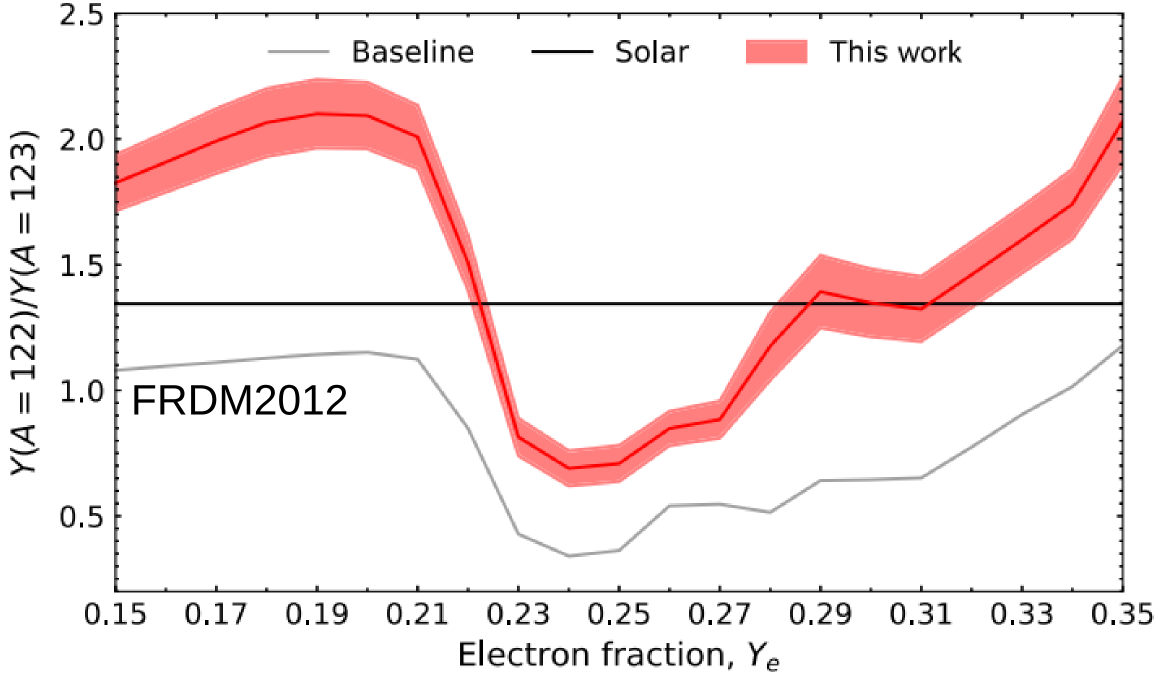
Impact on the r-process



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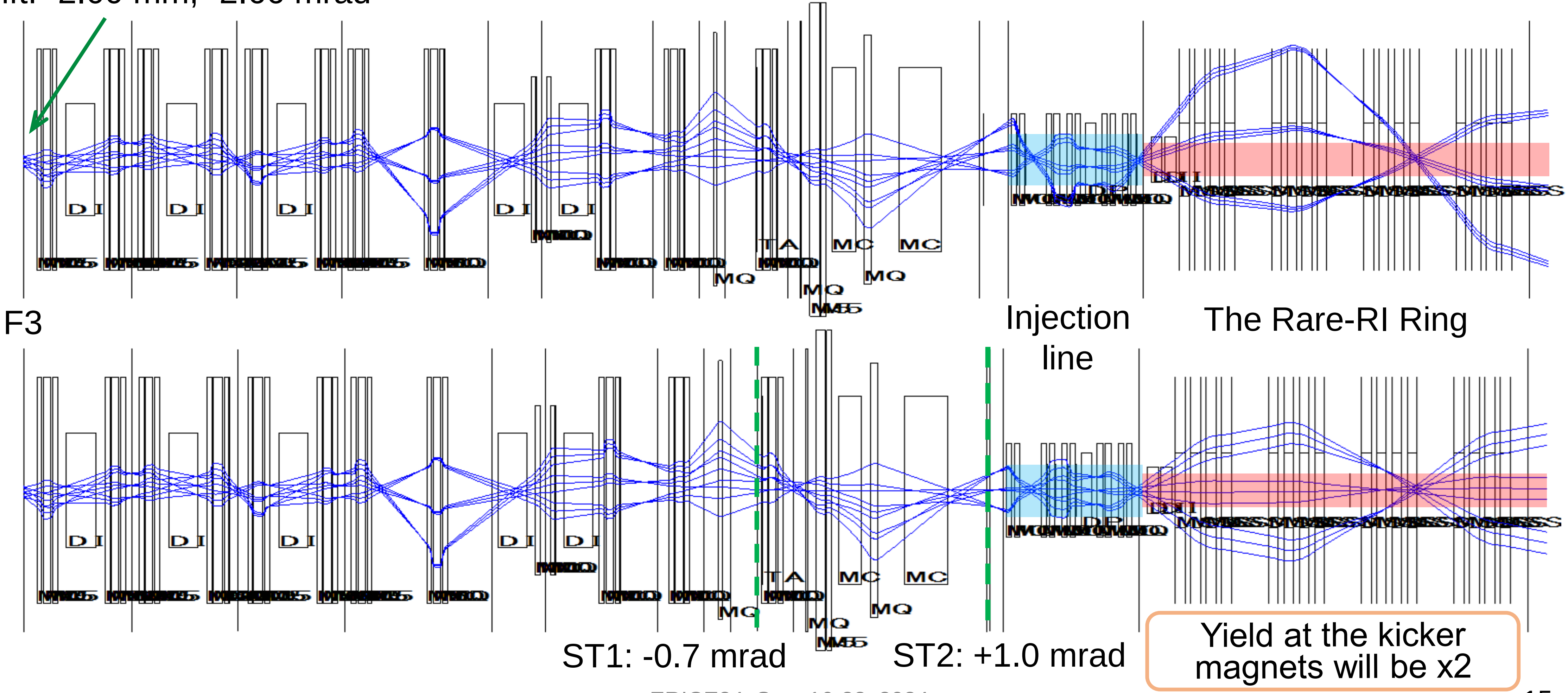
	AME20	R3
Mass excess [keV]	-60430	-60282
σ [keV]	790	265
δm/m	6.85×10^{-6}	2.30×10^{-6}

Contents

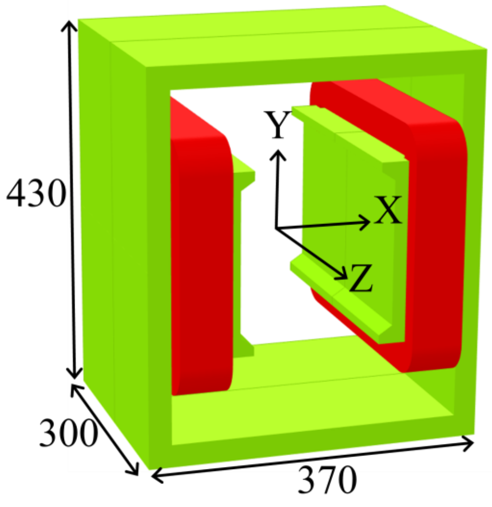
i. Steering magnets

The beam often goes out of the acceptance of R3 ➡ ~1% transmission efficiency

Shift: -2.00 mm, -2.66 mrad

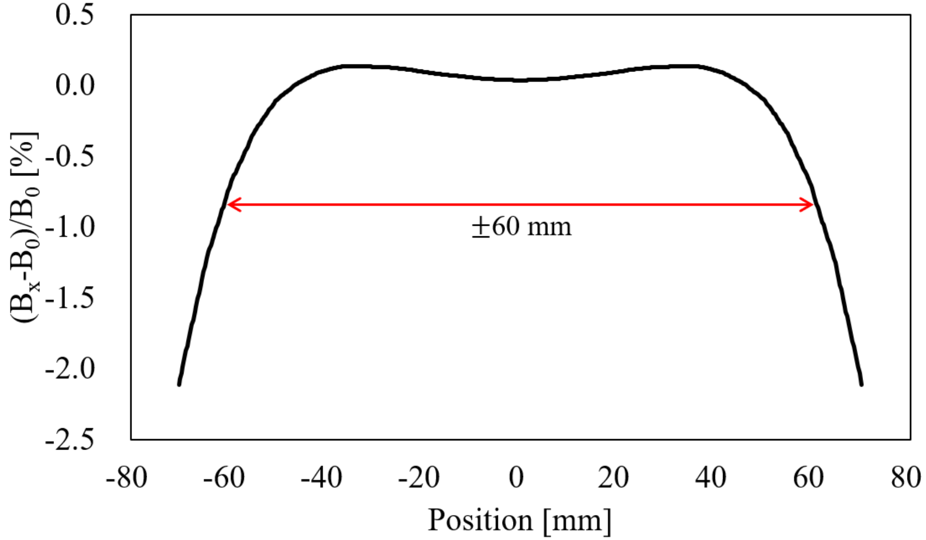


i. Steering magnets

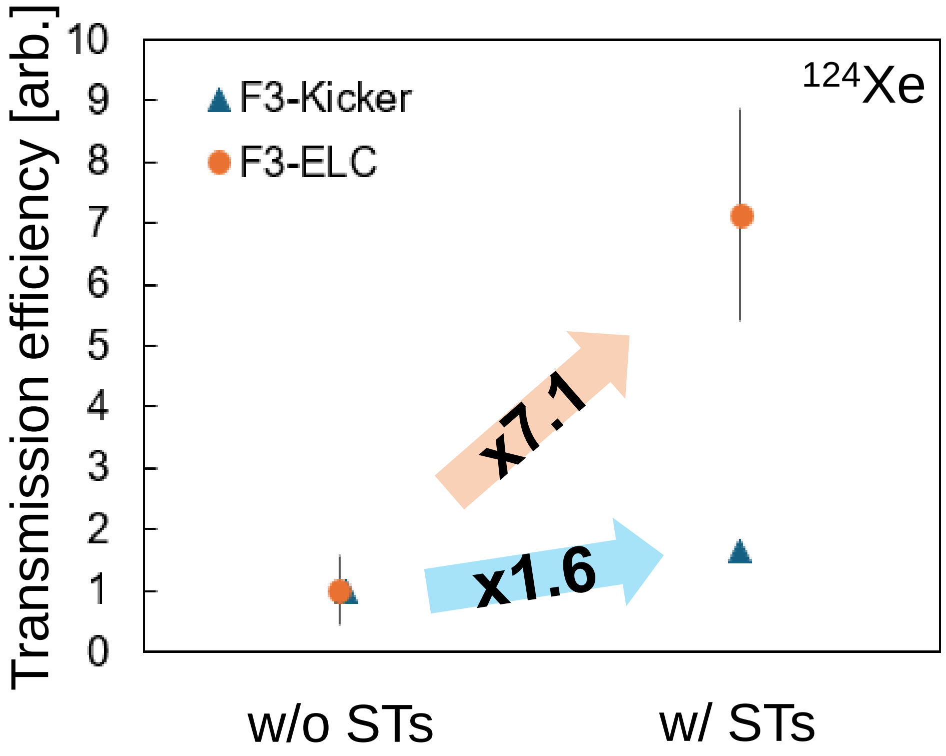


ST1

	ST1	ST2
Magnetic flux density	0.043 T	0.051 T
Current	15 A	13 A
Size	370×430×300 mm	310×360×250 mm
Pole gap	170 mm	125 mm
Pole length	300 mm	250 mm
Weight	180 kg	110 kg

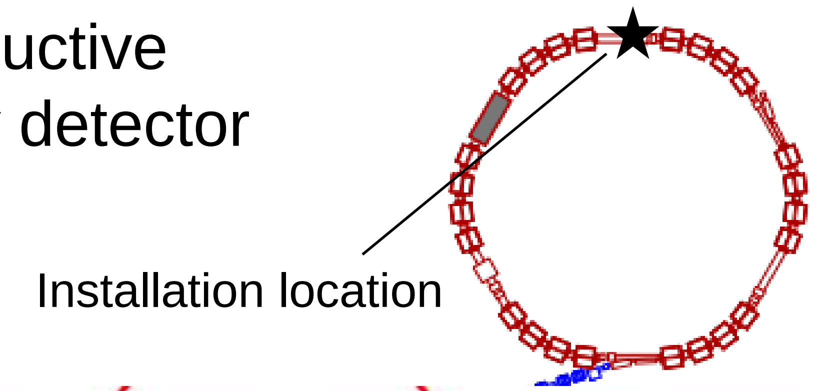


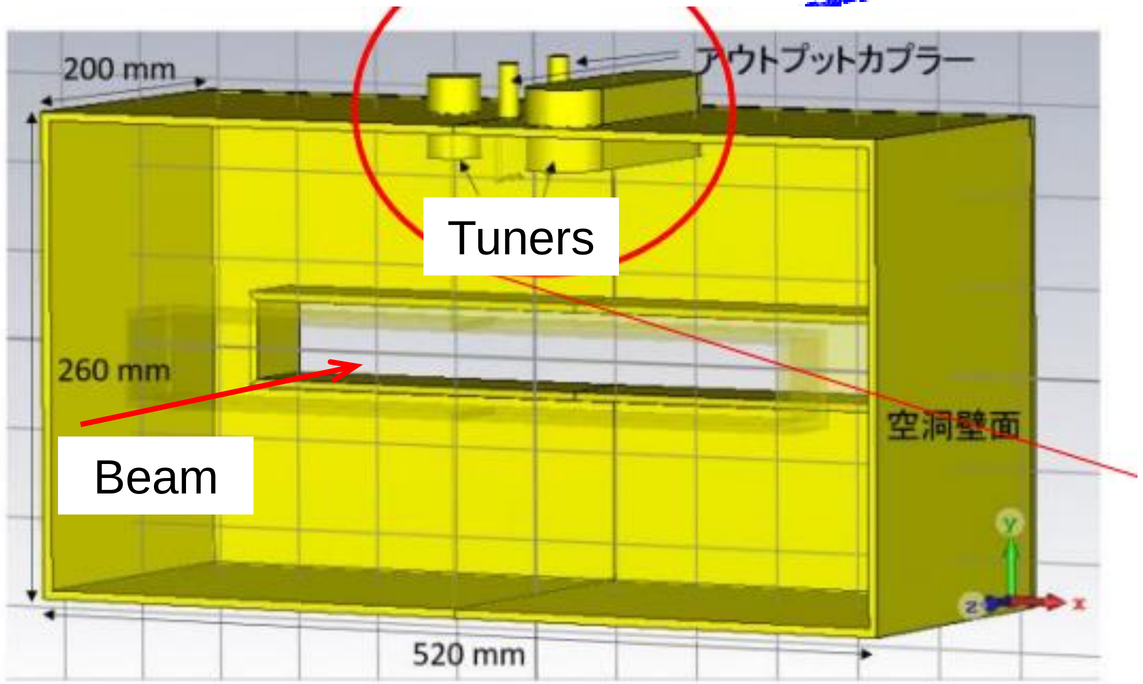
Improved transmission efficiency

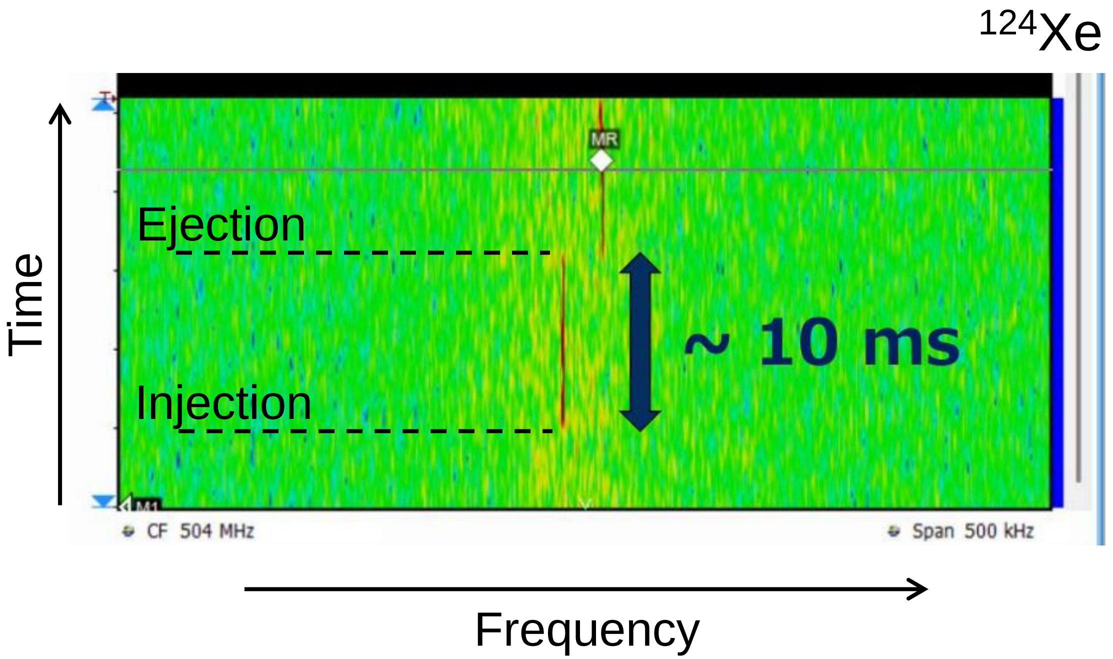


ii. Schottky pick-up detector

Non-destructive frequency detector







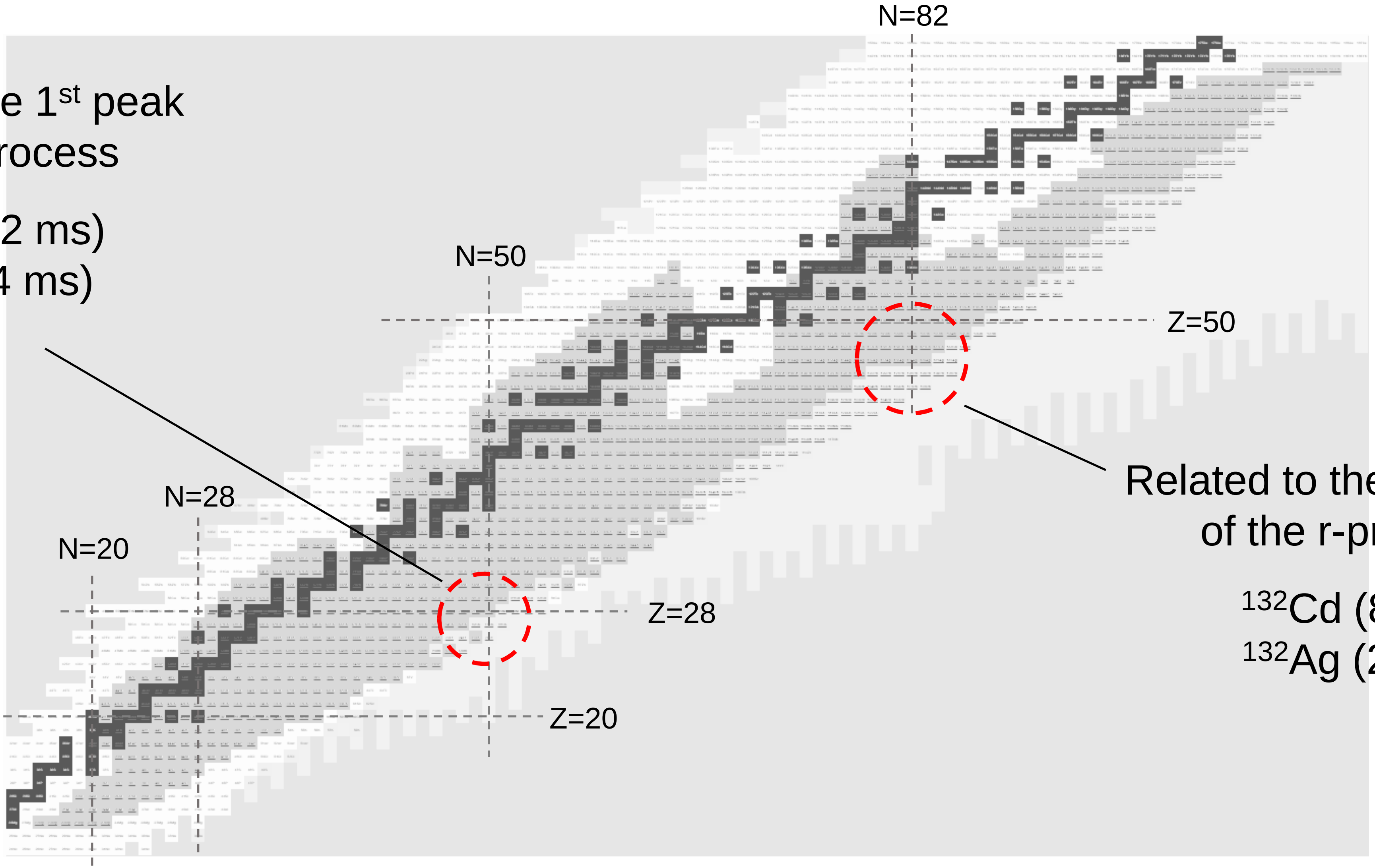
Particles can be detected in the order of ms
→Can be used for short-lived nuclei
- ✅ Isochronous tuning
- ✅ Life measurements

Contents

i. Mass measurements

Related to the 1st peak of the r-process

^{78}Ni (122 ms)
^{80}Ni (24 ms)

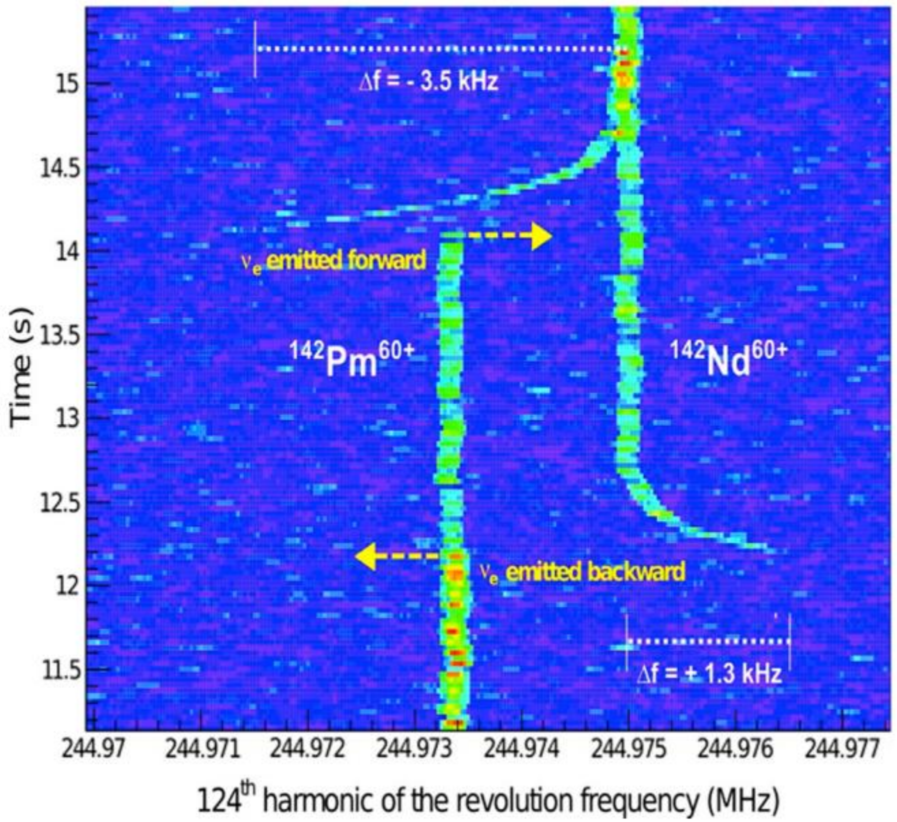


Related to the 2nd peak of the r-process

^{132}Cd (84 ms)
^{132}Ag (28 ms)

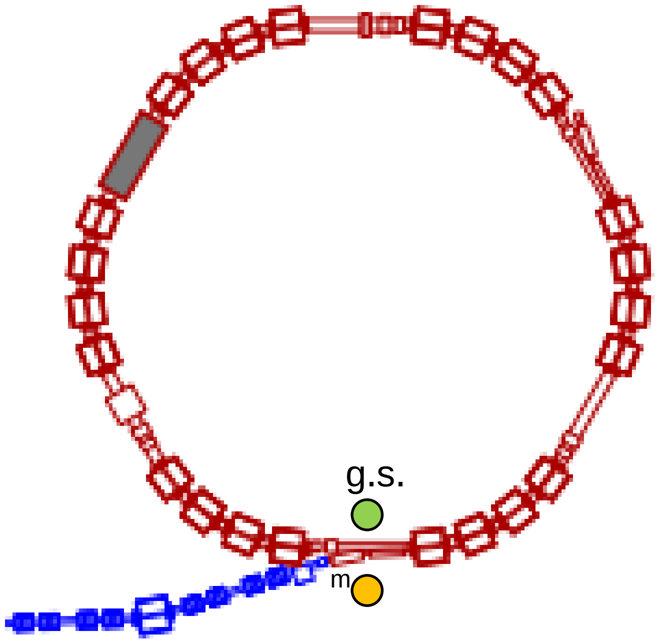
ii. Isomer measurements

β-decay measurement@GSI



P. Kienle *et. al*, PLB **726** (2013) 638-645

→Isomer can be measured as well



R3 isomer beam filter

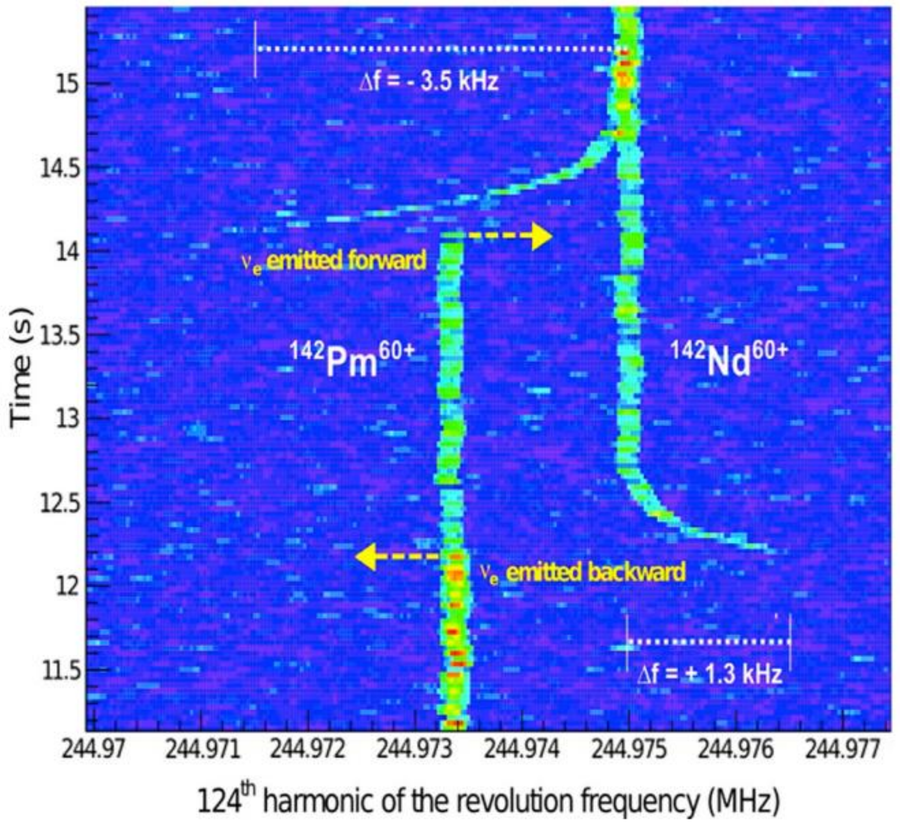
Lifetime:
>100 ms

Level:
>1 MeV

Beam:
<10 Hz

ii. Isomer measurements

β-decay measurement@GSI



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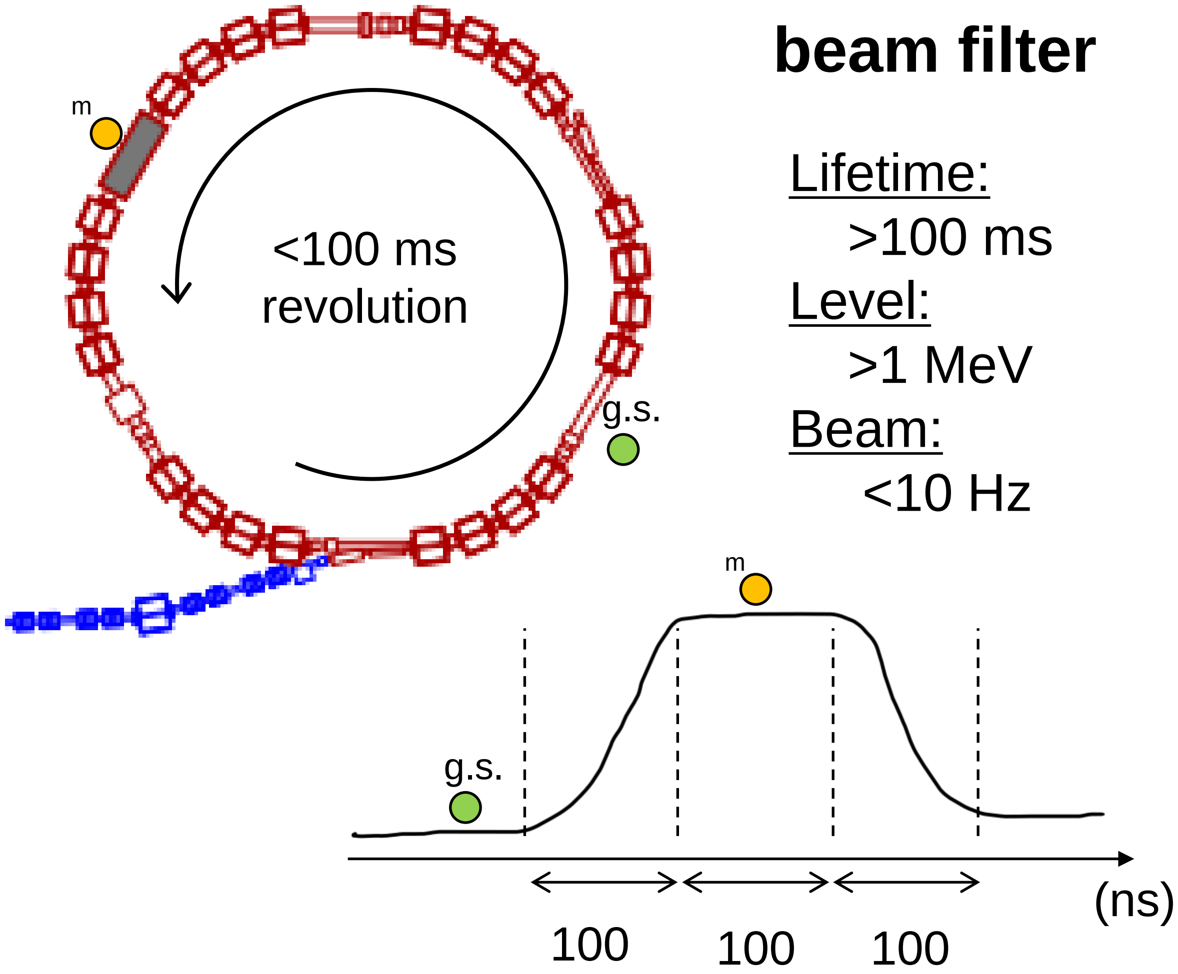
→Isomer can be measured as well

R3 isomer beam filter



<u>Lifetime:</u>
>100 ms
<u>Level:</u>
>1 MeV
<u>Beam:</u>
<10 Hz

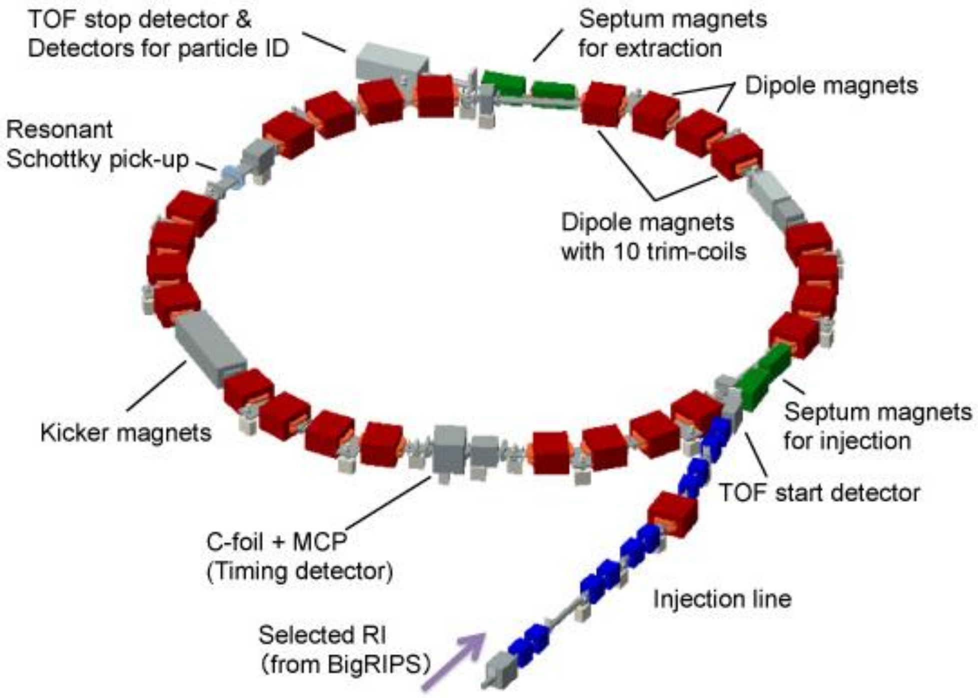
Summary

Nuclear masses far from stability;

✅ Important for astrophysics as well as nuclear physics

❌ Generally difficult to measure

→**The Rare-RI Ring**, a device specialized for rare RIs, is in operation.



A unique storage ring;

- Isochronous mass spectrometry
- Individual injection + ToF selection

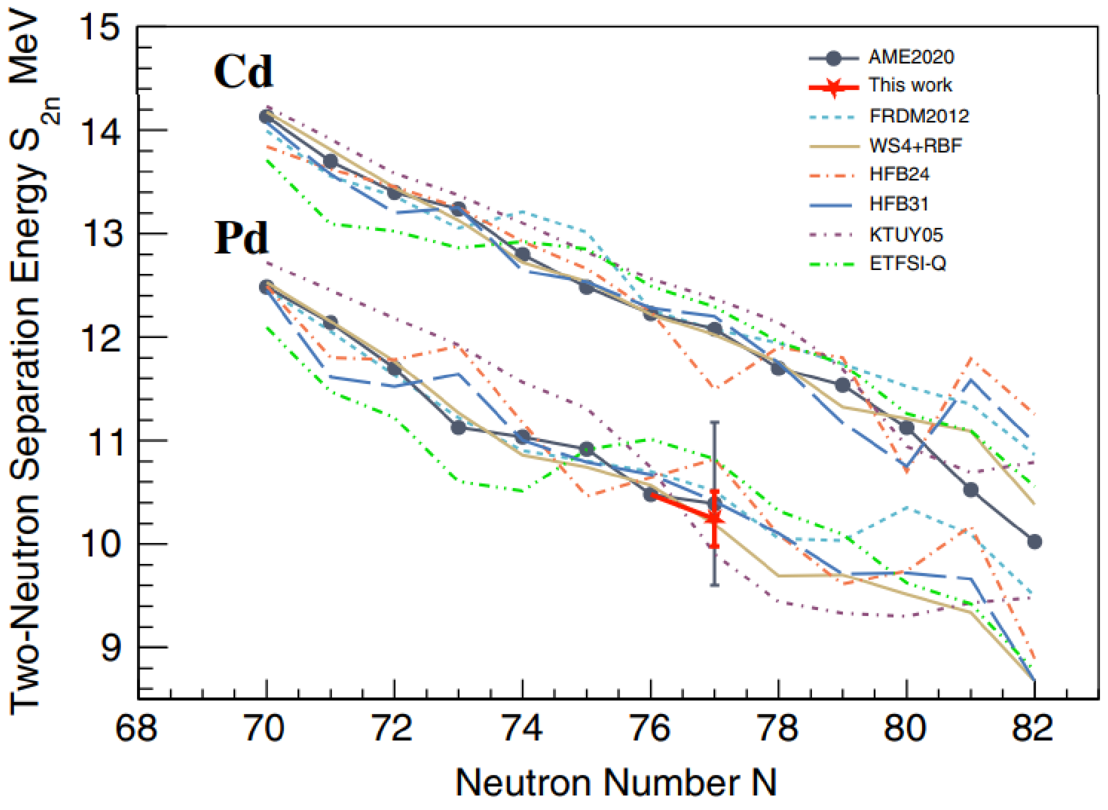
Recent upgrades;

- Steering magnets → Higher transmission efficiency
- Schottky detector → Fast tuning of the ring

Future plans;

- Mass measurements
- Life measurements
- Isomer beam filter

A highlight of R3



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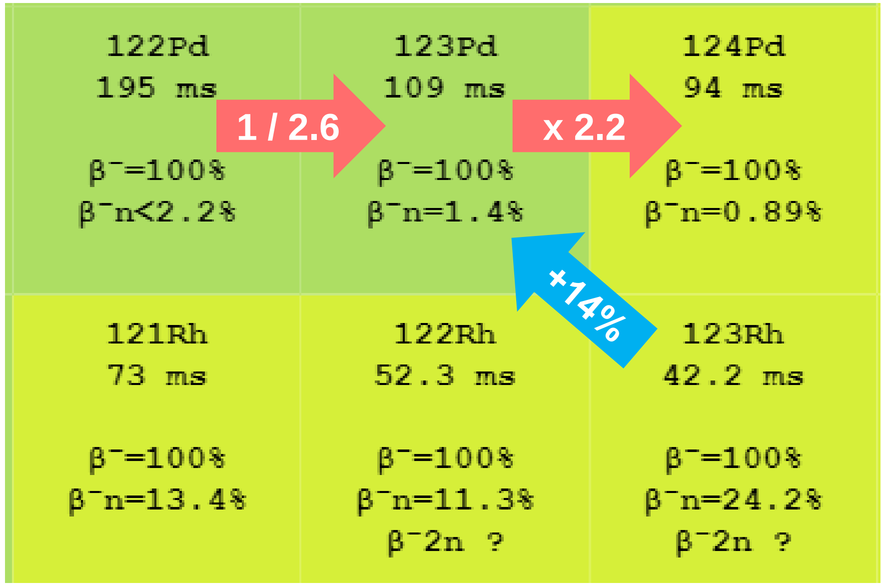
S_n, S_{2n} decreased;

- ✓ β-decay probability of ^{123}Rh increased by 14%
- ✓ The neutron capture cross section for ^{122}Pd decreased by a factor of 2.6
- ✓ The neutron capture cross section for ^{123}Pd increased by a factor of 2.2



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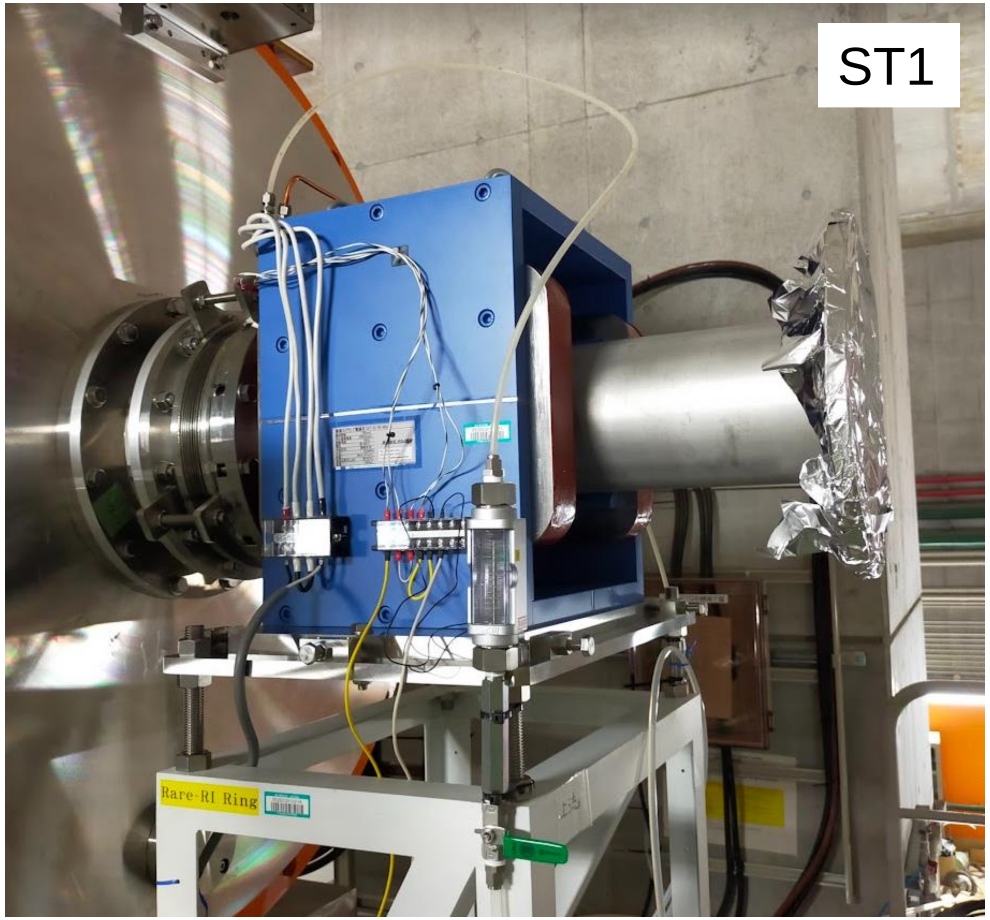

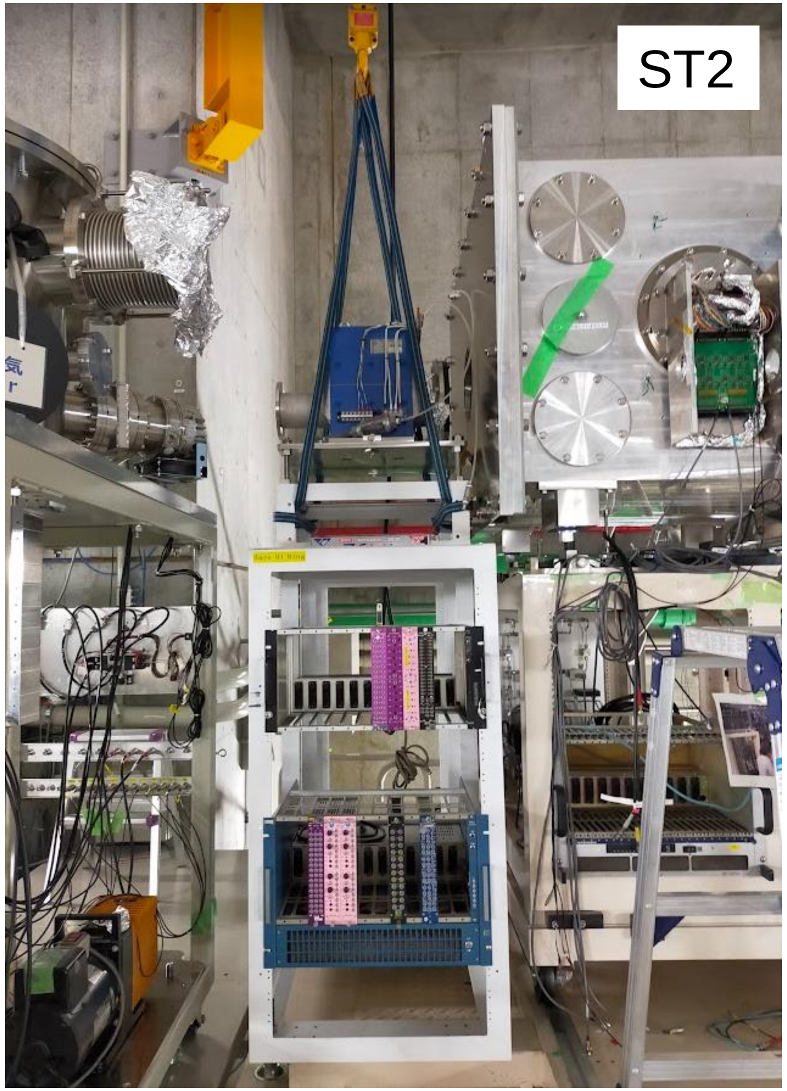

R3 isomer beam filter