
Rare-R1 Ring (R3) at RIBF/Riken

Mass measurement of
r-process nuclei

Sarah Naimi

Riken Nishina Center



NARRS National Amphibian and Reptile Recording Scheme



Home

How to
take part

Surveys:

Widespread
Amphibian &
Reptile Surveys

Adder
Surveys

Latest News

NARRSNEWS

NARRSNEWS is the newsy new newsletter for news about NARRS and is sent to all registered persons as a pdf file. To read the latest NARRSNEWS, [click here](#).

NARRS Results

[Read the results from the first six years of NARRS surveys](#). NARRS survey results are also now submitted to the [NBN Gateway](#), usually over the summer, so please be patient if your survey results do not appear right away. You can search the Gateway for species in which you are interested and then zoom in on different areas and records using their interactive map.

NEW: Read the results of the NERC-funded project, led by DICE at the University of Kent, looking at amphibian and reptile survey protocols [here](#). This advice is NOT specifically for NARRS but will inform different types of survey. The most recent NARRS protocols are found under [Resources for Surveyors](#).

NARRS is led by Amphibian and Reptile Conservation (ARC) in partnership with ARG UK and many other partners. Through volunteer-based surveys, we aim to monitor the conservation status of all UK amphibian and reptile species. Click on the buttons or links to each side for more information. Following feedback from users we have made substantial changes to the appearance and usability of this website. We hope you approve but your feedback will always be welcome.

Resources for
Surveyors

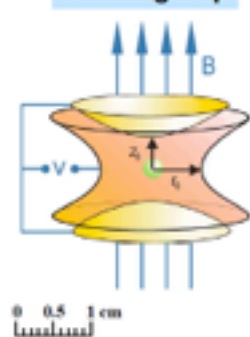
Resources for
Training

The latest:

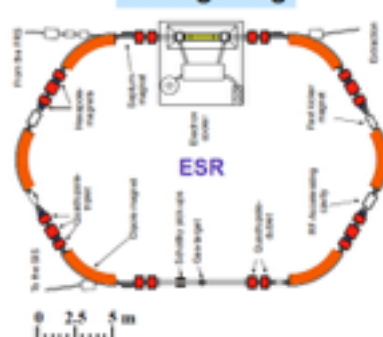
Training
Events

News &
Results

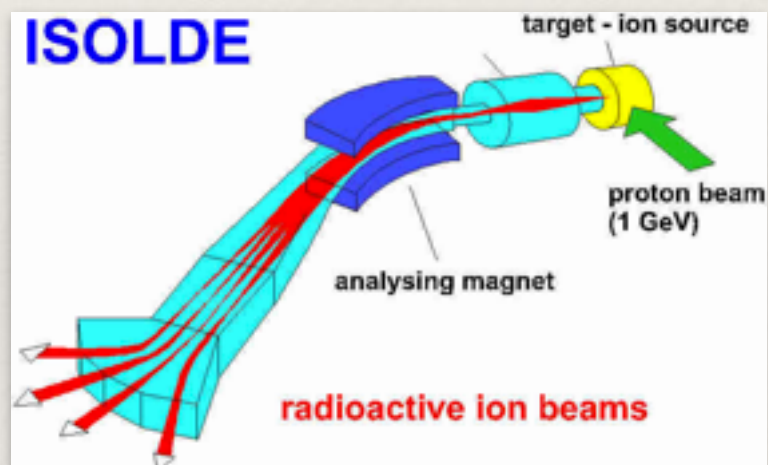
Penning trap



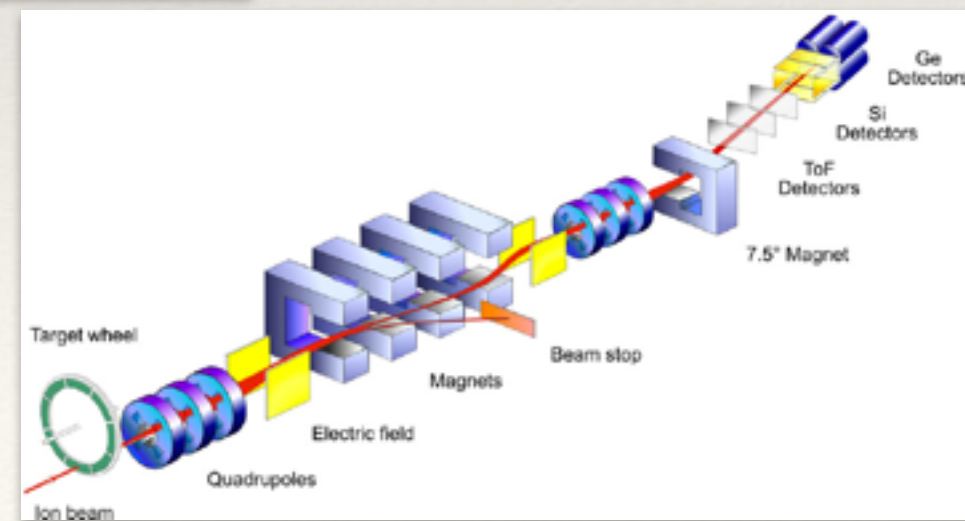
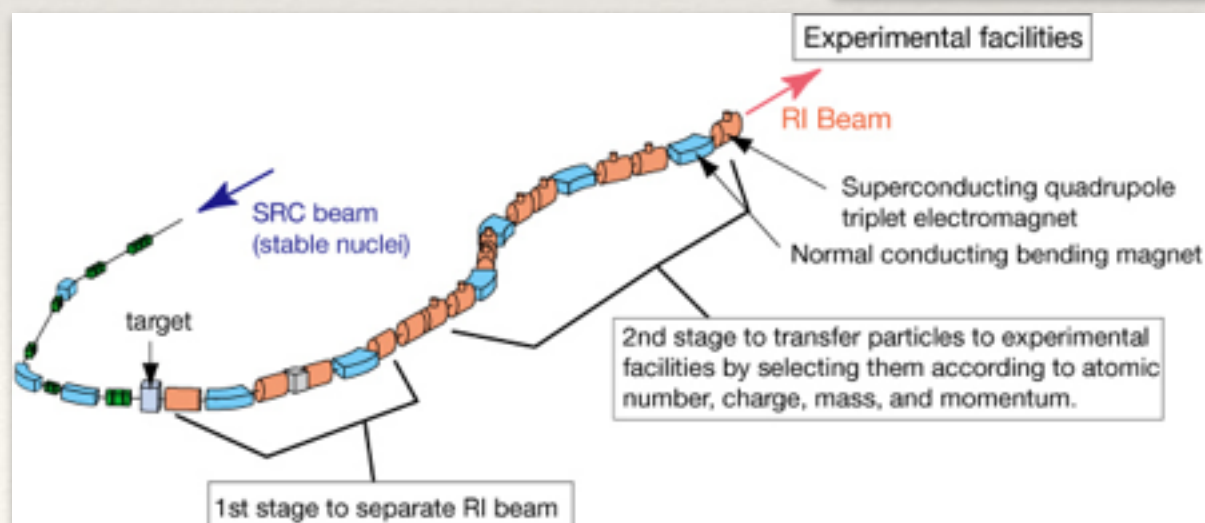
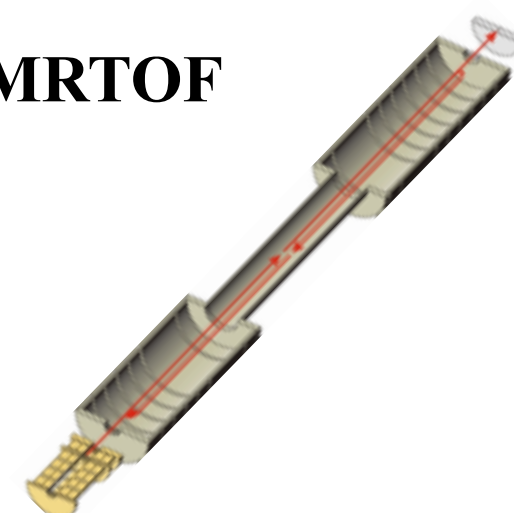
Storage ring



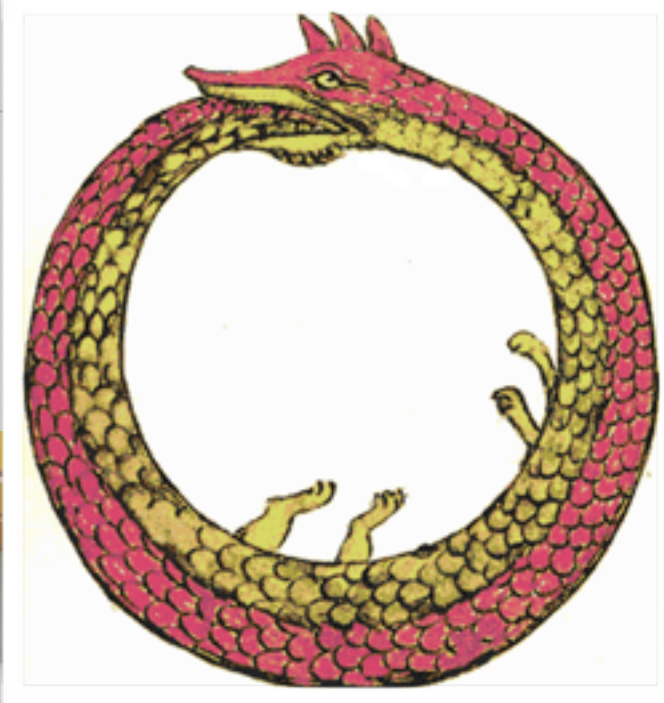
ISOLDE



MRTOF



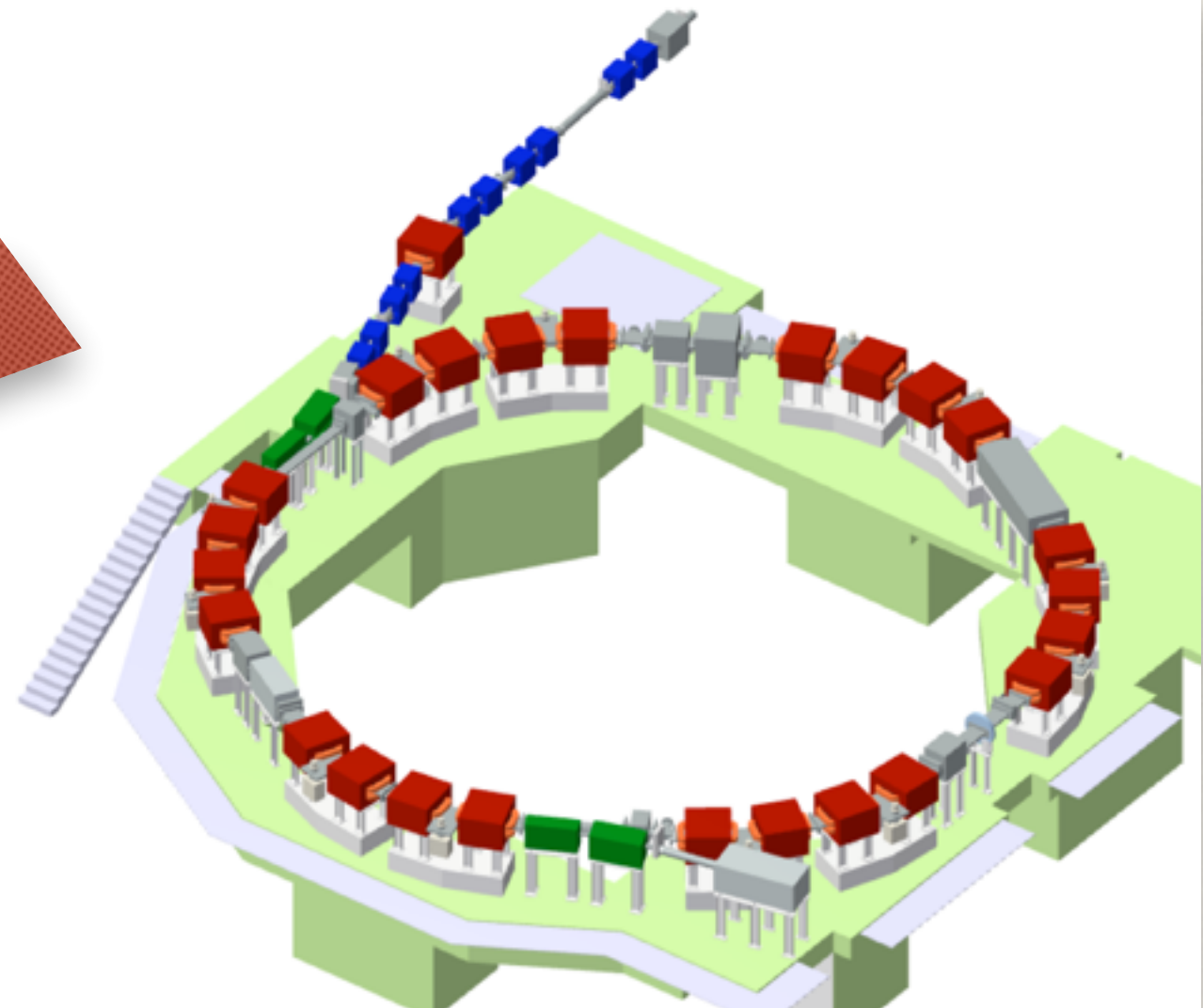
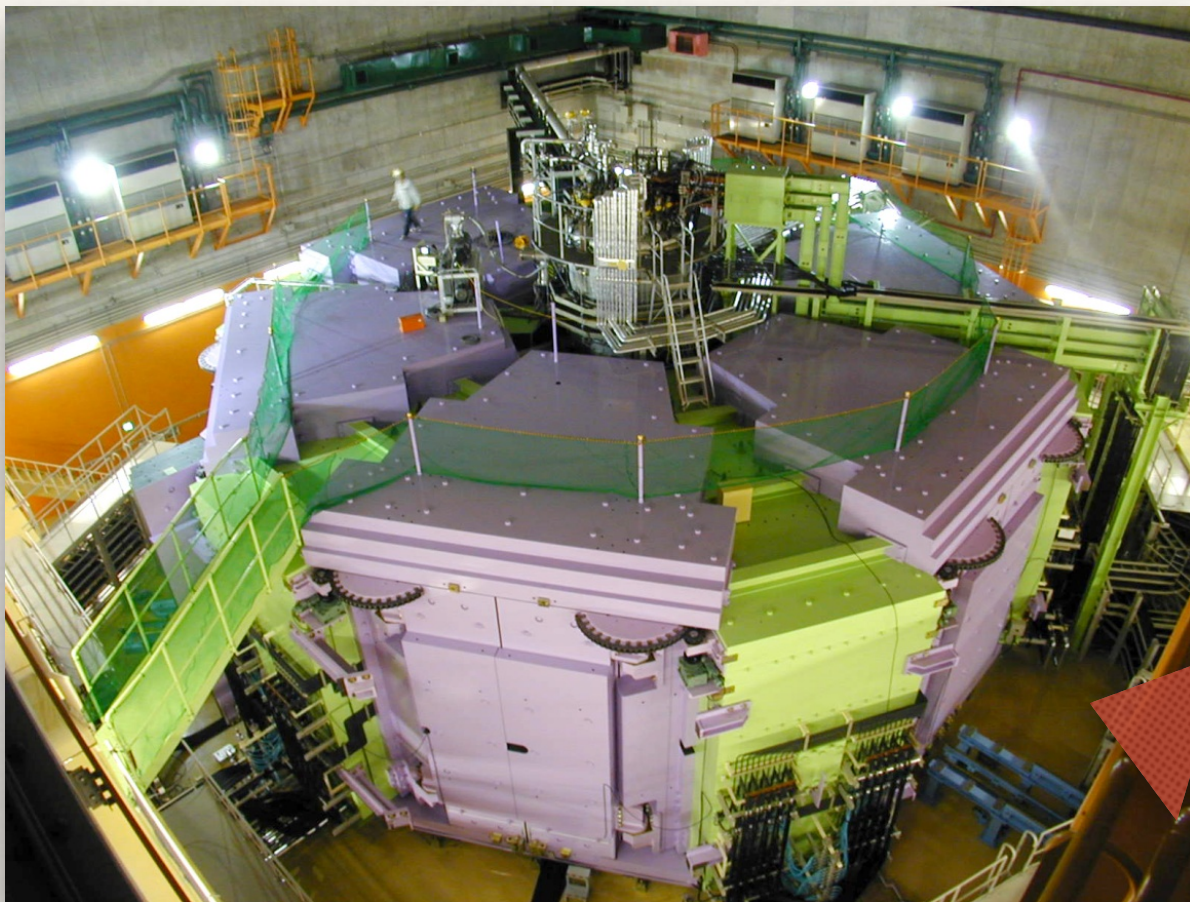
The Rare-RI Ring (R3)



Union of storage ring & cyclotron

Critical Mismatch!!

DC beam vs. pulsed beam
How to solve?



TYPES OF
BEARDED
DRAGONS



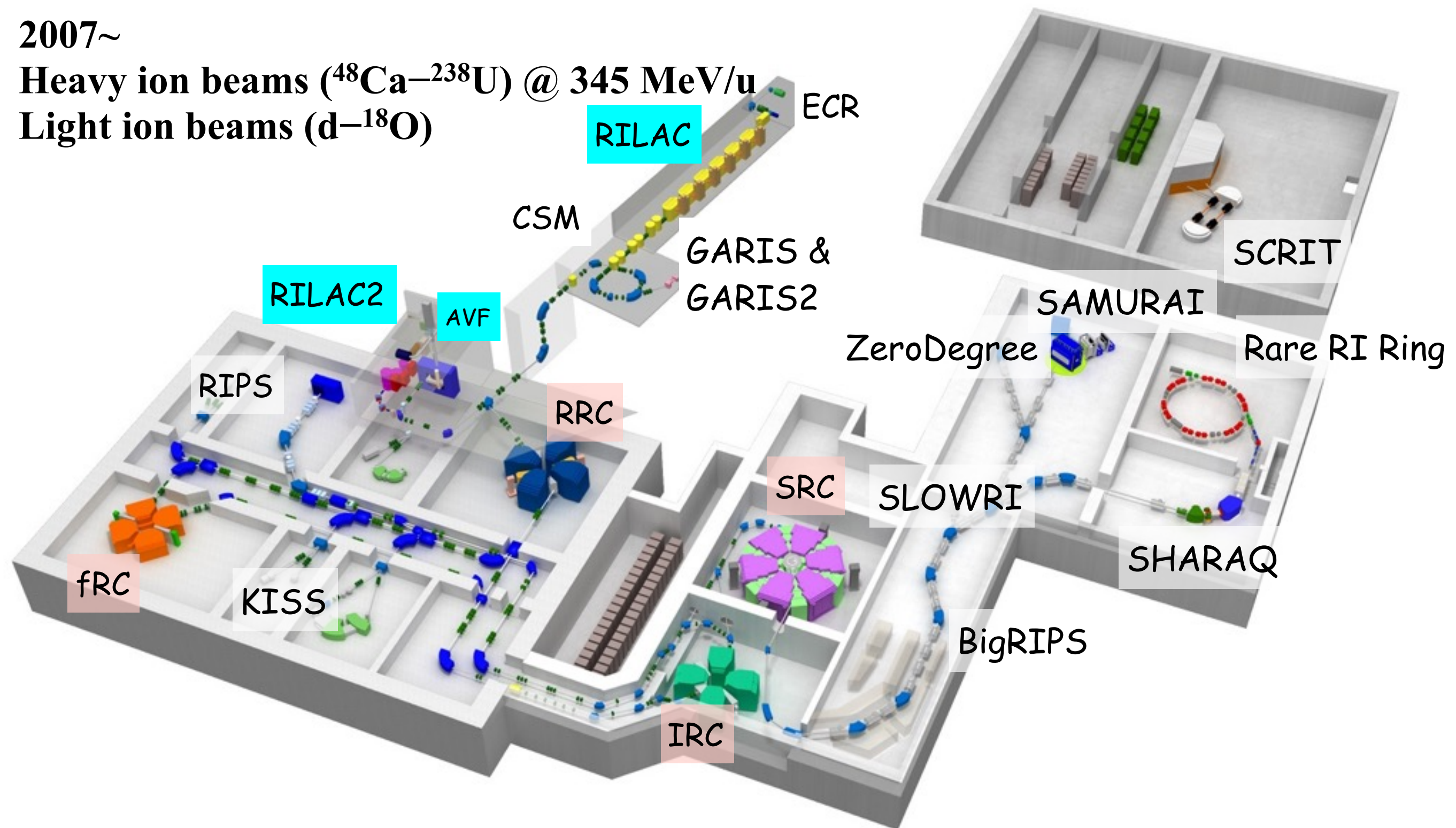
Fastest Reptile on earth 40km/h

RI Beam Factory at RIKEN

2007~

Heavy ion beams (^{48}Ca – ^{238}U) @ 345 MeV/u

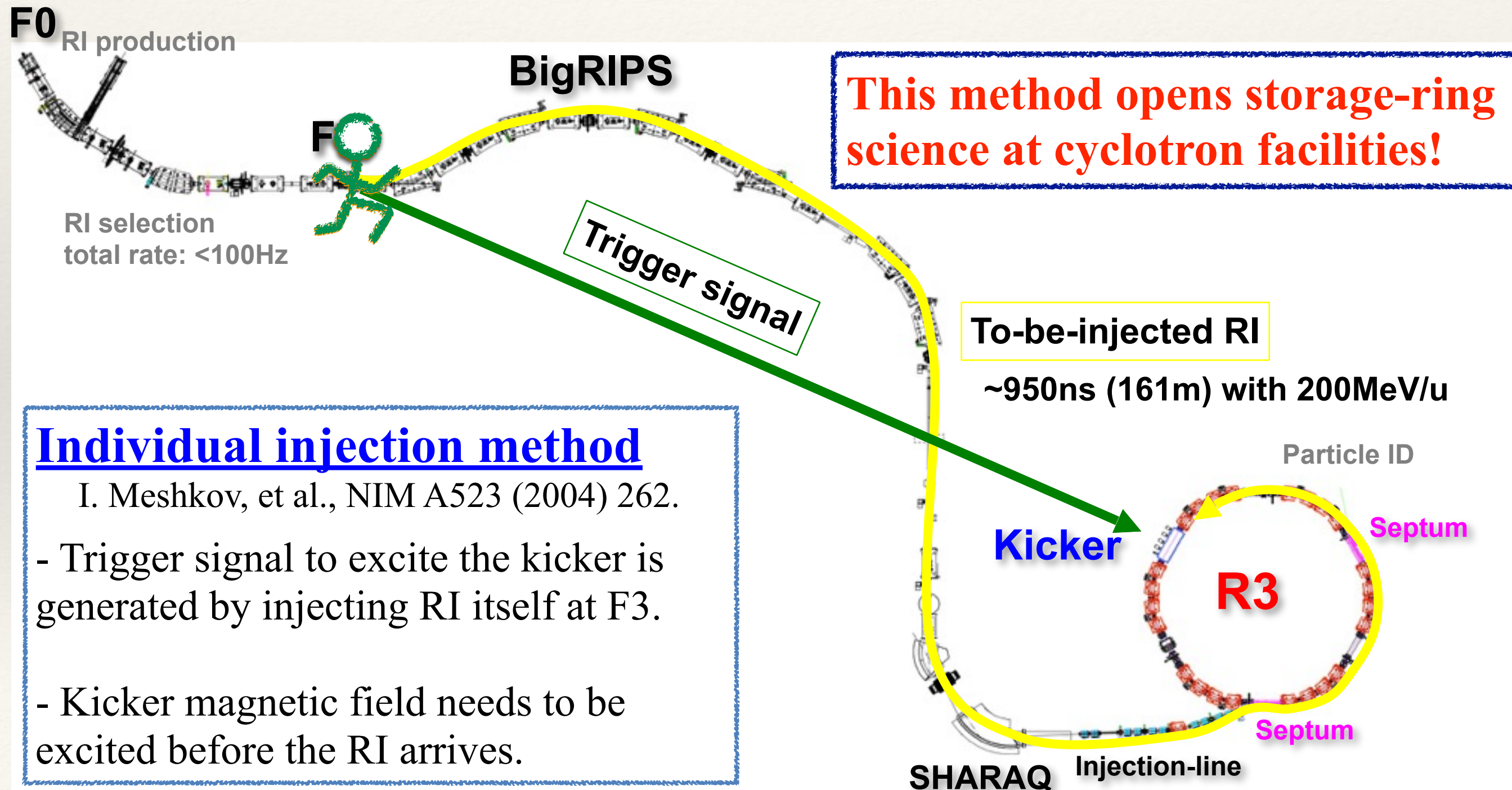
Light ion beams (d – ^{18}O)



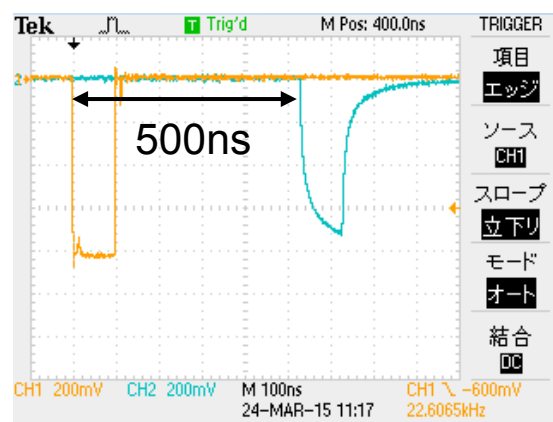
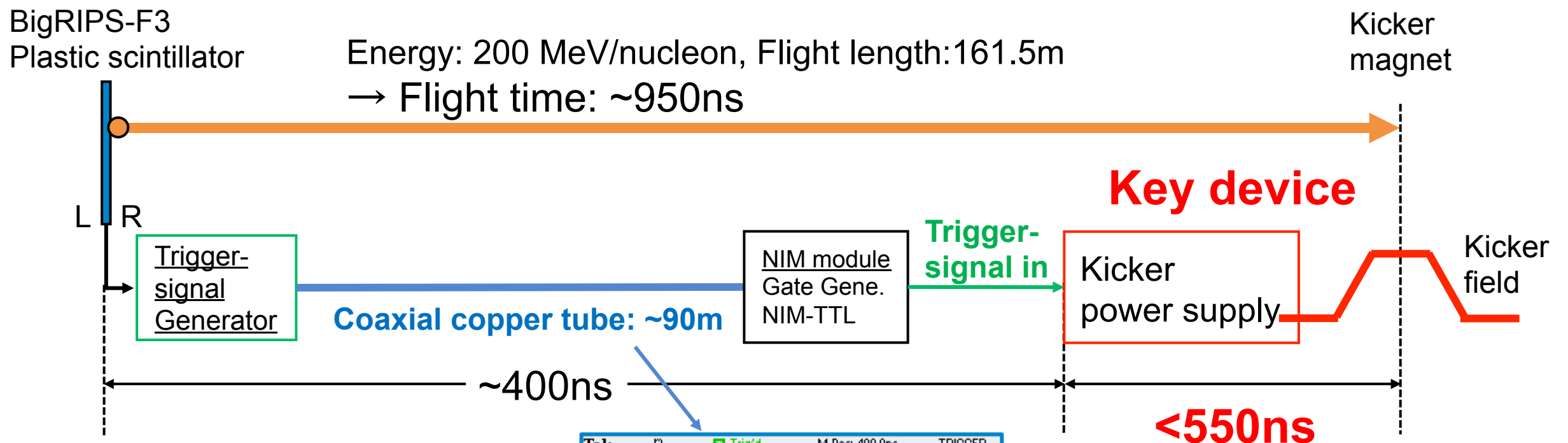


Individual injection

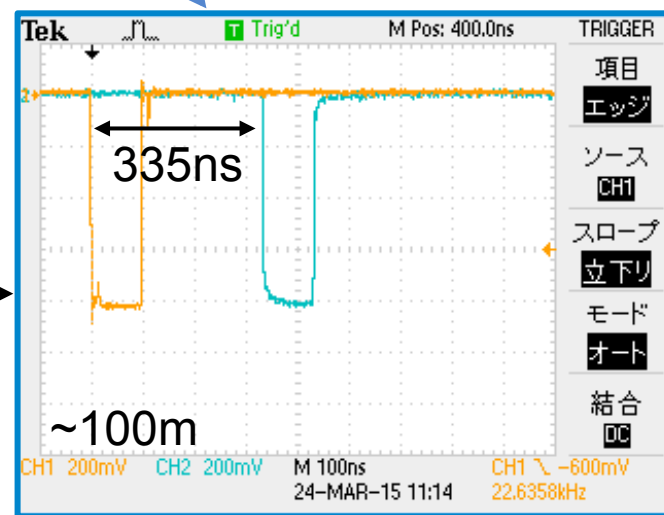
Nucleus of interest itself triggers its injection to the ring!



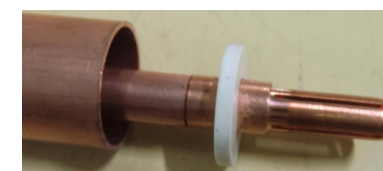
Synchronisation



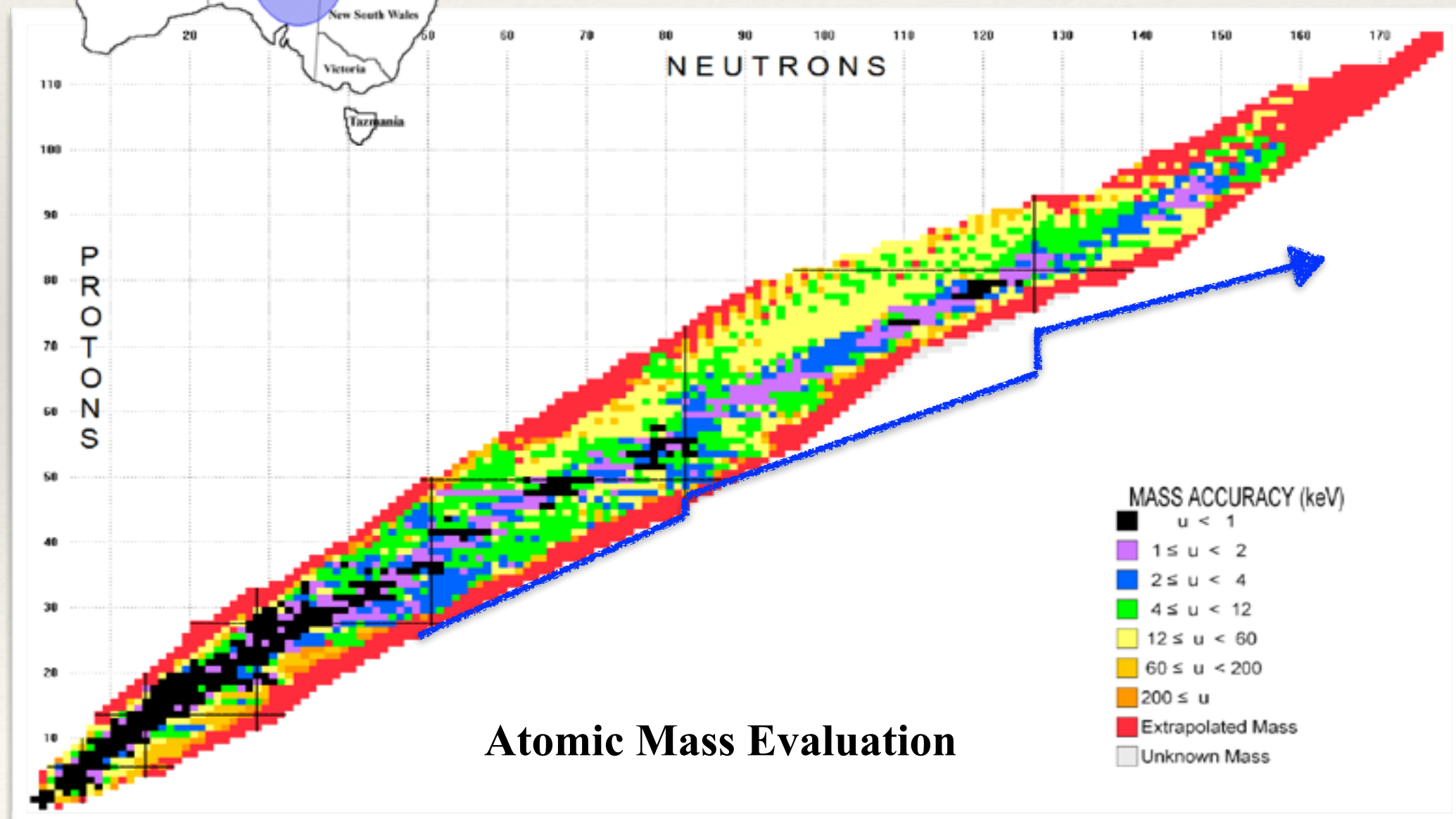
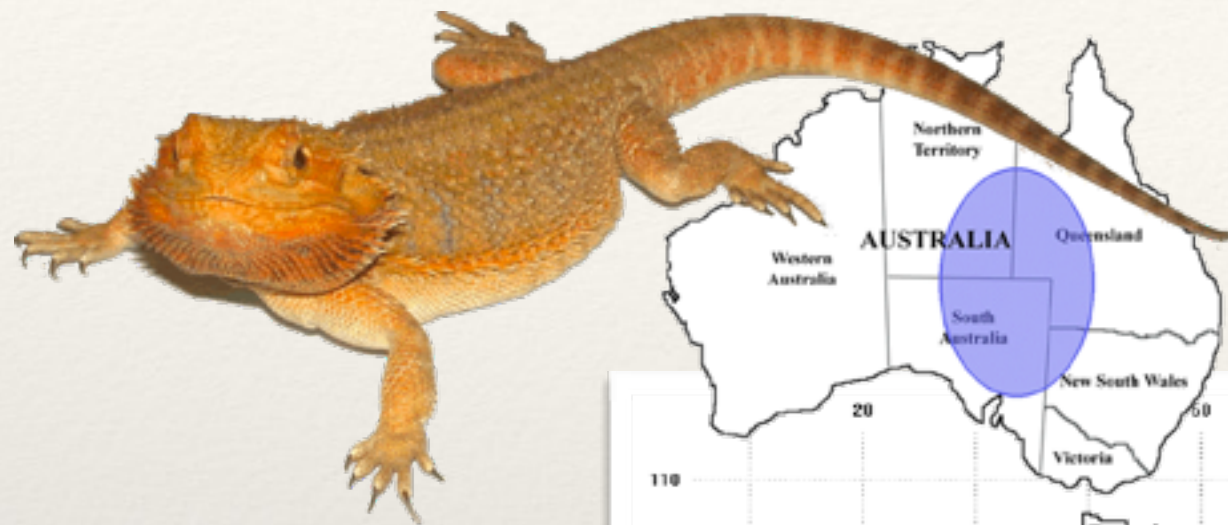
Standard coaxial cable (100m)



Propagation velocity $\beta \sim 0.986$

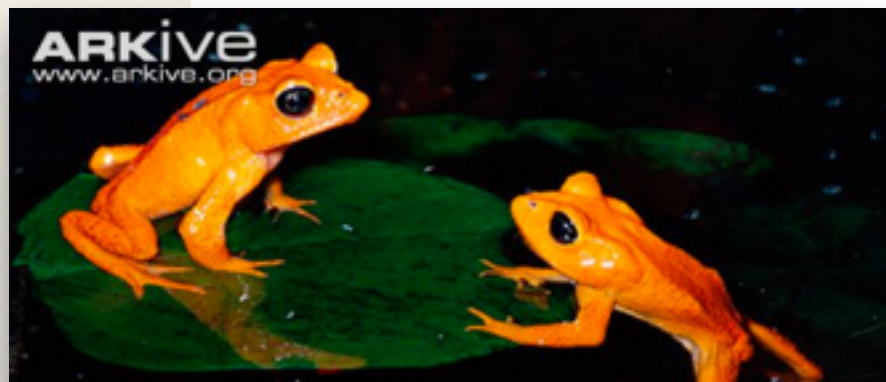


R-process nuclei in remote territory

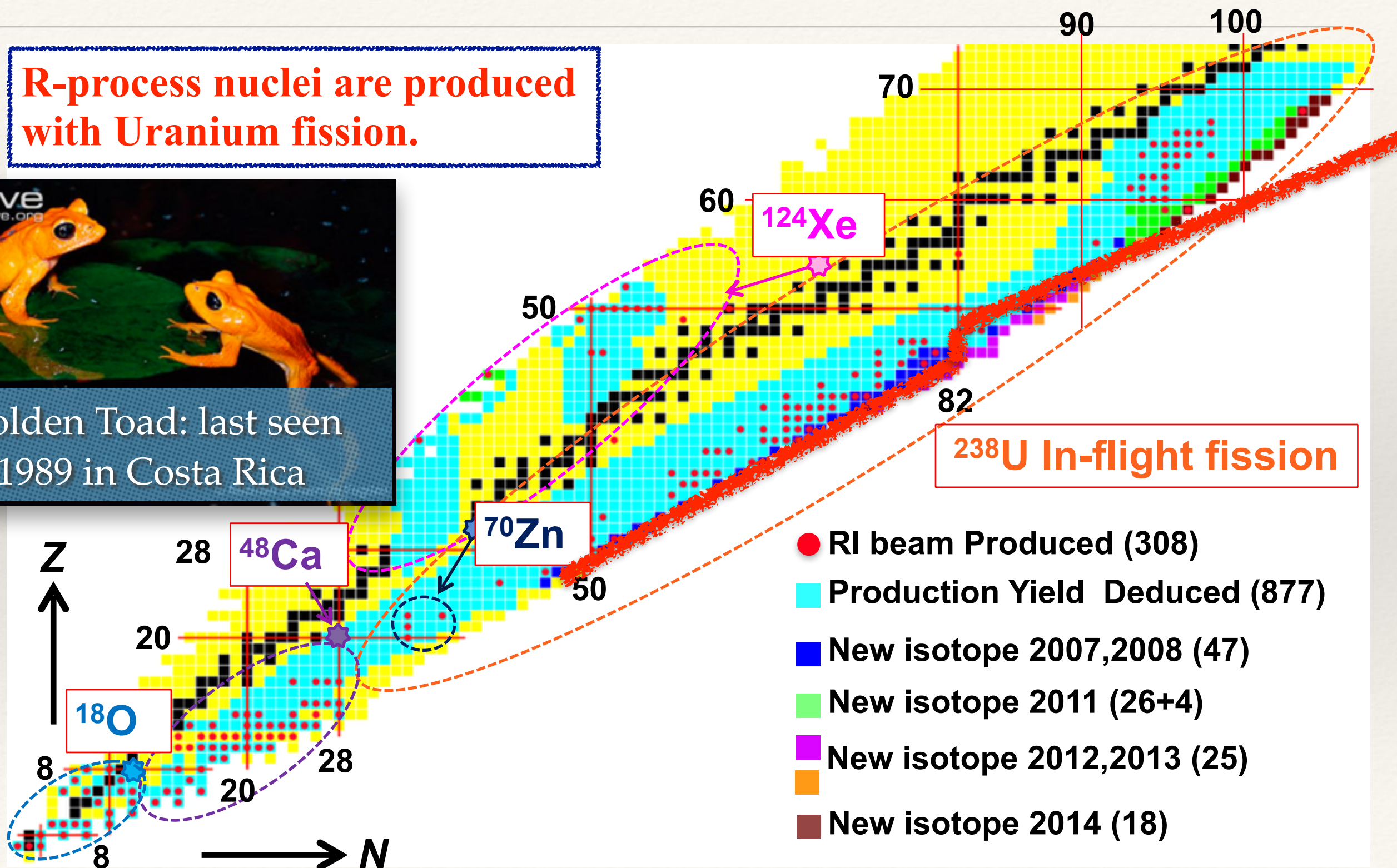


Remote regions can be reached at RIBF

R-process nuclei are produced with Uranium fission.



Golden Toad: last seen 1989 in Costa Rica

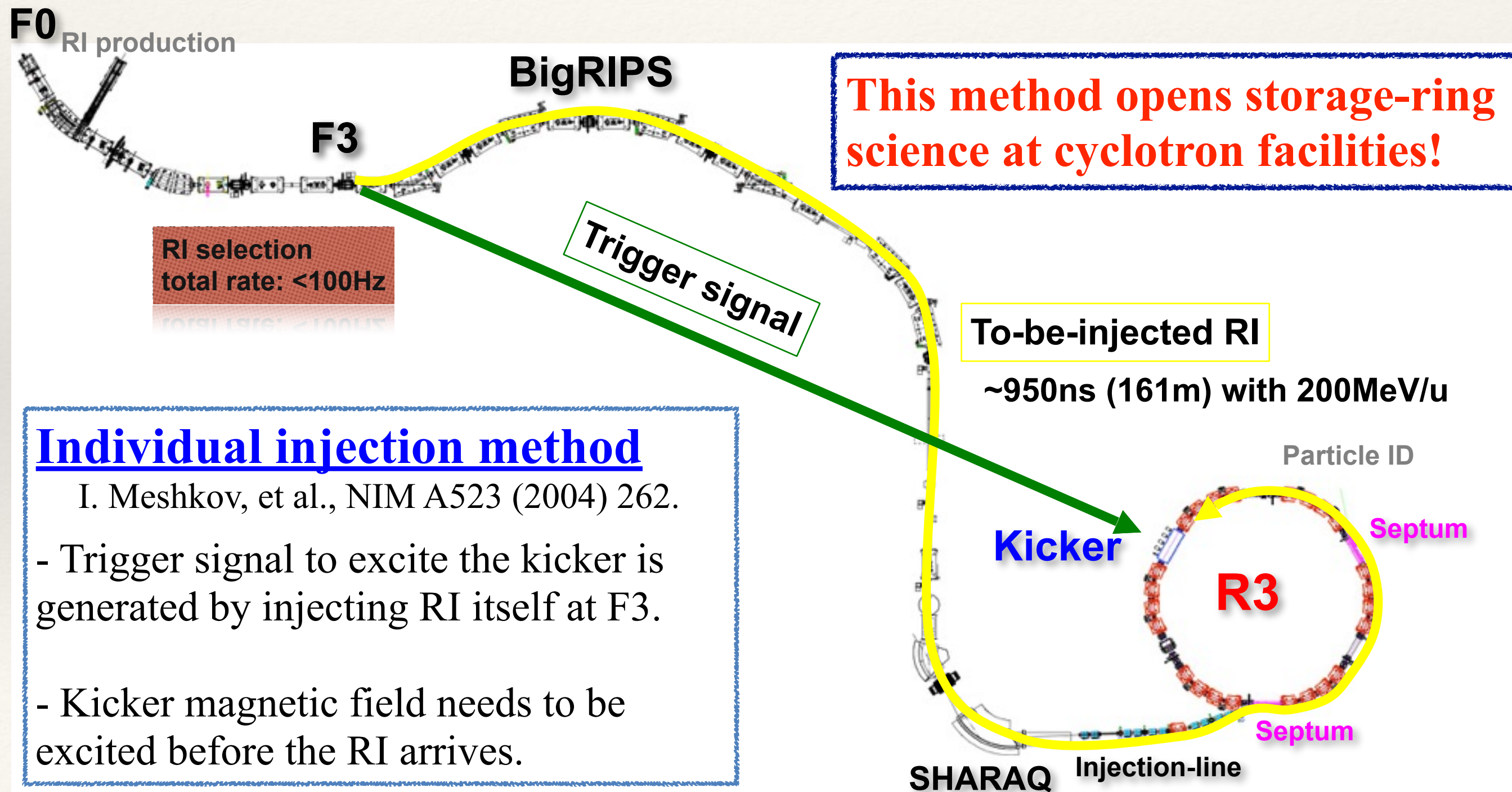


Kubo and BigRIPS team



Individual injection

Nucleus of interest itself triggers its injection to the ring!



Isotope-Selectable Self-triggered Injection



Phys. Scr. **T166** (2015) 014039

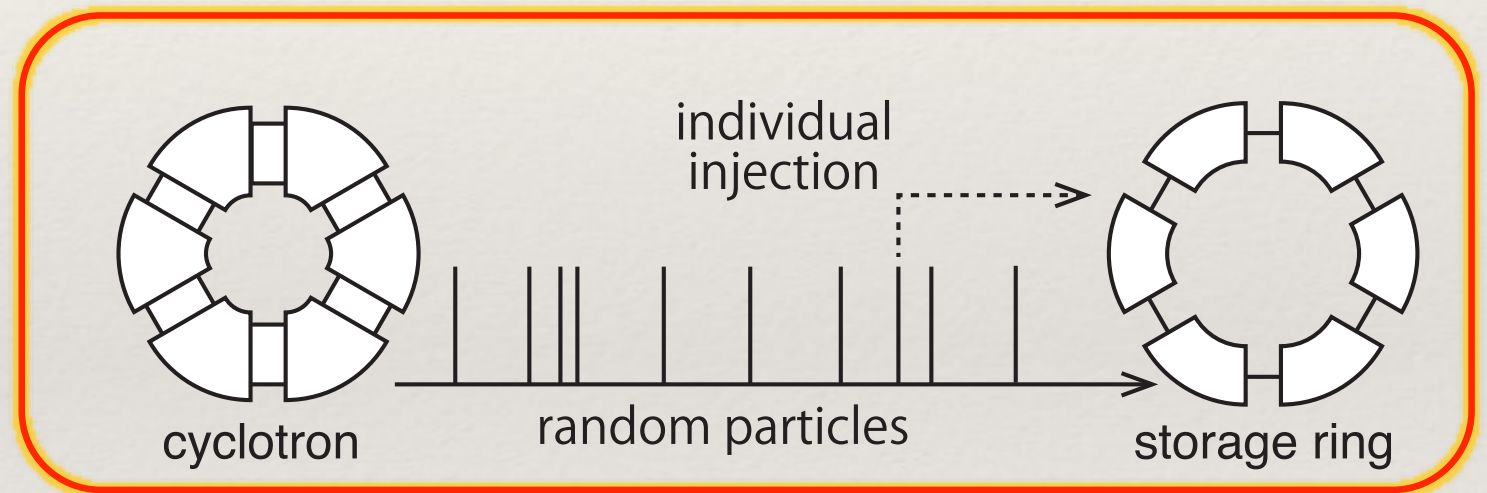
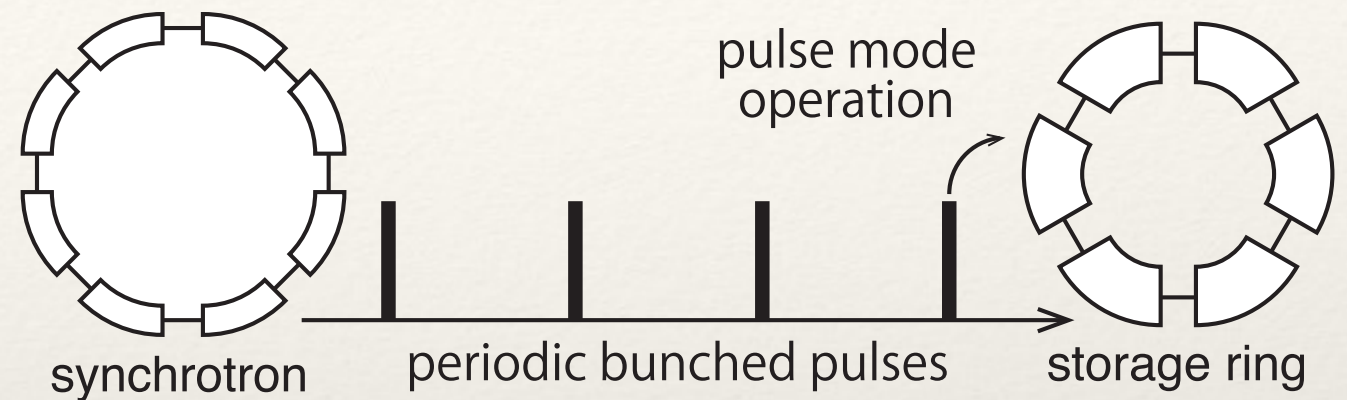
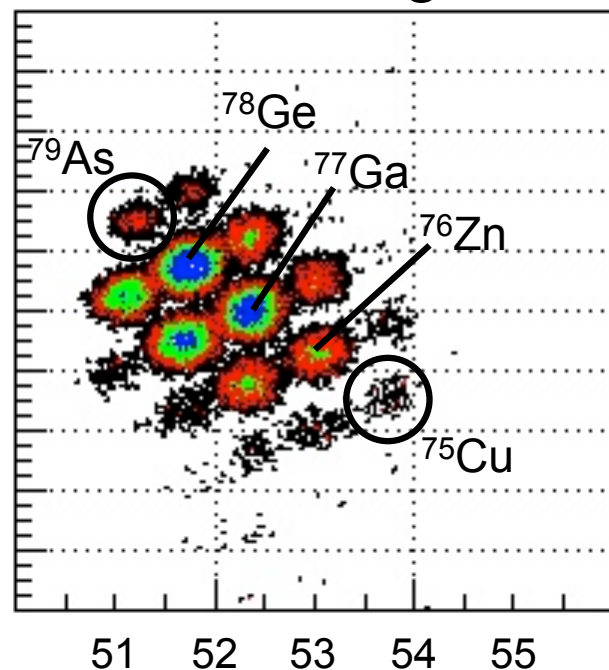


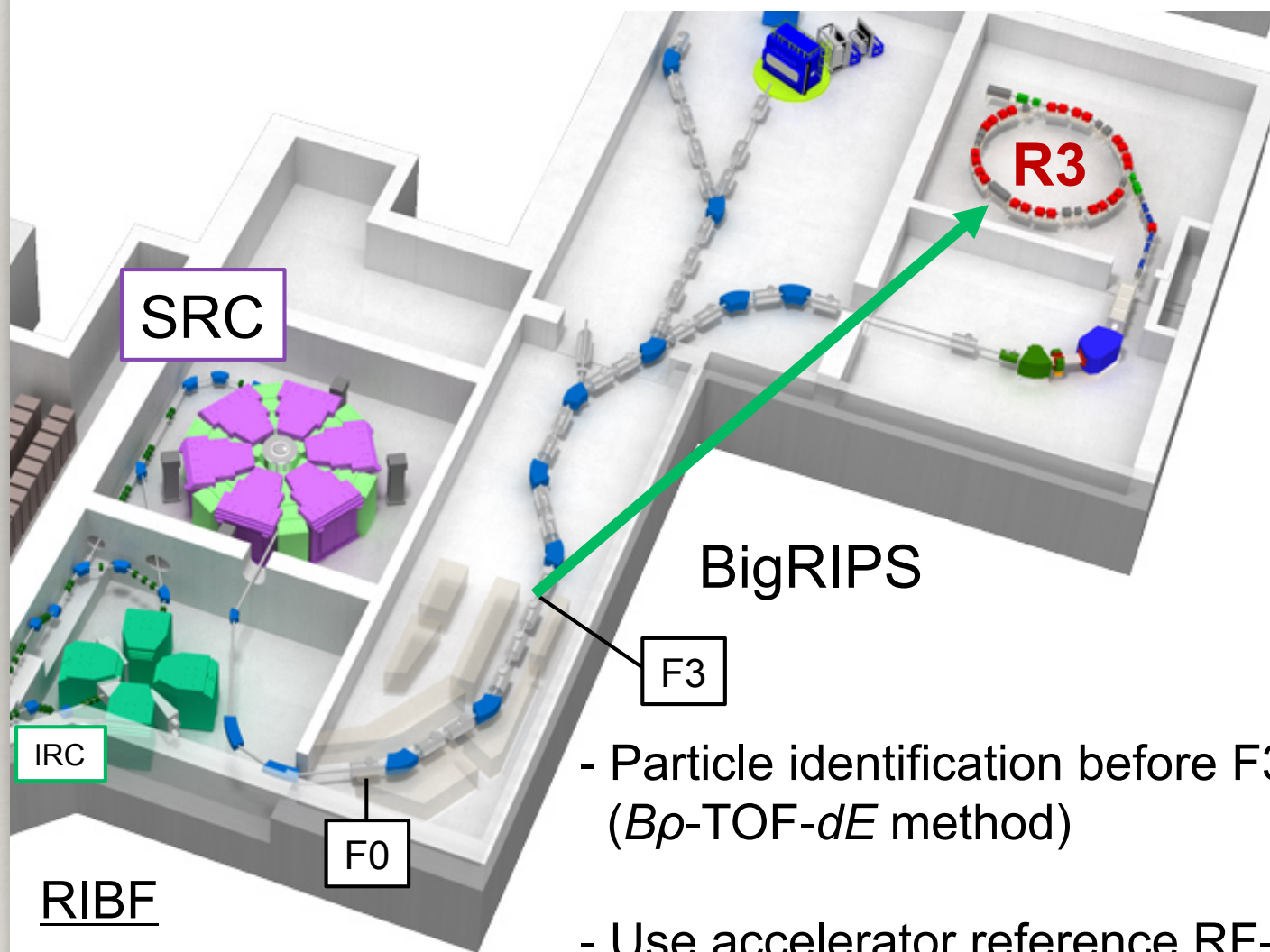
Figure 1. Schematic drawing of the beam structures of the synchrotron- and cyclotron-based storage ring.

without TOF-gate



- Select a particle of interest
- Inject it into storage ring individually

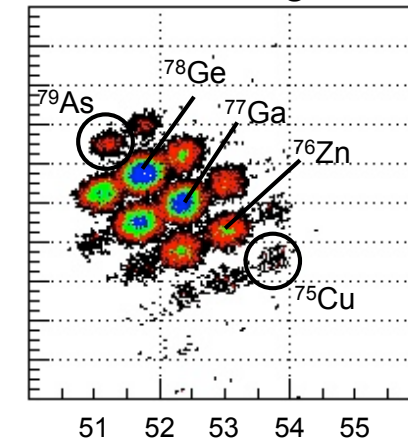
Isotope selection



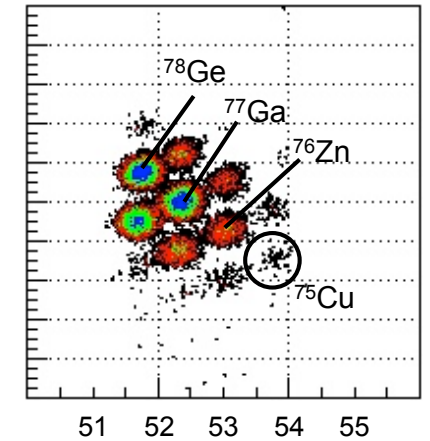
- Particle identification before F3
($B\rho$ -TOF- dE method)

- Use accelerator reference RF-signal
to make veto-signal (**TOF-gate**) for **trigger-signal** generation

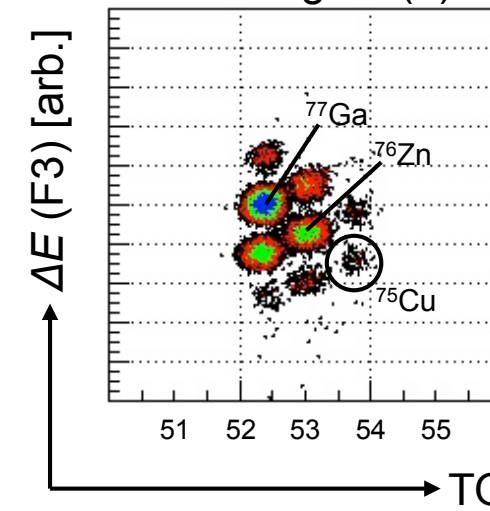
without TOF-gate



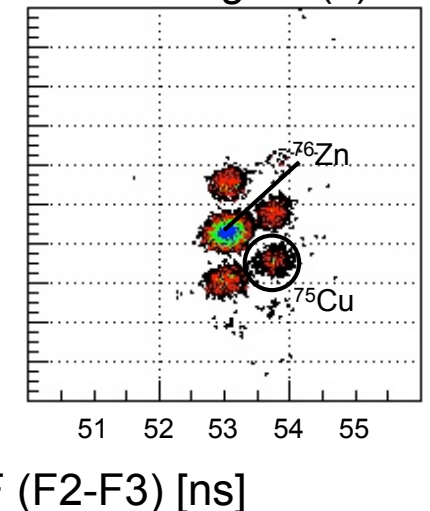
with TOF-gate (a)



with TOF-gate (b)



with TOF-gate (c)



Mass Measurement Market

Our product: Nuclear masses of rarest isotopes that could be produced

Short half-lives & low production!

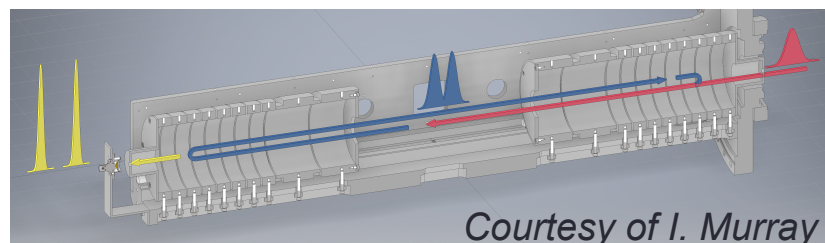
Penning, MR-TOF-MS

100ms~1s



Precision $<10^{-8}$

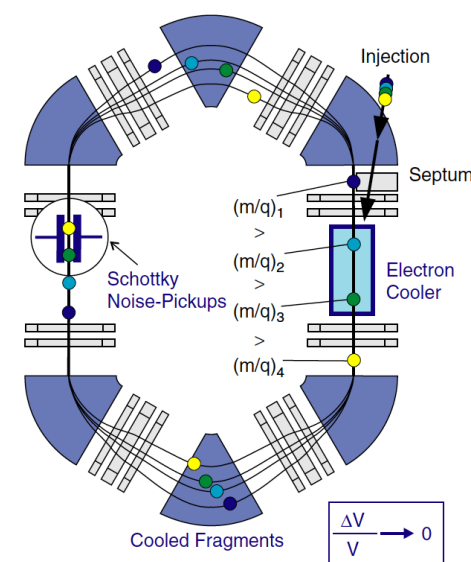
1~10 ms



Precision 10^{-7}

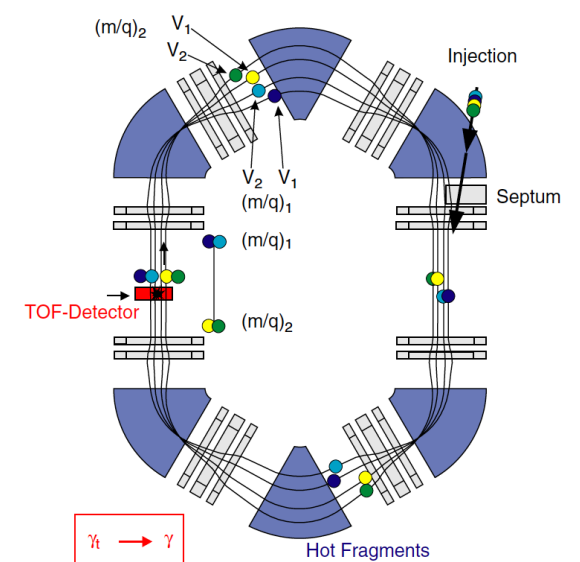
Storage Rings

1~10 s



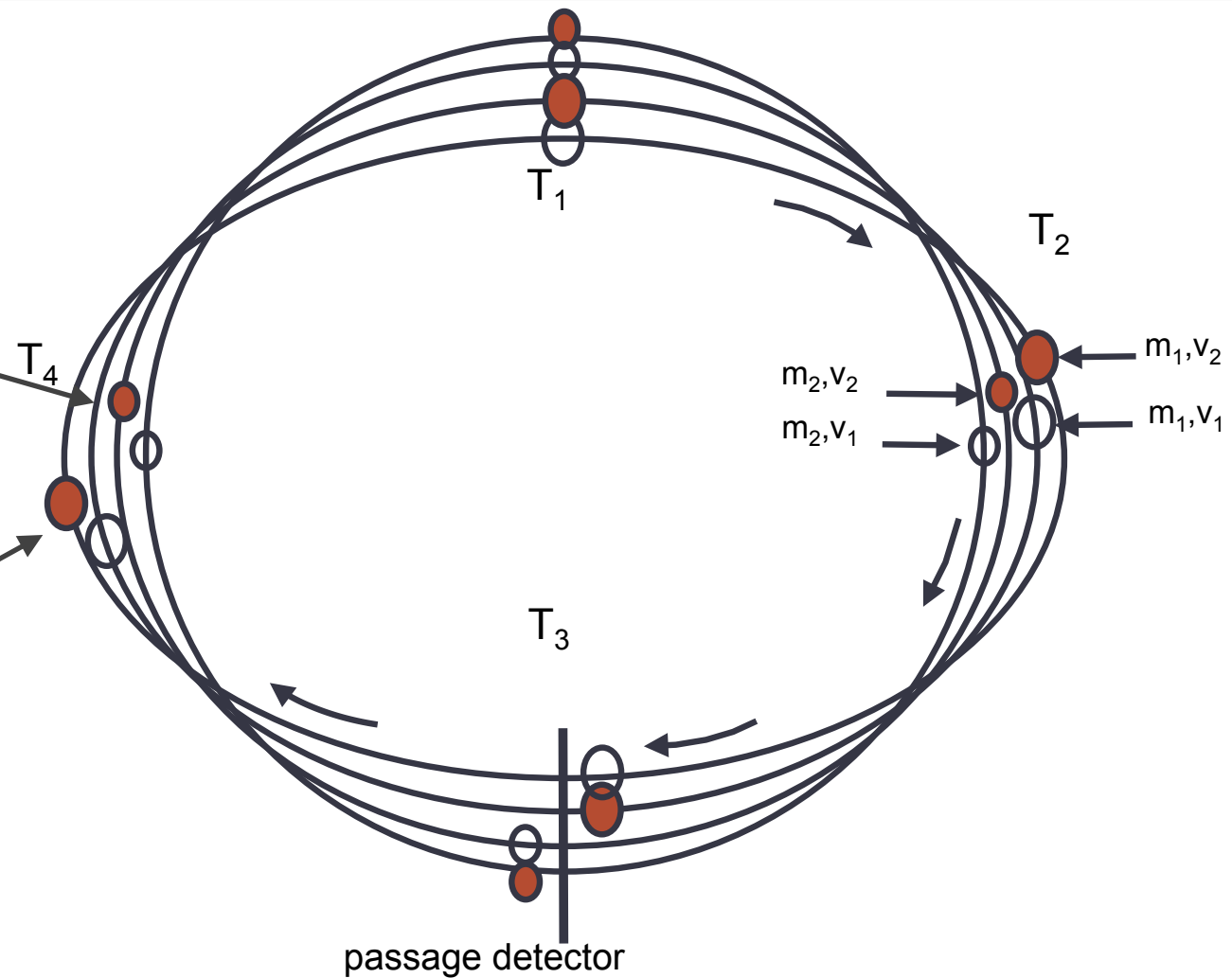
Precision 10^{-7}

$< 1\text{ms}$



Precision 10^{-6}

Isochronous Storage Ring

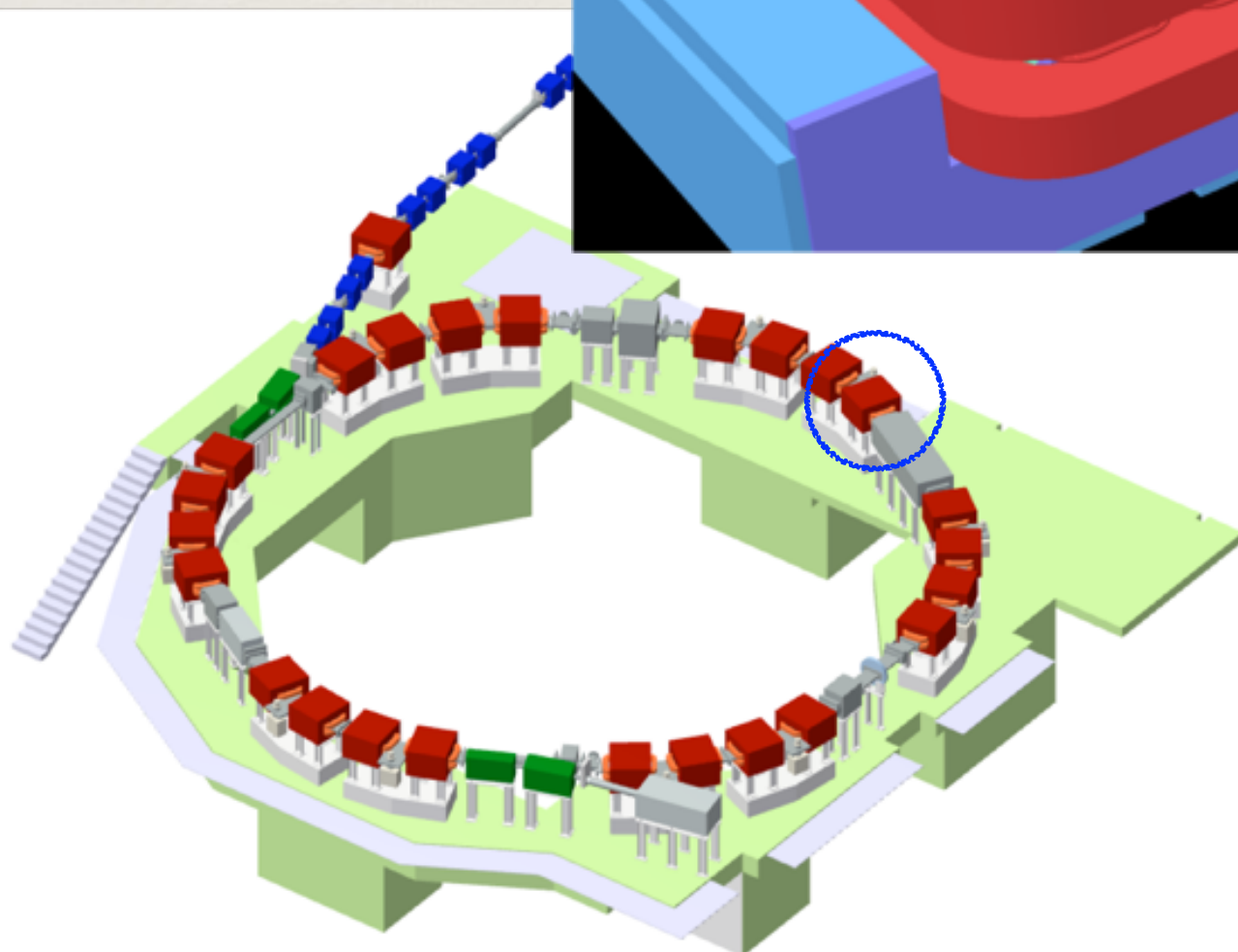
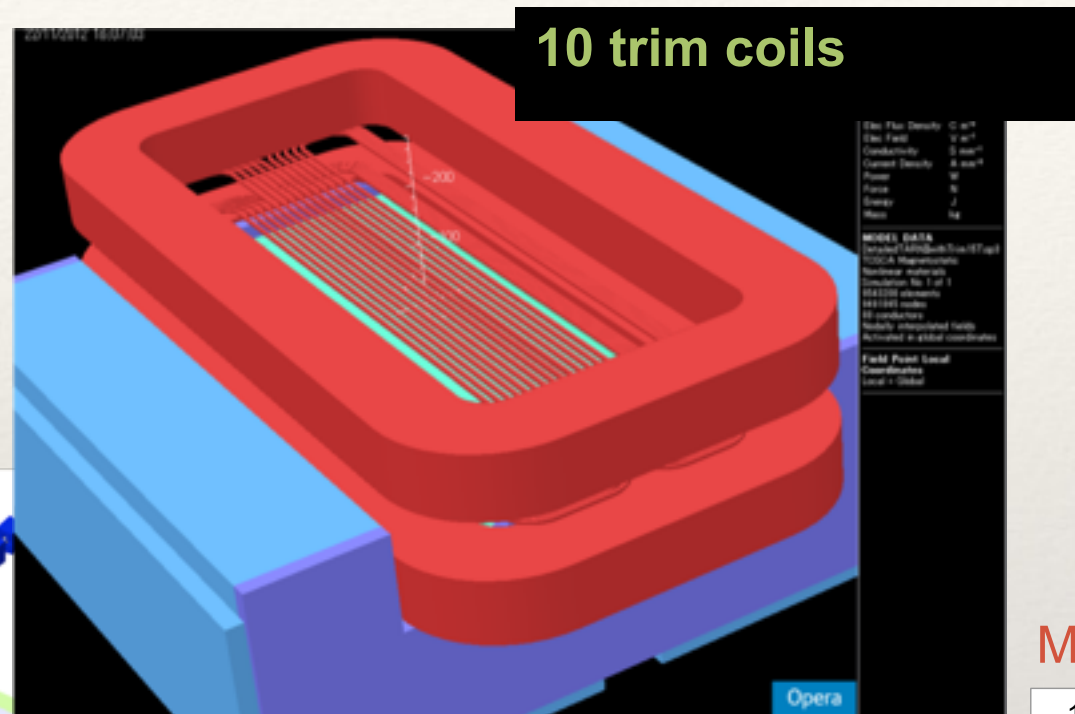


Isochronous = Time-of-flight independent of the KE

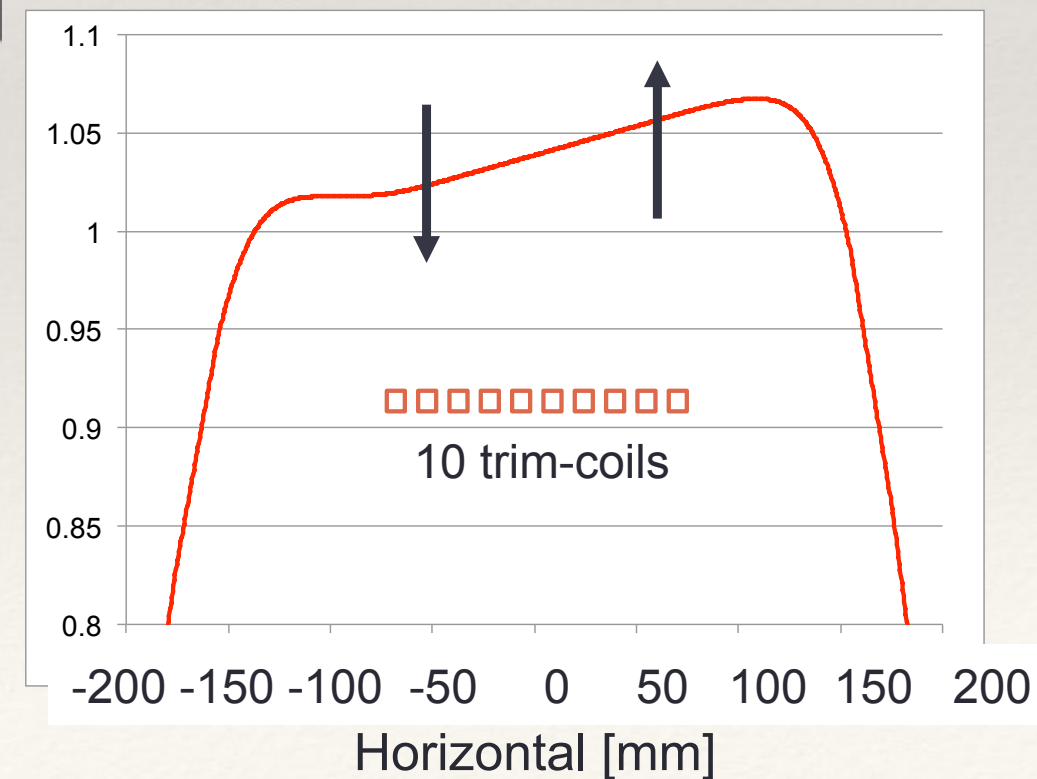
Magnetic field tuning will determine the achieved precision

Courtesy of Prof. Wollnik

Rare-RI Ring isochronicity



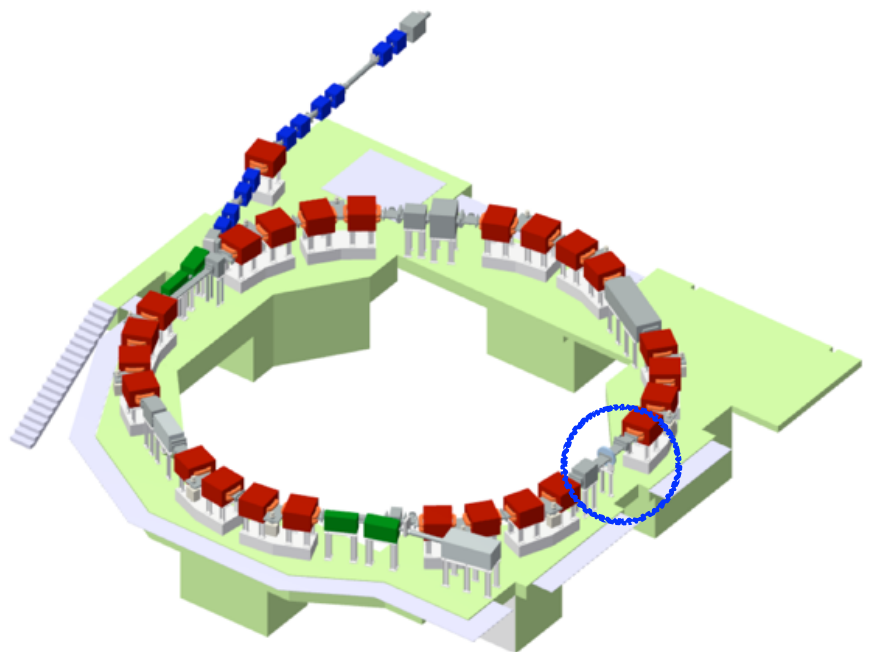
Magnetic field distribution



Resonant Schottky pickup detector

**Non-destructive detector
for revolution frequency measurement**

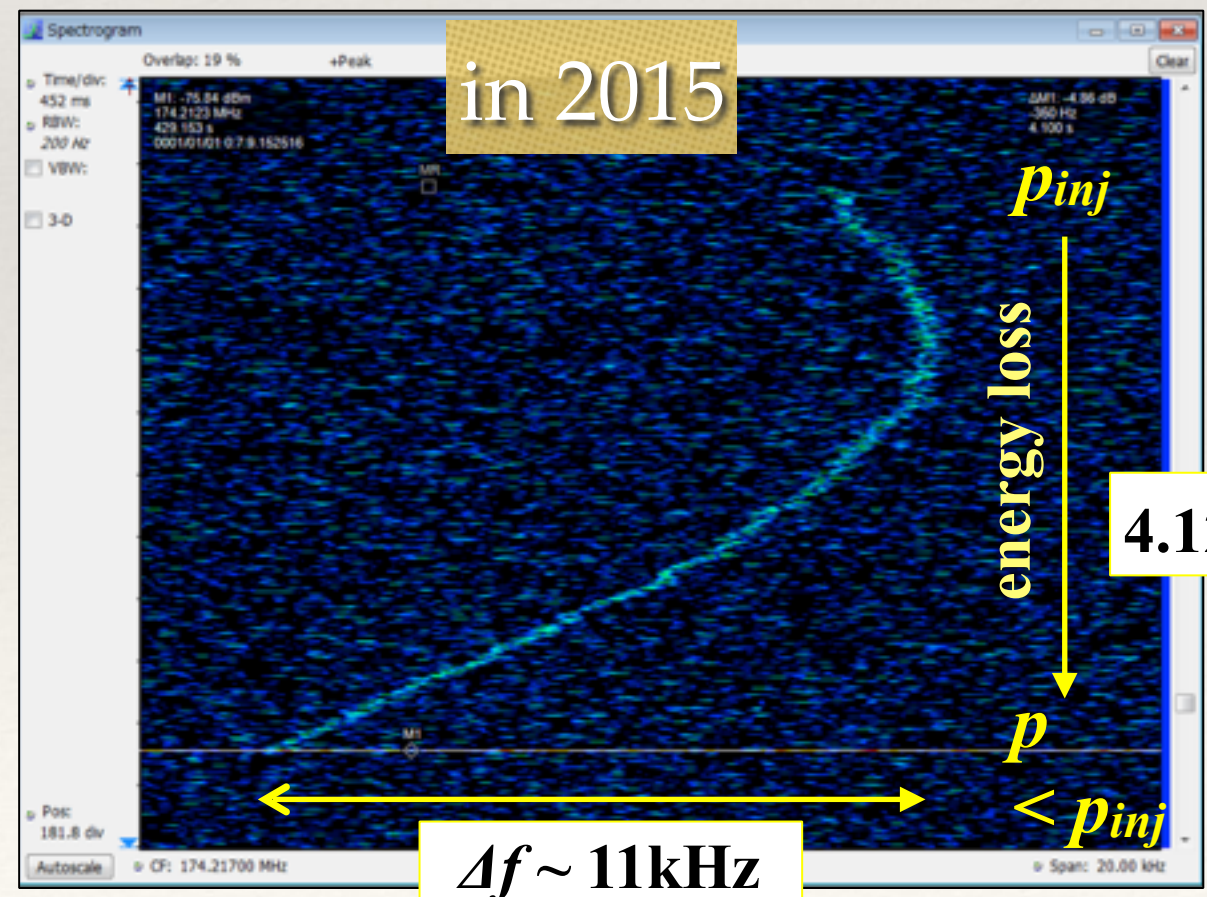
invented in GSI (F. Nolden et al., NIMA 659 (2011) 69)



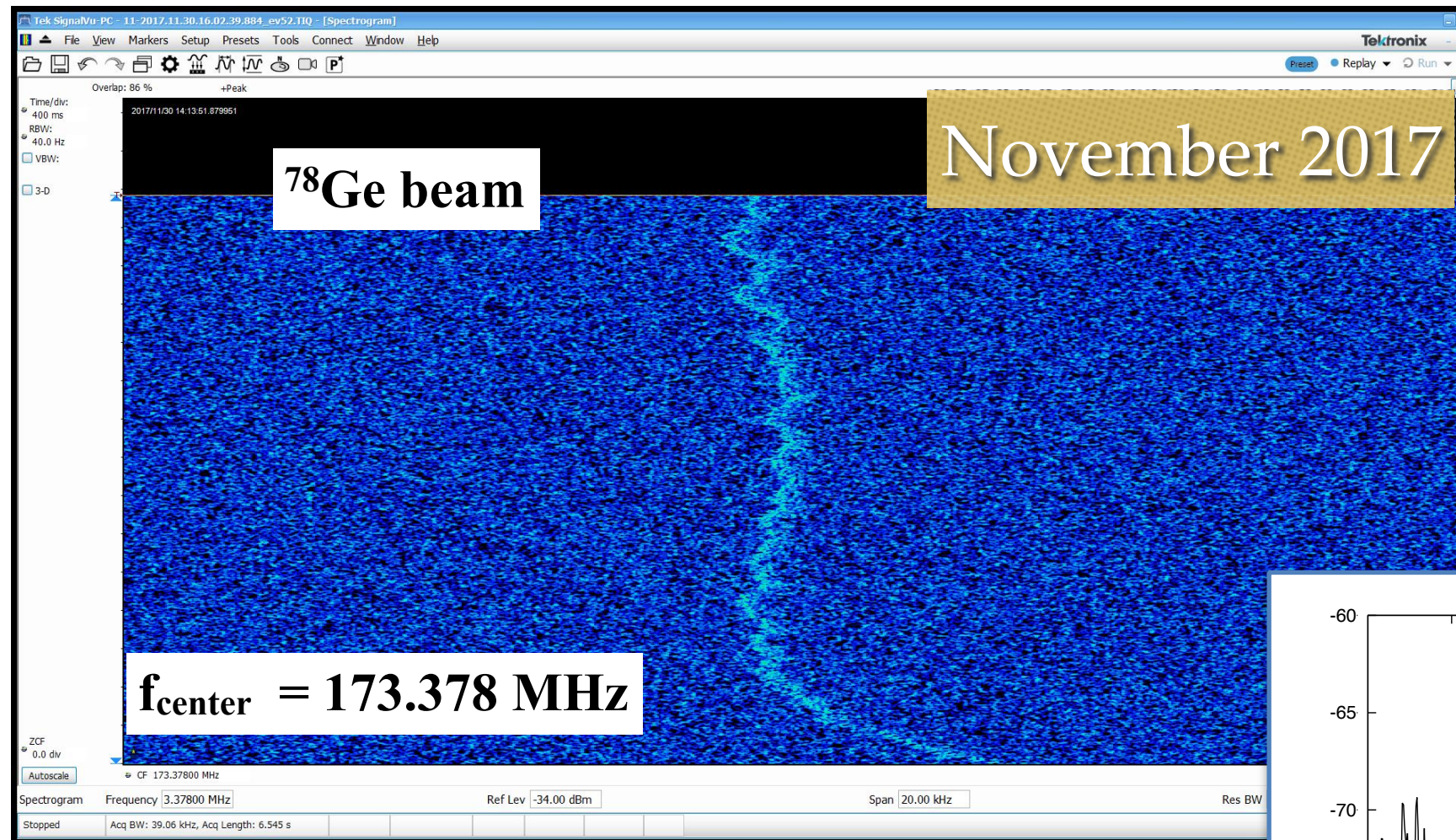
Pillbox-type cavity	
Resonant frequency	171 MHz
Shunt impedance ($\Leftrightarrow$ sensitivity)	163 kΩ
Q-value	1880



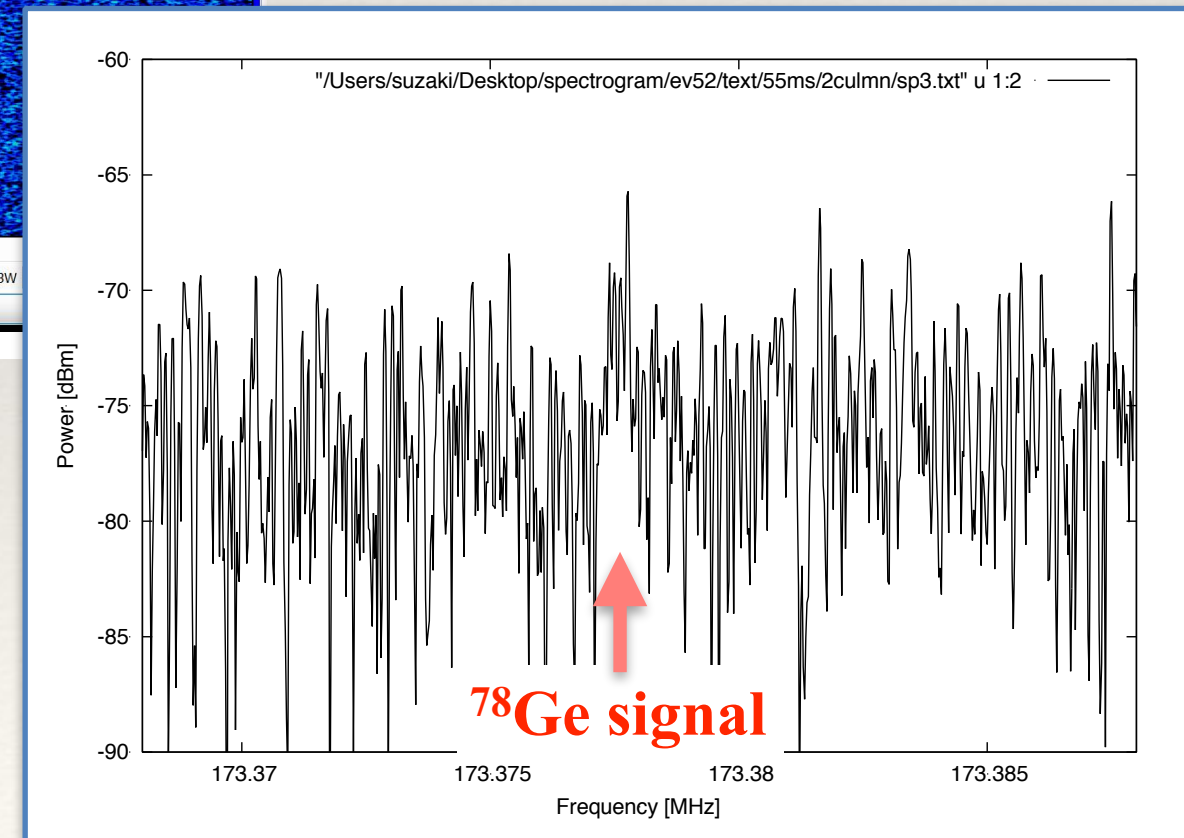
Fumi Suzaki
Ph.D with
this work
SPDR
(FY2018~)



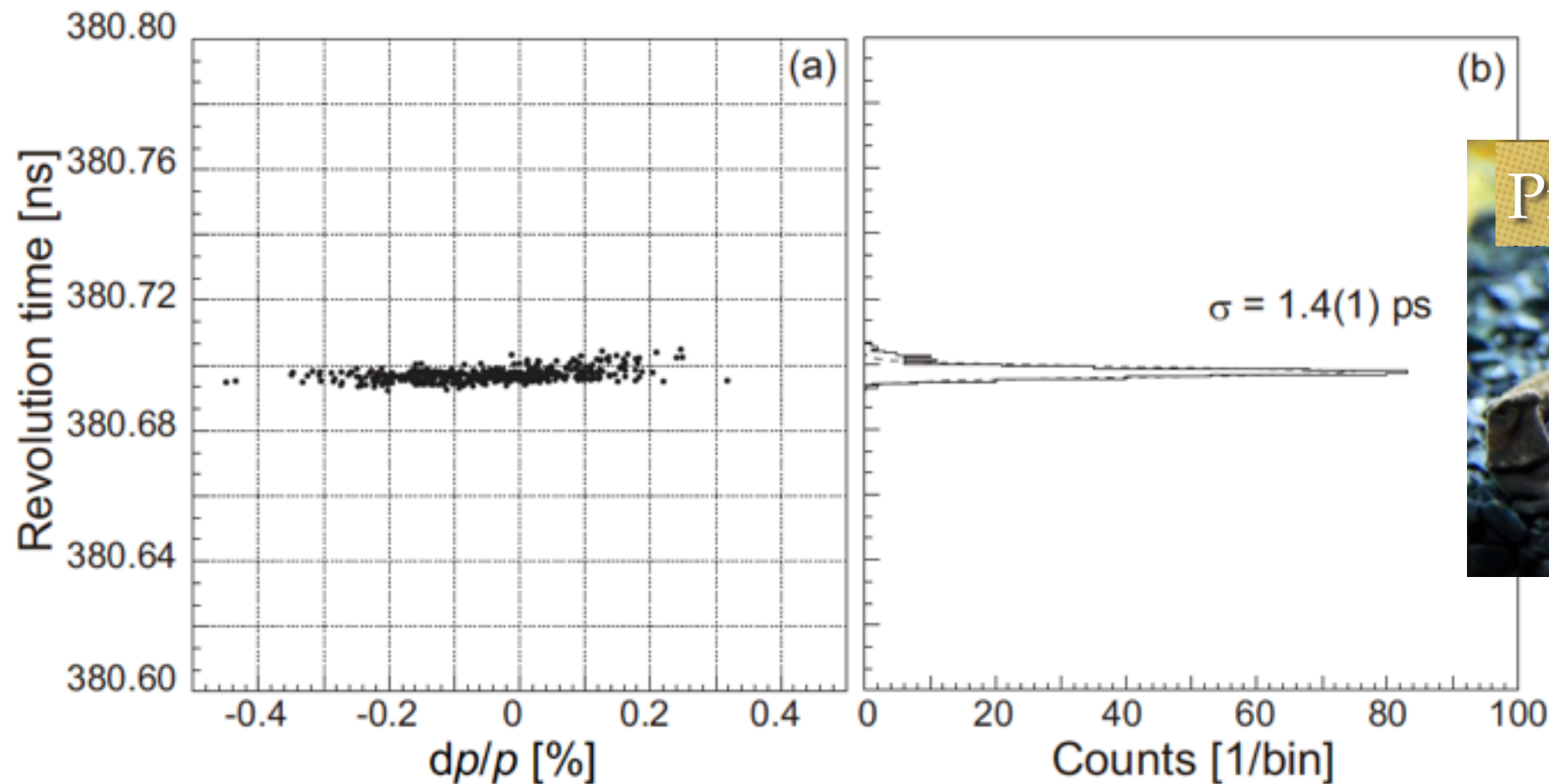
(almost) Perfect Isochronicity!



Highest sensitivity Schottky pickup detector
→ detection of Z=32 (lightest isotope ever)



(almost) Perfect Isochronicity!



Pipa pipa toad



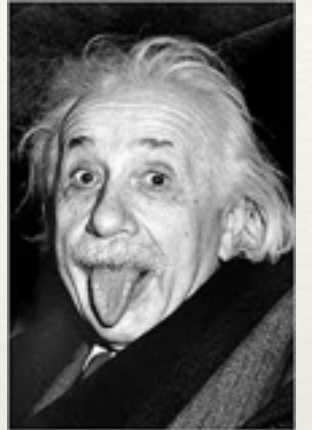
Yasushi Abe
Ph.D with this work
SPDR(FY2015—17)

$$\frac{\Delta T}{T} = \frac{1.4 \text{ ps}}{380 \text{ ns}} = 3.6 \times 10^{-6}$$

Mass determination

Relativity modifies the relation

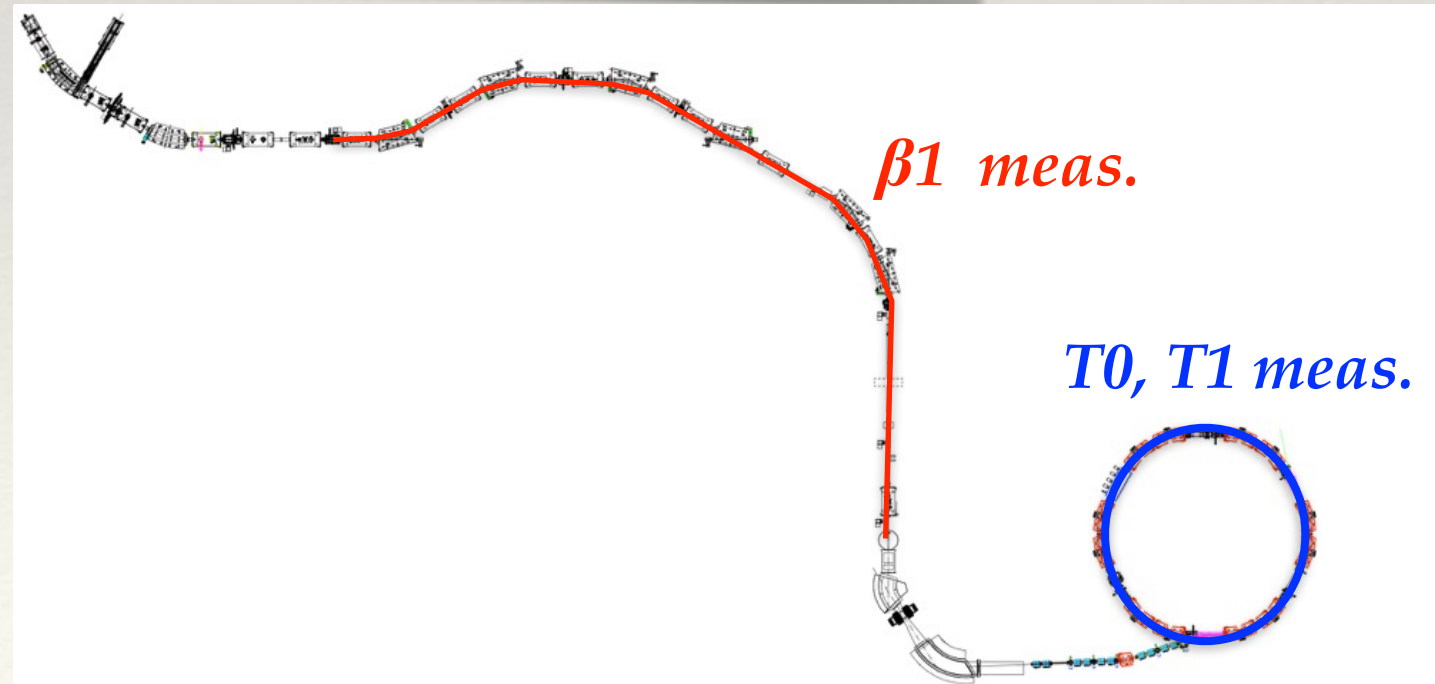
$$\frac{T}{2\pi} = \frac{m/q}{B} \quad \longrightarrow \quad \frac{T}{2\pi} = \frac{m\gamma/q}{B}$$



$$\frac{m_1}{q_1} = \left(\frac{m_0}{q_0} \right) \frac{1}{T_0} T_1 \sqrt{\frac{1 - \beta_1^2}{1 - \{(T_1/T_0)\beta_1\}^2}} = \left(\frac{m_0}{q_0} \right) \frac{T_{1corr}}{T_0}$$

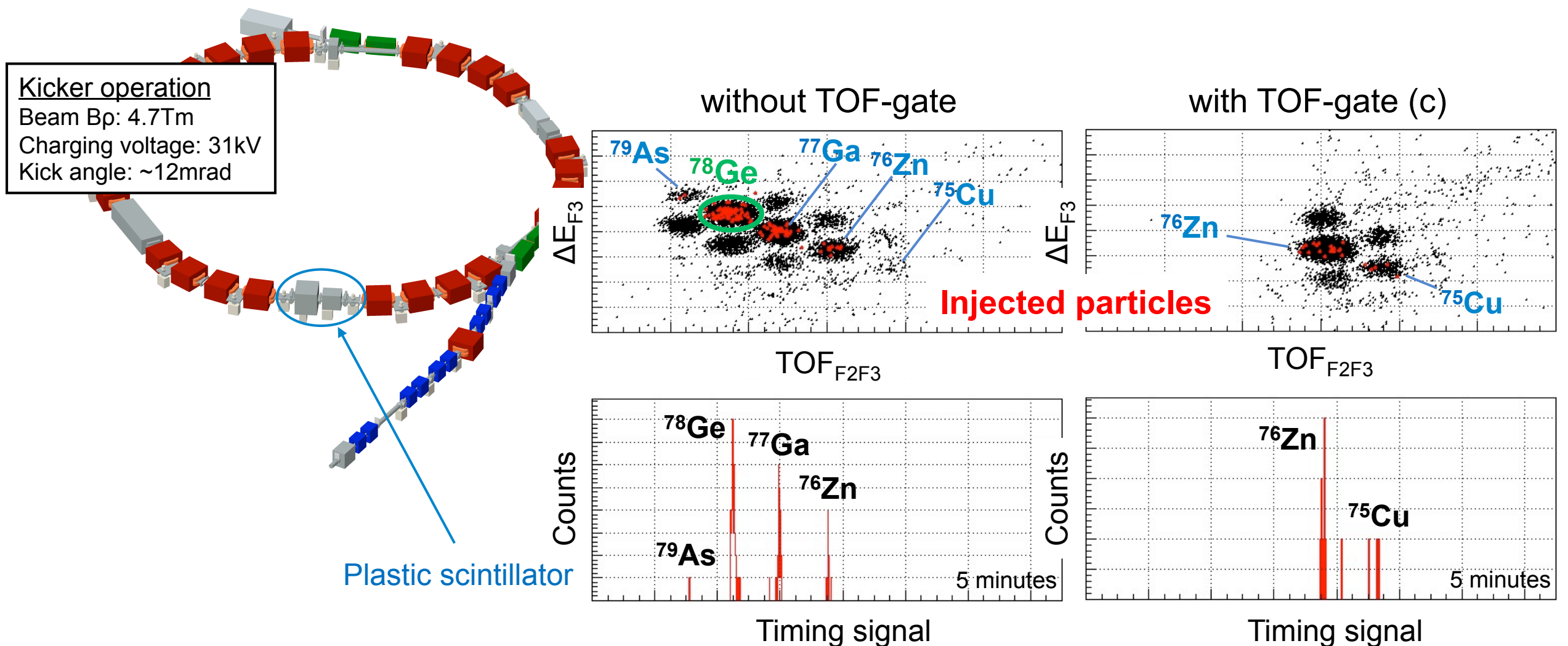
Unknown mass

known mass



Commissioning experiment

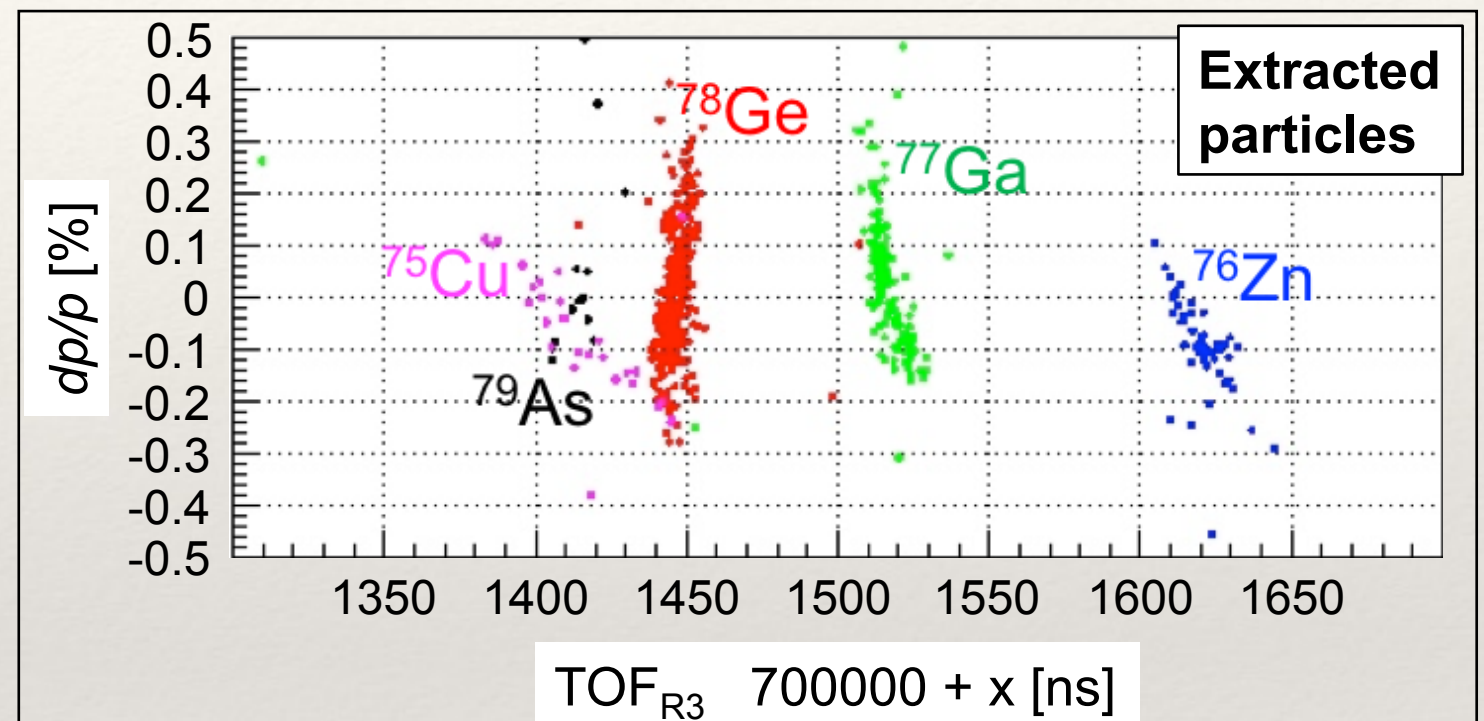
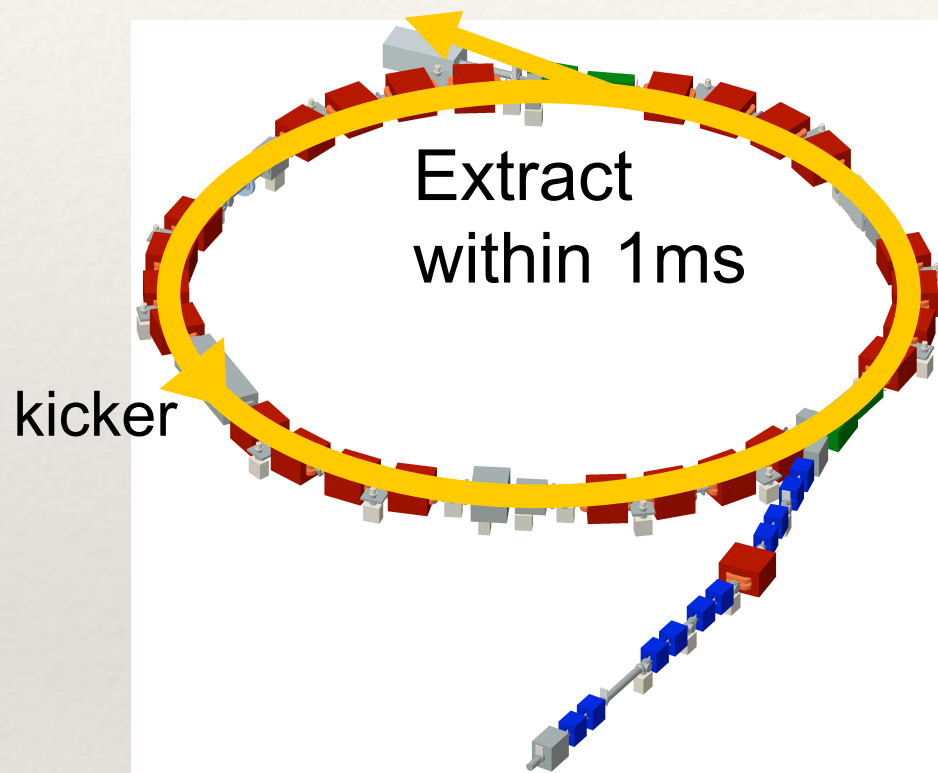
First neutron-rich isotopes injected in Rare-RI Ring, Z=46 isotones @168MeV/u



Isotope selection + self-triggered injection !

Commissioning experiment

TOF_{R3} measurement

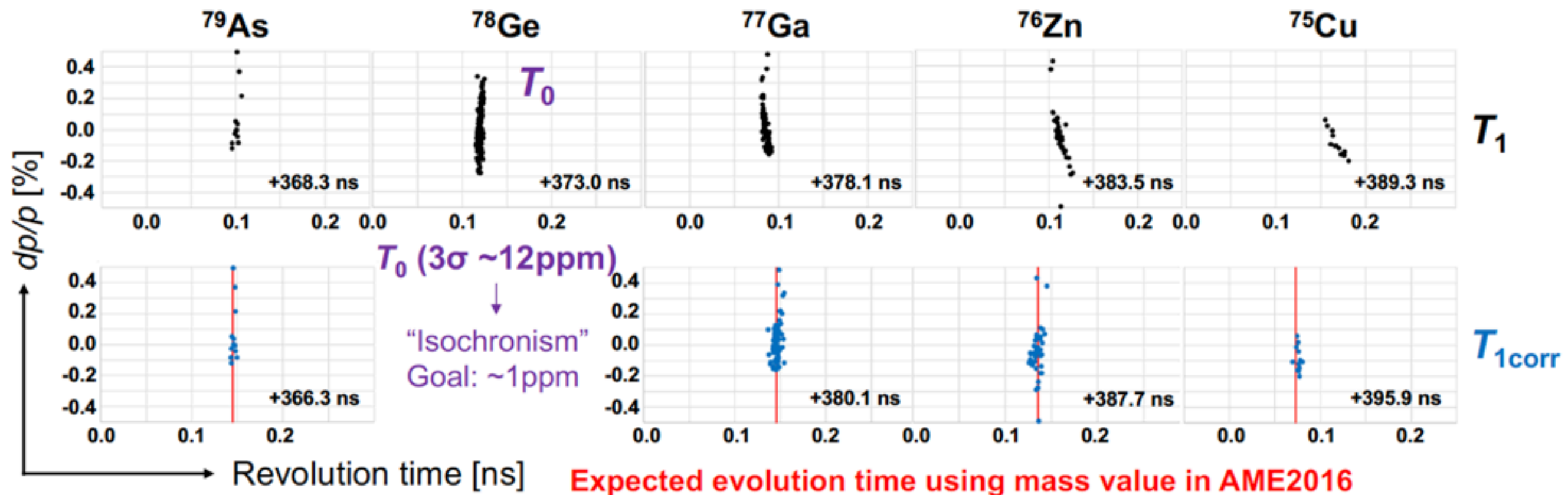


$$\frac{m_1}{q_1} = \left(\frac{m_0}{q_0} \right) \frac{1}{T_0} T_1 \sqrt{\frac{1 - \beta_1^2}{1 - \{(T_1/T_0)\beta_1\}^2}} = \left(\frac{m_0}{q_0} \right) \frac{T_{1corr}}{T_0}$$

Commissioning experiment

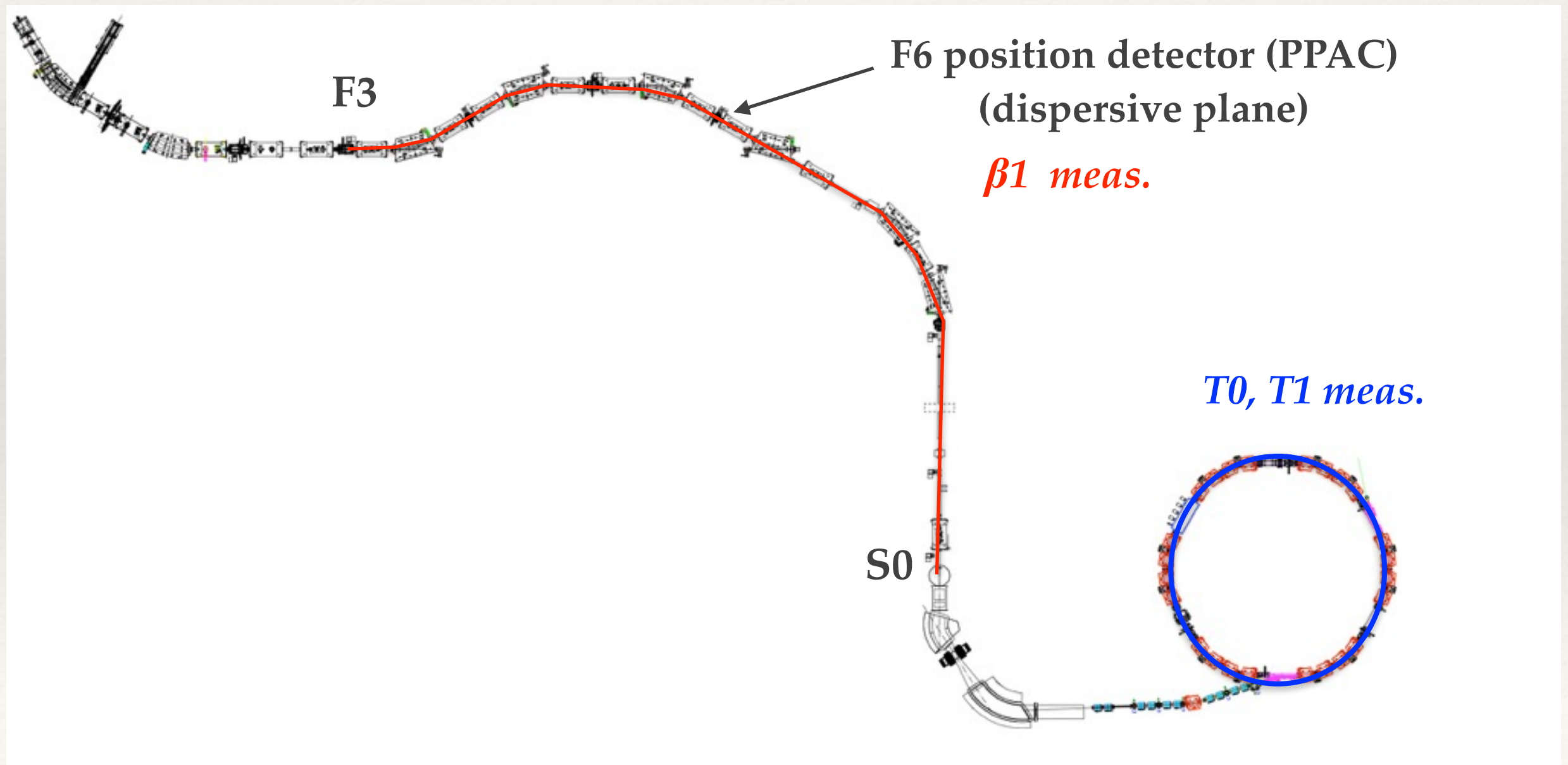
New capability of Isotope-Selectable Self-Injection method!

=> Event-by-event determination of γ via Bp measurement

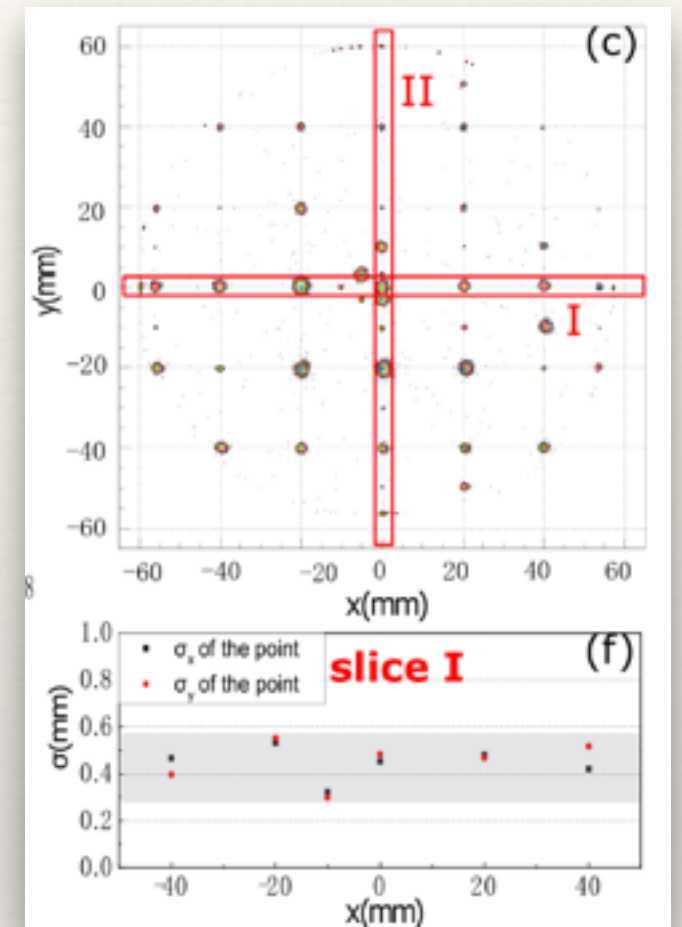
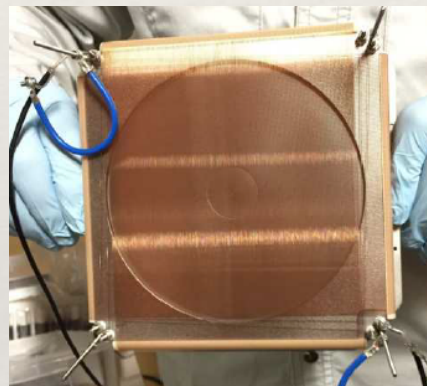
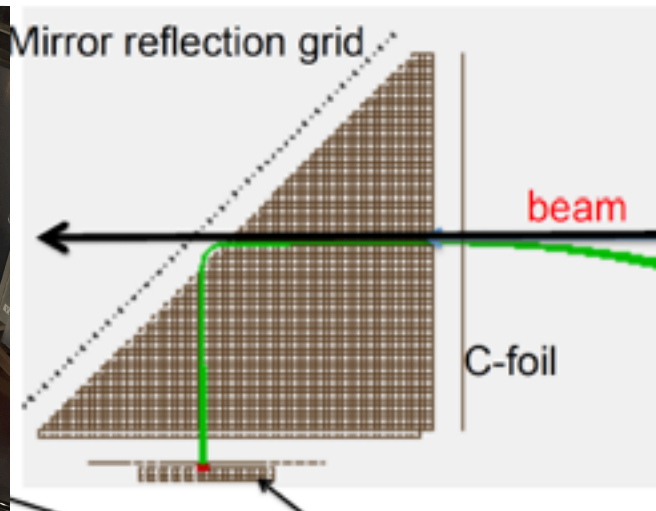
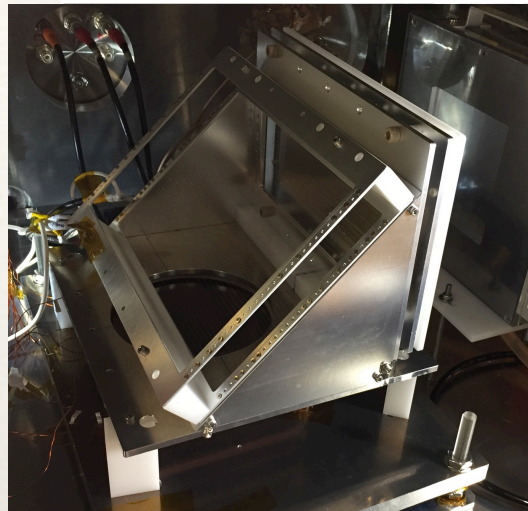


Accuracy of beta measurement

Position detector is too thick, energy loss introduces uncertainty in beta measurement!

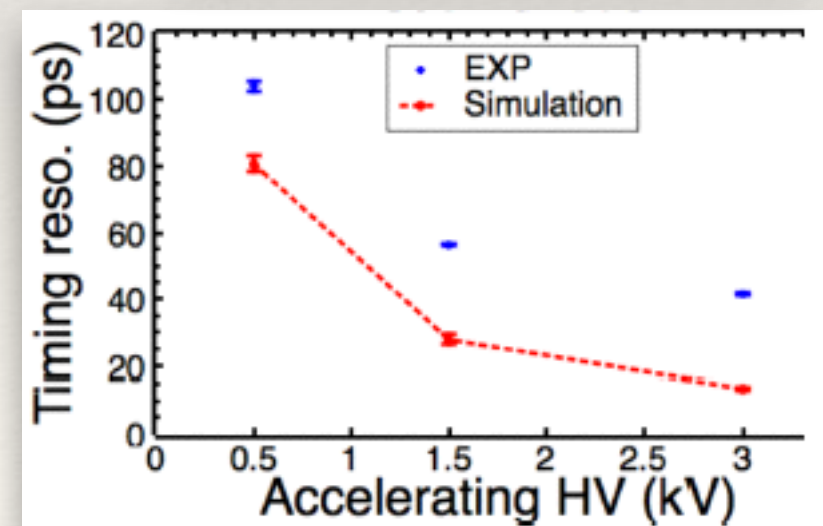
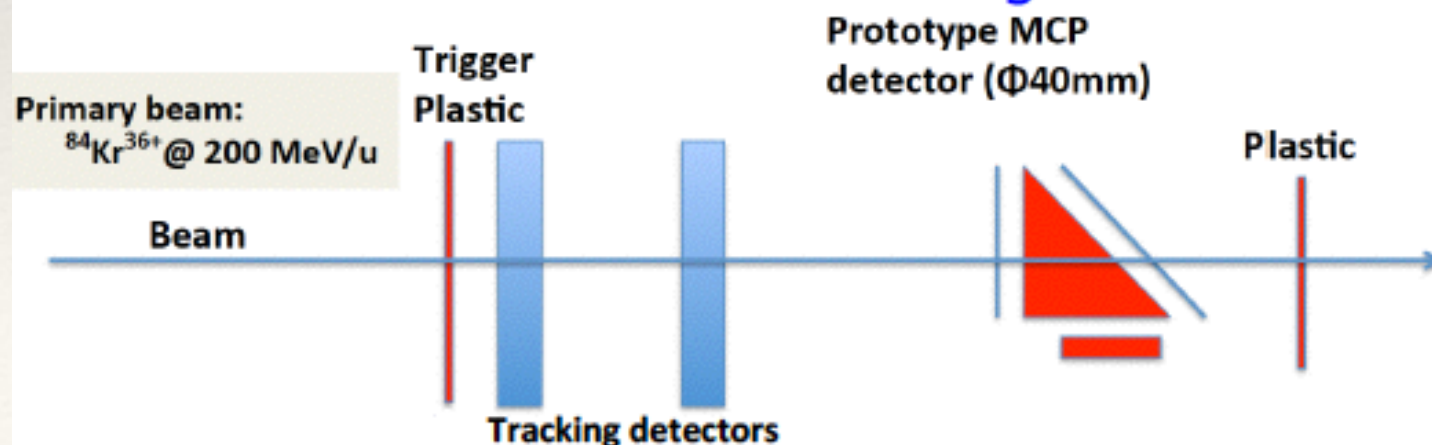


Improving mass accuracy

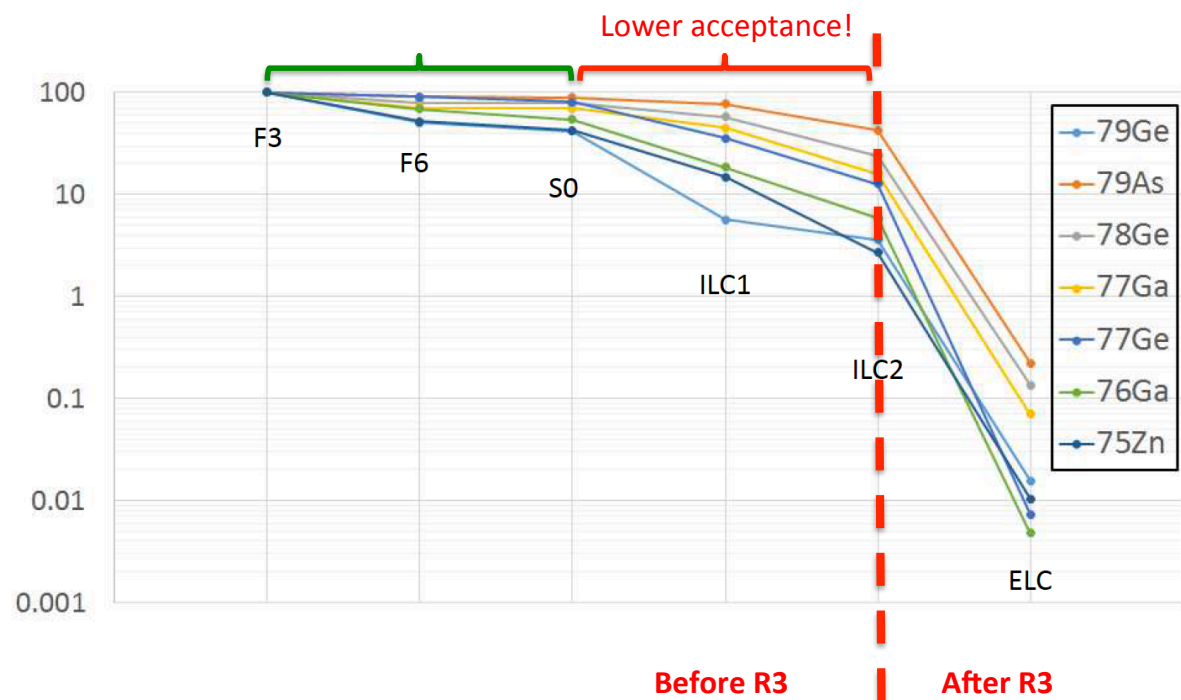


Zhuang Ge
Saitama university & IMP Lanzhou

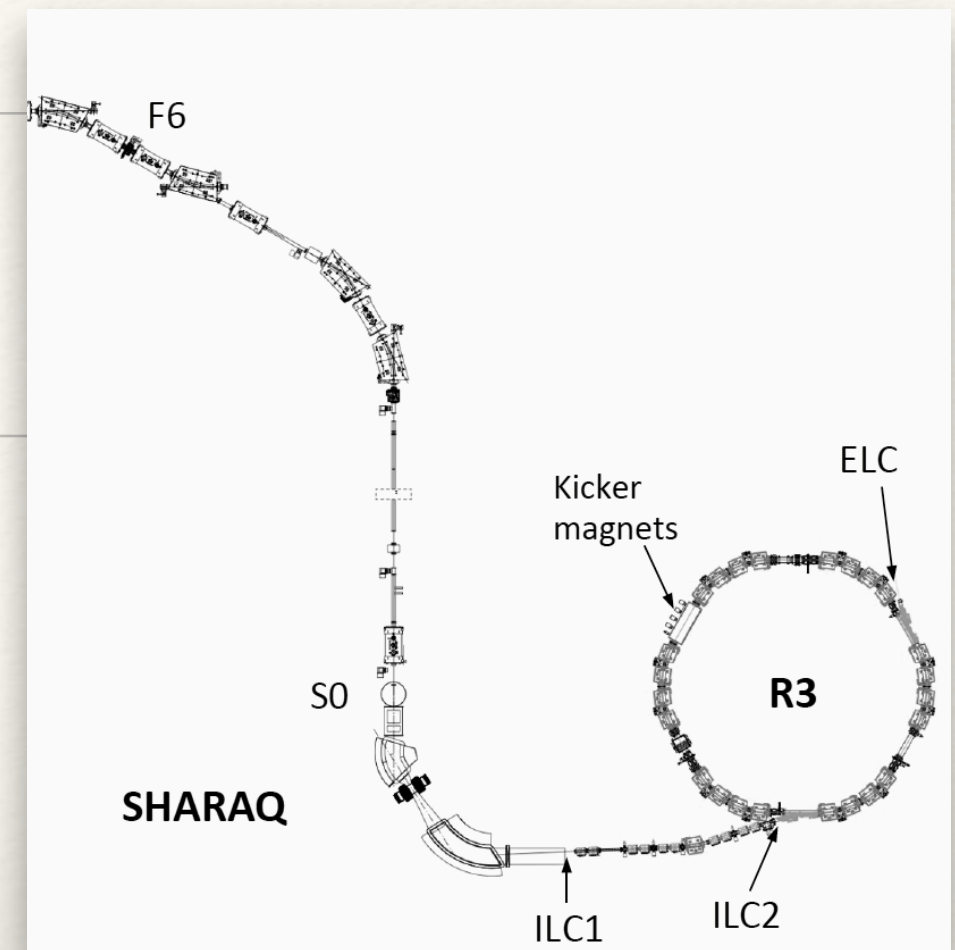
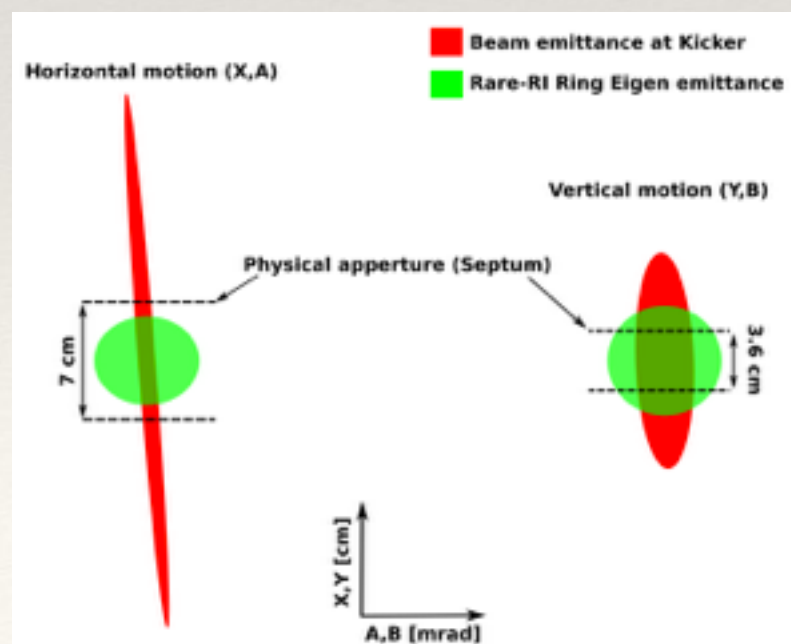
HIMAC online test of Timing resolution



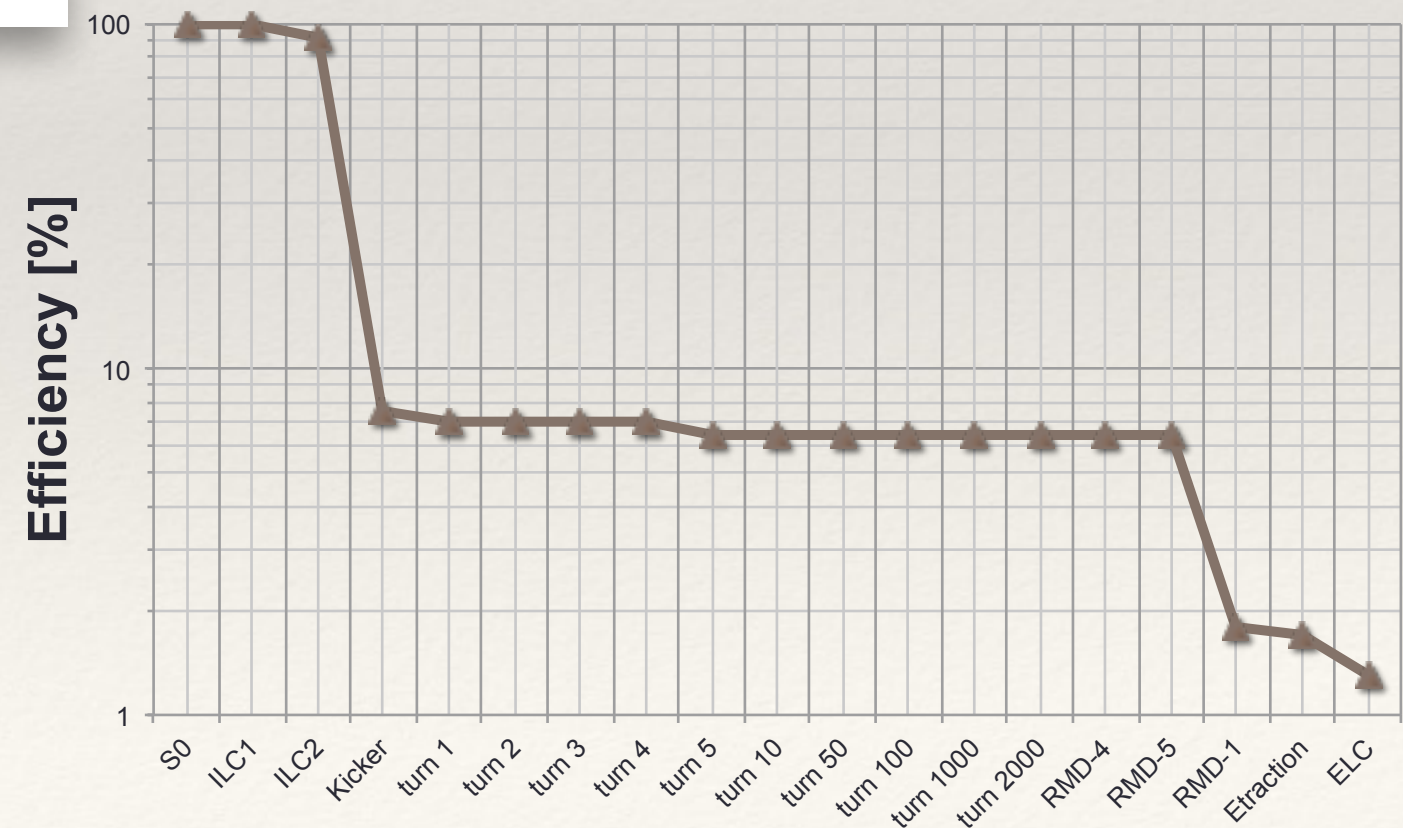
Efficiency Issue!



Experiment

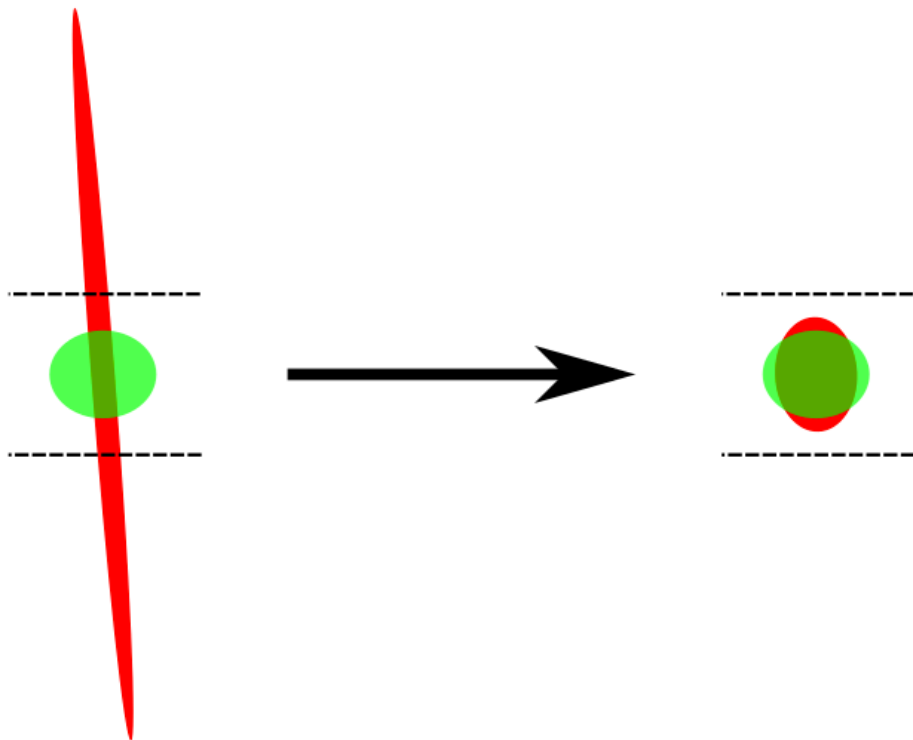


Simulation

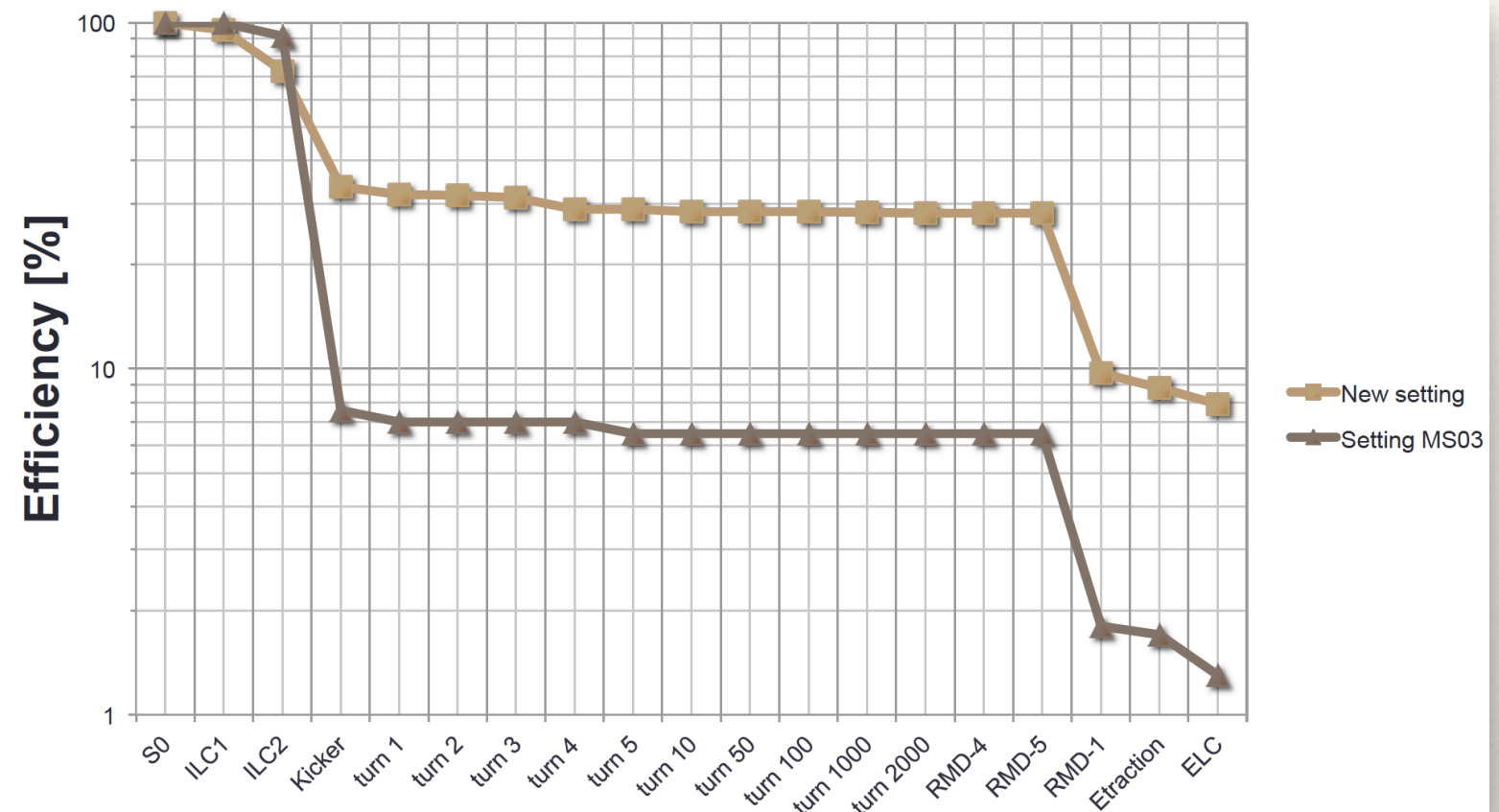
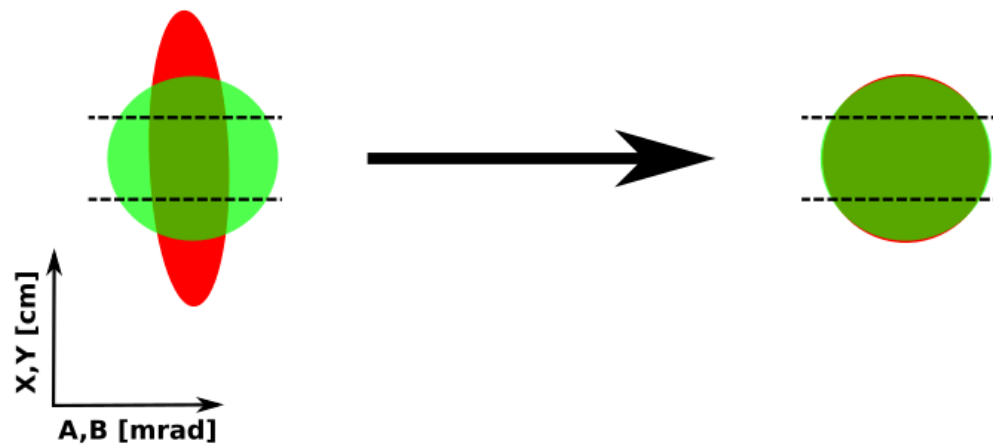


Solving the efficiency issue

Horizontal motion (X,A)

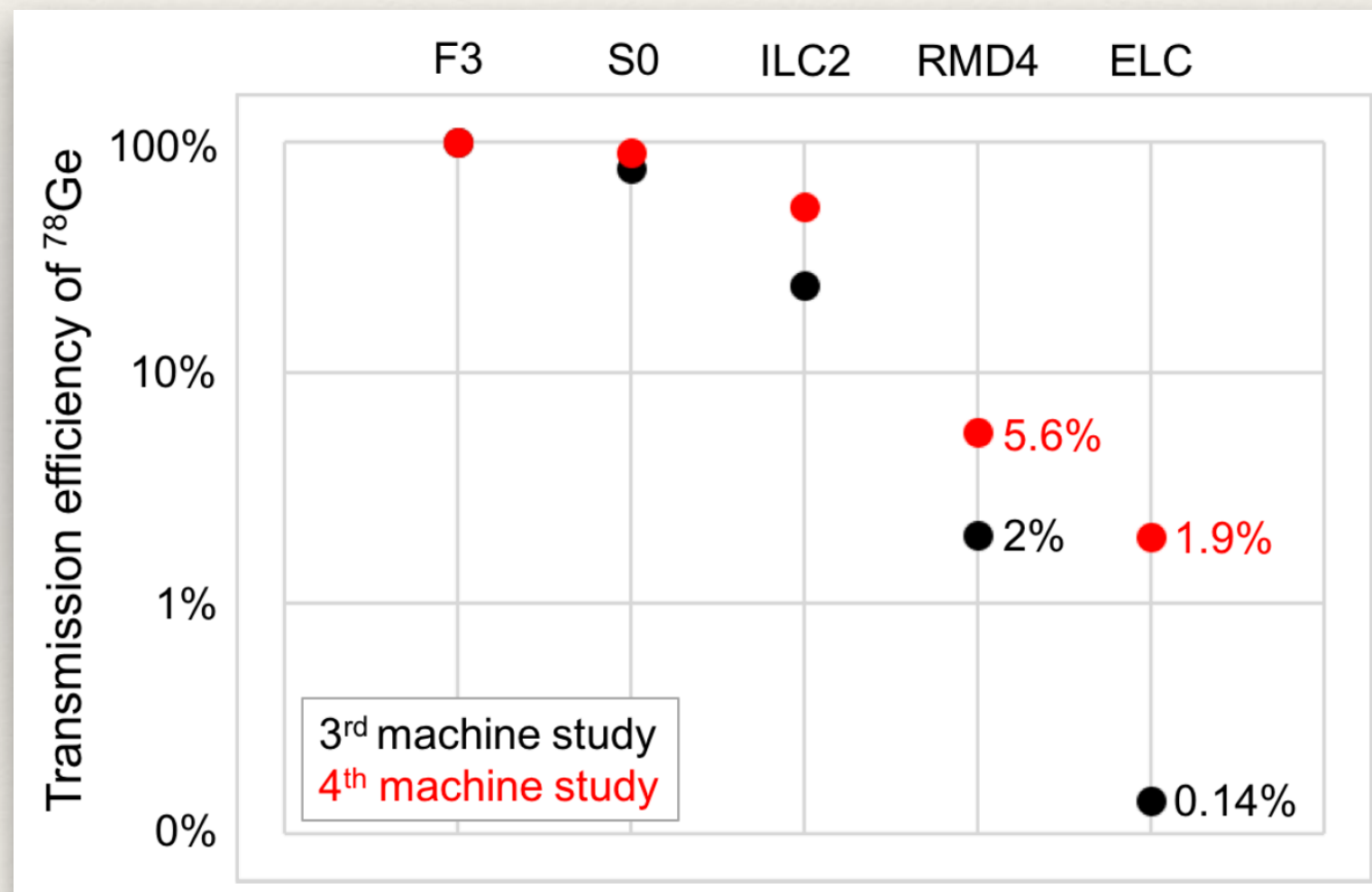


Vertical motion (Y,B)



Matched emittance: Online result

Efficiency: x14 times
Total R3 eff. 2%



Technical Hurdles cleared!



Isotope-Selectable Self Injection

→ **Open the use of storage rings at cyclotron facilities**

Single particle detection with Schottky pickup detector

→ **Detection of $Z=32$ isotope (smallest Z ever)**

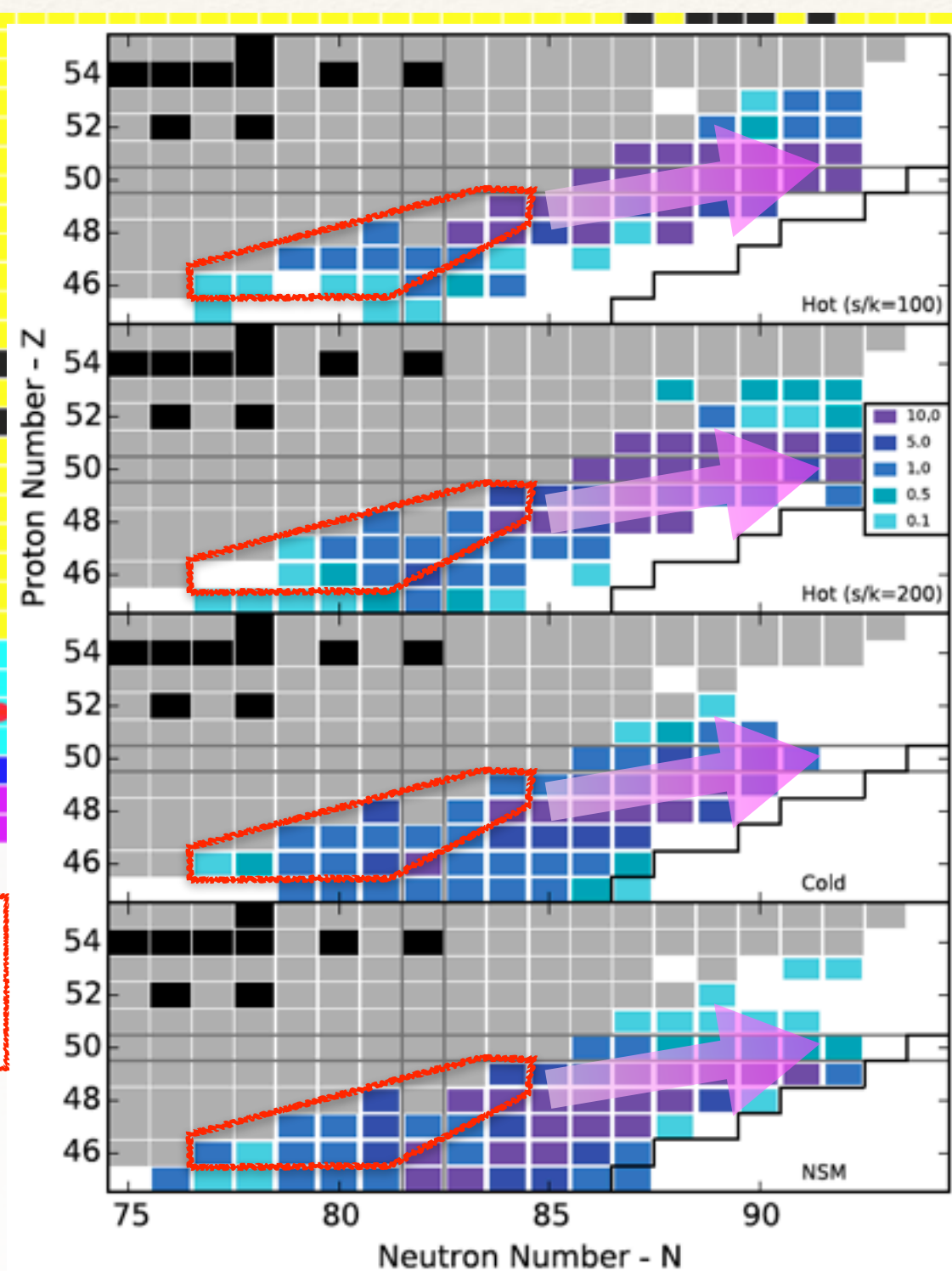
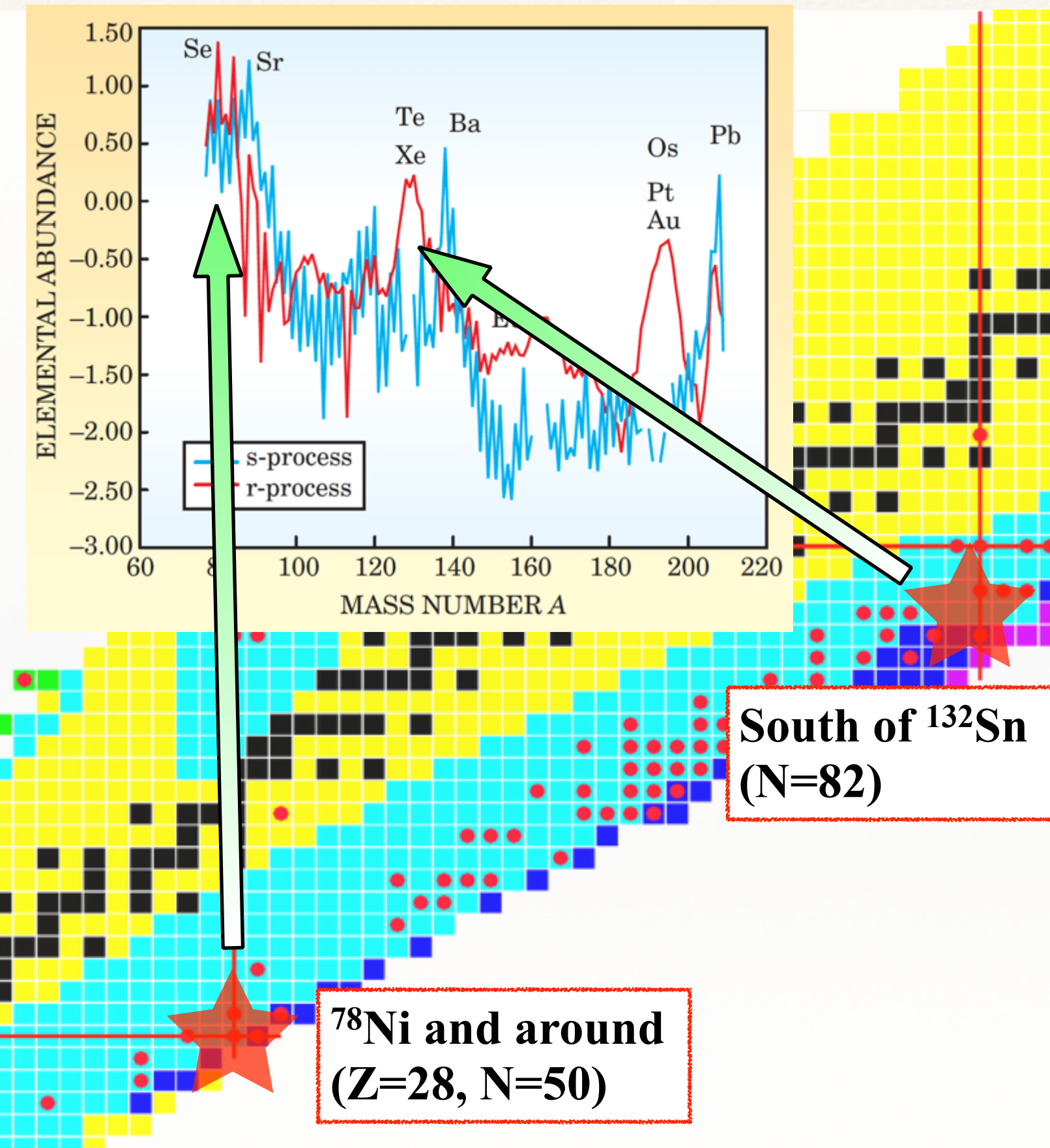
**Achievement of Isochronous field ($\sim 10^{-6}$)
in a wide momentum range ($\Delta p \sim 0.6\%$)**

Event-by-event correction of particle $B\rho$

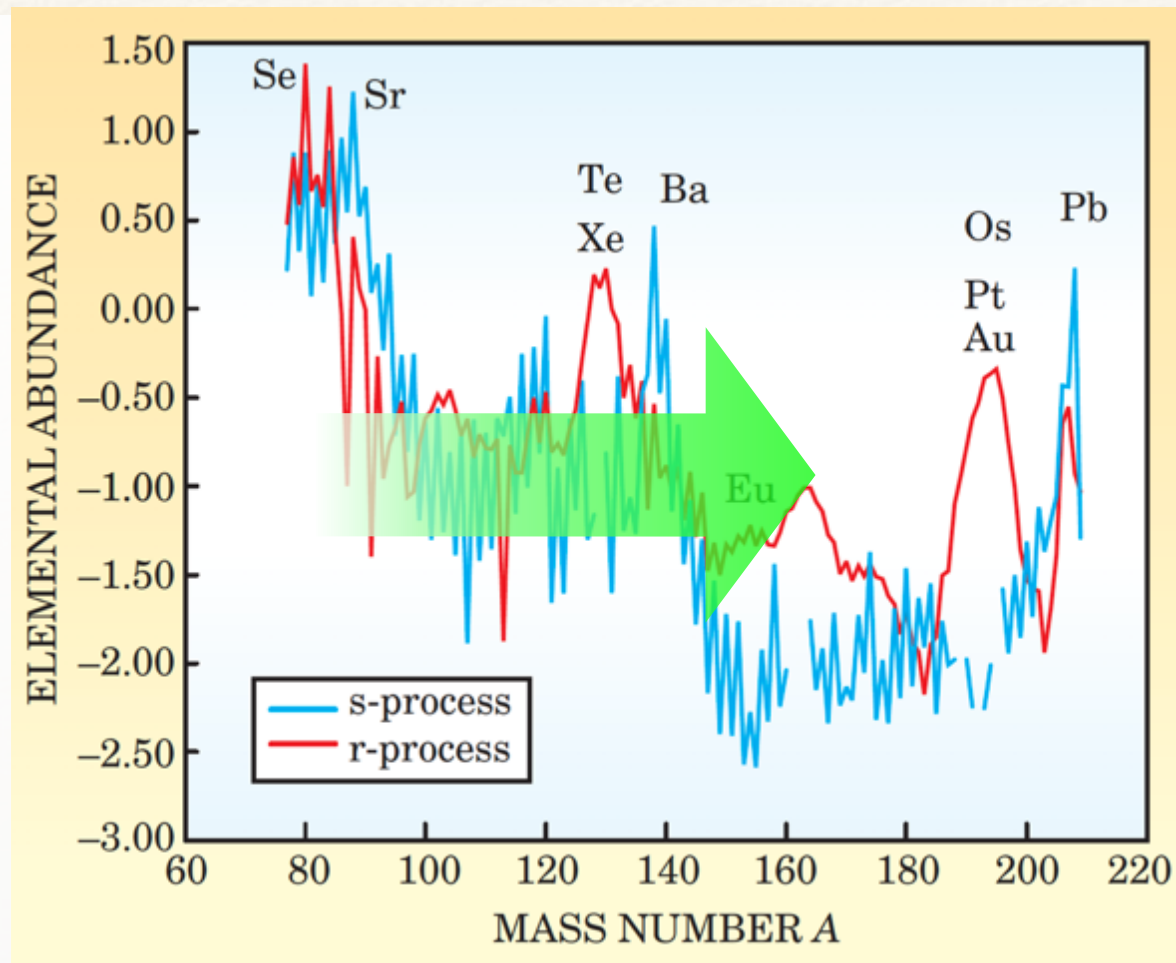
Improvement of injection efficiency

Mass Measurement

Mass measurements planned in FY2018



Future mass measurements



FY2018 ^{78}Ni , south of ^{132}Sn
FY2019– Along the r-process path
 up to rare isotope peak ($A \sim 160$)
 + N=Z region (collab. with Lanzhou)
 + Halo nuclei (^{22}C , ^{31}Ne , ^{37}Mg . . .)



Who wants to win Wasabi KitKat?

- ❖ How many amphibians I showed?
- ❖ How about reptiles?

