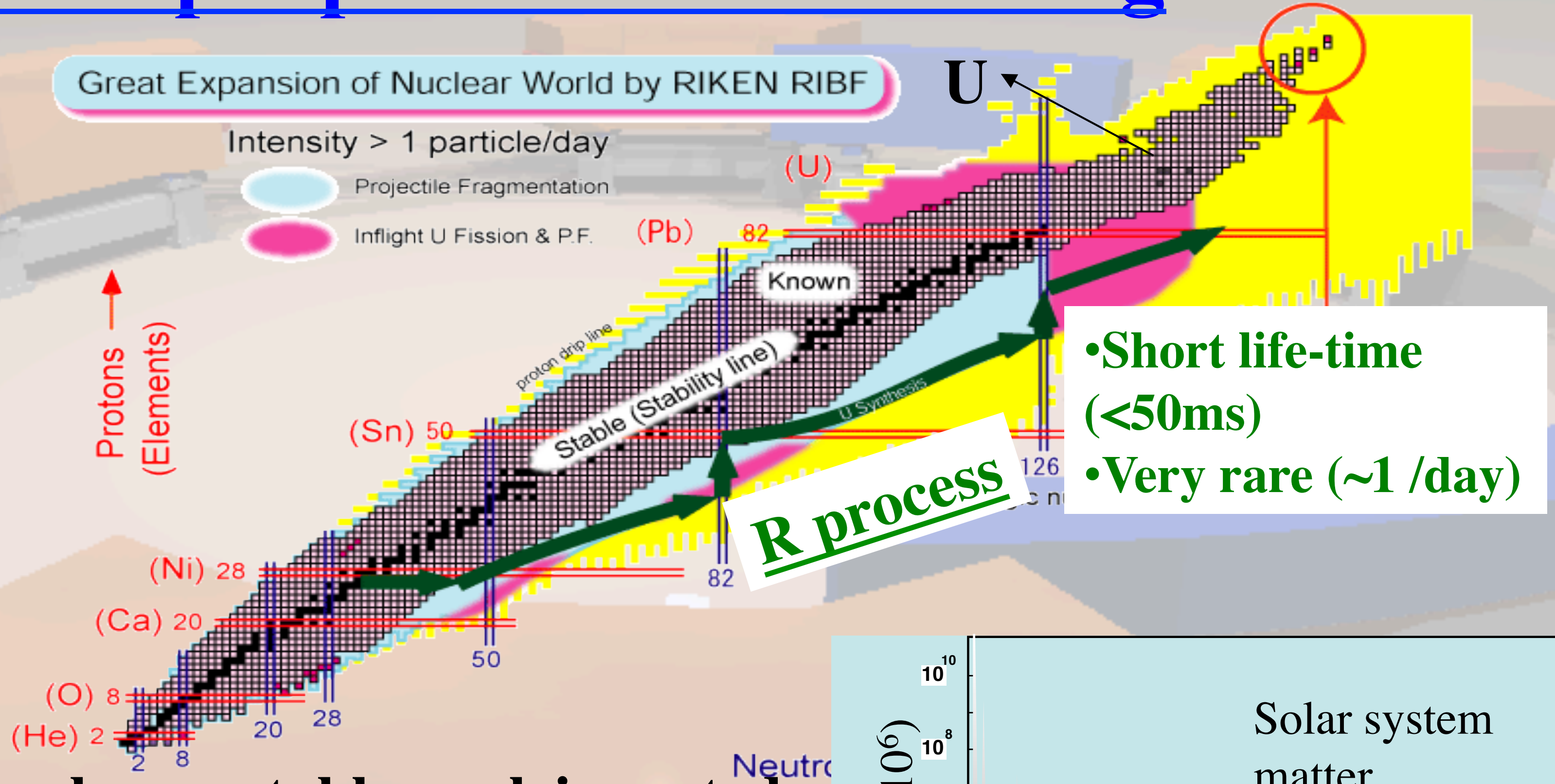
Overview of Rare-RI Ring and Mass measurements

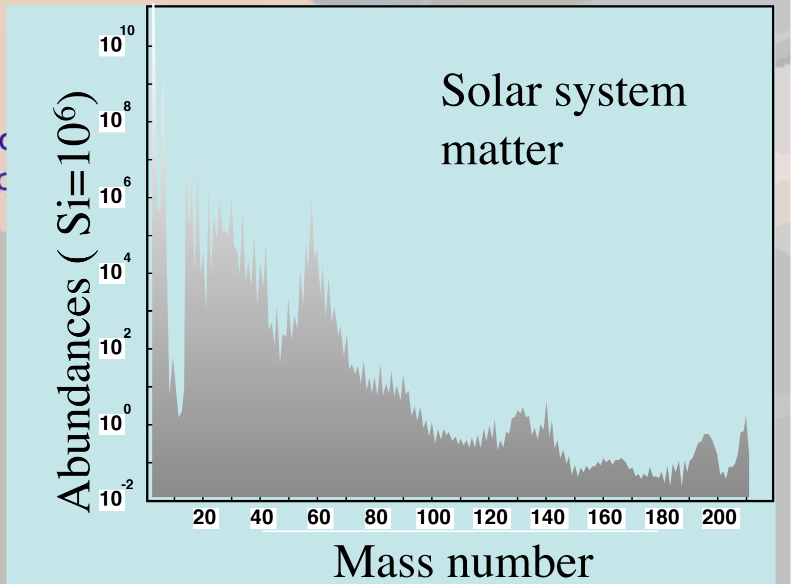
A. Ozawa (University of Tsukuba)

Contents

Main purpose of Rare-RI Ring



- How are heavy stable nuclei created in universe ?
- Can we reproduce observed abundances ?

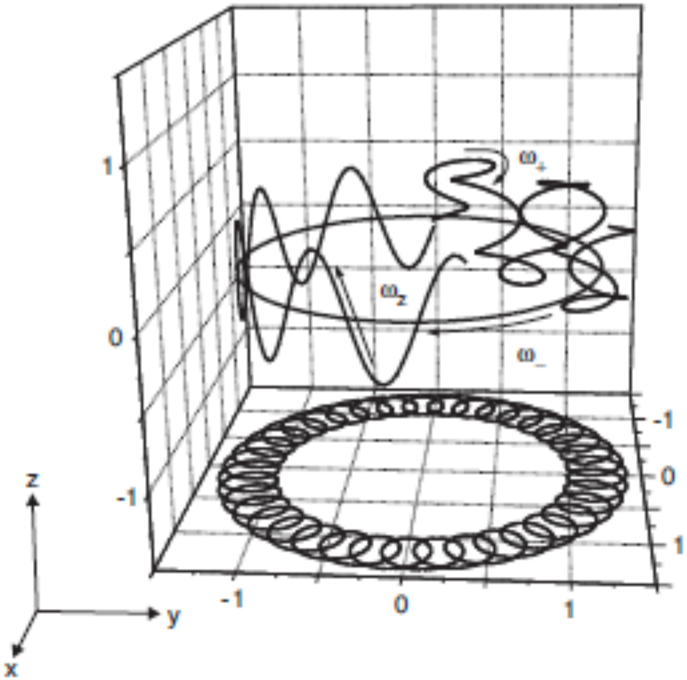


Mass measurements are indispensable.

Mass measurements in Penning Trap

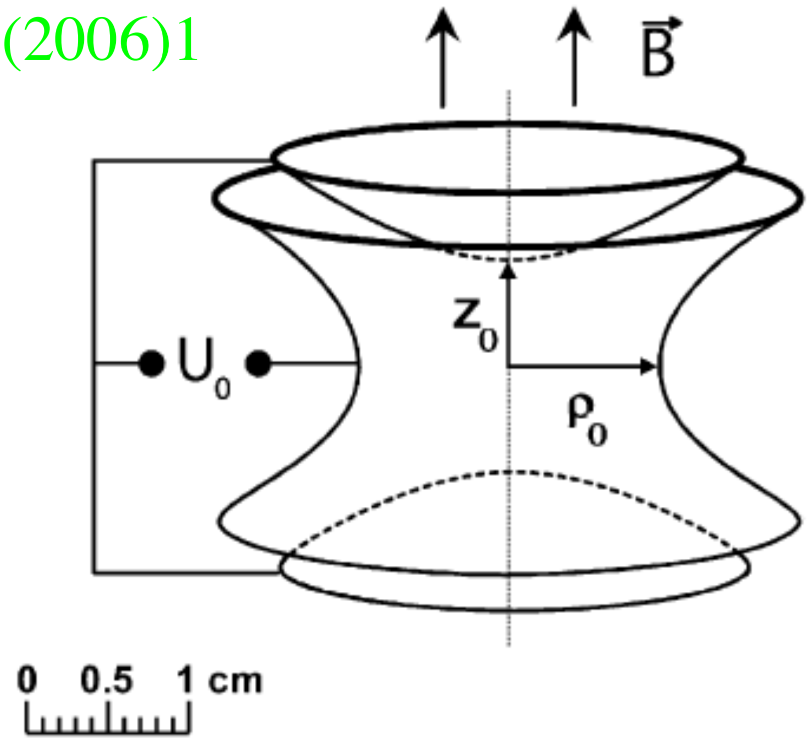
PR 425(2006)1

Cyclotron frequency: ω_C
Magnetron frequency



$$\omega_C = \omega_+ - \omega_-$$

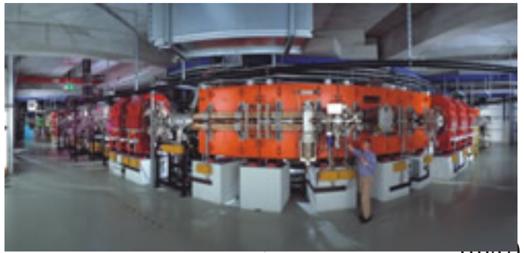
$$\omega_C = \frac{qB}{m}$$



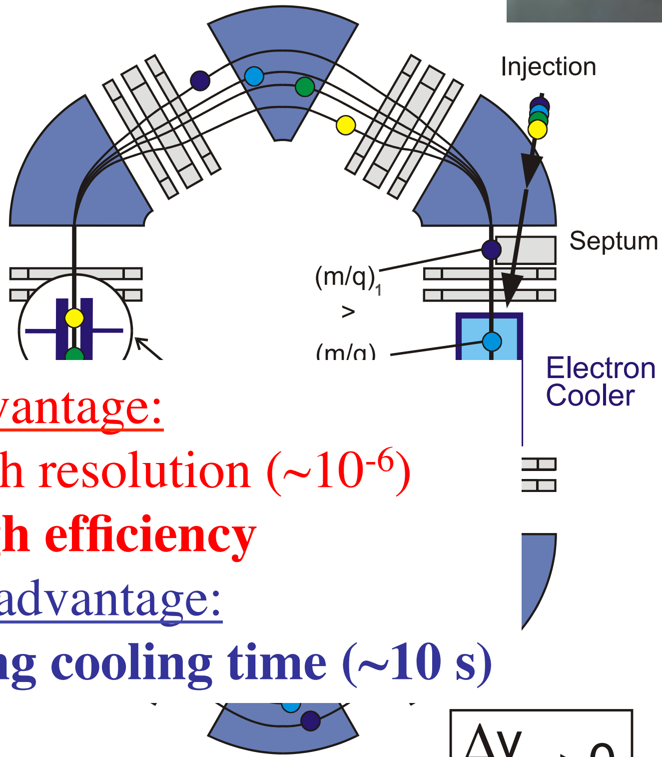
Advantage:
High resolution (<10^{-6})

Disadvantage:
Low energy RI beams
Long measurement time (~1 s)
Specified isotopes

Mass measurements in ESR/GSI



SCHOTTKY MASS SPECTROMETRY



Advantage:

High resolution (~10^{-6})

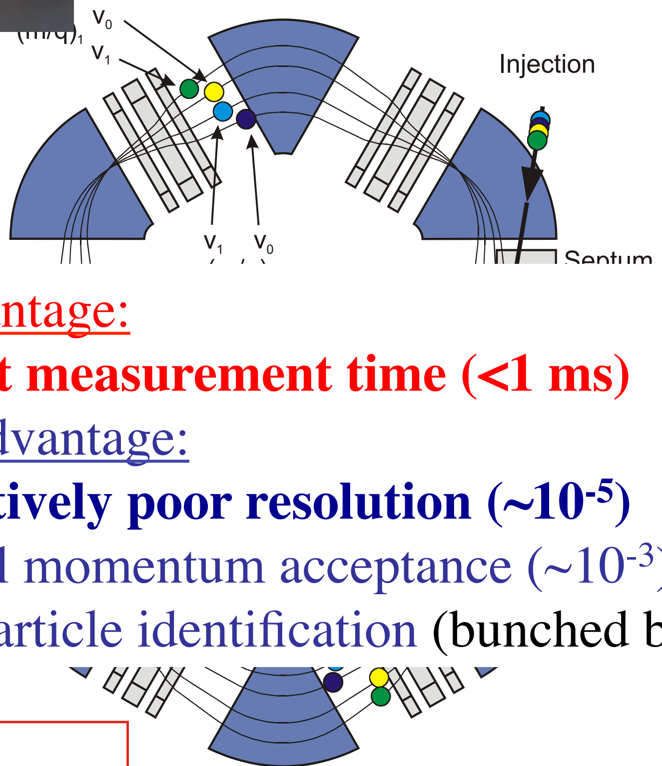
High efficiency

Disadvantage:

Long cooling time (~10 s)

Cooled Fragments

ISOCHRONOUS MASS SPECTROMETRY



Advantage:

Short measurement time (<1 ms)

Disadvantage:

Relatively poor resolution (~10^{-5})

Small momentum acceptance (~10^{-3})

No particle identification (bunched beam)

Hot Fragments

$$\frac{\Delta v}{v} \rightarrow 0 \qquad \gamma_t \rightarrow \gamma$$

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

Overview of Rare-RI Ring

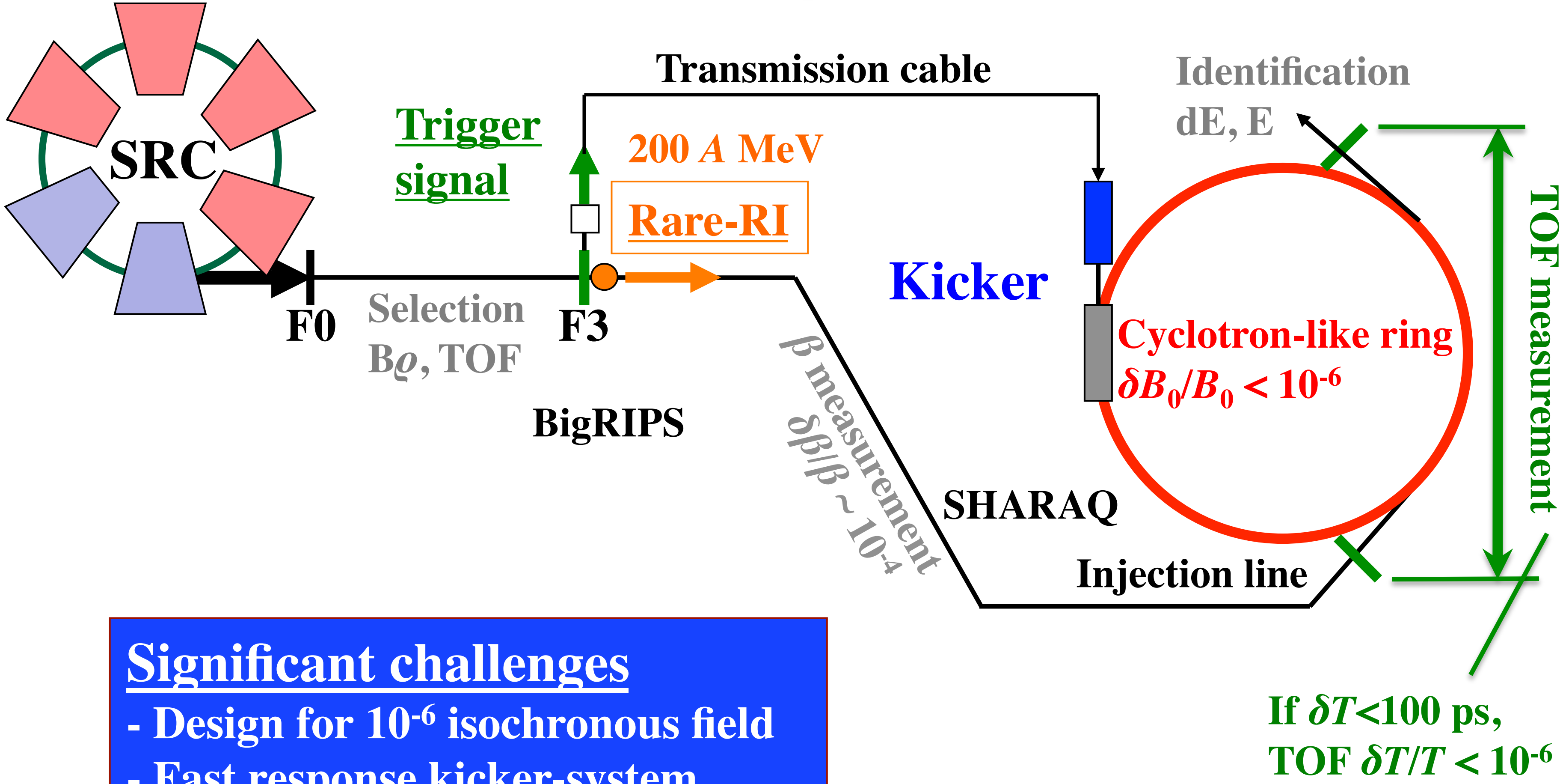
Similar to IMS in ESR

- Isochronous field $<10^{-6}$
- Beam-triggered individual injection

⇨ Short measurement time (<1 ms)

⇨ Good resolution ($<10^{-6}$)

⇨ High efficiency (~100%) even for continuous beam



Significant challenges

- Design for 10^{-6} isochronous field
- Fast response kicker-system

Principle of mass measurements

Based on $f_c = \frac{1}{2\pi}\frac{qB}{m}$ **: cyclotron frequency**

$$T_0 = 2\pi \frac{m_0}{q}\frac{1}{B}\gamma_0 = 2\pi \frac{m_0}{q}\frac{1}{B_0}$$

Isochronous optics

For $m_1/q = m_0/q + \Delta(m_0/q)$

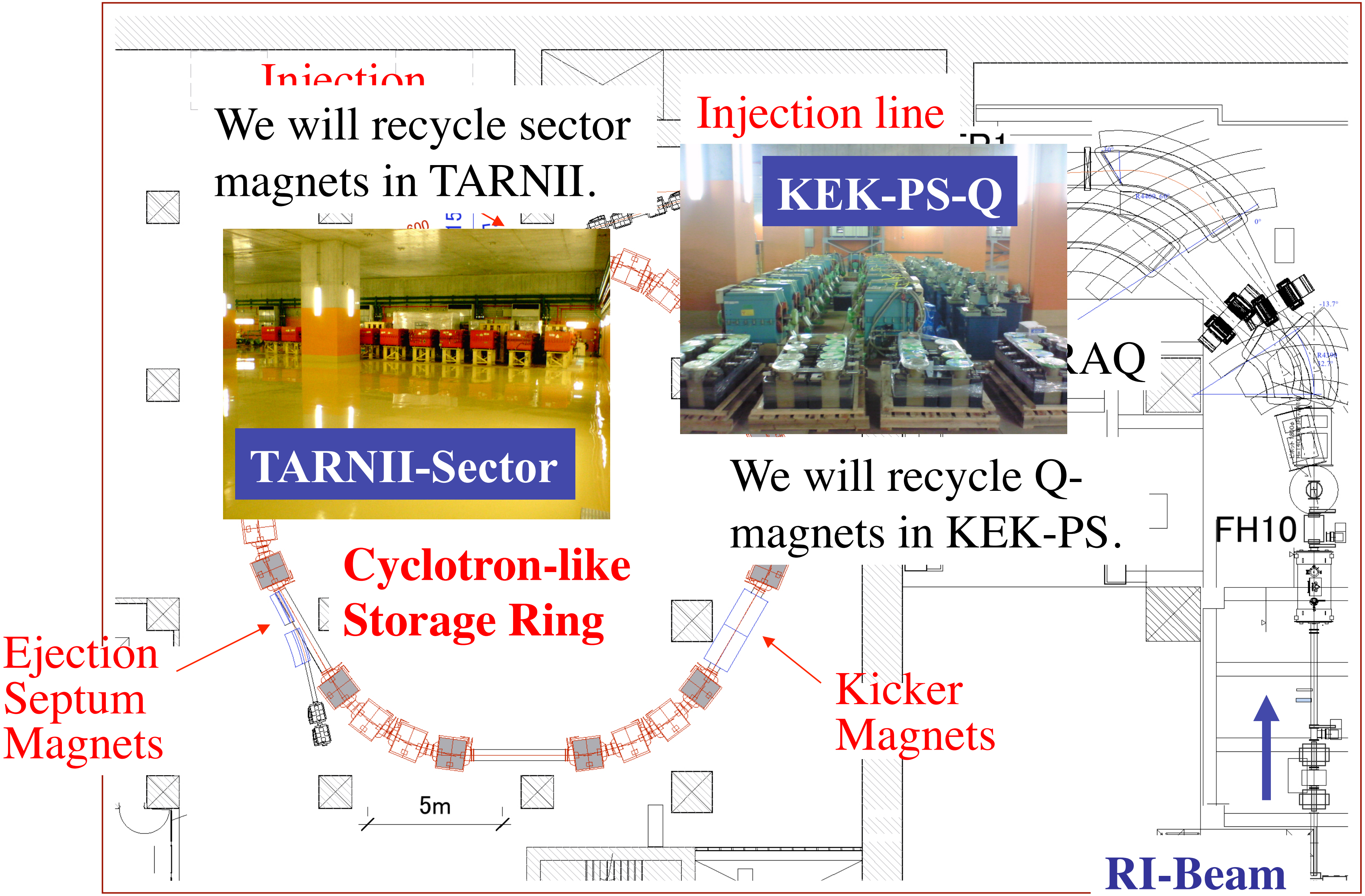
Isochronism is no longer fulfilled.

$$\frac{m_1}{q} = \left(\frac{m_0}{q}\right)\frac{T_1}{T_0}\frac{\gamma_0}{\gamma_1} = \left(\frac{m_0}{q}\right)\frac{T_1}{T_0}\sqrt{\frac{1-\beta_1^2}{1-\left(\frac{T_1}{T_0}\beta_1\right)^2}}$$

⇨ **Measurements of β is indispensable.**

$\delta\beta/\beta \sim 10^{-4}$ ⇨ $\delta(m_1/q)/(m_1/q) \sim 10^{-5}$ for 10% m/q difference

Present floor arrangement @ RIBF B2F



Beam-triggered individual injection

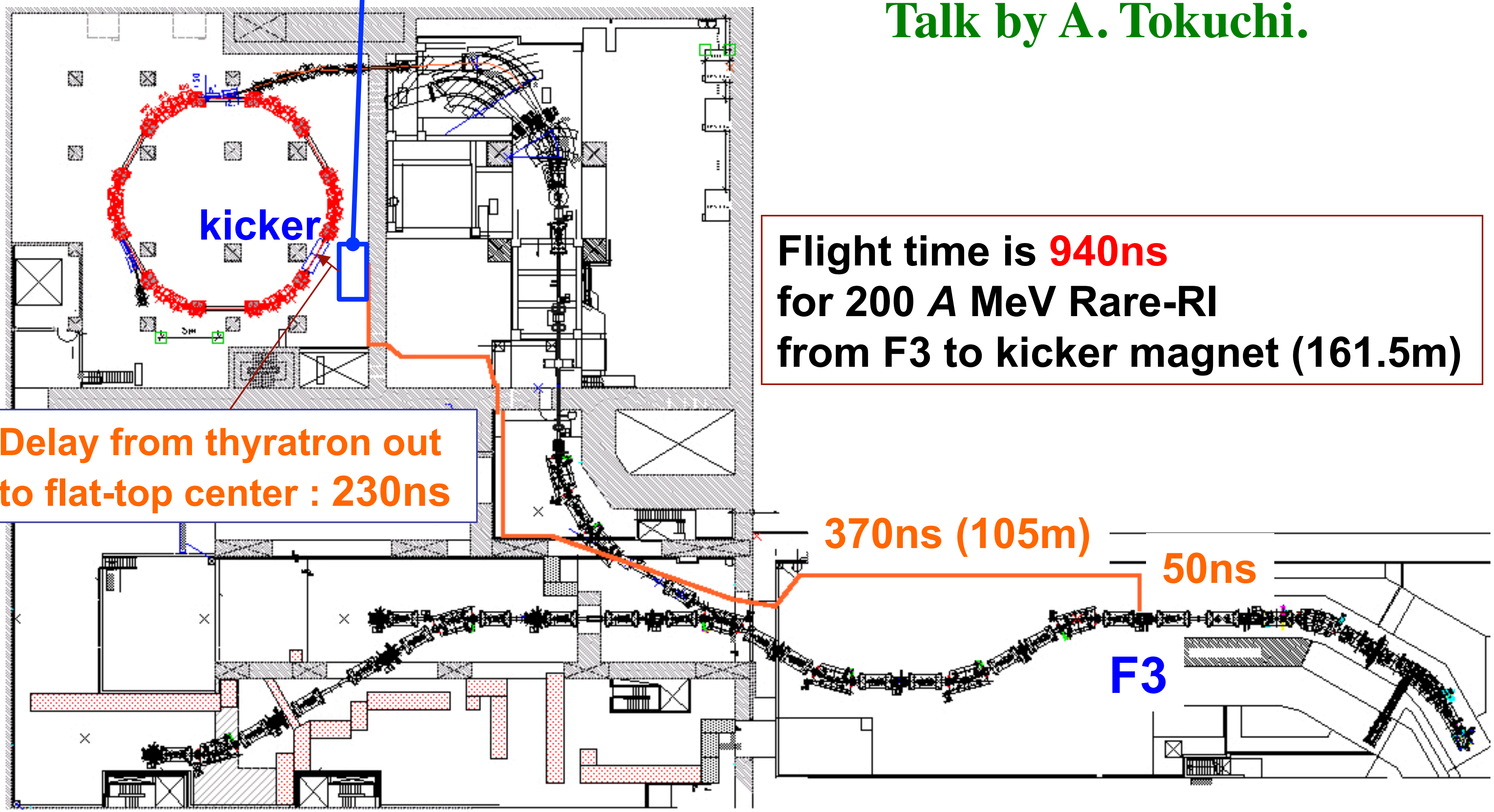
Response time of kicker power supply should make less than 290ns.

By R&D in 2010 275 ns is possible!

Talk by A. Tokuchi.

Flight time is 940ns
for 200 *A* MeV Rare-RI
from F3 to kicker magnet (161.5m)

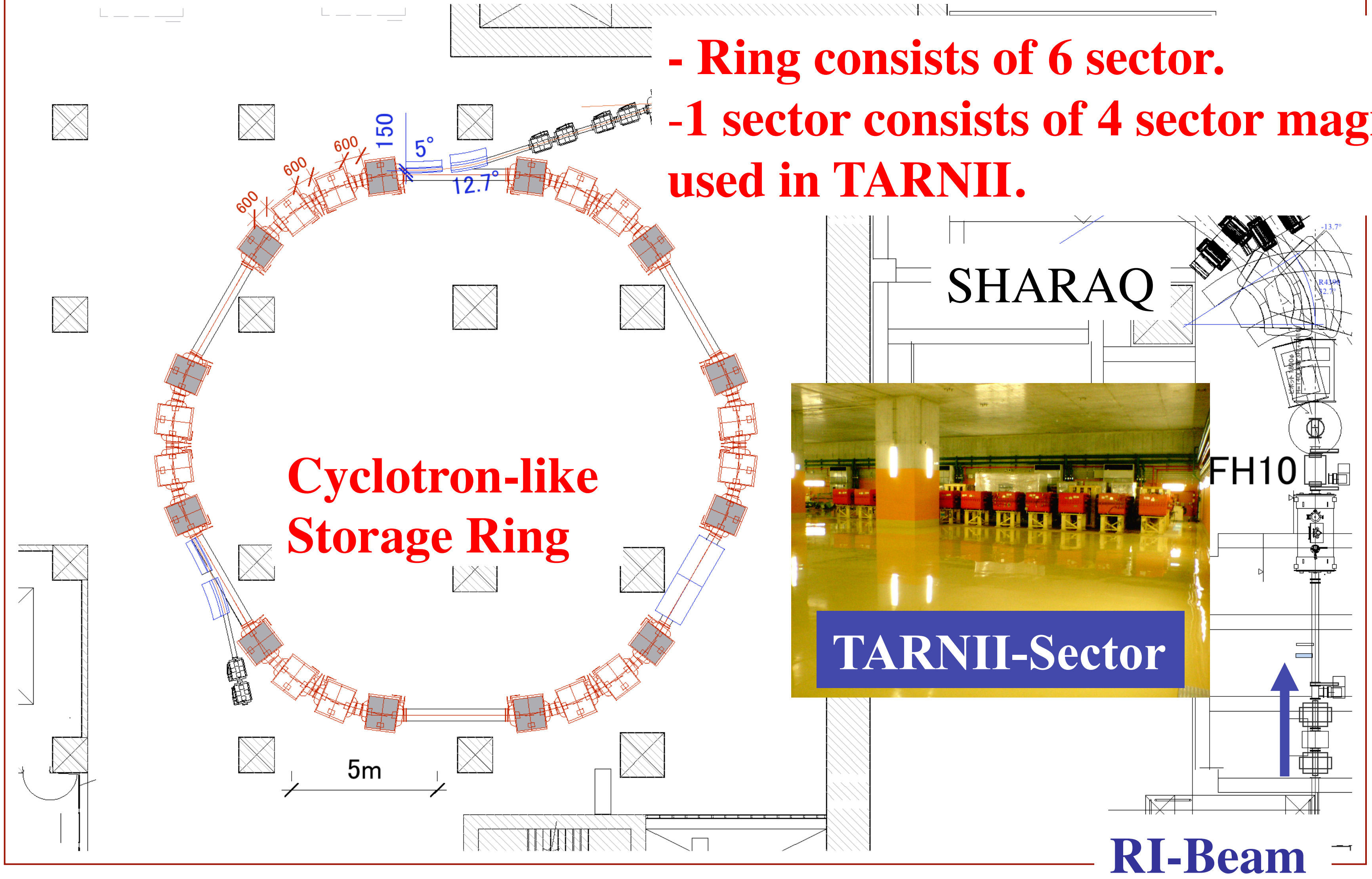
Delay from thyratron out
to flat-top center : 230ns



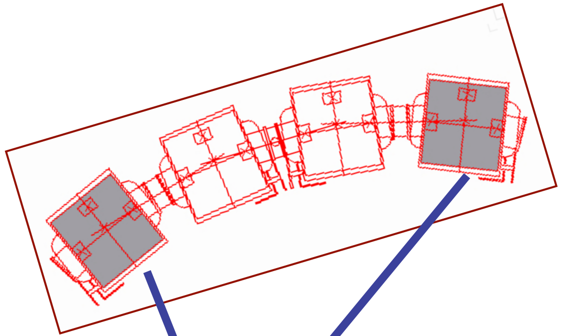
Cyclotron-like storage ring

We will recycle sector magnets used in TARNII.

- Ring consists of 6 sector.
- 1 sector consists of 4 sector magnets used in TARNII.

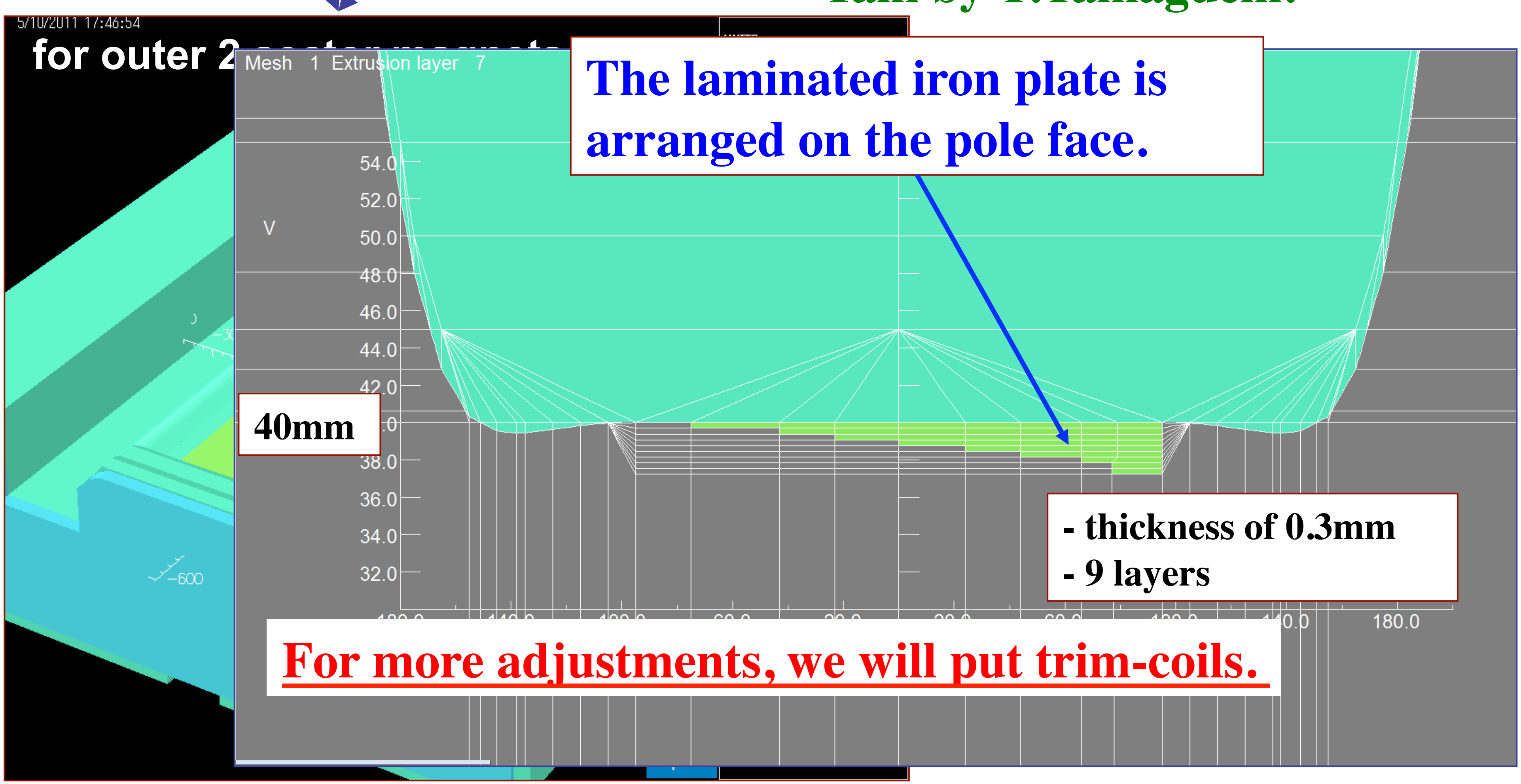


- Outer 2 sector magnets are modified to achieve a precise isochronous field.



Design of cyclotron-like storage ring

Talk by Y.Yamaguchi.



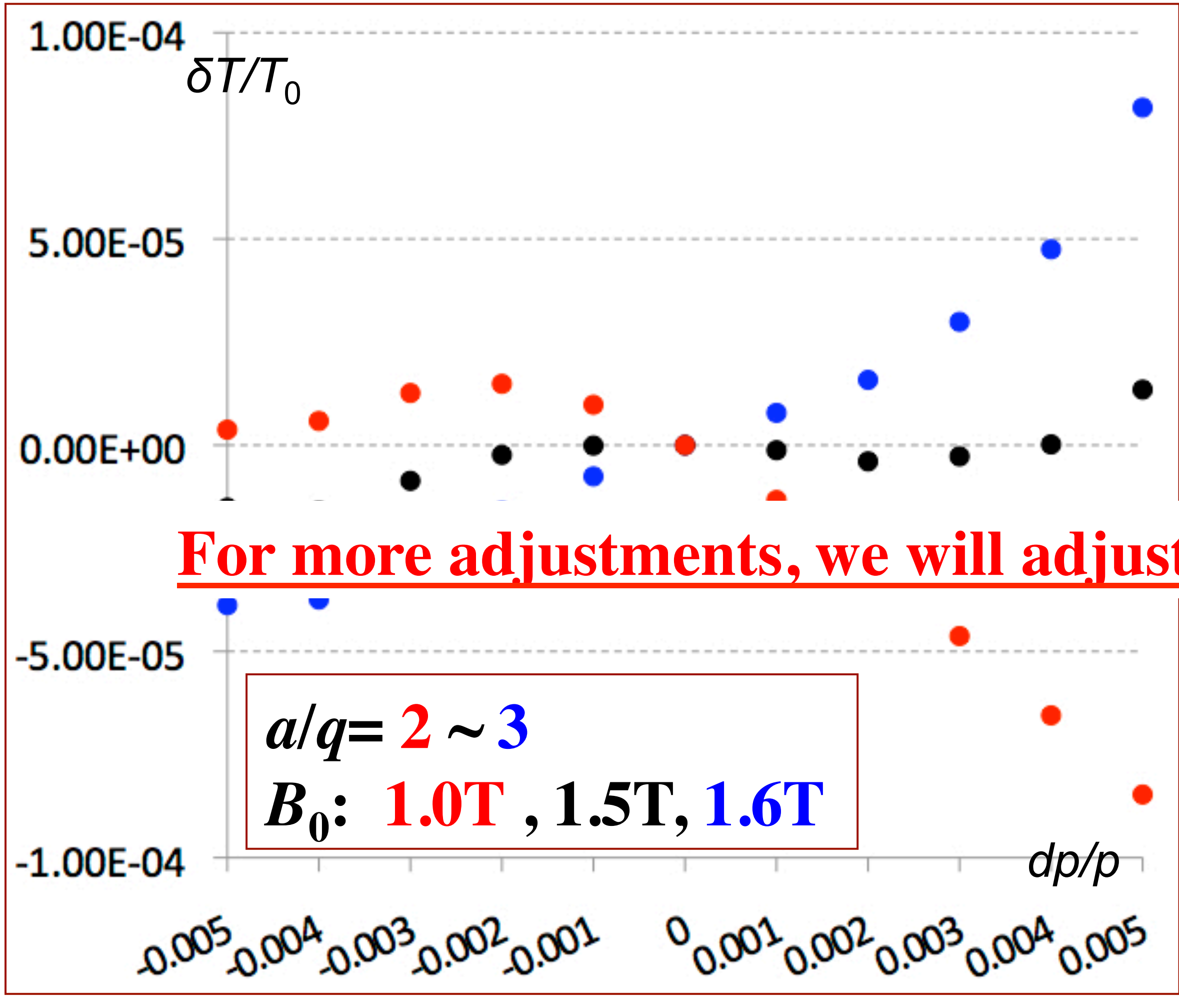
The laminated iron plate is arranged on the pole face.

40mm

- **thickness of 0.3mm**
- **9 layers**

For more adjustments, we will put trim-coils.

First order isochronous field can be achieved!

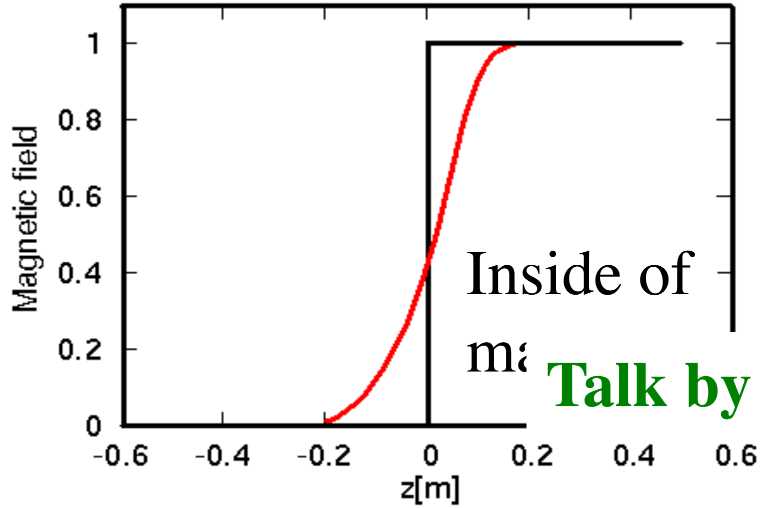


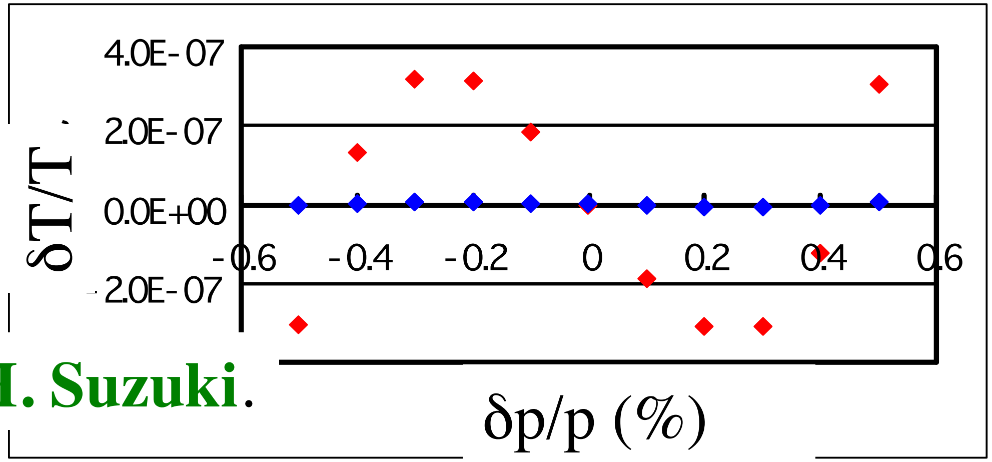
For more adjustments, we will adjust trim-coils.

$\delta B/B_0 < 10^{-4}$ in momentum spread 1%

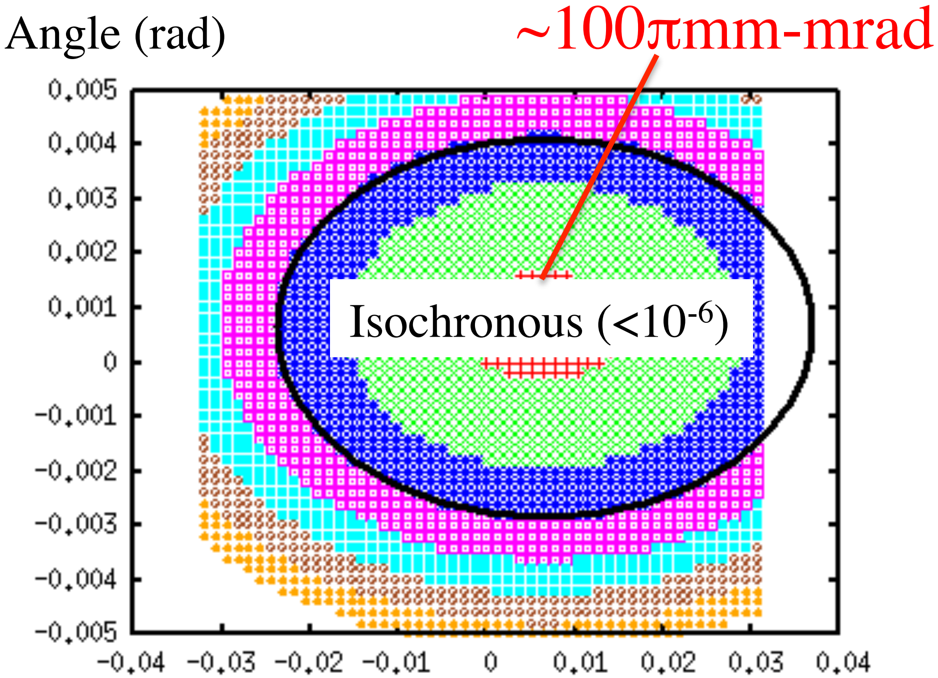
Simulation for ideal case

Isochronous magnetic field

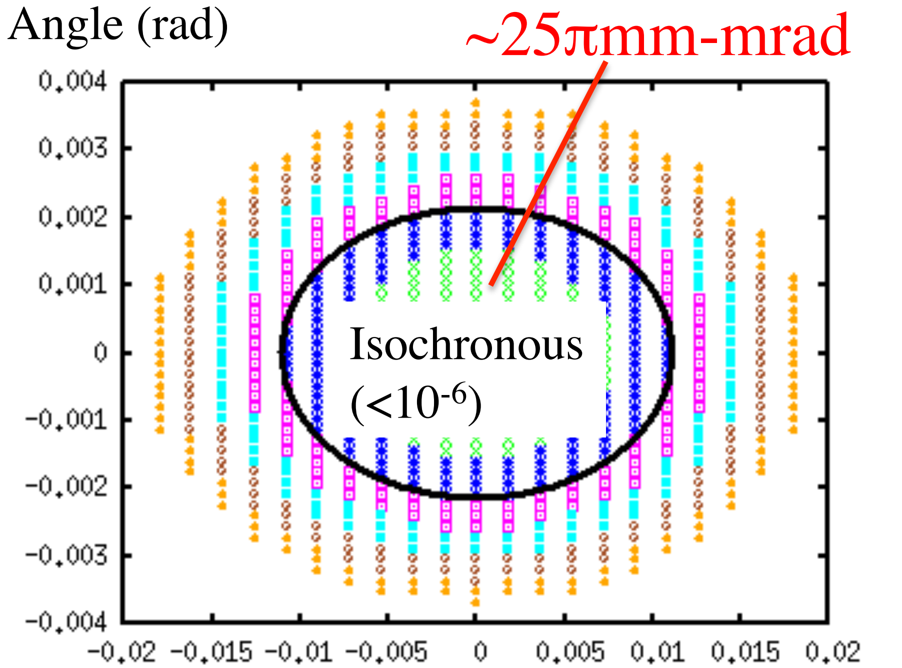




Talk by H. Suzuki.



Emittance (X) (1000 turns)



Emittance (Y) (1000 turns)

Basic characteristics of cyclotron-like storage ring

- Beam energy :	200 *A* MeV
- Lorentz factor γ :	1.2147
- Circumference :	60.3507 m
- Momentum acceptance :	1.0%
- Harmonics :	13
- Revolution frequency :	2.82 MHz
- Revolution time :	355 ns
- Normalised gradient $k1$:	0.074 m^{-2}
transition γ_{tr} = 1.2146 ≒ γ at dp/p=0	
- Betatron tune :	$Q_x = 1.22$, $Q_y = 0.88$
- Max. β fuction :	$\beta_x = 8.1$ m , $\beta_y = 12.5$ m
- Dispersion of straight part :	66.91 mm/%

Beam optics in injection

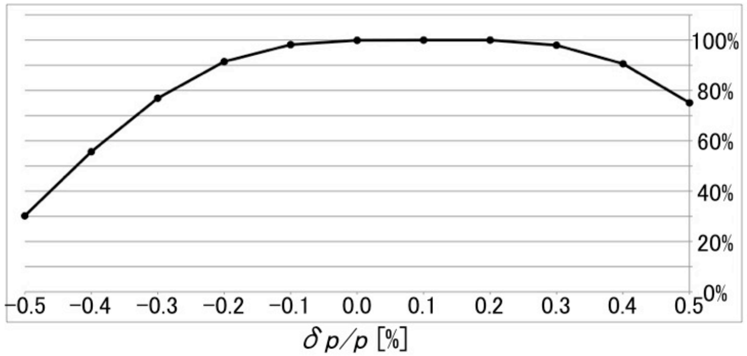
- Optimize the injection trajectory by 3rd-order calculation

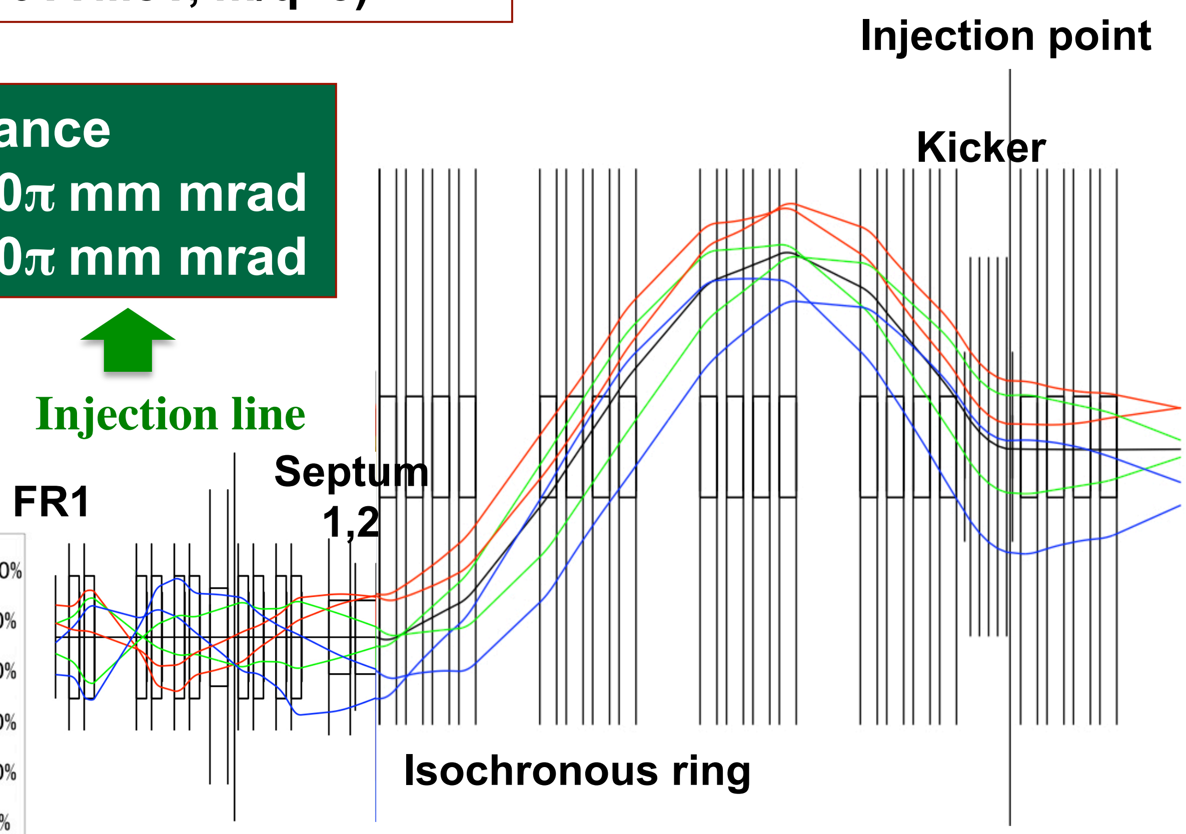
a_0 = ±15mrad
dp/p = -0.5%, 0.0%, 0.5%
(200 A MeV, m/q=3)

- Kick angle is 19mrad
- Dispersion matching

Injection beam emittance
Horizontal : $\varepsilon_x = 30\pi$ mm mrad
Vertical : $\varepsilon_y = 10\pi$ mm mrad

-Transmission from BigRIPS-F0 to kicker

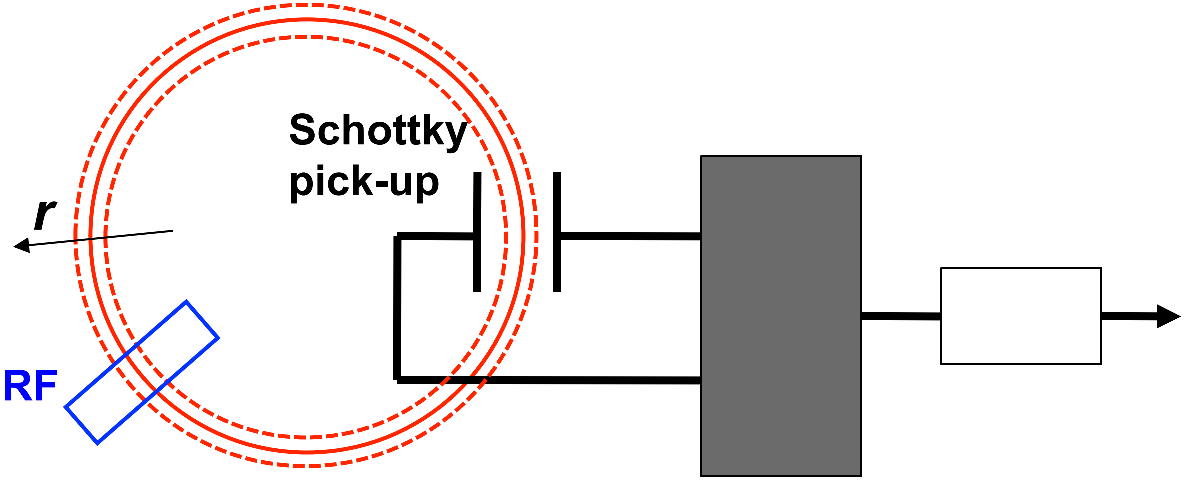




Adjustments of isochronous magnetic field

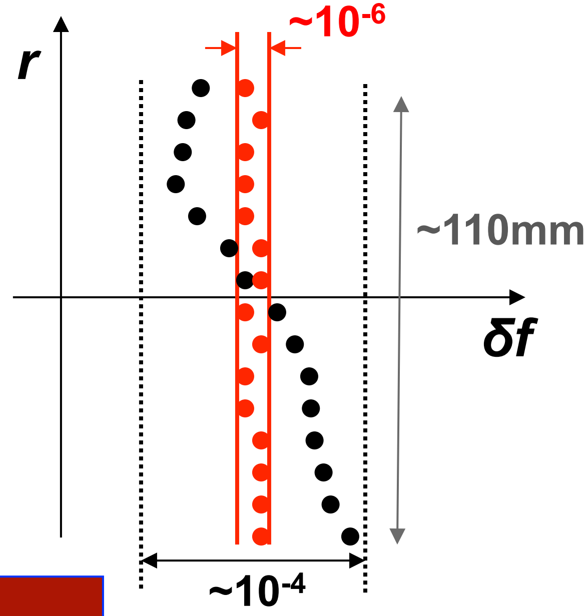
- Measure the revolution frequency of primary beam by schottky pick-up system

Isochronous field: ~10^{-4}
by laminated iron plate



Stored primary beam

before fine tuning by trim-coils
after fine tuning by trim-coils

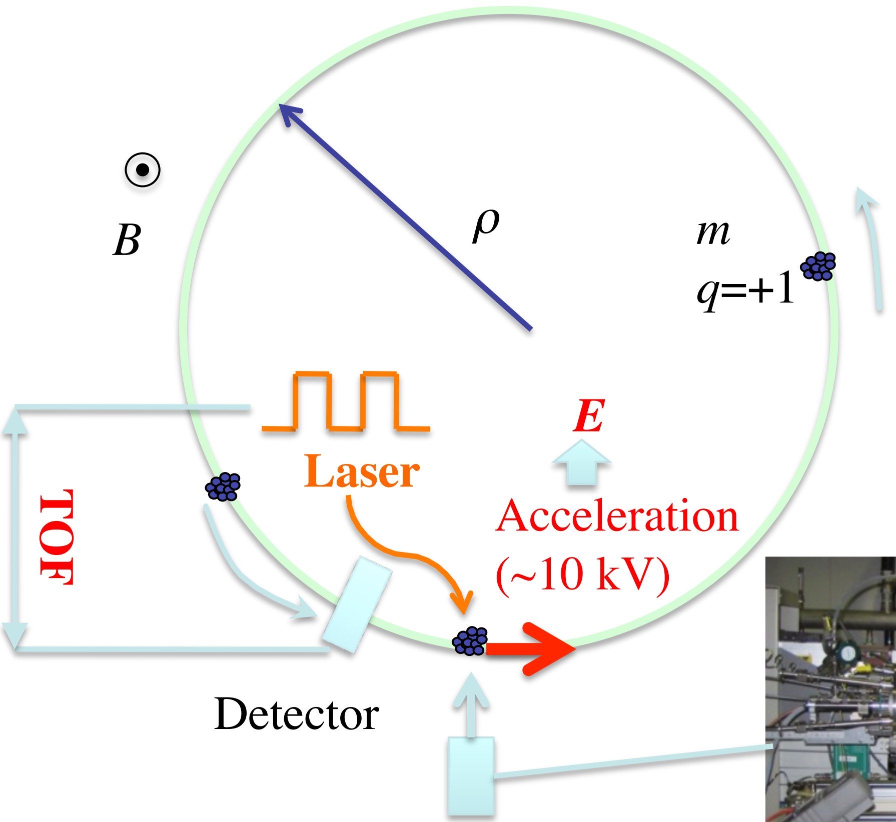


We will install Schottky pick-up.

R&D for Cluster ion-source as the calibrator

Principle and methods

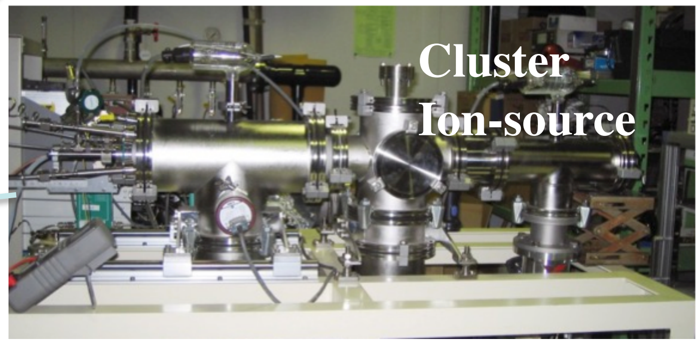
- **Rigidity of atomic cluster ($Cu_{n=800}$) can be matched to Rare-RI in the storage ring.**
- **By the cluster we can measure the flight length in the storage ring.**
- **If we measure the flight length with 10^{-6}, we can determine the magnetic field with 10^{-6} in the storage ring.**



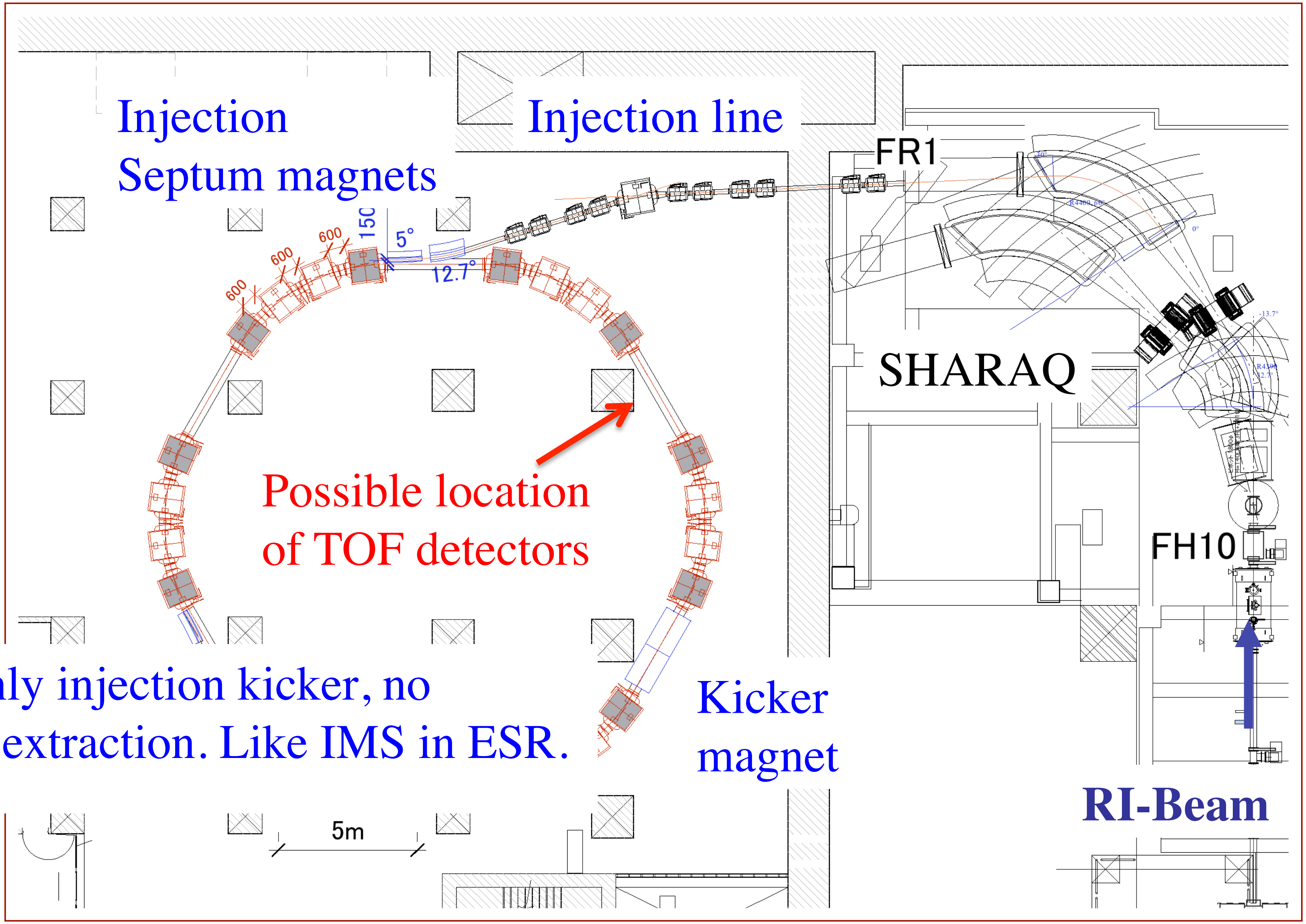
TOF→*L*→*B*

$$B\rho = \frac{\sqrt{2mE}}{q} = \sqrt{2mE}$$

$$L = 2\pi\rho$$



Probable first experiment?

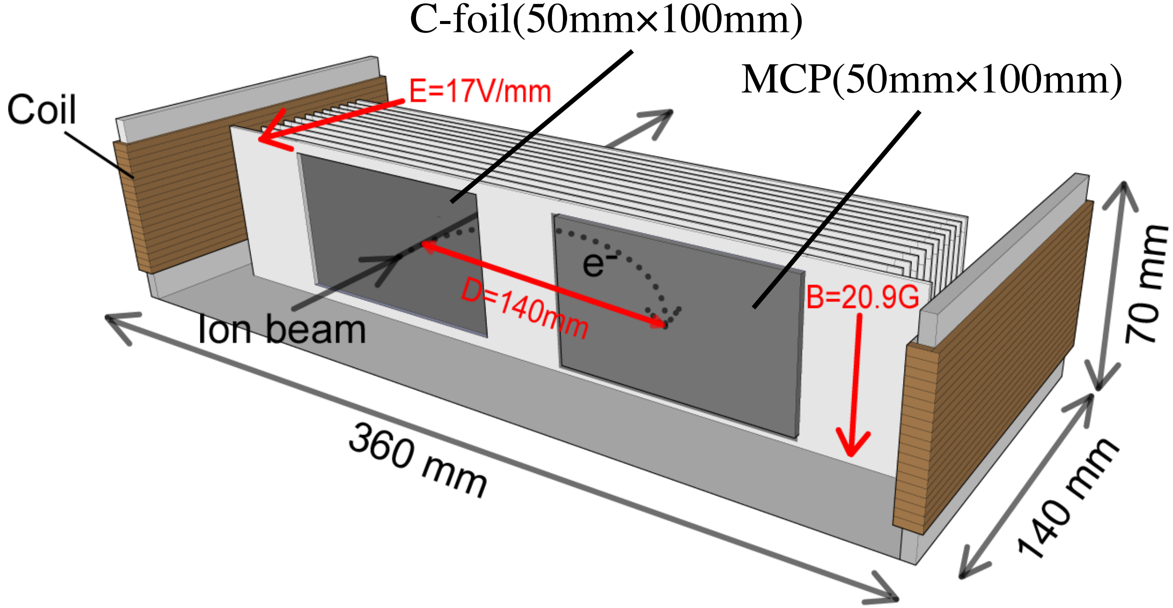


R&D for TOF detectors

1) Similar detectors used in IMS in ESR.

2) Large size due to the large beam-size (~120mm×50mm).

$$D = \frac{2\pi m_e}{q}\frac{E}{B^2}$$



D : Distance

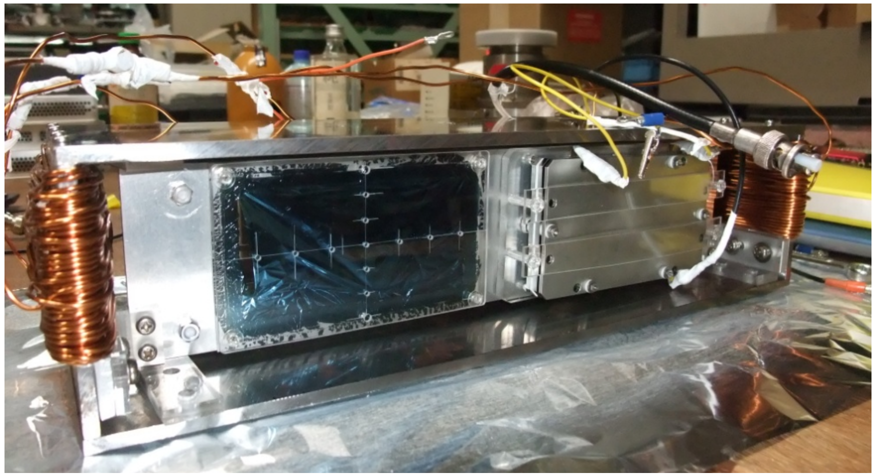
m_e : Electron mass

q : Charge

E : Electric field

B : Magnetic field

Nucl. Instr. and Meth. 148 (1987) 503.



Talk by D. Nagae.

Mass measurements in Rare-RI Ring

Possible measurement procedure (case for ^{78}Ni) :

1) Tuning for isochronous field

We use primary beam: $^{78}Kr^{28+}$ with 200 *A* MeV, that can be accelerated in RIBF.

Schottky probe and rf-cavity are needed.

$^{78}Kr^{28+}$ can be used for reference of mass.

2) We change primary beam from $^{78}Kr^{28+}$ to ^{238}U.

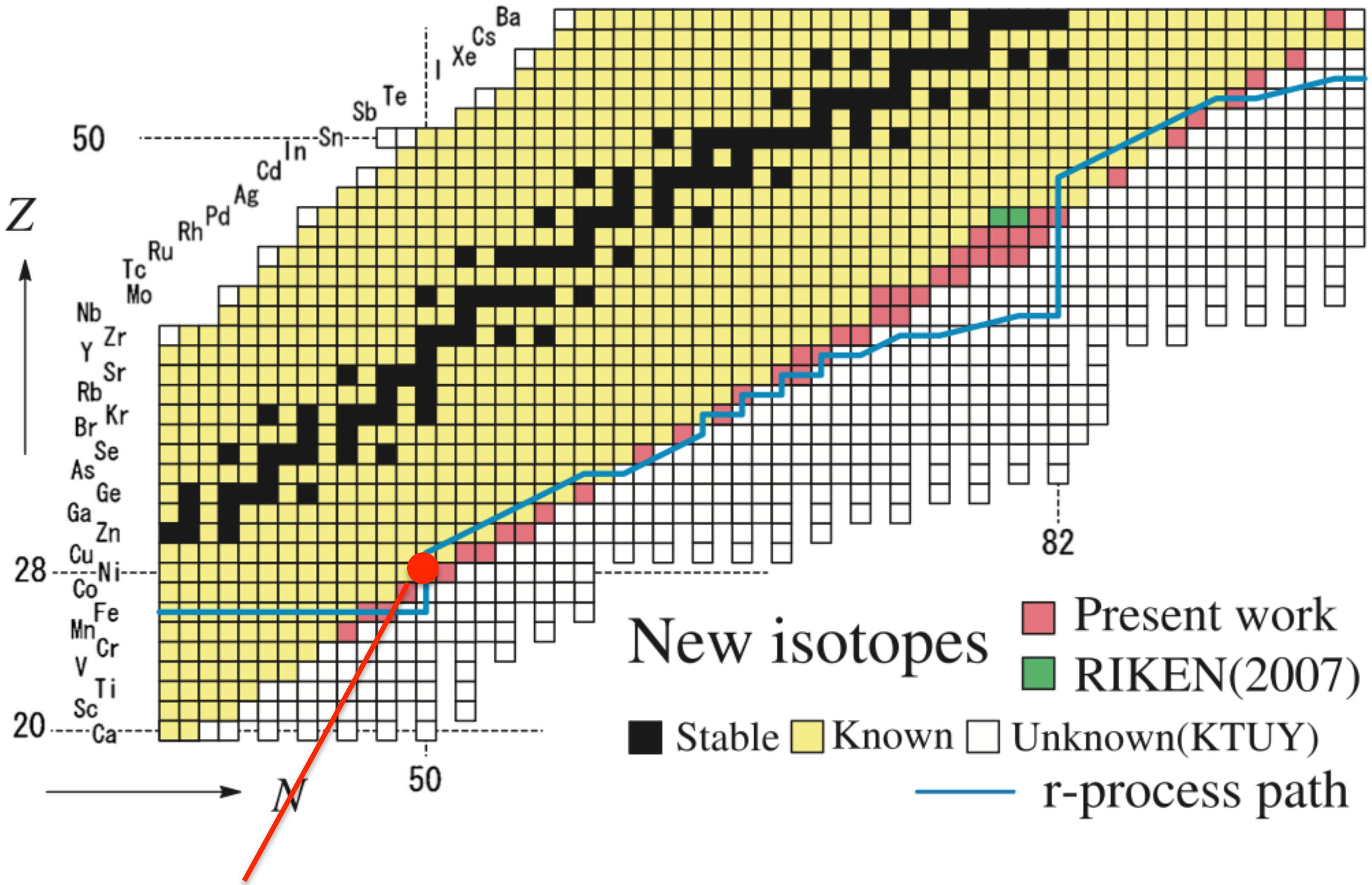
$^{78}Ni^{28+}$ is tuned in BigRIPS to the ring.

3) We measure ToF (~2000 turns, ~0.7ms) by ToF detectors.

4) Mass of the nuclei around ^{78}Ni can also be measured.

β can be used as corrections.

RIBF allows us to access R-process.



^{78}Ni (~0.005cps/pnA in BigRIPS)

JPSJ 79, 073201

Yield estimation of ^{78}Ni in Rare-RI ring:

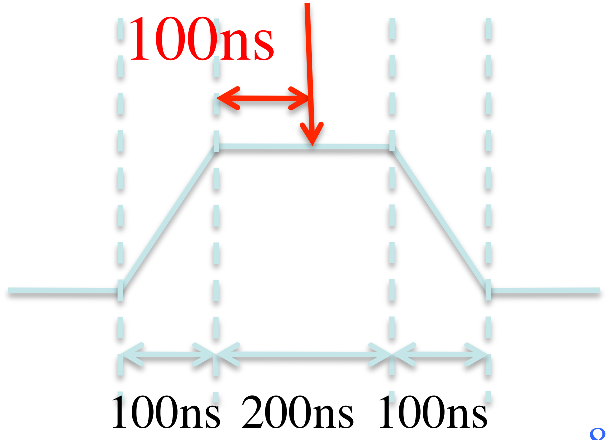
~5×10^{-3} cps/pnA in BigRIPS (Full acceptance)

	Reduction factor from BigRIPS
Energy: ~290 *A* MeV→200 *A* MeV	~0.9
Momentum acceptance 6% → 1%	1/6
Angular acceptance 80πmm mrad→~20πmm mrad	~1/16
Transmission eff. at injection	~0.8
Total	~0.0075

4×10^{-5} cps/pnA → ~3 events/day/pnA in Rare-RI ring

Still feasible!

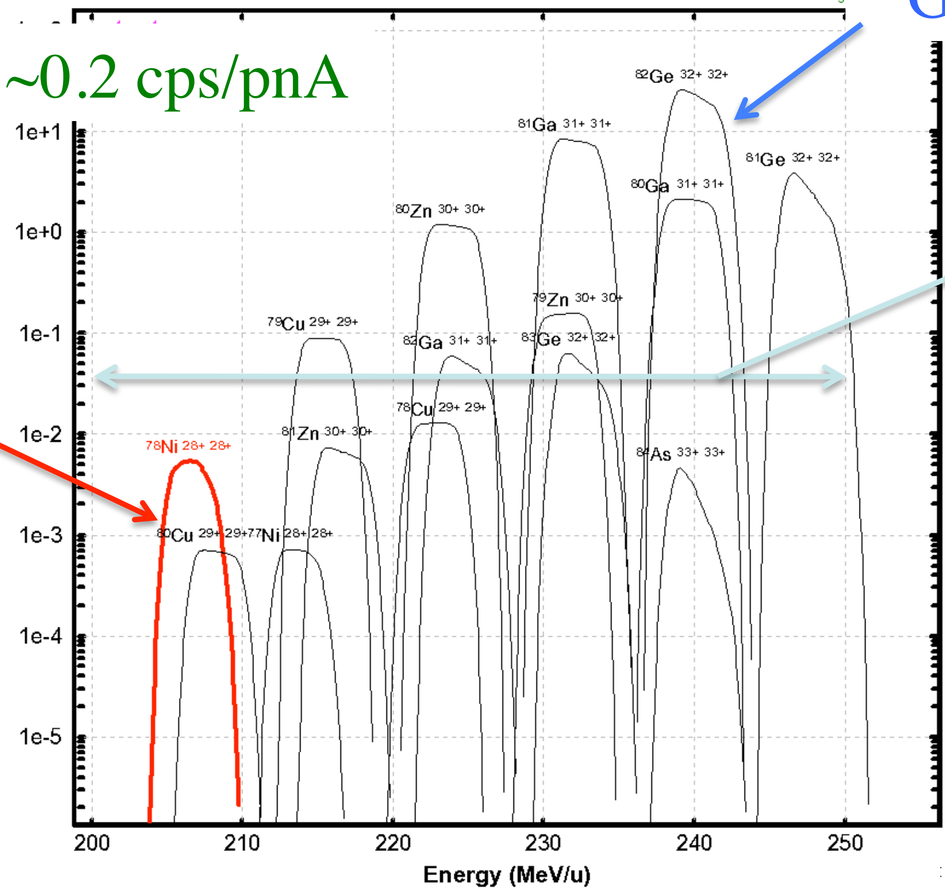
Possible
Kicker timing



$^{82}Ge^{32+}$(~0.17cps/pnA)

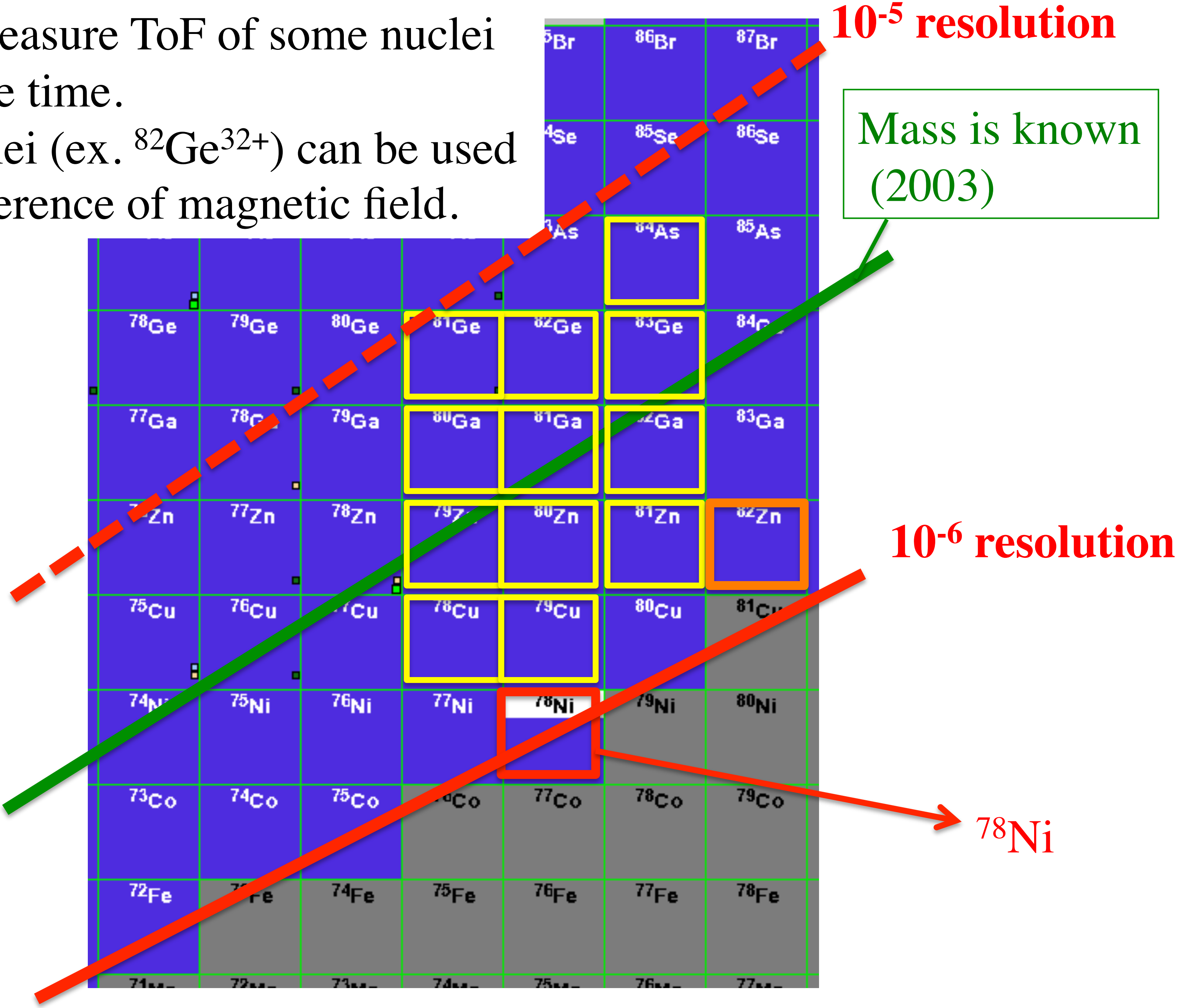
Total rate: ~0.2 cps/pnA

$^{78}Ni^{28+}$



Time difference:
75 ns

We will measure ToF of some nuclei at the same time.
Some nuclei (ex. $^{82}Ge^{32+}$) can be used for the reference of magnetic field.



Summary

- Rare-RI Ring consists of long injection line, fast kicker system and cyclotron-like storage ring (isochronous ring).
- Fast kicker magnet allows to inject 200 *A* MeV Rare-RI beam by individual injection.
- Isochronous field can be made by fixed laminated plates (1st order, ~10^{-4}) and adjustable trim-coils (2nd order, ~10^{-6}).
- In the storage ring, $\delta T/T<10^{-6}$ can be achieved with large emittance (~30π mm mrad) and large momentum spread (±0.5%).
- Schottky probe and RF-cavity are needed for tuning of trim coils by primary beam.
- Mass measurements of ^{78}Ni is feasible in Rare-RI Ring.

Rare-RI Ring Collaboration

A.Ozawa, Y. Abe, I.Arai, Y.Ito, T.Moriguchi, D.Nagae
(Univ. of Tsukuba)
T.Fujinawa, N.Fukunishi, A.Goto, H.Hasebe,
T.Ohnishi, H.Sakurai, H. Suzuki, M.Wakasugi,
Y.Yamaguchi, Y.Yano (RIKEN)
T.Suzuki, T.Yamaguchi (Saitama Univ.)
T.Kikuchi, A.Tokuchi (Nagaoka Univ. of Technology)
T.Ohtsubo (Niigata Univ.)
Y.Yasuda (RCNP, Osaka Univ.)
S.Kubono (CNS, Univ. Tokyo)