理研 稀少RIリングの現状と見通し

The Rare-RI Ring Facility at RIBF

The 3rd storage ring for radioactive ion beams in the world

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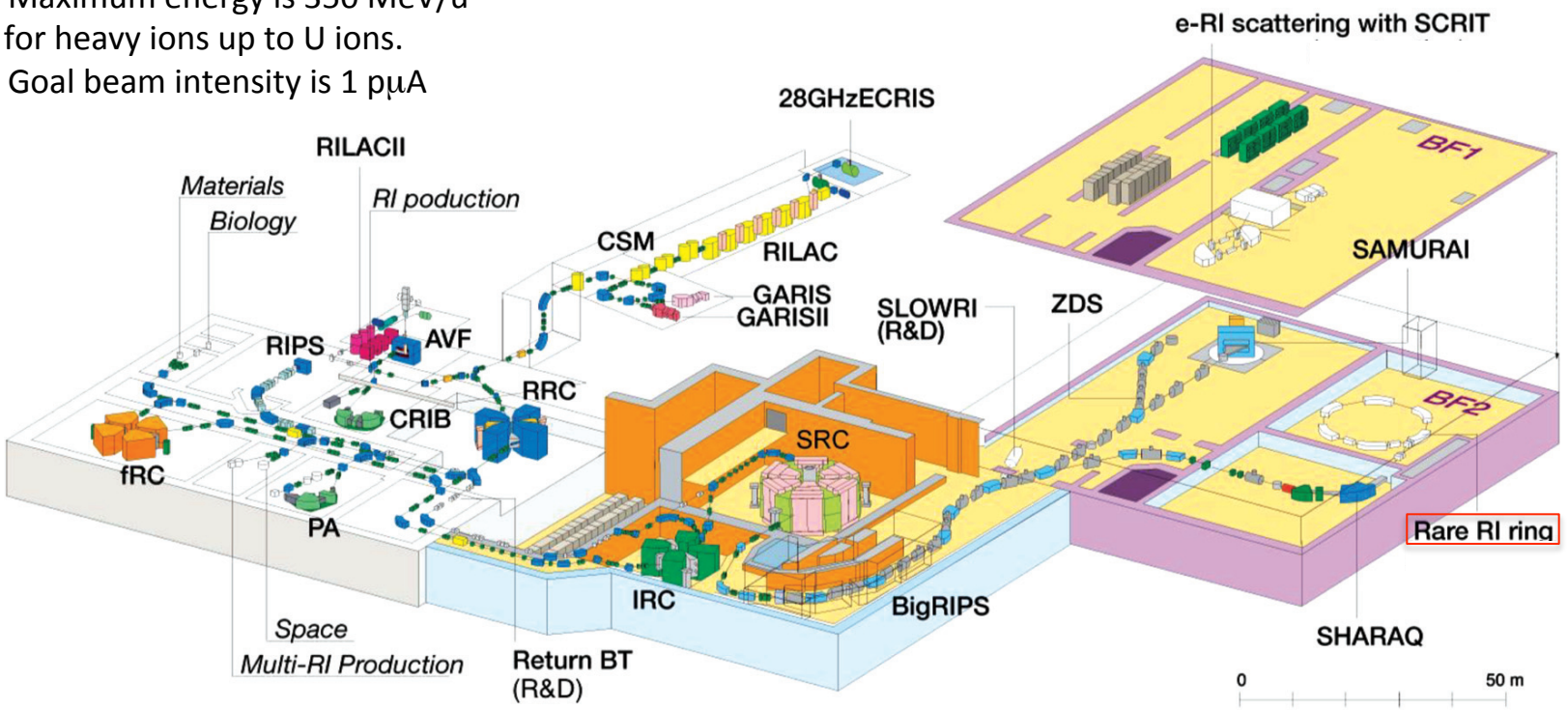
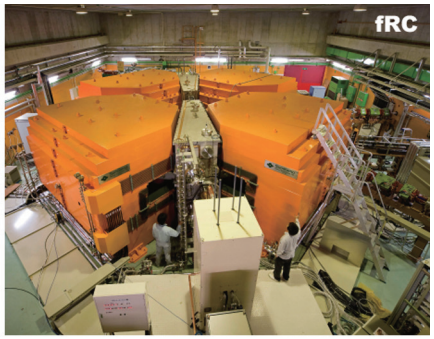
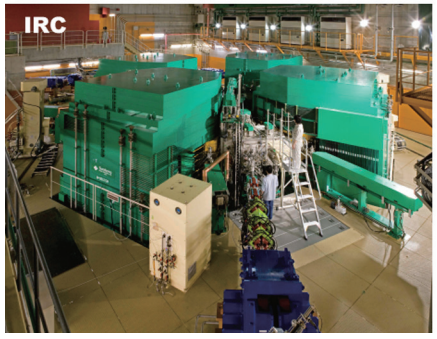
「宇宙核物理実験の現状と将来」
2014年8月7-8日, RCNP

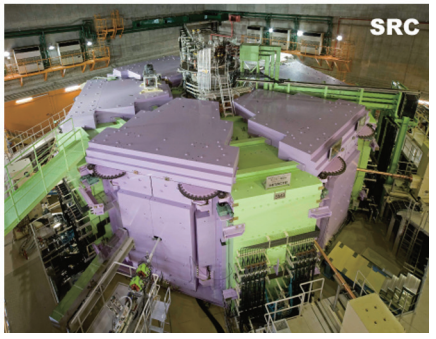
RIKEN RI Beam Factory (RIBF)

- Maximum energy is 350 MeV/u for heavy ions up to U ions.
- Goal beam intensity is 1 pμA









RI beams at RIBF

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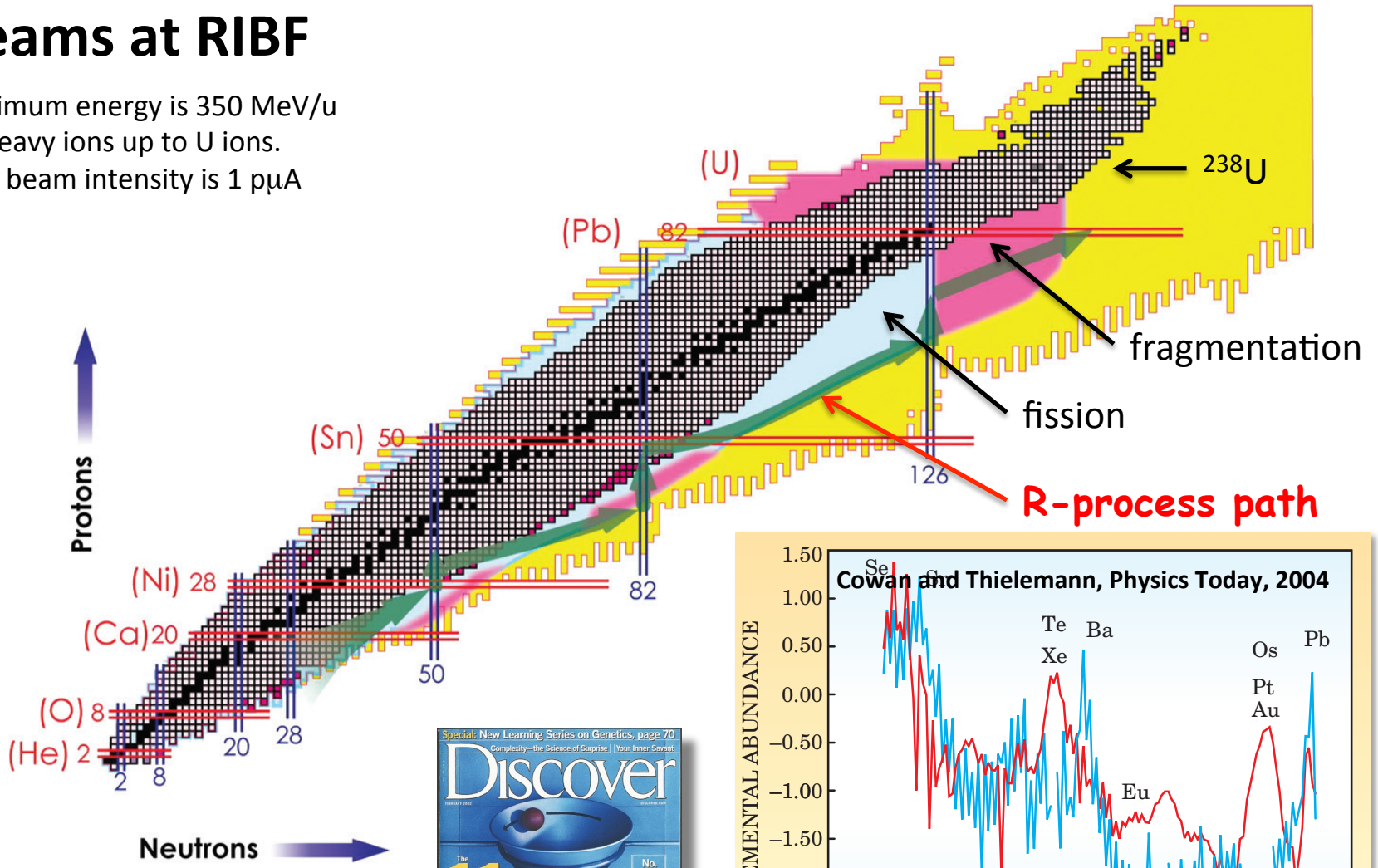
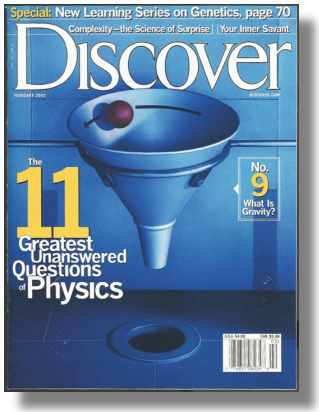
- Goal beam intensity is 1 pμA

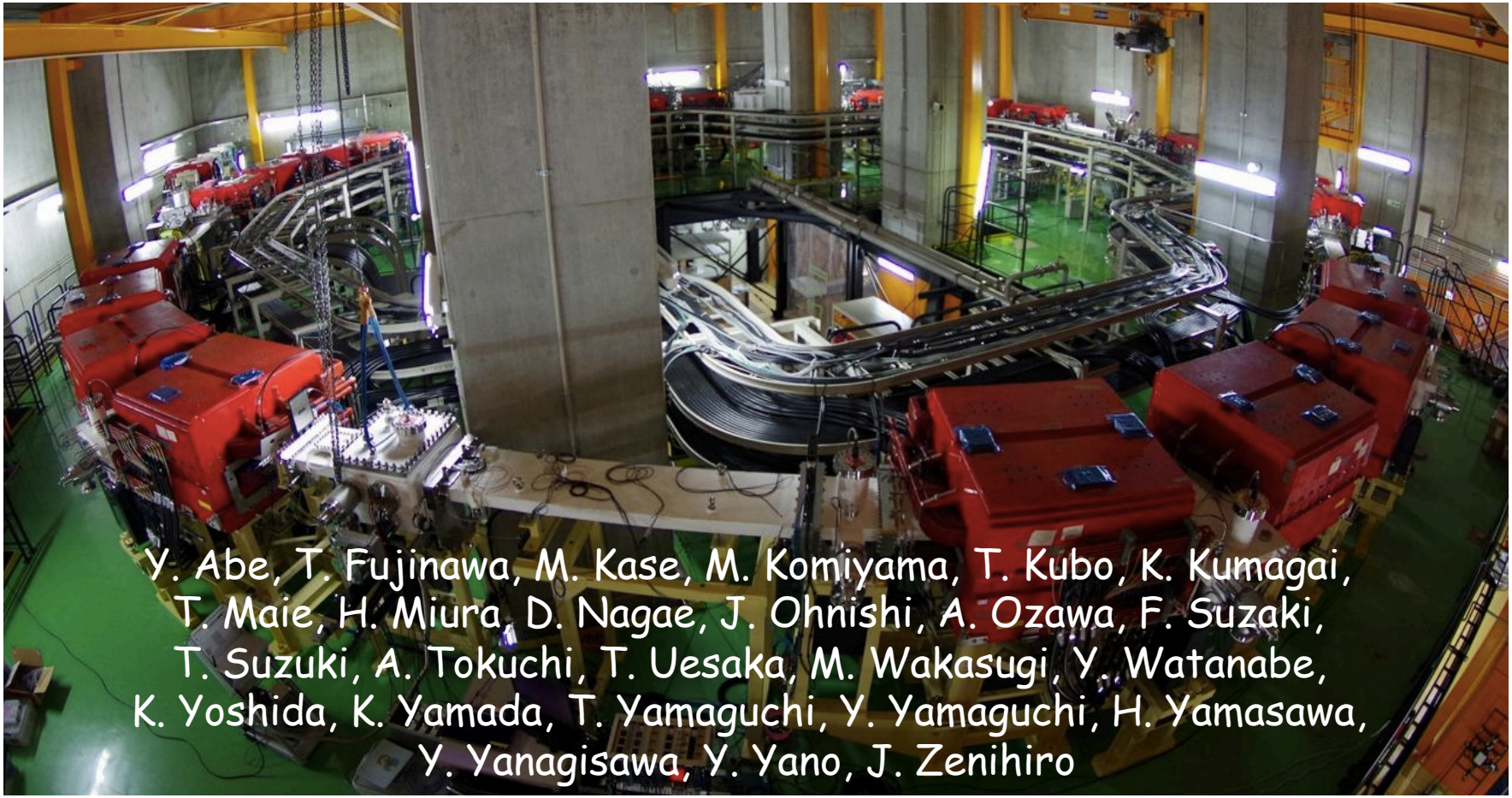




Question 3:
How were the heavy elements from iron to uranium made?

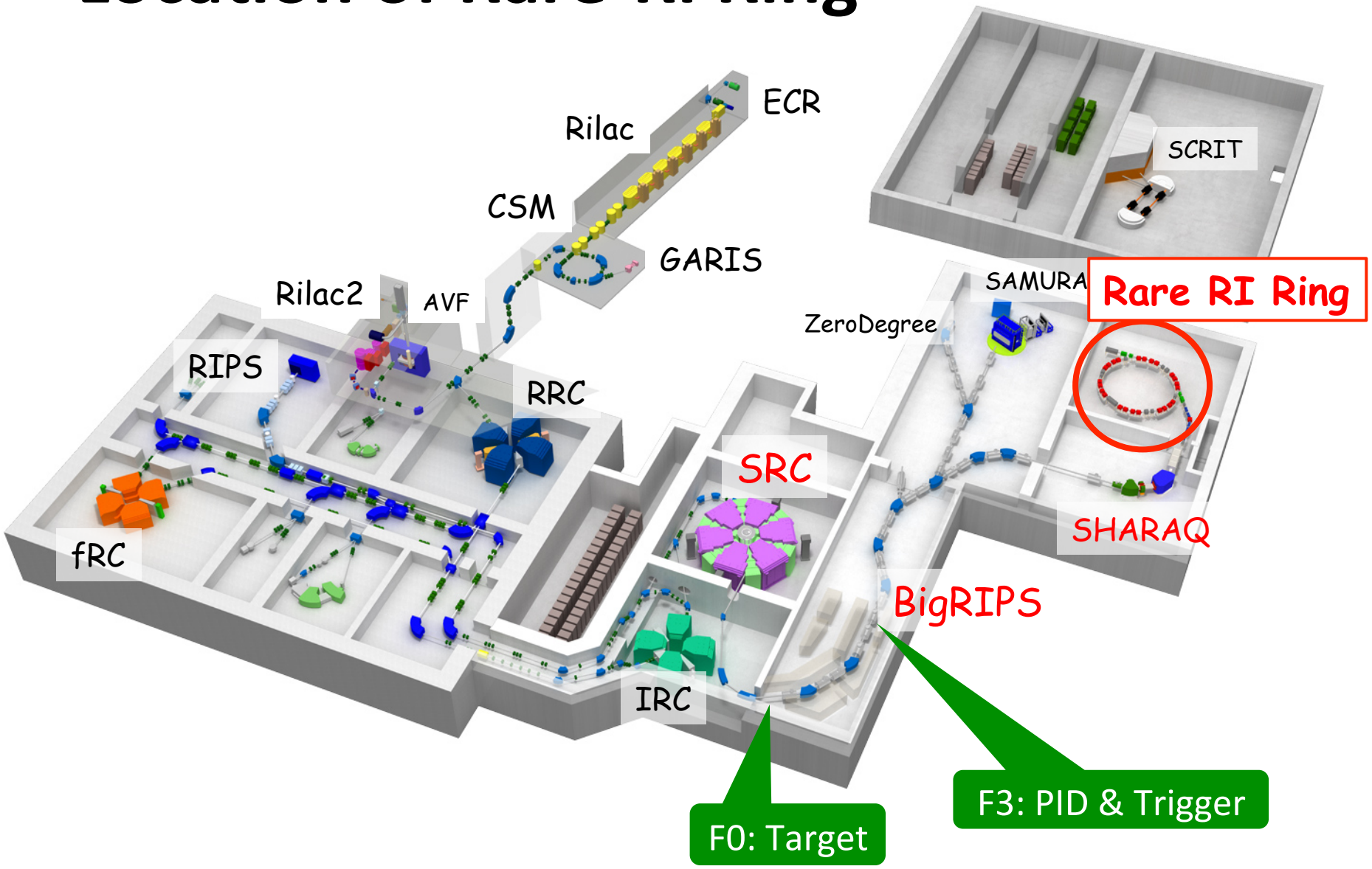
Rare-RI Ring (R3) collaboration

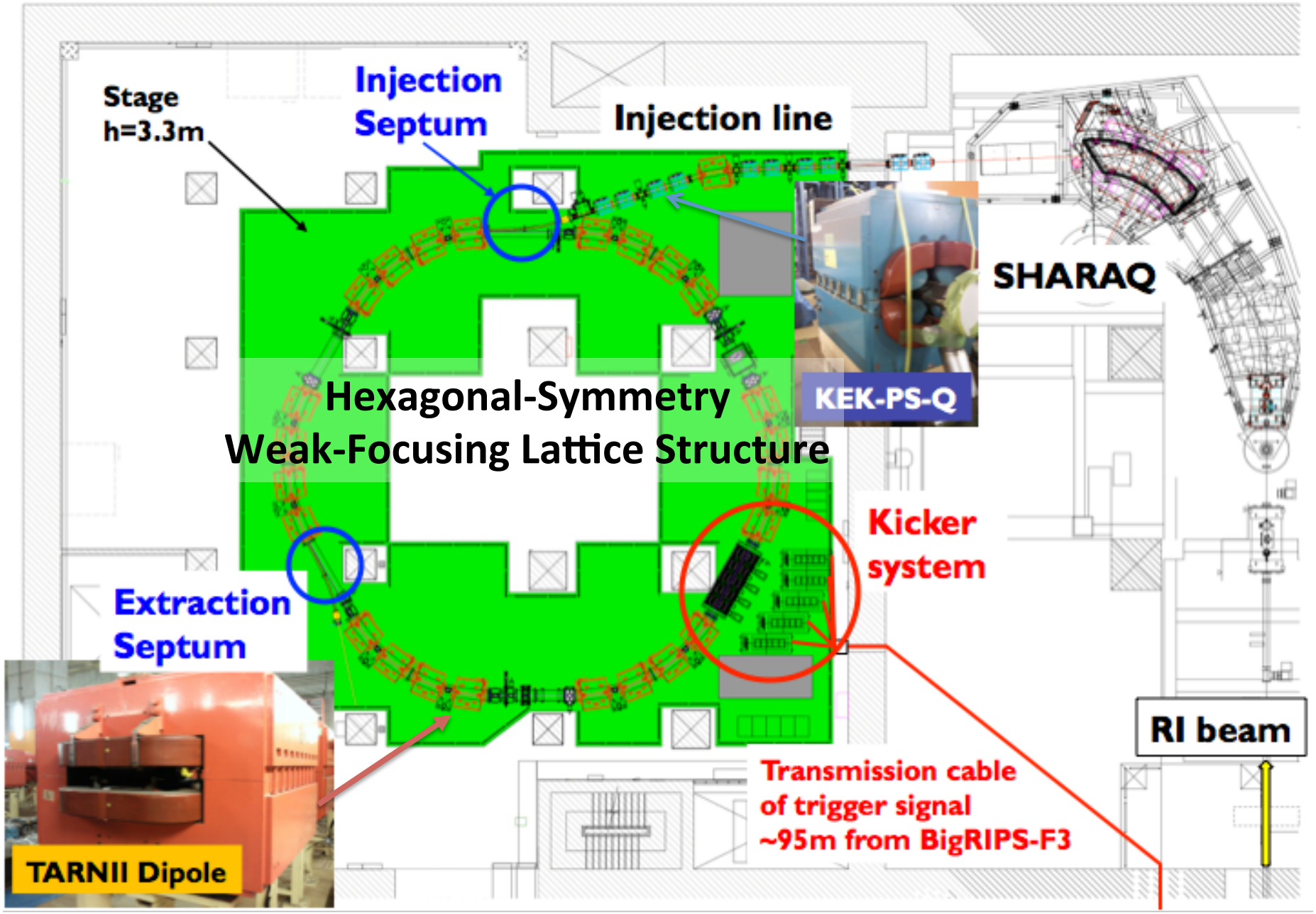
Heavy-ion storage ring dedicated to mass measurements
based on Isochronous Mass Spectrometry



Y. Abe, T. Fujinawa, M. Kase, M. Komiyama, T. Kubo, K. Kumagai,
T. Maie, H. Miura, D. Nagae, J. Ohnishi, A. Ozawa, F. Suzaki,
T. Suzuki, A. Tokuchi, T. Uesaka, M. Wakasugi, Y. Watanabe,
K. Yoshida, K. Yamada, T. Yamaguchi, Y. Yamaguchi, H. Yamasawa,
Y. Yanagisawa, Y. Yano, J. Zenihiro

Location of Rare-RI Ring



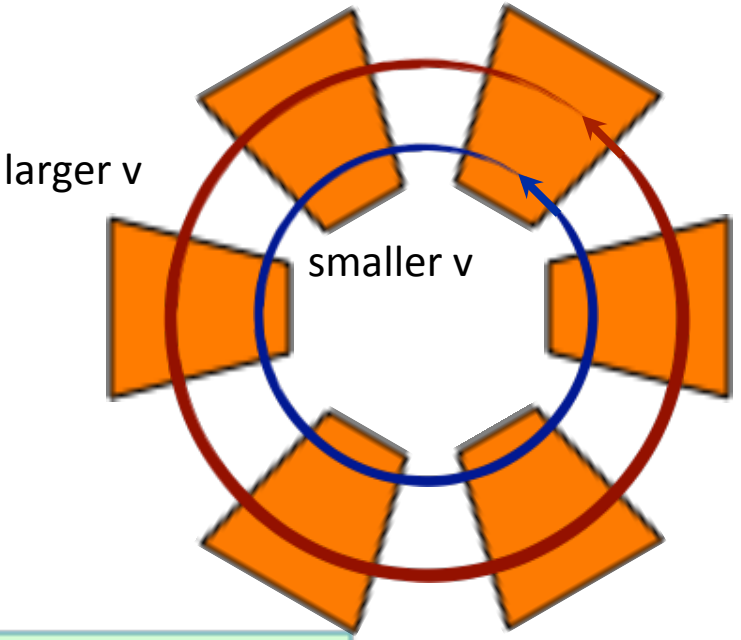

Stage
h=3.3m
Injection
Septum
Injection line
SHARAQ
KEK-PS-Q
Hexagonal-Symmetry
Weak-Focusing Lattice Structure
Kicker
system
Extraction
Septum
TARNII Dipole
RI beam
Transmission cable
of trigger signal
~95m from BigRIPS-F3

Rare-RI Ring

- Principle of mass measurements

Cyclotron → Isochronous field

$$f_c = \frac{1}{2\pi}\frac{qB}{m}$$



10^{-6} precision in mass

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

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

Large acceptance

Velocity measurements are essential!

Uncertainty of mass

desired accuracy : $\delta m_1/m_1 \sim 10^{-6}$

$$\frac{\delta(m_1/q_1)}{m_1/q_1} = \frac{\delta(m_0/q_0)}{m_0/q_0} + \frac{\delta(T_1/T_0)}{T_1/T_0} + k\frac{\delta\beta_1}{\beta_1}$$

Well-known Reference Mass ~ 10^{-6}

TOF (T_0, T_1) Measurement ~ 10^{-6}
T ~ 700μs (2000turns)
δT ~ 100ps

k~10^{-2}

$$k = -\frac{\beta_1^2}{1-\beta_1^2} + \left(\frac{T_1}{T_0}\right)^2 \frac{\beta_1^2}{1-(T_1/T_0)^2\beta_1^2}$$

β_1 Measurement ~ 10^{-4}

Isochronism of ~10^{-6} is required during measurement

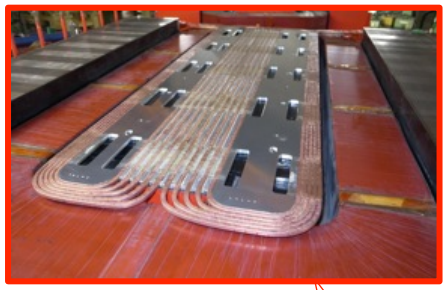
Mass measurements of exotic nuclei at R3

IMS (isochronous mass spectrometry) + New technique

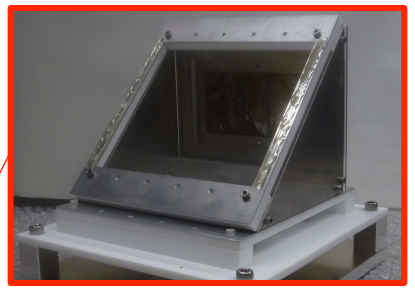
- **Individual injection : Store 1 particle!**
  - ✓ Fast kicker system
  - ✓ Long beam line
  - ✓ Particle identification event-by-event
  - ✓ Emittance (velocity) correction

- **Cyclotron-type storage ring**
  - ✓ Weak focusing lattice
  - ✓ Large momentum acceptance
  - ✓ Large dispersion
  - ✓ Precision isochronous field by trim coils

R3: Cyclotron-like Lattice Structure



Sector magnets
with 10 trim coils



C-Foil timing
detector

Injection septum magnets

(Start)

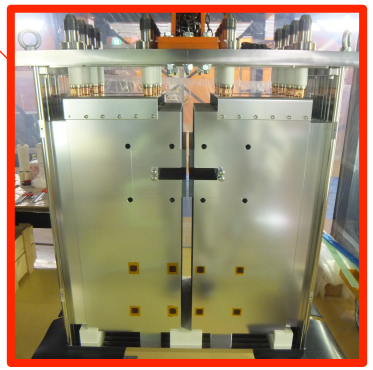
Injection beam line

Sector magnets

Extraction
septum magnets

(Stop
and PID)

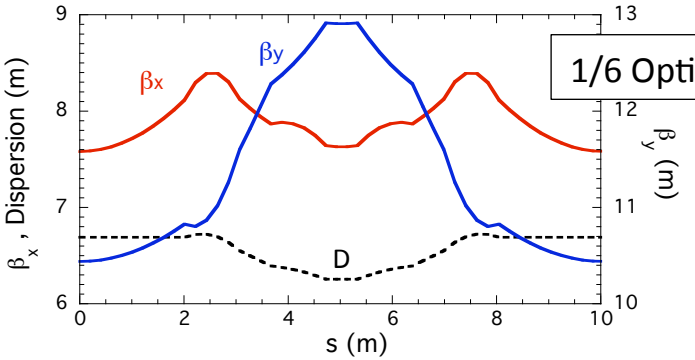
Cavity-type
Schottky pickup



Fast-response
Kicker magnets

Hexagonal-Symmetry
Weak-Focusing Lattice Structure

Circumference : 60.3m



Tunes: 1.21 / 0.84

Acceptance :

Momentum $\Delta P/P=\pm 0.5\%$

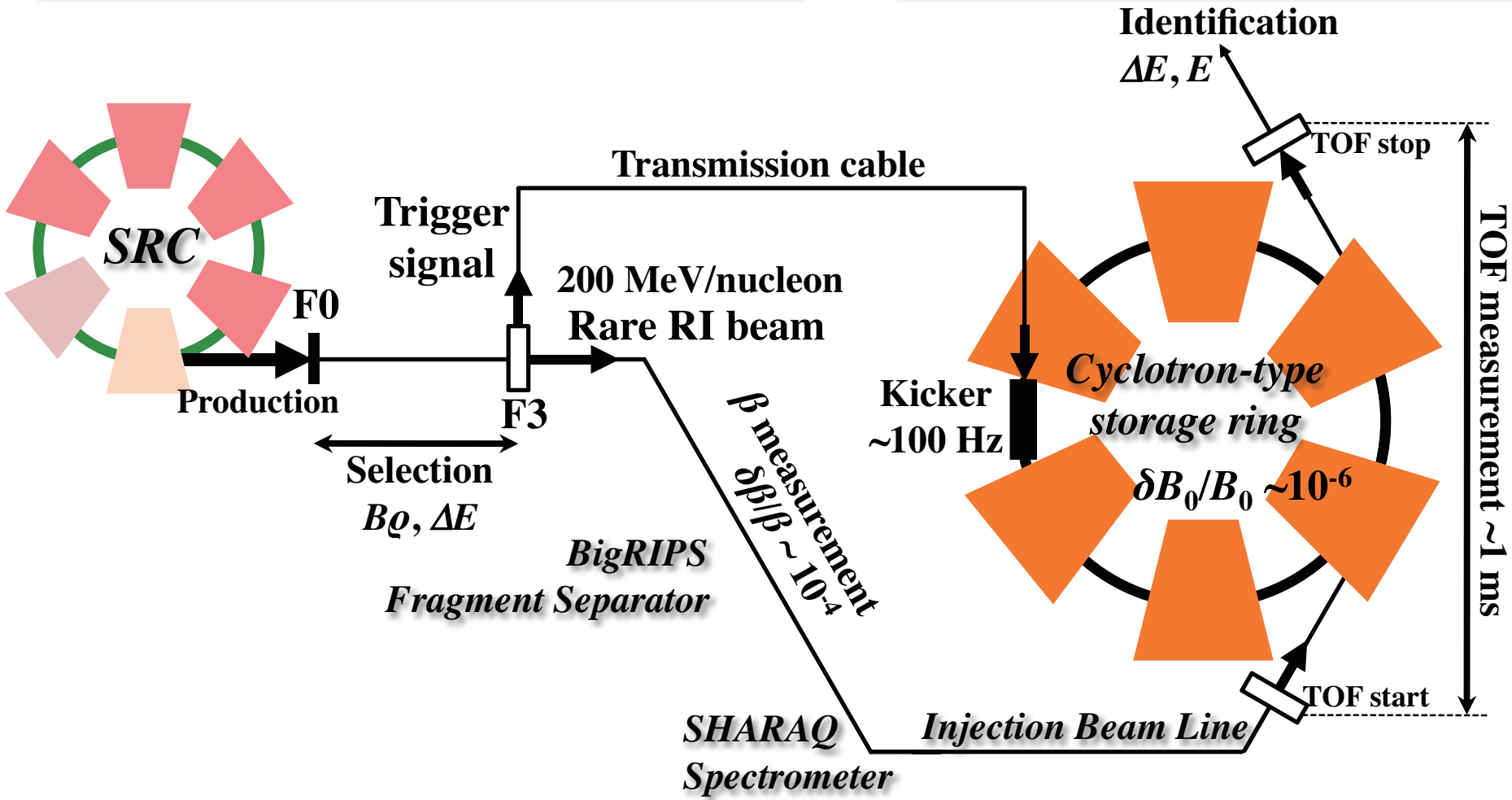
Transverse 20π / 10π mm mrad

Scheme for Mass Measurements

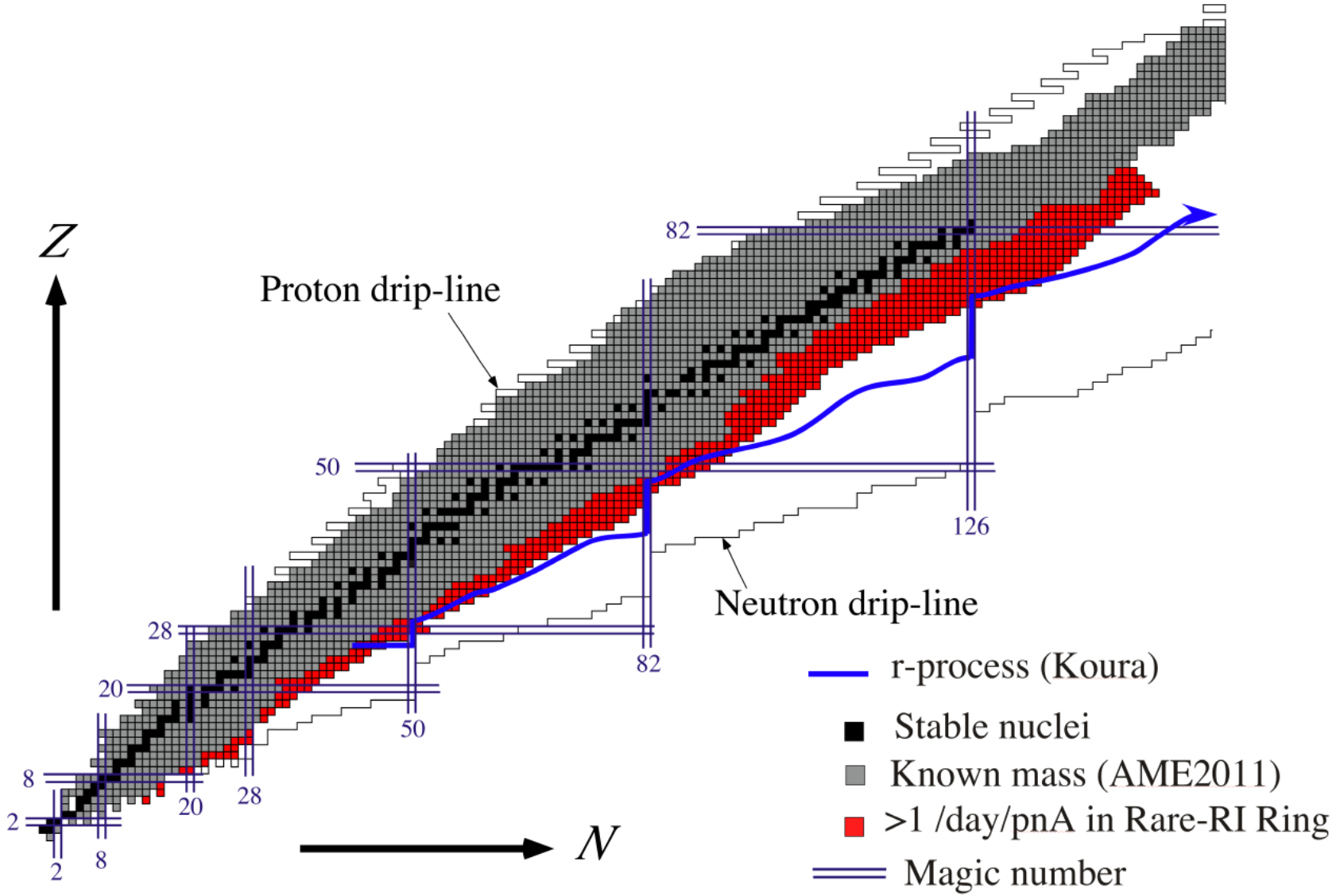
Only 1 particle (200 *A* MeV) is stored !

Isochronous mass spectrometry
- Isochronous field ~10^{-6}
- Beam-triggered individual injection

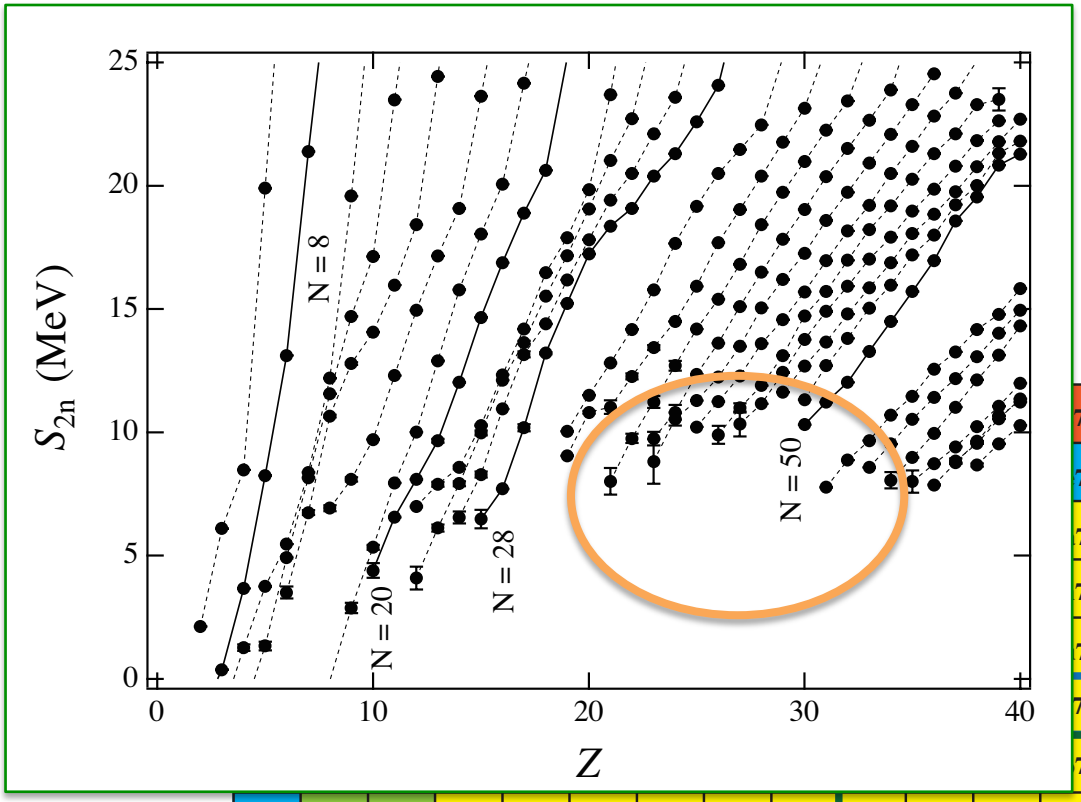
→ Short measurement time (<1 ms)
Good resolution (~10^{-6})
High efficiency (~100%)



Accessible Area by Rare-RI Ring



Day-1: ^{78}Ni doubly magic



																				Kr86	Kr87	Kr88	Kr89	Kr90			
															Br81	Br82	Br83	Br84	Br85	Br86	Br87	Br88	Br89				
														Se80	Se81	Se82	Se83	Se84	Se85	Se86	Se87	Se88					
												77	As78	As79	As80	As81	As82	As83	As84	As85	As86	As87					
												76	Ge77	Ge78	Ge79	Ge80	Ge81	Ge82	Ge83	Ge84	Ge85	Ge86					
												75	Ga76	Ga77	Ga78	Ga79	Ga80	Ga81	Ga82	Ga83	Ga84	Ga85					
												74	Zn75	Zn76	Zn77	Zn78	Zn79	Zn80	Zn81	Zn82	Zn83	Zn84					
												73	Cu74	Cu75	Cu76	Cu77	Cu78		Cu80	Cu81	Cu82	Cu83					
												72	Ni73	Ni74	Ni75	Ni76	Ni77	Ni78	Ni79	Ni80	Ni81	Ni82					
												71	Co72	Co73	Co74	Co75	Co76		Co78	Co79	Co80	Co81					
		Fe58	Fe59	Fe60	Fe61	Fe62	Fe63	Fe64	Fe65	Fe66	Fe67	Fe68	Fe69	Fe70	Fe71	Fe72	Fe73	Fe74	Fe75	Fe76	Fe77	Fe78	Fe79	Fe80			
Mn55	Mn56	Mn57	Mn58	Mn59	Mn60	Mn61	Mn62	Mn63	Mn64	Mn65	Mn66	Mn67	Mn68	Mn69	Mn70	Mn71	Mn72	Mn73	Mn74	Mn75	Mn76	Mn77	Mn78	Mn79			
Cr54	Cr55	Cr56	Cr57	Cr58	Cr59	Cr60	Cr61	Cr62	Cr63	Cr64	Cr65	Cr66	Cr67	Cr68	Cr69	Cr70	Cr71	Cr72	Cr73	Cr74		Cr76		Cr78			
V53	V54	V55	V56	V57	V58	V59	V60	V61	V62	V63	V64	V65	V66	V67	V68	V69	V70	V71	V72	V73		V75					
Ti52	Ti53	Ti54	Ti55	Ti56	Ti57	Ti58																					
Sc51	Sc52	Sc53	Sc54	Sc55	Sc56	Sc57																					
Ca50	Ca51	Ca52	Ca53	Ca54	Ca55	Ca56																					

4×10^{-5} cps/pnA

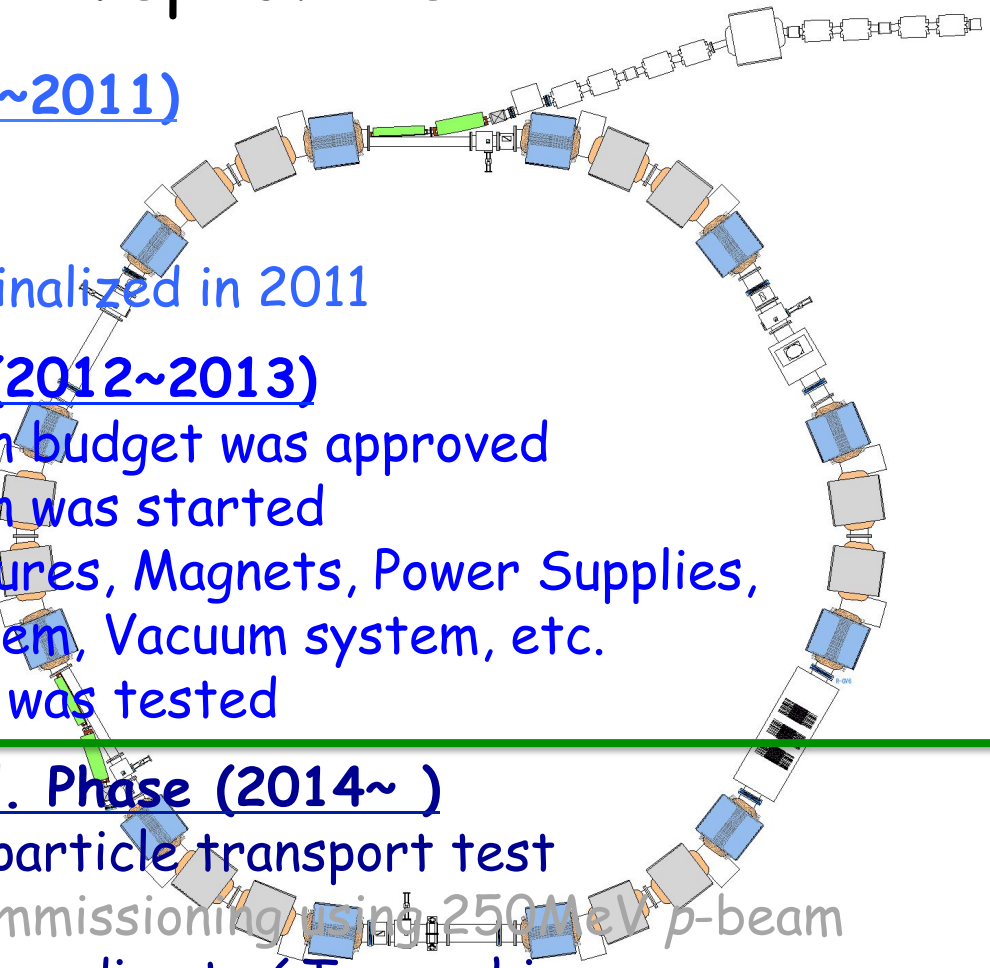
~3 events/day/pnA in Rare-RI ring

Status and Perspectives

Short History

1st. Phase (2002~2011)

Design study
R&D study
Ring design was finalized in 2011



2nd. Phase (2012~2013)

Construction budget was approved
Construction was started
Infrastructures, Magnets, Power Supplies,
Control system, Vacuum system, etc.
Each device was tested

3rd. Phase (2014~)

We are here

α-particle transport test
Commissioning using 250MeV p-beam
Upgrading to 6Tm machine
Construction of field-stabilization system
Improving detector system

2015~

- Commissioning using heavy-ion beams
- 1st Production run, mass measurements

稀少RIリング(R3)の中長期的展望（まとめ）
―R-process質量測定の観点から―

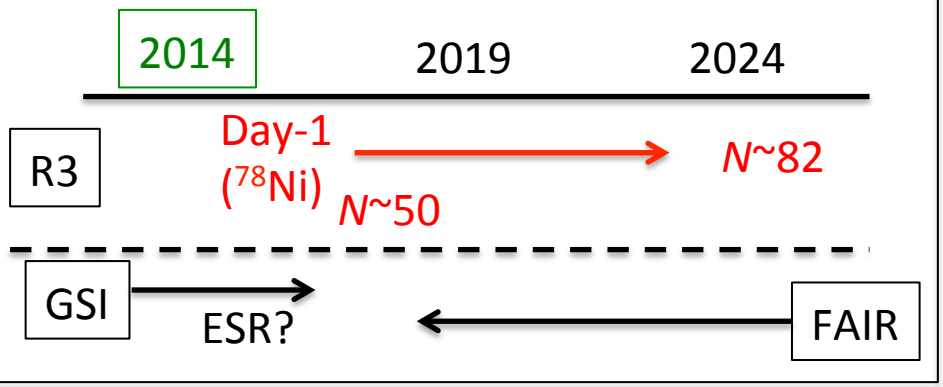
Boundary

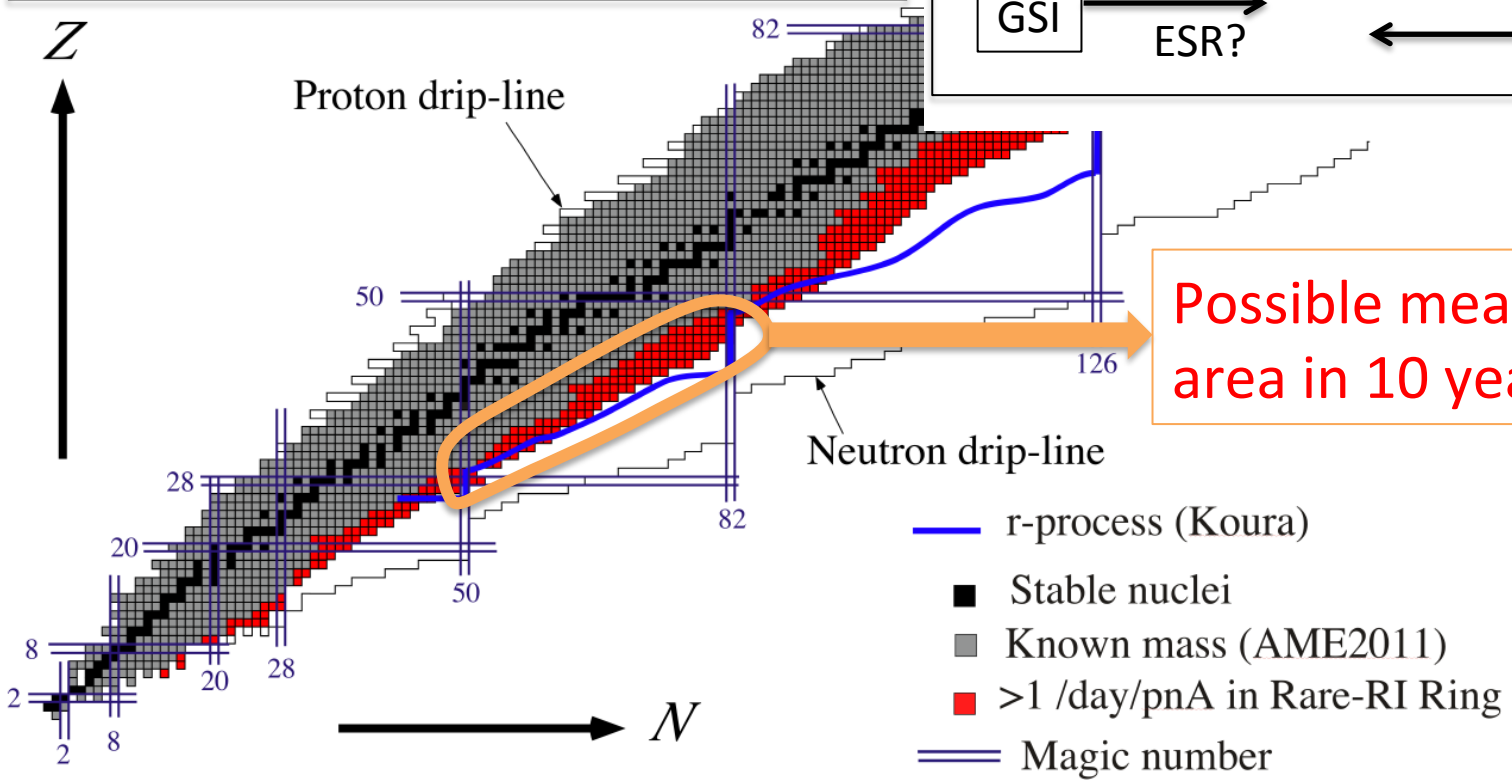
MT in RIBF: 2 weeks/year (max.)

→ ~5 new mass / year

→ ~50 new mass / 10 years

Possible schedule?





Possible measurements area in 10 years?