Advanced Research Center for Beam Science
– Particle Beam Science –

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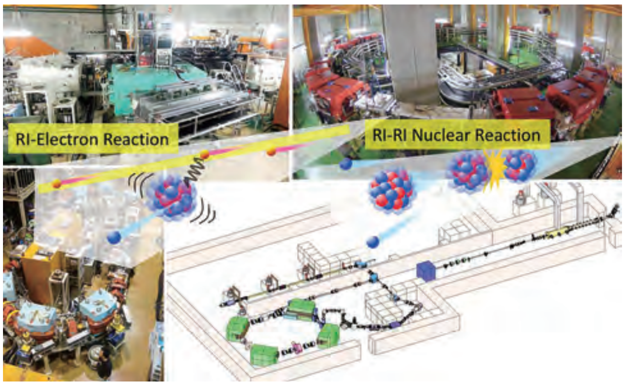
Scope of Research

One of our research is an experimental research for unstable nuclear structures by means of the electron and heavy-ion accelerators. We address the technical development in an RI beam production driven by a high-energy electron beam, an electron scattering from the RI's in combination with the RI target inserted in an electron storage ring, and the precision mass measurement for extremely short-lived and rare exotic nuclei using a heavy-ion storage ring. We will address some technical development aiming at a nuclear photo-absorption cross-section measurement and the beam recycling in a heavy-ion storage ring to study the nuclear reactions involving rare exotic nuclei.

KEYWORDS

Beam Physics
Accelerator Physics
Unstable Nuclear Physics
Storage Ring
Electron Linac



Recent Selected Publications

Li, H. F.; Naimi, S.; Sprouse, T. M.; Mumpower, M. R.; Abe, Y.; Yamaguchi, Y.; Nagae, D.; Suzaki, F.; Wakasugi, M.; Arakawa, H.; Dou, W. B.; Hamakawa, D.; Hosoi, S.; Inada, Y.; Kajiki, D.; Kobayashi, T.; Sakaue, M.; Yokoda, Y.; Yamaguchi, T.; Kagesawa, R.; Kamioka, D.; Moriguchi, T.; Mukai, M.; Ozawa, A.; Ota, S.; Kitamura, N.; Masuoka, S.; Michimasa, S.; Baba, H.; Fukuda, N.; Shimizu, Y.; Suzuki, H.; Takeda, H.; Ahn, D. S.; Wang, M.; Fu, C. Y.; Wang, Q.; Suzuki, S.; Ge, Z.; Litvinov, Yu. A.; Lorusso, G.; Walker, P. M.; Podolyak, Zs.; Uesaka, T., First Application of Mass Measurements with the Rare-RI Ring Reveals the Solar r-Process Abundance Trend at A = 122 and A = 123, *Phys. Rev. Lett.*, **128,** 152701 (2022).

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Nagae, D.; Abe, Y.; Okada, S.; Omika, S.; Wakayama, K.; Hosoi, S.; Suzuki, S.; Moriguchi, T.; Amano, M.; Kamioka, D.; Ge, Z.; Naimi, S.; Suzaki, F.; Tadano, N.; Igosawa, R.; Inomata, K.; Arakawa, H.; Nishimuro, K.; Fujii, T.; Mitsui, T.; Yanagisawa, Y.; Baba, H.; Michimasa, S.; Ota, S.; Lorusso, G.; Litvinov, Yu. A.; Ozawa, A.; Uesaka, T.; Yamaguchi, T.; Yamaguchi, Y.; Wakasugi, M., Development and Operation of an Electrostatic Time-of-Flight Detector for the Rare RI Storage Ring, *Nucl. Instrum. Meth. A*, **986,** 164713 (2021).

Omika, S.; Yamaguchi, T.; Tadano, N.; Abe, Y.; Amano, M.; Ge, Z.; Kamioka, D.; Moriguchi, T.; Nagae, D.; Naimi, S.; Ozawa, A.; Suzaki, F.; Suzuki, S.; Suzuki, T.; Uesaka, T.; Wakasugi, M.; Wakayama, K.; Yamaguchi, Y., Development of a New in-Ring Beam Monitor in the Rare-RI Ring, *Nucl. Instrum. Meth. B*, **463,** 241 (2020).

Analytical Formalization of Beam Recycle Operation at RUNBA

A compact heavy ion storage ring RUNBA (Recycled Unstable Nuclear Beam Accumulator) is under construction at the RIKEN RI Beam Factory in collaboration with ICR. It aims to develop beam recycling techniques, which will provide a new tool for precise nuclear reaction studies, especially for rare radioactive nuclides (RIs). It is assumed that a few RIs are accumulated in a RUNBA with an internal target and the RIs hit the target many times until a nuclear reaction occurs. This is a beam recycling, which is established by compensating the energy loss, energy straggling, and angular straggling. Therefore, the RUNBA will be equipped with a radio-frequency cavity, an energy dispersion corrector (EDC) and an angular diffusion corrector (ADCh, ADCv). These devices correctly modulate the beam motion in 6D phase space on a turn-by-turn basis. Assuming a thin internal target, beam information such as the timing and position of the beam as it passes through the target can be obtained. The beam information is converted into correction signals, which are transported to each corrector in synchronization with the arrival of the beam. As this is the first time such a process has been attempted in a storage ring, we formulate analytical equations describing the beam motion under the above configuration and situation.

The beam motion is described by a Hamiltonian with canonical variables q and p, and the invariant of motion is defined as $W(q, p)$. The target changes the variables stochastically and the correctors change them compensatory manner. Including those effect, the change of the invariants is expressed as $\Delta W = W(q+\Delta q, p+\Delta p) - W(q, p)$. The time differential equation is obtained from it divided by the revolution time T. Assuming the probability density function $\Psi(\Delta p)$ for straggling at the target and $\phi(\delta)$ for uncertainty in the beam information measurement, averaged differential coefficient is expressed as

$$\langle \frac{dW}{dt} \rangle = \frac{1}{T} \iint \Delta W \psi(\Delta p) \phi(\delta) d\Delta p d\delta \quad .$$

The numerical values in (q, p) phase space are shown in Fig. 1(a) for transverse case and Fig. 2(a) for longitudinal. Since this value depends on the position (q, p), it should be averaged in the acceptance of RUNBA as

$$\Lambda(\kappa) = \frac{1}{S} \iint \langle \frac{dW}{dt} \rangle dq dp \quad ,$$

where S is a volume of the acceptance and κ is a parameter of the correction at EDC and/or ADC. An example of $\Lambda(\kappa)$ for transverse motion is shown in Fig. 1(b) and that for longitudinal motion is shown in Fig. 2(b) in the case of 10-MeV/u $^{12}C^{6+}$ beam accumulated in RUNBA with 10^{18}/ cm^2-thick ^{12}C target. The calculations show that the minimum correction required to maintain beam circulation is κ - 3 μrad/mm and that a technically realistic ADC field of 2 kV/m gives an adequate correction.

We formulated the Fokker-Planck equation for the beam recycling process to reveal the time evolution of the probability density distribution $f(W, t)$ of circulating particles in phase space. That for transverse motion is expressed as

$$\frac{\partial f(W,t)}{\partial t} = -\frac{\partial f(W,t-\Delta t)}{\partial W} F(W,\kappa) + \frac{\partial^2 f(W,t-\Delta t)}{\partial W^2} D(W,\kappa) \ ,$$

where β is a beta function at the target, $V(\kappa)$ a function of the correction parameter, σ_t a standard deviation of the straggling. The friction term is expressed as $F(W, \kappa) = \{\beta\sigma_t^2 + V(\kappa)W\} \ / \ T$, and the diffusion coefficient as $D(W, \kappa) = \{3\beta^2\sigma_t^4 + 2\beta\sigma_t^2 V(\kappa)W + V(\kappa)^2 W^2\} \ / \ 2T$. This formulation completely generalizes the beam recycle process, which is new concept.

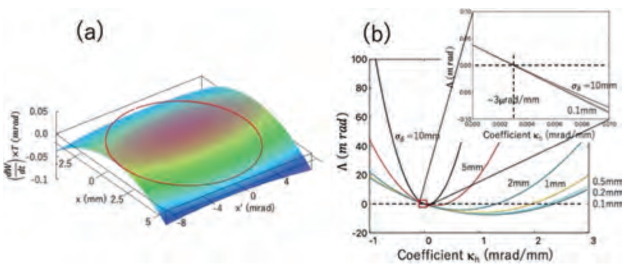

Figure 1. (a) Numerically calculated averaged time differential coefficient <dW / dt> in transverse phase space and (b) $\Lambda(\kappa)$ values as a function of ADC correction in some cases of beam information measurement uncertainty.

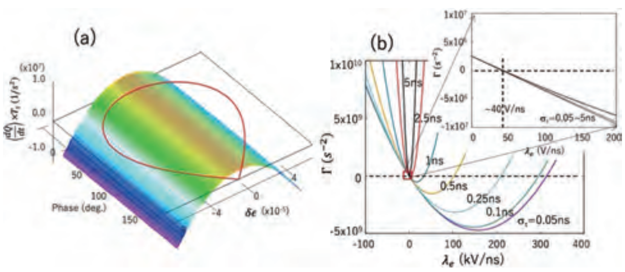

Figure 2. (a) Numerically calculated averaged time differential coefficient <dQ / dt> in longitudinal phase space and (b) $\Gamma(\kappa)$ values as a function of EDC correction in some cases of beam information measurement uncertainty.