Performance of a precise isochronous magnetic field over a wide momentum range in the Rare-RI Ring†

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The nuclear masses of exotic nuclei located around the expected r-process path are crucial for understanding nucleosynthetic scenarios. Obtaining nuclear masses is always challenging because of the short lifetimes (10 ms or less), extremely small production rates, large momentum spread, and large transverse emittance of radioactive isotope (RI) beams. The storage ring is required to provide a large momentum and transverse emittance acceptance to accept hot RI beams from the fragment separator. The "Rare-RI Ring (R3)" has been designed as a cyclotron-like structure for satisfying these requirements. This cyclotron-like structure enables a high-precision isochronism over a wide momentum range, which results in more efficient measurements. A horizontally nonuniform magnetic field is generated by 10 trim coils to achieve the isochronous condition.

The isochronism and acceptance were evaluated using a particle-tracking simulation based on the fourth-order Runge-Kutta calculation under a realistic magnetic structure. The tracking calculations for particles with finite emittance were performed under an isochronous condition. Although some higher-order (more than the fifth order) components remained, the precision of the isochronism of 0.9 ppm standard deviation was obtained from the practical trim coil currents.

Further, we performed the commissioning experiment to evaluate the performance of R3. We selected the $^{78}Ge^{32+}$ nucleus with an energy of 175 MeV/nucleon as the reference. Five isotones with neutron number $N = 46$, ^{75}Cu, ^{76}Zn, ^{77}Ga, and ^{79}As, were successfully injected and extracted. Figure 1 shows events in the $(dp/p, (t-t_0)/t_0)$ plane for all isotones measured in this experiment. Isochronism was evaluated from the width of the revolution time distribution for ^{78}Ge to be

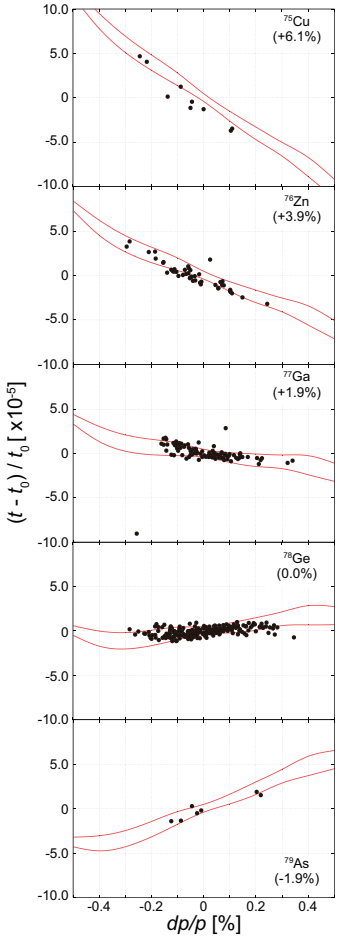

Fig. 1. Correlations between revolution time $(t-t_0)/t_0$ and momentum difference dp/p relative to the central momentum for each nucleus. Here, t_0 represents the mean value of the revolution time for ^{78}Ge and t represents the revolution time of each particle. The red solid lines indicate the expected region from the simulations including the fluctuation of the magnetic field. The values in percentage are relative differences of m/q with respect to the reference nucleus ^{78}Ge.

4.7×10^{-6} for the standard deviation. As an expected relationship, $(t-t_0)/t_0$ for ^{79}As demonstrated a positive correlation, whereas the others showed a negative correlation. The experimental data are well explained by the simulation. We can understand the performance of R3 with the simulations and found that R3 performed as designed.

Developments are in progress to achieve an 1-ppm isochronous window. In the near future, high-precision mass measurements of rare RIs will be started.

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