Direct mass measurements of fp-shell nuclei near the proton dripline

S. Hanai,[*1] S. Michimasa,[*1] N. Imai,[*1] R. Yokoyama,[*1] D. S. Ahn,[*2] M. Amitani,[*3,*4] H. Baba,[*4] T. Chillery,[*1] M. Dozono,[*5,*4] F. Endo,[*6,*4] M. Fukuda,[*7,*4] N. Fukuda,[*4] C. Fukushima,[*3,*4] M. Fukutome,[*7,*4] T. Haginouchi,[*6,*4] S. Hayakawa,[*1] Y. Hijikata,[*5,*4] J. W. Hwang,[*2] E. Ideguchi,[*8,*4] S. Ishio,[*6,*4] N. Iwasa,[*6,*4] K. Kameya,[*6,*4] K. Kawata,[*1] R. Kojima,[*1] K. Kusaka,[*4] J. Li,[*1] Y. Nakamura,[*3,*4] H. Nishibata,[*9,*4] D. Nishimura,[*3,*1,*4] K. Okawa,[*1] S. Ota,[*8,*1] D. Suzuki,[*4] H. Suzuki,[*4] T. Saito,[*1] Y. Shimizu,[*4] S. Shimoura,[*1,*4,*8] T. Sumikama,[*4] H. Takahashi,[*3,*4] H. Takeda,[*4] H. Tanaka,[*9,*4] M. Tanaka,[*4] T. Teranishi,[*9,*4] T. Tomiyama,[*3,*4] T. Uesaka,[*4] R. Urayama,[*6,*4] K. Yako,[*1] Y. Yanagisawa,[*4] K. Yoshida,[*4] and M. Yoshimoto[*4]

Certain nuclei near the proton dripline are known to undergo decay through proton emission rather than β^+ or α decays. The phenomenon of two-proton radioactivity ($2p$ decay), where two protons are simultaneously emitted during nuclear decay, was theoretically predicted over 60 years ago[1] and was eventually discovered in proton-rich nuclei such as ^{45}Fe[2,3] and ^{48}Ni[2] in the early 2000s. The energy level structure and one- and two-proton separation energies must be understood for the evaluation of the probability for two protons tunneling simultaneously through the Coulomb and centrifugal potential. The separation energies can be directly determined from the mass differences with one- and two-proton removal nuclei. Therefore, systematic mass measurements around the $2p$ radioactive nuclei are essential for comprehending the emission mechanism of two protons from a nucleus.

We conducted direct mass measurements of proton-rich fp-shell isotopes near the proton dripline, including ^{45}Fe, using the TOF-$B\rho$ technique[4] at the OEDO-SHARAQ. A schematic of the beamline is shown in Fig. 1. Proton-rich isotopes were produced by the fragmentation of the ^{78}Kr primary beam at 345 MeV/nucleon in a ^{9}Be target with a thickness of 2.2 g/cm^2. The fragments were separated via the BigRIPS separator and transported to the OEDO beam line followed by the SHARAQ spectrometer. The time-of-flight (TOF) was measured using diamond detectors[5] installed at the focal planes F3 and S2. Two multiwire drift chamber (MWDC) tracking detectors[6] were also installed at both F3 and S2 to correct the flight-path length. To measure the $B\rho$ value, a strip-readout parallel-plate avalanche counter (SR-PPAC), newly developed for measuring high-rate heavy-ion beams,[7] was used at the intermediate focal plane S0. A silicon strip detector (SSD) was mounted at S2 to identify the atomic numbers of beam ions. Further, gamma-ray detection systems were placed after S2 to identify isomers, which could shift the peak in the measured mass spectra. The measurements were performed using a combination of these state-of-the-art detectors and the high-resolution performance of the OEDO-SHARAQ dispersion-matching mode, which had a momentum resolution of 1/15000.[8]

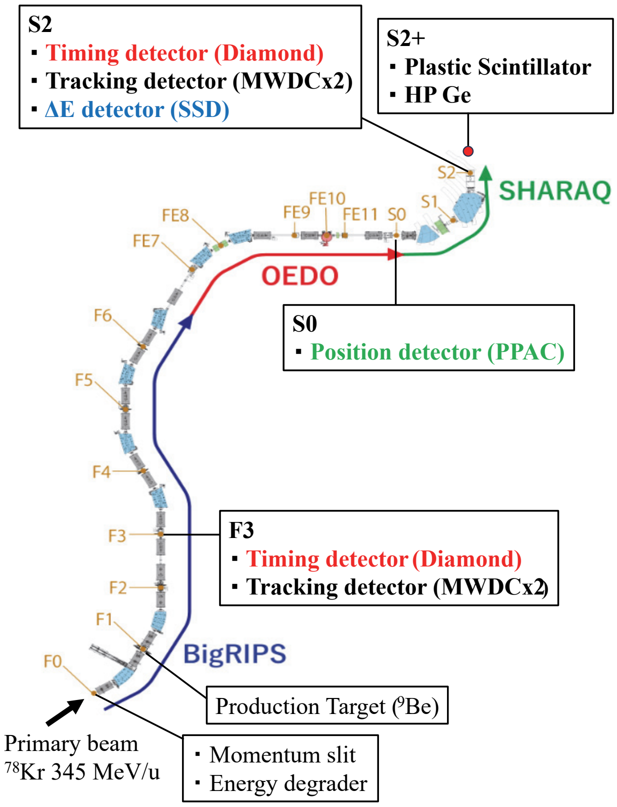

Fig. 1. Schematic of the beamline and detector configuration used for mass measurement.

Figure 2 presents the preliminary mass spectrum obtained from the current measurements. The horizontal and vertical axes represent mass-to-charge ratio and yields, respectively. The obtained spectrum included proton-rich Ti, Cr, Fe, and Ni isotopes in the vicinity of the proton dripline. The known masses of isotopes measured simultaneously, labeled by $A = 2Z-1$,

*1 Center for Nuclear Study, University of Tokyo
*2 Center for Exiotic Nuclear Studies, Institute for Basic Science
*3 Department of Natural Sciences, Tokyo City University
*4 RIKEN Nishina Center
*5 Department of Physics, Kyoto University
*6 Department of Physics, Tohoku University
*7 Department of Physics, Osaka University
*8 Research Center for Nuclear Physics (RCNP), Osaka University
*9 Department of Physics, Kyushu University

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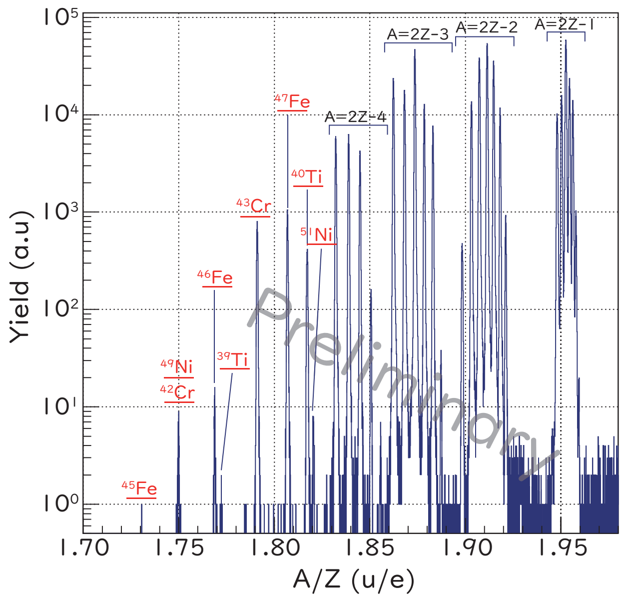

Fig. 2. Mass spectrum of the current measurements.

$2Z-2$, $2Z-3$, $2Z-4$, were utilized for calibrations of the atomic masses.

A detailed analysis is currently in progress, and the masses of underlined nuclei will be determined for the first time. The new insights into masses at the proton dripline from Ca to Ni isotopes from this experiment is expected to impact our understanding of nuclear structural evolution towards two-proton radioactivity.

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