Direct mass measurement of a $T_{1/2} = 10$ ms nucleus with a relative precision of 10^{-7} level

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Comprehensive mass measurement of all available nuclides is an important mission for nuclear physics, in particular for understanding astronomical nucleosynthesis. So far masses of 2300 nuclei were experimentally determined with relative precisions of better than 1 ppm while other 1000 nuclei were identified; however, the masses are still unknown.[1)] The half-lives of those unmeasured nuclei are distributed in a few orders of magnitude, but dominantly in 10–100 ms range (Fig. 1).

In the past, there were no universal mass spectrometers suited for very short-lived nuclei having half-lives of ≈10 ms if a relative precision of 10^{-7} level is required. We developed a multi-reflection time-of-flight (MRTOF) mass spectrograph[2)] to cover the *blanc zone* at the GARIS-II facility of RIBF. Fusion-evaporation products were separated from the primary beam by the gas filled recoil ion separator and the energetic RI-beams were then thermalized in a cryogenic gas cell. The thermal ions in the gas cell were extracted by a traveling wave rf carpet and accumulated in the two stages of a triplet rf ion trap system. The bunched ions in the trap were provided to the MRTOF for time of flight measurements. The main purpose of this setup was to measure relatively long-lived trans uranium elements such as Md or Es,[3)] so that the setting was not for quick extraction and short trap sequence. The average transport time from GARIS-II to MRTOF was about 30 ms. Even with this condition, we could measure the mass of ^{219}Ra having a half-life of 10 ms with a precision of 2×10^{-7}(Fig. 2).

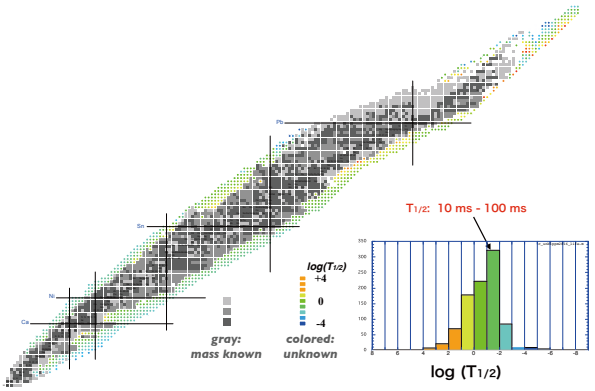

Fig. 1. Half-lives of mass unknown nuclides (colored ones). Gray boxes indicate masses known with better than 1 ppm precision but the light gray ones are indirectly measured nuclides. Insert shows distribution of half-life for mass unknown nuclides.

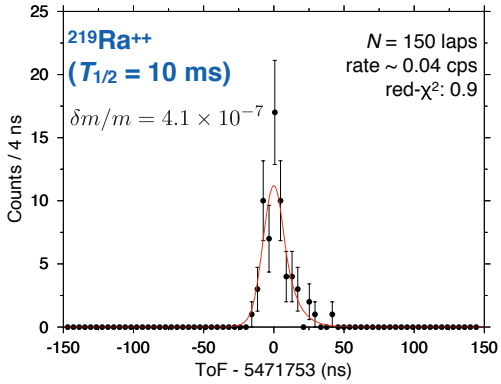

Fig. 2. ToF spectrum for $^{219}Ra^{2+}$ ions. A mass precision of 2×10^{-7} was achieved with four sets of spectra.

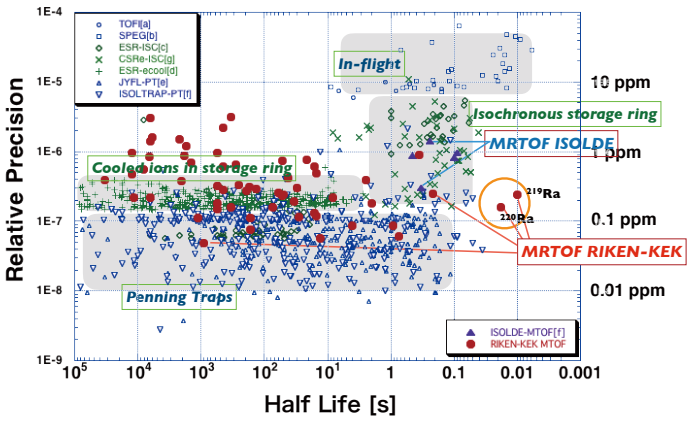

Fig. 3. Plot of mass precision as a function of the half-life with different mass measurement devices. With the MRTOF ≈80 nuclides were measured in FY2016–17.[3–6)]

Figure 3 shows correlations between the mass precisions and half-lives for various mass spectrometers. Present ^{219}Ra measurement placed a milestone at the *blanc zone*.

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