Measurement of muon spin rotation in muonic hydrogen atom

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A muonic atom is a bound-state consisting of a negative muon and a nucleus. The charge radius of the nucleus can be obtained by measuring the Lamb shift in a muonic atom. In 2010, the Lamb shift of muonic hydrogen (μp) measured at the Paul Scherrer Institute indicated a significantly smaller proton charge radius than previously known from hydrogen spectroscopy and electron-proton scattering.[1)]

In addition to the charge radius, the proton's size is expressed by the Zemach radius, which is defined by convolving the charge and magnetic moment distribution. The Zemach radius is derived from the hyperfine splitting (HFS), in contrast to the charge radius derived from the Lamb shift. For the Zemach radius, the consistency between muonic and electronic measurements has not been fully discussed due to muonic measurements' limited precision. To tackle this problem, we are preparing for laser spectroscopy of the ground-state HFS in μp atoms.[2)]

In the experiment, a circularly polarized laser beam excites μp atoms in the spin-singlet state to the spin-triplet one. However, excited μp atoms are quenched by spin-exchange collisions with protons.[3)] There is no experimental result of this hyperfine quenching rate for μp atoms; therefore, we performed a muon spin rotation (μSR) measurement using a low-density gaseous hydrogen target. Only μp atoms in the spin-triplet state show muon spin precession.

Figure 1 illustrates an experimental setup at Port 4 of the RIKEN-RAL muon facility. A pulsed negative muon beam irradiates hydrogen gas filled in an aluminum vessel. The momentum of the beam was set to 20 MeV/c. The gas pressure was 0.1 atm at room temperature. A transverse magnetic field of 66.7 mT was applied using a Helmholtz coil. Under these conditions, the quenching time of the triplet state and the spin precession period are expected to be 500 ns and 320 ns, respectively. The electrons from the muon decay were counted by a detector consisting of scintillating fibers and silicon photomultipliers (SiPMs). Kalliope front-end electronics[4)] processed the signal from the SiPM, and a multi-hit time-to-digital converter (TDC) recorded the time.

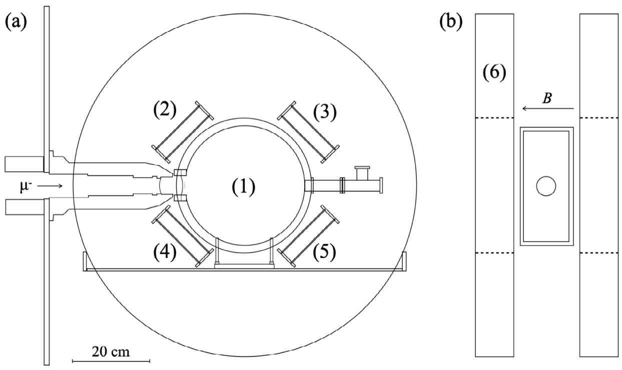

Fig. 1. Experimental setup: (a) cross-sectional view; (b) view from upstream. The numbers in the parentheses denote (1) hydrogen gas contained in an aluminum vessel, (2-5) electron detectors, (6) Helmholtz coils. Note that the electron detectors are not shown in (b).

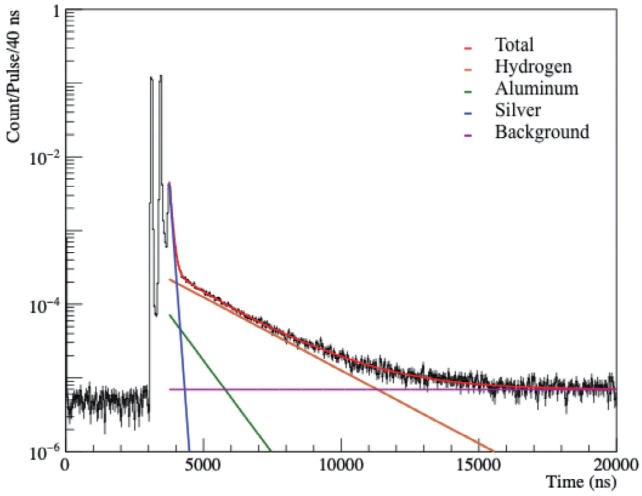

Fig. 2. Decay electron time spectrum with protium gas target at 0.1 atm. A transverse magnetic field of 66.7 mT was applied. Each line corresponds to the respective fitting result. The vertical axis is normalized by the number of beam pulses.

Figure 2 shows a decay electron time spectrum. The spectrum has components corresponding to hydrogen, aluminum, silver, and constant background events. The beam has a double-pulse structure with a 320 ns interval. The first two peaks of the spectrum correspond to prompt electrons. Detailed analysis to extract the μSR asymmetry is in progress.

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References

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