Precision measurement of muonium hyperfine splitting at J-PARC; development of high-rate positron detector

S. Kanda,[*1,*2] on behalf of J-PARC MuHFS Collaboration

Muonium is the bound state of a positive muon and an electron. In the standard model of particle physics, muonium is considered as the two-body system of structureless leptons.

At J-PARC, we plan to measure muonium's hyperfine splitting precisely. Our experiment has three major objectives: test of QED with the highest accuracy, precision measurement of the ratio of muon's magnetic moment to proton's magnetic moment, and search for CPT violation via the oscillation with sidereal variations.

The experimental methodology is microwave spectroscopy of muonium. Figure 1 shows the conceptual overview of the experiment. Spectroscopy of the energy states can be performed by measurement of positron decay asymmetry.

The uncertainty of the most recent experimental result[1] was mostly statistical (more than 90% of total uncertainty). Hence, improved statistics is essential for higher precision of the measurement. Our goal is to improve accuracy by an order of magnitude compared to the most recent experiment. For the improvement of precision, we use the J-PARC's highest-intensity pulsed muon beam and highly segmented positron detector with SiPM (Silicon PhotoMultiplier). After the improvement of statistical precision, reduction of systematic uncertainty becomes more important to reduce systematic uncertainty. Thus, we reduce the systematic uncertainty by using a longer cavity, a high-precision superconducting magnet, and an online/offline beam profile monitor.

The detector system consists of several layers of hodoscopes and fast readout circuits with custom ASIC and FPGA-based multi hit TDC. Important requirements of the positron detector are high event rate capability and high detection efficiency. The designed muon beam intensity at J-PARC MUSE H-Line is $1 \times 10^8\ \mu^+/\mathrm{s}$.

To establish the optimal design of the positron detector, we developed GEANT4-based Monte-Carlo simulation tools. Figure 2 shows a simulated muon stopping distribution in the target gas chamber. Under realistic conditions, the highest instantaneous event rate is about 3 MHz/cm^2. The resonance lineshape was calculated numerically, and the systematic uncertainty of the resonance frequency due to the detector specification was evaluated as a function of the detector performance. Based on the results of the simulation study, a new prototype of the detector is under development and a test experiment with high-intensity pulsed muon beam at J-PARC was performed in February of 2014.

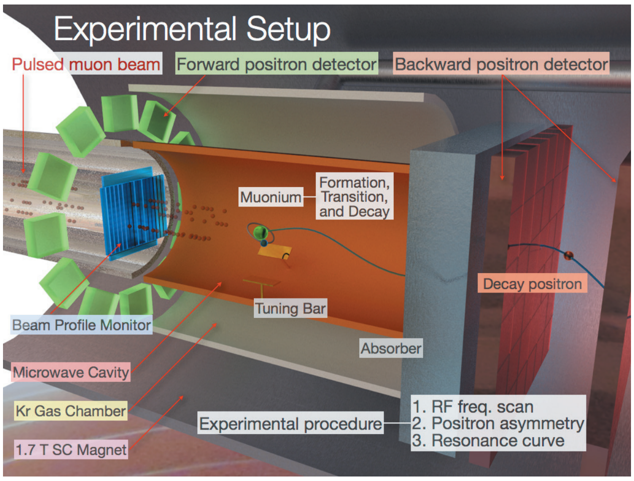

Fig. 1. Experimental overview

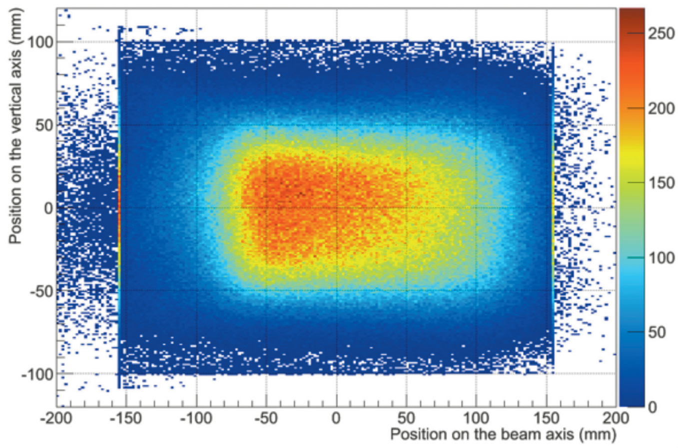

Fig. 2. Simulated muon stopping distribution

References
1) W. Liu et al.: PRL. 82, 711 (1999).
2) S. Kanda et al.: KEK-MSL Progress Report 2012B0117 (2013)
3) S. Kanda et al.: Proceedings of the USM2013 (to be published)

*1 RIKEN Nishina Center
*2 Department of Physics, University of Tokyo