FAMU experiment: studies on the muon transfer process in a mixture of hydrogen and higher Z gas

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The final objective of the FAMU experiment is to measure the proton Zemach radius by measuring the hyperfine splitting of the μp ground state[1),2)]. The experimental method requires a detection system suited for time resolved X-ray spectroscopy. The results of the first measurements performed at the RIKEN-RAL muon facility are presented in this paper.

The characteristic X-rays from muonic atoms formed in different targets have been detected using a HPGe detector and five scintillating counters based on LaBr3(Ce) crystals, whose output was recorded for 5 μs using a 500 MHz digitizer to measure both energy and time spectrum of the detected events. With a detailed pulse analysis, considering also the pile-up events, the expected characteristic X-rays and lifetimes of various elements were measured.

The measurement of the Zemach radius of the proton Rp was measured in ordinary hydrogen; therefore, a comparison with the value extracted from muonic hydrogen may reinforce or delimit the proton radius puzzle. In the proposed laser spectroscopy experiment[3),4)], muonic hydrogen atoms are formed in a hydrogen gas target. In subsequent collisions with H2 molecules, the μp de-excite to the thermalized μp in the (1S) F =0 state. A laser tuned on the HFS resonance induces singlet-to-triplet transitions; therefore, the μp atoms in the (1S) F =1 state are de-excited back to the singlet state and the transition energy is converted into additional kinetic energy of the μp system. Thus the μp atom gains about two-thirds of the hyperfine transition energy (≈ 120 meV).

The energy dependence of the muon transfer from muonic hydrogen to another higher-Z gas is exploited to detect the occurred transition in μp. Although in theory, the muon-transfer rate at low energies λpZ is energy independent, this is not the case for few gases. Oxygen[5),6)] exhibits a peak in the muon transfer rate λ_{pZ}^{epith} at the epithermal energy. Thus, by adding small quantities of oxygen to hydrogen, one can observe the number of HPF transitions, which take place from the muon-transfer events, by measuring the time distribution of the characteristic X-rays of the added gas.

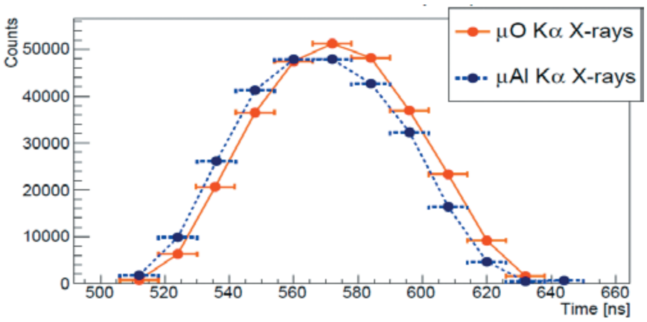

Fig. 1. Time difference between prompt signal (Aluminium X-rays) and delayed signal (Oxygen X-rays).

In the first FAMU experimental test, four different targets were exposed to the muon beam: a pure graphite block and three gas mixtures (pure H2, H2+2%Ar, H2+4%CO2) contained in an aluminum vessel. The aim was to study detector response in the environment of the muon beam at RIKEN-RAL through the measurement of the muon transfer rate at room temperature.

The characteristic X-rays of muonic atoms were detected using scintillating counters based on LaBr3(Ce) crystals (energy resolution 2.6% at 662 keV and decay time τ = 16 ns) readout by Hamamatsu R11265-200 PMTs and two HPGe detectors were used to obtain a benchmark spectrum. Hence, the waveforms were processed off-line to reconstruct the time and energy of each detected X-ray. By studying the differences between the time distribution (see Fig. 1) of prompt events, represented by X-rays originating from μAl atoms formed in the vessel and the delayed X-rays emitted by μO(Ar), atoms it was possible to measure the muon transfer rate from hydrogen to oxygen (argon). The results will be submitted for publication in an international journal.

At present, the collaboration is focussed on the measurement of the temperature dependence of the muon transfer rate by the mean of the cryogenic target in order to determine the best high-Z gas type, concentration and temperature. The experiment is on-going at RIKEN RAL. Figure 2 shows the top view of the apparatus. Beam pipe is on the left and the target is surrounded by the hodoscope, 9 LaBr3(Ce), four HPGe, and three lutetium aluminate detectors. Measurement of the Zemach radius with laser setup will be carried out in 2017.

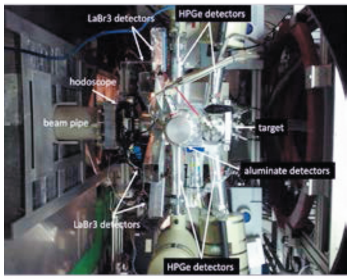

Fig. 2. FAMU, 2016 layout.

References

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