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Improvement of systematic uncertainties for the neutron lifetime experiment at J-PARC

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A neutron decays into a proton, an electron, and antineutrino in a lifetime of about 880 s. The neutron lifetime is one of the important parameters for particle physics and astrophysics. For instance, it dominates the uncertainty on 4He abundance in the Big Bang Nucleosynthesis and it also determines Vud term in the Cabibbo-Kobayashi-Maskawa quark mixing matrix. Although the neutron lifetime is very important in modern physics, there is a 4-sigma (8.5 s) discrepancy between the results of two typical methods: the beam method and the storage method. The beam method measures the neutron flux and decay protons by different detectors, and the storage method counts survival neutrons after some storage times. The discrepancy is called the neutron lifetime puzzle and is not yet settled. The possibility that unknown systematic errors and new physics such as dark decays are the cause has been discussed.
To solve the lifetime puzzle, a new neutron lifetime experiment with a different method is in progress at J-PARC. In this method, the neutron flux and decay electrons are measured simultaneously by a Time Projection Chamber (TPC) filled by working gas and 3He to evaluate the neutron flux. The systematic uncertainties are different from the previous beam method because we measure the decay electrons whereas the previous beam experiments measured decay protons. Our goal is to determine the neutron lifetime with accuracy of 1 s (0.1%).
This experiment published the first result of this experiment in 2020 as 898 +/- 10 (stat.) +15/-18 (sys.) s. Towards 1 s accuracy, improvements of the systematic uncertainties are essential. In this presentation, we report on the upgrades we have performed to reduce systematic uncertainties as follows:
1) 3He with pressure of about 100 mPa is used to measure the neutron flux. The 3He gas is injected into a smaller container with high pressure (~ 3 kPa), then released into the vacuum chamber in which the TPC is. The ratio of the small container and the vacuum chamber is necessary to be measured with high accuracy. We developed a measurement method of the volume ratio with higher accuracy by installing a new transducer with larger dynamic range. Working gas we are using is He and CO2, thus a small amount of 3He contains. To determine the 3He amount in the working gas, we developed a new method using 14N(n,p)14C reaction.
2) Space charges formed by ionized electrons reduce the gain of wire chambers. The space charge effect should be implemented in the Monte Carlo simulation to reproduce the energy loss distributions of the experiment which affect calibration discrepancy between simulation and experiment. We have implemented a new model of space charge effect and improved the reproducibility of energy loss distributions of beta decay and 3He(n,p)3H reaction.

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