# 論文の内容の要旨

## Measurement of the Neutron Lifetime by Counting the Beta Decay at J-PARC

## (J-PARC におけるベータ崩壊の計数による中性子寿命の測定)

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The neutron decays into the proton, the electron and the neutrino with lifetime of about 15 minutes. This is simple picture of semi-leptonic process mediating $W$ boson and the neutron lifetime is studied as a tool to probe the theory of weak interaction, cosmology and production of light nuclei in the early universe.

The neutron lifetime is derived from the measurement of the absolute neutron flux and number of neutron decay. For the precise measurement, key issues arise from high statistics, determination of the neutron flux and the reduction of the backgrounds. We performed the neutron lifetime measurement with the intense beam and low background condition. In this thesis, we report our first result of the measurement and analytic approaches are detailed.

The lifetime experiments are classified into two methods, depend on the way to count neutron decay. The first neutron lifetime measurement was performed by in-flight method. The neutron beam is passed through the decay volume and the neutron decay is measured by detecting the decay products. The in-flight method have an advantage in statistics, while the points at issue are precision of the measurement of beam flux and unpreferable background condition. The other one is called bottle method, where neutrons are stored in a bottle and the remaining neutrons are counted after a certain storage time. Although the important uncertainties are derived from non-beta decay losses, the storage technics have been improved recently and more experiments with high precision have been reported. There have been recent interests in improving the uncertainty on the neutron lifetime to below 0.1 %, because the observed values deviate by $3.8\,\sigma$ between two methods. As the point of view of systematical uncertainty, two methods are completely different and precise measurement with both approaches is beneficial.

Our experiment is conducted with accelerator based pulsed neutron beam at Japan Proton Accelerator Research Complex (J-PARC) and we have an advantage to increase the beam flux, while most of previous experiments were performed at research reactors. The pulsed proton beam hit the mercury target with repetition rate of 25 Hz, and the neutrons are derived from spallation reaction. At the beam power of 300 kW operation, we obtained $2.9 \times 10^7$ neutron/sec at the exit of the polarized beam branch.

The low background condition was established by originally developed time projection chamber (TPC) and by a new optical device called spin flip chopper (SFC). In common with in-flight method experiments, major problems are derived from the detection of the decay products. Our signal is the decay electron and significant backgrounds are generated by $(n, \gamma)$ reactions and radioactive sources. The sources of backgrounds have been reduced by applying the material called PEEK for TPC which is free from radioactive contamination. This is the first attempt in the usage for a gas chamber. Also, LiF tiles are installed inside TPC and that has great contribution to reduce the $(n, \gamma)$ reactions. In practical applications, our TPC is used as a calorimeter rather than a tracker.

Further, chopped neutron beam and time-of-flight method are applied to improve the signal-to-noise ratio. A single pulse is formed into five bunches and the neutrons in the range between $500 \sim 1200\,\mathrm{m/s}$ are provided. This is performed with SFC, which consists of spin flippers and magnetic super mirrors. The neutrons are polarized in the upstream, and SFC selectively reflects the neutron to TPC or beam dump depend on the neutron spin. When the neutrons are guided to beam dump, the intensity is about 1/400 compared with ones go to TPC, thus the leakage of neutron is highly suppressed. Consequently, we have achieved $1.7 \times 10^5$ neutron/sec inside TPC at the 300 kW operation.

It should be noted that our experiment is based on the in-flight method with a He-filled TPC proposed by ILL-ISL-LAPP collaboration and the beam flux is measured by detecting $^3\mathrm{He}(n,p)^3\mathrm{H}$ reaction. The uncertainties in the different beam flux and neutron velocity can be canceled because both of neutron decay and beam flux are measured with TPC simultaneously. Our TPC have been sealed after the gas introduction, therefore the amount of outgas would be gradually increased and it affects attenuation. Continuous data cumulation is restricted to about 10 days at longest in order to avoid the uncertainty in energy calibration.

We have carried out engineering data taking in 2014 and 2015 that correspond to two measurement series with a new gas mixture for each run, and established the procedure of analysis. The first physics data set have been taken in 2016 at the 170 kW operation. We employ the blind analysis to avoid the possibility of biasing, and $^3$He density was disclosed after the other analyses have been fixed. The backgrounds originated from neutron interactions were studied in detail and they were removed by data driven approach, as much as possible. Monte Calro (MC) simulation was used to estimate the efficiency and the backgrounds induced by neutron scattering. Combined with the engineering data, six series of measurements which correspond to 12 days of beam time, have been acquired. We present the obtained neutron lifetime,

$$\tau_n = 899 \pm 10\,(\mathrm{stat.}) \pm {}^{9}_{11}\,(\mathrm{syst.})\,\mathrm{sec.}$$

Our result showing the inclination for the in-flight method. Statistical and systematical errors account for about 1 % respectively. Most significant systematical error was generated in the process of separating the neutron decay and $^3\mathrm{He}(n,p)^3\mathrm{H}$ reaction and the accuracy of energy calibration was also accountable. As the future prospects, it is practically possible to improve the statistical accuracy by long-term operation at 500 kW. In addition, we have plans to upgrade the setup. Increased statistics can help to reduce some of systematical uncertainties, and also the uncertainties will be suppressed by improving the analytic methods.