# Neutron lifetime experiment with pulsed cold neutrons at J-PARC

Go Ichikawa (KEK)
On behalf of the J-PARC neutron lifetime collaboration

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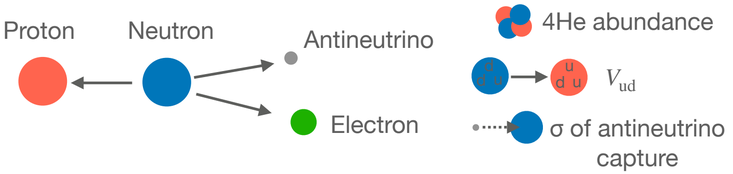
## Abstract

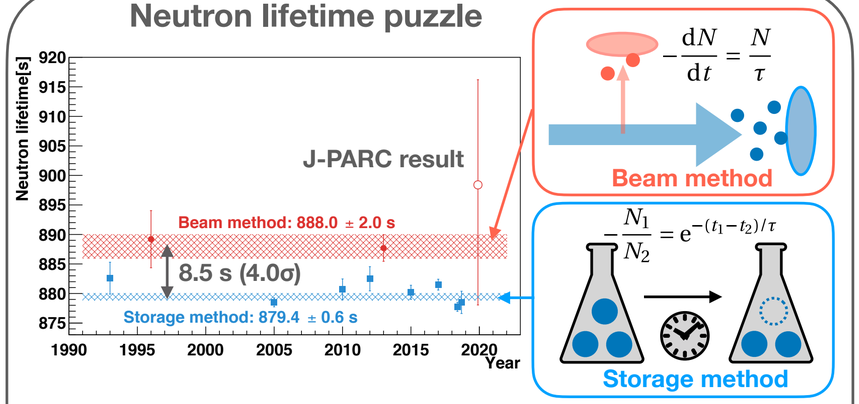
Neutron lifetime is one of the important parameters in modern physics, but there seems discrepancy between the result depending on experimental methods. This is called the neutron lifetime puzzle.
To solve the puzzle, we are aiming for 1 s (0.1%) accuracy by a new method using a Time Projection Chamber at J-PARC. Our first result was $898 \pm 10\,{}^{+15}_{-18}$ s.
We are now installing and testing a new neutron optics of 3 times flux to reduce both statistic and systematic errors.

## Neutron beta decay



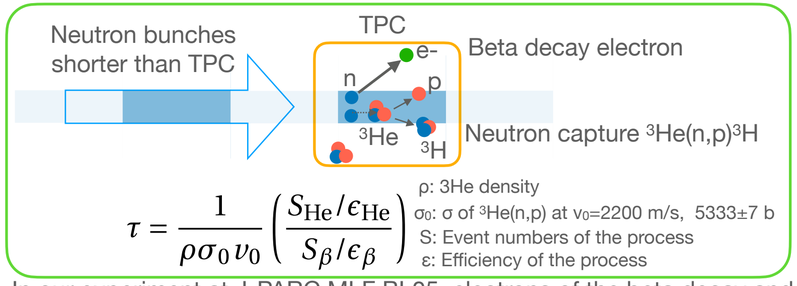

A free neutron decays into a proton, an electron, and an antineutrino with a lifetime of 879.4 ± 0.6 s (PDG2021).
Neutron lifetime is one of the important input parameters for both cosmology and particle physics: 4He abundance of Big Bang Nucleosynthesis, $V_{ud}$ of CKM matrix element, the cross section of antineutrino capture reaction, and so on.

## Neutron lifetime puzzle



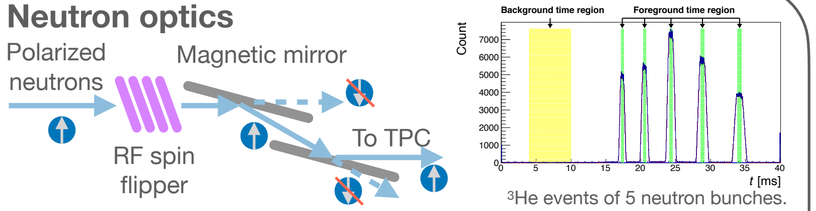

The neutron lifetime measurements were performed by beam or storage method. The central values of each method differ by 8.5 s (4.0σ).
This is called the "neutron lifetime puzzle", and it is still unsettled whether it is due to unconsidered systematic effects or any new physics.
If a neutron decays into undetectable particles (mirror neutron or dark particles) with 1% branching ratio, the puzzle can be solved.

## Neutron lifetime experiment at J-PARC




In our experiment at J-PARC MLF BL05, electrons of the beta decay and neutron capture events of $^3$He(n,p) are measured simultaneously by a Time Projection Chamber (TPC) filled with a $^3$He containing working gas. This method has a different systematic effect from that of other beam and storage experiments. Our goal is 1 s (0.1%) accuracy to solve the puzzle.

## Neutron optics

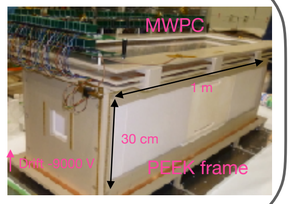



$^3$He events of 5 neutron bunches.

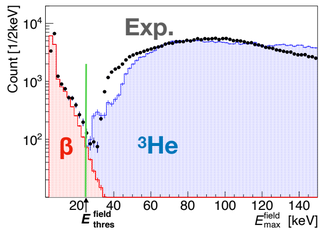
To reduce the background (BG) events, the pulsed neutron beam is chopped into bunches shorter than TPC by the Spin Flip Chopper (SFC). SFC chops the neutron beam by magnetic mirrors and spin flippers.

## TPC

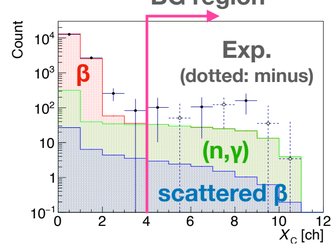
The TPC frame is made of PEEK and shielded by LiF to reduce (n,γ) BG. Ionized electrons are drifted upward to Multi-Wire Proportional Chamber (MWPC) above the TPC. The MWPC has 6 mm$^2$ meshes of anode/field and cathode wires to detect track positions. The waveform is recorded by FADC.




## Event selection




Max. energy deposit to wire (dE/dx).



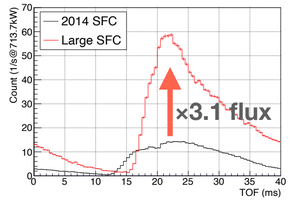

Distance btw. hit wire and center.

Detected events are classified by energy and topology. $^3$He events have large dE/dx. Most of the small dE/dx events are β but contaminated by BG. A topological cut is applied to estimate the amount of BG.

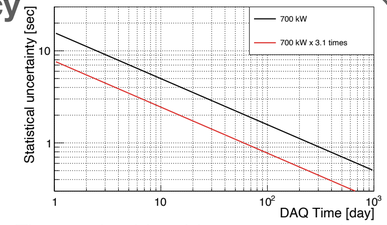
## First physics result

The data during 2014 and 2016 were analyzed. Our first result was $898 \pm 10\,{}^{+15}_{-18}$ s. The results of beam and storage methods were within the uncertainty of ours. The uncertainty was dominated by (n,γ) BG of +2/-14 s. Improvements of both statistic and systematic uncertainties are needed to achieve 1 s (0.1%) accuracy.

## Toward 1 s (0.1%) accuracy




Neutron flux before and after upgrade.




Time and achievable stat. uncertainty.

We installed large neutron optical devices and achieved 3.1 times neutron flux. 1 s (0.1%) statistic uncertainty can be achieved in 60 days. For reduction of systematics, the beam phase space was measured and a stricter cut will be applied thanks to higher statistics.