Neutron lifetime experiment using a pulsed neutron source at J-PARC

SCHOOL OF SCIENCE THE UNIVERSITY OF TOKYO

Neutron Optics and Physics

Takanori Mogi (The University of Tokyo) on behalf of the J-PARC neutron lifetime collaboration

Motivations

- Neutron decays into electron, proton and antineutrino ($n \to p + e^- + \bar{\nu_e}$) in $\boldsymbol{\tau_n = 878.4 \pm 0.5\ s}$ (PDG2022).
- Neutron lifetime dominates:
  - ^{4}He abundance in the Big Bang Nucleosynthesis
  - V_{ud} term of CKM matrix
- There is a discrepancy of **9.5 s (4.6σ)** between the results of two methods.

[PTEP 2022, 083C01]

- Beam method:

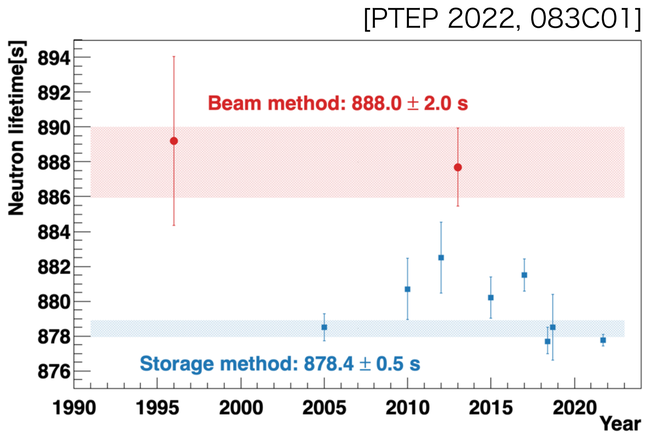
Measure **decay protons**

$$-\frac{dN}{dt} = \frac{N}{\tau}$$

- Storage method:

Count **survival neutrons**

$$\frac{N(t_1)}{N(t_2)} = \exp\left(-\frac{t_1 - t_2}{\tau}\right)$$



- The cause of this discrepancy is not yet settled.
- It is called **"Neutron Lifetime Puzzle"**. (Unknown systematics?, new physics?)
- New experiment with a **different method** is in progress.

Neutron lifetime experiment at J-PARC

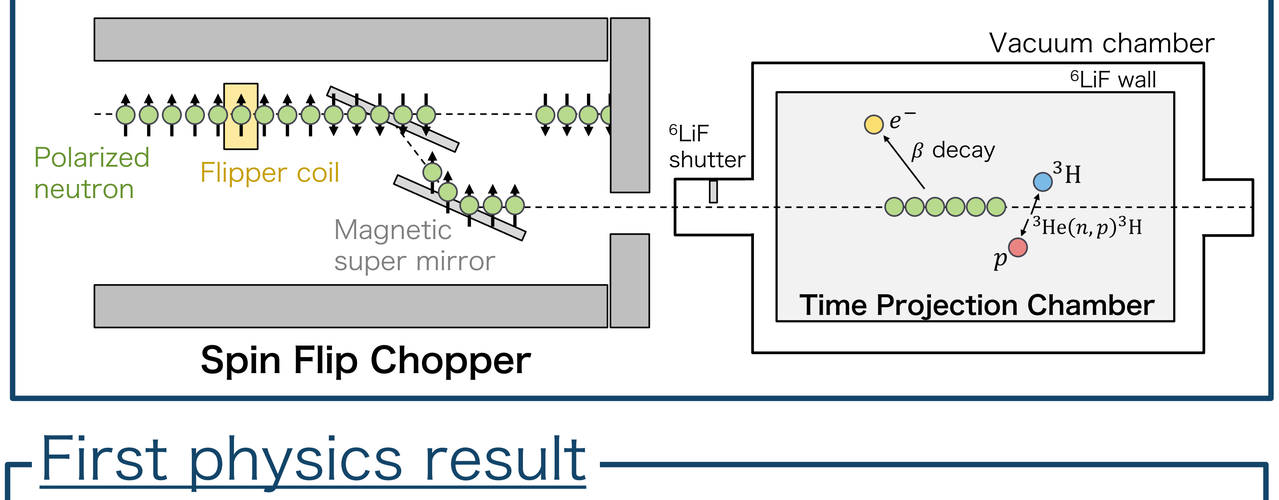
- Neutron lifetime experiment using pulsed neutron beam at J-PARC MLF BL05 (NOP) have been performed.
- The apparatus consists of two components:

■ **Spin Flip Chopper (SFC)**

- Divide polarized neutron beam into some bunches by flipper coils and magnetic supper mirrors.
- Bunches are shorter than the TPC and injected into the TPC.

■ **Time Projection Chamber (TPC)** [NIMA 799, 187-196]

- Consist of MWPC, PEEK flame, and **^{6}LiF internal wall**.
- Filled by gas mixture of ^{4}He, CO_2 and ^{3}He.
- Measure decay electrons and $^3\mathrm{He}(n,p)^3\mathrm{H}$ reactions, or neutron flux, **simultaneously**.



First physics result

- Neutron lifetime is determined as below:

Counted by signal selection

$$\tau_n = \frac{1}{\rho \sigma_0 v_0} \frac{(S_{\mathrm{He}}/\varepsilon_{\mathrm{He}})}{(S_\beta/\varepsilon_\beta)}$$

Measured density

Estimated by MC

v_0	Velocity of neutron
σ_0	Cross section of $^3\mathrm{He}(n,p)^3\mathrm{H}$
ρ	Number density of ^{3}He
S_{He}	Number of $^3\mathrm{He}(n,p)^3\mathrm{H}$ events
S_β	Number of β decay events
ε	Efficiency

$\sigma_0 v_0$: 5333 ± 7 barn @$v_0 = 2200$ m/s

- First result of this experiment (2014-2016):

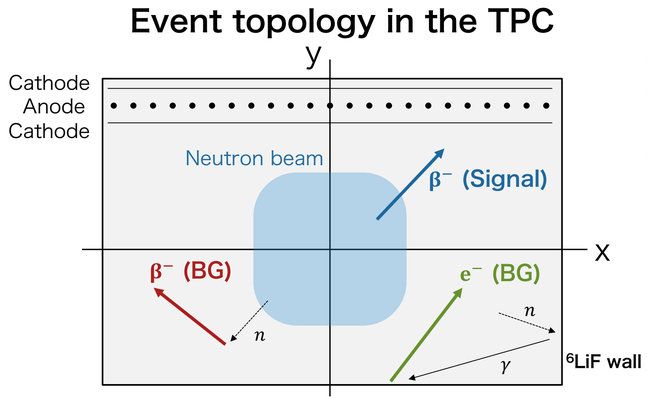
$\boldsymbol{\tau_n = 898 \pm 10(\mathrm{stat.}) + 15/-18\,(\mathrm{sys.})\ [\mathrm{s}]}$ [PTEP 2020, 123C02]

- Consist with beam and storage method.
- Need to improve systematical uncertainties.

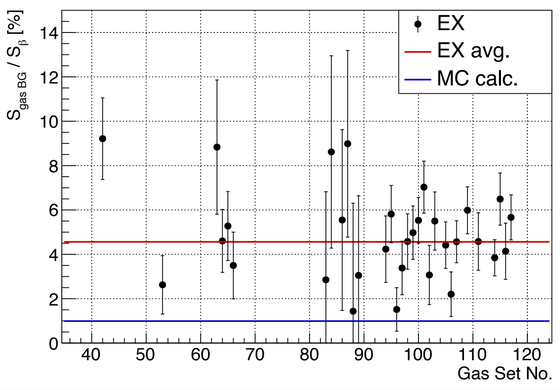
Gas Induced background

- Scattered neutron makes background electrons via the (n,γ) reactions at ^{6}LiF wall.
- The amount of gas induced background is 4.6 times different between measured and calculated value.
  - Measured BG: $S_{\mathrm{gas\ BG}}/S_\beta = 4.6$ %
  - MC calculation: $S_{\mathrm{gas\ BG}}/S_\beta = 1.0$ %
- Uncertainty due to this difference is +2/-14 s.

Event topology in the TPC



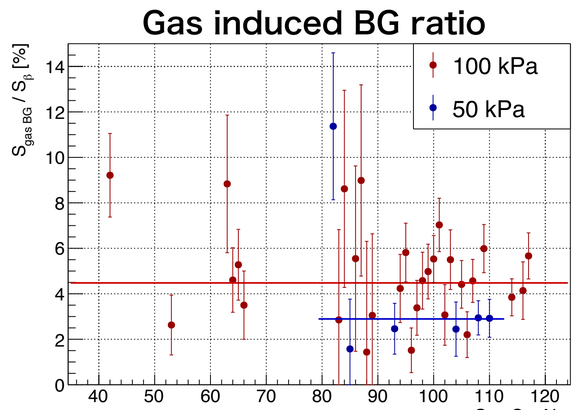
Gas induced BG ratio



Low gas pressure measurement

- To reduce gas scattered neutrons, measurements with lower operating gas pressure have been taken place.
  - Gas pressure of 50 kPa instead of the conventional 100 kPa.
- The amount of gas induced BG is reduced to 59 ± 11%.
  - 100 kPa: $S_{\mathrm{gas\ BG}}/S_\beta = 4.6 \pm 0.2$ %
  - 50 kPa: $S_{\mathrm{gas\ BG}}/S_\beta = 2.7 \pm 0.5$ %
- Systematical error for gas BG **can be reduced to 60%** by lower gas pressure operation.

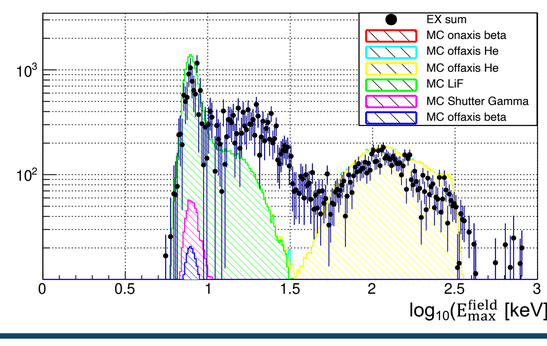
Gas induced BG ratio



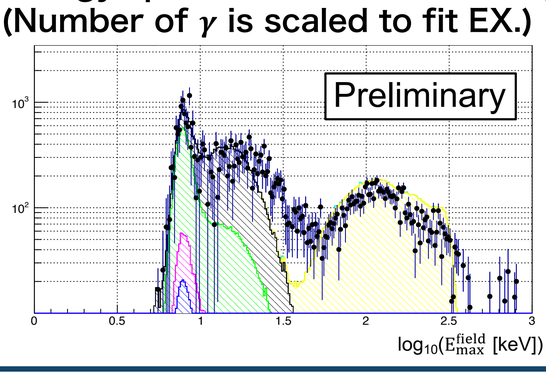
Low energy gamma measurement

- Difference in the number of gas induced background events suggests the presence of unaccounted events.
  - Candidate of the background is low energy γ-ray from ^{6}LiF wall.
  - $^6\mathrm{Li}(n,\alpha)^3\mathrm{H}$ → $^{19}\mathrm{F(t,t)}^{19}\mathrm{F}^*$, $^{19}\mathrm{F}(\alpha,\alpha)^{19}\mathrm{F}^*$, $^{19}\mathrm{F(t,p)}^{21}\mathrm{F}^*$ or $^{19}\mathrm{F(t},n)^{21}\mathrm{Ne}^*$
- Measured γ-rays intensity by irradiating neutron to ^{6}LiF plate.
- Evaluation of the amount of γ-rays from ^{6}LiF is ongoing.

Energy spectrum of gas BG events



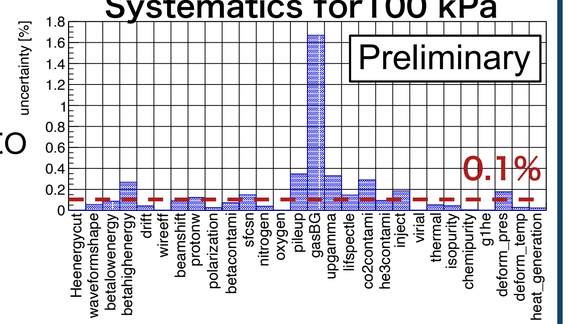
Energy spectrum with measured γ (Number of γ is scaled to fit EX.)



Summary and prospects

- We have performed lifetime measurements until 2022.
- All acquired data corresponding to a **statistical accuracy of 2.0 s**.
  - Statistics of 2.7 s (100 kPa meas.)
  - Statistics of 3.0 s (50 kPa meas.)
- Our goal is to determine lifetime with an accuracy of 1.0 s (0.1%).
  - Statistical accuracy of 0.1% **can be achieved within 110 days** of measurement.
  - Uncertainty for gas BG is **reduced by about half** by lower gas pressure operation.
  - Systematics is under improving.

Systematics for100 kPa



Systematics for 50 kPa