Neutron Lifetime Puzzle

Saturday 13 September 2025 - Saturday 13 September 2025

PSI

Book of Abstracts

Satellite Workshop “Neutron Lifetime Puzzle —Measurements, Systematics, and Theoretical Implications at PSI2025”
We look forward to a dynamic workshop focused on recent and ongoing efforts to measure the neutron lifetime, addressing experimental techniques, systematic uncertainties, and implications for the Standard Model of Particle Physics.
Beyond lifetime measurements, we also encourage discussions on neutron beta decay parameters, and connections to precision tests of weak interactions. Looking ahead, we want to assess future experimental strategies and theoretical perspectives that could refine our understanding of neutron decay.

Workshop chairs:
Bernhard Lauss (PSI)
Dieter Ries (PSI)
Noah Yazdandoost-Kosravi (PSI/TRIUMF)

Contents

Future Measurements and Experimental Strategies / 2

UCNProBe a beam-type experiment using ultracold neutrons

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UCNProBe is an upcoming experiment at Los Alamos National Laboratory designed to measure the lifetime of a free neutron, τ_n. Currently, there is a significant discrepancy of about 10 seconds (4.5 sigma) between the two primary methods used for this measurement. One approach involves using a cold neutron beam to detect the charged products of neutron beta decay. The other relies on ultracold neutrons (UCN), which are stored in physical or magnetic traps. UCNProBe will follow the beam-type measurement method but uniquely incorporate UCN characteristics. In this setup, UCN will be confined within a material bottle made of deuterated polystyrene box that will also serve as an in-situ detector for electrons from the beta decay. For neutron counting, a boron-coated YAP:Ce crystal scintillator will be used. This presentation will provide an overview of the experiment and the latest updates on its development.

Recent Advances in Neutron Lifetime Measurements / 3

A new results of neutron lifetime measurement with cold neutron beam at J-PARC

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The "neutron lifetime puzzle" arises from the discrepancy between neutron lifetime measurements obtained using the beam method, which measures decay products, and the bottle method, which measures the disappearance of neutrons.
To resolve this puzzle, we conducted an experiment using a pulsed cold neutron beam at J-PARC. In this experiment, the neutron lifetime is determined from the ratio of neutron decay counts to ^{3}He(n,p)^{3}H reactions in a gas detector. This experiment belongs to the beam method but differs from previous experiments that measured protons, as it instead detects electrons, enabling measurements with distinct systematic uncertainties. By enlarging the beam transport system and reducing systematic uncertainties, we achieved a fivefold improvement in precision. Analysis of all acquired data yielded a neutron lifetime of $\tau_{\rm n} = 877.2 \pm 1.7_{\rm (stat.)}\,{}^{+4.0}_{-3.6}{}_{\rm (sys.)}$ s. This result is consistent with bottle method measurements but exhibits a 2.3σ tension with the average value obtained from the proton-detection-based beam method.

We will present about the new results.

4

Beamline and magnetic field preparation for correlation coefficients measurements in the BRAND experiment

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BRAND is a precision experiment that will investigate free polarized neutron beta-decay [1] at the PF1B cold neutron beamline of the Institut Laue-Langevin (ILL), which offers the world's highest cold neutron flux [2]. The experiment will perform simultaneous measurements of 11 correlation coefficients in neutron beta-decay [3], including five that have never been measured before. This enables a sensitive search for possible scalar or tensor interactions beyond the Standard Model through the analysis of transverse elec-tron polarization. The first beamtime for the BRAND-2 setup is planned in the first half of 2026, and will require both uniform magnetic field and targeted beamline preparations.

Neutrons are polarized by PF1B's supermirror polarizer which provides beam-averaged polarization up to 99.7% [4]. A highly uniform magnetic field of low magnitude is required within BRAND's fiducial volume in order to, on one hand, align and preserve the neutron polarization, and, on the other hand, to minimize deflections of charged decay products, facilitating accurate reconstruction of their trajectories. To achieve this, an Active Magnetic Shielding system (AMS), similar as [5,6], will fully enclose the BRAND detection apparatus. The AMS will actively compensate for static magnetic perturbations –such as the Earth's mag-netic field –as well as dynamic fluctuations that can be caused by nearby instruments at the ILL. Addi-tionally, efficient spin transport is necessary between the polarizer, which operates with a transversal field, and the decay chamber, where a longitudinal field is needed.

BRAND aims for precision measurements of correlations between the momenta of decay products and the spins of both the neutron and the electron, requiring a high and precisely known neutron polarization. Measuring the polarization of the neutron, and conversely, deriving it from the measured beta asymmetry A, allows for cross-checks of the beam polarization. This makes neutron polarization one of the critical tools to validate the BRAND-2 setup, and assess systematic effects.

This poster presents the simulation results of the final design of the Active Magnetic Shielding system built for the BRAND experiment. It also includes results from McStas simulations of the PF1B beamline, aimed at improving the accuracy of the beamline model. Finally, the preliminary design of the beamline for the BRAND-2 setup, and the polarization measurement plans will be presented.

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Recent Advances in Neutron Lifetime Measurements / 5

The NIST Beam Neutron Lifetime Experiments

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A series of neutron lifetime measurements using the beam method has been conducted at the National Institute of Standards and Technology (USA) for more than 30 years. In these experiments, a cold neutron beam passes through a quasi-Penning trap where protons from free neutron decay are captured and subsequently counted by a silicon detector. We will review the previous BL1 experiment (2005, 2013); discuss the current BL2 experiment and systematic issues we have focused on, in particular proton charge exchange with residual gas in the trap; and describe BL3, a new next-generation version of the experiment with improved systematics and capable of a high precision result at the <0.3 s level.

Future Measurements and Experimental Strategies / 6

τSPECT- towards a new measurement of the free neutron lifetime in a full-3D magnetic trap

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Neutron physics can provide cornerstone ingredients for a high-precision test of the Cabibbo-Kobayashi-Maskawa (CKM) matrix unitarity without nuclear structure corrections. The matrix element Vud is extracted from the combination of a high-accuracy determination of λ, the ratio of axial-vector and vector coupling strength of the weak interaction, a commensurate theoretical description of neutron beta decay, and a high accuracy determination of τn. In a first step, τSPECT aims to determine τn with an uncertainty of < 0.3 s to illuminate the neutron lifetime puzzle, a significant disagreement of τn measurements using complementary methods. The τSPECT experiment confines ultracold neutrons (UCNs) in a full 3D magnetic gradient field trap. We have operated the instrument at the UCN source of the Paul Scherrer Institute since 2023. After filling and holding UCNs for hundreds of seconds in the trap, τSPECT counts the surviving UCNs and extracts τn from the storage curve. Quasi-trapped
UCNs could leave the trap on the timescale of τn, and a strict control of these marginally trapped UCNs is required to avoid a bias towards a low value of τn. In 2023, τSPECT was transferred from JGU Mainz to PSI and reassembled. In 2024, τSPECT has performed a first blinded science data run with an anticipated statistical precision of 1 s on τn. The most important systematic bias effects could be investigated for the first time with high statistics, and dedicated background studies were performed. We will present the current instrument's performance, selected aspects of the ongoing data analysis, and near-term performance upgrade opportunities. The τSPECT setup provides an indispensable test bed for future full-magnetic trap setups featuring larger volume and deeper trapping potential.

Systematic Effects, Physics beyond the Standard Model / 7

Experimental limits on an excited neutron state as an explanation of the beam-bottle neutron lifetime discrepancy.

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Koch and Hummel[1] suggest a new solution to the neutron lifetime enigma[2]. The neutron lifetime enigma arises from the 4.4 standard deviation difference between the lifetime measured for bottled neutrons[3] and measurements of lifetime from a beam of cold neutrons[4]. Koch and Hummel point out the beam experiments measure the decay rate of neutrons very close in time to their source whereas the bottle measurement use neutrons ˜1000 s after their production. They postulate the existence of an excited state of the neutron, n*, that has a longer β-decay lifetime than the ground state, n, and that a transition could occur between these two states by γ-ray emission with a decay time shorter than the holding time used for bottle lifetime measurements. Here, we will present an analysis of the UCN_τdata aimed a searching for an explanation of this difference using the model proposed by Koch and Hummel

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Future Measurements and Experimental Strategies / 8

The path to first measurements with the superconducting magnetic storage ”PENeLOPE”

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Over the past decades we have designed and constructed a superconducting magnetic trap for ultra cold neutrons (PENeLOPE). With the large storage volume of about 550 liters as well as the design allowing for real time detection of decay protons, we aim at a high precision measurement with unprecedented systematic and statistical uncertainties. The system was constructed and set up at the Technical University of Munich in 2020. Following initial tests, PENeLOPE was transferred to TRIUMF in 2024 to perform first measurements at the new TUCAN UCN source.
I will outline our setup and present data from the cryostat tests performed ealier this year.

Systematic Effects, Physics beyond the Standard Model / 10

The Bound Beta Decay of the Free Neutron - A Possible Solution to the Neutron Lifetime Puzzle

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The Bound Beta Decay of the Free Neutron - A Possible Solution to the Neutron Lifetime Puzzle

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The discrepancy in neutron lifetime measurements between storage experiments with ultracold neutrons and beam experiments with cold neutrons has persisted as a significant puzzle in particle physics. Storage experiments typically involve trapping neutrons and observing their decay over time, while beam experiments measure the decay products, such as electrons and protons, as neutrons pass through the decay volume. Interestingly, the average lifetimes obtained from these two methods differ by nearly 10 seconds, despite reduced statistical and systematic errors.
A promising yet controversial explanation for this discrepancy involves the bound beta decay of the neutron into a hydrogen atom and a anti-neutrino. Traditional theoretical estimates suggested a branching ratio of approximately $\sim 10^{-6}$, which seemed too small to account for the observed differences. However, recent theoretical developments propose a significantly larger branching ratio of $\sim 10^{-2}$, potentially bridging the gap between the two experimental findings.
In this presentation, I will explore the implications of these new theoretical predictions and present my own calculations, which question their validity. By critically evaluating these findings, I aim to shed light on whether bound beta decay could indeed resolve the neutron lifetime puzzle or if alternative explanations need to be considered.

Systematic Effects, Physics beyond the Standard Model / 11

How Small Heating of Ultracold Neutrons could be related to the Neutron Lifetime Puzzle

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After cooling and trapping, Ultracold Neutrons (UCNs) reacquire kinetic energy over a relatively long period of time. This process is called Small Heating and it is not yet fully understood. Most intriguingly, this process wears off to some extent.

In 2024 we have proposed a dressed quark model that could explain the Neutron Lifetime Puzzle (NLP). The neutrons in the beam could be in so-far undetected low-energy excited states, while neutrons in the bottle are in the ground state. Neutrons in excited states have more restricted beta decay channels and are thus longer lived than their ground-state versions.

We revisit the Small Heating phenomenon in the light of the excited-state hypothesis. We suppose there is a chain of electromagnetic decays from a neutron in one of the excited states to the ground-state neutron. If this chain is sufficiently long-lived that cold neutrons arrive in the bottle still being in one of the excited states, they may undergo a part of the decay chain inside the bottle. The recoil of each decay event could contribute to the Small Heating of UCNs at an early stage after trapping before wearing off. From the time evolution of the statistical moments of the kinetic energy of UCNs during Small Heating we could infer information on the decay chain and the average photon energy.

Future Measurements and Experimental Strategies / 12

The BL3 Neutron Lifetime Experiment

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The goal of the BL3 Beam Neutron Lifetime Experiment is to improve the precision of beam-based neutron lifetime experiments to the 0.3 s level while performing a thorough evaluation of potential systematic effects at the same level to help resolve the neutron lifetime puzzle. This experiment will utilize an all new, larger apparatus with a larger proton trap and detector; an improved neutron flux monitor; and an upgraded version of the alpha-gamma device that provides the absolute calibration of the neutron flux monitor. This talk will discuss the measurement technique used by the BL3 experiment; the major improvements over previous similar experiments; a status update on the construction of the new apparatus; and a plan and timeline for mounting the experiment.

Opening Session: Welcome and Introduction / 13

The Neutron Lifetime: Why do we keep measuring it?, Why do we keep getting it "wrong"?

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Morning Session / 14

Welcome & Introduction

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Morning Session / 15

The Neutron Lifetime: Why do we keep measuring it?, Why do we keep getting it "wrong"?

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Opening Session: Welcome and Introduction / 16

Welcome & Introduction

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Opening Session: Welcome and Introduction / 17

Addressing the neutron lifetime anomaly with correlation parameters

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Combining measurements of the lifetime with measurements of (angular) correlation parameters in neutron beta decay, we strive to most precisely determine the matrix element V_{ud} of the CKM quark mixing matrix. The goal is to test CKM unitarity on the 10^{-4} level.

Alternatively, combining the determination of V_{ud} from superallowed nuclear decays and neutron correlation parameters, allows for a rather precise determination of the neutron lifetime.

In this talk, I will present the current status and prospects of correlation measurements (which exhibit their own anomaly), and discuss the connection to the neutron lifetime.

Recent Advances in Neutron Lifetime Measurements / 18

Current status and future activities of UCNtau+

Future Measurements and Experimental Strategies / 19

Round Table Discussion

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Discussion on the future.
Where is / should be neutron lifetime 10 years from now:

Moderator: Peter Geltenbort

Panelists:
Felix Hummel
Kenji Mishima
Chris Morris
Dieter Ries
Fred Wietfeldt

Future Measurements and Experimental Strategies / 20

Closing Words

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