PROCEEDINGS OF SCIENCE

The status of JSNS^2 and JSNS^2-II

Takasumi Maruyama for JSNS^2 and JSNS^2-II collaborations.[a,*]

[a] *KEK, IPNS,*
1-1 Oho, Tsukuba, Ibaraki, Japan

E-mail: takasumi.maruyama@kek.jp

The search for sterile neutrinos is one of the hottest topics in neutrino physics in this decade. JSNS^2 (J-PARC Sterile Neutrino Search at the J-PARC Spallation Neutron Source) and the second phase of the experiment JSNS^2-II aim to search for neutrino oscillations with Δm^2 near 1 eV^2 at the J-PARC Materials and Life Science Experimental Facility (MLF). With the 1 MW of 3 GeV proton beam created by Rapid Cycling Synchrotron (RCS) and spallation neutron target, an intense neutrino beam from muon decay at rest is available. Neutrinos come predominantly from μ^+ decay: $\mu^+ \to e^+ + \bar{\nu}_\mu + \nu_e$. The oscillation searched for is $\bar{\nu}_\mu$ to $\bar{\nu}_e$, which is detected via the inverse beta decay interaction $\bar{\nu}_e + p \to e^+ + n$, followed by gammas from neutron capture of Gd. The JSNS^2 detector (and the near detector in the JSNS^2-II) with a fiducial volume of 17 tonnes is located 24 m away from the mercury target. The new far detector of the JSNS^2-II that is being newly constructed is located outside the MLF building with the baseline of 48 m. This far detector has a 32 tonnes of the fiducial volume. These experiments directly test the LSND anomaly.

Additional physics programs include the cross section measurements with neutrinos with order 10 MeV from muon decay at rest and with monochromatic 236 MeV from kaon decay at rest. These are important for the potential observation of a supernova explosion using neutrinos and nuclear physics.

JSNS^2 started data taking in 2020 and the accumulated Proton-On-Target (POT) is 1.45×10^{22}. The far detector of JSNS^2-II is under the construction. This article describes the status of these experiments.

**** The 22nd International Workshop on Neutrinos from Accelerators (NuFact2021) ****
**** 6–11 Sep 2021 ****
**** Cagliari, Italy ****

[*] Speaker

1. Introduction

The Nobel Prize in 2015 was awarded for the discovery of neutrino oscillations in 1998 [1]. However, there are still a lot of things to be investigated in oscillation phenomena and the one of the hottest topics is to decisively confirm or refute of the existence of the sterile neutrinos with neutrino oscillations.

The existence of the sterile neutrinos was indicated by the LSND experiment originally in 1998 [2]. They have no weak interaction, thus they are only sensitive to the gravity.

However, there have been no final conclusions from experiments so far, especially some other indications are shown to be in contradiction with LSND [3–5]. Many ongoing experiments have continued the search recently. For these other experiments, please refer to the NuFact2021 proceedings.

JSNS^2 [6] (J-PARC Sterile Neutrino Search using J-PARC Spallation Neutron Source) will make a direct test of the LSND result. Also the new detector of the next phase of the experiment, JSNS^2-II [7], using two detectors with different baselines, is under construction. This article briefly explains the current status of both JSNS^2 and JSNS^2-II.

2. Setup and principle of the experiments

Figure 1 shows the setup and sensitivities of the experiments. 3 GeV protons hit the mercury target and the collisions create the pure $\bar{\nu_\mu}$ via μ^+ decay-at-rest. The neutrino oscillation ($\bar{\nu_\mu} \to \bar{\nu_e}$) is studied using two liquid scintillator detectors at two short baselines: 24 m and 48 m.

The current JSNS^2 experiment has 50 tonnes of liquid scintillator detector and is located on the third floor of the MLF. This includes 17 tonnes of Gd loaded liquid scintillator (Gd-LS) inside an inner acrylic tank. JSNS^2 is taking data and it will accumlate POT, which corresponds to 1 MW (beam power) $\times$ 3 years. This detector will also be used as the near detector of JSNS^2-II after the designed JSNS^2 POT has been reached. The JSNS^2-II experiment adds 163 tonnes of liquid scintillator detector outside of the MLF building. This includes 32 tonnes of the Gd-LS inside an inner acrylic tank. JSNS^2-II aims to start data taking from 2023. Using two different baselines, the neutrino oscillation and therefore the LSND anomaly will be investigated direclty. JSNS^2-II provides a better sensitivity in the low Δm^2 region than that of the current JSNS^2, as shown in the bottom two plots in Fig. 1. The new far detector therefore is essential in the investigation of the LSND anomoly.

If the $\bar{\nu_\mu} \to \bar{\nu_e}$ oscillation or conversion occurs, this will be observed via the Inverse-Bata-Decay (IBD) reaction in the Gd-LS: $\bar{\nu_e} + p \to e^+ + n$. The resulting neutron is thermalized and captured by Gd, and the coincidence with the signals between IBD prompt (e$^+$) and delayed (n-Gd) can be detected. Using this coincidence eliminates most of the accidental background.

MLF has an excellent short-pulsed beam profile: two bunches with 100 ns width and seperated by 600 ns. The frequency of the repetition of these two bunches is 25 Hz. To reduce the cosmic ray-induced and beam-related backgrounds, this timing structure is ideal.

Compared to the LSND experiment, the low duty factor beam and Gd-LS are strong advantages (LSND used a Linac beam with a poor duty factor and pure liquid scintillator). JSNS^2 and JSNS^2-II

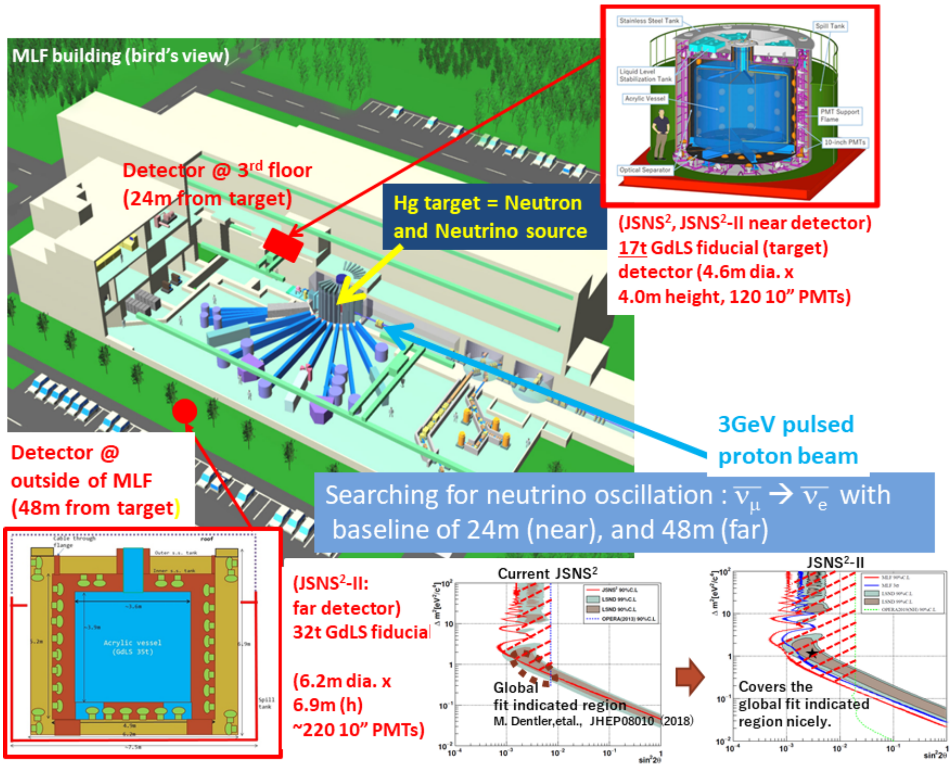

Figure 1: The setup and the sensitivities of the JSNS^2 and JSNS^2-II experiments.

will have a smaller accidental background rate and therefore JSNS^2(-II) will be a direct and ultimate test for the LSND anomaly.

3. Current status

3.1 JSNS^2

JSNS^2 started data taking from 2020. The accumulated POT is 1.45×10^{22} POT, which corresponds to approximately 13% of the designed POT.

The analysis of the accumulated date is on-going. As shown in the recent paper [8], the neutron background induced by cosmic rays is the dominant background for the JSNS^2. To address this, JSNS^2 dissolved 10% Di-Isopropyl-Naphthalene (DIN) by weight into the Gd-LS in 2020-2021. DIN will improve the Pulse-Shape-Dismination (PSD) power between neutrons and positrons and thus help to reduce any accidental coincidences due to the cosmic ray induced background.

As a result of the DIN dissolution, the neutron rejection power is 97.4±0.5%, while the positron efficiency is 94.2±2.6% in the detector central region (Fig. 2). The goal of the neutron rejection factor is ∼100 and therefore we are achiving the good PSD capability which is near to the goal. Note that the rejection factor and the efficiency are estimated by the Michel electron made by stopped muons inside the detector and the fast neutrons control sample. Currently, the impurity inside the control samples is being estimated.

In addition to the sterile neutrino search, the events created by the monochromatic 236 MeV from kaon decay-at-rest (KDAR) are being studied. KDAR neutrinos provide quasi-elastic interac-

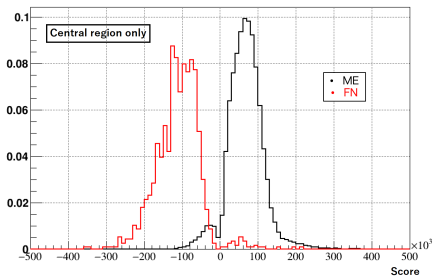

Figure 2: The Pulse Shape Discrimination (PSD) capability of the JSNS^2. The black graphs shows Michel electrons (ME) and the red shows fast neutrons (FN). The events with scores above zero correspond to "electron-like" and those below zero correspond to "neutron-like".

tions inside the Gd-LS, resulting in a sequence of scintillation light events from the muon and proton (the prompt signal) to the Michel electron created from the prompt muon (the delayed signal). A detailed analysis is on-going.

The next physics run will start in February 2022. The JSNS^2 collaboration is currently preparing for the data taking.

3.2 JSNS^2-II

The construction of the new far detector was started in September 2021, and being performed smoothly. Figure 3 shows the status of the construction of the stainless steel (s.s.) tank. The base,

Figure 3: The status of s.s. tank construction of the JSNS^2-II as of 17 December 2021. The inner s.s. tank can be seen in the back, while the base of the detector and the support structure of the outer s.s. tank can be seen in the front.

the support structure and the inner s.s. tank have already been produced and the outer s.s. tank for the veto region is being built at present. The construction of the s.s. tank will be completed by March 2022.

The acrylic tank will be produced in 2022. The liquid scintillator and Gd-LS were already donated by the Daya-Bay experiment. Thirty PMTs will be donated from the Double-Chooz experiment. The remaining ~180 PMTs will be purchased from Hamamatsu company or donated from Double-Chooz further. The installation of the PMTs will be completed in 2022.

Most of the construction schedule follows the original schedule in the reference [7]. The data taking will start in 2023.

4. Summary

JSNS^2 is directly testing the LSND anomaly using the same neutrino source, the neutrino target and the detection principle (IBD). The JSNS^2-II will continue this test with higher precision. JSNS^2 has accumulated data corresponding to 1.45×10^{22} POT. The data is extensively being analyzed. The new far detector of JSNS^2-II is being built at present. The construction is progressing smoothly and the data taking will start in 2023.

5. Acknowledements

We thank the J-PARC staff for their support. We acknowledge the support of the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) and the JSPS grants-in-aid (Grant Number 16H06344, 16H03967, 20H05624), Japan. This work is also supported by the National Research Foundation of Korea (NRF) Grant No. 2016R1A5A1004684, 2017K1A3A7A09015973, 2017K1A3A7A09016426, 2019R1A2C3004955, 2016R1D1A3B02010606, 2017R1A2B4011200, 2018R1D1A1B07050425, 2020K1A3A7A09080133 and 2020K1A3A7A09080114. Our work has also been supported by a fund from the BK21 of the NRF. The University of Michigan gratefully acknowledges the support of the Heising-Simons Foundation. This work conducted at Brookhaven National Laboratory was supported by the U.S. Department of Energy under Contract DE-AC02-98CH10886. The work of the University of Sussex is supported by the Royal Society grant no.IES\R3\170385

References

[1] Y. Fukuda *et al*. (Super-Kamiokande Collaboration), Phys. Rev. Lett. 81, 1562, 567 (1998).

[2] A. Aguilar *et al.*, Phys. Rev. D **64**, 112007 (2001).

[3] A. A. Aguilar-Arevalo *et al*, Phys. Rev. Lett. **110** 161801 (2013).

[4] C. Giunti and M. Laveder, Phys. Rev .C 83 065504 (2011)

[5] Th. A. Mueller et al. Phys Rev C 83 054615(2011)
P. Huber, Phys.Rev.C 84 024617 (2011).

[6] M. Harada, *et al*, arXiv:1310.1437 (2013)
S. Ajimura, *et al*, arXiv:1705.08629 (2017)
S. Ajimura, *et al*, Nucl. Inst. Meth. A 1014 (2021) 165742

[7] A. Ajimura *et al*, arXiv:2012.10807 (2020)

[8] Y. Hino *et al*, arXiv:2111.07482 (2021)