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Measurements from JSNS^2 and the status of JSNS^2-II

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The goal of the JSNS^2 (J-PARC Sterile Neutrino Search at the J-PARC Spallation Neutron Source) experiment is to search for neutrino oscillations (from anti-muon to anti-electron neutrinos) with 24 m baseline at the J-PARC Materials and Life Science Experimental Facility (MLF). Data taking began in 2020, and we finished our 4th long physics data-taking run in 2024. Additionally, we've recently completed construction on a far detector for JSNS^2-II (the second phase of the JSNS^2 experiment). The second detector has 32 tonnes of fiducial mass and has a baseline of 48m. This will provide a better sensitivity for the sterile neutrino search in the low Δm^2 region. This manuscript describes the latest measurements from JSNS^2-I and the status of JSNS^2-II.

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1. Measurements from JSNS^2

1.1 JSNS^2 experiment

The existence of sterile neutrinos has been indicated by various experiments [1–4], including the Liquid Scintillator Neutrino Detector (LSND). JSNS^2 [5] which was proposed in 2013, uses the same neutrino source (μ Decay-At-Rest (DAR)), the same neutrino interaction target (free protons in liquid scintillator), and the same detection principle (Inverse Beta Decays (IBD)) as LSND[1]. Therefore, JSNS^2 provides a direct test of the LSND experiment's results. In addition, JSNS^2 utilizes the short-pulsed 1 MW and 3 GeV proton beam with 25 Hz repetition from the J-PARC facility and uses gadolinium (Gd) loaded liquid scintillator (GdLS). These factors provide significant improvements for JSNS^2's signal-to-noise ratio compared to that of LSND. The JSNS^2 detector, which is located on the MLF 3rd floor with a baseline of 24 meters, consists of 3 layers, a target, a gamma catcher and a veto. To improve our detector's Pulse Shape Discrimination (PSD) performance, Di-Isopropyl-Naphthalene (DIN) dissolved into our target volume scintillator. When 3 GeV protons collide to the MLF mercury target, $\bar{\nu}_\mu$ is generated from μ^+DAR, and neutrino oscillation ($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$) could occur as the neutrino travels the 24 m baseline if sterile neutrino exist. If so, the $\bar{\nu}_e$ can be detected via the IBD process ($\bar{\nu_e} + p \rightarrow e^+ + n$) in our detector volume. The coincidence of the IBD prompt e^+ and delayed neutron captured on Gd provides significant background reduction.

We have four long term physics runs so far, and 4.85×10^{22} Protons-On-Target (POT), which corresponds to 42.5% of the approved POT data of phase-I of JSNS^2 has been accumulated. Using this data, several different analyses, including the sterile neutrino search, are on-going. This proceeding detail some our analysis results.

1.2 Electron neutrino flux measurement via $^{12}C(\nu_e,e^-)^{12}N_{g.s.}$

The neutrino flux is an essential parameter for our sterile neutrino search. However, no measurements on the neutrino parent particle ($\pi^\pm$) production rates for 3 GeV protons on a mercury target have been performed so far. μ^+DAR simultaneously produces a ν_e and a $\bar{\nu}_\mu$, so measuring the ν_e interaction rate can be used to constrain the $\bar{\nu}_\mu$ production rate. The ν_e flux can be measured via the $^{12}C(\nu_e,e^-)^{12}N_{g.s.}$ interaction. This interaction creates an electron as a prompt signal and a positron as a delayed signal in the detector target. Since the Q-value of the reaction is 17.3 MeV, the maximum energy of the prompt electron signal is ($m_\mu/2 - 17.3$) MeV, where m_μ is a mass of muon. $^{12}N_{g.s.}$ has a β^+ decay with the maximum energy of 16.83 MeV and the life time of 15.9 ms [6]. These coincidence of two signals give an excellent reduction of accidental backgrounds.

Using our 2021 and 2022 datasets, we observe 79 candidate events with an estimated 42.2 ± 6.5 (stat.) ± 1.7 (syst.) background events. See the reference [7] for more details for the event selection. Considering the selection efficiency, the number of ^{12}C target and the averaged cross section from other experiments, the estimated ν_e flux is [6.7 ± 1.6 (stat.) ± 1.2 (syst.)] ×10^{-9} cm^{-2} proton^{-1} at the JSNS^2 detector, which is consistent with FLUKA within 1 sigma as shown in Fig. 1.

1.3 Kaon Decay-At-Rest (KDAR) measurement

When K^+ mesons, generated by the interaction between the 3 GeV proton and the mercury target, decay to a 236 MeV mono-energetic muon neutrino with 63.56% of branching ratio. These KDAR neutrinos can provide a unique opportunity to study the neutrino-nucleus interactions at this energy range. JSNS^2 measured such KDAR neutrinos interactions using 2021 dataset. The K^+ production rate at the mercury target in this experiment is totally unknown, thus only relative energy spectrum measurement is reported. KDAR neutrinos can be tagged by a coincidence between quasi-elastic scatted muon plus proton from the interaction with a carbon and a subsequent Michel electron from the muon. JSNS^2 observed 621 KDAR candidates with an estimated $\sim$ 80% signal purity. To provide a better understanding of the low energy neutrino-nucleus interactions, the visible energy spectrum is estimated using Iterative Bayes (D' Agostini) unfolding as shown in the Fig. 2. Further details of our KDAR analysis are provided in reference [8].

2. Status of JSNS^2-II

JSNS^2-II is the second phase of JSNS^2 [9]. The current detector of JSNS^2-I will be redefined as the near detector, and the new far detector with 32 tonnes of fiducial mass, is placed outside the MLF building, 48m from mercury target. The second detector with a longer baseline provides a better sensitivity in the low Δm^2 region for our sterile neutrino search. Using two detectors, with two different baselines, JSNS^2-II will provide a solid conclusion on the LSND anomaly. We are in the final phase of detector construction. We completed filling the far detector with scintillator in August 2024, and will begin taking data with it soon.

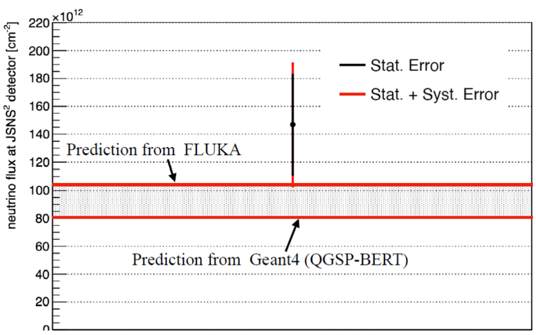

Figure 1: The measured neutrino flux in JSNS^2.

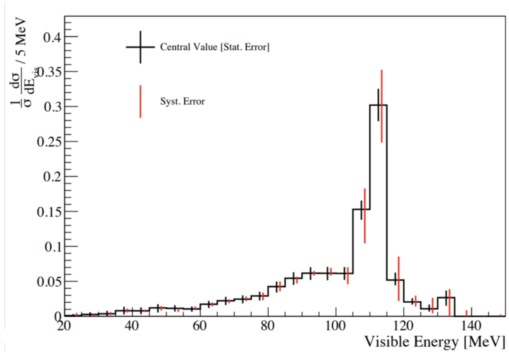

Figure 2: The unfolded spectrum of the KDAR events.

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