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Status of the KDAR neutrino measurement with $JSNS^2$

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The The J-PARC Sterile Neutrino Search at the J-PARC Spallation Neutron Source ($JSNS^2$) experiment has the unique ability to precisely measure monoenergetic 236 MeV neutrinos from charged Kaon decay-at-rest (KDAR). J-PARC's Material and Life Science Facility (MLF) 3 GeV primary proton beam incident on a mercury target generates the world's most intense source of KDAR which can be used to make neutrino cross-section measurements using known-energy neutrinos. In this study, the analysis status of the KDAR neutrino measurement will described. The analysis uses data from $JSNS^2$'s first long-term physics run, obtained in 2021.

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1. Introduction

The charged Kaon decay-at-rest(KDAR) neutrino across multiple aspects of particle and nuclear physics is one of the important physics topics. Charged kaons decay to a muon and a muon neutrino ($K^+ \rightarrow \mu^+ + \nu_\mu$) with a branching fraction of 63.5%[1]. When this decay occures at rest, the emitted muon neutrino is monoenergetic at $236 MeV$. Unlike typical neutrino sources at particle accelerator (e.g. pion decay-in-flight neutrino beams), these KDAR neutrinos are monoenergetic and hence enable a rich program of physics with known-energy neutrinos. The only other significant source of monoenergetic neutrinos produced at accelerators is from pion decay-at-rest (DAR), but these neutrinos are relatively low energy ($\sim 29.8 MeV$) and thus cannot participate in charged current interactions. KDAR neutrinos were previously measured by the MiniBooNE experiment[2]. This initial measurement was limited by beam timing resolution and significant pion decay-in-flight (DIF) backgrounds. But $JSNS^2$ is expected to produced to yield the cleanest and world's stringest KDAR signal.

2. Motivation

Neutrino interaction models are a crucial part of all accelerator-based neutrino physics programs including neutrino oscillation measurements. Cross-sections rely on extrapolating the near detector flux to the far detector. But, current neutrino cross section at low energies are poorly known. KDAR neutrino have been identified as a promising tool for studying neutrino interactions. A monoenergetic neutrino ($E_\nu = 236 MeV$) simplifies the modeling of the neutrino interaction and comparing the experimental results to theoretical predictions. Recently, MiniBooNE measured KDAR neutrino for the first time. Not only the neutrino-nucleon interaction calculation, but also cross section at low energies via KDAR was measured. MiniBooNE could measure shape-only cross section due to the kaon production uncertainty. JSNS2 has the unique ability to precisely measure monoenergetic 236 MeV neutrinos from KDAR. The J-PARC MLF 3 GeV primary proton energy is sufficient to produce kaons efficiently and, also in consideration of the facility's beam intensity (eventually 1 MW, currently 700 kW), represents the best facility in the world to accomplish this physics. With the higher statistics, better timing, and energy resolution at $JSNS^2$ we expect to make a more precise measurement of the KDAR neutrino interaction cross-section. Furthermore, We will be able to measure the visible energy spectrum of KDAR primary event for the first time. [3]

3. $JSNS^2$ Experiment

The J-PARC Sterile Neutrino Search at the J-PARC Spallation Neutron Source ($JSNS^2$) is short baseline neutrino oscillation experiment. JSNS2 has started a study of neutrino oscillations with $\Delta m^2 \sim 1 eV^2$ from muon anti neutrinos to electron anti neutrinos detected via Inverse beta decay (IBD). JSNS2 is utilizes a liquid scintillator (LS) neutrino detector consisting of an inner volume filled with Gadolinium (Gd) loaded LS and outer buffer and veto regions filled with unloaded LS. Scintillation light is collected by 120 10-inch PMTs including 24 PMTs in the veto region used to reject activity originating outside the detector. (Figure. 2)

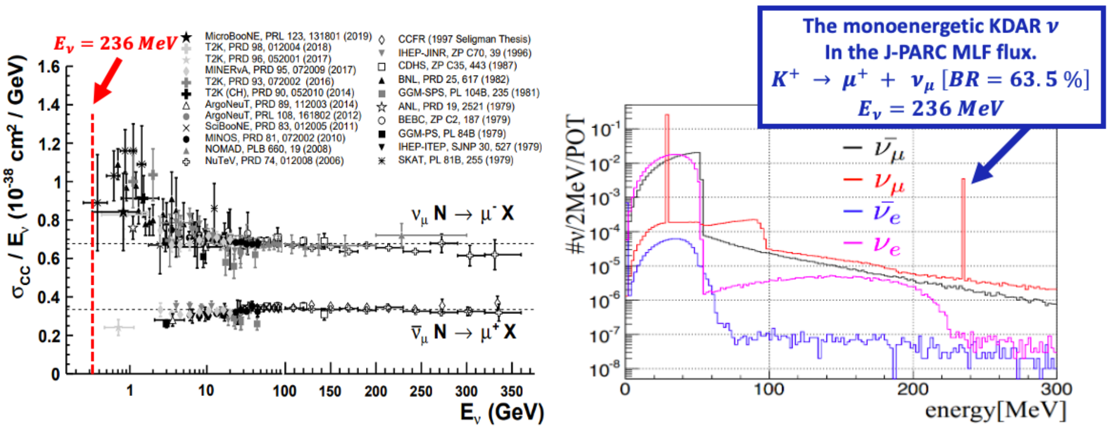

Figure 1: PDG review of the neutrino cross-section measurements[4] (left) and The neutrino flux at $JSNS^2$ detector from the MLF beam.(Right).

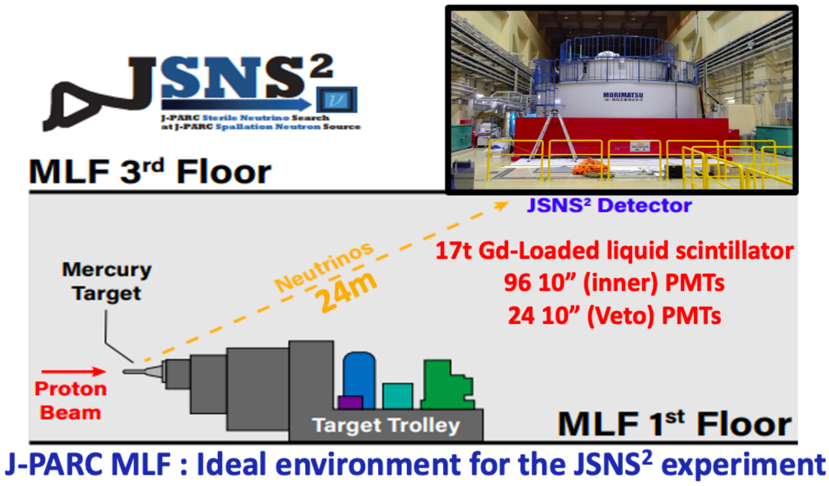

Figure 2: Schematic view of the $JSNS^2$ detector.

4. KDAR neutrino measurement

4.1 Signal

KDAR neutrinos are produced in the J-PARC MLF mercury target. The neutrino beam generated in the mercury target has a unique timing structure because of the short-pulsed beam and the lifetime of the mother particle of each neutrino. The proton beam periodically arrives in the MLF target at 25 Hz, which corresponds to the 40 ms time interval between beam spills.

In most events, the expected event signature is a double coincidence between the initial neutrino interaction products and the subsequent muon decay, Figure 3. Most commonly, the incoming KDAR neutrino will interact with a carbon nucleus in the detector producing a muon an causing one or more protons to be ejected from the nucleus, ($\nu_\mu +^{12} C \longrightarrow X + \mu^-$, where X represents a whatever hadronic/nuclear state) is the prompt events at a double coincidence. The visible energy of primary event is simply $E_{vis} = E_\nu(236MeV) - m_\mu(106MeV) \approx 130MeV$. However, multiple nuclear physics effects modify this distribution. One of a goal of this study is the measuring the visible

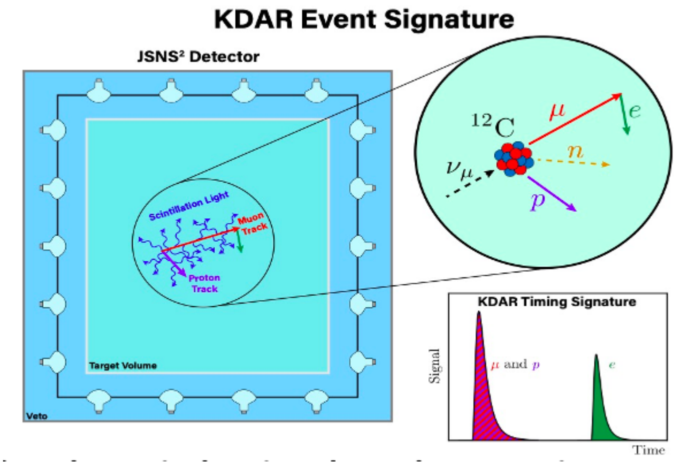

Figure 3: The schematic drawing about the KDAR signatures in JSNS2 [5]

energy spectrum of KDAR prompt event. Following the primary interaction there will be several secondary interactions including the muon decaying into a Michel electron ($\mu^- \to e^- + \bar{\nu}_e + \nu_\mu$) with a lifetime of 2.2 μs . The Michel electron is the delayed events in the coincidence with energies roughly 20 to 60MeV.

4.2 Backgrounds

As $JSNS^2$ is a surface based detector, we expect cosmic induced events to be the dominant source of backgrounds for this measurement. Cosmic muons can be produce a prompt & delayed event signature that is similar to that of KDAR neutrinos. We already measured the muon veto condition with no-beam data which means there is almost zero to muon interaction without cosmic induced muon. As shown in the the left plot of Figure 4, We can reject cosmic muon with 99% efficiency. KDAR events only interact within the detector volume, and not within the veto regino, so we are able to maintain high selection efficiency while rejecting nearly all cosmic muon events. Furthermore, applying 10us deadtime from the muon tagged event will be able to reject followed secondary particles via cosmic muon background. Beam related event also expected the background of KDAR neutrino measruement. The right of Figure 4 shows the timing profile of neutrinos generated in the mercury target obtained from the MC simulation. The black square pulse corresponds to the proton beam bunch timing, and the time distribution of neutrinos from pion, muon and kaon decays is shown. One can find that the neutrino from kaon is concentrated at the proton beam bunch timing. Thus, the analysis is able to reject events from most non-KDAR sources by selecting only events within a narrow timing window following the beam.

Additionally, the expected position correlation between the prompt and delayed KDAR events can be used as a selection cirteria. Monto-Carlo simulation is used to model this expect vertex correlation. From the coincidence event vertex difference investigation, the accidental event can be studied and removed.

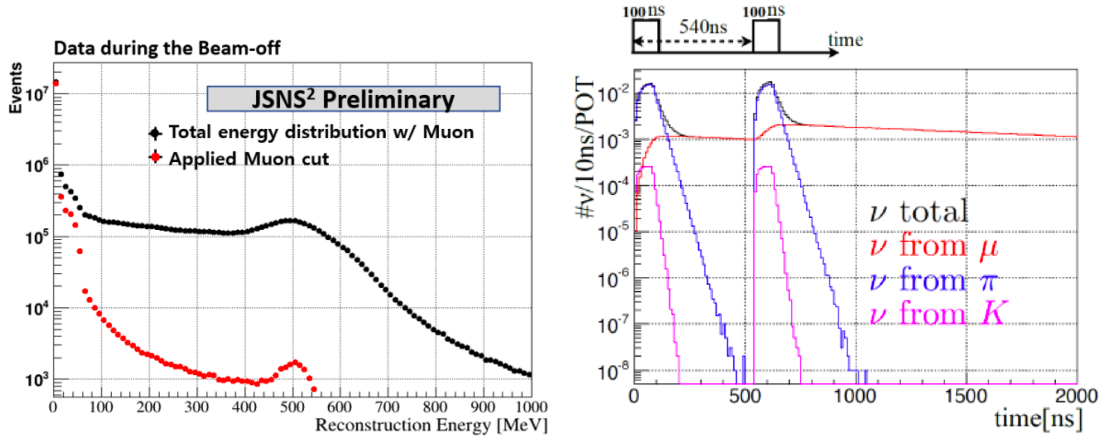

Figure 4: the total visible energy distribution at the beam-off period (Left) and The time distribution of neutrinos from pion, muon and kaon decays (Right). The origin of the horizontal axis corresponds to beam collision time. [6]

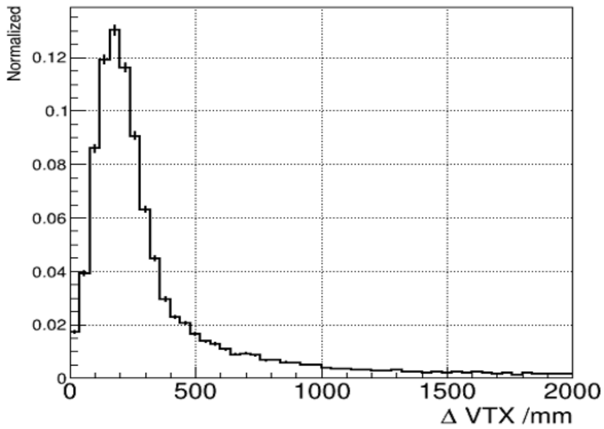

Figure 5: The vertex difference distribution between prompt and delayed event by MC.

5. MC Simulation

KDAR events are simulated in order to undestand the expected detector response. There are a number of varying predictions for KDAR visible energy spectrum, with significant contributions from different nuclear effects. Currently, no data can be validated in physics models of KDAR primary energy spectrum. One of a goal of this study is the measuring the visible energy spectrum of KDAR prompt event. Figure 6 shows the MC simulated KDAR energy spectrum as predicted by the NuWro simulation packaged.

6. Conclusion

The first physics analysis via KDAR neutrino interaction at the $JSNS^2$ experiment has been started. And using the first physics run data we are able to see KDAR events in a preliminary analysis. We are planning to measure the visible energy muon + nucleon apparent energies via

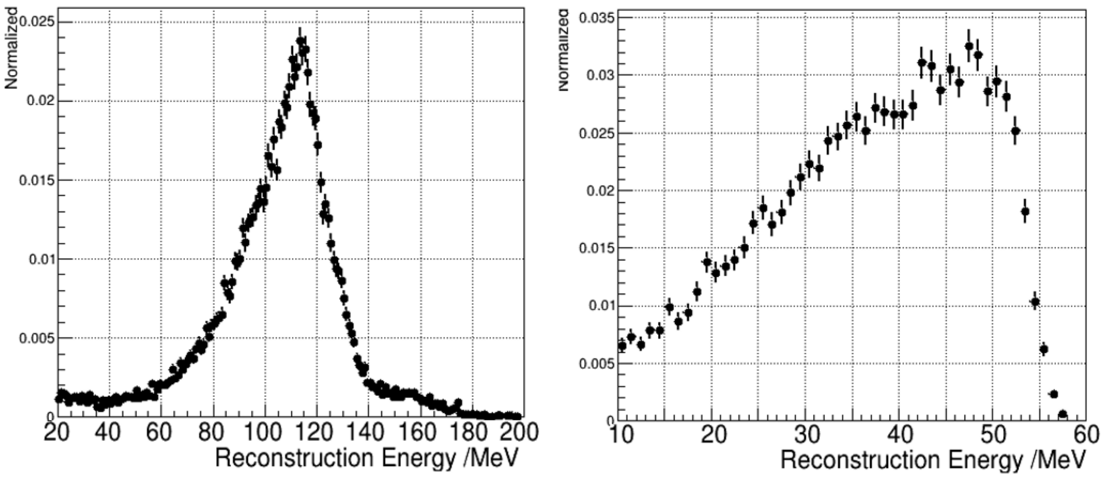

Figure 6: Muon (+Nucleon, e.g proton) event reconstructed energy distribution (Left) and subsequence Michel electron reconstructed energy distribution (Right).

selection optimization and background measurement. Additionally, we will be able to measure visible energy as a function of the number of neutrons created as a world-first measurement because the $JSNS^2$ experiment originally aims to search the IBD interaction which are tagged via gammas from neutron captures on Gd.

References

[1] P. A. Zyla et al. Review of Particle Physics. PTEP, 2020(8):083C01, (2020)

[2] A. A. Aguilar-Arevalo et al, Phys. Rev. Lett., 120(14):141802, (2018)

[3] Ajimura , S. et al, arXiv:1705.08692 (2017)

[4] Particle Data Group, https://pdg.lbl.gov/2021/reviews/rpp2020-rev-nu-cross-sections.pdf

[5] J Jordan, Neutrino 2020 Poster Presentation Num.482

[6] M.Jarada, et al, arXiv:1310.1437 (2013)