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Proposal of test experiment for technical improvements of neutrino measurements with nuclear emulsion detector

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Abstract

This is a proposal of test experiment to improve neutrino-nucleus interaction measurement with nuclear emulsion detectors. In this test experiment, we will install newly developed nuclear emulsion detectors and feedback the results to the future experiments. Also, many undergraduate and graduate students will contribute to this experiment, so they can gain experience of neutrino experiment. It's important in implementing future large-scale experiments. A large emulsion shifter, a scintillation tracker and Baby MIND which were used for the first physics run in the NINJA experiment will be re-used and four types of new detectors, 60 kg-lead target ECC, 8 kg-heavy water target ECC, a side emulsion shifter and an emulsion belt shifter will be installed at the B2 floor in the J-PARC Neutrino Monitor Building and test their performance. Neutrino beam exposure is planned from the end of Feb. 2021 to the end of Mar. 2021.

1 Introduction

1.1 Physics motivation

Precise neutrino-nucleus cross-section measurements are important for studying neutrino oscillations to resolve the matter-dominated universe and to validate the existence of sterile neutrinos because they are one of the main sources of their systematic uncertainties [1-3]. NINJA experiment has been performed for this purpose with nuclear emulsion detectors which has sub-micron spatial resolution and is suitable to investigate neutrino interactions in detail [4]. Especially, the detection of slow protons and electrons near interaction vertices gives new information for the better understanding of neutrino-nucleus interactions [5].

1.2 Status of the NINJA experiment

Since 2014, we have installed a variety of types of emulsion detectors in the underground places of the J-PARC Neutrino Monitor Building as shown in table 1. Currently the analysis of first physics run is going on and some neutrino events were detected as shown in figure 1. We plan to implement the second physics run after the J-PARC accelerator upgrade to complete 10^{21} POT which is requested in the proposal [6-8].

Table 1. History of exposure.

Period	POT	Detector	Site	Aim
Oct. 2014-Dec. 2014	1.3×10^{20}	• 2kg iron target ECC, • Small emulsion shifter, • INGRID	SS floor at NM	Feasibility study **done**
Jan. 2015-Apr. 2015	1.4×10^{20}	• 2kg iron target ECC, • Small emulsion shifter, • INGRID	SS floor at NM	Neutrino event detection **done**
May 2015-Jun. 2015	0.8×10^{20}	• 1.5kg water target ECC	SS floor at NM	Neutrino-water event detection **done**
Jan. 2016-May 2016	4.0×10^{20}	• 60kg iron target ECC • Medium emulsion shifter • INGRID	SS floor at NM	Detector performance study with high statistics **done**
Dec. 2016-Apr. 2017	5.9×10^{20}	• 1.5kg water target ECC	SS floor at NM	Detector performance study **done**
Nov. 2017-May 2018	7.1×10^{20}	• 3kg water target ECC • Scintillating Fiber Tracker • INGRID	SS floor at NM	Measurement of neutrino-water events with slow protons **done**
Nov. 2019-Feb. 2020	4.8×10^{20}	• 75kg water, 130kg iron and 15kg CH target ECC • Large emulsion shifter • Scintillation Tracker • Baby MIND	B2 floor at NM	First physics run Measurement of neutrino cross-sections with slow protons **ongoing**

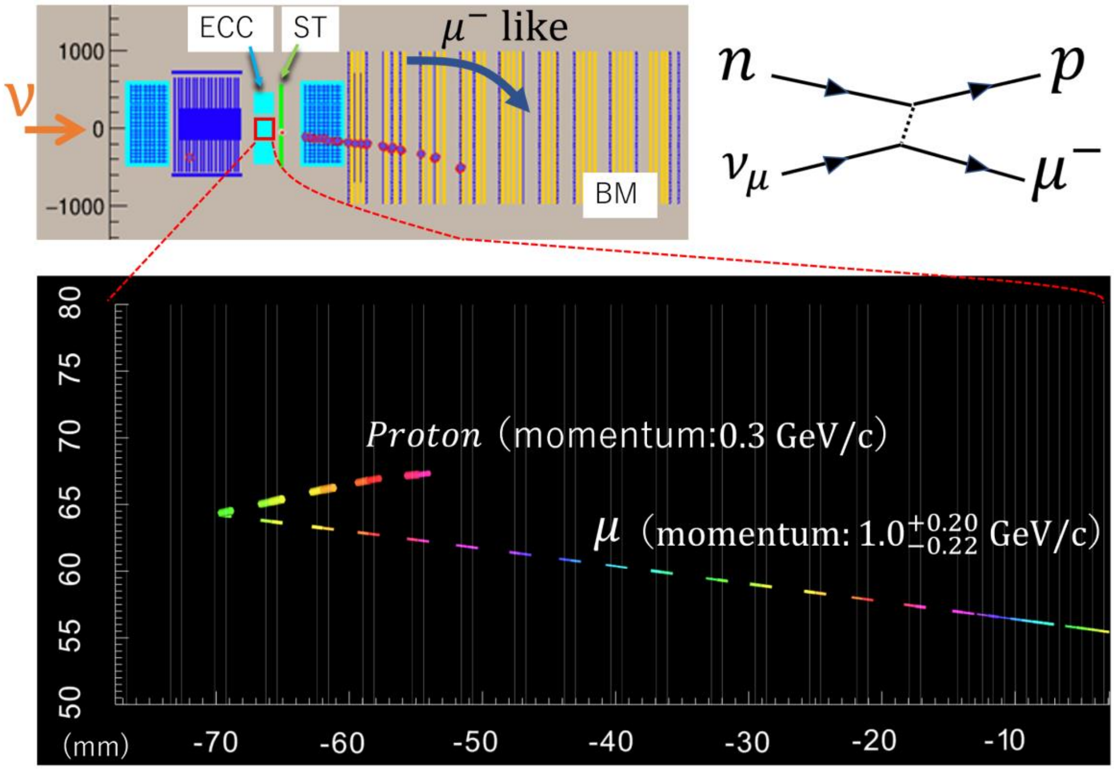

Figure 1. a neutrino event candidate detected in the first physics run.

2 Proposal of the test experiment from Feb. 2021

2.1 Motivation of this experiment

There are two motivations in this test experiment. One is the test of newly developed emulsion detectors to improve neutrino-nucleus interaction measurements. The other one is the training of newcomers in our collaboration to participate smoothly and play an active role in the second physics run. Actually 11 undergraduate school students and 1 master course student are contributed in this test experiment.

2.2 Experimental setup

In this test experiment, detector configuration and place are basically the same as the first physics run as shown in figures 2, 3. It means that the main components are the Emulsion Cloud Chamber (ECC) for analyzing neutrino events in detail, and the Large Emulsion Shifter and the Scintillation Tracker to provide a time stamp, and Baby MIND to identify and measure the momentum of muons. Therefore, we can analyze neutrino events with muon information.

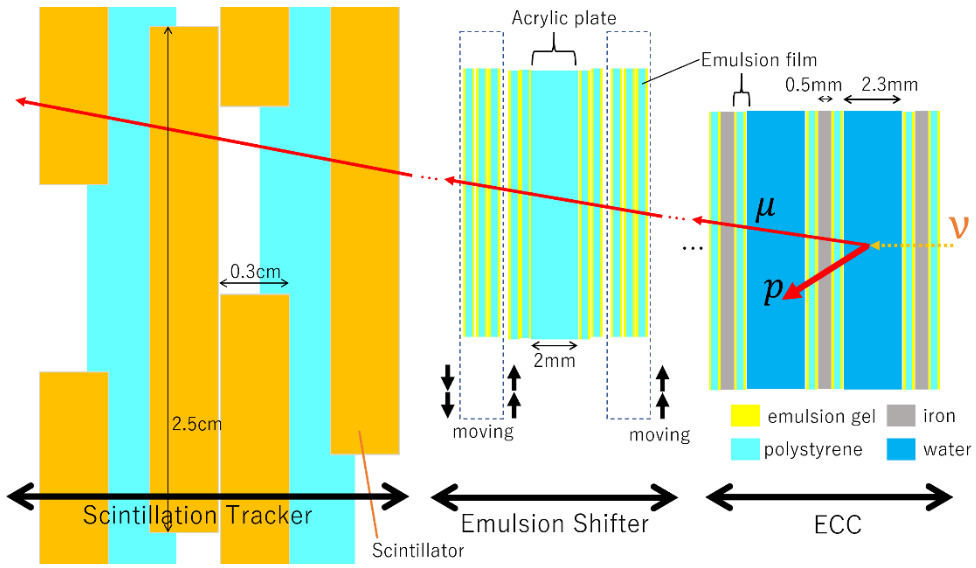

Figure 2. Detector components in the first physics run.

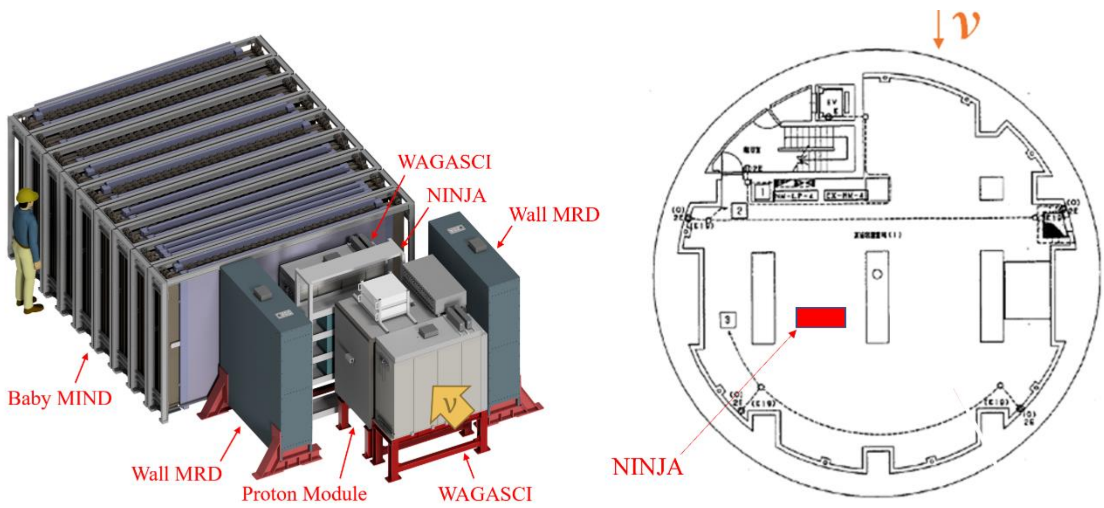

Figure 3. Detector place at B2 floor (right) and detailed position (left).

Then instead of water target ECC used in the previous physics run, we will introduce a lead target ECC and a heavy-water target ECC in this experiment. The lead target ECC has a sandwich structure of emulsion films and 0.3 mm-thick lead plates, and can obtain a lot of neutrino events because of its heavy weight. It is useful to collect electron neutrino events because the electron neutrino component in neutrino beam is only 0.5 %, much heavier target than the physics run is required to collect and statistically study the electron neutrino events. The heavy-water target ECC has same structure as water target ECC, but we fill heavy water in the tank. If we subtract the distribution of cross-section of neutrino interaction on water from one of neutrino interaction on heavy water, we can extract the distribution of cross-section on neutrino-neutron interactions. It is important because this gives information (almost) without nuclear effects in nuclei to us. So, in this test experiment, the feasibility study of the lead target ECC and heavy-water target ECC including the treatment of lead plates and heavy-water at the B2 floor is performed. If lead plates or heavy-water are not available, iron plates or water will be used instead of them. Additionally, we will install a side emulsion shifter (left of figure 4) and an emulsion belt shifter (right of figure 4) which give a time stamp to side escaping tracks from the ECCs. Since these devices are under developing, proto types of detectors will be installed and their performance will be tested in this experiment. The lead target ECC, the heavy-water ECC, the side emulsion shifter and the emulsion belt shifter will be installed on the middle of the detector rack as shown in figure 5.

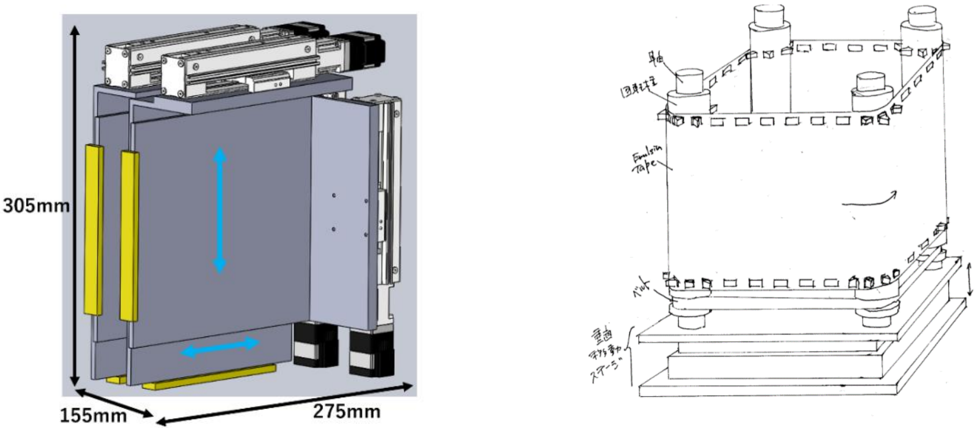

Figure 4. A side emulsion shifter (left) and an emulsion belt shifter (right).

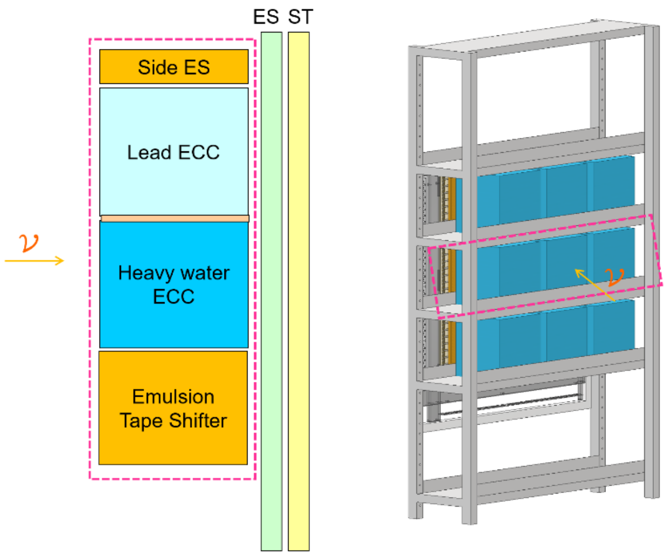

Figure 5. The place of detectors in the rack. Left is top view.

The target mass for the lead target ECC and the heavy-water target ECC are planned to be about 60 kg and 8 kg, respectively. Using these ECCs and assuming 1.6 x 10^{20} POT, the expected number of neutrino CC events will be ~300 events for lead and ~40 events for heavy-water in the neutrino beam mode, or ~100 events (neutrino event + anti-neutrino event) for lead and ~13 events (neutrino event + anti-neutrino event) for heavy water in the anti-neutrino mode. This test experiment can run parasitically with the T2K experiment, therefore we request no dedicated beam time nor beam condition.

2.3 Installation

2.3.1 Dark room

Before the installation of the ECCs and the shifters to the rack, the emulsion films should be packed in vacuum in a dark room. So, we build a temporary dark room at the B2 floor as shown in left of figure 6. This dark room is the same one as we used in the first physics run (right of figure 6). Outside area of the dark room is used as a working space as shown in figure 6. In this dark room, there is cooling boxes, vacuum systems with a heat sealer and working desks as shown in figure 7.

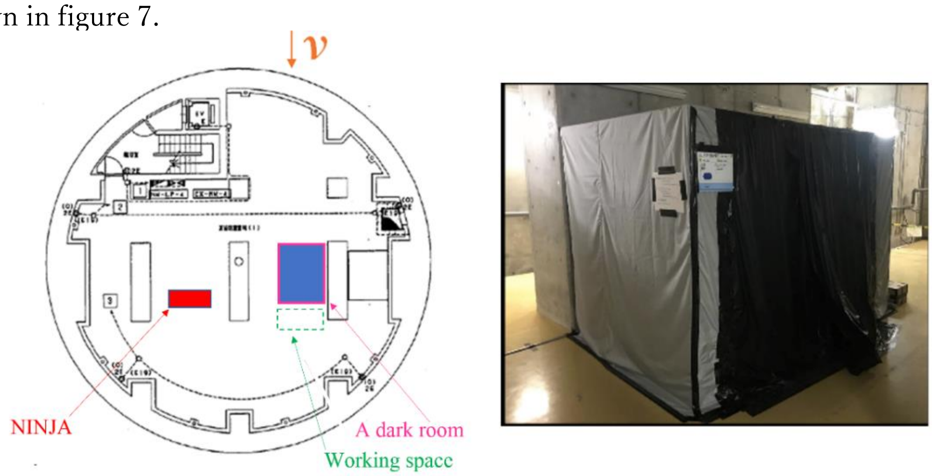

Figure 6. The position of the dark room at the B2 floor (left) and a photo of the dark room (right).

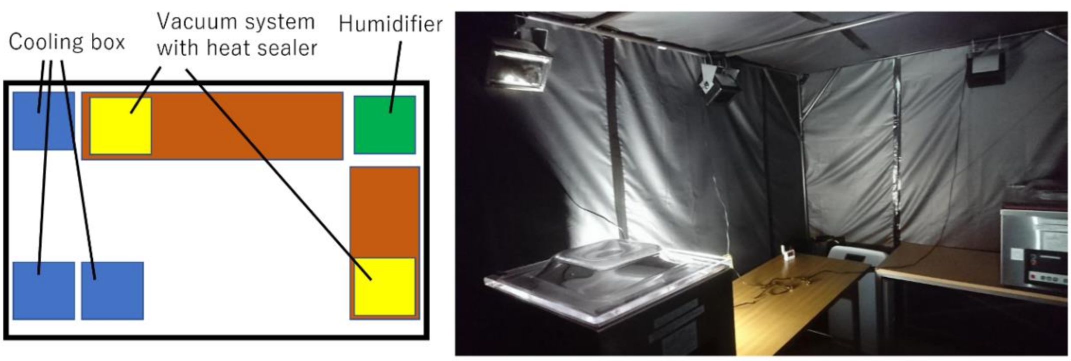

Figure 7. Inside of the dark room.

2.3.2 Cooling shelter

If emulsion films are put at room temperature (~20 deg. C), the tracks will get thinner and the efficiency becomes low because of fading effect. So, the detectors need to be kept as cool as possible. In first physics run, the detectors were surrounded by insulation and cooled by a compressor on the ceiling. In this experiment as well, the detectors will be surrounded by insulation. However, in the first physics run, the temperature in the insulation was 13 deg. C which is not sufficiently low to keep the film performance, so in this experiment, two compressors will be installed on the floor and a heat-insulating duct sends cold air as shown in figure 8. The heat-insulating duct which is fixed using cable ties along the wall so as not to cross the aisle is used as shown in Figure 9. The installation place and operation of cooling compressors will be well coordinated with the T2K-WAGASCI experiment [9].

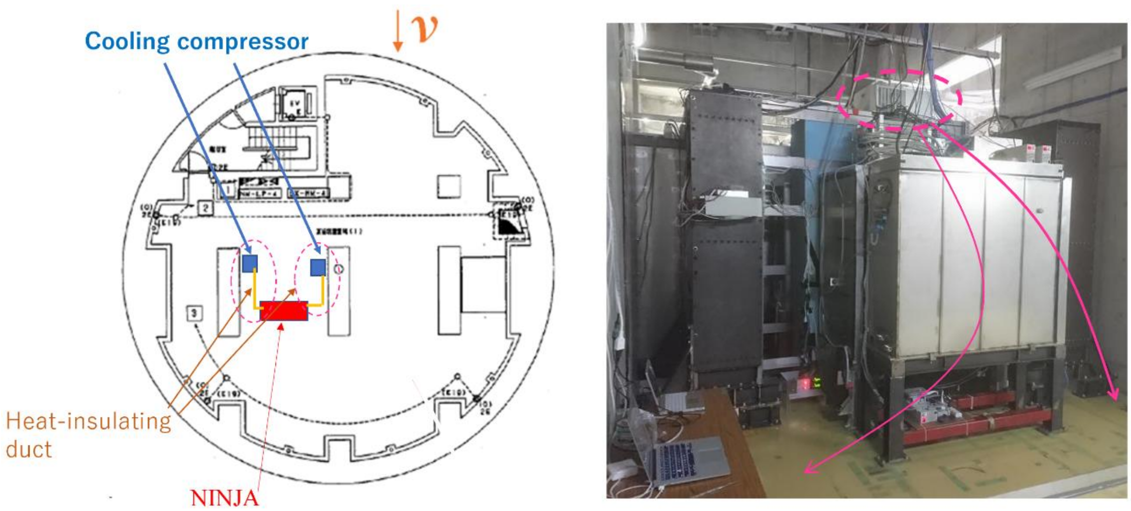

Figure 8. Cooling compressor

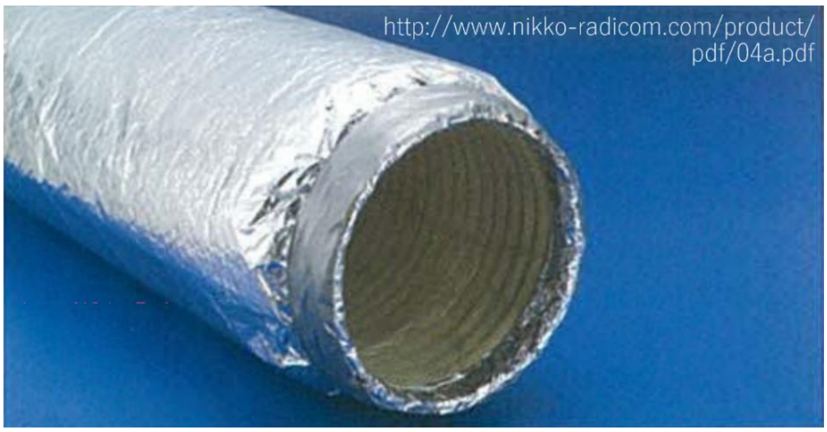

Figure 9. Heat-insulating duct

3 Schedule

The schedule for this experiment is shown in the following table 2. Each working place which is requested in section 4 is shown in Table 2 and Figure 10. We will start our activities at the B2 floor as soon as after this proposal is approved.

Table 2. Schedule

Task	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Film production	Nagoya U.					
Film packing			B2	(DR)		
Operation test of large emulsion shifter	Nagoya U.		B2(b)			
Operation test of scintillation tracker	YNU	B2(a)				
Development of side emulsion shifter	Nihon U.		B2(a)			
Development of emulsion belt shifter	Nihon U.		B2(a)			
Construction of dark room		B2(DR)				
Operation test of cooling shelter		B2(a)				
Installation				B2(a,b)		
Beam exposure and monitoring of detectors				B2		
Film packing and transportation to Nihon U.						B2(DR)

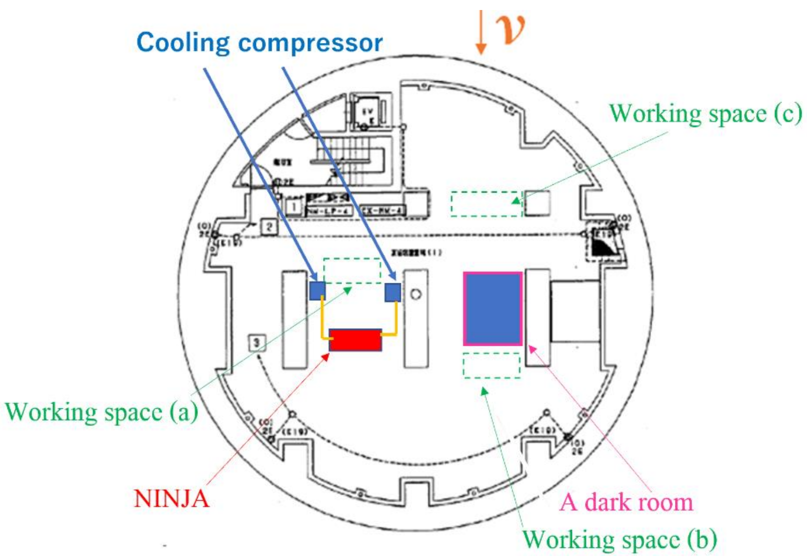

Figure 10. Request for working places in the B2 floor

4 Requests

- Experimental site and working place :

  - B2 floor

  For the detectors, 0.5m x 1.5m in front of downstream WAGASCI module from Dec. 2020 to the end of May 2021.

  For the cooling compressor and a PC desk, 0.4m x 0.8m near a central concrete wall from Dec. 2020 to the end of May 2021.

  For dark room, 2m x 3m of the south area from Dec. 2020 to the end of May 2021.

  For working space (a), it will be used for the operation test of the scintillation tracker, side emulsion shifter and emulsion belt shifter from Dec. 2020 to the middle of Feb. 2021, and temporarily for up to a few days for detector installation from the middle of Feb. 2021 to the end of Feb. 2021.

  For working space (b), it will be used as a working space to assemble the large emulsion shifter and heavy-water ECC, and a material storage area for the film packing from Dec. 2020 to the end of May 2021.

  For working space (c), it will be used as a material storage area from Dec. 2020 to the end of Feb. 2021.

  - NA Building

  From Dec. 2020 to the end of May 2021, (3 m x 3 m) for the emulsion treatment and PC work, and (3 m x 3 m) for material storage are requested as shown in red circles in Fig.11.

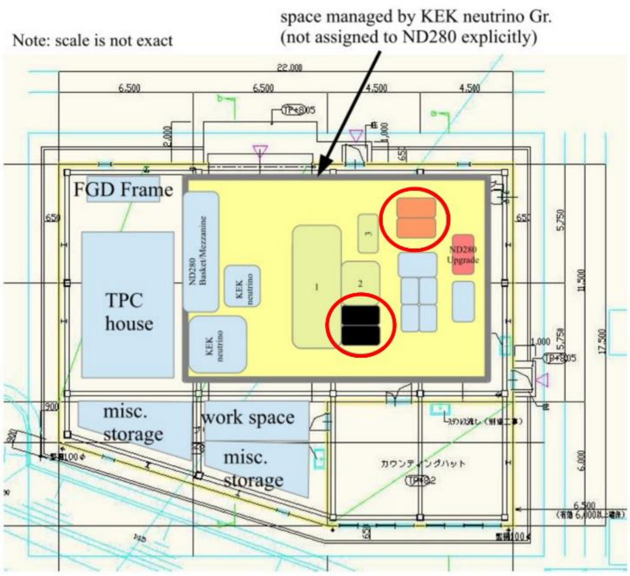

Figure 11. Working areas (red circles) in NA Building requested for this experiment

- Working desk :
  - B2 floor
  For dark room, 0.6 m x 1.8 m desk and 0.6 m x 1.2 m desk are requested as the working desk.
  For near detector, 0.5 m x 1 m desk are requested to put our note PCs.

  - NA Building
  Three of 0.9 m x 1.8 m desks and two chairs are requested for the working place as shown in Fig. 11.

- Power supply :
  Required power supply for each period and location is summarized in Table 3. This will also be well coordinated with the T2K-WAGASCI experiment.

Table 3. Required power supply

Floor	Place	Power consumption	Power supply	Period
B2	Dark room	2.0 kW	1-phase AC	Dec. 2020 – Feb. 2021, Apr. 2021 – May 2021
		2.0 kW	3-phase AC	
		0.5 kW	1-phase AC	Mar. 2021
	Detector	3.0 kW	1-phase AC	Dec. 2020 – Mar. 2021
NA	Working desk (Film handling)	0.5 kW	1-phase AC	Dec. 2020 – May 2021

- “Beam trigger”, “pre-beam trigger” and “spill number” signals for test experiment at B2 floor
- The JLAN network connection for the DAQ PC

5 Summary

We propose an experiment to test newly developed emulsion detectors (heavy-water ECC, lead ECC, side emulsion shifter and emulsion belt shifter) and give newcomers experience in neutrino experiments with the miniaturized setup of the first physics run of NINJA experiment at B2 floor in J-PARC Neutrino Monitor Building. We have discussed with the KEK Neutrino group about the use of space and the schedule, and obtained consent. The preparation of the detectors is already started. Data taking is planned from the end of Feb. 2021 to the end of Mar. 2021. After film development, the analysis will be started and we will feedback the future NINJA physics run with the results to improve neutrino-nucleus interaction measurements.

References

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