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A study of water Cherenkov detector for counting the number of neutrino at Near detector hall of J-PARC neutrino beam-line

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Abstract

We propose to study a water Cherenkov detector for counting the number of neutrino at Near detector hall of J-PARC neutrino beam-line.

In this test experiment, we will develop a water Cherenkov detector and test a capability of counting the number of neutrino interactions at rather high beam intensity environment.

A Collaborator list

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1 Motivation

The Tokai-to-Kamioka neutrino oscillation experiment (T2K, J-PARC E-11) have launched the physics data taking. It aims for

1. search for the not-yet discovered ν_μ to ν_e oscillation mode
2. precise determination of θ_{23} and Δm^2 by the measurement of muon neutrino disappearance.

Neutrino's produced at J-PARC are detected by giant water Cherenkov detector,Super-Kamiokande, after traveling 295km in earth. The properties of neutrinos just after their production are measured at the ND280 hall. In the previous K2K experiment, a water Cherenkov detector was used also at the near cite and enabled the large cancellation of systematic errors because the near and far measurement based on the same detection principle and the same nuclear target. However, same type of water Cherenkov detector as the K2K experiment would not work at the T2K case since the event rate is too high. Therefore, there is no water Cherenkov type detector in the current ND280 detector complex.

In this test experiment, we will develop a water Cherenkov detector and test a capability of counting the number of neutrino interactions at rather high beam intensity environment. Once the performance is proved as expected in this test experiment, we whould like to use this as one of the T2K near detectors and contribute to improve the T2K physics sensitivity. The target precision is 2%.

2 Experimental method

Water is used both as a neutrino interaction target and detector medium. Charged particles are generated when neutrino interact with hydrogen or Oxygen nucleus in water. Some of them, especially muon, generate the Cherenkov photons while traversing water. Photomultiplier-tubes placed around the water tank detect the photons.

The previous K2K experiment used a 1 kton water Cherenkov detector. With that large volume, multiple interaction even within one bunch would be expected at the T2K design intensity and the separation between events is not feasible. Therefore, we adopt a small ($\sim$ 2 ton) volume detector which is specialized to the number of events counting.

Figure 1 shows the schematic view of the detector. The water tank is 1.6m long and 1.4m in diameter, and will be placed along the beam direction. Inside the water tank, a 0.8m-diameter and 1.0m long acrylic vessel will be installed as the fiducial volume (FV). The tank will be filled with water, but the water in acrylic vessel is removable. The water around the acrylic vessel works as the detection medium. By counting the number of interactions both with and without water in the acrylic vessel, the number of interactions occurred inside the water in the acrylic vessel will be deduced.

We are planning to re-use HAMAMATSU R1652-01ASSY 3-inch PMT used for the TRISTAN and K2K experiments. The signal from PMTs will be read using FADC modules to enable bunch separation. The FADC modules will be triggered using the timing information from MR to synchronize to the beam. Actually, the signal will be branched from those for the T2K experiment and will not cause any effect on the T2K data taking.

T2K is adopting the off-axis beam method, in which the beam axis direction is off-centered from the Super-K direction intentionally. Depending on the off-axis angle, narrow energy spectrum is obtained. The ND280 off-axis detector was installed towards the Super-K direction in the B1 floor of the ND280 hall. We are planning to install our detector in the B2 floor, where the same off-axis angle and hence the same energy spectrum is expected. Figure 2 shows the planed detector position.

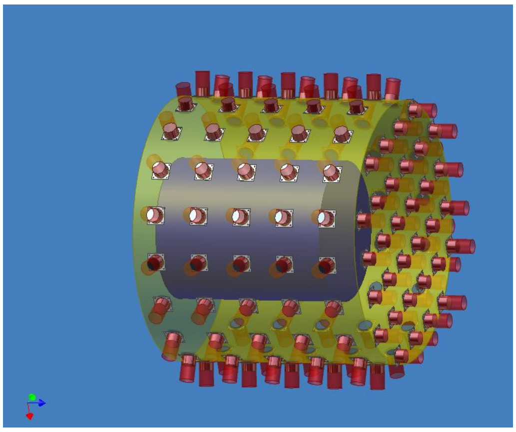

Figure 1: Schematic view of the detector.

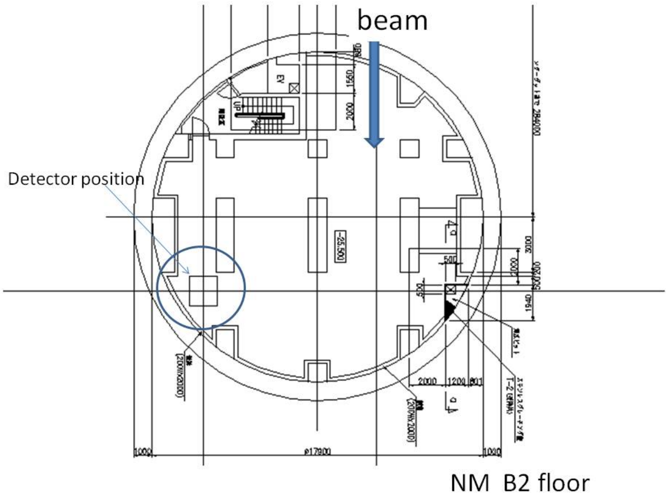

Figure 2: Detector position

3 Expected performance

Among particles produced by the neutrino interaction, main source of the Cherenkov photons is muon. The simulated event display for various muon energies, generation points and directions are shown in Figures 3∼7.

The basic strategy to precisely measure the number of neutrino interaction is to compare the measurement with and without water in FV. Figures 3∼7 are indicating that some additional event categorization is possible.

Figures 8 and 9 show the expected distribution of the number of photo-electrons and the number of hit PMTs for various muon kinetic energies. Here, muons are generated randomly in FV in the MC simulation. The light yield is sufficiently high to detect muons above the Cherenkov threshold velocity. The expected efficiency as a function of muon kinetic energy is shown in Fig.10.

3.1 Expected number of events

The expected neutrino flux is 6.5E10 /cm^2/spill at the J-PARC MR design intensity (750kW). (Here the repetition rate is assumed to be 3.52 sec.) The average neutrino energy is 0.7 GeV and the cross section with water is 0.63E-38 cm^2. Then 302 events/day is expected in FV (0.5ton). The number of interaction in FV will be estimated by subtracting the event rate without the FV water (2.0 ton water inside the tank) from that with the FV water (2.5ton). The ratio of data taking time for these two condition will be 2.0 : 2.5. If data is taken for 100 kW (750kW) $\times$ 100 days,

- 11,290 (84,700) events by 56days data taking with water in FV
- 7,110 (53,300) events by 44days data taking without water in FV

are expected.

4 Schedule

In 2010,

- September : Tank installation. Use the ND280 hall crane for 1 day.
- October∼November : Other installation including PMTs, electronics system and water circulation system

- December : start commissioning

. From 2011, start data taking.

5 Request of beam condition and beam time

This test experiment can run parasitically with T2K and therefore we request no dedicated beam time nor beam condition. We request 100 days of data taking in order to evaluate the feasibility of counting number of neutrino interactions.

Once its performance is proved, then another proposal to continue to use this detector as a part of near detector in T2K will be submitted to appropriate bodies, i.e. IPNS-PAC and T2K. In that case, we need at least for 100 kW x 270 days in order to reach the statistical precision of 2% .

6 Request of equipment

We request

- electricity (∼5 kW) for the electronics and water circulation system
- beam timing signal and spill information
- network connection
- 250 PMTs (HAMAMATSU R1652-01ASSY) used for the TRISTAN and K2K experiments

The infrastructure for all these are exsiting already. Equipment such as detector itself will be covered by external funds (Kakenhi).

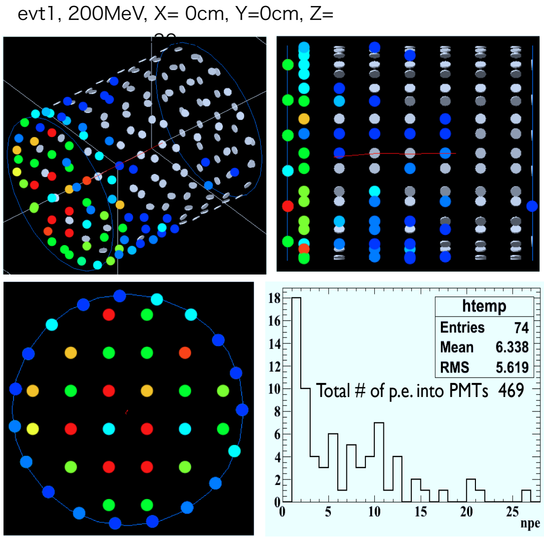

Figure 3: Event display for 200 MeV muons generated at x=0cm, y=0cm and z=-30cm. Here the z-axis is along the tank cylinder axis Muon is generated to the +z direction. The colors corresponds to the number of detected photo-electrons.

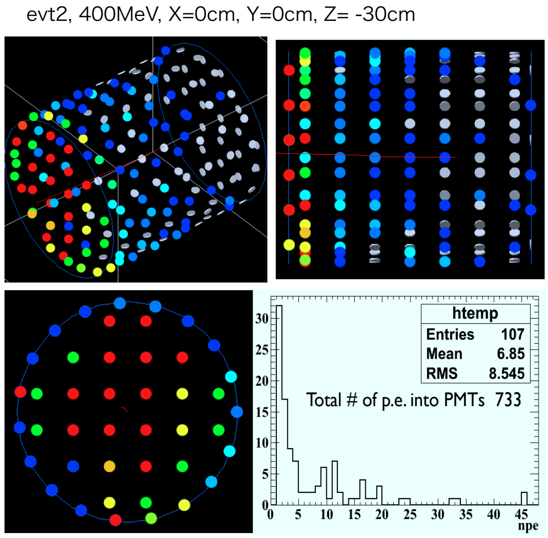

Figure 4: Same as Fig.3, but for 400 MeV muons.

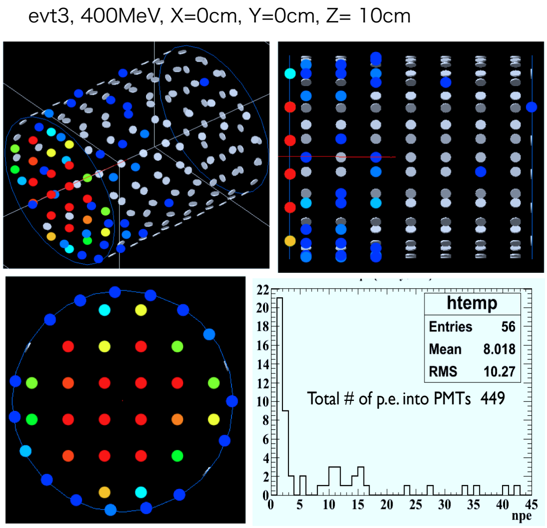

Figure 5: Same as Fig.4, but generated at z=10cm.

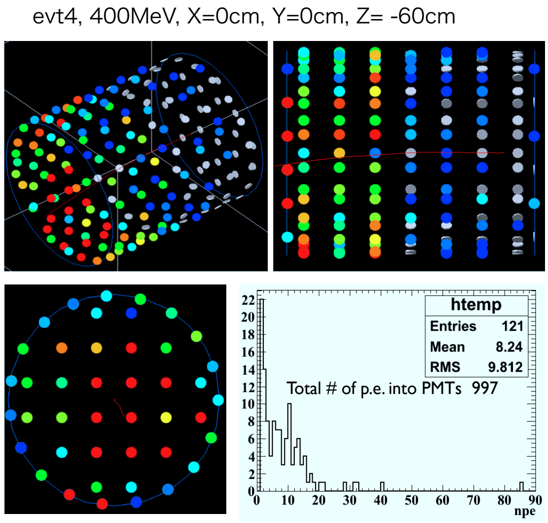

Figure 6:
Same as Fig.4, but generated at z=-60cm.

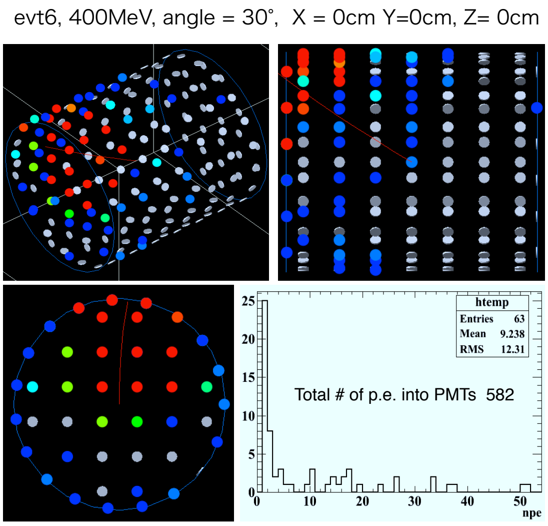

Figure 7: Same as Fig.4, but generated at z=0cm and in some angle.

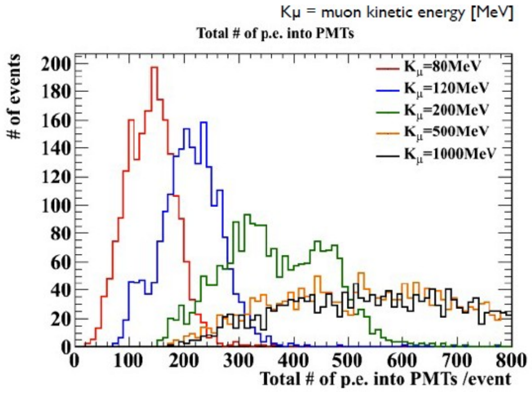

Figure 8: Number of photo-electron distribution for various muon momentum. Muons are generated randomly in FV in the MC simulation.

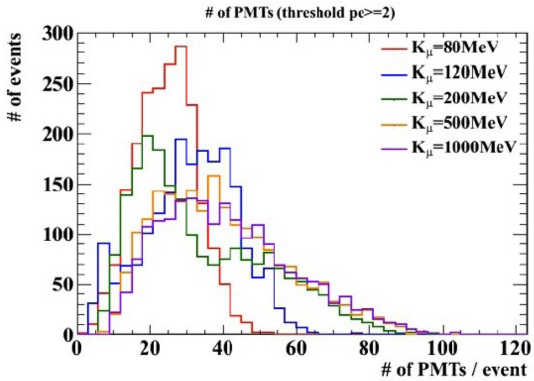

Figure 9: Number of hit PMTs distribution for various muon momentum. Hit PMT is defined as that who detected more than two photo-electrons.

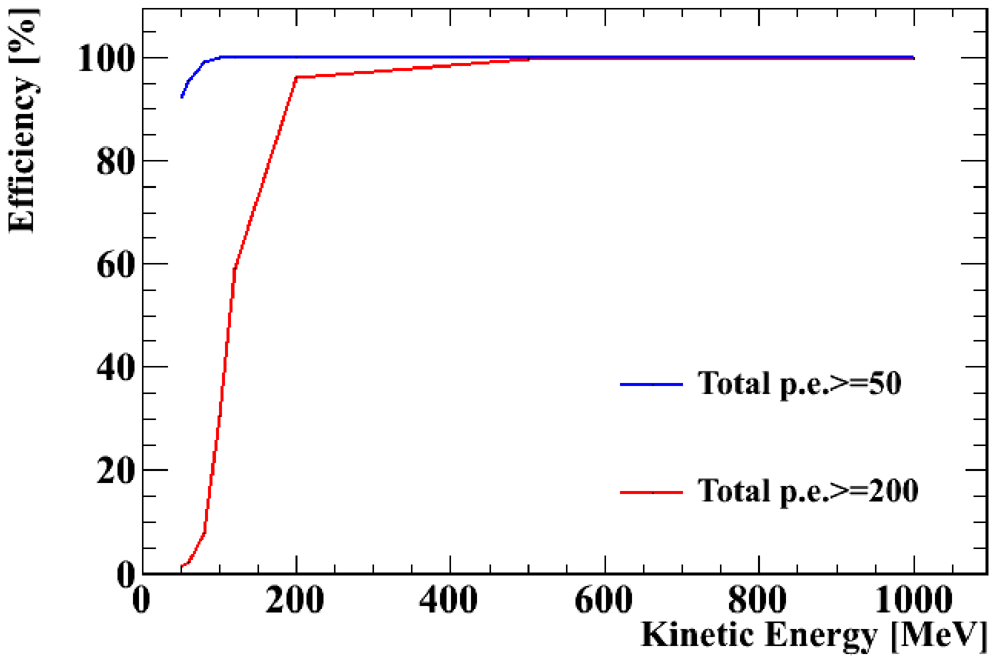

Figure 10: Detection efficiency as a function of muon kinetic energy.