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Study of Neutrino Mass Hierarchy with RENO-50

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A 5 kton of ultra-low-radioactivity liquid scintillator detector, located at roughly 50 km away from the Yonggwang(now Hanbit) nuclear power plant, is proposed to determine the neutrino mass hierarchy where the neutrino oscillation due to θ_{12} takes place at maximum with the baseline. The detector is expected to detect neutrinos from nuclear reactors, the Sun, Supernova, the Earth, any possible stellar object and the J-PARC neutrino beam. It could be regarded as a multi-purpose and long-term operational detector. The main goal is to measure the most accurate value of θ_{12} and mass squared difference, and to attempt determination of the neutrino mass hierarchy. We will describe physics goals and experimental arrangement of RENO-50 shortly and present its sensitivity based on a MC study, especially focused on the possibility of mass hierarchy. To measure mass hierarchy, the PMT coverage should reach more than 30% to get 3% of energy resolution, in the assumption that other properties like attenuation length of liquid scintillator, target vessel material (possibly acrylic), and light yield are comparable to RENO. In real experiment, we consider the bin size of $\sim$12bins/MeV and 3% energy resolution. With this bin size, we generated events for normal hierarchy and calculate chi-square based on hypotheses of normal hierarchy or inverted hierarchy. The MC Simulation result shows that at least 60000 events for 3σ determination is necessary, and thus needs $\sim$40 years of data-taking for RENO-50 (10 years for 20kton detector). In conclusion, a large (>20 kton) detector with 3% energy resolution is needed to determine mass hierarchy within 10 years.

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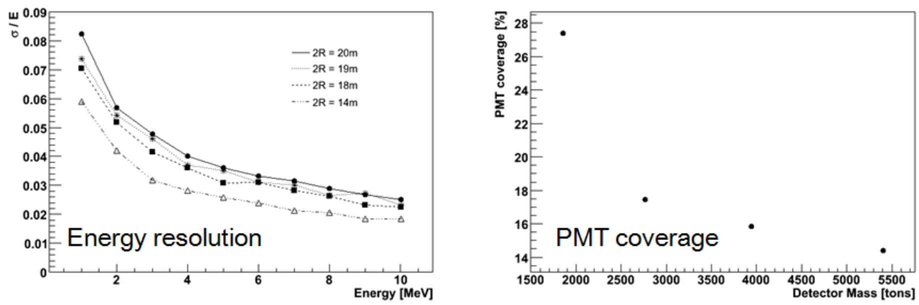

Figure 1: Energy resolution change via PMT coverages.

1. Description of RENO-50 Detector

1.1 Physics of RENO-50 Detector

RENO-50 is a proposed detector which is ultra-low-radioactivity, large liquid scintillator (more than few kton for target mass) without metal-doped, located roughly 50km away from the Hanbit nuclear power plant in Korea. 50km is the oscillation maximum place due to θ_{12}. This detector is expected to measure several kinds of neutrinos and could be served as a multi purpose detector and long-term neutrino telescope. The physics goal of RENO-50 is below.

- A challenging effort to determine neutrino mass hierarchy problem.
- World most accurate measurement of θ_{12} and Δm^2_{21}.
- Detect a neutrino burst from Supernova as a neutrino telescope.
- Accurate measurement of low-energy solar neutrino.
- Geo-neutrino search.
- Detection of neutrino from the J-PARC accelerator.

At this poster, we mainly focused the possibility of neutrino mass hierarchy determination problem.

1.2 Monte Carlo Simulation Study of RENO-50 Detecotr

For the Monte Carlo simulation study of RENO-50 detector, we supposed 5 kton cylindrical shape of liquid scintillator detector, like RENO (without γ-catcher region), with 6000 PMTs, and apart 50 km away from the reactor array. With this geometry, we studied energy resolution while varying the PMT coverages. For this, we fixed the number of total PMTs and change the target mass. If we shrink the target mass, PMT coverages will increase and we can get better energy resolution. Figure 1 shows the simulation result. We can get 3% energy resolution at 5MeV with 25% PMT coverage.

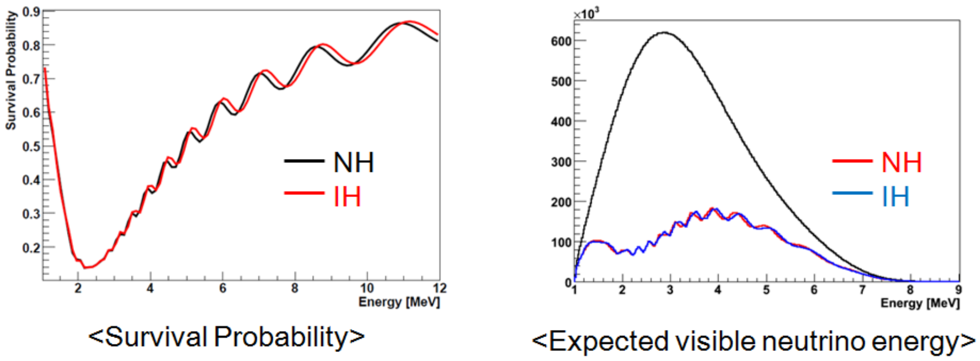

Figure 2: Survival probability and expected visible neutrino energy spectrum at RENO-50.

2. Sensitivity of Neutrino Mass Hierarchy at RENO-50

2.1 Survival Probability at RENO-50

Normal hierarchy and Inverted hierarchy shows different modulation ripple at the expected visible neutrino energy spectrum at RENO-50. Figure 2 shows the different energy spectrum. Left side is the survival probability and right side is the expected visible energy spectrum. The black envelop shape at the right side figure is the expected spectrum without oscillation. The ripple at 3$\sim$5MeV region shows certain different.

2.2 Mass Hierarchy

At the real experiment, we should consider the energy resolution and bin size effect. If the energy resolution is not sufficiently enough, the different ripple will be smoothed and will not distinguished. Also, if the statistics is not enough, we can't choose more fine bin size, and it also smoothed the difference of ripples. We performed simulation of these effect. First, we draw expected visible energy spectrum of Normal and Inverted hierarchy case and adopt energy resolution via Gaussian convolution method. After that, bin size effect come into play. For example, 3% energy resolution is roughly 12bin/MeV. Figure 3 shows the simulation result. Top plot is 6% energy resolution, bottom left is 3%, and bottom right is 2% energy resolution. Bin size was chose for the 3% resolution, 12bin/MeV, except top left plot.

Dashed line is ideal case, i.e. perfect resolution, and solid line is simulated one. One can see that at 6% resolution, we can't distinguish Normal and Inverted case even 50bin/MeV case. At this simple simulation, we can see that at least 3% energy resolution is needed to determine mass hierarchy problem.

2.3 χ^2 calculation test

At the preceding subsection, we assumed enough statistics. Now, consider the statistics effect. RENO-50 expects to observe $\sim$1500 events per year, after consider the oscillation effects, 70% assumed detection efficiency, and 5kton detector. Based on this number, we did χ^2 calculation test. First, generate events according to Normal hierarchy and calculate χ^2 based on the hypotheses of

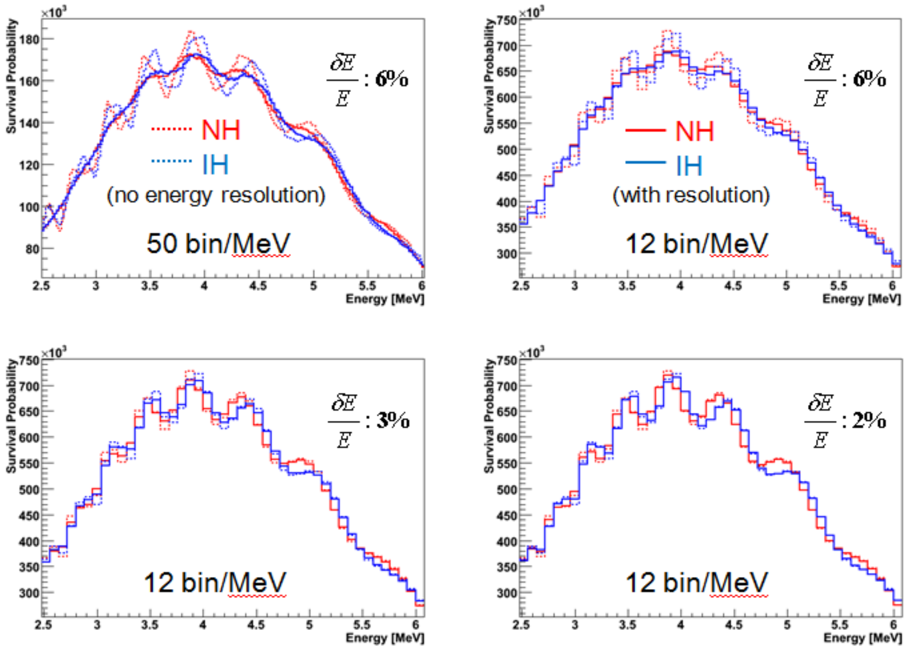

Figure 3: Expected visible energy spectrum after considering energy resolution and bin size effect.

Inverted hierarchy, so called exclude probability. We adopt 12bin/MeV and 3% energy resolution for the calculation. The result shows that we needs more than 60000 events for 3σ exclude probability and it takes almost 40 years when we using 5kton detector, quite long time. So we need to increase detector size also. However, increasing the detector size leads improvement of optical properties for the attenuation length of liquid scintillator is comparable with detector size.

3. Conclusion

5 kton detector is not enough to determine neutrino mass hierarchy within reasonable time limit. We need a large (∼20 kton) detector with 3% energy resolution is needed to determine the neutrino mass hierarchy within 10 years. For this, we should improve optical properties, like attenuation length of liquid scintillator, because of the huge size of detector, or we need modular detector component.