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Physics Potentials of the Hyper-Kamiokande Second Detector in Korea

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Hyper-Kamiokande (Hyper-K) succeeds the very successful Super-K experiment and will consist of a large detector filled with 260 kton purified water and equipped with 40% photo-coverage. Physics program of Hyper-K is broad, covering from particle physics to astrophysics and astronomy. The Hyper-K 1^{st} detector will be built in Japan, and the 2^{nd} detector is considered to be built in Korea because locating the 2^{nd} detector in Korea improves physics sensitivities in most cases thanks to the longer baseline (∼1,100 km) and larger overburden (∼1,000 m) for Korean candidate sites. In this talk, we present overview and physics potentials of the Hyper-K 2^{nd} detector in Korea.

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1. Introduction

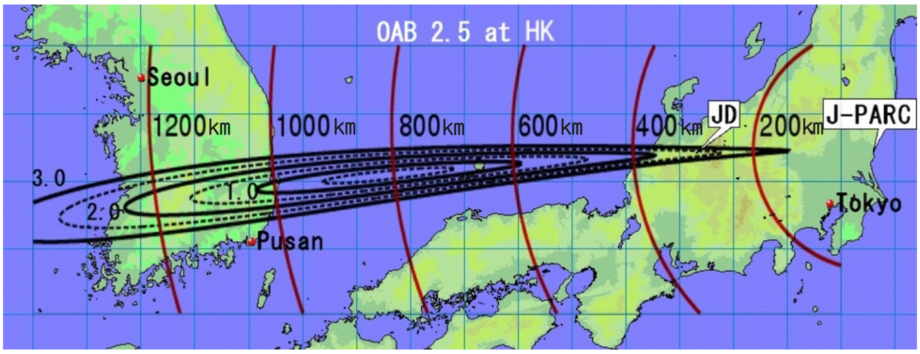

Figure 1: Baselines and off-axis angles of the J-PARC neutrino beam in Japan and Korea [2].

Hyper-Kamiokande (Hyper-K) is a next generation water Cherenkov detector consisting of two identical detectors with each 260 kton purified water and 40% photo coverage with a combination of 20 inch Hamamatsu PMTs and multi-PMTs (multiple 3 inch PMTs in one enclosure). Hyper-K will start its construction for the 1^{st} detector [1] in April 2020 at Tochibora site where the baseline from J-PARC is 295 km with 2.5° off-axis angle (OAA).

The neutrino beam produced at J-PARC currently reaches Korea with $1^\circ \sim 3^\circ$ OAA from 1,000 km to 1,260 km baselines (see Fig. 1). This gives an opportunity to locate the 2^{nd} detector in Korea since the longer baseline would benefit various physics potentials such as precise measurement of CP violation phase and neutrino mass ordering determination. Bi-probability plots in Fig. 2 clearly shows that it is easier to determine neutrino mass ordering and CP violation phase in a Korean Mt. Bisul site. This is due to the longer baseline and higher energy reach from the 1^{st} and 2^{nd} oscillation maxima. Table 1 shows two most favorable candidate sites in Korea. Thanks to larger overburden of ~1000 m in Korean candidate sites than Japan Tochibora site (650 m), low energy physics sensitivities such as solar neutrinos, supernova relic neutrinos are expected to be improved. Due to a very limited space here we present only some physics sensitivities, but more

Table 1: Two favorable sites of the Hyper-K 2^{nd} detector in Korea with off-axis angles between 1° and 2.5°. The baseline is the distance from the production point of the J-PARC neutrino beam to the candidate sites [3].

Site	Off-axis angle	Baseline (km)	Height (m)	Composition of rock
Mt. Bisul	1.3°	1,088	1,084	Granite porphyry, andesitic breccia
Mt. Bohyun	2.3°	1,043	1,124	Granite, volcanic rocks, volcanic breccia

details are found in [3].

2. Physics potentials

Sensitivity studies are performed using NEUT [4] 5.3.2 for neutrino interaction generator and full simulation of Super-K scaled to Hyper-K for the expected event rates, Prob3++ [5] for the

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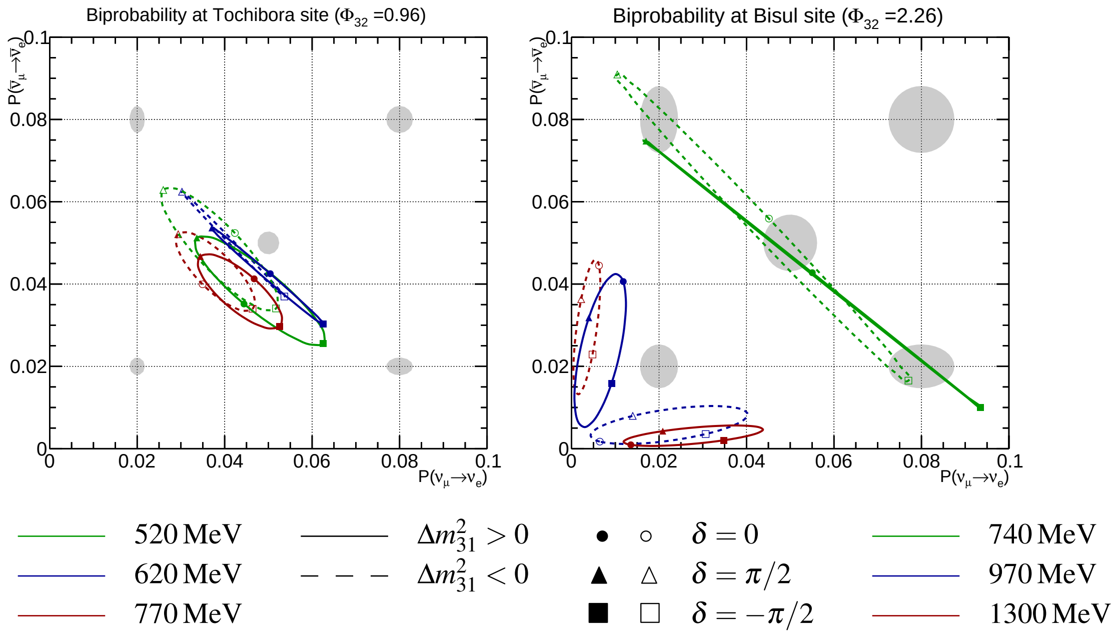

Figure 2: ν_e appearance bi-probabilities at the Hyper-K site in Tochibora, Japan (left) and Mt. Bisul, Korea (right). Grey ellipses show the sizes of statistical uncertainties for a ten year exposure of one Hyper-K detector, and $\Phi_{32} \equiv \frac{2}{\pi}\frac{|\Delta m^2_{32}|L}{4E}$ where $|\Delta m^2_{32}| = 2.5\times10^{-3}$ eV^2, $E = 620$ MeV(left), and 970 MeV (right) [3].

oscillation probabilities, and a constant matter density of 3.0 g/cm^2 for a 1100 km baseline with 1.5°, 2.0°, or 2.5° OAA for hypothetical Korean sites.

In our sensitivity studies, unless otherwise specified, 10 years of operation with 1.3 MW beam power is assumed with 1:3 ratio of neutrino to antineutrino modes, and this corresponds to 2.7×10^{22} proton on target (POT). A reasonable systematic uncertainty model is also applied [3].

According to our sensitivity studies, when the CP is maximally violated with known mass ordering, there is almost no difference in the CP violation sensitivity between Japan Detector (JD) plus Korean Detector (KD) configuration and two Japan Detectors (JD×2). However, when the CP is a little non-maximally violated JD+KD sensitivity is better.

Figure 3 left plot shows the progress of δ_{cp} violation discovery potential (minimum 5σ significance) with exposure for known mass ordering. Due to the limited statistics, the sensitivity of the first 4.5 years is worse for any JD+KD configuration than JD×2. After then any JD+KD configuration sensitivity gets better and reaches close to ∼60% fraction of δ_{cp}, while ∼55% for JD×2 limited by systematic uncertainties. The aim of Hyper-K is not only to determine CP violation or not but also precise measurement of δ_{cp} value. By locating the 2^{nd} detector in Korea we can improve this sensitivity and this is an important input for flavor symmetry models. Figure 3 right plot shows the 1σ precision of the δ_{cp} measurement as a function of the true δ_{cp} value with the mass ordering unknown for true normal ordering. When the CP is maximally violated cases, the precision changes from ∼ 22° (JD×1) and ∼ 17° (JD×2) to 13 ∼ 14° (JD+KD at 1.5° OAA).

Sensitivity to determine mass ordering is improved with JD+KD configuration. Atmospheric neutrinos add additional increase of the sensitivity. Figure 4 shows wrong mass ordering rejection significance as a function of different octant values for true normal ordering case. For any $\sin^2\theta_{23}$

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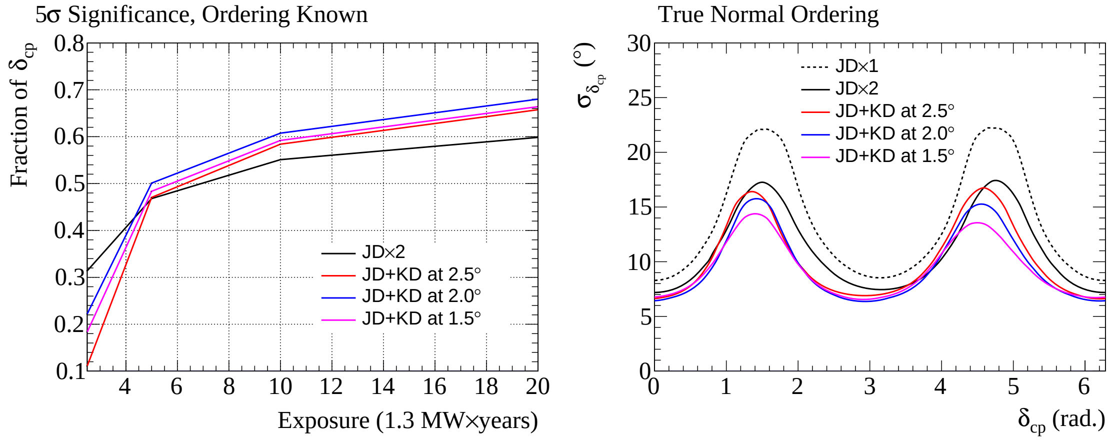

Figure 3: (left) The fraction of δ_{cp} values (averaging over the true mass ordering) to reject the CP conserving values of δ_{cp} with at least a 5σ significance for known mass ordering. (right) The 1σ precision of the δ_{cp} measurement as a function of the true δ_{cp} value with unknown mass ordering for true normal ordering [3].

value between 0.4 and 0.6, more than 8σ sensitivity is expected for JD+KD (Mt. Bisul) configuration when the atmospheric neutrinos are combined with beam neutrinos.

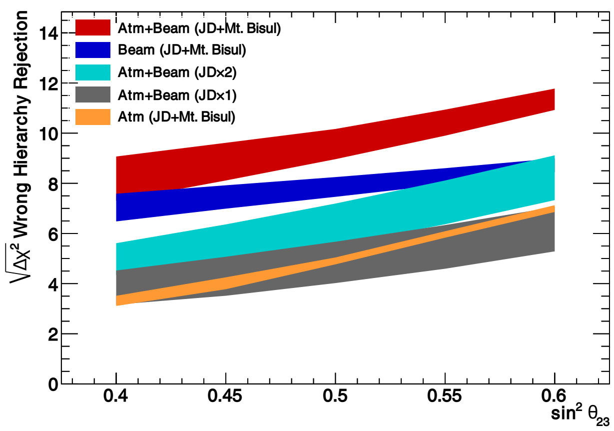

Figure 4: Sensitivity to reject wrong mass ordering assuming true normal ordering with a combined measurement of beam and atmospheric neutrinos for a 10 year exposure. The x-axis shows the possible ranges of $\sin^2\theta_{23}$ and the width of the bands comes from the variation in sensitivity with δ_{cp} [3].

References

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