【Grant-in-Aid for Specially Promoted Research】

Exploring New Frontiers in Neutrino Physics with Hyper-Kamiokande

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Purpose and Background of the Research

●Outline of the Research

Super-Kamiokande has led neutrino research, making it a key topic in particle physics. Its successor, Hyper-Kamiokande(HK), is now under construction (Figure 1). We will introduce a new "Intermediate Water Cherenkov Detector (IWCD)" and cutting-edge technology to enhance HK's capability, minimizing uncertainties and enabling more precise measurements of neutrino properties. We aim to uncover differences between neutrinos and their antiparticles, paving the way for new discoveries in the field.

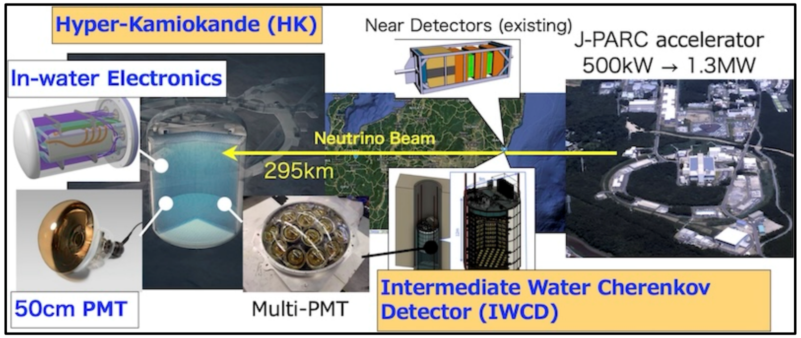

Figure 1. Overview of the Hyper-Kamiokande (HK) Project. A neutrino beam from the J-PARC accelerator will be observed 295 km away at HK to study neutrino oscillations, in which neutrinos change type during flight.

●Background of the Research

Every elementary particle has an antiparticle with the opposite charge, such as the positron for the electron. Particles and antiparticles can be created or annihilated in pairs (Figure 2). The universe is believed to have originated from an extremely hot, dense energy state, giving rise to matter, including stars and ourselves. Since matter and antimatter should have been produced in equal amounts, it remains a mystery why only matter exists today while antimatter seemingly disappeared. It is one of the greatest unsolved questions in modern physics. To explain this imbalance, there must be a difference between particles and antiparticles (CP violation). The Standard Model of particle physics cannot fully account for it, and neutrinos are considered a key to uncovering the unknown mechanism of CP violation. Using neutrino oscillations (2015 Nobel Prize in Physics), comparing neutrino and antineutrino measurements can reveal potential differences.

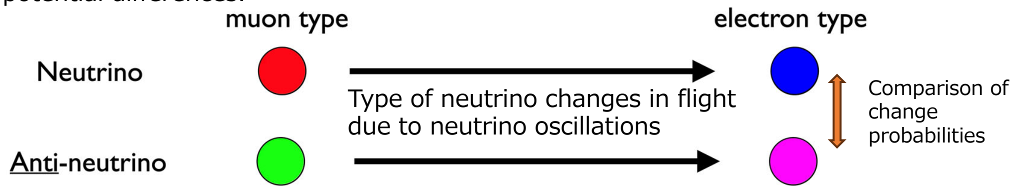

Figure 2. Using neutrino oscillations, comparing neutrino and antineutrino measurements can reveal differences in their properties.

●Goals of the Research

Currently, the T2K experiment at J-PARC and Super-Kamiokande is studying neutrino oscillations to explore CP violation. While hints have emerged, more data and precision are needed for conclusive evidence. HK is being built to observe neutrino and antineutrino beams from J-PARC, 295 km away, and measure their oscillations (Figure 1). Comparing these results will clarify particle-antiparticle differences. Maximizing HK's potential requires a deep understanding of its system and reducing uncertainties in neutrino interaction models. Thus, this Research focuses on three key objectives.

1. Build an IWCD (Figure 3) to precisely measure interactions of electron neutrinos, which serve as signals for observing CP violation.
2. Precisely calibrate the 20,000 photomultiplier tubes of the HK detector, along with electronics and the properties of purified water during operation (Figure 4), to minimize detector-related uncertainties.
3. Measure neutrino oscillations with the highest precision to test CP violation.

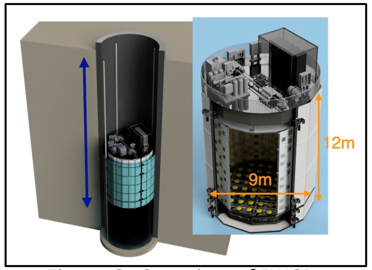

Figure 3. Overview of IWCD

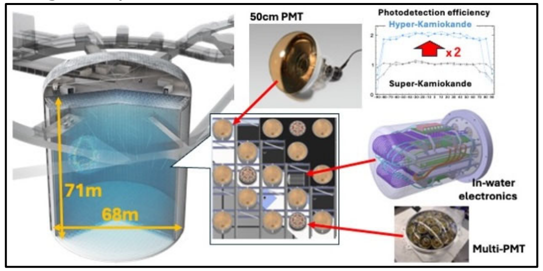

Figure 4. Overview of Hyper-Kamiokande Detector

Expected Research Achievements

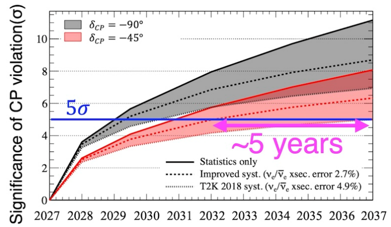

Figure 5: Estimated sensitivity of HK to CP Violation. Colors and lines indicate different assumptions.

●**Search for CP Violation** If CP violation is near its maximum, as suggested by T2K results, the Research could reach 5σ significance within the research period. Even if smaller, it will achieve over 3σ sensitivity for a wide range of parameters and could accelerate 5σ observation by about five years (Figure 5). Observing CP violation in neutrino oscillations will complete neutrino mixing studies, opening new research frontiers such as precise CP measurements, unitarity tests, and neutrino mass consistency checks.

●**Uniqueness of the Research** The IWCD will achieve the world's first "neutrino spectroscopy" by vertically moving a ~700 ton detector to utilize the energy distribution dependence on the position in the neutrino beam. It will also use multi-PMT sensors for high-resolution neutrino signal detection (Figure 6).

The HK detector will be the world's largest underground neutrino detector, with only DUNE in the U.S. pursuing similar research. By maximizing its capability with this Research, HK will be able to produce significant results from the very beginning and continue to lead the world.

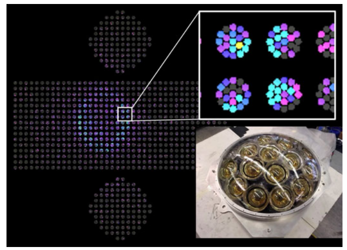

Figure 6: Event display of simulation for IWCD

●**Impact of the Research** The detector enhancements and neutrino cross-section measurements in this Research will benefit proton decay searches and other neutrino observations in HK, advancing particle physics and astrophysics. With two Nobel Prizes, neutrino research attracts strong public interest, helping to promote fundamental science in Japan.

Homepage Address, etc.	https://www-sk.icrr.u-tokyo.ac.jp/en/hk/