Multi-PMT modules for the Hyper-Kamiokande experiment

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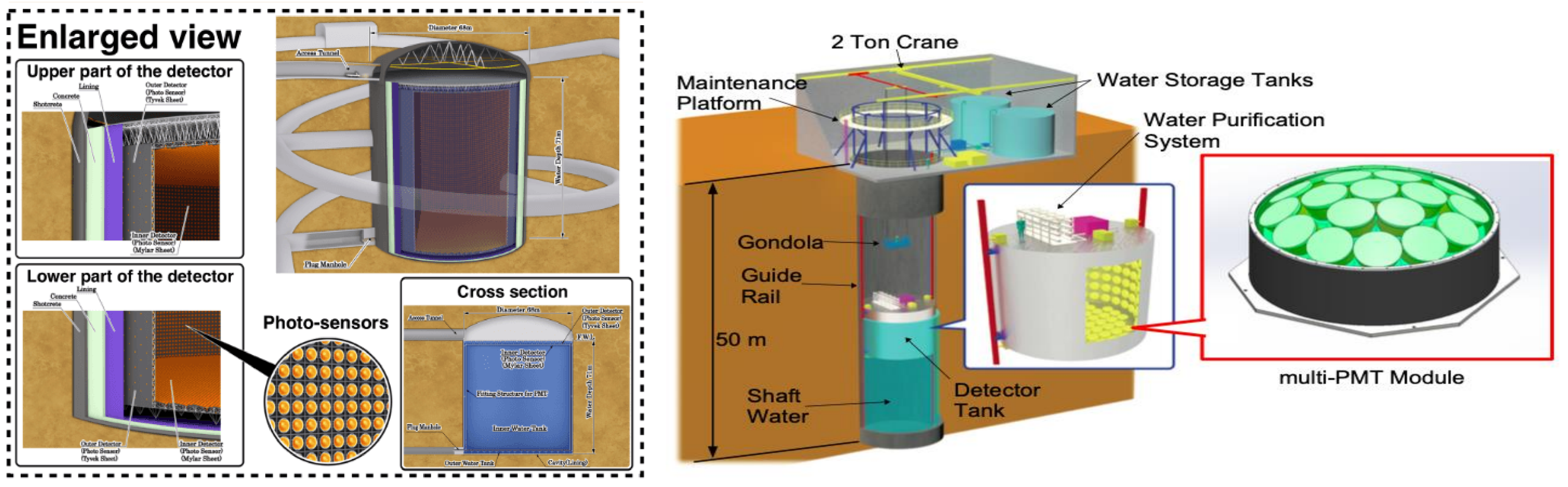
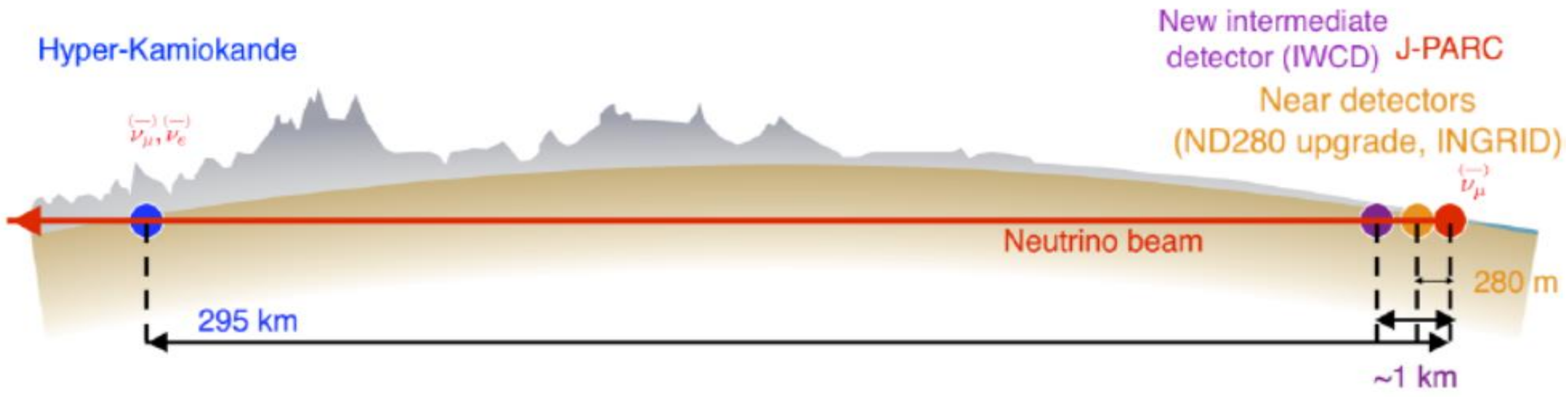
Hyper-Kamiokande experiment

The Hyper-Kamiokande experiment is a next generation underground water Cherenkov detector, based on the highly successful Super-Kamiokande experiment. It will serve as a far detector of a long baseline neutrino experiment for the J-PARC neutrino beam, with the main focus the determination of CP violation, and will also be a detector capable of observing - far beyond the sensitivity of the Super-Kamiokande detector - proton decay, atmospheric neutrinos, and neutrinos from astronomical sources [1].





Intermediate Water Cherenkov Detector

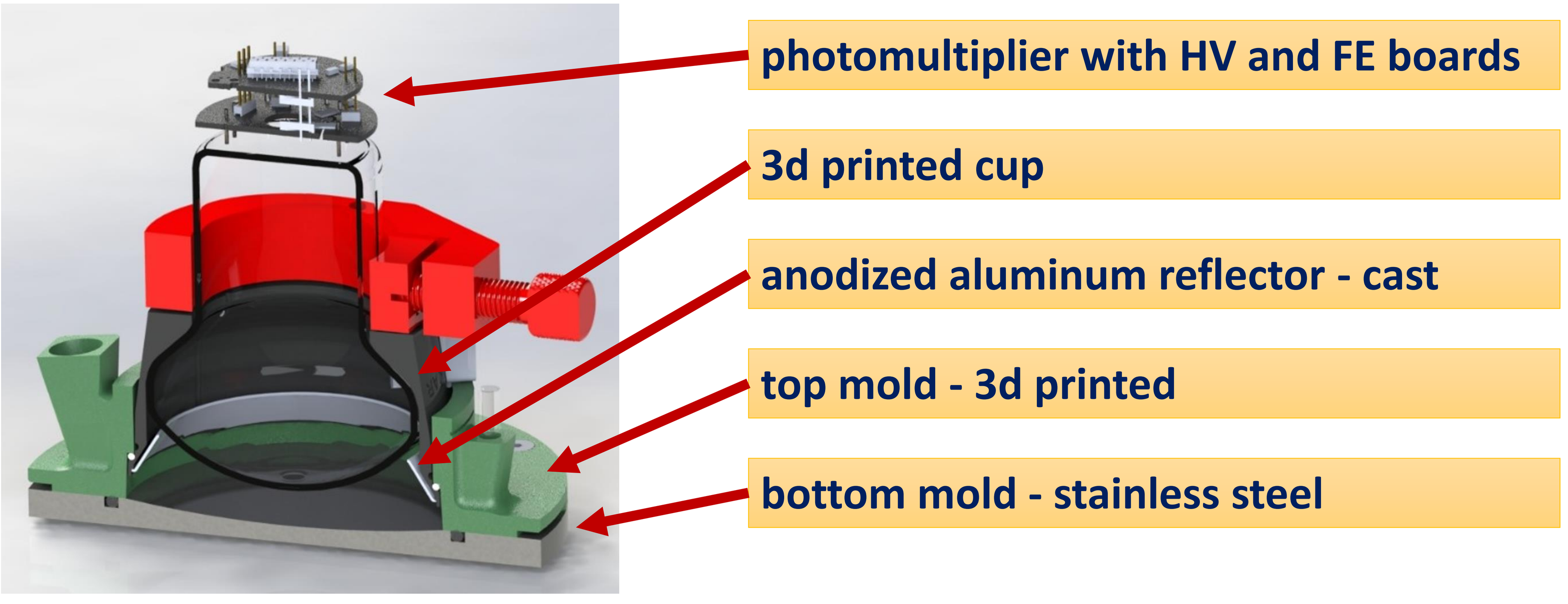
Many of systematic uncertainties are related to neutrino-nucleus interactions, and can be constrained by a detector placed close to the beam production point. Therefore, the Hyper-Kamiokande long-baseline program includes an Intermediate Water Cherenkov Detector (IWCD). This is a 500-ton water Cherenkov detector located approx. 1 km from the beam production point. This detector is able to move within a vertical shaft that covers a range of off-axis angles relative to the beam, from 1 to 4 degrees. The combination of large target mass, precise water Cherenkov reconstruction and off-axis angle flux dependence allows for high purity and high statistics electron neutrino and electron antineutrino samples [2].

Multi-PMT modules highlights:

- multi-PMT → 19 3'' PMTs in a pressure vessel,
- includes HV supply (Cockcroft-Walton base), front-end electronics,
- ~800 will complement 20'' PMTs in far detector,
- ~500 will fully equip IWCD (the only photodetector),
- optical gel used to couple PMTs to transparent, acrylic dome,
- single twisted-pair cable to connect power supply and transmit data & clock,
- directionality of PMTs,
- very good time resolution of 3'' PMTs,
- 2 variants with different front-end electronics:
  - Hyper-Kamiokande far detector (FD) optimized of pressure resistance and low-power consumption,
  - IWCD – optimized for higher pulse rates.

IWCD Multi-PMT: Gelling process

The gelling process utilizes an ex-situ technology approach. In this method, each photomultiplier is individually placed within a 3D-printed cup and then encapsulated with gel. The gelling mold comprises both a bottom and a top part. To ensure the desired curvature of the gel, a meticulously polished stainless steel bottom form has been specially designed for this purpose. The top part of the mold is engineered to maintain the appropriate spacing between the photomultiplier with the cup and the bottom mold, ensuring the integrity of the gelling process.



Gelled PMTs on bottom molds after top mold removal.

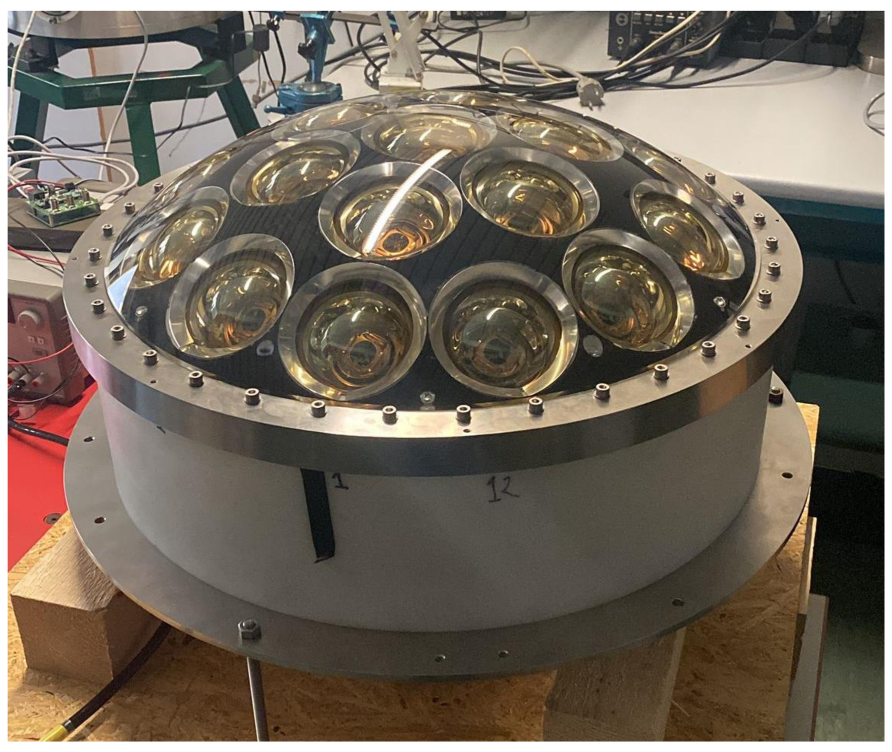
Matrix with 19 gelled PMTs before lowering acrylic cover.

Multi-PMTs in Hyper-Kamiokande

The Hyper-Kamiokande experiment will use approximately 800 multi-PMT modules to complement the primary photodetection system of the far detector. The primary purpose of this system will be to improve calibration of the detector (for example by resolving correlations between the absorption length and PMT angular response). They will also improve reconstruction of events close to the walls. Moreover, approx. 500 modules will be used as the photodetection system of the inner detector in IWCD.

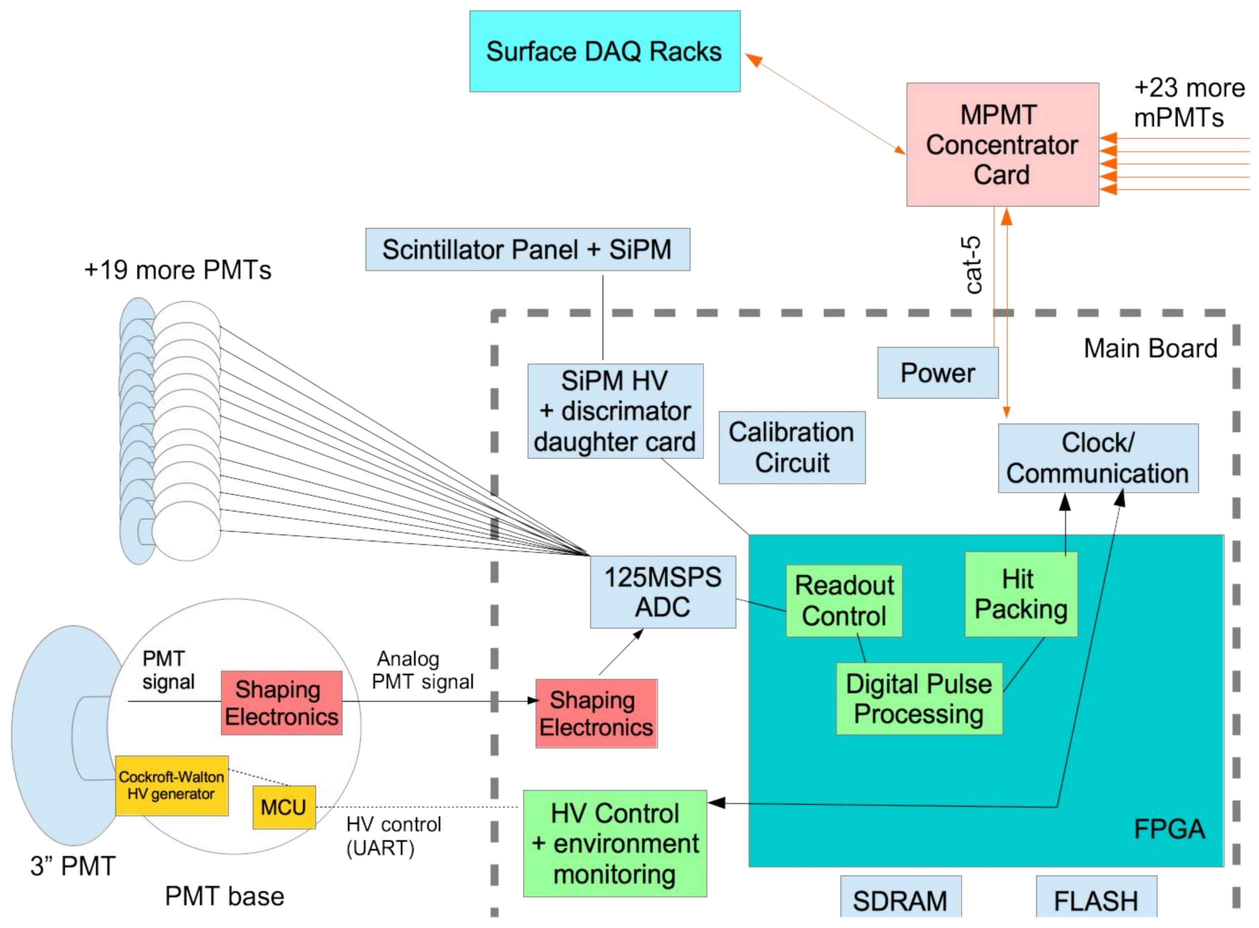
Multi-PMT for the Far Detector

For the FD mPMTs, the cylinders will be realized from POM-C, material with good mechanical strength, rigidity, and hardness, to withstand the high pressure in the Hyper-Kamiokande tank. The electronics is based on discrete components with a very low power consumption (below 4 W for the whole module).



IWCD Multi-PMT electronics

The electronics of multi-PMT for the IWCD are optimized to handle high event rates, with relaxed restrictions concerning power consumption. It comprises three distinct types of electronic boards. The primary board, known as the Big Read Board (BRB), encompasses 19 channel shaping circuits, five 4-channel 12-bit 125 MSPS Analog-to-Digital Converters (ADCs), and an FPGA System-on-Module (SOM). Additionally, each photomultiplier is paired with a High Voltage board (HV) and a Front-End board (FE). The HV board is responsible for generating high voltage through a Cockcroft-Walton multiplier, and it also includes a signal transformer to balance and symmetrize the PMT signal. The FE board serves as a digital controller and communicates with the BRB via the Modbus protocol. This FE board allows for the configuration of desired high voltage levels, and real-time monitoring of voltage, current and temperature. The BRB incorporates a self-trigger module, which takes into account both amplitude and integral of the incoming pulses. The time estimation is implemented using a digital constant fraction discriminator algorithm (CFD), which also employs additional correction bases on a Look-Up Table (LUT). Achieved timing resolution remains below 1.8 ns (FWHM).



References

[1] K. Abe et al. [Hyper-Kamiokande Working Group Collaboration], arXiv:1412.4673 [physics.ins-det].

[2] Charlie Naseby and the Hyper-Kamiokande Collaboration 2021 *J. Phys.: Conf. Ser.* **2156** 012121

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