The Hyper - Kamiokande Project

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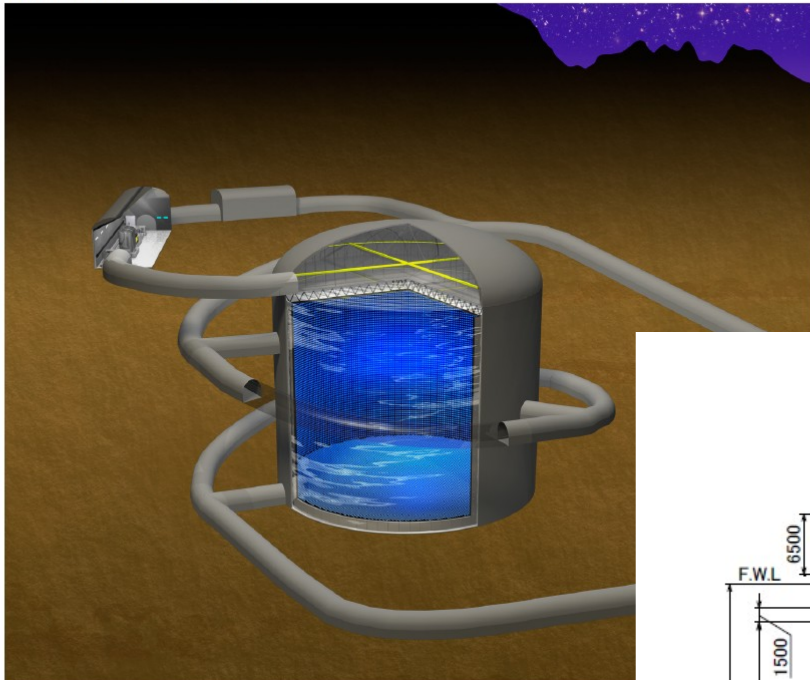
Hyper-Kamiokande

Design Report
(Dated: May 9, 2018)

TABLE I. Expected sensitivities of the Hyper-Kamiokande experiment assuming 1 tank for 10 years. TO BE UPDATED

Physics Target	Sensitivity	Conditions
Neutrino study w/ J-PARC ν		$1.3\,\mathrm{MW} \times 10^8$ sec
– CP phase precision	$< 23^\circ$	@ $\sin^2 2\theta_{13} = 0.1$, mass hierarchy known
– CPV discovery coverage	76% ($3\,\sigma$), 57% ($5\,\sigma$)	@ $\sin^2 2\theta_{13} = 0.1$, mass hierarchy known
– $\sin^2\theta_{23}$	± 0.017	1σ @ $\sin^2\theta_{23} = 0.5$
Atmospheric neutrino study		10 years observation
– MH determination	$> 2.2\sigma$ CL	@ $\sin^2\theta_{23} > 0.4$
– θ_{23} octant determination	$> 3\,\sigma$ CL	@ $\lvert\theta_{23} - 45^\circ\rvert > 4^\circ$
Atmospheric and Beam Combination		10 years observation
– MH determination	$> 3.8\sigma$ CL	@ $\sin^2\theta_{23} > 0.4$
– θ_{23} octant determination	$> 3\,\sigma$ CL	@ $\lvert\theta_{23} - 45^\circ\rvert > 2.3^\circ$
Nucleon Decay Searches		1.9 Mton-year exposure
– $p \to e^+ + \pi^0$	7.8×10^{34} yrs (90% CL UL)	
	6.3×10^{34} yrs ($3\,\sigma$ discovery)	
– $p \to \bar{\nu} + K^+$	3.2×10^{34} yrs (90% CL UL)	
	2.0×10^{34} yrs ($3\,\sigma$ discovery)	
Astrophysical neutrino sources		
– ^{8}B ν from Sun	130 ν's / day	4.5 MeV threshold (visible energy) w/ osc.
– Supernova burst ν	52,000–79,000 ν's	@ Galactic center (10 kpc)
	~10 ν's	@ M31 (Andromeda galaxy)
– Supernova relic ν	70 ν's / 10 years	10–30 MeV, 4.2σ non-zero significance
– WIMP annihilation in the Earth		10 years observation
(σ_{SD}: WIMP-proton spin	$\sigma_{SD} = 10^{-40}\mathrm{cm}^2$	@ $M_{\mathrm{WIMP}} = 10\,\mathrm{GeV}$, $\chi\chi \to b\bar{b}$ dominant
dependent cross section)	$\sigma_{SD} = 10^{-44}\mathrm{cm}^2$	@ $M_{\mathrm{WIMP}} = 50\,\mathrm{GeV}$, $\chi\chi \to \tau^+\tau^-$ dominant

Hyper-Kamiokande project



Hyper-K Detector

	Super-K	Hyper-K (1st tank)
Site	Mozumi	Tochibora
Number of ID PMTs	**11,129**	**40,000**
Photo-coverage	40%	40% (**×2 sensitivity**)
Mass / Fiducial Mass	50 kton / **22.5 kton**	260 kton / **187 kton**

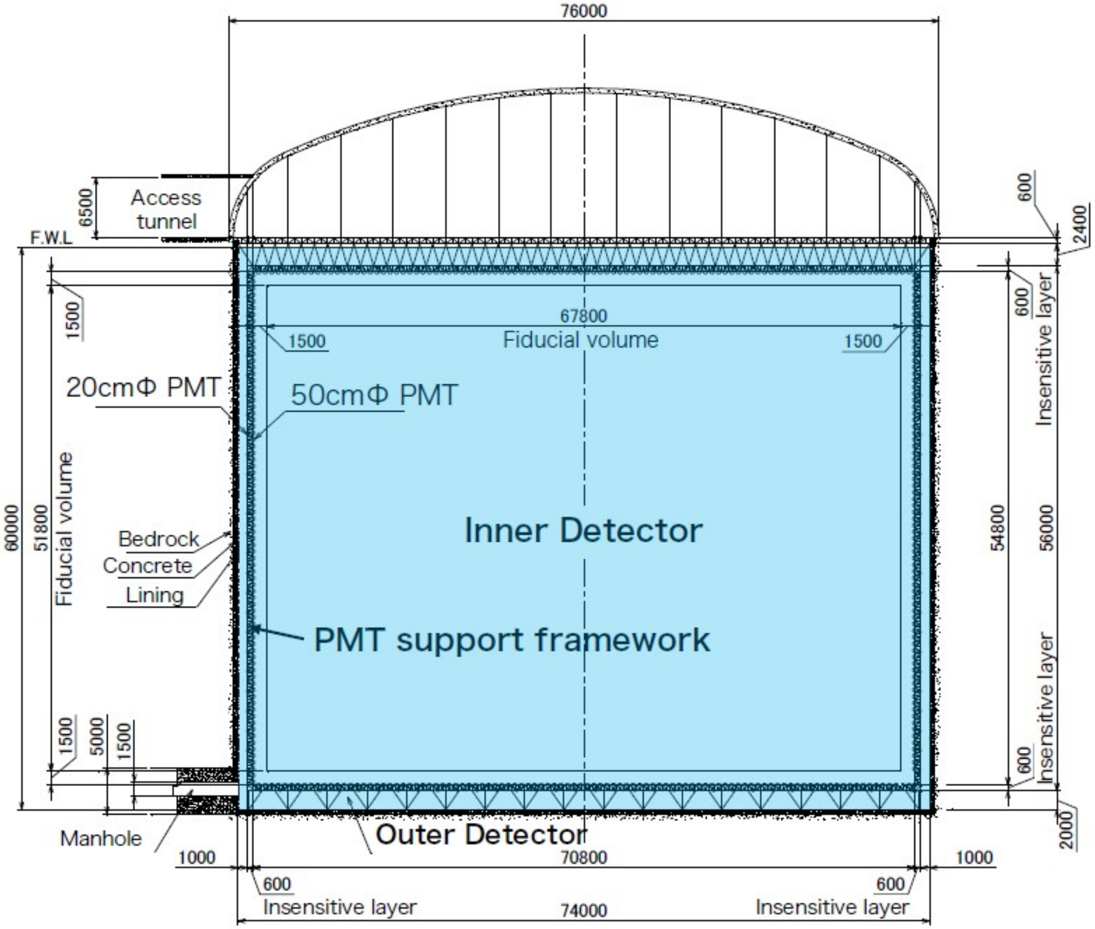
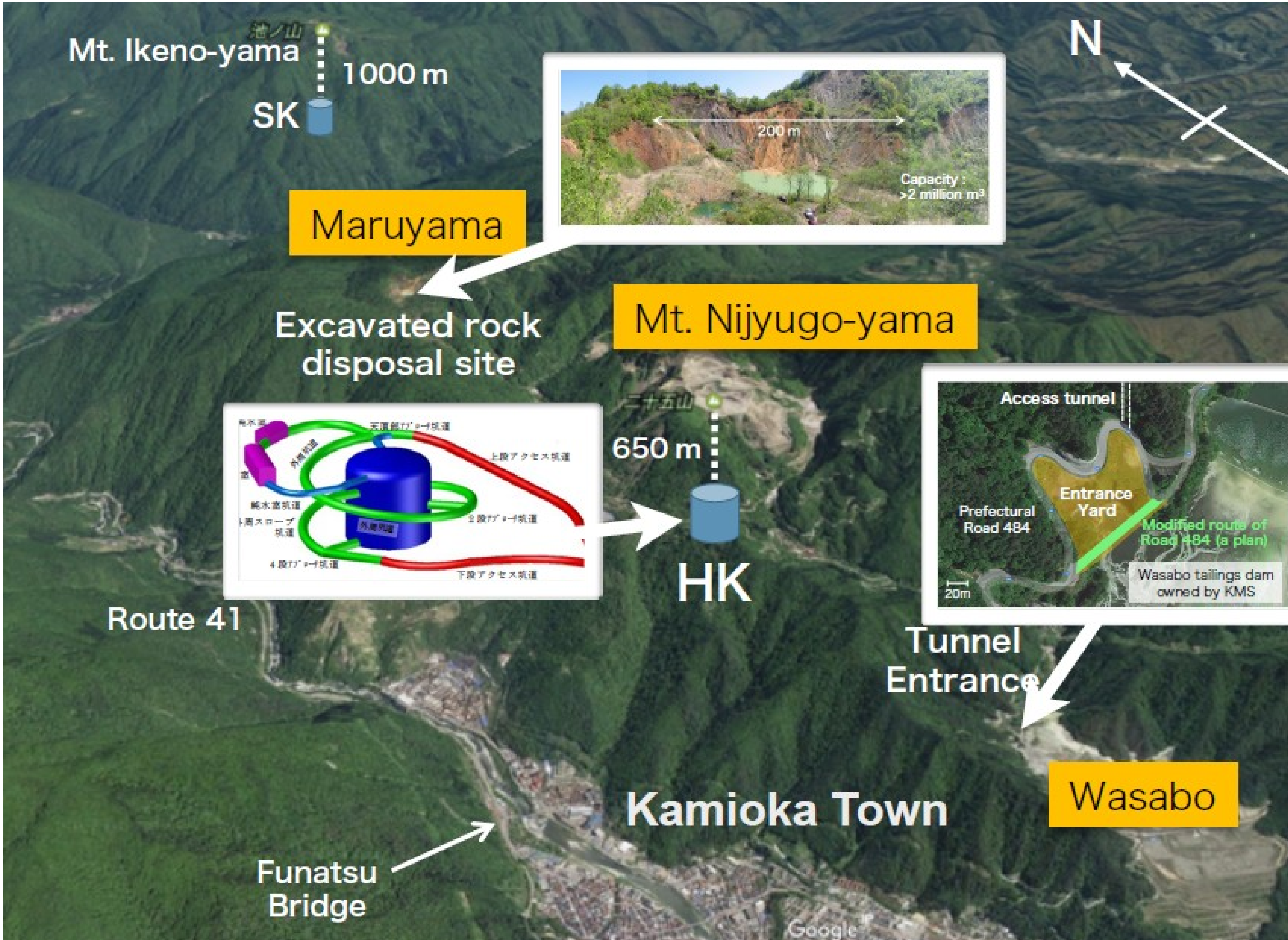
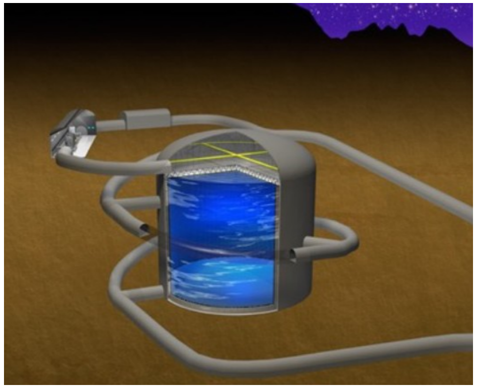


Figure 1: Schematic view of the Hyper-Kamiokande detector

Sensitivity goals were maintained for HK oscillations physics

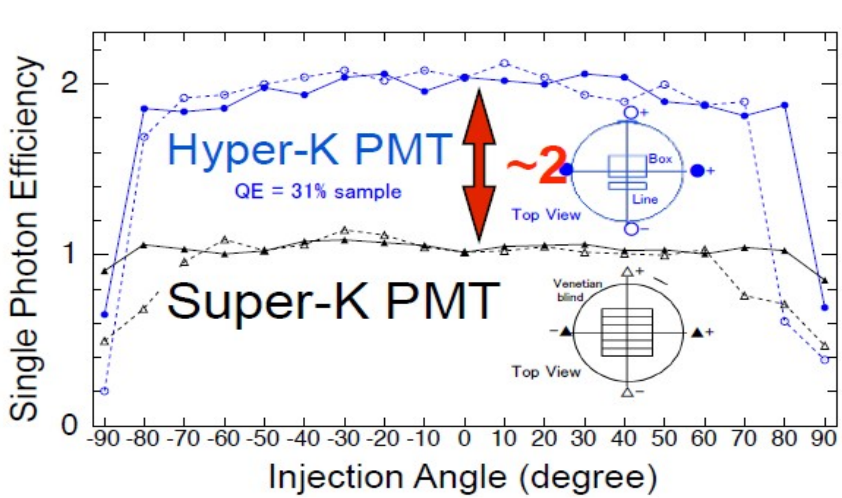

Mt. Ikeno-yama
1000 m
SK
N
200 m
Capacity : >2 million m³
Maruyama
Excavated rock disposal site
Mt. Nijyugo-yama
650 m
HK
Access tunnel
Entrance Yard
Prefectural Road 484
Modified route of Road 484 (a plan)
Wasabo tailings dam owned by KMS
20m
Route 41
Tunnel Entrance
Wasabo
Kamioka Town
Funatsu Bridge
Google

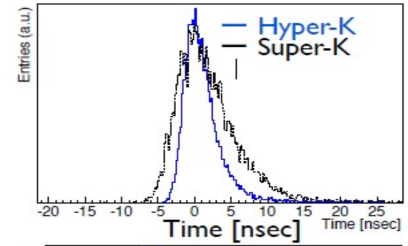


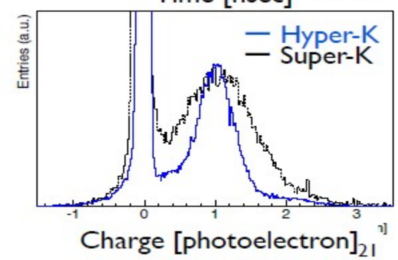
HK photosensors

New technologies and on going studies for PMT

50cm Ø PMT







Significant improvement of single photon efficiency

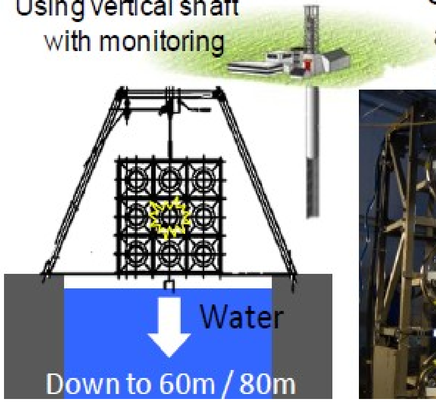
Better time and charge resolution (x 2 wrt SK)

Still possible mixed technologies in HK for PMT

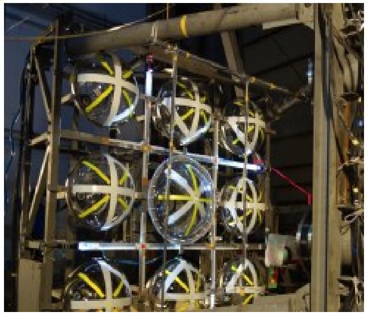
- Worldwide studies for new photo sensors detectors (JUNO, IceCube, KM3NET, …)
- Foreseen collaborative efforts of HK with other experiments

Validation test of cover at Kamisunagawa in 60 m / 80 m water

Using vertical shaft with monitoring



Confirmed with artificial implosion at central PMT



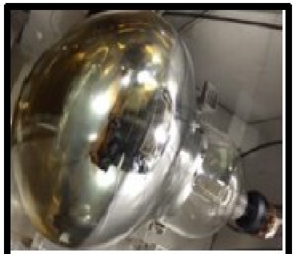
Prototype of cover to stop chain implosion

15 mm acrylic

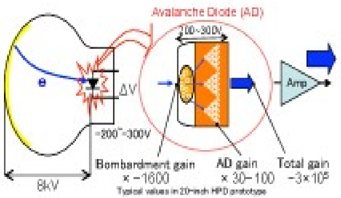
Stainless steel (3 mm)

- No damage for all tests
  - 3 times w/cover (2 with surrounding PMTs)
  - OK for 60 m (HK), and for 80 m also

Hybrid Photo Detectors (HPDs)

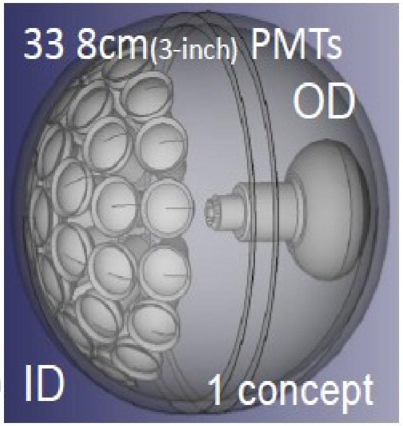


50cm HQE HPD w/ 20mm ϕ AD



Under viability study

Multi-PMTs



Working concept from KM3NeT but:

- peripheral ID/OD
- lower pressure tolerance required.
- ultrapure water.

International contribut.

- Worldwide studies for new photo sensors detectors (JUNO, IceCube, KM3NET, …)
- Foreseen collaborative efforts of HK with other experiments

IN2P3 contributions to the Japanese neutrino program: T2K, T2K-II, Super-K and Hyper-K

LLR and LPNHE neutrino groups

Prepared for the IN2P3 Scientific Council – June 2018

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7.3 Possible contributions for multi–PMTs

In addition to this baseline design, R&D on alternative photosensor options like hybrid photo-detectors, LAPPDs and multi-PMT modules is actively being carried on by several countries (mostly Canada, Italy, UK) with the goal of providing half of the photo–cathode coverage for Hyper-Kamiokande.

In particular the multi–PMTs option, based on design developed for Km3Net is particularly appealing, with the possible design of having the half sphere looking at the outer detector equipped with 6 3" PMTs and the half sphere looking at the inner detector equipped with 19 3" PMTs.

In this context there is some interest in using the existing Memphyno water tank [58] at APC for performing underwater tests of the multi-PMT modules developed in Europe. There is also a possibility of contributing to the development of electronics for the multi–PMTs readout based on a chip designed by the Omega laboratory.

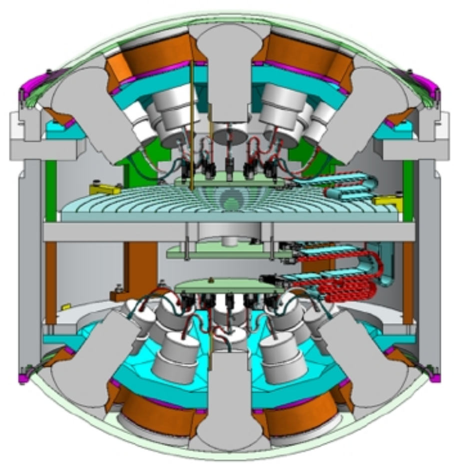

FIG. 86. Multi-PMT conceptual drawing with 19 7.7 cm PMTs as ID detectors and the OD detectors on the other half. Each small PMT has a reflector cone. An 50-cm acrylic covers on a cylindrical support is used as pressure vessel. Readout electronics and calibration sources are imbedded inside the vessel.

FIG. 87. A Hamamatsu R12199-02 7.7 cm PMT that is currently used in KM3NeT and considered for IceCube-Gen2 modules. As this passed the Hyper-K PMT requirements, it is also a good candidate for a Hyper-K mPMT.

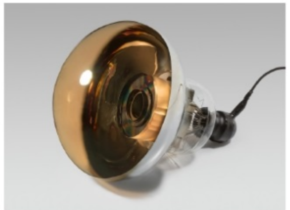

FIG. 57. Picture of the HQE 50 cm box-and-line R12860 PMT.

7.2 Possible Contributions for 20-inch PMT electronics

7.2.1 Introduction

The front-end electronics modules for the detectors are required to digitize all signals from photo-sensors that are above a certain threshold, i.e. the acquisition needs to be self-triggered. The digitized information is then either recorded or discarded, depending on the decision of the detector-wide trigger system.

The photo-sensor for the inner detector of HK is newly developed. In the baseline option, around 20,000 20-inch PMT R12860-HQE are used. The R12860-HQE PMT has better timing and charge resolution compared to the same diameter PMT (R3600), which has been used in SK. The dark (noise) rate is required not to exceed 4 kHz, which is a similar requirement to the R3600PMT. Based on this information, we have estimated the total data rate and concluded that it is possible to design the data acquisition system, which is similar to the concept of the SK-IV DAQ.

If we locate the front-end electronics modules on the top of the detector, it is necessary to run the cable from the PMT to the roof and the detector structure has to support the weight of the cables, which is expected to be 800 tons. Thus, it would be possible to simplify the detector structure if we can reduce the weight of the cables. Also, the maximum length of the cable is ~30% longer than in the SK case. This not only reduces the signal amplitude, but also degrades the quality of the signal – the leading edge is smoothed out due to higher attenuation of the cable in the high frequency region. Therefore, we plan to place the modules with the front-end electronics and power supplies for the photo-sensors in the water, close to the photo-sensors.

The current baseline design of the front-end module is prepared considering these requirements. The schematic diagram of the front-end module is shown in Figure 29.

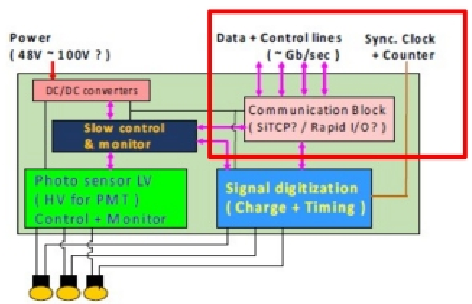

Figure 29: Schematic diagram of the front-end module with the possible contribution from IN2P3 highlighted by the red rectangle.

There are 4 main function blocks in the front-end board. The signal digitization block, the photo-sensor power supply block, the slow control block and the communication block. In the current baseline design, one module accepts signals from 24 photo-sensors, digitizes them and sends out the data.

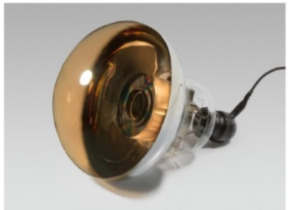

FIG. 57. Picture of the HQE 50 cm box-and-line R12860 PMT.

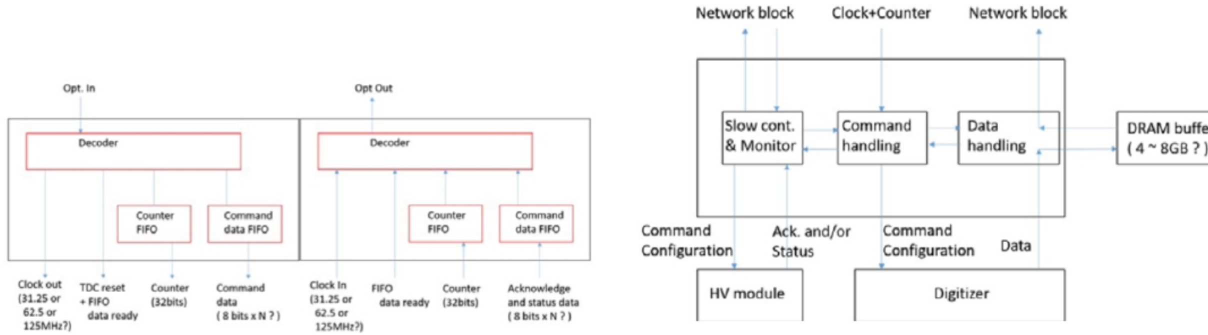

Figure 30: Possible diagrams of the clock and counter modules (left) and simplified schematic of the communication module (right).

Our foreseen contributions could be the parts in the red rectangle shown in Figure 29. We do have in our electronic group experts regarding these parts.

The main components are trimming synchronization, data handling and communication.

Synchronization of the timing of each TDC or FADC is crucial for precise measurement of the timing of photon arrival. In Hyper-Kamiokande, timing resolution of the photo-sensor is expected to be largely improved. Therefore, we have to be careful with the synchronization of the modules – the design should minimize the clock jitter, so that the timing resolution of the whole system is as good as possible. We are planning to distribute the common system clock and the reference counter to all the modules.

Possible diagrams of the clock and counter modules are shown in Figure 30.

Regarding the communication block, in order to reduce the amount of cables, we are planning to connect the modules in a mesh topology, with each module connected to its neighbours. Only the top modules would be connected to the readout computers. Each module will have several communication ports, so that a single point of failure would be avoided. In case of failure of one of the modules, the data would simply be re-routed to one of the neighbours, thus ensuring that communication path will be secured.