A multi-PMT photodetector system for the Hyper-Kamiokande experiment

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Hyper-Kamiokande

Hyper-Kamiokande (HK) is the next generation Water-Cherenkov detector with multi-purpose scientific goals:

- Investigation on CP-violation in leptonic sector;
- Neutrino oscillations (atmospheric, accelerator and solar);
- Determination of the neutrino mass ordering;
- Proton Decay;
- Observation of astrophysical neutrinos.

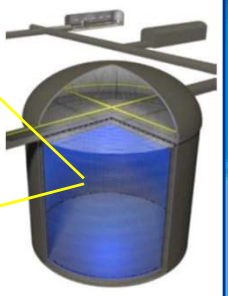
Hyper-Kamiokande Far Detector (HK-FD)

Cylindrical tank: Φ=68 m and H = 71 m;
Depth: 650 m;
Fiducial volume: 187 ktons of ultra-pure water;
Baseline design: 20% photo-coverage with 20,000 20'' B&L PMTs and multi-PMT.

Timeline:
HK is under construction
Operation will begin in 2027


B&L PMT

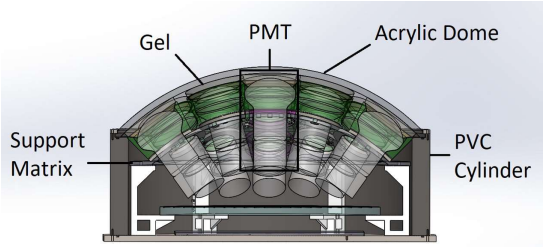

mPMT



The multi-PMT: design

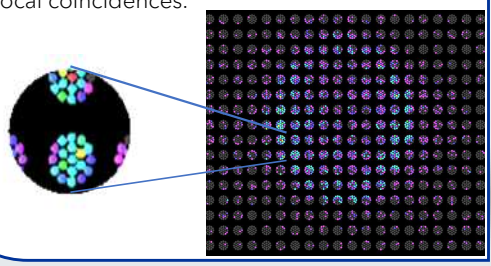
The multi-PMT (mPMT) was first designed for the KM3NeT experiment [1]. A new design, optimized for HK requirements, has been realized. The main features are:

- 19 3" PMTs inside a pressure vessel;
- Each PMT has a unique orientation;
- The effective area of PMTs is enhanched through a reflector ring installed around each respective photocathode;
- A UV-transparent acrylic dome serves as cover for the mPMT vessel;
- An optical gel fills the gap between the PMTs and the dome, serving as light guide and avoiding light distortion;
- A full electronics system is included in the vessel.



Advantages of mPMTs over single 20'' PMTs:

- Increased granularity;
- Overall lower dark rate;
- Better vertex resolution;
- Superior photon counting;
- Improved angular acceptance;
- Extension of dynamic range;
- Intrinsic directional sensitivity;
- Local coincidences.



Acrylic dome

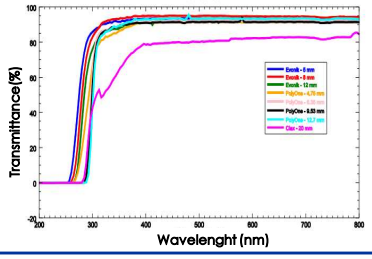
One of the requirement for the mPMT for HK-FD is the radio purity of materials.
In HK, low radioactive UV-transmitting acrylic is used for dome.
Tests to select the best material for the HK project included:

- Radioactive contamination;
- Radon emanation;
- Optical and mechanical performances;
- Pressure resistance.

Radioactive contamination for the chosen acrylic

Isotope	Activity	Contamination
	^{232}Th: Thorium series	
Ra-228	< 0.11 mBq/kg	< 0.027 ppb
Th-228	< 93 μBq/kg	< 0.023 ppb
	^{238}U: Uranium series	
Ra-226	< 65 μBq/kg	< 0.0052 ppb
Th-234	< 4.6 mBq/kg	< 0.38 ppb
Pa-234m	< 2.5 mBq/kg	< 0.20 ppb
U-235	(0.15 ± 0.07) mBq/kg	(3 ± 1)·10^{-1} ppb
K-40	< 0.69 mBq/kg	< 0.022 ppm
Cs-137	< 25 μBq/kg	-

→ Results from tests with acrylic materials from different providers show radioactivity contamination levels lower than HK requirements.




12 mm-thick vessel resisted to 1.3 MPa
(Constrain: 1.26 MPa)

mPMT prototypes

Several prototypes have been realized. The tests' purposes so far have been to:

I. Demonstrate the effectiveness of a vessel system with an acrylic dome;
II. Establish the best design for the installation of the electronics system in the vessel;
III. Optimize the mechanical design of the mPMT vessel;
IV. Test and optimize the mPMT assembly strategy.

Conclusions

- Measurements in HK will be enhanced with mPMT modules.
- mPMT R&D is almost completed.
- mPMT construction for HK FD will start in 2024.

[1] O. Kavatsyuk, et al., Multi-PMT optical module for the KM3NeT neutrino telescope, Nucl. Instr. And Meth. in Phys. Res. A, Volume 695, 2012, Pages 338-341, ISSN 0168-9002.