# Mechanical design of multi-PMTs for IWCD

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**Abstract**. Approximately 500 multi-PMTs (mPMTs) will be used as the photosensors for the Intermediate Water Cherenkov Detector (IWCD), a new near detector for the approved Hyper-Kamiokande experiment that will be built by 2025. The IWCD mPMT design has nineteen 3" PMTs enclosed in a water-tight pressure vessel, along with the associated electronics. The 3" PMTs provide excellent spatial imaging of the neutrino-induced Cherenkov light ring. This work will focus on the mechanical design of the mPMT vessel. In particular, design of the acrylic dome, use of optical gel to couple the dome to the PMTs, assembly procedures of dome and PMT sub-assembly (including the necessary jigs / fixtures), design of water-tight feed-through & plans for testing and results from several mPMT prototypes.

## 1. Introduction

The Intermediate Water Cherenkov Detector (IWCD) will deploy multi-PMT photosensors to detect Cherenkov photons produced in the inner detector. The mPMT vessel consists of an acrylic dome and a cylindrical section (with O-rings on both sides) blanked off by a 0.375” (≈10mm) thick stainless-steel plate. The vessel houses the nineteen 3” PMTs mounted on 3D printed (ABS plastic) PMT support structure with connection to an electronics mainboard via individual daughter boards and potentially a scintillator veto (figure 1) [1]. A feed-through connector for CAT 5e cable is provided on the stainless-steel plate for power and data transmission in and out of the mPMT module.

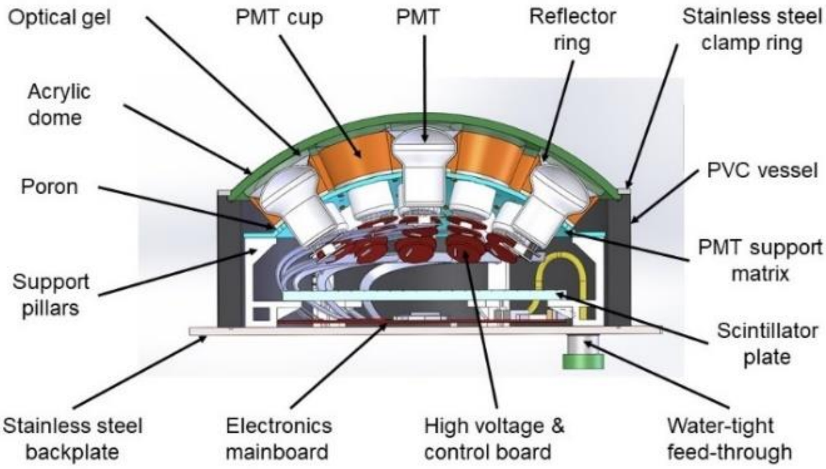



**Figure 1.** Schematic of multi-PMT module.

## 2. Mechanical Design of mPMT module

### *2.1. Design of UV Transparent Acrylic Dome and its Assembly*

UV transparent acrylic material is chosen for the dome. Material model was developed after comparing results (radius expansion and height reduction) of finite element model with initial mechanical tests (Compression test, behaviour of dome under static and cyclic loads). It showed that a 15mm acrylic window can sustain a pressure of 1.5MPa with less than 0.5mm deformation along the radial direction. Multiple samples of the acrylic dome were tested to measure their transmittance and reflectance in air and ultra-pure water, with and without a 5mm layer of optical gel (for some samples). Plexiglas GS UVT by Evonik has been selected as having the best optical properties for the mPMTs. For assembly of dome on the mPMT module, a jig is designed and the assembly steps are as follows-

i. Place the lower piece of jig on the outer rim of vessel (figure 2 [a])
ii. Grip the dome in the upper piece of jig (figure 2 [b]) by using vacuum gripping
iii. Place the upper piece of jig on the lower one and allow rotation of the upper jig using rollers (figure 2 [c])
iv. When the rollers align with the guide rails (figure 2 [c]) on the lower jig, upper jig assembly slides downward
v. Three fasteners are used to accurately lower the dome furthermore (figure 2 [d])
vi. Once the dome is placed, vacuum grip is released and jig is detached (figure 2 [e])

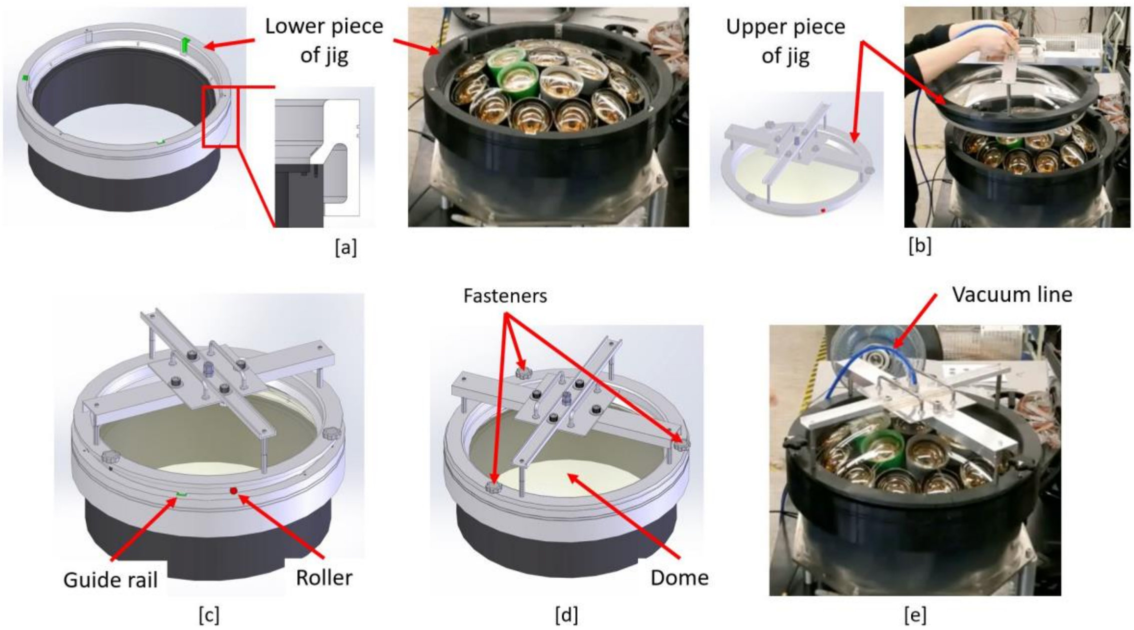
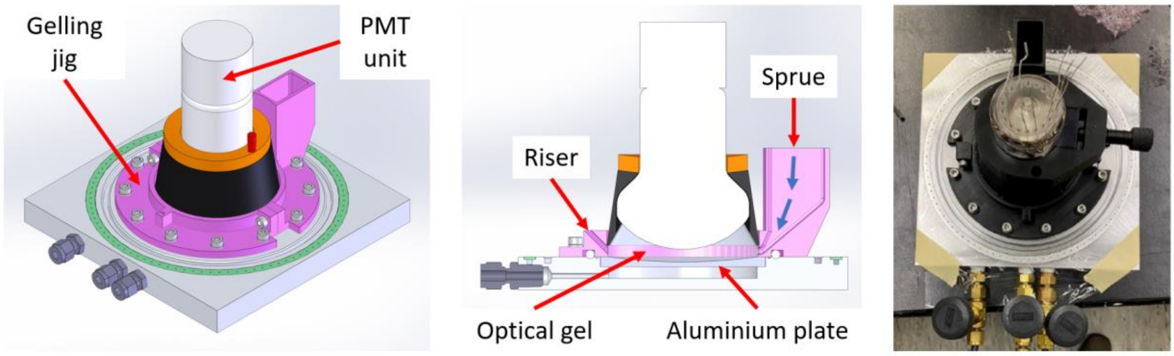



**Figure 2.** Schematic of assembly procedure of acrylic dome.

### *2.2. Design of PMT sub-assembly and Use of Optical Gel to Couple the Dome to the PMTs*

A PMT sub-assembly consists of PMT, poron, PMT cup, reflector ring & optical gel. The optical gel is used for optical coupling between the PMTs and the acrylic dome on the front of the module. The purpose of using the gel is to minimize the optical discontinuities at the boundaries, resulting in reduction in reflection. Multiple variants of optical gel were tested for their transmittance. Newest prototypes use Wacker Elastosil 604 optical gel. A gelling jig (figure 3) is designed for casting the gel directly onto the PMT sub-assembly. It is capped with a piece of machined aluminium that matches the radius of curvature of the dome, ensuring no gaps between the gel and the dome. PMT sub-assembly is assembled as per the following procedure-

i. PMT is inserted into the PMT cup and poron is attached from the bottom
ii. Reflector ring is inserted from the top and glued into the cup
iii. PMT + cup + reflector ring are placed in a mould, which is closed and tightened (figure 3 [a])
iv. Gel is poured into the mould till it oozes out of the riser (figure 3 [b])
v. After gel sets, mould is disassembled and the machined aluminium plate is peeled over the gel



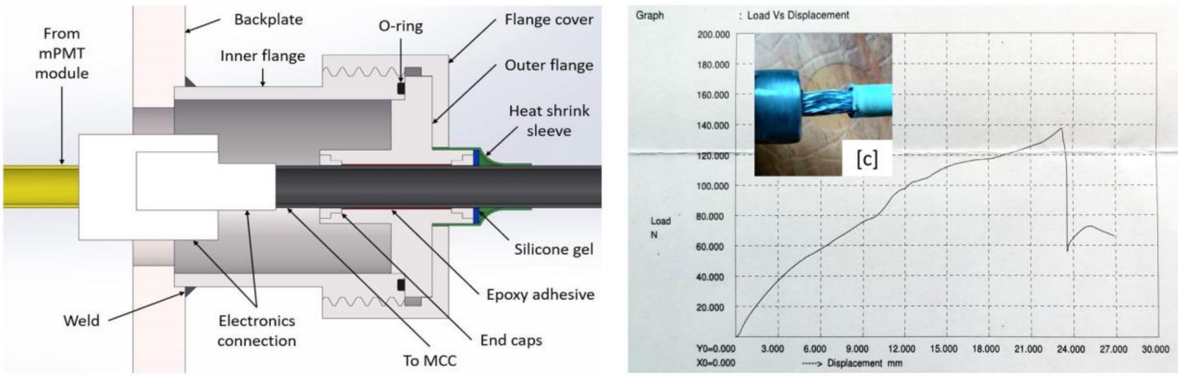

[a] [b] [c]

**Figure 3.** Schematic of gelling jig.

### *2.3. Design and Testing of Feed-through Connector*

A feed-through connects the electronics inside the mPMT module to Multi-PMT Concentrator Card (MCC) outside the detector using CAT 5e cable. The design of the connector (figure 4 [a]) provides waterproof feed-through, also allowing easy detachment in case of maintenance. The test strategy for the connector is as follows-

i. Hydrostatic pressure test [up to 1MPa] and cyclic pressure test [0.8MPa – 1.2MPa] to check the behaviour of the adhesive joint against water pressure. First prototype connector sustained the hydrostatic pressure of 1MPa.
ii. Tension (pull) test [up to 222N] to check the failure of adhesive bonding under axial pull. First prototype connector sustained the load up to 137N (figure 4 [b]), failure was observed at cable outer sheath (figure 4 [c]), while adhesive was intact.
iii. Immersion (soak) test [at 17 °C (operating temperature of the experiment) & 50 °C (for accelerated testing) in ultra-pure water] to check leaching of adhesive
iv. Temperature variation test [0 °C & 50 °C in air (for transportation)] to check the adhesive behaviour under temperature




[a] [b]

**Figure 4.** Schematic of feed-through connector and result of tension test on prototype connector.

## 3. Test Results from mPMT Prototypes

### *3.1. Pressure Test of Acrylic Dome*

To evaluate the deformation of the dome under water pressure, the mPMT vessel is placed inside a pressure vessel. The acrylic deformation is measured by two digital dial gauges, one place at the center of the dome while other near the edge (figure 5 [a]). A data logger records the digital gauge readings as the external pressure on the mPMT vessel is adjusted.

The deformation of the mPMT vessel was modelled in ANSYS. The simulation predicted the dial gauge reading of 0.3mm at 0.1MPa and 1mm at 0.3MPa. During experimentation, the external pressure was held at ≈0.3MPa during the daytime and released overnight. As a result, deformation of 1mm was observed (figure 5 [b]) which remained stable over 8 hours duration.

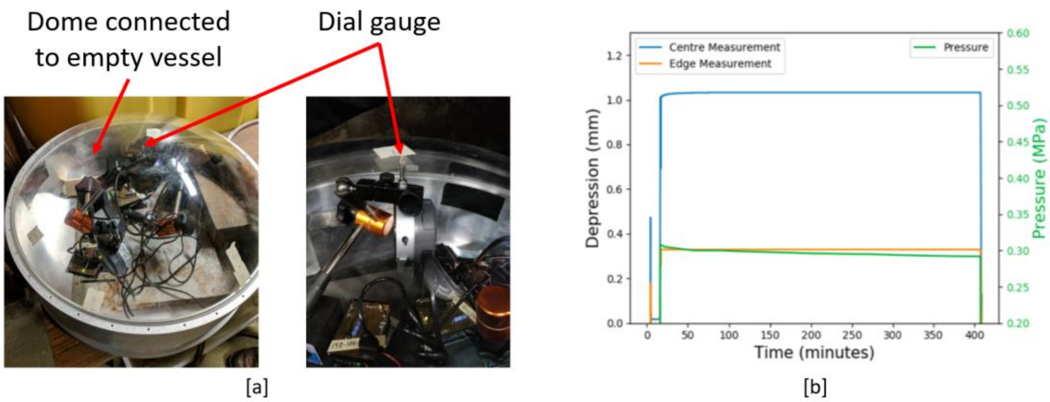



**Figure 5.** Pressure test on mPMT vessel.

### *3.2. Immersion Test of Enclosed mPMT Vessel*

A 5-month immersion test on an assembled mPMT vessel is being conducted to check water diffusion through the acrylic dome. A Wi-Fi enabled humidity sensor is installed inside the vessel (figure 6) to continuously monitor humidity.

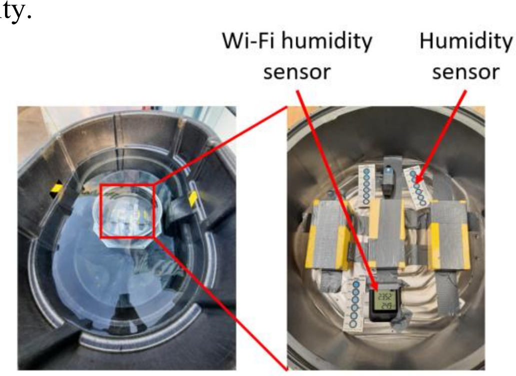



**Figure 6.** Setup of immersion test.

## 4. Conclusion

Mechanical design of mPMT vessel is nearly complete. Behaviour of mPMT vessel under hydrostatic pressure and under ultra-pure is being tested. Initial test results of hydrostatic pressure test are well within the permissible limit. Testing of the feed-through connector is underway. Prototype was successfully tested against hydrostatic pressure as well as axial load. Additional tests such as cyclic pressure test, immersion test etc. are planned for evaluation of adhesive behaviour.

## References

[1] K. abe et al. [Hyper-Kamiokande Design Report], arXiv:1805.04163v2 [physics.ins-det].