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A Multi-Photomultiplier Photosensor Module for IWCD/Hyper-K

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Hyper-Kamiokande
Introduction

• Hyper-K will be a long-baseline neutrino experiment, starting in 2026, in Japan.

• Objectives:
  - measure neutrino oscillation parameters;
  - solve neutrino-mass hierarchy;
  - measure CP violation in lepton sector;
  - survey proton decay, dark matter searches.

• An Intermediate Water-Cherenkov Detector (IWCD) to measure and characterize the unoscillated beam:
  - Located at ~1 km from J-PARC.
  - Intercept neutrino beam at a range of off-axis angles (1° to 4°), by moving vertically.
  - Enhanced multi Photo-Multiplier Tube (mPMT) module to detect Cherenkov light

• Minimize systematic uncertainties associated to neutrino flux extrapolations.
mPMT

- Development of multi-PhotoMultiplier Tube (mPMT) module has three main aspects:
  - **Detectors:** 19 3-inch PMTs at the top, under an acrylic dome, facing the water tank; one scintillator plate in the back.
  - **Electronics:** for PMT HV supply, pulse digitization and read-out; slow measurements (temperature, pressure, current, etc.); calibration systems.
  - **Mechanical:** 20-m water-depth tolerant vessel, support structures; assembly procedure and pressure tests.

![mPMT prototype at TRIUMF](image)
Detectors: PMTs

- The 19 PMTs detect the Cherenkov rings generated by particles in the tank.
- One model in test is the Hamamatsu R14374. PMTs need to meet several requirements, such as minimal generated after-pulse.
- PMTs are held inside of a cup and gelled, to be optically coupled to the dome.

![Graph showing afterpulse rate for Hamamatsu R14374]

- Controller & signal board
  - HV multiplier
    - Hamamatsu R14374
    - Gelled and soldered PMT
    - Gelling of PMT by Josh
Detectors: scintillator plane

- **Scintillation-based hit detector.** Particle excites the plastic scintillator, generating light collected by Wavelength Shifting (WLS) fibres and guided to a Silicon Photo-Multiplier (SiPM).
  - Part of a veto mechanism to reduce effects of backgrounds in the water tank: sand-generated muons, cosmic rays, etc.
- SiPM being considered: Hamamatsu MPPC S13360 series. Scintillator in test: Eljen EJ-204. WLS fibre: Kuraray Y11(150) M.
Electronics

- A main board is responsible for providing HV supply to the PMTs and for signal read-out.
  - 20 channels: 19 digitizers for the PMTs and one discriminator for SiPM.
  - Five quad-channel 125 MSPS analog-to-digital converter (ADC) in test.
- Read-out and data packets created and organized by a detachable field-programmable gate array (FPGA).
- Also makes slow measurements.

Rev. 2 mainboard designed and built at TRIUMF
Mechanical

- Water-tight vessel, tolerant to 20-m depth.
  - PVC cylindrical body and stainless steel backplate;
  - Feed-through for power supply and communication.
- PMTs are held in place, facing outwards, by a support matrix.
- Module assembly from bottom to top: final step is to lower the dome on top of the vessel.
Summary

• mPMT is an essential feature of IWCD, to reduce uncertainties in neutrino-oscillation measurements.
• 19 PMTs for faster timing and better resolution, along with secondary scintillator detector for vetoing purposes.
• Water-tight vessel with PVC body and stainless steel backplate, with 20-m water-depth tolerance.
• Mainboard provides voltage and read-out for the detectors.
• Working toward production 30 to 60 mPMTs in Canada next year.

Special thanks

• To Thomas Lindner and all members of Hyper-K Canada team.
References

• Hamamatsu PMT R14374 reference page.

• Hamamatsu MPPC S13360-1350CS reference page.


Afterpulse analysis

- Four Hamamatsu R14374 PMTs connected to rev. 1 mainboard.
  - Tamadenshi laser pulses hitting all PMTs simultaneously.
  - 125-Mps digitizers generated waveforms for each trigger event.
- More than 900,000 waveforms collected; their pulses identified and counted.
  - Afterpulse rate defined as ratio between count of afterpulses and count of laser pulses for a p.e. level.

Experiment diagram

Setup at TRIUMF
Scintillator plate and SiPM

• Scintillator plane: diameter of 350 mm and thickness of 10 mm; based on EJ-204 scintillator plastic.

• Kuraray Y11(150) 1-mm radius wavelength-shifting optical fibre. Minimum bending radius of 50 mm.
  - Different fibre patterns under study; inclined toward single-$S$ and double-$S$ configurations.

• SiPM: Hamamatsu Multi-Pixel Photo-Counter operating in Geiger mode: specific electronics were developed at Regina.