Research Report
ICRR Inter-University Research Program 2019

Research Subject: mPMT: an innovative photodetector system for Hyper-Kamiokande project
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Summary of Research Result: The research summary is hereby reported for every WP as detailed in the project:

WP1. The number and of the orientation of the single PMTs in the mPMT has been defined on the basis of simulation studies. Although, several manufacturers - Hamamatsu Photonics K.K., ET Enterprises Ltd., MELZ FEU Ltd. and HZC Photonics Ltd. - have developed similar 3" PMTs, we assumed the Hamamatsu R12199-02 PMT as the default tube for our design studies. Since these PMTs have previously been characterised and tested for compliance with the Hyper-K requirements by assessing the transit time spread (TTS), charge resolution, position dependence, we measured the dark count rate, gain and checked the waveform shape. Gain was found to be in the range 6-8 x10^6, whereas it was found that positive HV reduced the dark rate by a factor of 10.

Manufacturer	PMT	Gain (HV)	Dark Rate (kHz)		
			50% eff.	85% eff.	90% eff.
Hamamatsu	R14374: BC0032	5.2E+6 (−1159V)	0.21 ± 0.03	0.34 ± 0.06	0.37 ± 0.06
		6.5E+6 (−1200V)	0.50 ± 0.05	0.70 ± 0.08	0.73 ± 0.09
	R14374: BC0036	5.1E+6 (+1113V)	0.02 ± 0.02	0.04 ± 0.03	0.05 ± 0.03
		8.6E+6 (+1200V)	0.03 ± 0.02	0.06 ± 0.03	0.07 ± 0.03

WP2. The mPMT electronics has been projected and it is under testing to be fully compliant with , Hyper-K requirements which are: 1) timing resolution better than the 3" PMT transit time spread of 1.5 ns; 2) charge resolution of ~0.05PE, linear up to 25PE; 3) power consumption less than <4 W /mPMT (the HV board consumption has been found to be 237.5mW for mPMT module). Two different designs for the mPMT digitization have been developed. One is a Q/T digitization based on discrete components, while the other is one based on an FADC digitization, with on-board signal processing. Note that the Q/T digitization proposed for the mPMT is different from the Q/T digitization proposed for the ID PMTs. In fact, the mPMT solution uses discrete components to make the Q/T digitization, whereas the ID electronics uses the QTC ASIC+ an FPGA-based TDC. The mPMT electronics can be divided into two parts, a set of single channel Front End boards (FEB), and a Main Board (MB). The FEB are mechanically connected to HV boards that are placed very close to the individual PMTs. The MB is mounted in the centre of the module on the electronics support structure. The outputs of the single channel FEB are merged into the MB through individual flat cables. A very low power MCU is embedded in the Front End to control both the HV board and the FEB itself, and only one connector for both boards is needed. The time measurement circuit consists of a fast, high gain amplifier and a discriminator. The output of the amplifier is compared with a threshold set by the DAC and the output of the discriminator is sent to the main board using a differential signal. Then, it is used by the FPGA to produce a time stamp and generate a hold signal for the ADC. For the charge measurement the input signal is shaped

with a three-stage integrator and acquired with a 2 Msps 12-bit ADC. An energy resolution of 0.1 % FWHM and a time resolution of 100 ps have been measured for this digitization system, with a power consumption of 40.5 mW per channel. In the FADC digitization option, there is an analog shaping circuitry and HV generation on the PMT base. The shaped PMT signal together with HV control signals and the power supply for the PMT would all be on the same cable between the PMT base and the main board. The shaped signals travel as differential signals to the main board, where they would be further shaped and then digitized by an about 100 Msps/12-bit FADC. The ADC data is then transferred to an FPGA, where digital signal processing (DSP) techniques will be used to find pulses and calculate the charge and time for the pulses. A summary of the information on each hit is sent from the front-end electronics in the mPMT to the readout system via an ethernet cable. For more complicated pulses, and diagnostic purposes, the raw ADC samples can also be saved. Advantages of the FADC digitization are that it provides more information for complicated pulses and that it does not have any dead time.

WP3. The mPMT pressure vessel consists of an acrylic dome, which acts as a window for the PMTs to view the detector volume, and a cylindrical section that houses the PMT support structure, electronics and potentially a scintillator veto. The cylinder is blanked off by a stainless-steel plate. The radioactivity content of all the mPMT components are carefully screened and the materials chosen to satisfy the requirements of HK. The transmittance and reflectance in air and with optical gel have been measured and found compliant with HK, however, after completing the mechanical tests on several acrylic samples, the Plexiglas GS UVT by Evonik has been selected as having the best optical/mechanical properties for the mPMTs. Studies are still ongoing to identify a gel with very good UV transparency to act as optical interface between the PMT and the acrylic vessel. The pressure test on the acrylic vessel showed that a 15mm think cover withstands a pressure of 1.84MPa for 4 hours which is well beyond the 1.25MPa expected for HK. The crash test has shown that critical deformation occurs beyond 6MPa and the vessel breaks at 8.6MPa. The background emission was also verified, though preliminarily, and the contamination of ^{232}Th, ^{210}Pb and ^{40}K was found to be again compliant with HK requirements.

WP4. The detector is currently under long term testing in water and results, delayed due to Covid19 travel limitations are expected for late 2020. In summary a mPMT module has been fully designed and construction and testing is scheduled to be concluded by year 2020.

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