Evaluation of large area photomultipliers for use in a new Baksan Large Neutrino Telescope project

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Introduction

The Baksan Large Neutrino Telescope is a liquid scintillation neutrino detector with a target mass of 10 kt, which is supposed to be constructed at the Baksan Neutrino Observatory of the Russian Academy of Sciences at a depth of 4700 m.w.e. In addition to the main full-scale detector, this project includes prototypes with target masses of 0.5, 5 and 100 t. We evaluate twenty-five photomultipliers (PMTs) Hamamatsu **R7081-100** WA-S70 that are used in the first two phases of the project as the main ones [1]. Also, we evaluate twelve PMTs Hamamatsu **R5912-100** WA-S70 used for the muon veto system for the 5-t detector prototype. For PMTs evaluation, the quantum efficiency (QE), single photoelectron (SPE) response, timing characteristics, anode dark count rate, linearity and long afterpulses were measured.

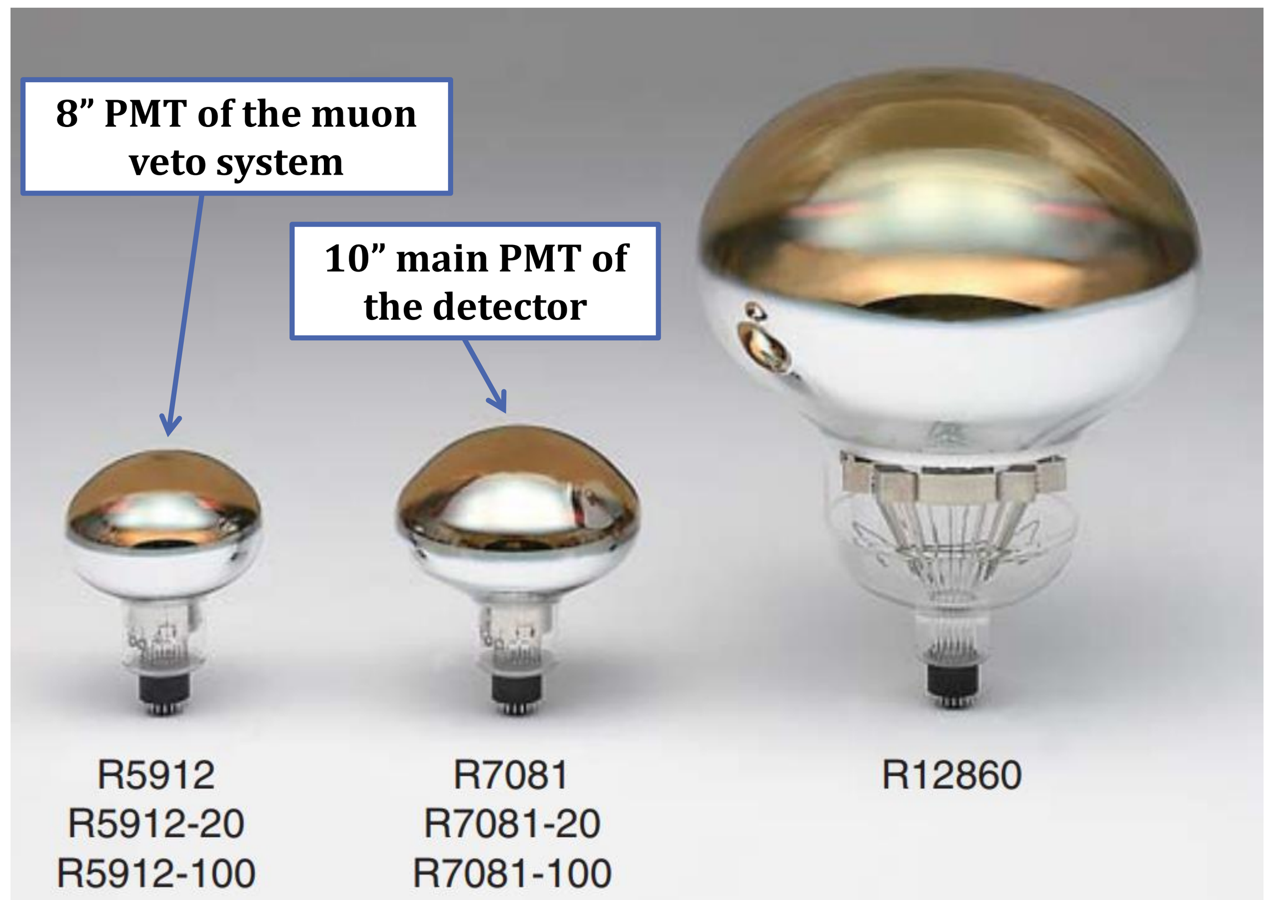

Figure 1: Large photocathode area PMTs by Hamamatsu.

Table 1: Characteristics of the most relevant hemispherical PMTs with a large photocathode area.

PMT	Minimum effective area, mm	Quantum efficiency at 390 nm, %	TTS (FWHM), ns
Hamamatsu Photonics [2]			
R12860	440	30	2.4
R7081-100	220	**35**	3.4
R5912-100	190		2.4
R7081-20	220	25	3.9
R5912-20	190		3
HZC Photonics [3]			
XP1802	206	~25	2.4
XP1804	247		3
XP1807	280		5

Quantum efficiency

The main advantage of the PMTs R7081-100 and R5912-100 is their high quantum efficiency. Measurement of the QE consists in measuring the anode current when the PMT photocathode is illuminated with monochromatic light in a certain wavelength range. In this case, the PMT operates in a diode mode. The certain wavelength was obtained using a xenon lamp and a monochromator. The results are compared with a pre-calibrated photodetector – the silicon photodiode Hamamatsu S1337-1010BQ.

According to the data obtained, QE exceeds 30% in the wavelength range from 330 nm to 450 nm, and at 390 nm QE reaches a maximum of almost 40%.

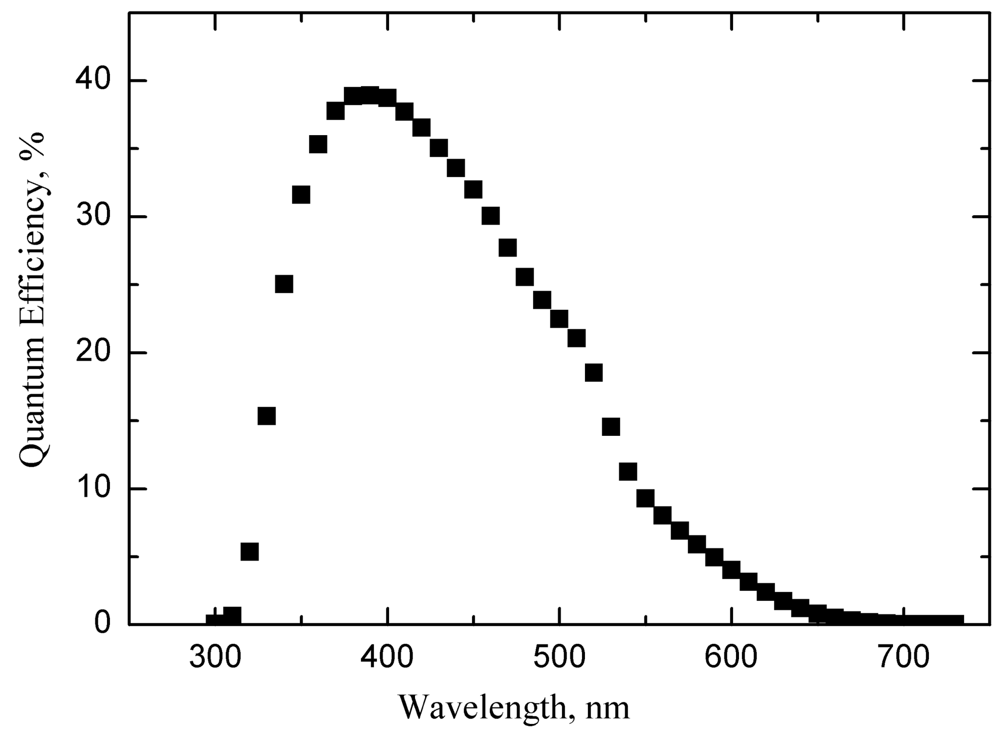

Figure 2: The dependence of QE on the wavelength for a PMTs R7081-100 and 5912-100 photocathode.

SPE response

Measurements were carried out with a PMT gain of about 10^7 and an fast amplifier gain of 10. The setup for measuring SPE parameters included a digitizer and an LED, synchronized with the digitizer using a generator. The 16-bit DRS4 with a sampling rate of 5 GS/s was used as a digitizer. The LED had a wavelength of 405 nm. The measurement results are shown in Table 2.

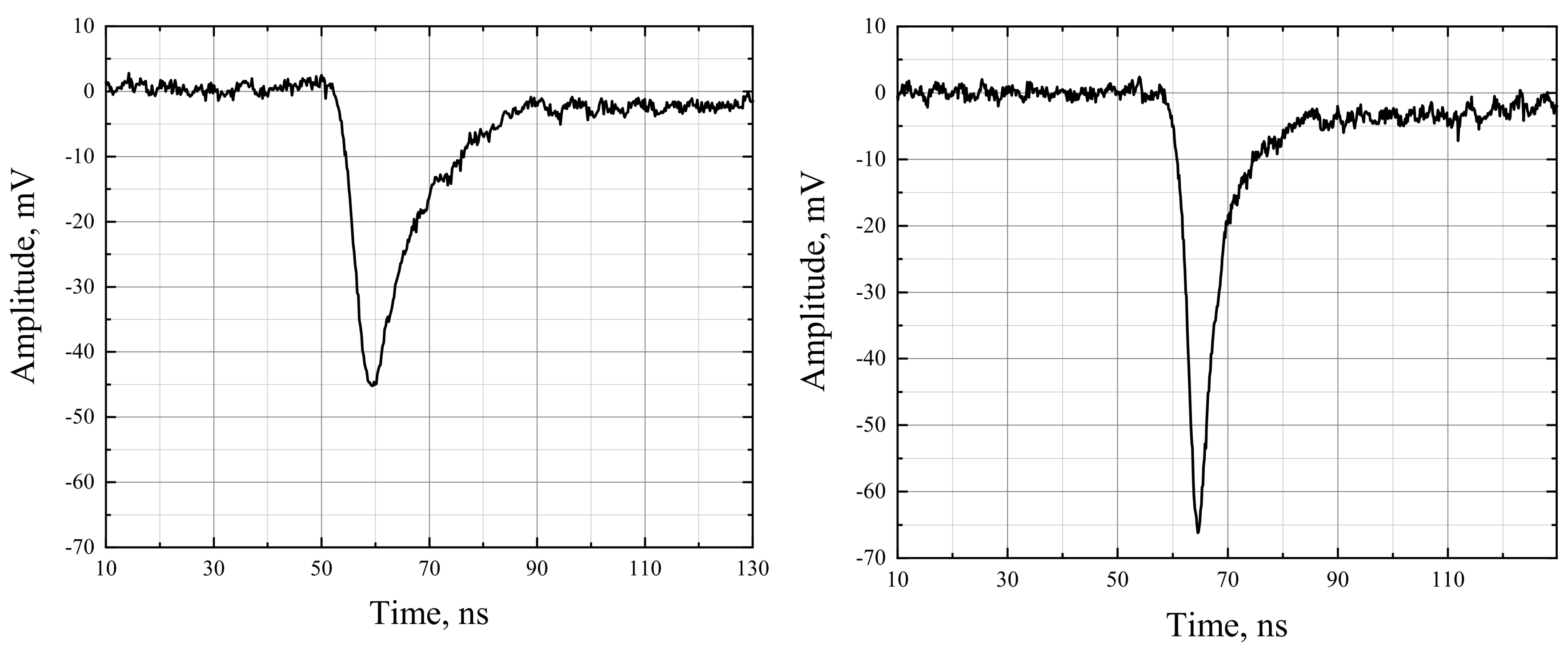

Figure 3: Single photoelectron pulse waveforms of the PMTs R7081-100 (left) and R5912-100 (right).

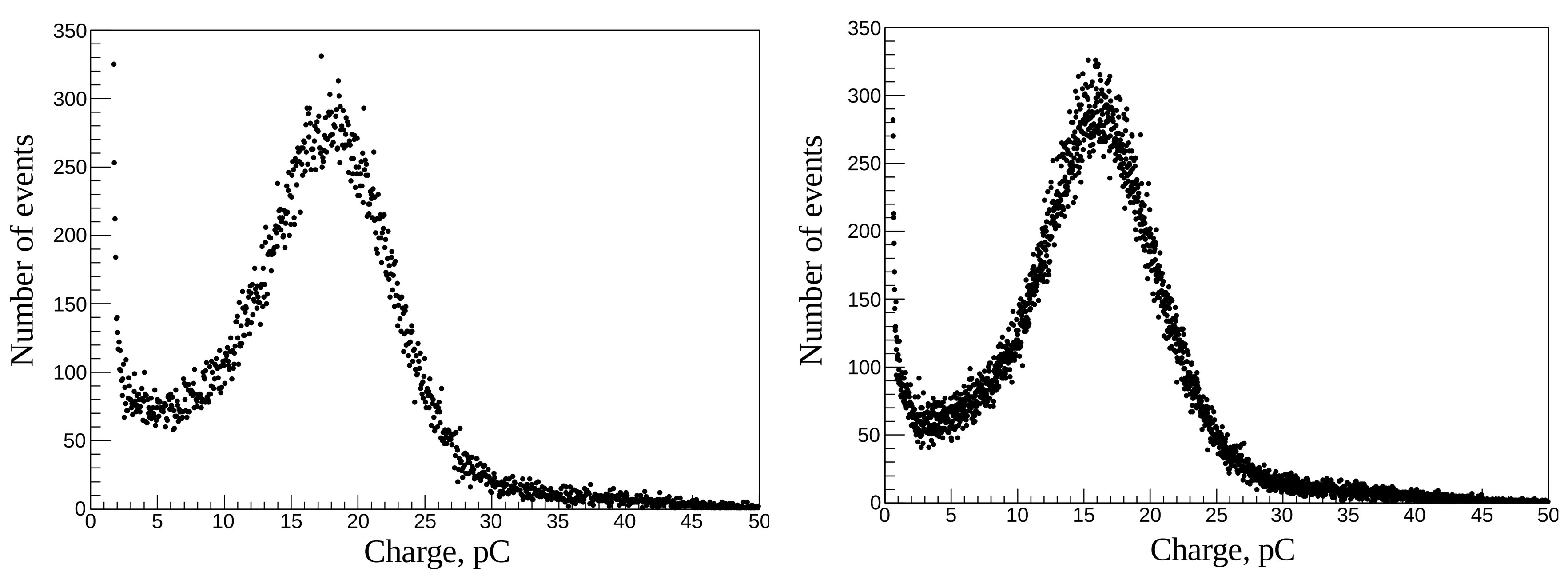

Figure 4: Typical single photoelectron spectra of the PMTs R7081-100 (left) and R5912-100 (right).

Transit time spread

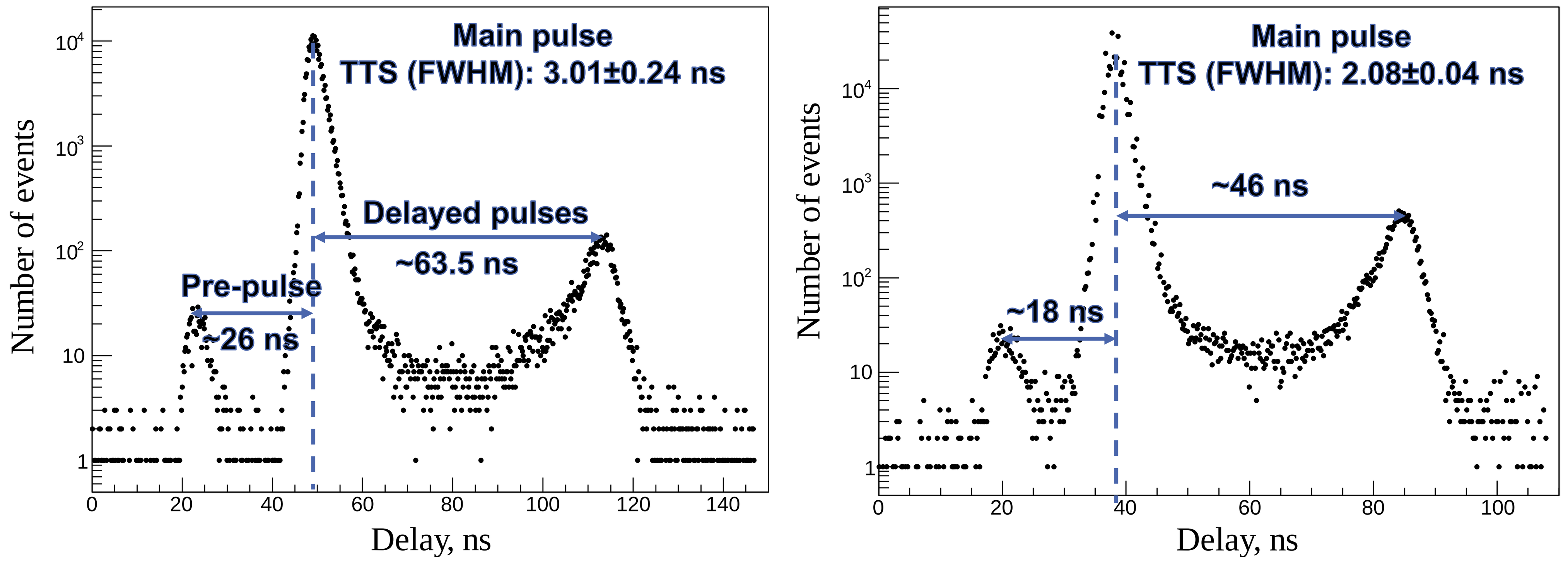

Figure 4: Typical TTS distributions of the PMTs R7081-100 (left) and R5912-100 (right).

Long afterpulses of R7081-100

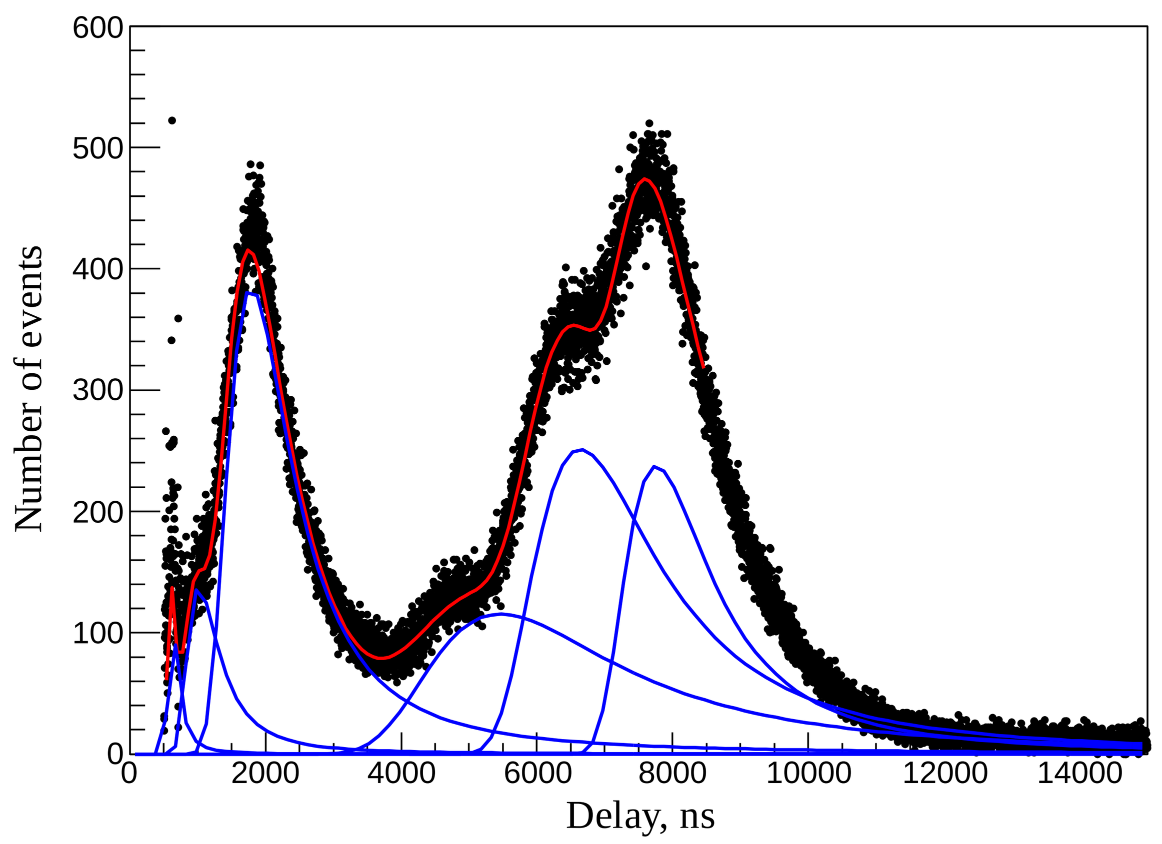

Figure 6: Typical delay distribution of long afterpulses for the PMTs and its fit.

Peak position, µs	Possible source	The probability of occurrence, %
0.605	H^+	0.02
1.047	H_2^+	0.08
1.854	He^+	0.44
5.657	Ions of some K-containing or organic compounds	0.37
6.768	K_2O^+	0.53
7.848	Xe^+	0.35

Results

Table 2: Results of evaluation of PMTs Hamamatsu R7081-100 and R5912-100.

PMT	QE at 390 nm, %	V/P ratio	SPE resolution	Dark rate, kHz	Pulse duration, ns	Rise time, ns	TTS (FWHM), ns
R7081-100	~39	3.73±0.56	0.68±0.06	1.74±0.87	~40	~4.1	3.01±0.24
R5912-100		4.54±0.52	0.67±0.04	0.847±0.042	~25	~3.9	2.08±0.04

References

[1] N.A. Ushakov et al., *New large-volume detector at the Baksan Neutrino Observatory: Detector prototype, J. Phys. Conf. Ser.* **1787** (2021) 012037.

[2] Official website of Hamamatsu Photonics. URL: https://www.hamamatsu.com

[3] Official website of HZC Photonics. URL: http://www.hzcphotonics.com

[4] B.K. Lubsandorzhiev, P.G. Pokhil, R.V. Vasiljev and A.G. Wright, *Studies of prepulses and late pulses in the 8" electron tubes series of photomultipliers, Nucl. Instrum. Methods Phys. Res. A* **442** (2000) 452.

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