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Photomultiplier tube selection for the Wide Field of view Cherenkov/fluorescence Telescope Array of the Large High Altitude Air Shower Observatory

Maomao Ge [a,b,*], Li Zhang [a,b], Yingtao Chen [a,b], Zhen Cao [c], Shoushan Zhang [c], Chong Wang [c], Baiyang Bi [c]

[a] *Department of Physics, Yunnan University, Kunming 650091, China*
[b] *Key Laboratory of Astroparticle Physics of Yunnan Province, Kunming 650091, China*
[c] *Institute of High Energy Physics, CAS, Beijing 100049, China*

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ABSTRACT

For the purpose of selecting the most suitable photomultiplier tubes (PMTs) for the Wide Field of view Cherenkov/fluorescence Telescope Array (WFCTA), we have performed extensive tests on seven models of 25.4 mm PMTs: Hamamatsu R1924A and R7899, Beijing Hamamatsu CR303, CR332A and CR364, and HZC Photonics XP3102 and XP3182. A dedicated test system has been developed to measure the PMT characteristics such as single photo-electron spectrum, gain, linearity, and spatial uniformity of anode output. The XP3182 and CR364 (R7899) tubes both meet the pivotal requirement due to their superior pulse linearity. The PMT test system, techniques used for these measurements, and their results are also reported.

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1. Introduction

The Large High Altitude Air Shower Observatory (LHAASO) [1,2] is a hybrid detector array designed to measure the individual cosmic ray spectrum around the 'knee' [3,4] and to survey the gamma ray sources above 100 GeV. It will be deployed at Haizishan (100°E, 29°N, 4400 m a.s.l.), Daocheng county, Sichuan province, China, and will consist of five types of detector array [5].

The Wide field of view Cherenkov/fluorescence Telescope Array (WFCTA) [6] is one of the main detectors of the LHAASO. The finished WFCTA will consist of 24 telescopes, whose main function is species discrimination of primary particles in conjunction with other detectors of the LHAASO. Fig. 1 depicts an individual WFCTA telescope. Each telescope consists of an array of 32×32 photomultipliers (PMTs), i.e. the camera, and a 4.7 m^2 spherical segmented mirror. The PMTs are coupled with the Winston cones [7] to maximize the collection efficiency of the light focused by the mirror. Unlike the narrow field of view (FoV) observations [8,9], each of the WFCTA telescopes has a $14° \times 16°$ FoV. Each PMT has a 0.5° FoV and is read out by front-end-electronics and digitized by a 50 MHz Flash-ADC (FADC) on the back board of the camera. These components are installed in a shipping container and mounted on a flat platform trailer. Benefiting from its versatile design, the WFCTA can be operated in both Cherenkov and fluorescence modes in four observation configurations by changing the locations, the elevation angle, the direction of telescope, and the gain of the PMTs in cameras. Table 1 lists a brief information about four observation configurations of the WFCTA.

In the case of the Cherenkov mode, the showers induced by higher energy primary particles produce more photons within the Cherenkov cone. Therefore, the higher energy showers can be detected with a lower PMT gain. As to the fluorescence mode, the fluorescence radiation produced by air showers is emitted isotropically, and the radiation intensity is generally weaker than the Cherenkov radiation. The PMT gain will be accordingly increased in the fluorescence mode. By measurement of the photon flux of Cherenkov radiation or fluorescent radiation, information on the lateral photon density distribution and longitudinal shower development can be recorded by the telescope cameras. Thus the telescope performance is relevant to the required characteristics of the PMTs that compose the camera. There will be about

* Corresponding author at: Department of Physics, Yunnan University, Kunming 650091, China.
E-mail addresses: gemaomao@ynu.edu.cn (M. Ge), lizhang@ynu.edu.cn (L. Zhang).

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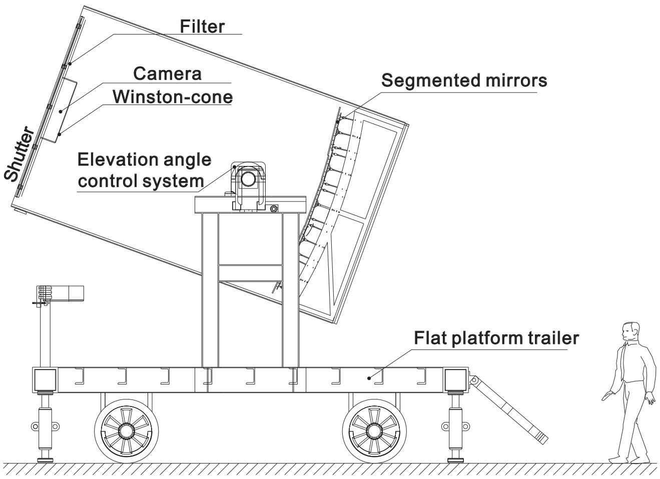

Fig. 1. Schematic drawing of a WFCTA telescope of the LHAASO.

Table 1
A brief information about four observation configurations of the WFCTA.

Phase	Mode	Target energy region	Expected PMT gain
1st	Cherenkov	10–500 TeV	2×10^5
2nd	Cherenkov	0.1–10 PeV	1×10^5
3rd	Cherenkov	5–100 PeV	0.5×10^5
4th	Fluorescence	> 50 PeV	2×10^5

Table 2
Specification Requirements for PMTs in the WFCTA.

Parameter	Requirement
Diameter	25.4 mm (1 in.)
Spectral response	300 nm–650 nm
Quantum efficiency	$> 25\%$ at 400 nm
Pulse linearity	$< \pm 2\%$ in 3.5 orders of magnitude
Gain	$g = 2 \times 10^5$
Operation voltage	< 1400 V
Spatial uniformity	$< 15\%$

27,000 PMTs in the whole WFCTA, including spares. Therefore, to choose the most suitable PMT and to balance the performance against cost, a detailed evaluation of candidate PMTs performances was required.

2. The candidate PMTs

According to results of the prototype at Yangbajing and the simulation of the telescope optical configuration [10], basic parameter requirements for the PMT, such as dimension, spectral response, gain, pulse linearity in dynamic range, and spatial uniformity, are determined. Table 2 lists detailed requirements for the PMTs. Since 2011, Hamamatsu and HZC Photonics[1] successively provided seven models of sample PMT to us. All the PMTs have a plano-concave window except for CR303, which has a planar cathode. The CR303, CR332A, and CR364 are manufactured by Beijing Hamamatsu. The CR303 and CR332A are developed from the R1924A, CR364 is developed from R7899. The CR364 (R7899) and XP3182 are specially optimized for large dynamic range applications according to our requirements. The basic information for the candidate PMTs are listed in Table 3.

Table 3
Basic information for the candidate PMTs in the WFCTA.

Model	Manufacturer	Dynode stages
R1924A	Hamamatsu	10
CR303	Beijing Hamamatsu	10
CR332A	Beijing Hamamatsu	10
R7899	Hamamatsu	10
CR364	Beijing Hamamatsu	10
XP3102	HZC Photonics	10
XP3182	HZC Photonics	8

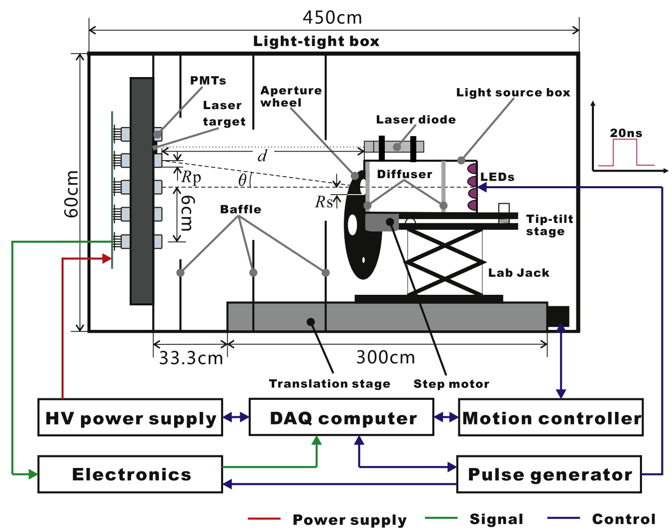

Fig. 2. Schematic drawing of the 1D-platform. 12 and 6 PMTs are symmetrically positioned along two concentric circles with a diameter of 12 cm and 6 cm respectively. One PMT is positioned at the center, these PMTs are inserted in a Nylon bracket locate on the left side of the box.

3. The PMT test system

Two test platforms have been built for candidate PMT selection. The '1D-platform' (see Fig. 2) is used for measurement of the single photo-electron (SPE) spectrum, voltage vs. gain characteristic, and linearity. Another platform, the '2D-platform', is used for spatial uniformity scans (see Fig. 4). The setups and key technologies of the two platforms are described in the following sections.

3.1. The 1D-platform

The 1D-platform is designed to test 19 PMTs in a single run automatically. The number of photons incident on PMT cathode can be adjusted by changing the distance from the PMT to the light source and the aperture of the light source. In the light source box, four pieces of NSHU551A-E 375 ± 3 nm[2] light-emitting diodes (LED) are powered by a BNC575-8C pulse/delay generator. Subsequently, the photons emitted from the LEDs are diffused by two pieces of opal glass with a thickness of 0.3 mm. The distance between the diffusers is 5 cm, the LEDs and the diffusers are sealed in an anodized aluminium box, then the outside surface of the second opal glass can be regarded as an approximate Lambertian light-emitting surface. The exit aperture of light source can

[1] HZC Photonics merged PMT branch of PHOTONIS in 2011, however, the PMT model names of former PHOTONIS are still used.

[2] This type of LED also has a relatively weak emission band at the wavelength range from 475 to 700 nm, centered at about 560 nm.

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