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Status of the 20 inch MCP-PMT prototype development for JUNO experiment

Feng Gao[a,b,c], Guorui Huang[d], Yuekun Heng[a,b], Dong Li[d], Hulin Liu[e], Shulin Liu [a,b], Weihua Li[e] , Zhe Ning[a,b], Ming Qi[f], Sen Qian[a,b], Ling Ren[d], Jianning Sun[d], Shuguang Si[d], Jinshou Tian[e], Yifang Wang[a,b], Yonglin Wei[e], Liwei Xin[e], Tianchi Zhao[a],

on behalf of the MCP-PMT workgroup

a. Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China
b. State Key Laboratory of Particle Detection and Electronics, Beijing 100049, China
c. University of Chinese Academy of Sciences, Beijing 100049,China
d. Nanjing, North Night Vision Tech. Ltd., NanJing 211106, China
e. Xi'an Institute of Optics and Precision Mechanics, Chinese Academy of Sciences, Xi'an 710068,China
f. Department of Physics, Nanjing Unversity, Nanjing 210093, China

Corresponding author. **Sen.Qian**, qians@ihep.ac.cn

Abstract. A new concept of large area photomultiplier based on MCPs was conceived for JUNO by the scientists in IHEP, Beijing. In the past 5 years by collaborative work of the MCP-PMT collaboration in China, 8 inch and 20 inch prototypes were produced. Test results show that this type of MCP-PMT can have similar photon counting performance as the traditional dynode type PMTs. With the better collection efficiency, low after pulse rate, low Low-Potassium Glass, the JUNO ordered 75% about 15,000 20 inch MCP-PMT from NNVT at the end of 2015.This manuscript just give the overview this type of MCP-PMT, the R&D process and the main characteristics.

1. Introduction

The JUNO (Jiangmen Underground Neutrino Observatory) [1] lead by the IHEP, Beijing and under construction in JiangMen, Guangdong province in south China is a generic underground national lab for neutrino physics and other research fields. Its neutrino program requires a high performance large detector, which employs approximately 20,000 pieces of 20 inch diameter photomultiplier tubes (PMTs) that have large sensitive area, high quantum efficiency, high gain and large peak-to-valley ratio (P/V) for good photon counting performance.

In the conceptual design proposed by researchers at IHEP a MCP (Microchannel Plate) assembly replaces the bulky Dynode chain in traditional large PMTs [2]. This concept is developed into prototypes in collaboration with a number of research institutions and industrial partners, in particular the North Night Vision Tech. Ltd. (NNVT) in Nanjing, China.

2. The R&D of the MCP-PMT

After several years R&D, a number of 8 inch prototypes were produced and their performance was tested at IHEP in 2013 by using the MCP-PMT evaluation system built at IHEP [3]. The 20 inch prototypes were followed in 2014 [4], with typical performance of quantum efficiency (QE) ~ 25% at 410nm, photoelectron collection efficiency (CE) ~ 60%, peak-to valley ratio (P/V) of single photoelectron spectrum (SPE) > 2.0. The typical SPE in fig.1, the left one with the No. of MCP-PMT-38# is an 8 inch prototype, the right one with the No. of MCP-PMT-56# is a 20 inch prototype.

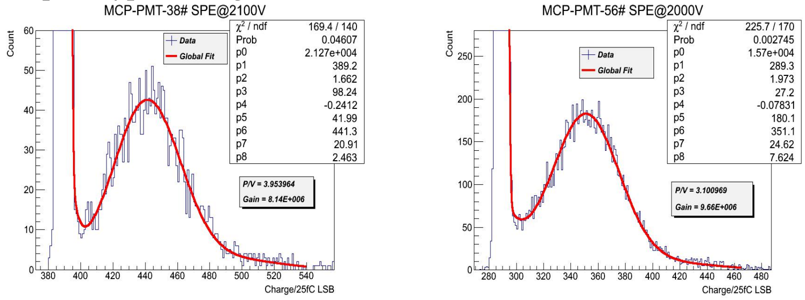

Fig.1 The typical SPE of the MCP-PMT, left one is a 8 inch prototype, right one is the 20 inch prototype.

In 2015, the performance of this type of MCP-PMT was further improved and QE ~ 26% at 410nm, CE ~100% and SPE P/V > 3.0 were achieved. The schematics and a photograph of the 20 inch MCP-PMT are shown in Fig. 2. The improvements were mainly due to using a new type of MCPs and design optimizations.

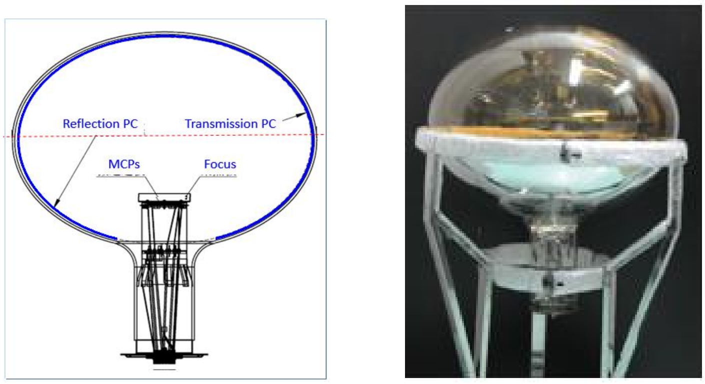

Fig.2 The schematics and a photograph of the 20 inch MCP-PMT

3. The evaluation system for the PMT

A PMT test and evaluation lab has been established at IHEP, Beijing consisting of sensitive electronics based on VME system, light sources, laser diodes of different wavelengths, picosecond laser units, a OPO laser, a light spectrometer, high voltage and low voltage power supply systems, 2D/3D rotational scanning platforms and other equipment.

Fig.3 The PMT performance evaluation lab in IHEP for the MCP-PMT R&D

This PMT evaluation system played a critical role in the MCP-PMT prototype development process by providing feedback to the manufactures to identify design flaws and other issues in the early prototypes. Fig. 3 shows the main room of the PMT lab.

4. The performance of the 20 inch prototype

The optical evaluation of the 20 inch MCP-PMT includes measuring the photocurrent vs. high voltage curves, QE vs. wavelength, and the mapping of the QE uniformity. Also the SPE charge spectra, gain vs. high voltage settings for the MCP assembly, ranges of gain linearity and dynamic range, Timing characteristics of output signals and transit timing spread (TTS) were measured. Noise characteristics and after pulse properties were studied at gain ~1.0×10^7.

Aging tests and performance earth magnetic field, high and low temperature test were already done. Typical parameters of early 2016 prototypes are listed in Table 1.

Table 1. Comparison of the 20 inch PMTs

Items	Units	MCP-PMT	R12860
QE at 400 nm	%	**26**	**30**
Relativity CE	%	**~110%**	**100%**
SPE P/V		**＞3**	**＞3**
TTS (top point)	ns	**~12**	**~3**
Rise time	ns	**2**	**7**
Fall time	ns	**10**	**17**
Anode dark rate	Hz	**~30 k**	**~30 k**
After pulses time delay	μs	**~4.5**	~4 and ~17
After pulse rate	%	**3**	10
Radiation background		**low**	high

The TTS of the MCP-PMT is rather low due to the relatively low voltage of approximately 400 V between the cathode MCP and also presumably limitations of electro-optical design. The after pulse rate of the MCP-PMT is lower than that of the Hamamatsu R12860 that uses traditional dynodes for electron multiplication.

The glass used for MCP-PMT has extra low potassium, low uranium resulting extra low radiation background that is critical for JUNO that is based on liquid scintillator.

5. The PMT purchase of JUNO

The JUNO Bidding started on Oct.23th 2015, and completed on Nov.17th 2015. Comparing the PMT performance between 20inch MCP-PMT and R12860 is in table.1. JUNO ordered 1,5000 20 inch MCP-PMT from the NNVT.

Acknowledgments

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