

The improvement of 20" MCP-PMT for neutrino detection

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For the next generation neutrino experiment, the MCP-PMT collaboration group has done a lot of work in China. After years of hard work, we have developed 20" MCP-PMT. The MCP-PMT has large sensitive area, high quantum efficiency, high gain and large P/V value for good photon counting performance. The high detection efficiency of 20" MCP-PMT will be used in neutrino detection, and we have got an order for 75% of the PMTs required for neutrino detection. To this end, the MCP-PMT collaboration group also completed the mass production line and batch test system in Nanjing. This presentation will introduce the improvement of 20" MCP-PMT for neutrino detection.

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1. Introduction

In 2013, the 8 inch MCP-PMT was produced with two shapes, vertical and horizontal ones, both of these two types of MCP-PMTs have the best MCP modules for the single photon detection, and the P/V of the SPE of them is better than the Dynode-PMTs. In 2014, the 20 inch glass was produced, and also the MCP-PMT was produced with two shapes, vertical and horizontal ones, and both of the two shapes were good in the SPE test. The performances of these types of 20 inch MCP-PMT were as good as the 8 inch ones. In 2015, JUNO (Jiangmen Underground Neutrino Observatory) ordered 15000 pieces 20" MCP-PMT from the NNVT [1-4].



Figure 1: 20" MCP-PMT

The mass production line was built by MCP-PMT collaboration group in 2016. At present, about 30 PMTs are produced every day. According to the requirement of JUNO project, each production PMT must be carefully tested. The batch test system has been designed and finished at the beginning of 2017. All the PMTs are tested in the factory before the delivery time. So far, we have tested about 7000 MCP-PMTs. As illustrated in Table 1, the parameters of the photocathodes are really improved during the mass production process. It is worth noting that the time characteristics of MCP-PMTs is not good enough. That is due to changes in the collection, the photocathode and technics of MCP.

Table 1: MCP-PMT performance parameters in the mass production by batch test

PMT parameters	Data in the contract	MCP-PMT prototype	~7000 PMTs
QE@400nm(%)	≥ 26.5	~ 26	30.1
QE Uniformity(%)	≤ 15	≤ 10	7.3
P/V of SPE	≥ 2.8	~ 5.6	7.08
HV@ 10^7 (V)	2800	~ 1930	1745
DE@400nm(%)	—	~ 26	30.1
DE@420nm(%)	≥ 24	—	27.61
DR(KHz)	≤ 50	~ 30	37.25
TTS(ns)	≤ 15	~ 12	20
APR(%)	≤ 5	≤ 2.5	0.63
Linearity<10%(pe)	≥ 1000	~ 1000	1299
RT(ns)	≤ 2	~ 1.2	1.41
FT(ns)	≤ 12	~ 10.2	24.91

2. The improvement of CE

At first we did lots of work to improve the QE and CE, but the CE was only 70%, not the same as we designed. The MCP-PMT work group did the best to improve the CE, such as using some special technology about the MCPs, adjusting the depth of output electrode, changing the diameter of MCP and channels, modifying the bias angle of channel, and so on. Finally, the CE of the MCP-PMTs was improved from 70% to 100% successfully [5]. As shown in Table 2, we tested 30 samples of Dynode-PMTs and MCP-PMTs, respectively. The results show that the collection efficiency of MCP-PMT is about 100%, which is better than Dynode-PMT's.

Table 2: Performance comparison of Dynode-PMT and MCP-PMT (DE=QE*CE)

30 pics 20" PMT	DE@420nm(%)	QE@420nm(%)	CE@420nm(%)
Dynode-PMT	28.08±1.02	30.48±0.87	93.19±1.44
MCP-PMT	27.15±0.32	27.56±0.4	101.4±1.2

3. The improvement of QE

What's more, we have adopted many methods to improve QE. Firstly, we use a method of evaporating metal film on the cathode substrate to increase the electron supplement ability of photocathode. Secondly, a transmissive film is vapor deposited on the substrate for enhancing the transmittance of incident light. Thirdly, we improve the cathode fabrication process and optimized different material compositions to improve photocathode performance as much as possible. In addition, we strictly control the processing of the glass bulb to make the surface clean.

Therefore, the quantum efficiency of the photocathode is really improved during the mass production process. As shown in Figure 2(a), the QE of the photocathode is improved from 30% to 35% at the peak wavelength. These MCP-PMTs have high QE and we call them HQE-MCP-PMTs. At present, the QE of MCP-PMT is better than that of the Dynode-PMT. So far, we have tested about 7000 MCP-PMTs. As can be seen from Figure 2(b), the QE of MCP-PMT is steadily improved. In particular, the latest two batches about 500 PMTs are HQE-PMTs.

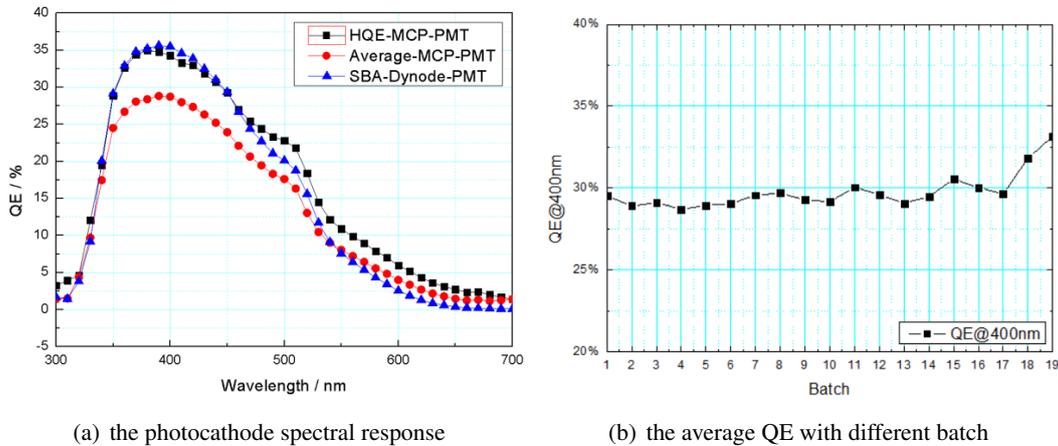


Figure 2: The improvement of quantum efficiency

Accordingly, the DE of MCP-PMT is also improved by the increasing of CE and QE. For the latest batch test of 336 HQE-MCP-PMTs, as shown in Figure 3, the average DE of these PMTs is 30.32% at 420 nm.

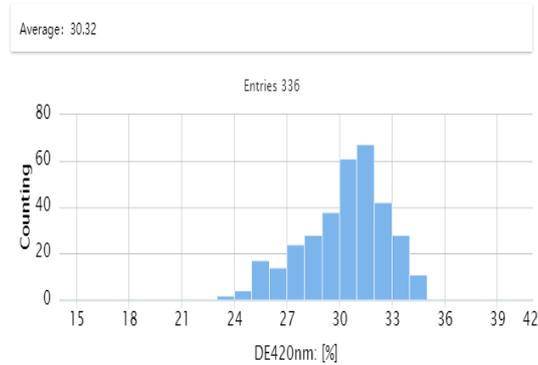


Figure 3: The DE of HQE-MCP-PMTs

4. Conclusions

The MCP-PMT group has already produced 7000 MCP-PMTs for JUNO. The average ED of these MCP-PMTs is 27.61% at 420 nm. What's more, we can produce HQE-MCP-PMTs with some technical improvements. The HQE-MCP-PMTs, whose DE is more than 30% at 420nm, will be used on JUNO project.

5. Acknowledgments

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