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Mass Production of MCP-PMT for JUNO and Development of 20-inch MCP-PMT with TTS Improved

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In order to meet the requirement of JUNO, 20-inch microchannel plate photomultiplier (MCP-PMT) was researched by the MCP-PMT collaboration, which was established by Institute of High Energy Physics (IHEP) and North Night Vision Technology Co., Ltd (NNVT) in 2012. By the breakthrough of the key technology, such as the electronic optics structure design, the high quantum efficiency photocathode process, and so on, the 20-inch MCP-PMT was developed successfully by 2015. The collection efficiency was about 98% and the detection efficiency (DE) was about 26%. At the same year, NNVT successfully bided for the 15000 PMTs of JUNO. In order to finish the contract of MCP-PMTs, the production line of 20-inch MCP-PMT was built on the 25th Nov of 2016. The production line was the domestic advanced photomultiplier production line with capable of 7500 pieces 20-inch MCP-PMTs a year. By building the batch test system, the charge performance of 32 pieces PMTs could be tested at the same time. Recently, NNVT had delivered JUNO total 7000 pieces 20-inch MCP-PMTs. The average DE was increased to 30% from 27% since June 2018, and the average dark count rate was about 30 kHz. Based on the research finding of 20-inch MCP-PMT for JUNO, the 20-inch MCP-PMT with good time response was researched to meet the requirement of Hyper-K project, and developed successfully. The new 20-inch MCP-PMT had a flower-like focusing electrode. The transit time spread was about 5 ns, namely FWHM, better than the one of the original 20-inch MCP-PMT with 14ns.

KEYWORDS: Microchannel plate, Photomultiplier, JUNO, Detection efficiency, Transit time spread

1. Introduction

The Jiangmen Underground Neutrino Observatory (JUNO), a 20kton multi-purpose underground liquid scintillator detector, was proposed with the determination of the neutrino mass hierarchy as a primary physics goal[1-3]. Photomultiplier tubes (PMTs) were a common component of particle physics and nuclear physics experiments, and their main role is to convert optical signals to electrical signals. To meet the demands on the core components of neutrino detection for national frontier of high energy physics development, the microchannel plate photomultiplier tube (MCP-PMT) collaboration established with the Institute of High Energy Physics (IHEP) and North Night Vision Technology Co. Ltd. (NNVT) started to study the MCP-PMT by the end of 2011[4]. By the breakthrough of the key technology, such as the electronic optics structure design, the high quantum efficiency photocathode process, and so on, the 20-inch MCP-PMT was developed successfully by 2015. The collection efficiency was about 98% and the detection efficiency (DE) was about 26%.

A procurement contract on 20-inch PMTs for the JUNO project was signed at IHEP on December 16, 2015. According to the contract, NNVT would produce 15,000 high-quality 20-inch MCP-PMTs for the JUNO project. In order to finish the mass production of 20-inch MCP-PMT for JUNO, a production line of 7500 tubes per year was built on November 25, 2016.

2. Mass production of 20-inch MCP-PMT for JUNO

According to the annual requirement of JUNO for 20-inch MCP-PMTs, we produced 4000 tubes per year. Till now, NNVT had delivered a total of 9000 PMTs from 2017s. The performance of the shipped MCP-PMTs in the last two years was as shown in Table I. Compared with the MCP-PMT prototype, the performance of 20-inch MCP-PMT was improved, such as DE, peak valley ratio (P/V), after pulse ratio, and linearity.

Table I. The performance of the shipped MCP-PMTs

PMTs	MCP-PMT prototype	~300 MCP-PMTs	~1000 MCP-PMTs	~7000 MCP-PMTs
DE @ Gain~1E7	26%	28.9%	29.3%	30.2%
Uni-QE @ 405nm	< 10.5%	8.1%	7.8%	7.3%
Dark count rate@ 0.25 PE	30.0 kHz	33.5 kHz	36.9 kHz	38.2 kHz
Peak valley ratio	5.6	8.2	7.1	7.1
Energy resolution	41%	30.9%	33.1%	30.1%
High voltage	1930V	1780V	1767V	1747V
Rise time	1.2ns	1.4ns	1.4ns	1.4ns
After pulse rate	2.5%	1.2%	0.8%	0.6%
Linearity <10%	1000 P. E.	1175 P. E.	1160 P. E.	1308 P. E.

In order to improve the DE of 20-inch MCP-PMT, we do some research on the improvement of photocathode process. There were two methods to improve the DE which concern two steps of Spicer three steps photoemission model. One way is to enhance the absorption of photons in the bulk of photocathode, and another is to increase the photoelectrons transmit to the surface of the photocathode.

After the technological breakthrough of photocathode, the average DE could be above 30% and all the PMTs are of high DE since June 2018. The result was published in ICHEP2018 in Seoul by IHEP, as shown in Fig.1. It showed that the DE was largely improved to 30.1% from 27.5%[5].

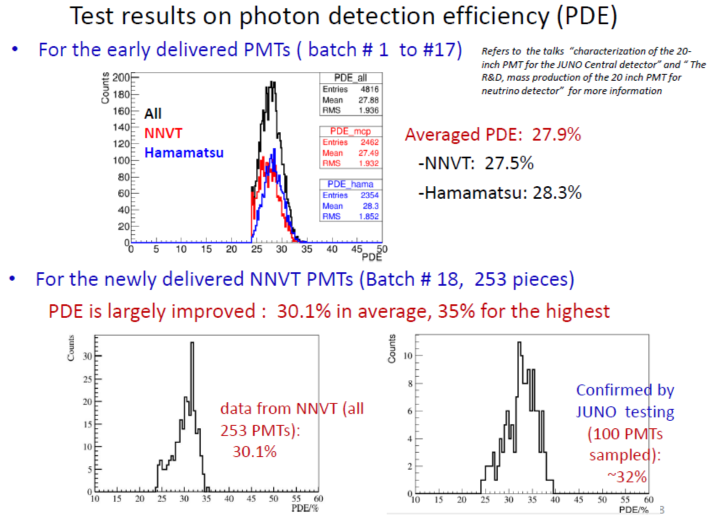


Fig.1 The High DE result was published in ICHEP2018 in Seoul by IHEP

3. The batch test system of MCP-PMT in NNVT

For 20-inch MCP-PMT, the photocathode performance was tested after production firstly, and then the anode output performance was tested in dark room secondly. The test system of MCP-PMT in NNVT included static parameter test system (photocathode performance) and dynamic parameter test system (anode output performance), as shown in Fig.2.

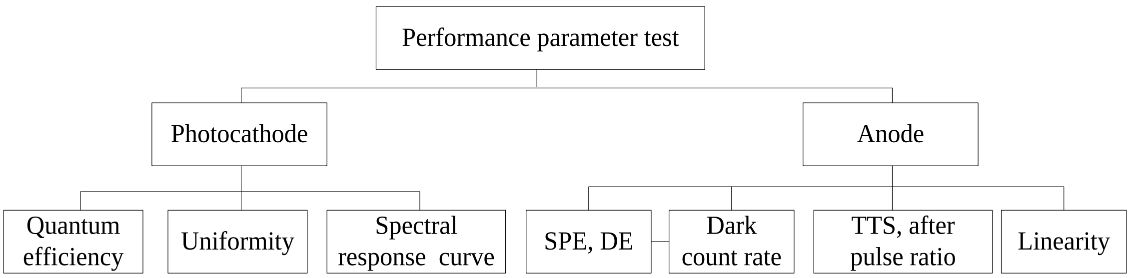


Fig.2. the test process of 20-inch MCP-PMT in NNVT

The static parameter test system was used to test quantum efficiency, uniformity of photocathode, and spectral response curve. The dynamic parameter test system was composed of seven parts: geomagnetic shielding dark room, surface light source, VME data acquisition system, NIM system, high voltage power supply system, pulse generator and oscilloscope. VME data acquisition system included QDC module, TDC module and scaler module. NIM system included low threshold discriminator module, fan-in and fan-out module and fast amplifier module. The diagram of the dynamic parameter batch test system was shown in Fig. 3.

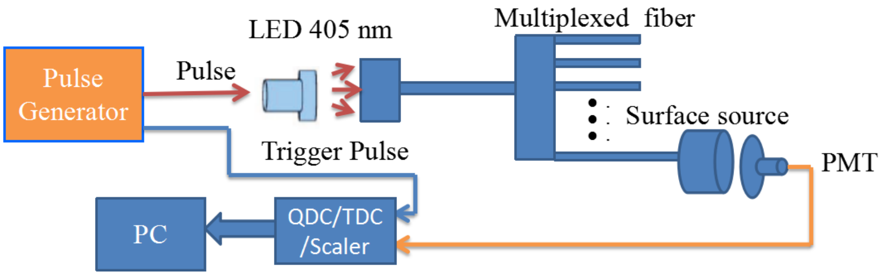


Fig.3. The batch test system schematic diagram

The batch test system could test 32 20-inch MCP-PMTs at the same time, and measured the performance parameters such as relative DE, single photoelectron spectrum(SPE), dark count rate, transit time spread (TTS), rise time, after pulse ratio, and dynamic range of photon count. The dynamic range of photon count was namely linearity in Table.1. The gain and P/V of MCP-PMT could be obtained by the SPE, and the SPE of MCP-PMT was shown in Fig.4.

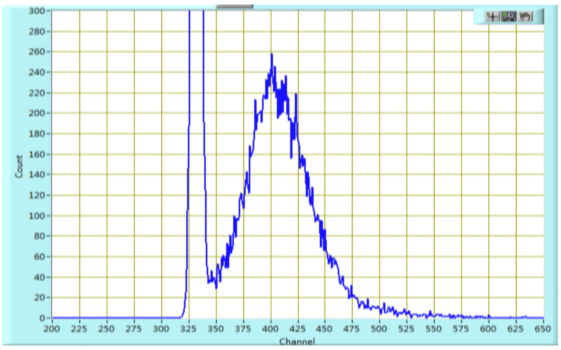
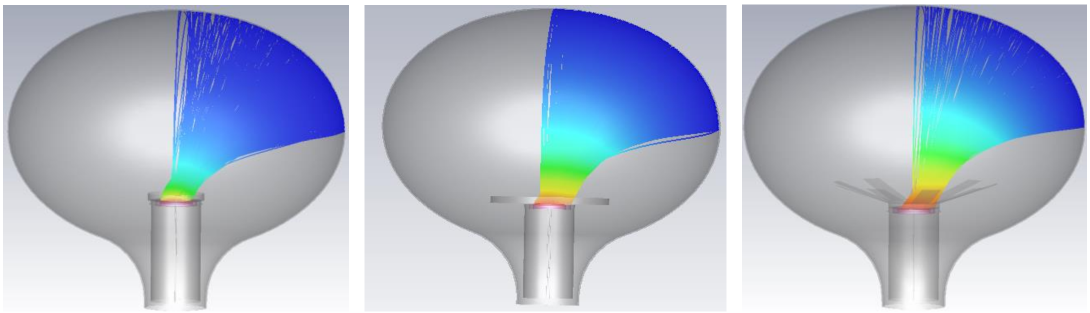


Fig.4. The single photoelectron spectrum of 20-inch MCP-PMT

4. Development of 20-inch MCP-PMT with TTS improved

The TTS is an important parameter of photomultiplier tube detection performance in the high energy physics field. TTS of the MCP-PMT occurred 1) between photocathode and MCP and 2) in the multiplication process inside the MCP. The former was mainly caused by the fact that the photoelectrons emitted from photocathode were with initial energy and angular distribution. Also, the shape of the potential distribution caused to give some TTS in general. The latter was due to the initial energy and angular distribution of the secondary electrons and the repetition of the collisions. These two cases were independent to each other and can be analyzed separately. The TTS occurred between photocathode and MCP input surface was researched in this paper.

Based on the structure of 20-inch MCP-PMT for JUNO, the theoretical model of the new MCP-PMT structure was established by the software, and the particle sources theoretical model was established according to the Monte Carlo integral sampling method of cosine distribution. Based on the establishment of theoretical models, the trajectories of photoelectrons were simulated in different 20-inch MCP-PMT structures, as shown in Fig.5.



(a) (b) (c)

Fig.5. The trajectory of photoelectrons in the 20-inch MCP-PMT

(a) Normal structure for JUNO; (b) The simulated structure with lager focusing electrode; (c) the structure for Hyper-K

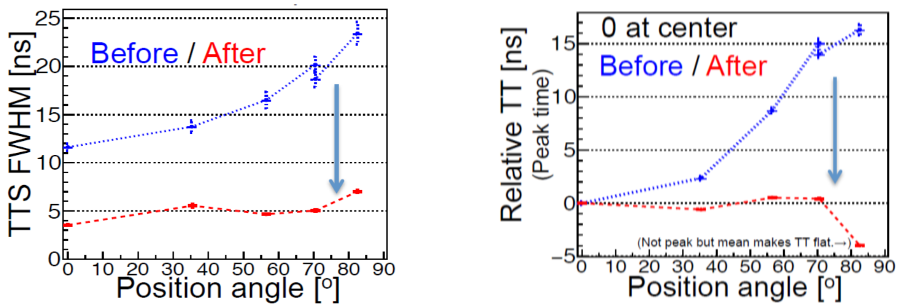
The influence of the focusing electrode structure and the divided voltage ratio between the photocathode and MCP on the TTS was analyzed. The simulation results were that, the larger the focusing electrode, the smaller the TTS. And the TTS could be improved greatly by adjusting the focusing electrode structure and the divided voltage. According to the theoretical simulation results and the dimension limit of bulb, the 20-inch MCP-PMT with flower-like focusing electrode was developed, and the new focusing electrode was shown in Fig.6.

(a) (b)

Fig.6. The structure of focusing electrode of different 20-inch MCP-PMT

(a) Normal focusing electrode; (b) Flower-like focusing electrode

As shown in Fig.7, the time response of 20-inch MCP-PMTs with flower-like focusing electrode (After) and normal focusing electrode (Before) were tested.



(a) (b)

Fig.7. Tested result in ICRR, University of Tokyo

(a) TTS (b) Relative transit time

After changing the structure of the focusing electrode, the TTS of the MCP-PMT using the flower-like one was improved from 14ns to 5ns, and the relative transit time was also improved.

5. Conclusion

Recently, NNVT had delivered a total of 9000 MCP-PMTs. All the PMTs were of high DE since June 2018, and the average DE was increased from 27% to 30%. The batch test system could test 32 pieces at the same time, and measure performance parameters such as relative DE, gain, SPE, dark count rate, TTS, rise time, after pulse ratio, and dynamic range. The TTS of the new 20-inch MCP-PMT with the flower-like focusing electrode were about 5 ns, better than the one of the original 20-inch MCP-PMT with 14ns. The research on the dark count rate and TTS will be ongoing in future.

Acknowledgment

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References

[1] F. P. An, G. P. An, Qi An, and et al: Neutrino Physics with JUNO. Journal of physics G-nuclear and particle physics, 2016 Vol.43 No.3 0954-3899.
[2] G. Ranucci: Status and perspectives of the JUNO experiment. Journal of Physics: Conference Series 2018 Vol.1056.
[3] J. Zhu, Z. Y. You Y. M. Zhang : Event Display in the JUNO Experiment. Journal of Physics: Conference Series 2018 Vol.1085 P032038 1742-6588.
[4] http://english.ihep.cas.cn/doc/852.html. Key components ordered for JUNO experiment. 2015-12-18
[5] Z. H. Qin, The report of "The 20-inch PMT system for the JUNO experiment" in ICHEP2018 in Seoul, P8, Jul.4-11.