

Status of the large area MCP-PMT in China

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On behalf of the MCP-PMT workgroup

Abstract: For the next generation neutrino experiment, number of experienced researchers and engineers in research institutes and companies related to PMT fabrication in China jointly worked on the large area MCP-PMT collaboration group. In the past 5 years by collaborative work, the 8-inch and 20-inch prototypes were produced. And also get the high detection efficiency 20-inch MCP-PMT for JUNO in 2015, and get the 75% order of the JUNO-PMT. This manuscript will introduce the progress of the R&D of this new design of the MCP-PMT, also the performance tested result in the PMT Lab in IHEP.

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1. Introduction

Researchers in the Institute of High Energy Physics (IHEP) have conceived a new concept of photomultiplier tube (PMT) for the next generation neutrino experiment in 2009[1]. The small Micro-channel Plate (MCP) units replace the bulky Dynode chain in the traditional large PMTs, called as MCP-PMT. In addition transmission photocathode on the front hemisphere and reflection photocathode on the back hemisphere are fabricated in the same glass bulb to form nearly 4π effective photocathode in order to enhance the efficiency of photoelectron conversion, as shown in figure 1.

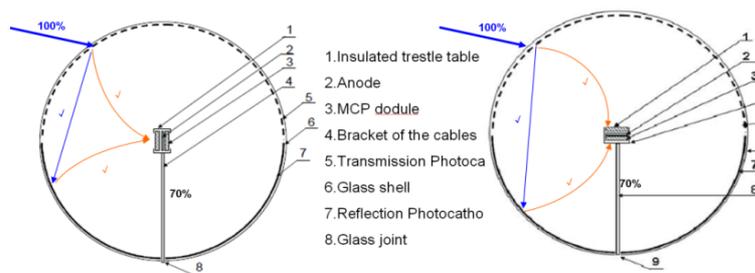


Fig. 1. The conceptual drawing of new large area MCP-PMT

A number of experienced researchers and engineers in research institutes and companies related to PMT fabrication in China jointly worked on the large area MCP-PMT project from 2011. After several years R&D, a number of 8-inch prototypes were produced in 2012 but can not test the single photoelectron spectrum (SPE), only with number quantum efficiency (QE) about 25%@410nm.

Then, at the end of 2013, the 8-inch MCP-PMT prototypes could with the peak-to valley ratio (P/V) of single photoelectron spectrum (SPE) > 2.0 and $QE \sim 25\% @ 410nm$. Also the other performances were carefully tested by the PMT evaluation system in the PMT Lab in IHEP [2], and the test data were shown in table.1.

In 2013, a generic underground national lab for neutrino physics was lead by the IHEP, and under construction in Jiangmen, Guangdong province in south China. The Jiangmen Underground Neutrino Observatory (JUNO) requires a high performance large detector, which employs approximately 20,000 pieces of 20-inch PMTs that have large sensitive area, high quantum efficiency, high gain and large P/V value for good photon counting performance [3].

So, the MCP-PMT collaboration group decided to produce the 20-inch MCP-PMT for JUNO. And the North Night Vision Tech. Ltd. (NNVT) in Nanjing, China, one of the members of the MCP-PMT collaboration group has produced this type of 20-inch MCP-PMT in 2014.

The performance of this type of 20-inch PMTs, the QE, the P/V of the SPE, the collection efficiency (CE), the transit time spread (TTS), Rise time / fall time of the waveform, the anode dark rate, et.al were also carefully tested in the PMT Lab in IHEP as shown in table.1.

Table 1. Characterists of the 8-inch and 20-inch MCP-PMTs

Items	QE @ 410 nm	CE	SPE P/V	TTS	Rise time	Fall time	Anode dark rate	After pulse rate
Units	%	%		ns	ns	ns	Hz	%
20 inch	25	70%	> 3	~ 12	2	10	~ 30 k	3
8 inch	25	70%	> 2	~ 3	5	6	~ 2.2 k	small

2. The Quantum Efficiency of the MCP-PMTs

The area coverage and the quantum efficiency (QE) of the PMT photocathode are critical in such experiments in order to capture as much signal light as possible from neutrino reactions in the detection media. Details of the QE experiments and corresponding results of MCP-PMTs will be presented in this paper.

To measure the QE of the photocathode, the cathode current should be measured carefully by the electrometer. A photocathode current at the monochromatic light (@410nm) versus voltage curve (I-V curve) as shown in figure 2 was measured first. The current plateau indicates that all photoelectrons emitted from the cathode are collected by the electrode, thus, the corresponding current value should be adopted in the QE calculation. The QE studied by measuring the I-V curves with a light spot illuminating the photocathode top center are shown in figure 2. the results show the QE of 20-inch MCP-PMT 78# are 23.25% @400nm.

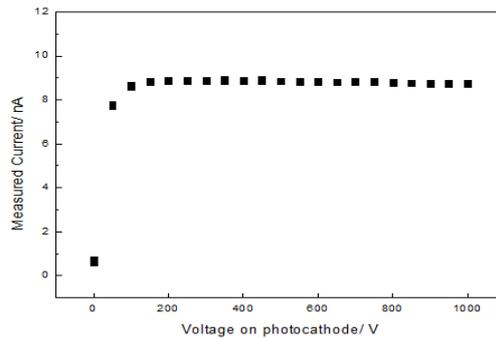


Figure 2. Measured current versus voltage curves for MCP-PMT @400nm:I-V

A tungsten-halogen lamp and a monochromator were utilized as the light source in the photocathode spectral response measurements. Monochromatic lights of 3 nm width were used in 10 nm steps from 300 nm to 700 nm to measure the QE at each corresponding wavelength.

The QE spectral response of one 20-inch MCP-PMT was shown in figure 3. The results indicate that QE value reaches a peak response around 390nm with a light spot illuminating the photocathode top center. And this MCP-PMT 78# achieves a peak QE value of 23.53% @410nm as the same data as shown in figure 2. The short different is mainly of the uniformity of large area photocathode in 20-inch MCP-PMT.

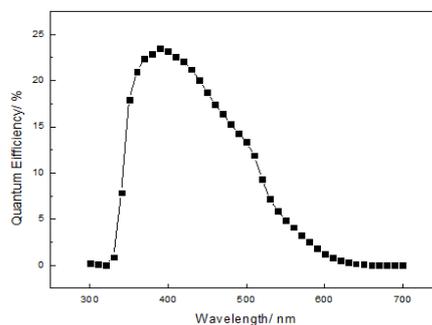


Figure 3. Quantum efficiency versus wavelength for MCP-PMT: QE-wavelength (nm)

The measurement data of the QE is different when the photocathode receive a beam of same incident light with different path. There are four incident paths as shown in figure4. Single transmission(a), two transmission(b), vertical incidence to reflection of aluminium(c), oblique incidence to reflection of aluminium (d) . Table 2 lists the measured QE in the different incident path using a same light at 410 nm.

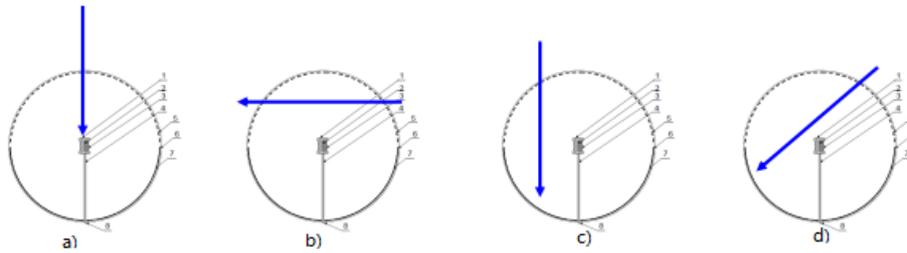


Figure 4. The different path of same incident light through photocathode of the 20-inch MCP-PMT

Table 2. The QE in the different mode photocathodes@410nm

Mode	a	b	c	d
78#	23.25%	26.98%	27.97%	31.55%

As the design of the MCP-PMT, the addition transmission photocathode on the front hemisphere and reflection photocathode on the rare hemisphere are fabricated in the same glass bulb to enhance the efficiency of photoelectron conversion. The photocathode coverage of this type of MCP-PMT is larger than the usual dynode-PMT, so it will capture as much signal light as possible from neutrino reactions in the detection media.

3. The High Detection Efficiency MCP-PMTs

In 2015, people in the collaboration group had get great progress for to improving the performance of the 20-inch MCP-PMT prototypes, especially the collection efficiency of the MCP [4]. For the primary prototypes, the CE of the MCP was depend on the open area ratio of the MCP $\sim 70\%$. With some special technology about the MCPs, to change the depth of the output electrode, the diameter of the MCP, the diameter of the channels, the inclined angle of the channels, and so on.

Finally, at the middle of 2015, the new 20-inch MCP-PMT prototype with high detection efficiency (HDE) was produced. This design was changed compared with the primary ones, only using one MCPs module at the downward part of the prototype to collect all the photoelectron from both the transmission photocathode and reflection photocathode, as shown in figure 5.

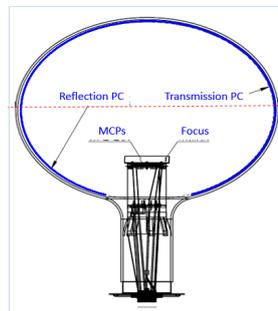


Fig.5 The new typical prototypes of the 20 inch HDE MCP-PMT

The characteristics of the 20-inch HDE-MCP-PMT were carefully studied by measuring the photocathode (Trans. PC), such as I-V curves, the quantum efficiency (QE) vs. wavelength, and the mapping of the QE uniformity. Also the SPE, the timing properties of anode signals, the anode linearity, the noise characteristics, the after pulse properties were studied at gain

$\sim 1.0 \times 10^7$. The main parameters could be seen in table.3, the primary MCP-PMT with 70% CE, the HDE, and also one prototype with dynode part.

Table 3. Comparison of the 20 inch PMTs

Items	Units	Pri-MCP-PMT	HDE-MCP-PMT	R12860
Size	inch	20	20	20
QE at 410 nm	%	25	26	30
Relativity CE	%	70	100	90?
Relativity DE	%	60%	~110%	100%
SPE P/V		> 2	> 3	> 3
TTS (top point)	ns	~10	~12	~3
Rise time	ns	2	2	7
Fall time	ns	10	10	17
Anode dark rate	Hz	~30 k	~30 k	~30 k
After pulses time delay	μ s	/	~4.5	~4 and ~17
After pulse rate	%	small	3	10
Radiation background		high	low	high

With the large area about the photocathode, the QE and DE will be improved, but the TTS and dark noise will be worse. So, the users need to get the balance between these above parameters for different physics aims.

Especially, the glass used for 20 inch MCP-PMT has extra low potassium, low uranium and the contents resulting extra low radiation background. The PMT purchase of JUNO

The JUNO Bidding started on Oct.23th 2015, and completed on Nov.17th 2015. Compensating the PMT performance with fiducially volume convert all specifications to cost, radioactivity, dark noise, TTS, and so on in table.3, the JUNO ordered 15000 pic 20 inch MCP-PMT from the NNVT.

4. Acknowledgments

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