



中国科学院高能物理研究所  
*Institute of High Energy Physics*  
*Chinese Academy of Sciences*



The Chinese Academy  
of Sciences

# The PMT Cathode Quantum Efficiency(QE) Test System

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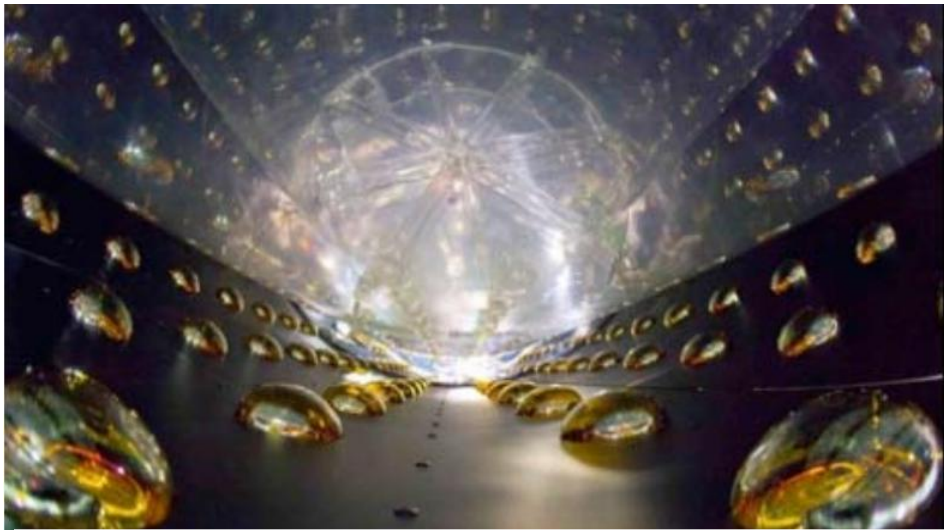
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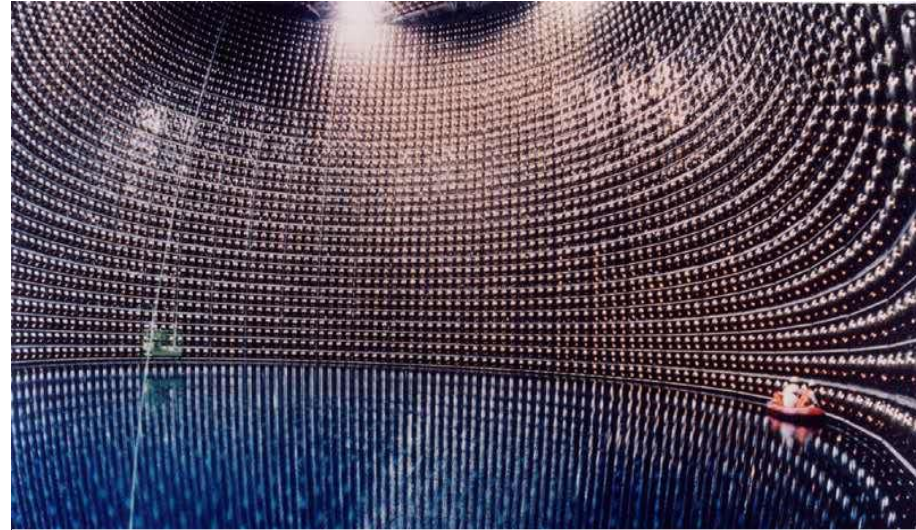
# Outline

- **1. Background and Status of the LAB;**
- **2. QE Testing System;**
- **3. The Uniformity of QE Scanning Plateau;**
- **4. Summary and Plan**

## ➤ 1.1 Background



PMT of Daya Bay Reactor Neutrino Experiment



PMT of Super-Kamiokande

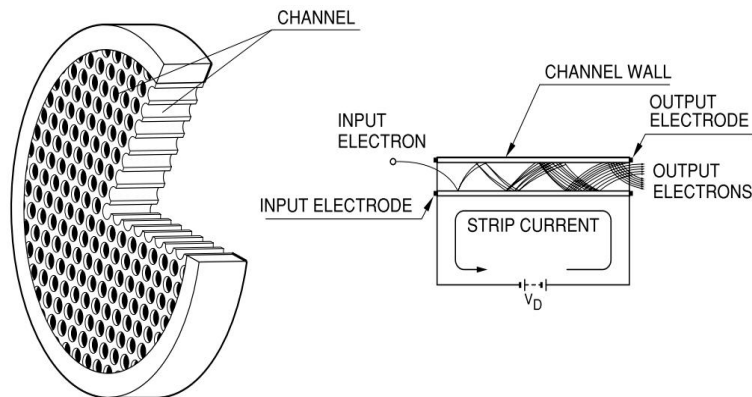
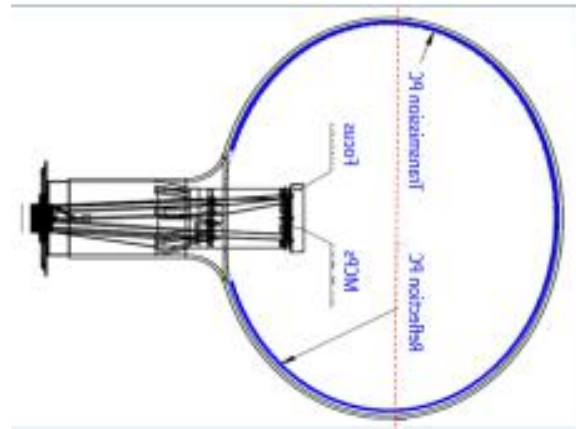


Different type PMT of hamamatsu



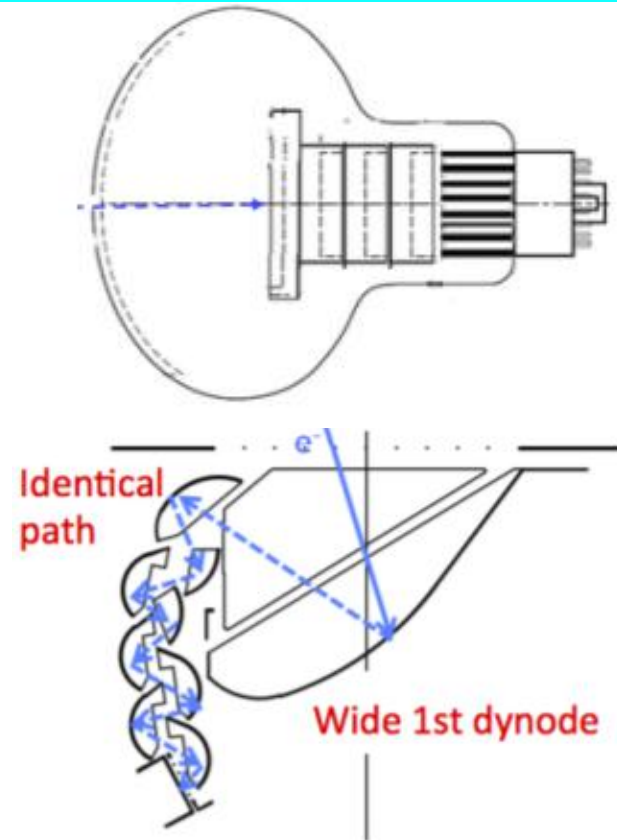
Different type PMT for JUNO (2015)

## ➤ 1.2 20 inch Dynode-PMT & MCP-PMT



(a) Schematic structure of an MCP

(b) Principle of multiplication



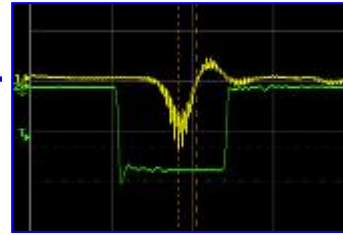
Box & Line

	MCP-PMT	Dynode-PMT	Test Mode
Cathode	Bialkali	Bialkali	pluse
Multiplier	microchannel plate	dynode	current

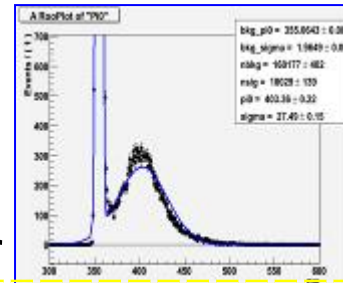


## ➤ 1.3 The Parameters of the PMT (Testing)

Anode test  
Pluse Mode



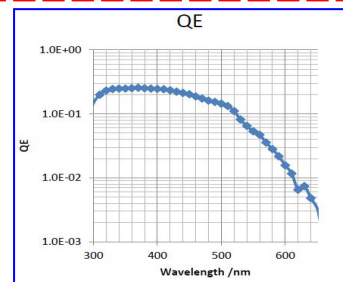
- Anode Pulse Rise Time;
- Pre/Late/After Pulse;
- Dark Count



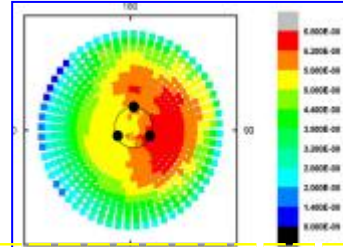
- The Single Photoelectron Spectrum;
- The voltage distribution (BASE) ;
- The Supply voltage;
- Typical Gain Characteristic;
- Anode Dark Current



Cathode test  
Current Mode



- Spectral Response;
- Wavelength of Maximum Response;
- Cathode Sensitivity: Luminous(2856K);
- Quantum efficiency with  $\lambda$



- Photocathode efficiency Area;
- Photocathode efficiency Uniform;
- The position of the Sb, K, Cs;

**Others**

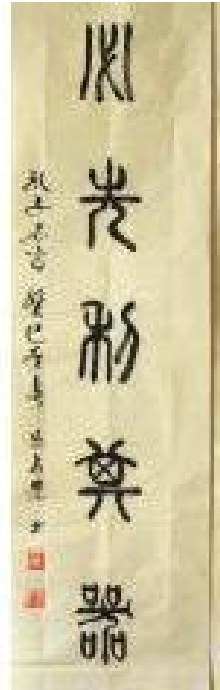
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- The linearity of the PMT
- Magnetic characteristics;
- Transit Time Spread (FWHM)

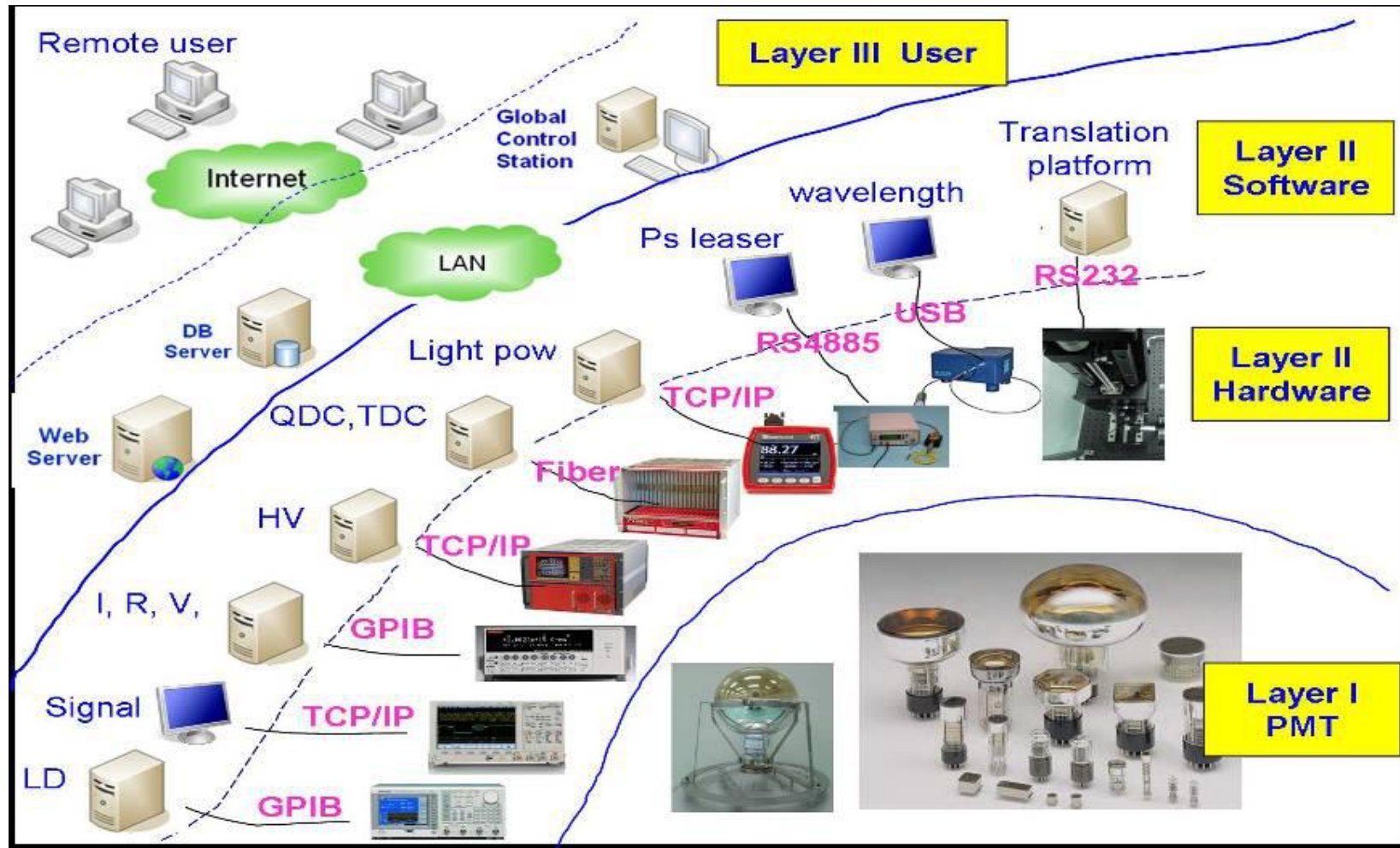
➤ 1.4 The design of the Lab's function

## The Large PMT evaluation Lab

- ◆ Location : underground of the Main Building;
- ◆ Function: Lab1: Aging of PMT  
Lab2: Cathode Performance  
Lab3: Timing information  
Lab4: Electromagnetic field shielding (SPE)



## ➤ 1.5 Progress of the test system



**The Large PMT evaluation system for PMTs**

➤ The test system could measure all the parameters of the PMT for R&D process;

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## 2.0 QE test system--method

*How to test the cathode QE ?-----The Methods in Lab, IHEP*

**Relative method I:** The incident light is divided into two equal beams by the light microscope to light the reference PD and PMT respectively. A Keithley 6517B electrometer measure the current of reference PD and PMT.

$$QE_{\text{unknown}} = QE_{\text{PD}} \frac{I_{\text{unknown}}}{I_{\text{PD}}}$$

**Relative method II:** A powermeter with nano-watt sensitivity is used to directly calibrate the intensity of the light that illuminates the unknown PMT.

$$S = \frac{I_{\text{unknown}}}{I_{\text{light}}} \quad QE_{\text{unknown}} = \frac{S \times h \times c}{\lambda \times e}$$

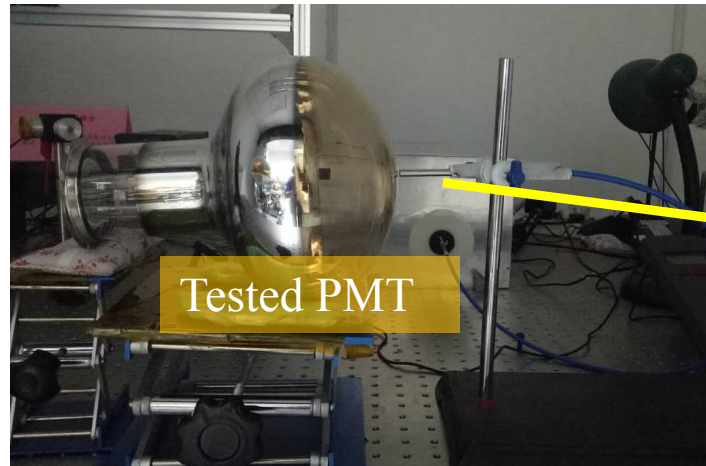
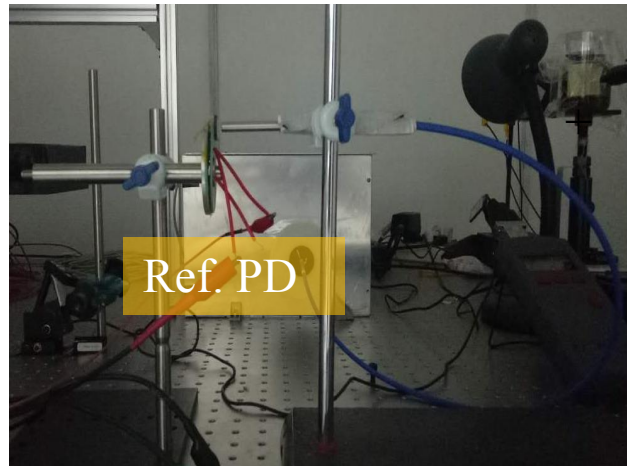
Measured QE@410nm via the relative methods.

Product Model	Method I QE / %	S / mA/W	Method II QE / %
Reference PD S274	Reference value:71.0	234.5	70.9
PMT XP2020	23.4	76.5	23.1
PMT R5912	24.7	82.1	24.8
PMT R5912-100	34.6	112.6	34.1

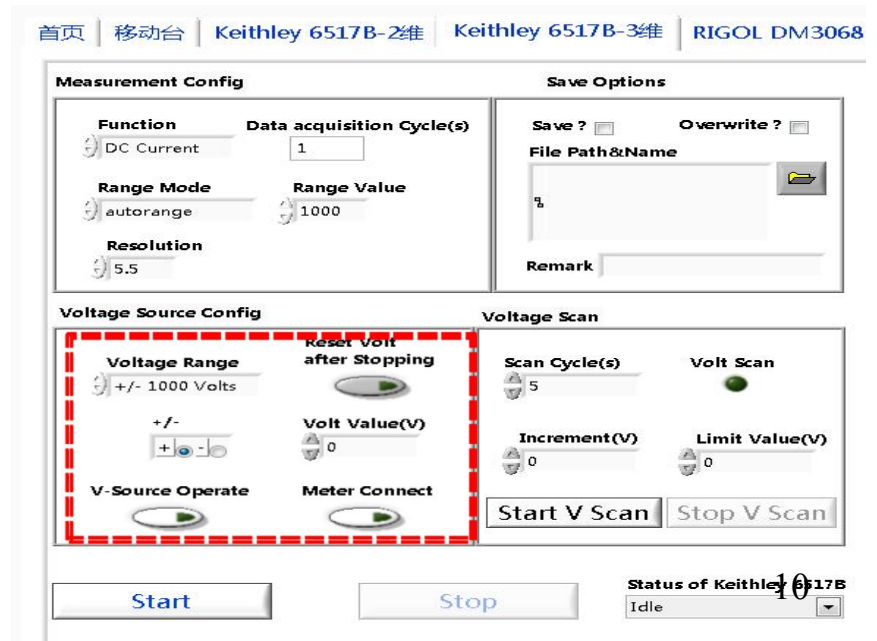
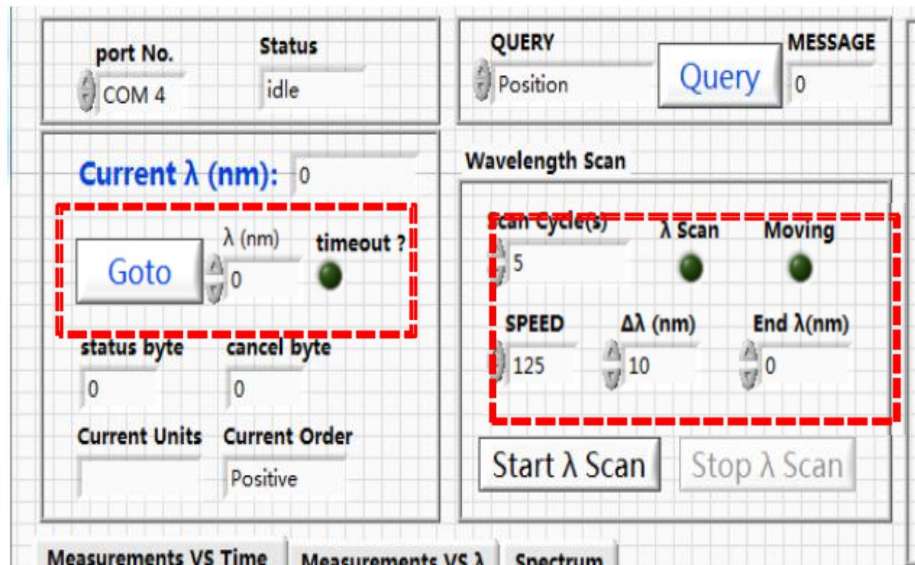
For different types of PMT,The relative method I is same with II.

## 2.1 QE test system--cathode spectral response(I)

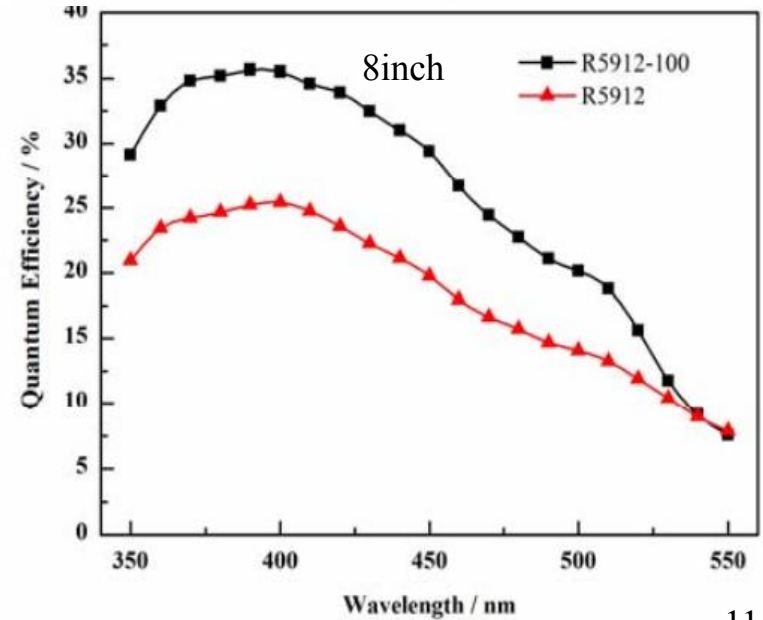
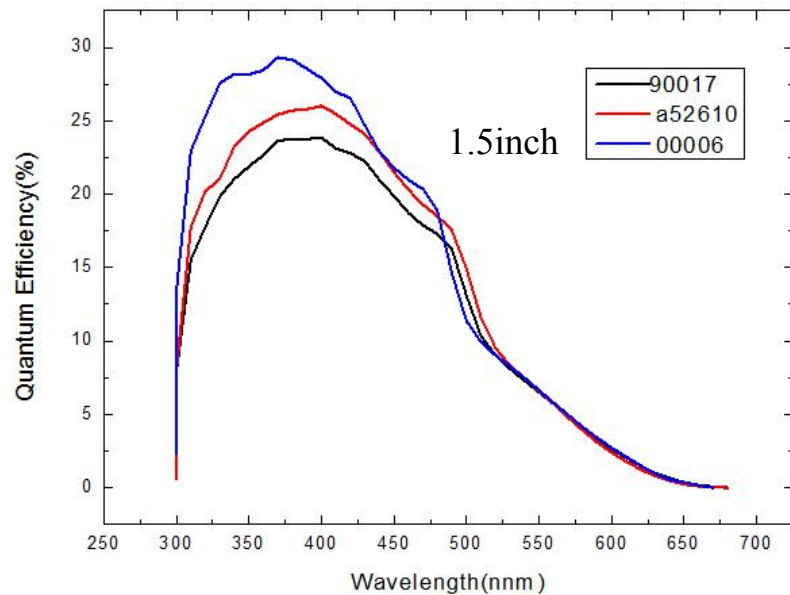
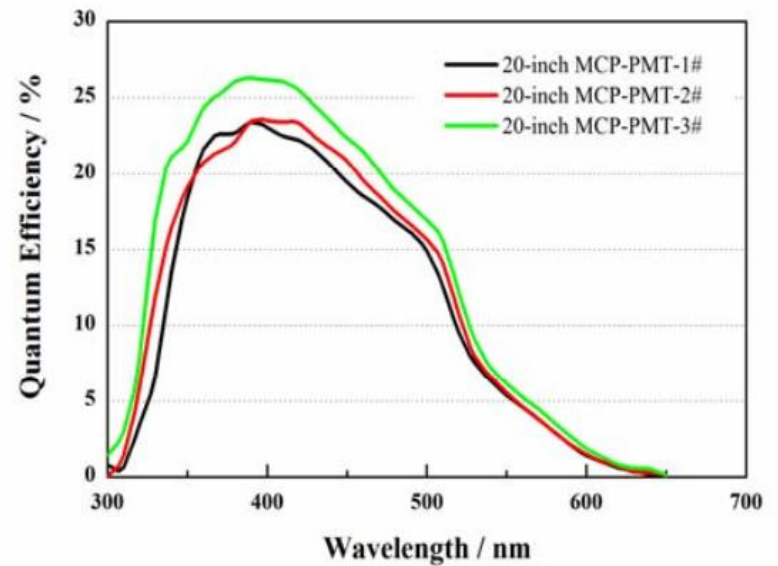
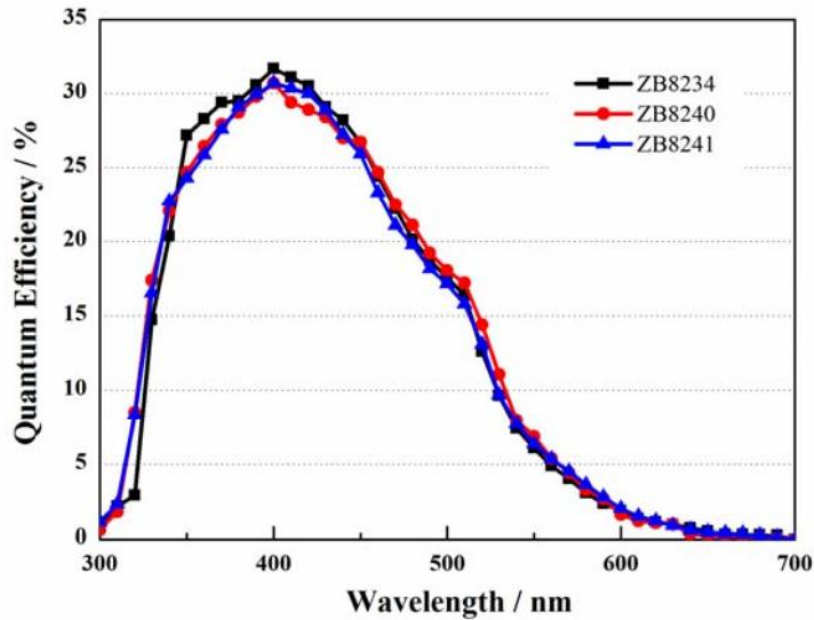
### ① Experiment setup (relative method I)



### ② Software design(change the wavelength and record the corresponding current)



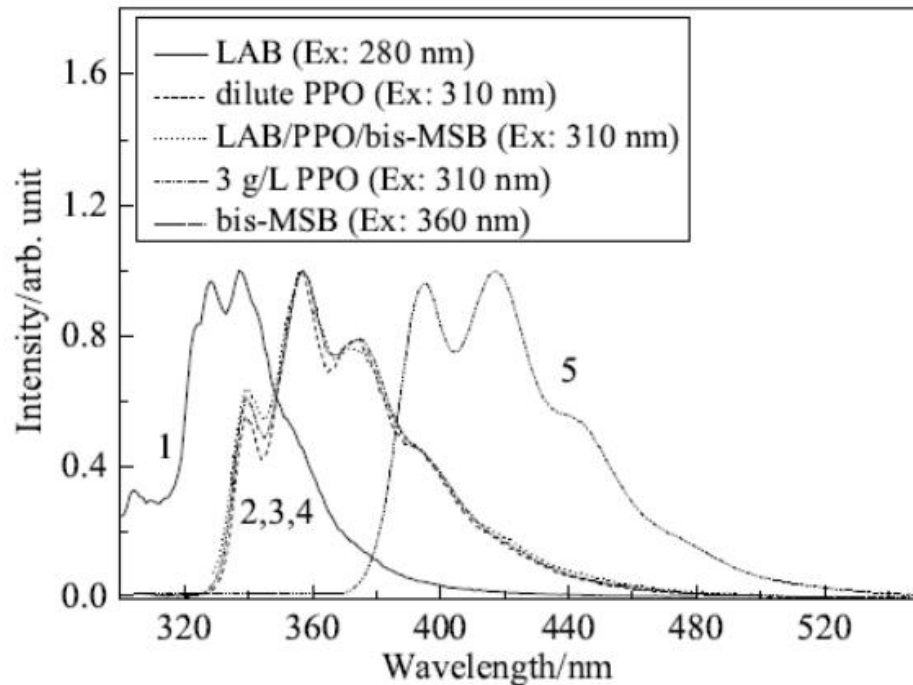
## 2.1 QE test system--cathode spectral response(II)



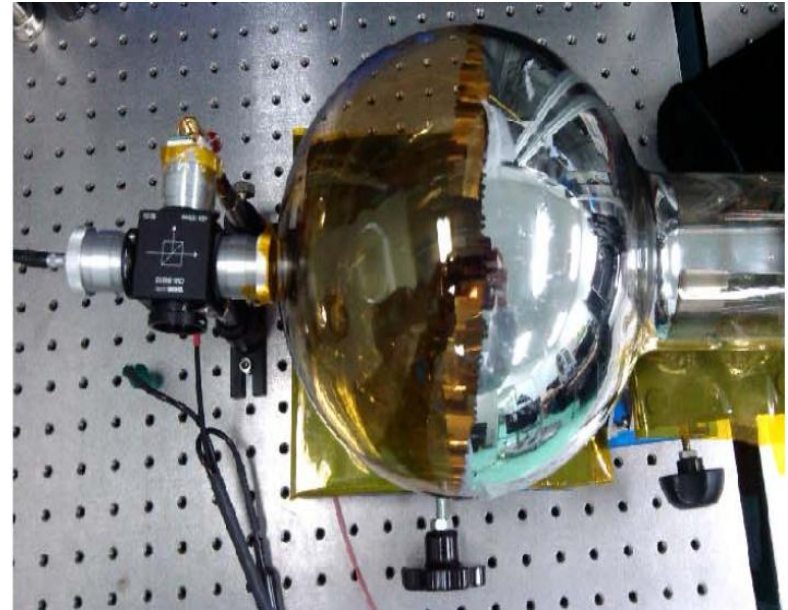
To evaluate the cathode performance by testing the QE at specific wavelength.

## 2.2 QE test system-- at specific wavelength

1. The wavelength range of different applications focusing on is different, such as neutrino experiments concerned about QE at 410nm.
2. The QE system measures the QE of Photoelectric detection devices by relative method at specific wavelength



LS emission spectrum in DyBay





## 2.3 QE test system--current plateau

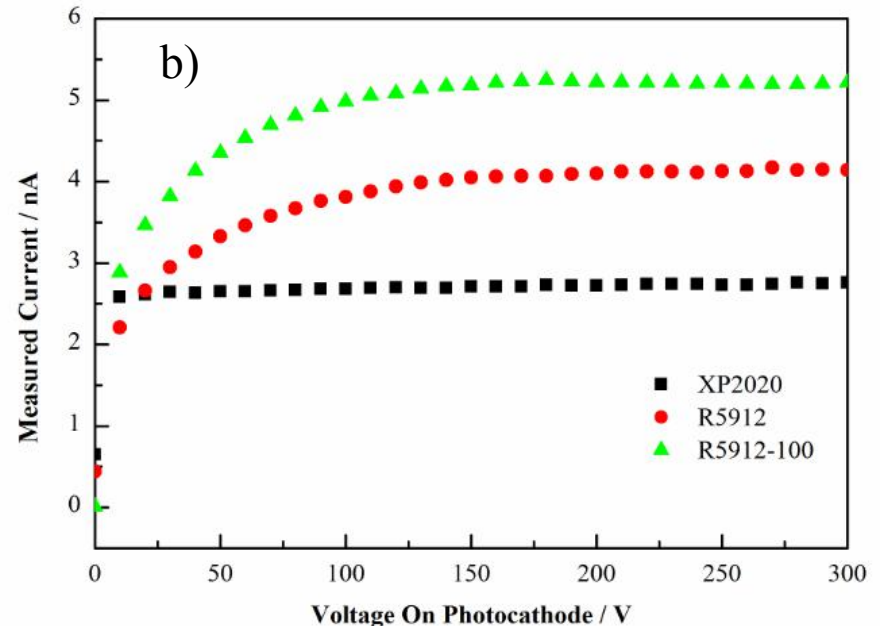
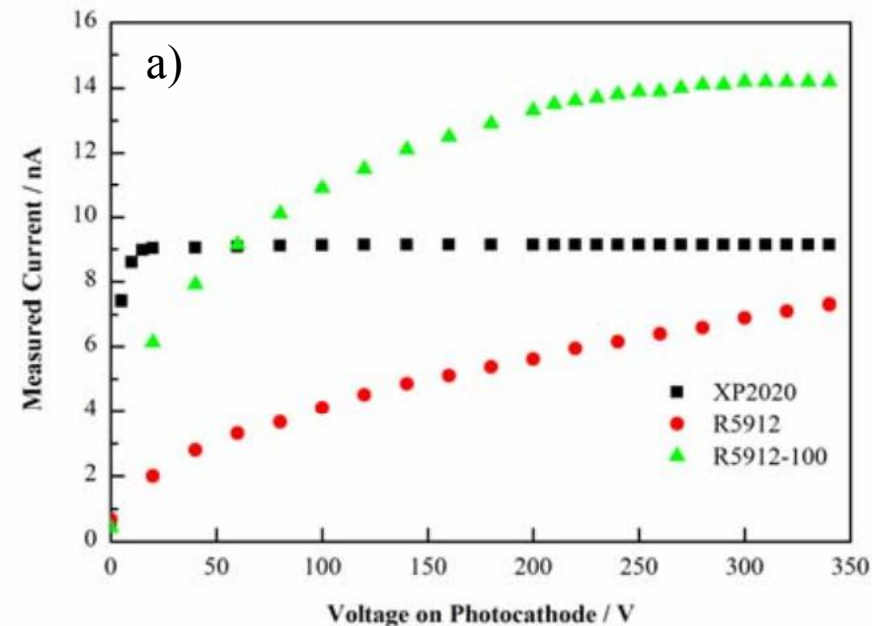
a) The photocathode current versus voltage curves for different PMT using same light

*All photoelectrons emitted from the cathode are not collected.*

b) The photocathode I-V for different PMT using different light intensity

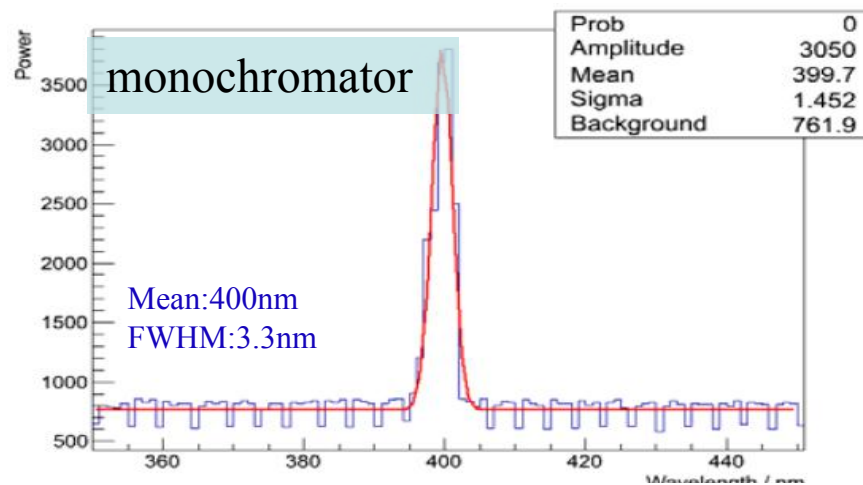
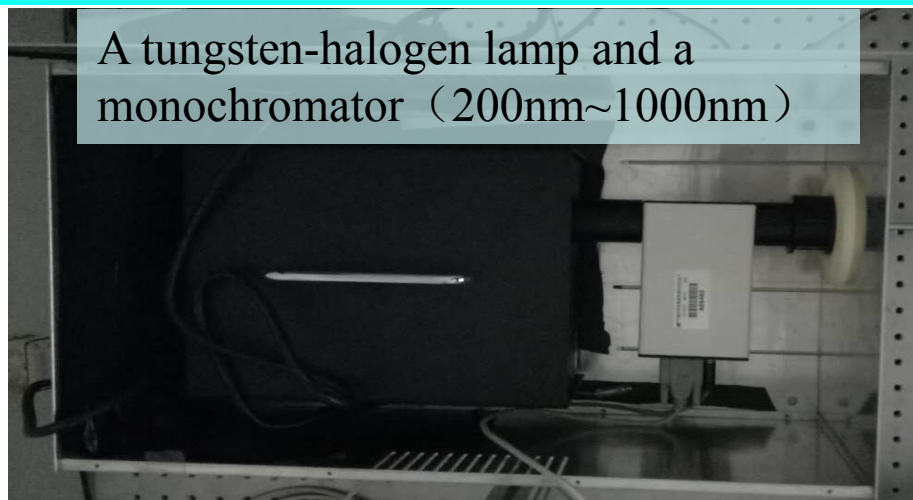
*All photoelectrons emitted from the cathode are collected, thus, the corresponding current value should be applied in the QE calculation.*

**Current plateau curve is the key in the QE calculation and the light intensity should be adjusted for searching the plateau curve.**

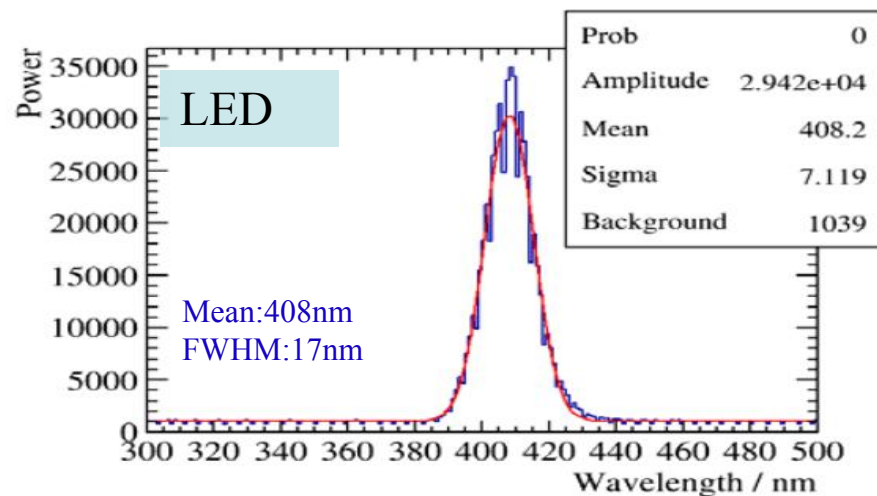
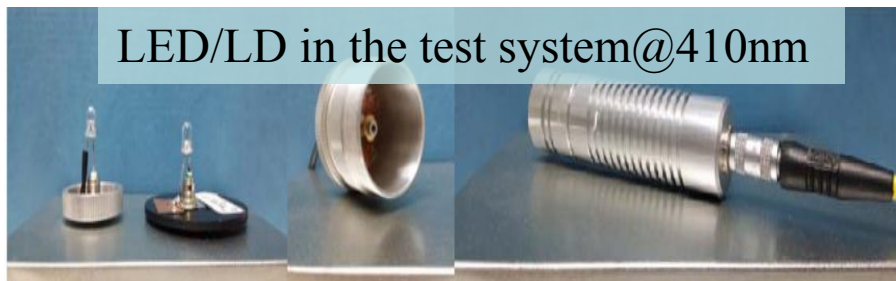


## 2.4 QE test system---light source

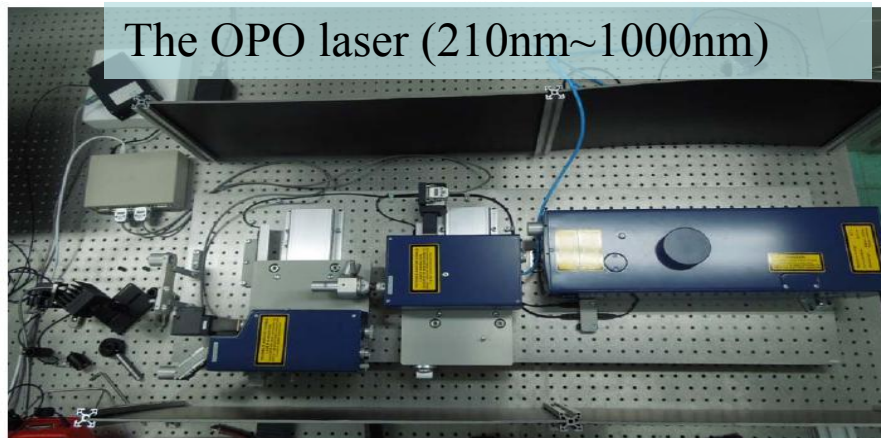
A tungsten-halogen lamp and a monochromator (200nm~1000nm)



LED/LD in the test system@410nm



The OPO laser (210nm~1000nm)



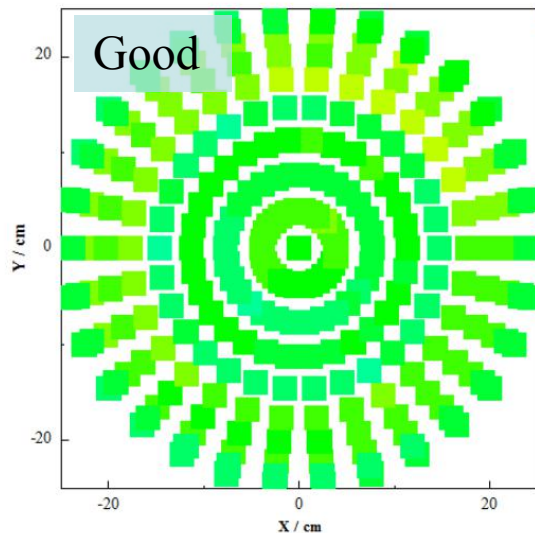
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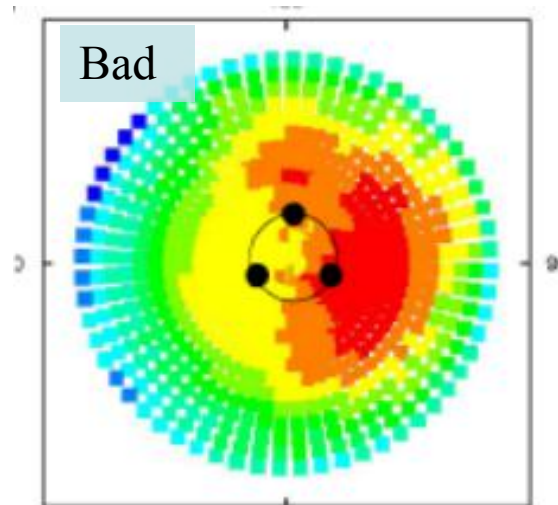
### ➤ 3.0 The cathode uniformity of PMT

#### *Why to test the cathode uniformity ?*

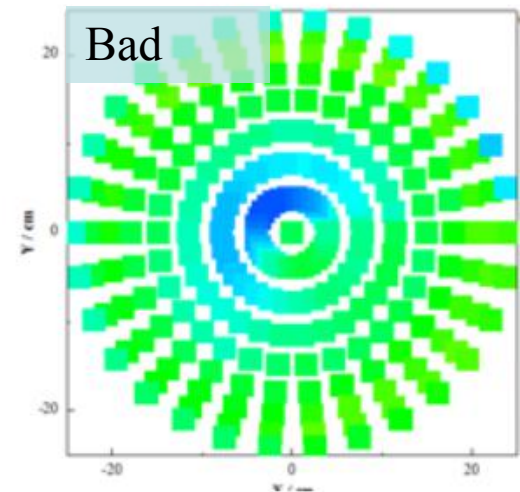
1. PMTs are required to possess good cathode uniformity property
2. Because of the work state of the metal, and the work temperature of the coating, the cathode uniformity isn't good enough and it will effect the detection efficiency but the uniformity can not be seen by the our eyes.



Normal




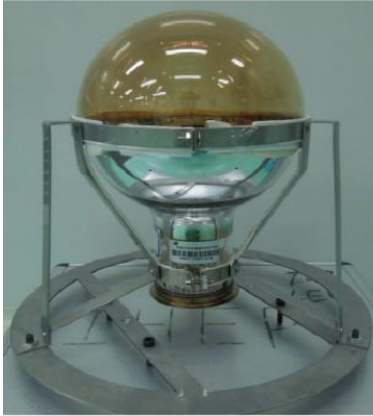

Affected by bialkali evaporation



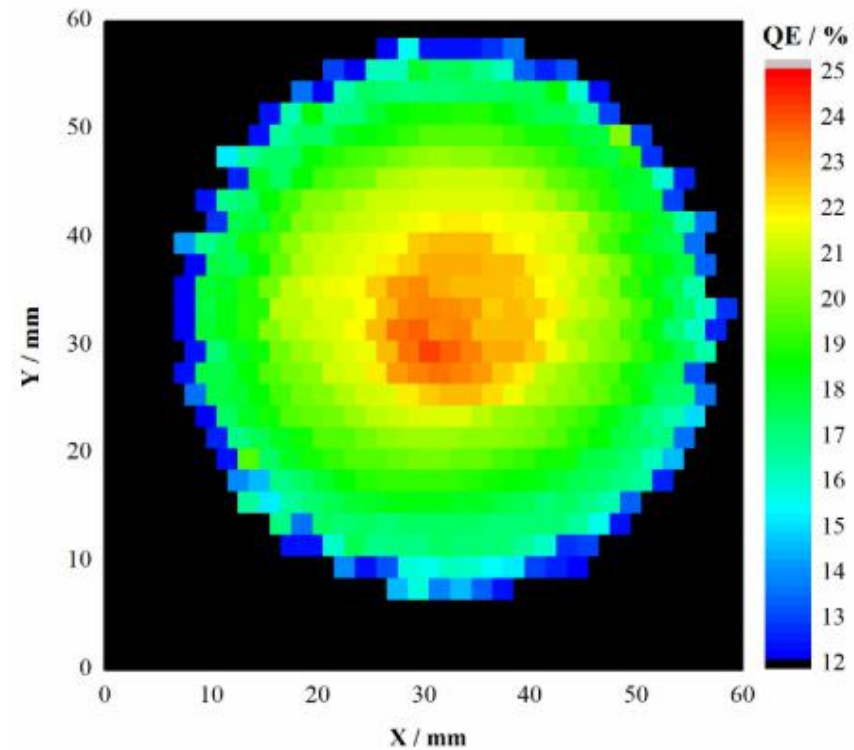
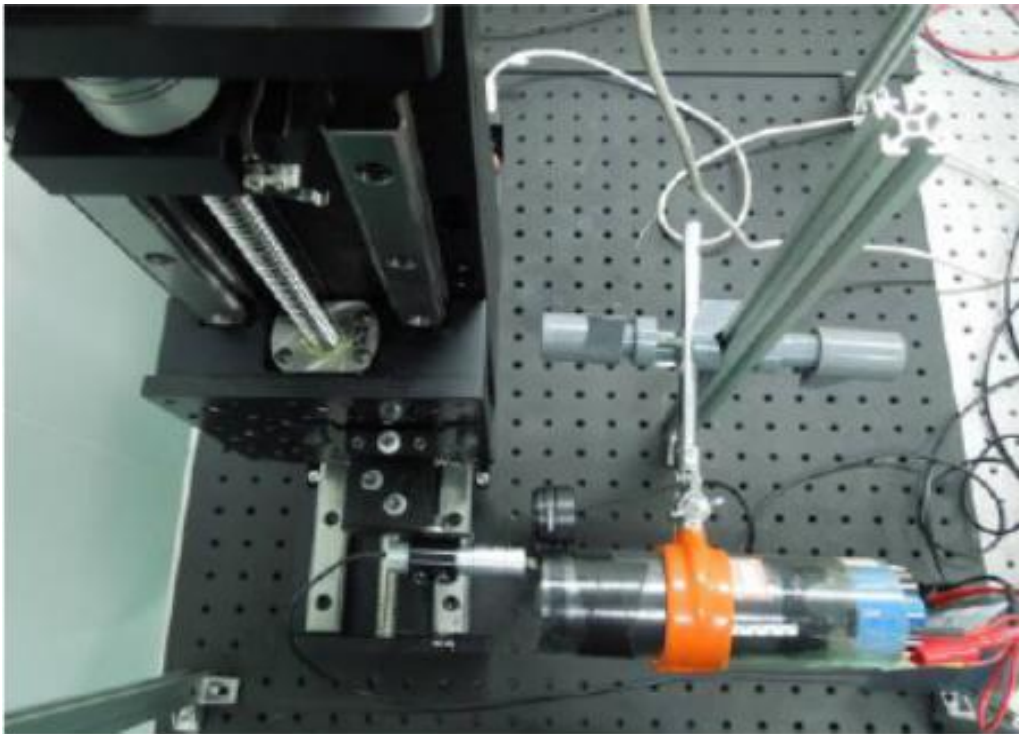
Affected by temperature



➤ 3.1 The overview of the scanning plateau for PMTs

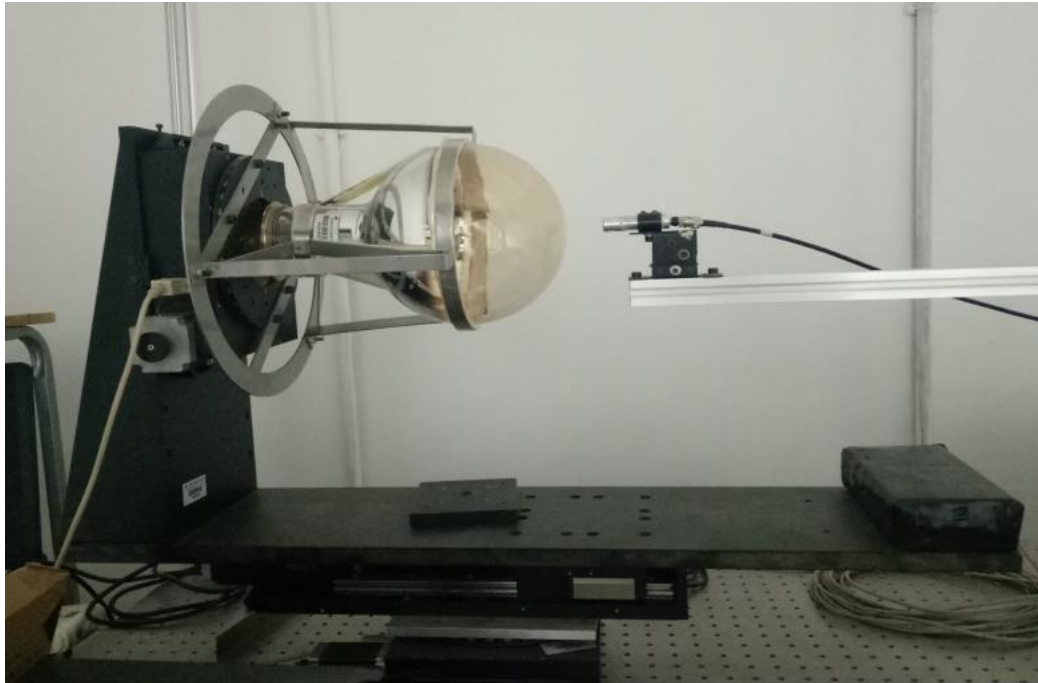
PMT			
Surface	Plane input window	Spherical surface	Spherical surface
Size	2 inch	8 inch	20 inch
Scanning Plateau	1. Two-dimensional (2013)	2. Three-dimensional (2014)	1. Light coupling (2014) 2. Electric coupling (2015) 3. Multi-fiber coupling (2016)

### ➤ 3.2 Two-dimensional scanning plateau for 2 inch (Finished by 2013)

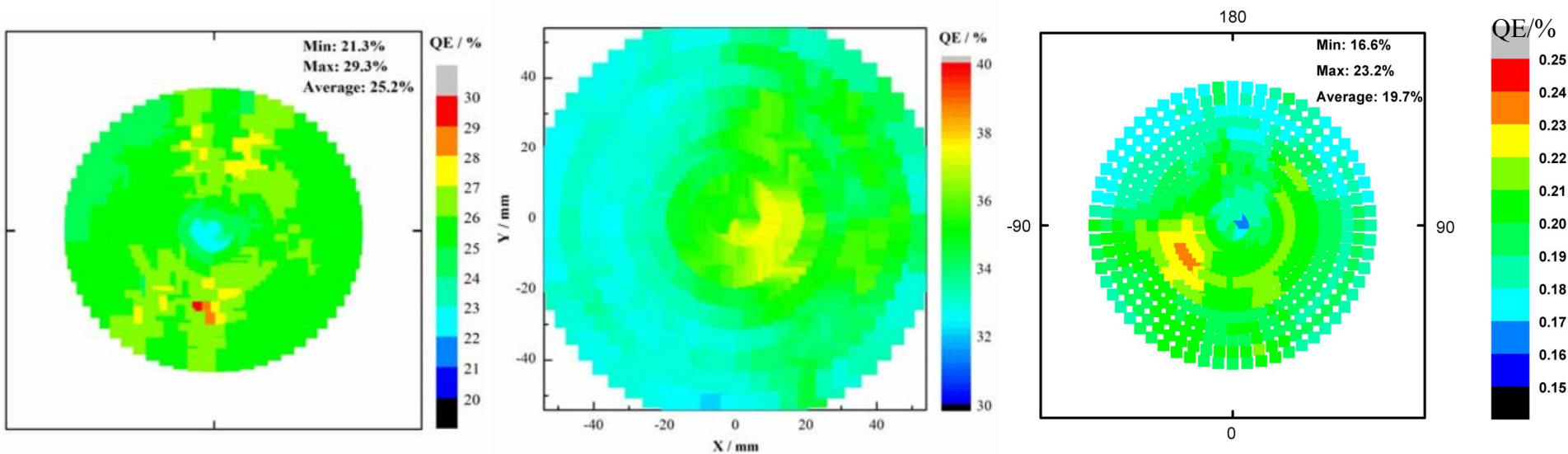


- The PMT is fixed on the optical platform;
- The LD is installed on a movable device
- Moving horizontally and vertically

### ➤ 3.3 Three-dimensional scanning plateau for 8 inch (Finished by 2014)



- The light source is fixed.
- PMT is rotated around a horizontal or a vertical axle
- Achieving the scanning along both the latitude and longitude on the PMT bulb.



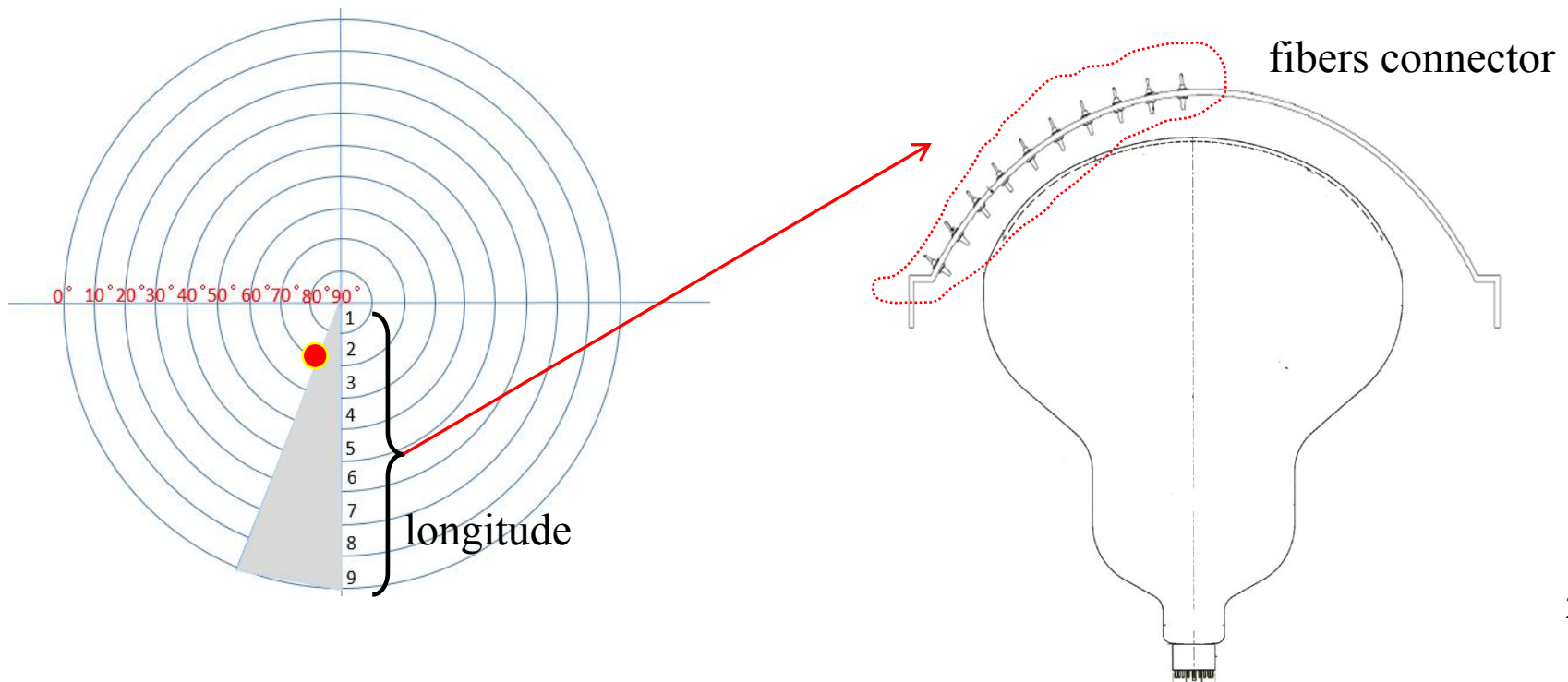
### ➤ 3.4 Light coupling/Electric coupling/Multi-fiber coupling

The compare of two spherical surface by three-dimensional scanning system

Size	Test Time	Mass
8inch	~3h	~1kg
20inch	---	~10kg

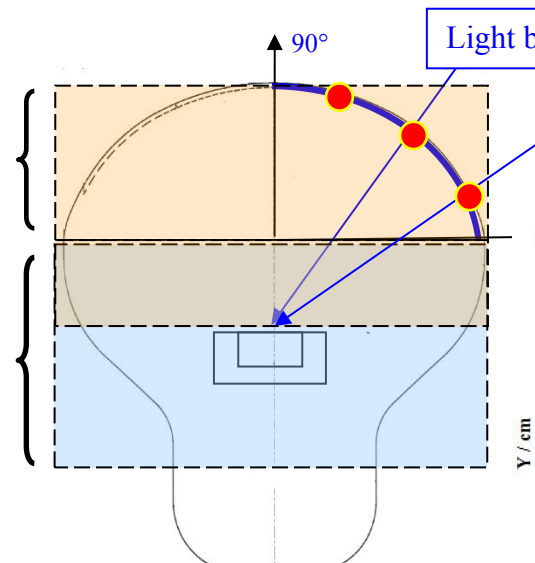
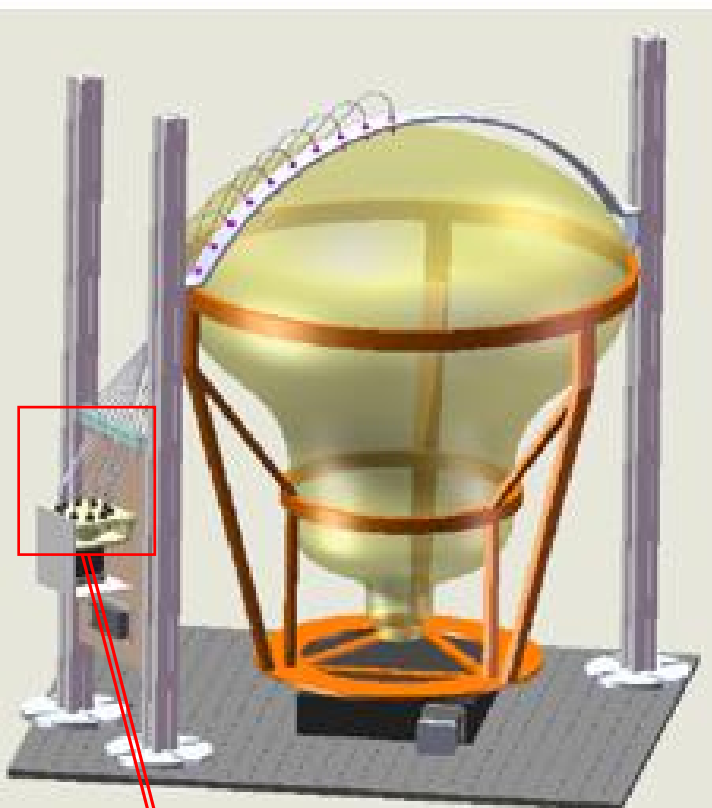
Question: 20inch PMT is so heavy that three-dimensional scanning can't afford it.

Solution: fibers+rotate (the key is to scan cathode along longitude and latitude)

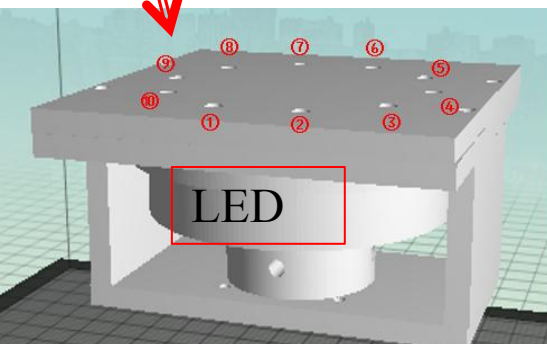
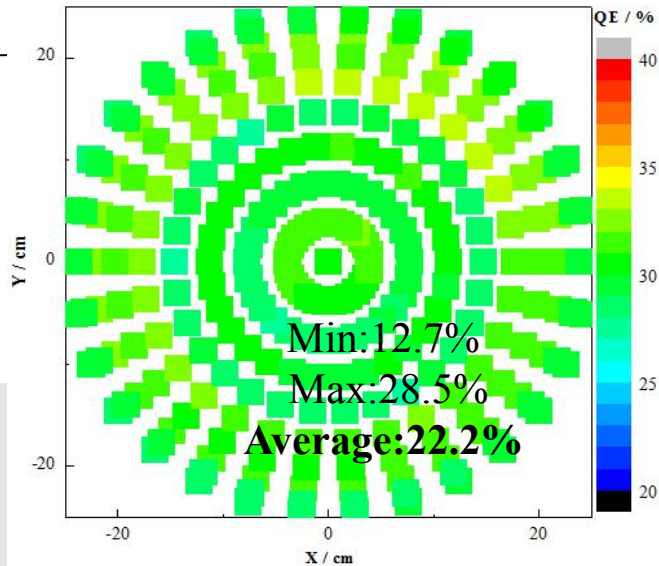




### ➤ 3.4.1 Light coupling scanning plateau for 20 inch PMT (Finished by 2014)

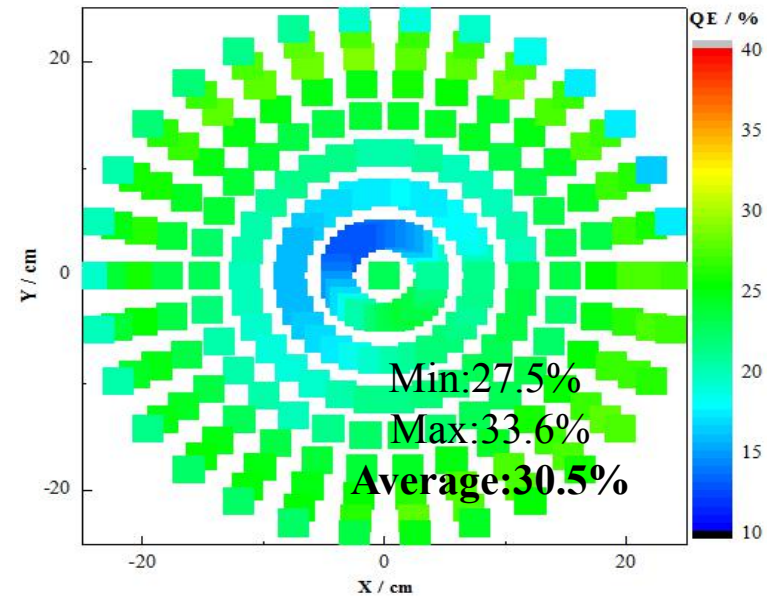
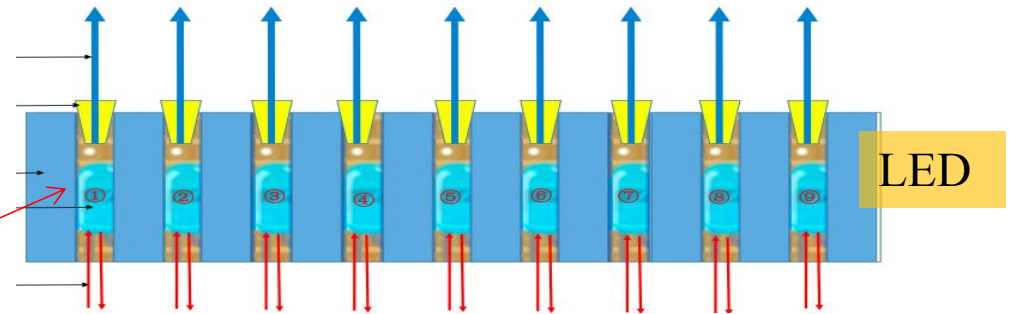
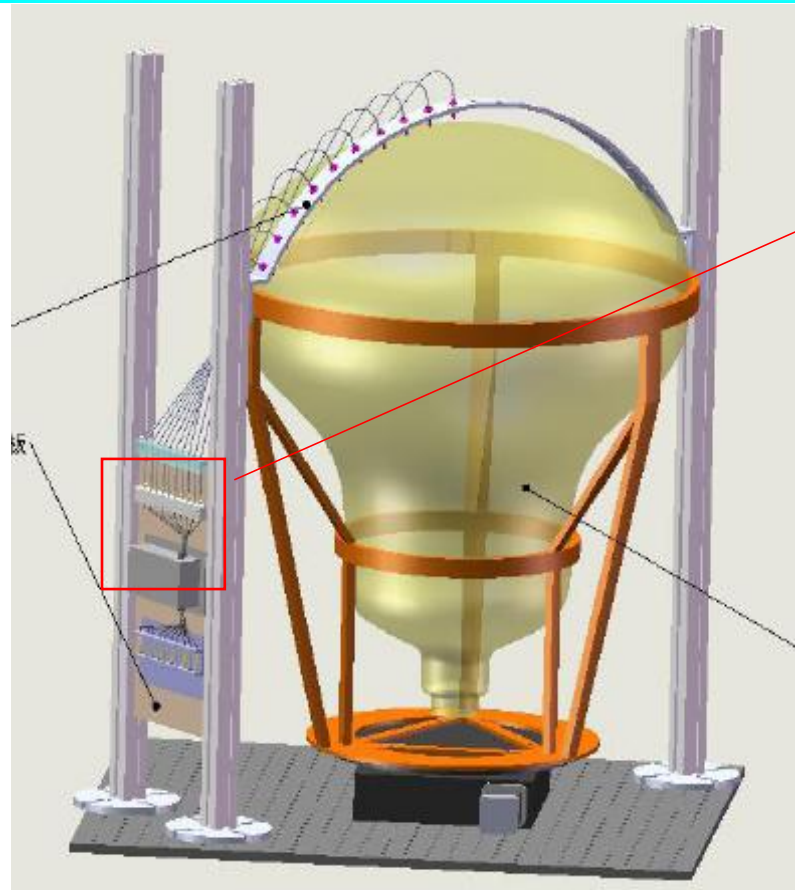


Along with the  
**Longitude**  
to Scanning the PMT



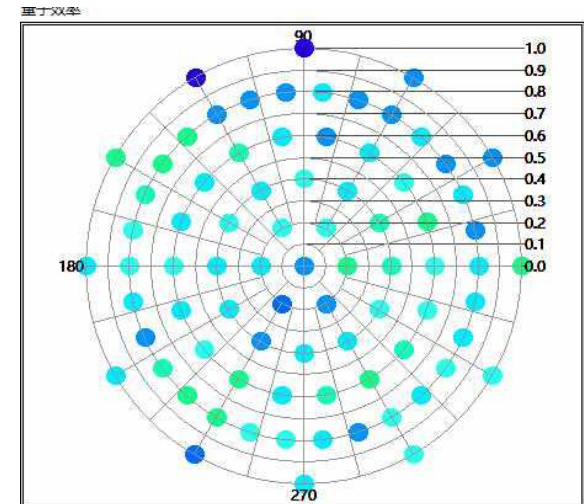
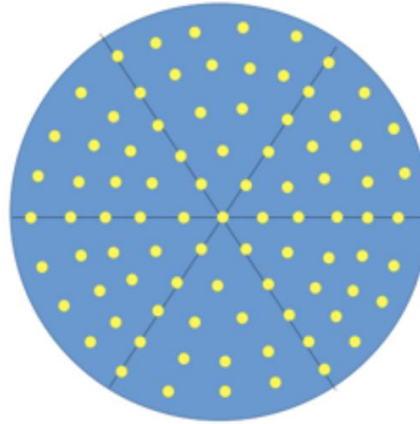
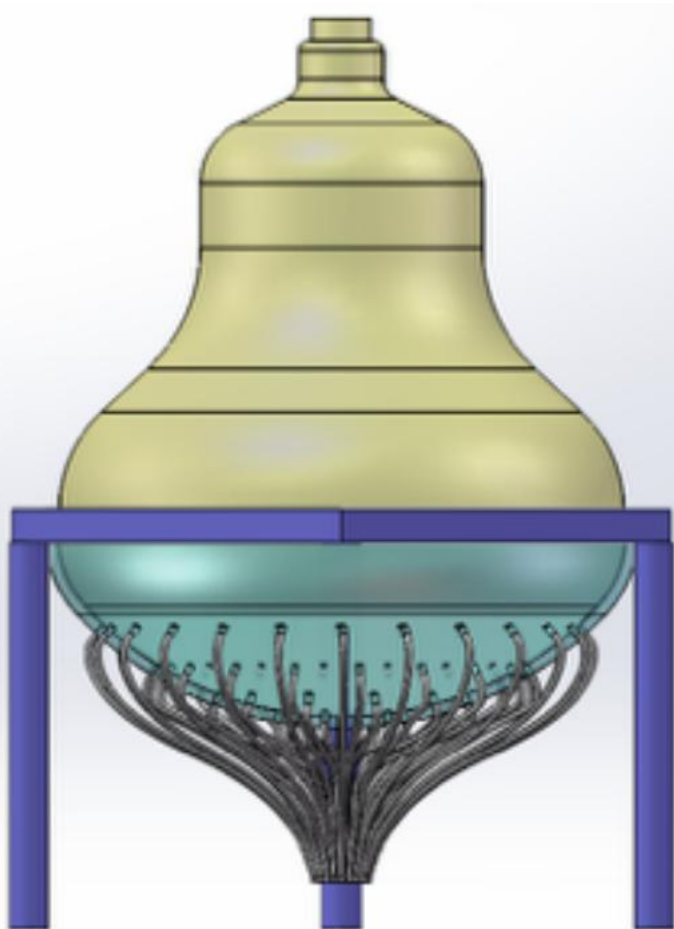
Key	Small rotating 1 LED + 9 fibers
Scanning Longitude	LED is rotated along position of fiber
Scanning Latitude	PMT is rotated around its polar axis

### ➤ 3.4.2 Electric coupling scanning plateau for 20inch PMT (Finished by 2015 )



Key	a programmable multi-channel generator 9 LED + 9 fibers
Scanning Longitude	9 LEDs are lighted up one by one
Scanning Latitude	PMT is rotated around its polar axis

➤ 3.4.3 Multi-fiber scanning plateau for 20inch PMT (Finished by 2016 )



Key	a programmable multi-channel generator 80 LEDs + 80 fibers
Scanning the whole	80 LEDs are lighted up one by one and light is transmitted by discrete optical fibers

### ➤ 3.4.4 Light coupling/Electric coupling/Multi-fiber coupling scanning plateau---conclusion

Scanning plateau	Light coupling	Electric coupling	Multi-fiber coupling
Size of PMT	20inch	20inch	20inch
Number of rotating device	2	1	0
Programmable multi-channel generator	No	Yes	Yes
Number of LED	1	9	80
Number of fiber	9	9	80
Test time	3h	1.5h	<b>10min</b>

From Light coupling scanning to multi-fiber scanning, the progress of test is from point to line to surface, and mechanical difficulty is reduced, while electronic requirement is improved, the end is decreasing of test time.

**Multi-fiber scanning plateau ensure that the cathode uniformity of all PMTs in batch test can be tested without the necessity for sampling.**

More Ref. *“Research on a method for measuring the uniformity of large scale photoelectric converter”*, Ma Yichao etc.



## Summary

Using a series of light sources and automated instruments in QE test system, the various types PMT can be researched and tested carefully. Not only can the system test the cathode spectrum response and QE, also test the cathode uniformity of different sizes PMT.

While the system has run for a long time, it's stability and convince.

## Plan

The long wave response of PMT like infrared.

# Thanks !

Thanks for your attention!  
Any comment and suggestion are welcomed!