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Institute of High Energy Physics
Chinese Academy of Sciences

Chinese Academy of Sciences

A Kind of Electrostatic Focusing MCP-PMT

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Outline

1. Introduction;

2. Simulation and Design;

3. R&D of the 8”and 20” MCP-PMT;

4. The performance of the MCP-PMT

5. Conclusions

1. INTRODUCTION

Jiangmen Underground Neutrino Observatory (JUNO)

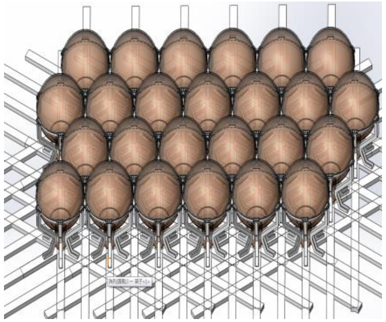
located in Kaiping city, Guangdong Province, China, 53 km from two nuclear power stations with a total thermal power of approximately 36 GW

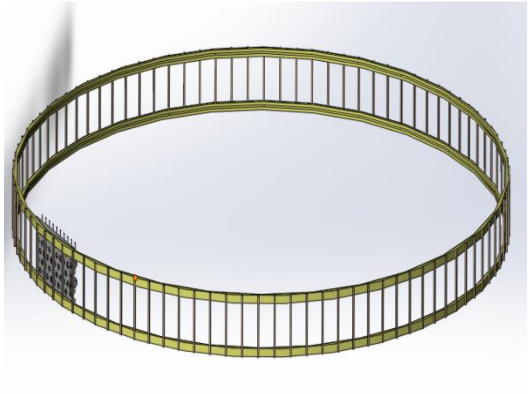
Location of JUNO

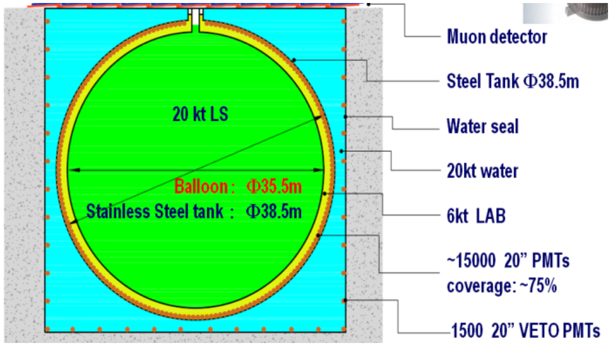
NPP	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operational	Planned	Planned	Under construction	Under construction
Power	17.4 GW	17.4 GW	17.4 GW	17.4 GW	18.4 GW

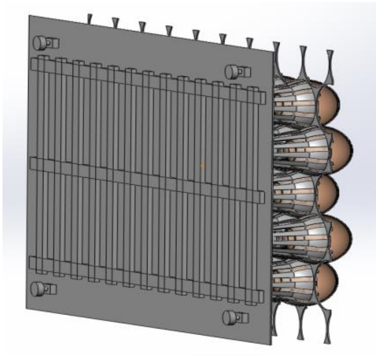
Conceptual Design of the JUNO Detector

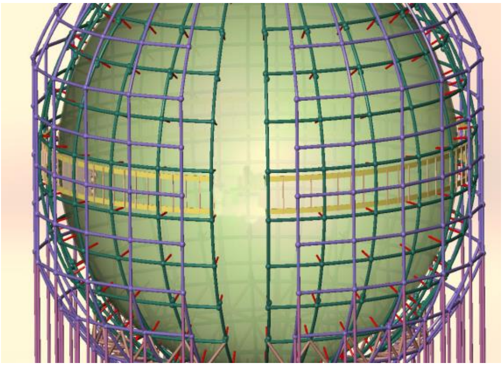
	KamLAND	JUNO
LS mass	~1 kt	20 kt
Energy Resolution	6%/√E	3%/√E
Light yield	250 p.e./MeV	1200 p.e./MeV

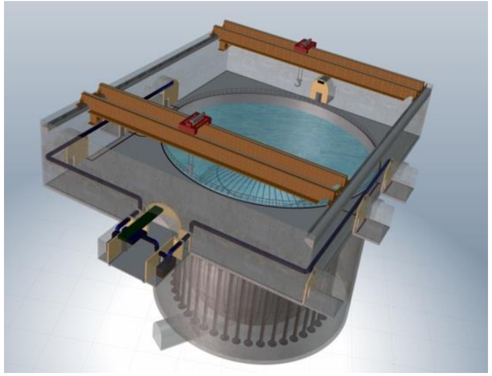












PMT requirements for JUNO central detector

(1) Optical coverage as large as possible (preferred 70~80%)

(2) > 15000 pieces high QE 20 inch PMT

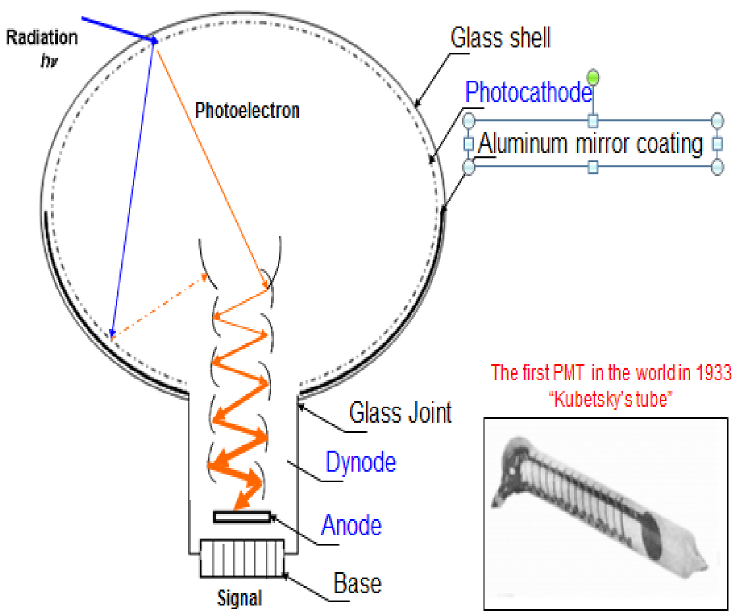
(3) Good single photoelectron detection capability and a large dynamic range

(4) Low radioactive background

(5) More than 20 years lifetime

(6) Can withstand 0.4MPa Pressure

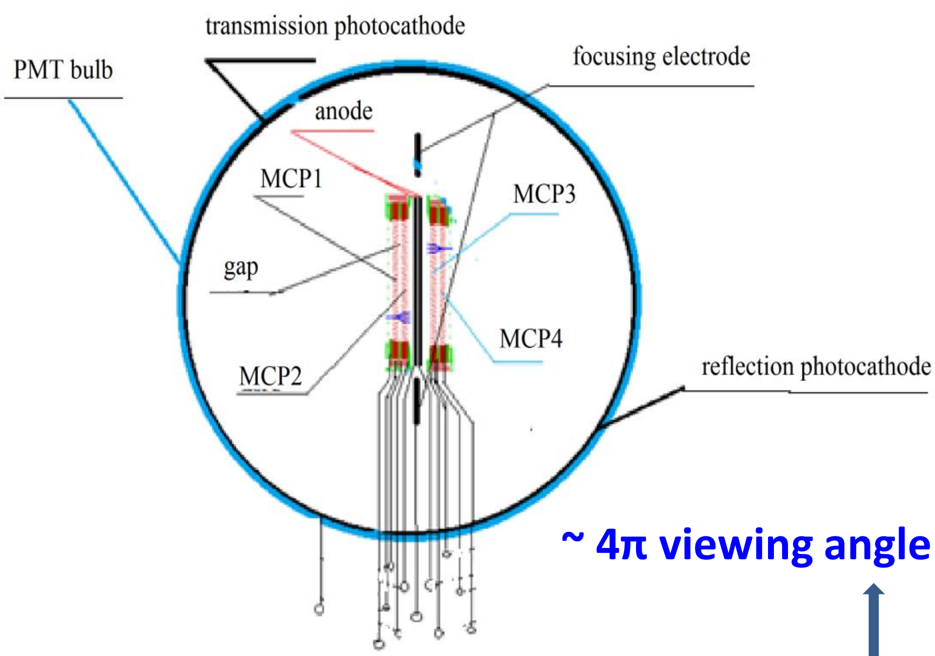
New design of electrostatic focusing type MCP-PMT



Photomultipliers are constructed from a glass envelope with a high vacuum inside, which houses a photocathode, several dynodes, and an anode.

Traditional design

Our design concept



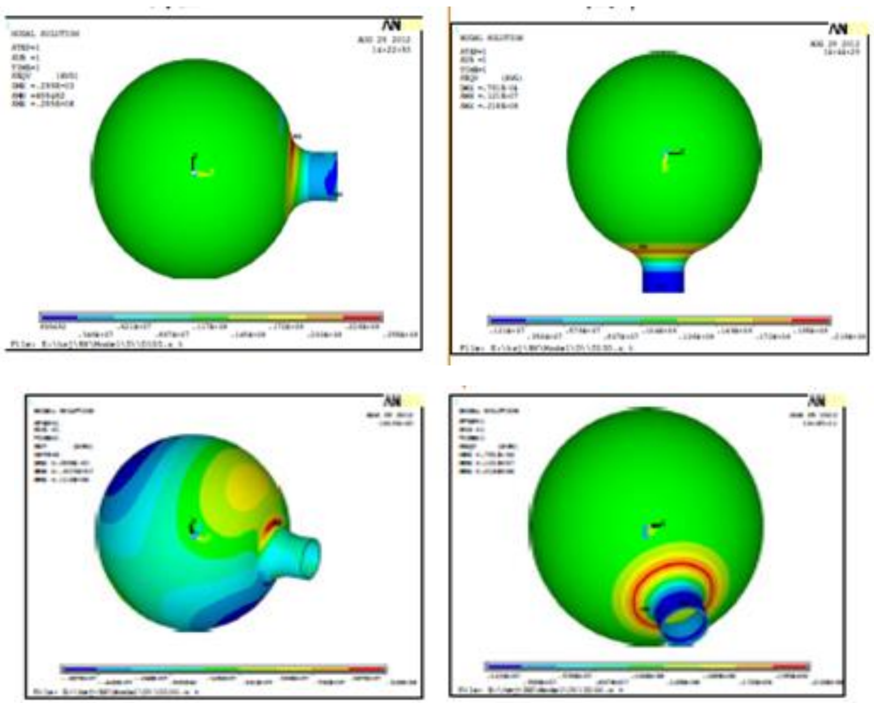
High photon detection efficiency + Single photoelectron Detection

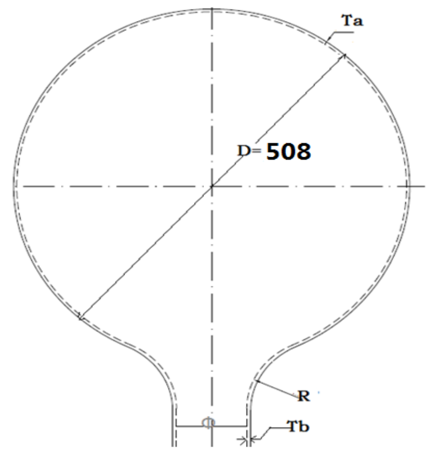
1) Using two sets of MCPs to replace the dynode chain

2) Using transmission photocathode (front hemisphere) and reflective photocathode (back hemisphere)

2. Simulation and Design

2.1 Mechanical Simulation and Bulb Shape Optimization



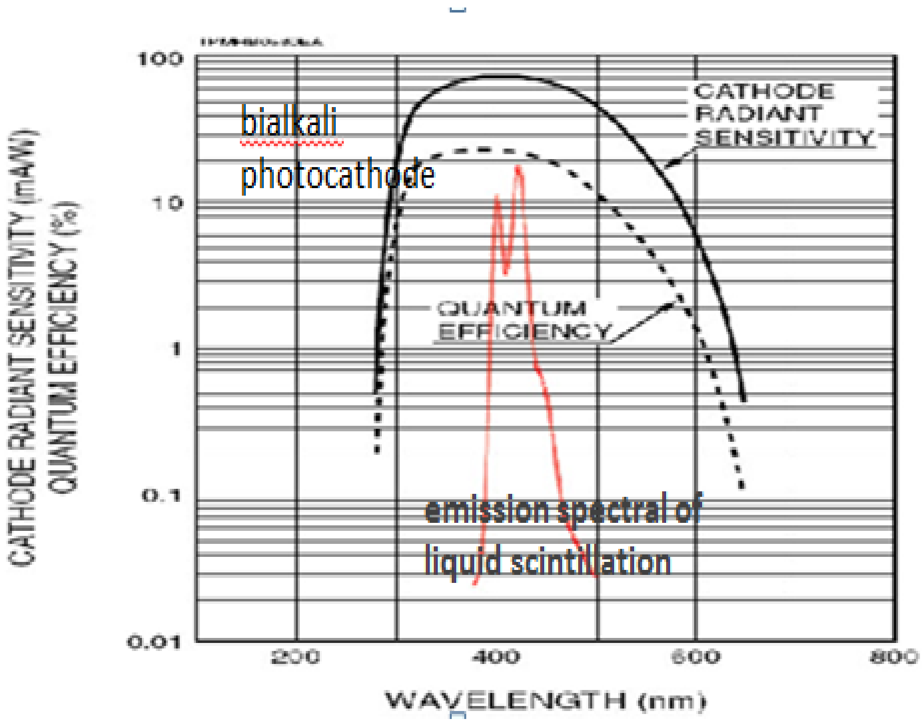


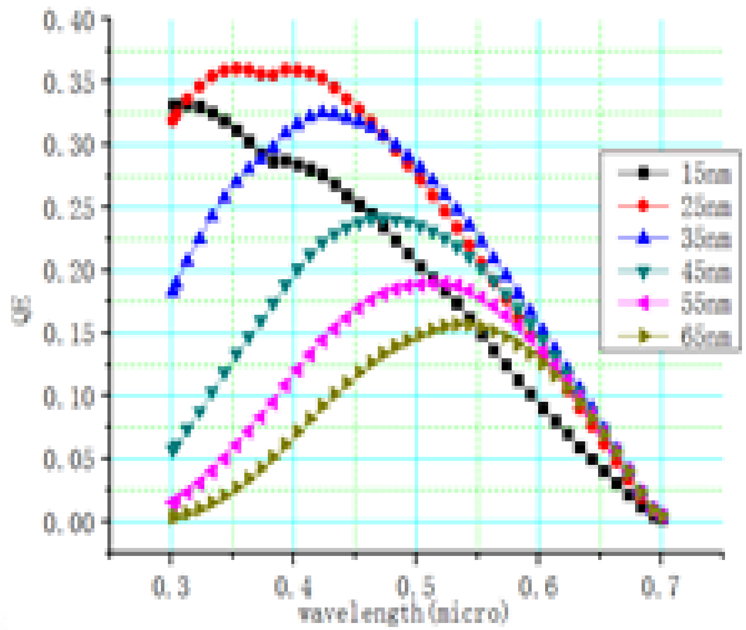
T_a=4 mm,
T_b=5 mm,

Φ=90mm and

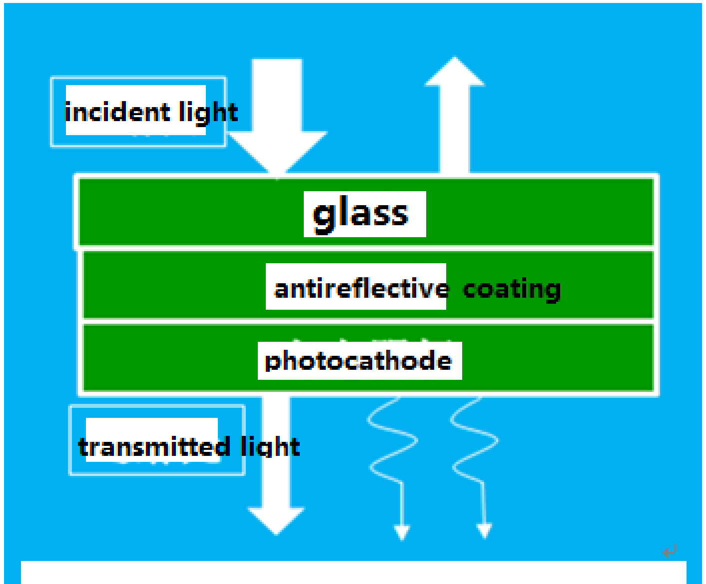
R=100mm

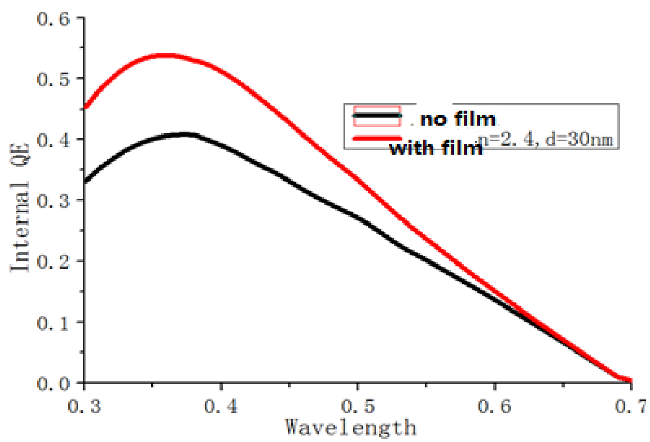
2.2 Optimizing the response of the photocathode

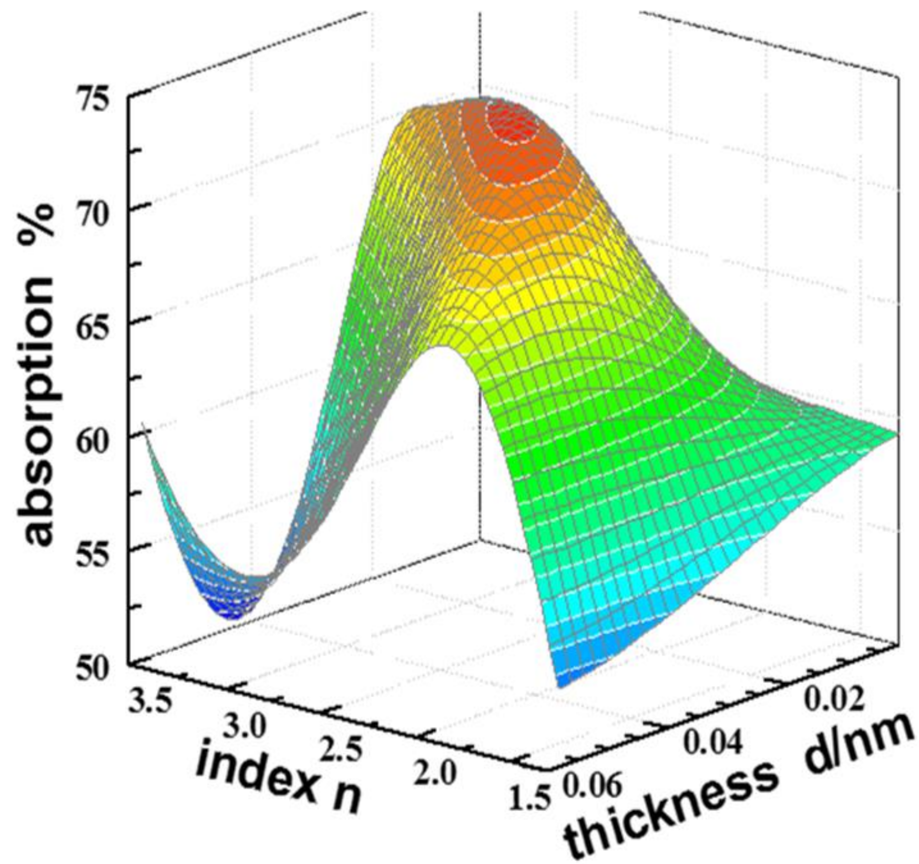




2.3 Antireflective coating between glass and photocathode







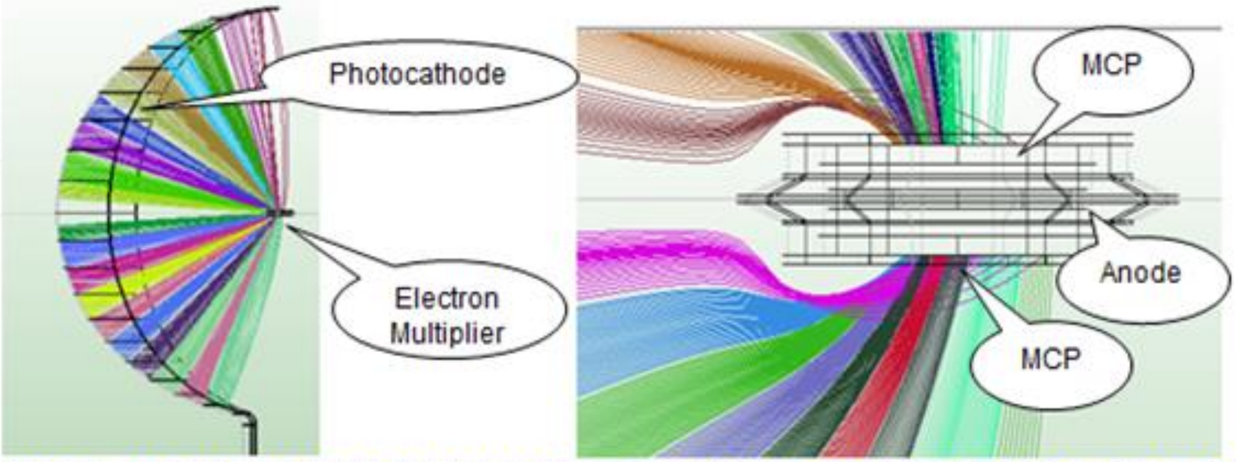
2.4 Simulation and design of electron optics

➤ **Simulate the possibility of the 20" spherical MCP-PMT**

--Electron Multiplier: small size MCP(φ=18(33)mm) ➔ Dynode chain ;

--photocathode area: transmission+ reflection, nearly 4π effective area ;

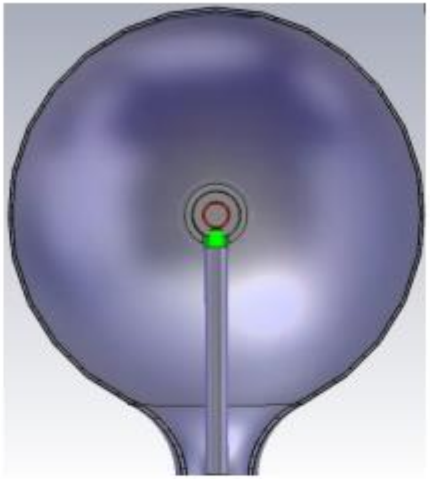
--Could the small Electron Multiplier MCP collect all the photoelectron?

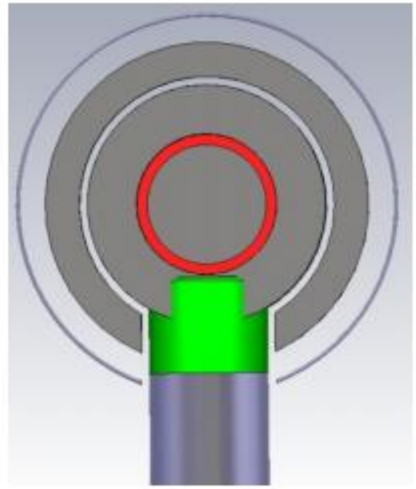


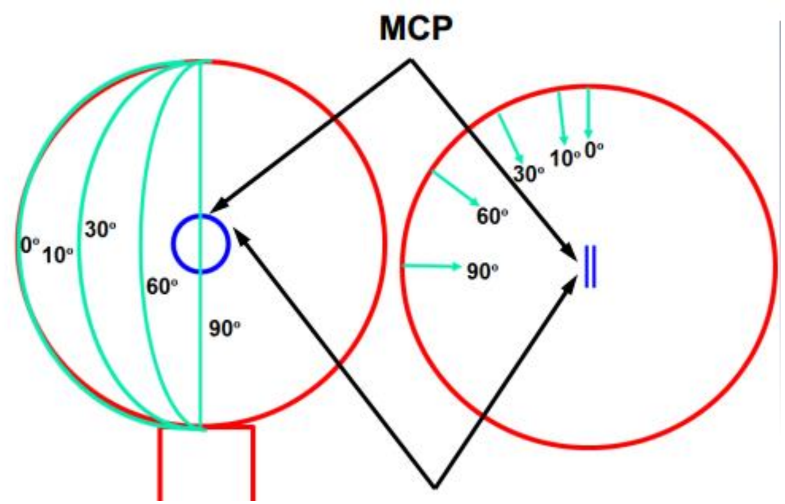
--Yes! Nearly all the photoelectrons could be collected by the small MCP!

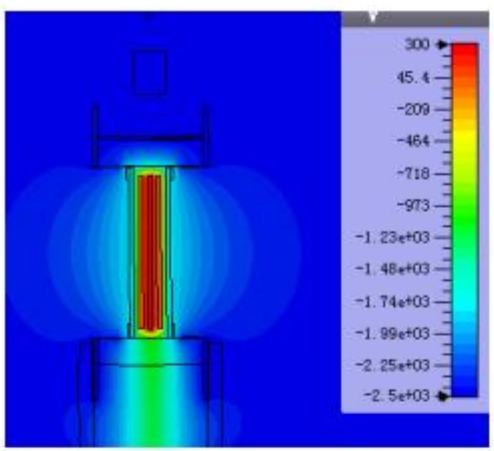
- Simulate the properties of MCP-PMT (8", 12", 20") with spherical and ellipse shell;
- Simulate the performance of different size MCP without the geomagnetic field (GM);
- Simulate the performance affected by the geomagnetic field; ……

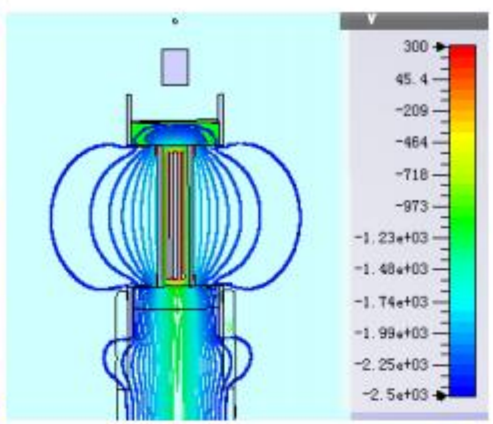
2.5 Optimizing focusing electrodes

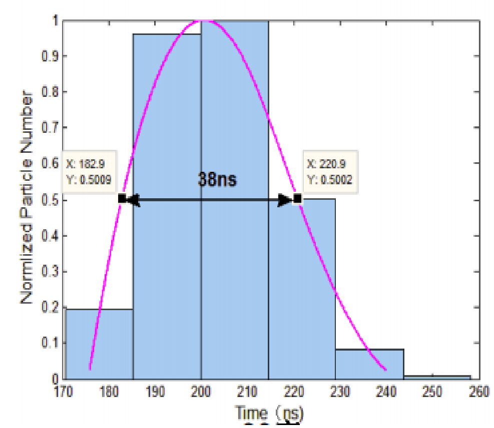




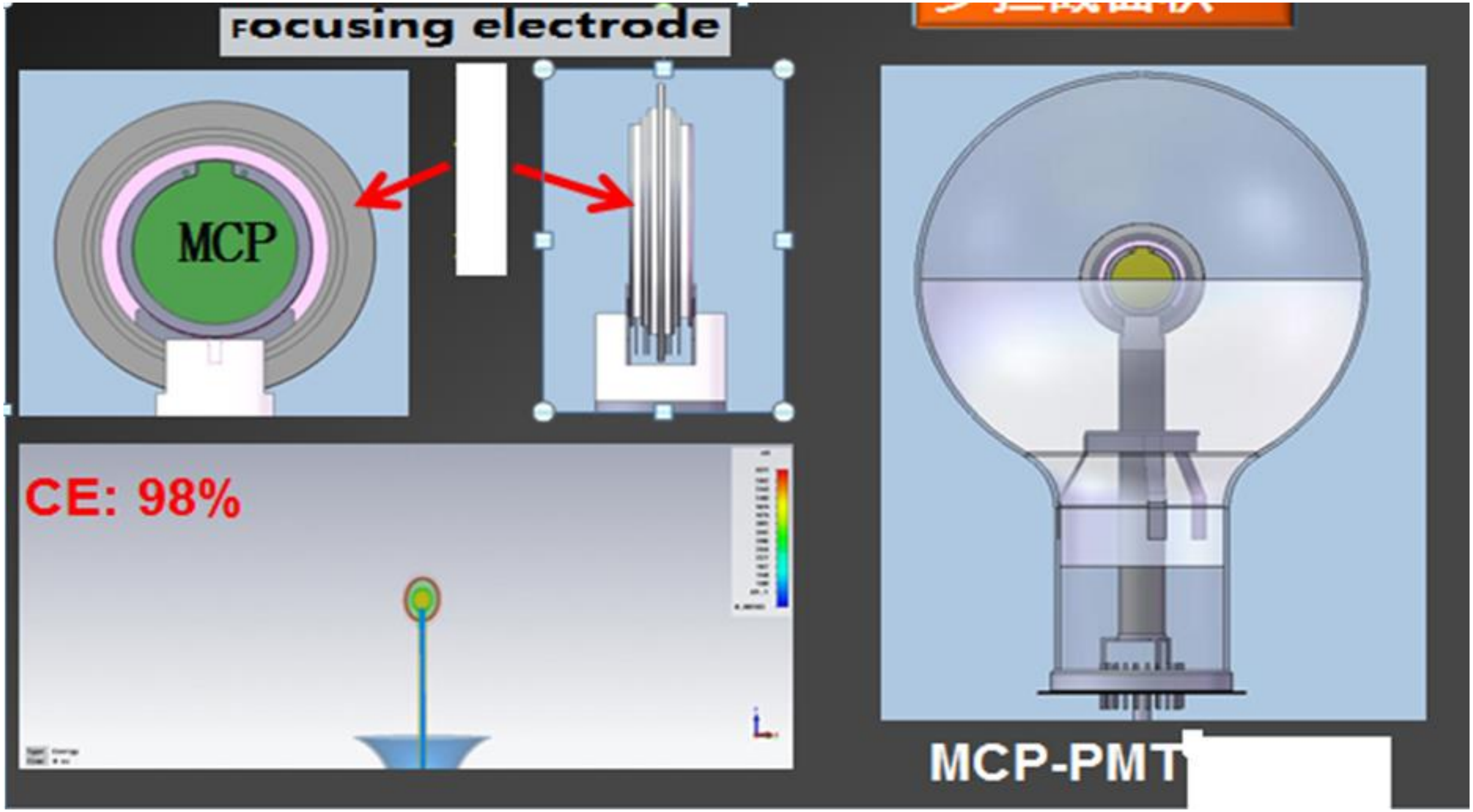




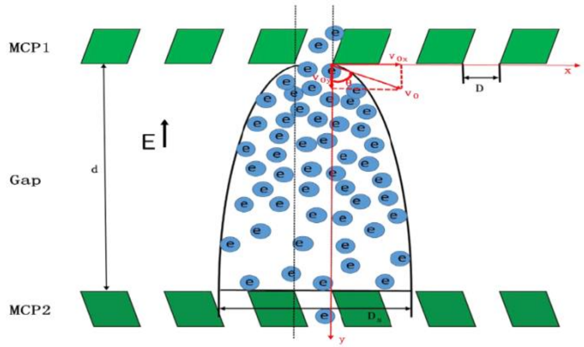




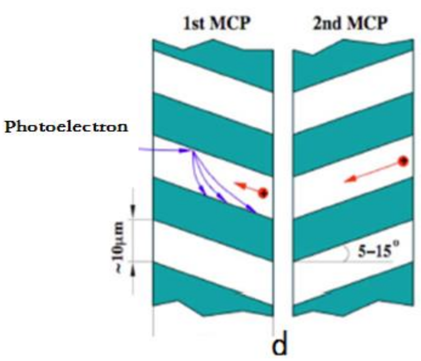
2.6 Design of focusing electrode

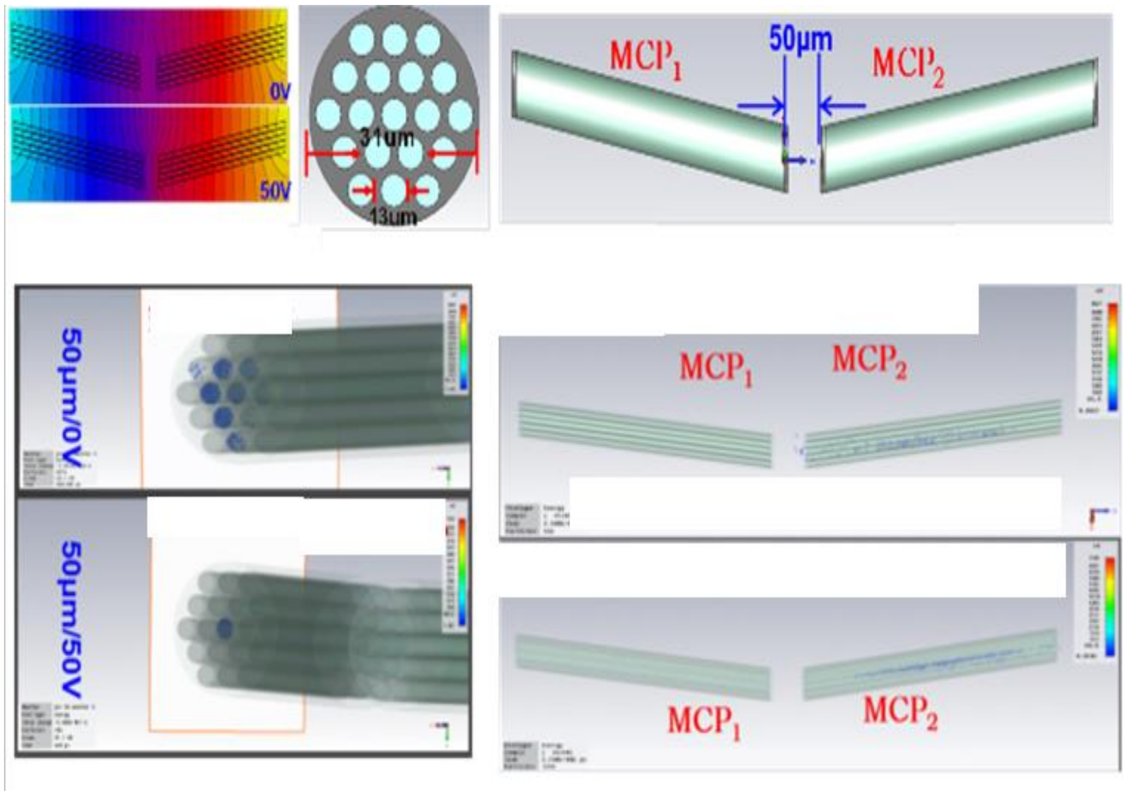


2.7 Simulation of the microchannel response



$$4dU_e^{\frac{1}{2}}[(U_e\cos^2\theta+U_G)^{\frac{1}{2}}-U_e^{\frac{1}{2}}\cos\theta]\sin\theta$$





2.8 Simulation and calculation of low background glass bulb

Event rate
(Schott Glass)

$$U^{238} : 1\ Bq/kg = 81\ ppb$$
$$Th^{232} : 1\ Bq/kg = 246\ ppb$$
$$K : 1\ Bq/kg = 32.3\ ppm$$

ALL PMT	U (MHz)	Th (MHz)	K (MHz)	Total
Acrylic	22 ppb	20 ppb	30 ppm	
Event rates	38.02*18306= 0.695994	8.13*18306= 0.148827	9.288*18306= 0.170026	55.438*18306= 1.014848(MHz)
Cut 600 PE	0	0.0004%	0.0008%	~
Event rates	0	5.9*10-7	1.36*10-6	1.95Hz

ALL PMT	U (MHz)	Th (MHz)	K (MHz)	Total
Balloon	22 ppb	20 ppb	30 ppm	
Event rates	38.02*18306= 0.695994	8.13*18306= 0.148827	9.288*18306= 0.170026	55.438*18306= 1.014848(MHz)
Cut 600 PE	0.001%	0.002%	0.0012%	~
Event rates	8.35*10-6	2.98*10-6	1.7*10-6	13.02Hz

3. R&D of the 8”and 20” MCP-PMT

3.1 Manufacture of Large Glass Bulb

General considerations

The PMT bulb for the JUNO experiment shall meet the following requirements:

(1) High strength low thermal expansion GG-17 glass (similar to Japan HARIO32 and American Pyrex)

(2) Highly transparent down to 350 nm in pure water with 4 bar water pressure

(3) Need a transition section to match the CTE of Pyrex glass and Kovar

(4) Can make high QE bialkali photocathodes for detecting light from liquid scintillator

(5) Low radioactive background (Raw materials that meet the requirements of JUNO have been found and tested)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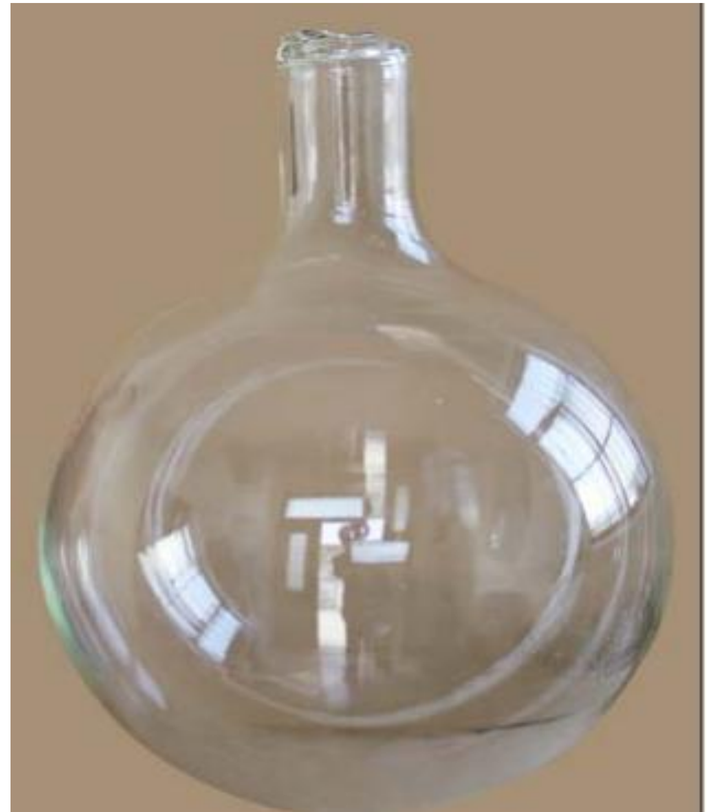
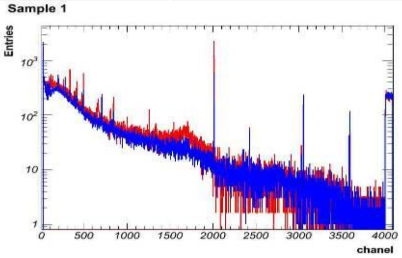



质量赢得尊严

3.2 Test analysis and selection of low background materials

Sample name	^{238}U activity concentration (Bq/Kg)	232Th activity concentration (Bq/Kg)	^{40}K activity concentration (Bq/Kg)	^{238}U content (ppb)	^{232}Th content (ppb)	K content (ppm)
quartz sand2#	≤0.25	≤0.18	0.89±0.11	≤22.25	≤44.48	28.7±3.6
quartz sand 9#	≤0.20	≤0.15	0.260±0.004	≤16.2	≤36.9	8.40±0.12
Boric acid 1#	≤0.26	≤0.20	1.24±0.14	≤21.06	≤49.20	4.74±0.53
Boric acid 5#	≤0.33	≤0.21	0.90±0.11	≤26.73	≤51.66	3.40±0.42
Boric acid 6#	≤0.25	≤0.19	0.39±0.05	≤20.25	≤46.74	1.47±0.20
Borax1#	≤0.29	≤0.19	1.78±0.19	≤23.49	≤46.74	6.72±0.73
Borax 2#	≤0.22	≤0.14	1.87±0.16	≤17.82	≤34.44	7.07±0.61
Na_2CO_3 1#	≤0.36	≤0.24	2.15±0.25	≤29.16	≤59.04	8.12±0.95
Na_2CO_3 2#	≤0.36	≤0.26	1.77±0.22	≤29.16	≤63.96	6.69±0.83
$Al(OH)_3$ 5#	≤0.55	≤0.70	1.59±0.17	≤44.55	≤49.19	6.01±0.63
$Al(OH)_3$ 6#	≤0.21	≤0.10	0.90±0.09	≤17.01	≤24.60	5.15±0.33
Refined salt	≤0.19	≤0.16	2.39±0.22	≤15.39	≤39.36	6.97±0.83

Low background gamma spectrometer at IHEP



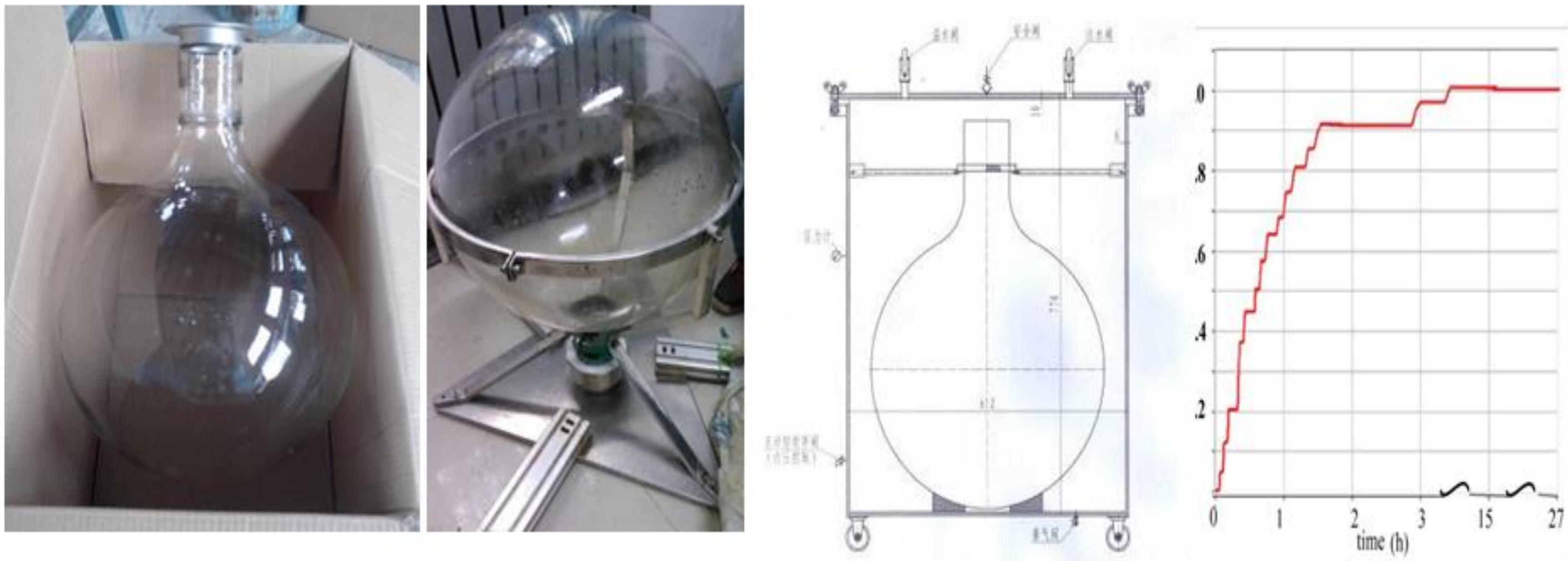
if SiO_2, B_2O_3, Na_2O and Al_2O_3 in the GG-17 glass composition were introduced from quartz sand 9#, boric acid 6#, Na_2CO_3 2# and $Al(OH)_3$ 6#, respectively, then the contents of ^{238}U, ^{232}Th and K in the bulb body with 8.5 Kg weight are less than 30 ppb, 40 ppb, 10 ppm separately.

3.3 Transition section and its sealing with Kovar

(a) (b) (c)

Transition section: (a) one section transition, (b) three sections transition and (c) multi-section transition

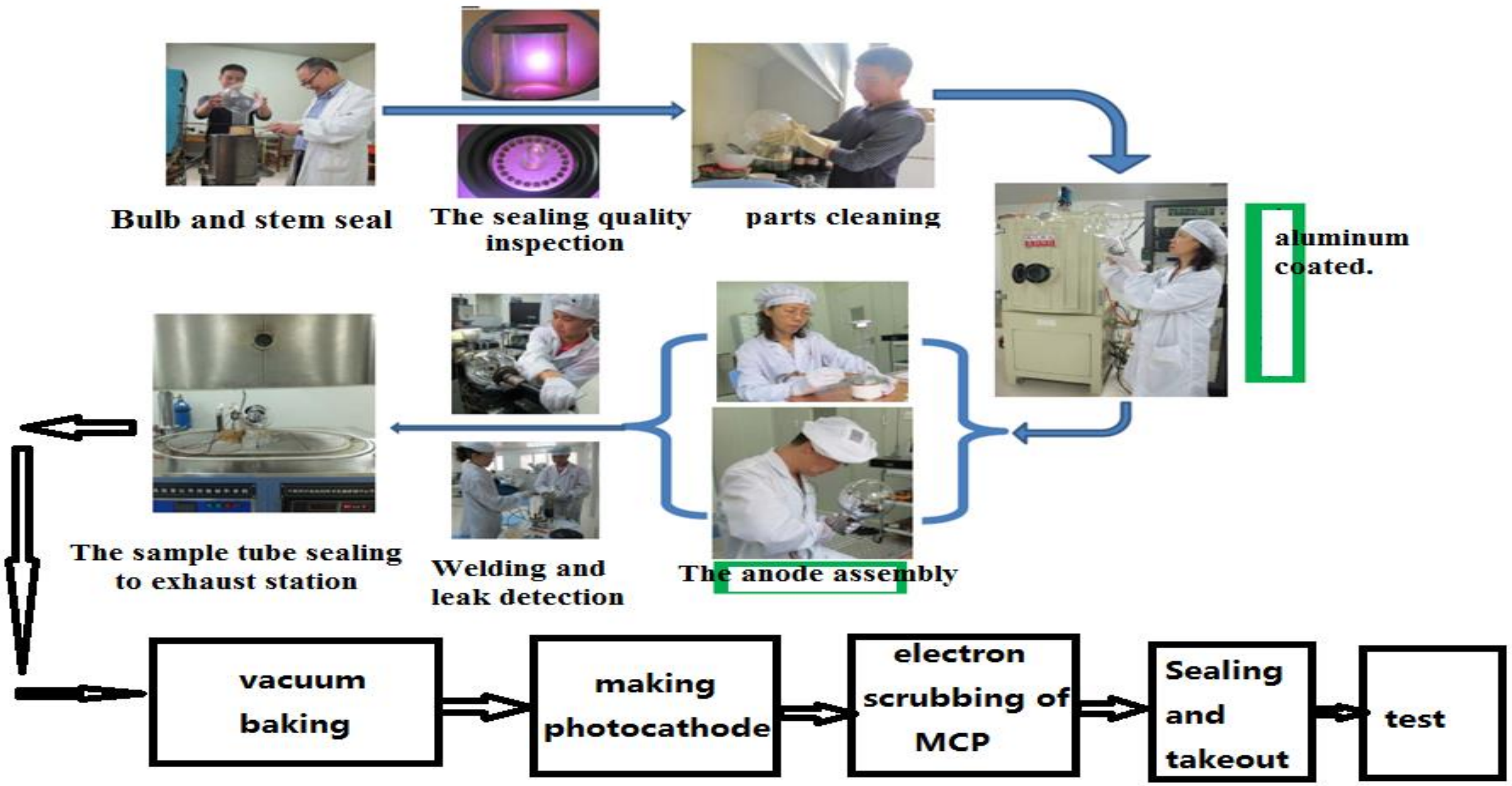
3.4 Bulb sealed with transition section and Kovar and its pressure test



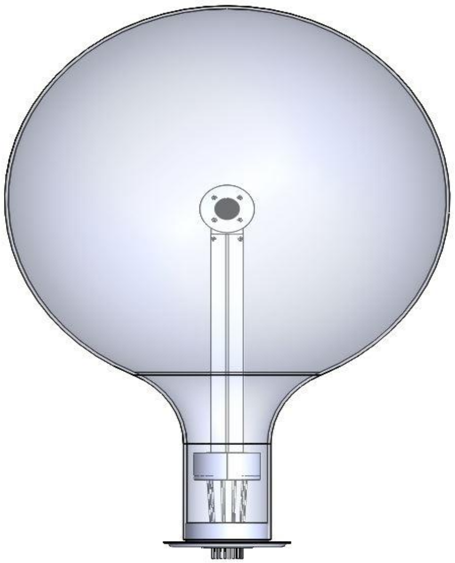
(a) (b) (c) (d)

(a) The bulb sealed with three sections transition and Kovar, (b) the bulb after pressure test, (c) equipment of pressure test, and (d) curve of pressure test

3.5 MCP-PMT making process



Simple of 20 inch MCP-PMT



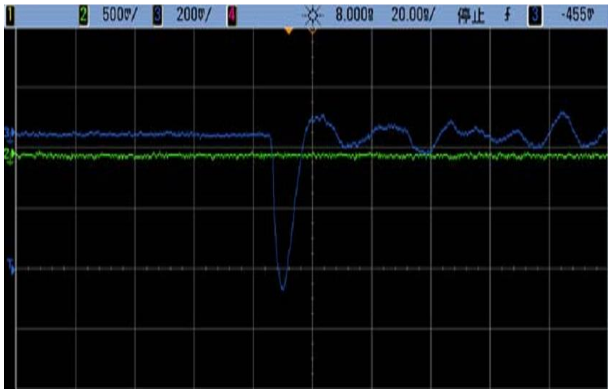
Simple of 8 inch MCP-PMT

4.The performance of the MCP-PMT

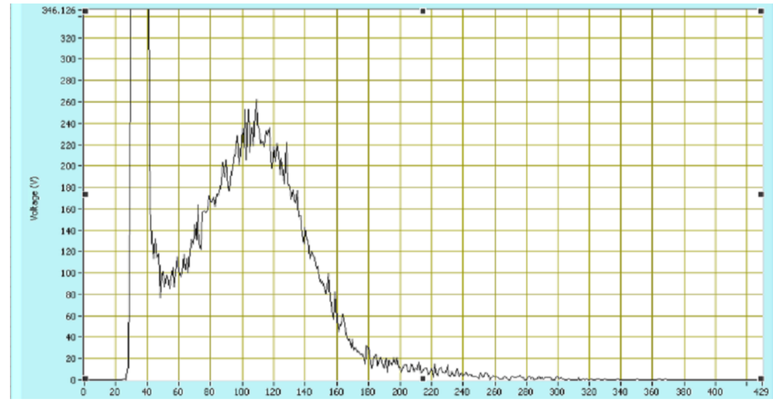
The Parameters of the MCP-PMT

1. The QE value / QE Uniformity of the Photocathode@ 410nm;
2. The Rise time and Fall time and Transit Time Spread (TTS);
3. The Signal Photoelectron Spectrum @ Gain=2*10^7;
4. The Gain Vs High Voltage;
5. The Anode dark count / Anode dark current @ Gain=2*10^7;
6. The linearity of the PMT;
7. The After-Pulse (Time Distribution / Ratio) of the PMT;
8. The dark noise distribution;
9. The resistance of the MCP of the PMT.

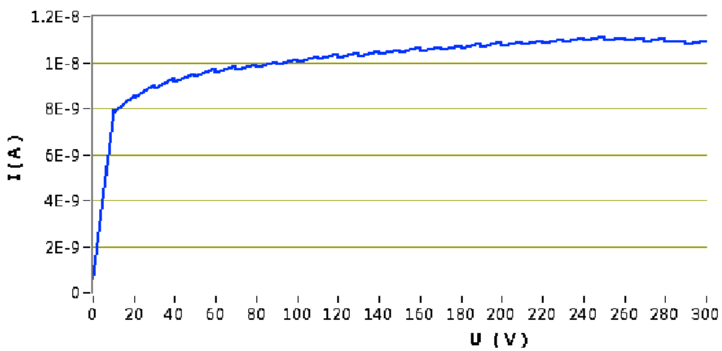
Some test figures



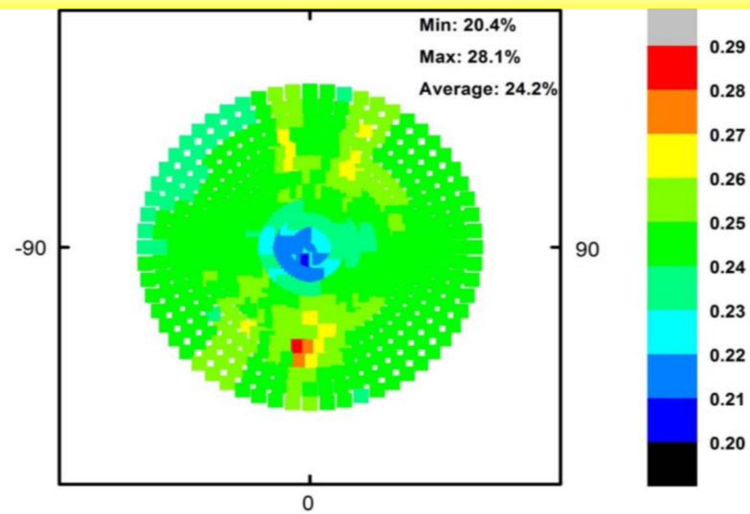
The Rise time and Fall time



The Signal Photoelectron Spectrum @ Gain~2*10^7



The QE of the Photocathode@ 410nm



The QE uniformity of the photocathode@410nm

Results of 8 inch MCP-PMT

THE End of 2013,from Qian Sen

PMT Type / Parameters	R5912	MCP-PMT
QE of the Photocathode@ 410nm	25%	20% (25%)
QE uniformity	?	±3%
Rise / Fall time of the SPE signal Gain=2*10^7	3ns / 4ns	5ns / 6.3ns
Amplitude of the SPE signal @Gain=2*10^7	17mV	17mV
Transit Time Spread (TTS)	5.5ns	3.5ns
P/V of the SPE signal @ Gain=2*10^7	> 2.5	1.5~2.5
The Voltage of the PMT @ Gain=2*10^7	1600V	2000V
Anode dark count @ Gain=2*10^7@ Tro.=0.25pe	< 1kHz	~2.2kHz
Anode dark current @ Gain=2*10^7	~1nA	~6nA
The Charge of the dark noise distribution	1 pe	1.4 pe
linearity of the PMT upto 40mA / < 60mA	±2% / ±5%	±2% / ±4%
After-Pulse time distribution: Fast / Slow	1.6us / 7us	0.3us / ?
After-Pulse Ratio of the PMT	1.79%	Very small ?

Main performance

recently obtained results

Glass material				pyrex glass（a kind of high borosilicate glass）			
photocathode				Sb-K-Cs /Sb-Na-Cs: transmission and reflective photocathode			
Quantum efficiency @410nm				~30%			
structure				MCP-Type			
	8inch			20inch			
photocathode	Min	Typ	Max	Min	Typ	Max	Unit
spectral response range		300-650			300-650		nm
wavelength of peak value		380~400			380~400		nm
photocathode luminous sensitivity		80			60		μA/lm
QE@410nm		30			25		%
operation voltage	-1800	-2050	-2700	-2000	-2300	-3000	V
Gain		1×10^7			1×10^7		
Anode sensitivity		800			800		A/lm
Dark current		100			500		nA
Single photoelectron peak to valley ratio		2.5			2.0		
Rise time		3			3		ns
FWHM		5			5		ns
TTS		9			35		ns

6. CONCLUSIONS

（1） Good progress has been made for 20-inch PMT glass bulb suitable for JUNO

（2） 8 inch MCP-PMT samples has shown good results

（3） 20 inch MCP-PMT samples have been successfully made and tests. Results are promising

ACKNOWLEGEMENT

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Thank you for your attention！