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 Status of Large Area MCP-PMT R&D in China

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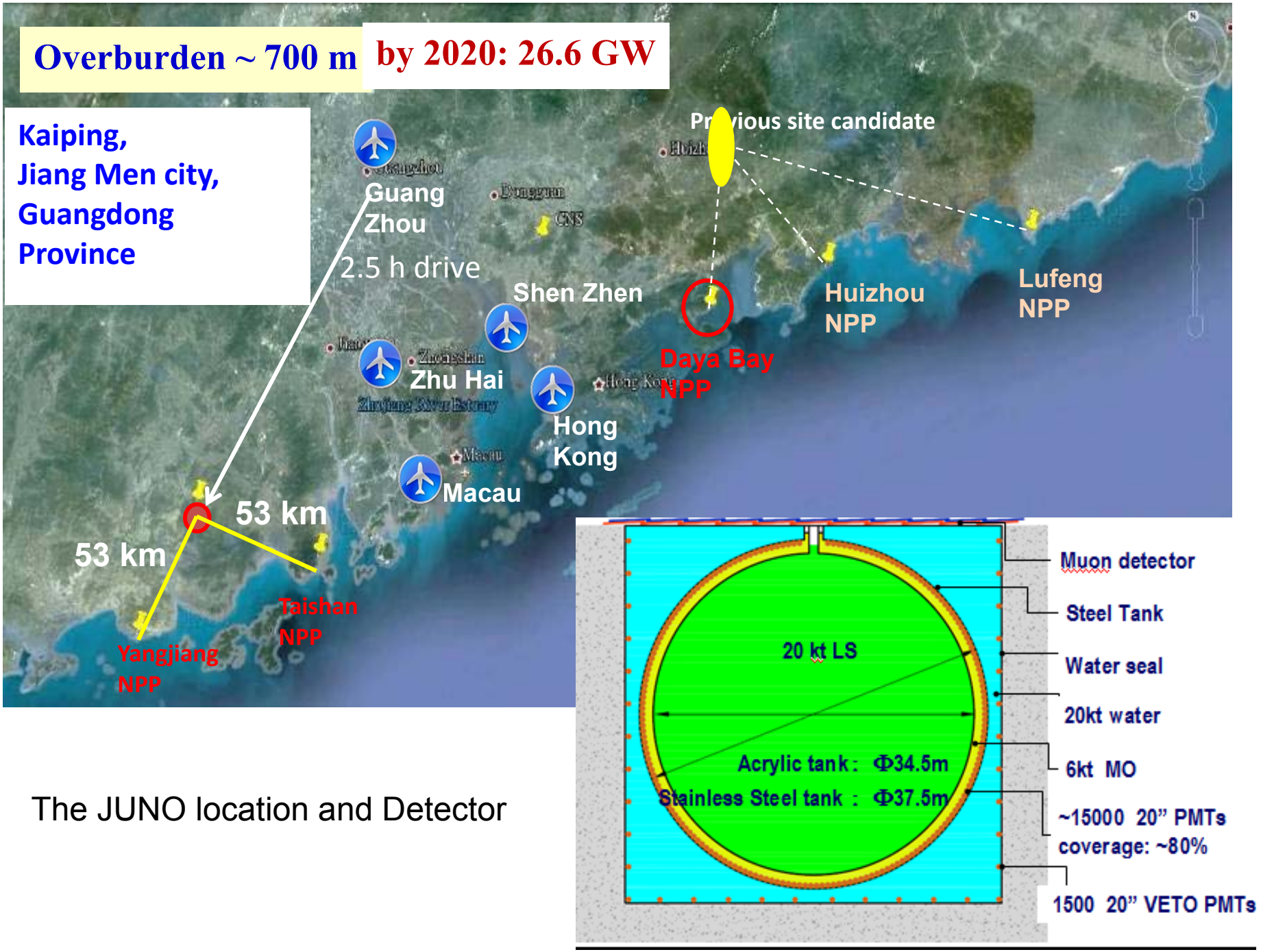
On Behalf of the Workgroup

Outline

- 1. JUNO and the new MCP-PMT;
- 2. Progress of the R&D process；
- 3. Performance of the MCP-PMT prototype；
- 4. Attempt to improve the performance of the prototype;
- 5. Summary and Plan



The JUNO location and Detector

➢ PMT requirement of JUNO

- LS volume: × 20 ➔ for more statistics (40 events/day)
- Light (PE) × 5 ➔ for better resolution ($\Delta M^2_{12}/\Delta M^2_{23}$ ~ 3%)

◆ **Three types of high QE 20" PMTs under development:**

⇨ **Hammamatsu PMT with SBA photocathode**

⇨ **A new design using MCP: 4π collection**

⇨ **Photonics-type PMT**

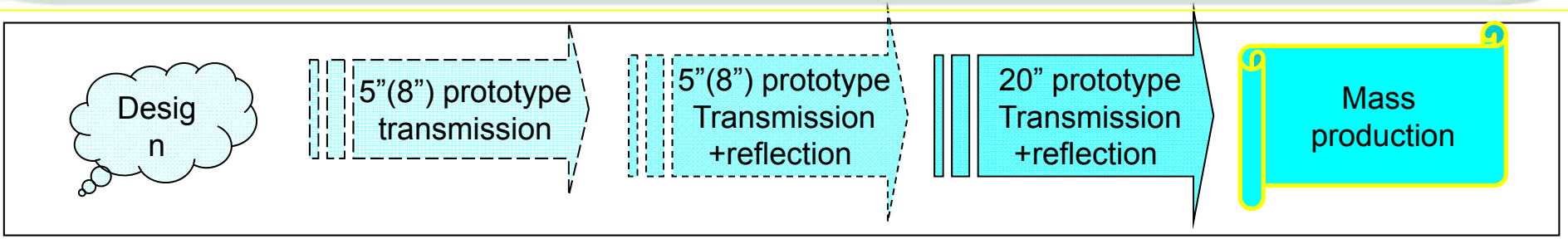
Requirement:

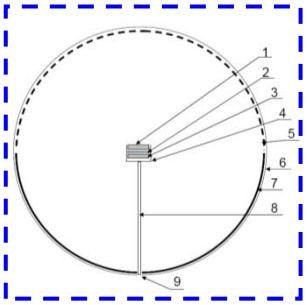
- ✓ High QE 20 inch PMT;
- ✓ Good SPE detection capability;
- ✓ Wide dynamic range;
- ✓ Low radioactive background;
- ✓ More than 20 years lifetime;
- ✓ Can withstand 0.4MPa Pressure;
- ✓ > 15000 pieces;

➢20" Hammamatzu PMT

➢20" MCP- PMT

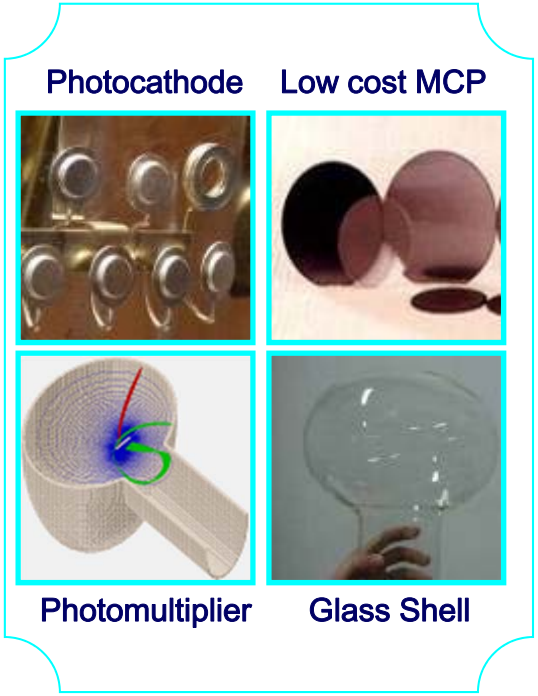
➢ The R&D plan of MCP-PMT （schedule）

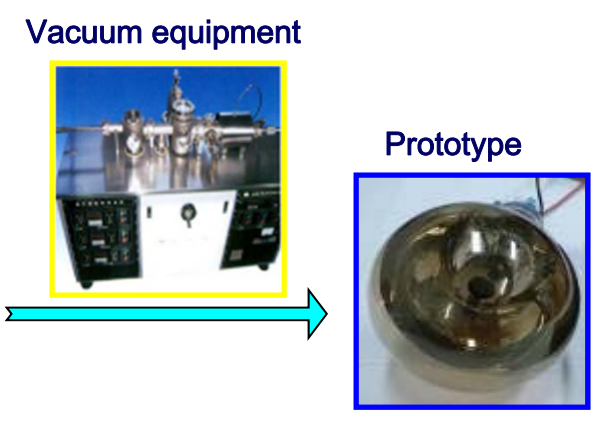




The design of the IHEP-MCP-PMT

The project of JUNO

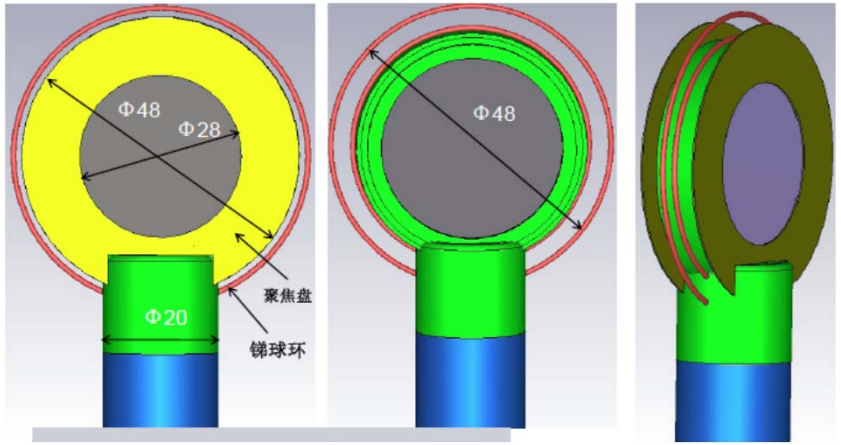




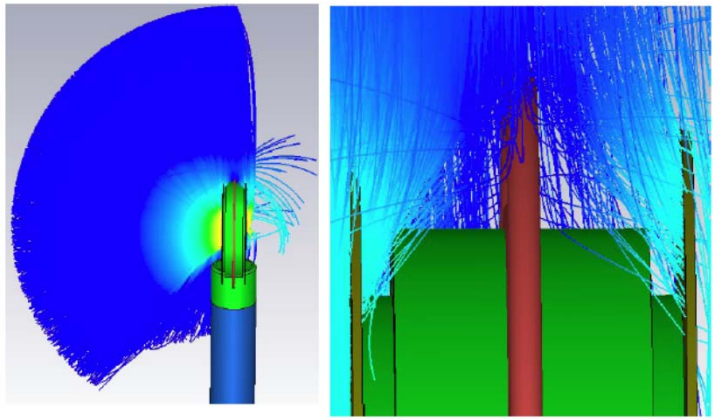
2. Progress of the R&D process；

- 2.1. Progress of the **Electron-Optics Simulation**
- 2.2. Progress of the **Glass bulb**
- 2.3 Progress of the **Photocathode**
- 2.4 Progress of the **MCP Module & Equipment**
- 2.5 Progress of the **Test System**
- 2.6 Progress of the **Prototypes**

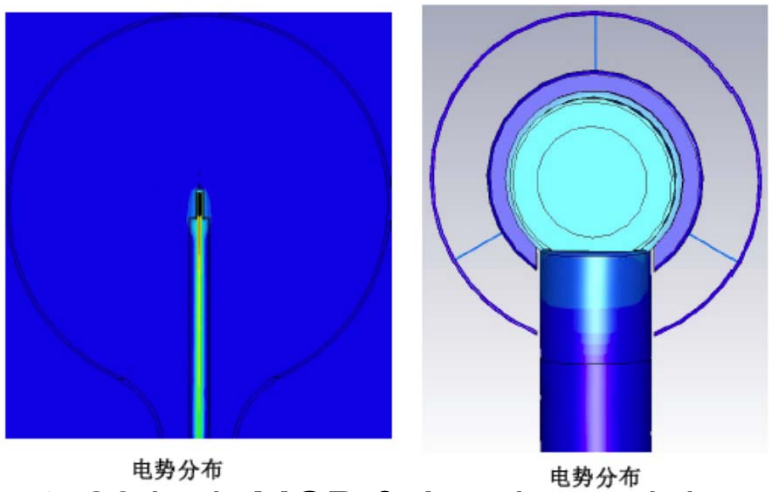
➢ 2.1. Progress of the **Electron-Optics Simulation**



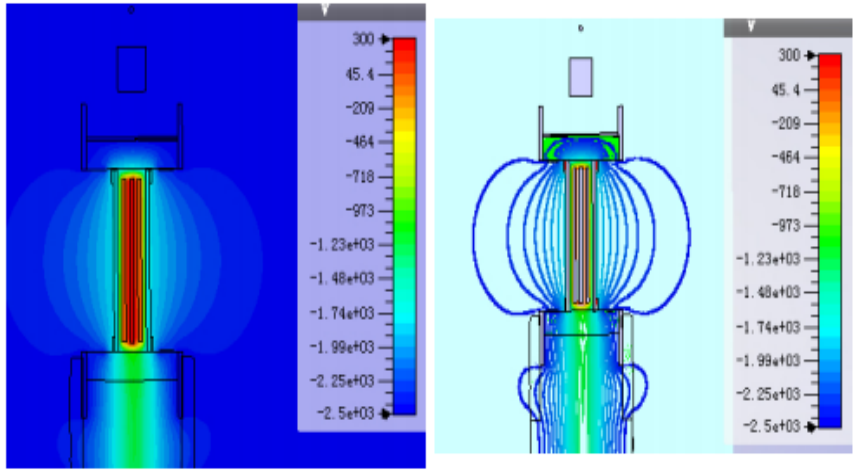
➢8 inch MCP & Anode Module;



➢The collection efficiency 8 inch



➢20 inch MCP & Anode module;

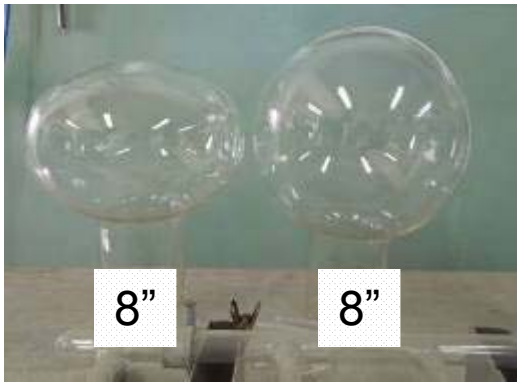


➢The collection efficiency 20 inch

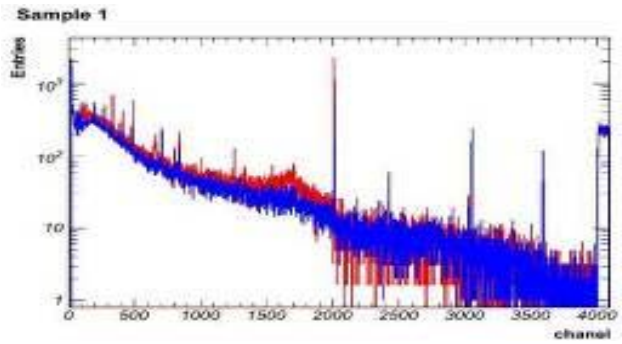
➢The simulation results show that the small MCP in the middle of the glass could collected the all the photoelectron from the large area photocathode!

➢ 2.2. Progress of the **Glass bulb**

➢Large area

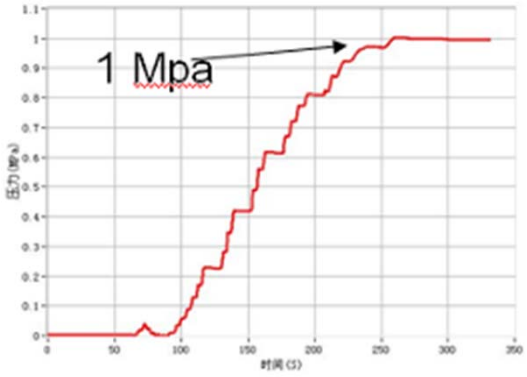


➢Low radioactive background



Low background gamma spectrometer

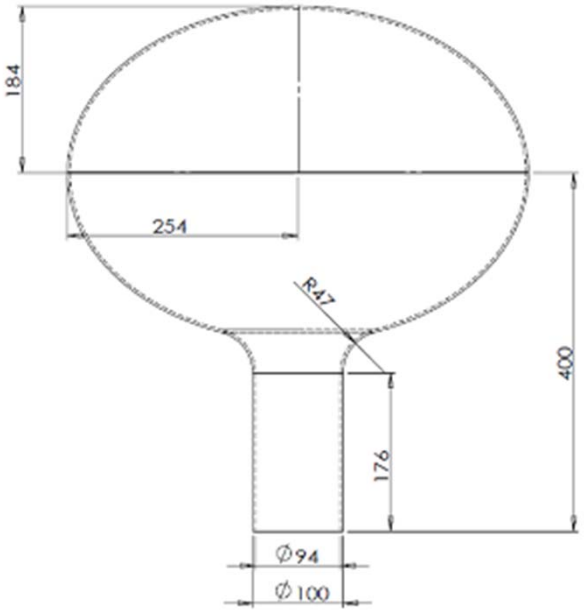
➢Superb water-resistance

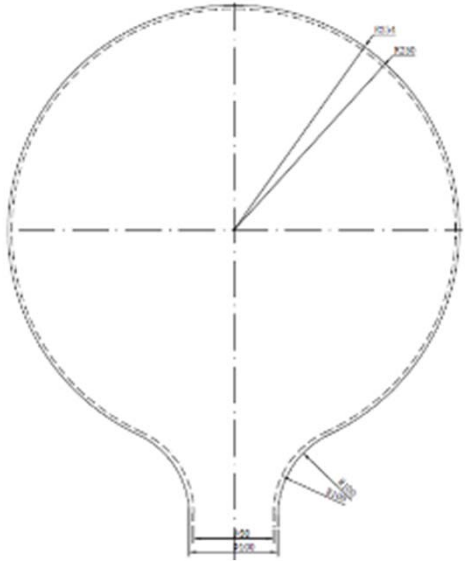


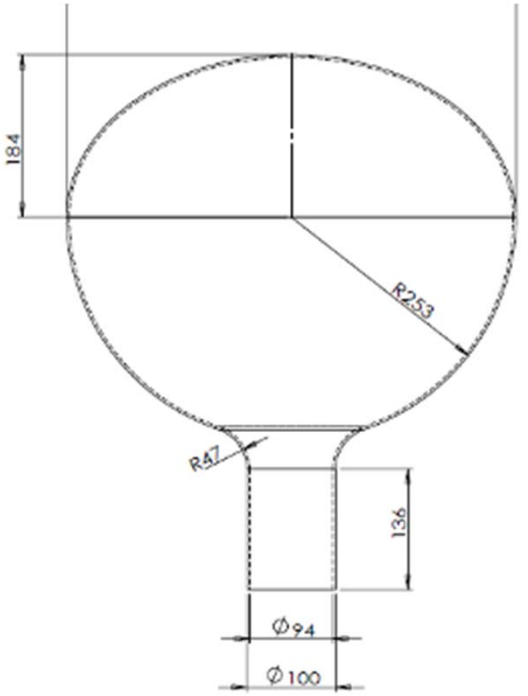
➢**The 20inch glass bulb was fine after the super water-resistance experiment;**

➢**The low back radioactive background glass material was found for the mass production**

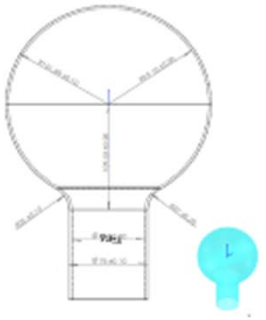
➢ The different Shape of the PMT prototype

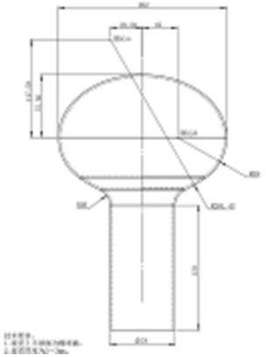




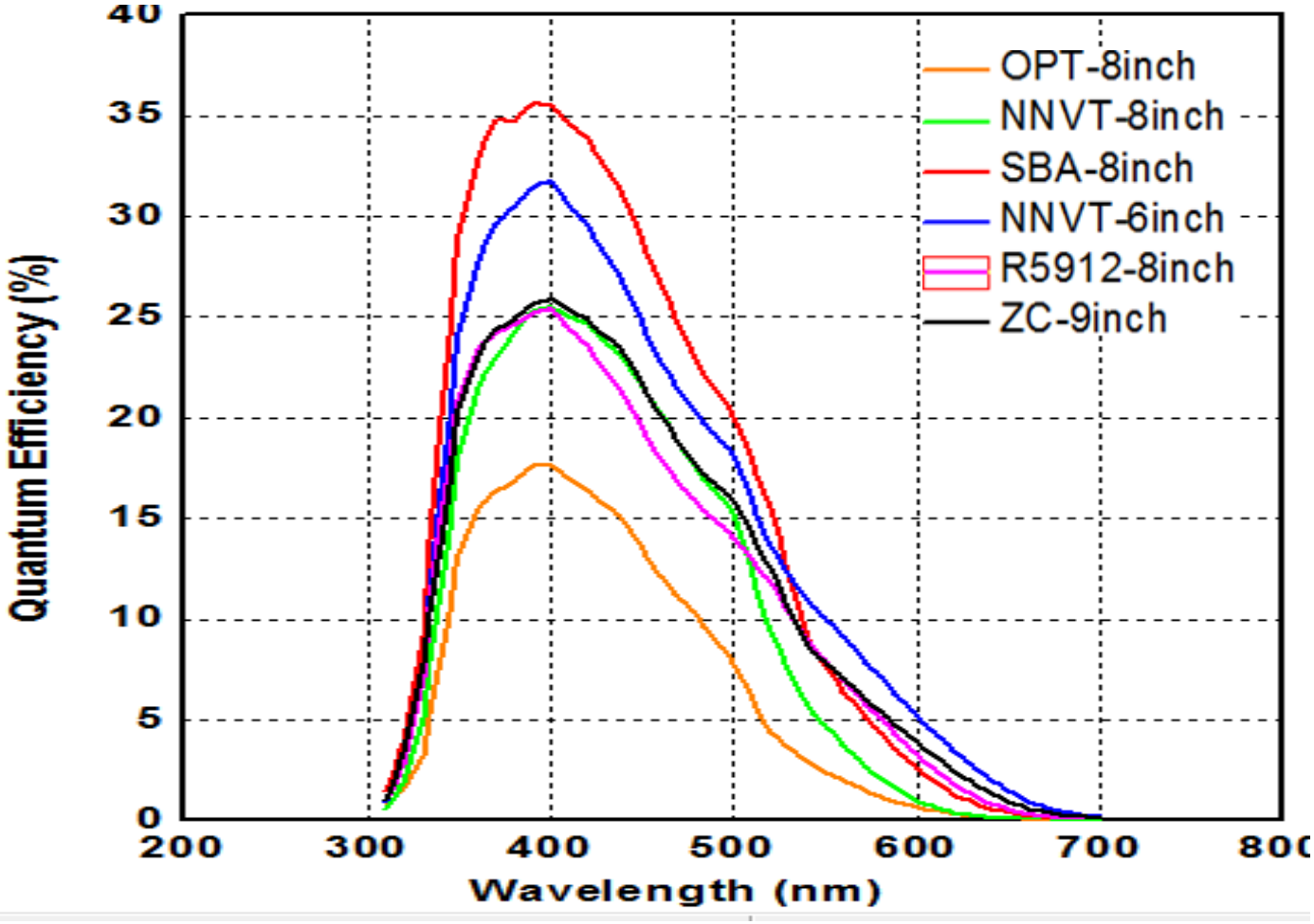


Type	Size	Shape	AMP
C0811-1	8 inch	sphere	MCP
C0800-1	8 inch	ellipsoidal	MCP
C0800-2	8 inch	ellipsoidal	MCP
C2011-1	20 inch	sphere	MCP
C2000-1	20 inch	ellipsoidal	MCP
C2001-1	20 inch	Hemisphere+ Hemiellipsoidal	MCP





➢ 2.3. Progress of the **Photocathode**



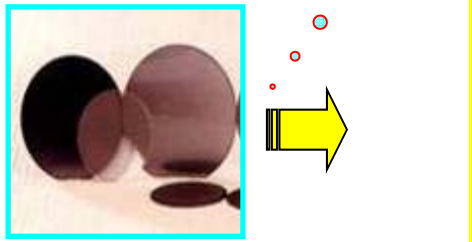
1. The MCP-PMT group could produce the 8 inch prototype with the 25% QE@410nm

2. For Large area photocathode, the AMS would be the one evaporated by current for better control the process. MCP-PMT group also use this method to improve the QE from **25% to 32%**

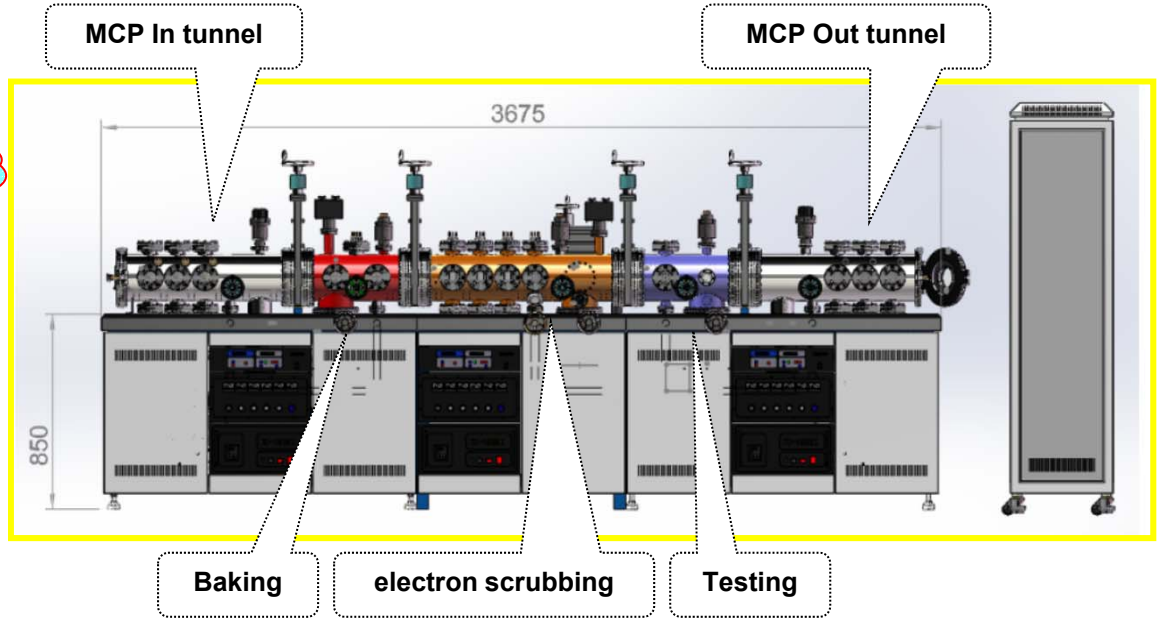
3. We try to produce the HQE PC in our large area prototype.

➢ 2.4 Progress of the **MCP Module & Equipment**

➢The Equipment for MCP pretreatment/test



Plan



Have already finished the design work, still debugging in the LAb **:**

Normal MCP

⇩

Treated MCP

for better: CE of the MCP; P/V for SPE; Aging of the MCP; Consistency of the MCPs;……

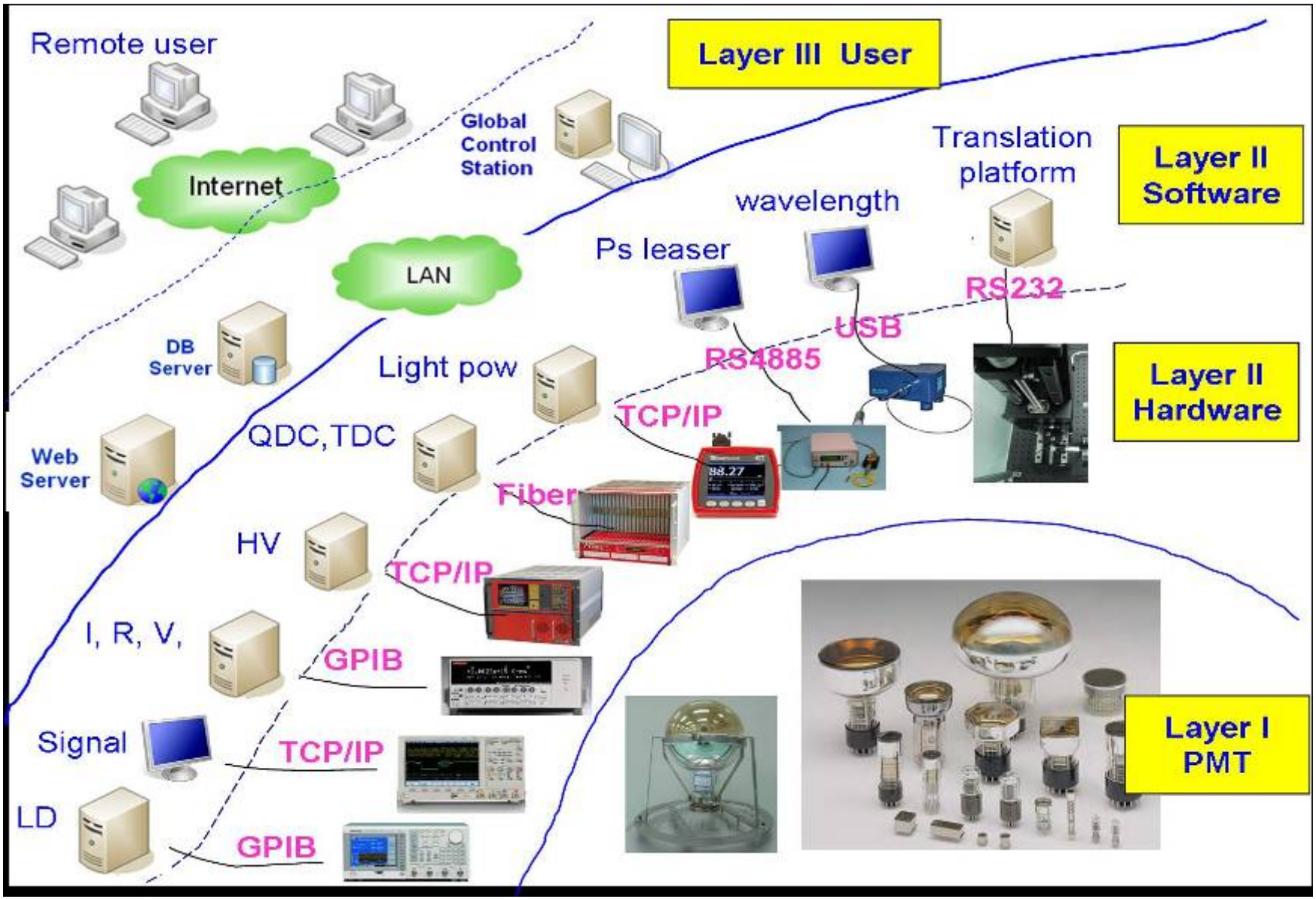
Un-transmission equipment

⇩

Transmission equipment

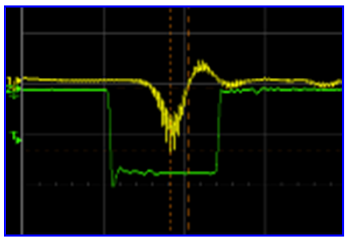
Better: QE and Uniformity of the PC; P/V for SPE;

➢ 2.5 Progress of the **Test System**

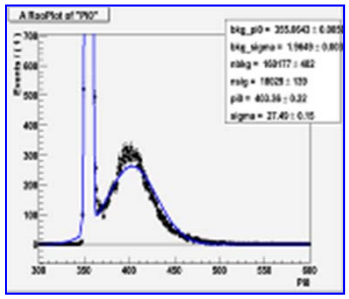


The Large PMT evaluation system for MCP-PMT of JUNO

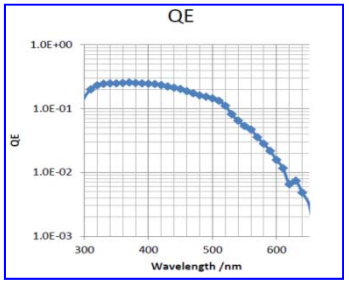
➢ The parameters of the MCP-PMT (testing)



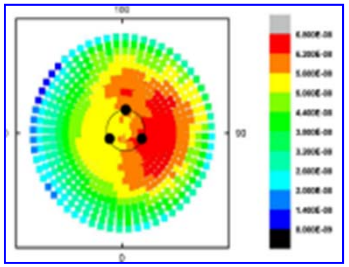
- ➢ Anode Pulse Rise Time;
- ➢ Pre/Late/After Pulse;
- ➢ Dark Count



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



- ➢ Spectral Response；
- ➢ Wavelength of Maximum Response；
- ➢ Cathode Sensitivity: Luminous(2856K);
- ➢ Quantum efficiency with λ



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

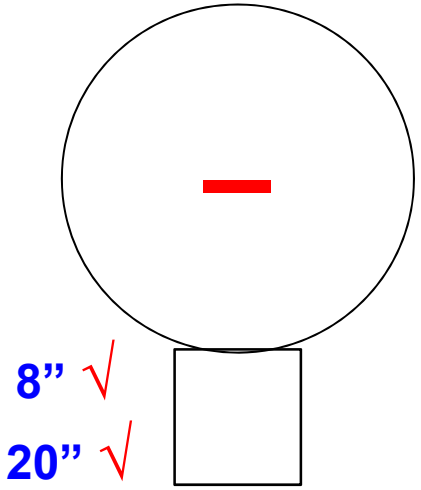
Others

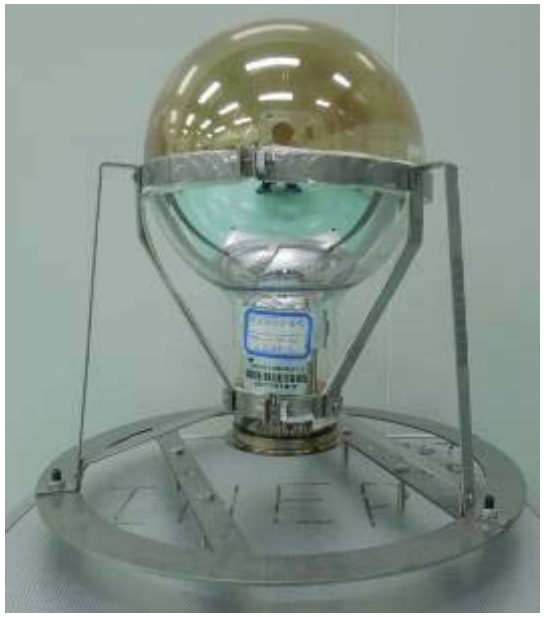
……

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

➢ 2.6 Progress of the **Prototypes**

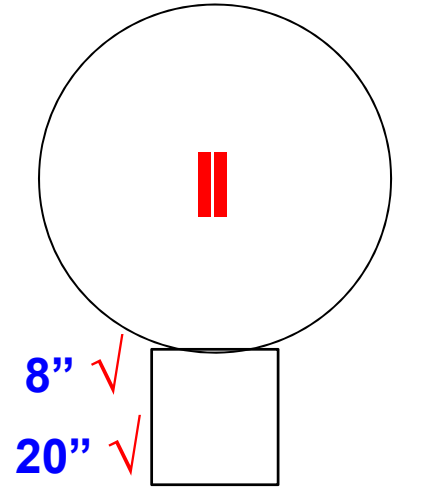
Sphere ball
One MCP module





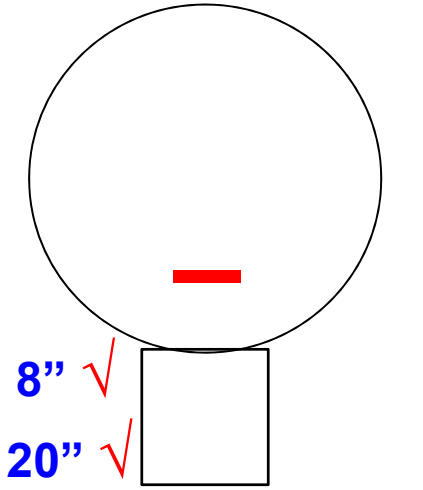
MCP-PMT-007#

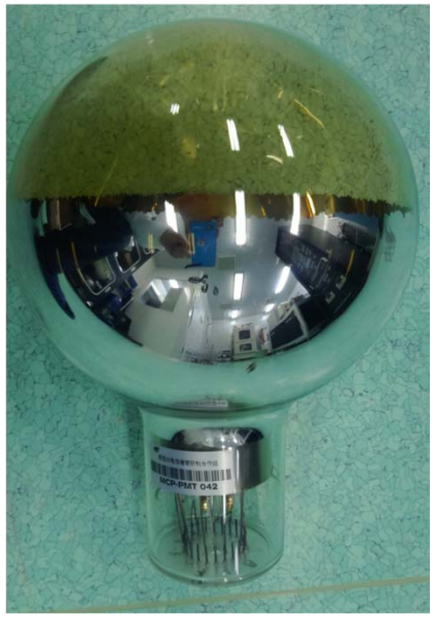
Sphere ball
Two MCP modules



MCP-PMT-031#

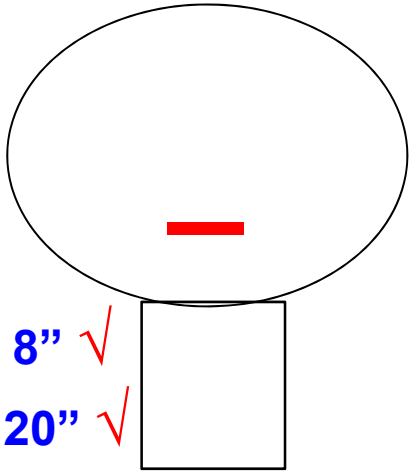
Sphere ball
One MCP module





MCP-PMT-042#

Ellipsoidal ball
One MCP module



MCP-PMT-044#

20 inch **sphere** Prototype

20 inch **ellipsoidal** Prototype

8 inch
sphere
Prototype

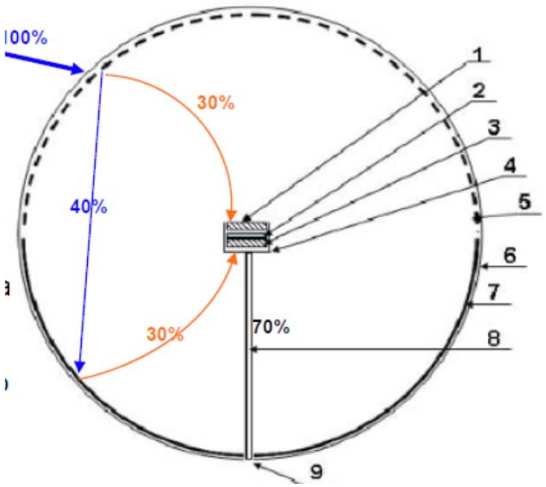
8 inch
ellipsoidal
Prototype

Outline

- 1. JUNO and the new MCP-PMT;
- 2. Progress of the R&D process;
- **3. Performance of the MCP-PMT prototype;**
- 4. Attempt to improve the performance of the prototype;
- 5. Summary and Plan

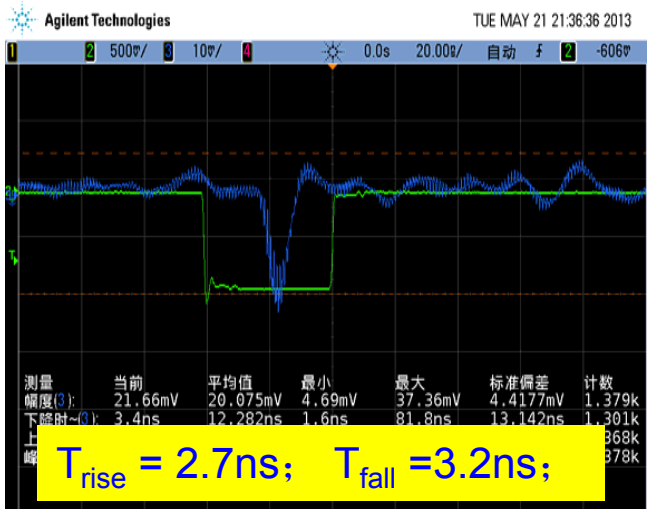
➢ 8 inch Prototype (007#) with horizontal MCPs in the middle

This is the first 8” (one MCP module) prototype for SPE by un-transmission equipment

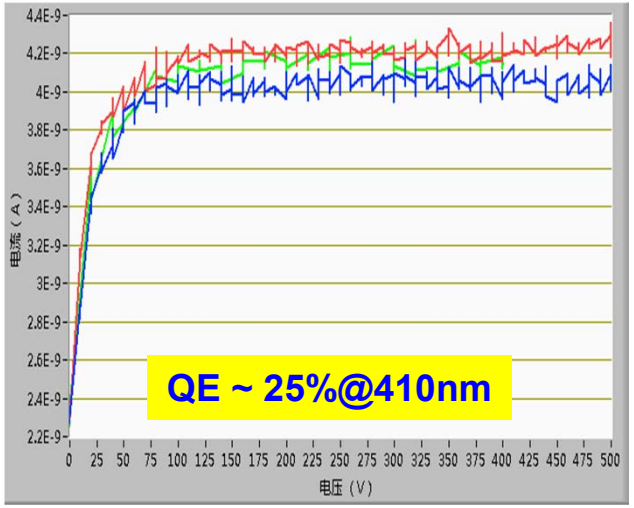


The Design MCP-PMT

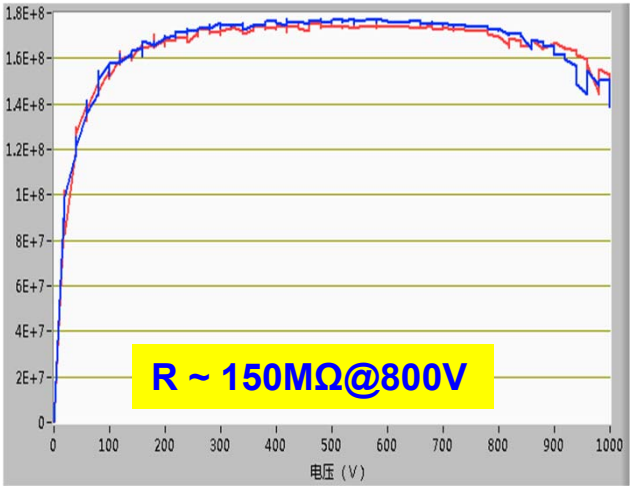
The Prototype



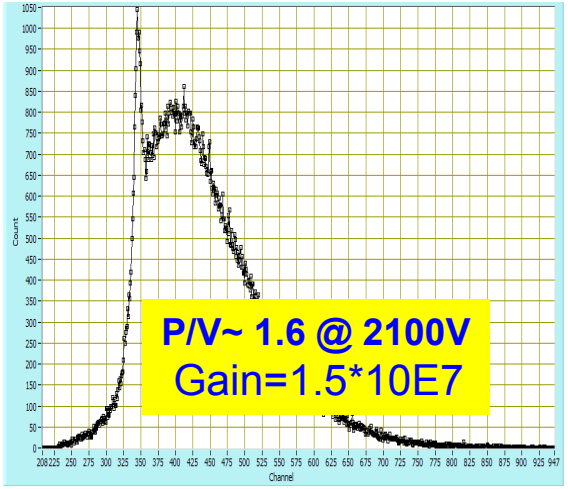
The signal of the 8 inch PMT



The I-V curve of the PC



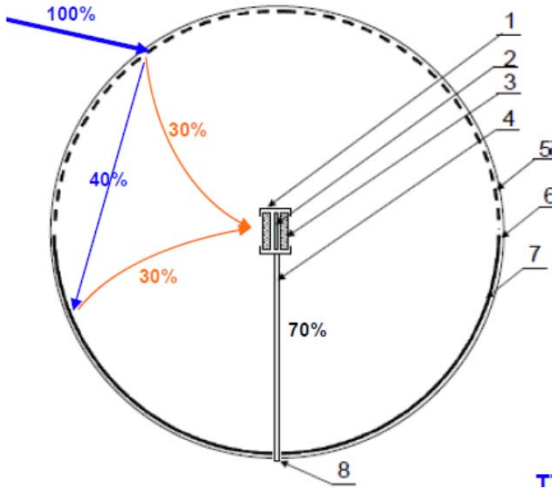
The body resistance of the MCP



The SPE of the PMT

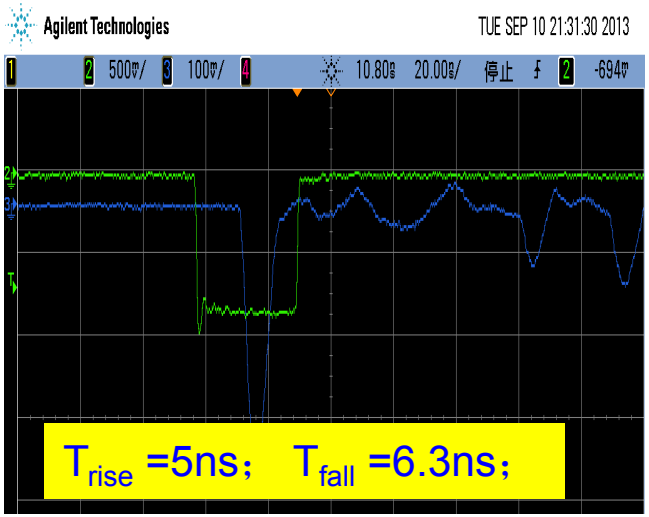
8 inch Prototypes (031) with Vertical MCPs in the middle

This is the first 8” (Two MCP modules) prototype for SPE by un-transmission equipment

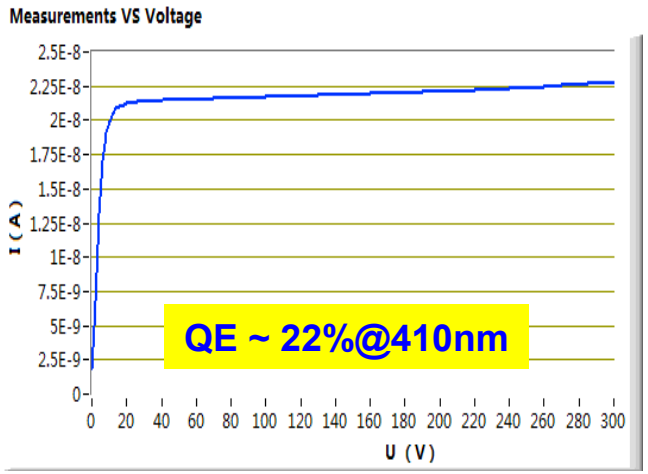


The Design MCP-PMT

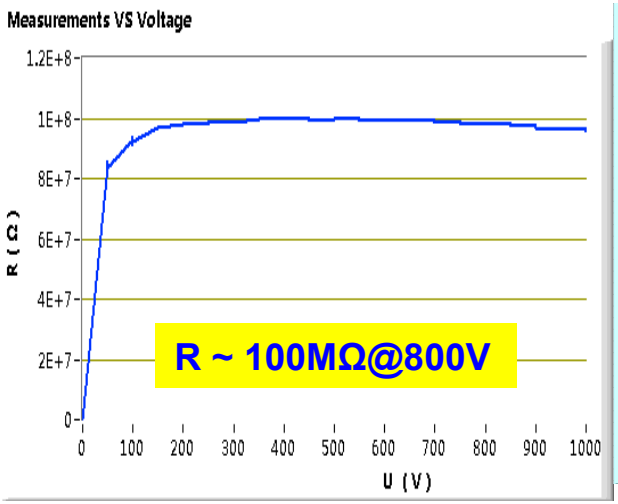
The Prototype



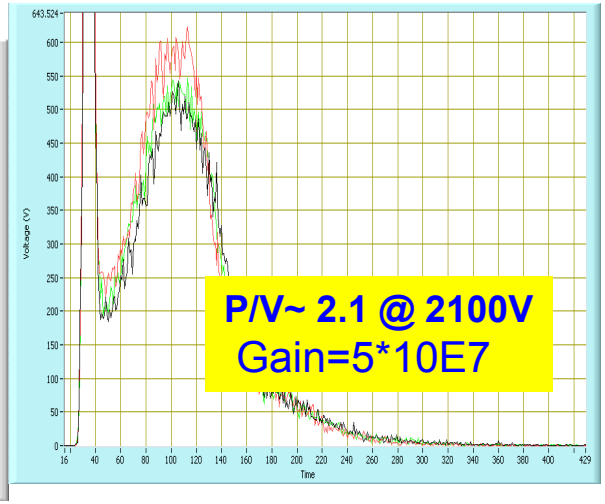
The signal of the 8 inch PMT



The I-V curve of the PC



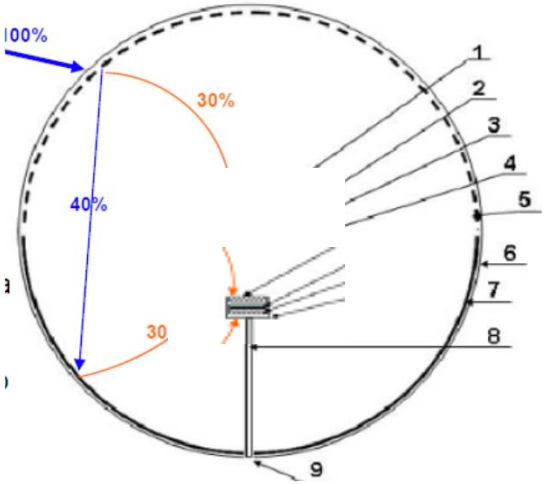
The body resistance of the MCP



The SPE of the PMT

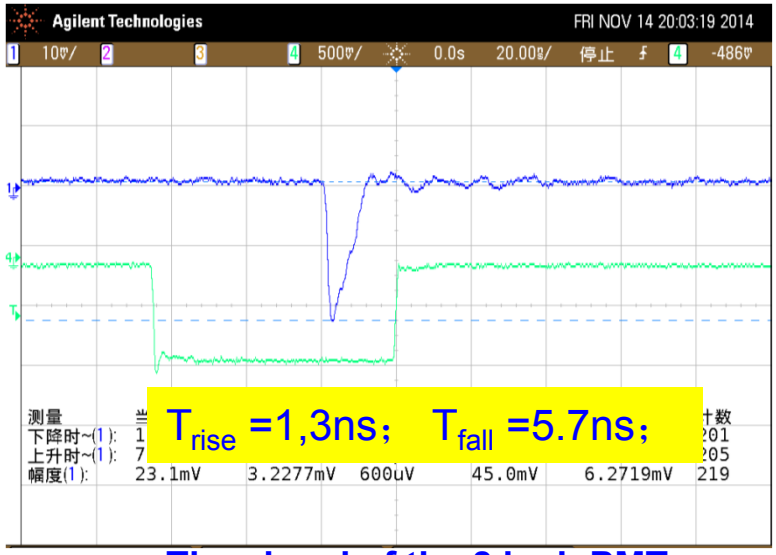
8 inch Prototype (042#) with horizontal MCPs near the bottom

This is the 8” (one MCP module) prototype for better CE and TTS uniformity by un-transmission equipment

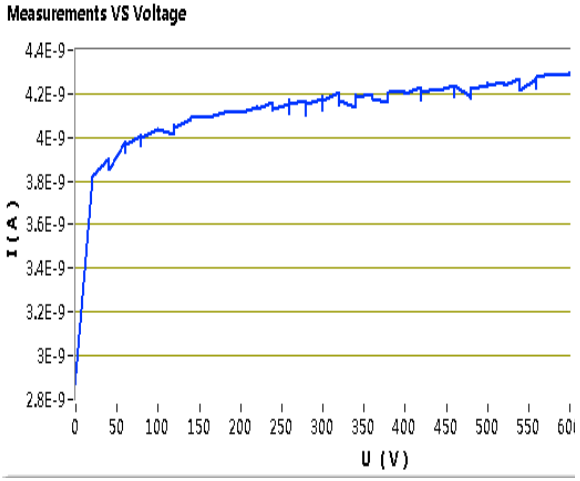


The Design MCP-PMT

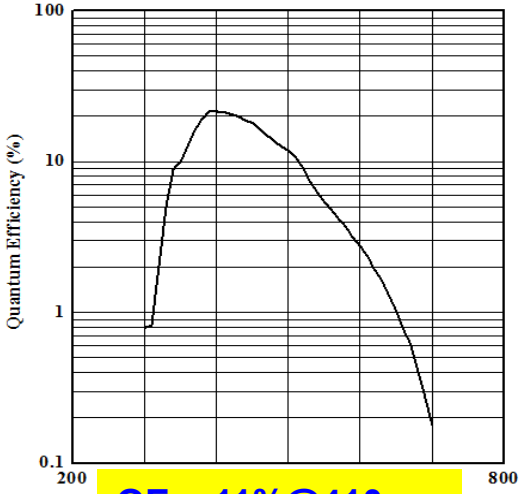
The Prototype

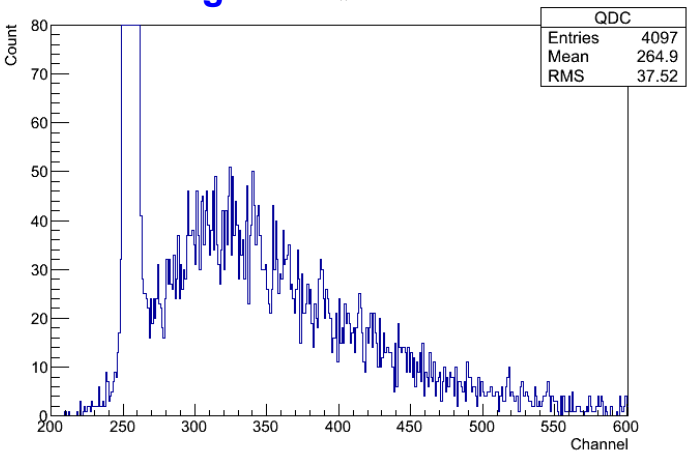


The signal of the 8 inch PMT



The I-V curve of the PC



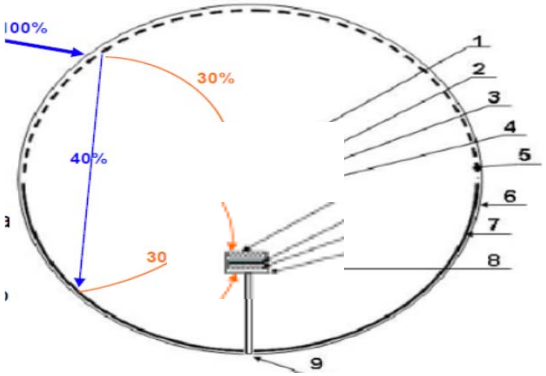


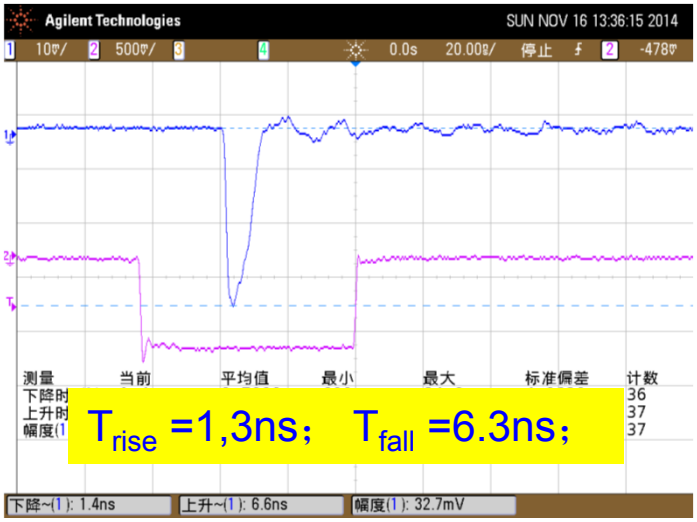
P/V~ 2 @ 1650V Gain=1*10E7

The SPE of the PMT

8 inch Prototype (044#) with horizontal MCPs near the bottom

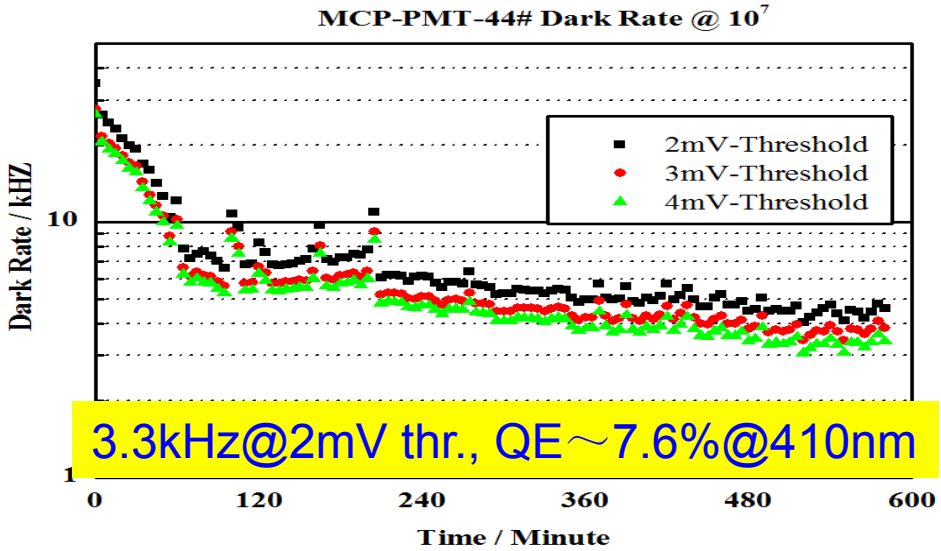
This is another 8” (one MCP module) prototype for better CE and TTS uniformity by un-transmission equipment



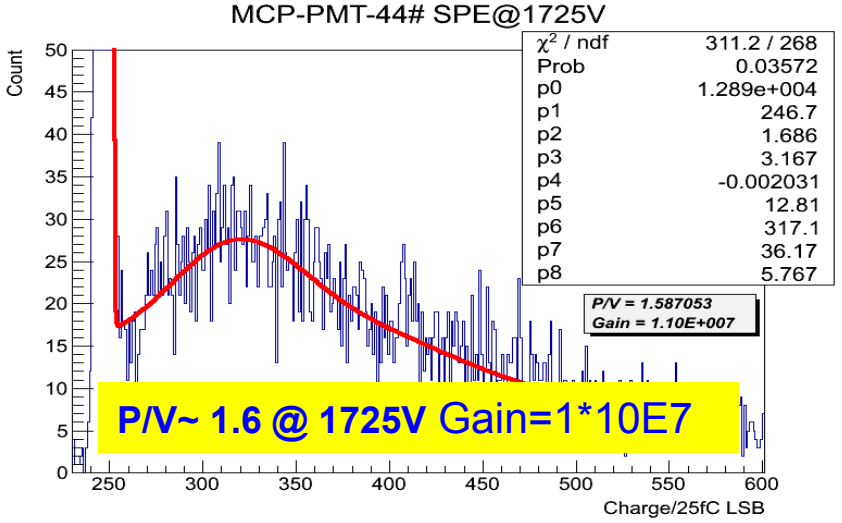


The Design MCP-PMT　　The Prototype

The signal of the 8 inch PMT



The Dark count ratio



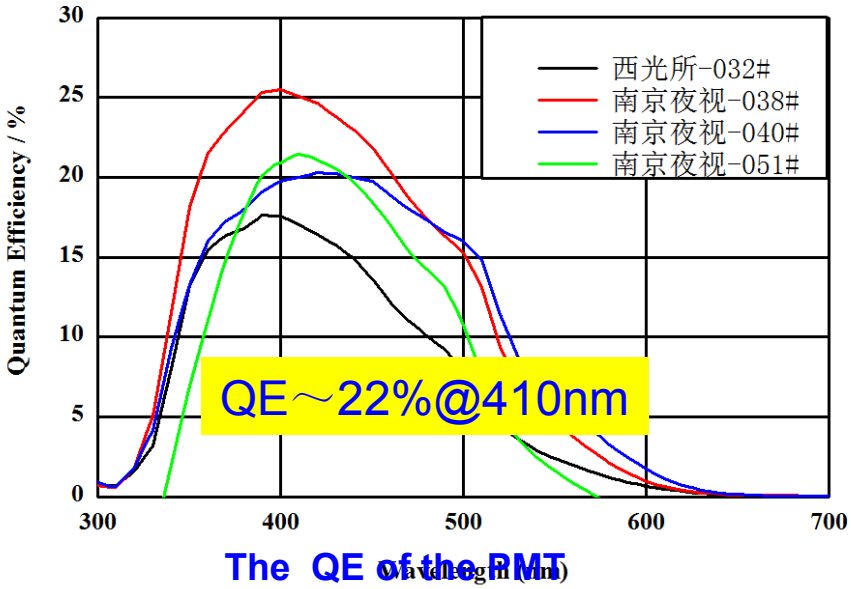
The SPE of the PMT

➢ The 20 inch Prototype (051#) with Vertical MCPs

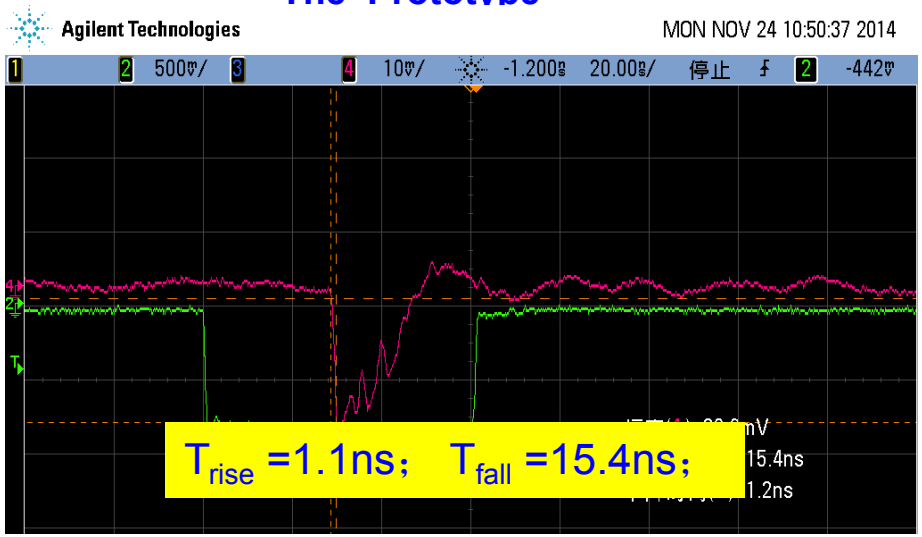
This is the first 20” (two MCP modules) prototype for SPE by transmission equipment

The Design MCP-PMT

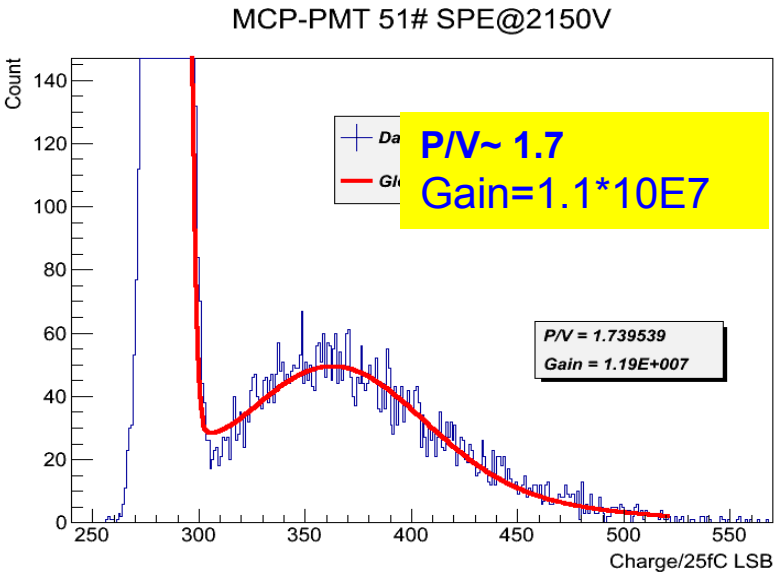
The Prototype



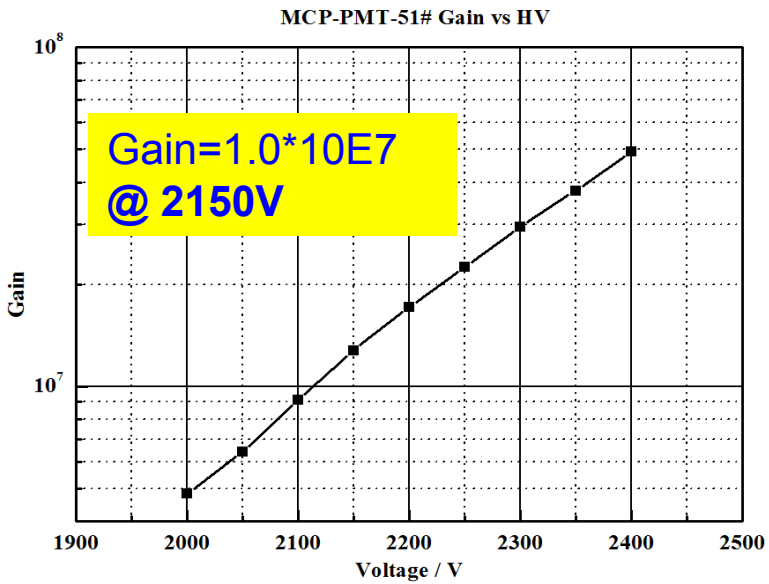
The QE of the PMT



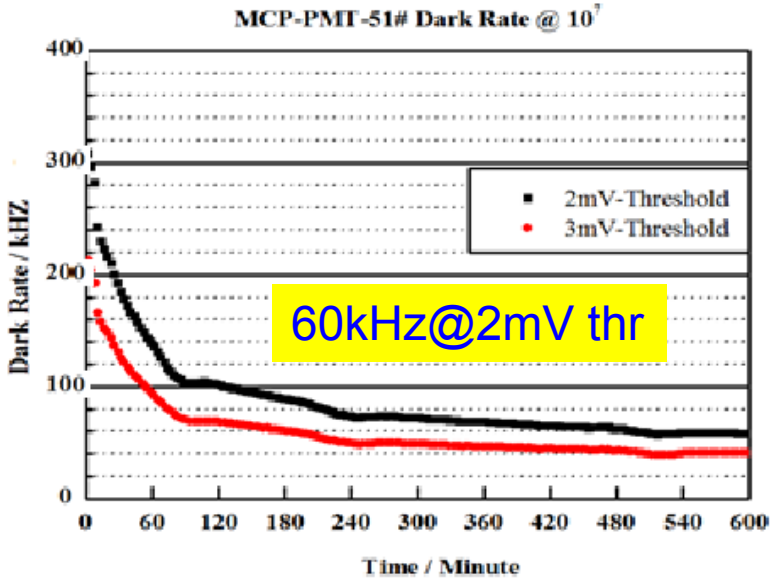
The signal of the 8 inch PMT



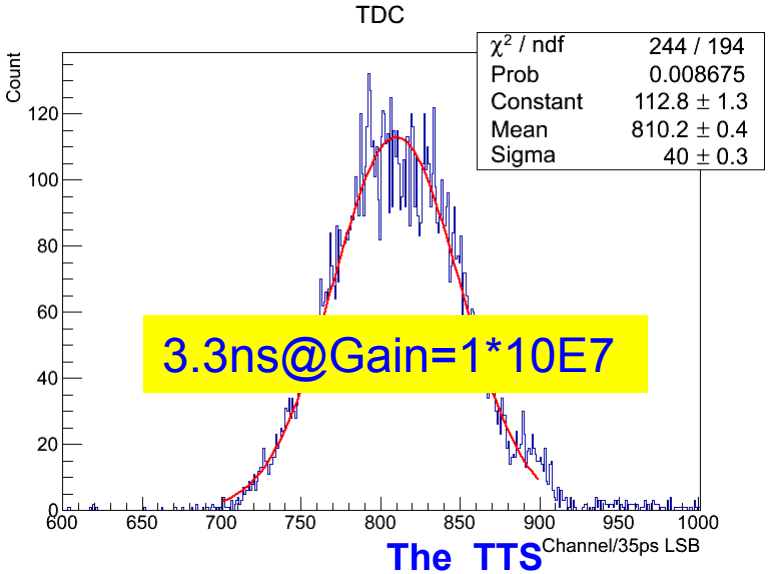
The SPE of the PMT



The HV-Gain curve



The Dark count ratio



The TTS

➢ The performance of the PMT prototypes

Characteristics	**unit**	**R5912-100 (Hamamatsu)**	**MCP-PMT-8 (IHEP)**	**R3600 (Hamamatsu)**	**MCP-PMT-20 (IHEP)**
size	inch	8	**8**	20	**20**
Spectral Response	nm	300~650	**300~650**	300~650	**300~650**
Photocathode Material	--	Bialkali-SBA	**Bialkali**	Bialkali	**Bialkali**
Electron Multiplier	--	Dynode	**MCP**	Dynode	**MCP**
Gain	--	$\geq 1\times 10^7$	**$\geq 1\times 10^7$**	$\geq 1\times 10^7$	**$\geq 1\times 10^7$**
Photocathode mode	--	transmission	**reflection + transmission**	transmission	**reflection + transmission**
Quantum Efficiency（400nm）	%	35	**25 (35)**	25	**22 (?)**
Electron Multiplier Collection efficiency	%	~ 60%	~ 60%	~ 70%	~ 60%
Anode Dark Count	Hz	~10K	**~5K**	~50K	**~60K**
Anode Pulse Rise Time	ns	3.8	**≤ 2**	6	**≤2**
Transit Time Spread (TTS)	ns	~2.4	**≤3?**	~3.5	**≤3?**
Anti-Magnetic characteristics	--	**normal**	**normal**	**normal**	**normal**
Glass	--	Low-Potassium Glass	**Low-Potassium Glass**	HARIO-32	**Low-Potassium Glass-**

Outline

- 1. The JUNO and the new MCP-PMT;
- 2. The progress of the R&D process;
- 3. The performance of the MCP-PMT prototype;
- **4. Attempt to improve the performance of the prototype;**
- 5. Summary and Plan

➢ 3.0. The challenge from Hamamatsu

New 20-inch photodetectors

- Hamamatsu Photonics is developing 2 new 20-inch photodetectors of HPD and PMT with box and line dynode type.

Model	R3600 (Used for 2-30 yrs)	R12850 (Under development)	R12860 (Under development)	
C.E.	80%	95%	93%	Calculated value in simulation
T.T.S. (FWHM)	5.5 ns	0.75ns (w/o Preamp.)	2.7 ns	
Bias voltage	2 kV bias	8 kV bias, 20mm ϕ AD	2 kV bias	

- Prototype of the 2 photodetectors will be ready within half a year, and its performance and feasibility are tested in the water tank.

R3600

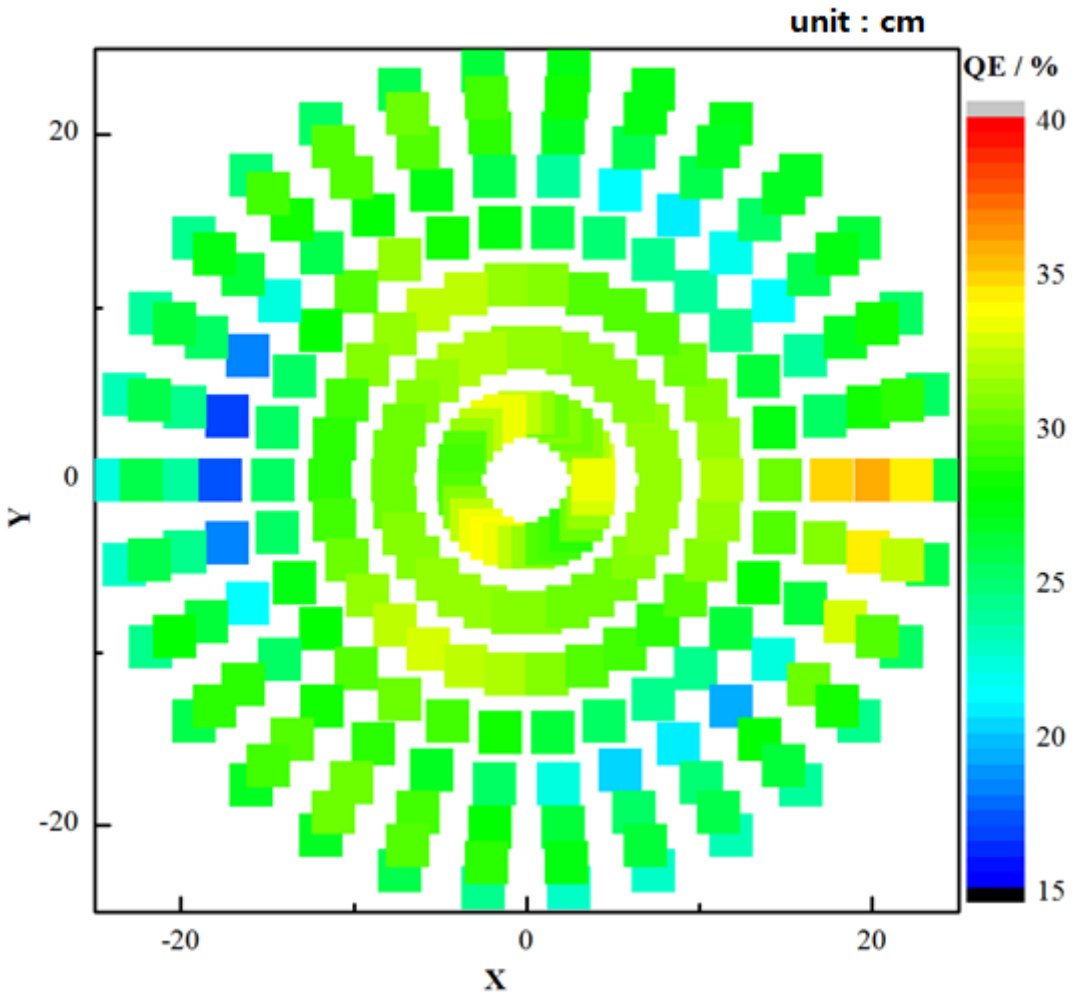
R12860

for better: QE: 25% → 33%

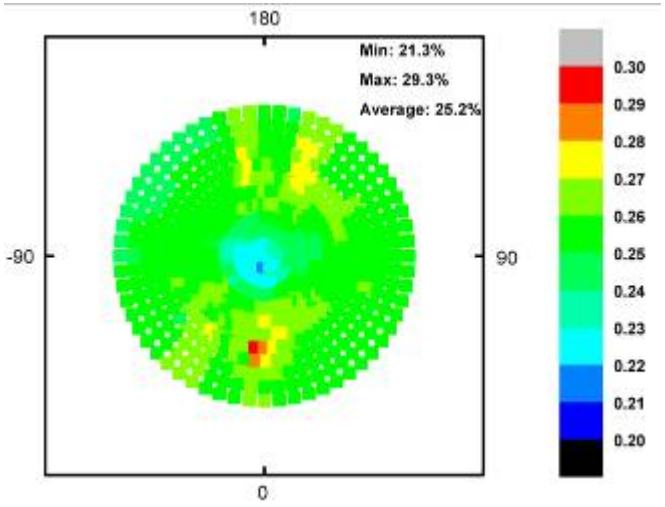
:CE 70%→ 90%

➢3.2. How to improve the Uniformity of the PC

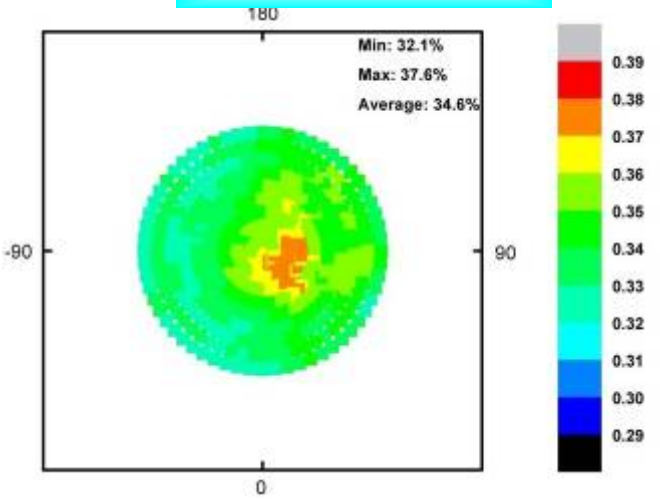
20”- R12860



8”- MCP-PMT-035#



8”-- R5912-100



We try our best to improve the uniformity of the photocathode in large area prototype. Using the Transmission equipment would be the best choice.

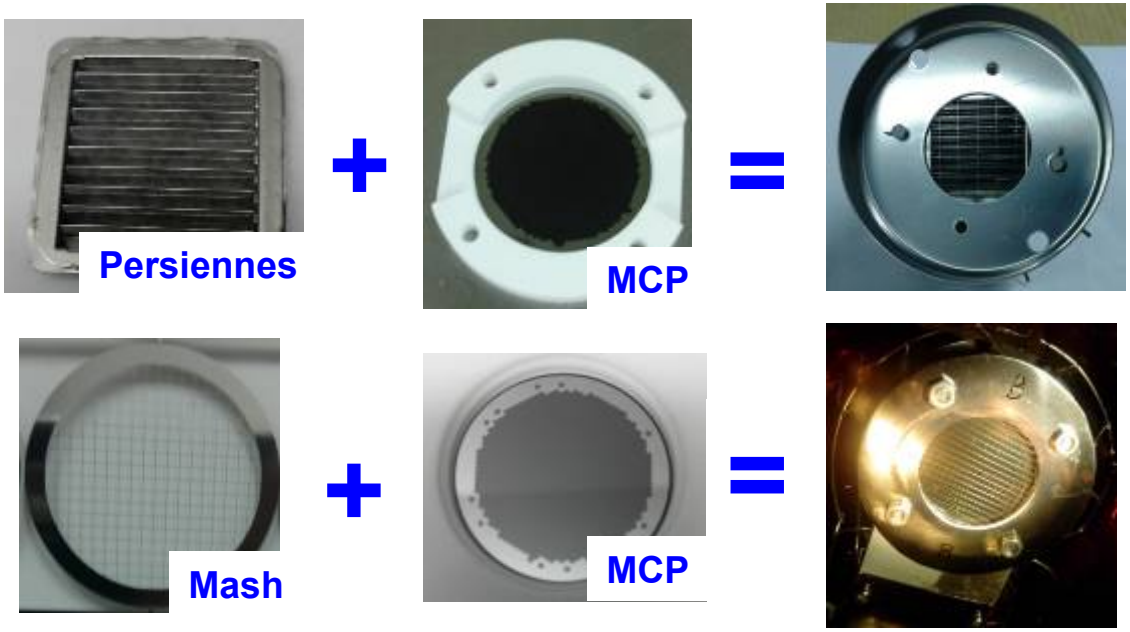
➢ 3.2. How to improve the CE of the MCP module

In order to improve the performance of the MCP module (better CE, P/V,……):

1. Different types of MCPs were produced:

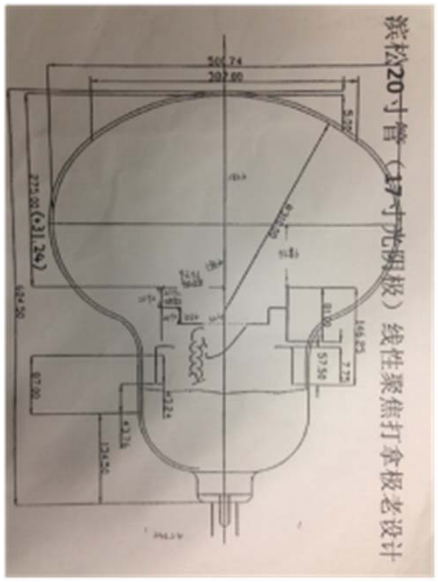
The Diameter of the MCP: **33mm; 56mm;**
The Diameter of the Hole: **6um; 8um; 10um; 12um**;
The Inclined Angle: **0°； 8°； 12°**；
The Open Area Ratio: **60%；77%**；
The Depth of output electrode:……

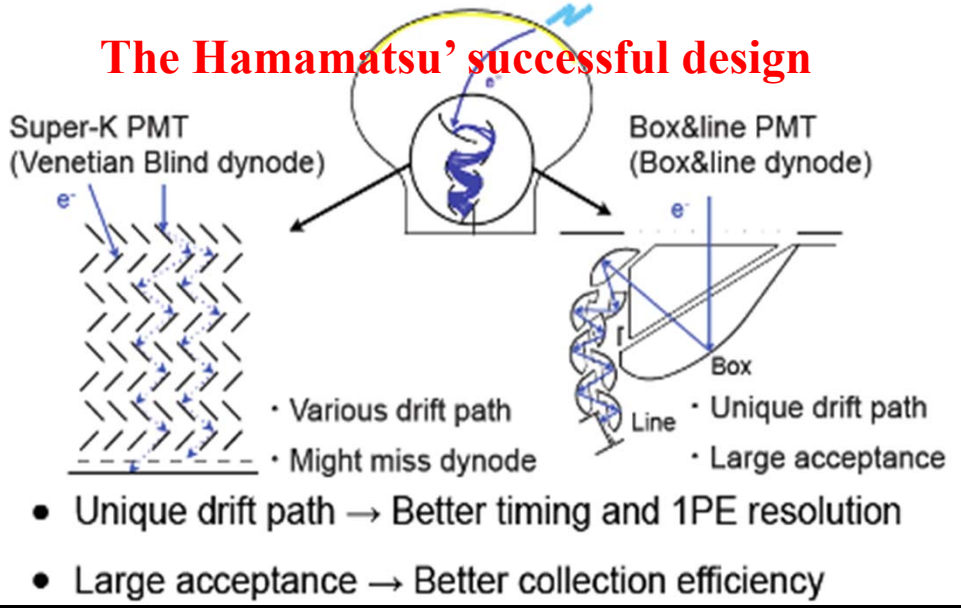
2. Different structure of MCP modules were produced:

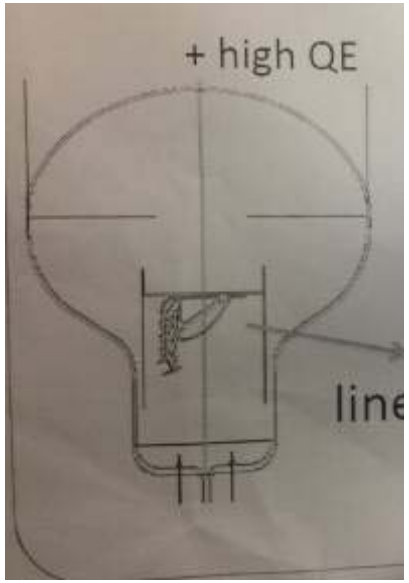


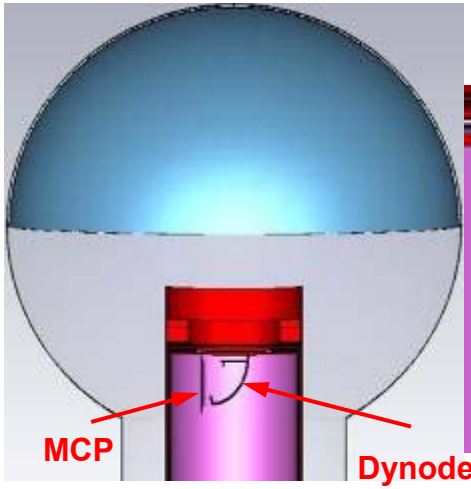
MCP module in 20” PMT

➢ 3.3. How to improve the performance by Electron-Optics

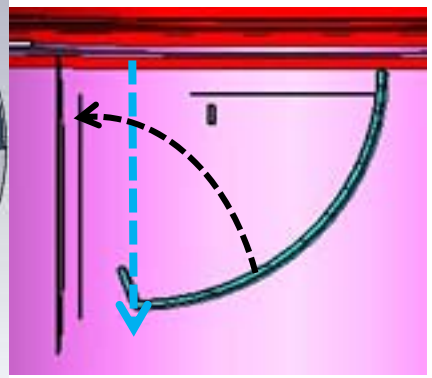


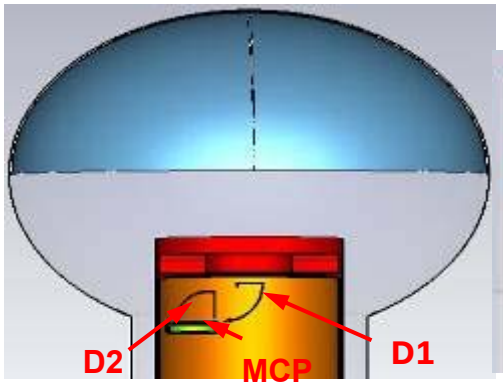




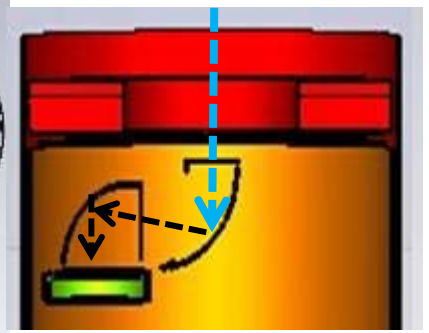


1 Dynode + MCPs





2 Dynodes + MCPs



As the Hamamatsu improved their design of the Dynode from **Venetian Blind** to **Box & Line dynode**，we also simulate the structure with Dynode + MCPs, for better CE and P/V ability **(just the simulation work).**

The performance of the 20 inch prototypes

Characteristics	unit	R3600 (Hamamatsu)	MCP-PMT-20 (IHEP)	R12860 (Hamamatsu)	MCP-PMT-20 (IHEP)
ststus		Finished	Finished	Finished	Plan
size	inch	20	20	20	20
Spectral Response	nm	300~650	300~650	300~650	300~650
Photocathode Material	--	Bialkali-HQE	Bialkali	Bialkali-HQE	Bialkali
Electron Multiplier	--	Dynode	MCP	Dynode	MCP
Gain	--	$\geq 1\times 10^7$	$\geq 1\times 10^7$	$\geq 1\times 10^7$	$\geq 1\times 10^7$
Photocathode mode	**--**	**transmission**	**reflection + transmission**	**transmission**	**reflection + transmission**
Quantum Efficiency（400nm）	**%**	**25**	**22 (?)**	**32**	**35 (?)**
Electron Multiplier Collection efficiency	**%**	**~ 90%**	**~ 60%**	**~ 90%**	**~ 80%**
Anode Dark Count	**Hz**	**~50K**	**~60K**	**~50K**	**~50K**
Glass	**--**	**HARIO-32**	**Low-Potassium Glass-**	**HARIO-32**	**Low-Potassium Glass-**

Outline

- 1. The JUNO and the new MCP-PMT;
- 2. The progress of the R&D process;
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Summary

- **1. A new type of MCP-PMT is designed for the next generation neutrino exp.**
  - ✓ Large ares: ~ 20";
  - ✓ High photon detection efficiency: ~30%, at least ×2 than normal PMT;
  - ✓ Low cost: ~ low cost MCPs;
- **2. The R&D process is composing with 3 steps.**
  - ① 5"(8") prototype with transmission photocathode;(**2010-2011**)
  - ② 5"(8") prototype with transmission and reflection photocathode; (**2012-2013**)
  - ③ 20" prototype with transmission and reflection photocathode; (**2014-2015**)
- **3. The R&D work is divided into 6 Parts to product the prototype to detect SPE:**
  - ①Photocathode; ②MCP; ③Glass; ④Photomultiplier;
  - ⑤vacuum equipment; ⑥PreAMP & Base;

- **MCP-PMT development:**
- **Technical issues mostly resolved;**
- **Successful 8” and 20”prototypes with normal performance;**
- **Three types of 8” prototypes;**
- QE ~ 25%@410nm; CE ~ 60%;
- P/V of SPE > 2.0;
- Dark count and dark current could be reduced by the transformed equipment;
- The QE uniformity could be increased by the transformed equipment;
- The After Pulse ratio really small;
- The CE and the uniformity of CE need be improved later;
- **Two types of 20” prototypes;**
- QE ~ 22%@410nm; CE ~ 60%;
- P/V of SPE > 2.0;
- SPE and QE uniformity were better than 8inch for using the transformed equipment;
- QE and CE uniformity need to be improved!
- **The better performance Prototype should be produced!;**
- QE ~ 35%@410nm; CE ~ 80%;

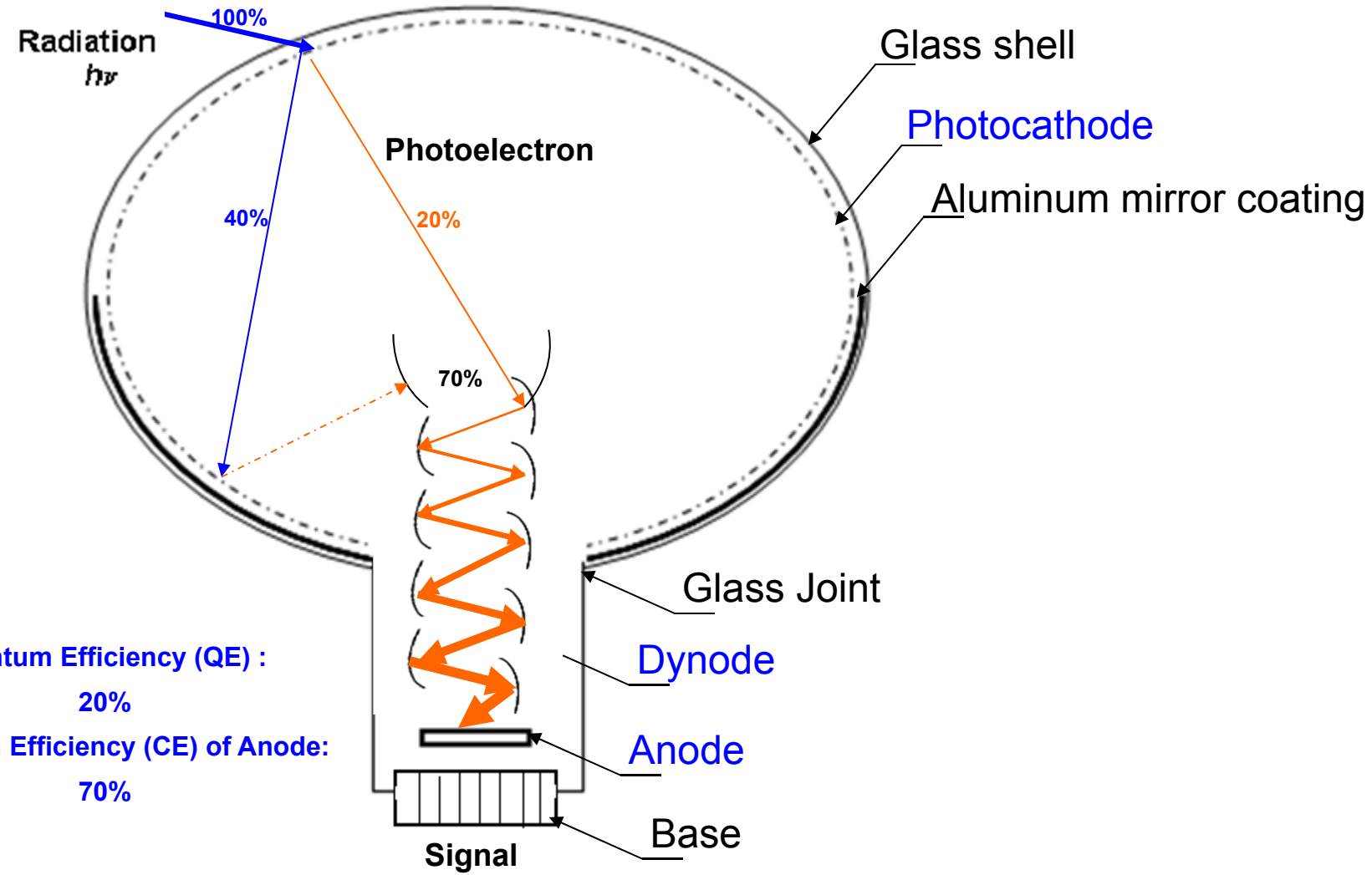
Thank！谢谢！

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


Welcome to Kaiping

Jiangmen Underground Neutrino Observatory (JUNO)

The Conventional PMT



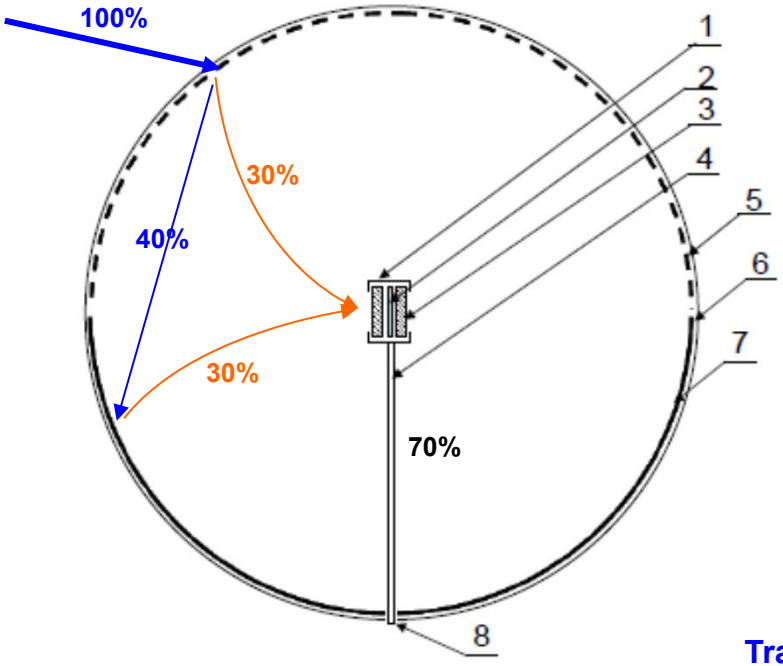
Photon Detection Efficiency (PE)= QE_{Trans} * CE = 20% * 70% = 14%

➢ The new design of a large area PMT

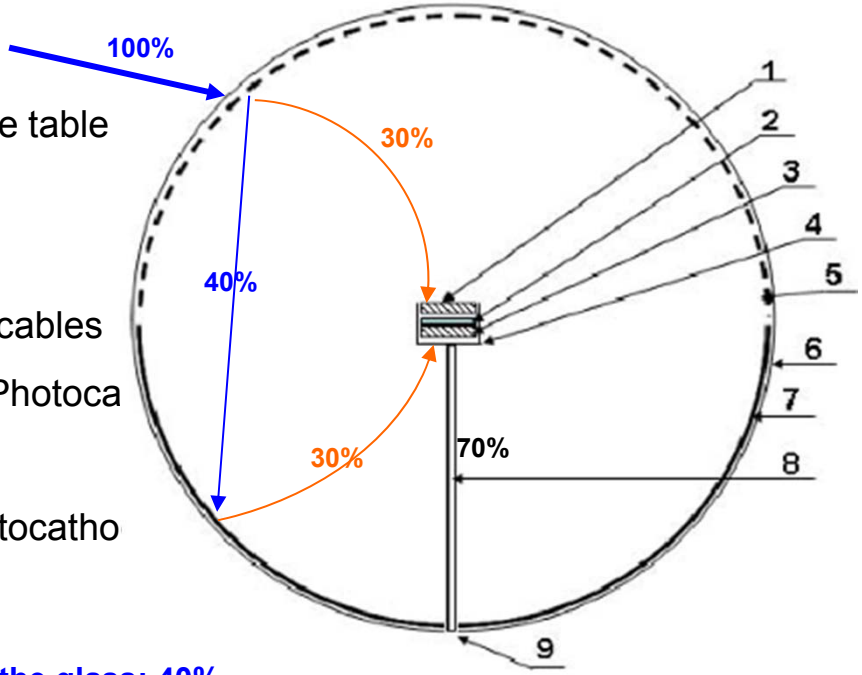
High photon detection efficiency + Single photoelectron Detection + Low cost

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

2) Using transmission photocathode (front hemisphere) and reflection photocathode (back hemisphere) } **~ 4π viewing angle!**



1.Insulated trestle table
2.Anode
3.MCP dodule
4.Bracket of the cables
5.Transmission Photoca
6.Glass shell
7.Reflection Photocatho
8.Glass joint



Transmission rate of the glass: 40%

Quantum Efficiency (QE) : of Transmission Photocathode 30% ; of Reflection Photocathode 30% ;

Collection Efficiency (CE) of MCP : 70%;

$$PD = QE_{Trans} * CE + TR_{Photo} QE_{Ref} * CE = 30\% * 70\% + 40\% * 30\% * 70\% = 30\%$$

Photon Detection Efficiency: 15% → 30% ; ×~2 at least !