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 Large Area MCP-PMT for Neutrino Detector

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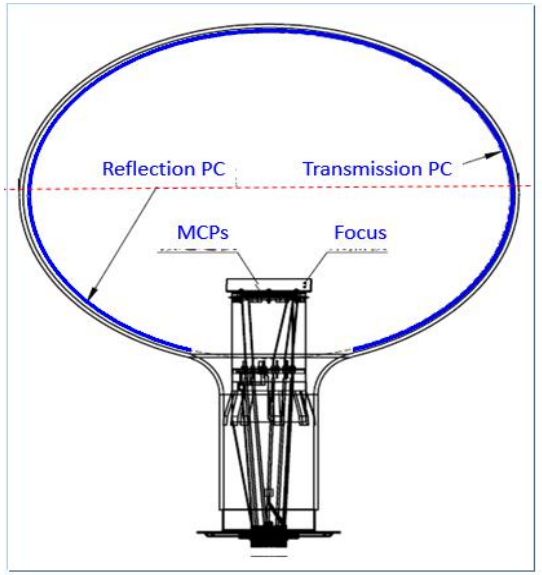
28th. July. 2020

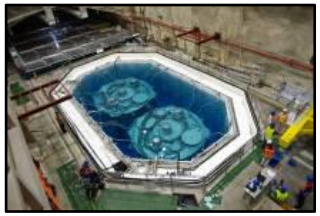
28 July 2020 to 6 August 2020 virtual conference

Outline

- I. The Motivation of the New MCP-PMTs;
- II. The R&D of 20 inch MCP-PMTs for JUNO;
- III. The Mass production of the 20 inch MCP-PMT;
- IV. The new design of the MCP-PMTs;



The Neutrino Experiment in China



Generation 1:

DayaBay:

~3,000 8-inch Dynode-PMTs

from Hamamatsu

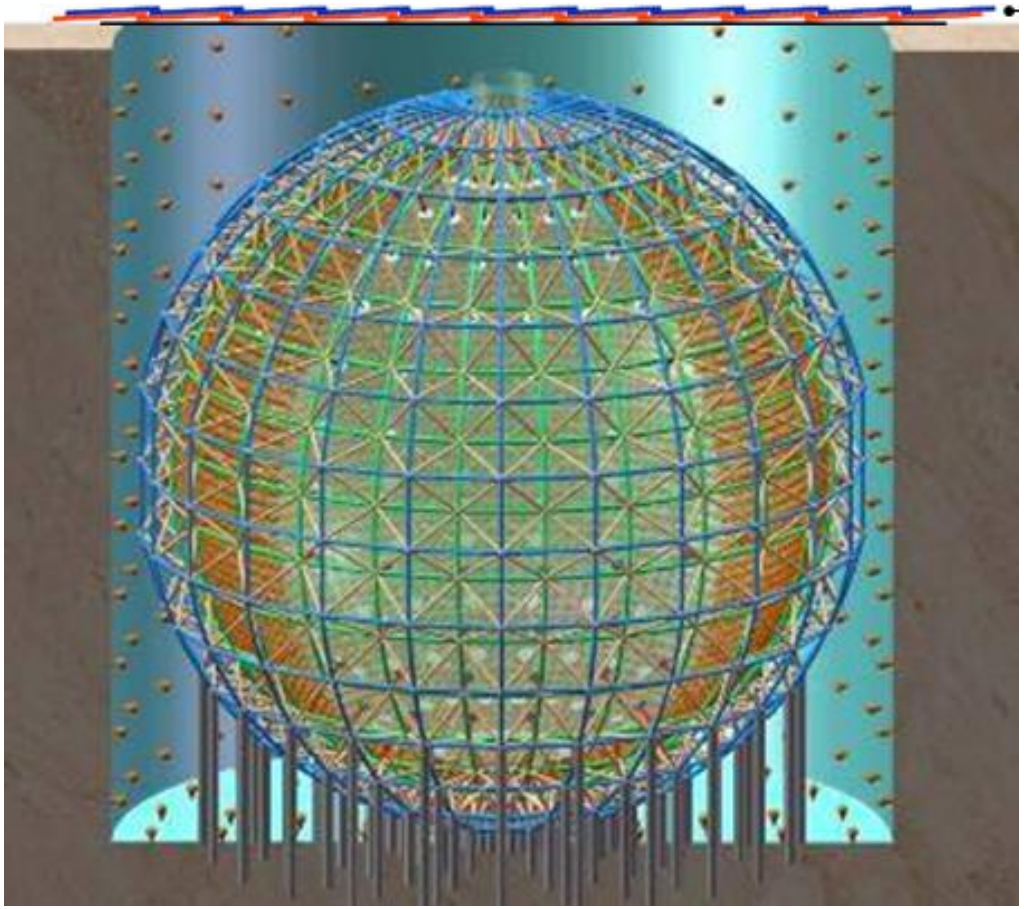
Generation 2:

JUNO:

~20,000 20-inch PMTs

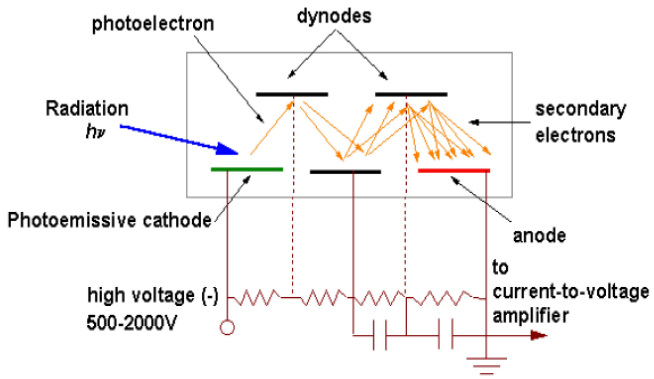
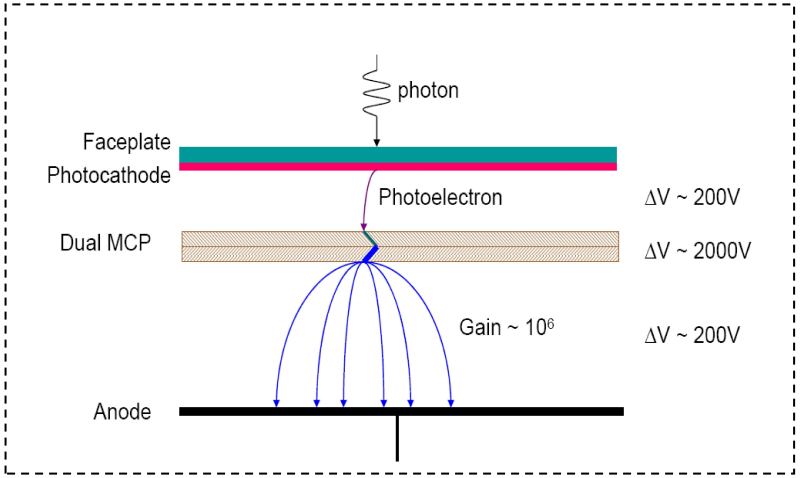
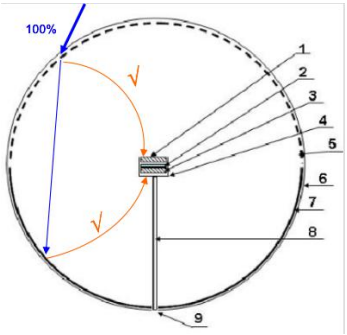
from Where?

➢ JUNO Experiment



	KamLAND	JUNO	Factor
Light yield	250 p.e./MeV	1200 p.e./MeV	5
Photocathode Area	34%	75%	2.2
PMT Detection Efficiency	20%*70% ~15%	30%	~ 2

➢ 1.2 The new design of a large area MCP-PMT

	Operation Principle	Small Size (proximity focusing)	Large Size (electrostatic focusing)
Dynode		2“ Dynode-PMT ✓ 	20“ Dynode-PMT ✓ 
MCP		1“ MCP-PMT ✓ 	20“ MCP-PMT ? 

IHEP design： Using two small sets of Microchannel plates (MCPs) to replace the large dynode chain，with high QE photocathode, and low cost!

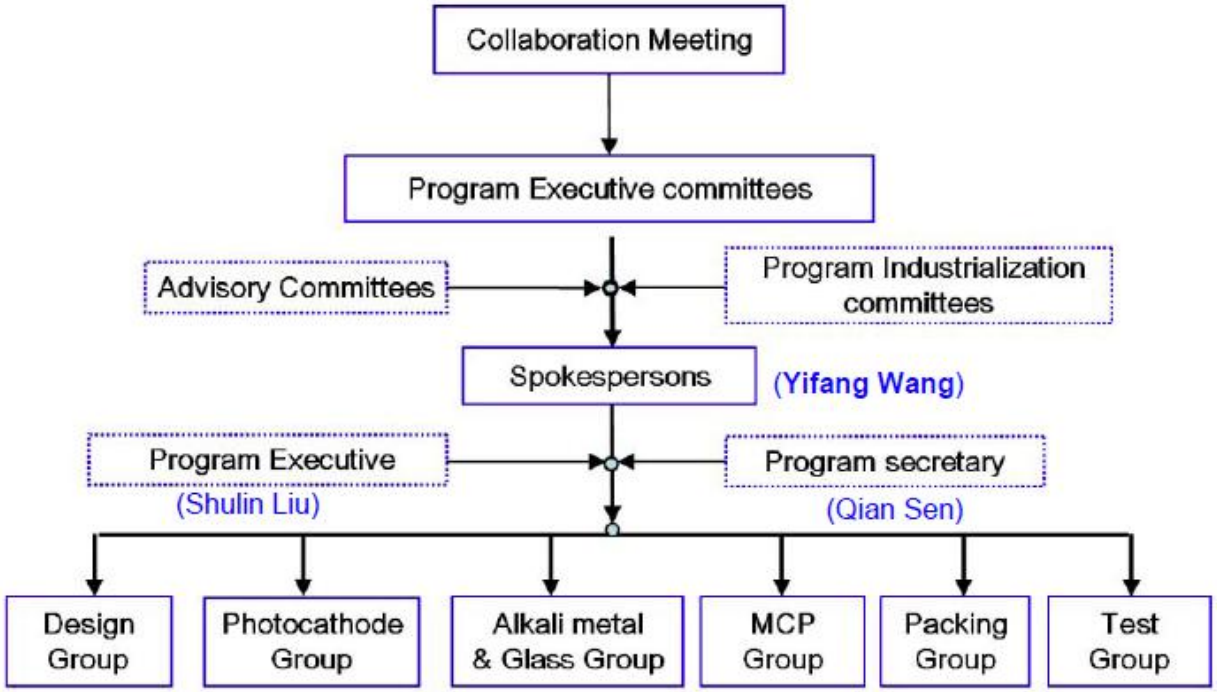
➢ 1.3 Project team and Collaborators

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

Institute of High Energy Physics, CAS

effort by **Yifang Wang;**

Microchannel-Plate-Based Large Area Photomultiplier Collaboration (MLAPC)



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中国科学院西安光学精密机械研究所
XIAN INSTITUTE OF OPTICS AND PRECISION MECHANICS OF CAS

中核（北京）核仪器厂
CNNC Beijing Nuclear Instrument Factory

南京大学

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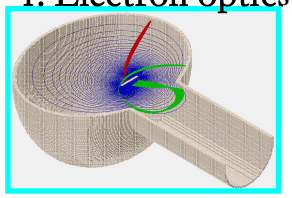
2.0 The Roadmap of the 20 inch MCP-PMT R&D

There are **4** Core technologies need to develop to produce this new type of 20 inch MCP-PMTs

1. Electron optics

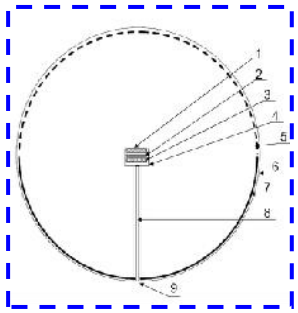


2.Glass shell

3. MCP module

4.Photocathode

0. New Design



Design 2009

2" MCP-PMT (2010)

8" MCP-PMT (2012-2013)

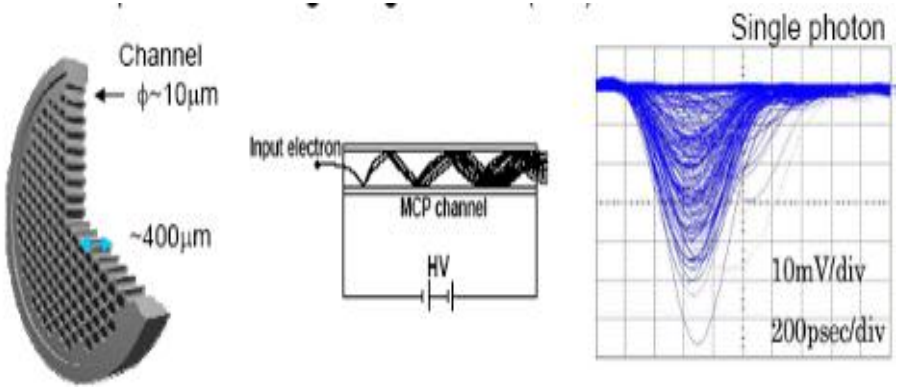
5" MCP-PMT (2011)

20" MCP-PMT (2015)

From 2010-2015，the prototyps with 2", 5",8" and 20" were produced, and the performance also were improved a lot for the good SPE test and High CE MCP modules.

➢ 2.1 The Electron optics design

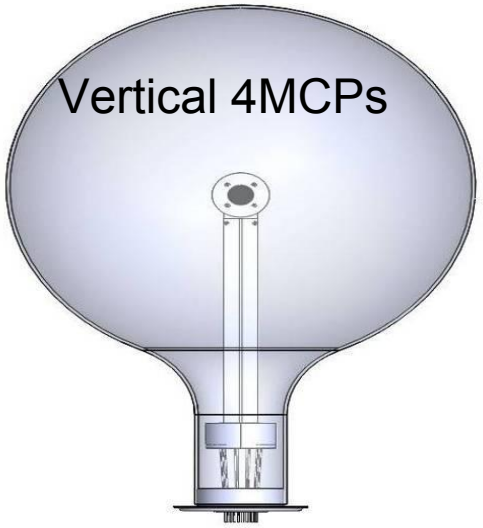
The principle of the MCP to amplify the electron



performance of the MCP:

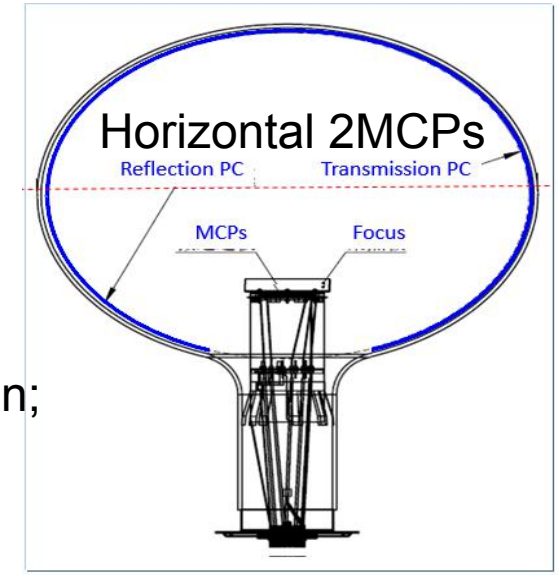
- ➢ High Gain： $1X10^4$ / 1 pic
- ➢ Small Size: Diameter=50mm
- ➢ Fast Signal：Rise time < 1ns

The perimal version in 2012 → **The final version in 2015**



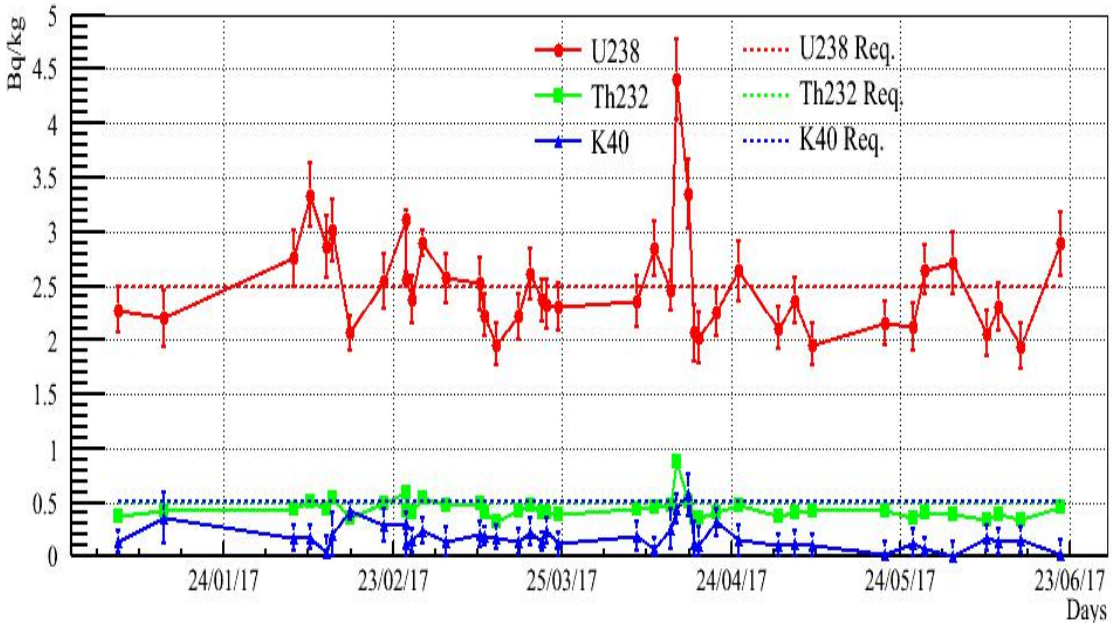
Why we change the construct?

- ➢ The crosstalk between the two MCPs modules;
- ➢ Need the different HV for the two MCPs module to get the same Gain;
- ➢ for better stable machine design；



➢ 2.2 The 20 inch Glass bulb

the radioactive test during the glass producing process

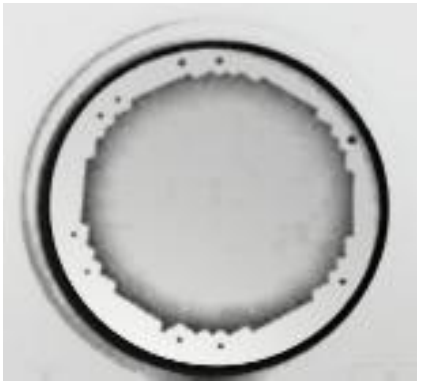


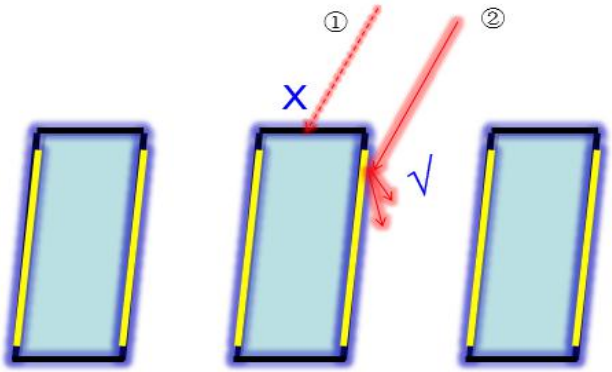
--> 20 inch Glass bulb was manual blowing by the skilled workers in China;

--> For better water compatible, using the hardness glass, transition Section(the thermal expansivity from 33 to 50) , welding with Kovar;

--> By controlling material, producing process and environment, **the radioactive background** of the glass was really low;

➢ 2.3 The MCPs module





CE = 70%

The p.e. into the channel directly ~70%

change

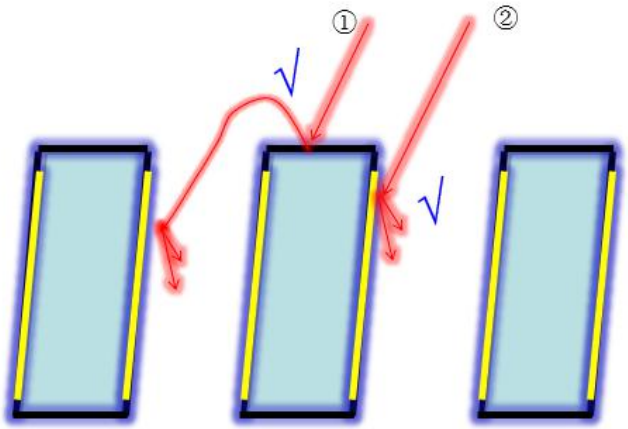
The Diameter of the MCP: **33mm; 50mm;**

The Diameter of the Hole: **6um; 8um; 10um; 12um;**

The Inclined Angle: **0°； 8°； 12°；**

The Open Area Ratio: 60%； 77%；

The Special Film by ALD for the same SEE material ……



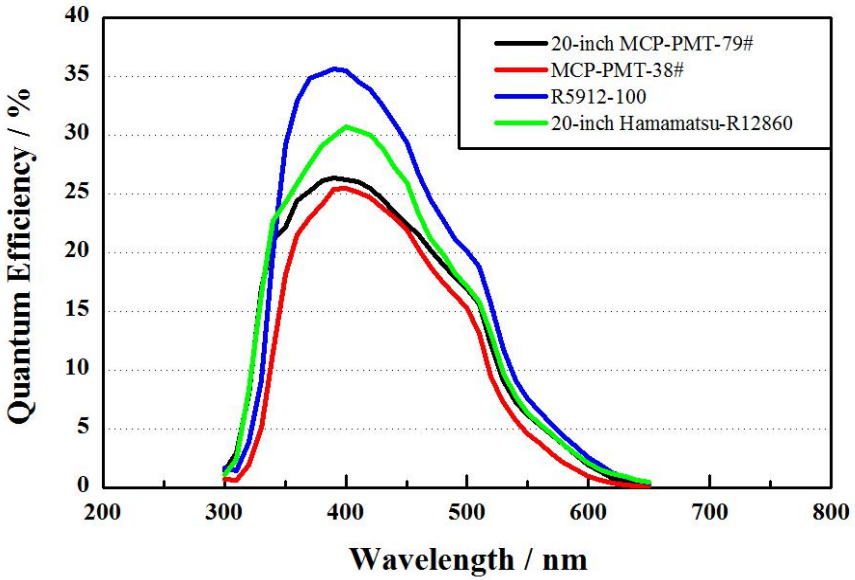
CE = 100%

The p.e. into the channel directly ~70%

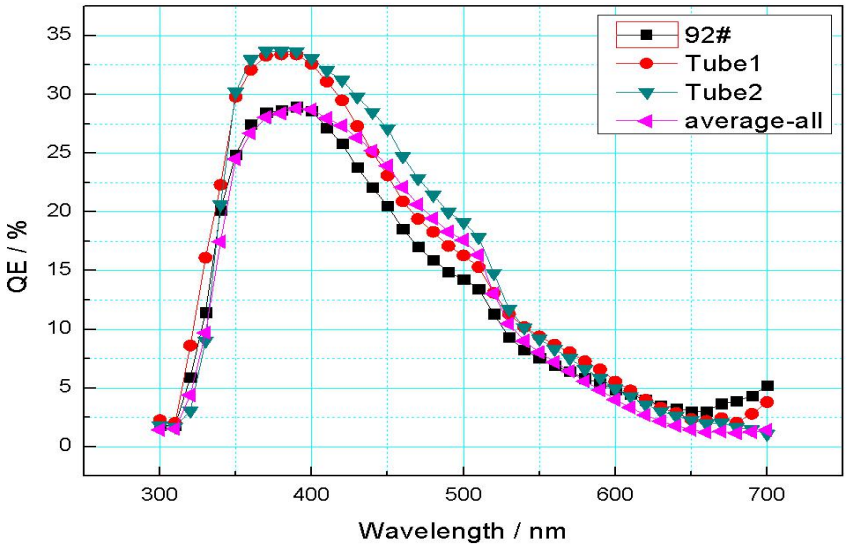
The p.e. from the electrod indirectly ~ 30%

➢ 2.4 The Photocathode

in 2017： 25% ----> 30%



in 2018： 30% ----> 35%



—During the mass production process, the IHEP&NNVT still do some research work to improve the QE of the photocathode of the MCP-PMTs;

—**In 2017**, Some HQE prototypes were produced with the QE larger than **30%.**

—**In 2018**, Some HQE prototypes were produced with the QE achiave to **35%.**

—The HQE photocathode is also the Bi-alkali PC, which peak wavelength is changing from 390nm to 380nm, just the Super-Bi-alkali (SBA);

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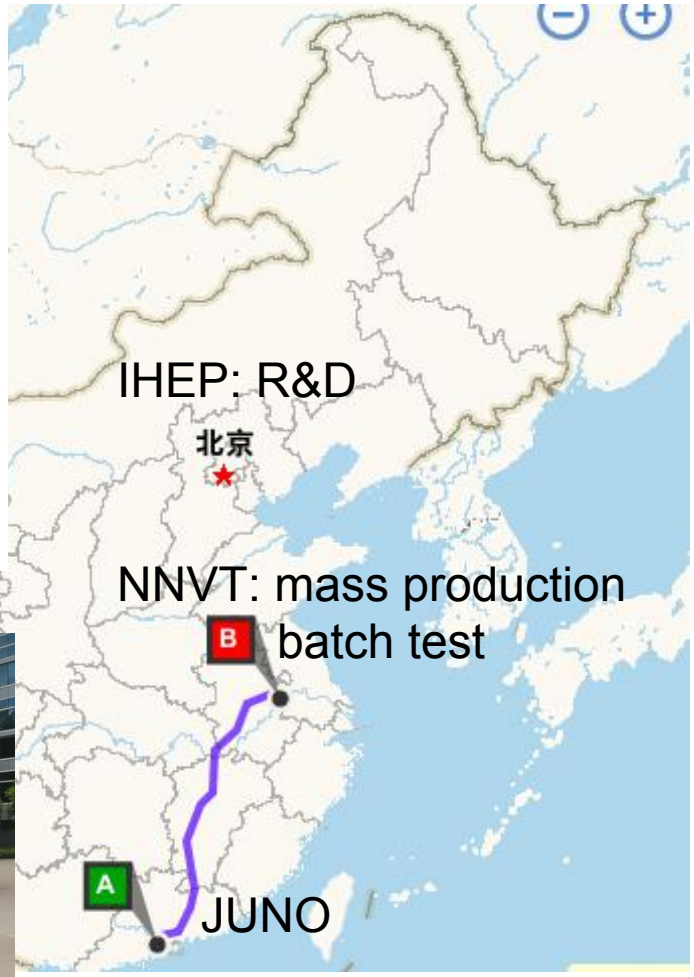
➢ 3.1 The Mass Production in NNVT

--The MCP-PMTs were produced in NNVT in Nanjing, and transfered by truck;
--The delivery time every 20days or 30days per time by a truck within 336 pics.

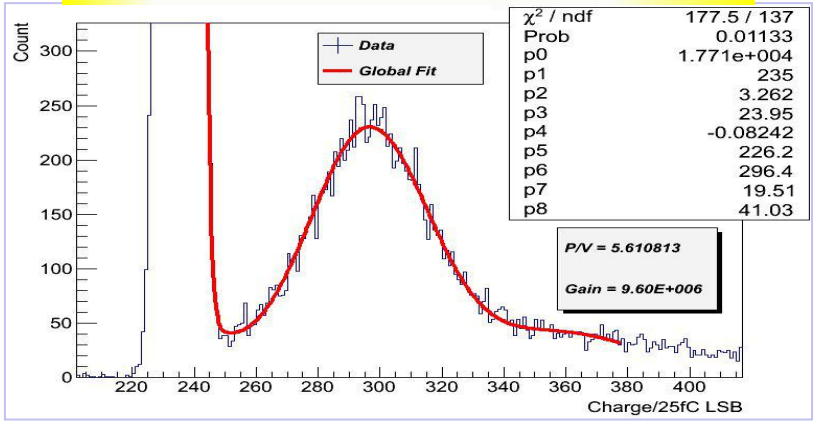
- ➢ 2009: New Design;
- ➢ 2010-2015: the R&D for the prototypes;
- ➢ 2016: Mass production line;
- ➢ 2017-2020: mass production & batch test;
- ➢ 2017.05.17: the 1st delivery 336 pics;
- ➢ ---------
- ➢ 2020.08.07: The 45th delivery 15000 Pics



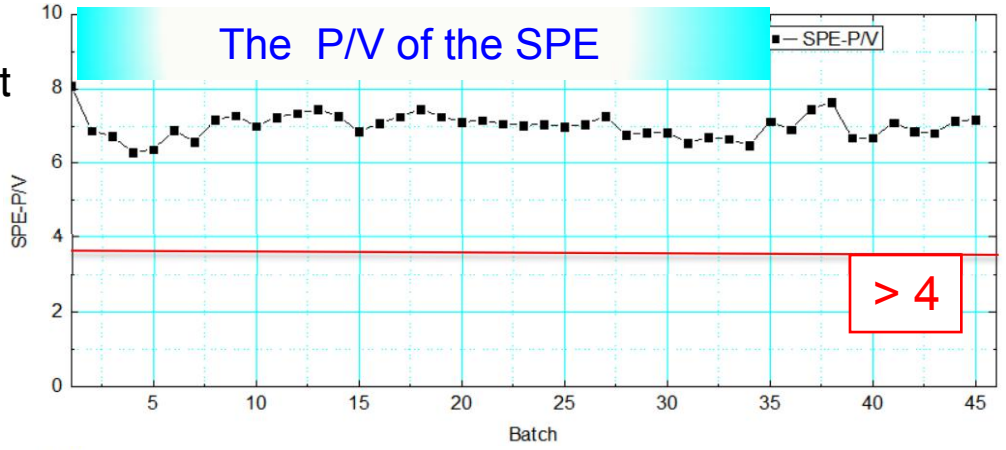
——The **Single PhotoElectron** Spectrum reflect the **Anode Performance** of the PMT.

——From the data of SPE of the Aonde, can get other data of P/V, ER, Gain and so on.

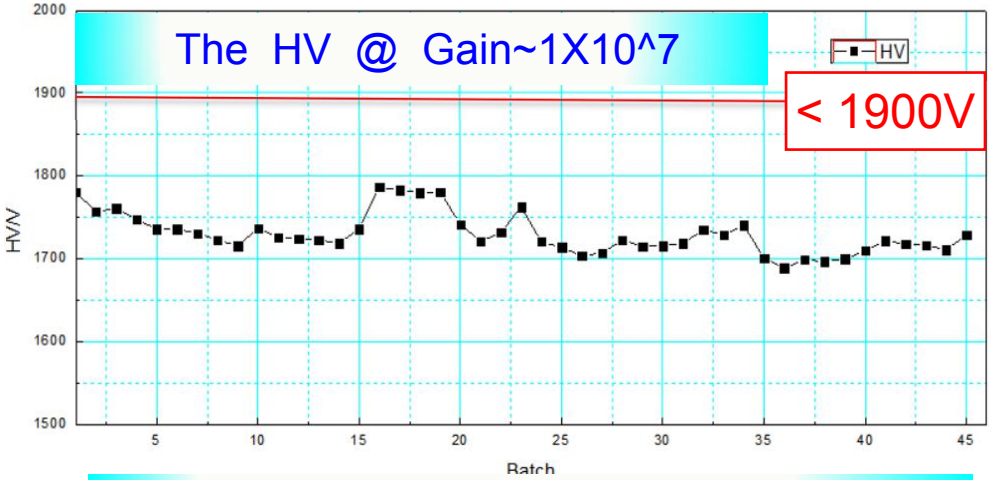
The SPE of the Prototype



The P/V of the SPE



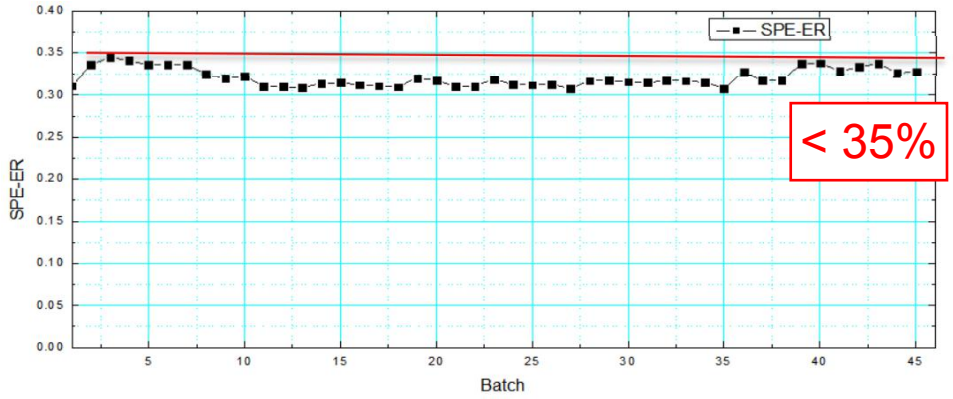
The HV @ Gain~1X10^7



——The performance of the P/V and Energy Resolution the SPE, the Gain were affected by the quality of the MCPs.

—— With different production batches of MCPs, these parameters has slight fluctuations, but were controled within the target range.

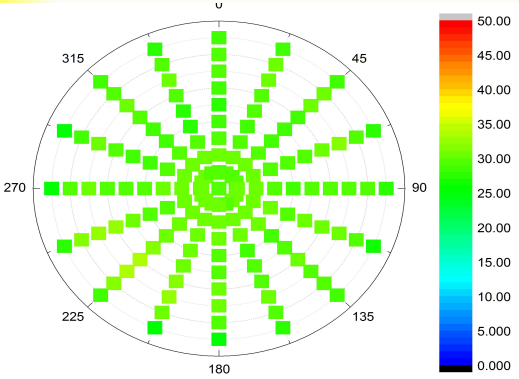
The Energy Resolution of the SPE



——The **Quantum Efficiency** reflect the **Photocathode Performance** of PMT.

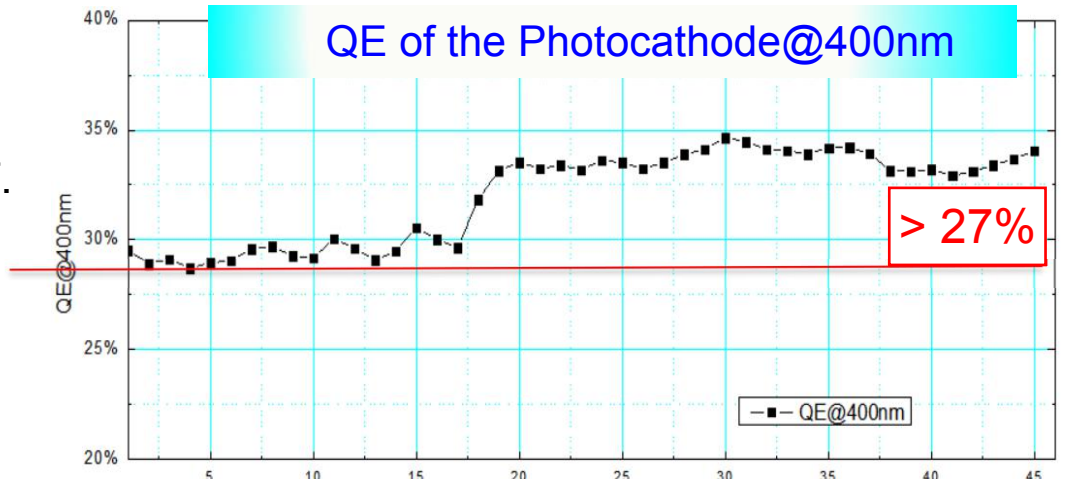
——For the large erea photocathode, the Uniformity of the QE is very important.

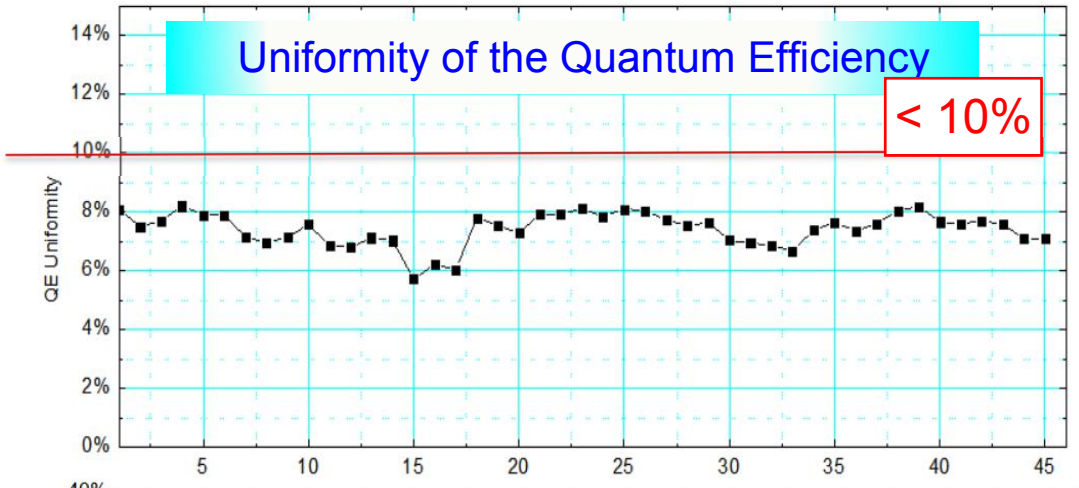
The Quantum Efficiency Map

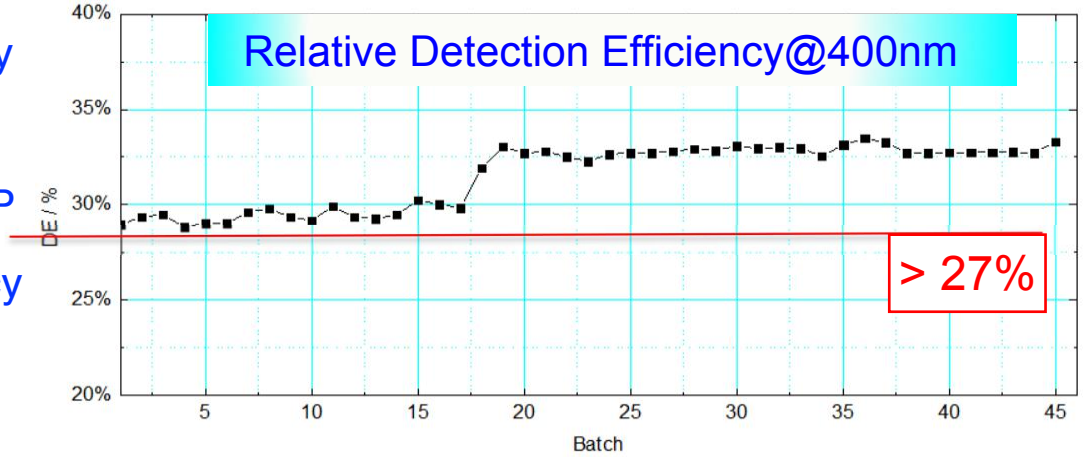


——During the production process, the company is still improving the technology of photocathode from 30%->35%.

—— The Collection Efficiency of the MCP is about 100%, so the Detection Efficiency is directly related to the QE.







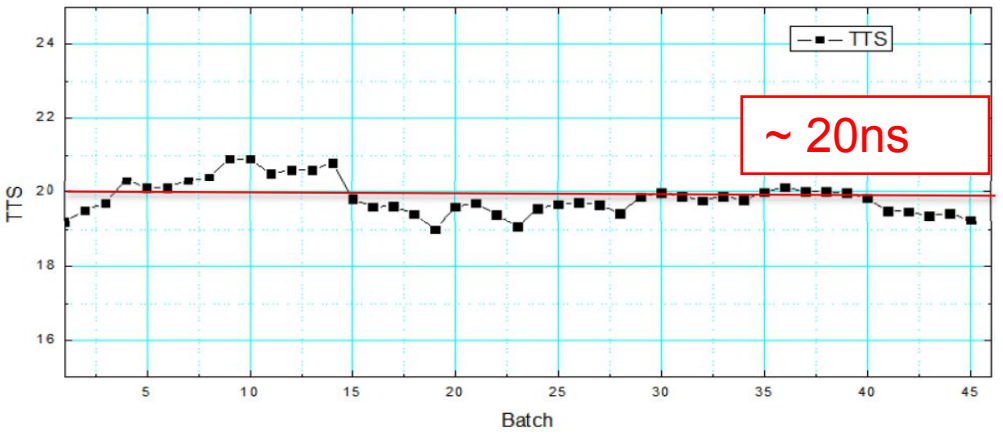
——The **Waveform** of the signal reflect the **Total Performance** of the PMT.

——From the waveform by the Oscilloscope, can get the **timing characteristic** of PMT

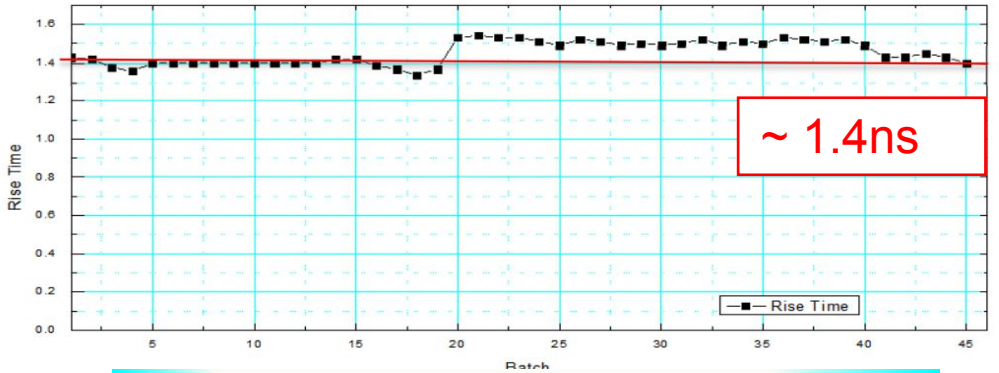
The Waveform of the Prototype

——THe timing performance of the PMT affected by the construction of the MCP-PMT. without any change of the PMTs, the data of these timing parameters keep in keep steady during the whole producing precess.

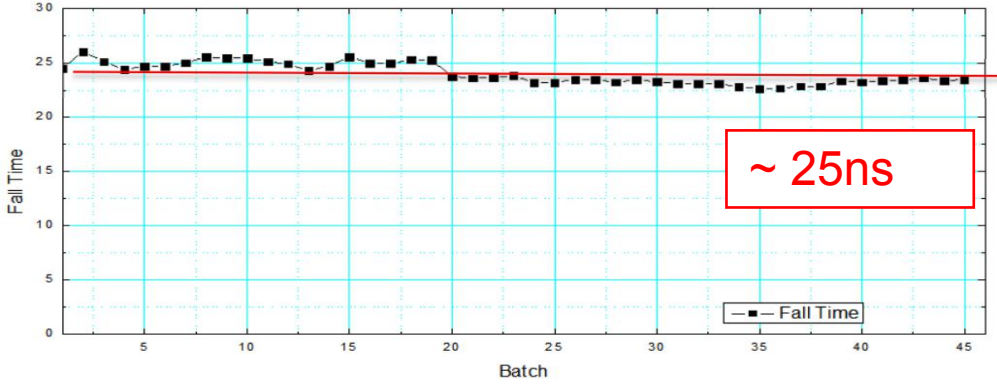
The TTS of the Prototype



The Rise time of the Prototype



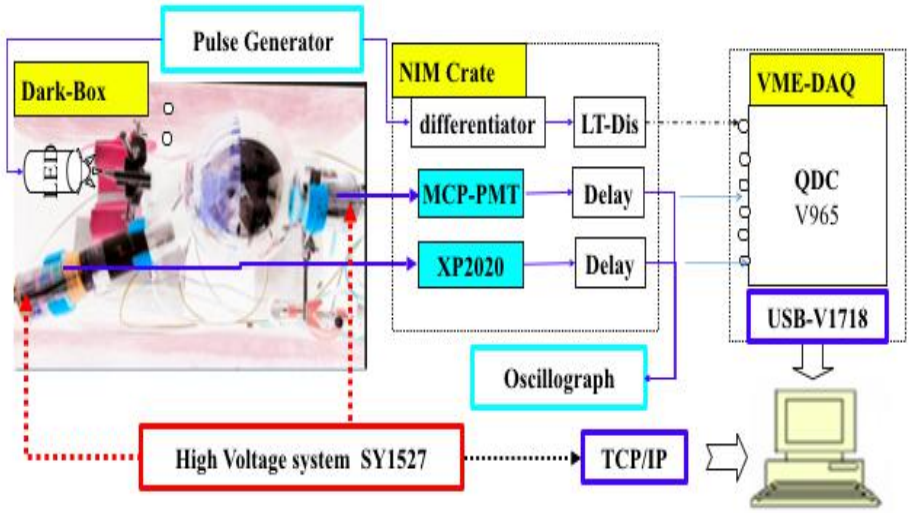
The Fall time of the Prototype



➢ 3.2 the MCP-PMT parameters Test in NNVT for JUNO

Characteristics （20inch）	unit	MCP-PMT Prototype（IHEP）	MCP-PMTs 15K pieces（NNVT）
Electron Multiplier	--	MCP	MCP
Photocathode Mode	--	reflection+ transmission	reflection+ transmission
Quantum Efficiency（400nm）	%	26 (T), 30 (T+R)	32%
Collection Efficiency		~99%	99%
Detection Efficiency（400nm）	**%**	**~ 27%**	**31.5%**
Detection Efficiency（420nm）	**%**	**--**	**28.3%**
P/V of SPE		＞ 5	7.1
TTS on the top point	ns	~15	~ 20
Rise time/ Fall time	ns	R~2 ， F~20	R~1.4 ， F~24
Anode Dark Rate	Hz	~30K	40K
After Pulse Time distribution	us	0.1， 4.5	0.2 , 0.8 , 3 , 4.5, 17
After Pulse Rate	%	2.5%	5.2%
Glass	--	Low-Potassium Glass	Low-Potassium Glass

➢ 3.3 The Aging behaviors of the MCP-PMT

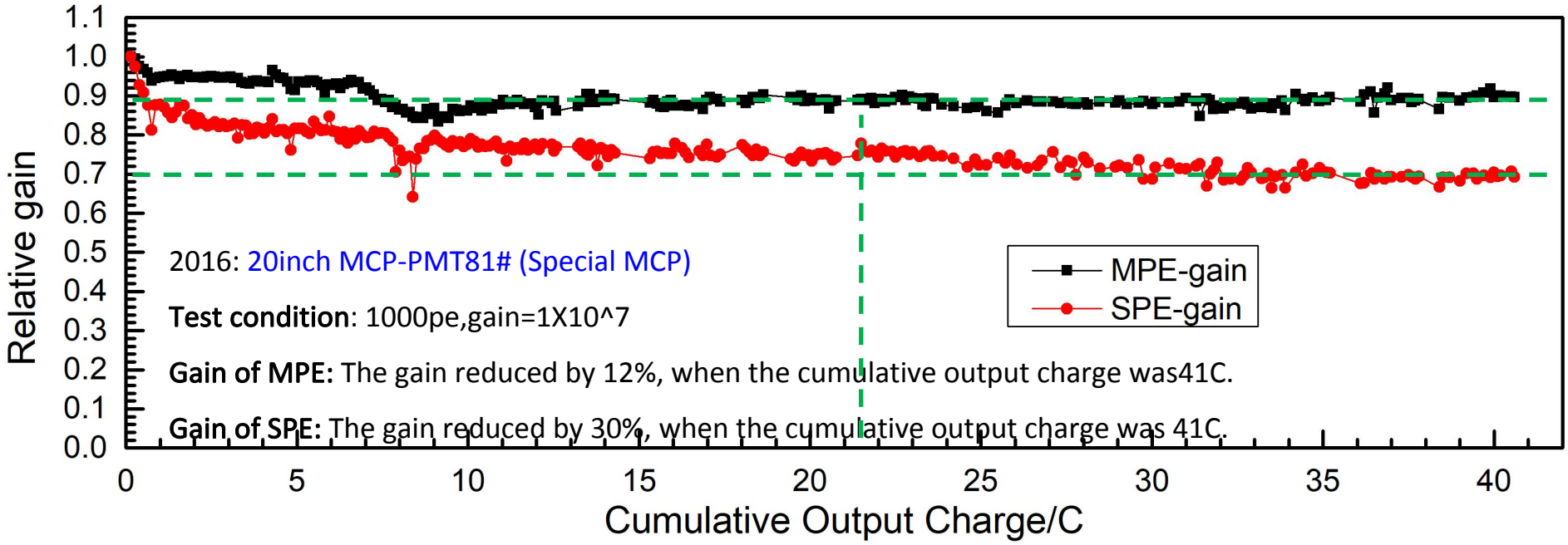


--> One 20 inch PMT was monitored within 1000 MPE for 1.5 year without stopping;

--> **The Aging behaviors could be acceptd by JUNO for 20 years operation;**

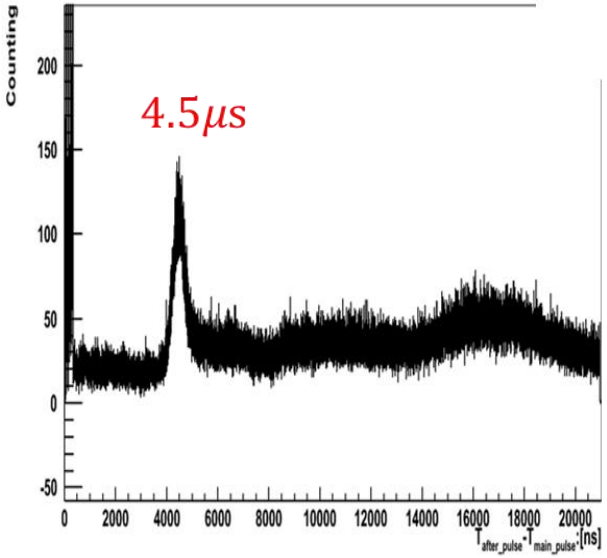
--> The lost gain could be enhanced by increasing the HV by less than 100V;

The performance of new type MCP-PMT was largely improved (420 days @ with operation 1000 pe)

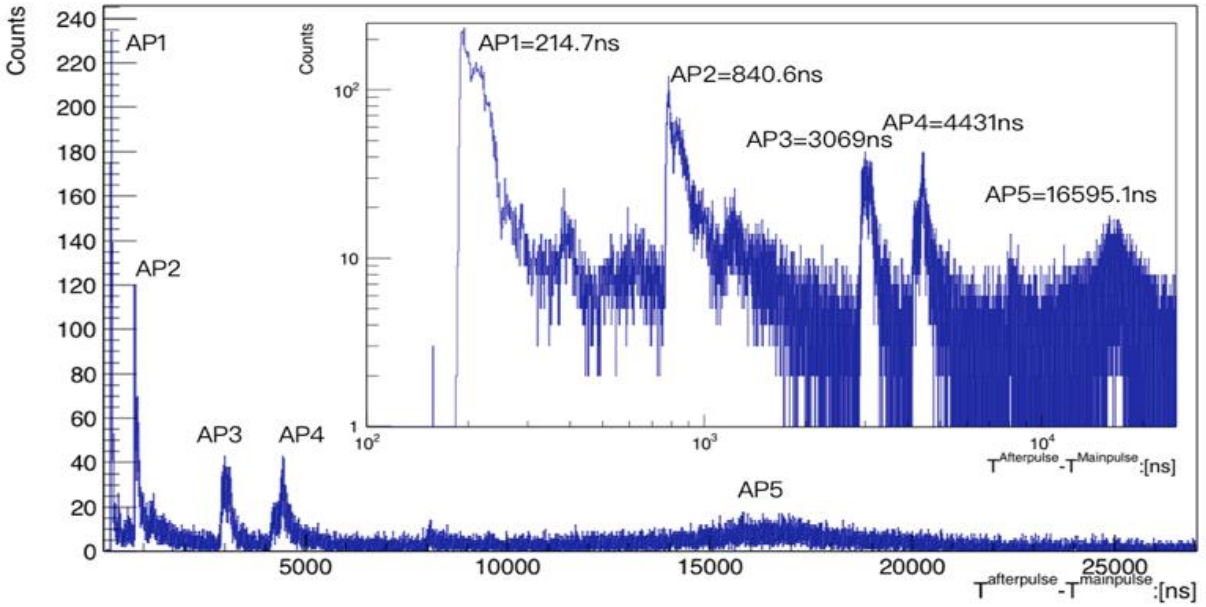


➢ 3.4 The After Pulse of the MCP-PMT

Low QE (25%) - MCP-PMT



High QE (35%) - MCP-PMT



After-pulse time distribution of the MCP-PMT prototype

——With the improvement of the High QE, the After-pulse was also changed a lot. The time distribution from 4.5us to five part (AP1=200ns, AP2=800ns, AP3=3us, AP4=4.5us, AP5=17us);

——AP1 is about 200ns after the main-pulse, caused by the back-scattered electrons on the outer surface of MCP; AP2~AP5 which are in the order of microseconds caused by different ions.

——**The APR of HQE PMT is about 5.2%,** but the low QE one only about 2.5% before.

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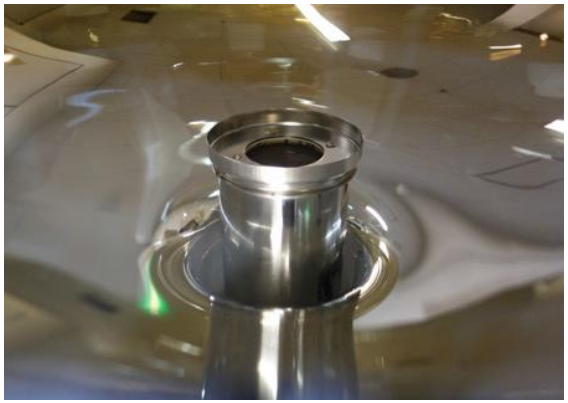
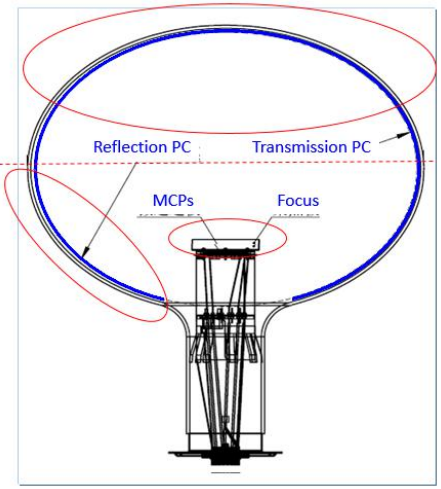
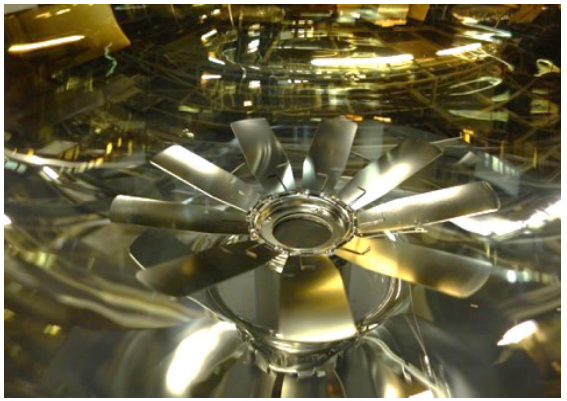
➢ 4.1 The New Prototype for better TTS

Normal focusing electrode





Flower-like focusing electrode

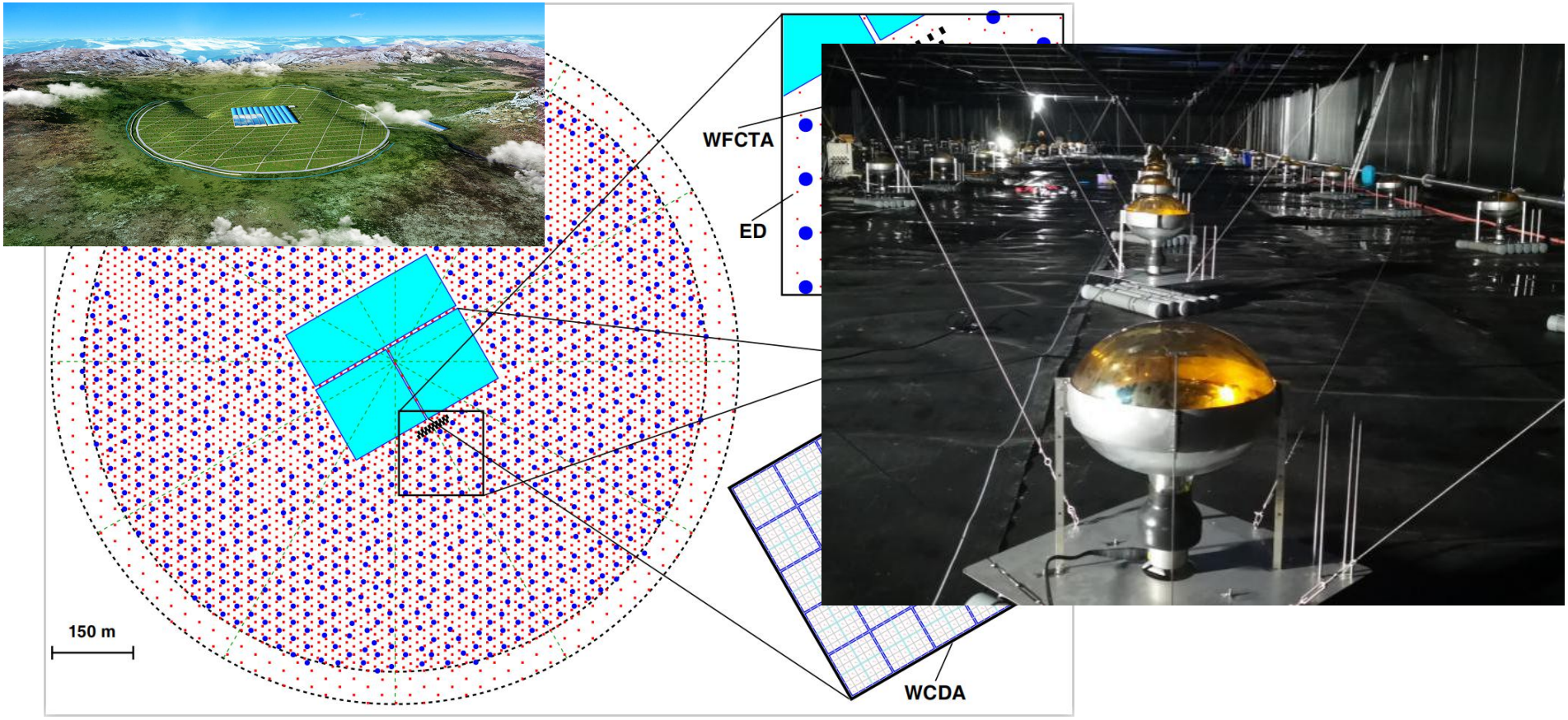


——By changing the constructer of the focusing electrode, using the flower-like one, the TTS of the PMTs is improving from 20ns to 5ns, but the CE of the prototype is decreasing to 85%,

——By decrease the area of the photocathode for better TTS, the dark rate of the PMT also much better than the normal one, from 40KHz to 20KHz.

Characteristics	Normal focusing electrode		Flower-like focusing electrode
QuantumEfficiency (400nm)	~30%	↓	~30%
Relativity Detection Efficiency	~ 100%	↓	85%
P/V of SPE	~ 7		~ 5
TTS on the top point	~20ns	↑	4.3 ns
Anode Dark Count	~40KHz	↑	~20KHz

➢ 4.2 The Flower-like-PMT for LHAASO



—LHAASO（**Large High Altitude Air Shower Observatory**), has already ordered 2270 pics 20" Flower-like-MCP-PMT.

—The 20 inch Prototype with potting has already post to the HyperK PMT Group in Tokyo University for the testing.

—The performance are different from the tubes for JUNO.

Parameters	JUNO	LHAASO
Total number	15000	2270
DE@400nm	30%	26.8%
Dark Rate	~ 40KHz	~ 15KHz
TTS	~20ns	~5.5ns

➢ V. The summary of the R&D of the MCP-PMT

We could successfully produce the 8 / 20 inch MCP-PMT for good SPE and QE

And better for CE of the MCP; Uniformity of CE,

We also try to improve our Design of the Prototype for other experiments.

谢　谢！

Thanks for your attention!

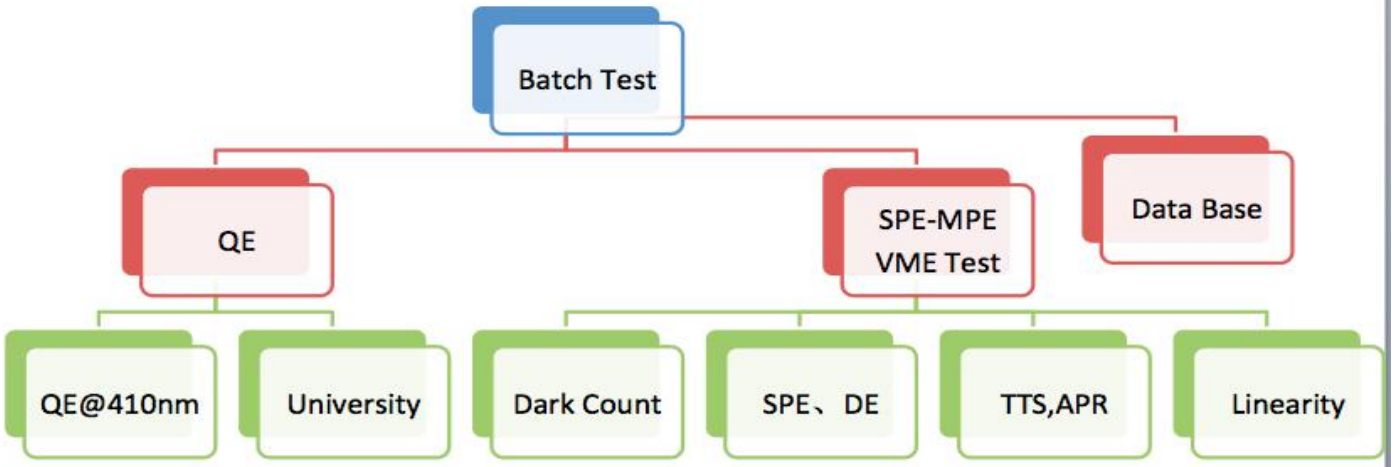
Any Comment & Suggestion are welcomed!

Back up

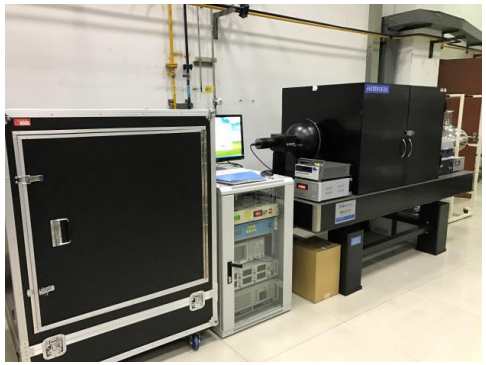
➢ 3.3 The Batch test platform in NNVT

PMT	JUNO Contract	NNVT test
QE@ 410nm	—	A
QE-Un	B	A
QE-λ	B	B
SPE	A	A
Gain	A	A
DE	B	A
TTS	B	A
APR	B	A
Linearity	B	A
RT/FT	A	A
DR	A	A

A: will be test 100% one by one;
B: will be test 10%~20%, part of them.



➢ QE sub-system



➢Equipment: 2 pic;
➢Time: 0.5h / PMT;
➢One Day: 30 PMTs;
➢Test Ratio: 100%;

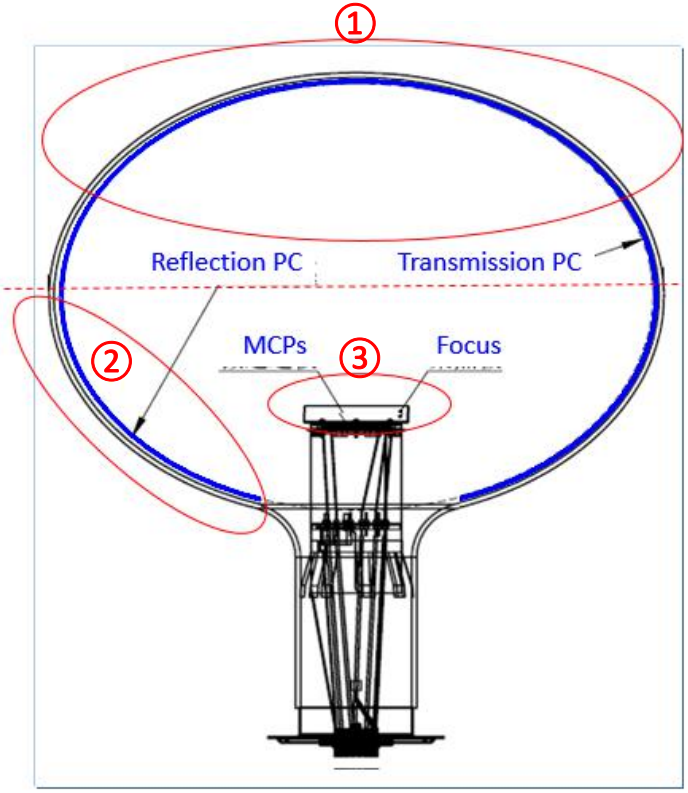
➢ SPE Batch Test sub-system

➢with soft iron to shielding EM

➢Equipment: 2+1 Dark Room;
—> 1 dark room = 32 PMTs
➢One Day: 30 PMTs;
➢Test Ratio: 100%;

➢ 4.1 How to improve the TTS of the large MCP-PMTs

Why is the TTS so Large!

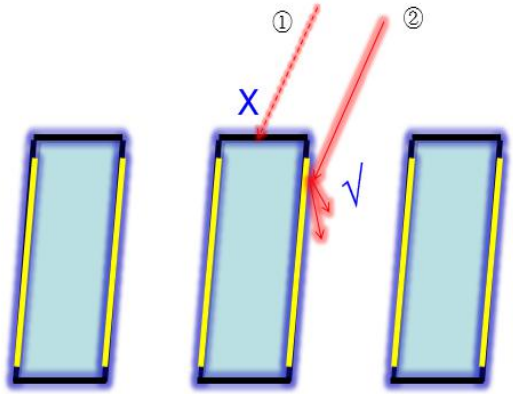


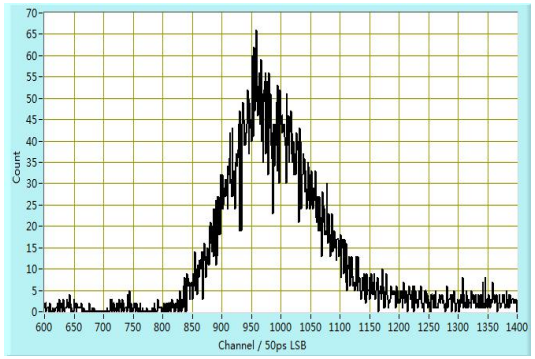
The prototype

--> with Trans.+Ref.PC for better QE;

--> with special MCP for better DE;

But the TTS will be worse!





➢With the contribution of the second electron from the electrode (30%),

the spectrum of the TTS present several peaks, which made it's TTS worse.