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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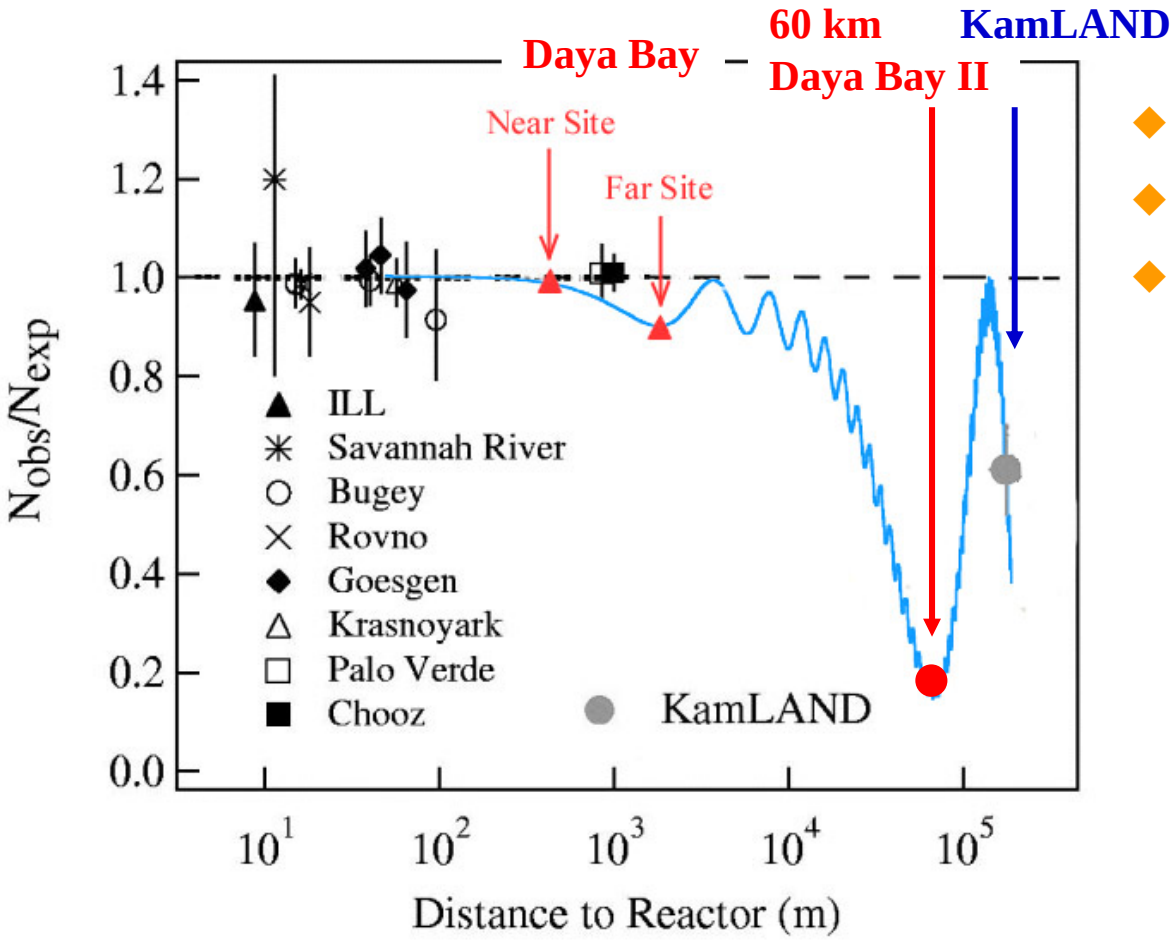
On Behalf of the Workgroup

Outline

- **1. The Motivation for JUNO;**
- **2. The Design of the new MCP-PMT;**
- **3. The status of the MCP-PMT prototypes;**
- **4. The performance of the 8” MCP-PMT;**
- **5. Summary and Plan;**

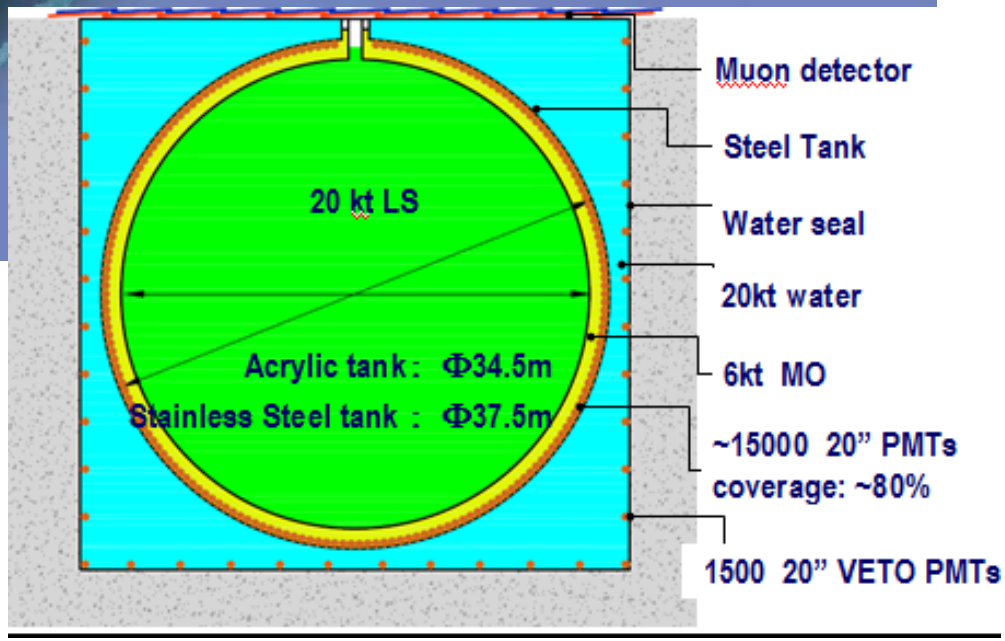
➢ The Jiangmen Underground Neutrino Observatory (JUNO) Experiment

As known Daya Bay II before;



- 20 kton LS detector
- 3% energy resolution
- Rich physics possibilities
  - ⇨ Mass hierarchy
  - ⇨ Precision measurement of 4 mixing parameters
  - ⇨ Supernovae neutrinos
  - ⇨ Geoneutrinos
  - ⇨ Sterile neutrinos
  - ⇨ Atmospheric neutrinos
  - ⇨ Exotic searches

Talk by Y.F. Wang at ICFA seminar 2008, Neutel 2011; by J. Cao at Nutel 2009, NuTurn 2012 ;
Paper by L. Zhan, Y.F. Wang, J. Cao, L.J. Wen, PRD78:111103,2008; PRD79:073007,2009



"The Central Detector of JUNO"

By Prof. Heng Yuekun

Poster: Board ID 29;

➢ The 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:**

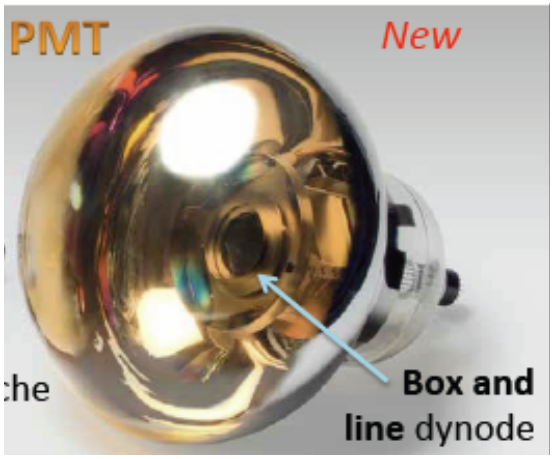
⇨ **Hammamatsu PMT with SBA photocathode**

⇨ **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;



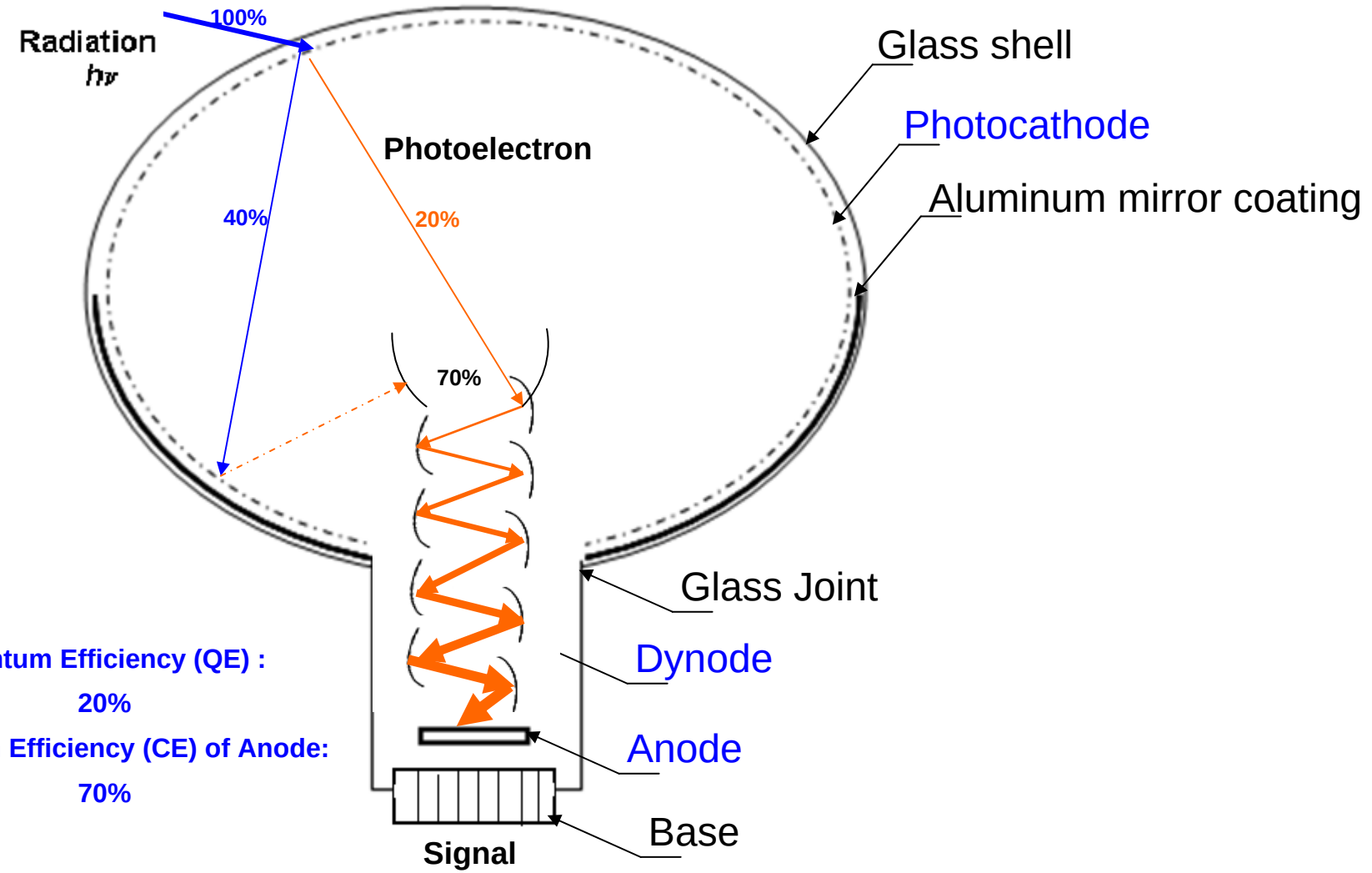
➢20" Hammamatzu PMT

➢20" MCP- PMT

Outline

- 1. The Motivation for JUNO；
- **2. The Design of the new MCP-PMT;**
- **2.1 The Conventional PMT and our new design;**
- **2.2 The Project team and Collaborators;**
- **2.3 The R&D plan of MCP-PMT （method）;**
- 3. The status of the MCP-PMT prototypes;
- 4. The performance of the 8” MCP-PMT；
- 5. Summary and Plan;

The Conventional PMT



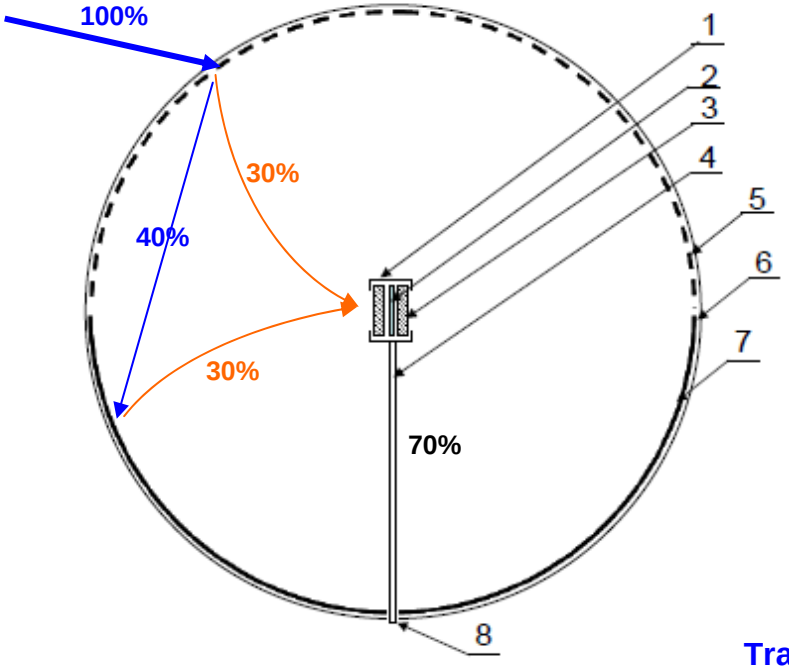
Photon Detection Efficiency (PE)= QE_{Trans} * CE = 20% * 70% = 14%

➢ The new design of a large area PMT

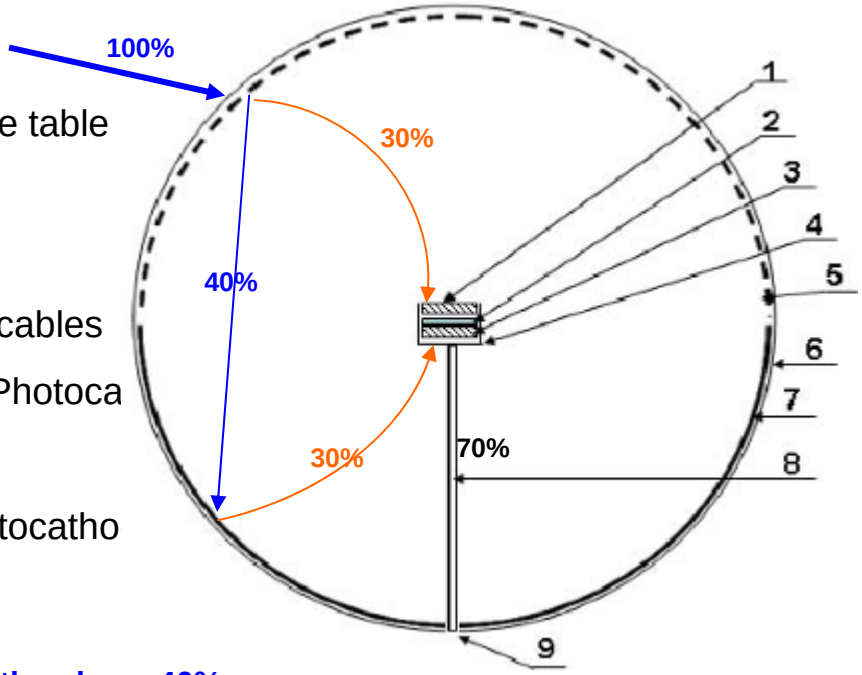
High photon detection efficiency + Single photoelectron Detection + Low cost

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 !

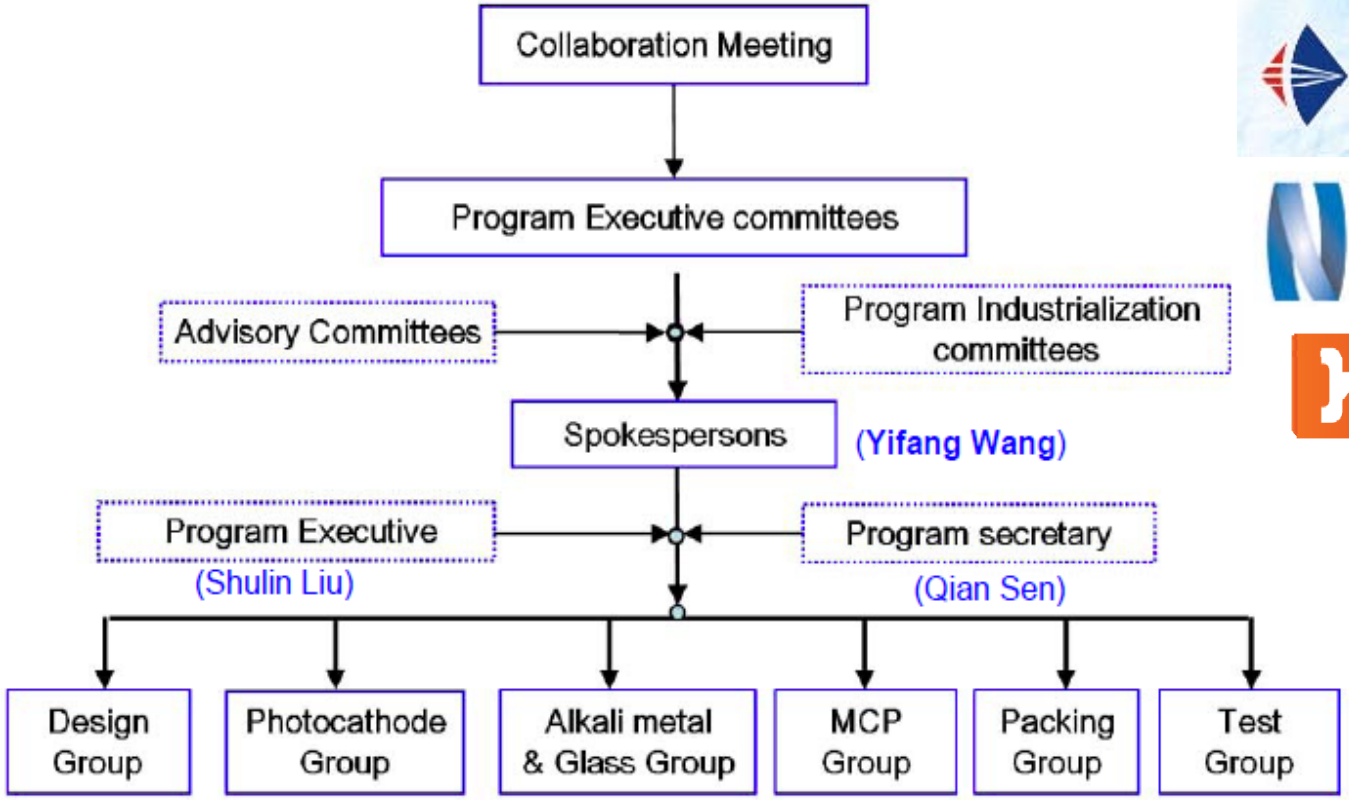
➢ the Project team and Collaborators

中国科学院高能物理研究所

Institute of High Energy Physics, CAS

effort by **Yifang Wang;**

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



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XIAN INSTITUTE OF OPTICS AND PRECISION MECHANICS OF CAS

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NORTH NIGHT VISION TECHNOLOGY CO.,LTD

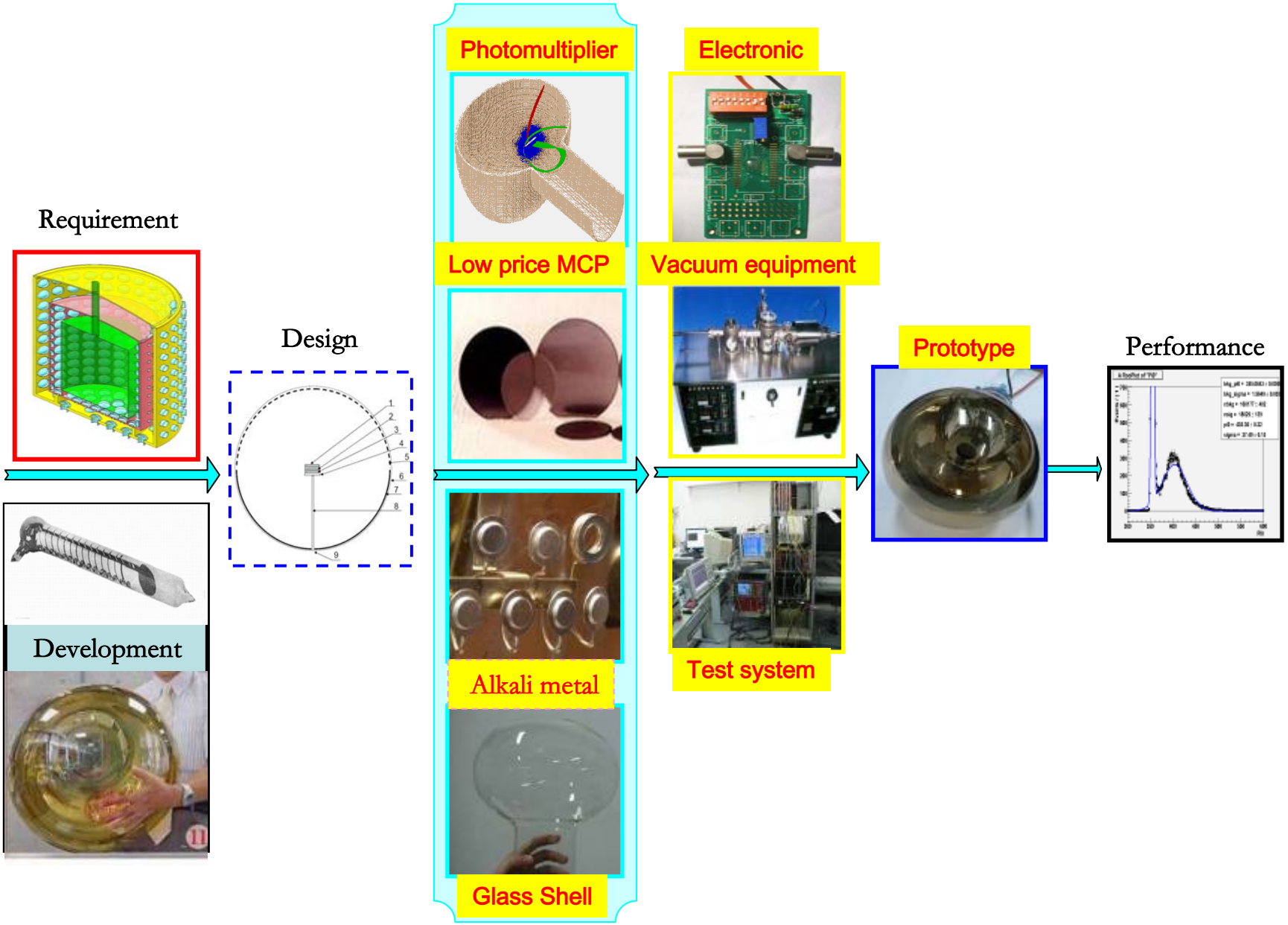
海南展创光电技术有限公司
HZC PHOTONICS

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

南京大学

宝光股份
BAOGUANG

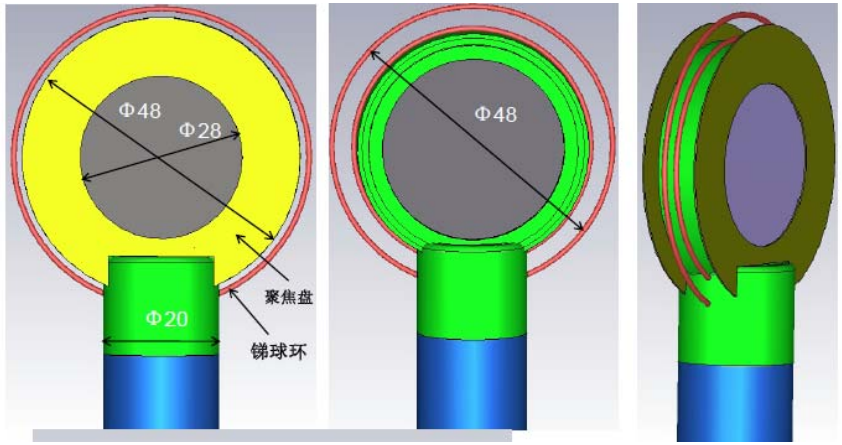
The R&D plan of MCP-PMT （method）



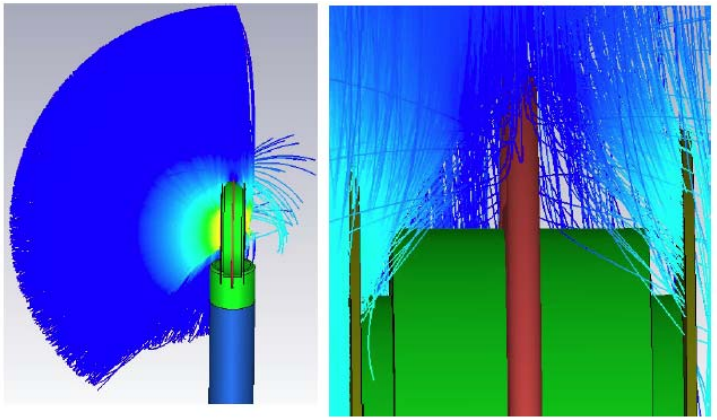
Outline

- 1. The Motivation for JUNO；
- 2. The Design of the new MCP-PMT;
- **3. The status of the MCP-PMT prototypes;**
- **3.1 The Simulation and design of electron optics;**
- **3.2 The large area glass bulb;**
- **3.3 The prototypes in four years;**
- **3.4 The successful 8 inch prototypes;**
- **3.5 The 20 inch prototypes;**
- 4. The performance of the 8” MCP-PMT；
- 5. Summary and Plan;

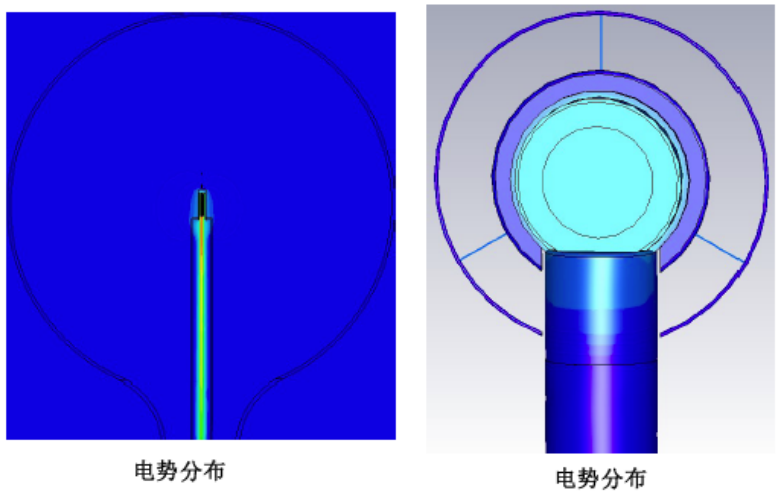
➢ The Simulation and design of electron optics



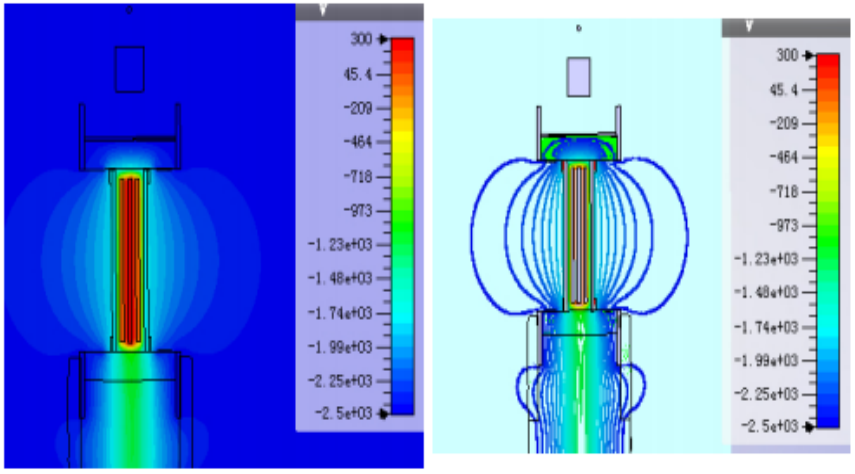
➢8 inch MCP & Anode Module;



➢The collection efficiency 8 inch



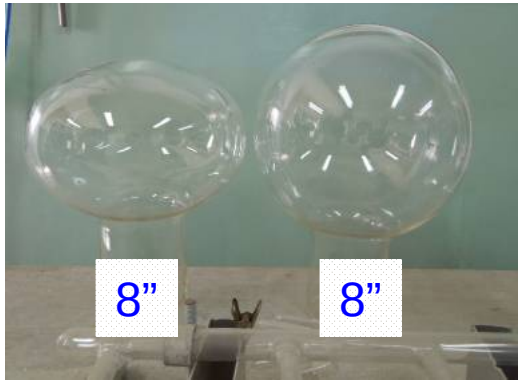
➢20 inch MCP & Anode module;



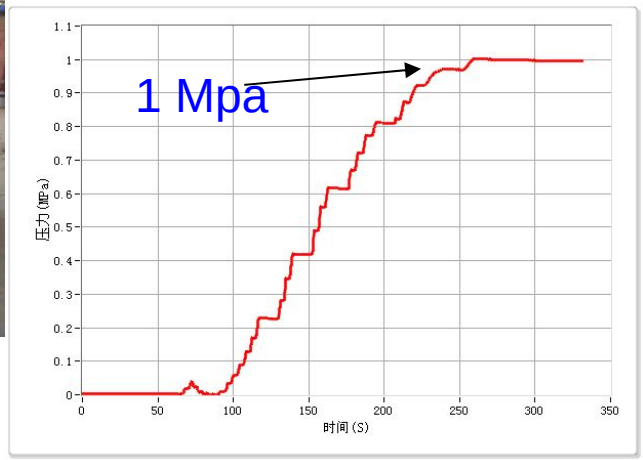
➢The collection efficiency 20 inch

➢ The 20 inch Glass bulb

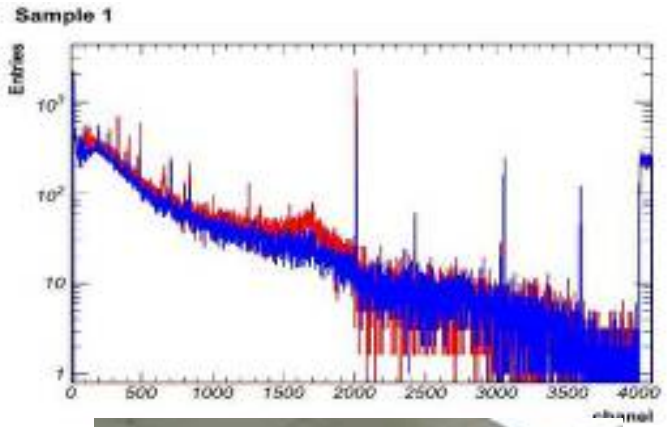
➢Large area



➢Superb water-resistance



➢Low radioactive background



➢Low background gamma spectrometer in IHEP

The Prototypes in four years

Prototype

2” MCP-PMT

8” MCP-PMT 5” MCP-PMT

8” MCP-PMT

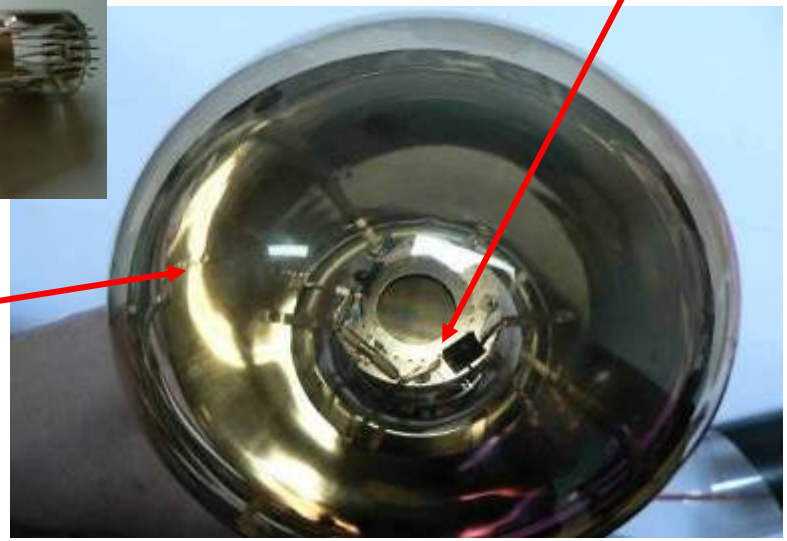
8” Dynode-PMT

8” MCP-PMT

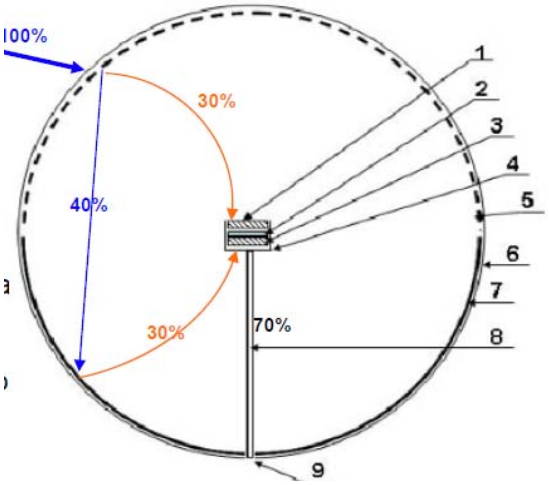
transmission photocathode

5” MCP-PMT

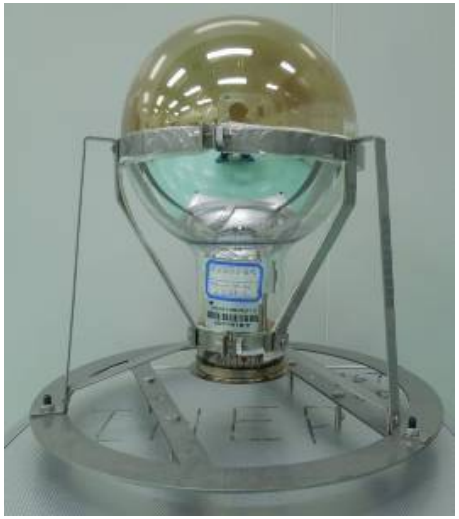
MCP



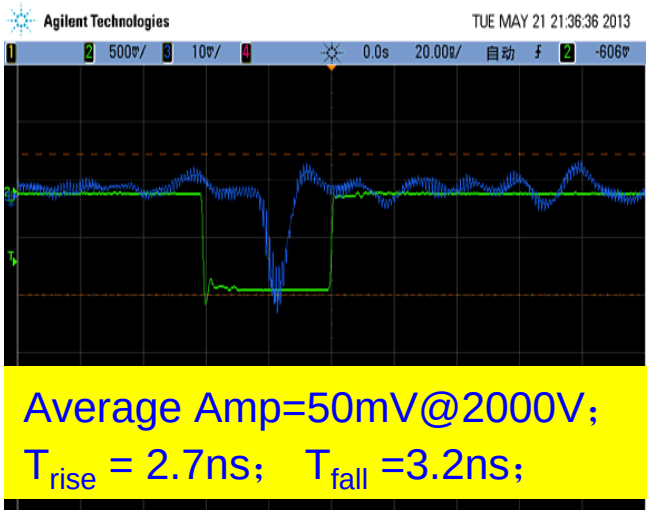
➢ The 8 inch Prototypes with horizontal MCPs



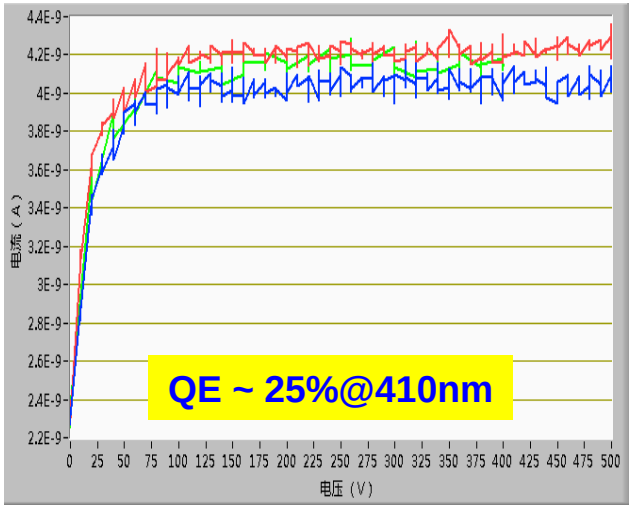
The Design MCP-PMT



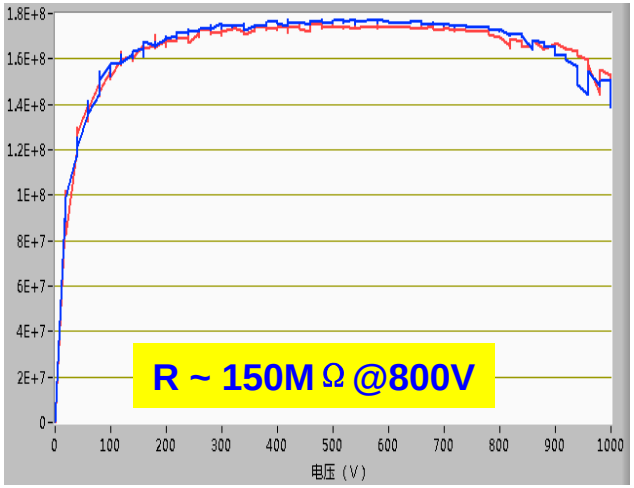
The Prototype



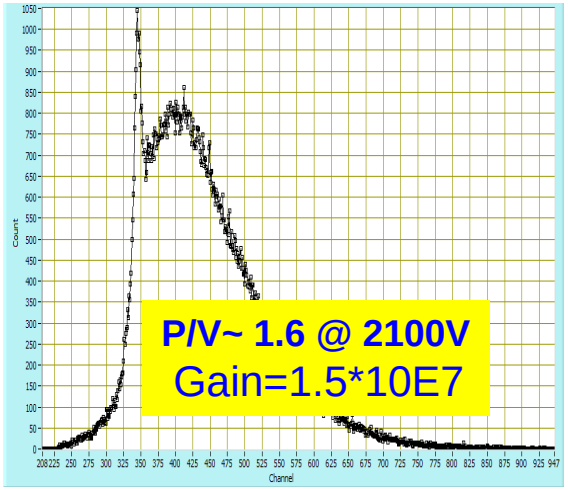
The signal of the 8 inch PMT



The I-V curve of the PC

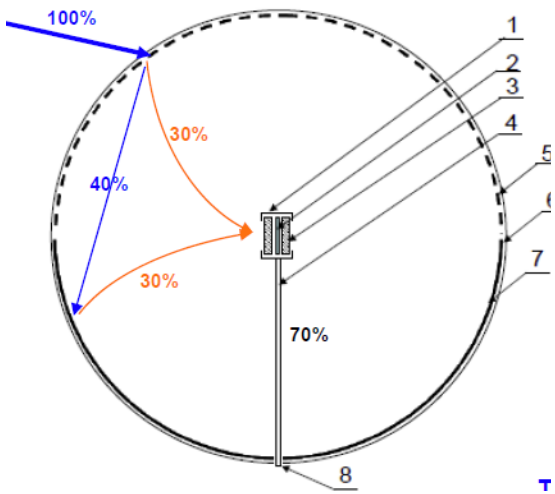


The body resistance of the MCP



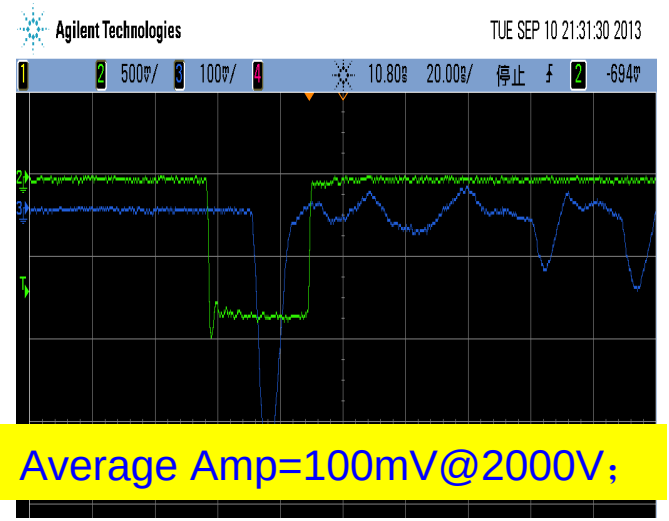
The SPE of the PMT

The 8 inch Prototypes with Vertical MCPs

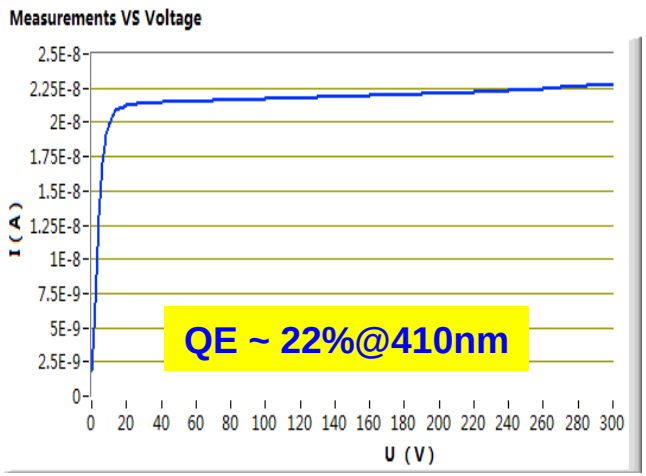


The Design MCP-PMT

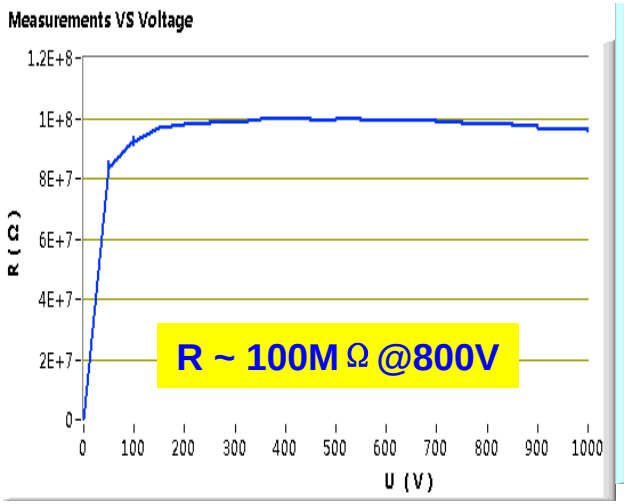
The Prototype



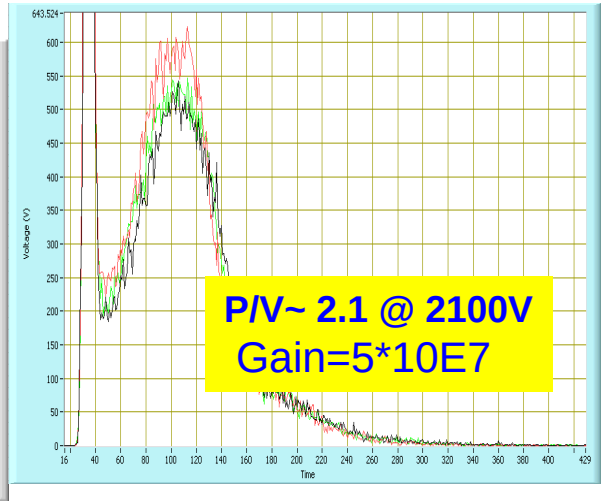
The signal of the 8 inch PMT



The I-V curve of the PC



The body resistance of the MCP

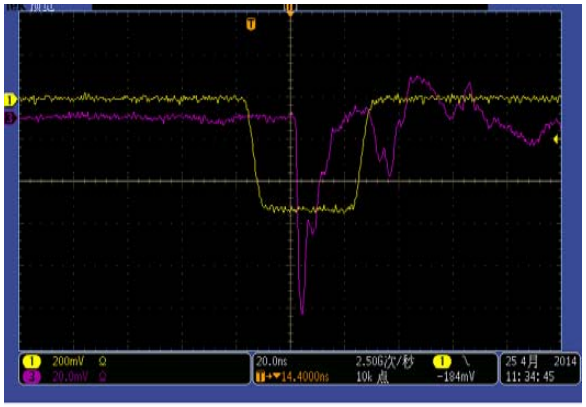


The SPE of the PMT

➢ The 20 inch Prototypes with Vertical MCPs

The Design MCP-PMT

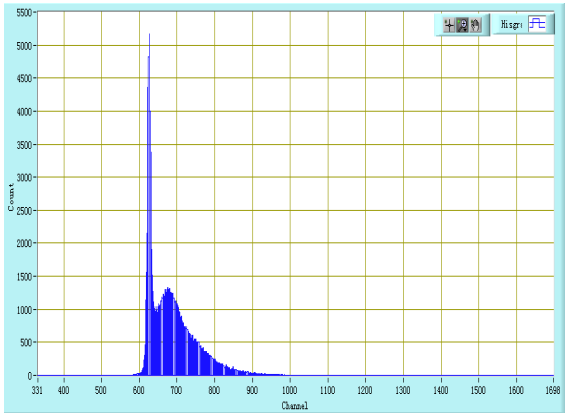
The Prototype



The signal of the 20 inch PMT

QE= **10.3% @410nm**;

Gain=**7.8E6 @2000V;**



The SPE of the PMT

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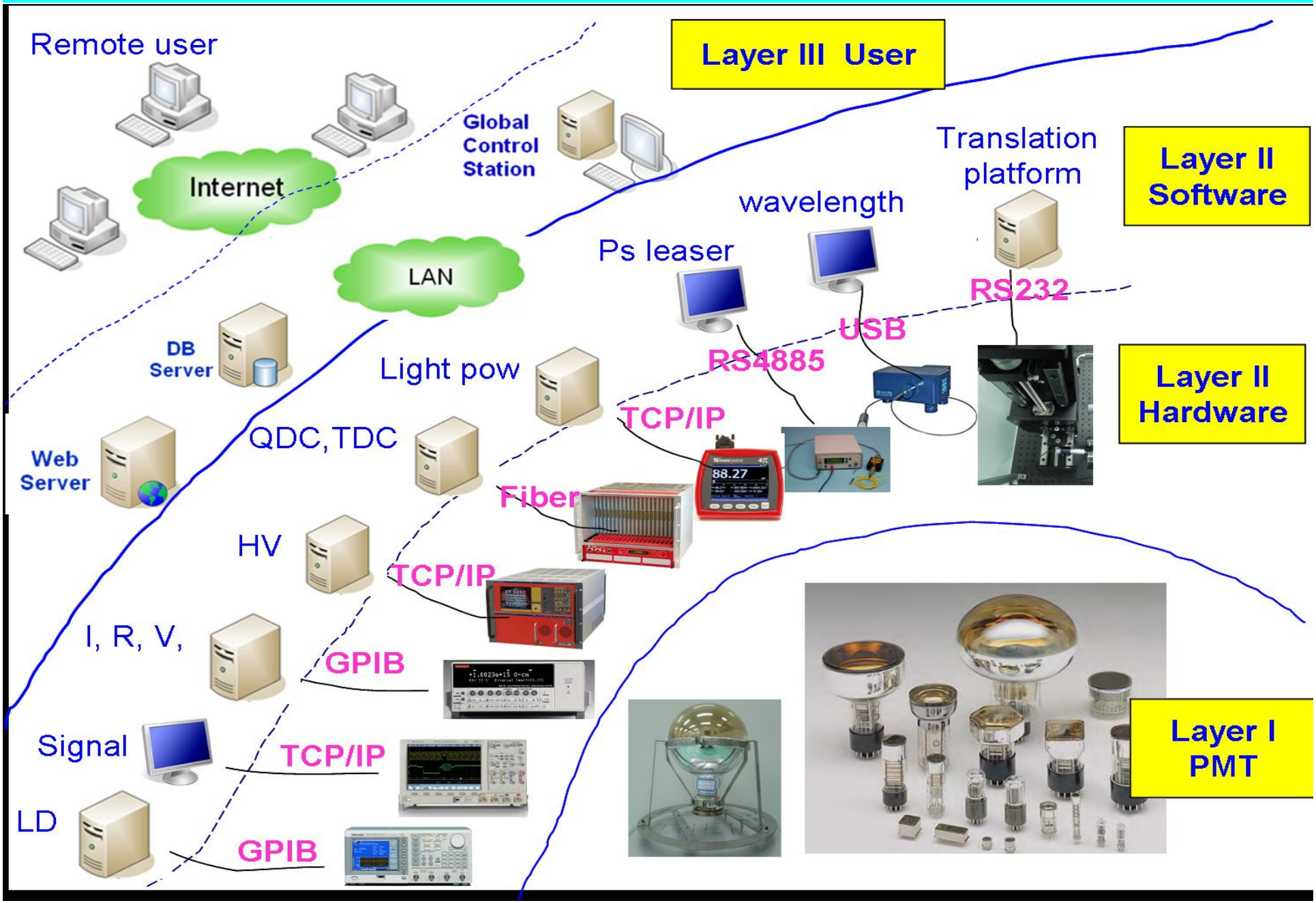
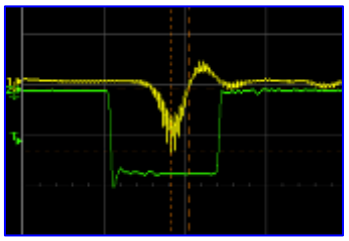
- 1. The Motivation for JUNO；
- 2. The Design of the new MCP-PMT;
- 3. The status of the MCP-PMT prototypes;
- **4. The performance of the 8” MCP-PMT；**
- **4.1 The Large PMT evaluation system for MCP-PMT of JUNO ;**
- **4.2 The description of the test experiments on 31# prototype;**
- **4.3 The performance of the 31# prototypes;**
- 5. Summary and Plan;

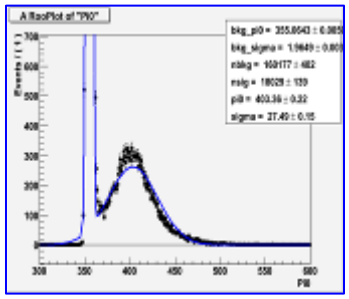
The Large PMT evaluation system for MCP-PMT of JUNO



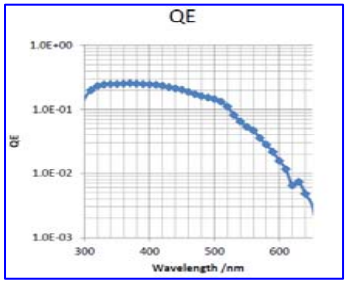
➢ The parameters of the MCP-PMT (testing)



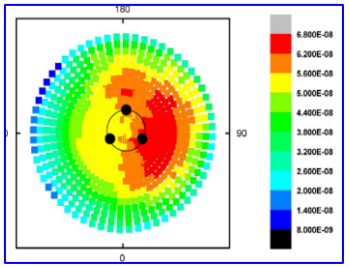
- ➢ Anode Pulse Rise Time;
- ➢ Pre/Late/After Pulse;
- ➢ Dark Count



- ➢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

……

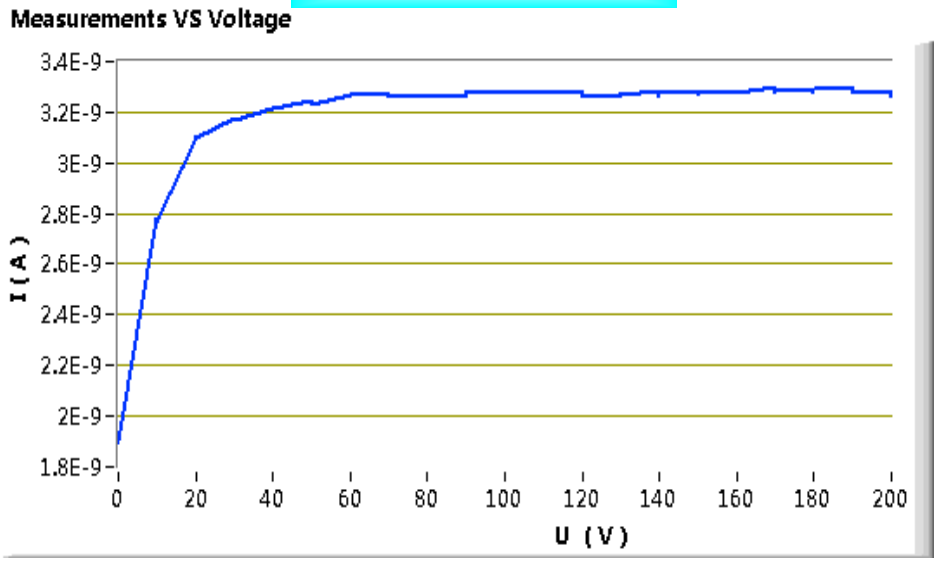
- ➢The linearity of the PMT
- ➢Magnetic characteristics;
- ➢Transit Time Spread (FWHM)

➢ The Parameters of the MCP-PMT

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

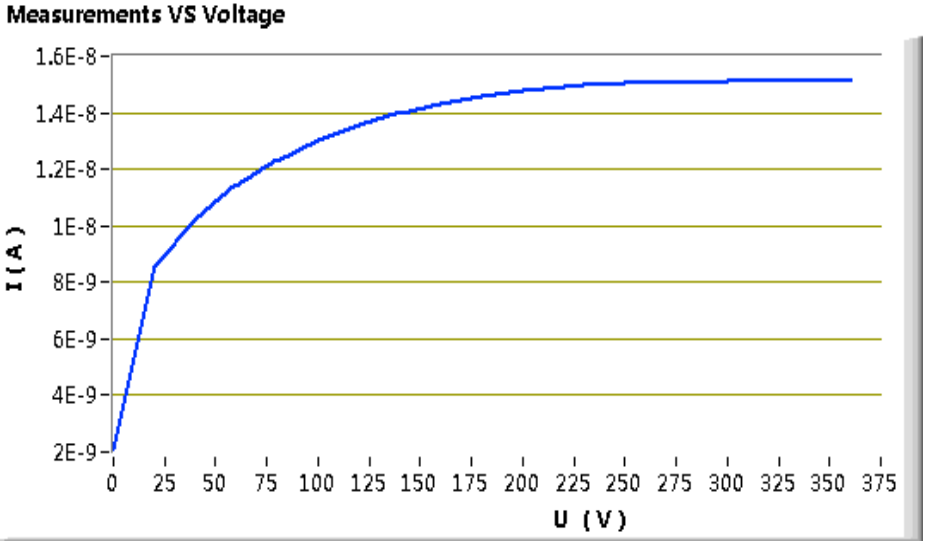
➢ The QE of the Photocathode@ 410nm

MCP-PMT-031#



R5912-DYB

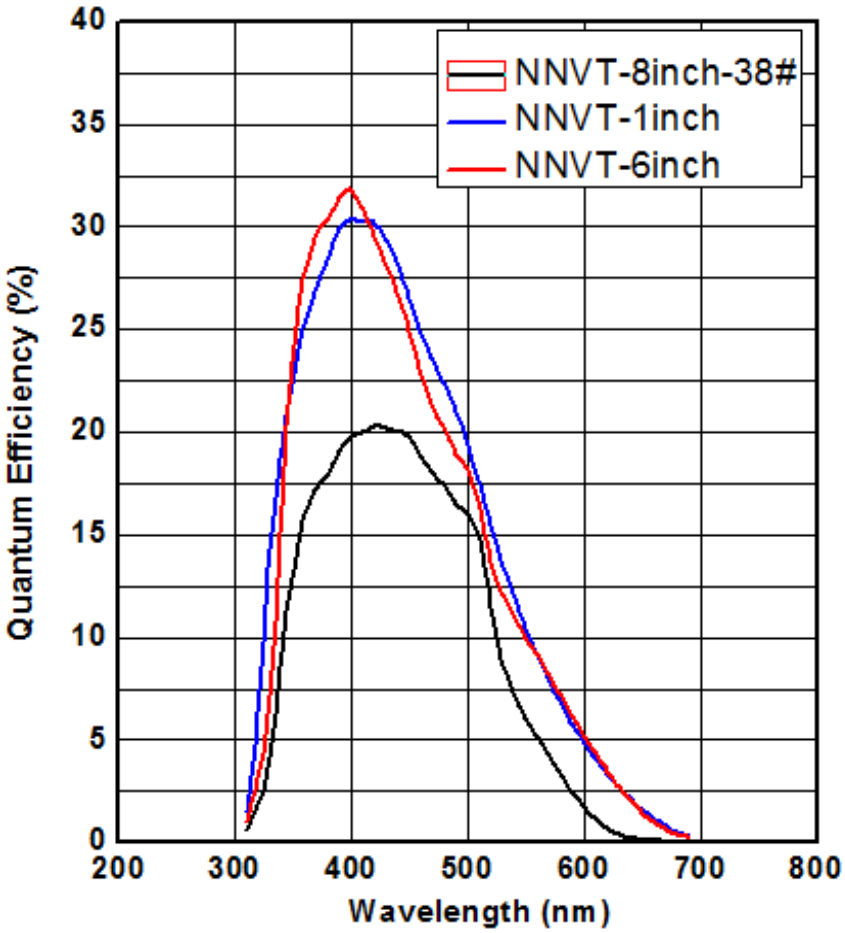
R5912-100



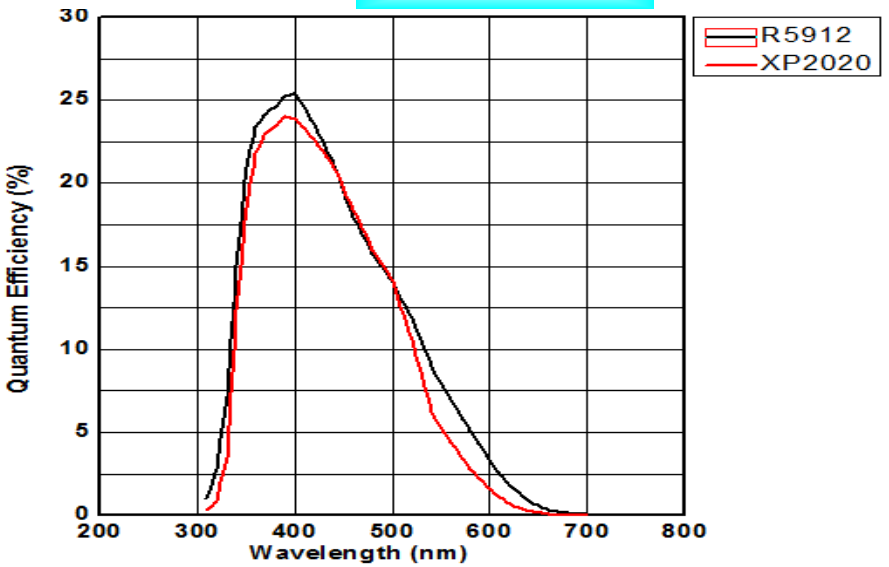
	Trans-PC	Trans+Ref PC
R5912	25%	?
R5912-100	35%	41%
MCP-PMT	20%	29%

➢ The Quantum efficiency with λ

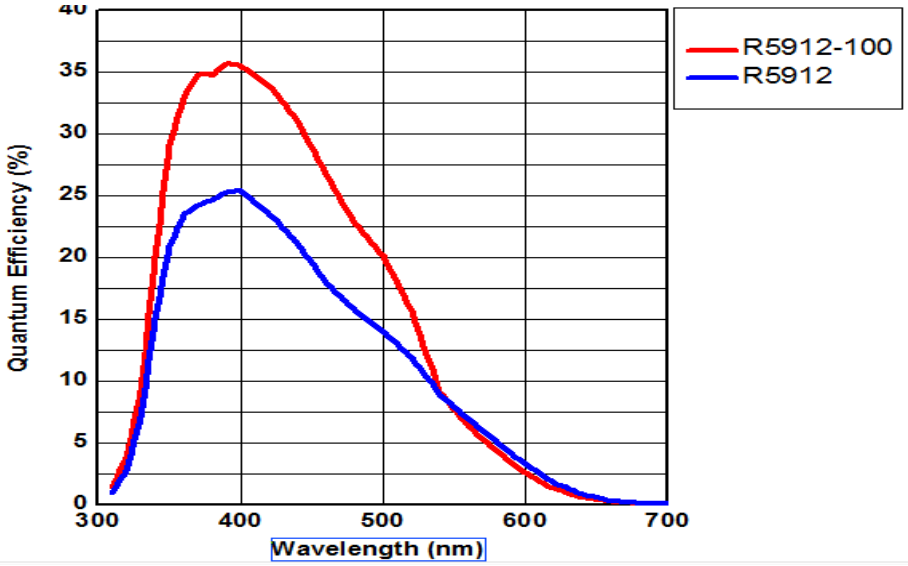
MCP-PMT



R5912-DYB

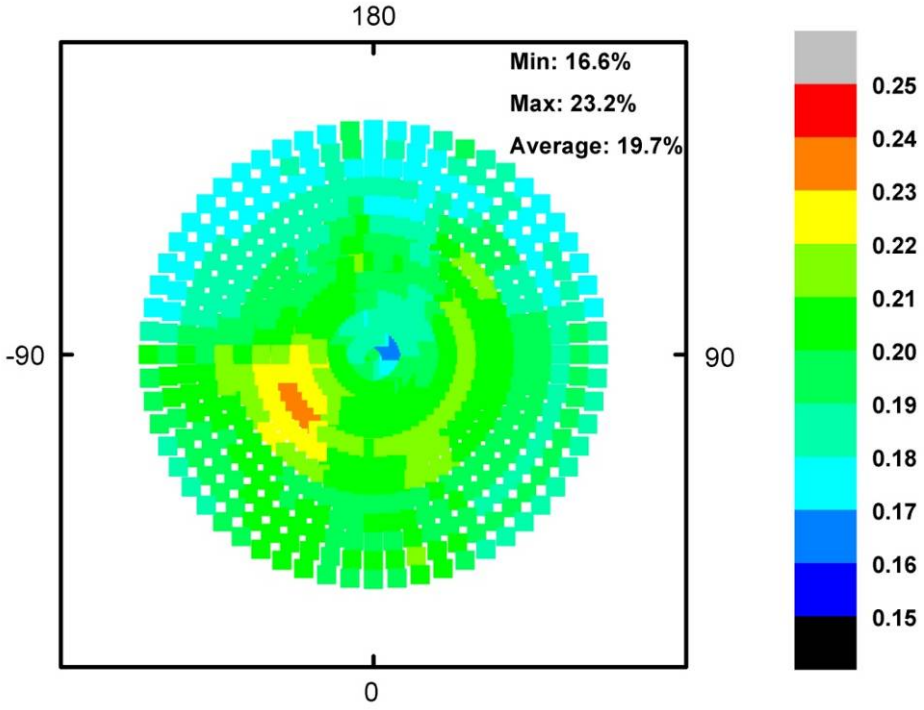


R5912-100



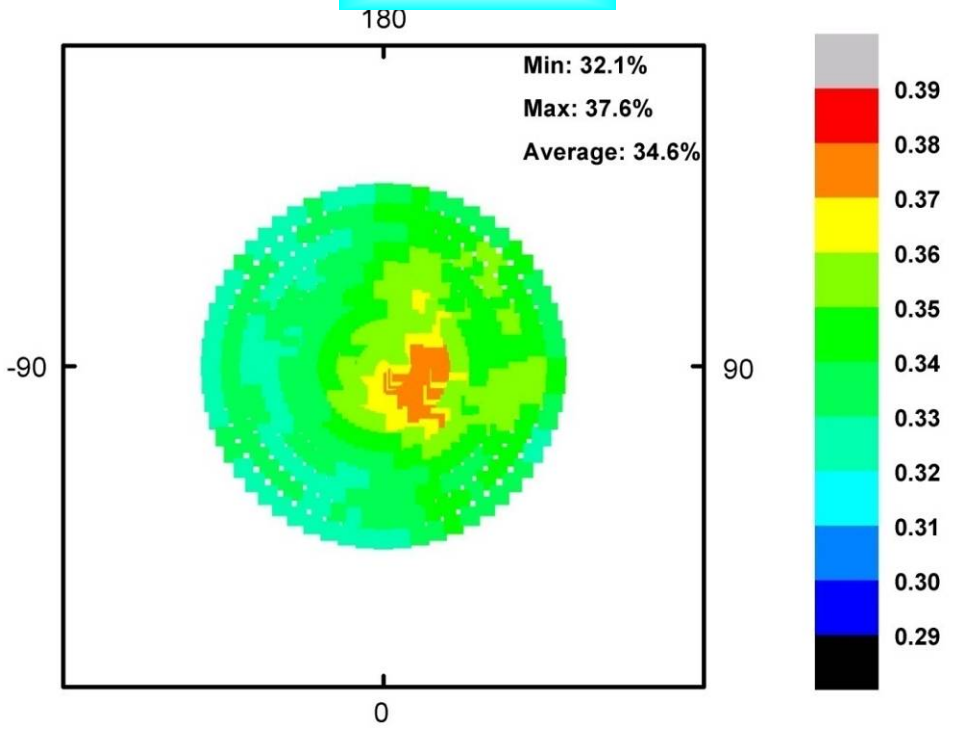
➢ The QE uniformity of the photocathode@410nm

MCP-PMT-031#



R5912-DYB

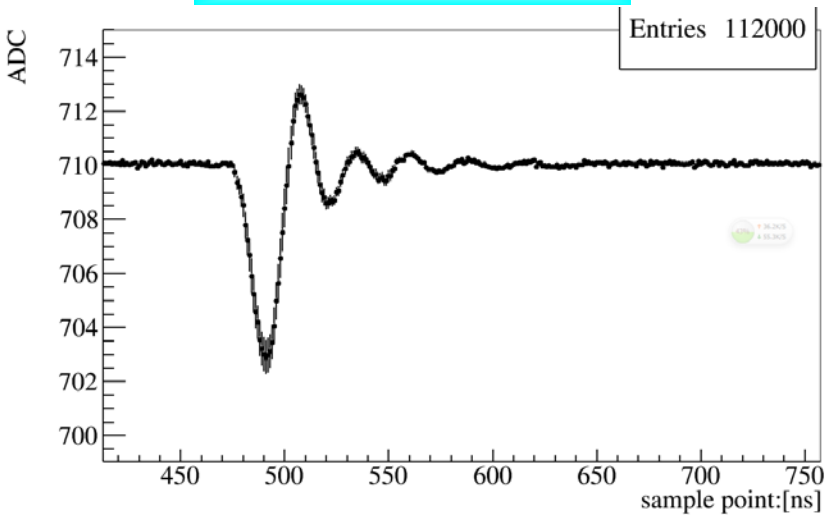
R5912-100



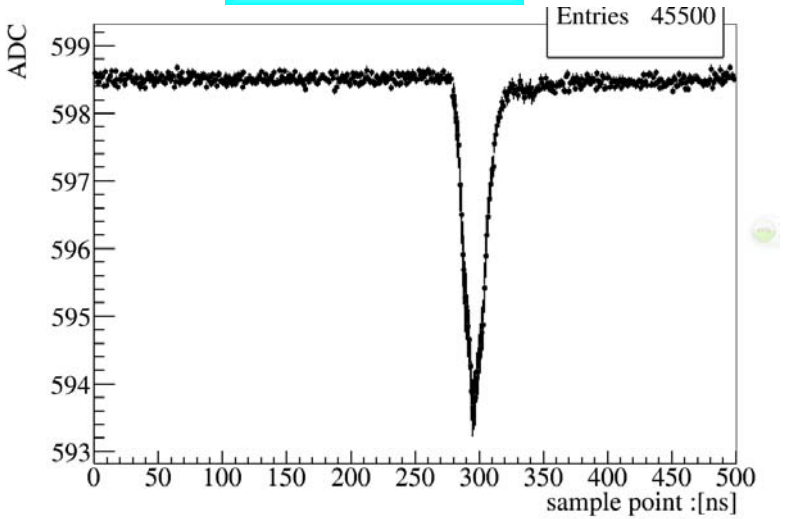
Trans-PC	min	Average	max
R5912	?	25%	?
R5912-100	32%	35%	38%
MCP-PMT	17%	20%	23%

➢ The Rise time and Fall time

MCP-PMT-031#-A

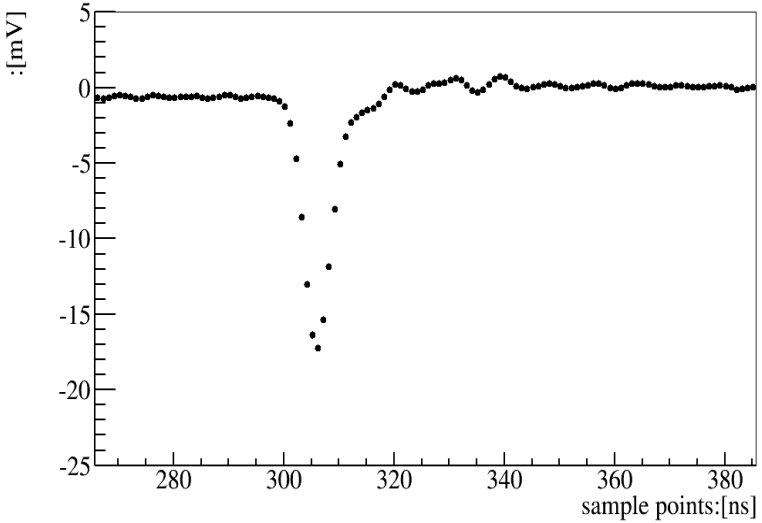


R5912-DYB



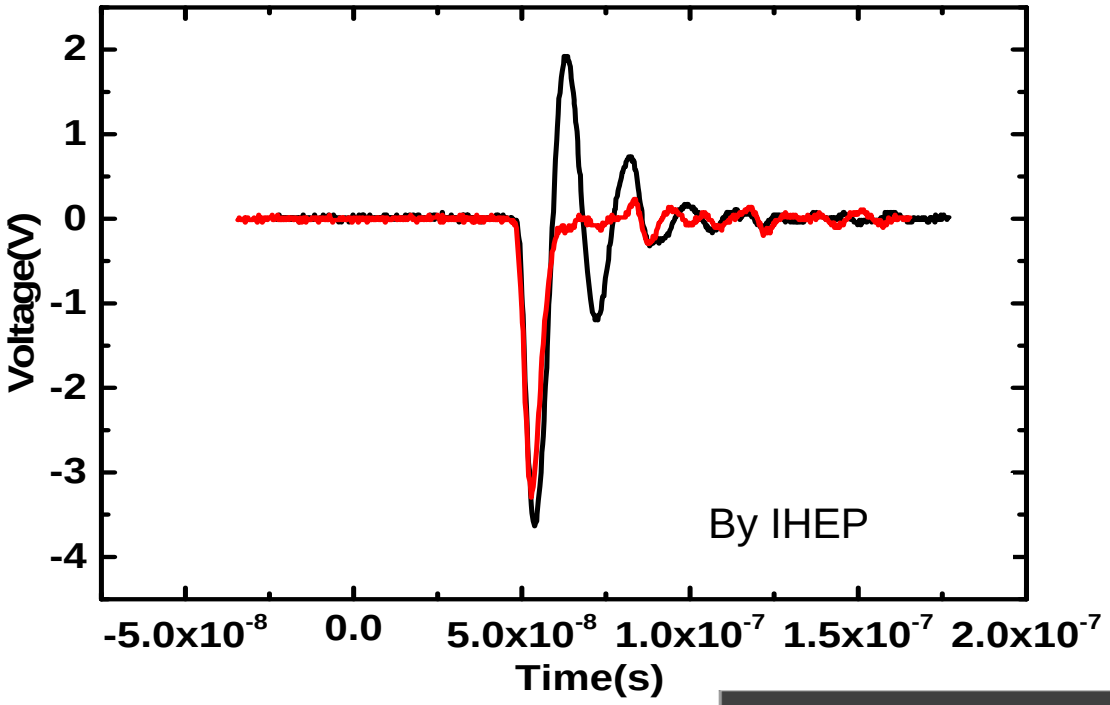
	Rise Time	Fall Time	Amplitude
R5912	~3ns	~4ns	17mV
R5912-100	~3.4ns	~4.6ns	18mV
MCP-PMT	~5ns	~6.3ns	17mV

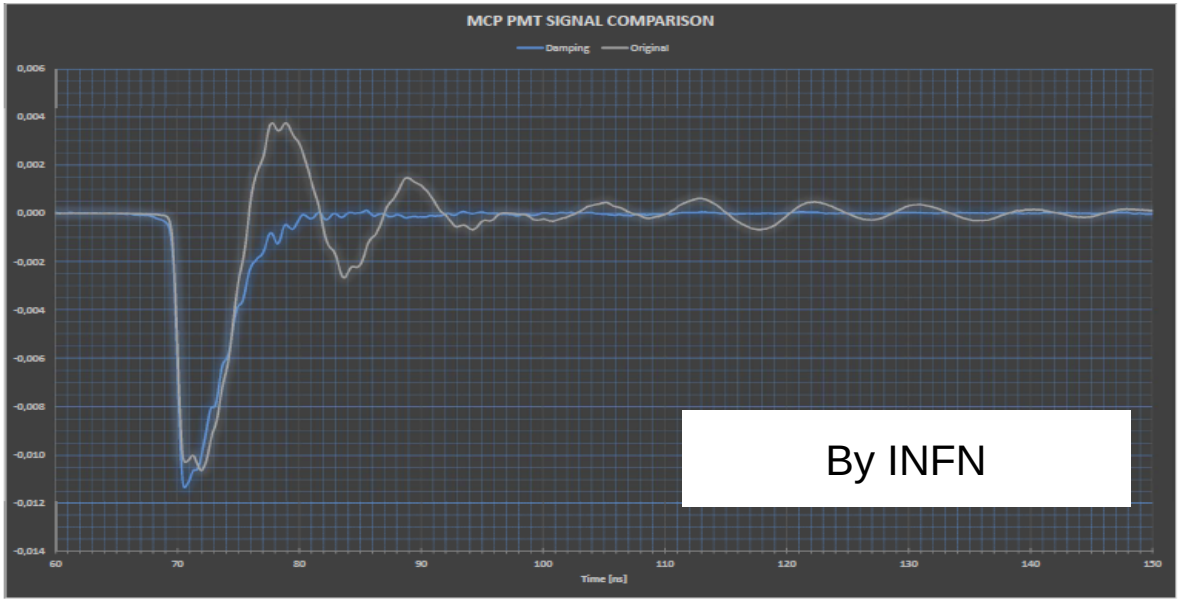
R5912-100



The data statistics by 10K count SPE signals @ Gain~2*10^7;

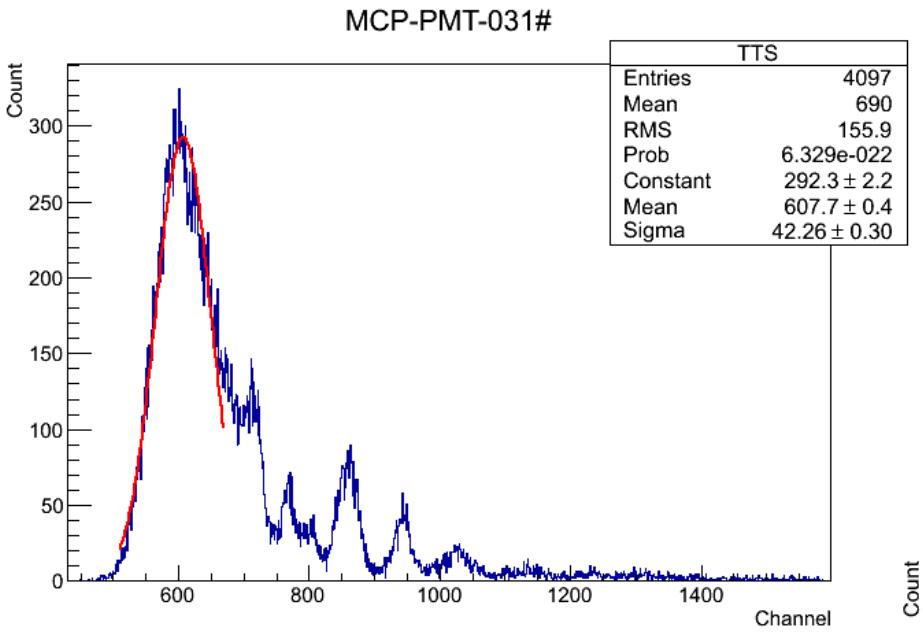
Modify the signal of the MCP-PMT by the BASE





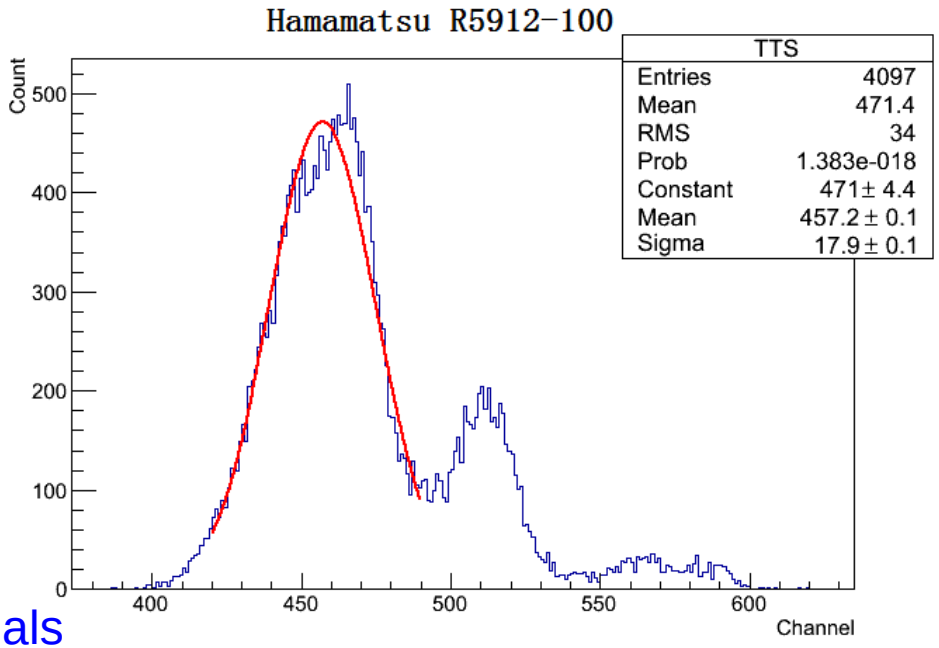
➢ The Transit Time Spread (TTS)

MCP-PMT-031#-A



R5912-DYB

R5912-100

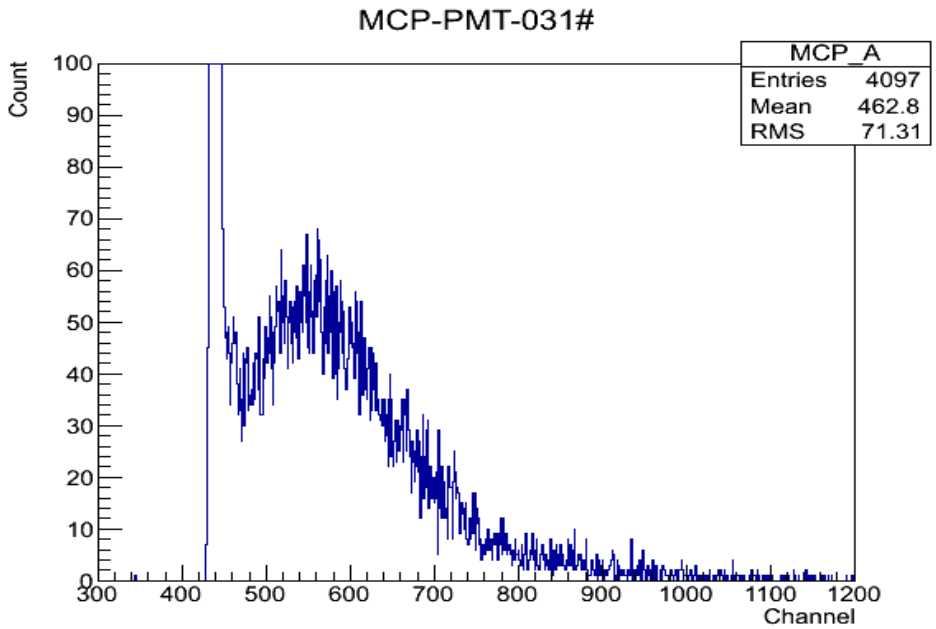


	TTS
R5912	5.5ns ?
R5912-100	1.5ns
MCP-PMT	3.5ns

The data statistics by the TDC with SPE signals

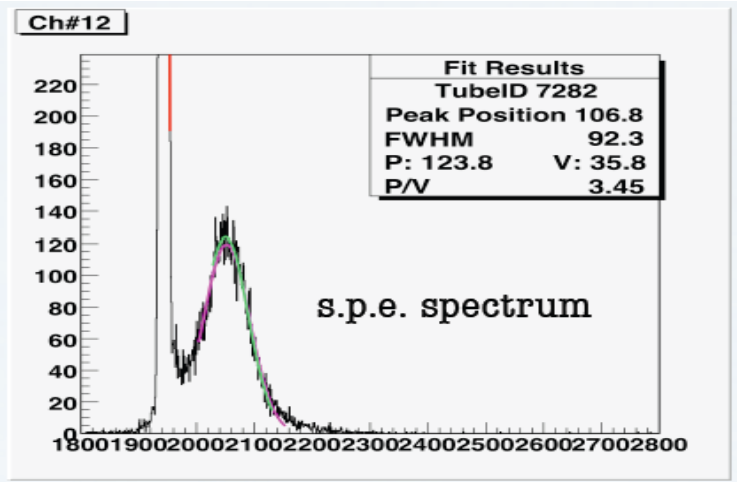
➢ The Signal Photoelectron Spectrum @ Gain~2*10^7

MCP-PMT-031#-A

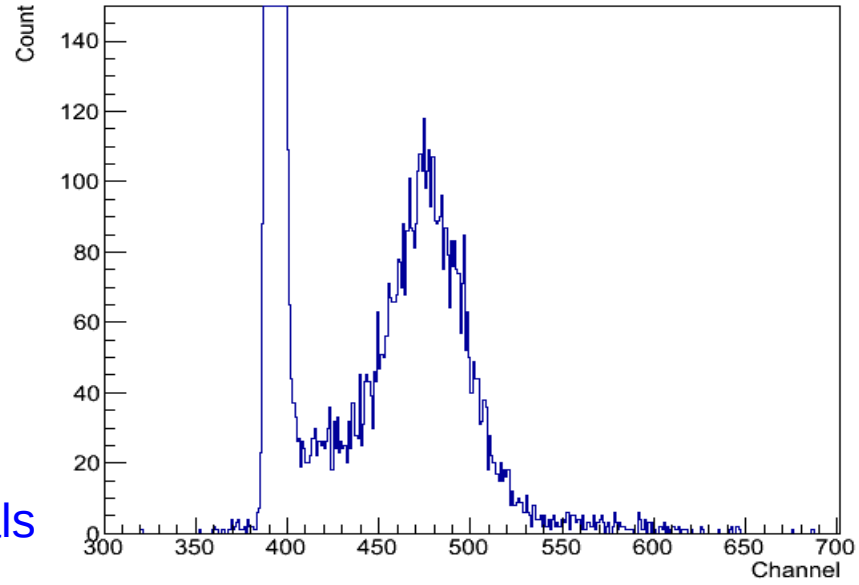


	P/V
R5912	> 2.5
R5912-100	>2.5
MCP-PMT	1.5~2.5

R5912-DYB



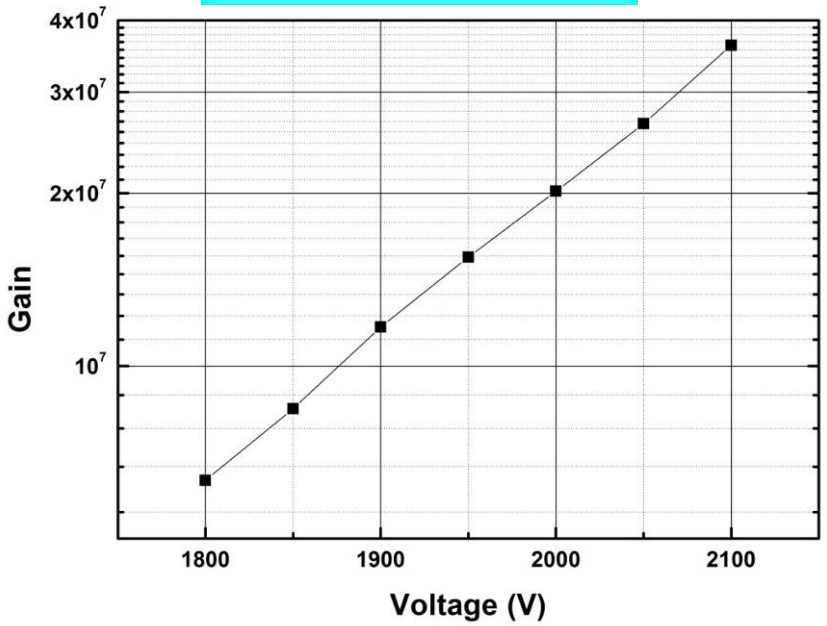
R5912-100



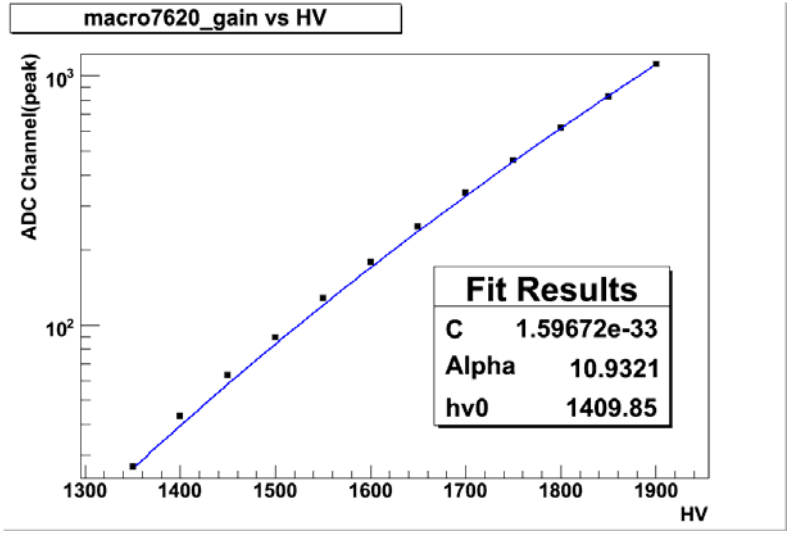
The data statistics by the QDC with SPE signals

➢ The Gain Vs High Voltage

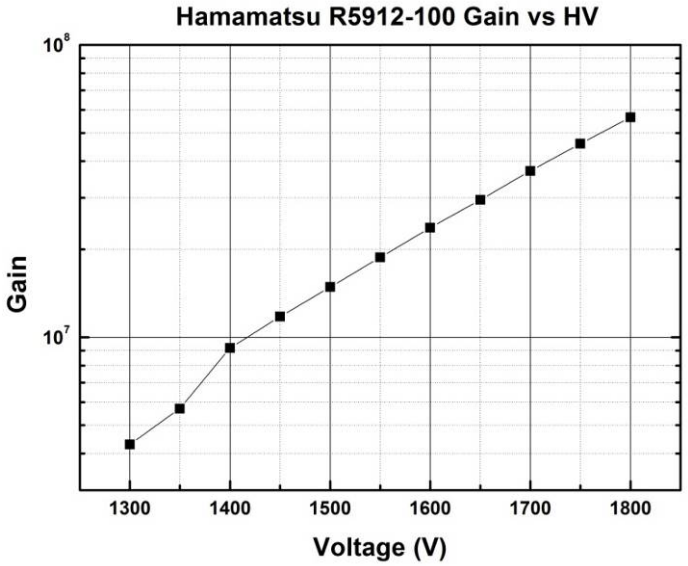
MCP-PMT-031#-A



R5912-DYB



R5912-100

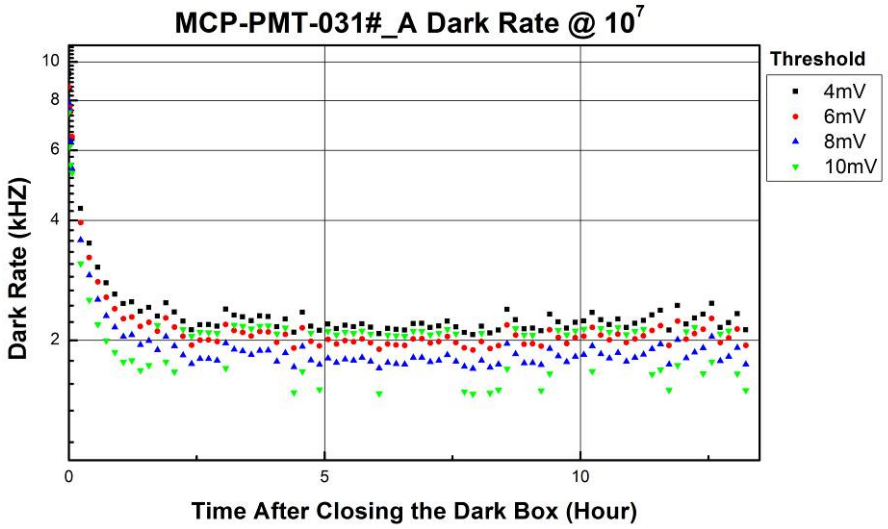


	HV@2 *10^7
R5912	1600V
R5912-100	1550V
MCP-PMT	2000V

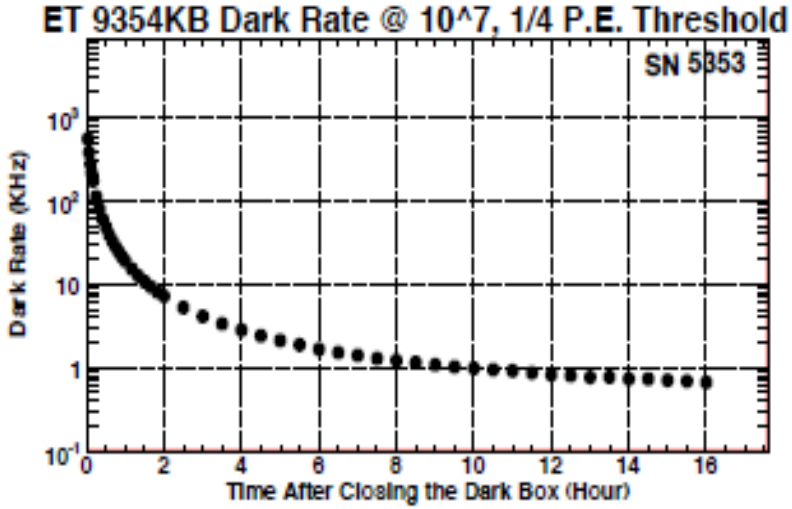
The data statistics by the QDC with SPE signals

➢ The Anode dark count with threshold @ Gain~2*10^7

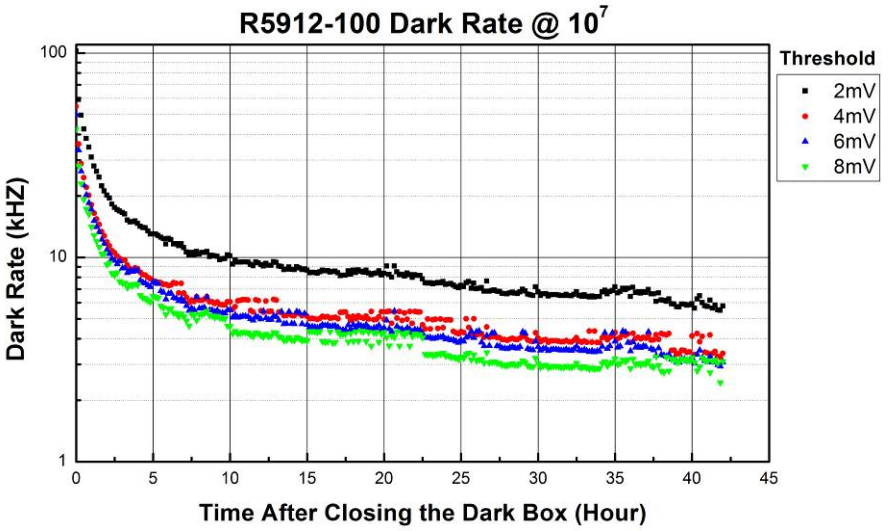
MCP-PMT-031#-A



R5912-DYB



R5912-100

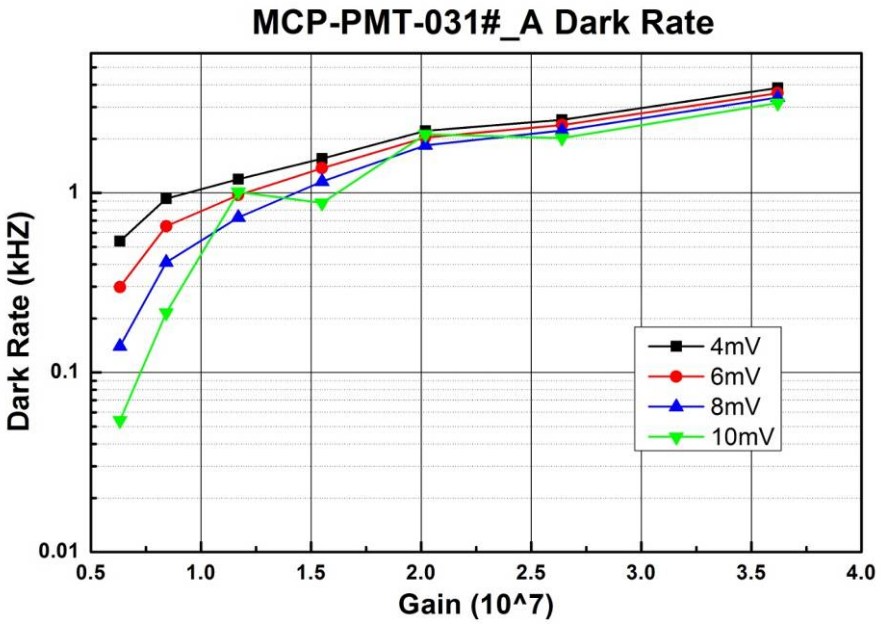


	HV	Dark rate (0.25PE)
R5912	1600V	< 1kHz
R5912-100	1500V	~3.5kHz
MCP-PMT	2000V	~2.2kHz

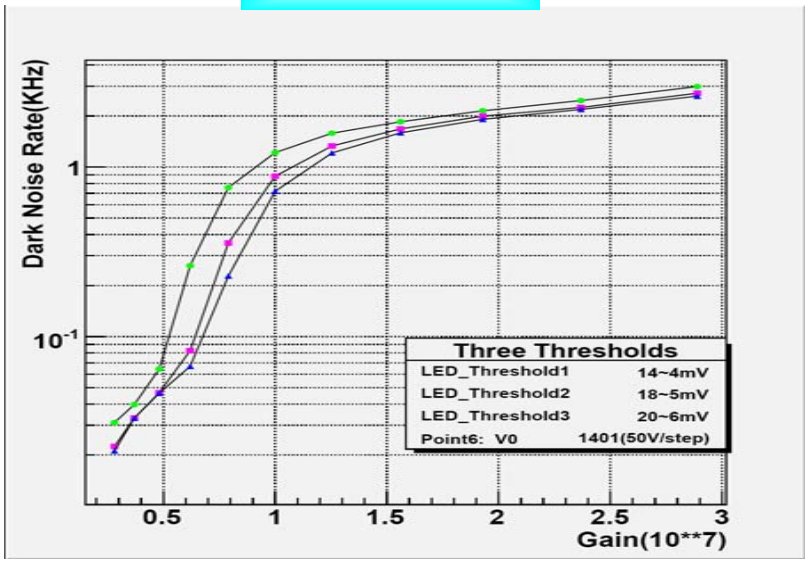
The data statistics after 10 hours later

➢ The Anode dark count with HV

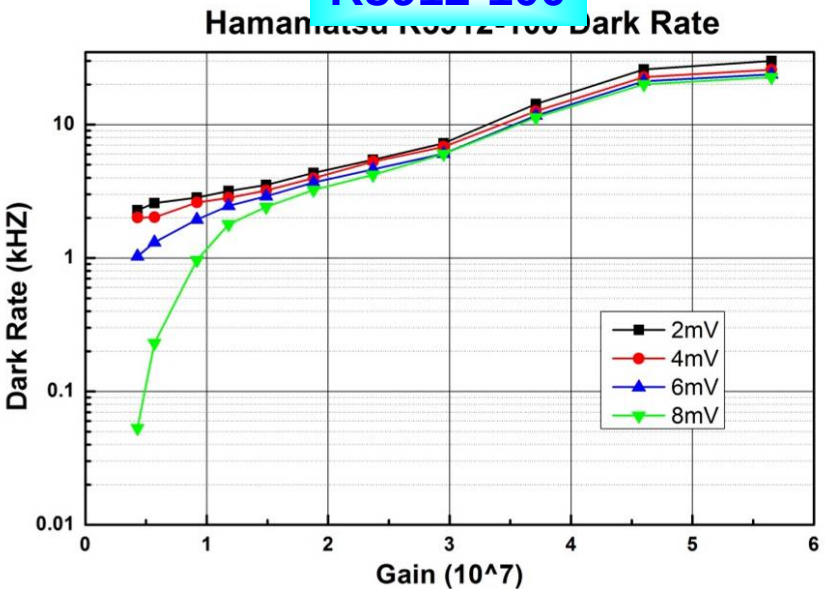
MCP-PMT-031#-A



R5912-DYB



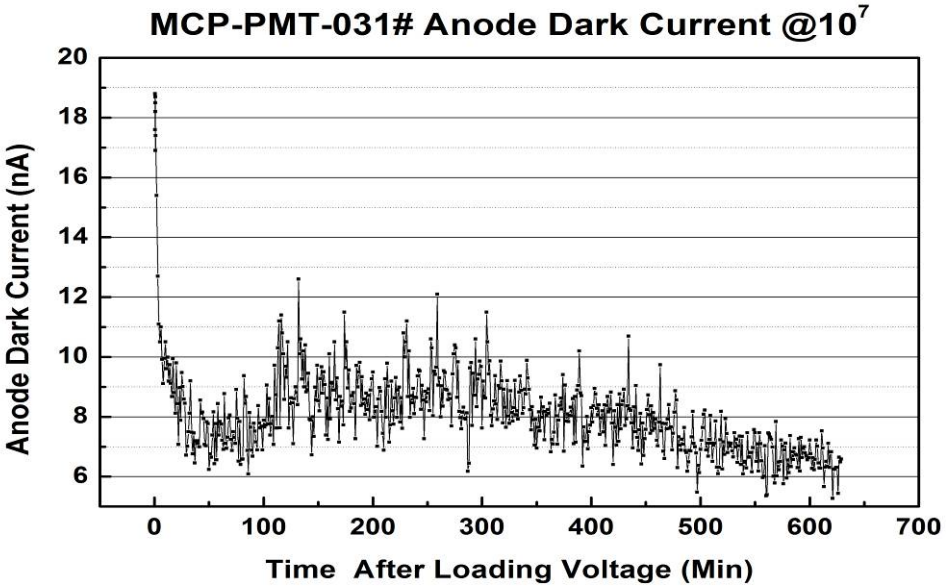
R5912-100



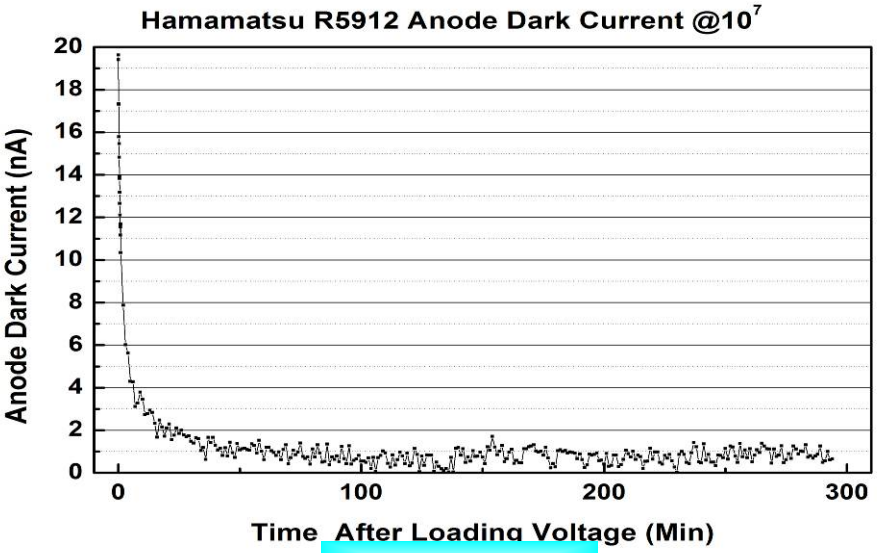
	HV	Dark rate (0.25PE)
R5912	1600V	< 1kHz
R5912-100	1500V	~3.5kHz
MCP-PMT	2000V	~2.2kHz

➢ The Anode dark current @ Gain~2*10^7

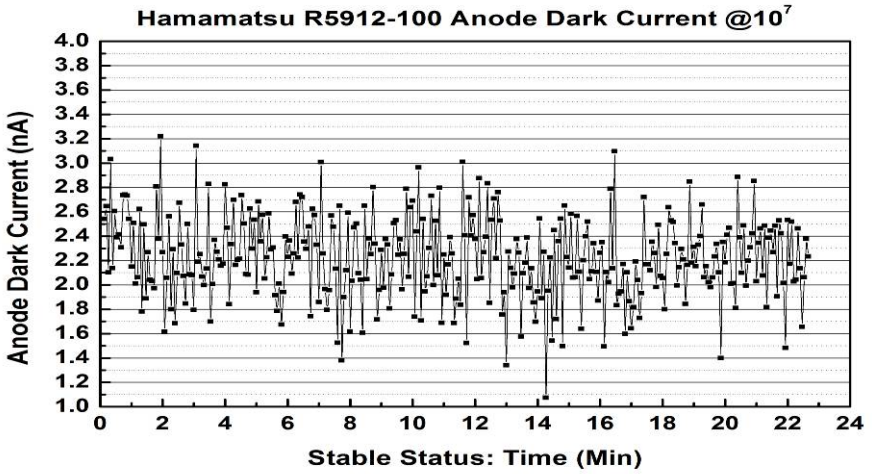
MCP-PMT-031#-A



R5912-DYB



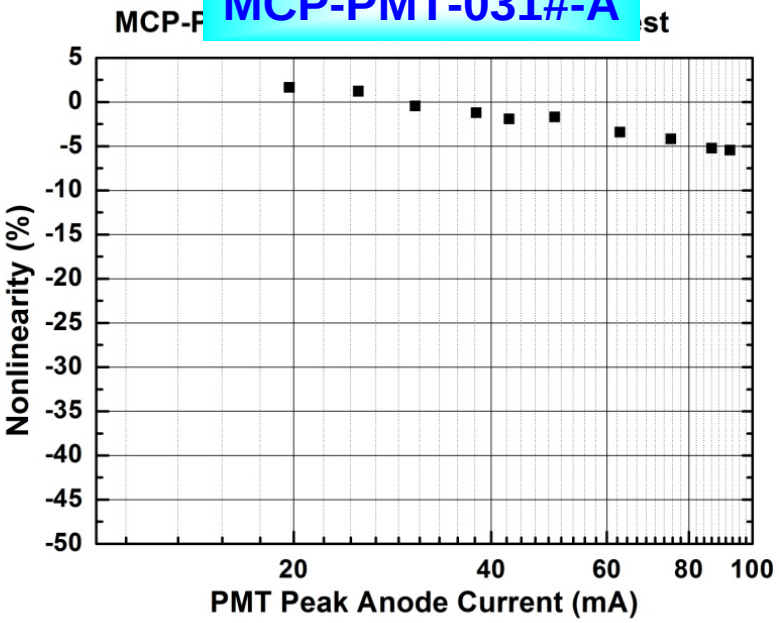
R5912-100



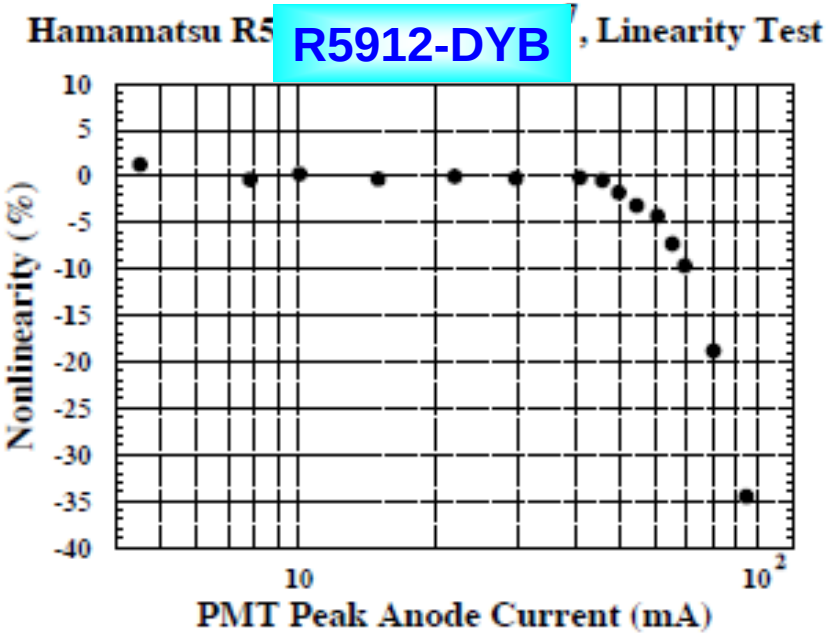
	HV	Dark current
R5912	1600V	~1nA
R5912-100	1500V	~2nA
MCP-PMT	2000V	~6nA

➢ The linearity of the PMT @ Gain ~ 2*10^7

MCP-PMT-031#-A

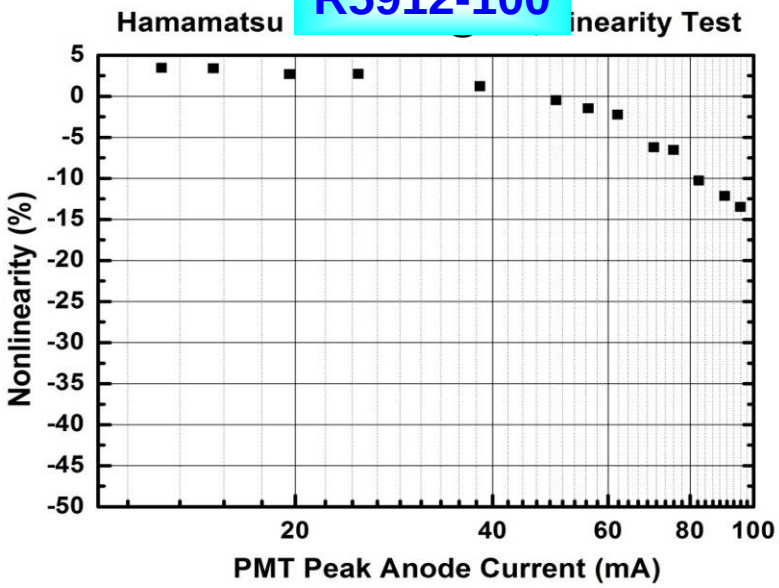


R5912-DYB



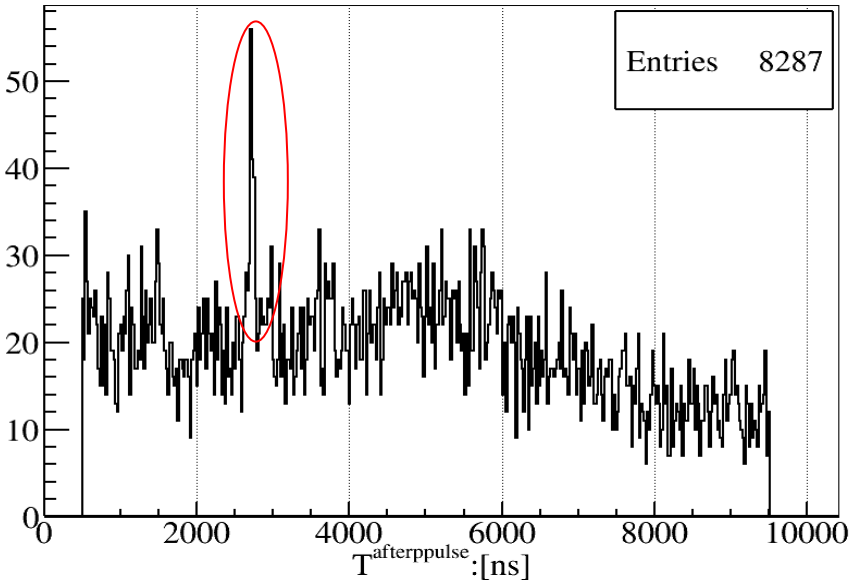
	Up to 40 mA	< 60mA
R5912	±2%	±5%
R5912-100	±2%	±4%
MCP-PMT	±2%	±4%

R5912-100

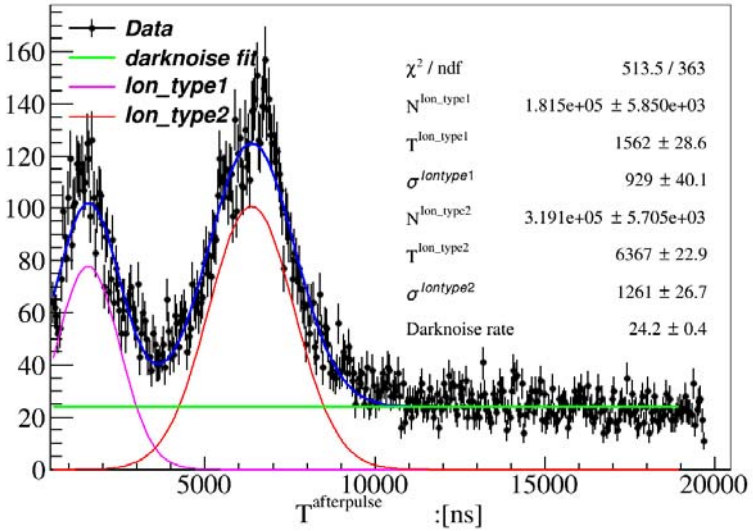


➢ The After-Pulse Ratio of the PMT (① time distribution)

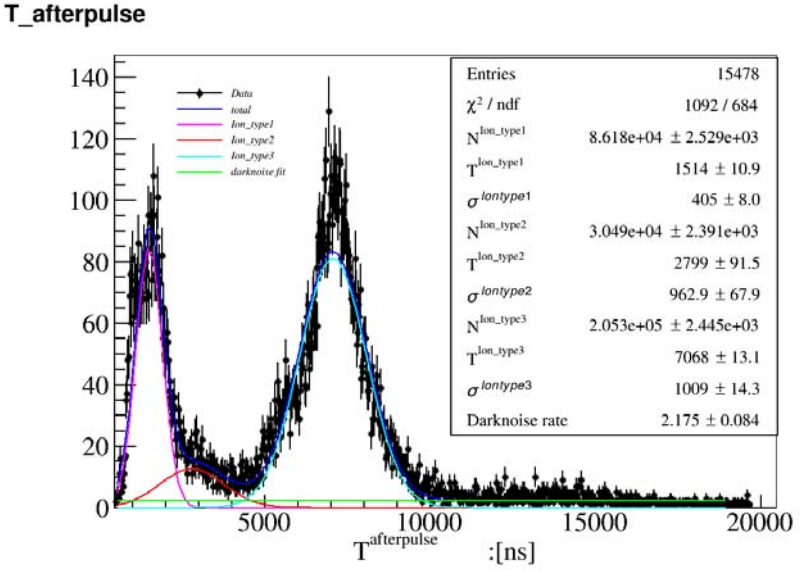
MCP-PMT-031#-A



R5912-DYB

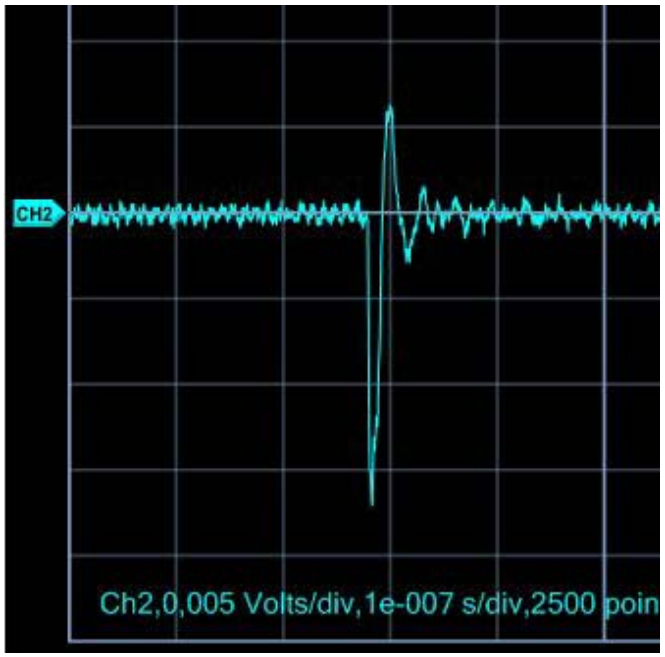


R5912-100

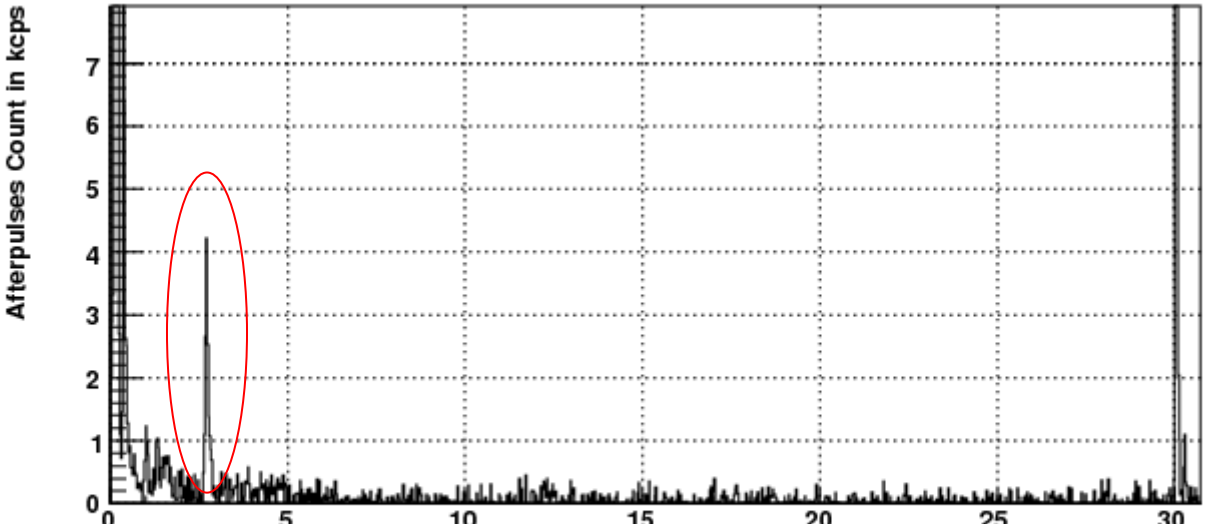


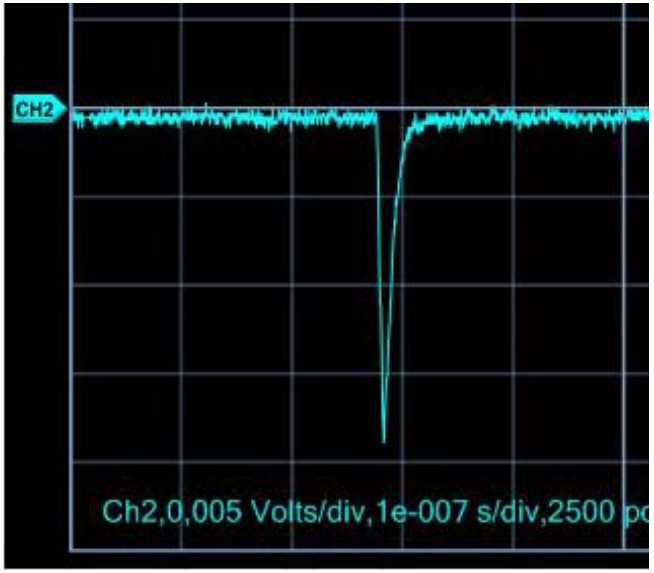
	Fast AP	Slow AP
R5912	1.6us	7us
R5912-100	1.5us	7.1us
MCP-PMT	3us	?

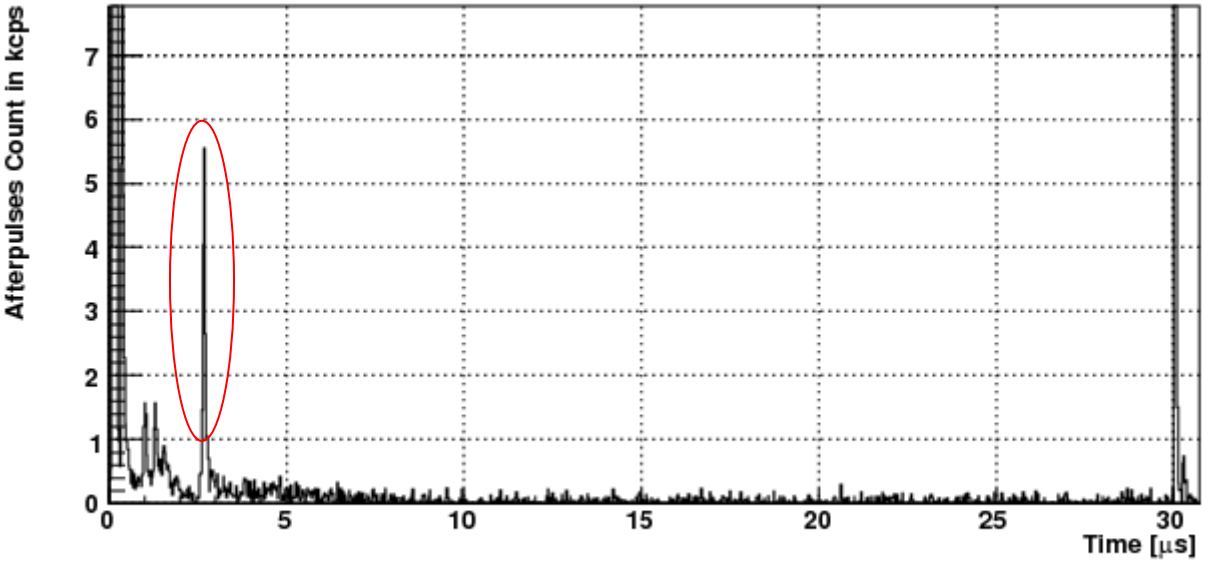
The After-Pulse Ratio of the PMT (① time distribution)--INFN



MCP-PMT-031#-A

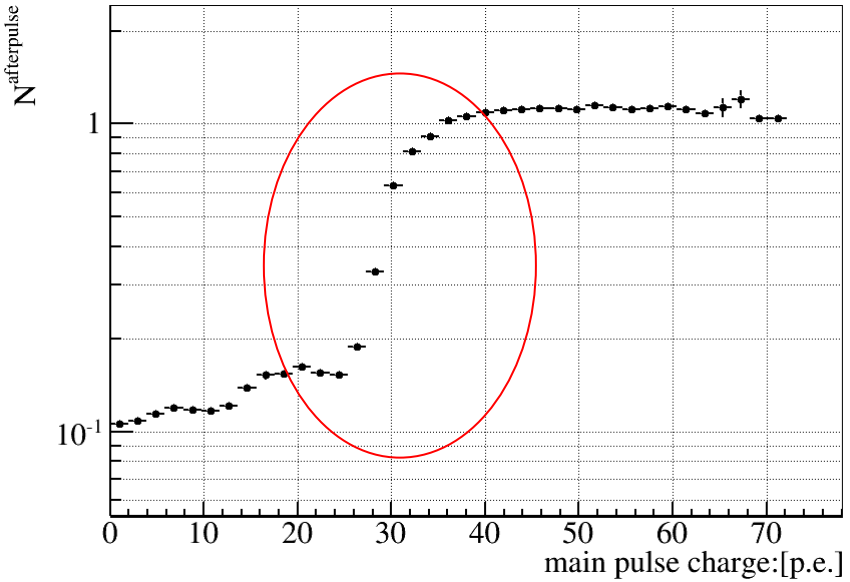




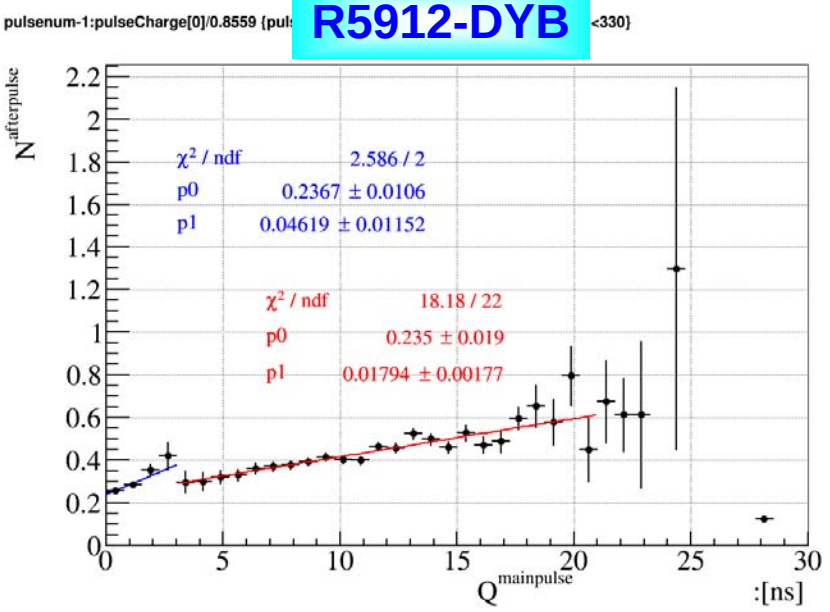


The After-Pulse Ratio of the PMT (① Ratio)

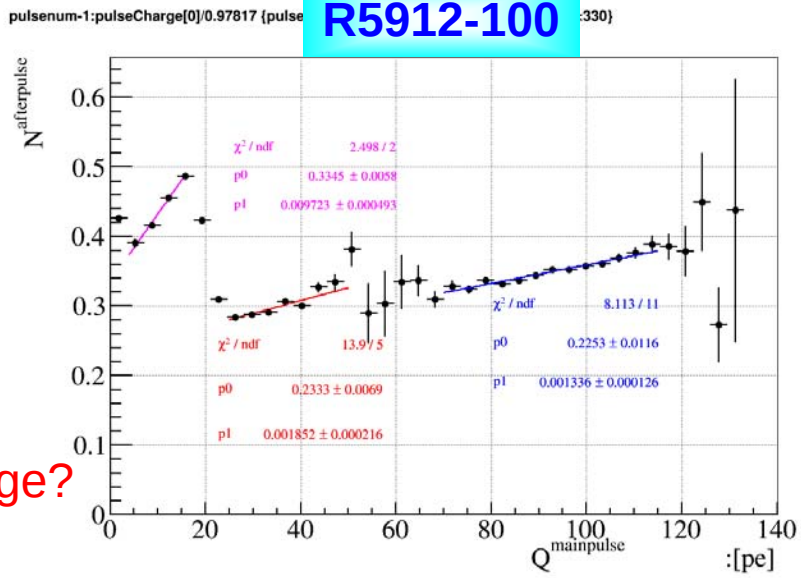
MCP-PMT-031#-A



R5912-DYB



R5912-100

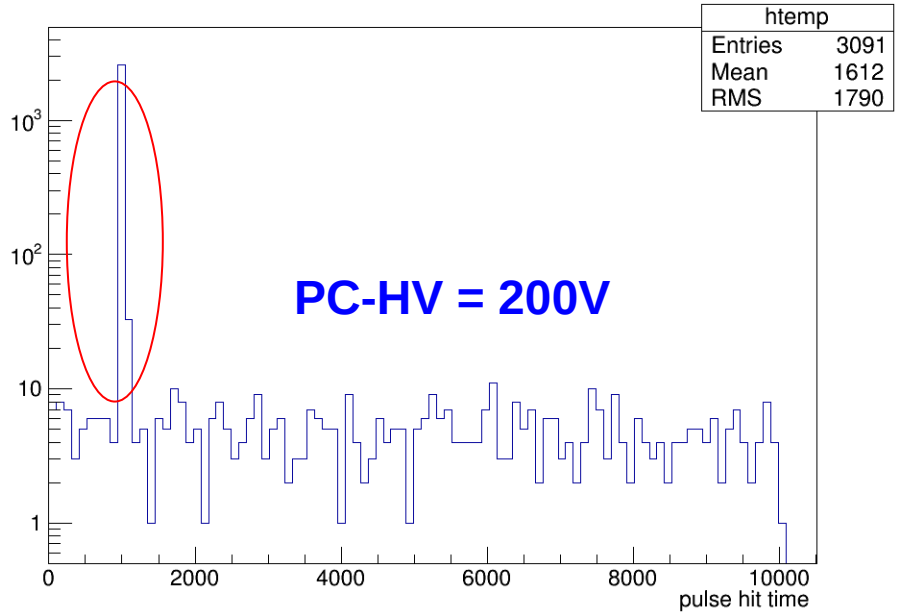


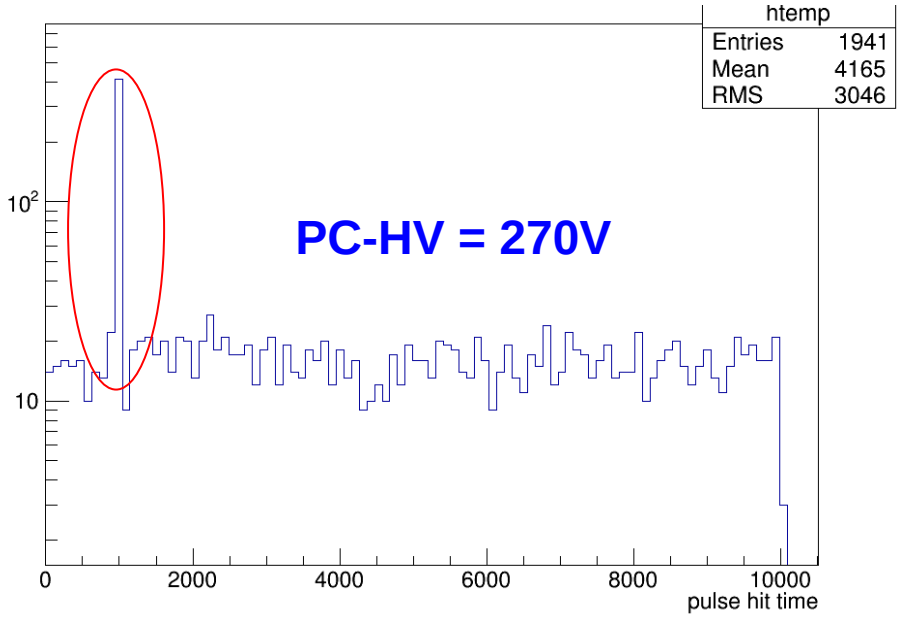
	APR
R5912	1.79%
R5912-100	0.1336%
MCP-PMT	Very small

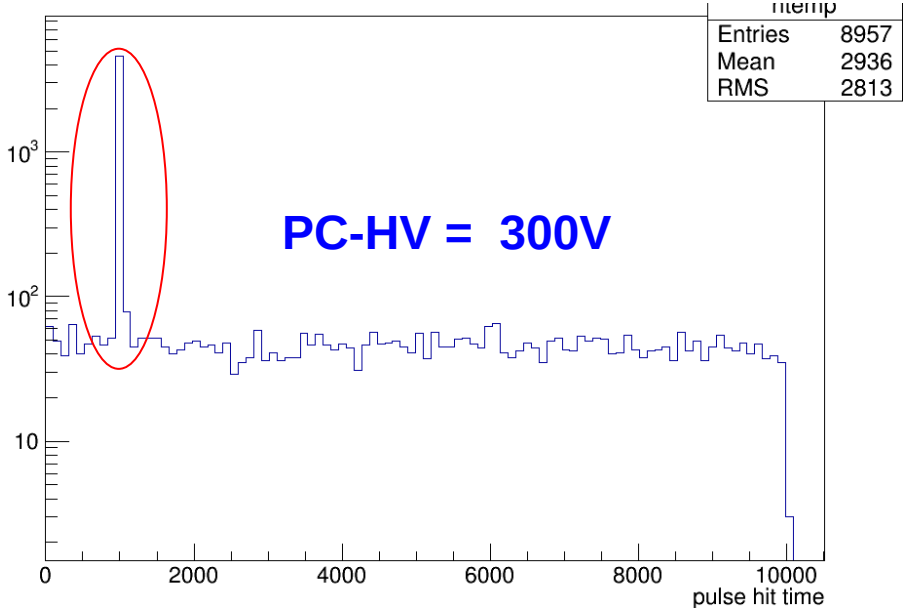
Q1: why the Ratio is so small?---200V PC voltage?

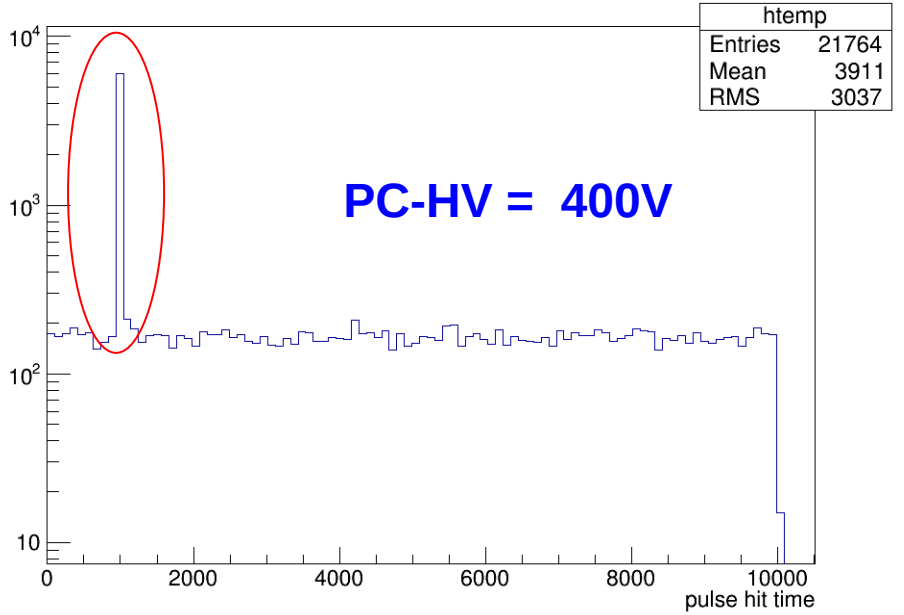
Q2:Why there is a jump in the graph at 30 P.E?

MCP-PMT-041#-A change the HV of PC, Keep the HV of MCPs



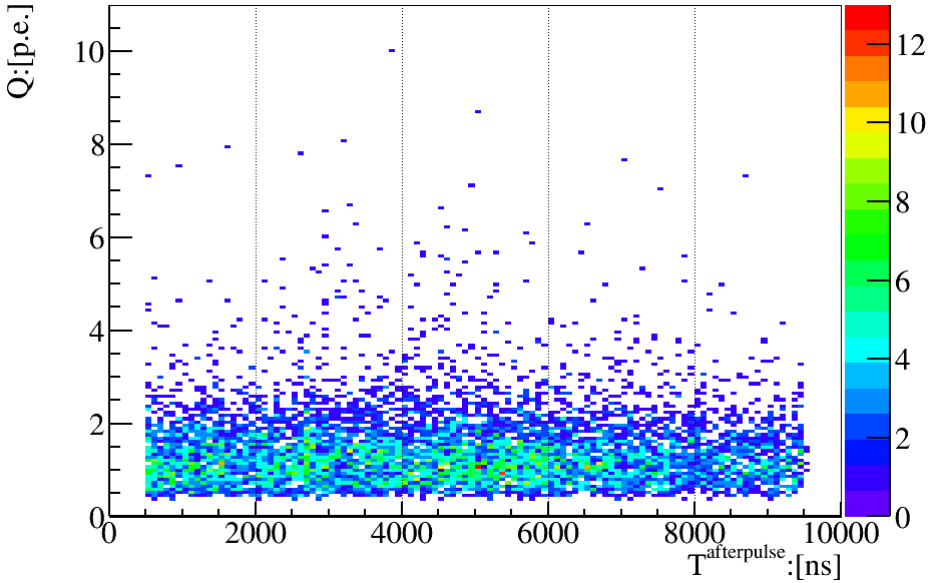




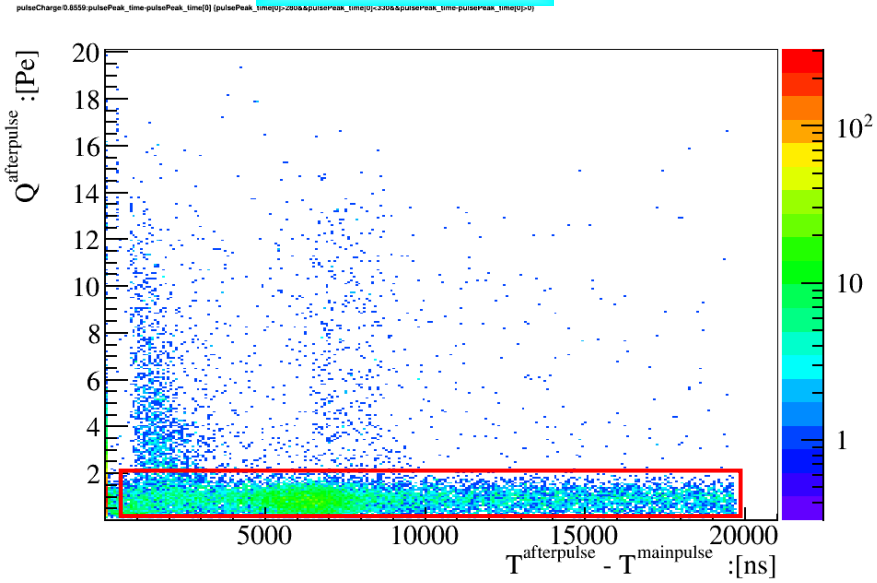


➢ The dark noise distribution

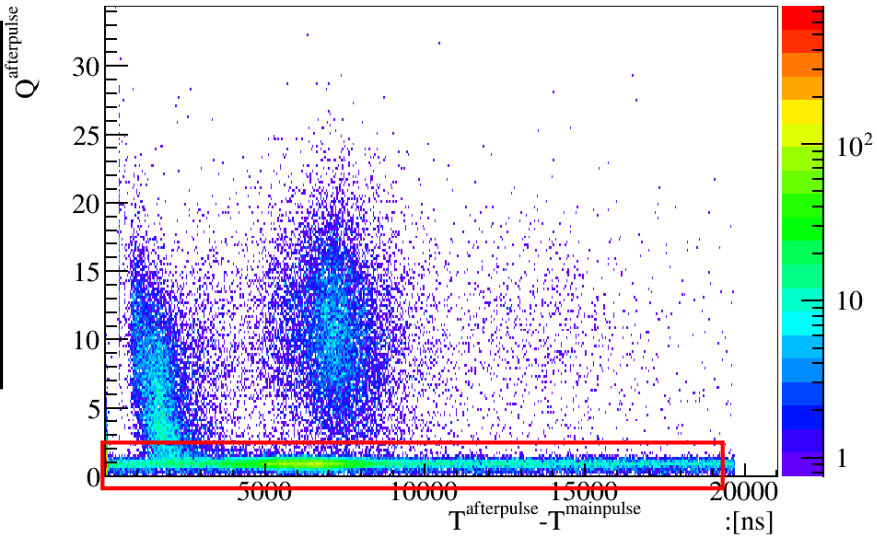
MCP-PMT-031#-A



R5912-DYB



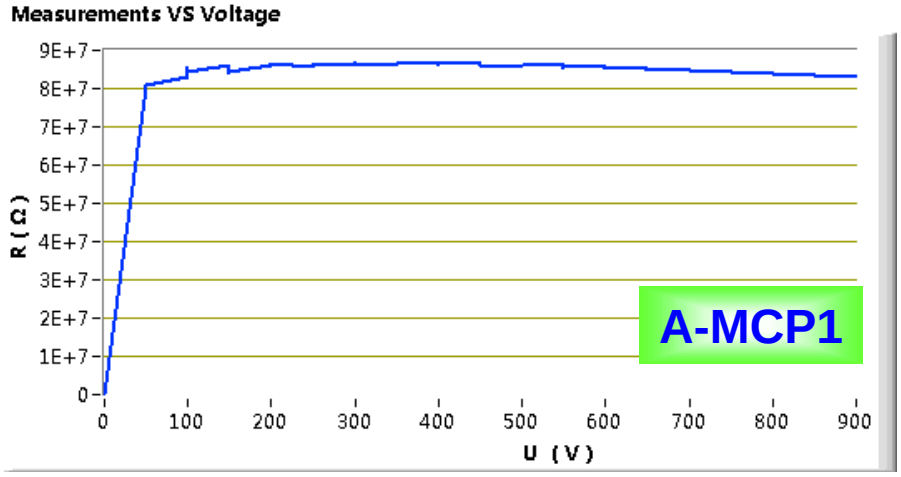
R5912-100

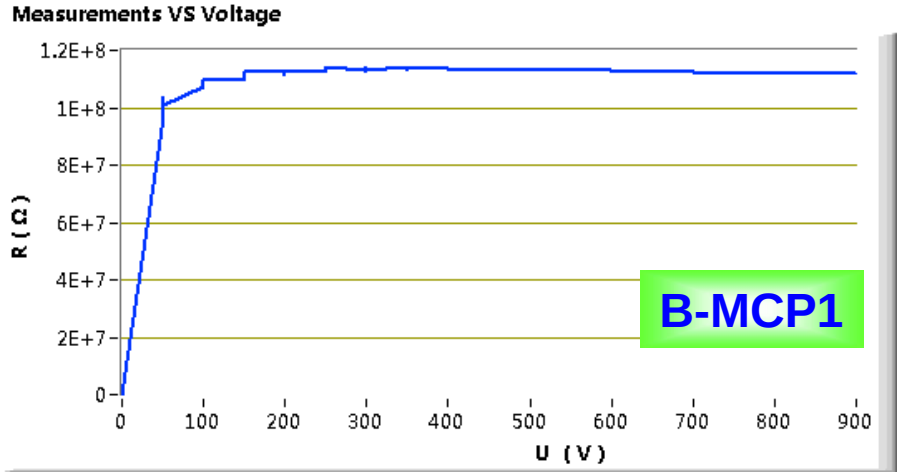


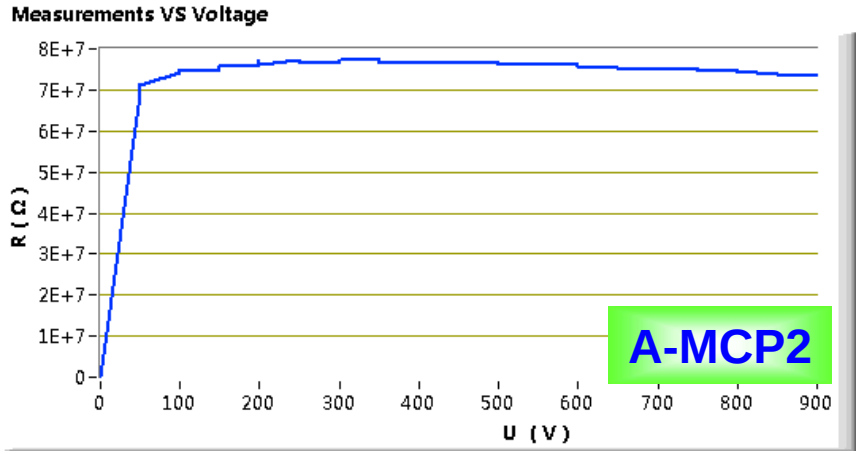
	Dark rate (0.25PE)	Dark current	The charge of the dark noise
R5912	< 1kHz	~1nA	1pe
R5912-100	~3.5kHz	~2nA	1pe
MCP-PMT	~2.2kHz	~6nA	1.4pe

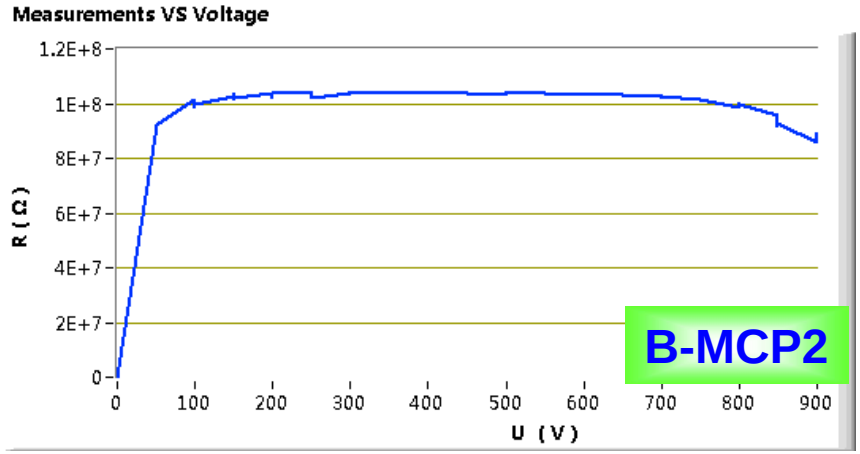
The MCP-PMT has low Dark Rate,
but High Dark Current

➢ The resistance of the MCP of the PMT









MCP module	A-MCP1	A-MCP2	B-MCP1	B-MCP2
@800V	83 MΩ	110 MΩ	74 MΩ	100 MΩ

Outline

- 1. The Motivation for JUNO；
- 2. The Design of the new MCP-PMT;
- 3. The status of the MCP-PMT prototypes;
- 4. The performance of the 8” MCP-PMT；
- **5. Summary and Plan;**

Parameters \ PMT Type	R5912	R5912-100	MCP-PMT
QE of the Photocathode@ 410nm	25%	35%	20% (25%)
QE uniformity	?	±3%	±3%
Rise / Fall time of the SPE signal Gain=2*10^7	3ns / 4ns	3.4ns / 4.6ns	5ns / 6.3ns
Amplitude of the SPE signal @Gain=2*10^7	17mV	18mV	17mV
Transit Time Spread (TTS)	5.5ns	1.5ns	3.5ns
P/V of the SPE signal @ Gain=2*10^7	> 2.5	> 2.5	1.5~2.5
The Voltage of the PMT @ Gain=2*10^7	1600V	1550V	2000V
Anode dark count @ Gain=2*10^7@ Tro.=0.25pe	< 1kHz	~3.5kHz	~2.2kHz
Anode dark current @ Gain=2*10^7	~1nA	~2nA	~6nA
The Charge of the dark noise distribution	1 pe	1 pe	1.4 pe
linearity of the PMT upto 40mA / < 60mA	±2% / ±5%	±2% / ±4%	±2% / ±4%
After-Pulse time distribution: Fast / Slow	1.6us / 7us	1.5us / 7.1us	3us / ?
After-Pulse Ratio of the PMT	1.79%	0.1336%	Very small !

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;
  - ② 5"(8") prototype with transmission and reflection photocathode;
  - ③ 20" prototype with transmission and reflection photocathode;
- **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;

There are lots of work to do!

- **MCP-PMT development:**
  - **Technical issues mostly resolved**
  - **Successful 8" prototypes**
  - **A few 20" prototypes**

Thank！谢谢！

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


Welcome to Kaiping