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 20 inch MCP-PMT R&D in China

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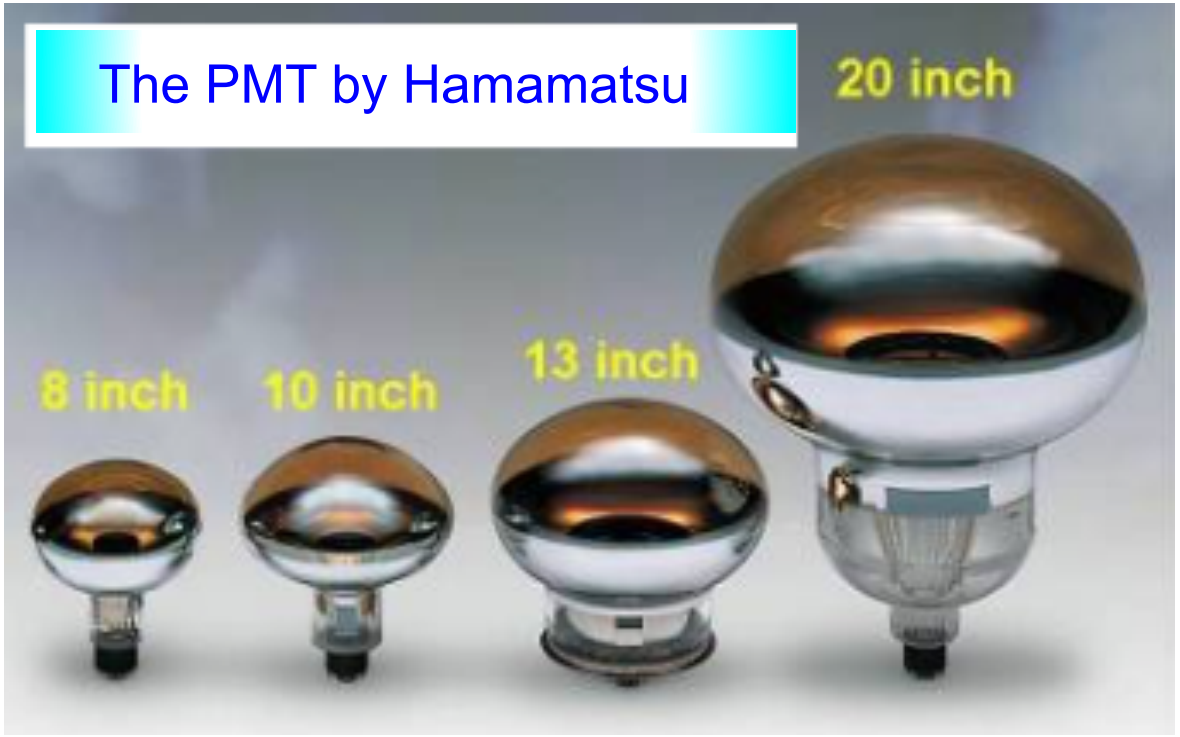


The MCP-PMT by IHEP+NNVT

Outline

- **1. The Neutrino Experiment in China;**

  The DayaBay；the DayaBayII；the JUNO；the PMT requirement；

- **2. The new design of the MCP-PMT;**

  The new design, the collaboration group, the evaluation Lab;

- **3. The MCP-PMT prototypes (2011-2014);**

  The 8 inch prototypes; the 20 inch prototypes;

- **4. The High PDE MCP-PMT—2015;**

  How to improve, QE, CE, DR, The new 20 inch prototypes ;

- **5. The Mass production Line and Batch test system;**

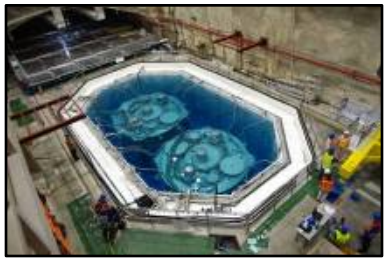
  The mass production, the batch test about 4700pics PMT；

- **6. The Batch test result;**

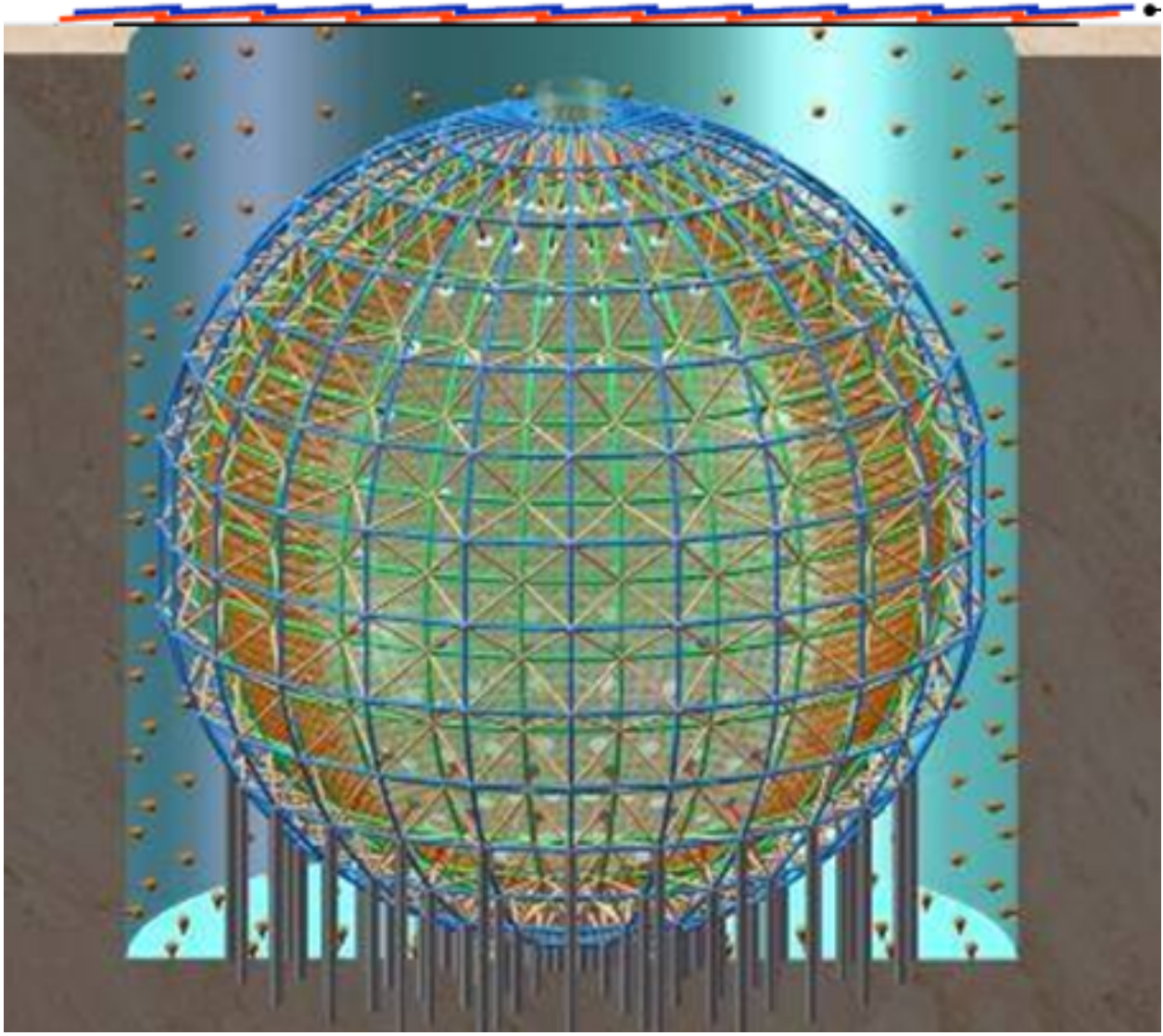
  The batch test data of 4700 Pics MCP-PMTs；

➢ 2 The Neutrino Experiment in China

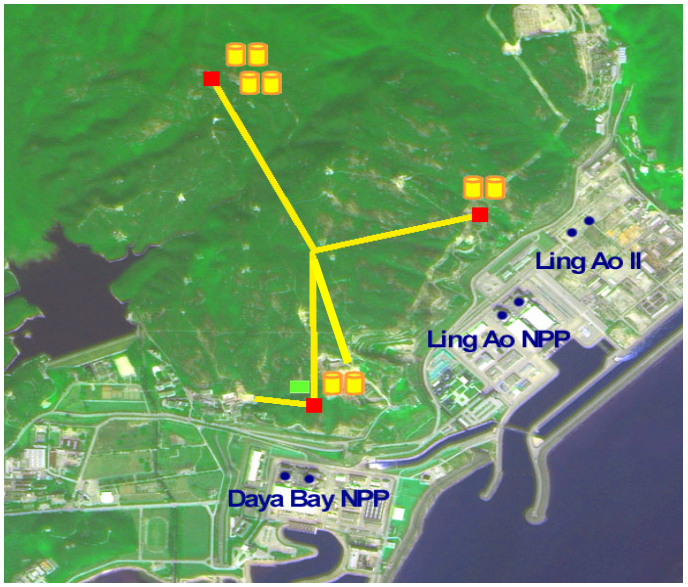
➢ **Daya Bay Experiment**

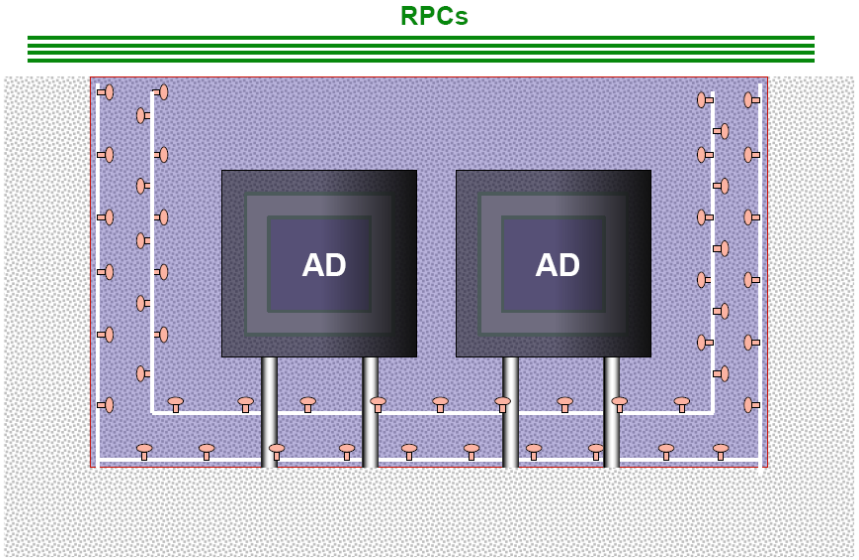


➢ **JUNO Experiment**

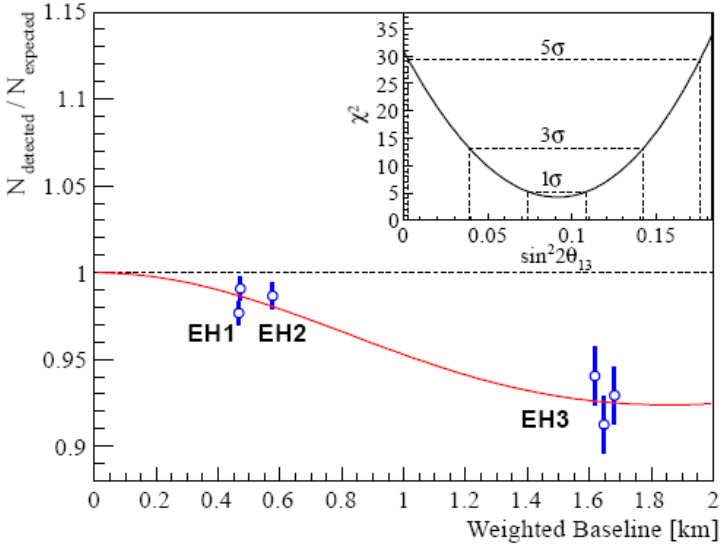


1.1 Daya Bay Experiment: Layout (2011)





- Relative measurement to cancel Corr. Syst. Err.
  - ⇨ 2 near sites, 1 far site
- Multiple AD modules at each site to reduce Uncorr. Syst. Err.
  - ⇨ Far: 4 modules, near: 2 modules
- Multiple muon detectors to reduce veto eff. uncertainties
  - ⇨ Water Cherenkov: 2 layers
  - ⇨ RPC: 4 layers at the top + telescopes

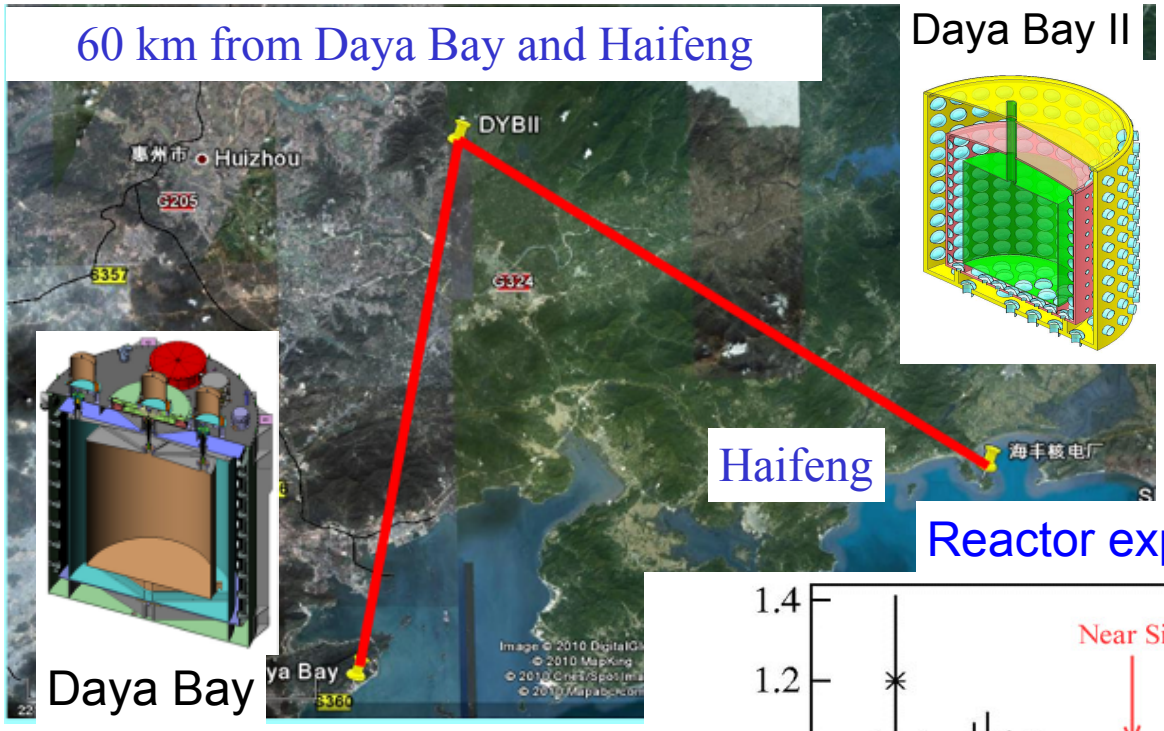


$\sin^2 2\theta_{13} = 0.092 \pm 0.016(\text{stat}) \pm 0.005(\text{syst})$

$\chi^2/\text{NDF} = 4.26/4$ 5.2 σ for non-zero θ_{13}

Neutrino Oscillation

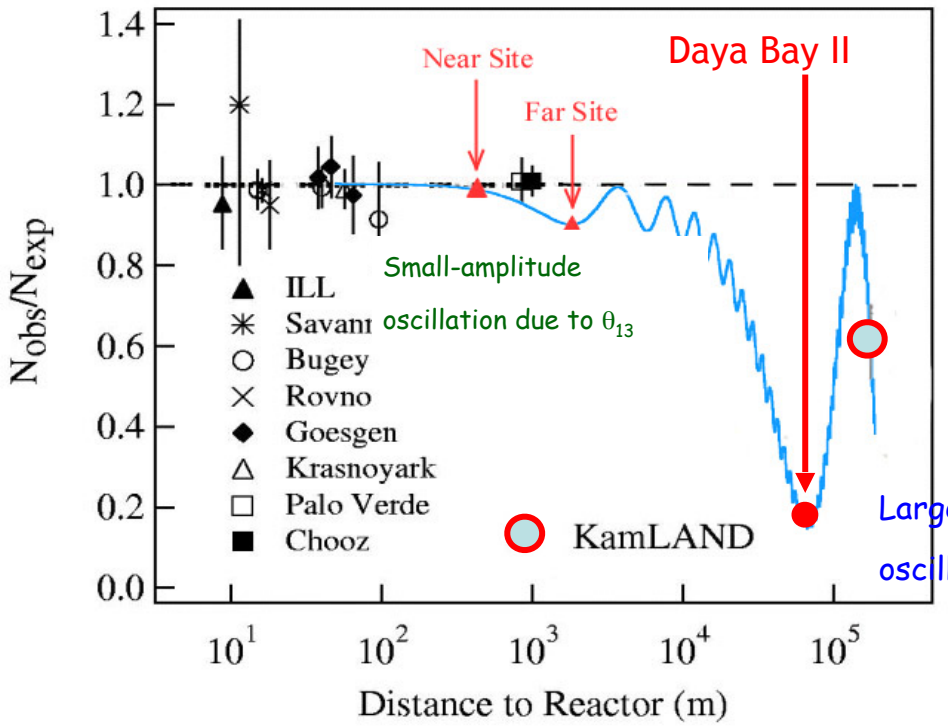
1.2 Next generation Neutrino Experiment in China (2009)—DayaBay II



The Main Scientific goals:

- ⇨ Mass Hierarchy
- ⇨ Mixing matrix elements
- ⇨ Supernovae
- ⇨ geo-neutrinos

Reactor experiments:



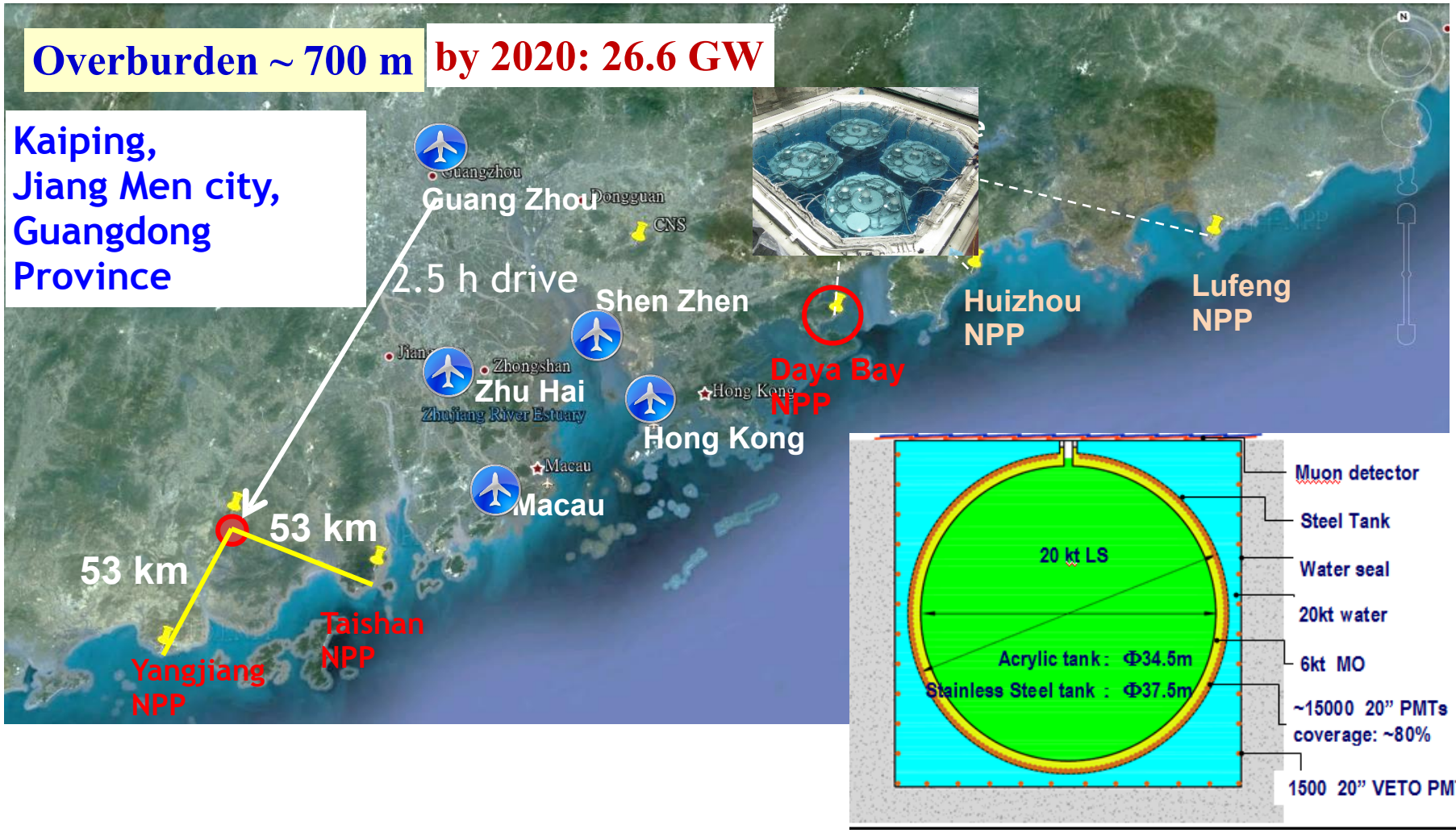
Measuring Mass Hierarchy

Huge Detector : LS + PMT

Energy resolution ~ 3%/√E

L. Zhan, et. al., Phys.Rev.D 78:111103,2008
L. Zhan, et. al., Phys.Rev.D 79:073007,2009

1.3 Jiangmen Underground Neutrino Observatory (JUNO) —2013

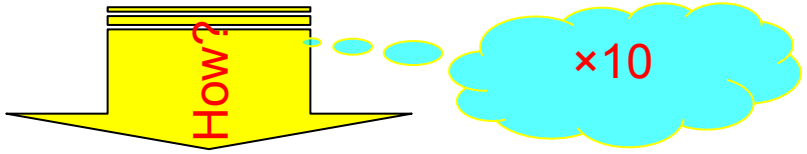


Requirement: High QE 20 inch PMT;Good SPE detection capability;Wide dynamic range;Low radioactive background;More than 20 years lifetime;Can withstand 0.4MPa Pressure;> 20000 pieces;

2009: Design; 2011: Collaboration; 2012: DayaBay result; 2013: JUNO

1.4 the requirement for PMTs

	KamLAND	Daya Bay II	JUNO
Detector	~1 kt Liquid Scintillator	10 kt Liquid Scintillator	20 kt Liquid Scintillator
Energy Resolution	6%/√E	2%/√E	3%/√E
Light yield	250 p.e./MeV	2500 p.e./MeV	1200 p.e./MeV



- Ongoing R&D:
  - Highly transparent LS: Attenuation length ;

    Attenuation length: 15m → 25m; the Light Yield (% standard): ×1.5

    Attenuation length: 15m → 30m; the Light Yield (% standard): ×2;
  - High light yield LS: increasing PPO%

    Light Yield (% standard): 30%→ 45%; × 1.5
  - Photocathode coverage :

    KamLAND: 34% → Daya Bay II : ~ 80% × 2 ~ 2.5
  - **High QE "PMT":Quantum Efficiency(or Photon Detection Efficiency)×2;**

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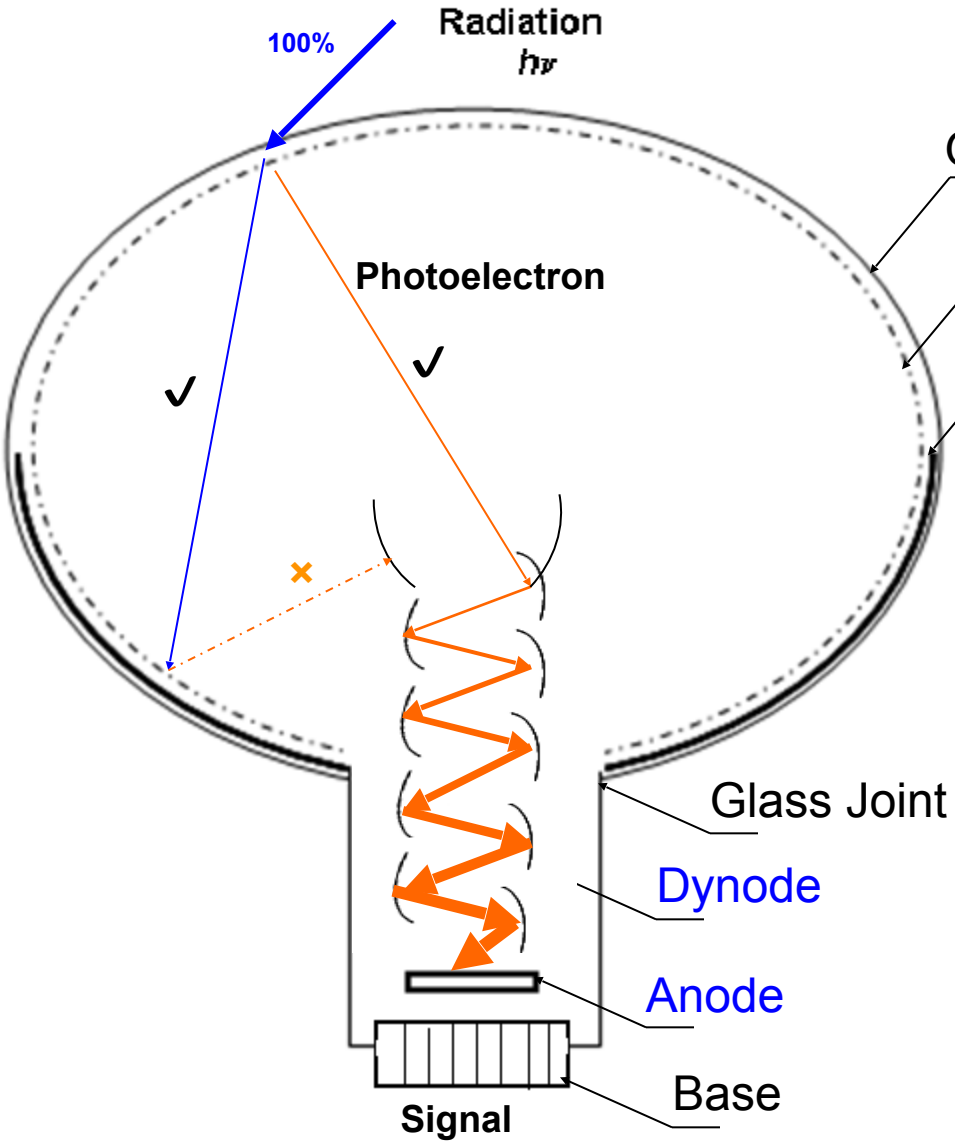
  the batch test data；

2 The new design of the MCP-PMT

The Conventional PMT



Quantum Efficiency (QE) :

20%

Collection Efficiency (CE) of Anode:

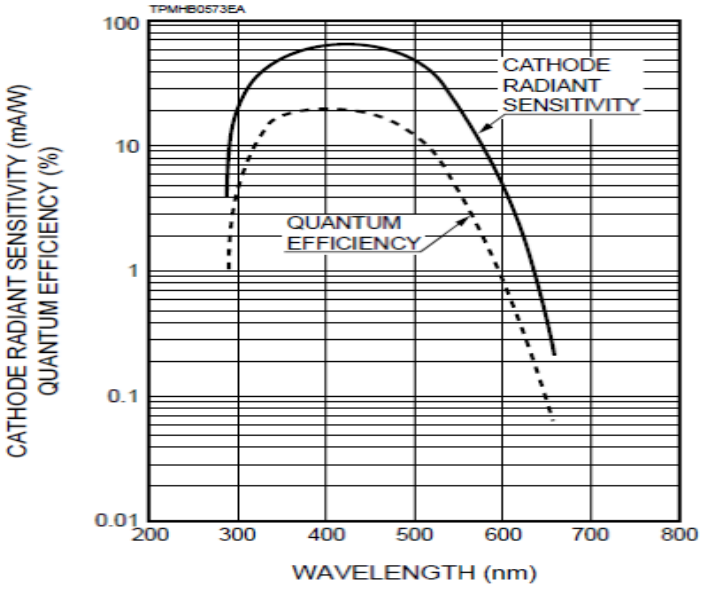
70%

Photon Detection Efficiency **(DE)**

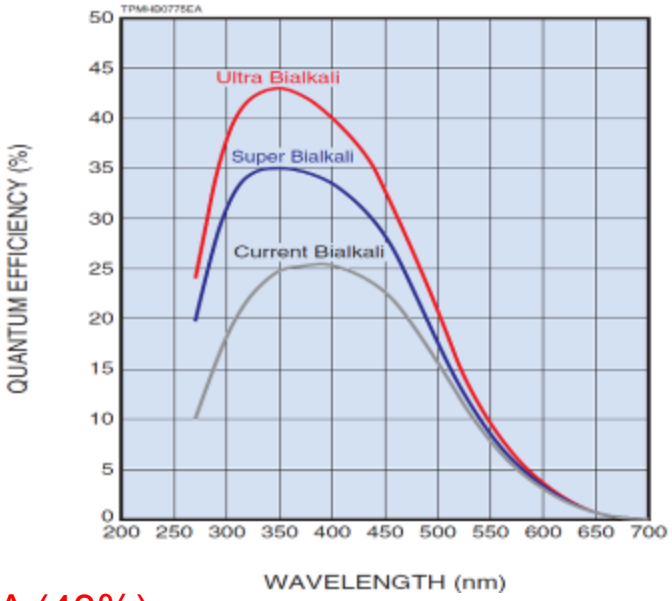
(PE) = QE_{Trans} * CE = 20% * 70%

= 14%

The QE of 20“ PMT-R3600



The QE of SBA/UBA



➢High QE PMTs: SBA (35%) and UBA (43%)

are only available in small format (< 5" diameter ?) (2011)

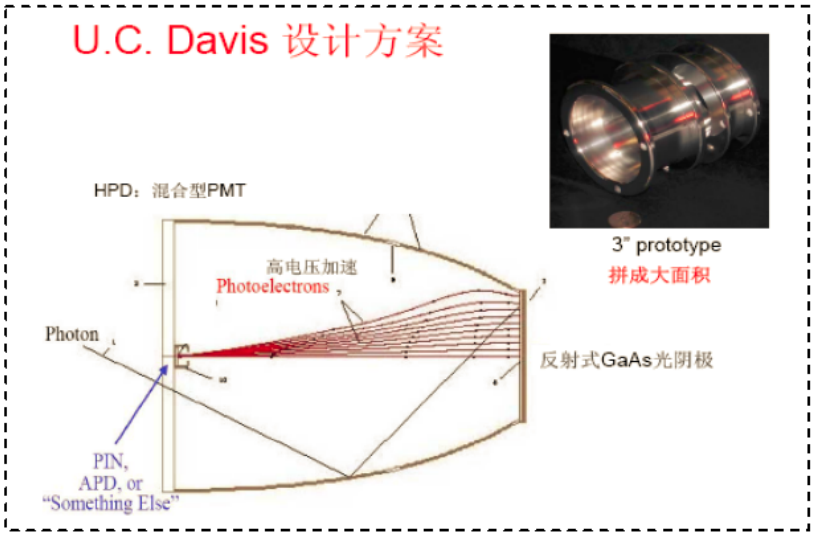
➢ Can we improve the Quantum Efficiency of Photocathode or Photon Detection Efficiency for the large area 20” PMT ?

?? 20” UBA/SBA photocathode PMT from Hamamatzu ? QE: 20% → 40%

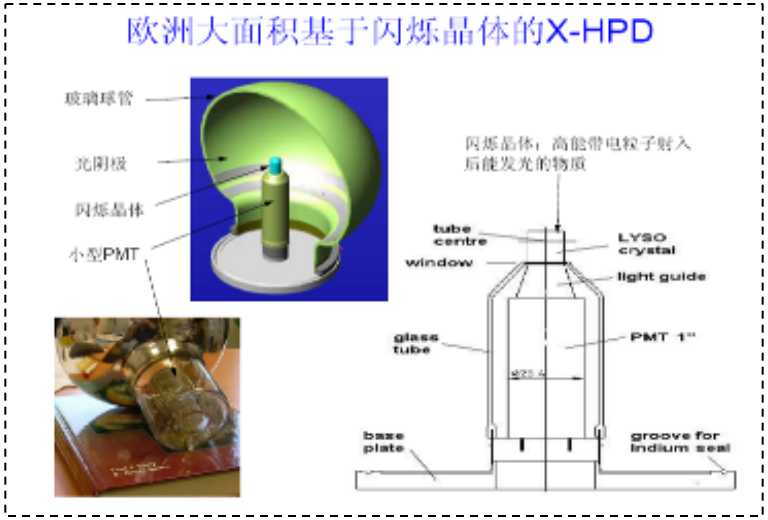
?? 20” New large area PMT ? Quantum Efficiency > 40% ?

or Photon Detection Efficiency: 14% → 30%

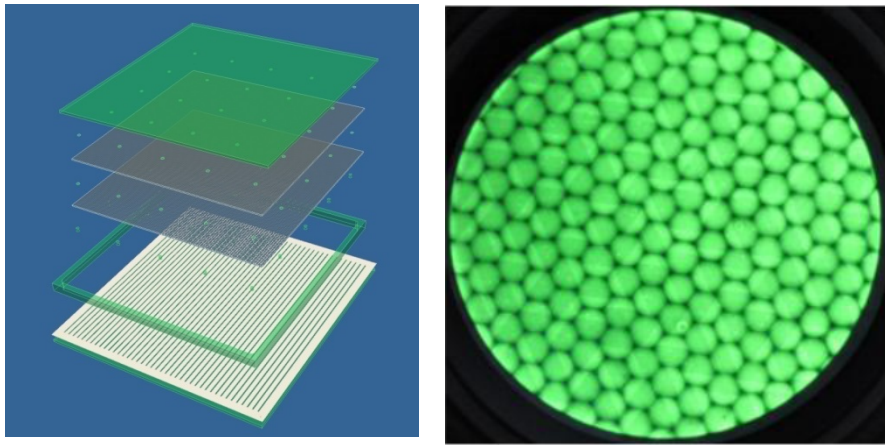
2.1 New type of PMTs under-development in ~2009



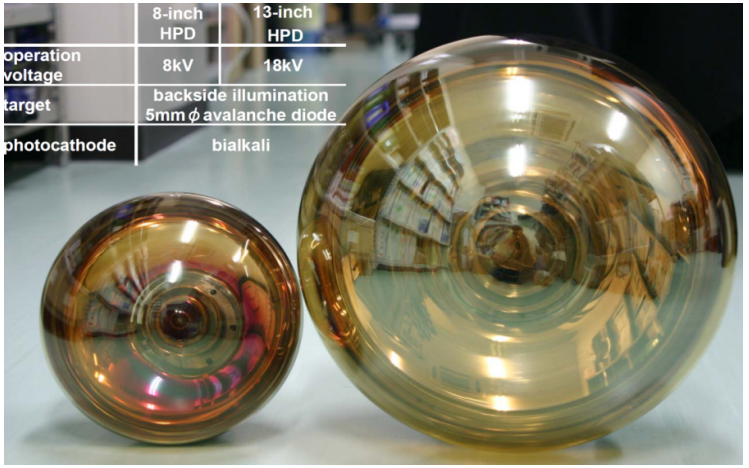
Reflective photocathode by UC Davis, Higher QE



Dynode replaced by Scintillator/APD



Large Area picosecond photo detectors(LAPPD)

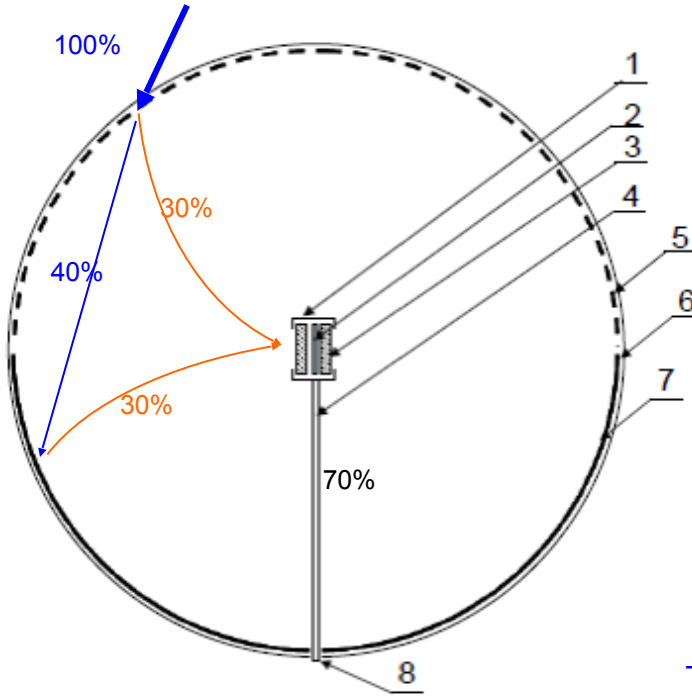


Hamamatsu Production：X-HPD， 8" and 13"; 18KV HV

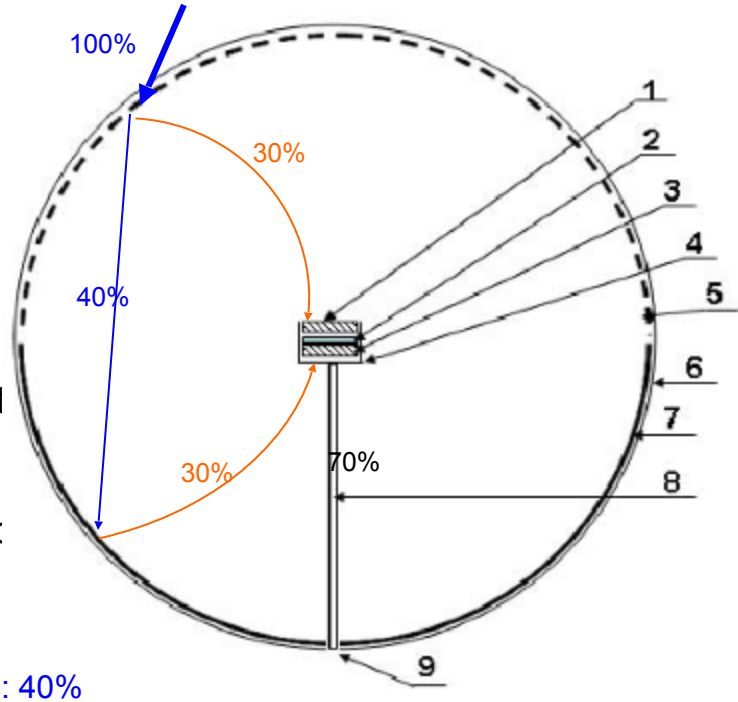
2.2 the primary design of the MCP-PMT in 2009

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 Photocat
6.Glass shell
7.Reflection Photocathoc
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 !

2.2 the large area MCP-PMT Patent

Inventor：

Yifang WANF（王贻芳）；

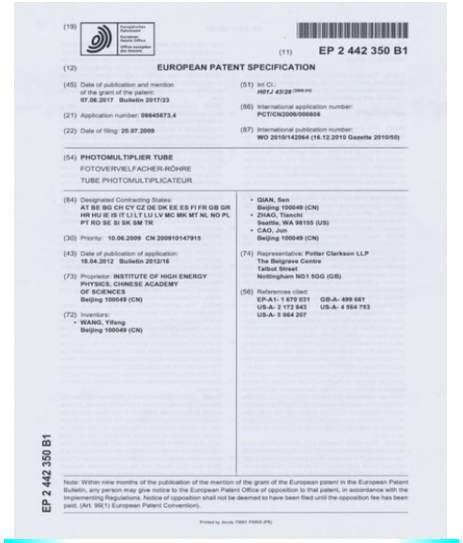
Sen QIAN（钱森）；

Tianchi ZHAO（赵天池）；

Jun CAO（曹俊）；

CHINA

USA



European Union

Japen

RUSSIA

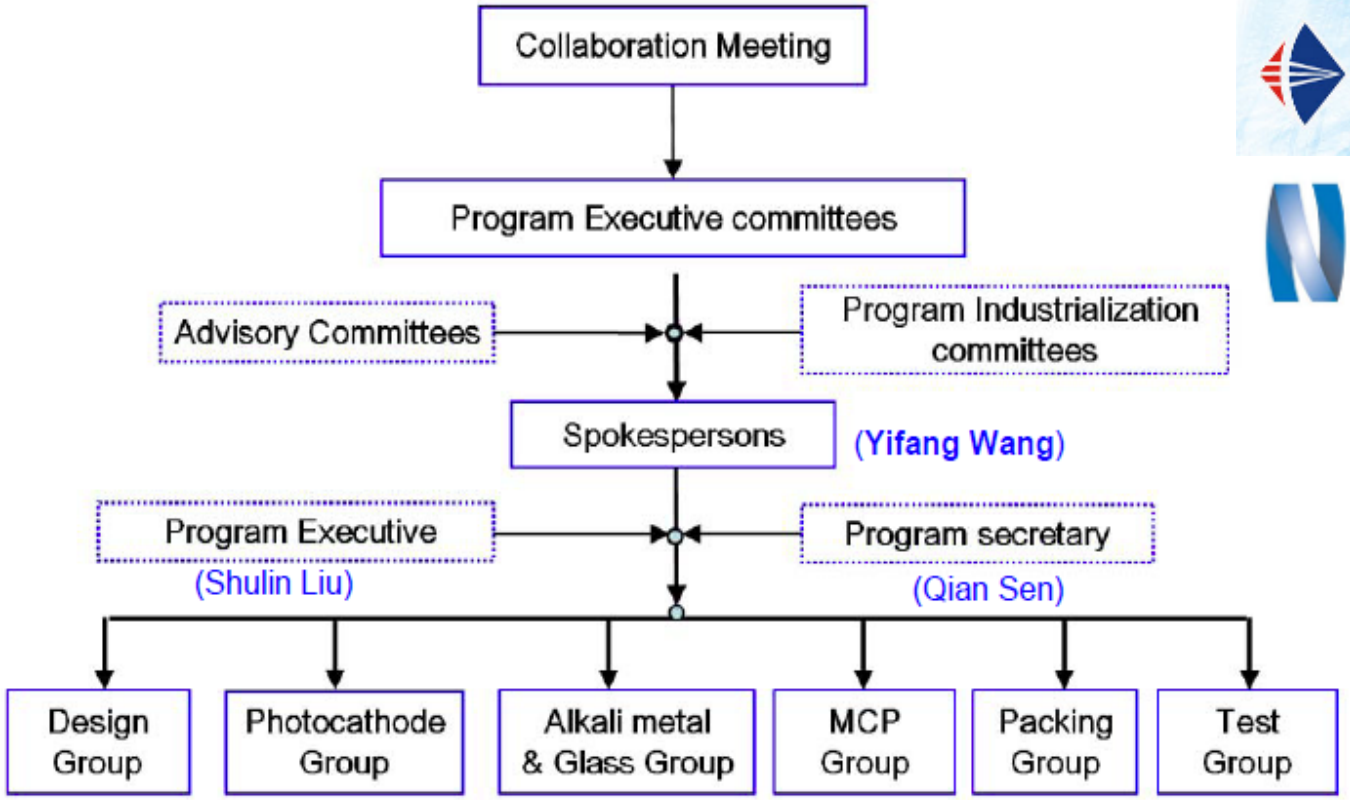
2.3 Project team and Collaborators

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)



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

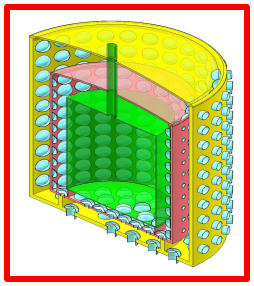
北方夜视技术股份有限公司
NORTH NIGHT VISION TECHNOLOGY CO.,LTD

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

南京大学

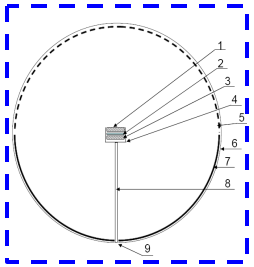
2.4 The R&D plan of MCP-PMT （Roadmap—Technology） （2009）

Requirement

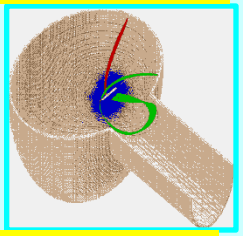


Development

Design



Photomultiplier

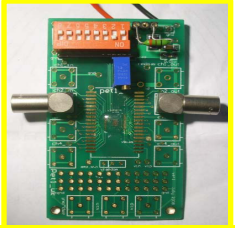


Low price MCP

Alkali metal

Glass Shell

Electronic

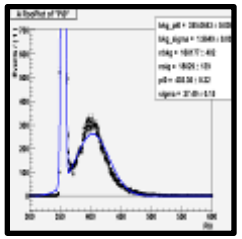


Vacuum equipment

Test system

Prototype

Performance



2.5 The Large PMT evaluation Lab

工欲善其事必先利其器 = Work must first of its profits

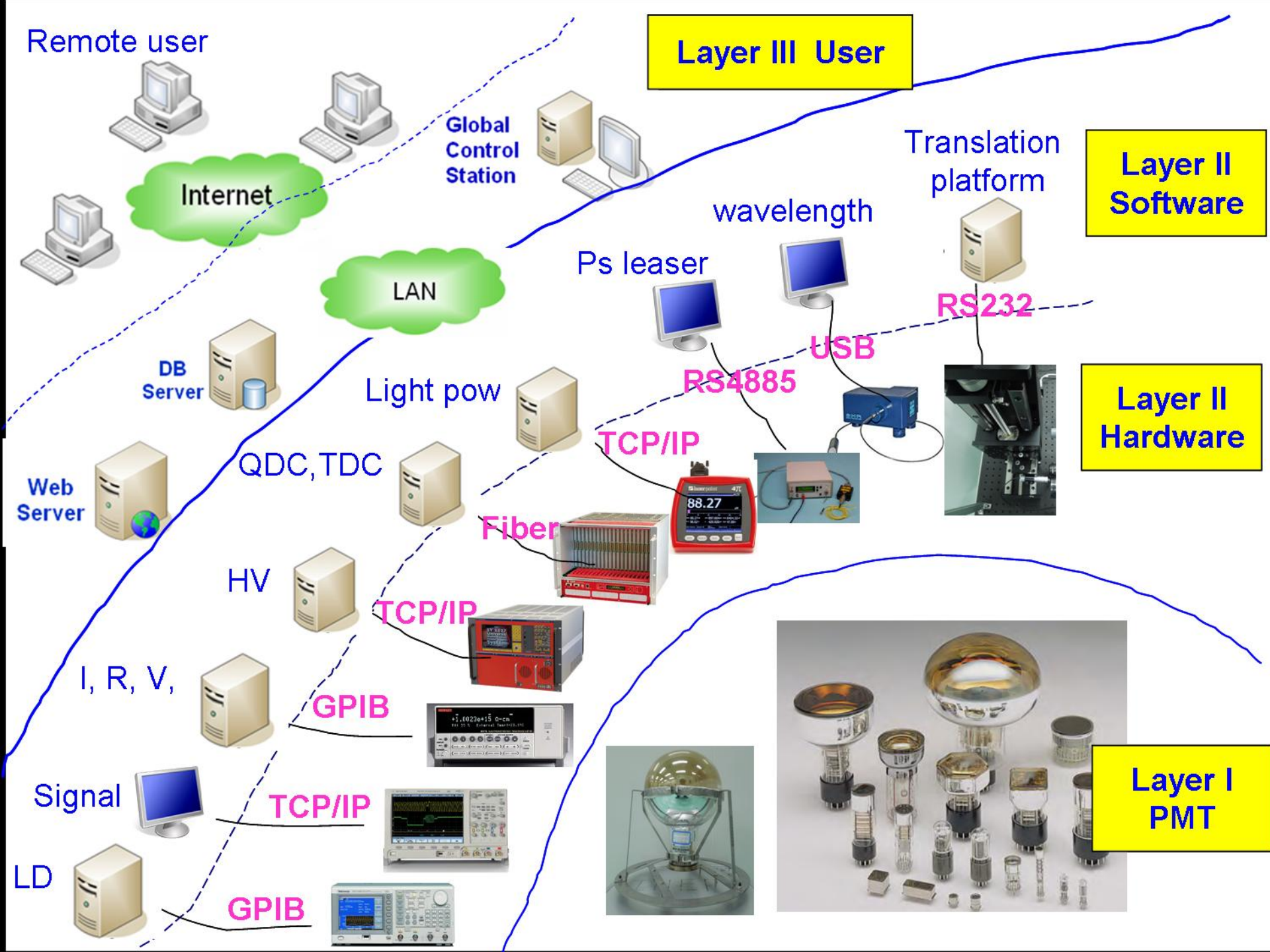
- Location： underground of the MainBuilding；
- Function： Four Dark Room

  Lab1： longtime aging test；

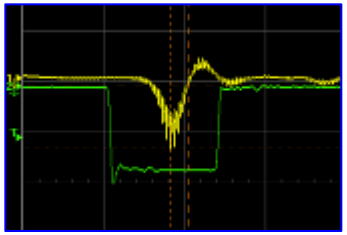
  Lab2： QE for PMT, PD, MPPC, Si-PMT；

  Lab3： Timing for PMT, PD, MPPC, Si-PMT；

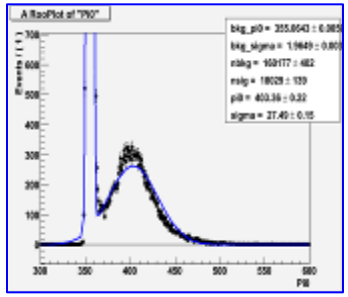
  Lab4： Geomagnetic field test for PMTs；


Remote user
Internet
Global Control Station
LAN
Layer III User
Translation platform
Layer II Software
wavelength
Ps leaser
RS232
USB
RS4885
DB Server
Light pow
TCP/IP
Layer II Hardware
Web Server
QDC,TDC
Fiber
88.27
HV
TCP/IP
I, R, V,
GPIB
Signal
TCP/IP
LD
GPIB
Layer I PMT

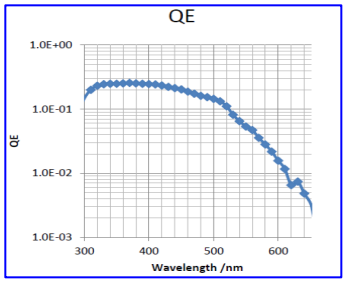
2.6 The parameters of the MCP-PMT (testing in Lab)



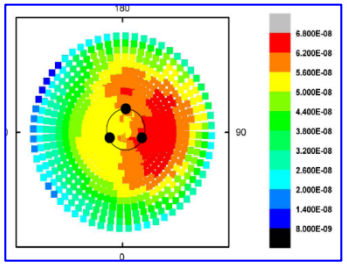
- Anode Pulse Rise Time;
- Pre/Late/After Pulse;
- Dark Count



- 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



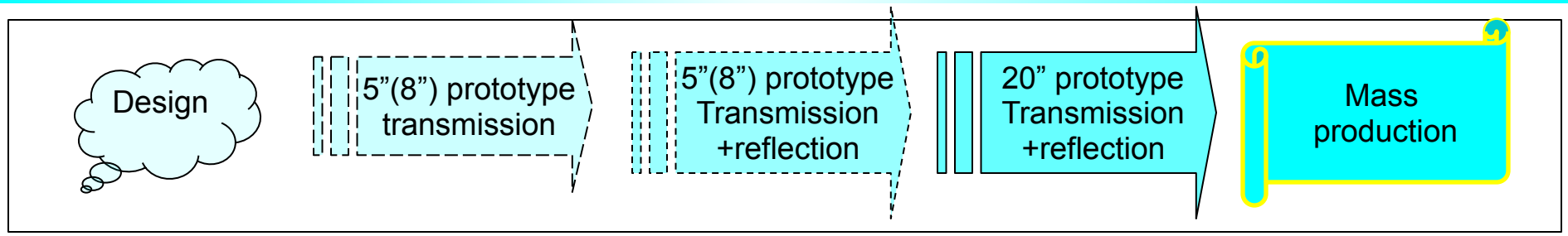
- Photocathode efficiency Area;
- Photocathode efficiency Uniform;
- The position of the Sb, K, Cs;

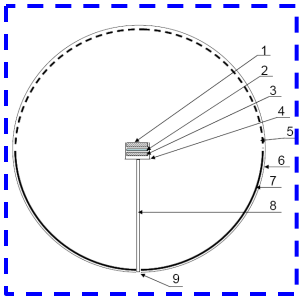
Others

……

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

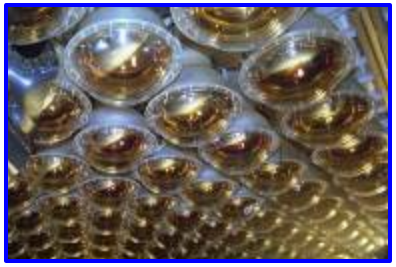
2.7 The R&D plan of MCP-PMT （Roadmap —time） （2009）



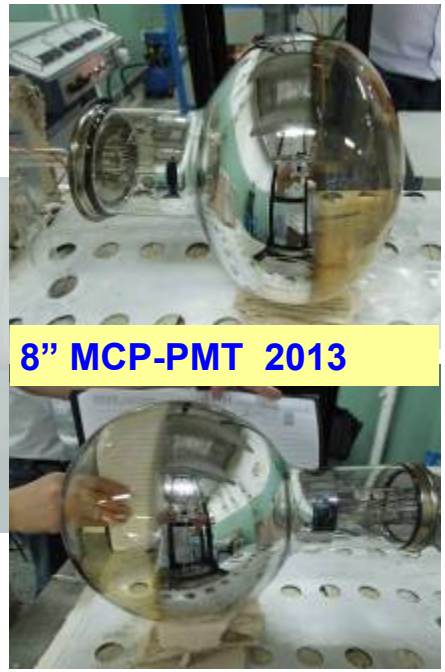


The design of the IHEP-MCP-PMT

The project of DayaBay II /JUNO



5” MCP-PMT 2010年



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  How to improve, QE, CE, DR, The new 20 inch prototypes ;
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  The batch test data of 4700 Pics MCP-PMTs；

➢ 3 The MCP-PMT prototypes (2011-2014)

➢ **Prototypes:** Successful 8” and 20”prototypes with normal performance; (2014)

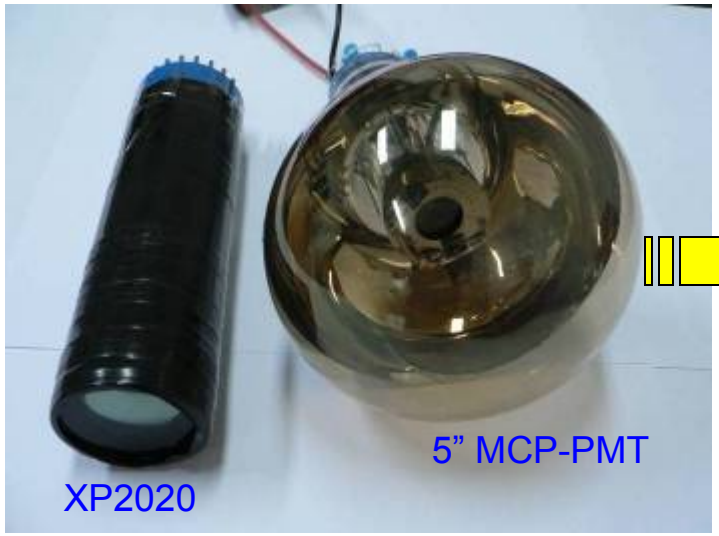
We could successfully produce the 8 / 20 inch MCP-PMT prototype for good SPE and QE

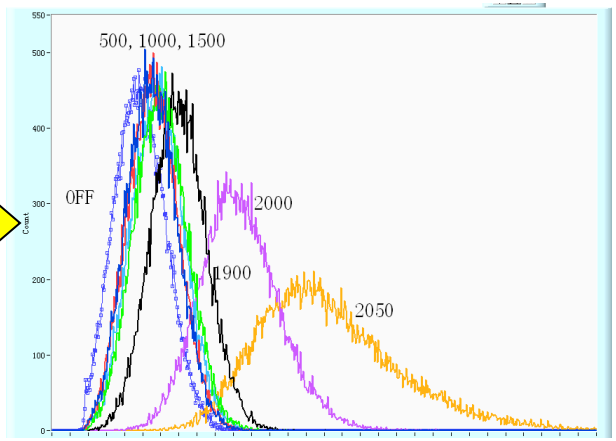
And better for CE of the MCP; Uniformity of CE, QE, TTS, in 2014;

we also try to improve our design of the prototype in 2015.

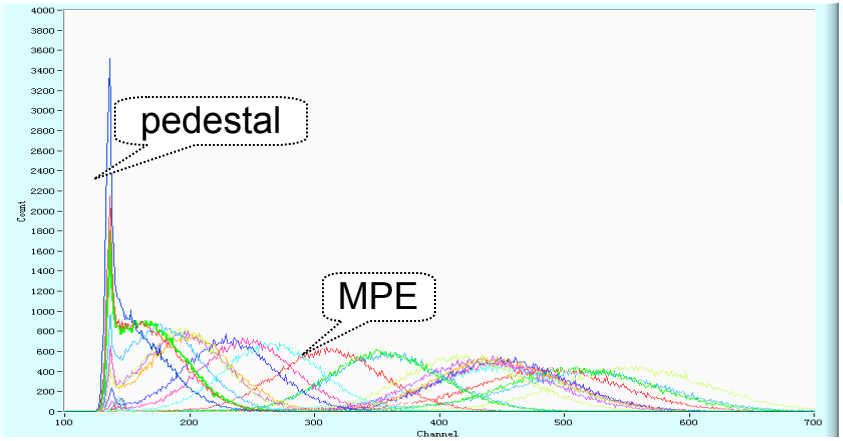
3.1 First 5”prototypes without SPE --2011

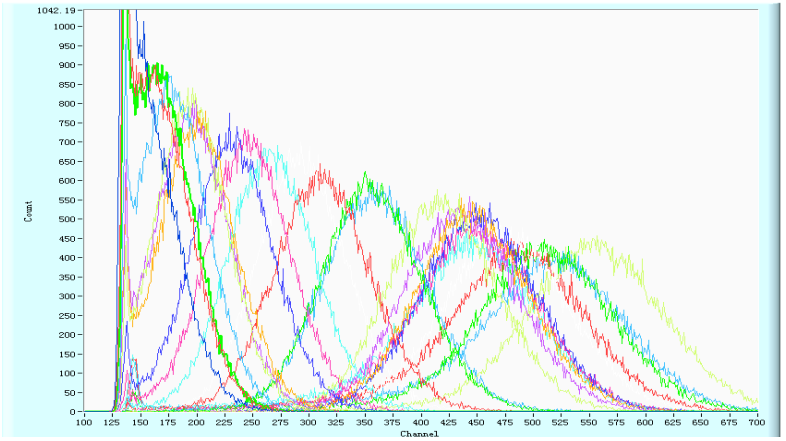
➢The photoelectron spectrum of a prototype: 5” IHEP-MCP-PMT





➢ MPE vs the Voltage of the PMT

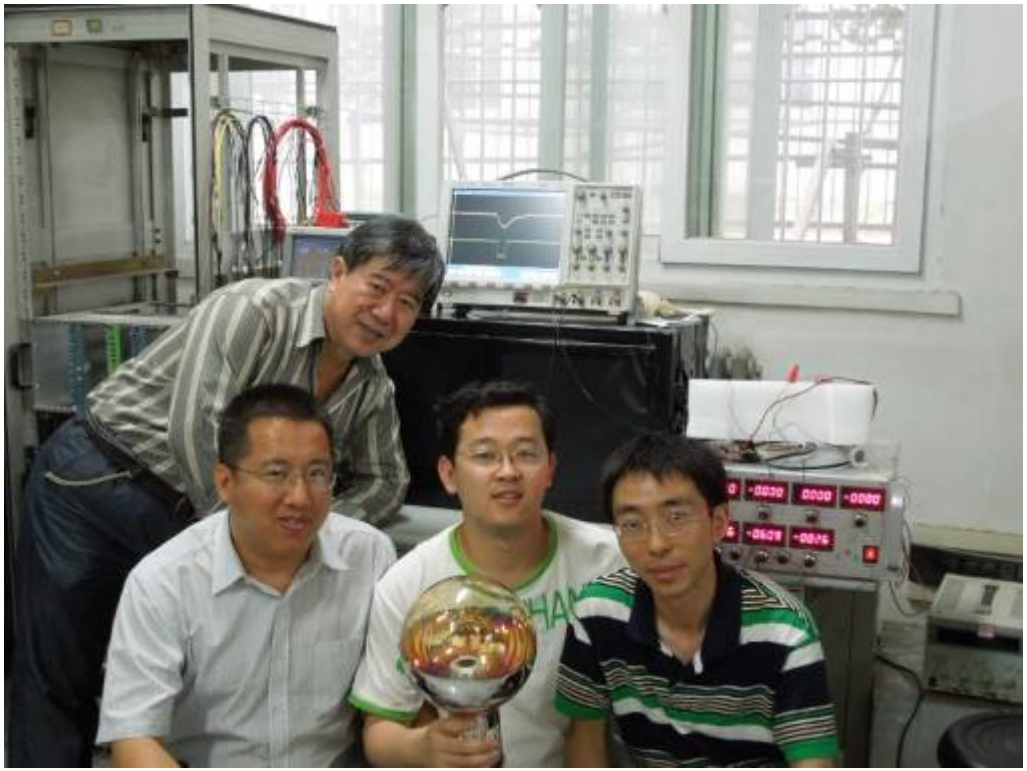


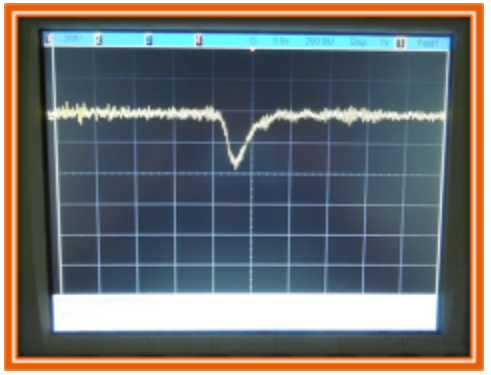


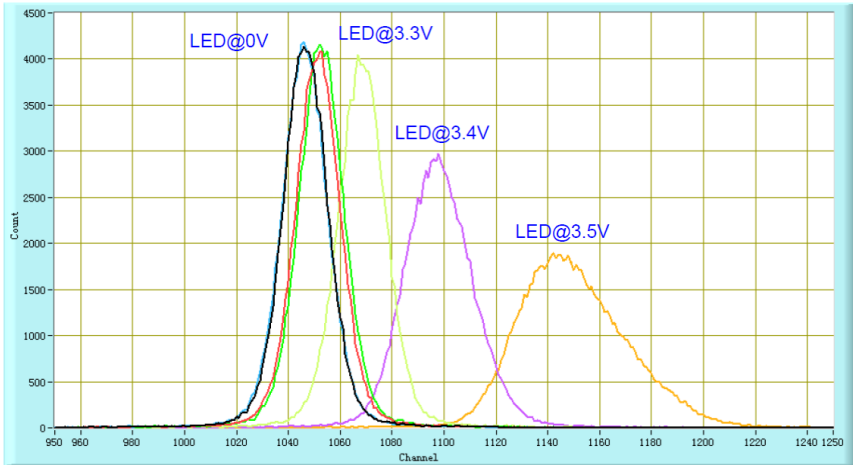
➢ MPE vs the luminance of the LED light

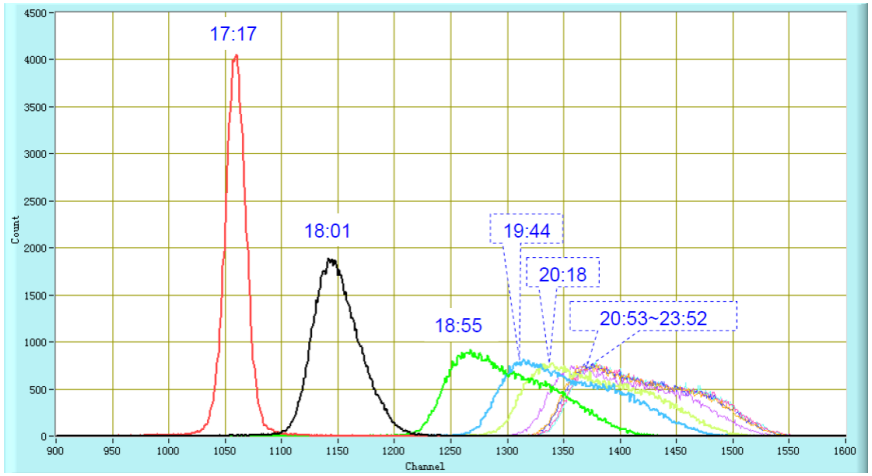
**--adjust the working voltage of the LED to adjust the luminance of the LED light.

3.2 First 8”prototypes without SPE--2012

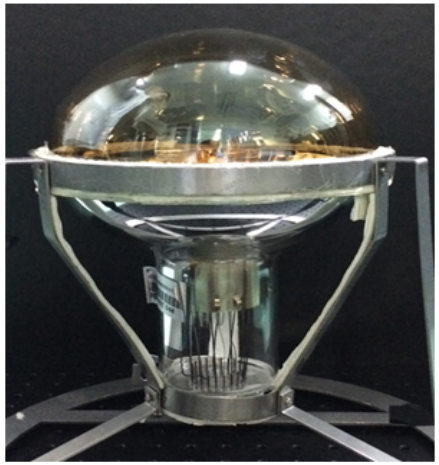


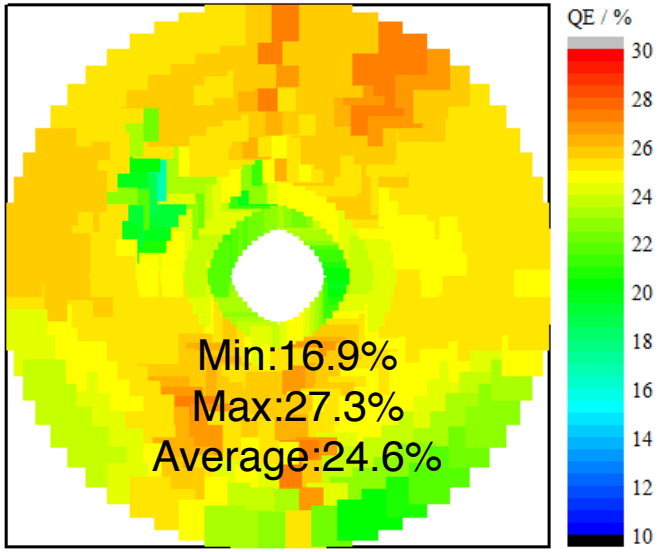


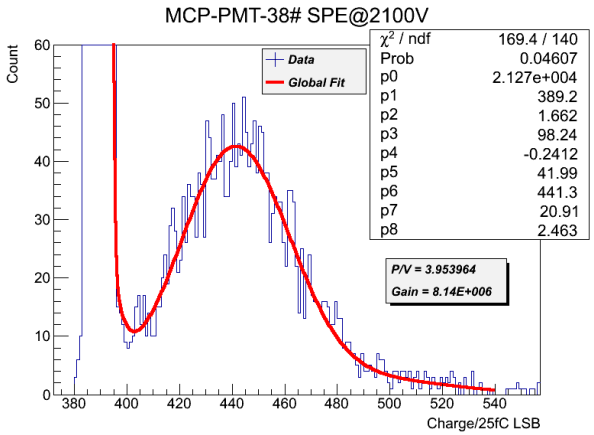


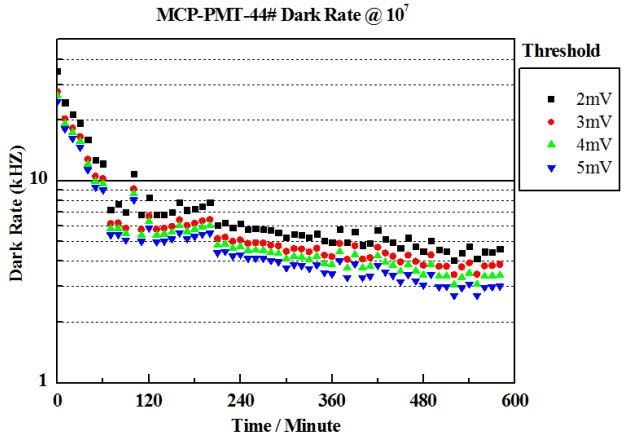


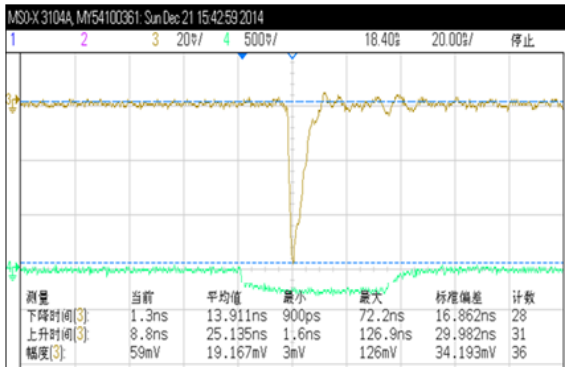
3.3 8”prototypes with normal performance--2013

8-inch IHEP MCP-PMT Vertical MCPs Sphere Glass	8-inch IHEP MCP-PMT Horizontal MCPs
	





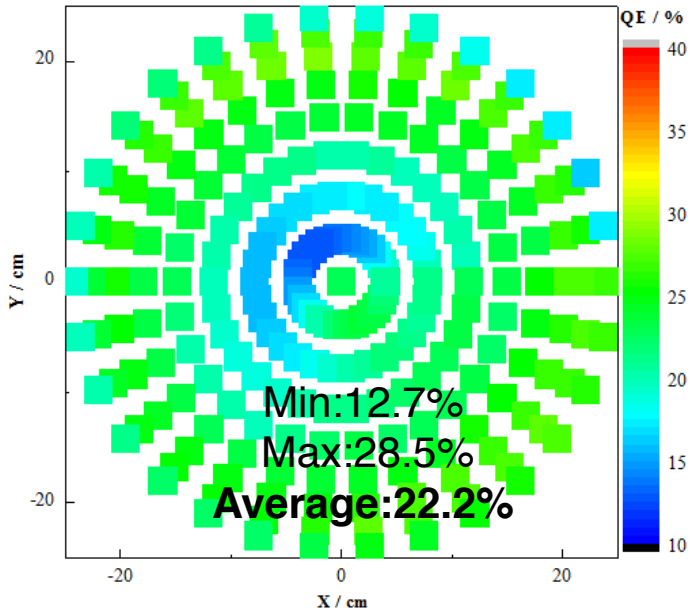


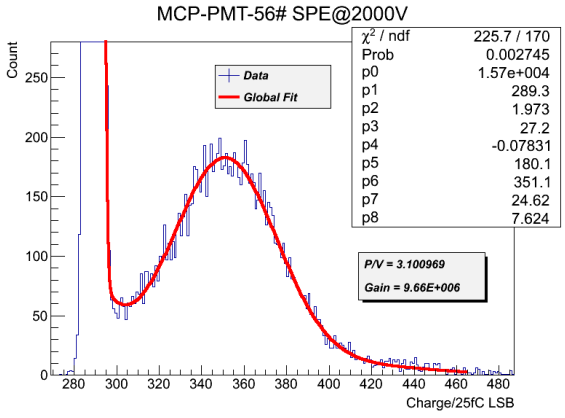


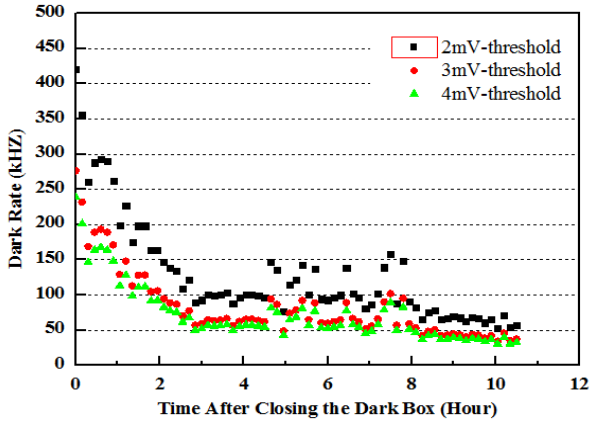
HV	Gain	P/V	Rise Time	Fall Time	Dark rate @1E7 Gain(0.25PE)
2100V	~1E7	~4	~1.3ns	~8.8ns	~3kHz

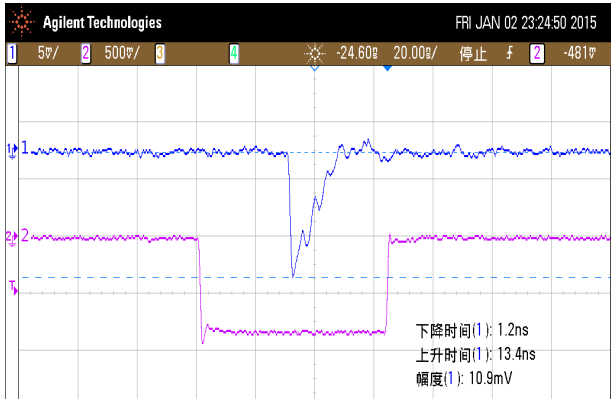
3.4 20”prototypes with normal performance--2014

20-inch IHEP MCP-PMT Vertical MCPs Sphere Glass	20-inch IHEP MCP-PMT Horizontal MCPs Ellipsoidal Glass
	







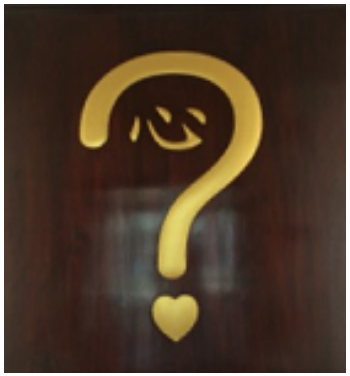


HV	Gain	P/V	Rise Time	Fall Time	Dark rate @1E7 Gain(0.25PE)
2000V	~1E7	~3	~1.2ns	~15ns	~50kHz

3.5 How to improve the performance of the prototype--2015

QE ? ?

CE ? ?

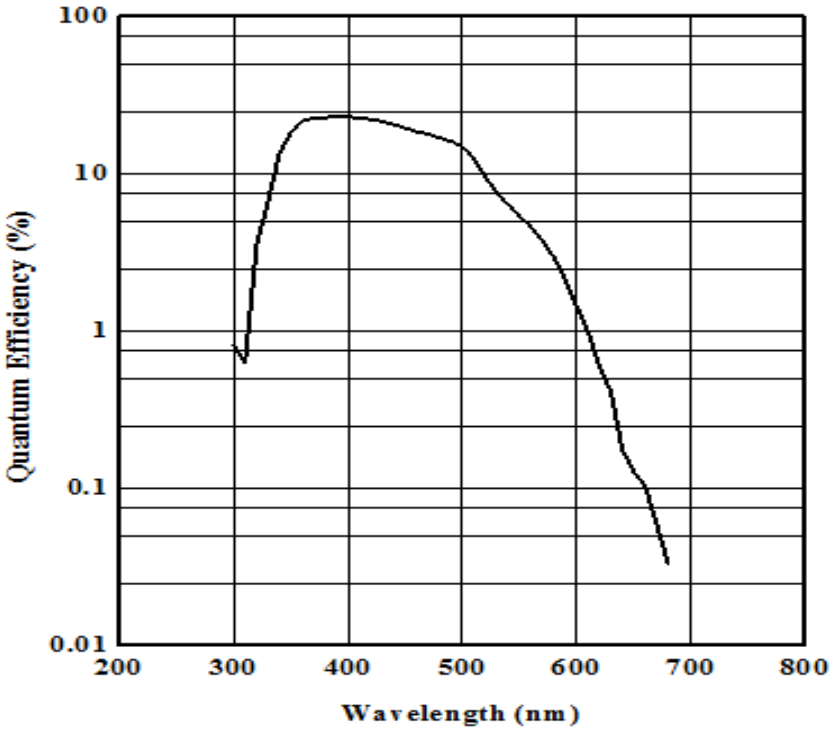


➢ 3.5.1 Improving the QE

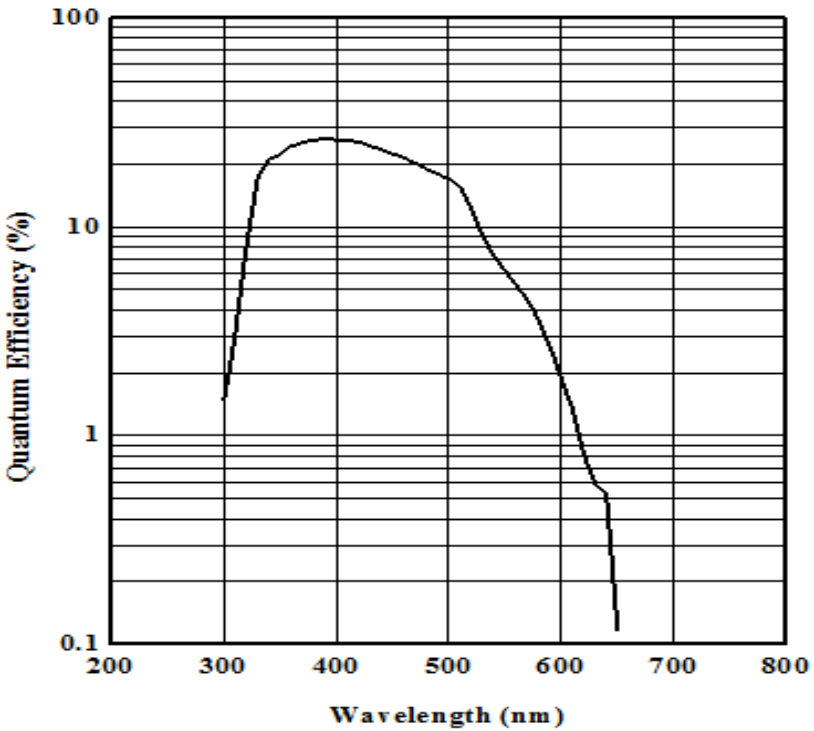
Prototype	MCP-PMT-56#	MCP-PMT-76#
QE （Average）@410nm	20%	26%

➢1. Using the Transmission equipment for producing the photocathode in prototype;

➢2. Improving the technology of PC producing process;



56# - MCP-PMT 20 inch

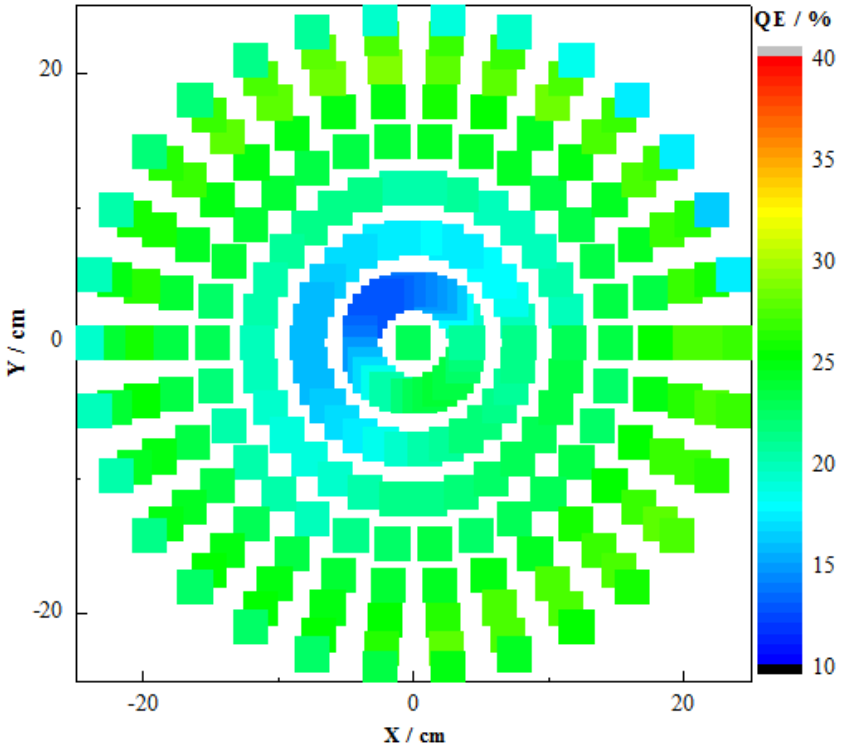


76# - MCP-PMT 20 inch

3.5.2 Improving the Uniformity of the Photocathode

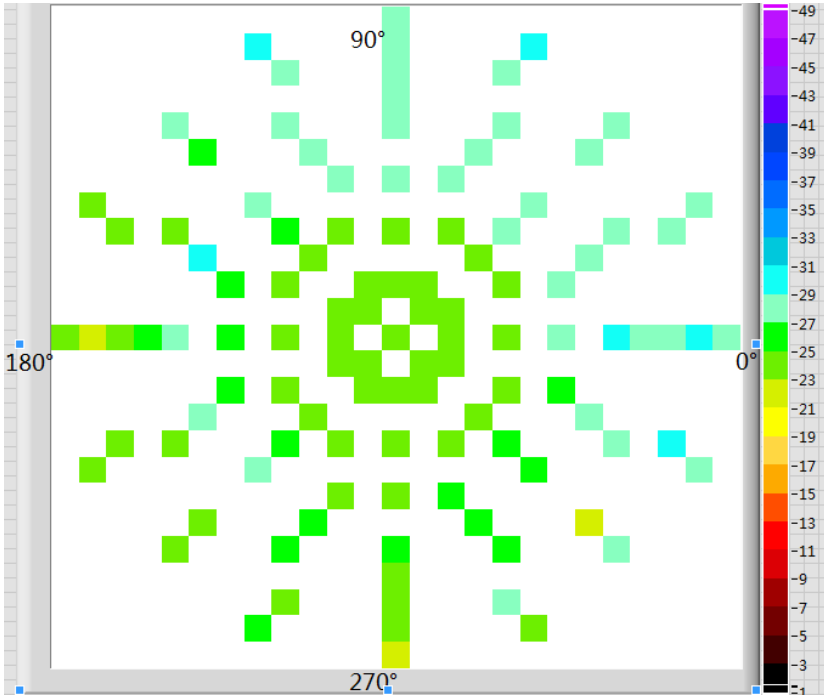
The methods we are trying:

1. Using the Transmission equipment for producing the prototype;



Min:12.7%
Max:28.5%
Average:22.2%

56# - MCP-PMT 20 inch



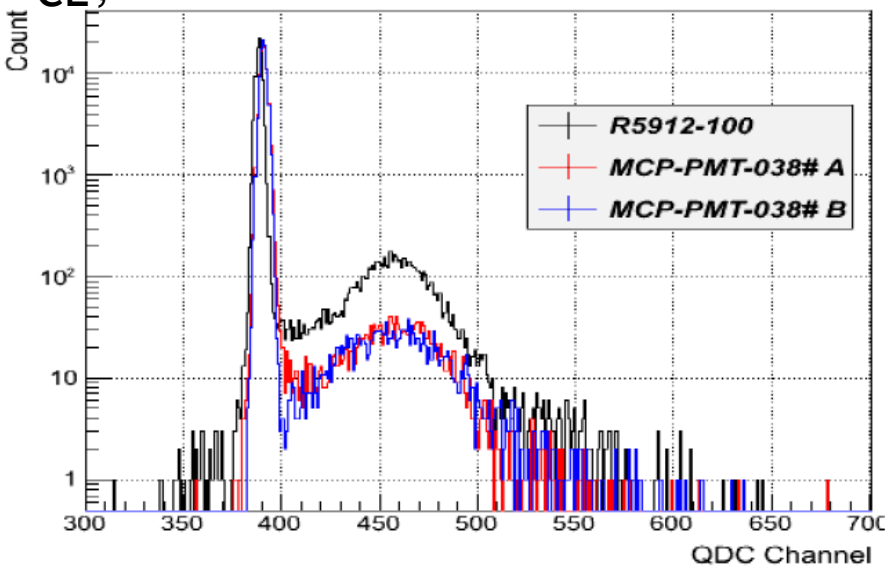
Min:24.5%
Max:29%
Average:26.5%

76# - MCP-PMT 20 inch

3.5.3 Improving the Collection Efficiency

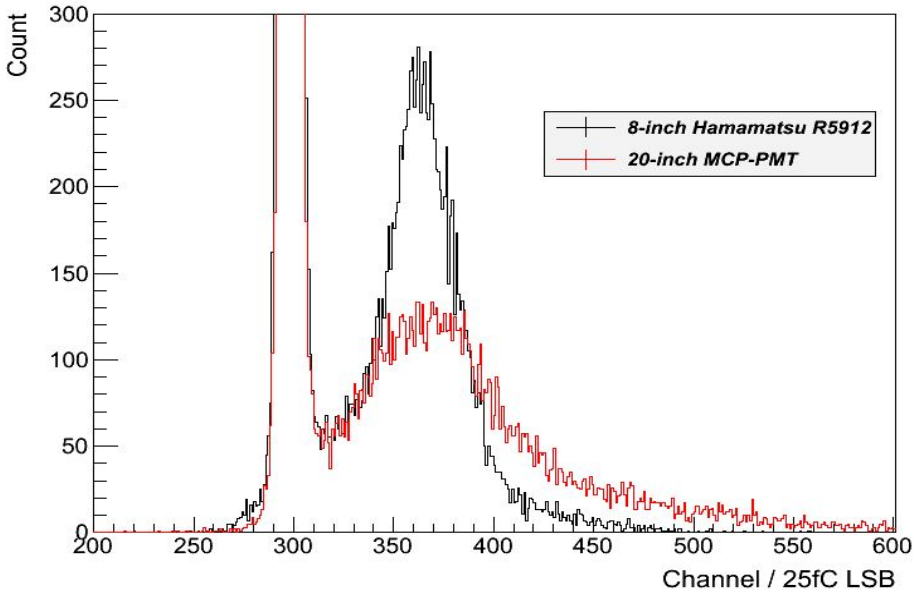
Prototype	MCP-PMT-56#	MCP-PMT-76#
Collection efficiency （Average）	< 60% (~Open Area)	> 95%

@ Gain=1.0*10^7, SPE mode. DE = QE X CE;



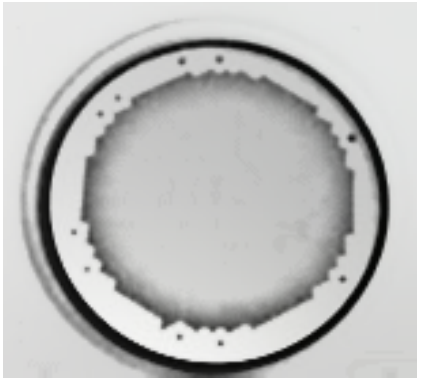
	DE	QE	CE
Dynode	1	35%	100%
MCP	0.3	20%	? ~60%

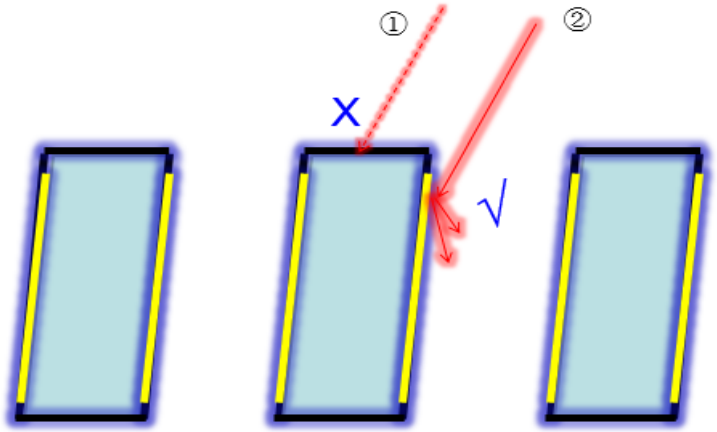
38# - MCP-PMT 20 inch



	DE	QE	CE
Dynode	1	25%	100%
MCP	1	26%	? ~ 110%

76# - MCP-PMT 20 inch





CE = 60%

The p.e. into the channel directly ~60%

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

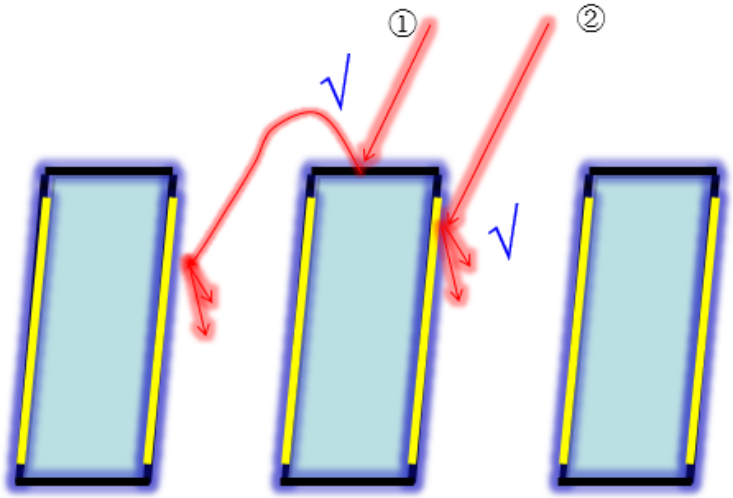
The Diameter of the Hole: **6um; 8um; 10um; 12um**;

The Inclined Angle: **0°**; **8°**; **12°**;

The Open Area Ratio: **60%**; **77%**;

The Depth of output electrode:……

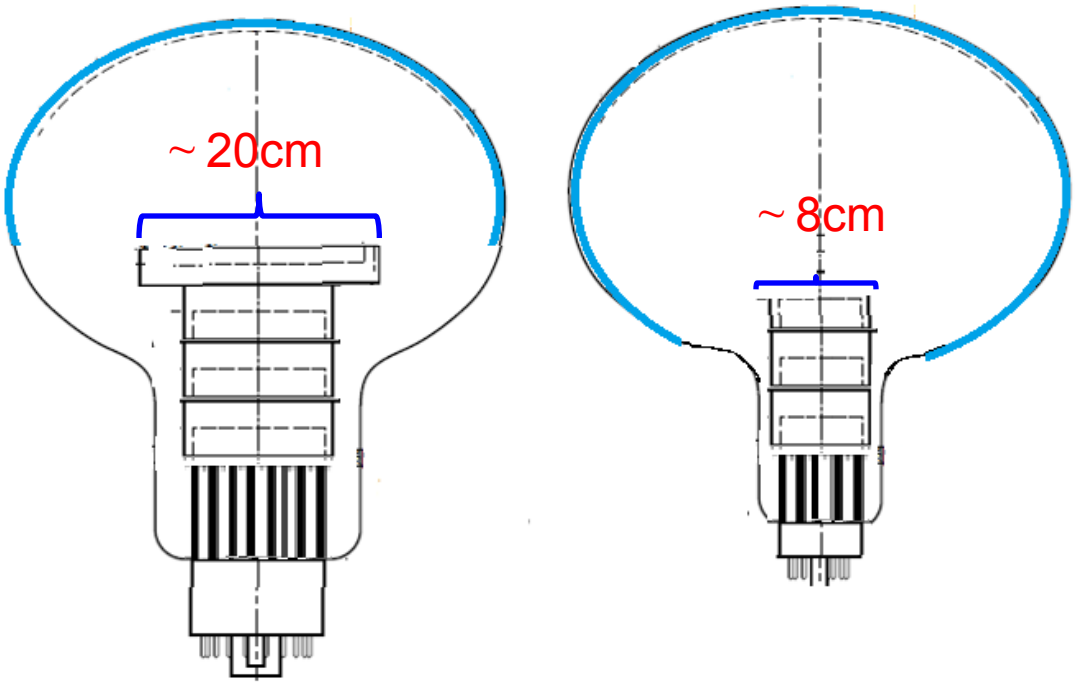
change



CE = 100%

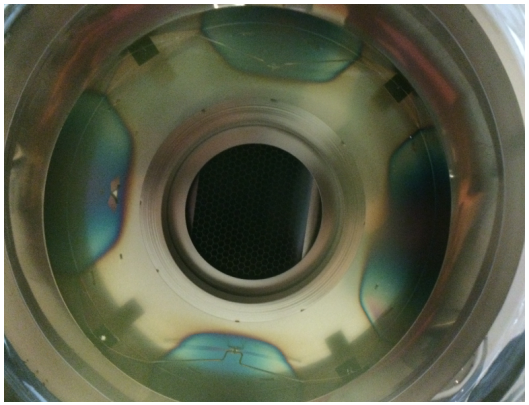
The p.e. into the channel directly ~70%
The p.e. from the electrod indirectly ~ 30%

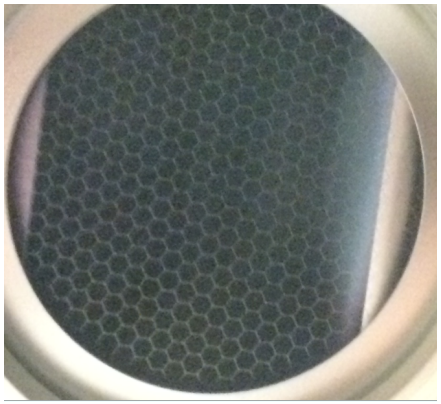
➢ MCP: Large area PC (Rrf. + Tran.)



Prototype	Relativity DE	Relativity DE
Dynode-PMT	100%	**90%**
MCP-PMT	110%	**100%**

➢ Dynode: A mesh covering the dynode



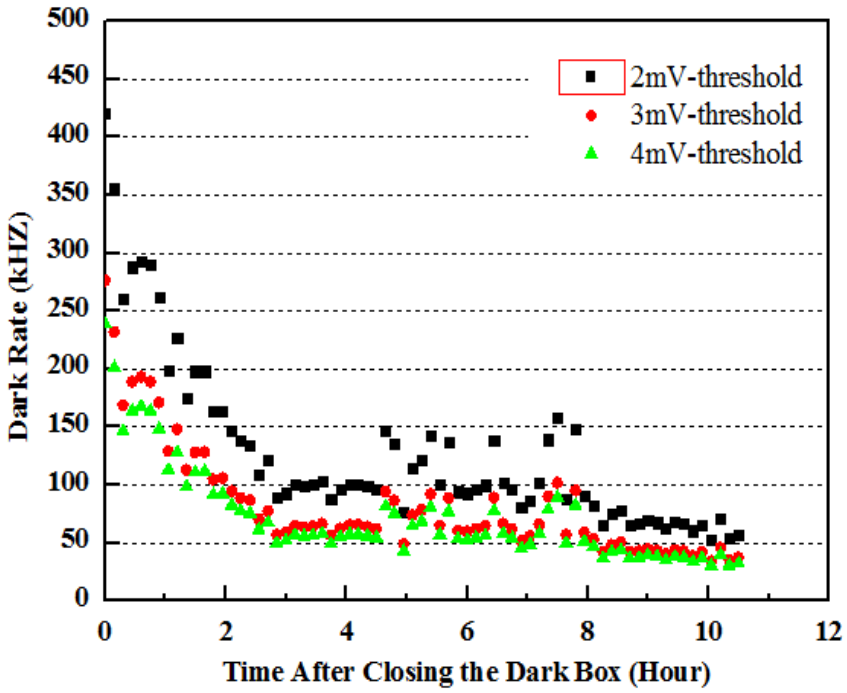


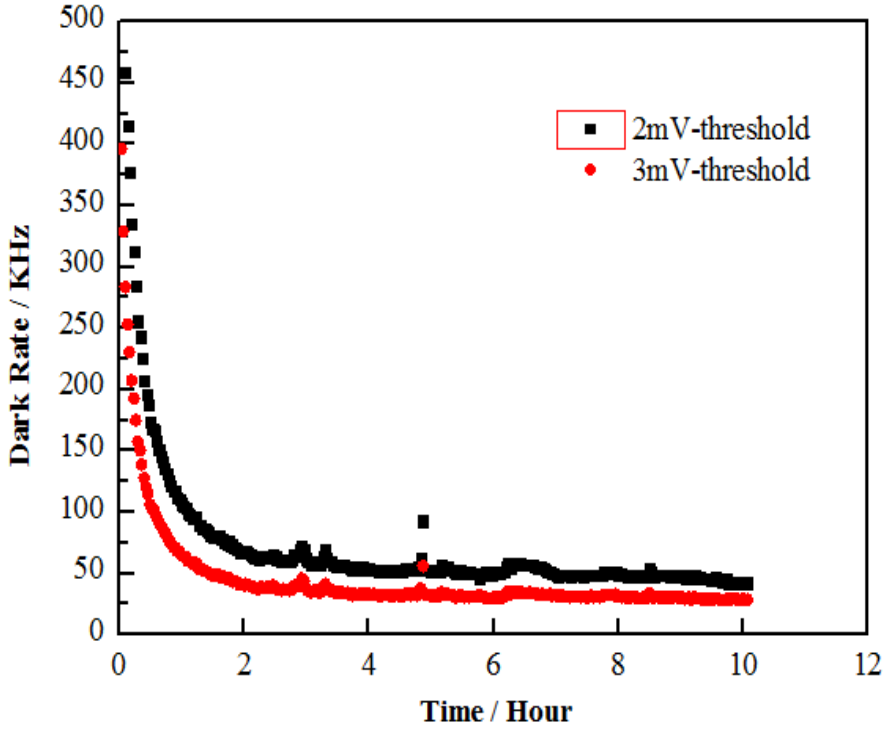
➢ MCP: Special MCP for CE~100%

3.5.4 Reducing the dark noise count

Prototype	MCP-PMT-56#	MCP-PMT-76#
Dark rate @1E7 Gain(0.25PE)	~50kHz	~30kHz

➢1. Using the Transmission equipment for producing the photocathode in prototype;





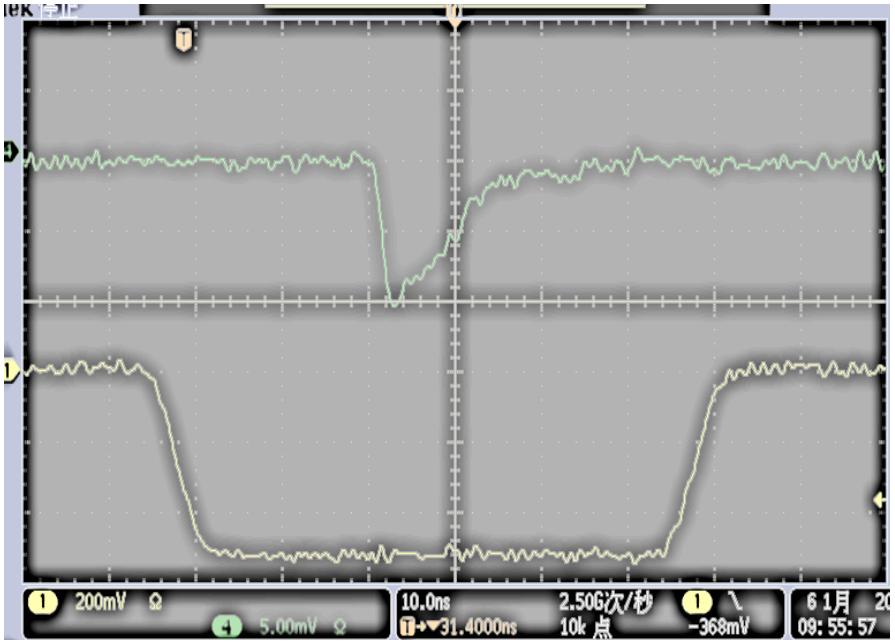
56# - MCP-PMT 20 inch

76# - MCP-PMT 20 inch

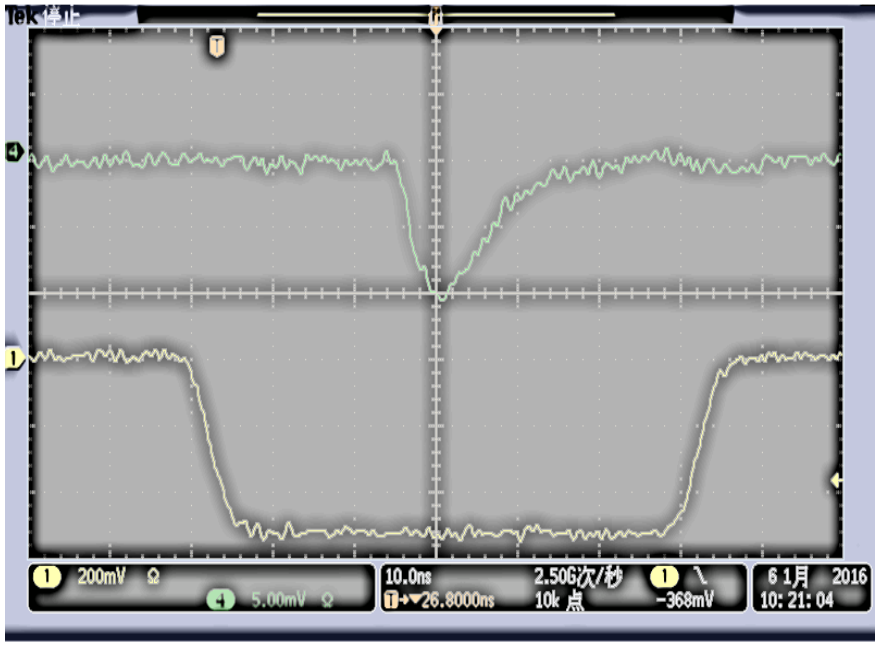
➢ 3.5.5 Slow down the Rise time of the prototype

Prototype	MCP-PMT- A#	MCP-PMT-B#
Rise Time	~1.7 ns	~4.5 ns

➢1. Adjusting the construct of the MCPs module;

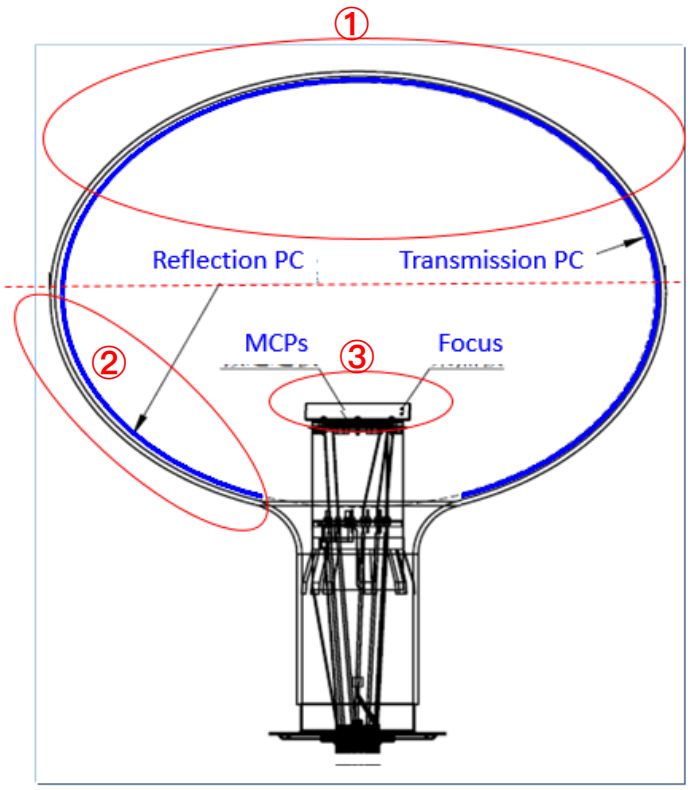


MCP-PMT A#



MCP-PMT B#

3.6 Why the TTS is Large



The prototype

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

--> with special MCP for better DE;

But the TTS will be worse!

The p.e. from where?

-->the Transmission Photocathode

-->the Reflection Photocathode

The p.e. to where?

-->to the channel of MCP directly

-->to the electrode and then reflect to the MCP channel indirectly

The contribution to the TTS

①The distance between the PC to the MCP;

==By adjusting the Electronic optical focusing

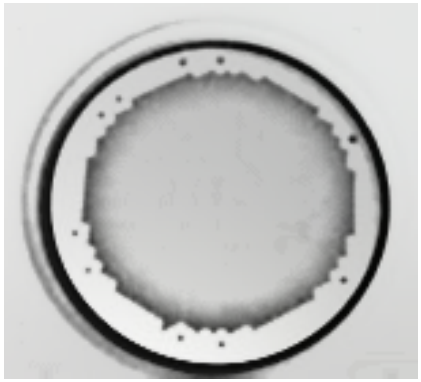
② The difference between the Trans. & Ref. PC;

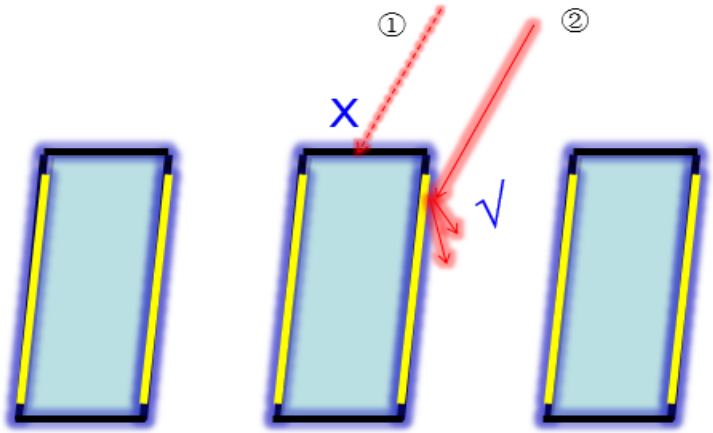
==No way to adjusting; (for better QE)

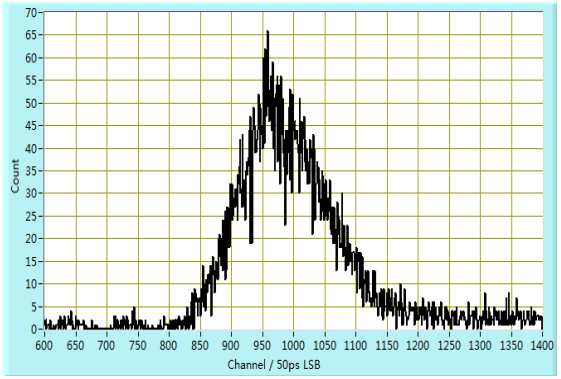
③ The second electron emission part of the MCP;

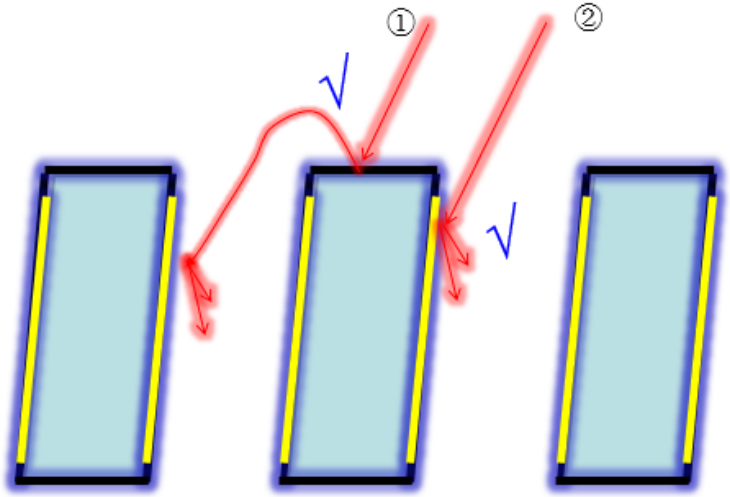
==No way to adjusting; (for better DE)

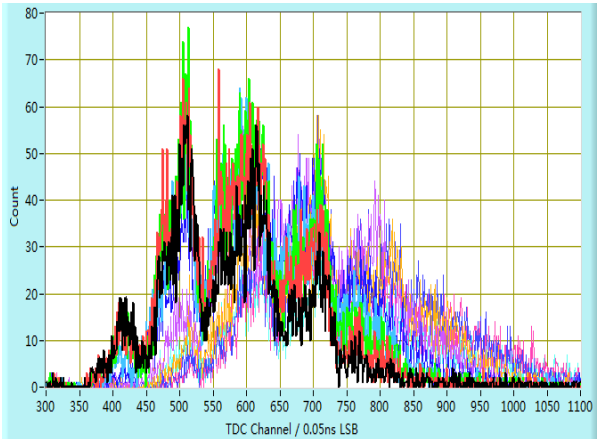
The second electron emission part of the MCP (channel or electrode);









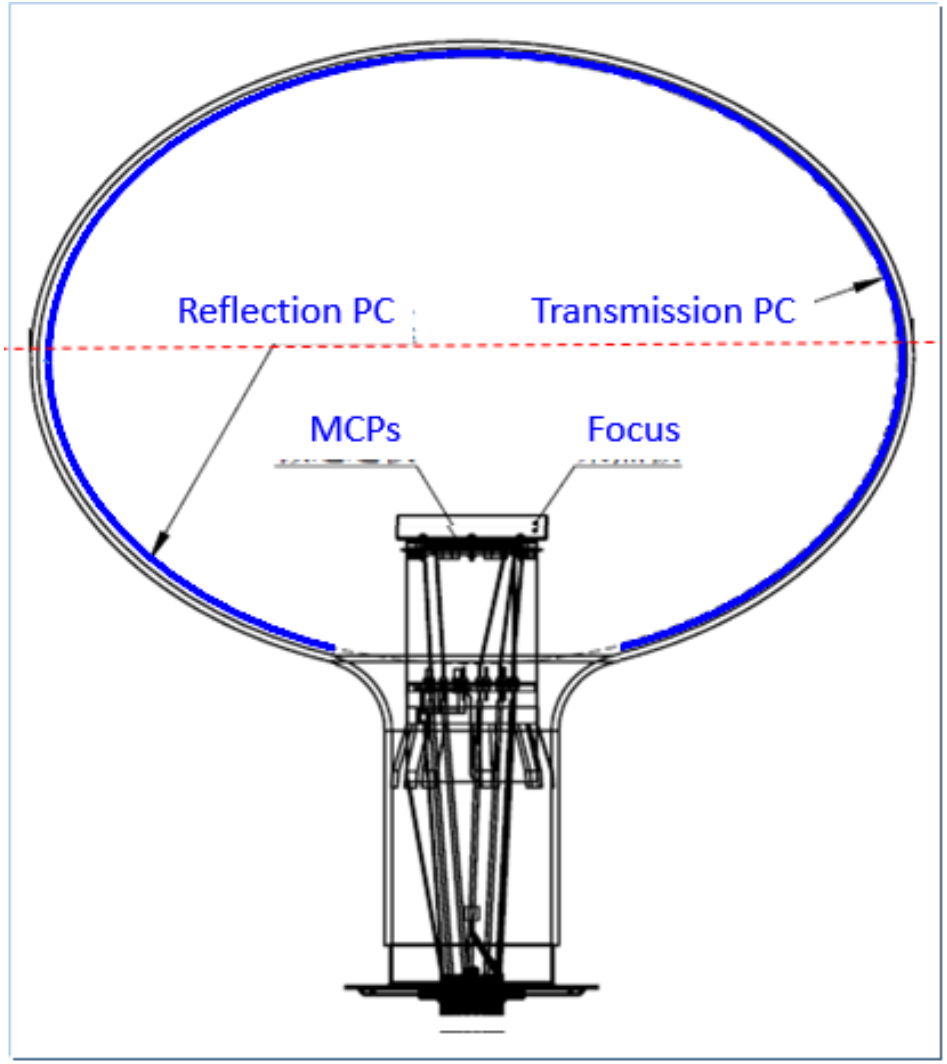


➢With the contribution of the second electron from the electrode (40%),

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

➢ The Transmission + Reflection QE of the Photocathode

The High Collection Efficiency MCP



Good situation：

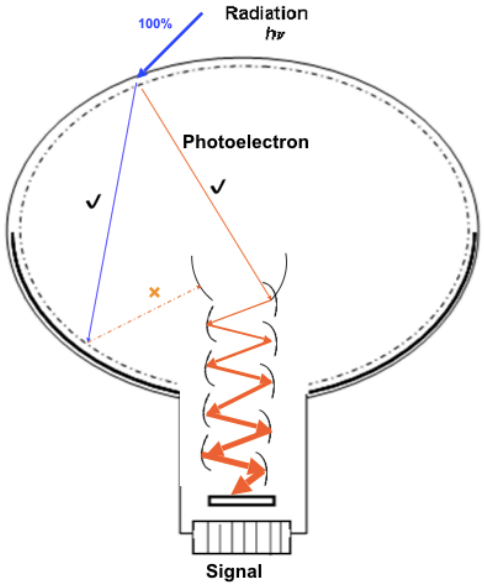
→ Improve the total QE;

→ Improve the Detection Efficiency;

Bad situation:

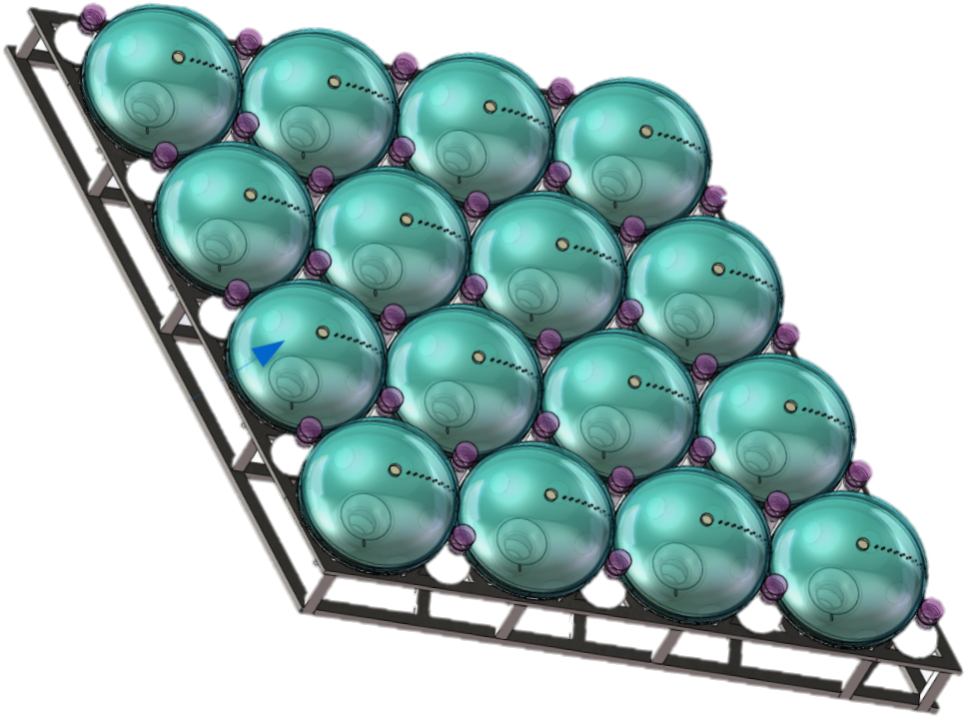
→ Larger Dark count;

→ larger TTS;



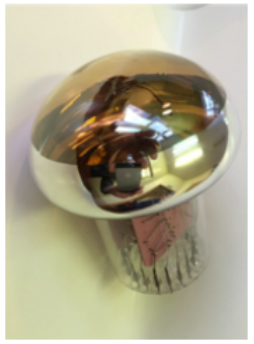
How to improve the JUNO PMT's time resolution?

- optical coverage: 78%
  → 15,000 large PMTs (20") → 75%
  → 36,000 small PMTs (3") → 3%
  (double calorimetry + timing)



HZC
3-inch
XP53B20

Hamamatsu
3-inch
R6091



MELZ
3-inch
10 dynodes

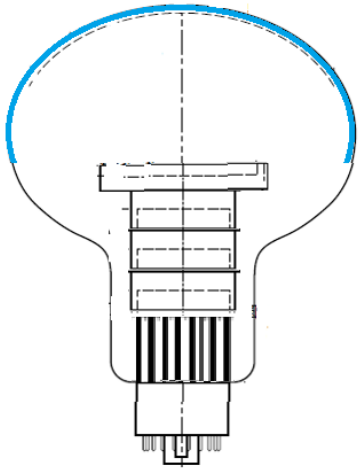
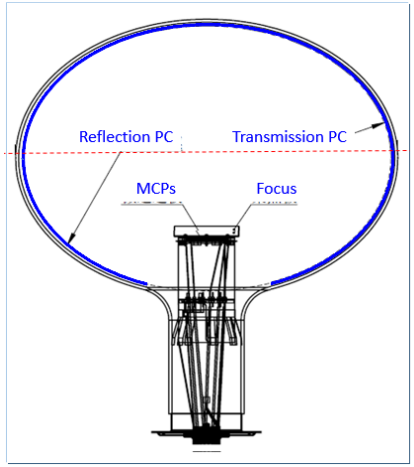
	TTS @ top center
R12860 (20")	~2.8ns
MCP-PMT(20")	~12ns
3" PMT	~1.5ns

Outline

- **1. The Neutrino Experiment in China;**
  The DayaBay；the DayaBayII；the JUNO；the PMT requirement；
- **2. The new design of the MCP-PMT;**
  The new design, the collaboration group, the evaluation Lab;
- **3. The MCP-PMT prototypes (2012-2014);**
  The 8 inch prototypes; the 20 inch prototypes;
- **4. The High PDE MCP-PMT—2015;**
  How to improve, QE, CE, DR, The new 20 inch prototypes ;
- **5. The Mass production Line and Batch test system;**
  The mass production, the batch test about 2500pics PMT；
- **6. The Batch test result of 2500 PMTs;**
  the batch test data；

➢ 4.0 The High PDE MCP-PMT--2015

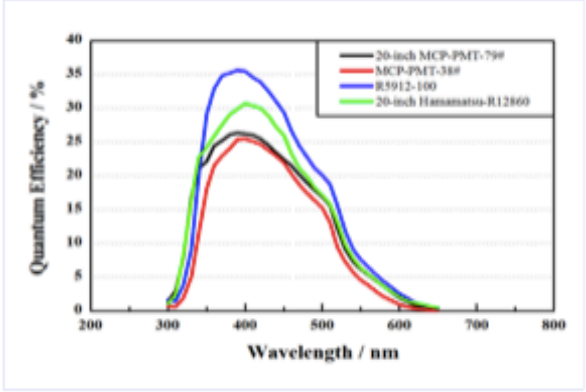
- **2014: 1st 20" prototype, with normal performance**
  - ⇨ **QE ~ 25%@410nm; CE ~ 60%; P/V of SPE > 2**
- **2015: 20" prototypes with normal performance**
  - ⇨ **QE ~ 26%@410nm; CE ~ 100%; P/V of SPE > 3**

20-inch Hamamatus PMT-Dynode Ellipsoidal Glass	20-inch IHEP-MCP-PMT-Ellipsoidal Glass
 	 

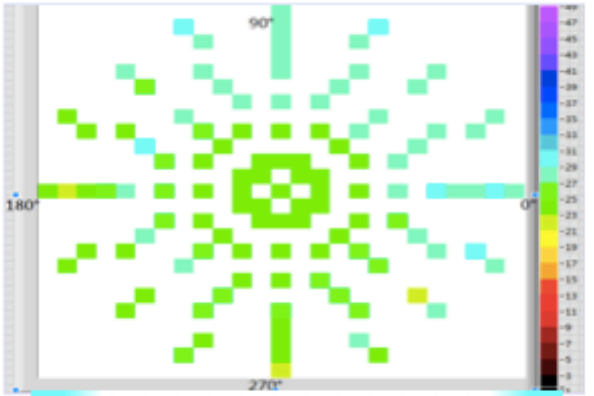
The typical performance of the 20 inch MCP-PMT

Waveform of the Prototype

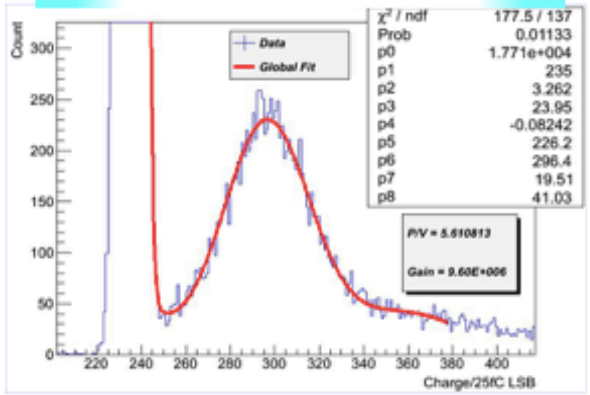
QE of the Photocathode



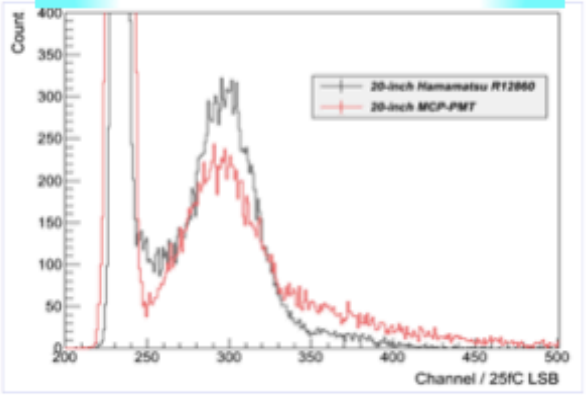
Uniformity of the Photocathode



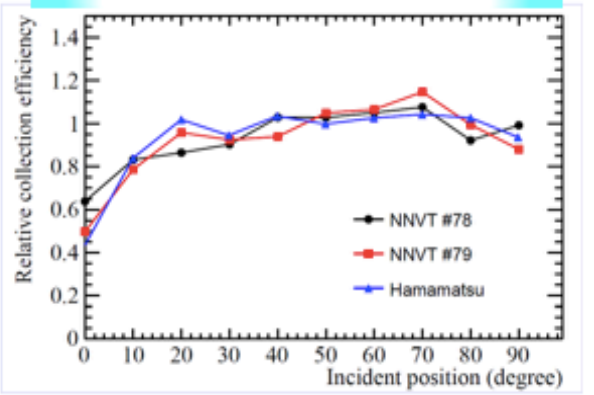
The SPE of the Prototype



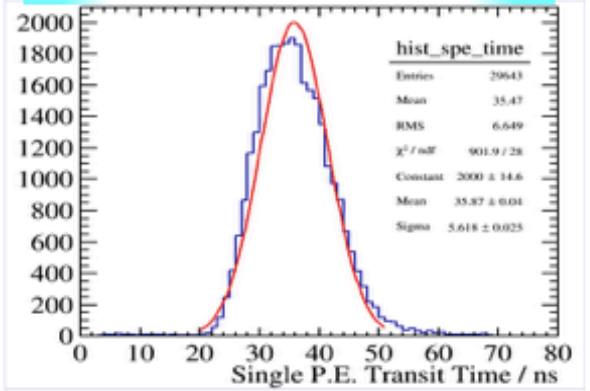
Relative Collection Efficiency



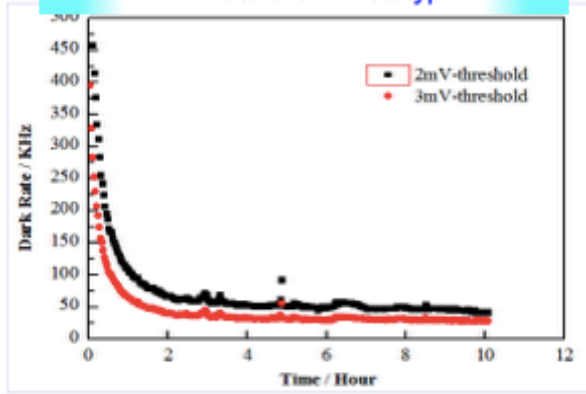
Uniformity of the Collection Efficiency



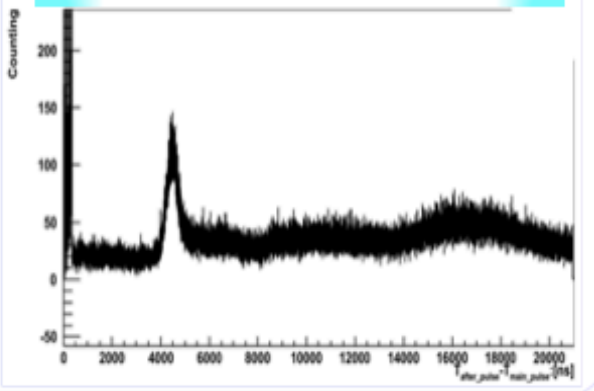
TTS of the Prototype



Dark rate of the Prototype

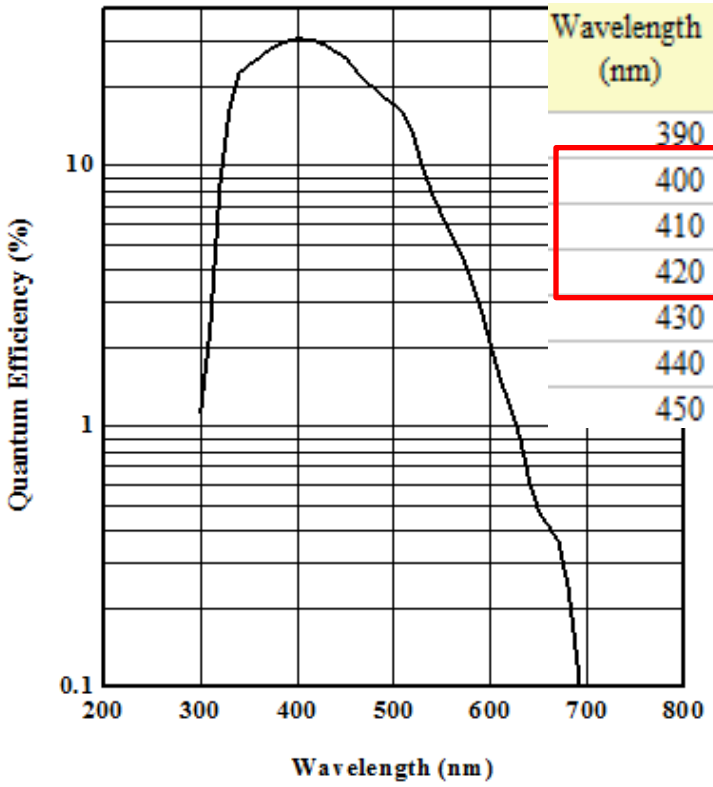


After Pulse of the Prototype

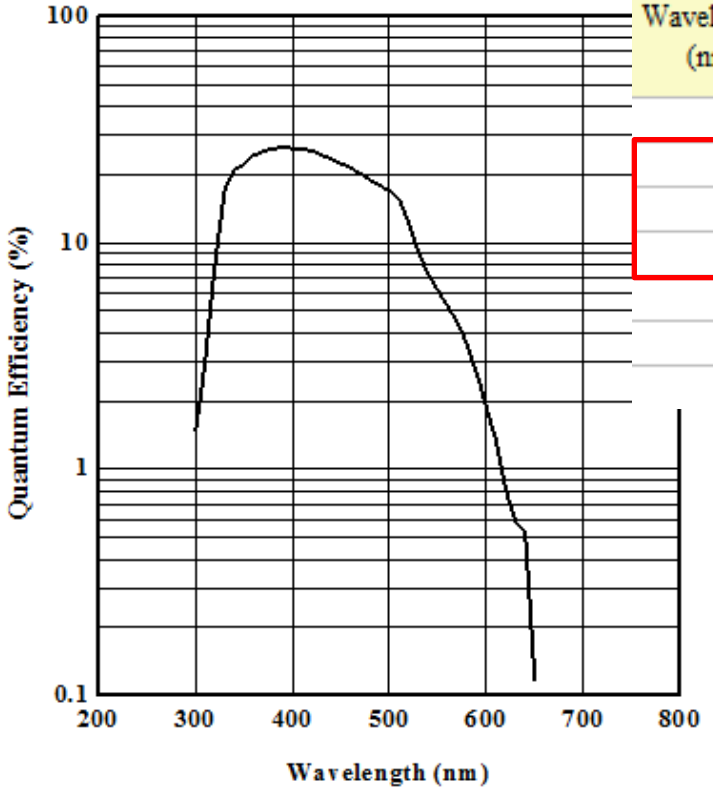


4.1 The QE of the Photocathode

20 inch Prototype	R12860	MCP-PMT
QE@410nm	~30%	~26%



Wavelength (nm)	QE
390	29.9283
400	30.7108
410	30.35535
420	29.9999
430	28.8817
440	27.253
450	25.9221



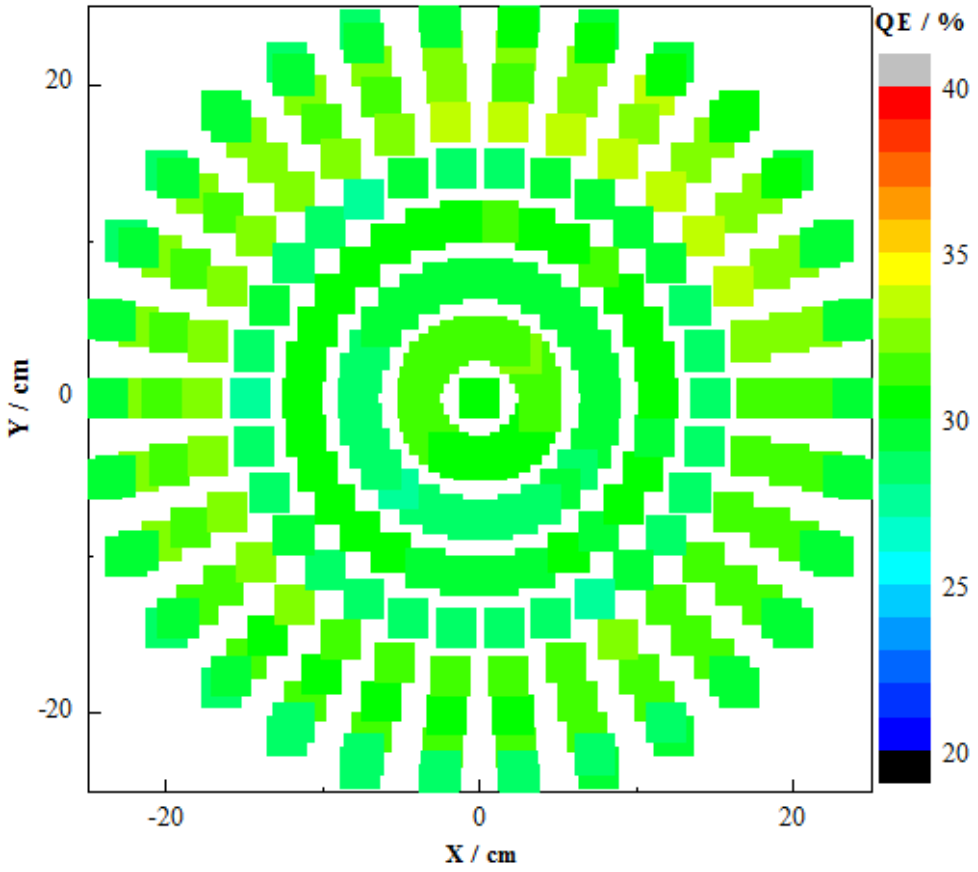
Wavelength (nm)	79#
390	26.32155
400	26.18978
410	26.058
420	25.4807
430	24.47675
440	23.4516
450	22.37645

Hamamatsu R12860

MCP-PMT

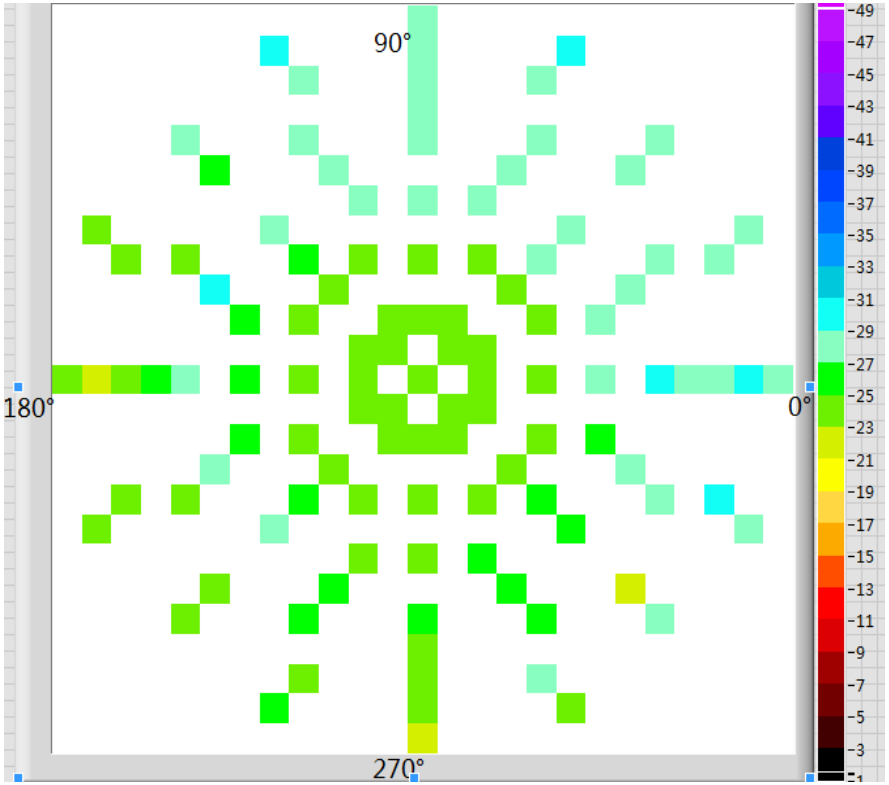
4.2 Photocathode QE Uniformity

Hamamatsu R12860



Min:27.5%
Max:33.6%
Average:30.5%

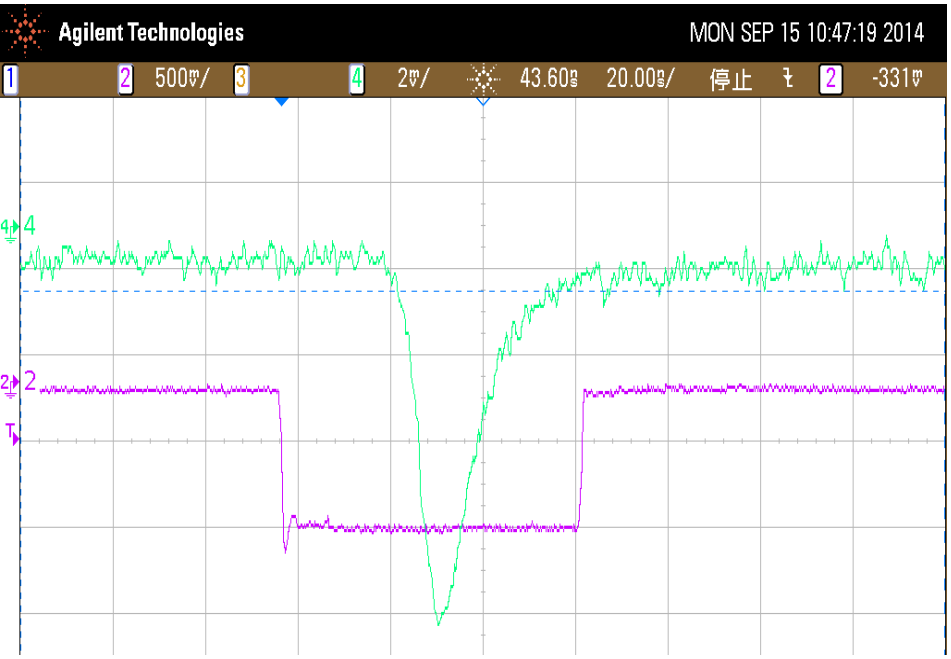
MCP-PMT

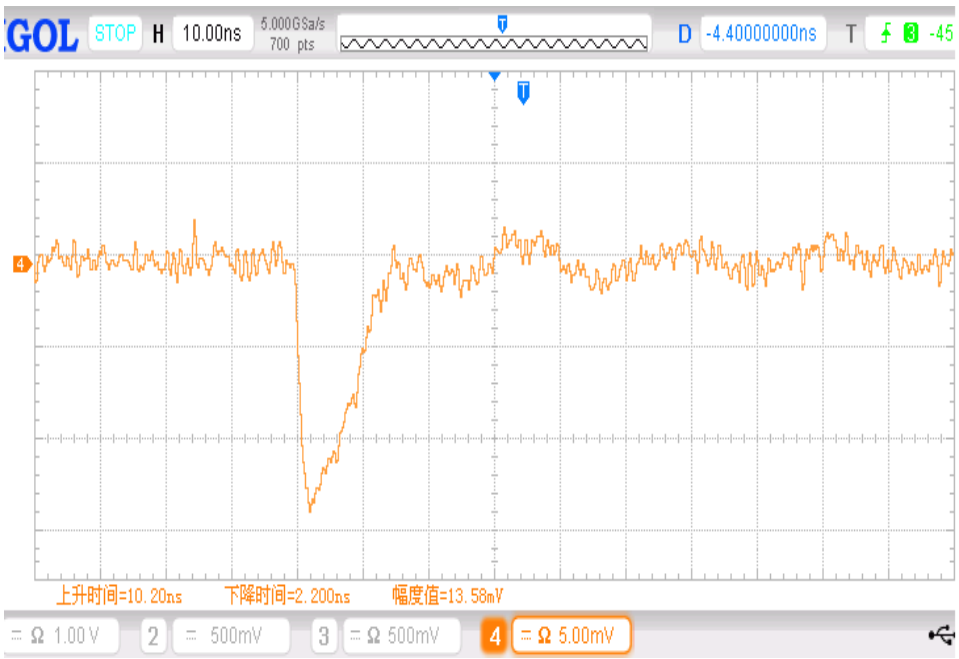


Min:24.5%
Max:29%
Average:26.5%

4.3 Waveform of the Prototype

	Rise Time	Fall Time
R12860	~6.7ns	~17.7ns
MCP-PMT	~2.2ns	~10.2ns



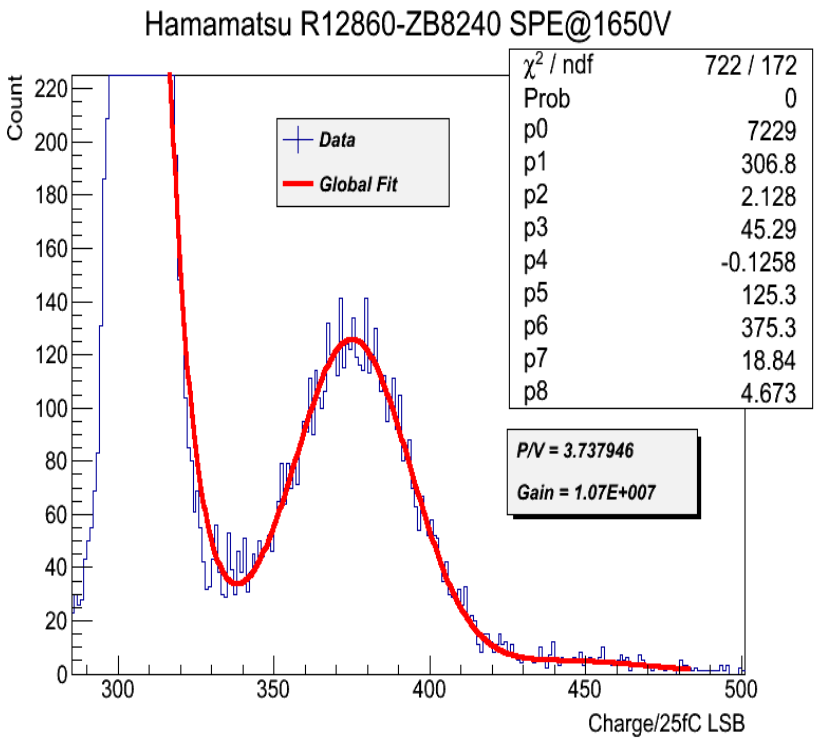


Hamamatsu R12860

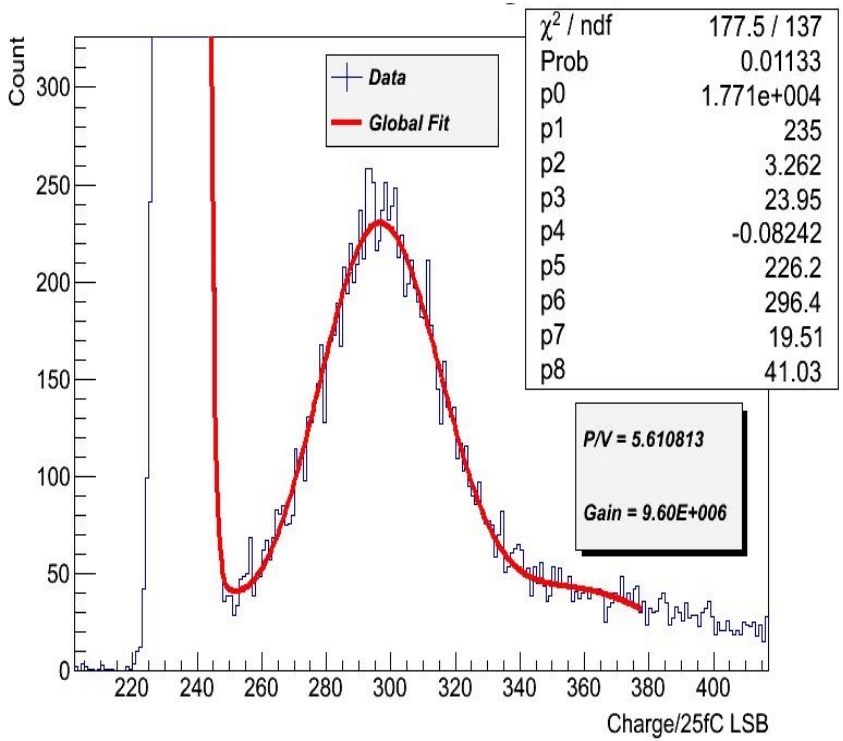
MCP-PMT

4.4 The SPE of the Prototype;

	HV	Gain	P/V
R12860	1650V	~1.1E7	~3.7
MCP-PMT	1930V	~9.6E6	~5.6



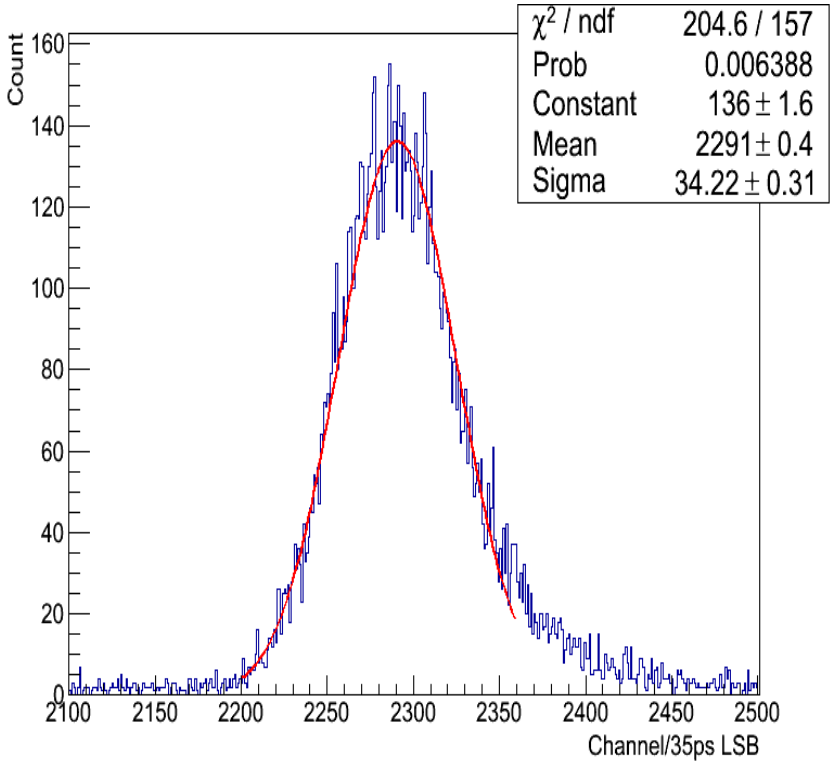
Hamamatsu R12860



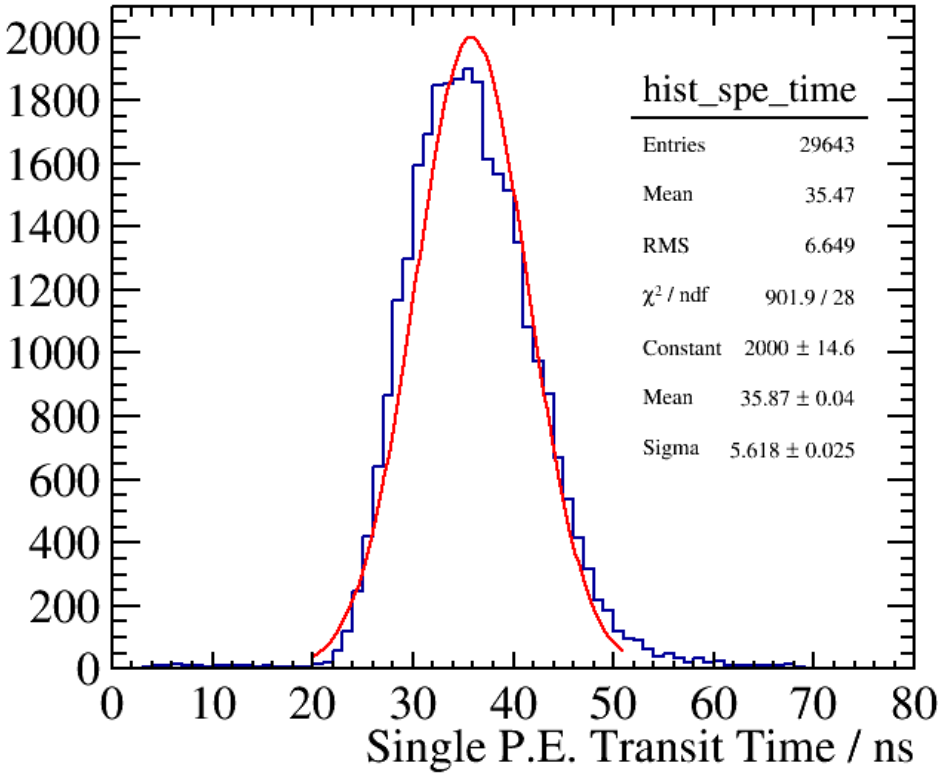
MCP-PMT

4.5 The TTS of the Prototype;

	HV	Gain	TTS @ top center
R12860	1650V	~1.1E7	~2.8ns
MCP-PMT	1930V	~9.6E6	~12ns



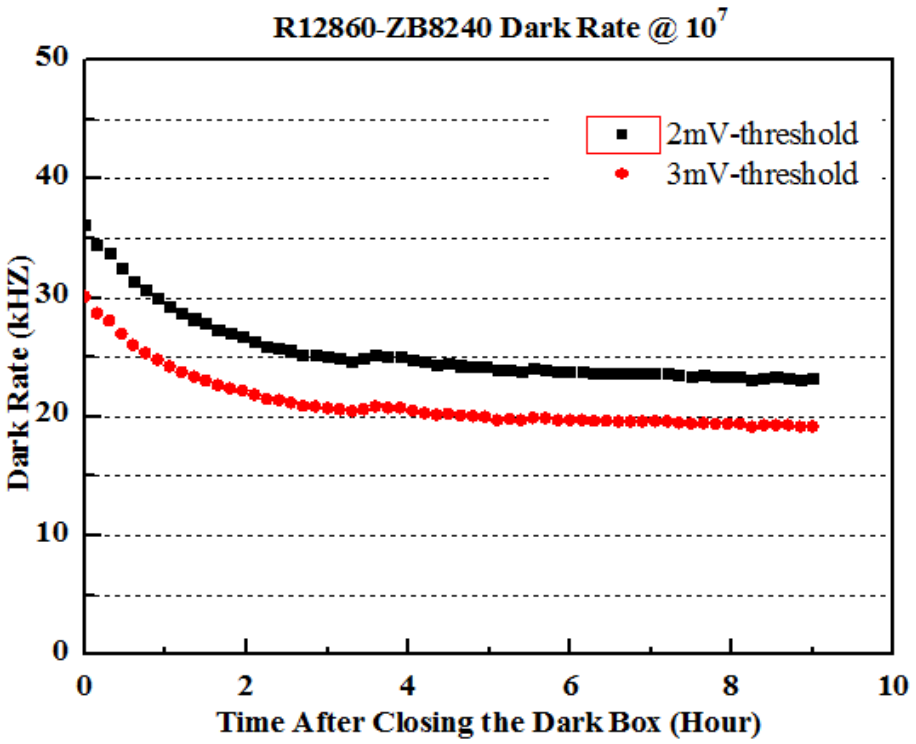
Hamamatsu R12860

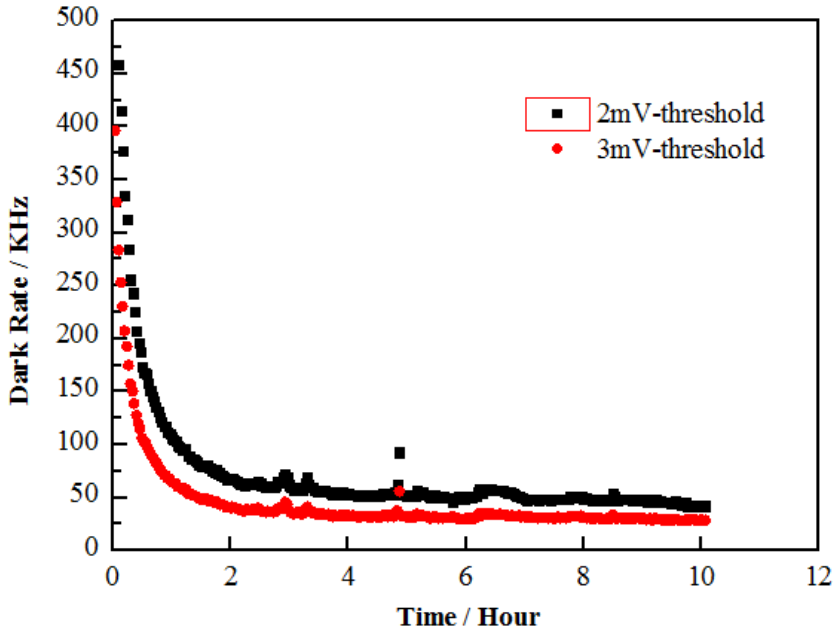


MCP-PMT

4.6 The Dark count of the Prototype;

	HV	Gain	Dark rate @ 0.25PE
R12860	1650V	~1.1E7	~25kHz
MCP-PMT	1930V	~9.6E6	~ 30kHz



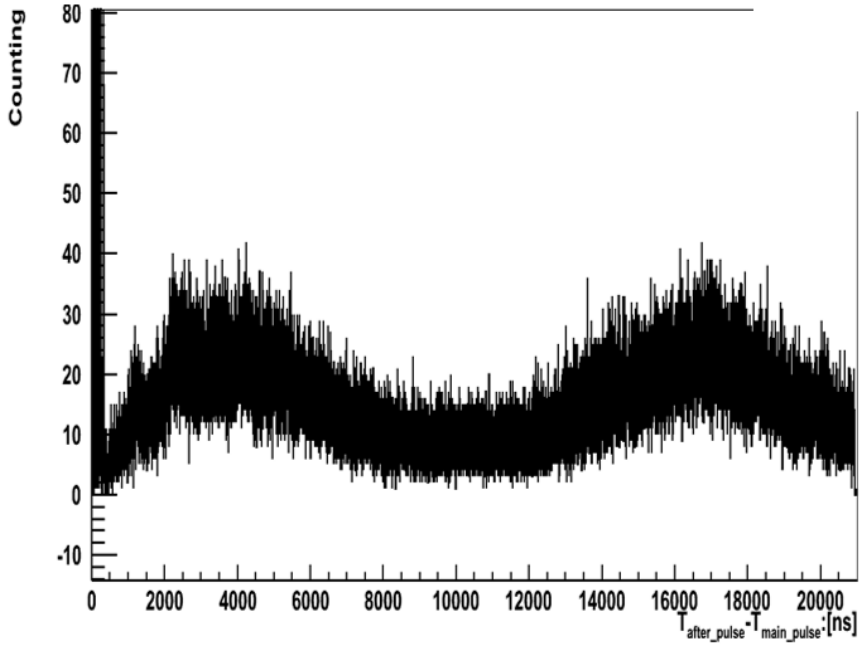


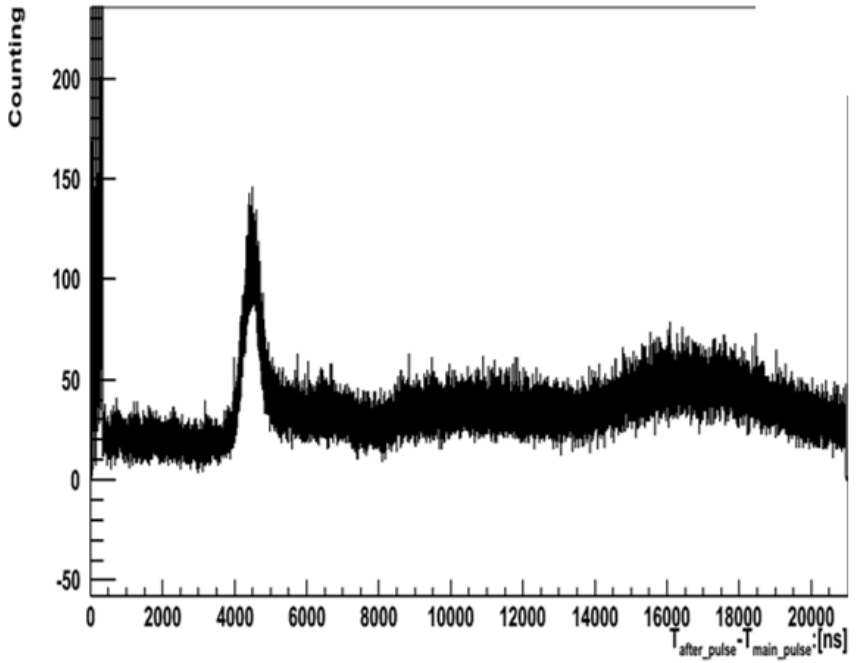
Hamamatsu R12860

MCP-PMT

4.7 The After Pulse Rate of the Prototype

	Time distribution	After Pulse Rate
R12860	4us, 17us	10%
MCP-PMT	4.5us	2.5%



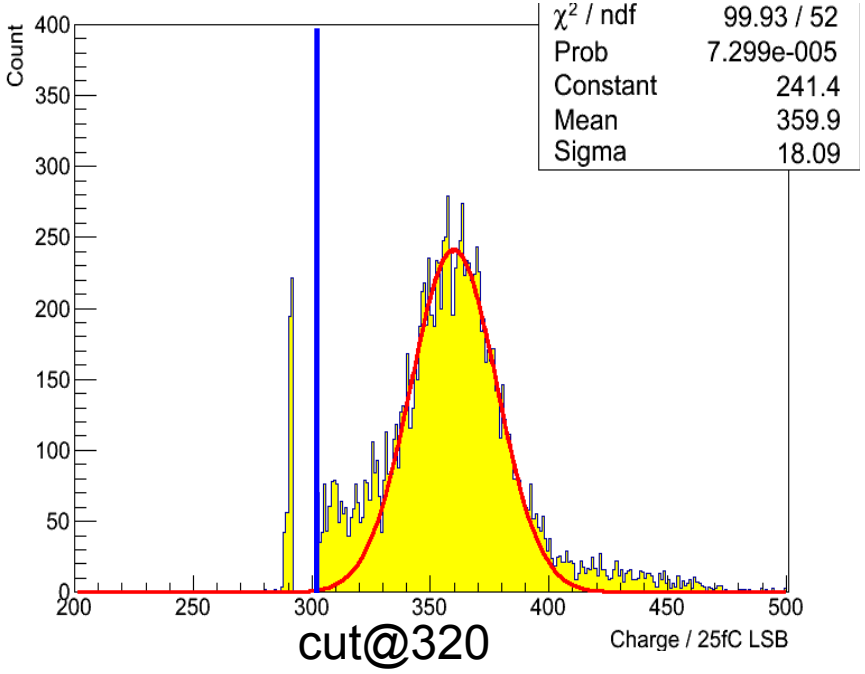


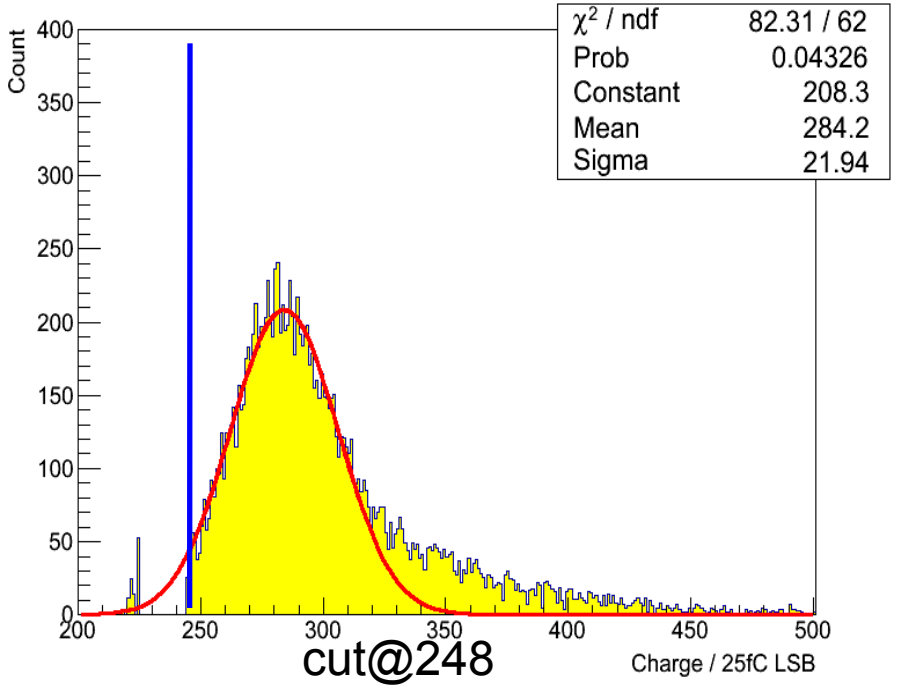
Hamamatsu R12860

MCP-PMT

4.8 The Relativity Detection efficiency of the Prototype

	HV	Gain	Relativity PDE
R12860	1650V	~1.1E7	90%
MCP-PMT	1930V	~9.6E6	100%





Hamamatsu R12860

MCP-PMT

The performance of the 20 inch prototypes

Characteristics	unit	MCP-PMT (IHEP+NNVT)	R12860 (Hamamatsu)
Electron Multiplier	--	**MCP**	Dynode
Photocathode mode	--	**reflection+ transmission**	transmission
Quantum Efficiency（400nm）	%	**26 (T), 30 (T+R)**	**30(T)**
Relativity Detection Efficiency	%	**~ 100%**	**~ 90%**
P/V of SPE		**> 3**	**> 3**
TTS on the top point	ns	**~12**	**~3**
Rise time/ Fall time	ns	**R~2 , F~10**	**R~7 , F~17**
Anode Dark Count	Hz	**~30K**	**~30K**
After Pulse Time distribution	us	**4.5**	4, 17
After Pulse Rate	%	**3**	10
Glass	--	**Low-Potassium Glass**	HARIO-32

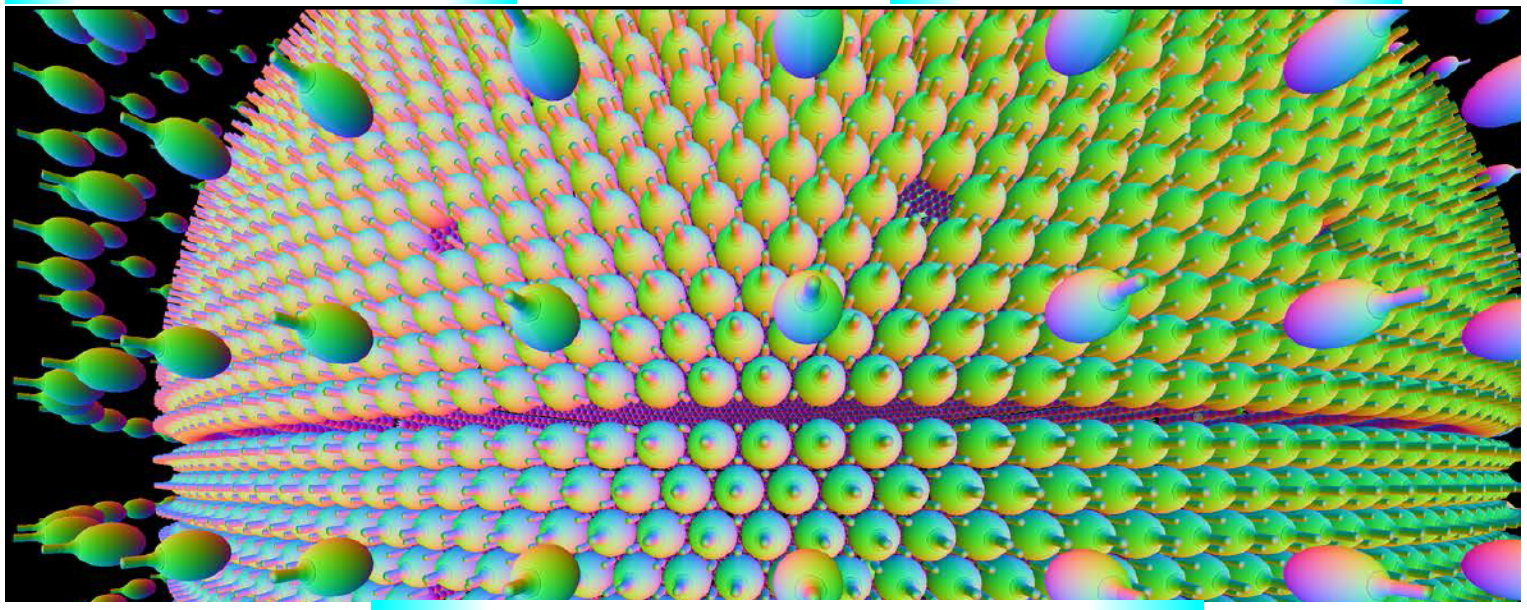
Outline

- **1. The Neutrino Experiment in China;**
  The DayaBay；the DayaBayII；the JUNO；the PMT requirement；
- **2. The new design of the MCP-PMT;**
  The new design, the collaboration group, the evaluation Lab;
- **3. The MCP-PMT prototypes (2012-2014);**
  The 8 inch prototypes; the 20 inch prototypes;
- **4. The High PDE MCP-PMT—2015;**
  How to improve, QE, CE, DR, The new 20 inch prototypes ;
- **5. The Mass production Line and Batch test system;**
  The mass production, the batch test about 2500pics PMT；
- **6. The Batch test result of 2500 PMTs;**
  the batch test data；

5.1 The Mass production Line and Batch test system

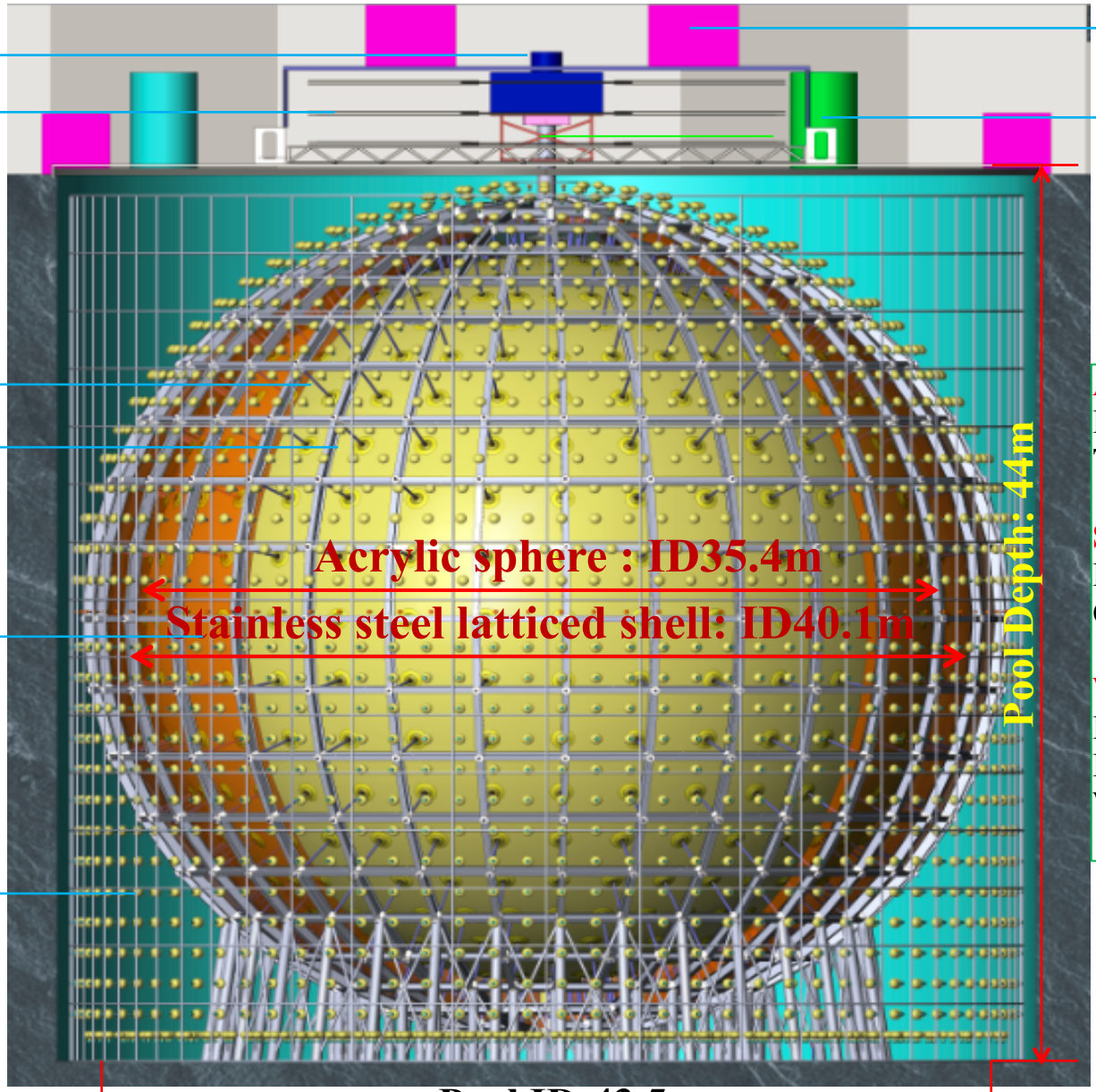
The MCP-PMT prototype

The MCP-PMT products



The design of the PMTs installed in JUNO

5.1 The JUNO Detector and the PMTs



Acrylic Sphere:
ID: 35.4m
Thickness:120mm

SSLS:
ID: 40.1m
OD: 41.1m

Water pool
ID: 43.5m
Height: 44m
Water Depth: 43.5m


➢ Dynode-PMT- 20”
➢ MCP-PMT- 20”
➢ MCP-PMT- 8”
➢ Dynode-PMT- 9”
➢ Dynode-PMT- 8”

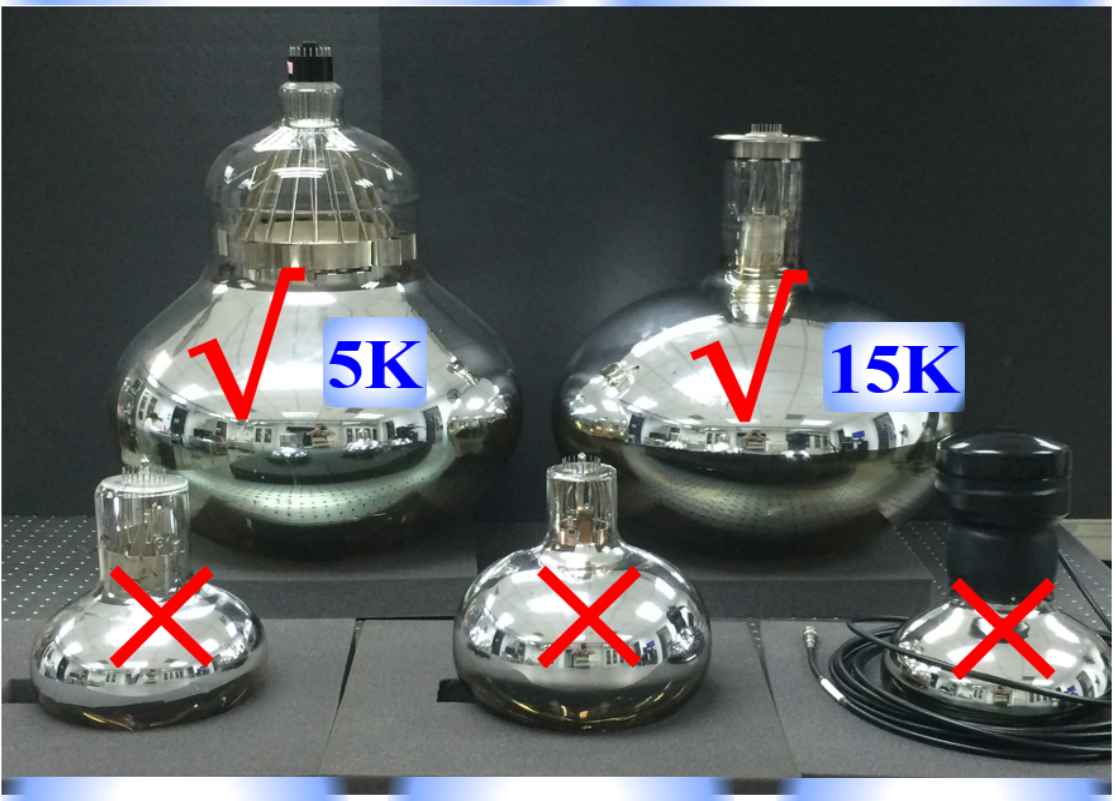
Specification in the Contracts

- Evaluate both the PMT characteristics' impacts on MH hierarchy and the cost.
- Finished 20" PMT bidding at end of 2015

Characteristics	unit	MCP-PMT（NNVC）	R12860 （Hamamatsu）
Detection Eff.(QE*CE*area)	%	27%, > 24%	27%, > 24%
P/V of SPE		3.5, > 2.8	3, > 2.5
TTS on the top point	ns	~12, < 15	2.7, < 3.5
Rise time/ Fall time	ns	R~2 , F~12	R~5, <7; F~9, <12
Anode Dark Count	Hz	20K, < 30K	10K, < 50K
After Pulse Rate	%	1, <2	10, < 15
Radioactivity of glass	ppb	238U:50 232Th:50 40K: 20	238U:400 232Th:400 40K: 40

5.2 the 75% order of PMT for JUNO (2015)

- Dynode-PMT- 20" from Hamamastu
- MCP-PMT- 20" from NNVT



- MCP-PMT- 8"
- Dynode-PMT- 9"
- Dynode-PMT- 8"

15k MCP-PMT (75%)

Contract for JUNO

Signed with NNVT

on Dec.16, 2015

5.3 The celebration for the 20 inch MCP – PMT production line (2016)

- **2** units were working already in 2015; ★
- **6** units were ready on the summer 2016; ☆
- **14** units were ready on the winter 2016; ★

One Unit could produce 3PMTs in Two days;

——> **22 Units for the mass production ;**

——> **33 PMTs / 1 day ;**

Aim:

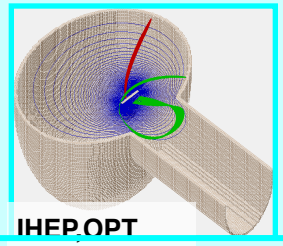
1PMT need 2 days

total 33 pic/ day;

30 pic PMTs (OK!) /day

5.4 The Batch test platform (2016.10-2017.02)

电场设计



收集效率（CE）

渡越时间涨落（TTS）

信号波形（RT/FT）

抗地磁场能力（EM）

MCP组件

增益（Gain）

单光子探测（SPE）

后脉冲率（APR）

探测效率（DE）

渡越时间涨落（TTS）

非线性（Linearity）

标准碱源

量子效率（QE）

后脉冲率（APR）

均匀性（Uniformity）

暗计数率（DR）

低本底玻壳

放射性本底 (Radioactive background)

机械尺寸（Size）

机械强度 （mechanical strength）

光阴极性能测试：（直流模式）
Photocathode test（Current Mode）

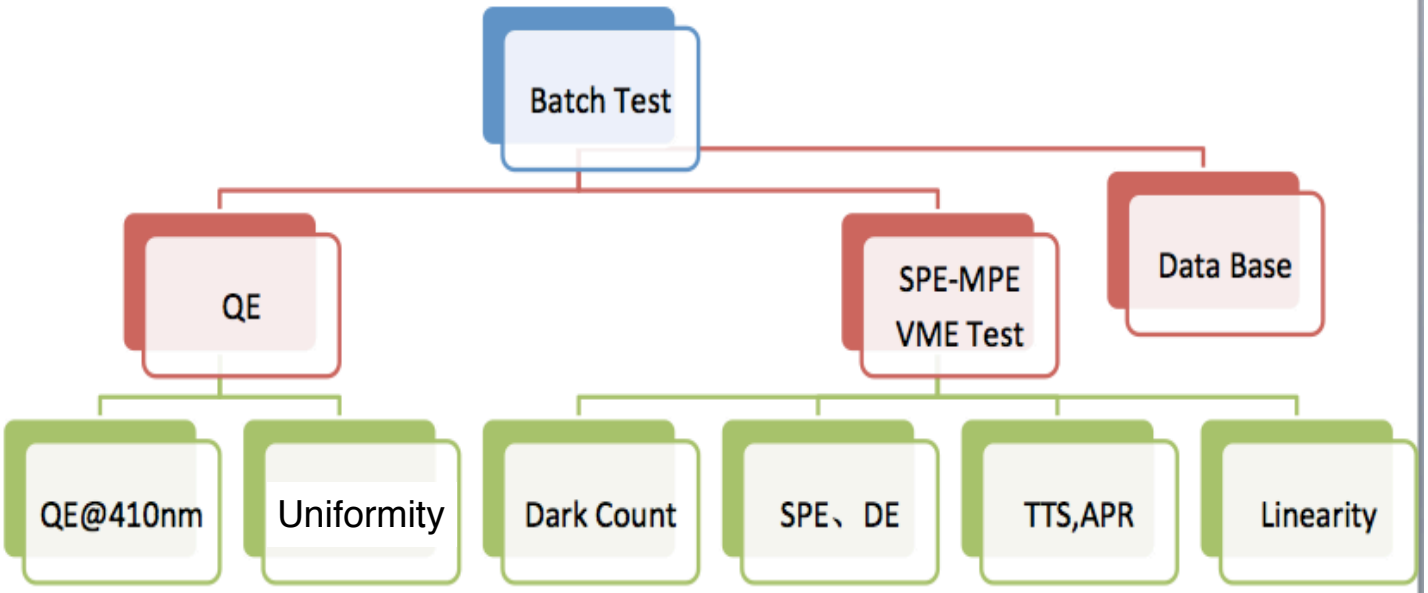
- 量子效率（QE）
  - 单波长 QE@410nm
  - 频谱响应曲线（QE-λ）
- 均匀性（PC Uniformity）

阳极性能测试：（脉冲模式）

Anode test （pulse mode）

- 单光子探测（SPE）
  - 增益（Gain）
  - 探测效率（DE）
  - 渡越时间涨落（TTS）
  - 抗地磁场能力（EM）
- 后脉冲率（APR）
- 非线性（Linearity）
- 信号波形（RT/FT）
- 暗计数率（DR）

PMT	JUNO Contract	NNVT test
QE@ 410nm	A	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



➢ QE sub-system

➢**Equipment: 2 pic;**

—> 80 LED for testing;

➢**Time: 0.5h / PMT;**

20min for cooling PMT;

10min for scanning test;

➢**One Day: 30 PMTs;**

➢**Test Ratio: 100%;**

➢ SPE Batch Test sub-system

➢**Equipment: 2+1 Dark Room;**

—> 1 dark room = 32 PMTs

➢**Time: 48h (2 days) / PMT;**

➢ One day: for training PMTs;

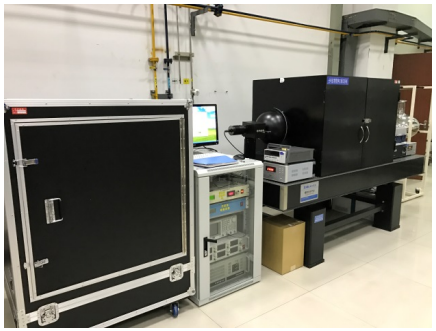
➢ One day: for testing PMTs;

➢**One Day: 30 PMTs;**

➢**Test Ratio: 100%;**

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

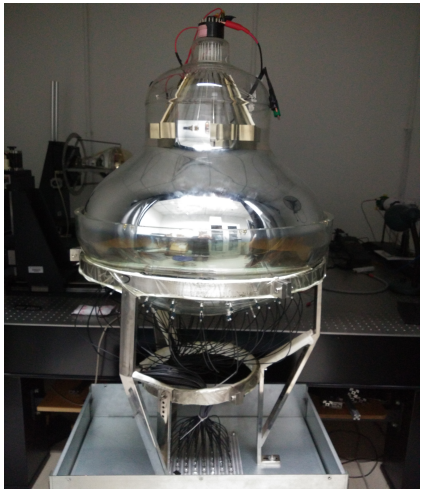
➢ QE sub-system

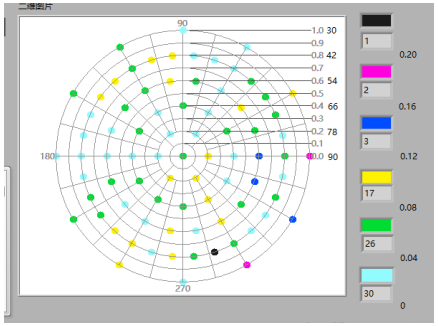


➢ SPE Batch Test sub-system

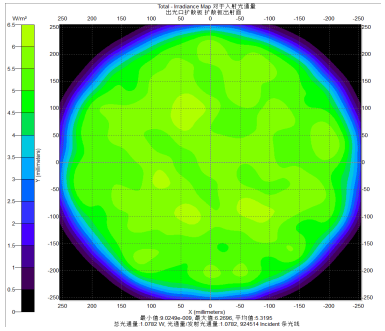
➢with soft iron to shielding EM

➢The QE Scanning sys.

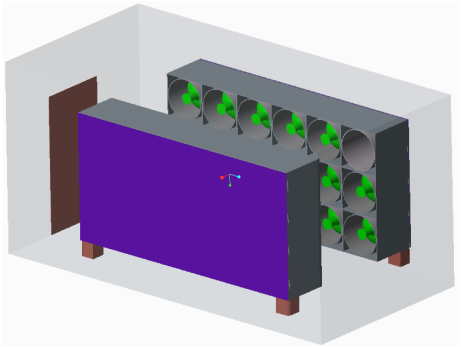




➢The surface light

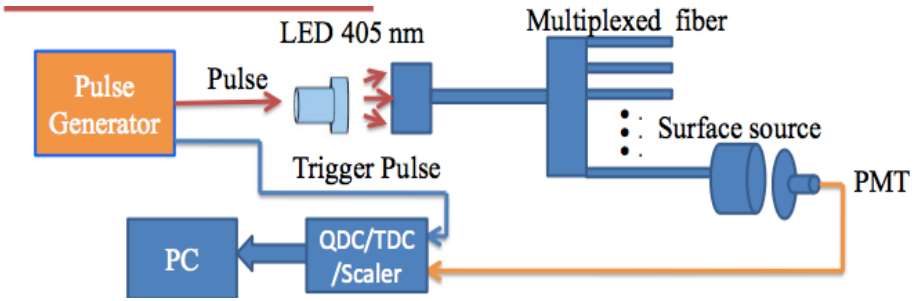


➢The container sys.



➢The DAQ sys.

➢The logic construction of the SPE test system



5.5 The MCP-PMT International Evaluation

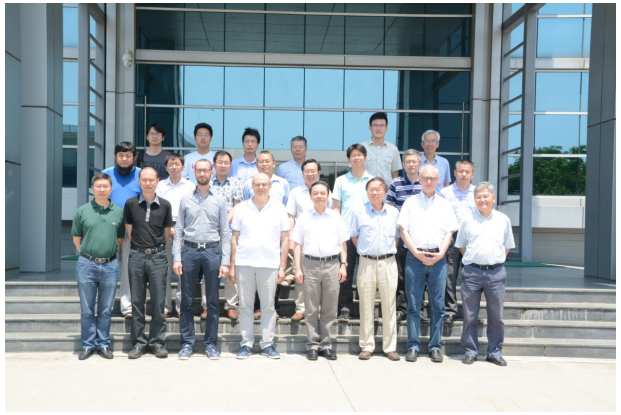
20 inch Micro-channel Plate Photomultiplier Tube International Evaluation on 28th.May 2017

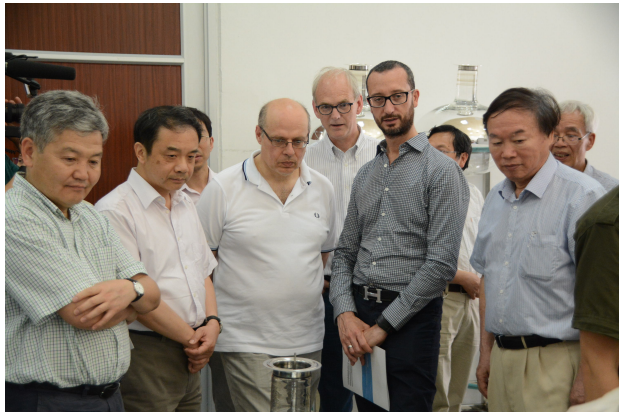
—> **The production line and testing procedures and equipment** are world-class with unique capabilities.

—> The design of the MCP-PMT has acquired a patent of invention and intellectual property rights.

The MCP-PMT Review Committee

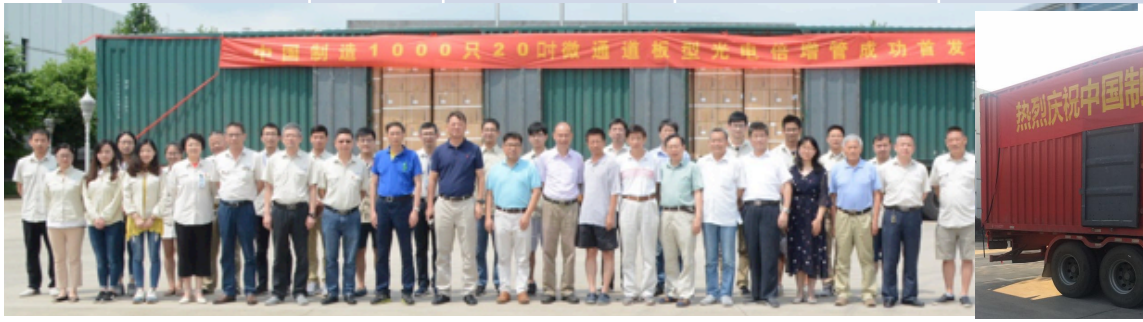
	Name	Company	Signature
Chairman	Weiguo Li	IHEP	
Member	Paolo Lombardi	INFN	
Member	Bayarto Lubsandorzhiev	INR	
Member	Demarteau Marcel	ANL	
Member	Gioacchino Ranucci	INFN	
Member	Zizong Xu	USTC	
Member	Jiawen Zhang	IHEP	





5.6 The transport by road for the MCP-PMT to JUNO

Status	Times	Date	AVDE（%）	Pics
finish-336	1	2017.5.15	28.95%	336
finish-648	2	2017.6.14	29.36%	312
finish-1008	**3**	**2017.7.4**	**29.47%**	**360**
finish-1344	4	2017.7.26	28.83%	336
finish-1680	5	2017.8.24	29.01%	336
finish-2016	**6**	**2017.9.12**	**29.09%**	**336**
finish-2351	7	2017.9.25	29.62%	336
finish-2687	8	2017.10.09	29.79%	336
finish-3023	**9**	**2017.10.26**	**29.35%**	**336**
finish-3360	10	2017.11.08	29.17%	336
finish-3696	11	2017.11.22	29.92%	336
finish-4031	**12**	**2017.12.21**	**29.35%**	**335**
finish-4366	13	2018.01.21	29.28%	336
finish-4703	14	2018.02.23	29.48%	337



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  How to improve, QE, CE, DR, The new 20 inch prototypes ;
- **5. The Mass production Line and Batch test system;**
  The mass production, the batch test about 4700 pics PMT；
- **6. The Batch test result of 4700 PMTs;**
  the batch test data；

6.0 the MCP-PMT parameters Test in NNVT for JUNO

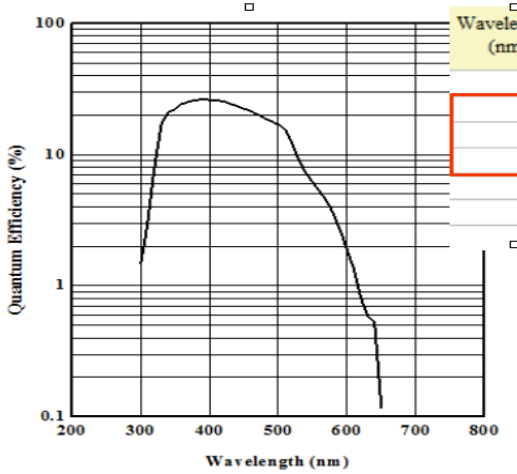
PMT Parmaeters	JUNO Contract	data in Contract	NNVT test	Prototype	mass production
单波长QE@410nm	A	≥ 26.5%	A	~ 26%	?
均匀性（QE Uniformity）	B	≤ 15%	A	≤ 10%	?
频谱响应曲线（QE-λ）	B	300nm ~ 650 nm	B(50%)	300nm ~ 650 nm	?
单光子探测（SPE-P/V）	A	≥ 2.8	A	~ 5.6	?
能量分辨率（SPE-ER）	A	≤ 40%	A	~ 41%	?
增益（Gain）	A	1E+07	A	1E+07	?
高压（HV）	A	≤ 2800V	A	~ 1980V	?
探测效率（DE）	B	≥ 24%	A	~ 26%	?
暗计数率（DR）	A	≤ 30KHz	A	~ 30KHz	?
渡越时间涨落（TTS）	B	≤ 15ns	A	~12ns	?
后脉冲率（APR）	B	≤ 5%	A	~ 2.5%	?
非线性（Linearity）<10%	B	≥ 1000pe	A	~ 1000pe	?
信号波形（RT）	A	≤ 2ns	A	~ 1.2ns	?
信号波形（FT）	A	≤ 12ns	A	~10.2ns	?

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

6.1 The Quantum Efficiency @ 405nm

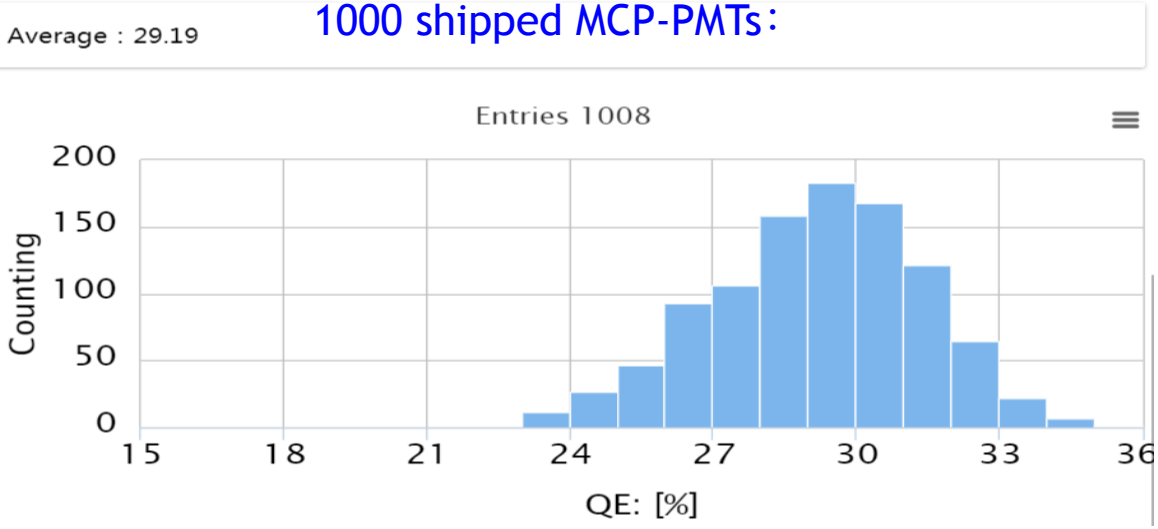
PMTs	Hamamatsu	MCP-PMT prototype	~300 MCP-PMTs	~1000 MCP-PMTs	~4703 MCP-PMTs
QE @ 405nm	30%	26%	29.5%	29.2%	29.3%

MCP-PMT-prototype

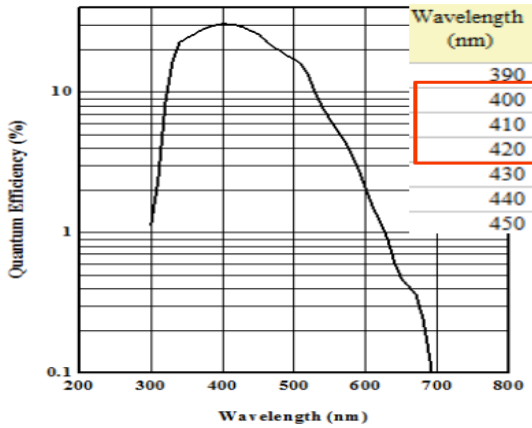


Wavelength (nm)	79#
390	26.32155
400	26.18978
410	26.058
420	25.4807
430	24.47675
440	23.4516
450	22.37645

1000 shipped MCP-PMTs:

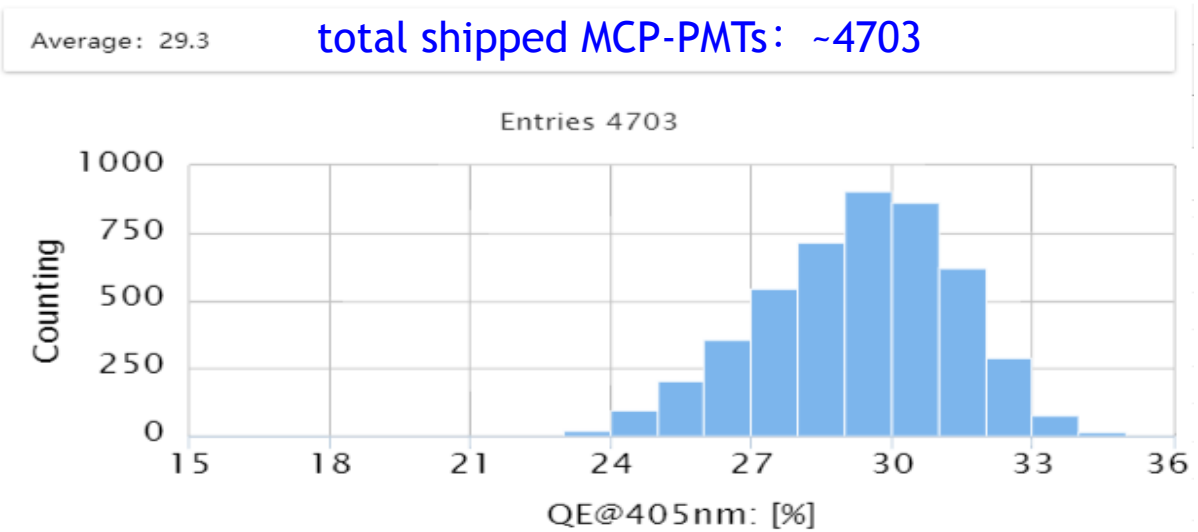


Hamamatsu Prototype



Wavelength (nm)	QE
390	29.9283
400	30.7108
410	30.35535
420	29.9999
430	28.8817
440	27.253
450	25.9221

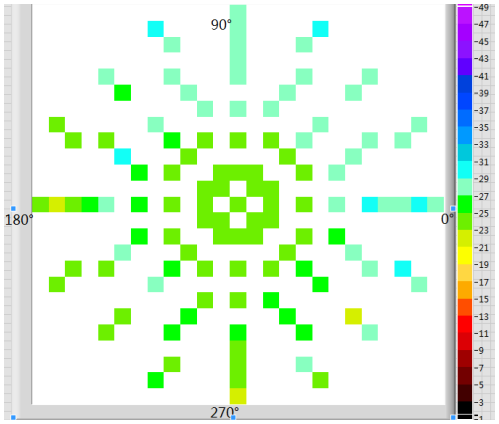
total shipped MCP-PMTs: ~4703



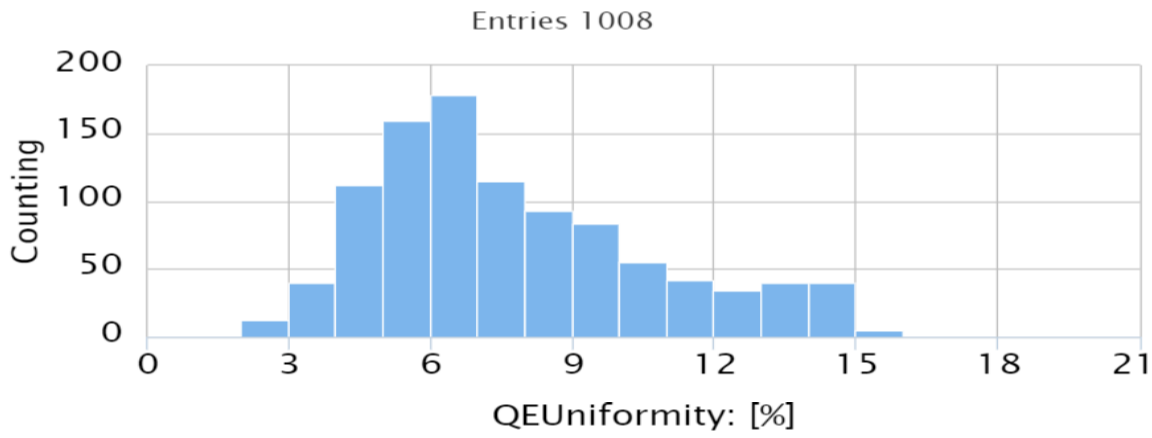
6.2 The Uniformity of the Photocathode

PMTs	Hamamatsu	MCP-PMT prototype	~300 MCP-PMTs	~1000 MCP-PMTs	~4703 MCP-PMTs
Uni-QE @ 410nm	< 10%	< 10%	8.1%	7.8%	7.4%

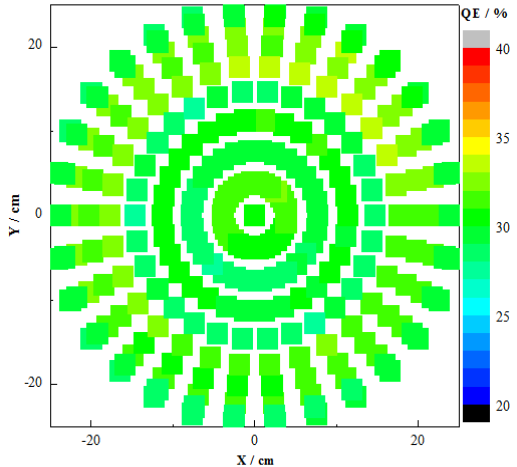
MCP-PMT-prototype



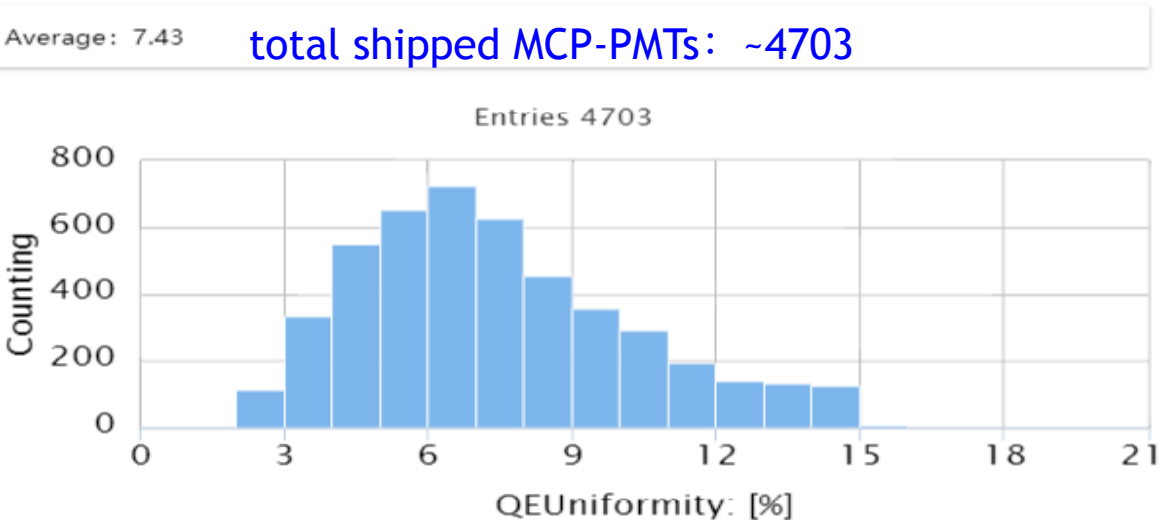
1000 shipped MCP-PMTs:



Hamamatsu Prototype

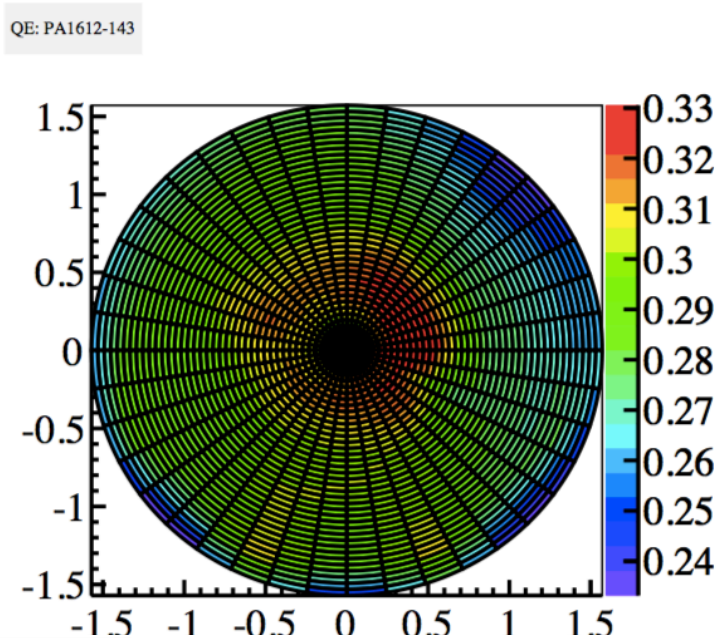


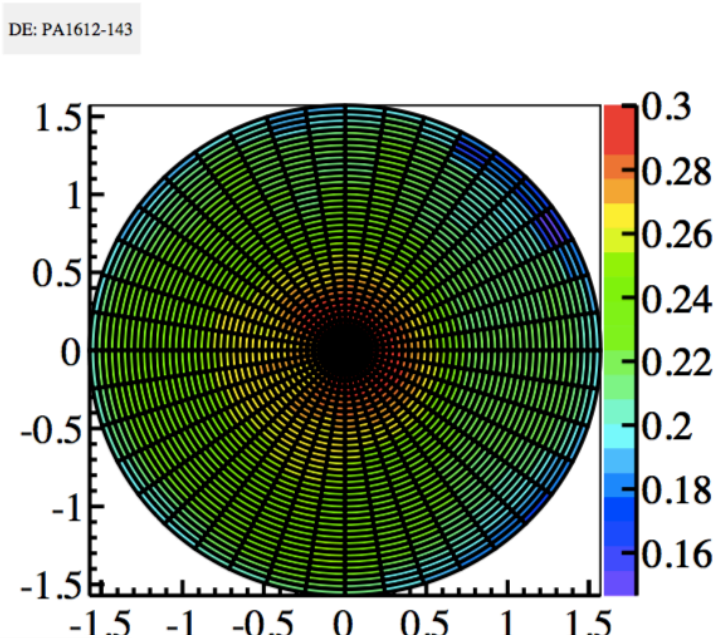
total shipped MCP-PMTs: ~4703

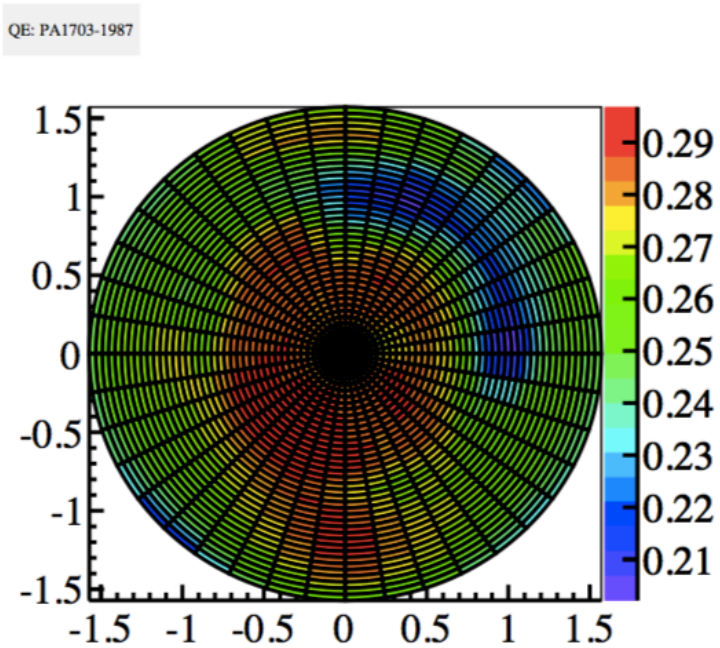


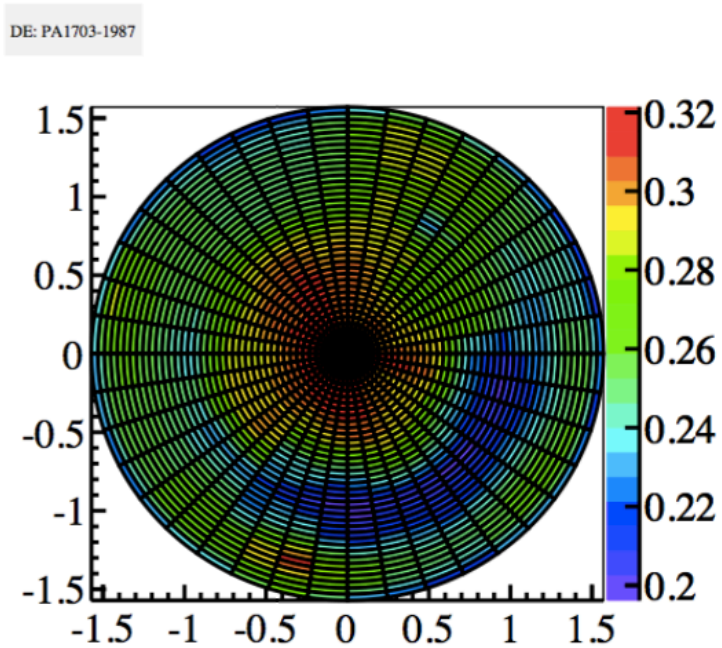
the Uniformity of the DE is mainly affected by the uniformity of QE

the Uniformity of the Quantum Efficiency in NNVT



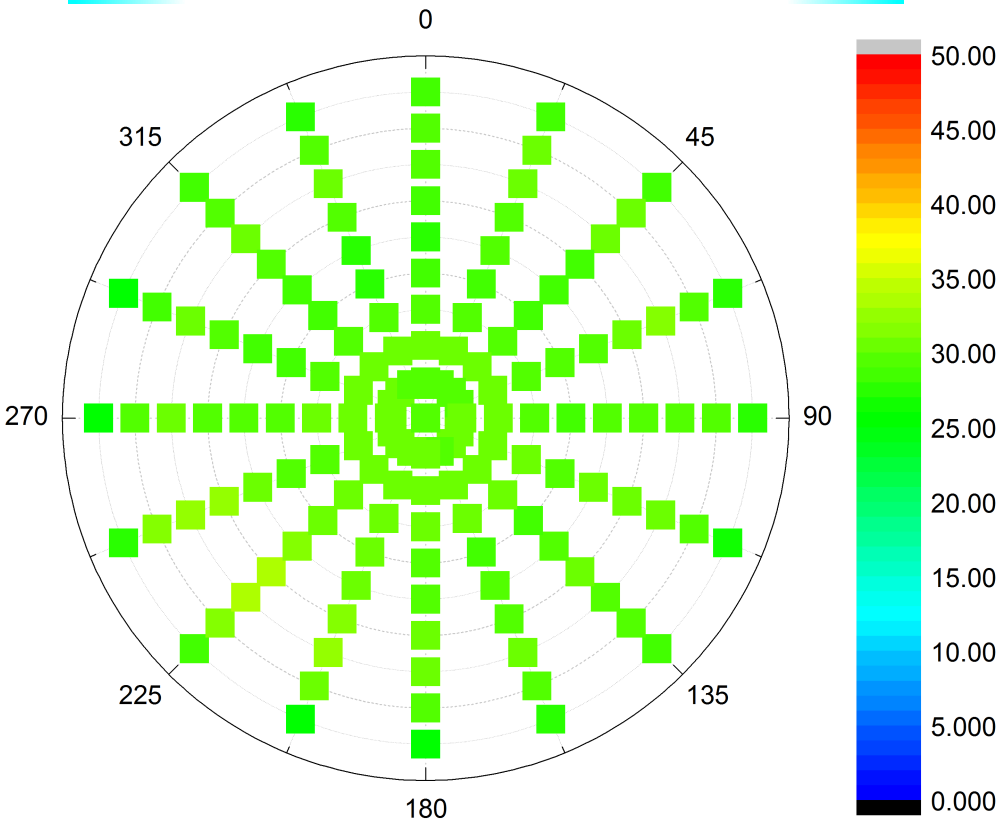




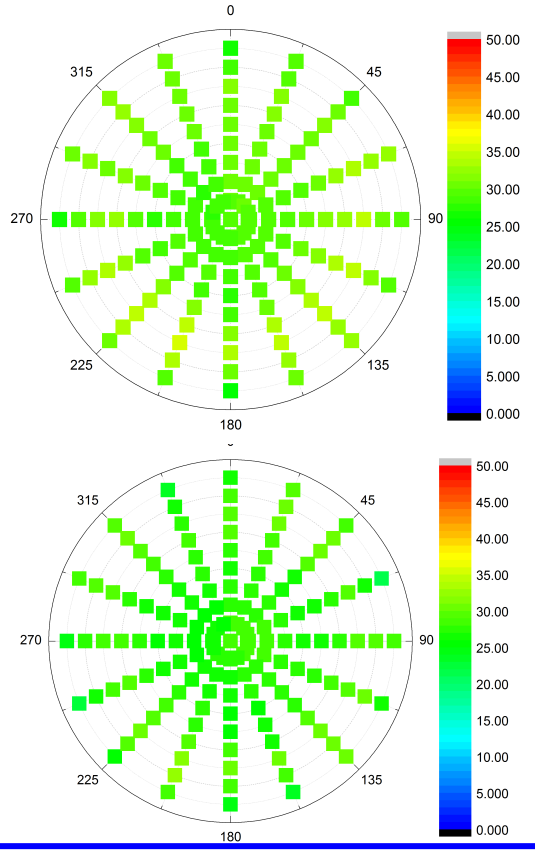


the Uniformity of the Detection Efficiency in FanYa

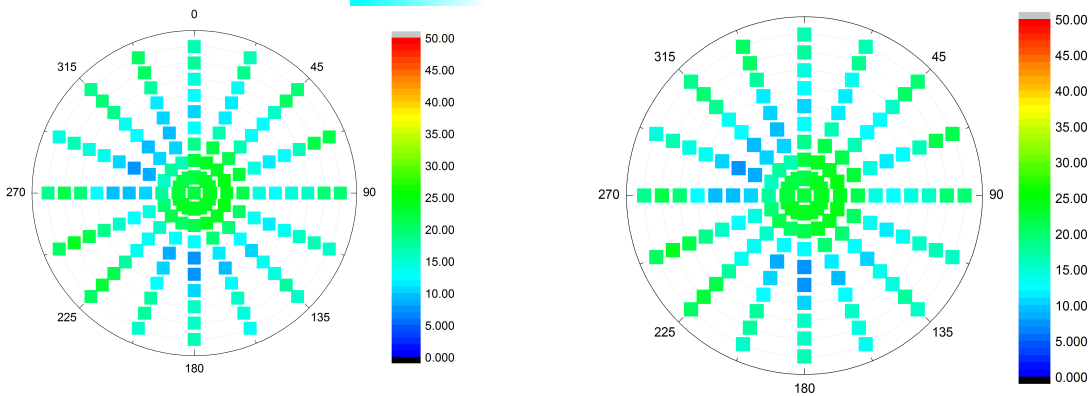
The average data of 2688 piece PMTs



The good situation



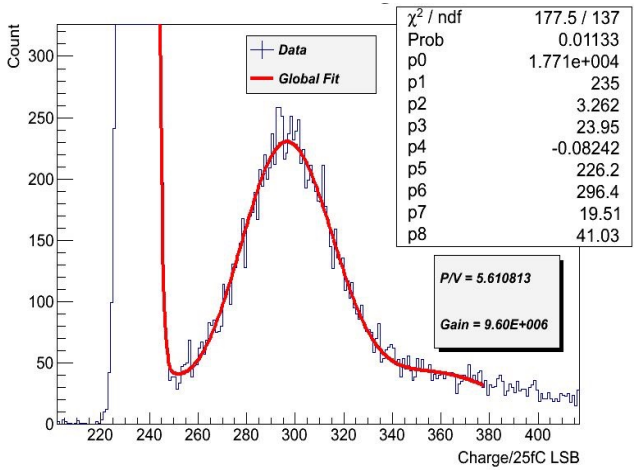
The bad situation of the QE uniformity



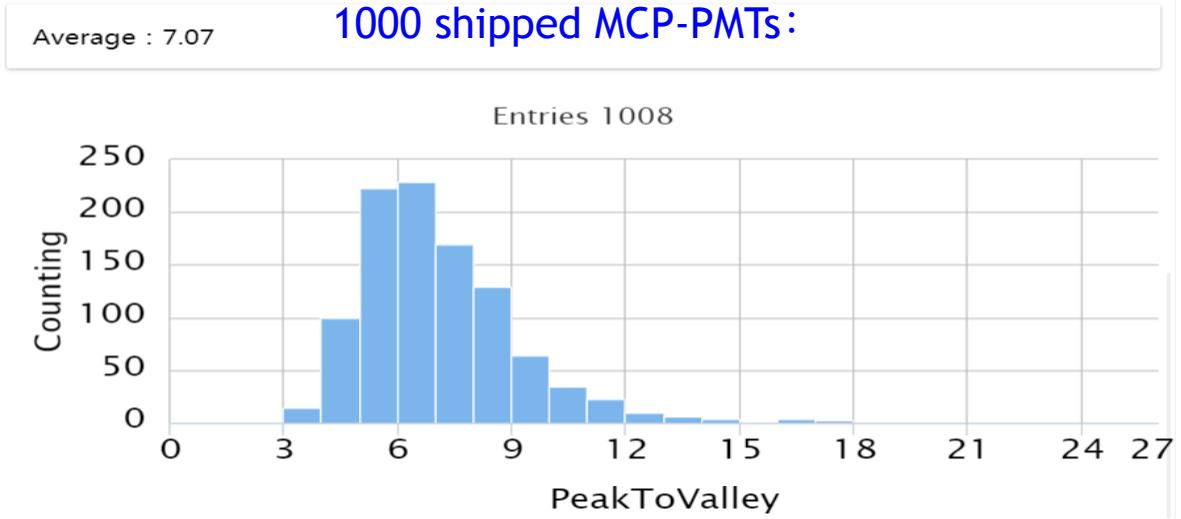
6.3 The P/V of the SPE

PMTs	Hamamatsu	MCP-PMT prototype	~300 MCP-PMTs	~1000 MCP-PMTs	~4703 MCP-PMTs
SPE @ Gain~1X10^7	3.7	5.6	8.2	7.1	7.0

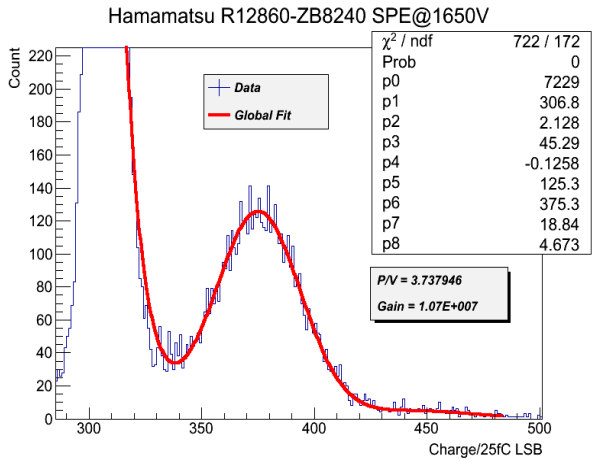
MCP-PMT-prototype



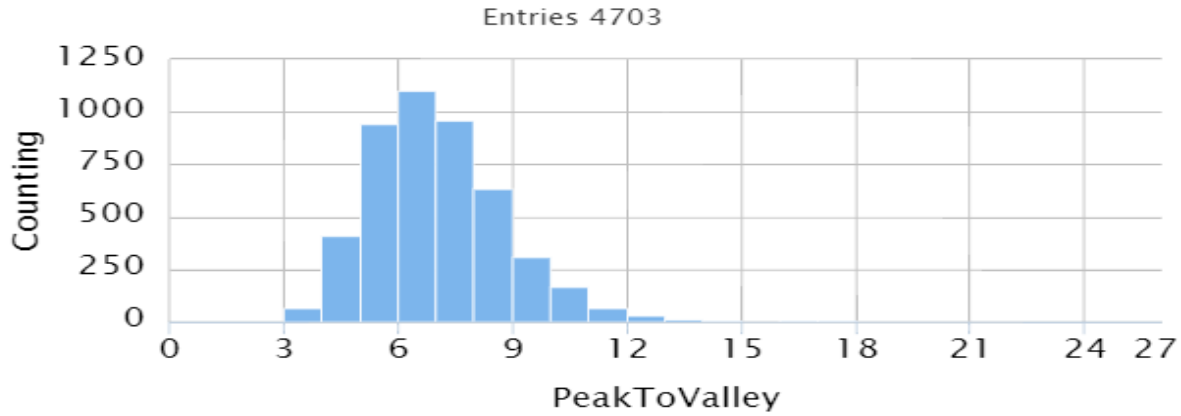
1000 shipped MCP-PMTs:



Hamamatsu Prototype



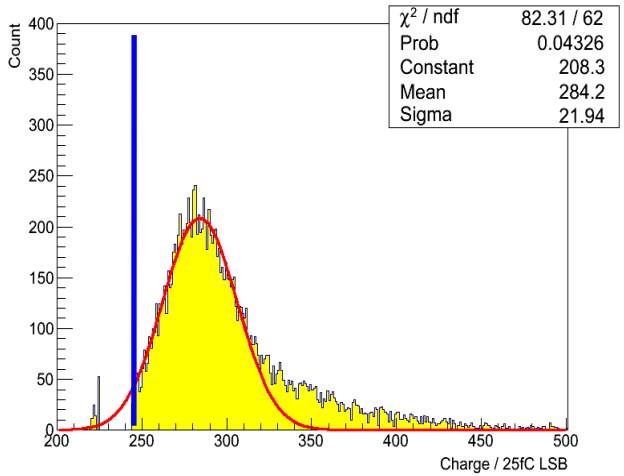
total shipped MCP-PMTs: ~4703



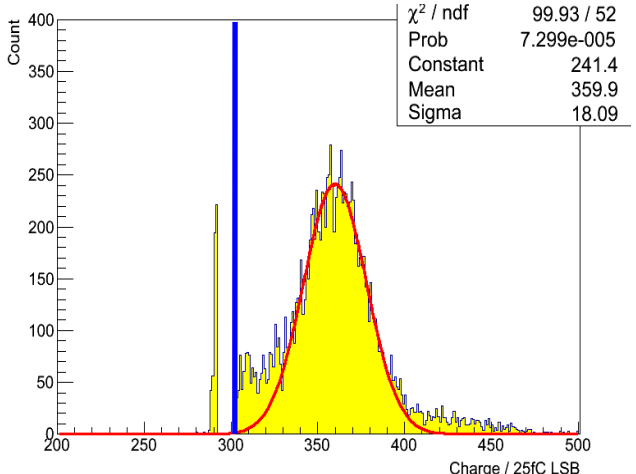
6.4 The Relativity Detection Efficiency of SPE @ 405nm

PMTs	Hamamatsu	MCP-PMT prototype	~300 MCP-PMTs	~1000 MCP-PMTs	~4703 MCP-PMTs
DE @ Gain~1X10^7	27%	26%	28.9%	29.3%	29.3%

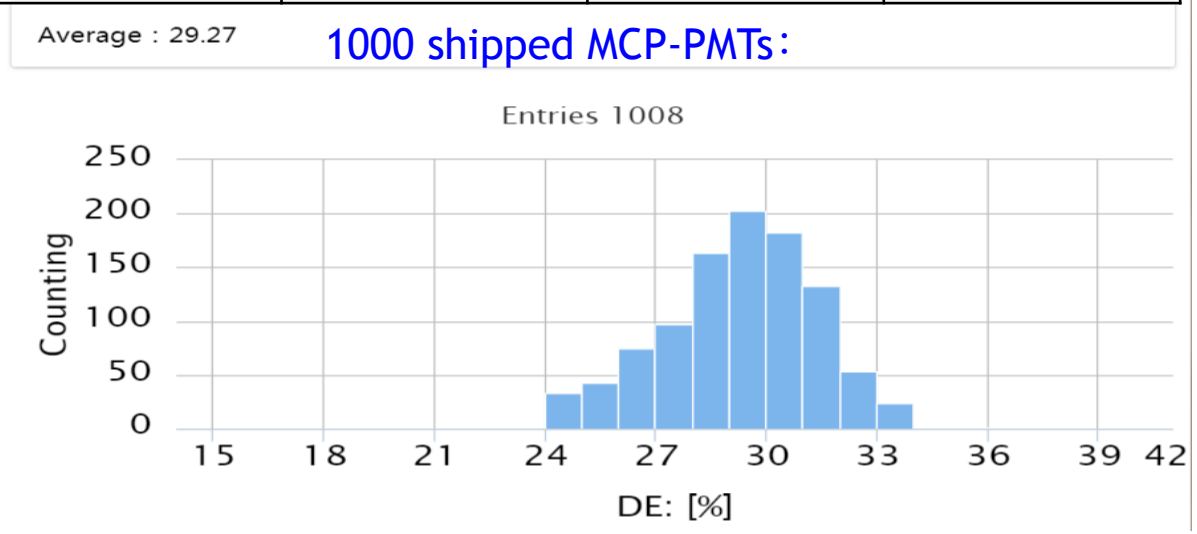
MCP-PMT-prototype



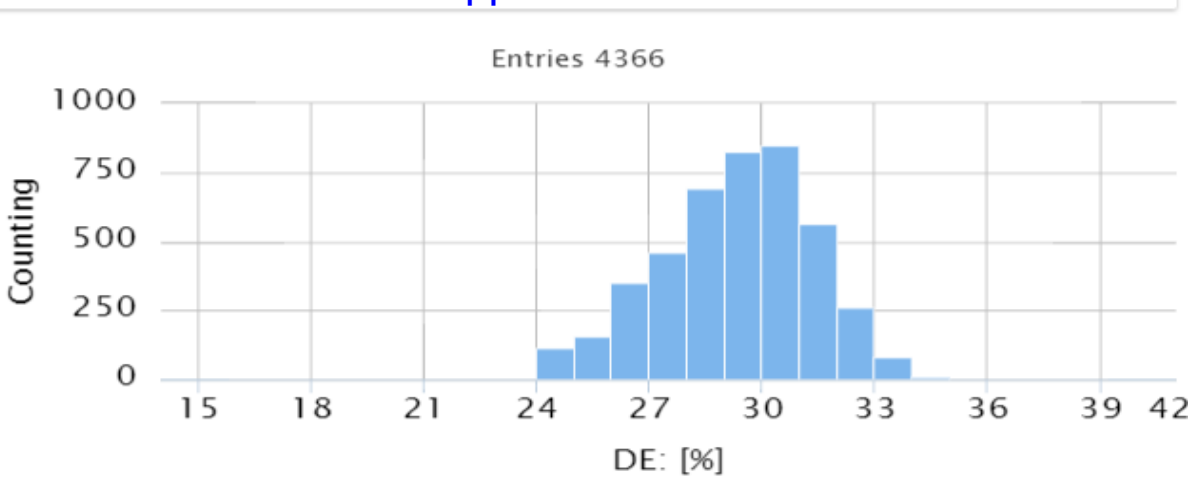
Hamamatsu Prototype



1000 shipped MCP-PMTs:



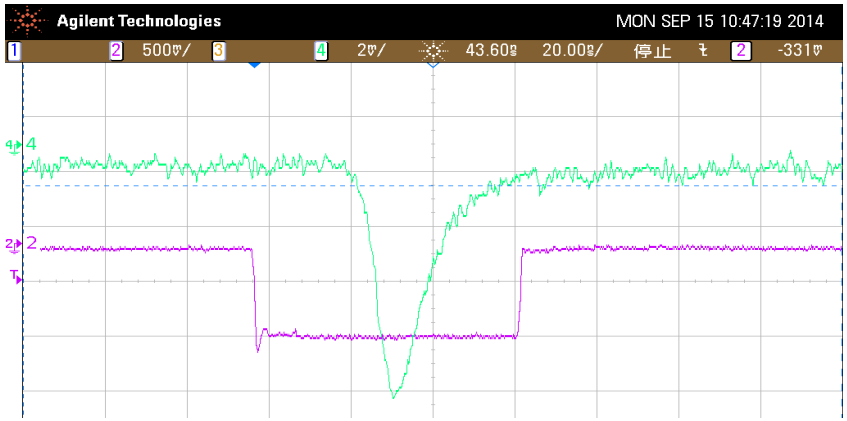
total shipped MCP-PMTs: ~4703



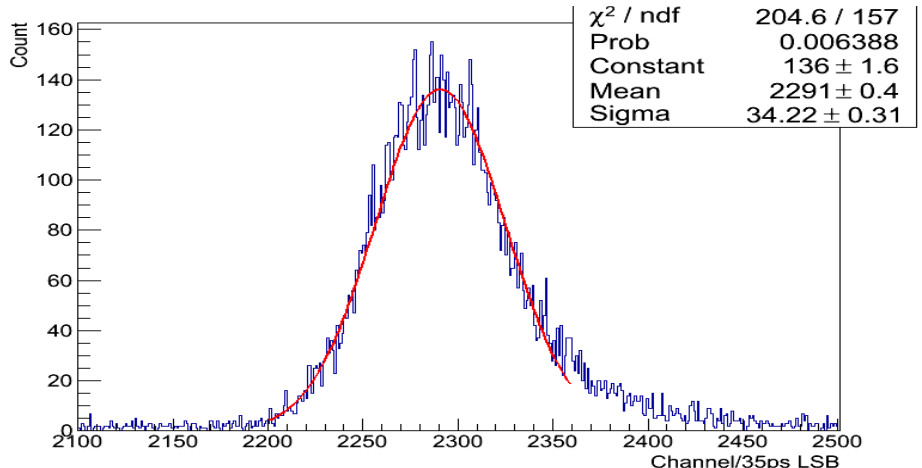
6.5 The time characteristics of the PMTs in JUNO @ Gain~1X10^7

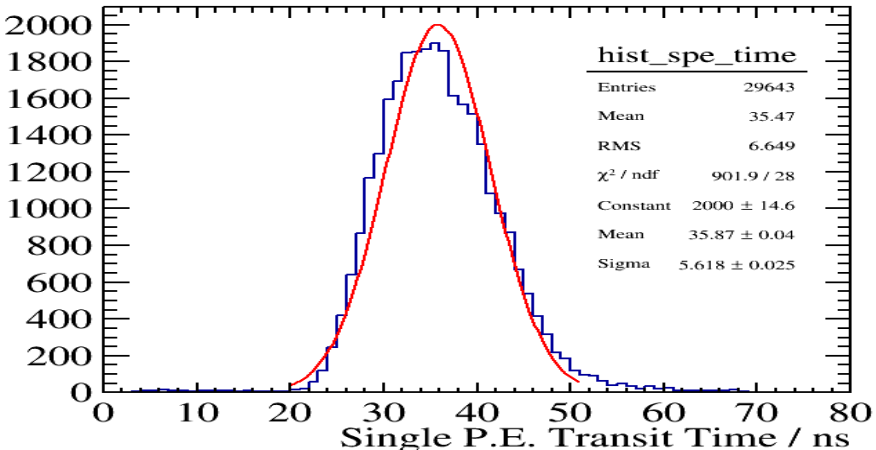
PMTs	Hamamatsu	MCP-PMTprototype	~300 MCP-PMTs	~1000 MCP-PMTs	~4703 MCP-PMTs
TTS @ FWHM	**2.8 ns**	**13.2 ns**	**19.2 ns**	**19.5ns**	**20.4ns**
TTS @sigma	1.19 ns	5.62ns	8.17ns	8.30ns	8.64ns
RT @ Gain~1X10^7	6.7 ns	1.2 ns	1.4 ns	1.4 ns	1.4 ns
FT @ Gain~1X10^7	17.7 ns	10.2 ns	24.4 ns	25.2 ns	25.5 ns

Hamamatsu Prototype

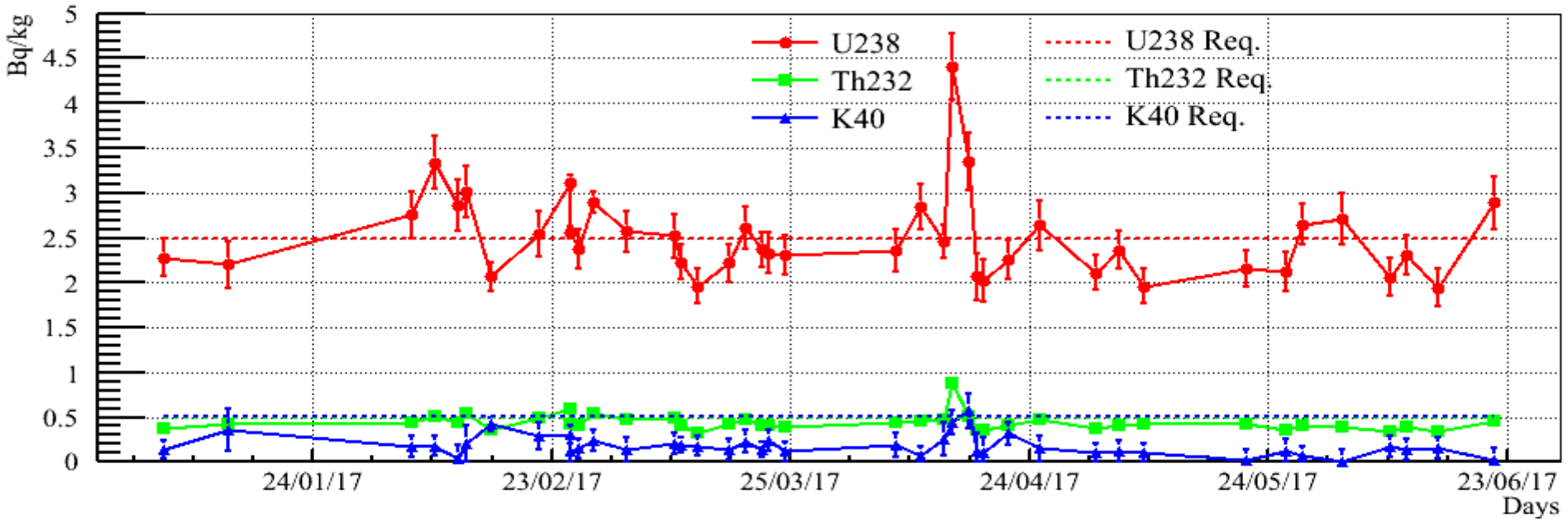


MCP-PMT-prototype



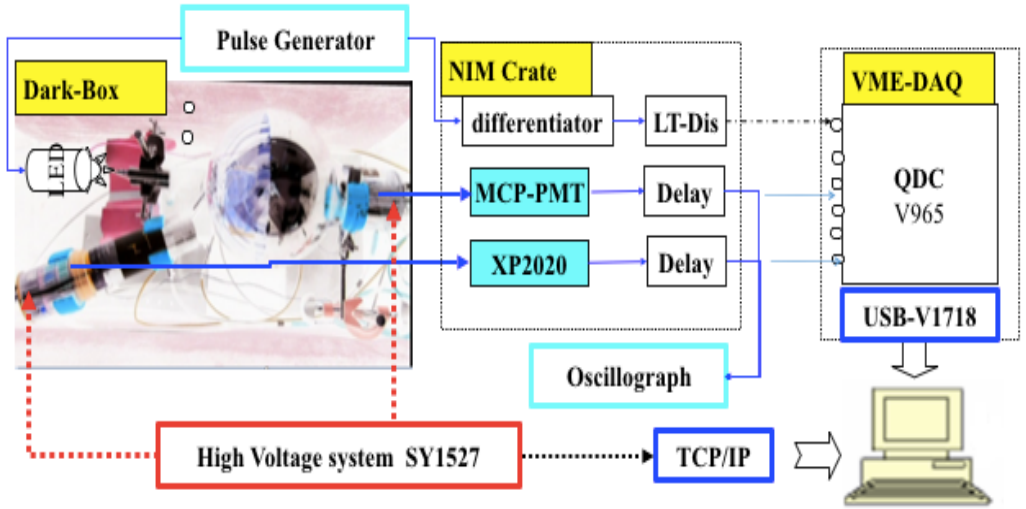


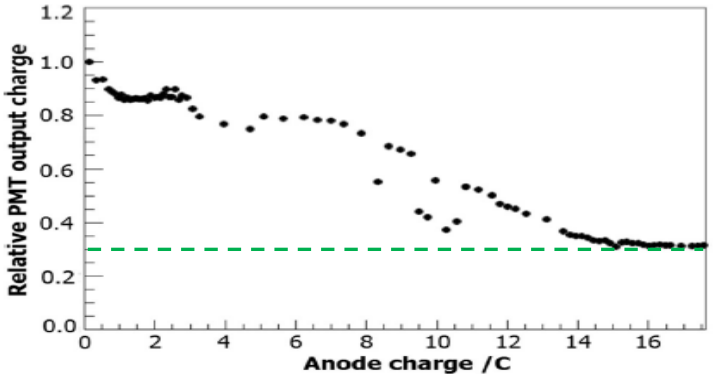
6.14 The low background glass of MCP-PMT



		U238(Bq/kg)	Th232(Bq/kg)	K40(Bq/kg)
Before improvement		5.4	4.3	7.6
Last year collaboration meeting results	5 days	2.96±0.08	1.39±0.04	2.8±0.3
	10 days	2.70±0.10	0.97±0.05	1.8±0.3
Last collaboration meeting results	Period1	2.0	0.7	1.2
	Period2	1.7	0.6	0.6
	Period3	1.5	0.4	0.2
Since last collaboration		2.5(with Ra226 correction)	0.3	0.3
PMT Requirement		**2.50**	**0.50**	**0.50**

6.15 The Aging behaviors of the MCP-PMT



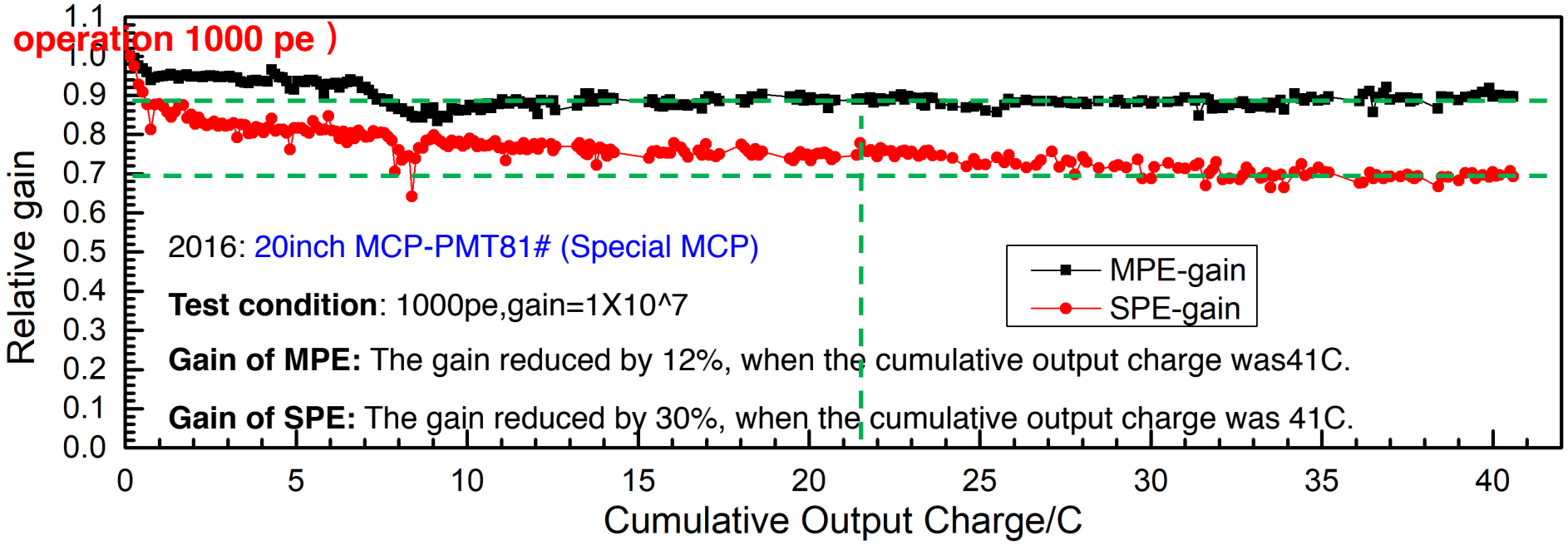


2014: 8inch MCP-PMT （normal MCP）

Test condition: 1000pe, gain=1X10^7

Gain of MPE: The gain reduced by 70%@ 16C

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



2016: 20inch MCP-PMT81# (Special MCP)

Test condition: 1000pe,gain=1X10^7

Gain of MPE: The gain reduced by 12%, when the cumulative output charge was41C.

Gain of SPE: The gain reduced by 30%, when the cumulative output charge was 41C.

6.6 the MCP-PMT parameters Test in NNVT for JUNO

PMT Parmaeters	JUNO Contract	data in Contract	NNVT test	Prototype	4000 mass production in NNVT	1000 BatchTest by JUNO
单波长QE@410nm	A	≥ 26.5%	A	~ 26%	29.2%	—
均匀性（QE Uniformity）	B	≤ 10%	A	≤ 10%	7.6%	7%
频谱响应曲线（QE-λ）	B	300nm ~ 650 nm	B(50%)	300nm ~ 650 nm	300nm ~ 650 nm	—
单光子探测（SPE-P/V）	A	≥ 2.8	A	~ 5.6	6.9	6.7
能量分辨率（SPE-ER）	A	≤ 40%	A	~ 41%	33.1%	32.7%
增益（Gain）	A	1E+07	A	1E+07	1E+07	1E+07
高压（HV）	A	≤ 2800V	A	~ 1780V	1743V	1810V
探测效率（DE）	B	≥ 24%	A	~ 26%	29.3% @405nm	27.3% @420nm
暗计数率（DR）	A	≤ 30KHz	A	~ 30KHz	39.8 KHz	23.4 KHz
渡越时间涨落（TTS）	B	≤ 15ns	A	~12ns	20.2ns	22.6ns
后脉冲率（APR）	B	≤ 5%	A	~ 2.5%	0.7%	0.4%
非线性（Linearity）<10%	B	≥ 1000pe	A	~ 1000pe	1285pe	—
信号波形（RT）	A	≤ 2ns	A	~ 1.2ns	1.4 ns	1.4ns
信号波形（FT）	A	≤ 12ns	A	~10.2ns	25 ns	25.4ns

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

Overview of the Design and Production of the MCP-PMT

2009

Design

2010-2013

5”(8”) prototype
Transmission
+reflection

2014-2015

20” prototype
Transmission
+reflection

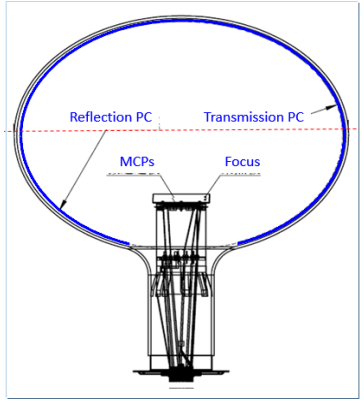
2016

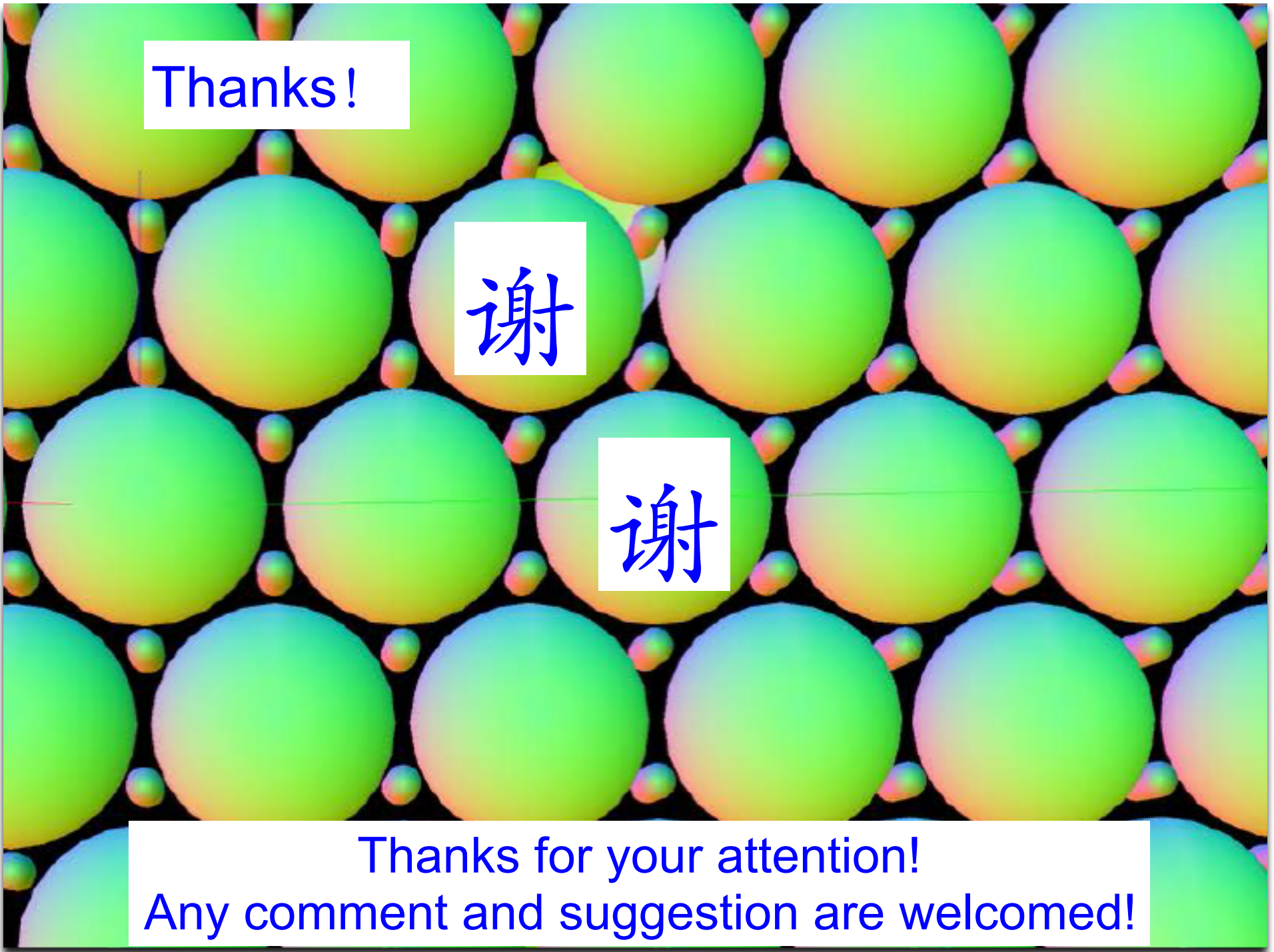
HQE
Production line
batch test sys

2017-2019

Batch
test

Mass
production




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