The Status of the R&D of the 20 inch MCP-PMT in China

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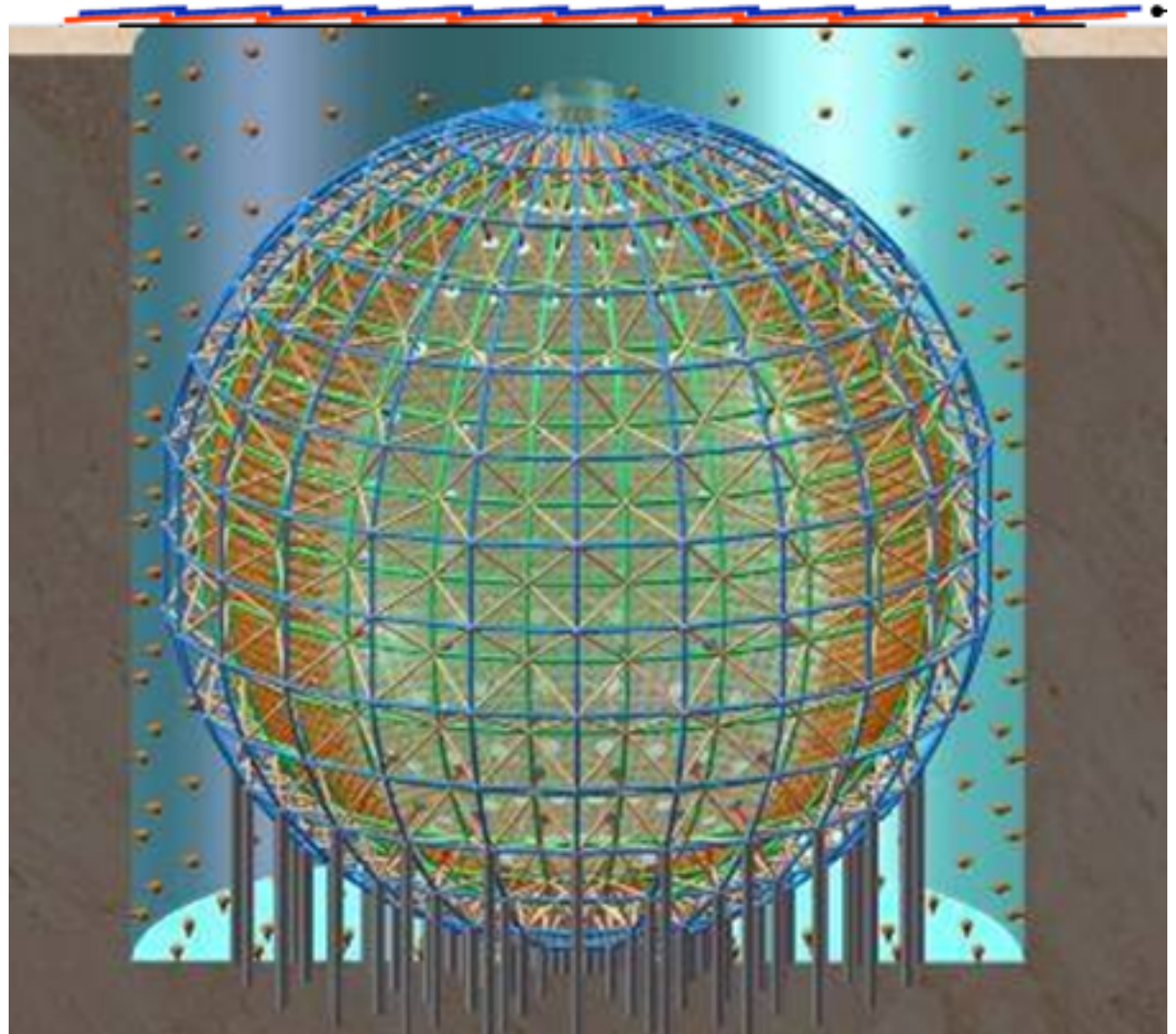
Asian Forum for Accelerators and Detectors
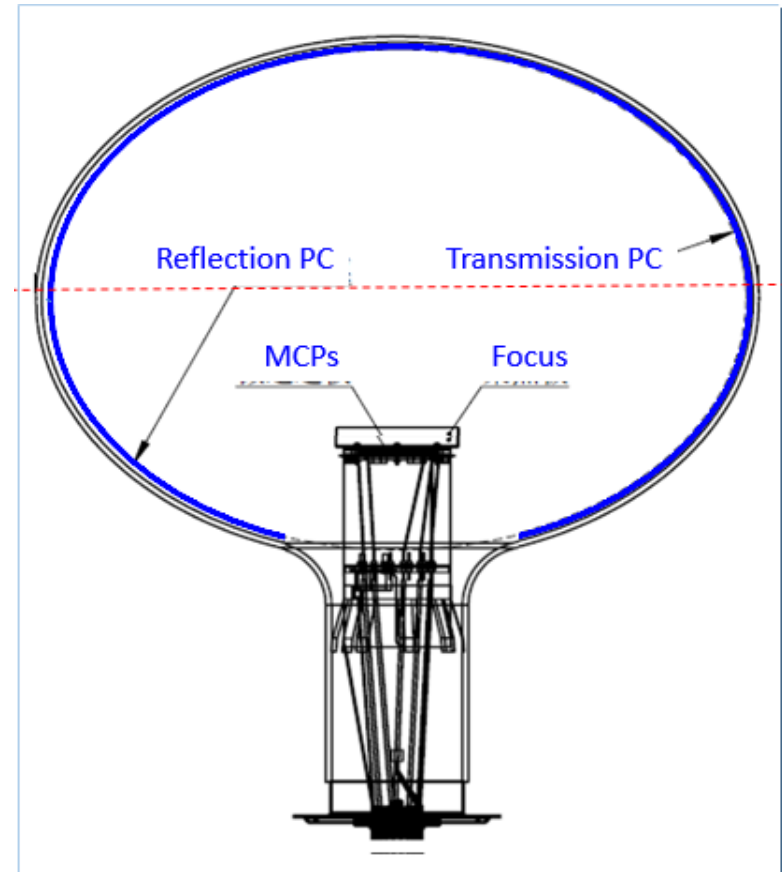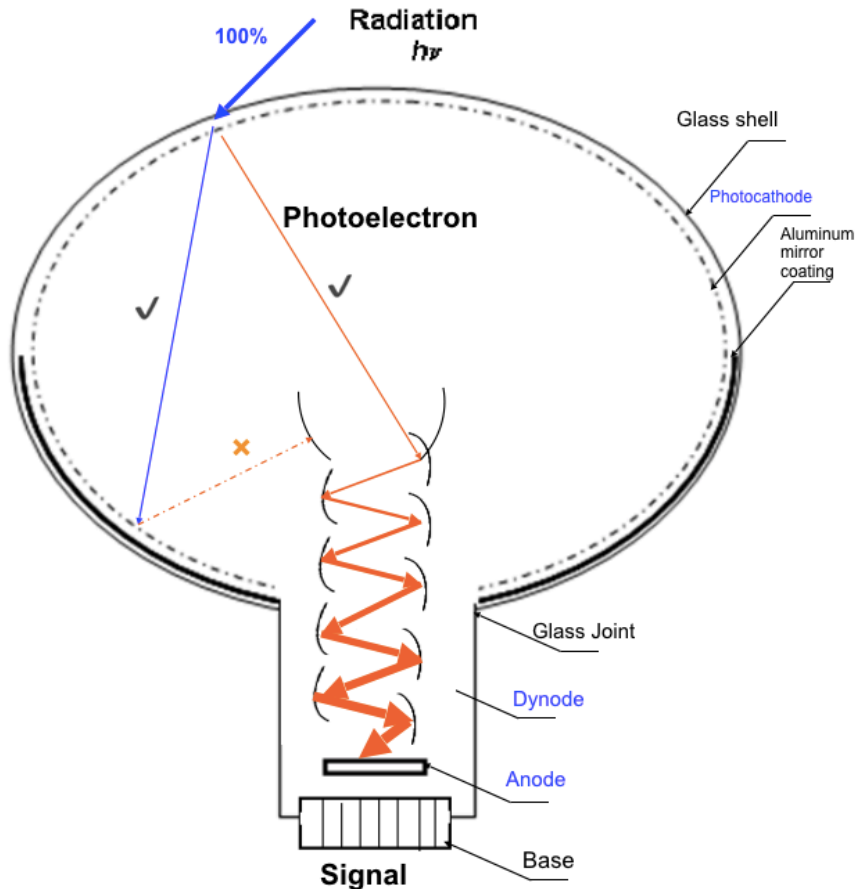
➢ **JUNO Experiment**

Daya Bay Experiment

Generation 1: DayaBay: ~3,000 8-inch Dynode-PMTs from Hamamatsu

Generation 2:   JUNO: ~20,000 20-inch PMTs from Where?

Photon Detection Efficiency (PE) $= QE_{Trans} * CE$

Dynode:(PE) $= QE_{Trans} * CE$

$= 20\% * 70\% = 14\%$ (2009)

$= 30\% * 90\% = 27\%$ (2015)

Dynode:(PE) $= QE_{Trans} * CE$

$= 27\% * 100\% = 27\%$ (2016)

中国科学院高能物理研究所   effort by Yifang Wang;

Institute of High Energy Physics,   CAS

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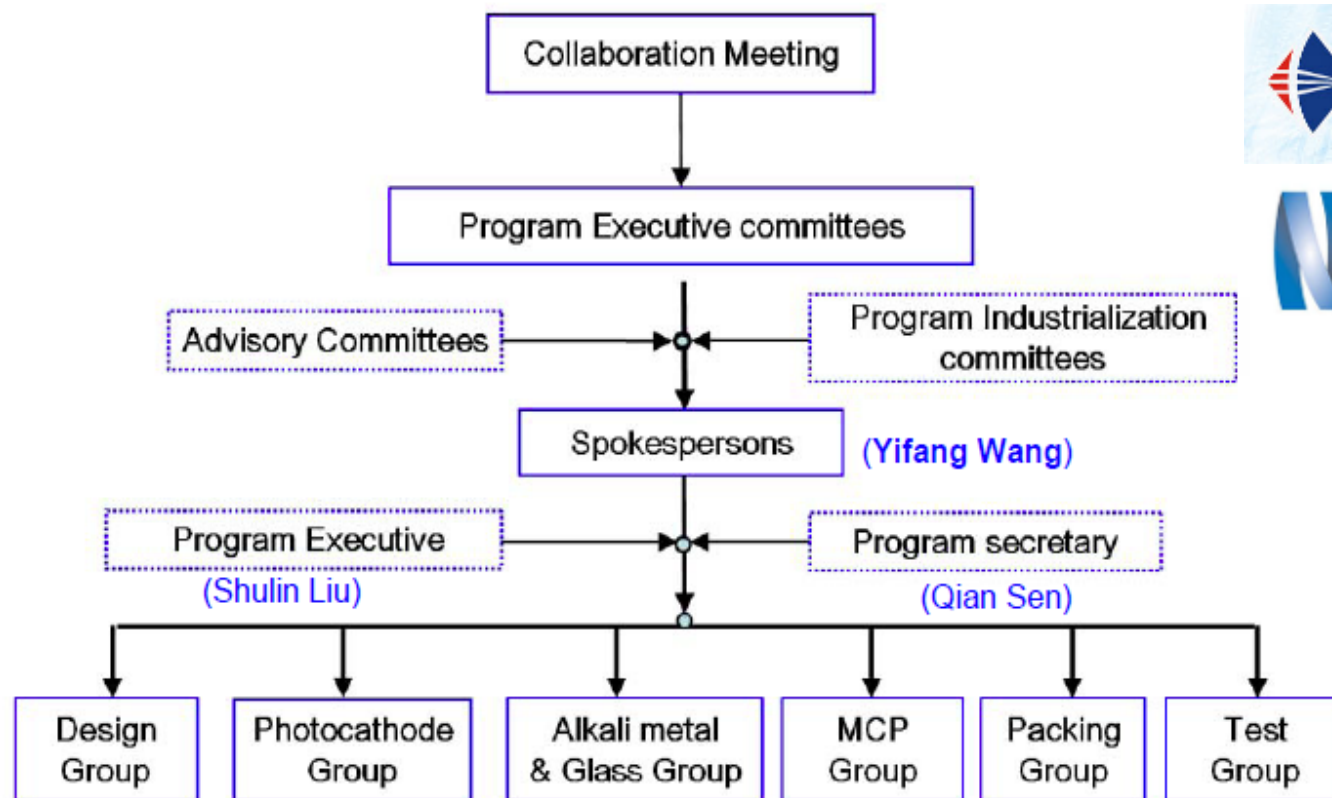
Requirement

Development

Design

Photomultiplier

Low price MCP

photocathode

Glass Shell

Electronic

Vacuum equipment

Test system

Prototype

Performance
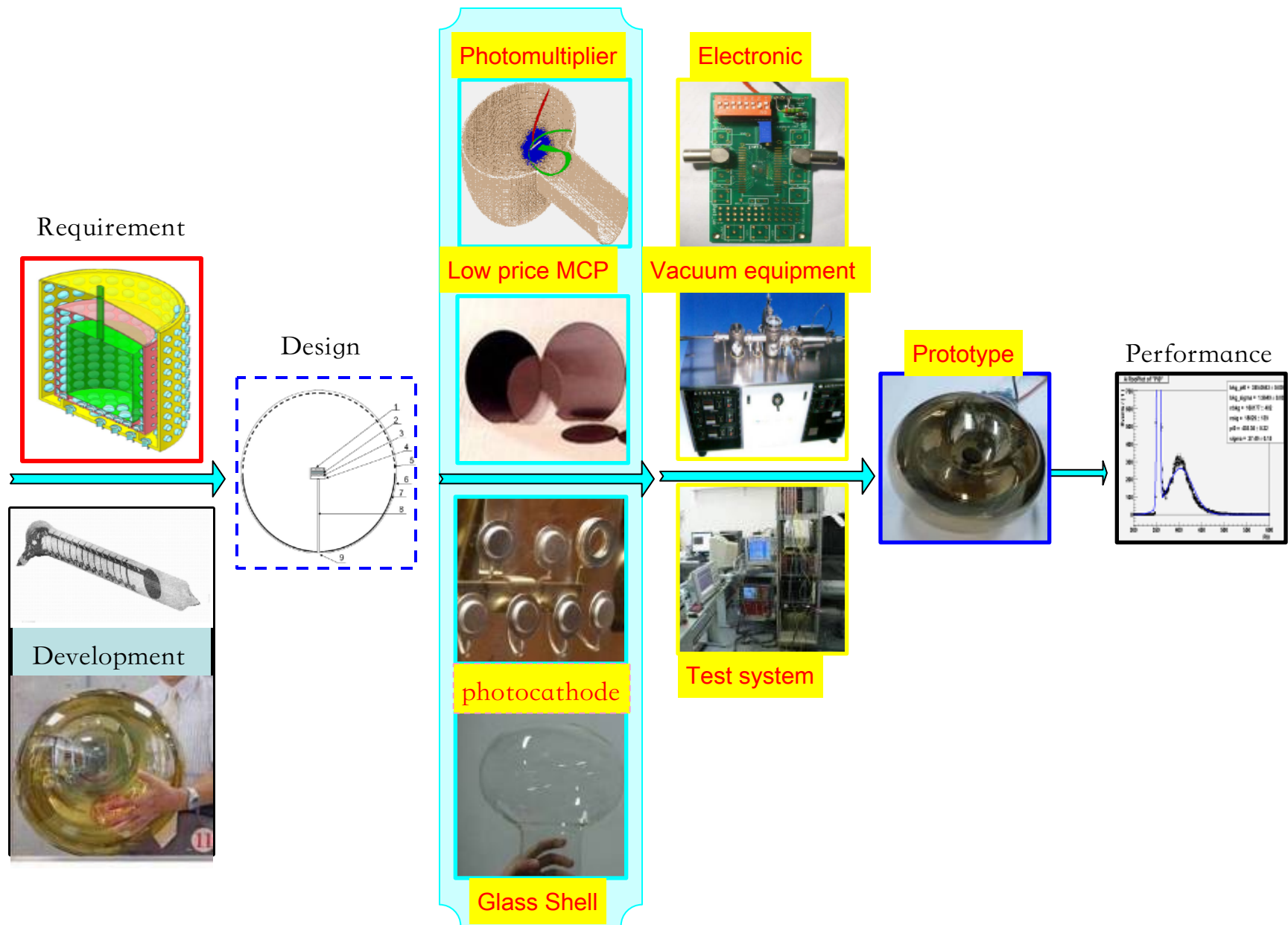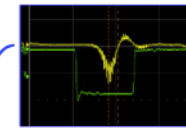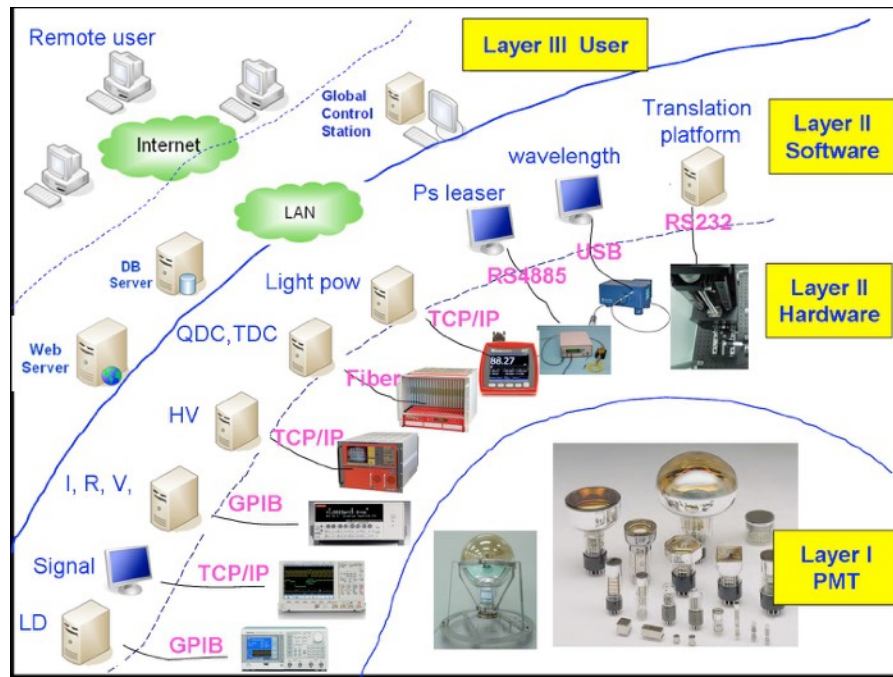
- Anode Pulse Rise Time;
- Pre/Late/After Pulse;
- Dark Count
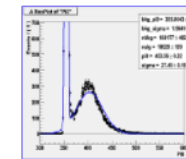
- The Single Photoelectron Spectrum;
- The voltage distribution (BASE);
- The Supply voltage;
- Typical Gain Caracteristic;
- Anode Dark Current
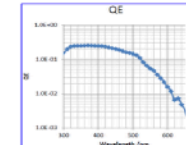
- Spectral Response;
- Wavelength of Maximum Response;
- Cathode Sensitivity: Luminous(2856K);
- Quantum efficiency with λ
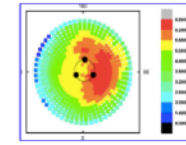
- Photocathode efficiency Area;
- Photocathode efficiency Uniform;
- The position of the Sb, K, Cs;

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

Others
......

Lab 1   Lab 2   PMT   Lab 3   Lab 4

Design → 5"(8") prototype transmission → 5"(8") prototype Transmission +reflection → 20" prototype Transmission +reflection → Mass production
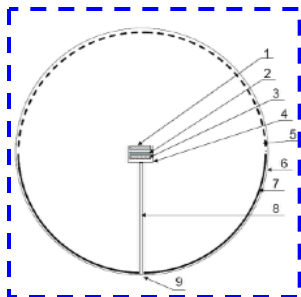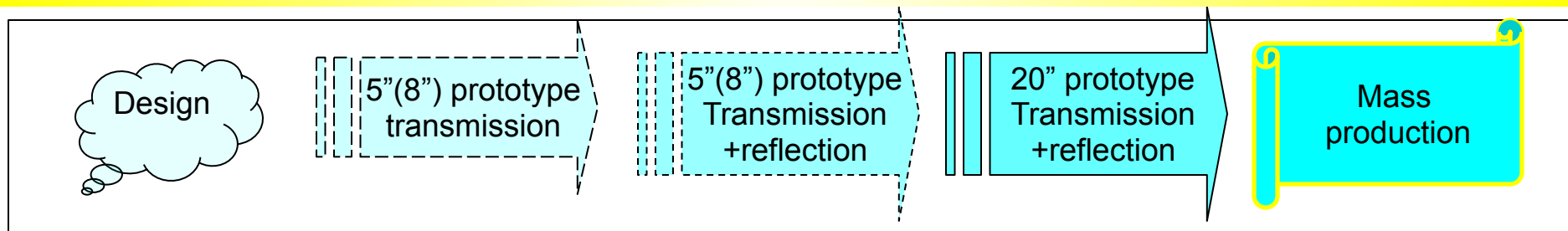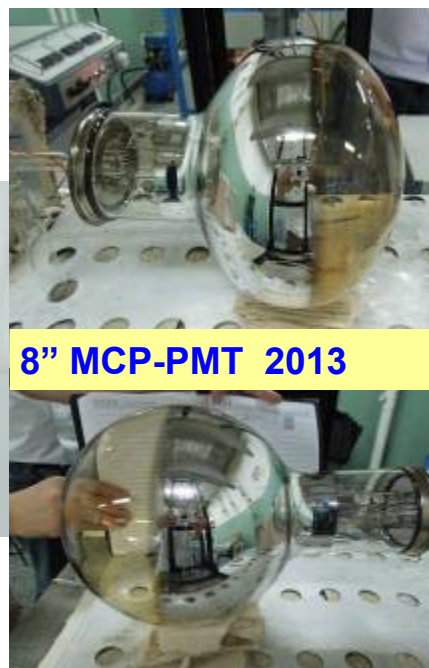
The design of the IHEP-MCP-PMT → The project of DayaBay /JUNO

2" MCP-PMT

5" MCP-PMT 2010年

8" MCP-PMT 2013

20" MCP-PMT 2015

Outline

8-inch IHEP MCP-PMT Vertical MCPs Sphere Glass	8-inch IHEP MCP-PMT Horizontal MCPs
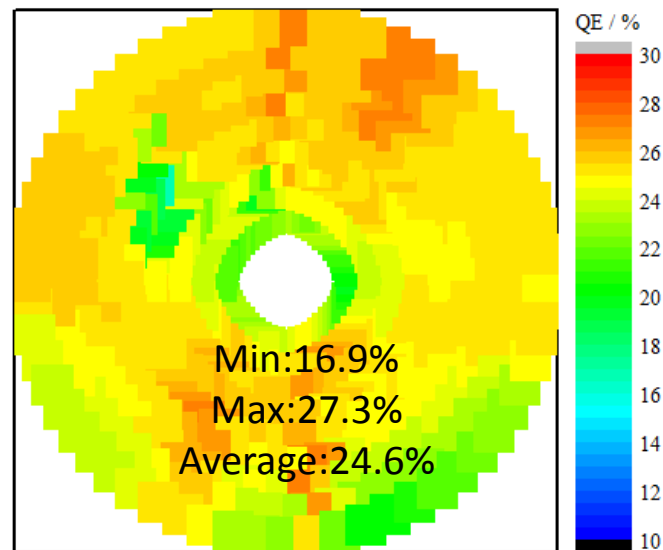
QE / %

Min:16.9%
Max:27.3%
Average:24.6%

MCP-PMT-38# SPE@2100V

χ²/ndf	169.4 / 140
Prob	0.04607
p0	2.127e+004
p1	389.2
p2	1.662
p3	98.24
p4	-0.2412
p5	41.99
p6	441.3
p7	20.91
p8	2.463

P/V = 3.953964
Gain = 8.14E+006

MCP-PMT-44# Dark Rate @ 10⁷

Threshold
- 2mV
- 3mV
- 4mV
- 5mV

MSO-X 3104A, MY54100361: Sun Dec 21 15:42:59 2014
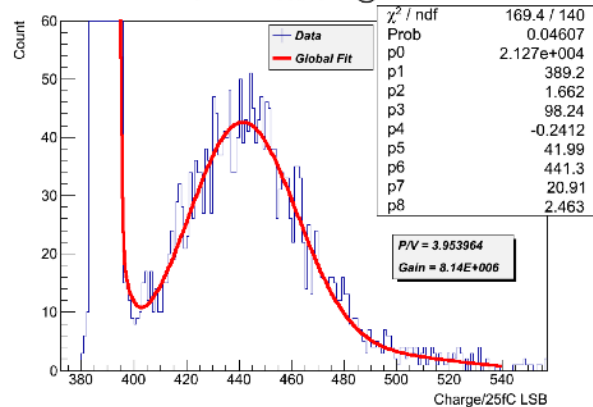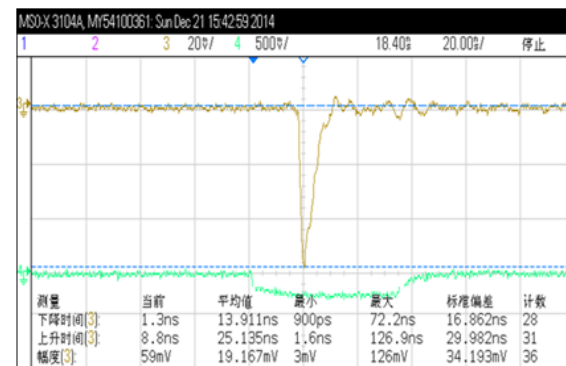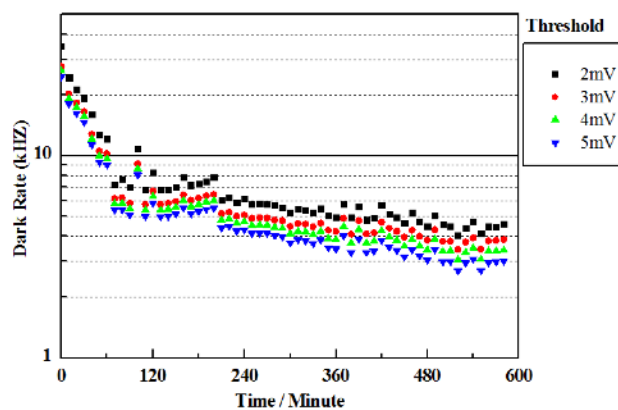
HV	Gain	P/V	Rise Time	Fall Time	Dark rate @1E7 Gain(0.25PE)
2100V	~1E7	~4	~1.3ns	~8.8ns	~3kHz

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

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

MCP-PMT-56# SPE@2000V

χ²/ndf	225.7/170
Prob	0.002745
p0	1.57e+004
p1	289.3
p2	1.973
p3	27.2
p4	-0.07831
p5	180.1
p6	351.1
p7	24.62
p8	7.624

P/V = 3.100969
Gain = 9.66E+006

■ 2mV-threshold
● 3mV-threshold
▲ 4mV-threshold

Time After Closing the Dark Box (Hour)

下降时间(1): 1.2ns
上升时间(1): 13.4ns
幅度(1): 10.9mV
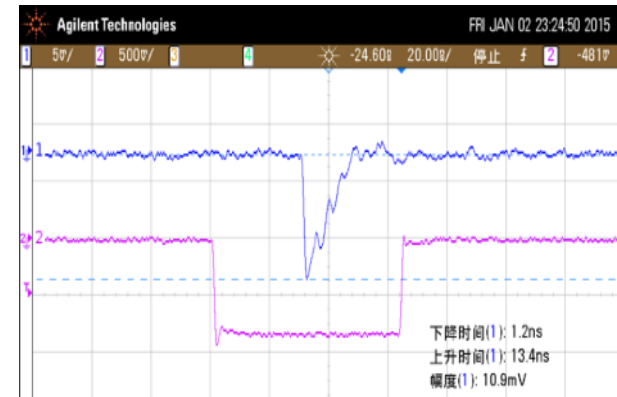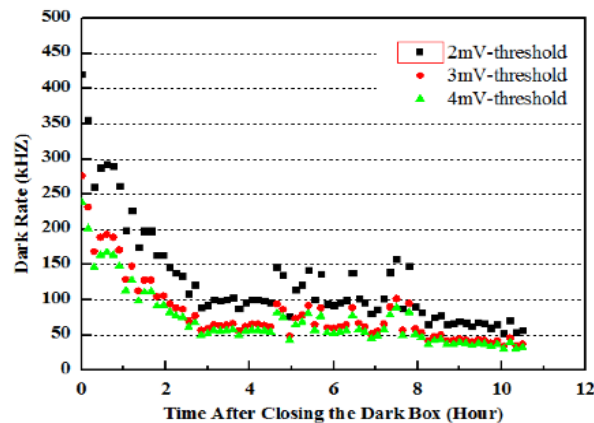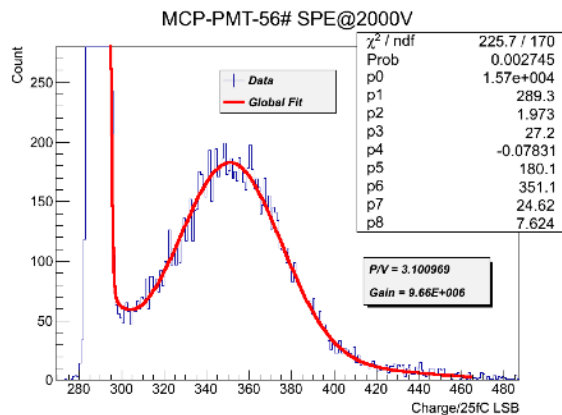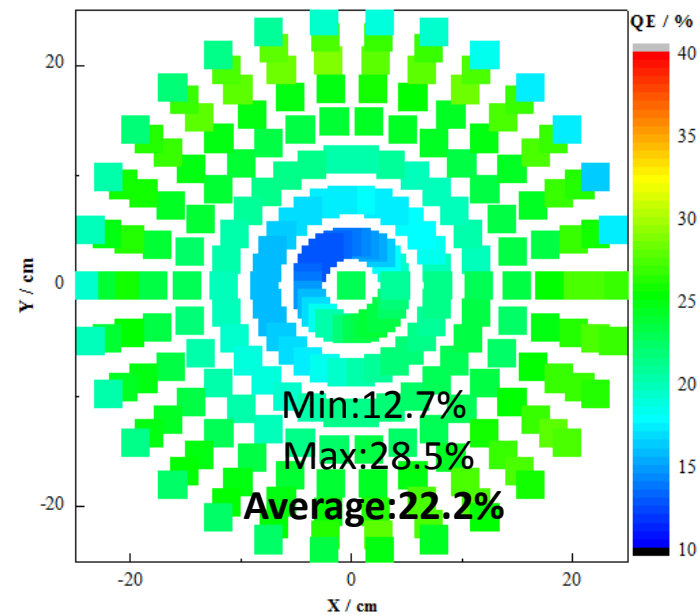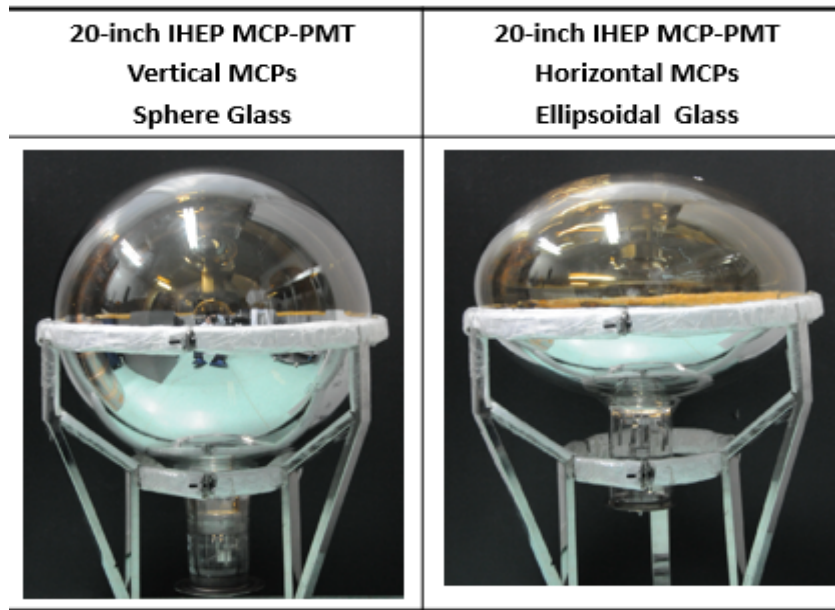
HV	Gain	P/V	Rise Time	Fall Time	Dark rate @1E7 Gain(0.25PE)
2000V	~1E7	~3	~1.2ns	~15ns	~50kHz

Waveform of the Prototype

SPE of the Prototype

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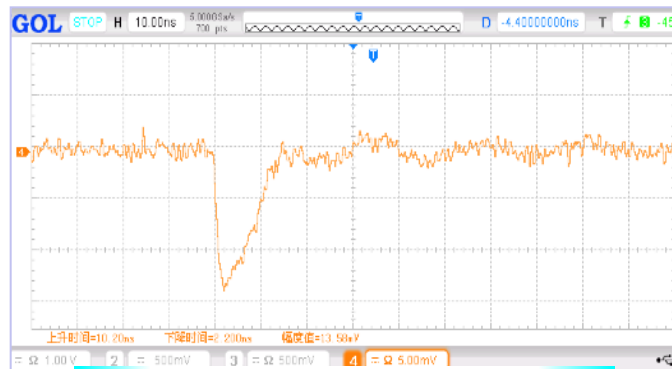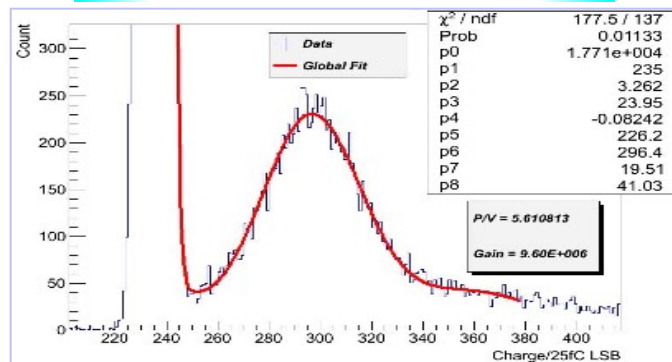
TTS of the Prototype
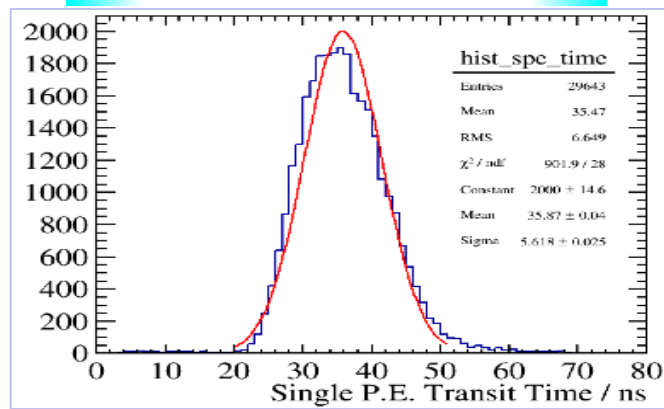
DR of the Prototype

QE Uniformity

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

5K   15K

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

Specification in the Contracts

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

15000 MCP-PMT (75%)

Contract for JUNO

Signed with NNVT

on Dec.16, 2015

Outline

- **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   （1PMT need 2 days）;**

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

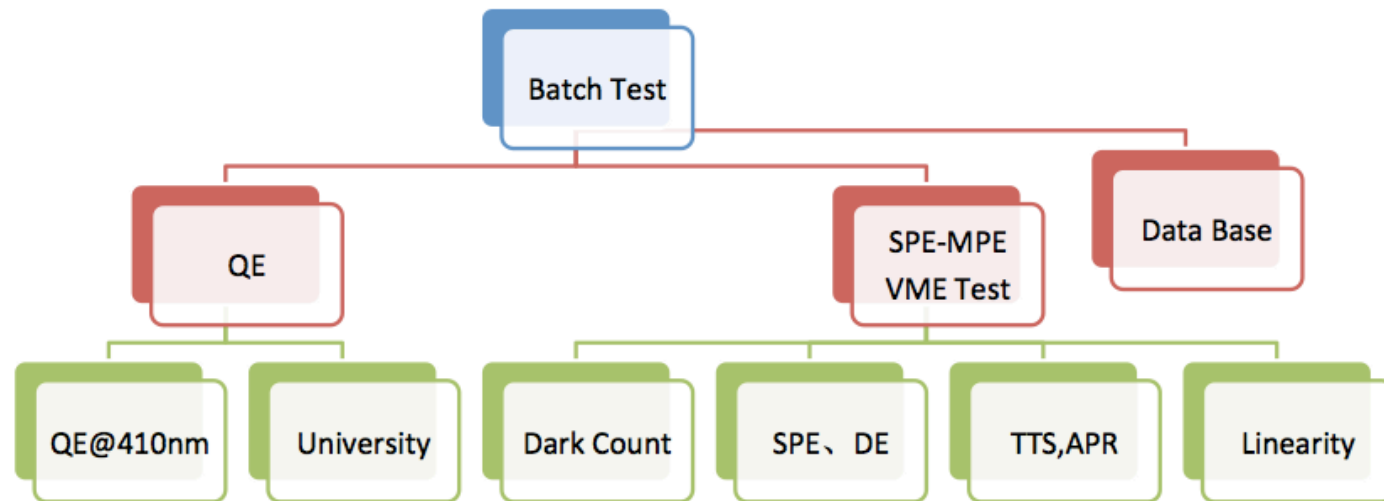**Aim:**

1PMT need 2 days

total 33 pic/ day;

30 pic PMTs (OK!) /day

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

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

➢ **QE sub-system**

➢**Equipment: 2 pic;**
➢**Time: 0.5h / PMT;**

➢**One Day: 30 PMTs;**
➢**Test Ratio: 100%;**

➢ **SPE Batch Test sub-system**

➢**with soft iron to shielding EM**

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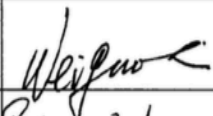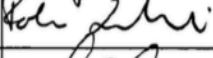—> 1 dark room = 32 PMTs
➢**One Day: 30 PMTs;**
➢**Test Ratio: 100%;**

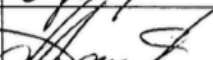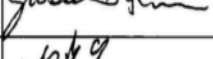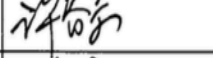**20 inch Micro-channel Plate Photomultiplier Tube International Evaluation on 28th.May 2017**

—> **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	
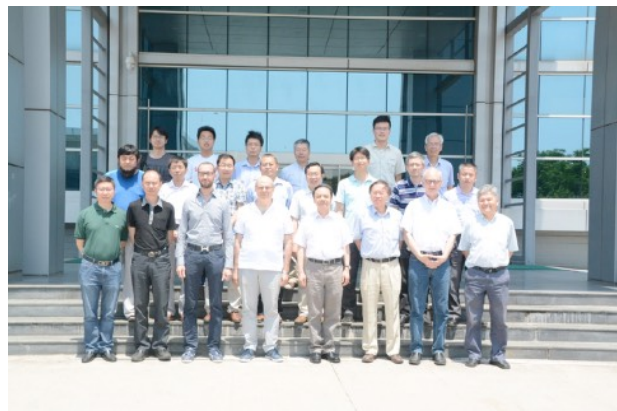
Status	Times	Date	AVDE（%）	Pics
finish-336	1	2017.5.15	28.95%	336
finish-648	2	2017.6.14	29.36%	312
finish-1008	**3**	**2017.7.4**	**29.47%**	**360**
finish-1344	4	2017.7.26	28.83%	336
finish-1680	5	2017.8.24	29.01%	336
finish-2016	**6**	**2017.9.12**	**29.09%**	**336**
finish-2351	7	2017.9.25	29.62%	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

➢ 3.5 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	~ 1780V	?
探测效率（DE）@405nm	B	?	A	~ 26%@405nm	?
探测效率（DE）@420nm		≥ 24%@420nm		?	?
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.

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

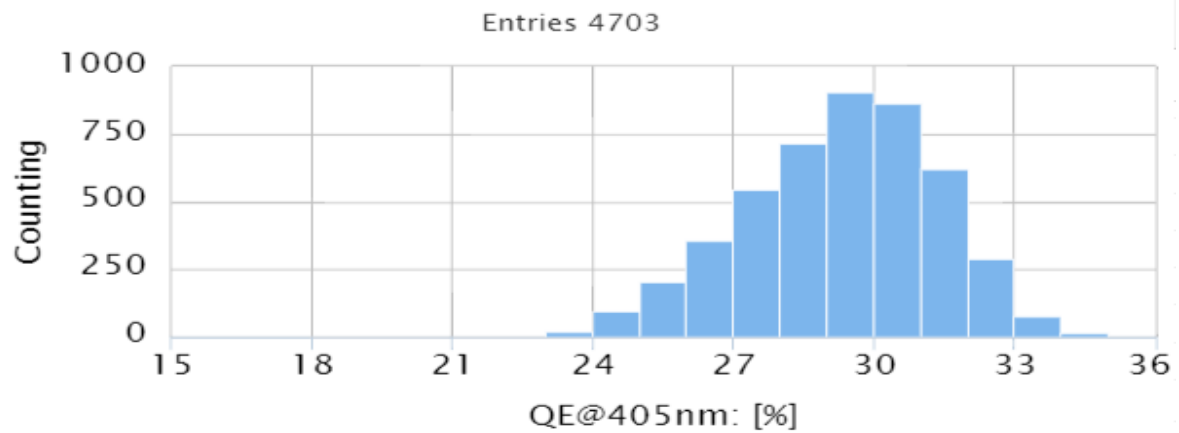**MCP-PMT-prototype**
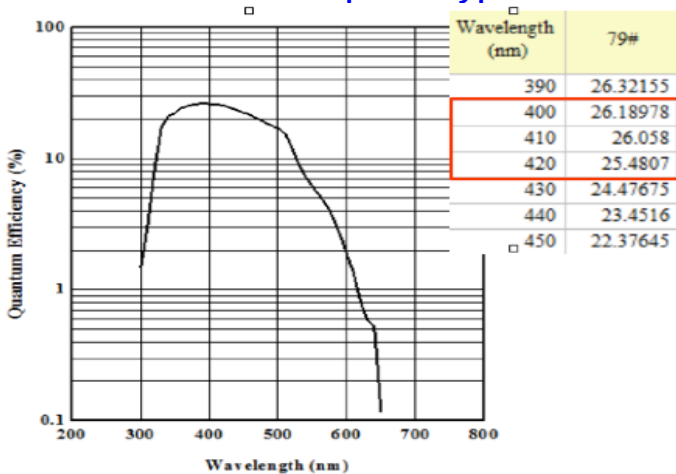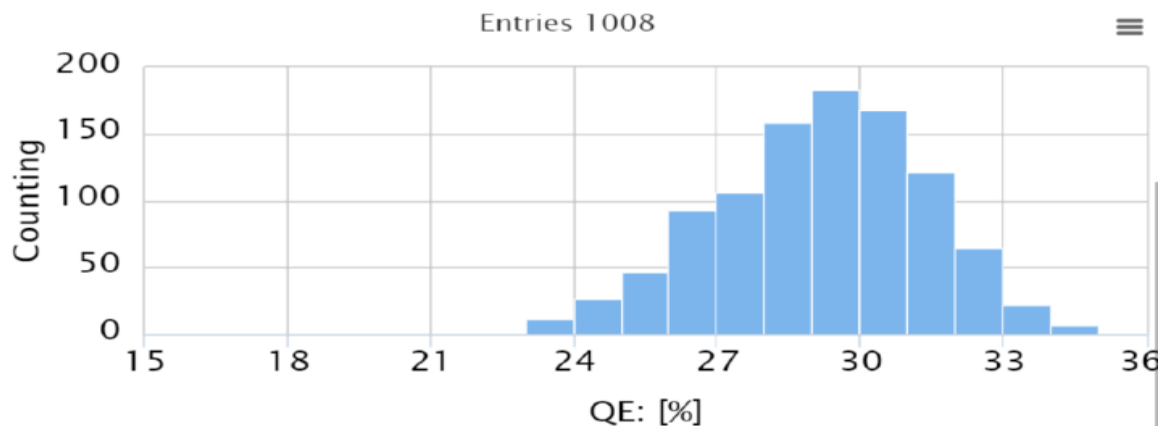
1000 shipped MCP-PMTs：
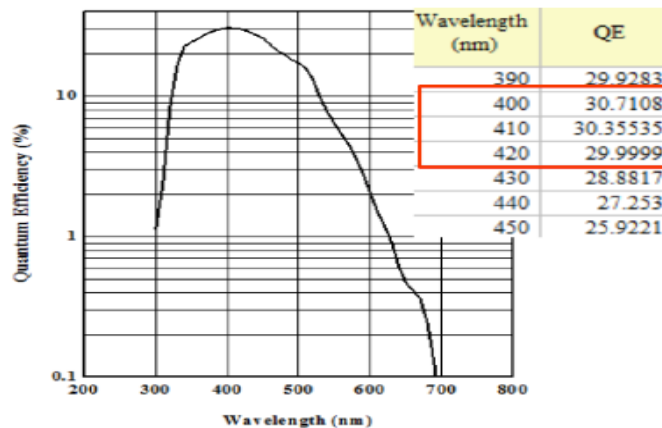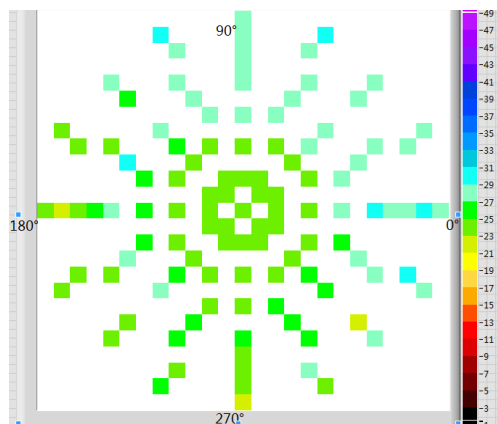

Hamamatsu Prototype

total shipped MCP-PMTs：~4703

3.5.2 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：
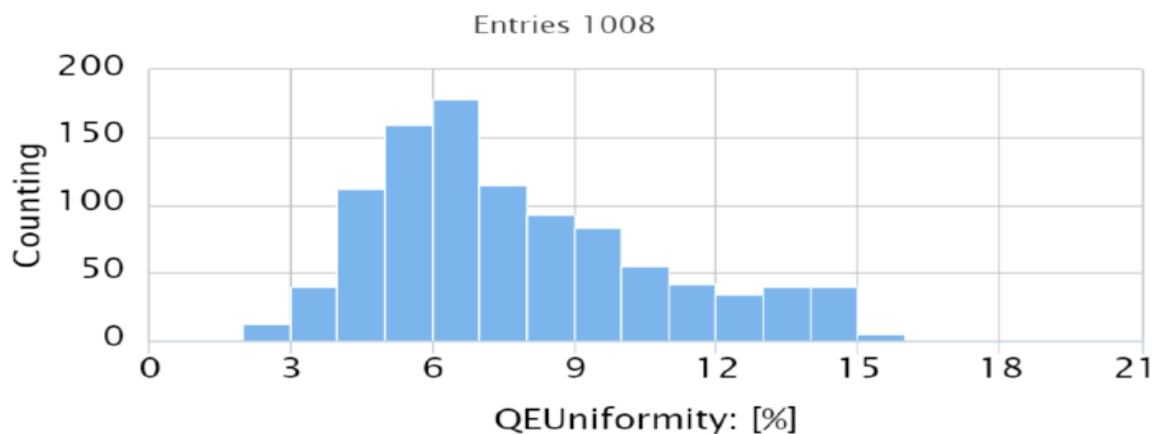
Average : 7.77

Hamamatsu Prototype
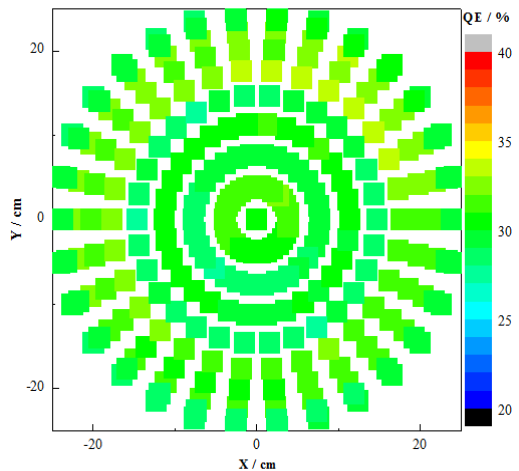
total shipped MCP-PMTs： ~4703

Average: 7.43
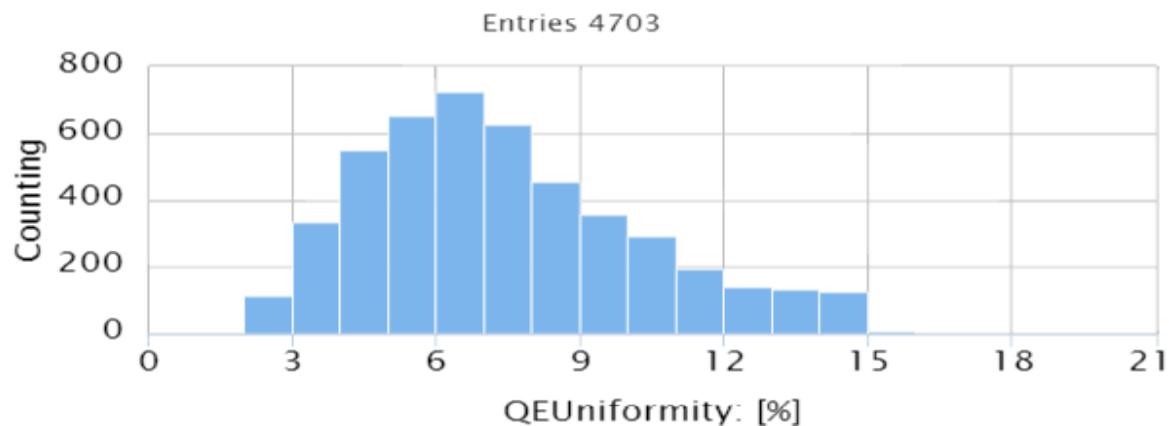
the Uniformity of the DE is mainly affected by the uniformity of QE

the Uniformity of the Quantum Efficiency in NNVT

the Uniformity of the Detection Efficiency in FanYa
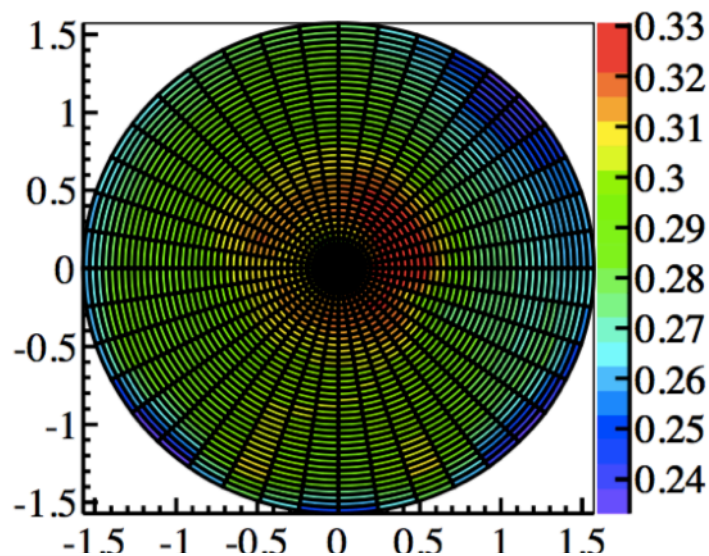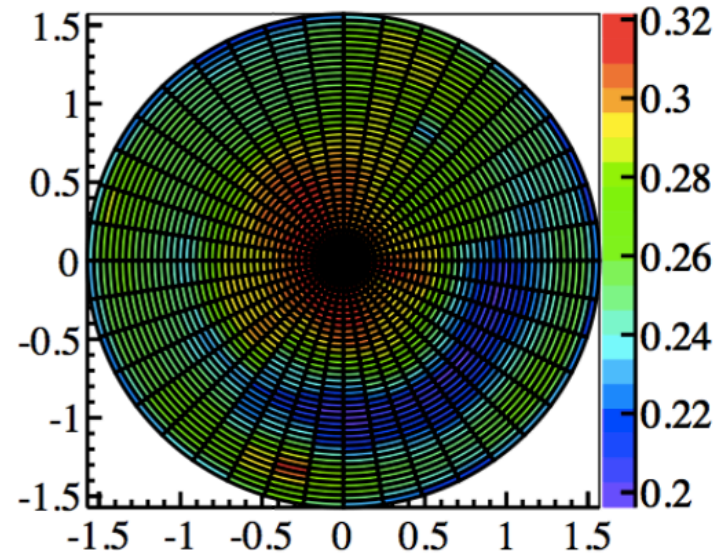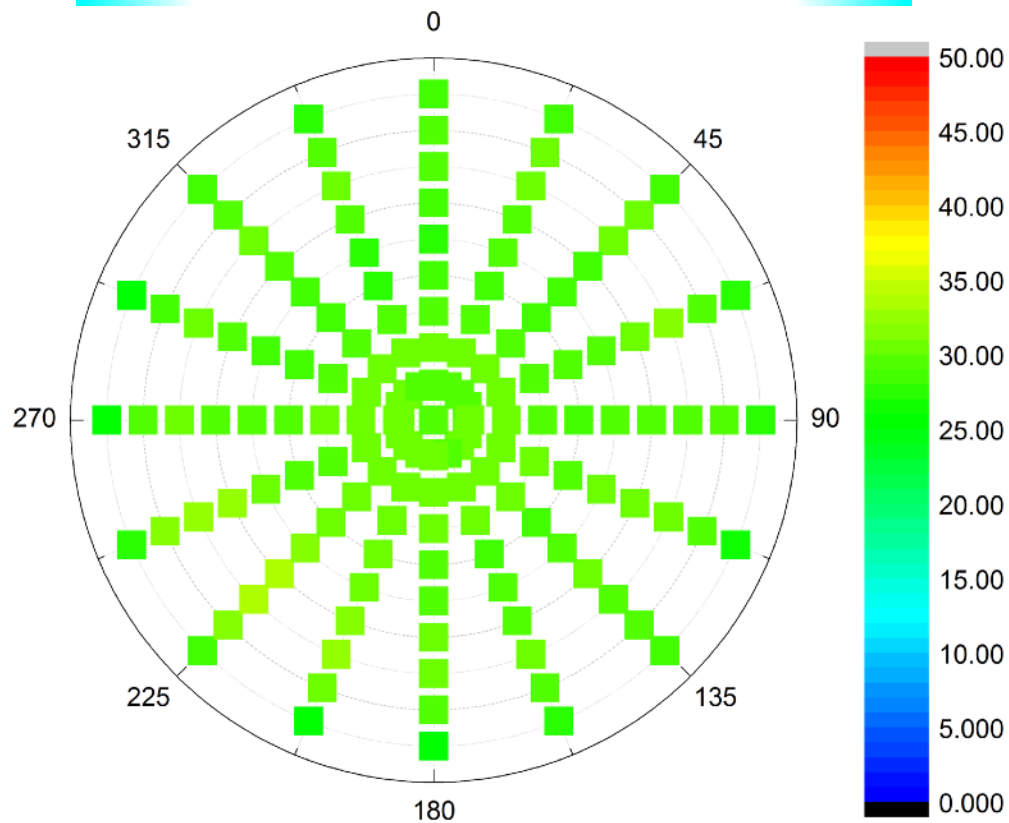
QE: PA1612-143

DE: PA1612-143
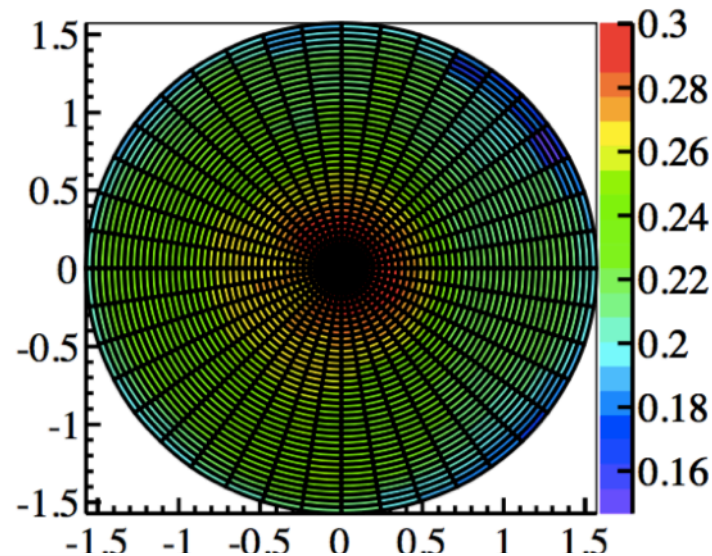
QE: PA1703-1987
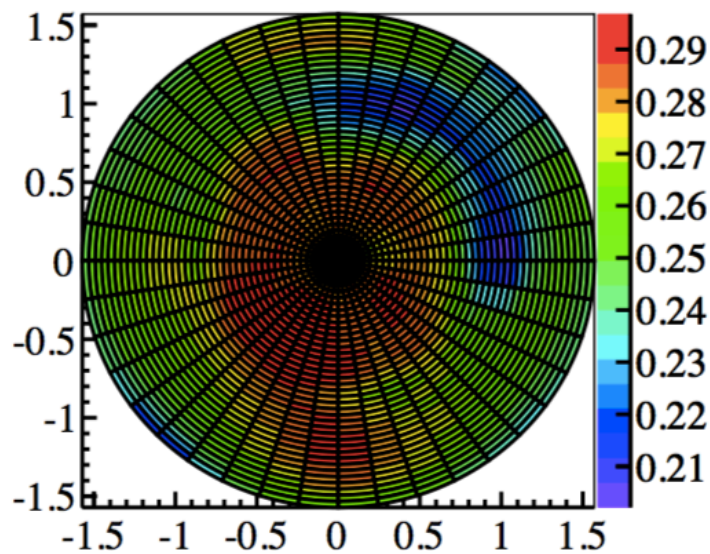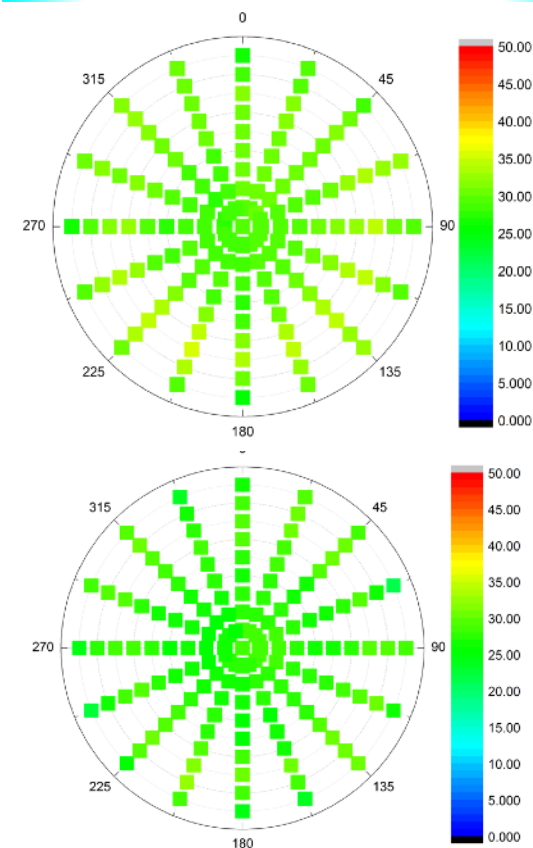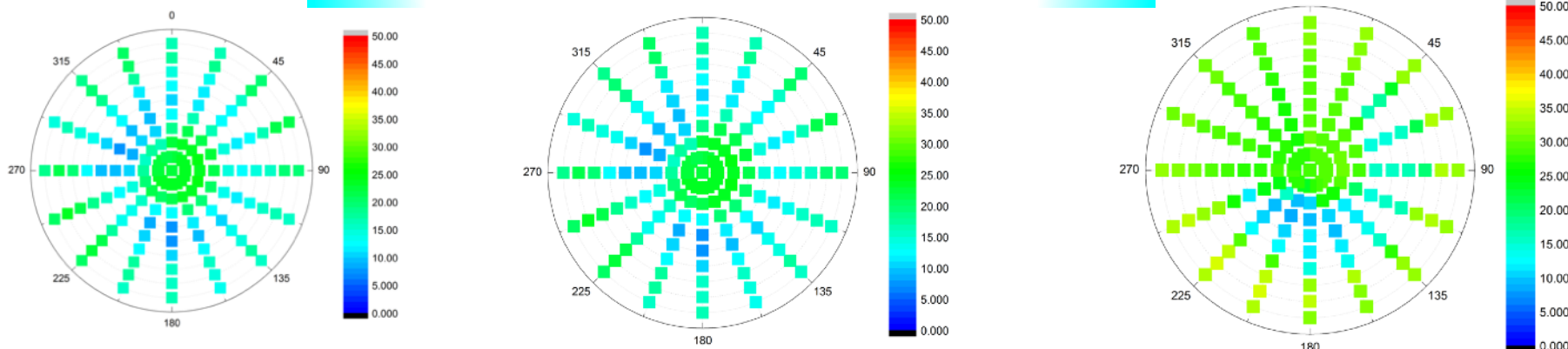
DE: PA1703-1987

The average data of 2688 piece PMTs
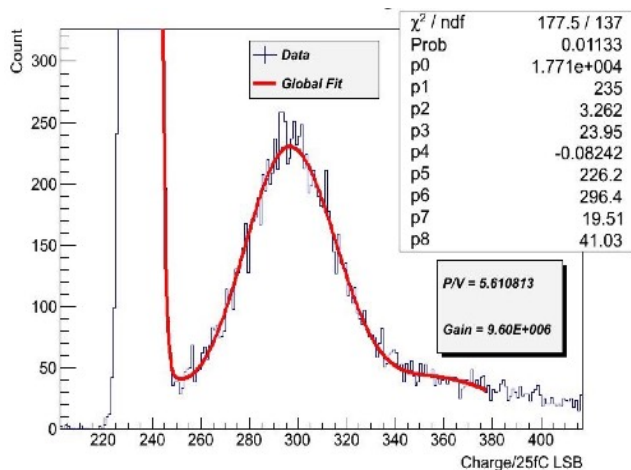
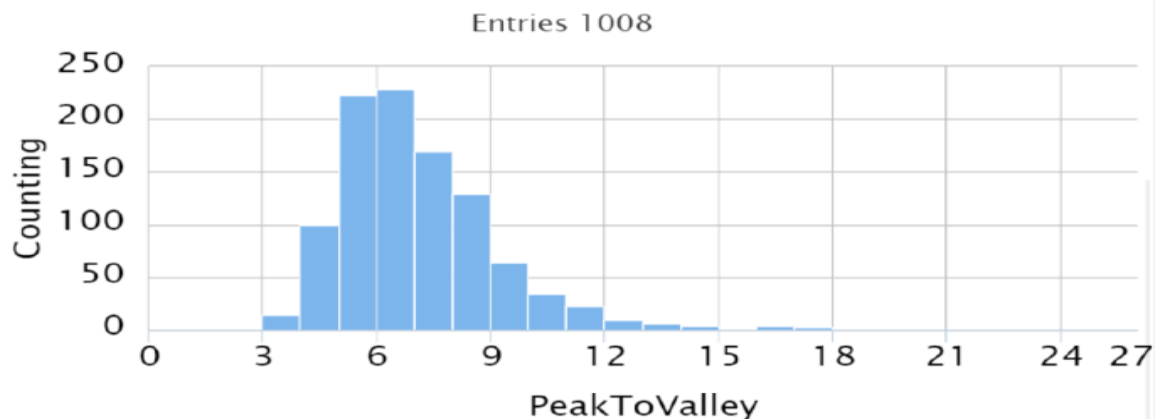The good situation

The bad situation of the QE uniformity

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
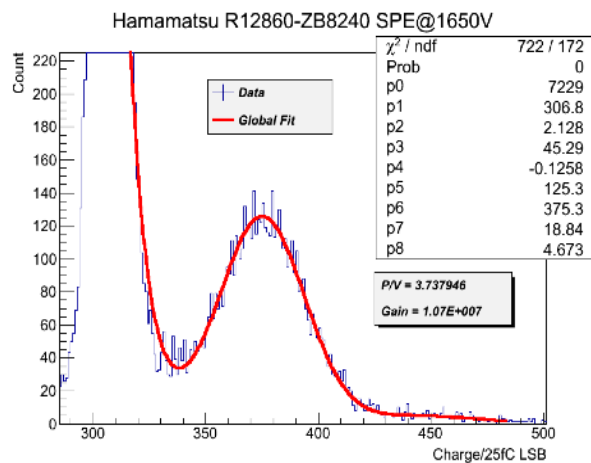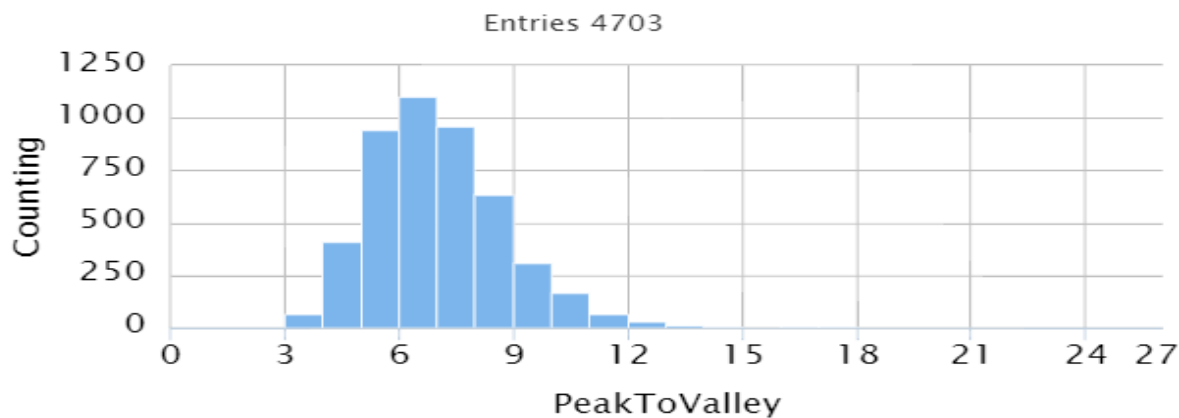
1000 shipped MCP-PMTs：

Hamamatsu Prototype

total shipped MCP-PMTs：~4703

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
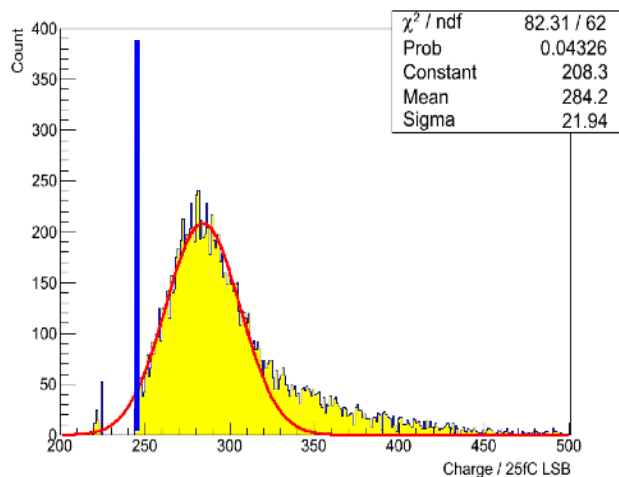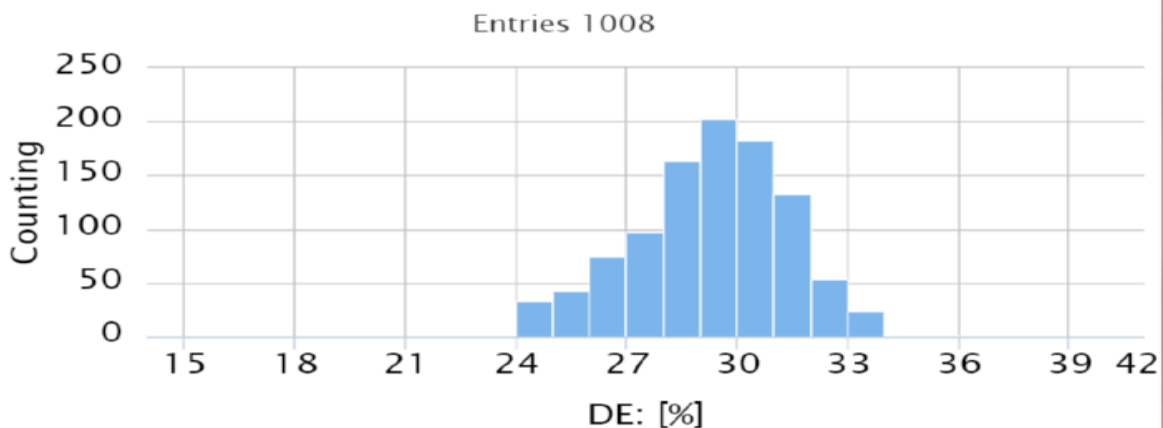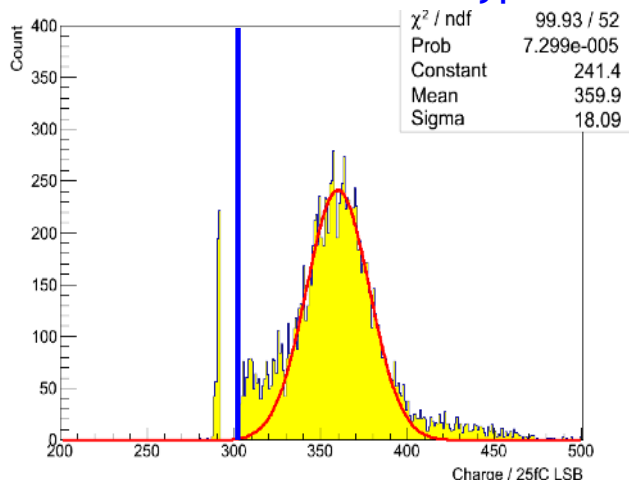
1000 shipped MCP-PMTs：

Average : 29.27

Hamamatsu Prototype

total shipped MCP-PMTs：~4703

Average: 29.32
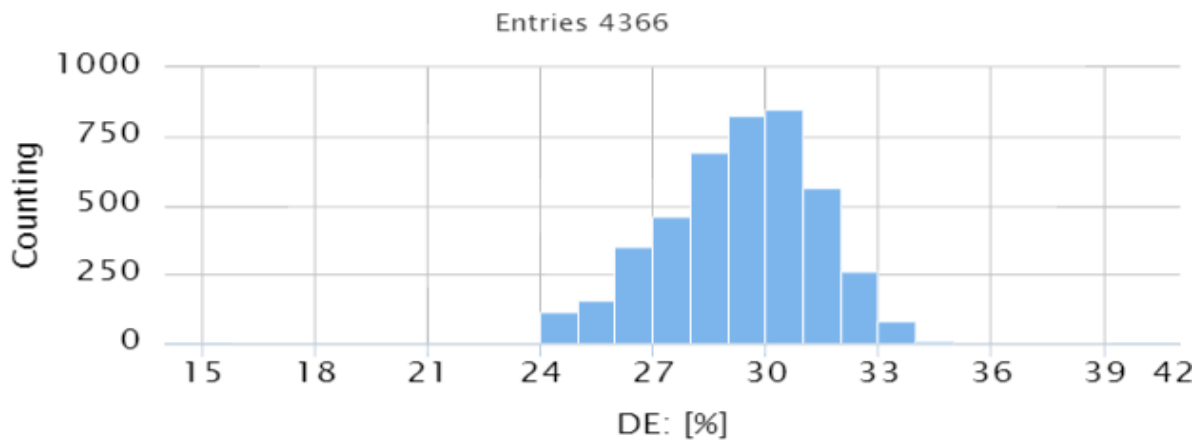
PMTs	Hamamatsu	MCP-PMTprototype	~300 MCP-PMTs	~1000 MCP-PMTs	~4703 MCP-PMTs
TTS @ FWHM	2.8 ns	13.2 ns	19.2 ns	19.5ns	20.4ns
TTS @sigma	1.19 ns	5.62ns	8.17ns	8.30ns	8.64ns

MCP-PMT-prototype
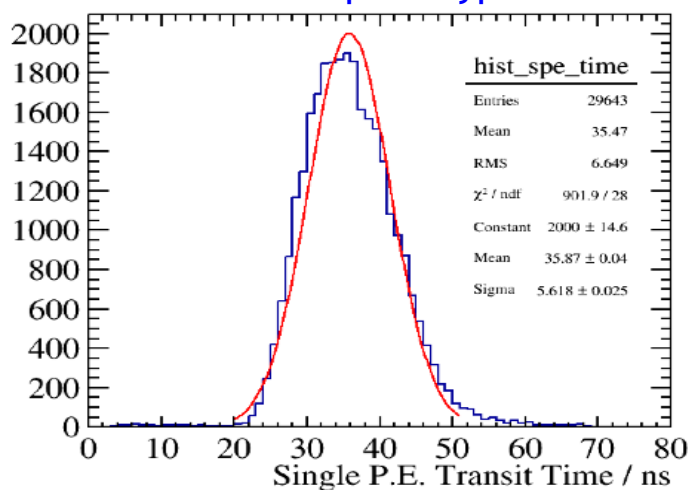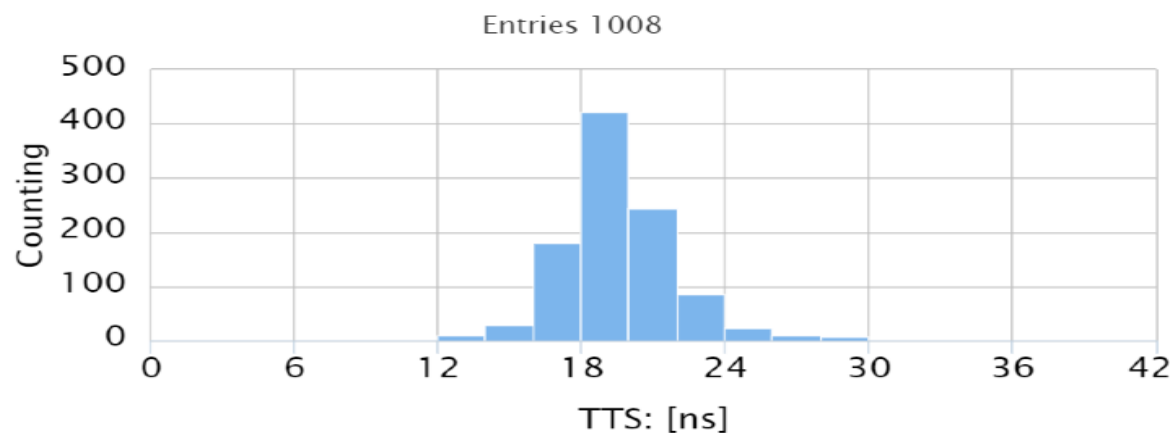
1000 shipped MCP-PMTs：

Hamamatsu Prototype
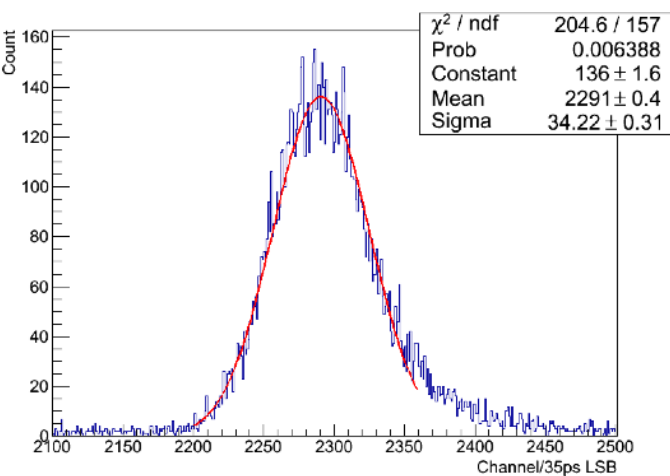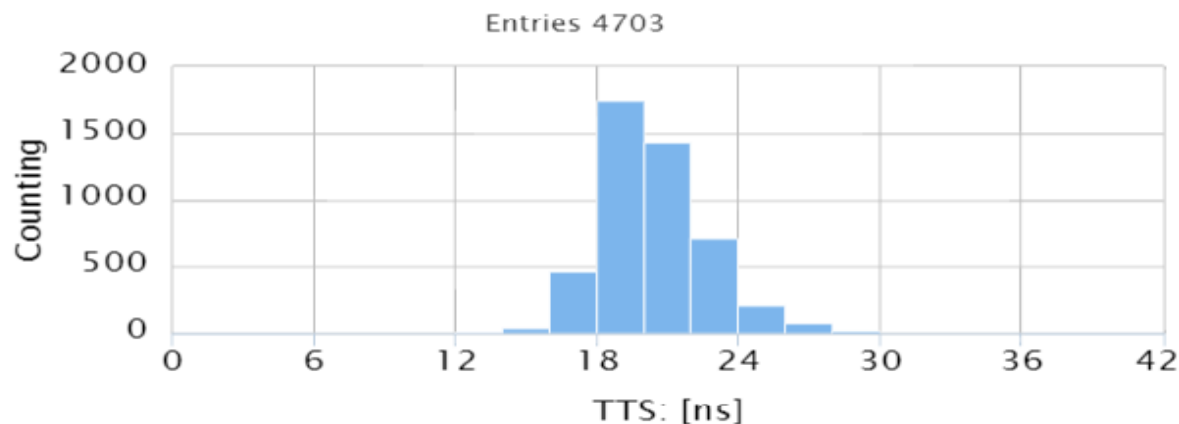
total shipped MCP-PMTs： ~4703

➤ Summary of the MCP-PMT R&D process

➤2009: the design of the MCP-PMT;

➤2010~2011: 5"MCP-PMT prototype without SPE;

➤2012: 8"MCP-PMT prototype without SPE;

➤**2013: 8"prototypes with normal performance;**

QE ~ 25%@410nm; CE ~ 60%; P/V of SPE> 2.0;

➤**2014: 20" prototypes with normal performance;**

QE ~ 25%@410nm; CE ~ 60%; P/V of SPE> 2.0;

➤**2015: 20" prototypes with HDE performance;**

QE ~ 26%@410nm; CE ~100%; P/V of SPE> 3.0;

➤2016: for the high QE、DE improvement；

  The mass production line preparation;

➤**2017: Mass production; Bunch Test;**

➤**2018-19: Mass production; Bunch Test;**

➤**AFAD 2013, Russia,**

➤**AFAD 2014, Australia,**

➤**AFAD 2015, Taiwan,China.**

➤**AFAD 2016, Japan.**

➤**AFAD 2017, China.**

➤**AFAD 2018, South Korea.**

Thanks!

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