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 Mass Production and Batch test of the 20 inch MCP-PMT

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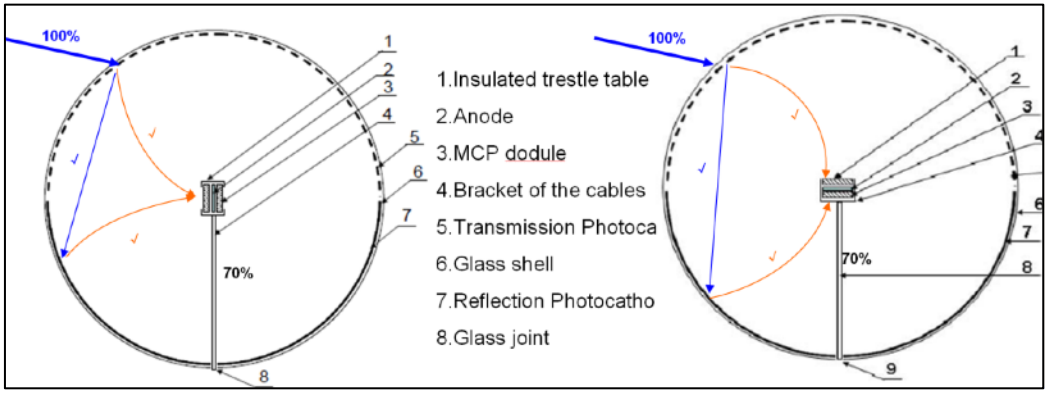
October 12-14 Albuquerque, New Mexico

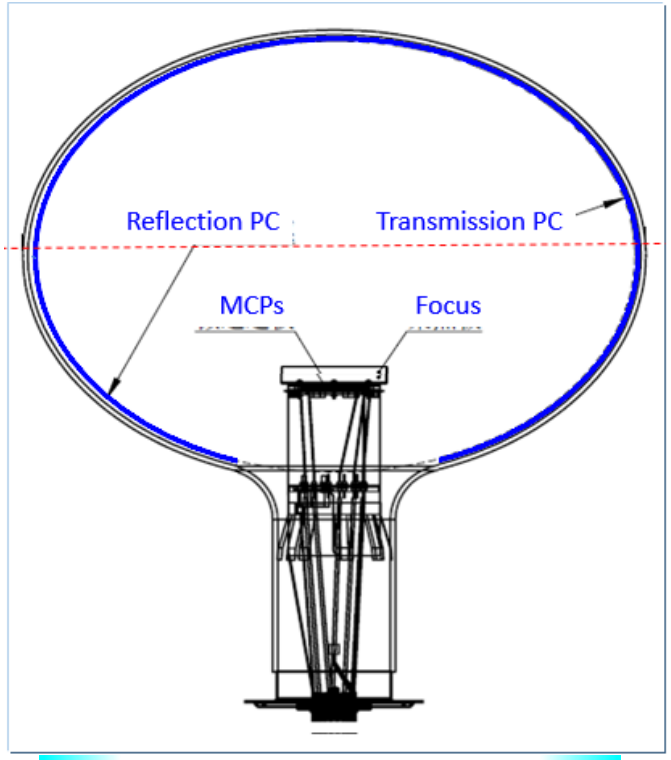
The 20 inch MCP-PMT R&D in China

The researchers of **MLAPC**（Microchannel-Plate-Based Large Area Photomultiplier Collaboration）in IHEP designed a new type of MCP-PMT for **JUNO** (Jiangmen Underground Neutrino Observatory）



The primary design in 2009

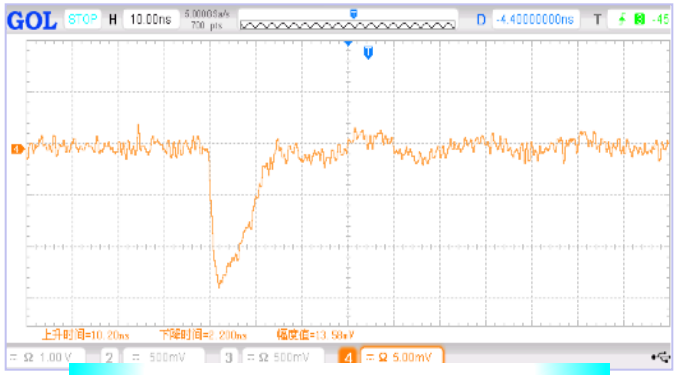
The small MCP unit instead of the large Dynode, the transmission and reflection photocathode were assembled in the same glass shell to form nearly 4π photocathode effective area to enhance the efficiency of the photoelectron detecting.



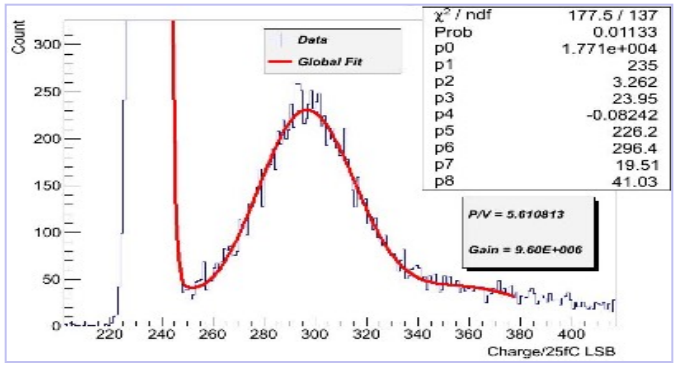
The final design in 2015

The typical performance of the 20 inch MCP-PMT

Waveform of the Prototype

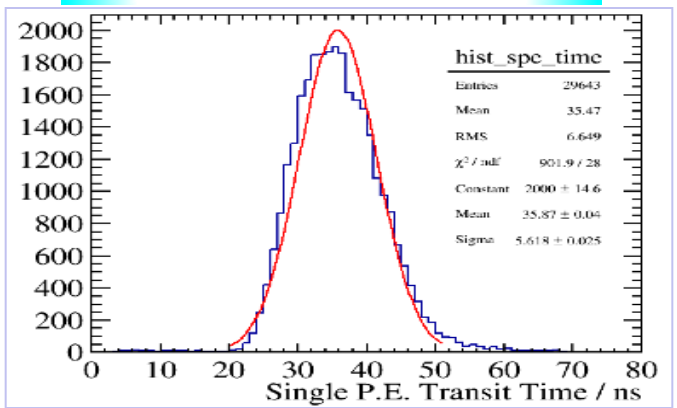


SPE of the Prototype

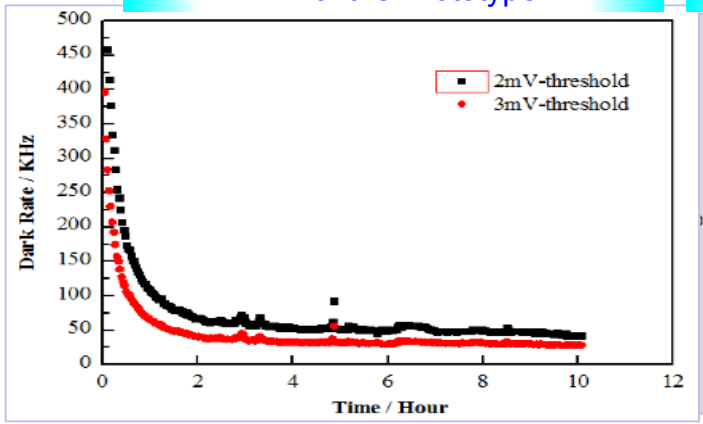


Characteristics	unit	MCP-PMT（IHEP）
Electron Multiplier	--	**MCP**
Photocathode mode	--	**reflection+ transmission**
QuantumEfficiency（400nm）	%	**26 (T), 30 (T+R)**
Relativity Detection Efficiency	%	**~ 100%**
P/V of SPE		**＞ 3**
TTS on the top point	ns	**~12**
Rise time/ Fall time	ns	**R~2 ， F~10**
Anode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

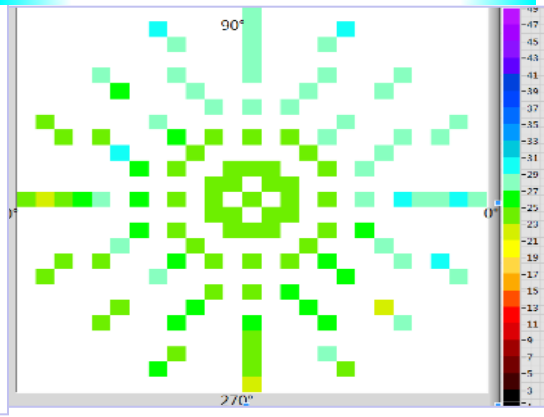
TTS of the Prototype



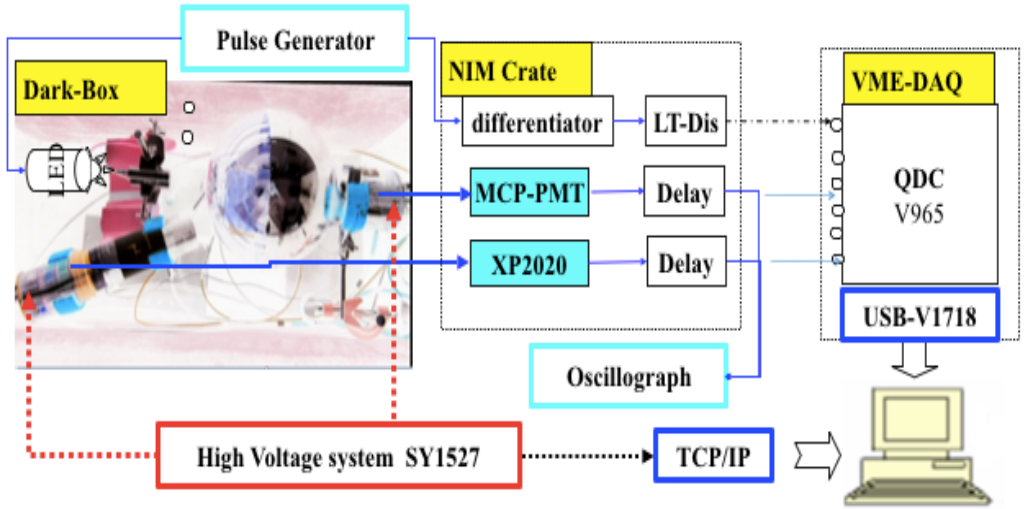
DR of the Prototype

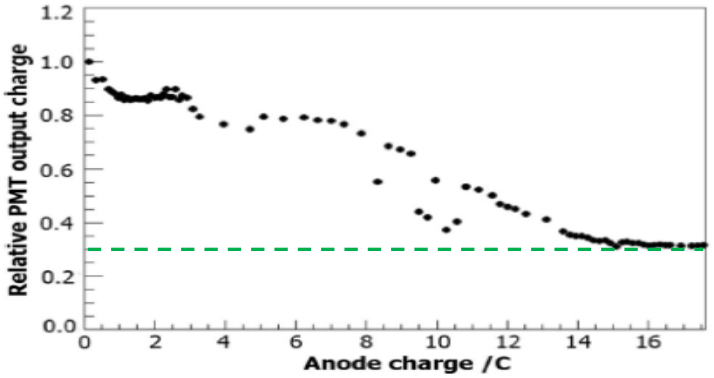


QE Uniformity



The Aging behaviors of the MCP-PMT



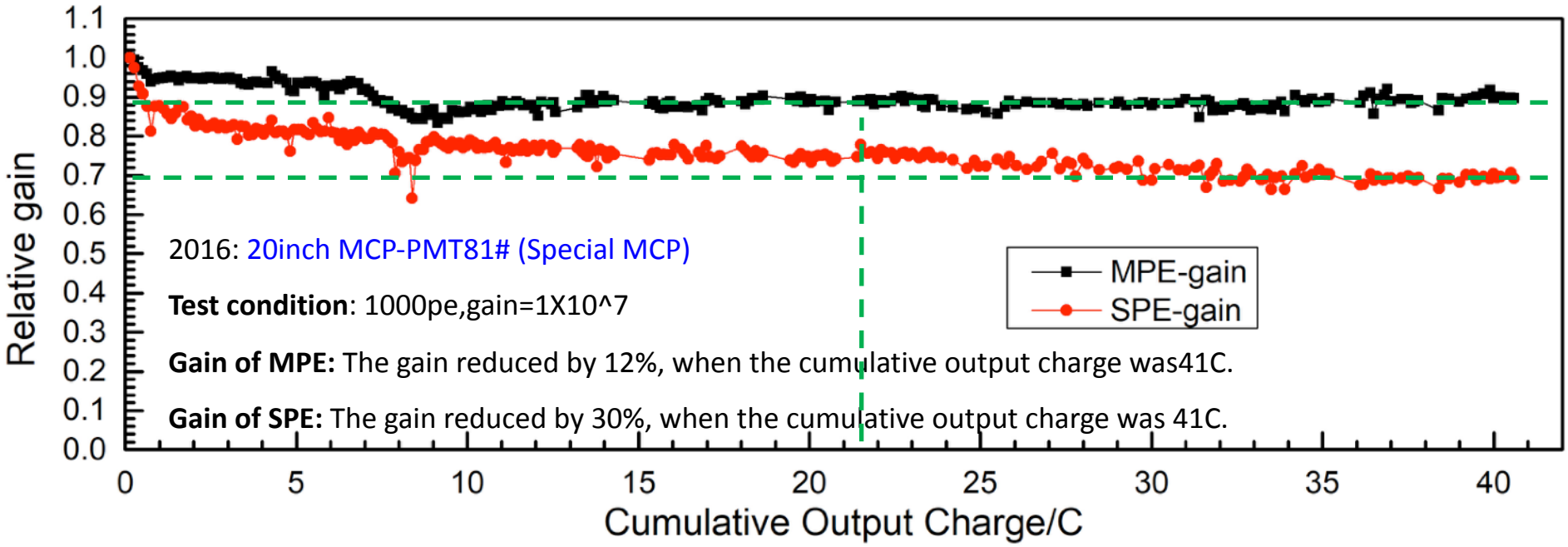


2014: 8inch MCP-PMT （normal MCP）

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.

➢ 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

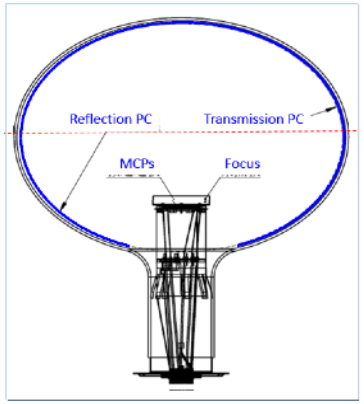
2016

HQE
Production line
batch test sys

2017-2018

Batch
test

Mass
production



Outline

- 1. The Mass Production of the 20 inch MCP-PMT;
  - - The production line;
  - - The batch test platform; the review； the transport；
- 2. The Batch Test of the 20 inch MCP-PMT ;
  - - The data base; The test result；

➢ 1.1 . 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 ;**

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

Aim:

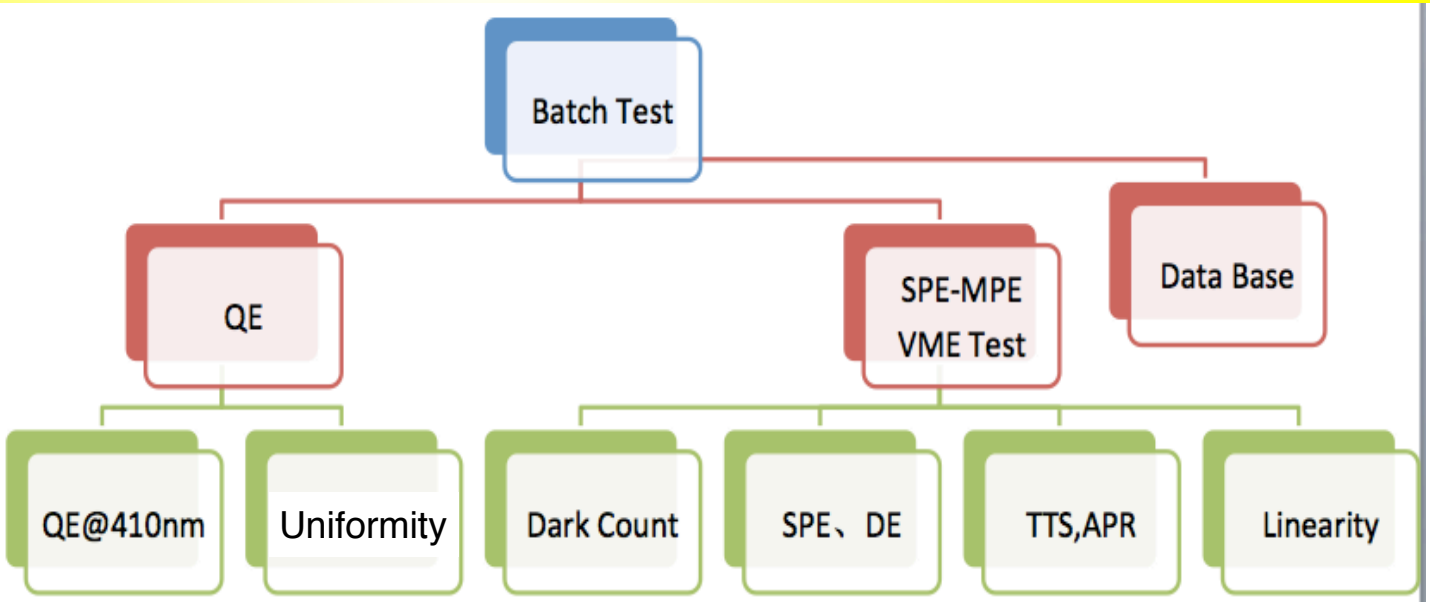
1PMT need 2 days

total 33 pic/ day;

30 pic PMTs (OK!) /day

➢ 1.2 The Batch test platform (2016. 10-2017. 02)

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;

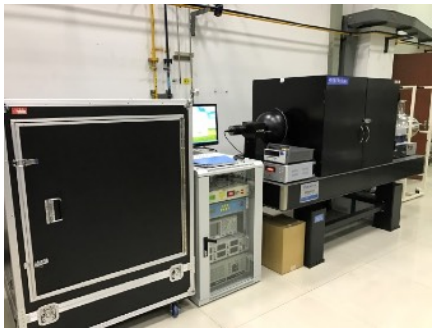
➢ One day: for testing PMTs;

➢One Day: 30 PMTs;

➢Test Ratio: 100%;

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

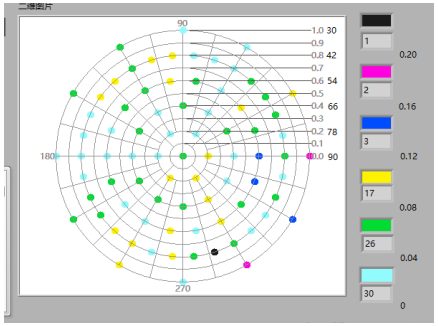
➢ QE sub-system



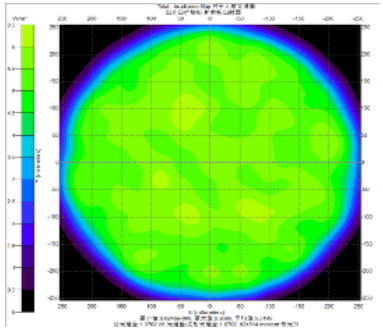
➢ SPE Batch Test sub-system

➢with soft iron to shielding EM

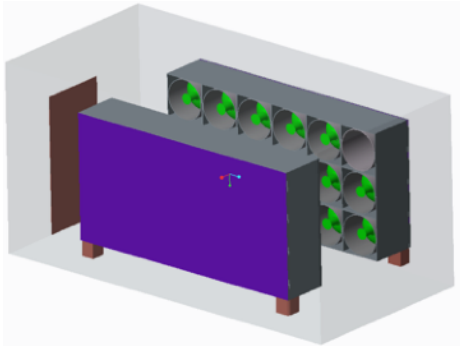
➢The QE Scanning sys.



➢The surface light

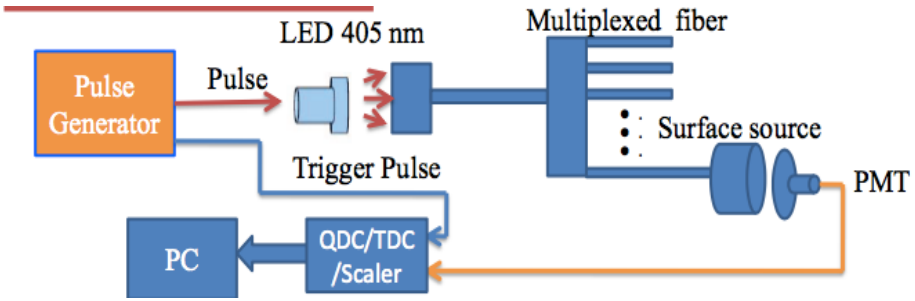


➢The container sys.



➢The DAQ sys.

➢The logic construction of the SPE test system



➢ 1.3 The MCP-PMT International Evaluation

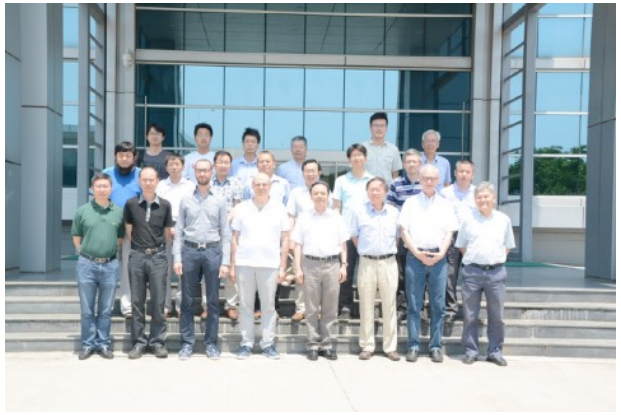
20 inch Micro-channel Plate Photomultiplier Tube International Evaluation on 28th.May 2017

—> **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.

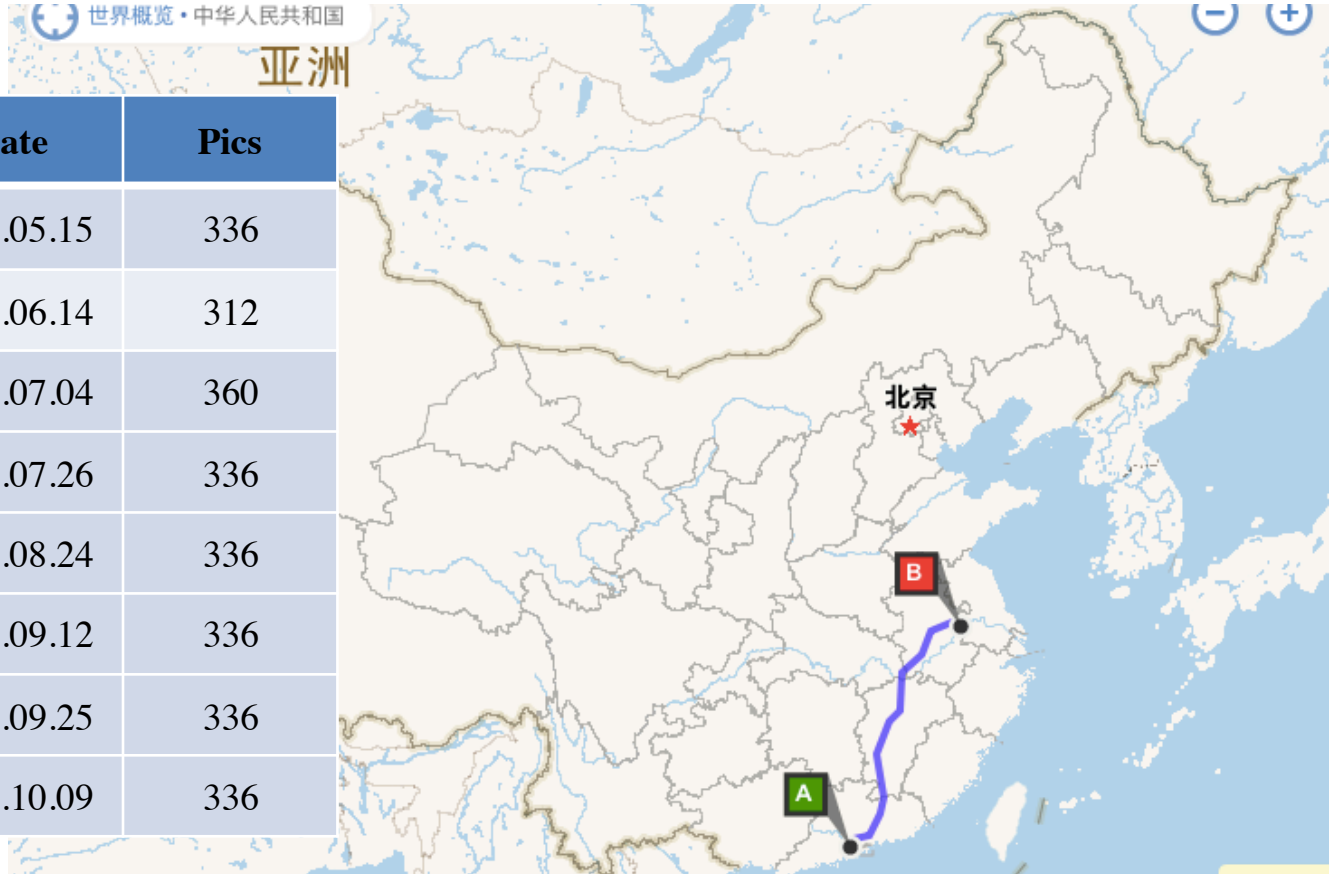
The MCP-PMT Review Committee

	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	

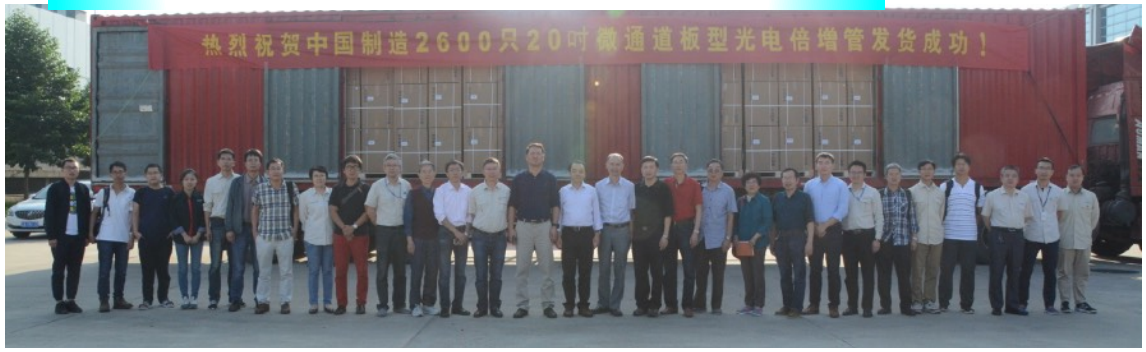


1.4 The transport by road for the MCP-PMT to JUNO

Status	Times	Date	Pics
finish-336	1	2017.05.15	336
finish-648	2	2017.06.14	312
finish-1008	3	2017.07.04	360
finish-1344	4	2017.07.26	336
finish-1680	5	2017.08.24	336
finish-2016	6	2017.09.12	336
finish-2351	7	2017.09.25	336
finish-2687	8	2017.10.09	336



The shipping by track from NNVT in Nanjing



The storage in JUNO in Guangzhou

Outline

- 1. The Mass Production of the 20 inch MCP-PMT;
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  - - The data base; The test result；

2.0 the MCP-PMT parameters Test in NNVT for JUNO

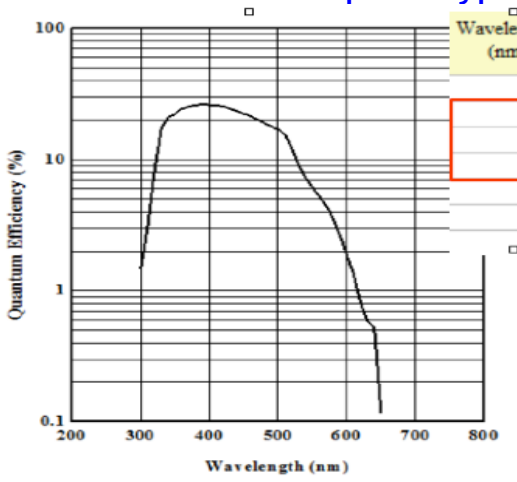
PMT Parmaeters	JUNO Contract	data in Contract	NNVT test	Prototype	mass production
单波长QE@410nm	A	≥ 26.5%	A	~ 26%	?
均匀性（QE Uniformity）	B	≤ 15%	A	≤ 10%	?
频谱响应曲线（QE-λ）	B	300nm ~ 650 nm	B(50%)	300nm ~ 650 nm	?
单光子探测（SPE-P/V）	A	≥ 2.8	A	~ 5.6	?
能量分辨率（SPE-ER）	A	≤ 40%	A	~ 41%	?
增益（Gain）	A	1E+07	A	1E+07	?
高压（HV）	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.

2.1 The Quantum Efficiency (1)

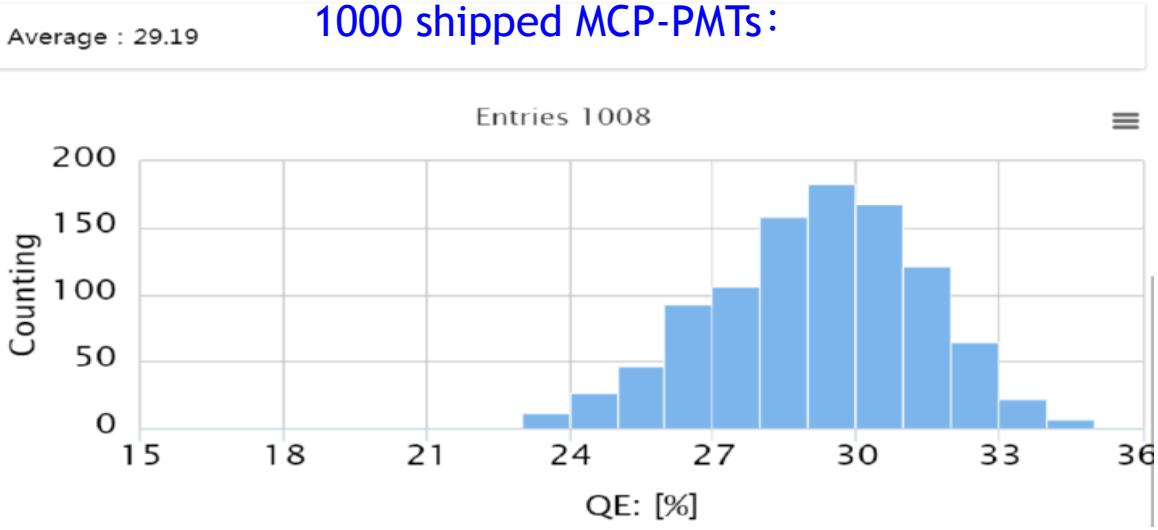
PMTs	Hamamatsu	MCP-PMT prototype	~300 MCP-PMTs	~1000 MCP-PMTs	~2687 MCP-PMTs
QE @ 410nm	30%	26%	29.5%	29.2%	29.2%

MCP-PMT-prototype

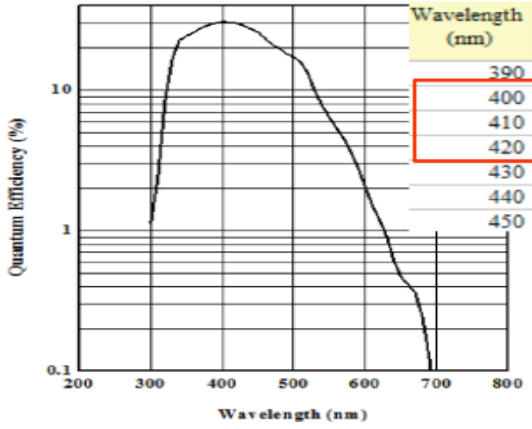


Wavelength (nm)	79#
390	26.32155
400	26.18978
410	26.058
420	25.4807
430	24.47675
440	23.4516
450	22.37645

1000 shipped MCP-PMTs:

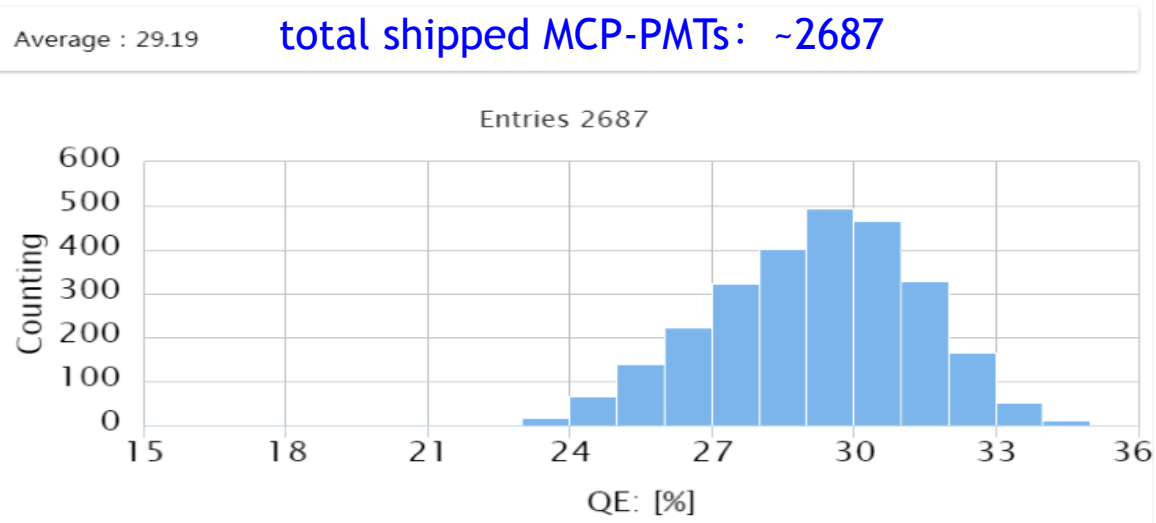


Hamamatsu Prototype

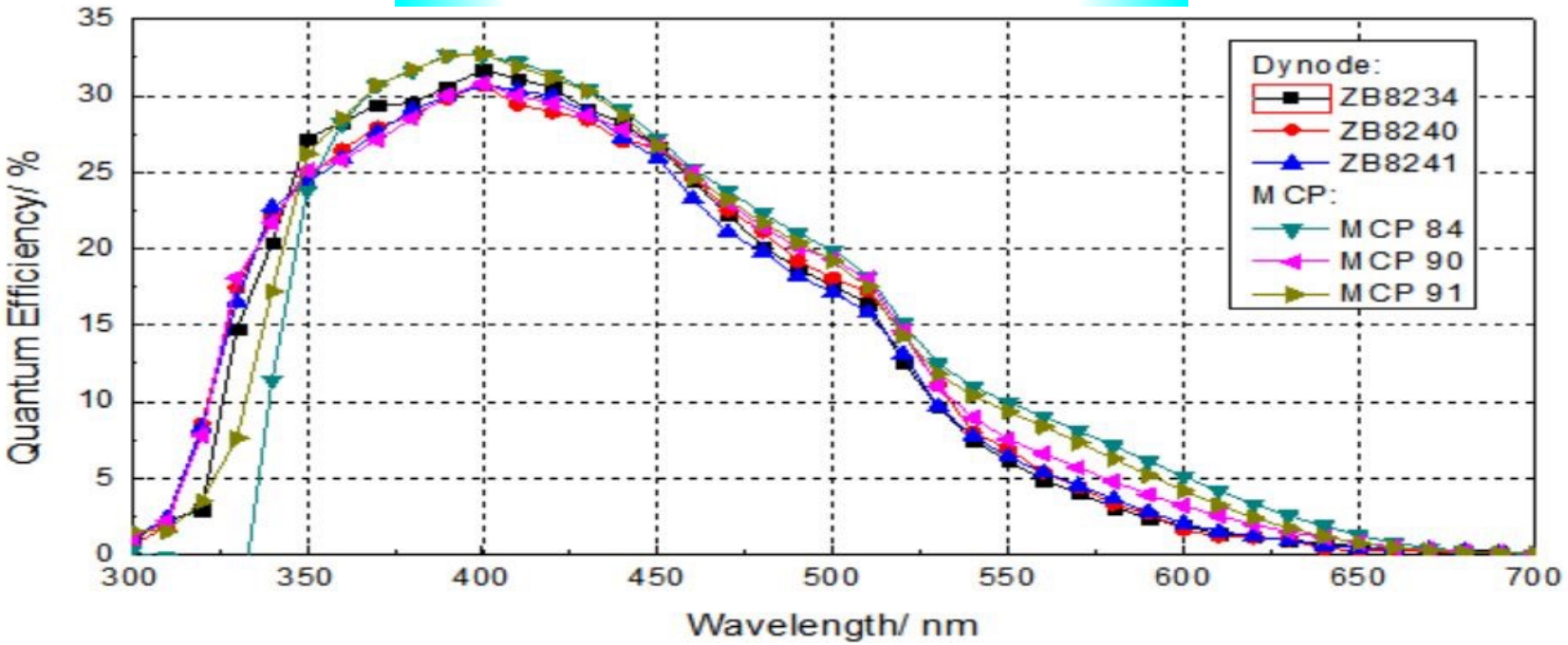


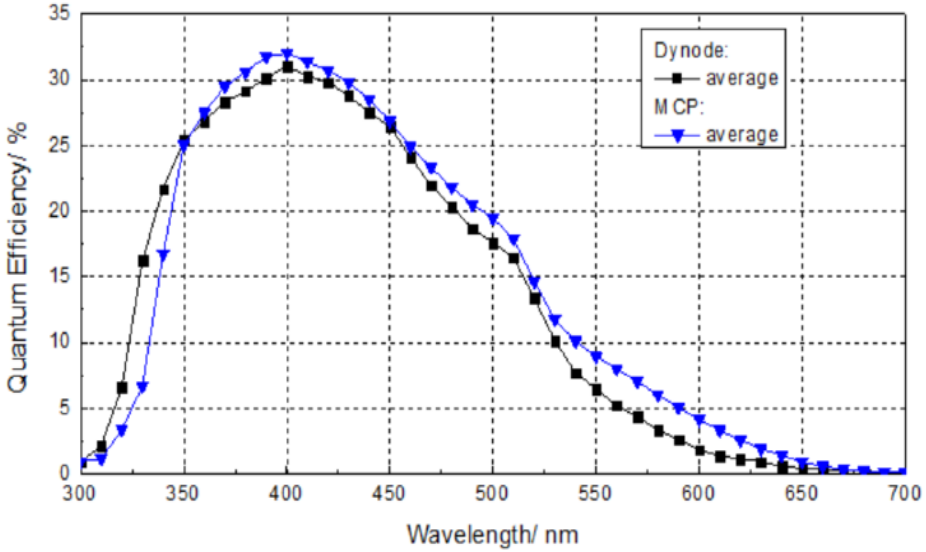
Wavelength (nm)	QE
390	29.9283
400	30.7108
410	30.35535
420	29.9999
430	28.8817
440	27.253
450	25.9221

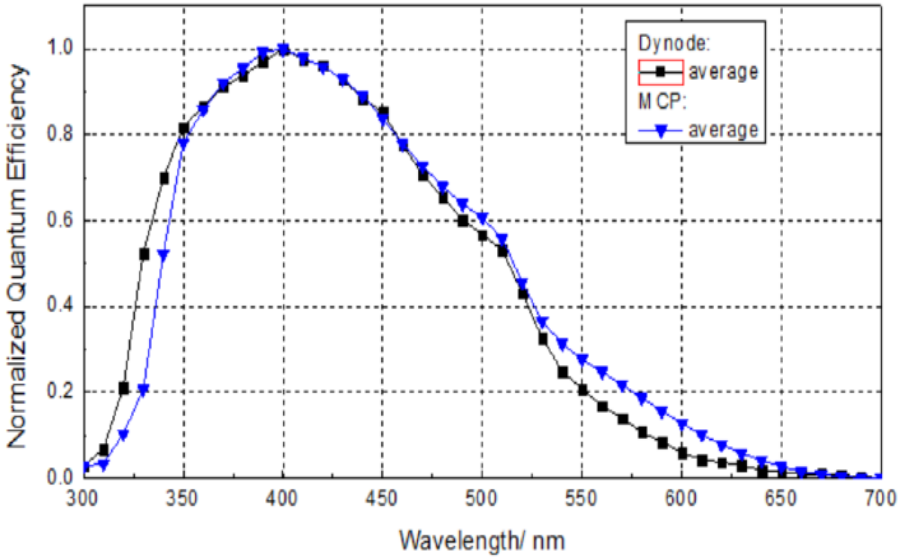
total shipped MCP-PMTs: ~2687



The QE graph with NNVT and Hamamatsu



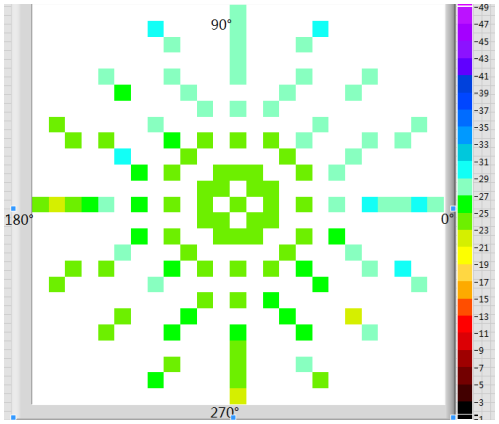




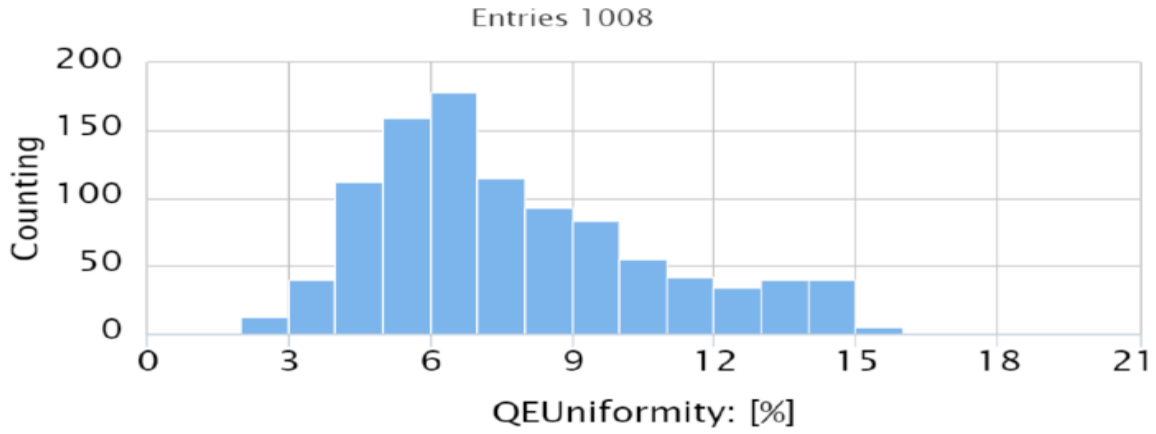
2.2 The Uniformity of the Photocathode

PMTs	Hamamatsu	MCP-PMT prototype	~300 MCP-PMTs	~1000 MCP-PMTs	~2687 MCP-PMTs
Uni-QE @ 410nm	< 10%	< 10%	8.1%	7.8%	7.7%

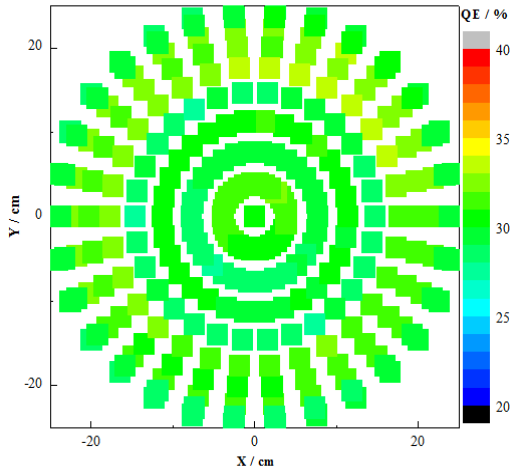
MCP-PMT-prototype



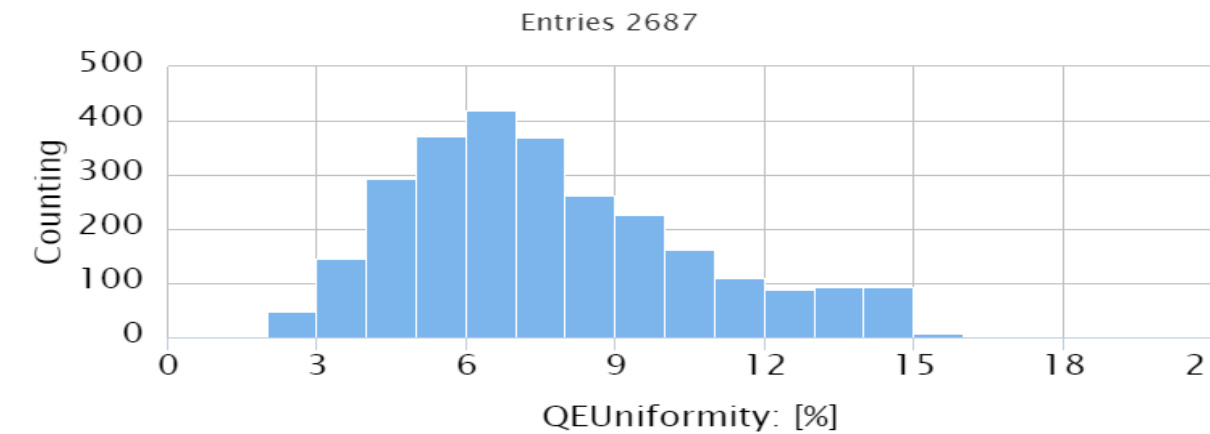
1000 shipped MCP-PMTs:



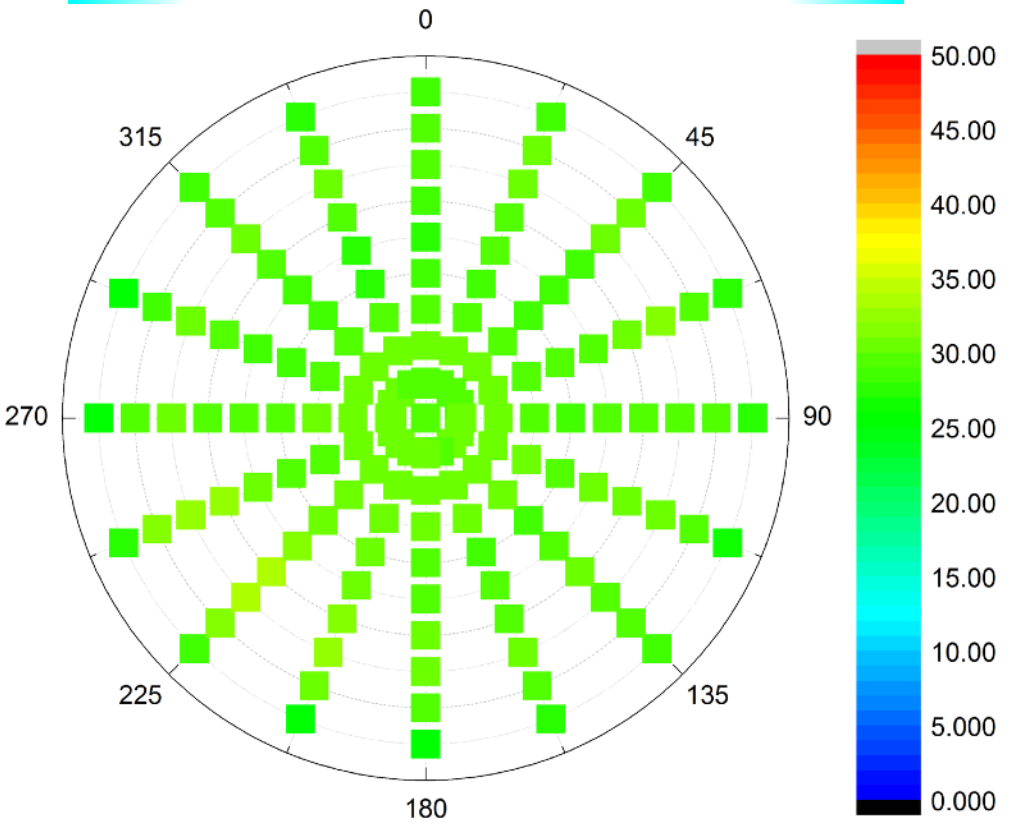
Hamamatsu Prototype



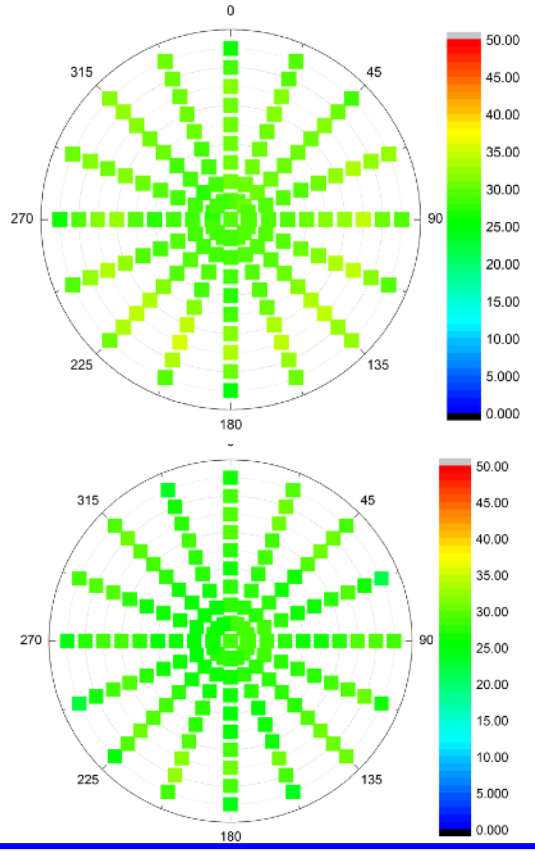
total shipped MCP-PMTs: ~2687



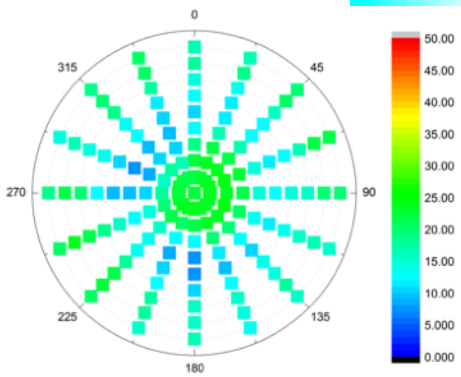
The average data of 2688 piece PMTs

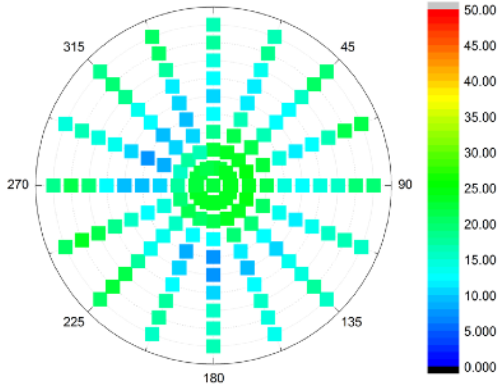


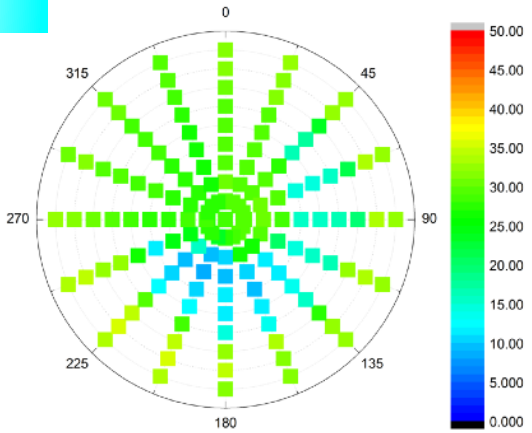
The good situation



The bad situation of the QE uniformity



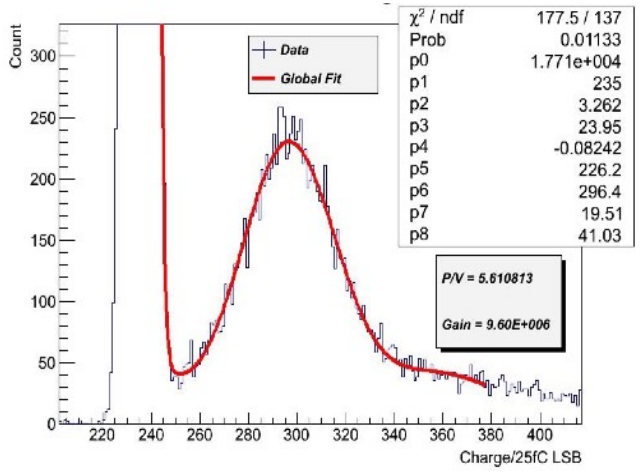




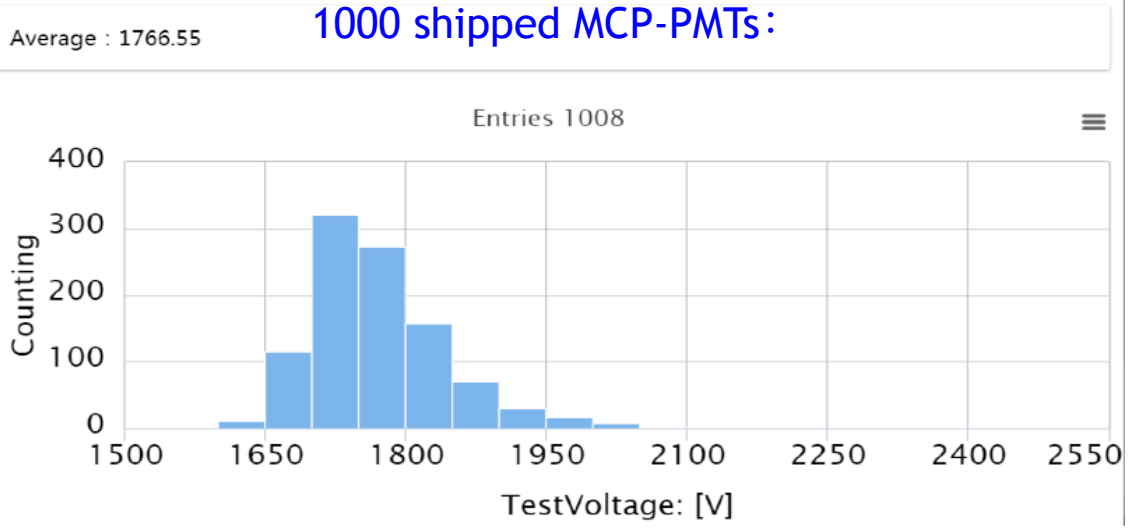
2.3 The HV @ Gain~1X10^7

PMTs	Hamamatsu	MCP-PMT prototype	~300 MCP-PMTs	~1000 MCP-PMTs	~2687 MCP-PMTs
HV @ Gain~1X10^7	1650V	1930V	1780V	1767V	1747V

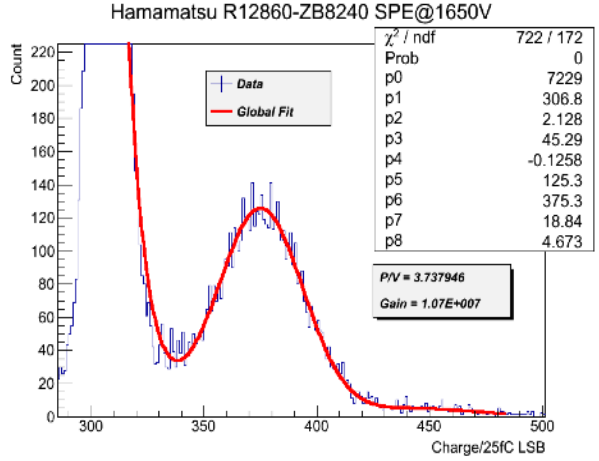
MCP-PMT-prototype



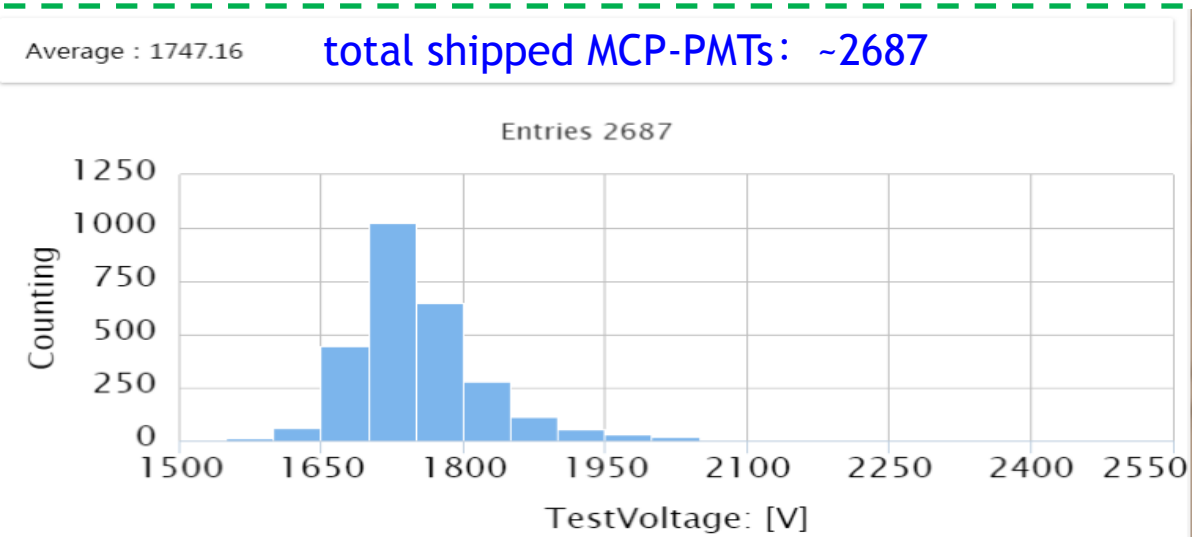
1000 shipped MCP-PMTs:



Hamamatsu Prototype



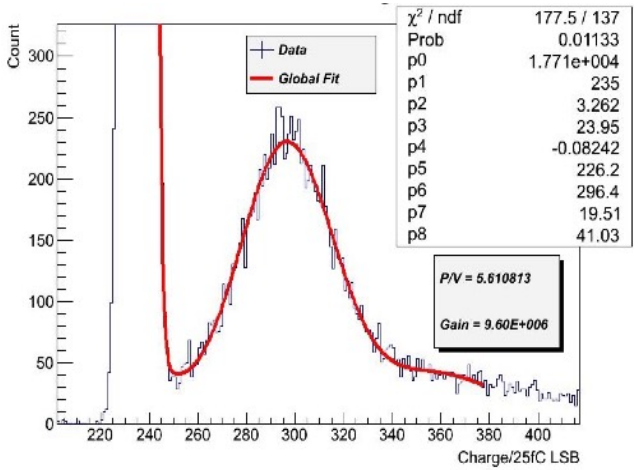
total shipped MCP-PMTs: ~2687



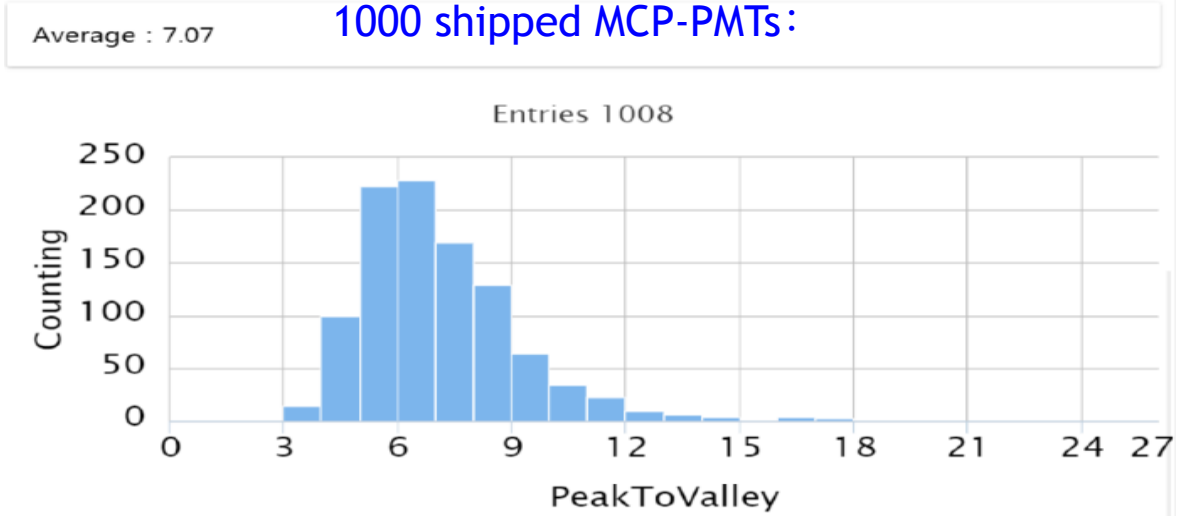
2.4 The P/V of the SPE

PMTs	Hamamatsu	MCP-PMT prototype	~300 MCP-PMTs	~1000 MCP-PMTs	~2687 MCP-PMTs
SPE @ Gain~1X10^7	3.7	5.6	8.2	7.1	6.8

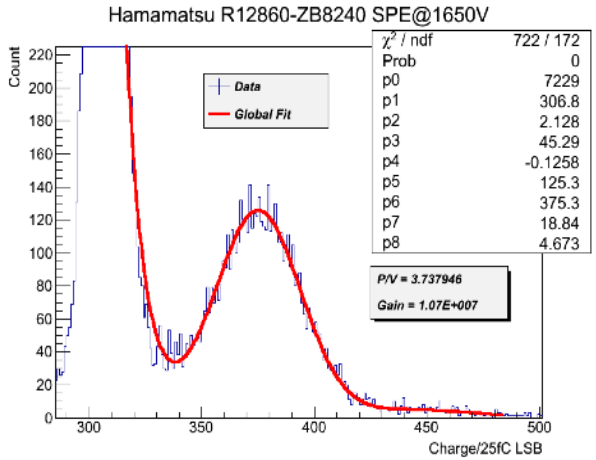
MCP-PMT-prototype



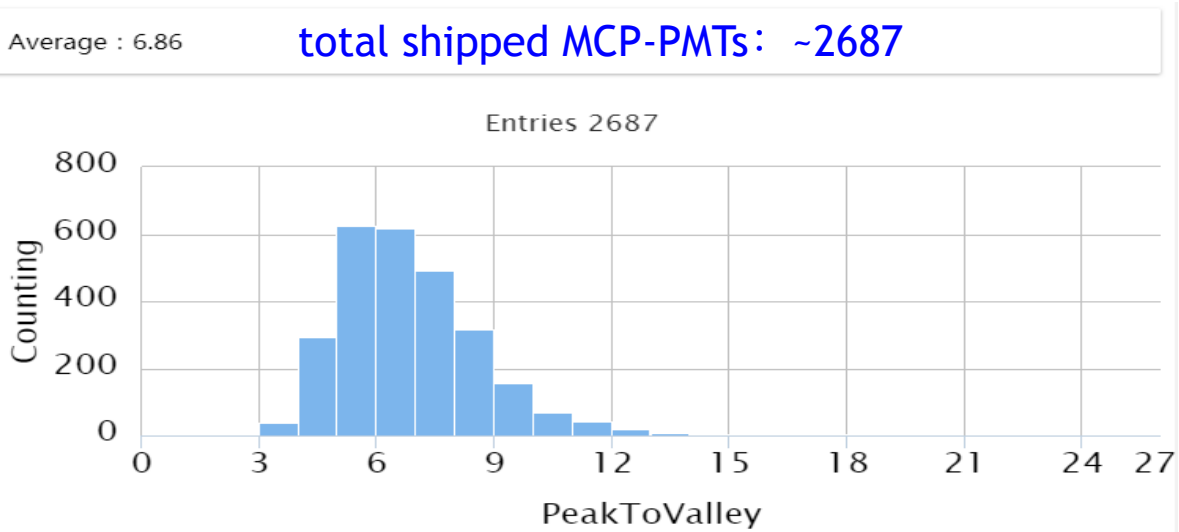
1000 shipped MCP-PMTs:



Hamamatsu Prototype



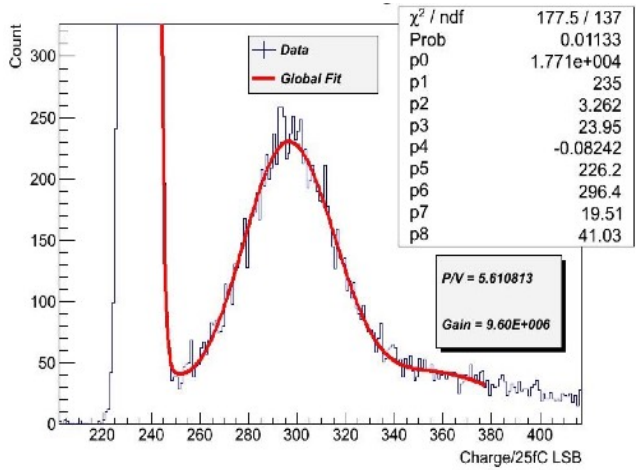
total shipped MCP-PMTs: ~2687



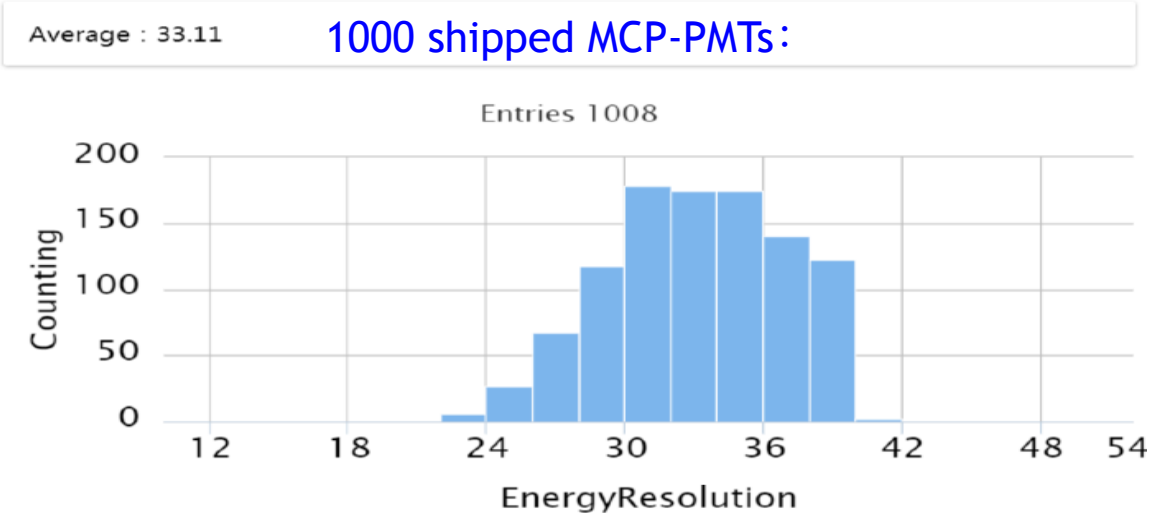
2.5 The Energy Resolution of the SPE

PMTs	Hamamatsu	MCP-PMT prototype	~300 MCP-PMTs	~1000 MCP-PMTs	~2687 MCP-PMTs
ER @ Gain~1X10^7	30%	41%	30.9%	33.1%	33.4%

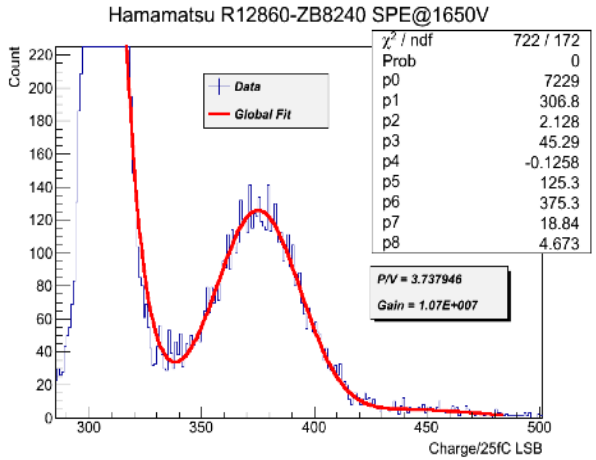
MCP-PMT-prototype



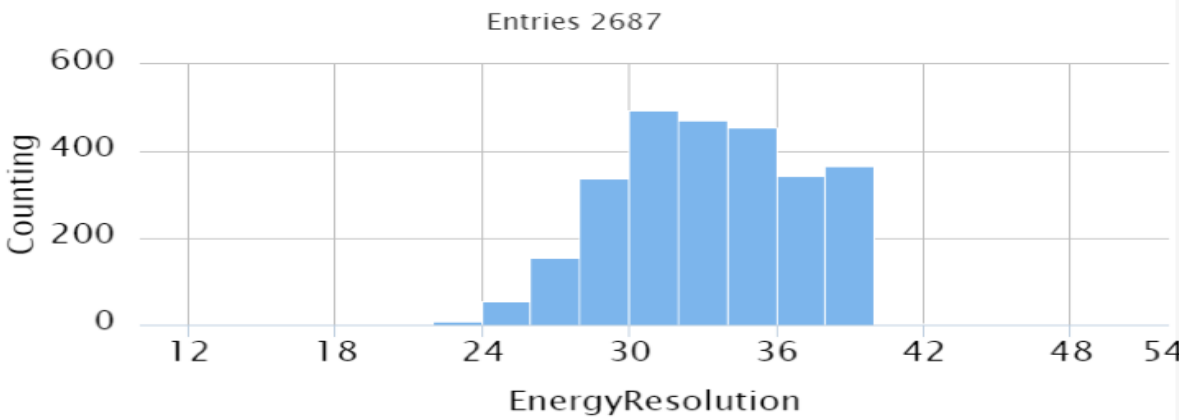
1000 shipped MCP-PMTs:



Hamamatsu Prototype



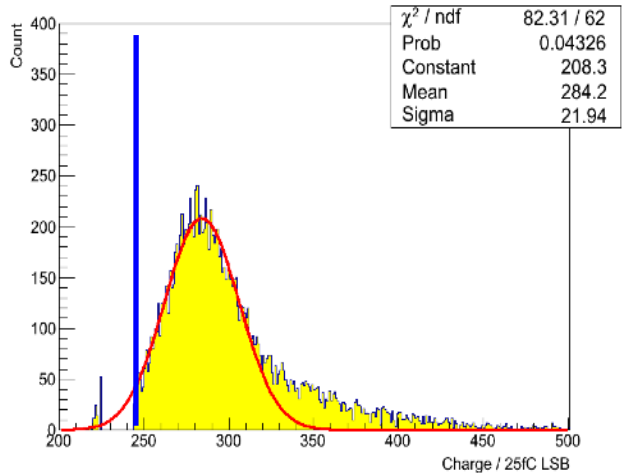
total shipped MCP-PMTs: ~2687



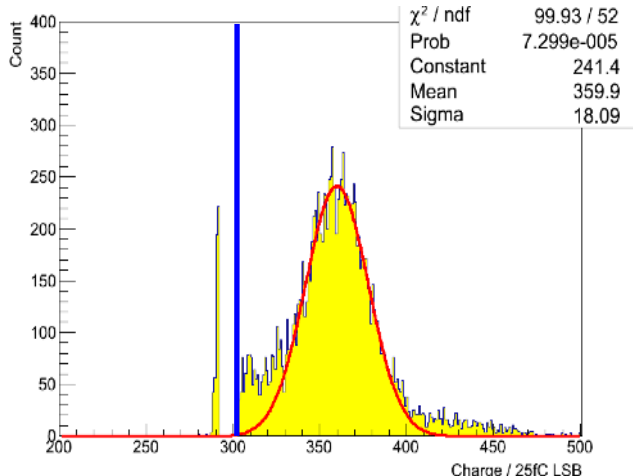
2.6 The Relativity Detection Efficiency of SPE

PMTs	Hamamatsu	MCP-PMT prototype	~300 MCP-PMTs	~1000 MCP-PMTs	~2687 MCP-PMTs
DE @ Gain~1X10^7	27%	26%	28.9%	29.3%	29.2%

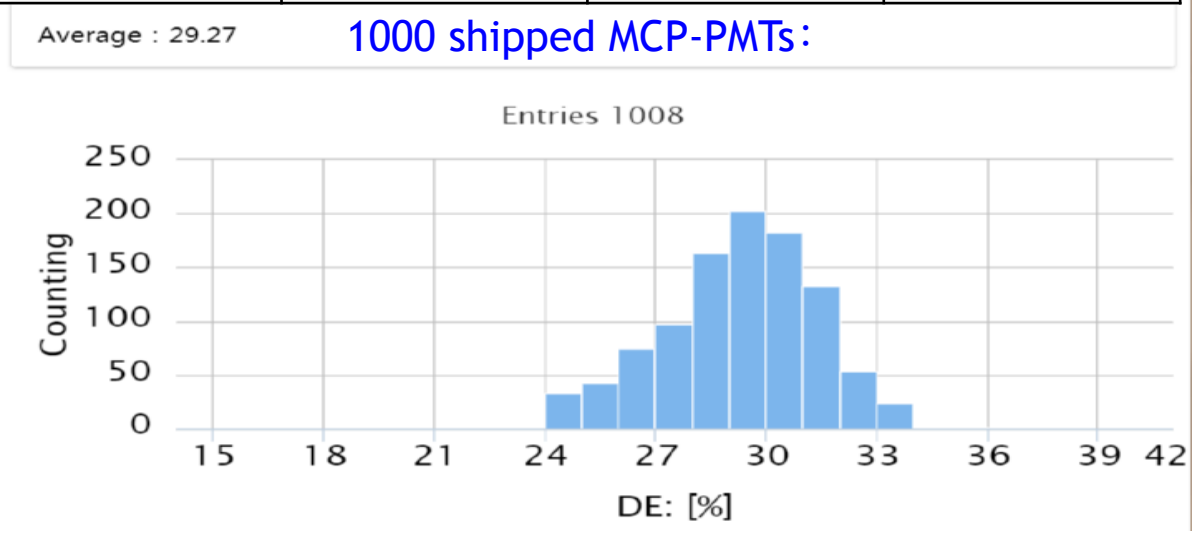
MCP-PMT-prototype



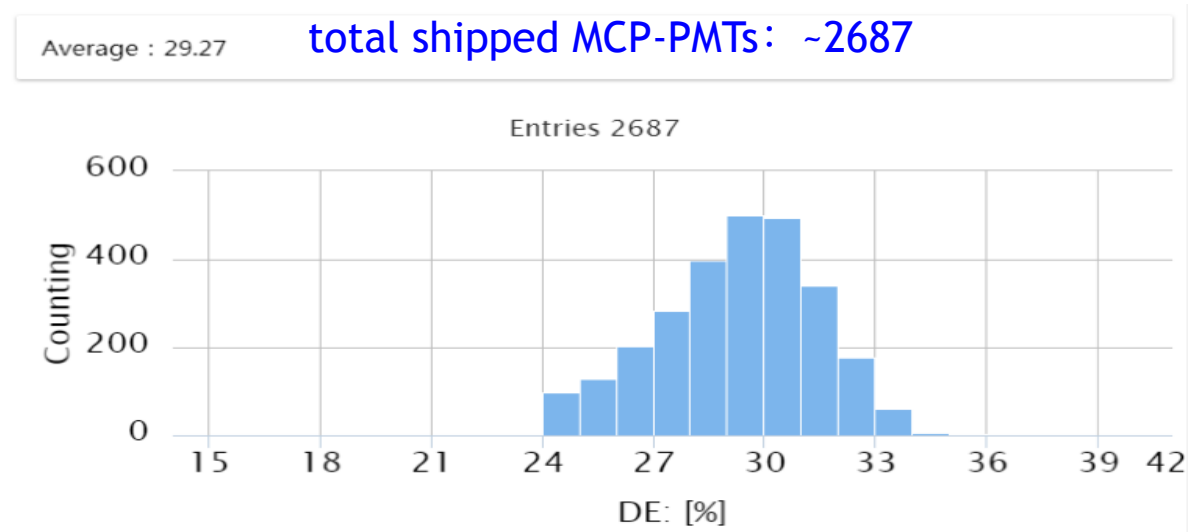
Hamamatsu Prototype



1000 shipped MCP-PMTs:



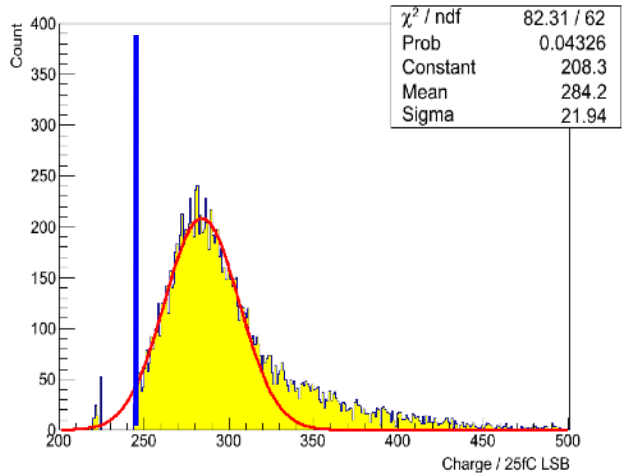
total shipped MCP-PMTs: ~2687



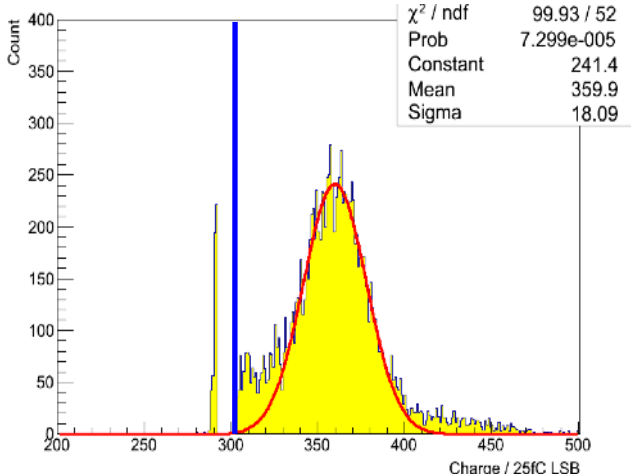
2.7 The Collection Efficiency of SPE

PMTs	Hamamatsu	MCP-PMT prototype	~300 MCP-PMTs	~1000 MCP-PMTs	~2687 MCP-PMTs
CE @ Gain~1X10^7	90%	100%	98%	100%	100%

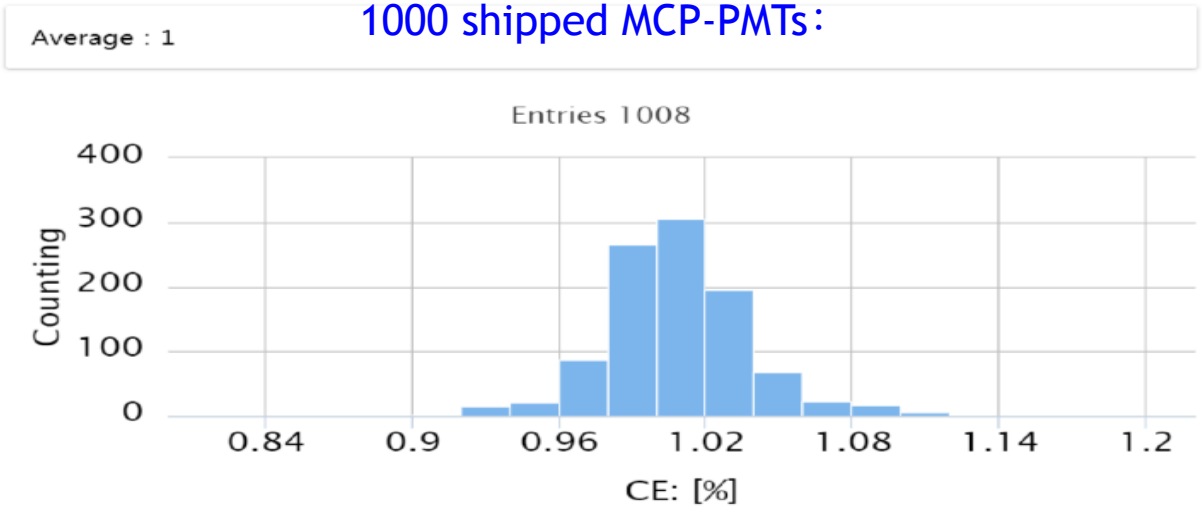
MCP-PMT-prototype



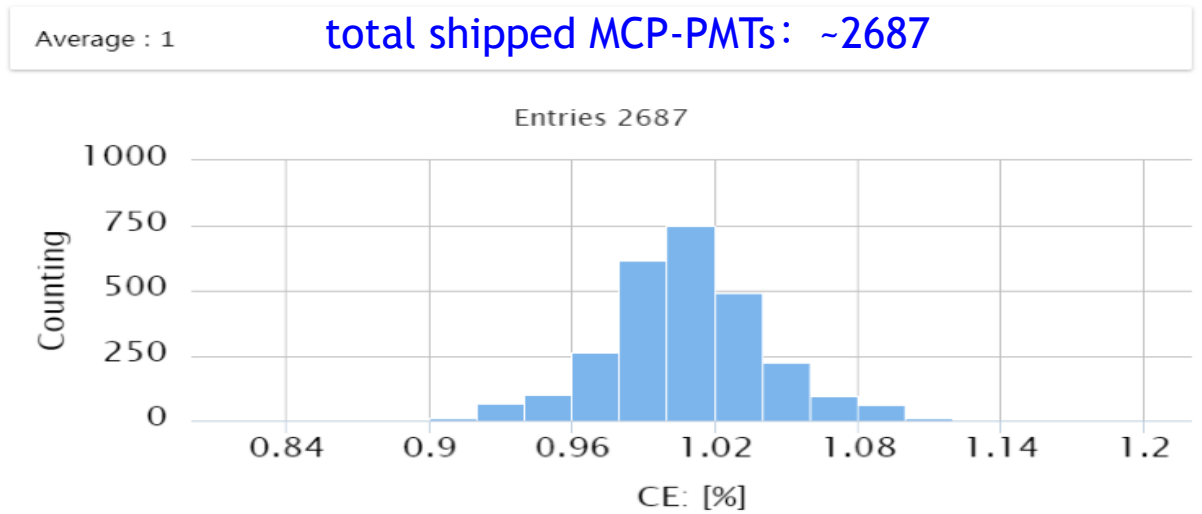
Hamamatsu Prototype

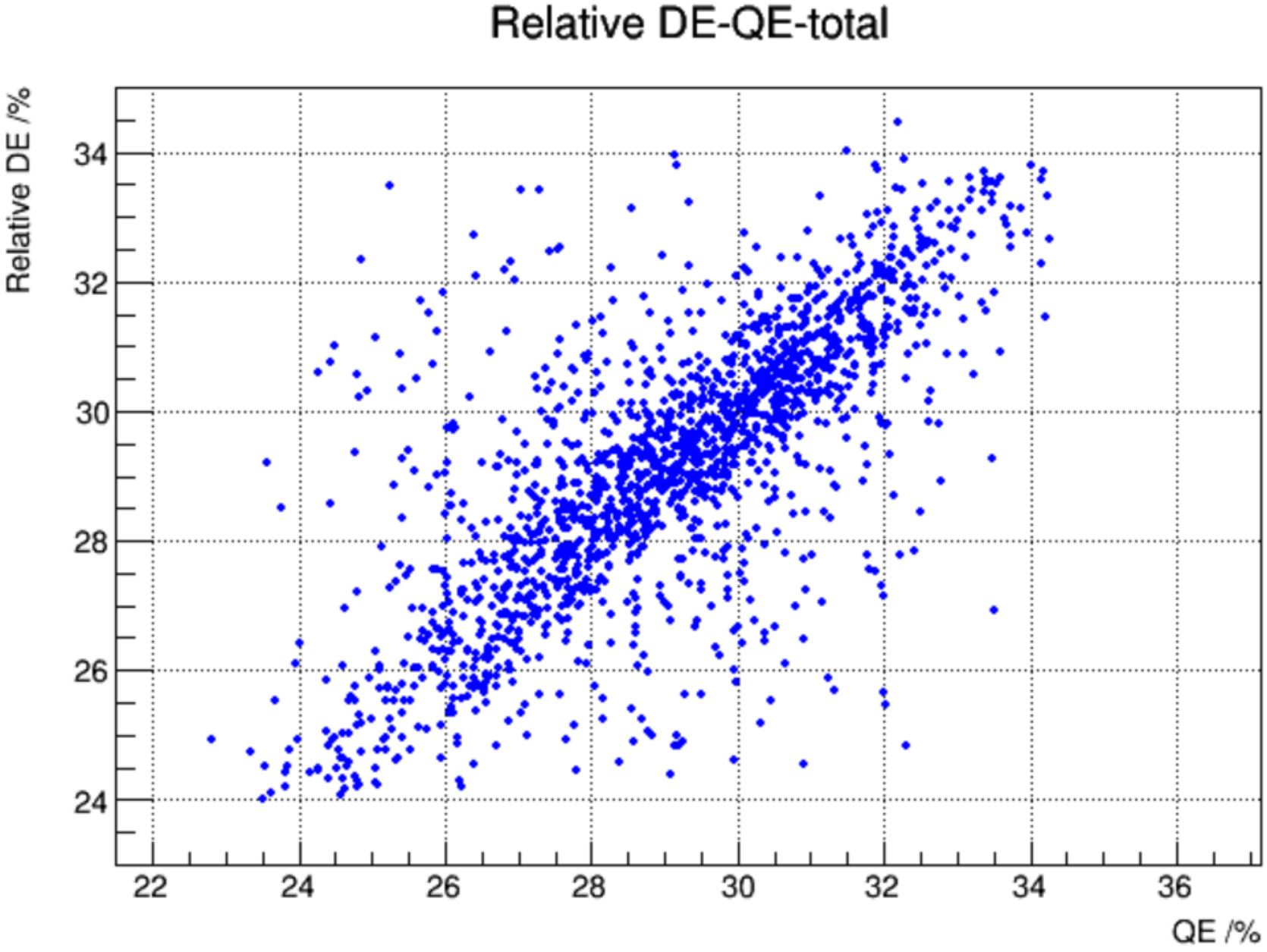


1000 shipped MCP-PMTs:



total shipped MCP-PMTs: ~2687

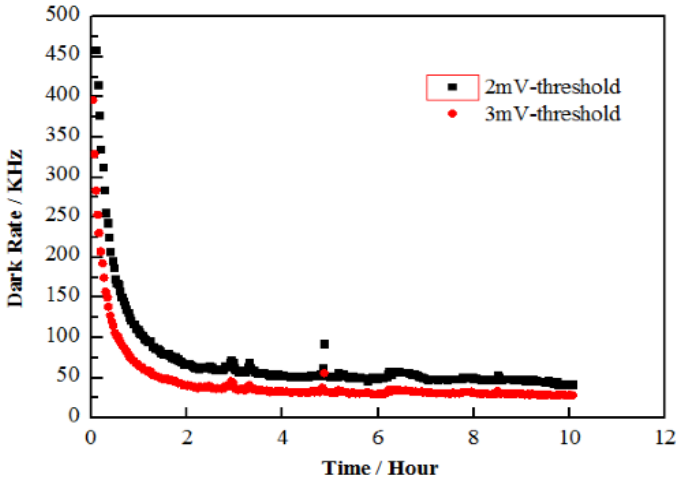



Relative DE-QE-total
Relative DE /%
34
32
30
28
26
24
22
24
26
28
30
32
34
36
QE /%

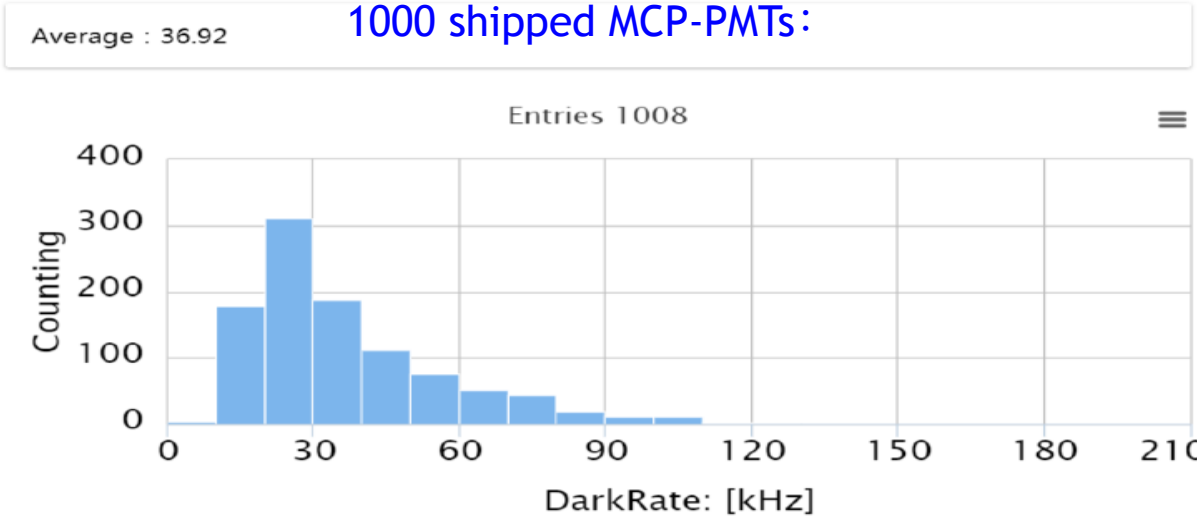
2.8 The Dark Rate @ Gain~1X10^7

PMTs	Hamamatsu	MCP-PMT prototype	~300 MCP-PMTs	~1000 MCP-PMTs	~2687 MCP-PMTs
DR @ 0.25 pe	25 KHz	30 KHz	33.5 KHz	36.9 KHz	40KHz

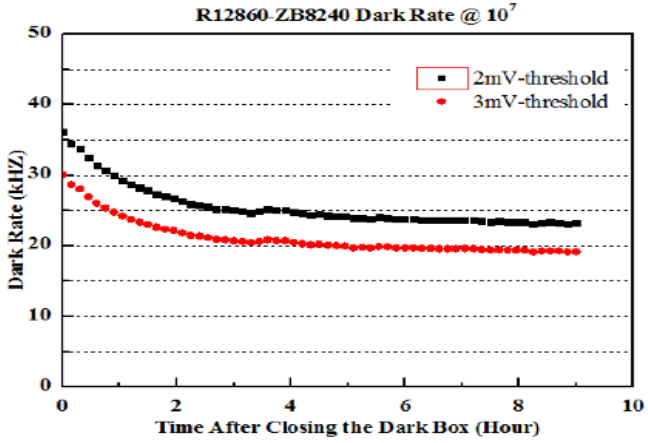
MCP-PMT-prototype



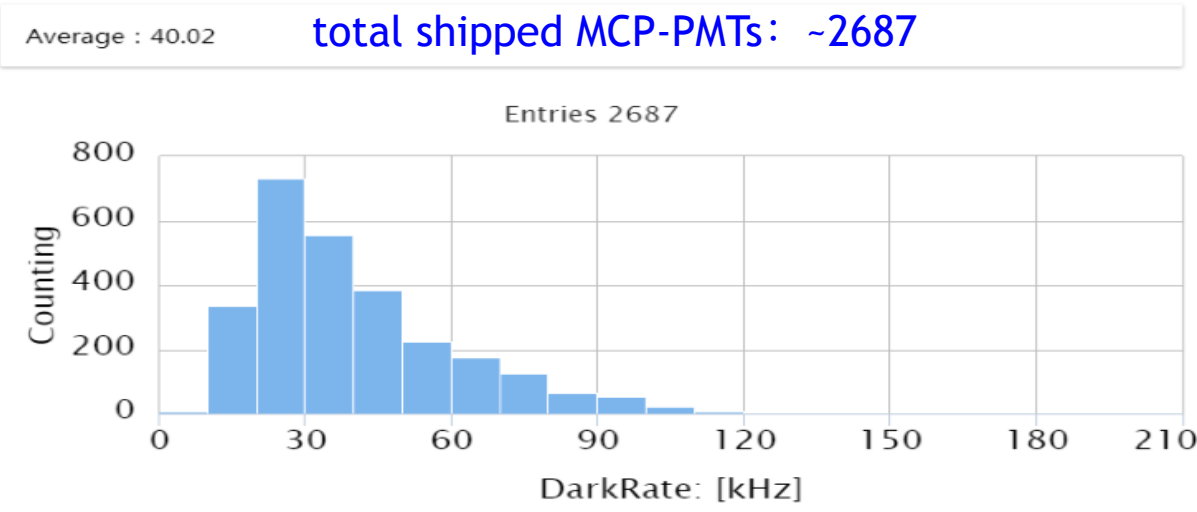
1000 shipped MCP-PMTs:



Hamamatsu Prototype

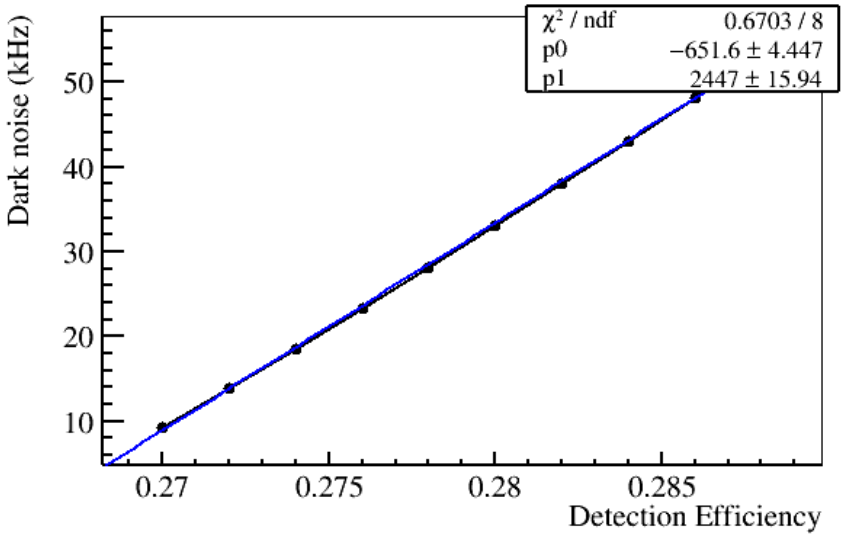


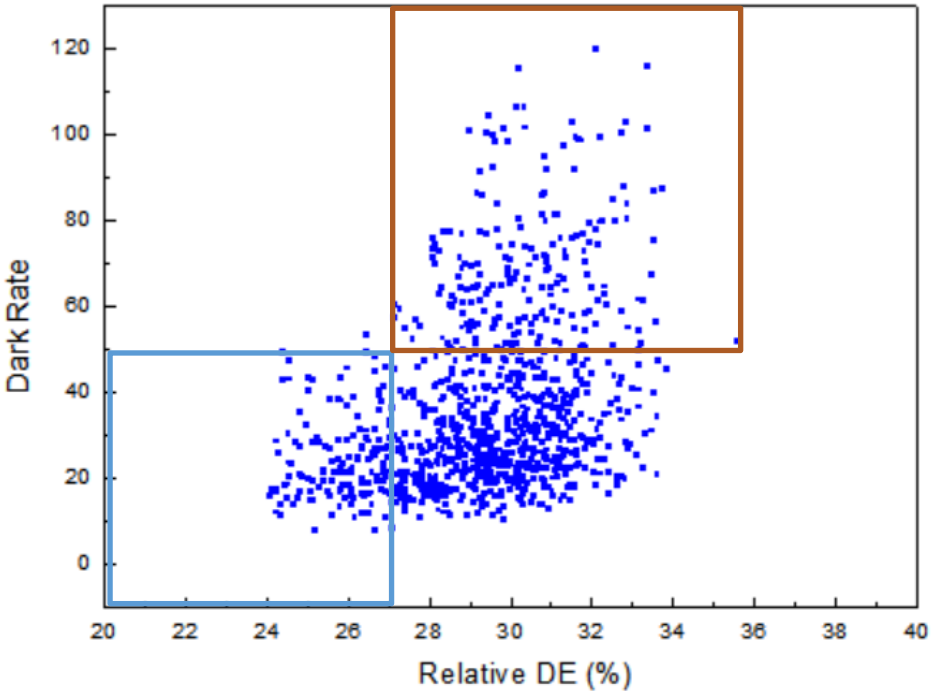
total shipped MCP-PMTs: ~2687



➢ Why the Dark Rate was large than 30KHz?

Contract	Hamamatsu	MCP-PMT
DT @ 1X10^7	≥ 24%	≥ 24%
QE @ 410nm	≥ 27%	≥ 27%
DR @ 0.25 pe	≤50KHz	≤30KHz





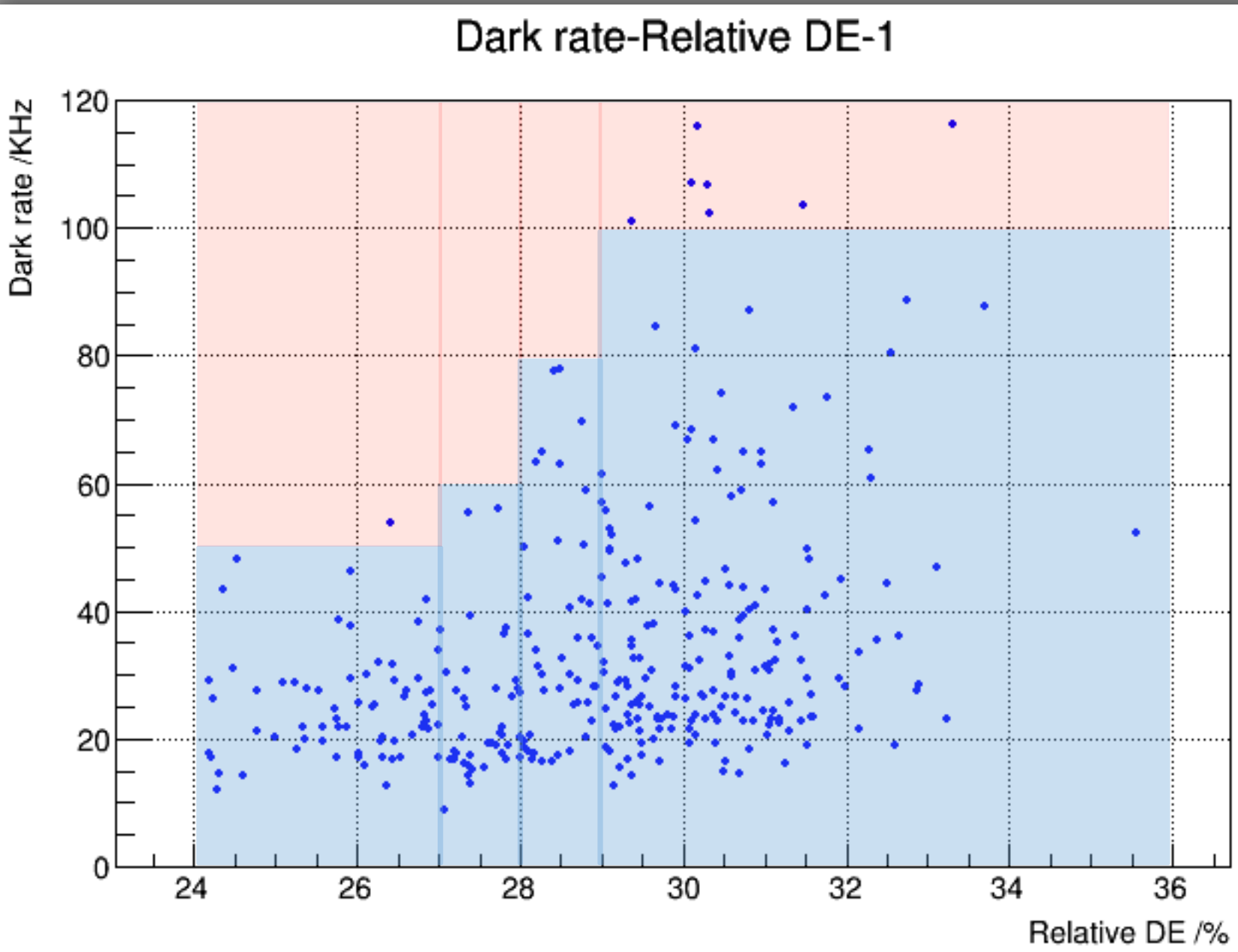
The better DE, the large DR could be accepted!

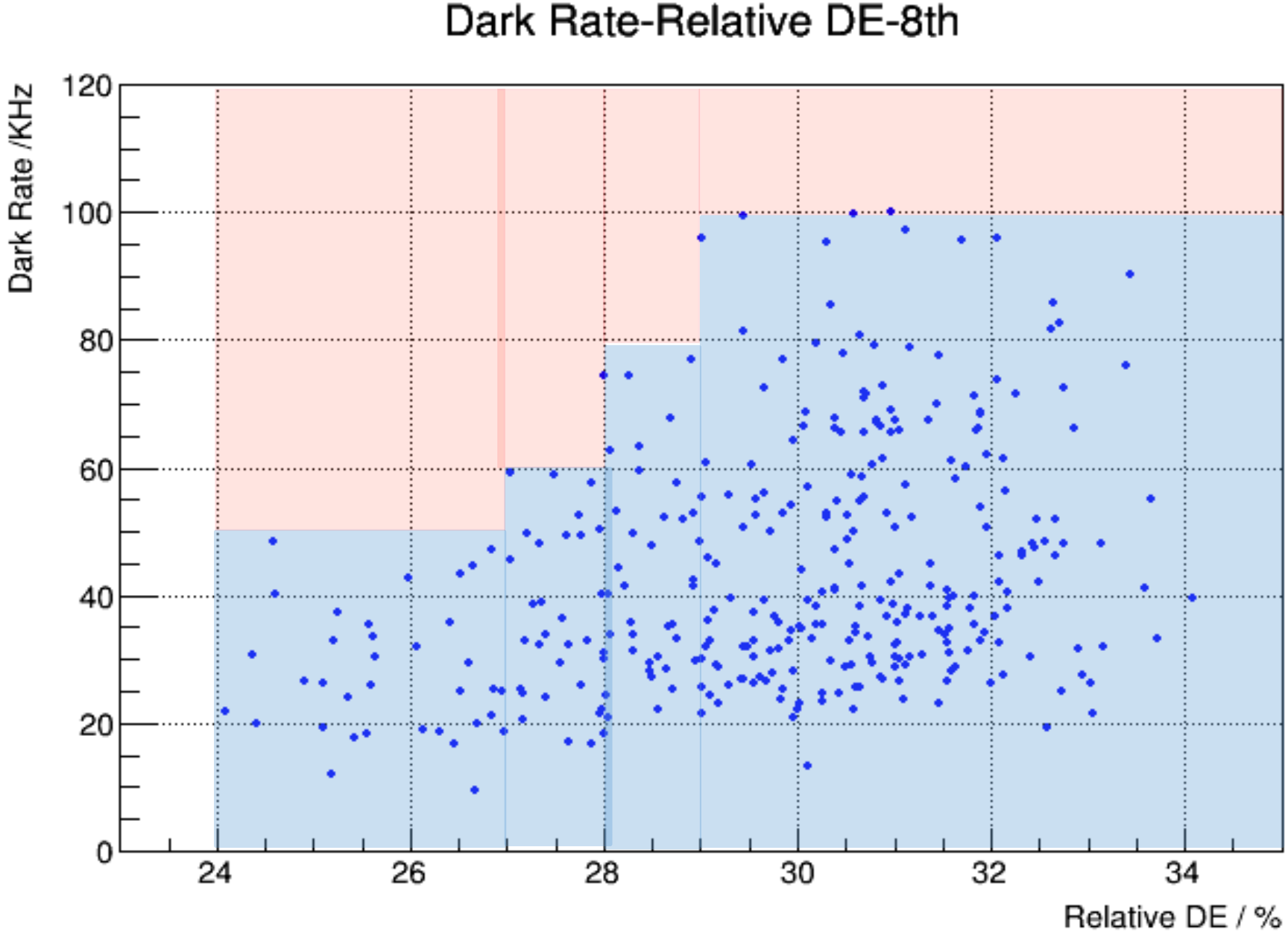
By simulation @Liangjian

Detection Efficiency	Dark Rate
≤27%	50KHz
27%<DE≤28%	60KHz
28%<DE≤29%	80KHz
> 29%	100KHz

Accept by the MCP-PMT collaboration group

2.8 The Dark Rate (2) —DR vs DE

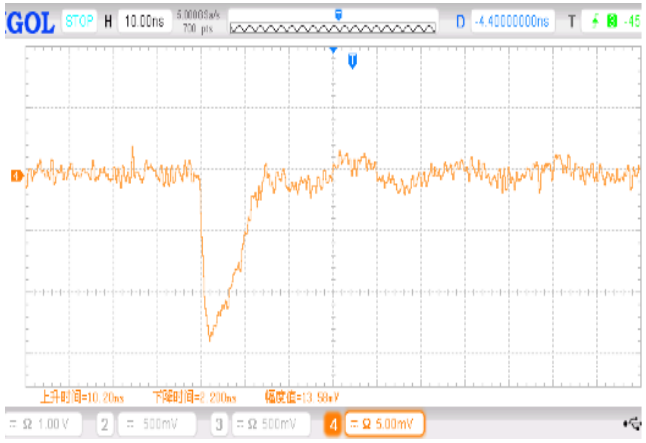



Dark Rate-Relative DE-8th
Dark Rate /KHz
120
100
80
60
40
20
0
24
26
28
30
32
34
Relative DE / %

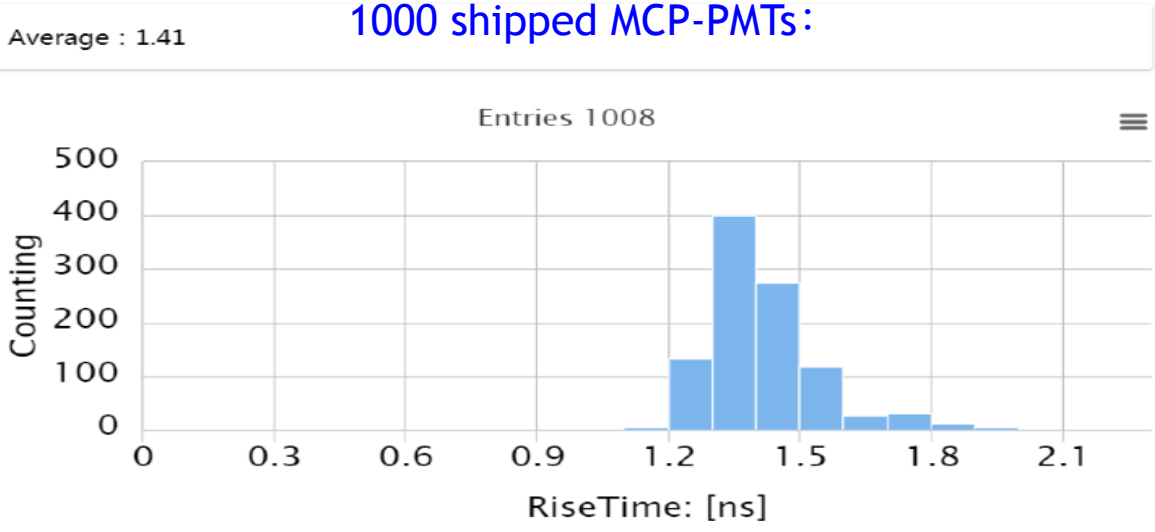
2.9 The Rise Time of the Waveform

PMTs	Hamamatsu	MCP-PMT prototype	~300 MCP-PMTs	~1000 MCP-PMTs	~2687 MCP-PMTs
RT @ Gain~1X10^7	6.7 ns	1.2 ns	1.4 ns	1.4 ns	1.4 ns

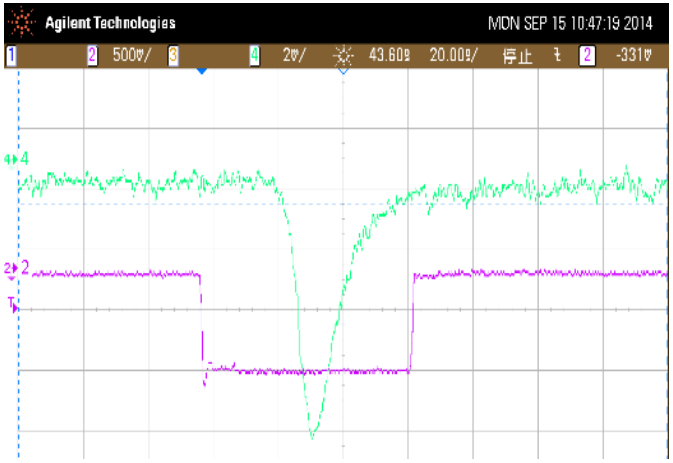
MCP-PMT-prototype



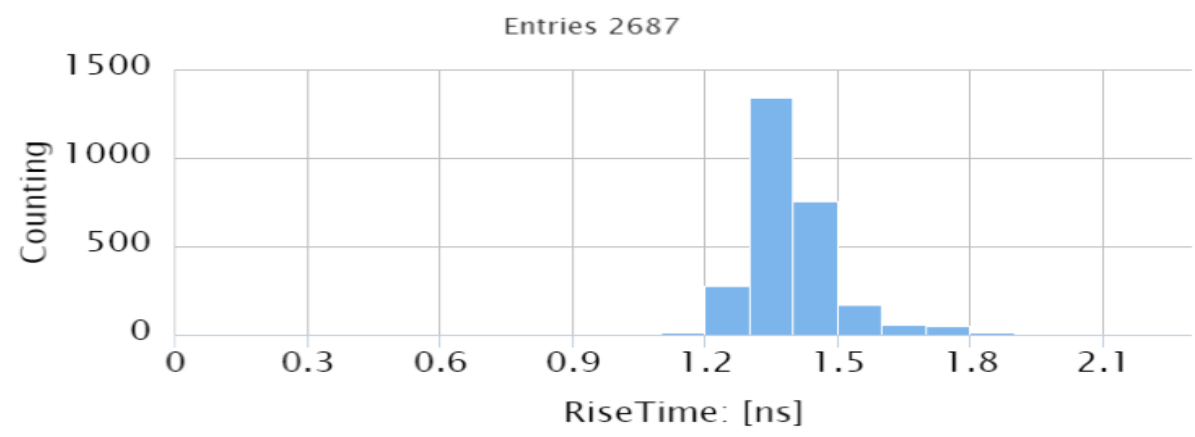
1000 shipped MCP-PMTs:



Hamamatsu Prototype



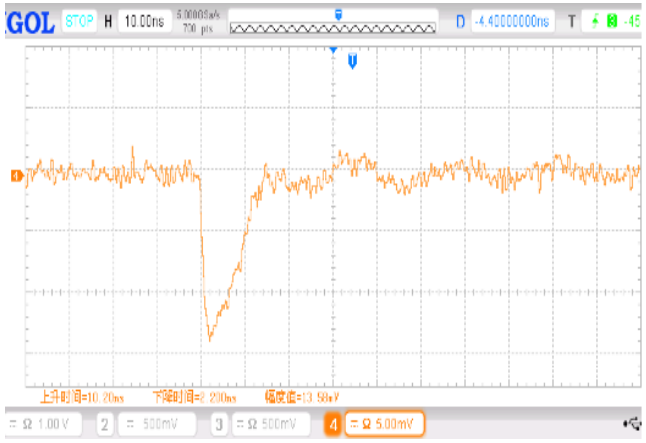
total shipped MCP-PMTs: ~2687



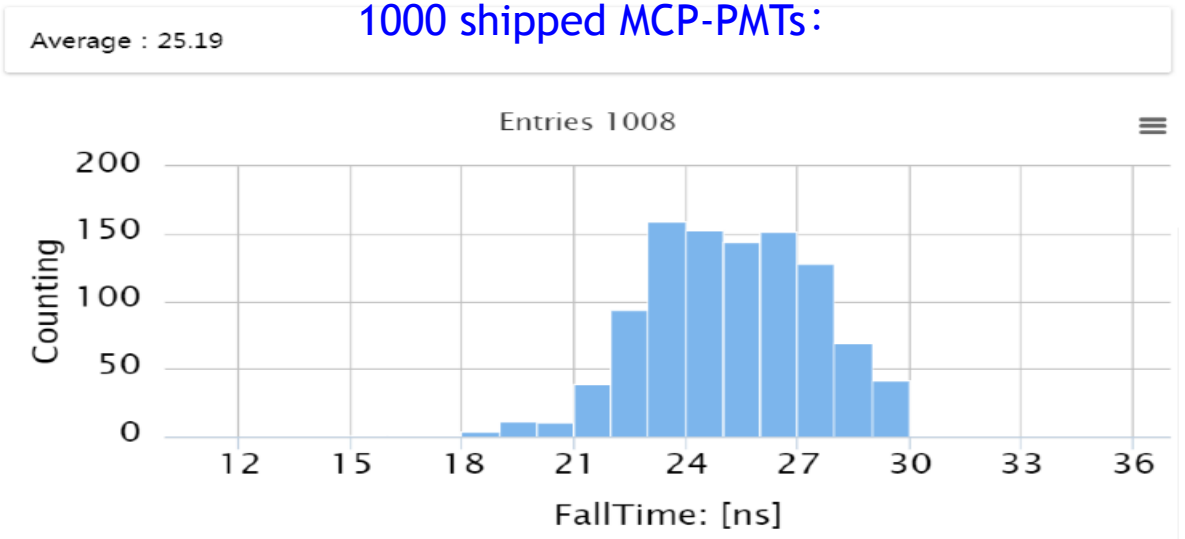
2.10 The Fall Time of the Waveform

PMTs	Hamamatsu	MCP-PMT prototype	~300 MCP-PMTs	~1000 MCP-PMTs	~2687 MCP-PMTs
RT @ Gain~1X10^7	17.7 ns	10.2 ns	24.4 ns	25.2 ns	24.9 ns

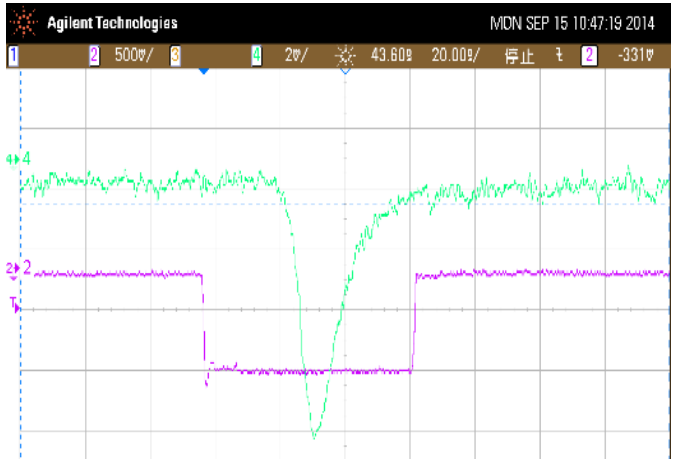
MCP-PMT-prototype



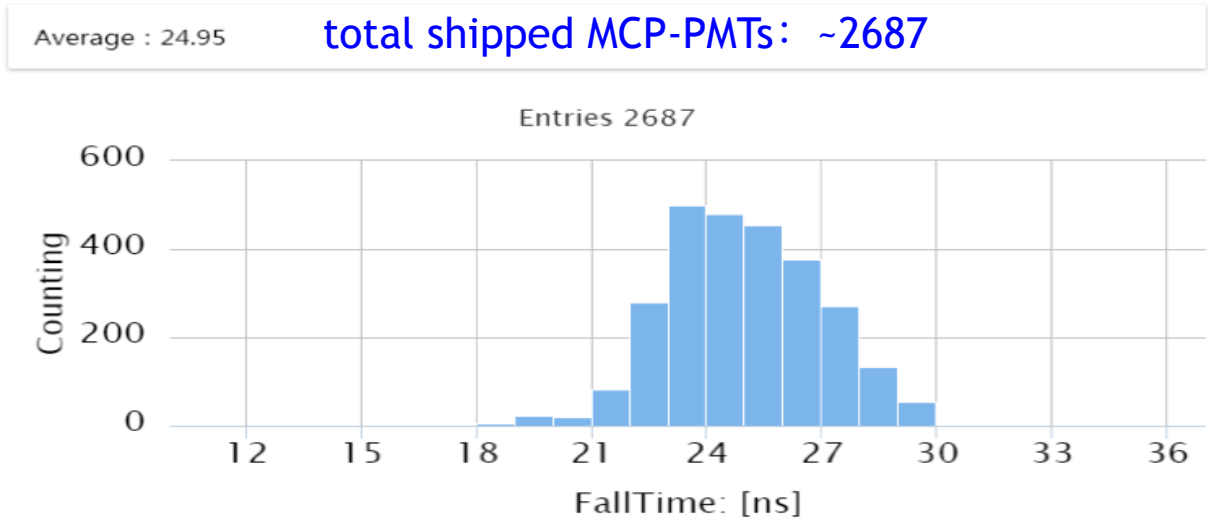
1000 shipped MCP-PMTs:



Hamamatsu Prototype



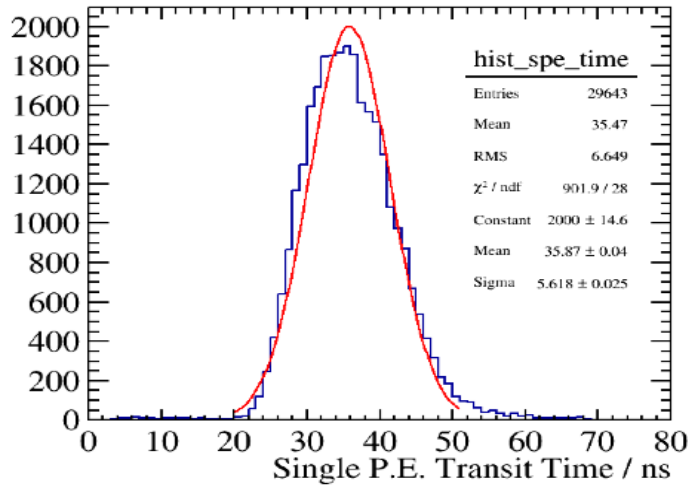
total shipped MCP-PMTs: ~2687



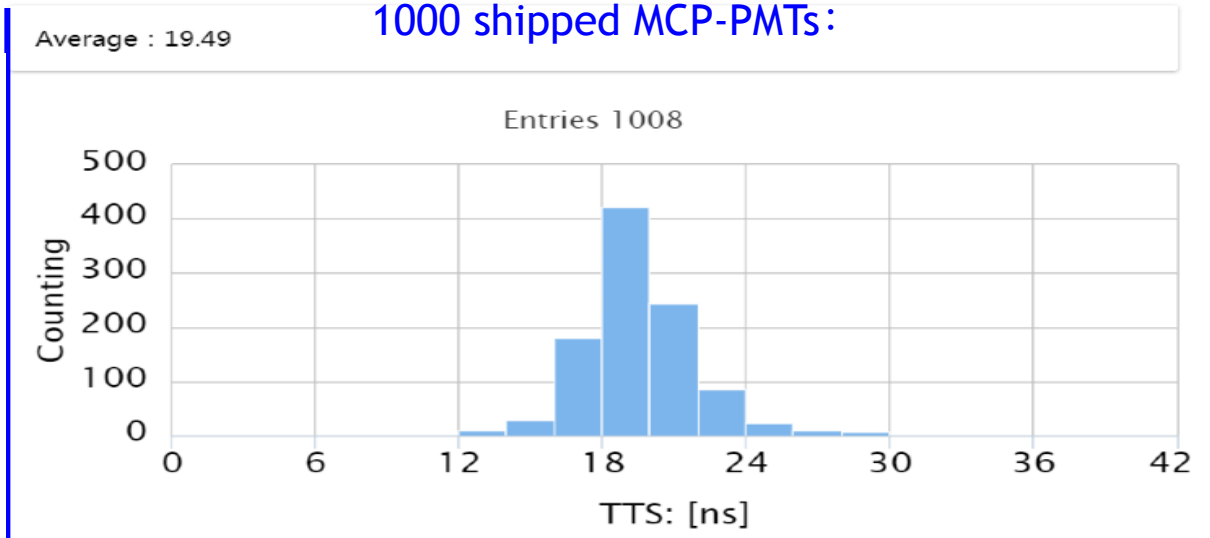
2.11 The TTS @ Gain~1X10^7

PMTs	Hamamatsu	MCP-PMT prototype	~300 MCP-PMTs	~1000 MCP-PMTs	~2687 MCP-PMTs
TTS @ Gain~1X10^7	2.8 ns	12 ns	19.2 ns	19.5ns	20.0ns

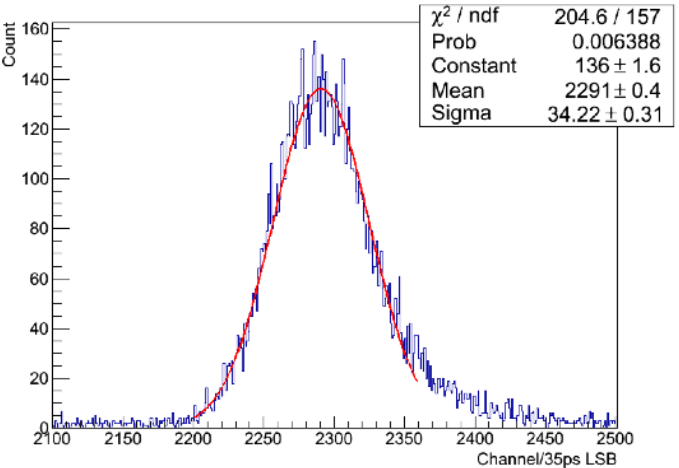
MCP-PMT-prototype



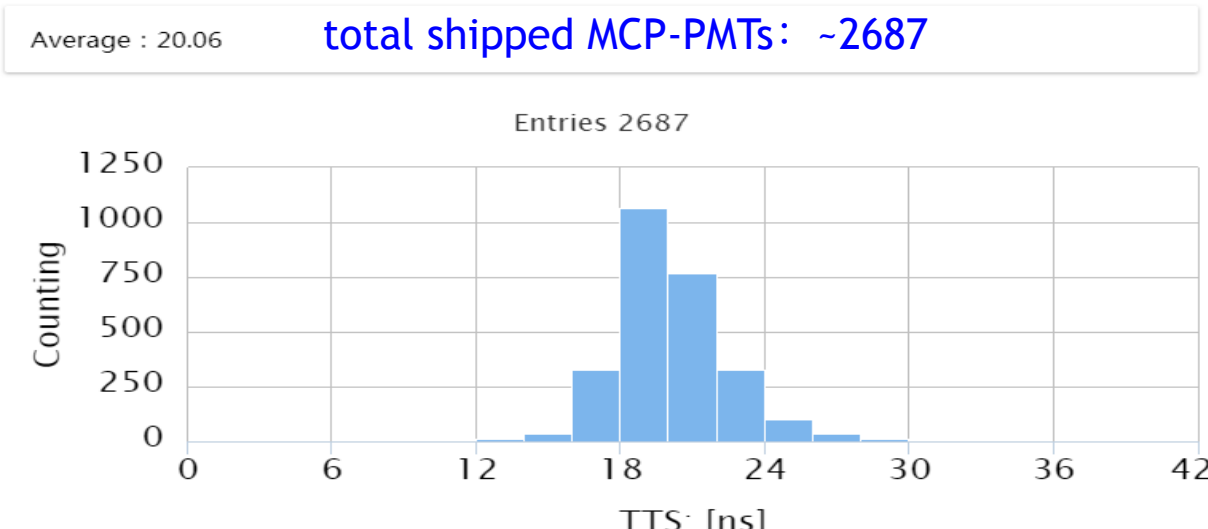
1000 shipped MCP-PMTs:



Hamamatsu Prototype



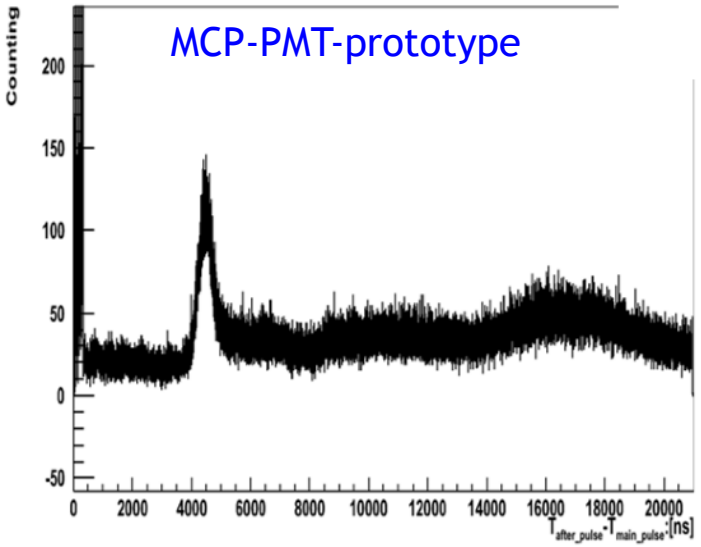
total shipped MCP-PMTs: ~2687



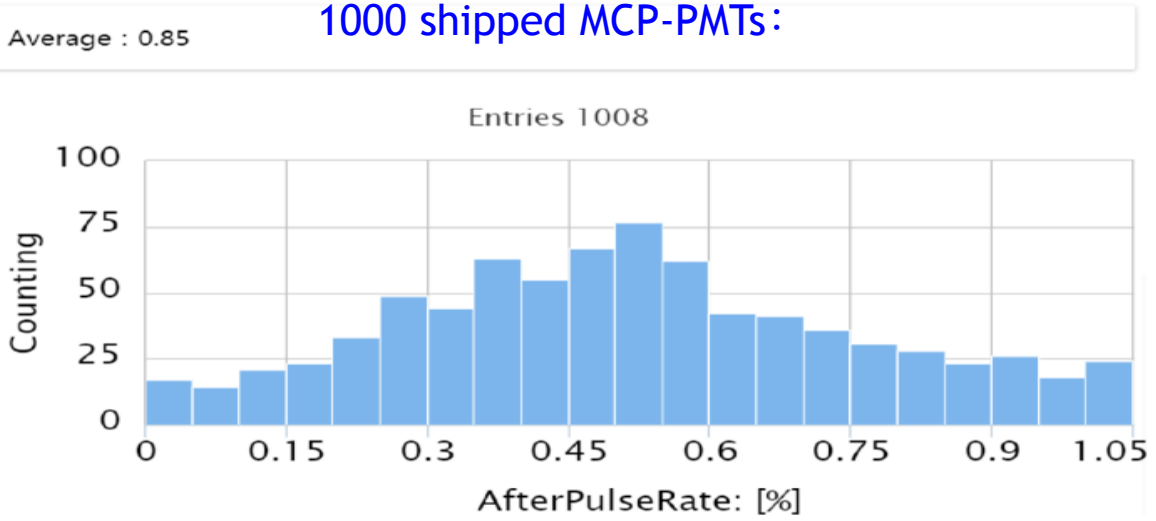
2.12 The After Pulse Rate @ Gain~1X10^7

PMTs	Hamamatsu	MCP-PMT prototype	~300 MCP-PMTs	~1000 MCP-PMTs	~2687 MCP-PMTs
APR @ Gain~1X10^7	10%	2.5%	1.2%	0.8%	0.71%

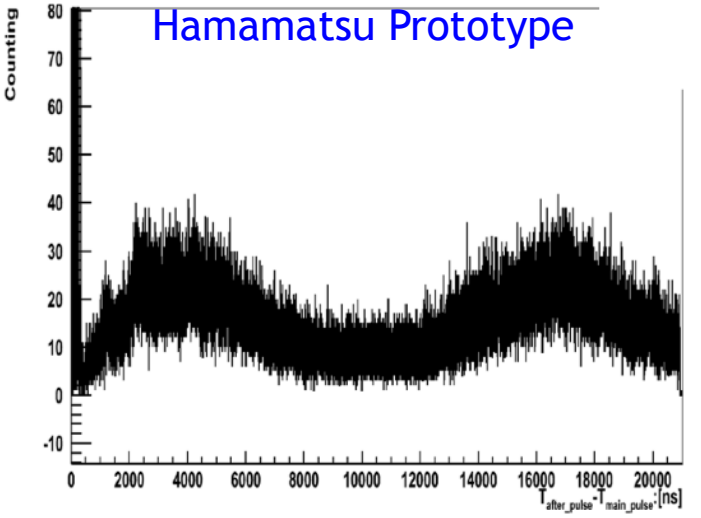
MCP-PMT-prototype



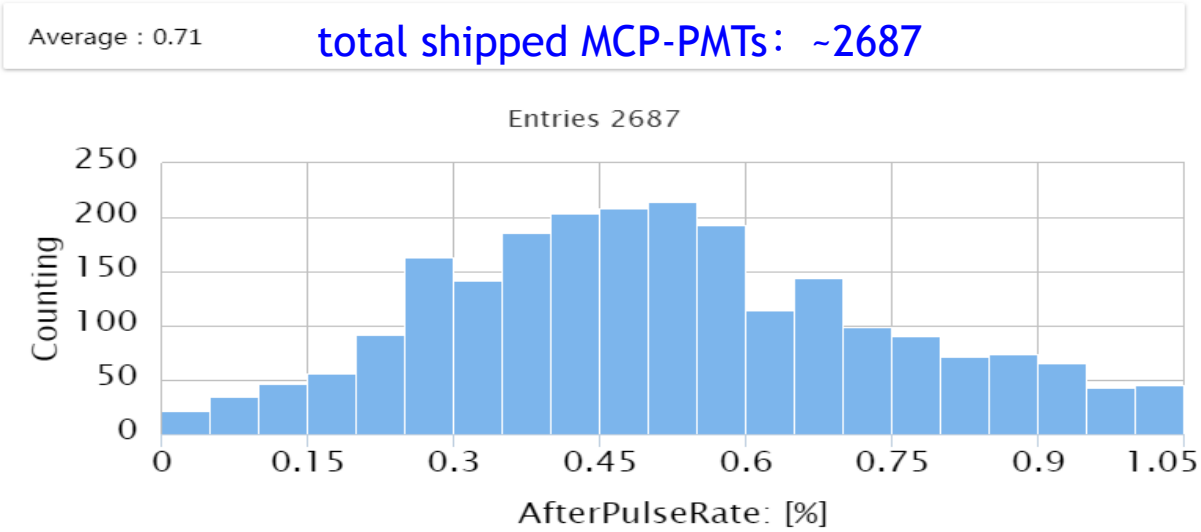
1000 shipped MCP-PMTs:



Hamamatsu Prototype



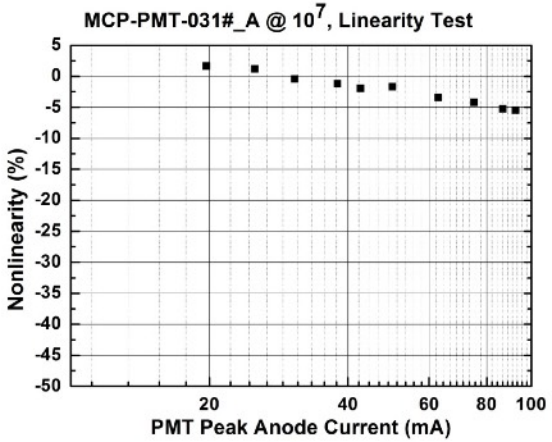
total shipped MCP-PMTs: ~2687



2.13 The Linearity of the MPE @ Gain~1X10^7

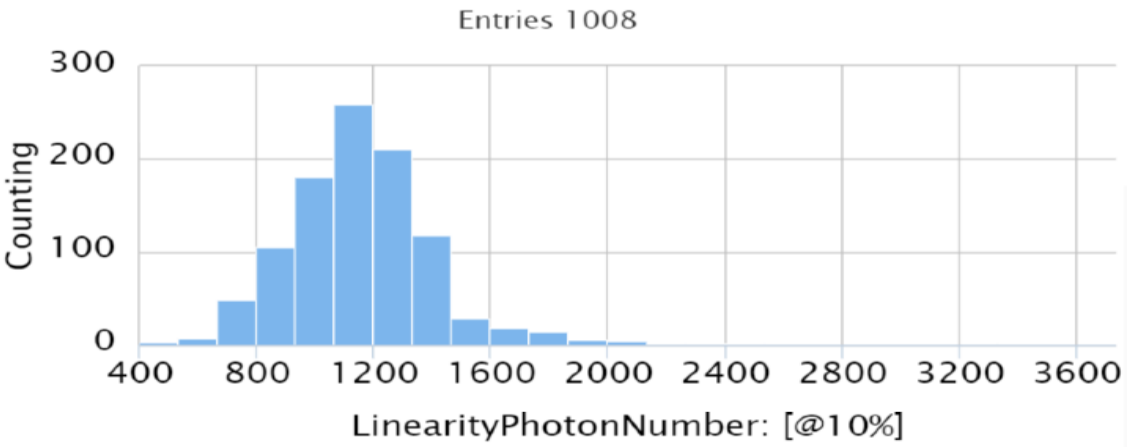
PMTs	Hamamatsu	MCP-PMT prototype	~300 MCP-PMTs	~1000 MCP-PMTs	~2687 MCP-PMTs
Lin @ <10%	1000pe	1000pe	1175pe	1160pe	1293pe

MCP-PMT-prototype

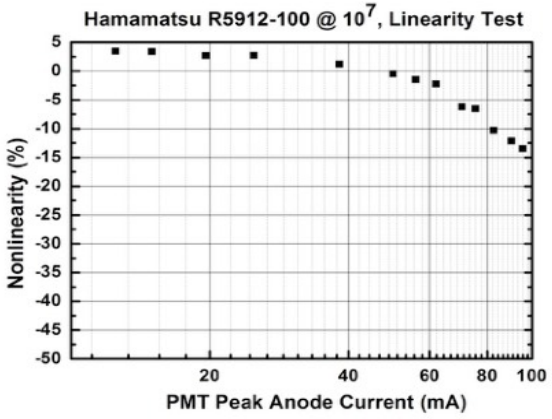


1000 shipped MCP-PMTs:

Average : 1160.81

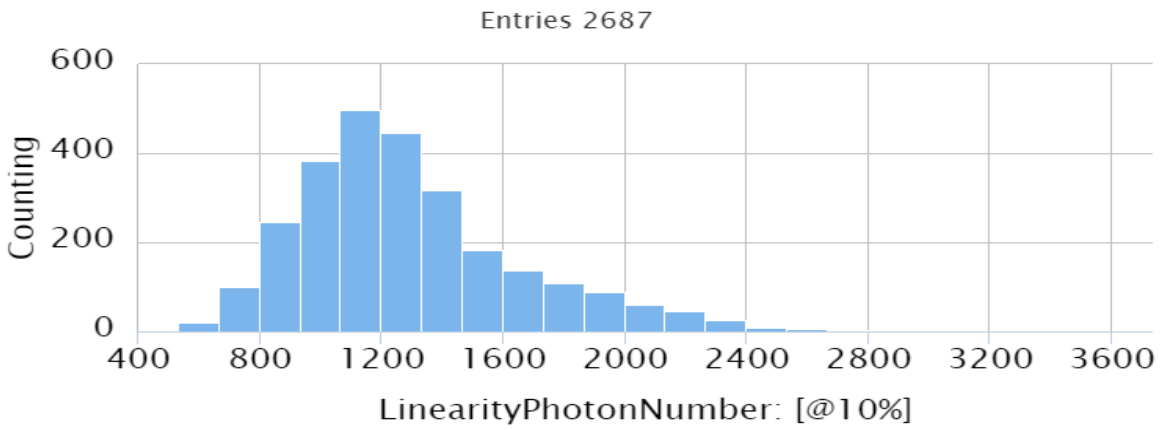


Hamamatsu Prototype

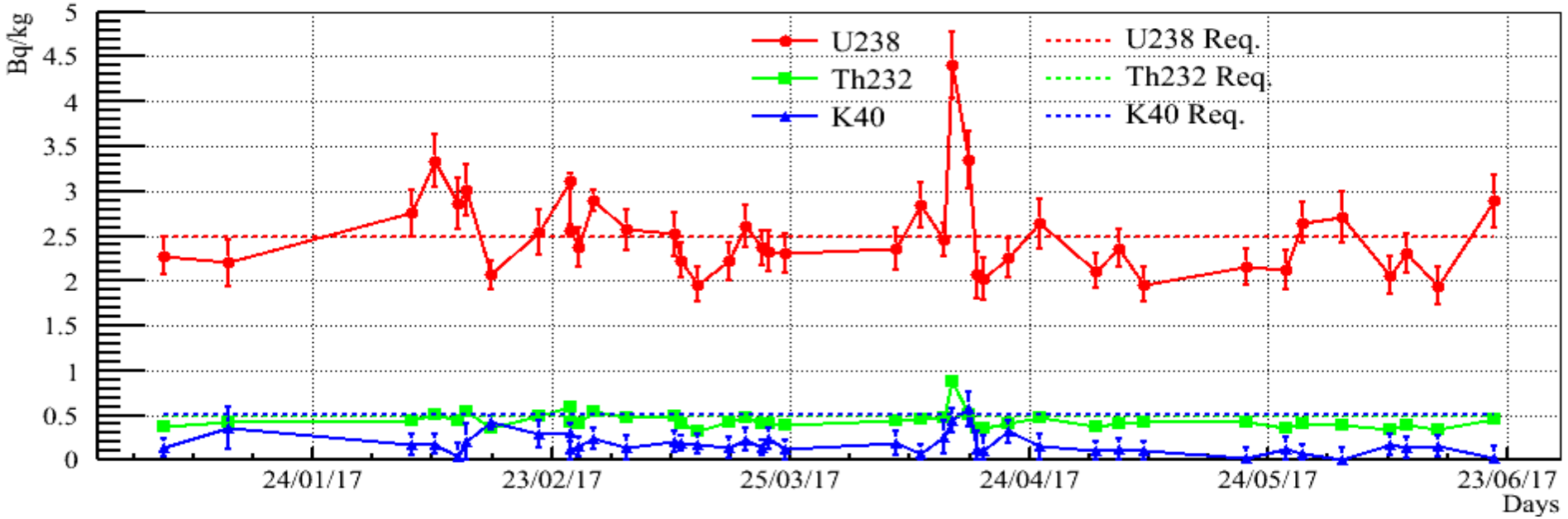


total shipped MCP-PMTs: ~2687

Average : 1293.21



2.14 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**

2.14 the MCP-PMT parameters Test in NNVT for JUNO

PMT Parmaeters	JUNO Contract	data in Contract	NNVT test	Prototype	1000 mass production	2000 mass production	2687 mass production
单波长QE@410nm	A	≥ 26.5%	A	~ 26%	**29.2%**	**29.1%**	**29.2%**
均匀性（QE Uniformity）	B	≤ 10%	A	≤ 10%	7.8%	7.9%	7.7%
频谱响应曲线（QE-λ）	B	300nm ~ 650 nm	B(50%)	300nm ~ 650 nm	300nm ~ 650 nm	300nm ~ 650 nm	300nm ~ 650 nm
单光子探测（SPE-P/V）	A	≥ 2.8	A	~ 5.6	7.1	6.9	6.9
能量分辨率（SPE-ER）	A	≤ 40%	A	~ 41%	**33.1%**	**33.4%**	**33.4%**
增益（Gain）	A	1E+07	A	1E+07	1E+07	1E+07	1E+07
高压（HV）	A	≤ 2800V	A	~ 1980V	**1767V**	**1754V**	**1747V**
探测效率（DE）	B	≥ 24%	A	~ 26%	**29.3%**	**29.1%**	**29.2%**
暗计数率（DR）	A	≤ 30KHz	A	~ 30KHz	36.9KHz	38.8 KHz	40.0 KHz
渡越时间涨落（TTS）	B	≤ 15ns	A	~12ns	19.5ns	20.0ns	20.6ns
后脉冲率（APR）	B	≤ 5%	A	~ 2.5%	0.8%	0.8%	0.7%
非线性（Linearity）<10%	B	≥ 1000pe	A	~ 1000pe	**1160pe**	**1274pe**	**1293pe**
信号波形（RT）	A	≤ 2ns	A	~ 1.2ns	1.41ns	1.4 ns	1.4 ns
信号波形（FT）	A	≤ 12ns	A	~10.2ns	25.2ns	25 ns	25 ns

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

Thanks！ 谢谢！

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