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

The 20 inch MCP-PMT R&D in China

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JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Cluster of Excellence
PRISMA
Precision Physics, Fundamental Interactions and Structure of Matter

FroST - Topical Workshop for THEIA

Oct. 23. 2016

Outline

- **1. The JUNO and MCP-PMT;**
- **2. The new design of the MCP-PMT prototypes;**

  the 4 π design; the 8 inch prototypes; the 20 inch prototypes;

- **3. The High PDE MCP-PMT—2015;**

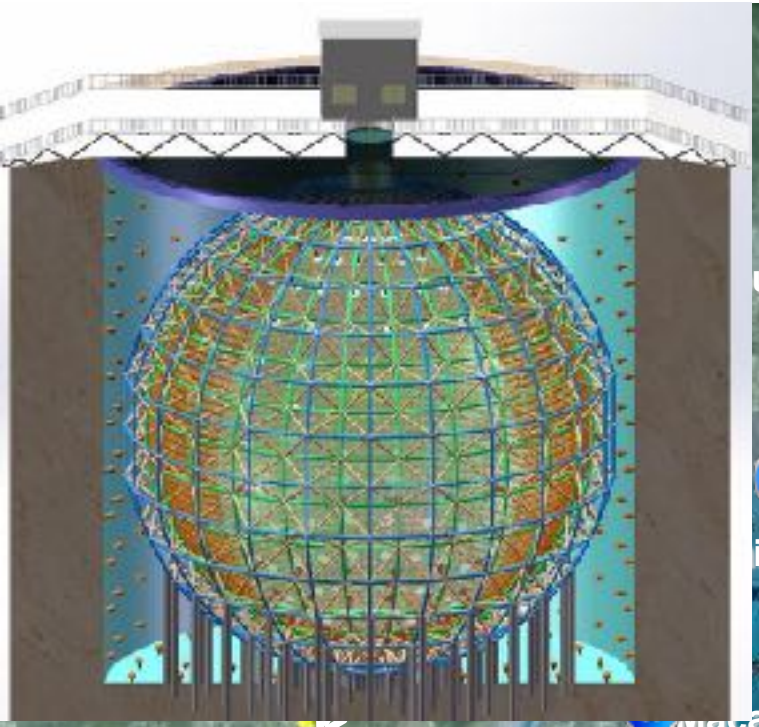
  the The performance of the 20 inch prototypes ;

- **4. The Special Behaviors of the MCP-PMT;**

  the High CE; The large TTS; the aging behaviors;

- **5. The PMT purchase of JUNO**

➢ 1. The JUNO and MCP-PMT



- **High QE 20" PMTs for JUNO:**
  - ⇨ Hammamatsu PMT with SBA photocathode（2012）
  - ⇨ A new design using MCP: 4π collection（2009）

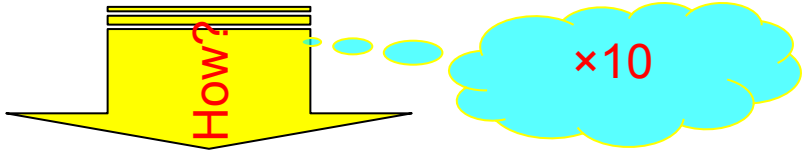
➢20“ Hammamatzu PMT

➢20” MCP- PMT-IHEP

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

	KamLAND	Daya Bay II	JUNO
Detector	~1 kt Liquid Scintillator	➢ 10 kt Liquid Scintillator	➢ 10 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

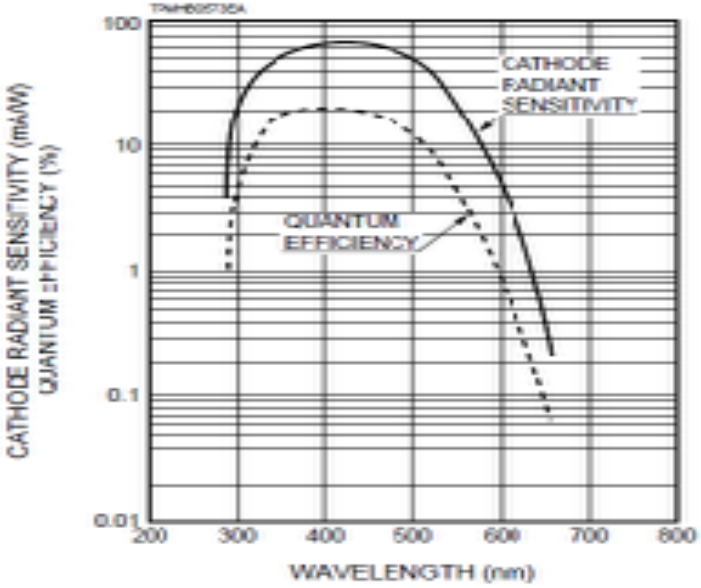
    Attenuation length: 15m → 30m; the Light Yield (% standard): ×2;
  - High light yield LS: increasing PPO%

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

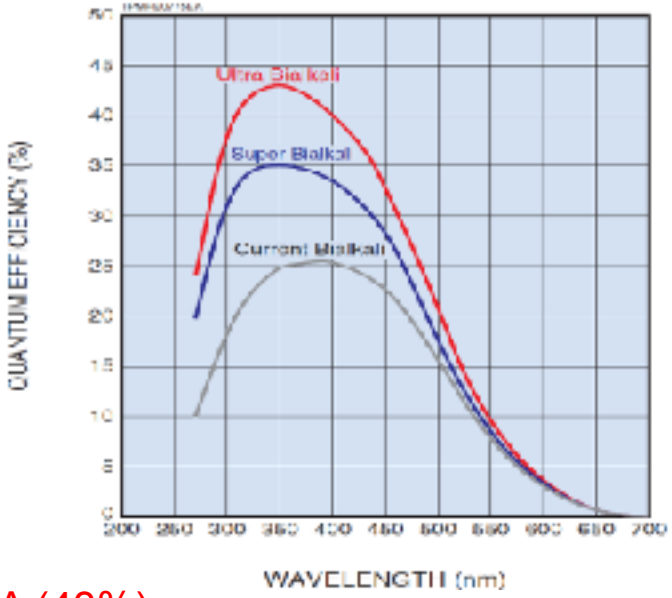
    KamLAND: 34% → Daya Bay II : ~ 80% × 2 ~ 2.5
  - **High QE "PMT": Quantum Efficiency**
  - **(or Photon Detection Efficiency)×2;**

The Quantum Efficiency of PMT (2009)

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 ?)

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

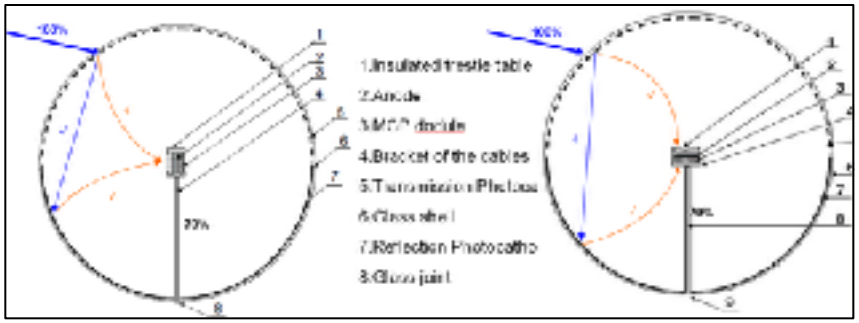
?? 20” UBA/SBA photocathode PMT from Hamamatzu ? QE: 20% → 40%

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

or Photon Detection Efficiency: 14% → 30%

➢ 2. The new design of the MCP-PMT prototypes;

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



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.

➢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;**

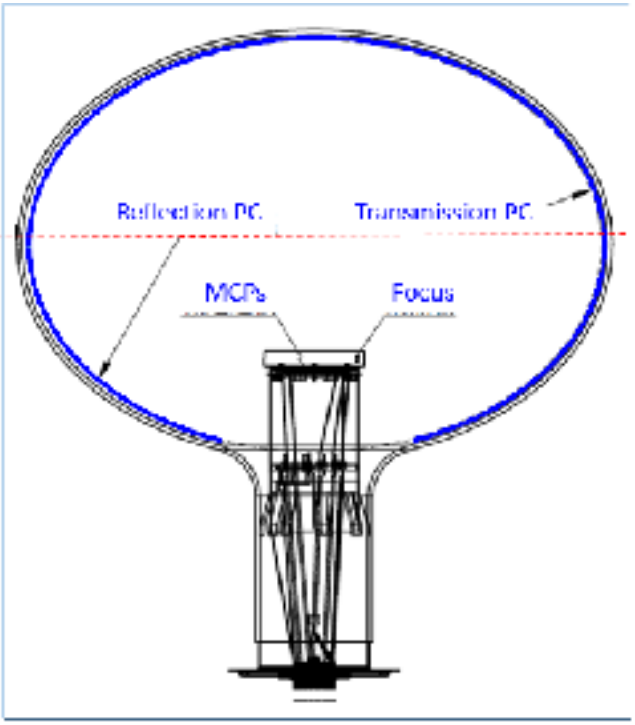
➢**2014: 20” prototypes with normal performance;**

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;

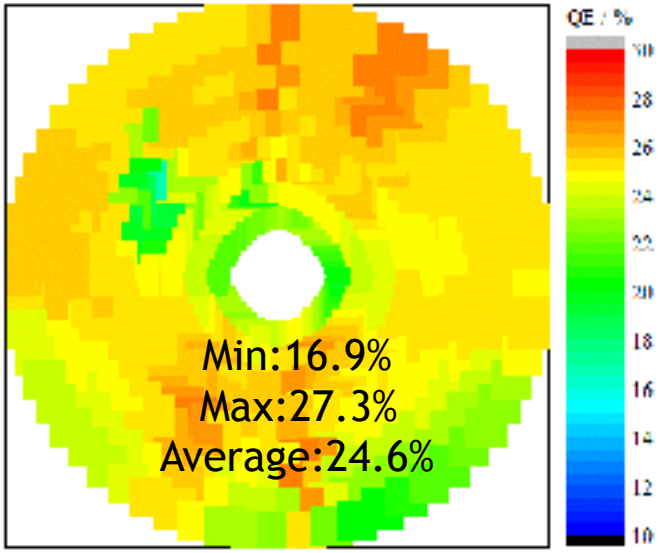
➢2016: for the high QE improvement.

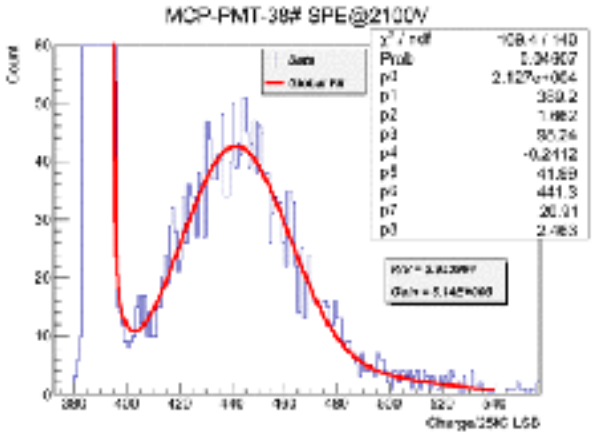


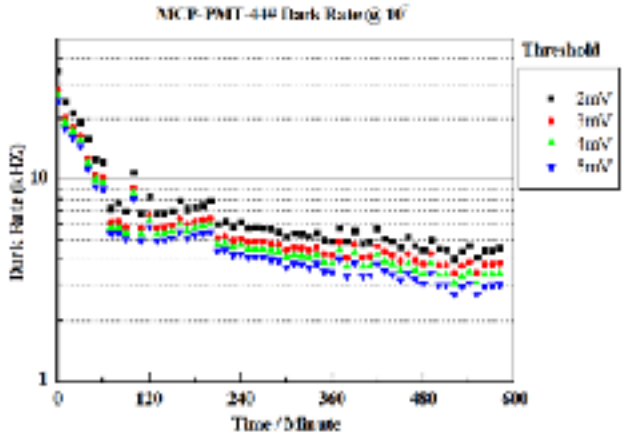
2.1 8”prototypes with normal performance--2013

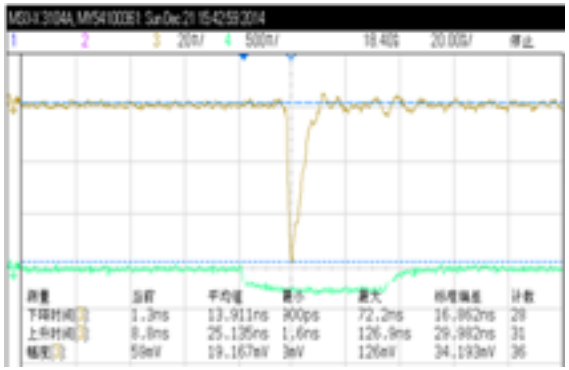
8-inch IHEP MCP-PMT
Vertical MCPs
Sphere Glass

8-inch IHEP MCP-PMT
Horizontal MCPs





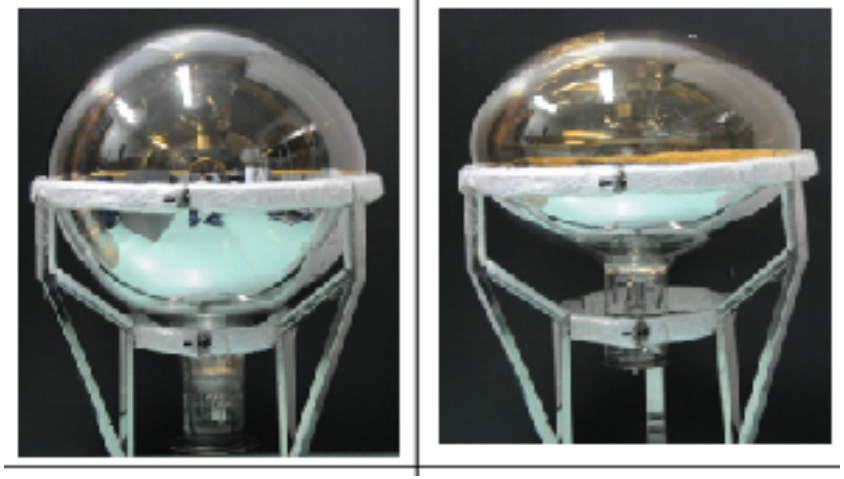


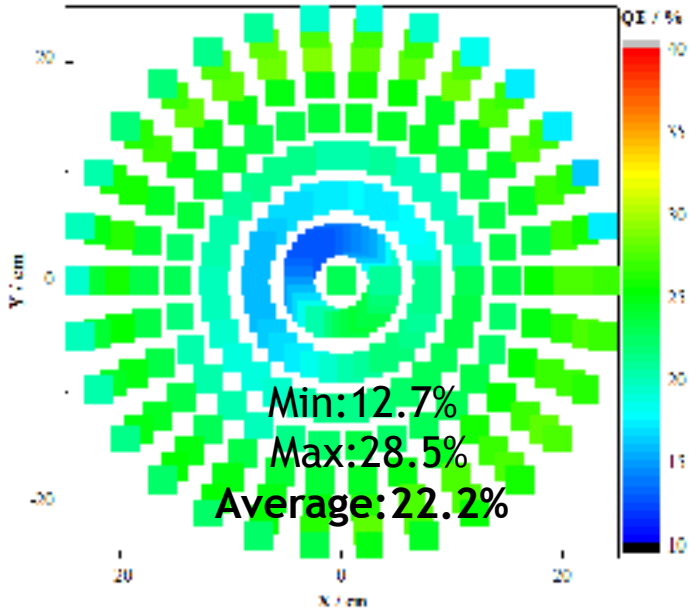


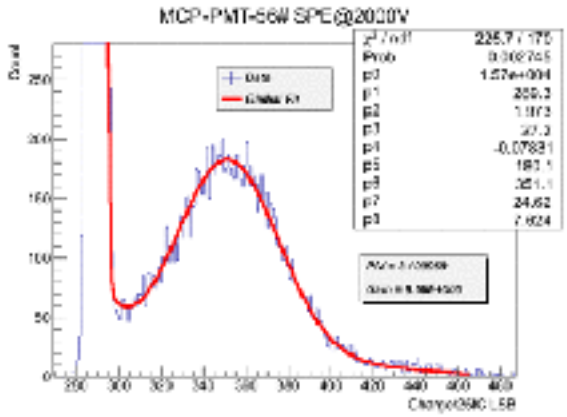
HV	Gain	P/V	Rise Time	Fall Time	Dark rate @1E7 Gain(0.25PE)
2100V	~1E7	~4	~1.3ns	~8.8ns	~3kHz

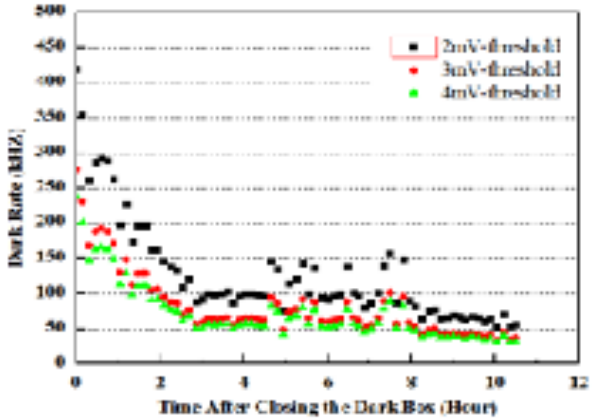
2.2 20”prototypes with normal performance--2013

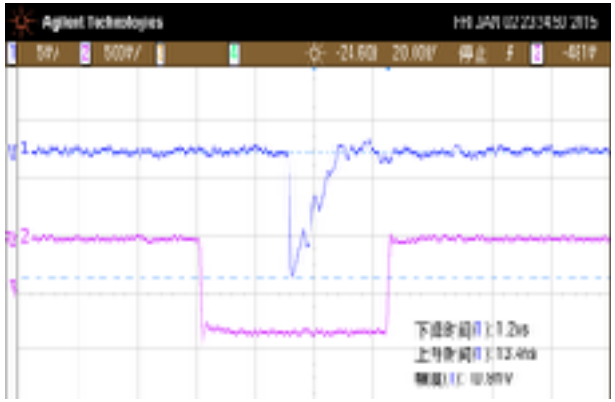
20-Inch II HP MCP-PMT	20-Inch III HP MCP-PMT
Vertical MCPs	Horizontal MCPs
Sphere Glass	Ellipsoidal Glass







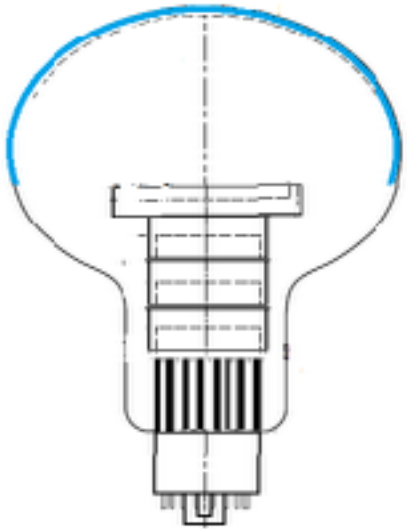


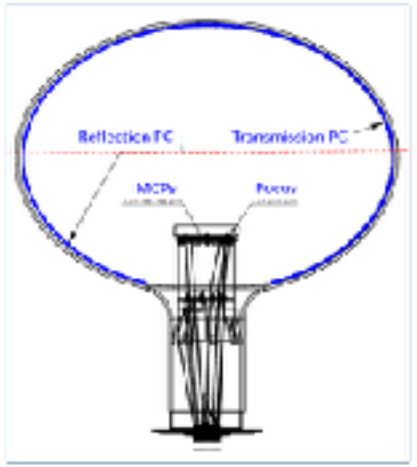


HV	Gain	P/V	Rise Time	Fall Time	Dark rate @1E7 Gain(0.25PE)
2000V	~1E7	~3	~1.2ns	~15ns	~50kHz

➢ 3. The High PDE MCP-PMT--2015

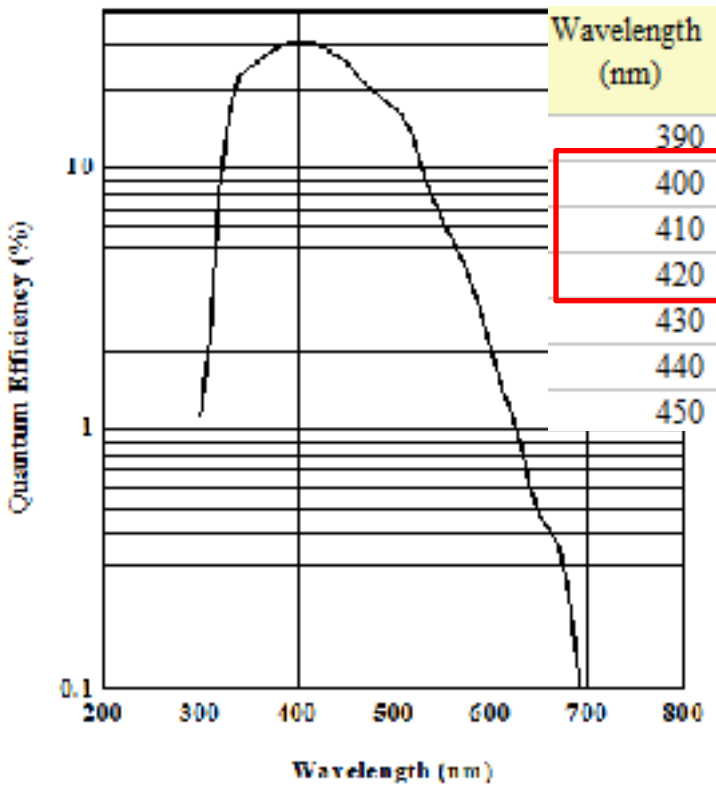
20-inch Hamamatus PMT-Dynode Ellipsoidal Glass	20-inch IHEP-MCP-PMT-Ellipsoidal Glass





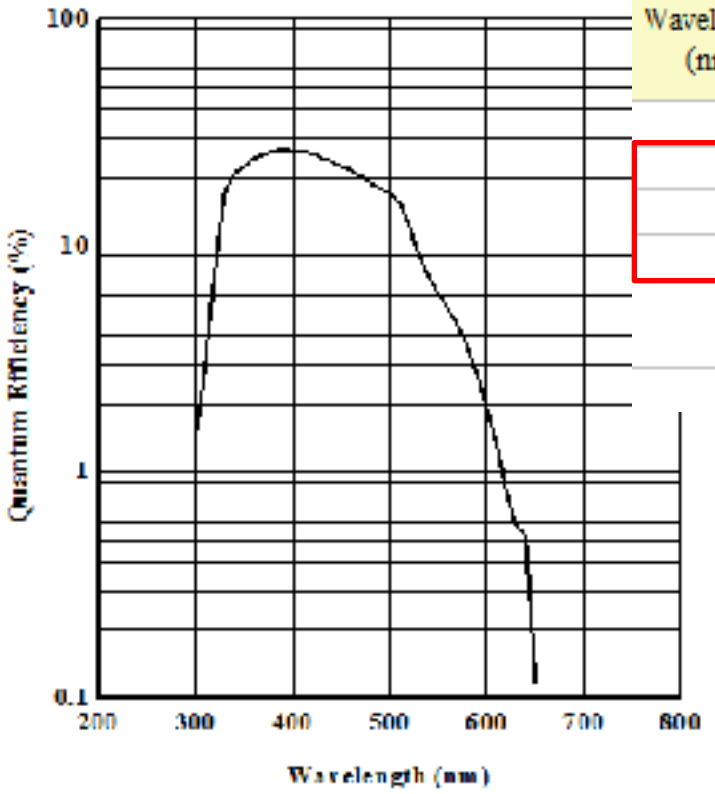
3.1 The QE of the Photocathode

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

Hamamatsu R12860

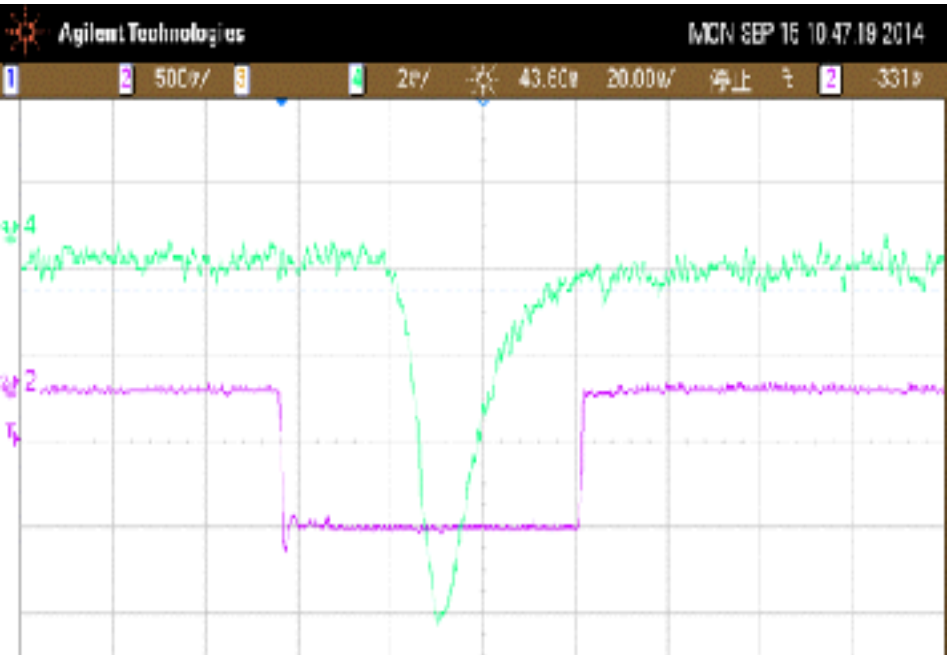


Wavelength (nm)	79#
390	26.32155
400	26.18978
410	26.058
420	25.4807
430	24.47672
440	23.4516
450	22.37645

MCP-PMT

3.2 Waveform of the Prototype

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

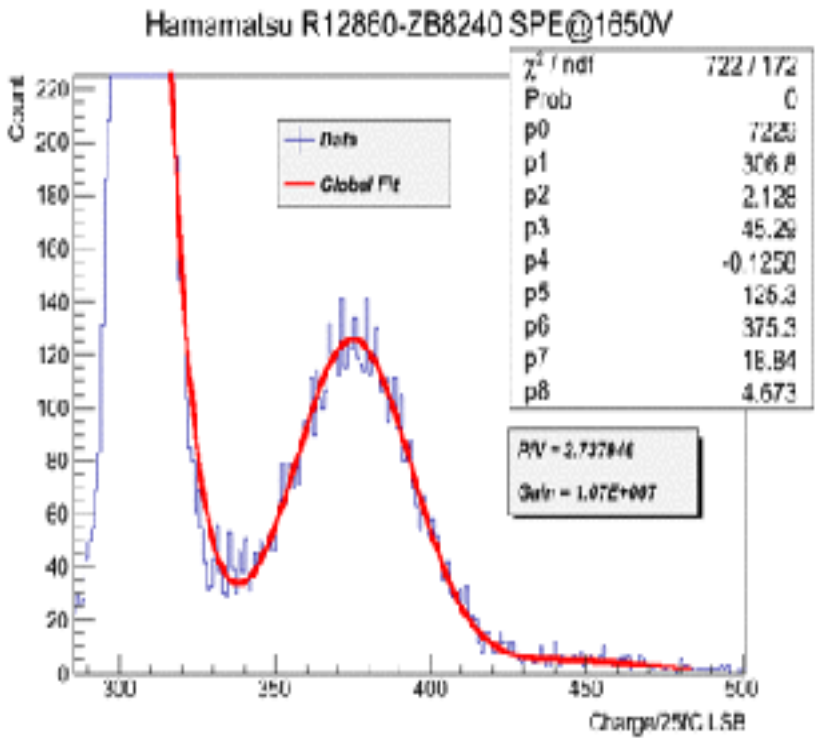


Hamamatsu R12860

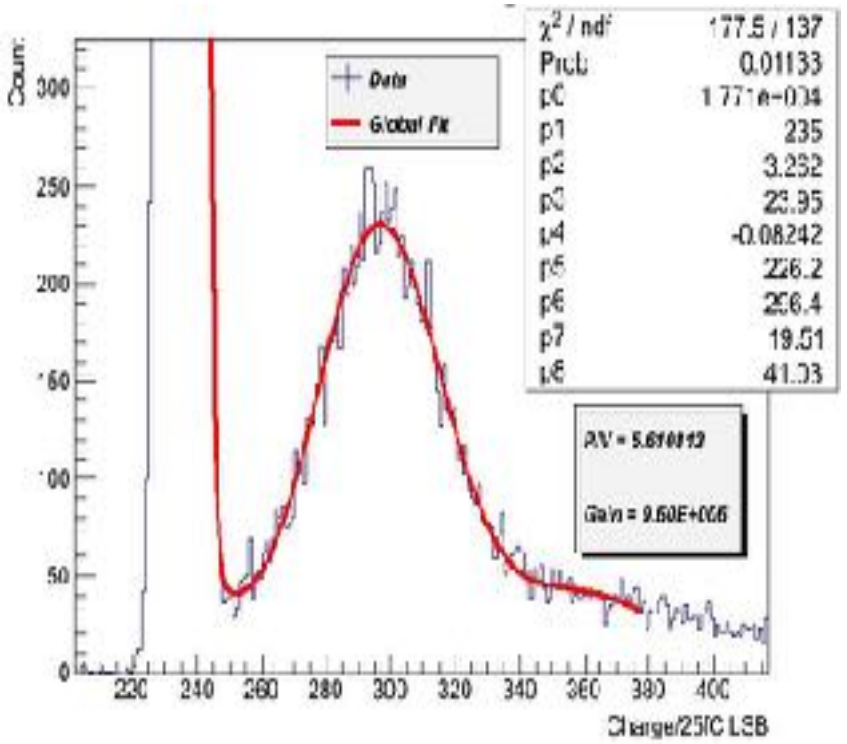
MCP-PMT

➢ 3.3. The SPE of the Prototype;

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



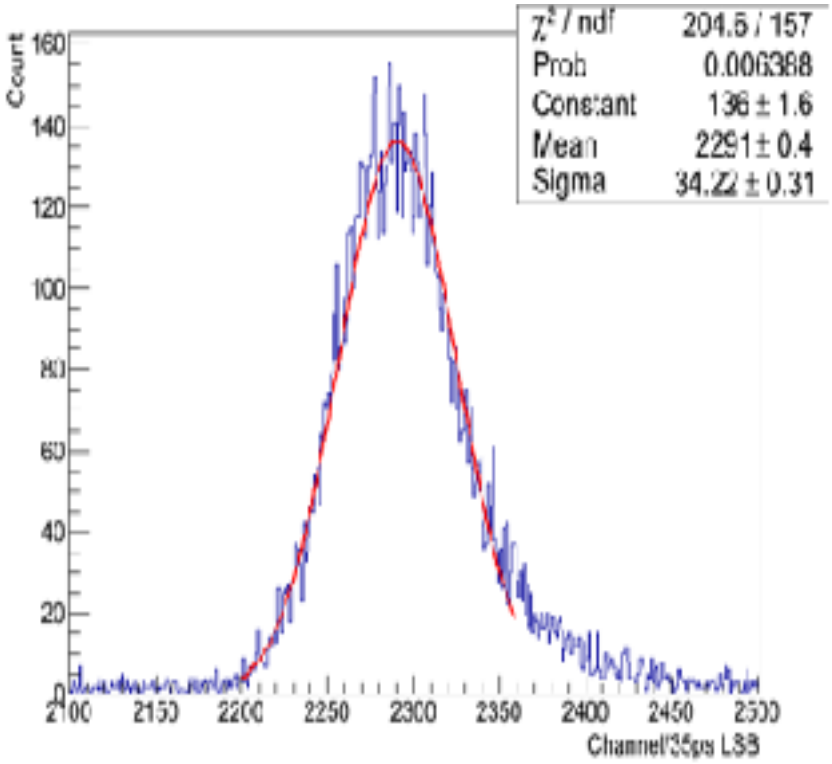
Hamamatsu R12860



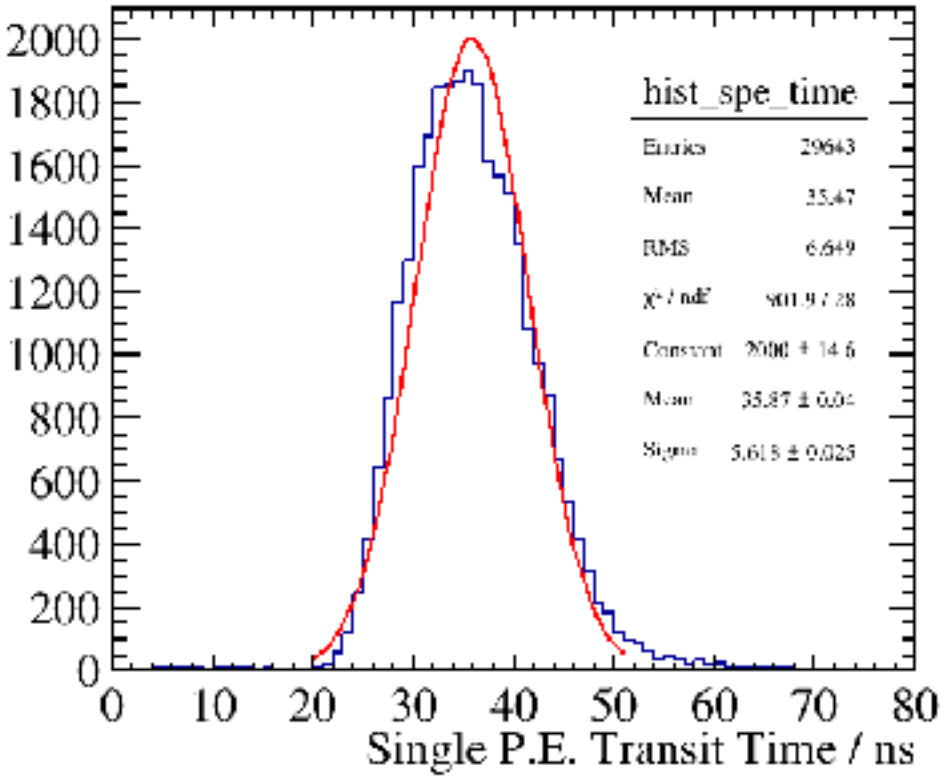
MCP-PMT

3.4. The TTS of the Prototype;

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



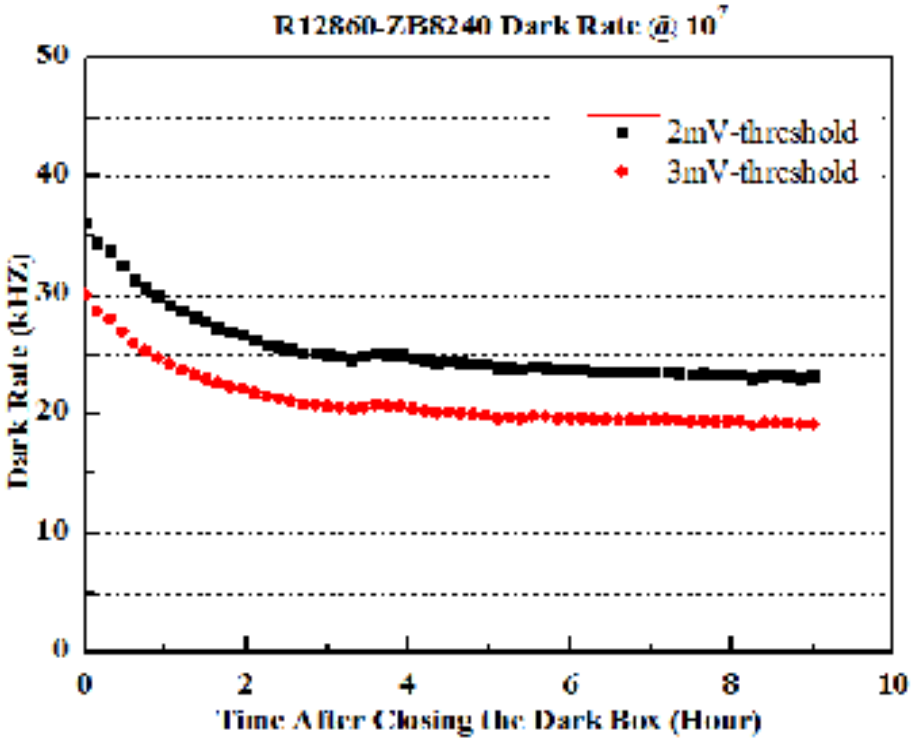
Hamamatsu R12860



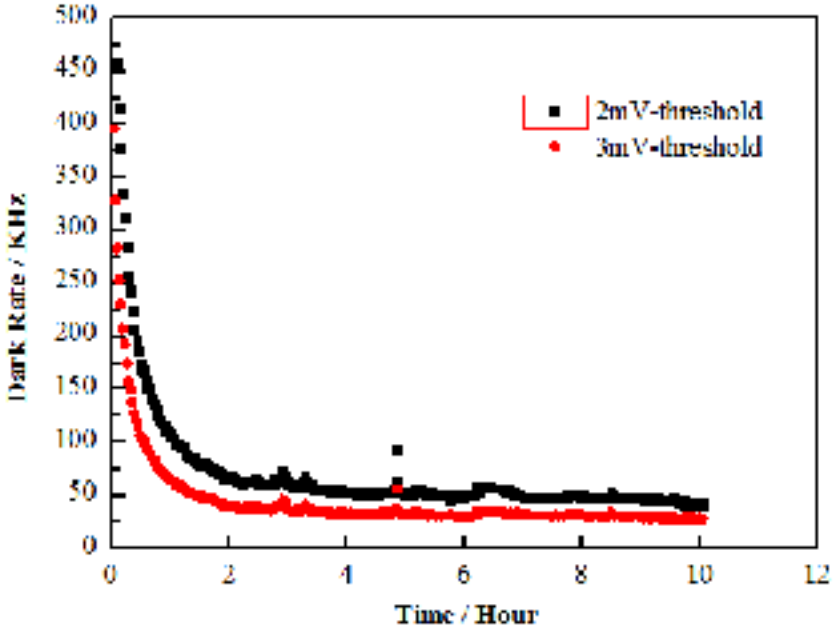
MCP-PMT

3.5. The Dark count of the Prototype;

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



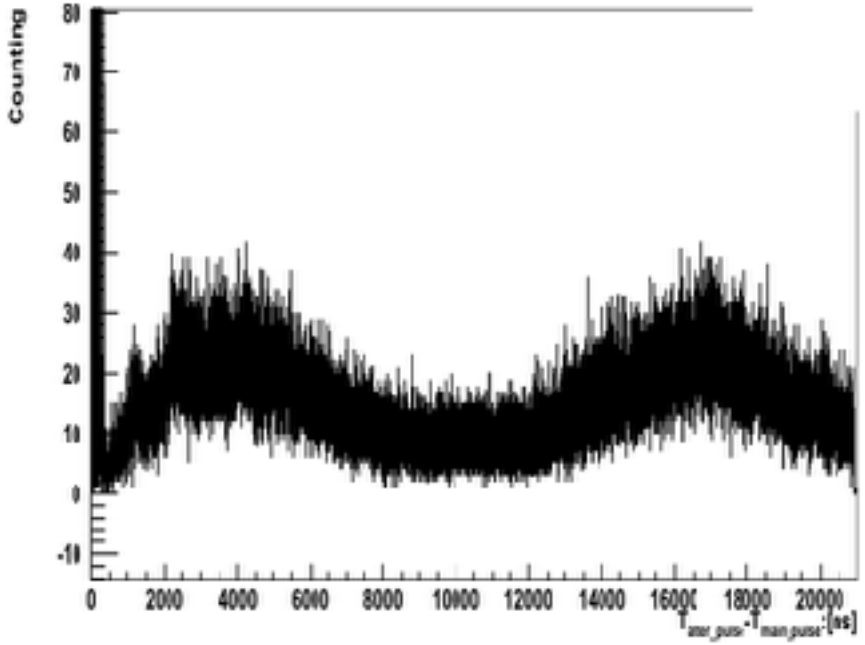
Hamamatsu R12860

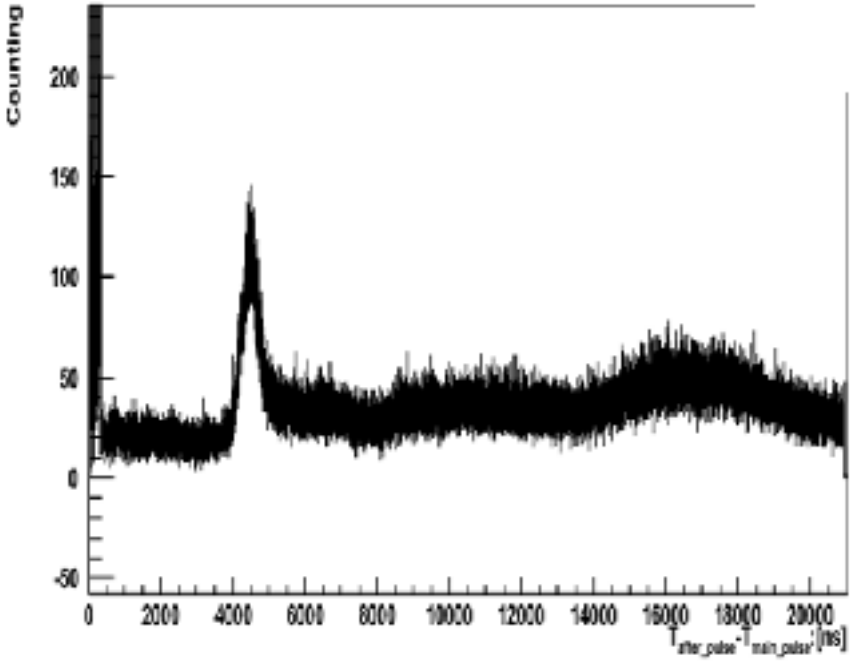


MCP-PMT

3.6. The After Pulse Rate of the Prototype

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



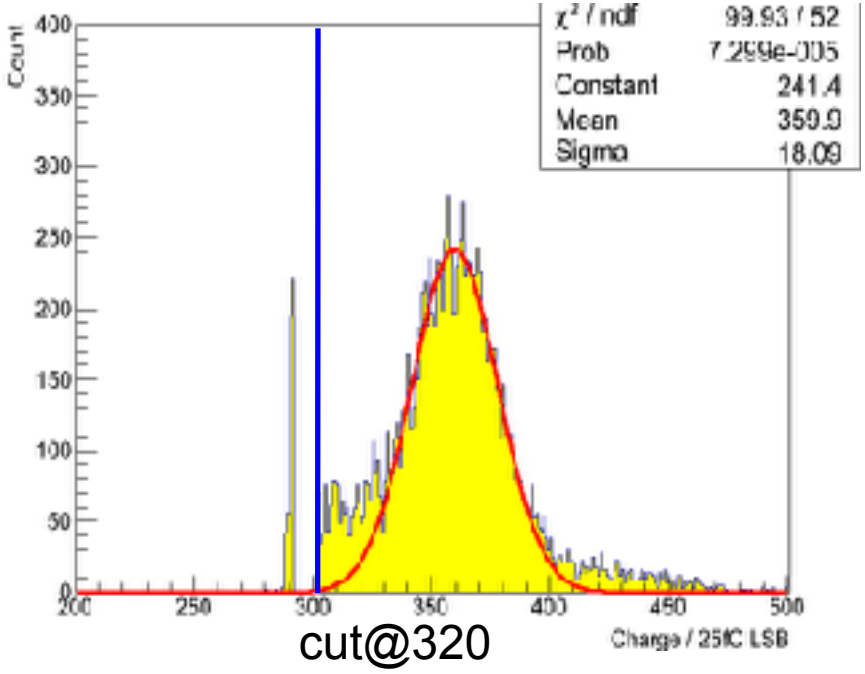


Hamamatsu R12860

MCP-PMT

3.7. The Relativity Detection efficiency of the Prototype

	HV	Gain	Relativity PDE
R12860	1650V	~1.1E7	100%
MCP-PMT	1930V	~9.6E6	110%



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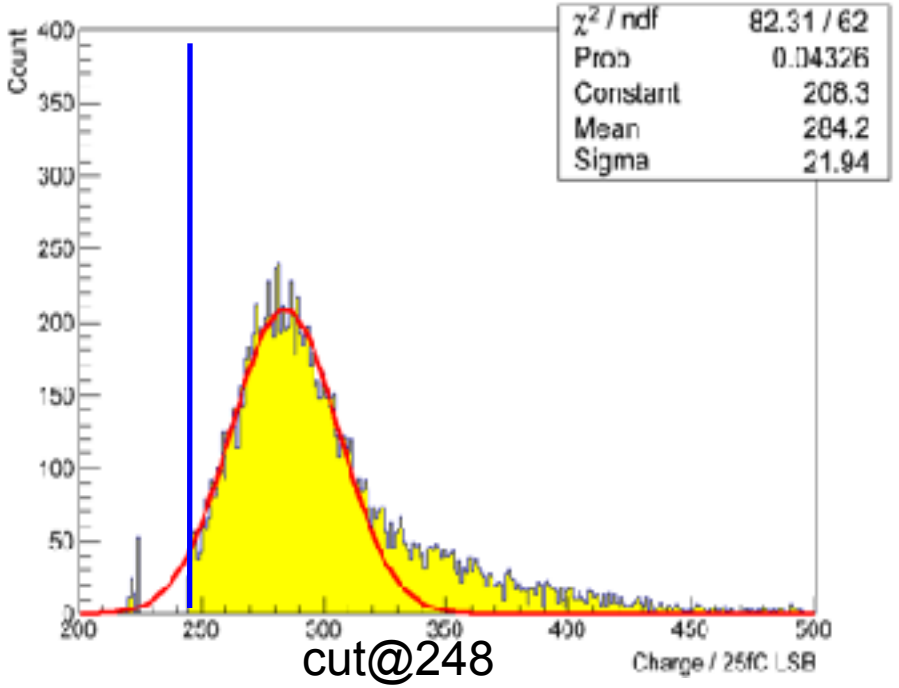


cut@248

Hamamatsu R12860

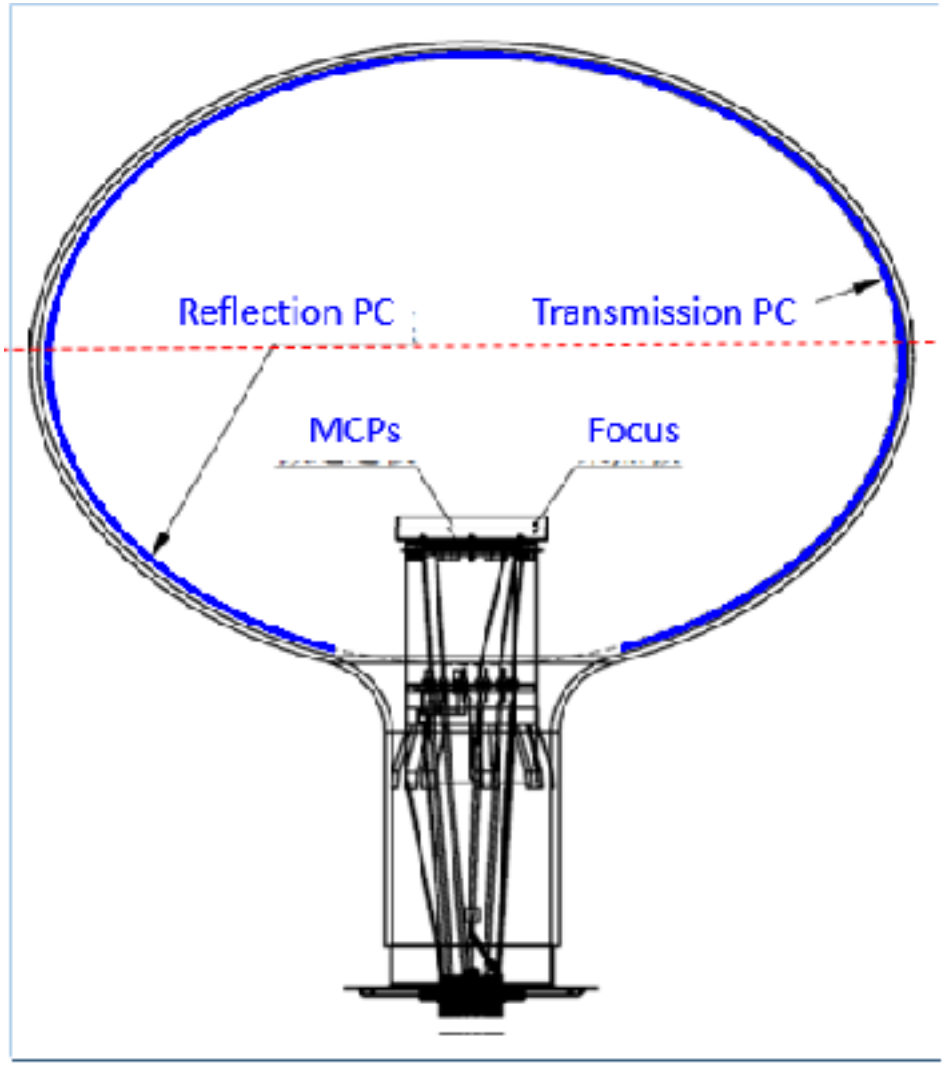
MCP-PMT

3.8 The performance of the 20 inch prototypes

Characteristics	unit	MCP-PMT（IHEP）	R12860 （Hamamatsu）
Electron Multiplier	--	**MCP**	Dynode
Photocathode mode	--	**reflection+ transmission**	transmission
Quantum Efficiency（400nm）	%	**26 (T), 30 (T+R)**	**30(T)**
Relativity Detection Efficiency	%	**~ 110%**	**~ 100%**
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

➢ 4. The Special Behaviors of the MCP-PMT

➢ 4.1. The Transmission + Reflection QE of the Photocathode



Good situation:

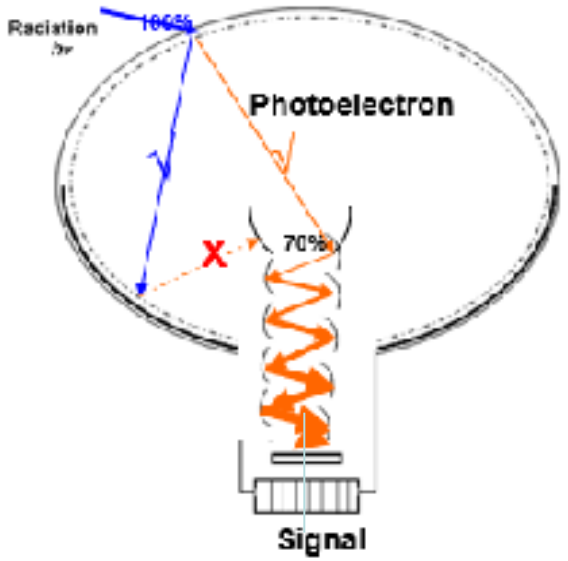
→ Improve the total QE;

→ Improve the Detection Efficiency;

Bad situation:

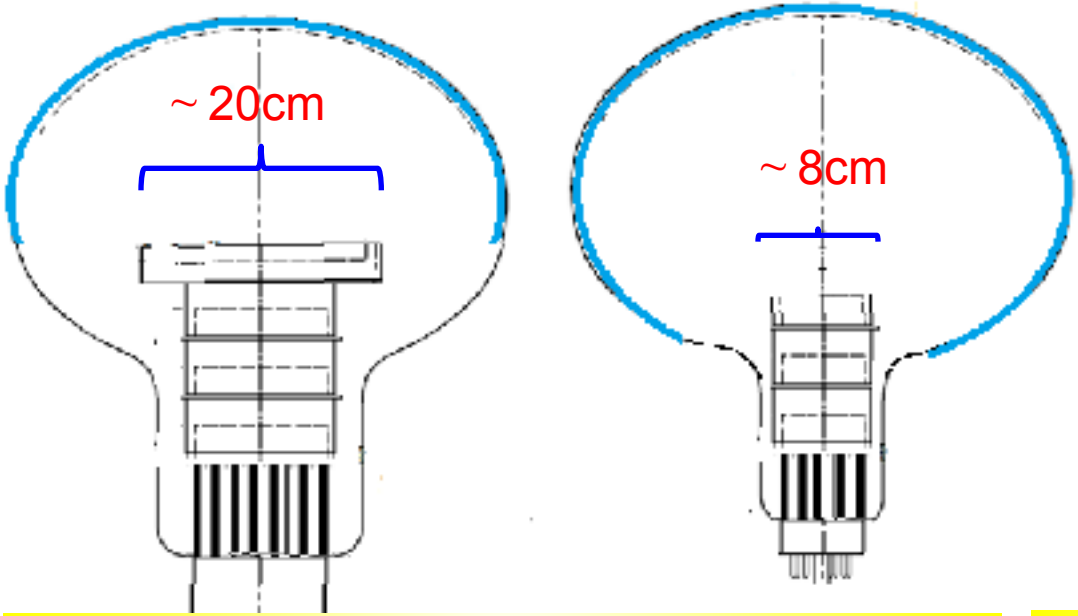
→ Larger Dark count;

→ larger TTS;



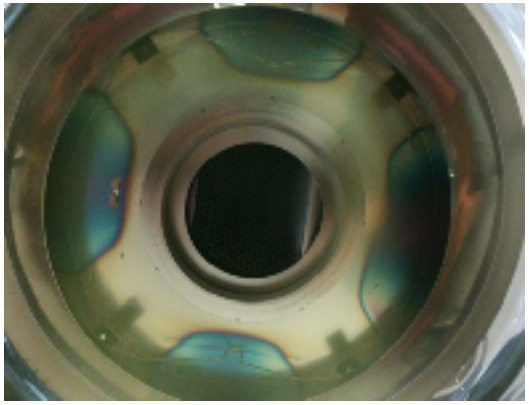
➢ 4.2. The High Collection Efficiency of the Prototype

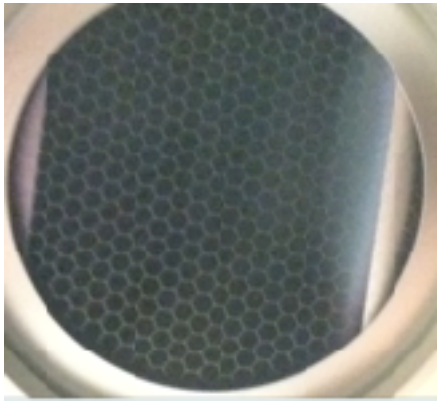
➢ MCP: Large area PC (Rrf. + Tran.)



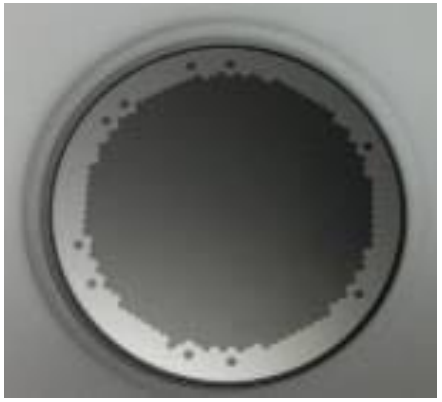
	Relativity DE
Dynode-PMT	100%
MCP-PMT	110%

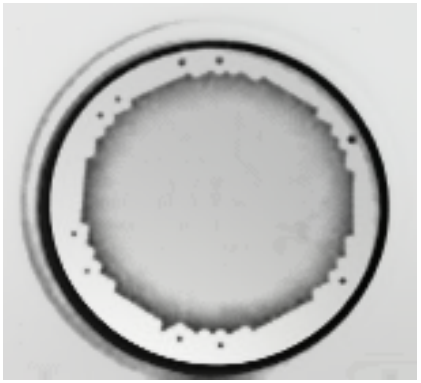
➢ Dynode: A mesh covering the dynode

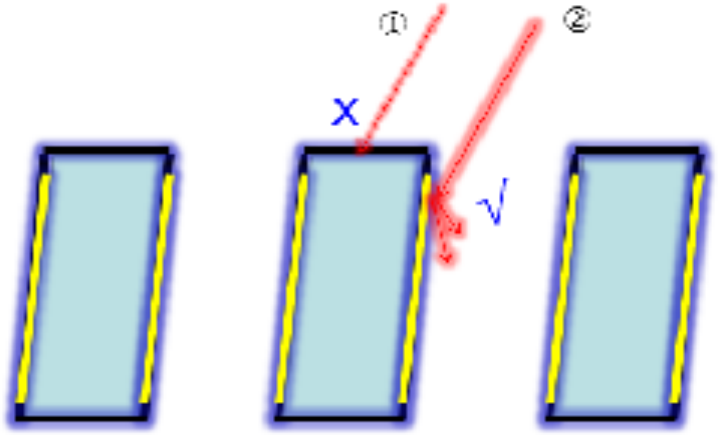




➢ MCP: Special MCP for CE~100%





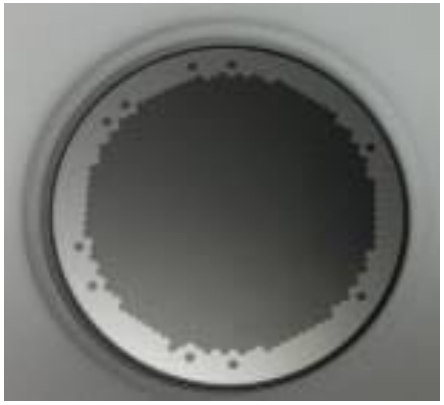


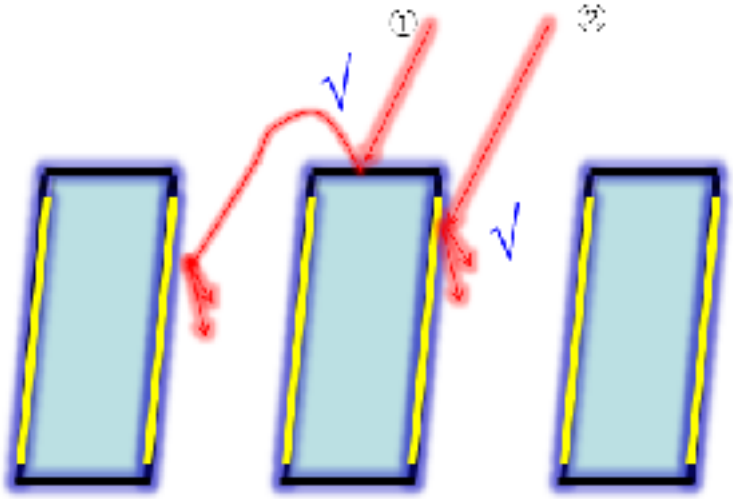
CE = 60%

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

change

The Diameter of the MCP: **33mm; 50mm;**
The Diameter of the Hole: **6um; 8um; 10um; 12um**;
The Inclined Angle: **0°**; **8°**; **12°**;
The Open Area Ratio: **60%**; **77%**;
The Depth of output electrode:……

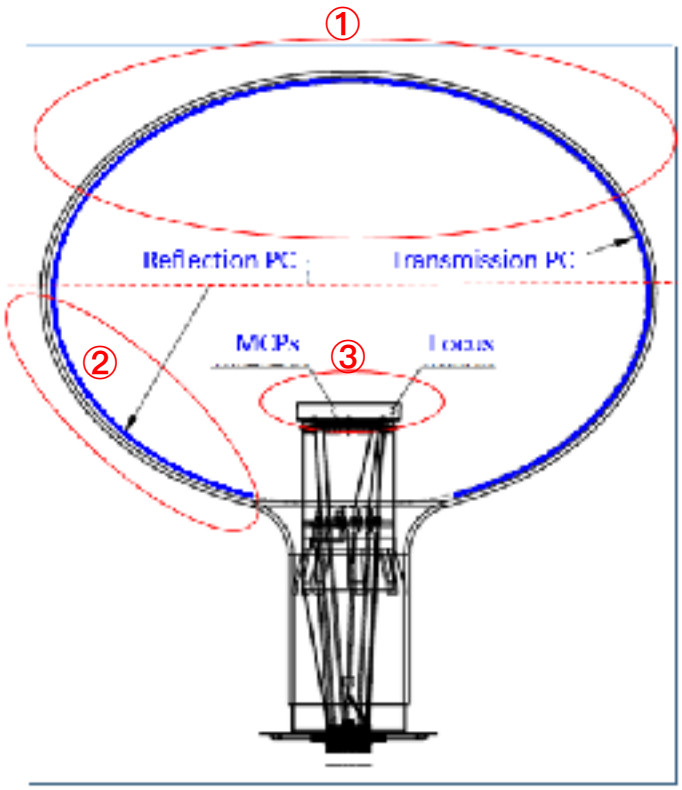




CE = 100%

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

➢ 4.3 Why the TTS is large?



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 prototype

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

--> with special MCP for better DE;

But the TTS will be worse!

The contribution to the TTS

①The distance between the PC to the MCP;

==By adjusting the Electronic optical focusing

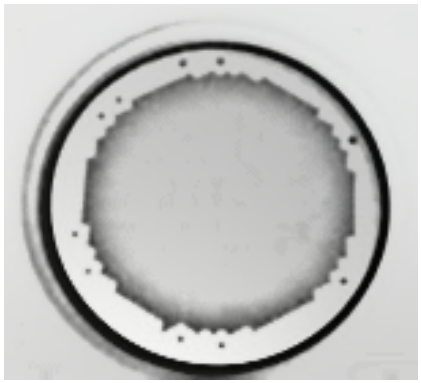
② The difference between the Trans. & Ref. PC;

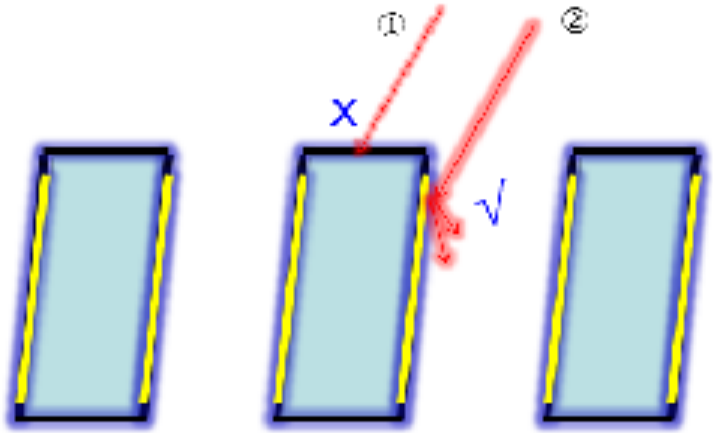
==No way to adjusting; (for better QE)

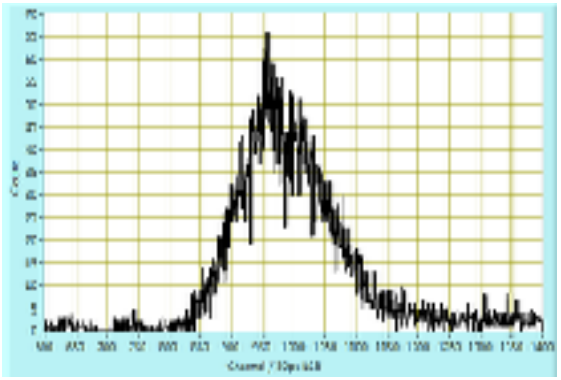
③ The second electron emission part of the MCP;

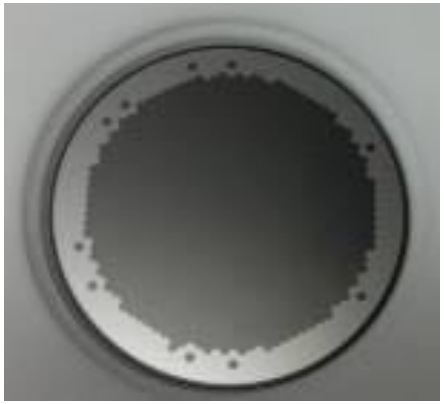
==No way to adjusting; (for better DE)

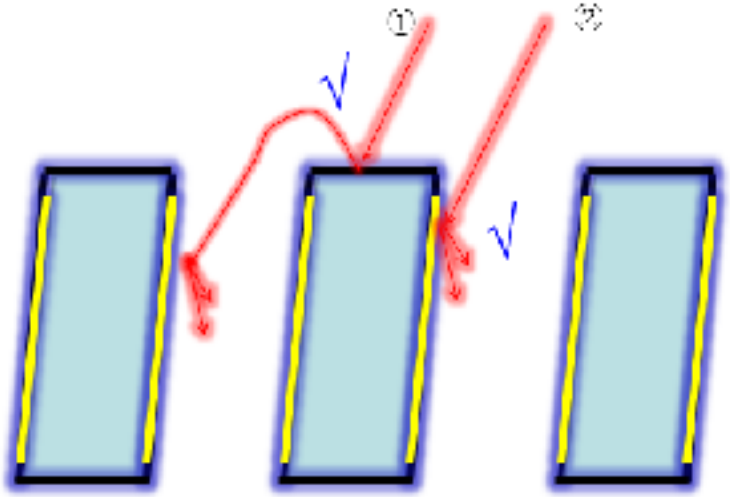
4.3.1 The second electron emission part of the MCP (channel or electrode);

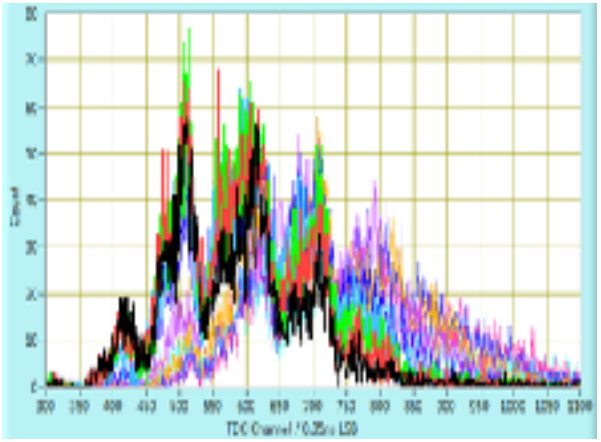












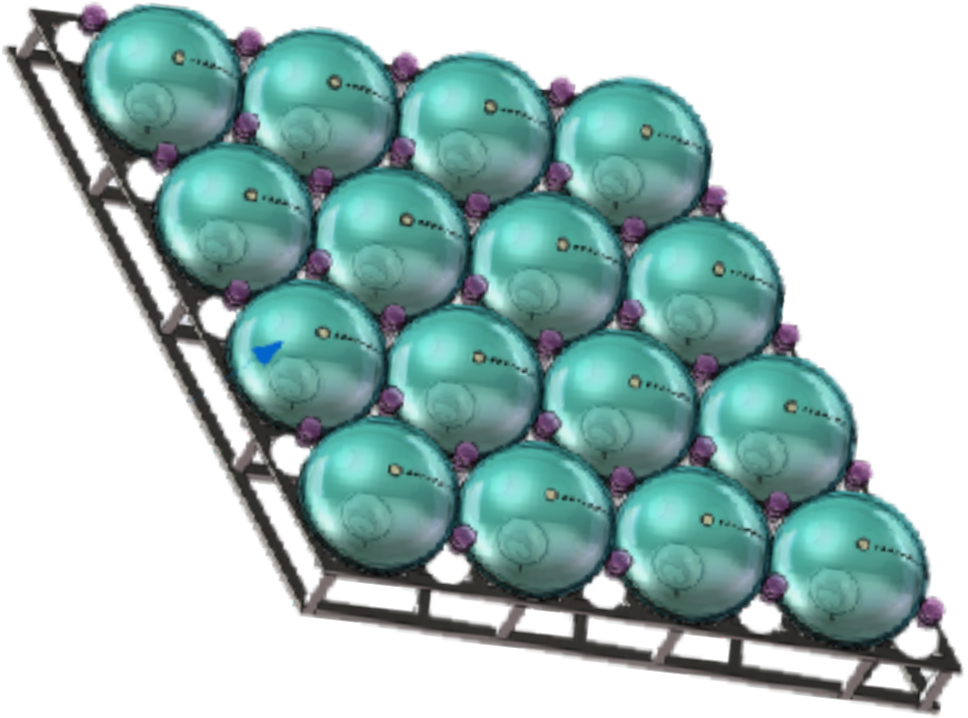
➢With the contribution of the second electron from the electrode (40%),

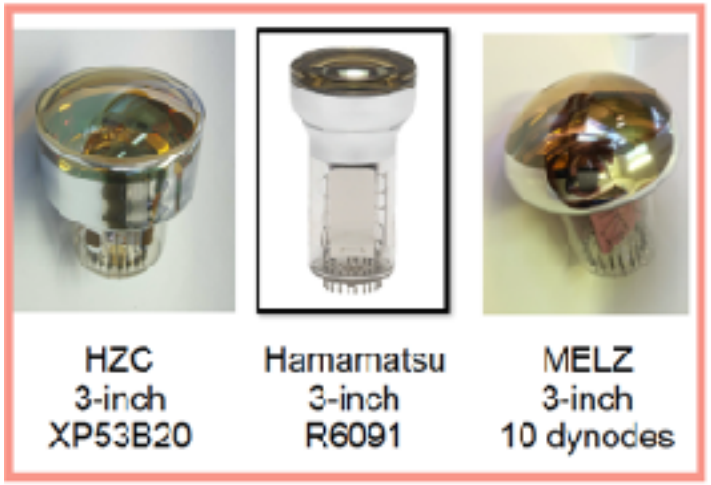
the spectrum of the TTS present several peaks, which made it's TTS worse.

4.3.12 How to improve the JUNO PMT's time resolution?

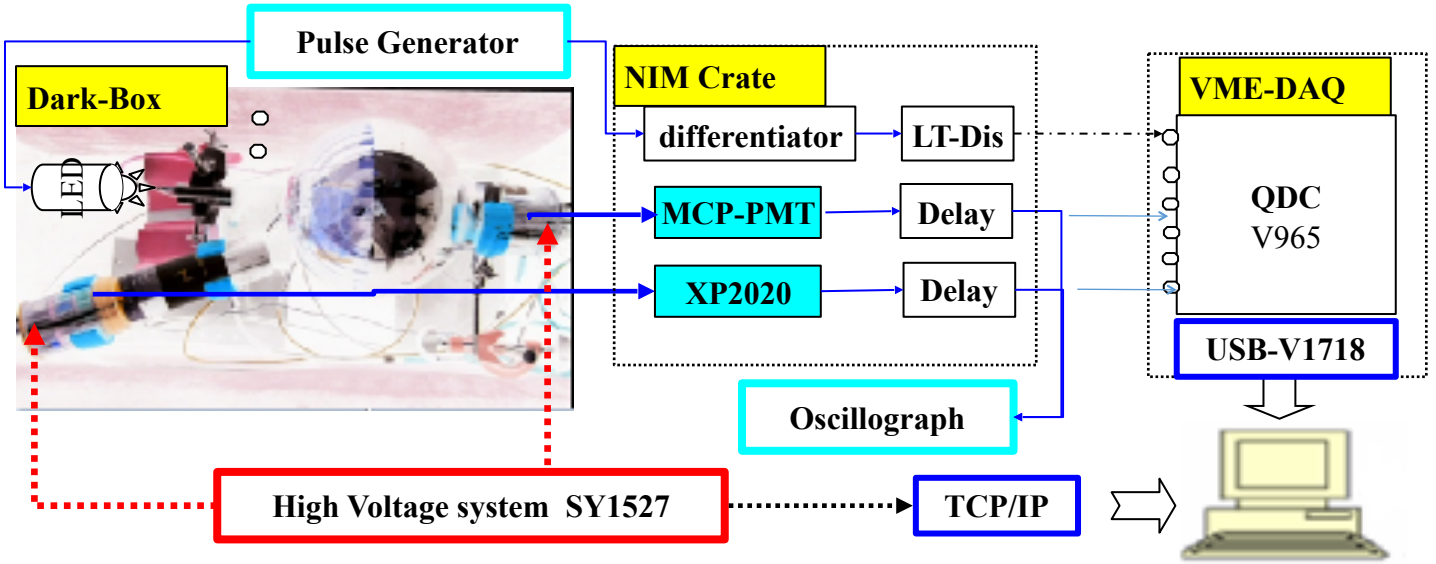
- optical coverage: 78%
  → 18,000 large PMTs (20“) → 75%
  → 36,000 small PMTs (3“) → 3%
  (double calorimetry + timing)

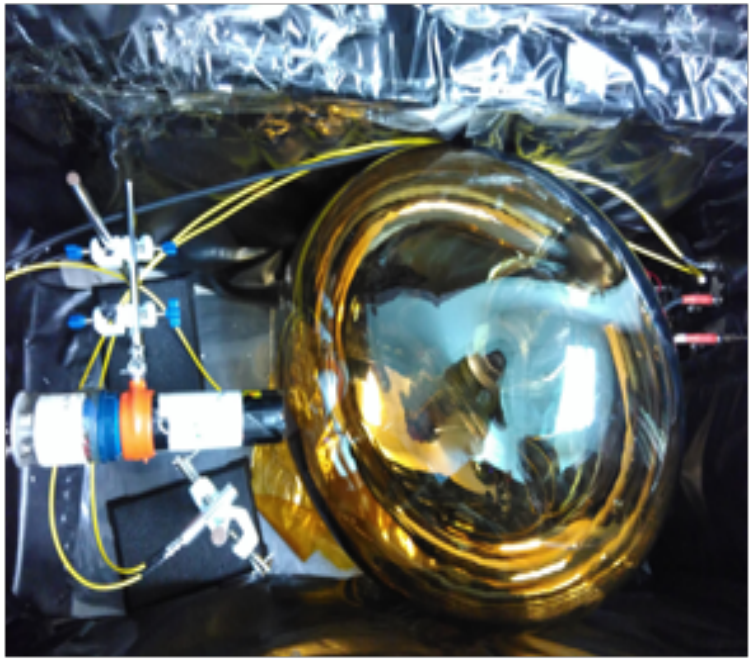
	TTS @ top center
R12860 (20”)	~2.8ns
MCP-PMT(20”)	~12ns
3” PMT	~1.5ns





➢ 4.4 The aging behavior of the Prototype;





➢ 2inch XP2020 （Reference PMT ）

----Monitoring the stability of the light and electronics.

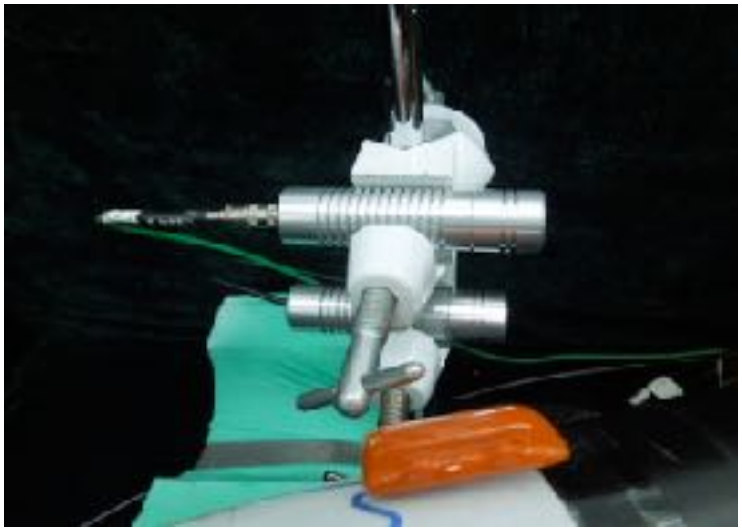
➢ **20inch MCP81** （Test PMT）

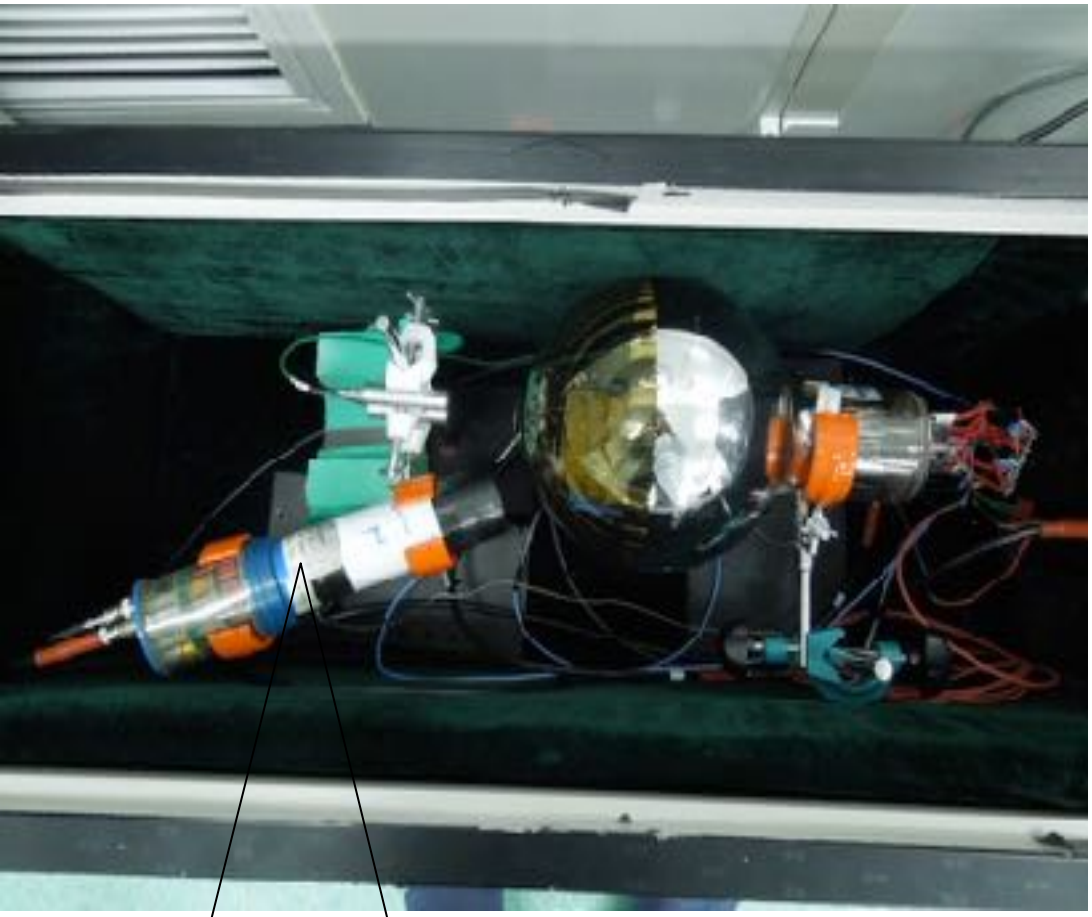
----Monitoring the SPE; ----> the stability of Gain

----Monitoring the MPE (~1000p.e.) the stability of Gain

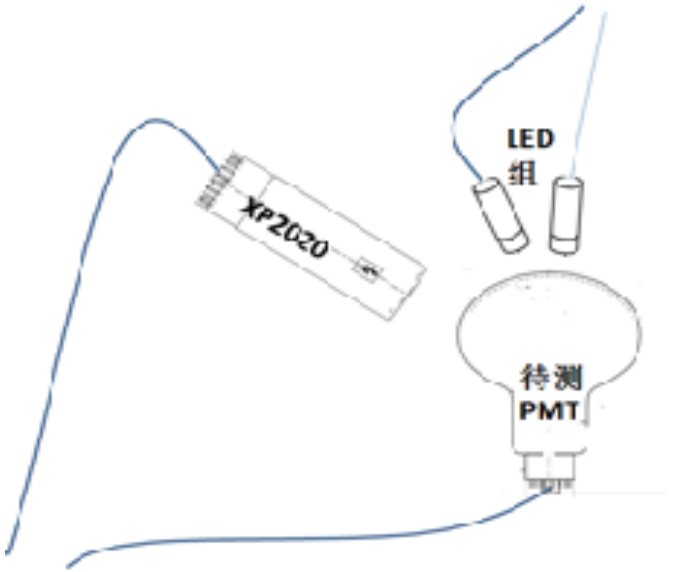
----Monitoring the pedestal; the stability of electronics;

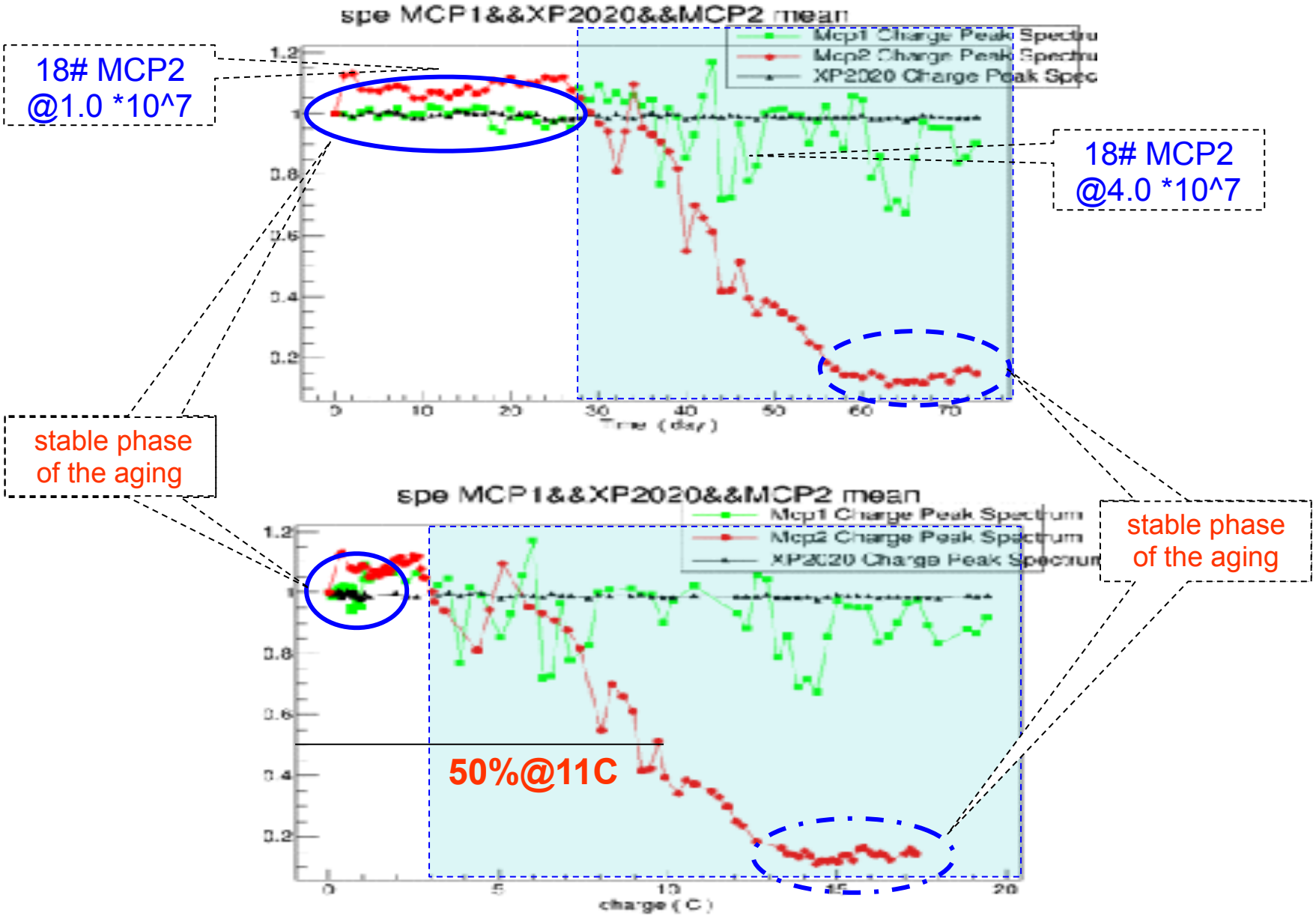
➢ 4.4.1 The Aging of the 8” MCP-PMT （with normal MCP）



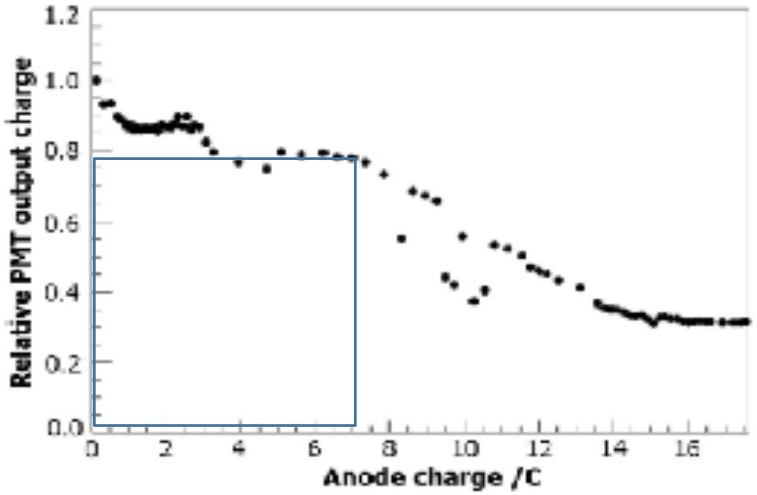


The reference PMT XP2020 for monitoring the stabilization of the LED light



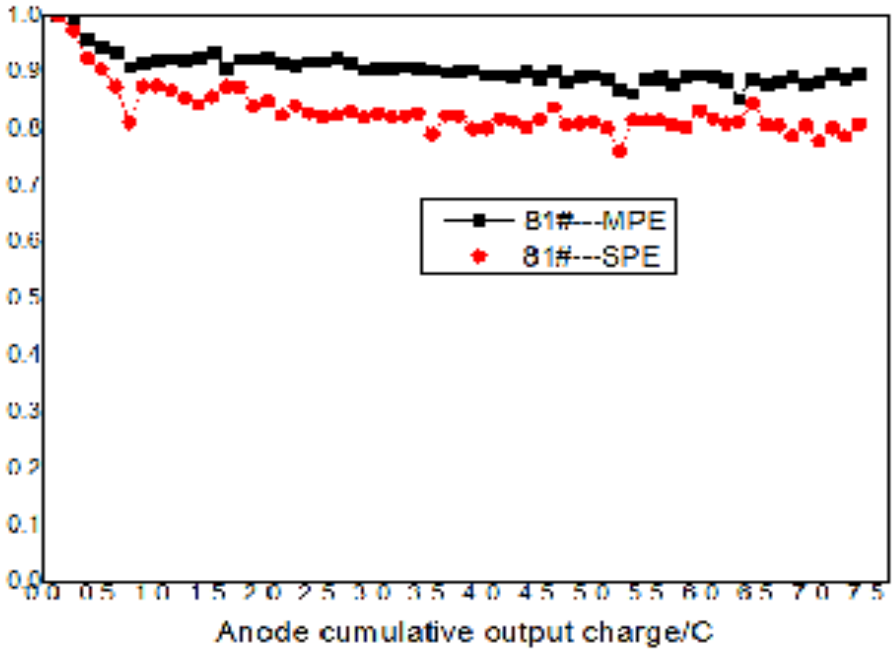


The gain of the MCP was decreased to 50% after its output 10C electric charge;
The characteristics of the MCP aging also need to monitored for different types of MCPs in the prototypes;



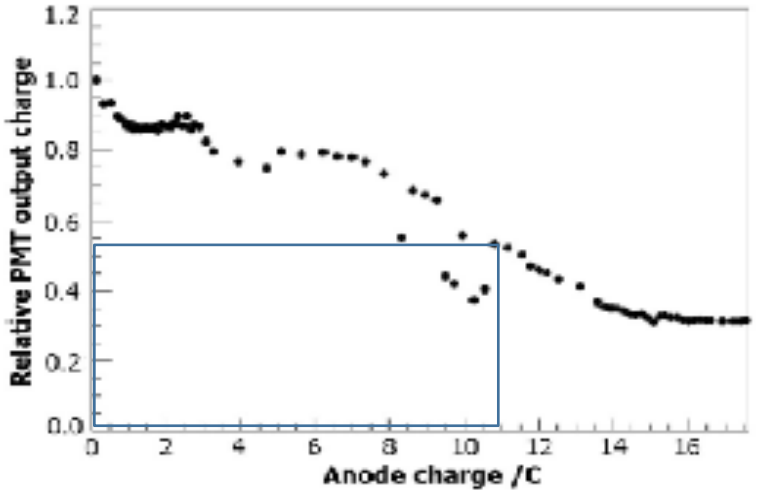
➢8” MCP-PMT in 2014 with ~1000p.e. enhanced aging test,

➢the Gain of the PMT changed to **80%@7C@1X10^7** with MPE;



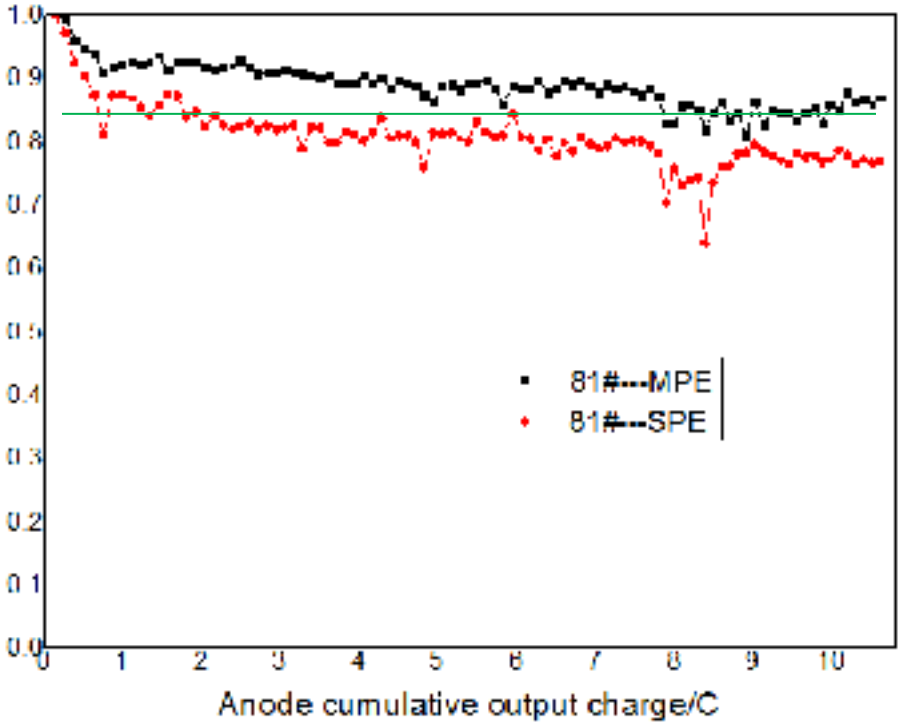
➢20” MCP-PMT in 2016 with ~1000p.e. enhanced aging test,

➢the Gain of the PMT changed to **90%@7C@1X10^7** with MPE;



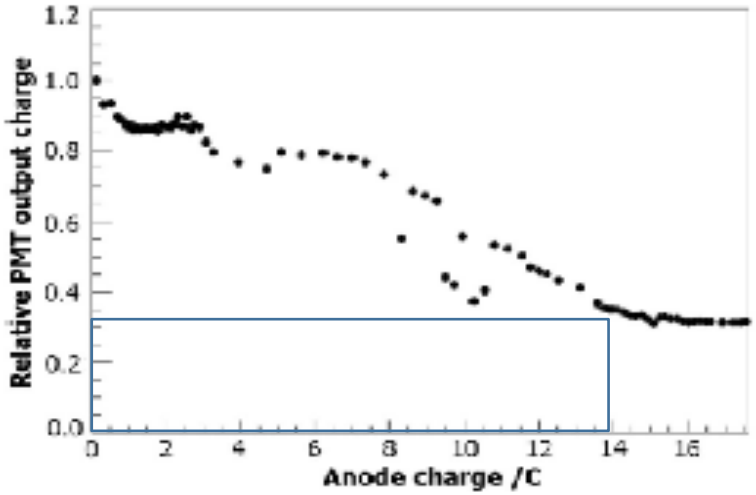
➢8” MCP-PMT in 2014 with ~1000p.e. enhanced aging test,

➢the Gain of the PMT changed to **50%@11C@1X10^7** with MPE;



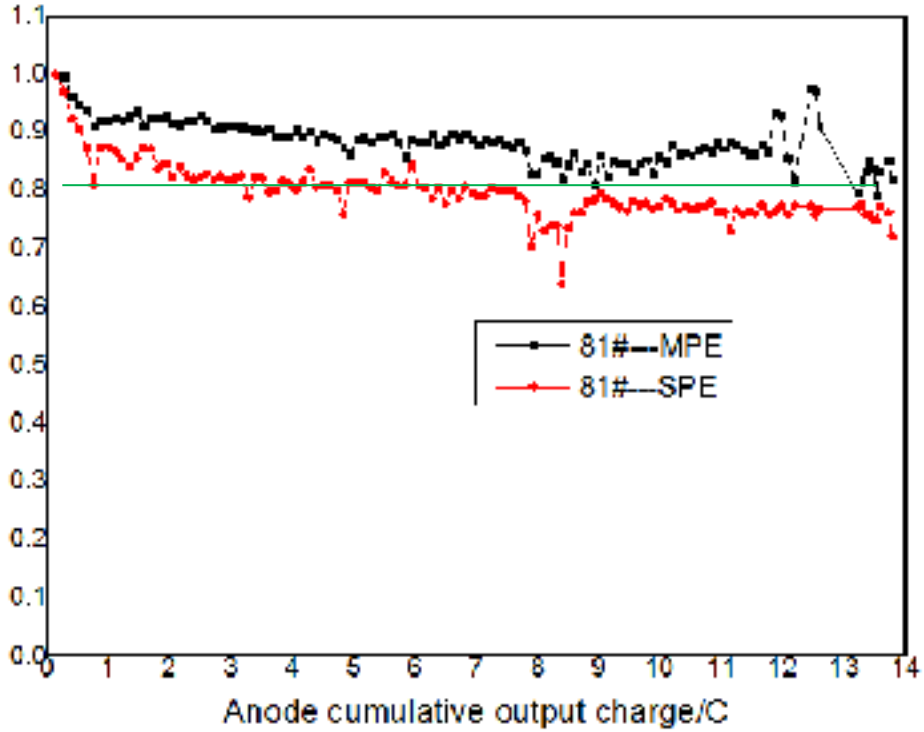
➢20” MCP-PMT in 2016 with ~1000p.e. enhanced aging test,

➢the Gain of the PMT changed to **85%@11C@1X10^7** with MPE;



➢8” MCP-PMT in 2014 with ~1000p.e. enhanced aging test,

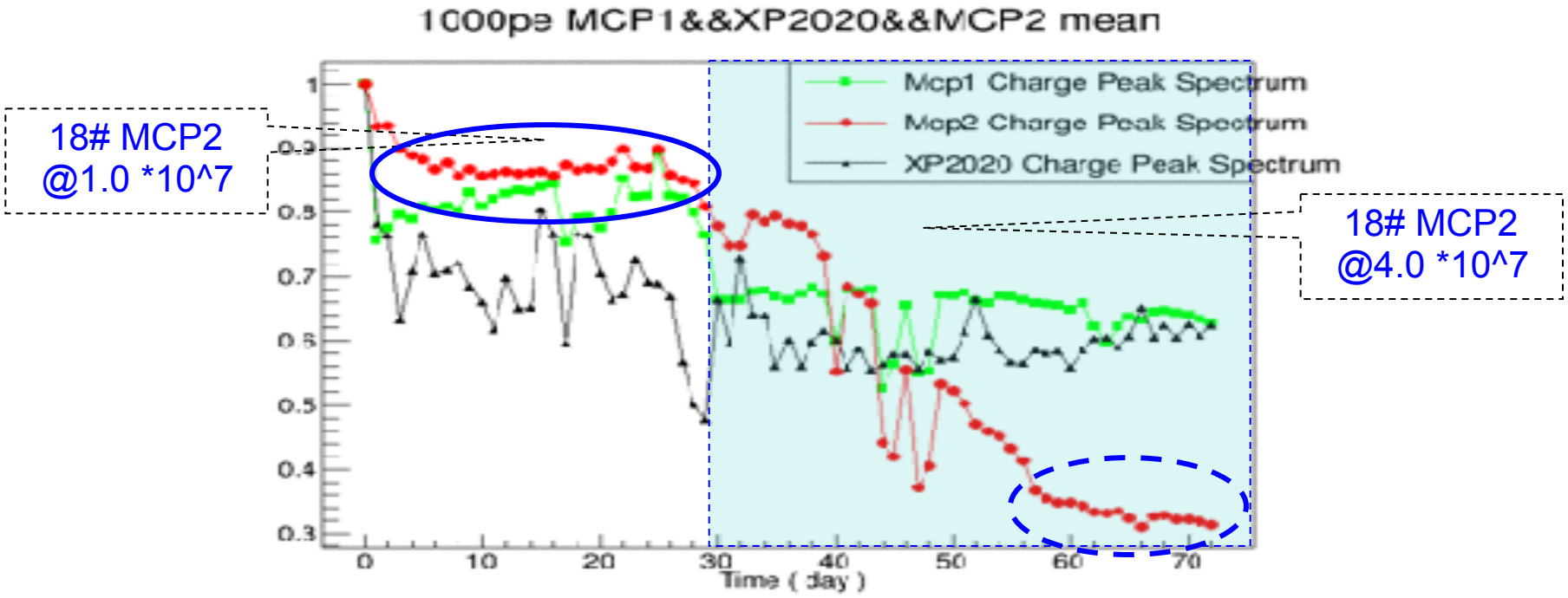
➢the Gain of the PMT changed to **35%@14@1X10^7** with MPE;



➢20” MCP-PMT in 2016 with ~1000p.e. enhanced aging test,

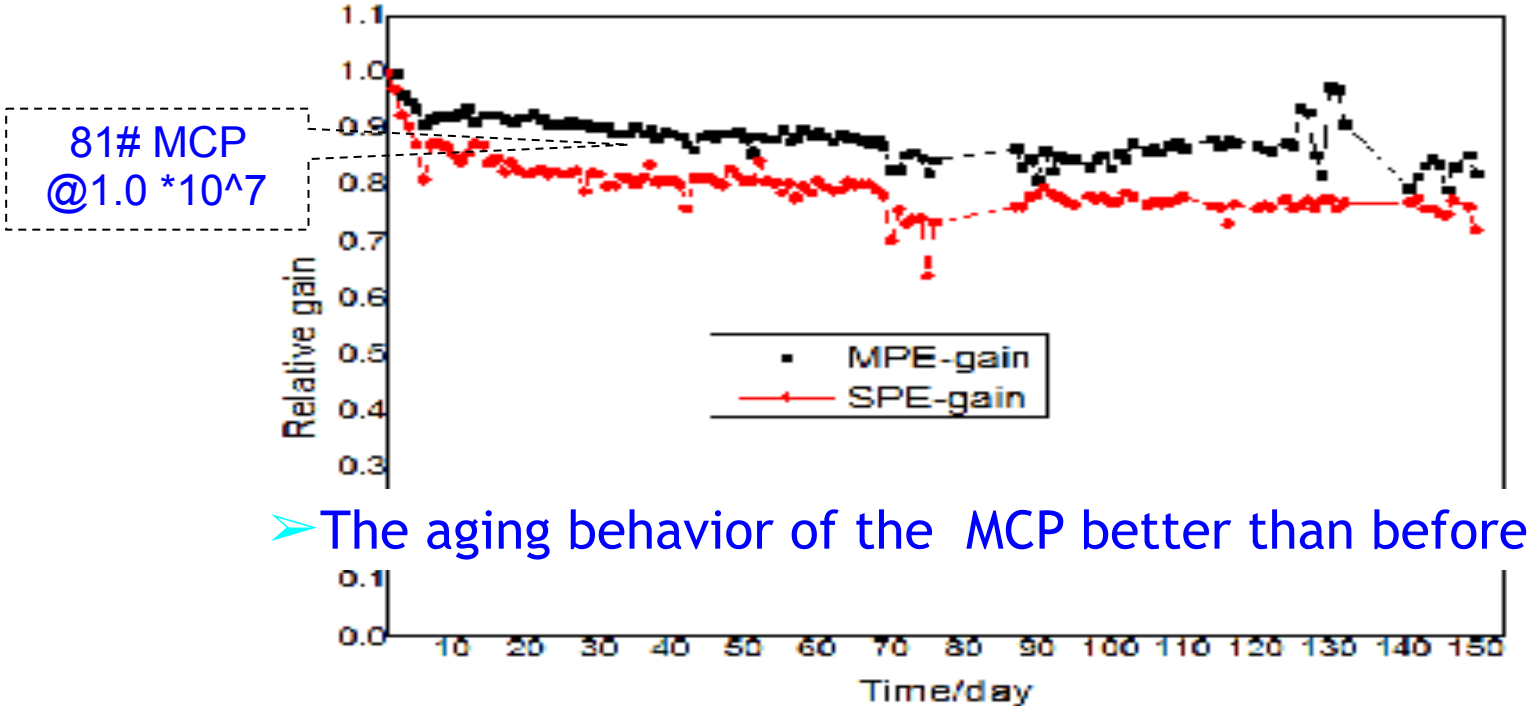
➢the Gain of the PMT changed to **80%@14C@1X10^7** with MPE;

➢The aging behavior of the MCP better than before.



18# MCP2 @1.0 *10^7

18# MCP2 @4.0 *10^7



81# MCP @1.0 *10^7

➢The aging behavior of the MCP better than before.

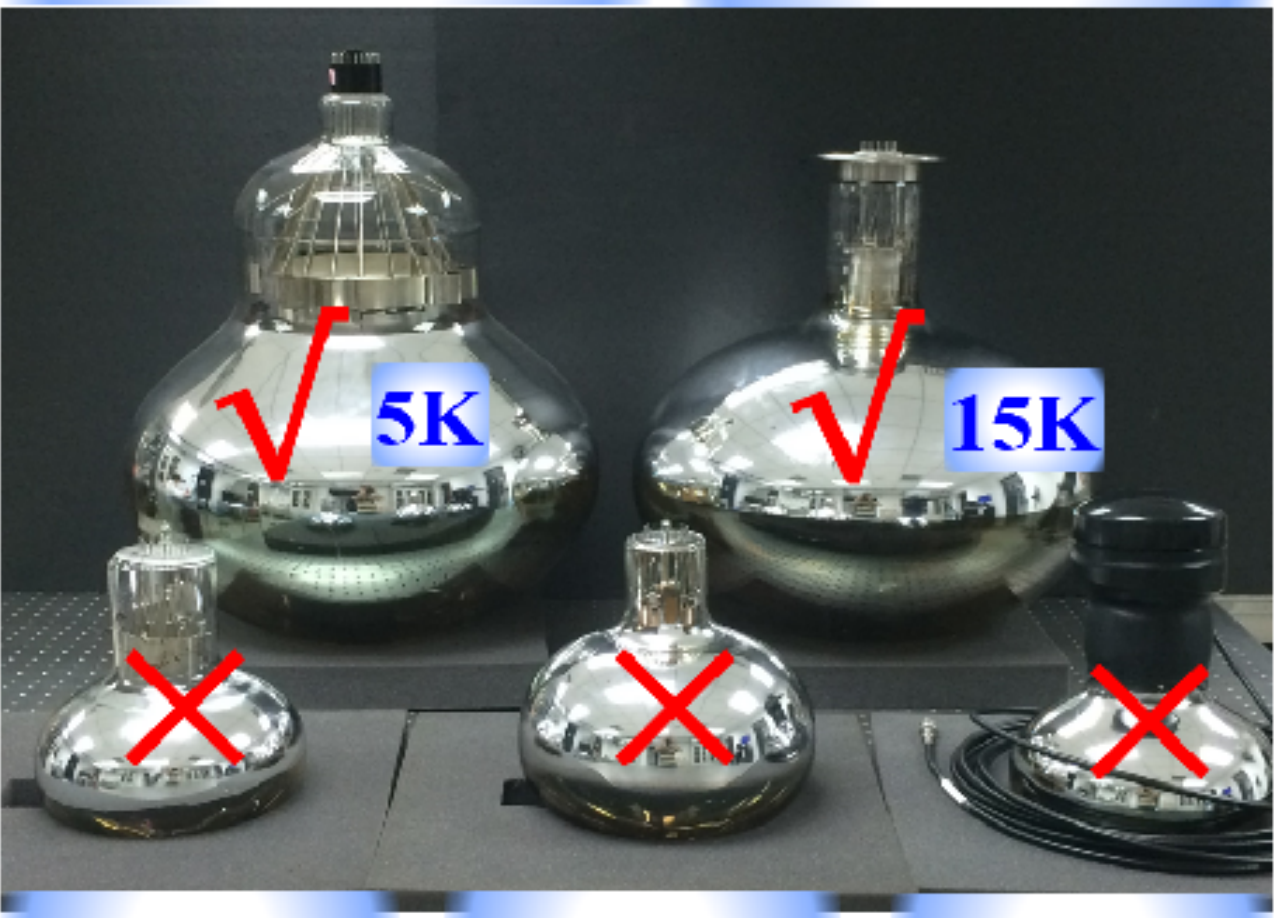
Specification in the Contracts

- 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

➢Dynode-PMT- 20" from Hamamastu

➢MCP-PMT- 20" from NNVT



➢MCP-PMT- 8"

➢Dynode-PMT- 9"

➢Dynode-PMT- 8"

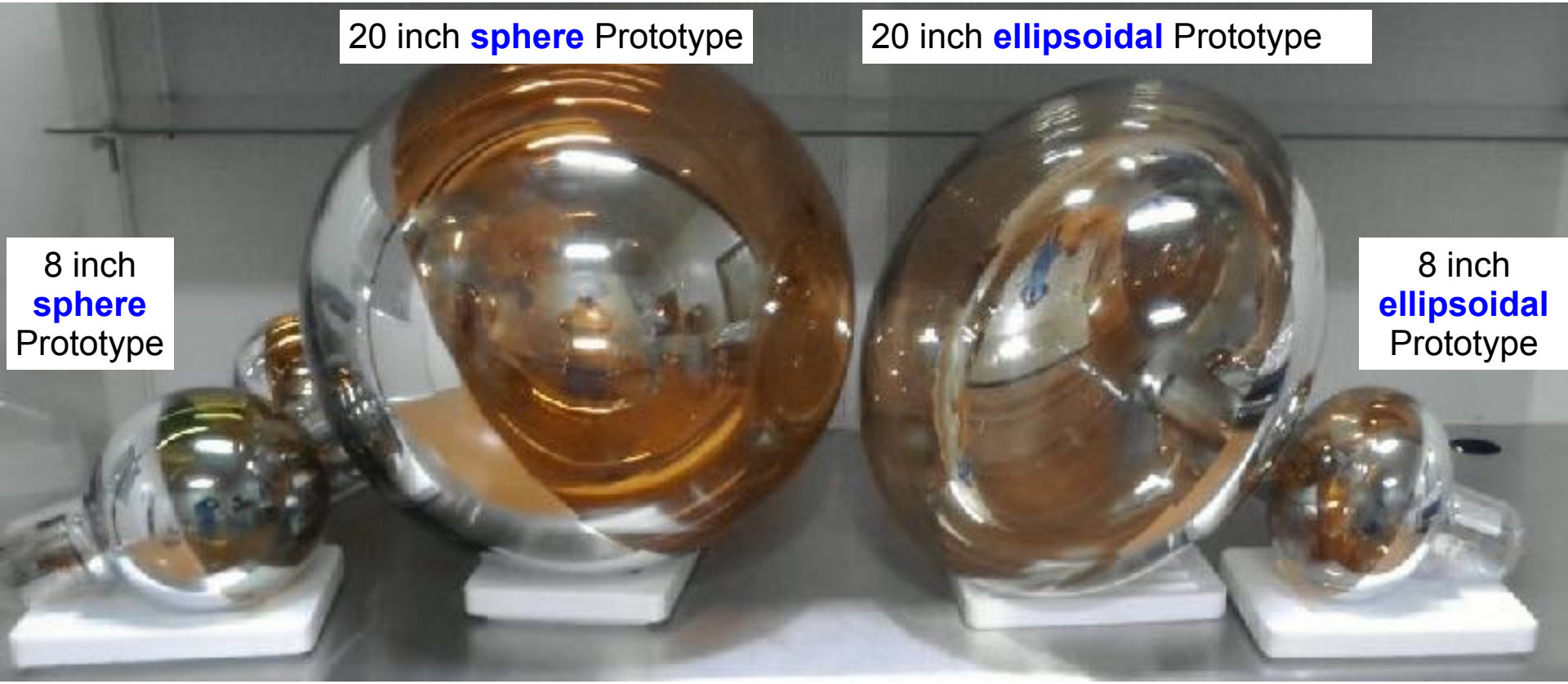
15k MCP-PMT (75%)

Contract for JUNO

Signed with NNVT

on Dec.16, 2015

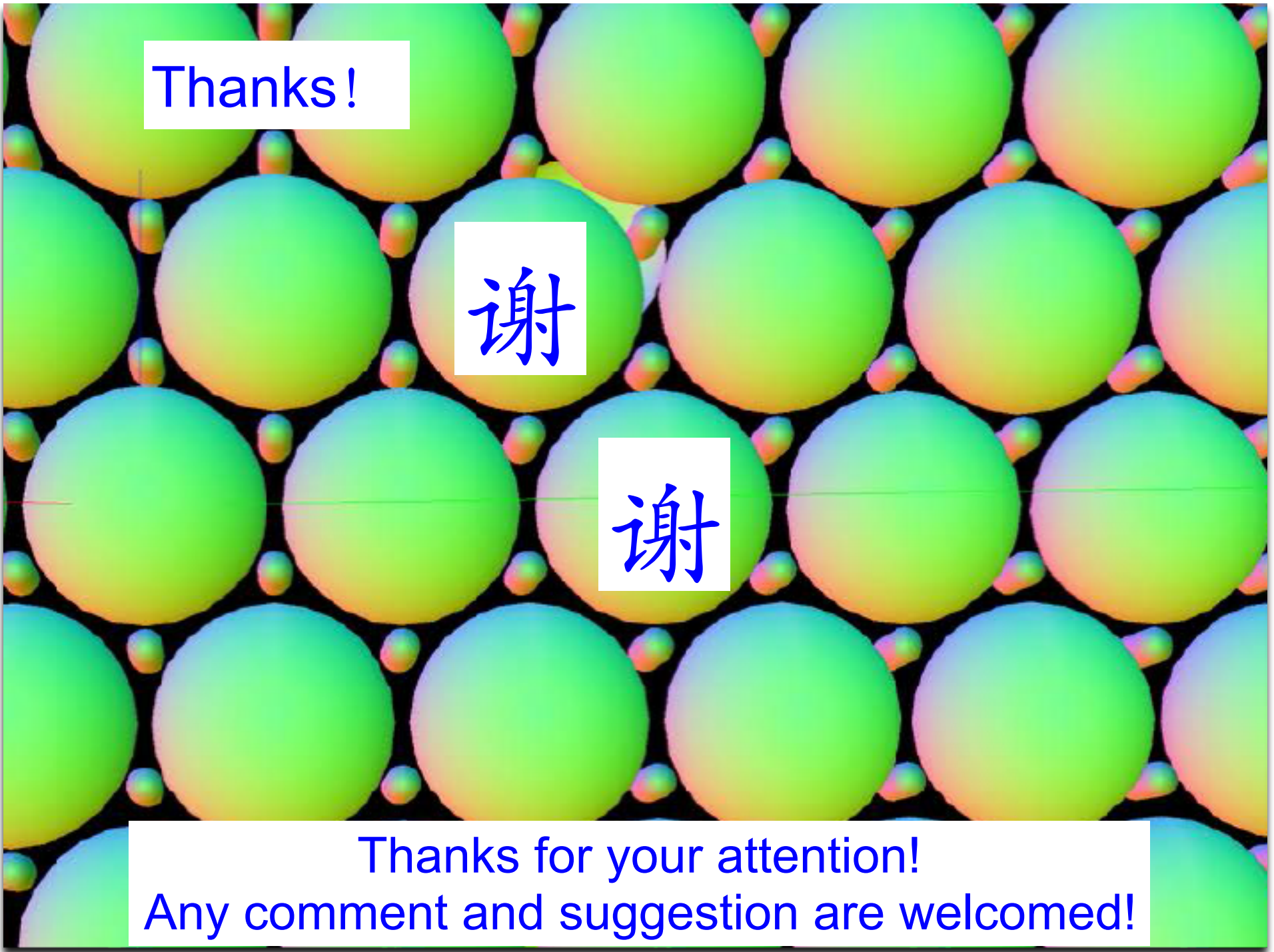
➢ **Prototypes:** Successful 8” and 20”prototypes with normal performance;



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,

we also try to improve our design of the prototype.


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


Welcome to Kaiping