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 R&D, Mass Production of the 20 inch MCP-PMT for Neutrino Detector

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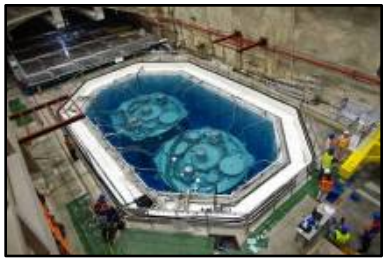
2018.06.22

Outline

- **1. The New Design of the PMT;**
- **2. The MCP-PMT prototypes (2011-2015);**
- **3. The Mass production Line and Batch test;**

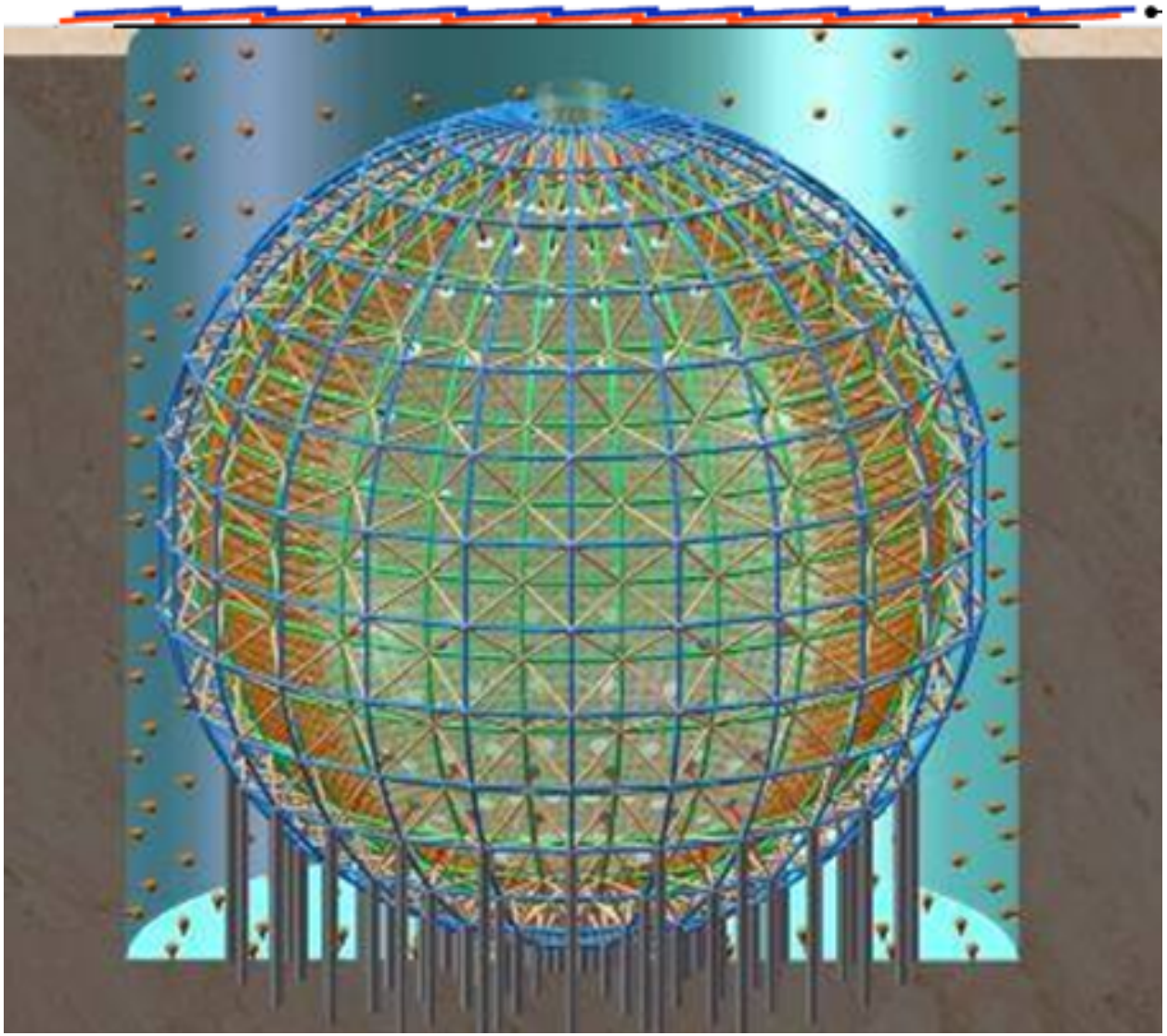
➢ 1 The new design of the MCP-PMT for Neutrino Detector

➢ Daya Bay Experiment



~3,000 pic 8inch PMTs

➢ JUNO Experiment



~20,000 pic 20 inch PMTs

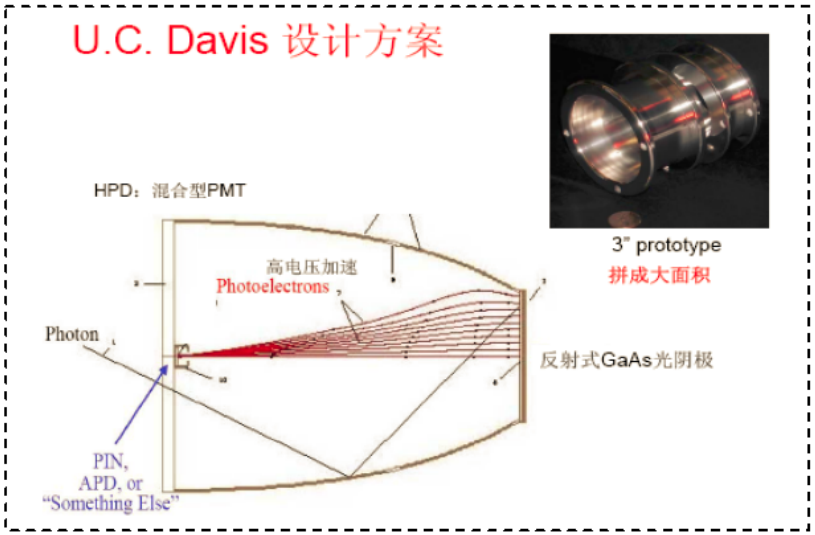
1.0 the requirement for PMTs of the Liquid Scintillator Detector

	KamLAND	JUNO	Improved factor
Liquid Scintillator	~1 kt	~20 kt	X 20
Energy Resolution	6%/√E	3%/√E	X 2
Light yield	250 p.e./MeV	1200 p.e./MeV	X 2
Number of 20 inch PMTs	2000	20000	X 10
Photocathode Coverage	34%	> 75%	X 2
PMT glass	normal glass	low radioactivity	
QE of the PMT	~20%	30%	
CE of the PMT	~70%	100%	
DE of the PMT	~14%	~30%	X 2
P/V of SPE	> 2	> 4	

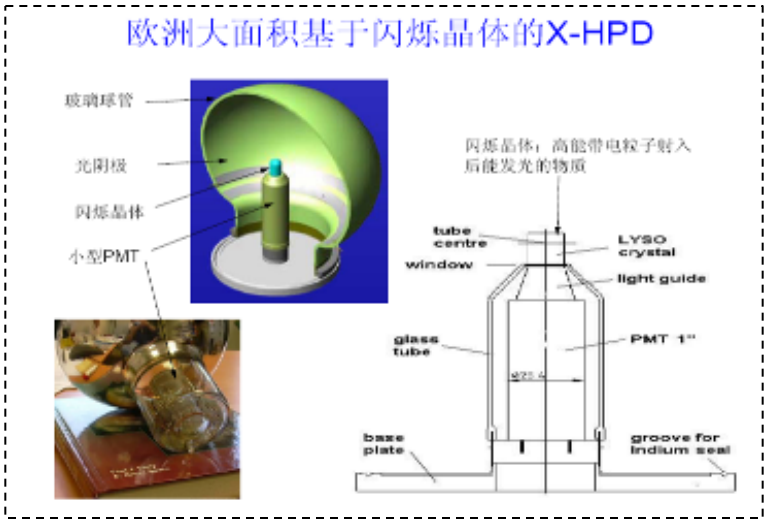
Requirement: High QE 20 inch PMT;Good SPE detection capability;Wide dynamic range;Low radioactive background;More than 20 years lifetime;Can withstand 0.4MPa Pressure;> 20000 pieces;

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

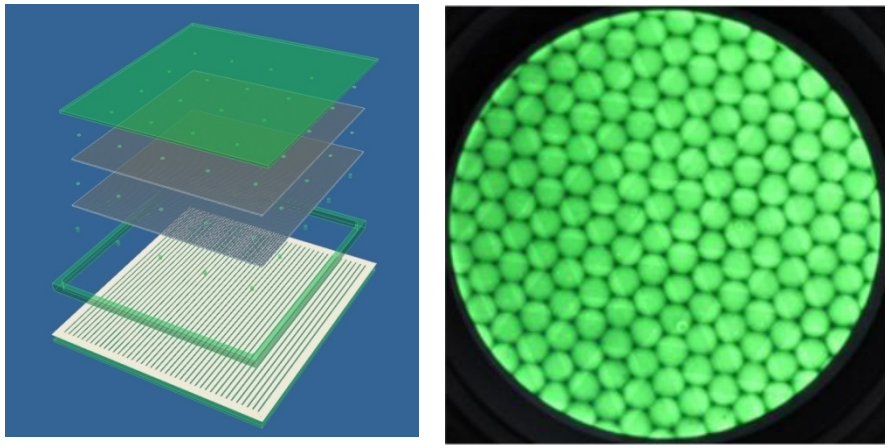
1.1 New type of PMTs under-development in ~2009



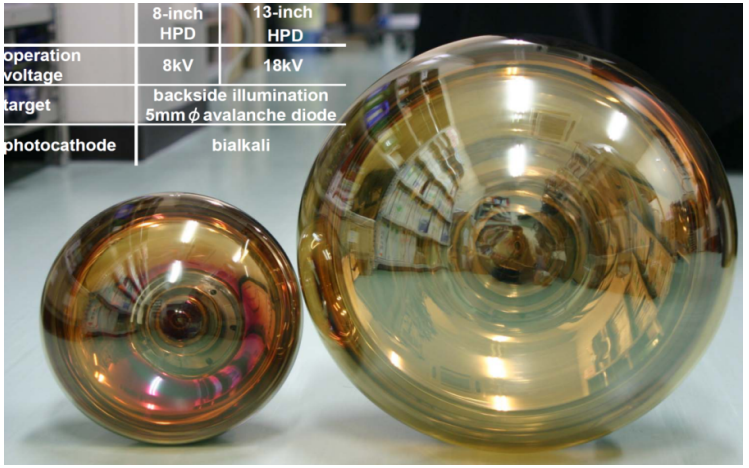
Reflective photocathode by UC Davis, Higher QE



Dynode replaced by Scintillator/APD

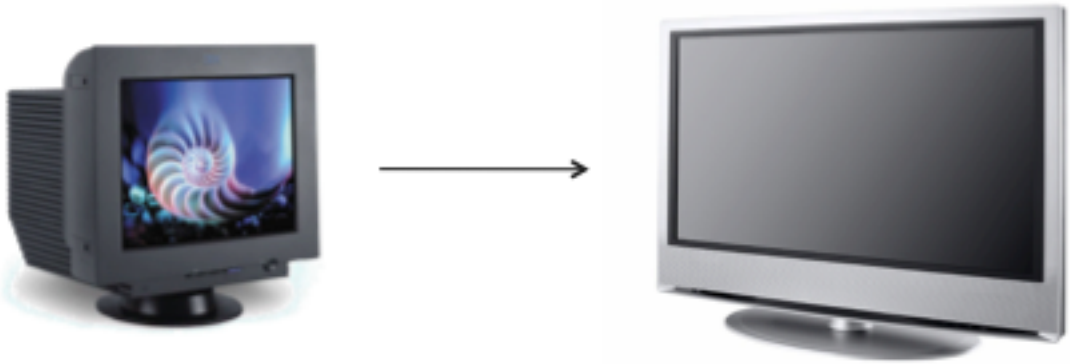


Large Area picosecond photo detectors(LAPPD)



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

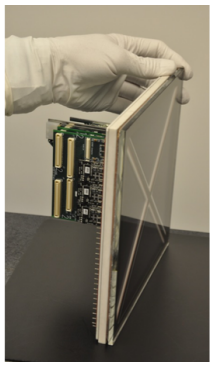
TV，LED，OLED： change the Electron to Light



PMT： change the Light to Electron

20 inch MCP-PMT

8 inch MCP-PMT



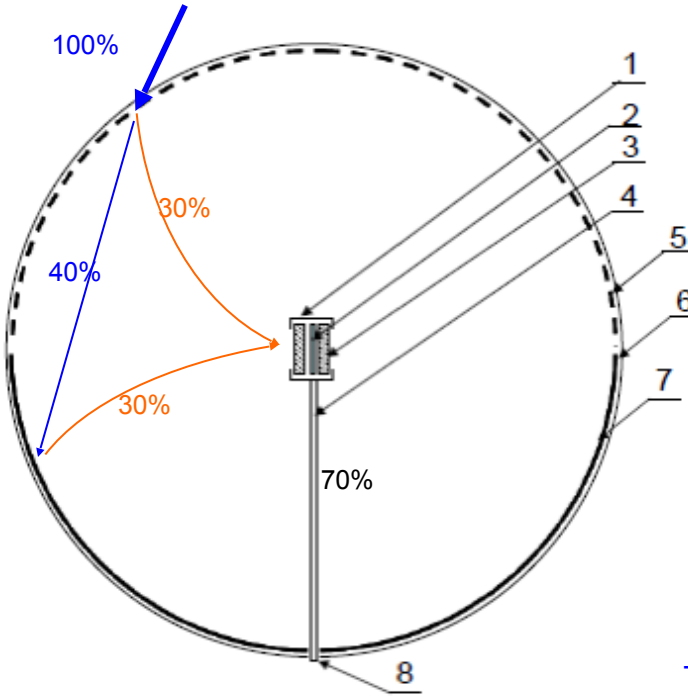
8 inch PMT

1.2 the primary design of the MCP-PMT in 2009

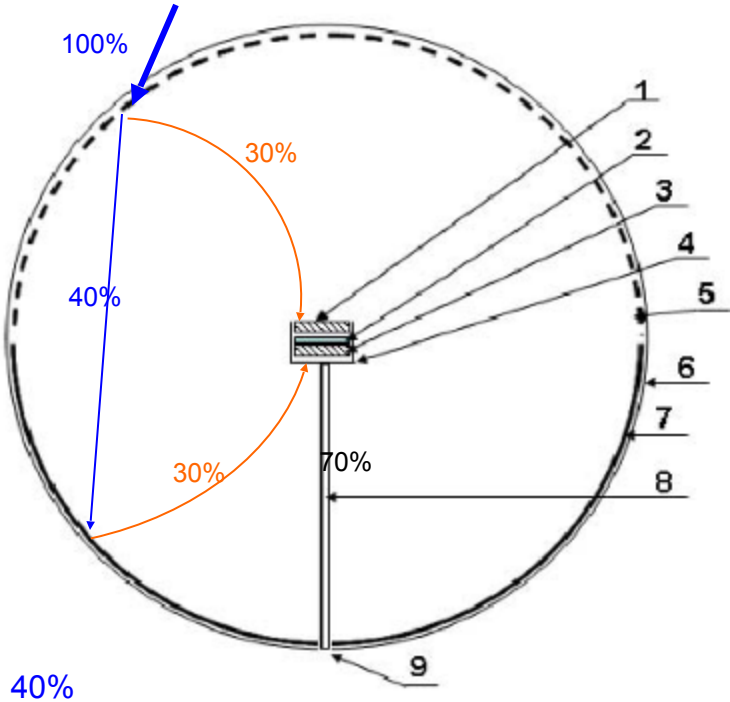
High photon detection efficiency + Single photoelectron Detection + Low cost

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



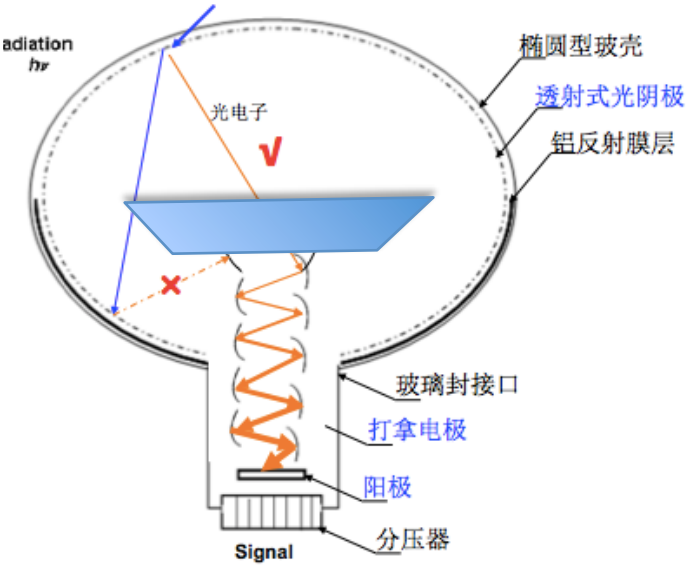
Transmission rate of the glass: 40%

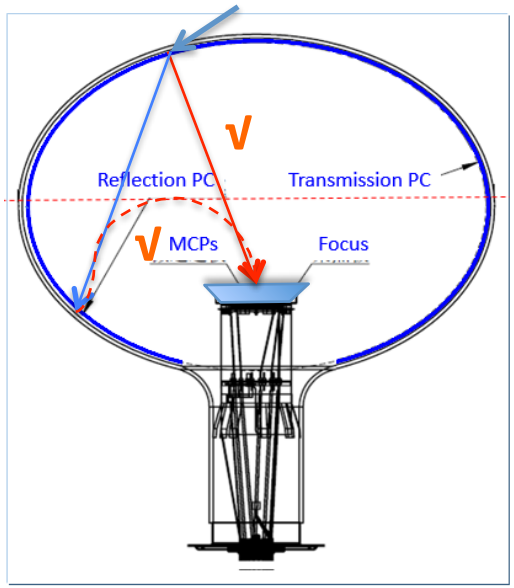
Quantum Efficiency (QE) : of Transmission Photocathode 30% ; of Reflection Photocathode 30% ;

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 !

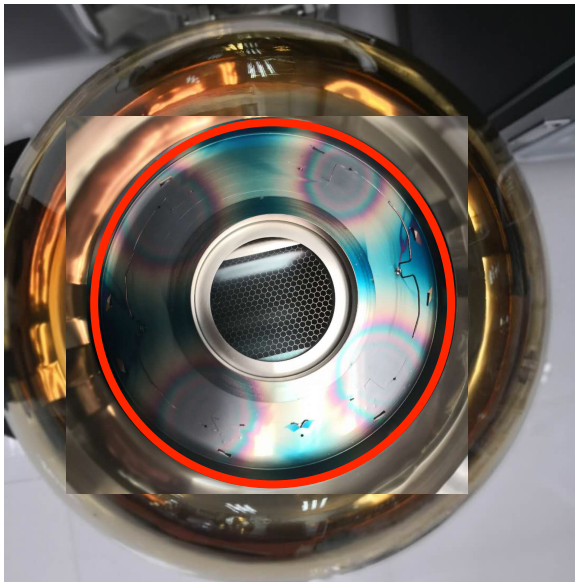


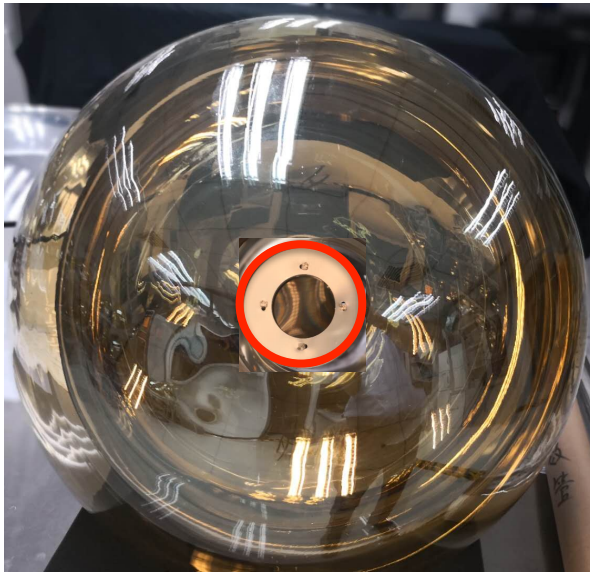


QE=20% → QE=30%

CE=70% → CE=90%

DE=14% → DE=27%





1.3 the large area MCP-PMT Patent

Inventor：

Yifang WANF（王贻芳）；

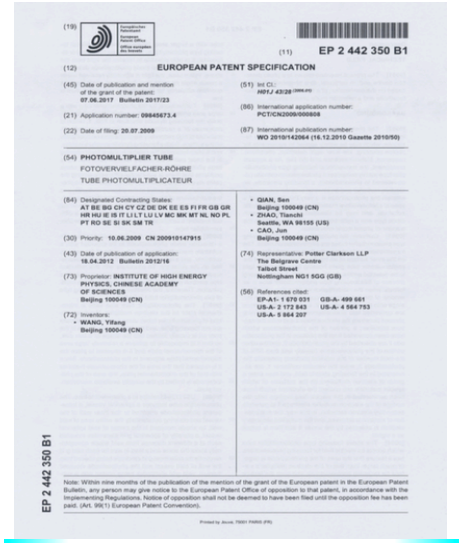
Sen QIAN（钱森）；

Tianchi ZHAO（赵天池）；

Jun CAO（曹俊）；

CHINA

USA



European Union

Japen

RUSSIA

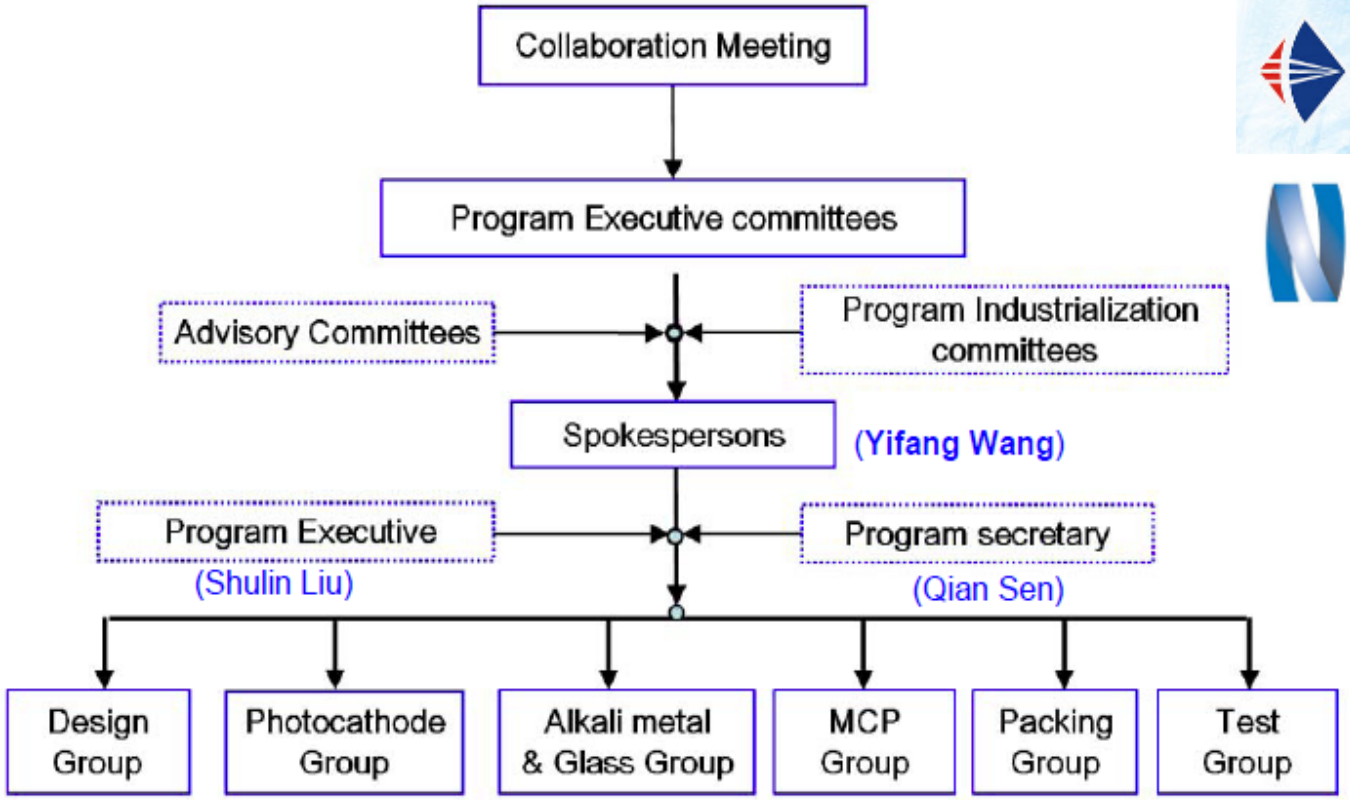
➢ 1.4 Project team and Collaborators

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

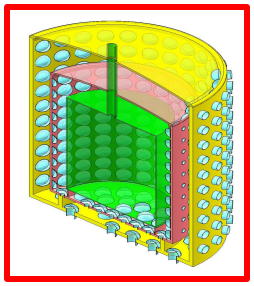
北方夜视技术股份有限公司
NORTH NIGHT VISION TECHNOLOGY CO.,LTD

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

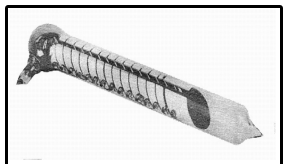
南京大学

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

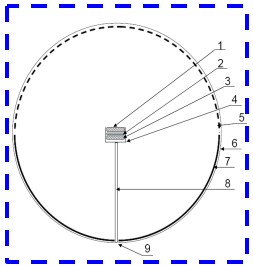
Requirement



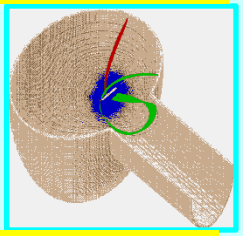
Development



Design



Photomultiplier

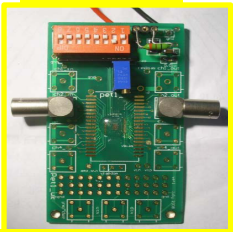


Low price MCP

Alkali metal

Glass Shell

Electronic

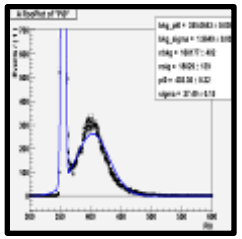


Vacuum equipment

Test system

Prototype

Performance



1.6 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

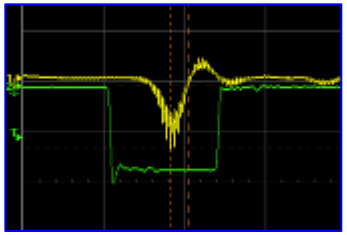
  Lab1： longtime aging test；

  Lab2： QE for PMT, PD, MPPC, Si-PMT；

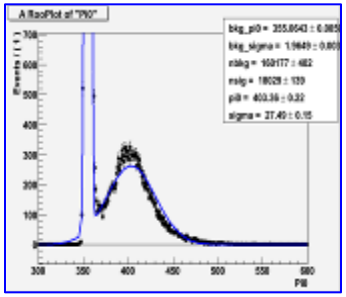
  Lab3： Timing for PMT, PD, MPPC, Si-PMT；

  Lab4： Geomagnetic field test for PMTs；

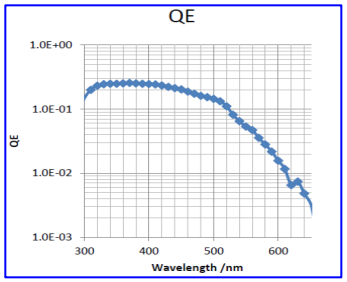
➢ The parameters of the MCP-PMT (testing in Lab)



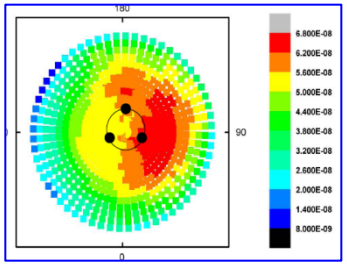
- ➢ Anode Pulse Rise Time;
- ➢ Pre/Late/After Pulse;
- ➢ Dark Count



- ➢ 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

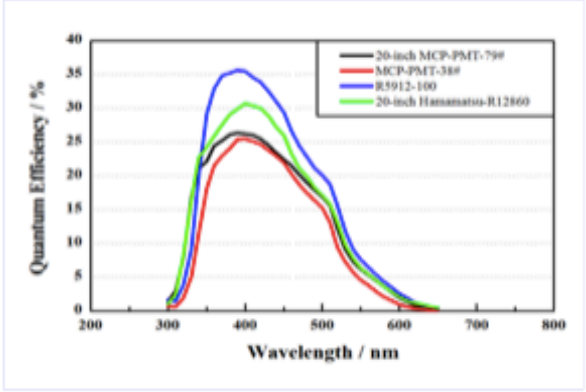
……

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

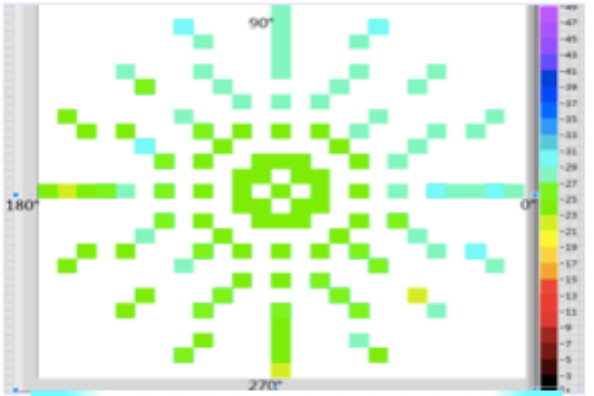
The typical performance of the 20 inch MCP-PMT

Waveform of the Prototype

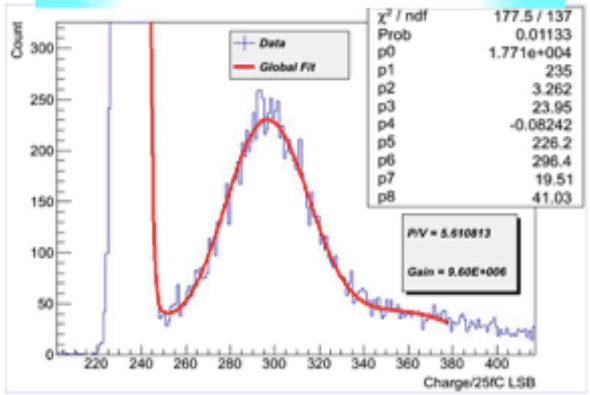
QE of the Photocathode



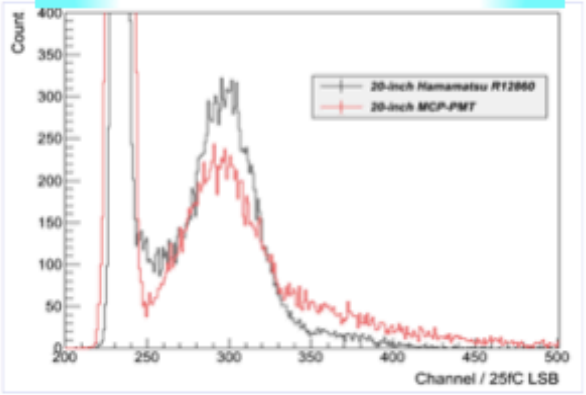
Uniformity of the Photocathode



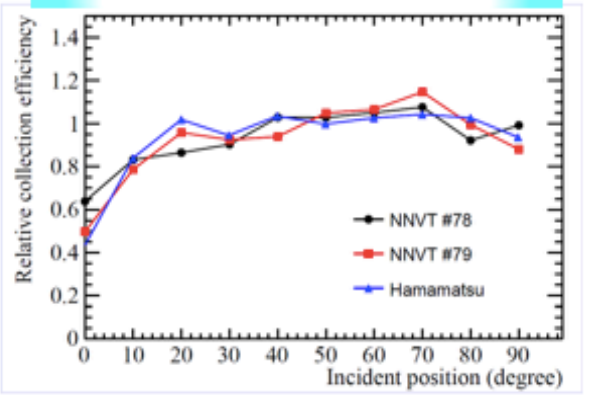
The SPE of the Prototype



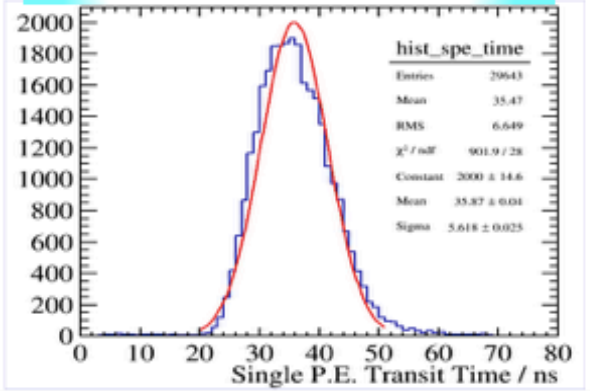
Relative Collection Efficiency



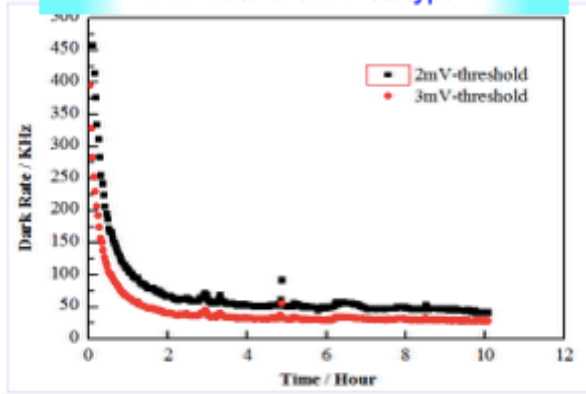
Uniformity of the Collection Efficiency



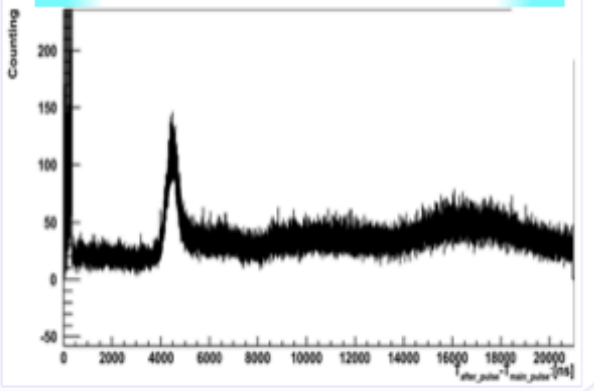
TTS of the Prototype



Dark rate of the Prototype



After Pulse of the Prototype



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- **2. The MCP-PMT prototypes (2011-2015);**
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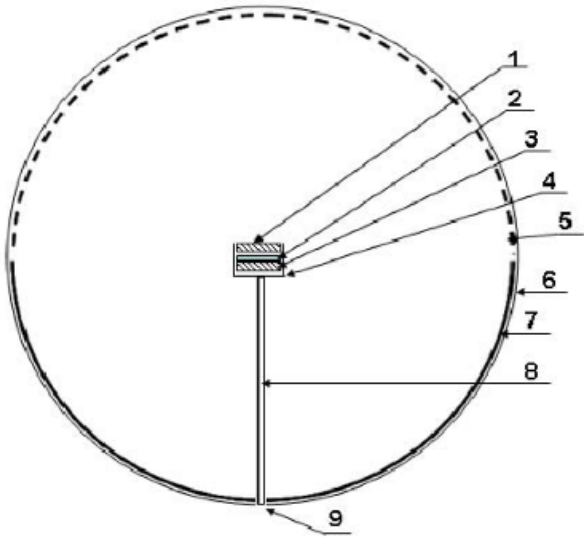
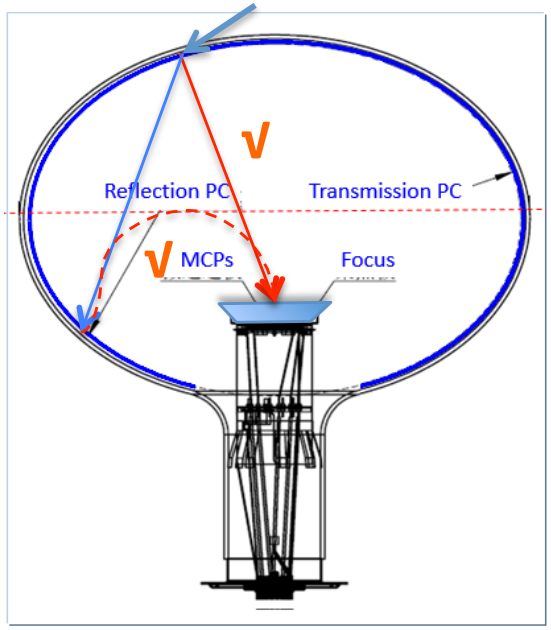
➢ 2 The prototypes of the MCP-PMT in the R&D process

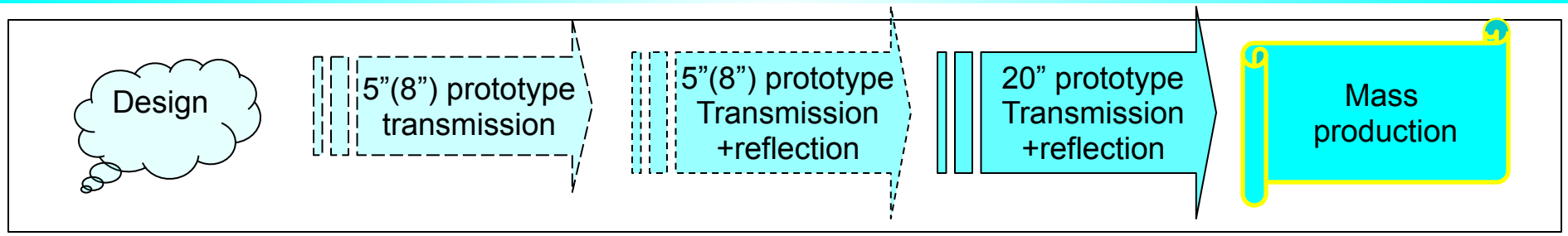
The Design of the MCP-PMT

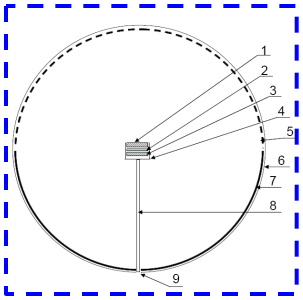




The MCP-PMT by IHEP+NNVT

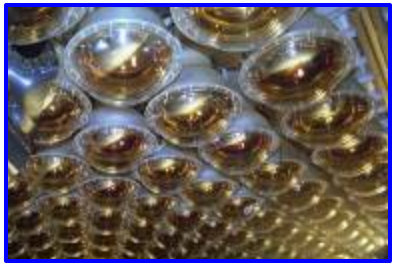
2.0 The R&D plan of MCP-PMT （Roadmap —time） （2009）



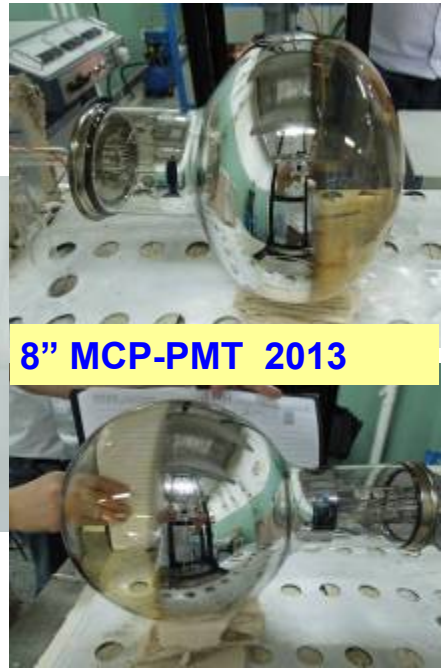


The design of the IHEP-MCP-PMT

The project of DayaBay II /JUNO

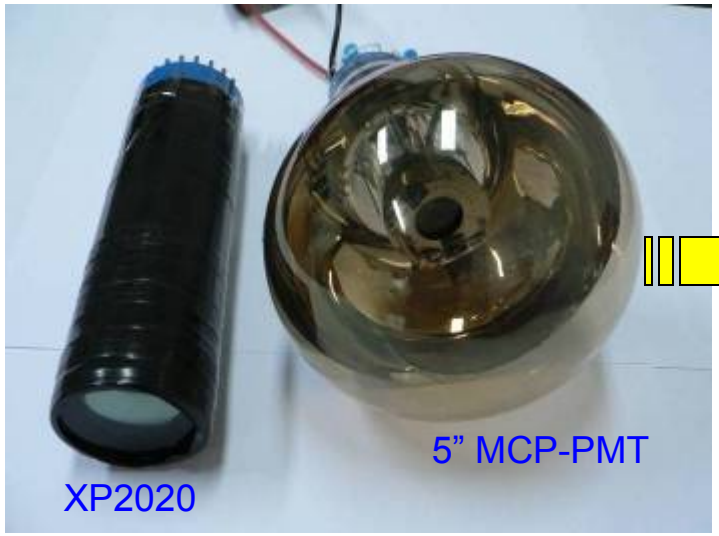


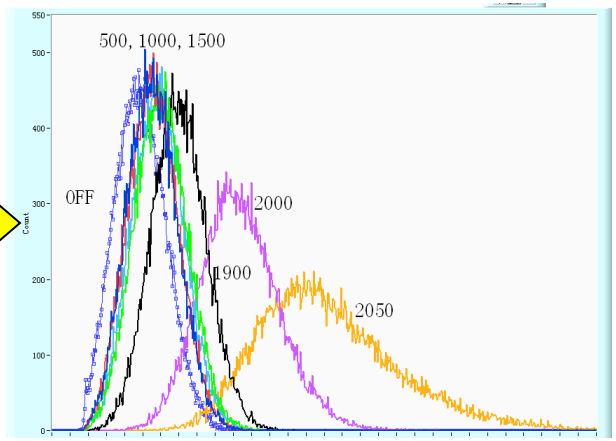
5” MCP-PMT 2010年



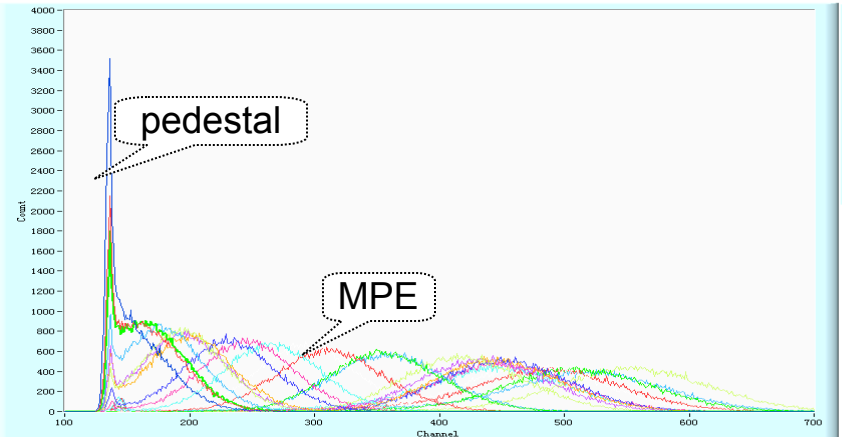
2.1 First 5”prototypes without SPE --2011

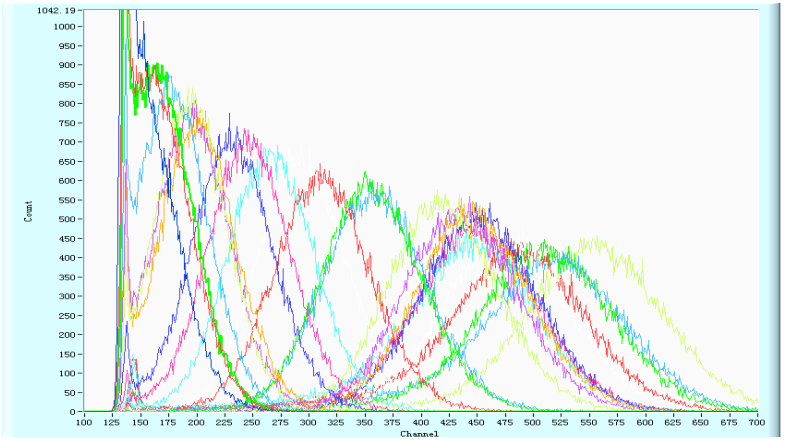
➢The photoelectron spectrum of a prototype: 5” IHEP-MCP-PMT





➢ MPE vs the Voltage of the PMT

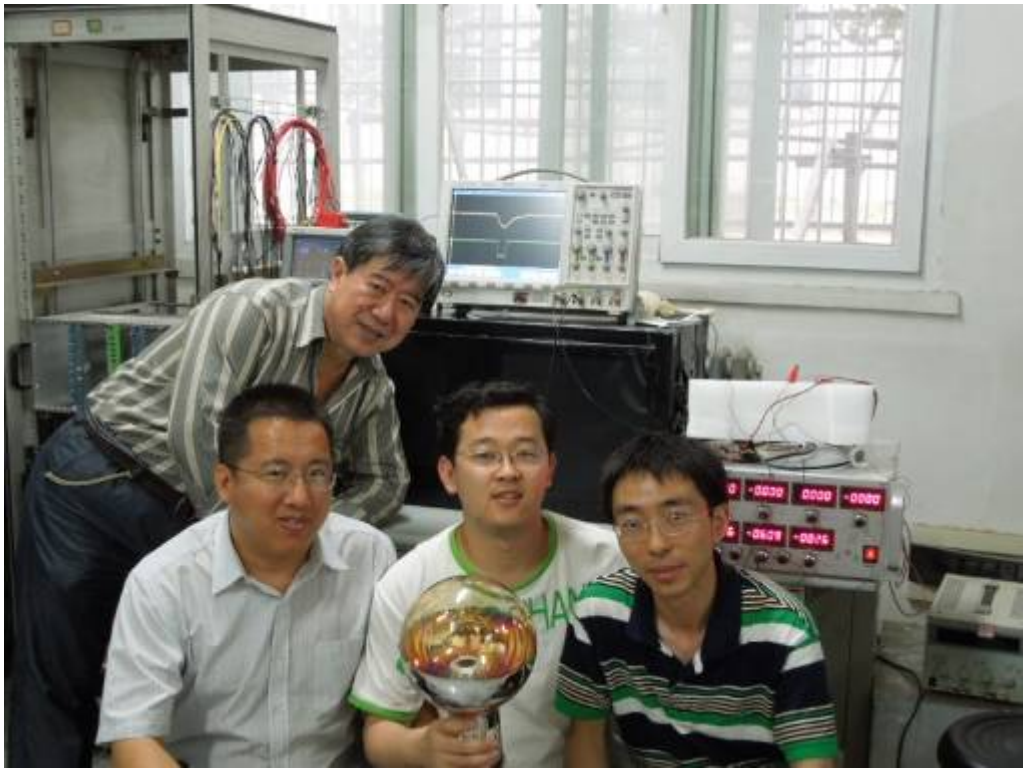


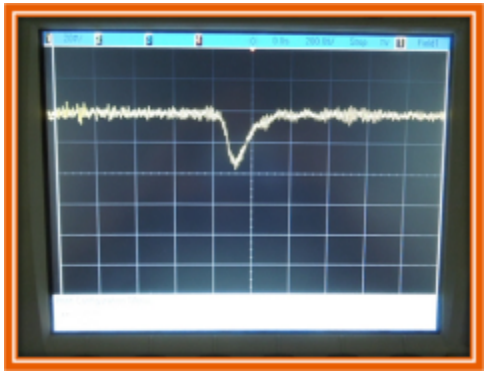


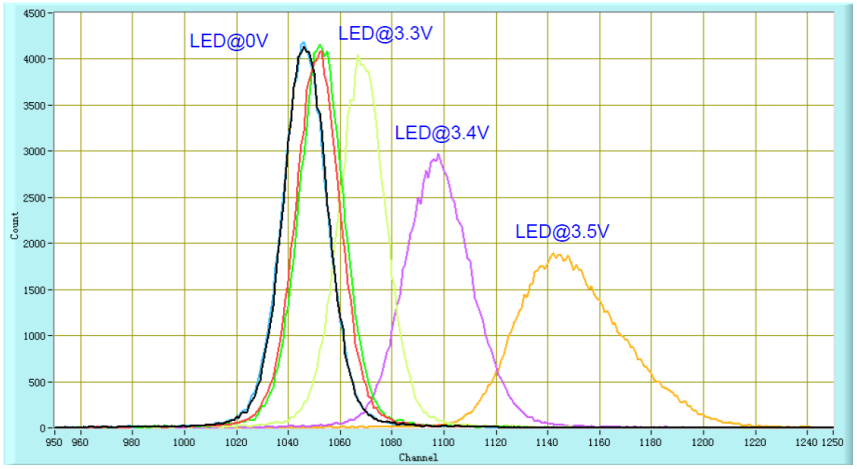
➢ MPE vs the luminance of the LED light

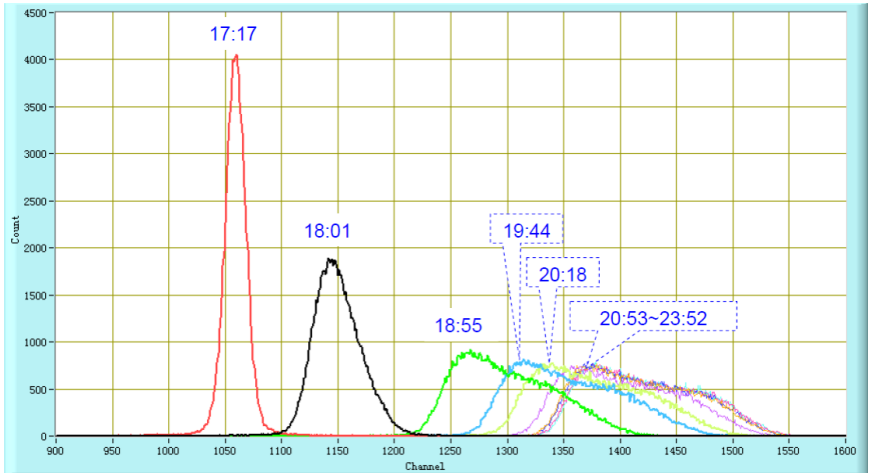
**--adjust the working voltage of the LED to adjust the luminance of the LED light.

2.2 First 8”prototypes without SPE--2012

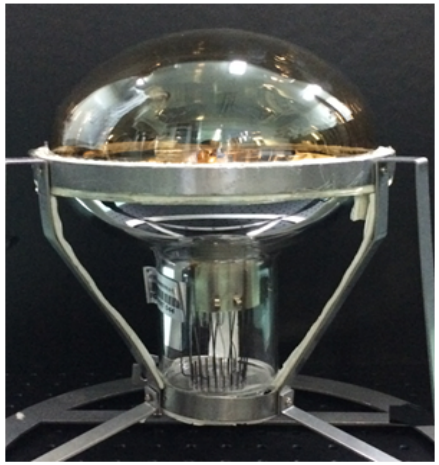


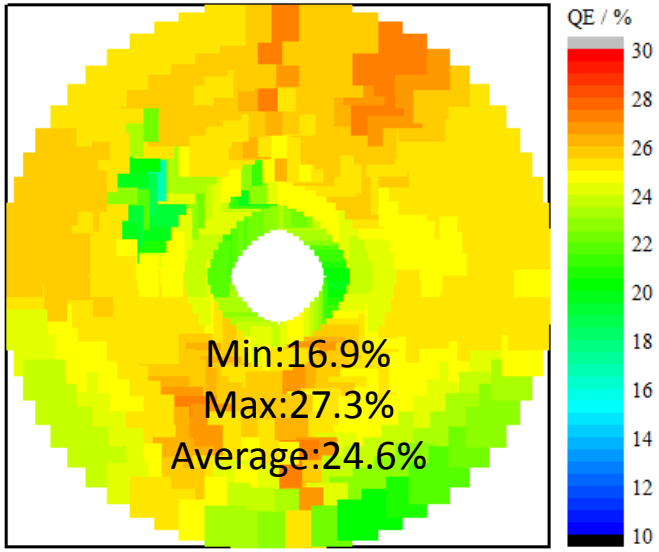


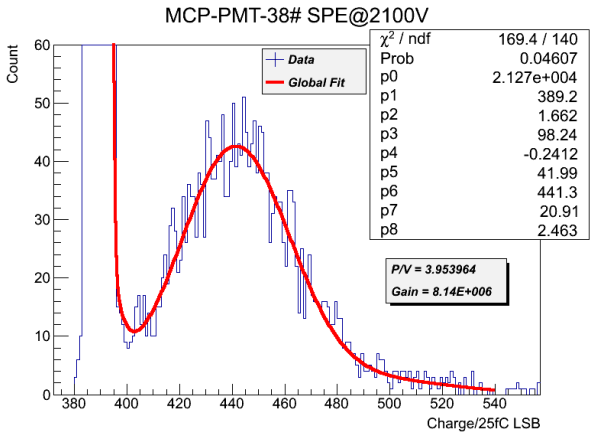


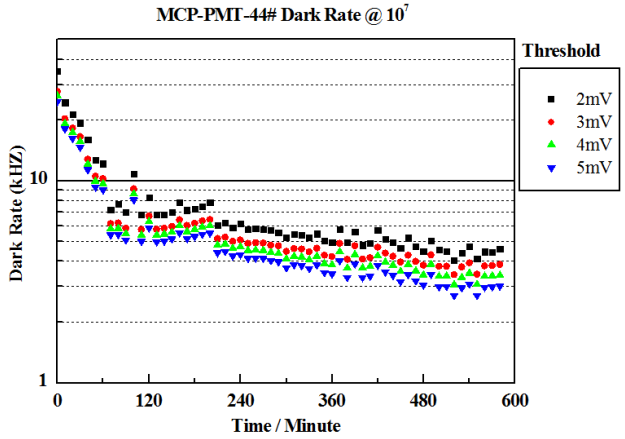


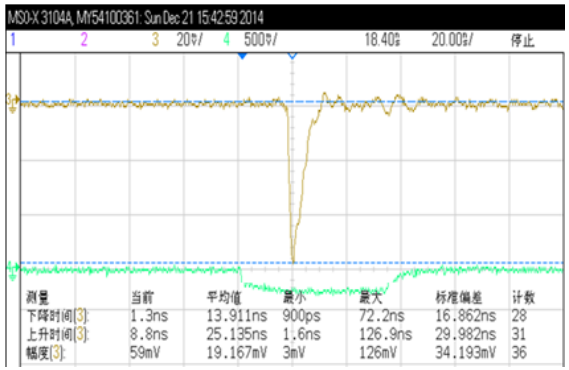
2.3 8”prototypes with normal performance--2013

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





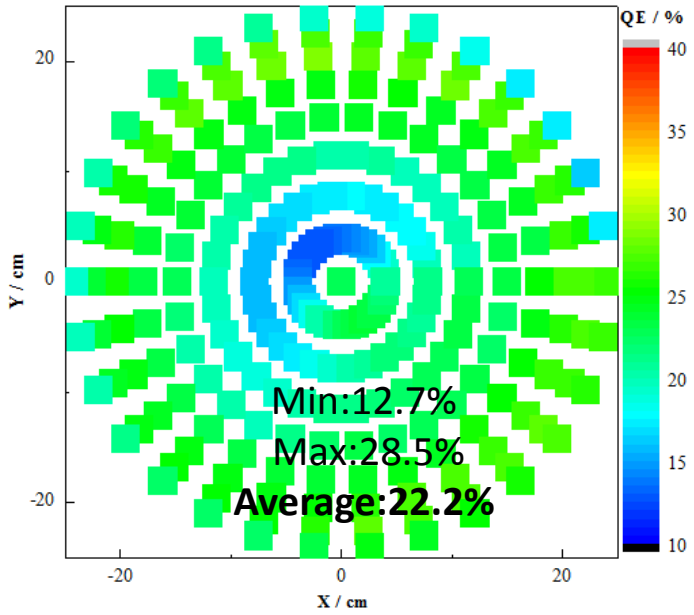


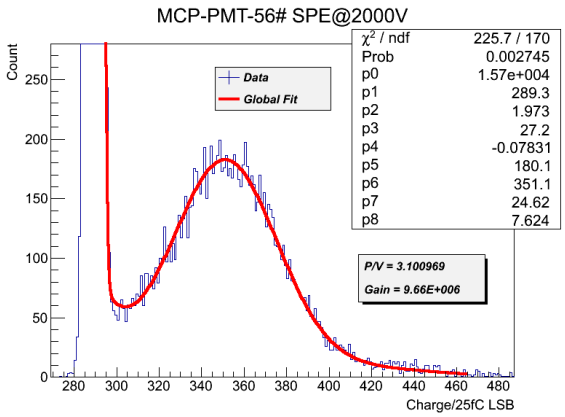


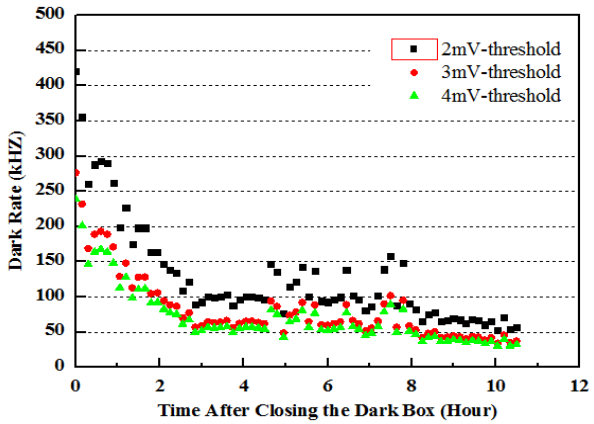
HV	Gain	P/V	Rise Time	Fall Time	Dark rate @1E7 Gain(0.25PE)
2100V	~1E7	~4	~1.3ns	~8.8ns	~3kHz

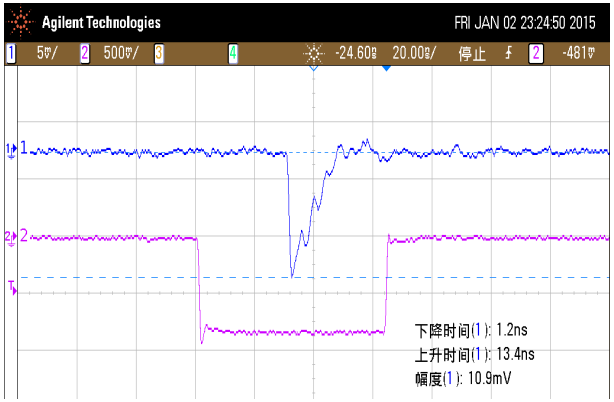
2.4 20”prototypes with normal performance--2014

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





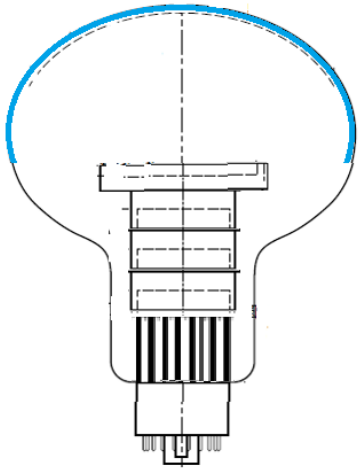
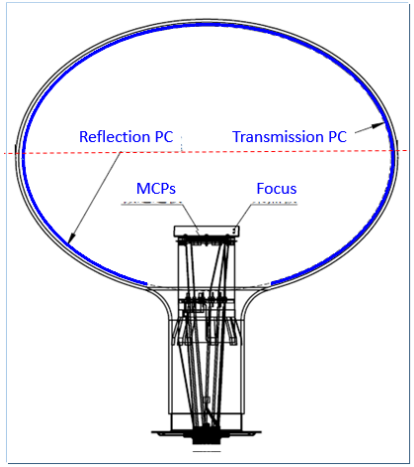




HV	Gain	P/V	Rise Time	Fall Time	Dark rate @1E7 Gain(0.25PE)
2000V	~1E7	~3	~1.2ns	~15ns	~50kHz

2.5 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 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

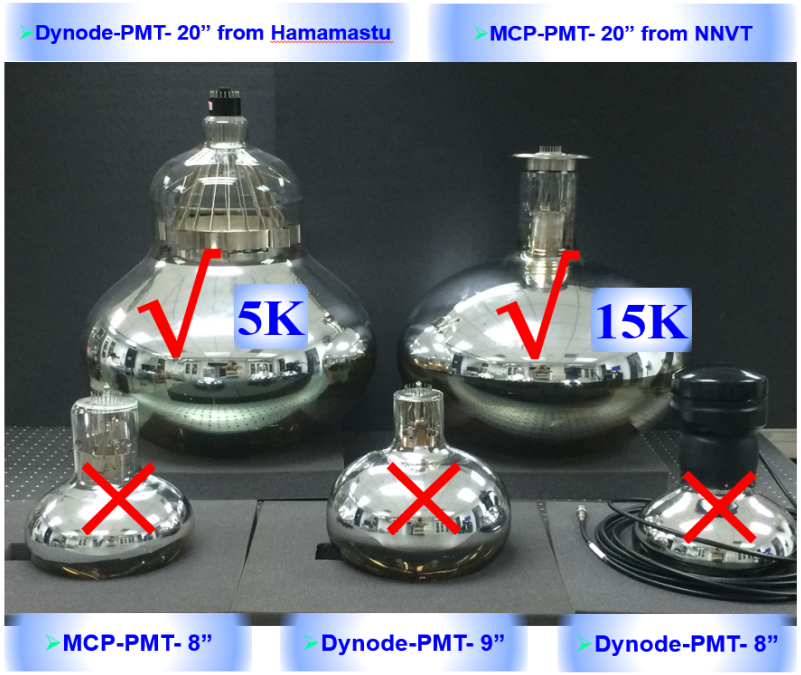
Outline

- **1. The New Design of the PMT;**
- **2. The MCP-PMT prototypes (2011-2015);**
- **3. The Mass production Line and Batch test;**

3. The Mass production Line and Batch test system

The MCP-PMT products

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



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

3.1 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

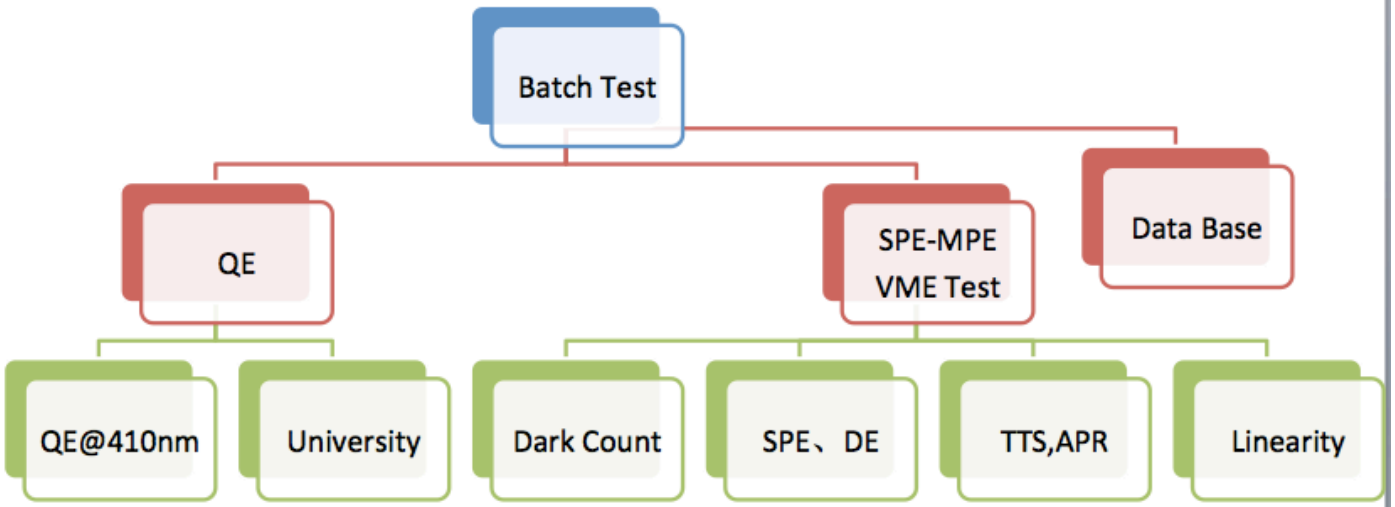
total 33 pic/ day;

30 pic PMTs (OK!) /day

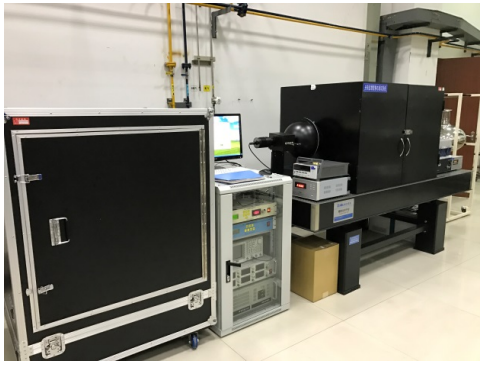
➢ 3.2 The Batch test platform (2016. 10-2017. 02)

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.

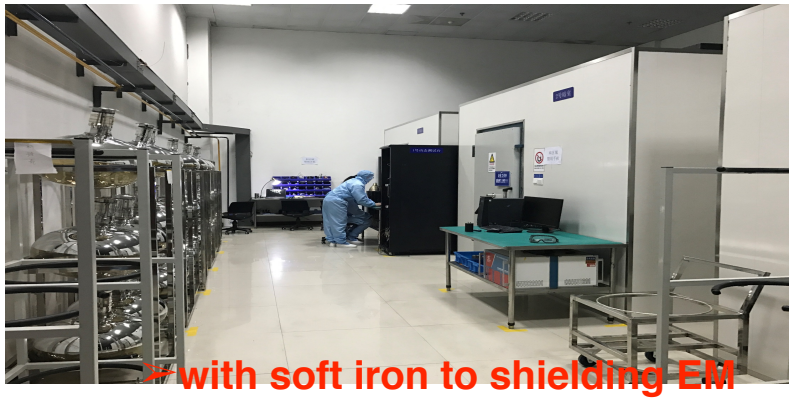


➢ QE sub-system



➢**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%;**

3.3 The MCP-PMT International Evaluation

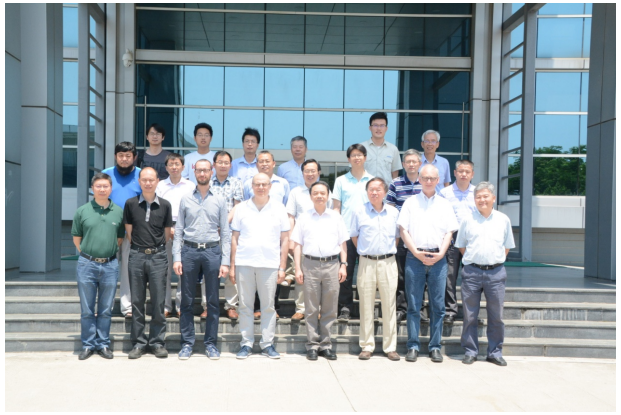
20 inch Micro-channel Plate Photomultiplier Tube International Evaluation on 28th.May 2017

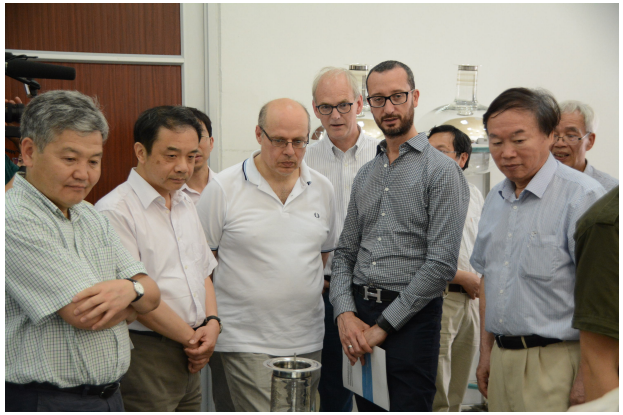
—> **The production line and testing procedures and equipment** are world-class with unique capabilities.

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

The MCP-PMT Review Committee

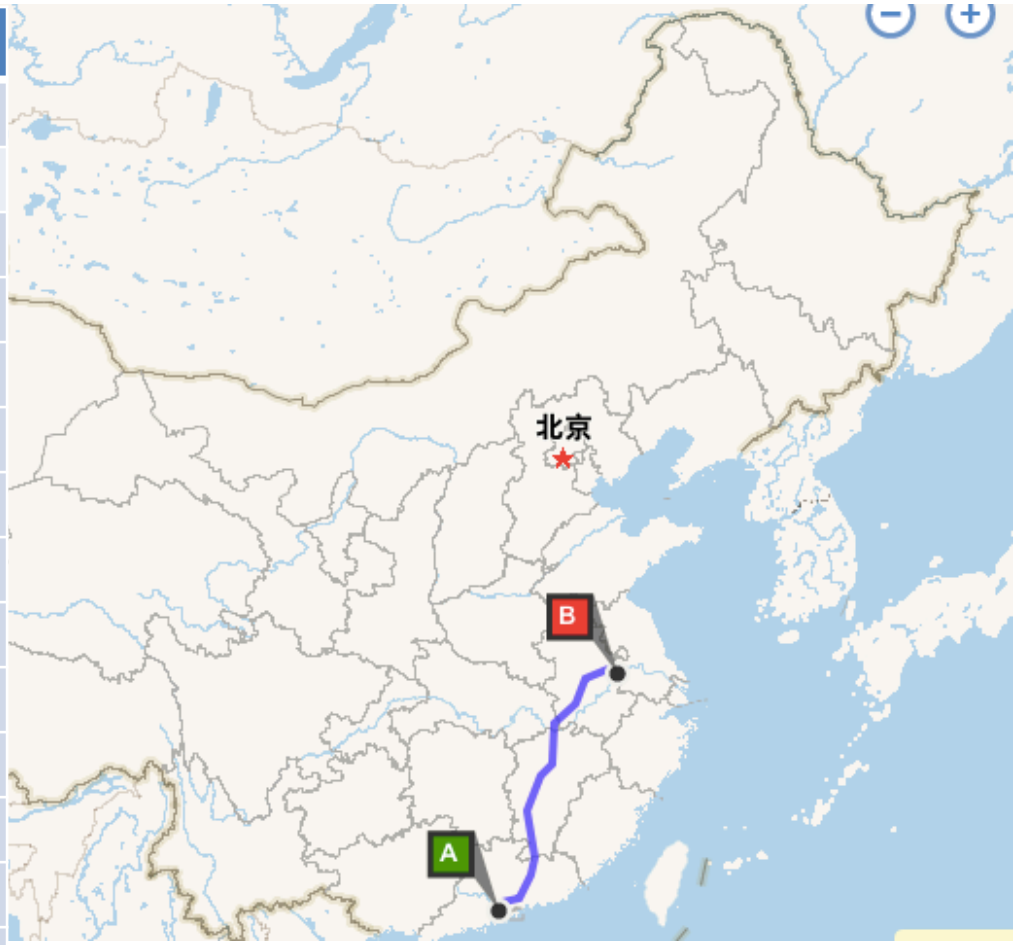
	Name	Company	Signature
Chairman	Weiguo Li	IHEP	
Member	Paolo Lombardi	INFN	
Member	Bayarto Lubsandorzhiev	INR	
Member	Demarteau Marcel	ANL	
Member	Gioacchino Ranucci	INFN	
Member	Zizong Xu	USTC	
Member	Jiawen Zhang	IHEP	

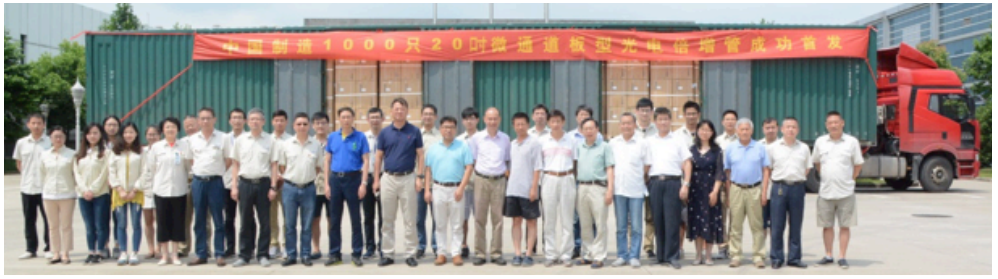




3.4 The transport by road for the MCP-PMT to JUNO

Status	Times	Date	Pics
finish-336	1	2017.5.15	336
finish-648	2	2017.6.14	312
finish-1008	**3**	**2017.7.4**	**360**
finish-1344	4	2017.7.26	336
finish-1680	5	2017.8.24	336
finish-2016	**6**	**2017.9.12**	**336**
finish-2351	7	2017.9.25	336
finish-2687	8	2017.10.09	336
finish-3023	**9**	**2017.10.26**	**336**
finish-3360	10	2017.11.08	336
finish-3696	11	2017.11.22	336
finish-4031	**12**	**2017.12.21**	**335**
finish-4366	13	2018.01.21	336
finish-4703	14	2018.02.23	337
finish-5040	15	2018.03.08	336
finish-5376	16	2018.04.09	336
finish-5712	17	2018.05.22	336
-6048	18	2018.06.25	336





3.5 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

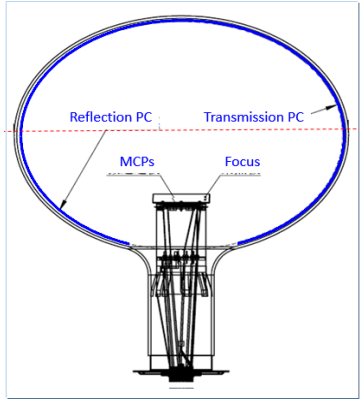
2016

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!