The R&D of Microchannel-Plate-Based Large Area Photomultiplier (MCP-PMT) at IHEP

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On Behalf of the Workgroup

The 4th Asian Forum for Accelerators and Detectors
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Outline

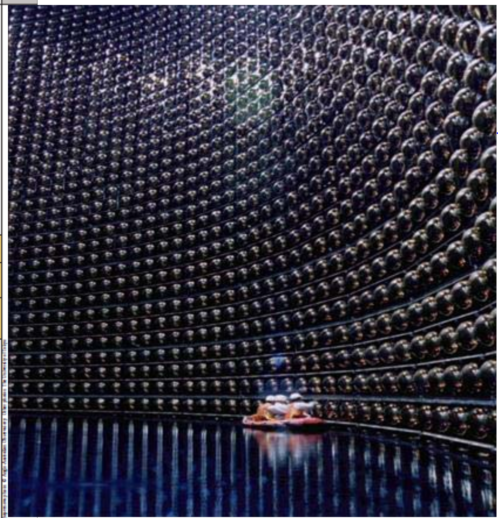
- 1. The Design of the new MCP-PMT;
- 2. The Research project;
- 3. The Challenge and Progress of the MCP-PMT;
- 4. The Prototypes and Summary;

Outline

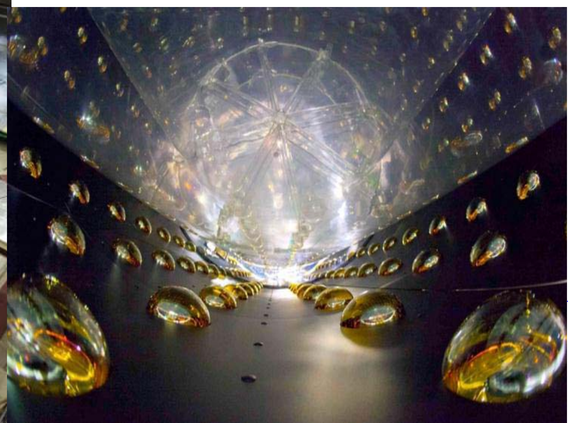
- 1. The Design of the new MCP-PMT;
  - 1.1 The relationship between the PMT and neutrino detection ;
  - 1.2 The Big demanding of PMT for DayaBay II;
  - 1.3 The Conventional PMT and the High QE PC;
  - 1.4 The R&D of the new type of PMT in the world;
  - 1.5 The new design of a large area PMT in IHEP

Large Area； High QE（double photocathode）； Low background

➢ 1.1 The relationship between the PMT and neutrino detection



- **Atmospheric neutrino exp.**
  - **SuperK,**
  - HyperK/UNO,
  - INO,TITAND,
- **Solar neutrino exp.**
  - **SNO,**
  - GALLEX/SAGE,
  - Borexino, XMASS,
- **Accelerator neutrino exp.**
  - **T2K,**
  - **Nova**,
  - Minos, OPERA,
  - MiniBooNE,
- **Reactor neutrino exp.**
  - **KamLAND** (Japan),
  - **Daya Bay** (China),
  - **Reno** (Korea),
  - **Double Chooz** (France)
  - …



➢ 1.2 The requirements of the PMT for the neutrino detection

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

More photons, how and how many ? **How?** **$*4.3 - * 5.0 \rightarrow (3.0 - 2.5)\% /\sqrt{E}$**

- Highly transparent LS: Attenuation length/D: 15m/16m → 30m/34m ×0.9
- High light yield LS: KamLAND: 1.5g/l PPO → 5g/l PPO

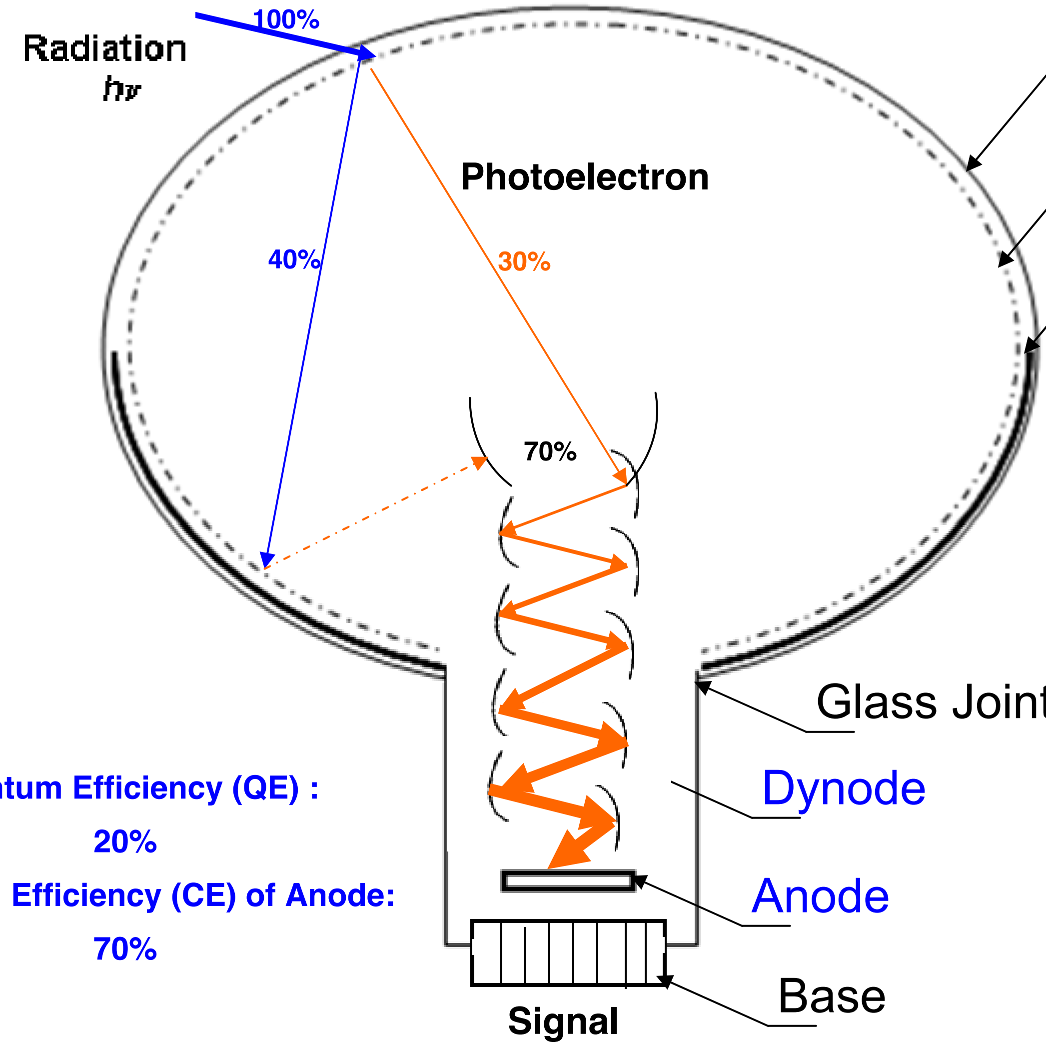
  Light Yield: 30%→ 45%; × 1.5
- Photocathode coverage : KamLAND: 34% → ~ 80% × 2.3
- High Quantum Efficiency (or Photon Detection Efficiency) "PMT":

  20" SBA PMT QE: 25% → 35% × 1.4

  or New PMT QE: 25% → 40% × 1.6

  Both: 25% → 50% × 2.0

➢1.3 The Conventional PMT



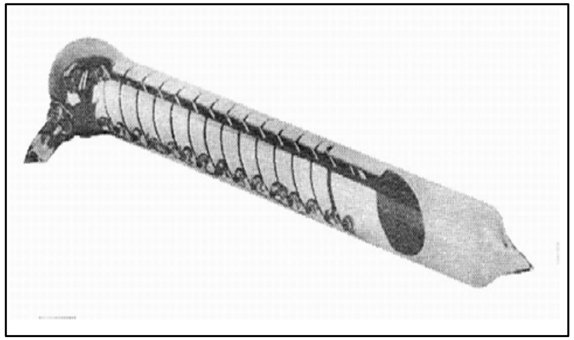
Quantum Efficiency (QE) :

20%

Collection Efficiency (CE) of Anode:

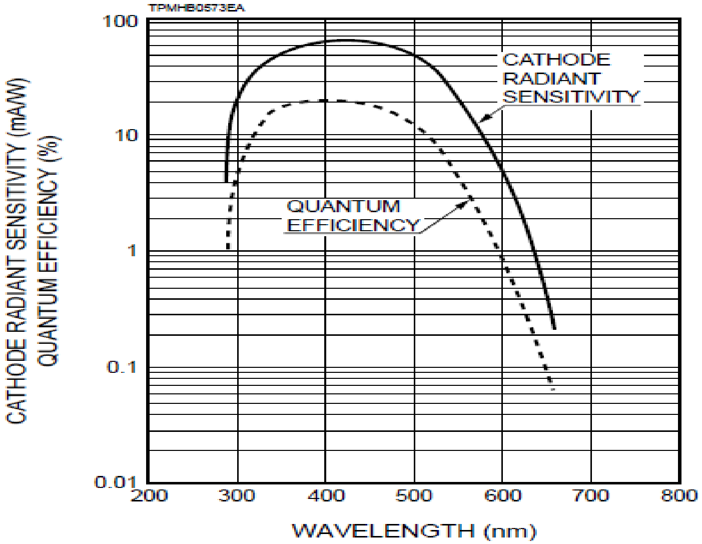
70%

The first PMT in the world in 1933
"Kubetsky's tube"

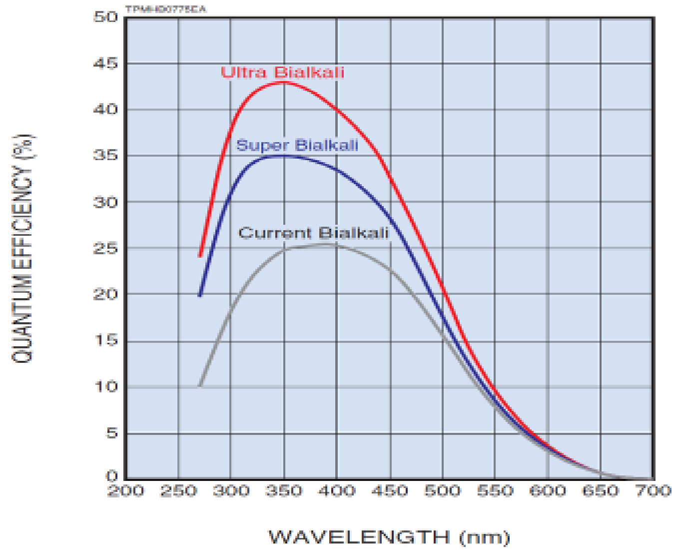


Photon Detection Efficiency (PE)= QE_{Trans} * CE = 20% * 70% = 14%

The QE of 20" PMT-R3600



The QE of SBA/UBA



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

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

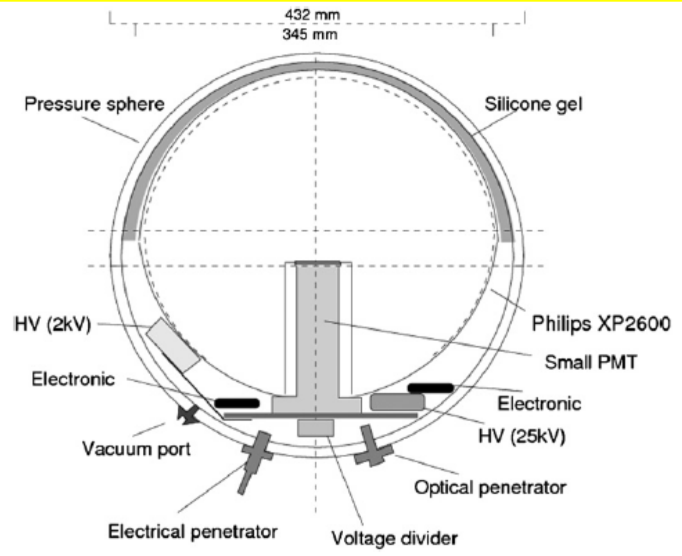
- **Can we improve the Quantum Efficiency of Photocathode or Photon Detection Efficiency for the large area 20" PMT ?**

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

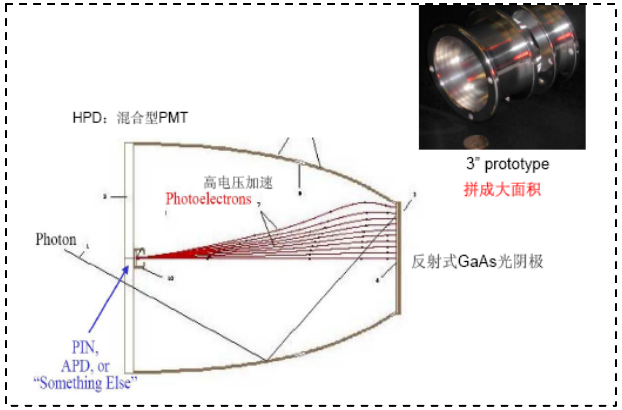
?? 20" New large area PMT ? Quantum Efficiency > 40% ?

or **Photon Detection Efficiency:** 14% → 30%

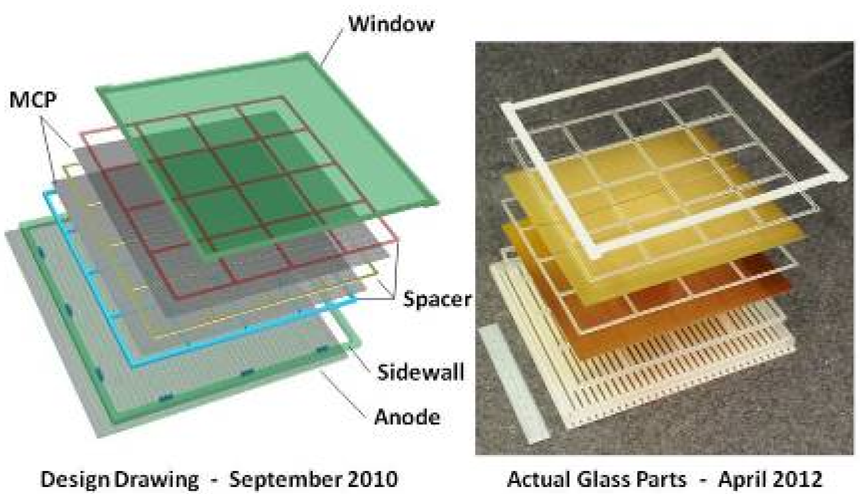
➢ 1.4 The R&D of the new type of PMT



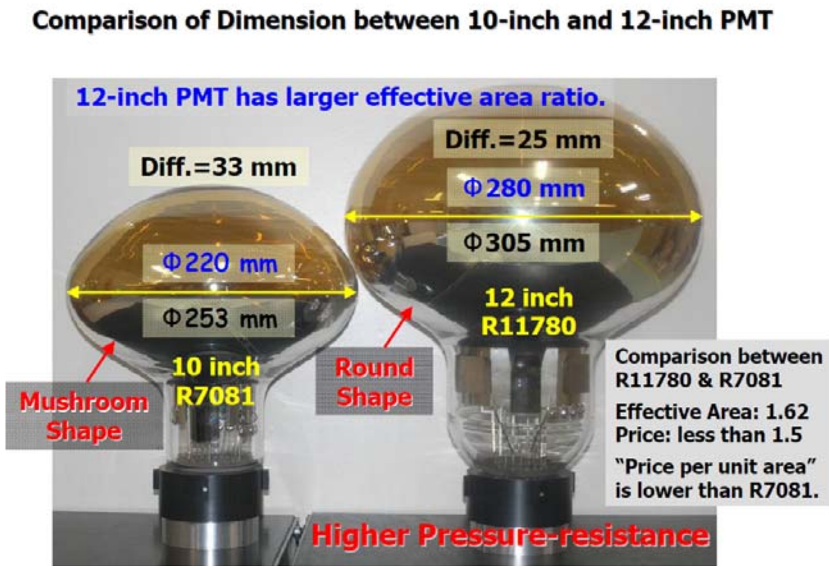
HPD—of DUMAND European optical module



HPD--U.C. Davis



LAPPD project – ANL, Chicago



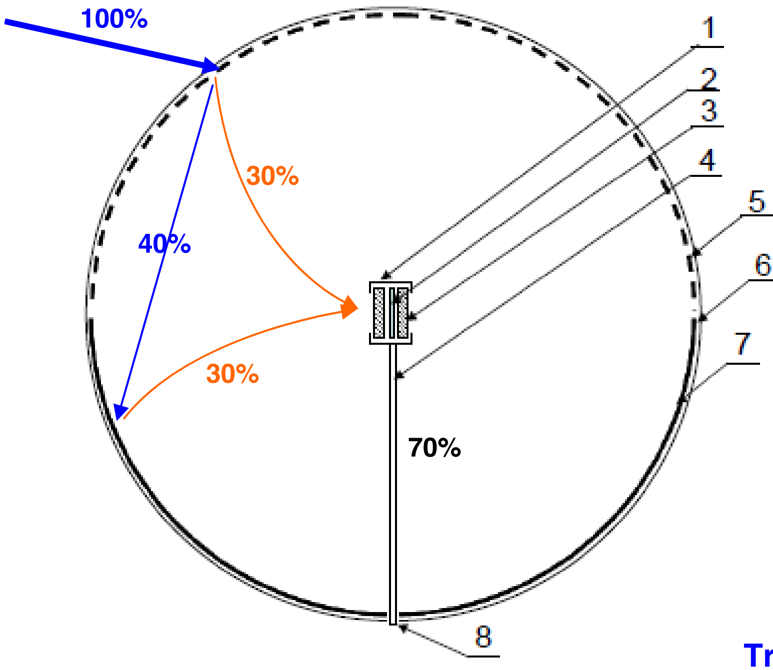
12" PMT with SBA photocathode--Hamamatzu

➢1.5 The new design of a large area PMT

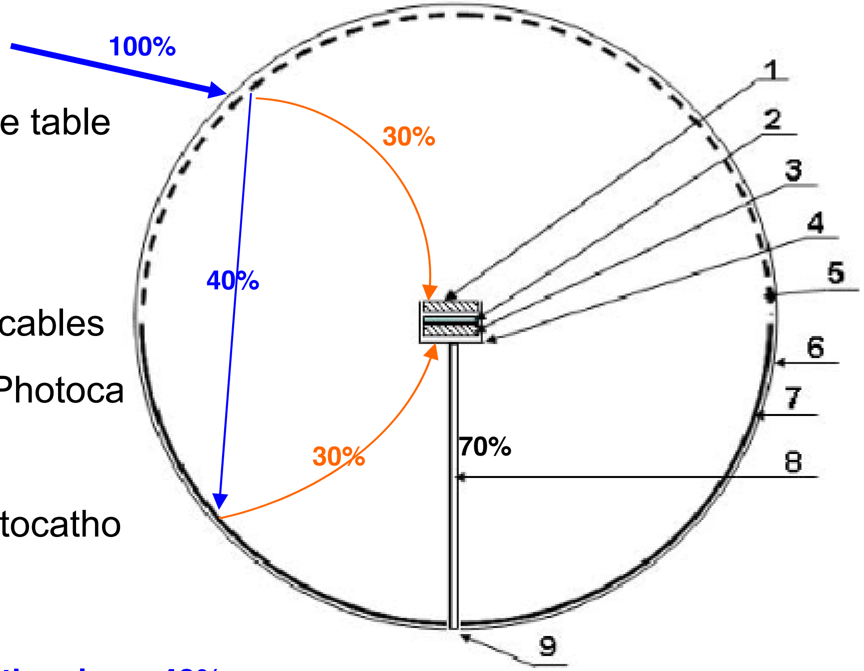
High photon detection efficiency + Single photoelectron Detection + Low cost

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 Photoca
6.Glass shell
7.Reflection Photocatho
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 !

Outline

- 2. The Research project;
  - 2.1 Project team and Collaborators;
  - 2.2 The Technical Workshop & Collaboration Meeting;
  - 2.4 The R&D plan of MCP-PMT （schedule）；
  - 2.5 The R&D plan of MCP-PMT （method）；

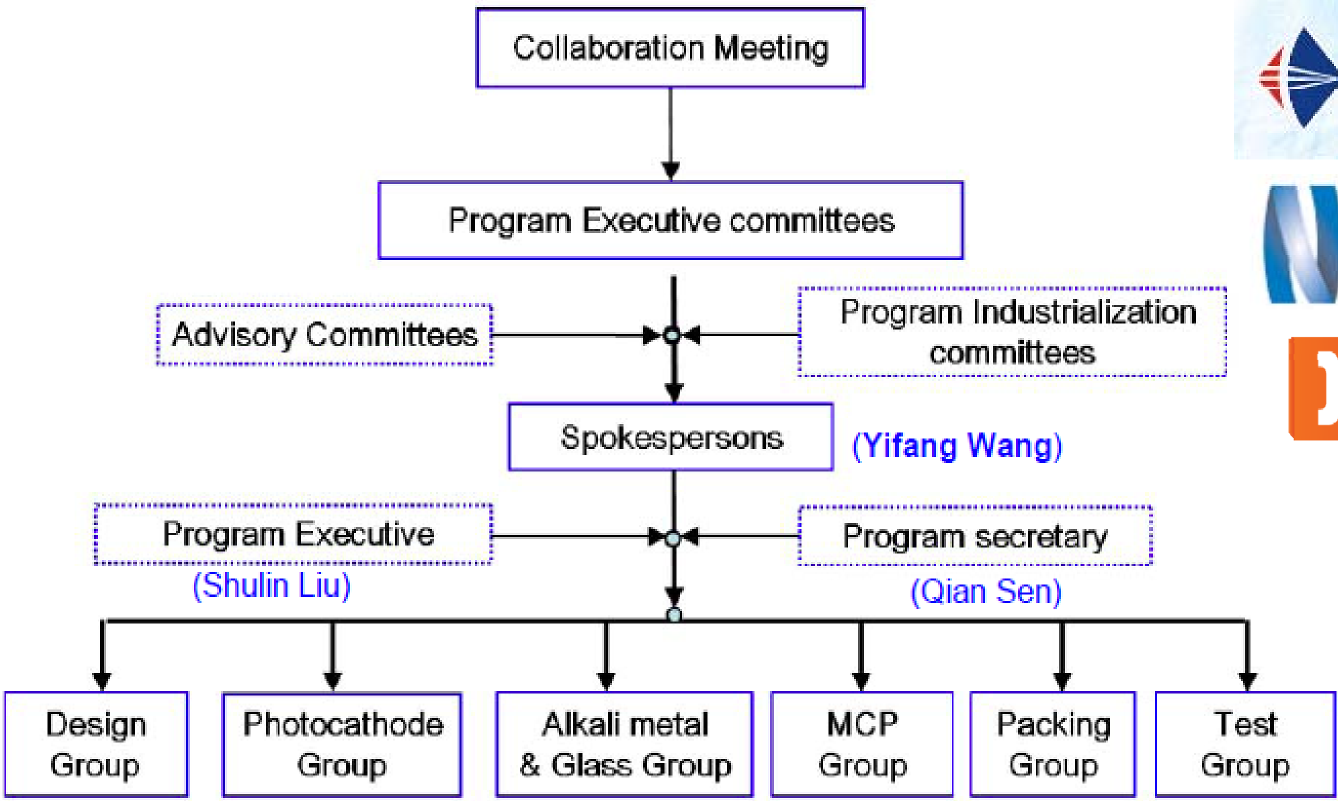
➢2.1 Project team and Collaborators

中國科學院高能物理研究所

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

海南展创光电技术有限公司
HZC PHOTONICS

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

南京大学

宝光股份
BAOGUANG

➢2.2 The Technical Workshop & Collaboration Meeting

Technical Workshop

KM-- 20110911
PMT

XA-- 20120227
Vacuum Equipment

NJ-- 20120620
MCP

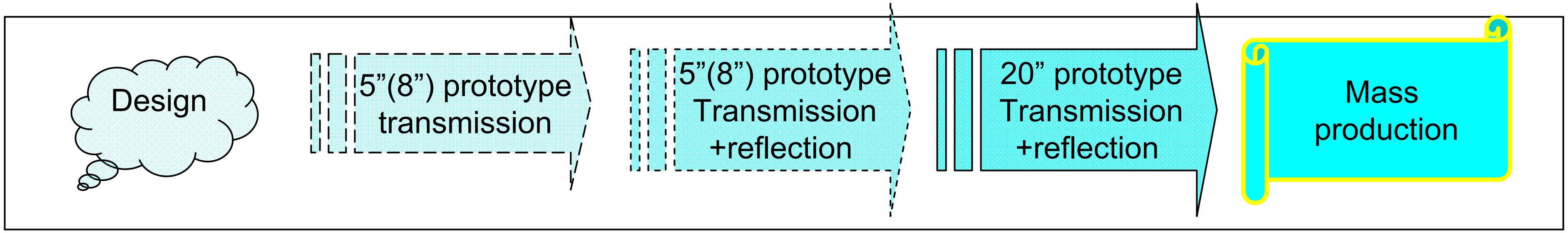
BJ-- 20121020
Photocathode

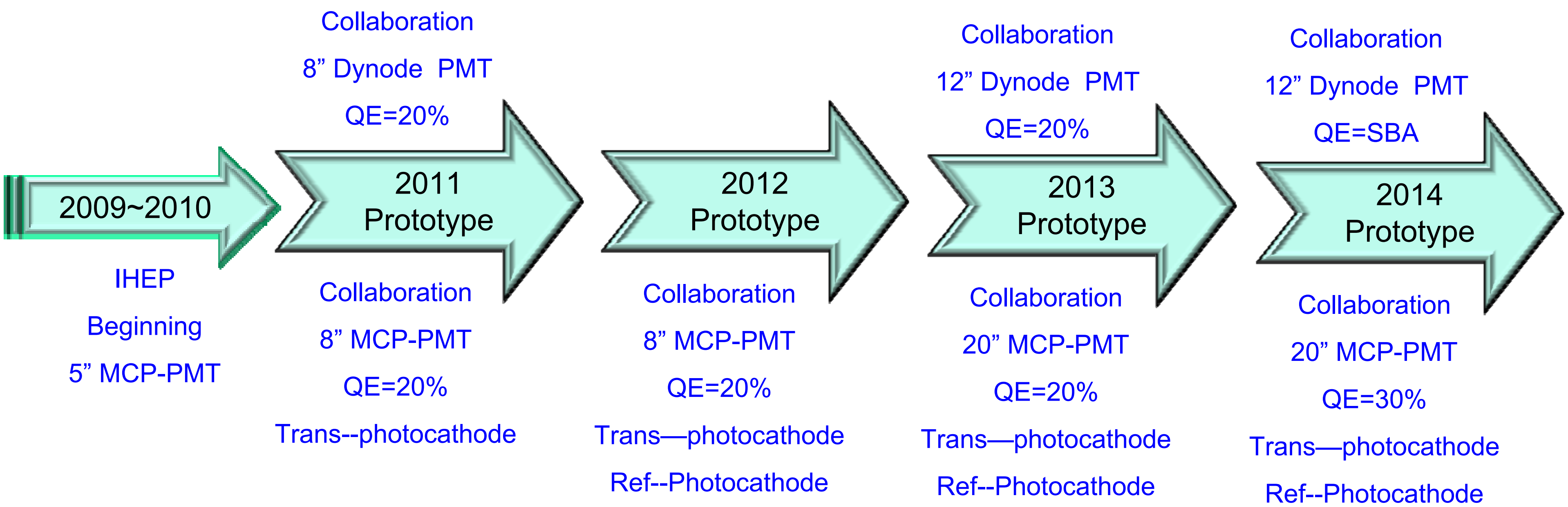
Collaboration Meeting

BJ-- 20111118

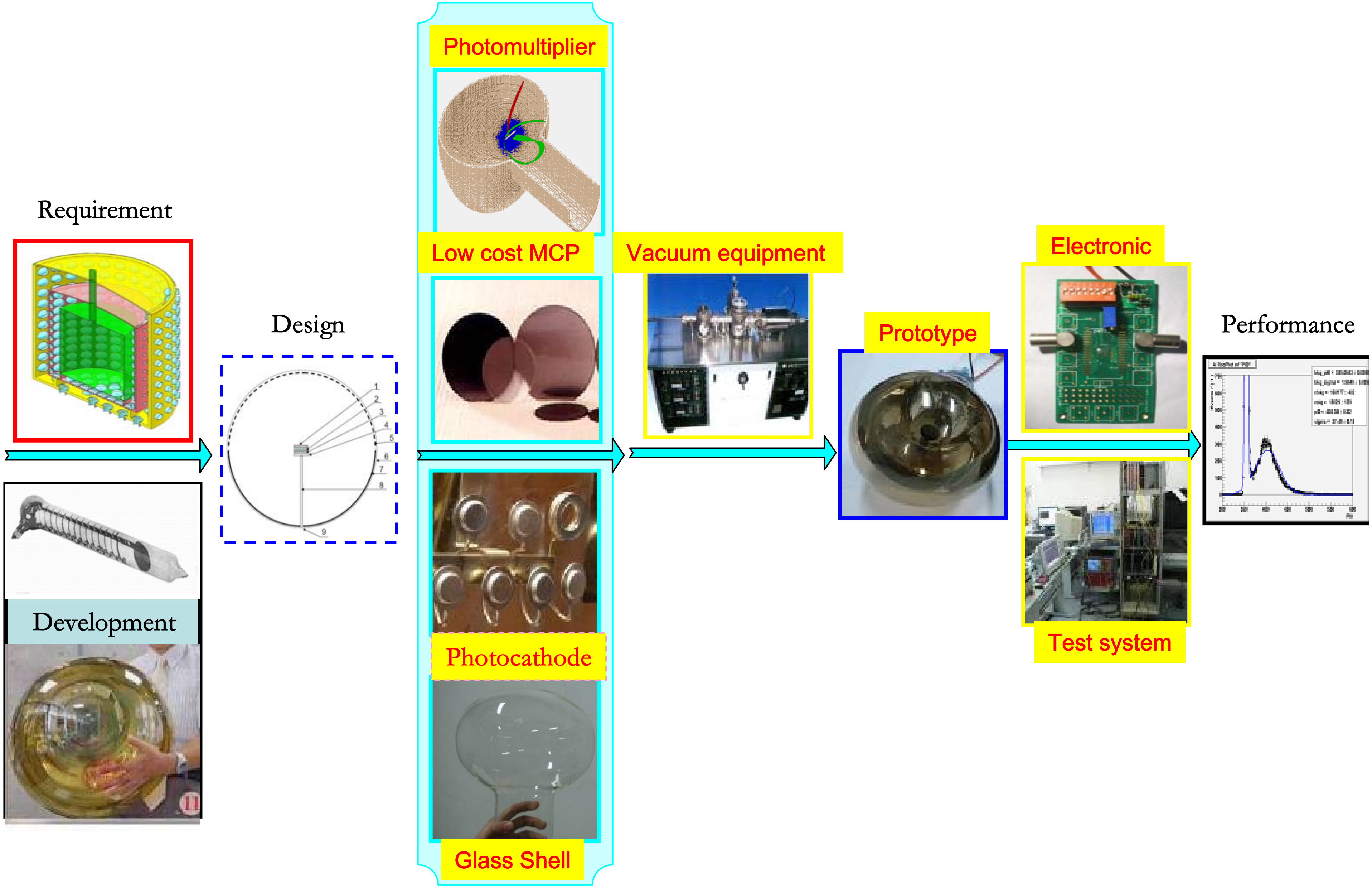
HK-- 20121212

➢2.3 The R&D plan of MCP-PMT （schedule）





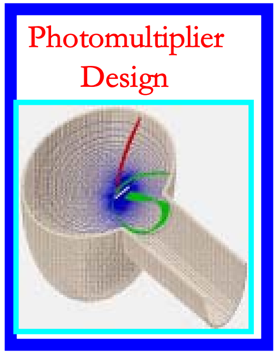
➢ 2.4 The R&D plan of MCP-PMT （method）



Outline

- 3. The Challenge of the Research Project ;
- 3.1 The Photomultiplier Design；
- 3.2 The Low radioactive background glass;
- 3.3 The Low cost MCP；
- 3.4 The Base with Pre-Amplifier；

➢ 3.1 The Photomultiplier Design

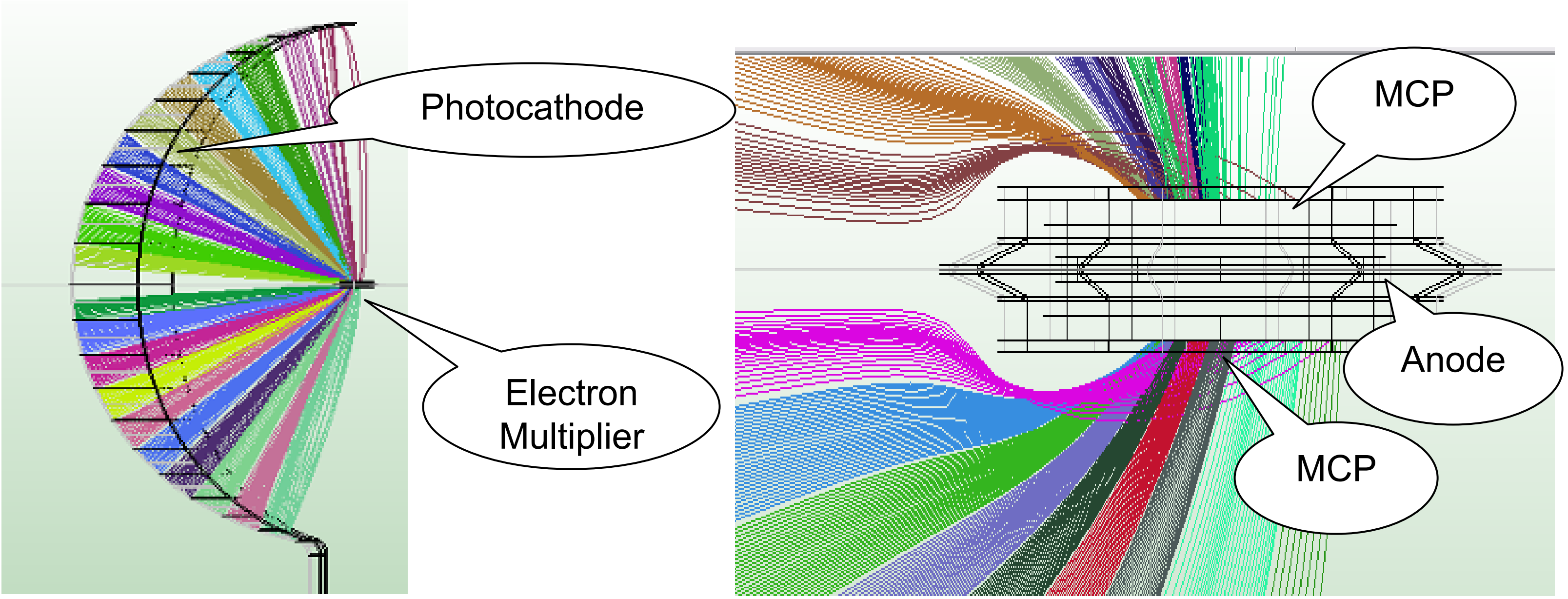


➢Simulate the possibility of the 20” spherical MCP-PMT

--Electron Multiplier: small size MCP(ϕ =18(33)mm) ➔ Dynode chain ;

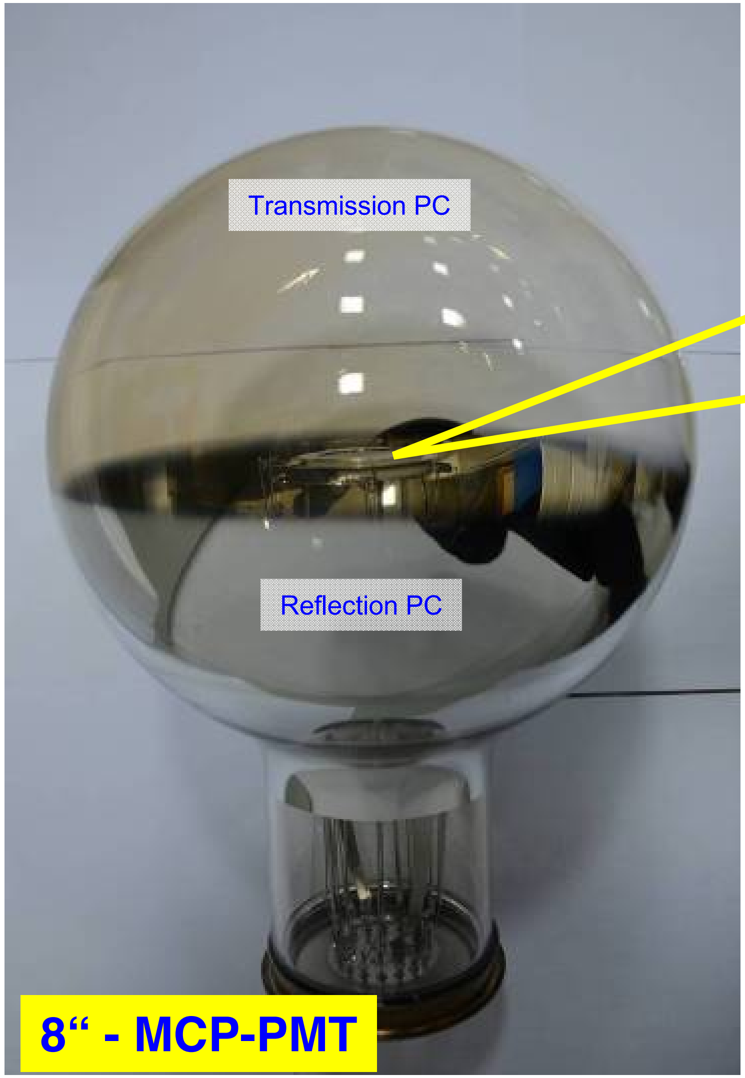
--photocathode area: transmission+ reflection, nearly 4π effective area ;

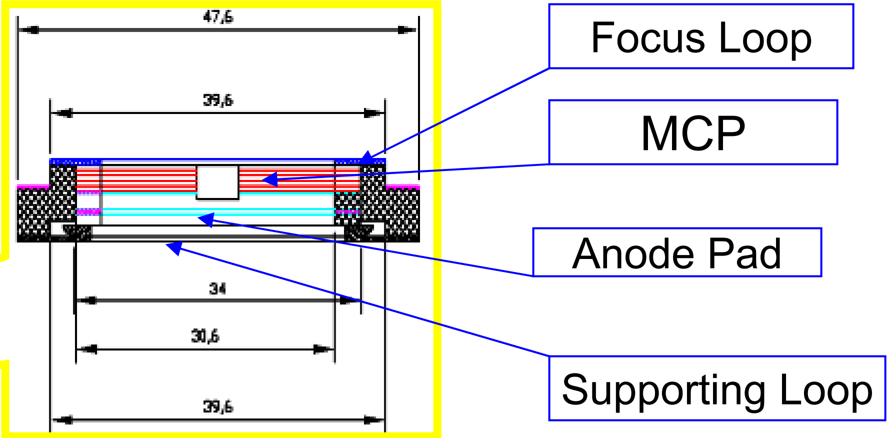
--Could the small Electron Multiplier MCP collect all the photoelectron?

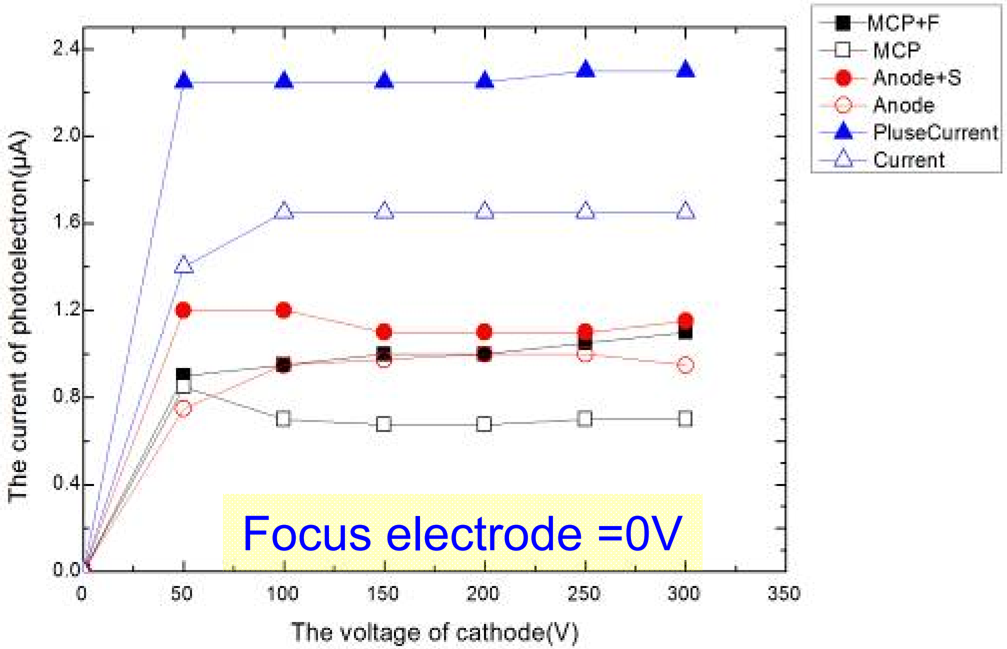


--Yes！ Nearly all the photoelectrons could be collected by the small MCP!

- ➢ Simulate the properties of MCP-PMT (8”, 12”, 20”) with spherical and ellipse shell;
- ➢ Simulate the performance of different size MCP without the geomagnetic field (GM);
- ➢ Simulate the performance affected by the geomagnetic field;





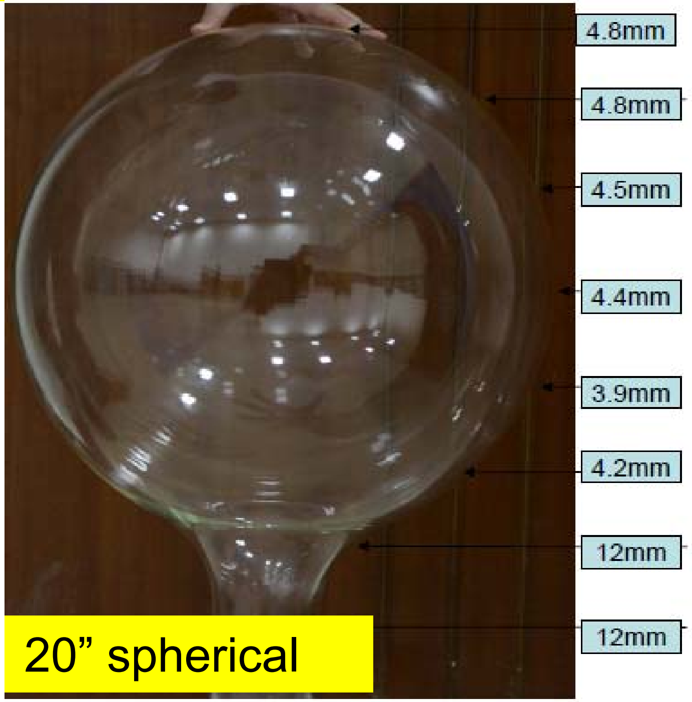


The Photo current = Trans PC current + Ref PC current = 2 * Trans PC current

Situation：LED Source（duty factor =1%，f=1kHz，Voltage=3.5V，Pluse signal）

➢ 3.2 The Low radioactive background glass

- ➢Large (8” , 20”);
- ➢Superb water-resistance characteristics;
- ➢Low radioactive background glass;

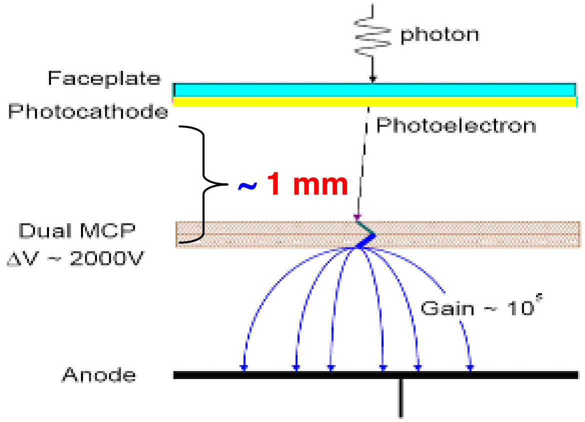


radioactive background test of different PMT glass (unit: ppb)

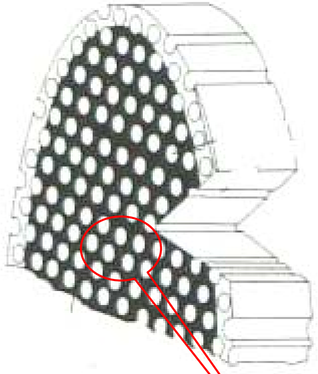
Glass	*DM-308*	*DM-305*	*CN-2# Glass*	*CN-2# Material*
Sample Mass	211.0g	131.1g	335.2g	280.9g
Test Time	311023	424110	315394	359618
^{238}U	21.50±0.10	42.40±0.14	14.96±0.08	<0.1
^{232}Th	18.50±0.32	6.43±0.23	4.78±0.16	<0.2
^{40}K	2.50±0.01	41.01±0.03	3.11±0.01	<0.01

Low background gamma spectrometer in IHEP

➢ 3.3 The Low cost MCP



MCP →



Why the cost of the MCP is usually high?

---- optoelectronic imaging device

---- High timing resolution device

Low production yield! ~ 20%

☐ MCP-PMT Operation Principle

cost

disqualified MCP for Imaging device

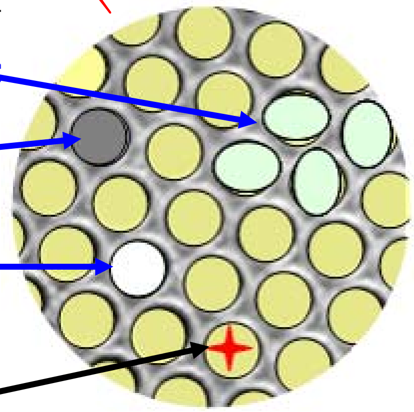
1。 asymmetrical surfac

2。 Blind channels;

3。 Non-uniform gain

of the channels ;

4。 emission flash



Acceptable MCP for SPE detection

cost

The MCP production company, which is the one of our partner has over 20 years of experience in MCP production.

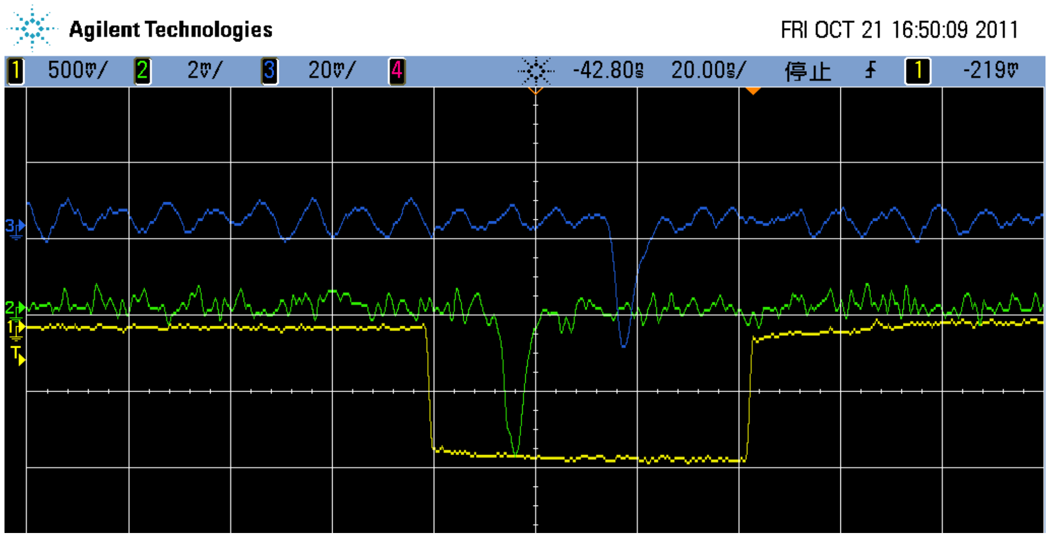
Could supply us the MCP with low cost.

➢ 3.4 The Base with Pre-Amplifier

The electron multiplier consists of two conventional MCP, ~ 10^5 gains (in our group)

Current-sensitive preamplifier

Equivalent noise charge	< 2000 electron
Unity-Gain bandwidth	300 MHz
Rise time	1~2 ns
Amplification	20× ~ 50×
Output impedance	50 Ω
Signal polarity	negative

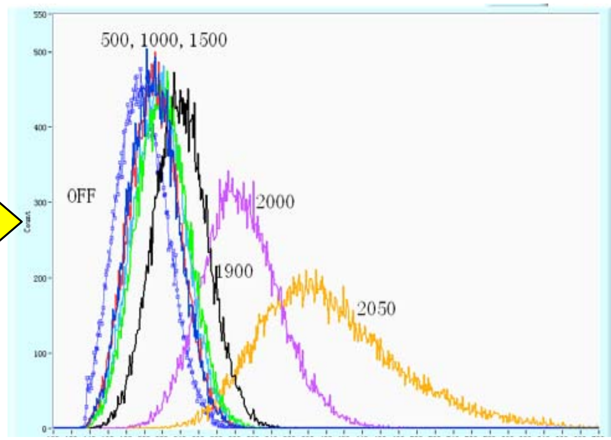


Outline

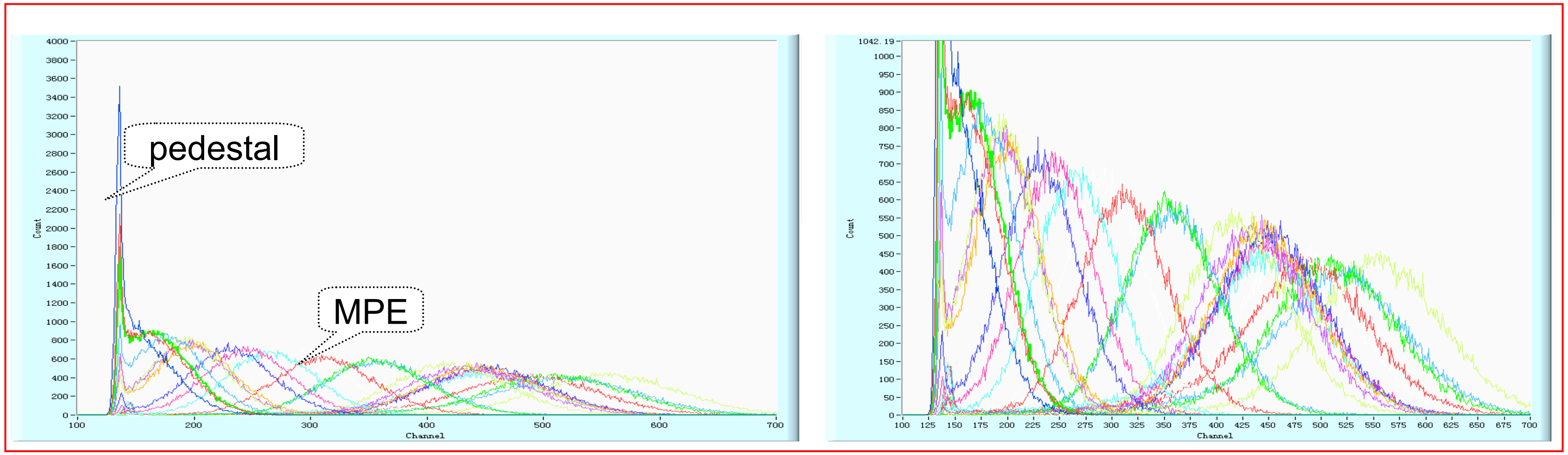
- 4. The Status of the Prototypes ;
- 4.1 The performance of 5” MCP-PMT；
- 4.2 The performance of 8” MCP-PMT；

➢ 4.1 Performance of the 5"MCP-PMT prototype

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



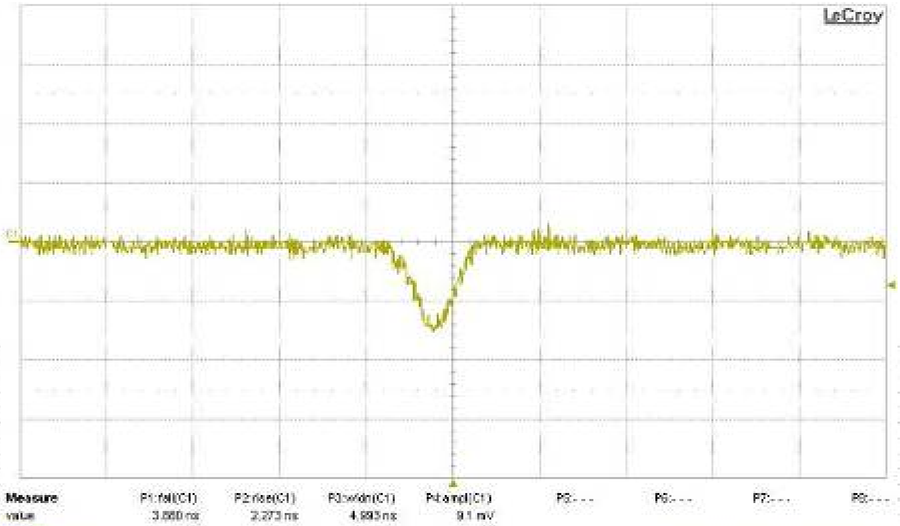
➢SPE? vs the Voltage of the PMT

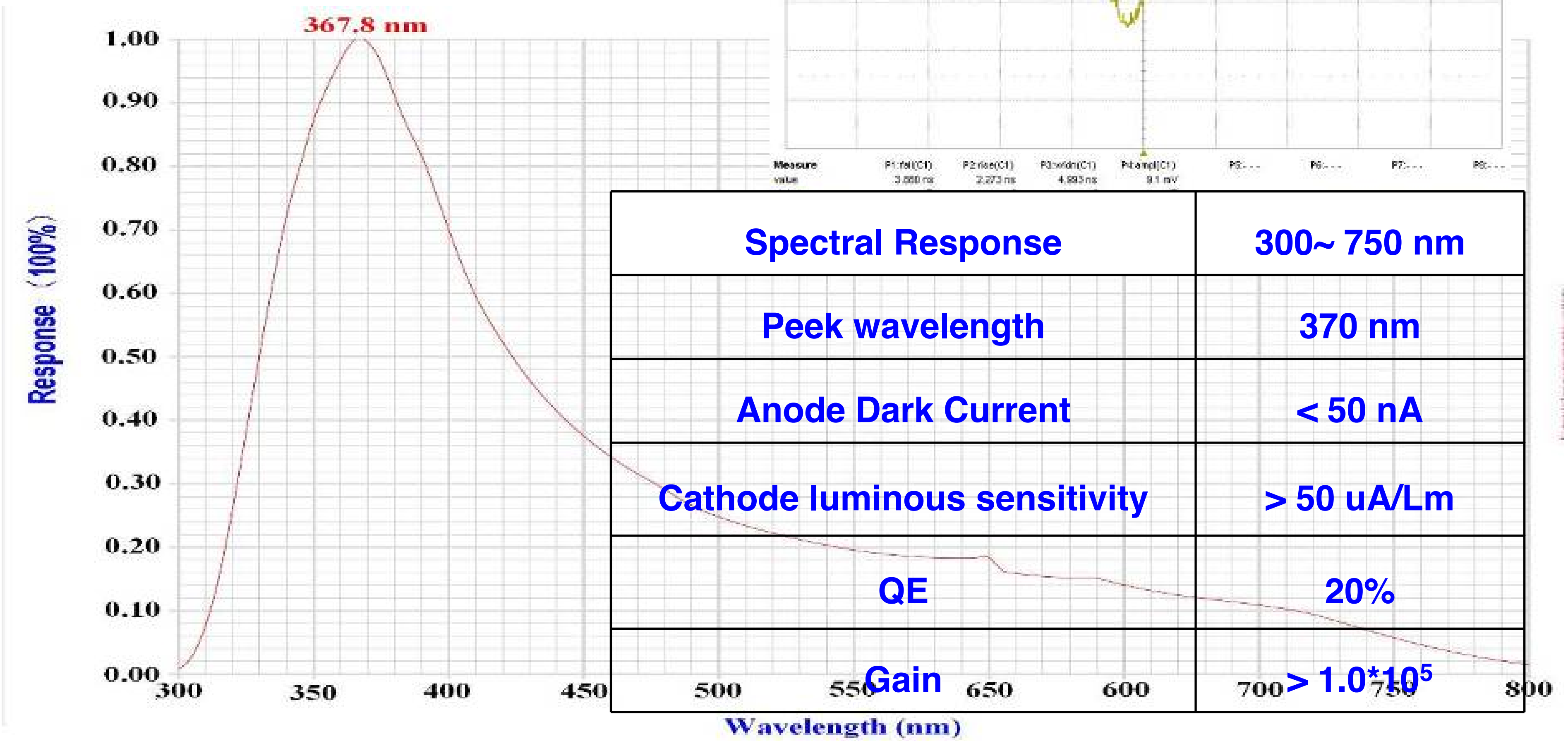


➢MPE vs the luminance of the LED light

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

- Rise time： ~ 2ns；
- Fall time: ~3ns；
- Signal amplitude ~7mV；



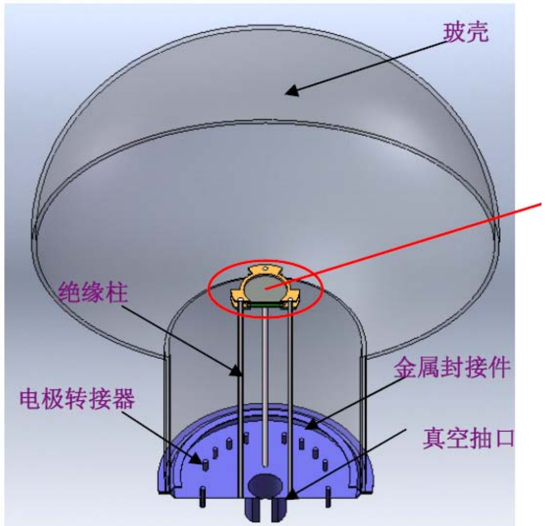


Spectral Response	300~ 750 nm
Peek wavelength	370 nm
Anode Dark Current	< 50 nA
Cathode luminous sensitivity	> 50 uA/Lm
QE	20%
Gain	> $1.0*10^5$

➢ 4.2 Performance of the 8” MCP-PMT prototype

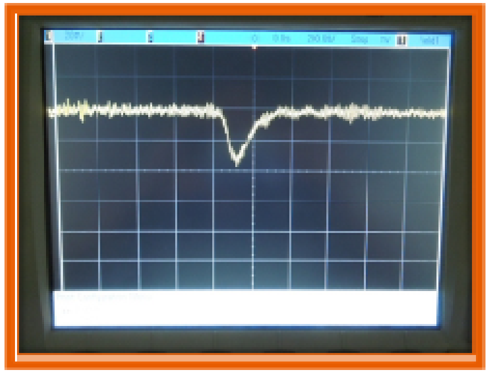
5” 8”

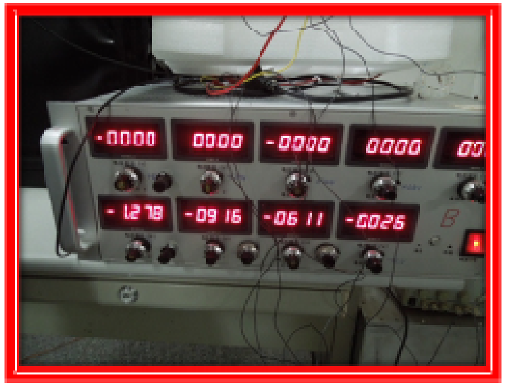
6”

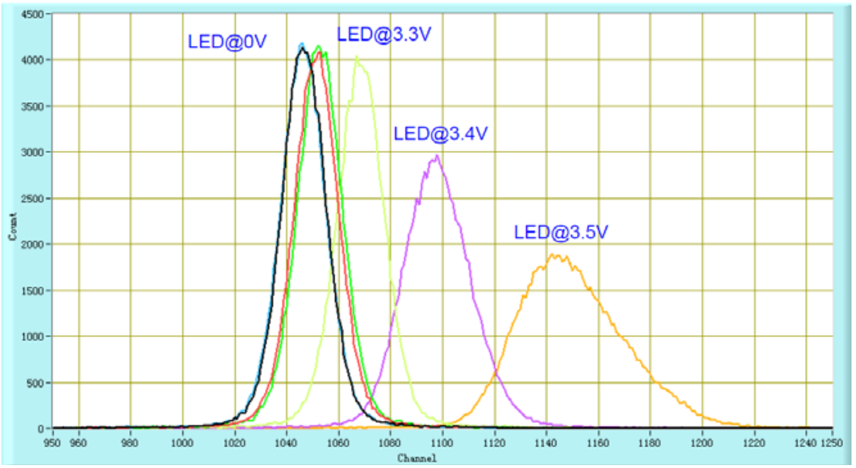


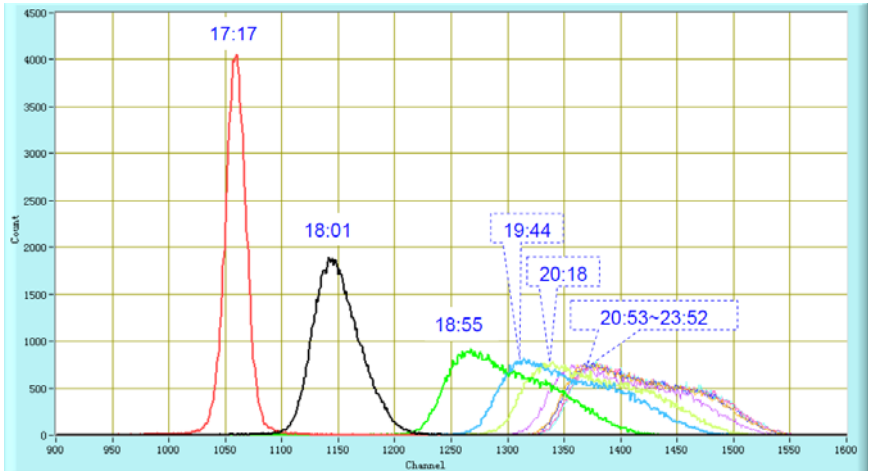
8” ellipse

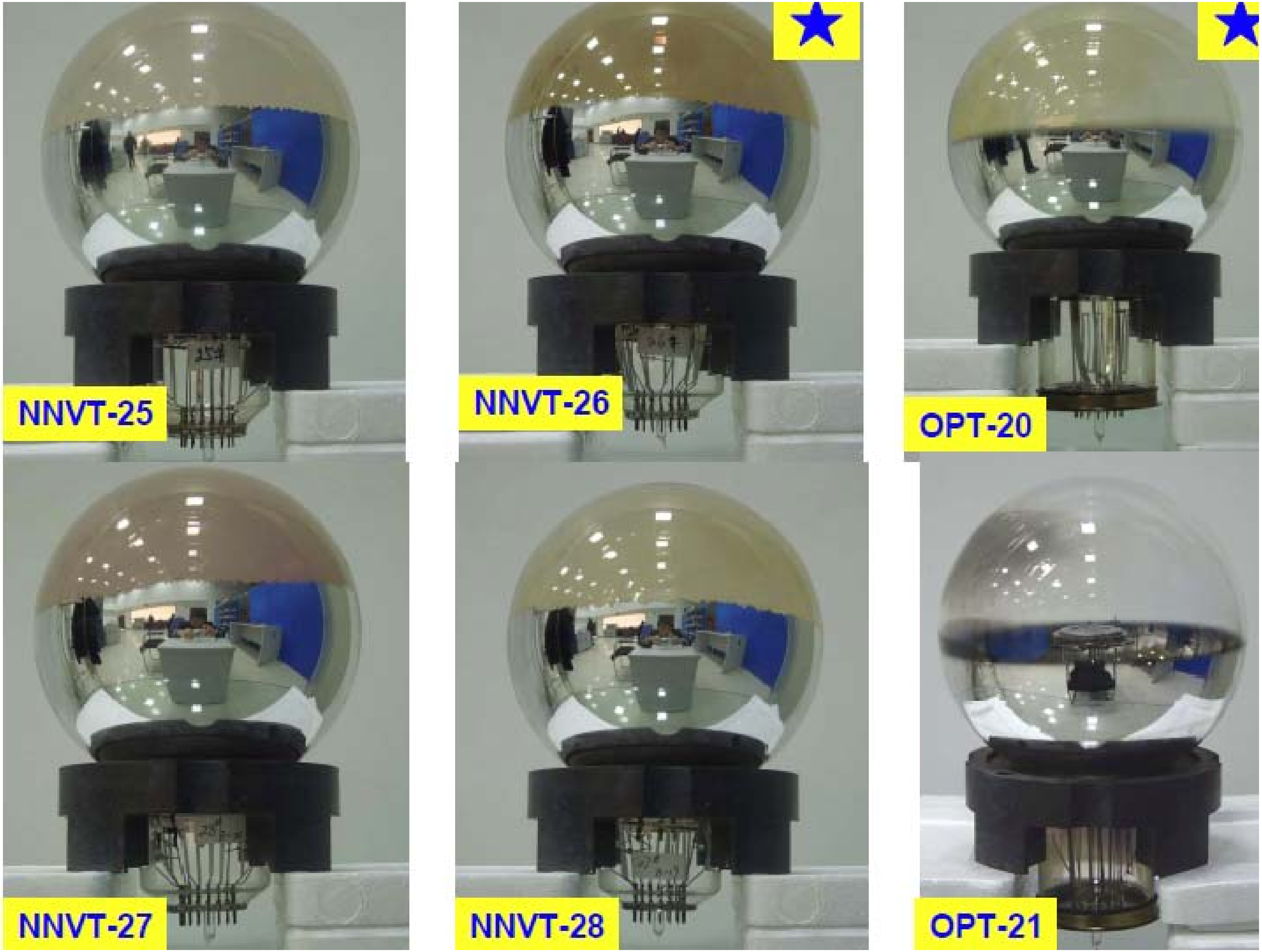
8” spherical

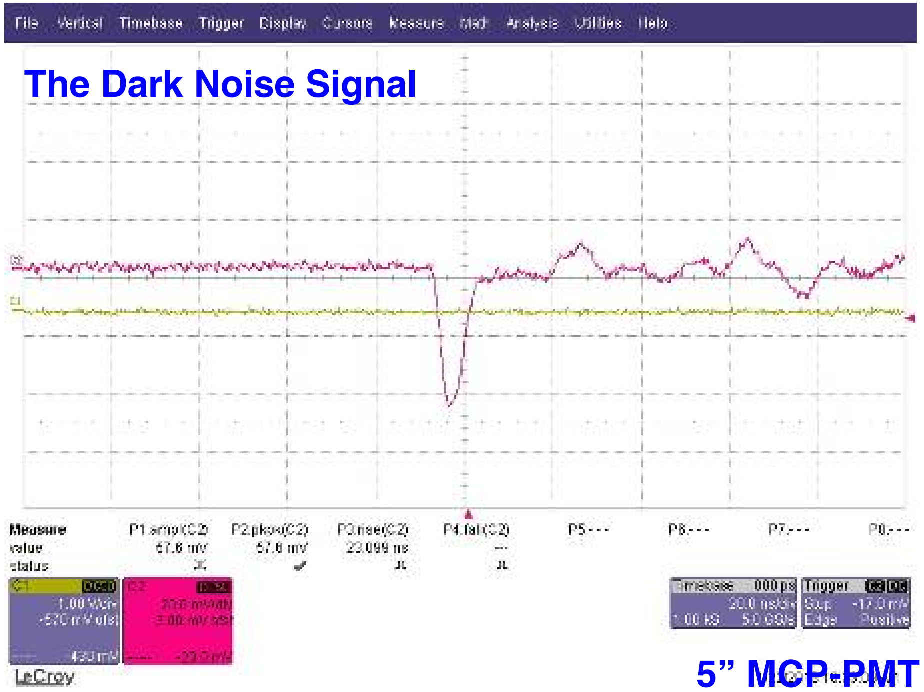


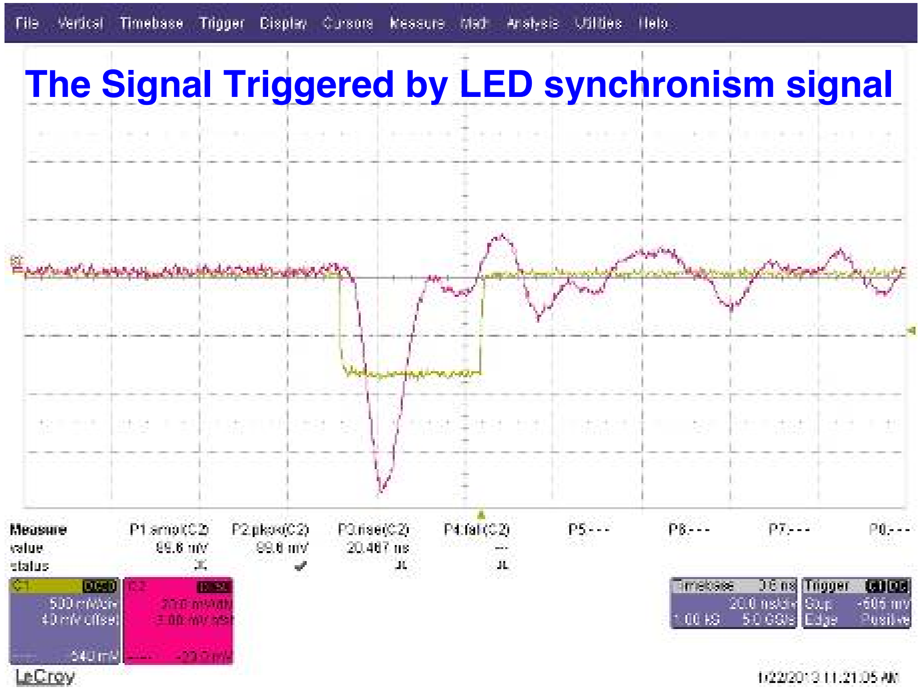


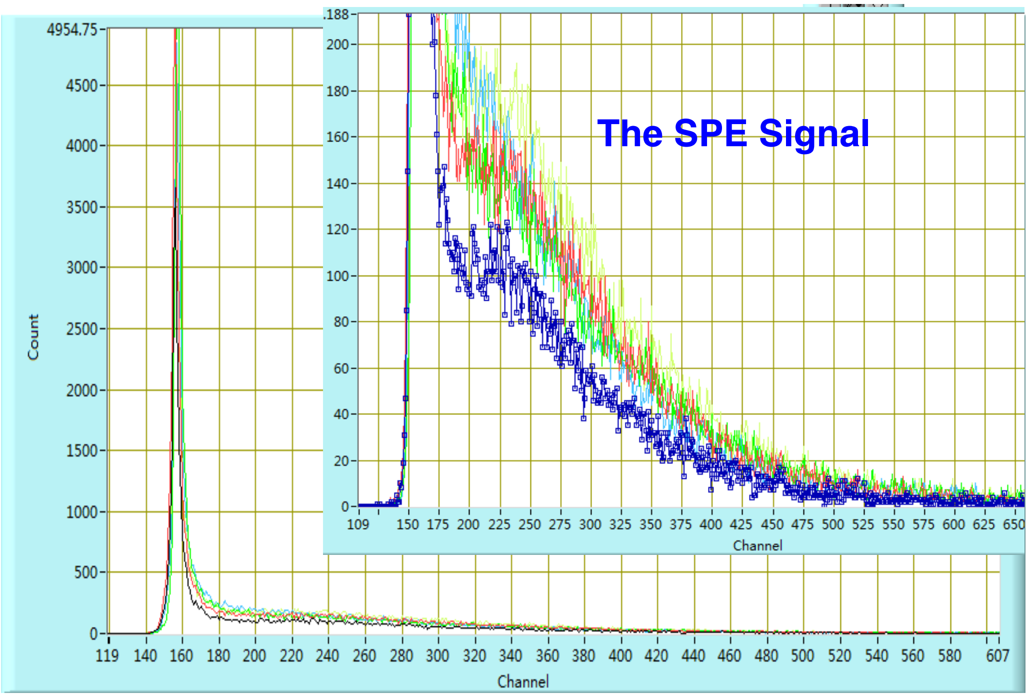

LED@0V
LED@3.3V
LED@3.4V
LED@3.5V
Count
Channel


17:17
18:01
18:55
19:44
20:18
20:53~23:52
Count
Channel


NNVT-25
NNVT-26
OPT-20
NNVT-27
NNVT-28
OPT-21







Test Situation:

LED Trigger =1.766 (0.001%);

High Voltage:

Photocathode: 2100V

MCP1: 775V

MCP2: 875V

Anode: 150V

Fast Amplifier: X10

Summary

➢**1. A new type of MCP-PMT is designed for the next generation neutrino exp.**

- ✓ Large ares: ~ 20”;
- ✓ High photon detection efficiency: ~30%, al least ×2 than normal PMT;
- ✓ Low coat: ~ low cost MCPs;

➢**2. The R&D process is composing with 3 steps.**

① 5”(8”) prototype with transmission photocathode;

② 5”(8”) prototype with transmission and reflection photocathode;

③ 20“ prototype with transmission and reflection photocathode;

➢**3. The R&D work is divided into 7 Parts to product the prototype to detect SPE:**

①Photocathode; ②MCP; ③Glass; ④Photomultiplier;

⑤vacuum equipment; ⑥Electronic; ⑦Test system;

There are lots of work to do!

We need any help from other institute and company!

Thank！ 谢谢！

Thanks for your attention!

Any comment and suggestion are welcomed!

➢ 2.5 The performance of the MCP-PMT

Characteristics	unit	R3809U-50（Hamamatsu）	R5912（Hamamatsu）	MCP-PMT-8（IHEP）	R3600（Hamamatsu）	MCP-PMT-20（IHEP）
size	inch	2	8	**8**	20	**20**
Spectral Response	nm	160~850	300~650	**300~650**	300~650	**300~650**
Photocathode Material	--	Multialkali	Bialkali	**Bialkali**	Bialkali	**Bialkali**
Electron Multiplier	--	MCP	Dynode	**MCP**	Dynode	**MCP**
Gain	--	2×10^5	$\geqslant1\times10^7$	$\geqslant1\times10^5$	$\geqslant1\times10^7$	$\geqslant1\times10^5$
Photocathode mode	--	transmission	transmission	**reflection + transmission**	transmission	**reflection + transmission**
Cathode Sensitivity	uA/lm	150	70	**70**	60	**70 ~100**
Quantum Efficiency（400nm）	%	--	22	**20~40？？**	20	**20~40？？**
Electron Multiplier Collection efficiency	%	~ 60%	~ 60%	~ 70%	~ 60%	~ 60%
Efficiency of detecting photoelectron	%	--	< 13	**> 20**	<12	**> 20**
Anode Dark Current	nA	100	≤700	**≤100**	≤1000	**≤100**
Anode Pulse Rise Time	ns	0.150	3.8	≤ 5	10	**≤10**
Transit Time Spread (TTS)	ns	≤0.025	2.4	**≤1**	5.5	**≤2**
Anti-Magnetic characteristics	--	Good	**normal**	**normal**	**normal**	**normal**
Glass	--	--	Low-Potassium Glass	**Low-Potassium Glass CN-2#**	HARIO-32	**Low-Potassium Glass- CN-2#**