A new design of large area MCP-PMT for the next generation neutrino experiments

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On Behalf of the Workgroup

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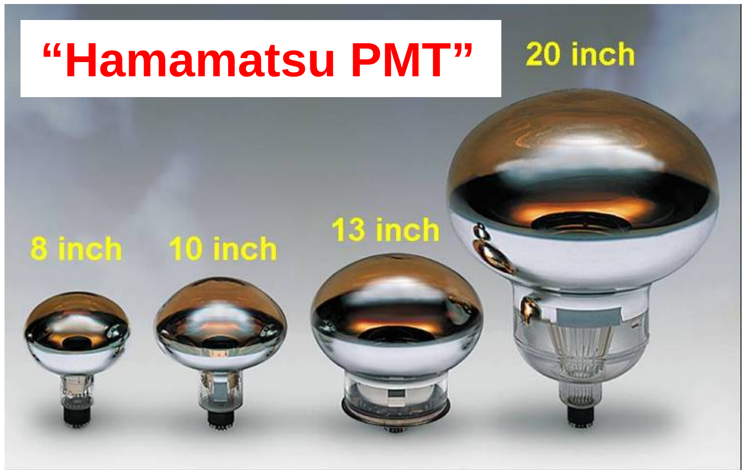
Outline

- 1. Motivation:
- 2. The Design of the new MCP-PMT:
- 3. The progress of the MCP-PMT R&D .
- 4. Summary.

➢ Current and Future Neutrino Experiments

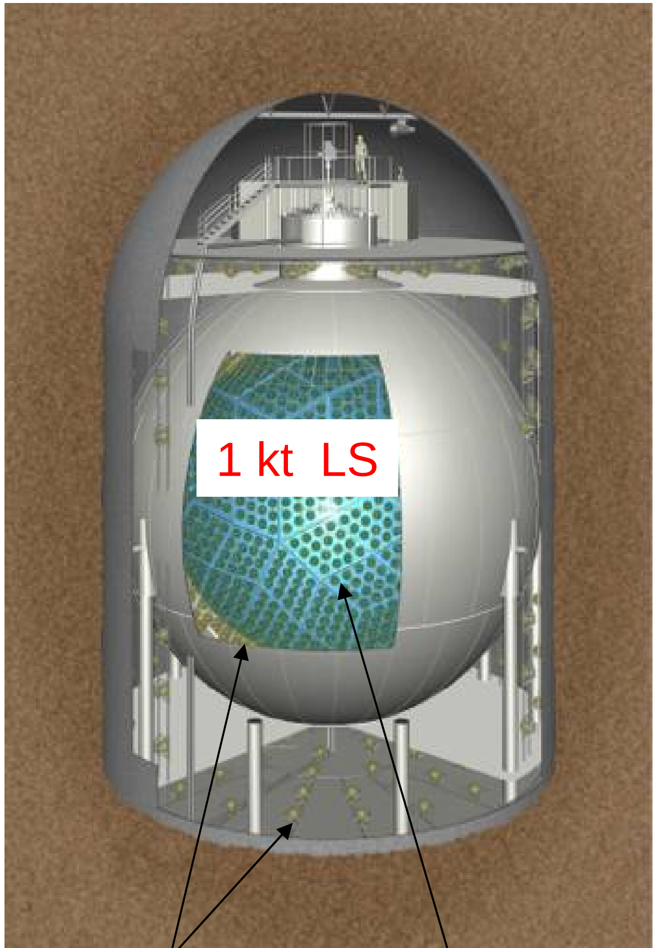
Large Format PMTs
for the Neutrino Experiments



- **Atmospheric neutrino exp.**
  - –**SuperK** (Japan)**,**
  - –HyperK/UNO,INO,TITAND,…
- **Solar neutrino exp.**
  - –**SNO** (Canada),
  - –GALLEX/SAGE, Borexino, XMASS, …
- **Accelerator neutrino exp.**
  - –**T2K** (Japan),
  - –**Nova** (American),
  - –Minos, OPERA, MiniBooNE,
- **Reactor neutrino exp.**
  - –**KamLAND** (Japan),
  - –**Daya Bay** (China),
  - –**Double Chooz** (France)
  - –**Reno** (Korea), **…**
- **The Future neutrino exp.**
  - –**Low Energy Neutrino Astrophysics**
  - –**LAGUNA-LBNO** (European)
  - –**Daya Bay II** (China), **……**

➢ KamLAND: an Example of Reactor Neutrino Experiment

KamLAND Detector



- **Current benchmark:**

Liquid Scintillator (LS)

–The Mass of LS: ~1kt

– Attenuation length of LS: ~15m

– Light yield of LS: ~~ 8000 photons/MeV

~~ PPO% ~ 1.5g/l

Photon Detector (PMT)

–Hamamatsu PMT:~~17 inch and 20 inch

–Quantum Efficiency **(QE):** ~20%

–Collection efficiency of first dynode **(CE):** ~70%

–Photon detection efficiency **(PDE):** ~14%

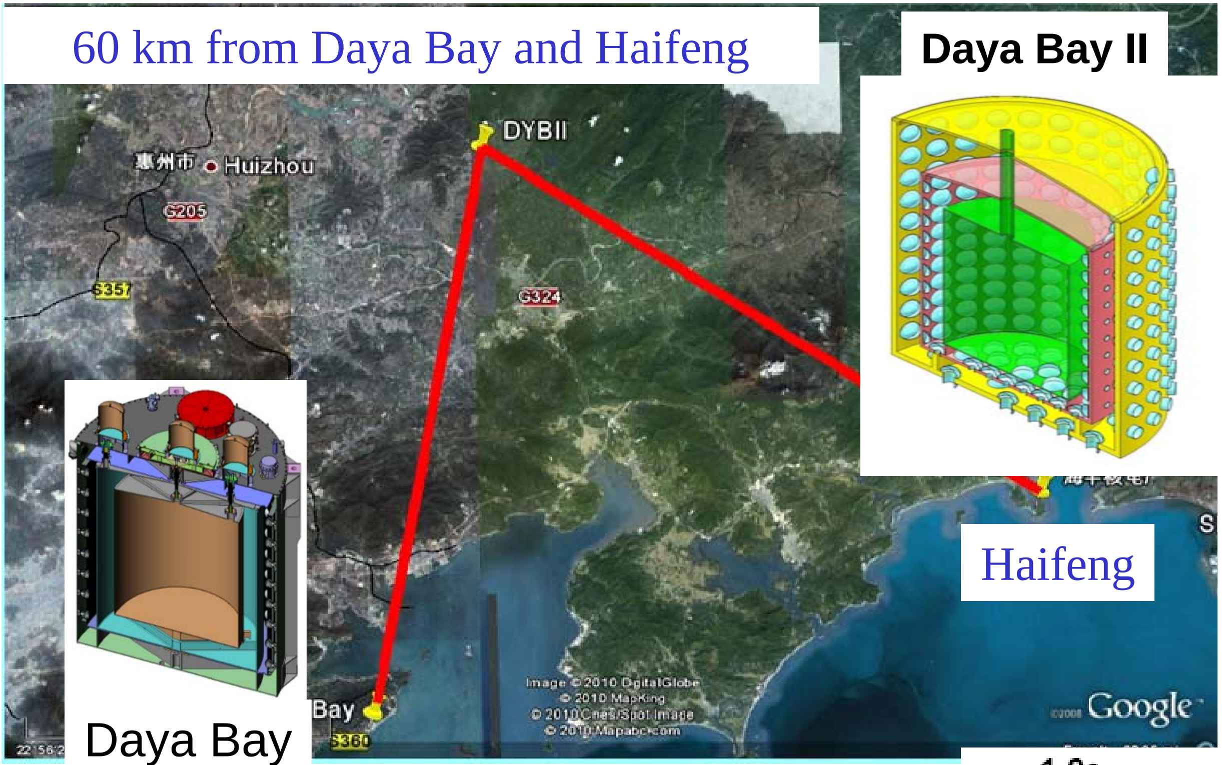
Photocathode coverage : ~34%

Light Yield of the Whole Detector:

250 p.e / Million electron volts energy (MeV)

The number of the detected p.e per neutrino reaction

➢ Next generation Neutrino Experiment in China



The Main Scientific goals:

- ⇨ **Mass Hierarchy**
- ⇨ Mixing matrix elements
- ⇨ Supernovae
- ⇨ geo-neutrinos

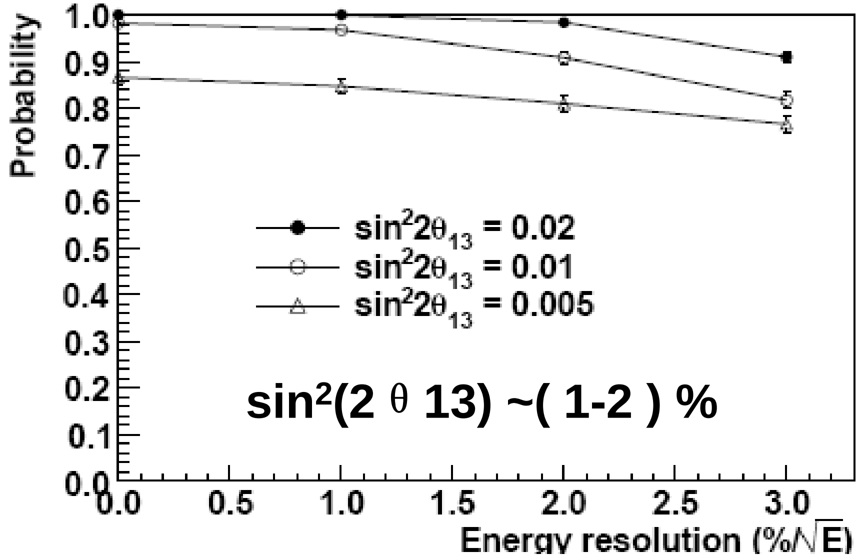
Measuring Mass Hierarchy

Huge Detector : LS + PMT

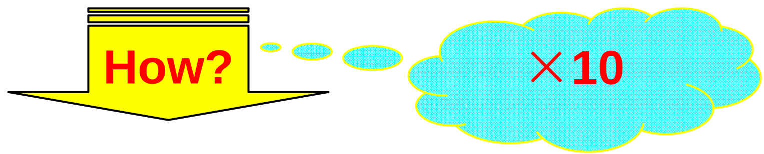
Baseline: 60 km from the Reactor

Energy resolution ~ 2%/√E

L. Zhan, et. al., Phys.Rev.D 78:111103,2008
L. Zhan, et. al., Phys.Rev.D 79:073007,2009



	KamLAND	Daya Bay II
Detector	~1 kt Liquid Scintillator	> 10 kt Liquid Scintillator
Energy Resolution	6%/√E	2%/√E
Light yield	250 p.e./MeV	2500 p.e./MeV



- **Ongoing R&D:**

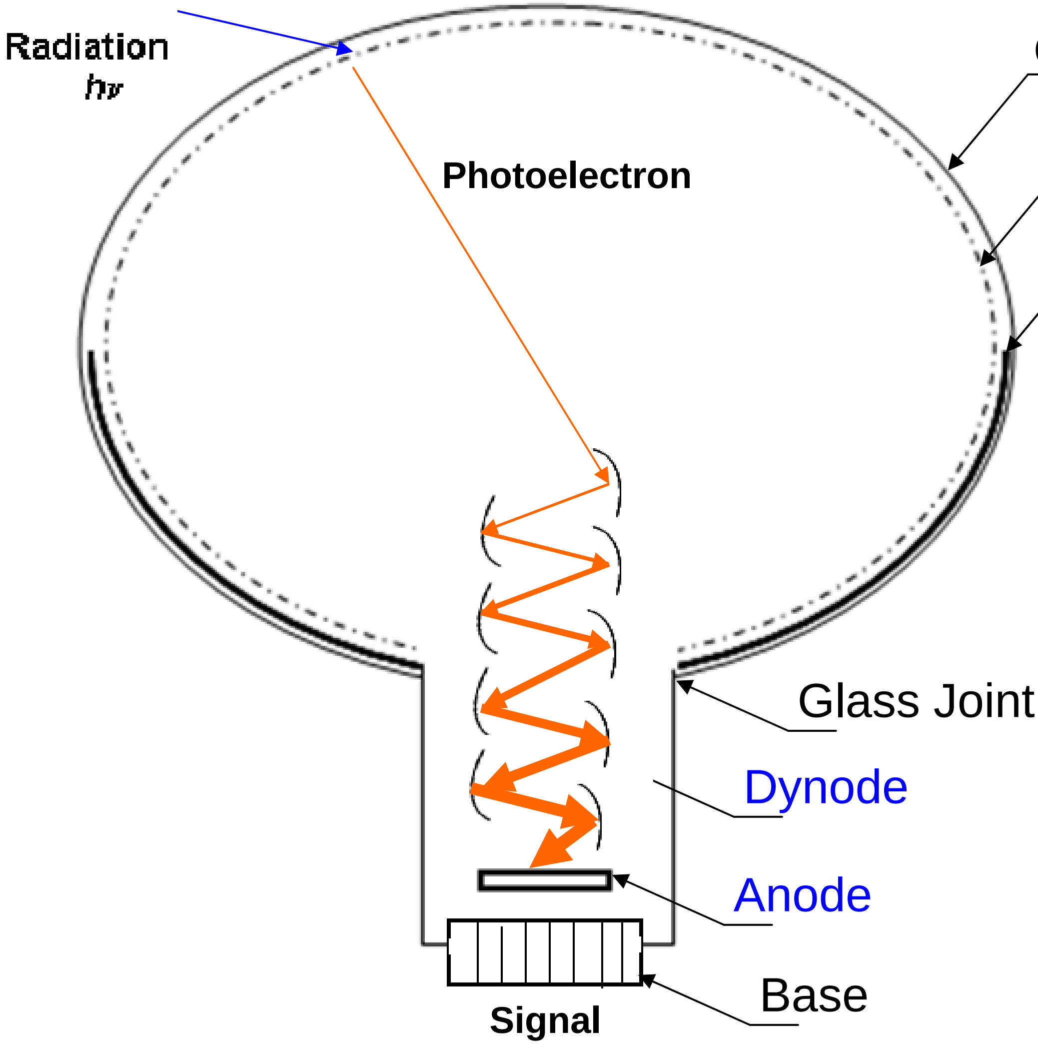
– **Highly transparent LS: Attenuation length ×2.5 ;**
KamLAND: 15m → Daya Bay II : 25m;

– **High light yield LS: PPO% × 3 ?? 30%→ 45%;**
KamLAND: 1.5g/l → Daya Bay II : 5g/l;

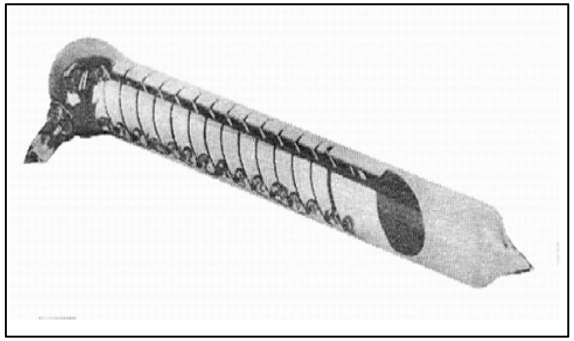
– **Photocathode coverage : ×2**
KamLAND: 34% → Daya Bay II : ~ 80%

– **High "PDE" PMT: Photon detection efficiency ×2;**
20" UBA/SBA photocathode PMT from Hamamatzu ? QE > 40%
New large area PMT ? QE > 40% ?

Conventional PMT



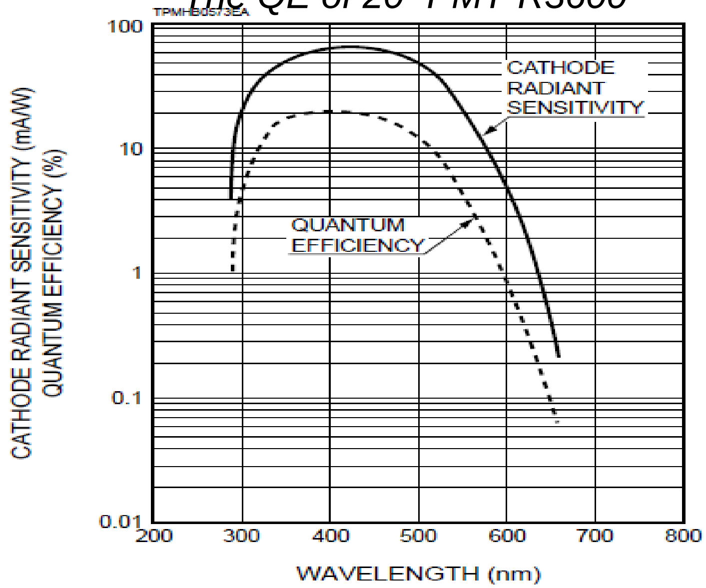
The first PMT in the world in 1933
"Kubetsky's tube"



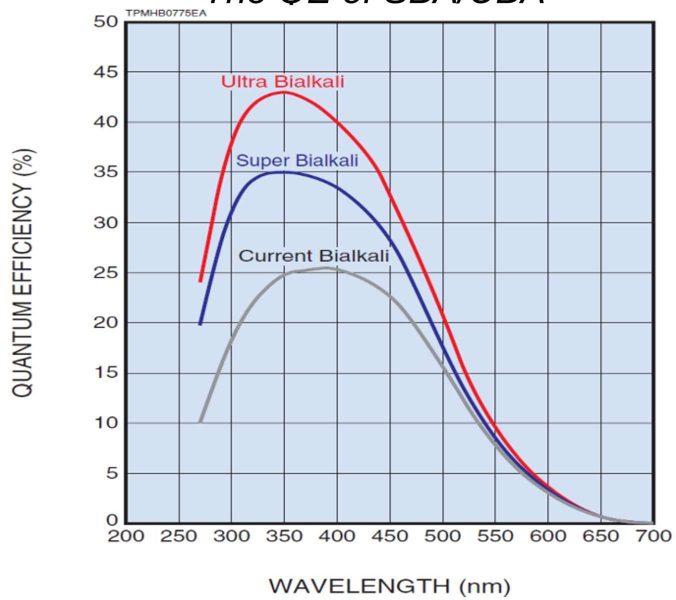
Photomultipliers are constructed from a glass envelope with a high vacuum inside, which houses a photocathode, several dynodes, and an anode.

The Quantum Efficiency of PMT

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 (< 3" diameter ?)

- **QE of photocathode ~ 20%**
- **CE of first dynode is ~ 70%**
- **PDE ~14%**

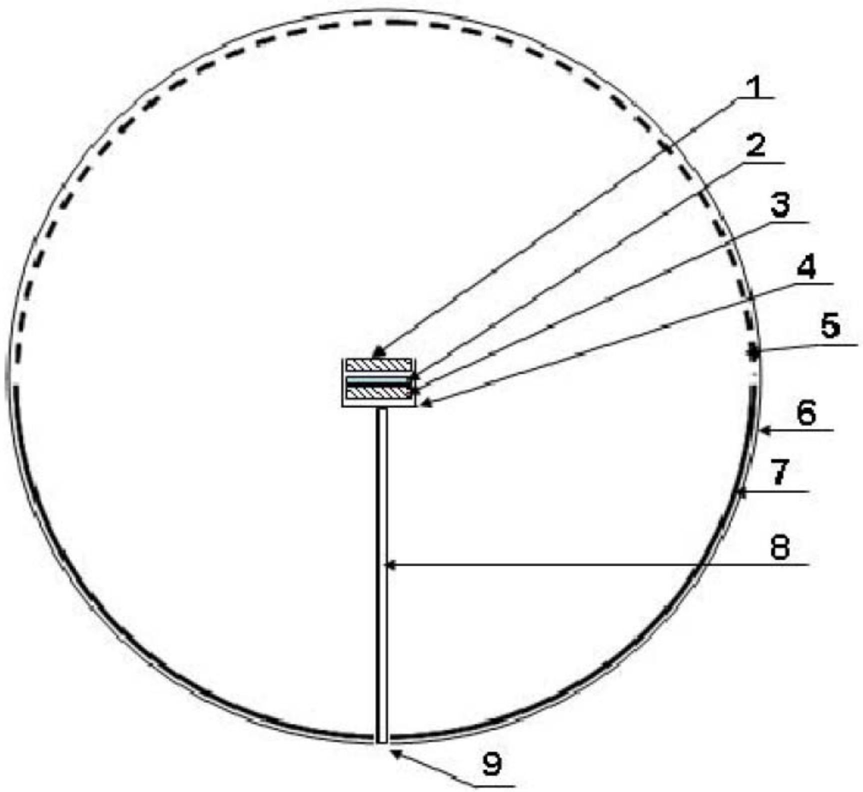
} Hamamatsu 20" PMT

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

➢ 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 reflective photocathode (back hemisphere) } ~ 4π viewing angle!!



1. up MCP
2. anode
3. down MCP
4. insulated trestle table
5. transmission photocathode → 20% * 60% = 12%
6. glass shell
7. reflection photocathode → 70% * 40% * 60% = 17%
8. bracket of the cables
9. glass joint

QE { Transmission cathode: 20%; Reflection cathode: 40% }

➢ MCP CE: 60%

PDE

➢ Total Photon Detection Efficiency: ~30%

Photon Detection Efficiency: 14% → 30% ; ×~2 at least !

Project team and Collaborators

Institute of High Energy Physics, CAS

R&D effort by **Yifang Wang;**

& Tianchi Zhao; Jun Cao; Yukun Heng, Sen Qian; et al

Collaborators

- **Xi'an Institute of Optics and Precision Mechanics of CAS;**

  JInshou Tian; Xiangyan Xu; Huling Liu; Xibing Cao;

- **Nanjing Electronic Devices Institute;**

  Huirui Li; Jun Shentu; Xiaoyun Wang; Deling Liu; Wenjin Zhao;

- **Nanjing University;**

  Ming Qi;

The R&D plan of the MCP-PMT

Design

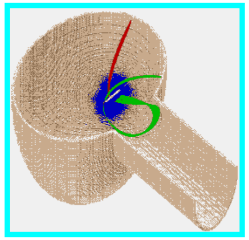
5”(8”) prototype transmission

5”(8”) prototype Transmission +Reflection

20” prototype Transmission +Reflection

Photocathode

MCP

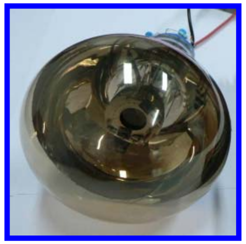


Photomultiplier

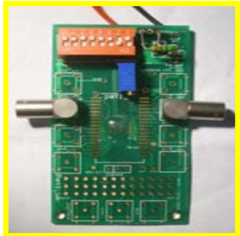
Glass

vacuum equipment

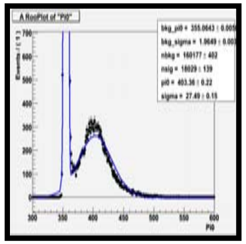
Prototype



PreAMP & Base



SPE



➢The **Progress** of the R&D currently

- **Photomultiplier design ------ Simulation !!**

  The possibility of the 20” spherical MCP-PMT;

  The properties of MCP-PMT (8”, 12”, 20”);

- **Photocathode ------ large area !!**

  Try to produce the alkali metal dispensers (AMD) to control the quality;

- **Glass ------ large and low radiation background !!**

  Superb water-resistance characteristics；
  Low radioactive background glass;

- **MCP ------ low cost !!**

  Try to find MCPs for SPE detection with lost cost (~ hundreds ￥);

Base ------ added with preamplifier !!

The gain of the 2-piece MCP-multiplier is about 10^5;

To detect the SPE, the Pre-amplifier is needed!

These Progress will be detailed discussed in the following Parts!

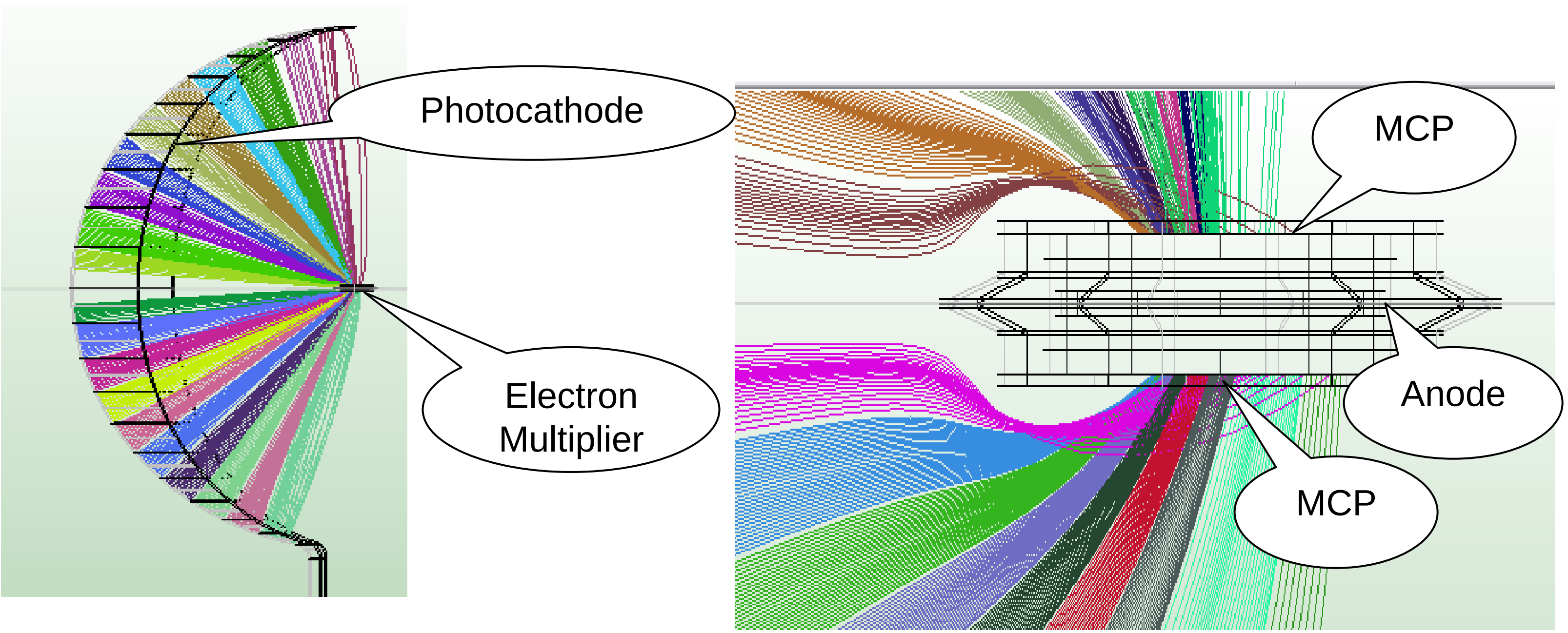
➢ The Simulation work – 20” MCP-PMT

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

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

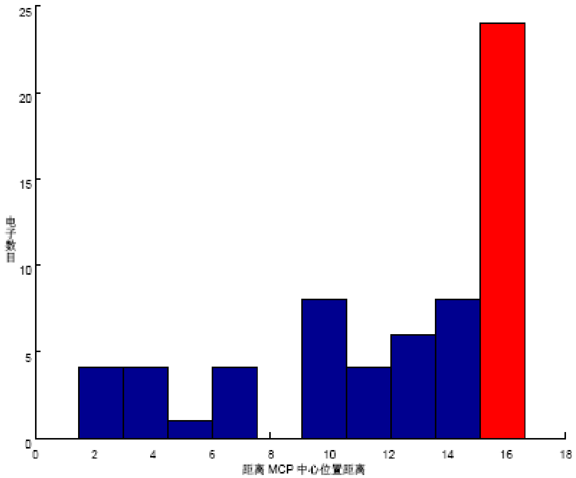
--photocathode area: transmission+ reflection, nearly 4π effective area ;

--Could the small MCP collect all the photoelectron from the photoelectron?

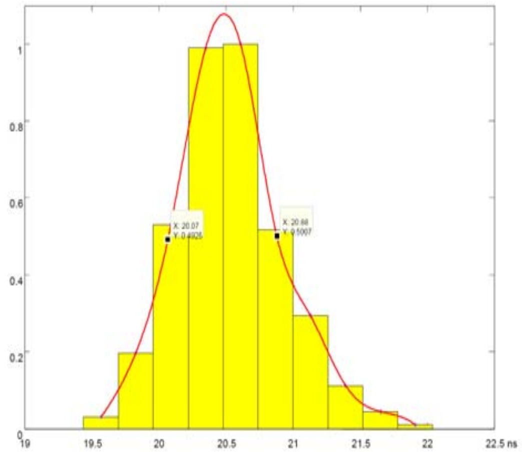


--Yes！ Nearly all the photoelectrons could be collected by the small MCP!

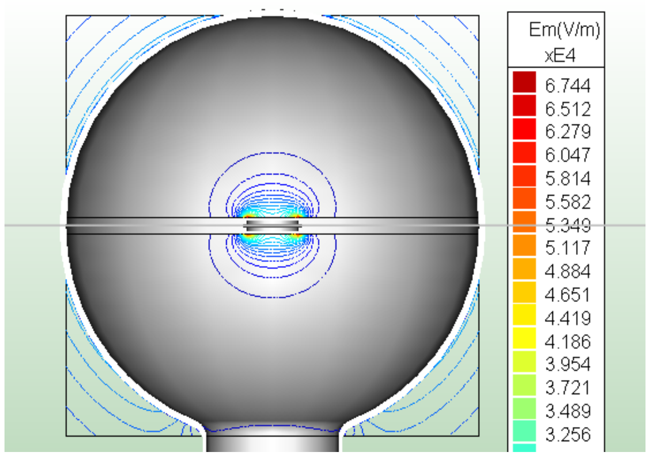
➢ The Simulation work – properties of MCP-PMT



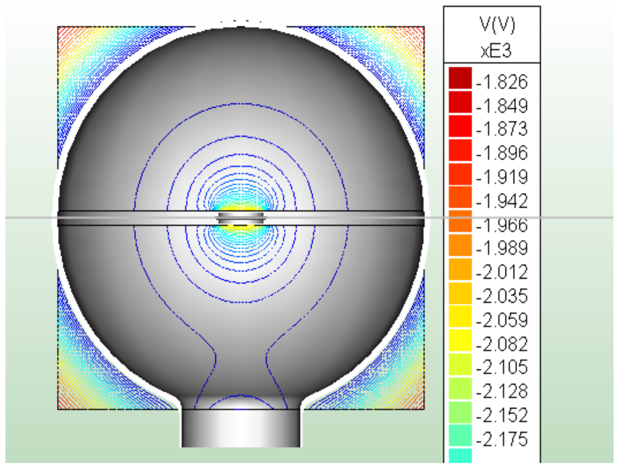
Hit position of the photoelectron in the MCP



Transit Time Spread（T.T.S）



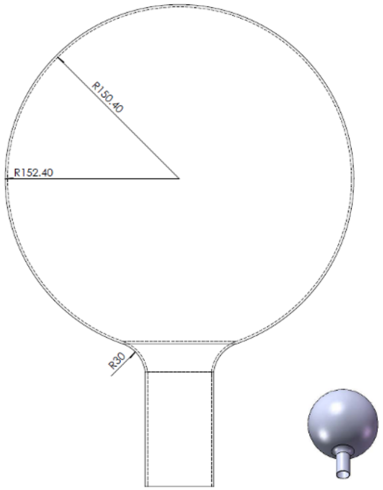
Electric field intensity distribution



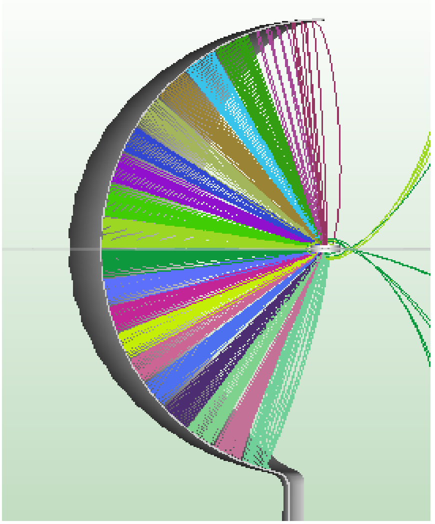
electric potential distribution

Effective diameter of MCP is 18mm;

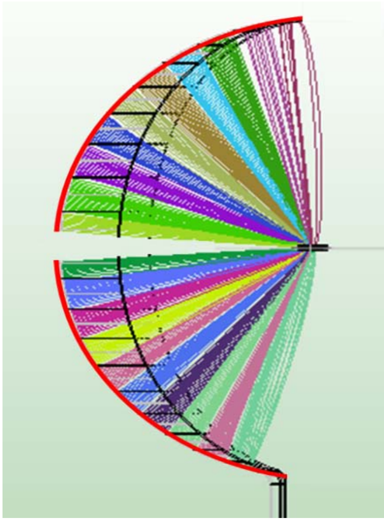
Working voltage: $V_{cathode}$=-2500V; $V_{focus\ electrode}$=-2000V; V_{MCP} =-2000V; V_{anode}=0V;



spherical symmetry
glass shell



photoelectron produced
from photocathode



photoelectron collected
by MCP

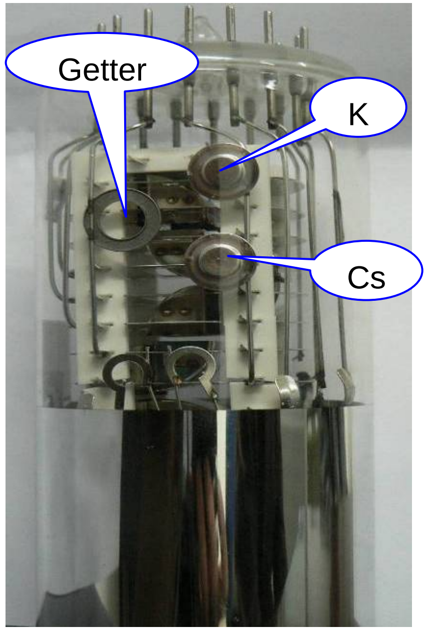
the performance of different MCP-PMT without the geomagnetic field (GM)

		Transmission photocathode			**Reflection photocathode**		
size	**Width of Blind Ring**	**Collection efficiency**	**Transit Time Spread （T.T.S）**	**Hit position In MCP**	**Collection efficiency**	**Transit Time Spread （T.T.S）**	**Hit position In MCP**
inch	mm	%	ns	mm	%	ns	mm
8	10	97.5	1	< 12	95.4	4.8	< 12
10	13	97.4	2.3	< 12	96.2	5.1	< 12
12	14	97.7	3.3	< 14	96.8	8.5	< 16
20	36	96.4	7.1	< 16	96.1	10.1	< 18

➢ Large area photocathode & Glass

1.Why we need the alkali metal dispensers (AMD)?

To achieve 20" large photocathode, the standard alkali metal dispensers could control the quality of the PMTs during the production process.



AMD used in a PMT

Glass bulb for the MCP-PMT

➢ **1. superb water-resistance characteristics;**

--to be submerged in liquid for long time in the experiment.

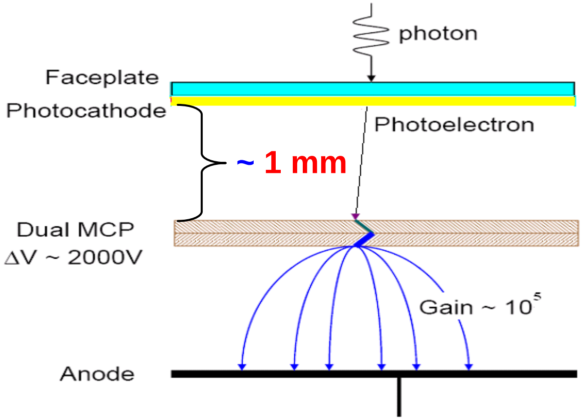
➢ **2. low radioactive background;**

--to reduce the background rates

Table: The background test of different types of electric vacuum glass (unit: ppb)

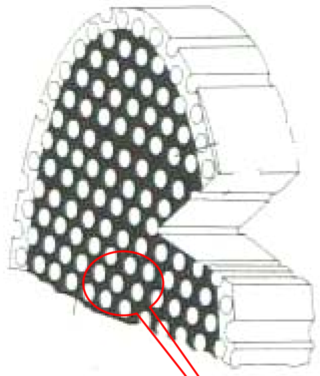
Project	Glass	U^{238}	Th^{232}	K^{40}
Daya Bay I	?	153±25	335±90	16.5±4.5
KamLAND	HARIO -32#	150	240	10
Daya Bay II	CN-2# (OLD Data)	**24.4**	**27.5**	**7.7**
	CN-2# (NEW Data)	On testing!		

➢ The low cost MCP



□ MCP-PMT Operation Principle

MCP →



Why the cost of the MCP is usually high?

----Low production yield! ~ 20%

----MCP mainly used for

optoelectronic imaging device

cost ↑

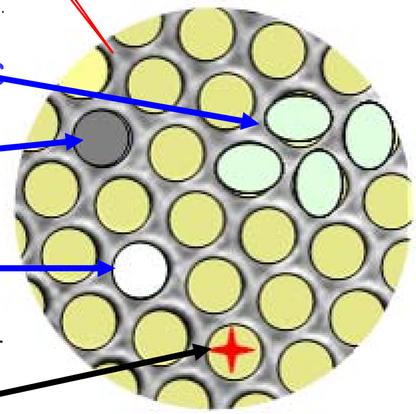
disqualified MCP for Imaging device

1。 asymmetrical surfac

2。 Blind channels;

3。 Non-uniform gain of the channels ;

4。 emission flash



Acceptable MCP for SPE detection

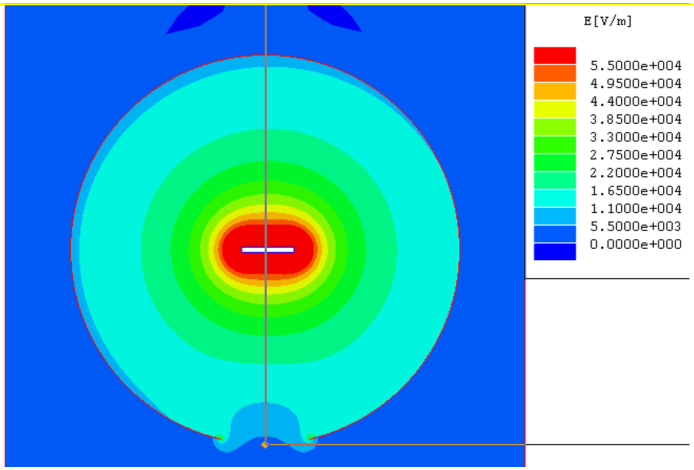
cost ↓

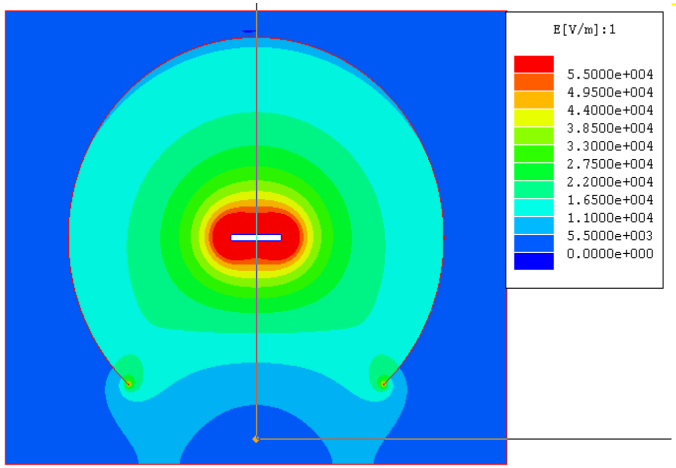
"North Night Vision Technology Limited Company" (NNVT),

our partner has over 20 years of experience in MCP production.

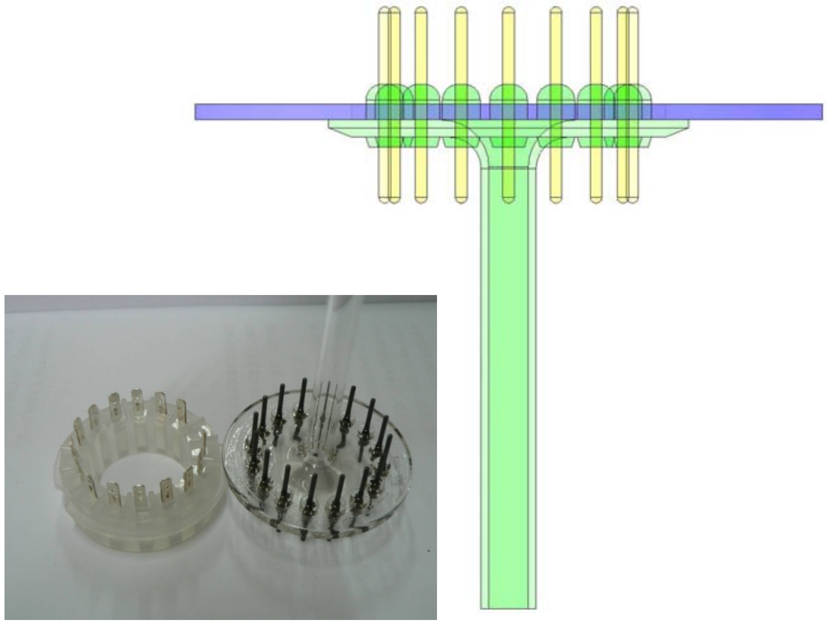
Could supply us the MCP used in 18mm with low cost.

➢ The size of the glass joint





The size of the joint of the glass will affected electric potential distribution



1. Better Mechanical strength—big size;

   Less distorted electric field– small size;
2. The size of the MCP for 20 inch PMT :

   Diameter of area: ~ 25 mm;
3. The diameter of the glass joint ~ 80 mm;
4. All the prototypes with different inch (5~20) ;

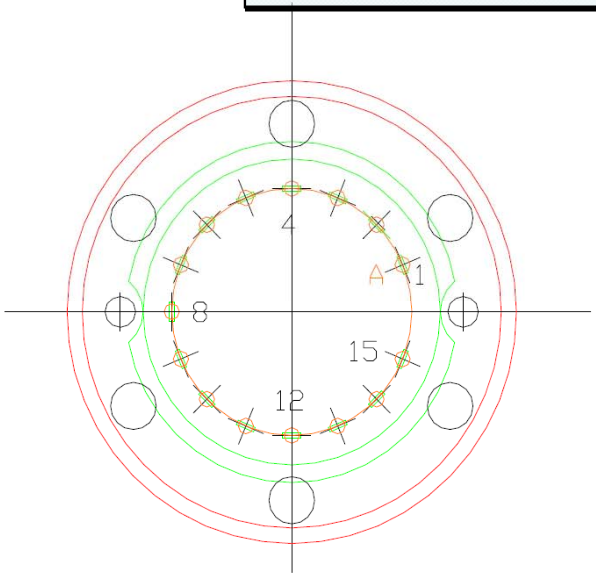
   using the same size glass joint ~ 2 inch

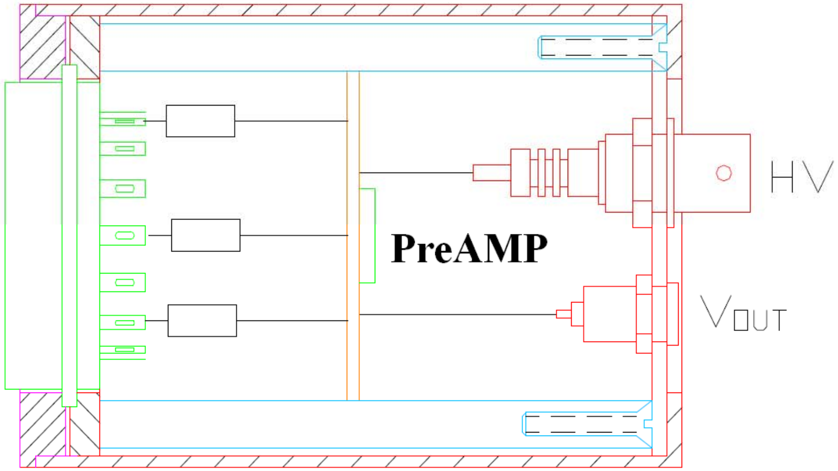
➢ The Base with preamplifier

The electron multiplier consists of two conventional MCP, ~ 10^5 gains

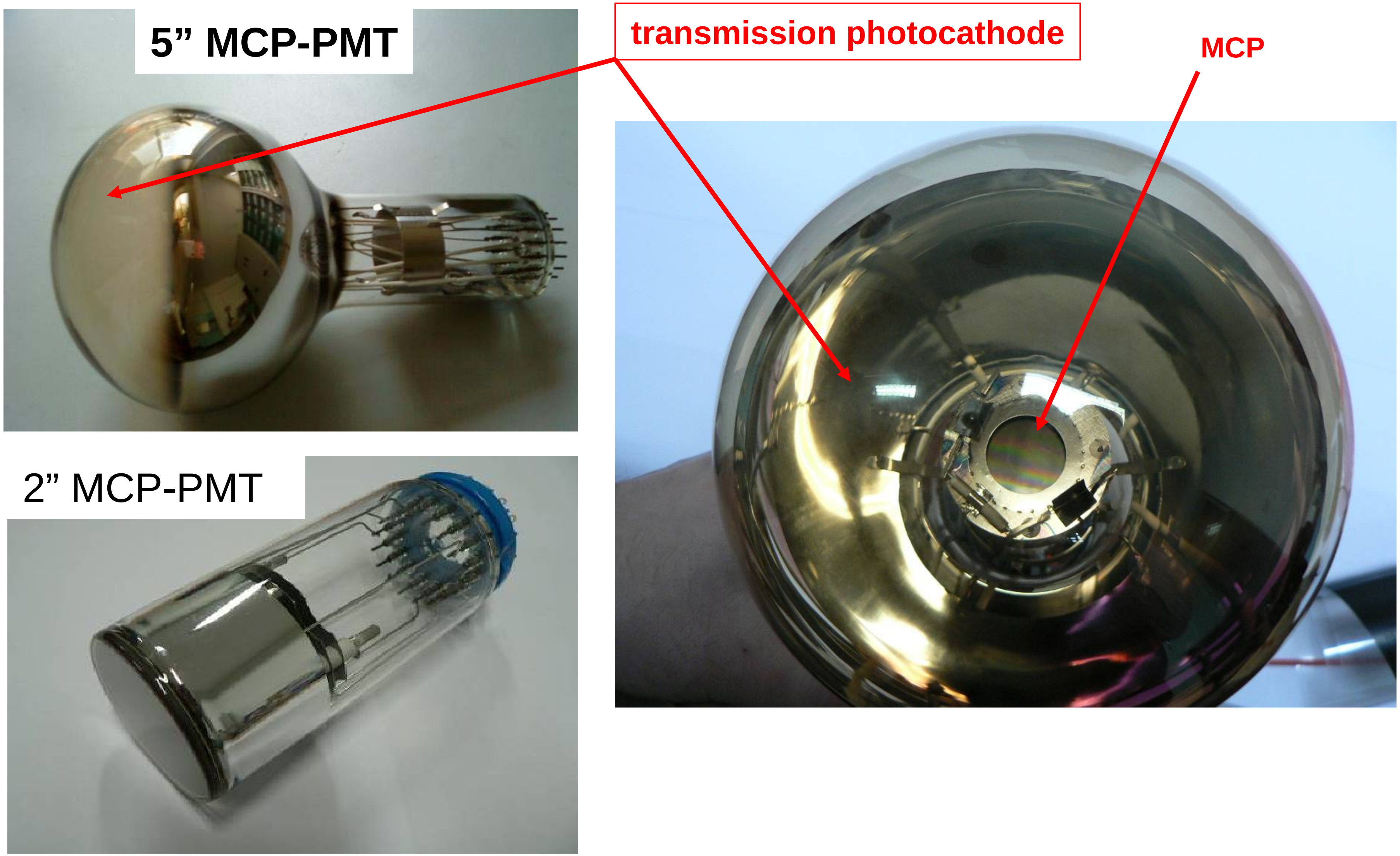
Current-sensitive preamplifier

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



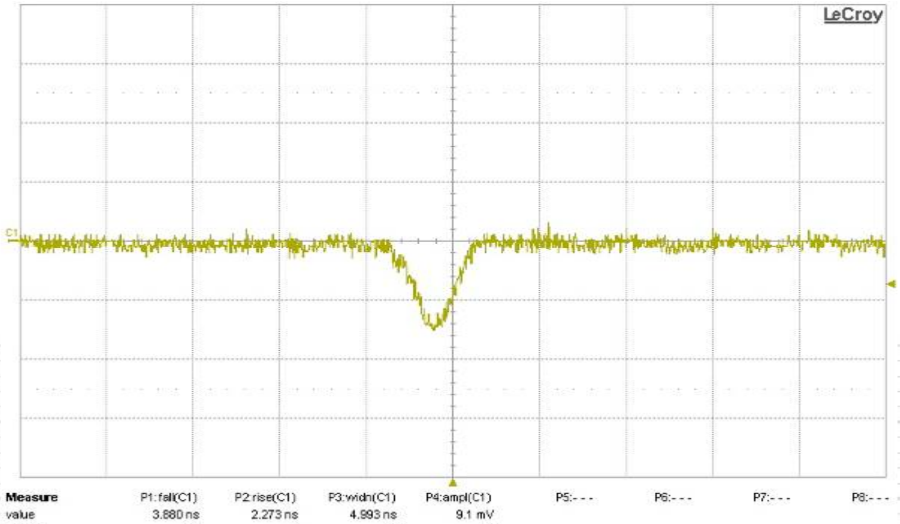


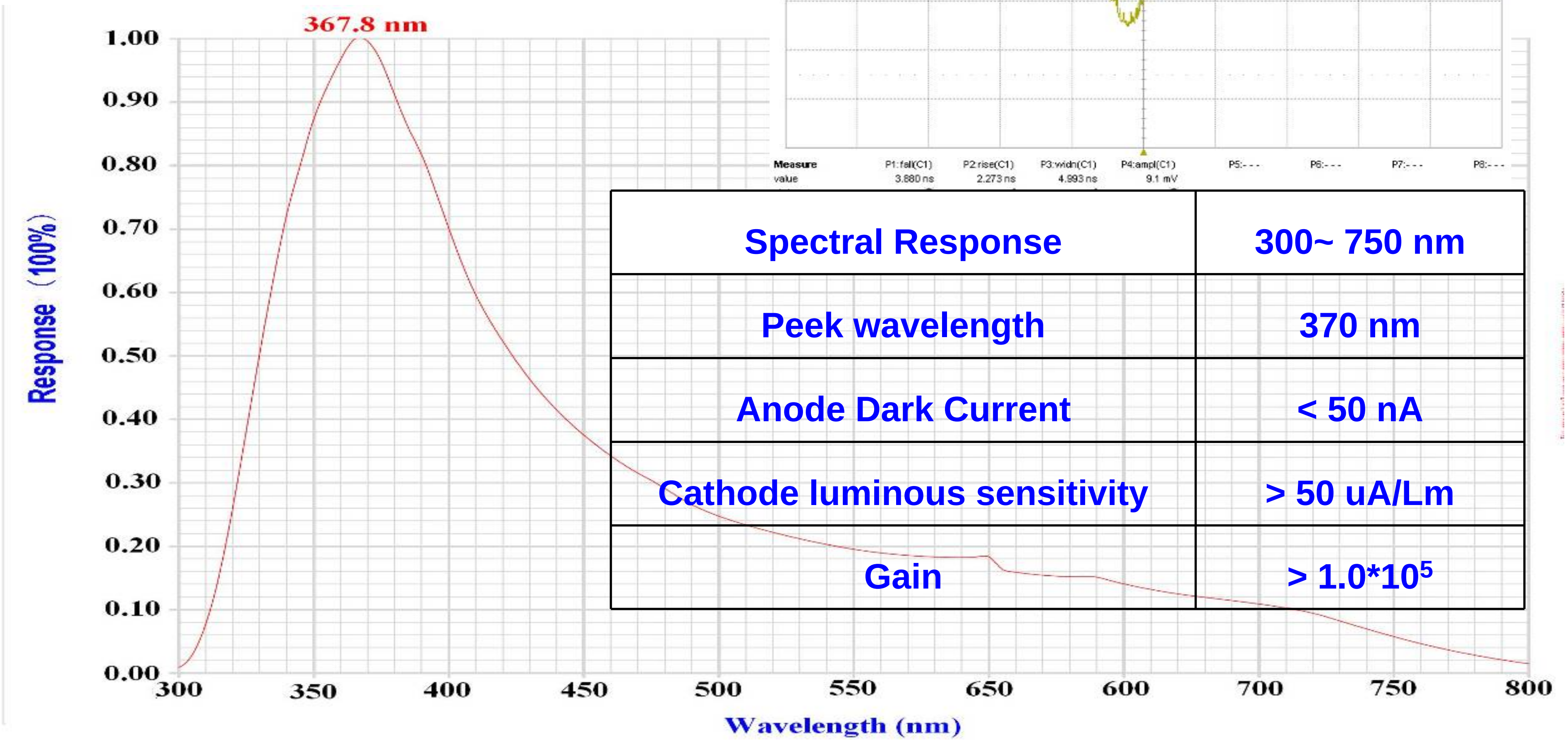
➢ Prototypes



➢ Performance of the 5”-prototype

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

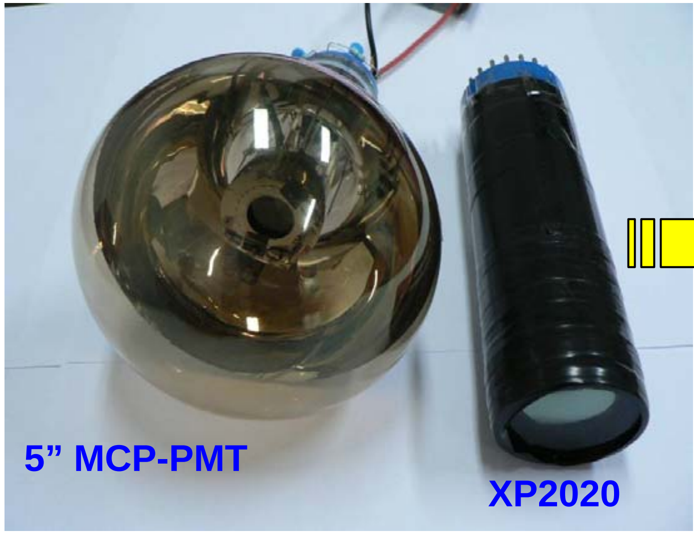


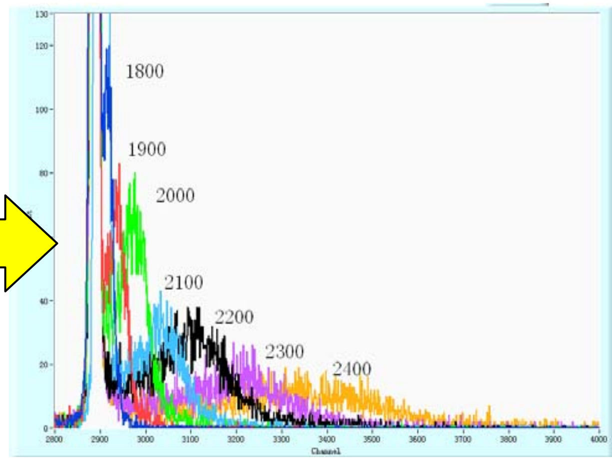


Spectral Response	300~ 750 nm
Peek wavelength	370 nm
Anode Dark Current	< 50 nA
Cathode luminous sensitivity	> 50 uA/Lm
Gain	> $1.0*10^5$

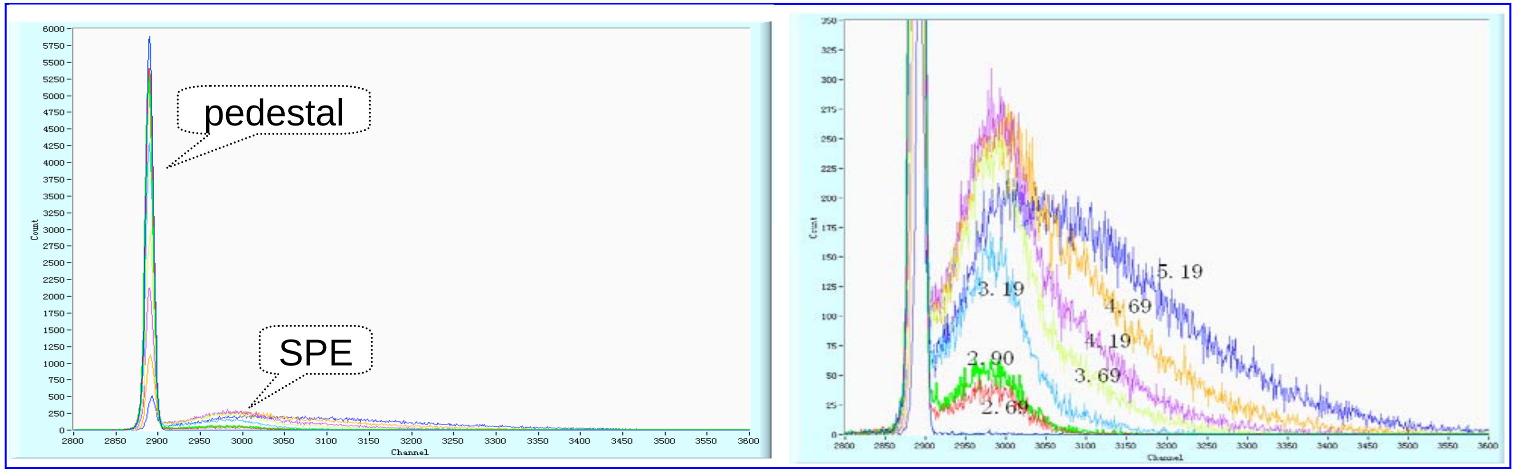
The single photoelectron spectrum and the multi-photoelectron spectrum of the PMT

➢**The photoelectron spectrum of the XP2020 PMT**





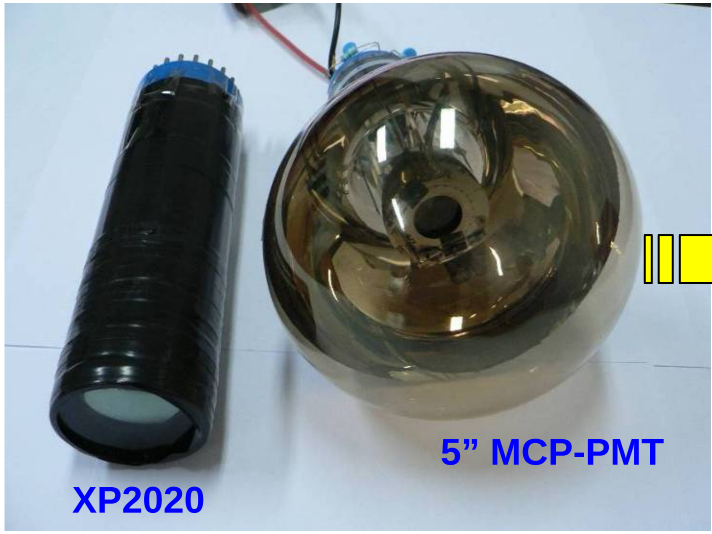
➢**SPE vs the Voltage of the PMT**

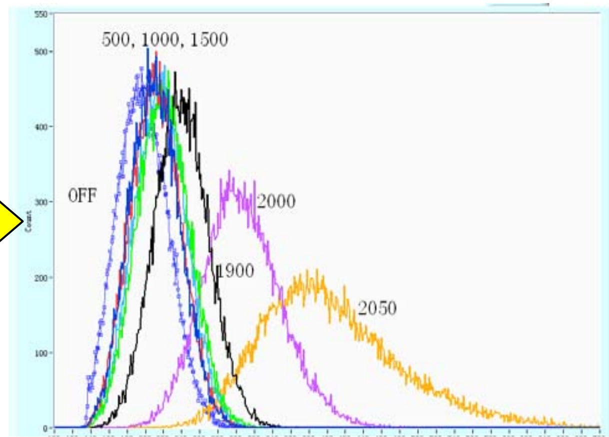


➢**SPE vs the luminance of the LED light**

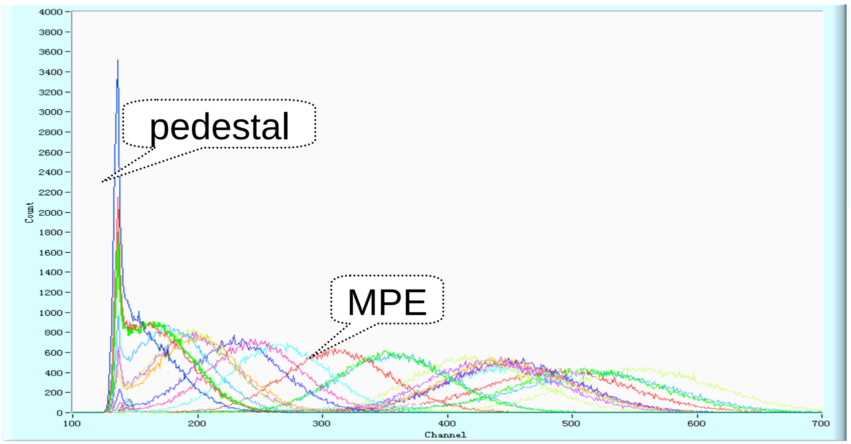
**--adjust the working voltage of the LED to adjust the luminance of the LED light.

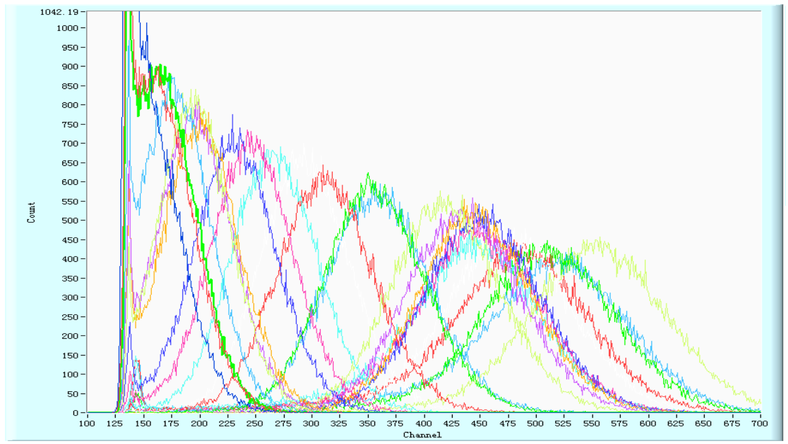
➢The photoelectron spectrum of a prototype: 5” IHEP-MCP-PMT





➢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.

➢8” ellipse MCP-PMT

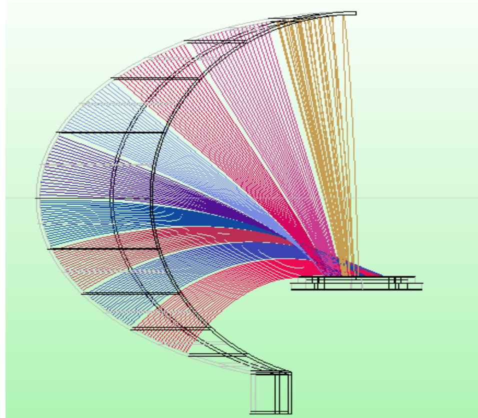
8” prototype transmission

--Electron Multiplier:

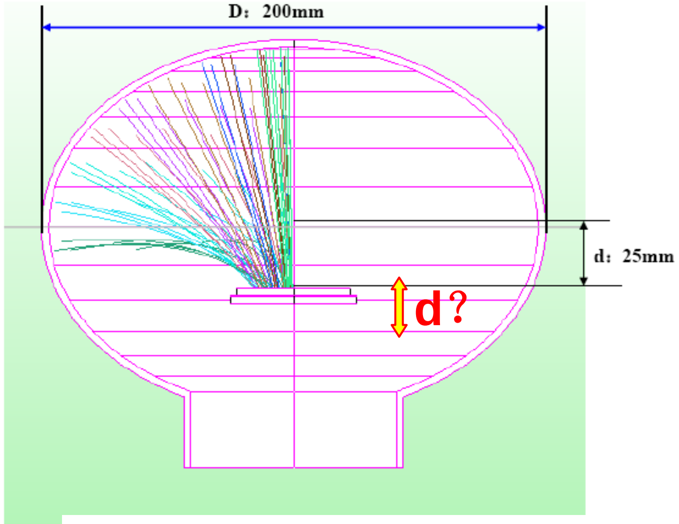
small size MCP (ϕ =18mm)

--photocathode area:

transmission + reflection photocathode



The photoelectron collected by the electron multiplier MCP



The overview of the prototype

The hit position of the photoelectron in MCP was affected by the distance between the MCP and the center of the ellipse. Whit is the best position for the better collection efficiency ?

Summary

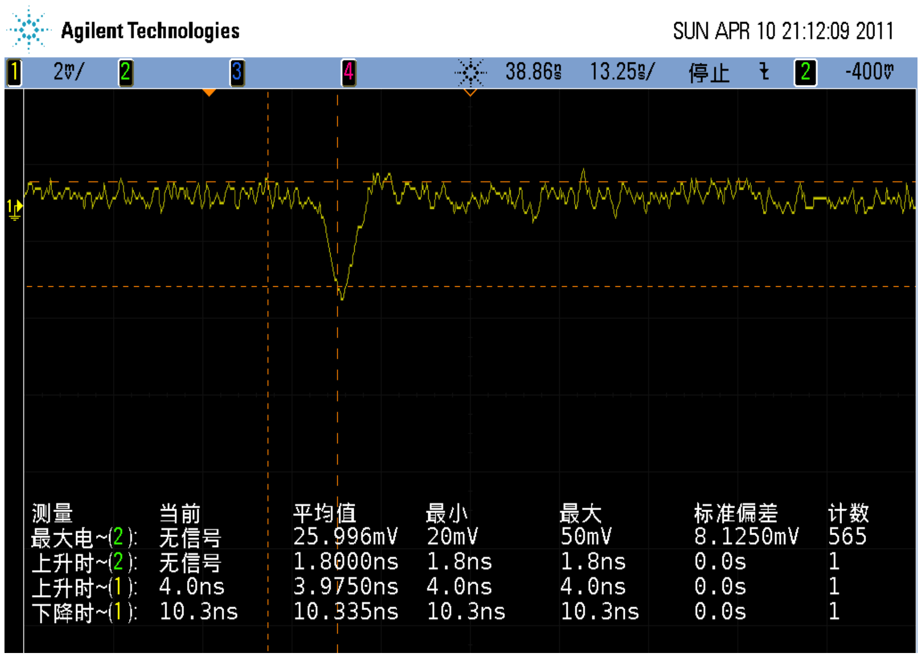
- **1. A new type of MCP-PMT is designed for the next generation neutrino exp.**
  - ✓ Large ares: ~ 20”;
  - ✓ High photon detection efficiency: ~30%, al least ×2 than normal PMT;
  - ✓ Low coat: ~ low cost MCPs;
- **2. The R&D process is composing with 3 step.**
  - ① 5”(8”) prototype with transmission 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 6 Parts to product the prototype to detect SPE:**
  - ①Photocathode; ②MCP; ③Glass; ④Photomultiplier;
  - ⑤vacuum equipment; ⑥PreAMP & Base;

There are lots of work to do!

The end！ 谢谢！

Thanks for your attention!

Characteristics		unit	13#	16#	22#	25#
Test voltage	v	V	-2000	-2000	-1970	-2020
Cathode current	I_K	nA	-1.2	-3.46	-10.56	-31
Cathode luminous sensitivity	S_K	uA/lm	4.5	12.9	39.5	117
Anode Current	I_A	nA	12.5	42	35.7	70
Anode Dark Current	I_D	nA	0.7	16.7	2.39	18
Anode luminous sensitivity	S_A	A/lm	2.57	5.5	7.22	9.15
Gain	G	-	$5.7*10^5$	$4.2*10^5$	$1.8*10^5$	$1.01*10^5$



$$S_k = \frac{I_k}{\varphi_k} \qquad S_A = \frac{I_A - I_D}{\varphi_A}$$

$$G = \frac{S_A}{S_k}$$

luminous flux: $\varphi_k = 2.67*10^{-4}$ lm

$\varphi_A = 4.59*10^{-9}$ lm