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

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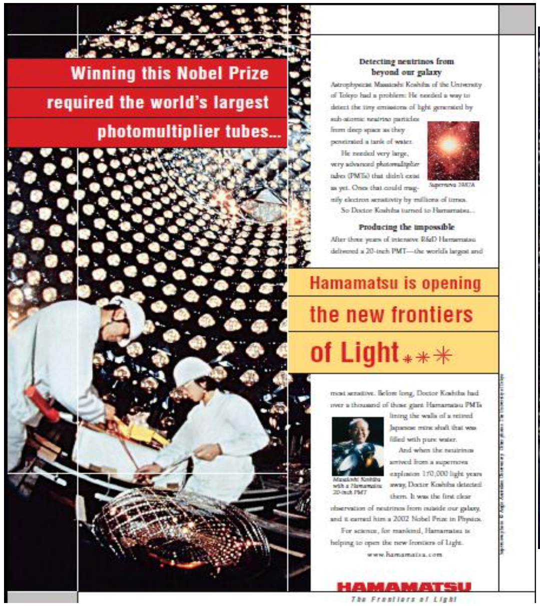
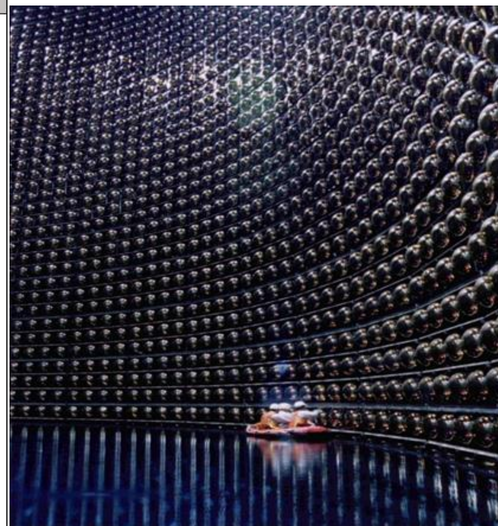
Representing the collaboration

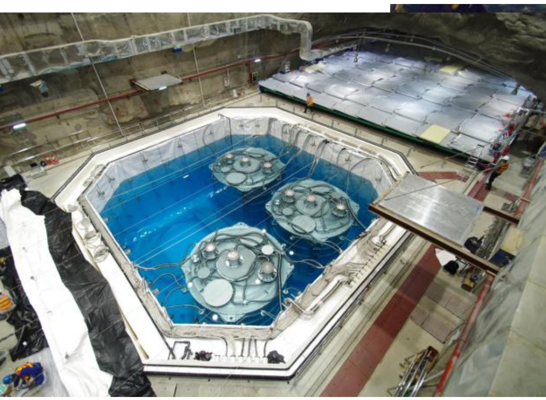
Outline

- Background and motivation
  - Neutrino Experiments
  - DayabayII Neutrino Experiment
- The Design of the new MCP-PMT
  - New Idea: double cathodes
  - Large area
  - Low background
  - High QE
- The progress of R&D
- Summary

Current and Future Neutrino Experiments

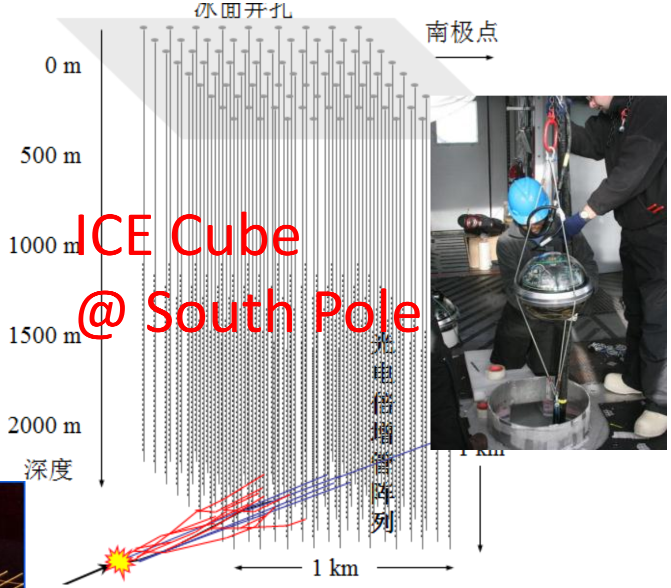


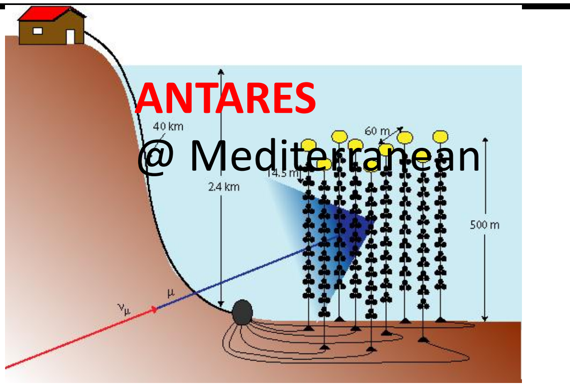


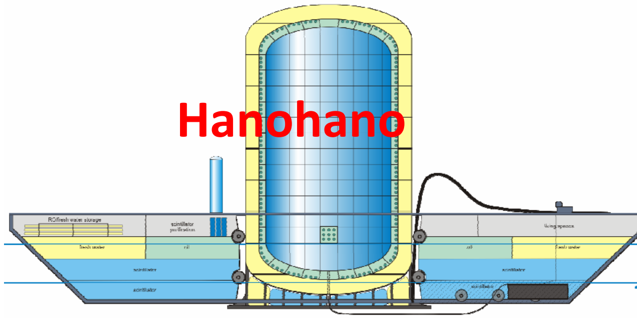


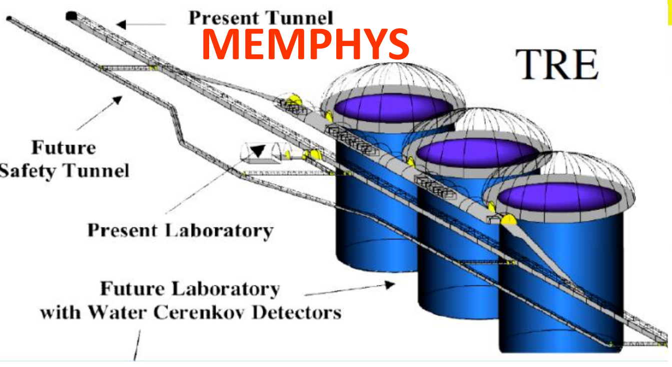
- Atmospheric neutrino exp.
  - SuperK，
  - HyperK/UNO，
  - INO,TITAND,…
- Solar neutrino exp.
  - SNO,
  - GALLEX/SAGE,
  - Borexino, XMASS, …
- Accelerator neutrino exp.
  - T2K,
  - Nova,
  - Minos, OPERA,
  - MiniBooNE,
- Reactor neutrino exp.
  - KamLAND (Japan),
  - Daya Bay (China),
  - Reno (Korea),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

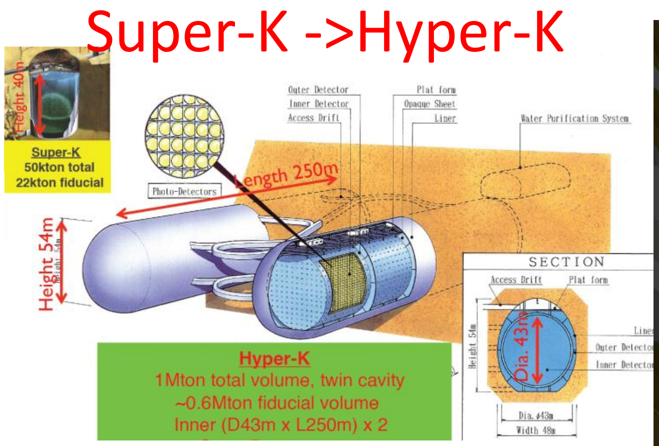
Neutrino Experiments



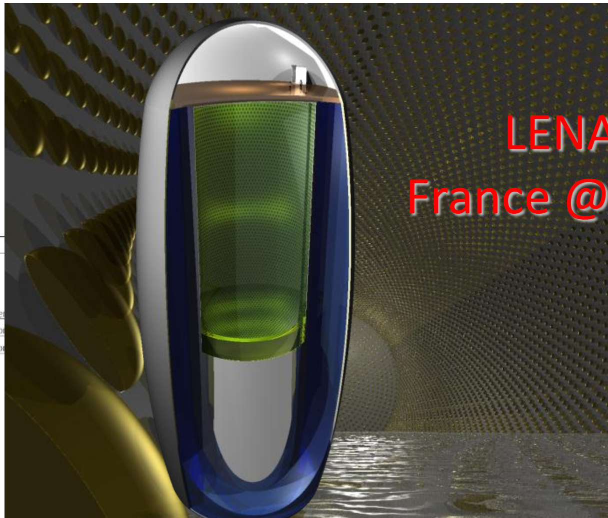






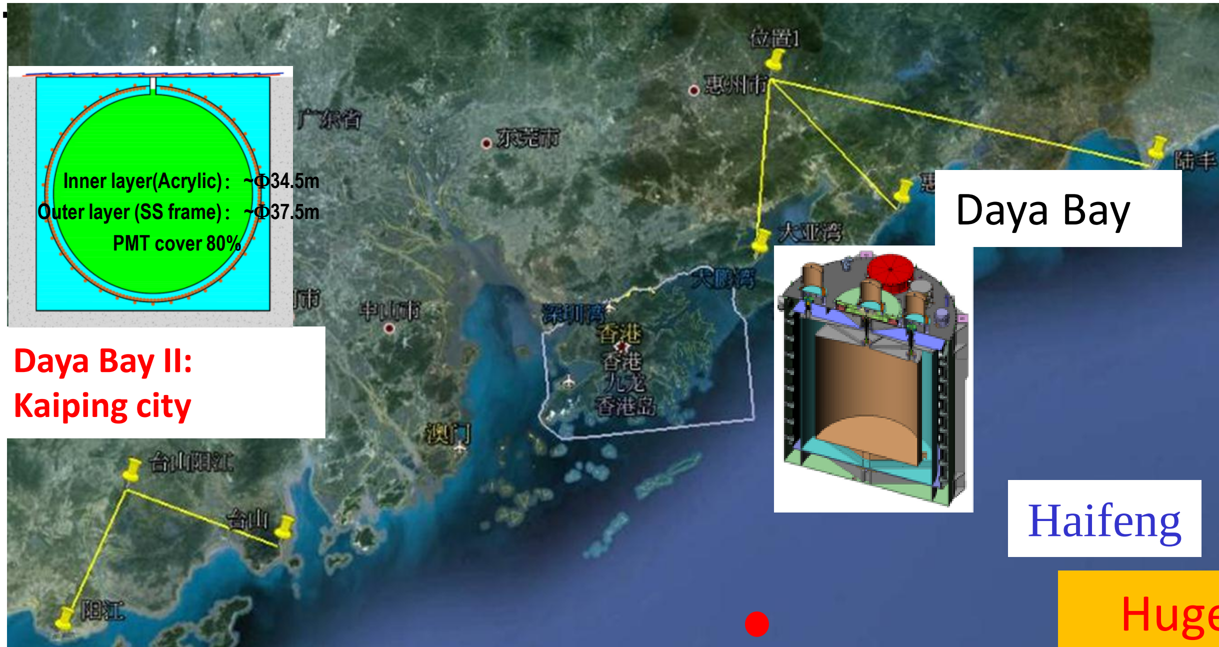


2nd Open Hyper-K meeting, HENG Yuekun



- Big demanding for PMT
  - **Large area**
  - **Big quantity: low prices**
  - **Low Radiation Background**
  - **High QE**

Dayabay II Neutrino Experiment in China

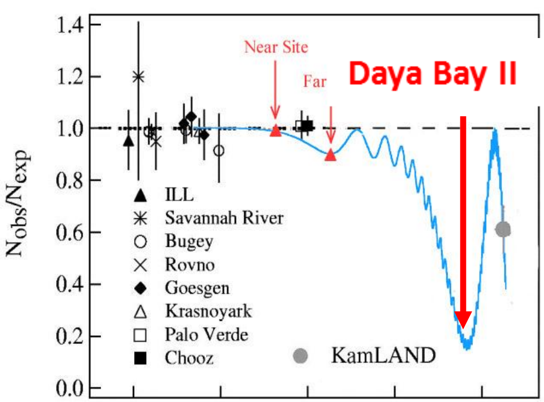


The Main Scientific goals:

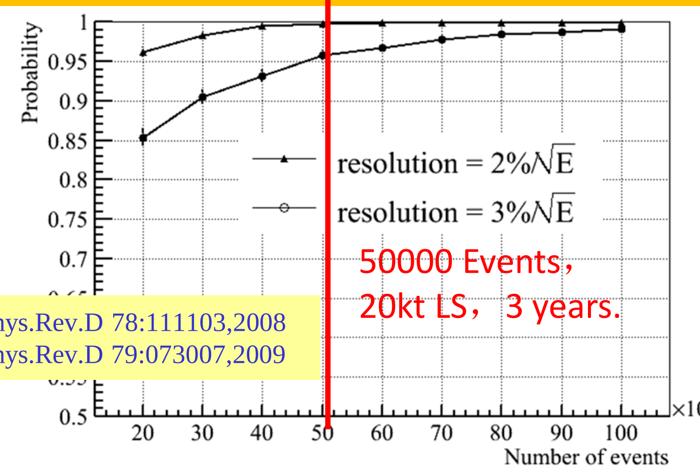
- ⇨**Mass Hierarchy**
- ⇨Mixing matrix elements
- ⇨Supernovae
- ⇨geo-neutrinos

Huge Detector : 20kt LS + 16000PMT

Energy resolution : 2~3%/√E



$\sin^2 2\theta_{13} = 0.089 \pm 0.010\ (\mathrm{stat}) \pm 0.005\ (\mathrm{syst})$



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

How to get the precisely energy measuring?

	KamLAND	Daya Bay II
Detector	~1 kt Liquid Scintillator	20 kt Liquid Scintillator
Energy Resolution	6%/√E	3%/√E~??2%/√E
Light yield	250 p.e./MeV	1000~??2500 p.e./MeV

How?

- Ongoing R&D:

– Highly transparent LS: Attenuation length ×2.5；

KamLAND: 15m → Daya Bay II : 25m;

– Photocathode coverage : ×2

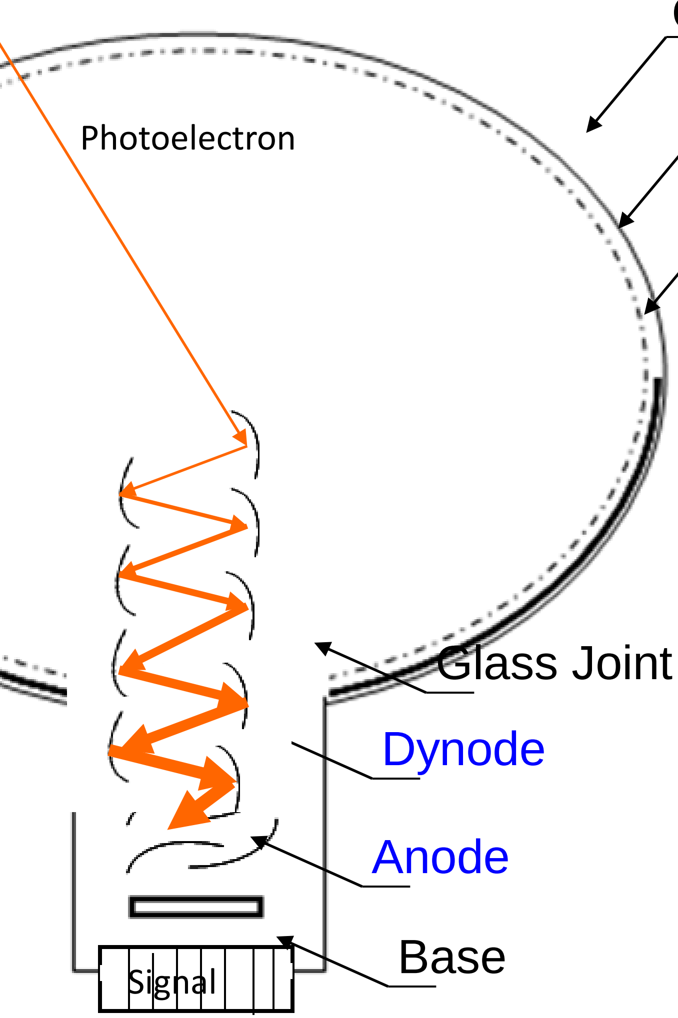
KamLAND: 34% → Daya Bay II : ~ 80%

– High QE "PMT"： Quantum Efficiency ×2;

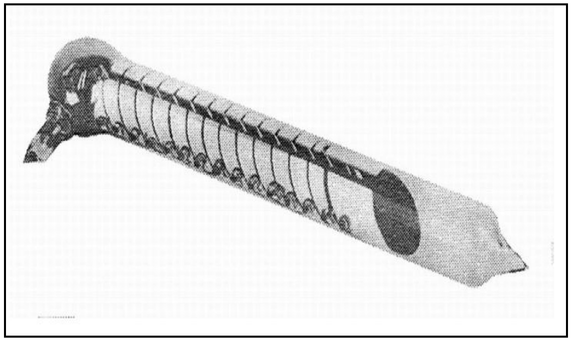
20" UBA/SBA photocathode PMT from Hamamatzu ? QE > 35%

New large area PMT ? QE > 35% ?

Conventional PMT

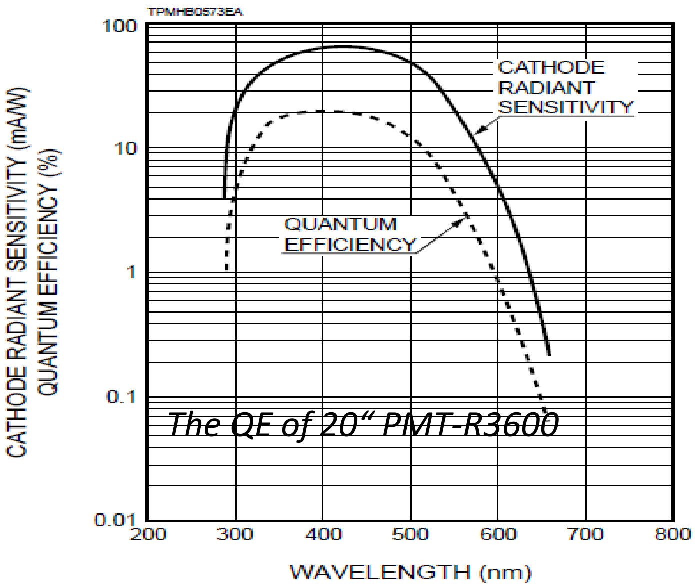


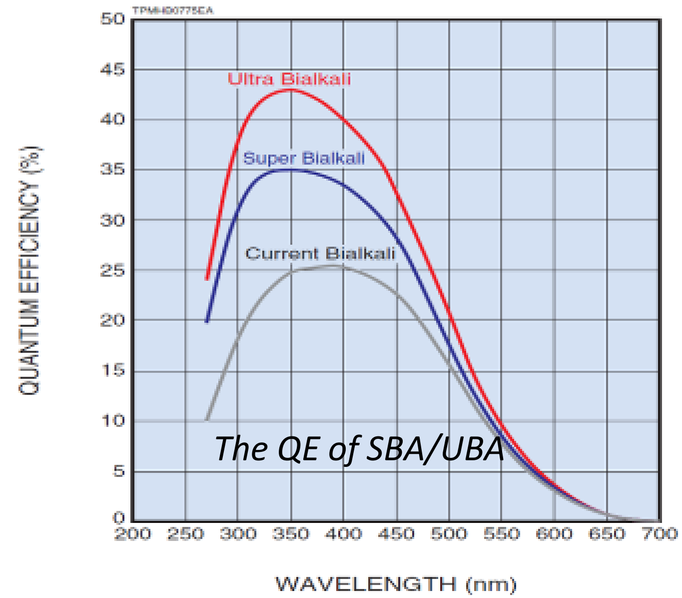
The first PMT in the world in 1933
"Kubetsky's tube"



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





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

  are only available in small format (< 3" diameter ?)
- QE of Hamamatsu 20" PMT photocathode is about 20%
- Photoelectron collection efficiency (first dynode) is ~ 70%
- Overall photon detection efficiency is ~14%

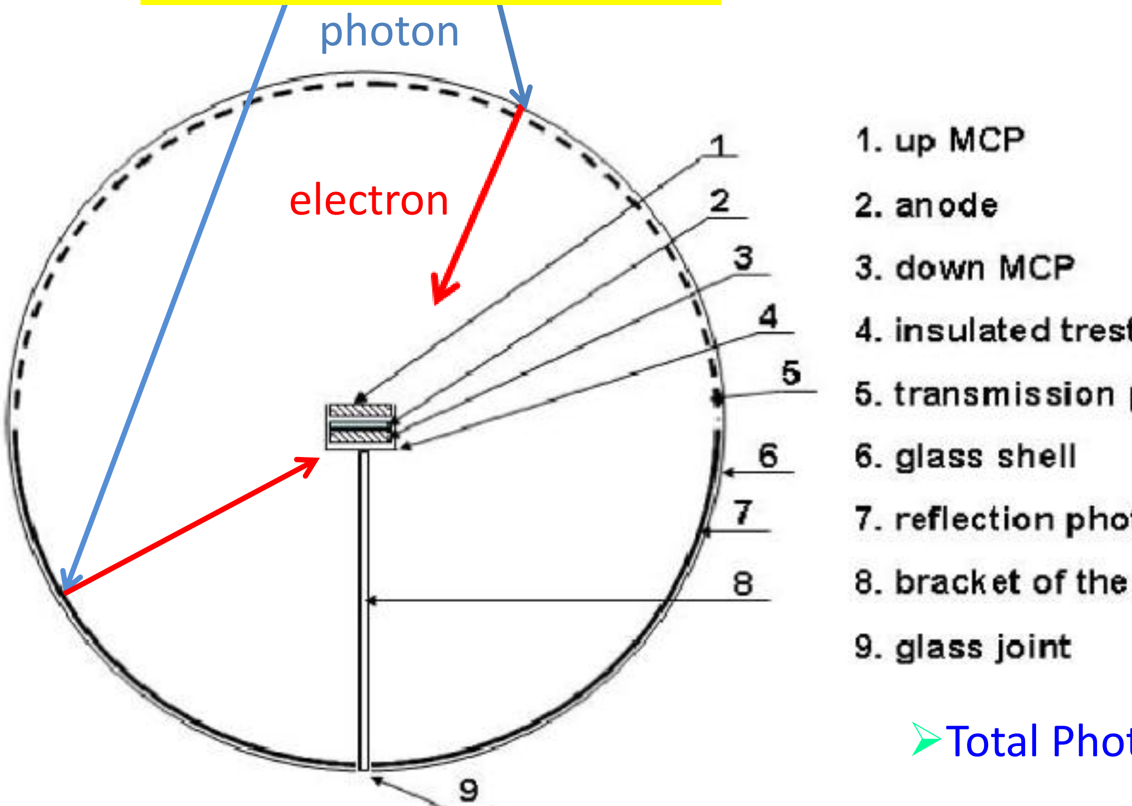
Can we improve the Quantum Efficiency of Photocathode or Photon Detection Efficiency for the large area 20" PMT ?

The new design of a large area PMT

1) Using two sets of Microchannel plates (MCPs) to replace the dynode chain

2) Using **transmission photocathode (front hemisphere)**
reflective photocathode (back hemisphere) } ~ 4π viewing angle!!

60% absorbed, 40% passed



- Quantum Efficiency:
  - Transmission photocathode: 20%
  - Reflection photocathode: 40%
- MCP Collection Efficiency: 80%

Photon detection efficiency:

→20% * 80% = 16%

→40% * 40% * 80% = 13%

➢ Total Photon Detection Efficiency: ~30%

Photon Detection Efficiency: 16% → 30% ; ×~2 at least !

Collaboration and organizing

中国科学院高能物理研究所
Institute of High Energy Physics, CAS

effort by **Yifang Wang;**

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

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

南京大学

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

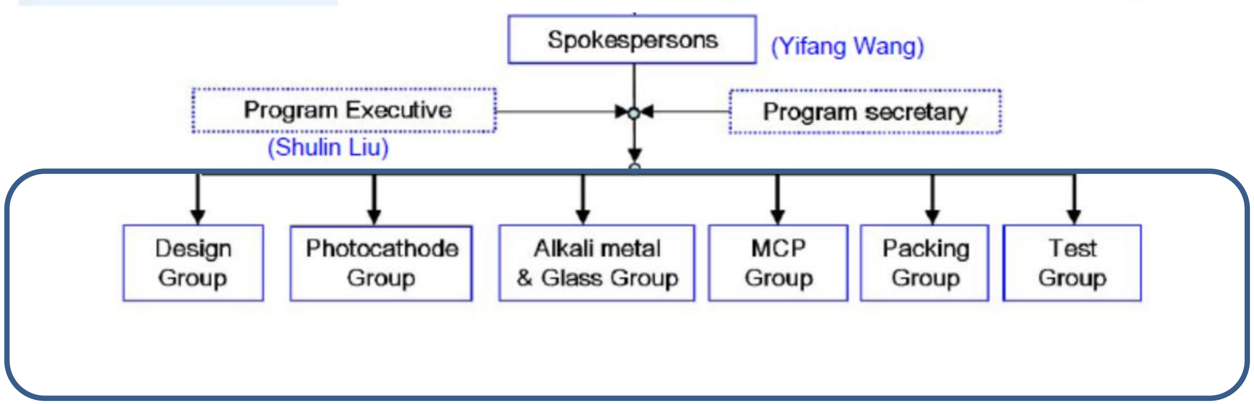
宝光股份
BAOGUANG

Other company and institute (cooperated but not join us yet)：……

南京电子器件研究所
Nanjing Electronic Devices Institute

華東電子

New PMT company in Hainan



The R&D plan of the MCP-PMT

Design

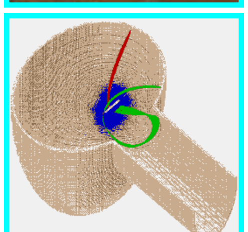
5”(8”) prototype transmission

5”(8”) prototype Transmission +Reflection

20” prototype Transmission +Reflection

Photocathode

MCP

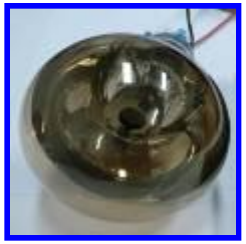


Photomultiplier

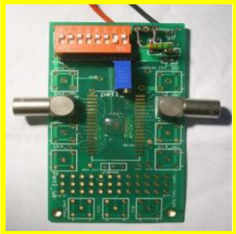
Glass

vacuum equipment

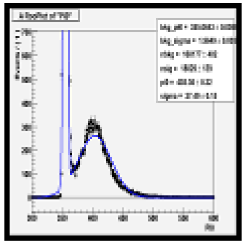
Prototype



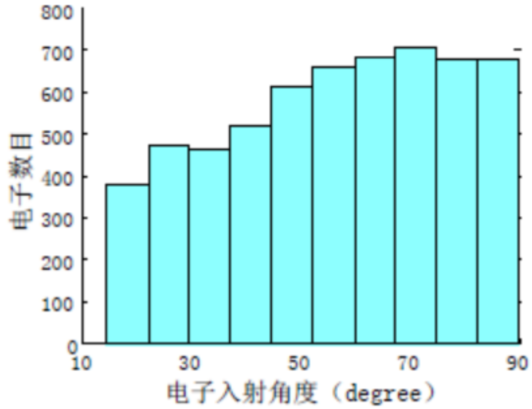
PreAMP & Base



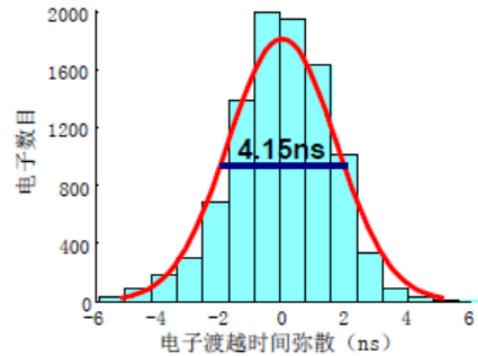
SPE



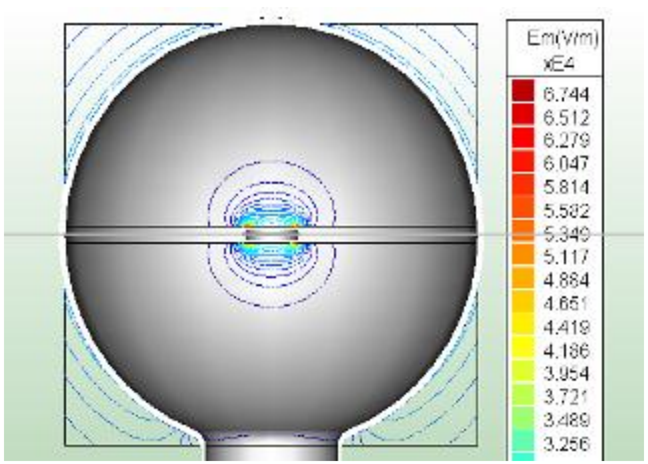
The Simulation work – properties of 8” MCP-PMT



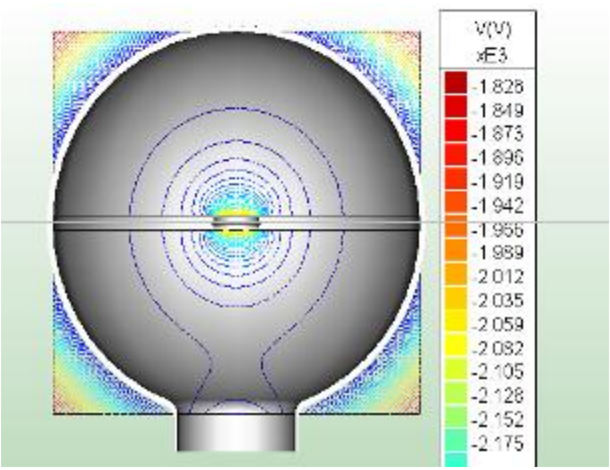
Hit Angle of the photoelectron in the MCP



Transit Time Spread（T.T.S）



Electric field intensity distribution



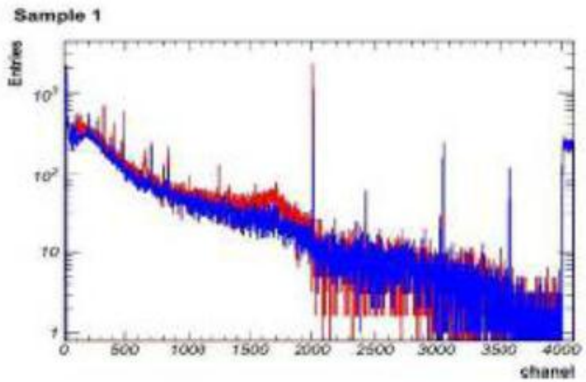
electric potential distribution

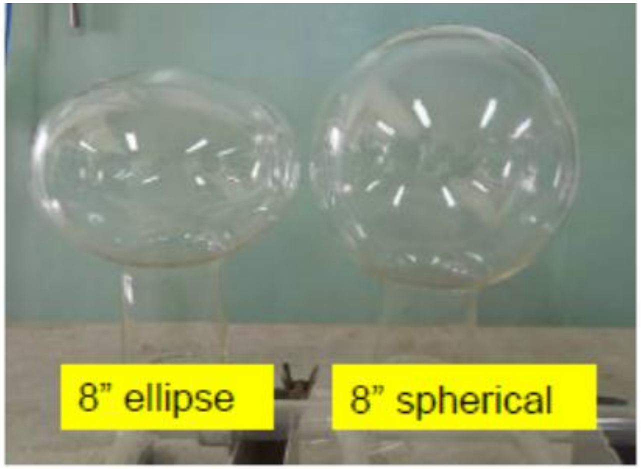
Effective diameter of MCP is 18mm;

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

The Low radioactive background glass

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





Low background gamma spectrometer in IHEP

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

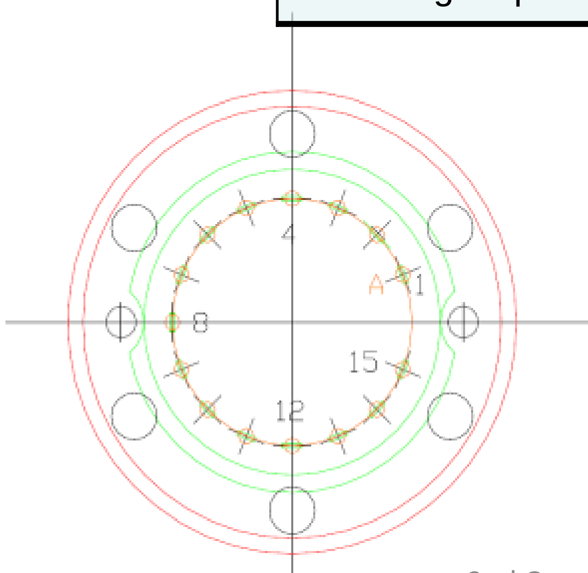
Glass	*DM-308*	*DM-305*	Hamamastu	*CN-2# Glass*	*CN-2# Material*
Sample Mass	211.0g	131.1g	53.8g	335.2g	280.9g
Test Time	311023	424110	598930	315394	359618
^{238}U	21.50±0.10	42.40±0.14	8.04±0.27	14.96±0.08	<0.1
^{232}Th	18.50±0.32	6.43±0.23	12.50±0.60	4.78±0.16	<0.2
^{40}K	2.50±0.01	41.01±0.03	0.3±0.02	3.11±0.01	<0.01

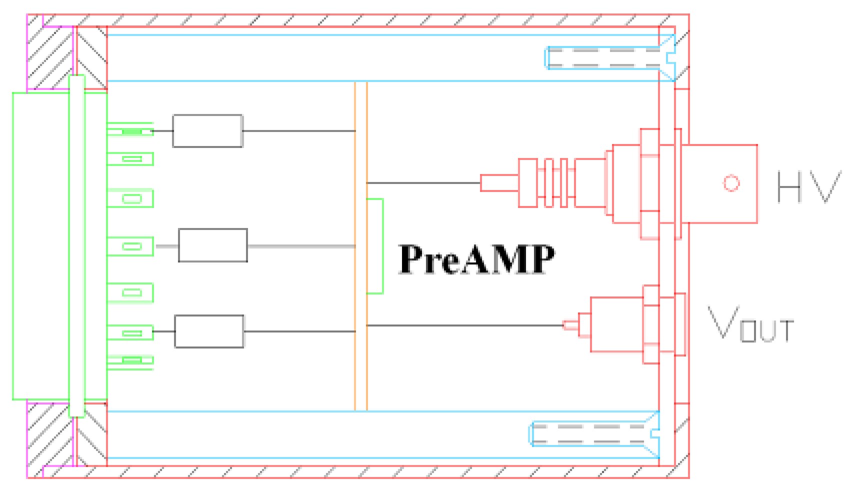
The Base with preamplifier

The electron multiplier consists of two conventional MCP, $10^5 \sim 10^6$ 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





Cathode

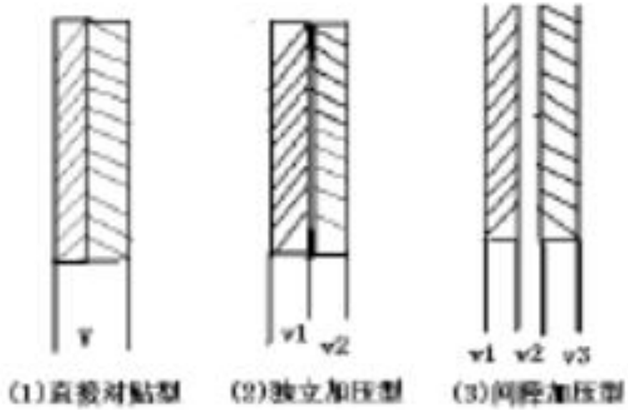
- Cs_3Sb on MnO (S11, λ_{peak} @400nm, QE ~ 20%)
- $(Cs)Na_2KSb$ (S20, λ_{peak} @400nm, QE ~ 30%)
- K_2CsSb (λ_{peak} @400nm, QE ~ 30%)
- $K_2CsSb(O)$ (λ_{peak} @400nm, QE ~ 35%)

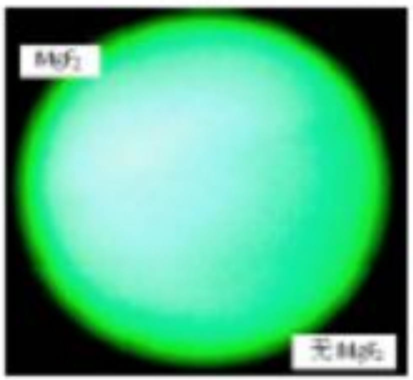
- Use of highly purified materials for the photo cathode;
- Optimal tuning of the material composition;
- Optimal tuning of the photo cathode thickness ;
- Optimal tuning of the anti-reflective layer;
- Optimal tuning of the Cs layer thickness ;

- Alkali Metal Dispensers （AMD）

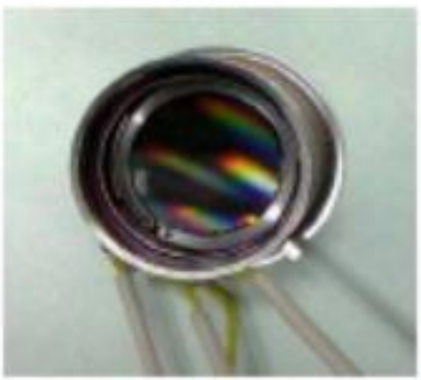
MCP

Method of HV setting





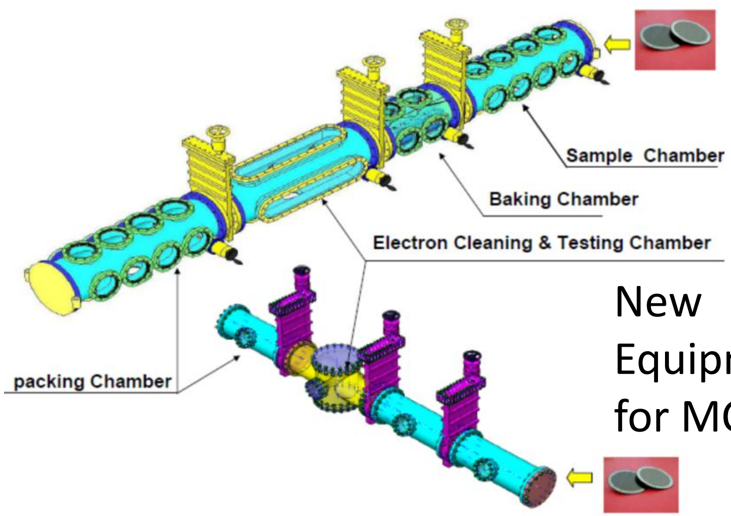
Coating MgF_2 and MnO



Assembly of two MCPs

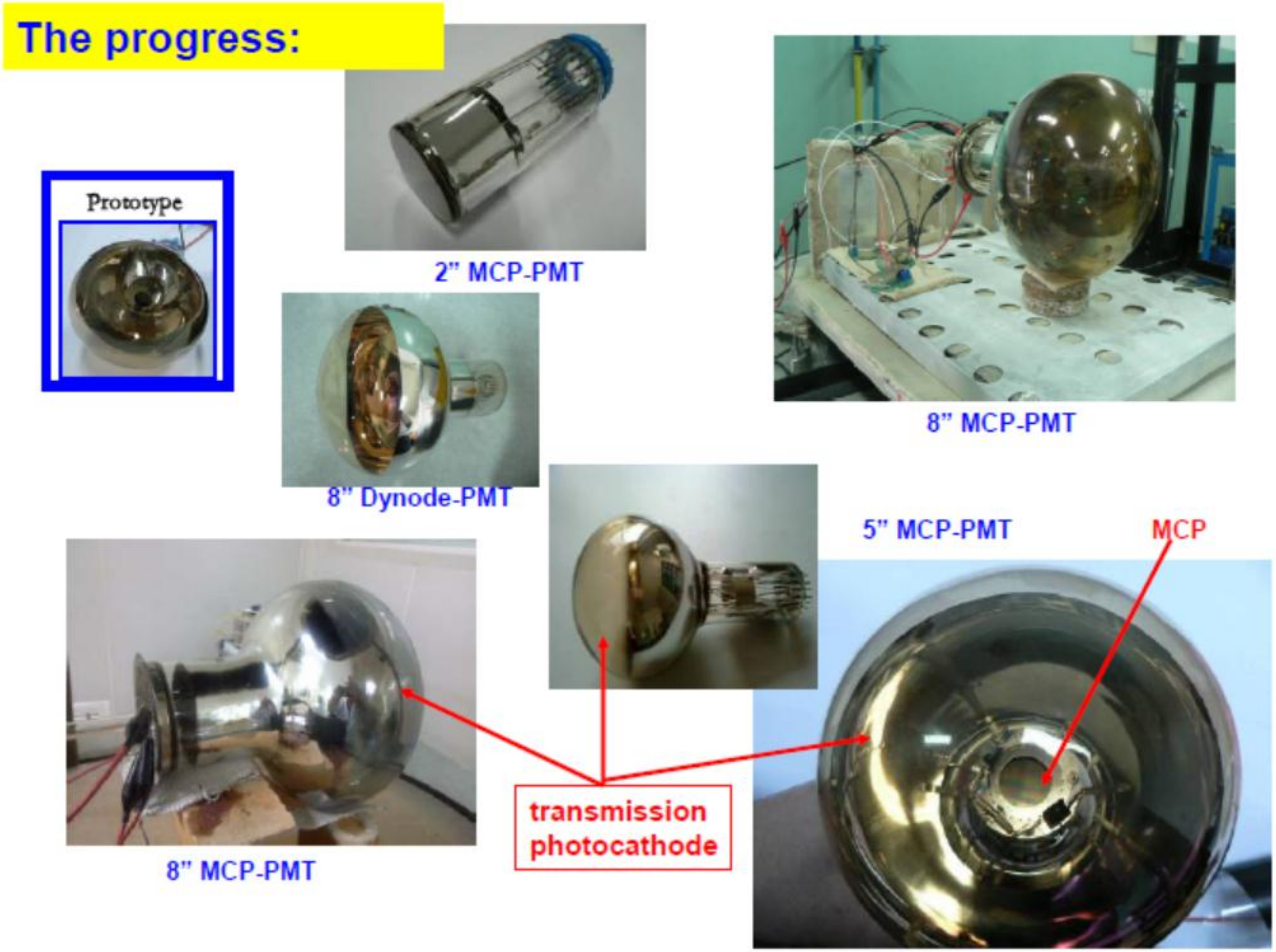
Test equipment for M

- HV
- Coating
- length-diameter ra



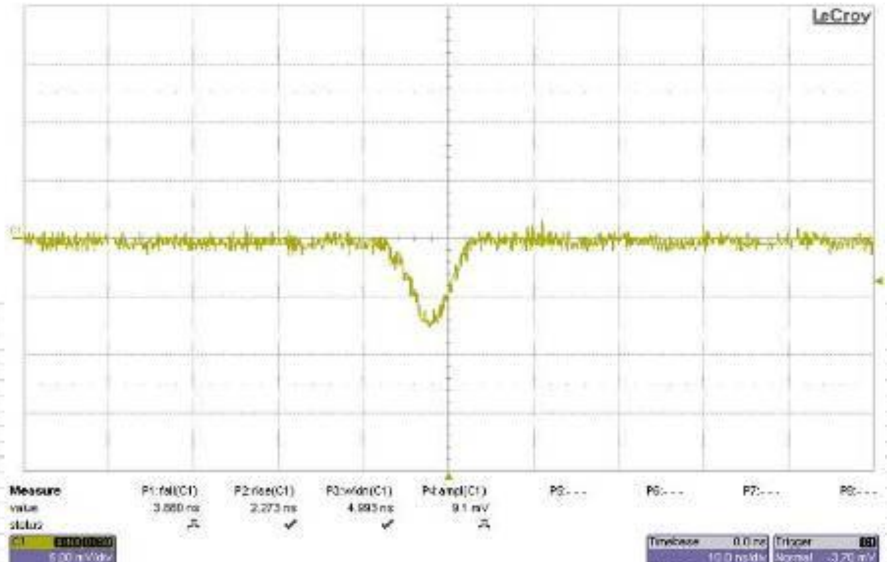
New Equipment for MCP test

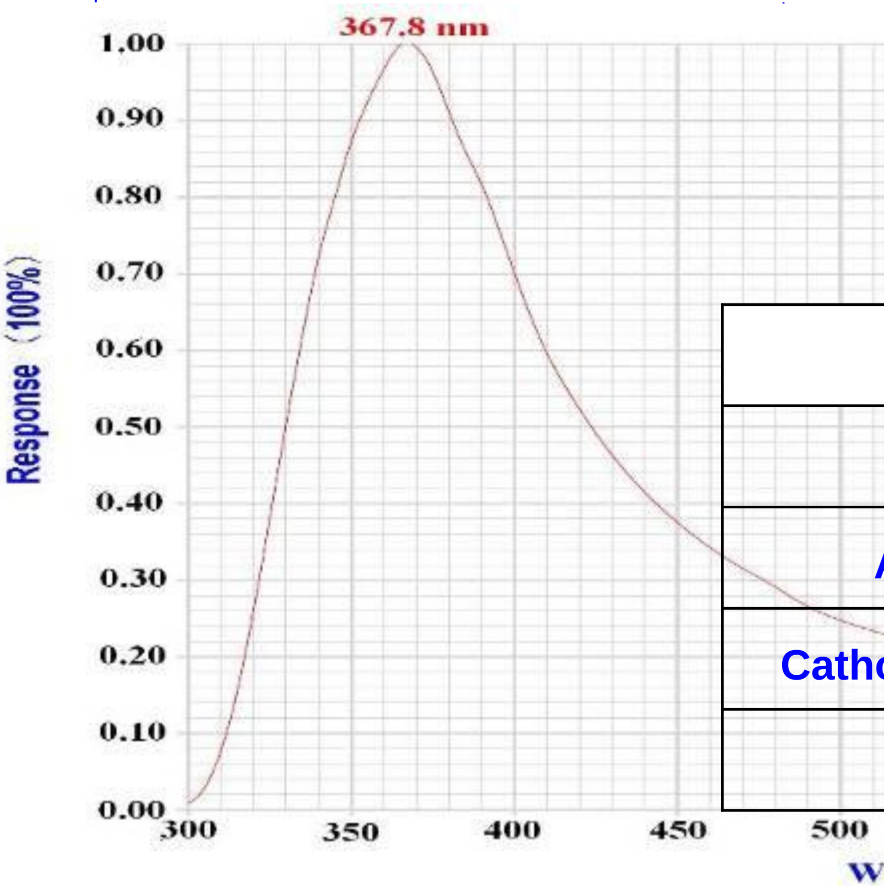
Prototypes


The progress:
Prototype
2" MCP-PMT
8" MCP-PMT
8" Dynode-PMT
5" MCP-PMT
MCP
transmission photocathode
8" MCP-PMT

Performance of the 5”-prototype

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

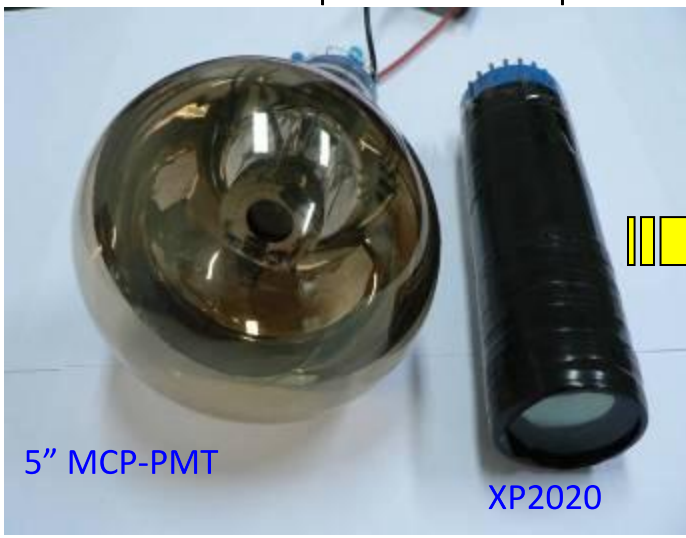


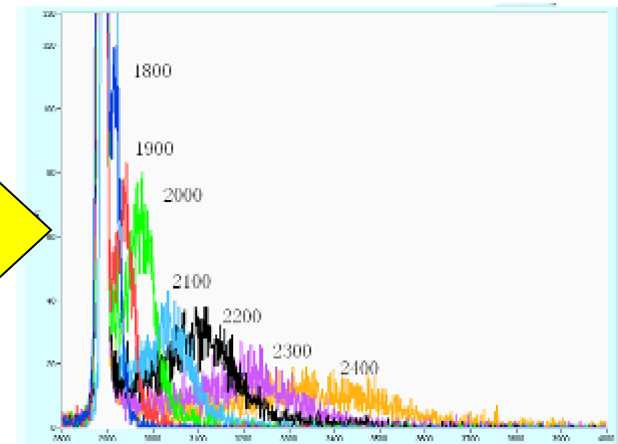


Spectral Response	300~ 750 nm
Peek wavelength	370 nm
Anode Dark Current	< 50 nA
Cathode luminous sensitivity	> 50 uA/Lm
Gain	> $1.0*10^5$

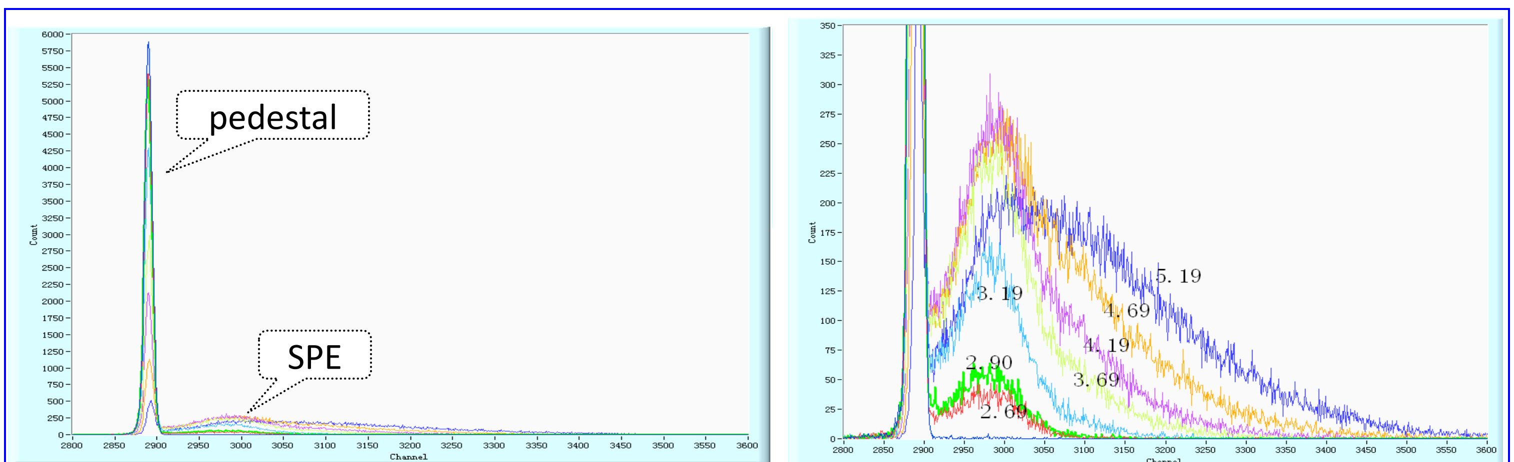
The single photoelectron spectrum and the multi-photoelectron spectrum of the PMT

The photoelectron spectrum of the XP2020 PMT





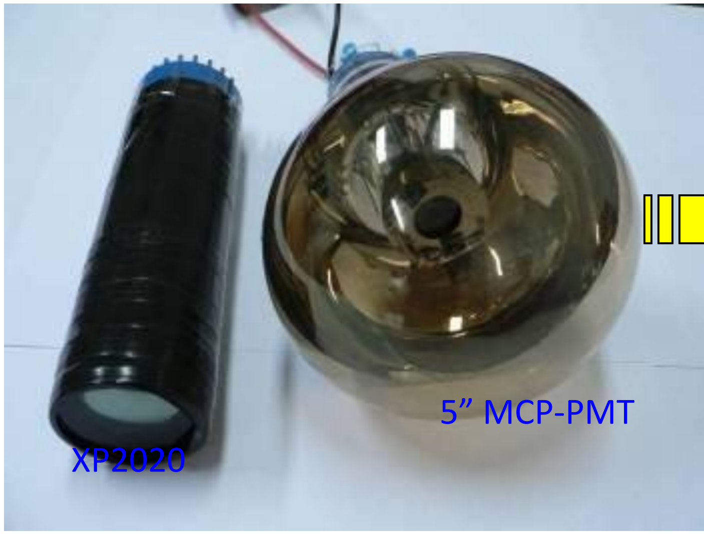
➢SPE vs the Voltage of the PMT

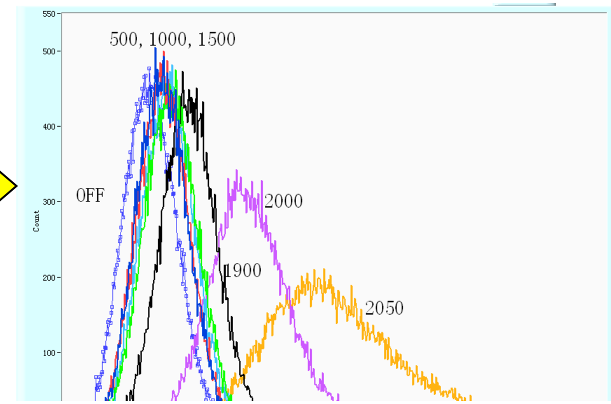


➢SPE vs the luminance of the LED light

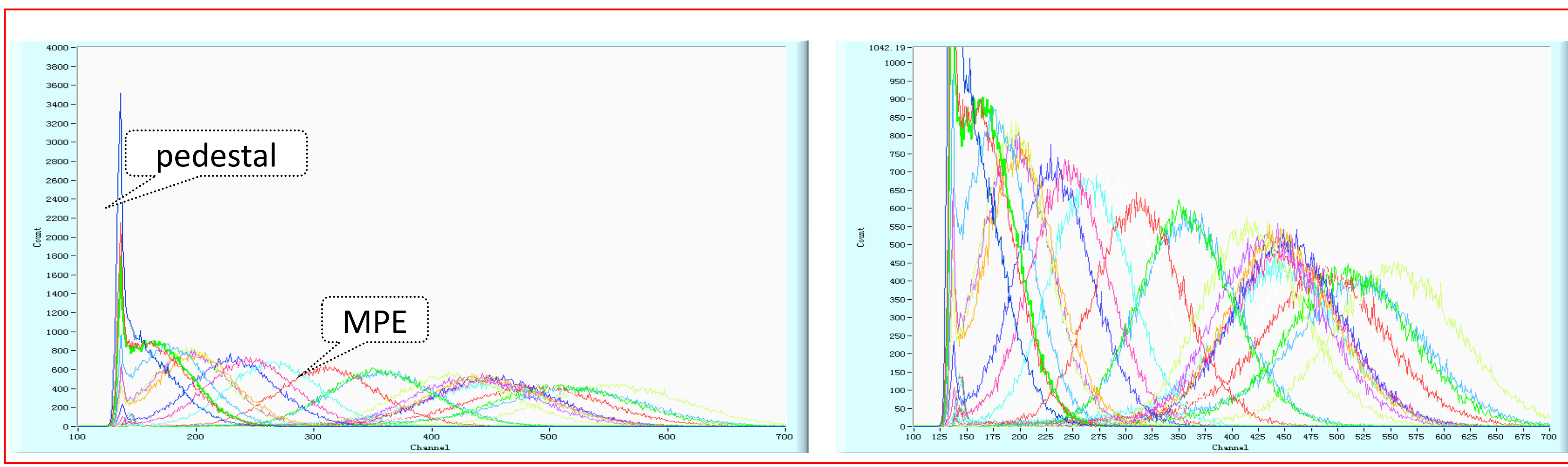
**--adjust the working voltage of the LED to adjust the luminance of the LED light.

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





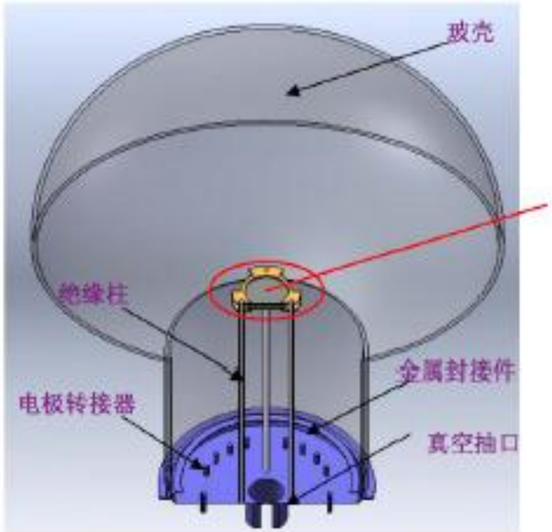
➢SPE vs the Voltage of the PMT



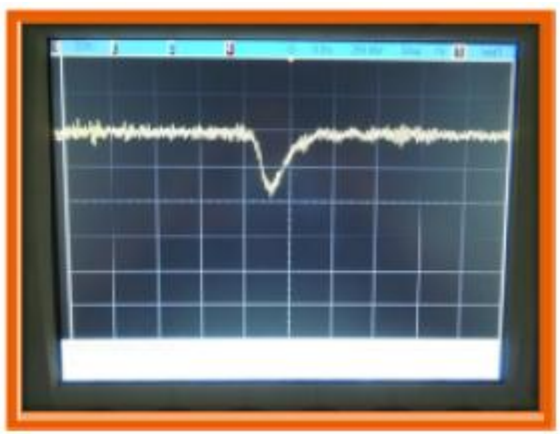
➢MPE vs the luminance of the LED light

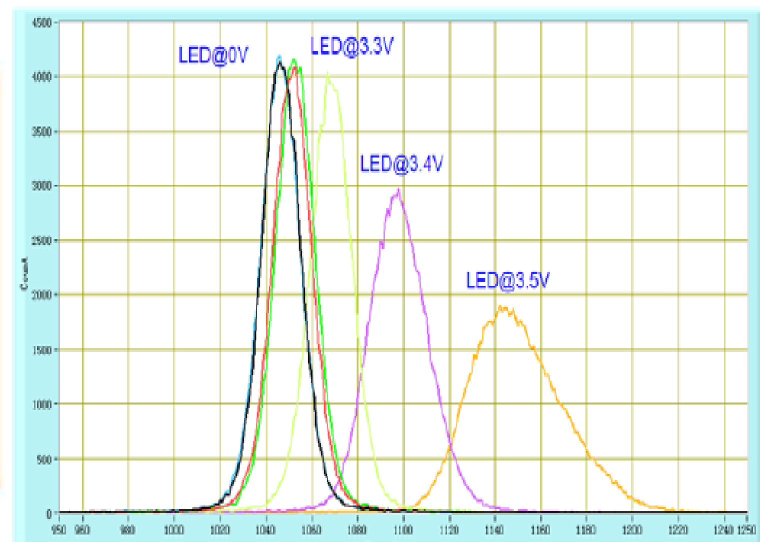
**--adjust the working voltage of the LED to adjust the luminance of the LED light.

8'' MCP-PMT



8'' ellipse　　8'' spherical

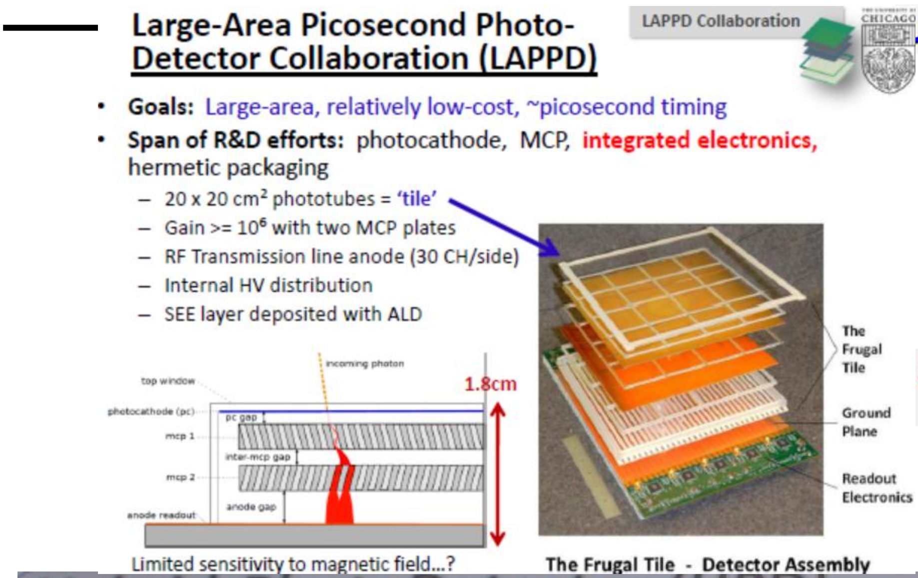


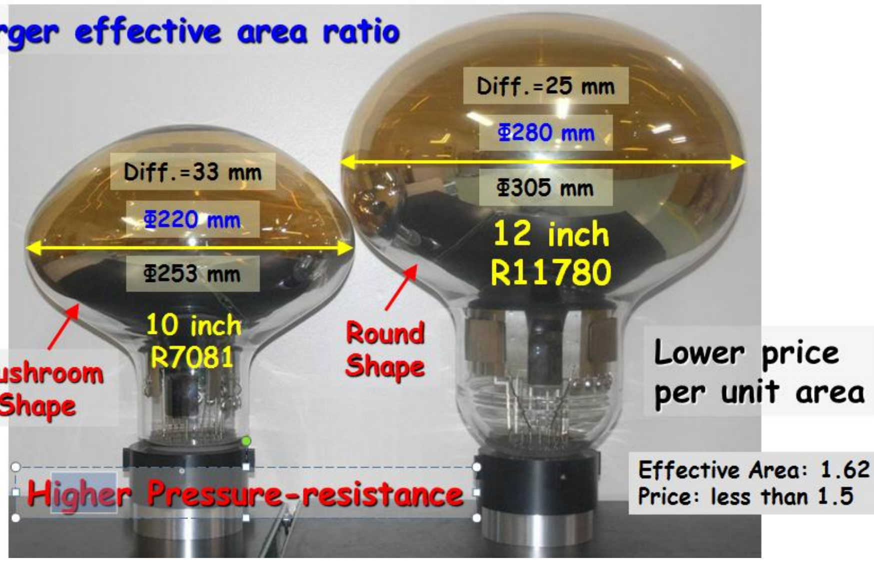


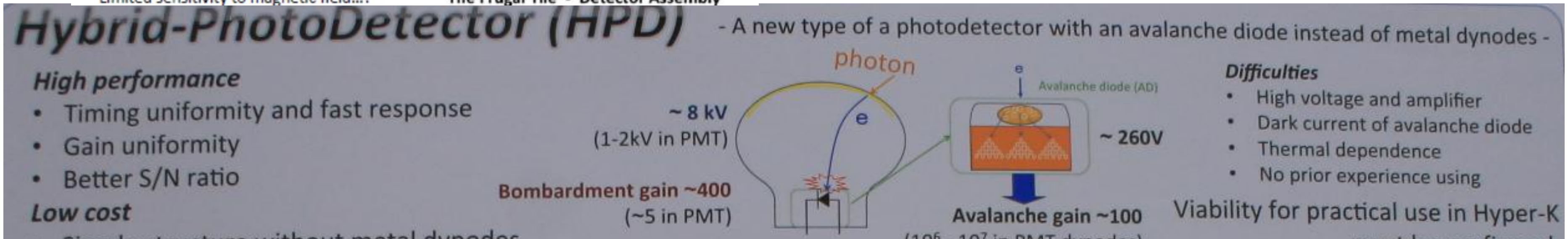
Schedule

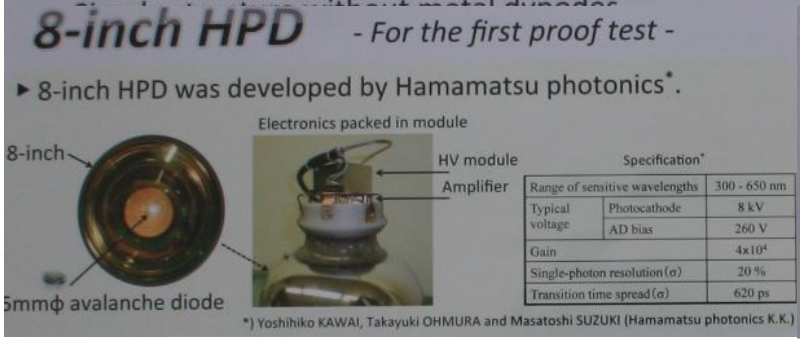
- 2009~2011, 5’’ MCP-PMT
- 2011~2012, 8’’ MCP-PMT prototype
- 2012~2013, 20’’ MCP-PMT prototype
- 2014~2015, 20’’ MCP-PMT prototype, performance good,
- 2015~2016, 20’’ MCP-PMT mass production preparing

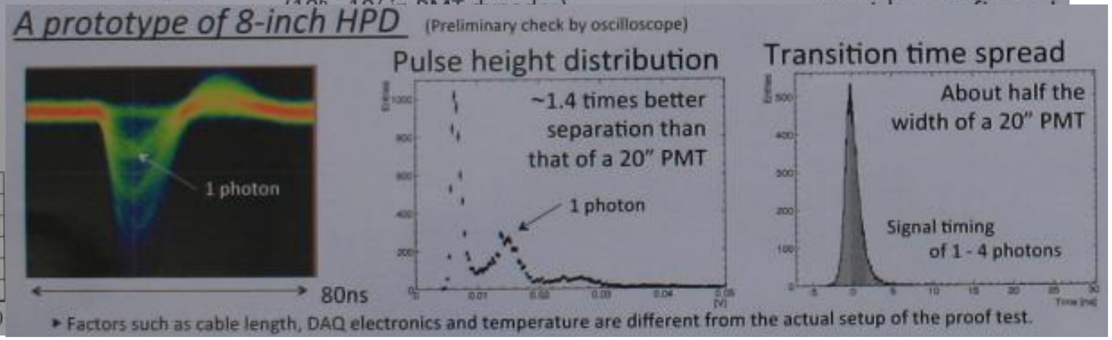
Some other R&D











Summary

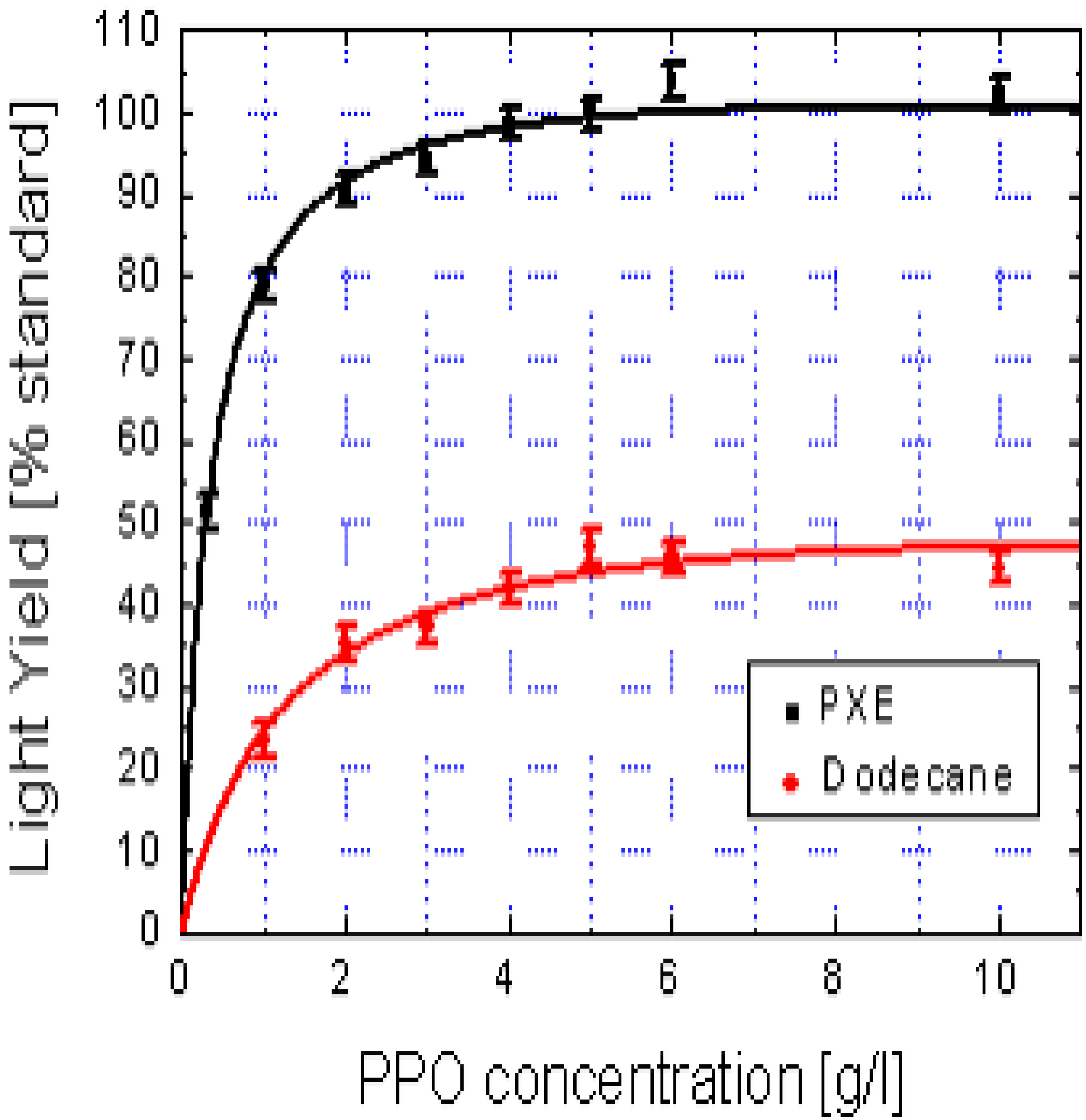
- 1. A new type of MCP-PMT is designed for the next generation neutrino exp.
  - **Large ares: ~ 20";**
  - **High photon detection efficiency: ~30%, al least ×2 than normal PMT;**
  - **Low cost: ~ low cost MCPs;**
  - **Low radiation background**
- 2. The R&D process is composing with 3 step.
  - 5"(8") prototype with transmission photocathode;
  - 5"(8") prototype with transmission and reflection photocathode;
  - 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; ⑥Test.

  The Prototypes are being made and tested, a lot of works continue!

The end！ 谢谢！

Thanks for your attention!



For PPO < 1g/l in PXE, PC,...

For PPO ~ 2.1 g/l in dodecane