# The R&D of the MCP based PMTs for High Energy Physics Detectors


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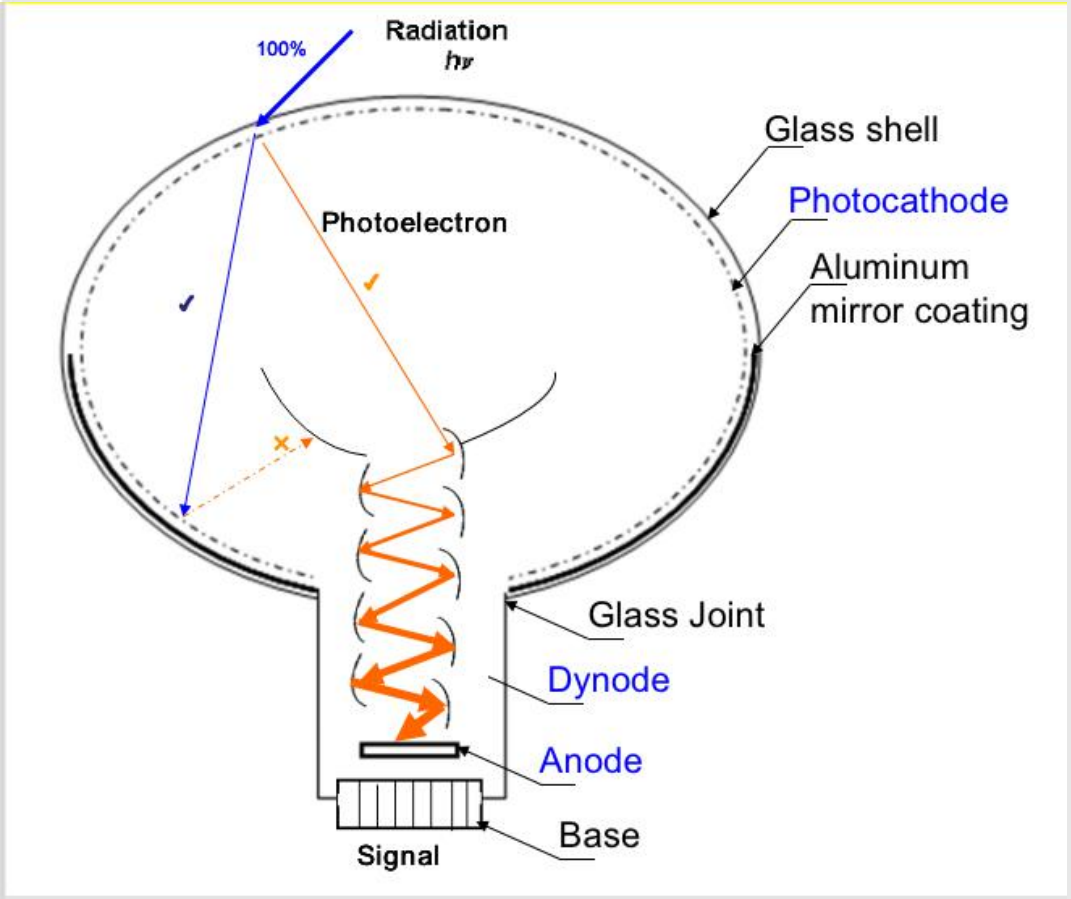
# Outline

- 1. The Conventional PMTs
- 2. The 20 inch MCP-PMT （LPMT）
  - 2.1 The new Design for LPMT；
  - 2.2 The Roadmap for the R&D of LPMT；
  - 2.3 The HPD LPMT for JUNO；
  - 2.4 The Fast LPMT for LHAASO;
- 3. The Fast timing MCP-PMT (FPMT)
  - 3.1 The Roadmap for FPMT；
  - 3.2 The Performance of FPMT；
- 4. Summary

# 1.1 The Conventional PMTs-- Dyonde-PMT

The 20 inch Dynode PMT




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

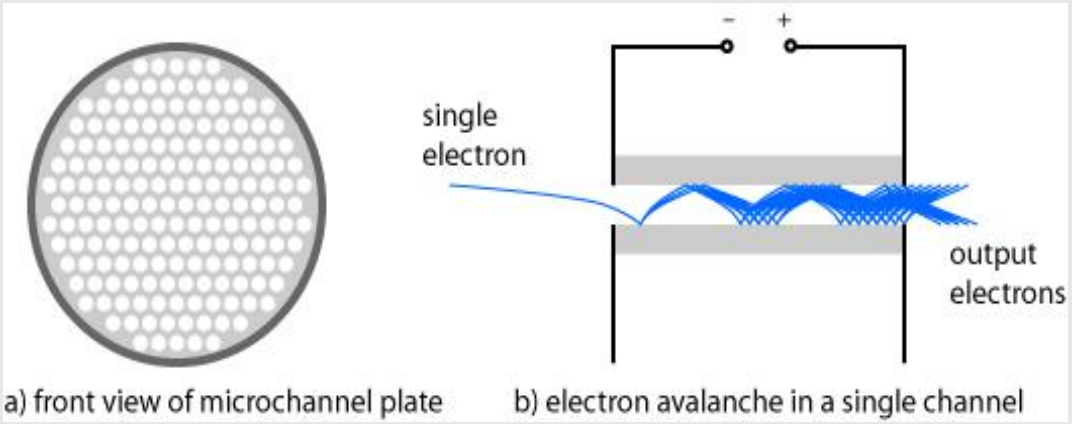
How to improve the PDE of PMT?

Quantum Efficiency (QE) :
20%
Collection Efficiency (CE) of Anode:
70%

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

# 1.2 The Conventional PMTs-- MCP-PMT

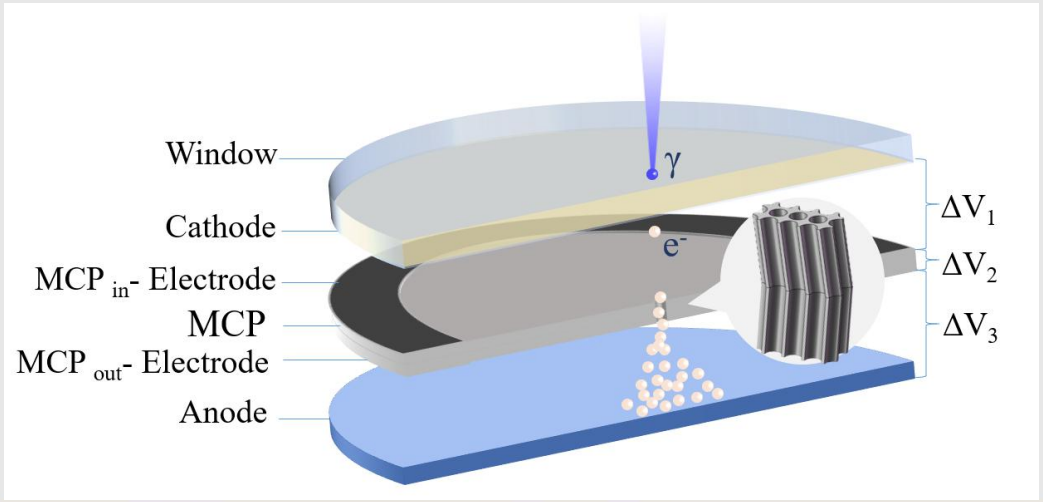
The Microchannel Plate MCP

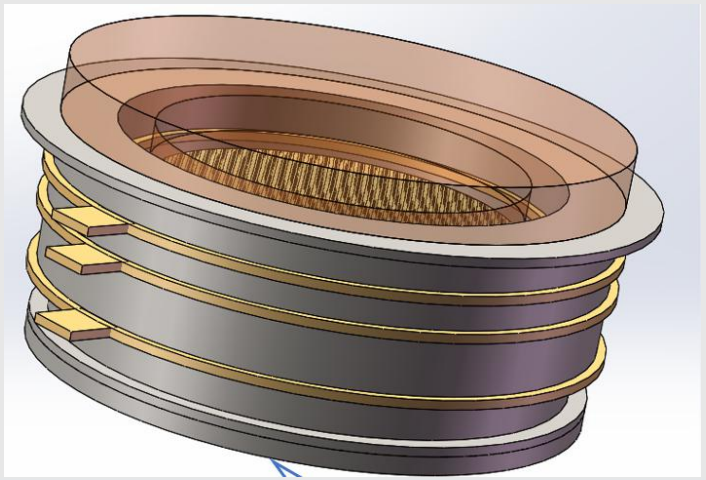



performance of the MCP:

- High Gain： 1X10$^4$ / 1 pic
- Small Size: Diameter=50mm
- Fast Signal：Rise time < 1ns
- TTS@SPE：~30ps

The Conventional small，fast timing MCP-PMT， FPMT

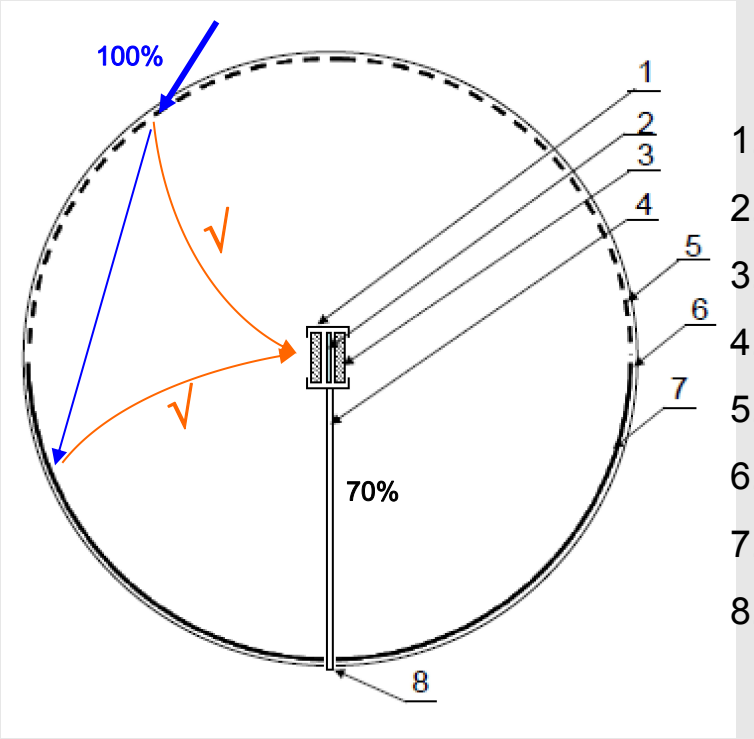


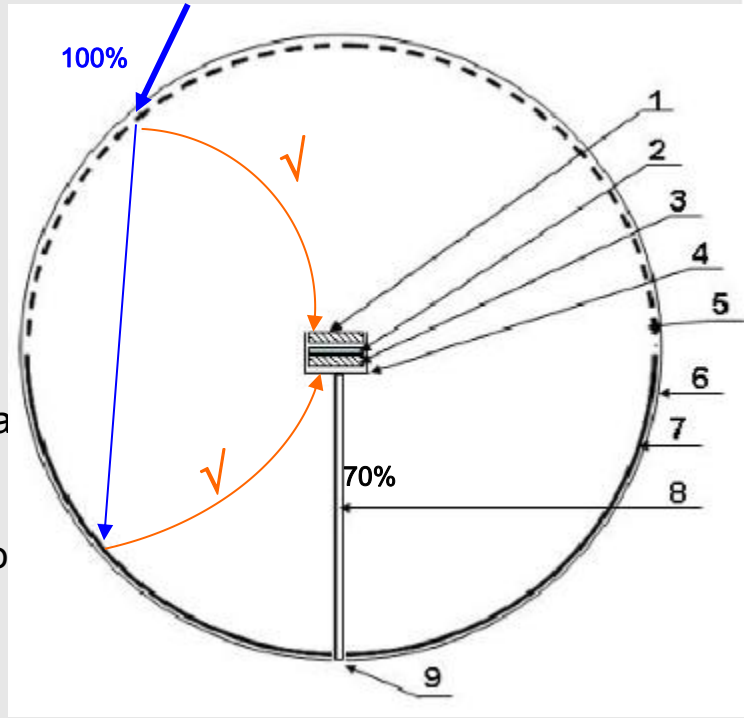
# 2.1 New design of a Large MCP-PMT

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



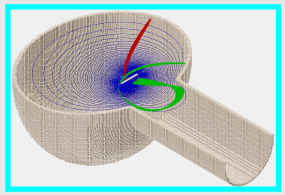

$$PD = QE_{Trans} * CE + TR_{Photo} QE_{Ref} * CE$$

Photon Detection Efficiency: 15% → 30% ; ×~2 at least !

# 2.2 The Roadmap -- （1） Prototypes

There are **4** Core technologies need to develop to produce this new type of 20 inch MCP-PMTs

1. Electron optics

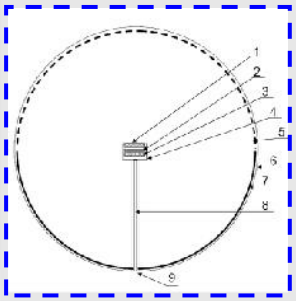


2.Glass shell

3. MCP module

4.Photocathode

0. New Design



Design 2009

2” MCP-PMT (2010)

8” MCP-PMT (2012-2013)

5” MCP-PMT (2011)

20” MCP-PMT (2015)

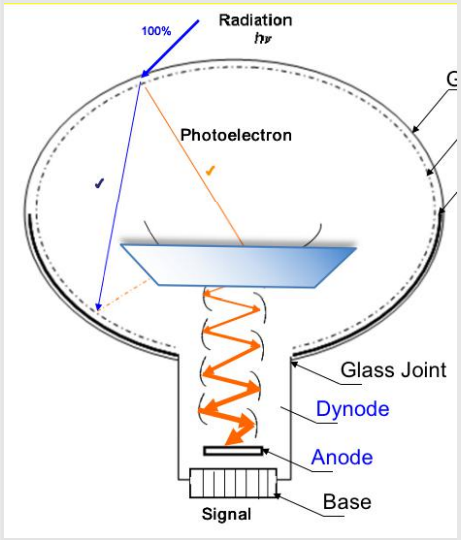
From 2010-2015，the prototyps with 2”, 5”,8” and 20” were produced, and the performance also were improved a lot for the good SPE test and High CE MCP modules.

# 2.2 The Roadmap -- （2）Technology

Dynode-PMT

① MCPs for the SPE test

MCP-PMT




Quantum Eff.=20%

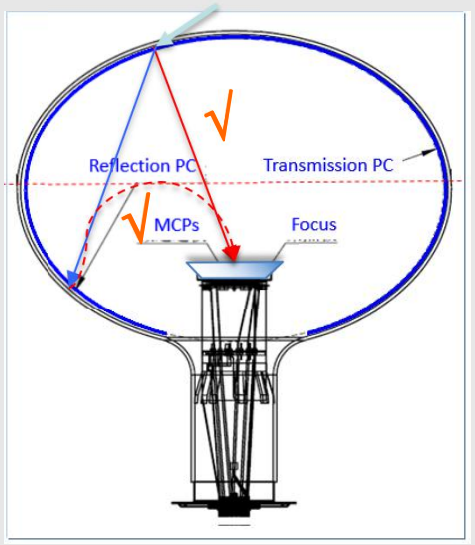
②QE=30%

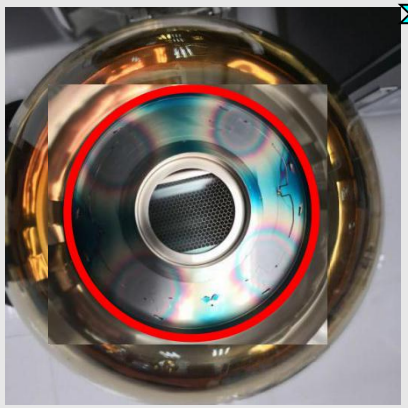
- new tech. for the Photochade

Collection Eff.=70%

③CE=100%

- ALD coatting for the MCP



Detection Eff.=14%

④DE=30%

⑤ Low-Potassium Glass

⑥ Low cost （3000$, 20KRMB）

# 2.2 The Roadmap -- （3）Parameters

| Characteristics （20inch） | unit | MCP-PMT Prototype（IHEP） | MCP-PMTs 15K pieces（NNVT） |
|---|---|---|---|
| Electron Multiplier | -- | MCP | MCP |
| Photocathode Mode | -- | reflection+ transmission | reflection+ transmission |
| Quantum Efficiency（400nm） | % | 26 (T), 30 (T+R) | 32% |
| Collection Efficiency | | ~99% | 99% |
| **Detection Efficiency（400nm）** | **%** | **~ 27%** | **31.5%** |
| **Detection Efficiency（420nm）** | **%** | **--** | **28.3%** |
| P/V of SPE | | ＞ 5 | 7.1 |
| TTS on the top point | ns | ~15 | ~ 20 |
| Rise time/ Fall time | ns | R~2 ， F~20 | R~1.4 ， F~24 |
| Anode Dark Rate | Hz | ~30K | 40K |
| After Pulse Time distribution | us | 0.1， 4.5 | 0.2 , 0.8 , 3 ， 4.5, 17 |
| After Pulse Rate | % | 2.5% | 5.2% |
| Glass | -- | Low-Potassium Glass | Low-Potassium Glass |

# 2.3 The High PDE 20” MCP-PMT for JUNO



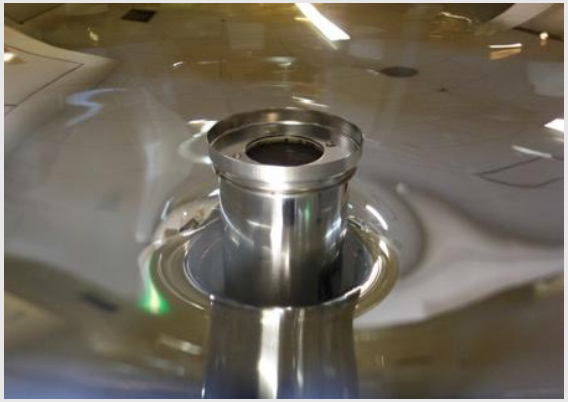
—JUNO（**Jiangmen Underground Neutrino Observatory**), has already supported the MCP-PMT collaboration group to R&D the 20 inch MCP-PMT from 2009 to 2020.

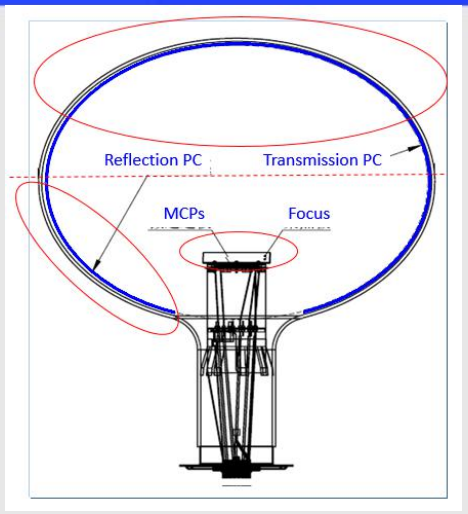
—Yifng Wang in IHEP is our group leader for this type of MCP-PMT development and the the company NNVT is the one to do the mass production work.

| Parameters | MCP-PMT | Dynode-PMT |
|---|---|---|
| Total number | 15000 | 5000 |
| DE@420nm | 28.3% | 27.6% |
| Dark Rate | ~ 40KHz | ~ 17KHz |
| P/V | ~7 | ~3 |

# 2.4 The FAST 20” MCP-PMT

Normal focusing electrode





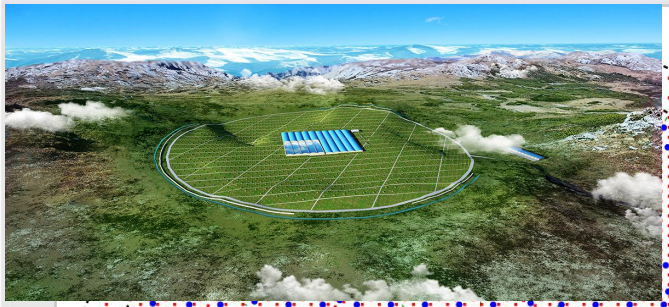

Flower-like focusing electrode

——By changing the construction of the focusing electrode, using the flower-like one, the TTS of the PMTs is improving from 20ns to 5ns, but the CE of the prototype is decreasing to 85%,

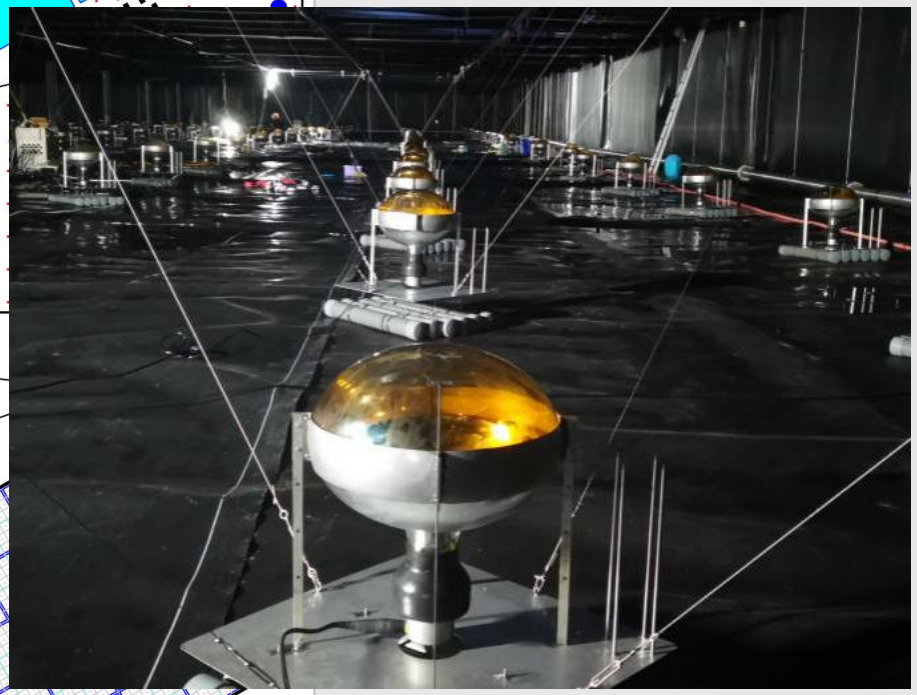
——By decreasing the area of the photocathode for better TTS, the dark rate of the PMT also much better than the normal one, from 40KHz to 20KHz.

| Characteristics | Normal focusing electrode | | Flower-like focusing electrode |
|---|---|---|---|
| QuantumEfficiency (400nm) | ~30% | | ~30% |
| Relativity Detection Efficiency | ~ 100% | ↓ | 85% |
| P/V of SPE | ~ 7 | ↓ | ~ 5 |
| TTS on the top point | ~20ns | ↑ | 4.3 ns |
| Anode Dark Count | ~40KHz | ↑ | ~20KHz |

# 2.5 The FAST 20” MCP-PMT for LHAASO





—LHAASO（**Large High Altitude Air Shower Observatory**), has already ordered 2270 pics 20” Flower-like-MCP-PMT.

—The 20 inch Prototype with potting has also post to the HyperK PMT Group in Tokyo University for the testing.

—The performance are different from the tubes for JUNO.

| Parameters | JUNO | LHAASO |
|---|---|---|
| Total number | 15000 | 2270 |
| DE@400nm | 30% | 26.8% |
| Dark Rate | ~ 40KHz | ~ 15KHz |
| TTS | ~20ns | ~5.5ns |

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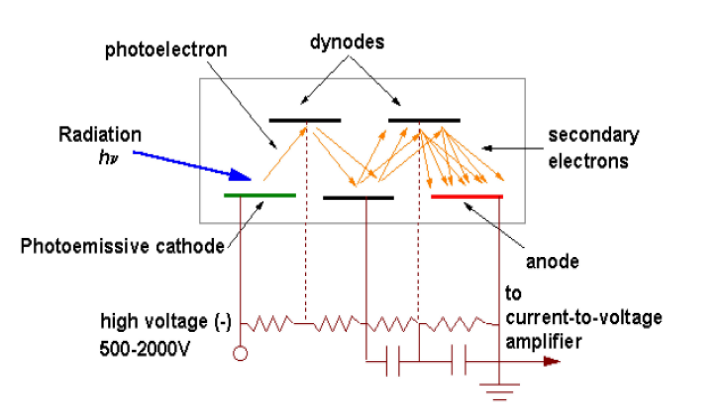
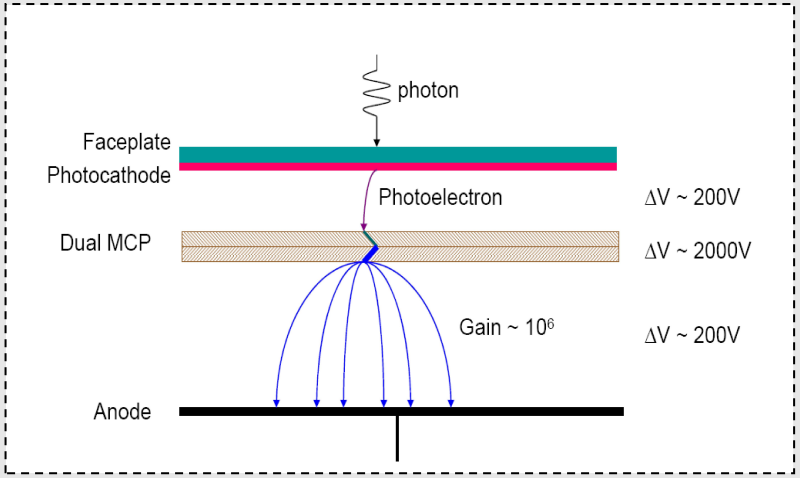
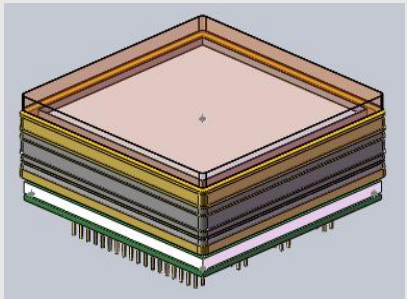
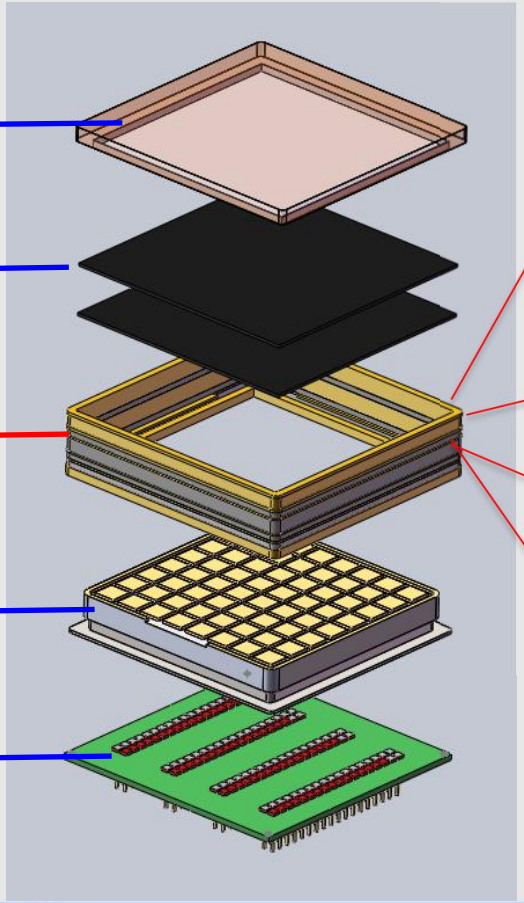
# 3.1 The Roadmap for FPMT-- （1）Purpose

| | Operation Principle | Small Size （proximity focusing） | Large Size （electrostatic focusing） |
|---|---|---|---|
| Dynode |  | 2“ Dynode-PMT ✓<br>  | 20“ Dynode-PMT ✓<br>  |
| MCP |  | 2“ MCP-PMT ?<br>  | 20“ MCP-PMT ✓<br>  |

# 3.1 The Roadmap for FPMT -- （2）Technology

--Five Core technologies are needed to produce this new type of 2 inch Fast MCP-PMT；
--We have the experience of the PC, MCP production, but need do more research on the sealing, the anode, and the electronics.



High QE **Photocathode**

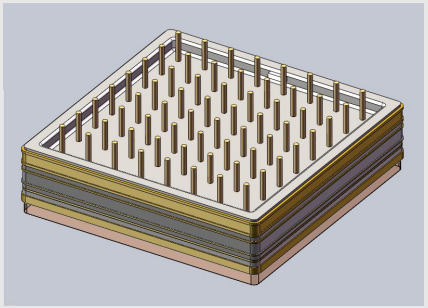
High Gain Low Noise **MCP**

High Vacuum **Sealing**

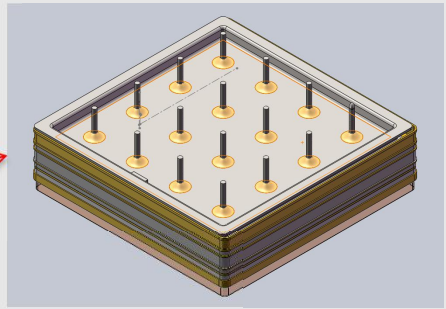
**Crosstalk-free Array Anode**

**High-density Electronics**

2 inch - 8X8 ch.



2 inch - 4X4 ch.



1inch- 1ch.

1inch- 4ch.

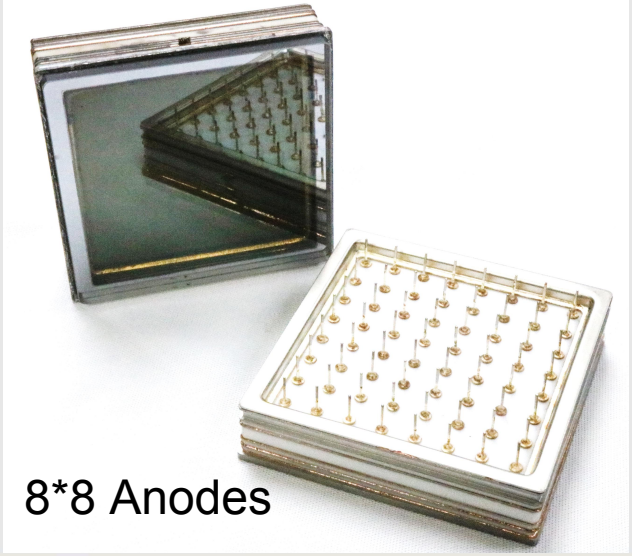
# 3.1 The Roadmap for FPMT -- （3） Prototypes

FPMT developed in IHEP+NNVT

Single Anode

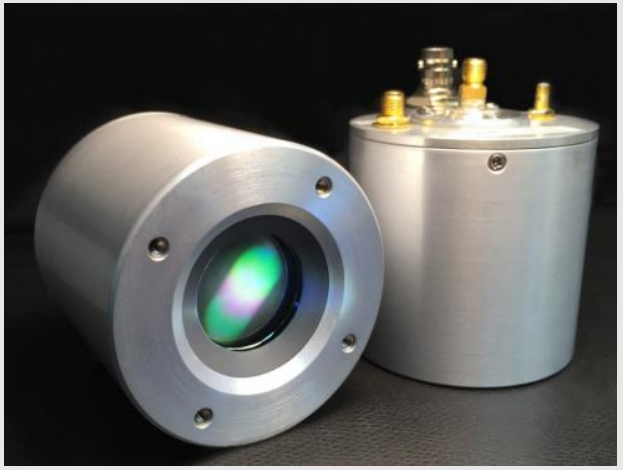
2*2 Anodes

4*4 Anodes

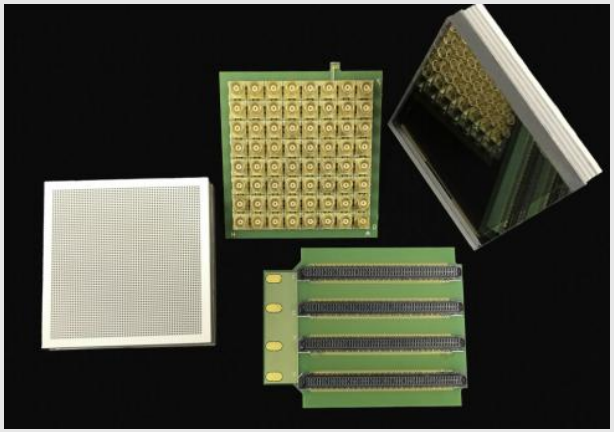


8*8 Anodes

FPMT developed in Photek



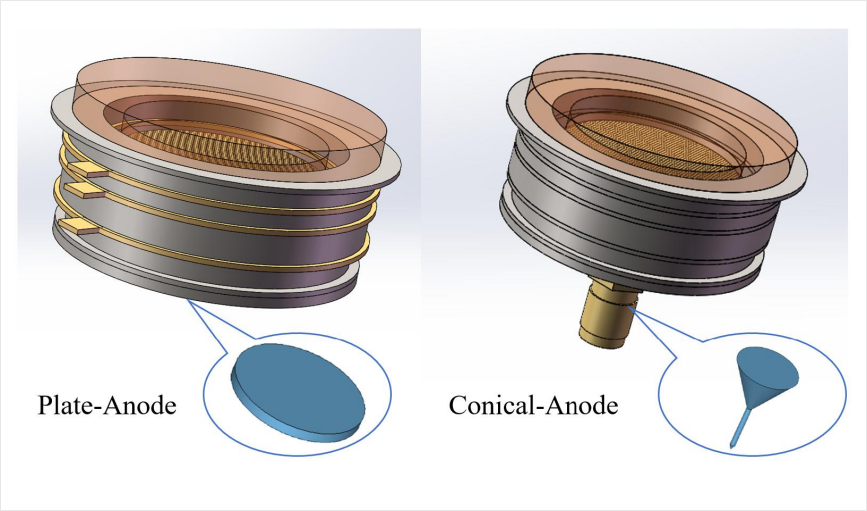
Photek Single anode

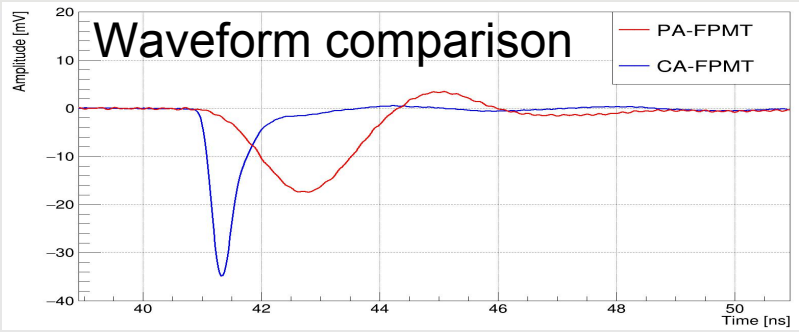


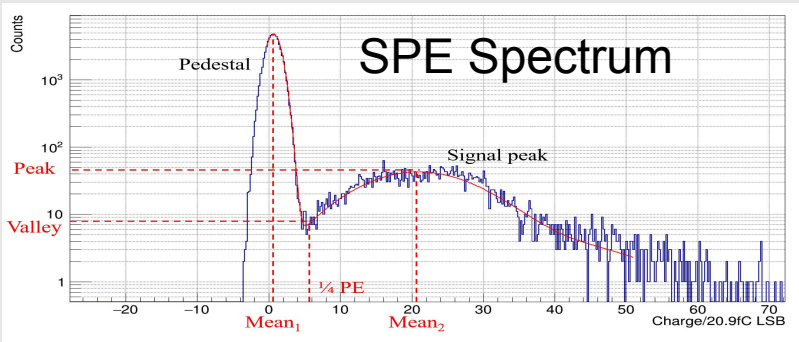
Photek Multi-Anode

# 3.2 The Performance -- （1） Single Anode FPMT

## Anode Optimization



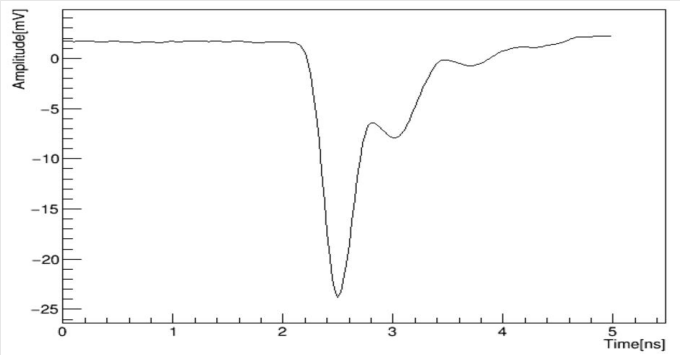




| | HV/V | Gain | P/V | Amp(SPE) | RT | FT | Width | TTS@SPE | TTS@MPE |
|---|---|---|---|---|---|---|---|---|---|
| **Photek 210** | -4700 | 2.9E6 | 2.0 | 93.2mV | **95.8ps** | 348ps | 190ps | **43.5ps** | 10.3ps |
| **Plate-Anode** | -2000 | 1.9E6 | 28.8 | 7.59mV | **1.41ns** | 1.42ns | 1.8ns | 71ps | 25ps |
| **Conical-Anode** | -3181 | 2.6E6 | 6.3 | 53mV | **153ps** | 419ps | 328ps | **27.2ps** | **4.2ps** |

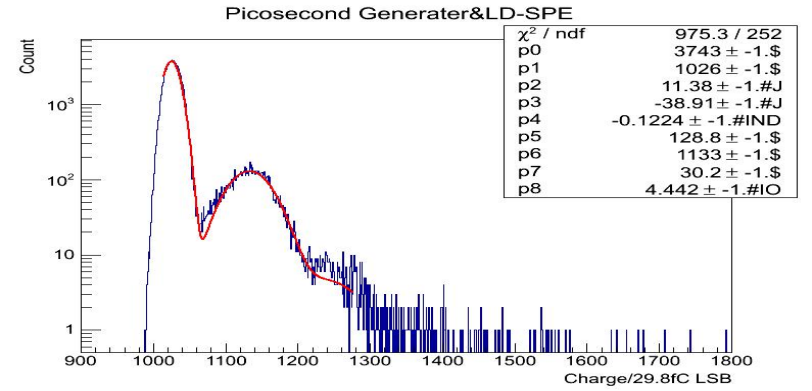
*Ref: Lishuang MA et al., R & D of a novel single anode fast timing MCP-PMT，2022，Pre-proof，NIMA.*

# 3.2 The Performance -- （2）2X2 Anode FPMT

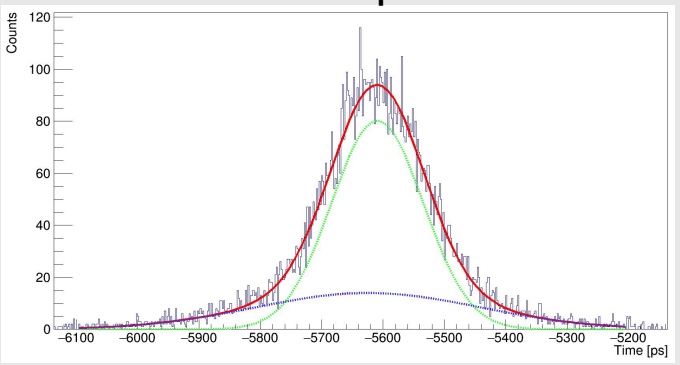
Average waveform for SPE




SPE Spectrum




SPE-TTS Spectrum

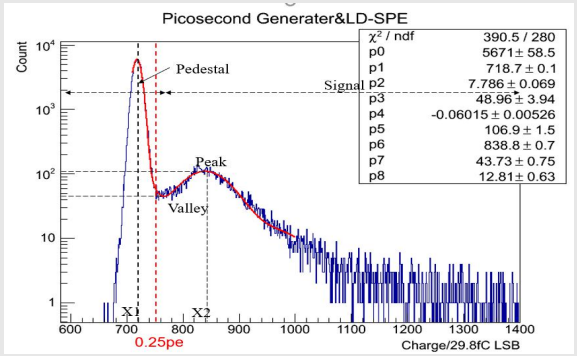



| | HV/V | Gain | P/V | Amp(SPE) | RT | FT | Width | TTS@SPE | TTS@MPE |
|---|---|---|---|---|---|---|---|---|---|
| Photek 210 | -4700 | 2.9E6 | 2.0 | 93.2mV | 95.8ps | 348ps | 190ps | 43.5ps | 10.3ps |
| 2X2-Anode | -2500 | 1.9E6 | 6.5 | 33.9mV | 243 | 516 | 378ps | **66.8ps** | 16.6ps |

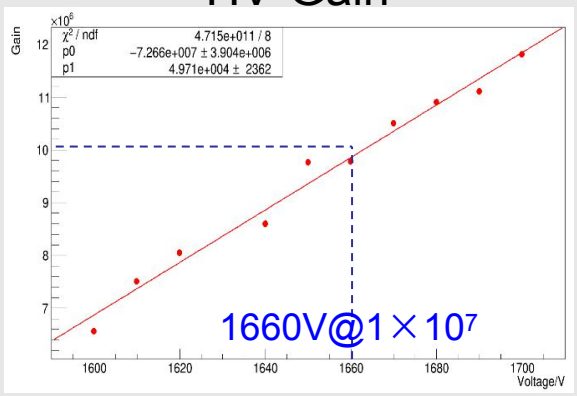
*Ref：Sen Qian，Oral report, The R&D of the Ultra Fast 8X8 Readout MCP-PMTs, ICHEP 2020*

# 3.2 The Performance -- （3）4X4 Anode FPMT

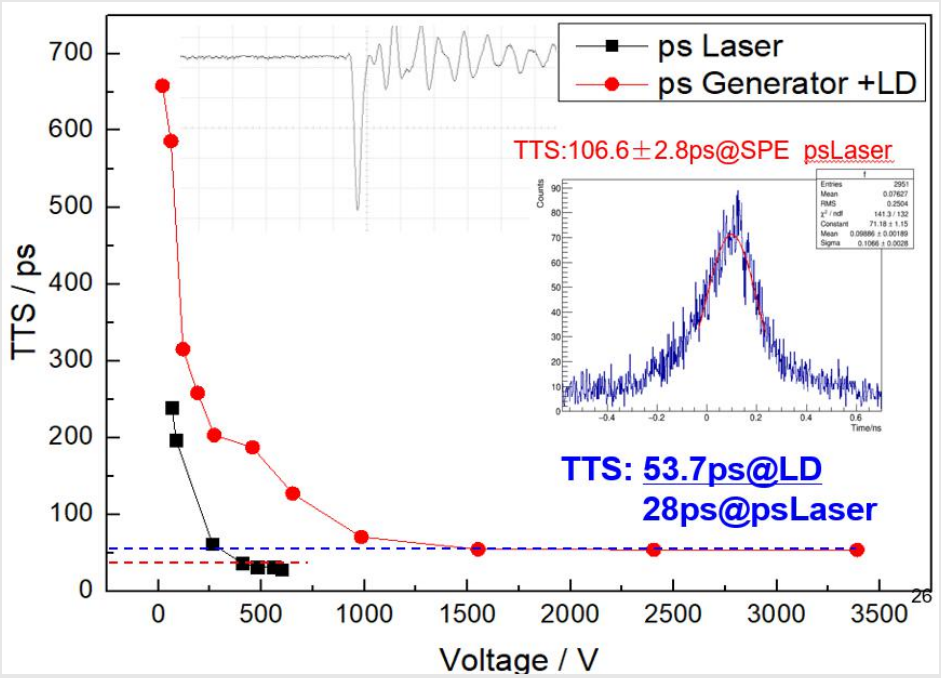
SPE Spectrum




HV-Gain

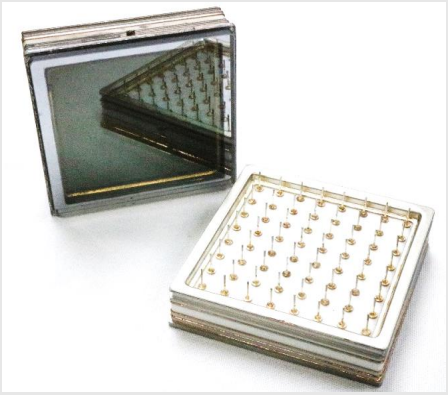



SPE-TTS Spectrum

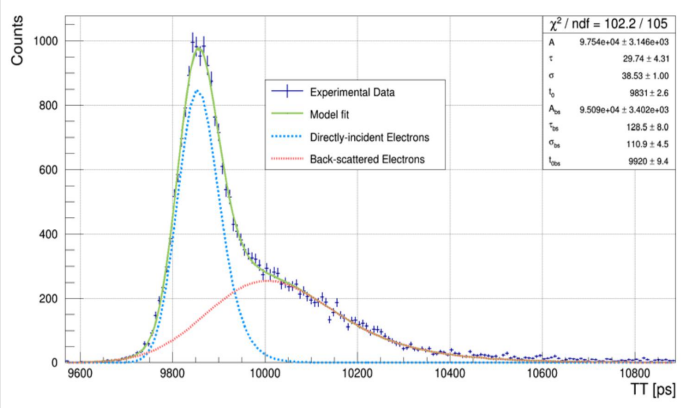



| | HV/V | Gain | P/V | Amp(SPE) | RT | FT | Width | TTS@SPE | TTS@MPE |
|---|---|---|---|---|---|---|---|---|---|
| Photek-253 | -2600 | 1.2E7 | 11.2 | 113mV | 490ps | 1.16ns | - | 44.3 ps | 16 ps |
| 4X4 -Anode | -1660 | 9.6E6 | 2.0 | 21.1mV | 430ps | -- | -- | 107ps | 28 ps |

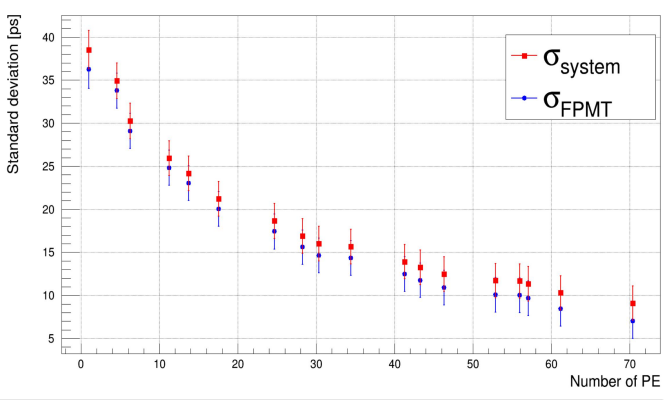
# 3.2 The Performance -- （4）8X8 Anode FPMT



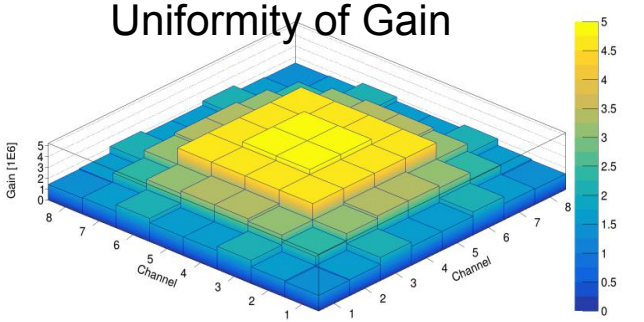
TTS Spectrum



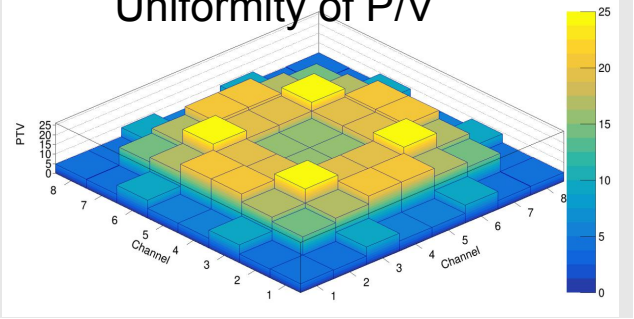

TTS Variation with the light intensity



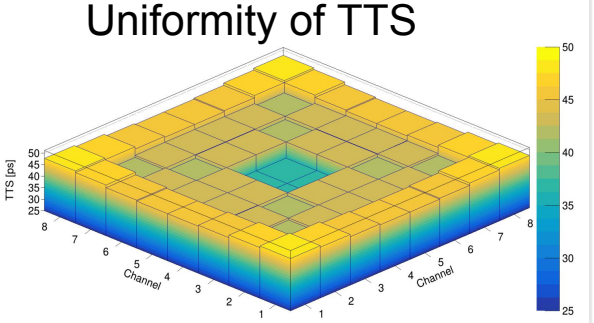

Uniformity of Gain




Uniformity of P/V




Uniformity of TTS



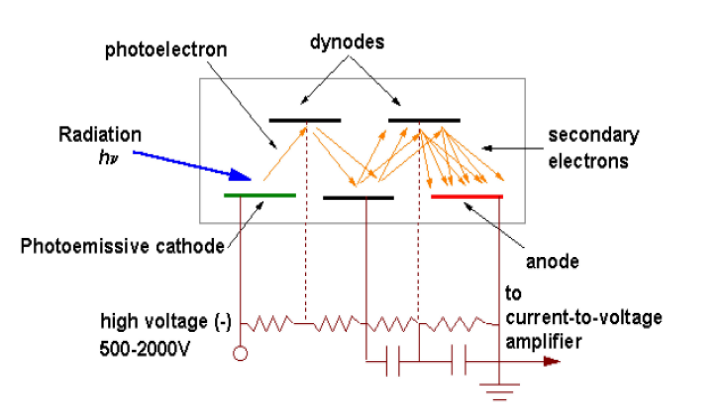
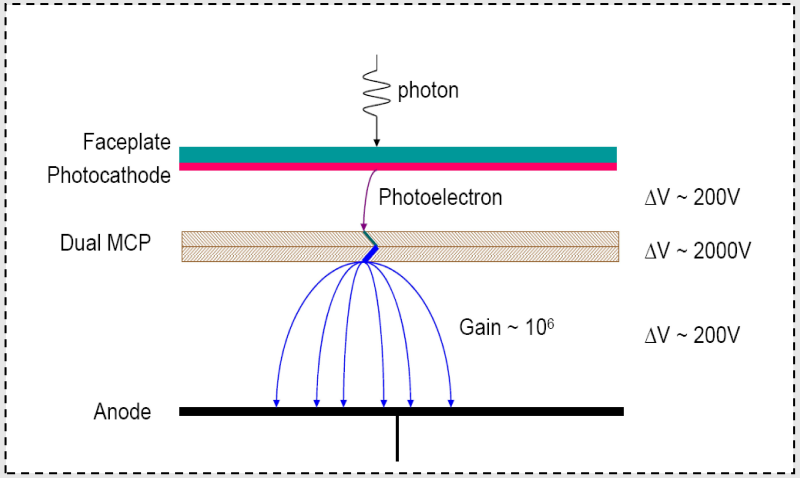
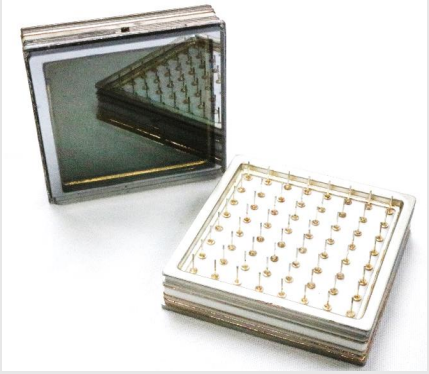

| | HV/V | Gain | P/V | Amp(SPE) | RT | FT | Width | TTS@SPE | TTS@MPE |
|---|---|---|---|---|---|---|---|---|---|
| **Photek-253** | -2600 | 1.2E7 | 11.2 | 113mV | 490ps | 1.16ns | ~1ns | **44.3 ps** | 16 ps |
| **8*8 Anodes** | -1500 | 3.9E6 | 18.6 | 45 mV | 334 ps | 660 ps | ~900ps | **38.5 ps** | **9.1 ps** |

*Ref: Qi Wu et al., R&D of ultra-fast 8 × 8 anodes MCP-PMT, 2022 JINST 17 T04002.*

# Out line

- 1. The Conventional PMTs
- 2. The 20 inch MCP-PMT （LPMT）
  - 2.1 The new Design for LPMT；
  - 2.2 The Roadmap for the R&D of LPMT；
  - 2.3 The HPD LPMT for JUNO；
  - 2.4 The Fast LPMT for LHAASO;
- 3. The Fast timing MCP-PMT (FPMT)
  - 3.1 The Roadmap for FPMT；
  - 3.2 The Performance of FPMT；
- 4. Summary

# 4. Summary-- （1） The PMTs

| | Operation Principle | Small Size （proximity focusing） | Large Size （electrostatic focusing） |
|---|---|---|---|
| Dynode |  | 2“ Dynode-PMT ✓<br>  | 20“ Dynode-PMT ✓<br>  |
| MCP |  | 2“ MCP-PMT ✓<br>  | 20“ MCP-PMT ✓<br>  |

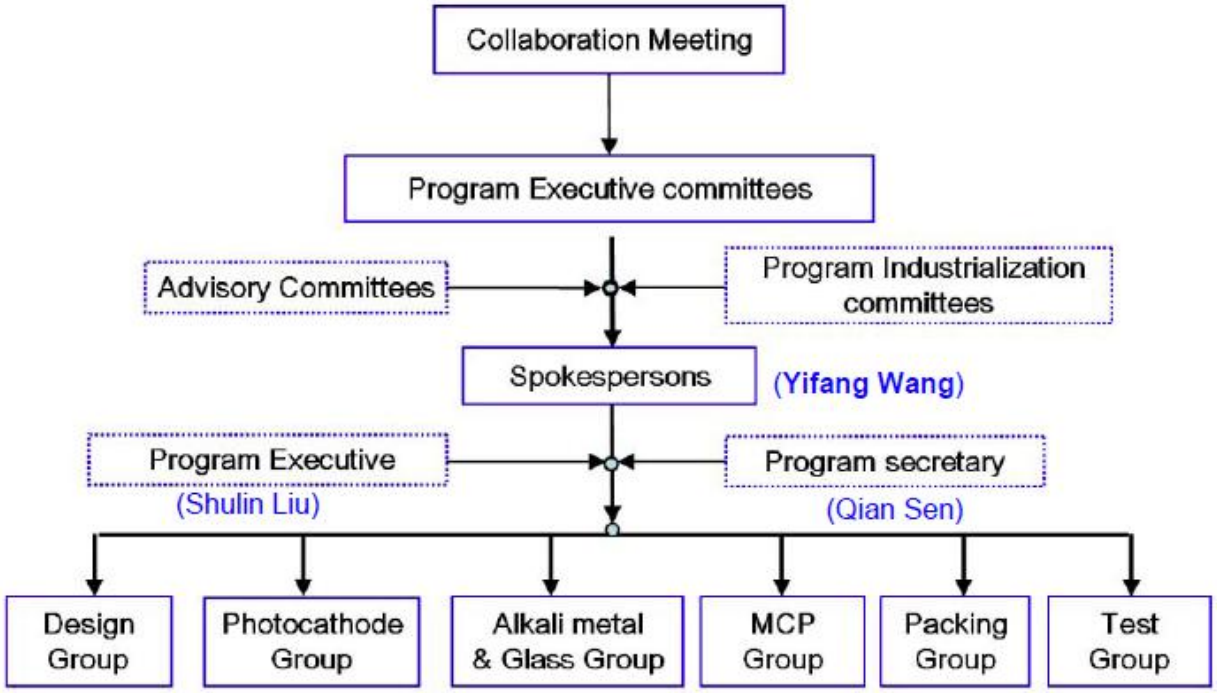
# 4. Summary-- （2）The Group

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

Institute of High Energy Physics, CAS

effort by **Yifang Wang**

**Microchannel-Plate-Based Large Area Photomultiplier Collaboration (MLAPC)**




北方夜视技术股份有限公司
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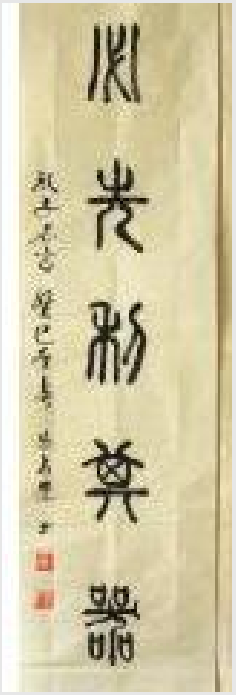
中国科学院西安光学精密机械研究所
XIAN INSTITUTE OF OPTICS AND PRECISION MECHANICS OF CAS

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

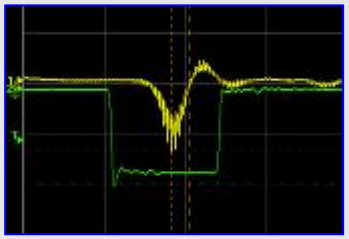
南京大学

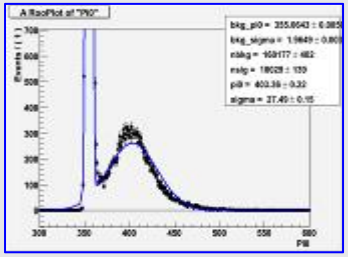
# 4. Summary-- （3）The PMT Lab in IHEP

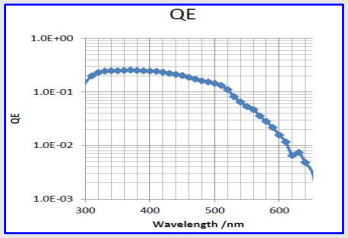
工欲善其事必先利其器 = Work must first of its profits

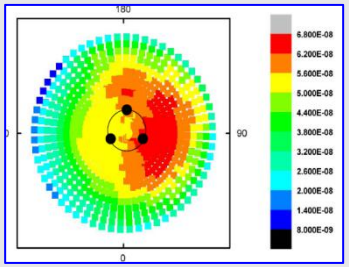


# The Test Facility for PMTs







**Others**

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

- The Single Photoelectron Spectrum;
- The voltage distribution (BASE) ;
- The Supply voltage;
- Typical Gain Characteristic;
- 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;

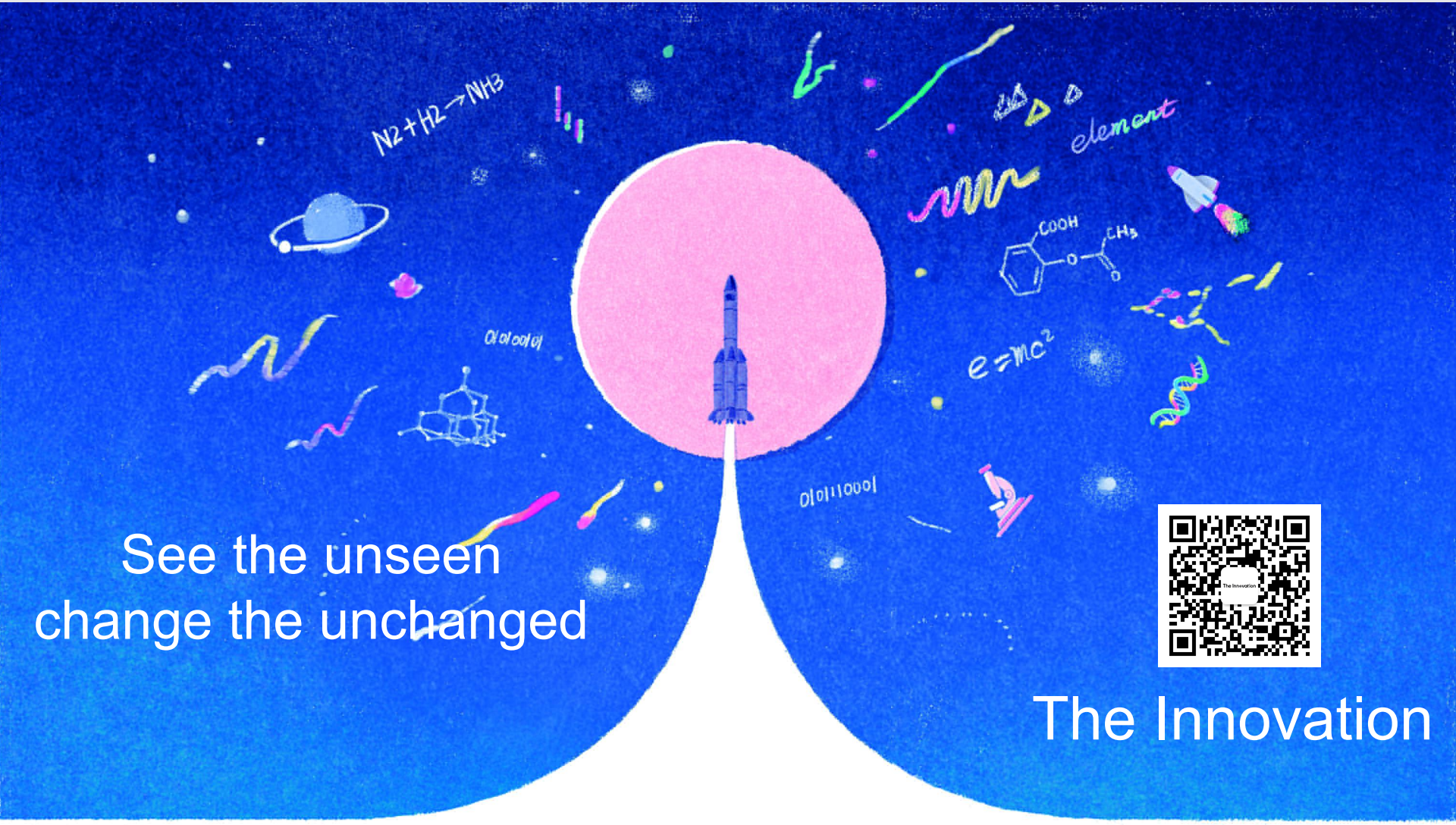
- The linearity of the PMT
- Magnetic characteristics;
- Transit Time Spread (FWHM)

谢谢！

Thanks for your attention!

Any Comment & Suggestion are welcomed!

# THANKS


N2+H2→NH3
element
COOH
CH3
e=mc²
See the unseen
change the unchanged
The Innovation