The R&D and Performance of the Fast Timing PMTs (FPMT)

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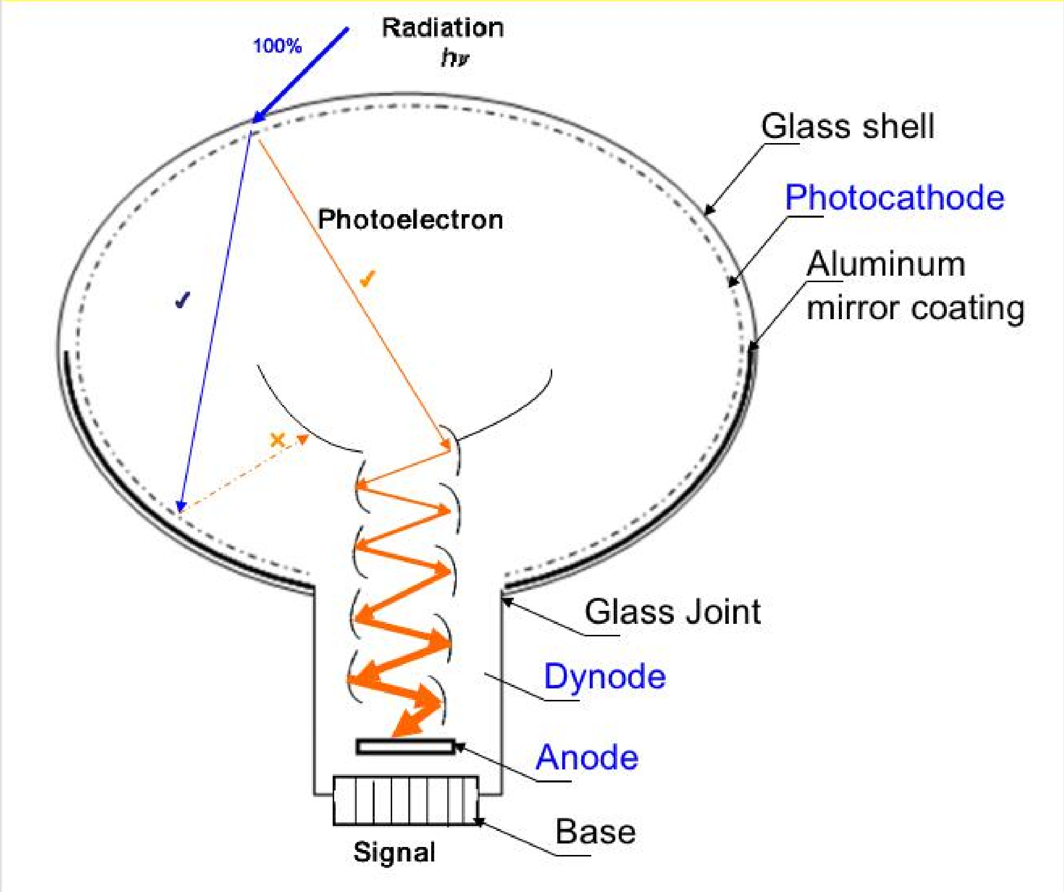
The 2022 international workshop on the high energy Circular Electron-Positron Collider (CEPC)

Outline

- 1. The Conventional PMTs
- 2. The 20 inch MCP-PMT （LPMT）
  - 2.1 The 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 2inch Fast timing MCP-PMT (FPMT)
  - 3.1 The Roadmap for FPMT；
  - 3.2 The Performance of FPMT；
  - 3.3 The CTR of FPMTs;
  - 3.4 The Proton Beam Test；
- 4. Summary

1.1 The Conventional -- 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?

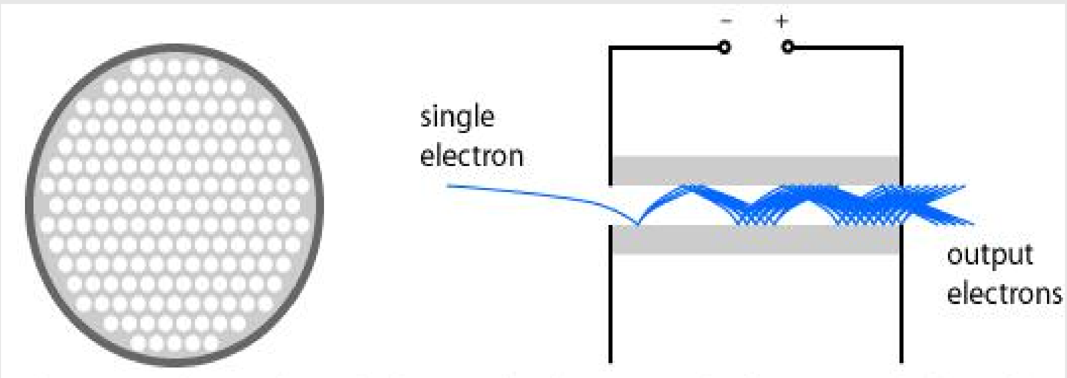
Quantum Efficiency (QE) :
20%

Collection Efficiency (CE) of Anode:
70%

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

1.2 The Conventional -- Small-MCP-PMT

The Microchannel Plate MCP

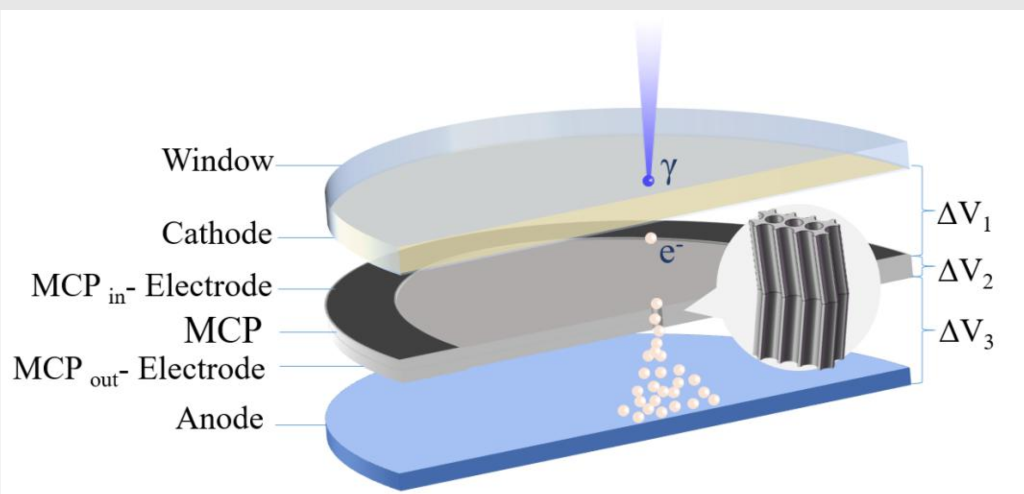


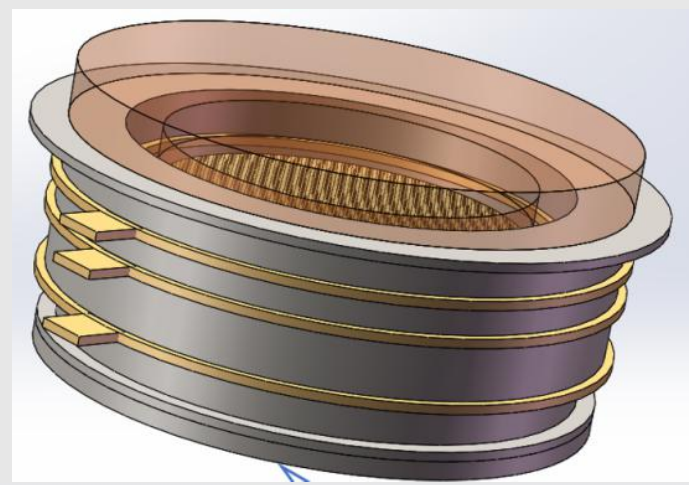
a) front view of microchannel plate b) electron avalanche in a single channel

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



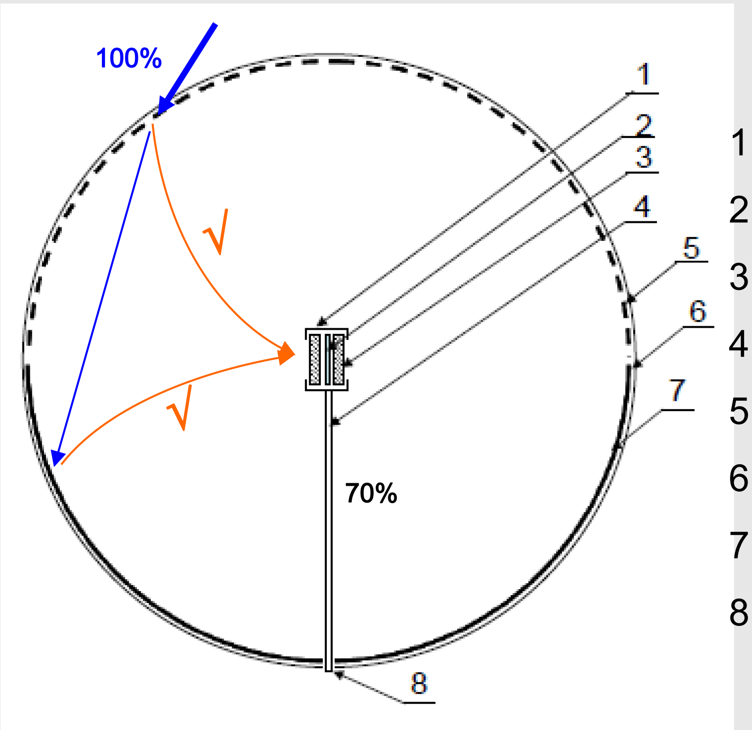


2.1 the design of a Large MCP-PMT

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

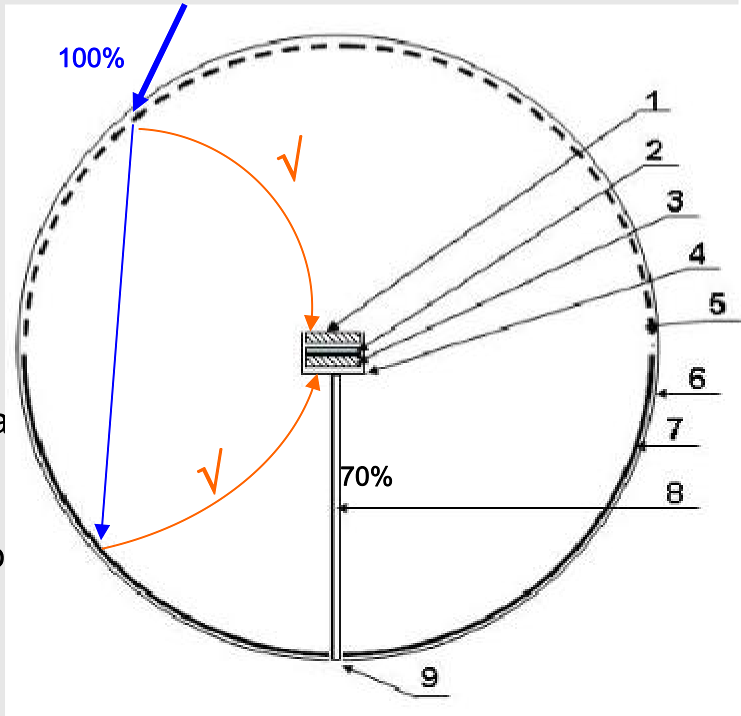
4.Bracket of the cables

5.Transmission Photoca

6.Glass shell

7.Reflection Photocatho

8.Glass joint

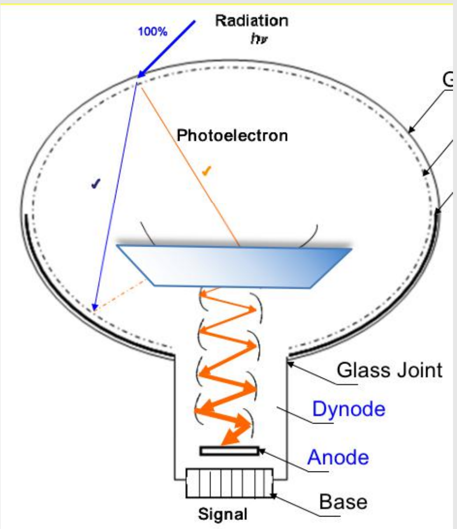


$$PD = QE_{Trans}*CE + TR_{Photo}QE_{Ref}*CE$$

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

2.2 The Roadmap -- （1） Technology

Dynode-PMT



① MCPs for the SPE test

Quantum Eff.=20% → ②QE=30%

- new tech. for the Photochade

Collection Eff.=70% → ③CE=100%

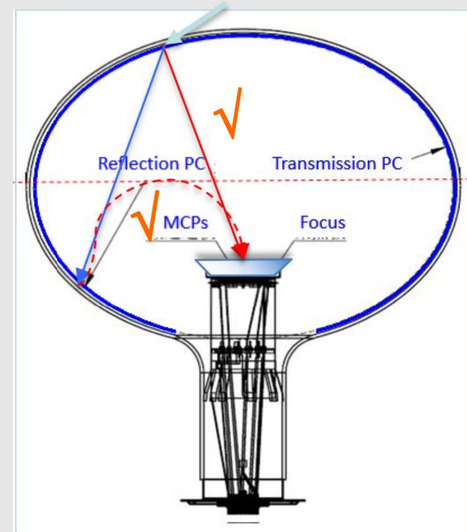
- ALD coatting for the MCP

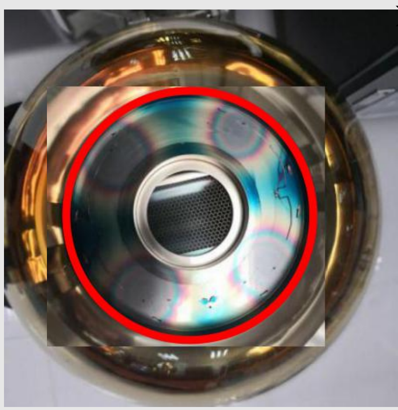
Detection Eff.=14% → ④DE=30%

⑤ Low-Potassium Glass

⑥ Low cost（3000$, 20KRMB）

MCP-PMT

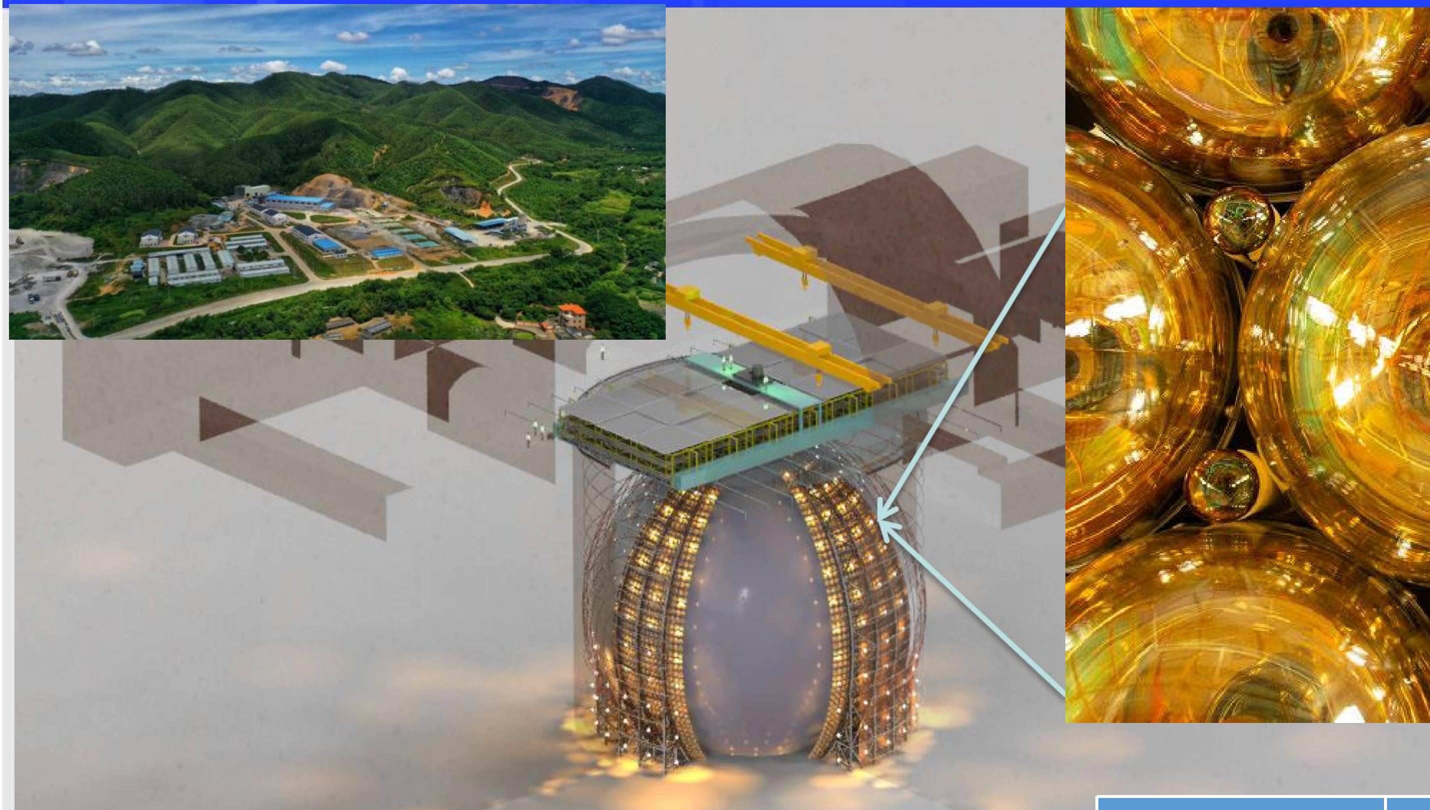


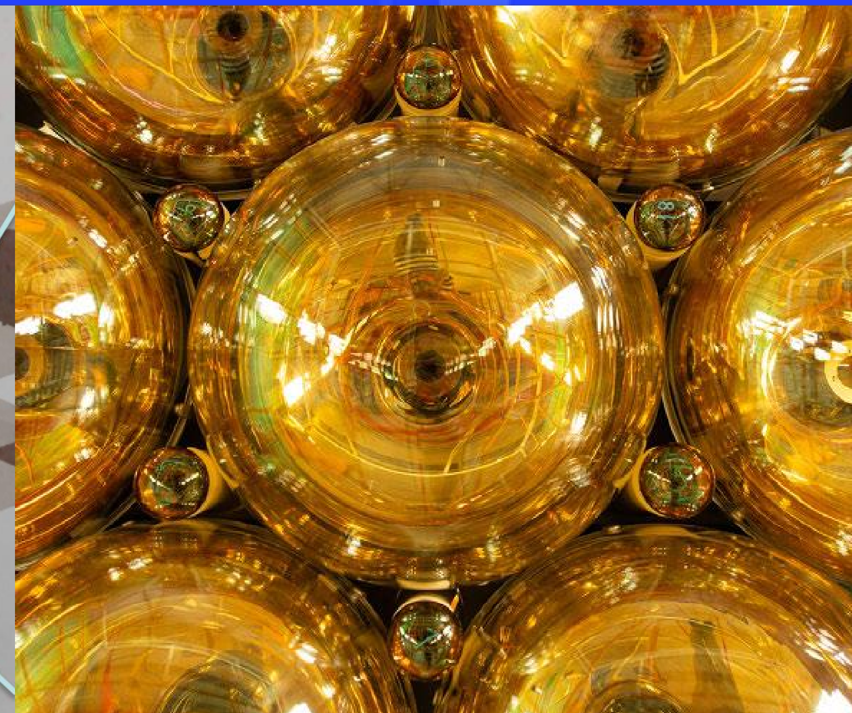


2.2 The Roadmap -- （2） Parameters

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





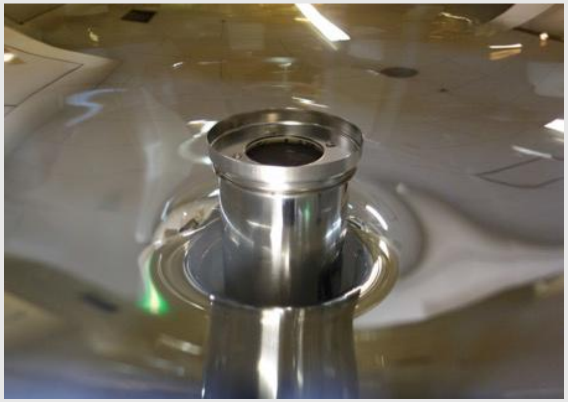
—JUNO（**Jiangmen Underground Neutrino Observatory**), has already supported the MCP-PMT collaboration group to R&D the 20 inch MCP-PMT from 2009 to 2020.

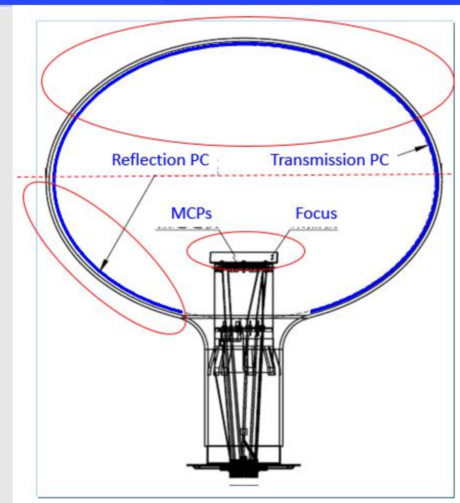
—Yifng Wang in IHEP is our group leader for this type of MCP-PMT development and the the company NNVT is the one to do the mass production work.

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 for LHAASO

Normal focusing electrode



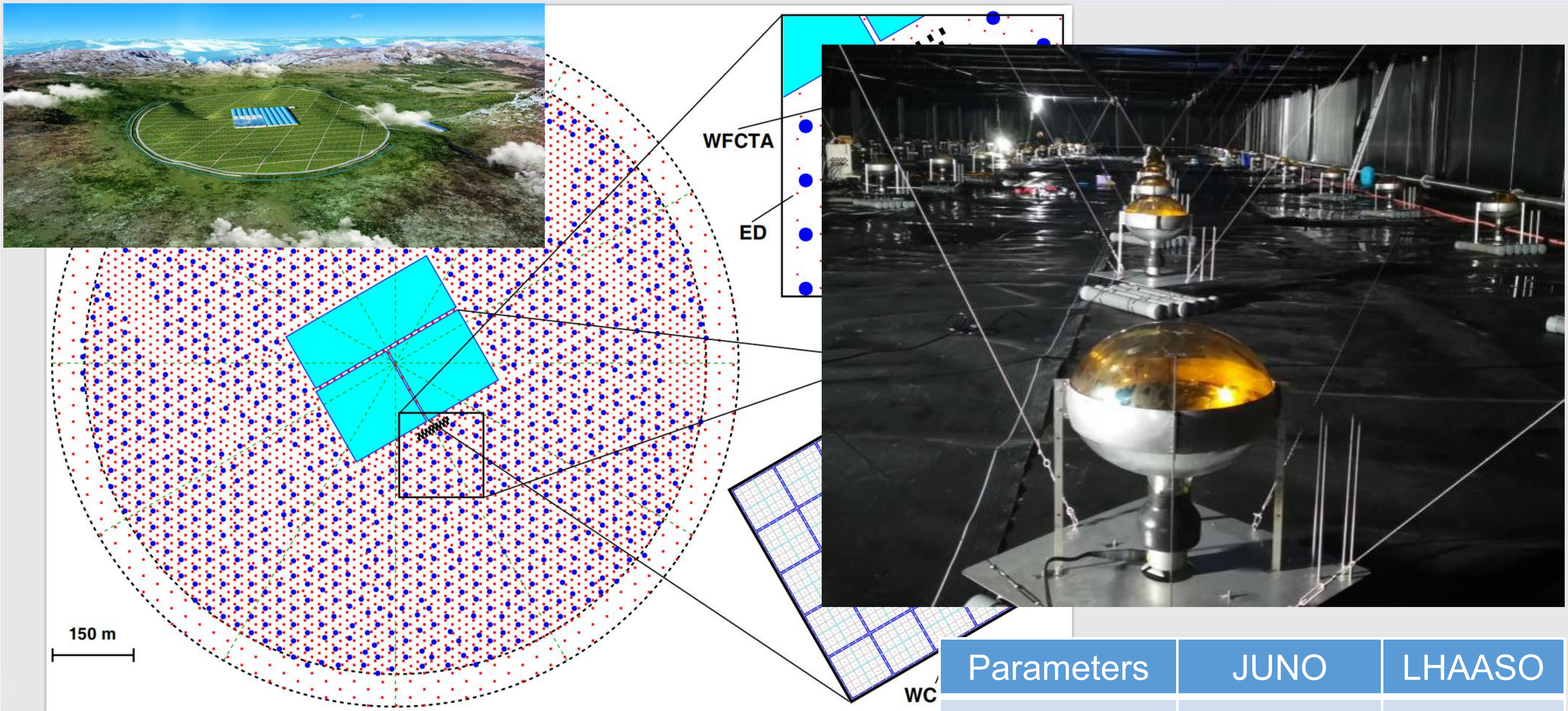


Flower-like focusing electrode

——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



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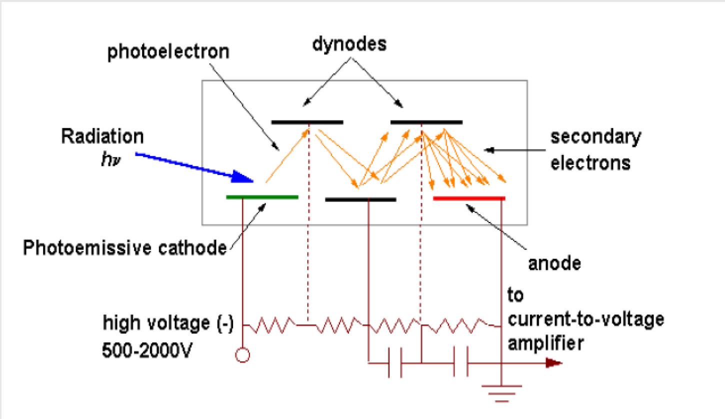
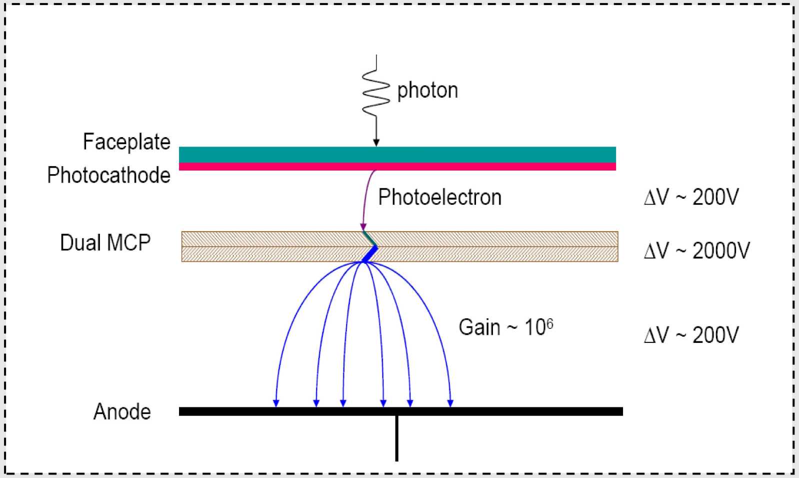
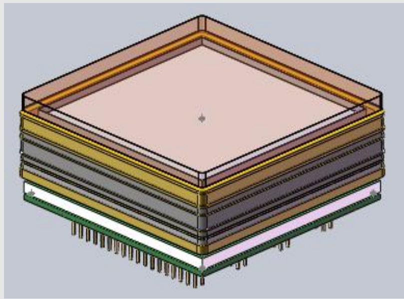
3.1 The Roadmap for FPMT-- （1） Purpose

<table>
<tr><th></th><th>Operation Principle</th><th>Small Size
（proximity focusing）</th><th>Large Size
（electrostatic focusing）</th></tr>
<tr><td>Dynode</td><td>
</td><td>2“ Dynode-PMT ✔

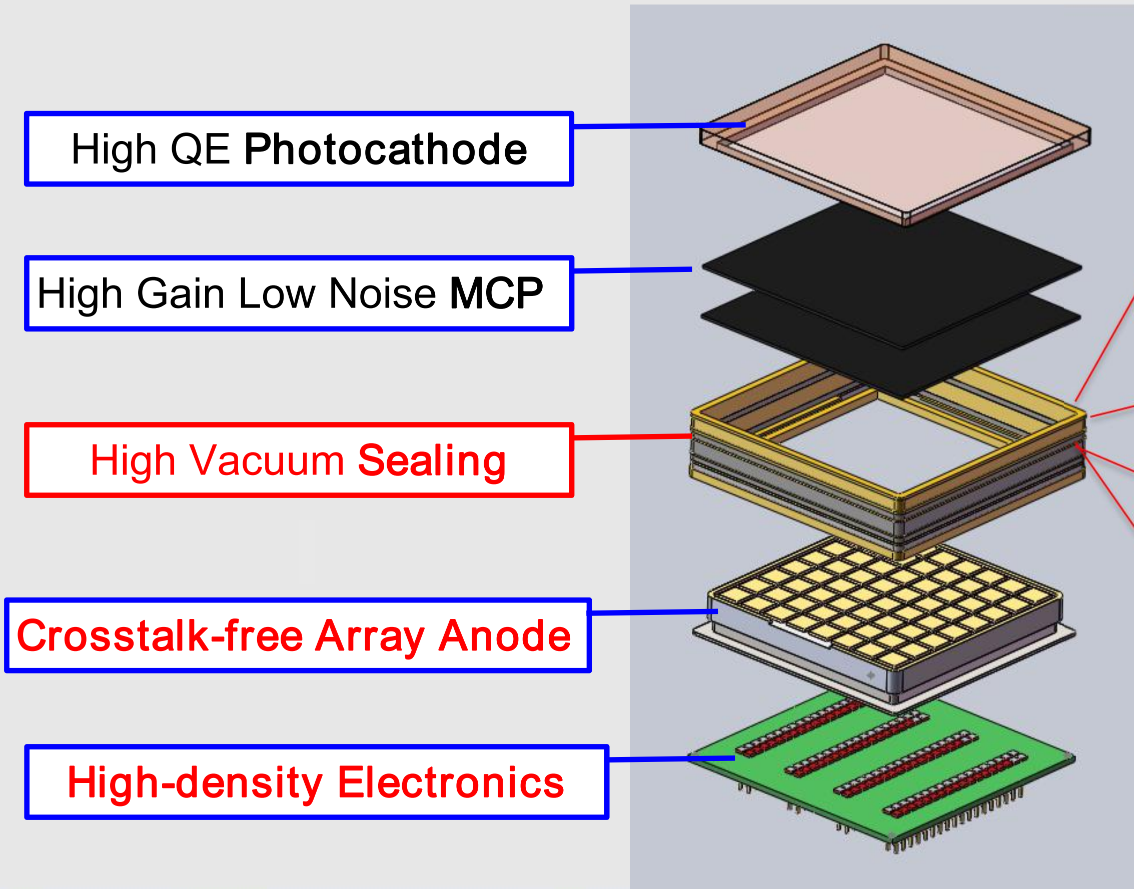
</td><td>20“ Dynode-PMT ✔

</td></tr>
<tr><td>MCP</td><td>
</td><td>2“ MCP-PMT ?
</td><td>20“ MCP-PMT ✔
</td></tr>
</table>

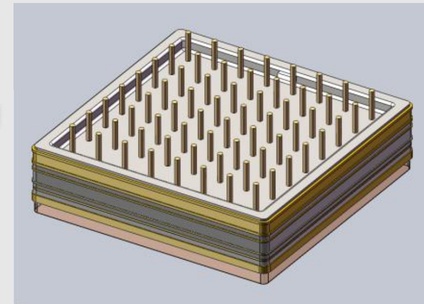
3.1 The Roadmap for FPMT -- （2）Technology

--Five Core technologies are needed to produce this new type of 2 inch Fast MCP-PMT；

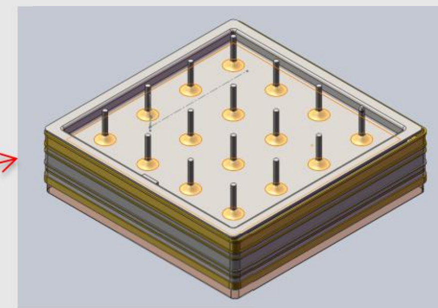
--We have the experience of the PC, MCP production, but need do more research on the sealing, the anode, and the electronics.



2 inch - 8X8 ch.



2 inch - 4X4 ch.



1inch- 1ch.

1inch- 4ch.

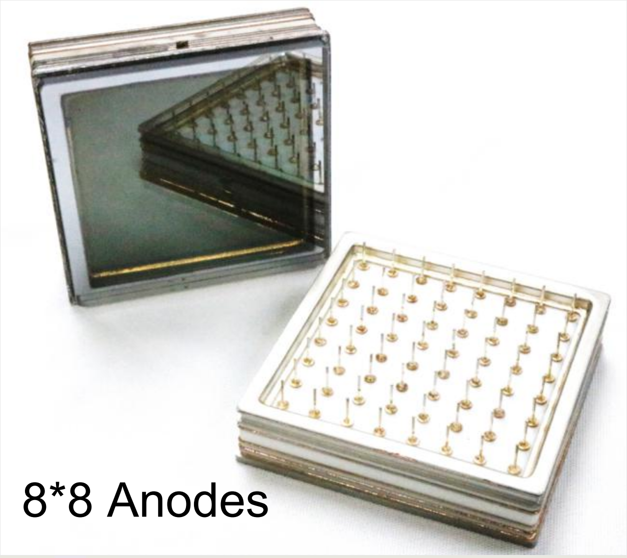
3.1 The Roadmap for FPMT -- （3） Prototypes

FPMT developed in IHEP+NNVT

Single Anode

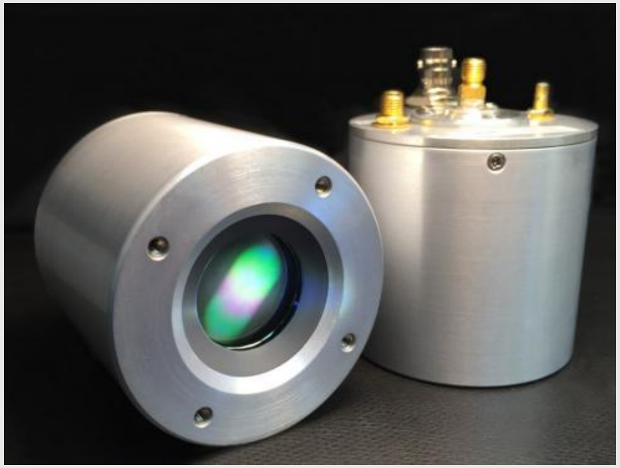
2*2 Anodes

4*4 Anodes

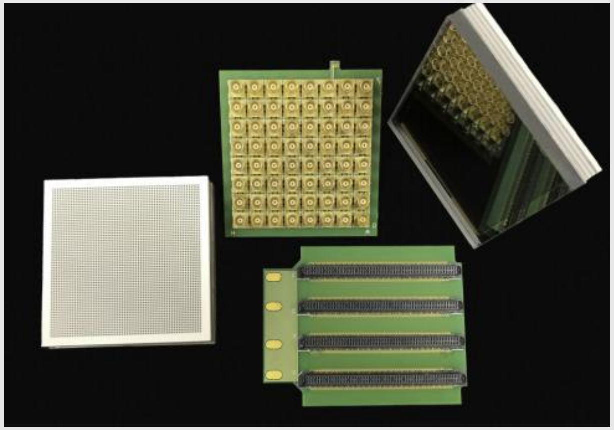


8*8 Anodes

FPMT developed in Photek



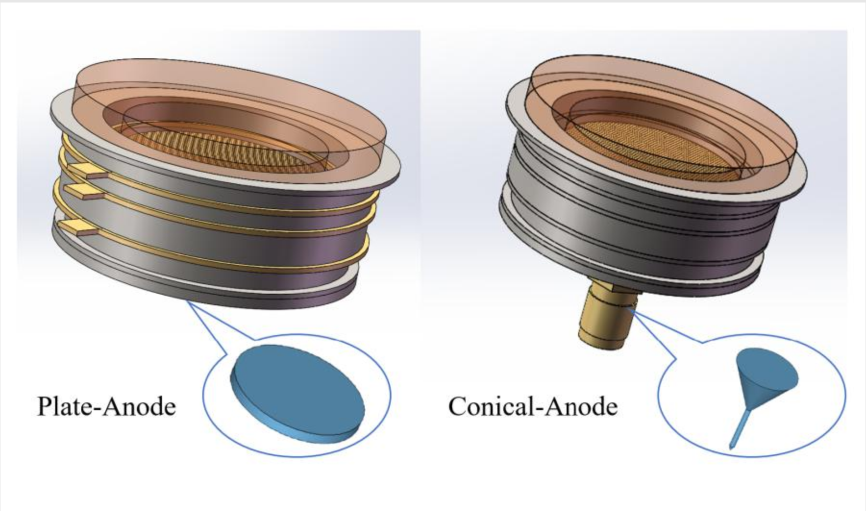
Photek Single anode

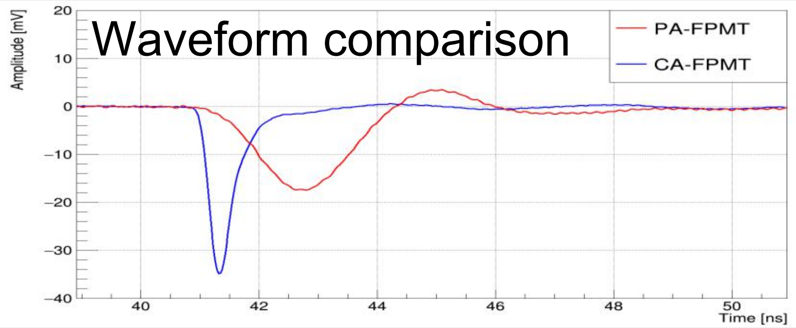


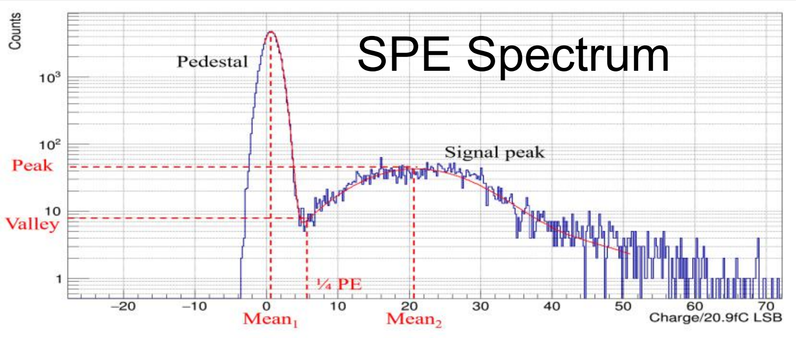
Photek Multi-Anode

3.2 The Performance -- （1）Single Anode FPMT

Anode Optimization





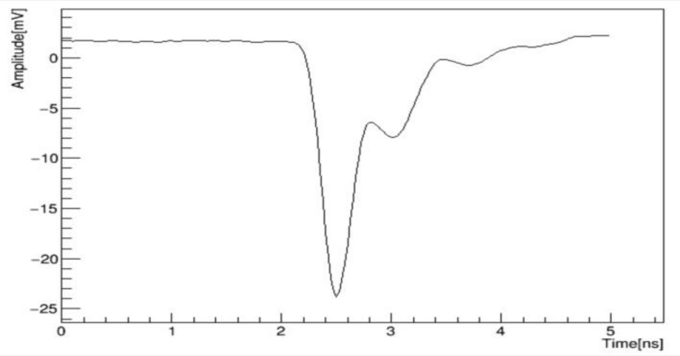


	HV/V	Gain	P/V	Amp(SPE)	RT	FT	Width	TTS@SPE	TTS@MPE
Photek 210	-4700	2.9E6	2.0	93.2mV	95.8ps	348ps	190ps	43.5ps	10.3ps
Plate-Anode	-2000	1.9E6	28.8	7.59mV	1.41ns	1.42ns	1.8ns	71ps	25ps
Conical-Anode	-3181	2.6E6	6.3	53mV	153ps	419ps	328ps	27.2ps	4.2ps

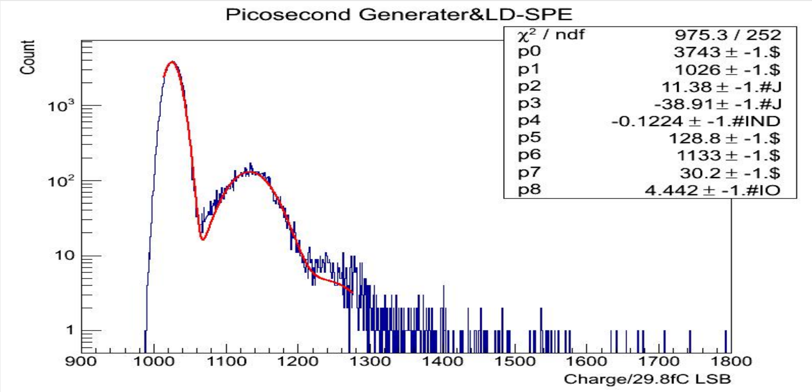
Ref: Lishuang MA et al., R & D of a novel single anode fast timing MCP-PMT，2022，Pre-proof， NIMA.

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

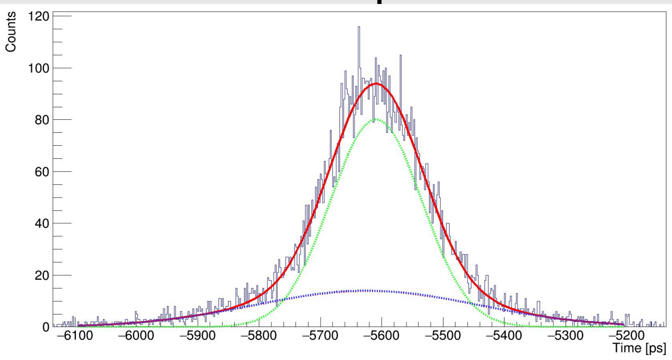
Average waveform for SPE



SPE Spectrum



SPE-TTS Spectrum

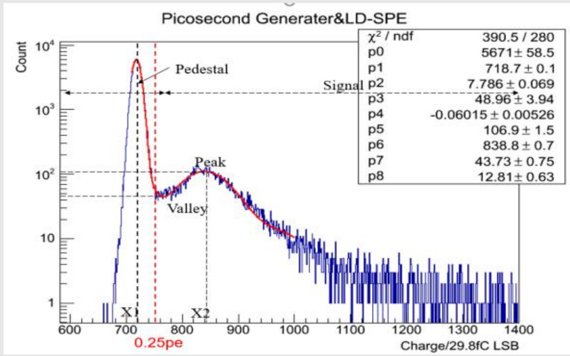


	HV/V	Gain	P/V	Amp(SPE)	RT	FT	Width	TTS@SPE	TTS@MPE
Photek 210	-4700	2.9E6	2.0	93.2mV	95.8ps	348ps	190ps	43.5ps	10.3ps
2X2-Anode	-2500	1.9E6	6.5	33.9mV	243	516	378ps	**66.8ps**	16.6ps

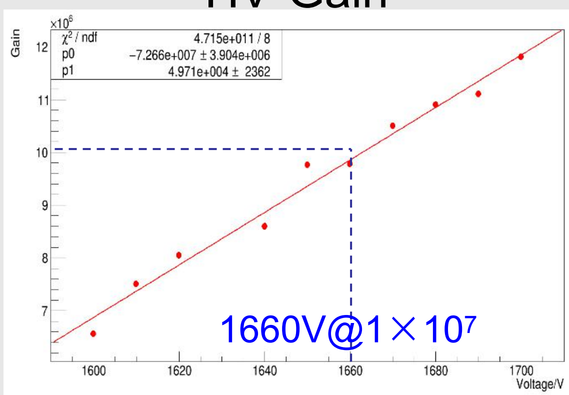
Ref： Sen Qian， Oral report, The R&D of the Ultra Fast 8X8 Readout MCP-PMTs, ICHEP 2020

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

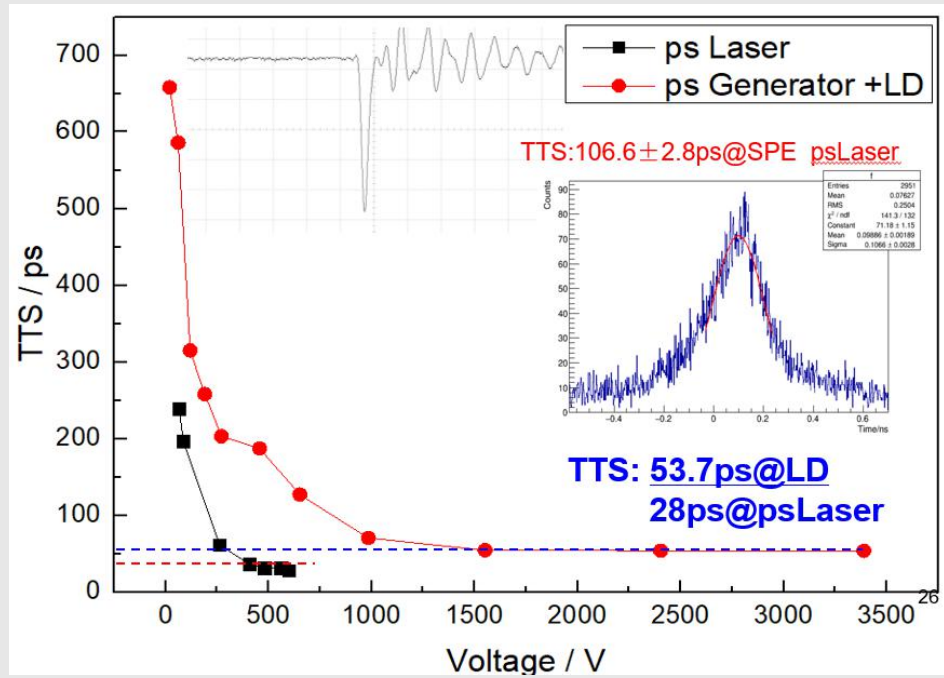
SPE Spectrum



HV-Gain

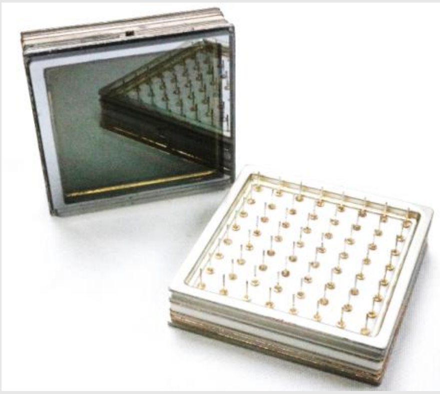


SPE-TTS Spectrum

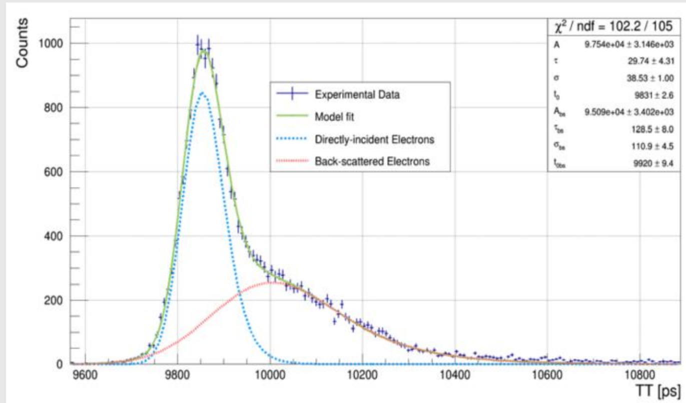


	HV/V	Gain	P/V	Amp(SPE)	RT	FT	Width	TTS@SPE	TTS@MPE
Photek-253	-2600	1.2E7	11.2	113mV	490ps	1.16ns	-	44.3 ps	16 ps
4X4 -Anode	-1660	9.6E6	2.0	21.1mV	430ps	--	--	107ps	28 ps

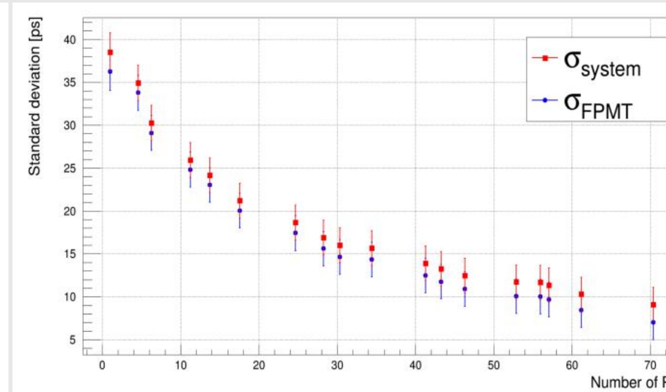
3.2 The Performance -- （4） 8X8 Anode FPMT



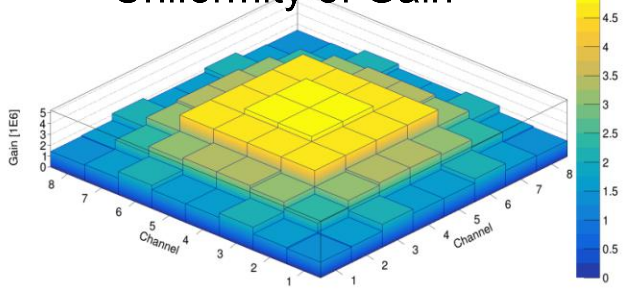
TTS Spectrum



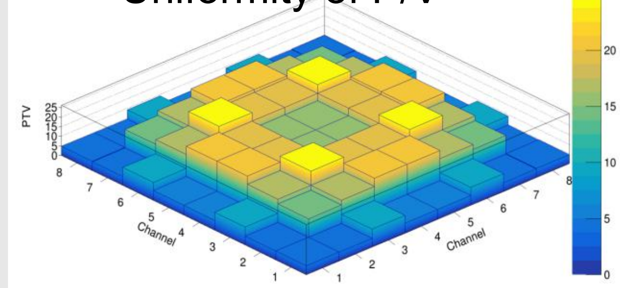
TTS Variation with the light intensity



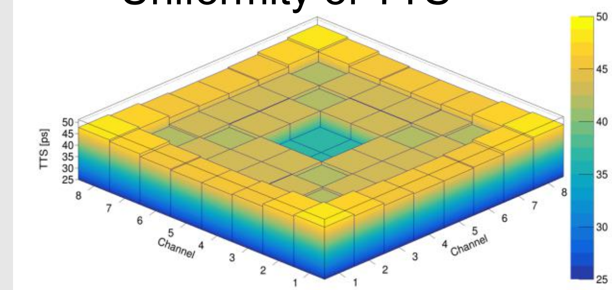
Uniformity of Gain



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.

3.3 The CTR of FPMTs

Radioactive sources： ^{22}Na，

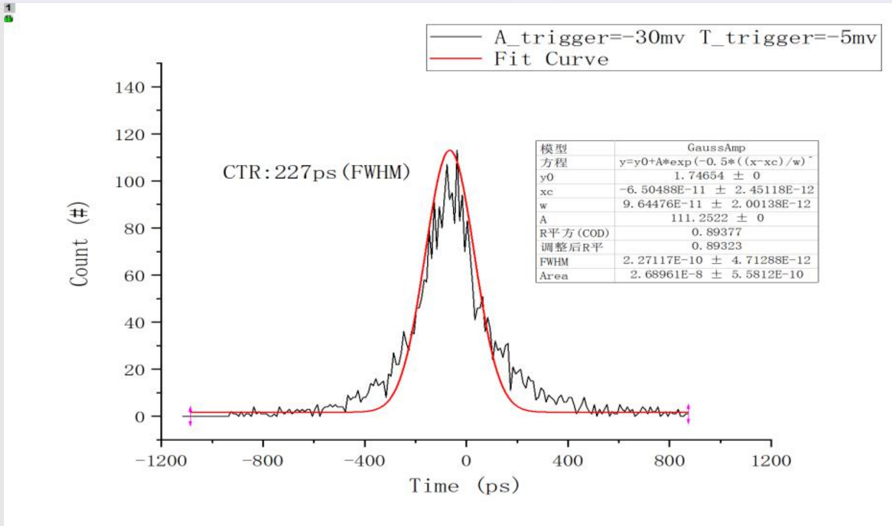
Crystal： PbF_2

DAQ： Oscilloscope

FPMT： NNVT-8*8 Anodes FPMT*2

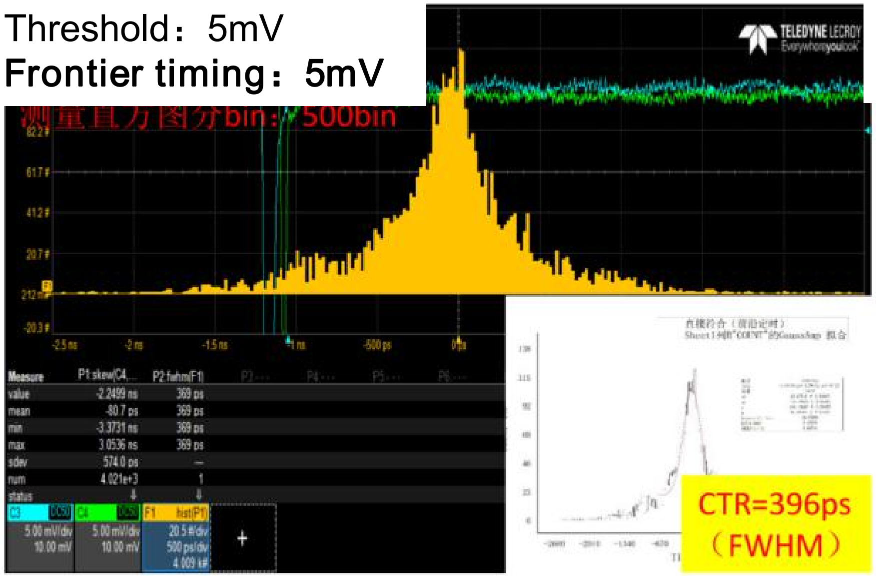
The best CTR：

CTR：227ps（FWHM）96.6ps （Sigma）



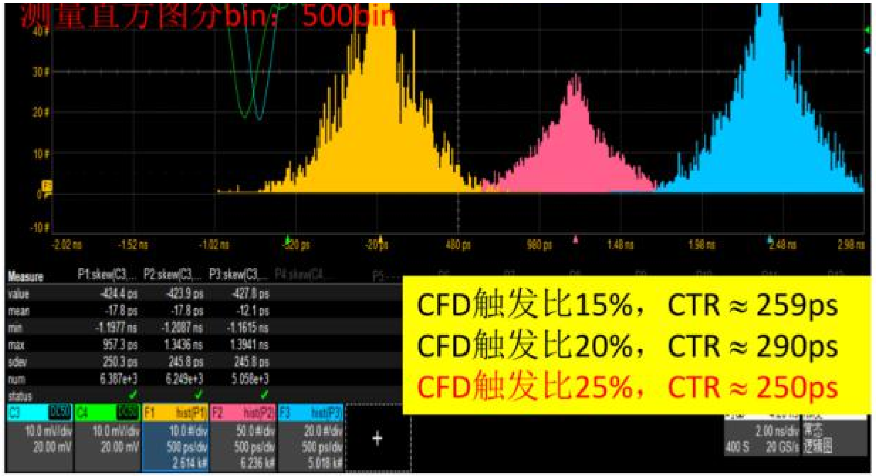
Threshold：5mV

Frontier timing：5mV

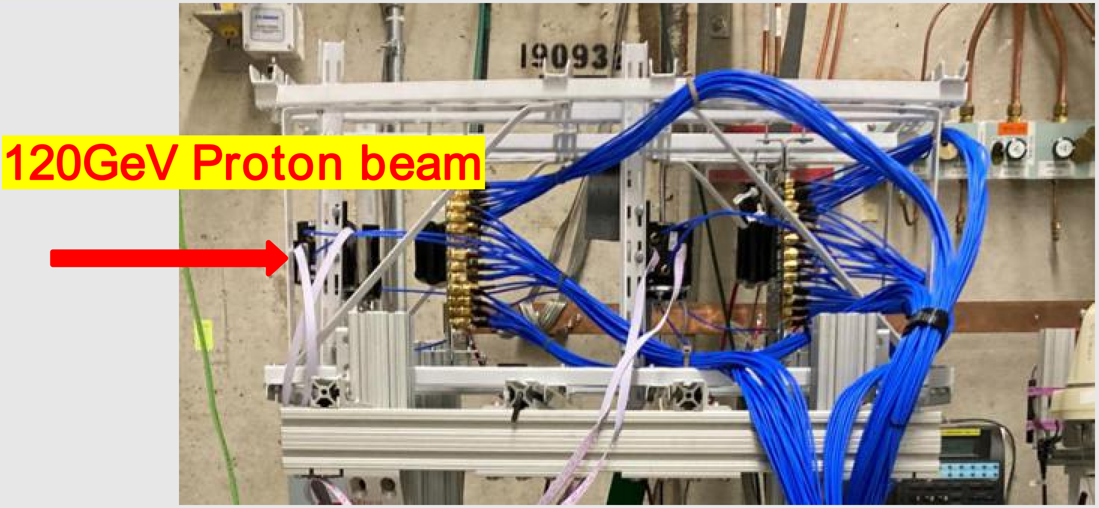


Threshold：5mV

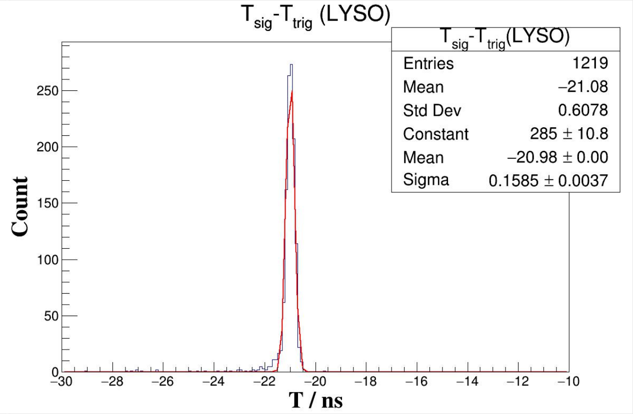
CFD：15%（yellow）、20%（Red）25%（Blue）



3.4 The Proton Beam Test

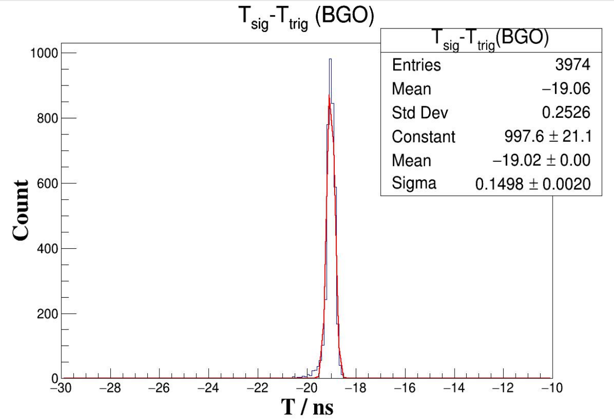


- Beam：120GeV Proton
- Crystal：LYSO & BGO
- PMT：NNVT 8*8 FPMT
- DAQ：CAEN V1742~50ps



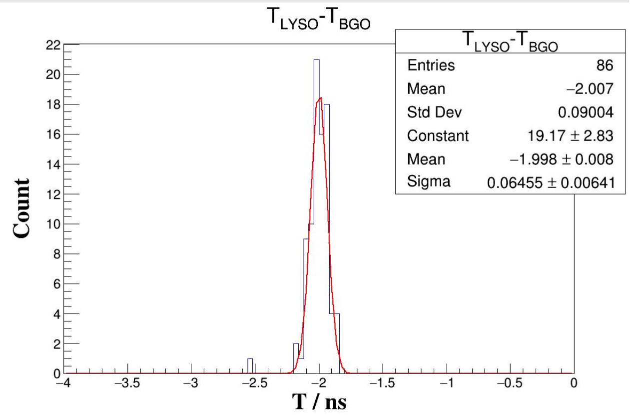
LYSO single channel Time Resolution

Sigma：158.5 ps



BGO single channel Time Resolution

Sigma：149.8 ps



LYSO & BGO
coincidence time jitter~64 ps
Single tube Time jitter ~45ps

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4. Summary-- （1） The PMTs

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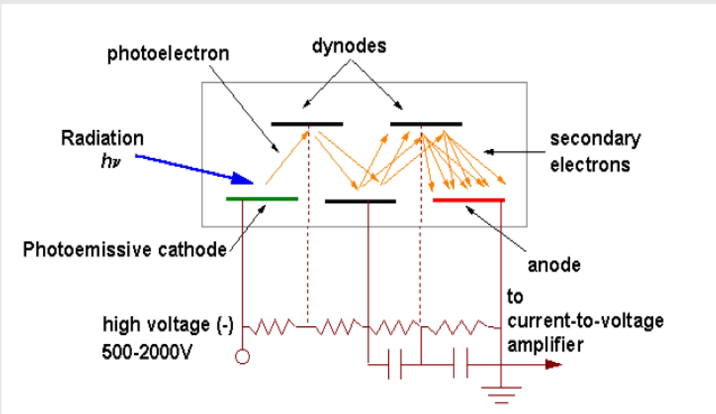
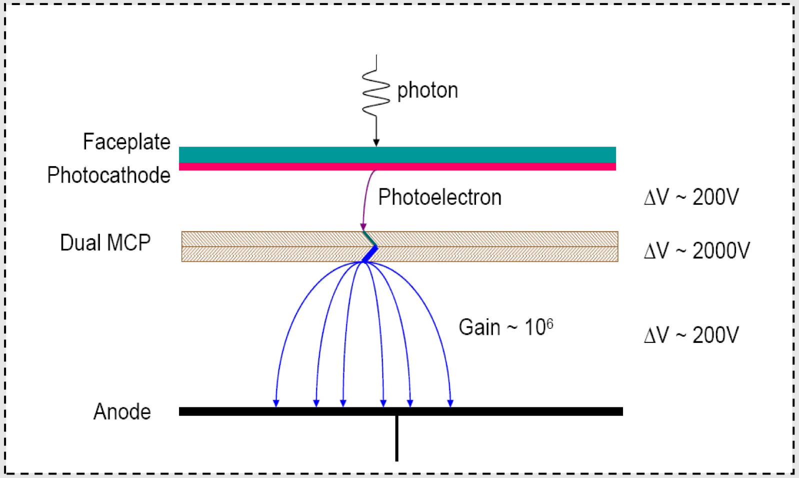
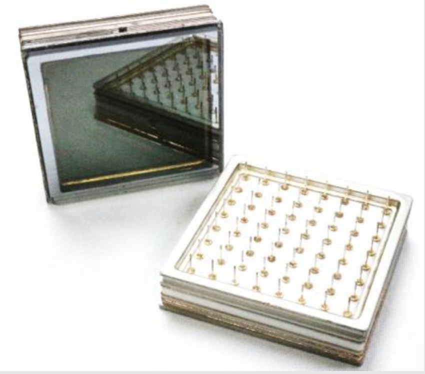
（proximity focusing）</th><th>Large Size
（electrostatic focusing）</th></tr>
<tr><td>Dynode</td><td>
</td><td>2“ Dynode-PMT ✓

</td><td>20“ Dynode-PMT ✓

</td></tr>
<tr><td>MCP</td><td>
</td><td>2“ MCP-PMT ✓
</td><td>20“ MCP-PMT ✓
</td></tr>
</table>

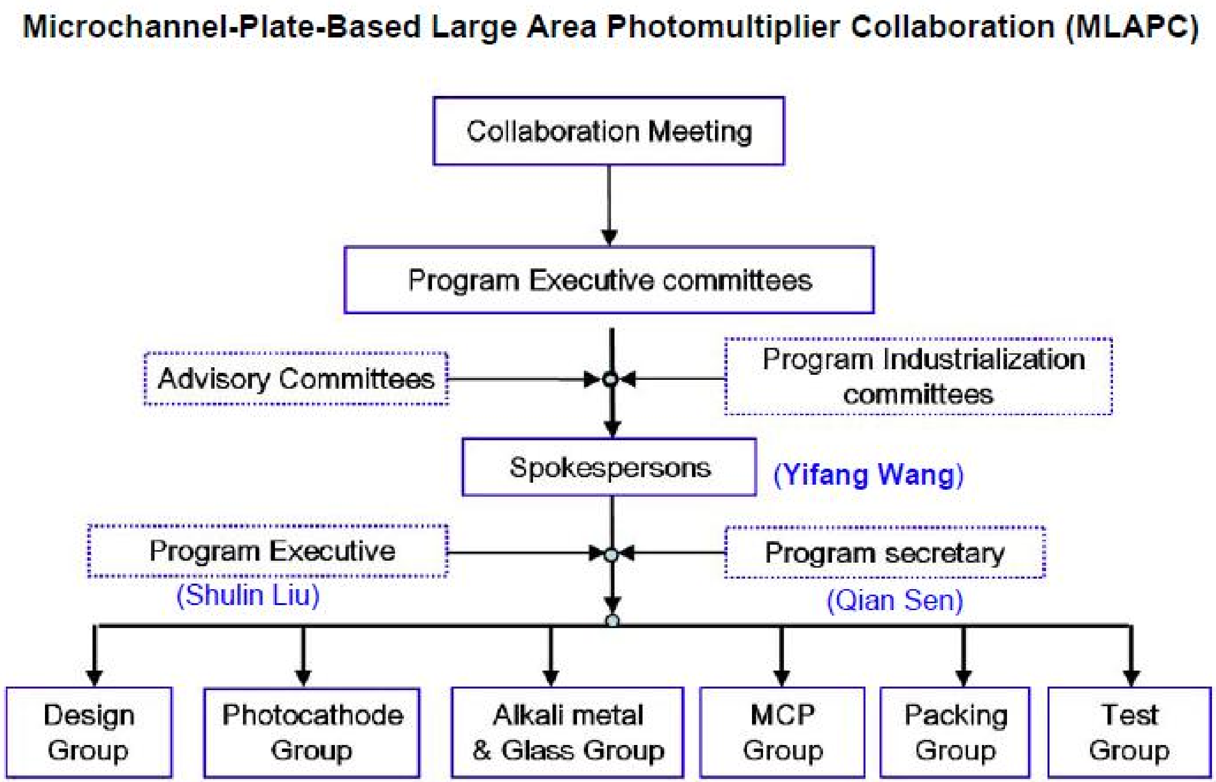
4. Summary-- （2）The Group

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**



北方夜视技术股份有限公司

NORTH NIGHT VISION TECHNOLOGY CO.,LTD

中国科学院西安光学精密机械研究所

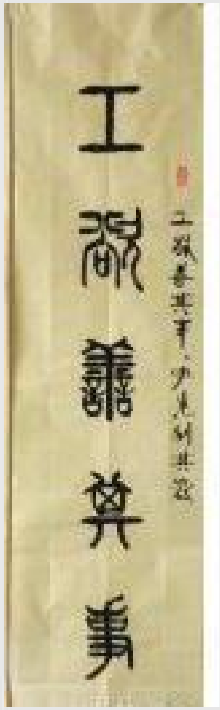
XIAN INSTITUTE OF OPTICS AND PRECISION MECHANICS OF CAS

中核（北京）核仪器厂

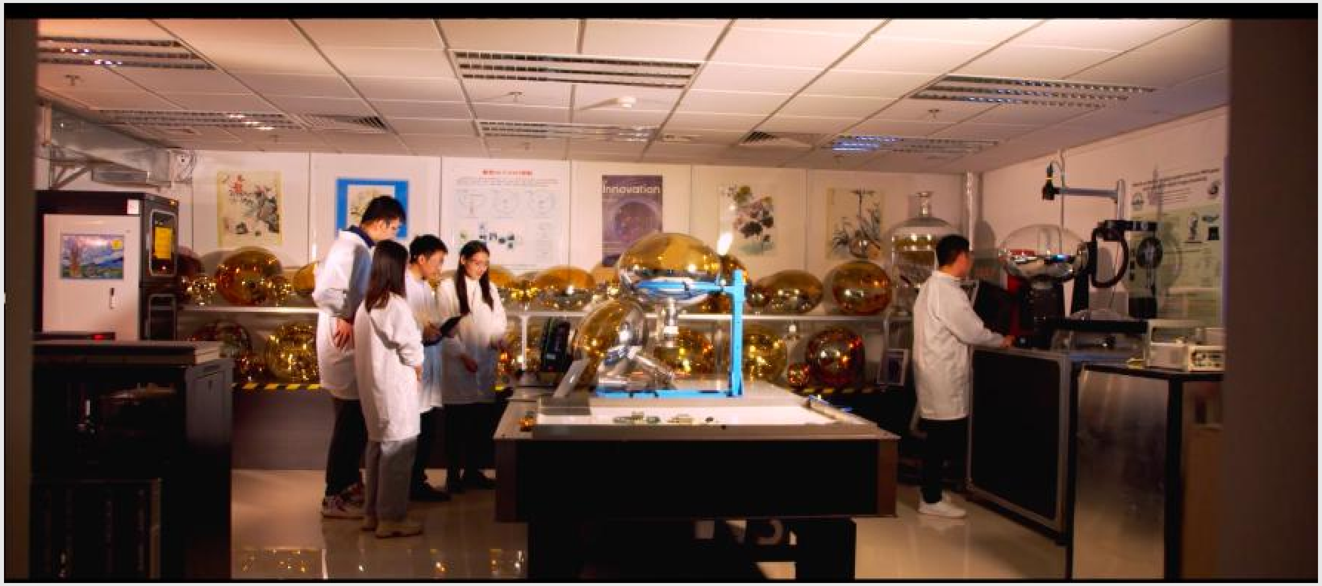
CNNC Beijing Nuclear Instrument Factory

南京大学

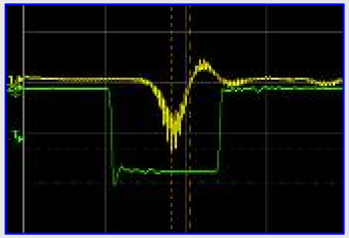
4. Summary-- （3）The PMT Lab in IHEP



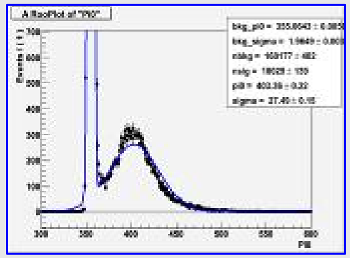
工欲善其事必先利其器 = Work must first of its profits



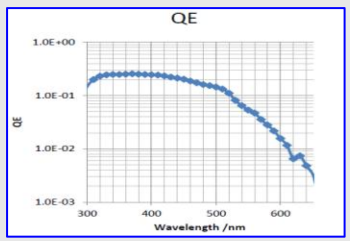
The Test Facility for PMTs



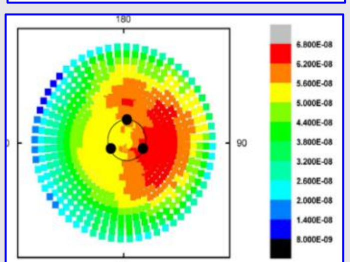
- Anode Pulse Rise Time;
- Pre/Late/After Pulse;
- Dark Count



- 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;

Others

……

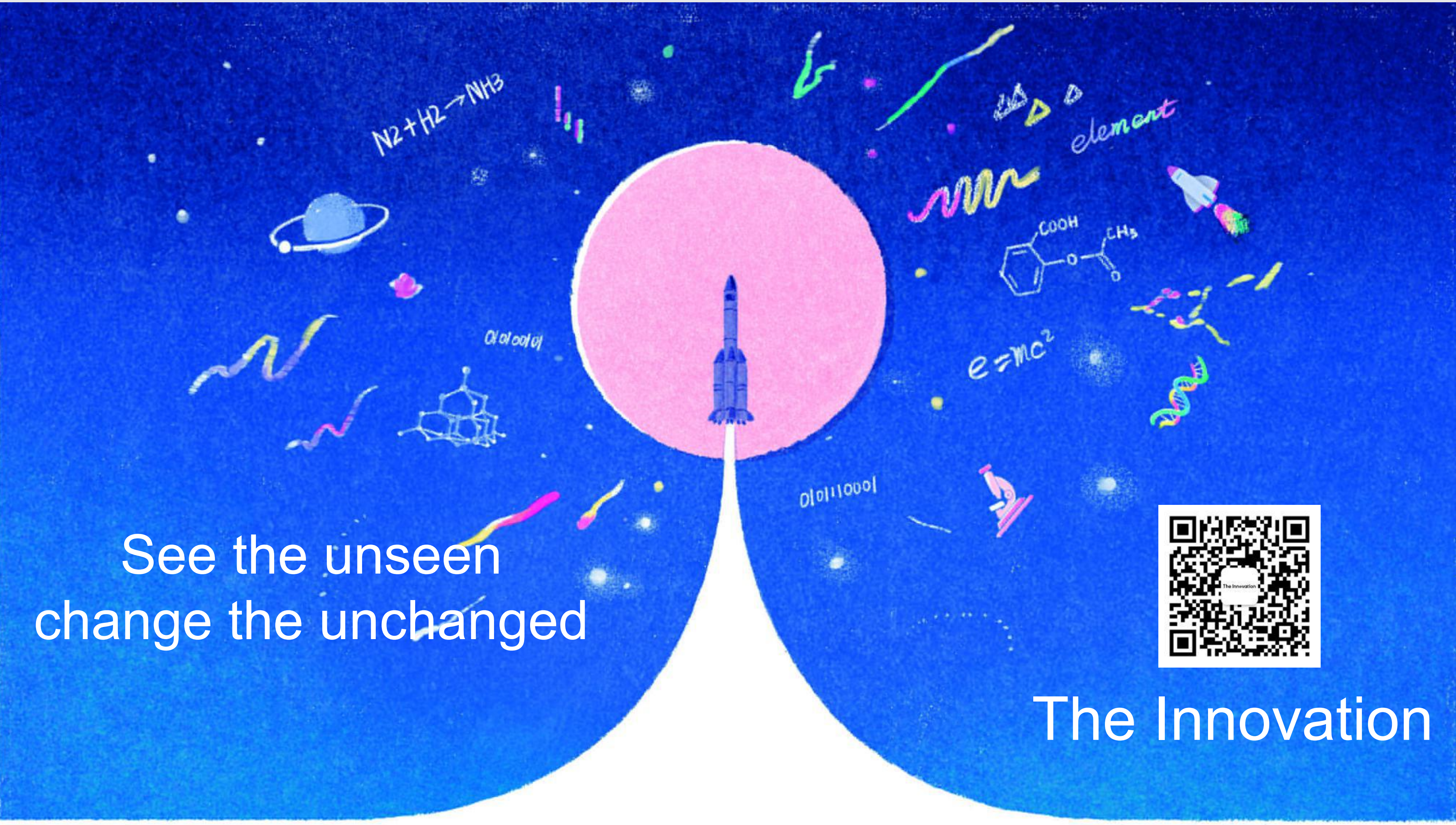
- The linearity of the PMT
- Magnetic characteristics;
- Transit Time Spread (FWHM)

谢谢！

Thanks for your attention!

Any Comment & Suggestion are welcomed!

THANKS



See the unseen
change the unchanged

The Innovation