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

The Chinese Academy of Sciences

The R&D of the Ultra Fast MCP-PMTs for High Energy Physics

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中国物理学会高能物理分会第十三届全国粒子物理学术会议（2021）

第十三届全国粒子物理学术会议（2021）

Outline

- **I. The Motivation of the FPMTs;**
- **II. The key technologies of the FPMTs;**
- **III. The Prototypes of the FPMTs;**

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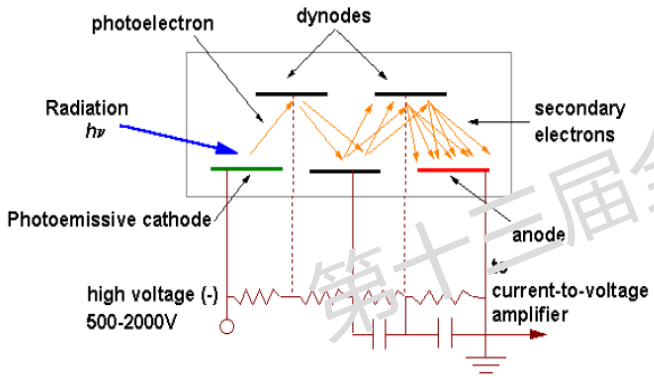
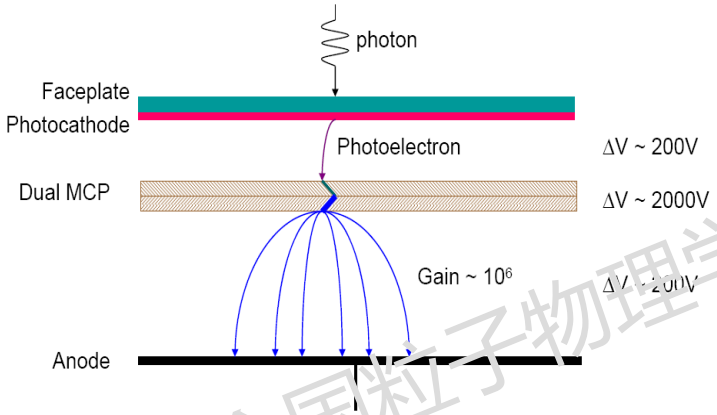
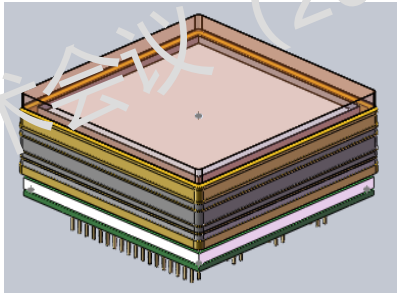
1.1 The design of the 2 inch Fast MCP-PMT

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

IHEP Design： After the successfully 20 inch MCP-PMT R&D， the PMT group in IHEP try to design and produce the 2 inch FPMT(Fast PMT),with high QE photocathode, and low cost!

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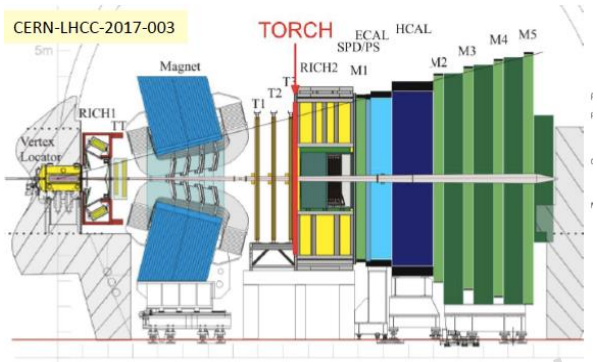
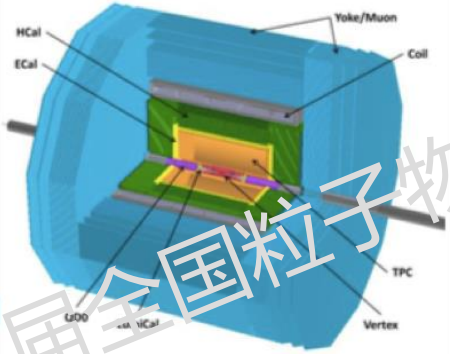
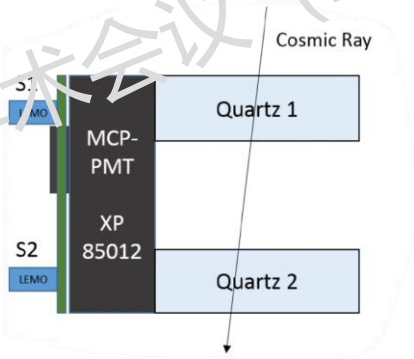
➢ 1.2 The potential applications of FPMTs



TORCH--LHCb upgrade

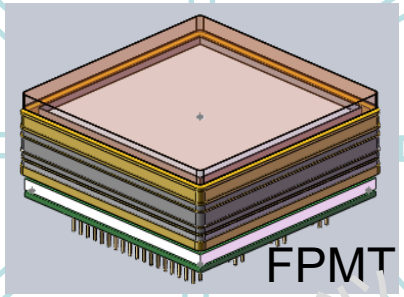


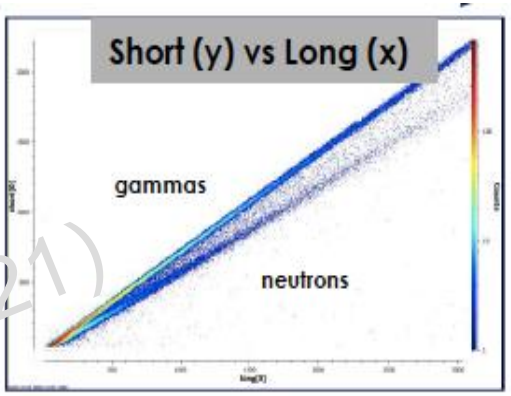
TOF--CEPC/STCF



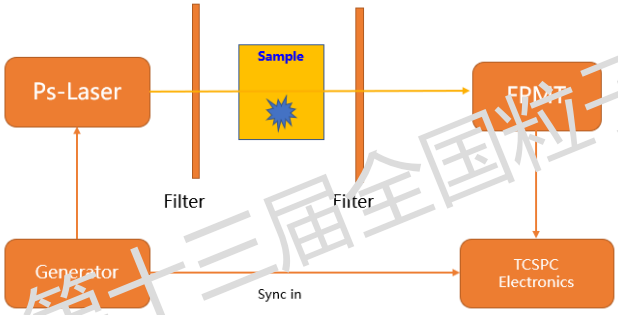
Cherenkov T0 detector

TOF-PET

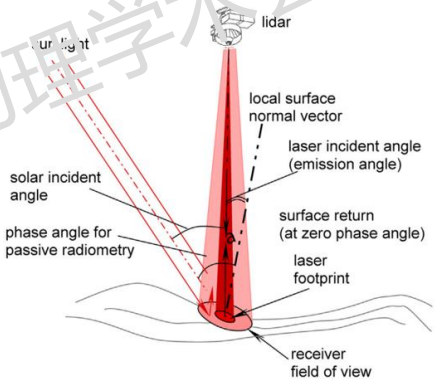




Neutrons/gamma Discrimination



Time-Correlated Single Photon Counting



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1.3 The Ability of the R&D for the MCP-PMTs

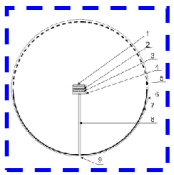
20” MCP-PMT (2015)

20” MCP-PMT (2017-2020)

8” MCP-PMT (2012-2013)

5” MCP-PMT (2011)

Design 2009



2” MCP-PMT (2010)

The Core technologies for PMTs

- The High QE photocathode;
- The High Gain low Noise MCPs;
- The low radioactive glass;
- The Vacuum transfer equipment;

PMTs	Large MCP-PMT	**Fast MCP-PMT**
QE @ 400nm	30%	**30%**
Area	20 inch	**2 inch**
Anode	1	**8X8**
RT@1pe	1.5ns	**100ps**
TTS@1pe	~5 ns	**~ 50ps**
Gain	1X10^7	**1X10^7**
DR	50K/PMT	**1Hz/mm²**
Cost	low	**low**

From 2010-2020，the 2”, 5”,8” and 20” MCP-PMT prototypes were successfully produced, and the performance were also improved for the production of High CE MCP modules and high QE photocathode.

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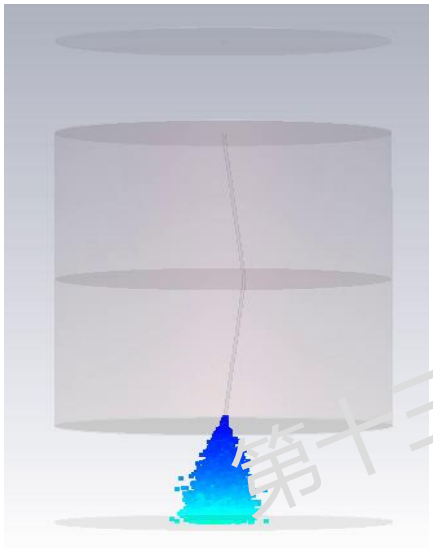
➢ 2.1 The FPMT simulation models

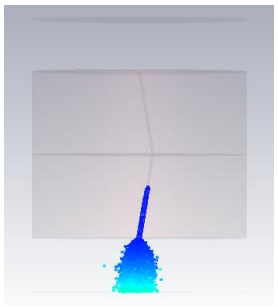
Cathode

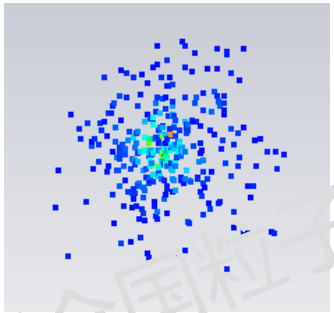
MCP

Anode

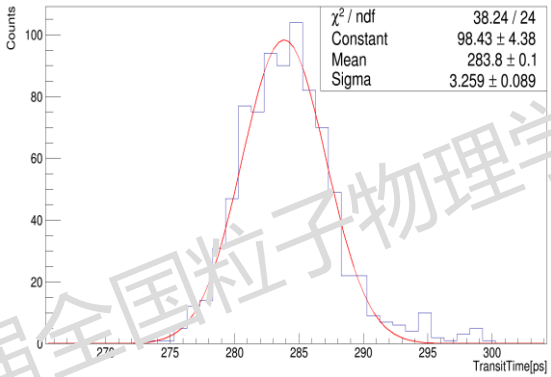


Structural parameters are consistent with the samples



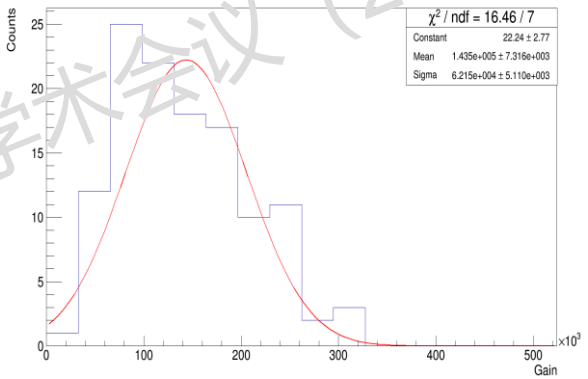


① Angle distribution of output electrons



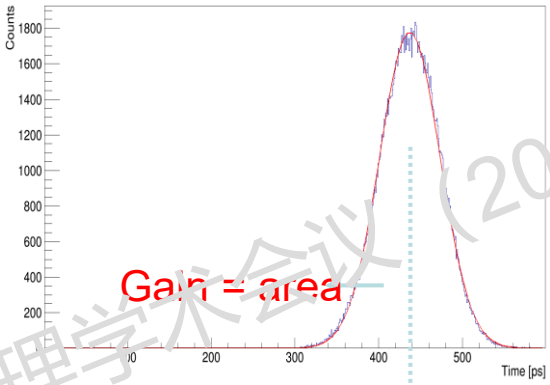
② Spread of TT

TTS = Sigma



③Spread of gain

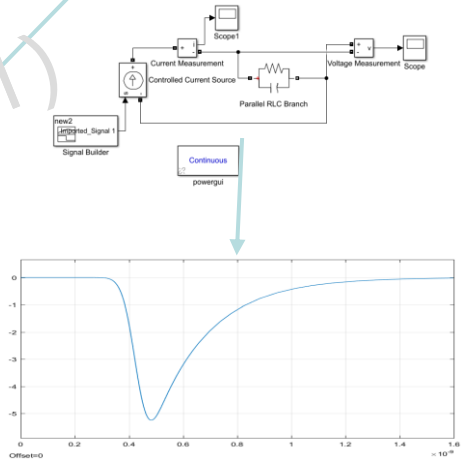
ER = Sigma/Mean



Gain = area

④ Single photoelectron spectrum （SPE）

Read-out analog circuit



⑤ RT from the output signal

Available parameters: **Gain**, **TT**, **TTS**, **ER**, **RT**, **Electrons angle distribution**

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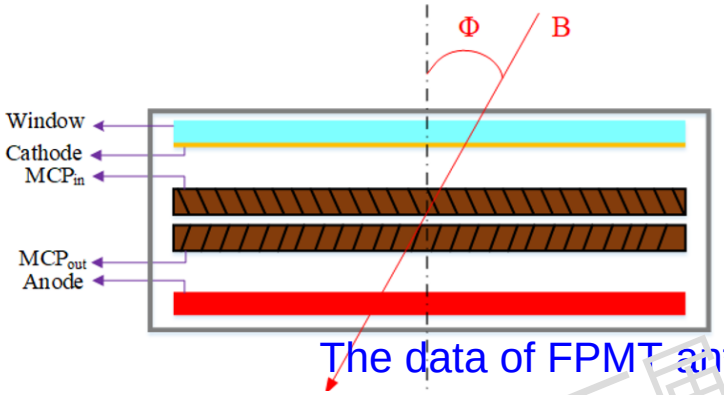
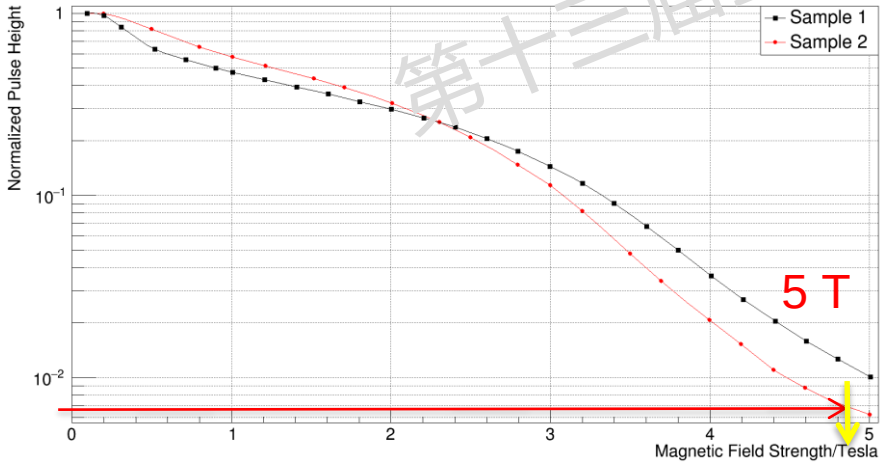
FPMT anti-magnetic performance simulation



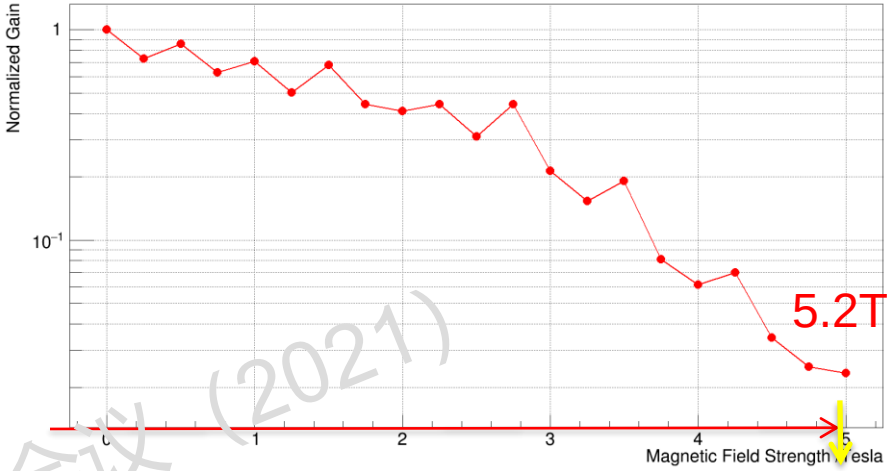
Φ is the angle between the magnetic field and FPMT

The magnetic field strength when the gain is reduced to 1/100 is used to evaluate the anti-magnetic performance.

The data of FPMT anti-magnetic performance experiment in IHEP



Test result of the FPMT Sample



Simulation result of the FPMT modle

----The simulation results are in good consistence with the test results with the same construction, ------ proving the reliability of the model.

----With this correct simulation model, we can do the correct design for the new construction of different types of FPMTs.

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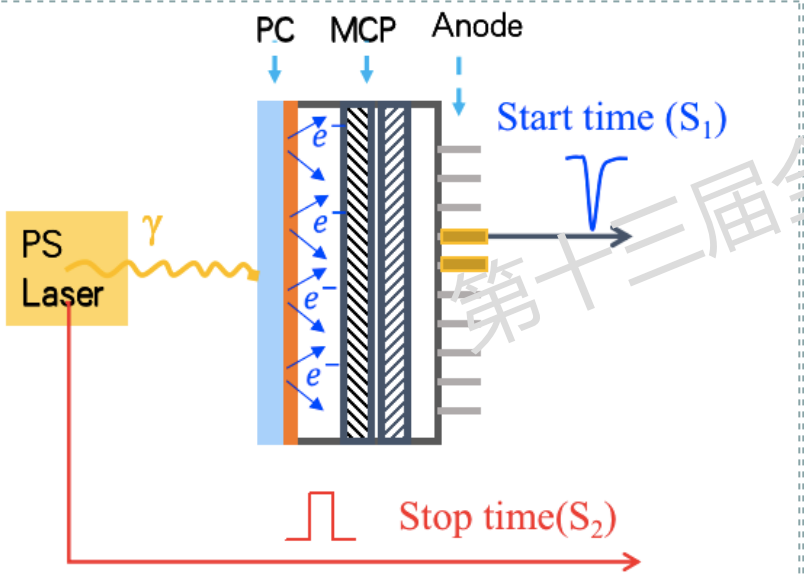
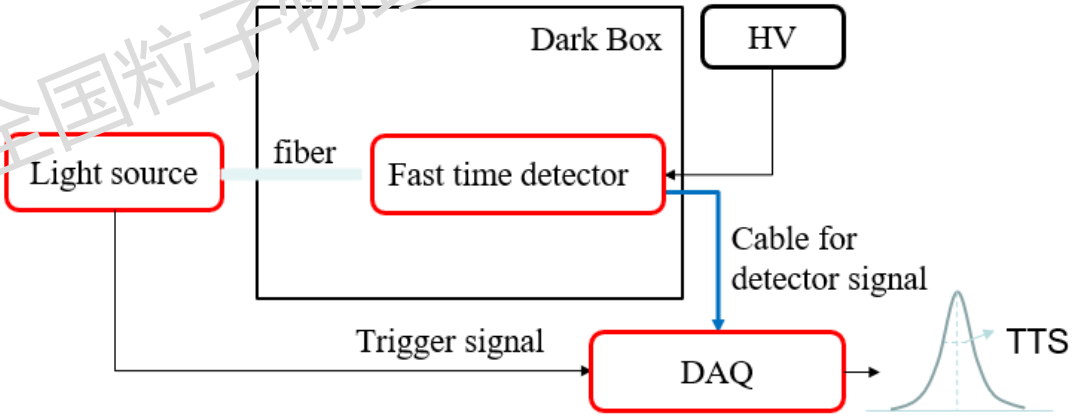
Ref: Yao Zhu et al., Sensors and Actuators A 318 (2021) 112487.

2.2 The Fast Timing test with Outside Synchronous trigger

Outside Synchronous trigger



Test principle diagram



$$TTS_{\text{test-pslaser}} = \sqrt{TTS_{\text{test-system}}^{\ 2} + TTS_{FPMT}^{\ 2}}$$

Test result — system-TTS — FPMT-TTS

$$TTS_{Test-System} = \sqrt{TTS_{\text{jitter-pslight}}^{\ 2} + TTS_{\text{jitter-}DAQ}^{\ 2}}$$

System-TTS — Pslight-jitter <3ps — DAQ-jitter <1ps

The PS laser to light the FPMT and its synchronous signal to be the Start Time;

The FPMT anode signal is the Stop Time;

The TTS is the sigma of the TT;

System time resolution = **~3.2ps**

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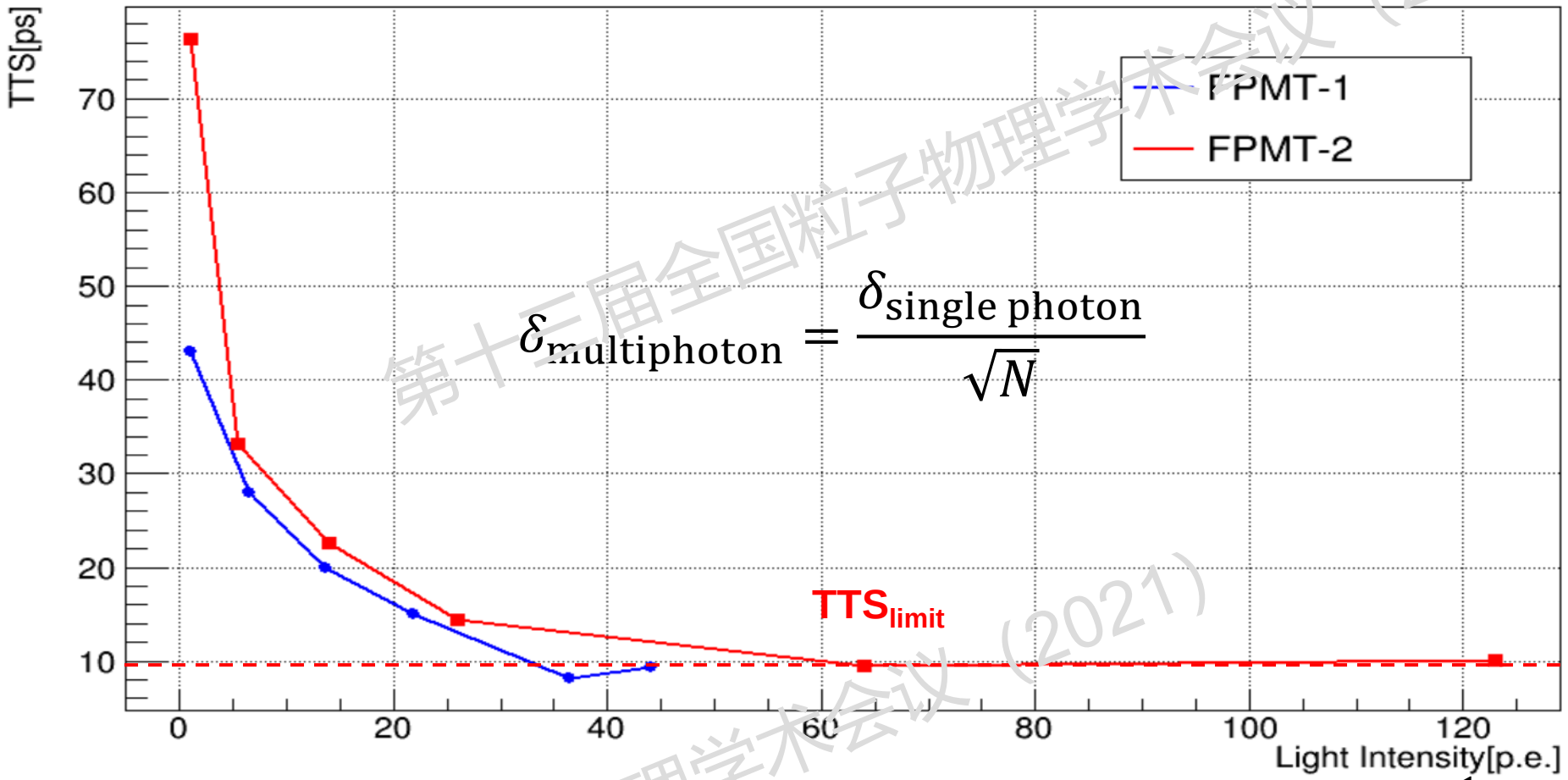
➢ 2.2.1 The Limit Time Resolution of the FPMTs



- The relationship between the number of photons and TTS is in line with $\frac{1}{\sqrt{N}}$

----With enough photons, the TTS of the FPMT will get stable value，the Limit Time Resolution, the best TTS of the FPMT.

----Some FPMT can not test the SPE spectrum and the TTS_{SPE}, but can get this **TTS_{limit}**.

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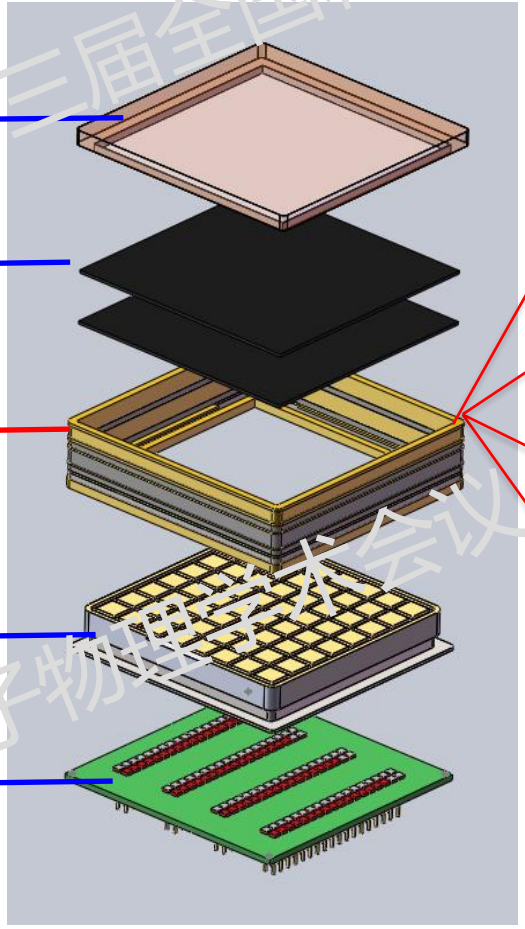
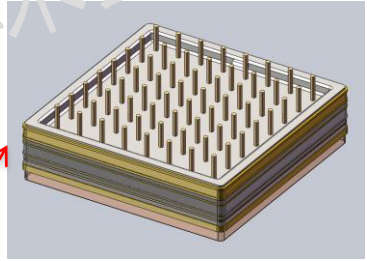
➢ 2.3 The Roadmap of the R&D of the FPMTs

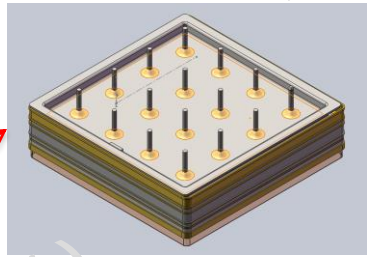
--Five Core technologies are needed to produce this new type of 2 inch Fast MCP-PMT;
--We have the experience of the PC, MCP production, but need do more research on the sealing, the anode, and the electronics.



8X8 Channels，2 inch



4X4 Channels，2 inch



2X2 Channels，1 inch

1 Channel，1 inch

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➢ 3.1 1 inch FPMT prototypes

	HV/V	gain	P/V	Amplitude (SPE)	RT	Width	TTS @SPE	TTS @400mV
Single Anode FPMT	-1500	**1.0E7**	13	10mV	1400ns	2.3ns	205ps	30ps
2*2 anodes FPMT	-2500	1.9E6	6.5	33.9mV	243ps	378ps	**66.8ps**	16.6ps

The development of FPMTs with single anode or 2*2 anode with in 1 inch size have been completed in the early stage, and good performance has been obtained and reported in international conferences.

Ref: Qian sen, reported in RICH 2018， ICHEP 2020.

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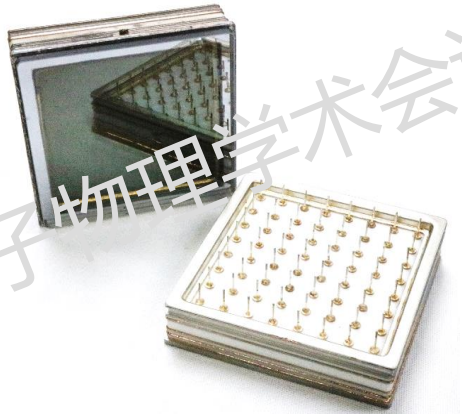
➢ 3.2 2 inch FPMT prototypes



	HV/V	gain	P/V	Amplitude (SPE)	RT	Width	TTS @SPE	TTS @MPE
4*4 anodes FPMT	-1650	9.6E6	1.83	21.13mV	431.2ps	1.2ns	106.6ps	28ps @1.2V
8*8 anodes FPMT	-1700	3.7E6	2.78	40.5mV	391ps	768ps	**49.9ps**	**11.3ps** @1.7V

The 8*8 sample tube achieves a single-photon time resolution of less than **50ps** and a multi-photon time resolution close to 10ps.

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Summary

- FPMT sample tubes from single anode to 8*8 anodes have been successfully developed.
- The TTS@SPE of 8*8 anode FPMT has achieved **49.9ps**, TTS@MPE is near 10ps.
- The single anode FPMT with new structure is being developed, and the base is being optimized to obtain more excellent time performance.

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谢　谢！

Thanks for your attention!

Any Comment & Suggestion are welcomed!

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