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Coincidence time resolution of ultrafast photomultiplier tube coupled with LYSO crystal

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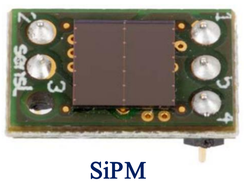
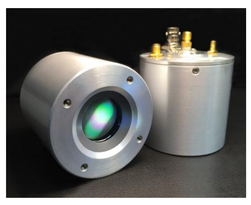
Introduction

This manuscript aims to use two ultra-fast photomultiplier tubes (FPMT) coupled with $Lu_{1.8}Y_2SiO_5$:Ce (LYSO) crystals to perform a coincidence time resolution (CTR) test applied to Time of Flight- Positron Emission Tomography (TOF-PET). The FPMT used in this work refers to a Micro Channel Plate-PMT(MCP-PMT) with rise time of 100ps, TTS of 46ps in a single photon mode. The scintillation light waveform of the LYSO crystal appears "separated" when it is detected by the FPMT. At the same time, it is found that the setting of the timing threshold has a greater impact on the results of the time resolution. The waveform processing algorithm is optimized by interpolation, and the acquired waveform is processed by the method of aspect ratio timing. The whole test is carried out under the radiation background of 22Na, the sigma of CTR measured by LYSO crystal coupled with FPMT is 40ps.

1.The Fast timing Photodetector



SiPM



MCP-PMT

Photodetector	SiPM	MCP-PMT
Product	SenSL J30035	Photek MAPMT210
QE@400nm	PDE: 47%	~16.5%
CE		>90%
Operating voltage	26.7V	-4800V
Gain	10^6	10^6
Sensitive area	3*3mm²~6*6mm²	Φ10mm~Φ40mm
Dark counts	~50KHz/mm²	<3Hz/mm²
Rise time @SPE	1ns -> 90ps	~100ps
TTS@SPE(σ)	1ns ->~60ps	~40ps

--**SiPM** has good single-photon time resolution, it has a small sensitive area and high noise. Thousands of SiPMs must be used for large-area detection, which is a big challenge for electronics, and the suppression of noise is also a big issue that needs to be considered.

--**MCP-PMT**, it has faster time resolution, low noise, and multi-anode MCP-PMT can achieve multi-channel readout. For large-area detection applications, MCP-PMT is a more suitable detector.

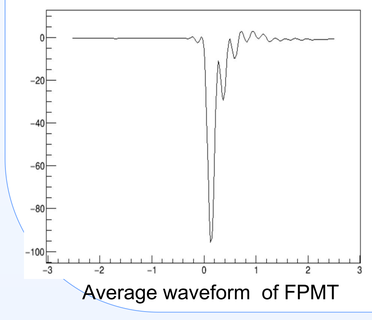
2. Fast time resolution MCP-PMT performance test

--The MCP-PMT with short rise time and small transit time spread (TTS) is called fast timing PMT (FPMT).

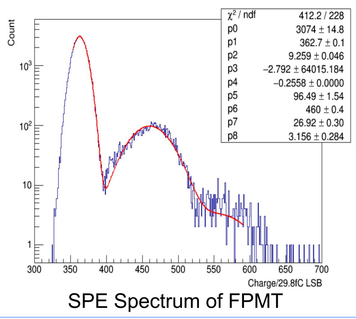
--Two FPMTs were used in this CTR experiment. Their waveforms and SPE spectrums were shown below.

--The the rise time of the FPMT is at the level of 100ps, and the TTS of the FPMT can reach to 29ps.

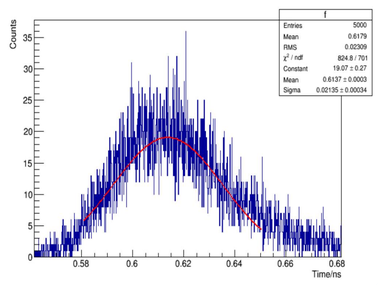
	HV/V	QE @Peak	Gain	P/V	Amplitude @SPE	Rise Time	Fall Time	Width	TTS @SPE	TTS @MPE
FPMT-1	-4800	19.2% @290nm	1.8E6	10.9	23.3mV	111ps	176ps	195ps	29ps	~20ps
FPMT-2	-4800	18.1% @350nm	2E6	4	38.6mV	104ps	278ps	178ps	46ps	21.4ps



Average waveform of FPMT



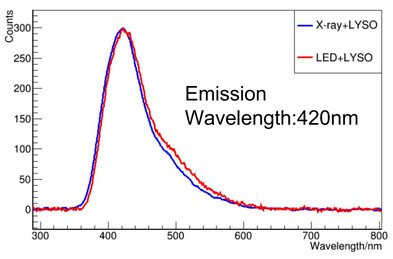
SPE Spectrum of FPMT



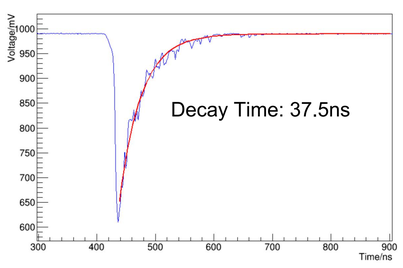
TTS@MPE of FPMT

3. Choice of Scintillator Crystal

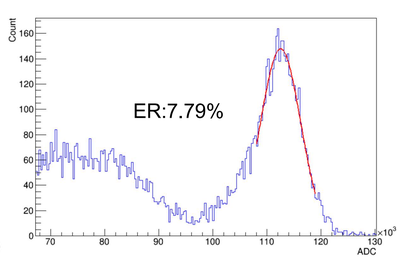
	Luminosity (ph/MeV)	Decay Time (ns)	Z_{eff}	Density (g/cc)	Atten. Length (mm)	Energy Resol.	Wavelength (nm)	Hygroscopic
BGO	8200	~300	74	7.1	11	12%	480	NO
BaF2	800/8000	0.6/660	54	4.9	25	12%	220/325	NO
LYSO	30000	~40	66	7.4	12	7.79%	420	NO



Emission spectrum of LYSO



Decay Time of LYSO



Energy Resolution of LYSO

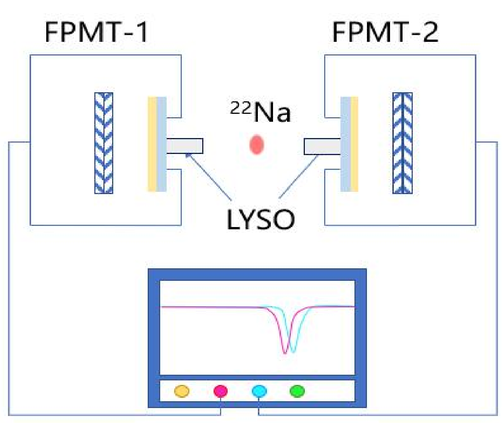
--The performance data of several scintillator crystal were shown in the table.

--The luminosity and the decay time are key data for time resolution of the CTR experiment.

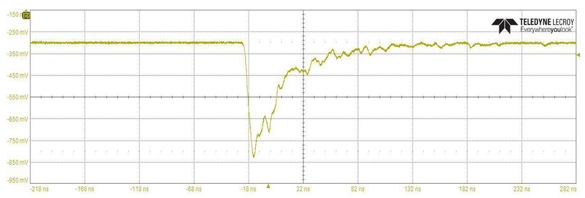
-- Compared with various parameters, LYSO crystal is the most suitable crystal for CTR experiment.

--Considering the size of the light window of the FPMT and the flicker of LYSO itself, a 3*3*5mm³ LYSO crystal is selected for the CTR test.

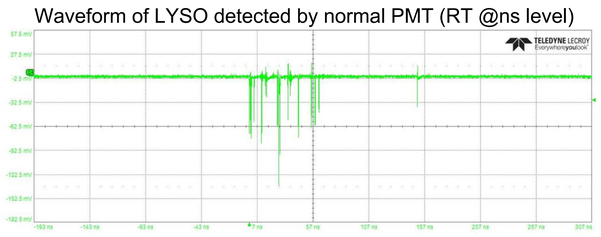
4. Setup and Result



Setup of CTR experiment



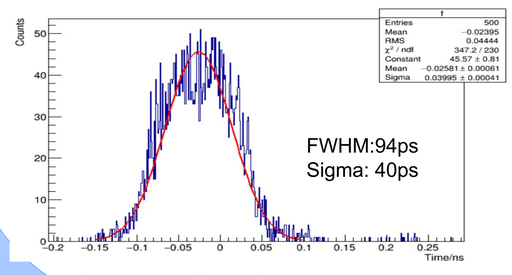
Waveform of LYSO detected by normal PMT (RT @ns level)



Waveform of LYSO detected by FPMT (RT @100ps level)

--The test device is shown on the left, and a high-sampling oscilloscope (bandwidth 4GHz, sampling rate 40Gs/s) is used for waveform acquisition.

--When the FPMT was used for the waveform measurement, the waveform appears to be separated as is shown in the right figure. The leading edge timing method is used in the CTR test. The timing threshold is set to -10mV.



Coincidence Time distribution

The Coincidence Time distribution can be obtained like the left figure, the CTR can be character by the sigma which is 40ps. Follow-up work will continue to optimize this result.

Acknowledgement

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