Study on the Optimized Energy Resolution of Scintillator Detectors Based on SiPMs and LYSO:Ce

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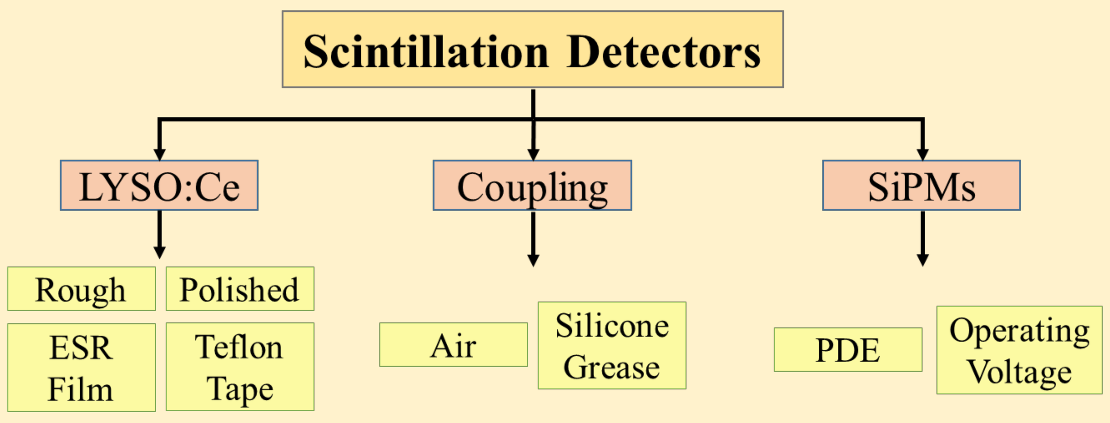
1.Introduction

- Main advantages of the cerium-doped lutetium yttrium silicate (LYSO:Ce) crystal: high density, high light output, fast decay time and non-hygroscopic
- Silicon Photomultipliers (SiPMs): high gain, immunity to magnetic fields, compact structure and single photon detection capability
- Scintillator detectors combining SiPMs and LYSO show great potential to improve the performance

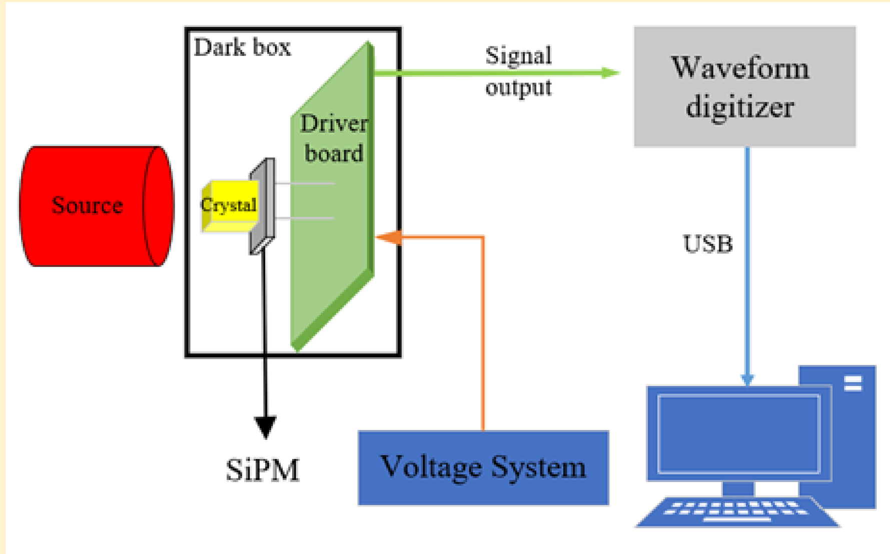
2.Material and Methods

- 3 types of SiPMs from Hamamatsu
- 2 pieces of LYSO:Ce crystals (3x3x3 mm^3) with different surface finish, wrapped by different reflectors
- 2 kinds of coupling methods

Parameters	S13360-6050CS	S13360-6025CS	S12572-010C
sensitive area	6 x 6 mm^2	6 x 6 mm^2	3 x 3 mm^2
V_{bd}	53±5 V	53±5 V	63±5 V
pixel pitch	50 µm	25 µm	10 µm
PDE@420nm	40%	20%	12%
total pixels	14400	57600	90000



- Source with 662 keV gamma-rays from ^{137}Cs
- Waveform sampling with CAEN DT5751



Test setup for energy resolution measurement

3.Optimization for Energy Resolution (ER) Measurement

Operating Voltage
- 10 um SiPM: 69.23 V
- 25 um SiPM: 57.19 V
- 50 um SiPM: 54.46 V

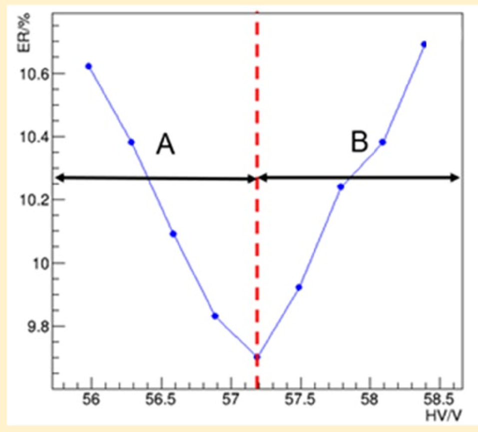
SiPM Types (PDE)
- Polished-ESR-SG
- ER (10 um): 14.04%
- ER (25 um): 9.7%
- ER (50 um): 5.41%

Surface Finish

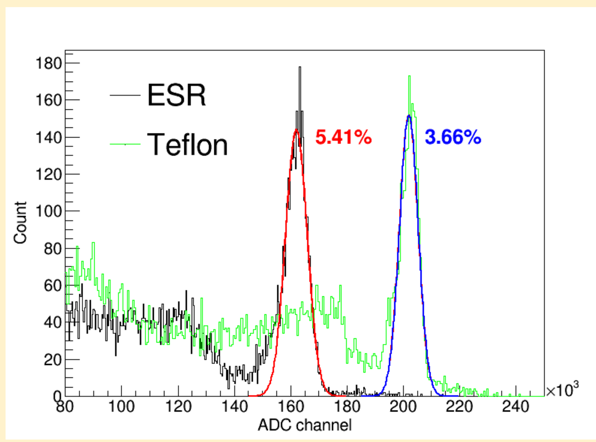
*SG: Silicone Grease
- 50 um-ESR-SG
- ER (polished): 5.41%
- ER (rough): 5.06%

Coupling Methods
- 50 um-Polished-ESR
- ER (Air): 5.97%
- ER (SG): 5.41%

Reflectors
- 50 um-Polished-SG
- ER (ESR): 5.41%
- ER (Teflon): 3.66%



operating voltage optimization for SiPMs

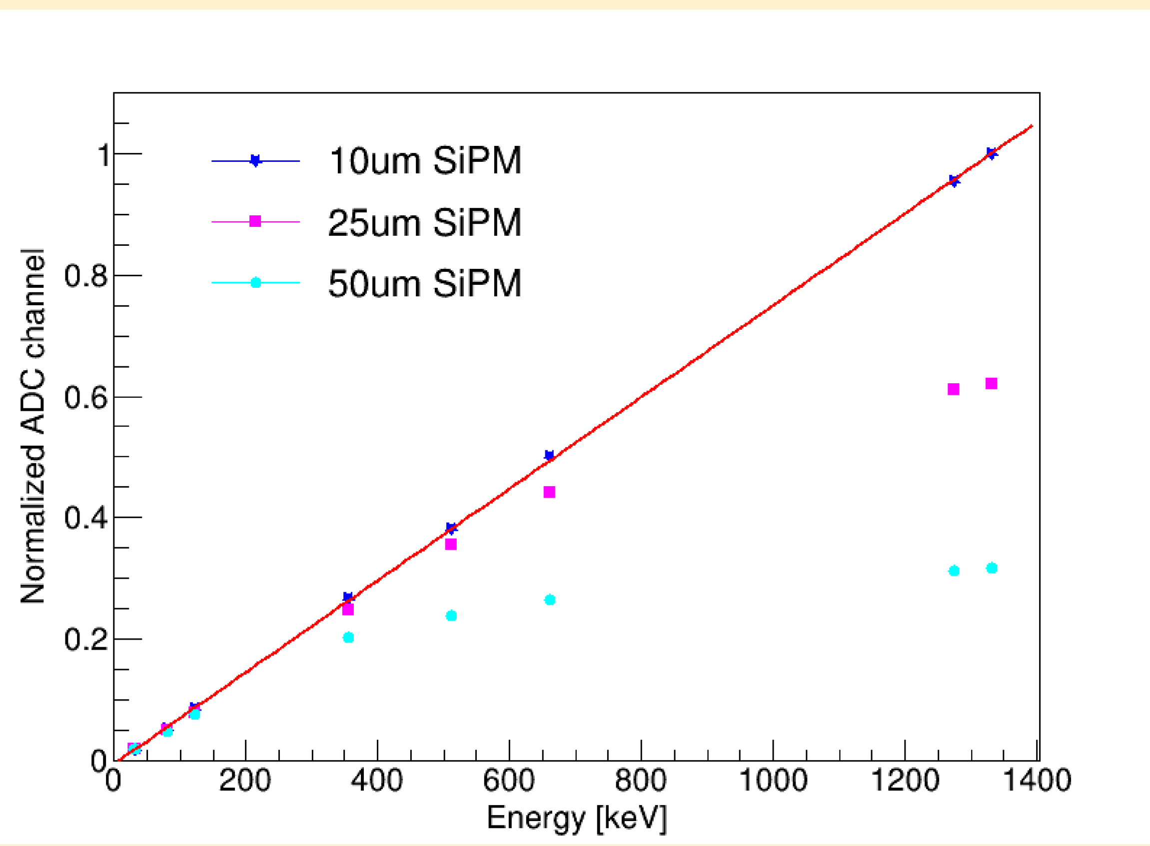


energy resolution in the case of different wrappers

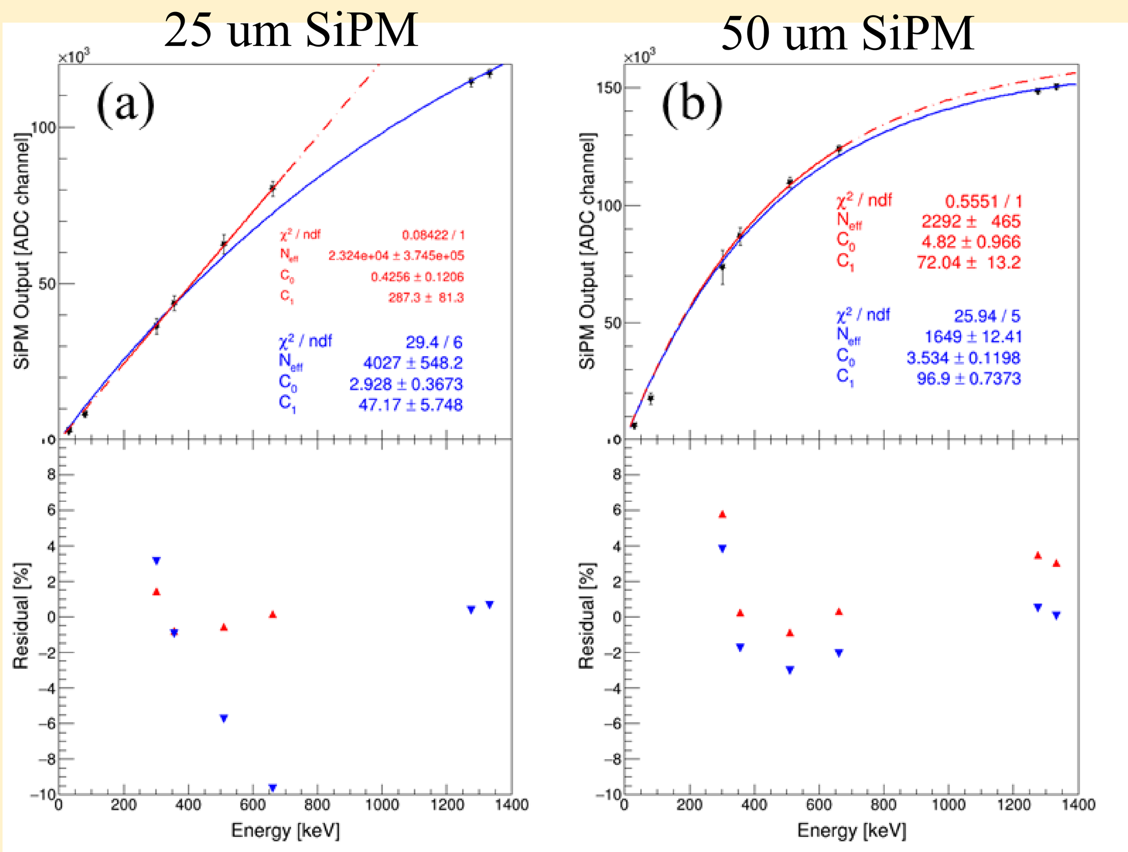
- The PDE and excess noise (i.e. cross talk and after pulse) will reach a balance at the optimized operating voltage, thus a optimized energy resolution can be obtained
- Higher PDE, rough surface finish, silicone grease coupling and Teflon wrapper will contribute to a optimal energy resolution

4.Energy Resolution with Saturation Correction

- Considering that the response of SiPMs will deviate from linearity in the case of high light intensity, a preliminary saturation correction method is applied to obtain the actual energy resolution



- 31 keV, 81 keV and 356 keV γ from ^{133}Ba, 511 keV and 1274 keV γ from ^{22}Na, 32 keV and 662 keV γ from ^{137}Cs, and 1332 keV γ from ^{60}Co were used to characterize the linearity.



- Fitting Function:

$$ADC = C_1 \cdot N_{\rm eff} \cdot \left(1 - e^{-C_0 \cdot E / N_{\rm eff}}\right)$$

- blue line: the global fitting (i.e. all data points are used for fitting)
- red line: the local fitting (i.e. only data points between 200 keV and 700 keV are used for fitting)

Fitting Methods	Parameters	25 um SiPM	50 um SiPM
Global Fitting	Mean/keV	755.6	694.2
	ER/%	9.3	8.4
Local Fitting	Mean/keV	660.9	658.2
	ER/%	6.9	7.6

- Deposited energy obtained from:

$$E = \ln\left(\frac{C_1 \cdot N_{\rm eff}}{C_1 \cdot N_{\rm eff} - ADC}\right) \cdot N_{\rm eff} / C_0$$

- In the case of local fitting, the ER obtained by the SiPM of 25 um microcells is better than that of 50 um microcells

5.Conclusion

- The measurement conditions for the optimized energy resolution have been studied, including the wrapper, the coupling method, the type of SiPMs and the operating voltage of SiPMs
- A preliminary saturation correction method was developed and the energy resolution of 662 keV gamma-rays measured by the SiPM of 50 µm microcells can reach 7.6% after the correction

Reference

[1] S. Yin, H. Guo, M. Yan, et al., "Study on performance test plan of inorganic scintillator", Opto-Electron Eng, vol. 48, no. 6, Jun. 2021.
[2] M. Moszyński, A. Syntfeld-Kazuch, L. Swiderski, et al., "Energy resolution of scintillation detectors", Nucl. Instrum. Methods A, vol. 805, pp. 25-35, Jan. 2016.