Read-out of YAP and LuYAP crystal matrix using wave-length shifter

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Abstract

In the purpose of building an inexpensive positron emission tomography device with a good spatial resolution, a read-out system of 1 mm x 1 mm x 20 mm scintillator crystals forming a 16 × 16 matrix has been developed. X and Y position, separately, of a hit are detected respectively with eight wave-length shifter fibers, used as light-guides, connected each to a channel of multi-anode H6568 photomultiplier. The spatial resolution has been measured with a method using 137Cs source and a collimator.

1. Introduction

The Positron-Emission Tomography (PET) device based on the current technique is expensive, and this factor, although the device is known to be useful, prohibits the device from becoming popular. We believe that if the read-out method using wave-length shifter is successfully applied to the detection of 511 keV gamma's, PET should be produced with a much lower cost. We've been trying a read-out method using wave-length shifter so that many more scintillator crystals are read-out with fewer photomultipliers[1]. This allows to use smaller crystals and thus, increases the spatial resolution of detection. We aim at improving it to about 1 mm.

Last year, by using YAP crystals and Kuraray B-2 (800) wave-length shifter, we obtained a spatial resolution of the order of 1 mm (FWHM) for 622 keV gammas from ^{137}Cs

Concentrated effort has been made for one year to clarify the following two points about the read-out of scintillating crystals;

1. How to transport maximum amount of light emitted in the scintillator crystal to the photomultiplier (PM) . We tried to understand systematically how the photons are lost at each stage in

order to improve the light transmission.

2. How to improve the spatial resolution of the detector. We tried to reproduce in a coincidence measurement the good spatial resolution observed in a measurement with one detector with a collimator.

In addition to the YAP crystal, we made test with LuYAP crystal, and compared the results. The experimental results are presented in the present report. First of all, the components used in the experimental work are explained here.

1.1. Scintillator crystal

The scintillator crystals used for the detection of 511 keV gamma-ray are YAP(Ce) and LuYAP(Ce). The physical characteristics of these crystals are shown in Table 1 together with those of LSO(Ce) which is also going to be tested in the near future.

crystal	YAP(Ce)	LuAP(Ce)	LSO(Ce)
composition	Y Al O3	Lu Al O3	Lu2 Si O5
refractive index	1.94	1.95	1.82
density g/cm3	5.37	8.34	7.35
effective Z	36	65	66.4
decay time ns	25	18	40
Yield photons/MeV	14500	9600	27000

Table 1 Physical properties of the tested scintillator crystals

1.2. Wave-length shifter

The light emitted in the crystal is transported to the PM by means of a light guide. The wave-length shifter (wls) B-2(800) produced by Kuraray company has been used for that purpose. One wls fiber is used to read-out many crystals aligned so as to reduce the cost of construction. Fig. 1 shows how the x- and y- coordinates of the crystals are read-out by the light guides. The wls used has a section of 1 mm by 1 mm and covered with a single layer clad. The refractive index of the core is 1.59, and that of the clad is 1.49.

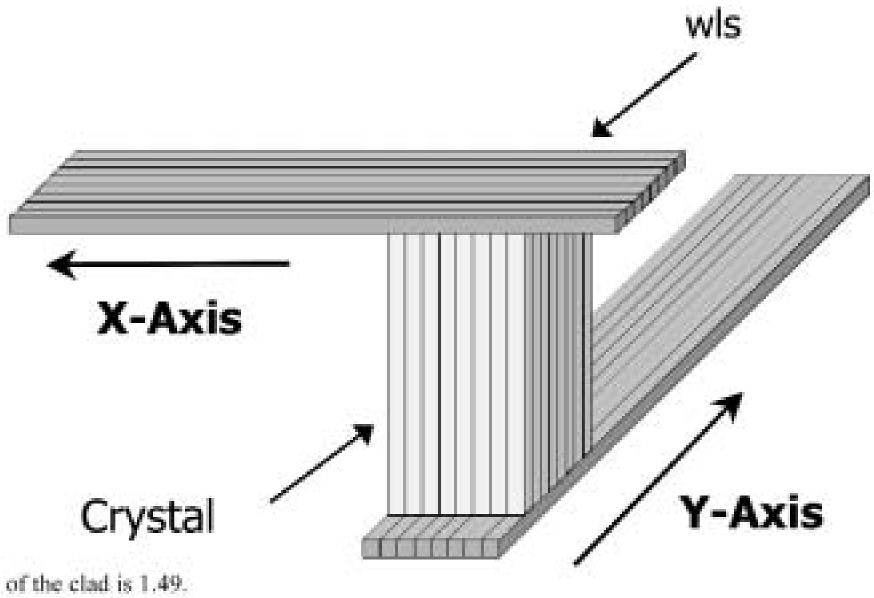

Fig. 1 Read-out method of the crystals

1.3. Photomultiplier

The ends of the wls are mounted vertically on the photocathode of 16-channel photomultiplier H6568MOD produced by Hamamatsu Photonics company by means of a small plastic piece in which 16 holes are drilled. Thus 16 wls fibers are connected to one PM.

2. Amount of collected light

2.1. Summary of the past experiments

Table 2 shows what amount of light is lost at each stage of the light transport from the scintillator crystal to the photomultiplier in the past experiment. This is a result of a simulation in which one million gamma-ray is sent to the crystal. The amount of light produced in the crystal has been calculated using egs program[2]. Then the reflections of the light in the crystal as well as in the wls are simulated using a program written in C++. The size of the crystal is assumed to be 1 x 1 x 20 mm^3. The effect of the self-absorption inside the crystal is assumed to be 0.5/cm[3]. The self-absorption inside LuYAP is not known. We assumed the same attenuation of the light in both crystals.

To improve the amount of collected light, we performed experiments described hereafter.

2.2. Removal of the air gap between the crystal and wls

It is known that when the light goes from one material with a lower refractive index to another material with a higher refractive index, insertion of a thin layer with an intermediate refractive index between two materials increases the light transfer. In the current case, the light goes from the scintillation crystal whose refractive index is about 2 to wls whose refractive index is about 1.5 or 1.6, and one cannot use the same technique. However, it is possible that a thin layer of air makes the light transfer difficult, and a removal of this air layer might improve the transfer situation.

A layer of elastic silicon rubber with a refractive index of 1.41, transparent to the near ultraviolet light was inserted as a trial between the crystal

and the wls. The results are shown hereafter. For the comparison, the last dynode signal from the PM

(inverted), which is the sum of the output of all 16 channels, has been used.

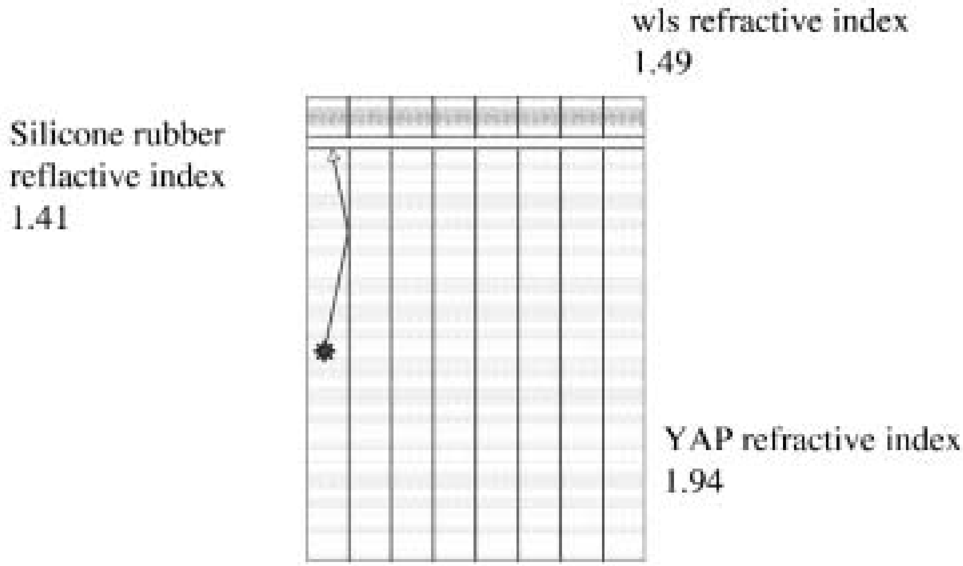

Fig. 2

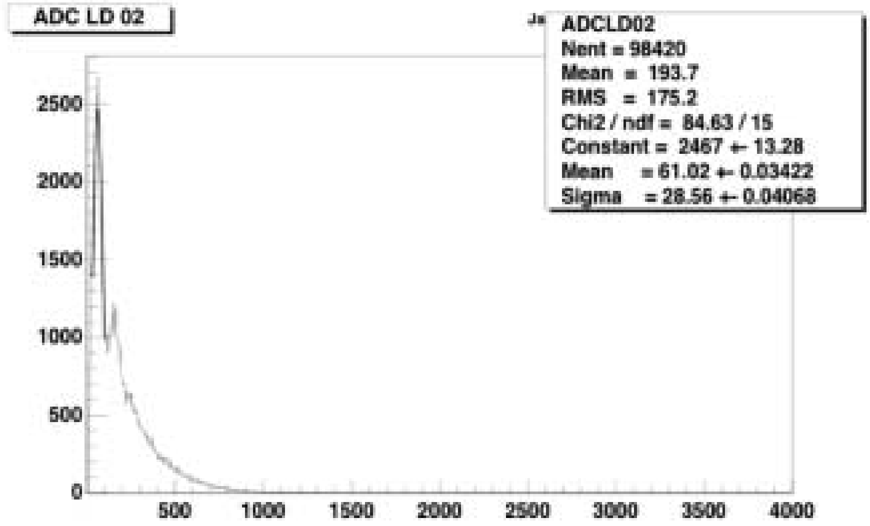

Fig. 3 Nothing inserted, just air

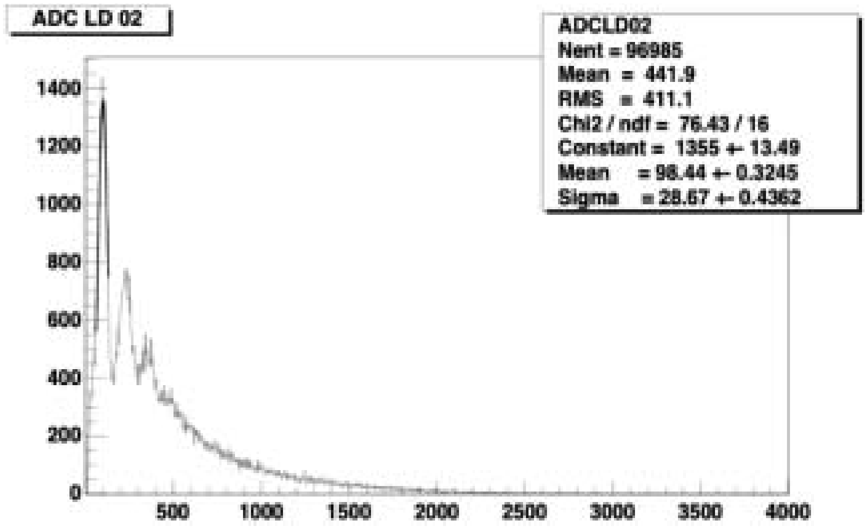

Fig. 4 Layer of silicon rubber inserted

Fig. 3 shows the ADC spectrum in the setup without the silicon rubber, and Fig. 4, with it. The improvement is clear. The single photoelectron peak, very clearly visible with the PM, was fitted to find out its position. The average number of photoelectrons was calculated by dividing the average of the spectra by the position of the single photoelecron peak. By inserting the silicon rubber, the average number of photoelectrons changed from 3.174 to 4.489. The piece of silicon rubber we could obtain has a thickness of 1.5 mm, and thus certainly harmful for a good spatial resolution. This problem is talked in 3.2.

	YAP (14500 Photons/MeV)		LuYAP (9600 Photons/MeV)	
	^{22}Na(551 keV)	^{137}Cs(662 keV)	^{22}Na(551 keV)	^{137}Cs(662 keV)
Amount of energy transferred to the crystal from gamma	117.255 keV	155.401 keV	189.228 keV	220.414 keV
Photons em-mitted at the interaction point	1700.198	2253.315	1816.589	2115.974
Number of photons transmitted to the wls(3.732%)	63.449	84.090	67.792	78.965
Number of photons reflected back at the end of the crystal (13.271%)	225.635	299.039	241.081	280.813
Number of photons transmitted from the wls to the photocathode (8.430%)	5.349	7.089	5.715	6.657
Number of photoelectrons obtained (20%)	1.070	1.418	1.143	1.331
Number of photons transmitted to the wls (8.251%)	140.287	185.925	149.890	174.593
Number of photons reflected back at the end of the crystal (8.946%)	152.103	201.586	162.516	189.299
Number of photons transmitted from the wls to the photocathode (8.430%)	11.826	15.674	12.636	14.719
Number of photoelectrons obtained (20%)	2.365	3.135	2.527	2.944

Table 2 Resume of the number of transmitted photons (egs used for the light emission in the crystal). Part in thick frame: air between the crystals and the wls. Part in double frame: silicon rubber inserted between the crystals and the wls Verification of the conversion efficiency of the wls

2.3. Verification of the conversion efficiency of the wls

To confirm the assumption that the conversion efficiency of the light inside the wls is already good, the following test has been performed. The reason for this test is, we observed an improvement of the conversion efficiency when we switched from the dye density from 400 to 800. (Now, 800 is used.) a layer of wls was superposed on the normal layer of wls as shown in Fig. 5.

We try to find if the amount of light increases when two wls are read in stead of one.

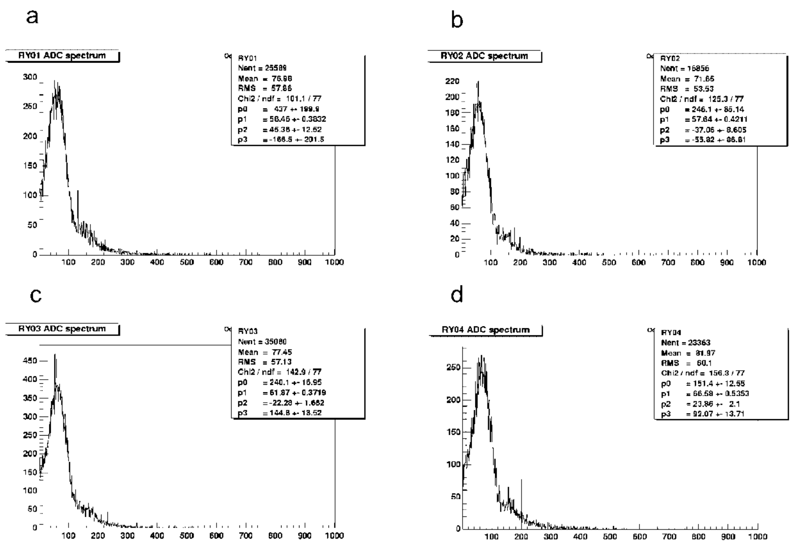

Fig. 5 Light output from wls 5(a), 6(b), 7(c) and 8(d)

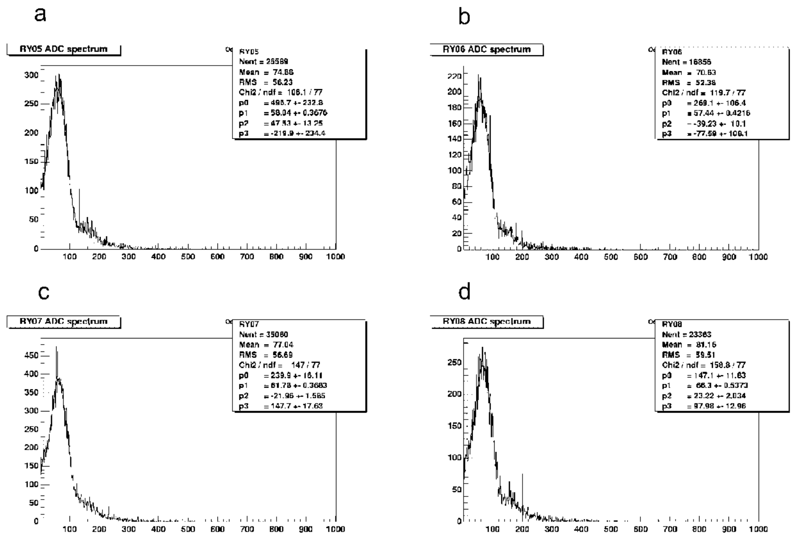

Fig. 6 Sum of the outputs from wls 1 and 5(a), 2 and 6(b), 3 and 7(c), 4 and 8(d)

In Table 3, the second column shows the average number of photoelectrons observed when only one layer of wls was read. The 3rd column contains average number of photoelectrons when the ADC output from two superposed wls are added (see Fig. 6). One can observe a slight increase when two layers are read, but the difference is almost negligible. Thus we can conclude that the efficiency of the conversion is almost 100 %.

	First layer only	Sum of 1st and 2nd layers
1	1.29	1.31
2	1.23	1.24
3	1.25	1.25
4	1.22	1.23

Table 3 Light output from single and superposed layers

3. Investigation of the spatial resolution

3.1. Summary of the past experiments

The ^{137}Cs source has been used as a gamma-ray source. As the scintillator crystals, 1 mm by 1 mm by 20 mm YAP crystals are bundled as a pad (16 x 16) to form a detector. A 40 mm thick collimator made with lead with a slit of 0.8 mm has been used to select gamma-ray in a small area to be sent to the detector from the source. The distance between the source and the detector was 260 mm.

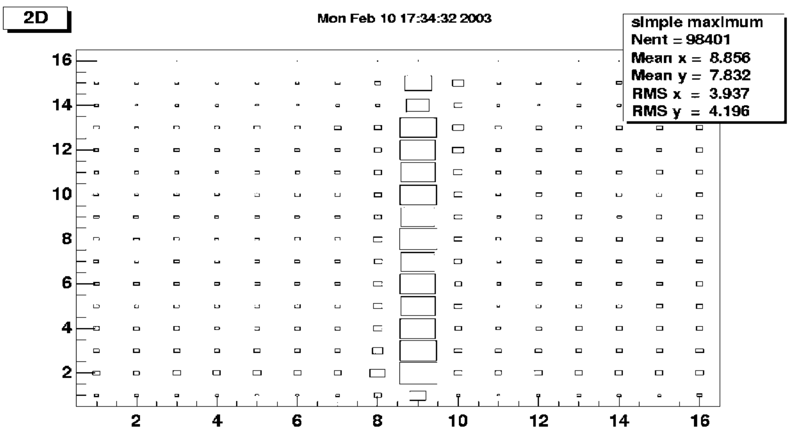

Fig. 7 2-dim. histogram of the detected gamma-ray

Fig. 7 shows the experimental result obtained with the single-detector setup. The histogram is presented with rectangles whose size represents the yield. Fig. 8 shows the projection to the vertical axis of the 2-dim histogram in Fig. 7.

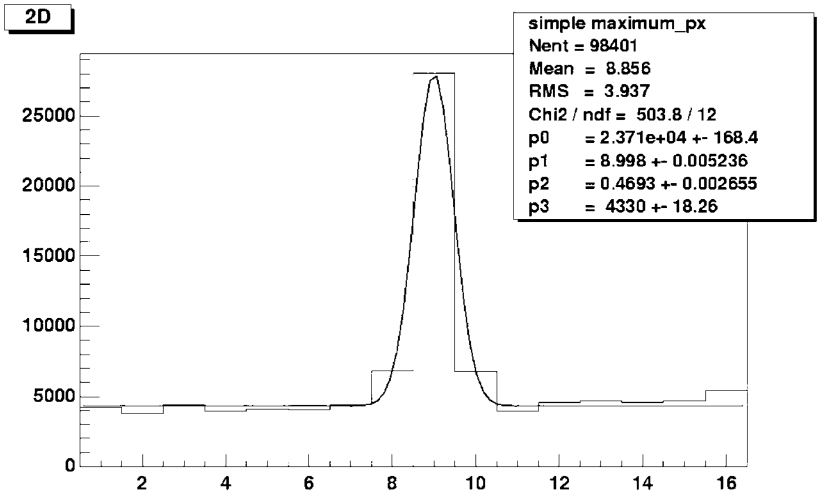

Fig. 8 Projection and fit of Fig. 7

$$p_0 e^{-0.5[(x-p_1)/p_2]^2} + p_3 \qquad -----(1)$$

By fitting this histogram with a Gaussian and together with a constant background (see expression 1), it was found that the width of the peak is 0.47 channels which means 0.47 mm in RMS. To show that this is not due to an irregularity of a wls fiber nor due to a single channel of PM, we also did the same test by putting the slit in a diagonal direction, and obtained the similar result. Thus the main component of the detected gamma-ray shows a spatial resolution better than 1 mm in FWHM.

3.2. Summary of inserted the silicon rubber

The ^{22}Na source has been used as a gamma-ray source. As the scintillator crystals, 1 mm by 1 mm by 20 mm YAP crystals are bundled as a pad (8 x 8) to form a detector. Other measurement condition is same as 3.1. The thickness of scillicon rubber is 0.3mm.

Fig. 9 Result of inserted the silicon rubber.

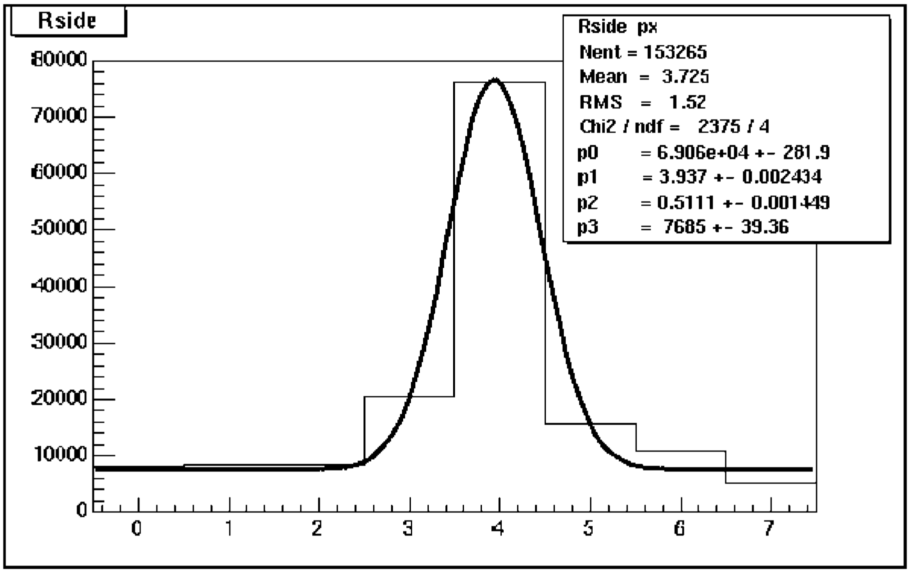

Fig. 9 shows the result with scillicon rubber.

Fig. 9 is fitted with a expression 1. Sigma of Gaussian $p2$ is 0.51 channels which means 0.511mm in RMS. Thus the main component of the detected gamma-ray shows that spatial resolution is 1.21 mm in FWHM. This result means that the method of inserted scillicon rubber is not harmful way.

4. Conclusion

We tried to increase the light yield. Now, we lose the spatial resolution a little, but we gain average number of photoelectron much more. The method of using scillicon rubber must be used in our study. And, the spatial resolution obtained with our method is 1.21mm in FWHM. With YAP(Ce) crystals, a spatial resolution of about 0.5 mm RMS with a method using ^{137}Cs source and a collimator has been obtained. Measurement of the spatial resolution with two detectors in coincidence and a ^{22}Na b^{+} source is also tried out. The study is extended to LuYAP(Ce) and LSO crystals. Several methods to improve the light collection are attempted.

Acknowledgement

The authors would like to thank Prof. M. Toyama for his constant encouragement and help.

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