Improvement on Gamma Energy Resolution of Plastic Scintillator by Adding PMMA Light Guider or Chamfer

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Abstract: Traditional plastic scintillator has respectively low gamma energy resolution. Space radiation detection need the plastic scintillator to keep a relatively better energy resolution for gamma. Thus we did experiments to study how to get it enhanced by adding light guider and chamfer. A 9000Bq radioactive source 60Co has been utilized to make the experiment and results came that when keeping other conditions same, the height of poly methyl methacrylate (PMMA) light guider changes from 12mm to 40mm and the energy resolutions varied from 72.3% to 63.5% respectively. Furthermore, another contrast experiment was made to decide whether plastic scintillator with light guiders or integrated chamfer can get better energy resolution. In conclusion the plastic scintillator with integrated chamfer got 55.0%. Through the study of adding light guider or chamfer to plastic scintillator, the gamma energy resolution has been improved greatly from 72.3% to 55.0%.

Key words: energy resolution; plastic scintillator; light guider; energy spectrum

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0 Introduction

The plastic scintillator has fast responding, high detect efficiency, high photon yield and stable mechanical property. It has important application in high intensive pulse measurement. We have researched a great variety of plastic scintillators and in the end HND-S2 plastic scintillator has been chosen[1]. It takes the polystyrene ($(C_8H_8)_n$) as substrate, the p-terphenyl as wave shifter. The peak of its emission spectrum is nearly 435 nm which is very closely to the fast responding SiPM utilized in the detector. We developed detectors to make experiment and utilized gated measurement technology to obtain the gamma energy spectrum of a 9000Bq radioactive source ^{60}Co. Then it's been found that the energy resolution varies with height of PMMA light guider and when the height of light guider is 12 mm it get the best energy resolution. Afterwards we alternate the PMMA light guider into chamfer and get a better value of about 55.0%.

1 Experiment

The HND-S2 plastic scintillator together with the PMMA light guider or chamfer is shaped as is depicted in Fig. 1. 3D structure has been drawn utilizing 123D design. And the respective three viewsare depicted in Fig. 2. In the experiment we keep the size of the plastic scintillator and other conditions the same. The scintillator was shaped of straight four prism and 30 mm (h) ×30 mm (w)×130 mm (l) sized.

The photosensitive area of C-series' SiPM utilized in the experiment is approximately 7 mm×7 mm, while the effective area of which is 6 mm×6 mm. The photon collection spectrum range is about 375—500 nm of which the peak is about 425 nm. HND-S2 plastic scintillator's spectrum emission peak is also in the neighborhood of 425 nm, best matching SiPM's. Besides

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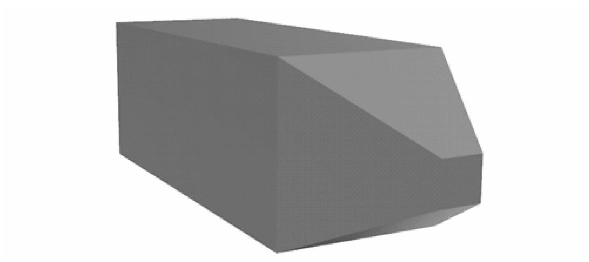


Fig. 1 3D structure of plastic scintillator with PMMA light guider or chamfer

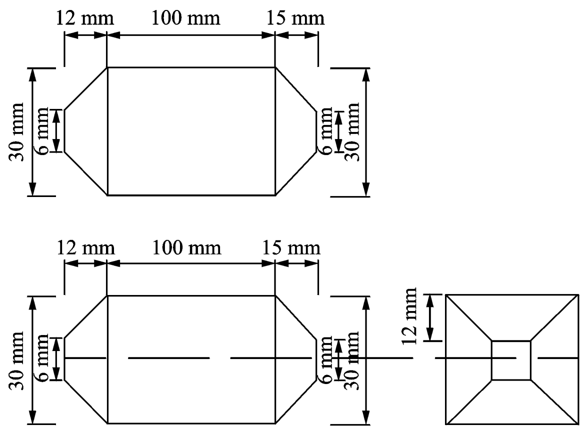


Fig. 2 Three views of plastic scintillator with the PMMA light guider or chamfer

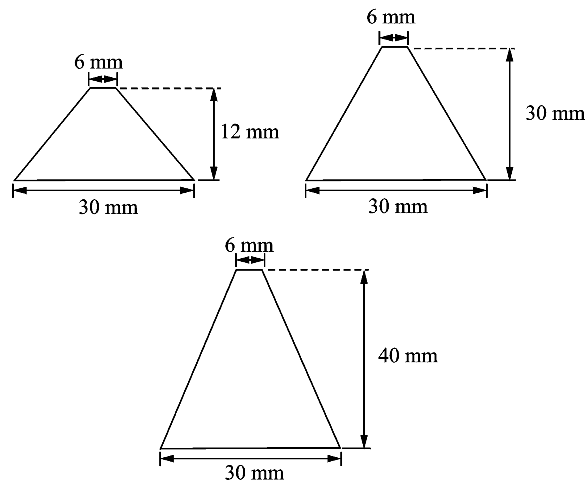


Fig. 3 Structure of PMMA light guide utilized in the experiment

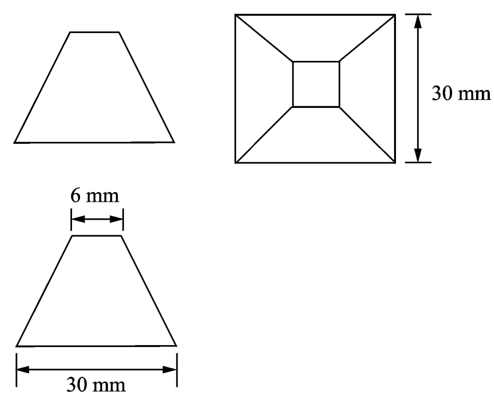


Fig. 4 Three heights of PMMA light guiders' design

it has low background current, low bias voltage and other advantages[2]. So with respect of the effective area of the SiPM, we design the PMMA light guider which shrinks from a flat 30 mm×30 mm to another 6 mm×6 mm which is shown in Fig. 3. The PMMA light guider of different heights is depicted in Fig. 4 and the products is depicted in Fig. 5.

The digitizer CAEN's DT5751 with 2 GS/s sampling rate used in the experiment is mainly smaller, lighter and easier to use and carry. It can be used for mobile detection platform. ADC, the matching FPGA firmware, related access software and a laptop can build up a complete set of movable particle detector data acquisition system. In the meantime, the digitizer has a higher sampling rate and support for bilateral sampling. Digital acquisition software Wavedump supports 1 ns acquisition accuracy, matching the ADC, in whose configuration file we can change signal threshold, waveform baseline, waveform recording length, bilateral sampling settings and other parameters to meet the experimental demands.

Gamma ray interacts with matter mainly by the photoelectric effect, Compton effect and electron pair effect, and because plastic scintillator consists mainly of elements with relatively low atomic number, the gamma ray almost can only be seen the Compton peak in the plastic scintillator[3].

According to productmanual of C-series' SiPM[4], 6 mm×6 mm sized SiPM equivalent capacitance is 3 400 pF and with the charge sensitive preamplifier circuit and slow time characteristic RC circuit, they led to the width of output digital signal waveform being mostly 200—400 ns. The increasing time width of waveform is more suitable for the experiment that need to obtain the energy information. We set the record

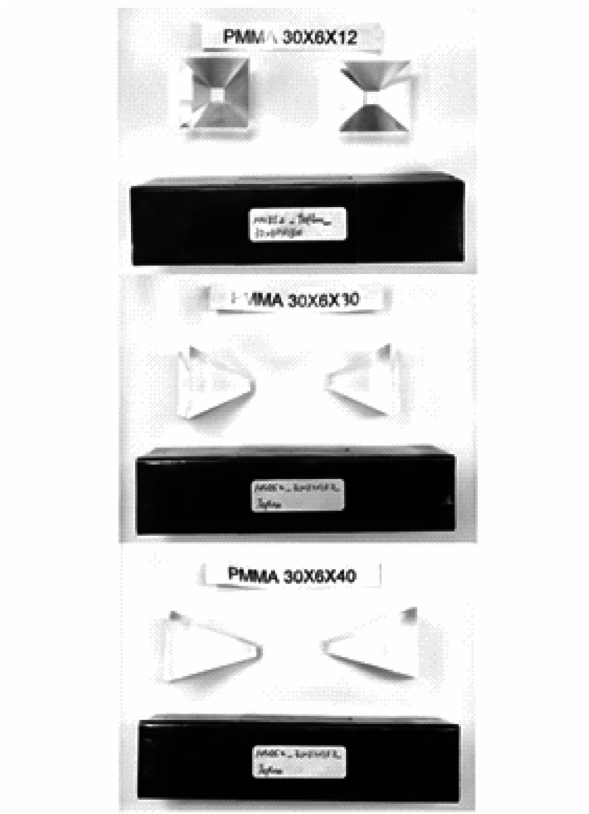


Fig. 5 PMMA light guider of different heights and scintillator

length to 400 ns which can entirely compass the digital waveform of gamma ray pulse from the output of digitizer as is depicted in Fig. 6.

The gamma energy resolution is defined to be the ratio offull width at half maximum (FWHM) and peak value of energy spectrum. In the energy spectrum of plastic scintillator it can mostly be seen the Compton peak, so the energy resolution can be obtained utilizing the Compton peak[5-6].

The gated measurement technology utilizes the widths of short gate and long gate to analyze the waveform which is exactly setting a time range and then integrate the waveform. Different width of gates could have an important impact. If too short the characteristic of waveform cannot be analyzed, and if too long there will be more noise recorded into spectrum. The acquisition of energy resolution is by the following formula and the setting of widths of short gate and long gate is shown in Fig. 6.

$$\eta=\frac{E_{\mathrm{FWHM}}}{E}\times 100\%=\frac{2.335\times\sigma}{Q_{\mathrm{long,peak}}}\times 100\% \quad (1)$$

where E_{FWHM} stands for the full width at half maximum of the peak, and E the corresponding energy. In the experiment the width of short gate is set to 100ns as the width of long gate is set to 170 ns. Meanwhile, the threshold is set to 10 mV to keep the true events detected as possible as it can.

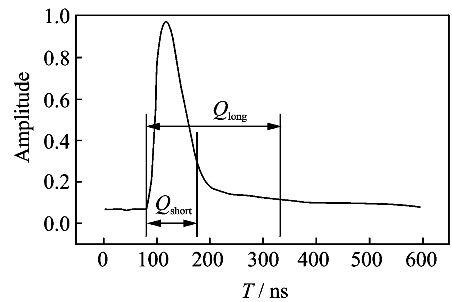
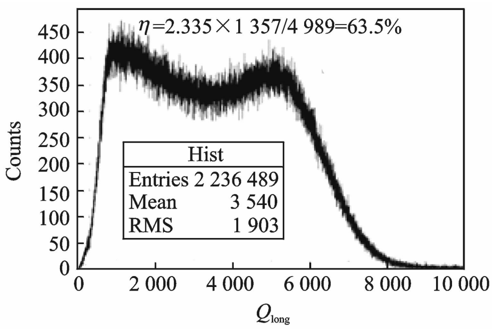


Fig. 6 Widths of short gate and long gate

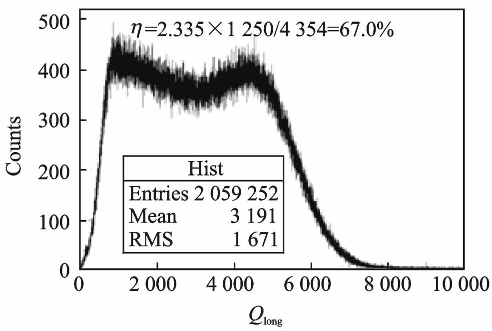
The experiment has been made when varying the heights of PMMA light guiders in the meantime keeping the other experimental conditions the same, such as the amplifiers and digitizers' sampling rate. In order to expose the plastic scintillator to the radioactive source to fully receive the radiation, the source was placed in the middle of the scintillator and within 5 cm of the side face. Meantime, the collimator was utilized to make sure that the ray is sent through the scintillator in 90 degrees. In the experiment, ^{60}Co standard exempt gamma radioactive source was utilized and it was monochromatic of energy.

The results came that when keeping other conditions the same, the height of poly methyl methacrylate (PMMA) light guider changes from 12 mm to 40 mm and the energy resolutions varied from 72. 3% to 63. 5% respectively as is shown in Fig. 7.

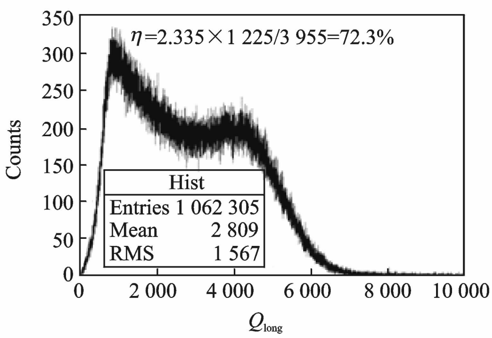
The inclination is from 45 degree to 73 degree. We particularly chose three typical heights of light guider which is 12 mm, 30 mm and 40 mm and their inclination is respectively 45 degree, 68 degree and 73 degree. The variable relationship between the height and the respective energy resolution is shown in Fig. 8. It can be inferred that as the height of light guider comes larger, the inclination of it is enlarged and so the



(a) 12 mm



(b) 30 mm



(c) 40 mm

Fig. 7 Gamma energy spectrum of typical heights of light guider and the respectively energy resolution

photon's range must come longer to be collected into the SiPMs. The detecting efficiency of SiPM becomes lower. So fewer of pulse waveforms recorded from the output of the digitizer can be a relatively high amplitude. In the energy spectrum, the factor of high energy become less complete owing to the lacking of much pulse waveform integration of high energy range. Then the energy corresponding to the peak decreases making the energy resolution value increase.

Next we push forward to switch the design of adding the light guider to integrated chamfer as is shown in Fig. 9. Then we acquired the respectively energy resolution by making the detecting ex-

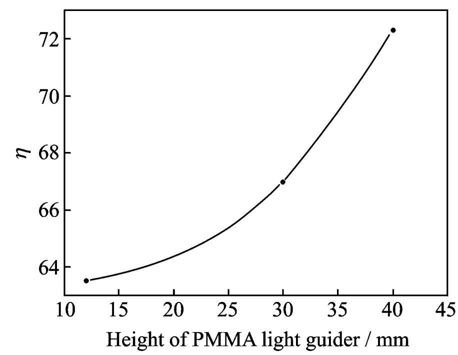


Fig. 8 Variable relationship between height and respective energy resolution

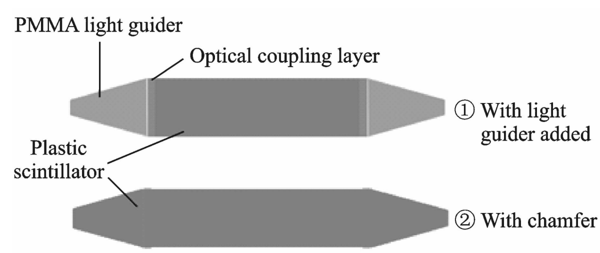


Fig. 9 Plastic scintillator with light guider added or with integrated chamfer

periment again. The heights of the light guider and the integrated chamfer are both 12 mm, which inclination is 45 degree. We obtain the energy resolution which is 55.0%. And that switch reduces two more times of photon reflection into the SiPMs to be collected. The reflection can block much photons and back them into scintillators which can lead to more decaying of energy and reduce more detecting events. Ultimately we optimize the energy resolution to 55.0% which is an apparent improvement.

2 Conclusions

It's been considered that the transmitting process of the photons in the plastic scintillator is not accorded with the theoretical process. It's a complicate process and for the mean time we made efforts to improve the efficiency of collection and reduce the decaying of the energy. Thus the high energy factor can be much detected and it can lower the value of energy resolution. There would be more factors to influence the energy resolution such as the stability of electronic system and the inherent material of the scintillator, while in this paper we have the discuss about the transmitting and collection process of the photon. Although the plastic scintillator can't have relatively better energy resolution, it still can be optimized from 72.3% to 55.0%.

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