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MSE/SSE discrimination methods of the PC-HPGe detector*

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Abstract: Having advantages of low capacitance and low energy threshold, the PC-HPGe (Point-Contact High Purity Germanium) detector has found its application in the direct detection of WIMP(Weak Interaction Massive Particle) in CDEX (China Darkmatter Experiment). The MSE (Multi-Site Event) and SSE(Single-Site Event) discrimination methods of the PC-HPGe detector are introduced in this article, including their physical basis, the electronics system and the algorithms to implement them. Behaviors of the PC-HPGe detector are studied intensively through this research and finally the experimental results of the LE discrimination method are presented.

Key words: PC-HPGe, MSE, SSE, discrimination

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1 Introduction

Having the advantages of low capacitance, low noise and low energy threshold, the PC-HPGe detector is used for the direct detection of WIMP in CDEX [1–3]. The detector group of CDEX try to manufacture PC-HPGe detectors by themselves and intensive studies of behaviors of PC-HPGe are now carried out. The PC-HPGe detector has a strong capacity of discrimination of MSE (Multi-Site Event: an incident particle interacts with the detector and has more than one energy deposition point that can be distinguished by electronics) and SSE (Single-Site Event: an incident particle interacts with the detector and only has one energy deposition point that can be distinguished by electronics). The MSE/SSE discrimination capacity of the PC-HPGe detector is confirmed and studied in this article. The characteristics of induced signal of incident particles in the PC-HPGe detector are studied through this research.

The discrimination of SSE and MSE has found its application in the detection of neutrinoless double beta decay and got a remarkable result in the compression of background events [3, 4]. The detector used in this application is a ULE-HPGe(Ultra Low Energy High Purity Germanium) detector (the area of the P+ electrode of the ULE-HPGe detector in the reference literature is much bigger than that of the PC-HPGe detector and can not be classified as a PC-HPGe detector) while this article is mainly on the PC-HPGe detector. The discrimination method in the reference literature is called the A/E method which is reviewed and investigated in depth. Then another discrimination method called the LE method is proposed and compared with the A/E method in this article. The feasibility of the discrimination of SSE and MSE in the PC-HPGe detector including the physical basis of discrimination methods and related algorithms to realize the discrimination methods based on the electronics system are verified and presented.

The configuration of the electronics system for the discrimination of SSE and MSE is shown in Fig. 1, including the PC-HPGe detector, charge sensitive

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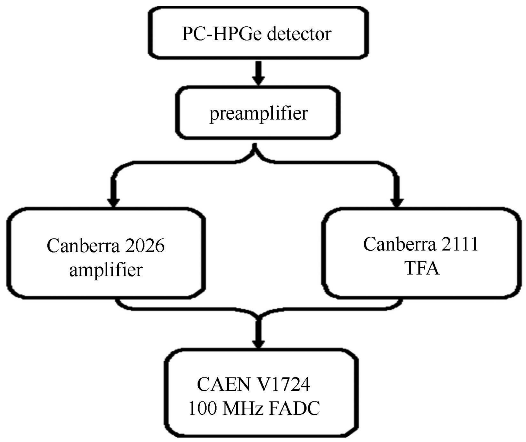

Fig. 1. Configuration of the electronics system.

preamplifier, Canberra 2026 amplifier, Canberra 2111 TFA (Time Filter Amplifier) and CAEN V1724 100 MHz Flash ADC.

The shaping time of the Canberra 2026 amplifier is set at 6 μs to get the best energy resolution and its amplitude of output reflects the total energy deposition of the incident particle. The integration time constant and differentiation time constant of the TFA are set at 10 ns and the FWHM (Full Width at Half Maximum) of the TFA output signal is about 200 ns.

2 Signal characteristics analysis

The induced current of energy depositions in the PC-HPGe detector is simulated first [5–7]. Assume that there are two EDPs (Energy Deposition Point) in the detector and their EDVs (Energy Deposition Value) are equal. The induced current of these two EDPs is shown in Fig. 2.

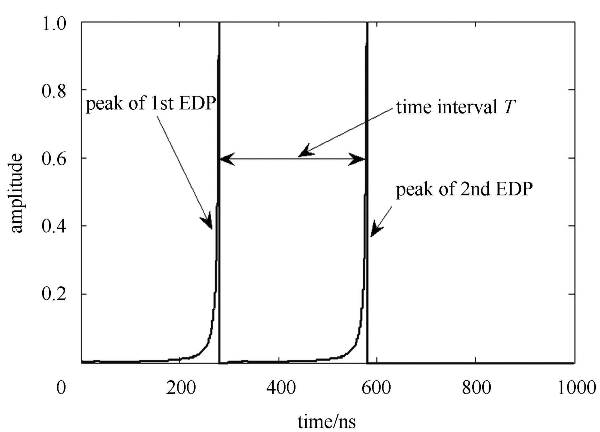

Fig. 2. The induced current of the EDPs.

The FWHM of the current peak of the induced current is very small(about 10 ns) due to the special electrode configuration of the PC-HPGe detector. The amplitude of each current peak reflects the EDV of the corresponding EDP. The time interval T between two current peaks reflects the distance of two EDPs. Spatial distance of 1 mm between the two EDPs in the PC-HPGe detector results in about 10 ns time interval between the two current peaks. The output signal of the TFA is simulated by convolving the induced current with the pulse response of the TFA.

As shown in Fig. 3, the output signals of the TFA change as the time interval T changes. Fig. 4 shows the output signals of the TFA when the ratio of the EDVs of the two EDPs changes while the T stays at 500 ns.

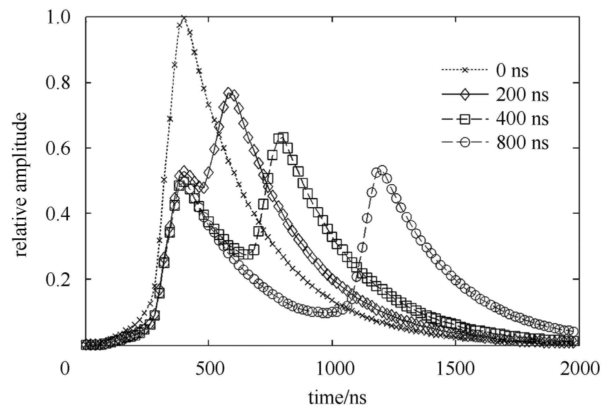

Fig. 3. The output signals of the TFA at different time intervals between current pulses. The maximum value of the output signal of the TFA decreases when the time interval increases.

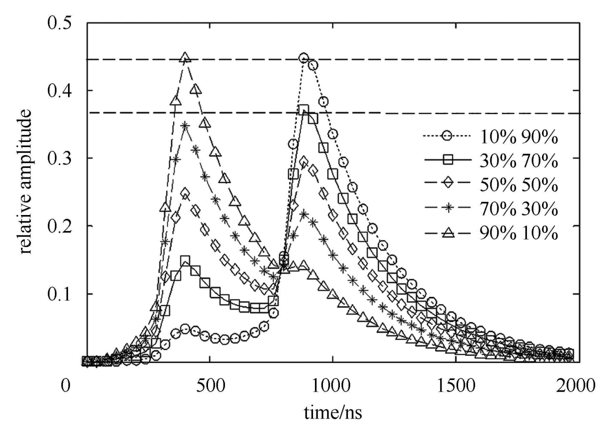

Fig. 4. Output signals of the TFA with different EDV ratios. The maximum value of the output signal of the TFA varies with the EDV ratio. Legend in this figure, for example, "10% 90%" means that the EDV of the first EDP is 10% of the total EDV, and the EDV of the second EDP is 90% of the total EDV.

Because the FWHM of the current peak is about 10 ns, if the spatial distance of the EDPs is less than

1 mm, the induced current peaks of these EDPs will pile up and these EDPs will be indistinguishable; such events will be identified as SSE. So the first requirement of MSE is that there should be enough distance between the EDPs, especially for EDPs which have the two maximum EDVs.

If the EDV of one EDP is much larger than the others, no matter how long the distance between the EDPs is, the event will be identified as SSE for the reason that there is definitely a discrimination ability limitation of the electronics system (S/N ratio of the TFA output signals is worse than the main amplifier). So the second requirement of MSE is that the EDVs of two EDPs which have the two maximum EDVs should be comparable and have the same magnitude.

The ratio of the maximum value of the TFA signal (A) to the amplitude of the main amplifier signal (E) is called the A/E value and the discrimination method based on the A/E value is called the A/E method [3, 4, 7]. It is tested with single escape events and double escape events, since most of the single escape events are MSE while nearly all the double escape events are SSE. The reciprocal of the A/E value is called E/A in this article. The E/A value varies with the distance of the EDPs and the EDV proportion of the EDPs according to Fig. 3 and Fig. 4; this means that the E/A value also reflects two requirements of MSE and can also be used for the discrimination of SSE and MSE.

3 Physical basis of the discrimination methods

The physical basis of the discrimination methods is simulated using Geant 4 in this section. The simulated PC-HPGe detector is 50 mm and the radius is 25 mm. The incident particle source is a gamma source of 1.332 MeV (^{60}Co). There are two physical variables simulated in this article. The first one is the EDR (Energy Deposition Ratio), the expression of it is shown below:

$$\mathrm{EDR}=\frac{E2}{E1}. \tag{1}$$

Here, $E2$ is the second maximum EDV. $E1$ is the maximum EDV. If there is only one EDP in the detector, then $E2$ is equal to zero. Assume that there are only two prominent EDPs (their EDVs constitute the majority of the total EDV) and the pulse response of the preamplifier+TFA is delta (t), then

$$E/A \propto \mathrm{EDR}+1. \tag{2}$$

The second physical variable is the LMEDR (Length Multiply Energy Deposition Ratio), the expression is shown below:

$$\mathrm{LMEDR}=L\times\mathrm{EDR}. \tag{3}$$

Here, L is the distance between the EDPs which have the two maximum EDVs. If there is only one EDP in the detector, then L is equal to zero. The EDR value and LMEDR value of SSE are almost equal to zero. The distribution of EDR and LMEDR of full energy peak, Compton continuum, single escape events and double escape events are shown in Fig. 5.

The LMEDR value and EDR value reflect the difference of MSE and SSE. There is a significant difference between the single escape events and double escape events of EDR and LMEDR distribution. The difference between the full energy peak and Compton continuum is not so prominent.

Comparing LMEDR and EDR, one can see:

1) The LMEDR takes advantage of more physical information of the EDPs than the EDR. One can see from Fig. 3 that the distance between EDPs influences the discrimination of SSE and MSE, and the LMEDR takes this parameter, so it is more scientific than the EDR to represent the characteristics of MSE in theory.

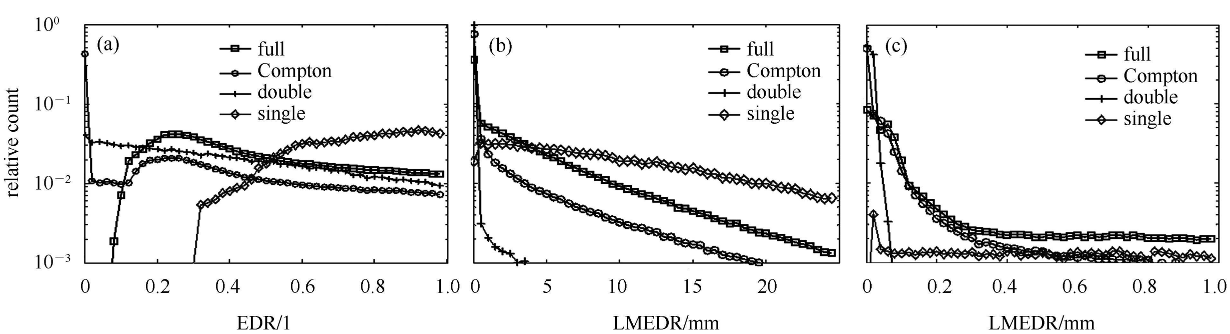

Fig. 5. (a) The distribution of the EDR for different events; (b) The distribution of the LMEDR; (c) The detailed distribution of the LMEDR when the distance of the two events with maximum EDVs is less than 1 mm.

2) The LMEDR expands the range of the EDR if the PC-HPGe detector is large enough. This characteristic provides convenience for setting the threshold for the discrimination. What's more, we can find that the LMEDR enlarges the difference of the EDR between SSE and MSE because the distance of the EDPs of the majority of MSE is more than 1 mm while the distance of the EDPs of SSE is less than 1 mm. So here we propose another method, named the LE method based on the LMEDR value.

4 *LE* discrimination method based on the electronics system

The algorithm of the LE method is shown as the following expressions:

$$Sum = \sum_{i=1}^{\text{total}} n[i], \text{while } n[i] > Th; \tag{4}$$

$$Aver = \sum_{i=1}^{\text{total}} n[i] \times i, \text{while } n[i] > Th; \tag{5}$$

$$Aver = Aver/Sum; \tag{6}$$

$$LE = \sum_{i=1}^{\text{total}} \frac{n[i]}{Sum} \times |i - Aver| \times E/A, n[i] > Th. \tag{7}$$

Here, Th is the threshold, $n[i]$ is the digitized output of the TFA. Assume that there are only two prominent EDPs and the pulse response of the preamplifier+TFA is delta(t), then the relation of the LMEDR and the LE is shown as the following expression approximately:

$$LE \propto \text{EDR} \times T \propto \text{LMEDR}. \tag{8}$$

Here, T is the time interval of two induced current peaks. In fact, T indicates the distance of the energy deposition points. Change the time interval T and $Ea/(Ea+Eb)$ (Ea is the EDV of the first induced current peak and Eb is the EDV of the second induced current peak) in Fig. 2, the normalized E/A and LE distribution are shown in Fig. 6.

The output signal of the TFA is treated as the induced current of the incident particle in the reference literature, and in that case the pulse response of the preamplifier+TFA is assumed to be delta(t) and the E/A value indicates the EDR value. However, the pulse response of the preamplifier+TFA is not an ideal delta(t), so the E/A value represents the LMEDR value in some degree.

To compare the A/E method and LE method, one can see:

1) The LE method takes advantage of more information of the output signal of the TFA. Assume that the total EDVs of incident particles are the same,

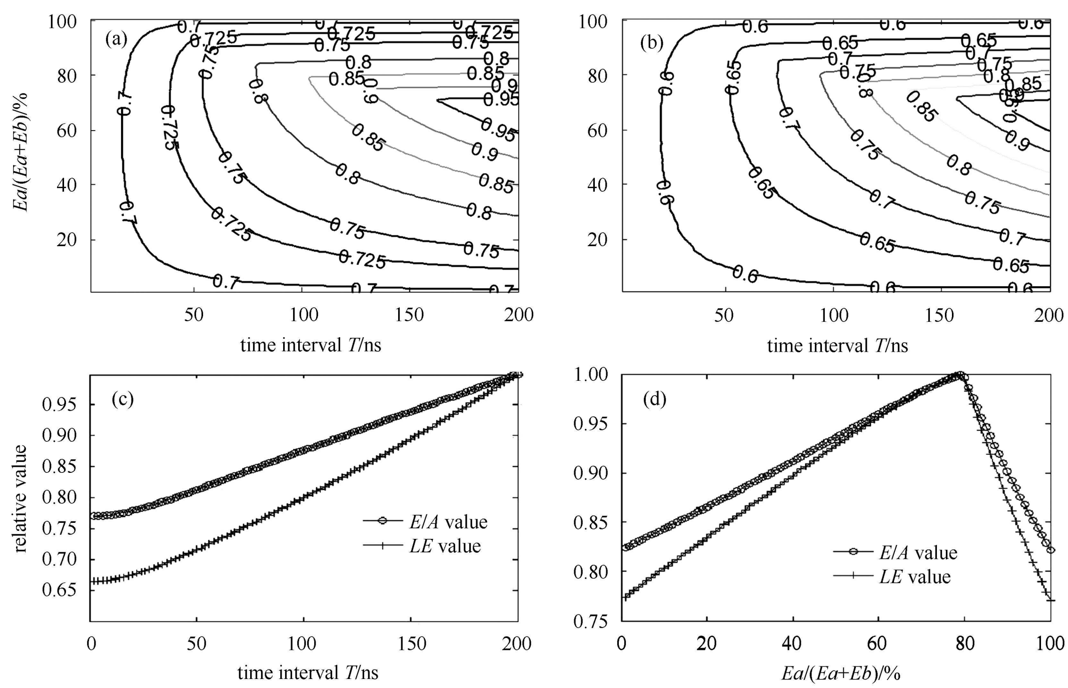

Fig. 6. Distribution of E/A (a) and LE (b). Both the E/A value and LE value change with the time interval T and $Ea/(Ea+Eb)$ because the real pulse response of the preamplifier+TFA is not delta (t). (c) is the detailed distribution of E/A and LE when $Ea/(Ea+Eb)$=50%, (d) is the detailed distribution of E/A and LE when T=100 ns.

then the TFA output signals of the EPDs of SSE will overlay each other almost fully, the total waveform of this condition is exactly like the waveform of a single EDP. But for MSE, the TFA output signals of the EDPs will be staggered and only overlay each other partially, so the total waveform of MSE as shown in Fig. 3 will be flatter than the waveform of SSE and LE reflects this difference. Another discrimination method makes use of this difference of the output signals between SSE and MSE, but the discrimination method is more complicated than the LE method [8].

2) LE value expands the range of E/A value and provides convenience for setting the threshold for the discrimination. LE value also enlarges the difference of E/A value of SSE and MSE according to equations throughout (4) to (7) and the difference of SSE and MSE output signals mentioned in the previous paragraph.

So the LE method is more powerful than the A/E method in principle at least, although the A/E method does an excellent job already in discriminating single escape events (MSE) and double escape events (SSE) according to the reference literature.

5 Experimental results of the *LE* discrimination method

The experimental results of the LE discrimination method and the simulation results of the LMEDR are compared in this part to prove that the LE value reflects the LMEDR value well.

As shown in Fig. 5, the difference of the LMEDR distribution of single escape events and double escape events is more prominent than that of the full energy peak and Compton continuum. If the LE method can discriminate SSE and MSE in the full energy peak and Compton continuum, there will not be any problem for the LE method to discriminate MSE and SSE in the single escape peak and double escape peak. Since the E/A discrimination method can be used for the discrimination of SSE and MSE according to the reference literature, so the experimental results of the E/A method and LE method are compared in this part to prove that the LE method can get similar results with the E/A method and can be used for the discrimination of SSE and MSE in the full energy peak and Compton continuum. The relative count of the Compton continuum when the LE value of events smaller than the given LE value (EDR, LMEDR, LE and E/A can get a similar result) is shown in Fig. 7, the diameter of the detector is 17 mm and the height is 10 mm. The average LMEDR and EDR value increase with the increase of the total EDV in the Compton continuum indeed. So the smaller the LMEDR value is, the higher the proportion of the relative count of the low energy spectrum is.

There is another parameter called SR, it is defined as:

$$SR = \frac{N1}{N0}. \tag{9}$$

Here $N0$ is the number of events before discrimination, $N1$ is the number of events (for the LE discrimination method, it is the number of events whose LE value are smaller than the given value) after discrimination. The SR value of the full energy peak and Compton continuum and the ratio of peak to Compton under the LE discrimination method is shown in Fig. 8. It matches the simulated result very well.

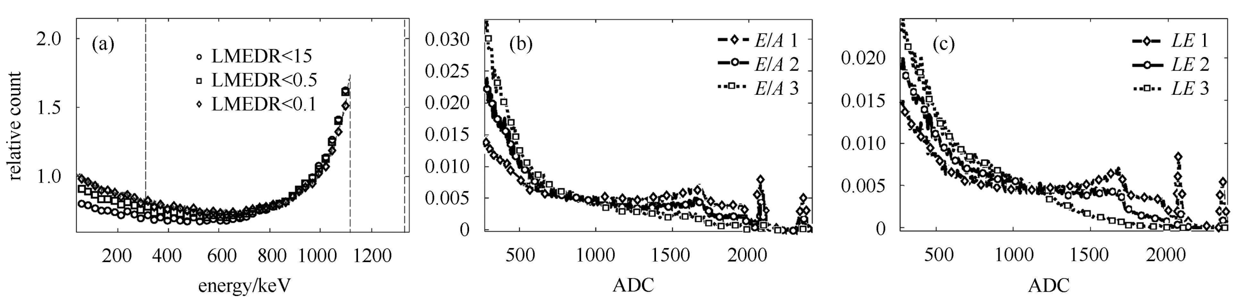

Fig. 7. (a) is the simulation result. (b) is the A/E discrimination result, $E/A1 > E/A2 > E/A3$. (c) is the LE discrimination result, $LE1 > LE2 > LE3$. The relative count of Compton continuum changes with the LMEDR value in (a). The experimental results are in accordance with the simulation result. The LE method and A/E method get similar results. Spectrums in (b) and (c) are the real spectrum of ^{60}Co.

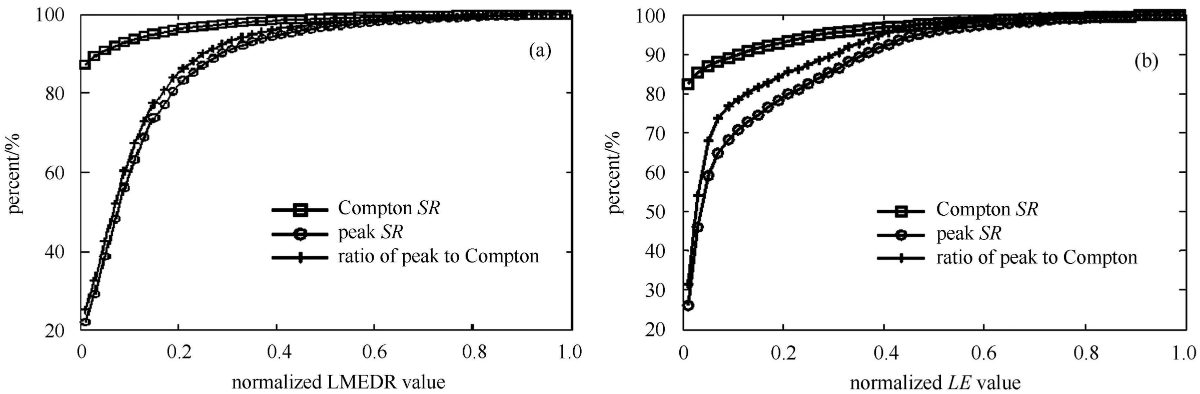

Fig. 8. (a) is the MC simulation result and (b) is the experimental result. The *LE* discrimination result agrees with the LMEDR simulation result well.

6 Summary and discussion

Both the *LE* and *A*/*E* method can be used for the discrimination of SSE and MSE for the PC-HPGe detector. The *LE* method is more powerful than the *A*/*E* method in theory and its value reflects the simulated LMEDR value very well.

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