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A pulse shape discrimination of CsI(Tl) crystal with ^{6}He beam

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Abstract The performance test of a CsI(Tl) crystal (70×27×23 mm^3) was performed by applying the pulse shape discrimination technique for identification of light charged particles . The crystal is coupled to a photomultiplier tube during an experiment with ^{6}He beam. The pulse waveform is fully recorded by employing a high precision digital oscilloscope. The fast and slow gates are used for the pulse shape discrimination and the best values for the gate widths were determined to be 0.5 μs and 1.67 μs, respectively. The ^{6}He, ^{4}He and ^{3}He are successfully discriminated with this technique.

Key words CsI(Tl) crystal, Pulse shape discrimination, Light charged particles

1 Introduction

CsI(Tl) crystals are widely used for detecting charged particles, and suitable for a large solid angle detector assembly because of their easy handling, low cost, and light output performance[1]. The crystals have been fabricated into a number of 4π detector arrays with particle identification capability, such as at, e.g., Dwarfball/DwarfWall[2], MSU Miniball[3], Microball [4], and others[5]. The particle identification with CsI(Tl) crystal can be performed with different techniques, such as *ΔE-E* and pulse shape discrimination (PSD). PSD is advantageous with less detector layers [1,4,6].

Light pulses generated in a CsI(Tl) crystal have fast and slow components, from different atomic excitation mode depending on the type and ionizing power of the incident particles. Therefore, based on analysis of the pulse charge in the fast and slow gates [7–9], the waveform of light output signal is used to identify particles by analyzing the pulse shape using the photomultiplier tube (PMT) or photodiode. PMTs coupled to CsI(Tl) crystals are preferred for PSD due to its fast response performance.

Recently, a large amount of CsI(Tl) crystals are produced by the Institute of Modern Physics (IMP), Chinese Academy of Sciences. It is interesting to study their performance in comparison with other products. In this study, crystals produced at IMP are employed in a nuclear physics experiment using ^{6}He beam. ^{6}He, ^{4}He, and ^{3}He were successfully discriminated by PSD. Our results show that the crystal performs well in particle discrimination, and is a good choice for future experiments.

2 Experiment

Radioactive beam of ^{6}He at 65 MeV/u is provided by the RIBLL beam line at the Heavy Ion Research Facility in Lanzhou (HIRFL) [10]. The experiment was performed with four charged particle telescopes (D0, D2, D11, and D12), and C and $(CH)_n$ targets (Fig.1).

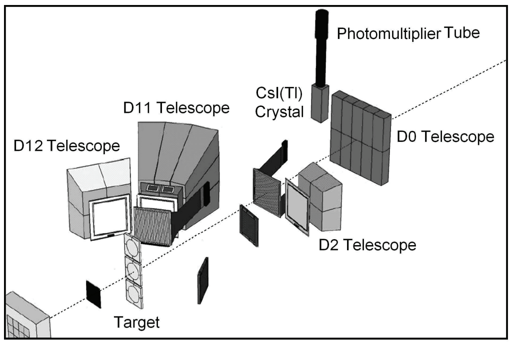

Fig. 1 A schematic view of the experimental setup.

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Although the setup is mainly used for studying the structure of the exotic nucleus ^{6}He, we focus here on studying the particle discrimination performance of a CsI(Tl) crystal, which is separately installed beside the D0 telescope (at the upper right corner of Fig.1). The crystal (70 mm×27 mm×23 mm) was attached to a photomultiplier tube (R1213, Hamamatsu) by coating a thin layer of silicon grease, and was placed in a vacuum chamber. The side surfaces of the crystal were wrapped with several layers of Tyvek paper, and the front side was covered with a thin aluminized Mylar foil (12 μm). The distance was 605 mm from the setup to the target, which inclines about 10° from the beam axis. All signals from this crystal were recorded independently by employing a high precision digital oscilloscope (National Instruments NIPXI6652), in which data were sampled with a minimum rate of 60 MHz. With the fully stored pulse waveform, various combinations of fast and slow gates could be applied during the offline data analysis.

The D_0 telescope consists of ten CsI detectors coupled to photodiodes, together with a silicon strip detector that provides energy loss ΔE of the traveling particle and the corresponding precise position. In the present study, the D_0 telescope was used as double check of particle identification applying different ΔE-E methods. When an incident ^{6}He ion hits the target, it may be elastically scattered to various angles but keep its identity as incident ^{6}He. It may also breakup into ^{4}He + 2n or hydrogen isotopes. Particle discrimination can then be performed against ^{6}He, ^{4}He and hydrogen isotopes.

3 Analysis and discussions

To identify particle with PSD technique, both fast and slow time gates were adopted [1]. In Fig. 2, one typical signal recorded by the digital oscilloscope together with the applied fast and slow time gates is shown. Total length of the light pulse signal is about 6 μs, whereas the pulse amplitude is nearly 0.1 V. The fast gate was delayed by a d1 time relative to the starting signal, and the slow gate was delayed by d2 plus the fast gate width, relative to the fast gate, so that we could analyze all combinations of gates and delays.

Firstly, we checked the testing CsI(Tl) crystal with γ (^{60}Co) and α (^{241}Am) sources. In Fig. 3 the charge accumulated within the slow gate is plotted against that accumulated within the fast gate, with the results of γ and α sources being shown in the upper and lower band, respectively.

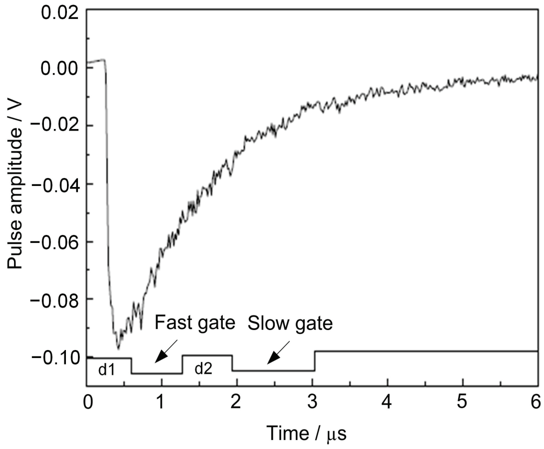

Fig. 2 One signal of light output from CsI(Tl) crystal.

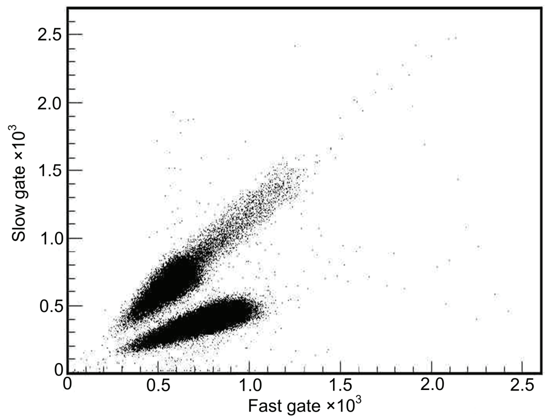

Fig.3 The PSD spectrum for CsI(Tl) crystal checked with γ and α sources, presented in upper and lower bands, respectively. The charge accumulated during the slow gate is plotted against that accumulated during the fast gate.

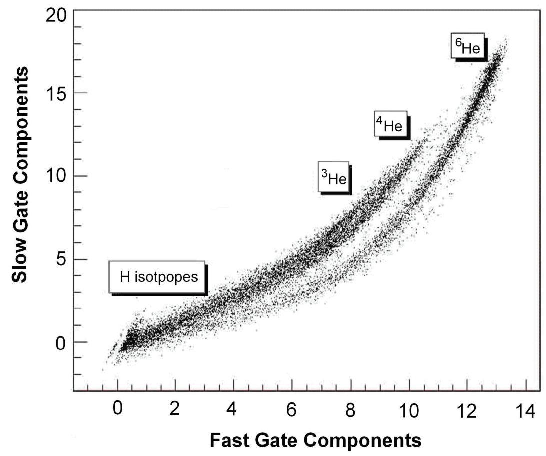

Fig.4 Plot of slow gate component versus fast gate component, showing the discrimination of particles.

Next, the crystal was tested in beam experiment. The results of the particle discrimination are presented by two major bands in Fig.4, with the upper one filled by ^{4}He and ^{3}He particles and the lower one by ^{6}He particles. Also, hydrogen isotopes can be seen at the lower end of the bands. With more ionizing particles, more excitons responsible for the fast component of scintillation will be produced, and more lights will be emitted by the fast scintillation component of the crystal for ^{6}He ions than that for ^{4}He ions, as can be seen in Fig.4.

In order to confirm the correct identification of the helium and hydrogen isotopes, we plot the ratio of the fast *vs* the slow gate components against the total pulse area (Fig.5). The total pulse area (horizontal axis) is approximately proportional to the total energy deposited in the crystal. In the experiment, the highest energy part of ^{6}He is approximately 3/2 times larger than that of the ^{4}He and 2 times than ^{3}He, due to the direct reaction mechanism. These ratios are well displayed in the experimental spectrum. Some Z=1 isotopes are located at much lower energy side of the spectrum. It can be understood that these hydrogen particles came from evaporation of the compound nucleus produced by the fusion reaction between the ^{6}He projectile and the target nucleus ^{12}C.

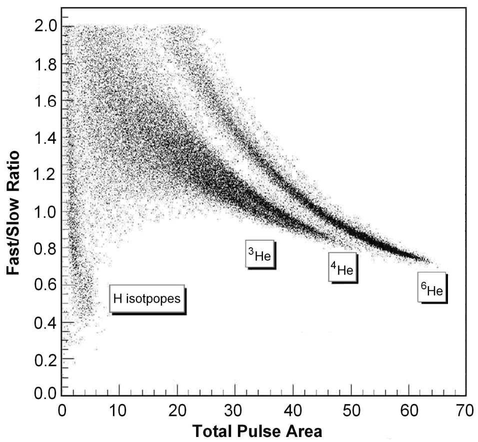

Fig. 5 Ratio of fast and slow components *vs* total pulse area.

The above particle identification is further confirmed by the adjacent D0 telescope using independent *ΔE-E* method, and it was found that the energy range and ^{6}He percent were similar to ^{4}He and hydrogen isotopes, as shown in Fig. 4.

Both the gate widths (fast gate and slow gate) and delay times (d1 and d2) can disturb the discrimination performance. By changing the gate widths from 0.1 μs to 5.5 μs, the best values of 0.5 μs and 1.67 μs for the fast and slow gates, respectively, could be obtained. Similarly, the best delay parameters are 0.3 μs and 0.8 μs for d1 and d2, respectively. These values are adopted in the plot of Fig. 4.

The results demonstrate that the helium isotopes in the energy range of a few tens of MeV/u can well be discriminated by the CsI(Tl) crystal produced at IMP. The performance is as good as reported in Ref.[8]. It should be noted that only the direct application of fast and slow gates to a single scintillation crystal is adopted in the present study. If one thin layer of plastic scintillator is inserted in front of the CsI(Tl) crystal to provide the fast signal, forming the so-called Phoswich detectors[11,12], the particle discrimination performance should be further improved and expanded to heavier isotopes.

4 Conclusion

The particle discrimination performance of a CsI(Tl) crystal produced in Lanzhou was tested by using ^{6}He radioactive nuclear beam. The pulse shape discrimination technique is applied thanks to the capability of recording the full pulse waveform by a high precision digital oscilloscope. It is found that the ability to identify light charged particles, such as ^{6}He, ^{4}He, ^{3}He and proton, is comparable to the previously reported results[8], indicating a good property of this crystal. The best values for the fast and slow gates are 0.5 μs and 1.67 μs, respectively. The values for the delay time d1 and d2 are 0.3 μs and 0.8 μs, respectively. It is suggested that, for the widely used CsI(Tl) crystal, the PSD technique is applied to identify light isotopes instead of using more complicated "*ΔE-E"* method. The optimum gate widths and delay times are obtained by independent of waveforms recorded using a high precision digital oscilloscope, which are applied to the electronics circuit in normal nuclear physics experiment.

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