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Particle identification using CsI(Tl) crystal with three different methods

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Abstract Three pulse-shape-discrimination (PSD) methods are applied to study the particle identification (PID) by using CsI(Tl) crystal, especially for identifying light charged particles. The zero-cross time method, fast and total component method and signal rise time method are used. The experiment, data analysis and results are compared. Good PID for p, α and γ can be achieved with a CsI(Tl)-photomultiplier assembly.

Key words CsI(Tl) crystal, PID, PSD

CLC numbers O571.1, TL812

1 Introduction

A 100 MeV proton cyclotron (CYCIAE-100) is under construction at China Institute of Atomic Energy (CIAE)[1]. On this machine, 70~100 MeV neutrons can be produced by the ^{7}Li(p, n) reaction, and measurement of the double-differential cross-sections (DDX) of light charged particles induced by 70~100 MeV neutrons was proposed[2]. A reaction chamber to study the (n, x) reactions at intermediate neutron energy has been constructed. It consists of a Φ 100 cm × 60 cm vacuum chamber and 8 ΔE-ΔE-E telescopes for measuring light charged particles from a few MeV to 100MeV[3]. CsI(Tl) crystal has been chosen for the E detectors of the telescopes because of its high stopping power and intrinsic capacity of particle identification [4].

In this paper, we report the pulse-shape- discrimination (PSD) study of CsI(Tl) crystal for particle identification based on particle-dependent response of CsI(Tl) crystals and the different decay times in different spectral regions[5-7]. This work is to derive the particle discrimination to identify p, α and γ from the shape of the signal from CsI(Tl) crystal coupled with a photomultiplier, with emphasis on obtaining good particle separation with three methods. This can be of help in choosing a better method to do particle identification (PID) in future experiments.

2 Experiments

The experiments were carried out with a Φ40 mm × 30 mm CsI(Tl) crystal coupled to an XP-2020 photomultiplier. The crystal is wrapped with several layers of Teflon for light reflection and coupled to the photomultiplier with silicon oil. During the experiments, several radioactive sources were used to produce different particles (γ, p and α).

The energy resolution was estimated by the energy spectra measured with γ-ray from a ^{137}Cs source and α particles from a ^{239}Pu source (Fig.1). The resolution for 662 keV γ-ray of ^{137}Cs is 11.9% (FWHM). From the peak corresponding to 5.15 MeV α particles of ^{239}Pu, the resolution is $\Delta E/E$=5.3%.

The protons were from an Am-Be neutron source. Between the crystal and neutron source, a polyethylene film was placed to produce protons via the (n, p) scattering.

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For investigating particle identification properties of the CsI(Tl) detector, three PSD methods were employed: (A) the zero-cross time method, (B) the signal rise time method, and (C) the fast and total components method. The layout of the electronics used in the experiment is shown in Fig.2.

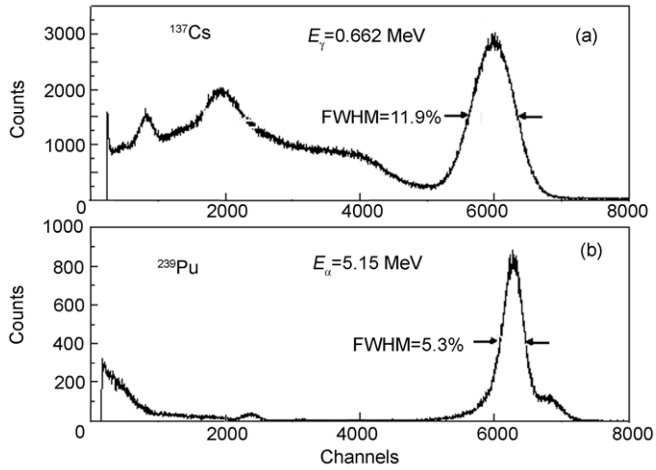

Fig.1 Energy spectra of 662 keV ^{137}Cs γ-ray (a) and 5.15MeV α particles from a ^{239}Pu source (b), with a Φ40mm×30mm CsI(Tl) crystal coupled to an XP-2020 photomultiplier.

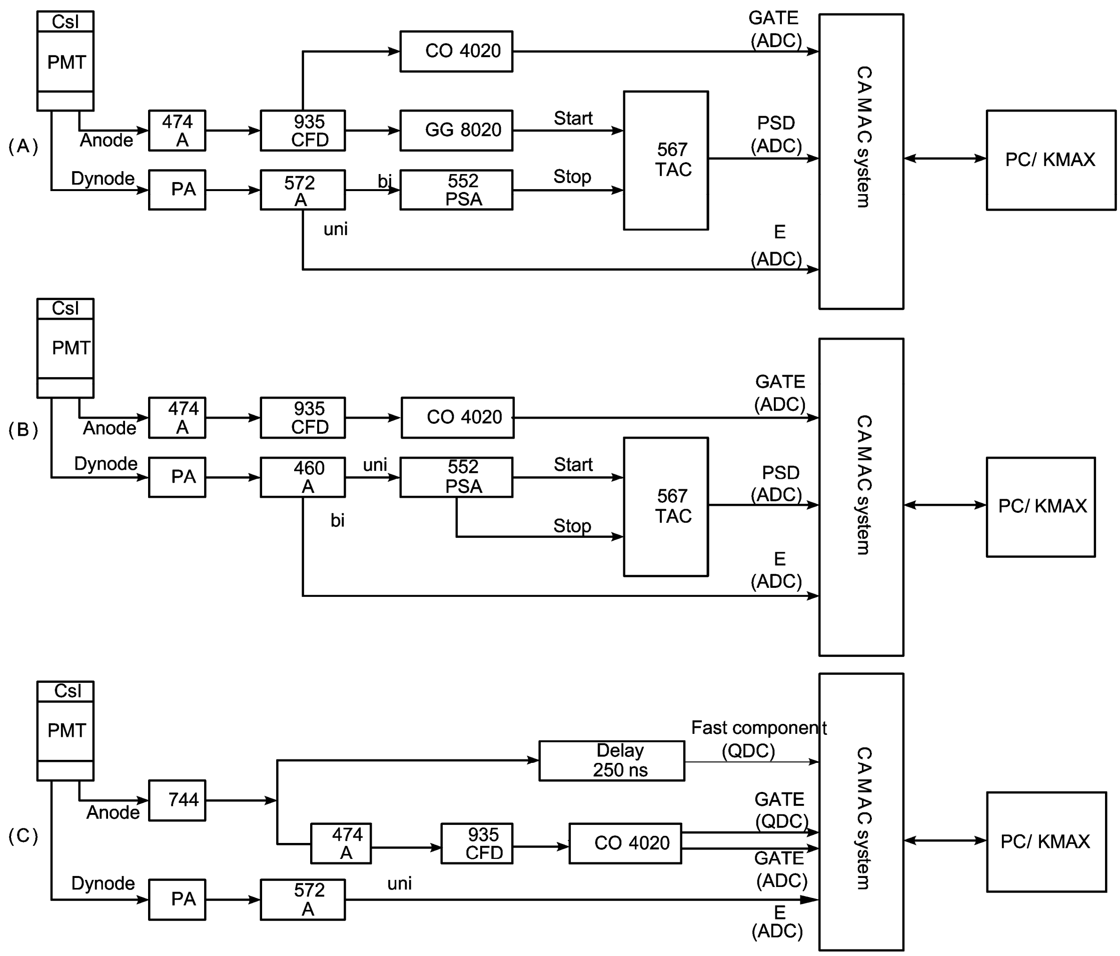

Fig.2 Diagram of the electronics used in the experiment for (A) the zero-cross time method ,(B) the signal rise time method, and (C) the fast and total components method.

2.1 The zero-cross time method (Fig.2A)

Protons, α particles and γ-rays interact with the scintillator and produce current pulses at the photomultiplier dynode, with the pulse decay time being determined by decay time of the scintillations produced in the scintillator. A pulse passes through a bipolar filter that is sensitive to its shape, and the time from pulse arrival to zero crossing is used as the PSD parameter. The anode signal is amplified by a fast amplifier (474A), and fed into a constant fraction discriminator (CFD) to get the arrival time of the signal. The GG8020 is used to delay the arrival time and adjust an appropriate time interval between start and stop. The CFD output is used to generate a gate signal required by the CAMAC ADC. The gate signal width is adjusted by the CO4020 module.

The dynode signal is amplified by a pre-amplifier (PA), and fed into a shaping amplifier (572A) of 3 μs shaping time. The unipolar output signal is digitized by CAMAC ADC as particle energy parameter (E), while the bipolar signal is used to get the zero-crossing time with 552-PSA module. The time from signal arrival (start) to zero-crossing (stop) is converted to amplitude via the time-to-amplitude converter (TAC), and digitized by the ADC. The start-stop time difference serving as PSD parameter is measured with E parameter simultaneously. The detector was bombarded by α particles, protons or γ-rays with the same electronic parameters (i.e. high voltage, gain of the amplifier, etc.) during the experiment. Fig. 3 shows a plot of pulse height versus the zero-crossing time. It can be seen that the particles can be separated clearly.

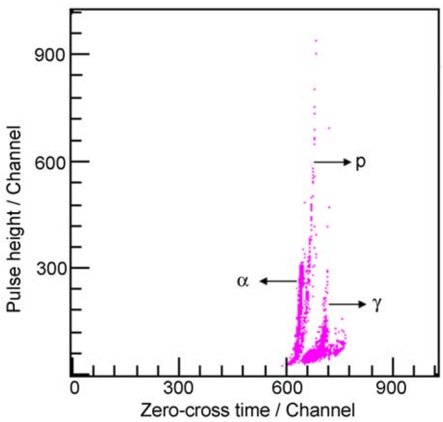

Fig.3 Scattering plot of the pulse height versus the zero-crossing time.

2.2 The rise time method (Fig.2B)

The signals are divided into two processing chains to measure, respectively, the signal amplitude and the signal rise time with a delay line amplifier (ORTEC-460). The output signal falling time from the ORTEC-460 amplifier is proportional to the rise time of the signal from the scintillator. This falling time is measured by a pulse-shape analyzer (PSA) and a TAC. A dual-parameter data acquisition code (KMAX) is required so as to associate the amplitude measurement with the rise time measurement. Fig. 4 shows the result of this method. Also, good PID can be obtained even at low energies.

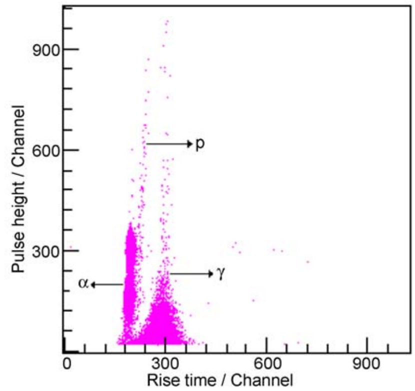

Fig.4 Two-dimensional plot of pulse-height versus pulse-shape (rise time) signal.

2.3 The fast and total component method (Fig.2C)

Decay time of the light emitted by CsI(Tl) differs for different particles. This makes the ratio of fast to the total component vary with different particles, hence the PID capability of the method.

All the modules are conventional ones. The 744 module is used to fan out the anode signal linearly. One branch of the outputs is used to get the fast component and the other is used to generate gates. Amplifier 474A is used to give the pulses delivered by the charge preamplifier a sufficient height to trigger the CFD. The CFD outputs are used to produce two gate signals to gate the QDC (charge-to-digital converter) and ADC, respectively. The QDC is used to measure the fast component of the signals, while the ADC is used to measure the total component.

Fig.5 shows the two-dimensional plot of the charge of fast component versus the total energy. Good PID for protons, α particles and γ-rays can be obtained.

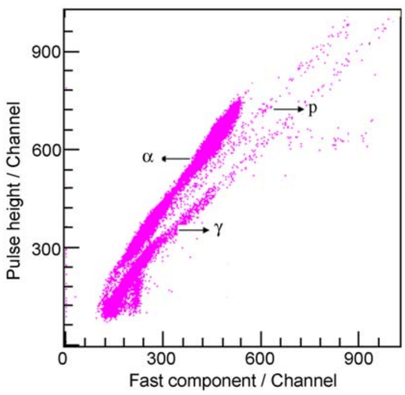

Fig.5 The two dimensional plots obtained with the fast and total components method.

3 Data analysis and results

Each of the methods has different electronic parameters (gain, shaping time, etc.). Therefore, γ calibration for the CsI(Tl) detector was carried out before comparing the three methods. Fig. 6 shows typical results of the calibration using ^{22}Na and ^{137}Cs sources for the signal rise time method. A linear fit was found with the γ-ray energy and channel number (Fig. 7). From the γ-ray calibration, the electron equivalent energy, E_{ee}, could be derived, and the lower limits of the particle separation for the three methods could be compared (Table 1).

Table 1 Lower limits of PID for different methods

Methods	Threshold (E_{ee}*)
Zero-cross time method	~ 0.6 MeV
Rise time method	~ 2.1 MeV
Fast and total components method	~ 2.2 MeV

Note: E_{ee}*, electron equivalent energy, is derived from the γ calibration

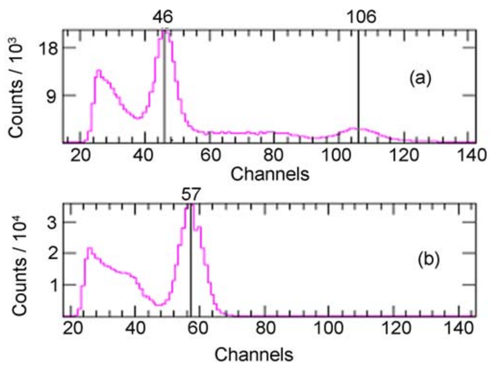

Fig.6 The γ calibration spectra of (a) ^{22}Na (0.511 and 1.274 MeV) and (b) ^{137}Cs (0.662 MeV)

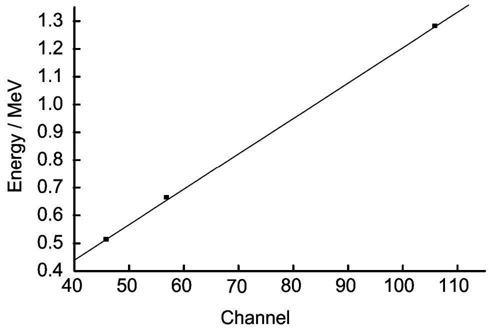

Fig.7 Fitting result for the γ calibration of the rise time method

From the results, good PID for protons, α particles and γ-rays can be obtained with the three methods. However, Table 1 shows that the zero-cross time method is the best, with the lowest limit for particle separation.

4 Summary

In this work, three pulse-shape discrimination methods have been studied for PID of protons, α particles and γ-rays. All the methods can separate the particles well and satisfy the requirement of doing good PID from a few MeV to 100 MeV. It should be noted, however, that the energy resolution of the CsI(Tl) detector used in this work is not very good. Its scintillation wavelength does not fit the cathode of XP-2020 PMT best. This is to be improved.

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