Characteristics of a 4-fold segmented clover detectore*

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Abstract Four high-purity germanium 4-fold segmented Clover detectors have been applied in the experiment of neutron-rich nucleus ^{21}N. The performance of those four Clovers have been tested with radioactive sources and in-beam experiments, and the main results including energy resolution, peak-to-total ratios, the variation of the hit pattern distribution in different crystals of one Clover detector with the energy of γ ray, and absolute full energy peak detection efficiency curve, were presented.

Key words clover, direct mode and add-back mode, absolute efficiency

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1 Introduction

The excellent performance of Clover detectors is interesting for β-decay experiments in recent years. For example, four high-purity germanium 4-fold segmented Clover detectors purchased from Eurisys, France by IMP(Institute of Modern Physics), were employed to detect γ rays following the β-decay of ^{21}N in order to construct the β-decay scheme of ^{21}N using β-n-γ three-fold coincidence[1].

In this paper, the characteristics of one Clover were studied, and the main results, including the energy resolution, the hit pattern and the add-back factor, as well as the absolute full energy peak efficiency curve, were shown.

2 Experimental setups

The figures and detailed description of experimental setups can be found in Ref. [1]. The Clover consists of four co-axial N-type High-Purity Germanium crystals, which were arranged like a four leaf clover. Each crystal electrically segmented into four segments has a diameter of 60 mm and a length of 90 mm. The distance from the center of each Clover's front face to the center of the β detector is only about 12 cm.

Standard radioactive sources such as ^{60}Co, ^{207}Bi and ^{152}Eu with the activity of 0.16 μCi, 1.43 μCi and

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4.48 μCi respectively, as well as radioactive beams of ^{17}N and ^{19}O(the impurity to ^{16}C beam) with well-known γ ray energies and branching ratios were used to study the characteristics of Clover detector. The primary beam of ^{26}Mg at 68.8 MeV/nucleon was provided by the HIRFL(Heavy Ion Research Facility in Lanzhou) and impinged on a ^{9}Be primary target. The produced fragments were separated, purified, and collected by the RIBLL (Radioactive Ion Beam Line in Lanzhou)[2]. The average intensities for the second beam of ^{17}N and ^{19}O was about 1900 pps and 160 pps with the purities of 86% and 48%, respectively.

3 Experimental results

3.1 Direct mode and add-back mode

The full energy peak detection efficiency of Clover detector with four crystals can be operated in two modes: direct mode and add-back mode. In direct mode, each crystal is considered independently as a single detector, even if the hit multiplicity is higher than 1, thus the full energy peak detection efficiency is simply the sum of the individual full energy peak efficiencies of each four crystal, ie. $\varepsilon_{\rm direct} = \sum_{i=1}^{4} \varepsilon_i$. In add-back mode, coincidence events in different crystals are summed resulting in the reconstruction of full-energy signals and the full-energy efficiency are the sum of one-fold events efficiency, two-fold events efficiency , three-fold events efficiency and four-fold events efficiency, ie. $\varepsilon_{\rm add-back} = \sum_{i=1}^{4} \varepsilon_i + \varepsilon_{2-\rm fold} + \varepsilon_{3-\rm fold} + \varepsilon_{4-\rm fold} = F * \sum_{i=1}^{4} \varepsilon_i$, where F is defined as add-back factor, and $F = \varepsilon_{\rm add-back}/\varepsilon_{\rm direct}$.

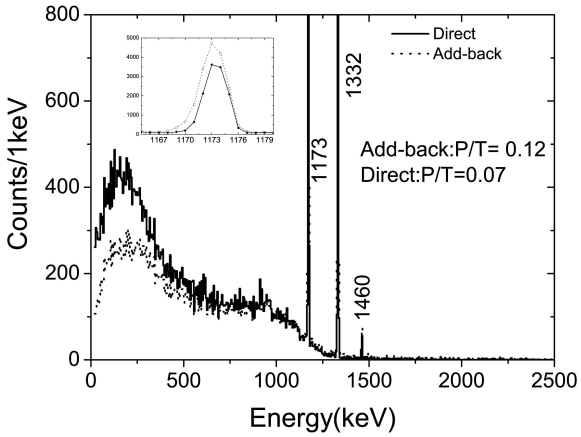

Fig. 1. The γ spectra of ^{60}Co source in both direct mode and add-back mode. Insert picture in the left top corner is the enlarged picture of 1173 keV full-energy peak.

As an example, the γ ray spectra (both in direct mode and add-back mode) obtain from one Clover with the ^{60}Co source was shown in Fig. 1. The reduction of Compton-background in add-back mode compared to the direct mode can be clearly seen from Fig. 1, especially in the low-energy part. The peak-to-total ratio improves from 0.07 to 0.12 as shown in the right part of Fig. 1. However, the energy resolution in add-back mode (3.00 keV) is worse than that in direct mode (2.5 keV), which can be clearly seen from the insert picture in the left top corner of Fig. 1.

3.2 γ spectra of ^{17}N and ^{19}O

Figure 2 shows the beta-delayed γ ray spectrum from ^{17}N measured by four Clovers. Two γ rays with energies of 871 keV and 2184 keV and with weak absolute intensities 3.3% and 0.34% respectively[3] can be identified clearly in Fig. 2, and another γ ray obtained from the β-decay of ^{20}F with the energy of 1634 keV and with the strong absolute intensity of 100%[4] can also be seen clearly in Fig. 2. Five γ rays from ^{19}O beam with the energies from 110 keV to 1554 keV were observed in this experiment.

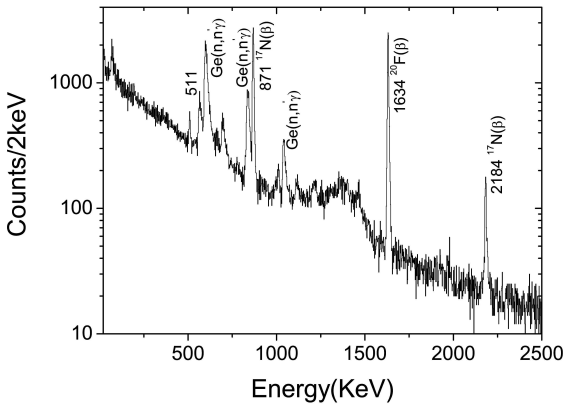

Fig. 2. β-delayed γ spectrum from ^{17}N measured by four Clovers. The energy (in keV) and the origin for each γ peak are labelled.

3.3 Hit pattern

The hit pattern distribution of different crystals in one Clover detector using only in-beam data with energy was shown in Fig. 3. For energies less than 200 keV, the probability of one hit events is almost 100%.

For energies below 871 keV, Fig. 3 shows the sharp decrease of one hit probabilities from 100% at 110 keV to nearly 72% at 871 keV, and corresponding to quick increase in two hit probability from 0% at 110 keV to nearly 26% at 871 keV.

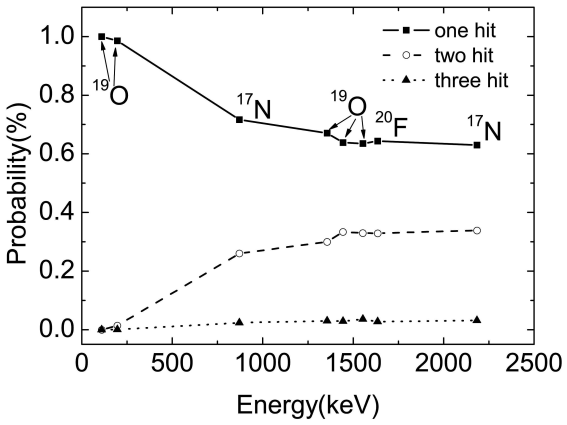

Fig. 3. Distribution of hit pattern with energy.

Above 871 keV, the hit pattern more or less stabilizes up to 2184 keV. It shows very slow increase in two and three hit probabilities, and slow decrease of one hit probability in this energy range. The one hit probability decreases from 72% of the total events at 871 keV to 63% at 2184 keV, the two and three hit probabilities increase from 26% and 2% to 34% and 3% in this energy range. The maximum of three hit probability is only 3% at 2184 keV.

3.4 Add-back factor

Another interesting parameter of the Clover detector is the add-back factor F corresponding to the gain in efficiency by summing the signals from different crystals fired simultaneously. In Fig. 4, the variation of add-back factor F with energy from 74 keV to 2184 keV was shown. The F factor at low energies starts from 1 indicating that the direct and add-back modes do not differ in efficiencies at low energies, since most of these γ rays with lower energies deposit their full energy in one of the crystals only. The factor then starts increasing sharply till 871 keV where the add-back mode contribution comes in. Although the rate of increase is less for γ rays with energies higher than 871 keV, the factor continues to increase steadily for energies up to 2148 keV. The value of F factor is up to 1.6 for 2184 keV γ ray.

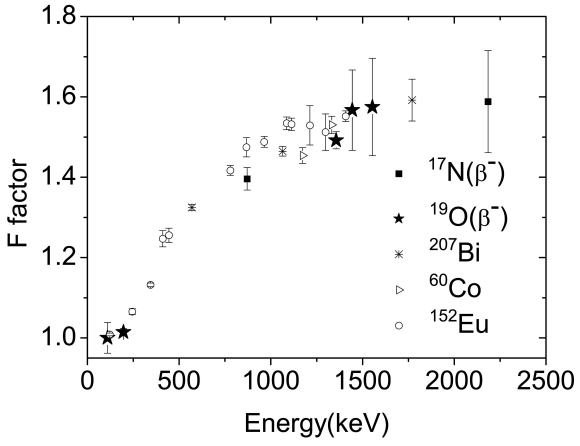

Fig. 4. Variation of F factor with energy.

The F factor obtained at 1408 keV is 1.53±0.03 in this test, which is in good agreement with 1.56±0.03 in Ref. [5].

3.5 Absolute efficiency

The absolute efficiency in add-back mode was calculated for the full-energy peak with energy range from 74 keV to 2184 keV. A special exponential decay curve with formula $y = y_0 + A_1 * \exp(-(x-x_0)/t_1) + A_2 * \exp(-(x-x_0)/t_2) + A_3 * \exp(-(x-x_0)/t_3)$ is presented along with data points for the total efficiency of one Clover in the Fig. 5.

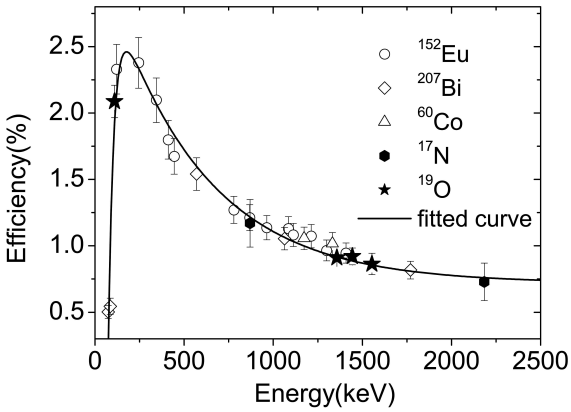

Fig. 5. γ detection efficiency as a function of γ energy in add-back mode for one Clover detector. The empty circles and solid dots indicate the experimental results obtained by applying radioactive sources and accelerated beams, respectively, and the solid curve is a fit to the experimental result.

The absolute efficiency is 1.22±0.09% for 1 MeV γ ray when the distance between the source and the Clover detector is about 12 cm. When the distance is about 11 cm, the GEANT 4 simulation result is 1.42% for 8-fold segmented HPGe detector with the same dimension as Clover discussed in this paper[6]. Take the difference of geometry efficiency into consideration, our test result is consistent with the simulated result.

4 Summary

The properties of a 4-fold segmented Clover were studied in this paper. The direct mode and add-back

mode were compared to each other, and the differences of two modes were discussed. The results of F factor, and absolute detection efficiency were inconsistent with previous results. The performance study of Clover is the basic work for physical experiments.

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