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WIMPs search by means of thin NaI(Tl) array

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Abstract. A thin plate of NaI(Tl) with the dimension of 5cm×5cm×0.05cm has been developed for WIMPs search. The thin NaI(Tl) showed the good performance for energy resolution and low energy threshold. The advantages for WIMPs search, especially, inelastic excitation of nuclei by spin-dependent interaction between WIMPs and ^{127}I is discussed.

1. Design of thin NaI(Tl) scintillator

The array of thin NaI(Tl) detector system was developed to search for a particle candidates of WIMPs (Weakly Interacting Massive Particles) dark matter. Since the good position and energy resolution is needed for the present project, the thin and wide area detector was designed. The principle of the search for WIMPs by means of thin NaI(Tl) detector is described in the previous paper [1].

The interaction between a WIMPs particle and a nucleus is divided into three types, spin-independent elastic scattering (SI), spin-dependent elastic scattering (SD) and nuclear excitation by inelastic scattering (EX). The NaI has the great advantage to searching for WIMPs because ^{23}Na is sensitive to both SI and SD types, and ^{127}I is sensitive to SI, SD and EX types. Since ^{127}I has a low energy excited state at 57.6keV which is excited via M1 transition, it is sensitive to only spin-dependent interaction [2, 3]. Recently atomic ionized electrons and hard X rays following WIMPs nuclear interactions are shown to be used for exclusive measurements of nuclear recoils from elastic scatterings of WIMPs off nuclei [4, 5].

Thin segmented NaI(Tl) has the following advantages.

(i) The range of a recoil nucleus is enough short to stop in one segment. Thus the signal event is observed by only one segment (S1 in Fig.1).

(ii) In the case of inelastic excitation of nucleus or atomic electron, the low energy γ ray or X ray is emitted. The γ ray or X ray escapes the segment and it is detected in the other segment(S2 in Fig.1).

(iii) The background event is mainly due to Compton scattering of high energy γ rays. Since the scattered *gamma* ray is detected by another segments, the background events is efficiently identified and rejected.

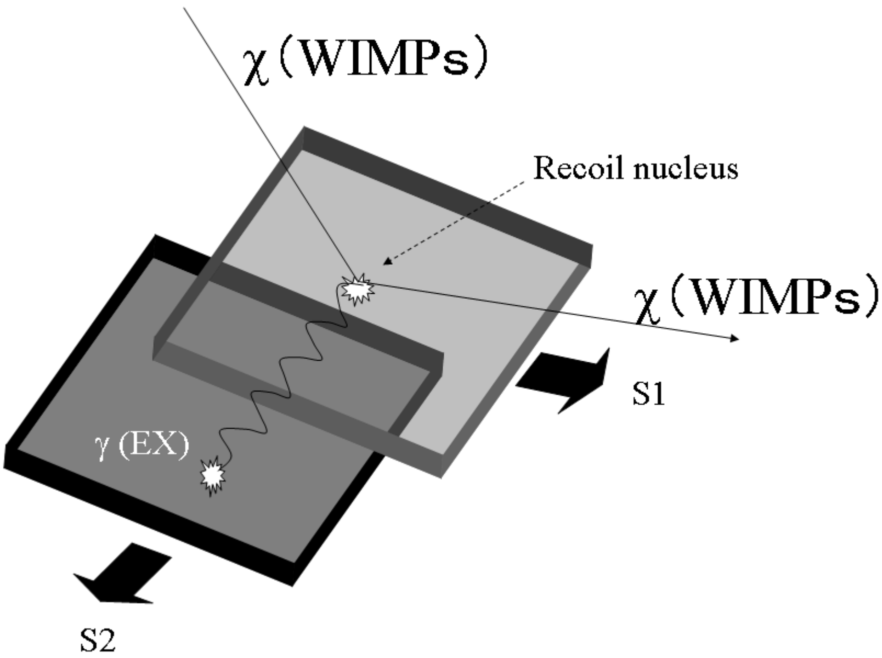

Figure 1. The schematic drawing of the detection principle of recoil energy and γ ray or X ray.

The dimension of the thin NaI(Tl) was 0.05cm in thickness in order to establish the good position resolution, and 5cm×5cm in area in order to enlarge the acceptance. The scintillation photons are collected from four thinner edges of the crystal through light guides. The light guide also acts as the damp course.

2. Energy resolution of thin NaI(Tl)

The energy resolution and the low energy threshold were measured by means of low energy gamma rays and X rays. The pulse height spectra for ^{57}Co, ^{133}Ba and ^{241}Am was measured. The energy spectra of ^{57}Co (left panel of Fig.2) and ^{133}Ba (right panel of Fig.2) are shown. The electronic noise was negligible in all the measurement, which was observed below a few ch in ADC spectrum.

The low energy X rays of Fe (6.4keV K_α) was clearly observed at around 50ch in left panel. It is remarkable for the case of ^{133}Ba, the low energy L-X ray of Cs (4keV) was observed at around 30ch. The energy threshold was determined about 3keV.

The energy resolution was calculated from many peaks of gamma rays. The good energy resolution was obtained by extremely thin NaI(Tl) plate as they are listed in table1. It was shown that the large fraction of scintillation photon was collected by PMTs.

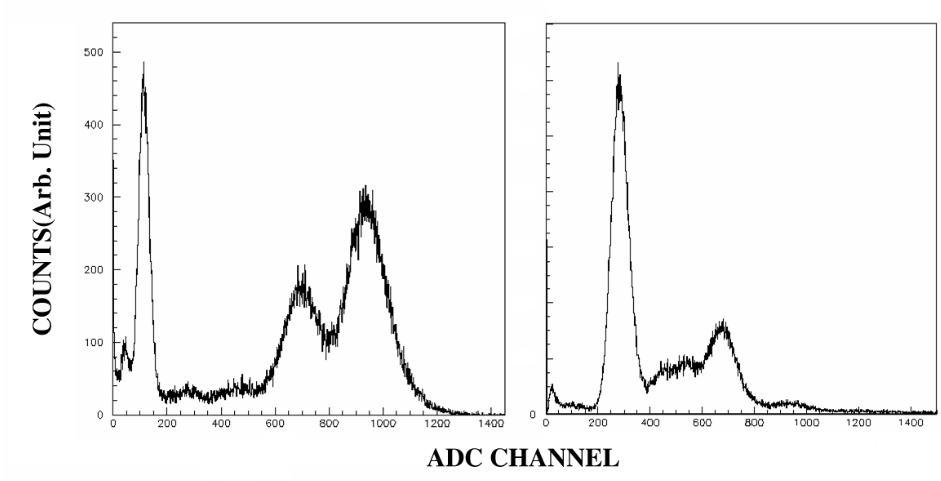

Figure 2. Pulse height spectra for low energy gamma rays. Left: ^{57}Co. Right: ^{133}Ba. The horizontal axes are ADC channel.

Table 1. Energy resolution for low energy photons in FWHM. The number of photo-electron was indicated in the fourth column.

Source	Energy (keV)	$\Delta E/E$ (FWHM)	# of P.E.
^{57}Co	122	0.14	282
^{133}Ba	81	0.13	328
^{241}Am	60	0.18	171
^{133}Ba	31	0.25	89

3. Position sensitivity

The position information in the wide area of the thin NaI(Tl) plate was estimated. Since about 170 photo-electron was collected from four edges of thin NaI(Tl) plate, good position resolution was expected. The position of the interaction of a radiation was analyzed by a roll-off ratio R which was defined by the formula,

$$R_{x,y} = \frac{P_{x1,y1} - P_{x2,y2}}{P_{x1,y1} + P_{x2,y2}}. \tag{1}$$

Where P_{x1} and P_{x2} are pulse heights of PMT output which are placed on the opposite side of NaI(Tl) on x-direction, P_{y1} and P_{y2} are the ones on y-direction. The position sensitivity was measured with collimated 60keV γ-ray. The position resolution in the wider side (5cm×5cm) was as good as 1cm in FWHM. It was found that higher segmentation is successfully performed by means of the roll-off analysis and the sensitivity is enhanced.

Acknowledgments

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