The high selective scintillator for dark matter search

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Search for dark matter candidates is one of the most important task in views of nuclear physics, astro physics and particle physics. So far, huge number of works were devoted to search for WIMPs dark matter. The DAMA group has reported a significant signal for the annual modulation signal of WIMPs [1]. However, another high sensitive measurement reported the no significant signal due to WIMPs [2, 3].

The present project proposes the selective measurement of WIMPs-nucleus interactions by means of a highly selective scintillator. The weak interaction between a WIMPs particle and a nucleus is classified into three types; spin-independent elastic scattering (SI), spin-dependent elastic scattering (SD) and spin-dependent inelastic excitation (EX). The most of the WIMPs search investigates the elastic interaction of WIMPs (SI and SD). On the other hand, a few groups reported the upper limits on the interaction rate of EX by NaI(Tl) [4] and liquid Xe [5].

A NaI(Tl) has the great advantage for the highly selective search for WIMPs dark matter because of the low lying excited state (ΔE =57.6keV) and the large nuclear matrix element with good accuracy [6]. The matrix element for inelastic excitation is expressed as

$$\lambda_N = \langle A^* \left| \mathrm{s} \right| A \rangle , \tag{1}$$

where $|A\rangle$ and $|A^*\rangle$ are the ground state and the excited state, s is the spin operator. In the case of the spin-streched transition to the excited state with spin $J' = J + 1$, the spin matrix element is related to the M1γ matrix element of $\langle A \left| M1 \right| A^* \rangle$ as

$$\langle A \left| \mathrm{s} \right| A \rangle = \sqrt{\frac{sJ' + 1}{2J + 1}} \cdot \frac{1}{g_M} \langle A \left| M1 \right| A^* \rangle , \tag{2}$$

where g_M is the M1γ coupling constant given by $(e\hbar/2M)(3/4\pi)^{1/2}(g_s - g_e)/2$ and $\langle A \left| M1 \right| A^* \rangle$ is obtained from the M1γ transition rate.

However, the sensitivity of EX by the previous detector system has been not sufficient to find the signal due to WIMPs because of the large background and the poor selectivity. The segmentation of the detector enlarges the sensitivity to the WIMPs signal because of high selectivity. The inelastic excitation of nuclei by WIMPs deposits the recoil energy and the following gamma ray. The highly segmented detector separately measures the recoil energy and the gamma ray by the different segment of the detector.

The thickness of the detector crystal is one of the most important feature, thus the "coincidence efficiency" was estimated by monte carlo simulation. In this paper, the "coincidence" is defined that the reoil energy and the gamma ray are observed by the another segment of the detector. The "coincidence efficency" is defined that the fraction of the "coincidence" events in the inelastic excitation.

The monte carlo simulation was performed with GEANT 3, the gamma ray energy was 57.6keV and the thickness of the NaI(Tl) was 0.5mm, 0.75mm, 1.0mm and 1.5mm, and the area of NaI(Tl) was 5cm×5cm. The "coincidence efficiency" was listed in table 1.

Table 1: The "coincidence efficiency" of 57.6keV gamma ray by the thin NaI(Tl) plate.

Thickness (mm)	Efficiency
0.5	0.21
0.75	0.18
1.0	0.15
1.5	0.11

To create the extremely thin and large NaI(Tl) plate was quite difficult because of NaI(Tl) is quite fragile and highly deliquescent. Recently the method to create large and thin NaI(Tl) has been established. The segmented and stacked NaI(Tl) detector will be soon made.

References

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