Simulation Study of Sn bolometer for 0νββ

Vivek Singh, Y. Gowda, V. Nanal*, R.G. Pillay
Department of Nuclear and Atomic Physics,
Tata Institute of Fundamental Research, Mumbai - 400005, INDIA
** email: nanal@tifr.res.in*

Introduction

Search for Neutrinoless double beta decay (0νββ) is one of the most interesting problems in the present era. Presently, this is perhaps the only experiment that will tell us the true nature of neutrino (Majorana or Dirac) and its absolute effective mass. A feasibility study of 0νββ in ^{124}Sn using a cryogenic bolometer has been initiated [1]. The constancy of sum energy of two emitted electrons is the signature the 0νββ process and good energy resolution is of extreme importance. Low specific heat of Tin in sub-Kelvin range enables its use as a bolometer. However, for rare events like 0νββ the bolometer size needs to be very large and an array of several small crystals is essential [2]. The sensitivity of detector is critically dependent on the reduction of background. The cosmogenic background is significantly reduced in underground laboratories, but the decay of radioactive trace impurities present in the detector and in surrounding material also contributes to the background. It is essential to discriminate these background gamma-ray events from electron events of interest. Unlike electrons, photons would typically interact with more than one detector element. Hence, by using the multiplicity information from a segmented array the e-γ discrimination can be achieved, in a limited manner. We have therefore carried out the simulations to study the background resulting from gamma ray interactions for different crystal configurations.

Bolometer Crystal Size

The size of an individual bolometer crystal needs to be optimized for a measurable temperature rise (ΔT). The ΔT depends on specific heat of the material, which varies strongly with temperature. At low temperatures (< 50 mK) the specific heat of material is very small allowing for greater ΔT per unit mass. In order to achieve an energy resolution ~ 0.2%, it is desirable to have $\Delta T \geq 100\ \mu K$ for 1 MeV energy deposition. Corresponding values for maximum permissible volume of a Tin crystal at different base temperatures are listed in Table 1.

Table 1: Crystal volume at different base temperatures

Base Temp. (mK)	*Volume (in cc)*	*Approx. size (a) of cubic crystal (cm)*
10	106	4.7x4.7x4.7
15	30	3.1x3.1x3.1
25	7	1.9 x1.9x1.9

Simulation using GEANT4:

The simulations were performed using GEANT4 [3]. Photons of different energies (E_γ = 511, 1460, 2615 keV) were randomly generated on a spherical surface enclosing a 3D array of 27 uniform cubic tin crystals of different sizes (a = 2, 3, 5 cm). The radius of the sphere was kept much larger than crystal size to ensure uniform illumination of the array. The spacing between the individual crystals within the array was also varied between 2 to 10 mm. The photon energies considered cover the range of interest for natural background radiations.

If the multiplicity of an event is denoted by M, then total events detected in the array can be written as

$$N_{total} = (N_p+N_b)_{M=1} + (N_p+N_b)N_{M>1}$$

where N_p and N_b are photopeak and background events respectively. As mentioned earlier, M >1 events are expected to predominantly arise from photons. The photopeak events ($N_{p,M=1}$) also can be clearly identified even with M=1. Therefore, difficulty arises for identification and rejection of M=1 background events ($N_{b,M=1}$) only. It is thus essential to choose an array configuration where $N_{b,M=1}$ is minimized.

Figure 1 (a) shows the ratio $N_{b,M=1}/N_{total}$ (open symbols) and $N_{p,M=1}/N_{total}$ (filled symbols) as a function of energy for different crystal sizes but for same inter-detector spacing (2 mm). The ratios $N_{b,M>1}/N_{total}$ and $N_{p,M>1}/N_{total}$ for events with higher fold (M>1) are shown in panel (b). The background and photo peak efficiency ratios for M=1 events for the central crystal of the array are shown in panel (c). This is an indication of shielding effects of surrounding elements. The effect of inter-detector spacing on M=1 events for 3x3x3 cm^3 crystal is shown in panel (d). It is evident that $N_{b,M=1}/N_{total}$ is minimum and photopeak efficiency is maximum for larger crystal size, while the $N_{b,M>1}/N_{total}$ is only weakly dependent on the crystal size. As expected the background also increases with inter-detector spacing.

The present results indicate that the 3x3x3 cm^3 crystals with a minimum inter-detector spacing would be preferable for the prototype module, to operate in the temperature range of 10−15 mK.

References

[1] V. Nanal, Proceedings of NDBD workshop, p45 Ed. *V.K.B. Kota and Utpal Sarkar*, Narosa publishers (2007)

[2] E. Previtali *et al.* Nuclear Instruments and Methods in Physics Research A**518**, 256 (2004)

[3] www.cern.ch/geant4

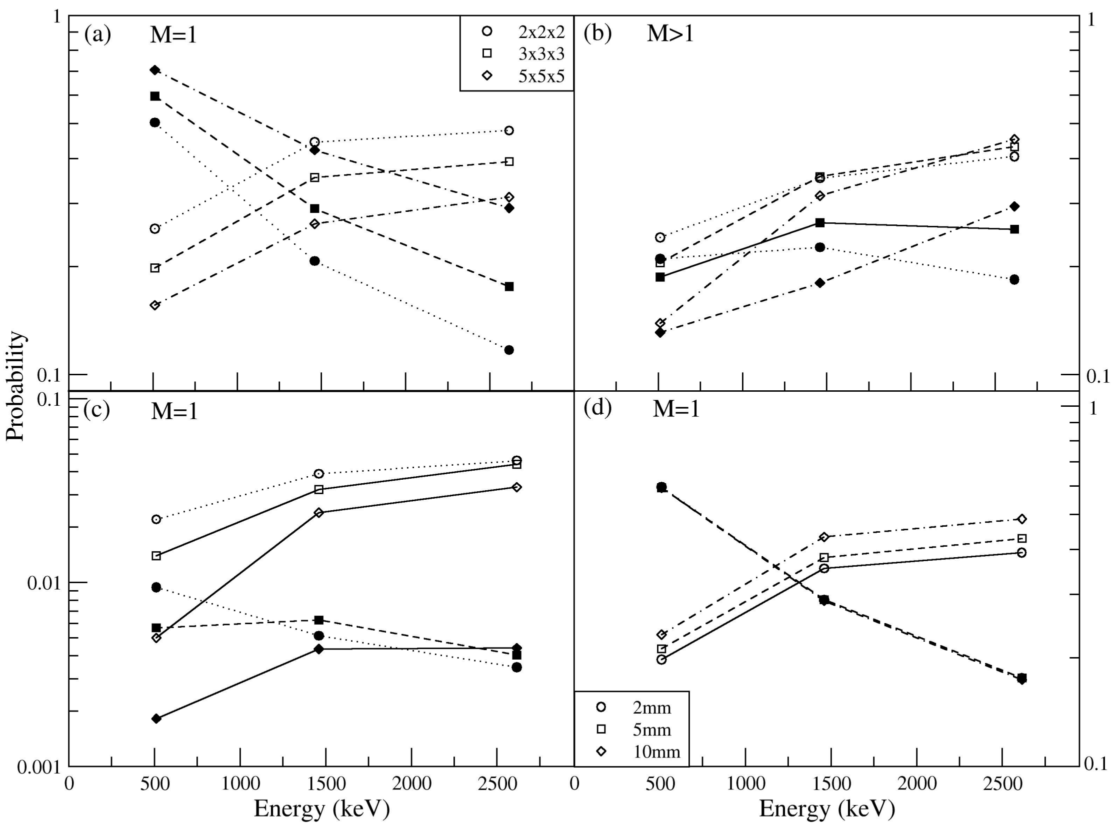

Fig. 1: Plots of variation of N_b/N_{total} (open symbols) and N_p/N_{total} (filled symbols) with crystal volume for the whole array (a) with M = 1, (b) with M > 1; (c) $N_{b,M=1}/N_{total}$ and $N_{p,M=1}/N_{total}$ for the central detector and (d) Effect of inter-detector spacing for a given crystal volume (3x3x3 cm^3).