Monte-Carlo Simulation of CdWO₄ Scintillator Detector

S. K. Ghorni¹,², *, P. K. Rath², P. K. Raina¹, A. K. Singh¹, F. Cappella³, and R. Cerulli⁴

¹Dept. of Physics & Meteorology, IIT Kharagpur, INDIA  
²Dept. of Physics, Lucknow University, INDIA  
³Dip. di Fisica, Università di Roma “La Sapienza” and INFN, ITALY and  
⁴INFN - Laboratori Nazionali del Gran Sasso, Assergi (AQ), ITALY

Introduction
The positive evidence of neutrino oscillation from atmospheric, solar and reactor neutrino experiments established that neutrino has non-zero mass [1]. The investigation of neutrinoless double beta (0νββ) decay is one of the most sensitive experiments to probe the absolute value of neutrino mass and the nature of neutrino (i.e., if it is Dirac particle or Majorana particle).

¹⁰⁶Cd is one of the promising candidates for double beta decay experiment because of its high transition energy (Q_{ββ}=2771 keV). Experimentally it is less challenging to reduce the background for double beta decay isotope with high Q_{ββ}. Also the contribution of cosmogenic activation is less at higher energies. Recently the R&D is under progress to develop enriched ¹⁰⁶CdWO₄ crystal scintillators to search for double beta decay processes in ¹⁰⁶Cd [2].

Here we present the simulation of a typical CdWO₄ crystal (enriched in ¹⁰⁶Cd) scintillator detector using "GEANT4" simulation toolkit and Decay0 event generator [3].

Detector Description
The detector is made of 321.5 gm of CdWO₄ crystal enriched in ¹⁰⁶Cd isotope to 68%. The scintillating detector is cylindrical in shape (Ø3.6 × 4.0cm) and placed inside a 10 cm thick Copper (Cu) box of inner dimension 80 × 40 × 27 cm with symmetry axis along z-axis of the world volume. The Cu box again is surrounded by 15 cm of lead. Two Photo-multiplier Tubes (PMT) are connected to both sides of the scintillator along z-axis by 10 cm long quartz lightguides that are also taken as cylindrical shape with radius 1.8 cm for simplicity. Two 10cm × 10cm × 10cm NaI(Tl) detectors are symmetrically placed along y-axis to study the coincidences.

Results
The expected response functions of CdWO₄ detector for various mode of ¹⁰⁶Cd double beta decay are simulated for 0νβ⁺β⁺, 0νECEC, 2νβ⁺β⁺, 2νβ⁺EC and 2νECEC decays of ¹⁰⁶Cd for the transition to ground state of ¹⁰⁶Pd. The spectra of 0νβ⁺β⁺ and of 0νβ⁺EC without requiring signals in the outer NaI(Tl) detectors are presented in Fig. 1.

As a typical case, the coincidence patterns studied to search for double beta decay of ¹⁰⁶Cd for 0νβ⁺β⁺(0⁺ → 0⁺) are

- **case (a)** the response of the CWO detector in coincidence with one of the NaI(Tl) detector(s) in the energy window : 481-541 keV(±1σ around 511 keV),
- **case (b)** triple coincidence among CWO, NaI1 and NaI2 for same energy window as case (a) for NaI(Tl) detectors.

Similar studies have been done for the case of 0νβ⁺EC(0⁺ → 2⁺) and 0νβ⁺EC(0⁺ → 2⁺) decay modes. The details of results shall be discussed during the presentation session.

The detection efficiencies of the CdWO₄ detector in double and triple coincidence with NaI(Tl) detector(s) for the case of 0νβ⁺β⁺(0⁺ → 0⁺) are reported in the Table I. The resolutions of the NaI detectors are same as in ref. [4].

Conclusions
The smallness of the detector taken for the
FIG. 1: Response of the CdWO₄ detector for ββ decay of $^{106}$Cd (g.s. to g.s.)

TABLE I: Efficiency of CdWO₄ detector in coincidence with NaI(Tl) detector(s)

<table>
<thead>
<tr>
<th>Decay mode</th>
<th>Selection criteria</th>
<th>CdWO₄ energy window (in keV)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0\nu\beta^+\beta^+$ case (a)</td>
<td>1100-2100</td>
<td>9.65</td>
<td></td>
</tr>
<tr>
<td>$0\nu\beta^+\beta^+(0^+ \to 0^+)$ case (a)</td>
<td>2150-2450</td>
<td>7.55</td>
<td></td>
</tr>
<tr>
<td>case (b)</td>
<td>1100-2100</td>
<td>1.17</td>
<td></td>
</tr>
</tbody>
</table>

Simulation makes the coincidence technique a powerful tool to search double beta decay of $^{106}$Cd with a low background. Two low background NaI(Tl) detectors have been placed in opposite side of central CdWO₄ detector to study coincidences. The detection efficiency of CdWO₄ in coincidence with NaI(Tl) detector(s) in the energy window 2150-2450 keV is within 7-8% for different cases studied above. Also at this energy range the background will be comparatively lower, therefore this channel could be more promising to search for double beta decay of $^{106}$Cd.

Acknowledgments

The author (SKG) would like to record special thanks to R. Bernabei for facilitating visit to Gran Sasso. Fruitful discussions with other members of group, P. Belli, A. Incicchitti, F. A. Danevich and V. Tretyak alongwith financial assistance from INFN is gratefully acknowledged.

References