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Study of the background ^{137}Xe for the neutrinoless double-beta decay search with ^{136}Xe

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Neutrinoless double-beta ($0\nu\beta\beta$) decay if observed would establish the Majorana nature of neutrino and constraint effective Majorana neutrino mass ($m_{\beta\beta}$).^{136}Xe is an attractive candidate for $0\nu\beta\beta$ decay search with a high $Q_{\beta\beta}$ = 2457.83 ± 0.37 keV. Search requires low background in the region of interest. Neutron induced production of ^{137}Xe could mimic the $0\nu\beta\beta$ decay signal and therefore must be reduced in the currently running and planned experiments. In this article, we presented the simulation results of the production of ^{137}Xe at different neutron resonance energies.

1. Introduction

Neutrinoless double-beta decay is a hypothetical nuclear decay in which two neutrons simultaneously decay in two protons without the emission of neutrino in the final state. $0\nu\beta\beta$ decay is forbidden in the Standard Model and the decay if observed would violate the conservation of the lepton number. $2\nu\beta\beta$ decay is observed in few even-even nuclei including ^{136}Xe [1]. Several experiments are planned to observe $0\nu\beta\beta$ mode : $^{136}\mathrm{Xe} \rightarrow {}^{136}\mathrm{Ba} + 2e^-$. KamLAND-Zen measured the lower limit on the $0\nu\beta\beta$ decay half-life $T^{0\nu}_{1/2} > 3.8\times10^{26}$ yr at 90 % C.L. and upper limit on $m_{\beta\beta}$ are in the range 28 - 122 meV [2].
While observing the signal for $0\nu\beta\beta$ decay in ^{136}Xe ($Q_{\beta\beta}$ = 2457.83 ± 0.37 keV), several intrinsic and extrinsic backgrounds are present including muon induced neutrons and radiogenic neutrons. ^{137}Xe is produced via thermal neutron capture process as $^{136}\mathrm{Xe}(n,\gamma)^{137}\mathrm{Xe}$. The resulting ^{137}Xe is radioactive with a half-life of 3.8 min, which undergoes β^- decay. This energy spectrum overlaps with the $0\nu\beta\beta$ decay ROI ($Q_{\beta\beta} \pm 1\sigma$ [3]) as shown in figure 1.

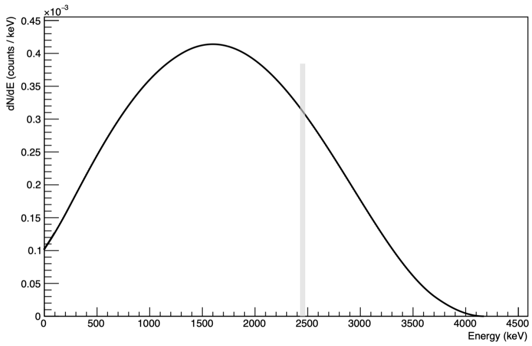

FIG. 1: Energy distribution of ^{137}Xe β^- decay. Grey band depicts the region of interest. Data is taken from Ref.[4].

2. Simulation Setup

The LUX-ZEPLIN (LZ) detector is located in Davis cavern at the Sanford Underground Research Facility (SURF) in Lead, South Dakota. LZ is a WIMP dark matter experiment and will also be sensitive for $0\nu\beta\beta$ decay search with ^{136}Xe. LZ consists of a time projection chamber (TPC) filled with 7 ton of liquid Xe (LXe) with an abundance 8.857% of ^{136}Xe with a mass 623 kg. TPC is surrounded by Gadolinium loaded liquid scintillator, which is further shielded by water.
We are using GEANT4 [5–7] to simulate the

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production of ^{137}Xe via neutron capture. Our simulation consist of a titanium cryostat (4 mm thick) filled with LXe (density 2.953 gm cm^{-3}) in a radius of 75 cm and height 150 cm (this is the same dimension as LZ TPC). Cryostat is kept in a stainless steel tank of radius 381.2 cm with a height of 592.4 cm filled with water.

3. Result and Discussion

For the preliminary analysis, we are distributing the mono-energetic neutrons of energy 2.154 keV in the active volume region. The criteria behind this energy selection is that for ^{136}Xe(n,γ)^{137}Xe reaction we observe first resonance at 2.154 keV with the cross-section of 16.77 barn as shown in fig.2.

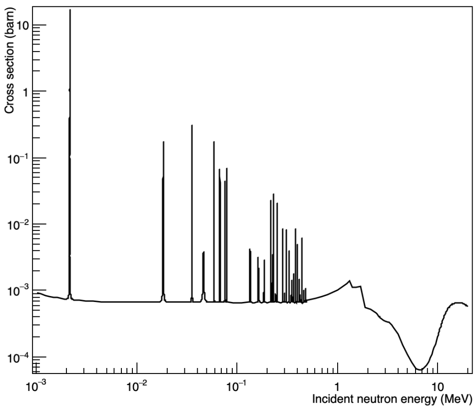

FIG. 2: Cross-section as a function of incident neutron energies for ^{136}Xe(n,γ)^{137}Xe. Data is taken from [4].

In an attempt to study the backgrounds we are observing the production of ^{137}Xe through neutron capture inside the TPC. Only one ^{137}Xe production is observed when minimum of seven neutrons are distributed in the TPC. The same process is repeated for the energies above and below the resonance energy and we do not observe any neutron capture by ^{136}Xe, however these neutrons undergoes elastic scattering with ^{136}Xe. In addidion to $0\nu\beta\beta$ isotope, natural LXe also consist of other xenon isotopes: ^{124}Xe(0.09%), ^{126}Xe(0.089%), ^{128}Xe(1.91%), ^{129}Xe(26.401%), ^{130}Xe(4.071), ^{132}Xe(26.909%), ^{134}Xe(10.436). These isotopes can also proceed the neutron-capture reaction at their respective resonance energies. The production of a single daughter isotopes via reaction (n-γ) with minimum number of neutrons are distributed in TPC are summarised in table I.

TABLE I: n-capture reactions at first resonance energy of different isotopes of liquid xenon.

n-capture process	**Ist resonance energy (eV)**	**Min. neutron reach at LZ TPC**
^{124}Xe(n,γ)^{125}Xe	5.089	1
^{126}Xe(n,γ)^{127}Xe	9.8796	1
^{128}Xe(n,γ)^{129}Xe	100.16	1
^{129}Xe(n,γ)^{130}Xe	9.569	1
^{130}Xe(n,γ)^{131}Xe	430	2
^{132}Xe(n,γ)^{133}Xe	114.9	1
^{134}Xe(n,γ)^{135}Xe	338.99	2
^{136}Xe(n,γ)^{137}Xe	2154	1

In future, we are planning to study how the enrichment of ^{136}Xe as well as the atmospheric neutrons will effect the backgrounds of $0\nu\beta\beta$ decay.

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