Sensitivity of PPC HPGe detectors to Reactor Antineutrinos

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Introduction

Reactors are source of copious amounts of $\bar{\nu}_e$s, producing $\sim 10^{17}\bar{\nu}_e$s/MW$_{th}$. This has been exploited by various experiments to measure neutrino oscillation parameters like mixing angles and mass squared differences. These experiments rely on the Inverse Beta Decay (IBD) process $\bar{\nu}_e + p \rightarrow n + e^+$ which has a 1.8 MeV energy threshold. Due to this threshold and small cross section of the IBD process ($\sim 10^{-17}$ barn), experiments based on it need large detector volumes and/or long duration data taking to achieve significant statistics.

Coherent Elastic Neutrino Nucleus Scattering (CEνNS) process [1] provides another avenue for the study of neutrino properties using reactor antineutrinos. CEνNS is a flavour blind process with zero threshold. It also benefits from coherent amplification of the interaction cross-section by (number of neutrons)^2, thus allowing for statistically significant data to be collected using smaller detectors. The downside to this is that the nuclear recoils generated in this process are $O(keV)$ which are quenched to $O(100eVee)$ detectable energy, thus requiring low threshold detectors for detection.

P-type Point Contact High Purity Germanium (PPC HPGe) detectors have been demonstrated to achieve threshold of 200eVee [2] thus allowing for measurement of reactor $\bar{\nu}_e$s via CEνNS. The low thresholds and absence of any correlated signal in this process however result in large backgrounds in the region of interest. The large amounts of γ's and neutrons produced by reactors need to be attenuated, absorbed or rejected to allow for measurement of this rare (low cross-section) process. This necessitates design of proper shielding incorporating both active and passive elements. In this paper we present our calculations for event rates in PPC HPGe detector and preliminary simulation results of shielding design for the same.

CEνNS Event Rate

We consider a setup comprising of net 10 kg of PPC HPGe detectors as described in [3]. The event rate in detector is given by:

$$\frac{dR}{dE_{nr}} = \frac{M_{det}}{M} \times \int_{E_{min}}^{\infty} \frac{d\sigma}{dE_{nr}} f(E_\nu) dE_\nu \quad (1)$$

where M_{det} and M are the masses of the detector and the target nucleus respectively, $f(E_\nu)$ is the $\bar{\nu}_e$ flux at detector, $d\sigma/dE_{nr}$ is the CEνNS cross-section [4] and E_{min} is the minimum neutrino energy required to produce a nuclear recoil of E_{nr}. To get the differential rate in electron equivalent energy (dR/dE_{ee}), we multiply Eq. 1 with $dE_{nr}/dE_{ee} = Q^{-1}(1 - E_{nr}dQ/dE_{ee})$, where '$Q$' is the quenching factor. This is shown in Figure 1 for three Indian reactors. Also shown is the targeted background level of 10/keV/kg/day, which will allow for 5σ detection in two years. Table I gives the expected counts/year at these reactors for two different thresholds.

Reactor	Power (MW_{th})	Distance (m)	Threshold(E_{ee}) 200eV	300eV
Dhruva	100	13	108	12
Tarapur	1800	30	360	36
Kudankulam	3000	30	612	84

TABLE I: Expected counts/year in 10 kg PPC HPGe detector at different reactors

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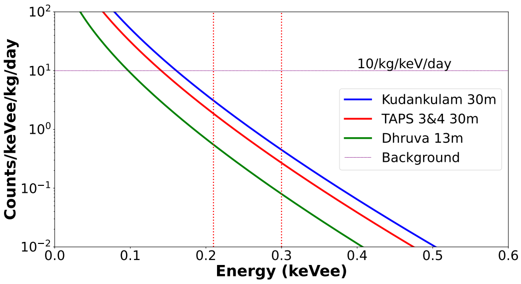

FIG. 1: Recoil spectra in HPGe and expected Background

Shielding Simulation

A conceptual design of the layered shielding for mitigating reactor induced background in the proposed experiment is given in [5]. The outermost layer of shielding is made of plastic scintillators for tagging muons and other external background. This is followed by a 10cm thick layers of HDPE followed by Borated Polyethylene for thermalizing and absorbing fast neutrons. A 10cm thick layer of lead is next for attenuating gamma rays followed by a second layer of HDPE to stop residual neutrons from conversion processes. This is followed by an internal veto system with the detector being placed in an OFHC copper housing.

The shielding design was simulated in GEANT4 for 10^7 incident neutrons (0.1-4 MeV) and gammas (0.1-10 MeV). Figure 2 shows the ratio of γ and neutrons entering the experimental volume for different incident γ and neutrons energies. As γ & X-rays deposit their entire energy, only [0-10] keV will contribute appreciably to the background in CEνNS energy range of interest. In case of neutrons however, elastic scattering dominates in keV energy range. The maximum energy of the recoiling nucleus (E_r) for neutron of energy E_n incident on nucleus of mass A is given by $E_r = 4E_nA/(1 + A)^2$, which is approximately $0.04E_n$ for Ge. With a quenching factor of around 10-15%, only neutron energies $\gtrsim$ 80keV will contribute to the background above achievable energy thresholds of 200eV. This is plotted as dashed green lines in Figs. 2(a) & 2(b). It is seen that our shielding design is capable of reducing γ induced background by $\sim$ 6 orders of magnitude while neutron induced background reduces by 3-7 orders of magnitude over the simulated energy range.

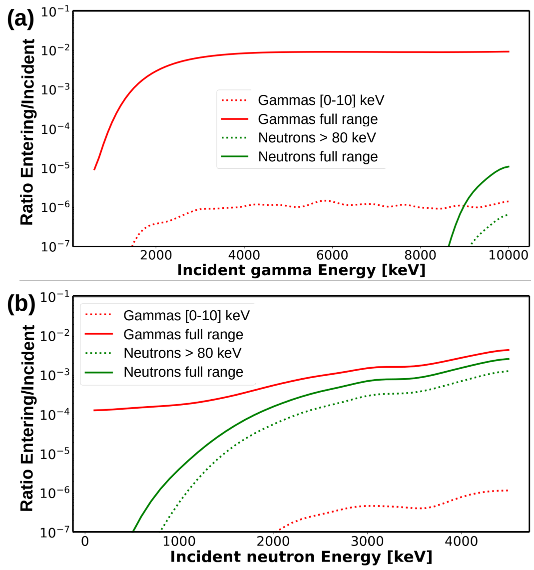

FIG. 2: Ratio of particles of all energies (solid line) and those contributing to background in [0.2-1]keV (dashed line) entering detector volume for different incident (a) γ-ray & (b) neutron energies.

Future Prospects

We plan on taking long duration measurement of neutron and gamma backgrounds at the identified reactor sites and using them for evaluation of expected background rate and spectra. For experimental site located outside the reactor dome, muon induced background is expected to contribute more than γ and neutron induced background.

References

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