Simulation of detector response for antineutrinos and reconstructing their energy spectrum with plastic detector array

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Introduction

A series of experiments measuring neutrino spectrum from different sources viz. solar, atmospheric, reactor, and accelerator have been persued to study neurtino physics. Recently these studies lead to observation of neutrino oscillation. Neutrinos from reactor are not only used for studying the neutrino oscillation phenomena but also for monitoring and safeguarding [1] the nuclear reactor. The antineutrino spectra is affected by relative yields of fissioning isotopes which depend on the isotopic composition of the core. Hence, the change in composition can be observed or monitored without directly accessing the core itself. Measurements of antineutrino spectra could therefore offer an alternative means for verifying the power history and fissile inventory of a reactor.

In a nuclear reactor, power comes from the energy produced by the fission of heavy elements (i.e. U and Pu) into neutron rich fragments. These fission products undergo β-decay and produced neutrinos. The antineutrino flux emitted by a 100 MWth reactor is 1.5×10^{19} antineutrinos/second. Albeit the interaction cross section between matter and neutrinos is very small ($\sim 10^{-43}$ cm^2), the huge emitted flux allows us to detect their signal with a relatively small detector (1 ton scale) placed at a few meters from the core of the reactor.

Detection Principle

Antineutrinos from the reactor interact with protons in the detector which consists of Gadolinium wrapped plastic scintillator bars,

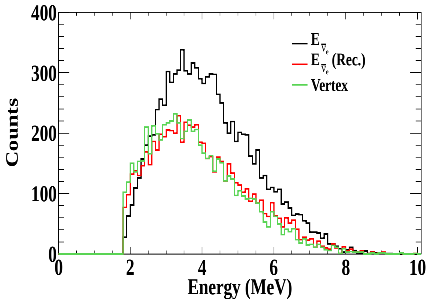

FIG. 1: Comparisons of reconstructed and input $E_{\bar{\nu}_e}$ distribution, black line input energy, red line and green line show reconstructed and vertex energy of neutrino respectively

via the Inverse Beta Decay (IBD) reaction

$$\bar{\nu}_e + p \rightarrow n + e^+ \tag{1}$$

The Q-value of the reaction is -1.80 MeV. The positron which carries almost all of the energy rapidly loses its energy in the detector and gets annihilated producing two gamma rays. The energy loss of the positron constitutes the prompt signal along with the Compton scattered annihilation gamma rays given by . Hence,

$$E_{prompt} = E_{\bar{\nu}_e} + Q + 2m_e c^2, \tag{2}$$

where $E_{\bar{\nu}_e}$ is the energy of antineutrino. This prompt pulse is followed by a delayed signal induced by the radiative capture of the thermal neutron by Gadolinium with the emission of a gamma cascade of total energy $\sim$8 MeV. In Eq.(2) the factor Q implies a kinematical threshold of IBD reaction. The correlation between the prompt and the delayed signal uniquely identifies the IBD event.

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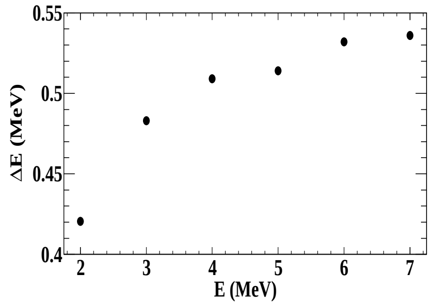

FIG. 2: Response of monoenergetic positron

Simulation and reconstruction

In order to stduy the performance of the detector, the object oriented simulation toolkit GEANT4 [2] was used for the detailed simulation of the detector for positron and neutron produced due to $\bar{\nu}_e$ interactions with detector. The detector which is modeled consists of 100 plastic scintillator bars, each having a dimension of 100 cm $\times$ 10 cm $\times$ 10 cm arranged to form a cube of 1 m^3. Each bar is wrapped with a 25 μm mylar foil coated with Gd paint ($\sim$ 4 mg/cm^2) as the neutron capture cross section is very high ($\sim$10^5). The scintillator ($C_{10}H_{11}$) material with a density of 1.032 g/cm^3 will act as the target as well as the detector. A sample of 10^4 events with energies upto 10 MeV are randomly generated within volume of the detector. Two configurations, 4 $\times$ 4 and 10 $\times$ 10 plastic scintillator detectors array were used to study the performance of the detector. For each IBD event, the pulse height (putting a threshold of 5 mV) and time of each detector is recorded.

Results and Discussions

The inforamtion for each event obtained from simulation was used to reconstuct the neutrino energy, multiplicity and efficiency of both detector configurations. The response of the detector for monoenergetic neutrinos is studied for the energies 2MeV, 4MeV,5MeV and 7MeV. The obtained energy spectrum for each energy is fitted with a gaussian function

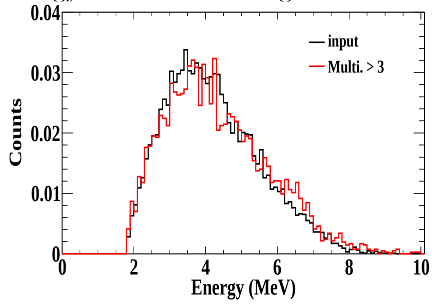

FIG. 3: Comparisons of input and reconstructed neutrino energy distribution, black and red line show normalized input and reconstructed (multiplicity >3) energy respectively

and the shift in maen position is plotted in Fig.2. The partial deposition of the energy of anihilation photon corresponds to the shift in mean. The pulse height of detector is linearly calibrated with electron energy. The energy of neutrino has been reconstructed by putting the conditition that prompt timing (τ_p) of positron should be $0 < \tau_p < 20$ ns. To get the vertex position of the event, we consider the maximum pulse height of the detector. Both reconstructed (red line) and energy corresponding the maximum pulse height (vertex position of the detector, green line) almost matches with the input energy (black line) of neutrinos as shown in Fig.1. The normalized reconstructed neutrino energy spectrum obtained by imposing cut on multiplicity (>3) with the input spectrum as shown in Fig.3. Similar response is found 10 $\times$ 10 plastic scintillator detectors array. Effect of threshold on the reconstructed energy spectrum is being studied.

References

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