Time distribution measurements of prompt-delay events at the Dhruva reactor for detection of antineutrinos

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Introduction

The measurement of the antineutrino spectrum from reactors is an effective tool to investigate the fundamental aspects of neutrino physics and to monitor the status and composition of reactor cores. A recent re-analysis of short-baseline reactor neutrino experiments has revealed a discrepancy between observations and the predicted antineutrino flux [1]. It might be a signal of oscillation to an additional 'sterile' flavour beyond the global 3-flavor neutrino and antineutrino picture [2]. The changes in the reactor antineutrino emission rate can be correlated with the evolution of the reactor power [3] and fissile inventory [4]. A large plastic scintillator array is planned to be installed at the Dhruva reactor hall, BARC for these investigations and reactor monitoring purposes [5]. The antineutrinos are conventionally detected via the inverse beta decay interaction $\bar{\nu_e} + p \rightarrow n + e^+$, which takes place typically on a proton in the plastic scintillator detector with the energy threshold of 1.8 MeV. The positron deposits energy via ionization, and emits two gamma rays by annihilation, together providing the prompt signal. The neutron is thermalized in the plastic and captured some time later by gadolinium wrapped on the scintillators bars, and a gamma ray cascade is produced with total energy of about 8 MeV, referred to as the delayed event. The antineutrino interactions can be identified through the correlation of the prompt positron signal and a delayed neutron capture signal. However, the enhanced background due to neutrons and their radiative capture at the reactor site and the neutrons produced by cosmic muons needs to be discriminated from the true antineutrino interactions.

Detector Setup and Measurements

The proposed detector consists of 100 plastic scintillator bars (100cm x 10cm x 10cm) wrapped with gadolinium (Gd) coated mylar films (4.9 mg/cm^2). The segmentation of the detector allows the energy deposit in each module to be recorded separately and therefore, it becomes possible to use the event topology information to tag the antineutrino events and to discriminate them from background. Each plastic scintillator bar is readout by directly coupling it to the photomultipliers (PMTs) at the both ends. To start with, 12 scintillator bars (100cm x 6cm x 6cm) have been assembled in a 3 x 4 matrix and placed inside a 10 cm thick lead shielding. It is installed 13m from the centre of the reactor core inside the Dhruva reactor hall. Fig. 1 shows the photographs of the scintillator matrix assembled inside the Dhruva reactor hall.

Fig. 1: Photographs of the prototype detector array for background studies with a matrix of 3 x 4 scintillators inside the lead shielding in the Dhruva reactor hall

Various measurements have been performed with this prototype setup. Measurements have been performed in the conditions when the reactor is on and off to investigate the response and performance of these scintillator bars and study the background conditions. The goal of these measurements is to quantify the neutron and radiation induced backgrounds and decide upon the shielding required. Further, the analysis conditions relevant to identification of events related to antineutrino interactions are optimized by using the measurements from this prototype setup. For the energy calibration of each scintillator, the pulse height distribution from the gamma rays of ^{60}Co, ^{137}Cs, ^{22}Na and Am-Be sources were recorded using the PMTs on both sides with sources kept at different locations on the scintillator bar. The calibration has been performed for all the 12 scintillator bars by performing fits to the energy spectra to extract the energy values corresponding to the Compton edges and subsequently taking the geometric mean of the two readout energy values.

Time distribution Measurements

Energy spectra for a pair of neighbouring scintillator bars were measured in coincidence when reactor was operating at ~ 90MW power. Analysis of the energy spectra of scintillator bars for different time windows over a large time period showed a remarkable stability of the reactor power and the detector response during the period in which the data was acquired. Apart from the energy depositions in two scintillator bars, the spectrum of time interval between energy depositions into these bars was also recorded using a time to amplitude converter (TAC) module. The time distribution of the energy deposition in two bars when the reactor is off (ROFF) and the reactor is on (RON), were measured for similar acquisition time. The measured TAC spectra for these two conditions are shown in Fig. 2.

The background in the RON conditions are more than three order of magnitude higher than the ROFF conditions. In the ROFF conditions, the measured time distribution shows two clear features as shown in Fig. 3. In the 0-100 μs region, the time distribution has a fast decaying component that corresponds to correlated background. This component can be fitted with an exponential, with a slope consistent with the neutron capture time. Beyond this time region in the time interval (100-350 μs) the time distribution has a slow component, which can be fitted with an almost flat distribution. It is due to the random coincidence of two sequential background events when signals in two bars exceed the relevant energy thresholds.

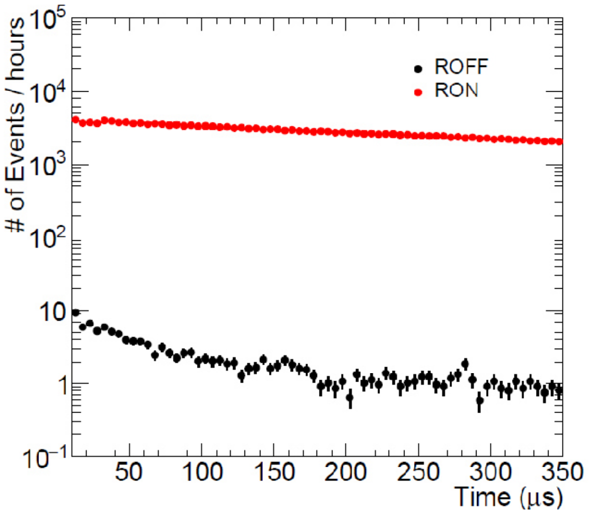

Fig. 2: Time interval distribution for background events for conditions when the reactor is on and reactor is off in two scintillator bars.

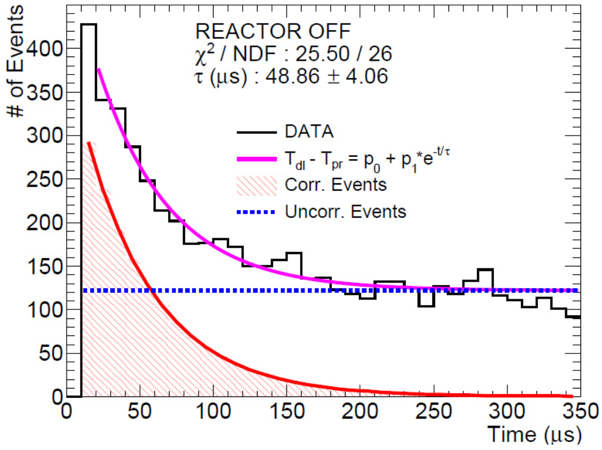

Fig. 3: Measured time interval distribution in the condition when the reactor is off, fitted with correlated and the uncorrelated components.

The contribution of the correlated background events which mimics the actual antineutrino interaction event of a prompt-delayed pair can be estimated by subtracting the random background as shown in Fig. 3. Similar, two - component time distribution is not visible in the RON time distribution, where the background levels are much higher, and it can be fitted with a single exponential in whole range showing a large contribution from the uncorrelated random background. Measurements with the full 12 scintillator matrix by using the additional shielding of boronated flexible rubber sheets (2 x 5 mm thick with 50 % Boron) will be performed soon, which is expected to reduce the background due to neutrons substantially.

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