Study of neutron production from stopping muons

H. Krishnamoorthy[1,2],* G. Gupta[3], A. Garai[1,2], A. Mazumdar[1,2], A. Reza[3], V. Vatsa[1,2], R. Pachuau[3], S. Pal[4], V. Nanal[3], R.G. Pillay[5], and A. Shrivastava[2,6]
[1]*India based Neutrino Observatory, Tata Institute of Fundamental Research, Mumbai - 400005, India*
[2]*Homi Bhabha National Institute, Anushaktinagar, Mumbai - 400 094, India*
[3]*DNAP, Tata Institute of Fundamental Research, Mumbai -400005, India*
[4]*PLF, Tata Institute of Fundamental Research, Mumbai -400005, India*
[5]*Department of Physics, IIt Ropar, Rupnagar, Punjab - 140001 and*
[6]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, India*

Introduction

TIN.TIN collaboration at TIFR aims to develop cryogenic Sn bolometer for the study of neutrinoless double beta decay ($0\nu\beta\beta$) in ^{124}Sn. Given the rarity of the process ($T^{0\nu}_{1/2} > 10^{25}$ years), background reduction is extremely important to achieve the required sensitivity levels. Neutrons constitute an important background for neutrinoless double beta decay and often acts as the limiting background [1, 2]. The origin of neutrons is twofold: from natural radioactivity in the detector and surrounding materials and from cosmic muon induced reactions. At the sea level, the dominant contribution to the neutron production arises from the stopping μ^-, which is captured by the atomic nucleus.

Muon Induced Neutron measurement setup at TIFR (MINT) is designed to measure the secondary neutrons originating from cosmic muon interactions in different target materials. We present the results for the neutron contribution arising from stopping muons for Pb target.

Experimental setup

The MINT setup consists of two detectors namely, Cs_2LiYCl_6 (CLYC)(1" dia × 1" height) [3] and NaIL (2" dia × 4" height) for neutron detection. The detectors are surrounded by 10 cm of high density polyethylene (HDPE). Pb blocks of 30 cm thickness and 40cm × 40cm footprint are placed above and surrounding the HDPE blocks (see FIG.1). The choice of Pb and HDPE thickness were done with separate measurements and simulations. Fast neutrons ($E_n \sim 15$MeV) produced in the cosmic muon interactions in Pb, gets thermalized in the HDPE. These thermal neutrons produce a unique signal in CLYC/NaIL with 3.2 MeVee light output by $^6\mathrm{Li}(\mathrm{n},\alpha)^3\mathrm{H}$ reaction. The CLYC and NaIL detectors have high intrinsic efficiency for thermal neutrons($\sim$ 25% and 50% respectively) and excellent pulse shape discrimination (PSD) capability for n-γ separation. Four plastic scintillators of dimensions 50 cm × 50 cm are employed for the cosmic muon trigger. The data is acquired with CAEN V1730B digitizer (500 MHz, 14 bit) on an event by event basis. ROOT [4] based analysis is used for extracting the coincidence between neutron detectors and plastic scintillators.

Data analysis and results

Cosmic muons passing through the MINT setup are identified by the plastic scintillators. Two plastic scintillators, P1 and P2 are placed on the top of the setup and the other two, P3 and P4 are placed at the bottom. In order to tag a muon event, events in the the plastic scintillators within a window of 100 ns are identified. Coincidence search is performed between the set of identified muon triggers and the neutron detector events in a time window of ±10 ms to extract the delayed neutron coincidence events which are produced as the result of cosmic muon interactions in the Pb target. To specifically identify the contri-

*Electronic address: `harisree.krishnamoorthy@tifr.res.in`

bution from stopping muons, the coincident neutron events were restricted to the ones in which only P1 and P2 had fired and P3 and P4 did not detect the muon event. Fig 2 shows the distribution of the time difference between the thermal neutrons events in NaIL detector and muon events in plastic scintillator in the coincidence window. A sharp rise in the detector thermal neutron counts can be seen in the time window of 0 to 0.7 ms. This defines the prompt time gate for event definition. The contribution to the background from neutrons from non-triggered muons as well as from natural radioactivity is obtained by gating the chance part of the time spectrum. Runs without any target material, is used for obtaining the background correction.

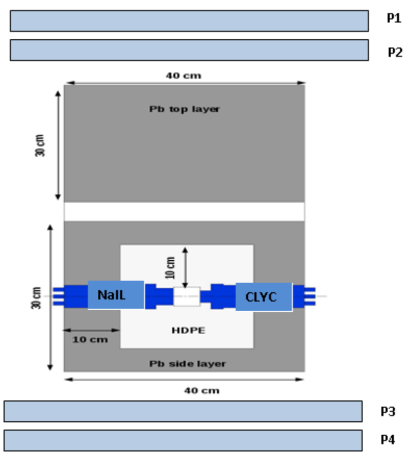

FIG. 1: A schematic of MINT detector setup

Fig 3 shows a comparison of counts in the thermal neutron peak in NaIL detector for the runs with and without Pb. For a mean muon path length of 30 cm in Pb target, we obtain a neutron production rate for stopped muons as $3.5 \pm 0.1 \times 10^{-5}$neutrons/$\mu$/g/cm^2. The error quoted is statistical.

Monte Carlo simulations using GEANT4 [5] for neutron production from stopping muons in MINT setup is in progress for Pb target. Future runs in MINT are planned for neutron production in different targets from stopping muons.

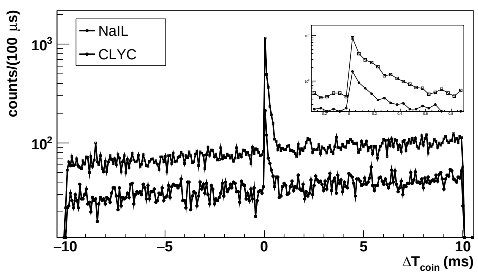

FIG. 2: Coincident time spectrum for CLYC and NaIL detectors. The spectrum is gated on the neutron PSD and plastic trigger condition for stopping muons.

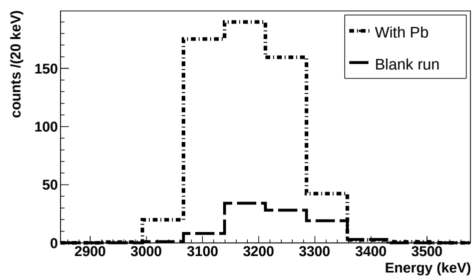

FIG. 3: Thermal neutron peak in NaIL detector for Pb loaded and blank runs (in prompt time window, for stopping muons)

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