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Monte Carlo simulation of muon interactions in mini-IRAND segmented detector using FLUKA code

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Abstract

Muons are the most intense cosmic rays that arrive the sea level earth. Therefore, they play a significant role in all sorts of nuclear radiation detectors. However, large-volume detectors contribute more to the response. It is well-known reactor antineutrino detectors are vulnerable to incoming cosmic muons because they could produce signals that may be incidentally classified as genuine neutrino events. This means that it is essential to understand muons' behavior in every neutrino detector, especially those particles that could mimic the neutrino signals. Iranian Reactor Anti-Neutrino Detector (IRAND) is a segmented plastic scintillation assembly designed to detect reactor antineutrino particles. This paper reports on a Monte Carlo simulation study of an early version of this detector (i.e., mini-IRAND) using FLUKA code, reporting the analysis of its response to the incoming muon and anti-muon. As the IRAND has a segmented configuration, the research would report on the distribution of energy deposition and the variations of an optical light collection concerning space and time in different segments. The central segment (cell 22) could be assumed as the main detector cell surrounded by other cells. As an illustrative example of the whole detector behavior, its response to muons with 80 MeV incoming energy will be reported briefly. This study shows that the simulated signal has two distinct peaks, very similar to the time distribution of a neutrino inverse beta decay event.

Keywords: Cosmic ray, Muon, Neutrino Detector, IRAND, Scintillator, FLUKA

Introduction

Cosmic muons, which result from the interaction of cosmic rays with air molecules in the atmosphere, are charged particles with a mass of approximately 105.658 MeV. Muons have a lifetime of 2.2 µs, after which they decay into an electron, a neutrino, and an antineutrino. A typical muon would only travel approximately 660 m before decaying without considering relativity. However, because of time dilation in the rest frame of the muon and its relatively weak interaction with other particles, it travels much farther and can be detected at the earth's surface [1]. Cosmic muons are typically detected using active shields or "veto" detectors. This method in large dimensions causes a significant increase in the system's weight. It causes the electronic structure and even the mechanical design to be insufficiently robust, especially the mobility or portability of the device is reduced or lost. Therefore, detecting muon events only by using the energy distribution, spatial, and time of the scintillation photons in segmented detectors can lead to the complete elimination of the veto detector. For this purpose, it is necessary to accurately simulate the detector and the interaction of the input particles using the Monte Carlo computational method [2]. One of the severe limitations of neutrino detection is the detection of reactor neutrino signals against the background of cosmic muons. Because during the interaction of muon with protons in the environment of the detector or in the detector itself, a neutron and a neutrino are produced (similar to neutrino inverse beta decay event). Therefore muons act as a neutron source inside and outside the detector [3] and can lead to the production of signals that are similar in time and spatial characteristics to signals from reactor neutrinos. In other words, cosmic neutrons can falsify neutrino signals [4]. Recent or current projects in this field include the PANDA detector in Japan, the CORMORAD in Italy, the DANSSINO in Russia, the PROSPECT in the United States, and the AKKUYU in Turkey [5].

Detection system

Mini-IRAND is a 3×3 array of cubic segments having dimensions of 11.8 cm × 11.8 cm × 10 cm on each side.
Each segment is a NE102 detector. The initial source was simulated as a single-energy beam of muons irradiating vertically to the detector, normal direction for simplicity was considered. Figure 1 shows a simple layout of the geometry and the simulated source. The quantities of deposited energy distribution, time, and spatial distribution of scintillation photons produced in the scintillators for different initial energies of the muon beam (20 MeV, 40 MeV, 80 MeV, and 100 MeV) were calculated. The number of primary 10^5 particles were considered.

Results and discussion

To calculate the deposited energy distribution of muons and the spatial distribution of the scintillation photons that prodused in the scintillators, the USRBIN card was used in Fluka. The results are shown in figure 2 and figure 3, respectively. According to the results, these muons are fully stopped in cell 22. The energy deposited by muons with 80 MeV incoming energy (Figure 4) and variation of the light collection in the central segment (Figure 5) were calculated using USRYIELD and USRTRACK cards, respectively. According to Figure 5, the light collection time variation in the central segment has two distinct peaks in about 2.95 ns and 1.86 µs. It is well-known that interaction of neutron with protons in plastic scintillators (via IBD process) also produce a prompt signal (due to positrons), followed by a delayed event (due to neutrons). It is evident that these timing of signals (for muons and for IBD) is similar, assuring that they could mimic neutrino events. It is also known that in cell 32 only the prompt signal was generated clearly and in other cells no similar signall (prompt or delay) was observed.

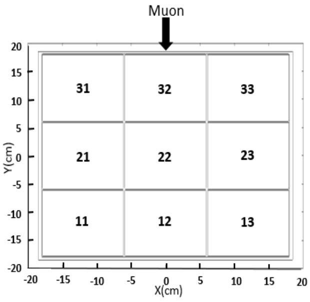

Figure 1. A schematic representation mini-IRAND 3x3 array.

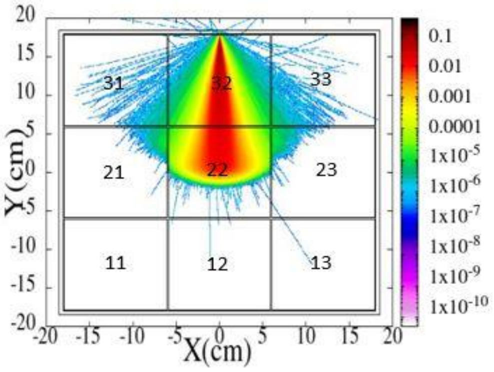

Figure 2. Deposited energy distribution of muons with 80 MeV incoming energy.

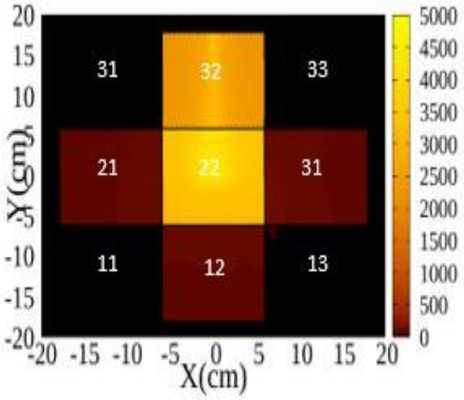

Figure 3. Spatial distribution of the scintillation photons produced in the scintillators.

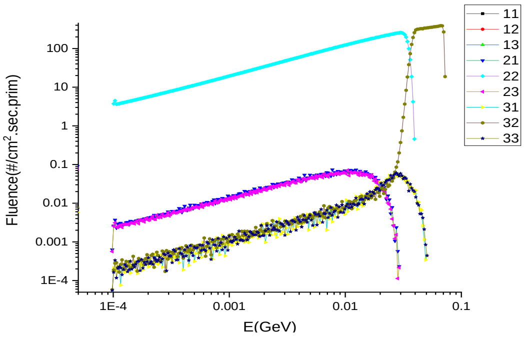

Figure 4. Deposited energy of muons with 80 MeV incoming energy in each of the cells.

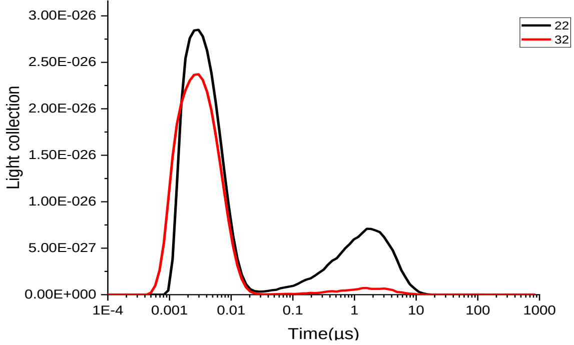

Figure 5. Time variation of the light collection in cells.

Conclusions

Cosmic muons constitute a wide incident energy spectrum for near sea level laboratories. However, only some portion of this spectrum wich have a chance to fully stop in the detector may produce detecting events that have a prompt signal, followed by a delayed one. Therefore by means of a segmented detector one could effectively detect the identify and even characterize the incoming muons. Therefore, cosmic muons could be cosidered as the most important source interfering events in IRAND. Understanding the progression of events that a generic muon could produce in the detector is essential for remedial strategies. Here, the case of incident muons with 80 MeV energy were reported, and it is found that the output scintillation signal clearly shows a prompt and a delayed portion. We know that this behavior is considered for every detecting neutrino interaction in scintillators.

References

[1] Boulicaut, E. L., “Cosmic Ray Muon Detection,” Gustavus Adolphus College, (2018).

[2] IAEA, “Final Report: Focused Workshop on Antineutrino Detection for Safeguards Applications Report,” STR-361 (2008).

[3] Mukhopadhyay, N.C., “Nuclear Muon Capture,” *Physics, Reports*, Vol. 30(1) p. 1-144 (1977).

[4] Bonomi, G. , et al., “Applications of cosmic-ray muons,” *Prog. in Part. Nucl. Phys.* Vol. 112 (2020) 103768.

[5] Fischer, V. and E. Tiras, “Water-based Liquid Scintillator detector as a new technology testbed for neutrino studies in Turkey,” *Nucl. Instr. Met. A* Vol. 969, (2020) 163931.