Monte Carlo simulation of a parallel plate ionization chamber operating in air using GEANT4

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Introduction

The investigation of prompt fission neutron and gamma spectra has garnered renewed attention, particularly due to its significance in the advancement of Generation IV reactors and accelerator-driven systems aimed at the transmutation of nuclear waste [1,2]. Currently, there exists a scarcity of such experimental data in the case of ^{232}Th(n,f) across varying excitation energies. Consequently, we have embarked on a research initiative to measure such data produced during ^{232}Th(n,f) at various incident neutron energies. A parallel plate ionization chamber designed for operation in air has been used to generate fission triggers for the measurement of prompt fission neutron and gamma spectra resulting from the fast neutron-induced fission of actinides. In order to assess the performance and the fission fragment detection efficiency of the ionisation chamber, we have conducted Monte Carlo simulations of the ionization chamber using Geant4 [3].

The chamber and GEANT4 simulations

The fission trigger detector was constructed using a parallel plate ionization chamber featuring two distinct sections, designed to operate in air. Each section of the detector comprised of a cathode and an anode, both fabricated from copper plated G-10 discs that are 1.5 mm thick and have a diameter of 7.5 cm. They were separated by Teflon spacer rings having thickness of 2 mm. On the cathode of both sections, ^{232}Th foils, approximately 2 mg/cm^2 in thickness and measuring 1cm X 1 cm, were affixed. The anode plates were supplied with a bias voltage of +410 V, while the cathode plates were maintained at ground potential. The fission fragments deposit a fraction of their energy in the trigger chamber by creating electron-ion pairs, which in turn generate an electrical signal. The detector geometry has been constructed in Geant4 using the DetectorConstruction class [3]. Fission fragment (FF) tracks generated inside the air gap are shown in blue (light fragments) and pink (heavy fragments) colours in figure 1.

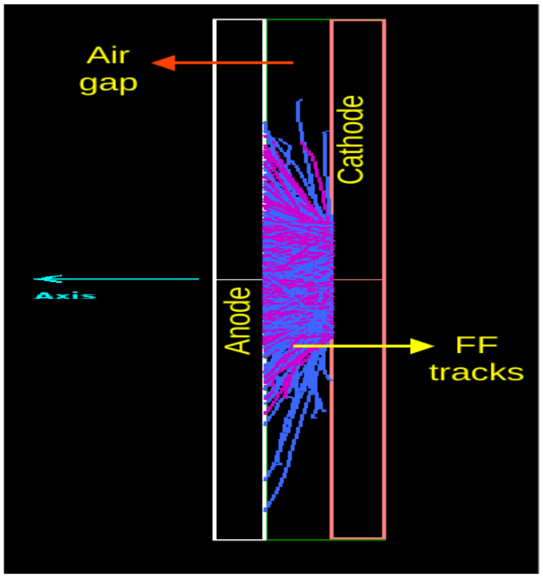

Fig. 1 Fission fragment tracks generated inside the air gap are shown in blue (light fragments) and pink (heavy fragments) colours.

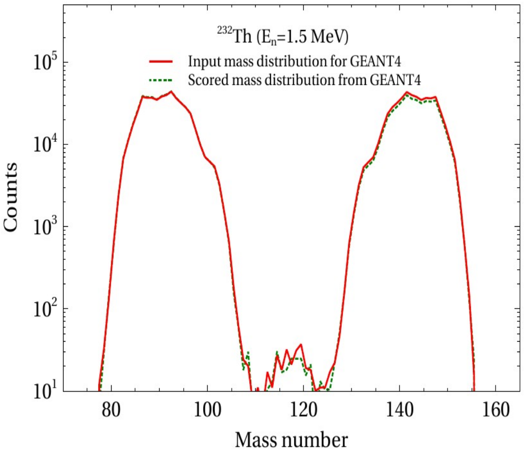

Fig. 2 Input mass distribution (red line) provided for the simulation along with the scored mass distribution (green line).

In the context of Geant4 simulation, the primary mass distribution, kinetic energy distribution <KE> and the standard deviation of kinetic energy σ_{KE} derived from the established semi-empirical model GEF [4] for an incident neutron energy of 1.5 MeV in the case of ^{232}Th(n,f) were utilized as input parameters for event generation in the primary generator. All electromagnetic phenomena have been included via the EM Standard Physics List.

Results and discussion

The co-ordinates of the nuclei undergoing fission were randomly allocated throughout the volume of the ^{232}Th foil, whose dimensions were kept the same as that in the experiment. Angular distribution of the fragments was simulated to be isotropic. For every fragment, the energy deposited in the air gap between the cathode and the anode was recorded, along with its mass and the angle of emission (θ) relative to the detector axis. Figure 2 illustrates the input mass distribution represented by the red solid line, derived from the GEF model [4], alongside the scored mass distribution indicated by the green dashed line, which is obtained from the Geant4 simulation. The data presented in figure 2 reveals a relative loss of less than 10% for the heavier fragments, attributed to their stoppage within the ^{232}Th target foil. To enhance clarity, both the scored mass distribution and the input mass distribution have been normalized in relation to the light fragments.

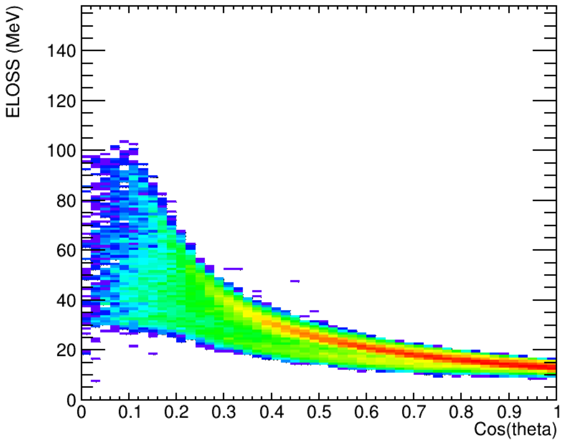

Fig. 3 2D plot of energy deposited by the fission fragments along with their emission angle.

Figure 3 presents a two-dimensional representation illustrating the relationship between energy deposited by the fission fragments in the air gap and their emission angle. It shows the angular dependence of the counts which are recorded within air gap of the ionization chamber, which results from the loss of fragments that are fully stopped in the target foil. We also estimate the detector's efficiency to be 74% based on simulations. We have also observed a constant efficiency for angles where cos(θ) is higher than 0.6 and a decline in efficiency for angles where cos(θ) is approximately 0.6 or lower, attributable to the stoppage of fragments in the target foil. Notably, this reduction appears to be uniform across different masses, indicating that the considerable thickness of the ^{232}Th target foil contributes minimally, if at all, to bias in the extracted prompt fission neutron and gamma spectra.

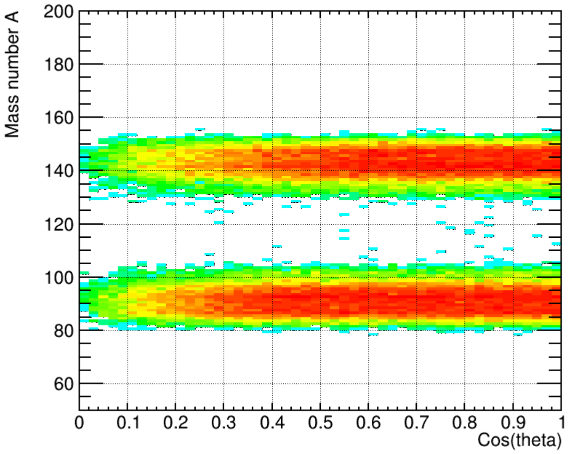

Fig. 4 2D plot of the scored fission fragment mass distribution along with their emission angle.

Figure 4 shows a 2D plot of scored fission fragment mass distribution along with their emission angle. Further details on the detection efficiency of the ionization chamber for varying target thicknesses will be presented in the symposium.

References

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