Numerical Studies on Alpha Tracks in TPC

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Introduction

Two important areas of nuclear astrophysics are to envisage relative abundance of the elements and the energy generation in stars. In this context, studying nuclear reactions of astrophysical interest at sub-Coulomb barrier energies is an important step. The alpha cluster decay and (p,α) reactions are few such reactions which play vital role in astrophysical processes. In studying these reactions, the use of Active Target Time Projection Chamber (AT-TPC) can be advantageous due to its design and tracking capability. By construction, TPC [2] is a gas filled device equipped with two-dimensional position sensing segmented readout plane. A charged particle while moving through the gas medium of the TPC ionizes the gas molecule and produces electron-ion pairs along its track. These primary electrons drift under the action of the uniform applied electric field towards the readout plane. The two-dimensional position information is obtained from the current induced on the readout electrodes by the electronic avalanche created by application of very high electric field near the readout. The third position information of the particle is determined by measuring the drift time of the primary electrons. In an AT-TPC, the filling gas acts as the target which has definite edges over the solid targets. In addition, the cylindrical geometry of the TPC allows a solid angle coverage of 4π along with measurement of short tracks of low energy particles precisely if the readout has a high enough granularity. In this work, we have studied the effect of primary ionization caused by alpha particles on the electric field numerically which can further influence the working of the TPC.

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Simulation Framework

We have used Geant4 [1] monte carlo simulation to determine primary ionization created by alpha particle of 5.5 MeV at atmospheric pressure in the drift volume of TPC. A gas mixture of Argon and Carbon dioxide in the volumetric ratio of 70:30 has been used. The cylindrical gas volume of the TPC has 10 cm height and a radius of 12.5 cm.

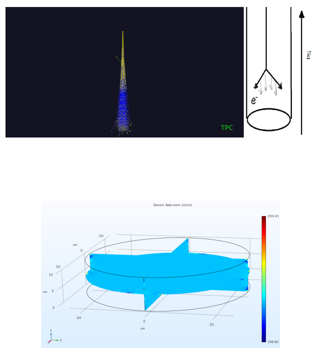

FIG. 1: Top image: Geant4 model with alpha track, Bottom image: Electric field within drift volume

In the simulation study, the generation and tracking of primary electrons have been governed by physics models, namely, Livermore, Penelope, and Photo Absorption and Ionization (PAI), and the amount of ionization deposited by the 5.5 MeV alpha particle. We have found from the simulation that about 33.6×10^3 primary electrons are produced per event per cm.The track length of the alpha particle is 4.7 cm in the drift volume. The electric field has been simulated using a Finite Element Method (FEM) package named as COMSOL Multiphysics [3]. The electric field is almost uniform with an average value of 200 V/cm, as shown in figure 1. We have used hydrodynamic approach to transport the primary electrons in the drift volume. We have used MAGBOLTZ [4] to determine drift velocity and diffusion coefficients in the gas mixture The following drift-diffusion reaction equations are solved in COMSOL for the field dependent charge transportation. The following drift-diffusion reaction equations are solved in COMSOL for the field dependent charge transportation.

$$\frac{\partial c_e}{\partial t} + \vec{\nabla}(-D_e\vec{\nabla}c_e + \vec{u_e}c_e) = S_e \qquad (1)$$

$$S_e = (\alpha(\vec{E}) - \eta(\vec{E}))|\vec{u_e}|n_e \qquad (2)$$

where c_e,S_e,$\vec{u_e}$ and D_e in equation 1 denotes the concentration, rate of production, drift velocity, diffusion coefficients for electrons respectively. Similarly,n_e,α and η in equation 2 denotes concentration, first Townsend coefficient and attachment coefficient for electrons respectivel The transport of the charged species (electrons and ions) in the applied electric field region has been simulated by Transport of Dilute Species (TDS) module of COMSOL.

Results

In this work we have considered electrons and ionized gas molecules as charged species. The electric field and electron concentration has been calculated at at each time step. The time evolution of electron cluster in the drift volume is shown in figure 2. The ions will move much slower than the primary electrons shown in figure 3. so they will create a space charge density which will influence the drift field.

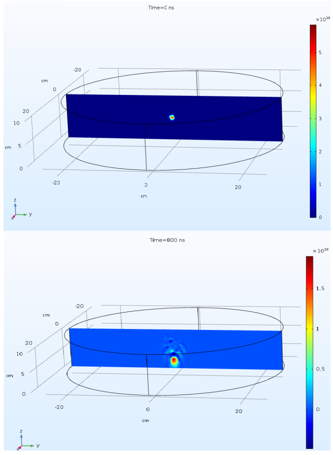

FIG. 2: Transport of primary electrons in drift volume

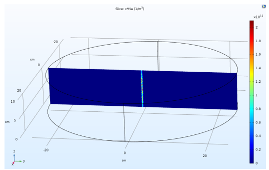

FIG. 3: Space charge distribution in drift volume

Acknowledgments

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