Space charge effects in a small TPC due to the passage of highly ionizing charged particles

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Outline

- Motivation
- Time Projection Chamber
- Space charge effects in low energy nuclear physics experiments
- Simulation of Primary Ionisation in TPC
  - Garfield++
  - Geant4

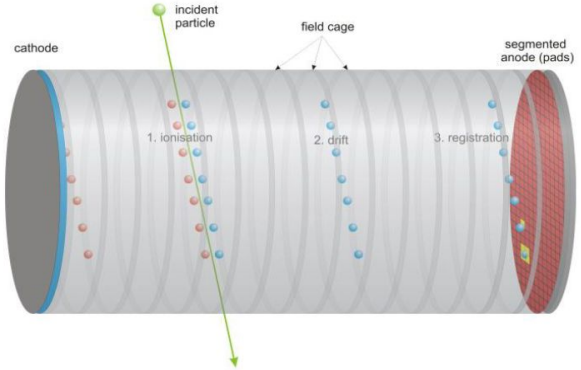
- Simulation of electronic signal in anode plane of TPC
- Conclusion
- Future Plan

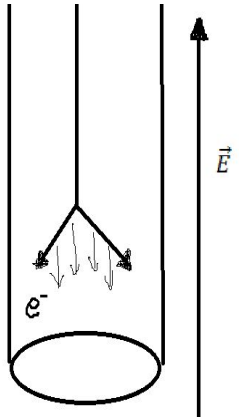
Motivation

- **Particle tracking is an important task to determine many physical observables like momentum (In the magnetic field) and directionality**
- **Reconstruction of tracks created by charged particles leads to identify and measure their directionality which provides complete information about the reaction vertex kinematics in low-energy nuclear and high energy physics**
- **Time Projection Chamber(TPC) is capable of 3D tracking for its long drift chamber with readout plate by GEM or Micromegas and the Z coordinate is determined from the Time of Flight which is measured by the trigger and the readout plate detector**
- **A numerical study has been conducted with space charge effect of high Ionizing low energy particle to estimate the space charge effect on the track and drift field**

Time Projection Chamber (TPC)

- TPC has an active gas volume with a good position-sensitive electron collection system inside an electric field and a charged particle will produce primary ionization along its track





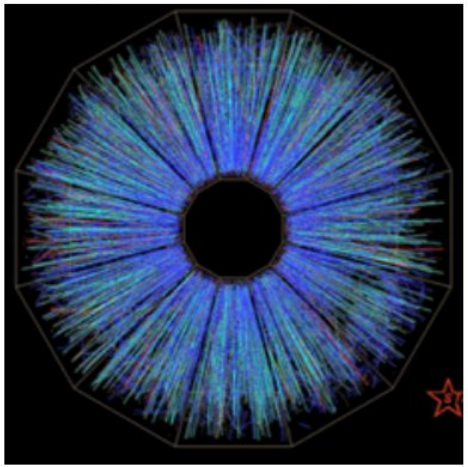
- The primary electrons drift under the action of the uniform electric field towards the end equipped with an electron multiplier for collecting signal producing a 2d image of the track
- 3rd dimension from the drift time of electrons
- Information
  - Angles, Energy (from range or charge), particle identification

Particle tracking TPC

PROPOSAL TO INVESTIGATE THE FEASIBILITY OF A NOVEL CONCEPT IN PARTICLE DETECTION

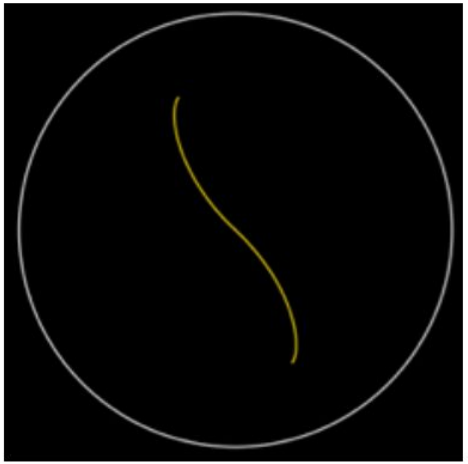
David R. Nygren

High Energy Physics



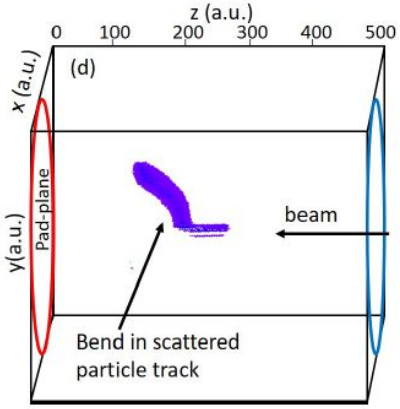
- Many tracks
- Tracks leave sensitive volume
- Low Ionizing High energy Particles

Low Energy Nuclear Physics



- Few tracks
- Tracks stop sensitive volume
- High Ionizing low energy particles
- May not need magnetic field

Space charge effects in low energy nuclear physics experiments

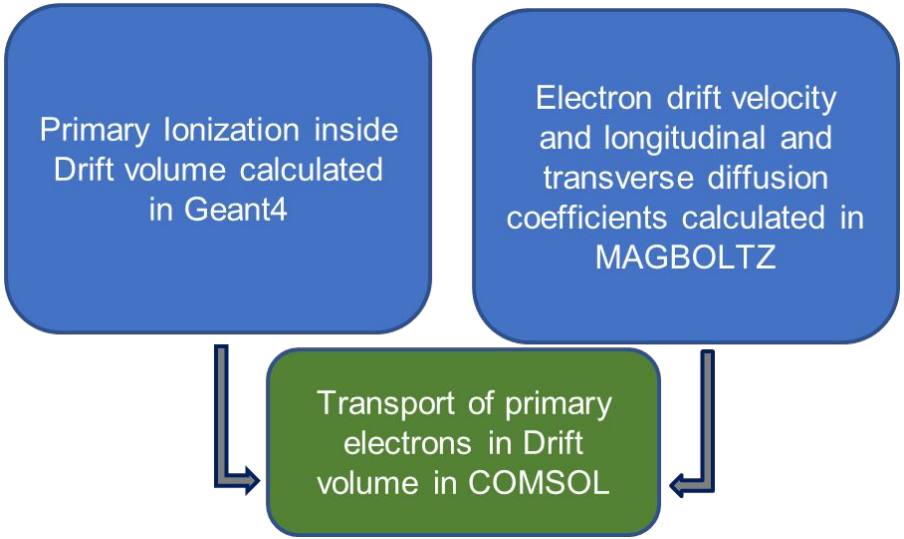


- Tracking capabilities of TPC depends on
  - Homogeneity of drift field
  - Ion BackFlow (IBF) Due to secondary ionization
- Space-charge effects
  - Distortion in Electric field
  - On Ion mobility and impact on track distortion
  - low-energy nuclear physics experiments are mainly expected to be induced by the high ionizing beam particles

Jaspreet S. Randhawa et. al, NIM-A, 2019
"Beam induced space-charge effects in Time Projection Chambers in low-energy nuclear physics experiments"

Introduction to simulation framework

- Our goal is to find the amount of primary ionization by a charge particle in a sensitive volume of TPC and its transport parameters respectively.
- The particle generation and tracking were governed by low energy ElectroMagnetic physics list Livermore, Penelope and PAI.
- Transport parameters of primary electrons and ions has been obtained from MAGBOLTZ in Garfield++ package
- A Finite Element Method (FEM) package, COMSOL used for time evolution of primary electrons in drift volume

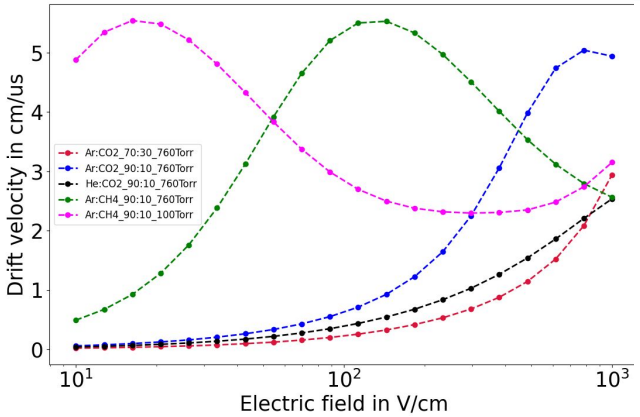


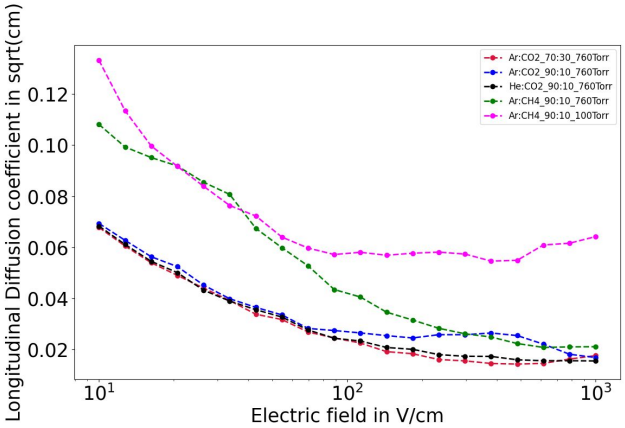
Transport properties of different gas mixtures

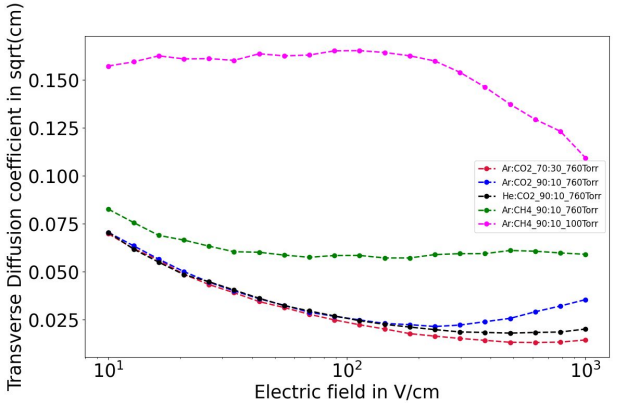
- This simulation utilizes the transport parameters from Garfield++ to perform the simulation.
- Diffusion and drift velocity for different drift field have been calculated for different pressure.
- The positive ions and negative electrons are considered to be charged fluid in the gas volume.
- The hydrodynamics is governed by convection and migration mechanism which is governed by drift-diffusion reaction.

$$\frac{\partial c_i}{\partial t} + \vec{\nabla}\left(-D_i\vec{\nabla}c_i + \vec{u_i}c_i\right) = S_i$$

$$\vec{E} = -\vec{\nabla}V \qquad \vec{\nabla}\cdot\vec{D} = -\rho$$

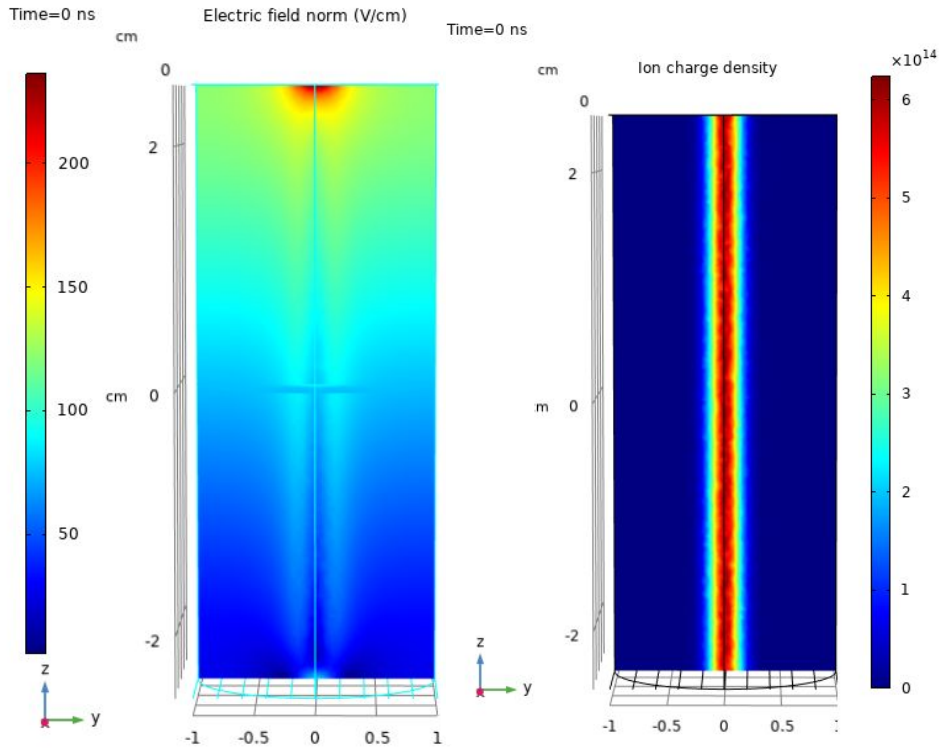




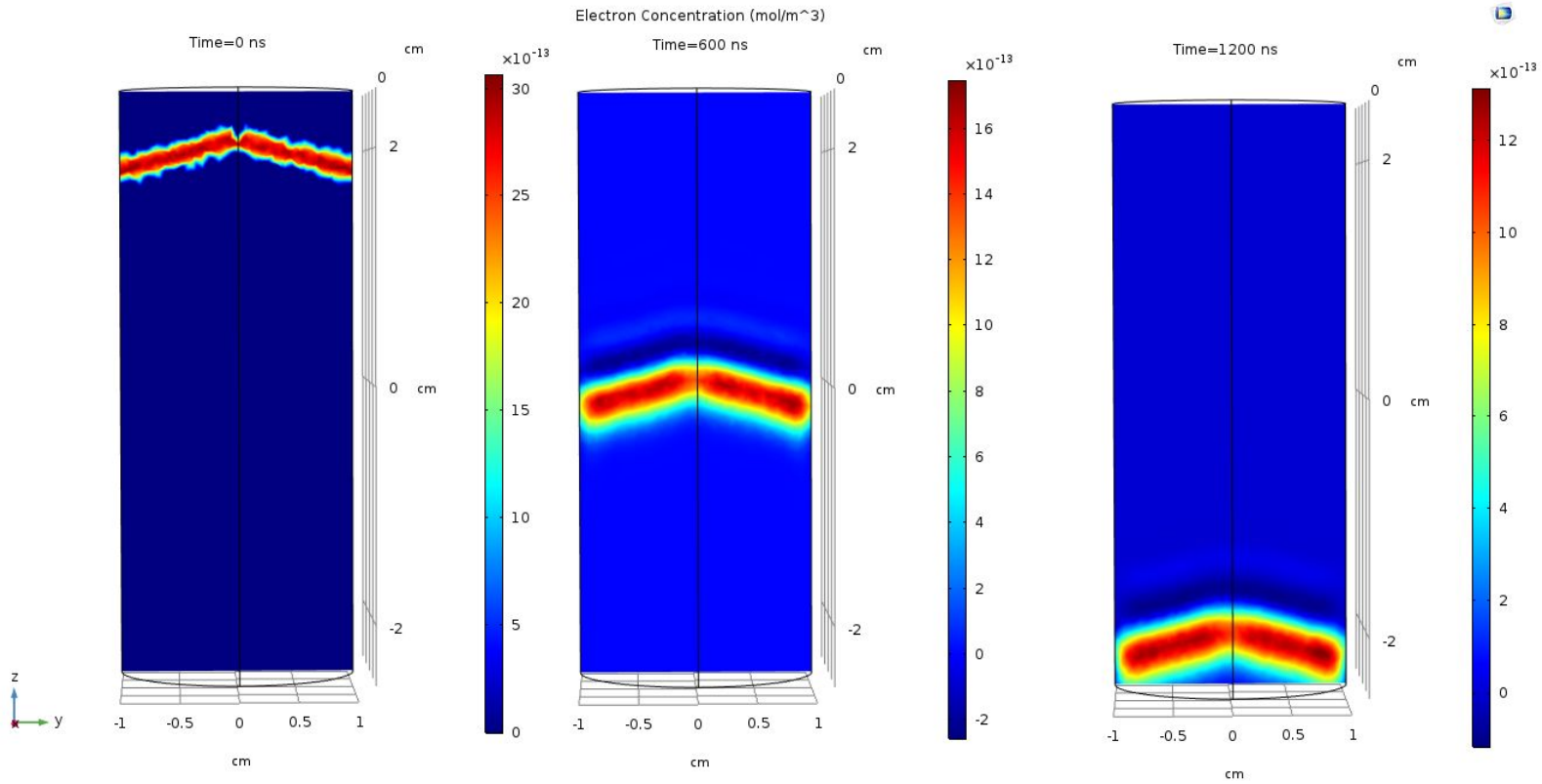


Space charge effect

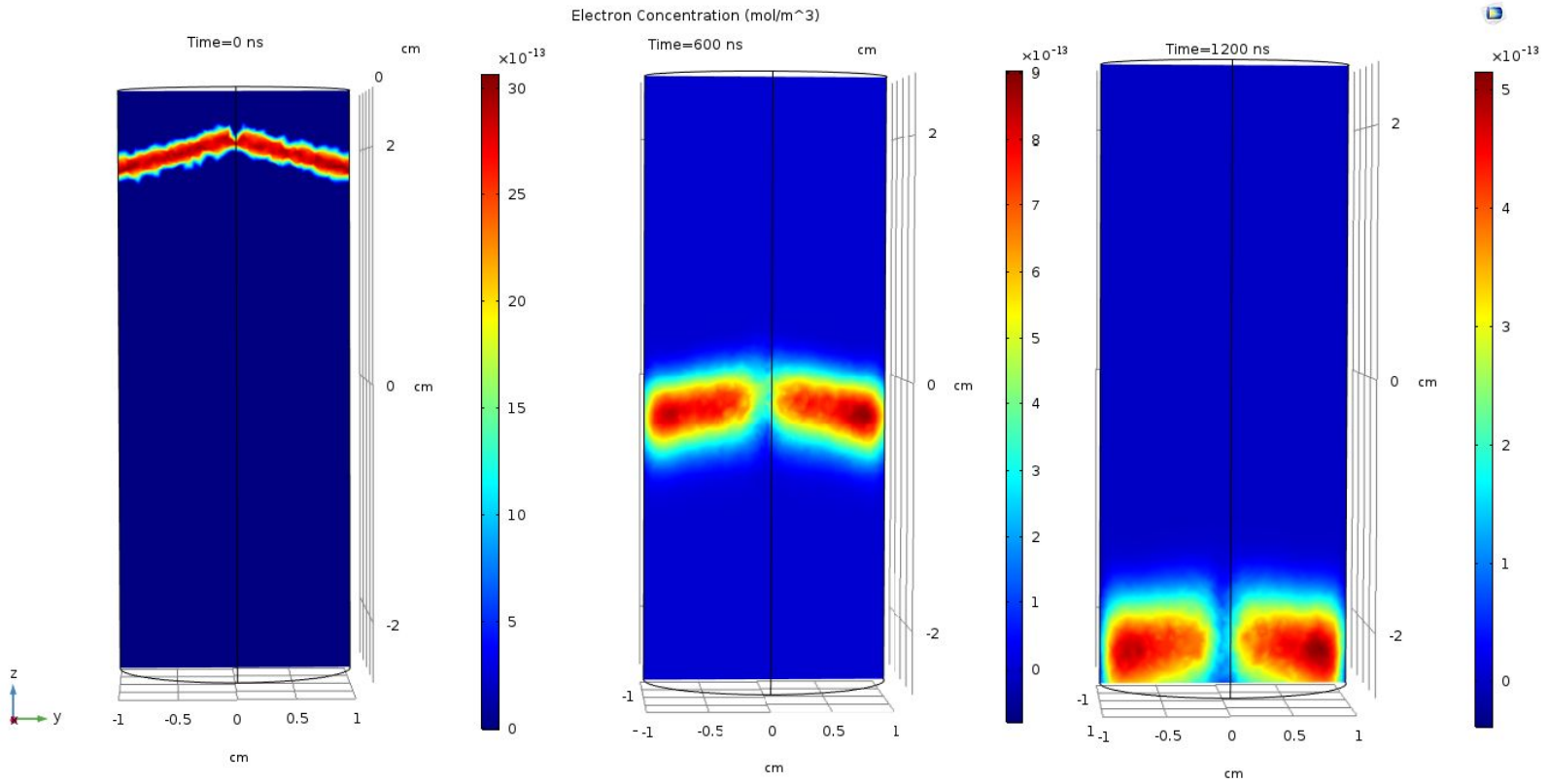
- Accumulation of ions in the drift volume produce space charge effect which distort the drift field in TPC.
- Space charge of 10^{-4} C/m^3 by 4.6 MeV/u 46K has been distributed in a gaussian beam profile .
- Here we report the time evolution of scattered particle track distortion due to space charge in Ar:CH_4 gas at 100 Torr.



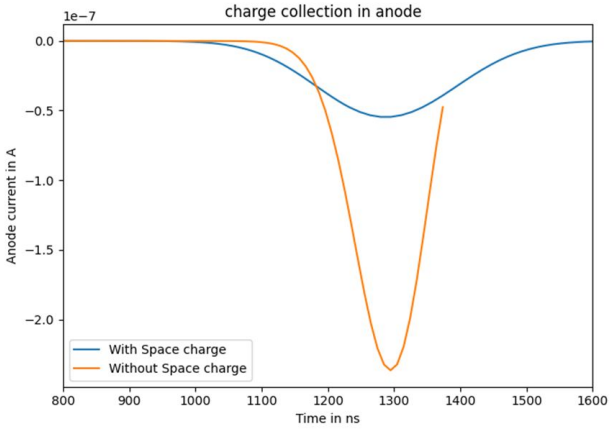
Transport of primary electrons in absence of space charge



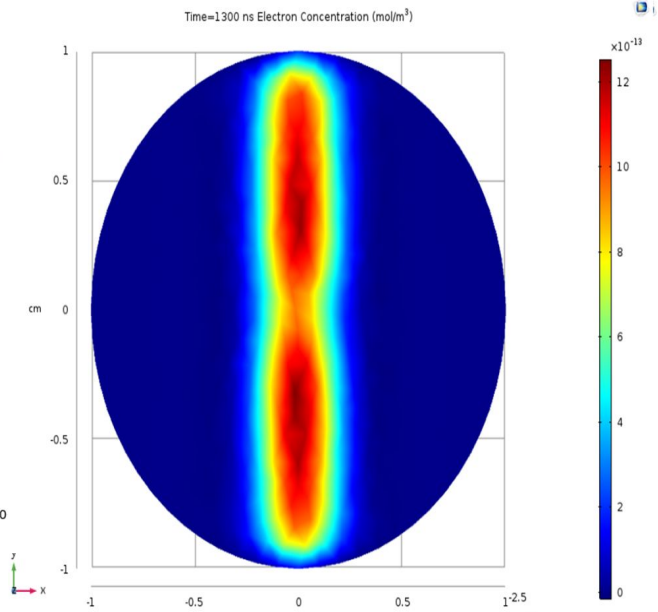
Transport of primary electrons in presence of space charge



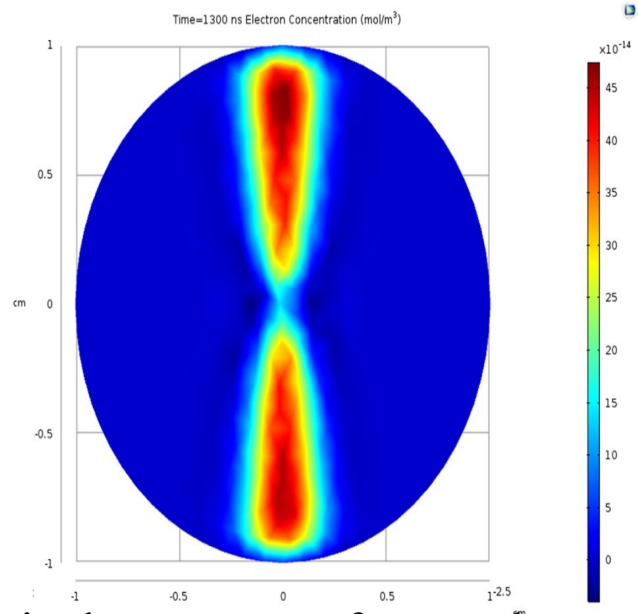
Importance of Primary Ionization in low pressure



Without space charge



With space charge



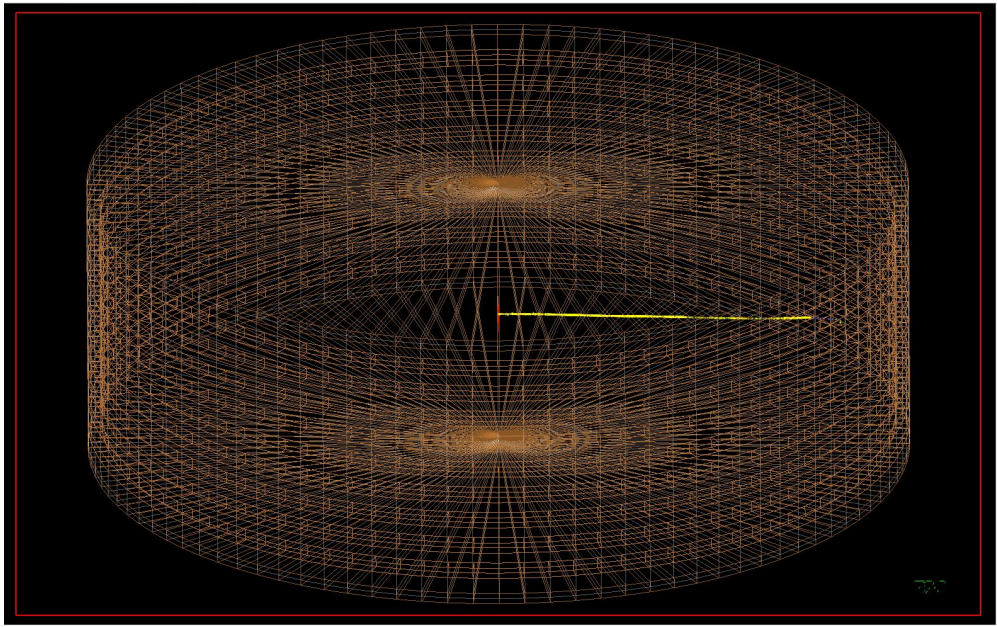
- 2D projection of the pad plane shows a distortion of the track in the presence of space charge near the beam region
- Charge collection at anode plane shows a reduction in charges due to space charge effect

Transport of primary electrons in drift volume

- Geant4 is a toolkit for the simulation of the physics interaction , tracking of geometric propagation
- It is mostly used in of High energy and nuclear Physics and also in the areas of medical and space science
- We define detector geometry, physics process, position and energy of particle and stepping action in Geant4
- High Energy ElectroDynamics (HEED) used for simulation of interaction of fast charged particles with matter and its ionization

Simulation Framework

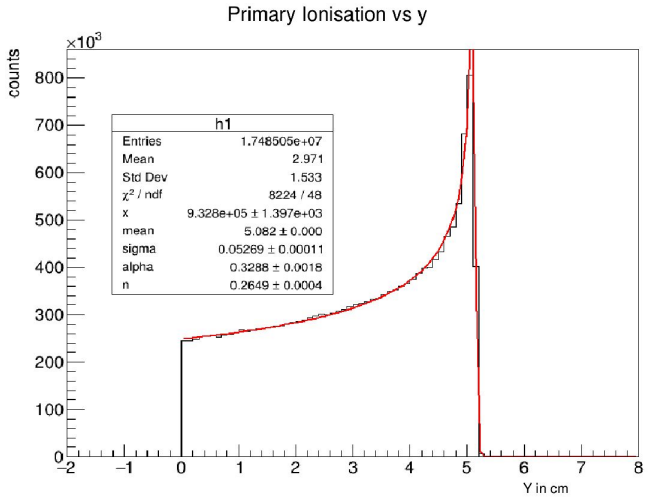
- Geant4 is a toolkit for the simulation of the physics interaction , tracking of geometric propagation
- Our goal is to find the amount of ionization deposited in the sensitive volume of a detector
- simulation consist of a cylindrical Volume which has 10 cm height and 30 cm diameter with a gaseous mixture of He and CO_2(90 : 10)
- The particles generation and tracking were governed by low energy physics list Livermore Penelope and PAI

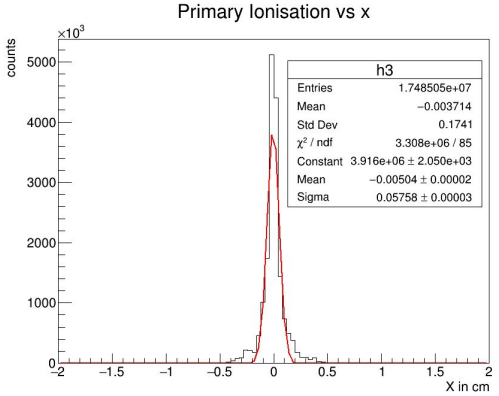


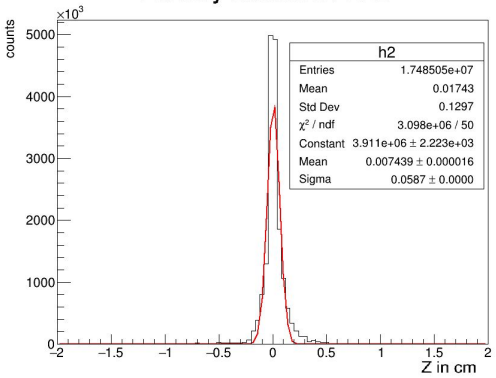
Primary Ionization in Drift volume

$$-\frac{dE}{dx} = 2\pi N_a r_e^2 c^2 \rho \frac{Z}{A} \frac{q^2}{\beta^2} [ln(\frac{2m_e\gamma^2\nu^2 W_m ax}{I^2}) - 2\beta^2 - \delta - 2\frac{C}{Z}]$$

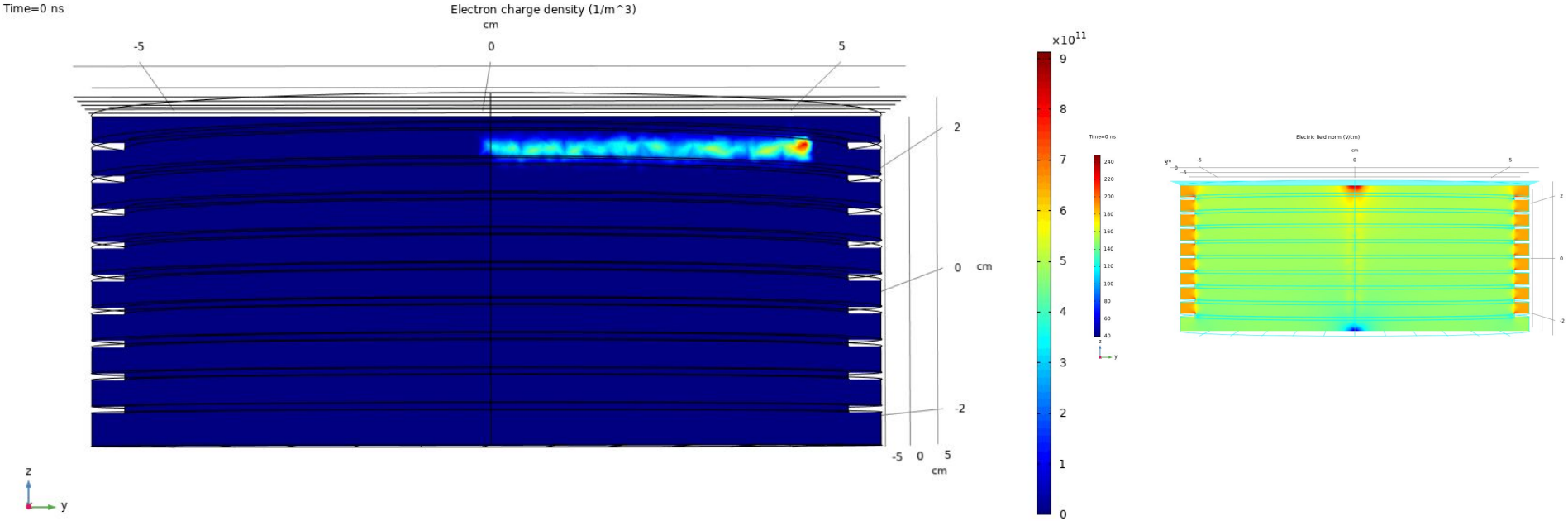
- Energy deposition by 5.5 MeV alpha in Ar:CO_2 in 90:10 volumetric ratio
- Y coordinates of primary electron function fitted with crystal ball function
- X and Z coordinates of primary electron function fitted with gaussian function



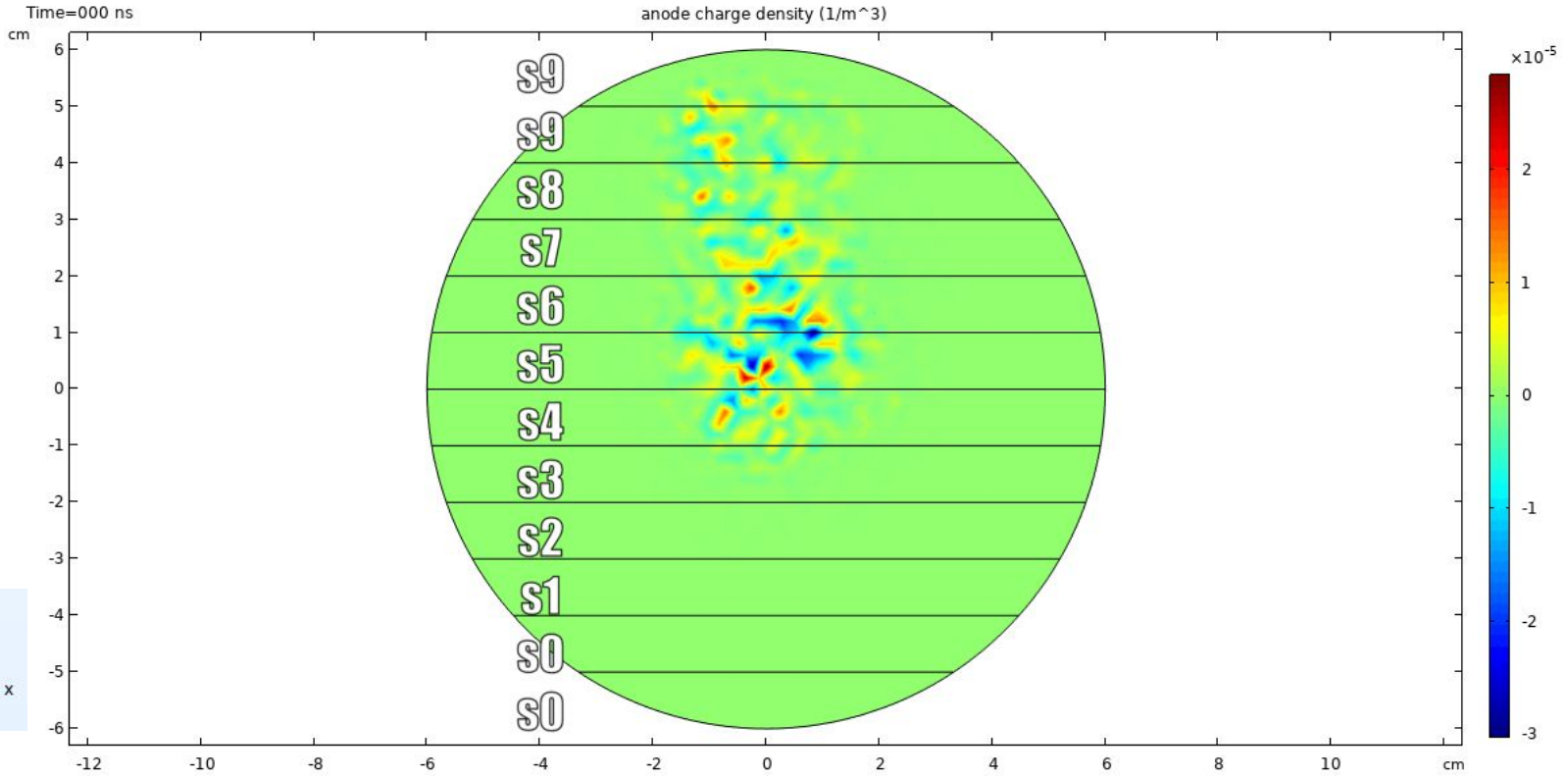




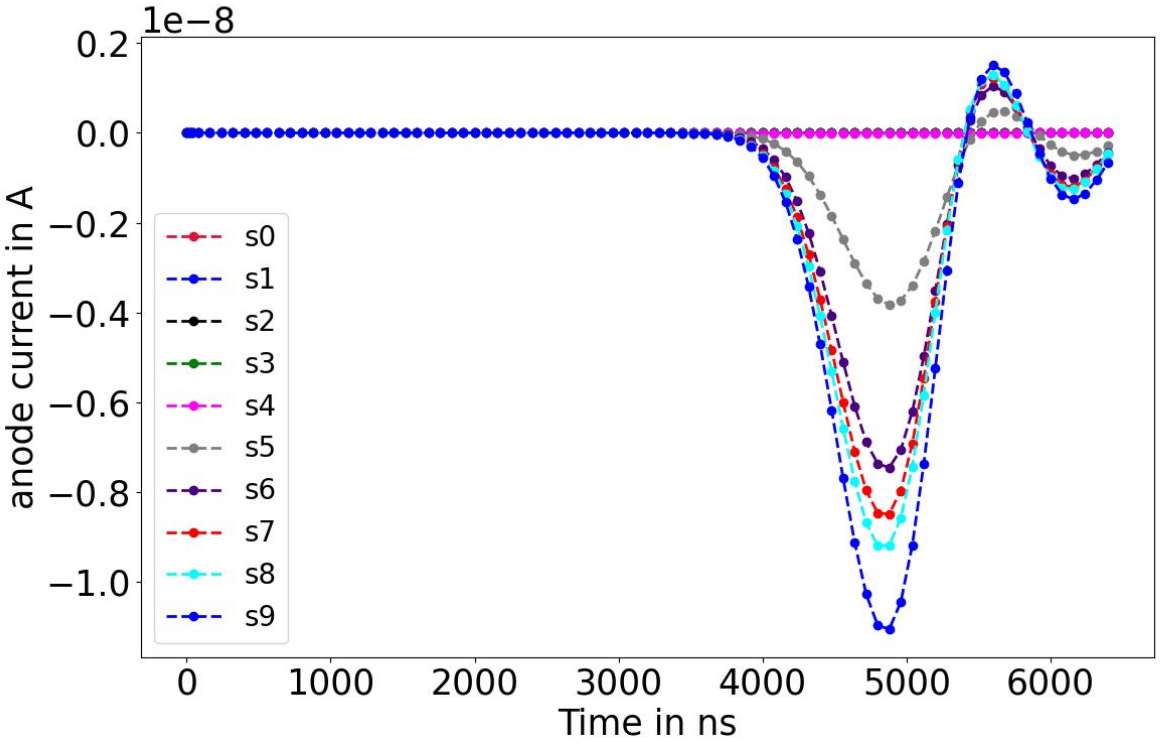
Transport of primary electron in drift region of TPC



Alpha track on anode plane



Induced current in anode plane



Conclusion

- We have studied the primary ionization using Geant4 and electron transport using Hydrodynamic simulation in TPC.
- Effect of space charges and its influence on particle track have been studied. Significant amount of track distortion has been noticed for the space charge density In the drift volume.
- Drift time information which is required for measuring z coordinate of the track determined from the time evolution of charge collection at the anode of TPC.

Future Work:

- Time and position information from the segmented TPC readout
- Development of prototype time projection chamber
- Track reconstruction of alpha cluster decay and (p,α) reactions

Thank you for your kind attentions
Questions,Comments, suggestions?