Simulation of Space Charge Effect on Time Resolution in Resistive Plate Chambers

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Introduction

India Based Neutrino Observatory (INO) will use 28,800 Resistive Plate Chambers (RPCs) in its 50 kton magnetized Iron Calorimeter (ICAL). RPCs are gaseous parallel-plate detectors that contain a small gas gap between two parallel plates which are kept under a high voltage of a few kVs. The main features of this detector are excellent spatial resoluion and time resolution. These detectors have been successfully used in many particle physics experiments and are well suited for fast space-time particle tracking as required for the muon trigger at the LHC experiments. The RPC can be operated either in the streamer or in the avalanche mode. In order to study the signal generation from the RPC, space charge effect is an important phenomenon to be considered. We have compared the simulated time resolution with the measured time resolution in the avalanche mode for different gas mixtures in our previous work, without considering the space charge effect[1]. If the number of charge carriers in the avalanche reaches large values they influence the electric field and the gas gain in the gap. This phenomenon is called space charge effect. In this paper, we take into account the space charge effect to calculate time resolution.

Field due to a point Charge

To calculate the space charge effect, the electric field solutions of a point charge in an infinite plane condensor are necessary[2]. Fig. 1 shows a three layer dielectric configuration.

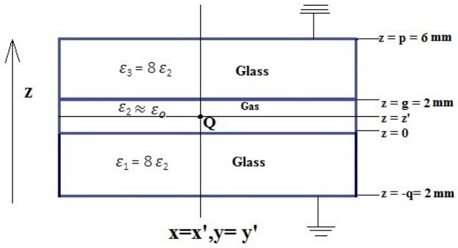

FIG. 1: Single gap RPC with 2 mm gas gap.

The layer-2 is the gas gap with a dielectric constant assumed to be equal to that of air (ϵ_0). The other two layers (layer-1 and layer-3) are made of glass with a dilectric constant, $\epsilon_1 = \epsilon_3 = 8\epsilon_0$. The potential at the point $r(x, y, z)$ due to a point charge located at the point $r'(x', y', z')$ is

$$\phi(r) = \frac{Q}{\epsilon} G(r, r') \quad (1)$$

Electric field due to a point charge in layer-2 as shown in Fig. 1 can be calculated as

$$Ez(\rho, \phi, z, \rho', \phi', z') = -\frac{\partial \phi(\rho, \phi, z, \rho', \phi', z')}{\partial z} \quad (2)$$

Time Resolution

The intrinsic time resolution of RPC has been given by[3],

$$\sigma = \frac{1.28}{(\alpha - \eta) v_d} \quad (3)$$

where α is the townsend coeffcient, η is the attachment coefficient and v_d is the electron

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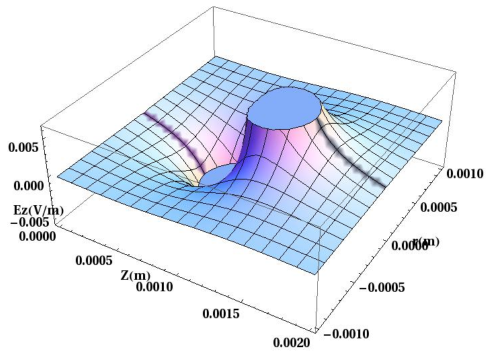

FIG. 2: Electric field when point charge at z = 1 mm.

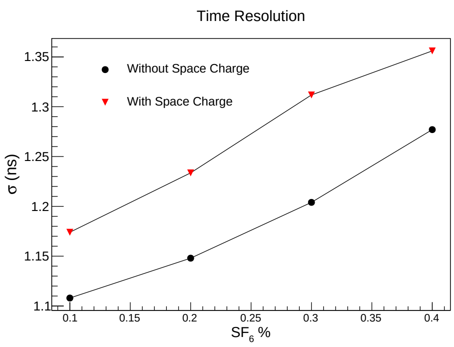

FIG. 3: Time resolution with and without space charge for different percentages of SF_6 in the gas mixture.

drift velocity. The space charge effect is incorporated by calculating the z-component of the electric field dynamically at every point in the 2 mm gap of the RPC, where the charge cloud is located. Now, the electron drift parameters are no more constant and they are functions of electric field(α(E), η(E) and $v_d(E)$).

Results And Discussion

The primary electrons created by the passage of a charge particle through the RPC are accelerated under the influence of the applied electric field. These accelerated electrons may collide with the nearby gas molecules and produce secondary electrons and so on. This process creates many avalanches that proceed towards the electrode. Now each charge created inside the gap produces its own electric field. The effect of this internal electric field will be considerable when the produced charge is very large. In this work, the electron drift is considered only in z-direction and the transverse and the longitudinal diffusion effects are also not considered. Fig. 2 shows the electric field due to a point charge located at z = 1 mm. The resultant external and internal electric fields modify the gas parameters and hence the gas gain. Fig. 3 shows the simulated time resolution with (triangle) and without (circle) space charge effect for different percentages of SF_6 in the gas mixture. The gas mixture used in the avalanche mode of operation is $C_2H_2F_4/C_4H_{10}/SF_6$. In this study Iso-butane is fixed at 4.5%, while SF_6 concentration is varied between 0.1% to 0.4% and Freon (R134A) making the rest of the mixture. We can see that time resolution of the RPC worsens with increase of SF_6 fraction[1]. We can also see that inclusion of space charge effect in the simulation worsens the time resolution. Reason for both of these effects is reduction of effective electric field within the gas gap and reduced gas gain which finally results in reduced signal.

Acknowledgments

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References

[1] M. Salim et.al, "Simulation of efficiency and time resolution of resistive plate chambers and comparison with experimental data", Journal of Instrumentation, 10, C04033, 2015.

[2] T. Heubrandtner et.al,"Static electric fields in an infinite plane condenser with one or three homogeneous layers", Nucl. Instr. and Meth. A, 489, 439, 2002.

[3] W. Riegler et.al, "Detector physics and simulation of resistive plate chambers", Nucl. Instr. and Meth. A 500, 144, 2003