PROCEEDINGS OF SCIENCE

# Simulation studies on the Effect of $SF_6$ in the RPC gas mixture

PoS(RPC2012)034

**S. Mohammed***,[a] **R. Hasan**[a], **N. Majumdar**[b],**S. Mukhopadhyay**[b], **B. Satyanarayana**[c]
[a] *Department of Physics, Aligarh Muslim University, 202002, INDIA*
[b] *Applied Nuclear Physics Division, Saha Institute of Nuclear Physics, 1/AF Bidhannagar, Kolkata 700064, INDIA*
[c] *Department of High Energy Physics, Tata Institute of Fundamental Research, Mumbai 400005, INDIA*
*E-mail:* `saliminamu@yahoo.com`

The India based Neutrino Observatory (INO) collaboration is planning to build a 50 kton magnetized iron calorimeter (ICAL) detector to study neutrino oscillations and measure their associated parameters. ICAL will use 28,800 glass Resistive Plate Chambers (RPCs) of 2mX2m size, operated in the avalanche mode, as its active detector elements. As a part of detector R & D to develop the RPCs required for this detector, we studied the effect of Sulfur hexaflouride ($SF_6$) on various RPC parameters. In this paper, we present a comparative study of charge development on the RPC pick-up electrodes using simulation and experimental data. The primary interaction parameters of the incident particle in RPC gas volume is calculated using HEED, while the electron transport parameters are computed using MAGBOLTZ. We have used nearly exact Boundary Element Method (neBEM) solver to calculate the weighting field and electric field accurately. Finally, the induced charge is obtained following the Ramo's theorem.

*XI workshop on Resistive Plate Chambers and Related Detectors - RCP2012,*
*February 5-10, 2012*
*INFN Laboratori Nazionali di Frascati Italy*

---

*Speaker.

## 1. Introduction

For the details of INO experiment, refer to[1]. A prototype of ICAL has been developed at the Tata Institute of Fundamental Research (TIFR). The detector consists of 12 layers of 1 m X 1 m RPCs with 32 strips on either planes. RPCs are widely used in High Energy Experiments for particle detection[2]. ICALś RPC is made of two parallel electrodes (each 3mm thickness float glass with resistivity of about $10^{12}$ $\Omega$cm). The gas gap is maintained 2mm by highly insulating spacers. RPC is operating in avalanche mode with a gas mixture consists of R134a ( $C_2H_2F_4$, 95.2%), Isobutane ($C_4H_{10}$, 4.5%) and Sulphur Hexafluoride ($SF_6$, 0.3%). A high voltage of about 10kV is applied. $SF_6$ is a strong quenching gas in the RPC gas mixture due to its high electron affinity. Adding $SF_6$ to $C_2H_2F_4/C_4H_{10}$ gas mixture suppresses streamer production in the RPC[3]. This will results in the reduction of gas gain and hence charge developed on the pick-up strips is reduced. Current study attempts to compare charge production on the RPC pick-up electrodes both experimentally and theoretically by varying $SF_6$ in small concentration in the RPC gas mixture.

## 2. Experimental Setup

The routinely used VME based Data Aquisition System (DAQ)[4] had to be modified for this study as it records only the strip hit positions, their corresponding timings and noise rate. This DAQ has several blocks (see, Fig.1) for signal processing namely:

- Pre Amplifier: Since the RPCs are operated in avalanche mode, they are amplified by pre amplifier of gain 80.
- Analog Front End (AFE): This houses the discriminator(discriminator threshold adjustable up to 500 mV) and Trigger Logic.
- Digital Front End (DFE): This block takes discriminated signal from the AFE and stretches the signal to 700 ns. It also accepts handshake signal from Control and Data Router (CDR) and Trigger TDC Router (TTR) for strip hit/noise rate latches.

The DAQ system houses (a) TDC for timing measurement, (b) controller/read-out module for sending/recieving signal and for reading strip hit data and (c) scalar for noise rate monitoring in VME crate. The current study requires the modification of this DAQ by the addition of a QDC module (CAEN V792) in this VME. The analog pulses from the pre amplifier of the RPC layer under study had to be connected to the linear FIFO in order to produce three buffered outputs. One of the output signal is connected to QDC. The other signal is connected to the usual DAQ signal path and the third signal is connected to oscilloscope. Cosmic muons are used to test the RPC. This study is done with only one of the 32 strips of an RPC in the stack. Three scintillator paddles arranged vertically one above the other are used for generating the trigger. This trigger set up is placed appropriately so that the strip under study is sandwiched between them. The Charge measured with DAQ system and Oscilloscope for different gas mixtures is shown in Fig.2.

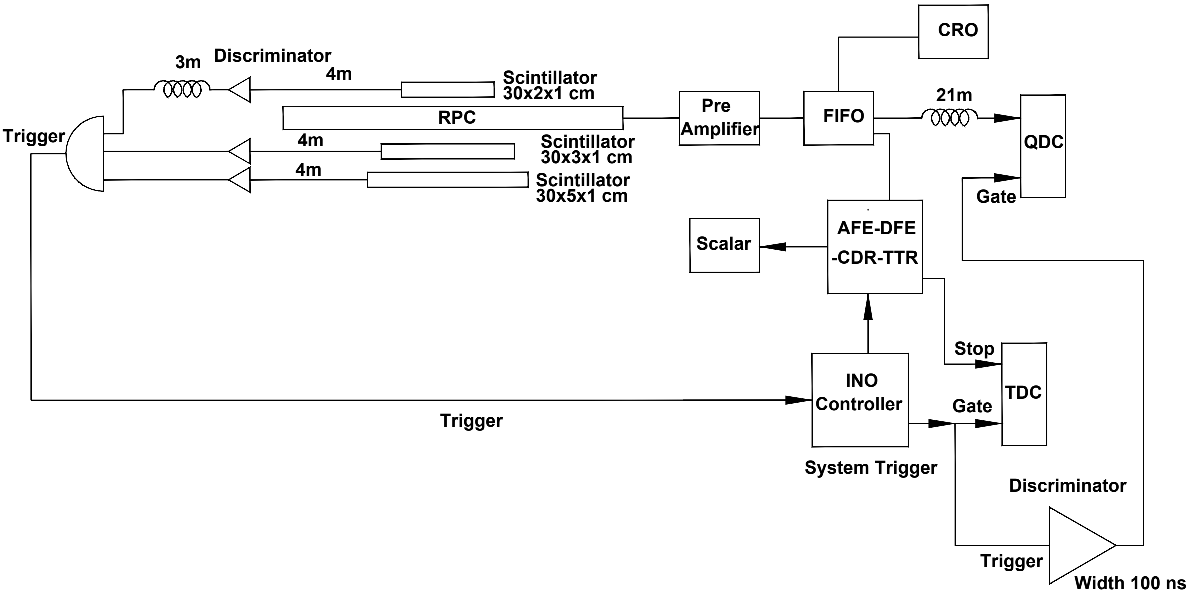

**Figure 1:** Experimental setup.

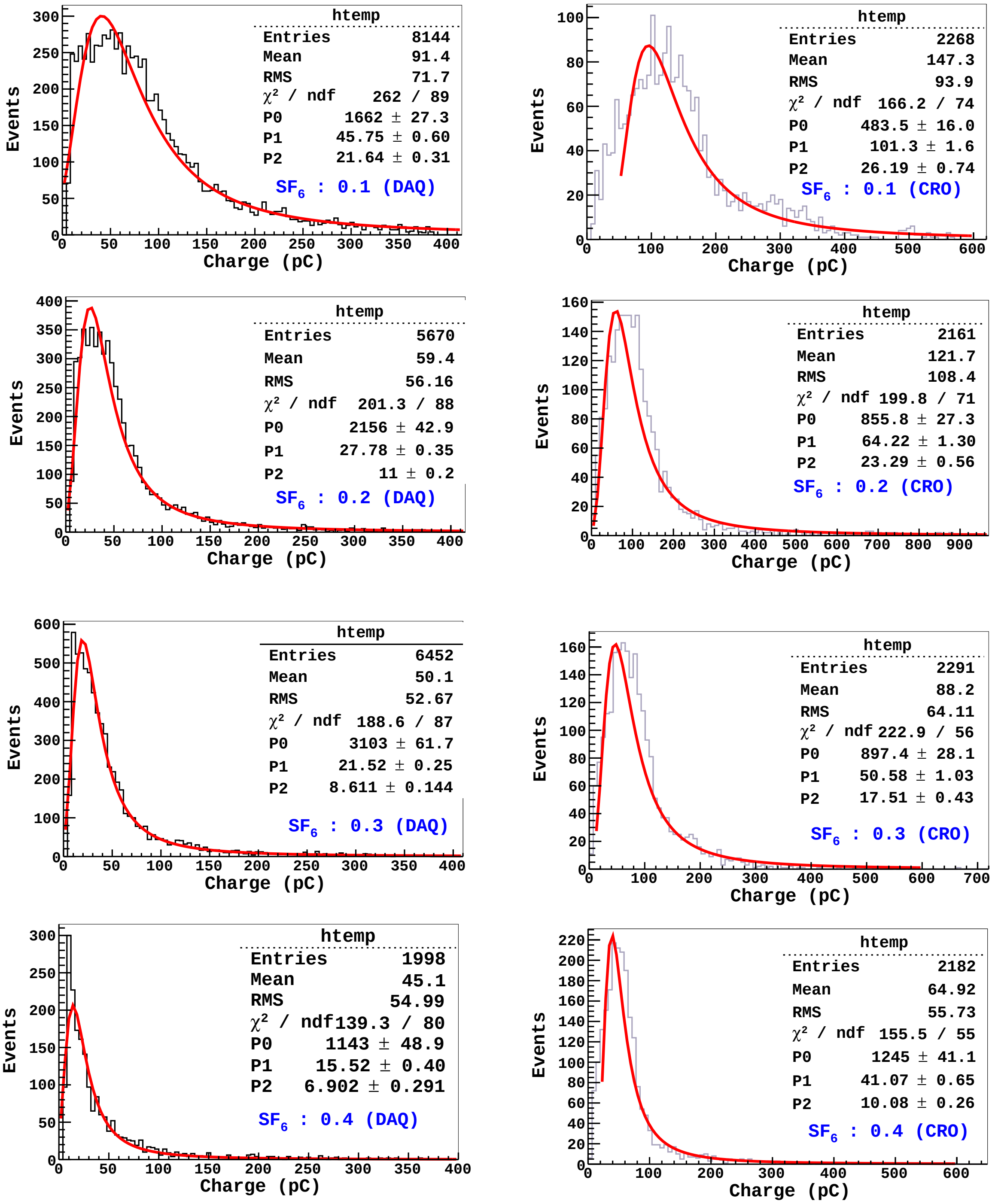

**Figure 2:** Charge measured with DAQ system and Oscilloscope for different gas mixtures.

## 3. Simulation

The simulation scheme is shown in Fig.3. Initially,the particle travelling through the RPC ionizes the gas medium and clusters are formed along the particle trajectory. The primary cluster density ($\lambda = 7.6mm^{-1}$) and average number of electrons per cluster ($\mu$ = 2.0) are calculated by HEED[5] for a 4 GeV muon. The electrons created by the primary ionization are further accelerated by the electric field. For the realistic RPC geometry,the nearly exact Boundary Element Method (neBEM)[6] calculates the electric field map (Fig.4). Though neBEM computes 3 dimensional field map for the given geometry of the device, here we are considering only 2 dimensional geometry since we are assuming particle trajectory only in vertical direction. The accelerated charged particles undergo secondary ionization by colliding with the nearby gas molecules. This process continues and the avalanche developed proceeds towards the corresponding electrodes. The electron transport parameters are calculated by MAGBOLTZ[7]. The townsend coefficient and attachment coefficient for different gas mixtures are shown in Fig.5.

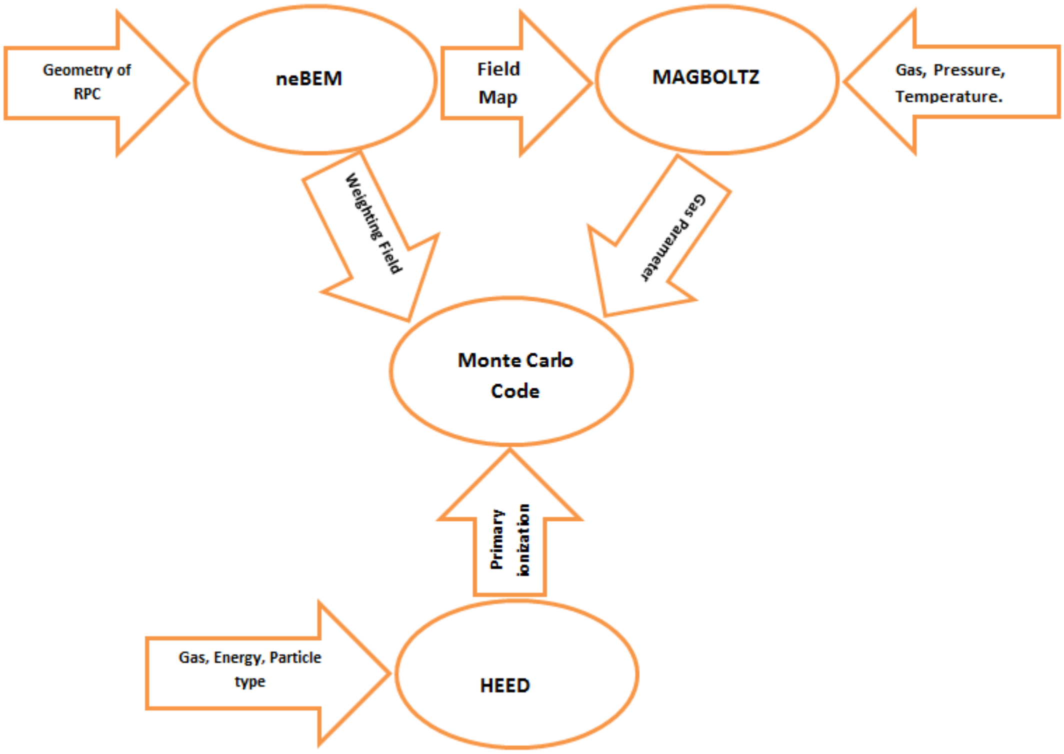

**Figure 3:** Simulation Scheme.

### 3.1 Monte Carlo Model

The simulation model[8][9] first considers an inoizing particle passing through the detector. The probability , $P_{cl}$ that $k$ clusters are generated in the gap is given by the Poisson distribution,

$$P_{cl}(n_{cl} = k) = \frac{(g\lambda_{eff})^k}{k!} e^{-g\lambda_{eff}} \tag{3.1}$$

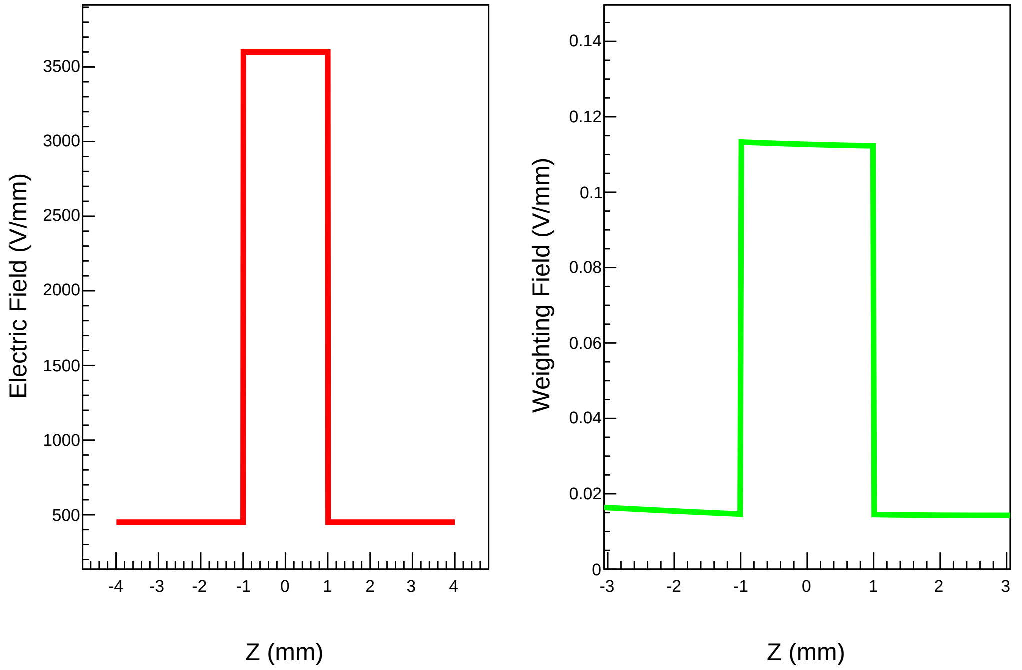

**Figure 4:** Electric Field and Weighting Field along z-direction.

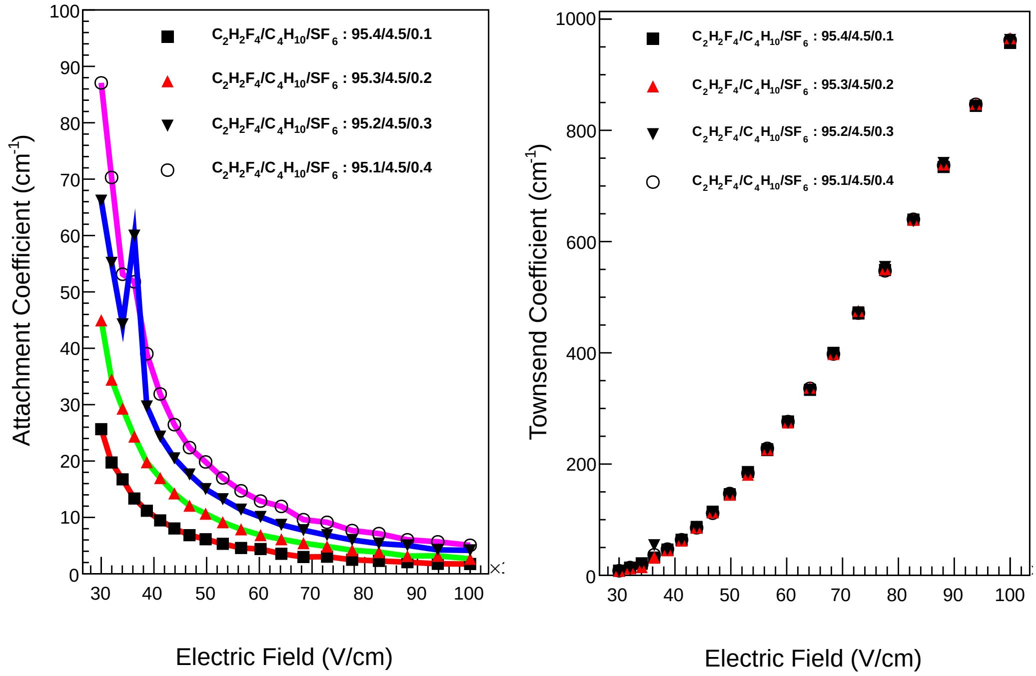

**Figure 5:** Attachment coefficient ($\alpha$) and Townsend coefficient ($\eta$) for different gas mixtures .

where,

$$\lambda_{eff} = \frac{\lambda}{\cos\phi}$$

$\lambda$ is the primary cluster density , $\phi$ is the azimuthal angle of the incident particle and g is the gap width. The probability distribution $P_p^j(x)$ of the initial position $x_0^j$ of the $j$th cluster is given by Poisson statistics

$$P_p^j(x_0^j = x) = \frac{\lambda_{eff}}{(j-1)!}(x\lambda_{eff})^{j-1}e^{-x\lambda_{eff}}, 0 < x < g. \tag{3.2}$$

Total charge $q$ at position $x$ is

$$q(x) = \sum_{j=1}^{n_{clust}} q_e n_0^j M_j e^{(\alpha-\eta)(x-x_0^j)} \tag{3.3}$$

where $n_0^j$ is the number primary electrons of the $j$th cluster which obeys poisson distribution,

$$P_{n_0^j}(n) = \frac{\mu^n}{n!}exp(-\mu) \tag{3.4}$$

$\alpha - \eta$ is the effective Townsend coefficient and $M_j$ accounts for the stochastic fluctuations of the exponential growth. For high values of $E/p$, a Polya distribution must be used[10].

$$P_P(n_{av} = n) = \left[\frac{n}{N}(1+\theta)\right]^{\theta} exp\left[-\frac{n}{N}(1+\theta)\right] \tag{3.5}$$

where,

$$N = n_0 e^{(\alpha-\eta)(g-x_0)}$$

and $\theta$ is taken as 0.5[10]. The induced current $i_{ind}(t)$ on the external pick-up electrodes is calculated from the Ramos theorem[11].

$$i_{ind}(t) = -v_d.E_W q_e e^{(\alpha-\eta)v_d\Delta t} \sum_{j=1}^{n_{cl}} n_0^j M_j \tag{3.6}$$

$E_W$ is the weighting field calculated from neBEM[6]. Induced charge is obtained by the direct integration of equation(3.6).

$$q_{ind} = \frac{q_e}{(\alpha-\eta)} E_W \sum_{j=1}^{n_{cl}} n_0^j M_j \left[e^{(\alpha-\eta)(g-x_0^j)} - 1\right] \tag{3.7}$$

The simulated charges at an electric field 3.6 kV/mm and at 5 kV/mm for different gas combinations are given in Figs 6 and 7.

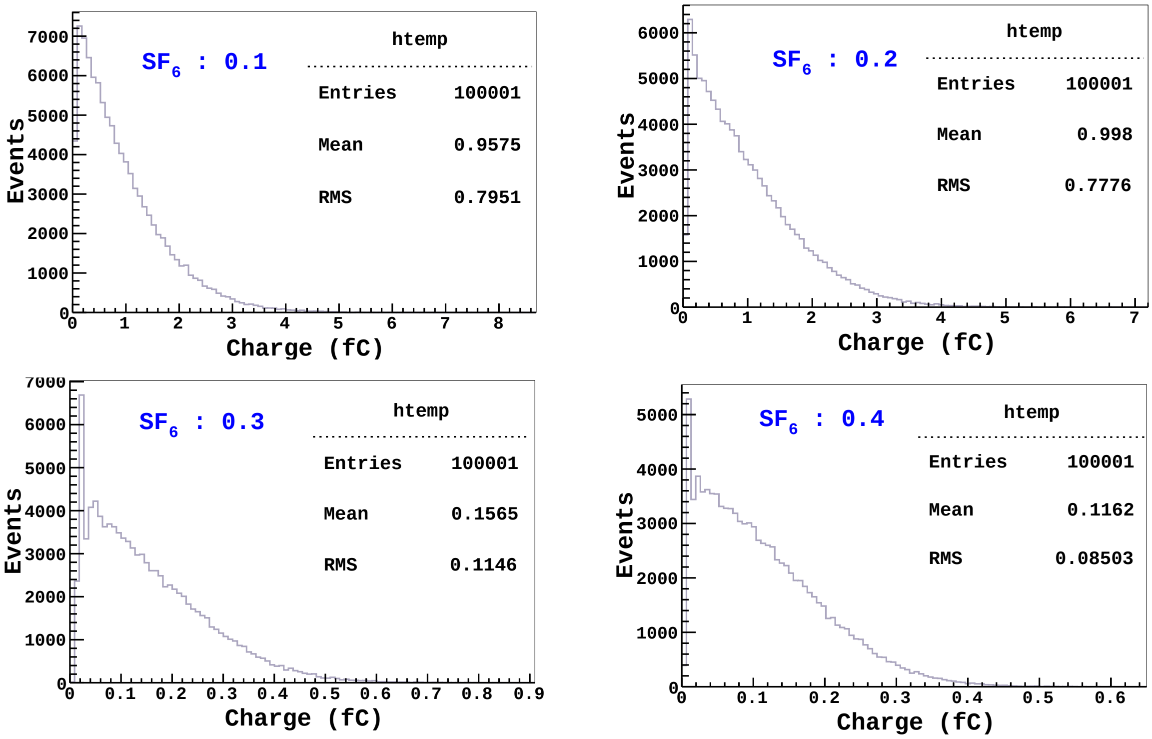

**Figure 6:** Simulated charge at electric field 3.6 kV/mm.

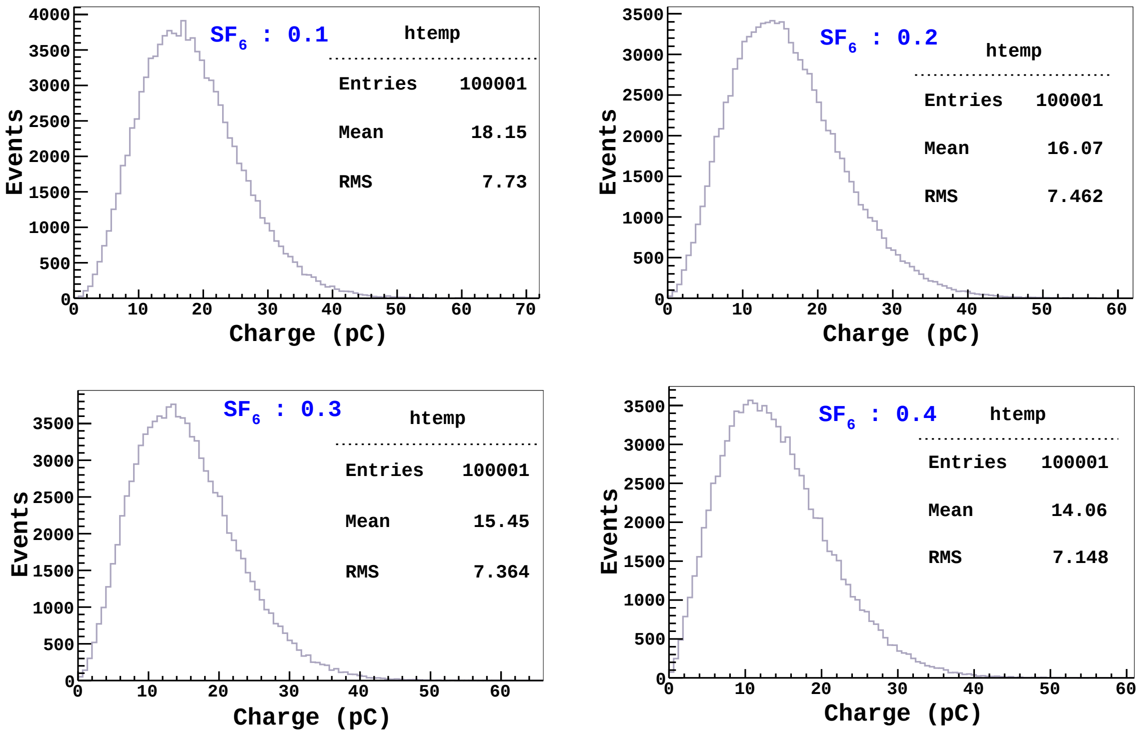

**Figure 7:** Simulated charge at electric field 5kV/mm.

## 4. Discussion and Conclusions

From our data, we observed that the experimental and the model results follow the same trend, namely the induced charge decreases with increase in $SF_6$ concentration. However, there is a 3 orders of magnitude difference between simulated charge and the measured value (see Table 1). This is possibly beacuse of the very low field (3.6 kV/mm, Fig.4) which we obtained when we had considered the realistic RPC geometry in simulation. Also errors from various sources like dielectric constant for the particular float glass which we used and slight error in the Townsend and attachment coefficients can result in significant deviations from the actual value. These effects have to be studied in detail to get a closer picture of the charge development in the RPC.

| Gas Mixture ($C_2H_2F_4/C_4H_{10}/SF_6$) | Charge(CRO) (pC) | Charge(DAQ) (pC) | Simulated Charge (at 3.6 KV/mm in fC) | Simulated Charge (at 5kV/mm in pC) |
|---|---|---|---|---|
| 95.1/4.5/0.4 | 0.51 | 0.19 | 0.11 | 14.06 |
| 95.2/4.5/0.3 | 0.66 | 0.27 | 0.16 | 15.45 |
| 95.3/4.5/0.2 | 0.85 | 0.35 | 0.99 | 16.07 |
| 95.4/4.5/0.1 | 1.29 | 0.57 | 0.96 | 18.15 |

**Table 1:** Comparison of measured and simulated charge spectra.

## References

[1] INO Project Report, INO/2006/01, May 2006.

[2] R. Santonico *et al*, *Development of resistive plate counters*, *NIM* **187:377**, (1981).

[3] P. Camarri *et al*, *Streamer suppression with $SF_6$ in RPCs operated in avalanche mode*, *NIM A* **414:317**, (1998).

[4] D. Samuel *et al*, *VME-based data acquisition system for the India-based Neutrino Observatory prototype detector*, *NIM A* **661:S73**, (2012).

[5] I. Smirnov, *HEED, program to compute energy loss of fast particles in gases*, Version 2.10, CERN.

[6] N. Majumdar, S. Mukhopadhyay, *Simulation of three-dimensional electrostatic field configuration in wire chambers:A novel approach*, *NIM A* **566:489**, (2006).

[7] S. Biagi, *MAGBOLTZ, program to compute gas transport parameters*, Version 8.9.6, CERN.

[8] M. Abbrescia *et al*, *The simulation of resistive plate chambers in avalanche mode: charge spectra and efficiency*, *NIM A* **431:413**, (1999).

[9] S. H. Ahn *et al*, *Performance and Simulation of a Double-Gap Resistive Plate Chamber in the Avalanche Mode*, *JKPS* **45:1490**, (2004).

[10] H. Genz, *Single electron detection in proportional gas counters*, *NIM* **112:83**, (1973).

[11] S. Ramo, *Currents Induced by Electron Motion*, in proceedings of *IRE* **27:584**, (1939).