Simulation of Resistive Plate Counter (RPC) Pulse Height Spectrum

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Abstract

The pulse height responses of Resistive Plate Counters of same size, operating voltage and gas mixture, but with two different gas gaps (1mm and 2mm) are studied here. A simulation model is developed for events giving rise to induced pulse using Monte Carlo Method. Simulated pulse height spectra are compared with measured spectra.

Keyword: Primary Ionization, Avalanche, Pulse height

Introduction

A Resistive Plate Counter (RPC) (Fig.1.) is a particle detector utilizing a constant and uniform electric field inside a gas mixture produced by two parallel resistive plates, made of a material with high bulk resistivity (approximately 10¹⁰-10¹¹ ohm cm). Passage of charged particles induces a highly localized discharge inside the enclosed gas leading to the formation of a streamer which can be picked up as a signal. Signal pick up strips are placed over the two plates orthogonally to record the signal.

![Image of RPC cross section]

**Figure 1:** Cross section of RPC.
The RPC’s having size 15cm×15cm with gas gap 1mm and 2mm respectively are biased by 7.8kV, and a gas mixture of 50% P-10 and 50% Freon gas is used. The pulse height were captured by DSO (TDS-520A, 500 MHz) and continuously recorded by PC (P4) through GPIB (IEEE 488) interface bus.

The physical processes occurring inside the RPC are modeled using Monte Carlo method. The details of pulse production including primary ionization, avalanche multiplication and induced signal are discussed. The recorded data are analyzed and compared with the simulated data and performance in terms of pulse height response is studied.

**Primary Ionization**

When a charged particle enters the RPC gas, it produces ionization. The primary ionization produced in the RPC gas is characterized by the average number of clusters produced per unit length and the probability distribution for the number of electrons per cluster. These numbers are calculated using Heed [3] and reported in [4]. The average number of clusters per mm for our gas mixture is calculated as a function of \((\gamma-1)\) of the particle using the measurement of cross section in different gases reported in reference [5]. For ground level cosmic ray muons of average energy 2GeV, we find on average ~6.5 clusters/mm. So the average distance between clusters is \(\lambda = 154\mu m\).

This distance is exponentially distributed, so the probability to find the first cluster between position \(x\) and \(x+dx\) is,

\[
P(x) = \frac{1}{\lambda} e^{-x/\lambda}
\]

The cluster size distribution for our gas mixture is parameterized using the graph of number of electrons per cluster \((n_e)\) versus probability \((p_e)\) as given in [4]. This parameterization is expressed as,

\[
\log_{10}(n_e) = 0.8 - 0.4 \log_{10}(p_e)
\]

For simulation, we put the primary clusters with distance following equation (1) after normalizing within the interval \((0, d)\) where \(d=\text{RPC gas gap distance}\). The number of electrons for each cluster is simulated from the cluster size distribution using equation (2)

**Avalanche Multiplication**

Each electron in a cluster starts an avalanche due to electron multiplication. This is characterized by the Townsend co-efficient \(\alpha\) and attachment co-efficient \(\eta\), which depends on the applied electric field. These parameters are calculated using the program Imonte [6] and plotted as function of electric fields for different gasses in
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While the electrons in the gas gap drift towards the anode, their multiplication will fluctuate around an average given by an exponential law.

\[ \bar{n}(x_i) = e^{(\alpha - \eta) x_i} \]  

Where \( x_i \) = distance measured from cluster position. It shows that the average electron number depends on effective Townsends co-efficients. \( \alpha_{eff} = \alpha - \eta \).

Induced Signals

The movement of the electrons in the electric field finally induces a current signal on the RPC electrodes, depending on the drift velocity \((v)\). The signal induced by negative and positive ions are much smaller due to their drift velocity and are neglected. Drift velocities for different gases are predicted by Magboltz [7] and reported in [4]. The current signal induced on an electrode is given by,

\[ i(t) = \frac{E_w V}{V_w} e_0 N(t) \]  

Where \( e_0 \) is the electron charge, \( E_w \) (Weighting Field) is the electric field in the gas gap if we put the electrode to potential \( V_w \) and ground all other electrodes, \( v \) is the electron drift velocity and \( N(t) \) is the number of electrons present at time \( t \). \( N(t) \) is calculated by simulating the avalanches of individual primary electrons. The weighting fields depend on detector geometry. For our RPC

\[ \frac{E_w}{V_w} = \frac{\varepsilon_r}{2b + d \varepsilon_r} \]  

Where \( \varepsilon_r \) = Resistive material permittivity, \( b \) = Resistive material thickness & \( d \) is the gas gap.

Monte Carlo Simulation procedure for a single event:
1. Positions of primary clusters are simulated using an exponential distribution[equation(5)] with mean=6.5
2. Primary electrons are put to each cluster following the cluster size distribution equation(1)
3. Avalanche for each single electron is simulated using equation (2) and procedure outlined in reference [4], this provides \( N(t) \), the number of electrons at time ‘t’.
5. Induced current signal is then calculated using equation (4)
6. Detector electronics is included by convoluting the RPC signal with the amplifier delta response.

\[ F(t) = t/\tau \exp (1 - t/\tau) \]

Where \( \tau \) is the response time of the amplifier.

**Result and Discussion**

**1mm RPC:**
Experimental data for output pulse heights of 1mm RPC, recorded in a file containing 1000 rows are analyzed using a FORTRAN program. Pulse heights are first read into an array; maximum, minimum and range are found, and compared with simulation result for the same number of events. Class intervals are suitably adjusted and both experimental and simulated data are histogrammed and compared in fig.1. There is slight discrepancy in the lower pulse heights up to 340mV. Mean and standard deviations are found for experimental data (mean=446mV, sd=58.9mV) and also for simulated data (mean=443mV, sd=60.9mV) and there is good agreement. Goodness of fit is tested by finding the value of chi-square per degree of freedom between 340mV to 540mV, which is calculated as, 12.

**2mm RPC:**
For the case of 2mm RPC same procedure is followed as for 1mm RPC data, but while performing simulation, space charge effects are considered by simply stopping the avalanche growth at the number of electrons corresponding to that of the maximum for 1mm RPC. Results are shown in fig.2. There is discrepancy in the higher pulse height region. Mean and standard deviations are found for experimental data (mean=383mV, sd=48.6mV) and for simulated data (mean=362mV, sd=43.7mV) and there is agreement within error limit. Chi-square per degree of freedom is found to be 58.4, which is much higher than that for 1mm RPC. However, the width of the pulse height spectrum for 2mm RPC is much less, both for experimental and simulation results, indicating a better resolution.

**Conclusion**
We have presented an RPC simulation procedure starting from primary ionization, avalanche production finally giving induced charge and current. The output signal is simulated by taking into account the detector response. When compared with the experimental pulse height spectrum, 1mm RPC gives better fit with simulation
compared with 2mm RPC. However, the width of the pulse height spectra is less for 2mm RPC, indicating a better performance. A more realistic model for space charge effect may be considered for future work.

**Figure 2:** Experimental and Simulated Pulse height spectrum for 1mm RPC.

**Figure 3:** Experimental and Simulated Pulse height spectrum for 2mm RPC.

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