Comments on RPC's for the Daya Bay Reactor Neutrino Experiment

Changguo Lu, Kirk T. McDonald

Joseph Henry Laboratories, Princeton University, Princeton, NJ 08544

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1 Principles of Operation of RPC's

An RPC is a Resistive Plate Chamber formed by two parallel sheet of uniform, resistive material such as Bakelite or glass, as shown in Fig. 1.

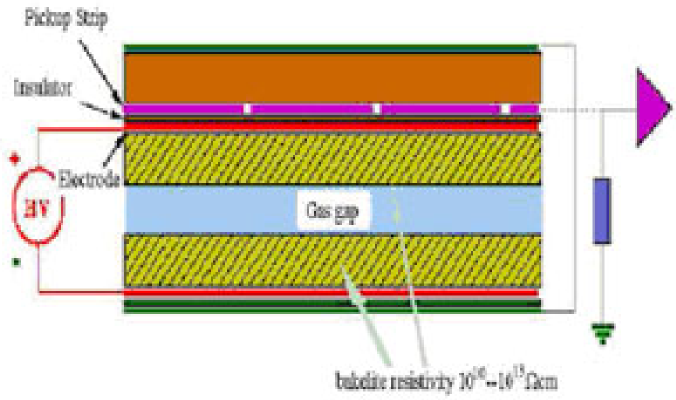

Figure 1: Sketch of a Resistive Plate Chamber (RPC).

High voltage is applied to the outside surfaces of the resistive sheets, which have enough conductivity that each sheet is an equipotential. Thus, the entire applied high voltage appears across the gap between the sheets. A typical gap width is 2 mm, and a typical high voltage is 8 kV.

The gap is filled with a nonflammable gas such as $C_2H_2F_4$(Freon R134A)/C_4H_{10}(isobutane) /Argon: 42/8/50. The resulting structure is a parallel plate avalanche chamber. When a minimum-ionizing particle such as a muon crosses the gap it creates a train of electron-ion pairs with density about 6 clusters/mm with an average of 2.4 electron-ion pairs per cluster. The uniform electric field in the gap pulls the electrons towards the anode (= higher voltage sheet) with a typical drift velocity of 10 cm/μs, as shown in Fig. 2. As the electrons drift they gain energy before colliding with gas molecules, and if the energy gain is sufficient, the collision can liberate electrons from the gas molecule, leading to a so-called Townsend avalanche. If the electrons have traveled a distance x in an electric field E, then the number of electrons in the avalanche is described by the exponential gain formula,

$$n(x) = n_0\, e^{\alpha(E/P)x}, \qquad (1)$$

where n_0 is the number of electrons at $x = 0$, α is the Townsend coefficient, which is a function of the ratio of the electric field to the gas pressure P. The Townsend coefficient can be modeled by the computer program MAGBOLTZ [1] based on empirical input. Figure 3 shows a calculation of the Townsend coefficient for the typical RPC gas mixture, and one with more argon/less Freon. A higher Townsend coefficient permits operation of the chamber at lower voltage to achieve the same gas gain.

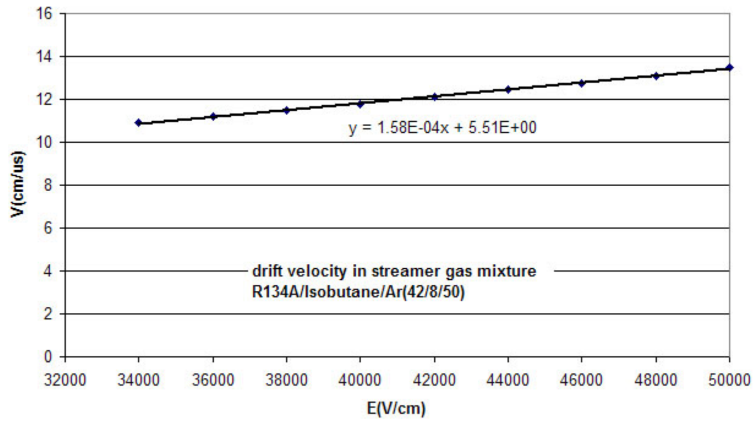

Figure 2: Drift velocity in the RPC gas mixture Freon/Isobutane/Argon: 42/8/50 at 1 atmosphere pressure, calculated using the MAGBOLTZ program [1].

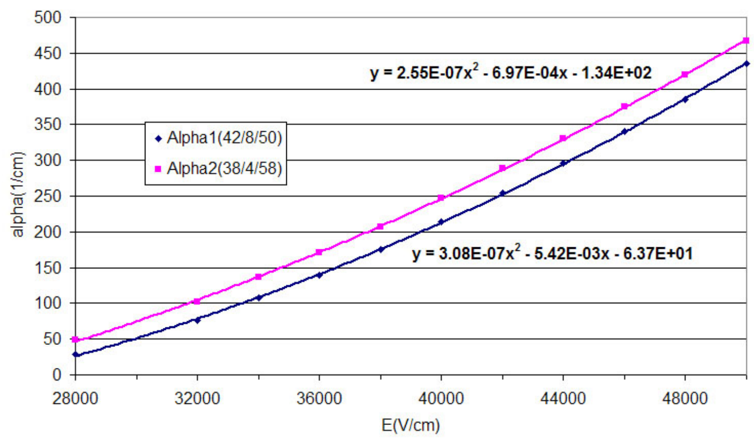

Figure 3: Townsend coefficient for two RPC gas mixtures, Freon/Isobutane/Argon: 42/8/50 and 38/4/58 at 1 atmosphere pressure, calculated using the MAGBOLTZ program [1].

The electron-molecule collisions also result in non-ionizing excitations of the molecules, whose de-excitation includes the emission of ultraviolet photons. Some of these photons can ionize other molecules, which increases the gain of an avalanche, but which can also result in unstable operation of the chamber if the UV photons propagate to the cathode before ionizing gas molecules. Hence, it is desirable that the chamber gas include a "quenching" component that absorbs the UV photons close to their production point. Isobutane is the "quencher" in the RPC gas mixture.[1]

If the Townsend avalanche grows until the number of electrons is in excess of about 10^8 it generates a streamer in which the bulk electric field of the electron cloud is sufficient to further ionize the chamber gas [6, 7]. If the gas is not strongly quenching, the streamer quickly develops into a spark. A stable, limited streamer mode of operation, in which the charge of the streamer is about 50 times that of the Townsend avalanche that initiates it, is very desirable for RPC's in that this permits use of low-cost front-end electronics.

References

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[1]Argon is a good "host" gas in that it is nonflammable and does not "attach" the drifting electrons. However, it is a poor quencher. A gas mixture of argon/isobutane that has good quenching is flammable. Substitution of large fraction of argon by nonflammable Freon provides reasonably good quenching (and improves the density of electron-ion pairs). However, the Townsend avalanches cause Freon to react with water vapor in the gas mixture to produce HF acid which is damaging to the chamber, particularly if it is made of glass [3, 4, 5]. This problem is more severe in a high-rate environment, but it will still be prudent to control both the water vapor content of the chamber gas, and the humidity of the air in contact with the RPC's in the Daya Bay experiment.