RPC: STATUS AND PERSPECTIVES

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1 Historical Remarks

Most of the existing gaseous detectors are based on the electric field generated by a positively charged wire. The strong dependence of this field on the distance r from the wire $E \propto 1/r$ has basic consequences on the detector working mode:

- It limits the extension of the "multiplication region" and therefore the radial size of the discharge, to a distance of the order of the wire diameter.
- It makes the detector very stable, the field strength being very low at the cathode walls.
- It makes the detector time resolution modest due to the jitter of the electrons drift motion up to multiplication region near the wire.

The Geiger-Muller counter invented in the years '20 was the first detector which used a charged wire to produce a field inside a gas. It can be considered as the common "ancestor" of a large family of detectors which were created to fulfill specific needs of the experiments and includes multiwire proportional chambers, limited streamer tubes and also, more recently, microstrip gas counters.

The wire detectors had an impressive impact on the experimental physics.

A much higher time resolution with respect to the wire detectors can be achieved by the planar detectors which are based on the uniform electric field generated by two parallel electrode plates. Their common ancestor is the Keuffel spark counter [1] from which Pestof counters [2] and resistive plate chambers[3] were derived. Planar detectors, except in their pulsed version of the optical spark chamber, had so far a modest impact on the experimental physics in spite of their intrinsic interest.

The RPCs have recently proven to be a detector capable of real applications to experiments demanding both space and time resolution over large detection areas [4].

The experience accumulated in the experiments that used them so far makes the RPCs a natural candidate technology for the muon detection at the future hadronic colliders and for the cosmic rays physics.

2 A simple working model

The sketch of a RPC is shown in fig. 1. Two parallel electrode plates of bulk resistivity $\rho = 10^{10\div 12}\Omega\, cm$ generate a uniform, intense electric field, usually about $4KV/mm$, in a $2mm$ gas gap filled with a mixture of Argon, butane (about 60/40 in volume) and Freon $(3-5\%)$ at normal pressure.

The electrode plates are coated, on the external sides, with thin graphite layers connected to high voltage and to ground respectively. Due to their high surface resistivity of about $0.1M\Omega/\Box$, these graphite electrodes are transparent to the transients of electrical discharges generated inside the gas. The capacitive signal read out is therefore possible through virtually grounded pads which are fixed or simply pressed on the detector walls.

A PVC-Polyethylene film $0.3mm$ thick, glued on the graphite layer, is used to insulate the high voltage electrodes from the read out pads which can be arbitrarily shaped being completely independent from the mechanical structure of the detector. As an example, X and Y orthogonal read out strips are shown in fig. 1.

The RPC just described has the structure of a two dielectrics planar capacitor. A correct description of the system has to take into account the finite resistivity of the real dielectrics as in the equivalent circuit shown in fig. 2a.

Two cases have to be considered:

- The case of a non-ionized gas corresponds to an infinite gas resistivity,

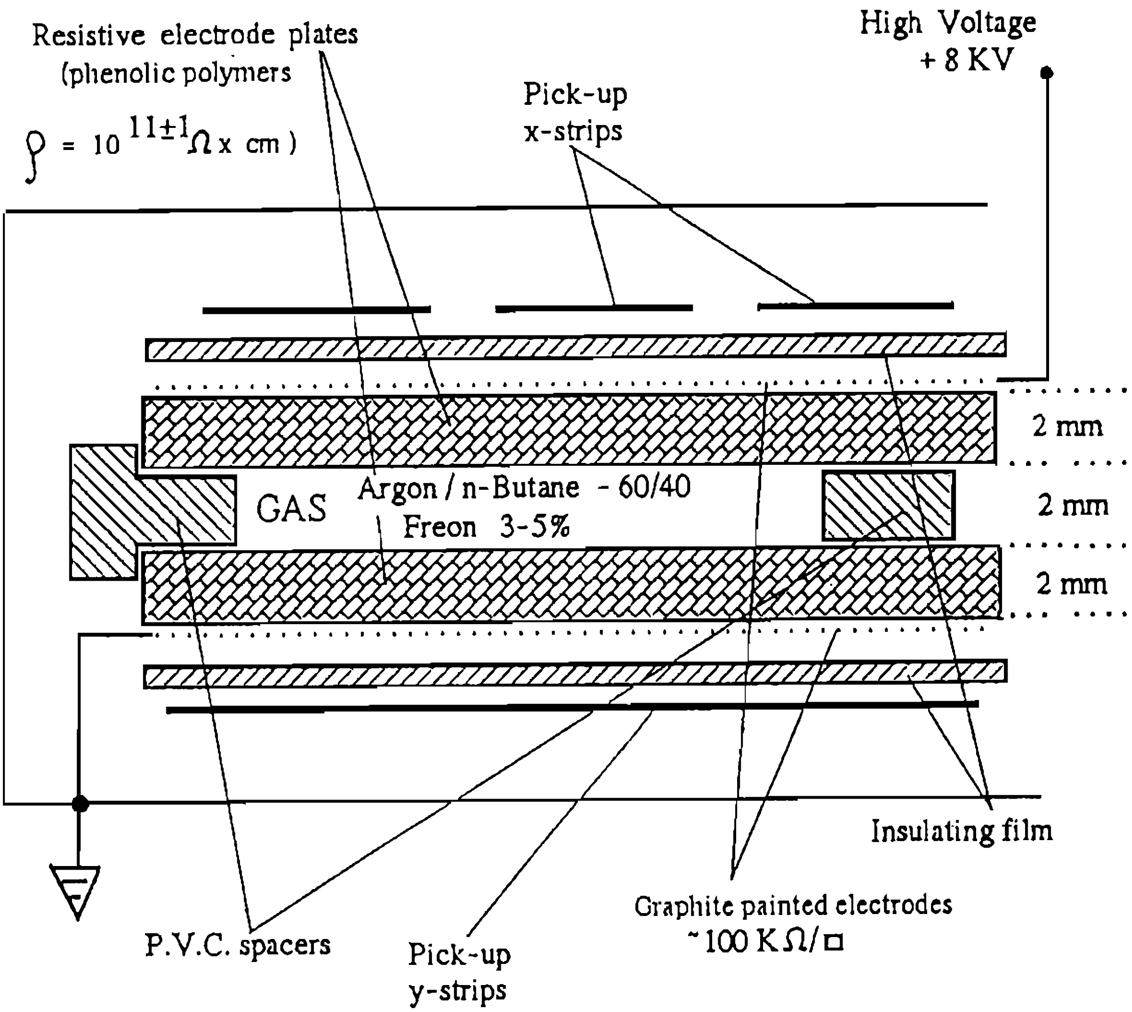


Figure 1: Sketch of a resistive plate chamber

$R_g = \infty$ in fig. 2a. Therefore in the steady situation the supplied voltage is entirely applied to the gas gap.

- When the gas is crossed by a ionizing particle, the electric discharge generated in the gas can be described by a current generator (fig. 2b) which discharges the "gas capacitor" C_g so that the voltage initially applied to the gas is transferred to the resistive plate described by the capacitor C in fig. 2b. The system goes back to the initial condition following an exponential law with a characteristic time constant τ which is independent from the size of the capacitor:

$$\tau = R(C + Cg) = \rho\epsilon_0(\epsilon_r + 2d/g)$$

where ϵ_r is the relative dielectric constant and d is the thickness of the plates and g is the gas gap.

The above relationship gives $\tau \sim 10\,msec$ for $\rho = 10^{10}\Omega\,cm$. This characteristic time constant has to be compared with the discharge duration that, for the gas and voltage conditions that are usual for RPCs, is only $10\,ns << \tau$. In such a short time the electrode plates behave like insulators and the discharge occurring in the gas cannot be fed. This quenching mechanism is at the basis of the working principle of the detector.

It has been suggested by Pestov that a chamber with resistive electrode plates is intrinsically divided in a large number of small "discharge cells" which are to some extent independent from one another. The area of each cell is proportional to the total charge Q freeded in the gas:

$$S = \frac{Qg}{\epsilon_0 V}$$

The parameter Q is a crucial one in determining the rate capability of an RPC. The discharge occurring in the gas indeed can only be fed by a limited current that can flow across a pair of high resistivity electrode plates. A small value of Q allows therefore to keep the operating current small and the detection efficiency high, even in presence of an intense flux of ionizing particles and provided that the frontend electronics can offer enough amplification and bandwidth.

3 Signal Charge and Gas composition

RPCs can be efficiently operated even with gas mixtures containing large amounts of electronegative gases like freons. Wire detectors on the contrary require non electronegative gases for an efficient operation because free electrons can be captured in their drift motion to approach the wire. The

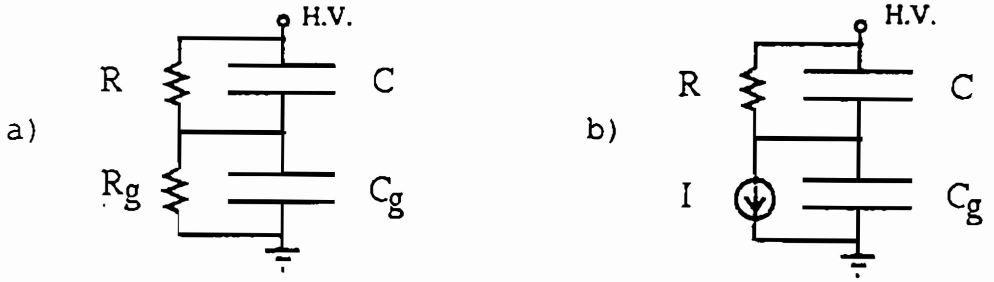


Figure 2: Equivalent circuit of the "discharge cell". The capacitors C and C_g correspond to the resistive plates and to the gas gap respectively. For a non ionized gas (figure 2a) $R_g = \infty$ and the supplied voltage is entirely applied to the gas gap. A current generator (figure 2b) describes the effect of the electric discharge. The voltage initially applied to the gas is transferred to the resistive plate

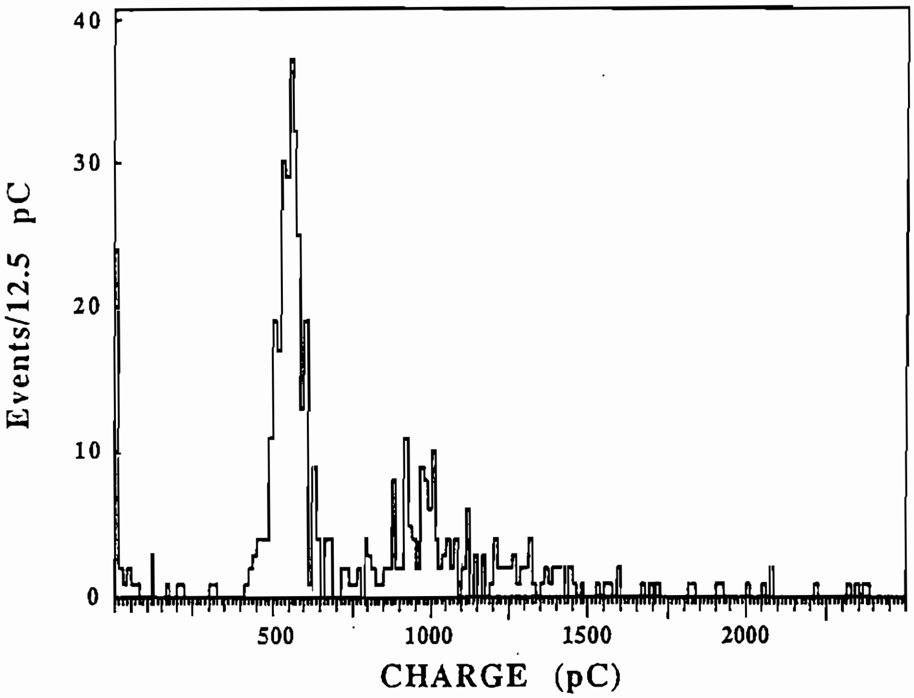
addition of relatively small amounts of some kind of freons, e.g. CF_3Br, to the RPC gas has the effect of reducing the size of the electric signal induced on the pick-up strips.

The signal charge distribution of a RPC operated with a fixed Argon/ Butane ratio of 60/40 in volume and different amounts of freon, for a $0.5\mu sec$ integration gate is shown in fig. 3.

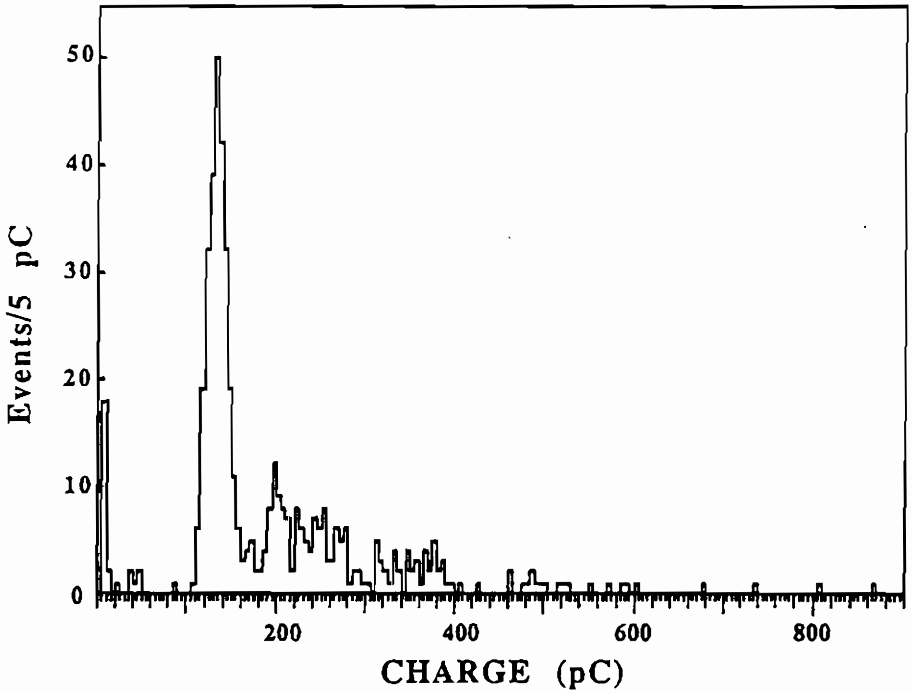
The case of a freonless gas (fig. 3a) and of one containing 4% (fig. 3b) and 8% (fig. c) respectively are reported. The detection efficiency is approximately the same, 96%, for the three cases and the operating voltage is slightly increasing with the freon concentration. All three distributions show a sharp peak corresponding to single discharges, followed by a tail due to multiple discharges. The average of the single discharge peak decreases of about one order of magnitude, from 500 to $50\,pC$, for an increase of the freon concentration from zero to 8%. As a conclusion the freon concentration in the gas has a drastic effect of reduction on the signal charge.

As discussed above this effect improves the rate capability of the detector. But for considerably larger amounts of freon a high amplification and bandwidth frontend electronics is needed.

A RPC operating with pure CF_3Br has been successfully tested at the CERN RD5 test beam up to a maximum rate of $10KHz/cm^2$ [5]. The signal


Events/12.5 pC
40
30
20
10
0
500
1000
1500
2000
CHARGE (pC)

a)


Events/5 pC
50
40
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20
10
0
200
400
600
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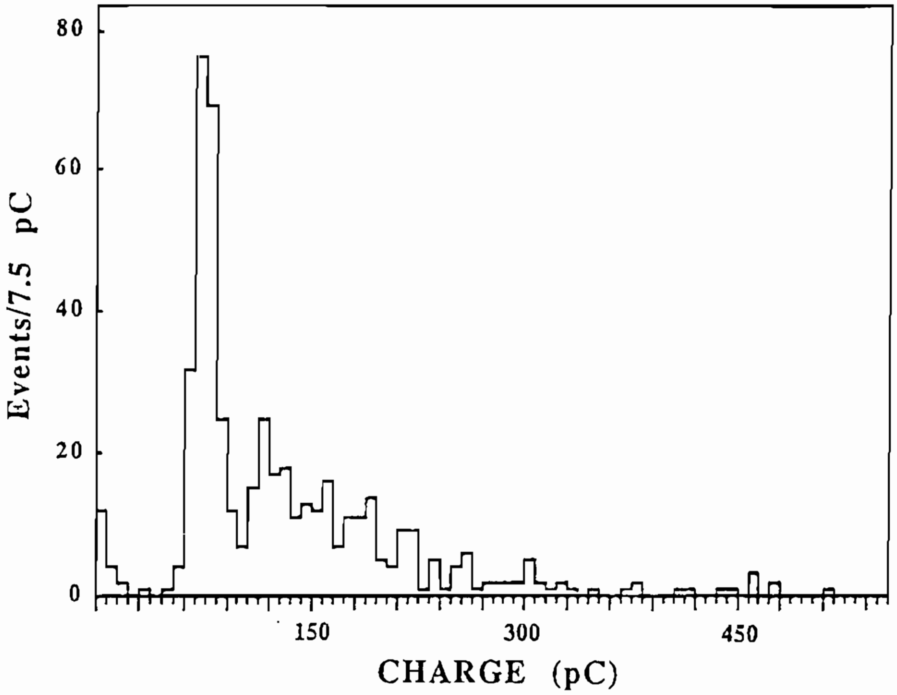
CHARGE (pC)

b)



c)

Figure 3: Signal charge distribution for fixed Argon/Butane ratio (60/40 in volume) and different amounts of CF_3Br in the gas mixture: 0% a), 4% b), 8% c)

charge in this operating condition was $< 1pC$, i.e. a factor 10^2 smaller than in the usual operating condition. A similar factor is gained in rate capability.

The area of the elementary cell corresponding to this extremely small charge is of the order of $S = 10^{-2} mm^2$ and the linear dimensions are much smaller than the gas gap !.

In this condition two contiguous cells can hardly be independent and the oversimplified model of the independent discharge cells described above must be revised.

4 Signal Pick-up

The pick-up electrodes of the RPCs can be shaped as strips or squared pads. The strips have the advantage to behave as signal transmission lines of well defined impedance that allow to transmit the signals at large distance with minimal loss of amplitude and time information.

The main advantage of the squared pads is the unambiguous bidimensional localization of the particle trajectory.

The disadvantages are the higher number of frontend electronic channels and a more complicated and sometime non obvious way to connect the pads to the frontend discriminators. When a low spacial resolution is required it may be attractive the idea to use very large pads to reduce the number of frontend channels. But the following considerations show that the pad size cannot be arbitrarily large.

The current produced by the discharge in the gas induces a signal on the pick up electrode. A systematic study of the distribution of the charge induced on a small number of contiguous strips $6mm$ wide, around the discharge position, [6] [7] show that the induced charge is concentrated over a "pick up area" which turns out to be of the order of only $1\,cm^2$. The equivalent circuit of the read out electrode can be described as a current generator charging a capacitor C in parallel to a resistor R, as shown in fig. 4 where C is the electrode capacity and R the resistance connecting the electrode to ground.

Lets consider two particularly interesting cases. A long read out strip can be treated to a good approximation as a signal transmission line. The capacity C, in this case is independent from the length of the strip and, for an ideal transmission line of width greater $1\,cm$ it is proportional only to the

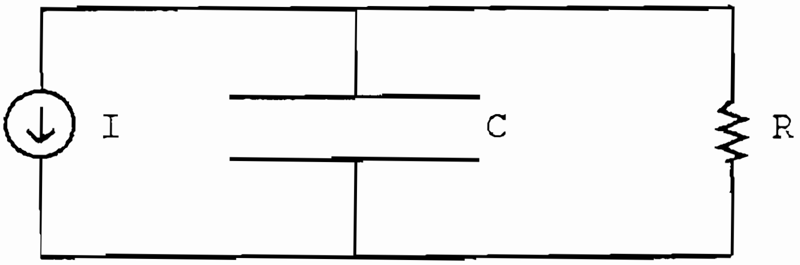


Figure 4: Equivalent circuit of the readout electrode

pick up area mentioned above, i.e. C about $1\,pC$. If Z is the characteristic impedance of the line, $R = Z/2$, as the signal propagates in both directions along the strip and, for a 50Ω line, the time constant RC is of the order of $25\,ps$ i.e. much shorter than the rise time of the signal.

In this case, according to the equivalent circuit in fig. 4, there is no signal integration. The current injected in the strip is at any instant proportional to the current of the discharge in the gas and the amplitude is $V_0 = R\,I_{max}$.

A squared pad on the contrary can be treated to a reasonable approximation as a concentrated capacitor so that $C = C_{pad}$. In this case R is the input impedance of the frontend discriminator connected to the pad and the time constant RC, for very large pads, could be much longer than the signal duration. In this condition the output signal would be strongly integrated, with an amplitude $V_0 = Q/C$ decreasing with the pad capacity and a long exponential fall time. A $30 \times 30\,cm^2$ pad connected to a 100Ω input impedance discriminator for example, would give a time constant of about $100\,ns$, a factor of 10 longer than the discharge duration with the standard gas.

This latter case would be particularly critical in connection with a pure freon operation.

5 Problems with the Neutron Background at the future Colliders

I has been recently pointed out that at the LHC experiments the rate of the detectors far away from the interaction region, like the muon detectors, will be largely dominated by the soft neutron and gamma background. At ATLAS e.g. a neutron background of $10^6/cm^2\,sec$ interesting the muon detector has been estimated [8].

This background would presumably induces in a RPCs system a much larger counting rate than that expected from the muon background.

A dedicated test to measure the neutron and gamma sensitivity, the rate capability and the ageing under neutron irradiation for RPCs, is therefore of basic importance in view of the use of RPCs as muon detectors at the future colliders.

The first test in this direction has been realized at MIT [9]. It measured a neutron sensitivity of 3×10^{-3} at a few MeV neutron energy for a standard RPC and a lifetime $> 8\,years$ at a rate of $2Hz\,cm^{-2}$.

This rate would correspond to a neutron background of $700Hz\,cm^{-2}$ according to the measured sensitivity, a value considerably smaller than the one expected now.

Nevertheless it could be extrapolated to a more realistic situation according to the following argument. As stated above the pure freon operation gives signals of charge a factor of 10^2 smaller than in the standard operation.

Therefore, as far as the ageing effects depending only on the total charge flowing in the gas are concerned, the same RPC if operated with pure freon would have the same lifetime under a neutron flux of $10^5 Hz\,cm^{-2}$.

6 Mass production

The production of very large modular detectors is a serial work particularly suited for industrial production.

RPCs are currently produced in the industry. The muon detectors of the experiments WA92 and RD5 at the CERN are realized with RPCs of industrial production.

In the next future a large system of 400 RPC modules will be constructed to upgrade the L3 experiment at LEP in the forward-backward regions [10] .

The present mass production capability is $\sim 20\, m^2/day$ for standard RPCs.

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