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Performances of a Resistive Plate Chamber operated in avalanche mode under ^{137}Cs irradiation

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Abstract

A 2 mm gas gap Resistive Plate Chamber with bakelite plates has been operated in avalanche mode under a ^{137}Cs source irradiation. We report on measurements of the efficiency in cosmic rays detection and of the charge developed in the gap, performed for two different gas mixtures: the first containing a high percentage of environmental friendly ”freon” $C_2H_2F_4$; the second one having a high percentage of argon. We show that the freon based mixture exhibits a wide full efficiency plateau with low streamer probability, whilethe argon based mixture allows to reduce the detector power consumption.

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1 Introduction

Recent developments about the possibility to operate Resistive Plate Chambers (RPCs) in avalanche mode [1] have led to the proposal of using such chambers to build large dedicated trigger detectors for future LHC experiments [2]. However, due to the high foreseen background (10 to 100 Hz/cm^2) the detectors are supposed to withstand both in ATLAS and CMS, demanding performances on efficiency, temporal and spatial resolution are imposed.

Although rate capability seems not to be an issue anymore [3], one has still to compel with two major requirements: the first is the need of keeping the uncertainty on bunch crossing identification as small as possible; to this respect, fast gas mixtures, i.e. mixtures with high electron drift velocity, have to be preferred. Freon based mixtures have proven to be a suitable choice which also allows high rate detector operation.

The second problem is represented by the detector power consumption at high rate which, even in presence of low gas amplification, may exceed tolerable limits. This is especially true in CMS where, according to the proposal, RPCs should be integrated with the drift tube muon chambers and embedded in the iron return yoke of the magnet.

The above requirements are clearly in conflict: in fact using the freon on one hand reduces the charge collection time, thus improving the timing; on the other hand increases the power consumption, due to its high electronegativity. Only a small fraction of electrons produced in the avalanche contributes to the signal, the majority of them being attached to freon molecules. It is therefore useful to study the behaviour of non electronegative gas mixtures to see wether they could allow lower power consumption without degrading considerably other performances.

In this paper we report on measurements on a CMS-like double gap RPC module operated under a 0.65 mCu ^{137}Cs source irradiation. We have compared performances of two different gas mixtures: the former composed of 90% $C_2H_2F_4$ and 10% i-C_4H_{10} (here briefly referred as the ”freon” mixture). This mixture, with minor variations in percentage, is widely used by groups developing narrow gap RPCs. The latter is composed of 70% argon, 5%i-C_4H_{10}, 10% CO_2 and 15% $C_2H_2F_4$ (referred as the ”argon” mixture).This mixture is commonly used by groups working on wide gap RPCs.

It is worth to point out that $C_2H_2F_4$ is an environment friendly ozone safe gas, which is going to be widely used in place of the old ozone depleting CF_3Br.

2 Experimental set-up

A 50×50 cm^2 double 2 mm gap RPC with oiled bakelite plates was used for measurements. A cross section of the chamber is shown in Fig. 1. The read-out strips (1.5 cm wide) are located in the middle. The high voltage is connected independently to the gaps, so that the chamber could also be operated in single gap mode by disconnecting the high voltage from one of them. A set of scintillators placed above and below the chamber was used to trigger upon the passage of cosmic rays. The geometry was arranged to cover one strip (Fig. 2a).

Moreover the ^{137}Cs source could be moved above the apparatus to irradiate the chamber at an average counting rate of about 500 Hz/cm^2 on an area of 10×10 cm^2.

One end of the strips was connected to a Le Croy NIM 612 AM amplifier having voltage gain 40 and bandwidth 140 MHz. The other end was terminated on 50 Ω.

Efficiency was measured by means of NIM scalers after 20 mV threshold discrimination, which corresponds to about 50 fC charge threshold when the signal shape is taken into account. Signals from the strip defined by the trigger coincidence were sent to a Le Croy 300 MHz digital oscilloscope which stores the waveforms on a disk memory for an off-line measurement of the charge and of the streamer probability. We define the streamer probability as the fraction of events in which an additional signal with charge at least 10 times greater than the average avalanche one, appears in a time window of 200 ns. Due to the 50 Ω termination on both ends of the strips, only half of the charge induced on the strip was measured by the system.

A scheme of the acquisition chain is shown in Fig. 2b.

3 Efficiency and streamer probability

The efficiencies vs the high voltage for freon and argon mixtures in absence of irradiation are shown in Fig. 3a and 3b respectively. In each plot data are given for both single and double gap operation mode. In addition the streamer probability is also plotted.

The fraction of streamers produced at a given voltage is an important parameter to characterize the operation mode of the chamber. According to Crotty et al. [1], who consider the streamer probability as a function of the dynamic range of gas gain, we can get an idea of such probability with different gas mixtures.

If we aim at an efficiency in excess of P%, using an electronics sensitive to a single cluster, with a given detection threshold (thus with a given minimum gas gain), then, at least one primary cluster must lye, with probability P, within a x_{max} maximum distance from cathode. Therefore for a double gap RPC

$$P_1[0, x_{max}] \times P_2[0, x_{max}] = e^{-2\lambda x_{max}} = 1 - P$$

where $P_i[\cdot]$ is the probability that, in the gap i, no clusters are found within x_{max} from cathode, and λ is the mixture cluster density. Thus

$$x_{max} = -\frac{\ln(1-P)}{2\lambda}$$

and the dynamic range is

$$R = \frac{e^{\eta d}}{e^{\eta(d - x_{max})}} = e^{\eta x_{max}}$$

the denominator being the given threshold,η the effective Townsend coefficient and d the gap width. With another mixture, having cluster density λ'

$$R' = \frac{e^{\eta' d}}{e^{\eta'(d - x'_{max})}} = e^{\eta' x'_{max}}$$

From the threshold equality

$$\eta' = \eta \frac{d - x_{max}}{d - x'_{max}}$$

One can see that if $\lambda' < \lambda$ then $R' > R$. For example with $P = 95$ %, d=2 mm, $\lambda = 5$ mm^{-1} (typical for freon mixtures), $\lambda' = 2.5$ mm^{-1} (typical for argon mixtures), $\eta = 9$, we have $R = 15$, $R' = 704$. The use of light gases increases the streamer probability. As already outlined by Crotty et al. [1], the use of wider gaps is in this case mandatory.

Fig 3a and 3b show that, below a given voltage (9500 V in freon, 5200 V in argon), where the streamer probability is negligible, the chamber may be assumed to work in pure avalanche mode. At higher voltages the percentage of streamers grows rapidly and the chamber works in a sort of mixed mode: an increasing fraction of avalanche signals is accompanied by delayed streamer signals [4].

As explained above, efficiency is higher in freon for a given streamer probability, due to the higher gas density. In addition the plateau region of operation (defined here as the voltage interval where efficiency is greater than 95% and streamer probability is less than 10%) is wider in freon.

Double gap efficiency and streamer probability under irradiation are shown in Fig. 4a and 4b for freon and argon respectively. For comparison, results with no source are plotted once more. While there is a small loss of efficiency in freon, the effect is more relevant in argon and it is accompanied by a narrowing of the plateau.

4 Charge

The fast charge induced on the strip when the chamber is operated in avalanche mode has been measured in many different working conditions (source - no source, single gap - double gap). A summary of experimental average results is given in Fig. 5a and 5b for freon and argon respectively. Since, as already pointed out, we measure half of the fast induced charge, the results of the measurements must be multiplied by a factor 2. In the following we shall always refer to the total induced charge q_e=2q_{meas}. For sake of reference we also show in Fig. 6a and 6b the fast charge spectrum in two cases: single gap, no source operation in freon at HV=9500 V (Fig. 6a) and single gap, no source operation in argon at HV=5200 V (Fig. 6b).

It can be seen that the chamber operated in freon exhibits a larger (by a factor 2) fast charge compared to the argon case. Therefore the achievement of high efficiency in argon requires a more demanding front-end electronics or a lower discrimination threshold.

5 Power consumption

Concern has been raised about the use of an electronegative gas such as $C_2H_2F_4$ that could lead to severe power consumption at the LHC background conditions. In fact, during the development of an avalanche a sizeable amount of the produced electrons are attached and do not further contribute to the multiplication process. It is a simple matter to show that the fast charge induced on the pick up electrode is only a small fraction of the total charge developed into the gap and moved by the power supply. Whatever the gas mixture, in a single avalanche the ratio *fast charge* q_e*/total charge* q_s can be evaluated as :

$$\frac{q_e}{q_s} = \frac{1}{\alpha d}$$

where α is the first Townsend coefficient of the gas mixture, d the gap width and q_s is the charge moved by the applied voltage into the circuit outside the gap. In avalanche mode the fast visible charge is, at most, about 7% of q_s, ($\alpha \simeq 9$) in case of non electronegative gases and becomes even less in the case of electronegative ones. Of course the power consumption is determined by the total charge q_s. When an electronegative mixture is used, for a given signal on the pick up electrode more total charge is involved and the consumption is larger, as compared to the case of a non electronegative gas.

We estimated the power consumption with the freon mixture by measuring the increment of the current drown by the high voltage supply, when the chamber is operated under irradiation, compared to the current with no irradiation. In Fig. 7 the power consumption for a single gap is plotted vs the high voltage. Of course these measurements refer to the situation in which only a small part of the RPC is irradiated. An estimate of the power consumption at the CMS background condition can be obtained by evaluating first the amount of total average charge q_s moved by the power supply when a single avalanche is developed in the gas. This can be computed as the increase of the single gap current, normalized to the counting rate, when the radioactive source is positioned on the chamber. In Fig. 8a this quantity is plotted as a function of high voltage. At 9500 V we find q_s = 41 pC, which is about 50 times larger than the corresponding fast charge induced on the pick up electrode.

The power consumption, for a 1 m^2 chamber uniformly irradiated at an equivalent counting rate of 100 Hz/cm^2, can than be estimated as:

$$(41pC) \times (100Hz/cm^2) \times (10^4cm^2) \times (9500V) = 400mW \tag{1}$$

Therefore a 1 m^2 double gap RPC operating in avalanche mode with $C_2H_2F_4$ at the CMS background condition would dissipate less then a 1 W/m^2.

In Fig. 8b the ratio *fast charge* q_e*/total charge* q_s is plotted vs high voltage: it decreases to about 2% due to the gas electronegativity, as compared to the typical 7% of non electronegative mixtures.

The power consumption with argon mixture can also be evaluated. From Fig. 5b, the fast induced charge is 0.2 pC at 5200 V, which is equivalent to 0.4 pC, if the strip termination is taken into account. On the other hand, the argon mixture is known to have negligible electronegativity. Therefore we can assume $\alpha \cdot d \simeq 18$ in avalanche mode with moderate gas gain, obtaining $q_s = 0.4 \times 18 \simeq 7$ pC. In analogy to (1) we can evaluate the power consumption as 40 mW.

Nevertheless, the factor 10 reduction, with respect to freon, in power consumption is only apparent, because efficiencies of the two mixtures are not comparable (70% in argon, 95% in freon). A more realistic estimate can be performed by imposing equal efficiencies. By using the results shown in Fig.s 3 and 7 we rather find a factor 5.

6 Conclusions

The performance of a double gap RPC, as proposed for CMS, has been studied in detail using two different gas mixtures: one with high content of "ecological" freon $C_2H_2F_4$, the other with high content of argon. A ^{137}Cs source has been also used to irradiate the chamber at an equivalent rate of 500 Hz/m^2 on a region of 10×10 cm^2. Efficiency, streamer probability and charge have been measured with and without source in avalanche mode.

The freon mixture seems to be more suitable than the argon one to reach high efficiency with limited streamer fraction. Also the power consumption, which could be an issue being $C_2H_2F_4$ electronegative, is limited and acceptable for the CMS background running conditions.

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M.Abbrescia et al., **Nucl. Phys.** B 44 (1995) 218-221

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Figure captions

Figure 1: Cross section of double gap RPC

Figure 2: a) Scheme of the experimental setup
b) Scheme of the data acquisition flow

Figure 3: a) Efficiency and streamer probability in freon without source
b) Efficiency and streamer probability in argon without source

Figure 4: a) Comparison of efficiency and streamer probability for double gap operation in freon with and without source
b) Comparison of efficiency and streamer probability for double gap operation in argon with and without source

Figure 5: a) Average measured fast charge in freon
b) Average measured fast charge in argon

Figure 6: a) Fast charge spectrum in freon
b) Fast charge spectrum in argon

Figure 7: Single gap power consumption for our 50×50 cm^2 chamber irradiated with a 0.65 mCu source

Figure 8: a) Variation of the current drown by a single gap with and without source, normalized to the measured rate
b) Ratio of the fast charge to the total charge driven by the power supply for an avalanche in single gap mode

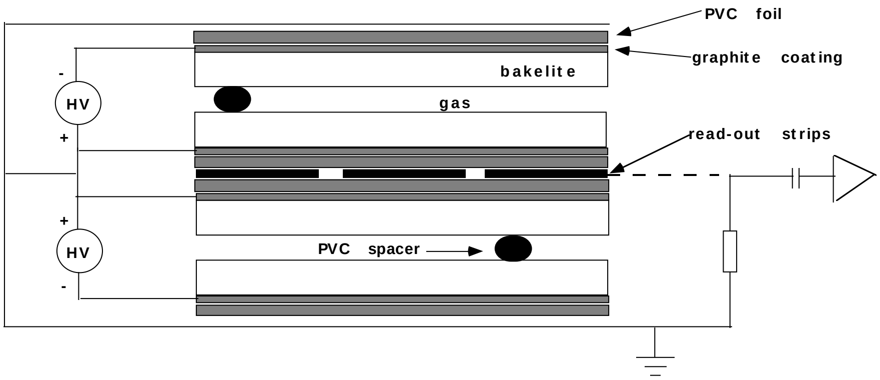

Figure 1: Cross section of a double gap RPC

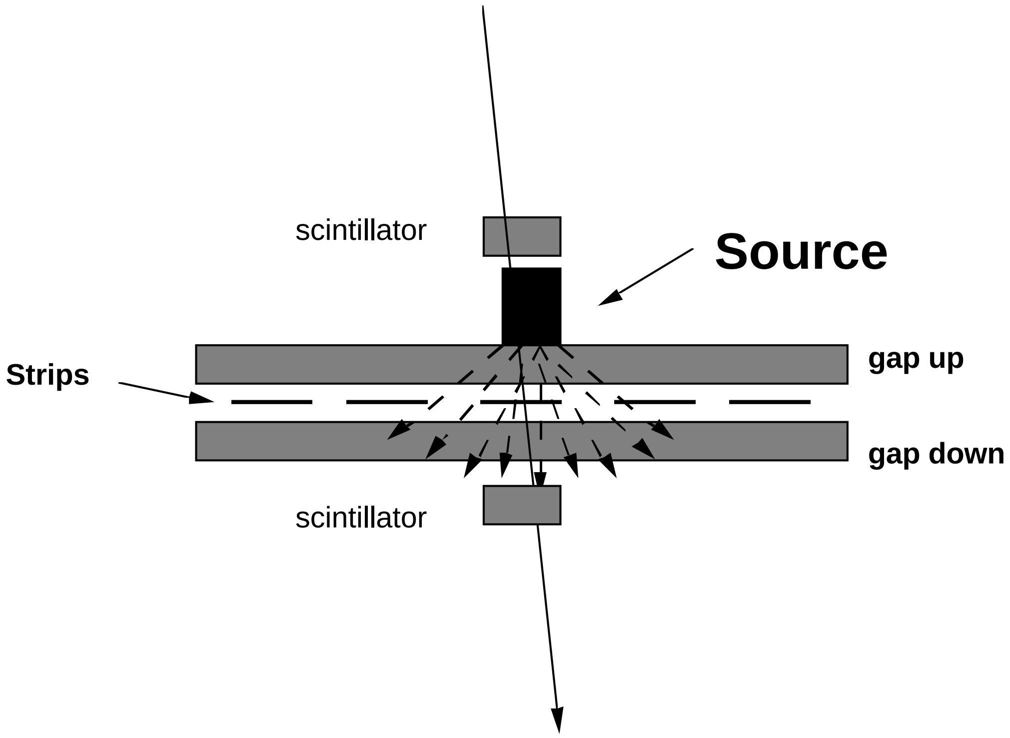

Figure 2a: Scheme of the experimental setup

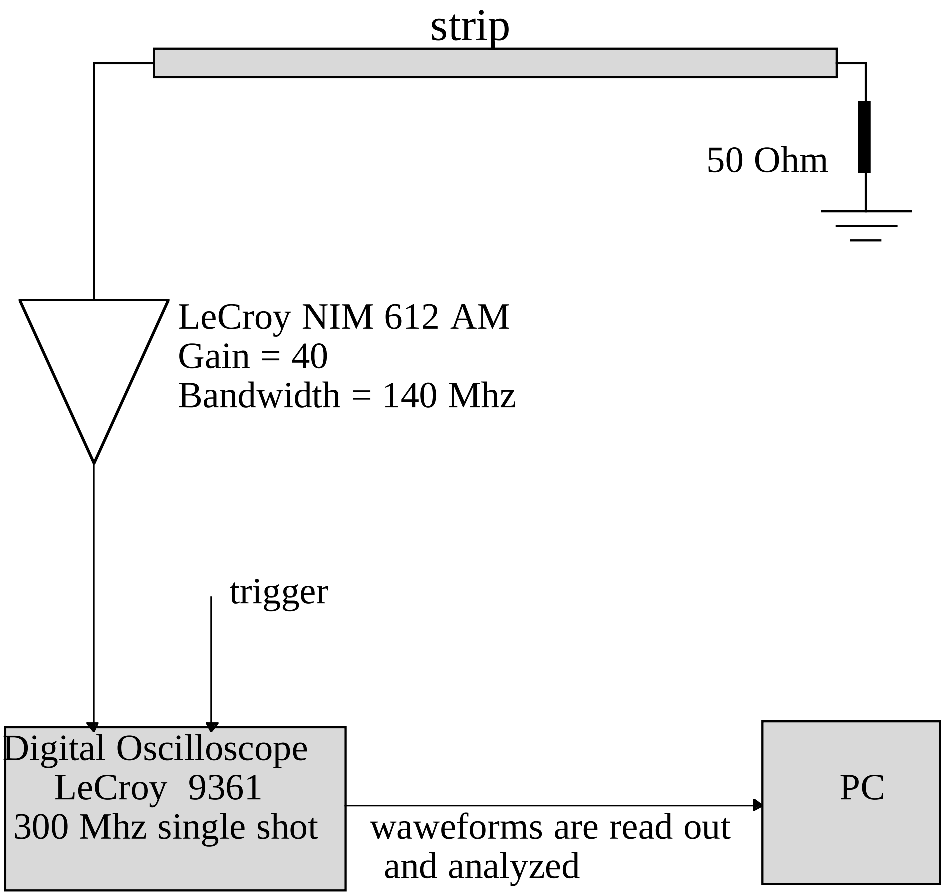

Figure 2b: Scheme of the data acquisition flow

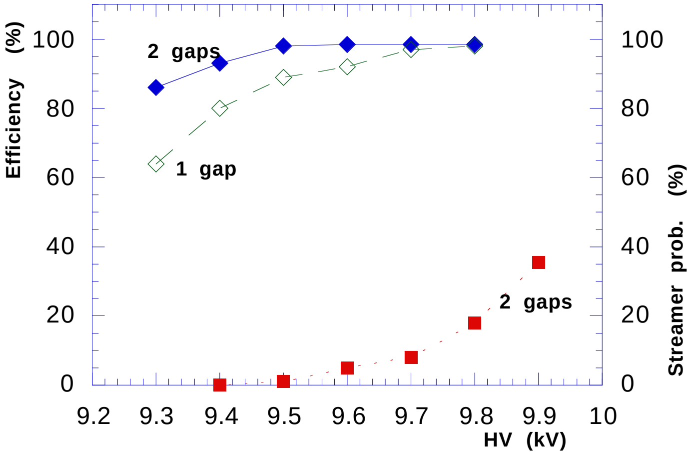

Figure 3a: Efficiency and streamer probability in freon with no source

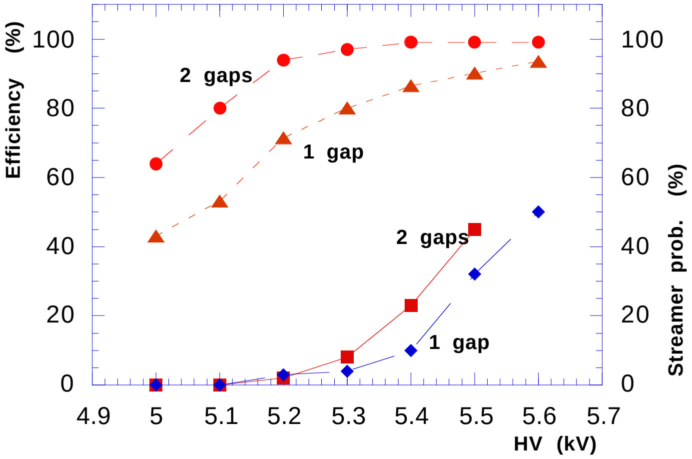

Figure 3b: Efficiency and streamer probability in argon with no source

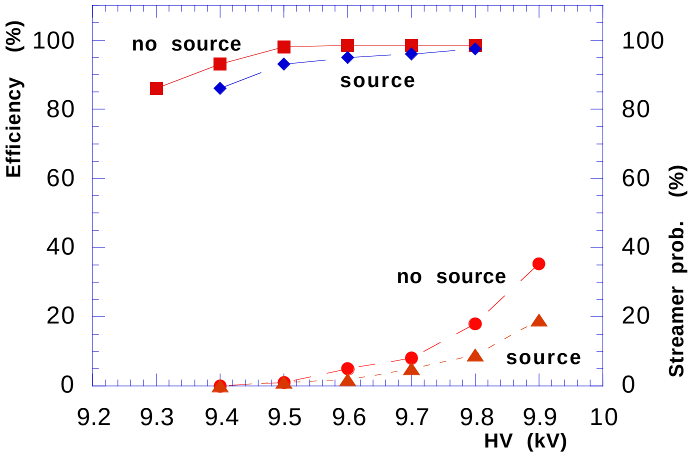

Figure 4a: Comparison of efficiency and streamer probability for double gap operation in freon with and without source

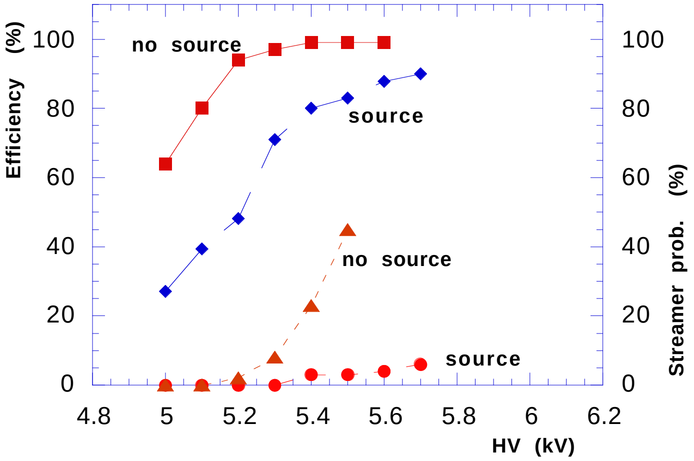

Figure 4b: Comparison of efficiency and streamer probability for double gap operation in argon with and without source

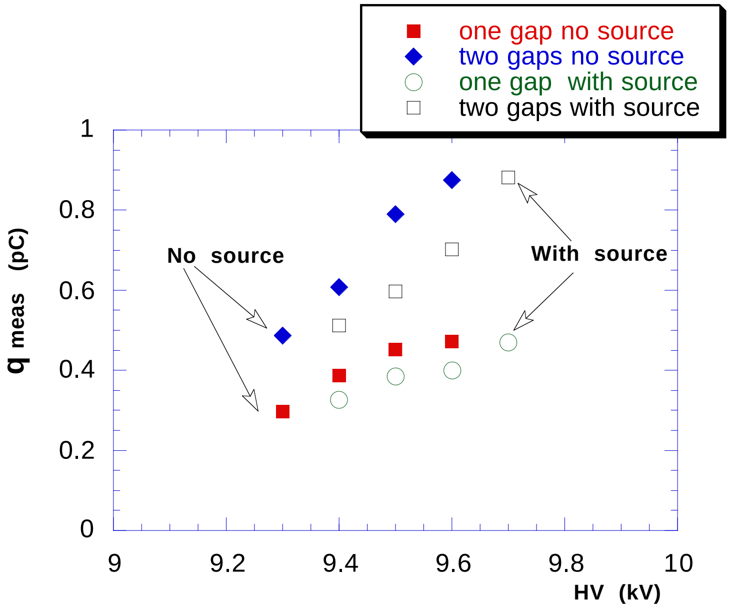

Figure 5a: Average measured fast charge in freon

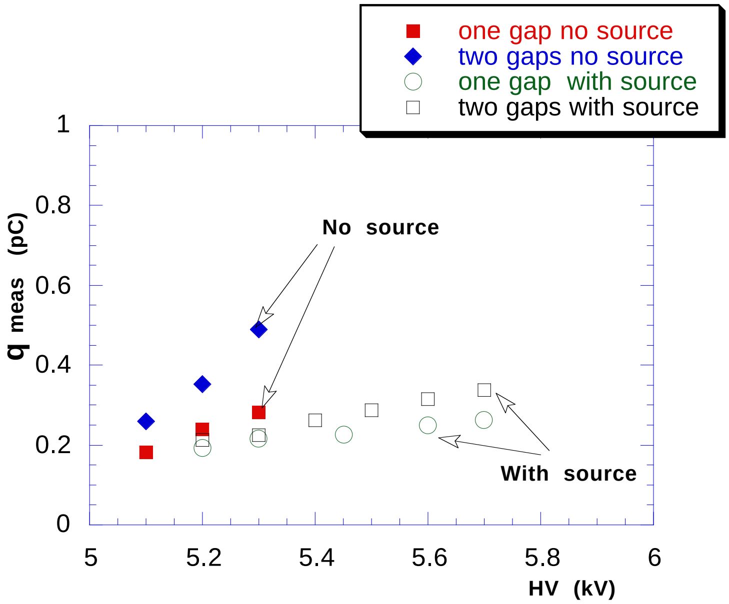

Figure 5b: Average measured fast charge in argon

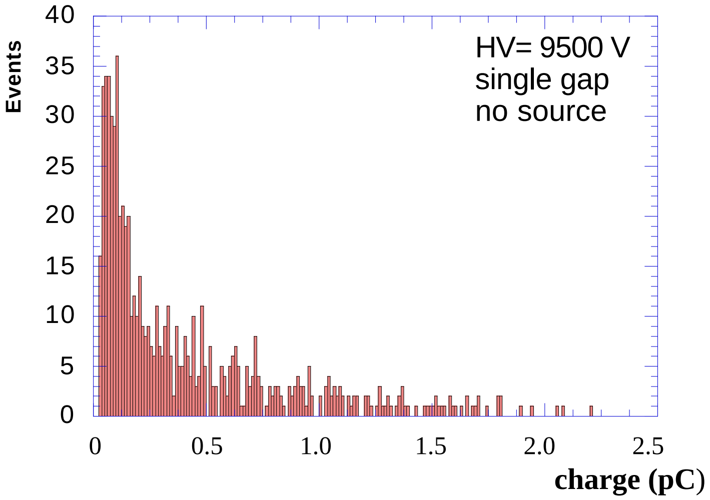

Figure 6a: Fast charge spectrum in freon

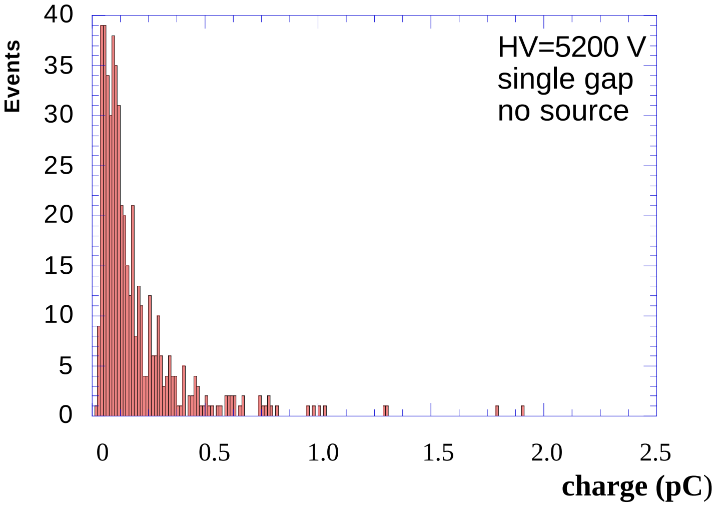

Figure 6b: Fast Charge spectrum in argon

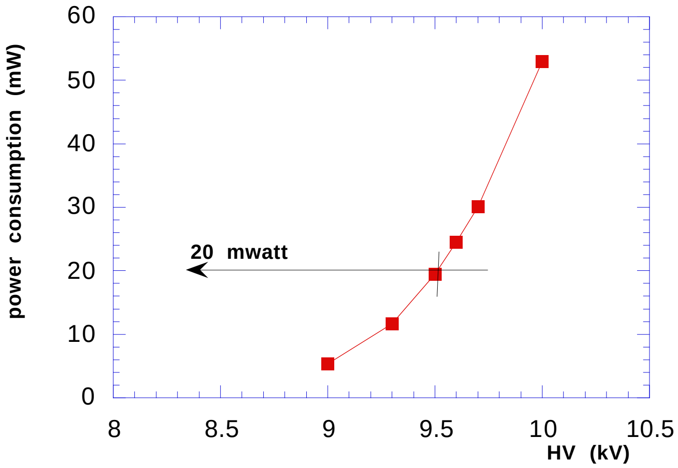

Figure 7a: Single gap power consumption for our 50 cm x 50 cm chamber irradiated with a .65 mCurie source

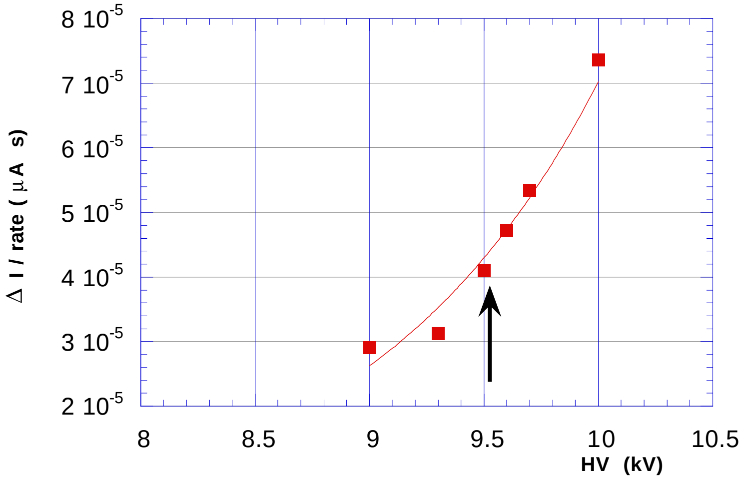

Figure 8a: Variation of the current drown by a single gap with and without source, normalized to the measured rate

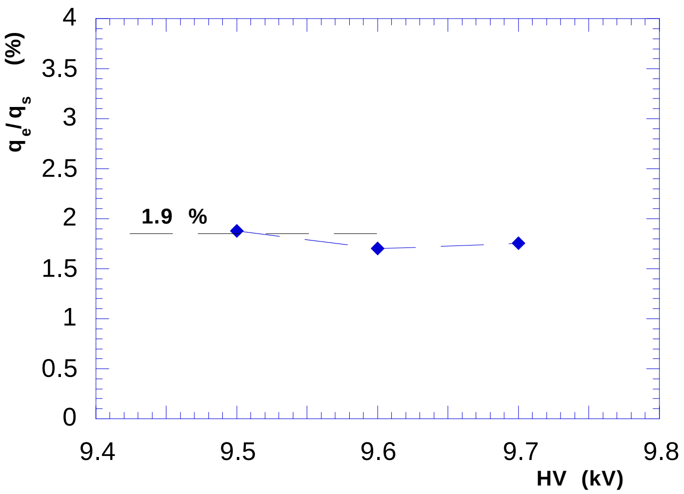

Figure 8b: Ratio of the fast charge to the total charge moved by the power supply for an avalanche in single gap mode