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PERFORMANCE OF RESISTIVE PLATE COUNTERS WITH LOW PERCENTAGE OF ISOBUTANE

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Abstract

The performance of a new kind of double gap resistive plate counter (RPC) has been studied using cosmic rays. The detector was operated with a mixture containing low percentage of isobutane. A comparison with the behaviour of RPC flowed with standard mixture is presented.

1 Introduction

Resistive Plate Counters (RPCs)[1] have been used during the last years in several high energy physics experiments as muon detectors as well as beam bunch crossing identifiers[2] because of their good performances at a relatively low cost. Nevertheless some problems have to be faced for a hypothetical use of the RPCs in experiments at the future accelerators where large areas covering will be required. Among others the potential flammability of the gas mixture in case of leakage in the air; the need to recover the inefficiency due to the spacers inside the RPCs (doubling the counters without increasing the cost of the electronics) and finally the possible RPC operational degrade due to neutron and gamma background[3]. Since the test reported in this paper has been accomplished using cosmic rays, we studied only the first two items, leaving the analysis of gammas and neutrons background for future experimentation with accelerators or nuclear reactors.

We investigated the first issue studying the RPC performances by continuously reducing the percentage of isobutane in the mixture. The addition of a fourth gas -carbon dioxide[4]- as quencher was needed to compensate the effect of the isobutane decrease. So far we fully tested the RPC lowering the percentage of isobutane to 8% of the total mixture volume (71% argon (Ar), 8% isobutane (iC_4H_{10}), 16% carbon dioxide (CO_2), 5% freon (CF_3Br)).
The behaviour of one RPC flowed with this mixture has been compared with the behaviour of the same RPC with a standard flammable mixture ($\sim 2/3\ Ar, \sim 1/3\ iC_4H_{10}, CF_3Br$).

The second requirement has been solved using a new kind of double gap RPC made of two high voltage planes and only one common central readout plane, allowing to use the same number of electronics channels needed for a single gap RPCs.

2 Flammability

The use of gas mixtures containing quenching molecules like methane (CH_4) or isobutane (iC_4H_{10}) as part of the sensitive component of large size detectors, will be limited in the near future by strong requirements because of the potential flammability of the gas in case of leakage into the experimental vessels.

RPCs belong to this class of detectors and the study of their characteristics and performances with low percentage of isobutane (the standard quencher used for RPCs) is crucial. In this case one could avoid expensive gas-leak monitoring systems and exploit the low cost instrumentation of large experimental areas with this kind of detectors.

In order to determine the ideal non flammable RPCs gas mixtures it is useful to consider the behaviour of combustibles in air. It is well known that each combustible in air is flammable only within a restricted concentration range (usually expressed as % in volume) delimited by a lower (**LL**) and an upper limit (**UL**). The former is the lowest concentration of combustible able to lead to ignition; the latter is the minimum combustible percentage above which the air content is too poor to propagate the flame. Lower and upper limits for CH_4 are 5% and 15% respectively (20^0C, 1 Atm)[5]. This means for instance that a mixture of 10% CH_4 and 90% air is flammable.

Above the methane **UL** in air a mixture of these two gases is not flammable unless the oxygen concentration does increase. In this case (as for a leakage into a hypothetical experimental vessel) the combustible is diluted in air and the combustible-air mixture can reach a concentration level in the flammability range.
The addition of inert gases to the combustible/air mixture strongly reduces the upper limit (**UL**), keeping almost unchanged the lower one (**LL**). In a diagram *combustible concentration* versus *inert gas concentration*, each point corresponds to a ternary gas mixture composed by X % inert, Y % combustible and Z = [100 - (X+Y)]% air. The area of the plot is bounded by such unitary constraint and consequently the diagram presents a trapezoidal shape. As an example, fig. 1 shows the case of a methane/nitrogen/air mixture [6].

Three different regions (indicated as **A**, **B**, **C** in fig. 1) identify the flammability behaviour of a generic X %, Y %, Z % ternary mixture. Mixtures belonging to region **A** are flammable; the intersection of the boundaries for region **A** with the vertical axis delimits the usual methane/air flammability range (**LL** = 5% and **UL** = 15% methane).

A mixture corresponding to an arbitrary point in region **B** is not flammable by itself but could cross the flammability region **A** in case of gas leakage in the experimental vessel. In fact by dilution with air, the composition of the mixture changes along the straight line connecting the initial point in B to the origin of the diagram. Such an evolution intersects the flammability region **A** (see fig. 1). This is not the case for mixtures belonging to region **C** from which it is impossible to cross region A by dilution in air. Choosing the appropriate combustible concentration in the gas mixture of a particle detector within the **C** region insures the non flammability of the gas both for normal operation and in case of gas leakage.

Another important parameter i.e. the minimum oxygen concentration that allows flame propagation, can be inferred from the flammability plot. All the straight lines at 45^o with both X and Y axis (fig. 2) define mixtures with a constant oxygen content[6]: $O_2\% = 0.21 \times [100 - (X + Y)]\%$. The tangent to the flammability region selects the ternary mixtures with the minimum oxygen content to allow the flame propagation. Gas mixtures containing less O_2 than the minimum oxygen concentration (7.14% for the case shown in fig. 2) are not flammable.

Direct measurements are needed to determine the flammability diagram of a ternary gas mixture, since theoretical computations have been so far unable to produce accurate predictions. Nevertheless empirical correlations can be inferred by comparing available experimental data.

Existing diagrams for butane/carbon dioxide/air and butane/
nitrogen/air (superimposed in fig. 3) could be useful to understand the flammability behaviour of the RPC gas mixture (isobutane/argon/carbon dioxide/freon). The comparison is feasible taking into account that butane and isobutane have similar flammability limits[7] and assuming the argon flammability behaviour similar to the one of nitrogen.

The use of CO_2 in a gas mixture instead of argon reduces the flammability region (see fig. 3 and 4), since CO_2 has a grater heat capacity. Such an effect is more noticeable if argon is replaced by freon[6] (see fig. 4 where the influence of several diluents upon the gasoline flammability is shown). If these three inert gases are simultaneously present in mixtures with isobutane, a flammability behaviour intermediate between the worst (only argon as inert) and the best (only freon as inert) case has to be expected.

The flammability behaviour of the mixture is likely to be a weighted average of the different isobutane/inert/air plots, depending upon the relative gas concentration. Such an assumption allows us to estimate the maximum isobutane concentration in the RPC gas mixture in order to prevent flammability. The butane (isobutane) upper limit in an atmosphere of CO_2 is 9.5% (see fig. 3), while the one in a $N_2(Ar)$ atmosphere is 5.4%. Since the gas mixture used for RPC in the present experiment contains 16% CO_2 and 71% Ar, it is reasonable to estimate an isobutane upper limit of 6.2% to avoid the possible flammability of the RPC gas mixture accidentally released in air. The presence of 5% Freon (CF_3Br) in the RPC gas mixture certainly increases such a limit.

In the previous discussion the presence of forced air circulation (to prevent a local accumulation of isobutane in case of massive gas leakage) and a standard pressure inside the hypothetical experimental vessel has been assumed. The effects of parameters such as temperature and pressure could infact influence the flammability limits (usually their increase causes an extension of the flammability range of the gas mixture).

3 RPC structure

Each RPC module (180 x 50 cm^2) used in our test[8] consists of two chambers assembled in the same mechanical structure (fig. 5), facing each other, with two independent high voltage (HV) planes and one common central readout plane. Each chamber is composed of two bakelite plates with a volume resistivity of about $10^{11}\Omega cm$, separated by a 2 mm sensitive gas gap. A conductive graphite paint, connected to the HV electrodes, overlays the outer faces of the bakelite, allowing the distribution of the HV on the surface of the counter. A number of PVC spacers located on a 10 x 10 cm^2 grid assures the geometrical gap uniformity. In order to avoid anomalous discharges, the graphite paint has been removed along the edges of the chamber and in correspondence of the spacers. The spacers are staggered in the two chambers of the RPC module to recover the geometrical inefficiencies due to the presence of the spacers themselves. The readout plane is placed between the two chambers and segmented into 3 x 50 cm^2 aluminium strips. One side of the strips is terminated with a 50 Ω load. The other side is connected to the front-end electronics[9] by means of twisted pair flat cables.

4 Test apparatus

A trigger system (see fig. 6) composed by slabs of $NE110$ plastic scintillator with the following dimensions: 200x27x2 cm^3, 100x27x2 cm^3 and 20x25x2 cm^3 was installed. Each slab is viewed by an $EMI9364B$ photomultiplier at both ends.

The plateau efficiency of each trigger counter was measured, and the photomultipliers voltages as well as the corresponding discriminators thresholds were optimized accordingly. Signals from each trigger counter and from the OR of the bottom two were used to form a 5-fold coincidence implemented with Programmable Logic Units (PLU).

The observed trigger rate of cosmic rays passing across the RPCs region under test was 0.45 Hz in good agreement with predictions based on the geometrical acceptance of the trigger setup (computed with a Montecarlo simulation) and their efficiency. Signals coming from the detector were handled by a new kind of electronics[9]. A Macintosh Personal Computer, equipped with LabView 2 package, read the new modules and accumulated data for analysis.

5 Experimental Results

A comparison between two different operational conditions has been made using the following mixtures:

- Standard mixture (SM): 68% Ar, 27% iC_4H_{10}, 5% CF_3Br
- Low Isobutane percentage mixture (LM): 71% Ar, 8% iC_4H_{10}, 5% CF_3Br, 16% CO_2

Fig. 7 shows detection efficiency versus high voltage in SM and LM conditions. In LM mode the detector reaches the full efficiency at a considerably lower operating voltage. Single rate as a function of the high voltage are shown in fig. 8. It is interesting to note that in the working region the single rate in LM mode is two times less than in the SM one, probably due to the quenching effect of the CO_2 that compensates the reduced content of isobutane. Currents are of the order of few μA.

Fig. 9 shows the efficiency of the two single gaps of one RPC module superimposed to the efficiency of the bigap, in LM condition. It is evident that by working with the double gap module it is possible to recover the loss of efficiency due to the spacers and to reach the plateau at a lower HV.

Because of the different impact point of cosmic rays with respect to the strip axis, it is important to set the appropriate HV and threshold to certainly detect the particles hitting the RPC. If a particle hits the detector in between two strips, it could give no signal at all or could generate a signal in two adjacent strips, depending, at a fixed HV, on the threshold value. For these reasons an important parameter is the average number of fired strips versus HV and threshold. As one can see in fig. 10, the average number of fired strips increases with HV at fixed threshold, while decreasing with increasing threshold (fig. 11) at a fixed HV.

For a given gas mixture the choice of the threshold working point depends upon the optimization of many different parameters. For instance, a high threshold (say Thr. $> -100\ mV$) reduces the average number of fired strips (multiplicity), but degrades the time resolution (due to the RPC signal rise time). Furthermore, to compensate the lower efficiency due to the high threshold a higher voltage is required, with a consequent increase of the multiplicity as a side effect. A low threshold value (see fig. 11) increases the multiplicity because the signal/noise ratio is lower than using a high threshold. We found that a threshold set at $-70\ mV$ is a good compromise among numerous different requirements.

Finally the RPC time resolution has been measured. The PMs output signals of scintillation counter 4 (see fig. 6) have been connected to a mean timer that fed a coincidence with the trigger signal. This coincidence has been used as a common start of a LeCroy 2229 Time Digital Converter (TDC). The OR of 16 strips, properly delayed to take into account the trigger generation time, was used as stop signal.

A typical TDC spectrum is shown in fig. 12 for a fixed operating voltage of 5.8 KV and a threshold of $-70\ mV$. The corresponding time resolution was about 1.5 ns. Fig. 13 shows RPC time resolution versus HV. Once again the results are comparable with those obtained with standard gas mixtures.

6 Conclusions

The use of double gap RPCs with a common central readout plane allows to recover the spacers geometrical inefficiencies and to reach a detection efficiency larger than 99% without increasing the cost of the electronics. Moreover the use of low percentage isobutane mixture satisfies the safeguard conditions for the gas flammability allowing at the same time to improve some of the RPC parameters (single rate and current).

It is also important to note that good working conditions hardly correspond to the setting of only one single quantity to its best value (i.e. efficiency or time resolution), but a general overview of all the parameters values has to be taken into account and an optimized setting chosen accordingly. Table 1 summarize the most important measured parameters in LM mode.

Table 1: The operating voltage, the corresponding efficiency, single rate, average strips multeplicity, current drawn and time resolution of the double gap RPC under test are listed for a threshold of $-70\ mV$

HV (KV)	Eff (%)	Single Rate (KHz/m^2)	Mult.	Current (μA)	Time res. (ns)
4.6	31.2	.324	1.10	3	-
4.8	72.8	.512	1.12	3	-
5.	91.2	.720	1.26	4	-
5.2	97.8	.916	1.48	5	-
5.4	98.4	1.092	1.50	5	2.72
5.6	99.6	1.292	2.12	5	2.15
5.8	99.4	1.532	2.54	6	1.55
6.	99.6	1.840	3.34	7	1.25
6.2	99.6	2.340	5.09	9	1.03
6.4	99.2	2.940	6.24	13	1.11

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Figures Captions

Fig. 1 : Flammability diagram for methane/nitrogen/air mixture.

Fig. 2 : Minimum oxygen concentration.

Fig. 3 : Flammability diagram for Isobutane/Argon and Isobutane/CO_2 mixtures.

Fig. 4 : Influence of diluents upon the gasoline flammability region.

Fig. 5 : Cross-section (not to scale) of a double gap module RPC.

Fig. 6 : Sketch of the test apparatus.

Fig. 7 : Detection efficiency vs operating voltage: a) LM conditions, b) SM conditions.

Fig. 8 : Single rate vs operating voltage: a) LM conditions, b) SM conditions.

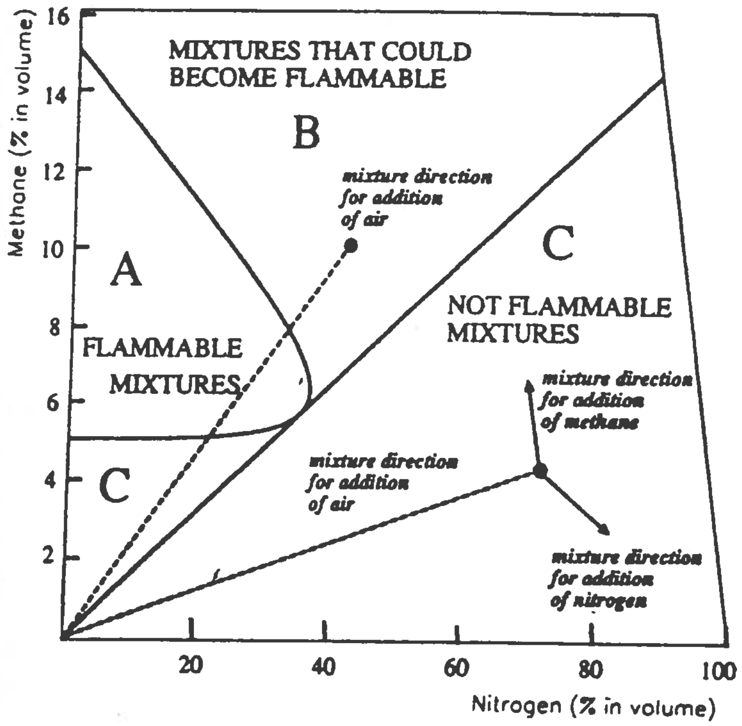
Fig. 9 : Efficiency vs operating voltage for the single gaps of one RPC and for the bigap.

Fig. 10 : Average number of fired strips vs operating voltage.

Fig. 11 : Average number of fired strips vs threshold.

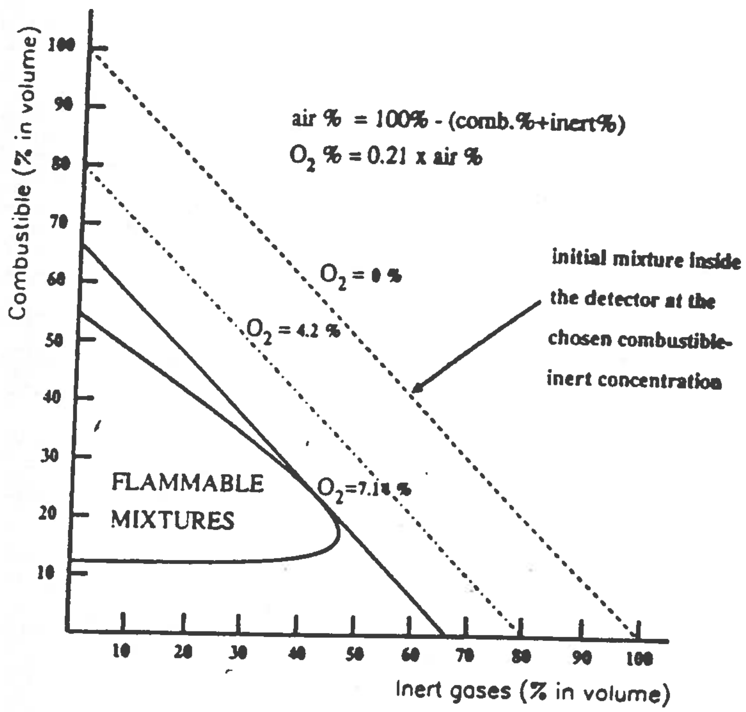
Fig. 12 : RPC time distribution at $5.8KV$.

Fig. 13 : RPC time resolution vs operating voltage.



Methane (% in volume)
MIXTURES THAT COULD BECOME FLAMMABLE
B
mixture direction for addition of air
A
FLAMMABLE MIXTURES
C
NOT FLAMMABLE MIXTURES
mixture direction for addition of methane
mixture direction for addition of air
C
mixture direction for addition of nitrogen
Nitrogen (% in volume)

Fig. 1



Combustible (% in volume)
air % = 100% - (comb.%+inert%)
O_2 % = 0.21 x air %
O_2 = 0 %
O_2 = 4.2 %
initial mixture inside the detector at the chosen combustible-inert concentration
FLAMMABLE MIXTURES
Inert gases (% in volume)

Fig. 2

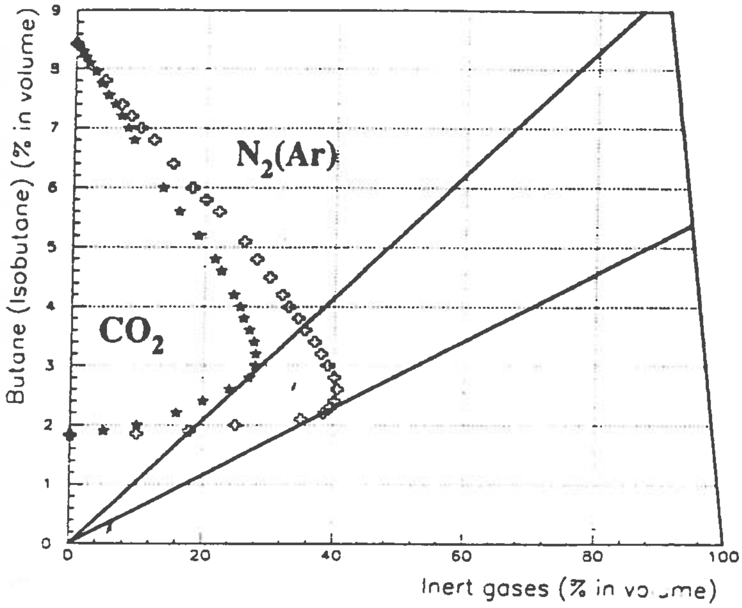

Butane (Isobutane) (% in volume)
Inert gases (% in volume)
$N_2(Ar)$
CO_2
0
1
2
3
4
5
6
7
8
9
0
20
40
60
80
100

Fig. 3

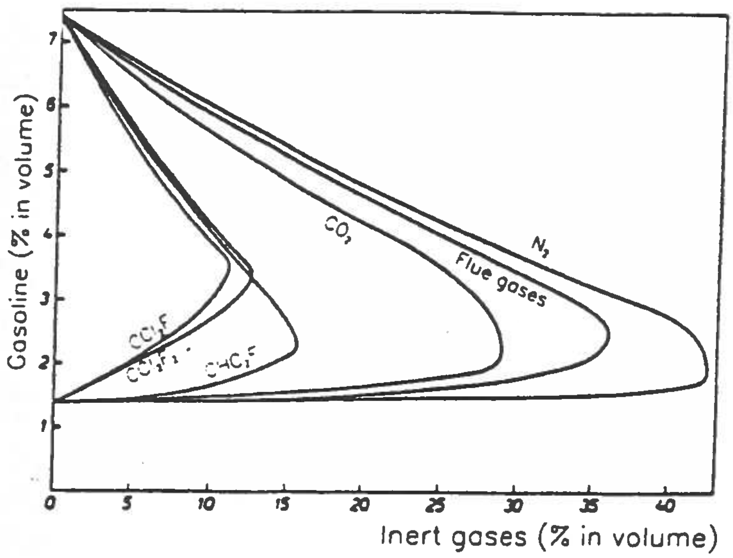

Gasoline (% in volume)
Inert gases (% in volume)
N_2
Flue gases
CO_2
CHCl$_2$F
1
2
3
4
5
6
7
0
5
10
15
20
25
30
35
40

Fig. 4

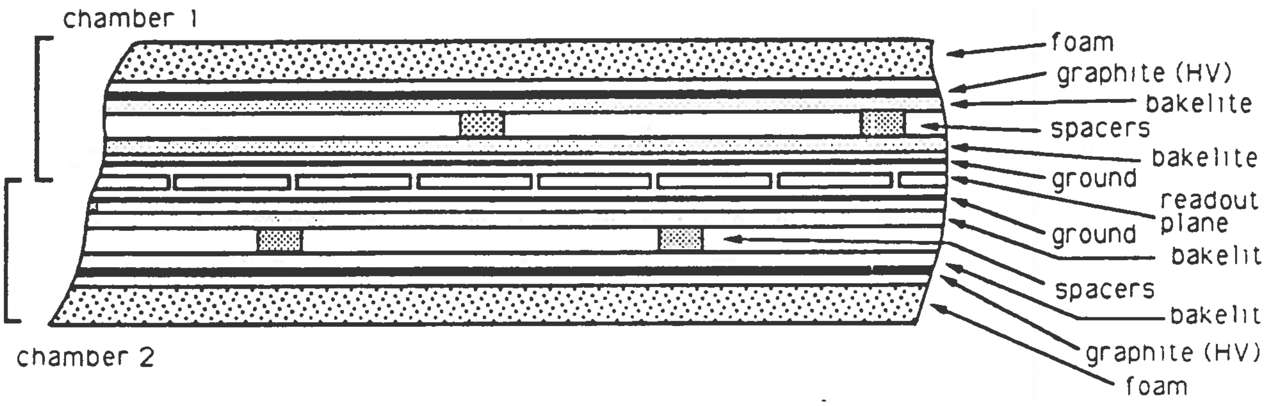

chamber 1
chamber 2
foam
graphite (HV)
bakelite
spacers
bakelite
ground
readout
plane
ground
bakelit
spacers
bakelit
graphite (HV)
foam

Fig. 5

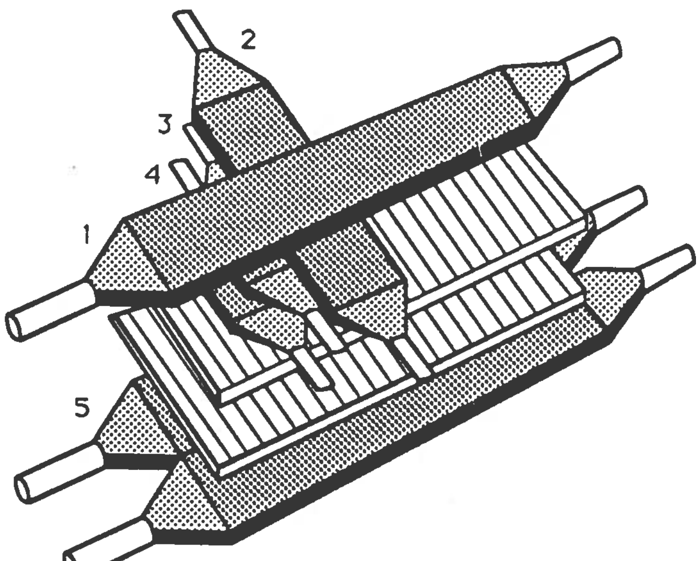

2
3
4
1
5
6

Fig. 6

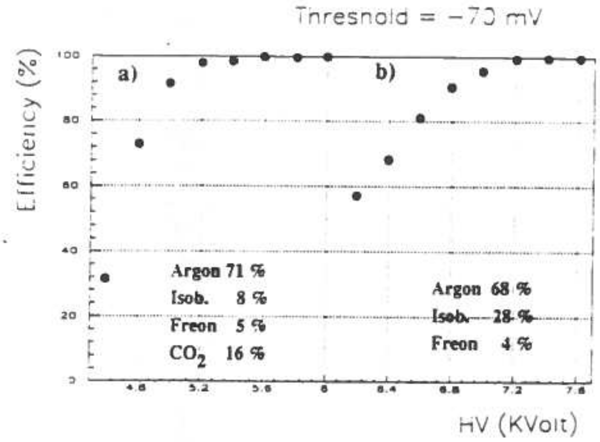
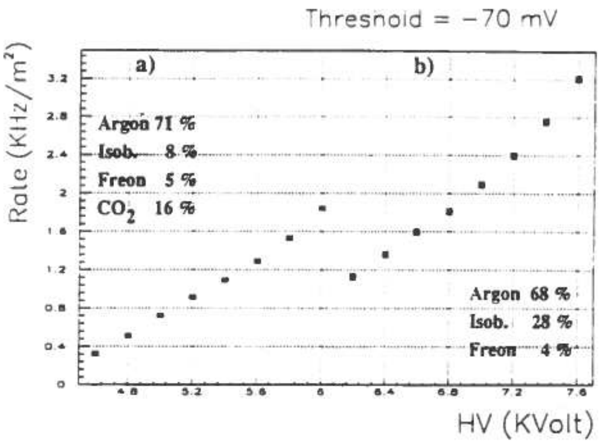


Fig. 7

Fig. 8



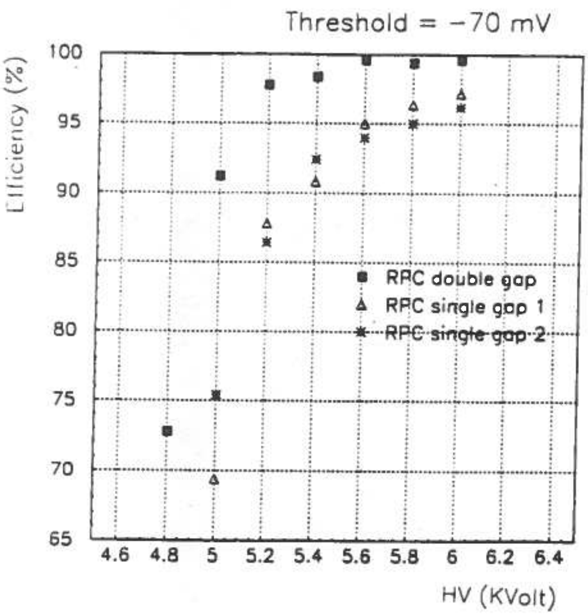


Fig. 9

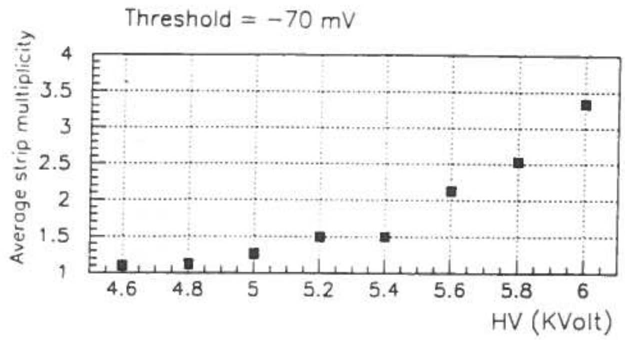


Fig. 10

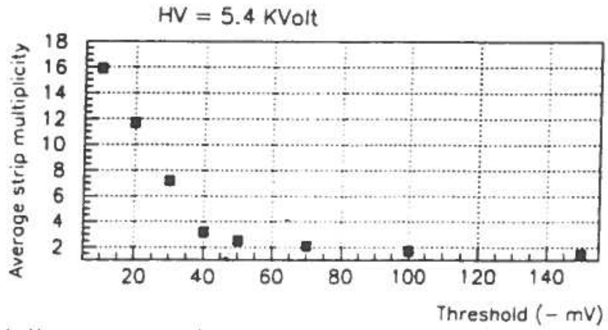


Fig. 11

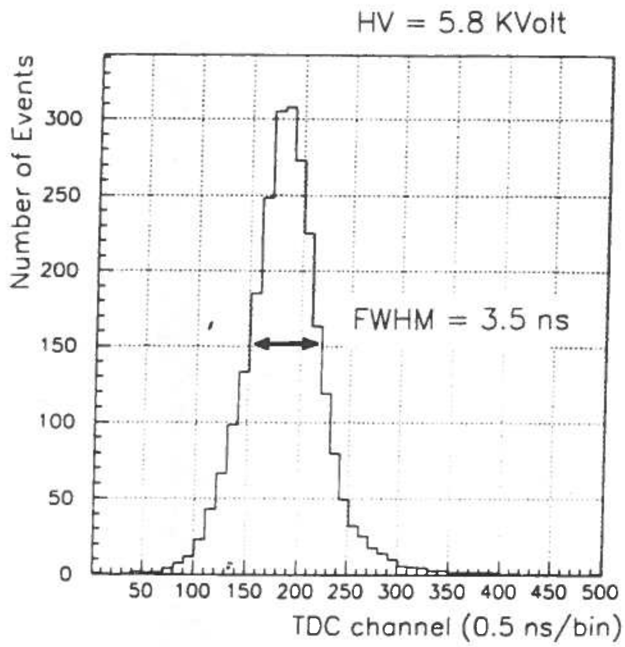


Fig. 12

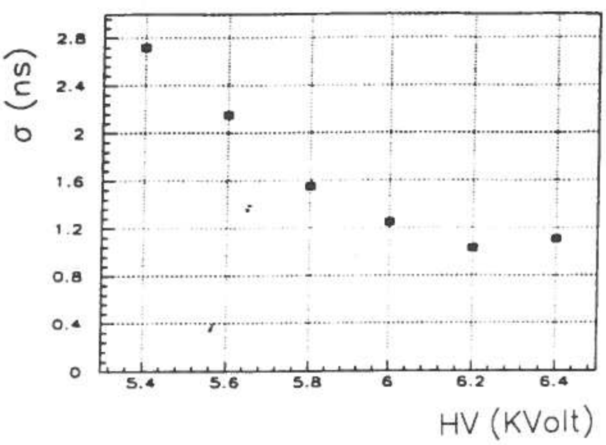


Fig. 13