March 18, 1996

THE MULTIGAP RESISTIVE PLATE CHAMBER

E. Cerron Zeballos[1,2], I. Crotty[1], D. Hatzifotiadou[1,2], J. Lamas Valverde[1,2,3], S. Neupane[1,2], M.C.S. Williams[1] and A. Zichichi[4]

1) LAA project, CERN, Geneva, Switzerland
2) World Laboratory, Lausanne, Switzerland
3) University Louis Pasteur, Strasbourg, France
4) University of Bologna and INFN, Bologna, Italy

Abstract

This paper describes the multigap resistive plate chamber (RPC). This is a variant of the wide gap RPC. However it has much improved time resolution, while keeping all the other advantages of the wide gap RPC design.

1. INTRODUCTION

The goal of current R&D on Resistive Plate Chambers (RPC) is to produce a low cost detector that has good timing, space resolution sufficient for trigger purposes (readout strips of several cm width) and can withstand a flux of several kHz/cm^2 (i.e. a device for the muon trigger at LHC). Two types of RPCs can be considered as candidates. The more conventional RPC with a 2 mm gas gap was initially developed to operate in streamer mode at very low flux. However it has been shown that one can operate it with a high fraction of freon (e.g. 85% freon 13B1) in avalanche mode. Another approach is to have a wide gap RPC and operate it in avalanche mode with more conventional freon-free gas mixtures. We have discussed the relative differences in performance previously [1]. One finds a smaller dynamic range of gain for the wide gap, thus one can operate it with a lower average avalanche charge for a given threshold. This leads to a higher rate capability and lower power dissipation in the gas volume; however it is easier to get good timing with narrow gap RPC. In this paper we discuss a new development of the RPC: the multigap RPC. We show that with this detector one can keep the advantages of the wide gap RPC, but have substantially improved timing. We also found other significant advantages with the multigap design which results in a longer efficiency plateau and better rate capability; the reasons for this enhanced performance will be discussed in a subsequent paper.

2. THE REASON FOR THE MULTI-GAP

In a parallel plate chamber, the gas gap is used both for the creation of the primary ionization clusters and also for the gas gain. The signal generated is by avalanche multiplication across the gap. The number of electrons, N, in an avalanche is given by: $N=N_o e^{\alpha x}$, where α is the first Townsend coefficient, x the distance the avalanche has progressed from its initial position and N_o the initial number of electrons. Thus the generated signal depends on the position of the primary ionization clusters. With conventional non-flammable gas mixtures used in gaseous detectors, the number of primary ionization clusters is 3-4 clusters/mm. Primary ionization follows Poisson statistics; thus to work at efficiencies close to 100%, a detectable avalanche signal needs to be produced from a single electron cluster located anywhere within the closest 1-1.5 mm to the cathode. This has been previously discussed in our paper concerning the wide gap RPC [2]. The variation in the position of the initial clusters of primary ionization generates a time jitter. Typically, at the electric fields usual in the wide gap RPC, the drift speed of electrons is ~10 ns/mm; thus we would expect time resolutions with a full width at base (FWAB) in the order of 15 ns. This is what we observe [1]. The 2 mm gap RPC has been operated in avalanche mode with a high fraction of Freon 13B1 by us [1] and other researchers in this field [3,4]. Since Freon 13B1 is heavy, the number of primary ionization clusters should be ~10 clusters/mm. Thus variations in the position of primary ionization within the first 300-400 μm will define the time resolution. It is no surprise that the 2 mm gap chamber has a better time resolution.

Our goal is to improve the time resolution of the wide gap RPC without undue sacrifice of its other good qualities. The principle advantage is the lower dynamic range of signal; this leads to smaller current flowing through the gas gap and resistive plates. This allows operation at a higher rate and also lower power dissipated in the gas gap. Another advantage is that the larger gap is less sensitive to unavoidable variations of the gap width; thus mass production of large areas becomes easier.

One way around this problem of the distribution of primary ionization over 1.5 mm (i.e. the cause of the large time jitter) is to divide up this 1.5 mm into smaller slices. For example in figure 1 we show (schematically) a 9 mm gap divided into 3 x 3 mm gaps. The voltage is still applied on electrodes mounted on the outside surfaces of the chamber. The internal plates are electrically floating, taking a voltage due to electrostatics. On average each sub-gap produces a detectable avalanche for a through going minimum ionizing particle, but the limiting case is when just one sub-gap generates a detectable avalanche. In this limiting case the initial cluster of primary ionization is within 0.5 mm of one of the three cathode surfaces; thus one could expect a threefold reduction in time jitter.

Obviously it is necessary to operate these two devices with a different Townsend coefficient, α. For example, we consider an RPC with one 9 mm gap filled with a gas that produces an average of 3 primary ionization clusters per mm for a minimum ionizing particle. 99% of through-going charged particles produce ionization within the 1.5 mm closest to the cathode. If we set the gas gain to be 10^6 over the remaining 7.5 mm, then a single electron avalanching over this distance would produce a signal of 10 fC (only 7% of the total charge generates the fast signal due to the movement of the electrons). This 10 fC signal appears to be a reasonable lower limit for the threshold for electronics in use today on large area detectors. The gas gain of a single electron avalanching over the full 9 mm would be 1.6 10^7. We refer to this ratio of gain as the 'dynamic range of gain' (=16 in this case). In order to have this gas gain, the value of the Townsend coefficient has to be $\alpha/p = 0.024$. In the case of 3 x 3 mm gas gaps, 99% of through-going charged particles produce ionization within any of 0.5 mm regions closest to the cathode plate of all sub-gaps (as shown in figure 1). The minimum signal is when only one gap has a detectable avalanche, with a single electron avalanching over 2.5 mm. Since the avalanche forms over a factor 3 shorter distance, the induced signal is a factor 3 smaller; thus to produce a 10 fC signal we need an avalanche that generates 3 10^6 electrons. An electron that avalanches over the full 3 mm would produce an avalanche of 5.9 10^7 electrons. In this case the dynamic range of gain is 20 (similar to the value of 16 obtained for the 9 mm mono-gap), but we need to operate with an α/p of 0.078. In general α/p increases exponentially with electric field [5]; thus a higher α/p implies also a larger $d\alpha/dE$. Sharma and Sauli [5] were unable to measure values of α/p much above 0.04 due to the onset of spark breakdown in their test cell. Thus we find that this triple gap chamber has a similar dynamic range of gain to the 9 mm mono-gap, but a much increased Townsend coefficient. Our concern was that for such a high value of the Townsend coefficient, it may be difficult to find a gas that gives a long stable efficiency plateau. However, as the results of section 4 show, a suitable gas can be found.

The two LHC experiments, ATLAS and CMS, propose using double gap RPCs in 'OR' [6,7]. Is the principle of operation of these double gap RPCs different from the multigap RPCs described in this paper? Obviously the multigap allows a greater number of sub-gaps; we are now building a 6 gap version (3 sub-gaps on each side of a read out strip board in a similar manner to the device proposed for LHC). We have also built a multigap RPC consisting of 2 x 4 mm gas gaps. In a comparison with the 3 x 3 mm multigap, one would expect the 2 x 4 mm chamber to have a degraded time resolution, but maybe an improved efficiency plateau (since one works at a lower Townsend coefficient) and also an improved rate capability (since there is one less resistive plate in the chamber). However the 3 x 3 mm has a longer efficiency plateau, especially at high fluxes. This suggests these intermediate plates have an unexpected beneficial effect on the performance of the chamber. Some reasons are suggested in section 5; obviously a more in-depth study is needed. In addition the proposed RPCs for LHC use a 2 mm gap; thus unavoidable gap variations have a much larger effect than the 9 mm triple gap design discussed here.

3. CONSTRUCTION OF THE MULTI-GAP RPC

We use a similar construction technique as for our more standard wide-gap RPCs. The outer resistive plates are made from melamine-phenolic foils 0.8 mm thick. The surface facing the gas is melamine; the electrodes are fixed to the phenolic surfaces. The intermediate dividing plates are melamine-phenolic-melamine foils 0.8 mm thick. A printed-circuit board with strips forms the anode; the strips are on a 15 mm pitch with 0.25 mm inter-strip gaps. This is glued to the melamine-phenolic resistive plate with an epoxy* with a volume resistivity, $\rho = 10^{11-13}\ \Omega$ cm. The cathode is a pad of conductive nickel paint (1 $\Omega/\square$). The intermediate plates were held in place with spacer bars 6 mm wide and 3 mm in height. These spacer bars run the length of the chamber with a small gap at the end to allow for gas flow. These spacer bars and the wider (3 cm wide) bar that made the frame around the edge of the chamber were glued to the melamine surfaces with double-sided tape. The glue layer of this tape has a thickness of 100 µm. When the chamber had been fully assembled we potted the outside edges with dilute CAF-4#; this made the chamber gas tight and reduced any corona from the edge of the melamine sheets. These spacer bars were offset from layer to layer so that any through-going particle would only miss one layer due to spacers. The active area of the chamber is 24 x 24 cm^2.

4. TEST BEAM RESULTS

This chamber was tested in the T9 test beam in the East-hall at CERN. The polarity of the final quadrupole was reversed in order to defocus the beam so that the whole active area of the chamber was exposed to a uniform flux (i.e. flood illumination). The total length of the spill was 400 ms with a 250 ms flat top. The electronics used was similar to the electronics used for our previous RPC tests [8]. The threshold is ~10 fC and peaking time 5 ns. The efficiency versus voltage is shown in figure 2; we also show the dark current. The gas mixture used was 86% Argon, 8.5% CO_2, 0.5% C_4F_{10} and 5 % DME. We did not obtain a good efficiency plateau for gas mixtures without the addition of 0.5% C_4F_{10}. We have worked with C_4F_{10} previously (with a single wide gap chamber) [8], obtaining a better plateau but losing in rate capability. Previously, we had also found that the shape of the plateau changed with rate. For the multigap chamber, we see no change in plateau shape, just

---

* CY1311-HY1300, Ciba-Geigy Araldite Electronics Resins, Ciba-Geigy Plastics, Duxford, Cambridge, England

\# Rhodorsil CAF-4 (Usine Silicones B.P. 22, 69191 Saint-Fons Cedex) diluted with cellulose thinners.

an overall reduction of efficiency at the highest rate. The rate capability is more than equal to the best of the wide gap chambers [1].

The time spectra of the average of the leading and trailing edge of the signal (similar to what one would expect from a constant fraction discriminator) is shown in figure 3 for an applied voltage of 16 kV (200 V above the knee of the efficiency plateau). The charge spectrum of the fast signal is shown in figure 4, also for a voltage of 16 kV.

5. DISCUSSION

We have tested a new type of RPC: the multigap RPC. Basically we have taken a conventional wide gap RPC and added some inner resistive plates to divide the wide gap into sub-gaps. In this example, we have tested a 3 x 3 mm gap RPC. One worry is that these inner resistive plates are electrically floating; how can we ensure that they take the voltages as shown in figure 1? We could add some electrode within the frame and apply a voltage to these inner resistive plates (around the edge of the chamber); however we do not think that this is necessary. The reason is that these inner resistive plates are in a strong electric field and therefore take a voltage due to electrostatics. If for any reason the voltage on one plate deviates, this will cause an increase of electric field in one sub gap and a decrease in the other; the gap with the higher field will produce larger avalanches (i.e. more charge) compared to the other sub-gap producing smaller avalanches. We see that this will restore the voltage to its proper value so as to equalize the field in the two sub-gaps. We have now tested this chamber with a variety of gases and rates and find the behavior consistently good. We therefore suspect that leaving these inner plates electrically floating is a stable solution. Obviously we will test larger chambers to verify this concept.

The multigap technique allows us to add many internal spacers, thus we can arrange to have through-going particles passing through a maximum of one spacer. Also since the spacer has a higher relative dielectric constant ($\varepsilon \sim 4$) than gas, the electrostatic coupling between the avalanche (in the remaining sub-gaps) and the pick-up strips is enhanced. This will help alleviate any reduction in efficiency around a spacer. However it should be noted that these internal spacer bars will help eliminate the need for external large flat plates, originally thought necessary for constructional purposes.

We can build a multigap RPC on either side of a pick-up strip board (similar in concept to those proposed for the CMS experiment). Thus the timing will further improve and the efficiency plateau extend to lower voltages. We intend to test this concept. The only disadvantage (compared to the conventional wide gap RPC) is an increase of the strip multiplicity. Indeed we observe an increase, but it is small (the average increases from 1.5 to 2 strips per cluster). Since we suspect that some of our cluster size is caused by cross-talk within the pre-amplifiers mounted on the chamber, we avoid giving a precise number until we have studied this problem in more detail.

One problem with the conventional RPC is that extra large avalanches charge a local spot on the surface which results in local inefficiency. If these internal plates are thin enough, a local deposition of charge on a surface of one of these will indeed cause a local decrease in electric field (and thus efficiency) in one sub-gap, but the neighboring sub-gap will have an increase in field. This compensation helps to produce a longer efficiency plateau. It should be noted that all these internal resistive plates have electrons from avalanches fed into one side, and positive ions into the other. On average there should be no net flow of charge into or out of these plates.

6. CONCLUSION

Our initial tests of a new type of RPC are extremely promising. The time resolution is equal to the best we have obtained with the 2 mm gap chamber (operating in pure avalanche mode). The rate capability is equal to the best we ever managed with a conventional wide gap RPC. In addition the dark current is very low and the efficiency plateau long and stable. Recently we have discovered that avalanche fluctuations play a key role in the understanding of the benefit of the multigap; this will be addressed in a future paper.

Acknowledgement

In all our work we are indebted to the service of the PS division, which provides such a useful facility of test beams in the CERN East hall. In addition, we have had to parasite on the beam allocation to other groups in order to test this chamber. We thank everyone that has helped make this such a pleasant possibility.

References

1. A comparison of the wide gap and narrow gap Resistive Plate Chamber. E. Cerron Zeballos, I. Crotty, D. Hatzifotiadou, J. Lamas Valverde, S. Neupane, V. Peskov, S. Singh, M.C.S. Williams and A. Zichichi, CERN PPE/95-146, CERN/LAA-MC 95-21 and submitted to Nucl. Instr. and Meth.

2. The Wide Gap Resistive Plate Chamber, I. Crotty, E. Cerron Zeballos, J. Lamas Valverde, D. Hatzifotiadou, M.C.S. Williams and A. Zichichi, Nucl. Instr. and Meth. A 360(1995)512.

3. R. Cardarelli, A. Di Ciaccio, R. Santonico, Nucl. Instr. and Meth. A333(1993)399.

4. C. Bacci et al. Nucl. Instr. and Meth. A352(1995)552.

5. See for example: A. Sharma and F. Sauli, Nucl. Instr. and Meth. A 334(1993)420.

6. ATLAS Technical Proposal, CERN/LHCC/94-43, LHCC/P2, Dec. 15, 1994.

7. The CMS Technical Proposal, CERN/LHCC 94-38, LHCC/P1, Dec. 15, 1994.

8. Latest Results of the Wide Gap RPC, E.□Cerron□Zeballos, I.□Crotty, D.□Hatzifotiadou, J.□Lamas□Valverde, S.□Neupane, V.□Peskov, S.□Singh, M.C.S.□Williams and A.□Zichichi, presented at the 3rd International Workshop on Resistive Plate Chambers and Related Detectors, Pavia, Italy. 11-12 Oct. 1995.

9. E.□Cerron□Zeballos et al., Nucl. Instr. and Meth. A 367(1995)388.

FIGURE CAPTIONS

1. Schematic diagram and principle of operation of multi-gap RPC compared to a conventional 9 mm single gap RPC.

2. Efficiency versus high voltage for various fluxes. The beam was defocused, thus the whole active area of the chamber exposed. The gas mixture was 86% Argon, 8.5% CO_2, 0.5% C_4F_{10} and 5% DME.

3. Time spectra of the average of the leading and trailing edge timing at 16 kV (200 V above the knee of the efficiency plateau).

4. Charge spectrum of the fast signal taken at 16 kV (200 V above the knee of the efficiency plateau).

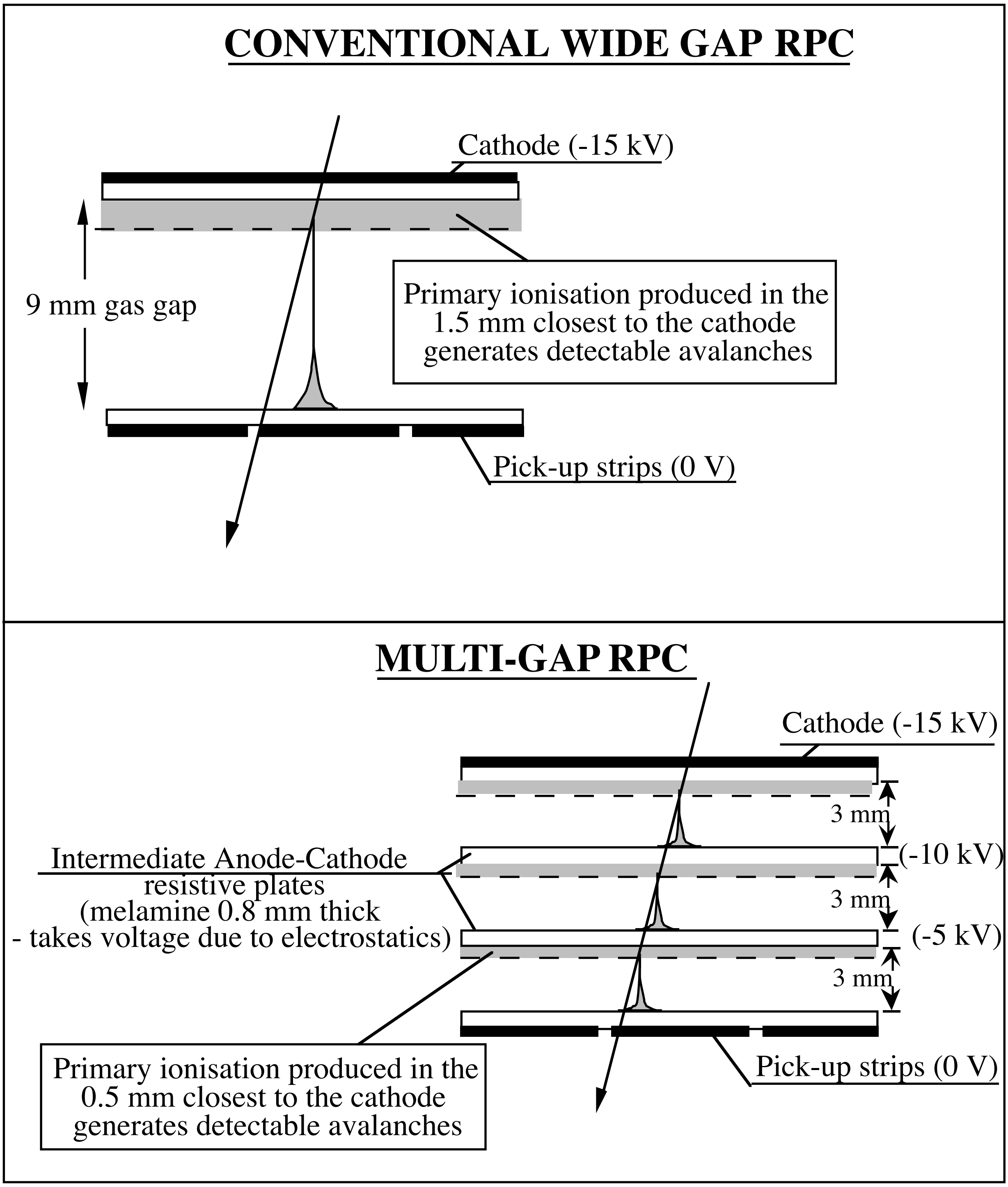
CONVENTIONAL WIDE GAP RPC
Cathode (-15 kV)
9 mm gas gap
Primary ionisation produced in the 1.5 mm closest to the cathode generates detectable avalanches
Pick-up strips (0 V)
MULTI-GAP RPC
Cathode (-15 kV)
3 mm
(-10 kV)
Intermediate Anode-Cathode resistive plates (melamine 0.8 mm thick - takes voltage due to electrostatics)
3 mm
(-5 kV)
3 mm
Primary ionisation produced in the 0.5 mm closest to the cathode generates detectable avalanches
Pick-up strips (0 V)

Figure 1

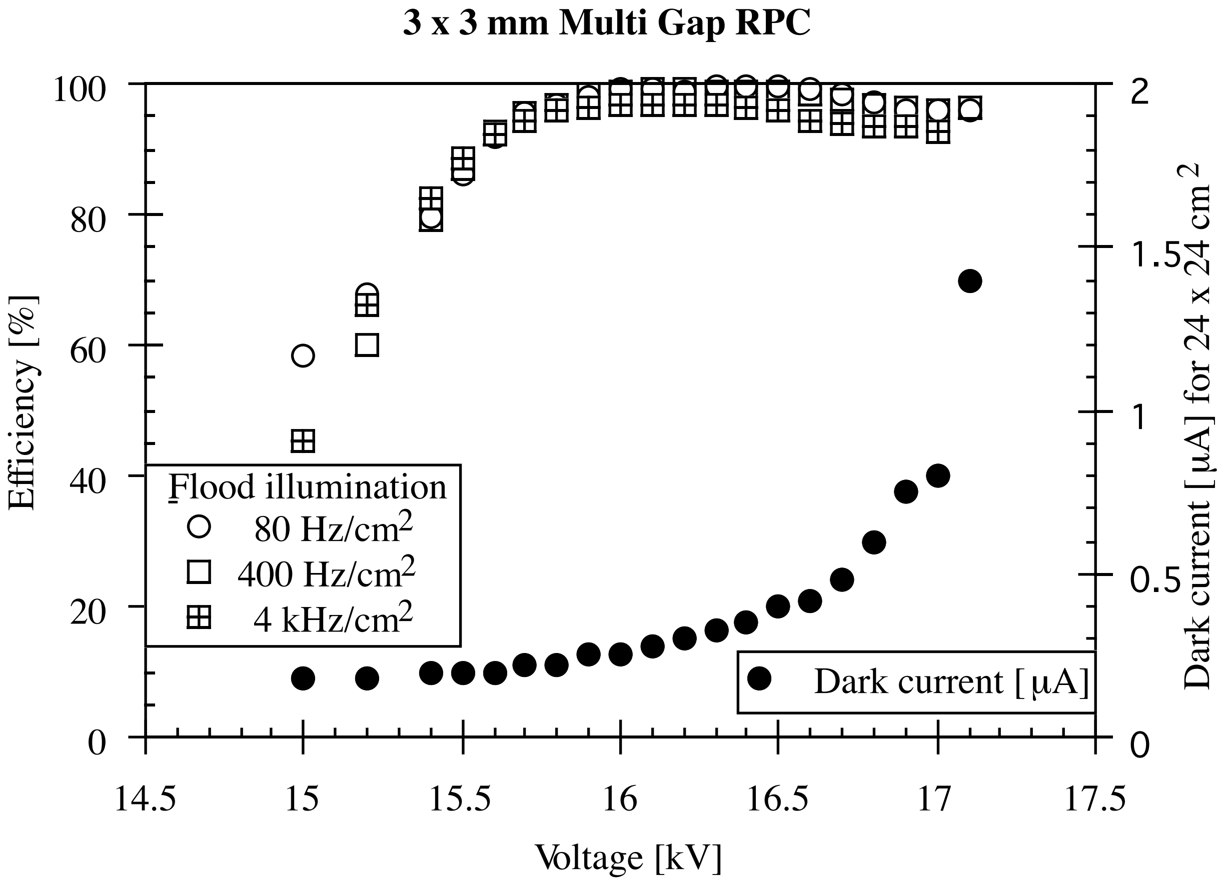
3 x 3 mm Multi Gap RPC
Efficiency [%]
Dark current [μA] for 24 x 24 cm 2
Voltage [kV]
Flood illumination
80 Hz/cm2
400 Hz/cm2
4 kHz/cm2
Dark current [μA]
100
80
60
40
20
0
2
1.5
1
0.5
0
14.5
15
15.5
16
16.5
17
17.5

Figure 2

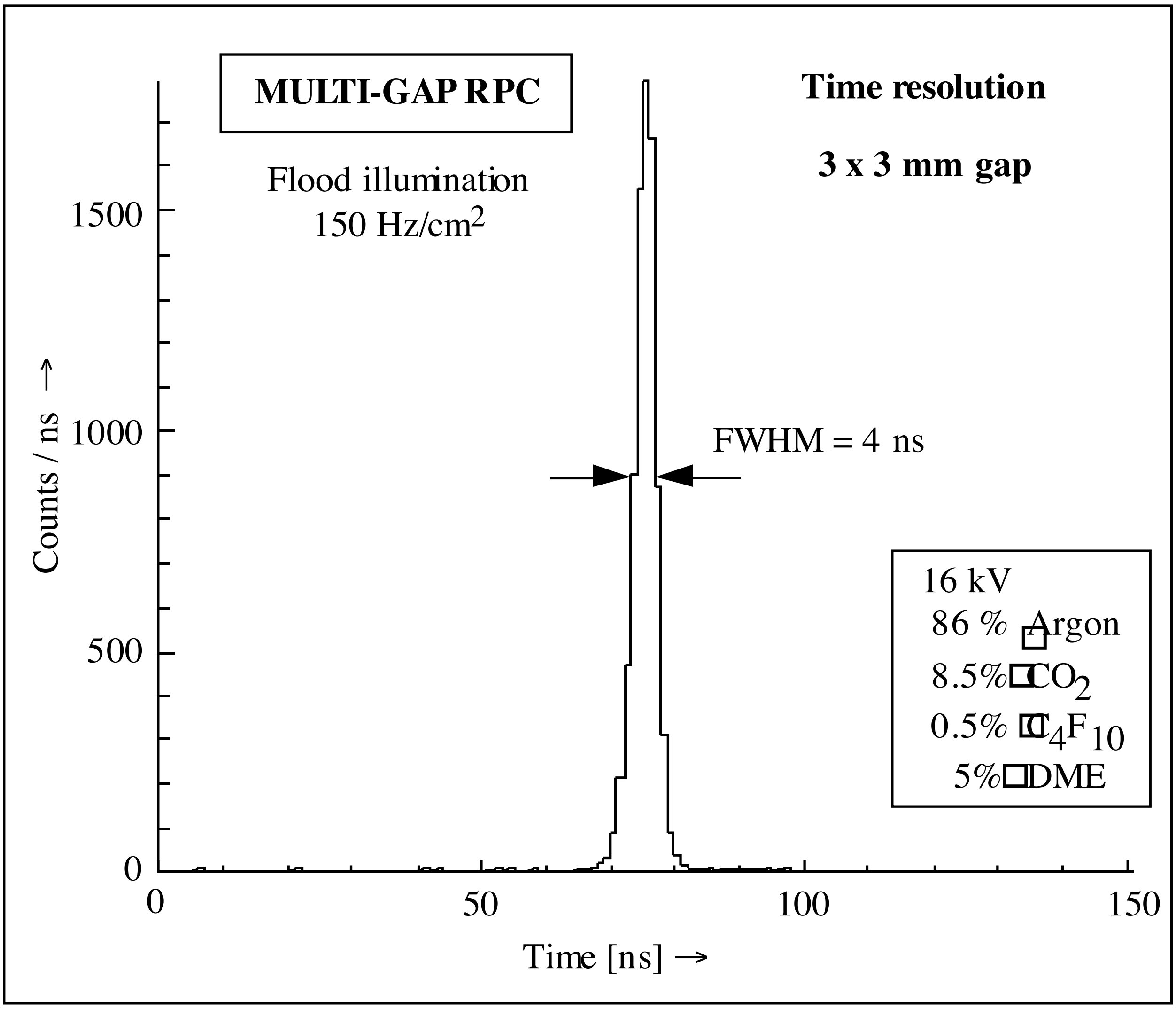
MULTI-GAP RPC
Flood illumination
150 Hz/cm2
Time resolution
3 x 3 mm gap
FWHM = 4 ns
16 kV
86 % Argon
8.5% CO2
0.5% C4F10
5% DME
Counts / ns →
Time [ns] →
1500
1000
500
0
0
50
100
150

Figure 3

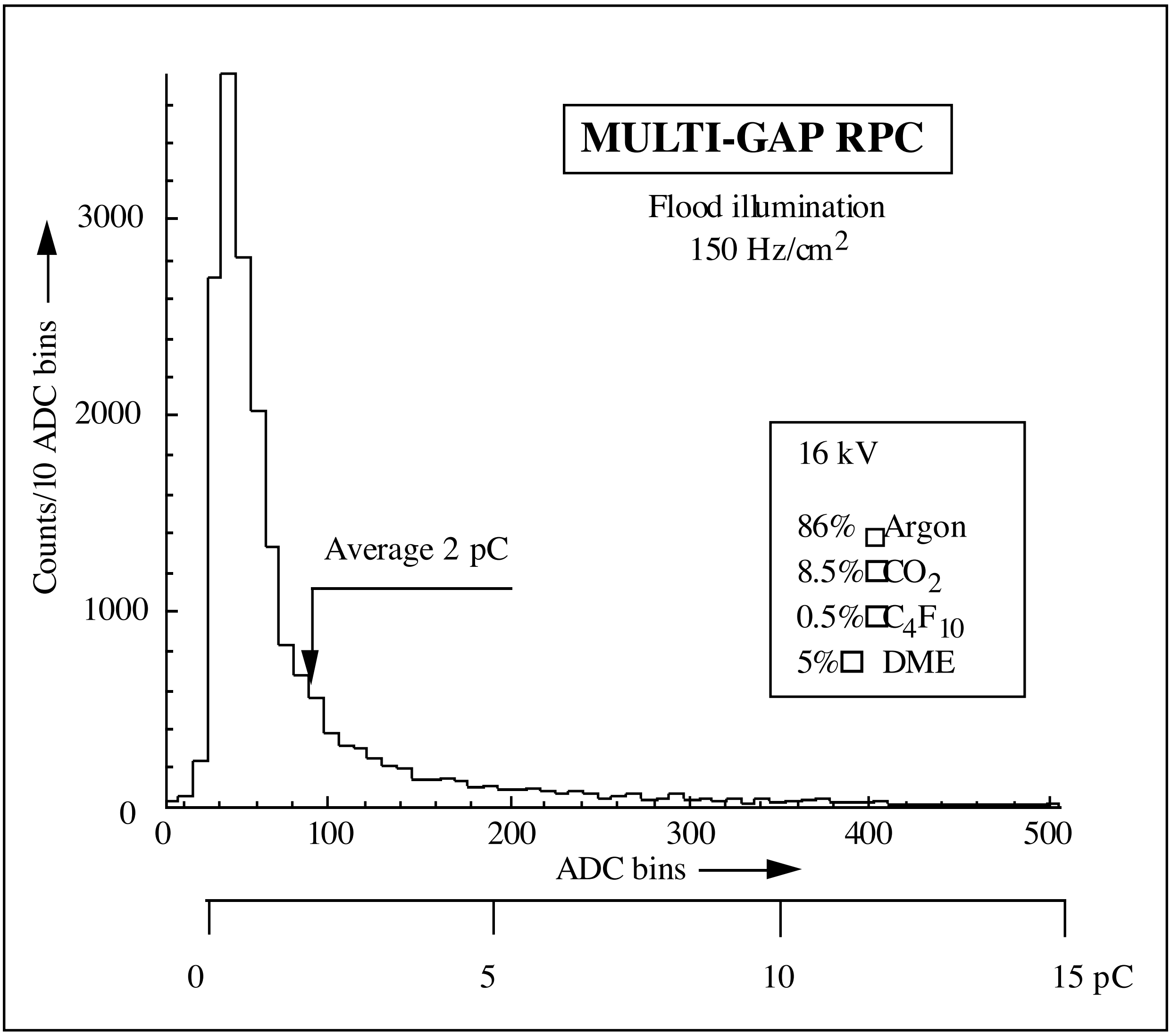
MULTI-GAP RPC
Flood illumination
150 Hz/cm2
16 kV
86% Argon
8.5% CO2
0.5% C4F10
5% DME
Average 2 pC
Counts/10 ADC bins
3000
2000
1000
0
0
100
200
300
400
500
ADC bins
0
5
10
15 pC

Figure 4