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Test for upgrading the RPCs at very high counting rate

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ABSTRACT: Very large systems of RPCs with 2 mm gas gap are presently working at LHC as muon trigger detectors. In order to conceive a new generation of RPCs, fully adequate to the needs of the high luminosity super-colliders of the next future, two aspects have to be reconsidered: the gap width which determines the amount of charge delivered in the gas per detected avalanche and the front end electronics which determines the minimum charge that can be discriminated from the noise. Both aspects have a crucial effect on the rate capability. We present here the results of a cosmic ray test carried out on small size RPCs of gap width 2.0, 1.0 and 0.5 mm respectively. The wave forms of both the prompt signal due to the fast drifting electrons and the signal generated in the HV circuit, which is dominated by the slow ion drift, are recorded for each detected cosmic muon. The analysis of these signals is crucial to understand the RPC working features.

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1. Introduction

The purpose of the new RPCs is to handle rates above 10kHz/cm^2 without increasing the operating current, which determines aging and power dissipation of the detector.

To do this it is necessary to be sensitive to smaller signals, in order to reduce the average charge per count: the most significant contribution in this direction comes from the introduction of a new front end electronics, with a very high signal/noise ratio.

Another aim for new RPCs is to have a sub-ns time resolution in order to reject both uncorrelated background and correlated particles in the forward regions of hadronic colliders.

For this reason it was also studied the response of the detector for different gas gap sizes and with a bigap structure to verify that small gap RPCs are also suitable for working at very high rates.

To work at high rates without suffering of a decrease of efficiency it is necessary to keep the same tension on the gas gap, which depends on the voltage drop on the electrode following the relation – valid at high rates –

$$V_{gas} = V_a - R\,I = V_a - \rho\, d\, \phi\, Q(V_{gas})$$

where V_{gas} is the tension on the gas gap, V_a the applied voltage to the RPC, ρ and d respectively the resistivity and thickness of the electrodes, ϕ the particle flux and Q the average charge/count.

The reduction of the average charge/count is the most effective way to work at high rates without incurring in ageing effects: indeed it has been demonstrated [1] that the ageing of the detector increases with the operating current.

2. Experimental results

2.1 Systematic study of the delivered charge in a cosmic ray test

A systematic study of the delivered charge was carried out on small (8x50 cm^2) RPCs at cosmic ray rates, using a gas mixture of $C_2H_2F_4$/i-C_4H_{10}/SF_6 = 94.5%/5.0%/0.5%.

In this test both the prompt signal due to fast drifting electrons and the signal detectable in the HV circuit (dominated by the ion drift motion) have been recorded using a scope of 1GHz analog band and, for the prompt signal, a sampling rate of 10 points/ns.

The ionic signal is measured by putting a pick-up wire on the graphite, thus evaluating the charge developed in a single event.

The typical duration of this slow signal depends on the readout resistor and is about 10-20μs for a 10kΩ resistance.

For what concerns the prompt signal, it was measured by sending it directly to the scope or by amplifying it with the new front end [2].

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2.1.1 Performance of the new front end electronics on a 2mm gap RPC

In the following (figure 1) is showed a comparison between the efficiency curve for a 2mm gas gap RPC with an ATLAS like threshold (1.5mV) and with the new amplifier using a fixed 40mV threshold. The applied voltage is corrected for pressure and temperature.

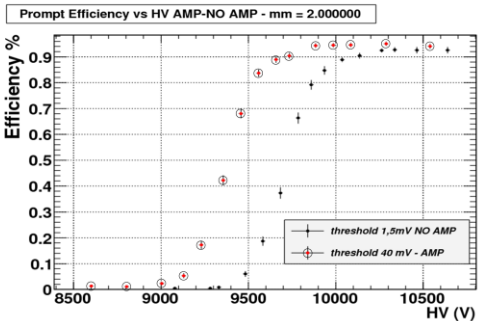
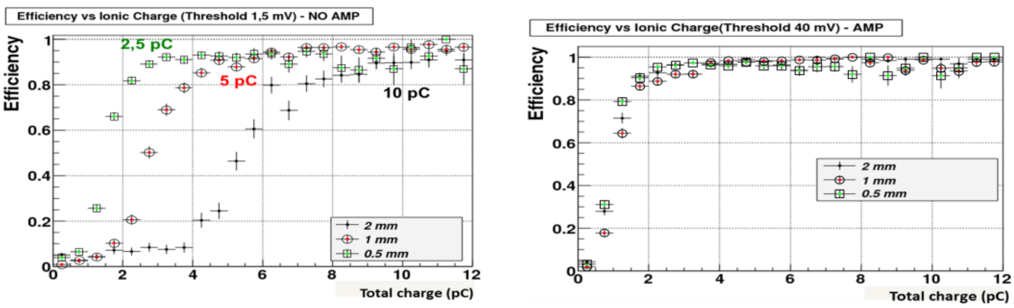


Figure 1: Efficiency vs HVeff. New front-end (in red), Atlas Like threshold (in black)

It may be seen that with the new FE there is an anticipation of the efficiency curve of about 400V at 90% efficiency. This leads to a reduction of the charge/count from 18pC to 6pC.

2.1.2 Delivered charge for different gas gap sizes

For comparison of different gas gaps it is interesting to measure the efficiency as a function of the total charge, no matter at which tension the avalanche has been produced (as long as it is a saturated avalanche). Detection efficiency is defined when the signal is above a fixed threshold (1.5mV without amplification and 40mV with the front-end electronics under study).



Figures 2,3: Efficiency vs Total Charge. left: without amplification; right: using the new Front-End

Without the amplifier (figure 2) smaller gaps are efficient at a lower total charge because the width of the signal scales with the gas gap, so signals with the same amplitude have a higher charge for larger gaps.

When using the new amplifier (figure 3), which is a charge amplifier, the threshold in total charge is quite the same for all the gaps.

Even if the threshold is the same there is still an advantage at working with smaller gaps because of the difference in charge distribution at the first HV working point with full efficiency for the three gas gaps (figure 4).

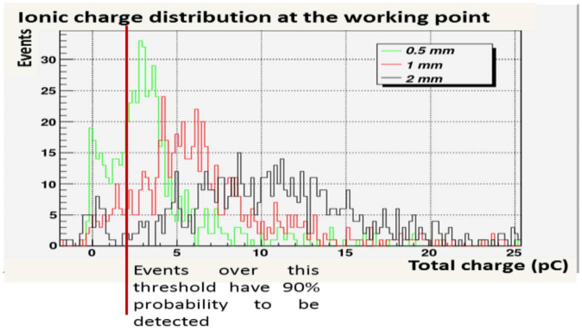


Figure 4: Total charge distribution at the working point with the front-end under study.

A direct confrontation of the charge/count as a function of the efficiency in high voltage steps shows that smaller gaps have also lower charge (table 1).

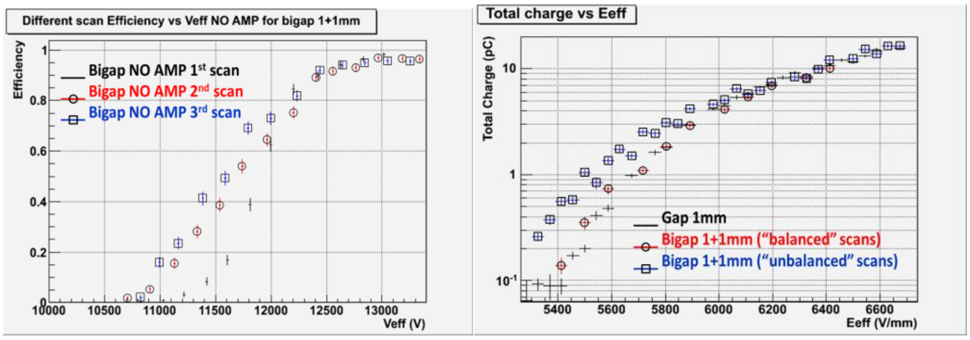
Gap size	Efficiency at knee	Tension- No Amp	Total charge- No Amp	Tension- Amp	Total charge- Amp
2 mm	88%	10040 V	18 pC	9660 V	6 pC
1 mm	90%	6260 V	8.5 pC	6010 V	4.5 pC
0.5 mm	77%	4000 V	3.95 pC	3780 V	2.8 pC

Table 1: Charge delivered on efficiency for 2mm, 1mm and 0.5mm gap with/without new FE.

2.1.3 Cosmic ray test on a 1+1mm bigap chamber

The study of a 1+1mm bigap was carried out on a prototype of the same area.

The gap had a central floating electrode 2mm thick, which is expected to work properly at high rates, when the gap current itself acts as a controller of the balance of the electric field in the two gaps (the condition is that the physical current due to the particle flux must be significantly higher than the dark current). From the test we have actually observed that bigap chambers with intermediate floating electrode work as expected only if the operating current exceeds a proper threshold: the compared measurements of efficiency and total charge as a function of the applied tension supports the interpretation of this effect as due to the imbalance of the floating electrode (figures 5 and 6) in the low counting regime.



Figures 5,6: Unbalanced bigap chamber efficiency measured at different times (left plot). Total charge comparison between 1 mm gap detector and the 1+1 mm bigap chamber with and without conditioning (right plot).

Before the test a long conditioning of the gaps had been done, so that the Ohmic current of the two gaps was much lowered and the applied voltage appeared to be almost the same for both the gaps. This condition however may not be long time stable.

From the comparison of the amplified curve for the 1mm monogap and the bigap it can be seen how the bigap structure itself allows to work at a lower electric field applied (figure 7).

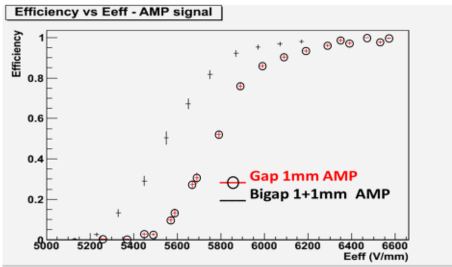


Figure 7: Efficiency vs electric field for the 1+1 mm bigap and the 1 mm monogap equipped with new front-end electronics.

To exclude an anticipation of the curve only due to an unbalance of the gaps the most significant measurement is the average charge as a function of the efficiency, in order to verify that there is an actual advantage working with this structure at high rates (figure 8).

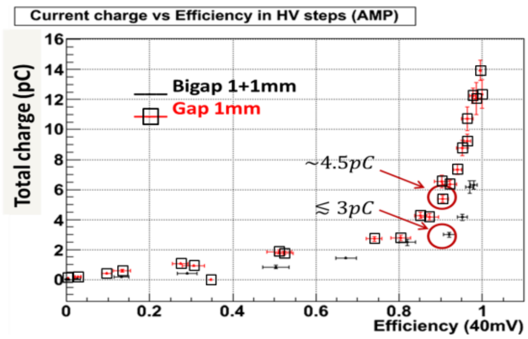
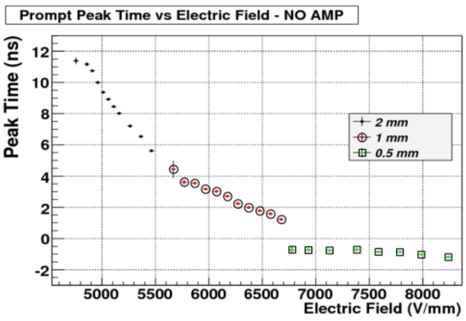
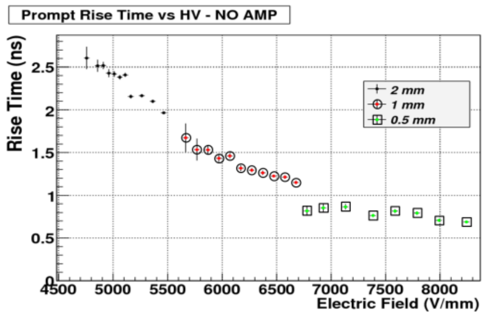


Figure 8: Total Charge vs Efficiency in HV steps. It can be seen how at the same efficiency the bigap works at a lower average total charge.

2.2 Time performance for different gaps

We verified that the peak time and the rise time of the prompt signal without amplification are almost continuous functions of the electric field for different gaps, with a single relevant discontinuity for the 0.5mm gap (figures 9 and 10).





Figures 9,10: Peak and rise times of prompt signals as a function of the electric field for different gas gap widths. The peak time offset is due to the trigger.

The signal duration decreases continuously for an increasing electric field too.

For the bigap it was possible to make a confrontation with the 1mm monogap and verify how the peaking time without the amplification is in both cases a linear function of the electric field, whose slope does not depend on the number of the gaps (figure 11).

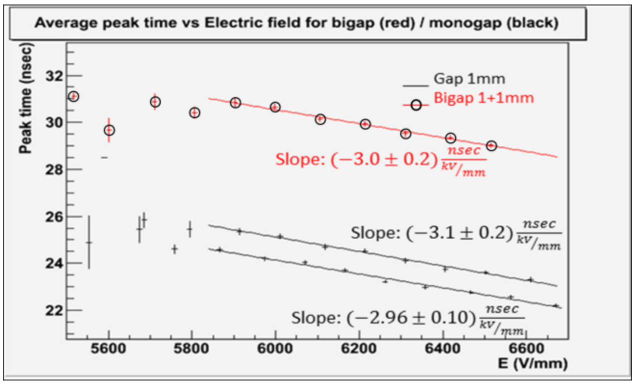


Figure 11: Confrontation peak time for the 1+1 mm bigap and the 1 mm monogap.

The offset in this case is only due to a different delay with respect to the trigger.

3. Conclusions

From the measurements it is possible to state that the improved FE electronics allows to operate at a much lower gas gain – and thus at much higher rate – with respect to the RPC systems presently working at LHC.

The study of different gas gaps also showed how for fixed efficiency (with respect to the plateau knee of the efficiency curve with the front-end under study) thinner gaps have a sharper charge distribution and a lower average charge/count. Another factor 2 in charge reduction would be possible introducing a bigap structure, but at the cost of a lower stability of the detector in a low counting rate regime.

The reduction of the gap means a raise of the electric field at the working point, and this implies faster signals for thinner gaps.

The study of the time performance of the bigap is in progress, in particular under high fluxes.

References

[1] G.Aielli et al., *Ageing test of ATLAS RPCs at CERN's gamma irradiation facility*, Nuclear Science Symposium Conference Record, 2004 IEEE Volume 1, 16-22 Oct.2004, 226 - 230.

[2] R. Cardarelli, *RPC performance vs. front-end electronics*, Nuclear Instruments and Methods in in Physics Research A, doi: 10.1016/j.nima.2010.09.136 .