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Performance of the first RPC station prototype for the CMS barrel detector

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Abstract

A full-size prototype of the second barrel RPC station (RB2) for the CMS detector has been tested under high-irradiation flux at the CERN Gamma Irradiation Facility (GIF) during the 1999 beam test. The main requirements of RPCs as trigger detector have been studied: cluster size, time resolution, efficiency and rate capability. The timing features of a new front-end electronics were also investigated. Only the results obtained with the detector working in single-gap mode are reported here. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Spatial resolution; Timing; Efficiency

1. Introduction

The Compact Muon Solenoid (CMS) Collaboration has chosen the Resistive Plate Chambers (RPCs) as dedicated detectors for the first-level muon trigger system [1]. The detector will work in a very high background environment: in the barrel region of CMS the background flux due to low energy photons (up to about 100 MeV) will reach the level of 10^3 cm^{-2} s^{-1}, while in the forward 10^5 cm^{-2} s^{-1}.

During summer 1999, for the first time, a full-size prototype of the RB2-type RPC chamber for CMS was tested at the CERN GIF. The chamber, 250×250 cm^2, was equipped with the new front-end electronics recently developed [2]. Data have been collected in single- and double-gap mode: the analysis is in progress and here we focus our attention only on single-gap data.

2. Experimental set-up

The GIF is located downstream the final dump of X5 beam line at CERN. Inside the zone a 740 GBq ^{137}Cs gamma source creates background conditions similar to the ones expected during the

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LHC machine operation. The ^{137}Cs isotope emits 661 keV photons: a system of lead filters, that can be moved in front of the source, allows to reduce the flux up to a factor 10 000. The tests were performed with absorption 1 (ABS 1, i.e. source open and no filters in front of the source), absorption 5 (ABS 5, nominal absorption factor 5 with respect to ABS 1) and with source off. A system of scintillators was used to trigger on the beam particles. The muon flux from the X5 beam was tagged by two wire Beam Chambers (BCs), characterized by a spatial resolution <200 μm. During the test one RB2-like chamber, with bakelite resistivity $\simeq 7\times10^{10}$ Ω cm, was positioned vertically inside the irradiation area at a 3 m distance from the source. The sensitive volume was filled with a 95% $C_2H_2F_4$, 4% iso-C_4H_{10}, 1% SF_6 gas mixture. The signals were picked-up by 2.5×124 cm^2 aluminum strips located between the two gaps, terminated at one end with a 40 Ω resistor. The strips were read-out by a new version of front-end electronics based on an eight channels chip, designed and manifactured in 0.8 μBiCMOS technology by AMS. The amplifier charge sensitivity was 2 mV/fC and the discrimination threshold was 80 fC.

The main improvement of the new electronics concerns the timing performance: to have an amplitude-independent timing response the technique of zero crossing was implemented in the front-end chip. In order to mask a second trigger, a 100 ns pulse shaper followed the discriminator: a 4% dead time should be expected at the maximum rate ($\approx$400 kHz/strip) achieved in this test. The shaped signals were read-out by a multi-hit common stop TDC (LeCroy 2227), with a 64 μs gate and 1 ns sensitivity.

3. Experimental methods and results

The data from TDCs have been used to study the time and spatial properties of the chambers under different radiation fluxes. In the following, to account for different temperatures T and pressures P during the data taking, the applied voltage is normalized at the reference values $T_0 = 293$ K and $P_0 = 1000$ mbar, according to the relation [3]:

$$HV_{eff} = HV \times \frac{P_0}{P} \times \frac{T}{T_0}.$$

A single minimum ionizing particle often produces signals over the threshold in several adjacent strips, forming a cluster. Also Compton electrons produce a signal consisting of more than one strip, mainly due to the scattering angle. We define a cluster by grouping adjacent strips with signals inside a $\Delta t = 100$ ns time window. It was checked that the cluster rate values, with and without irradiation are not affected by the choice of the time window. An independent reconstruction of the muon impact point on the RPC surface has been obtained after extrapolating the track informations from the BCs: the relative RPC position with respect to the two BCs has been introduced and the track crossing point has been traslated to the RPC local reference system. In Fig. 1 we show the average cluster size in muon triggered events (cluster in a 100 ns time window around the average chamber response) and in random triggered events at different source conditions as a function of the operating voltage.

3.1. Chamber counting rate

The chamber counting rate measured under irradiation is originated mainly by the Compton

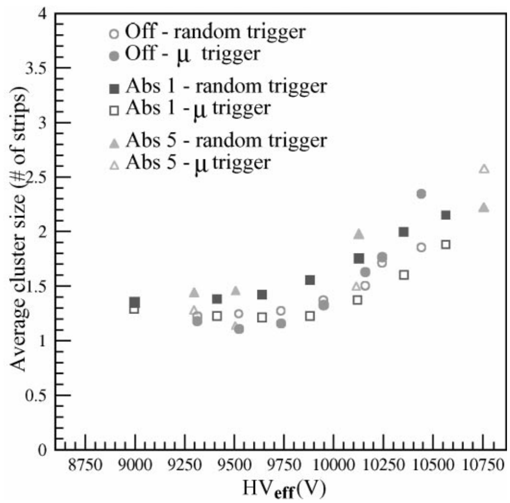

Fig. 1. Average cluster size vs. applied voltage at ABS 1, ABS 5 and no-source, in-time and out-of-time window.

electrons coming from the photons emitted by the source and interacting into the bakelite layers. Time differences between random events with uniform distribution in time, as the decays of a long-lived radiation source, are well described by an exponential distribution characterized by a probability density function

$$f(t) = A\exp(-at)$$

where t is the time and a represents the average rate at which events are occurring. Since Compton electrons produce, typically, clusters, we first ordered in time all the signals and then searched for the clusters. In Fig. 2 time differences between two consecutive clusters with ABS 1 are shown: here the slope (a) gives directly the counting rate (in ns^{-1}). This behavior has been already shown [4]. During no-source operation the counting rate has been measured by counting the number of clusters not associated with the extrapolated muon tracks in a 10 μs gate window opened before the muon trigger time. In Fig. 3 the counting rates for ABS 1, ABS 5 and source off are reported vs. applied voltage.

3.2. Spatial resolution

In order to evaluate the RPC spatial resolution, two estimators of the cluster position have been

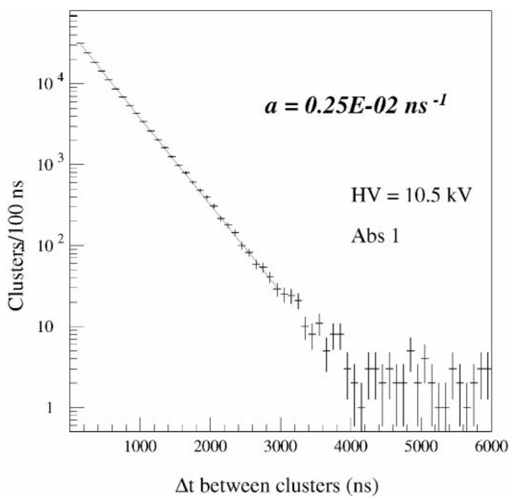

Fig. 2. Time difference between two consecutive clusters at ABS 1.

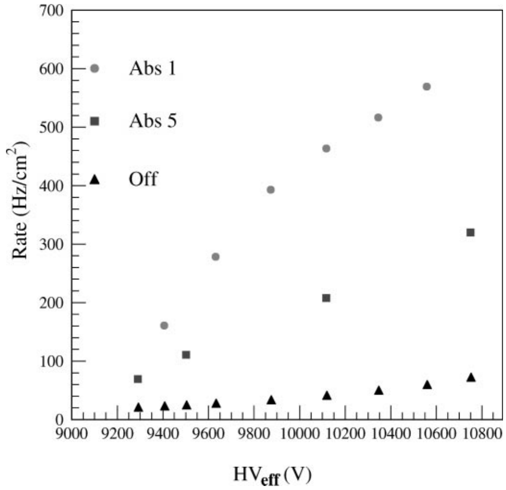

Fig. 3. Counting rate vs. applied voltage at the two different irradiation conditions and without source.

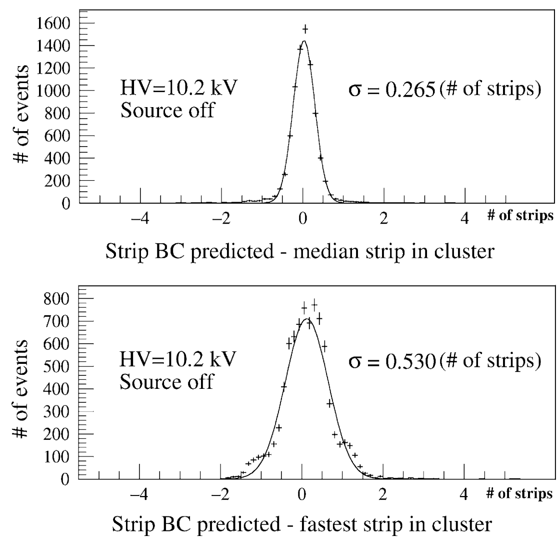

Fig. 4. Distribution of the distance between the median or the fastest strip in cluster and the extrapolated track crossing point.

considered:

- the position of the median strip in the cluster
- the position of the fastest strip in the cluster

In Fig. 4 the distance between the track impact point extrapolated from the BCs and the cluster position is plotted for the two estimators. The Gaussian fits to the distributions of residual, in units of strips, are shown. The median strip in the cluster (upper plot) gives a better estimation of the impact point with respect to the fastest strip. The σ is ≈ 0.26 strips, namely 0.66 cm.

3.3. Timing

To study time properties we looked for the cluster associated to the muon track. The timing of the RPC response, t_{RPC}, is defined by the arrival time of the median strip in the cluster with respect to the trigger time t_0. In Fig. 5 the time response at 10.5 kV and ABS 1 is plotted: here only signals in a ± 10 ns range with respect to the average chamber time response are taken into account. Different cable lengths and electronics jitter among the channels have been corrected off-line. Photons hitting the chamber before the muons are responsible for 2% of events in the left tail of the distribution. In Fig. 6 the average time responses (the mean of previous distribution) of the chamber under three different rates conditions are reported as a function of the operating voltage. We observe a decrease of the average signal arrival time as the operating voltage increases: this behavior is related to the increase of the drift velocity and the effective Townsend coefficient [5]. A slight difference in the mean arrival time is reported at the different rates. The time resolution, defined as sigma of the Gaussian fit to the arrival time distribution, as a function of the operating voltage is reported in Fig. 7: its values is ≈ 1 ns with source off (full circles) and does not change as a function of the applied voltage. The degradation of the time resolution at higher operating voltage for ABS 1 and ABS 5 can be due to variations of the effective voltage inside the gap when a high particle flux invests the chamber.

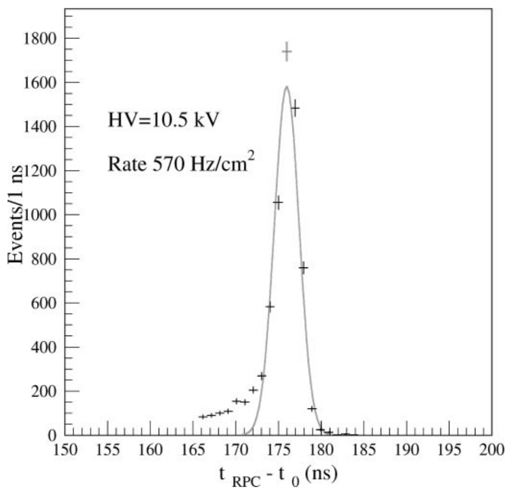

Fig. 5. Time response at 10.5 kV and ABS 1.

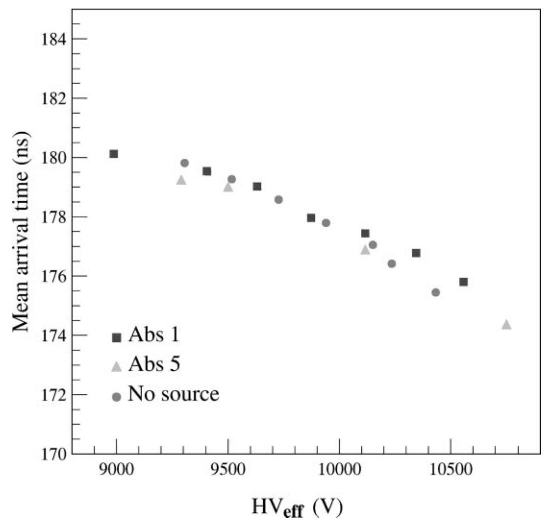

Fig. 6. Average time response vs. applied voltage with ABS 1, ABS 5 and source off.

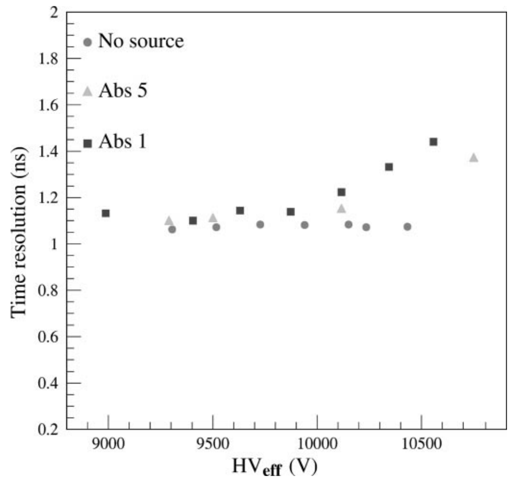

Fig. 7. Time resolution vs. the applied voltage with ABS 1, ABS 5 and source off.

3.4. Efficiency

We consider the RPC as efficient if at least a cluster in an area of ± 5 cm around the expected impact point is found. Moreover, the arrival time of the median strip in the cluster should stay in a ± 10 ns range with respect to the average chamber time response. Fig. 8 shows the efficiency value as a function of the absorption factors for two values of the applied voltage. The probability of accidental coincidences has been taken in account. Without the gamma background, the chamber reaches $98.3 \pm 0.3\%$ efficiency plateau. The inefficiency is compatible with 1% of events impinging the chamber in the regions of the spacers (the spacers have 0.8 cm diameter and are located on a grid of 10 cm pitch). On top of Fig. 9 the impact points of muon track as predicted by the BCs is shown when the chamber was inefficient; on bottom of the same figure the corresponding strip position is reported: 3% of events fall in the enlarged area (circles) of 2.5 cm^2 around the spacers: 40% of these tracks have been lost. At the higher counting rate the lower value of efficiency plateau ($90.5 \pm 0.4\%$ at ABS 1 and $94.0 \pm 0.4\%$ at ABS 5) with respect to the no-source condition is due to a reduction of the effective electric field applied to the gas gap and to the dead time from the electronics.

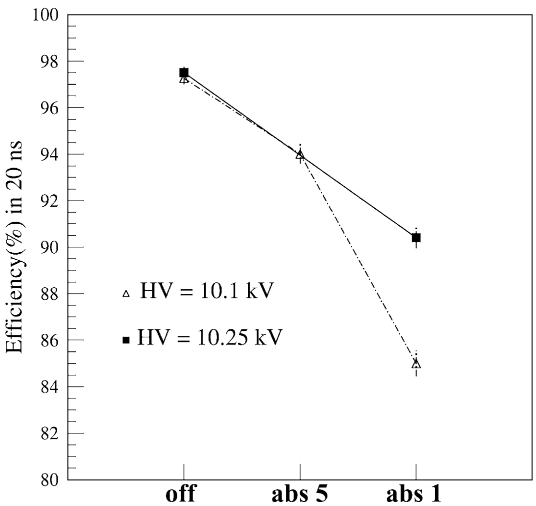

Fig. 8. Efficiency curves with ABS 1, ABS 5 and source off.

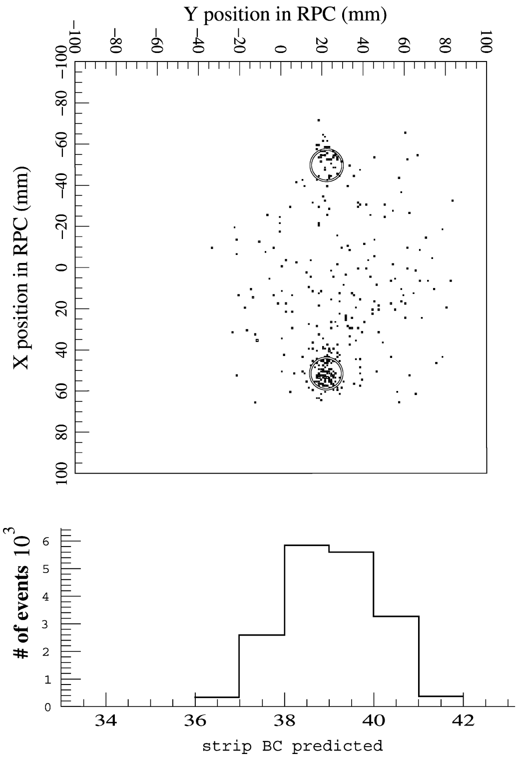

Fig. 9. The impact point (X, Y) (top) and the corresponding strip position on chamber (bottom) of muon track on the RPC in events when inefficiency was reported.

4. Conclusions

A full-size prototype of RB2-type RPC chamber for CMS has been tested under high-irradiation flux at the CERN Gamma Irradiation Facility. The performance of the new front-end electronics have been studied. The results on the single gap confirm good timing performances: the average time response is slightly affected by the high background rate and the time resolution is better than 1.5 ns. The chamber can reach high operation efficiency even in severe gamma radiation conditions (about 570 Hz/cm^2).

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