Aging study for Resistive Plate Chambers of the CMS Muon Trigger Detector

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Abstract

A long-term aging test of a Resistive Plate Chamber (RPC) was carried out with an intense gamma ^{137}Cs source. The detector was operated in avalanche mode and had the bakelite surface treated with linseed oil. After the irradiation the estimated dose, charge and fluence were approximately equal to the expected values after 10 years of operation in the CMS barrel region. During and after the irradiation, the RPC performance was monitored with cosmic muons and showed no relevant aging effects. Moreover, no variation of the bakelite resistance was observed.

1 Introduction

Resistive Plate Chambers (RPCs), chosen as dedicated trigger muon detectors for the CMS experiment, will work in a high photon and neutron background environment. In 10 years of operation, which correspond to an effective time of about 7-10 $\cdot$ 10^7 s, a photon and a neutron fluence of about 5-10 ^{10} γ/cm^2

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and 10 ^{11} n/cm^2 will be integrated in the CMS barrel region. The total charge and the total dose expected will be about 0.05 C/cm^2 gap and 1 Gy[1].

Consequently, the operation of the RPCs will have to cope with possible radiation problems. In order to spot aging effects, we carried out an extensive test programme in recent years by operating the detector in realistic background conditions. For example, a CMS-like double-gap RPC, without oil coating of the electrodes, was irradiated with a gamma source in 1998/1999 integrating a dose and a charge approximately equal to what will be expected in 10 years at LHC. In this case no significant variation in detector performance was reported [2].
Moreover, according to recent simulations of the CMS muon trigger system, in order to achieve an acceptable first level total muon trigger rate ($\sim$15 kHz), the RPC noise should not exceed a value of about 10 Hz/cm^2 [3]. Such a low noise rate can be achieved if the bakelite surface is treated with linseed oil. It is well known that this treatment has the effect of reducing the RPC noise and the dark current without affecting the detector performance (efficiency, cluster size, etc.)[4].

However, concern has been raised about possible aging effects of the oil coating, which could degrade the detector performance. Also recent problems reported by the Babar experiment have been traced back to bad oil coating on the electrodes [5]. It is therefore very important to experimentally verify the long-term performance of "oiled chambers", with extensive gamma and neutron irradiation tests.

The behaviour under gamma background has been studied by exposing one "oiled chamber" to a flux of about $1.2{\cdot}10^7$ $\gamma/\mathrm{cm}^2\mathrm{s}$, the maximum available gamma rate, at the CERN Gamma Irradiation Facility (GIF) over a period of several months. In this paper we present the results concerning this test.

Neutron irradiation of both "oiled" and "non-oiled chambers" was also recently performed at "Centre de Recherches du Cyclotron", Louvain la Neuve (Belgium). The results concerning this test will be presented in a forthcoming publication [6].

2 Experimental set-up

The GIF is a test area equipped with a 740 GBq radioactive ^{137}Cs gamma source, which produces a high background photon flux. A set of movable filters located in front of the source allows the reduction of the gamma rate. Several positions are possible, corresponding to different absorption factors (ABS $\sharp$) [7].

An RPC prototype (60×70 cm^2) was irradiated from October 2000 to May 2001. The detector was positioned vertically at 50 cm distance from the source and operated with a constant high voltage in presence of the maximum gamma flux (ABS 1).

The detector was operated in avalanche mode with a gas mixture of 96.5% of $C_2H_2F_4$ and 3.5% of iso-C_4H_{10}. The signals were picked up by 2.2×60 cm^2 strips located between the two gaps and read out by two 16-channel front-end boards [8]. These boards were connected to LVDS receivers which provided the ORs of 8 channels.

The high voltage (HV) was connected independently to the two gaps in order to facilitate either single- or double-gap mode operation. Here results of one of the two single gaps are presented.

3 Experimental method and results

During the irradiation the chamber rates and currents were continuously monitored. The chamber rate was evaluated by counting the number of clusters; it was measured as the average of the OR signals. In the absence of background radiation, this rate (noise) is produced only by spontaneous discharge.

The values of current were used to estimate the total accumulated charge. The fluence and the dose were estimated by a detailed simulation of the GIF area [7].

The laboratory temperature and pressure were also monitored during the irradiation. To take into account their variations, all results will be reported by scaling the high voltage according to the known relationship [9] and taking 20^{o}C and 1000 mbar as reference values, respectively.

To verify possible aging problems related both to the effect of the gamma flux and to the deposited charge, we performed two studies during the irradiation. First, the stability of the chamber performance was periodically monitored under cosmic muons and without gamma background. Second, the chamber rates and the currents were measured at different values of the gamma flux.

3.1 Test with cosmic muons

Four sets of measurements were taken according to the following schedule:

- measurement $\sharp$1, before the irradiation;

- measurement ♯2, during the irradiation;
- measurement ♯3, at the end of the irradiation;
- measurement ♯4, two months after the irradiation.

Before each set of measurements the chamber was rotated to a horizontal position and four scintillation counters were positioned above and below its central region. The efficiency was measured triggering on cosmic rays.

Dose, charge and fluence (quantities defined as aging factors), accumulated from the start of the test to the time of each set of measurements, are reported in table 1.

measurements ♯	dose (Gy)	charge (C/cm^2)	fluence γ/cm^2
1	0	0	0
2	30	0.02	$3\ 10^{12}$
3	100	0.05	$1\ 10^{13}$
4	100	0.05	$1\ 10^{13}$

Table 1
Aging factors corresponding to each measurement.

Efficiency

The chamber efficiency is plotted as a function of the applied high voltage (HV) in Fig. 1. The efficiency ϵ is obtained using the relationship [10]:

$$\epsilon = \frac{N_{ev}/N_{trig} - P_s}{(1 - P_s)}, \tag{1}$$

where N_{ev} is the number of events in coincidence with the trigger in a 100 ns time window (Δt), N_{trig} is the number of triggers, and P_s is the probability of accidental coincidences. P_s is computed in a time window with the same duration of Δt, but delayed with respect to the arrival time of the trigger signal. The plateau value (99 $\pm$ 0.5 %) is compatible with the geometrical extent of the dead area due to the spacers (about 1%); no significant depletion has been observed during the irradiation.

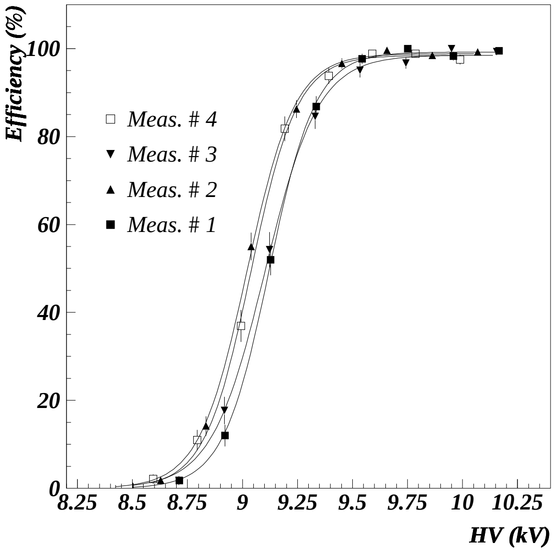

Fig. 1. Chamber efficiency as a function of HV for the 4 different measurements.

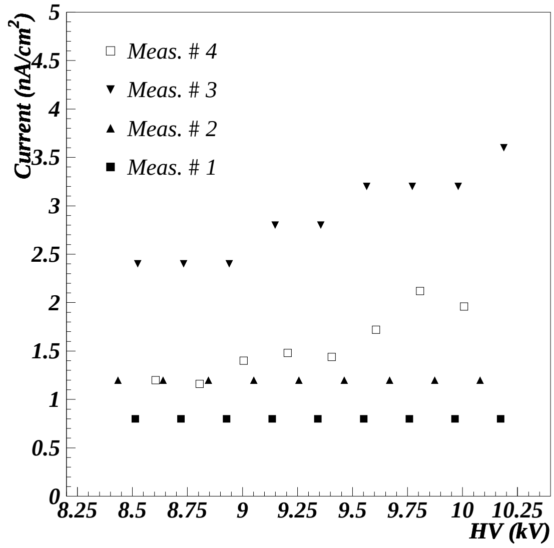

Fig. 2. Chamber currents (nA/cm^2) as a function of HV for the 4 different measurements.

Currents and noise

Chamber currents and noise rates are reported for each measurement in Fig. 2 and in Fig. 3. An increase of these quantities is observed during the irradiation. However, this increase does not seem to be irreversible, since current and rate tend to decrease for measurement ♯ 4, which was taken two months after the irradiation. Such behaviour could be an indication that no permanent damage

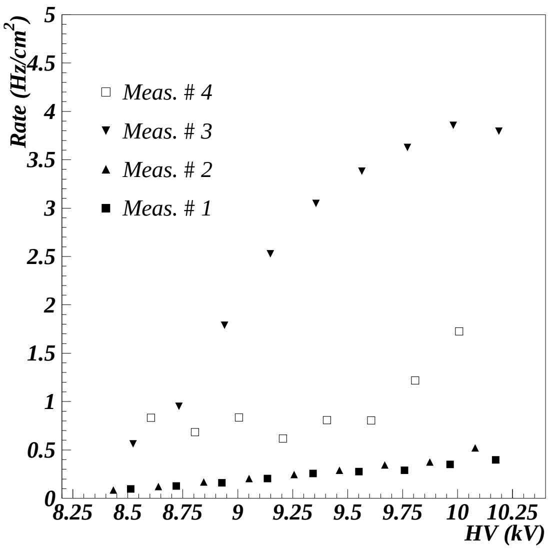

Fig. 3. Chamber noise as a function of HV for the 4 different measurements.

of the detector took place.

Strip profile

To verify possible local aging effects due to irradiation or accumulated charge, the counts due to noise were considered strip-by-strip (strip profile). The profiles for the central region of the chamber are reported at different HVs for measurements ♯ 1 and ♯ 4 (before and after the irradiation) in Fig. 4.

It is clear that after a period approximately equal to 10 CMS years, no significant variation of the strip profile or dead strips have been observed. In both cases the strip counting rate remains less than 2 Hz/cm^2 at the efficiency plateau (HV=9.6 kV).

3.2 Test at different gamma fluxes

During the irradiation, the chamber behaviour was also monitored for different background conditions. Chamber currents and rates were measured as a function of the applied voltage with several values for the ABS factors of 10, 50, 100, and 500. Three sets of measurements were taken during the test.

For each ABS the simulated photon flux value (ϕ_{ABS}) impinging on the chamber is given in table 2 [7]. In the same table, the rate of expected hits (N_{ABS}) due to converted photons is shown. N_{ABS} is calculated by scaling the photon

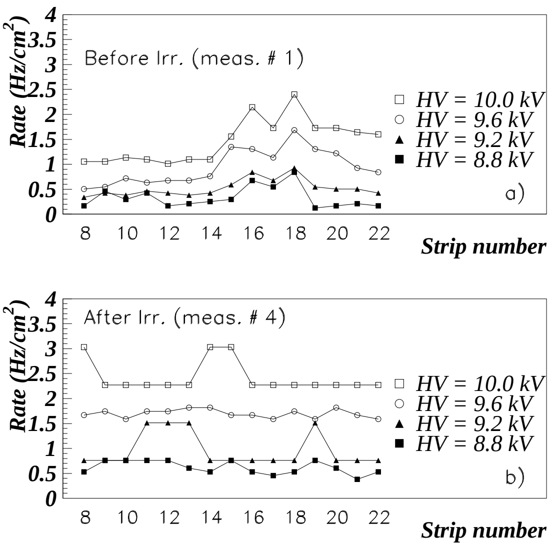

Fig. 4. Strip profiles in the central region of the chamber before the irradiation a) and after b).

flux values with the RPC sensitivity. In the evaluation of the sensitivity, due to its energy dependence, contributions both of the direct photons (0.662 MeV energy) and of diffuse photons (lower energy) should be considered. However, the average value of (2 $\pm$0.2) 10^{-3} was always used [11].

ABS ($\sharp$)	ϕ_{ABS} (γ/cm^{2}s)	N$_{ABS}$ Hz/cm^2
10	1.6 $10^6 \pm 0.1\%$	3200 $\pm$ 680
50	4.4 $10^5 \pm 0.2\%$	880 $\pm$ 105
100	2.3 $10^5 \pm 0.2\%$	460 $\pm$ 55
500	5.4 $10^4 \pm 0.9\%$	108 $\pm$ 12

Table 2
Simulated gamma flux and corresponding number of expected hits for different ABS factors.

The average charge $< q >$ developed in the gap per ionizing event can be estimated as:

$$< q >= \frac{I_{ABS} - I_{off}}{N_{ABS} S}, \tag{2}$$

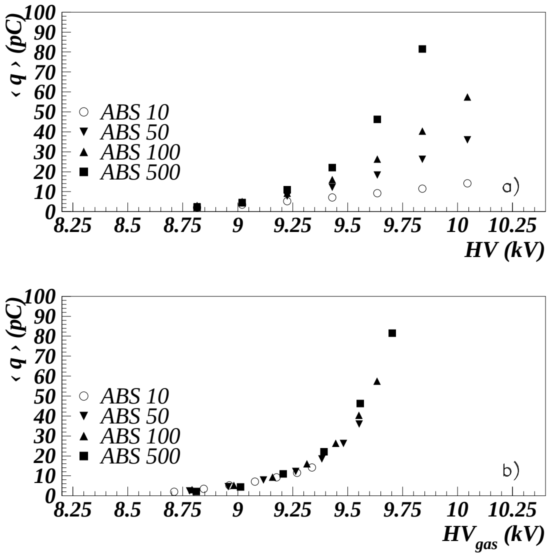

Fig. 5. Average charge as a function of a) HV, and b) HV_{gas}.

where I_{ABS} is the current drawn by the chamber at a given ABS, I_{off} is the current without gamma background, and S is the chamber area.

Fig. 5a shows $< q >$ as a function of the applied voltage at different ABSs. These results refer to the data collected in the first measurement, after an accumulating a charge of about 0.01 C/cm^{2}gap in the chamber.

The passage of current through the bakelite plates is proportional to the ionizing particle rate. This current causes a reduction of the effective electric field inside the gap which is proportional to the bakelite resistivity. We can than define HV_{gas} as:

$$HV_{gas} = HV - (I_{ABS} - I_{off})R, \tag{3}$$

which should represent the effective potential drop across the gas gap, with R being the resistance of the bakelite.

The charge $< q >$, if plotted as a function of HV_{gas}, should not depend on the background conditions, if the operation regime of the detector is invariant with respect to HV_{gas}.

In order to verify if such a scaling behaviour shows up in our data, a fit of the parameter R is performed by minimizing, for each HV_{gas} value, the spread of the relative charge values computed at different ABSs [12].

The fit converges and gives the value of 3.7 ± 0.3 MΩ for R.

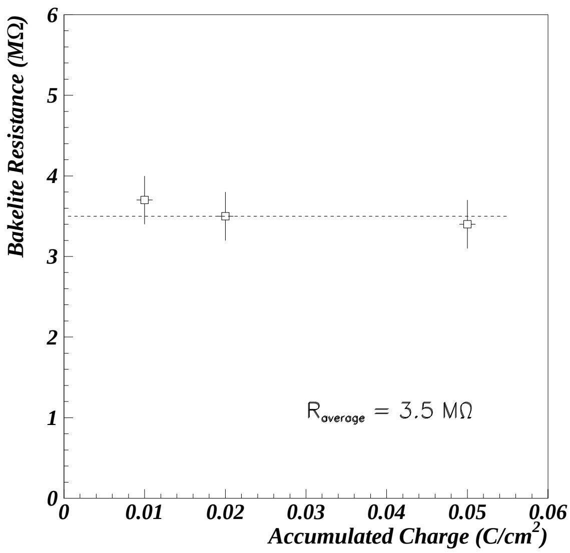

Fig. 6. Bakelite resistance as a function of the accumulated charge during the irradiation.

In Fig. 5b the average charges are plotted again as a function of HV_{gas} at different ABS, by using this value of R in equation (3). A nice scaling of $< q >$ vs. HV_{gas} is evident, which proves the reliability of our R measurement.

This procedure is repeated for different sets of data taken during the test. The obtained resistance R is shown in Fig. 6 as a function of the accumulated charge. No significant variation is observed, which confirms that no deterioration of the material took place under the irradiation.

Equation (3) can also be rewritten as

$$\Delta V = HV - HV_{gas} =< q > SRN_{ABS}, \tag{4}$$

where ΔV is the potential drop across the bakelite electrodes.

It is also useful to represent our data in terms of equation (4) to understand what variations of the background rate could be allowed during operations without altering the detector working condition. In fact, normal operation is at constant HV but detector performance is driven by HV_{gas}.

In Fig. 7 the potential drop ΔV, as previously determined, is plotted as a function of the hit rate N_{ABS} at $HV_{gas} = 9.5$ kV. Within the errors, a linear dependence is confirmed. A straight line with angular coefficient $k =< q > SR \approx 0.4$ is also superimposed.

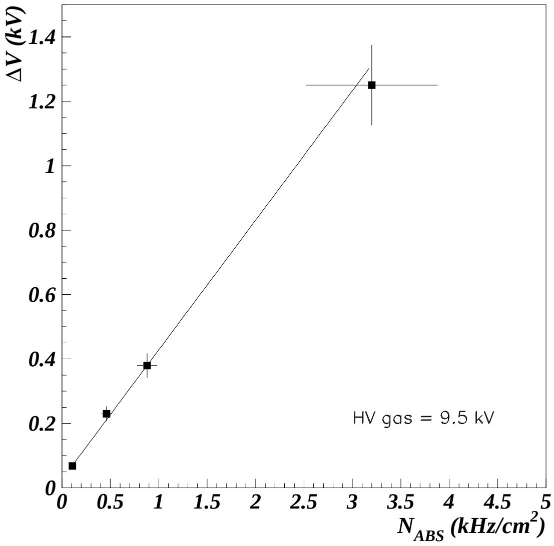

Fig. 7. The drop in potential ΔV as a function of the expected hits.

4 Conclusions

An aging test was performed with an "oiled chamber" in a high gamma background environment. Values of aging parameters (charge, dose and fluence), approximately equal to those expected in 10 years of CMS operation, were integrated. The detector performance, periodically measured under cosmic muons, remained almost unchanged. Finally, a way to evaluate possible bakelite resistivity drift is discussed. Results do not show any variation of this parameter.

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