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Neutron irradiation of RPCs for the CMS experiment

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Abstract

All the CMS muon stations will be equipped with Resistive Plate Chambers (RPCs). They will be exposed to high neutron background environment during the LHC running. In order to verify the safe operation of these detectors, an irradiation test has been carried out with two RPCs at high neutron flux (about 10^8 n cm^{-2} s^{-1}), integrating values of dose and fluence equivalent to 10 LHC-years. Before and after the irradiation, the performance of the detectors was studied with cosmic muons, showing no relevant aging effects. Moreover, no indication of damage or chemical changes were observed on the electrode surfaces.

Keywords: Resistive plate chambers; CMS; Neutron irradiation

1. Introduction

All the LHC experiments (LHC-b, ATLAS, ALICE and CMS) will be equipped with RPCs. In recent years, strong efforts have been made to investigate the performance stability of these detectors, in view of the extremely hard radiation environment expected at LHC.

In CMS the RPCs have been chosen as dedicated muon trigger detectors. They will be located both in barrel and end-cap muon stations and they will be exposed to an average dose of about 10 Gy, over 10 years of LHC operation at the nominal luminosity of 10^{34} cm^{-2} s^{-1} [1].

Aging effects could be developed in the detector due to neutron or gamma fluence. According to Monte Carlo simulations the expected fluences in the muon stations (considering 10 years of LHC operation) will reach the maximum levels of about 10^{12} n cm^{-2} and $5 \times 10^{11} \gamma$ cm^{-2}, respectively.

No aging related to gamma fluence has been observed after extensive tests performed by exposing RPC prototypes at the CERN Gamma Irradiation Facility [2] and at the Bari Telescope [3].

In order to spot possible damage or performance variations due to neutron background, two RPC prototypes were irradiated with a neutron beam at "Centre de Recherches du Cyclotron", Louvain la Neuve (Belgium). The performance of the irradiated RPCs has been studied with cosmic muons and compared with previous measurements done before the irradiation.

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2. Experimental environment

The isochronous cyclotron at the Louvain-la-Neuve accelerates deuteron up to 50 MeV. An intense neutron beam is produced via the reaction $^{9}Be + d -> n + X$, on 1-cm-thick beryllium target (other particles, X, are also produced in the reaction). The energy spectrum of the produced neutrons goes up to 50 MeV, with a peak at about 25 MeV.

Two RPCs were positioned at a distance of 90 cm from the target; the corresponding neutron flux and the dose were estimated using for the neutron yield the experimental data by Bernier et al. [4]. At the distance where the RPCs were located, the maximum neutron flux was about $10^{7}\ n\ s^{-1}\ cm^{-2}\ \mu A^{-1}$, and the dose rate about $28 \times 10^{-4}\ Gy\ s^{-1}\ \mu A^{-1}$ (both selected by tuning the beam current).

Both irradiated detectors were 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 $2.2 \times 60\ cm^2$ strips located between the two gaps and read-out by two 16-channel CMS front-end boards [5]. The high voltage (HV) was connected independently of the two gaps in order to allow either single or double gap mode operation. Results concerning one of the two single gaps are presented in this paper.

One chamber (in the following RPC A) had the internal bakelite surfaces coated with linseed oil, while the second (RPC B) had no oil treatment.

3. Results and discussion

3.1. Chamber irradiation

Two irradiation cycles were carried out with high neutron flux: $3 \times 10^{7}\ n\ cm^{-2}\ s^{-1}$ and $2 \times 10^{8}\ n\ cm^{-2}\ s^{-1}$. Each cycle consisted of about 1 h of irradiation followed by 1 h of beam off.

Dose and fluence accumulated during each irradiation cycle are reported in Table 1.

The neutron flux value was chosen in order to integrate the same fluence and dose expected in 10 LHC-years. However, such neutron flux should produce a rate of signals [6] exceeding by a large factor (> 10) the chamber rate capability, and resulting, therefore, in a low chamber efficiency. For this reason the total accumulated charge inside the gas gap is lower than what expected if the chamber had been fully efficient.

During the test, the current and the counting rate of the chambers were monitored. A constant high voltage of 9.4 kV was applied during the irradiation. The chamber rate was calculated as the average of the single strips rate.

The counting rate of RPC B is reported as a function of time during the first cycle in Fig. 1. In the plots, from 0 to 50 min the neutron beam is ON while from 51 to 110 min the beam is OFF.

To explain the increase of the rate as a function of the irradiation time (Fig. 1a), the contribution of the neutron activation should be added. About 50 min after the start of the irradiation, this increase (ΔR) is $\approx 550\ Hz\ cm^{-2}$. In Fig. 1b, as

Table 1
Dose and fluence integrated during the irradiation cycles

Cycle #	Dose (Gy)	Fluence $n\ cm^{-2}$
1	4	$\approx 10^{11}$
2	50	$\approx 10^{12}$

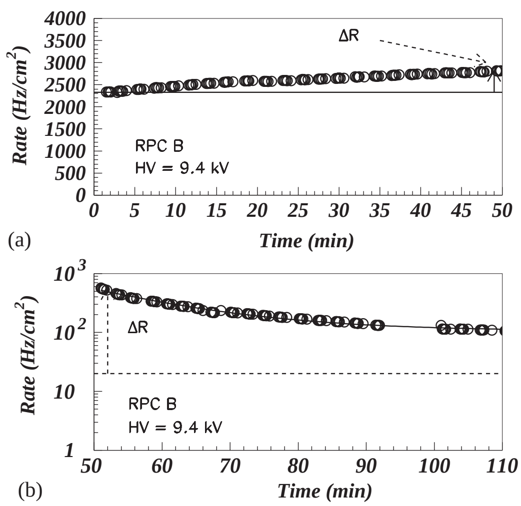

Fig. 1. Counting rate of RPC B (at constant HV) as a function of time during the first irradiation cycle.

expected, the chamber rate is decreasing following a multiple exponential decay law, starting from the value of about $\Delta R = 550\ \mathrm{Hz\,cm^{-2}}$. However, 1 h after the end of the irradiation, the chamber rate is still greater than the value measured before the irradiation (indicated with the dashed line in Fig. 1b). This effect could be explained considering the contribution of the isotopes with long decay time. In fact, taking into account the neutron beam energy and the detector materials, the following reactions are likely to happen (the produced isotopes and their half lives, $T_{1/2}$, are also reported):

- $^{63}\mathrm{Cu(n,2n)}^{62}\mathrm{Cu}$, $T_{1/2} = 9.8$ min,
- $^{27}\mathrm{Al(n,p)}^{27}\mathrm{Mg}$, $T_{1/2} = 9.4$ min,
- $^{65}\mathrm{Cu(n,2n)}^{64}\mathrm{Cu}$, $T_{1/2} = 12.7$ h,
- $^{27}\mathrm{Al(n,\alpha)}^{24}\mathrm{Na}$, $T_{1/2} = 15$ h.

Both RPCs were subject to the second irradiation cycle. Similar results were observed about the current and the rate behaviour during the irradiation.

At the end of the cycles no dead strips were observed in both irradiated RPCs.

Finally, taking into account the neutron fluence, the time needed to reduce the contribution of the activations to a value less than 1% of the initial chamber rate has been estimated. This "recovery time" has been found to be about 180 h.

3.2. Aging of RPC performance

To spot possible aging problems related both to the effects of the neutron fluence and dose, the chambers performance was studied with cosmic muons before and after the irradiation. The latter measurement has been done 10 days after the irradiation cycles at a time greater than the "recovery time".

The experimental set up and the methods are already described in Ref. [2]. The efficiency was measured triggering on cosmic rays. The chamber rate was again evaluated as the average of the strip rate. The variations of the laboratory temperature and pressure have been taken into account: all results will be reported by scaling the high voltage according to the known relationship [7] and taking as reference values 20°C and 1000 mbar, respectively.

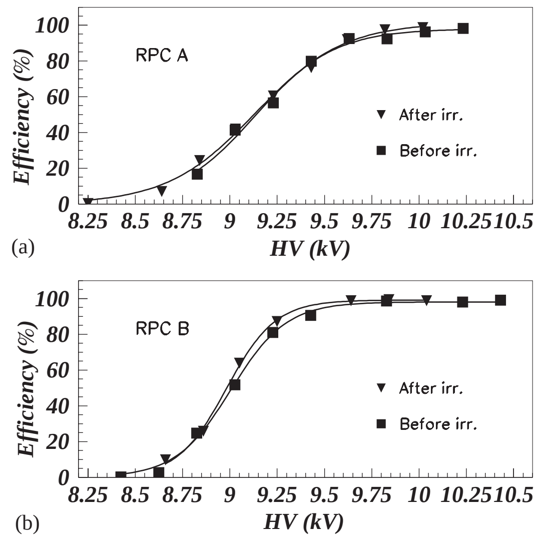

Fig. 2. Efficiency of RPC A in (a) and RPC B in (b) as a function of HV before and after the irradiation.

The efficiency is plotted as a function of the applied HV in Fig. 2a and b for RPC A and B, respectively. In both cases, the plateau value is about 99%. Moreover, comparing the efficiency before and after the irradiation, no significant depletion or shift in operating voltage has been observed.

The counting rates of RPC A and B are reported in Figs. 3a and b. No significant variation, due to the neutron irradiation, was observed. Moreover, at the knee of the efficiency plateau, the detector noise is about $2\ \mathrm{Hz\,cm^{-2}}$ and $20\ \mathrm{Hz\,cm^{-2}}$ for RPC A and B, respectively. According to recent simulations in order to limit the rate of false trigger within acceptable values the RPC noise should not exceed a value of about $10\ \mathrm{Hz\,cm^{-2}}$ [8]. For this reason the CMS collaboration is planning to use RPCs with the linseed oil treatment.

3.3. RPC autopsy

At the end of test, both RPCs were opened to inspect the internal electrode bakelite surfaces. In both cases the bakelite surfaces were very clean

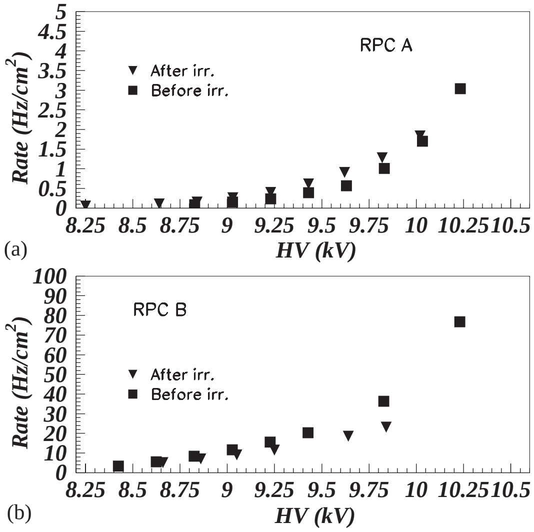

Fig. 3. Noise rate of RPC A in (a) and RPC B in (b) as a function of HV before and after the irradiation.

and smooth. In the case of RPC A the linseed oil appeared hard and no oil drops were found.

Samples of oiled bakelite of RPC A were also subject to chemical analysis and they were compared with non irradiated samples. The Fourier Transform Infrared Analysis (FTIR) [9] spectra verified the complete polymerization of the linseed oil and its good stability after the irradiation.

4. Conclusions

Two RPCs were subjected to neutron irradiation cycles, integrating values of dose and fluence equivalent to 10 years of detector operation in CMS. The performance of the detectors before and after the irradiation was compared. No significant change was found. The observed increase of counting rate and current of the chambers during the irradiation can be explained as due to neutron activation.

The inspection and the chemical analysis of the internal electrode surfaces showed reassuring results about the possible damage of the linseed oil coating.

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