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Long-term performance of double gap resistive plate chambers under gamma irradiation

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Abstract

In this paper, we describe a dedicated test to study possible long-term aging effects on Resistive Plate Chambers (RPCs). A double gap detector was operated under gamma irradiation for a period approximately equal to 10 years of LHC in the CMS-barrel region: an integrated dose of about 1.6 Gy and a total charge of about 0.05 C/cm^2 gap were accumulated on the chamber. The results show no relevant aging effect. Also the RPC sensitivity to ^{60}Co gamma energies is measured. © 2002 Elsevier Science B.V. All rights reserved.

1. Introduction

Resistive Plate Chambers (RPCs) have been approved as dedicated detectors for the muon trigger system at future high energy and luminosity hadron collider (LHC). At a luminosity of 10^{34} cm^{-2} s^{-1} the detector will work in a high background environment. According to recent Monte Carlo calculations [1], in the barrel and forward regions 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} and 10^5 cm^{-2} s^{-1}, respectively.

The simulation has estimated that the total dose integrated in 10 years of LHC operation will be about 1 Gy in the barrel and in most of the forward muon system.

Therefore, aging problems may develop in the detector, related both to the effect of the irradiation on the bakelite electrodes (which might produced variation of resistivity) and to the deposited charge. Variation of the ohmic current, reduction of the plateau, excessive currents and sparking are all possible indications of aging.

It is, thus, of primary importance to prove experimentally the safe operation of RPCs by reproducing the expected gamma background environment.

A dedicated test was performed in Bari during last year by modifying the existing horizontal muon telescope (MINI experiment) [2] and by creating in the middle a dedicated irradiation facility.

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2. Experimental set-up

The horizontal muon telescope is composed by eight $2 \times 2\ m^2$ RPC chambers which have been in operation in streamer mode for 8 years. Four of them are equipped with horizontal strips and four with vertical ones, to allow the reconstruction of the crossing muons tracks in the two orthogonal projections.

The irradiation area is equipped with three ^{60}Co sources (10 mCi total activity), located inside a cylindrical lead collimator, which can be remotely opened and closed. The ^{60}Co isotope emits two photons at 1.17 and 1.33 MeV in 100% of the decays with a half-life of 5.27 years.

A large CMS like double gap RPC ($130 \times 120\ cm^2$) with bakelite resistivity $\simeq 2 \times 10^{11}\ \Omega$ cm is positioned vertically inside the irradiation area. The sensitive volume is filled with a gas mixture of 95% of $C_2H_2F_4$ and 5% of iso-C_4H_{10}. The signals are read-out by $3.5 \times 130\ cm^2$ aluminum strips located between the two gaps and terminated at one end on a 40 Ω resistor. At the other end of the strips a hybrid charge amplifier (of the same type described in Ref. [3]) is connected. The signals are discriminated with a 50 mV threshold and input to a common stop TDC (LeCroy 2228A), with 250 ps time resolution and a time window of 500 ns. More technical details can be found in Ref. [4].

In order to evaluate the gamma and electron fluxes on the chamber surface and the accumulated dose, a detailed simulation of the source, the collimator and the shielding geometry was performed using the MCNP-4b Monte Carlo code [5].

Fig. 1 shows the space distribution of the total (direct and diffuse) gamma flux on the chamber surface. The maximum value at the center of the chamber is $\sim 2 \times 10^4\ cm^{-2}\ s^{-1}$.

The absorbed dose can be computed as

$$D = \phi_\gamma \times [\mu_{en}/\rho]_{Bak} \times E_\gamma \quad (Gy/s)$$

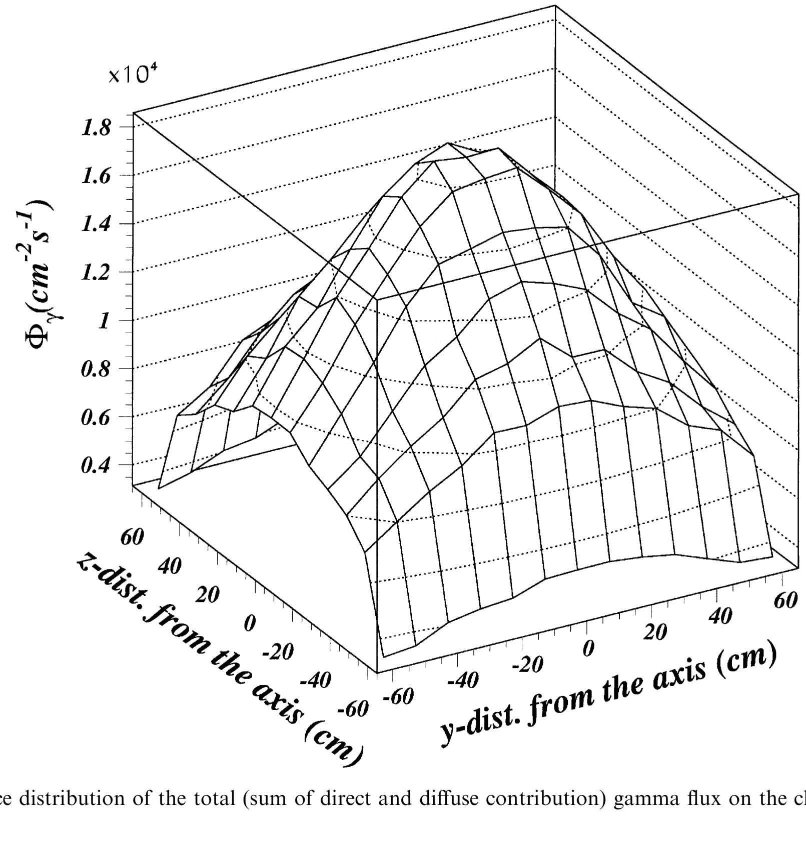

Fig. 1. Space distribution of the total (sum of direct and diffuse contribution) gamma flux on the chamber surface.

where ϕ_γ is the calculated γ flux ($cm^{-2}\ s^{-1}$), $[\mu_{en}/\rho]_{Bak}$ ($cm^2\ g^{-1}$) is the energy mass coefficient in bakelite (with ρ bakelite density), E_γ (MeV) is the energy of gammas emitted.

In Fig. 2, the integrated dose as function of the irradiation time is shown. The total dose, about 1.6 Gy, is approximately equal to the one expected in the CMS barrel region and in most of the forward region during 10-years of LHC operation. The simulation can also be used to predict the RPC sensitivity by evaluating the flux of electrons ϕ_e generated by the interaction of photons and crossing the chamber gas gap, whose geometry was also simulated. The ratio ϕ_e/ϕ_γ gives an estimation of the sensitivity. We find $1.6 \pm 0.1 \times 10^{-2}$. More detail on the simulation and the sensitivity computation can be found in Ref. [6].

3. Experimental results

Events were collected starting from March 1998 until May 1999 at different operation voltages and different irradiation conditions.

After rejection of showers (about 35% of the total sample) and events for which the number of hits is not enough to define a track (about 15%), good single muon tracks are selected by required in the fit procedure a $\chi^2/\text{d.o.f.} \leqslant 2$. The muon impact point on the irradiated chamber is then predicted and the distance to the closest hit is calculated. The chamber is considered efficient if a hit is present in an area of 5 cm from the extrapolation. In Fig. 3, the distribution of residual is shown: the sigma of the Gaussian fit is 1.1 cm and is in agreement with the expected spatial resolution of the telescope ($\sigma_s = L/\sqrt{12} \simeq 1.0$ cm, where L is the strip width [7]). No relevant variations of the spatial resolution has been found during the operation at different voltages and irradiation conditions.

In the following, to account for different temperatures (T) and pressures (P) at which the data samples were taken, the applied voltage (HV_a) is normalized according to relationship [8]

$$HV = HV_a \times \frac{P_0}{P} \times \frac{T}{T_0}$$

where T and P are the average laboratory temperature and pressure during the data taking and $T_0 = 293$ K and $P_0 = 1020$ mbar define the reference values.

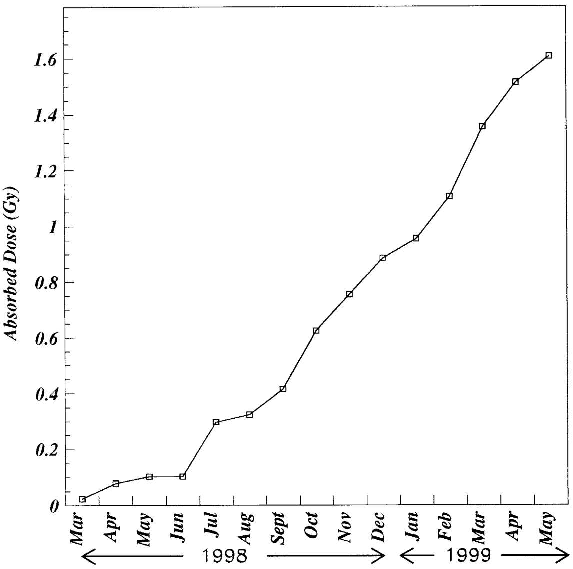

Fig. 2. The accumulated dose on the chamber as a function of the irradiation time.

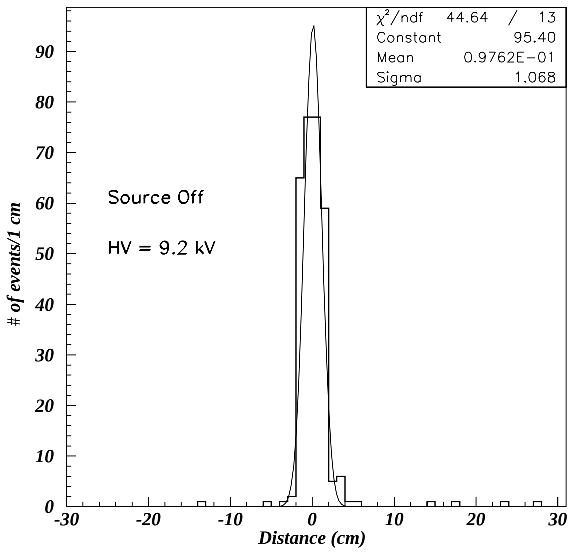

Fig. 3. Distribution of the distance between the closest hit and the reconstructed crossing point on the chamber.

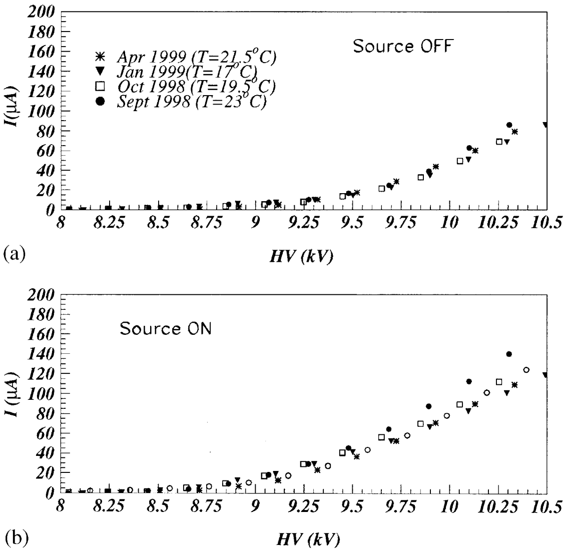

Fig. 4. Currents drawn by the chamber under irradiation for different irradiation conditions and different measurement period. (The ohmic current was subtracted).

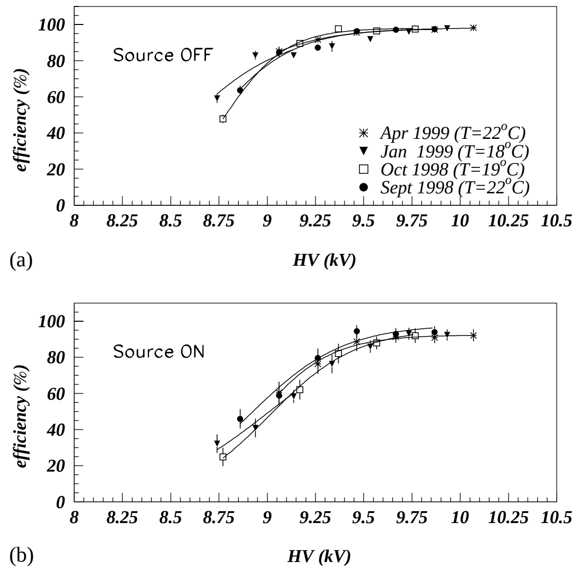

Fig. 5. Efficiency as function of HV for different irradiation conditions and different measurement period.

3.1. Currents

In Fig. 4, the currents drawn by the chamber under irradiation, after subtraction of the "ohmic" contribution, are reported for different conditions and different measurement periods. No sensible variation is observed as a function of the irradiation time. The total accumulated charge, evaluated by integrating the currents during the test period, is about $0.05\ \mathrm{C/cm^2}$ gap. This value should be compared with the total charge expected in CMS (barrel regions) after 10 years of LHC operation: for a rate of charged particles of about $40\ \mathrm{Hz/cm^2}$ (r), the total charge would be

$$T_{\mathrm{tot}} \times r \times \langle q \rangle = 0.04 \quad (\mathrm{C/cm^2}\ \mathrm{gap})$$

assuming 20 pC average charge per hit ($\langle q \rangle$) and a total operation time (T_{tot}) of 5×10^7 s.

3.2. Efficiency and strip multiplicity

In Fig. 5, we report the efficiency curves for the chamber under irradiation. The errors due to the fraction of accidental coincidences (estimated by acquiring events with random trigger [9]) are summed in quadrature with statistic error.

The value at the plateau ($\simeq$ 98%) without gamma background is compatible with the geometrical extension of the dead area (estimated about 2%) [3]. In the presence of gamma background, the measurements show a shift of the efficiency plateau toward higher voltage, as expected because of the relatively high value of the electrode resistivity [4]. However, no significant degradation of the detection efficiency is observed as a function of the irradiation time.

The average value of the strip multiplicity versus HV is reported in Fig. 6. The different shape of the two set of curves obtained with and without gamma background could be explained as due to a reduction of the effective electric field applied to the gas gap.

3.3. Chamber rate and gamma sensitivity

The chamber counting rate (R) has been computed by counting the number of clusters not associated to the extrapolated muon tracks, as

$$R = \frac{N_{\mathrm{cl.}}}{N_{\mathrm{events}} A \Delta t}$$

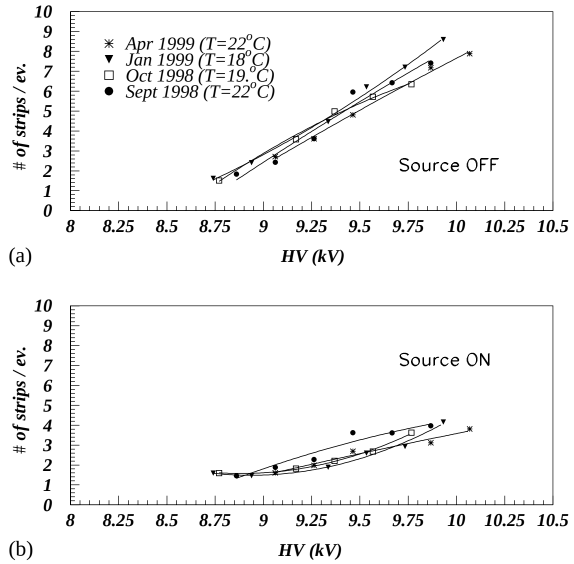

Fig. 6. Average number of the strip multiplicity as function of HV for different irradiation conditions and different measurement period.

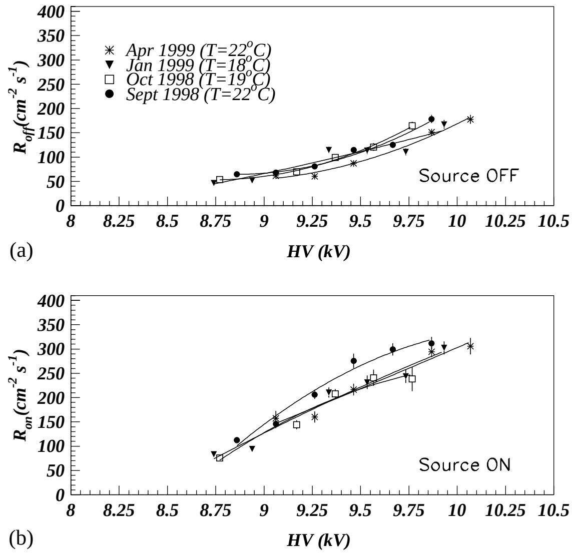

Fig. 7. Chamber rates versus HV for different irradiation conditions and different measurement period.

where $N_{cl.}$ and N_{events} are the number of clusters and total events, respectively, A is chamber area and Δt is the TDC time window. In Fig. 7 the chamber rates, with their statistic errors, are reported versus HV.

The knowledge of both the effective rates, (R_{on} and R_{off}) with and without source, and the gamma flux (ϕ_γ) impinging on the chamber, allows to estimate, at a given HV, the RPC sensitivity to ^{60}Co gammas

$$S_{HV} = \frac{(R_{on}/\varepsilon_{on}) - (R_{off}/\varepsilon_{off})}{\phi_\gamma}$$

where the rates are normalized to the measured efficiencies ε_{on} and ε_{off}. The statistics errors $\sigma_{S_{HV}}$ are also calculated.

We define the plateau sensitivity S_p as the weighted mean computed considering only the last three HV values:

$$S_p = \frac{\sum_{HV=1}^{3} S_{HV}/\sigma^2_{S_{HV}}}{\sum_{HV=1}^{3} (1/\sigma^2_{S_{HV}})}.$$

In Fig. 8, S_p is reported as function of irradiation time. No sensible variation of the sensitivity is observed during the test. The average value, about $1.4 \pm 0.1 \times 10^{-2}$, is in agreement with the simulated one reported in Section 2.

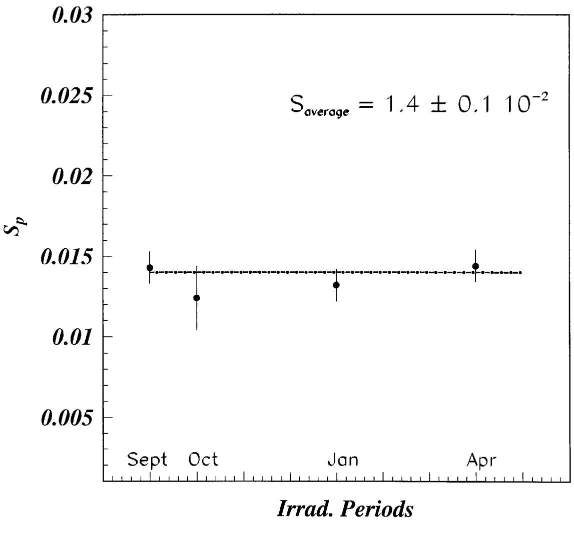

Fig. 8. Sensitivity of RPC at ^{60}Co Gammas energy calculated in different period of measurement.

4. Conclusions

After long-term irradiation test on a double gap RPC in a high background environment no significant variation in detector performance was observed. The current draw by chamber, the efficiency plateau value, the average cluster size and the counting rate, both for the detector under γ flux and without remained almost unchanged. Also the RPC sensitivity to ^{60}Co gamma energies is measured.

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