Preliminary results of an aging test of RPC chambers for the LHCb Muon System

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Abstract. The preliminary results of an aging test performed at the CERN Gamma Irradiation Facility on a single–gap RPC prototype developed for the LHCb Muon System are presented. The results are based on an accumulated charge density of 0.42 C/cm^2, corresponding to about 4 years of LHCb running at the highest background rate. We observe a rise in the dark current and noise measured with source off. The current drawn with source on steadily decreased, possibly indicating an increase of resistivity of the chamber plates. The performance of the chamber, studied with a muon beam under several photon flux values, is found to still fulfill the LHCb operation requirements.

Keywords: rpc, aging

Introduction. The LHCb experiment [1] has chosen to equip about 48% of the Muon System [2] with Resistive Plate Chamber (RPC) detectors. These detectors will be subject to a very large particle flux, potentially dangerous from the point of view of detector aging [2]. In the regions covered by RPCs, the maximum particle rate is expected to vary between 0.19 in region 4 and 0.75 kHz/cm^2 in region 3 (see [2] for a definition of the regions). This leads, under reasonable hypothesis [3], to total integrated charge densities between 0.35 C/cm^2 (region 4) and 1.1 C/cm^2 (region 4) for 10 years running. These charge densities are significantly larger than those expected by ATLAS [3] and CMS experiments [4], whose aging tests accumulated at most about 0.3 C/cm^2 [6], clearly insufficient to draw conclusions about LHCb RPCs. An extensive aging program has been therefore devised for the LHCb needs exploiting the large CERN Gamma Irradiation Facility (GIF) [7], where a ^{137}Cs gamma source of about 655 GBq is available. This paper reports the preliminary results of the first part of the test performed with a prototype chamber during January-December 2001. The second part, currently under preparation, will be done with close-to-final LHCb chambers and is expected to start March 2002.

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[2]Aging in RPCs is due mostly to the current flowing through the resistive plates; it has been shown, indeed, that the irradiation of bakelite slabs with photons up to an integrated dose of 20 kGy does not produce any degradation in the bakelite properties [5].

[3]Namely: *i)* running at half maximum rate; *ii)* assuming an average avalanche charge of 30 pC [5].

Setup of the aging test. The prototype RPC used for the test (*irradiated RPC*) is a single gap oiled chamber, with active area 50x50 cm^2, made with 2 mm thick phenolic bakelite plates with nominal resistivity $\rho = 9 \cdot 10^9\ \Omega$ cm. This RPC was placed in front of the source at a distance varying between 0.5-1 m and a photon flux of about 1-2 kHz/cm^2. To facilitate disentangling the effects due to variations in the environment parameters - such as temperature, pressure or gas quality - from those due to the irradiation, a second chamber (*reference RPC*), identical to the irradiated one, was placed just outside the irradiation area. The RPCs were operated with a gas mixture consisting of 95% $C_2H_2F_4$, 4% $i{-}C_4H_{10}$, 1% SF_6. To simulate the LHCb conditions and perform the test in a reasonable amount of time, the applied voltage was chosen in such a way to have an average avalanche charge Q_γ of about 50 pC, which, at the rate quoted above, yields a current density of about 80 nA/cm^2. All the relevant parameters of the test - temperature, pressure, high voltage and currents drawn by the chambers - were continuously recorded. In Fig. 1a the current drawn by the irradiated RPC and by the reference RPC during the aging test are shown as a function of time; these currents have been corrected for temperature variations, assuming $I = I_0 \exp(\alpha T)$ with α chosen such that intra-day fluctuations are eliminated. As it is clearly visible from the top plot, the current drawn by the irradiated RPC decreased with time. The current drawn by the reference RPC is reasonably stable and constant during the test. By integrating the measured current, the total charge accumulated by the irradiated RPC has been found to be 0.42 C/cm^2, representing about 4 LHCb years in regions 3 and to more than 10 LHCb years in regions 4. The charge integrated by the reference RPC is 0.02 C/cm^2.

Measurements after the aging test. The general behavior and performance of the irradiated RPC has been checked using the source and the muon beam available at the GIF. The combined use of the gamma source and the beam allows a test of the chamber performance under background conditions very similar to the ones encountered in the experiment. Measurements were performed with different photon fluxes, ranging from zero (source off) up to a maximum of about 1 kHz/cm^2. The chambers were operated in the same conditions as in the aging test. The efficiency was evaluated by tracking the beam particles with a scintillator hodoscope and with an additional 10×10 cm^2 RPC. The photon fluxes were estimated from the chamber counting rates measured during dedicated off-spill gates. Data were collected at three different source attenuation values, namely attenuation 1, 2 and 5 corresponding roughly to 1 kHz/cm^2, 0.7 kHz/cm^2 and 0.4 kHz/cm^2 photon fluxes respectively.

The performances of the irradiated RPC are still very good and basically indistinguishable from the ones of reference chamber; as an example the efficiency curves are shown in Fig. 1b for different photon fluxes [4].

In Fig. 1c the dark currents drawn by the two RPCs as a function of the applied voltage - measured before, during and at the end of the aging test - are shown. A large increase of the dark current drawn by the irradiated RPC can be clearly observed. The effect of the irradiation amounts, at a possible working point, to about 1.5 nA/cm^2. This increase is correlated with a corresponding increase in dark noise rate, but its origin is still under

[4] The shift in the plateau position was observed also before the irradiation test and is probably due to a relative mis-calibration of the two sets of readout electronics; it is also compatible with a difference in gap size within tolerances.

investigation. However, this increase in dark current density is still significantly below the limit of 3 nA/cm^2 set in the LHCb-μ TDR [2].

The currents drawn by the two chambers under irradiation and different photon fluxes are shown in Fig. 1d: the irradiated RPC clearly draws less current than the reference one, indicating that Q_γ, which can be obtained from the ratio of current to measured-hit-rate, is smaller in the irradiated RPC.

The effect can be interpreted within a model introduced in Ref. [8] in which it is assumed that, under a high particle flux, the RPC working point is determined by an effective voltage $V_{\rm gas} = V - IR$ where V is the applied voltage, I the current drawn by the RPC and R the resistance of the resistive plates. Under these assumptions, quantities such as Q_γ are universal functions of the gas properties and of V_{gas}. Figure 1e shows that this assumption works reasonably well when the appropriate value for R is used: $R_{\rm irr} = 23.1\,{\rm M}\Omega$ and $R_{\rm ref} = 6.6\,{\rm M}\Omega$ respectively corresponding to equivalent bakelite resistivities $\rho_{\rm irr} = 1.4 \times 10^{11}\,\Omega{\rm cm}$ and $\rho_{\rm ref} = 4.1 \times 10^{10}\,\Omega{\rm cm}$. This model, therefore, suggests that the radiation caused a significant increase of resistance in the irradiated RPC.

An increase in resistivity would result in a limitation of the rate capability of the detectors. Figure 1f shows the efficiency of the two chambers, normalized to the value obtained with source off, as a function of the photon flux for three different high voltage values. No evidence of a different behavior between the two RPCs up to a flux of more than 1 kHz/cm^2 is observed, showing that these RPC can satisfy the LHCb requirements at least for 4 years running in the worst expected background conditions.

Summary and conclusions. A charge density of 0.42 C/cm^2 has been accumulated on a single gap, oiled, low-resistivity RPC. Dark currents and noise rates, measured with source off, clearly rose. The current measured with source on steadily decreased, possibly indicating an increase of the bakelite resistivity. The performances of the chamber are not affected at least up to 1 kHz/cm^2, still satisfying the LHCb requirements. The integrated charge corresponds to about 4 years of LHCb at the highest expected background rate.

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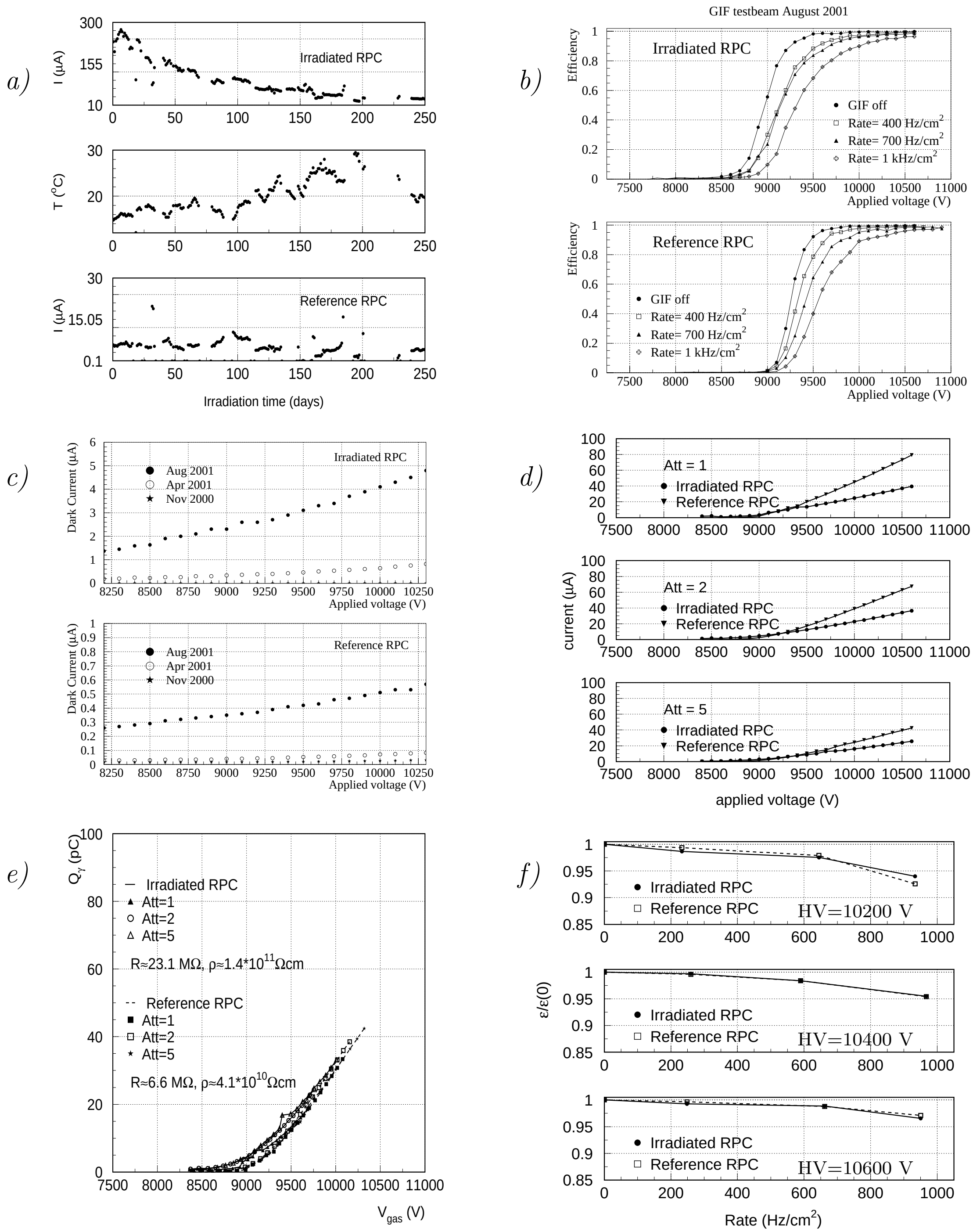

Figure 1. Panel *a)*: relevant quantities monitored during the aging test; *top*: current drawn by the irradiated RPC as a function of time; *middle*: temperature; *bottom*: current drawn by the reference chamber. Panel *b)*: chamber efficiencies measured at GIF at the end of the aging test under several photon fluxes. Panel *c)*: dark currents, measured before (Nov 2000), during (Apr 2001) and at the end (Aug 2001) of the aging test. Panel *d)*: RPC currents under source irradiation at different photon fluxes measured at the end of the aging test. Panel *e)*: average avalanche charge Q_γ as a function of V_{gas} measured at the end of the aging test under several photon fluxes. Panel *f)*: efficiency versus rate for the two RPCs at three different high voltage values; the efficiencies are normalized to those obtained with the source off.