First results from an aging test of a prototype RPC for the LHCb Muon System

A. Bizzeti[a], G. Carboni[b], G. Collazuol[a], S. De Capua[b], D. Domenici[b], G. Ganis[b], R. Messi[b], G. Passaleva[a,*], E. Santovetti[b], M. Veltri[a]

[a]University of Florence and INFN – Florence, Via G. Sansone 1, I–50019, Sesto F.no, Florence, Italy

[b]University of Rome "Tor Vergata" and INFN – Rome II, Via della Ricerca Scientifica 1, I–00133 Rome, Italy

Recent 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 of about 0.45 C/cm^2, corresponding to about 4 years of LHCb running at the highest background rate. The performance of the chamber has been studied, under several photon flux values, exploiting a muon beam. A degradation of the rate capability above 1 kHz/cm^2 is observed, which can be correlated to a sizeable increase of resistivity of the chamber plates. An increase of the chamber dark current is also observed. The chamber performance is found to fulfill the LHCb operation requirements.

1. Introduction

Resistive Plate Chamber (RPC) detectors have been adopted by the LHCb Collaboration to cover a large fraction (about 48%) of the Muon System [1,2]. The LHCb experiment [3] covers the forward part of the solid angle and is therefore subject to a very large particle flux. In particular, the particle rates expected in the Muon System are significantly larger than those expected by the ATLAS [4] and CMS [5] experiments. In the regions covered by RPCs, the maximum particle rate is expected to vary between 0.25 and 0.75 kHz/cm^2, depending mainly on the polar angle. These large rates are potentially dangerous from the point of view of RPC aging, which must be carefully studied and evaluated.

The main aging effect for RPCs is produced by the current flowing through the resistive plates. It has been demonstrated, 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 [6]. The most important parameter to evaluate the aging effects is given therefore by the total charge flow across the detector during its lifetime. Assuming an average avalanche charge of 30 pC [6], the total charge integrated by the LHCb RPCs over 10 years of operation ranges from 0.35 C/cm^2 in the regions of the Muon System, where the particle flux is smaller, to about 1.1 C/cm^2 in the high rate regions.

Aging tests performed by the RPC groups of ATLAS and CMS have shown that their detectors can withstand the radiation doses expected in those experiments. However, these tests are based on an integrated charge of at most 0.3 C/cm^2 [7,8] which is four times smaller than the maximum expected in LHCb RPCs.

To cope with the LHCb requirements, an extensive aging research program was devised, which started in January 2001, and is expected to last, at a first stage, until December 2001. It exploits the large CERN Gamma Irradiation Facility (GIF) [9], where a ^{137}Cs gamma source of about 655 GBq is available.

2. Setup of the aging test

The aging test entails irradiating a single-gap RPC (*"irradiated RPC"*) at the GIF facility for

*corresponding author

about one year. The closest distance to the source available for the chamber is about 1 meter, where the photon flux is roughly 1.5 kHz/cm^2. Another chamber (*"reference RPC"*) is installed just outside the irradiation area. Both chambers share the same gas and high voltage lines so that they are operated under the same conditions. In this way it is possible to disentangle the effects due to variations in the environment parameters, such as temperature, pressure or gas quality, from those due to the irradiation.

RPCs are operated with a gas mixture consisting of 95% $C_2H_2F_4$, 4% iC_4H_{10}, 1% SF_6. To simulate the LHCb conditions and perform the test in a reasonable amount of time, we chose the applied voltage in such a way that an average avalanche produces about 50 pC charge. At the rate quoted above, this yields a current density of about 80 nA/cm^2. This gives an integrated charge of about 0.8 C/cm^2 in one year of irradiation, which corresponds to about 7 LHCb years under the worst background conditions.

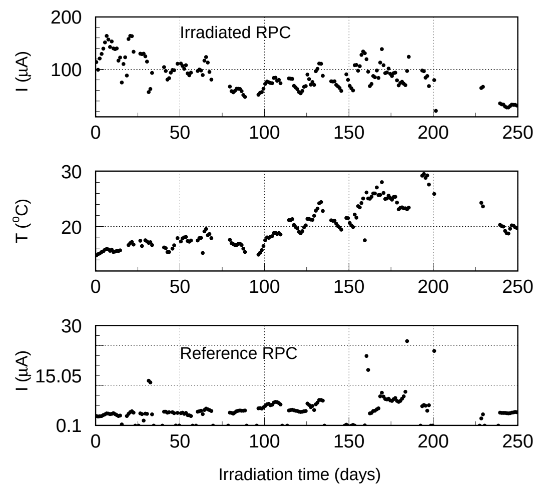

Figure 1. Current drawn by the irradiated RPC as a function of irradiation time (top), monitored temperature (middle), and current drawn by the reference chamber (bottom).

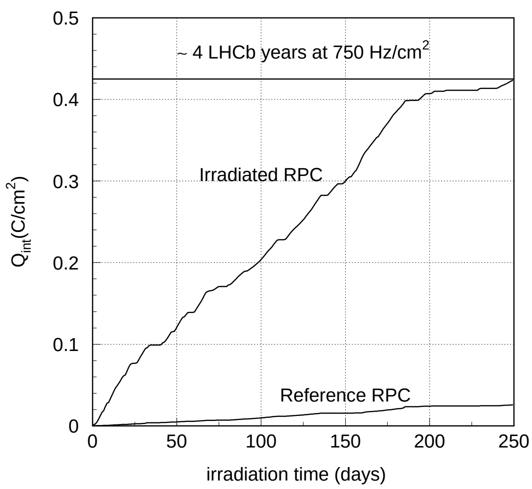

Figure 2. Integrated currents versus time from the beginning of the aging test.

The two RPCs prepared for the aging test have resistive plates made of phenolic bakelite with resistivity $\rho = 9 \cdot 10^9\ \Omega$ cm. The plates are oiled with linseed oil. The size of both chambers is 50x50 cm^2. The readout strips of the irradiated RPC are 3 cm wide and have been cut in half in the middle, so that the final strip area is $3{\times}25$ cm^2. The strips of the reference chamber, instead, are 3 cm wide and 50 cm long. The

All the relevant parameters of the test, i.e. temperature, pressure, high voltage and currents drawn by the chambers, are continuously monitored and recorded on a PC. In Fig. 1 the current drawn by the irradiated RPC is shown as a function of time (top plot) along with the temperature (middle plot). In the bottom plot the current drawn by the reference RPC is also shown. The latter is reasonably stable and constant over the whole aging test, showing that the chambers have been operated rather smoothly and no large systematic effects are expected to affect the performance of the two RPCs. In Fig. 2, the integrated charge as a function of time is shown. The irradiated RPC has accumulated about 0.45 C/cm^2 corresponding to about 4 LHCb years in the regions with the highest background rate and to more than 10 LHCb years in the low background regions.

To check the performance of the irradiated chamber at this intermediate aging stage, we performed a beam test using the muon beam available at the GIF. In the next sections the results of this test will be described.

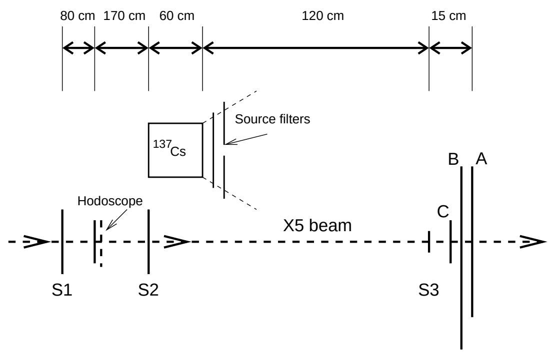

Figure 3. Setup of the test at the GIF. A=irradiated RPC; B=reference RPC; C=10×10 cm^2 RPC.

3. Beam test results

The irradiated and the reference RPCs have been carefully tested exploiting the muon beam available at the GIF. The test setup is sketched in Fig. 3. The combined use of the gamma source and the beam allows a test of the chamber performance parameters, such as efficiency, cluster size, and rate capability, under different photon fluxes ranging from zero (source off) up to a maximum of about 1 kHz/cm^2 in this set-up. The chambers were operated in the same conditions as in the aging test from the point of view of the gas and high voltage. The chamber efficiency was evaluated by tracking the beam particles with a scintillator hodoscope and with an additional small 10 × 10 cm^2 RPC. The photon fluxes were estimated from the chamber counting rates measured during dedicated off-spill beam gates. The measurements described in the next sections were obtained 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.

3.1. Analysis of currents

The current drawn by the irradiated chamber with the source on, was found to be about a factor of two smaller than that of the reference RPC as can be seen from Fig. 4.

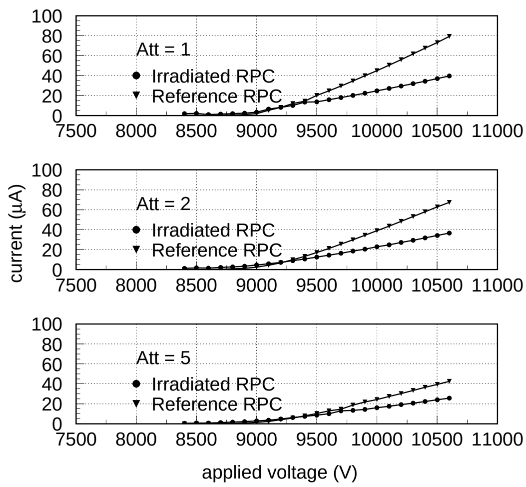

Figure 4. RPC currents versus the applied voltage at different photon fluxes.

This effect can be interpreted within a model introduced in [10]. In this simple model one assumes that under a high particle flux, the RPC working point is determined by an effective voltage $V_{gas} = V - IR$ where V is the applied voltage, I is the current drawn by the chamber and

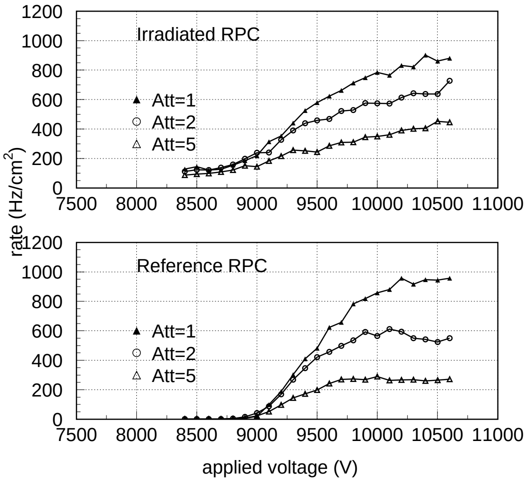

Figure 5. RPC counting rates as a function of the applied voltage.

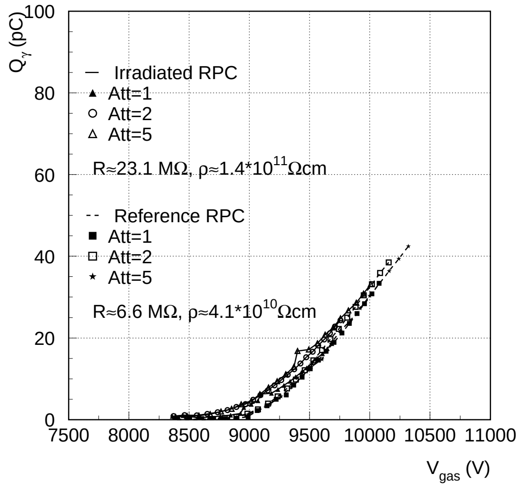

Figure 6. Distribution of Q_γ as a function of V_{gas} for the two RPCs at different photon fluxes.

R is the resistance of the resistive plates. In this framework, quantities such as the average avalanche charge Q_γ or the chamber efficiency ε are only functions of the gas properties and of V_{gas}. This means that once the correct value of the resistance R has been determined, the functions $\varepsilon(V_{gas})$ and $Q_\gamma(V_{gas})$ must be universal functions independent of the particle flux and of the plate characteristics. This method allows a non-destructive estimation of the plate resistivity that can be monitored on–line during the aging test.

Q_γ is measured by normalising the current drawn by the chambers to the rate of converted photons, which can be obtained from the chamber counting rate at the plateau, corrected for the efficiency. The measured counting rates are plotted in Fig. 5.

The distributions of Q_γ for the two RPCs are plotted at different photon fluxes as a function of V_{gas} in Fig. 6; they are fairly consistent with a single curve. The resulting values of the plate resistance, for the irradiated and the reference RPCs are $R_{\rm irr} = 23.1 {\rm M}\Omega$ and $R_{\rm ref} = 6.6 {\rm M}\Omega$, respectively, corresponding to equivalent bakelite resistivities $\rho_{\rm irr} = 1.4 \times 10^{11} \Omega$ cm and $\rho_{\rm ref} = 4.1 \times 10^{10}\ \Omega$ cm. Compared to the original resistivity value and to the reference chamber, a large increase in the plate resistivity can be observed for the irradiated RPC, which can be ascribed to the radiation effect and accounts for the current drop mentioned above.

The efficiencies of the two RPCs are plotted as a function of V_{gas} in Fig. 7. Again, the curves are consistent with a universal function $\varepsilon(V_{gas})$.

3.2. Efficiencies and rate capabilities

Because of the stringent requirements imposed by the LHCb muon trigger [1], the RPCs are required to have an efficiency above 95% up to the maximum expected background rate. In order to test the ability of the irradiated RPC to work within the LHCb operational parameters, we carefully tested the rate capability of the two RPCs. In Fig. 8 the RPC efficiency is shown as a function of the photon flux for three different high voltage values. The efficiency values are normalised to those obtained with the source off. At

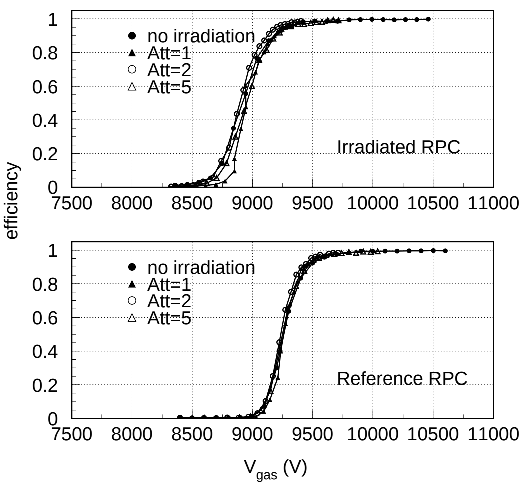

Figure 7. Efficiencies versus V_{gas} at different photon fluxes.

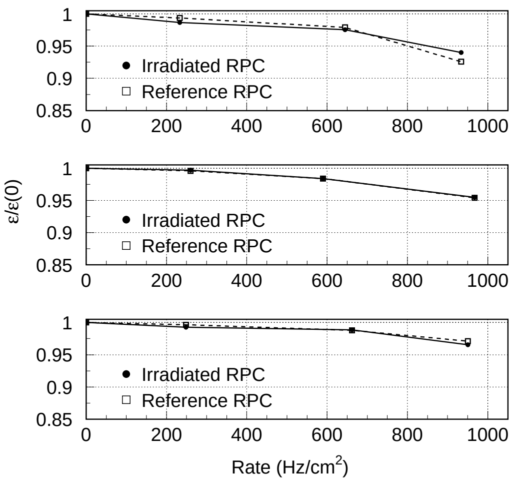

Figure 8. Efficiency versus rate for the two RPCs at three different high voltage values. The efficiencies are normalised to those obtained with the source off.

the nominal applied voltage of 10.2 kV, the efficiency exceeds 95% for both chambers up to a photon flux of about 0.8 kHz/cm^2. However, as soon as the high voltage is raised by a few hundred volts, the RPCs recover their full efficiency up to a flux of more than 1 kHz/cm^2. Moreover, there is no evidence of a different behaviour between the irradiated and the reference RPC. From this test it is possible to conclude that the RPCs under test can be safely operated, from the point of view of aging, at least for 4 LHCb years in the worst expected background conditions.

3.3. Dark currents

In the design of RPCs for LHCb, the level of dark currents drawn by the chambers is of concern, especially from the point of view of aging. The contribution of the dark current to aging must be kept below the aging caused by the particle flux. Considering as acceptable an extra-aging of 25%, the dark current density must be kept below 3 nA/cm^2 over the experiment lifetime.

To check if these constraints are fulfilled, we studied the behaviour of the dark currents of the chambers under test. In Fig. 9 the dark currents drawn by the two RPCs as a function of the applied voltage, measured at different intermediate times during 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 to about 2 nA/cm^2. This behaviour is still under investigation and no interpretation can be worked out, yet. Anyhow, it is worth to stress that the dark current observed in the irradiated chamber is still below the maximum allowed value for the LHCb Muon System.

4. Summary and conclusions

The results of an aging test of an RPC prototype for the LHCb muon system have been described. The irradiated prototype was tested with a muon beam at the GIF after a charge of 0.45 C/cm^2 had been integrated, corresponding to about 4 years of LHCb at the highest expected background rate and to more than 10 LHCb years

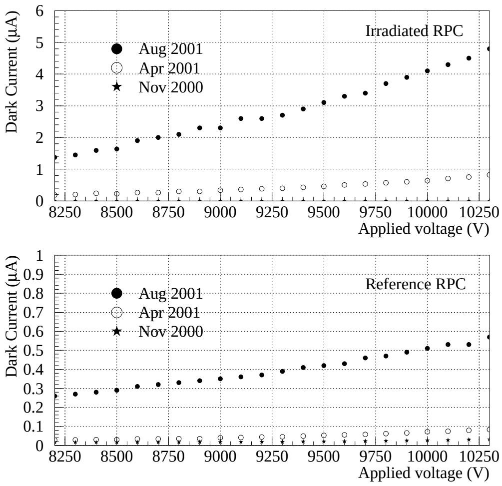

Figure 9. Dark currents, measured at different intermediate times of the aging test, versus the applied voltage.

in the lower rate regions of the Muon System. The performance of the irradiated RPC was compared to that of a reference chamber. As a result of the irradiation, a large increase of the resistivity of the chamber plates in the irradiated RPC was observed; a clear increase of the dark current was also observed. The irradiated RPC prototype is still well efficient up to the maximum rate expected in the LHCb Muon system, and the dark current level is under control.

REFERENCES

1. The LHCb Collaboration, LHCb Muon System Technical Design Report, CERN/LHCC 2001-010 (2001).
2. A. Bizzeti, et al., Design and Construction of the RPC Detector for the LHCb Muon system, Note LHCb 2001-027 (June 2001).
3. The LHCb Collaboration, LHCb Technical Proposal, CERN/LHCC 98-4 (1998).
4. The ATLAS Collaboration, ATLAS Muon Spectrometer Technical Design Report, CERN/LHCC 97-22 (1997).
5. The CMS Collaboration, CMS Muon Technical Design Report, CERN/LHCC 97-32 (1997).
6. M. Adinolfi, et al., Proposal for the RPC muon detector, LHCb Note 2000-053 (May 2000).
7. G. Aielli, et al., Further advances in aging studies for RPCs, these proceedings.
8. M. Abbrescia, et al., Aging study for Resistive Plate Chambers of the CMS Muon Trigger Detector, these proceedings.
9. S. Agosteo, et al., CERN-EP-2000-031 (2000), submitted to Nucl. Instr. and Meth. A.
10. G. Aielli, et al., Nucl. Instr. and Meth. A 456 (2000) 126.