First results of an aging test of a full scale MWPC prototype for the LHCb muon system

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Aging studies for a multi-wire proportional chamber of the LHCb muon system have been performed using the CERN Gamma Irradiation Facility. The irradiated four-gap chamber corresponds to a full size prototype with 1500 cm^2 sensitive area and has been operated with an $Ar/CO_2/CF_4$ (40:50:10) gas mixture. A linear charge of ~ 0.25 C/cm for 100 m wire length has been accumulated over a period of 6 months, which corresponds to the charge collected in 5 LHCb years. The aging influences observed do not prohibit the use of these chambers in the LHCb experiment.

1. Introduction

Multi-wire Proportional Chambers (MWPCs) with anode and cathode pad readout are a substantial part of the LHCb muon detector [1]. The maximal hit rate expected for these chambers is about 37 kHz/cm^2, which includes a safety factor of 5 on the estimated particle flux. The accumulated charge density for 10 years of LHCb operation under these conditions would be 0.5 C/cm on the anode wires and 1.7 C/cm^2 on the cathodes, operating the chamber at its working point.

A prototype chamber has been exposed in the CERN Gamma Irradiation Facility (GIF) to the very intense Cs 137 source (675 GBq in February 2001). The estimated photon count rate was about 30 kHz/cm^2 at the nearest distance to the source, comparable to the maximal hit rate expected under worst conditions. In order to obtain irradiation results in a reasonable time, the chamber has been operated above its working point. The irradiation results presented here are based on the analysis of the chamber behaviour after accumulating charge densities of up to 0.255 C/cm on the anode wires and 0.83 C/cm^2 on the cathodes. This corresponds to about 5 years of operation in LHCb at the position of the largest flux.

The detector lifetime due to aging depends critically on the nature and purity of the gas mixture, on materials used in the chamber construction and in the gas system, on the material of the electrodes and on the electric field strength at their surface. For the aging test discussed here attention was payed to the choice of the electrode materials and the various aspects of the gas system. However, it should be noted that mistakes were made in the choice of some other materials used in the chamber construction, which explain some of the results and require future improvements. The chamber specifications are discussed in some detail in the following section before the aging parameters and the test results are discussed.

2. Chamber specifications and operational conditions

2.1. Chamber description

The irradiated MWPC is a full size prototype with four sensitive gaps [2]. The basic parameters of the chamber are summarised in Table 1. The chamber is assembled from five panels, as shown in Figure 1. The inner panels are made of two 0.8 mm copper-cladded and gold-plated fire-retardant fibreglass epoxy foils (FR-4) glued on a honeycomb sheet. For the outer panels 3.2 mm thick copper-cladded and gold-plated FR-4 sheets have been used, which are much less stiff than the honeycomb panels and therefore will not be used for the final production (see also Section 2.4). The cathode-pad structure consists of 40 pads of

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Table 1
Main MWPC parameters

Parameter	Design value
Gas Gap	5 mm
Wire spacing	1.5 mm
Wire diameter	30 μm
Guard wire diameter	100 μm
Operating voltage	$\sim$ 3.1 kV
Wire surface field	260 kV/cm
Cathode surface field	8 kV/cm
No. of gaps	4
Gas mixture	Ar / CO_2 / CF_4 (40:50:10)
Gas flow rate	2.75 l/hour
Chamber volume	3 l
Sensitive area	1500 cm^2
Charge / 5 mm track	$\simeq$ 0.8 pC

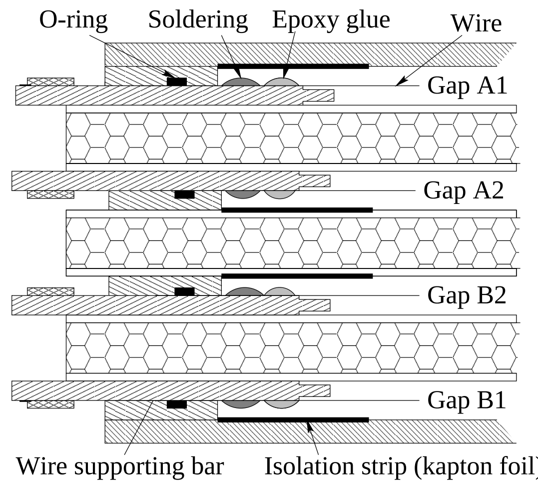

Figure 1. Cross-section of the irradiated MWPC.

22.5 cm^2 or 45 cm^2 area. The pads are combined in five groups to measure the pad to ground resistance. Gold-plated tungsten wires from Luma were glued (with Adekit A 145/50) and soldered (with a low temperature solder) to the wire fixation bars. The wires are grouped in pads of four or eight. The gap-size of 5 mm is defined by bars of FR-4 and Stesalit glued along the panel perimeter. The gas volume is closed with O-rings of natural rubber. As the material for the O-ring is of rather low resistivity ($10^4\Omega$/cm) and the origin of some deposits observed, it will not be used in the final production.

2.2. Gas system

An open loop gas system has been used for the aging test. The gas pipes were made of stainless steel (supply) and copper (exhaust). The gas flow-rate and gas-mixture composition has been fixed with electronic mass-flow controllers. The gas purity was Ar-46(0.99996), CO_2-40, CF_4-45. The leak rate was about 7 cm^3/min or $\sim 2\times10^{-3}$ chamber volumes. The admixture of O_2 is $\sim$400 ppm. The gaps are connected in series and the gas flows from gap B1 $\rightarrow$ B2 $\rightarrow$ A2 $\rightarrow$ A1.

2.3. Operational conditions

In the long running time the current fluctuations due to changes in ambient conditions (pressure, temperature and humidity) can mask the real effects of the aging process. This influence can be minimised if the currents of the tested gaps are measured together with the current of a reference gap, which is only for short times per day (10-20 minutes) under high voltage. In this aging test gap B1 has been used as the reference gap.

2.4. Gas-gain uniformity

The gas-gain uniformity was investigated with an Americium source and the GIF before irradiation. The data obtained with the source are summarised in Table 2, where the average values of the currents together with ranges of the current variations across the chamber are given. One can clearly see that the inner gaps A2 and B2 are much more uniform than the outer. This is a consequence of the less stiff panels used for the outer gaps.

The ratio of currents between each gap and gap B2, obtained with the GIF source and the Am-source before irradiation, are summarised in Ta-

Table 2
Currents per gap measured with an Am-source before irradiation; the average values per gap and the range of current variation for the measurements at 24 positions across the chamber are listed.

Gap	A1	A2	B2	B1
Current (nA)	28	28	27	35
Range (nA)	19	8	2.5	21

Table 3
Ratios between the currents in each gap and gap B2 before irradiation.

Rel. currents	A1/B2	A2/B2	B1/B2
GIF	0.58	1.01	0.85
Am-source	0.7	1.06	0.9

ble 3. The relative gain values (corresponding to the ratio of currents) of the gaps A2 and B2 are very similar. Due to the much less stiff outer panels and the slight gas overpressure in the system the relative gain of the outer gaps A1 and B1 is smaller than those of gaps A2 and B2. Only a 50 μm increase in gap size is required to decrease the gain by about 10%. This value also indicates the level of precision of the gain measurements with the GIF source.

3. Aging parameters

The effects of aging include a permanent and continuous degradation of operating characteristics of a detector under irradiation [3]. In case of MWPCs it includes:

- Proportional gain decrease due to a direct deposition on the anode wires;
- Appearance of Malter currents [4] due to deposits on the cathodes which can induce discharges by secondary electron emission;
- Etching of the surfaces of the chamber materials.

The decrease of the gain and Malter effects are of particular importance for MWPCs. These effects have been studied by measuring the variations of gain and dark currents while the chamber was exposed to high radiation fluxes.

The currents in the gaps were in the range of 150-250 μA under full irradiation by the source. The Am-source was also used to measure the local gain variations through the source-induced current.

The Malter (discharge) current appears as a self-sustaining current provoked by irradiation. The value of this current is often comparable with the beam current. It is usually suppressed when the voltage drops. The main reason for the appearance of this current is a deposit of high resistivity on the cathodes preventing the positive charges from neutralising. All the cathode surfaces of our chamber were gold-plated to minimise the depositing process. The gold-plated cathodes will be used for all the chambers situated in the highest irradiation positions. Aging effects on the cathodes were controlled by regular measurements of the dark currents with the 1 nA resolution current monitors. The ground to cathode-pad resistance is also a characteristic of the cathode quality.

4. Irradiation results

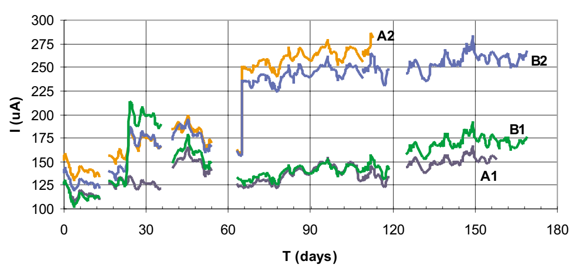

Figure 2. Currents drawn in each of the four gaps as a function of time. The breaks in the data indicate periods where the aging test was interrupted.

The irradiation in GIF started on the 7th of February 2001. Initially the voltages were adjusted so that the currents in each gap were about 100 μA. The voltages of gaps A1 and B1 were not changed during the test and stayed at 3.15 kV. The voltages for gaps A2 and B2 were increased after 2 months from 3.0 to 3.2 kV. Figure 2 shows that the final currents were in the range of 120-160 μA in gap A1 and 240-280 μA in gaps A2 and B2 (depending on the temperature and pressure). The linear current density was smaller than 0.03 μA/cm. Several times per day the source was turned off to measure the dark currents.

The test was concluded on the 27th of July 2001 after collecting a maximal charge equivalent to five LHCb years in gap B2. The reasons for interrupting the test were a broken wire in gap A2 close to the wire fixation bar on the 4th of June and a high voltage instability of the gap A1 on the 16th of July.

The chamber was opened to replace the broken wire and to investigate the current instability in gap A1. As the wire tension of only 60 g is far from the elasticity limit (140 g), the wire breakage is probably a random event.

No firm conclusion about the current instability in the A1 gap can be drawn. However, the HV instability is related to the irradiation under large HV. Without irradiation this gap has the same HV behaviour as the other gaps. In addition, some carbon deposits appeared on the wire fixation bars at the position of the O-ring after irradiation under HV, which seem to be related to the rather low resistive material for the O-ring and might have contributed to the observed instability.

4.1. Integrated charge

The final charges collected in the different gaps are shown in Table 4. The linear charge collection versus time is plotted in Fig. 3. During the aging test the average duty factor of GIF was about 70%.

The relative current dependence on time is shown in Fig. 4. The gaps indicate periods where some intervention in the GIF area or on the chamber took place. In general the fluctuations of the relative currents go in the same direction for the three irradiated gaps at all times, indicating that they are rather related to the behaviour of the reference gap B1 and not to aging effects in the irradiated gaps.

The final measurement results with the source are given in Table 5. No deterioration of the B2/B1 and A2/B1 ratios is observed within the relative precision of the measurement, which is about 5%. The decrease of about 18% in the A1/B1 ratio is difficult to interpret, since A1 is an outer gap which might have undergone gain variations due to insufficient stability in gap size.

Table 4
Total charge collected in each gap

Gap	A1	A2	B2
Total charge (C)	1470	1700	2540
Linear density (C/cm)	0.15	0.17	0.255
Cathode density(C/cm^2)	0.49	0.57	0.83
Equivalent LHCb years	3	3.4	5.1

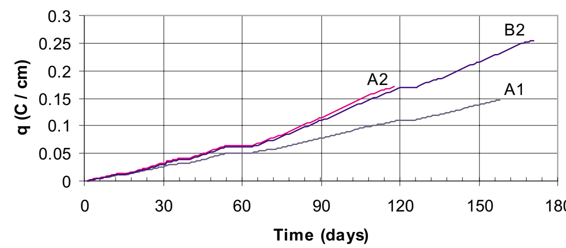

Figure 3. Linear charge accumulation versus time for the full aging test.

Table 5
Ratio of average amplitudes of source currents with standard deviations.

Date	04/02/01	10/04/01	20/08/01
A1/B1	0.79±0.04	0.72±0.03	0.65±0.04
A2/B1	0.80±0.03	0.82±0.03	0.80±0.03
B2/B1	0.76±0.03	0.76±0.03	0.77±0.02

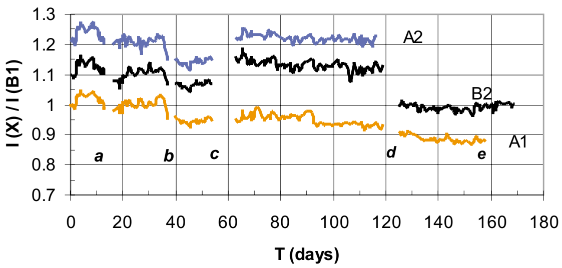

Figure 4. Relative current of gaps A1, A2 and B2 to B1 as a function of irradiation time, measured at the initial HV applied to each gap (3.0 kV for A2 and B2 and 3.15 kV for A1 and B1).

Table 6
Dark currents or each gap

Gap	A1	A2	B2	B1
Initial current (nA)	1.3	1.2	1.6	1.2
Final current(nA)	3	9	3	3

4.2. Dark currents

The dark currents before and after irradiation are given in Table 6 for each gap. The minor increase of the dark currents due to irradiation is insignificant in terms of the chamber performance. Malter currents were not observed for the irradiated gaps. Small discharge currents at the level 1 μA were sometimes observed when the GIF source was switched off, however only with a probability of less than 8%. These currents did not show any tendency to increase in magnitude or probability of appearance. They are the result of the cathode surface impurities that were not removed by cleaning at the time of chamber construction.

The pad to ground resistances were more than 200 GΩ when the aging test started and decreased by factor 10-100 within the first weeks of the test (corresponding to about 0.7 LHCb years). They remained stable afterwards at a level well above 1 MΩ.

4.3. Deposits and etching

The cathodes show some minor deposits after the irradiation. The deposits are often correlated with the wiring structure. Typically this deposit starts at a distance larger than 10 mm from the gap border. There are also two brownish spots located near the gap border on the wired planes. One spot is located in the A2 gap close to the broken wire, the other in the A1 gap where the HV instability occurred (Fig. 5).

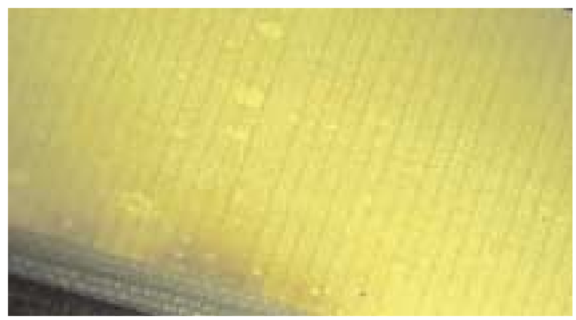

Figure 5. The photo shows the position of the broken wire and some dark spots underneath, indicating some sparking at that position.

The wire planes do not show any strong aging effect. Two small groups of wires (~100 wires or 8% of the total amount) located over the two brownish cathode spots mentioned above have small black dots. However, the total area of this covering is less than 10^{-3}, hence will have negligible influence on the chamber.

Some chemical activity of the gas in the irradiated gaps appears as etching on the surface of the FR-4 bars exposed to the gas. This effect is absent in the reference gap B1. It has not been observed before and needs additional investigation. Others have reported [5] about anode and cathode etching effects due to the fluorine in the gas mixture, which have been moderated by adding a few hundred ppm of water vapour to the gas

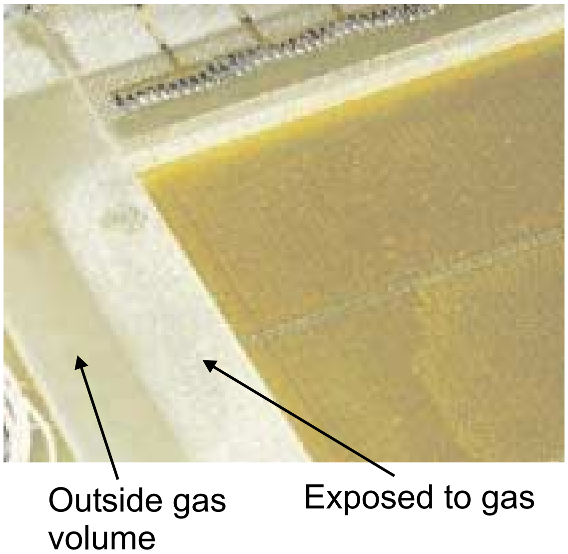

Figure 6. The FR-4 bars show clearly some change in surface colour due to etching

mixture. Similar solutions should be tried for our chambers.

5. Summary and conclusions

The analysis of the data after a radiation dose corresponding to about 5 years of LHCb operation in the region of highest irradiation did not show any deterioration in performance which would prohibit the use of these chambers in the LHCb experiment.

The gold-plated cathodes provide a good protection of the cathode surfaces against aging. The gaps do not show any Malter-current.

Some materials used for the chamber construction such as the 3.2 mm FR-4 sheets used for the outer panels will have to be changed in order to improve the chamber behaviour.

Further optimisation of the gas mixture in order to improve the chamber stability under HV and irradiation are indicated, without changing the main operational parameters of the chamber.

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