Precise gain measurement of the LHCb muon chambers

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The muon detector of the LHCb experiment, which will operate at the Large Hadron Collider (LHC) at CERN, consists of five muon tracking stations placed along the beam axis and equipped mainly with multi-wire proportional chambers (MWPC). In the present paper we report the results of a precise measurement of the gain of the MWPC's as a function of the anode voltage. A precise evaluation of the primary ionization current (of about 5 pA) was performed. The absolute gain of the chambers was deduced as a function of the anode voltage and compared with the prediction of the Diethorn formula.

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1. Introduction

The muon detector of the LHCb experiment [1] that will operate at the Large Hadron Collider (LHC) at CERN, consists of five muon tracking stations (M1-M5) placed along the beam axis and equipped with 1368 MWPC's. These are two-gap chambers in station M1 and four-gap chambers in stations M2-M5. In all chambers the anode wire planes are centered in a 5 mm gas gap and consist of 30 μm diameter gold-plated tungsten wires [2] with a 2 mm spacing. An Ar/CO_2/CF_4 (40/55/5 %) mixture is used. In the present paper we report a systematic study of the gain of a four-gap chamber belonging to the station M3. The results are valid for all the chambers of the muon detector.

2. Experimental setup

The set-up for measuring the gain of the chamber consists of a steady table of about 160 × 40 cm^2, on which the chamber to be tested is placed and of a 1.3 GBq ^{137}Cs source, screened by a lead case (Fig.1), which can be moved by an automated mechanical system over the whole surface of the table. The chamber is flushed with the above mentioned gas mixture, at a rate of about 50 cm^3/min. The source is collimated and emits photons downwards. When the source is positionned on the chamber the area of the chamber illuminated by the source is circular and has a diameter of about 10 cm. A 5 cm thick lead layer is placed under the chamber for radioprotection. The thickness of the chamber plates and the albedo from the lead layer are so that the ionization in the 4 gaps are equal within few percent. The current (i) drawn by the chamber is read by a Keithley 6485 [3] picoammeter connected to the pad-cathode of the four gaps, the other cathodes being grounded.

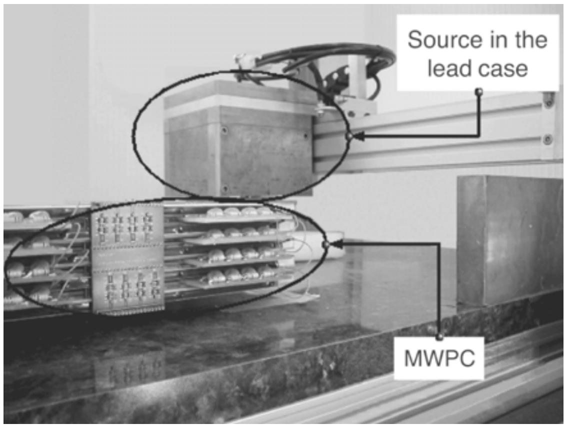

Figure 1. Picture of a fourgap chamber during a measurement. The chamber and the lead case containing the radioactive source are indicated.

The chamber current (i) measured with the source on the chamber (“ON” position) fluctuates

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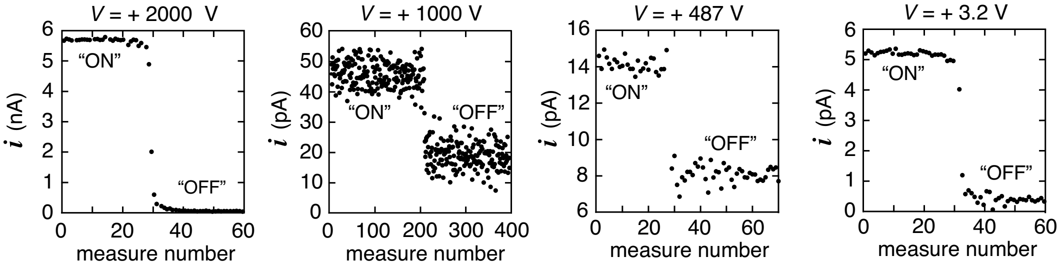

Figure 2. Typical result of a series of current measurements. The four figures refer to different values of the wire voltage V. In each figure the first half of the points are taken with the source in the "ON" position. the source is moved its "OFF" position and the second half of the points are obtained.

because of some eddy currents. Therefore for each value of the anode voltage V, this current is measured several tens of times in the "ON" position. Then the source is moved from the chamber to a lead photon dump ("OFF" position) and the current measurements are repeated. As an example we report in Fig. 2, for four different wire voltage V, a series of measurements of the current i in the "ON" and "OFF" source position. The difference beetween the average current measured with the source in the "ON" and in the "OFF" positions represents the chamber current $I(V)$ due to the radioactive source. For $V \geq 500$ V the power supply was a CAEN [4] model SY2527 mounted on a rack and connected to the chamber through a ~ 5 m long high voltage cable. With this experimental setup the fluctuations on the measured current increase in percentage as the voltage V is decreased (first two charts in Fig. 2) and becomes comparable with the current itself at $V \simeq 500$ V. At voltage $V < 500$ V the fluctuations on the measured current were strongly reduced by replacing the power supply with a variable number of 9 V and 1.5 V standard alkaline batteries connected in series and placed close to the chamber (last two charts in Fig. 2).

3. Experimental results

With this experimental setup the current due to primary ionization could be easily measured even at low voltage (Fig. 3). As a check, the chamber current was also measured with a reversed polarity of the wires. In that case the electrons of the primary ionization are collected by the cathodes so that no multiplication occurs in the chamber and the current is independent of the voltage V, as shown in Fig. 3. From these measurements we deduce that the current due to primary ionization is $I^* \simeq 4.76 \pm 0.20$ pA.

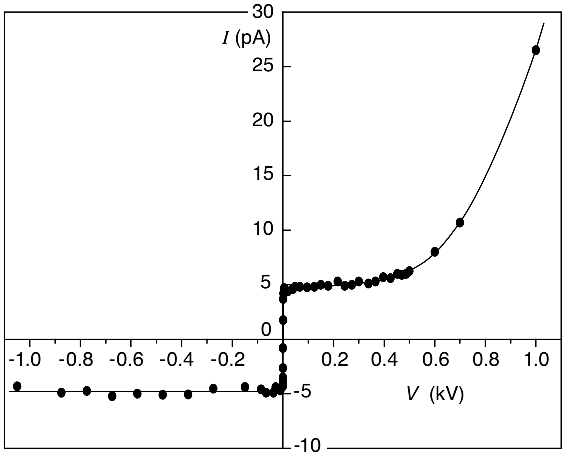

Figure 3. Current measured for positive and negative anode voltage. For negative voltage and for low positive voltage only the primary ionization is collected, while at larger positive voltage the charge multiplication is observed.

The gain $G(V)$ of the MWPC at a given wire voltage (V) is therefore given by $G(V) = I(V)/I^*$. In Fig. 4 the chamber gain is reported as a function of the voltage V.

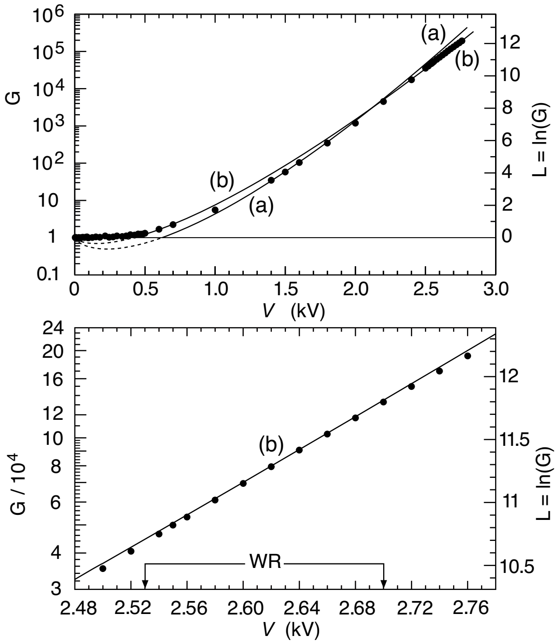

Figure 4. Chamber gain as a function of the anode voltage V. Lines (a) and (b) are the predictions of the Diethorn formula for two different sets of the parameters E_{min} and ΔV (see text). An expanded view of the high-voltage region is shown in the lower chart. The working region (WR) [5] of the chamber ($V = 2615 \pm 85$ V) is shown.

4. Comparison of the experimental results with the Diethorn formula

The dependence of the gain G on the voltage V is often described by the Diethorn formula [6] which assumes that the first Townsend coefficient is proportional to the electric field. According to that formula the function $G(V)$ is given by:

$$G(V,\rho) = \left(\frac{V}{A(\rho)}\right)^{\left(\frac{V}{B}\right)} \tag{1}$$

where:

$$A(\rho) = r_a \ln(r_c/r_a)\, E_{min}\, \frac{\rho}{\rho_0} \tag{2}$$

$$B = \frac{\ln(r_c/r_a)\,\Delta V}{\ln 2} \tag{3}$$

and where r_a is the radius of the anode wires, r_c is the "equivalent cathode radius" [7], E_{min} is the minimium electric field needed to start the avalanche at the normal gas density ρ_0 and where ΔV (multiplied by the electron charge) is the average energy required to produce one more electron in the avalanche [8]. For all the LHCb muon chambers, $r_a = 15$ μm and $r_c = 16.2$ mm. The gas gain is expected to be function of the gas density [9, 10]. At normal gas density ($\rho = \rho_0$) the two parameters E_{min} and ΔV fully determine the function $L(V)$ and its derivative $D(V)$:

$$L(V) \equiv \ln[G(V,\rho_0)] = \frac{V}{B}\ln\bigl(\frac{V}{A(\rho_0)}\bigr) \tag{4}$$

$$D(V) \equiv \frac{\mathrm{d}L}{\mathrm{d}V} = \frac{1}{B}\bigl(1 + \frac{BL(V)}{V}\bigr) \tag{5}$$

From equations (2)–(5) we obtain:

$$E_{min} = \frac{V\exp[L(V)/(L(V) - VD(V))]}{r_a\ln(r_c/r_a)} \tag{6}$$

$$\Delta V = \frac{V\ln 2}{(VD(V) - L(V))\ln(r_c/r_a)} \tag{7}$$

The two quantities E_{min} and ΔV are proper to the gas, so the expressions (6) and (7) should be independent of V in the voltage interval where the Diethorn formula is valid. To determine E_{min} and ΔV from equations (6) and (7) we use the 26 points (Fig. 4) at $V_i \geq 500$ V ($i = 1, 26$). At a voltage below ≈ 500 V the Diethorn formula gives a gain ≤ 1 and is therefore out of its range of validity.

While $L(V_i)$ are obtained directly from the data, $D(V_i)$ have been calculated as the derivative of a second order polynomial passing through the considered i-th point $L(V_i)$ and through the two neighbouring points $L(V_{i-1})$ and $L(V_{i+1})$. The result of these calculations, reported in Fig. 5, shows that in the interval $1.6 \leq V \leq 2.5$ kV E_{min} and ΔV are practically independent of V and given by $E_{min} \simeq 60 \pm 2$ kV/cm and $\Delta V \simeq 32 \pm 1$ V. Therefore the Diethorn formula is valid in the interval $1.6 \leq V \leq 2.5$ kV and the abovementioned values of E_{min} and ΔV are characteristic of the gas mixture used.

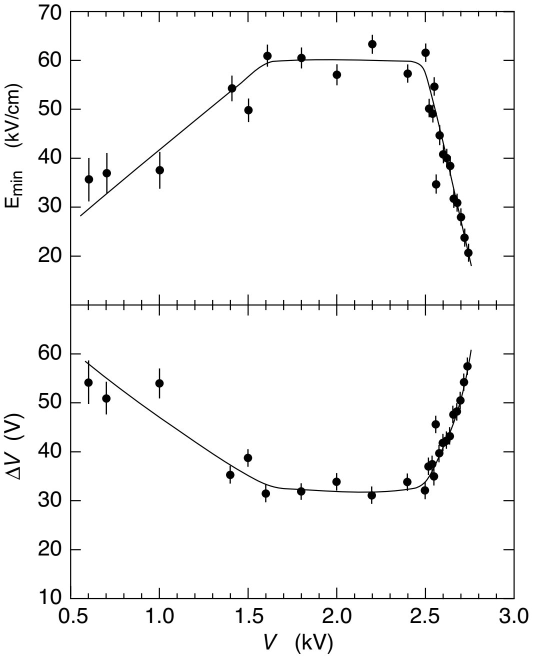

Figure 5. Calculated values of the two Diethorn parameters E_{min} and ΔV, as a function of anode voltage V. The curves are drawn to guide the eye.

In Fig. 4 (curve a) we show the function $G(V)$ calculated according to equation (1), assuming $E_{min} = 60$ kV/cm and $\Delta V = 32$ V. As expected this curve fits quite well to the experimental points in the region $1.6 \leq V \leq 2.5$ kV.

At voltage outside the interval $1.6 \leq V \leq 2.5$ kV the Diethorn formula con still be used to fit the experimental values of G(V). But in that case E_{min} and ΔV are only two parameters of the fit without any relation with the gas characteristic. As an example we report in Fig. 4 (curve b) a fit to the experimemental points in the nominal working region of the chamber. In this fit the two parameters E_{min} and ΔV assumed the values of 40 kV/cm and 42 V respectively.

5. Conclusions

The gain of a typical muon chamber of the LHCb experiment has been measured with a high precision as a function of the anode voltage. The chamber was filled with a $CO_2/Ar/CF_4$ gas mixture, 55/40/5 % in volume. In the interval $1.6 \leq V \leq 2.5$ kV the Diethorn formula is found to be valid and fit quite well to the experimental gain values $G(V)$. The two parameters E_{min} and ΔV, which are proper to the gas mixture have been determined to be $E_{min} = 60 \pm 2$ kV/cm and $\Delta V = 32 \pm 1$ V.

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