Systems for the MWPC test at the LNF production site

M. Anelli, P. Campana, E. Dané, U. Denni, C. Forti, A. Frani, G. Martellotti,
G. Penso, D. Pinci, R. Rosellini, M. Santoni, A. Sarti and A. Sciubba

***Abstract*—**

THe performance needed for the Level-0 trigger of the experiment LHCb traslates in very stringent requirements on the quality of the detectors equipping the Muon System. In this paper, the test systems adopted at the "Laboratori Nazionali di Frascati" production site for the quality control of the Multi-Wire Proportional Chambers for the LHCb Muon System are described.

After wire winding and gluing the wire pitch is measured by means of digital cameras with a precision of about 20 μm. For the evaluation of the wire mechanical tension a system which find the wire resonance frequency by measuring the variations of the capacitance between the measured wire and a reference one was developed achieving a resolution of about 1 g. Once all elements of the chamber are assembled, the gas tightness of the detector is verified by monitoring the decrease of an overpressure applied. After a suitable chamber conditioning, the gas gain uniformity is measured by using a ^{137}Cs source. The detectors, fully-equipped with the front end electronics, are tested under cosmic rays to measure their efficiency and time resolution.

***Index Terms*— Multi-Wire Proportional Chamber, quality control, wire tension measurement.**

I. INTRODUCTION

The LHCb muon system ([1], [2]), presently under construction, will be composed of five detector stations (M1-M5) equipped with 1380 Multi-Wire Proportional Chambers. Each station is subdivided in four regions (R1-R4). The chamber typology depends on the station and on the region occupied. The total active area will be abut 435 m^2. The LHCb Level-0 trigger requires a fast measurement of the muon transverse momentum and a high capability of bunch-crossing identification. Then a high efficiency and a good spatial resolution are required to the detector. The LHCb MWPCs were designed in order to fulfill these requirements. In stations M2, M3, M4 and M5 (placed downstream the calorimeter) the chambers will be composed of four 5 mm gaps coupled in two pairs. In a pair (double-gap) the signal from corresponding pads (wire or cathode) are added together via a simple wire-OR and sent to front-end electronics. A further logical OR between the two double-gap signals is performed by the electronics (Fig.1). A 30 μm diameter gold-plated tungsten wire is used with a pitch of 2 mm.

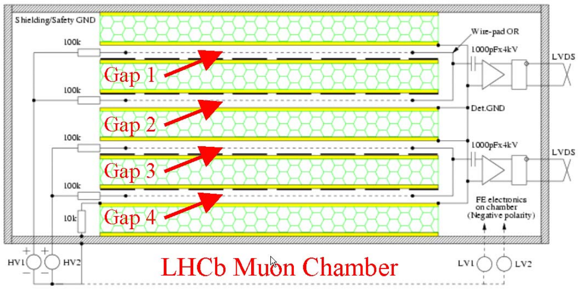

Fig. 1. Side-view of a four-gap LHCb multi-wire proportional chamber.

The station M1 will be placed upstream the calorimeter. In order to limit the material amount, the MWPC of M1 will be made by two single-gaps OR-ed by the electronics.

The use of a high yielding and fast gas mixture (Ar/CO$_2$/CF$_4$ (40/40/20)) allows to achieve very good time performance in proportional operation mode. The chamber will work with a gas gain of about 5 $\times$ 10 ^{4}. A time resolution of about 3.5 ns is obtained [3] as shown in Fig 2.

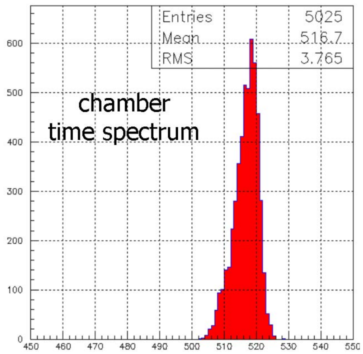

Fig. 2. Typical time spectrum of a four-gap chamber for a gais gain of about 5 $\times 10^4$.

II. CHAMBER REQUIREMENTS

The requirements that each double-gap must satisfy in order to provide the suitable performance for the whole chamber are

- efficiency in 20 ns higher than 95%;
- average pad-cluster size lower than 1.1;

M. Anelli, P. Campana, U. Denni, C. Forti, A. Frani, R. Rosellini, M. Santoni, A. Sarti and A. Sciubba are with the INFN-Laboratori Nazionali di Frascati, Italy.

E. Dané, G. Martellotti, D. Pinci (correspondig author, E-mail: davide.pinci@roma1.infn.it) and G. Penso are with Università "La Sapienza" and INFN sez. di Roma.

- ageing properties ensuring a good operation for 10 LHCb years (about 1 C/cm of wire in the hottest region).

These requirements define the limits of the allowed HV working region. During tests at CERN beams, a working region from 2.54 kV to 2.70 kV was found (Fig. 3).

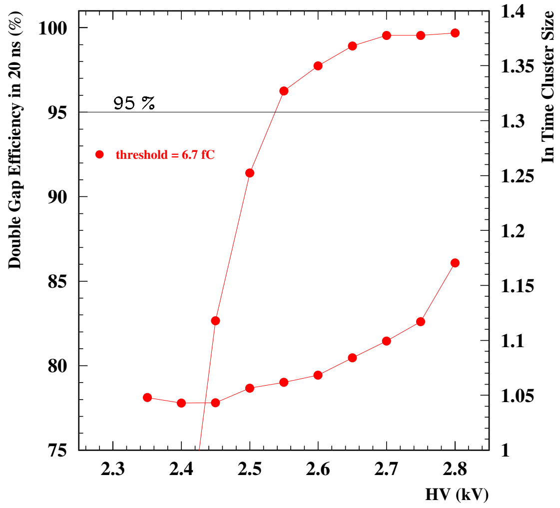

Fig. 3. Efficiency and pad-cluster size multiplicity of a double-gap MWPC as functions of the high voltage.

The ageing test performed at ENEA-Casacca proved that the ageing is not an issue for these voltage values [4] and the the upper limit of the working region is set by the limit of the pad-cluster size. The effective working region results 160 V wide and the chambers will work at the centre of this region. Since the gas gain G doubles each 105 V, the ± 80 V requirement is satisfied if the chamber gain is in the window:

$$\mathrm{G}_0/1.70 < \mathrm{G} < \mathrm{G}_0 \times 1.70.$$

where G_0 is the nominal gas gain at the centre of the plateau.

To evaluate the impact of this requirement on the mechanical precision (wire position and tension and gap size) needed during the production, a detailed numerical calculation of the electric field in the MWPC gaps was performed [5].

III. PITCH CONTROL

The requirement for the wire pitch (WP) is:

$$\text{WP = 2 mm} \pm 50\mu\text{m (95\% of wires)} \pm 100\mu\text{m (5\% of wires)}.$$

The wire position is precisely determined by the pitch of the wiring machine combs, however it is important to check that no wire is out of the acceptance. The WP measurement is performed with an automatic device based on two TV cameras scanning the panel and a software for image acquisition and analysis. An accuracy of 20 μm is obtained. The result of the pitch measurement for a whole "M3R3" panel (664 wires) is shown in Fig. 4. The range 2 mm ± 50 μm corresponds to the red lines drawn at 211 ± 6 pixels.

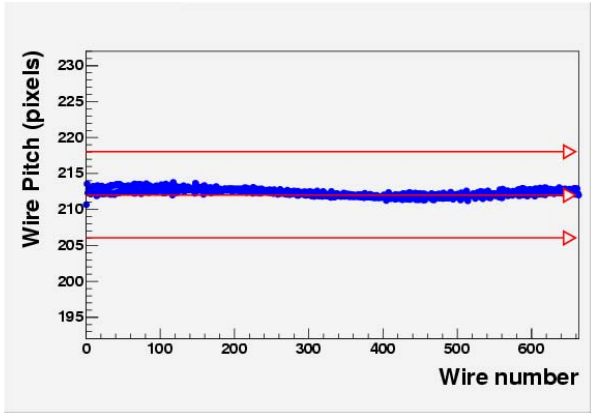

Fig. 4. WP measurement: the range 2 mm ± 50 μm corresponds to the red lines drawn at 211 ± 6 pixels.

IV. WIRE MECHANICAL TENSION METER

Since on the experiment the MWPC wire will be vertical, the gravitational sagitta is not an issue. The lower limit on the mechanical wire tension τ is given by the request of mechanical stability due to the wire electrostatic reciprocal repulsion (about 30 g). The upper limit is set by the elastic limit (about 120 g). A safe condition is then:

$$50g < \tau < 90g$$

The system developed [6] calculates the wire mechanical tension by measuring its mechanical resonance frequency ν_0 with the formula:

$$\tau = \lambda(2\mathrm{l}\nu_0)$$

where λ and l are respectively the mass per unit length, the length of the wire. To measure the resonance frequency ν_0, mechanical oscillations of the wire to be tested are induced by applying a periodic voltage of about 900 V with a frequency of 300 ÷ 400 Hz, between this wire and a non-oscillating sense wire placed parallel and close (about 1 mm) to it. The oscillations result in a variation of the capacitance C^* between the two wires:

$$C^*(t) = \frac{2\pi\epsilon_0 l}{\ln(d^2(t)/ab)}$$

where $d(t)$ is the time dependent effective distance between the two wire axes, a and b are their radii. In order to measure the variation of C^* , this capacitance is coupled to the LC circuit of a high-frequency (about 20MHz) oscillator which oscillates at a frequency f given by:

$$f = \frac{1}{2\sqrt{L(C^* + C)}}$$

When the wire is oscillating at a frequency ν, the capacitance C^* and therefore the frequency f vary periodically with time.

At a given frequency, two values of f are measured in different positions of the wire during its oscillation: f_a and f_b. By varying the HV frequency we search for the maximum value of $\Delta f = f_a - f_b$ that occurs for $\nu = \nu_0$. In Fig. 5 the resonance peak of a chamber wire is shown. A resolution of about 1 g was achieved.

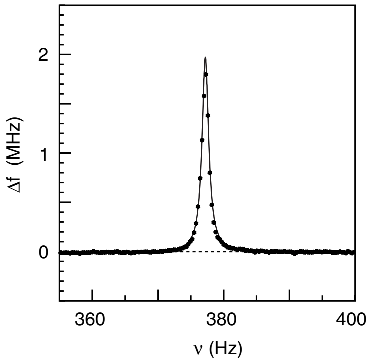

Fig. 5. Example of a wire resonance peak.

A whole panel (664 wire) can be measured in less than one hour (Fig. 6).

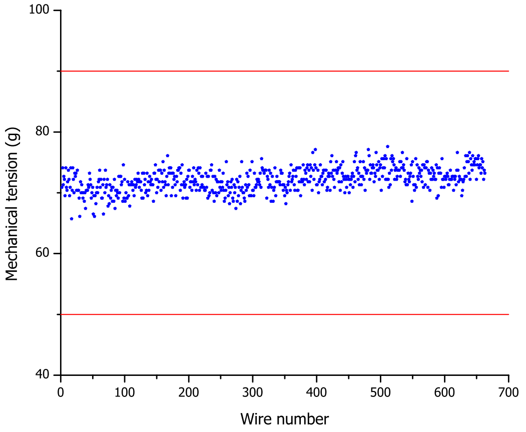

Fig. 6. Result of the wire tension measurement of a whole panel. The red lines indicate the allowed region.

V. TEST OF THE GAS TIGHTNESS

The maximum leakage rate allowed for each chamber of the Muon System is 2 mbar/hr. To verify the gas tightness, the chambers are inflated with nitrogen up to an overpressure ΔP of 5 mbar, with respect to the atmospheric pressure. Then, we record ΔP(t) as a function of time, during about one hour (Fig. 7 (Top)). The measurement is heavily affected by variations of the temperature. In order to correct this effect, the ΔP(t) of a gas-tight chamber, placed in the same isolated box, is used as a reference . The leakage rate is obtained by substracting the overpressures of the two cambers (Fig. 7 (Bottom)). An accuracy of 0.1 mbar/hr is obtained.

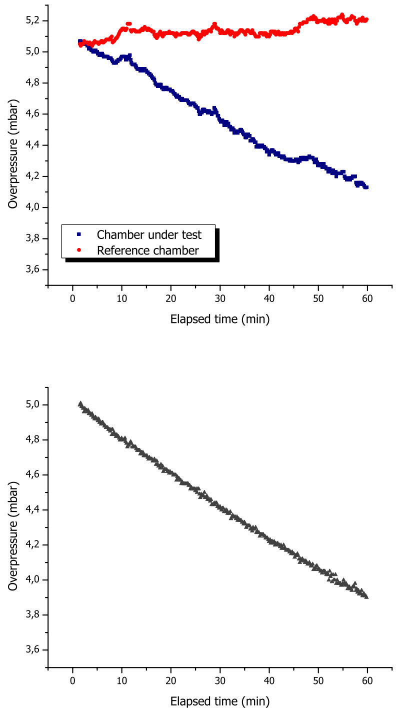

Fig. 7. Top: overpressure measurements for the chamber in test and for the reference one. Bottom: overpressure behavior of the chamber in test after correction is performed.

VI. MEASUREMENT OF THE GAS GAIN UNIFORMITY

Once the chamber has been properly conditioned the uniformity of the gas gain inside each gap is tested with a 40 mCi ^{137}Cs source. The layout of the test table is shown in Fig. 8.

The wires of the chamber are set at 2.75 kV and the current drawn by each gap is recorded while a lead case containing the source is moved by means of a mechanical arm on the whole chamber surface. For example, the chambers of the M3R3 region, which consist of four gaps with 2 rows of 48 pads on the segmented cathode, are scanned in 3×48 positions of the source. These measurements allow to check the gas gain uniformity within each gap and to compare the different chambers among them.

The requirement on the gain uniformity reported in Sect. II simply translates in a requirement on the current [7]:

$$I_0/1.70 < I < I_0 \times 1.70$$

where I_0 is the current drawn at the nominal gain G_0. In Fig. 9, it is shown that the source test allows to identify the presence of a bent panel between two adjacent gaps of a chamber.

However, the distribution of the total current of the two gaps is still uniform. Since each pair of adjacent gaps are OR-ed

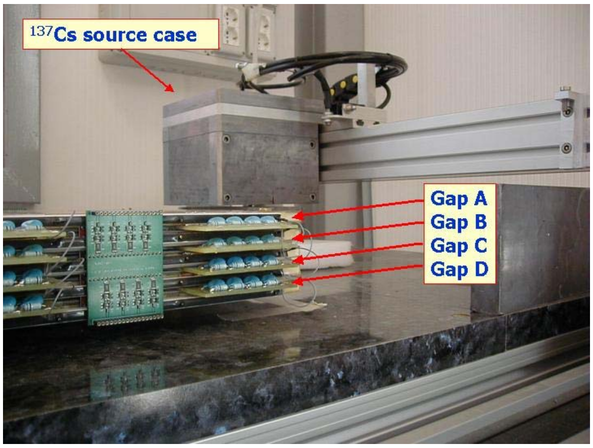

Fig. 8. Profile of a "M3R3" MWPC on the source test table

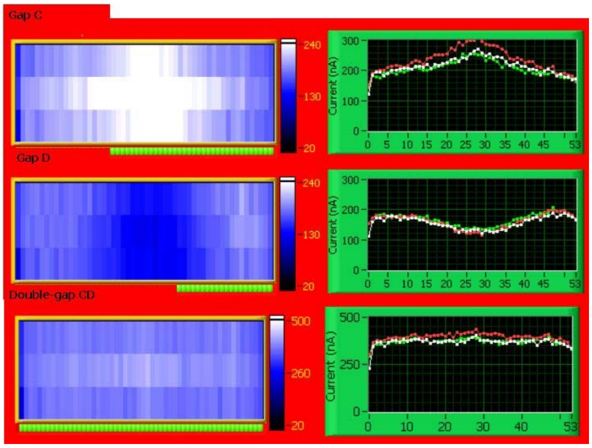

Fig. 9. Results of 137Cs source scan for a chamber with a bent panel inside

hardware before connection to the FEE, the basic detectors are double-gaps. A detailed study with cosmic rays, shown in Sect. VII, suggested to set the acceptance conditions on double-gap currents, at least in those regions where the aging is not a concern.

All the chambers built for the M3R3 region were tested. For each position of the source, the current was recorded in each of the four gaps A,B,C and D. The quality of the chamber was determined by the average and the spread of the currents in the double-gaps AB and CD, defined as the sums of the gap currents: $I_{AB} = I_A + I_B$ and $I_{CD} = I_C + I_D$. The requirement for both double-gaps of each chamber is:

$$I_0/1.70 < I_{\mathrm{AB\ or\ CD}}(i) < I_0 \times 1.70, \text{ for all i=1 ,..., 144.}$$

where I(i) is the current recorded when the source is in the i^{th} position. In Fig. 10 the distribution of all measurements in all double-gaps is shown. Only the two double-gaps of chamber 4 are above the 80 V limit.

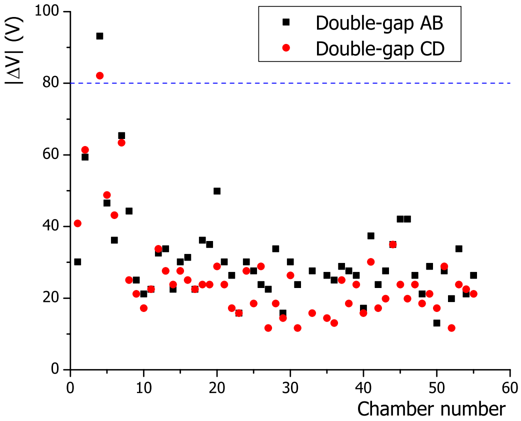

Fig. 10. $|\Delta V$— for each double-gap of each chamber, with respect to the average current in all double-gaps (I_0=470 nA).

VII. COSMIC RAY STAND

After the scan with the radioactive source, the performance of MWPC fully equipped with final front-end electronics are studied in details by means of cosmic rays. Chambers are placed on a stand designed to house up to 6 detectors where they are flushed in parallel with an Ar/CO_2/CF_4 (40/40/20) mixture and where it is possible to power them.

A trigger system was developed based on three large plastic scintillators, one above and two below the stand, read-out on both sides with six photomultipliers. The coincidence between the six discriminated signals gives the trigger signal and the reference time with a jitter of about 2.8 ns.

The chambers are equipped with the CARIOCA read-out electronics [8] for signal amplification, shaping and discrimination with logical LVDS outputs. After a custom LVDS-ECL traslator, the signals are acquired by VME TDCs.

A digital multiplexer, under costruction, will allow to acquire 600 channels simultaneously. With the current set-up, 192 channels (two MWPCs fully equipped) can be acquired.

The chamber with the bent panel (Sect. VI) was studied with the cosmic rays. In order to improve the time resolution of the trigger signal a 20 × 2 cm^2 scintillator finger with a resolution of about 1 ns was used to give the reference time. In the configuartion the chamber muon illumination is displayed in Fig. 11.

The results of a high-voltage scan are shown in Fig. 12. The total efficiency and the efficiency in 20 ns for the double-gaps AB and CD are similar for a voltage higher than 2.6 kV within the working region. For a voltage lower than 2.6 kV the low efficiency of gap D deteriorates the performance of the double-gap CD.

This test confirmed that the most important parameter to be checked, in order to assess the quality of a chamber, is the gain uniformity of the two double-gaps.

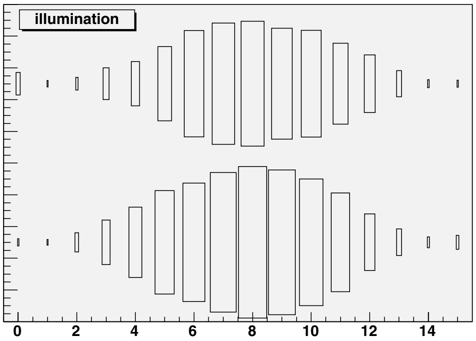

Fig. 11. Chamber muon illumination with a 20 × 2 cm^2 scintillator finger in the trigger.

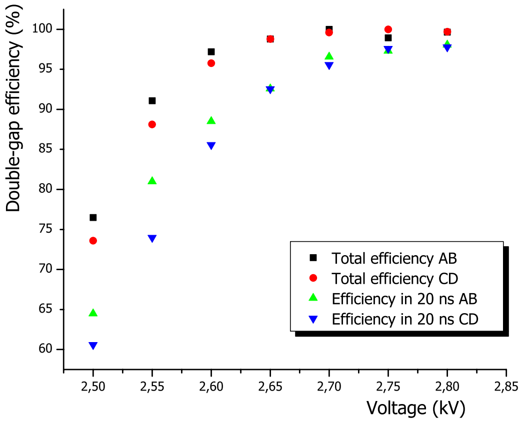

Fig. 12. Efficiency of two double-gaps AB and CD. For a voltage within the working region (higher than 2.6 kV) the behaviors of the two double-gaps are the same. The effect of the bent panel between gaps C and D is not visible.

VIII. CONCLUSION

The systems for the quality control of chambers at the LNF production site result to be very useful for the mass production. The measurements of the wire pitch and mechanical tension allow to check, with the needed accuracy, the quality of the wire winding before chamber assembling. The gas leakage can be measured with the sensitivity required. The study of the gas gain uniformity inside each gap is a fast feedback on the quality of the chamber, allowing to improve the assembly procedure. The eest with cosmic rays gives the possibility to study in details the efficiency and time performance of the chambers. In eight months of production, 58 chambers have been assembled and only one does not satisfy the requirements on gain uniformity.

REFERENCES

[1] LHCb Collaboration, “LHCb Muon System Technical Design Report”, CERN/LHCC 2001-010 (2001).

[2] LHCb Collaboration, “Addendum to the Muon System Technical Design Report”, CERN/LHCC 2003-002 (2003).

[3] M. Anelli *et al.*, “Test of MWPC prototypes for region 3 of station 3 of the LHCb Muon System”, LHCb 2004-074 (2004).

[4] M. Anelli *et al.*, “Ageing test of a prototype of quadrigap MWPC for the region 3 of the LHCb muon system”, LHCb 2003-040 (2003).

[5] W. Riegler, “Chamber requirements and specifications”, Talk at the Engineering Design Review, CERN, 16 April 2003. `http://agenda.cern.ch/fullAgenda.php?ida=a03841`.

[6] P. Ciambrone *et al.*, “Automated wire tension measurement system for LHCb muon chambers” in printing by Nucl. Instrum. Meth. A.

[7] C.Forti, ”Chamber quality control and acceptance criteria”, Talk at LHCb Week, Chia, 30 September 2004, `http://agenda.cern.ch/fullAgenda.php?ida=a044096`

[8] W. Bonivento *et al.*, “Development of the CARIOCA front-end chip for the LHCb muon detector,” Nucl. Instrum. Meth. A **491** (2002) 233.