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First results from the MRPC production for the ALICE TOF system

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Summary. — The double-stack Multigap Resistive Plate Chamber (MRPC) is the detector chosen for the large time-of-flight array of the ALICE experiment at CERN LHC. The system has to cover an area of 160 m^2 and will consist of 1638 of such a detector. In this paper the quality assurance tests for mass production of MRPCs are described, together with the results of the tests over a sample of 18 detectors performed at the PS facility at CERN.

PACS `29.40.Cs` – Gas-filled counters: ionization chambers, proportional, and avalanche counters.
PACS `07.77.-n` – Atomic, molecular, and charged particle sources and detectors.
PACS `52.80.Dy` – Low-field and Townsend discharges.

1. – Introduction

ALICE (A Large Ion Collider Experiment) [1] is the experiment at the CERN Large Hadron Collider (LHC) devoted to the study of the nuclear matter at extreme densities and temperatures. The experiment (see fig. 1 for the layout) is specifically designed for high-energy heavy-ion collisions; in the case of lead ions, the energy at the centre of mass will be ~ 5.5 TeV per nucleon pair.

One of the main problems addressed at the LHC is the connection between phase transition involving elementary quantum fields, fundamental symmetries of nature and the origin of mass. In this picture ALICE will study the role of chiral symmetry in the generation of hadrons mass; moreover ALICE will investigate equilibrium as well as nonequilibrium physics of strongly interacting matter in the energy density regime $\epsilon \sim 1$–1000 GeV/fm^3, the structure of the QCD phase diagram and the transition toward a new state of matter where quarks and gluons are deconfined (quark-gluon plasma).

The ALICE strategy is to study concurrently all the probes in the same experiment together with global information on the event topology, as particle multiplicity and forward and transverse energy. The experiments at the LHC will operate under severe multiplicity conditions: in Pb-Pb collisions it is expected to have up to 8000 charged particles per

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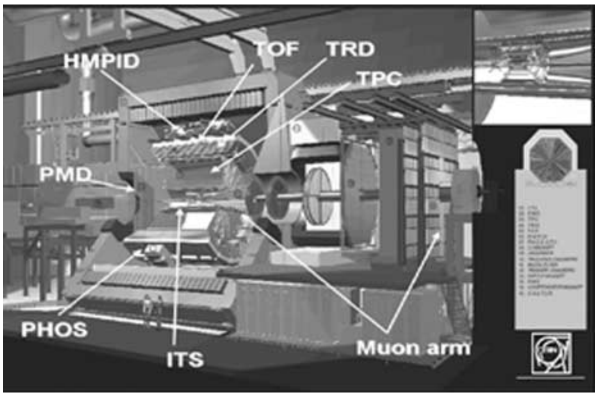

Fig. 1. – Layout of the ALICE detector.

unit of rapidity (fig. 2). As a consequence, in this scenario particle identification (PID) will play a fundamental role.

The Time-of-Flight (TOF) detector [2,3] is inside the ALICE solenoid, it has a polar acceptance $| \theta - 90° | < 45°$ and full coverage in ϕ; the inner radius of the TOF cylinder is 3.70 m from the beam axis. It has to provide PID information in the momentum range from 0.5 GeV/c up to a few GeV/c. In order to do that it has to have:

- large area $\sim 160\,\mathrm{m}^2$;
- high segmentation, with about 160000 channels of ~ 10 cm^2 readout pads to limit the occupancy at the level of about 15%;
- high efficiency $> 99\%$;
- good rate capability > 50 Hz/cm^2;
- excellent global time resolution < 100 ps to efficiently separate π/K up to 2.5 GeV/c.

The Multigap Resistive Plate Chamber (MRPC) detector for the ALICE TOF is the best choice in order to satisfy all the demanding requirements listed above.

2. – The Multigap RPC

The MRPC [4] derives from the well-known RPC and has been developed during the last decade within the LAA project at CERN. The MRPC is a gaseous detector consisting of a series of equally spaced parallel resistive plates, resulting in a series of gas gaps. High voltage is applied by a resistive layer to the outer surface of the external plates, while all the internal plates are electrically floating. The use of resistive plates allows to work with very high electric fields with no sparks and to have a readout as segmentated as one likes, with pickup pads located outside the stack and insulated from the high-voltage electrodes. The main problem with the standard RPC is that two trends are in conflict, *i.e.*

- small gaps improve the time resolution;
- the larger the gaps, the higher the efficiency.

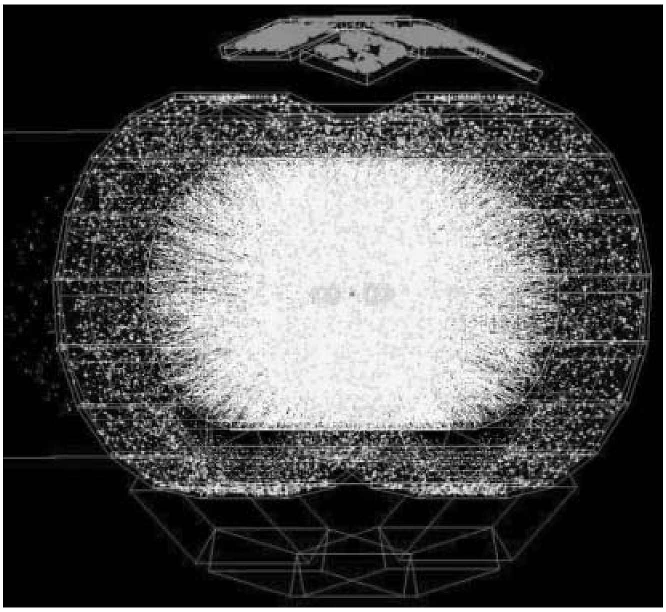

Fig. 2. – Event display of a Pb-Pb collision in the ALICE detector.

The drift of the electrons in the electric field induces a current signal on the MRPC electrodes; this signal growth distribution is independent of the position of the primary electron in the gas gap. The position only determines when the avalanche hits the electrodes, *i.e.* it determines when the signal is stopped. That signal will be detectable if it overcomes a certain threshold. Inside the MRPC, the electric field is constant and high, so the primary electrons start immediately the avalanche multiplication, and the drift velocity v_D of the charge inside the gas gaps is costant. The signal will be detectable if the avalanche will travel a certain distance l_0. Since the number of electrons after a distance l_0 is $n_0 = e^{\alpha l_0} = e^{\alpha v_\mathrm{D} t_0}$, the time resolution will be of the order of $\Delta\tau \approx 1/\alpha v_\mathrm{D}$, where α is the Townsend coefficient. A more precise explanation can be found in refs. [5,6]. If a very high electric field $E \approx 100$ kV/cm is applied, then $v_\mathrm{D} \approx 100$ μm/ns, $\alpha \approx 100$ mm^{-1} and finally $\Delta\tau \approx 0.1$ ns.

In order to work in an efficient way at very high rate, one should be able to operate in a proportional regime, *i.e.* $e^{\alpha L} \leq 10^8$ where L is the full gap width. To maintain a proportional regime, L should be $\approx 10^{-1}$ mm. This also implies the need to consider many small gaps to have a good efficiency. In conclusion, to obtain a time resolution of the order of hundred ps and a good rate capability, many small gaps and very high Townsend coefficients are needed.

2˙1. *The MRPC for ALICE TOF.* – The MRPCs for ALICE TOF are designed as double-stack strip of 120 ×7.4 cm^2 active area with a central anode and 5 + 5 gas gaps of 250 μm; these gaps are obtained with a nylon fishing-line spacer stretched between plexiglass pins across the internal plates. A cross-section of the double-stack MRPC is shown in fig. 3. Pickup pads (96 per strip) have an area of 3.5 ×2.5 cm^2 each and they are arranged in two-row arrays on printed circuit boards (PCBs), as shown in figs. 3, 4. The cathode signals are brought to the central PCB, where there are the connectors

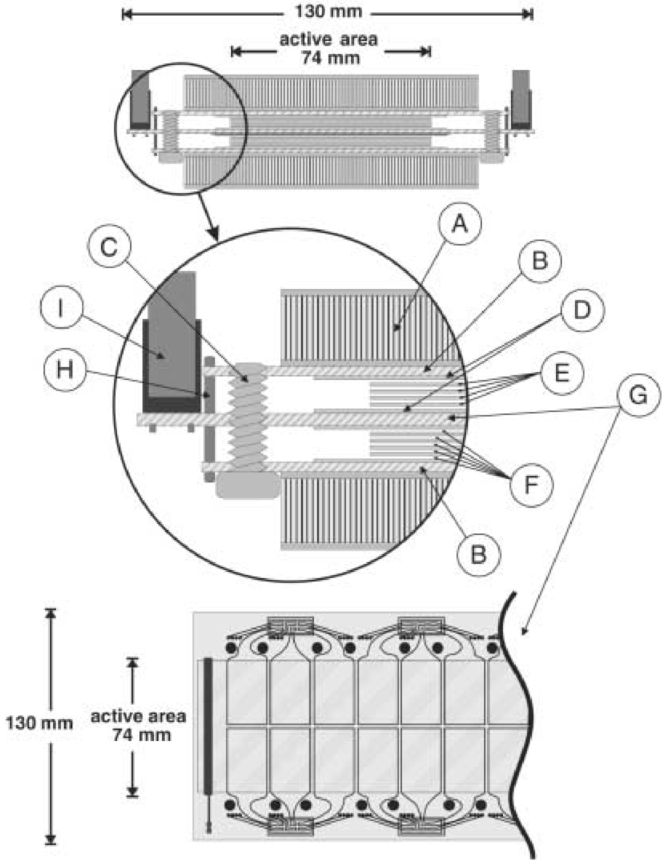

Fig. 3. – Schematic cross-section of a double-stack MRPC strip. (A) 10 mm thick honeycomb panel; (B) PCB with cathode pickup pads; (C) Plexiglass pins to hold the fishing-line spacer; (D) 0.55 mm thick external glass plates; (E) four 0.4 mm thick internal glass plates; (F) five gas gaps of 250 μm; (G) central PCB with anode pickup pads; (H) metallic pins to bring the cathode signals to the central readout PCB; (I) flat cable connector for MRPC signal trasmission to front-end electronics.

used to transmit the differential signal to the front-end electronics; what is measured is the sum of the signals from the two stacks. The resistive plates are made of "soda-lime" glass manufactured by Glaverbel(1) with volume resistivity of $\sim 10^{13}\Omega\cdot$ cm; the internal plates are 400 μm thick, while the outer plates are 550 μm thick. The external surface of the outer plates is painted with a resisitve coating of a few M$\Omega/\Box$ (acrylic paint loaded with metal oxides)(2).

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(1) Glaverbel VERTEC sales, 166 Chaussée de La Hulpe, 1170 Brussels, Belgium.

(2) DETEC di Orietti M.L., viale E. Thovez 16/a, 10131 Torino, Italy.

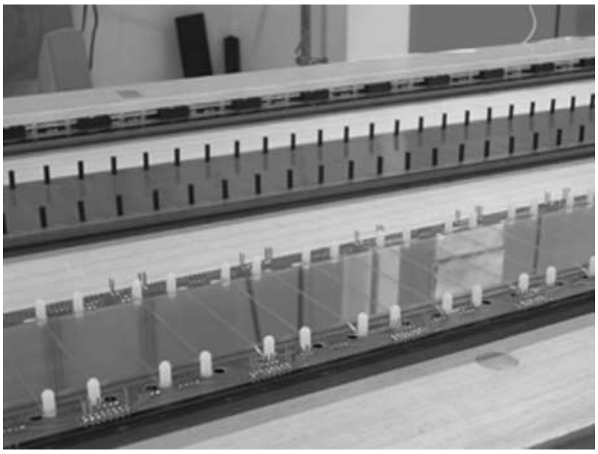

Fig. 4. – Picture of MRPC strips during different assembly steps: a PCB after having been glued on a honeycomb panel (middle), a PCB with glasses during the stretch of the fishing-line (bottom), and a finished MRPC strip (top).

3. – The mass production

The final design and assembly procedure of the MRPCs was successfully carried out after an intense R&D work [3]; a detailed description of the assembly procedure can be found in ref. [7]. The ALICE TOF array will consist of 1638 of such a detector. To support a such massive production, automatic procedures and a series of quality assurance tests are mandatory. These tests should affect both the components with which the MRPCs are built and some important features of the devices. To summarize, the quality assurance tests can be classified as follows:

- tests on components, as PCB planarity and glass resistivity;
- tests on strip overall features, as gap width and electrical connections;
- tests on performance, as efficiency and time resolution estimation.

3˙1. *Automatic procedures*. – Automatic precedures are necessary to minimize time and manpower. Each strip needs eight 400 μm glasses. A system of three tanks and one hoven has been prepared to wash all the glasses with ultrasound waves and a dedicated soap, to rinse them with cold water, and to dry them. Thanks to a suitable basket it is possible to wash up to one hundred glasses at the same time. Moreover, a first prototype of wiring machine meant to stretch the fishing-line across the detector (it takes a few minutes to place each layer) has been built. A machine devoted to automatically make the 1664 solderings for each individual strip has been designed and is presently under costruction (fig. 5).

3˙2. *Tests on components*. – First of all, the honeycomb panels (A in fig. 3) and the PCBs have to be checked in order to reject those which are not planar enough and which show construction faults. The resistivity value of the acrylic paint is an important parameter: low values may cause a very broad signal that can affect more than one pad,

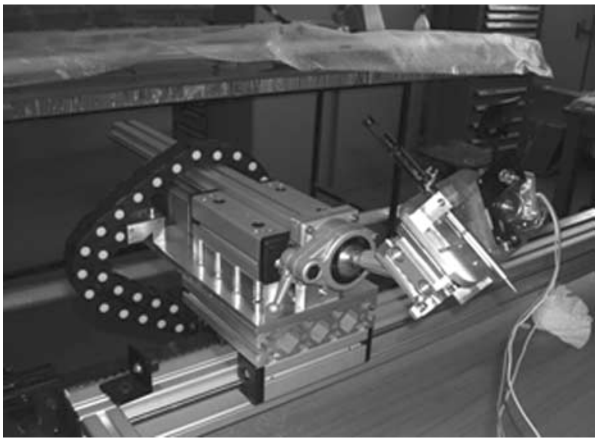

Fig. 5. – Picture of the first prototype of the soldering machine currently under costruction.

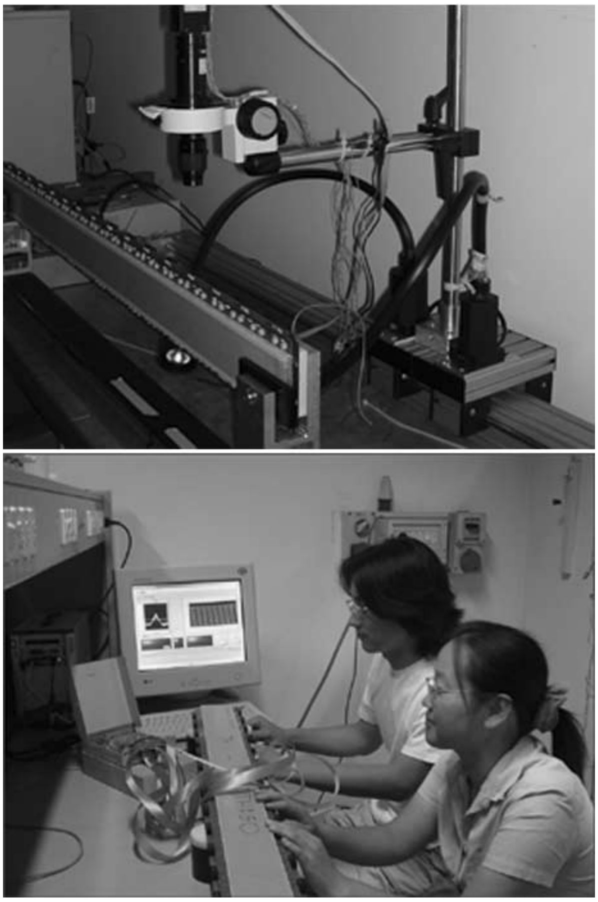

Fig. 6. – Pictures of two quality assurance facilities. The set-up with microscope and CCD camera to investigate the gap width (top), and the pulsing tests on the MRPCs (bottom).

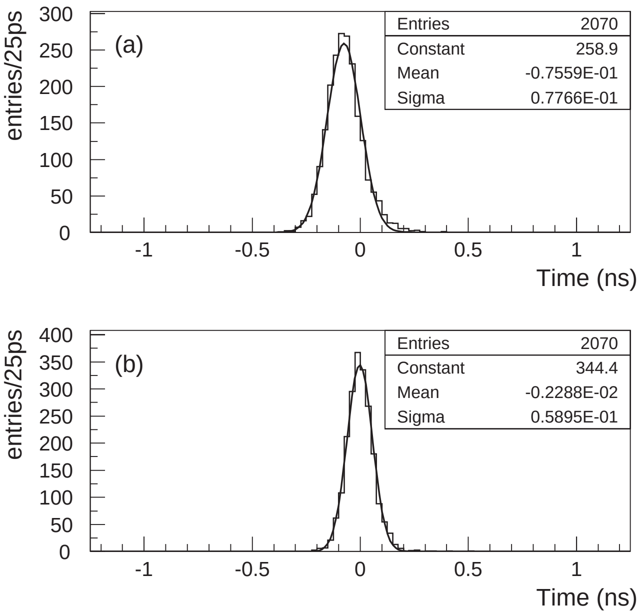

Fig. 7. – Example of time resolution of a MRPC pad before (a) and after (b) time-slewing corrections.

while too much high values could increase the dead time of the detector, compromising its rate capability. Studie had shown that acceptable values range from 1 M$\Omega/\square$ to around 10 M$\Omega/\square$. All the 550 μm glasses with acrylic paint are measured in five different positions in order to check the uniformity along the glass; glasses with too low or too high resistivity are rejected. The results of these measurements are stored in a database and the four glasses selected for each MRPC are as much as possible similar the one to the other. The overall resistance of the four painted glass is also measured after the assembly, in order to check whether damages have occurred.

3˙3. *Tests on features.* – After the assembly procedure the strip has to pass some important tests. First, with a microscope and a high-resolution analog CCD device (top in fig. 6), the gap width is measured in five different positions along each strip using a National Instruments IMAQ 1409 frame grabber for data aquisition and a LabVIEW software for the user interface program. The tolerance is fixed within ±20 μm.

Then, all the electrical connections and the solderings of the detector have to be checked. For this reason, in one of the external PCB a 50 Ω impedance line is implemented in order to induce a signal pulse on pads (bottom in fig. 6). This line will be crucial during the running of the experiment because it will allow to test the whole readout chain, *i.e.* the MRPC pads, the front-end electronics, the cables and the TDC.

Finally, a voltage of ±3 kV is applied to each strip in air in order to see if a dark current or, in the worst case, some discharge appears. This would be related to bad insulation between electrodes or between electrodes and pads that are connected to the ground, or eventually to the PCBs themself. Values of the current below few hundreds of nA are accepted.

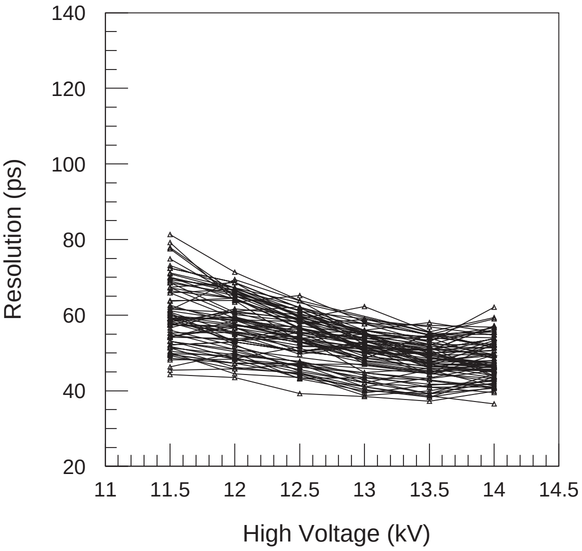

Fig. 8. – Time resolution as a function of total applied voltage in 76 pads from 18 MRPC strips.

3˙4. *Tests on performance.* – The MRPC strips are assembled and stay in a clean room until they will be put inside a module of the TOF array, except for samples which are tested with cosmic rays in the laboratory. An appropriate facility has been built with allows efficiency and time resolution studies for five MRPCs at the same time. Due to the low rate of cosmic radiation, a minimum of one week is needed to collect enough statistics for sufficiently accurate results.

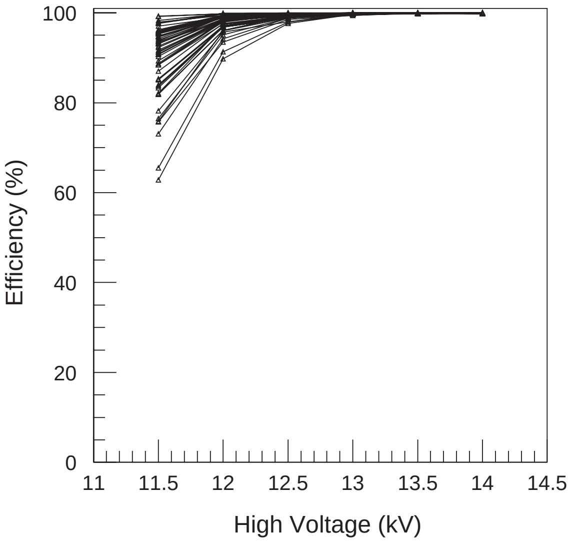

Fig. 9. – Efficiency as a function of total applied voltage in 76 pads from 18 MRPC strips.

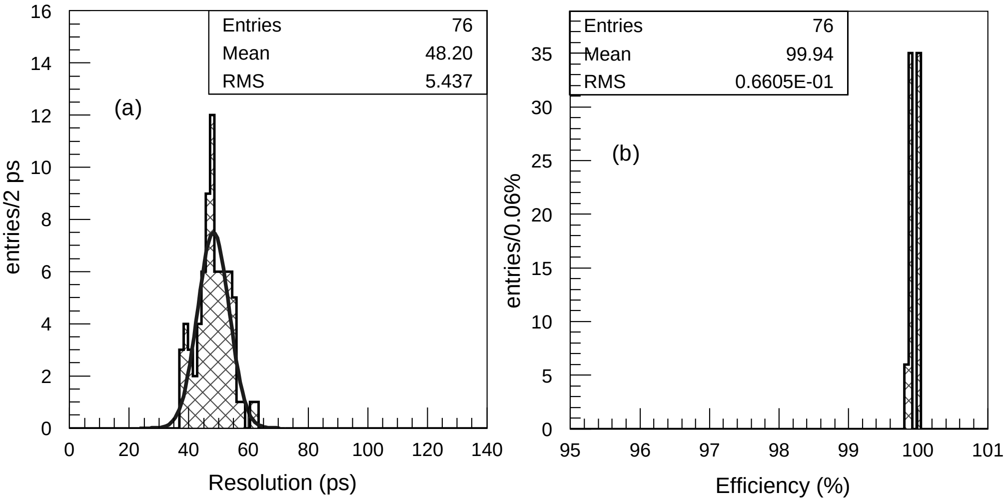

Fig. 10. – Time resolution (a) and efficiency (b) distribution for all tested pads at HV = 13.5 kV.

4. – Results of a sample MRPC

During July 2004, a sample of 18 double-stack MRPCs from the mass production was tested at the CERN T10 beam line with a 7 GeV/c beam of negative particles (π and μ) coming from the PS. The MRPCs were put in alluminum boxes filled with a gas mixture of 93 % $C_2F_4H_2$ and 7% SF_6. A detailed explanation of the experimental set-up of the T10 area can be found in ref. [7]. The main purpose of these tests was to study the uniformity of the performance of the MRPC strips, in particular with respect to the time resolution and efficiency. Figure 7 shows the typical time resolution of the detector. The upper plot is the distribution of the difference between the time measured by the MRPC and an accurate time reference ($\approx$ 30 ps of resolution) obtained with two fast scintillator bars equipped with two photomultipliers each, discriminated by constant fraction discriminators. In order to obtain the true time resolution, a correction has to be made according to the pulse height of the signal (*i.e.* a time-slewing correction). Since our front-end electronics has no analog output, an estimation of the pulse height is obtained by the time during which the signal stays over the threshold of the discriminator, *i.e.* Time-over-Threshold (TOT). Amplification and discrimination are provided by a custom NINO-ASIC, while the TDC uses a HPTDC chip with 24.4 ps of resolution per bin. The plot at the bottom in fig. 7 is the resulting time-corrected distribution; the time resolution is the sigma of the superimposed Gaussian fit, with the contribution of the scintillator system quadratically subtracted. The events outside $\pm 2\sigma$ are about the 2% of the total. The distribution in fig. 7 corresponds to an uncorrected time resolution of 80 ps and a corrected one of 50 ps (in fig. 7 the contribution of the scintillator system has not been subtracted jet).

Figure 8 shows the time resolution as a function of the total applied voltage for the sample of 18 MRPC strips, corresponding to 76 scanned pads (about four pads for each strip). Figure 9 shows the efficiency for the same measurements; at a fixed voltage value of 13.5 kV (the working voltage) all the pads under test have an efficiency of about 100% and a time resolution below 60 ps.

Figure 10 shows the time resolution and efficiency distributions at 13.5 kV applied voltage. The time resolution peaks at an excellent value of 48 ps, while the efficiency is close to 100%for all the tested pads.

During September 2004 a sample of 5 MRPCs were irradiated at the CERN Gamma Irradiation Facility (GIF), located in the X5 area of the West Hall. This facility allows a device to be irradiated with 662 keV photons from a 740 GBq ^{137}Cs source (at full source); at the same time its performance can be studied using a 150 GeV/c muon beam from the SPS, varying the intensity of the source with some absorbers. These tests are devoted to study the response of both the detector and the front-end electronics. Results are not jet available, but a similar tests carried out in 2002 showed that this device can operate far in excess of the 50 Hz/cm^2 [8], which is the maximum rate expected in ALICE at the TOF array location.

5. – Conclusions

Since the first half of 2004 the mass production of the MRPC strips for the ALICE TOF has started. The assembly procedure has been fixed and is under control. Facilities for quality assurance have been developed and built in order to ensure an excellent quality of the detector. The results over a sample of MRPCs have shown very good performances in terms of time resolution, efficiency and uniformity both along each single strip and within the entire sample. These performances fully satisfy to the strict requirements of the ALICE TOF project.

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