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Final results of the tests on the resistive plate chambers for the ALICE muon arm

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ABSTRACT

The trigger for the ALICE muon spectrometer will be issued by single-gap, low resistivity bakelite resistive plate chambers (RPCs). The trigger system consists of four $5.5 \times 6.5\,\mathrm{m}^2$ RPC planes arranged in two stations, for a total of 72 detectors.

One hundred and sixteen detectors have been assembled and tested in Torino. The tests have been performed with the streamer mixture developed for heavy ion data-taking. The tests include: the detection of gas leaks and parasitic currents; the measurement of the efficiency with cosmic rays, with particular regard to the uniformity of the efficiency throughout the whole active surface, with a granularity of about $2 \times 2\,\mathrm{cm}^2$; the measurement of the dark current and of the mean and localised noise rate.

All the RPCs produced have been characterised. Among them, the detectors to be finally installed in ALICE and some spare have been selected; 17% of all the produced detectors have been discarded.

A short description of the test set-up is given. The results of the tests are presented, with particular regard to the performance of the selected detectors.

1. Introduction

The muon spectrometer [1] of the ALICE [2] experiment at LHC has as its primary goal the detection and analysis of heavy quarkonia in both heavy ion and p–p collisions, through their muonic decays.

The muon spectrometer is equipped with a trigger system, whose aim is to select high momentum muons ($p_T > 1-2\,\mathrm{GeV}/c$), thus rejecting most of the background from light hadron decays. The muon momentum is estimated via the deviation of the track between the two stations, relative to a track with infinite momentum pointing to the IP.

The trigger system of the muon spectrometer is composed of four planes of resistive plate chambers [3] (RPCs) arranged in two stations of two planes each. The trigger stations are located 16.1 and 17.1 m away from the interaction point. Each plane is composed of 18 RPCs, that come in three different shapes and six different sizes, the size of the largest detectors being $76 \times 276\,\mathrm{cm}^2$. The detectors are read on both sides with orthogonal strips. The pitch of the strips ranges from 10.6 to 45.6 mm, depending on the distance of the strip from the beam axis.

2. RPCs for the ALICE muon arm

After extensive research devoted to the optimisation of spatial resolution [4] ($\sigma \simeq 5\,\mathrm{mm}$ with 2 cm wide strips in streamer mode), rate capability [5] (up to $100\,\mathrm{Hz/cm}^2$) and detector lifetime [6–8], the design of the detector has been defined: the ALICE RPCs are single-gap (2 mm) detectors, with low-resistivity bakelite electrodes ($\rho = 2-8 \times 10^9\,\Omega\,\mathrm{cm}$) internally coated with a double layer of linseed oil. For A–A collisions, a streamer gas

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mixture will be used, made of 50.5% Ar, 41.3% $C_2H_2F_4$, 7.2% i-C_4H_{10} and 1% SF_6; for p–p collisions, a highly saturated avalanche mixture will be used, made of 89.5% $C_2H_2F_4$, 10% i-C_4H_{10} and 0.5% SF_6. The choice of two different operation modes is due to the different requirements to be met in A–A collisions (strip occupancy and space resolution) and in p–p collisions (detector lifetime [8]). The ADULT [9] dual threshold method for signal discrimination has been implemented in the front end chip, to improve the time resolution in streamer mode (1−2 ns).

3. Testing the final production

The gas gaps for the ALICE RPCs have been produced by General Tecnica (Colli, Italy); quality assurance [10] on the gas gap mechanical characteristics has been performed at the INFN Laboratori Nazionali Gran Sasso. Strip planes, stiffening planes and mechanical supports have been produced and assembled at the INFN laboratories in Torino; 116 gas gaps have been produced.

Extensive tests on the produced detectors have been carried out in Torino. Such tests include the following measurements:

- the detection of gas leaks;
- the current-HV curve and the detection of leakage currents;
- the local efficiency-HV curve;
- the high-granularity efficiency map at working HV;
- the dark current absorbed at working HV;
- the mean noise rate and the noise map of the detector, with the self-trigger method.

The aim of the first two measurements in the above list is to promptly discard all the detectors with serious construction flaws. Eight percent of the produced detectors have been discarded during these preliminary tests.

The tests have been carried out with the streamer mixture described in Section 2. The detector efficiency has been measured with cosmic rays (muons) by means of a dedicated test bench (Fig. 1), composed of an hodoscope (three planes of nine scintillators each), two reference RPCs and four test slots. The two reference RPCs provide spatial information which can be used to determine the impact point of the muons on the detector under test, thus performing a local measurement of the efficiency. More details about the test bench and the methods used for the measurement of efficiency and noise can be found in Ref. [10].

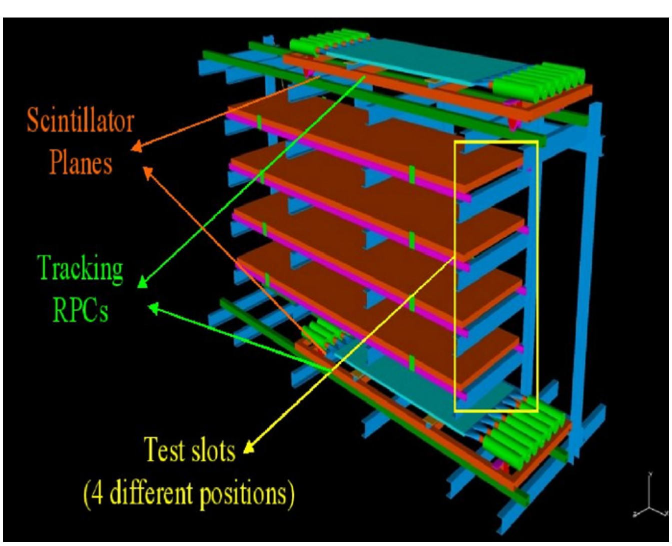

Fig. 1. The Turin test bench for the RPCs of the ALICE muon arm.

The local measurement of efficiency is affected by a systematic uncertainty, due to fake tracks reconstructed by the tracking RPCs, or scattering of the muons off the structures of the test bench. Such uncertainty has been estimated to be about 3−4%. This is not a major concern since the efficiency measurements presented here are not meant to evaluate the absolute RPC efficiency, but rather the uniformity of the efficiency throughout the surface of the detector.

4. Analysis and results

4.1. Uniformity

The local efficiency as a function of high voltage is measured by virtually dividing the detector surface in cells (area $\simeq 20 \times 20\,cm^2$). For each cell, the efficiency curve is plotted and parametrised by means of a fitting procedure.

The spread of the parameters of the efficiency curve in different regions of one same detector can be used to evaluate the uniformity of the detector; in particular, the analysis focused on the high voltage at 50% efficiency (HV_{50}), since this parameter is only marginally affected by the above-described uncertainty on the measurement of efficiency. For each detector, the distribution of HV_{50} over all the cells has been plotted (Fig. 2). The full width of the distribution (i.e. the voltage range in which all cells reach 50% efficiency) has been taken as a quantitative estimate of the uniformity. The distribution of this variable over all the tested detectors is shown in Fig. 3: it is peaked around 300 V. Since $HV_{50} \simeq 7500$ V, 300 V represent a 4% spread.

To evaluate even better the uniformity of the detector, high granularity efficiency maps (Fig. 4) have been measured at two voltage values, 8200 and 8100 V: such values are right above the working voltage for most chambers. The area of the cells in the efficiency maps is about $2 \times 2\,cm^2$. The efficiency maps of all detectors have been visually inspected, to detect all possible imperfections (i.e. regions with efficiency lower than 95%). The detectors have been classified according to the number and entity of imperfections. Sixty two percent of the tested detectors have

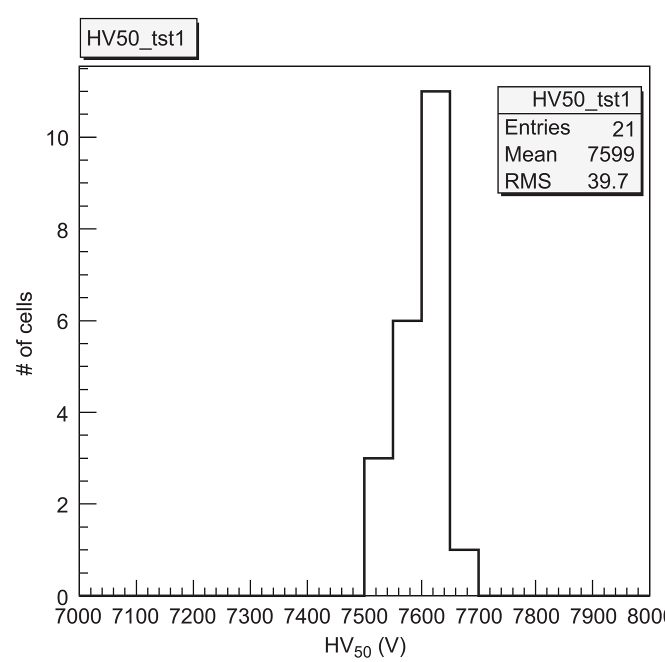

Fig. 2. Distribution of the voltage at which the detector reaches 50% efficiency for cosmic rays, over 21 $20 \times 20\,cm^2$ cells of a half-detector.

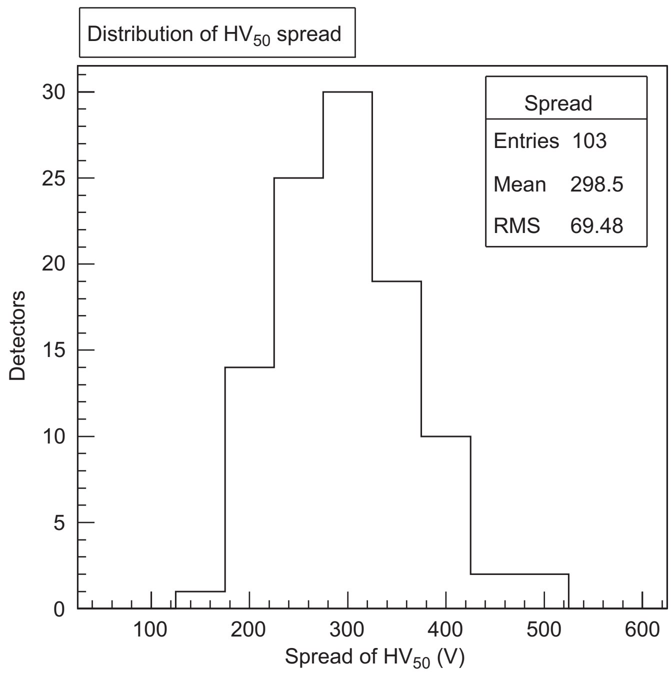

Fig. 3. Distribution over 103 detectors of the voltage range in which all $20 \times 20\,cm^2$ cells of the detector reach 50% efficiency.

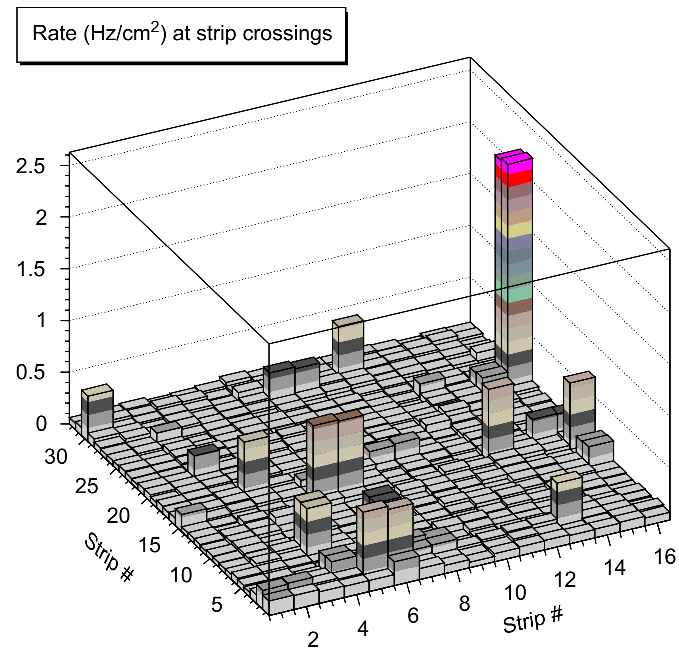

Fig. 5. Noise map at 8200 V of a detector showing good performance. The noise rate is plotted as a function of the strip number in the x and y directions.

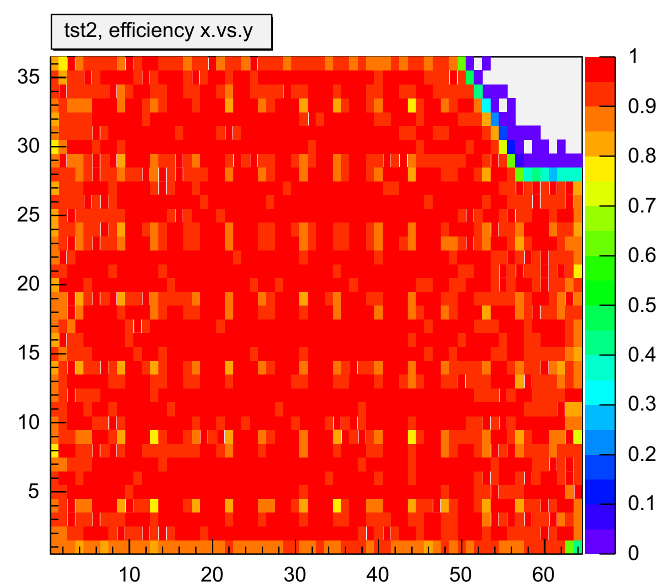

Fig. 4. Efficiency map of a half detector operated at 8200 V, showing high uniform efficiency throughout the whole surface. The x and y coordinates define the position of the $2 \times 2\,cm^2$ cells. The low efficiency cells that appear every 10 cm correspond to spacers. The top right corner of the map reflects the shape of the detector.

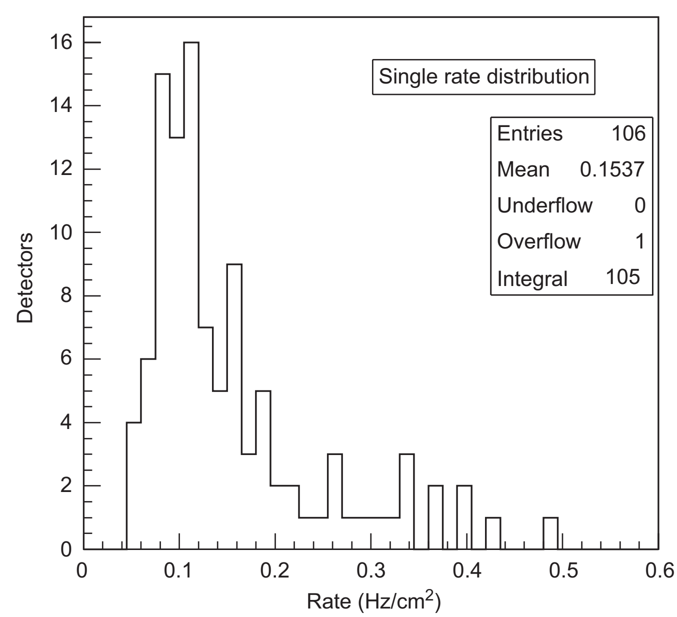

Fig. 6. Distribution of the mean noise rate at 8200 V over 106 detectors.

shown uniform efficiency throughout the whole surface, with no imperfections at all; 31% of the tested detectors have shown minor imperfections of various entity; 7% of the tested detectors have shown major imperfections, preventing them from being used.

4.2. Noise and current

The mean and local noise of the detectors have been measured for a wide range of high voltages.

The counting rate has been measured locally with the self-trigger method [10], which provides noise maps such as the one in Fig. 5, on which noisy spots can be detected. The noise of each detector has been quantified with two variables: the mean counting rate and the number of hot spots (i.e. spots with local rate higher than $20\,Hz/cm^2$). The distribution of the mean noise rate over the tested detectors (Fig. 6) is peaked around $0.1\,Hz/cm^2$. On average, the number of hot spots is 2 per detector, while the number of spots with local rate between 5 and $20\,Hz/cm^2$ is 9.

The current absorbed by the detector is an important parameter because ageing effects are roughly proportional to the current drawn during long-term operation. The current values measured in Torino will be a reference for the evaluation of ageing. The distribution of the dark current per surface unit at

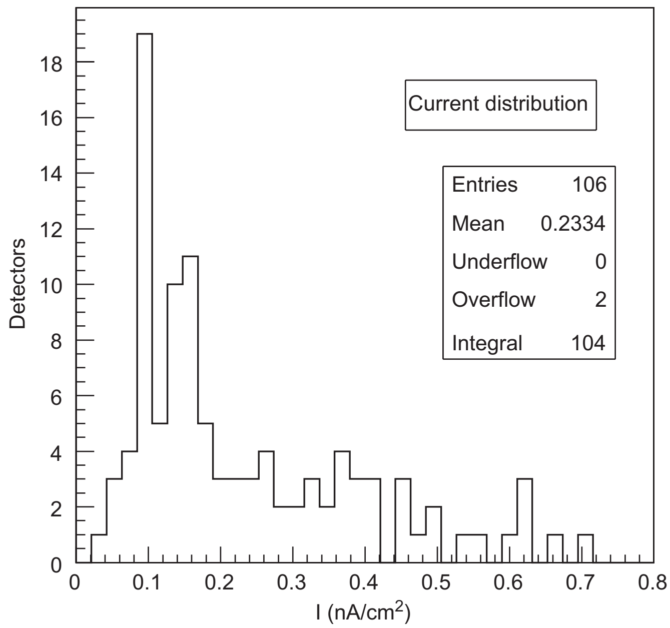

Fig. 7. Distribution of the dark current at 8200 V over 106 detectors.

Table 1
Mean value of four quality parameters for detectors considered sufficient, good and excellent.

Parameter	Excellent	Good	Sufficient
Counting rate (Hz/cm^2)	0.11	0.14	0.21
Number of spots with rate >20 Hz/cm^2	0.7	1.4	4.3
Current (nA/cm^2)	0.13	0.19	0.33
Full width of HV$_{50}$ distribution (V)	277	293	317

The counting rate, the number of hot spots and the current have been measured at HV $=$ 8200 V.

8200 V is shown in Fig. 7: the peak value is about $0.1-0.15$ nA/cm^2, corresponding to a total current of about 2 μA for the biggest chambers.

It is worth noting that the distributions of the counting rate and of the current (and, to a lesser extent, the distribution of HV$_{50}$ as well) show a common structure: a peak around normal working values and a tail where the problematic detectors lie.

4.3. Selection criteria

Detectors with too large or too many inefficient regions have been discarded; detectors with too high current or noise rate have also been discarded. The remaining have been assigned to three quality classes (sufficient, good or excellent) according to the combined evaluation of uniformity, noise and current. The characteristics of such classes are summarised in Table 1, where the mean values of four quality parameters are reported for the three classes.

5. Conclusions

The results of the test on the final production can be summarised as follows:

- 17% of the produced detectors have been discarded (8% during the preliminary tests and 9% for insufficient performances);
- 26% of the produced detectors have shown sufficient performances: they have been selected for use in ALICE as spare detectors or in peripheral regions of the trigger system;
- 57% of the produced detectors have shown good (33%) or excellent (24%) performances, suitable for use in ALICE.

All detectors have been fully characterised; the results of the tests have been stored in a database available for reference to the collaboration. The 72 final detectors have been selected and installed in the ALICE cavern by summer 2006 [11]. Further production and testing sessions are foreseen in order to increase the number of spare detectors.

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