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R&D on RPC for the Muon Trigger System for the ALICE experiment in view of p-p data taking

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***Abstract*—ALICE (A Large Ion Collider Experiment) is the heavy-ion dedicated experiment at LHC. The Resistive Plate Chamber detector (RPC) with low-resistivity bakelite electrodes was selected for the trigger system of the muon spectrometer. Although the main goal of ALICE is the study of nucleus-nucleus collisions, reference data in p-p interactions will be collected as well. If, on one hand, RPC operation in streamer mode is adequate for data taking with ion beams, on the other hand, the more severe ageing requirements for p-p data taking lead us to explore the possibility of operating the detector in "highly-saturated avalanche" regime. A detailed study of the signal was carried out with cosmic rays to get a more precise view of the intrinsic properties of the gas mixture (among others the streamer fraction vs. HV). The possibility of detecting avalanche signals with our FEE designed for the streamer mode was successfully investigated. Furthermore, tests with muon beam at CERN were carried out with satisfactory results in terms of efficiency, time resolution and cluster size. An analysis of the exhaust gas showed a low HF content: this is an encouraging result in view of long term stability of the detector which is at present under test.**

***Index Terms*—ALICE, Muon Trigger, RPC, Avalanche**

I. Introduction

THE muon spectrometer [1] is one of the main components of the ALICE experiment [2] at LHC. The muon trigger system is based on single gap Resistive Plate Chambers (RPC) [3] made with low-resistivity bakelite electrodes. Although the main goal of ALICE is the study of nucleus-nucleus collisions, reference data in p-p interactions will be collected as well. In fact the ALICE experiment will exploit LHC proton beams to collect reference data for the study of heavy ion collisions. In addition, the study of p-p collisions is interesting in itself due to the new energy domain covered [4]. The p-p running will be also used for the detector commissioning.

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The requirements for heavy-ion data taking, in particular the rate capability and the position resolution, are fulfilled by operating the detector in streamer mode (for more details see Ref. [5]). The situation is different for p-p data taking: the requirements on the position resolution are less stringent but the integrated rate could be much higher compared to heavy ion running, leading to more severe requirements on the detector lifetime. During p-p runs, interactions of beam particles with the residual gas in the vacuum chamber increase the background in the detector (this is a machine-induced background). Simulations of this radiation environment [6], at nominal LHC beam intensity, give a maximum rate of 50 $Hz{\cdot}cm^{-2}$ on the most exposed chamber (with our present knowledge of the vacuum quality). In these conditions, the maximum integrated rate would significantly exceed 100 $Mhits{\cdot}cm^{-2}$, which represents the limit of the detector lifetime in the streamer mode [7].

II. "Highly-saturated avalanche" operation

According to the specific aspects of p-p data taking for ALICE and in particular to the ageing requirements, an operation mode referred as "highly-saturated avalanche" was investigated. The R&D carried out by ATLAS and CMS have shown that operation in avalanche mode results in a higher detector lifetime compared to the streamer mode.

The main goal of this research was actually to investigate if it would be possible to work in "highly-saturated avalanche" mode with our dual-threshold Front End Electronics (ADULT) [8] specially developed to improve the timing performance in streamer mode. Indeed, this electronics does not include an amplification stage, and therefore the minimum threshold is a few mV. For the streamer mode, the two thresholds are respectively set at 10 mV, in order to trigger on the avalanche precursor and 80 mV to confirm the streamer formation.

Among several highly quenched mixtures studied in cosmic rays, a mixture composed of $C_2H_2F_4$ (88%) + C_4H_{10} (10%) + SF_6 (2%) has been finally selected. Then we performed a detailed study to get the actual running performances in such conditions and in conjunction with our FEE. In particular the working plateau, which has to be at least 400 V wide, was investigated.

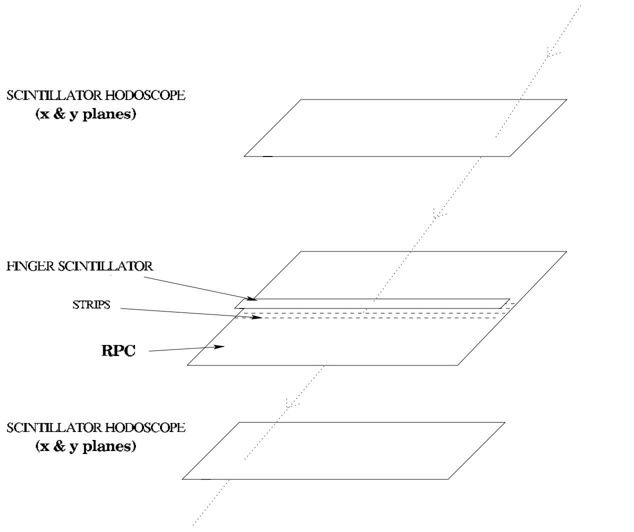

Fig. 1. Set-up for the cosmic tests. The trigger consists of the coincidence of a finger scintillator and two scintillator hodoscopes. The finger scintillator is centered on 3 strips. The drawing is not in scale.

III. SIGNAL STUDIES

These tests were carried out with cosmic rays. We used a small RPC prototype (50x50 cm^2, single gap). The detector was read-out by mean of strips 50 cm long and 2 cm wide. To carry out these tests, a finger scintillator (2 cm wide and 50 cm long) was centered on 3 strips (see Fig. 1). The trigger consisted of the coincidence of the finger scintillator and two scintillator hodoscopes. The signals of the strips were sent without any amplification to a digital oscilloscope. It was able to record, event by event, the shape and the timing (relative to the trigger) of each signal with 1 GHz sampling. The signals were sent in parallel to the FEE with both thresholds set at 10 mV for efficiency measurements.

These data allow to reconstruct the signal shape in different operating conditions. Figure 2 shows three signal types for increasing voltages: a large avalanche signal (top), a delayed streamer signal and its avalanche precursor in time with the trigger (center) and a prompt streamer signal in time with the trigger (bottom). We can see that the large avalanche signal amplitude is about 60 mV. Different relevant quantities can be inferred from shape analysis of the stored signals: the charge induced on the strips (obtained by integrating the signal), the signal amplitude and the timing. These are obtained by summing up for each event the stored signals of the three strips. Thus, for each voltage, looking at these different relevant quantities, we can distinguish avalanche from streamer signals. The efficiency knee, which is the voltage for 90 % of full efficiency, is at 10700 V with cosmics.

In Fig. 3, the plots (A) and (D) give the charge distributions (in negative values) at two different voltages (11100 V and 11500 V, i.e. 400 V and 800 V above the knee respectively). A significant streamer contamination is present only for the highest voltage. In fact the peak at about -50 pC (which corresponds to streamer signals) is present in Plot (D) but not in Plot (A).

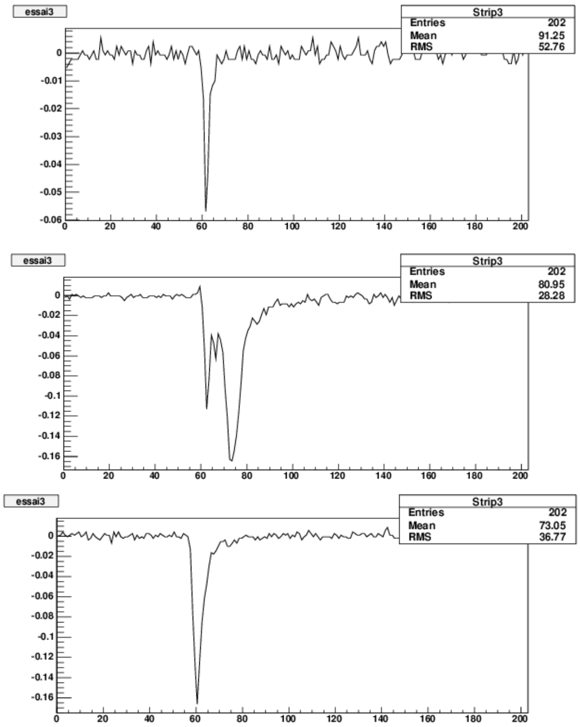

Fig. 2. Signal shape as a function of time (ns) - top: avalanche, center: avalanche followed by delayed streamer, bottom: prompt streamer. The units of the vertical scale are Volts.

The plots (B) and (E) show the signal amplitude as a function of the charge for the same running voltages.

The plots (C) and (F) show the peak timing as a function of the charge for the same running voltages. The peak timing is defined as the time (relative to the trigger) corresponding to the maximum of the signal.

The plots (B) and (C) show that at 11100 V the avalanche signals are concentrated in a restricted area (low charge), whereas the plots (E) and (F) for 11500 V show that the streamer signals are more dispersed both in time and in amplitude. Thus, for each operating voltage, we can apply cuts (wrt charge, amplitude, timing) to determine accurately the streamer percentage as a function of HV. The results are shown in Table 1. As it can be seen, the streamer contamination remains below 10 % up to 11100 V. Therefore we can assert that the detector (in conjunction with our FEE) can be operated in "highly-saturated avalanche" in a region of about 400 V above the plateau knee.

IV. TESTS WITH MUON BEAM AT GIF

After the encouraging results of the signal shape studies, a test with muon beam was carried out in August 2003 at the CERN Gamma Irradiation Facility (GIF-SPS). The detector was a preproduction RPC (210 cm x 70 cm), identical to

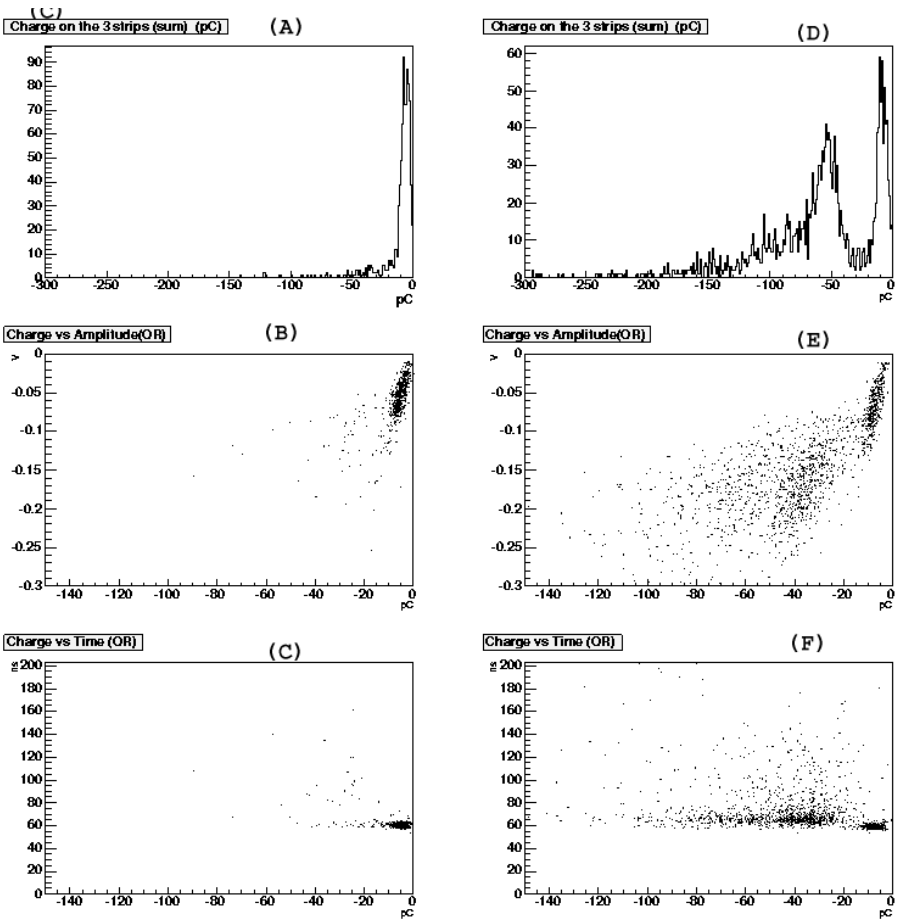

Fig. 3. (A,D): charge distribution (pC in negative values) - (B,E): signal amplitude (V) vs. charge (pC) - (C,F): peak timing (ns) vs. charge (pC) - Left column: plots (A,B,C) for 11100 V - Right column: plots (D,E,F) for 11500 V.

TABLE I

PERCENTAGE OF STREAMER CONTAMINATION FOR DIFFERENT VOLTAGES

HV (V)	Streamer percentage (%)
11100	8.0
11200	12.5
11300	21.0
11400	38.5
11500	60.5

the one which will be used in ALICE in the central part of the first trigger station. The detector has strips of 3 different pitches (1 cm, 2 cm and 4 cm). The detector was operated in streamer mode with FEE thresholds set at 10 and 80 mV and in “highly-saturated avalanche” with both FEE thresholds set at 10 mV.
The experimental set-up (Fig. 4) consisted of 2 tracking chambers and two couples of scintillators to identify the muons coming from the beam. The RPC can be moved horizontally and vertically in order to study each different strip width region. In order to achieve high rates, we operated the detector both with the muon beam and with the gamma source

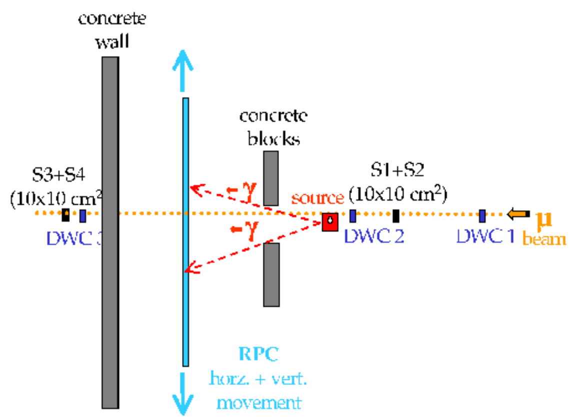

Fig. 4. Set-up for tests with muon beam at CERN SPS.

of GIF (rate of 80 Hz·cm^{-2}); these irradiation conditions are called “GIF on”, while an exposure with the muon beam only is called “GIF off”.

The timing properties for the “highly-saturated avalanche”

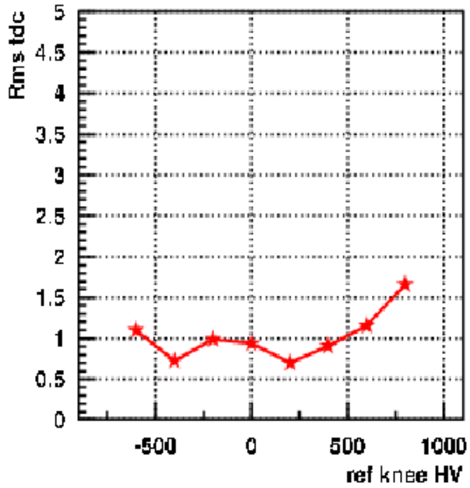

Fig. 5. Rms of the tdc distribution for GIF on conditions. On horizontal scale, the zero corresponds to the voltage of the efficiency knee.

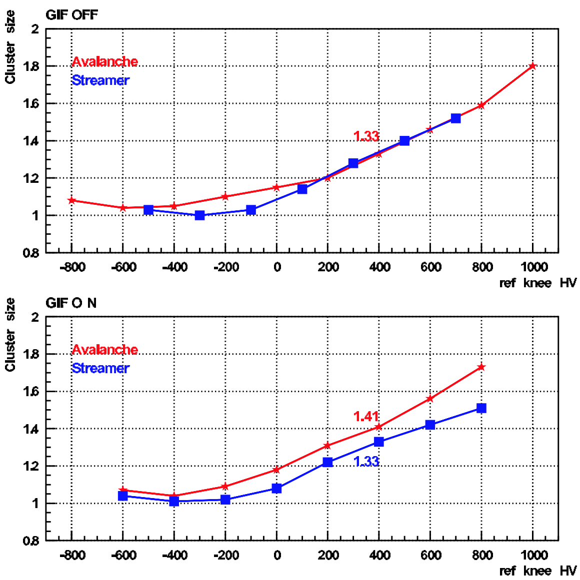

Fig. 6. Mean values of the cluster size vs. HV (the zero corresponds to the knee voltage) for 2 cm wide strips, given for GIF off (upper panel) and GIF on conditions (lower panel). The squares refer to the streamer mode and the stars refer to the "Highly-saturated avalanche" mode.

mode are summarized in Fig 5, where the rms of the tdc distribution is shown as a fonction of HV. As it can be seen the rms remains of the order of 1 ns up to about 500 V above the knee. Beyond, we can note that a degradation starts to appear due to the delayed streamers.

In Fig. 6 and 7 there is presented a comparison of the cluster size between the streamer and the avalanche mode. For the 2 cm strips (Fig. 6), the cluster size values are close one to the other. But for the 1 cm strips (Fig. 7) we note an increase of cluster size in avalanche mode compared to streamer mode. However these values are still acceptable, considering that the occupancy is not a major problem in p-p.

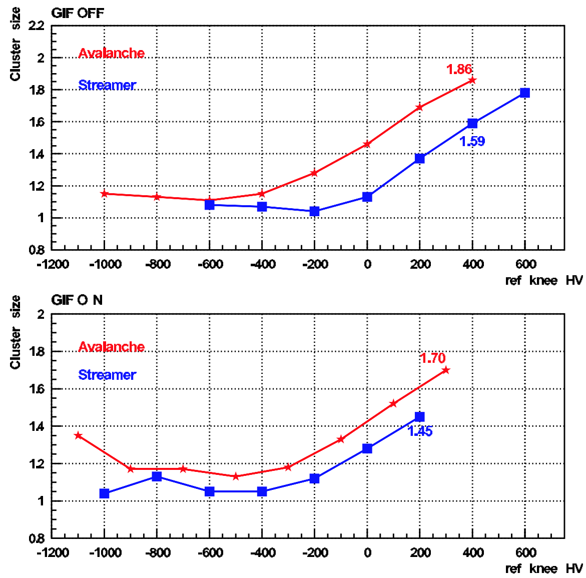

Fig. 7. Same as Fig. 6 but for 1 cm wide strips.

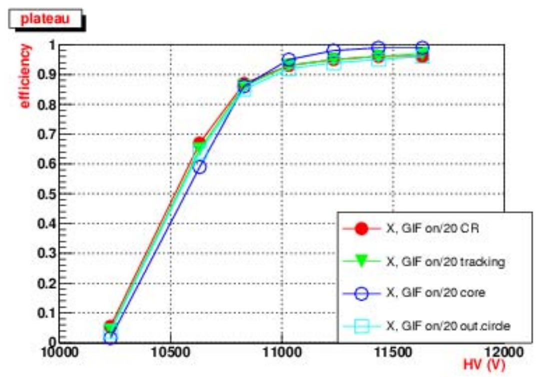

Fig. 8. The efficiency curves at GIF on (with T/p corrections).

The results indicate that, in "highly-saturated avalanche" operation the detector showed a stable behaviour with:

- dark current (with source off): 1 μA at most;
- dark single rate (with source off): 0.1 Hz·cm^{-2} at most;
- current drawn with source on: 1/3 of the current drawn in streamer mode for the same irradiation conditions;
- efficiency $\geq 95\%$ (see Fig. 8).

During these tests at GIF, chemical analysis of the exhaust gas were performed both for streamer and "highly-saturated avalanche" operation (see Table II). With respect to the streamer mode, avalanche operation gives a smaller content of impurities and a spectacular decrease of HF content. HF being a source of potential problems [9], these results send us a positive message in terms of ageing.

V. Conclusion

The possibility of detecting avalanche signals with the FEE designed for the streamer operation of the RPCs used in

TABLE II

CHEMICAL ANALYSIS OF EXHAUST GAS

	avalanche	streamer
HF (μg/l)	0	30
% of impurities	0.091	0.549

the ALICE dimuon trigger was investigated. The preliminary results indicate that with a highly quenched gas mixture, a safe operation plateau of about 400 V can be achieved. In this voltage range, the time resolution and the cluster size for strips width ≥ 2 cm were found to be similar to the ones in streamer mode. Only for 1 cm strips there is an increase of the cluster size. Chemical gas analysis indicate a small content of impurities and in particular of HF molecules. Ageing tests for RPCs operated in "highly-saturated avalanche" are at present under ways at GIF [7].

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