ALICE /98-16
Internal Note /DIM
March 1998

RPC tests for the ALICE dimuon trigger

A.Baldit, N.Bastid, G.Blanchard, P.Dupieux, B.Espagnon, J.Fargeix, F.Manso, V.Ramillien, O.Roig - **LPC Clermont-Fd**

L.Luquin, A.Rahmani - **Subatech Nantes**

R.Arnaldi, L.Bardi, P.Cortese, N.De Marco, M.Gallio, A.Musso, A.Piccotti, E.Scomparin, C.Soave, E.Vercellin -**INFN - Torino**

1. Goal of the tests

The RPC (Resistive Plate Chamber) detector [1,2] is a possible candidate for the ALICE dimuon trigger. We have started a first round of cosmic rays and beam tests to optimize the detector according to our requirements. The results are reported in this note.

The main requirements for the dimuon trigger detector [3] are :

- ❒ Efficiency > 95%
- ❒ Flux capability > 100 Hz/cm^2 (FLUKA simulations)
- ❒ Time resolution < 2-3 ns
- ❒ Cluster size < 1.5 (mean number of adjacent strips fired) with ~2cm wide strips

These parameters are a priori compatible both with the streamer and proportional regime of the RPC's. We started our R&D program essentially in **STREAMER MODE** even though some preliminary tests in proportional mode were also done.

The preliminary RPC gas optimization for streamer mode has been done with cosmic rays. Gas mixtures which give small pulses, and hence a better flux capability and smaller cluster size, have been investigated. Two different gas mixtures for streamer mode were finally selected for a beam test. The results of this test concerning the parameters listed above are given in this note. Another goal of this beam test was to operate a RPC in the vicinity of a thick lead absorber, i.e. in condition close to the one in ALICE. The absolute background yield has been measured and compared with the one predicted by the simulations.

2. RPC gas studies for streamer mode

2.1 Cosmic ray test set-up

We used a 50×50 cm^2 single gap RPC with strips 3 cm wide terminated by a 50 Ω resistor at one end and connected to the Front End Electronics (FEE) at the other end. The trigger consists of a coincidence of 3 scintillators Sc1, Sc2 and Sc3 which matches the geometrical acceptance of one strip of the RPC (so-called “central strip”, see Figure 1).

The efficiency is defined as the ratio N_2 / N_1 with :

- N_1 : coincidence counting rate of the scintillators
- N_2 : coincidence of scintillators and chamber (taking actually the logical OR of 5 strips centered around the central strip).

We define the “neighbour efficiency” , removing the central strip when counting N_2 : small values of the neighbour efficiency are obviously correlated with a small cluster size.

The shape of the RPC signal is also studied.

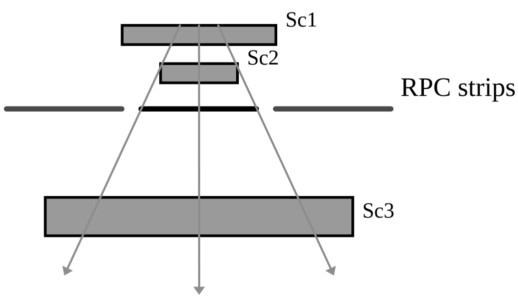


Figure 1 : schematic view of the experimental setup for the laboratory tests.

2.2 Results

Mixtures with different percentages of Argon, Isobutane (C4H10), Forane (C2H2F4) and SF6 are tested.

The running HV is chosen about 400V above the “knee” of the efficiency curve and corresponds to a RPC efficiency close to 100% (apart from geometrical inefficiency). The discriminator thresholds in the FEE are set at 35 mV.

Some results of these analyses are summarized in table 1. The mixture Ar 49%, Isobutane 7%, Forane (C2H2F4) 40%, SF6 4% (line 2 of table 1) gives the best results i.e. good efficiency, low neighbour efficiency, small charge and very stable pulses. Two other gas mixtures more usual for streamer mode are listed for comparison. The mixture without Forane (line 1 of table 1) gives quite good results too but the pulses exhibit a lot of secondary peaks. The mixtures without SF6 (line 3 and 4 of table 1) are quite different, showing the necessity for the addition of a small percentage of a very electro-negative gas like SF6 to reduce the pulse charge.

GAS	HV (V)	plateau efficiency	neighbour efficiency	charge (pC)	time resol (ns)	mean amplitude (mV)
Ar/ISO 80/20 SF6 4%	7300	94%	13%	70 ± 40	< 2	144 ± 51
Ar 49% ISO 7% Forane 40% SF6 4%	9500	94%	11%	48 ± 25	< 2	113 ± 44
Ar/ISO 70/20 Forane 10%	6700	92%	46%	330 ± 160	< 2	393 ± 173
Ar 10% ISO 7% Forane 83%	10000	94%	15%	106 ± 43	< 2	183 ± 53

Table 1 :Parameters of the gas study in streamer mode.

3. Beam test

3.1 General test conditions

They are divided in two parts called “efficiency test” and “absorber test”. The set-up for the two parts of the beam test are quite different and will be described in the corresponding sections. Here are given some general common conditions.

We have used two pion beams of 120 GeV and 60 GeV. The beam intensity is adjustable with collimators and its spatial definition, at the target level, can be tune from a focused /unfocused ($\sigma \approx 36$ mm) beam.

We used a 50×50 cm^2 single gap RPC equipped on both side of the gas gap with strips 2 cm wide (pitch 2.3 cm) opened at one end and connected to the Front End Electronics (FEE) at the other end. The bakelite resistivity of the chamber, which is a relevant parameter for the flux capability, is $\rho \sim 8\ 10^{11}\ \Omega$.cm. The RPC is placed on a motorised table.

The online control and data acquisition was done with a HP workstation. The main data written on tape were :

- the hit patterns of the vertical and horizontal strips
- beam counters (trigger number, flux ...)
- event time within the burst
- the ADC and TDC value of the vertical strips
- the burst scalers - beam counters and RPC information

3.2 Efficiency test

The experimental set-up is sketched in figure 2 . The CRV (Vertical) and CRH_i (horizontal) scintillators are placed just behind the RPC chamber. The CRV (2 cm wide) geometrically covers one vertical strip, the so called « central » strip. The coincidences CRV- CRH_i define three areas on the chamber corresponding to three different beam particle fluxes. These areas, of a few cm^2 each, are named σ_1, σ_2 and σ_3 respectively from the higher to lower fluxes : σ_1 is centered around the beam axis, σ_2 and σ_3 are distant respectively of 4 and 9 cm from the beam axis. A large X-Y scintillator hodoscope of 40×40 cm^2 covers almost all the chamber.
The trigger is defined by the coincidence of $S1\times CRV\times X\times Y$. All the results are obtained with an unfocussed beam sent directly on the RPC.

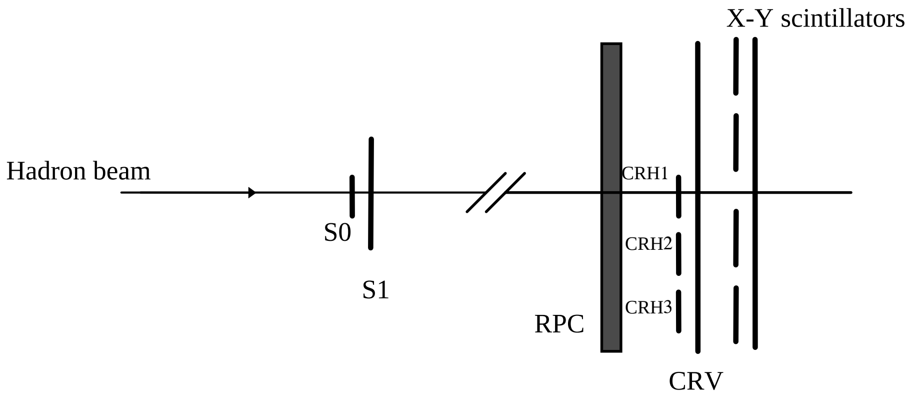


Figure 2 : schematic view of experimental setup for the efficiency test (detectors are not drawn at the same scale)

3.2.1 Streamer mode results

The signals of all horizontal strips were transferred in the counting room through long coaxial cables (60 m). In the vertical direction, 5 strips around CRV are read-out (CRV takes part in the trigger). The vertical strips pulses are transferred in the counting room through high quality coaxial cables (minimum signal attenuation). The discriminator thresholds applied to the vertical and horizontal signals are 50 mV and 70 mV respectively because of the different coaxial cable quality and attenuation. The threshold values and also the HV applied to the chamber are slightly different from the ones given in section 2 for the same gas mixture due to different setup conditions.

After discrimination, the vertical and horizontal strip signals are sent to a pattern unit module. The pulse charge and time resolution are measured on the vertical strips by mean of an ADC (0.25 pC/ch) and a TDC unit (0.1 ns/ch) respectively, in each zone σ_i . For the vertical strips, constant fraction discriminators were used.

The results for 3 gas mixtures are shown in figure 3. Without Forane a good efficiency (>95%) is reached only for very low particle rate on the RPC ($\leq$ 1Hz/cm^2). The gas mixture composed of Ar 49%, Isobutane 7%, Forane 40%, SF6 4% (line 2 of table 1) give better results (figure 3). The efficiency is good up to 5 Hz/cm^2. The flux capability of the RPC is found to be quite low.

The sensitivity of the efficiency on the flux is due to a large part to the high resistivity of our test chamber. This time, necessary to recharge the bakelite plate surface after a spark, is determined by the current that can flow across the parallel high resistivity planes and then is strictly related to the bakelite resistivity. Lower resistivity RPC (10^9 and 10^{10} Ω cm) are under construction and will be tested in 98 in order to investigate the possibility of improving the rate capability of a RPC working in streamer mode.

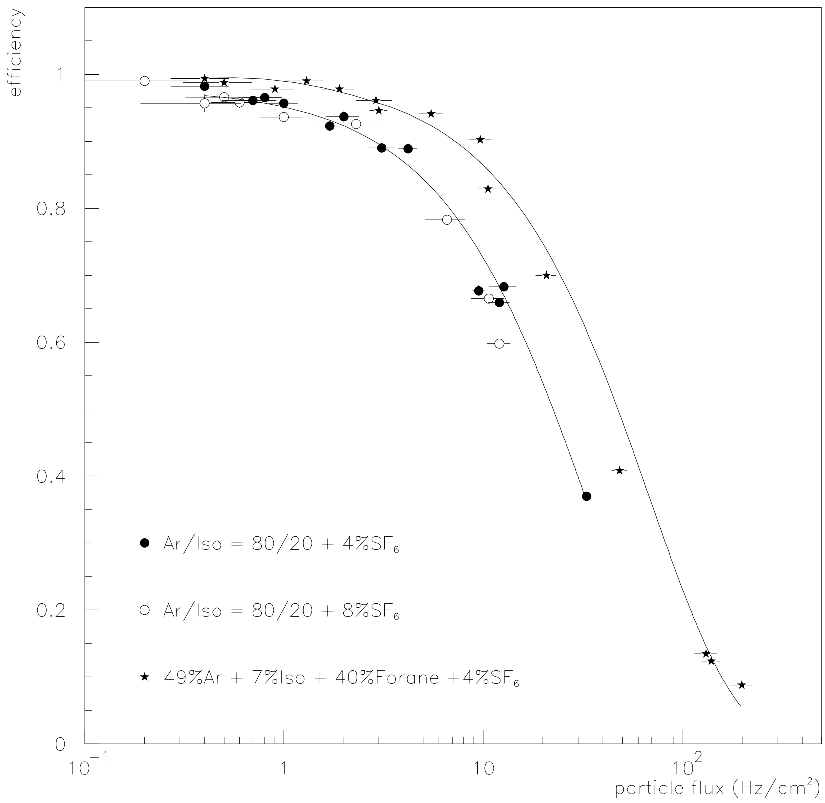


Figure 3 : RPC efficiency as a function of the particle flux in streamer mode for three different gas mixtures.

In what follows, we only show results with the Ar 49%, Isobutane 7%, Forane 40%, SF6 4% gas mixture which gives the best performance with respect to particle flux.

Chamber efficiency versus high voltage is plotted in figure 4 with the percentage of events with only one vertical strip (the « central » strip) fired. In this measurement, the chamber was exposed to a particle flux of 1.8 Hz/cm^2 in the σ_1 zone.

Consequently, a 9000 V operating high voltage was chosen.

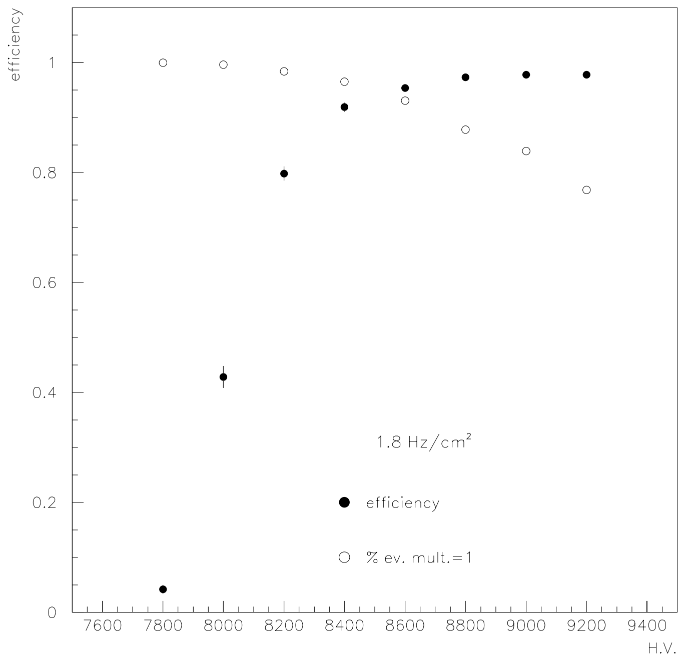


Figure 4 : RPC efficiency and percentage of events with only one vertical strip fired versus high voltage for a particle flux of 1.8 Hz/cm^2.

In figure 5 the RPC efficiency as a function of the particle flux is plotted for the chamber operating at 9000 V. The full points correspond to the efficiency measured in the σ_1 zone (same as figure 3). The curve is a fit of the values.

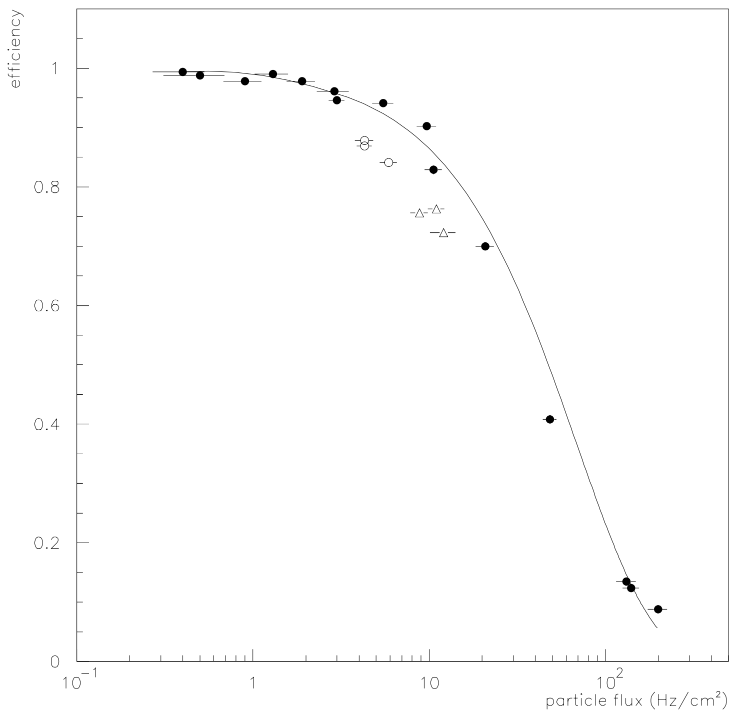


Figure 5 : RPC efficiency versus particle flux.
full circles : efficiency in σ_1;
open triangles : efficiency in σ_2 with flux on σ_1 >100 Hz/cm^2 ;
open circles : efficiency in σ_3 with flux on σ_1 > 100 Hz/cm^2.

.

The effect of a high particle rate on σ_1 induces an efficiency drop on the nearby areas σ_2 and σ_3 illuminated at lower rates (figure 5 : open points, corresponding to the efficiencies in the σ_2 and σ_3 zone). The incident flux ratio between σ_1 and σ_2 (σ_1 and σ_3) are about a factor 5 (20). This effect, even though not dramatic, means that the chamber recharging process is not just local, but current may also flow on the surface of the bakelite plate.

To check the resitivity effect upon chamber efficiency, some water vapor was introduced inside the RPC bubbling the gas mixture through water. After several hours, the water vapor absorbed by the bakelite surface has reduced the plane resistivity and new efficiency measurements were performed. An improvement of a factor 2 at least in the RPC rate capability was obtained confirming that the relevant parameter is indeed the resistivity.

The evolution of the efficiency during the burst is measured. The burst duration (2.4 s) is divided into 4 equal time intervals and the chamber efficiency is evaluated in each interval. The results of these measurements, reported in figure 6, show that the decrease of the efficiency during the burst is more important at higher rates, an then an increase of the slope for the last three burst intervals with respect to the first one. This effect is again produced by a too long recharging time and must be taken into account for the future as the LHC beam conditions will correspond to a continuous irradiation of the chamber.

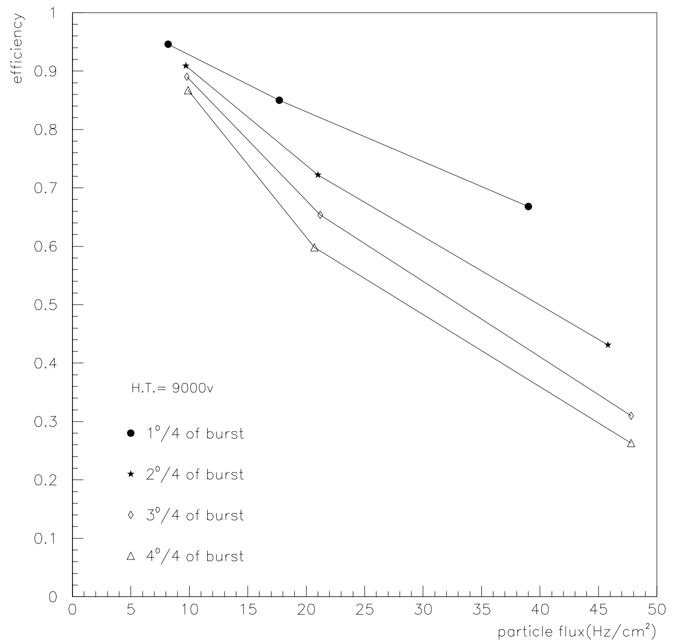


Figure 6 : RPC efficiency as a function of the particle flux in four equal time intervals of the burst duration (0.6 s each).

Figure 7 shows the multiplicity distribution of the vertical strips of the RPC chamber at a high voltage of 9000 V : a mean value of 1.1 was obtained. Note that this value is not the cluster size since the CRV in the trigger imposes strong constraints on the geometry. The actual value of the cluster size is certainly larger.

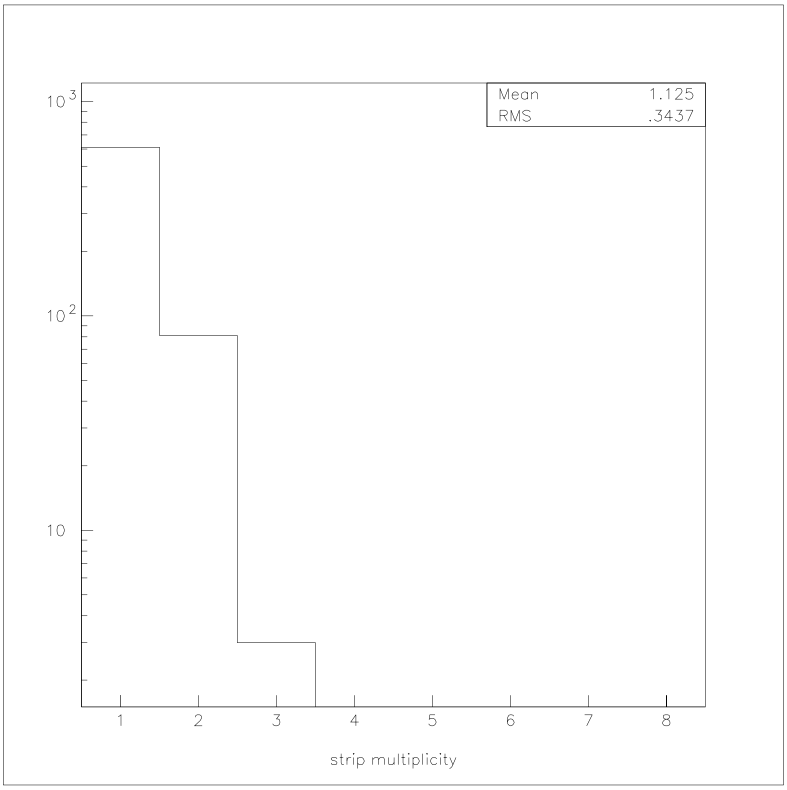
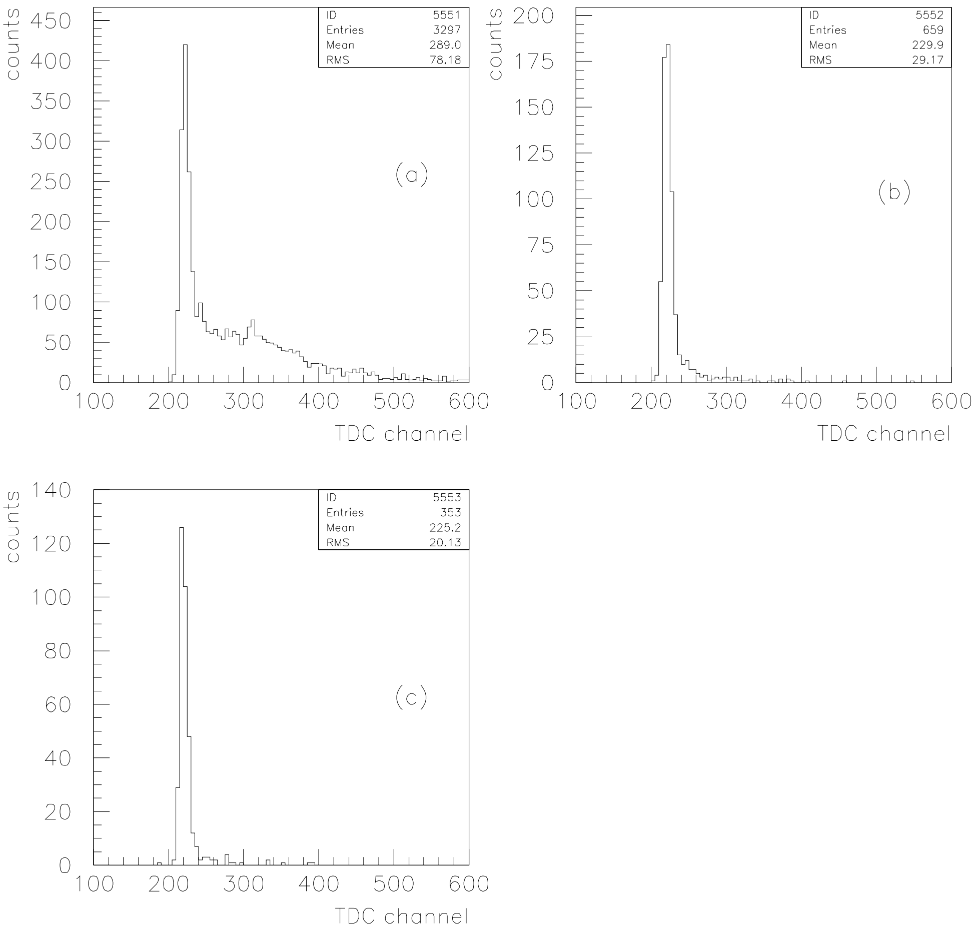


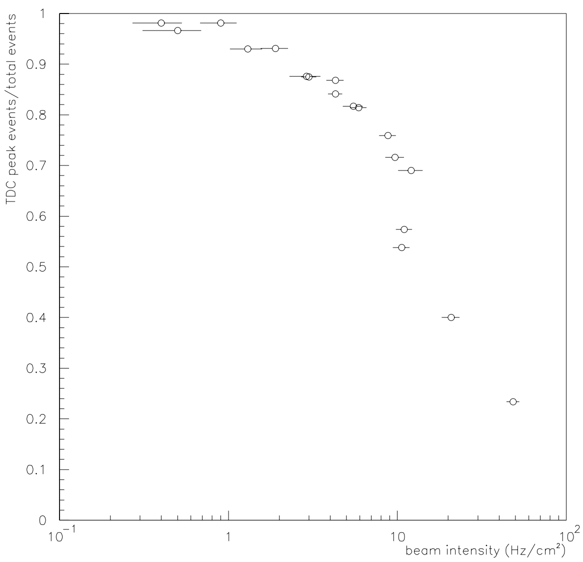
Figure 7 : Multiplicity distribution of the vertical strips of the RPC obtained for a particle flux of 2 Hz/cm^2 in σ_1.

The time resolution of the chamber, operating at 9000 V, was measured at different rates. The time distributions are presented in figure 8 for particle fluxes of 20 Hz/cm^2 (a), 3 Hz/cm^2 (b) and 1 Hz/cm^2 (c) : it is evident that besides a narrow peak (~ 1 ns rms) there is a tail of late signals which becomes more important for higher rates.

In figure 9 we report the ratio between the number of events in the peak and the total number of events : for fluxes larger than 5 Hz/cm^2 this ratio becomes lower than 0.85 as the number of late signals increases. This is due to the dependence of the streamer timing on the high voltage [4,5]. Since at large fluxes local drop of the high voltage in between the RPC planes occurs it reflects on the time spectrum we measure.



<u>Figure 8</u> : TDC distributions (0.1 ns/ch) for different particle fluxes :
(a) 20 Hz/cm^2, (b) 3 Hz/cm^2, (c) 1 Hz/cm^2



<u>Figure 9</u> : Ratio between the number of events in the TDC peak and the total number of events as a function of the particle flux

Figure 10 shows the r.m.s values of the time distributions as a function of the incident flux on σ_1 : the time resolution of the chamber is good (< 2 ns r.m.s) for low rates (~1Hz/cm^2) but quickly gets worse with increasing rate.

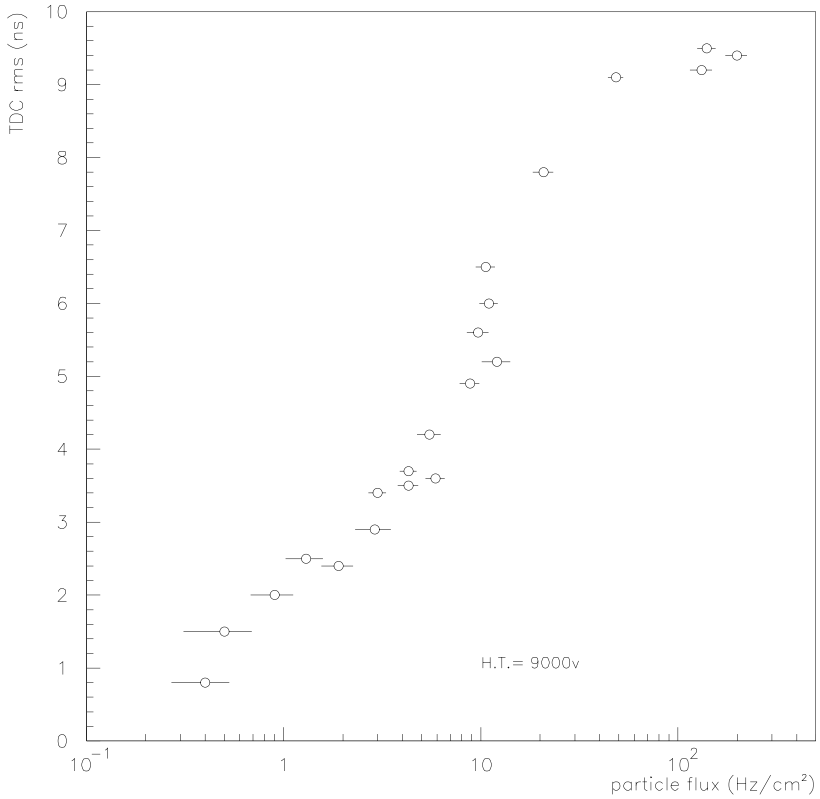
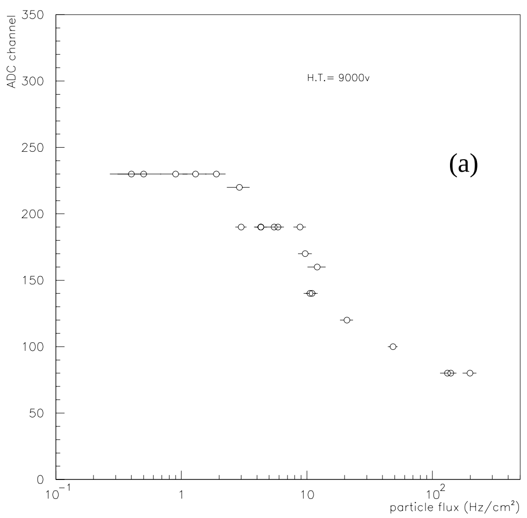


Figure 10 : r.m.s values of the TDC distributions as a function of the particle flux in the central zone of the RPC chamber

A collected pulse charge of ~50 pC (peak value) is measured when the chamber is exposed to low rates (figure 11 b). At 9000V multi-streamer signals are also observed in about 15% of the events (see the second peak of the ADC distribution around 300-400 channels). The charge is plotted in figure 11 (a) as a function of the incident flux on σ_1 . It is clear that the decrease of the charge for the rates higher than 5 Hz/cm^2 is the result of a local high voltage reduction across the gas gap again due to the long recharging time of the chamber. This effect is obviously correlated with the efficiency drop versus the incident flux previously described and the deterioration of the timing performances.



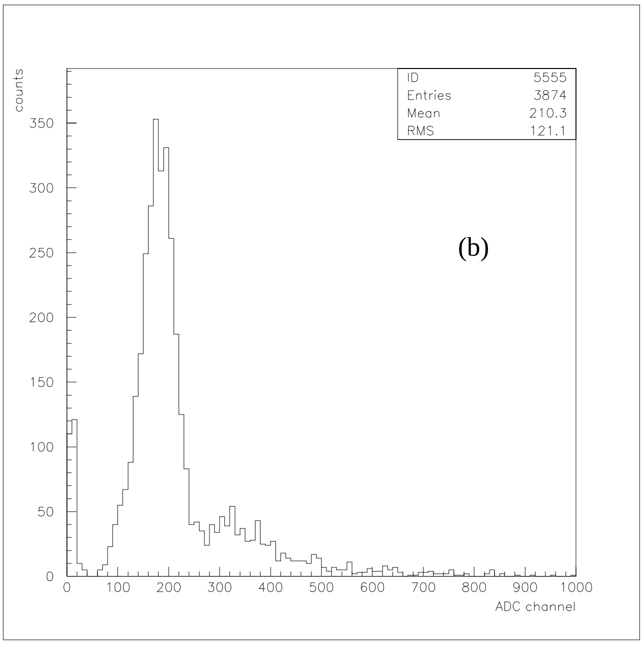


Figure 11 : (a) : collected charge vs particle flux in the σ_1 zone.
(b) : example of charge distribution measured on the central strip (5,5 Hz/cm^2 on σ_1). The events around ADC=0 correspond to inefficiencies.

3.2.2 Preliminary results in Proportional mode

As stressed previously, our main effort for this round of tests was devoted to the streamer mode. However, in order to have a very first idea on the proportional operating mode of a RPC, we have equipped the 5 vertical strips (centered around CRV) with amplifiers (amplification $\times$ 100). Once again, the gas mixture, the noise reduction, the amplification and the thresholds (70 mV after amplification) were not optimized.

These results were obtained with the gas mixture 10% Ar, 7% isobutane and 83% Forane.

Figure 12 shows the efficiency curve as a function of high voltage. The particle flux on σ_1 is 40 Hz/cm^2 . When the RPC is efficient, the percentage of events with only one strip fired as well as the percentage of streamers are also shown on the same figure.

The working high voltage has been chosen at 8400 V where the RPC efficiency is 97 % and 50 % of the events have only one strip fired. At this point the percentage of streamers is negligible. We can not tolerate a too large proportion of streamers (> 1-2 %) because, after amplification, a large number of strips would be fired, deteriorating the cluster size.

To evaluate the fraction of streamers versus high voltage, one strip is equipped with an attenuator of 30.5 dB and the signal is sent to an ADC.

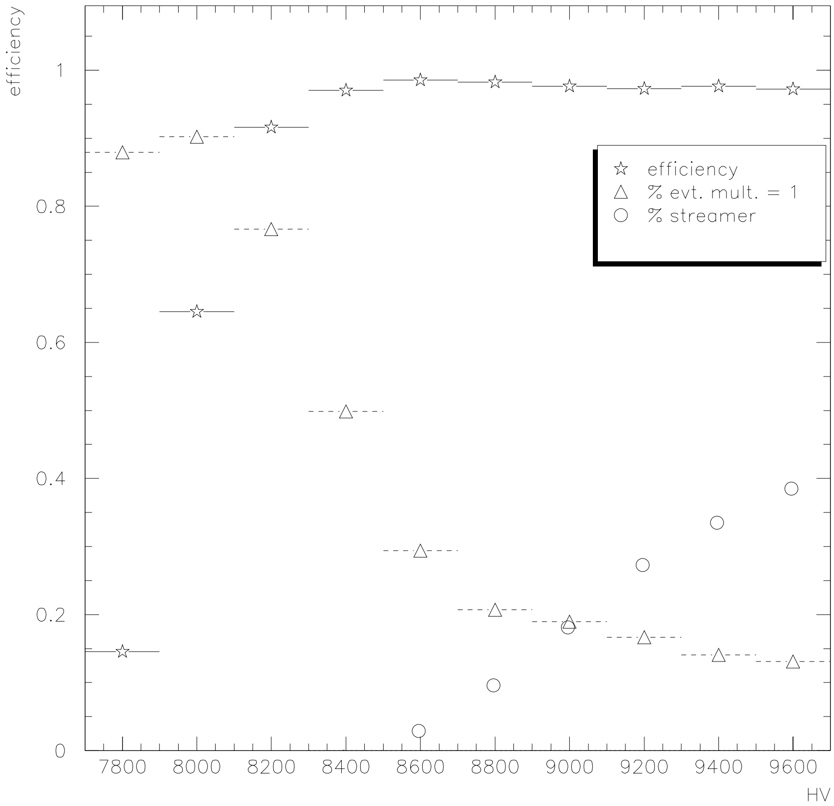
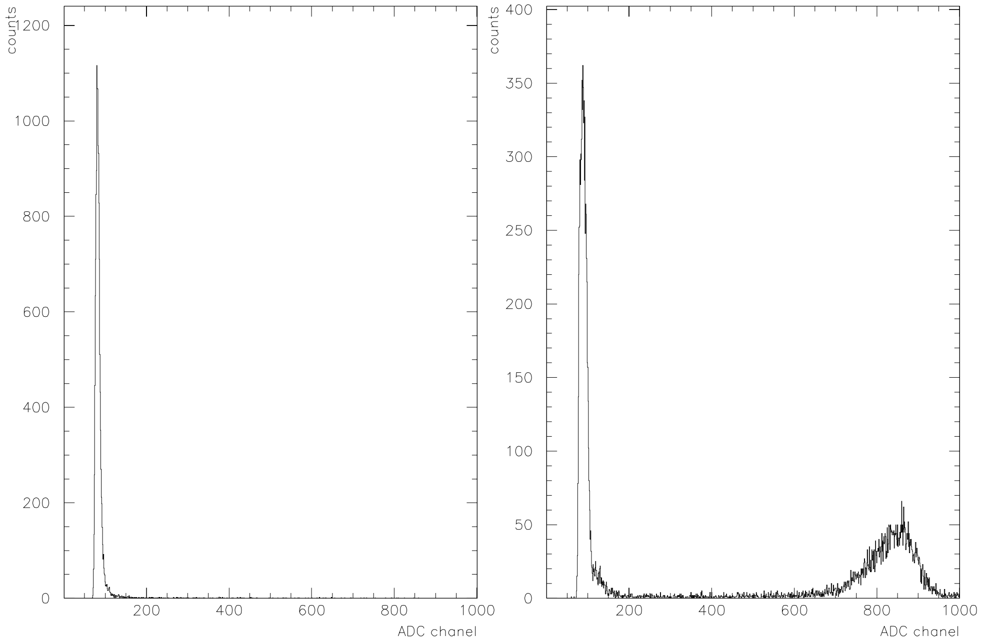


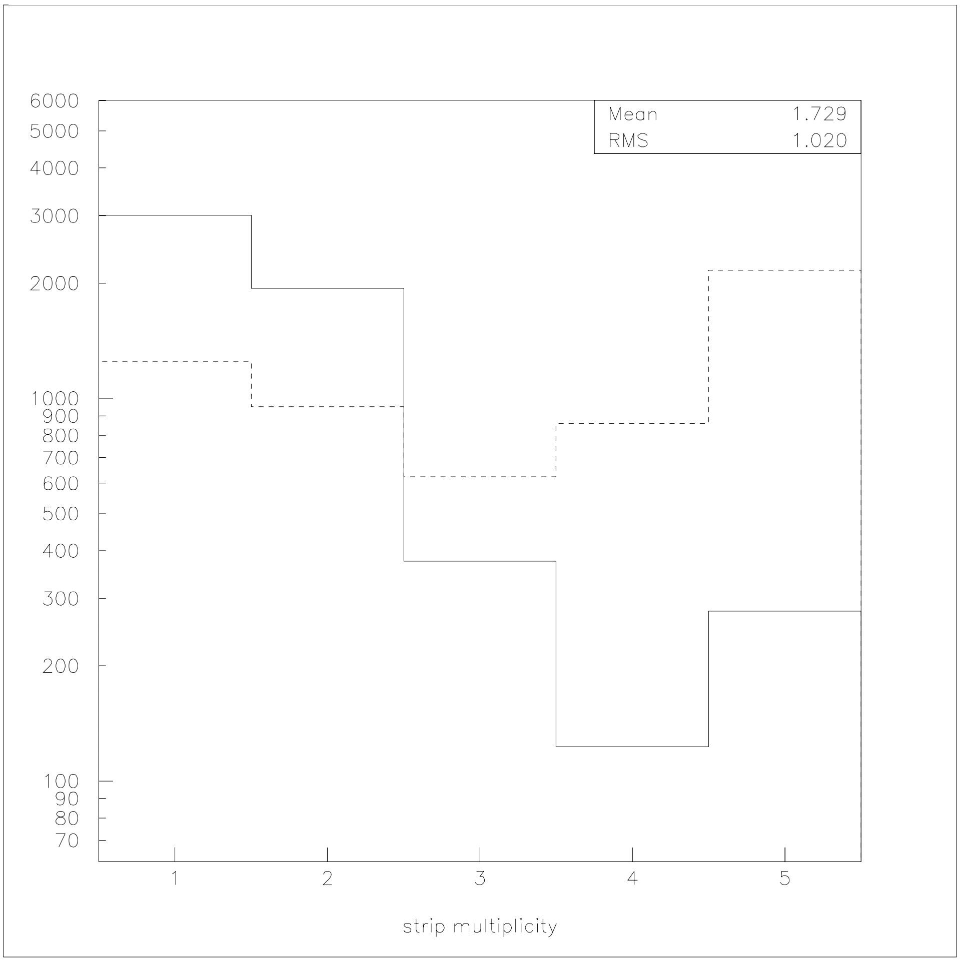
Figure 12 : RPC efficiency, proportion of events with only one strip fired and proportion of streamers are represented as a function of the high voltage for a particle flux of 40 Hz/cm^2 in the σ_1 zone.

Figure 13 clearly shows the big proportion of streamers at 9600 V (right peak) whereas no secondary peak is observed at 8400V.

The multiplicity distribution of fired strips corresponding to the proportional mode is presented in figure 14 (HV=8400V). The maximum multiplicity is of course 5 since only 5 strips are used. The mean multiplicity is about 1.7 strips (3.4cm). This number is to be compared to 1.1 strips obtained in streamer mode (figure 7), on the other hand for HV = 9000 V the mean multiplicity is significantly higher, of the order of 3.3 ± 1.6 strips. This is a consequence of the larger fraction of streamer at higher high voltage.



<u>Figure 13</u> : ADC distributions with attenuation 30.5 dB (left 8400 V, right 9600 V)



<u>Figure 14</u> : Multiplicity distributions of fired strips in proportional mode : full line for the operating high voltage (8400 V) and dashed for a higher high voltage (9000 V).

The chamber efficiency in streamer and in proportional mode as a function of the incident particle flux in the central region σ_1 are compared figure 15. For the streamer mode, we show the results of the best gas mixture Ar 49%, Isobutane 7%, Forane 40%, SF6 4%. For a flux of 50 Hz/cm^2 in the central region of the RPC, we obtain in the streamer mode an efficiency of 35% to be compared to 95% in the proportional mode. This is a well known effect due to the fact that the pulses are smaller in proportional mode [6] : the amplification is done by the electronics while it is done by the gas mixture in streamer mode.

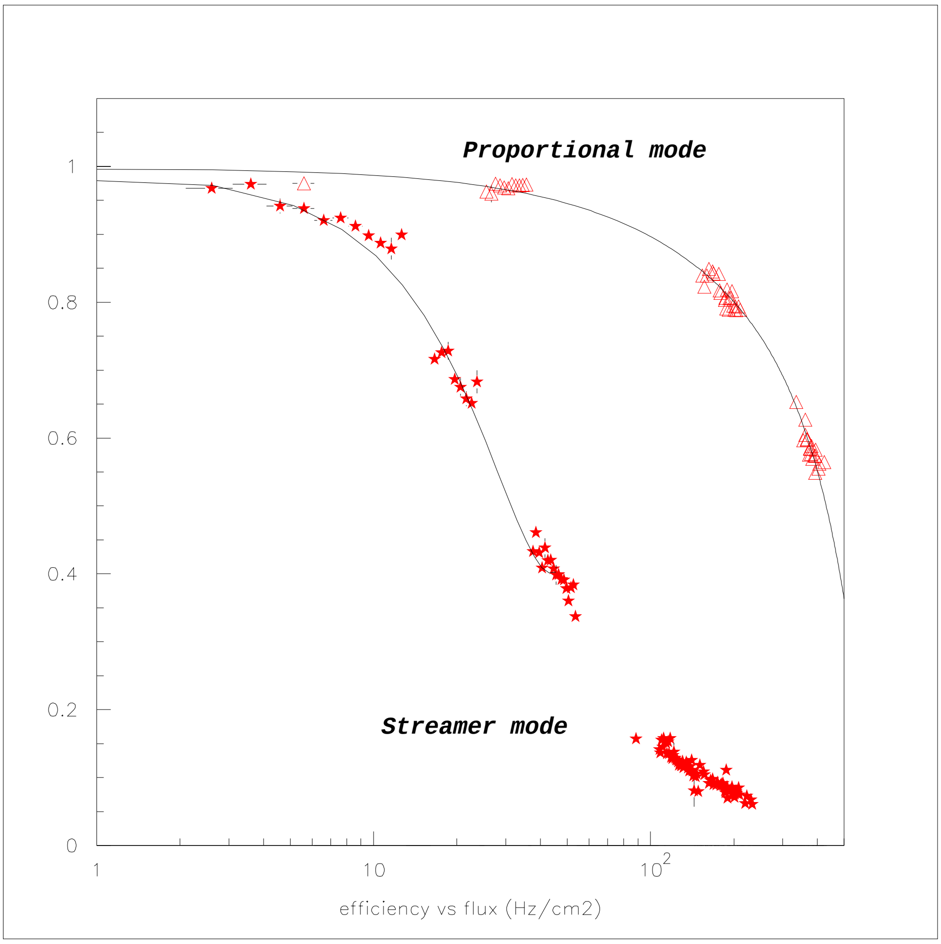


Figure 15 : RPC efficiency as a function of the particle flux for the streamer and the proportional mode.

Figure 16 shows the evolution of the time resolution with the incident particle flux (40-400 Hz/cm^2) and figure 17, the time distributions in the σ_1 zone for 40 Hz/cm^2 and 400 Hz/cm^2. Contrary to the behavior in streamer mode, the time distribution stays Gaussian in this range of incident flux. The time resolution is about 0.8 ns at 40 Hz/cm^2 and 1.5 ns at 400 Hz/cm^2.

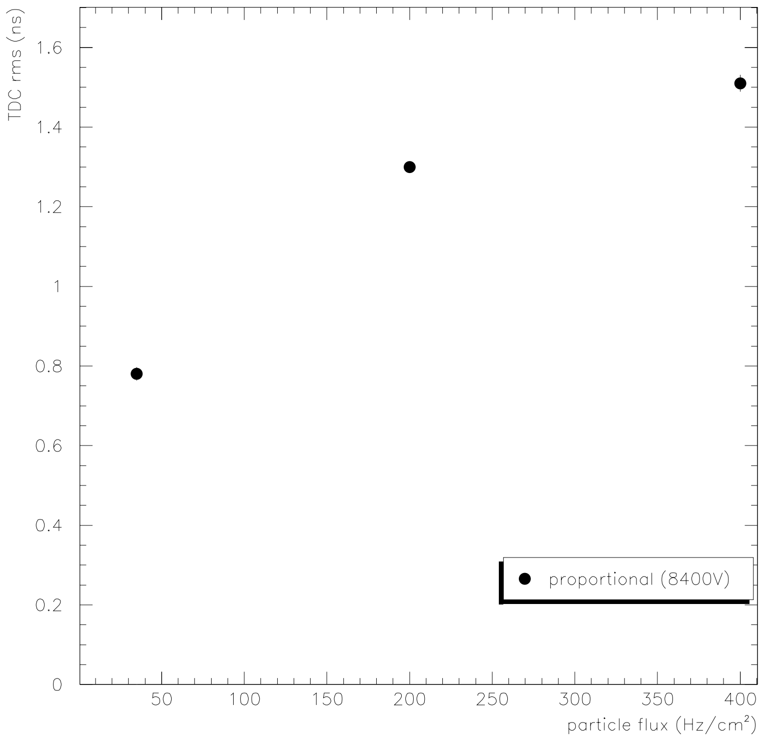


Figure 16 : r.m.s value of the TDC distributions as a function of the particle flux in the central zone of the RPC chamber

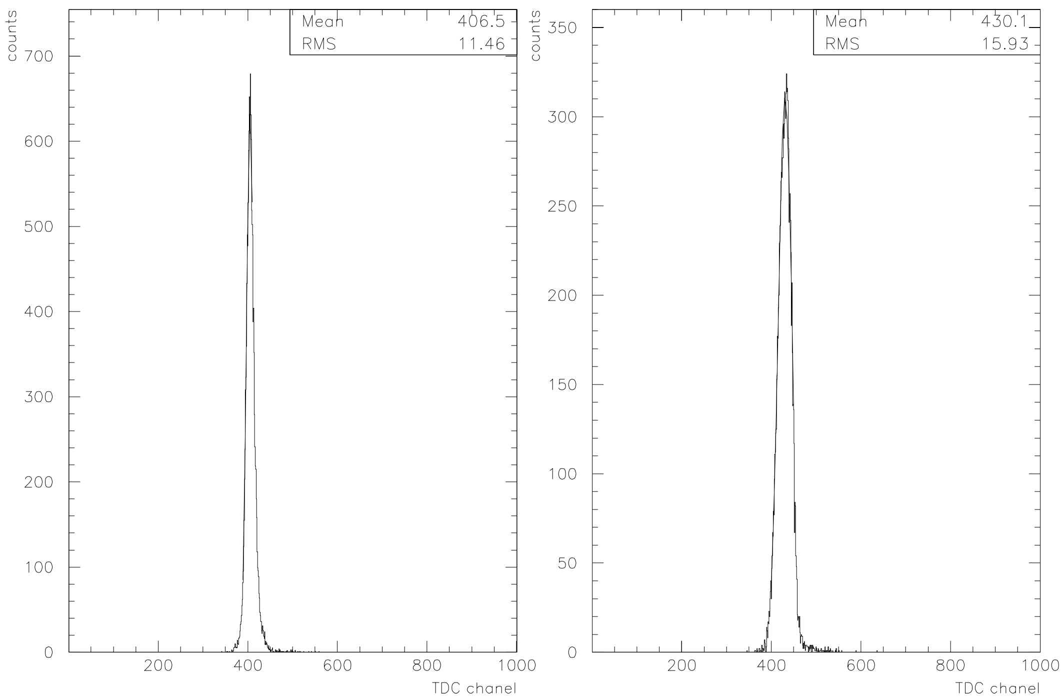


Figure 17 : TDC distribution in proportional mode (left = 40 Hz/cm^2, right = 400 Hz/cm^2).

The collected pulse charge measured by the ADC is about 0.5 pC (figure 18). It decreases when the incident particle rate increases (see figure 19) . The explanations of the phenomenon have been previously given in the streamer part of this paper.

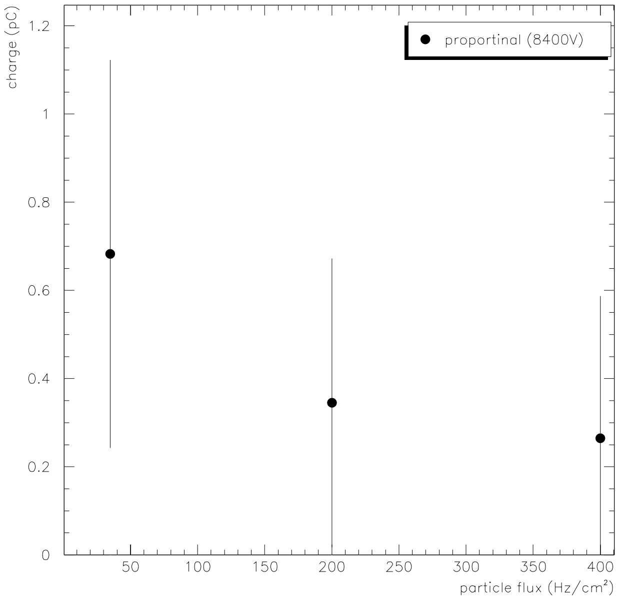


Figure 18 : Mean value of the collected charge as a function of the particle flux.

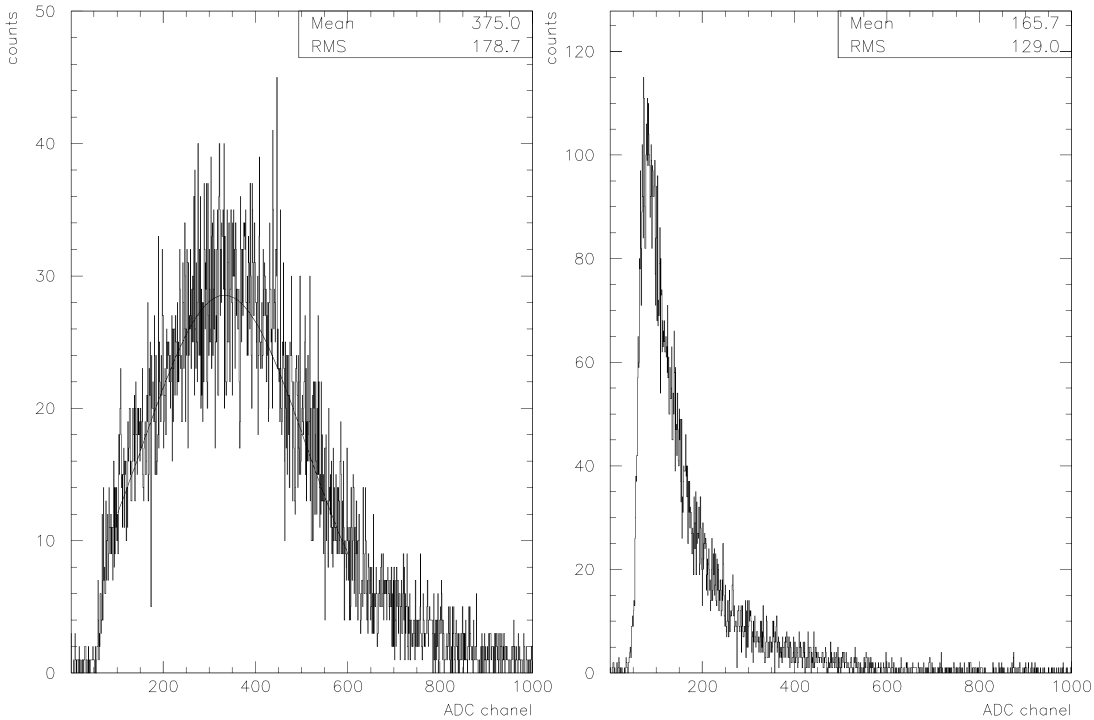


Figure 19 : Charge distribution in proportional mode (left = 40 Hz/cm^2, right = 400 Hz/cm^2).

3.3 Absorber test

In ALICE, energetic hadrons (~100 GeV) emitted during the ion collision intercept the beam shielding and develop hadronic showers. The charged particles leaking out from this absorber are responsible for most of the background on the trigger.

For this reason, in the second part of this test, we studied the behavior of the RPC operating in the vicinity of a thick hadron absorber. The goal of the experiment is twofold :

- cross-check the simulation absolute yields in term of hits on the RPC
- operate the RPC in such "unusual" conditions : the simulations indicate for instance that the incident angle of the particles on the detector is peaked around 50° .

The hadron beam is dumped in a thick lead absorber which simulates the ALICE beam shielding. The RPC is placed on the side of the lead absorber, orthogonally to the beam, at 60cm from its entry face (figure 20). The lateral thickness of lead *e* between the beam axis and the RPC was varied between 20 and 40 cm.

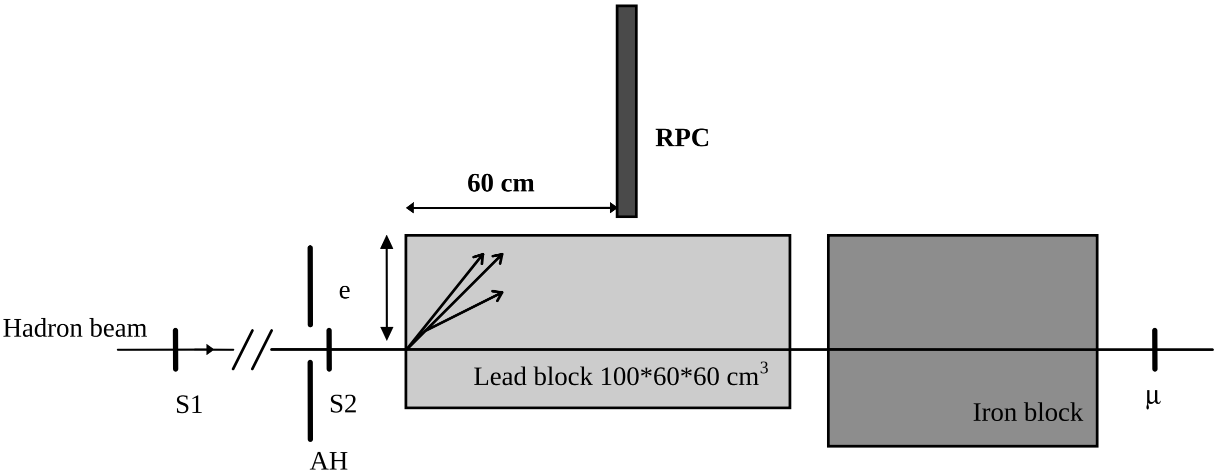


Figure 20 : experimental setup for the absorber test.

The RPC chamber was the one used in the efficiency test (50*50 cm^2). The first strip is 15 cm away from the absorber due to the mechanical support. The test is done in **streamer mode**.
We used a focused hadron beam at 60 and 120 GeV. The trigger is defined by S1, S2 (2*2 cm^2) , the anti-halo AH and the μ counter which rejects the beam muons.

3.3.1 Results

The lateral punchthrough distribution was measured with 22 vertical strips. We show results for the gas mixture Ar 49%, Isobutane 7%, $C_2H_2F_4$ 40% and SF_6 4% (see table 1).

We analyze the background radial distributions as a function of beam energy (60 and 120 GeV) and for 20, 30 and 40 cm lateral lead thickness (figure 21).

The particle rate on the RPC is very low (< 10^{-1} Hz/cm^2) and no flux effects are foreseen.

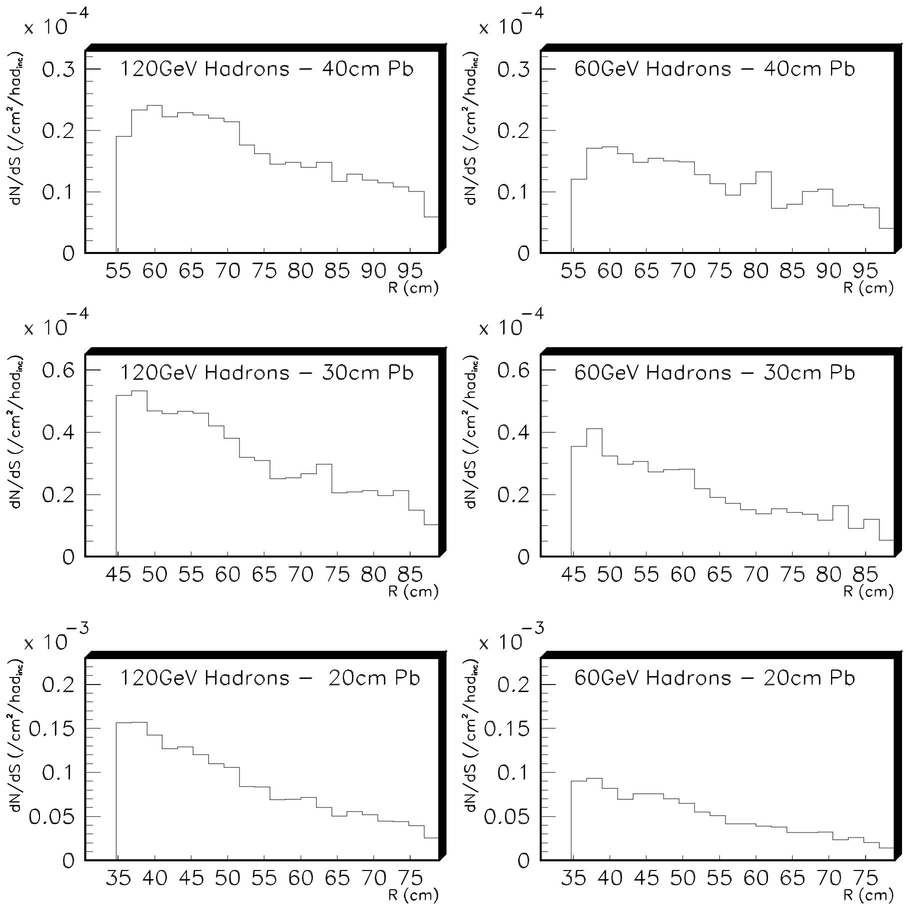


Figure 21 : Hit distributions per cm^2 and per incident hadron for 20, 30 and 40 cm lateral lead thickness and for a beam energy of 60 and 120 GeV.

The hit distributions on the RPC are normalized per cm^2 and per incident hadron. The abscissa (R in cm) represents the lateral distance of the strips from the beam axis. We observe a maximum near the lead absorber. The rate dN/dS increases with the beam energy and decreases as the lateral thickness of lead increases. Such results are in agreement with the simulations and with measurements done in 96 with a Multi-Wire Proportional Chamber [7].

Simulations of the experimental test are done using the GCALOR and the FLUKA packages. GCALOR uses the GEANT code for the electromagnetic interactions and a part of the CALOR code replaces GHEISHA for the hadronic interactions. This improved version of GEANT is used to produce and track the neutrons (MICAP code) with a 10^{-3} eV energy threshold. The energy threshold of photons and charged particles is 10 KeV. Most of the layout material which could increase the background on the RPC chamber is taken into account in GEANT. A simplified geometry is introduced in FLUKA to simplify the programmation. A charged particle is detected by the RPC if its energy loss in the chamber gas is greater than 10 eV and if the hit is produced before 500 ns with respect to the parent particle. The results are independent of energy detection threshold up to 30 eV.
The GCALOR simulation shows that photons and neutrons interact mainly in the Bakelite material, respectively by Compton effect and recoil proton production. The interactions in the gas are important only for the lowest energetic part of the neutral particles. Hence the RPC efficiency to photons and neutrons is not very sensitive to the kind of gas mixture in the chamber.

Simulations of the hit distributions are made with a beam of 120 GeV hadrons and two lateral lead thicknesses of 20 cm and 30 cm, and are compared with the experimental data (figure 22).

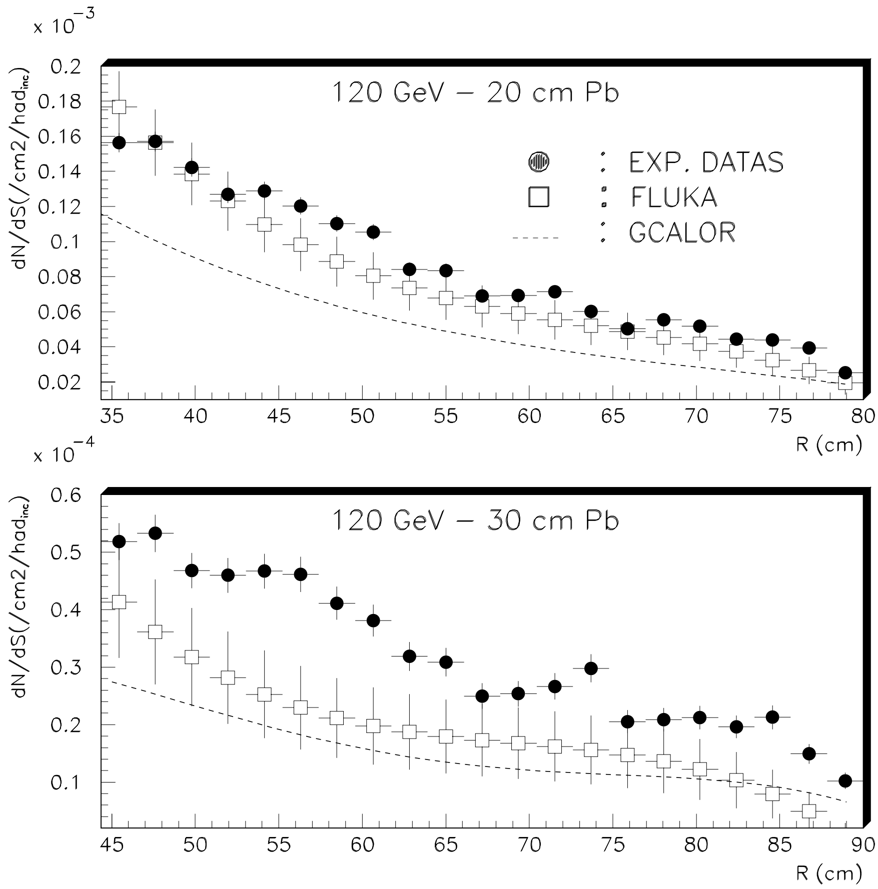


Figure 22 : Comparison between the experimental hit distributions and the results of FLUKA and GEANT-CALOR simulations of the test.

For the 20 cm lateral lead thickness, the FLUKA simulation is in good agreement with the data, both in shape and in absolute value. The simulation shows that the slope of the lateral hit distribution depends appreciably on the material environment. GCALOR underestimates the experimental datas by a factor ~ 1.5 but reproduces the shape of the distribution.
The agreement simulation/experiment is worse in case of the 30 cm lead thickness for the absolute normalization as well as for the shape of the distribution.
An accurate description of the materials surrounding the experimental setup would be required to take better into account the low energy part of the background.
In conclusion, the GCALOR improves the results of the simulation compared to the standard version of GEANT [7] but the FLUKA code gives better results in all cases.

Another important point of this study is the cluster size obtained with the RPC chamber in these operating conditions. In figure 23 we present the cluster size and the cluster multiplicity in case of a 40 cm lateral lead thickness and a 120 GeV hadron beam. The mean value of the cluster size is 1.4 strips (strips 2 cm wide). This is quite satisfying under such operating conditions.

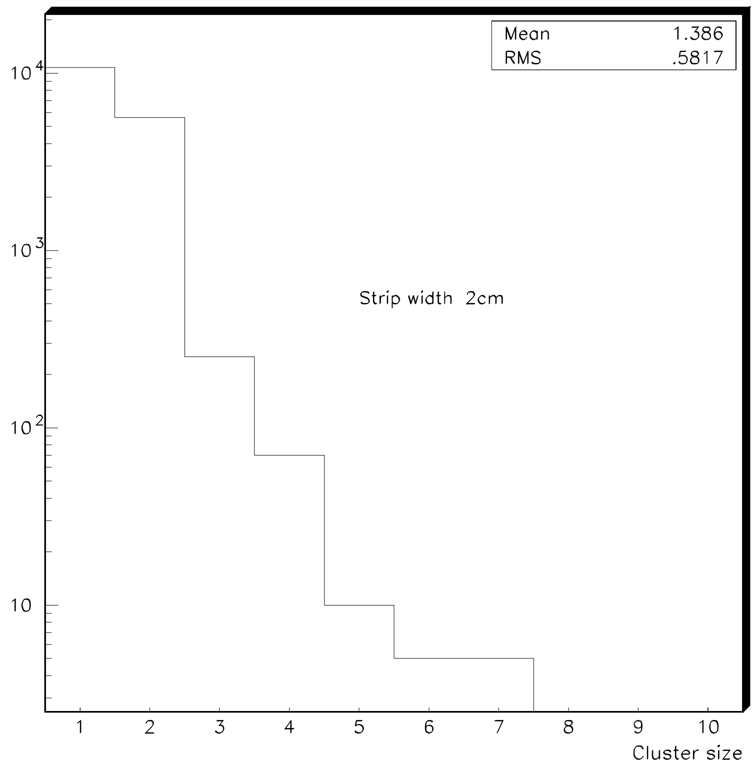


Figure 23 : Cluster size obtained in case of a 40 cm lateral lead thickness and a 120 GeV hadron beam.

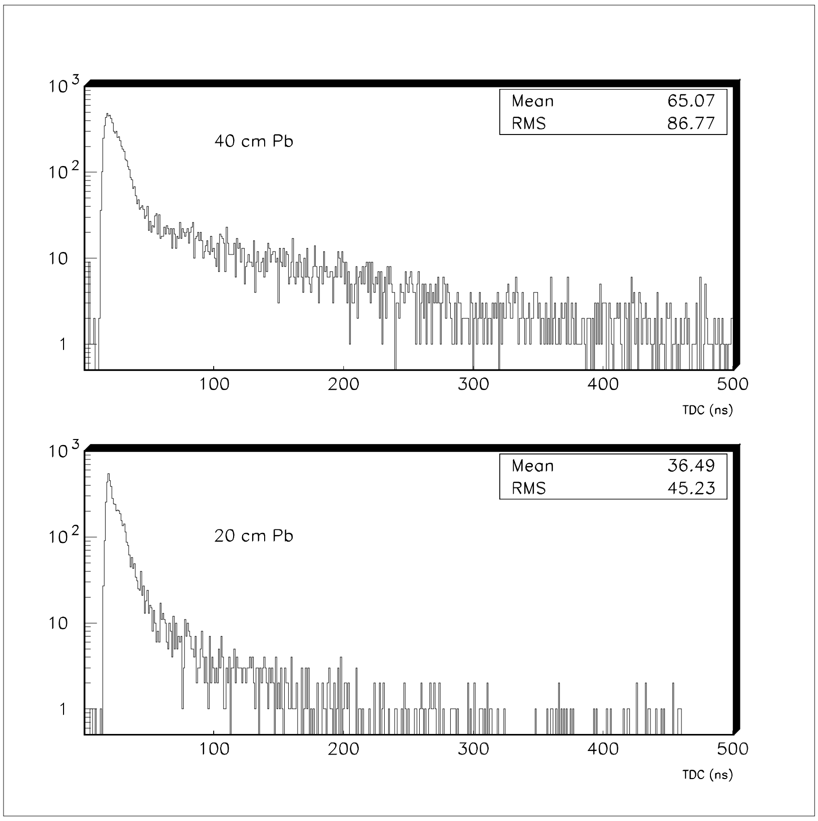


Figure 24 : Time distribution of the hits on the RPC for 20 and 40 cm lateral lead thickness.

We show in figure 24 the time distribution of the hits on the RPC, for 20 and 40 cm lateral lead thickness. The zero of the abscissa is arbitrary. Most of the events are contained in the first 50 ns but a long tail can be seen and becomes more pronounced for larger lateral lead thickness. These results are in agreement with the simulations : the tail is attributed to slow neutron interactions in the gas or in the chamber materials.
This spread in time is important because we propose in ALICE to reject a large fraction of this background by mean of a time cut of about 20 ns. Due to the different geometrical conditions, this spread in time will be much more pronounced in ALICE.

4. Conclusion

The results in streamer mode are quite encouraging. Lower resistivity RPC will however be tested in order to try to match our rate capability requirements which are not yet satisfied.
Systematic studies are started with cosmics in proportional mode. This year, we plan basically to repeat the beam test of 97 in this operating mode.

Comparisons streamer-proportional mode should then be available in the context of what is needed for ALICE. We hope of course that one of these two modes will satisfy the ALICE trigger detector requirements.

References

[1] R. Santonico et al, NIM 187 (1981) 377.
[2] R. Cardarelli et al, NIM A263 (1988) 20.
[3] The forward muon spectrometer. Addendum to the ALICE technical proposal, CERN/LHCC 96-32
[4] II International Workshop on the RPC in particle physics and astrophysics. (Pavia June 15 /93)
[5] III International Workshop on the RPC and related detectors. (Pavia Oct 11-12/95)
[6] A. Di Ciaccio et al, NIM A384 (1996) 222.
[7] A. Baldit et al., ALICE internal note / DIM / 96-14