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PERFORMANCE OF E771 RPC MUON DETECTOR

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The technique of Resistive Plate Counters, equipped with pad readout instead of strips, has been successfully used for the first time in a high rate environment. The performance of the muon detector of E771, based on this technique, is illustrated in detail, including the dependence of the efficiency on the local rate of incident particles.

1. – INTRODUCTION

The primary objectives of experiment E771 at Fermilab [1,2] are the production of beauty particles and the study of their decays by means of a high intensity, high momentum proton beam on a silicon target. The strategy adopted to detect beauty events is to trigger on dimuons coming from J/ψ produced at a secondary vertex.

The E771 detector is located in the High Intensity Lab at Fermilab and is an upgrade of the former E705 spectrometer. The current set-up includes a new 800 GeV/c beam line, a segmented silicon target, a silicon micro strip detector (12 planes), new drift chambers (CC/WC) with pad and strip readout and a muon detector made of Resistive Plate Counters (RPC). In addition, new Fastbus readout electronics, RPC based muon triggers, and a Data acquisition chain have also been implemented.

2. – MUON DETECTOR

The muon detector consists of three planes of RPC modules separated by hadron absorbers at the downstream part of the E771 spectrometer (Fig 1).

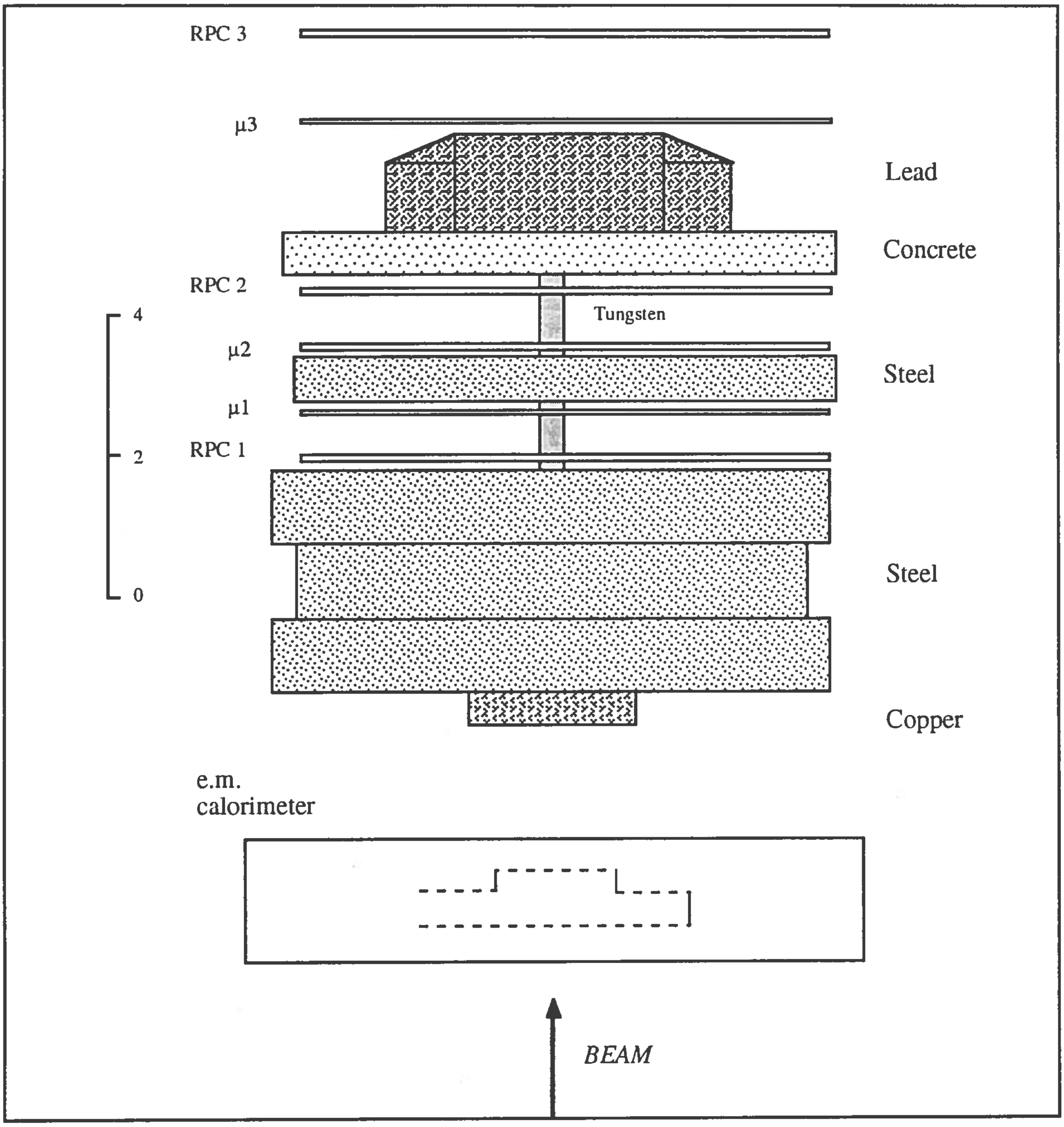

FIG. 1 – E771 Muon detector. Scale is in meters.

RPCs are thin gap (2 mm) gas devices [3] operating in streamer mode in a high uniform electric field (40 kV/cm). Their main characteristics are good time resolution, low cost and large area coverage. Figure 2 shows a cross sectional view of an RPC module. The counters are filled with a mixture of 53 % Argon, 42 % Butane and 5 % Freon 13B1. The charge produced by the streamer process is picked up by external copper pads facing the high voltage side. At the nominal setting of 8.2 kV the signals range from 100 to 200 mV (depending on the pad size) with a 3-4 ns rise time and 20 ns width. An aluminum frame surrounds the counters to ensure rigidity and to support the signal connectors and gas inlets and outlets.

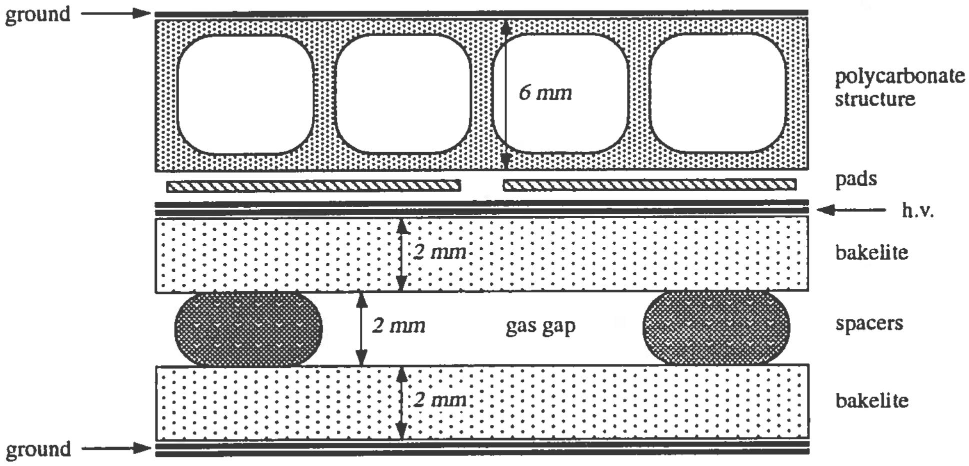

FIG. 2 – Cross sectional view of a Resistive Plate Counter.

Ten 2×1 m^2 RPC modules are assembled together to form a detector plane. Slight overlapping of the modules is necessary to recover dead zones along the perimeter of the detector due to the supporting frame. The beam plug in the first two muon planes has forced the construction of L-shaped modules in order to completely cover the area for the first two planes. A standard module is used for the third plane where no plug is present. Figure 3 shows the resulting pad configuration, identical for the three planes, as seen from the beam. The different pad sizes have been chosen as a compromise between good granularity (especially in the central region) where most of the flux is impinging, and multiple scattering in the hadron absorber. The pad surface is 6×6 cm^2 for the central modules and ranges up to 12×12 cm^2 in the outer regions.

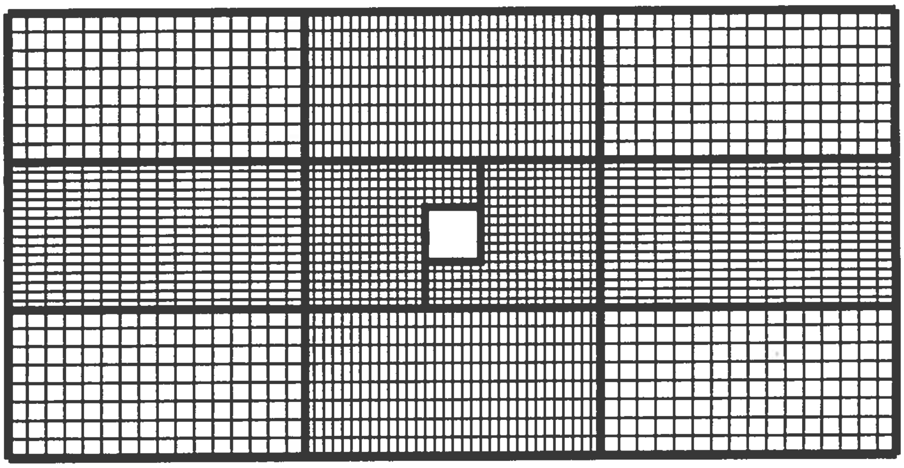

FIG. 3 – Pad configuration.

Mass flow meters control the gas mixture ensuring 1% stability and precision. Each counter is connected to a separate gas line, to a ball flow meter and to a high precision manometer (for mechanical reasons the large area of the RPC does not allow pressures higher than 2-3 mbar). A safety system set at 3.5 mbar (including the pressure drop after 60 m nylon tubing) prevents accidental build up of over-pressure along the lines.

A computer controlled system [4], which can operate up to 15 kV with 1 mA current limit, supplies the high voltage to the RPC modules and, through a CAMAC interface, all the parameters are continuously monitored. The gas and high voltage systems communicate through a custom-made interface control box [5] which operates on the high voltage when the gas mixture falls out of pre-defined limits.

3. – READOUT AND FASTBUS FRONT-END ELECTRONICS

A readout board [6] discriminates (at a threshold of about 60 mV) and shapes (with 20 ns time width) the signals coming from the counters. Each board serves 16 pads and gives fast signals in ECL and TTL logic, respectively to the acquisition chain and to the trigger electronics together with the 4 additional logical OR of 2×2 adjacent pads. A crate allocates 8 boards and 16 crates serve a detector plane (for a total of 6144 channels). For the first plane all the channels are sent to the data acquisition system, while for the other two planes only the OR-*ed* signals are acquired.

The ECL signals are sent, after 20 meters of twisted pairs cables, to the Fermilab FASTBUS data acquisition system [7] which is capable of associating an event with a single Tevatron RF bucket (20 ns) and of completely recovering within one or two buckets by operating synchronously with the 53 MHz accelerator clock. A digital memory is used to provide a trigger delay, which is adjustable in one bucket steps up to a maximum of 4.8 μs.

The front end electronics system consists of a set of Fermilab FASTBUS modules which delay, encode and read the detector hit information and is based on 2 fully loaded crates for a total of 3072 channels.

4. – DATA TAKING

The E771 detector has been exposed, during the running period of 1991-92, to the 800 GeV/c Tevatron proton beam of about 4×10^7 protons per second intensity with a spill length of 23 seconds every 54 seconds. This corresponds approximately to 2×10^6 interactions per second on a 5% interaction length thick silicon target.

Two different, parallel triggers, both based on programmable logic arrays, have been used. The first one (1A trigger or μ trigger) [8] used triple coincidences of the three RPC planes to define the presence of muons of momenta greater than 6 GeV/c. The second one (1B or p_T trigger) [9] used triple coincidences of the first RPC plane with two of the four upstream CC/WC's pad planes, selecting pre-defined hit patterns loaded in the trigger logic corresponding to trajectories with $p_T > 0.8$ GeV/c.

The single muon trigger rate was about 100 kHz at the maximum interaction rate, corresponding to roughly $25 \div 30$ incident particles per cm^2 averaged over the entire surface of the central RPC modules of the first plane. Figure 4 shows the trigger profile obtained in each of the 32 groups (superOR) in which the 1A trigger is subdivided.

In order to check both RPC and trigger performance, a muon trigger, similar to the one of E705, based on the coincidences of the scintillator planes placed next to the RPC planes, was set-up and used as monitor.

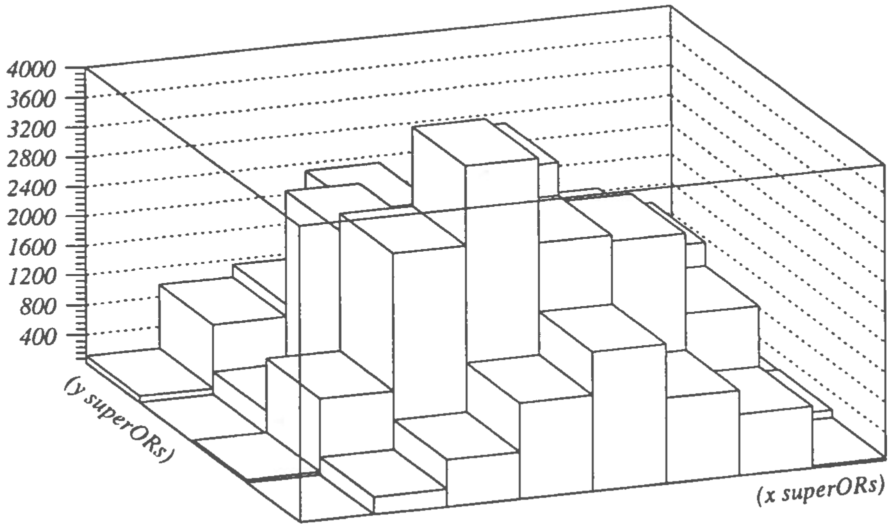

FIG. 4 – Trigger profile. Beam is coming from the top.

5. – PERFORMANCE OF THE RPCS.

The resistivity of the bakelite electrodes and the gas amplification of the mixture have been indirectly measured, for each one of the 29 RPC modules, through their voltage to current characteristics in the absence of beam (Fig. 5), by assuming that the conduction occurs only through the spacers. Figure 6 shows the relatively homogeneous value of the resistivity for the entire sample of RPCs.

The RPC have been operated at a voltage of 8.2 kV, about 200 volts above the onset of the efficiency plateau. With this setting the currents were as high as 700 μA (in the central modules of the first plane) during beam spills.

Figure 7 shows the hit distributions on the pads of the first plane. The central hole due to the beam plug and the advantages of the bi-dimensional arrangement of the pads are evident, as well as some noise due to the spacers. The hit multiplicity per module due to passing muons was very low. The noise (mainly due to punch-through particles) has been defined as the fraction of hits not belonging to the reconstructed muon tracks. Figure 8 shows this value for the 29 modules.

The cross-talk between adjacent pads has been studied carefully in order to understand the extent of the optimization of the pad size. The cross-talk is mainly due to the capacitive coupling between adjacent pads and is therefore dependent on the length of their perimeter. Figure 9 shows the cross-talk distribution for pads sharing a side or a corner pad, the average is of the order of 8 %. A small contribution to the cross-talk is also due to the electronics (including cables) and is measured to be about 10% of this. Finally figure 10 shows the distribution, for the entire sample of RPC modules, of the equivalent distance from the edge of the pad below which a hit induces cross-talk on an adjacent pad. Its mean value is consistent with the size of the gap between adjacent pads.

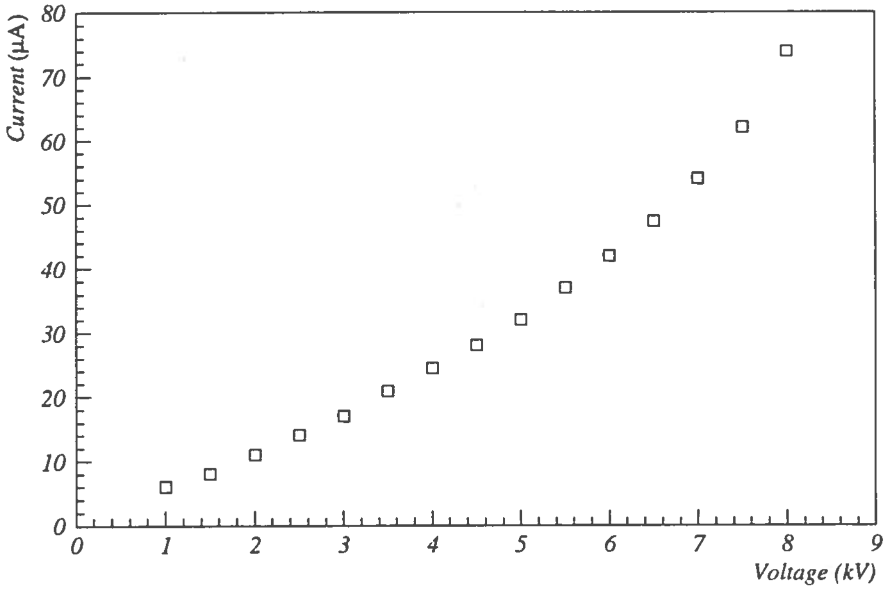

FIG. 5 – Current-voltage characteristics for a tipical module.

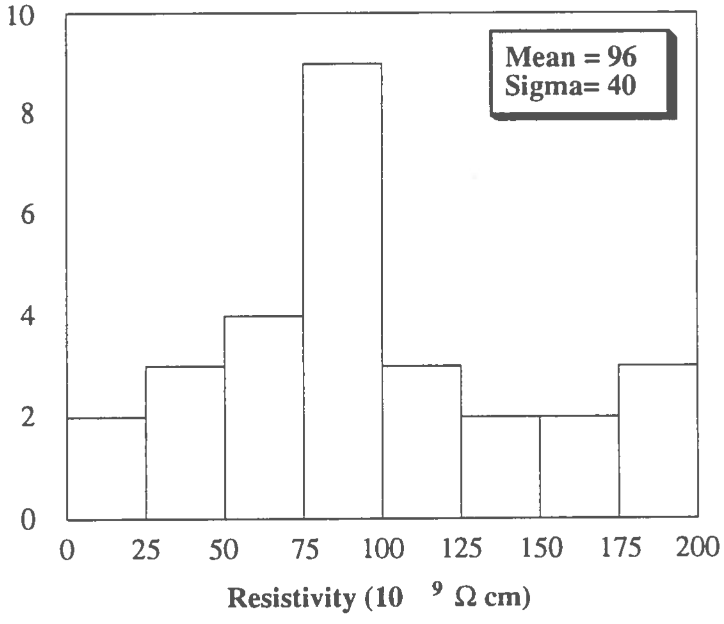

FIG. 6 – Distribution of resistivity.

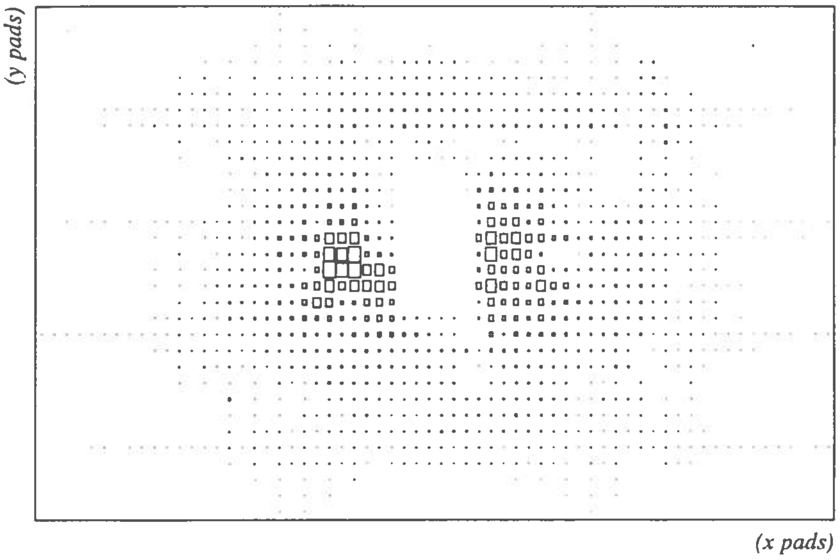

FIG. 7 – Hit distribution on first RPC plane.

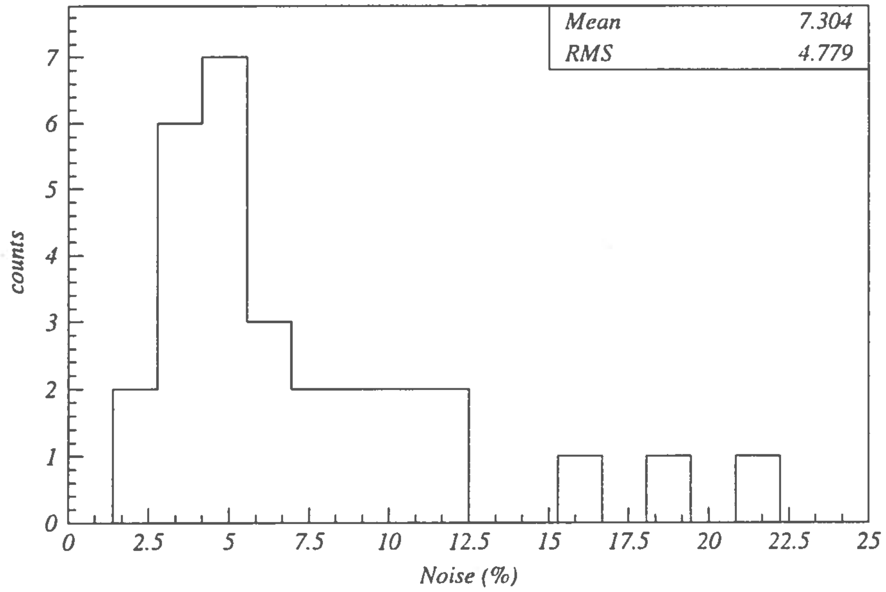

FIG. 8 – Distribution of the fraction of hits not belonging to a reconstructed track.

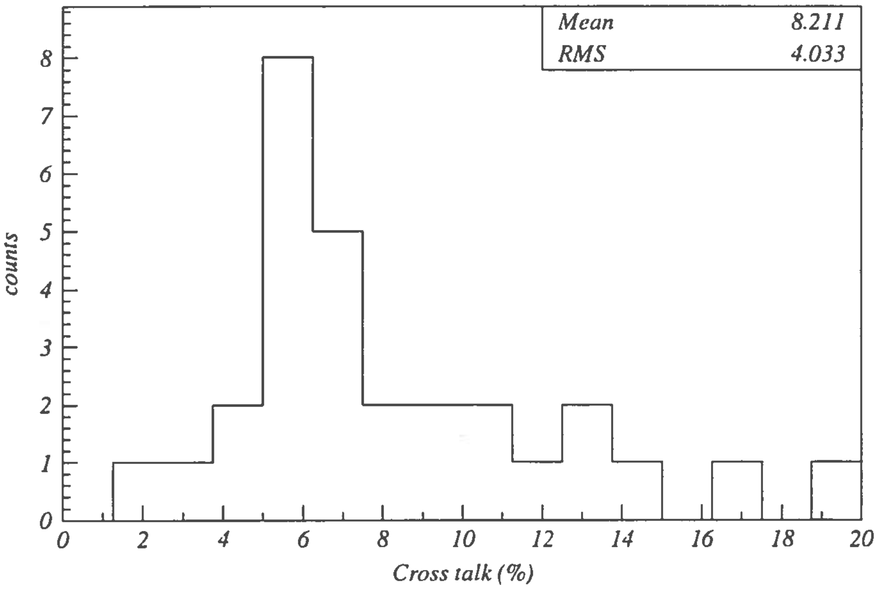

FIG. 9 – Distribution of cross-talk (side and corner pads).

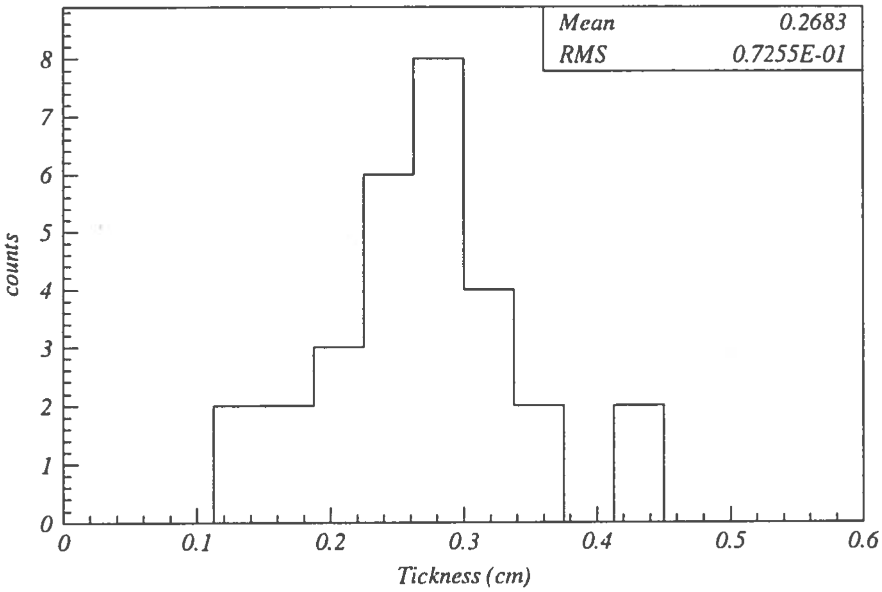

FIG. 10 – Equivalent thickness for cross-talk.

The time resolution σ_T has been measured trough TDC's installed on all the RPC modules belonging to a quadrant of the muon detector. Figure 11 shows σ_T for low rates of incident particles. The average resolution of 4 ns doesn't depend on the pad size because of the larger contributions due to cables, read out, and front end electronics. The intrinsic detector resolution has been measured to be about 1 ns [10] and is dependent on the incident particle rate. Figure 12 shows this behavior both for the time resolution and the signal delay.

A tracking program, based on the existing muon scintillator planes, corrected for acceptance, has been used for the evaluation of the efficiencies. These are consistent with those expected and due to the spacers (about 96%) when measured at low incident rates, but decrease with beam intensity. Fig. 13 shows the average efficiency for the second plane of RPC versus the average incident rate as computed from the interaction triggers. The rate of decrease is not in agreement with that measured in a test beam at CERN [11]. In order to fully understand this discrepancy we have computed the efficiencies by de-convoluting the timing dependence of the RPC on the incident rate. The resulting efficiency is plotted in Fig. 14. The rate dependent efficiency, corrected for this effect, becomes thus consistent with the measurements in [11] where a much wider gate (100 ns instead of 20 ns) was applied.

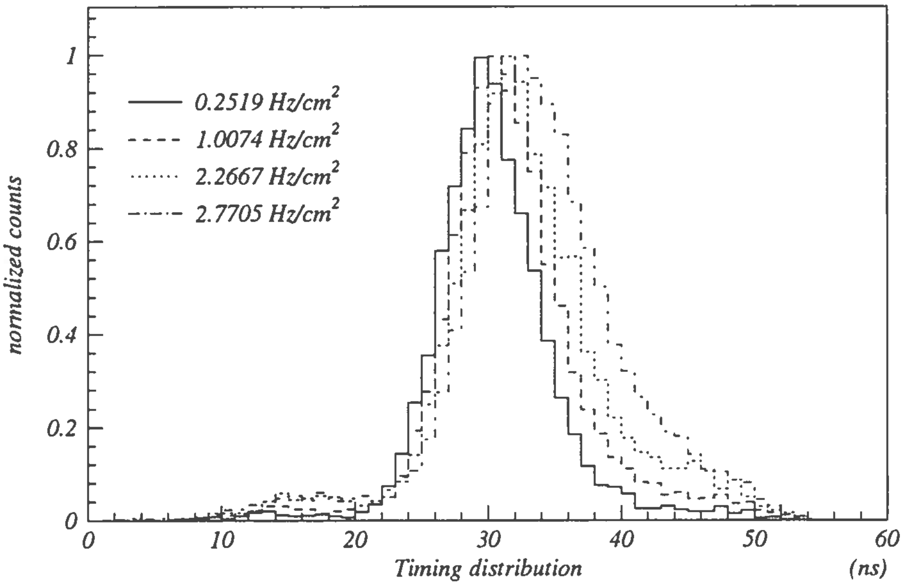

FIG. 11 – Time distribution at different rates of incident particles.

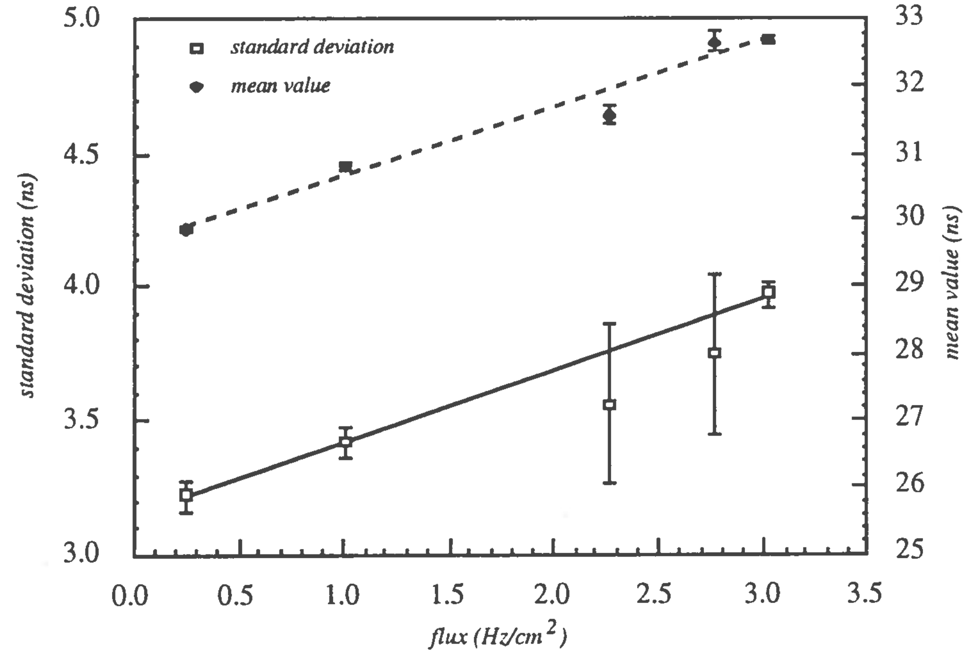

FIG. 12 – Resolution and signal delay vs. particle flux.

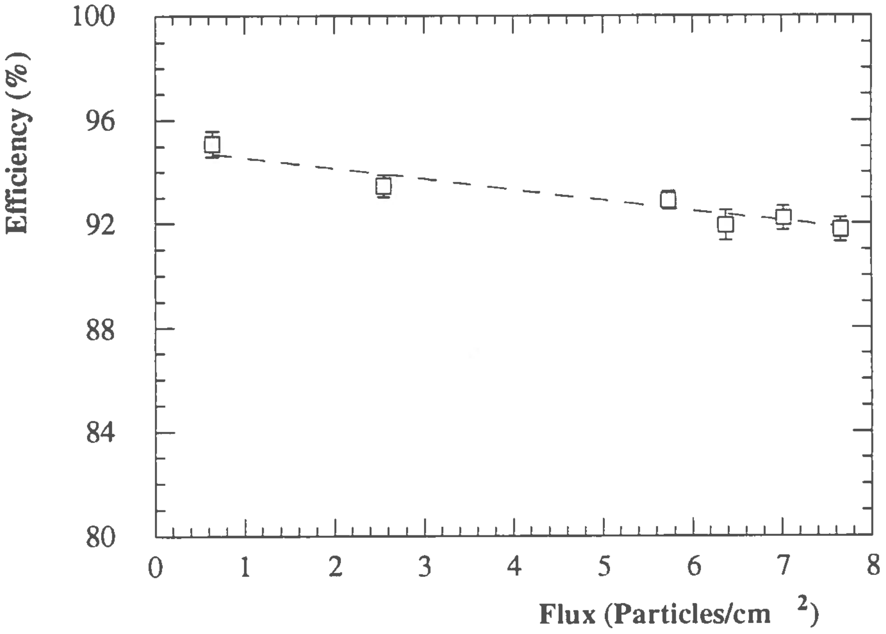

FIG. 13 – Efficiency vs. particle rate. Measured with muon tracking.

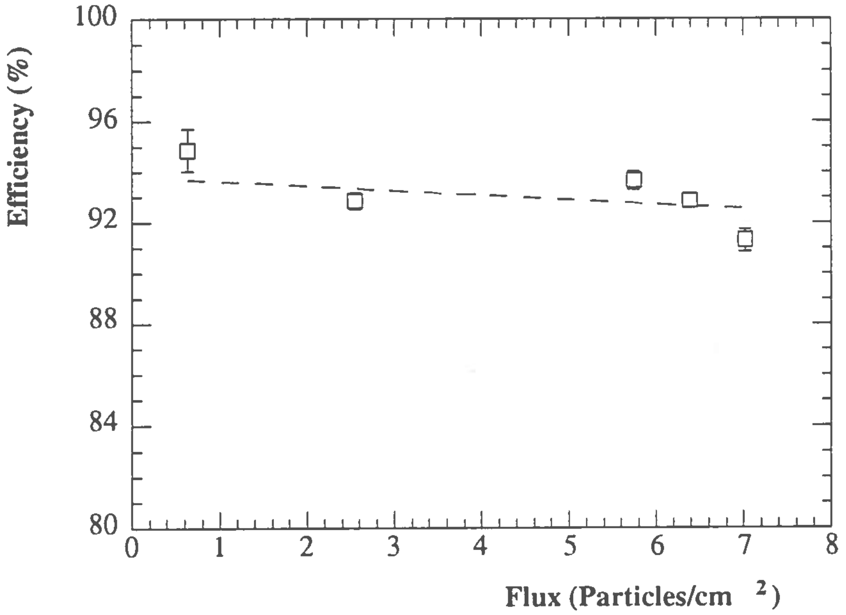

FIG. 14 – Efficiency vs. particle flux. Measured through timing distributions.

6. – CONCLUSIONS

Resistive Plate Counters equipped with pad readout, as opposed to strips, have been successfully used for the first time in a high rate environment. The technique appears to be very promising in virtue of the high stability of operation and the excellent timing properties, which makes it ideal as the active volume of muon detectors.

Cross talk between adjacent pads and noise have been measured and shown to be whitin acceptable limits. Geometric efficiency is limited by the size and the number of the gap spacers, which are also the main source of noise.

Rate dependent efficiencies have been observed at incident rates of the order of $25 \div 30$ particles per cm^2 over large surfaces and are mainly explained by timing effects.

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