

A New High-Resolution Time-Of-Flight Technology

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Abstract

In the framework of the ALICE Collaboration, we have recently studied the performance of the multigap Resistive Plate Chambers, which were operated in avalanche mode and at atmospheric pressure for Time-Of-Flight measurements. The detector provided an overall (detector plus electronics) timing accuracy of 120 ps sigma at an efficiency of 98% for MIP's.

The chambers had four 0.3mm gas gaps, limited by both a metallised ceramic plate and a glass plate, with an active dimension of 4x4cm². The gas mixture contained C₂H₂F₄+5%isobutane+10%SF₆.

The streamer discharges, at a rate level of a few percent, each releasing about 20pC, were tolerated without any noticeable problem.

This detector opens the perspectives for affordable and reliable, high-granularity large area TOF detectors, with efficiency and time resolution comparable to existing scintillator-based TOF technology, but with significantly, up to an order of magnitude, a lower price per channel.

Introduction

The ALICE experiment at the Large Hadron Collider heavy ion program at CERN will include a large area Time of Flight (TOF) system, spanning over a hundred square meters with about 100,000 individual read-out channels. Up to 10,000 charged particles are detected per unit of rapidity per event at midrapidity by this detector. The TOF technique covers the particle identification of most of these particles. Several types of TOF detectors, including gaseous, have been considered for this application, aiming to provide the required timing accuracy at an affordable cost [1].

One new possibility is the Resistive Plate Chamber (RPC) described in this paper, which was recently developed and tested. Our approach contrasts with a previous application of RPCs to TOF (the Pestov counter [2]) in that we operate a multigap [3] detector in avalanche mode with a non-flammable gas mixture at atmospheric pressure, although at the sacrifice of some timing performance.

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Detector Description

The detector is formed by two identical square-shaped RPC cells, which are electrically connected in parallel. Each cell has an active area of $4 \times 4 \text{ cm}^2$ and is constituted by two metallic electrodes placed on each side of a central glass plate, defining two gas gaps. No electrical connection is made to the central glass plates, which are made with a commercial variety of dark glass having a resistivity of about $10^{12} \Omega \cdot \text{cm}$. The metallic electrodes were deposited on profiled ceramic plates [4], and electrical contact was made through a small perforation in the plate, which was placed outside the active gap volume. The width of each gas gap was defined by a set of four spacers placed in the corners of the ceramic plates, which was also lying outside the active gap volume. A schematic description of the detector is shown in Figure 1.

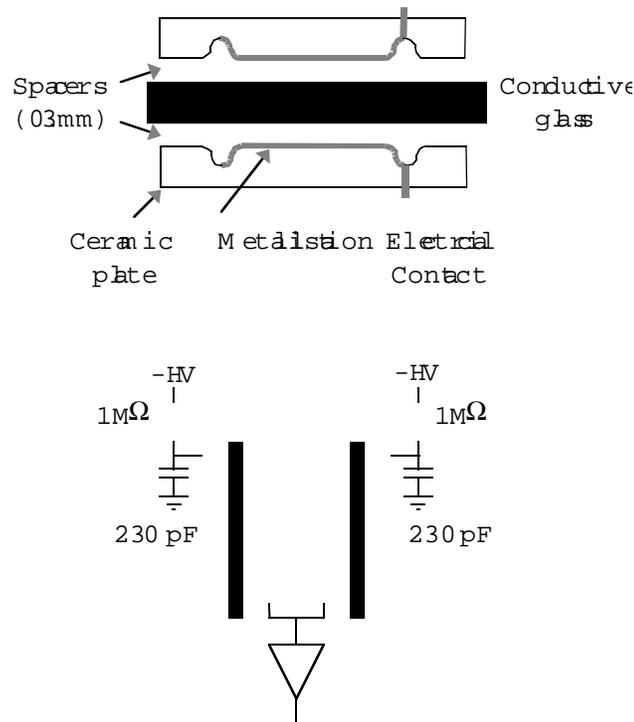


Figure 1 – Schematic representation of the structure of a single RPC cell, made with two metalised, profiled, ceramic plates placed on each side of a central glass plate. Two such cells are electrically connected in parallel to form a single detector.

The chamber signals were amplified by a 2 ns rise-time current amplifier, which was developed specially for this application [5], followed by a fixed threshold discriminator connected to a TDC with a 50 ps bin width. The output of the amplifier was also sent to a charge integrating ADC that measured the fast signal charge. The charge information was

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used to correct the finite rise time of the amplifier offline (slewing correction). The contribution of the electronics noise to the timing jitter was measured to be 50 ps sigma for a signal level of 1.5 pC, with a discriminator level of 20 fC.

The detector was filled with a nonflammable gas mixture consisting of $C_2H_2F_4 + 10\% SF_6 + 5\%$ isobutane [6] and tested at the CERN PS using a secondary beam of 7 GeV pions. Two identical scintillation counters provided a time reference with a resolution of 120 ps sigma, and a scintillator-based telescope selected those particles that crossed the detector in a central area of 1 cm^2 .

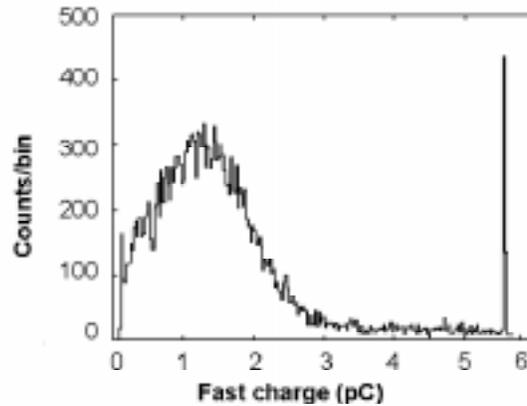


Figure 2 - Fast charge spectrum for MIP's, corresponding to an average charge of 1.5 pC. Above 2 pC the shape of the spectrum is influenced by the nonlinearity of the amplifier.

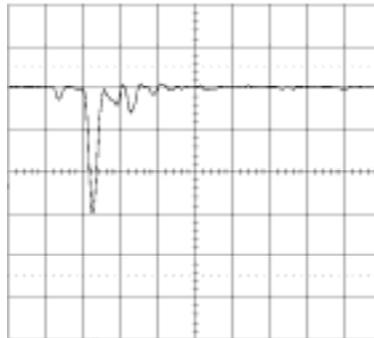


Figure 3 – A typical streamer current pulse, directly observed on a $50\ \Omega$ resistor. The horizontal scale corresponds to 20 ns/division and the vertical scale to 1 mA/division. Each square corresponds to a charge of 20 pC. A clear precursory avalanche is visible at 15 ns prior to the main pulse, which corresponds to the development and quenching of the streamer [8].

The fast charge spectrum for minimum ionizing particles is shown in Figure 2, which corresponds to an average fast signal of 1.5 pC in avalanche mode. The sharp left cutoff corresponds to the ADC pedestal, and the narrow peak, close to 6 pC, corresponds to the saturation of the ADC. The overall shape of the spectrum, above 2 pC, is influenced by the nonlinearity of the electronics. About 2% of the particles triggered the formation of

streamers, each developing at about 20 pC, and are in qualitative agreement with Ref. 7. A typical streamer pulse is shown in Fig. 3.

In Fig. 4, we show a typical time difference spectrum between the start counters and our detector, with a resolution of 107 ps sigma, after the quadratic subtraction of the start counters contribution (120 ps).

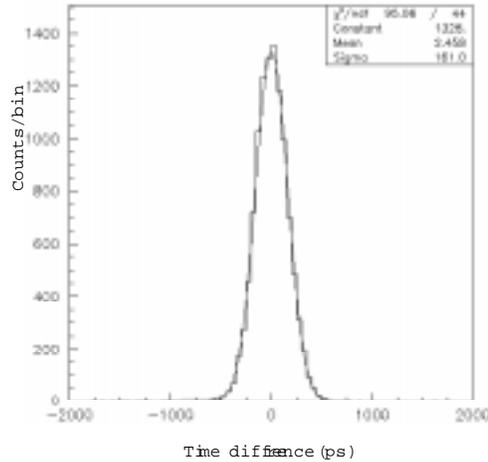


Figure 4 – Typical time difference spectrum between the start counters and our detector, with a resolution of 107 ps sigma, after the quadratic subtraction of the start counters contribution ($\sqrt{161^2 - 120^2} = 107$).

The timing resolution for MIP's was between 100 and 120 ps with a detection efficiency above 98% at counting rates below 800 Hz/cm² (see Fig. 5). The performance was degraded at higher counting rates, presumably due to time-dependent voltage drops across the resistive plate.

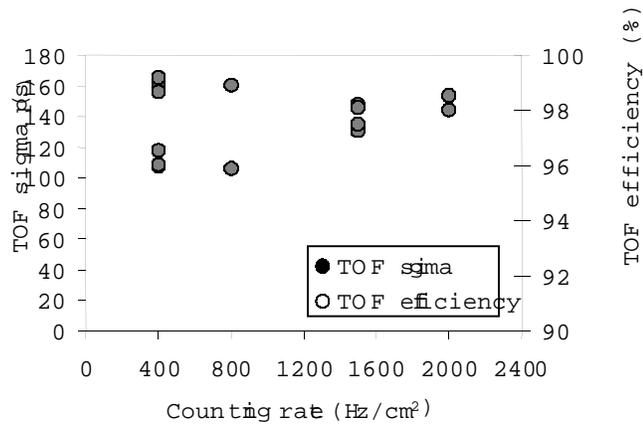


Figure 5 - Timing resolution and efficiency as a function of the counting rate per unit area. For counting rates below 800 Hz/cm², resolution of better than 120 ps sigma was achieved with an efficiency above 98%.

Other similar detectors with gas gaps of 0.4 and 0.6 mm were also tested, and the available data (see Fig. 6) suggests that the timing resolution of thin gap parallel geometry detectors depends mainly on the width of the gas gap. One can approximately describe this dependency by a straight line with a slope of 40 ps/0.1 mm.

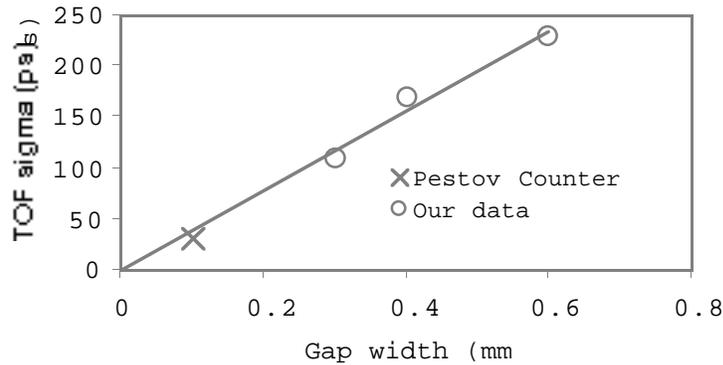


Figure 6 - Tests performed with other detectors featuring different widths of the gas gap suggest that the main contribution to the time jitter is associated to the amplification process in the gas. The timing resolution seems to depend almost linearly on the gap width, with a slope of approximately 40 ps/0.1 mm.

This observation suggests that, in principle, further gains in timing accuracy may be achieved by reducing the gap width. For very small gas gaps, one expects a reduction in efficiency, but this can be compensated by increasing the number of intermediate resistive plates. However, in order to reach timing resolutions comparable to those featured by the Pestov Counter [2] (30 ps sigma), but working in proportional mode and at atmospheric pressure, further progress in electronics must also be made.

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