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Single-gap timing RPCs with bidimensional position-sensitive readout for very accurate TOF systems

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Abstract

In this work, we report the development and performance of single-gap timing RPCs equipped with a 3 mm FWHM resolution bidimensional position-sensitive readout and reaching a timing resolution of 55 ps σ at an efficiency of 75% for MIPs. These chambers are aimed to be applied in a multilayer geometry, forming small and very accurate TOF systems. The avalanche localization capability would provide information for accurate flight-path determination and allow the offline correction of any position dependent effects in the chamber, like gap inhomogeneities or edge effects. The multilayer geometry would provide redundant timing information, which, besides improving the timing resolution, can be used for reducing the timing tails and for the self-calibration of the device. From the experimental single-chamber data it can be calculated that a four-layer configuration of such chambers would yield a time resolution of 33 ps σ at a 95% efficiency, essentially free of timing tails.

1. Introduction

The development of timing Resistive Plate Chambers (RPCs) [1] opened the possibility to build fine-granularity high-resolution TOF systems at a quite reduced cost per channel when compared with the standard scintillator-based technology

Previous work yielded a timing resolution better than 50 ps σ at 99% efficiency for single four-gap chambers [2] and an average timing resolution of 88 ps σ at an average efficiency of 97% for a 32 channel system [3]. It has been also shown that each amplifying gap of 0.3 mm thickness reaches a detection efficiency close to 75% and that the avalanche develops under the influence of a strong space charge effect [4,5].

A large chamber, with an active area of $160 \times 10\,\text{cm}^2$, readout by only 2 or 4 electronic channels was also demonstrated [6], having in view applications in medium or low multiplicity experiments.

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In this paper, we describe smaller ($16\,cm^2$) single-gap position-sensitive chambers, to be used in multilayer configurations for small and accurate TOF systems. The position information would improve the measurement of the particle's trajectory and, if needed, could be used to correct offline for any inhomogeneities in the gas gap spacing. The redundant time information gathered from the multiple layers would allow the control of the timing tails, to improve the time resolution of the system and would provide a self-calibration capability.

2. Chamber construction and experimental setup

The chambers were made from commercial tainted glass[2] that was thinned to a thickness of 2 mm and had the inner face lapped to a flatness of $\sim 1\,\mu m$, estimated by optical interferometry. A 0.5 mm deep trench was carved around each corner of the glass plates, forming a pillar that supported 0.3 mm thick high-resistivity glass spacer disks. The trench protected the spacer edge, forming an essentially noiseless spacing structure. A schematic drawing of the chamber construction and wiring is shown in Fig. 1. Further details concerning the experimental setup, gas mixture, time readout circuitry and data analysis may be found in Ref. [7].

To estimate the effect of the position readout circuitry on the timing accuracy some chambers had the position-sensitive electrode replaced by a conductive plate connected to the signal ground ("time only" version).

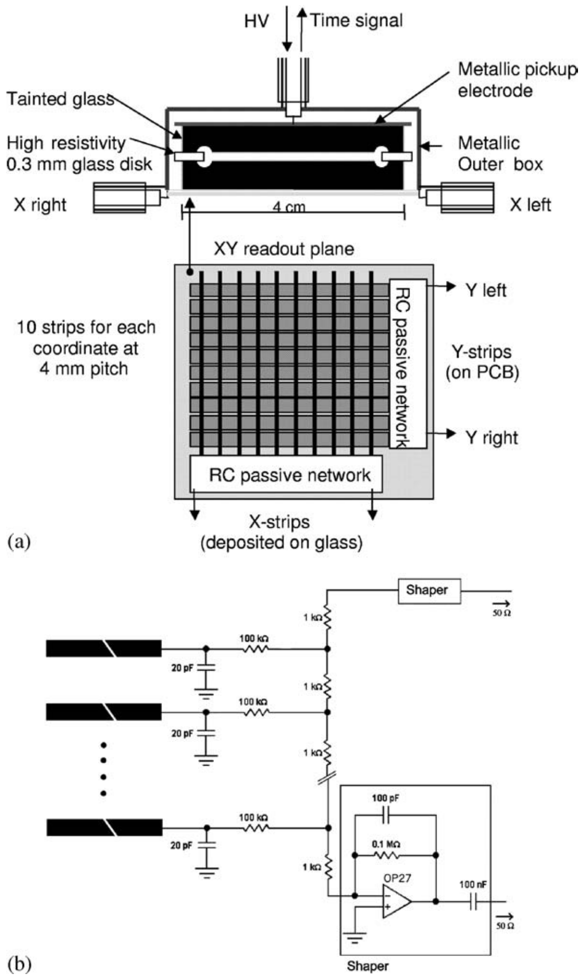

Fig. 1. (a) Schematic diagrams of the single-gap position-sensitive chamber construction and wiring. (b) Resistive-division position encoding network and front-end readout circuit. The avalanche position is estimated by the charge difference between the upper and lower branches.

3. Results

3.1. Efficiency and timing accuracy

At the optimum voltage settings the efficiency of the chambers for the almost minimum ionizing $7\,GeV/c$ negative pions that composed the test beam (relativistic rise $\sim 15\%$) ranged from 75% to 80%, as shown in Fig. 2. Typical single-gap signal charge distributions can be seen in Ref. [4].

The measured time distributions were typically slightly non-Gaussian, with a small excess of events in the longer times. A typical example (corresponding to the events also shown in Fig. 4) is shown in Fig. 3. A time resolution of 60 ps σ was measured following the procedure described in Ref. [2], along with moderate timing tails of a few percent. (The "300 ps tails" are defined as the fraction of events outside the ± 300 ps boundaries, with a similar definition of the "3σ tails".)

[2] SCHOTT ATHERMAL™.

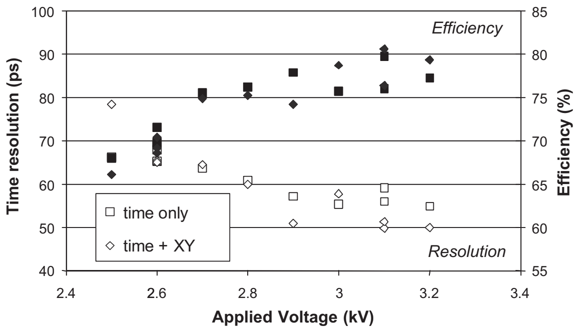

Fig. 2. Efficiency (solid symbols) and time resolution (open symbols) as a function of the applied voltage. There is no appreciable difference between the time-only (□) and the position-sensitive (◇) chambers.

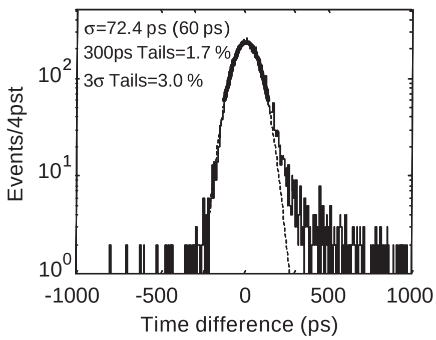

Fig. 3. Typical distribution of the time difference between the reference scintillators and the RPC. The distribution has a width of 72.4 ps σ, corresponding to an intrinsic time resolution of 60 ps σ after subtraction of the measured contribution of the start scintillators. Moderate tails are also visible.

The variation of the time resolution as a function of the applied voltage is shown in Fig. 2, ranging at the optimum voltage from 50 to 60 ps σ. No appreciable difference could be found between the "time only" and the position-sensitive chamber versions, showing that the bidimensional measurement of the avalanche position is fully compatible with the accurate measurement of time.

3.2. Position resolution

For estimating the position resolution of the chambers we selected, by proper positioning of the trigger scintillators, those events occurring in the lower-right region of the chamber (Fig. 4a). The procedure created four edges in the event density distributions by whose transition width the FWHM position resolution may be estimated. However, due to the beam divergence and to particle scattering effects, the trigger scintillators cannot possibly select a perfectly sharp boundary. The corresponding finite-width edges are folded into the results, which constitute upper limits to the chambers actual resolution.

Results are shown in Fig. 4b from which resolutions of 3 mm FWHM in X and 2 mm FWHM in Y can be estimated by analysis of the distribution edges. The positions of the 4 mm pitch

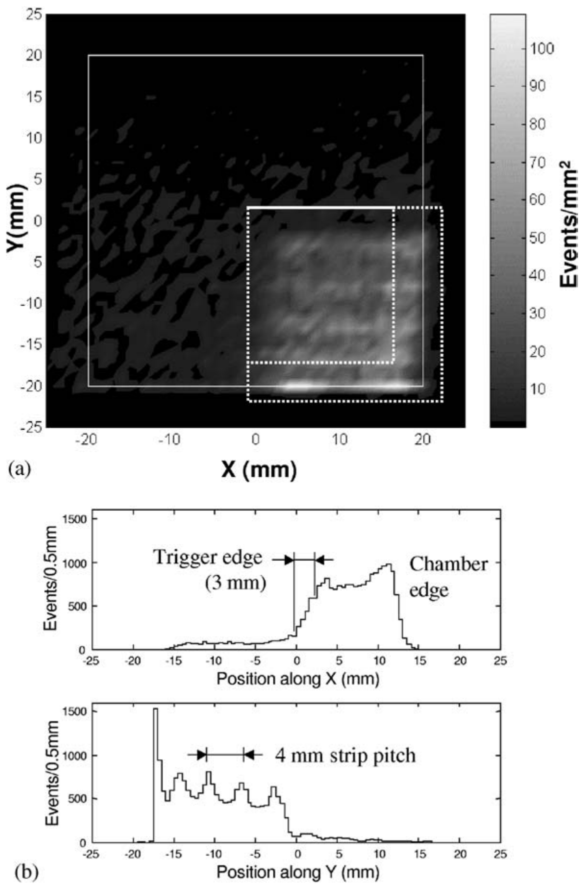

Fig. 4. Event density map (a) and the corresponding projections in the X- and Y-axis (b) when the trigger scintillators selected events in the lower-right quarter of the chamber. The coarsest edge created shows a width of 3 mm. The position of the 4 mm pitch pickup strips is clearly visible in the Y-axis.

Y pickup strips are also easily visible in the corresponding projection. A similar artifact is not visible in the X projections due to the coarser position resolution in this axis.

It should be noted that the present position resolution is already adequate for the purpose in view and therefore no effort was made to improve on it.

3.3. Edge effects

Taking advantage of the avalanche localization capabilities of the chamber any position dependent effects, like mechanical inhomogeneities of the gap or edge effects, either electrical or mechanical in origin, may be identified and corrected.

Particularly likely would be the occurrence of a different response along the chamber edges. To evaluate this situation the data set shown in Fig. 3 (corresponding to the events shown in Fig. 4), was divided in ‘‘central’’ and ‘‘edge and corner’’ parts defined by the dotted lines shown in Fig. 4a). These data sets were analyzed separately and the results are shown in Fig. 5.

No appreciable difference between both data sets could be observed, nor between these sets and the full data set shown in Fig. 3, suggesting a negligible variation of the chamber response along its edges.

3.4. Multilayer configurations

It is expected that the redundant information provided by a multilayer arrangement of such chambers, with independent readout of each chamber, would provide a better timing resolution along with a reduction of the timing tails after appropriate cuts.

If the layers are assumed to be statistically independent, such multilayer system may be accurately simulated by Monte-Carlo using the measured single-layer data. In the present study the Monte-Carlo generated events were subject to the following selection algorithm:

1. events showing hits in only one layer were rejected, adding to the system inefficiency;
2. events showing hits in two layers were rejected if their time difference was larger than twice the chamber resolution σ (adding to the system inefficiency) or otherwise averaged;
3. events showing hits in three or four layers had the two hits of minimum time difference averaged and the remaining hits rejected.

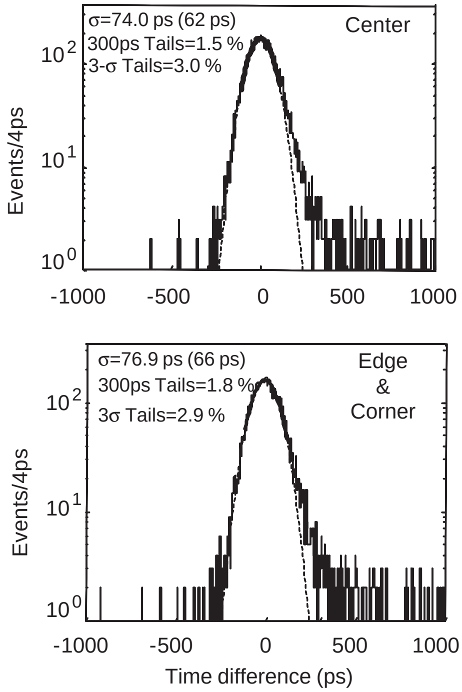

Fig. 5. Time distributions corresponding to ‘‘central’’ and ‘‘edge and corner’’ events defined by the dotted lines shown in Fig. 4a. There is no appreciable difference between both sets, suggesting a very small degradation of the performance along the chamber edges.

It should be noted that the cuts rely only on the time difference between hits, which are almost independent from the particles flight time. Application of this algorithm suggests that a four-layer device would yield a time resolution of 32 ps σ essentially free of timing tails and an efficiency of 95% (after the rejection of tails), as shown in Fig. 6.

4. Conclusions

In the present study we tested mechanically accurate single-gap timing RPCs equipped with

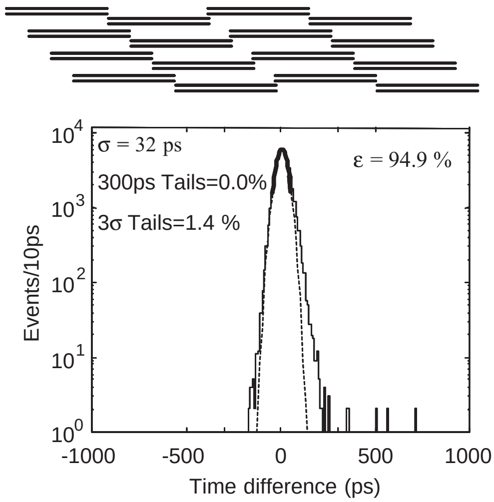

Fig. 6. Calculated performance of a four-layer system, showing a time resolution of 32 ps σ, essentially free of timing tails, along with a 95% efficiency.

bidimensional position-sensitive readout. The chambers have shown a time resolution of 55 ps σ with an efficiency of 75% for MIPs, along with a simultaneous position resolution of 3 mm FWHM.

Moderate timing tails were observed, on the order of only a few percent, and the chamber has shown the same response in the central and in the edge regions.

The millimetric avalanche localization capability would provide additional tracking information for the estimation of the particles flight path in a TOF chamber and may be used to correct for eventual mechanical inhomogeneities that could arise in a large chamber production.

It was calculated that a four-layer chamber based on the present device would enjoy a time resolution of 32 ps σ essentially free of timing tails and an efficiency of 95% (after the rejection of tails). The redundant information gathered would also allow the self-calibration of the device by requiring that multiple hits should show a null average time difference.

Excellent time resolution along with the control of timing tails maybe of critical importance for applications were a small population of slower particles is to be separated from a large background of slightly faster particles.

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