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A large-area glass-resistive plate chamber with multistrip readout

M. Petrovici[a,b,*], N. Herrmann[c], K.D. Hildenbrand[b], G. Augustinski[b], M. Ciobanu[a,b], I. Cruceru[a], M. Duma[a], O. Hartmann[b], P. Koczon[b], T. Kress[b], M. Marquardt[b], D. Moisa[a], M. Petriş[a], C. Schroeder[b], V. Simion[a,b], G. Stoicea[a], J. Weinert[b]

[a] *National Institute for Nuclear Physics and Engineering, Bucharest, P.O. Box MG-6, R-76900 Bucharest, Romania*
[b] *Gesellschaft für Schwerionenforschung, Darmstadt, Germany*
[c] *Physikalisches Institut der Universität Heidelberg, Heidelberg, Germany*

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Abstract

A completely new configuration of a glass resistive-plate chamber (GRPC) was built and tested. It consists of a double two-gap structure of electrodes with an active area of about 400 cm^2 and is read out via a central multistrip printed circuit board. In measurements with a ^{60}Co source and p, d particles of 1.5 A GeV time resolutions better than 80 ps, position resolution along the strips of 5–6 mm and efficiencies larger than 95% were obtained using available fast standard electronics. These results open the possibility of constructing compact TOF detectors of high resolution and high granularity. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

The measurement of the products' time of flight (TOF) is an important and frequently used tool in particle identification techniques in relativistic and ultra-relativistic heavy ion collisions. High velocities and large multiplicities of the fragments in these collisions require detectors with time resolutions of the order of 100 ps and high granularity. However, the standard solution based on plastic scintillators read out by phototubes becomes prohibitively expensive above a certain number of channels. At present the only realistic alternative seems to be gaseous detectors.

For the ALICE project at CERN, two types of such detectors have been considered: Pestov counters [1,2] and glass resistive plate chambers (GRPC) [3]. Both are characterized by very narrow gaps between solid electrode plates in which extremely fast primary signals develop under the influence of a high electric field.

*Corresponding author. Address for correspondence: National Institute for Nuclear Physics and Engineering, Bucharest, P.O. Box MG-6, R-76900 Bucharest, Romania. Tel.: +40-1-404-2392; fax: +40-1-789-6295.

E-mail address: mpetro@ifin.nipne.ro (M. Petrovici).

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Pestov counters work in the spark regime; they are operated at 12 bar with a highly quenching gas mixture. The gap of 0.1 mm is formed by a conductive electrode (normally a polished aluminum plate) and a semiconductive glass plate. This special so-called "Pestov glass" has a resistivity of about $5 \times 10^9\ \Omega\,\mathrm{cm}$. The streamer is followed by a spark which is quenched very quickly. The output signals are high; they can be plugged directly into double-threshold discriminators [4] which guarantee a walk-free timing.

These spark counters have been investigated for many years. About 40 counters, each of $30 \cdot 4\ \mathrm{cm}^2$ size, have been used successfully in the NA49 experiment at CERN [5]. Ninety centimeter long prototypes (area $380\ \mathrm{cm}^2$), developed at GSI, have reached time resolutions of about 60 ps [6]. These counters are read out on both sides via 16 individual anode strips; the TOF is derived from the mean of the two times recorded at the two ends. The time difference yields a spatial resolution of ~ 2.5 mm along the strip; in transverse direction one obtains $\sim 350\ \mu\mathrm{m}$ by weighting the charges recorded on neighboring strips fired in an event. The measured time spectra are not completely Gaussian; they develop an exponential tail to the side of longer times. Detailed studies of this effect have shown that it is at minimum if the counter is operated with a Ne-based gas mixture [6].

The technological difficulties in building Pestov detectors, e.g. the preparation of the electrodes, the technique of the 0.1 mm high spacers, the gas vessel holding 12 bar and the extreme requirements in cleanness during mounting and operation can in principle be overcome [6]. The biggest problem at present is the melting of the semiconducting glass; it is very difficult to obtain raw material in sufficiently good quality and large sample size.

A GRPC is a parallel plate chamber with glass electrodes having a resistivity of the order of $10^{12}\ \Omega\,\mathrm{cm}$ which is at least 100 times higher than that of Pestov glass. With a proper gas mixture the streamer development is strongly suppressed and sparks no longer ignite at the operation voltages normally used. Hence, the chamber operates in avalanche mode and needs a fast amplifier for its signals. For fast timing applications normally a gap size of 0.3 mm is chosen; in order to obtain a reasonably high primary signal at 1 bar pressure one uses a stack of glass plates separated by gaps; since the intermediate resistive electrodes are transparent for the fast signals, the resultant signal is formed by the sum of the avalanches in the individual gaps. The principles of a multigap structure and its timing performance which is potentially better than that of a one-gap chamber of same total active thickness are discussed in Ref. [7]. On one side of the stack the HV is connected to a metallic electrode, the signal is taken from a conductive plate on the other side. In practice, more often a symmetric design is chosen with the anode in the middle of the stack, requiring one HV electrode on the top and another at the bottom.

The state of the art in application of this principle is described in Refs. [3,8]. The work has concentrated on single-cell chambers of not more than $20\ \mathrm{cm}^2$ size. For example with a $3 \times 3\ \mathrm{cm}^2$ detector a time resolution of 44 ps and an efficiency of 99% has been measured [3,8]. Our own tests of comparable counters gave similar values [9]. In such small single cells, the position dependence of the timing may be kept within certain limits; edge effects, on the other hand, could influence the time resolution as well as the efficiency. To bypass the construction of a huge number of individual cells, the ALICE collaboration has begun studies of prototypes where individually read out anode pads are placed on large-area glass stacks [3]. Time resolution of 62.5 ps and 95% efficiency have been obtained with such a geometry. However, a position dependence of the time resolution and efficiency is similar to those observed for single cells.

The idea to read out a GRPC with the mean-timing method—in order to avoid position dependencies—and in a multiple-anode scenario—to minimize edge effects and the effort in the construction—is straightforward. Our aim was to combine the described advantages of the GRPC principle and of the Pestov counters.

With this in mind, we have started tests of GRPC prototypes with active areas of 120 and $400\ \mathrm{cm}^2$ which are read out via multistrip anodes very similar to our Pestov detectors, i.e. having 16 (or 12) strips over the 40 mm width; each strip is read out at both ends. This is a completely novel detector concept which was realized for the first time and documented in Ref. [10]. Recently, we learned that the Coimbra group has built and tested a similar device, a detector of 160×10 cm^2 size with two anode strips of 50 mm width [11]. As a conceptual difference, our design is able to measure the position perpendicular to the strips with an accuracy better than the strip width.

This paper contains the first results of measurements with our prototypes. The next section describes the principal construction scheme of the detectors, details of the built prototypes and of the experimental setup used in tests with a ^{60}Co source and p and d-beams of 1.5 A GeV at the SIS of GSI, Darmstadt. The obtained results are presented in Section 4.

2. Description of the detectors and the test setup

2.1. Principle configuration

The principal configuration of all detectors is depicted in Fig. 1. The central readout board divides the two identical detector halves. It is 0.6 mm thick with the strip structure on both sides; the corresponding strips on the upper and lower surface are connected at the outer left and right end.

Each half houses three plates separated by 2 gaps of 0.3 mm, defined by a fishing rod placed between the plates; the innermost plates are in direct contact with the strip board. Both outermost conductive plates are connected to the negative HV. All non-conductive electrodes were floating; so far we have not yet tried to connect the edges of the middle plate to an intermediate potential as proposed in Ref. [8]. The whole ensemble is held together by a support structure of extruded polycarbonate which guarantees the mechanical precision as well as an enforced gas flow through the gaps.

The gas containers are aluminum or stainless steel tubes of 50 mm diameter with 1 and 0.5 mm wall thickness, respectively. The readout board with the signal strips, the high voltage and the gas in- and outlet are led through the lateral flanges.

As counting gas we use the standard mixture [3] of 85% $C_2F_4H_2$, 10% SF_6 and 5% C_4H_{10} (isobutane) which is flushed at normal pressure.

The main characteristics of the two prototypes are summarized in Table 1.

2.2. Details of the prototypes used

The first prototype built (type I) has 16 readout strips with a pitch of 2.54 and 1.1 mm gap width. All plates are 41 mm wide and 300 mm long. As outermost plates, we use the 2 mm thick aluminum

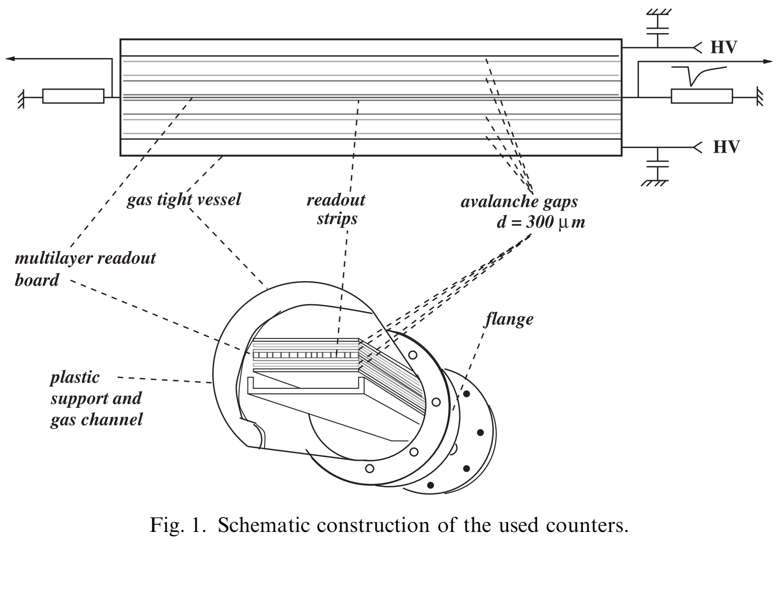

Fig. 1. Schematic construction of the used counters.

Table 1
The main characteristics of the two prototypes of RPC described in the text

Prototype	Length (mm)	Width (mm)	Pitch (mm)	Gap (mm)	Resistive electrodes	Cathode	No. of strips	Spacers (μm)
I	300	41	2.54	1.1	2 mm glass	2 mm Al	16	300
II	900	41	3.44	1.14	1 mm glass	2 mm Al	12	300

cathodes of our Pestov counters; they are surface-milled to a close-to-optical quality. The middle and inner plates are of 2 mm thick float glass (resistivity a few 10^{13} Ω cm).

Besides the pure float glass version we have also studied mixed scenarios such as

(i) Pestov glass as inner plates (the original Pestov counter anodes),
(ii) dark so-called welding glass (resistivity a few 10^{12} Ω cm) as middle electrodes.

The results of the source measurements described in the next section did not vary significantly among these different versions, so for reasons of cost and simplicity we have used only float glass later on. Such float glass plates can be purchased edge-polished from commercial suppliers; their thickness does not vary by more than 10 μm.

The second counter (type II) has the same active width of 41 mm but is 900 mm long. This length was chosen because the FOPI collaboration at GSI intends to build a TOF shell in the form of a 90 cm long cylinder around its central drift chamber [12]. The outer plates are of 2 mm thick milled aluminum, however, all inner glass plates are of 1 mm thick float glass which decreases the total counter thickness quite a bit.

The results we present below have been obtained with a slightly modified readout plane compared to type I; it had only 12 strips with a pitch of 3.44 and 1.14 mm wide gaps.

2.3. Experimental setup

Tests with type I detector were meant to demonstrate the principle feasibility of the concept as well as to study e.g. various glasses (cf. previous section) or spacer techniques. They have been performed in the laboratory with a ^{60}Co source. It was placed between the detector housing and an NE102 scintillator coupled directly on the front window of an XP2020 phototube; the scintillator had a diameter of 25 mm and was 20 mm long.

The GRPC signals were amplified in ORTEC 421 amplifiers and split for the amplitude and time measurement. The amplitude signals were amplified once more, stretched and digitized in peak-sensing ORTEC AD811. The timing signals were sent to GSI CF4000 constant-fraction discriminators (CFD) the outputs of which were used as stop signals for a LeCroy 2228A TDC. The phototube signals were also discriminated in a CF4000 and after a coincidence with the GRPC used as a common start for the TDC.

The in-beam tests of type II detector were performed at the SIS accelerator of GSI in Darmstadt, using p and d beams of 1.5 A GeV shot directly through the setup. The beam rate was downgraded to a few hundred projectiles per second and the focus was widened to a spot of a few centimeters square size.

The setup used is depicted in Fig. 2. Two scintillator monitors M_1 and M_2 (active area 45×20 mm^2) are placed a few cm in front and behind the prototype. They are read out by HAMAMATSU H2431 hybrid phototubes and provide the time reference. In some of the runs an additional "finger" plastic scintillator F_1 ($10 \times 5 \times 80$ mm^3) was positioned in between the GRPC and M_2; mounted either perpendicular or parallel to the long axis of the other counters it delivered a trigger for confined positions of incidence.

All phototube signals were split, the time branches triggered in CF4000 constant fraction discriminators and digitized by LeCroy 2228A

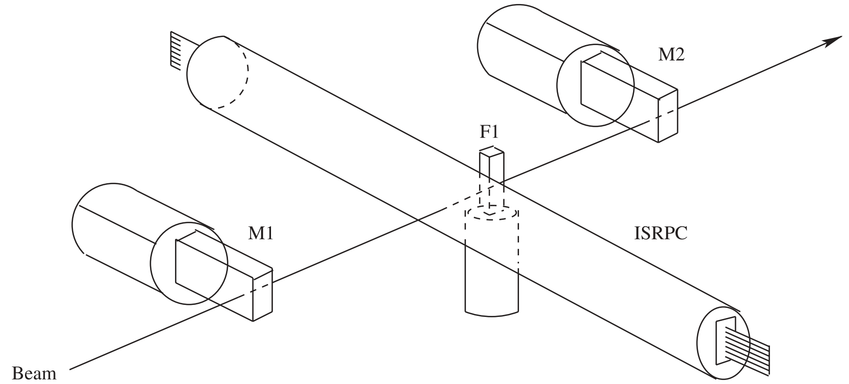

Fig. 2. Schematic view of the experimental configuration during the in-beam tests of prototype II with p and d beams of 1.5 A GeV.

TDCs and the charge digitized by 2249W ADCs, respectively.

As amplifiers for the GRPC signals we used

(i) GSI 810L amplifiers developed many years ago for Parallel Plate Avalanche Detectors (PPAD) [13] used in heavy-ion experiments at low and intermediate energies; their gain of 300 fits exactly to our case of minimum ionizing particles.

(ii) A new generation of fast amplifiers, called Detector Broad-Band Amplifier (DBA), recently developed at GSI [14] for diamond detectors for high resolution timing with heavy ion beams [15]. Their maximum gain of 80 was too low to guarantee a satisfactory efficiency, so we also cascaded two units with an attenuator in between to reach a gain factor of a few hundred.

The amplified signals were split and sent to the ADCs and the discriminators, respectively; their logic output went to the TDCs. We used CES-510 leading edge discriminators; among various commercial types we have tested they yielded by far the best resolution. For digitization we again took LeCroy 2249W and 2228A.

3. Results

3.1. Source measurements with prototype I

Out of the many results we have obtained with the ^{60}Co source, we present just one typical example to demonstrate that meaningful information can be obtained in this way.

Due to the use of CFDs the centroid of the distribution $t_{\mathrm{sum}} = \frac{1}{2}(t_{\mathrm{left}} + t_{\mathrm{right}})$ is constant as a function of the amplitudes; it exhibits, however, the typical broadening for small pulses which therefore have been cut in the analysis. Under this condition one finds the t_{left} vs. t_{right} correlation shown in Fig. 3. With an additional window on the time difference t_{dif} corresponding to a position bin of 2.5 cm one obtains the t_{sum} spectrum of Fig. 4.

The Gauss fit delivers $\sigma_t = 154 \pm 10$ ps; after folding out the scintillator contribution of 125 ps, measured separately between two identical scintillator/phototube assemblies, one finds a GRPC sum-timing resolution of 90 ± 18 ps. The HV in this specific measurement was 5.8 kV.

3.2. In-beam tests with the 90 cm prototype II

Since we have used LE-discriminators the measured time spectra have to be corrected off-line for walk.

Fig. 5 shows a typical charge distribution measured on one side of a strip, equipped with a DBA amplifier. The middle part of the figure displays in a contour plot the correlation of this charge vs. time. The bottom shows the walk, i.e. the mean values of the former distribution over the charge. The dashed curve is a polynomial fit used for the linearization ("walk correction").

With the walk-corrected time from each side one obtains the mean-time spectrum $t_{\mathrm{sum}} = \frac{1}{2}(t_{\mathrm{left}} + t_{\mathrm{right}})$ shown in Fig. 6. Time reference is the averaged time of the two monitors $\mathrm{M}_1, \mathrm{M}_2$.

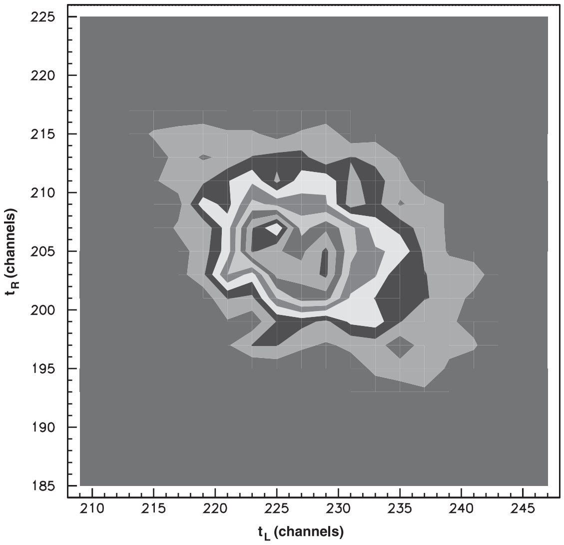

Fig. 3. Correlation t_{left} vs. t_{right}, measured with a ^{60}Co source and prototype I in the configuration shown in Fig. 1.

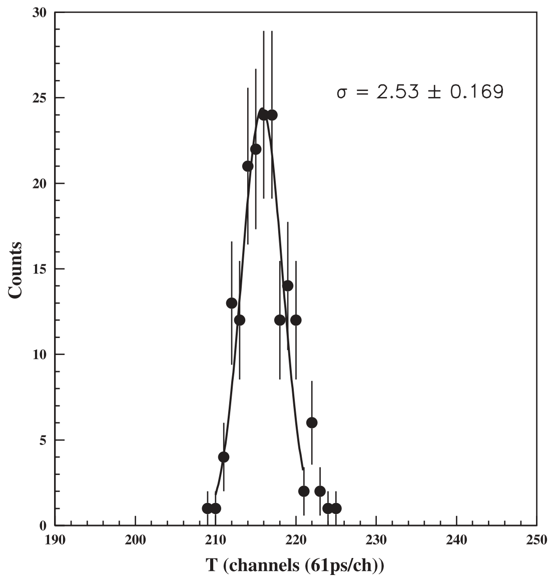

Fig. 4. $t_{sum} = \frac{1}{2}(t_{left} + t_{right})$ spectrum of the GRPC with the scintillator as time reference.

These are read out on one side only (cf. Section 2.3 and Fig. 2); with a beam spot of a few centimeter there remains a position dependence which cancels in first order in the relative time of M_1, M_2, but not in their sum used as reference in Fig. 6.

For the spectrum of Fig. 7 a coincidence with the scintillator F_1 (see Fig. 2) is required hence selecting a position bin along the strip which is comparable to the expected resolution. In principle, this could have also been achieved by another walk correction on the position measured in the GRPC itself.

The Gauss fits in Figs. 6 and 7 deliver resolutions of 96 and 88 ps, which decrease to 90 and 80 ps after folding out the 34 ps contribution of the reference counters (obtained from the time spectrum of M_1 vs. M_2, cf. Fig. 2). The non-Gaussian tails in both spectra originate mainly from low amplitudes and depend somewhat on the walk-correction; they amount to 0.13 and 0.95%, respectively. The quoted resolutions have errors of $\pm 5\%$.

The finger counter F_1 allowed also to determine the position resolution along the strip to 5–6 mm. An estimate based on the given mean time resolution and the signal propagation velocity along the strips delivers a value twice as high. This means that the intrinsic signal formation [7] introduces a scatter in the single times which contributes in a significant way to the TOF resolution. In the time difference it cancels, however; therefore the measured position resolution is determined mainly by the electronics contribution.

With the low gain of our DBA amplifiers the amplitudes are relatively small, and (compared to the expected resolution) sizable walk-corrections are needed for the lower part of the amplitude spectra (cf. Fig. 5). For the same reason the efficiency reached a value of 95.6% only at 6.7 kV.

Hence, we have performed a test with a few strips equipped with two cascaded DBA amplifiers on each side (cf. Section 2). As seen in Fig. 8 in comparison to Fig. 5 the charge distribution now exhibits a clear minimum, requiring a much weaker correction for the lower part of the spectrum. The corresponding time spectrum is shown in Fig. 9. After correction for the monitors' contribution we obtain a resolution of 79 ps at an efficiency of 96%; the tail fraction in this run was 1.5%. This value has to be compared to the

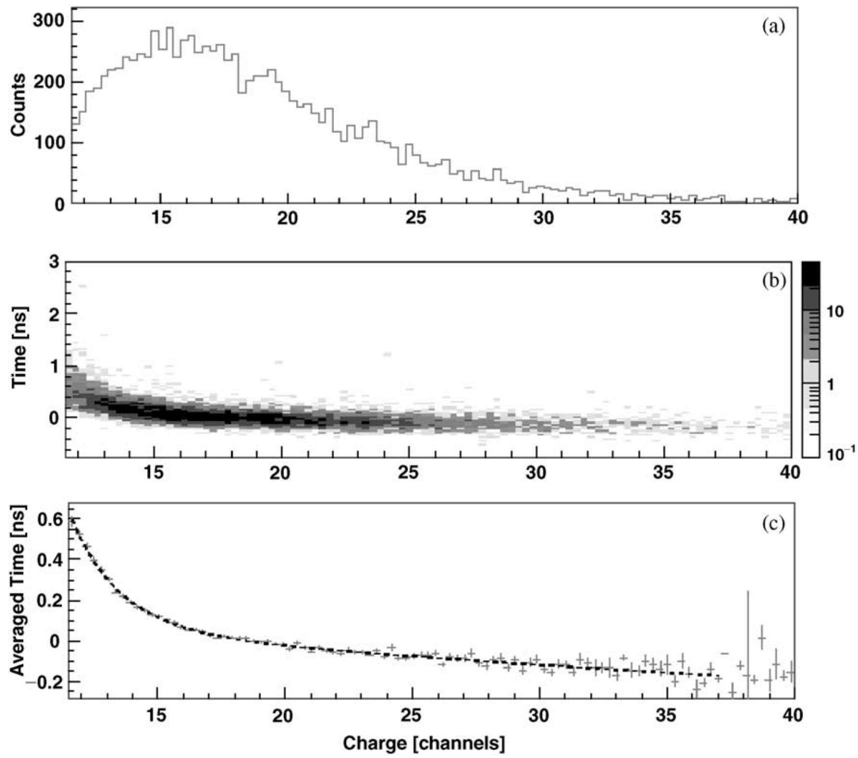

Fig. 5. (a) Charge distribution, (b) time-charge correlation as scatter plot; the yield is denoted by the different steps from light gray to black, as indicated on the right side of the frame and (c) averaged time against charge. The dashed curve in (c) is used to linearize the curve (walk correction).

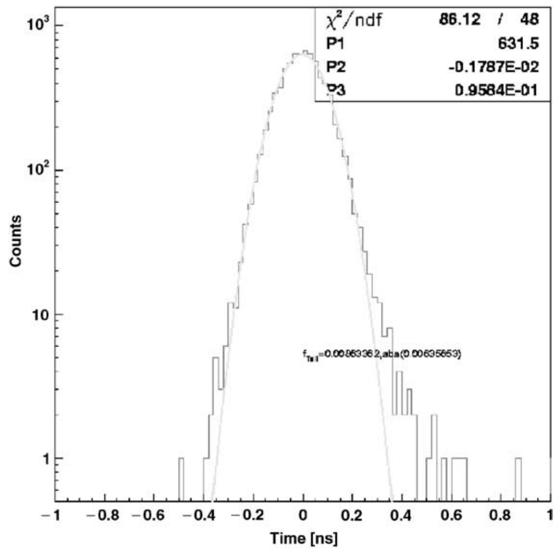

Fig. 6. Mean-time spectrum of the 90 cm prototype; see text for details.

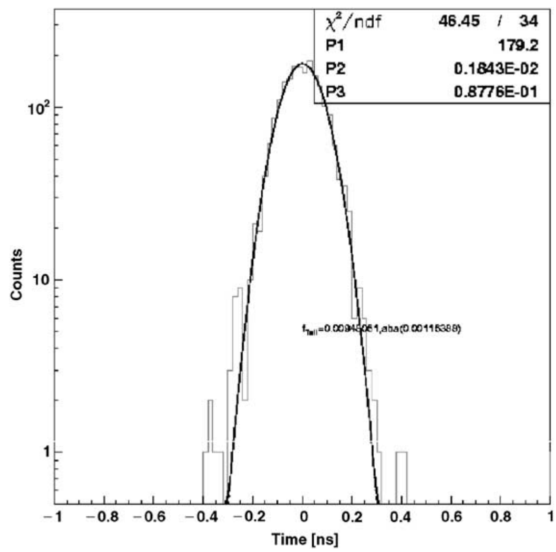

Fig. 7. Same as Fig. 6 with a position condition on the finger scintillator, cf. Fig. 2.

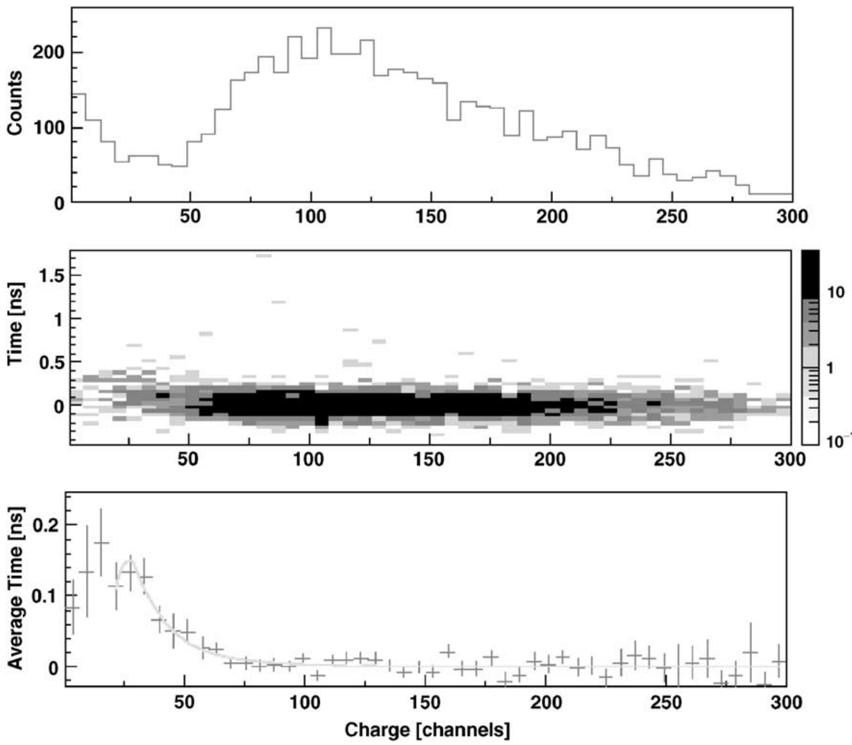

Fig. 8. Same spectra as in Fig. 5, obtained with cascaded amplifiers on both sides of the strips.

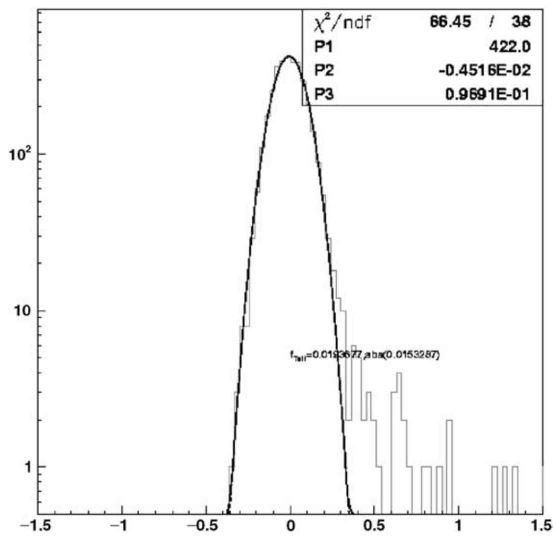

Fig. 9. Time spectrum of the 90 cm prototype, measured with cascaded amplifiers (see text).

corrected 90 ps quoted for the single-DBA result of Fig. 6. In the present run we did not use the finger scintillator, so a further improvement was not possible.

As mentioned in Section 2 we have also tested an older amplifier, GSI-type 810L, with a gain of about four times larger than the single DBA amplifiers, and obtained 77.5 ps without the finger scintillator, almost exactly the value we have reached with the cascaded DBAs at comparable efficiencies and tail fractions. This value decreased to 73.5 ps with the finger.

4. Summary and outlook

We have built and successfully tested various prototypes of glass resistive-plate chambers (GRPC) of 4×90 cm^2 active area which are read out on each side via a central plate of 12 individual anode strips. The counters have four active gaps of 0.3 mm and the electrodes are made of 1 mm float glass.

The signals are processed in commercial fast amplifiers and LE-discriminators which requires an off-line correction of walk effects. Time resolutions of 70–80 ps (errors $\pm 5\%$) have been reached, an attractive figure for TOF measurements. We believe that this value can even be improved, i.e. by setting the amplifiers close to the read-out boards (so far separated by 60 cm LEMO cables).

The time spectra show non-Gaussian tails of the order of 1%. The efficiency is about 95%. Measurements along the counter (center and ± 35 cm, i.e. 10 cm from the ends) have shown similar results in terms of time resolution, tails and efficiency. The resolution does not depend very much on the strip number across the counter; for the two outermost strips only (nos. 1 and 12, respectively) a degradation by about 20% is observed, a value which can potentially be improved by a different solution for the edge region. The quoted values have been obtained at voltages around 6.4 kV. Higher voltages did not improve the resolution; lowering the HV to 6 kV leads to a loss in resolution of the order of 10–20%.

The position resolution along the counter is estimated to be 5–6 mm. A direct determination of the position resolution perpendicular to the counter axis was not possible in these measurements. We measured, however, the cluster size, i.e. the average number of neighboring strips which fire in an event: it is 2.4 at $U = 6.2$ kV and increases to 3.2 at $U = 6.7$ kV. These values are similar to the ones we have found in our Pestov counters; so we assume that the resolution across the strips will be comparable, i.e. well below 1 mm.

We conclude that these multistrip GRPCs are a promising new line of development of high resolution, large-area gas TOF detectors. Our next investigations will deal with possible technical improvements and tests of even wider counters, i.e. a larger number of strips in one detector. The performance in the case of a multihit also remains to be studied.

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