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V. Ammosov, V. Gapienko, A. Semak, V. Sen'ko,
Yu. Sviridov, V. Zaets, E. Usenko

FOUR-GAP GLASS RPC AS A CANDIDATE TO A LARGE AREA THIN TIME-OF-FLIGHT DETECTOR

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Abstract

Ammosov V., Gapienko V.,Semak A. et al. Four-Gap Glass RPC as a Candidate to a Large Area Thin Time-of-Flight Detector: IHEP Preprint 2002-10. – Protvino, 2002. – p. 9, figs. 13, refs.: 6.

Four-gap glass RPC with 0.3 mm gap size was tested with hadron beam as a time-of-flight detector having resolution of ∼100 ps. Thickness of detector together with front-end electronics is ∼12 mm. Results on time resolution dependently on pad size are presented. This paper contains first result on the timing RPC (with ∼100 ps resolution) having strip read-out. Study has been done within the the HARP R&D work. Obtained data can be useful if a design of large area thin timing detector has to be done.

Аннотация

Аммосов В., Гапиенко В., Семак А. и др. Четырехзазорная стеклянная РПК как кандидат в тонкий времяпролетный детектор для больших площадей: Препринт ИФВЭ 2002-10. – Протвино, 2002. – 9 с., 13 рис., библиогр.: 6.

Четырехзазорная стеклянная РПК с 0.3-мм газовым зазором тестировалась в адронном пучке в качестве временного детектора с разрешением ∼100 ps. Толщина детектора, включая накамерную электронику, составляет ∼12 мм. Приводятся результаты по временному разрешению в зависимости от размера сигнального электрода. Статья содержит первый результат по временной РПК (с разрешением ∼100 ps) при съеме информации со стрипов. Исследование было проведено в рамках R&D работы для эксперимета HARP. Полученные результаты могут быть полезны при проектировании тонких временных детекторов для покрытия больших площадей.

Introduction

This study was initiated by necessity to get thin timing detector for the HARP experiment (CERN-PS214 [1]). Multigap RPC operated in avalanche mode at atmospheric pressure was suggested to use as a Time-Of-Flight (TOF) detector in [2]. Then a set of papers with results obtained during the ALICE TOF R&D tests were published (see, for example, [3], [4], [5]). However, thickness of prototypes (chamber itself plus front-end electronics) developed for the ALICE experiment is rather few ten cm what did not satisfy a HARP request on TOF system: it thickness should be less than 14 mm. New R&D work had to be done.

As the final result of our work, the TOF system covering 10 m^2 and having 368 readout channels has been realized in the HARP experiment. Its construction and basic characteristics were given in [6]. But a lot of interesting results obtained during the *R&D* study are not published yet and here we present them.

To minimize a number of resistive electrodes and thus to get thin detector we fixed our attention on 4-gap RPC with gap thickness of 0.3 mm. Operation of this type of RPC working as TOF detector was described in [4]. However, detector developed in [4] looks like array of 32×32 mm^2 independent cells mounted in two layers following a chessboard-like pattern. In our study we tried to get TOF detector consisting of one chamber added with set of pick-up electrodes.

Tracking system of the HARP detector provides with coordinates of point where a particle crosses the TOF RPC what allows to do not worry about time propagation along signal electrode because it can be taken into account. Testing chambers with different pad size we tried to understand how time resolution depends on signal electrode area for to minimize number of channels in the future TOF system. Furthermore we checked idea to summarize (with electronics) signals arriving from several signal pads. First result on timing RPC with strip read-out line is presented.

1. Experimental setup

Data were obtained at CERN in T10 test area with 7 GeV/c pion beam. In tests we used gas line, DAQ system and other set-up of the ALICE TOF group. Four trigger scintillating counters in the front and behind of our chambers provided a selection of beam particles inside of 1×1 cm^2 spot. Last fact helps us do not worry about a time jitter coming from the difference in the propagation time. Start scintillating counters provided with 30 ps time accuracy giving time mark for precise measurements. As working gas the following tetrafluorethane based mixture was used: $C_2H_2F_4/C_4H_{10}/SF_6(90/5/5)$.

1.1. RPC construction

Several small 4-gap chambers have been built with use of two different kinds of glass: two chambers having 130×200 mm^2 active area were constructed with 1 mm glass taken from the CERN workshop, one smaller chambers of 70×130 mm^2 size and one long detector, 70×1000 mm^2, were made of 0.6 mm thick glass which is used to build prototypes of the ALICE TOF detector. Resistivity of 0.6 mm glass was measured by us (with test voltage of 1 kV) as $\sim 9 \times 10^{12} \Omega \star$ cm, for 1 mm glass plates we found that resistivity is $\sim 7 \times 10^{12} \Omega \star$ cm. Construction was similar for all chambers. The cross-section of four-gap RPC is shown in Fig. 1: a pair of identical double-gap RPCs made of three glass plates with 0.3 mm (in diameter) fishing line as a spacer between plates, and peak-up electrodes, (pads or strips) between two double-gap chambers. In counter made of 0.6 mm glass three fishing lines were put in each gas gap with spacing of 35 mm between them. Four fishing line with 40 mm space between them were in chambers made of 130×200 cm^2 plates. Few small drops of “5 minutes” epoxy were enough to fix fishing lines between glass plates. High voltage was applied to each of double-gap RPCs through electrodes made of high resistive ($\sim$1 $M\Omega/\Box$) carbon film. Each of five chambers were put in its aluminium box. Two 200 μm mylar sheets one at top and one at bottom provide with an isolation between high voltage electrodes and walls of boxes. Each box can be easily opened and a system of pads can be changed in few ten minutes.

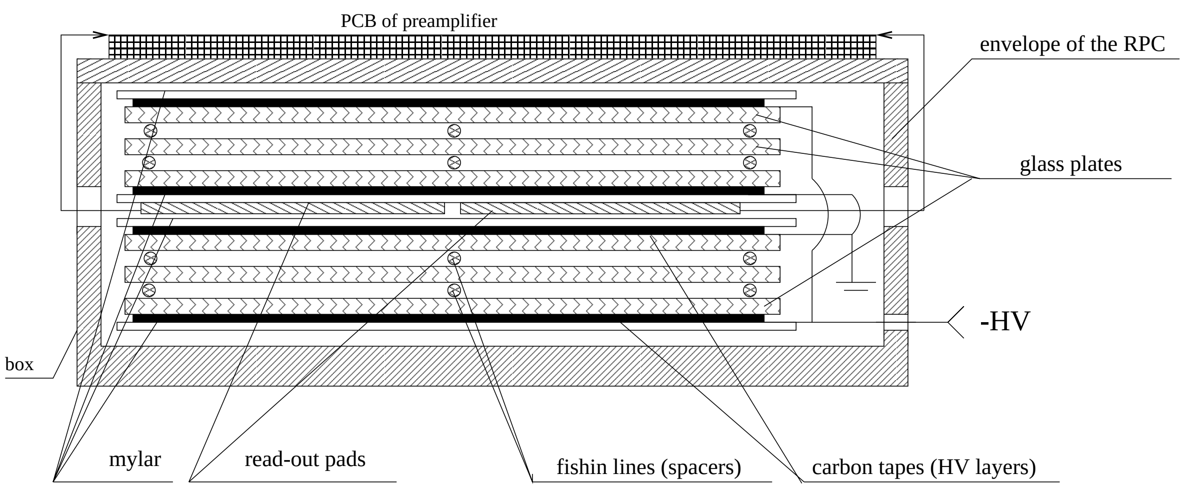

Fig. 1. Construction of the four-gap RPC counter.

1.2. Front-end electronics

Front-end electronics (FEE) used in most of present tests consisted of four-input preamplifier and splitter/discriminator (SD), both “home-made”. Scheme of preamplifier is presented in Fig. 2. Input circuits contain KT368A9 transistors. Signals from four inputs are summarized with AD8009AR amplifier having 1 GHz bandwidth. Variation in time of propagation for different inputs is about 10 ps, accuracy of the amplitude summarizing is $5-7\%$. Coefficient of transformation for the preamplifier was measured as -85mV/pC. Inputs of preamplifier were connected to pads with short ($\sim 1-3$ cm) wires. Thickness of aluminium box together with preamplifier PCB attached to RPC house (as it is schematically shown in Fig. 1) was about 12 mm.

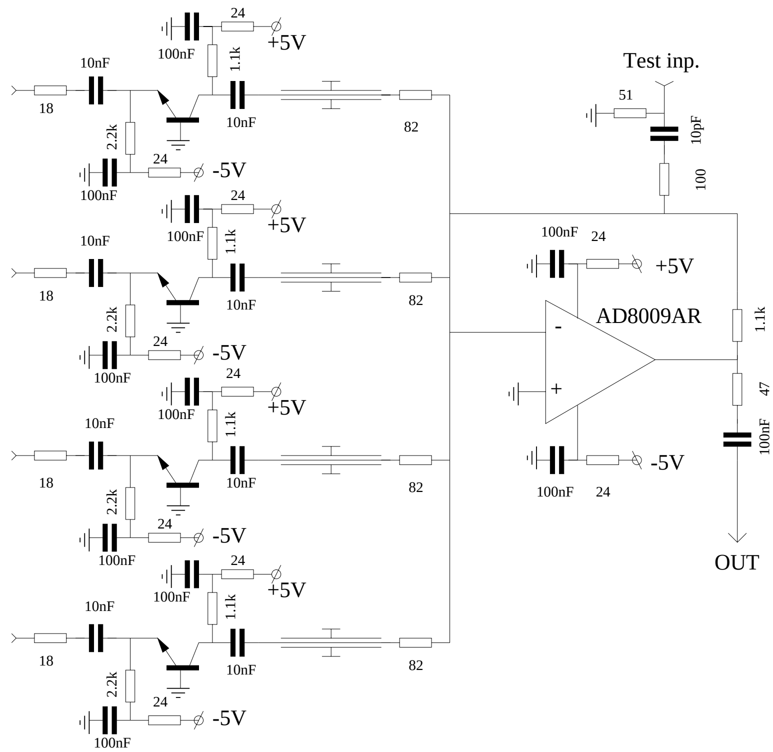

Fig. 2. Scheme of the four-input preamplifier.

Output of preamplifier was connected by coaxial cable to SD with adjastable (∼3 − 10 mV) threshold of discrimination. SD module has two outputs: one for analog signal and one for discriminated signal (NIM level). Output with analog signal was directly fed to a LeCroy 2249W ADC, digital signal was sent to a LeCroy 2229 TDC with a 50 ps bin width. Information from ADC was used to find correlation between "time" and "amplitude" and then to correct the data for time-charge slewing.

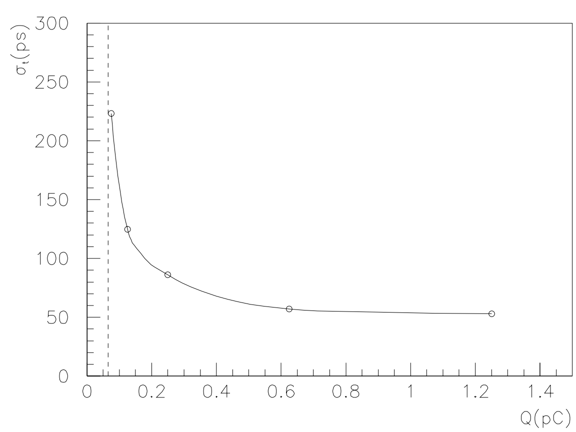

Fig. 3. Time resolution of electronics dependently on input charge.

Time resolution of FEE in described above set-up has been tested with pulse generator: we enjected charge through the test input of preamplifier and measured time jitter between generator pulse and output signal from the discriminator as a function of input charge. Data in Fig. 3 describe time resolution of the preamplifier when no one of inputs was connected to pads. During this measurement preamplifier was attached to aluminium box of RPC, but no high voltage was applied to chamber. Vertical dashed line in the figure corresponds to chosen by us the threshold of 65 fC.

Our home-made 4-input preamplifier and SD were taken as a prototypes for the HARP TOF electronics. When first examples of 8-input preamplifier produced for the HARP detector was available we used one of them to see how time resolution changes if to summarize signals from several pads.

2. Experimental results

Time resolution of a detector working near threshold of electronics can be estimated after correction for time-amplitude correlation. Example of typical time-charge scatter plot what we saw during tests of our RPCs is given in Fig. 4a. Solid curve in this figure presents result of fit with polynomial expression. Polynomial functions obtained in such approximation were used to correct time distribution for time-charge correlation. Example of corrected time distribution obtained from data shown in Fig. 4b. Approximation of corrected time distribution with gaussian law, as it is shown in Fig. 4b by curve, gives value of time resolution (σ_t).

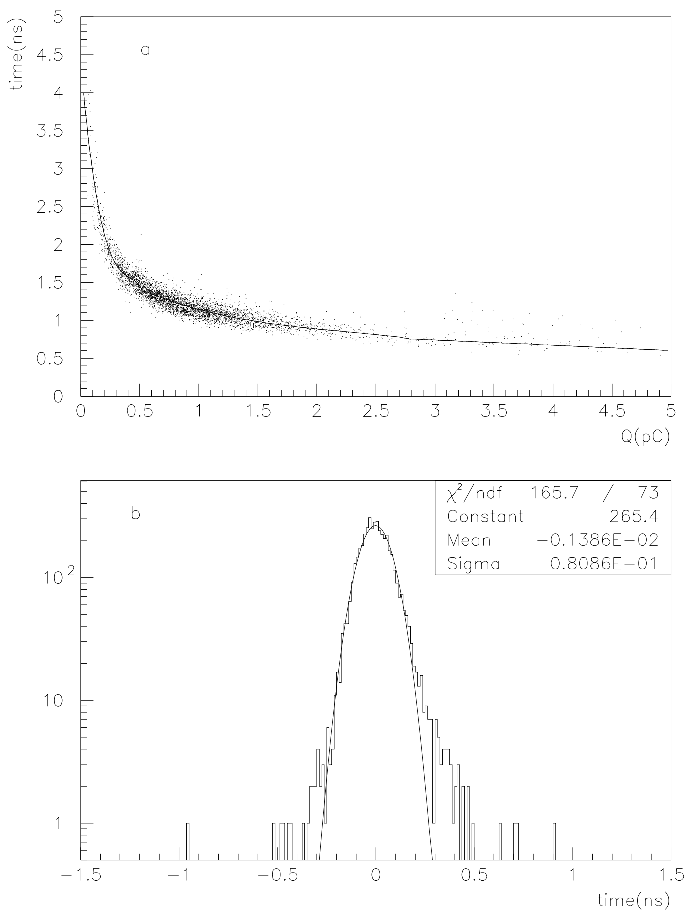

Fig. 4. **a** — example of charge-time plot: points are experimental points, curve is the result of approximation with polynomial expression; **b** — time distribution after correction for the charge-time correlation, it included resolution of start scintillating counters (30 ps).

2.1. Time resolution and efficiency in dependence on pad size

Working voltage, HV, for choosed variant of four-gap RPC is relatively low. Behavior of σ_t as a function of HV is presented in Fig. 5 as it was observed for chambers with different pad size: 3×3 (triangles), 10×10 (boxes) and 11×18 cm^2 (circles). Solid curves in the figure are drawn for the eyes guide. One pad only was connected to amplifier in last measurement. The figure shows that the best time resolution can be reached at HV=6.2 kV. This conclusion was well for all chambers we tested in spite of differences in thickness of glass used to build chambers. Value of 6.2 kV was chosen as a working voltage in further tests.

In Fig. 5 and in all other figures where data on time resolution are plotted, error in σ_t shows an accuracy with which we could reproduce our result next time. All points presented in Fig. 5 were obtained with a chamber passed a training under high voltage during several days.

Charge distribution measured for induced signal at HV=6.2 kV is shown in Fig. 6. Mean value of induced charge is $\sim$1 pC. Taking into account the FEE resolution as a function of charge (Fig. 3) and real charge distribution from Fig. 6 one can estimate resolution what can be reached in our tests: it is $\sim$65 ps. Last estimation is ultimate – it does not includes deterioration in resolution due to noise from pads when HV is on.

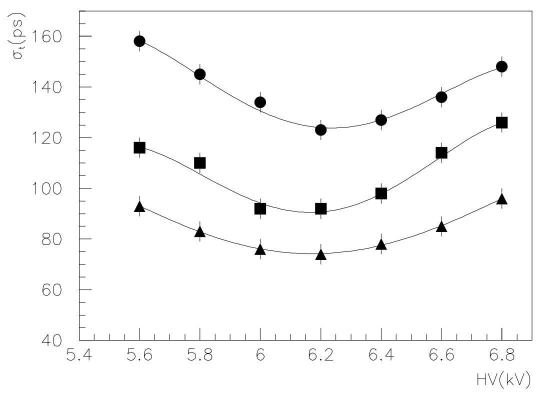

Fig. 5. Resolution versus high voltage. Triangles, boxes and circles show data obtained with RPC having correspondently 3×3 cm^2, 10×10 cm^2 and 11×18 cm^2 single pad.

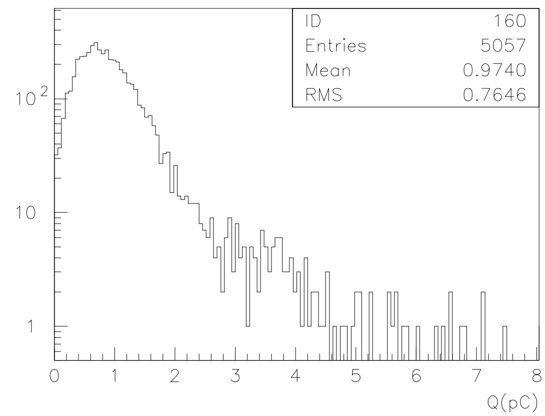

Fig. 6. Charge distribution measured at HV=6.2 kV.

Just first our attempts to measure σ_t showed that the data are unstable with time: improvement of the resolution was observed if to keep a chamber under working voltage for several days. Example given in Fig. 7 demonstrates importance of training process: if fresh chamber showed $\sigma_t \approx 170$ ps, after 100 hours the resolution drops down below 120 ps. A chamber was considered completely trained, if after several days of training process it showed stable result on σ_t.

Time resolution dependently on pad area, S, is given in Fig. 8 with triangles for case when one pad only was connected to preamplifier. Approximation of the data obtained for single pad with expression $\sigma_t = A + B \star S$ (solid line in the figure) brings $A = 70$ ps and $B = 0.26$ ps/cm^2. First value is close to resolution what we expected from our electronics for charge spectrum shown in Fig. 6. Parameter B depends on how noisy chamber is.

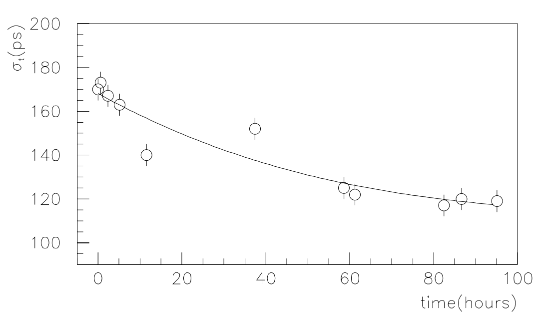

Fig. 7. Example of the RPC training: improvement of σ_t with time. Pad area is $11{\times}18$ cm^2.

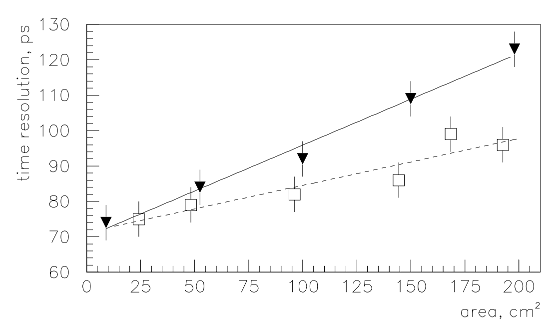

Fig. 8. Time resolution in case when preamplifier reads one pad (triangles) and several pads (boxes) as a function of signal electrode area.

All tested RPCs showed high efficiency. Two types of efficiency were considered by us: total efficiency, ε — probability to get a reply from chamber inside 15 ns gate and so-called 3σ-efficiency, $\varepsilon_{3\sigma}$, as a probability that a reply is inside $\pm 3\sigma_t$ interval. Values of ε (closed circles) and $\varepsilon_{3\sigma}$ (open circles) measured for chambers with different pads are given in Fig. 9 as a function of pad size. Both efficiencies were calculated, of course, after correction for the time-charge correlation. Looking at Fig. 9 one can see that both efficiencies go down with growth of pad size. Equaling to 97% for 25 cm^2-pad, 3σ-efficiency drops down to $\sim$94% when pad size is $\sim$200 cm^2.

Another problem was found for big pads. It was appeared that for a pad having size of about 10×10 cm^2 and larger a value of time resolution is not uniform, it depends on point of discharge inside RPC. Example of such nonuniformity is shown in Fig. 11a for 11×18 cm^2 pad. Ten hatched squares in this figure show places where beam crossed RPC during the pad scan. Two values at each square present time resolution (first value) and 3σ-efficiency (second value). Deterioration in the resolution can be seen in the region close to point where signal wire is soldered to pad. Attempts to eliminate the effect by changing of the amplifier input impedance brought no positive result.

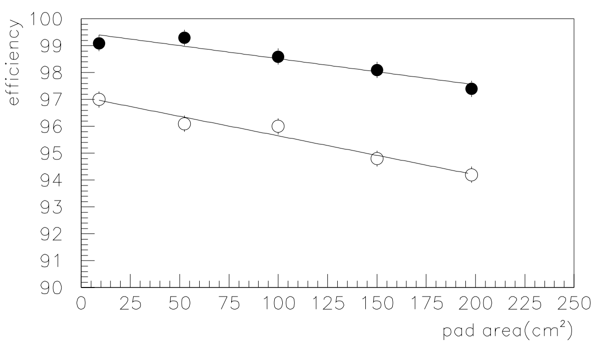

Fig. 9. Total efficiency (closed circles) and 3σ-efficiency (open circles) as functions of pad size.

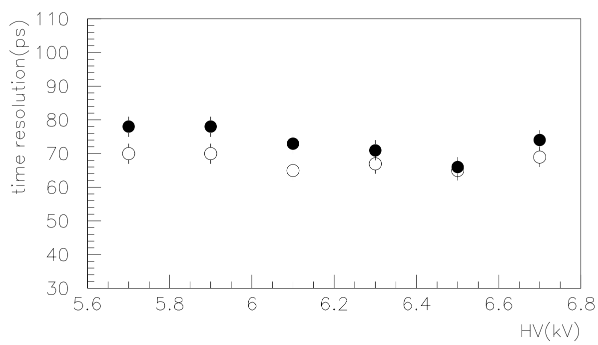

Fig. 10. Corrected time resolution (open circles) found in case when two-stage amplifier was followed with standard discriminator in comparison with not corrected resolution (closed circles) obtained with CFD.

All data in figures where time resolution is presented dependently on pad size were obtained with beam going through the pad centre.

It was described above that σ_t values were extracted from time distribution after its off-line correction for the time-amplitude slewing. However, it was interesting for us to check a possibility to get "on-line" timing with use of constant fraction discriminator (CFD). As CFD we took ORTEC CF4000 module. Because of high level of discrimination in CF4000, gain of our "standard" amplifier was not enough to work with CF4000. In operation with CFD we organized a chain of two amplifiers: MAX3760 (first stage) and AD8009AR (second stage, gain=5). Results obtained with two-stage amplifier are shown in Fig. 10. Open circles describe resolution obtained when output of the MAX3760 preamplifier was sent to fixed threshold discriminator. Off-line correction for time-charge correlation was done before plotting these points. Closed circles show data obtained with CFD instead of usual discriminator. The figure demonstrates a possibility to get good time resolution even without off-line correction if CFD is used.

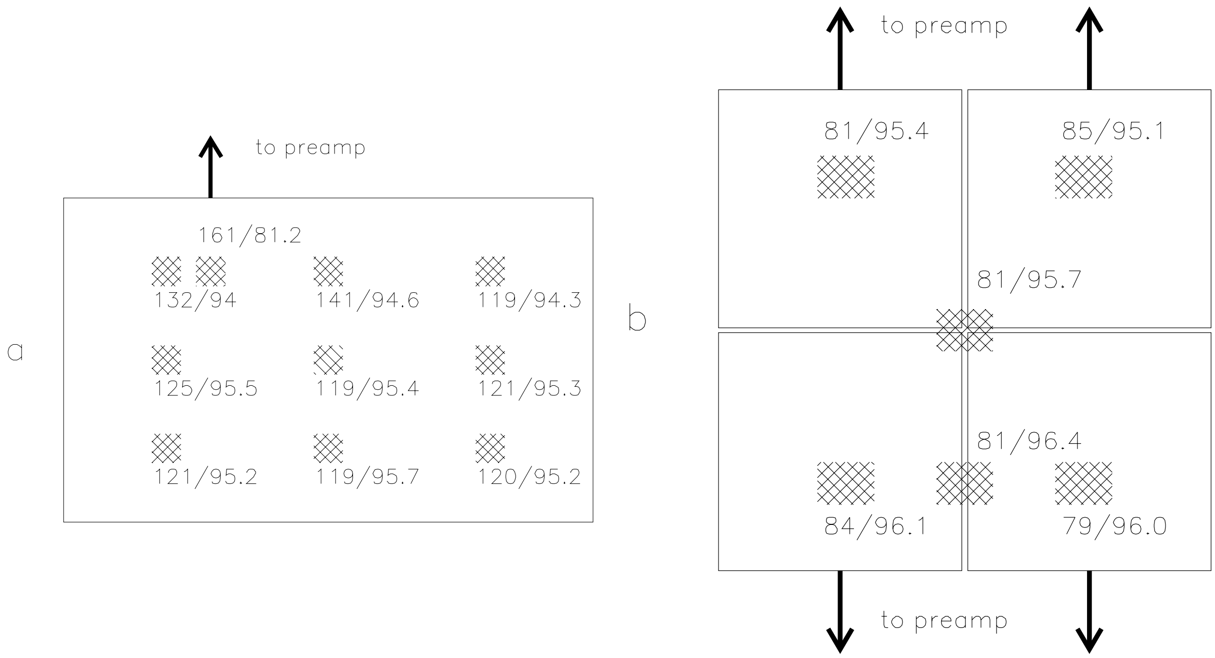

Fig. 11. Time resolution and efficiency ($\varepsilon_{3\sigma}$) at different places of **a)** 11×18 cm^2 single pad and **b)** four-pad system. Size of a small pad in last case is 4.3×5.6 cm^2.

2.2. Summarizing of signals from several pads

After clear deterioration of resolution with growth of pad size was observed, we tried to improve situation by splitting one big pad into several smaller ones for to read them by one multiinput amplifier. Firstly we looked does any nonuniformity in efficiency and σ_t for a system of small pads connected to one amplifier exist if to expose different places of RPC. To check this we used RPC having four pads with size of 4.3×5.6 cm^2 each. Pads were connected to different inputs of 4-input amplifier. Result of the four-pad system scan is presented in Fig. 11. Hatched areas in the figure show place where beam crossed the system of four electrodes. Two values written at each dashed square are: first — time resolution, second — 3σ-efficiency. The figure demonstrates that in limit of our errors no variation in σ_t or $\varepsilon_{3\sigma}$ depending on exposure place was observed even in case when axis of beam was between four adjacent pads. Main conclusion from the figure is that the amplifier summarizes signals without problem for resolution or efficiency.

One module of 8-input amplifier produced as a final version for the HARP TOF system was used by us to see how resolution depends on "read-out area" if to summarize signals from set of small pads. Scheme and main parameters of final amplifier were practically the same as it was described above for 4-input. Eight pads having size of 4.3×5.6 cm^2 each were connected (one-by-one) to eight inputs and the time resolution degradation was studied. Fig. 8 displays σ_t as a function of the signal electrodes area for case of single pad (triangles) and for case when several pads (boxes) are connected to one preamplifier. As it is seen from Fig. 8, degradation of resolution with growth of area goes slower for multipad system than for single read-out pad. Two lines in the figure present the results of approximation with linear law done separately for two sets of the data. Data obtained with 8-input amplifier can be described with $\sigma_t = 0.71 + 0.13 \times S$ (dashed line in Fig. 8).

2.3. Strip read-out

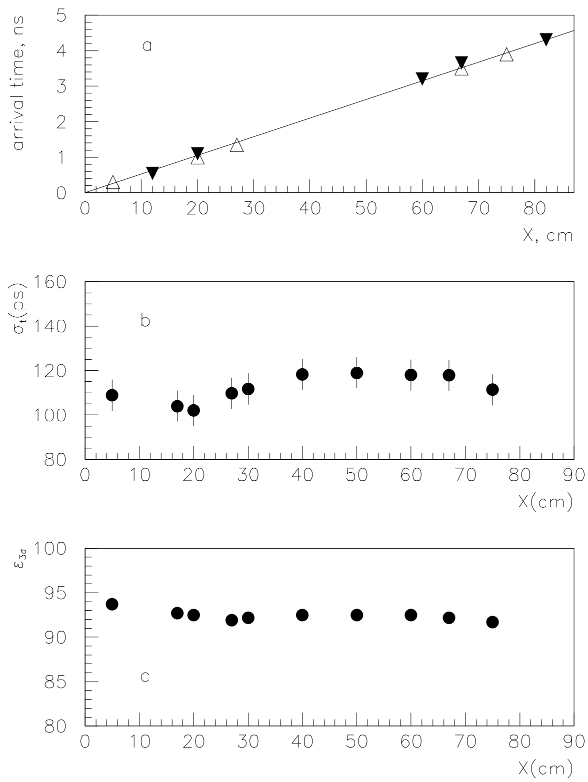

Fig. 12. **a** — arrival time, **b** — time resolution and **c** — 3σ-efficiency dependently on distance between strip end and beam.

To conclude what time resolution can be reached if long strip is taken instead of pad, 1 m length RPC was added with 90 cm strip line having width of 2.5 cm. Each end of strip was connected to its own preamplifier. Impedance of strip line was measured as $20 \pm 5\Omega$. To avoide possible oscillations due to reflection of signal at ends, strip line should be terminated with 20Ω loading. Resistor was added in input circuit of preamplifier to change it impedance to needed resistivity of 20Ω.

Different places of 1 m length RPC were exposed to beam, and reply of the detector was studied dependently on distance, X, between beam line and strip end. Fig. 12a shows mean arrival time as a function of X. Two sets of points in the figure, open and closed triangles, belong to different ends of one strip line. Linear approximation of the data gives slope of ~50 ps/cm.

Time jitter for half of sum of times coming from opposite ends after corrections, $t_{12} = (t_1 + t_2)/2$, was measured along strip for different distances taken relatively to one of ends . The results on t_{12} resolution are in Fig. 12b. As the figure demonstrates, values of resolution found during “scanning” along strip are inside 110-120 ps. In limit of experimental errors they do not depend on X. If to read one end of strip only, time resolution was found to be about 160 ps.

Fig. 12c presents 3σ-efficiency estimated from width of t_{12}-distribution. No dependence of $\varepsilon_{3\sigma}$ on X is seen in last figure.

2.4. Glass RPC at different particle rate

Glass is a high resistive material. That is why glass RPC even operated in avalanche mode should be sensitive to particle rate.

Within set-up what we had in T10 test area we estimated the rate using counting rates from set of scintillating counters installed in front and behind of our chambers. However, we could not control particle rate with accuracy better than ~30%, because few detectors tested by other groups were installed at the same time in the beam line.

The rate what we show in the figures below was calculated as a number of particle crossing 10×10 mm^2 square (with center at beam line) per spill divided by spill duration of ~300 ms. It should be noticed that because of beam halo not only 1×1 cm^2 RPC area was exposed to beam. Number of particles going through 4.5×5 cm^2 scintillating counter installed just before tested RPC was ~15 times higher than number of particles going trough the central 10×10 mm^2 area.

Fig. 13 shows: (a) time resolution and $\varepsilon_{3\sigma}$ efficiency (b) at different values of rate. RPC having 10×15 single pad was exposed to beam to get these distributions. Both distributions demonstrate a deterioration in RPC work with growth of particle rate.

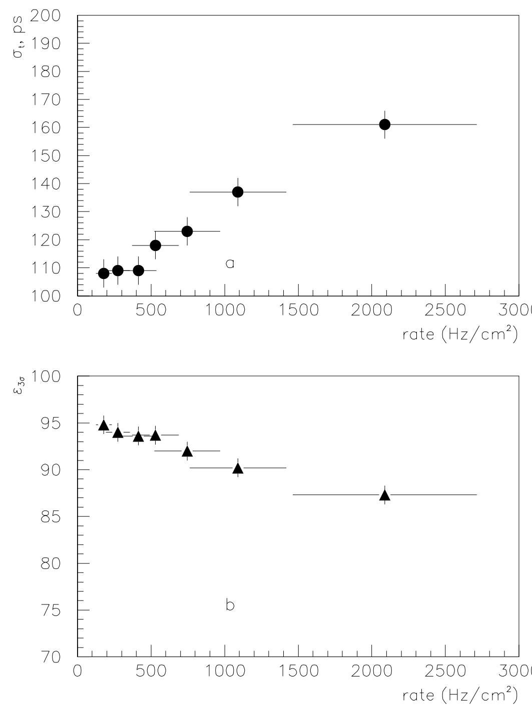

Fig. 13. **a** — time resolution vs particle rate, **b** — efficiency at different rates.

Conclusions

We designed, built and tested prototypes of thin TOF detector. Four-gap glass RPCs added with different pick-up electrodes were exposed to 7 GeV/c pion beam to find what resolution and efficiency can be reached.

Time resolution as a function of pad size was found to show linear dependence on pad area (S): σ_t=$A + B \times S$, where $A = 70$ ps is the intrinsic resolution of our FEE, and $B = 0.26$ ps/cm^2. Value of 3σ-efficiency is 97% for small pad (25 cm^2) and drops down to 94% with growth of pad area to ~200 cm^2.

Situation with time resolution and efficiency for "big" read-out area can be improved if to split one pad into set of smaller ones and to read them with summing amplifier. Using 8-input amplifier we found that $\sigma_t = 0.71 + 0.13 \times S$.

We tested timing RPC with strip read-out. Resolution of $110 - 120$ ps was reached for 90 cm length strip having 2.5 cm width when signals from both ends were recordered.

Our results can be useful if development of large area TOF detector with thickness of $10 - 15$ mm is needed.

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