18

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New Time-of-Flight Technology Based on Gaseous Detectors of Parallel Plate Geometry Operated in the Avalanche Mode

Part I. Single Cell Performance

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NEW TIME-OF-FLIGHT TECHNOLOGY BASED ON GASEOUS DETECTORS OF PARALLEL PLATE GEOMETRY OPERATED IN THE AVALANCHE MODE. PART I. SINGLE CELL PERFORMANCE: Preprint ITEP 08–01/

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The possibility of fine timing measurements, accompanied with high MIP registration efficiency, by means of the simplest gaseous detector of parallel plate geometry operated in the avalanche mode, was first shown.

R&D on Parallel Plate Chamber (PPC) involved simulations of gas discharge, choice of detector material and construction, of filling gas. A major step-forward in developing fast and low noise electronics was made.

PPC showed about 200 ps timing resolution with more than 90% registration efficiency, its main disadvantage being suffering in rare cases of breakdown events.

Впервые продемонстрирована возможность точных и высокоэффективных измерений времени пролета ионизующих частиц при помощи простейшего газонаполненного плоско-параллельного детектора, работающего в лавинном режиме газового усиления.

Изучение и проектирование плоско-параллельной камеры (ППК) включало в себя симуляцию газового разряда, выбор материала и конструкции детектора, рабочей газовой смеси. Серьезный прорыв достигнут в разработке быстрой низкошумящей электроники.

С помощью ППК удалось получить временное разрешение на уровне 200 пс при эффективности регистрации ионизующих частиц более 90%. Основным недостатком камеры является ее уязвимость в редких случаях газового пробоя.

Fig. - 12, ref. - 14 name.

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1. Introduction

The R&D described later in this article was a part of the ALICE Time-of-Flight (TOF) project at LHC (CERN), started in 1992, and aimed in developing a new gaseous TOF technique. The task is to build at affordable price a high granular TOF system with more than 150 000 separate channels and an over 100 m^2 surface, allowing timing measurements with a 100–200 ps accuracy, and an almost 100% registration efficiency for MIP.

In this article, the results of the initial stage of the R&D are given, during which charcteristics of single cells of the TOF system were investigated.

2. Avalanche TOF Technique

Contrary to a well-known TOF technique, based on spark detectors described in [1], the possibility of using parallel plate gaseous detectors working in the avalanche mode for the large, precise, and efficient TOF system, required by ALICE, had not been investigated. The avalanche signal, produced before the spark conditions occur inside the gas volume, could be expected to make a good time reference. The smaller value of discharge could provide a better rate capability, slow down the chamber aging, and probably could help to avoid many other technological problems, which had blocked the way for the spark detectors.

An R&D started from a simple Parallel Plate Chamber (PPC). At the beginning, there was a little hope that it might work as an efficient TOF detector for MIP. One of the major problems was a small value of the avalanche signal, which required special sensitive electronics to be developed. On the contrary, to build up an electronic channel demanded a detailed knowledge of the signal shape. To solve the contradiction, the R&D was performed step-by-step, and has gone through 4 main stages. During the first stage, it was confirmed that PPC can principally work as a good timing detector. At the second stage, different factors influencing the PPC time resolution and efficiency were being systematically improved. Third, it was shown that a rather large sensitive area, with PPC as a base cell and with some fast sensitive electronics, could be built and operate without significant cross-talks. At the fourth stage, a new improved avalanche technique for TOF measurements was proposed, which appeared to be free of the main PPC disadvantages.

3. PPC as a Detector for MIP: Principles of Operation, Main Characteristics, Reasons for Using in ALICE

As described in [2, 3, 4, 5], a Parallel Plate Chamber is a single gap gaseous detector working in the avalanche mode. It consists normally of two planar electrodes made of metal, or metallized ceramic or plastic, and kept at a fixed (0.5–2 mm) distance apart by precise spacers with 5–10 μm accuracy. The inner surfaces of the electrodes are carefully polished to create a high and uniform electric field. The standard flatness precision is kept within approximately 10 μm and depends on the gap width. The electrode sizes range from 10×10 mm^2 to 100×100 mm^2 or even larger, the total detector thickness depends on the material and the design and usually equals to a few milimeters.

A high electric field of 2–6 kV/mm between the electrodes makes immediate Townsend avalanche amplification of the primary ionization possible at any point of the working volume.

As described in [6], the motion of an electron avalanche induces a very fast signal on the electrodes, with the rise time of less than 1 ns. The signal is followed by a much slower one which lasts for several microseconds and corresponds to the motion of positive ions. Depending on the gas filling, the gain of the order of 10^3–10^4 can be reached with a very low spark probability (see [7]).

The advantages of the PPC technique, as summarised in [7], include a very fast response and a high rate capability of up to 10^7 Hz/cm^2 without particular problems. Thanks to these features, PPCs were widely studied for LHC applications at CERN during the early 90s, particularly for the very forward muon calorimetry and the forward muon trigger within the RD5 and RD37 frameworks.

Possible application of PPC in efficient high resolution timing measurements for MIP were not under investigation at that time due to two main reasons.

1. A naïve opinion dominated that the PPC timing resolution must be of the order of 1–2 ns for a 1 mm gas gap, stipulated by the intrinsic jitter of the avalanche. This statement was supported by the experience of Pestov spark counters gained since 1966. As discussed in [1], the high timing resolution may be obtained with Pestov counters only under special conditions including extremely large value of the electric field (60 kV/mm which is an order of magnitude higher than in PPC), a very narrow gas gap (100 μm), and a high gas pressure (13 bars).

2. The PPC signals are small, about 1–10 fC. The amplitude spectrum in case of pure avalanche amplification has a 1/A-shape with maximum of events being close to the pedestal. This made measurements rather inefficient, since even a low noise of FEE could provide the signal-to-noise ratio being equal to several units and the total detector efficiency achieved on CO_2, i-C_4H_{10} and CH_4-based gas mixtures being 50–80% without any observable plateau. FEE required for fine timing measurements is much noisier and thus could make a lot of harm both to the efficiency and the time resolution.

Besides, there existed problems of signal discrimination on a few mV level, noise of an electronics above the threshold, probability of sparks killing sensitive amplifiers, and others.

An R&D on PPCs for precise and efficient TOF applications was launched at ITEP (Moscow, Russia) with participation of INFN (Florence, Italy) (see [7]), and then continued in the slopes of ALICE R&D with participation of CERN, ITEP, MePhI (Moscow, Russia), YerPhi (Erevan, Armenia), JINR (Dubna, Russia), and PNPI (Gatchina, Russia).

There were two main reasons to propose PPC as a base detector of the ALICE TOF system.

1. Basing on RD5/RD37 experience, the cost estimate of the PPC-based TOF system yielded an approximate amount of 50–100 CHF per channel. This value is about one order of magnitude less than that for the classical solution based on scintillators and photo-multipliers. Thus a possibility to build a huge TOF system with 100–200 K channels at affordable cost of about 10–20 MCHF could be opened.

2. The Pestov spark counter design, which was the general option for TOF in ALICE, involved extremely complicated techniques and could hardly be extended to a large number of channels both for technical and financial reasons. Its exclusive intrinsic time resolution of $\sim$ 10 ps exceeded the requirements for the ALICE TOF system.

4. First Test Results at ITEP

To prove the possibility of using PPC as a base detector in ALICE TOF and to predict its timing properties, computer simulations of the processes taking place in the chamber were performed, which were based on a general assumption that PPC operates in a Townsend mode of gas amplification (see [8]). Consider a single-gap PPC crossed by MIP as shown in Fig. 1*a*.

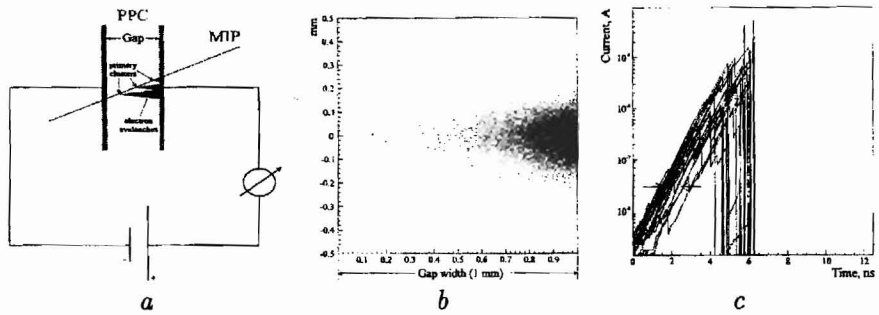
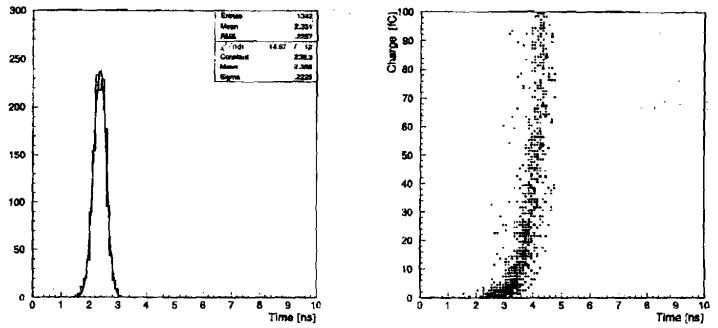


Fig. 1. Simulations of the PPC operation, gap width — 1 mm, gas filling — pure i-C_4H_{10}: *a* — ionising particle crossing the chamber (schematic drawing); *b* — charge produced in a simulated avalanche; *c* — examples of electric currents induced in the outer circuit.

Due to a high electric field applied between the PPC electrodes, electrons produced during the primary ionization give birth to avalanches developing towards the anode. Fig. 1*b* shows the positive charge distribution inside the chamber volume right after the avalanche has passed. The separation of positive and negative charges inside the chamber induces an electric current in the outer circuit, which occurs right at the moment the MIP crosses the chamber gap and which is actually registered. The quantity deviation of primary ionization and the location of primary pairs inside the gap, as well as statistical fluctuations of the number of ionising collisions at the first stage of the avalanche development, influence the resulting amplitude much. Fig. 1*c* summarises several simulated events showing the outer circuit currents. An interval pointed with the arrows is roughly what may be called the PPC TOF resolution.

All performed calculations showed that the PPC time resolution should be about 100–200 ps as long as the electronics is not accounted (see Fig. 2*a*). A two-dimensional plot of the charge integrated on the discriminator input versus the time jitter is shown in Fig. 2*b*. A large part of events prevailed in the low-amplitude region. It may be seen however that establishing the threshold of discriminator at a 3 fC level still left a significant number of events in the efficient region. This was approximately the threshold which later was actually used in the PPC tests.

The R&D at ITEP was first focused on 1.5 mm-gap ceramic PPCs previously used in RD37 project (see Ref. [7]), and later on specially designed ceramic and metal PPCs, including a detector with an externally adjusted between 0.5 and 2 mm gas gap. The ceramic electrodes were covered with Cr, Au and Cu. The cell sizes varied between 20×20 and 50×50 mm^2. One-, two- and three-component gas mixtures were based on CO_2, i-C_4H_{10} and Ar with different working high voltage regions and different absorptions to the self-produced ultraviolet. FEE was being step-by-step upgraded, starting from the very beginning and passing through many versions. Fast amplification was performed in two steps — a preamplifier and a main amplifier,



a *b*

Fig. 2. Simulation results for 0.6 mm PPC filled with pure i-C_4H_{10}: *a* — time jitter at a 3 fC threshold; *b* — induced charge versus time jitter.

different types of very low threshold discriminators (both CFD and LED) were tested. The most important part of the electronics were sensitive preamplifiers with the following typical characteristics:

- rise time — 0.5–3 ns,
- noise with a zero capacitance on the output — 1000–5000 e^-,
- amplification — 100–1000 mV/pC.

Discriminators with thresholds of 2–5 mV were used.

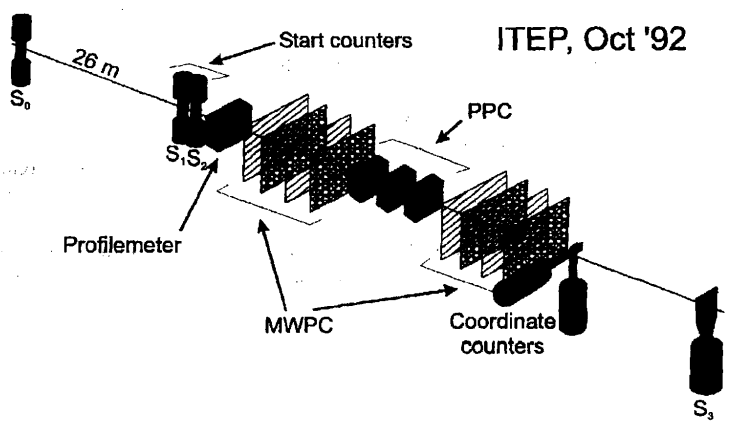


Fig. 3. PPC beam test facility.

The beam tests with MIP performed at ITEP PS for several years, involved 3–10 GeV/c pions and protons. Fig. 3 shows the setup. The start signal was produced by a standard Sc/PM timing detector S_1. Initially measured TOF resolution (both with CFD and LED) was of the order of 1 ns. A discovered correlation between PPC TOF (T) and the collected charge on the amplifier input (A) was used off-line to calculate the PPC time resolution and opened the way for using PPC as a detector for TOF.

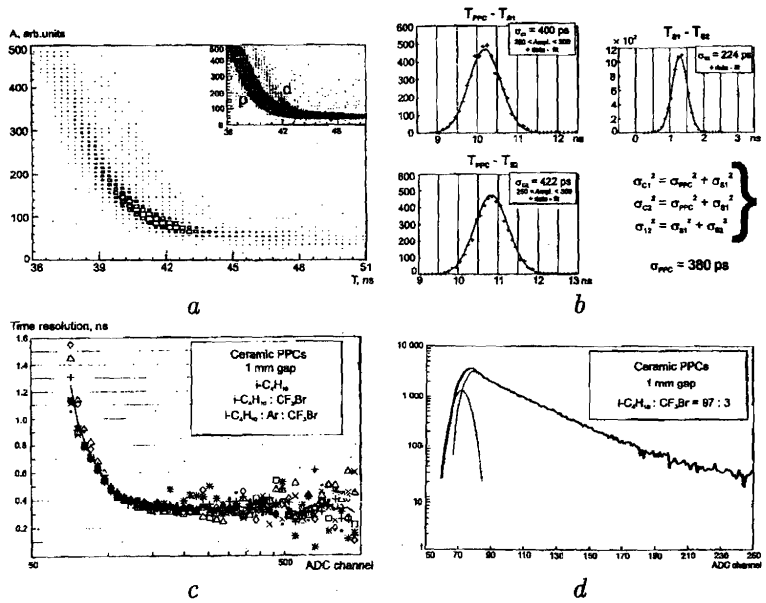


Fig. 4. First ITEP beam test results on the PPC timing characteristics: a — T(A)-dependence, the plot in the right top corner shows that an admixture of deutrons in the proton beam could be distinguished; b — the TOF measurements idea, involving two identical start scintillator counters; c — TOF resolution at different amplitudes measured on several gas mixtures; d — amplitude apectra measured with a small admixture of CF_3Br.

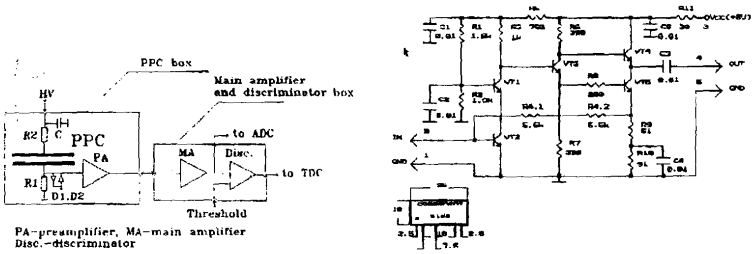
One of the first results is shown in Fig. 4a. The time difference between the stop (PPC) and the start, measured with LED, depended on the amplitude, measured with a charge-sensitive ADC. Off-line T(A) correction and quadratic subtraction of the start system jitter led to a 300–400 ps TOF resolution (see Fig. 4b). This value included the intrinsic resolution of FEE being between 250 and 200 ps for different amplitudes, and depended on the value of the collected charge and the LED threshold (see Fig. 4c). With all the studied gas mixtures, moving away from the pedestal to higher amplitudes makes the TOF resolution more constant though decreases the detector efficiency down to 10–20%.

A 5–10% admixture of a highly electro-negative gas CF_3Br changed the situation dramatically. Under the same conditions, the average collected charge grew up to 30–50 fC, the amplitude distribution became much broader (see Fig. 4d), what resulted in the 200 ps PPC resolution after subtracting the electronics jitter, and in 50–70% registration efficiency

for MIP. In Fig. 4*c* one can clearly see that the TOF resolution did not depend on the gas filling, probably because of the very large FEE contribution. The first beam test results may be found in Ref. [7].

5. R&D on Single Cells in 1995–97

During the R&D, a huge work was done on constructing the electronic channel for PPC. The main idea of FEE which was used in the PPC timing measurements and is used now with modern TOF detector options lies in a double amplification of the signal, as shown in Fig. 5*a*.



a *b*

Fig. 5. Electronic channel for PPC: *a* — main idea of the FEE connection; *b* — example of the preamplifier design.

The preamplifier was placed as close to the PPC cell as possible, one of the reasons for doing so was to avoid possible cross-talks in the future modules. The diodes on the preamplifier input prevented the transistor damage in spark cases. More than 10 different types of hybrid preamplifiers were constructed with the participation of ITEP, CPTA, PNPI, IHEP and CERN (see [9], for example). All of them were tested under the working conditions and showed close characteristics summarised in the top part of Table 1. One of intermediate versions of the preamplifier is shown in Fig. 5*b*. The ITEP preamplifier design used a usual cascade scheme and negative feedback to decrease the input impedance, it also proved to retain its properties in the mass production. The main amplifier MAR6, commercially produced by Hewlett Packard and based on INA-02184 chip, was usually distanced from the detector (see bottom part of Table 1 for its characteristics).

Preamplifier	
Rise time for a 2 ns test signal	2ns
Gain	0.2–10 mV/fC
Noise	0.3–1.0 fC
Main amplifier	
Gain at 1 GHz	28 dB
Noise	2 dB
Input/output impedances	50 Ohm

Table 1. PPC front-end electronics parameters.

Two types of discriminators were studied: a Constant Threshold Discriminator (CFD) and a Leading Edge Discriminator (LED), which both showed good operation with PPC. Using CFD and omitting further T(A)-correction showed worse results than LED measurements followed by such correction. With CFD, amplitude dependence of TOF was also observed, but it had a shape different from that seen with LED. This proved that the rise time and the signal shape from PPC depended on the amplitude. After different T(A)-corrections, performed with both discriminator types, similar results were obtained. Since LED is a simple, cheap and stable device, the choice was finally fixed on it.

As a result of R&D, a fast and low-noise FEE with well-measured characteristics was developed. From then on, it could be considered to be a part of the detector, and its intrinsic time resolution was not longer to be subtracted from the total detector TOF resolution.

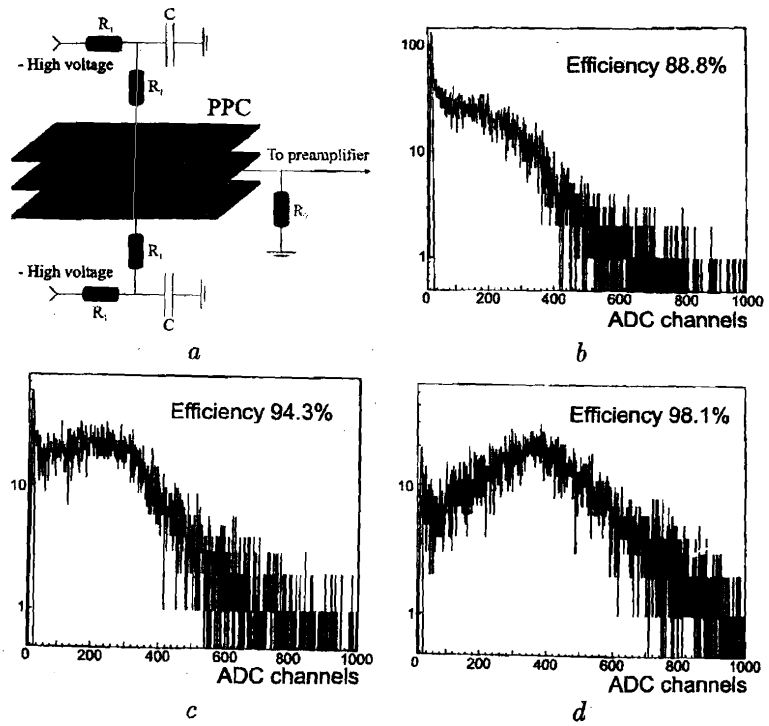


Fig. 6. Double-gap PPC: *a* — construction (schematic drawing); *b* — amplitude spectrum measured on Ar + i-C_4H_{10} + freon; *c* — amplitude spectrum measured on Ar + DME + freon; *d* — amplitude spectrum measured on DME + freon.

Meanwhile, large improvements were made to PPC itself. In 1995, the ITEP group proposed to use a double-gap design for each individual cell, schematically drawn in Fig. 6*a*. Simulations had shown that, compared to a single gap, the amplitude spectrum of the double-gap detector should have a non-zero maximum in the low part. Setting up the threshold in the

amplitudes might thus allow to cut off the pedestal events without a large loss of efficiency. Just the very first measurements with double-gap PPCs confirmed the conclusion. Fig. 6*b* shows the amplitude spectrum measured on one of the 'standard' gas mixtures Ar + i-C_4H_{10} + freon with new FEE. It is clearly seen that the pulse-height spectrum had a non-exponential shape with a very narrow pedestal and a much better signal-to-noise ratio.

The next step in the detector improvement was choosing the working gas with a higher amplification. Different mixtures were studied under as similar conditions as were possible: the electronic channel, the gap width, the chamber type, the gas box, the beam parameters were kept unchanged. Figs. 6*b–d* show amplitude spectra for gas mixtures based on Ar, i-C_4H_{10} and DME in different proprtions, always with a 5% admixture of freon CF_3Br. It was seen that using DME instead of i-C_4H_{10}, and later instead of Ar, had given significant increase of the signal-to-noise ratio and had led to a high registration efficiency for MIP. Gap width of 1 mm and more, accompanied with a reasonable discriminator threshold, kept the final efficiency almost at a 100% level, within a high voltage plateau being more than 200 V wide.

Freon CF_3Br admixture also proved to be important for the detector efficiency. Fig. 7 shows the double-gap PPC efficiency for MIP at two fixed discriminator thresholds of 10 mV and 20 mV as a function of the applied high voltage. The plots 7*a–d* correspond to different admixtures of freon to DME. In all the cases, a plateau on a more than 90% level may be seen. For a 12% freon admixture, the plateau is 150 V wide and corresponds to 95% of efficiency. Since the CERN environmental requirements did not allow to use freon CF_3Br, harmful for the atmospheric ozone, gas mixtures based on $C_2H_2F_4$ were suggested. Basing on the data presented in Fig. 7*e*, the choice for 0.6 mm gaps was fixed on a 75% fraction of freon. DME had to be replaced because of its negative effect on the chamber material. Basing on the RPC R&D experience, an inflammable mixture of i-C_4H_{10} and SF_6 was finally chosen. With all the tested gases, the collected charge became more than one order of magnitude higher than in RD5/RD37 conditions, reaching 100 fC in the average. Enforced with new FEE, this led up to 2 orders of magnitude gain in the signal-to-noise ratio.

It had been found that the narrower the gap width, the better time resolution of PPC might be achieved. On the other hand, decreasing the width entailed the lower gas amplification, hence worsening the efficiency and the signal-to-noise ratio. As a result, narrower gaps yielded better resolutions within high amplitudes, but worse results close to the pedestal. The simulations had confirmed that the resolution could be raised by decreasing the gap width. No solution on the optimal width was made during the R&D at ITEP. In 1997, special beam tests, involving new gas mixtures and FEE, were held at ITEP and CERN. Different gaps from 0.5 mm to 2 mm (varied by using quartz fibres of different diameters as spacers) were studied under the same conditions. A gap width of 0.6–0.65 mm (turning out to be 1.2–1.3 mm in the double gap design) appeared to be the best as providing a sufficient efficiency and a better than 200 ps time resolution within the whole amplitude range.

The sensitive cell size was subject for special simulations described in [10], the main parameters being the occupancy and tracks matching from TPC to the TOF barrel. In the chamber itself, the size might be crucial for the propagation time of the induced signal towards the preamplifier, which was usually placed at a corner of the cell. Simulations had predicted 80–90 ps jitter for a 50×50 mm^2 area. Special measurements showed that intrinsic propagation of the signal was about 50 ps/cm (see Fig. 8) which was insignificant for the detector with the 200 ps time resolution.

Concerning the PPC material, the R&D was pushed towards four options: ceramic, glass, plastic and metal. All electrodes, except the plastic, were spaced with quartz fibres of different

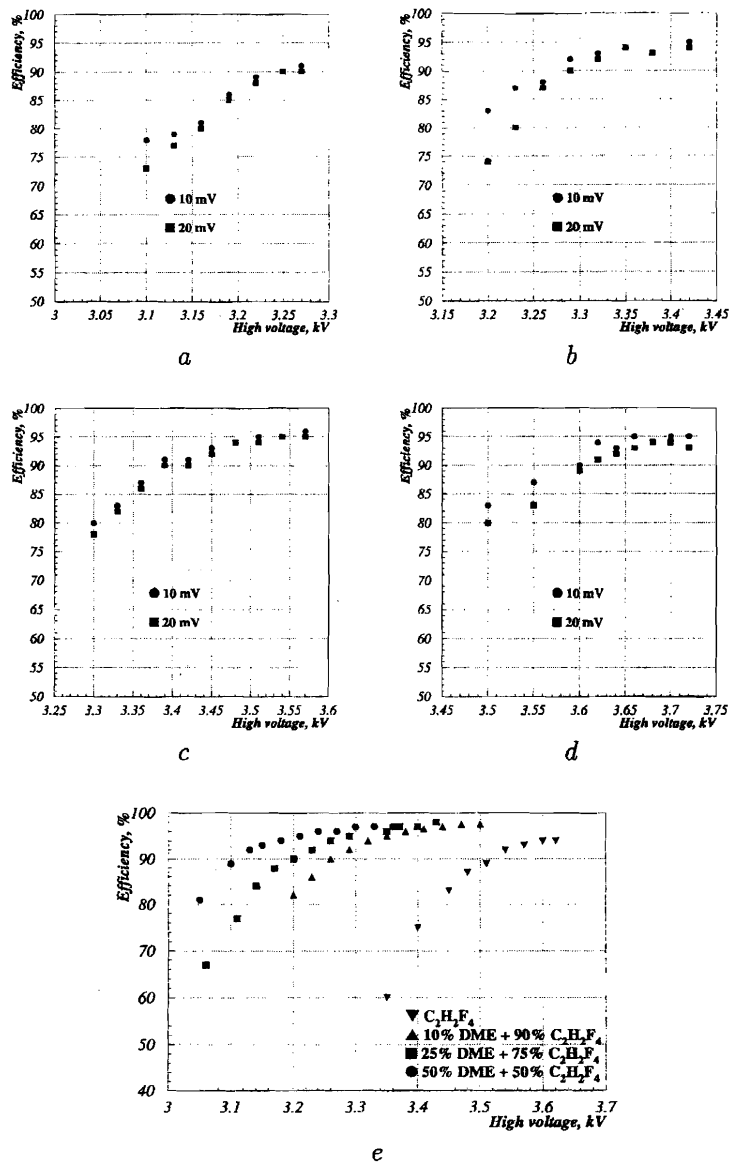


Fig. 7. Efficiencies of the double gap PPC with 0.6 mm gaps for various gas mixtures: *a* — 98.7% DME + 1.3% CF_3Br; *b* — 96.2% DME + 3.8% CF_3Br; *c* — 88% DME + 12% CF_3Br; *d* — 79% DME + 21% CF_3Br; *e* — DME and $C_2H_2F_4$ in different proportions.

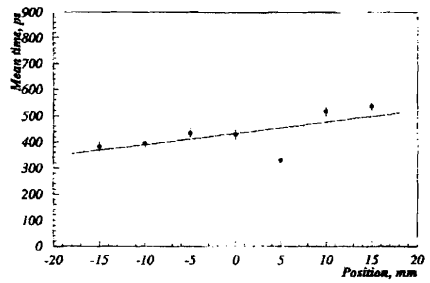


Fig. 8. Propagation of the signal towards FEE from different parts of the cell.

diameters. From then on, the chambers consisted of two gaps.

- Ceramic electrodes had been used earlier for CMS and ALICE applications at CERN and ITEP. Special designs of the ceramic electrodes were made for the TOF purposes, the drawing may be seen in Fig. 9*a*. Alumna substrate Al_2O_3, used as the electrode material, is rigid enough to be processed by a polishing machine with a required accuracy of better than 5 μm. Grooves with rounded profiles shown in the drawing, metallized up to about a half of their width, were made near the edges of the electrodes to prevent breakdowns stipulated by the electric field increase in this region.

- Cheap optic glass, available on sale and used to produce glass electrodes by approximately the same scheme, is smooth and flat enough to skip the polishing procedure.

- A few options of metal electrodes were made of alumna and stainless steel plates. An electro-chemical etching of large plates was used to prevent internal stresses during the aluminium electrodes production.

- To avoid polishing, plastic electrodes were stamped from polysulfone and polycarbonate at a very high pressure of more that 100 bar to achieve the required surface quality, in accordance with the drawing in Fig. 9*b*. The spacers in this case were made as parts of the electrodes. A special low-temperature metal evaporation technique had to be employed to prevent the plastic from deformation. The plastic version of the detector is cheap and simple for fabrication and assembly.

Regardless of the material used, all the detectors showed similar surfacial characteristics while studied by MIP. Typical TOF resolution and efficiency dependence on the 1×1 mm^2 beam position are presented in Fig. 10. The measurements were performed on ceramic electrodes, the scan was directed from the centre of the cell to its edge. It may be seen that all the efficiency edge effects could take place only in a 1–2 mm wide zone, which size was comparable to the size of the beam. The TOF edge was a bit wider — 2–3 mm, which was about 10% of the electrode linear size, or 20% of its surface. This was not dramatic since the quantitative reduction of the TOF resolution at the edge zone was only 10–20%.

The last single cell beam tests were performed in 1997 on PS and SPS at CERN. The PS beam consisted mostly of 3 GeV/c pions, the SPS beam — of 400 GeV/c pions. The PS

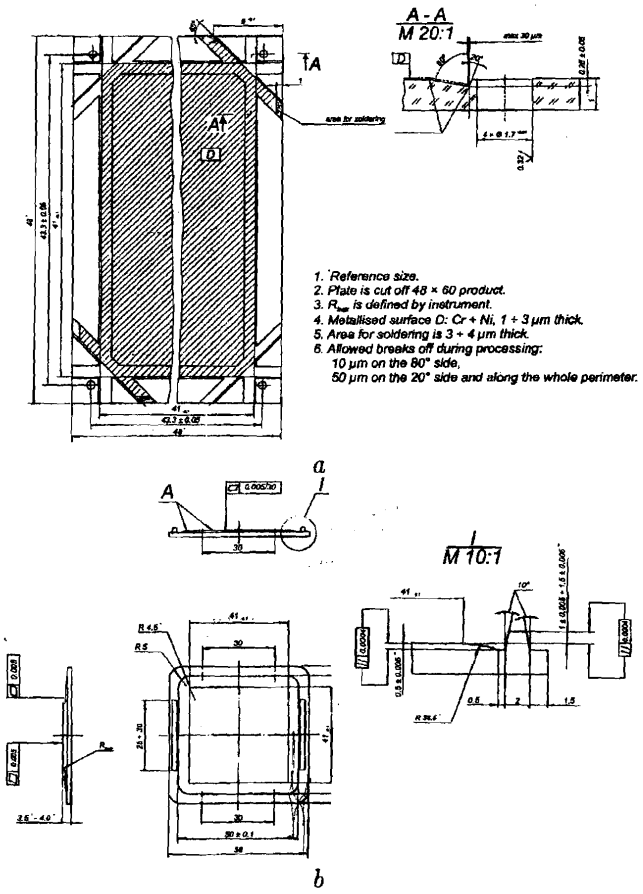


Fig. 9. PPC plates drawings: *a* — ceramic version; *b* — plastic version.

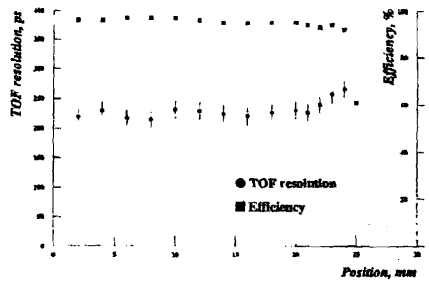


Fig. 10. Scan of the TOF resolution and efficiency along the detector surface.

beam size at the detector plane usually equaled to several cm^2, the SPS —less than 1 cm^2. Particle fluxes in both cases were about 10^4 per accelerator spill, or between 100 Hz/cm^2 and several kHz/cm^2. Different types of detectors (ceramic, metal, etc.), various gap widths and numbers of gaps (from 1 to 4), different gas mixtures, preamplifiers, post-amplifiers and discriminators were studied. The best results were achieved with the following detector options and parameters:

detector	ceramic or metal, 50×50 cm^2;
spacers	quartz fibres;
gap width	0.6 mm;
detector design	double-gap;
preamplifier	ITEP design;
main amplifier	ITEP design;
discriminator	LED;
gas	DME + 3–15% CF_3Br,
	or $C_2H_2F_4$ + 25% DME;
gas pressure	atmospheric;
high voltage	3.4 kV/gap,
	(for DME + 3.8% freon);
efficiency on the plateau	> 100 V;
TOF resolution	
(including the electronics jitter)	200 ps.

Fig. 11 shows a typical for those beam tests measurement result. A two-dimensional distribution of the raw-data in ADC and TDC units is plotted in Fig. 11*a*. This data was subject for further T(A)-correction. The vertical width of the stripe in the plot corresponds to the TOF resolution. The stripe is almost parallel to the abscissa axis, excluding the lower region, where the curve exists due to the discriminator threshold and noise contribution — hence only a slight correction was needed. The TOF resolution was calculated separately for narrow amplitude slices, using a Gaussian fit. In Fig. 11*b*, it may be seen that the resolution lied within 200 ps in all the spectra, except the lower region. After polynomial T(A)-correction and a small cut in the amplitudes, the total TOF resolution was calculated. As shown in Fig. 11*c*, the detector resolution, contributed from PPC and the electronics, was found to be 187 ps at a 93% level of efficiency. Close values of about 200 ps above 90% efficiency were

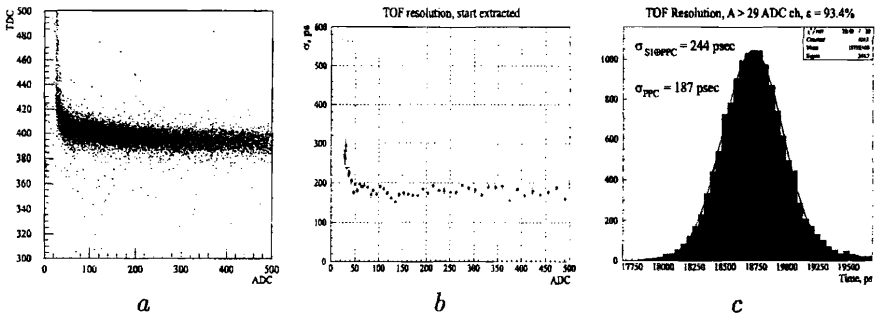


Fig. 11. PPC TOF measurements results, 1997: *a* — raw data in ADC and TDC units (ADC ch = 0.25 fC, TDC ch = 50 ps); *b* — TOF resolution for different amplitudes; *c* — resulting TOF resolution.

many times obtained and confirmed in different measurements. It had been specially shown, that the FEE jitter was about 150 ps, and because of low input amplitudes this value could not be significantly improved. This led to a conclusion that the intrinsic jitter of the PPC avalanche had reached 100–150 ps.

The experimental observations were later quantitatively confirmed with more accurate Monte Carlo simulations of gas discharge inside PPC [11, 12]. The calculations took into account the FEE influence on the detector time resolution. In particular, it may be learned from [11] that the intrinsic FEE jitter in response to the typical PPC amplitudes, is about 150–200 ps and cannot be significantly improved.

The PPC TOF resolution had always been calculated with Gaussian methods. For ALICE PID by means of TOF, it was very important to know the real shape of the timing spectra, mostly its right, or *slow* part, down to a level of 0.1% and even less. One of the examples showing that this really values might be the π/K separation: the yield of kaons is one order of magnitude lower than that of pions, and the kaons must be distinguished regardless of *tails* in the pions timing spectra. 1%-*tails* in the pions spectra turn out to be 10% of additional background for the kaons. First investigations of the *tails* had been made by GSI group in concern with the Pestov spark counters, which had huge *tails* [1] because of delayed secondary processes, contributing 300 ps to the TOF resolution with 30% probability, thus resulting in extra 150 ps in TOF for PID. The PPC timing spectrum was under study in 1997 at both PS and SPS under different conditions. The conclusion was that for PPC with the total TOF resolution of 200 ps, there were no special sources of *tails*, and all deviations from the Gaussian shape were a result of the TOF dependence on the amplitudes, as shown in Fig. 11*b*. The TOF distribution was a symmetric integral of Gaussian curves with slightly changing sigmas. Approximation of such a function with a sum of two Gaussians showed a 10–15% admixture of a wide distribution with a 300–350 ps sigma. This led to 220–230 ps in the effective sigma and did not spoil the TOF performance significantly.

Conductive electrodes turned out to be one of the main PPC disadvantages, since they did not provide any self-quenching mechanism, and *overflow* (OVF) signals with huge amplitudes might occur with a certain probability. The origin of the OVF signals could be the geometry, the gas, streamers or sparks with tremendous energy deposit. The probability of the OVF

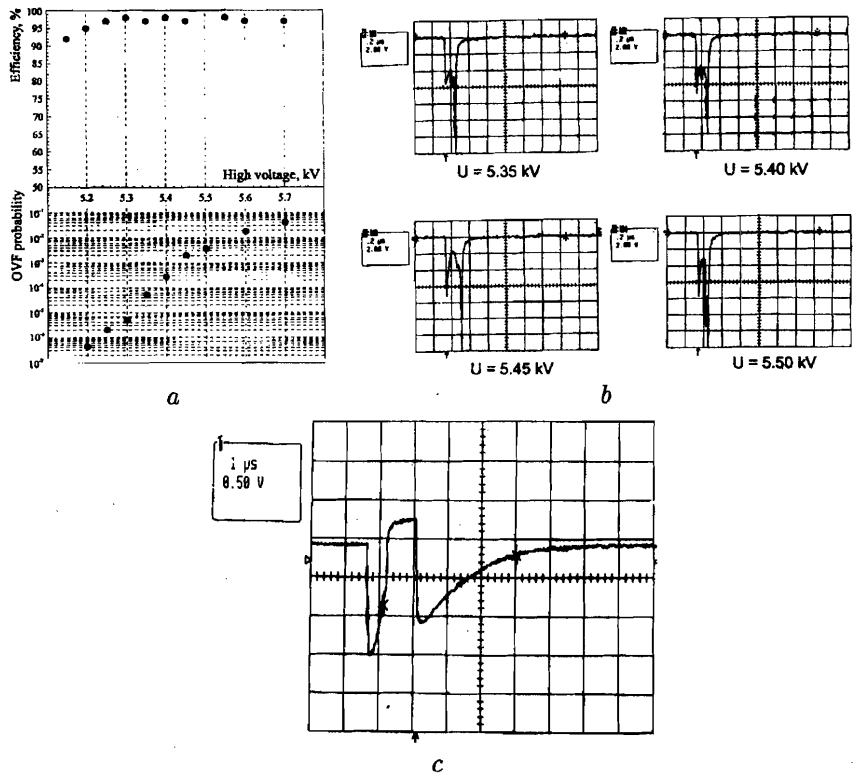


Fig. 12. OVF signals study: *a* — PPC efficiency and OVF probability versus the high voltage for 68% Ar + 30% i-C_4H_{10} + 2% freon; *b* — OVF signal shapes at several high voltages, scale units: 0.2 μs for the time, 2 V for the amplitude; *c* — amplifier response for an OVF signal, scale units: 1 μs for the time, 0.5 V for the amplitude.

signals had been studied in the RD37 framework for the PPC usage in calorimetry, as reported in [13]. It had been found there that for a low gas gain of 10^2–10^3 the OVF probability was very low. In highly efficient TOF detectors, the gas gain was much higher, and the effect had to be studied again. It was, and the results for a single-gap PPC with a 1 mm gap are shown in Fig. 12. A special trigger for very high amplitudes was employed to distinguish the OVF signals, the other setup worked in the standard way. Fig. 12*a* (bottom) shows the measured probability of OVF signals for different high voltages which can be compared to the efficiency dependence (top). It may be seen that even at the high efficiency region, the OVF probability was still small, about 10^4.

To learn the nature of the OVF signals, separate studies were undertaken. Distinguished by a special trigger, the signals of large amplitudes were sent directly to an oscilloscope without any amplification. Fig. 12*b* shows sevaral OVF examples observed for different high voltage

values within a 150 V range. All the OVF signals had two peaks of a few Volts each, with a total duration of about 200 ns, and with about 10 V amplitudes. No afterpulses were observed.

Energy deposits were approximately the same in all cases, and corresponded to the total energy of PPC as a capacitance charged to 100 nC. A natural conclusion was made that the OVF signals were sparks discharging the chamber completely, which was also confirmed with a fact that energy deposits did not depend on applied high voltage in the 5.35–5.55 kV range, contary to the avalanche case when the same variations of the high voltage led to 15–20 times changes in the amplitude. Compared to the $\sim$ 100 fC avalanche signals, the OVF signals appeared to be 10^6 times higher.

Special FEE was designed to fit with the difficulties, as described in [14]. The amplifier response to a spark event is shown in Fig. 12*c*. Right after a signal arrived, the amplifier became saturated, then got back to rest with some over-shut. Output signals after FEE were of the order of 1 V, they lasted for a few microseconds only. Finally, it was concluded that a single detector based on PPC could normally operate with rare large signals. Remaining unsolved problems were dead zones inside the gas volume after spark events (with a lifetime of about 1 ms or less), and possible cross-talks between neighbouring cells inside a large detector module.

6. Cost Estimations of the Detector

PPC is currently under investigation as a possible element of the TOF system of the ALICE experiment at CERN with up to 150 000 channels. The detector cost thus appears to be very essential. It has been estimated that the PPC-based channel for ALICE TOF costs about \$40–50, including development of a new FEE and readout electronics, prototype construction, etc. This price is more than an order of magnitude less, than which might be required for TOF based on scintillator methodics.

Moreover, it is obvious that timing measurements are not the only possible employment of such a simple and cheap detector.

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References

[1] V. Parchomchuk, Yu. Pestov and N. Petrovych. Nucl. Instrum. Methods **93**, p. 269, 1971.

[2] J. Christiansen and Z. Augewandte. Phys. **4**, p. 46, 1956.

[3] R. Bouclier, G. Charpak and F. Sauli. CERN NP Internal Report 71–12, 1971.

[4] A. Peisert and F. Sauli. Nucl. Instrum. Methods **A247**, p. 229, 1983.

[5] Yu. Galaktionov *et al.* Nucl. Instrum. Methods **A317**, p. 116, 1992.

[6] A. Arefiev *et al.* Preprint DFF 173/10/1992.

[7] V. Akimov *et al.* Nucl. Instrum. Methods **A344**, p. 120, 1994.

[8] K. Voloshin. Thesis for Master of Physics degree, MIPT, Russia, 1994.

[9] R. D'Alessandro *et al.* Preprint ITEP 51–95, 1995.
A. Martemianov. Proc. of the 1st Workshop on Electronics for LHC Experiments, Lisbon, 11–15 Sept., 1995.

[10] A.Smirnitsky, K.Voloshin and B.Zagreev. Internal Note ALICE/TOF 94–16, 1994.
S.Kiselev *et al.* Internal Note ALICE/SIM 96–17, 1996.

[11] A. Malinine (ITEP) and E. Spiridenkov (PNPI). Private communications.

[12] M. Abrescia (INFN, Bari). Private communications.

[13] A. Arefiev *et al.* CMS IN/95–0730, 1995.

[14] A. Akindinov *et al.* Preprint ITEP 47–00, 2000.

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