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Dielectric Resistive Plate Chamber — the First Step in New High-Resolution TOF Technology

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DIELECTRIC RESISTIVE PLATE CHAMBER — THE FIRST STEP IN NEW HIGH-RESOLUTION TOF TECHNOLOGY: Preprint ITEP 13-02/

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Modern high-energy nuclear physics experiments, in which many thousands of particles are produced, require qualitatively new detectors for particle identification (PID). Dielectric Resistive Plate Chamber (DRPC) is one of the first options of a new high-resolution time-measuring technology. It was invented and studied during the initial stage of R&D for the ALICE/LHC PID system based on Time-of-Flight (TOF) measurements. In this article, the main DRPC features are described.

Современные эксперименты по ядерной физике высоких энергий, в которых за одно событие рождается до нескольких тысяч вторичных частиц, требуют использования качественно новых детекторов для идентификации частиц. Диэлектрически-резистивная плоско-параллельная камера (ДРПК) стала одним из первых воплощений новой высокоточной технологии измерения времени. Она была изобретена и изучалась во время начальной стадии разработки системы идентификации частиц на основе измерений времени пролета в рамках эксперимента ALICE/LHC в ЦЕРНе. В настоящей статье рассматриваются основные свойства ДРПК.

Fig. - 5, ref. - 6 name.

A copy of this preprint is available on the Web at
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1. Necessity of New TOF Technology

Modern experiments studying heavy-ion collisions at high energies (like those at SPS, RHIC and future LHC) operate at extremely tough conditions in terms of particle multiplicities. Physical tasks of such experiments often demand detailed secondary particle identification (PID) on event-by-event basis. A barrel-like Time-of-Flight (TOF) detector built around the point of collision may become an essential part of the PID system as it allows to measure the velocities of secondary particles.

Physical conditions of a particular experiment dictate demands on the TOF detector performance. Farther in the energy spectrum one wants to separate π/K and K/p secondaries, better have to be efficiency and time resolution of the TOF system. High particle multiplicities require the TOF barrel to cover large area and be very granular, thus leading to an extremely big number of separate channels. In this sense, essential becomes the detector cost.

TOF systems meeting all the mentioned requirements can hardly be constructed using the traditional methodology based on scintillators and photomultipliers. Instead, some principally new technique has to be found and developed.

As an example, we consider the ALICE experiment at LHC in which the PID is planned to be realized exactly with a TOF barrel. Pb–Pb collisions at 2.7 TeV/nucleon energies will produce the following general requirements for the TOF system:

load	20 000 particles per event
sensitive area coverage	177 m^2
number of channels	150 000
time resolution	<100–150 ps
efficiency for minimum ionizing particles	100%

Additional complications include external magnetic field of 0.2–0.4 Tl, and absence of continuous tracking from inner systems. The TOF system will deal with relatively low counting rate, will have to have low material budget and low power consumption.

2. Gaseous Detectors of Parallel Plate Geometry

Investigation of gaseous detectors as a possible alternative to scintillator counters in precise and efficient TOF measurements was launched in the framework of the ALICE TOF R&D programme in 1992.

The research was first concentrated on Pestov spark counters which showed excellent TOF resolution of about 30 ps, see Ref. [1], but appeared to be rather demanding in terms of construction technology and operating conditions.

The attention was then moved towards the avalanche technique. A Parallel Plate Chamber showed good results, but rare sparks with 10^6 times more than usual energy deposit, making large harm to the chamber itself and to read-out electronics, could not be avoided, see details in Ref. [2].

The next essential step was made when two detectors, the Parallel Plate Chamber and the Resistive Plate Chamber, were combined to form a new parallel plate gaseous detector with one resistive electrode. In case of sparks, the resistivity allowed to localize the place of the discharge and to reduce energy deposit by prolonging it in time, see Ref. [3].

In compliance with this idea, three main options of the new TOF technique were under study, which are listed below in the chronological order of their appearance. First was the Dielectric Resistive Plate Chamber (DRPC) which is described later in this article, as well as in Refs. [4]. The second option was the Glass Resistive Plate Chamber (GRPC), in which resistive glass was introduced inside the chamber volume, as described in Ref. [5]. Third implementation, the Multi-Gap Resistive Plate Chamber (MRPC), is currently under study as the main option for the ALICE TOF system, its description may be found in Ref. [6].

3. Principles of Operation and Main Features of DRPC

In terms of priciples of operation, DRPC combines features of two detectors, the PPC and the RPC. Particles are detected in a narrow (from 0.1 to several milimeters) gas gap formed with two planar parallel electrodes. A schematic drawing in Fig. 1 shows the basic principles of DRPC construction. One of the electrodes is conductive. The other is made of dielectric which is covered, from the gap side, with semiconductive ceramics (SiC). The resistivity of the layer may be widely varied by choosing SiC resistivity ($10^3 - -10^{12}\Omega\cdot$ cm) and changing the surface thickness. The external side of this dielectric-resistive (DR) electrode is conductive and is used for readout purposes.

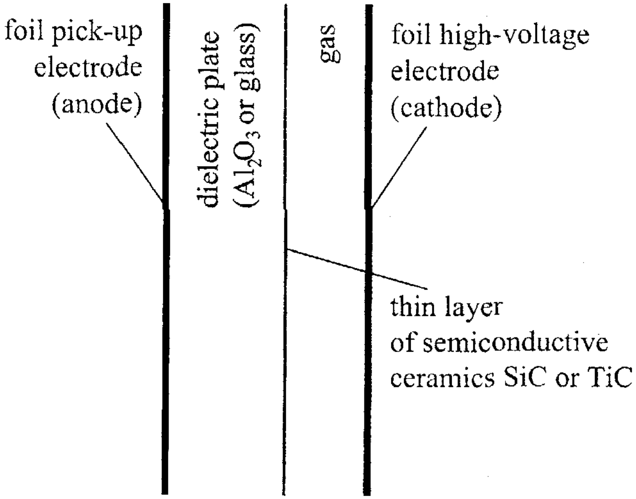

Fig. 1. Schematic drawing of DRPC constructon.

A high electric field of 6 8 kV/mm, applied between the electrodes, initiates immediate Townsend avalanche amplification of primary ionization at any point within the sensitive volume, providing a gain of up to $10^6 - 10^7$. Electron avalanches induce a very fast (with the rise time of less than 1 ns) signal on the inner surfaces of the electrodes, and immediate fast signal on the outer surface of the DR electrode. In case of a breakdown, the dielectric layer strongly suppresses spark energy resolution, by charging an elementary plate condensator, formed by the two surfaces of the dielectric layer in the place directly exposed to the breakdown. Subsequently, this condensator slowly discharges through the surface covered with resistivity. In that way, DRPC combines three separate and — what is of particular importance — independently adjusted features:

- fast signal propagation (like in PPC)
- spark suppression by local fall of the electric field as the breakdown charge localizes on the DR electrode
- subsequent remove of the localized spark charge through the resitvive surface.

The detector has shown stability of operation in the avalanche mode within a wide range of applied voltages. As semiconductive ceramics SiC has a pure electron mode of conductivity, no charge accumulation on the surface or inside the DR electrode, and no characteristics degradation have been observed.

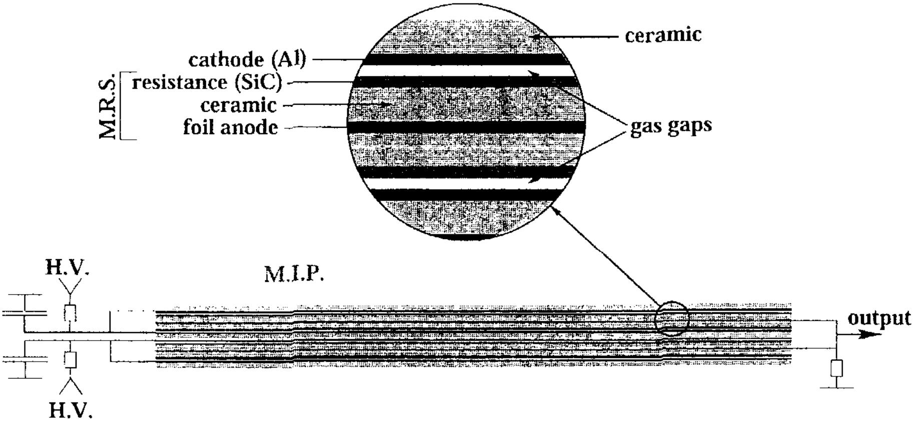

Fig. 2. Four-gap DRPC construction and readout.

Two- and four-gap DRPCs (see Fig. 2) with the total gap width of 1.2 mm and the working area of 4 × 4 cm^2 were filled with freon-based gas mixtures. A stable energy resolution in the avalanche mode has been obtained for all fast signals with the average charge of 1–3 pC. The registration efficiency for MIP was found to be not less than 97% with 100 mV discriminating threshold. There existed a counting plateau, 400–800 V wide. Specially designed fast-response amplifiers, connected to all the gas gaps, provided 70–80 ps of the detector time-of-flight resolution.

Fig. 3 shows amplitude and timing spectra obtained during beam-tests of a DRPC with 4×0.3 mm gas gaps. To change its ionizing properties, the beam could be made of pions and protons of various energies. The four columns in Fig. 3 correspond to $\mathrm{d}E/\mathrm{d}x$ being equal to 1 MIP, 1.2 MIP, 1.5 MIP, and 2 MIP (rising from left to right). In all the cases, it may be seen that the amplitude spectra has a peak standing quite far from the narrow pedestal. Timing distributions have shapes close to gaussians, with the resolution of about 80 ps.

The counting rate capability of the initial non-adopted detectors allowed to keep the characteristics unchanged under the beam intensitites of more than $5{\cdot}10^3$ Hz/cm^2. A 1% admixture of streamer signals at the end of the counting plateau did not influence the detector operation and characteristics.

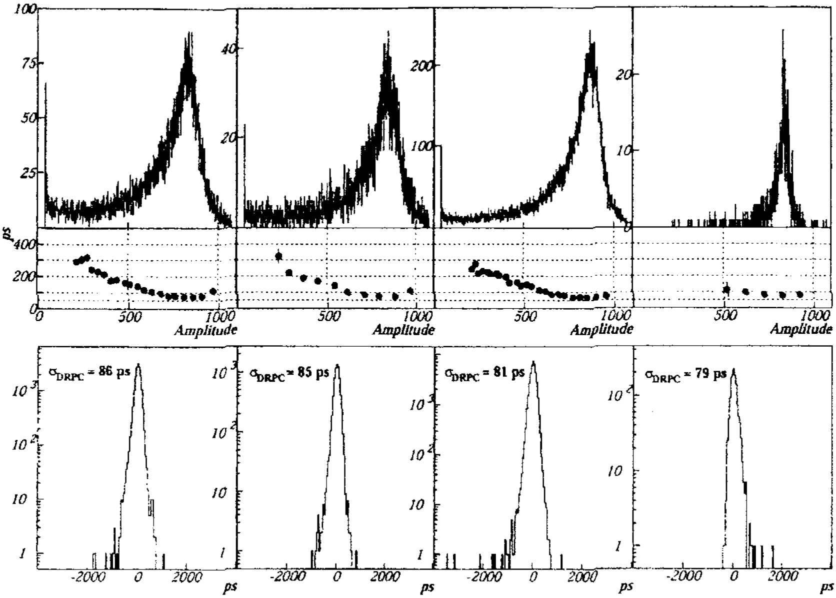

Fig. 3. Amplitude spectra, amplitude dependences of time resolution and total time resolutions measured with DRPC for different ionizing particles. dE/dx increases from left to right.

The results prove that, in case of TOF, the DRPC technique shows the same performance as the standard (Scintillator-Phototube) one.

It was estimated that a channel price of a DRPC-based TOF detector is about an order of magnitude less than that of a detector based on the standard technique. This means that the relevant applications of DRPC may be large-scale high-granular cheap mosaic TOF detectors for studying high energy nucleus-nucleus collisions.

4. PID Performance by DRPC under ALICE Conditions

A special study of π/K separation under real beam conditions was undertaken, which showed a very good quality of kaon separation by means of TOF performed with DRPC, at up to 1.5 GeV/c beam momentum, 3.5 m flight distance, and a 10% admixture of kaons in the pion beam.

PID performance by DRPC, with a natural admixture of *tails* in the timing spectra of the detector, was studied experimentally at ITEP PS. The beam was constituted of different sorts of particles (π, K, p, d), which quantities could be varied. An excellent PID was performed by means of a long-base TOF system and a system of gaseous Čerenkov counters, established on the beam line. These facilities allowed to know the sort of each beam particle in advance, before DRPC TOF measurements, and thus to check the quality of PID performed by DRPC.

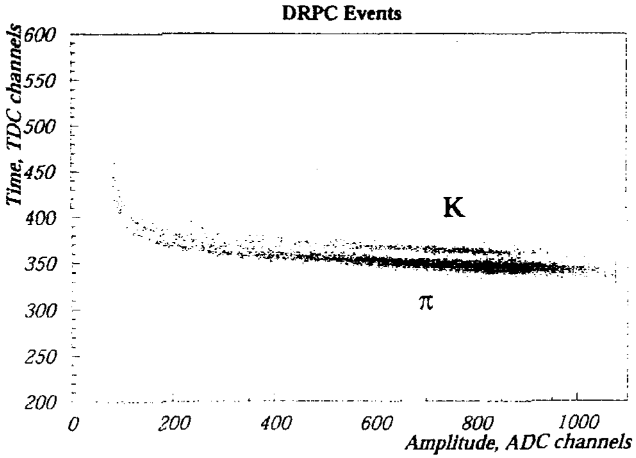

Fig. 4. π and K events in DRPC at $p = 1.3$ GeV/c and $l = 3.8$ m (ALICE conditions).

Fig. 4 shows a T A distribution of π and K events in DRPC. The beam momentum (1.3 GeV/c), the TOF base length (3.8 m) and the K admixture into π events (10%) were chosen in accordance with the ALICE conditions. One can see that π and K events are clearly separated, and a gap between two regions can be evidently observed.

A quantitive result of the separation is presented in Fig. 5. The main part of the plot shows two peaks in the timing spectrum corresponding to π and K, after T(A)-correction applied to the whole data. Since the sorts of particles were reliably known in advance, pions and kaons were distinguished even in the intermediate region. Both peaks were approximated with 2 Gaussian distributions. The time resolution for pions is 89 ps, 8%-*tails* are 260 ps wide. The kaons time resolution is 82 ps, 9%-*tails* are 270 ps wide. Fig. 5 illustrates how crucial *tails* are in the task of PID; were if not for them, the spectrum would be described only by single Gaussian fits, and an unmistakable separation could be done almost everywhere. In reality, presence of K's in π's distribution is low, while π's contamination into K's may be significant, depending on a cut parameter t_{sep}. Shifting t_{sep} to higher times leads to less contamination on the one hand, but to less K's registration efficiency on the other. Plot in the right upper corner of Fig. 5 demonstrates this conclusion quantitively. In the middle position, where the peaks intersect, the registration efficiency of kaons is close to 100%, the pion contamination is about 4%. Moving to upper t_{sep} decreases the contamination rapidly, which reaches 1% at 95% of K efficiency, and almost disappears at 90% of K efficiency.

5. Conclusion

Launched in 1992, R&D on the ALICE TOF system has lead to a discovery of the new TOF technique based on gaseous detectors of parallel plate geometry operated in the avalanche mode. Resistivity, variously introduced inside gas volumes of such detectors, stabilizes their operation and prevents them from harmful spark breakdowns. The MRPC was recently chosen

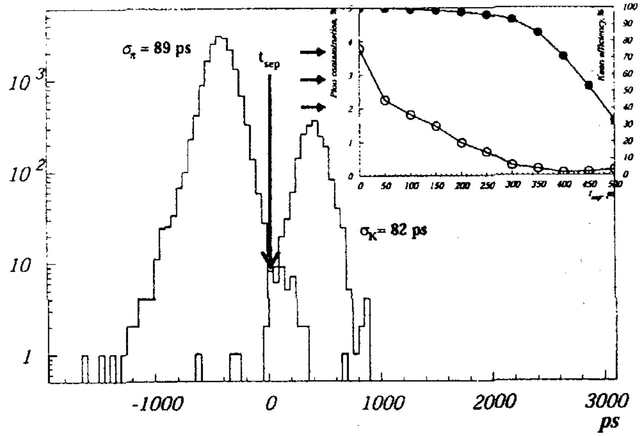

Fig. 5. π/K separation by means of DRPC-based TOF at $p = 1.3$ GeV/c. π contamination and K registration efficiency depending on TOF separating parameter are shown in the top right corner.

to be a basic element of the ALICE TOF system, which construction will be launched in 2002.

A possibility to change surface resistivity of the DRPC resistive electrode, by varying the resistive layer thickness and material, is an important peculiarity of this detector making it a frontier device between PPC and RPC. The three main features of DRPC, described in Section 3, may be changed independently which grants flexibility in possible detector implementation. Being used for TOF measurements, the DRPC turns out to be a high-resolution, stable and cheap detector. The DRPC is far from being well studied and understood, and requires further R&D.

A special emphasis should be made on using semiconductive ceramics SiC and TiC as a material to create surface resistivity of the DRPC electrodes. Industrial experience proves these materials to be stable, rather cheap and easily evaporated over many substrates. An electron conductivity of such ceramics prevents negative charge to be accumulated on the DRPC resistive electrodes.

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