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ELECTROSTATIC IMAGING OF PARTICLE TRAJECTORIES

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ABSTRACT

The ions liberated in a high-pressure gas or in some liquids can be collected, by electric fields, on the surface of insulators and can be accurately localized.

In a simulation of this method at atmospheric pressure, we applied it to α particles, with the additional amplification from a parallel grid gap. By directly measuring the static electric charges collected on mylar foils, we observe tracks of 1 mm FWHM and charge densities as low as 10^4 electrons/mm². The combination of multistep gated avalanche chambers with this read-out method should permit high-accuracy measurements of minimum ionizing particles. The limits of the method and some conditions for detection by liquid toners are discussed.

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1. INTRODUCTION

Wire chambers and drift chambers have serious limitations in the imaging of complex configurations of charged particles close to the interaction vertex of high-energy nuclear particles inside a target.

We describe a new approach to this problem, which applies to gaseous targets and also to some specific liquid or solid targets where the ions liberated by the ionizing particles can drift along electric field lines.

From the first results reported here it is clear that our method opens up the way to very high accuracies in the measurement of particle trajectories in gases, as well as to additional potential diverse applications.

2. PRINCIPLE OF ELECTROSTATIC IMAGING OF IONIZING PARTICLES

The starting idea is the following (fig. 1a): if an ionizing particle liberates free ions in a gas, it should be possible to attract the ions of a given sign to an insulating surface, where they are trapped and can be revealed by the appropriate methods. Indeed in such a device only a projection of the trajectories is obtained, but at the present stage of high-energy physics considerable interest is attached to the search for very short-lived particles, decaying within a range of tens or hundreds of microns near the interaction vertex. In this case a high resolution in one projection can be sufficient to clarify complex configurations, while additional gaseous detectors can give the missing coordinates.

The imaging of ionizing radiations in gases or insulating liquids has been the subject of many investigations over the last 25 years, aimed at measuring X-ray spatial distributions for medical applications, or detecting β -ray distributions for use in chromatography. These methods have been extensively reviewed by one of the pioneers in this field, W. Boag¹⁾. In fact they are closely related to techniques used in xerography²⁾, where the latent image is an electrostatic distribution on a dielectrics or a photoconductor. It should be emphasized that they all result in the detection of variable ionization densities, corresponding to an integration over a large number of particles. Even in the case where

additional gaseous amplification was used in order to decrease the doses of X-ray irradiation, only integrated distributions have been reported³⁾.

We have investigated the use of commercial powder or liquid toners to reveal the distribution of charges collected on dielectrics from ionization of the gas by charged particles. These materials have a threshold of about 2×10^7 electrons per mm^2 , thus even at pressures of 500 bar of argon, we are below the threshold.

In view of this limitation we describe here a method of direct measurement of the electrostatic charges, which seems to be of adequate sensitivity. We used α particles in argon at atmospheric pressure as a simulation for minimum ionizing particles. We also used an amplifying gap, composed of two parallel grids, which permitted us to vary the final electron density^{4,5)} at will, before collecting the electrons on an insulating mylar foil. The foil surface was then scanned and the charge distribution measured. With this flexible set-up we observed narrow linear charge distributions characteristic of α trajectories, and we are now in a position to make a realistic evaluation of the prospects and limits of our approach.

3. EXPERIMENTAL SET-UP

The experimental set-up is illustrated in fig. 1b. The ^{241}Am α source is placed inside a drift space from which the ionization electrons can be extracted and transferred, by the appropriate field, to the amplification gap A. The source is grossly collimated in a direction parallel to the electrodes. The avalanche electrons are transferred to the space T, 1 mm deep, and are collected on the 125 μm mylar foil, which is backed with a layer of conductive material. The gas filling consisted of argon with a small admixture of propane or acetone, and the range of the α particles is close to 4 cm.

The transfer voltage ($V_4 - V_3$) (fig. 1b) is applied for a few seconds. Meanwhile, the pulses on the anode are monitored and show that some avalanches have been transferred. The foil I is then removed and scanned with a dedicated electrometer^{*)}, which consists of a probe shielded by a metallic housing with a 0.6 mm

*) Electrostatic millivoltmeter model 1015. Monroe Electronics, INC, Lyndonville, NY.

diameter hole, through which penetrate the lines of force of the charges deposited on the foil. The hole is at about 0.5 mm from the foil. The operation principle of the electrometer consists of bringing the probe to the same potential as the charges facing the hole, thus setting to zero the electric field between the probe and the foil. The ground of the instrument is connected to the conductive backing of the foil.

If the thickness of I is small with respect to the width of the charge distribution, we can simply calculate the voltage as if we had a capacitor with two conducting electrodes. This applies to our case very well, where we expect a charge distribution width of about 1 mm.

4. EXPERIMENTAL RESULTS

We have taken data, varying the range of the following parameters: the gain in A, the depth of T, and the gas composition. We report a few results which illustrate the potential power of the method and clarify its limits. Figure 2 shows the voltage distribution observed along a mylar foil scanned in a direction roughly orthogonal to the tracks direction. We observe signals of about 1 mm FWHM and a few volts maximum amplitude. At some places we observe signals from six tracks (fig. 2a). By scanning successive lines, we can reconstruct the path of the tracks (fig. 2b). Figure 3a shows the variation of charge profile along a given track; fig. 3b shows the variation of ionization along the track.

The observed width of the charge distribution is a function of several factors: i) the intrinsic width of the avalanche, which increases with a decrease in acetone content, as observed elsewhere⁴⁾, and increases with the depth of T; ii) the considerable space charge of the amplified electron cloud, which produces a field that exceeds the drift field, and might cause an "explosion" of the electron cloud before it reaches the insulator foil I; iii) integration due to scanning procedure.

The distribution of charge intensity along a track shows a characteristic Bragg behaviour, as demonstrated in fig. 3b.

The data of figs. 2 and 3 were obtained with a gain in A of about 10^4 , giving rise to about 30% of transferred electrons. This gives a linear charge density of about 10^7 e/cm, where e is the electron charge. These data permit us to appreciate the limits of the method.

5. SENSITIVITY OF ELECTROSTATIC IMAGING

There are two sources of noise in the present method: the initial charges and dipoles existing in all good insulators, and the noise of the read-out instrument.

The initial charges can lead to very high local fields, well above 10 kV/cm. It is almost impossible to work with a mylar foil taken from the shelf. The charges can be eliminated by heating -- or better, by γ -ray irradiations to levels of the order of a 10^6 rad with a good conductive contact on the surface to permit the evacuation of the charges. We chose the first method, and after simple chemical degreasing, the foils were heated at 180° for 30 minutes. This brought the noise down to levels giving rise to signals below 5 mV in our case.

The electronic noise of the electrometer is claimed by the manufacturer to be 3 mV. This would correspond to a charge of about 2000 electrons on our foil, on the surface of 0.6×0.6 mm² viewed by the probe. A minimum ionizing particle in 500 atm of argon for instance, would liberate nearly this charge over a length of 0.6 mm; we are thus at the threshold for detection without any need for amplification.

We have, however, several other ways of improving the signal-to-noise ratio.

- i) A straightforward way is to reduce the capacitance of the system. By stretching a thin 10 μ m foil at a distance of 250 μ m from the collecting electrode, we gain a factor of close to 6 with respect to our present design.
- ii) The lateral diffusion is strongly reduced by the high pressure and by the possible adjunction of a magnetic field parallel to the electric field. The width of the electron cloud can then be brought down to levels well below 100 μ m. We therefore have to reduce the width of the read-out probe accordingly, which seems possible.

iii) Since the read-out is non-destructive we can repeat a measurement any number of times and find the centroid to an accuracy of the order of one percent of the width and the charges stay for a long time. We observed a loss of about 25% in 48 hours probably due to air conduction produced by the radiation background and to charge compensation and transport on the foil itself. If the charge image is to be kept for a long period, better foils than mylar can be used (polypropylene, Teflon) which can also be stored in vacuum.

One of the main advantages of the method is, that in contrast to ordinary gaseous detectors where the electrons are absorbed by the electrodes after a measurement, here the electrons are kept in a memory and permit a quite different approach to the read-out. In this respect we have the same situation as in photographic emulsion, but with the essential difference that the trajectory is produced in gas and the ionization electrons can be monitored and gated with electric pulsed fields.

iv) Finally, even with the present tools, we can hope to detect minimum ionizing particles in high-pressure gases or in liquids such as liquid argon or tetramethyl-tin.

6. APPLICATIONS

The above discussion shows that our initial goal -- to detect charged particles in high pressure gases or liquids, without amplification -- is compatible with the physical limits of the method. The reduction in diffusion should lead to good particle resolution, and the possibility of a static centroid measurement should permit good position accuracy.

For the detection of minimum ionizing particles in gases at atmospheric pressures, it is possible to use a double-step parallel-plate amplifying gap, with an intermediate gating. Our work at CERN⁵⁾ has shown that gains of 10^6 can be achieved even at high rates. A single avalanche of 1 mm width with 10^6 electrons, collected on a 10 μ m mylar foil subtended at a distance of 250 μ m from our electrode, would rise, with respect to this electrode, at a potential of about

1.5 V. In other words, it is measurable even in our present conditions. We are investigating this possibility since it is of a great interest, both for the high-accuracy measurement of ionizing particles and for the imaging of VUV photons in photoionization detectors. Despite the width of the tracks introduced by the double-step amplification, we think that the peculiarity of the stored distribution should permit a high accuracy for the centroids determination.

Needless to say, for heavy ions the situation is even more favourable. The fact that the energy loss is measurable along the track is an important advantage for particle identification.

There are a few more situations where this method may be attractive. For example, interest has recently developed in avalanche streamer chambers at atmospheric or at high pressures, with low gains of about 10^5 , and with the help of light amplifiers. The collection and detection of the electrons or the ions in such chambers would be an easy task. The level of ionization should then be sufficient for the use of powder or liquid developers. Also, the choice of gases may be broadened since the emission of visible light is not required. It is indeed intriguing to compare the quality of the optical and the electrical read-out. We are undertaking to investigate this subject, and as a first step we have tried to estimate the threshold for obtaining a visible line with Kodak liquid toner MX 1112 for a linear distribution of charges on mylar. Figure 4 shows the picture obtained with accumulated charges from an α source collimated to 0.3 mm, giving rise to a peak voltage of 15 V. We see a narrow fine line of only 0.04 mm width, with the liquid toner. At the voltages below 10 V we do not observe a line. There is probably room for much progress in this direction also, and a considerable variety of other methods of visualizing small charge distribution have already been tested or envisaged^{1,2)}.

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Figure captions

Fig. 1 : Electrostatic imaging of ionizing particles.

- a) High-energy particles produce a reaction in a very high pressure gaseous target, or in a liquid target. The ions are collected on the insulating foil I.
- b) Schematic view of the experimental set-up. Alpha particles ionize mixtures of argon and vapours at 1 atm. The primary electrons drift to the amplification gap A, where they produce an avalanche. They are then transferred to T and collected on the insulator I.

Fig. 2 : Distribution of charges across tracks.

- a) Charge distribution across tracks at two positions along the beam. M1015 Monroe probe at 0.5 mm from I.
- b) Reconstruction of the trajectories.

Fig. 3 : Charge density along an α -track.

- a) Measured charge along a track.
- b) Extrapolated charge density distribution.

Fig. 4 : Track image produced by accumulated charges from the collimated α source. An amplitude of 15 V (2×10^7 electrons/mm²) is visible with liquid developer, Kodak MX 1112.

Fig. 1

Fig. 2 a)

Fig. 2 b)

Fig. 3 a)

Fig. 3 b)

1 mm

Fig. 4