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AN OPTICAL, PROPORTIONAL, CONTINUOUSLY OPERATING
AVALANCHE CHAMBER

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ABSTRACT

We describe a simple structure, made of two parallel transparent meshes at a distance of 9 mm from each other, which permits one to observe avalanches generated by radiations with an image intensifier with a moderate Townsend amplification factor of about 4×10^4 . The filling gas contains triethylamine, which emits a light spectrum peaked at 280 nm, in the proportion of around one photon per ionized atom in the avalanche. Examples of tracks from various radiations, obtained by amplifying the ionization electrons in a drift space filled with the gas or with a high-density grid, show a good recognition capability, even for a complex pattern of trajectories under conditions where the collected charges and emitted light are proportional to the energy lost in the gas, over a rather wide range. The present study could demonstrate the possibilities of applying this chamber to the detection of complex events and the observation of rare ones.

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1. INTRODUCTION

In recent years several successful attempts have been reported of the photography of avalanches in wire-chamber or parallel-grid chambers, with the help of image intensifiers [1-5]. These avalanches are initiated by ionization electrons of various origins: ultraviolet light, charged particles, and X-rays. The aims of the studies are varied: for example, the imaging of Cherenkov radiation, the observation of double beta decay in xenon, and the detection of showers from proton decay. The main advantage of optical readout over electronic readout of the charges induced on electrodes is the capacity of analysing complex or rare events obscured by background; although this method gives only a two-dimensional projection of the ionization pattern, it is believed that additional spatial or energy information can be retrieved from the measurement of the flow of charges, as a function of time, on appropriate wires or electrodes.

The recording of avalanches with the help of image intensifiers is now a routine method in the operation of streamer or avalanche chambers, where the electric field is a short applied pulse. On the other hand, from the view point of the application of the imaging chamber to the fields mentioned above, it is desired essentially that the imaging chamber should work in the proportional mode, under a steady electric field, to obtain information about the energy. There are several technical problems and advantages in the photography of avalanches produced in steady electric fields, as follows:

- i) While single-step parallel-grid chambers can be operated with gains above 10^8 in the pulsed mode, they can rarely be operated with gains above 10^6 in steady electric fields,

which results in a strong reduction in the number of photons emitted from avalanches.

- ii) The optical spectrum of the photons emitted by gas mixtures which are favourable for high gains in steady operation may be quite unfavourable for photography.
- iii) The advantage of the projection chamber is that no depth of focus is required and the maximum possible aperture can be used.

As we have reported [1, 5, 6], these technical problems have been solved by finding a gaseous mixture containing triethylamine (TEA), which emits light effectively at a peak of 280 nm. With this gaseous mixture, we are now at a stage where we can define the specifications of a detector in which the amplifying structure works in the proportional mode (as checked on the collected charge or on the emitted light intensity), in which the wires have been eliminated as the amplifying element (the amplification occurs between parallel transfer meshes, thus giving an isotropic response). We have investigated the qualities of this amplifying structure -- which has a gaseous drift space or a high-density grid structure -- with muons, electrons, and gammas.

2. EXPERIMENTAL SET-UP

As shown in fig. 1, the chamber has a drift space and an amplification structure. The drift space has an entrance window of mylar and its drift length is 5 cm. The amplification structure consists of two grids, at a distance of 9 mm from each other, made of a mesh of wires of 50 μm diameter with a space of 500 μm . The electric field strengths are 2.0×10^2 V/cm and 8.6×10^3 V/cm in the drift space and the amplification gap,

respectively. The avalanches are viewed through an Aclar^{*)} window, transparent to ultraviolet light above 250 nm, with an active area of 14 cm x 14 cm. The gas used in the chamber is Ar (90%) + CH₄ (8%) + TEA (2%). After passing argon through a bubbler with liquid TEA, the gas is mixed with methane, and then introduced into the chamber. The temperature of the liquid TEA is kept at 1.2 ± 0.8 °C during this experiment.

The proportionality of collected charge and of light intensity to the energy deposited in the drift space is studied with charges generated by 5.9 keV X-rays from ⁵⁵Fe or by 22 keV X-rays from ¹⁰⁹Cd. Both sources are well collimated. The charges collected on the anode mesh are detected with a charge-sensitive preamplifier which has a sensitivity of 134 mV/pC. The output from the preamplifier is fed into a linear amplifier, whose differential and integral time constants are 0.1 μs. The shaped output pulses from the linear amplifier are measured with a pulse-height analyser. The light emitted from the chamber is detected with a photomultiplier which is sensitive down to 180 nm. The photomultiplier is set at a distance of 4.5 cm from the anode mesh. The dynode pulses of the photomultiplier are shaped with an amplifier with a differential and an integral time constant of 500 ns, and then measured with a pulse-height analyser.

After the measurement of charge and light, the chamber is located on a beam line where 7 GeV/c electrons, muons, and pions are available. The whole system is shown schematically in fig. 2a. The chamber is sandwiched between two plastic scintillators detecting the passage of the electron beam. The optical

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*) Laminated polyester (polychlorotrifluoroethylene).

readout system viewing the chamber is almost the same as described in our previous papers [5] and consists of a quartz lens of 3.75 cm focal length with a 1 cm diameter diaphragm, an image converter, an image intensifier, and a video camera. While the nominal operating voltage is 15 kV, the image converter is operated at 10 kV because no significant image improvement is observed when increasing the voltage to higher than 10 kV. Triggered by the coincidence signal from the scintillators, or triggered by the charge signal detected on the anode mesh, the image coming from the optical system is stored in a video disk and observed on a TV monitor.

As mentioned in the previous paper [5], an avalanche chamber coupled with a high-density converter could be a candidate to search for proton decay. In the present study, we have tested a high-density chamber which has a parallel-plate avalanche chamber as an amplification structure, as shown in fig. 2b; a multiwire proportional counter was used as the amplification structure in the previous study. The high-density grid structure, which is almost the same as there, is composed of sheets of copper which are insulated by sheets of kapton. Both the copper and the kapton sheets have a photochemically etched pattern of 3 mm x 3 mm square holes [7]. The high-density structure has an average density of 2.7 g/cm^3 and a total width of 2.1 radiation lengths. The amplification structure consists of two meshes, at a distance of 9 mm from each other, as in the other chamber. The electric field strengths are kept at $5 \times 10^2 \text{ V/cm}$, $5 \times 10^2 \text{ V/cm}$, and $8.1 \times 10^3 \text{ V/cm}$ for the high-density structure, for the space between the last copper sheet and the first mesh, and for the amplification gap, respectively. With the same optical readout system as described above, the ava-

lanches are also observed through an Aclar window which has an active area of 14 cm x 14 cm. The gas introduced into this chamber is Ar (91%) + CH₄ (7%) + TEA (2%) (the concentration of CH₄ is slightly lower than that used for the other chamber). This structure is also tested in a beam of 7 GeV/c electrons, pions, and muons.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Collected charge and light intensity

In the charge measurement, the photopeaks are clearly observed with FWHMs of 12% and 23% for 22 keV X-rays from a ¹⁰⁹Cd source and for 5.9 keV X-rays from a ⁵⁵Fe source, respectively, confirming that the chamber is working in the proportional mode. In the light measurement, the photopeaks are also observed satisfactorily with FWHMs of 13% and 25% for 22 keV X-rays from the ¹⁰⁹Cd source and 5.9 keV X-rays from the ⁵⁵Fe source, respectively, proving that the light intensity is proportional to the energy deposited in the drift space as well as the collected charge. The spectrum of light intensity obtained for ¹⁰⁹Cd X-rays is shown in fig. 3.

Since the energy deposition of X-rays, per unit track length of the photoelectrons, is much higher than that of the high-energy radiation, we may expect a good proportionality in the amount of light along tracks, perhaps as good as in the amount of charge collected by segmented electrodes, such as strips of wires replacing the continuous grid. The detection of the collected charge or the detected light, as a function of time, should thus give the depth differences of the various parts of an ionizing event together with the amount of ionization energy loss.

Here, it is worth while mentioning the measurement of the charge gain of the chamber and of the number of photons emitted from the chamber [8]. Using an X-ray generator, we have measured the charge gain with a charge-sensitive amplifier and with a picoammeter. It has been confirmed that the chamber is operated with a charge gain of 4×10^4 under the same conditions as described above. At the same time, we have estimated the number of photons through the measurement of photoelectrons detected by a photomultiplier. It has been found that the number of photons emitted by an electron-ion pair formed in the drift space is around 4×10^4 . This indicates that the number of electrons produced is almost equal to the number of photons emitted in the electron avalanche.

3.2 Images obtained with a gas-filled drift space

Figure 4 shows examples of tracks produced by photoelectrons from low-energy γ -rays and tracks produced by a high-energy muon beam, indicating a satisfactory pattern recognition of the optical readout system. As mentioned before, the isotropic response is one of the great advantages of a parallel-mesh structure, and is shown in fig. 5. Although our photographic system is unsuited to a large dynamic range -- i.e. δ -rays, or large avalanches, give spots that are too bright -- the system can be improved by replacing the video camera with a charge-coupled device (CCD) camera: the storage of the information in such a camera should permit exploitation of information on the energy contained in the avalanches much better than that in the video camera. Figure 6 shows the two-track separation capability of the system, which can also be very much improved by the use of a CCD camera.

Since the ionization track produced by the minimum ionizing particle contains about 100 electron-ion pairs per cm in this gas mixture [9], we could expect that the number of photons arriving on the image converter from a segment of 1 cm of the ionization track is about 100; this can produce 20 photoelectrons in the image converter, by taking account of the solid angle of the optical readout system to the chamber and of the quantum efficiency of the photocathode of the image converter for the TEA emission. Although this number seems to be sufficiently large to have a continuous image even for the minimum ionizing particle, our tracks are not continuous, showing that the sensitivity of the entire system, including the chamber itself, is not high enough to detect a single electron. The discontinuity observed in the tracks is most probably due to the fluctuation in the size of a single Townsend avalanche, and/or due to the threshold in the optical readout that avoids noise images which may have the same level as the single electrons.

3.3 Images obtained with a high-density drift space

As can be seen from fig. 7, some events show the beginning of electromagnetic showers initiated by 7 GeV/c electrons. Some scattered electrons or vertices show the high quality of the detector for the signature of complex vertices. The distance between the spots is equal to the distance between the holes of the high-density grid structure, showing that the two-track resolution of the chamber is indeed better.

It is clear that track reconstruction with the help of the charges stored in a CCD camera should have much better resolution. With single photoelectrons, a similar gas mixture containing TEA, and with a multistep avalanche chamber, Gilmore et

al. have shown that the position resolution of an avalanche initiated by a single electron is of the order of $250\text{ }\mu\text{m}$ [3]. In our case, with a single step, and with avalanches originating from more than one electron, we can expect pretty good position resolution for every point of the track. The quality of the picture achieved encourages us to build a large-scale high-density chamber and verify that the energy of an electromagnetic shower can be obtained from the measurement of the light intensity collected by the CCD camera.

4. CONCLUSION AND PROSPECT

We have reported the results obtained under conditions where we did not have to 'stretch' the properties of the different components of our system to the limit of their possibilities. Although the parallel-grid counter, made of two meshes, had to operate at gains of about 4×10^4 , the image converter worked below its nominal value. The aperture of the lens was $f/4$, and we obtained images of tracks or ionizing events of a quality which seems to us to point to possible applications in all fields where the rarity of the events requires a maximum of information. In the gaseous drift chambers, events such as double beta decay in xenon would give a good signature: i.e. the range of electrons and energy loss along the track. In a high-density detector, without going to the extremes of a large-size detector for proton decay, we see applications in cases where high-energy γ -rays have to be identified, their energy measured, and their direction assessed -- with a highly redundant picture permitting the rejection of associated background --, or in neutrino physics, where the possibility of choosing the atomic

number of the high-density grids over a wide range could be attractive.

It should also be mentioned, in this respect, that the possibility of extracting electrons from liquid or solid noble gases such as argon or xenon could be of interest as a replacement for high-density grids, provided the low temperature does not exclude the use of a favourable light-emitting quencher such as TEA. However, the great progress observed recently in the large-scale purification of liquids with a high mobility of electrons at room temperature, such as tetramethylsilane or tetramethylpropane, opens up new prospects. If electrons can also be extracted from these liquids, they can probably be associated with TEA vapours or other light-emitting vapours, thus permitting the visualization of tracks in a continuous medium containing hydrogen atoms.

For the detection of single electrons generated by a vacuum ultraviolet (VUV) photon it is necessary to have more amplification in the chamber. Multistep operation is one way, since it can be operated with a gain above 10^8 . We have also experimented, in collaboration with A. Breskin, the possibility of having larger gains in the chambers by applying pulsed voltages on the parallel grids. Larger gains are indeed obtained. In general, these are attractive not only for VUV photon detection but also for any applications. In addition, even though the gaseous mixture containing TEA provides us with a satisfactory operation of the imaging chamber, the feasibility and reliability for future projects could be increased if another molecule exists which is similar to TEA but emits visible light, since it would result in a great reduction of cost and complexity of the optical readout system.

From this viewpoint, together with that of introducing a CCD system as mentioned here, our main effort is directed towards optimizing the amplification and finding a vapour emitting in the domain of visible light.

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Figure captions

- Fig. 1 : Schematic of a parallel-grid chamber for the measurement of collected charge and light intensity. HV: high voltage supply, PM: photomultiplier, CP: charge-sensitive preamplifier, TFA: timing filter amplifier, LA: linear amplifier.
- Fig. 2 : Schematic of a parallel-grid chamber with a drift space (a) and with a high-density drift space (b), together with an optical readout system. PM: photomultiplier, HV: high-voltage supply, CP: charge-sensitive preamplifier, TD: timing discriminator, CC: coincidence circuit.
- Fig. 3 : Measured spectrum of light intensity for ^{109}Cd with the imaging chamber.
- Fig. 4 : Photographs showing the quality of pattern recognition of vertices.
- Fig. 5 : Photographs illustrating the isotropic character of the projection. The curvature of the tracks is due to multiple scattering.
- Fig. 6 : Photographs demonstrating the capacity of the chamber to separate close pairs of particles.
- Fig. 7 : Electromagnetic showers generated by 7 GeV/c electrons or pions in the high-density imaging chamber with a total path length of 2.1 radiation lengths.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7