ON THE OPTICAL READOUT OF GAS AVALANCHE CHAMBERS
AND ITS APPLICATIONS

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ABSTRACT

Gaseous avalanche counters with mixtures containing the vapour of triethylamine, are coupled to an optical readout system. Different configurations are studied in order to visualize ionization tracks produced by high-energy particles or images caused by vacuum ultraviolet light. This instrument has potential applications in the study of rare or complex events -- such as the search for double-beta and proton decay -- or in Cherenkov ring imaging.

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1. **INTRODUCTION**

Some problems of high-energy physics require types of detectors whose pattern-recognition capability is much better than the present ones. This trend has encouraged new developments [1, 2] such as that of scintillating glass fibres [3]. Sampling of trajectories is often too expensive for a large system. In an attempt to solve this problem, we have investigated the coupling of an optical readout giving the pattern with a limited number of analog electronic channels.

The gaseous avalanche chamber followed by an optical readout system has been investigated by several groups [4-8]. The basic concept behind it is to recognize ionization tracks through the observation of light emitted from electron avalanches initialized by the charged particles. Though it is limited to a projection, the pattern-recognition capability of the system is supposed to be sufficient, since the full information for the orientation of tracks produced in the detection volume is available using the information from the flow of the charges to the detecting planes.

In the course of the development of this new technique, we have studied various amplification structures, several gas mixtures, and different optical readout systems. We have found that argon + isobutane + triethylamine is one of the most promising gas mixtures since it has a continuous emission spectrum from 270 nm up to 310 nm [8]. In the present work two different chamber configurations are examined with an optical readout system whose spectral sensitivity effectively matches the emission spectrum of our mixture. The examined configurations are (i) a drift projection volume coupled to a multiwire proportional chamber (DC-MWPC) and (ii) a high-density drift converter coupled to a multiwire proportional chamber (HDC-MWPC). Both structures were used for the visualization of charged particles. We have also attempted to image VUV photons, using a multistep avalanche chamber (MSAC) [9] filled with helium + methane + triethylamine. In the present work we describe the method, summarize the results, and discuss some potential applications.

2. **EXPERIMENT**

2.1 **The drift-chamber (DC-MWPC) configuration**

As shown in Fig. 1, the first configuration examined is composed of a drift volume coupled to a multiwire proportional chamber (MWPC). The drift cage has a volume of $10 \times 10 \times 10 \text{ cm}^3$, in which the electric field is defined by 25 conducting strips, 4 mm apart, printed on its inner surface. The multiwire proportional sensing element has an anode plane made of gold-plated tungsten wires, whose diameter and spacing are 35 $\mu$m and 4 mm,
respectively. We have observed that with thinner wires we enter into Geiger mode propagation along the wire. The cathode planes, at a distance of 5 mm from the anode wires, are cross-wire meshes with 50 μm wire diameter and 500 μm spacing. The detector has an optical window made of a 50 μm thick Aclar *) foil. It is transparent to the emission spectrum of our gas mixture. The electric field strength in the drift chamber is 300 V/cm, and the applied voltage for the anode wires is 4.6 kV.

The optical readout system viewing the chamber consists of a lens, an image converter, a glass-fibre plate, an image intensifier, and a video camera. The lens is made of quartz with a focal length of 3.75 cm and an effective diameter of 4.6 cm. The image converter has a bialkali photocathode on the fused silica window of 25 mm diameter. The image intensifier is coupled to the image converter through a glass-fibre plate. The output window of the image intensifier is viewed by a video camera. Triggered by the charge signal, detected on the anode wires, the image coming from the optical system is stored on a disk and observed on a TV monitor.

The chamber gas used is an argon (75%) + isobutane (18%) + triethylamine (7%) gas mixture. Argon and isobutane have purities of 99.96% and 99.5%, respectively. After mixing argon with isobutane, the gas is introduced into the detector through a bubbler filled with liquid triethylamine. The liquid triethylamine has a purity of 99%. Its temperature is kept at 23.5 ± 0.5 °C during the experiment.

Typical images of cosmic rays recorded with this system are shown in Fig. 2. The track length is about 10 cm. Figure 2a shows a particle submitted to a multiple scattering process. In Fig. 2b an interaction can be clearly observed near the centre of the view, and it has a typical 'kink' structure. These pictures are practically free from noise.

2.2 The high-density chamber (HDC-MWPC) configuration

High-density 'target-detector' imaging devices could be of considerable importance in studying rare phenomena such as neutrino interactions or proton decay. We have investigated a structure consisting of a high-density drift converter followed by a multiwire proportional element that has a sensitive area of 200 × 200 mm². The converter is 27.5 mm thick, and the wire geometry is the same as in section 2.1. As illustrated in Fig. 3, it is made of 25 copper plates of 0.8 mm thickness. Each plate has a pattern of square holes photochemically etched, whose size and pitch are 2.5 mm and 3 mm, respectively [10]. Kapton foils of 0.3 mm thickness are inserted between the

*) Laminated polyester (polychlorotrifluoroethylene).
plates and have an identical square pattern. The effective density of the converter is about 2.1 g/cm³. The electric field strength across the converter is 1.1 kV/cm, and the applied voltage on the anode wire in the multiwire proportional counter is 4.8 kV. The gas mixture and the optical readout system used are exactly the same as in the case of the DC-MWPC configuration.

Typical examples of tracks recorded with this configuration are shown in Fig. 4. The track length is about 10 cm. Further investigations of this configuration are carried out with high-energy electron beams in order to evaluate the pattern-recognition capability for multitrack events.

2.3 **VUV photon imaging with a multistep structure (MSAC)**

The optical recording of several simultaneous VUV photons can offer an efficient solution for Cherenkov ring imaging. For the purpose of this study of imaging electrons photoproduced in the photosensitive gas volume, we have used a multistep detector [9] that offers two orders of magnitude higher gaseous gain than that of the previously used MWPC.

The experimental set-up is shown in Fig. 5. The VUV light source used is essentially a scintillation proportional counter, whose structure is nearly the same as that described earlier [8]. The filling gas is a rare gas mixture of argon (90%) + krypton (10%). The photons are emitted from this gas mixture with a continuous emission spectrum distributed between 130 and 160 nm [11]. This spectrum is well matched with the region where triethylamine has the highest quantum efficiency of photo-ionization [12]. The VUV light source is coupled to the MSAC through a vacuum pipe in which an optical pattern is located.

As can be seen from Fig. 5, the MSAC has entrance and exit windows made of CaF₂ with a thickness of 4 mm and of Aclar with a thickness of 50 μm, respectively. It has an absorption region with a gap of 6 mm, a pre-amplification region with a gap of 4 mm, a transfer region with a gap of 5 mm, and a MWPC with anode wires of 35 μm diameter 4 mm apart. These regions are defined by cross-wire meshes of 50 μm wire diameter and 500 μm spacing. The electric fields of the absorption region, the pre-amplification region, and the transfer region are 0.9 kV/cm, 11.2 kV/cm, and 2.0 kV/cm, respectively, and the applied voltage for the anode wires is 2.2 kV. While the optical readout is the same as for the other cases, the gas mixture used in this configuration is helium (78%) + methane (20%) + triethylamine (2%) instead of argon + isobutane + triethylamine. For a VUV photon detector used in Cherenkov ring imaging, helium is better than argon because of its lower sensitivity to minimum ionizing particles. In addition, the quenching gas
should be almost transparent to the light which has to photo-ionize triethylamine. It is, therefore, reasonable not to use isobutane but methane since the cut-off wavelengths of isobutane and methane are 170 nm and 120 nm, respectively [13]. The optical pattern used and the observed VUV light image are shown in Figs. 6a and b, respectively. The size of the picture is 5 cm x 6.3 cm.

3. DISCUSSION

In addition to the high capability of pattern recognition reported in this paper, the optical readout system coupled to a gaseous avalanche counter has some other advantages. i) The electronics associated with the anode plane for two-dimensional readout, which is inevitable for normal tracking detectors, is unnecessary for this system, resulting in a great reduction of complex electronics. ii) The charge signals can be used as a trigger for the optical system in order to minimize the exposure time of the system and select the events under study. iii) For a gaseous detector, it is relatively easy to have a large detection volume.

One of the suitable applications of this system could be the search for double-beta decay of \(^{136}\text{Xe}\), for which several projects have been proposed [14]. Since xenon gas can effectively replace argon gas [8], one could imagine a large DC-MWPC device filled with a xenon + isobutane + triethylamine gas mixture for this purpose. The advantage described under (ii) permits operation of the system in such a way that the image will be taken only when the charge observed in the chamber corresponds roughly to the energy of 2.48 MeV, which is the total kinetic energy of two electrons released in the double-beta decay of \(^{136}\text{Xe}\) [14]. The discrimination of the real events from noise should be sufficiently good because the pattern of the ionization tracks is fully available.

The pattern-recognition capability achieved in the present study with the HDC-MWPC configuration may allow us to propose this system as a new tracking calorimeter for proton-decay research. In the current tracking calorimeters used in the search for proton decay [15], many counters are distributed spatially all over the detection volumes in such a way, for example, that plates of heavy material are separated by layers of counters. The optical readout system covers only one side of the detection volume, giving full information on the pattern, while strips of anode wires give the energy distribution and orientation of the tracks and showers. This should result in a reduction of the cost per detection volume with an increase of the quality of information necessary for very rare events.
Although several of the present Cherenkov ring-imaging detectors are sufficiently powerful for particle identification [16], they may encounter situations where so many Cherenkov rings are overlapping each other that they cannot resolve the pattern of the rings. This could happen in colliding-beam experiments yielding highly complex events [17] or heavy-ion experiments. In the latter case, the number of photons emitted by the ions is so high that the analysis of the ring image is nearly impossible because of multifiring of the sense wires in the detectors. The optical readout system coupled to the MSAC configuration could be a solution for these problems, and this was precisely the origin of the first work on optical readout undertaken by Gilmore et al. [5], who have also come to the conclusion that triethylamine is an efficient vapour.

4. CONCLUSION

The present study shows that the optical readout system of gaseous avalanche counters is now at a stage where it can visualize ionization tracks or VUV light in gaseous detectors containing triethylamine. This opens a wide field of applications for the imaging of rare or complex events. It should be noticed, however, that more research has still to be done in terms of chamber configuration, gas mixtures, and the optical readout methods, in order to optimize the whole system.
REFERENCES


Figure captions

Fig. 1: Schematic of the drift volume coupled to the multiwire proportional sensing element and of the optical readout system.

Fig. 2: Ionizing particle images obtained with cosmic rays in the DC-MWPC configuration, showing (a) the multiple scattering process and (b) a 'kink' event.

Fig. 3: Schematic of the high-density drift converter coupled to the MWPC and of the optical readout system.

Fig. 4: Images of typical events obtained with cosmic rays intersecting with the high-density converter of the HDC-MWPC configuration.

Fig. 5: Schematic of the multistep parallel-plate counter irradiated by the VUV light source and of the optical readout system.

Fig. 6: a) The optical pattern with the star shape; b) the obtained image of VUV light.
Fig. 6