ČERENKOV RING IMAGING USING A TELEVISION DIGITIZER

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ABSTRACT

A Čerenkov ring imaging device using as photon detector a multistep spark chamber coupled to a television digitizer is described. Results of a test run using triethylamine as photo-ionizing vapour are presented, as well as preliminary results obtained with a new vapour having an extremely low ionization potential.

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1. INTRODUCTION

Čerenkov ring imaging techniques using as localization elements gaseous electronics detectors filled with a photo-ionizing vapour have been proposed by Seguinot and Ypsilantis¹⁾ and developed since by several authors²⁻⁷⁾. The usefulness of this approach in particle identification at high energies has been analysed in detail in the quoted references and will not be discussed here. Two major problems appear however. The first is the very reduced domain of photon wavelength sensitivity, contained between the photo-ionization threshold of the vapour and the cut-off of the window separating the radiator from the detector; the second comes from the requirement of localizing with good space accuracy single photoelectrons produced in the gas, which implies extreme values of gain in the detector. The last point is particularly relevant, since one obviously cannot use in the detector a gas mixture having the photon-quenching properties of conventional proportional chamber mixtures, and since photon-induced secondary effects seriously limit the stable proportional gain obtainable.

A possible solution to the last problem has recently been investigated in the course of the development of the multistep chamber^{8,9)}, a device that appears to allow large gains in a photosensitive gas mixture; a two-step proportional detector has indeed been used successfully by the authors of refs. 5 and 7 for photon detection.

Concerning the first problem, the introduction of triethylamine (TEA) having 7.5 eV threshold⁵⁻⁷⁾ as photo-ionizing vapour has considerably extended the domain of sensitivity, allowing also the use of CaF₂ windows (with a cut-off around 9.5 eV) instead of the delicate and unstable LiF or MgF₂ crystals required in conjunction with benzene or acetone as in the early work on the subject²⁻⁴⁾.

In this paper we describe the experimental results obtained using a multistep spark chamber in the detection of photons produced by Čerenkov effect, along the lines illustrated in ref. 5, but replacing the film recording of events with an automatic television image digitizer which allows faster and more accurate analysis

of the ring patterns. For most of the experiment TEA was used as photo-ionizing vapour, but in the last section we describe some results, of a very preliminary nature, obtained using tetrakis (dimethylamino) ethylene (TMAE), a vapour with 5.4 eV photo-ionization threshold. Advantages and problems connected with the use of a vapour with such a low ionization potential will also be discussed.

2. EXPERIMENTAL SET-UP

As radiator and photon detector (fig. 1) we used essentially the same devices as described in ref. 5, with however a new mirror and a better quality CaF_2 window; both the radiator and the associated optics were lent to us by the authors of ref. 7, in whose paper they are described in more detail. The Čerenkov radiator tube, 1 m long and 20 cm in diameter, was filled with research grade argon and operated at absolute pressures between 1 and 1.8 bar; the focal length of the reflecting mirror, 100 cm, was equal to the distance between the mirror and the CaF_2 window. The size of the 3 mm thick window, 5 in. in diameter, matched the sensitive area of the detector and completely contained the image produced by particles in our running conditions, the typical ring radius being around 30 mm.

The multistep spark chamber detector (fig. 2) was a multiple-grid structure having a conversion volume where photo-ionization of the gas occurred, followed by a d.c. operated preamplification and transfer region. As a second step we used a triggered spark chamber, pulsed in time with the arriving swarm of preamplified charges corresponding to a trigger. The thickness of the conversion space, 5 mm in the case of TEA, was increased to 20 mm for the trial using TMAE, as will be discussed later. The detector was installed in a medium-energy non-separated beam mainly consisting of negative pions (with about 3.5% contamination of K^- and $\bar{\text{p}}$); the beam momentum could be increased to about 12 GeV/c, the Čerenkov threshold for π^- and 1.6 bar of argon in the radiator being around 4.2 GeV/c. A pair of small scintillation counters defined a $4 \times 4 \text{ mm}^2$ area of the beam, selecting tracks roughly centred on the detector and aligned with the mirror axis; as we will see later, the alignment was indeed not perfect and the beam track (also detected in the multistep chamber) typically lay 1 mm off the centre of the ring image.

A television camera, mounted at 90° to the beam axis, was used to observe and record the spark pattern, as seen in a 45° flat mirror (see fig. 1).

3. IMAGE DIGITIZATION AND DATA TAKING

For the analysis and recording of the images produced in the multistep spark chamber we employed a commercial television camera coupled to a CAMAC-based digitizer recording, on each trigger, the event pattern^{10,11}). Use of the standard raster imposed a resolution of 304 lines per frame, although more refined systems can be implemented to improve the resolution, as shown in ref. 10. A read command initiated the digitization of the image, starting from the first line of the frame immediately following the trigger; since in general the trigger was asynchronous with the electron beam continuously scanning the target, a partial erasing of the lower part of the image resulted. An option was indeed provided in the control module to blank the beam until the start of the digitizing sequence, but in our running conditions and because of the poor quality of the tube this mode of operation resulted in an unacceptable accumulation of noise; use of a better tube, Vidicon or Plumbicon, is foreseen to solve the problem.

Partial erasing of the image in the asynchronous mode is the cause of the observed smaller number of photons in the lower part of the spark chamber images as will be shown later. The time digitizer had a 64 MHz clock, and a single counter was used for digitization of the spark coordinates along each line, thus providing a resolution of 3584 counts per line. The equivalent space accuracies in the horizontal (x) and vertical (y) image planes were 0.04 mm and 0.34 mm, respectively, not taking into account other sources of dispersion. The x coordinates corresponding to one line were stored in an intermediate buffer memory, and the address of the line stored only when there was any information in the line. The system allowed two modes of operation. In the first one the discriminated signal was differentiated, thus recording the contours of the images of sparks. An example of an event digitized in this mode is given in fig. 3a. In the second mode the centre of gravity of the part of a spark belonging to one line was digitized. In that mode, individual sparks consist of several points in subsequent lines, as

shown in fig. 3b. The coordinates stored in the buffer memory were transferred via CAMAC to the on-line HP 21MX minicomputer and then written on magnetic tape. The typical event rate was very low, one per beam spill (500 ms long at 2.5 s intervals), mainly because of limitations in the HV pulser available; the digitization system could, in principle, be operated up to 20-25 Hz, two full frames being necessary for reading and erasing of the image.

4. EXPERIMENTAL RESULTS WITH TEA AS PHOTO-IONIZING VAPOUR

We acquired about 1500 events at 10 GeV/c and 1200 events at 7 GeV/c, with the same radiator conditions (1.6 bar). The data analysed here were taken in the second of the described modes, i.e. the television digitizer recording the centres of gravity of sparks. We thus had on tape the x and y coordinates of single points belonging to a given spark. We found it reasonable to assume that two points (x_i, y_i) and (x_j, y_j) belong to the same spark if $|y_i - y_j| \leq 2$ and $|x_i - x_j| \leq 20$, x and y being the clock count and the line number, respectively. Figure 4 presents the reconstructed number of sparks as a function of the number of points belonging to one spark, with the described assumption; the large number of sparks consisting of a single point is understood as being partly due to the large intrinsic noise of the camera. Figure 5 presents an overlap of about a hundred events produced by 10 GeV/c pions; the Čerenkov ring pattern, about 60 mm in diameter, and the shape of the beam-collimating counters are clearly identified. Figures 6a and b show projections along the x and y axes of narrow strips cut into the image of fig. 5; the strips are 1.6 cm wide and are chosen in the centre of the image in such a way as to include the beam sparks. A small asymmetry in the number of photons detected in the upper and lower parts of the chamber is visible in fig. 5b; the right-hand side of the histogram corresponds to the lower part of the image, which in many cases was erased before being digitized in the asynchronous mode of operation, as mentioned in the previous section. Figure 7 presents the distribution of sparks as a function of their distance from the centre of the ring; this centre is defined as being at half the distance between the two photon peaks in figs. 6a and b. The smaller peak in fig. 7 corresponds to the beam which, as mentioned, was not coinciding with the optical axis of the mirror in the radiator.

To better understand the origin of digitized sparks consisting of a single point (about 15% of all sparks), we have plotted in fig. 8 the distribution of the distance of these points from the centre of the ring. Comparing with fig. 7, one can see that the single-point sparks are due both to a uniformly distributed background and to real photons, in about equal proportions; we have therefore included the single-point sparks in the analysis. One can see in the figures that most of the sparks, apart from the ones corresponding to the beam, are inside a ring of inner and outer radii of 2.5 and 3.5 cm, respectively, where we indeed expect the Čerenkov ring image. In 80% of the events there are no points outside the larger circle. For the further analysis we have taken into account only the sparks inside the ring between 2.5 and 3.5 cm.

Figure 9 shows the distribution of distances between all pairs of photons in each event; there is a visible peak near zero, which is not expected for photons uniformly distributed inside the ring. Sparks which are close to one another may come from reconversion of photons emitted by a primary spark in the chamber itself; it is also possible that our criteria for defining a spark create two or more coordinates for a single flash: this point requires further investigation.

The experimental distribution of the number of photons produced by the beam particles (mainly negative pions at 10 GeV/c) at 1.6 atm pressure of argon is presented in fig. 10. It has the characteristics of a Poisson distribution with an average of 6.8 photons. The relatively large number of events with no photons (3.5% of total) is consistent with the estimated number of K^- mesons and antiprotons in the beam; both particles are below the Čerenkov threshold for this radiator and are not selected out by the trigger.

From the general expression providing the number of detected photons, $N = N_0 L \sin^2 \theta_c$, where L is the radiator length and θ_c the Čerenkov angle, the measured average implies $N_0 \approx 80 \text{ cm}^{-1}$, a value which is on the higher side of the range provided by the detailed calculation that takes into account reflection and transmission losses and TEA quantum efficiency^{5,7,12}). The result implies, in particular, an efficiency of detection of photoelectrons in the multistep chamber very close to 100%.

From our data, we calculated the radius of the Čerenkov ring in two different ways. First we assumed that we knew its centre defined as described above (see figs. 6a and b) and calculated the radius for each image as a mean value of the distances of photons to the centre. The distributions of radii obtained in this way for 7 GeV/c and 10 GeV/c momenta are shown in fig. 11; their mean values are 26.9 mm and 30.1 mm, respectively. The full widths at half maximum are 2.1 and 1.6 mm, respectively, which gives a radius resolution of 3% and 2.3% (relative standard deviation). The corresponding σ_Y/γ resolution is about 10%.

The second way we analysed the events was by calculating both the radius and the coordinates of the centre of the ring, using a least squares fit of the measured points in a circle; of course, this can only be done for events having three or more photon points. Figure 12 presents the distribution of radii for 10 GeV/c particles, computed with this method. The mean value and resolution are essentially the same as obtained with the previous method, but the distribution has a few points scattered on long tails; they are generated by events where all photons happened to be very close to each other, thus leading to a bad fit of the circle.

5. PRELIMINARY RESULTS USING TMAE AS PHOTO-IONIZING VAPOUR

There are many reasons to look for a gas or a vapour having an ionization potential substantially lower than TEA as photo-ionizing agent in a detector for Čerenkov ring imaging. Firstly, fused silica windows which transmit photons up to 7.5 eV could be used; they are cheaper and mechanically less fragile than the fluoride crystal, and can be manufactured in larger sizes. Secondly, the absorption cross-section of oxygen and water, possible contaminants of the gas in the radiator, is almost two orders of magnitude smaller for 7 eV than for 8 eV photons; moreover, the chromatic aberrations are smaller for longer wavelengths, thus resulting in a better intrinsic resolution of the radius of the Čerenkov ring. The problem is of course that most elements with ionization potential below 7 eV exist only in the solid phase at room temperature and have exceedingly small vapour pressures. A vapour having 5.4 eV ionization potential, TMAE¹³⁾, has recently been used by Anderson to detect the light from a xenon-filled gas scintillation proportional counter¹⁴⁾.

Although only the relative shape of the quantum efficiency dependence on wavelength is known at this point for TMAE¹³⁾, the results of the quoted experiment and of a similar one realized in our laboratory indicate an integral quantum efficiency, for the detection of the Xe secondary emission line through a spectroscopy window, of about 25% for an 18 mm thick proportional counter saturated with TMAE at room temperature. This implies a peak quantum efficiency around 35% at 7.5 eV, comparable with the value measured for TEA at 8.5 eV, and an absorption length at the same energy between 15 and 20 mm for saturated vapour at room temperature [the vapour pressure of TMAE at 20 °C is measured to be about 0.35 Torr¹⁵⁾].

We made a very preliminary test, using TMAE in our detector and the set-up described above; to obtain a good absorption we increased the photon conversion space in the multistep chamber from 5 to 20 mm. The angular error introduced by the use of such a long conversion gap is small at very high momenta, but obviously for large Čerenkov angles it may significantly decrease the radius resolution. For our running conditions, the parallax error introduced by the 20 mm gap approaches 0.7 mm full width, a contribution similar to that expected from other sources of dispersion (such as chromatic aberration and detector resolution). We operated the spark chamber with a mixture of argon and 3% methane, saturated with TMAE at 20 °C. Owing to the thickness of the conversion space, to obtain full efficiency, we had to apply to the spark chamber a high-voltage pulse about 500 ns long in order to catch all photoelectrons. This tended to produce large sparks and many secondaries, especially in the beam region, as visible in fig. 13, where an overlap of 10 events is shown as seen on a television monitor (i.e. before digitization). For this reason, the present data should be considered as very preliminary. About 400 events induced by 10 GeV/c particles in the radiator at about 1.35 bar pressure were recorded, and the analysis performed in the same way as for TEA, as described above. Figure 14 shows the distribution of distances of all sparks from the centre of the ring; the first peak near zero corresponds to the beam. The second peak, close to the first, is formed by secondary sparks. Only points between 23 and 34 mm were considered for the calculation of the ring radius and

of the number of photons as before; the corresponding distributions are shown in figs. 15 and 16. The average measured radius, 27.1 mm, corresponds to that expected at the operating pressure in the radiator. The radius resolution, 1.2 mm standard deviation, is worse than that measured for TEA, both because of the smaller number of detected photons and because of the increased parallax error as mentioned. The mean value of detected photons is 2.2, considerably lower than that for TEA; one has to consider, however, that our knowledge of the operating conditions with TMAE is insufficient at this point, and this result is indeed very encouraging [the first measurement with TEA, in similar conditions, gave 1.7 as the average number of photons⁵⁾].

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Figure captions

- Fig. 1 : Čerenkov ring imaging with a gas radiator. The mirror and window are optimized for good response in the far UV region of sensitivity of the detector, a multistep spark chamber. The recording of images is obtained by a television camera and a television digitizer, as shown.
- Fig. 2 : The multistep chamber consists of a preamplification and transfer element followed by a triggered spark chamber; a CaF_2 window, 3 mm thick, transmits the photons into a conversion region where photo-ionization may take place.
- Fig. 3a : Image of one event digitized in the differential mode of operation of the time digitizer. The digitized points represent contours of sparks.
- Fig. 3b : Example of an event recorded using the centre-of-gravity option in the digitizer. On each scan line, the middle point between the two edges of the discriminated signal is digitized; sparks appear then as a vertical sequence of contiguous points.
- Fig. 4 : Number of sparks as a function of the number of digitized points belonging to one spark, operating with Ar + TEA.
- Fig. 5 : Integrated image over ~ 100 events obtained with the apparatus shown in figs. 1 and 2, the spark chamber being filled with Ar + TEA. The Čerenkov ring pattern appears clearly, with a radius of about 30 mm. The central spot corresponds to the overlap of the sparks developed on the direct ionization of the beam particles (10 GeV/c pions); its size, $4 \text{ mm} \times 4 \text{ mm}$, is determined by the beam-defining scintillation counters.
- Fig. 6 : Projections a) on the x and b) on the y axis of bands cut into the image presented in fig. 5. The bands are 1.6 cm wide and are chosen in the centre of the image in such a way as to include the beam sparks.

- Fig. 7 : Number of sparks as a function of their distance from the centre of the ring. The centre is defined as being at half the distance between the two photon peaks in figs. 6a and b. The first peak corresponds to the beam, which was not aligned with the axis of the mirror.
- Fig. 8 : Number of sparks as a function of their distance from the centre of the ring. Only those sparks were plotted which consist of a single digitized point.
- Fig. 9 : Number of pairs of photon sparks as a function of their distance (in cm). The distances were calculated in each event separately. The peak near zero is not expected for a uniform distribution of points over the ring; it probably comes from secondary sparks generated by the primary ones in the spark chamber itself. It is also possible that our criteria for defining a spark sometimes create two or more coordinates for a single flash.
- Fig. 10 : Measured distribution of the number of photoelectrons detected by the set-up shown in figs. 1 and 2 with TEA as photo-ionizing vapour in the spark chamber. The histogram corresponds to a Poisson distribution having a mean value of 6.8; the few events with no spark at all (about 3.5% of the total) are produced by triggers induced by K^- mesons and antiprotons (both below Čerenkov threshold).
- Fig. 11 : Overlap of the measured distribution of ring radii produced by 7 GeV/c and 10 GeV/c pions, and computed making use of the ring's centre. The mean values are 26.9 mm and 30.1 mm, respectively.
- Fig. 12 : Distribution of radii at 10 GeV/c, computed with a least squares fit to the photon point only (i.e. not using the ring's centre). Only events with three or more points have been considered.

- Fig. 13 : Overlap of 10 events, as seen on a TV monitor, obtained using TMAE as photo-ionizing vapour. The conversion gap in the detector was increased to 20 mm for this measurement. The large central spot is due to secondary sparks induced by the primary beam spark, and represents one of the unsolved problems in the practical use of such a low ionization potential vapour (5.4 eV) in a spark chamber.
- Fig. 14 : Distribution of the distance of digitized sparks from the centre of the image obtained with TMAE: the beam and the photon peaks are clearly identified. The spurious peak in between is due to the secondary sparks as discussed.
- Fig. 15 : Distribution of the number of photoelectrons detected using TMAE. The mean value obtained is 2.2 photoelectrons.
- Fig. 16 : Measured distribution of the ring radii produced by 10 GeV/c pions in the gas radiator at 1.35 bar pressure and detected in the spark chamber filled with TMAE as photo-ionizing vapour.

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Fig. 6b

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