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Use of Flash-Tube Hodoscope Chambers with Particle Accelerators.

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1. – Hodoscope chambers with electrodeless flash tubes have been and are being used extensively for cosmic-ray research [1]. As yet they have never been employed, however, in experiments with particle accelerators, even though their potential utility for this application was pointed out already 17 years ago [2], when the technique was first introduced at Pisa. This happened because the spark chamber, developed a few years later, after the work carried out especially at Pisa [3], Harwell [4] and in Japan [5], was in general more suited than its parent hodoscope chamber [6] to operate in conjuction with particle accelerators. In fact, these two types of « electrically

(1) Due mostly to the great impulse given to the development of this technique by A. W. WOLFENDALE and his collaborators at Durham, large installations of flash tubes for cosmic-ray investigation have been used by groups from England, Germany, Hong-Kong, India, Japan, Poland, South Africa, West Africa and the USA. For the first application to a cosmic ray experimental project (Pisa, 1956-57) see: L. BERTANZA, M. W. BRUIN, G. RINALDI FORNACA and G. P. MURTAS: *Proceedings of International Conference on Mesons and Recently Discovered Partices, Padova-Venezia, 22-28 September, 1957*, p. XIII-43.
(2) M. CONVERSI and A. GOZZINI: *Nuovo Cimento*, **2**, 189 (1955).
(3) S. FOCARDI, C. RUBBIA, G. TORELLI and F. BELLA: *Nuovo Cimento*, **5**, 275 (1957). Although reporting for this first time results on the behaviour of a triggered spark counter, this work—carried out at Pisa as an extension of that of ref. (2)—is never quoted in the literature. Probably it remained unnoticed, being published only in Italian.
(4) T. E. CRANSHAW and J. F. DE BEER: *Nuovo Cimento*, **5**, 1107 (1957).
(5) S. FUKUI and S. MIYAMOTO: *Nuovo Cimento*, **11**, 113 (1959).
(6) S. FUKUI and S. MIYAMOTO: *A study of the hodosope chamber* INS-TCA 10 (1957) (Institute for Nuclear Study technical report, University of Tokyo). One of the authors (M.C.) wishes to thank Prof. SHUJI FUKUI for calling his attention on this paper which clarifies the genetical connection between the hodoscope chamber and the « discharge chamber » of ref. (5), from which the final version of the ordinary spark chamber was derived.

pulsed track chambers » (EPTC), although working on the same basic principle (7), differ from each other in many specific characteristics which we recall briefly below.

With respect to the hodoscope chamber, the ordinary spark chamber has the advantage of a shorter recovery time, a better space resolution, and a greater efficiency in detecting single ionizing particles and revealing their paths in three dimensions. It contains furthermore only gas (rather than glass tubes) and, consequently, can be realized with smaller amount of insensitive material. Moreover, its sensitive time can be adjusted easily at the desired value by means of a clearing electric field. These characteristics—together with the ability, common to all EPTC's, of discriminating a particular event out of a background—make the spark chamber extremly useful for many experiments with particle accelerators and apt, in particular, for the accurate determination of particle trajectories in a magnetic field.

On the other hand, flash-tybe chambers have several features which commend them, especially when large sensitive volumes and/or a 4π geometry are required. They are unexpensive, reliable in operation over periods of many years (9), do not require replacement of the filling gas. They are especially flexible, as can be made of tubes of any diameter greater than a few millimeters, prepared in the shape best suited to the geometry of any particular experiment. The energy involved in the discharge of a flash tube is negligible in comparison with that involved in a spark, so that high triggering repetition rates can be reached in principle using ordinary high-voltage (low-current) power supplies. Unlike the case of the spark chamber, accurate parallelism of the chamber plates is not required (10) and high-voltage pulses of comparatively low rise time can be employed to trigger the hodoscope chamber. The individuality of the tubes in such a chamber brings up a number of other interesting possibilities: i) detection with high efficiency of multitrack events with any angular inclination of the tracks, ii) statistical determination of the ionization of single charged particles traversing many layers of flash tubes (11), iii) digitization of the information. This last possibility, most appealing for future experiments with particle accelerators, has been exploited already in cosmic neutrino experiments using light sensors (12). It appears now particularly promising, after the development of a very simple method of digitization using probes placed outside the electrodeless flash tubes (13).

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(7) All EPTC's (hodoscope chambers, spark chambers, streamer chambers ...) make use of the same principle, based on the idea (first introduced in ref. (2) and, independently, in a work by A. A. TYAPKIN (8)) that a gas usually does not contain free charges, except for a short time after the passage of an ionizing particle Any EPTC is normally « insensitive » and is made capable of revealing particle's paths only for a short time, by means of a strong electric field pulse, applied soon after the occurrence of a physical event selected by suitable counters and some « logic circuit ». This triggering method gives the EPTC a stability of operation far greater than that of any particle detector working under continuous elecetric fields.

(8) A. A. TYAPKIN: *Prib. . Techn. Exper.*, No. 3, 51 (1956); see also I. M. VASILEVSKIJ, V. V. VISHNYAKOV, E. ILLIESCU and A. A. TYAPKIN: *Proceedings of the International Conference on High-Energy Accelerators and Instrumentation* (Geneva, 1959), p. 589 (presented by V. P. DZHELEPOV).

(9) Flash tubes built in 1954-55 (those of the original work of ref. (2)) do operate correctly still today. See also: H. COXELL and A. W. WOLFENDALE: *Proc. Roy. Soc.*, **75**, 378 (1960).

(10) This is, of course, because the field required to produce an avalanche and thereby a flash in a tube containing noble gases at a pressure of the order of 1000 torr or less, is much smaller than the breakdown electric field of air at atmospheric pressure.

(11) F. ASHTON, R. B. COATS, J. KING, K. TSUJI and A. W. WOLFENDALE: *Journ. Phys. A: Gen. Phys.*, **4**, 895 (1971). See also: M. F. CROUCH, K. MORI and G. R. SMITH: Case Western Reserve University Report (1971), for another search for relativistic quarks based on a different use of the flash tubes.

(12) F. REINES: *Proc. Roy. Soc.*, **A301**, 125 (1967). See also H. COXELL, M. A. MEYER, P. S. SCULL and A. W. WOLFENDALE: *Suppl. Nuovo Cimento*, **21**, 7 (1961).

(13) C. A. AYRE and G. M. THOMPSON: *Nucl. Instr. and Meth.*, **69**, 106 (1969).

The applicability of the hodoscope chamber technique to experiments with particle accelerators has been investigated with the help of the apparatus of the « μπ-group » ([14]) installed at « Adone », the Frascati storage ring ([15]). As will be shown in this letter ([16]), flash tubes of a type not much different from the standard ones adopted by many cosmic-ray groups ([17]), can well be employed to the advantage of many experiments with particle accelerators, notwithstanding the present limitation already pointed out in one ([18]) of the many papers of flash tubes ([16,18,19-22]) and their applications ([11]) which appeared in the year 1971. As a matter of fact, large chambers with long tubes of ~ 2 cm diameter, are no being used in the modified version ([23]) of the apparatus of the « μπ-group at Adone ».

2. – The flash tubes adopted for the tests at Adone were made of Jena G-20 glass. They were filled with a Ne-He 30/70 mixture at a pressure of 375 torr ([24]). Their outer diameter was 2 cm (wall thickness 0.08 cm) and their length was either 100 cm or 145 cm They were placed in bigap chambers triggered by high-voltage pulses having about 0.1 μs risetime and 7 μs exponential decay time. During the measurements taken at Adone the peak value of the corresponding electric field, E_{max}, was 7 kV/cm and the delay, θ, between instant of particle traversal and application of the high-voltage pulse, was ~ 0.5 μs. The tubes gave flashes nearly as bright as the sparks of ordinary spark chambers; flashes and sparks, in fact, were recorded together on the same film, from a distance of about 15 m.

Other characteristics of these flash tubes and of other similar tubes of 1 cm diameter, were investigated in the laboratory in Rome ([25]). The sensitive time t_s, *i.e.* the « memory » of the passage of an ionizing particle through the tube, was evaluated by measuring the tube efficiency η as a function of the delay θ. We defined t_s through the condition $\eta(\theta = t_s) = \frac{1}{2}\eta(\theta = 0)$. It was found that t_s increases with increasing E_{max}. For $E_{max} = 7$ kV/cm t_s was nearly 10 μs for the tubes of 2 cm diameter and 2 μs for the smaller ones. The recovery time t_r (*i.e.* the time necessary, after a tube has been set a

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([14]) B. Borgia, F. Ceradini, M. Conversi, L. Paoluzi, W. Scandale, G. Barbiellini, M. Grilli, P. Spillantini, R. Visentin and A. Mulachiè: *Phys. Lett.*, **35** B, 340 (1971); *Lett. Nuovo Cimento*, (in press, 1972); M. Conversi: *Proceeding of the Erice International School of Subnuclear Physics* (1970), (seminar).

([15]) F. Amman, R. Andreani, M. Bassetti, M. Bernardini, A. Cattoni, V. Chimenti, G. F. Corazza, D. Fabiani, E. Ferlenghi, A. Massarotti, C. Pellegrini, M. Placidi, M. Puglisi, F. Soso, S. Tazzari, F. Tazzioli and G. Vignola: *Lett. Nuovo Cimento*, **1**, 729 (1969).

([16]) The content of the present letter and further data and information appeared in an internal report by the same authors, of July 1971, circulated in a preliminary version among physicists interested to the flash tube technique.

([17]) Most of the « standard » flash tubes today in operation in the world (procedure by the *International Research Development*, Co., Ltd., Newcastle) are fitted with commercial Neon at a pressure of 600 torr and have a memory (~ 100 μs) much longer than that of the tubes adopted in the present work (see below).

([18]) W. M. Evans and J. C. Baker: Internal report RHEL/M/H/4 (March 1971).

([19]) H. F. Hampson and B. C. Rastin: *Nucl. Instr. Meth.*, **95**, 337 (1971).

([20]) H. F. Hampson and B. C. Rastin: *Nucl. Instr. Meth.*, **96**, 197 (1971).

([21]) H. Ferguson and B. C. Rastin: *Nucl. Instr. Meth.*, **96**, 405 (1971).

([22]) F. Ashton, J. M. Breare, F. W. Holroyd, K. Tsuji and A. W. Wolfendale: *Lett. Nuovo Cimento*, **2**, 707 (1971).

([23]) R. Visentin: *Proceedings of the Congresso della Società Italiana di Fisica, L'Aquila, October 1971.*

([24]) Before being filled the tubes were cleaned with a chromium mixture, washed with distilled water and evacuated while being kept for a few hours at a temperature of 300 °C. Tubes evacuated at ordinary temperature exibited shorter sensitive and recovery times; but we do not know yet if they are equally stable under long periods of operation. We wish to thank Dr. R. Habel and his collaborators of the « Gruppo Tecnologia » for their help in preparing the flash tubes at Frascati.

([25]) Fur further details see: A. Bogazzi: Thesis, University of Rome (in preparation). See also ref. ([27]).

light, for the restoration of its correct operation) was also found to be an increasing function of E_{max}. It depends furthermore, to some extent, upon the external conditions (temperature and humidity). Typical values at $E_{max} = 7$ kV/cm were 0.2 s and 0.9 s, respectively for 1 cm and 2 cm diameter tubes [25].

The probability p_s for a spurious flash to occur was also measured. For $E_{max} < 10$ kV/cm no spurious flashes appeared to occur in our tubes outside of those expected from the background of particles traversing at random the tubes during their sensitive time t_s: If n_b is the rate of background particles per tube, then $p_s = 1 - \exp[-n_b t_s]$ or $p_s = \sim n_b t_s \ll 1$ if the condition $n_b \ll 1/t_s$ is fulfilled.

It is important to point out that since flash tubes of the type adopted in the present work can be made to operate efficiently with sensitive times of a few microseconds, the condition $p_s \ll 1$ is practically satisfied if the number of particles traversing each tube is not much in excess of 10^4/s. This means that cylindrical *hodoscope chambers* containing arrays of some 100 flash tubes *can be used* for 4π geometry experiments placing them *around the crossing region of intersecting beams, even if sone* 10^6 *ionizing particles per sec were produced (uniformly) over* 4π.

3. – The performance of the flash tubes of 2 cm diameter was investigated in the presence of a machine background installing three hodoscope chambers (HC1, HC2, HC3) at various distances from Adone's vacuum chamber [26], as shown in Fig. 1. These chambers, as well as the spark chambers (SC) reproduced in the Figure, were triggered on the occurrence of essentially two types of events: *a*) single-track events, due mostly to cosmic-ray muons unrejected by our electronics; *b*) multitrack events due to the development of electromagnetic showers associated with wide angle $e^+e^- \to e^+e^-$ elastic scattering. These last events, recorded at energies of 1 GeV per beam, were unambiguously identified by the redundant information obtainable from the electronics and from inspection of the photograph of the events [14,23]. The response of the flash tubes was thus investigated in the presence of a background which depended in particular on the intensities of the e^+ and e^- beams. The effect produced on the probability p_s by increasing the beam currents (and thereby the background) is clearly shown in Fig. 2. Even at the highest attained beam intensities 2 cm diameter tubes placed at only a few cm from Adon's vacuum chamber, have a small probability (few percent) to flash spuriously. Even better results are expected of course for smaller tubes [26]. A check was made also to insure that the frequency of spurious flashes is, statistically, uniformly distributed among the various flash tubes.

In Fig. 3 the behaviour of spark chamber SC3 is compared with that of hodoscope chamber HC2, for single-track and multi-track events. For the latter events a bidimensional map of the track multiplicity in the chambers HC2 and SC3 is also given in the Figure. The average multiplicity m of these events, normalized to the detection efficiency for single-track events, is found to be

$$m = 3.2 \pm 0.15 \text{ flashes per gap of chamber HC2},$$

$$m = 1.45 \pm 0.04 \text{ sparks per gap of chamber SC3}.$$

(26) The tests were made just a few days before the spring shutt-down of Adone and we were unfortunately unable to extend them to the inner telescope of the « $\mu\pi$-group » and to chambers containing 1 cm diameter flash tubes.

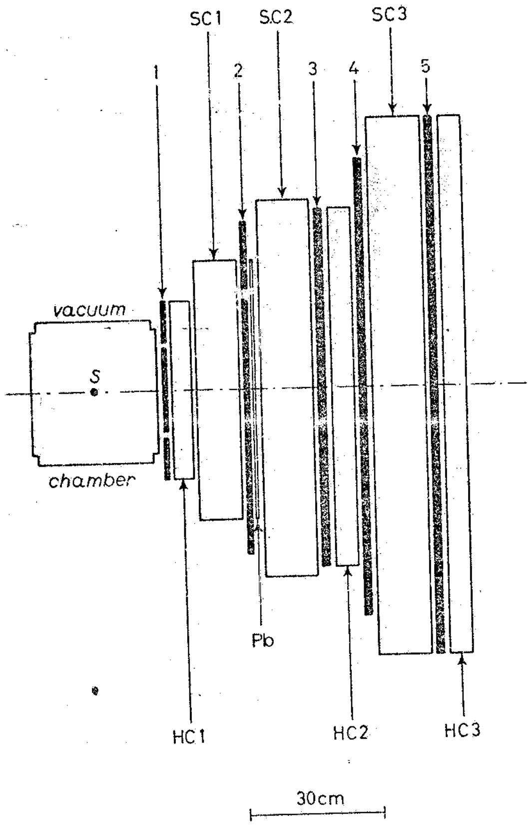

Fig. 1. – Installation of bigap hodoscope chambers (HC1, HC2, HC3) in the apparatus of the « $\mu\pi$-group at Adone » (14). This apparatus involves two identical telescopes, placed symmetrically on opposite sides of Adone's vacuum chamber. For the sake of simplicity only part of one of the two telescopes is reproduced here. The other telescope contained only one hodoscope chamber (like HC3) (26). Plastic scintillators from both telescopes (1, 2, ..., 5) were used to form suitable concidences and thereby to select the events produced at the « source » S by the collision of the e^+, e^- bunches (travelling perpendicularly to the Figure). The events were then observed with the help of spark chambers (SC1, SC2, SC3 ...) on both telescopes. Each hodoscope chamber contained two layers (one per gap) of 2 cm diameter flash tubes, placed normally to the figure plane. The length of the tubes was 100 cm for HC1 and HC2 and 145 cm for HC3.

One sees that hodoscope chamber HC2 has a much greater efficiency than spark chamber SC3 as a detector of the many particles involved in electromagnetic showers of 1 GeV total energy.

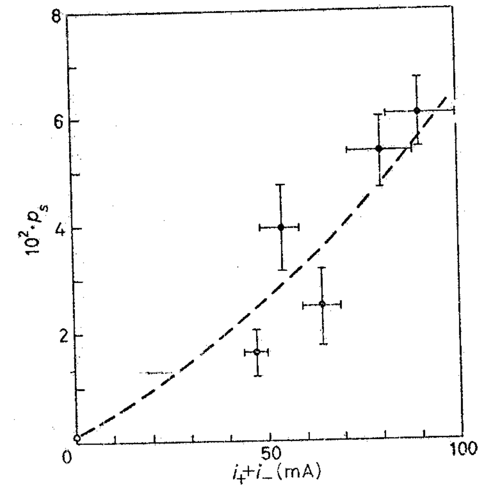

Fig. 2. – Percent probability of spurious flashes observed in HC1 as a function of the total current circulating in Adone.

Probably, the most serious limitation for the applicability of the technique to experiments with particle accelerators is, as now, the comparatively long recovery time of the present flash tubes (27). This prevents, in fact, hodoscope chambers from being operated at a repetition rate in excess of ~ 1/s. There are nevertheless still many experiments for which a data acquisition of the order of 1/s is satisfactory. Then the possibility of using chambers of any size and shape, with digitized flash tubes of the type described above, may well represent a very simple, flexible and economical solution (28). It should be also enphasized, in this connection, that by a minor change (25) of the digitization method of AYRE and THOMPSON (13), it becomes possible to retain fully the light emitted by the flash tubes. Then one may hopefully exploit all the optical information just in the rare cases of very complex events unresolved by the electronics associated with the digitized probes. Finally, an interesting alternative (29), fully exploiting the light emitted by the tubes, is represented by the « Plumbicon », already in use for ex-

(27) Preliminary results on tubes of low-resistivity glass, filled with a commercial neon-helium mixture, indicate the possibility of overcoming this difficulty.

(28) See also the remark by one of us (M.C.) after the invited talk by G. CHARPAK: *Proceedings of the International Conference of the E.P.S. on Meson Resonances and Related Electromagnetic Phenomena, Bologna, 14-16 April, 1971* (in the press).

(29) One of us (M.C.) wishes to acknowledge stimulating conversation he had with Prof. E. AMALDI on this alternative possibility.

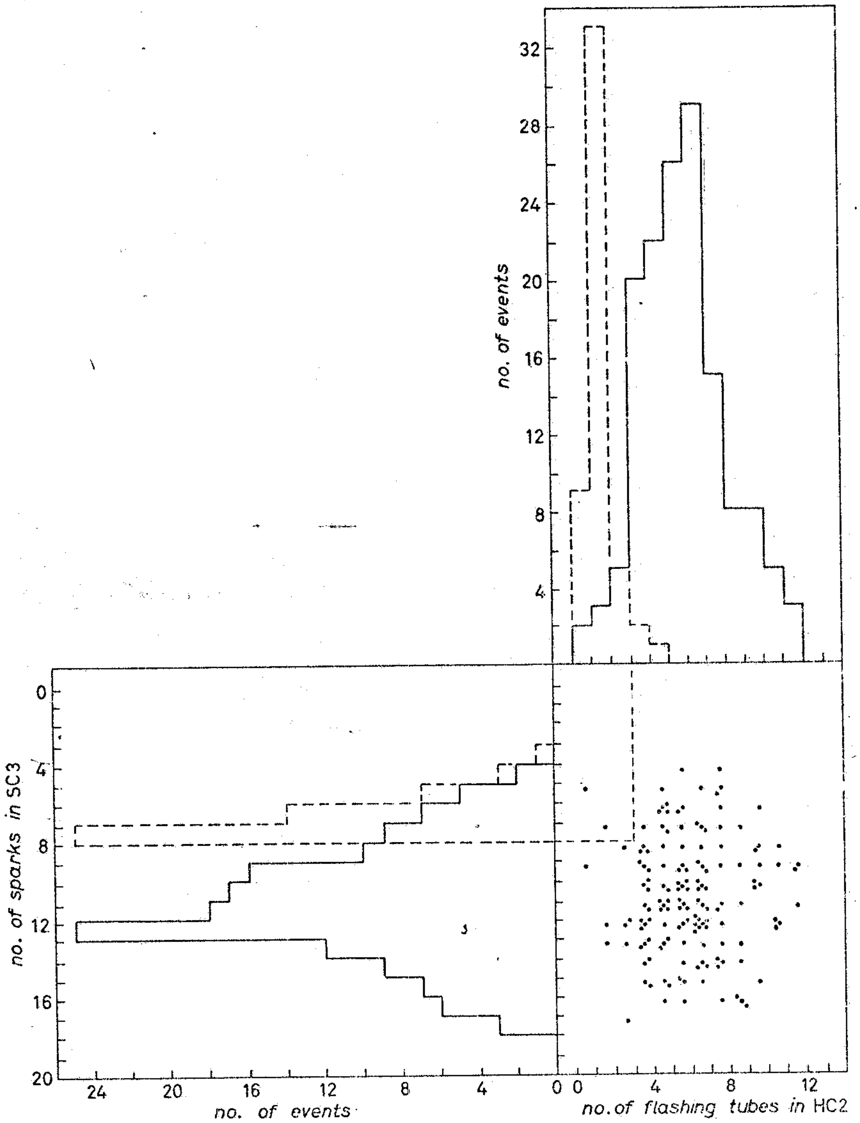

Fig. 3. – Comparison between the response of the 8-gap spark chamber SC3 and the bigap hodoscope chamber HC2 (Fig. 1) to single-track events (cosmic-ray muons) and multitrack events (electromagnetic showers due to ~ 1 GeV e^+ or e^- from wide angle $e^+e^- \to e^+e^-$ elastic scattering): — — — single-track events, ·—— multitrack events.

periments with spark chambers ([30]), which has a resolution well balanced with that of any practical system of hodoscope chambers.

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We acknowledge the co-operation of all members of the « $\mu\pi$-group at Adone » and wish to thank in particular Mr. A. Bogazzi, Dr. E. Iarocci, Mr. G. Nicoletti and Prof. R. Visentin, who have contributed help and suggestions.

([30]) See, *e.g.*, F. Krienen: *Nucl. Instr. and Meth.*, **81**, 310 (1970).