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THE DEVELOPMENT OF THE FLASH AND SPARK CHAMBERS IN THE 1950's

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1. - Introduction -

Most of the discoveries which have led during the period of history covered by the present Colloquium to our progressive understanding of particle physics were made possible, as in the case for all fields of modern Science, by the invention and development of new instruments and experimental techniques. A remarkable advance in new methods for particle detection occurred in the 1950's through the invention and development of two new families of track detectors: bubble chambers (propane, hydrogen, heavy-liquid bubble chambers) and "electrically sensitized track detectors" (flash, spark and streamer chambers) of which the spark chamber became the most popular due to its widespread use during the 1960's in experiments at high energy accelerators. The present article is dedicated to the historical development of the latter family of detectors(*), the eldest member of which, the flash chamber, was born at the University of Pisa in 1955.

When I arrived in Pisa in 1950 to take up the only chair of Physics then available at that University, I had the good fortune to find Adriano Gozzini there. He was the only member of the small staff of the Physics Institute then actively engaged in advanced research, which he carried out on microwave spectroscopy with the collaboration of a few students and one technician. The diversity of our fields of research did not prevent us from communicating but was instead an incentive for having frequent discussions of our work; and I believe that the complementarity of our knowledge played an essential role in the conception and development of the flash chamber.

(*) Not including the streamer chamber and other important developments that occurred after 1960.

2. - The development of the flash chamber -

The starting point for the development of the new technique was the observation of Gozzini in 1954 that a neon bulb, which is known to glow when placed near an ordinary radiowave (RF) transmitter if RF emission is actually occuring, does not glow at all if the bulb is kept in the dark and irradiated by the short (1 μs), high power (1 Mw), single RF pulse emitted from a radar system; whereas it glows again if it is illuminated, even when irradiated by a similar pulse of a much lower power.

When discussing this, Gozzini and I reached the conclusion that in the absence of light, and therefore of photoelectric emission from the body of the bulb, no free electron was present among the $\sim 10^{20}$ neon atoms filling the bulb, unless some ionizing particle had crossed the gas just before or during the 1 μs radar pulse(*).

We estimated that the rate (ν) of particles crossing the neon bulb (cosmic rays and some local radioactivity) was of the order of 1/s, whereas the "disappearence time" (τ) of the ~10 electrons freed in the gas by a minimum ionizing particle had to be much shorter than 1 s(**). Then the probability for the neon bulb to flash when subjected to the powerful but short RF radar pulse had indeed to be very small ($\nu\tau \ll 1$), in agreement with the observation.

We then thought that a new type of detector of particle tracks, characterized by an unprecedently high over-all space-

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(*) Of course the luminous electric discharge of the glowing bulb is always initiated by some free electrons strongly accelerated by the intense electric field.

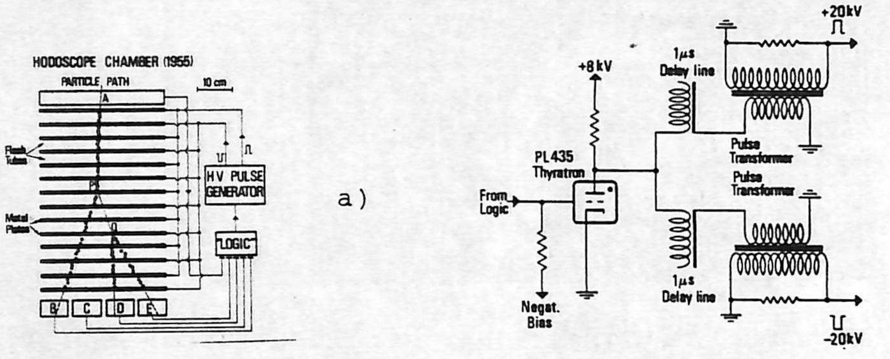
(**) Later in a discussion with Carlo Franzinetti, whom we consulted for his past experience with spark counters, we clarified that even neglecting the recombination with possible electronegative impurities present in the neon, the ionization electrons do in fact disappear in times of the order of 10^{-5}s by diffusion to the glass walls of the bulb where they stick[1)], thus becoming ineffective.

time resolution, could be realized by stacking a large number of thin, wireless, neon tubes covered with black paper for light screening, and subjecting them to an intense impulsive electric field, applied immediately after the passage of the particles to be detected. Due to the acceleration impressed by this field (a few kVolt/cm according to our estimate) the electrons freed in the gas by the particles should in fact give rise to a luminous electric discharge, which propagates through the length of the tubes via photoionization processes, thus making the particle tracks visible as a sequence of flashes emitted from the tubes crossed by the particles. The three dimensional path of the particles could be registered by arranging the tubes - as stated in the paper we published later[2] - in "alternating layers perpendicular to each other and taking photographs in two directions at right angle". For this "flash chamber"(*) to work efficiently it was essential to switch on the sensitizing impulsive electric field as soon as possible after the occurrence of the event to be recorded, so as to avoid the disappearence of the ionization electrons through recombination or diffusion to the bulb walls. We thought that this could be achieved by using a system of counters and an associated "logic circuit" to trigger a high voltage pulse generator connected to the plates of a parallel plate condenser containing the "flash tubes", on the occurrence of the event to be recorded (see Fig. 1a)).

We quickly constructed and assembled all that was needed to test our idea, in particular using for the high voltage pulse generator two pulse transformers of a radar modulator providing rectangular pulses of up to 20 kVolt, 2 μs duration, arranged in "push-pull" as shown in Fig. 1b), so as to obtain up to 40 kVolt (and therefore an electric field of up to ~10 kVolt/cm) between any successive pair of chamber plates.

(*) This denomination gradually replaced the original one: "hodoscope chamber"[2].

The first test was made successfully on March 25, 1955, using soda glass tubes of 1.5 cm diameter filled with spectroscopically pure argon at half atmospheric pressure. It was an exciting experience to immediately observe the tracks of cosmic ray muons appearing as a sequence of flashes on a straight line when the chamber was triggered by counter coincidences, and to check that no tube flashed, on the other hand, when the high voltage pulse was applied at random. The work proceeded with the help of two students, Sergio Focardi and Giampaolo Murtas, and of Carlo Franzinetti, whom we invited to join us from Rome in this enterprise. The argon tubes were replaced by neon tubes of 0.65 cm diameter, and the first pictures of cosmic ray muons and electro-



b)

Fig. 1: a) Sketch of first flash chamber showing its working principle. A time-coincidence mode of the pulses of counters A, B, ...E selected by the "logic" is used to trigger a high voltage pulse generator, which is connected to the plates of a parallel plate condenser. The gap (a few cm) between any pair of contiguous plates is filled with neon tubes (not shown in the figure). Tracks of ionizing particles are "seen" as sequences of flashes (black spots in the figure) emitted from the tubes crossed by the particles. P and Q represent interaction points.
b) The triggering system used to obtain two 20 KV rectangular pulses (2 μs width) of opposite polarity.

magnetic showers were taken (see Fig. 2). The results, published in a letter[2)], were reported in greater detail at the 1955 Pisa International Conference on Elementary Particles[3)]. Further results obtained later with the collaboration of three other students, Gabriella Barsanti, Carlo Rubbia and Gabriele Torelli, were reported at the 1956 CERN Symposium[4)].

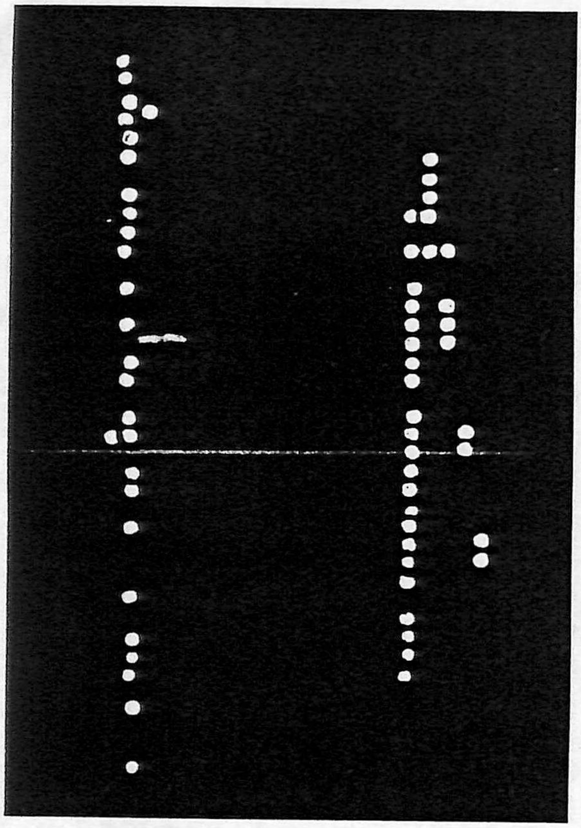


Fig. 2: Two of the first pictures of cosmic ray events recorded in 1955 by triggering the flash chamber with two different coincidence modes selected by the "logic": single track (left) due to a muon; two-track event presumably due to an e^+e^- pair from the interaction of a γ-ray in one of the chamber plates.

The new technique was applied successfully in subsequent cosmic ray research by A.W.Wolfendale and his collaborators at Durham[5)], England, and extensively utilized later by several other groups, including those of M.G.K.Menon (India), S.Miyake (Japan), F.Reines (USA), J.Trümper (Germany).

3. - The selective electronic trigger -

The counters and associated electronics used in the flash chamber provided the possibility of selecting a particular class of events (e.g. "single track","shower", etc.) by a suitable arrangement of the "logic circuit". It is worthwhile stressing that this selective electronic trigger, by which the chamber was generally maintained insensitive and was sensitized only for a very short time just after the occurrence of the event to be recorded, is a common feature, and indeed the basic principle, underlying the operation of all similar track detectors of improved space and time resolution (spark chamber, wide-gap chamber, streamer chamber) developed later. Due to their long recovery time, an essential condition for these detectors to operate properly in the presence of a high flux of ionizing particles, is that they be kept really insensitive for all times with the exception of the tiny interval needed to observe the event selected by the logic circuit.

An electronic trigger of this type was first applied in 1948 by O.Piccioni[6] to a hodoscope of GM counters in a cosmic ray experiment searching for photons from muon capture. Even though not directly linked to the historical development of the flash and spark chambers, this important work contained the basic idea of associating space and time resolutions to gain in rejection power against spurious events (those simulating photons in that case). Shortly later, but independently of the Pisa work[2], A.A. Tyapkin[7], applied a similar technique to pulse a hodoscope of discharge counters for use with particle accelerators. In this case the idea was, basically, to render a comparatively slow detector capable of operating in the presence of an intense background.

Instead, in the work of P.G.Henning[8], parallel plate spark counters[9] filled with an argon-vapour mixture were operated under continuous voltage supply, and the sparks were enhanced by the discharge of a capacitor triggered by a counter coincidence. Hence, even though this instrument resembles the optical spark chamber developed later, and it certainly merits quoting in a historical review of this technique, it did not fulfill the above mentioned condition of being kept "normally insensitive", which is of vital importance for making the detector capable of operating under high particle fluxes, and therefore useful in particular for experiments at particle accelerators.

On the other hand, when the condition of "normal insensitivity" is fulfilled, the triggered detector acquires a high degree of stability, and it becomes capable of working with (impulsive) electric fields much in excess of those permissible under conditions of constant voltage supply. This latter point was proved experimentally in a rather impressive way in a work carried out at Pisa in 1956[10)] in which the idea of the electronic trigger was applied for the first time to the parallel plate spark counter, using a counter developed a few years before in Rome[11)]. Since this Pisa work remained unnoticed, probably because it was published only in Italian, its main results are reported in Fig.3. As shown by this figure, a spark counter having a "plateau" of a few hundred Volt centered at 3.5 kVolt can work at a much higher voltage under conditions of impulsive operation; the probability of a spurious spark being in fact smaller than 10^{-4} for pulses of 13 kVolt lasting about 1 μs. Incidentally this explains why the spark chamber (which is a multiplate triggered spark counter filled with some noble gas mixture) does not require the mechanical refinements (rigorous parallelism and polishing of the electrode plates) needed for the parallel plate spark counter first developed by J.W.Keuffel[9)].

4. - The transition from the flash to the spark chamber -

This transition was correctly reported in at least one book[12)] and two popular articles[13,14)] on the subject. In contrast, other books[15)] and survey articles[16)] accepted the historically incorrect[(*)] account of the first review[17)] on the development of the spark chamber. This latter instrument was developed indeed starting from the flash chamber, and not from the parallel plate spark counter. It was in fact in the course of their investigations on the flash chamber technique[18)] that S. Fukui and S.Miyamoto developed their "discharge chamber"[19)],

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(*) Ref. 17) contains the wrong statement that the flash chamber (defined as a "modification of the spark chamber" developed a few years later) was derived from the work of Ref. 11).

usually and correctly referred to as the first example of a properly operating spark chamber.

As a matter of fact, the selective electronic trigger used in the flash chamber might have led immediately to the final version of the optical spark chamber developed 4 or 5 years later, had it been correctly applied to the pre-existing spark counter[9,11]. But the two works which were directed along this line, at Pisa[10] and especially at Harwell[20], did not entirely reach the goal for the reasons explained below.

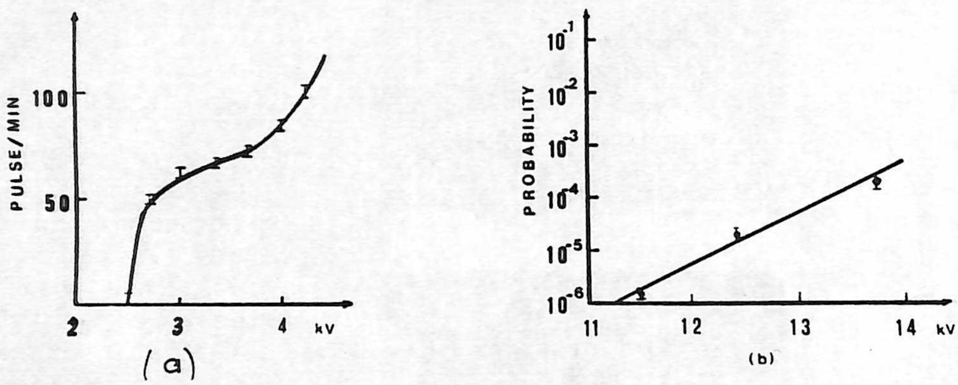
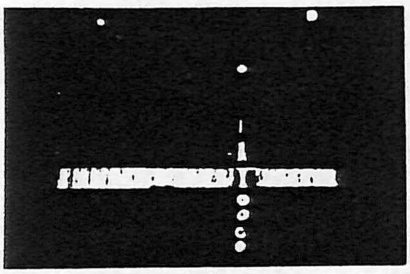
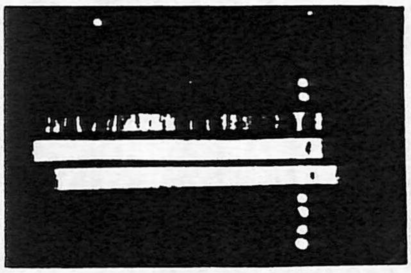


Fig. 3: a) The "plateau curve" of a d.c. operated parallel plate counter.
b) Probability of "spurious" sparks occuring in the same counter triggered with 1 μs rectangular pulses of the amplitude given in abscissa (from Ref. 10).

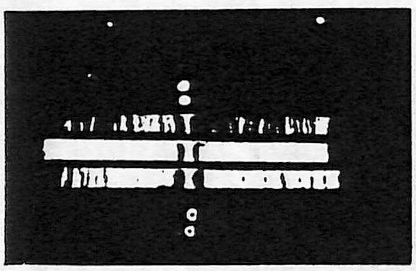
The results of the Pisa work reported in Fig. 3 clearly suggested the possibility of using a multiplate triggered spark counter (i.e. a "spark chamber") in order to see the tracks of ionizing particles as a series of sparks aligned along the particle paths. Gozzini, Giuseppe Martelli and I discussed to some extent this possibility and its potential advantages with respect to the technique already in our hands: lack of "dead material" (such as the glass of the flash tubes), improved space resolution, and possibly a better time resolution, since the "memory" of the passage of the particle (i.e. the detector sensitive time, which for the flash chamber was many tens of μs) could presumably be adjusted in this case by a "clearing field", which we had found to be ineffective in the case of the flash chamber[*]. However we thought (and we were wrong) that a chamber needed first to be evacuated and then filled with some noble gas of high purity in order to operate efficiently. This implied that it would have been very hard and expensive to construct large chambers for use in experiments on extensive cosmic ray showers, such as those being considered at that time in Pisa.



(5KV/2cm)



(8KV/2cm)



(10KV/2cm)

Fig. 4: Photographs of the discharge in a flash tube observed laterally by Fukui and Miyamoto[18]. The path of the primary ionizing particle was identified by the flashes of other tubes placed perpendicular to the former one. The discharge appears always as a bright column at the position of the particle crossing.

(*) As explained later by the Durham group, the charges deposited on the high resistivity glass walls after the tube discharge rearrange their distribution under the effect of the clearing field, so as to counteract the action of the latter.

On the other hand we considered (and we were right) that large flash chambers were particularly suited to experiments of this type since, contrary to the case of the sparks, the discharges occurring in the flash tubes do not involve high intensity currents, and the tubes are "independent" of one another, thus making it possible to record efficiently the many tracks of a large shower(*).

For these reasons, and also because of the intensive involvement at that time of the small staff of our Institute in research on different frontiers of physics(**), the idea of developing a multiplate triggered spark counter was withdrawn.

The "triggered spark counter" developed at Harwell by T.E. Cranshaw and J.F.De Beer[20] was specifically conceived as an application of the triggering principle of the flash chamber to the pre-existing parallel plate spark counter[9]. Three bi-gap spark counters lined up in the solid angle of a GM-counter telescope were triggered by the GM-counter coincidences. These authors were thus able to observe the tracks of cosmic ray muons as six sparks usually aligned collinearly. Their instrument was therefore essentially identical to the spark chamber developed later, in all respects except for the gas filling which was air at atmospheric pressure. Since in air the ionization electrons recombine in a time much shorter than the "triggering time", the

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(*) By alternating plates of dense material with planes of flash tubes a new type of total absorption shower detector, which allows to derive the energy of the primary particle from the number of tube hits, has been developed in the 1970's[21]. Such "hit calorimeters" made of flash chambers of plastic material[22] are part of present-day experiments and large-scale projects in neutrino physics, search for nucleon instability, etc.

(**) Among the many students working at that time in Pisa on the frontier of particle physics I wish to recall here the late Bruno Tallini who in the last period of his life, prematurely interrupted on September 1981, contributed ideas and enthusiastic work to the project of the proton decay experiment, based on the use of large fine-grain "flash calorimeters", now being prepared by a French-German Collaboration for the Fréjus underground laboratory.

observed sparks were initiated by the slow positive ions. Due to their much larger mass, the ions need a considerably larger electric field than do the electrons to be accelerated up to the critical value required for the spark to occur. Under these conditions, each parallel plate counter charged by the applied high voltage pulse tends to discharge through a single spark, so that a multi-track event cannot be observed in general as in the case of a neon filled spark chamber, or even better in a flash chamber.

Historically, the relevant step in the transition from the flash to the spark chamber was the observation, made by Fukui and Miyamoto in 1957, that the light emitted in the discharge of a flash tube has a maximum intensity concentrated at the position through which the particle passed (see Fig. 4). It was, in fact, this observation that suggested to them, as quoted in one of their papers[18)], "the possibility of developing a new instrument which can detect the path of the particle more precisely". This instrument was the "discharge chamber"[19)] developed in 1959, later extensively investigated and further improved in many laboratories[(*)] (and called ever since "spark chamber") especially after the experimental demonstration, given in particular by J.W.Cronin and G.Renning[23)], that it could stand and operate properly in a beam of up to one million particles per second.

(*) See Proceedings of the International Conference on Instrumentation for High Energy Physics (Berkeley, 1960; Interscience Publishers, New York) and of the Argonne Spark Chamber Symposium (Rev. Sci. Instr. 32, (1961) 479).

5. - Concluding remarks -

The historical reconstruction of the events reported in the present article shows that the development of the flash chamber[2] and its transition to the spark chamber[19] occurred independently of the pre-existing parallel plate spark counter[9]. Although the subsequent transition to the streamer chamber has not been considered because it occurred after the period covered by this Colloquium, mention has to be made here of the early attempts of A.R. Bevan[24] and G.Charpak[25], which were potentially relevant to, even though not directly influential in the historical development of the new technique.

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