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Introduction

The health physicist working around high-energy accelerators has the advantage over identical professionals working in more conventional centers of being associated with the most advanced techniques in many scientific fields, particularly those connected with particle detection. Many of the peculiar problems they are bound to solve require the use of some of these sophisticated new techniques. Moreover, it is my opinion that it is also one of their duties to provide a linkage between the physics and the correlated technical activities that they are involved in (or look upon). This applies especially to the fields of biology and medicine, to which, as health physicists, they are necessarily (though perhaps indirectly) related. This liaison has benefits for all.

Spark chambers are tools commonly used nowadays in nuclear physics for locating the tracks of ionizing particles. In their primitive form they consisted of two parallel metallic plates separated by a gap filled with an appropriate gas. If, when an ionizing particle crosses the chamber, a high voltage pulse is applied to the plates, a visible spark develops along the path of the ionizing particle; a photographic camera (or better two orthogonal cameras) triggered by the event took pictures of the event itself. A stack of many of these two-plate modules put close together allowed a complete view of the track of the particle to be recorded on the film.

Films from spark chambers had to be scanned afterward like the films from the bubble chambers. The advantage of spark chambers over bubble chambers is that a spark chamber can be triggered to be sensitive only when interesting particles cross it, so that only the "good events" are recorded, thus reducing notably the number of pictures to be scanned for an experiment. A wide variety of ingenious semiautomatic scanning and measuring systems for the spark chamber pictures was developed. However, this step of analyzing photographic pictures of the events from the spark chambers represented a tedious and time-consuming interval between the recording of the event and the display of the result; the characteristics property of the spark chamber of being triggered only by "good events" did not fully compensate for the finer resolution and other advantages intrinsic in other track detectors such as bubble chambers or nuclear emulsions.

Studies leading to filmless spark chambers providing direct electrical readout of the chamber data were undertaken around 1964. The most successful were:

(a) The Vidicon system, in which the spark chamber image projected onto a Vidicon photocathode is scanned by the electron beam and the digitized position of the beam is recorded whenever a spark is detected. A minimum readout time of about 10^{-4} sec for a 2-m-side chamber was achieved.

(b) The sonic system, in which one takes advantage of the sound emitted by the spark, which is propagated through the gas at constant velocity. The time of flight to several transducer probes is digitized and used to locate the x and y coordinates of the spark. A minimum readout time of about 6×10^{-3} sec for a 2-m-side chamber was achieved.[1, 2]

Subsequently the idea of replacing the two conducting plates with two arrays of parallel wires (the wires of one plane are perpendicular to those of the other) was introduced. In such a system the location of the spark is reduced to the identification of the two wires between which the spark took place. This idea led to the development of readout techniques for this new kind of chamber. The most successful have been:

(a) Wire magnetic core. Each wire of the two plates is threaded through a magnetic core which is "interrogated" (as to state of magnetization) after being set by the spark current.

(b) Magnetostrictive. A wire of magnetostrictive material (e.g., nickel) lies above and across all the wires of the array forming a chamber electrode, and is then magnetically coupled with them.[3] The spark in one wire of the array produces a local deformation in the wire (magnetostrictive or Joule effect), which travels along the wire at the velocity of sound in that material. The time of transit is digitized and provides a coordinate of the spark. The other coordinate may be determined similarly, using the wires of the other electrode; alternatively, the current ratio between signals picked up from magnetostrictive elements at both ends of the wires on one electrode can be used.

The magnetostrictive multiwire spark chambers present many advantages over other types of spark chambers, and are at present the most widely used in high energy research.

Our projects are based on the use of this type of detector, and we describe them in greater detail in what follows.

Multiwire Spark Chambers With Magnetostrictive Readout

A multiwire spark chamber consists of two or more grids of parallel wires (such as aluminum or tungsten) stretched on insulating frames. An appropriate gas (normally a mixture of Ne and alcohol) is circulated at atmospheric pressure in the space between these grids. The diameter of those wires can be as small as about 50μ, and they can be spaced as close as about 1 mm apart. The distance between the wires sets the spatial resolution of the chambers. For wire spacing of 1 mm one can achieve, with the magnetostrictive readout system, a resolution of about 0.3 mm by interpolating the pulse height from two adjacent wires. The dimensions of the grids are limited only by mechanical factors. Chambers up to 10×10 m have been realized for particular experiments, but these dimensions pose severe mechanical and electrical problems. Chambers 1×1 m are easy to operate. In a two-grid chamber the wires of the grids are at 90 deg to each other. More grids with wire oriented at different angles can be introduced for improving the spatial resolution.

One two-(or more)-grid spark chamber measures two spatial coordinates of the trajectory of a charged particle; the spacing between the grids influences the resolution in the determination of the position in the plane of the chamber as well as the resolution in the third dimension, which is used when a tracing of the particle trajectory is required. A normal spacing between the grids is 1 cm.

The magnetostrictive readout system consists of a metallic wire (usually nickel), magnetized to a suitable level, placed in close proximity to the wires of one grid of the chamber in such a way that they are magnetically coupled to the magnetostrictive wire. A current pulse in one wire of the grid (a spark) produces, by magnetostrictive effect, a local deformation of the nickel wire (in nickel a longitudinal contraction), which travels along it with the velocity of sound in nickel, i.e., 5000 m/sec. At one end of the wire is placed a suitable transducer--a microphone or an inductive coil--followed by appropriate electronic shaping units. The time interval between the spark formation and the arrival of this pulse is measured (or, better, the time distance between this pulse and one produced in one fiducial wire), which gives one coordinate of the spark. The other coordinate is extracted from the other grid. Figure 1 shows a schematic diagram of a two-grid spark chamber. The spark pulses collected at the magnetostrictive transducer are of the order of a few tens of millivolts, so they can be easily amplified.

A multiwire spark chamber can give the coordinates of one point of the track of an ionizing particle with a precision within less than ± 0.3 mm, and these coordinates can easily be extracted in digital form so that they can be fed directly into a computer program. The dead time of these chambers is about 1 msec. An array of chambers can easily picture the track of an ionizing particle that crosses them. The total thickness of a chamber can be made very small ($\approx$ 1 cm of gas at atmospheric pressure plus less than 50μ of Mylar, equivalent to less than 5×10^{-3} g/cm^2 of carbon), which allows the measurement of very-low-energy particles.

However, a spark chamber usually has to be triggered by another detector, and scintillators are used, which introduces additional thickness. A method has been developed[4] that eliminates the necessity of triggering scintillators. A third grid with wires widely spaced is introduced between the sparking grids or outside the gap near one of the two grids. A dc voltage is maintained between this grid and the other such that when an ionizing particle crosses the chamber, a proportional or GM pulse is collected at the grid. This pulse is then used for triggering the high sparking voltage to the sparking grids. We will see an application of this type of self-triggering chamber in Chapter 4.

Multiwire Proportional Chambers

The multiwire proportional chamber is a recently "rediscovered" type of detector which allows the location of the track of an ionizing particle and presents some advantages over the multiwire spark chamber. Our group, simultaneously with other groups in different centers,[5] is pursuing studies on this new instrument.

In our study, this chamber consists of a grid of wires stretched between two metallic meshes. A dc voltage is applied between the grid and the meshes such that, when a particle crosses the chamber, a proportional or GM pulse is collected at the wire closest to the trajectory. When this wire is identified (see below), a coordinate of the track is recorded. Wires with diameters up to 10 μ spaced up to less than 1 mm can be used, which could allow a spatial resolution of the order of 0.2 mm by interpolation between the wires, but at those dimensions, the operating conditions are quite critical. (We have easily operated chambers with wires 40 μ diameter spaced 3 mm apart. Those chambers show a precision in the location of the track better than 1 mm). The counting rates that one can achieve with these detectors are higher than 3×10^5 per sec per wire and, if the chamber is operated in the proportional region, a selection of particles with different specific ionizations is possible.[5]

The second coordinate of the track can be obtained by replacing the meshes with grid wires at 90 deg or (this is under study) by putting two grids of wires close to each other between the meshes.

The readout method involved the use of an amplifier per wire,[6] which is tedious to construct and somewhat costly. We have developed a readout system using a ferrite delay cable coupled with the wires which gave a resolution of 3 mm.[7] Figure 2 is a schematic of the system we used. Studies for improving this resolution are under way.

We summarize the properties of the multiwire proportional chamber at the present state of the art:

(a) The chamber is able to detect two coordinates of a point of the trajectory of a charged particle with a spatial resolution of the same order of magnitude as that of a spark chamber (less than 1 mm).

(b) The output pulse can be made proportional to the specific ionization of the particle, such that methods can be worked out that allow a selection of the recorded events with requirements even more strict than those allowed by a triggering system for spark chambers.

(c) The proportionality of the pulses also permits collection of information about dE/dx for each particle.

(d) The counting rate seems to be limited only by the associated electronics. Rates of $\approx 10^6$ counts/sec per wire have already been recorded.

(e) The readout system, which was posing economic limits to the use of those chambers when an amplifier per wire was used, is now reaching the simplicity of that used in spark chambers. The method we studied, which already allows a resolution of 3 mm, will certainly allow the same resolutions as the magnetostrictive system used with spark chambers. Other systems are under study.

(f) Much care has to be put into building and operating these chambers. The material used for the construction, the composition and pressure of the gas, and the stability of the high voltage have more strict requirements than for usual spark chambers.

Application of Spark Chambers to Fields Other Than High Energy Physics

Medical Use: Localizing γ-Ray and Positron Emitters in the Body

The use of radioisotopes for labeling has become a powerful tool in medical diagnostics as well as in physiology and morphology studies. Instruments which visualize, from outside the body, the shape (in space and time) of the labeled zones with both high resolution and high sensitivity are very much to be desired.

We first studied the possibility of using wire spark chambers with magnetostrictive readout for the location of γ emitters.[8] This involves the use of a lead collimator for the γ rays and a lead converter in front of the chamber. In Figure 3 we show a schematic view of the apparatus. Due to the high resolution of the spark chamber, the resolution of the system is dictated by the resolution of the collimator. The efficiency of the system is a combination of the efficiency of the collimator and that of the converter (the detection efficiency of the chamber for the electrons crossing it is 100%); this latter is of the order of 3% for γ rays in the energy range 0.5 to 1.5 MeV. Several chambers can be stacked for obtaining higher efficiencies. In Figure 4 we show a computer picture obtained from a wire of ^{60}Co, 62 mm long and 0.5 mm in diameter, with a 15-cm-thick Pb collimator with a 5-mm-diameter hole and 3-mm septa.

Another apparatus has been built for the localization of positron emitters. This based on the simultaneous detection of the two collinear 0.5-MeV γ rays emitted by the annihilation of the positrons. This method makes unnecessary the use of the lead collimator that is required for the single γ-ray imaging systems and that is by far the most inefficient, expensive, and cumbersome element in that system. The detection of the two γ rays emitted in opposite directions allows determination of the line on which the emitter was situated and, by accumulation of a statistically meaningful number of determinations, a computer program maps the positron source. In Figure 5 we show a schematic view of the system.

Preliminary experiments run at the Lawrence Radiation Laboratory using ^{22}Na and ^{11}C sources and magnetostrictive multiwire chambers with a gap of 1 cm and wire spacing of 1 mm and 45×45 cm area showed that spatial resolution within less than 8 mm can easily be achieved.[9]

Limitations on the sensitivity are imposed by the efficiency of the lead converters (about 3%) and by the absorption of low-energy conversion electrons in the material between the converter and the triggering scintillator. The latter obstacle can be overcome by use of proportionally triggered or dc spark chambers. Then an overall efficiency of the order of $\approx 10^{-3}$ can be achieved, allowing the mapping of sources of less than 1 μCi of activity. Moreoever, there are no limitations on the dimensions of the chambers that can be employed.

Locating Stopped Negative Pions

The use of a π^- beam for cancer therapy is a very promising technique, and may become a routine practice as soon as high-intensity cyclotrons are available.

The differences in density and composition of the biological materials in which the pions are stopped, as well as the uncertainty in the knowledge of the exact energy of the pions in the beam, make the exact calculation of the pion stopping region somewhat difficult, and when biological materials are to be irradiated a measurement of this region in loco will be impossible. Several methods taking advantage of the flexibility of the spark chamber for locating tracks of ionizing particles can be devised which define the stopping region by detecting the particles emitted when π^-'s are absorbed.

We have tested one which made use of the γ rays of energy higher than 1 MeV which follow pion capture in nuclei of C, O, and H. The geometry of the apparatus we used is roughly the same as that used for the medical chamber: The γ rays are required to pass through a Pb collimator, they are converted in a layer of Pb, and the emitted electrons are detected in a scintillator which triggers the spark chamber (see Figure 6).

Because the most important information is the distribution of stopped pions along the beam direction, we used in the experiments a slotted collimator which provides a one-dimension picture but sensibly increases the efficiency of detection.

The relative yield of the γ rays following pion capture in different material is not known, but we expected to have at least one useful γ ray per pion stopped. For a collimator with slots 3 mm thick, spaced by 3 mm, and placed at about 50 cm from the beam, a collimating efficiency better than 10^{-3} could be expected; taking a conversion efficiency of $\approx 10^{-2}$, the overall efficiency of 10^{-5} made the measurement feasible even at the present intensities of the π^- beams ($\sim 10^6$ π^-/sec). Some preliminary experimental results have been collected by using a 25-cm-thick collimator with 3-mm slots. They showed an overall efficiency of about 5×10^{-6} triggering events per stopped pion. Figure 7 indicates the special shape of the recorded output from the chamber, showing a peak with a half maximum full width of 2 cm, which is comparable to that of the stopped-pion region in Lucite. Further experiments are in progress.

Neutron Spectrometry

Spark chambers have already been used for spectrometry in neutron fields. A group from the Princeton-Pennsylvania Accelerator and the Health Laboratory in New York used an optical spark chamber setup made by the Philco-Ford Corporation for measuring spectra of mono-directional neutrons of energy between 20 and 150 MeV.[10] The instrument consists of a series of 15 sparking gaps separated by suitable absorbers. A polyethylene radiator 0.348 g/cm^2 thick is put in front of the spark gaps. The chamber accepts the neutrons coming from one direction (neutron beam) and takes pictures of the tracks of the protons scattered at small angles from the direction of the incoming neutrons (less than 22.7 deg).

An efficiency ranging from 7×10^{-4} for 10-MeV neutrons to 6×10^{-5} for 200-MeV neutrons and an energy resolution of about 13% have been achieved. The apparatus has been used for measuring the neutron cascade generated at different angles by the interaction of high energy neutrons (from 2.9-GeV protons) in iron.

However, if the direction of the incoming neutron is unknown, a single scattering is no longer sufficient for evaluating the energy of the neutrons; moreover for energies of the neutrons higher than about 15 MeV the scattering is no longer isotropic in the c.m. system.

A group from the Max-Planck Institute in München has been studying the possibility of using optical spark chambers for measuring solar and atmospheric neutrons in the energy range from 50 to 150 MeV.[11] The principle of measurement is the double scattering process of neutrons on hydrogen atoms. By a Monte Carlo method they studied different geometries of spark chamber arrays: for a quite sophisticated system of six sections in coincidence, with each section consisting of an array of eight sandwiches of double spark chamber, scintillator, and polyethylene radiator, they calculated an efficiency of 1.2×10^{-3} for neutrons of 100 MeV.

We have made a study proposal (not published) for a neutron spectrometer using a filmless multiwire spark chamber with magnetostrictive readout. The apparatus will measure neutron spectra in the energy range from about 20 to 200 MeV in an anisotropic neutron field (neutron source location unknown) for fluxes down to less than 10^{-2} n/cm^2 sec^{-1} MeV^{-1} through the measurement of double scattering events of neutrons on hydrogen.

In Figure 8 we show a schematic view of the apparatus. It consists of two sections: each section is composed of an array of eight two- or three-gap multiwire spark chambers alternated with plastic scintillator and polyethylene radiator (proportionally triggered spark chambers can alternatively be used). A coincidence between any two chambers of the two sections is required for triggering the system (i. e., a double scattering event has to take place, with recoils occurring in the upper and lower sections). An average efficiency of 0.3×10^{-3} has been calculated; using chambers of 50 cm square, an event rate of ≈ 0.75 events/sec is expected for a field of 10^{-2} n/cm^2 sec^{-1} MeV^{-1}. A first rough calculation gives an energy resolution better than 10% for 1-cm-gap chambers with wires spaced 1 mm apart.

The information from the chambers will be sent directly to a computer (it can be connected on line) which produces the final neutron spectra. The direction of the incoming neutrons can also be determined with this apparatus. It can also be used, with minor modifications in the triggering logic, for spectrometry in the energy region (< 15 MeV) where the recoil distribution is isotropic in the c. m. system.

Conclusions

We explored only some of the possible applications of one of the detecting techniques developed for research in high energy physics. I would like to briefly mention the possibility of using a multiwire proportional chamber for the measurements of microdosimetric quantities such the Y's of particles and their distribution considering the chamber as a series of wall-less proportional counters. Many others will certainly be found in the near future; also, the many improvements which will be required for using them in a particular field will constitute a useful feedback to high energy physics, from which they originated.

I wish to express my gratitude to H. Wade Patterson, who is allowing me to devote part of my time to these interesting studies, and to Victor Perez-Mendez, who accepted me in his high energy group.

The experimental results mentioned in this paper have been obtained in collaboration with J. M. Sperinde, A. J. Miller, and H. A. Wollenberg.

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FIGURE CAPTIONS

Fig. 1. Scheme of two-grid multiwire spark chamber with magnetostrictive readout. The transducer is shown as a coil. Note the connections between the fringe wires for providing the fiducial pulses. The grids are put into a gastight box (not shown in figure) in which an appropriate gas is circulated.

Fig. 2. Scheme of a one-dimension multiwire proportional chamber. The gastight box containing the system in which a mixture of argon and methane is circulated at atmospheric pressure is not shown in the figure.

Fig. 3. Diagram of the system used for the mapping of a γ-emitting source.

Fig. 4. Computer picture obtained by exposing a ^{60}Co wire (0.5 mm diameter, 62 mm long) on the collimator of the system shown in Fig. 3. No background subtraction. Scale in cm.

Fig. 5. Diagram of the system used for the mapping of positron sources.

Fig. 6. Diagram of the system used for mapping the π^- stopping region.

Fig. 7. Preliminary result obtained with the system diagrammatically shown in Fig. 6. A 90-MeV π^- beam was stopped in 30 cm of Lucite. The 25-cm-deep Pb collimator was made of 3-mm-thick slots, spaced 3 mm apart. An absorber of Al about 6 mm thick was put between the triggering scintillators for selecting the energy of the triggering electrons. The beam intensity was $\approx 6 \times 10^5$ π^-/sec. The graph is plotted from a pulse-height analyzer record. An exposure of about 40 min was required for accumulating about 10^4 events. Scale in cm.

Fig. 8. Diagram of a proposed neutron spectrometer using spark chambers for recording double scattering events of neutrons on protons.

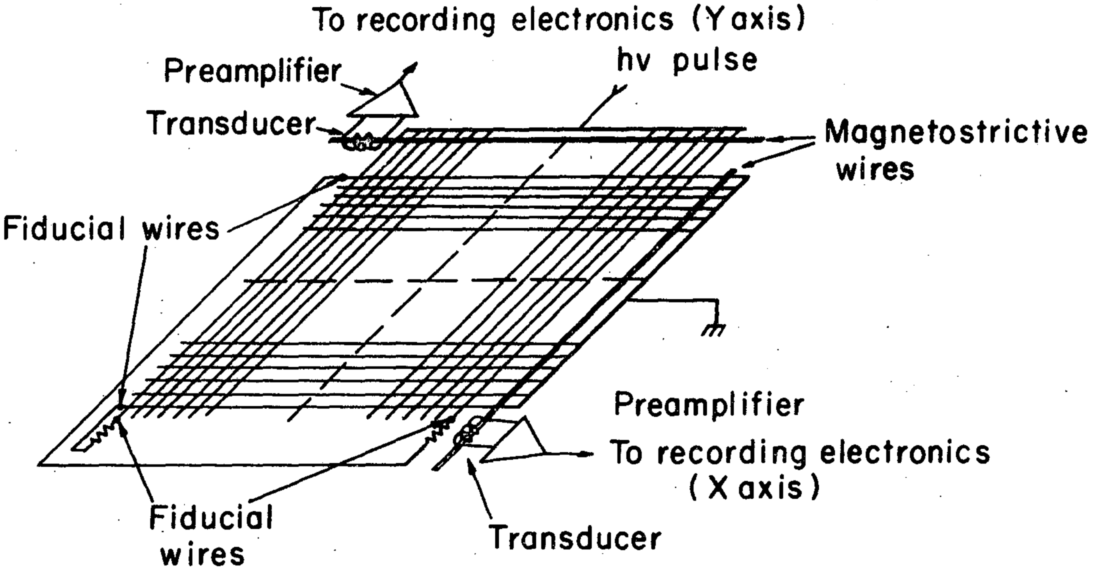

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Fig. 1

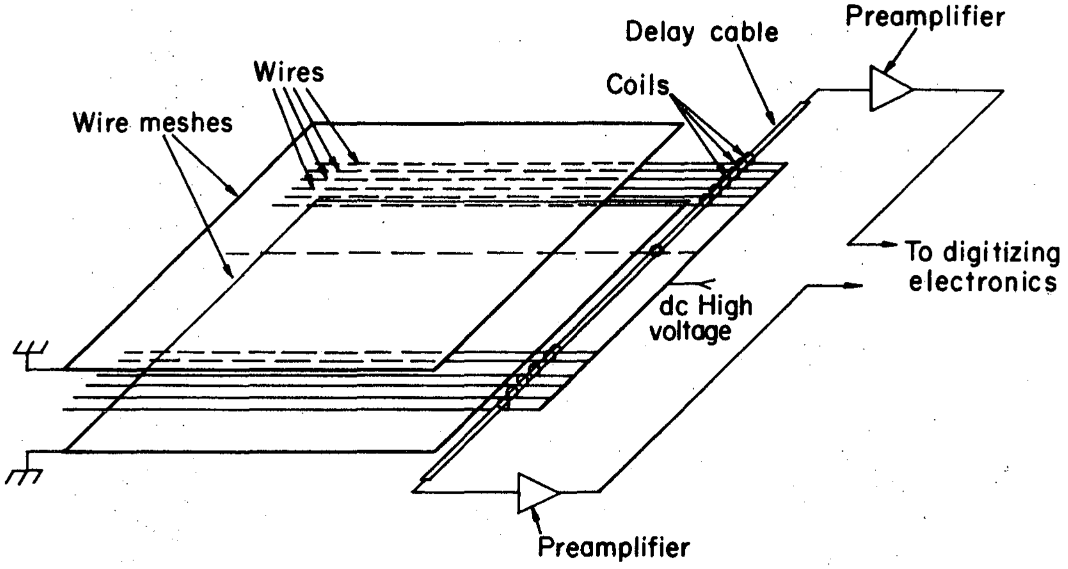

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Fig. 2

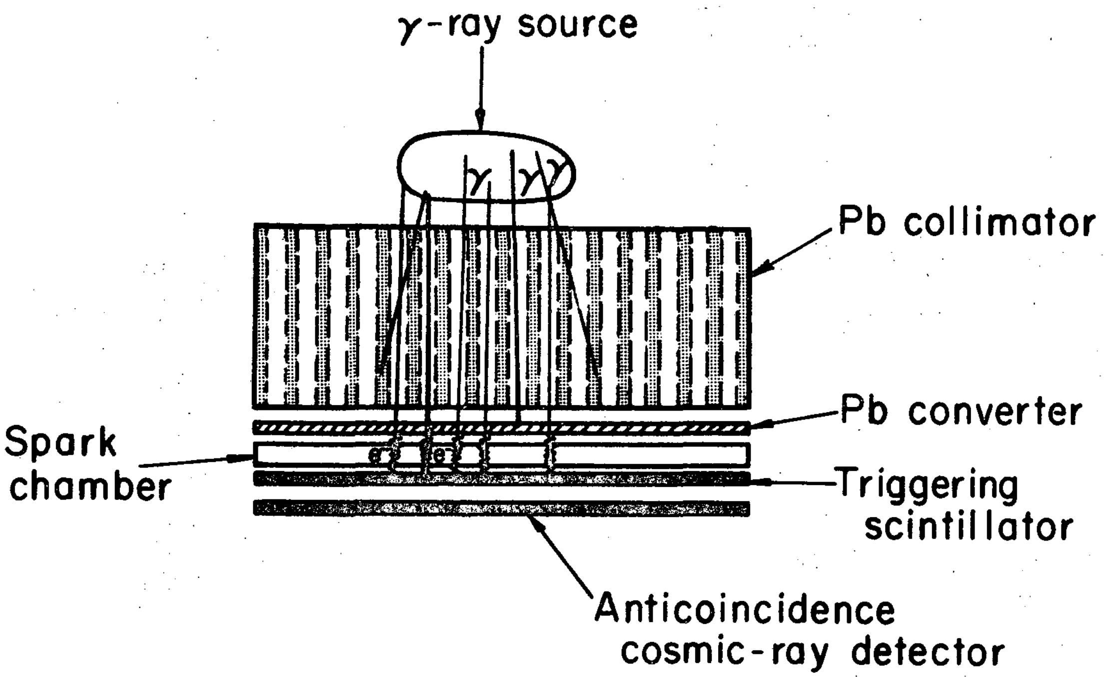

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Fig. 3

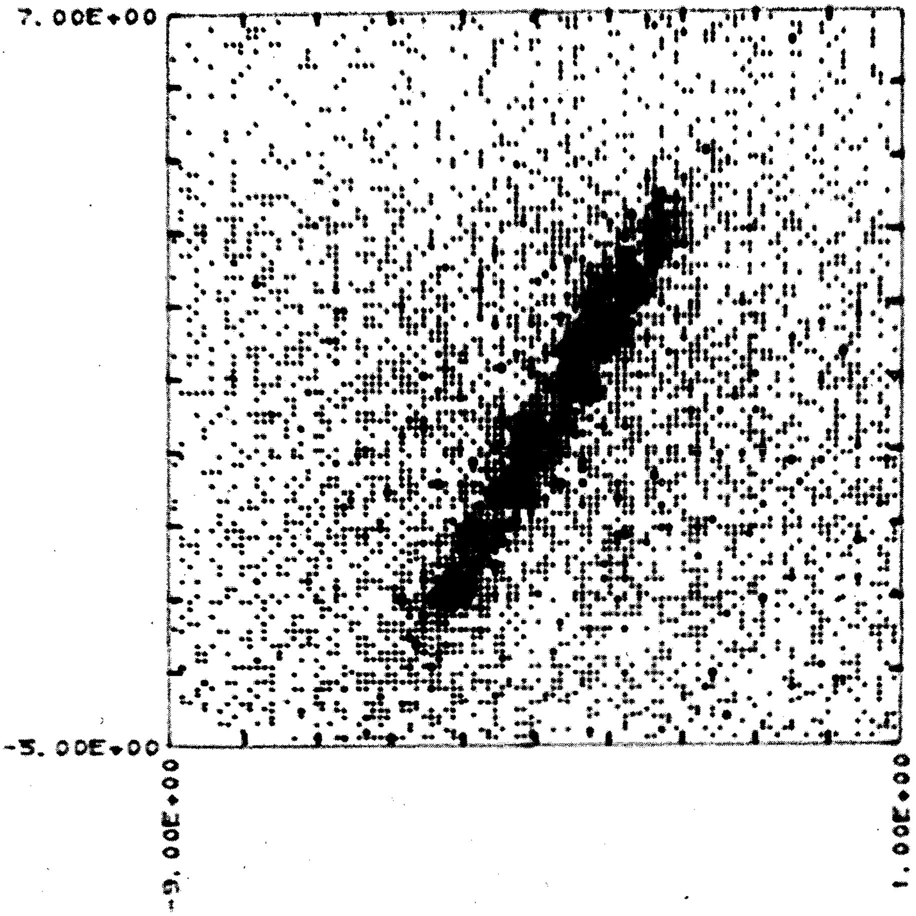

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Fig. 4

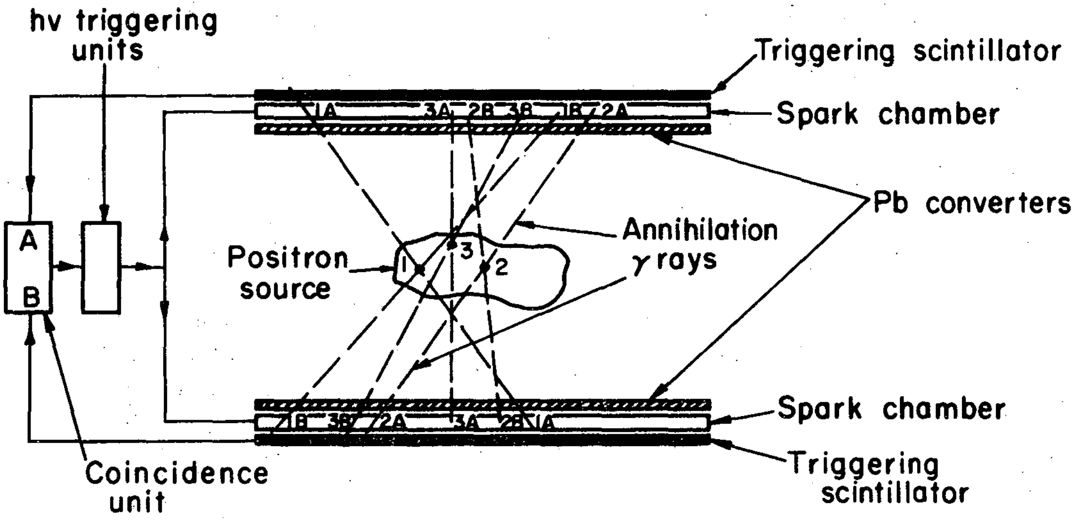

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Fig. 5

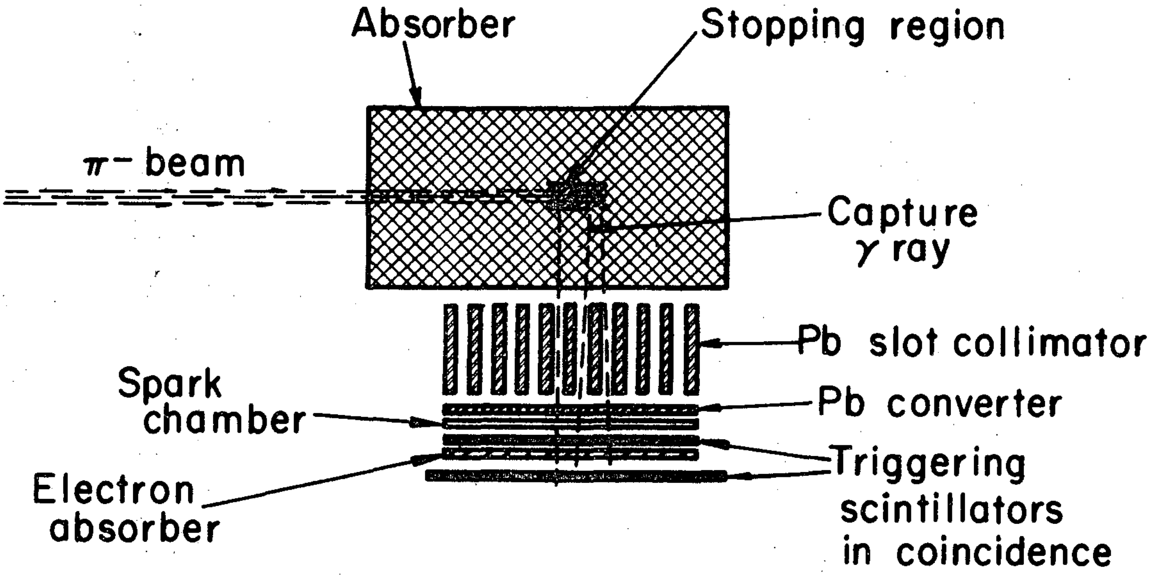

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Fig. 6

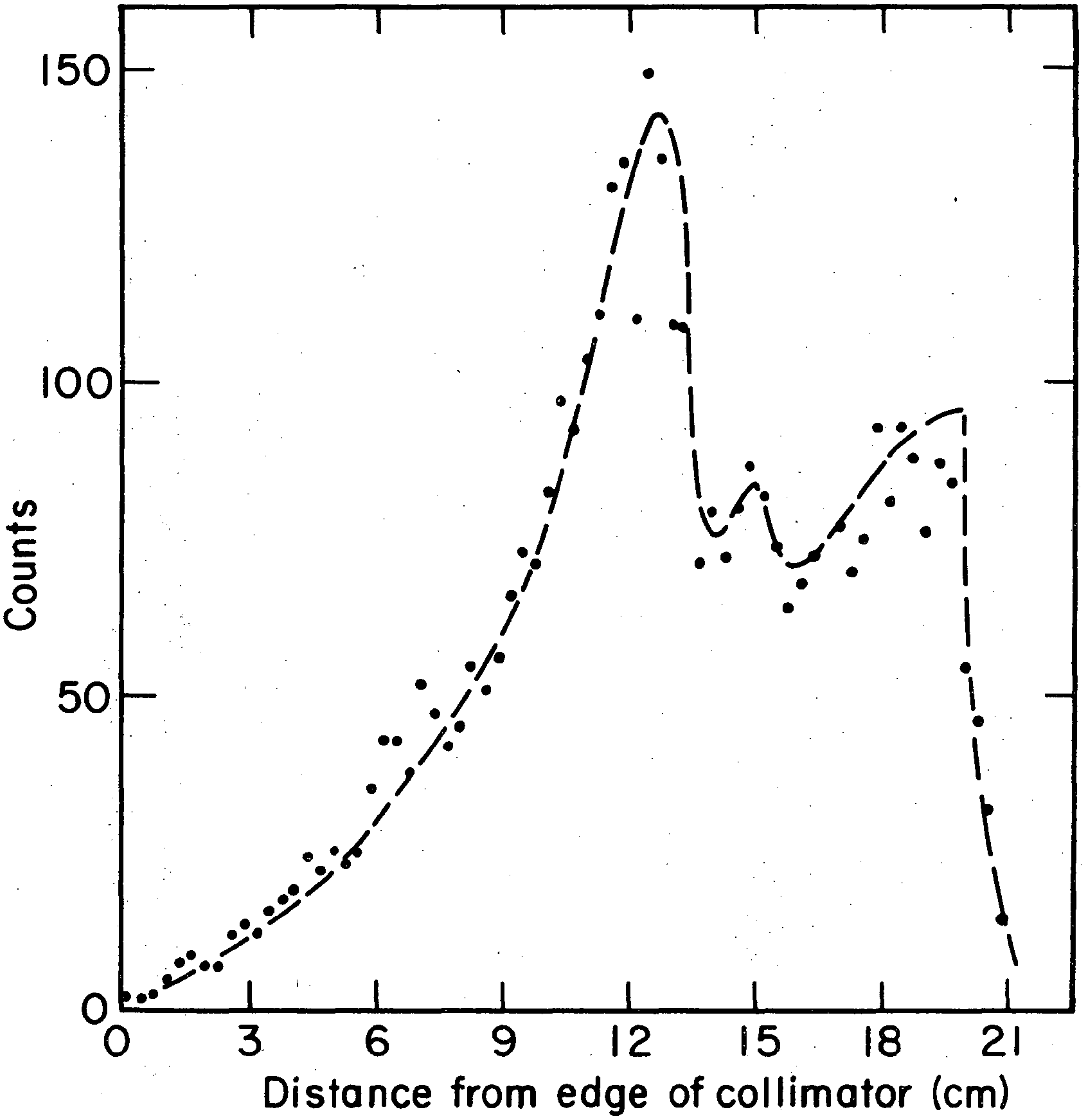

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Fig. 7

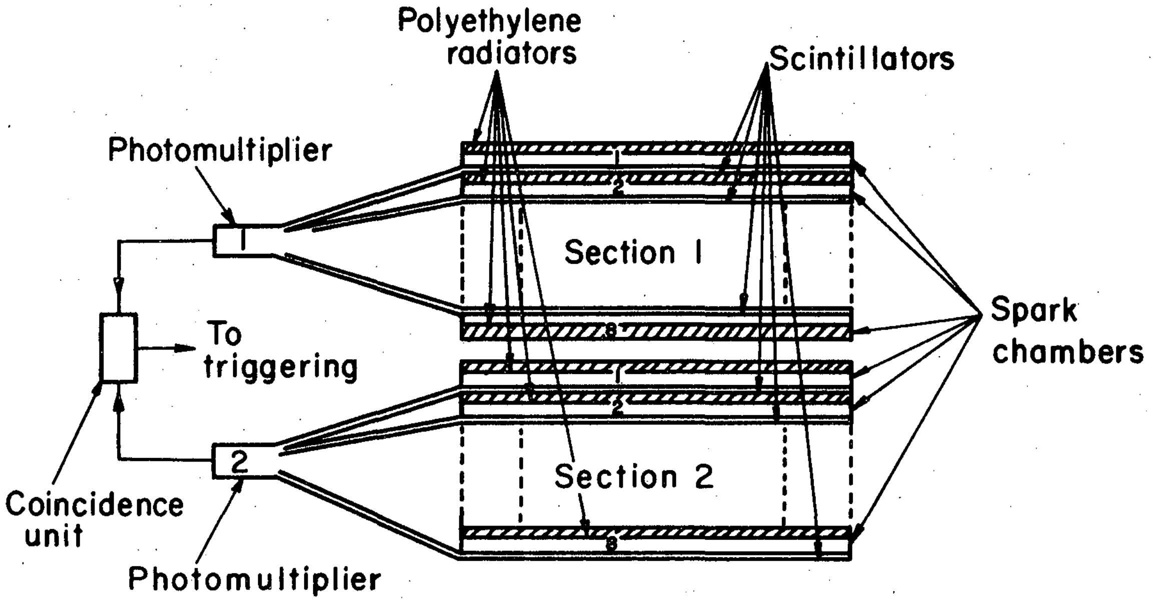

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Fig. 8