1
Introduction

1.1 Historical background

The foundations of modern gaseous detectors can be traced back to the works of Ernest Rutherford, 1908 Nobel Laureate in Chemistry. In the course of his studies of the atomic structure, he conceived an instrument capable of detecting individual ionization trails left in a gas by natural radioactivity. Knowledgeable of John Sealy Townsend's studies on collisional charge multiplication in gases at high electric fields, and with the help of Hans Geiger, he built a tool capable of amplifying the weak primary ionization signal. The device consisted of a thin metal wire, the anode, coaxial with a gas-filled cylindrical cathode; on application of a potential difference between the electrodes, electrons released in the gas drift towards the anode, undergo inelastic ionizing collisions in the fast increasing field and multiply in an appropriately named electron–ion avalanche. Restricted to a narrow region around the wire, the multiplication process amplifies the charge released in most of the gas volume and yields a signal proportional to the primary charge, hence its name 'proportional counter' (Rutherford and Geiger, 1908). Large multiplication factors, or gains, could be achieved, permitting the detection of small amounts of primary charge with the rudimentary electrical instrumentation available at the time. Further developments of the device by Geiger and Walther Müller permitted them to reach the ultimate goal of detecting single electrons released in the counter's gas (Geiger and Müller, 1928).

Proportional counters of various sizes and shapes were employed for decades in the detection of ionizing radiation; Geiger–Müller counters are still widely used for radiation monitoring. Arrays of proportional counters have been built to cover larger areas; however, limited in location to their physical size, they could hardly satisfy the tracking requirements of the emerging high-energy particle physics. Already in the 1930s, this goal was mainly achieved using photographic emulsions, capable of recording the trails left by the passage of charged particles.

Figure 1.1 A cosmic ray detected in a four-gap spark chamber (Fukui and Miyamoto, 1959). By kind permission of Springer Science+Business Media.

The development of other types of detector having excellent imaging capability, such as the cloud chamber (Charles Thomson Wilson, 1927 Nobel Laureate) and the bubble chamber (Donald Arthur Glaser, 1960 Nobel Laureate), relegated the use of emulsions to specialized nuclear physics investigations. Bubble chambers, at the same time target and detector and providing accurate three-dimensional optical images of complex events, were successfully used for decades in particle physics and still powerful tools of investigation in the 1960s. However, these devices have a major drawback: they are made sensitive under the action of an external mechanical control only during a selected time interval, uncorrelated to the physical events under study. Well adapted to the analysis of frequent processes, they are less suited for the study of rare events.

A new type of gas counter that could be made sensitive in coincidence with selected events, the triggered spark chamber, was developed in the late fifties (Fukui and Miyamoto, 1959). On application, shortly after the passage of a charged particle, of a high voltage pulse across a thin gas layer between two electrodes, a detectable spark would grow along the ionization trails left in the gas. A system of external coarse devices, as a set of scintillation counters, provides a signal to trigger the chambers in coincidence with specific geometrical or energy loss requirements; the concept of selective event trigger was born.

Figure 1.1, from the reference above, is one of the first pictures of a cosmic ray track detected with a four-gap spark chamber. Stacks of thin-gap spark chambers could thus provide a sampled image of tracks crossing the detector within a short

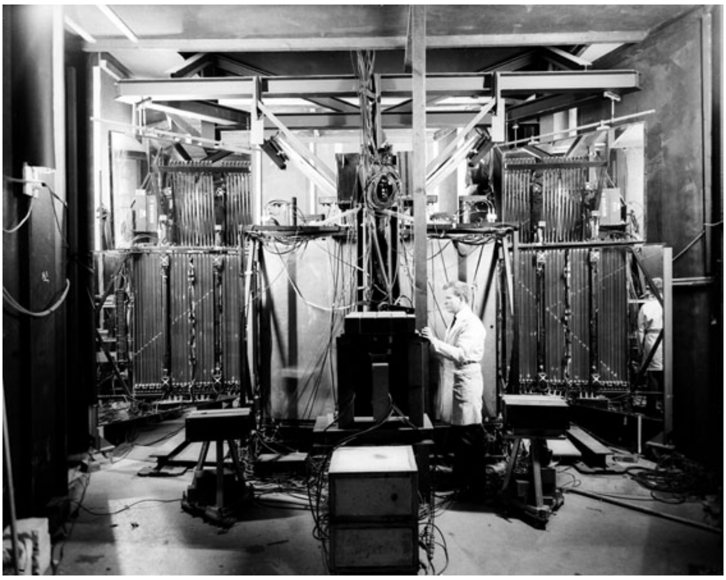

Figure 1.2 PS11, an optical spark chamber experiment at CERN's Proton Synchrotron, with accidental cosmic rays tracks. Picture CERN (1967).

time window, and were extensively used in particle physics experiments, cosmic ray studies and other applications. Recording of the events was done by photography or, in the later times, electronic video digitization. Figure 1.2 is an example of an experimental setup with several optical spark chamber stacks surrounding a target, operating in the 1960s at CERN.

Limited originally by the slow picture recording process, spark chambers evolved into faster electronic devices thanks to the development of methods capable of detecting the current pulse produced by a spark on electrodes made with thin wires. The most successful employed small ferrite core beads, used at the time in computer memories, interlaced with the wires and read out with a sequence of electrical pulses (Krienen, 1962). Simple to implement, the magnetostrictive readout method, introduced in the early sixties, relied on the detection of the sonic waves induced by a discharge on an external wire transducer, perpendicular to the wire electrodes; coordinates were then deduced from the time lapse between the spark and the detection of the sound pulse at the two ends of the pickup wire (Perez-Mendez and Pfab, 1965). Other methods included capacitive charge storage and direct detection of the spark sound with microphones located in strategic positions; for a review see for example Charpak (1970).

In thin-gap chambers, the applied high voltage pulse causes a discharge propagating from anode to cathode. Further developments of the technology led to the introduction of a more powerful family of devices, named streamer chambers: these

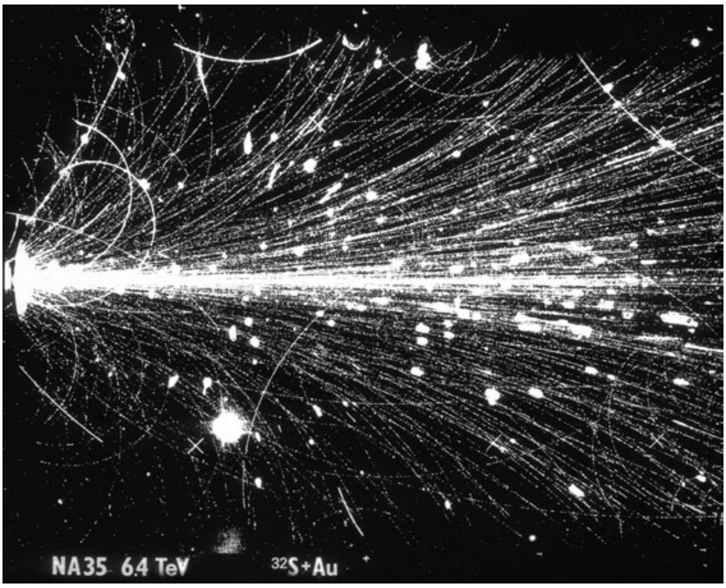

Figure 1.3 Heavy ion collision recorded with CERN's NA35 streamer chamber. Picture CERN (1991).

are large volume detectors in which a very narrow and high voltage pulse induces the formation of short local discharges following the ionized trails in the gas. While having rate capability limited to a few hertz, needed to generate nanosecond-long, hundreds of kV/m voltage pulses, the streamer chambers had an impressive multi-track imaging capability, as shown by the example of Figure 1.3, recorded with the NA35 streamer chamber at CERN on a relativistic heavy ion collision (Brinkmann *et al.*, 1995). In many ways, later developments with gaseous detectors, the main subject of this book, have been inspired by the challenge to achieve similar image qualities with faster, fully electronic devices. For a review of streamer chambers development and performances see Rohrbach (1988).

1.2 Gaseous detectors: a personal recollection

In the late 1960s, as a post-doc at the University of Trieste (Italy), I contributed to the realization of a detector system using wire spark chambers with magnetostrictive readout, used in an experiment at CERN. While a technical staff was in charge of the chamber's construction, the delicate but tedious work of winding the miniature coils used to detect the sonic pulse on the acoustic sensing wire was a task for the young students. The results of the test beam measurements of efficiency and position accuracy with a set of detectors are described in my first

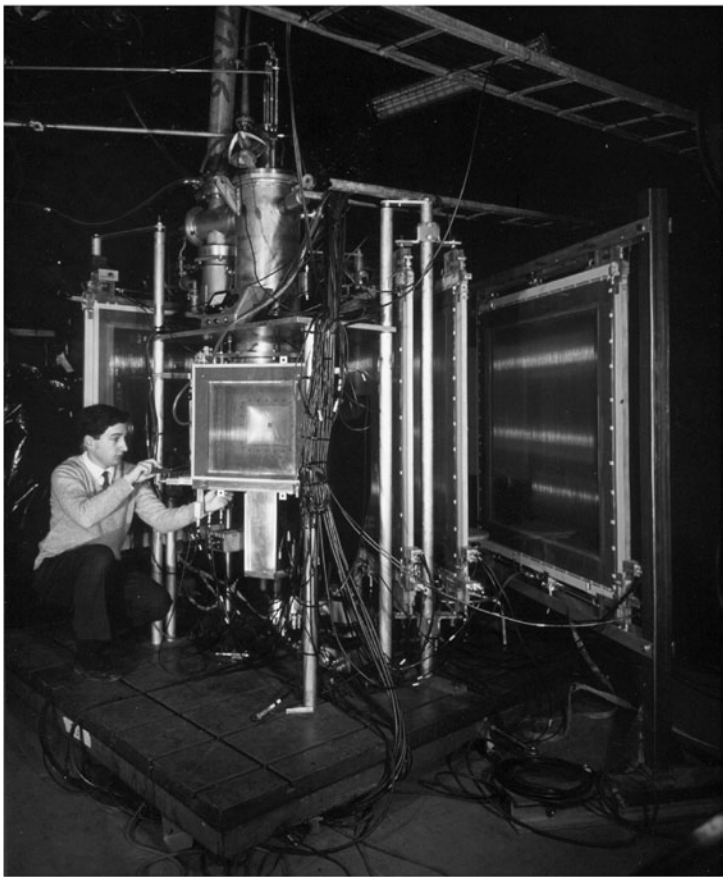

Figure 1.4 The author with the CERN–Trieste magnetostrictive spark chambers setup. Picture CERN (1967).

publication (Bradamante and Sauli, 1967); I can be seen in in Figure 1.4 working on the experimental setup, a fixed target experiment to study proton–proton and proton–deuteron interactions at (for that time) high energies.

Albeit selective and faster in response than previous generations of detectors, spark chambers are limited in operating rate to a few tens of hertz, due to the time needed to clear the excited and ionized species from the region of a spark before the application of another pulse, in order to prevent re-firing.

In the late 1960s, the need for large area and faster electronic detectors acquired paramount importance, motivated by the challenging requirements of the increasingly high-energy particle physics. The multi-wire proportional chamber (MWPC), invented in 1967 by CERN's Georges Charpak, revolutionized the field of position-sensitive detectors (Charpak *et al.*, 1968). In Figure 1.5 Charpak's technician, Roger Bouclier, stands next to the first MWPC, with 24 anode wires

Figure 1.5 Roger Bouclier with the first multi-wire proportional chamber. Picture CERN (1968).

and 10×10 cm^2 active area.[1] For his invention, and the contribution of the new family of detectors to fundamental research, Charpak received the 1992 Nobel Prize for Physics.

The outstanding innovative performances of the new device were soon recognized, despite the challenge posed at the time by the need of using individual recording electronic channels on many wires a few mm apart: nanosecond time resolution, sub-mm position accuracy, continuous sensitivity and high rate capability. The new detector technology, swiftly adopted by several experiments, gave Charpak resources and support to continue and expand the research activity on gaseous detectors. I joined Charpak's group in 1969, contributing for many years to the development and applications of innovative gaseous detectors; after Georges' retirement in 1989, I took the leadership of the group then named Gas Detectors Development (GDD) until my own retirement in 2006. During all those years, the continuing challenge posed by the increasing requirements of particle

[1] There is no known picture of Charpak himself with the early MWPCs; Figure 1.8, taken several years later, is sometimes quoted to be one.

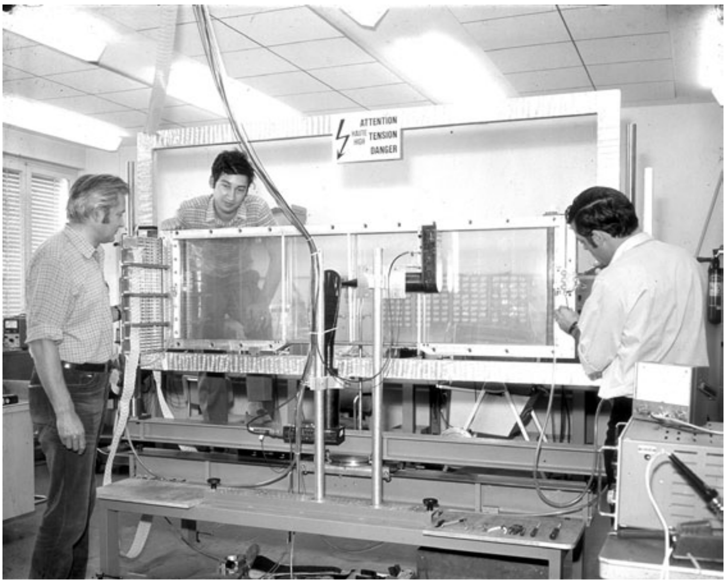

Figure 1.6 A large MWPC prototype, with (left to right) Georges Charpak, Fabio Sauli and Jean-Claude Santiard. Picture CERN (1970).

physics experimentation motivated the search for faster and more performing devices that exploit the properties of charge transport and multiplication in gases.

The original MWPC could attain avalanche gains around 10^5; detection of the signal released by fast particles (a few tens of electron–ion pairs) required the use of low noise amplifiers, which was possible but rather demanding for the electronics of the time. A major discovery by Charpak's group, and possibly a reason for the fast spread of the technology, was a gas mixture in which saturated gains above 10^7 could be reached, providing pulses of amplitude independent of the primary ionization release, thus leading to simpler requirements for the readout electronics. Quite appropriately, this mixture (argon-isobutane with a trace of freon) was named 'magic gas' (Bouclier *et al.*, 1970).

The first MWPC was only 10 cm on the side; soon, a large effort was put into developing the technology for manufacturing larger detectors. However, unexpected problems of electrostatic instability, discussed in Section 8.4, resulted in a dramatic failure of the early prototypes; the problem was solved with the introduction of internal insulating supports or spacers. Figure 1.6 shows one of the first large size working devices, about one and a half metres on the side, built by the group in 1970 (Charpak *et al.*, 1971).

Suitable for fixed target experiments, the heavily framed construction of the chamber seen in the picture was not optimal for use within a magnet, due to the unfavourable ratio of active to total area; a lighter design of the detector, which

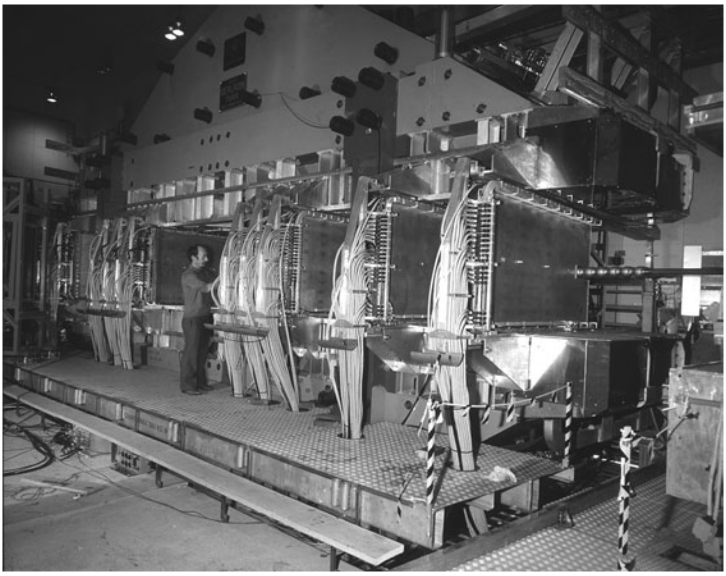

Figure 1.7 The 40 MWPC array of the Split Field Magnet Detector spectrometer. Picture CERN (1973).

made use of self-supporting, light honeycomb panels holding the wires, was developed by the group to equip the multi-particle spectrometer of the Split Field Magnet experiment at CERN's proton–proton storage rings (Figure 1.7) (Bouclier *et al.*, 1974). Deploying 40 large MWPC modules, the instrument featured data taking rates of several kHz, a performance unthinkable when using older tracking devices, and operated for many years for systematic measurements of particle yields in proton–proton collisions. One of the searches, the quest for free quarks, yielded no results for fundamental reasons that become clear only later; however, it motivated one of my early works to estimate the detection efficiency of MWPC on charge 1/3 particles (Breidenbach *et al.*, 1973).

In the initial conception of the MWPC, space accuracy was determined by wire spacing, a few mm at best. As anticipated in seminal work by Charpak and collaborators, sub-mm position accuracies could be achieved by exploiting the time lag, or drift time, of the detected charge in respect to an external trigger (Charpak *et al.*, 1970). Developed in the early seventies, and using several centimetres wire spacing, drift chambers provided position accuracies between 300 and 400 μm, while substantially reducing the number of electronics channels (Walenta, 1973). A thorough optimization of the electric field structure and detailed studies on the electrons' drift properties permitted them to reach position accuracies around 50 μm for fast particles perpendicular to the detector (Charpak *et al.*, 1973). Figure 1.8 shows Charpak with an early prototype of the High

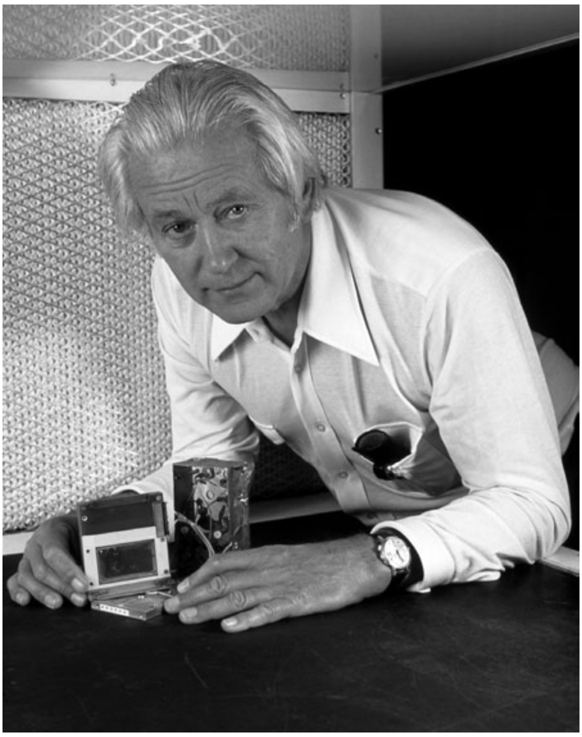

Figure 1.8 Georges Charpak with the first prototype of the high accuracy drift chamber. By permission of SPL Science Photo Library (1982).

Accuracy Drift Chamber, a single cell 50 mm wide; curiously, in the absence of a picture of the inventor with the first MWPC, this picture is sometimes referred to as such. In Figure 1.9, Guy Schultz and Amos Breskin, former members of the group, are seen inserting a set of medium-size high accuracy drift chamber prototypes in a magnet for systematic measurements of performances in magnetic fields. As will be discussed in more detail in Chapter 9, each chamber provided two perpendicular coordinates, resolving the right–left ambiguity, intrinsic in a time measurement, thanks to the use of anode wire doublets mounted at a close distance.

The temperature dependence of the drift properties, crucial for a stable long-term use of the devices, was studied thoroughly with dedicated detectors, and led to the choice of operating gases having a saturated drift velocity, with minimal variation with temperature (see Section 4.7). Requiring the heating of the detectors while operating, these studies resulted often in spectacular failures due to the appearance of heavy discharges in flammable gas mixtures (Figure 1.10).[2]

[2] This event is colloquially named ‘Breskin’s thermodynamics experiment’ from the name of the team member in charge of the measurement.

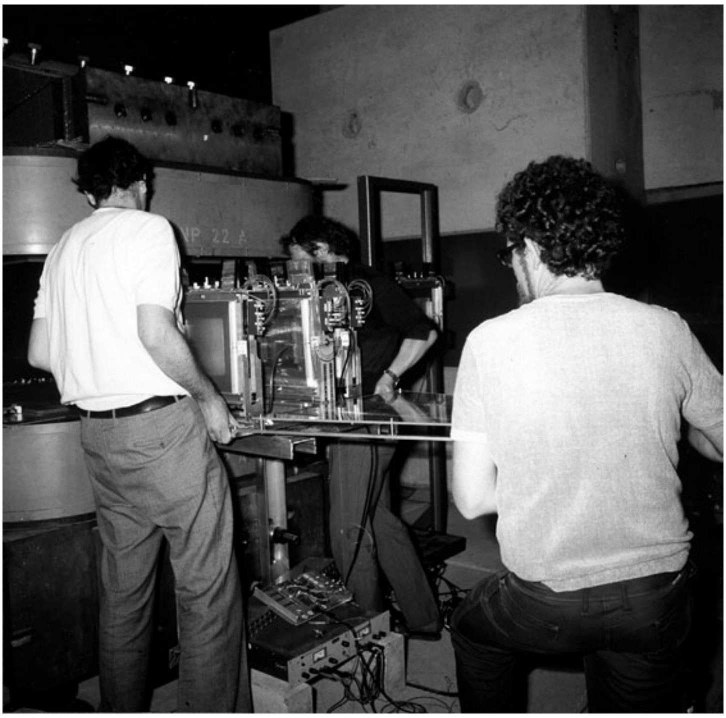

Figure 1.9 Guy Schultz (left) and Amos Breskin (right) inserting a set of high accuracy drift chambers in a magnet. Picture CERN (1972).

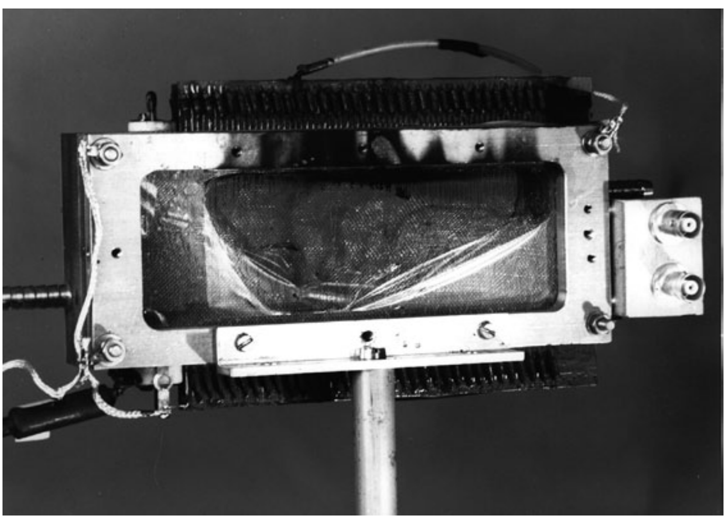

Figure 1.10 Burned-out drift chamber, the end of a temperature dependence study. Picture by the author at CERN (1972).