Introduction

Every act of seeing leads to consideration, consideration to reflection, reflection to combination, and thus it may be said that in every attentive look on nature we already theorise.

Johann Wolfgang von Goethe

The development of particle detectors practically starts with the discovery of radioactivity by Henri Becquerel in the year 1896. He noticed that the radiation emanating from uranium salts could blacken photosensitive paper. Almost at the same time X rays, which originated from materials after the bombardment by energetic electrons, were discovered by Wilhelm Conrad Röntgen.

The first nuclear particle detectors (X-ray films) were thus extremely simple. Also the zinc-sulfide scintillators in use at the beginning of the last century were very primitive. Studies of scattering processes – e.g. of α particles – required tedious and tiresome optical registration of scintillation light with the human eye. In this context, it is interesting to note that Sir William Crookes experimenting in 1903 in total darkness with a very expensive radioactive material, radium bromide, first saw flashes of light emitted from the radium salt. He had accidentally spilled a small quantity of this expensive material on a thin layer of activated zinc sulfide (ZnS). To make sure he had recovered every single speck of it, he used a magnifying glass when he noticed emissions of light occurring around each tiny grain of the radioactive material. This phenomenon was caused by individual α particles emitted from the radium compound, striking the activated zinc sulfide. The flashes of light were due to individual photons caused by the interaction of α particles in the zinc-sulfide screen. A particle detector based on this effect, the *spinthariscope*, is still in use today for demonstration experiments [1].

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Scintillations in the form of 'northern lights' (aurora borealis) had already been observed since long. As early as in 1733 this phenomenon was correctly interpreted as being due to radiation from the Sun (Jean-Jacques D'Ortous De Mairan). Without knowing anything about elementary particles, the atmosphere was realised to be a detector for solar electrons, protons and α particles. Also, already about 50 years before the discovery of *Cherenkov radiation*, Heaviside (1892) showed that charged particles moving faster than light emit an electromagnetic radiation at a certain angle with respect to the particle direction [2]. Lord Kelvin, too, maintained as early as 1901 that the emission of particles was possible at a speed greater than that of light [3, 4]. At the beginning of the twentieth century, in 1919, Madame Curie noticed a faint light emitted from concentrated solutions of radium in water thereby operating unknowingly the first Cherenkov detector. Similarly, Cherenkov radiation in water-cooled reactors or high-intensity radiation sources is fascinating, and sometimes extremely dangerous (e.g. in the Tokaimura nuclear reactor accident) to observe. The human eye can also act as Cherenkov detector, as the light flashes experienced by astronauts during their space mission with eyes closed have shown. These light emissions are caused by energetic primary cosmic rays passing through the vitreous body of the eye.

In the course of time the measurement methods have been greatly refined. Today, it is generally insufficient only to detect particles and radiation. One wants to identify their nature, i.e., one would like to know whether one is dealing, for example, with electrons, muons, pions or energetic γ rays. On top of that, an accurate energy and momentum measurement is often required. For the majority of applications an exact knowledge of the spatial coordinates of particle trajectories is of interest. From this information particle tracks can be reconstructed by means of optical (e.g. in spark chambers, streamer chambers, bubble and cloud chambers) or electronic (in multiwire proportional or drift chambers, micropattern or silicon pixel detectors) detection.

The trend of particle detection has shifted in the course of time from optical measurement to purely electronic means. In this development ever higher resolutions, e.g. of time (picoseconds), spatial reconstruction (micrometres), and energy resolutions (eV for γ rays) have been achieved. Early optical detectors, like cloud chambers, only allowed rates of one event per minute, while modern devices, like fast organic *scintillators*, can process data rates in the GHz regime. With GHz rates also new problems arise and questions of *radiation hardness* and *ageing* of detectors become an issue.

With such high data rates the electronic processing of signals from particle detectors plays an increasingly important rôle. Also the storage of data on magnetic disks or tapes and computer-aided preselection of data is already an integral part of complex detection systems.

Originally, particle detectors were used in cosmic rays and nuclear and particle physics. Meanwhile, these devices have found applications in medicine, biology, environmental science, oil exploration, civil engineering, archaeology, homeland security and arts, to name a few. While the most sophisticated detectors are still developed for particle physics and astroparticles, practical applications often require robust devices which also function in harsh environments.

Particle detectors have contributed significantly to the advancement of science. New detection techniques like cloud chambers, bubble chambers, multiwire proportional and drift chambers, and micropattern detectors allowed essential discoveries. The development of new techniques in this field was also recognised by a number of Nobel Prizes (C.T.R. Wilson, cloud chamber, 1927; P. Cherenkov, I. Frank, I. Tamm, Cherenkov effect, 1958; D. Glaser, bubble chamber, 1960; L. Alvarez, bubble-chamber analysis, 1968; G. Charpak, multiwire proportional chamber, 1992; R. Davis, M. Koshiba, neutrino detection, 2002).

In this book the chapters are ordered according to the object or type of measurement. However, most detectors are highlighted several times. First, their general properties are given, while in other places specific features, relevant to the dedicated subject described in special chapters, are discussed. The ordering principle is not necessarily unique because *solid-state detectors*, for example, in nuclear physics are used to make very precise energy measurements, but as solid-state strip or pixel detectors in elementary particle physics they are used for accurate track reconstruction.

The application of particle detectors in nuclear physics, elementary particle physics, in the physics of cosmic rays, astronomy, astrophysics and astroparticle physics as well as in biology and medicine or other applied fields are weighted in this book in a different manner. The main object of this presentation is the application of particle detectors in elementary particle physics with particular emphasis on modern fast high-resolution detector systems. This also includes astroparticle physics applications and techniques from the field of cosmic rays because these activities are very close to particle physics.

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