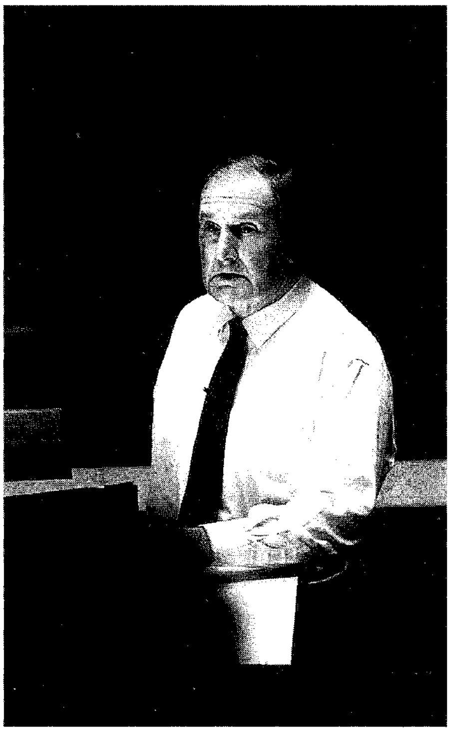
Particle century - fifty years ago, in 1947, half a century after the discovery of the electron, Don Perkins, working at London's Imperial College, was the first to observe a clear example of what appeared to be the nuclear capture of a meson, producing a nuclear disintegration. On 17 April, Perkins gave a presentation at CERN on one hundred years of elementary particles. One half of this particle century is spanned by his own contributions.



trace their parentage back to 1897. Blackett was awarded the Nobel Physics Prize in 1948 and Powell in 1950. These discoveries were to be the last major particle physics revelations of a war-torn Europe. The next European milestone - the discovery of the neutral current in 1973 - had to await the establishment of CERN.

Sighting the pion and unravelling its decay liberated physics from more than a decade of dilemma, and the pion looked full of promise. Perhaps this new particle held the key to the mysterious forces which held the nucleus together. However this hope, cherished since the time of Yukawa, was not to be fulfilled, and the significance of the pion as a particle has diminished as our understanding of nuclear forces in terms of a deeper layer, quarks, has advanced. If the pion does play a special role, it is because it is the lightest strongly interacting particle.

More than anything else, the 1947 discoveries made physicists realize that the subnuclear world was more complex than had been suspected by looking at everyday nuclei. The discovery of the pion and its subsequent decay highlighted the role of the muon (discovered by Anderson and Neddermeyer in 1936), while the Vs were the first examples of 'strange' particles containing a third type of quark.

The following article by Owen Lock, formerly of Bristol, Manchester, Birmingham and CERN, recalls the pion discovery. Another article later this year will cover the discovery of V-particles.

Half a century ago - the pion pioneers

While the classic discoveries of Thomson and Rutherford opened successive doors to subatomic and nuclear physics, particle physics may be said to have started with the discovery of the positron in cosmic rays by Carl Anderson at Pasadena in 1932, verifying Paul Dirac's almost simultaneous prediction of its existence.

Anderson used a cloud chamber, expanded at random, in a high magnetic field. At the same time, Patrick Blackett at Cambridge was joined by an inventive young Italian, Giuseppe Occhialini, sent by a master of counter coincidence techniques, Bruno Rossi, then in Florence, to learn about cloud chambers. Very soon Blackett and Occhialini had built a counter-controlled chamber with which they discovered electron-positron pair production, a key prediction of Dirac's ideas.

Cloud chambers played a major role in cosmic ray studies in the following years, leading to the discovery of the 'mesotron' in 1937, originally identified as the nuclear force carrier postulated by Hideki Yukawa in 1935. However, several difficulties soon arose with this hypothesis, even though pictures of its decay to an electron, as postulated by Yukawa to explain beta-decay, were observed in cloud chamber pictures in 1940. In particular, the mesotron appeared to have a very weak nuclear interaction with matter, conclusively demonstrated by the counter experiments of Marcello Conversi, Ettore Pancini and Oreste Piccioni in Rome from 1943-1947.

A possible explanation of these difficulties had been put forward in Japan in 1942 and 1943 by Yasutaka Tanikawa and by Shoichi Sakata and Takeshi Inoue, who suggested a two-meson hypothesis with a Yukawa-type meson decaying to a weakly interacting mesotron. Because of the war their ideas were not published in English until 1946 and 1947, the journals in question not reaching the USA until the end of 1947.

Unaware of the Japanese work, Robert Marshak had put forward a similar hypothesis in June 1947, at a conference of American theoreticians on Shelter Island (off Long Island), and which he published later that year with Hans Bethe. None of the scientists at the conference knew that such two-meson decay events had already been observed some weeks earlier by Cecil Powell and his collaborators in Bristol, using the then little known photographic emulsion technique, but which in Powell's hands became a powerful research tool.

In the immediate post-World War II years, cosmic ray experiments using photographic emulsions at Bristol made historic discoveries. The picture shows Cecil Powell (standing) with M.G.K. Menon in the emulsion laboratory.

Powell had been a research student under C.T.R. Wilson at the Cavendish Laboratory in Cambridge, before joining the H.H. Wills Physics Laboratory, (also known as the Royal Fort), at Bristol University in 1928 as an assistant to the Director, Arthur Tyndall. They worked together on the mobility of ions in gases until 1935 when Powell became interested in nuclear physics, inspired by the discoveries in Rutherford's Cavendish Laboratory. Together with a young lecturer, Geoffrey Fertel, he embarked on the construction of a 750 keV Cockcroft-Walton accelerator, which they brought in to operation in 1939.

The original intention was to study low energy neutron scattering using a Wilson cloud chamber. However, in 1938 the theoretician Walter Heitler (then in Bristol) mentioned to Powell that in 1937 two Viennese physicists, Marietta Blau and Herta Wambacher, had exposed photographic emulsions for five months at 2,300 m in the Austrian Alps and had seen the tracks of low energy protons as well as 'stars' or nuclear disintegrations, probably caused by cosmic rays. Heitler commented that the method was so simple that 'even a theoretician might be able also to do it'. This intrigued Powell, and Heitler travelled to Switzerland with a batch of Ilford half-tone emulsions, 70 microns thick, and exposed them on the Jungfraujoch at 3,500 m. In a letter to *'Nature'* in August 1939, they were able to confirm the observations of Blau and Wambacher.

The half-tone emulsions could only record the tracks of low energy protons and alpha particles and Powell realised that to do useful work it was necessary to increase their sensitivity by increasing the concentration of silver bromide.

World War II interrupted the work, but with the existing emulsions Powell was able to show that for scattering studies they gave results superior to cloud chambers, as well as being much faster.

Blackett (who had been a contemporary of Powell in the Cavendish Laboratory) then played a decisive role through his influence with the Ministry of Supply of the 1945 UK Labour Government. He was largely responsible for the setting up of two panels, one to plan accelerator building in the United Kingdom (which he chaired) and one to encourage the development of sensitive emulsions (chaired by Joseph Rotblat, recently awarded the Nobel Peace Prize for his Pugwash work).

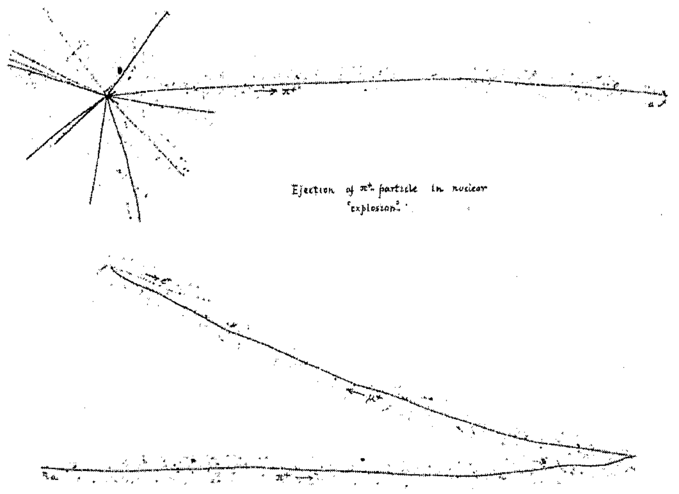
Towards the end of the war, Blackett had invited his erstwhile collaborator Occhialini, then in Brazil, to join the British team working with the Americans on the atomic bomb. Occhialini arrived in the United Kingdom in mid-1945, only to learn that, as a foreign national, he could no longer work on the project. Instead, he joined Powell in Bristol, becoming a driving force behind the development of the new emulsion technique. He was joined by one of his research students, Cesare Lattes, towards the end of 1946.

Photographic manufacturers Ilford were soon able to supply 'Nuclear Research Emulsions' and in autumn 1946 Donald Perkins, then at Imperial College, London, exposed some at 9,100 m in an RAF aeroplane, while Occhialini took several dozen plates to the Pic du Midi at 2,867 m in the French Pyrenees. At that time access to the Pic was by a rough track in summer and by ski in winter, a small telepherique only being brought into service in the summer of 1952, but Occhialini had been a mountain guide in Brazil .

Examination of the emulsions in Bristol and in London revealed, as Powell later wrote, "a whole new world. It was as if, suddenly, we had broken into a walled orchard, where protected trees flourished and all kinds of exotic fruits had ripened in great profusion". This new world became a subject of intensive investigation. Occhialini has well described the atmosphere at Bristol:- "Unshaved, sometimes I fear unwashed, working seven days of the week till two, sometimes four in the morning, brewing inordinately strong coffee at all hours, running, shouting, quarrelling and laughing, we were watched with humorous sympathy by the war-worn native denizens of the Royal Fort". . . . "It was a reality of intense, arduous and continuous work, of deep excitement and incredibly fulfilled dreams. It was the reality of discovery....".

Perkins was the first to observe a clear example of what appeared to be the nuclear capture of a meson in

A classic Bristol pion. The track of the positively-charged pion produced in the interaction 'star' (top left) has been cut in two to facilitate presentation. Bottom right, the pion eventually decays into a muon, which after some 600 microns itself subsequently decays, producing an electron. This full decay chain was recorded in electron-sensitive emulsion, available from 1948, even more sensitive than the specially-developed nuclear research emulsions in which the pion was discovered in 1947.



Mosaic of photo-micrographs of a nuclear explosion accompanied by the ejection of a π^+-particle. The track of the π^+-particle is given in two parts which should join at the point 'a'. The π^+-particle shows the transmutation $\pi \rightarrow \mu \rightarrow e$.

PLATE V.

PHYSICAL SOCIETY PROGRESS REPORTS, VOL. 13 (C. F. POWELL).

the emulsion and producing a nuclear disintegration. Measurements of the multiple scattering as a function of residual range indicated a mass between 100 and 300 times that of the electron. Perkins' observations, published in January 1947, were confirmed by Occhialini and Powell, who published details of six such events only two weeks later. Mesons were easily distinguished from protons in the emulsion because of their much larger scattering and by their variation of grain density with range.

Yet another exotic fruit followed. In the spring of 1947 one of Powell's team of microscope observers, Marietta Kurz, found a meson stopping and giving rise to a second meson, which left the emulsion when nearly at the end of its range. Powell and a young Bristol graduate, Hugh Muirhead, were the first physicists to look at the event, which they immediately recognised as being two related mesons. Within a few days a similar event was found by Irene Roberts, the wife of the group technician, Max Roberts, who later worked at CERN for many years. In this event the secondary meson ended in the emulsion, with a range of 610 microns.

The two events gave such convincing evidence for a two-meson decay chain that Lattes, Muirhead, Occhialini and Powell published their findings in '*Nature*' in the issue of 24 May, 1947. Commenting on the problems surrounding the identification of the cosmic ray mesotron with the Yukawa nuclear force meson, they wrote:- "Since our observations indicate a new mode of decay of mesons, it is possible that they may contribute to a solution of these difficulties".

More evidence was needed to justify such a radical conclusion. For some time no more two-meson events were found in the Pic du Midi emulsions and it was decided to make exposures at much higher altitudes. Lattes proposed going to Mount Chacaltaya in the Bolivian Andes, near the capital La Paz, where there was a meteorological station at 5,200 m. Arthur Tyndall recommended that Lattes should fly BOAC to Rio de Janeiro. Lattes preferred to take the Brazilian airline Varig, which had a new plane, the Super Constellation, thereby avoiding a disaster when the British plane crashed in Dakar and all on board were killed.

Examination of the plates from Bolivia quickly yielded ten more two-meson decays in which the secondary particle came to rest in the emulsion. The constant range of around 600 microns of the secondary meson in all cases led Lattes, Occhialini and Powell, in their October 1947 paper in '*Nature*', to postulate a two-body decay of the primary meson, which they called π or pion, to a secondary meson, μ or muon, and one neutral particle. Subsequent mass measurements on twenty events gave the pion and muon masses as 260±30 and 205±20 times that of the electron respectively, while the lifetime of the pion was estimated to be some 10^{-8} s. Present-day values are 273.31 and 206.76 electron masses respectively and 2.6×10^{-8} s.

The number of mesons coming to rest in the emulsion and causing a disintegration was found to be approximately equal to the number of pions decaying to muons. It was, therefore, postulated that the latter represented the decay of positively-charged pions and the former the nuclear capture of negatively-charged pions. Clearly the pions were the particles postulated by Yukawa. This led to the conclusion that most of the mesons observed at sea level are penetrating muons arising from the decay in flight of pions created in nuclear disintegrations higher up in the atmosphere.

Powell was awarded the 1950

Nobel Physics Prize for his development of the emulsion technique and for the discovery of the pion; Occhialini was awarded the 1979 Wolf Prize (shared with George Uhlenbeck) for his contribution both to the pion discovery and to that of pair production with Blackett, who obtained the 1948 Nobel Physics Prize.

By Owen Lock

One hundred years ago.....

Marking a full century of subatomic physics, an occasional series of CERN Courier article looks back to what was happening exactly one hundred years ago.

All over the world, this year is being celebrated as the centenary of the discovery of the electron by J.J. Thomson at the Cavendish Laboratory, Cambridge, in 1897. At a time when sovereignty interests in science were much to the fore, it is surprising that this discovery has earned such universal recognition. It was not as if the electron came out of the blue.

The saga is described in Abraham Pais' masterpiece 'Inward Bound' (Oxford University Press). Despite having been investigated for many years, cathode rays were still controversial. Were they rays or particles? In 1895 Jean Perrin in France had revealed that they carried negative electric charge.

In 1897, Emil Wiechert in Konigsberg, after carrying out cathode ray experiments, said that cathode rays had to be carried by negatively-charged particles, assuming they had unit charge, carrying only a small fraction of the mass of a hydrogen atom. Walter Kaufman in Berlin was puzzled by the result that the charge/mass ratio of the cathode ray particles appeared to be the same, no matter what gas was used.

Thomson also measured this charge/mass ratio, and, like Wiechert, suspected that it was so small because the cathode ray particles themselves were small. Unlike Wiechert, Thomson had the temerity to state: 'Thus ... we have in the cathode rays matter in a new state, a state in which the subdivision of matter is carried very much further...'.

Two years later, Thomson had measured the charge on what would soon be universally called electrons (he preferred 'corpuscles') and had also investigated their photoelectric role. As several other researchers were to do in the ensuing century, Thomson took the baton of discovery and ran with it.

Emboldened by his electron discovery, he also proposed in 1897 that his electric corpuscles were a component of all atoms, the first step in what was to become his famous 'plum-pudding' model of the atom which was not overthrown until Rutherford's epic discovery of the nucleus some fifteen years down the line.

Thomson directed the Cavendish research with a firm hand, and the direction of Cavendish research had been profoundly altered by Röntgen's 1895 discovery of X-rays. In 1896 Thomson had published, with his student Ernest Rutherford, a classic paper on gas ionization by X-rays. For his part, in 1897 Rutherford was working on the 'Becquerel rays', discovered in Paris the previous year, and soon to become better known as radioactivity.

Elsewhere in physics, two topics were much discussed, both of them in connection with empirical formulas whose deep meaning would not become apparent for some time. In 1885 the Swiss scientist Jakob

Electron centenary

Many events are being organized to mark the centenary of the discovery of the electron by J.J. Thomson at Cambridge. Consult http://www.ioppublishing.com/Physics/Electron. However for a memorable guided tour through electron history, try the website prepared by the American Institute of Physics' Center for the History of Physics, http://www.aip.org/history/electron

This includes a recording of Thomson's venerable yet exultant voice from the soundtrack of the film, Atomic Physics, copyright © J. Arthur Rank Organization, 1948 - "Could anything at first sight seem more impractical than a body which is so small that its mass is an insignificant fraction of the mass of an atom of hydrogen? - which itself is so small that a crowd of these atoms equal in number to the population of the whole world would be too small to have been detected by any means then known to science." Thomson died in 1940, three years after the death of his famous pupil, Rutherford, who was 15 years his junior.