Frank Krienen: a talent for ingenious invention

Colleagues and friends of Frank Krienen recall some of his major contributions to experimental particle physics, from the 600 MeV Synchrocyclotron, CERN’s first accelerator, to wire spark chambers and measurements of g-2 for the muon.

Krienen, who died on 20 March (p43), began his long association with particle physics in 1952, before the European Organization for Nuclear Research officially came into being, in the days of the provisional council that gave CERN its name. He had spent the first few years of his professional life in the research laboratories of Philips at Hilversum. Combined with his academic background as an engineer-physicist at the University of Delft, this gave him the thorough training in the basics of materials and electromagnetism (radar) that was to manifest itself so clearly when he joined CERN.

Already an assistant to Cornelis Bakker at the Zeeman Laboratory at Amsterdam University, Krienen was perfectly suited to be one of the first recruits to the accelerator programme for the new European laboratory. The first project was the 600 MeV proton Synchrocyclotron (SC), with Bakker in charge. This was to be one of the highest-energy accelerators in the world, with the aim of providing a source of particles to initiate an experimental programme in pion and muon physics. The speed of construction was an important element, because CERN needed to become a focus for attracting many of the physicists who had migrated away from Europe. In the meantime, the planning and construction of the much more ambitious proton synchrotron (which became the 25 GeV PS) had also begun, although this was a longer enterprise by necessity.

A small team of young, enthusiastic people was established for the SC, led and advised by experts with more experience. Initially (1952 to 1954) they were scattered in small groups at European universities and laboratories that already had activities in particle physics research (Liverpool, Paris, Uppsala, Stockholm). They all moved to Geneva when the final choice of the CERN site was made.

Krienen had essentially two responsibilities: a specific one for the accelerating RF component of the machine and a more general one for keeping overall control and ensuring the necessary connections between the various groups. His competence made him the undisputed guide and mentor: critical at times, but always enthusiastic and forward-looking. His leadership in dealing at the highest level with industrial firms – some of them the largest in Europe – was an important contribution. Very soon the younger members of the SC team, some only 25 years old, learned enough to feel confident and carry on alone.

For the RF, most other high-energy synchrocyclotrons had adopted mechanical, rotating capacitors (reminiscent of the tuning capacitors of old-fashioned radio receivers). This allowed for the frequency modulation needed to accompany the relativistic energy increase that occurs in all circular accelerators with energies...
However, it was at the 1962 Conference on Instrumentation for High Energy Physics at CERN that Krienen presented the first extensive work on chambers with wire planes. He proposed the digital wire spark chamber, employing a novel method to read out wire planes with ferrite-ring core memories, as used in computers in those days. Each wire in a detector plane passed through a ferrite-ring core to ground or even to high voltage. The current through the wires touched by a spark, which was controlled and relatively low, set the magnetic cores, thus directly storing the track co-ordinate. This could be read out conveniently at high speed using the same procedures as used in computers.

The device marked a real breakthrough in the field of detectors. In the subsequent years, a large number were constructed and used in experiments at CERN, DESY, Brookhaven National Laboratory (BNL), Saclay and many other laboratories worldwide. However, a drawback of magnetic core read-out was that it could not be used in magnetic fields. This is one reason why spark chambers gradually became less popular. They were replaced by further developments of the wire chamber, such as multiwire proportional chambers, drift chambers, time-projection chambers, microstrip gas chambers, and finally by silicon trackers.

Krienen in the meantime continued to apply his inventiveness in the field of accelerators at CERN. In 1972 he made a major contribution to the 14 m diameter muon storage ring designed to measure the anomalous moment of the muon, $g-2$, to a few parts per million. This required a uniform magnetic field of 1.5 T with the vertical focusing provided by electric quadrupoles almost all of the way round the ring, operating at about 25 kV. Krienen, assisted by Wilfried Flegel, designed the quadrupole system and soon discovered that high-voltage quadrupoles in a magnetic field regularly spark over, even in the best vacuum. Studying the phenomenon, he realized that electrons were trapped in the combined fields (which resemble a Penning gauge) and that the breakdown occurred when the trapped charge had built up to a threshold value, which took a few milliseconds. However, the muon lifetime in the ring (lengthened by relativistic time dilation) was to be only 64 μs, and all would be gone in 800 μs, after which the quadrupoles could be switched off. So Krienen provided pulsed modulators to drive the electric plates and there was no significant breakdown.

The muons were injected by pion decay in flight inside the ring and filled all of the available phase space. Some passed close to the limiting apertures, so inevitably a small fraction (<1%) were lost per muon lifetime. This had a small effect on the $g-2$ measurement and limited the measurement of the time-dilated muon lifetime. Krienen then invented “electric scraping” to remove the muons at the edge of the population, which were the ones most likely to be lost. This was accomplished in a simple way by pulsing the quadrupoles asymmetrically at the beginning of the fill and then slowly bringing them up to the fiducial value. The loss was reduced to 0.1% per lifetime, and could be measured and a correction applied. Finally time dilation in a circular orbit was verified to 1 part in 1000 at a $\gamma$ of 29.6. This remains one of the most precise tests of Einstein's special theory of relativity.

In 1977 Krienen took charge of the design and development of the electron-cooling apparatus for CERN’s Initial Cooling Experiment (ICE) ring. Electron cooling, suggested by Gersh Itskovich Budker in 1966 and experimentally demonstrated in his laboratory in Novosibirsk in 1974 to 1976, consists of reducing the phase spread...
of ion beams circulating in a storage ring through Coulomb interactions with cooler electrons. Ions and electrons are mixed together along a straight section of the ring where they travel at the same average speed, the electrons being constantly renewed. At the limit, neglecting noises and instability, the temperature of the ions should be equal to that of the electrons, that is: \( T_i \sim T_e \rightarrow \theta_i \sim \theta_e \sqrt{(M_i/M_e)} \), where \( \theta_i \) and \( \theta_e \) are the angular divergences of the ion and electron beams respectively. The very small mass ratio \( M_i/M_e \) makes this method extraordinarily favourable.

ICE was an alternating gradient storage ring and was constructed at CERN in less than a year, metamorphosing the existing g-2 zero-gradient ring, which had just finished its task. The idea was to demonstrate the feasibility of intense antiproton beams with the aim of using them in the Super Proton Synchrotron (SPS), operating as a proton–antiproton collider. Carlo Rubbia was the initiator and strenuous supporter of the whole project, which was to produce and thereby discover the intermediate bosons \( W^\pm \) and \( Z^0 \) predicted by the Standard Model.

The decision was taken that the ICE ring should also incorporate the appropriate equipment for the stochastic cooling system that Simon van der Meer had invented at CERN in 1974, which had already been successfully partially tested at the Intersecting Storage Rings. Between late 1977 and spring 1978, the potential of stochastic cooling became so evident that this system was adopted alone in the proton–antiproton complex, ultimately with great success.

Krienen, however, was pursuing the hard work of completing the electron-cooling system. He could not go fast because he had to design every part of the apparatus from scratch, and then construct and adjust it, as well as develop the detailed theory. In 1979, about two years after the start of ICE, his apparatus worked properly, achieving a factor of 10^2 in the six-dimensional phase space density of the circulating protons. It was too late for the proton–antiproton project at the SPS, but new aims appeared. Krienen’s device was moved, with minor modifications, to the Low Energy Antiproton Ring. After a few years and more substantial improvements, it was moved again to the Antiproton Decelerator.

After his retirement from CERN, Krienen moved to the US, where he often returned to this cooling method, suggesting improvements and new applications in several papers. In 1986 he joined Boston University as professor of engineering and applied physics, and set to work on the new muon g-2 experiment at BNL. This was broadly similar to the CERN machine but had many improvements: the magnetic field was strictly zero, but inside the inner winding the field was uniform and the return flux was confined to the space between the windings. Working with his PhD student Wuhzeng Meng, Krienen proved the concept with model windings and the final superconducting version was made by Akira Yamamoto at KEK in Japan. This invention was crucial to the success of the g-2 experiment at BNL.

Kriennen was an inventive and original thinker with the ability to make his ideas work in detail. His work ranged from accelerator and beam optics through superconducting injection devices and slow extraction methods, to ion sources, RF and klystron technology, and many kinds of particle detector. His motivation was always the advancement of physics. He impressed his colleagues and friends with his vast knowledge of theory and practice, and with his enthusiasm and creativity, which he maintained until the end of his long life. He was a good team player with strong loyalty to colleagues. We will remember him with warm affection.

Résumé
Frank Krienen : le remarquable talent d’un inventeur

Frank Kriennen, qui nous a quittés le 20 mars, était une des premières recrues du CERN. Dans cet article, ses collègues se souviennent des contributions majeures qu’il a apportées à la physique des particules expérimentale, à commencer par le modulateur de fréquence à diapason pour le premier accélérateur du CERN, le synchrocyclotron. Dans les années 1960, Frank Kriennen s’était consacré à la trajectographie des particules, avec l’invention de la chambre à étincelles. Il avait ensuite développé l’anneau de stockage utilisé au CERN pour mesurer le moment magnétique anormal du muon (g-2), ainsi que des appareils de refroidissement par électrons. Aux États-Unis, il a contribué de manière inestimable à l’expérience g-2 du Laboratoire américain de Brookhaven.

Franco Bonaudi, Francis Farley, Guido Petrucci, Emilio Picasso and Henk Verweij, Kriennen’s former colleagues and friends.