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Alan Marmaduke Wetherell was a physicist of repute. During his career he excelled in the practice of his profession. As a research student he showed great promise at the University of Liverpool, where he conducted his doctoral work in the group of Professor James Macdonald Cassels from 1954 to 1957. He went on to write his thesis on the ratio of radiative to mesic capture of stopped negative pions by hydrogen. He continued in his research group doing experiments on polarized muon beams and on the radiative β-decay of the pion. In 1957 he was awarded a Commonwealth Fund Fellowship, which he used to visit the California Institute of Technology, where he worked on the photoproduction of kaons and pions. In 1959 he moved from California to Switzerland, where he joined the European Organization for Nuclear Research (CERN). He rose to become a senior research physicist in 1963 and was appointed the Division Leader of the Experimental Physics Division in 1981–84. He retired from the CERN staff in December 1997.

Early life and Liverpool University

Alan Marmaduke Wetherell was born on 31 December 1932 in South Shields, England. He was the only child of Margaret Edna Wetherell and Marmaduke Wetherell. His early life is not well known to me but I do know that he attended school at South Shields High School for Boys, where he obtained his School Certificate and later his Higher School Certificate, both issued by the University of Durham. He was clearly talented and decided to study at Liverpool University, where he went in 1950.

His life in Liverpool started with his first degree, which was a BSc obtained in 1954. He was an outstanding student and went on to perform research on the 380 MeV synchrocyclotron at the Nuclear Physics Research Laboratory of the university under the leadership of Professor James Cassels (F.R.S. 1959). He joined forces there with an Italian visitor named Giuseppe Fidecaro and they worked together there for a couple of years. Alan here got to know the mechanical technician, John Critchley, who was the life and soul of their small group. They all worked together in the laboratory-cum-workshop. He also met the engineer who had built the Liverpool synchrocyclotron, Mike Moore, who was a very visible person around the laboratory. One of their early research developments came from their efforts to produce a lead-glass counter to detect photons. This was the first time that such a technique had been implemented and it is now a standard method for measuring photons. They also worked on the design of distributed amplifiers; Alan's first paper was published with Giuseppe Fidecaro (1)*.

Alan's PhD thesis was on the ratio of radiative to mesic capture of negative pions by hydrogen (2). The result, now accepted as accurate, was nearly double that from the only previous experiment, and this removed an important discrepancy in low-energy pion physics. Alan continued other work in the Liverpool laboratory. He was an author of a paper on experiments with polarized muon beams (3) that gave an improved measurement of the muon g-factor and of two papers that concerned the radiative β-decay of the pion (4,5).

Before leaving Liverpool, Alan married Alison Morag Dunn. They were a charming couple and made many friends. Their son, Carl Sebastian, was born on 16 July 1957.

In 1957 Alan was awarded a Commonwealth Fund Fellowship, which took him to the California Institute of Technology. There he joined the group headed by Professor R.L. Walker, where they studied the photoproduction of pions and kaons (6). His first paper published alone was on the interference effects of the retardation term in pion photoproduction (7). His final paper from Caltech (8) was again on the study of kaon photoproduction in hydrogen, with the group. He left Caltech in the summer of 1959.

Starting work at CERN: the early years

In looking for his next place of work, he corresponded with his former colleague, Giuseppe Fidecaro, who was then working at CERN. Giuseppe suggested that Alan should apply for a job at CERN, and this he did. His application was successful and he joined CERN as a research physicist in September 1959. This was an exciting time at CERN because its large machine, the 24 GeV proton synchrotron, was almost ready to begin operations.

CERN was a new European laboratory and the planning for experiments with the 24 GeV proton synchrotron was not ready when the accelerator started to operate in November 1959. They had no beam lines and little in the way of magnets or power supplies to construct beam lines. Nevertheless, the teams of young physicists got busy and started to explore what could be done with the exciting new accelerator. The team that Alan joined was led by Giuseppe Cocconi, who was then a visitor at CERN from Cornell University. Their first paper was on total cross-section measurements, exploring the possibilities with a range of proton momenta from 10 to 28 GeV/c (9). A third member of the team who worked with Cocconi and Wetherell for many years was Bert Diddens, a jovial Dutch physicist, who had spent two years at Liverpool before joining CERN. He and Alan, together with their wives, Trajn and Alison, became very close friends and visited each other often.

* Numbers in this form refer to the bibliography at the end of the text.

When the laboratory finally obtained some magnets and power supplies to construct the first real beam lines, the team studied elastic and quasi-elastic collisions of protons with momenta between 9 and 25 GeV/*c* (10). At the time this work was very important and led to the descriptions of the 'shrinking' of the proton–proton elastic peak. Alan at this stage wrote an interesting review of the work on strong interactions at CERN for *Review of Modern Physics* (11). There followed a series of experiments that were mainly concerned with the elastic and inelastic scattering of protons on various targets, including hydrogen, deuterium and carbon (12–14). This was the time at which a group of British physicists came to CERN and joined in the work of the Cocconi group. The people were Geoff Manning, Eric Taylor and Gordon Walker, who all worked with enthusiasm for two or three years. They were also helped by the presence of Egil Lillethun, a Norwegian physicist.

A singular paper by Alan, 'High energy peripheral and diffraction scattering' (15), is worthy of special note. At this time, Cocconi returned to Cornell for a year and resigned as professor there to return definitively to CERN in 1963, where he stayed until his retirement in 1979. In 1962, the group published a paper, 'High energy proton–proton scattering' (16). During the absence of Cocconi in Cornell, the group was run by Eric Taylor, who was visiting from England. It is worth noting that in 1963, Alan Wetherell was promoted to become a senior physicist in CERN at the remarkably young age of thirty years. He was already a key member of the organization and this was recognized quite early.

The group continued its excellent physics research, concentrating on particle production (17, 19) and nucleon isobar production (18) in proton–proton collisions. In 1965 the group started measurements on small-angle elastic scattering and also produced results on the 1.40 GeV nucleon resonance (20, 21). This work led the group to measure real parts of the proton–neutron scattering amplitude at 19.3 GeV/*c* and also to cover the small-angle scattering at 10.0 GeV/*c* (22, 23); they also measured proton nuclei cross-sections at 20 GeV (24).

Work at CERN: the start of our collaboration

I arrived at CERN in 1965 and the first publication that I made together with Alan and the Cocconi group was in 1966: it was a search for fluctuations in the angular distribution of proton–proton scattering at 16.9 GeV/*c* (25). This measurement was made in a slowly ejected proton beam from the CERN proton synchrotron. The beam was approximately 4×10^{11} protons per burst over a spill time of 50 ms. The scattered protons were momentum-analysed and detected by scintillation counters on both sides of the beam. The results were well fitted by an angular distribution of the form $\exp(-p_T/b)$. Unfortunately, fluctuations were not seen in the angular distribution between 67° and 90°, despite having been predicted theoretically. This led the group to measure large-angle proton–proton scattering (26), which was a field that had already been explored by Cocconi.

This led to a series of measurements at smaller and smaller angles, which yielded the first evidence for the diffraction-like structure in the proton–proton angular distribution (27); this has now been so beautifully demonstrated by data taken with the higher energies that became available later with the Intersecting Storage Rings (ISR) at CERN.

To pursue our proton–proton scattering measurements to even smaller angles, we proposed and constructed a precise single-arm spectrometer that could be used to measure proton–proton elastic scattering (28) as well as particle production (31), or 'inclusive spectra' as they are now known. A number of precise experiments were performed with this instrument, including the study of nucleon resonance production out to large transverse momentum (29).

An interesting experiment that we performed at the proton synchrotron was a quark search with the use of the 'super-momentum' technique (32). This involved a search for fractionally charged particles in the beam from the CERN proton synchrotron. Such fractionally charged particles were the quarks now in favour as the substructure of the baryons and mesons. A special beam was constructed, with optimal acceptance for quarks, should they be produced in an internal target of the proton synchrotron. If quarks had been found, the experiment had a unique feature in that it incorporated a streamer chamber in which we would have photographed the anomalously ionizing tracks produced by the fractionally charged quarks. Unfortunately none were found in our experiment.

Work in Russia: the growth of our collaboration

In 1967 Alan Wetherell became the leader of the CERN group when Giuseppe Cocconi was appointed as a research director of the CERN laboratory. Alan was the natural group leader and he motivated the work of the group for many years.

The year 1967 was when Alan and I, together with Robert Meunier, an eminent French physicist, visited the Institute for High Energy Physics (IHEP) at Protvino, close to Serpukhov in Russia. As a result of the visit we established a collaboration to perform the initial experiments at the 76 GeV proton accelerator. This was then the highest-energy accelerator in the world. The first phase of this 'CERN–Serpukhov collaboration' was the beam survey of negative particles produced in an internal target performed in 1968 (30). For this measurement we had a fairly large collaboration of physicists with French and Belgian collaborators as well as the Soviet physicists and a number of CERN staff.

The collaboration at the 76 GeV proton accelerator involved the CERN physicists and their colleagues from Europe in passing considerable time in Protvino. This was when the country was under tight control by the Soviet authorities. We had many interesting experiences during our stay in Russia. We were, for example, limited in our freedom to move about the country. We were told that we must request permission one day before if we wished to move out of Protvino. However, we were allowed to travel on bicycles around the countryside, which led us to explore the neighbouring villages.

The Russians were in general friendly towards us and feared only the KGB! Our main shopping was done in Moscow in the shops that were open only to certain (privileged) foreigners. The trip to Moscow took at least two hours (by car) so we did the visit only about once a week. The work in Protvino lasted about nine months and we all learned something about life in Russia as well as doing our research.

Back at CERN

Meanwhile the work at CERN continued. The work with the spectrometer continued with a publication on the differential cross-sections for π^+ and ρ production at 21 GeV/*c* (31). The next experiment was on the separation of single and double scattering in proton–deuteron collisions at 19.2 GeV/*c* (33). This yielded an understanding of how the deuteron was broken up in proton collisions.

In 1970 we published a paper (34) that compared the inelastic cross-section for proton–proton scattering, which we measured with the equivalent deep inelastic cross-section for electron–proton scattering. This seemed to lead to a better understanding of the proton but we never found out the true secret.

The final papers published from research at the CERN proton synchrotron were on the energy dependence of the structure in high-energy proton–proton elastic scattering (35), the momentum transfer dependence of nucleon resonance production in proton–proton collisions at 24 GeV/*c* (36), the elastic scattering of protons on neutrons (38) and protons on protons (40) and the production of pions and ρ mesons in proton–proton collisions (39). After these two publications, the group moved to the Intersecting Storage Rings (ISR) at CERN. We published one more paper from our work at the CERN proton synchrotron, which was on the momentum spectra of secondary particles produced in proton–proton collisions at various momenta up to 24 GeV/*c* (43).

The Intersecting Storage Rings

In 1970 we formed a collaboration with a group in Rome that was under the leadership of Ugo Amaldi, and started a series of experiments at the newly constructed ISR. It is worth mentioning that the ISR gave us very large centre-of-mass energies because the collisions were no longer between a proton and a fixed target but between two protons colliding head-on. This yielded a greatly enhanced energy in the centre of mass. The construction of the ISR was a major advance in the technology of particle accelerators achieved by the accelerator specialists of CERN.

The new experiments were based on small-angle elastic proton–proton scattering, including the region of Coulomb–nuclear interference. The first experiment, with simple equipment, yielded the slope of the elastic scattering (37), which confirmed that shrinkage continued even up to ISR energies. Our more ambitious experiment, which used small scintillation counters located only 18 mm from the ISR beam, enabled us to measure the ratio of the real to imaginary parts of the forward scattering amplitude at centre-of-mass energies of 22 and 30 GeV (41).

The same equipment was then used to measure the optical point, from which we derived the total cross-section for proton–proton scattering at centre-of-mass energies of 22, 30, 44 and 52 GeV (42). This produced the definitive evidence of an asymptotically rising proton–proton total cross-section in the ISR energy region.

The early 1970s was a very hard time for Alan. My wife and I had formed a close friendship with the Wetherells and the Diddens and we often went out together. In 1971, we all attended a ball at CERN in honour of the successful start-up of the ISR. It was on this evening that Alison and Alan told us that she had been diagnosed as having signs of cancer. This was a serious blow to us all. Alison had all the usual cancer treatments and seemed to have overcome the illness about a year later. She was able to play tennis and continued her work at the Lycée des Nations school, at which she taught art. However, the cancer returned in 1973 and despite renewed efforts by the specialists, sadly, she died in March 1974.

Alan was devastated by the loss of Alison. He continued to work at CERN but was a person who appeared lost. It took him at least a year before he regained his former cheerfulness. His friends tried very hard to help him overcome the loss but we did not succeed very well.

A further experiment was performed at the ISR, in which a simple spectrometer was used to measure inclusive negative spectra at small angles. This turned out to be less interesting because the important physics was at large angles rather than small angles. Nevertheless, Alan led the group well and interesting physics was achieved.

The Super Proton Synchrotron (SPS)

During the latter phase of construction of the SPS, when I was the SPS physics coordinator, he became interested in the possibilities of neutrino physics with the SPS. As a result, he and his colleagues Amaldi, Cocconi and Diddens proposed an experiment to study neutral currents in the SPS neutrino beam. At the same time Klaus Winter, a German physicist on the CERN staff, was also proposing to study neutral currents, although his proposed liquid-argon calorimeter had not been approved. The CERN management encouraged us to join forces and what emerged, after we had been joined by several Member-State collaborators, was the CHARM collaboration. The spokesman of the experiment was Klaus Winter and we worked together for almost ten years.

The CHARM collaboration constructed a calorimeter optimized for the measurement of neutral-current interactions. The principal element in this calorimeter was the material, which was marble. The aim was to reduce to a minimum the multiple scattering, which would spoil the measurement of the hadronic showers produced by the neutrino interactions. In neutral-current interactions no muon is produced by the neutrino and therefore the only object that could be measured was the hadronic shower. The showers were measured by scintillators and detector chambers interspersed between plates of marble (45).

This device was used in the CERN neutrino beam from the end of 1977 to 1984 to study the polarization of the muons produced by charged-current antineutrino interactions (44, 55), inverse muon decay (46) and prompt neutrino production in 400 GeV/c proton–nucleus collisions (47). The fine-grained calorimetry of the neutrino detector was reported in *Nuclear Instruments and Methods* (48). The total cross-sections for neutrinos and antineutrinos (49) and the y- and x-distributions for neutral-current processes (50), including neutrino–electron and antineutrino–electron scattering (51) were all the subject of papers by the CHARM collaboration.

The group also studied the production of dimuons in neutrino and antineutrino interactions (52). We also did a 'beam-dump' experiment, which yielded puzzling results in that we saw an unexplained excess of muonless events at low visible energies, as well as an anomalous ratio of prompt electron neutrinos to prompt muon neutrinos. The final measurements on neutrino scattering from the wide-band neutrino beam (53) and also from the narrow-band neutrino beam (56) were published in 1982 and 1983. The response and resolution of the CHARM fine-grain calorimeter (54) was also published in 1982.

A significant result published by the CHARM collaboration is the value of the Weinberg angle obtained from a measurement of the purely leptonic reactions of scattering of neutrinos and antineutrinos on electrons. This measurement, based on the ratio of the observed cross-sections, had a systematic error of only 0.015, which is less than the statistical error from the measurements so far. Thus with more data and with improvements to the detector one could expect a final error in $\sin^2\theta_W$ of about 0.02.

Physics with the Large ElectronPositron Collider (LEP)

At the end of 1980, Alan Wetherell and I joined Ugo Amaldi and many physicists in designing an experiment for the LEP that became known as DELPHI. The collaboration had more than 400 physicists involved. Alan was named as the division leader of the Experimental Physics Division from the beginning of 1981 and served for three and a half years. After he completed his term of office he rejoined the DELPHI collaboration.

The DELPHI experiment was a huge effort and comprised many sophisticated parts. The detector was a solenoidal magnet with a superconducting coil providing a magnetic field of 1.2 tesla in which most of the detector was located. The centre of the coil was equipped with a micro-vertex detector housed in a triggering device. Outside this trigger chamber was the time projection chamber, which allowed the physicists to reconstruct in three dimensions the tracks registered by ionization in the chamber. This was followed by a special device known as a ring imaging Cherenkov counter, which would give signals for particles with velocities above a threshold. After, another tracking chamber was located an electromagnetic calorimeter, made from lead plates, that could recognize an electromagnetic shower from its shape and size. Finally, the hadron calorimeter completed the devices inside the magnetic field. After the superconducting coil, which was outside the hadron calorimeter, the only remaining detectors were the muon chambers, which detected particles that had passed through the return yoke of the magnet.

Alan worked for many years on the LEP, where he was the leader of the teams of physicists who constructed the hadron calorimeter. The teams that worked under Alan's leadership came from many different countries. A key role was played by the large number of institutes which came from what was then the Soviet Union. In addition, the Finnish physics group played their part by working on the electronics of the hadron calorimeter. The construction of the chambers used to read out the track information was partly done by Italians. However, the leader of this huge effort was Alan.

Alan's first task was to organize the construction of the chambers, which were built in Russia. He soon secured an appropriate laboratory where the chambers could be built and tested before delivery to CERN. He supervised the construction of the chambers and their installation in DELPHI, which took place in 1988–89. When the beam was first made available to the four LEP experiments, in August 1989, DELPHI was able to take its first experimental data on electron–positron annihilation at the energy of the Z^0 particle. These chambers have worked remarkably well and are still in use today because DELPHI will complete its data taking only at the end of this year (around October 2000).

I shall only describe one of the many experiments performed by the DELPHI collaboration, the measurement of the number of light neutrinos in the world (57). This was measured by a precise determination of the shape of the peak known as the Z^0. The world of particle physics contains a number of known and measured fundamental quarks. The question is: How many quarks are there? This can be linked to the number of neutrinos, which is the same as the number of quarks. The theory of the production of the Z^0 can be evaluated but the shape of the cross-section prediction depends on the number of neutrinos in the world. In the experiment, the hadron production was measured at several energies at and around the peak of the production. From the theory, one can readily see that only three neutrinos can explain the shape of the Z^0 peak. This number was measured in the first year of experimentation with LEP and has been re-measured during the six years of operation at the

Z^0 peak. For example, the number from one of the experiments is now 2.978 ± 0.014. All four of the LEP experiments agree on the number three and the precision is now extremely good.

Some final remarks about Alan Wetherell

After the death of his wife, Alison, in 1974, it was more than a year before Alan could re-establish his earlier relationships with his friends. He became friendly with Diana Maple, the head teacher of a small primary school, a part of the International School of Geneva. My wife knew Diana well because she also worked in the International School of Geneva on a different site. They came to dinners and parties at which my wife and I were also guests. This friendship with Diana lasted for thirteen years but eventually broke up. During these later years, Alan often looked up his old friend, Giuseppe Fidecaro, from his early days in Liverpool. Giuseppe had retired and his wife, Maria, also a physicist, knew Alan well because she had been in Liverpool with Giuseppe.

Alan became friendly then with the lady who eventually became his second wife, Mrs Linda Hardwick (*née* Darby), whom Alan eventually married in 1996. My wife and I knew her but not well because we did not interact with Alan as we had in the past, and his private life remained very personal.

The physics of the hadron calorimeter was the final work of Alan and he retired in December 1997, looking forward to a well earned retirement. His death was sudden and unexpected, a great loss to his second wife and his only son (by his first wife) as well as to his friends and colleagues.

Acknowledgement

The frontispiece photograph was taken in January 1981 and is reproduced with the permission of CERN.

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(54) (With M. Jonker, J. Panman *et al.*) The response and resolution of a fine-grain marble calorimeter for hadronic and electromagnetic showers. *Nucl. Inst. Methods* **200**, 183.

(55) 1983 (With M. Jonker, F. Udo *et al.*) Measurement of the polarization of positive muons produced in high-energy antineutrino interactions. *Z. Phys*. C **17**, 211.

(56) (With M. Jonker, F. Udo *et al.*) Experimental study of *x*-distributions in semileptonic neutral-current neutrino reactions. *Phys. Lett.* B **128**, 117.

(57) 1989 (With P. Aarnio *et al.*—DELPHI Collaboration) Measurement of the mass and width of the Z^0-particle from multihadronic final states produced in e^+e^- annihilations. *Phys. Lett.* B **231**, 539.

This last listed publication was followed by many more (a further 158) published by the DELPHI Collaboration. All except a few were under the name of ‘P. Aarnio *et al.*—DELPHI Collaboration’, just as in the last paper cited here. However, with more than 400 collaborators in the DELPHI Collaboration it is perhaps understandable that I do not list these final publications including the name of Alan Wetherell.