europhysics news
BULLETIN OF THE EUROPEAN PHYSICAL SOCIETY

J.A. Volume 10 Number 7/8 July/August 1979

Directors-General of CERN, past and present. From left to right: J.B. Adams, W. Jentschke, F. Bloch, V.F. Weisskopf, L. Van Hove.

Twenty five years ago, the European Organization for Nuclear Research formally came into existence as the necessary number of States signified their commitment to participate. This was the culmination of efforts made by the physics community and governments to establish a new organization in Europe in which scientific research could be pursued by many nations together in the traditional academic atmosphere of open communication. Encouraged by UNESCO, the first initiatives had led in 1953 to the signing of a Convention in Paris, under which a preliminary Council was set up that became known by its acronym CERN.

In a remarkably short time CERN became a household term in physics (that the substitution of the word Organization for Council did nothing to dislodge) symbolizing the spirit of international cooperation and the dedication to the principle that scientific integrity took precedence over any political expediency. CERN was followed in 1956 by the foundation of the Joint Institute for Nuclear Research, centred on Dubna in the USSR, and high energy and particle physics became one of the lead subjects where people from all over the world could meet and discuss the meaning of Nature without prejudice.

When the idea of CERN was first discussed, the exact field of study to be undertaken was only imperfectly defined and objectives were perhaps blurred by the possibility of discovering a new source of power. Physicists were determined, however, that the essential purpose was research into the structure of matter using particle accelerators; uncertainty disappeared, and CERN became clearly identified with high energy and particle physics, and the development of the machines necessary for research in this field.

To appreciate the advances that have been made in the subject since CERN first came into being, *Europhysics News* talked first to **Leon Van Hove,** Research Director-General of CERN. The following is a summary of the discussion.

What was in the forefront of the minds of particle physicists in 1954 ?

One very striking domain at the focus of attention was quantum electrodynamics. In 1947, the great developments of QED had taken place with the experimental discovery of the Lamb shift, and the theoretical discovery of the renormalization technique. The latter allowed us to transform the field theory of electrons and photons into a completely calculable theory to all orders of perturbation in the fine structure constant. For many years afterwards, physicists were engaged on experimental tests and the theoretical applications of renormalization.

A second very important area was the field of weak interactions, which was wide open. Following the discovery that the pi-meson and the mumeson were not the same and that the pion was, in fact, decaying into the muon, the search was continuing for the actual mathematical form of the weak interaction. The breakthrough came two years later in 1956 with the discovery of parity violation.

The third activity that must be mentioned was the theory of nuclear forces, as it was then called, now referred to as strong interaction theory. In the fifties, a great number of people were trying to construct a theory of the nuclear forces in terms of the proton, the neutron and the pion, and were conducting experiments on the new accelerators which were producing pions copiously.

Much attention was also paid to the strange particles that had first been detected in cosmic rays around 1947, becoming better established experimentally in the early 50's.

And today ?

Today, many of the old questions have been answered, but we have new questions and some of the old remain. Of particular interest is the progress towards an electro-weak interaction

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theory, i.e. a unification of quantum electrodynamics with weak interaction theory. Through the knowledge that the interaction of neutrinos with protons and neutrons gets stronger with increasing neutrino energy, and the discovery of the neutral current weak interaction, we have now very good hopes that a common theory, electroweak theory, will describe the two interactions. A lot of work in the future will concentrate on establishing to what degree this is valid and what is the precise mathematical nature of the electro-weak interaction.

This work is calling for energies beyond what can be reached with present accelerators. All the extrapolations from present knowledge indicate that there are very fundamental new phenomena to be revealed in an energy range which is beyond the capabilities of CERN's 400 GeV SPS as it is used at present; also beyond CERN's 31 + 31 GeV ISR. This highlights the importance of CERN's $p\bar{p}$ collider project, whereby antiprotons will be accelerated in the SPS at the same time as protons travelling in the opposite direction, so forming a collider with a centre of mass energy of 540 GeV. With this facility, it will be possible to make the first really crucial test of electro-weak theory in a search for the intermediate bosons, which are the weak interaction analogues of the photon; electro-weak theory predicts from existing data that the mass of the intermediate bosons will be in the range of 80-90 GeV. Clearly the electro-weak interaction is going to remain one of the crucial domains of research for some time to come.

But we have not forgotten the theory of strong interactions. Long ago we gave up hope that strong interactions could be described in terms of just protons, neutrons and pions. We now know that the strongly interacting particles (the hadrons) are very numerous, and that is explained by their being composite objects with quarks inside. So it is at the level of the quarks that we want to develop the theory of the strong interactions. The new theory here is called quantum chromodynamics, QCD, and a huge amount of work nowadays is aimed at finding out to what degree that type of theory can indeed describe strong interactions and the basic constituents of strongly interacting matter, which are the quarks and presumably the quanta of the field that mediates the strong interaction — the gluons. It is worth noting that both electro-weak interaction theory and quantum chromodynamics are gauge field theories based on non-abelian gauge groups.

A third domain of activity concerns the heavy types of what we now understand to be the basic constituents of matter — leptons and quarks. Leptons do not have strong interactions, quarks do; leptons come out from collisions quite freely, quarks seem to be confined in the sense that they seem to occur only in groups forming hadrons. There are evidently more types of lepton and quark than originally thought. Long after the electron, the muon, and their associated neutrinos were known, the tau-lepton was discovered in 1975. Since the quark concept was invented 15 years ago with three types of quark, we have from 1974 a fourth type, now indications of a fifth, and theoretical reasons for a sixth. The search for, and the systematic study of heavy leptons and quarks is, and will continue to be, a central line of research.

A more futuristic type of problem is the next step in unification — to unify electro-weak with strong interactions and possibly with gravity. For the moment, this is largely a theoretical domain, where it is difficult to find crucial experimental tests. The only one that has emerged as a real possibility is the stability of the proton.

What do you consider to have been the experimental results produced with the CERN machines, that can, on reflexion, be considered as land marks?

We can start with a very important experiment performed in 1958, when the first measurement was made of the decay of the pion into an electron and neutrino. Another first in the field of pion decays in the early 60s demonstrated the decay of a charged pion into a neutral pion, an electron and a neutrino. At about the same time, in the French 80 cm bubble chamber operated at CERN, the relative parity of the Λ hyperon and the Σ hyperon was established to be positive — so answering a crucial question on the validity of the SU(3) classification of the hadrons.

In the sixties, violation of CP (C = charge conjugation, P = parity) in weak interactions was very important and two of the results obtained at CERN may be mentioned: the validity of charge conjugation invariance in η decay (correcting an American experiment that claimed to establish violation), and the demonstration that time reversal invariance was violated in neutral kaon decay.

In another domain, that of proton-proton collisions which has been a speciality of CERN for many years, it was found that the diffraction peak of proton-proton scattering shrinks as the energy increases. A very remarkable diffraction minimum was also revealed in the angular distribution of elastic scattering, first indicated as a shoulder in the experiments on the PS and then fully unveiled at the much higher energy of the ISR. It was also at the ISR that it was found that at high energies the proton-proton total cross-section is steadily increasing with energy.

Another very important landmark in strong interaction physics, first found at the ISR, was that relating to large transverse momentum phenomena, whereby at very high energy, a small, but very significant fraction of particles, fly out of a collision sideways with very high momentum.

Perhaps the biggest discovery at CERN, in the neutrino beam of the PS with the Gargamelle bubble chamber, was the neutral current weak interaction — a new type of interaction of neutrinos of a strength comparable to their usual weak interactions. Made in 1973, this discovery was the real turning point in the development of electro-weak theory. That research, and later work in the neutrino beam of the SPS have also made major contributions to the quark description of neutrino interactions with matter. Indeed, it can be said that experiments made in the neutrino beam of the SPS have made the most important quantitative contributions by far to the description of neutrino interactions with protons and neutrons. They concern in particular the phenomenon of scaling violation which brings to light the binding effects of quarks inside protons and neutrons. To a quite good approximation, quarks are seen by the neutrino as if they were free for the short time of a collision; only later do the fields of force that confine them come into play, and this is now seen as scaling violation effects.

The very latest results that can be mentioned concern the first measurement of the life-time of charmed particles. Using emulsions exposed to neutrinos in front of the Big European Bubble Chamber in the SPS neutrino beam, a team of physicists found five good candidate events of charmed particle production which allowed them to determine the lifetime of charmed particles as being in the neighbourhood of 5×10^{-13} s, in accordance with what had been expected from theory.

Apart from what might be seen as landmarks, it should not be forgotten that many other experiments have made important contributions, such as the measurement of the gyromagnetic ratio of the muon — the so-called muon G-2 experiments ; also, the work of the on-line isotope separator, Isolde, on the systematics of unstable nuclei, and the study of exotic atoms and hypernuclei. The development of a fully coherent picture requires the assembly of a wide range of data.

Can we pick out experiments that are to be completed soon that will provide answers to significant theoretical questions ?

First I would mention the muon experiments at the SPS. The question here is the following : can the same quark structure of the proton and the neutron, describe successfully both muon scattering and neutrino scattering — a very vital question for our understanding of nucleon structure. We have also some critical questions regarding the inner structure of unstable particles, in particular pions, which can be studied by looking at the production of muon pairs in pion-nucleon collisions. This work has started in CERN and has also been done to some extent already at Fermilab, but so far the experiments are not sufficiently accurate and complete.

Following the life-time measurements mentioned above, we are now trying to photograph the tracks of a large number of charmed particles by using a miniature bubble chamber which is about 20 cm diameter and which will be run just for that. This is a very small device that has been built recently and has been dubbed LEBC — the Little European Bubble Chamber. It is all in plastic and can be pulsed very rapidly.

We are expecting other important results on collisions with large transverse momentum, and also in the field of some special mesonic resonances that seem to be strongly coupled to proton-antiproton pairs, i.e. the so-called baryonium states. It is a field where a number of very intriguing experimental indications have been obtained and where a lot of effort is going on now to transform them into firm results and compare them with the two classes of theoretical predictions existing for such states.

Looking a little further ahead when the SPS proton-antiproton collider will be operating, there is the search for the intermediate bosons mentioned already. Many other phenomena will also be investigated. It will be the first opportunity of studying with high statistics some curious phenomena seen in cosmic rays at high energies. It will also give a new look at large transverse momentum phenomena as the gain in energy compared to the ISR will be very large. Using the same antiproton source, we shall, in the ISR, be able to compare proton-antiproton with proton-proton collisions at the same energy and we envisage also a range of interesting antiproton experiments at very low energy.

You mention the interest in low energy antiproton experiments, yet the general trend seems always to be to higher energies. Will this continue ?

No reasonable scientist would make predictions about the distant future, but we can speak with some confidence about the next decade or two. As explained earlier, there is a clear scientific demand for energies higher than those reached by present accelerators. It is also extremely interesting that throughout the world, different approaches are being adopted. In Western Europe our choice is a very large electron-positron machine, LEP and we shall be making proposals to our governments soon. The United States and the Soviet Union have made different choices which is likely to lead in the 1990s to a complementarity of very high energy machines in the world.

Does this mean that only the very big laboratories have a part to play in particle physics — or will there still be a rôle for the smaller institutions ?

The answer here is absolutely clear and is yes, at least as regards university laboratories. It is through the university laboratories which can have access to the very large accelerators like those of CERN, that the essential relationship between high energy physics and the students and young research workers can be maintained. It is absolutely vital for any science that there should be a very intimate relation and interaction between research and university teaching at graduate level. It is by creating the possibility for university teams to use the large accelerators, that high energy physics will survive. In Europe, this is symbolized by the fact that out of about 1500 experimental physicists using the CERN accelerators, more than 1400 come from institutions outside CERN, mostly the Universities. Centralizing all research personnel in the accelerator laboratories would, in the long run I believe, be the intellectual death of high energy physics.

How then should it be organized ?

This is now well understood, as it has been practised at CERN for some 25 years. First the conception of the experiments and the construction of dedicated equipment including research on instrumentation is partly done in the Universities, often supported by national laboratories. Then, when the equipment has taken data on the accelerator, the very elaborate work of extracting the physics results can be, and should be done in the Universities.

For this reason, we are strongly supporting the development of links for fast data transfer between the Member States of CERN and CERN itself. Eventually that will be the best way of having teams working as much as possible in the Universities while still doing experiments on accelerators. To prepare for this, CERN already participates in the European experiments on satellite telecommunication, and we already have more conventional data links with various laboratories in Europe.

Does high energy physics still attract young people of a quality able to profit from such a complex research structure ?

Certainly. At CERN, we have every reason to be pleased by the quality of the young people who come here from the Universities to do research. Many are very good and can contribute to the work in hand from the moment they arrive. That indicates that the subject is in a very healthy state and attracts excellent young minds.