

Where are we now?

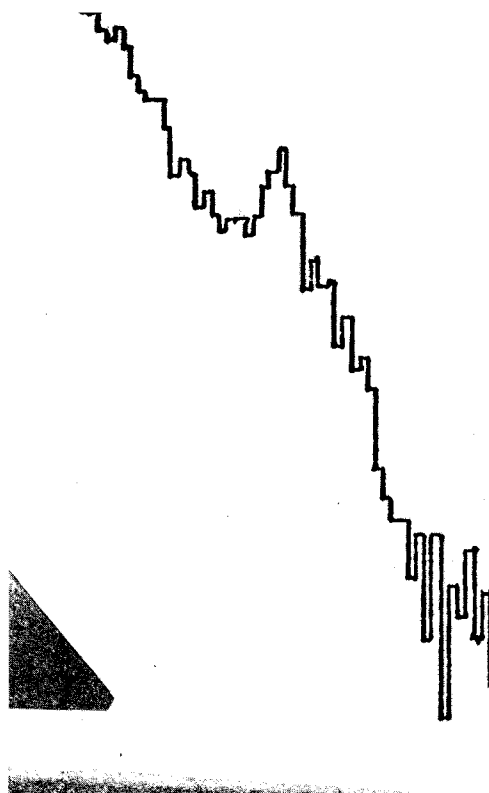
A brief review of some of the progress in particle physics during 1977

Perhaps the simplest and most honest answer to the question in the title is that we do not know. During the year several discoveries, or convincing confirmations of earlier discoveries, have opened a door that we thought we were closing. Just as theory was putting the produce of the experiments into order in a very promising way, there have been new findings that now need to be absorbed. However, we have certainly moved nearer to understanding the workings of Nature as a result of the research in 1977.

A simplified picture of where we were in our knowledge of hadrons at the end of 1976 would show us holding four types of quark (up, down, strange and charmed) as the constituents of all the hadrons — the particles sensitive to the strong force. We had absorbed the Brookhaven / Berkeley / Stanford discovery of the J/ψ particle at the end of 1974 by introducing the charmed quark and all the known families of hadrons could be built up from combinations of these four quarks in a calculable way.

During 1977 some empty corners of this picture have been painted in with results from the electron-positron storage rings at DESY and at Stanford. The J/ψ had already been interpreted as consisting of a charmed quark and charmed antiquark where the charm property was hidden. It was desirable, therefore, to identify particles with 'naked charm'. This has been thoroughly done in the study of D mesons, the first of which was found at Stanford in 1976, and in the discovery of F mesons at DESY announced in July. The Ds and Fs all exhibit naked charm in the ways that were predicted.

A question mark on the quark front was some data from a Fermilab experiment showing 'anomalous' behaviour of antineutrinos at high energy, for which one explanation was the existence of an additional type of quark. More neutrino data from CERN during 1977 has removed this anomaly but



The discovery of the year, the Upsilon particles of mass about 10 GeV, being announced by Leon Lederman at the Budapest Particle Physics Conference in July.

the possibility of a new quark has come back, again from Fermilab, though from a different direction and looking much more solid.

If a 1977 oscar is to be given to any particular particle for a starring role during the year, it must go to the muon. In July came the announcement that, in observing muon pairs emerging from high energy interactions at the Fermilab accelerator, new very heavy particles have been seen around a mass of 10 GeV. Known as the Upsilon particles, they are most frequently interpreted as consisting of a quark-antiquark pair of a new type.

The postulated new quark has been assigned names like 'beauty', 'top' or 'bottom'. Just as the J/ψ provoked the search for naked charm, so the Upsilon now offers physicists the exciting prospect in 1978 of looking for naked bottom.

The study of muons coming from high energy neutrino interactions ran

like a thread through the year. It began with 'dileptomania' — the attempt to learn more about the phenomenon of two muons coming directly from a neutrino interaction. Then in February Fermilab discovered three muons emerging. This result and the dimuon events were strongly reinforced by the start of high energy neutrino experiments at the CERN SPS, where much more data could be assembled. To round the year off, CERN discovered in November four muons emerging from a high energy neutrino interaction.

The origin (or origins) of this proliferation of muons is not clear. It may become so when we know more about new types of quark. Alternatively, it may be at least partly the result of the existence of new types of heavy lepton.

At the beginning of 1976 we could pretend that we had four leptons — the particles which do not feel the strong interaction. These are the

Other views of the four muon neutrino event shown on the cover, this time looking from the side. The CERN / Dortmund / Heidelberg / Saclay collaboration led by Jack Steinberger has amassed the enormous total of 5 million neutrino interactions (3.5 million of the charged current type, 1.5 million of the neutral current type). Among them are six thousand dimuon events, thirty-five trimuon events and this single four muon event.

electron, muon, electron-type neutrino and muon-type neutrino. This gave a pleasing symmetry with the four quarks which build up the hadrons and made the theoreticians happier in their attempts to develop a model which would incorporate all known particle behaviour.

However, a heavy lepton (tau) had already been discovered on the SPEAR storage ring at Stanford. Though people tried not to believe it and would really have liked to see it go away, this now seems a forelorn hope because during 1977 there has been still more evidence from Stanford and it is now also backed by data from DESY.

There were three highlights a little outside the main-stream of the development of particle physics. One was the annual discovery of an isolated quark, announced in April, this time in a Millikan-type experiment at Stanford University. It has not deviated theoreticians from their efforts to demonstrate

why it is not possible to see an isolated quark (see Physics Monitor).

A second highlight came from several experiments during 1977 which clearly established 'baryonium' as a way of life. These well-defined states have been seen in a number of spectroscopy experiments and have the peculiar property that, while they look superficially like mesons, they prefer to decay into a baryon-anti-baryon pair. Thus additional selection rules now have to be incorporated into the underlying quark model.

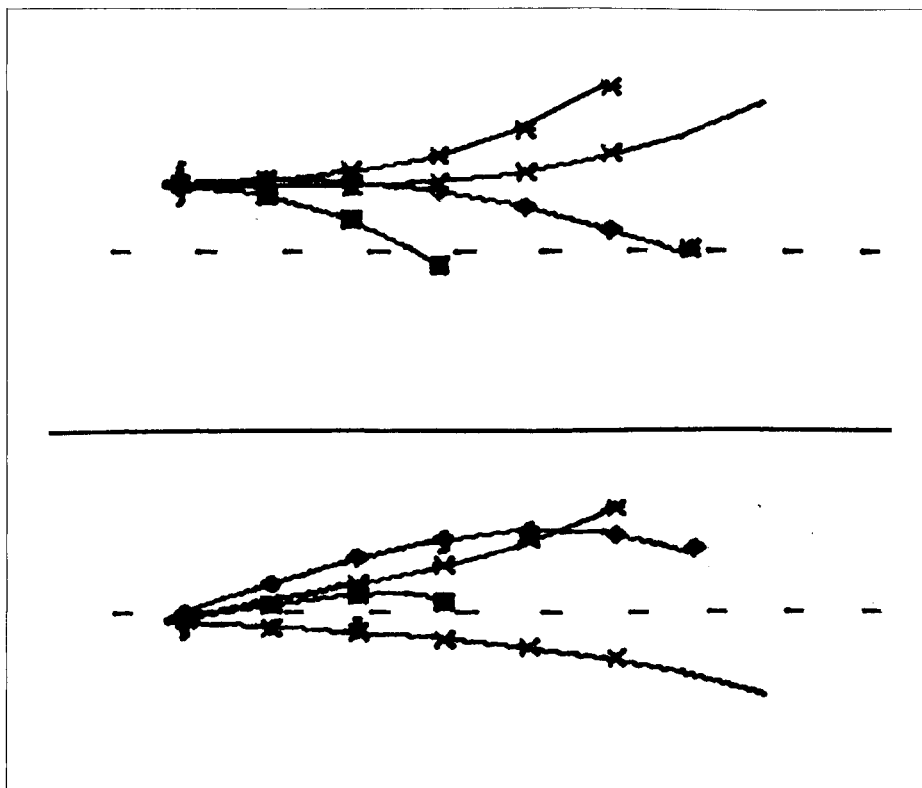
The third side highlight featured the muon again. Rumours circulated in February on the basis of very preliminary data from an experiment at SIN, that the muon had been seen to decay at a very low rate into an electron and a gamma ray. If such a decay were found, it would destroy the distinction between the electron and the muon which has always seemed absolute up to now. However, the

decay has not been confirmed by later data from SIN or from TRIUMF.

Some theoreticians would have been pleased to see this muon decay into an electron plus gamma. It can be predicted as occurring at a low rate from some gauge theory calculations. Gauge theories are all the rage, and an article on them can be found in the September issue. They have had wide success in explaining our present knowledge of particle behaviour and they have the fundamental attraction of being applicable to any force field—gravitational, weak, electromagnetic or strong. They thus hold out the long searched for holy grail of unifying our interpretation of all types of behaviour in Nature.

To date, they have welded together weak and electromagnetic behaviour, an achievement rubbed home by the discovery of neutral currents at CERN in 1973. The only cloud on that horizon is the failure to see neutral current effects in some other physics experiments where they might have appeared. Fortunately, for the moment, we can hide behind the complexity of some of the necessary calculations and believe that these are wrong, or that the structure of the neutral currents is more complex, rather than that the neutral current effect is not there.

Now gauge theories are being extended to absorb the observation of the Upsilon and the tau. The tau is likely to have its own neutrino, in analogy to its electron and muon confreres, bringing the total number of leptons to six. The Upsilon type of quark (if that proves to be the correct origin of the particle) is also likely to have a companion, bringing the total number of hadron constituents to six. The gauge theory manoeuvres with the extended list of particles may well absorb more easily a few uncomfortable phenomena, like the violation of charge-parity symmetry in the decay of the neutral kaon, which have been largely swept under the carpet in the



One of the completed octants of the electron-positron storage ring, PETRA, which has maintained a very rapid construction pace during 1977. The machine is scheduled for operation in 1978.

(Photo DESY)

general progress of our understanding of particle behaviour.

Turning to the machines on which particle physics research is done, a major event in 1977 was the start, in January, of the physics programme on the CERN 400 GeV proton synchrotron (the SPS) with some of the most intense beams and most sophisticated detection systems available.

Among the machines under construction the star has been the PETRA 18 GeV electron-positron storage ring at DESY where a cracking pace has been set and maintained throughout the year. They must now, however, look over their shoulder because the twin machine, PEP at Stanford, has begun building in earnest with formal ground breaking in June. Work on the Tevatron, with the addition of a superconducting ring to take the energy to 1000 GeV, continues at Fermilab. A variety of possibilities for colliding beams as well as 1 TeV fixed target physics will be opened up.

The 400 GeV proton-proton storage ring (ISABELLE) at Brookhaven has received its first construction money. Authorization is also through for the 8 GeV electron-positron storage ring (CESR) at Cornell. The same energy range will be reached by VEPP-4 at Novosibirsk which is nearing completion.

Europe, via the European Committee for Future Accelerators (ECFA), has decided that a very high energy electron-positron storage ring, to give about 200 GeV in the centre of mass, should have top priority as its future project. The Soviet Union continues its study of UNK, a several TeV fixed target proton synchrotron. And we welcome some new colleagues to the high energy physics community from China where a several hundred GeV proton synchrotron is planned.

It has been very satisfying to see that international use of new and planned facilities has been taken very much

to heart (for example at PETRA and ISABELLE) in line with the recommendation which emerged from the inter-regional discussions held in 1976. These same discussions led to the setting up of the Inter-regional Committee for Future Accelerators (ICFA) to keep alive the possibility of a 'world machine' in the years to come.

In the field of accelerator technology, the idea of beam cooling has been taken up at CERN and Fermilab in addition to Novosibirsk and the realization of high intensity antiproton beams, for proton-antiproton colliding beams and for other experiments, is probable only a few years away.

Other applications of accelerators continue to mushroom. They are being developed more and more for use in medicine. The synchrotron radiation community using electron rings is growing rapidly and many new dedicated rings are being built. Accelerators are also to be the source of

the intense neutron beams of the near future. The possibility of using accelerated heavy ion beams in fusion reactor systems is being keenly pursued in the USA.

All in all, it has been a very lively year in high energy physics holding out the promise of even livelier things to come.

