

The new particles

Anyone in touch with the world of high energy physics will be well aware of the ferment created by the news from Brookhaven and Stanford, followed by Frascati and DESY, of the existence of new particles. But new particles have been unearthed in profusion by high energy accelerators during the past twenty years. Why the excitement over the new discoveries?

A brief answer is that the particles have been found in a mass region where they were completely unexpected with stability properties which, at this stage of the game, are completely inexplicable. In this article we will first describe the discoveries and then discuss some of the speculations as to what the discoveries might mean.

We begin at the Brookhaven National Laboratory where, since the Spring of this year, a MIT/Brookhaven team have been looking at collisions between two protons which yielded (amongst other things) an electron and a positron. A series of experiments on the production of electron-positron pairs in particle collisions has been going on for about eight years in groups led by Sam Ting, mainly at the DESY synchrotron in Hamburg. The aim is to study some of the electromagnetic features of particles where energy is manifest in the form of a photon which materializes in an electron-positron pair. The experiments are not easy to do because the probability that the collisions will yield such a pair is very low. The detection system has to be capable of picking out an event from a million or more other types of event.

It was with long experience of such problems behind them that the MIT/Brookhaven team led by Ting, J.J. Aubert, U.J. Becker and P.J. Biggs brought into action a detection system with a double arm spectrometer in a slow ejected proton beam at the Brookhaven 33 GeV synchrotron.

They used beams of 28.5 GeV bombarding a beryllium target. The two spectrometer arms span out at 15° either side of the incident beam direction and have magnets, Cherenkov counters, multiwire proportional chambers, scintillation counters and lead glass counters. With this array, it is possible to identify electrons and positrons coming from the same source and to measure their energy.

From about August, the realization that they were on to something important began slowly to grow. The spectrometer was totting up an unusually large number of events where the combined energies of the electron and positron were equal to 3.1 GeV. This is the classic way of spotting a resonance. An unstable particle, which breaks up too quickly to be seen itself, is identified by adding up the energies of more stable particles which emerge from its decay. Looking at many interactions, if energies repeatedly add up to the same figure (as opposed to the other possible figures all around it) they indicate that the measured particles are coming from the break up of an unseen particle whose mass is equal to the measured sum.

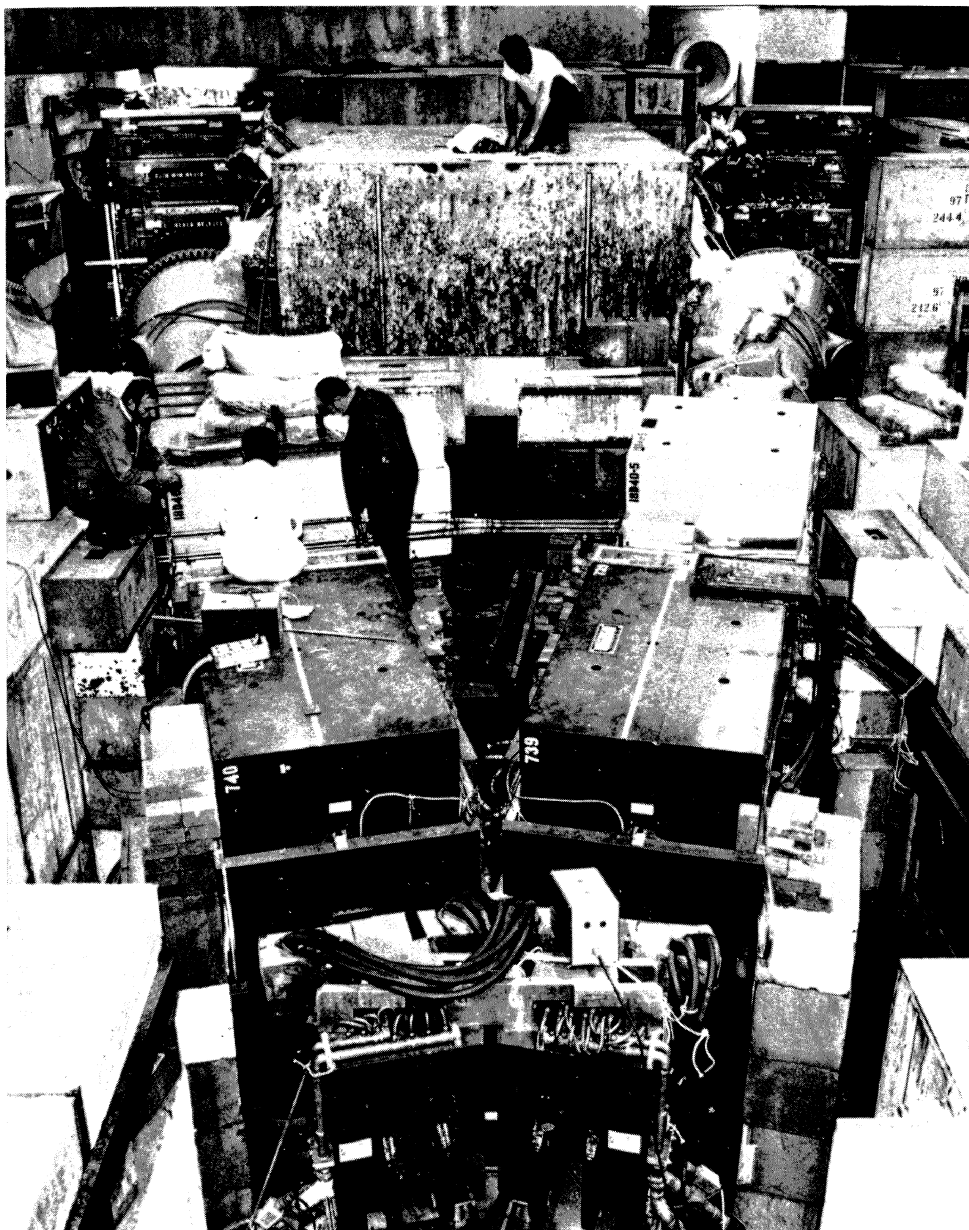
The team went through extraordinary contortions to check their apparatus to be sure that nothing was biasing their results. The particle decaying into the electron and positron they were measuring was a difficult one to swallow. The energy region had been scoured before, even if not so thoroughly, without anything being seen. Also the resonance was looking 'narrow' — this means that the energy sums were coming out at 3.1 GeV with great precision rather than, for example, spanning from 2.9 to 3.3 GeV. The width is a measure of the stability of the particle (from Heisenberg's Uncertainty Principle which requires only that the product of the average lifetime and the width be a constant). A narrow width means

that the particle lives a long time. No other particle of such a heavy mass (over three times the mass of the proton) has anything like that stability.

By the end of October, the team had about 500 events from a 3.1 GeV particle. They were keen to extend their search to the maximum mass their detection system could pin down (about 5.5 GeV) but were prodded into print mid-November by dramatic news from the other coast of America. They baptised the particle J which is a letter close to the Chinese symbol for 'ting'. From then on, the experiment has had top priority. Sam Ting said that the Director of the Laboratory, George Vineyard, asked him how much time on the machine he would need — which is not the way such conversations usually go.

The apparition of the particle at the Stanford Linear Accelerator Center on 10 November was nothing short of shattering. Burt Richter described it as 'the most exciting and frantic week-end in particle physics I have ever been through'. It followed an upgrading of the electron-positron storage ring SPEAR during the late Summer.

Until June, SPEAR was operating with beams of energy up to 2.5 GeV so that the total energy in the collision was up to a peak of 5 GeV. The ring was shut down during the late Summer to install a new r.f. system and new power supplies so as to reach about 4.5 GeV per beam. It was switched on again in September and within two days beams were orbiting the storage ring again. Only three of the four new r.f. cavities were in action so that the beams could only be taken to 3.8 GeV. Within two weeks the luminosity had climbed to $5 \times 10^{30} \text{ cm}^{-2}\text{s}^{-1}$ (the luminosity dictates the number of interactions the physicists can see) and time began to be allocated to experimental teams to bring their detection systems into trim.



The detection system of the experiment at Brookhaven which spotted the new particle. It consists of two symmetrical spectrometer arms, 20 m long. In the foreground in each arm are three magnets. They are followed by Cherenkov counters (looking like cement mixers) to identify particles (in addition to Cherenkovs in the magnets) and, finally, multiwire proportional chambers which determine precise particle positions. (Photo Brookhaven)

Sam Ting telling the new particle story in an auditorium packed with an enthusiastic audience at CERN on 21 November.

It was the Berkeley/Stanford team led by Richter, M. Perl, W. Chinowsky, G. Goldhaber and G.H. Trilling who went into action during the week-end 9-10 November to check back on some 'funny' readings they had seen in June. They were using a detection system consisting of a large solenoid magnet, wire chambers, scintillation counters and shower counters, almost completely surrounding one of the two intersection regions where the electrons and positrons are brought into head-on collision.

During the first series of measurements with SPEAR, when it went through its energy paces, the cross-section (or probability of an interaction between an electron and positron occurring) was a little high at 1.6 GeV beam energy (3.2 GeV collision energy) compared with at the neighbouring beam energies. The June exercise, which gave the funny readings, was a look over this energy region again. Cross-sections were measured with electrons and positrons at 1.5, 1.55, 1.6 and 1.65 GeV. Again 1.6 GeV was a little high but 1.55 GeV was even more peculiar. In eight runs, six measurements agreed with the 1.5 GeV data while two were higher (one of them five-times higher). So, obviously, a gremlin had crept into the apparatus. While meditating during the transformation from SPEAR I to SPEAR II, the gremlin was looked for but not found. It was then that the suspicion grew that between 3.1 and 3.2 GeV collision energies could lie a resonance.

During the night of 9-10 November the hunt began, changing the beam energies in 0.5 MeV steps. By 11.00 a.m. Sunday morning the new particle had been unequivocally found. A set of cross-section measurements around 3.1 GeV showed that the probability of interaction jumped by a factor of ten from 20 to 200 nanobarns. In a state of euphoria, the champagne

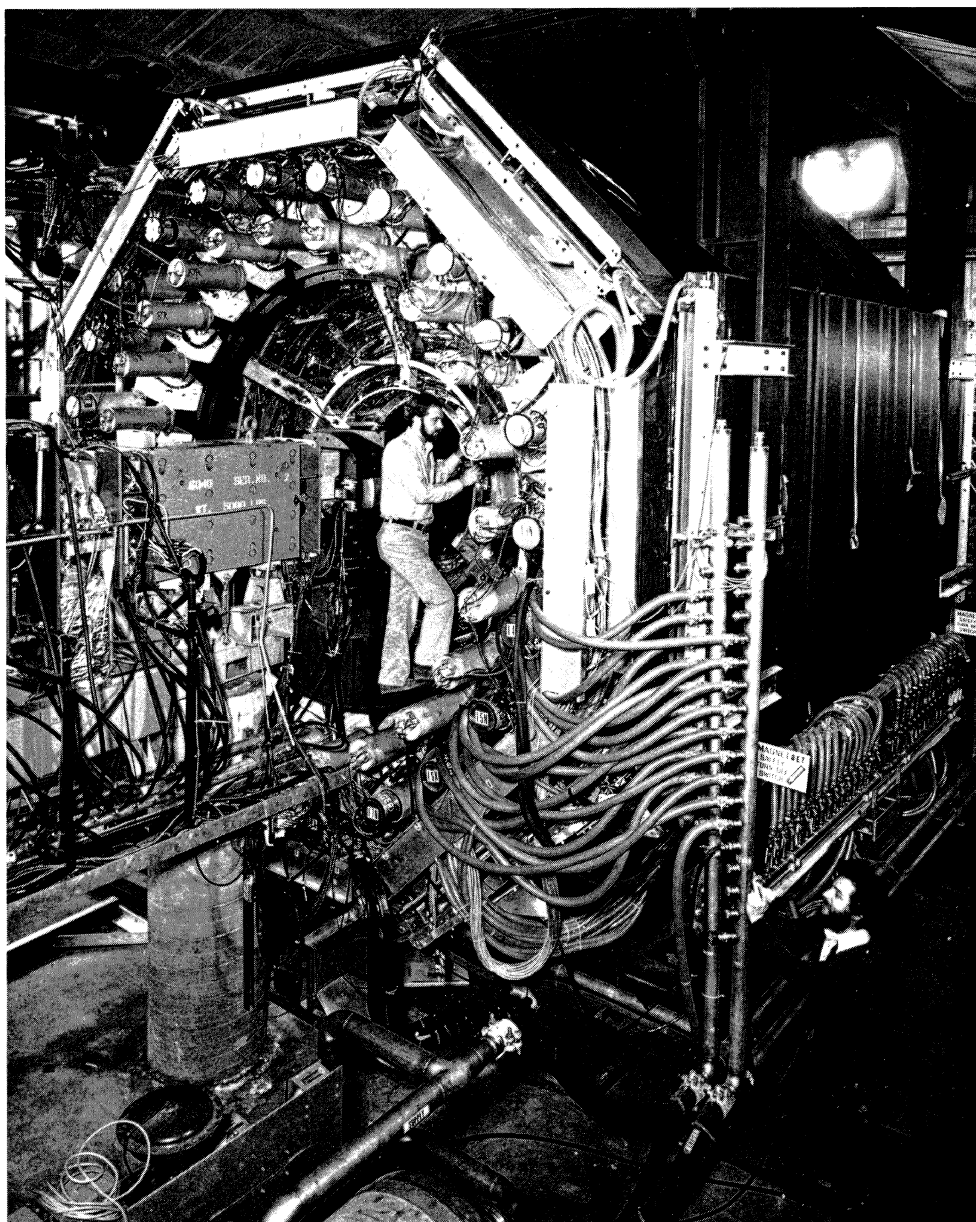
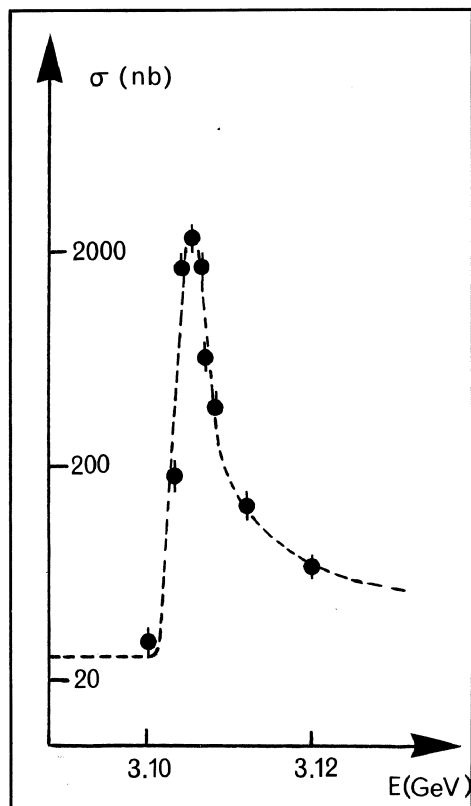


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The famous detection system at the SPEAR storage ring at Stanford, which already has the high hadron production rate to its credit, now adds the identification of new particles.

(Photo SLAC)

Below is the dramatic signal of the 3.1 GeV particle as seen at SPEAR. The vertical axis measures the cross-section in nanobarns for producing hadrons (in other words the probability that an interaction between an electron and positron will take place producing strongly interacting particles). Along the horizontal axis is the energy showing that the probability jumps a hundred times at 3.1 GeV.



was cracked open and the team began celebrating an important discovery. Gerson Goldhaber retired in search of peace and quiet to write the findings for immediate publication.

While he was away, it was decided to polish up the data by going slowly over the resonance again. The beams were nudged from 1.55 to 1.57 and everything went crazy. The interaction probability soared higher; from around 20 nanobarns the cross-section jumped to 2000 nanobarns and the detector was flooded with events producing hadrons. Pief Panofsky, the Director of SLAC, arrived and paced around invoking the Deity in utter amazement at what was being seen. Gerson Goldhaber then emerged with his paper proudly announcing the 200 nanobarn resonance and had to start again, writing ten times more proudly.

Within hours of the SPEAR measurements, the telephone wires across

the Atlantic were humming as information enquiries and rumours were exchanged. As soon as it became clear what had happened, the European Laboratories looked to see how they could contribute to the excitement. The obvious candidates, to be in on the act quickly, were the electron-positron storage rings at Frascati and DESY.

From 13 November, the experimental teams on the ADONE storage ring (from Frascati and the INFN sections of the Universities of Naples, Padua, Pisa and Rome) began to search in the same energy region. They have detection systems for three experiments known as gamma-gamma (wide solid angle detector with high efficiency for detecting neutral particles), MEA (solenoidal magnetic spectrometer with wide gap spark chambers and shower detectors) and baryon-antibaryon (coaxial hodoscopes of scintillators cover-

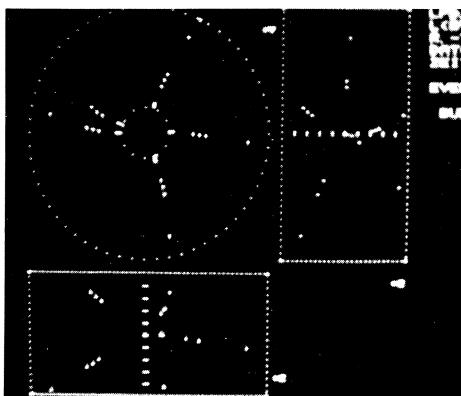
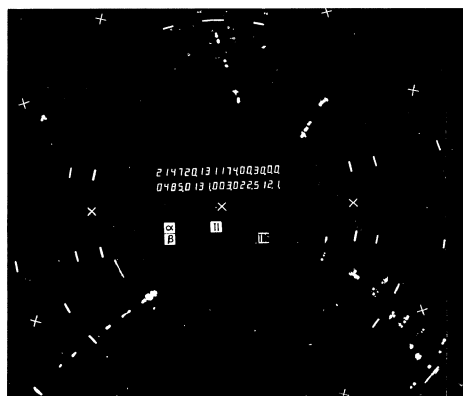
ing a wide solid angle). The ADONE operators were able to jack the beam energy up a little above its normal peak of 1.5 GeV and on 15 November the new particle was seen in all three detection systems. The data confirmed the mass and the high stability. The experiments are continuing using the complementary abilities of the detectors to gather as much information as possible on the nature of the particle.

At DESY, the DORIS storage ring was brought into action with the PLUTO and DASP detection systems described later in this issue on page 427. During the week-end of 23-24 November, a clear signal at about 3.1 GeV total energy was seen in both detectors with PLUTO measuring events with many emerging hadrons and DASP measuring two emerging particles. The angular distribution of elastic electron-positron scattering was measured at 3.1 GeV, and around it, and a distinct change was

Hadron production events at 3.1 GeV from:

1. The gamma-gamma group on the ADONE storage ring at Frascati where a large spark chamber array spots an event giving at least three charged particles plus an electromagnetic shower (bottom right)

2. The PLUTO detector on the DORIS storage ring at DESY where three projections of an event with five charged particles are displayed together via the computer.



1. seen. The detectors are now concentrating on measuring branching ratios — the relative rate at which the particle decays in different ways.

In the meantime, SPEAR II had struck again. On 21 November, another particle was seen at 3.7 GeV. Like the first it is a very narrow resonance indicating the same high stability. The Berkeley/Stanford team have called the particles psi (3105) and psi (3695).

No-one had written the recipe for these particles and that is part of what all the excitement is about. At this stage, we can only speculate about what they might mean.

First of all, for the past year, something has been expected in the hadron-lepton relationship. The leptons are particles, like the electron, which we believe do not feel the strong force. Their interactions, such as are initiated in an electron-positron storage ring, can produce hadrons (or strong force particles) via their common electromagnetic features. On the basis of the theory that hadrons are built up of quarks (a theory which has a growing weight of experimental support — see October issue, page 332) it is possible to calculate relative rates at which the electron-positron interaction will yield hadrons and the rate should decrease as the energy goes higher. The results from the Cambridge bypass and SPEAR about

2. a year ago showed hadrons being produced much more profusely than these predictions.

What seems to be the inverse of this observation is seen at the CERN Intersecting Storage Rings and the 400 GeV synchrotron at the FermiLab. In interactions between hadrons, such as proton-proton collisions, leptons are seen coming off at much higher relative rates than could be predicted. Are the new particles behind this hadron-lepton mystery? And if so, how?

Other speculations are that the particles have new properties to add to the familiar ones like charge spin, parity. . . As the complexity of particle behaviour has been uncovered, names have had to be selected to describe different aspects. These names are linked, in the mathematical description of what is going on, to quantum numbers. When particles interact, the quantum numbers are generally conserved — the properties of the particles going into the interaction are carried away, in some perhaps very different combination, by the particles which emerge. If there are new properties, they also will influence what interactions can take place.

To explain what might be happening, we can consider the property called 'strangeness'. This was assigned to particles like the neutral kaon and lambda to explain why they were always produced in pairs — the

strangeness quantum number is then conserved, the kaon carrying +1, the lambda carrying —1. It is because the kaon has strangeness that it is a very stable particle. It will not readily break up into other particles which do not have this property.

Two new properties have recently been invoked by the theorists — colour and charm. Colour is a suggested property of quarks which makes sense of the statistics used to calculate the consequences of their existence. This gives us nine basic quarks — three coloured varieties of each of the three familiar ones. Charm is a suggested property which makes sense of some observations concerning neutral current interactions (discussed below).

It is the remarkable stability of the new particles which makes it so attractive to invoke colour or charm. From the measured width of the resonances they seem to live for about 10^{-20} seconds and do not decay rapidly like all the other resonances in their mass range. Perhaps they carry a new quantum number?

Unfortunately, even if the new particles are coloured, since they are formed electromagnetically they should be able to decay the same way and the sums do not give their high stability. In addition, the sums say that there is not enough energy around for them to be built up of charmed constituents. The answer may lie in new properties but not in a way that we can easily calculate.

Yet another possibility is that we are, at last, seeing the intermediate boson. This particle was proposed many years ago as an intermediary of the weak force. Just as the strong force is communicated between hadrons by passing mesons around and the electromagnetic force is communicated between charged particles by passing photons around, it is thought that the weak force could also