1976 Nobel Prize for Physics

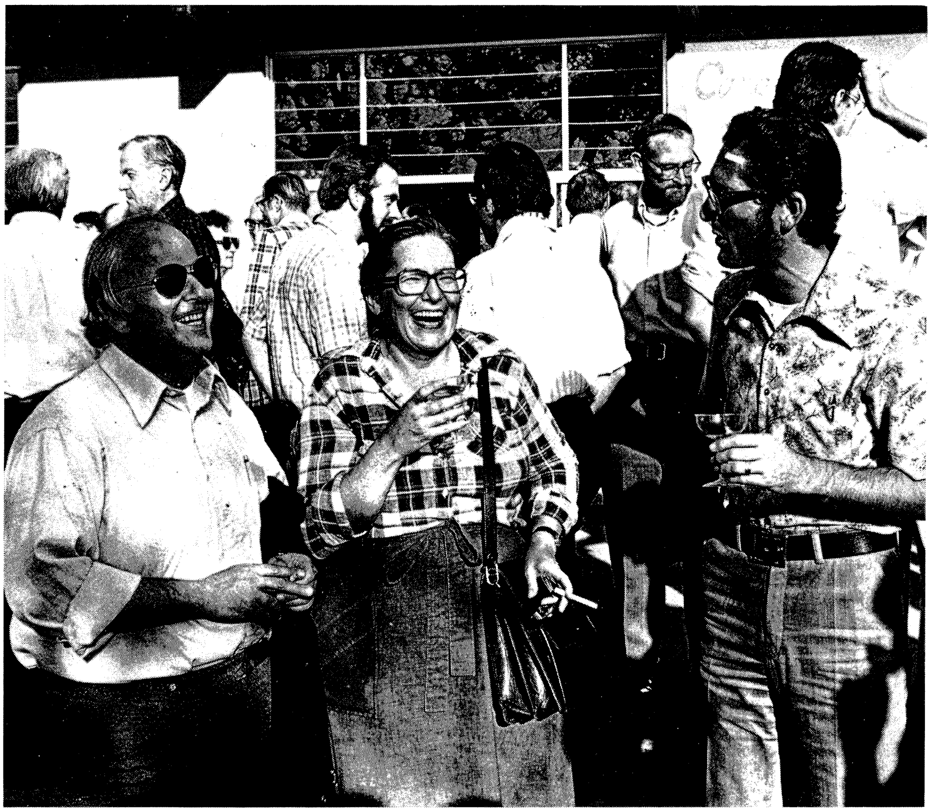
. . . to be shared equally between Professor Burton Richter, Stanford Linear Accelerator Center USA, and Professor Samuel C.C. Ting, Massachusetts Institute of Technology Cambridge USA, for their pioneering work in the discovery of a heavy elementary particle of a new kind.'

With this citation the physics Nobel Prize went to Burt Richter and Sam Ting who led the teams which found the J/psi particle just two years ago. It is rare that discoveries are so rapidly recognized by the highest award in science. This reflects the dramatic effect of J/psi on the world of high energy physics — so dramatic that since the events of 1974, we talk of 'the new physics'.

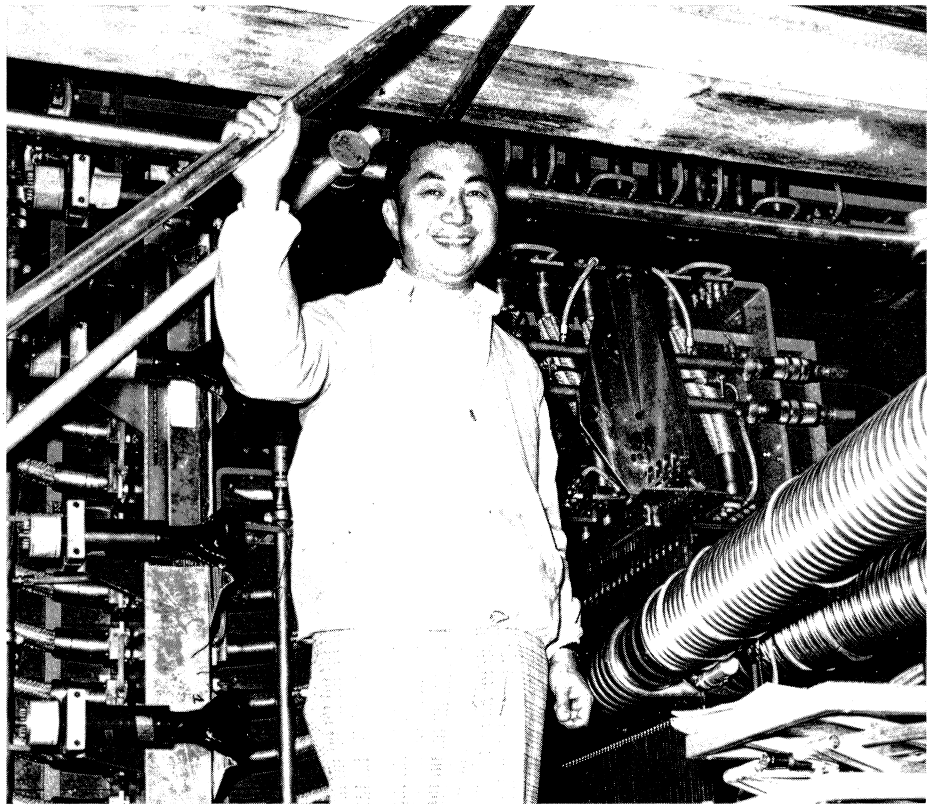
Sam Ting was born in the USA in 1936 of Chinese parents. His early years were spent in China in a University environment but without regular schooling until he was 12 years old. At the age of 20 he returned to the USA and took a physics degree at the University of Michigan. His first schooling in experimental techniques was at Berkeley with W. Jones and Martin Perl and then at CERN with Giuseppe Cocconi. He worked at CERN with Marcel Vivargent, Klaus Winter and Gustaf Weber. In 1965 he joined Columbia University, which was then blessed with Leon Lederman, Jack Steinberger, Mel Schwartz, T.D. Lee and I.I. Rabi, and a year later launched on a long, painstaking programme of research looking at lepton pairs emerging from particle interactions.

The programme started at the DESY electron synchrotron at Hamburg, then moved to the Brookhaven proton synchrotron and now continues at the CERN Intersecting Storage Rings. During this time, Sam Ting has refined to a remarkable extent the experimental techniques which are necessary to sift out leptons from whatever other particle debris is flying around. He has

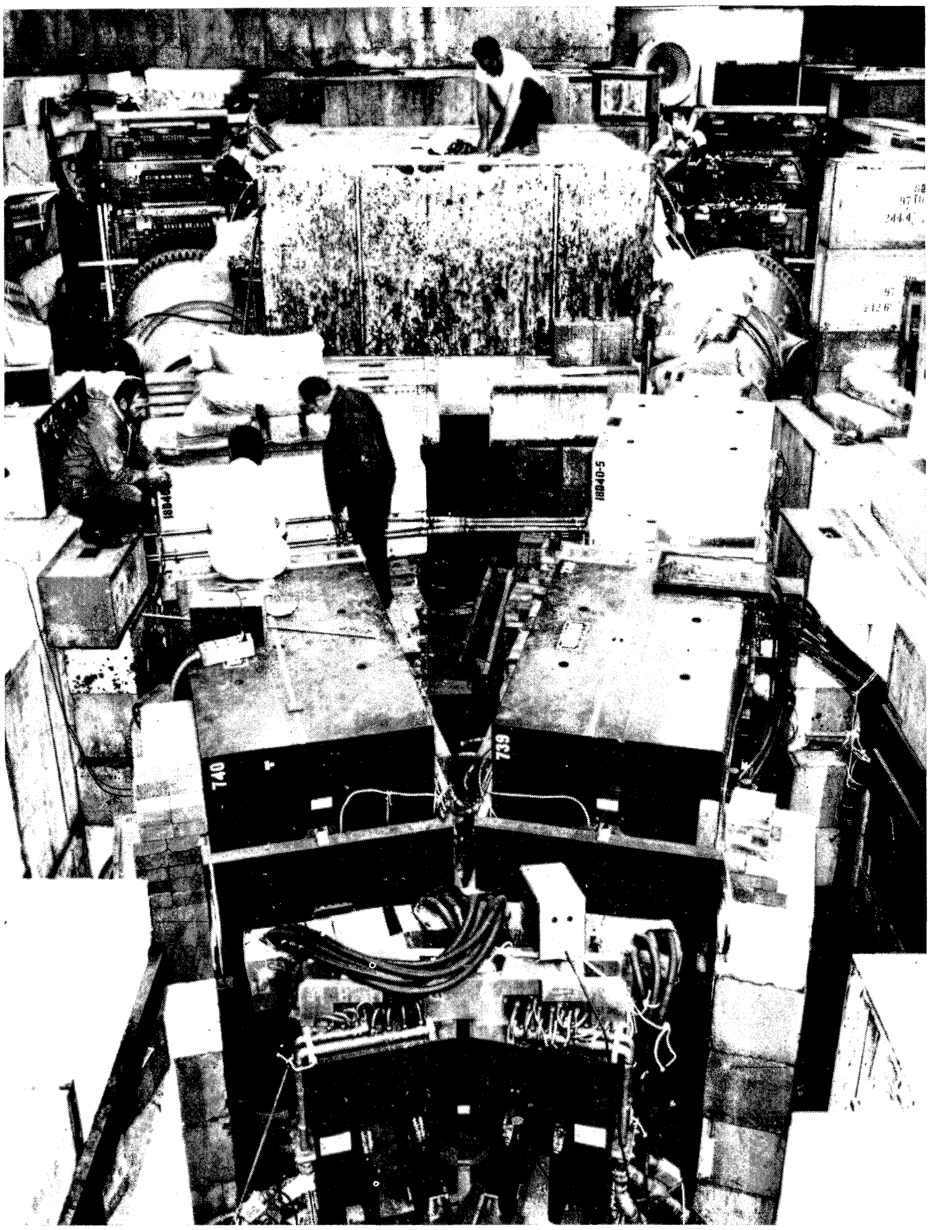
Burt Richter (left) with his wife Laurose enjoy a joke with Stan Flatté during the party at SLAC to celebrate the Nobel prize award. (Photo Stanford News Service)



A smiling Sam Ting at his experiment at the CERN Intersecting Storage Rings where he continues the search for leptons which has dominated his research life.



CERN 213.10.76



The double arm spectrometer of the MIT/ Brookhaven beam which detected electron-positron pairs coming from the decay of the J/psi particle. The measurement of the decay in the midst of a very high background from other interactions was a triumph of experimental technique.

(Photo BNL)

been driven by a strong intuition, now so abundantly confirmed, that good physics is hiding in the study of particles which materialize into lepton pairs.

Burt Richter was born in New York in 1931. In 1956 he took his Ph.D. at Massachusetts Institute of Technology (where he was particularly influenced by Francis Friedman) and moved to Stanford to devote his research life to electrons since the study of quantum electrodynamics at short distances had caught his imagination. A key point in determining his future career was involvement with Gerry O'Neil and others from Stanford and Princeton in the building of the 300 MeV electron storage rings which first collided beams in 1965. During the building of this machine he sketched, together with Dave Ritson, an outline of a 3 GeV electron-positron colliding beam facility which evolved to become the famous SPEAR storage ring at the Stanford Linear Accelerator Center.

The construction of SPEAR, under Burt Richter and John Rees, began in 1970 and was completed, with great rapidity and at modest cost, in 1972. At the same time he led, with Martin Perl, Willy Chinowsky, Gerson Goldhaber and George Trilling, a Berkeley/ Stanford team which built a multi-purpose detection system surrounding one of the SPEAR interaction regions.

This dual role of storage ring builder and experimenter gives him a rare understanding of the physics possibilities with colliding beams. Like Sam Ting he has been driven by a strong conviction that the electron-positron system, which does not have the complications of colliding hadron systems, is a clean way to extract physics.

Burt Richter continues to pursue the same path. He is prominent in the experimental programme being prepared for the Stanford PEP storage ring. Also, during a sabbatical year at CERN in 1975-76, in addition to participating in an ISR experiment, he outlined the physics interest and the design of an electron-positron storage ring with an energy of about 100 GeV per ring.

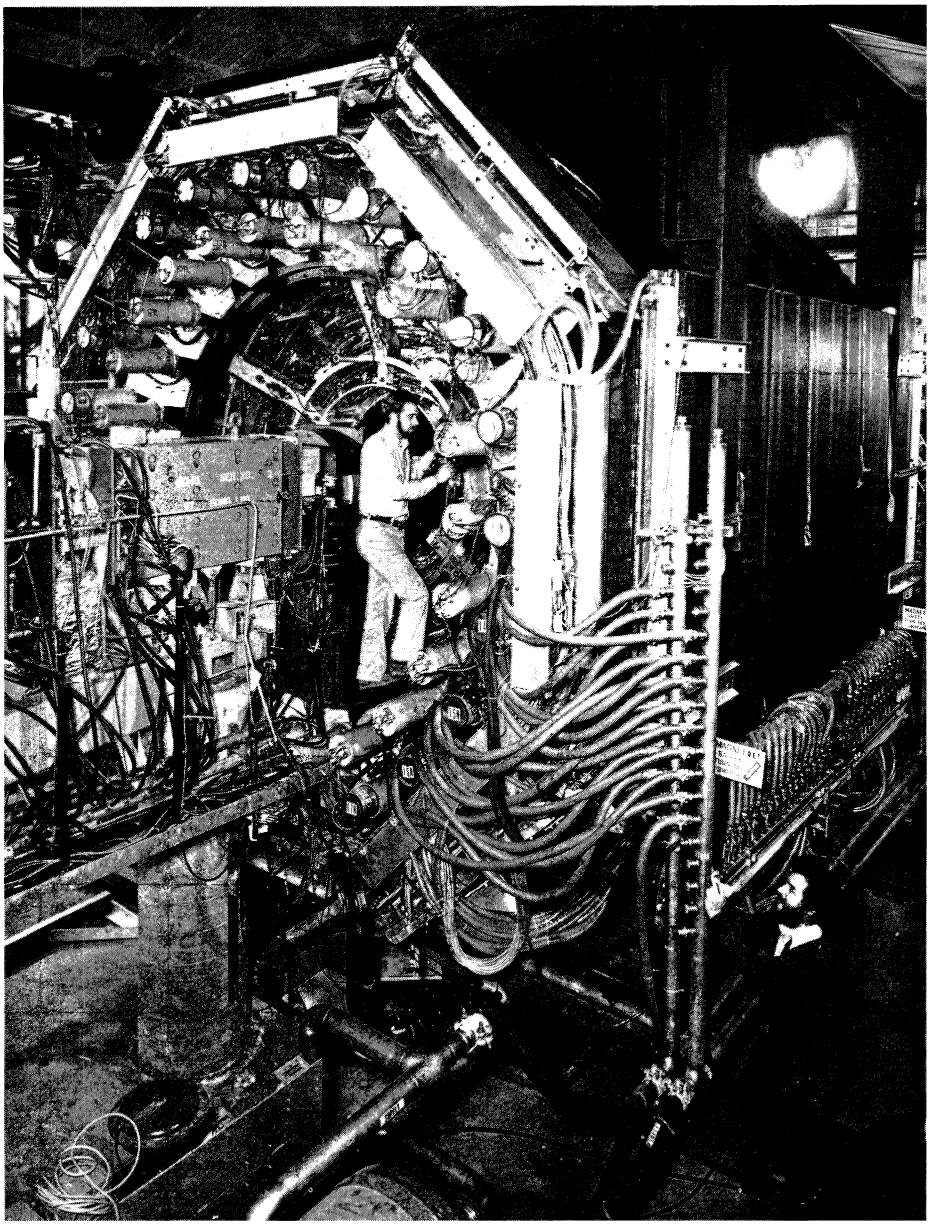
The discovery of J/psi

Returning to 1974, the story of the discovery which led to the Nobel Prize awards bears retelling:

Sam Ting led a MIT/Brookhaven team looking at collisions between two protons which yielded (amongst many other things) an electron and a positron. The aim was to study some of the electromagnetic features of particles where energy is manifest in the form of a photon which materialized 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, Jean Aubert, Ulrich Becker and Peter Biggs brought into action a detection system with a double arm spectrometer in a slow ejected proton beam at the Brookhaven 33 GeV synchrotron in the Spring of 1974. They used beams of 28.5 GeV bombarding a beryllium target.

From about August, the realization that they were on to something important began 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,



The famous magnetic detector of the Berkeley/Stanford team which surrounds one of the intersection regions at the SLAC SPEAR electron-positron storage ring. This detector found the J/psi and several other members of the 'charmonium' family of particles and, this year, has added the discovery of charmed mesons.

(Photo SLAC)

is identified by adding up the energies of more stable particles which emerge from its decay.

The particle decaying into the electron and positron they were measuring was a difficult one to swallow. The energy region has been scoured before, though not so thoroughly, without anything being seen. Also the resonance was looking 'narrow' — 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 and 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 the 3.1 GeV particle and were getting ready to publish their result. They baptised it J which is a letter close to the Chinese symbol for 'ting'.

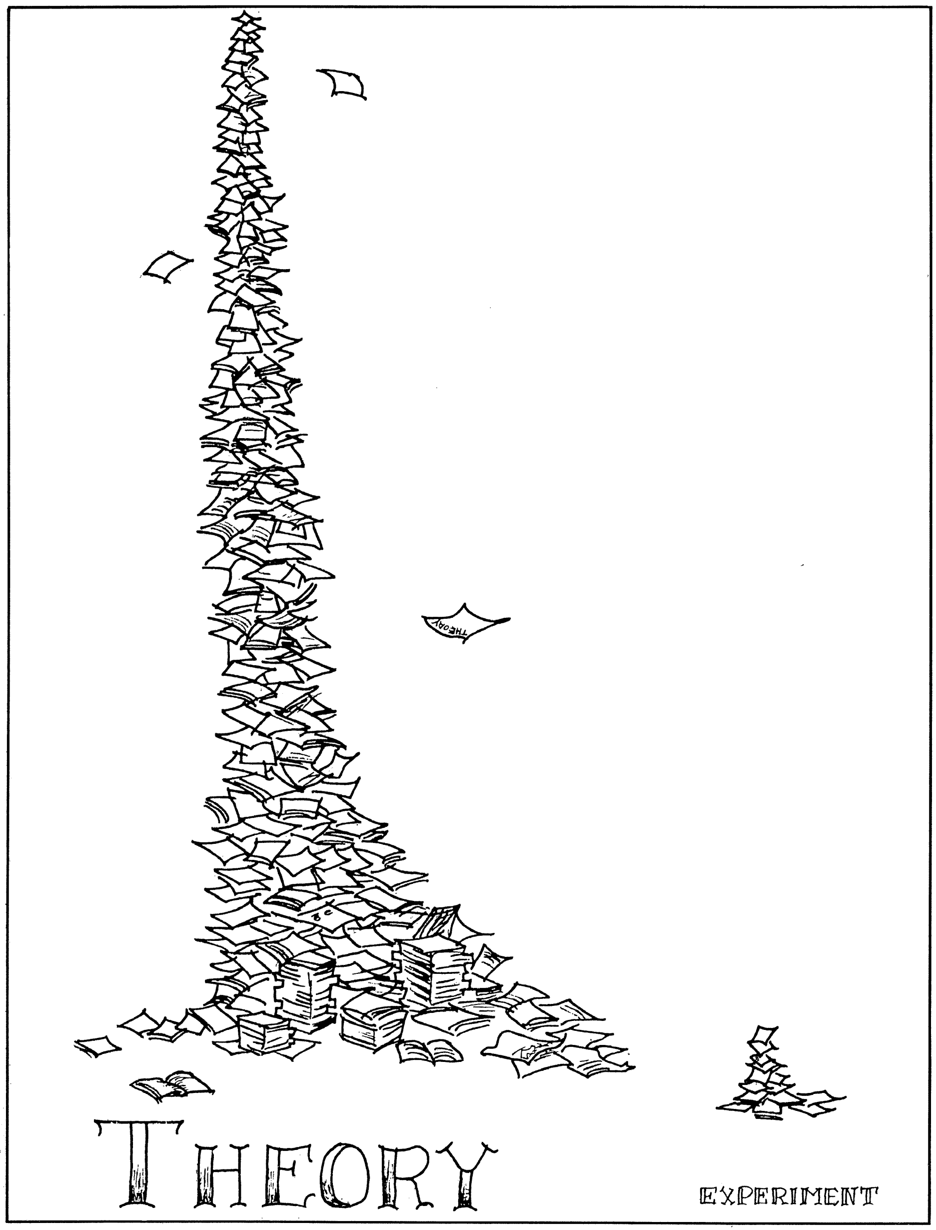
The apparition of the same particle at the Stanford Linear Accelerator Center was nothing short of shattering. Burt Richter described it as 'the most exciting and frantic week-end in particle physics I have ever been through'.

The Berkeley/Stanford team went into action during the week-end 9 - 10 November to check back on some 'funny' readings they had seen in June, when cross sections (the probability of an interaction between an electron and positron occurring) were measured with electrons and positrons at 1.5, 1.55 and 1.6 and 1.65 GeV energy in each beam. The measurement at 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). It was John Kadyk who first spotted the anomalies. Obviously, a gremlin had crept into the apparatus? While meditating in the following months during the transformation of the storage ring, 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 was cracked open and the team began celebrating an important discovery.

While Gerson Goldhaber retired to write up the findings 'on-line' for immediate publication, 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, paced around the control room invoking the Deity in utter amazement at what was being seen. This heavy particle, displaying such extraordinary stability, they called psi and they announced it in a paper beginning with the words 'We have observed a very sharp peak . . .'.

Within hours of the SPEAR measurements, the telephone wires across the Atlantic were humming as information, enquiries and rumours were exchanged. On the Monday morning following the week-end of the discovery at Stanford, Sam Ting was at SLAC to attend a scheduling committee meeting. He went to Burt



Dave Jackson's 'very sharp peak' in the number of theoretical papers stemming from a small number of experimental results. It illustrates what the discovery of J/psi has meant in attempting to interpret the workings of Nature.

Richter's office and announced 'Burt, I have some interesting physics to tell you about'. To which the reply came 'Sam, I have some interesting physics to tell you about'.

Very quickly afterwards, the electron-positron storage rings of Frascati and DESY were successfully in on the act (DESY adding some teutonic precision and correcting the SLAC mass value slightly by a more accurate calibration) and the theorists were let loose in pastures new where they have gorged themselves ever since (as is amusingly portrayed on Dave Jackson's cartoon).

The new physics

Why all the excitement! After all, we could draw up a list of some 200 particles, before the J/psi discovery. Why should one more provoke invocation of the Deity? The answer lies in its extraordinary stability. Such a heavy particle would normally have dozens of ways of breaking up and, with so many possibilities open to it, would not stay together for longer than about 10^{-23} seconds. In fact the particle is stable for 10^{-20} seconds. If a man lived for 70 000 years, rather than for 70, he also would be likely to provoke invocation of the Deity!

It is obvious that there must be some special characteristic of the J/psi which prevents it from breaking up. One characteristic had already been mooted for other reasons, though no convincing evidence of its existence had been seen; it is called 'charm'. (The use of everyday words to describe particle properties can be confusing but when observing a completely new phenomenon, it can be described by any word whatsoever. The choice of words like 'strangeness' and 'charm' only reveal the little known fact that physicists are human beings capable of indulging their own whimsies. 'Charm' is simply the word used for a particle property that has never been seen before.)

Charm was in the air as a consequence of the discovery of neutral current interactions at CERN in 1973. During neutrino experiments in the heavy liquid bubble chamber, Gargamelle, it was found that the neutrino can collide with a particle and emerge from the interaction as a neutrino. Previously only charged current interactions, where the neutrino converted to a muon, had been seen.

This discovery has broad implications for the interpretation of the weak and electromagnetic forces but, for the present story, the important consequence is that the existence of neutral currents should mean that other interactions (like the decay of a kaon into two muons) should be seen. Since they are not seen, the new property called charm was proposed (particularly by S.L. Glashow, J. Iliopoulos

One of our favourite cartoons from the era of the discovery of the J/psi is this projection by Bob Gould from SLAC of the reaction of the 'man in the street' at a time when high energy physicists were in a state of euphoria. Salutary reminder to all who attempt to popularize science.

and L. Maiani — leading to the notation 'the GIM theory') as the reason which prevents the interactions taking place.

It is by now well established that the properties of the strongly interacting particles, the hadrons, are carried by the quarks from which they are built. Prior to 1973/74, the evidence pointed to the existence of three quarks, called u (proton-like quark), d (neutron-like quark) and s (strange quark). The GIM theory suggested adding a fourth, c (charmed quark).

The J/psi was interpreted as a two quark combination, a meson, consisting of a charmed quark and a charmed antiquark sometimes known as 'charmonium'. (M.B. Einharn and C. Quigg of Fermilab maintained that the new property should have been called 'panda'. The J/psi would then have been 'pandamonium' which is a fair reflection of the furore its discovery provoked.)

The charmonium interpretation of the J/psi is in direct analogy to the interpretation of another very stable heavy meson, the phi meson. The phi is built up of a strange quark and a strange antiquark. Despite its high mass of about 1 GeV, it has difficulty breaking up because it likes to go to two kaons, which also each contain a strange quark or antiquark, so as not to lose the strangeness property. But the kaons are each of mass about 0.5 GeV and the phi has not enough mass to break up easily into kaons.

The stability of the J/psi is then interpreted as due to its charm quark constitution. It likes to go to two charmed particles which each contain a charmed quark or antiquark, so as not to lose the charm property. But the charmed particles are of too high a mass to allow an easy break up.

The idea explains the J/psi away but says a lot more besides. If we buy the idea of a charmed quark we must be able to build hadrons with it in three quark and two quark combinations just as we can build them with the u, d and s quarks. Thus previously unobserved families of particles must exist — for example, mesons such as D° ($u\bar{c}$), D^{-} ($d\bar{c}$) and baryons such as Λ_c (udc) etc. . . .

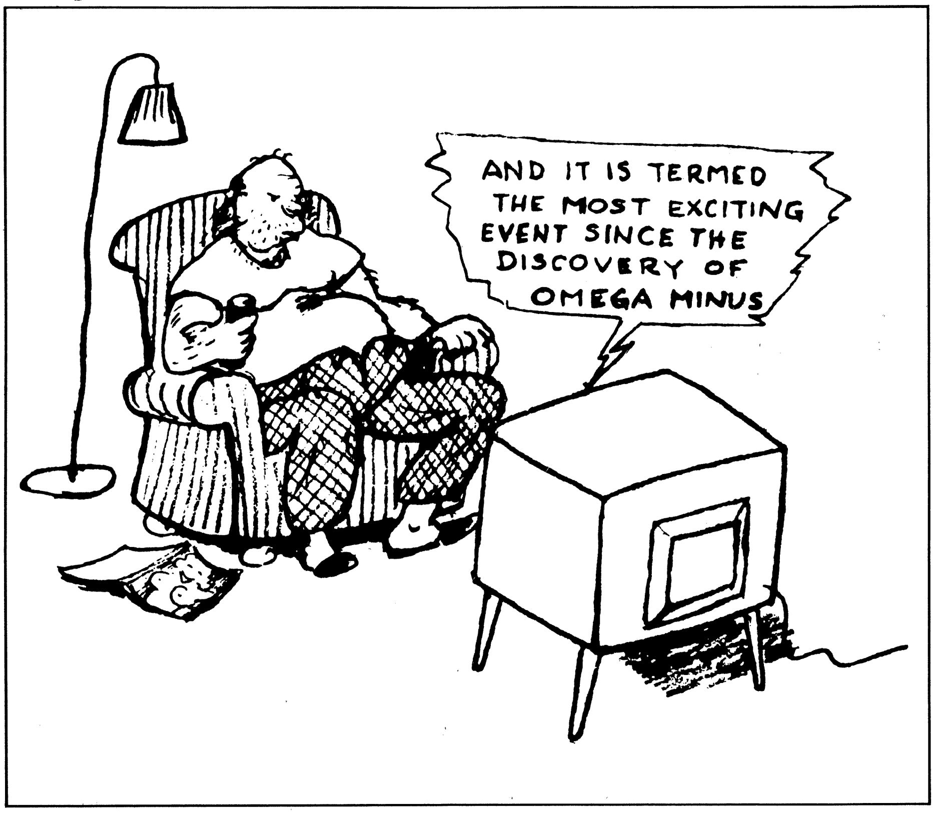
What has been found?

While the theorists have been wearing out pencils at high speed, experimentalists have been searching for signs of the charmed particles.

Ten days after the J/psi discovery, SPEAR struck again with a second psi at a mass of 3.7 GeV. The theorists were then able to predict a series of mass states of charmonium — equivalent to different configurations of the charmed quark and antiquark orbiting one another. (Such configurations have been familiar from back in the days of atomic physics when the positronium system of an electron and positron orbiting one another was studied.) The storage ring DORIS at DESY and SPEAR at Stanford have now clocked up at least seven members of the charmonium family, with masses in excellent agreement with the theoretical predictions. But these particles are not charmed particles, properly so called. The quark-antiquark combination cancels out the charm.

In looking for charmed mesons and baryons, the clue is the conversion of the charmed quark into a strange quark either in semileptonic decay where it would be accompanied by a positron and a neutrino or in hadronic decay where it would be accompanied by mesons.

During 1975 bubble chamber pictures of neutrino interactions in the 7 foot chamber at Brookhaven, in the Gargamelle chamber at CERN and in the 15 foot chamber at Fermilab



recorded interactions which could not be explained by the old physics but which fitted the new physics predictions of semileptonic decays of charmed particles. In addition there was a lot of evidence, particularly from Fermilab, of the direct production of two leptons in neutrino interactions which again requires new physics for their interpretation.

These observations could not, however, be used to estimate charmed particle masses with accuracy (though the Brookhaven event could have a good shot at it). Specific identification with mass assignments came this year. At SPEAR, the D mesons were seen via their hadronic decays — the neutral D meson with a mass of 1.86 GeV and the charged D mesons with masses of 2.02 GeV and 2.12 GeV. The same mesons have been seen in semileptonic decays on DORIS. At Fermilab the antiΛ_c baryon with a mass of 2.26 GeV has been seen in its hadronic decay.

The pro-charm evidence is now overwhelming.

The discovery of J/psi rejuvenated high energy physics. It has revealed aspects of Nature's behaviour which were totally unexpected and has prompted one of the major advances in understanding matter. The award of the 1976 Nobel Prize for Physics to Burt Richter and Sam Ting recognizes this achievement.

Physics at PETRA

Will the next generation of electron-positron storage rings be as successful as those now in action or even more so? The rush of high energy physicists to the interaction regions of PETRA, the storage ring under construction at DESY, indicates a world-wide belief that very interesting physics is going to be unearthed at centre of mass energies up to 40 GeV.

One obvious reason is that, at PETRA, physicists will be penetrating a new energy region and unexpected phenomena may be seen. They will also be able to ask some vital questions even on the basis of what we know now. For example, is there an interference between weak and electromagnetic interactions at the new high energies (this would be a crucial test of the theories which attempt to unify our interpretation of the two forces). Will R, the ratio of hadron production over muon pair production, become asymptotic at PETRA energies, or will a change indicate new degrees of freedom in hadronic matter and new 'flavours' for the quarks to add to strangeness, charm. . . ? Are there more heavy leptons and, if so, will we begin to see some reason for the lepton spectrum?

On 19 October, the PETRA research committee, PRC, met for its fourth meeting and had to do some crystal ball gazing on all these questions in order to make recommendations on the initial experimental programme to the DESY Directorate.

In view of the expected international participation, six experimental halls are under construction among the eight intersection regions of PETRA. One of the difficult decisions was to specify how many of these available halls should already be committed at this time. Since only a little more than two years remain until the start-up of PETRA, some people felt that experiments which were not recommended now would come too late for the first generation. On the other hand, a certain flexibility to leave the door open for new ideas and future proposals has to be preserved. As a result of these deliberations, it was decided that four interaction regions should be committed now, leaving two empty for later decision. Fortunately, it turns out that more than one experiment can be accommodated per hall thus, as far as space is concerned, more than four experiments can be installed.

The proposed experiments fell into two classes — those which are specifically designed for PETRA and those which use existing apparatus. Although the latter may have some shortcomings, they have the advantage of being fully tested and debugged with a complete set of analysis programs.

The PRC recommended five experiments, two others, 'PHOENIX' of an Athens / DESY / Frascati / Pisa / Rome / Stony Brook / Wisconsin collaboration and the 'Iron Ball' of a Pennsylvania / Wisconsin collaboration were not recommended, and two more will be considered at a later time. The experiments were approved under the following conditions:

It should be possible to remove the installation from the intersection region and to reinstall it in working condition within not more than five days for each operation, since long repairs cannot be tolerated at the intersection region. The installation should be such as to permit a second experiment to be installed in the same region. The PRC will review the preparations for experiments at regular intervals, and, if necessary, priorities will be recommended for the installation of various experiments at a later time. The running schedule for all experiments will be considered by the PRC at a later time.

The question whether four or only two interaction regions should get