# The New Particle Mystery: Solid Clues Now Lead to Charm

For eight months since two baffling new particles were discovered last fall, physicists have been waiting impatiently to find out whether experiments would support the leading hypothesis—namely that the particles were made of constituents having a hitherto undiscovered property called charm.

The wait has not been so long because of any winter indolence on the part of particle physicists. Nearly every high energy accelerator in the United States and Europe has been the scene of furious activity, and the new particles have been produced and studied in dozens of ways. High energy physicists have also been trying to find other particles that might exhibit charm even more directly than those discovered last fall. At an American Physical Society meeting in the spring, dozens of research groups presented carefully analyzed findings, but no consensus could be reached: the result was conflict and confusion.

But now the situation has changed. Just over a week ago a German research group announced the discovery of a crucial intermediate particle predicted by the theory of charm, and "the veil appears to be lifting," as one researcher said. Even the more conservative physicists now think that something like charm is the best bet, although they point out that the theory is not yet fully confirmed.

The intermediate particle has also been found at the Stanford Linear Accelerator Center, in Palo Alto, California, and word of the Stanford result is being spread widely in the physics community. However, because the work will be submitted to *Physical Review Letters*, whose policy it is to withhold publication of research that was previously announced in the news media, Stanford researchers cannot discuss their results publicly yet. The German research group, which was working at the Deutches Elektronen-Synchrotron (DESY) accelerator in Hamburg, expect to publish their results in *Physics Letters*, which has no such embargo against news coverage.

The two particles discovered last November were remarkable for their weight and their longevity, and were hailed as the first evidence of a new family of particles that might provide answers to the myriad problems that had been cropping up in high energy physics (*Science*, 6 December 1974). The particles are three to four times heavier than a proton, yet live much longer than expected for such massive entities. The lighter particle, with a mass of 3.1 Gev, was discovered simultaneously at Stanford and at Brookhaven National Laboratory, Upton, Long Island. The heavier one, with a mass of 3.7 Gev, was found less than two weeks later at Stanford. Subsequent research quickly showed that the heavier particle often decayed into the lighter one by emitting two charged particles (pions).

But the charm theory predicted that the heavier particle should also decay by a neutral process quite often, specifically by emitting gamma rays. In spite of a long and hard search, Stanford researchers working with Robert Hofstadter announced in April that they could not find the predicted gamma rays, even at a fairly sensitive detection level. The German researchers were also looking for the telltale gamma rays, as well as other aspects of the new particle interactions, with a powerful detector called the double arm magnetic spectrometer (DASP). The detector operates at one of the interaction regions of the DESY storage rings, where electrons and antielectrons collide (Fig. 1). When the electron beams are tuned so that their energies add equally to 3.7 Gev, the particle with that mass is produced in the interaction region.

What the DESY researchers found, in approximately 50 instances, was that two gamma rays were emitted as the heavier particle decayed to the lighter one. The discrete values of the gamma ray energies, 200 and 400 Mev, indicate that the particles are passing through an intermediate state as they decay. The intermediate particle has a mass of either 3.5 or 3.3 Gev, depending on which gamma ray is emitted first. On 11 July the group, composed of researchers from the Technical University in Aachen, the University of Hamburg, the Max Planck Institute for Physics in Munich, the University of Tokyo, and DESY, announced their result at a summer school for high energy physics in Erice, Sicily.

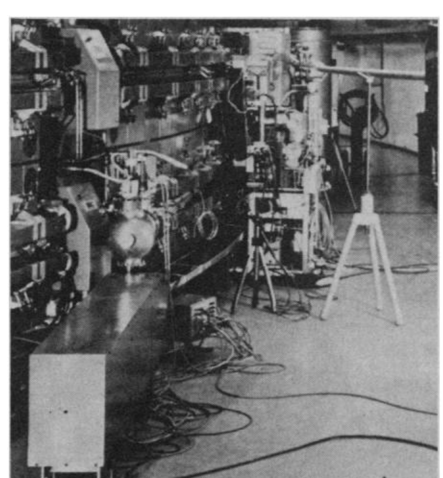


Fig. 1. The double storage rings at the DESY accelerator center in Hamburg, Germany, viewed at the point where positrons are injected into the upper ring. Detectors where the two rings intersect have found more new particles.

The DESY researchers have the reputation of being very conservative about their conclusions, and almost withheld the Erice announcement because they couldn't specify which of the two energies was correct. However, DESY may have had the data for some time, as there was a hint of the Erice announcement in the European particle physics magazine, the *CERN Courier*, a month earlier.

The Stanford data, however, clearly distinguish which gamma ray comes out first, and it is the lower energy one. The result indicates that the intermediate particle has a mass of 3.5 Gev, which is almost exactly what was predicted by charm theorists last winter in the first rush of papers attempting to explain the new particles. [The detailed argument that leads to the 3.5-Gev mass assignment is that, while Stanford researchers also see 200- and 400-Mev gamma rays occurring together, some of the time they see a 200-Mev gamma ray and four charged particles, probably pions. The four particles could only come from the decay of the intermediate state, which must therefore be 0.2 Gev lighter than the (3.7-Gev) particle that started the cascading decays.]

Charm is a property thought to be embodied by a fourth quark, in addition to the three quarks that have long been postulated as building blocks of the "elementary" particles. The charmed quark hypothesis was suggested in 1963 by Sheldon Glashow, now at Harvard, to explain some problems with the weak interactions. The charm-theoretical explanation of the heavy new particles is that they are composed of a charmed quark and its antiparticle, revolving about each other in orbits similar to those of a hydrogen atom. In accordance with the names of other hydrogen-like atoms, the quark construct has been called charmonium. The 3.7-Gev particle is thought to be an excited state of the 3.1-Gev particle, differing from it only in the fine details of the quark orbits. Both are assumed to be states formed by $S$ orbitals, in the terminology of atomic spectroscopy.

Pushing the analogy with hydrogen further, if $S$ states exist, $P$ states of the quark molecule should also be found—but with rather different properties. These are the particles predicted, and now apparently found, at 3.5 Gev. Simple theoretical considerations actually predict four of them, with nearly identical masses. Evidence for more than one may already be present in the data at DESY and Stanford, according to high energy rumors.

The theorists who have advocated charm are ecstatic over the latest development—coming as it does after a long period of discouraging news. "I am of course delighted," wrote Thomas Appelquist from a summer institute in Corsica. "It was one of the essential predictions of our work [H. D. Politzer] and other works on charmonium." Sheldon Glashow, lord of the realm of charmonium, is also pleased and is optimistic that the ultimate confirmation of the theory of charm will soon be realized. But even the charm theorists think it may be premature to pass judgment. One thing that bothers them is that the gamma ray transition proceeds at a rather low rate—about an order of magnitude slower than predicted in a careful study by E. Eichten and colleagues at Cornell University, Ithaca, New York. But the dynamical transitions of charmonium can be modeled in many ways, and a variation by John Kogut, at Cornell, may match the observed gamma ray rate.

The number of theoretical papers purporting to explain the new particles has outweighed the number of definitive experimental results to the extent that the height of the theoretical paper pile was the subject of a cartoon not very long ago. Now, says Glashow, "The only thing left is charm itself." James D. Bjorken, at Stanford, who also played a part in the early postulation of charm, is more conservative about the powers of the charm theory (and more conservative than most other theoretical physicists, by his own description). Bjorken thinks that charm is probably the best theory around but says, "I don't have much confidence that the physics will turn out to be exactly the way the theoretical consensus would have it to be." There are many variations possible on the charm theme, says Bjorken, and "it wouldn't take many twists in the theory to completely change the nature of the search."

The charm theory predicts that there are many more particles to be found, and failure to find some of them could still scuttle the theory. Clearly the strictest test will be the search for particles that exhibit charm directly.

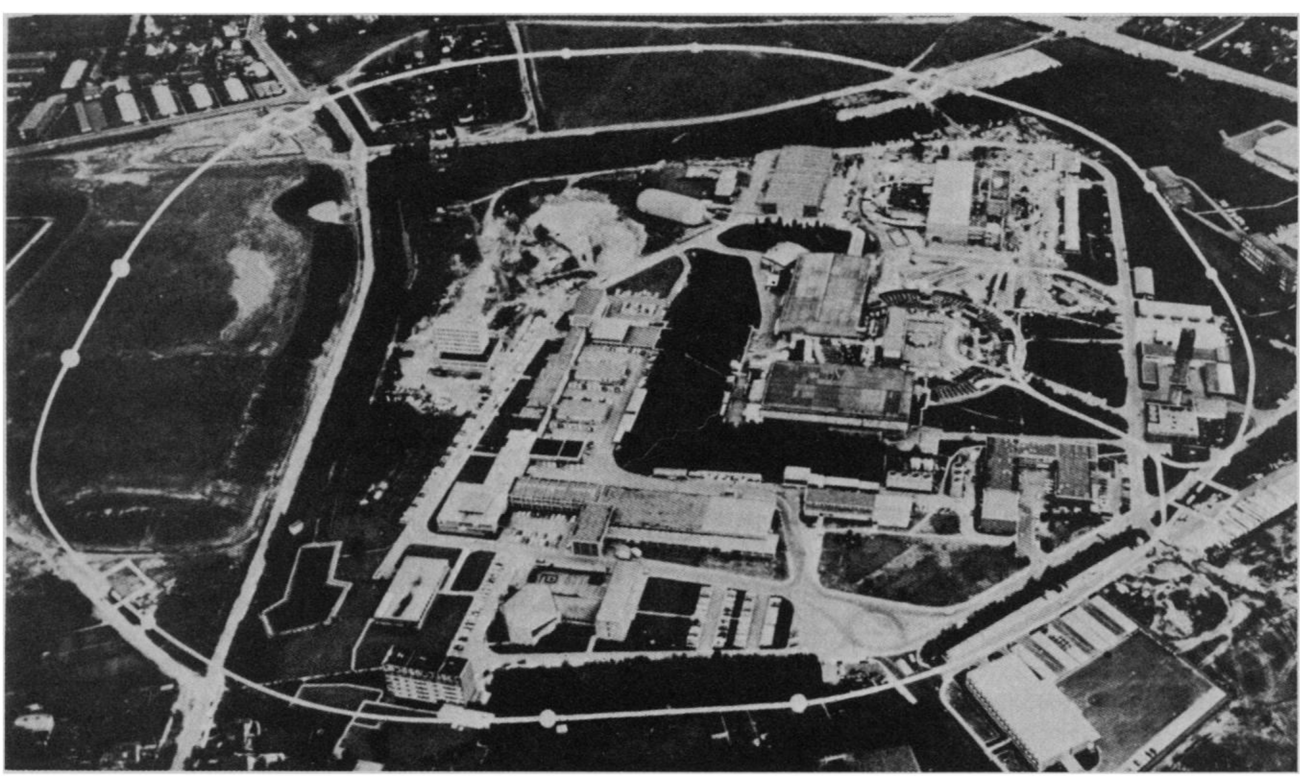
In the three new particles found so far, both the quark and the antiquark are presumed to have charm in opposite amounts, so the property is canceled out. But strongly interacting particles should also exist with net charm (that is, composed of one charmed quark and other normal quarks). Charmed mesons are expected to be found with masses of 1.9 Gev or more, and charmed baryons may have masses of 2.2 Gev or more. In each case, there should be a whole family of charmed particles.

To find these charmed particles and determine their properties is without doubt

# DESY: West Germany's Biggest Accelerator Center

The European accelerator that scooped Stanford by finding what appears to be the first confirmation that some elementary particles have a hypothetical property called charm is the Deutsches Elektronen-Synchrotron foundation (DESY).

The DESY laboratory has the largest electron accelerator facility in Europe, and its research capabilities are comparable to those at the Stanford Linear Accelerator in Palo Alto, California. At the present time, only these two electron accelerators have enough energy capability to produce both perplexing new particles that were discovered last fall. The



The circular building (right center) is the electron synchrotron accelerator at DESY, and the white building behind it sits above the present storage rings. A much larger storage ring is proposed (white line) for producing colliding beams of 19-Gev particles.

the most important problem ahead of the high energy physicists, says Bjorken. "Charmonium does not really imply charm," he says. "It implies a couple of new degrees of freedom in the elementary particles. But whether they should be identified with the charmed quark of the weak interactions—Glashow's charmed quark—that's an open question."

There are reports of new particles (besides the 3.1-, 3.5-, and 3.7-Gev ones) coming from almost every quarter, although the new findings are in most cases too vague to point directly to charm. Experimenters working with N. P. Samios at Brookhaven have found something that appears to be a charmed particle with a mass of 2.4 Gev, but with only one event the finding is open to question. Researchers working at the Fermilab are finding unusual effects in neutrino interactions that produce two muons. The interpretation is that a new particle with a mass between 2 and 4 Gev is being produced, and it could be a charmed baryon, although David Cline, Al Mann, Carlo Rubbia, and their colleagues are not committing themselves to the charm connection.

The list of new particle possibilities does not end with charm. Experiments measuring the probability that colliding beams of electrons and positrons produce strongly interacting particles of any kind [*Science* **184**, 782 (1974)] suggest that several more surprises will be found between 2 and 4 Gev. One such object is a heavy lepton—that is, a particle with the same properties as the electron and muon but many times heavier. As luck would have it, before the end of the announcement-filled month of July, Martin Perl at Stanford reported that researchers there had found a new charged particle, dubbed the U-particle, that is produced in pairs at the Stanford storage rings. Though the U's could be charmed particles, another hypothesis is that they are indeed heavy leptons.

In calmer days in the world of particle physics, it used to be the case that only the most refined—indeed almost effete—experiments were done at electron accelerators. Occasionally a challenge to the formal theory of quantum electrodynamics would arise, and after a brief burst of activity the excitement would end as experiments reaffirmed more conservative theories of physics. After all, electrons were only point-like bits of charge, without a size or shape. How could they be as interesting as the big, varied hadrons that kept popping out of proton collisions like schmoos out of an Al Capp comic strip?

Well, the answer appears to be that head-on collisions between electrons and positrons are remarkable events, releasing as much pure energy in a very small space as a "big bang" at the beginning of the universe might have done, according to some estimates. More than a few new elementary particles may also be produced in the process.—WILLIAM D. METZ

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Italian electron facility at Frascati can just reach the energy needed to produce the first new particle, which occurs at 3.1 Gev, but not the second one, at 3.7 Gev.

The new particle discoveries have shifted the focus of elementary particle research to electron accelerators, for the moment, and as a result DESY is now on a par with the larger multinational European laboratory, CERN, in Geneva, Switzerland. Unlike CERN, however, DESY is a national enterprise, with 90 percent of its $34 million budget coming from the Federal Republic of Germany and 10 percent from the city of Hamburg. Perhaps to emphasize the national character of its accomplishments, the acronyms for laboratory facilities often begin with D—and guess what letter DESY scientists have suggested to name the new particle they reported.

The Hamburg research center started operation in 1964, with a 100-meter-diameter synchrotron capable of accelerating electron beams to an energy of 7.5 Gev. That synchrotron remains at the heart of the laboratory operations today, and is also essential to plans to start upgrading the facilities as early as next year.

Not far away from the synchrotron is the storage ring facility, where the new particles are being studied. Fed from the synchrotron, the two storage rings, which lie on top of each other in the same circle, are filled with beams of electrons and positrons (antielectrons). At two points where the rings intersect the electrons and positrons collide head-on, annihilate each other, and produce new particles. The storage rings are named DORIS, an acronym taken from Doppel-Ring-Speicher. Other machines with colliding electron beams have only a single ring, in which the electrons and positrons circulate in opposite directions.

Construction of the DORIS storage rings began in 1969, and experiments just started last summer. DORIS now operates at energies up to 3.5 Gev for each of the colliding beams. After an August shutdown for improvements, it should reach 4.3 Gev. (Only 1.55 Gev in each beam was needed to produce the first new particle, which has an energy-equivalent mass of 3.1 Gev.) It takes about 20 seconds to fill the electron ring and 5 minutes to fill the positron ring. After that, the beams can be stored for 10 to 20 hours of useful data production before the rings have to be refilled.

The next step in the DESY expansion plan will be a much larger storage ring named PETRA, if the German science ministry, which now has a special committee reviewing the project, rules favorably. PETRA would be a single ring 2.3 km in circumference, with eight curved parts and eight straight sections (see photograph). It would encircle most of the present buildings at DESY. The proposed new storage ring could be built at the comparatively low cost of $40 million because the existing synchrotron and storage rings provide an ideal system for injecting beams into the larger storage ring, according to DESY officials. Having an intermediate-energy storage ring to accumulate positrons would be particularly valuable because intense positron sources are not available. The PETRA project would have a maximum energy of 19 Gev for each beam.

The energy of PETRA is comparable to that of the large storage ring, PEP, proposed by Stanford for the fiscal 1976 budget but originally turned down by the Office of Management and Budget. PEP was put back into the Energy Research and Development Administration budget, reportedly by Senator John Tunney (D–Calif.), and an $11.9 million appropriation has been passed by the House. The Stanford project has not, however, been finally authorized yet.

The special review of PETRA should be completed quite soon, and the project could be authorized by October. Since detailed planning of the project and a survey of the site are already complete, construction could begin as early as next spring.

No one knows, of course, what discoveries would be made with the proposed new electron storage rings, but they will probably not be succeeded by another generation of still higher energy machines—the pattern of succession that is now so familiar with proton accelerators. Electrons lose their energy much more readily than protons at higher energies, and to boost the energy of PETRA from 19 to 23 Gev the accelerating power would have to be doubled. From that point on, as one physicist put it, "you run into a stone wall."—W.D.M.