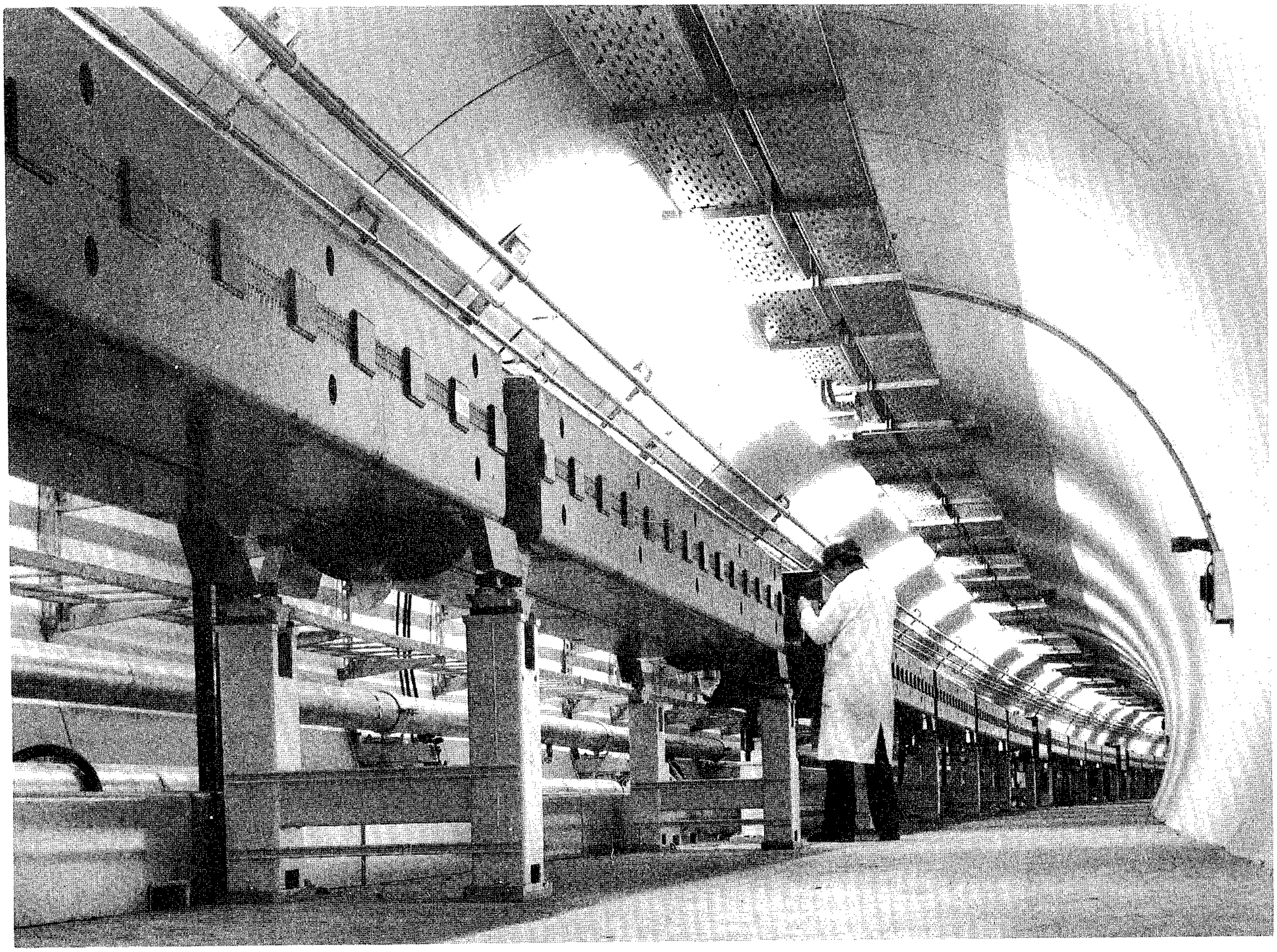
SLAC BEAM LINE

"There are therefore Agents in Nature able to make the Particles of Bodies stick together by very strong Attractions. And it is the Business of experimental Philosophy to find them out." -- Isaac Newton, Opticks (1704)

Volume 7, Number 7 *July 1976*



This photo shows a section of the CERN SPS (Super Proton Synchrotron), the 400-GeV accelerator that has recently begun operating at the CERN Laboratory in Geneva, Switzerland. *(Photo CERN.)*

Contents

**Note:* In this issue we report on the recent new-particle discovery at SPEAR in two different ways: (1) Pages *5-8* contain reprints of several popular descriptions from a newspaper and magazines. (2) The separate section on "Charmed Particles" is more complete but also more technical, and for this reason we plan to make a separate, smaller distribution (about 50%) of this article to *Beam Line* readers at SLAC. Additional copies can be obtained from (or extra copies sent back to) Bill Kirk, Bin 80, or Herb Weidner, Bin 20.

BK & HW

SLAC AFFIRMATIVE ACTION TASK FORCE

[Note: The June 21, 1976 memo from SLAC's Director, W. K. H. Panofsky, to All Hands described the recent establishment of a new Affirmative Action Task Force (AATF) at SLAC. The memo also listed the initial membership of the AAFT, which we repeat here (with Bin numbers):

Sal Alvarado	66	John Harris	20
Mike Dawson	51	Harold Ito	23
Dorothy Ellison	20	Blanche Kelley	51
Larry Feathers	31	Nancy Kowerski	55
Pauletta Fountilla	62	David Tsang	55

(Advisor: Joan Minor 11)

The Charter of the AATF is given below.]

CHARTER OF THE SLAC AFFIRMATIVE ACTION TASK FORCE

I. NAME

The name of the organization described here is the SLAC Affirmative Action Task Force, hereinafter referred to as AATF or the Task Force. This organization is established in accordance with the provisions of the Director's memorandum, dated June 21, 1976: "Establishment of an Affirmative Action Task Force."

II. PURPOSE

A. To provide an affirmative, responsive, and recognized channel of communication, as well as a forum for the concerns and problems of minorities* and women at SLAC to the extent that these concerns and problems relate to and affect their employment at SLAC or Stanford University.

B. To provide on a voluntary basis contributions to the administration of SLAC's Affirmative Action Program (AAP).

C. To provide a diversified forum to help achieve the objectives of the AA Office (AAO).

III. METHOD OF OPERATION

Under the approval and direction of the AAO the AATF will:

A. Advise and assist the AAO in fulfilling SLAC's responsibilities under the AAP and ERDA's affirmative action requirements.

B. Survey and analyze the racial, ethnic and sexism climate and employment conditions at SLAC, and make positove recommendations for changes as needed to secure equal opportunity and treatment.

C. Receive and act upon concerns and complaints identified by individual members of the SLAC staff, by members of the AATF, or by the Affirmative Action Office in an attempt to solve problems at the lowest possible level.

D. Interact with local communities and agencies in an attempt to achieve AA goals and foster improved relations.

E. Interface with the SLAC Personnel Department on Equal Employment Opportunity (EEO) matters.

F. Participate in a continuing program of education in affirmative action and human relations.

IV. MEMBERSHIP

A. Membership in this Task Force shall be open to all SLAC employees. Selection of members will be based on the following general criteria:

1. Interest in and commitment to AA principles.
2. Sincere desire to work with the AA Office to achieve AA goals.
3. Ability to exercise discretion and maturity in dealing with confidential matters.

B. Members will be nominated by an *ad hoc* committee convened by the Director, who will select members based on the above criteria.

C. The number of members shall be limited to 10.

D. The initial membership shall be appointed for one calendar year. To provide continuity, the terms of half of the membership shall be renewed for an additional six-month period. New appointments under the above procedure (IV.B) shall be made on a semi-annual basis thereafter in order to replace half of the membership.

E. Whenever vacancies occur, nominations for replacement shall be submitted to the Director by action of the Task Force.

V. RULES OF CONDUCT

A. Each member shall recognize an obligation to participate sincerely and fully in the work of the Task Force. Each member shall demonstrate fair consideration of the rights, concerns and opinions of his fellow members, as well as members of the diverse SLAC community.

B. Considering the sensitive and personal nature of the work of the Task Force, each member shall adhere to a stringent standard of confidentiality.

(continued)

*Defined as Black, Spanish Surnamed, Asian American, and Native American.

C. Reasonable release time during working hours will be given to members of the Task Force. It is incumbent upon the individual members to coordinate such time with their supervisors to minimize disruption of their normal duties.

D. Individual members shall disclose any potential conflict of interest relating to a specific activity of the Task Force.

E. Members who miss three consecutive meetings without a reasonable excuse or prior notification will be subject to replacement.

VI. PROCEDURES

A. The Affirmative Action Officer shall conduct the business of the AATF as Chairperson; he will not be a voting member of the AATF.

B. Deliberations of the AATF will result in oral or written reports to the AA Officer. Records of deliberations shall be kept.

C. If an informal consensus on the nature of a report cannot be reached by the AATF, the matter shall be resolved by a formal voting procedure.

D. No business requiring a vote may be conducted unless a quorum is present. A quorum shall consist of at least 6 members present, and each member shall have one vote. A simple majority of those present will decide issues subject to vote.

E. In the unlikely event that the Chairperson does not concur with a recommendation of the AATF, the Chairperson and one member will present the issue to the Director for resolution.

VII. MEETINGS

A. Meetings will normally be scheduled for the second and fourth Thursdays of each month in Room 231 of the A & E Building at 1:30 PM.

B. Special meetings may be convened on notification by the Chairperson.

C. During a regular meeting, the Task Force at its discretion may caucus without the Chairperson present; however, during such caucus no votes shall be taken, nor shall any formal reports be prepared.

VIII. AMENDMENTS TO CHARTER

Amendments to this Charter may be initiated by vote of at least two-thirds of the membership of the AATF and must be approved by the Director.

PIONIUM, ANOTHER NEW QUASI-ATOM

[Reprinted from *Science News*, June 5 & 12, 1976]

Of all the particles known to physics, the oddest and most useless may be the muon. Often referred to as the "heavy electron," the muon shares all the properties of the electron except mass and stability. The muon is about 207 times as heavy as the electron and has a lifetime of about 2 microseconds. . . .

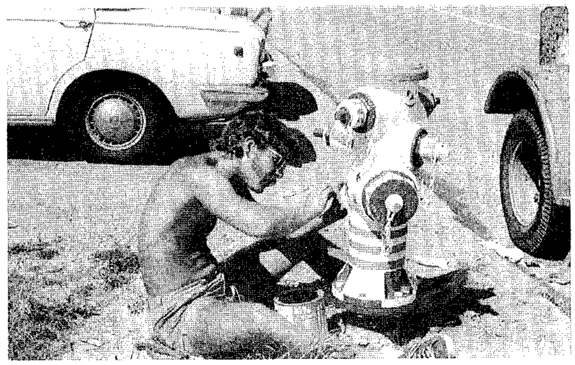
Some light may be shed on the nature of the muon by studies of a new kind of quasi-atom, called pionium, which has just been discovered at Brookhaven National Laboratory by a group led by Mel Schwartz of Stanford University. Quasi-atoms are systems in which particles not normally found in atoms become bound together in a way analagous to the proton and electron in a hydrogen atom and exhibit an atom-like hierarchy of discrete energy levels. Examples are positronium (electron and positron) and muonium (muon and electron). Quasi-atoms are generally unstable structures because they are subject to matter-antimatter annihilation (positronium) or because one or more of their constituents is radioactively unstable (muonium).

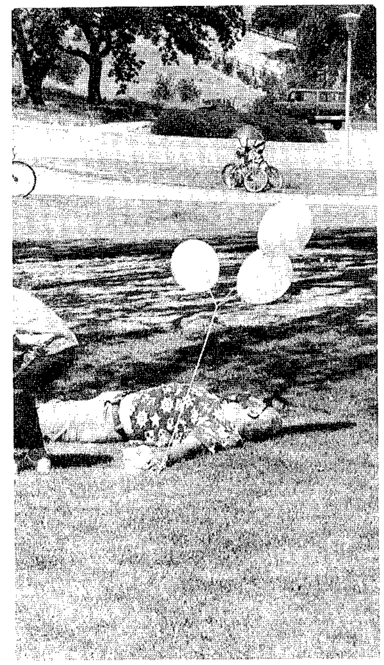
Pionium is a structure made of a muon and a pion. The pion is one of the particles believed to play a role in the exchange of forces that holds atomic nuclei together. It is much shorter lived than the muon, lasting only about 20 picoseconds.

The neat thing about pionium is that the only forces its constituents respond to are electromagnetic forces, and so the force that binds them must be purely electromagnetic with no admixture of other kinds of force. The theory of electromagnetic forces in particle physics, quantum electrodynamics, is the most thoroughly understood of all particle-physics force theories, and it will allow the expected force between the muon and pion to be calculated quite exactly. Faith in quantum electrodynamics is so strong that is experiment shows any discrepancy, the difference can be attributed to unknown properties of the muon, and it could give some insight into the outstanding mystery of this particle's existence.

Experimentally, pionium quasi-atoms appeared among the decay products of the long-lived neutral K-meson. (Long life in this case means 50 picoseconds.) Twenty-seven percent of all such decays yield a pion, a muon and a neutrino, but it is extremely rare that the pion and muon stick together as pionium instead of going their separate ways. In fact, it has never actually been seen before. The theoretically calculated probability of pionium's appearance is one chance in ten million. The experiment found 21 candidates for pionium (about one for every ten hours of running time) among many millions of K-meson decays. The experimental probability is now being calculated to see if it agrees with theory.

Schwartz and his group plan further pionium experiments at Brookhaven, and it is virtually certain that other physicists will soon get into the study of the new quasi-atom.





In these holdover photos from the SLAC Family Day shindig, Harvey Lynch recorded, from left to right: *Beam Line* photographer Joe Faust doing his thing; Alan Schmierer giving the hydrants a Bicentennial flavor; and Bob Sukiennicki trying to get his left hand airborne after giving up on the rest of the jaded organism.

(Photo by Joe Faust)

AL HOMER RETIRES TO TAHOE

Al Homer first came to SLAC as a carpenter who worked for the Time & Material contractor we had at that time. Since then he has held many different positions: Carpenter, Foreman Carpenter, General Foreman, and Contractor's Representative, depending on the number of men who were employed on the T&M contract.

Since Al has been with SLAC he has earned the respect of all who worked with him and the reputation of "getting the job done." He is a tough man to work for and a good man to have working for you. His versatility and many skills have been a great benefit both to his contract employer and to SLAC during the past 11 years. Al approaches any construction job, large or small, with equal enthusiasm. You name it and Al has built it for us--stairways, sewers, buildings, roofs, ramps, foundations, partitions, etc., as well as his particular speciality: concrete forms and the casting of many hundreds of concrete shielding blocks.

Al is a native of Minnesota. He came to California 30 years ago as a carpenter, and he worked for one contractor for 19 years before joining SLAC. He and his wife, Laura, have four children and four grandchildren. The Homers are now building themselves a home at Lake Tahoe, where they plan to retire.

All those who have worked with Al, especially me, will certainly miss him. Good luck, Al. We wish you all the best.

--Don Ewings

NEW ERDA ASSISTANT ADMINISTRATOR

Robert L. Hirsch has been confirmed by the Senate as the new Assistant Administrator for Solar, Geothermal and Advanced Energy Systems* at ERDA. Hirsch succeeds John M. Teem, who resigned the post in January. . . .

After he received his doctorate in nuclear engineering from the University of Illinois in 1964, Hirsch spent four years as a research physicist at ITT Industrial Laboratories, where he directed the nuclear engineering and plasma-physics department. In 1968 he joined the Atomic Energy Commission's CTR [Controlled Thermonuclear Research] program. He rose to the position of director of the CTR division in November, 1972, and continued in that role when ERDA was formed. . . .

--*Physics Today,* May 1976

[*This branch oversees ERDA's physical research program, which includes high energy physics.]

THE NEW PARTICLE DISCOVERY AS REPORTED BY OTHERS

On pages *5-8* we reprint four recent articles from a newspaper and three popular scientific magazines that describe the new-particle discovery at SPEAR. These articles are intended mainly for those readers who would like to find out about this recent discovery without having to wade through all the technical detail in the special pull-out section on "Charmed Particles" that is included as a separate part of this issue of the *Beam Line*. These reprinted articles appear in order of increasing complexity, with the first being the shortest and easiest to understand, etc.

A. A 'CHARMED' ATOMIC DISCOVERY

[*San Francisco Chronicle*, June 9, 1976]

Stanford and Berkeley scientists announced the discovery yesterday of what they think is a long-sought "charmed" sub-atomic particle.

If correct, they will have discovered a fundamental new property of matter, somewhat like electric charge, and helped make sense out of the bewildering complexity of hundreds of subatomic particles discovered by physicists in the past several decades.

Physicists have for years tried to find an underlying logic to the particles they have found in the atomic nuclei.

The result, largely from Caltech physicists Murray Gell-Mann and George Zweig, was the theory that three particles dubbed "quarks" could, if assigned the proper qualities, combine to form all the nuclear particles. In recent years the possibility of a fourth quark, with a quality called "charm," was added to the theory. Therefore discovery of a charmed particle lends great weight to the whole unifying theory of quarks.

The new particle was discovered by Stanford University and University of California Lawrence Berkeley Laboratory teams using colliding electron and positron beams at the SPEAR machine at the Stanford Linear Accelerator Center.

"Discovery of this particle is very, very exciting," said one of the project leaders, Berkeley physicist Gerson Goldhaber. "Of course, we need more proof to make sure what it is. The details are very complicated, but the important thing is that using the quark theory we predicted a charmed particle, and we found it just as predicted.". . .

--Charles Petit

B. NAKED CHARM REVEALED AT STANFORD

[*New Scientist*, 20 May 1976]

A nakedly charmed particle has been revealed at SPEAR, the US storage ring designed to collide electrons with positrons. The news comes 18 months after the discovery of the psi particle, which first raised hopes that charm was more than a theorist's dream. If the most popular model is right, the new particle consists of two quarks, one of which carries the special "charge" called charm. The psi particle in this model contains both a charmed quark and its antiparticle so that it exhibits no net charm. The new particle, on the other hand, would have a net charm of one.

. . . the SPEAR discovery is not the first claim to have discovered naked charm. Three bubble chamber experiments have thrown up evidence for its existence, and indirect evidence has come from two Fermilab counter experiments [see "Neutrino experiments may point toward charm" in the April 1976 *Beam Line*]. But all these experiments took place in neutrino beams where events are hard to come by (say a dozen events in a few million shots of counters or bubble chambers). SPEAR should be able to produce charm for examination more readily--although still with difficulty. So far SPEAR has produced 60 or 70 charmed particles out of a collection of about 25,000 events, an "efficiency" a few hundred times that of the neutrino experiments.

The SPEAR discovery is also made more prominent by the fact that it was expected much earlier. If SPEAR could make charmed quarks so prolifically when they were hidden in the psi, why did it not make them abundantly when they were separated? The hearts of charm theorists were already beginning to miss a beat or two over this problem. . . . Hence the recent success and sighs of relief among charmsters. The particle found by SPEAR is neutral and has a mass of 1.87 GeV. It has been found by summing all the data on electron-positron collision energies between 3.9 and 4.5 GeV, where the interaction rate between electrons and positrons has been known--since last summer--to show lots of bumps and dips. This structure was always thought to have something to do with the production of charm.

The particle appears to be made (as it should) in association with another particle or particles (with the opposite sign of charm) whose masses can be determined from the spectrum of mass recoiling against the 1.87 GeV object. . . . The 1.87 GeV particle decays into a K meson and a pi meson, just as it should if it were a charmed meson. Its decay into a K meson and 3 pi mesons has also been observed.

C. CHARM AT LAST: HOW SWEET IT IS

[*Science News*, June 5 & 12, 1976]

For more than a year and a half the running headline story in particle physics has been the discovery of one after another of the ultraheavy, oddly behaving particles designated psi or J. By now, something like nine members and cousins of the psionic family have been catalogued, and there may be more to come. Many theorists have attributed the odd behavior of the psi particles to a theoretically proposed new property (quantum number) that is whimsically named charm.

The problem with using the psi's as evidence for charm's actual existence is that they themselves do not display it openly . . . . Theory says the psi's contain both charm and anticharm since they are made of a charmed quark and an anticharmed antiquark. (Quarks are the building blocks out of which particles are constructed according to the most widely accepted theory.) Theory postulates that there should also be particles that exhibit charm nakedly (being made up of a charmed quark and an uncharmed antiquark), but these have not shown up experimentally until now.

This week the news from the SPEAR storage ring at the Stanford Linear Accelerator Center is that a candidate for the nakedly charmed particle has now been found. The experiment is the same one that was the codiscoverer of the original psi particle in November 1974. In it, beams of accelerated electrons and positrons are struck together so that they annihilate each other and produce new particles. The experiment, operated by a consortium of physicists drawn from the staffs of SLAC and the Lawrence Berkeley Laboratory, just keeps on running to see what more new things it can find. The experiment and the laboratory generally are funded by the U.S. Energy Research and Development Administration.

The supposed new particle has a mass of 1.86 billion electron-volts (1.86 GeV), very nearly twice that of the proton. It was first seen to decay into two familiar particles of the hadron class (a K meson and a pi meson). Later another decay mode, into a K and three pi's, was found. It is these characteristic decays that make the experimenters think the new particle conforms to the theoretical expectation of what a nakedly charmed particle should be. About 100 examples of the new particle were found among 24,000 electron-positron annihilation reactions. According to an ERDA announcement of the discovery on June 8, the physicists performed numerous checks to increase the certainty that they had what they thought they had.

The new particle's mass fits well into a scheme of related nakedly charmed particles of the class called mesons that was theorized last year . . . by Sheldon L. Glashow of Harvard University and collaborators. According to the general theory of how particles are made out of quarks, any meson should be made of one quark and one antiquark. Before the introduction of charmed quarks to the theory, there were three kinds of uncharmed quarks [called u, d and s] with corresponding antiquarks, and the Glashow theory uses all possible permutations to arrive at a family of six nakedly charmed mesons. Two of these lie at about the appropriate mass level, combinations of the charmed quark with the [u and d] antiquarks. Of these its seems most likely that the one found is the charmed quark plus [u] antiquark.

The reason the discovery was not made before now, according to Roy Schwitters of SLAC, one of the experimenters, is basically that there was just not enough data to pick up such rare events. The region around the energy of 4 GeV, where the experiment happens to be operating right now, is particularly rich in data and has a better signal-to-noise ratio.

Theory says a nakedly charmed particle should be made in conjunction with a nakedly anticharmed particle, and there appear to be some things recoiling from the 1.86 GeV particle that might be that. But Schwitters says that it is premature to put that interpretation on them. . . .

Of course there is a certain grain of salt to be taken with all this. As Schwitters says, the experimenters cannot definitely prove that they have an example of naked charm, but what has been seen fits the theoretical prediction so well that it seems convincing. As the ERDA announcement puts it, there is "much work to be done to see if it is really charm" and not some unexpected phenomenon. One part of that work is to search for some of the other five states predicted by Glashow. Schwitters says that the experimenters are looking at two particular points in the neighborhood of the 4-GeV energy range where they suspect others of Glashow's predicted states may appear.

D. ANOTHER NEW PARTICLE

CHARMED QUARKS LOOK BETTER THAN EVER

[*Science*, 18 June 1976]

The most talked about explanation for the J/ψ particle, whose discovery so shook up the world of elementary-particle physics 18 months ago, has been that it is a meson comprising hypothetical entities called a charmed quark and a charmed antiquark. In succeeding months, experiments gratifyingly verified features of this model qualitatively, if not always qualitatively. The major stumbling block to acceptance of this picture has been the researchers' failure to see a new particle consisting of only one charmed quark in combination with one uncharmed quark produced in electron-positron collision experiments.

At last, after an intense search lasting more than a year, this long-sought charmed particle--or at least a particle that bears every indication of being a charmed meson--has been found.

A group of 40 researchers from the University of California's Lawrence Berkeley Laboratory (LBL) and the Stanford Linear Accelerator Center (SLAC) announced the discovery last week. From their study of electron-positron collisions in the SPEAR storage ring at SLAC, the investigators concluded the new particle has a mass of 1.865 giga-electron-volts (GeV), a lifetime which may be longer than that of the J/ψ particle (10^{-20} second), no electrical charge, and a new physical property (quantum number).

PARTICLE MATCHES EXPECTATIONS

The experimenters themselves are stopping short of claiming that the new property is charm. But physicists around the world have been in a state of high excitement for the last month (rumors of the discovery have been circulating for that long) because the new particle has the same mass and decay products as predicted by the charmed quark theory.

If the charmed quark picture of the J/ψ is correct, then it is analagous to the ground state of a hydrogen-like atom. This subnuclear "atom" is sometimes referred to as charmonium. Various other particles that correspond to expected excited states of charmonium have in fact been found in SPEAR and in the DORIS storage rings at the DESY Laboratory in Hamburg, West Germany.

In the same analogy, when oppositely orbiting electrons and positrons collide and annihilate in the storage ring at sufficiently high energies, it ought to be possible to make the analog of an ionized atom, in which the charmed and anticharmed quarks are no longer bound together. It is a quirk of the quark theory, however, that free quarks, charmed or uncharmed, cannot be observed. Only combinations of quarks in the form of the various elementary particles of the hadron family (mesons and baryons) are observable. (Before the J/ψ all known hadrons had only uncharmed quarks as constituents.)

Thus, the free charmed and anticharmed quarks combine with uncharmed quarks to produce hadrons with a charm quantum number of plus or minus one (charmonium itself has a net charm of zero). Particles of this type had never before been observed in electron-positron collision experiments, although experiments involving collisions of neutrinos with nuclei at the Brookhaven National Laboratory, the European Organization for Nuclear Research (CERN), and the Fermi National Accelerator Laboratory strongly pointed to their existence.

The LBL-SLAC group has long had indirect evidence that this process might be occurring in the range of collision energies from about 4 to 4.5 GeV. Putative resonances sometimes called ψ'' at 4.1 GeV and ψ''' at 4.4 GeV are broad structures, indicating a short lifetime and rapid decay via the strong nuclear interaction. This is exactly what is expected if, for example, one of these particles were breaking up into two charmed mesons. In contrast, lower mass states, such as the J/ψ(3.1 GeV) and ψ' (3.7 GeV), researchers argued, had insufficient mass to break up into two charmed mesons and thus had to decay slowly, although via the strong interaction. Since the strong interaction conserves charm, decay via the weak interaction, which does not, is the only route available to a charmed meson and thus could account for its expected long life.

From various theoretical considerations, from the neutrino experiments, and from the ψ'' and ψ''' resonances, researchers had concluded that a charmed meson probably would have a mass near 2 GeV. Last year, for example, Sheldon Glashow, Howard Georgi, and Alvaro DeRújula at Harvard University predicted that a charmed meson with no electrical charge should exist with a mass of 1.83 ± 0.03 GeV.

To observe the particles produced when the collision energy is above the presumed threshold for creation of charmed meson pairs, the LBL-SLAC team measured what is termed an invariant mass distribution. With their detector, called a magnetic spectrometer, the investigators traced the paths in a magnetic field of charged particles produced in a decay event and deduced their momenta. From this information they could determine the mass of a particle from which the decay products could have emerged. They then plotted the events as a function of apparent mass and looked for a resonance-like increase in the number of events at a well-defined mass. A peak in the number of events at a particular mass was a signal of a real particle existing with that mass, whereas events at other masses constituted a background.

REEXAMINING OLD DATA

Successful searches for new particles depend critically on where one looks and what one looks for. In their hunt for the charmed meson, the LBL-SLAC investigators concentrated on what are called hadronic decays in which the charmed meson should decay into K mesons and π mesons. Only last summer, the group published the results of an unsuccessful search. As it happened, however, the negative results were obtained when the collision energy of the electrons and positrons in the storage ring was 4.8 GeV. The new particles are efficiently produced, it turns out, only when the collision energy is in the range 3.9 to 4.6 GeV.

A second crucial factor was the ability to distinguish between K mesons and π mesons in the decay products. The experimenters are now able to distinguish between these particles by measuring the time it takes each of them to reach a set of plastic scintillation counters in the detector from the collision region. This ability greatly enhances the sensitivity of the experiment to the putative charmed meson.

The discovery came early in May, according to Gerson Goldhaber of LBL, shortly after a particle physics meeting in which such strong procharm sentiments were expressed that Goldhaber felt compelled to reexamine with special care the data collected over the past year. At the same time, a visiting scientist in the group, Francois Pierre, who is on leave from the elementary particle physics department at Saclay, in France, was going over data himself. Within a few days, both had independently found evidence for the new particle. (One day on the way to lunch, each said to the other, "By the way, I have something to show you!")

Since then, the entire LBL-SLAC team has collected about 200 events, half with a decay into a K meson and a π meson and half into a K meson and three π mesons. According to Roy Schwitters at SLAC, a multihadronic decay event is detected about once a minute, and, in about 1 percent of these, researchers find a new particle.

Evidence for a second charmed meson produced in association with the first has also been obtained. Lack of such evidence would have been highly damaging to the charm model, since the mesons must be produced in pairs to conserve charm. The evidence rests on what is called a recoil mass spectrum. Knowing the energy and momentum that went into the collision and subtracting the energy and momentum of one of the products, the researchers can determine the energy and momentum of the "rest." It turns out that the mass of the "rest" is centered in a region between 2 and 2.2 GeV, indicating that the second particle has a mass different from the first. More data has to be accumulated, however, before the LBL-SLAC investigators will estimate the energy more precisely.

Less cautious in their interpretation are others who have seen the recoil data, which appears to show peaks at 2 and 2.15 GeV. Glashow and his associates at Harvard say the apparent structure is consistent with the simultaneous production of a charmed meson in either a 1.865-GeV ground state or a 2-GeV excited state and a second charmed meson in an excited state. Rapid decay of an excited charmed particle into its ground state could give rise to the particle observed in the invariant mass distribution.

The particles that the investigators found are electrically neutral. There should also be a charged meson with charm at about the same mass as the neutral meson and a second charged meson at a mass (in the ground state) of about 2 GeV. Neither of these particles has been observed as yet. Theorist Michael Chanowitz at LBL points out that they could be detected by their characteristic decays, but because the charged particles should be produced much less frequently than the neutral ones, much more data must be accumulated before a statistically valid identification could be made.

CHECKING CHARM'S CONSEQUENCES

Glashow, who is coinventor of the charm model, is obviously happy with the particle discovery, as well he might be. Charm was first postulated more than 10 years ago on what can fairly be described as esthetic grounds. Later on, the model was extended to explain certain discrepancies in the decay by weak interactions of strange particles, such as the K meson. It has to be regarded as deeply satisfying, argues Chanowitz, if a concept proposed years before for altogether different reasons should now be the key to understanding the surprises that have occurred in elementary particles during the last 2 years.

The task now is to verify the several predictions of the charm model that have not yet been observed. If, as SLAC's Sidney Drell points out, the LBL-SLAC group's experiment is by far the most convincing piece of evidence for charm up to now, until all its consequences are checked out, scientists must retain an open-minded skepticism.

For one thing, other decay routes of the neutral particle besides K-π and K-3π ought to be seen, observers agree. One important example of these, according to theorist Fred Gilman of SLAC, is called a semileptonic decay via the weak interaction in which charm is not conserved (none of the decay products have charm). In the semileptonic decay mode, the putative charmed meson should often decay into hadrons (including a K meson), a charged lepton (an electron, a positron, a muon, or an antimuon), and a neutrino.

The only other laboratory in the world able to duplicate the SPEAR experiment is DESY. In particular, the scientists there have a detector that is particularly suited for picking out electrons and positrons from other charged particles. Verification of the semileptonic decay might therefore come from DESY. Bjorn Wiik, a group leader at DESY, has reported that his group has seen electrons under the expected conditions. But, he cautions, it will be a few more weeks before enough data is in hand to ascertain whether the electrons are coming from the decay of the particle seen at SPEAR or from some other source.

--Arthur. L. Robinson

SUMMER SCIENCE PROGRAM

The 1976 Summer Science Program at SLAC opened on Monday, June 21, when the program's director, Ernest Coleman, and associate director, Vicente Llamas, welcomed the students in the auditorium. This year the program includes 25 students, 7 of whom also participated in last year's program. As in previous years, the educational background of the students ranges from the first year in college to graduating seniors. Geographically, 7 of the students are from Colorado, 6 from California, 5 from Georgia, 3 each from New Mexico and Massachusetts, and 1 from New Jersey. All of the students are science majors, with principal fields of study in physics, chemistry, biology, engineering and math.

Work-assignment placements for the students were arranged by Ron Koontz for SLAC's Technical Division and Rich Blumberg for the Research Division, with the assignments divided fairly evenly between the two Divisions. Among the assignments are those that involve computer programming, data analysis, gas chromatography, integrated circuitry, X-ray tuning, chassis wiring, and updating the interlock system of a small accelerator. These work assignments will take up anywhere from about one-half to two-thirds of the students' time while they are here at SLAC, with the balance devoted to lectures and various tours. The tours planned for this year include visits to the Stanford Research Institute, to the IBM facility in San Jose, and to the Lawrence Berkeley Laboratory. Lectures for the students will be given by program directors Drs. Coleman and Llamas and also by a number of Visiting Scientists who will be at SLAC for various periods during the summer.

A detailed calendar of the planned activities in the program is available to anyone who may be interested by requesting a copy from the Summer Science Office in Room 234 of the A&E Bldg. The Visiting Scientists who will participate in the program, lecturing on various topics, are listed below, along with the dates of their visits.

--Kathy Slavin

VISITING SCIENTISTS	DATES OF VISIT	LECTURE TOPICS
Ernest Coleman (Director, SLAC-SSP) Head, Central Laboratory Research Division of Physical Research, ERDA	June 21-23	(1) Energy: Science and Society (2) Recent Discoveries in High Energy Physics
Vicente Llamas (Associate Director, SLAC-SSP) Chairperson, Physics & Mathematics New Mexico Highlands University	June 21 - August 27	Bubble Chamber Physics and Elementary Particle Physics
Roger Chaffee Staff Mathematician SLAC Computation Group	July 6-16	Introduction to Fortran IV
Roland Koontz Staff Member SLAC Accelerator Physics Dept.	July 19-30	History and Operation of High Energy Accelerators
Rabindar Madan Professor of Physics North Carolina A & T	Month of July	Topics in Quantum Mechanics
Harry Morrison Professor of Theoretical Physics M.I.T.	July19 - August 17	Low Temperature Physics
Steven McGuire (SSP Participant, 1971) Doctoral Candidate, Nuclear Science Cornell University	Month of August	Neutron Physics & Fission
Shirley Jackson Staff Scientist Bell Laboratories	August 10 - September 10	Space-Time and Internal Symmetries
James Young Professor of Theoretical High Energy Physics, M.I.T.	August 9-20	Phase Transitions & Organization of Matter
Jose Cortez Project Leader, Earth Science Division Lawrence Livermore Laboratory	August 9-20	Atomic Properties & Plasmas

FATHER JUNIPERO SERRA, BY LOUIS DU BOIS

(Photo by Dave Thomas)

Some people like to travel when they retire. Others move to the Sierra or take up golf or gardening. But Louis Du Bois found something different to do following his retirement from SLAC in 1974. At his own expense, and with some help from his family, he fulfilled a life-long dream by using his creative talents to construct a 22-foot-high monument to the founder of the California Missions--Father Junipero Serra.

This large statue of Father Serra has been taking form since last August. It is located about 12 miles north of SLAC at the Crystal Springs Rest Stop on Interstate Highway 280. Long an admirer of Father Serra, Du Bois is building the steel-reinforced cement statue for the San Mateo County Historical Association with the cooperation of the California Department of Transportation as a gift to the people of California.

Louis Du Bois was born in Butte, Montana in 1910, but he has made his home in the Bay Area for the last 40 years. During the late 1920's he attended the Seattle School of Art, the Cornish School of Art, and the University of Washington.

It was about 200 hundred years ago that Father Serra founded a total of nine Missions in California. These include the famed Mission San Juan Capistrano and Mission Dolores in San Francisco, which he founded when he was 62 years of age. Father Serra had been a theologian for most of his life, but he "retired" to become a missionary. In his own retirement, Lou Du Bois came to identify closely with Father Serra.

The statue of Father Serra rests on a nine-sided base, and on each of the sides there is inscribed the name of one of the Missions that he founded. The statue has taken about ten months to build, and has required about one ton of steel and 39 tons of concrete.

Lou is still not about to settle down into an inactive retirement. He has always thought that a statue of Sir Fancis Drake would be an appropriate way to commemorate the 400th anniversary of Drake's landing on the West Coast in 1579. But whether the Drake statue becomes a reality or not, it's a safe bet that Lou will continue to devote his remarkable energies to his art.

--Bernie Lighthouse

FIENDS AT WORK IN THE LIBRARY

To SLAC Beam Line: *While straightening some shelves in the Library, I found a crumpled piece of paper with strange and curious writing. I have spent some time trying to decipher it, and send you a copy of the transcription, since it seems to explain certain things that have been happening lately.*

--Arsella Raman, SLAC Library

To: Rathphegor

From: Azaziel

Welcome to the demonic team in charge of confusion in the SLAC Library.

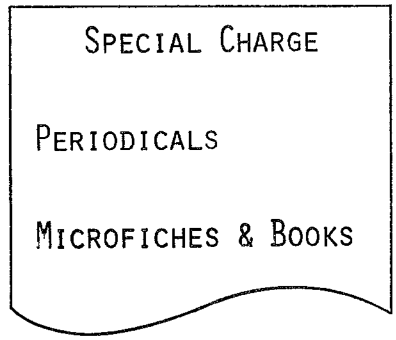
At this point in time we are concentrating our efforts on the periodicals section. This operation is now well under way, and many large and small ventures have been successfully completed. Earlier this year we persuaded a library user to "borrow" about a dozen volumes of the most important physics journals: *Nuclear Physics, Physics Letters, Physical Review D, Physical Review Letters,* thereby plunging the library into turmoil. It would have pleased you greatly to see the librarians checking all the journal shelves to see if the volumes had merely been displaced, spending a lot of time looking at all the shelves to get an idea of what was missing and wracking their brains trying to guess where the volumes might be. Unfortunately this project was never completed, since the user decided to take all the volumes back to the library about a month after the loss was discovered.

We have been more successful with single issues that have not yet been bound--after all, those volumes are a little conspicuous on the shelves in one's office! At present we have managed to extract from the library the following single issues:

1. *Physical Review D*, Volume 12, Number 1.
2. *Physical Review D*, Volume 13, Number 3.
3. *IEEE Transactions on Nuclear Science*, Volume 22, Number 3.

As you can see, we try to concentrate on the recent and most-asked-for. In instances where the library has two copies of a journal, a little coordination may be needed to remove the issue from the shelves <u>before</u> the other copy has returned from being routed.

Of course you must not let the users know how easy it is to let the library know if they absolutely need to take a journal from the library. That orange slip in the box on the circulation desk says "Special Charge" on top; just do not let them see the next line, where it says "Periodicals" in large letters. If they have already seen it, it might be a good idea to let it enter their minds that if they fill out the slip, the library might call them if another reader needs the journal. But of course keep out the slightest hint that they themselves might be that "other reader" another time. You should make it clear to the user that if the Xerox in the library is not working he really cannot be expected to stop and fill out the orange slip before lugging the volumes to another Xerox machine. After that it is easy to make the user forget to return the volumes to the library right away; tomorrow is soon enough, or somebody else could do it later . . .

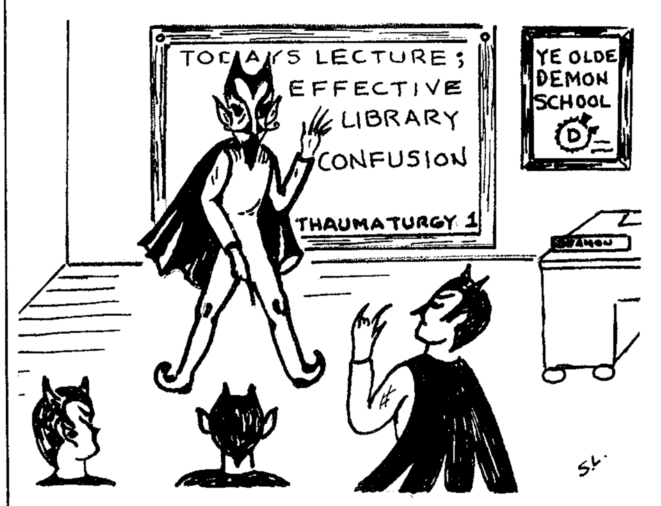


(The orange slip looks something like this)

You may not realize at this stage of your training how little effort is needed to make the library personnel completely insecure: checking the shelves every day, dreading the cost of replacement copies, frustrated at not finding journals when asked to find them, and threatening to lock the library after working hours.

Looking forward to a long and fruitful cooperation,

Fiendishly yours,
Azaziel



--Shirley Livengood

WE GOOFED

Last month's cover photo was mistakenly identified as a SLAC picture. The fact is that Stephen D. Gerber of the Lawrence Berkeley Laboratory took that excellent photograph of the SPEAR Mark I detector. We apologize to Mr. Gerber for our error. We also thank Carl Friedberg of LBL for bringing the matter to our attention.

BBC FILMS AT SLAC

The three gentlemen shown here are members of the British Broadcasting Corporation film crew who visited SLAC last month to film some footage at SPEAR and several other locations in the research area. The man on the left is Alec Nisbett, who is the executive producer of a film-in-progress that will be called "Key to the Universe," and will deal at length and in some depth with astronomy and high-energy physics. The film will be a year in the making, and will probably be shown in two one-hour segments sometime next year. Both the script and the people involved seemed to the SLAC staff members they worked with to be first-class, so "Key" should be something to look forward to. *(Photo by Joe Faust.)*

A VOTE OF THANKS

In last month's article on the SLAC Loan Committee, we neglected to extend our thanks to former Committee members Frankie McLaughlin and Ken Stewart for their long and hard work on the Committee during the past several years. Frankie was a charter member, with her service going back to August 1973. Ken's term was almost that long, since he replaced a charter member very early in the Committee's history.

SLED MILESTONE

The SLED program (*SLAC Energy Development*) is a plan for increasing the maximum beam energy of the SLAC accelerator from the present $\sim$ 23 GeV to about 33 GeV (Phase I), and perhaps eventually to about 40 GeV (Phase II). Phase I is now well under way.

Last June 15 we were able to complete our first full-scale SLED test using Sector 16 of the accelerator (Sectors 16 and 17 are now fully equipped with SLED cavities.) The experiment consisted of establishing a standard low-energy beam of 6.5 GeV and then measuring the total beam energy with the addition of Sector 16. With the SLED cavities detuned (not in the system), Sector 16 contributed about 740 MeV to the beam energy. Upon tuning the cavities, we were gratified to learn that Sector 16's contribution rose to about 1.06 GeV, an increment of about 320 MeV. This increase represents an improvement factor of 1.43, which checks very well with the theoretical prediction. We were also able to verify that the SLED energy as a function of time within the accelerator pulse varies according to the theoretical prediction.

This encouraging result is of course only a beginning. We are now in the process of testing Sector 17, but after that there are still 28 Sectors left to go! We are planning to install SLED equipment on 3 more Sectors during the accelerator shutdown this summer.

--*THE SLEDDERS*

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Note to readers at SLAC: Please return any extra copies to B. Kirk (Bin 80) or H. Weidner (Bin 20).

Charmed Particles

THIS ARTICLE DESCRIBES THE RECENT DISCOVERY AT THE SPEAR STORAGE RING OF A NEW PARTICLE THAT IS VERY PROBABLY THE FIRST EXAMPLE OF THE LONG-SOUGHT "CHARMED" PARTICLES. THE NEW PARTICLE HAS A MASS OF 1.865 GeV, AND IT WAS OBSERVED THROUGH ITS DECAY INTO K AND PI MESONS. THE NEW PARTICLE APPEARS TO BE PRODUCED IN ASSOCIATION WITH OTHER STATES OF SLIGHTLY LARGER MASS, WHICH MAY ALSO BE MEMBERS OF THE NEW FAMILY OF CHARMED PARTICLES.

Contents

Note: The experimental results given in Section III of this article deal with the new particle in the form in which it was originally observed--as an electrically neutral meson that decays into either one K and one pi meson or into one K and three pi mesons. Just before we went to press we learned that new experimental evidence has been obtained for the electrically charged form of the new particle, which decays into one K and two pi mesons. These late results are described briefly in Section IV.B, on page *C-12*.

I. A BRIEF SUMMARY

The Lawrence Berkeley Laboratory-SLAC collaboration of physicists working at the SPEAR storage ring at SLAC has discovered a new particle or "resonance" that is very probably the first example of the "charmed" particles that have been eagerly sought after in many different laboratories during the past 18 months. The new particle, which has not yet been formally named by the discoverers, has a mass of about 1.86 GeV, or roughly twice the mass of a proton. It was detected experimentally through its decay into the familiar K and pi mesons.

The LBL-SLAC group has been studying for the past several years those electron-positron annihilation events at SPEAR that result in the production of strongly interacting particles, or *hadrons*, the best-known of which are the protons and neutrons that together form the nuclei of all atoms. Ever since the early 1960's it has been speculated that the hundreds of different hadronic particles or "states" that have been observed in nature are not in themselves "elementary" objects, but rather that they are composite structures which are built up from simple combinations of only 3 *truly* elementary building blocks called *quarks* (plus, inevitably, 3 antiquarks). Since this 3-quark picture of particle structure was first introduced, it has had many impressive successes in explaining the known particles and in predicting the existence and properties of new states that were subsequently discovered.

In November 1974, however, the LBL-SLAC team at SPEAR co-discovered (along with an MIT-BNL group working at Brookhaven) the first of a remarkable new family of particles--*psi* particles or *psions*--whose very large masses and long lifetimes could not be accounted for by the usual 3-quark theory. Instead, the psions revived a 10-year-old theoretical idea concerning the need for a fourth kind of basic quark and antiquark which were assumed to possess a fundamentally new property of matter that had been given the whimsical name "charm." The new property was thought to be similar in certain ways to electric charge, in the sense that the new quark would have +1 unit of charm "charge," while its antiquark would have -1 unit of charm.

According to the charm interpretation, the psi particles were thought to be composed of a charmed quark temporarily bound together with a charmed antiquark. Thus in this view the *net* charm value of the psions is zero for the same reason that the net electric charge of a hydrogen atom is zero: the proton's +1 cancels out the electron's -1. So with the psions strongly suggesting charm but not overtly displaying it, the search was soon on for the predicted particles that *would* exhibit a net value of charm because they contained *either* a charmed quark *or* a charmed antiquark, but not both. A preliminary search for such overtly charmed particles was in fact carried out last year by the LBL-SLAC group, but without success.

This was the situation up until May of this year, when a fresh attack on the problem was begun by group members Gerson Goldhaber of LBL and Francois Pierre of Saclay, France, but presently on leave at LBL. The new search had the advantage of the much larger bloc of experimental data that had been accumulated since the previous effort, and also of an improved method of distinguishing between different kinds of particles in the SPEAR Mark I magnetic detector.

Positive results were not long in coming. From a total sample of about 24,000 hadron production events at SPEAR, first a handful and eventually more than 100 of these events proved to be certain two-body combinations of known mesons ($K^+\pi^-$ and $K^-\pi^+$) which appeared as the decay products of a single previously unknown particle, electrically neutral, and with a mass of about 1.86 GeV. The word spread quickly to other members of the group, many of whom joined the continuing analysis, and in short order the same 1.86 GeV new particle was identified as the source of certain four-body decays ($K^+\pi^-\pi^+\pi^-$ and $K^-\pi^+\pi^-\pi^+$).

What has been learned so far about the properties of this new 1.86 GeV particle is consistent with, and in fact strongly suggestive of, its identification as a charmed meson. More time and effort will be required to confirm this identification beyond any reasonable doubt, but such confirmation already seems to be well on the way. (Members of the experimental group can be expected to exercise some time-honored caution in reporting their results. Our attitude here will be that the charm interpretation of the new particle is almost a sure thing.)

II. SOME BACKGROUND INFORMATION*

In this section we review briefly three subjects that are important for understanding the significance of the new discovery: *quarks*, *psions*, and *the search for charm*.

References

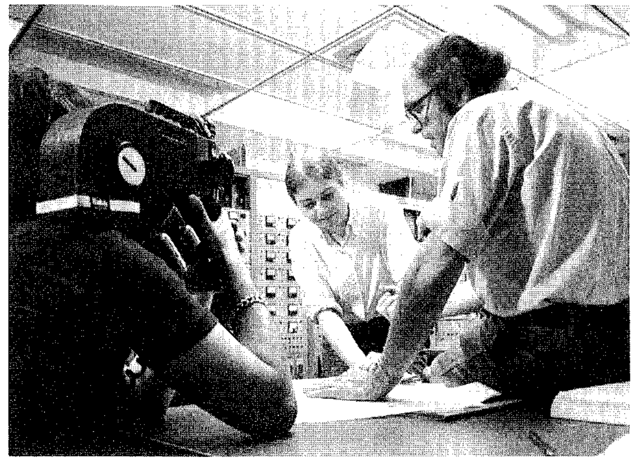
*For a more complete review of SPEAR physics than we have space for here, see the following *Beam Line* articles:

1. "An introduction to colliding beam storage rings," Aug. & Sept. 1974 *(pre-psi physics)*.

2. "We have observed a very sharp peak . . ." Dec. 5, 1974 *(original psi discoveries)*.

3. "More new particles," Oct. & Nov. 1975 *(the growing family of psions)*.

Notes in this article that look like this, *"(See Ref. 2, page 7),"* refer to the 3 articles listed above. Copies of these articles can be obtained from B. Kirk (#80) or H. Weidner (#20).



Gail Hanson of SLAC Experimental Group E and Gerson Goldhaber of LBL are shown here being filmed by a cameraman from the British Broadcasting Corp. Together with Francois Pierre, Goldhaber initiated the recent analysis of SPEAR data that led to the discovery of the new particle. Hanson played a similar role in the earlier attemps to find charmed particles at SPEAR. The BBC is filming material for a new TV program on particle physics and astronomy. *(Photo by Joe Faust.)*

A. QUARKS

With the exception of the unit of electromagnetic radiation called the photon, all of the known particles of matter can be grouped into two major families: the *leptons* (or "lightweights") and the *hadrons* (or "heavyweights"). At the present time there are only eight well-established members of the lepton family:

Leptons		*Antileptons*	
1. electron	(e^-)	5. positron or "anti-electron"	(e^+)
2. electron neutrino	(ν_e)	6. electron antineutrino	$(\bar{\nu}_e)$
3. negative muon	(μ^-)	7. positive muon	(μ^+)
4. muon neutrino	(ν_μ)	8. muon antineutrino	$(\bar{\nu}_\mu)$

Without stretching the truth too badly, we can summarize the strong family relationships among these eight particles in the follow ways:

(a) Neutrinos are similar to electrons or positrons that have lost their electric charge. They have a "legitimate" place in nature in the sense that they take part in certain radioactive decay processes.

(b) Muons appear to be exactly the same as electrons or positrons with the striking exception that they are about 200 times as massive.

The role they play in nature is a mystery. *(See Ref. 3, page 20, for even heavier "heavy leptons" that may have been found at SPEAR.)*

For our present purposes, the central fact about the leptons is this: down to the incredibly small explored distance of 10^{-15} cm, they appear to be simple, unstructured, point-like objects--that is, truly *elementary* particles.

But the same cannot be said of the other particle family, the hadrons. During the past 25 years new hadronic particles have been discovered at so rapid a rate that the total number now known exceeds 300. So large a number of supposedly "fundamental" particles was recognized many years ago as a ridiculous situation, but it was not until the early 1960's that a plausible way of explaining this embarrassment of particles was finally suggested. At that time M. Gell-Mann and G. Zweig, both of Caltech, each put forward a theory which postulated that the hundreds of different hadronic states could actually be built up from just three *really* basic particles (plus their three antiparticles, naturally). These still-hypothetical building blocks were given the name "quarks," and at the present time the original three quarks plus three antiquarks proposed by the theory are usually identified by the following letters:

Quarks	Antiquarks
u d s	$\bar{u}$ $\bar{d}$ $\bar{s}$

Up until late 1974 the 3-quark theory of hadronic structure had enjoyed a number of impressive successes in accounting for experimental data and in predicting the existence and properties of certain hadronic states that were subsequently discovered. At that point, however . . .

B. THE PSIONS

In November 1974 a remarkable new kind of particle was discovered simultaneously at Brookhaven National Laboratory (where is was called "J") and at SPEAR (where it was called "ψ" or "psi"). Since its mass was about 3.1 GeV, the designations J(3.1) or ψ(3.1) or even J/ψ(3.1) were adopted. Soon afterward a second, similar particle, the ψ'(3.7), was also discovered at SPEAR.

For particles of such large mass--roughly 3 to 4 times as massive as protons--the two new psi particles exhibited a "lifetime" (the time between their creation and eventual decay) that was roughly 1000 times longer than would be expected for a "normal" strongly interacting particle. Although this abnormally long lifetime could not be measured directly, it was reliably inferred from the measured "width" of the psi resonance peaks in the SPEAR data. (As a consequence of the famous "uncertainty principle," a narrow or "sharp" resonance necessarily corresponds to a relatively long lifetime.)

Soon after the psi discoveries were made there appeared a flood of theoretical papers which attempted to explain the particles' unusual properties. The most persuasive of these explanations (which revived a 10-year-old idea) were those which postulated that a new property of matter was embodied in the psi particles, and that this new property was "carried" by a fourth, previously unknown variety of quark. Since the old name "charm" was applied in a gen-

OBSERVATION IN e^+e^- ANNIHILATION OF A NARROW STATE AT 1865 MeV/c DECAYING INTO $K\pi$ AND $K\pi\pi\pi$[1]

G. Goldhaber[2], F. M. Pierre[3], G. S. Abrams, S. Alam, A. M. Boyarski, M. Briedenbach, W. C. Carithers, W. Chinowsky, S. C. Cooper, R. G. DeVoe, J. Dorfan, G. J. Feldman, C. E. Friedberg, D. Fryberger, G. Hanson, J. Jaros, A. D. Johnson, J. A. Kadyk, R. R. Larsen, D. Lüke[3], V. Lüth, H. L. Lynch, R. J. Madaras, C. C. Morehouse[4], H. K. Nguyen, J. M. Paterson, M. L. Perl, I. Peruzzi[5], M. Piccolo[5], T. P. Pun, P. Rapidis, B. Richter, B. Sadoulet, R. Schindler, R. F. Schwitters, J. Siegrist, W. Tanenbaum, G. H. Trilling, F. Vannucci[6], J. S. Whitaker, J. E. Wiss.

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Lawrence Berkeley Laboratory & Dept. of Physics
University of California, Berkeley, CA 94270

ABSTRACT

We present evidence from a study of multihadronic final states produced in e^+e^- annihilation at center-of-mass energies between 3.90 GeV and 4.60 GeV for the production of a new neutral state with mass 1865 ± 15 MeV/c^2 and decay width less than 40 MeV/c^2 that decays to $K^\pm\pi^\mp$ and $K^\pm\pi^\mp\pi^\pm\pi^\mp$. The recoil mass spectrum for this state suggests it is produced only in association with systems of larger or comparable mass.

(Submitted to *Physical Review Letters*)

[1]Work supported by the Energy Research and Development Administration.
[2]Present address: Miller Institute for Basic Research, Berkeley, California.
[3]Fellow of Deutsche Forschungsgemeinschraft.
[4]Permanent address: Varian Associates, Palo Alto, California.
[5]Permanent address: Laboratori Nazionali, Frascati, Rome, Italy.
[6]Permanent address: Institut de Physique Nucleaire, Orsay, France.

eral way to the new property of matter, the new charm-carrying quark was designated "c". More specifically, in the charm interpretation the psi particles were assumed to consist of the quark-antiquark pair $c\bar{c}$ temporarily bound together, and many of the experimental facts that have subsequently been learned about the psi particles support this interpretation. But it was pretty much agreed early on by charm theorists that there would be two particular tests of the theory that would be critically important:

1. *Radiative transitions*. If the psi particles are actually the combination of charmed quark and charmed antiquark posited by the theory, then they should behave in certain ways that are similar to such other two-particle systems as the hydrogen atom (e^-p) and the so-called "positronium atom" (e^+e^-). That is, the $\psi'(3.7)$ "excited state" should readily decay into certain lower mass states while emitting its excess energy in the form of characteristic gamma rays. During the summer of 1975 several such *radiative transitions* were in fact detected at the German storage ring DORIS and also at SPEAR. *(See Ref. 3, pgs. 16-19.)* Although these transitions do not appear to occur as "readily" as the theory predicts, the simple fact of their occurrence lends some weight to the general idea of charm.

2. *Charmed particles*. The $c\bar{c}$ bound state that charm theory assigns to the psi particles will not directly exhibit charm itself, for the following reason. Like electric charge, charm is assumed to be doled out to particles in units of +1 and -1. Thus the +1 charm of the c quark cancels out the -1 of the $\bar{c}$ quark to yield a *net* charm of zero. For this reason charm will only be directly observable in particles that contain either a c quark or a $\bar{c}$ quark, but not both. How such charmed particles can be produced and detected experimentally is the subject of the last section of this introductory information:

C. THE SEARCH FOR CHARM

The original quark theory of hadronic structure posited that all of the then-known hadrons could be made from only the three kinds of combinations of quarks that are described in the table at the bottom of this page. Thus if there really is such a thing as charmed quarks, they should be able to combine with the other three kinds of quarks to form charmed baryons, charmed antibaryons, and charmed mesons. Of these three classes of hypothetical charmed particles, the charmed mesons should have the lowest mass (fewer quarks), and for this and certain other reasons should be the easiest of the three classes to detect. So we'll concentrate on charmed mesons here, and for ease of reference we'll tentatively assign a class name to the simplest group of charmed mesons that can exist:

The charmed D mesons

$$c\bar{u} = D^0, \quad u\bar{c} = \bar{D}^0, \quad c\bar{d} = D^+, \quad d\bar{c} = D^-.$$

At SPEAR we would expect to observe the decay process

$$\psi(3.1) \text{ or } \psi'(3.7) \rightarrow D^0\bar{D}^0 \text{ or } D^+D^-$$

happen very rapidly if the total mass of a *pair* of D mesons is less than the mass of either psi particle. But we don't in fact observe that decay, which means that the lowest D meson mass must be larger than 1/2 of the ψ' mass of 3.684 GeV, or larger than about 1.84 GeV. By increasing the energy of the colliding beams at SPEAR above the ψ' mass, we should eventually reach a "threshold" energy where pairs of D mesons start to be created by the electron-positron annihilation process:

$$e^+ + e^- \rightarrow D^0 + \bar{D}^0 \text{ or } D^+ + D^-$$

3 POSSIBLE COMBINATIONS OF QUARKS ↓	*Examples: COMMON Hadrons Using Only Quarks u & d*		*Examples: STRANGE Hadrons Using Quarks u, d & s*		*Examples: CHARMED Hadrons Using Quarks u, d, s & c*	
	These quarks ↓	*make this* ↓	*These quarks* ↓	*make this* ↓	*These quarks* ↓	*make this* ↓
1. BARYONS consist of any 3 quarks	uud	proton	uus	sigma$^+$	uuc	(charmed baryons)
	udd	neutron	uds	sigma^0	udc	
	uuu	delta^{++}	dds	sigma$^-$	dsc	
	ddd	delta$^-$	sss	omega$^-$	ccc	
2. ANTIBARYONS consist of any 3 antiquarks	$\bar{u}\bar{u}\bar{d}$	antiproton	$\bar{u}\bar{u}\bar{s}$	antisigma$^+$	$\bar{u}\bar{u}\bar{c}$	(charmed antibaryons)
	$\bar{u}\bar{d}\bar{d}$	antineutron	$\bar{u}\bar{d}\bar{s}$	antisigma^0	$\bar{u}\bar{d}\bar{c}$	
3. MESONS consist of any quark/antiquark	$u\bar{d}$	pi$^+$	$u\bar{s}$	K$^+$	$u\bar{c}$	(charmed mesons)
	$d\bar{u}$	pi$^-$	$s\bar{u}$	K$^-$	$c\bar{s}$	
	$u\bar{u}$	rho^0	$s\bar{s}$	phi^0	$c\bar{c}$	psi^0

This pair-creation process was in fact looked for a number of months ago, in an effort that was led by Gail Hanson of SLAC Experimental Group E, but without success. (A look back at this earlier analysis after the recent discovery has in fact located a very small bump in the $K\pi$ decay mode at the correct energy of 1.86 GeV, but that particular mole hill was not at the time very convincing.)

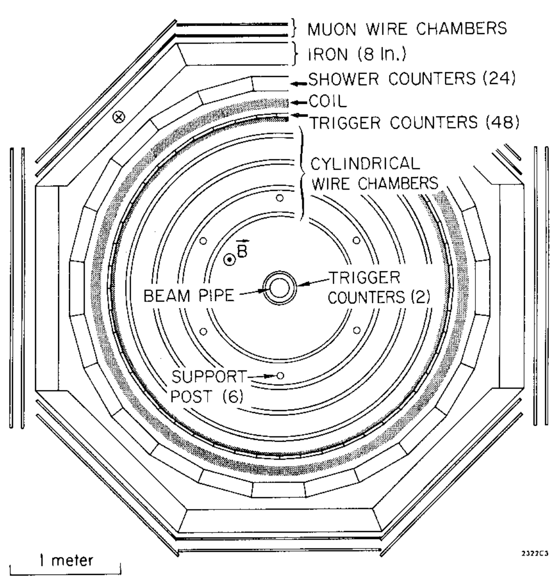
The charm searches carried out at SPEAR and elsewhere have had one additional theoretical handle to work with--namely the expectation that any charmed particles that are created will have a strong preference for decaying into strange particles. The reason for this charm → strange decay preference is too lengthy to describe here (*see Ref. 3, pgs. 14-15*), so we'll pass it and move directly on to the main business at hand--the new discovery.

III. EXPERIMENTAL RESULTS

In this section we describe the new-particle discovery after a brief look at the experimental set-up at SPEAR.

A. THE SLAC-LBL EXPERIMENT

Most SLAC readers will be familiar with the Mark I magnetic detector at SPEAR. The end-on view of the Mark I on this page shows the con-



The Mark I magnetic detector at SPEAR. Information from the 48 scintillation ("trigger") counters arranged in a cylindrical array at a radius of about 1.5 meters from the beam pipe has recently been incorporated in a system that measures particle time-of-flight, thus allowing much improved identification of pi and K mesons. This new system had an important role in the discovery of the new particle.

centric arrays of various kinds of counters and wire chambers that serve to track the paths of charged particles within the field of the large solenoidal magnet. Of particular interest for our present purposes is the cylindrical array of 48 scintillation counters (called "trigger" counters in the figure) located just outside the inner layers of wire chambers. These scintillation counters have recently been used to provide "time-of-flight" (and thus velocity) information as an added input to the data-analyzing system. This new information on particle velocities is combined with the earlier momentum measurements to determine the masses of the particles,

$$\text{momentum} = \text{mass} \times \text{velocity}$$

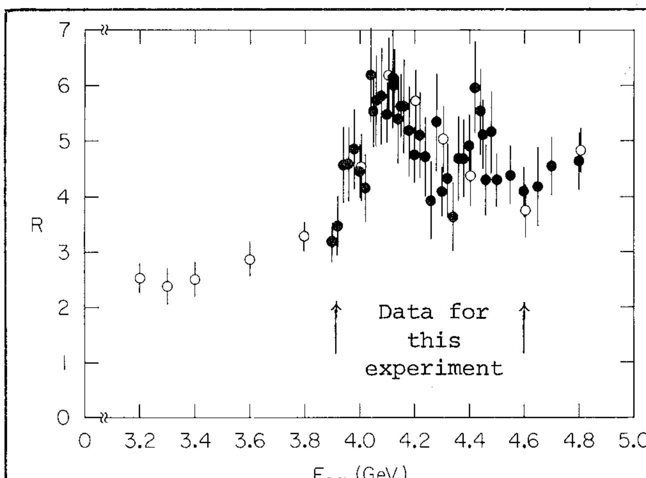
and thus to provide an important means of distinguishing between, for example, π and K mesons. This new time-of-flight (TOF) data played a key role in the new particle discovery.

B. THE NEW PARTICLE

We shall describe here the experimental evidence that led the LBL-SLAC group to the new particle discovery. We deal first with the data on the decay of the new particle into 2 charged hadrons and 4 charged hadrons, after which we describe what is now known about the properties--mass, width, etc.--of the new state.

1. Two-Body Decay Mode

The total sample of data analyzed in this work consisted of about 24,000 e^+e^- annihilation events at SPEAR center-of-mass energies between 3.9 and 4.6 GeV in which hadrons were produced. As noted earlier, the energy region to be explored was that above the ψ' resonance at 3.7 GeV. The 3.9 to 4.6 GeV energy range in fact spans the region where e^+e^- annihilation creates a wealth of fascinating effects that are only beginning to be unraveled. As a reminder, the figure below shows for this energy region the famous ratio, *R*, of hadron production to muon-pair production that we have discussed extensively in earlier articles (*Refs. 1-3*).



The first step in the analysis was done *without* using any of the time-of-flight information to help identify the particles. This consisted of gathering up all those events in which a neutral combination of two charged particles (a plus and a minus) was observed in the magnetic detector and measuring what is called the "invariant mass" of the pairs from each event. [Assuming that the observed particles are the decay products of a single parent particle, then the "invariant mass" is simply the mass of the parent. In the decay $\psi(3.1) \to e^+e^-$, for example, the invariant mass of the e^+e^- pair is 3.1 GeV.] Then the events are grouped into "bins" that are 20 MeV (.020 GeV) wide, and the number of events in each mass* bin is plotted.

The result of this first-step analysis is shown in the figure below, but notice that it is actually three figures rather than one. This is because--in the absence of any identification of the two particles--it is necessary to make some assumptions about what particular particles they in fact are. Since π mesons and K mesons are easily the most common hadrons produced at SPEAR, this first-step "make a guess" method of analysis can't do much better than simply to include all three alternate possibilities: (a) both particles are π mesons; (b) one is a π and one is a K; (c) both are K mesons.

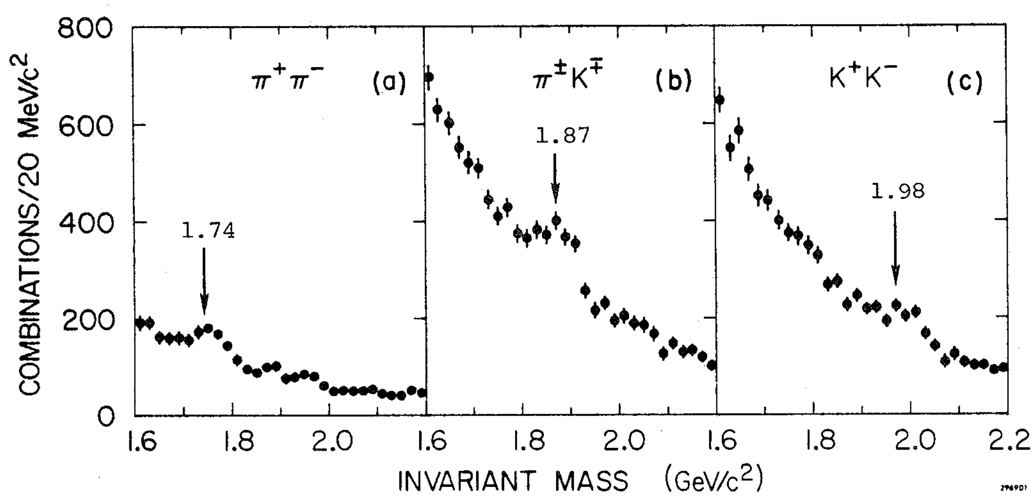
As the figure caption explains, making a wrong assumption about the identity of the two particles results in a "kinematic reflection" which causes the invariant mass to be either under- or overestimated.

However, after two paragraphs worth of noting the shortcomings of this preliminary method of analysis, it is important to notice that in each of the three figures below *something is there.* In each figure there is a distinct, if not alpine, "bump" at invariant masses, respectively, of 1.74, 1.87 and 1.98 GeV. That is, a pretty clear hint of some kind of resonance or state shows up even in the two figures out of three for which the particle-identification assumption must be wrong.

<u>Which is it--ππ, πK or KK?</u>

In order to establish which of the three possibilities is in fact the correct one, the next step in the analysis brings in the previously neglected time-of-flight information from the cylindrical array of scintillation

*The proper unit for mass is MeV/c^2 or GeV/c^2, but we will sloppily settle here for MeV or GeV.



This set of three figures shows the preliminary evidence that was used in detecting the new particle through its decay into two electrically charged particles. The data shown here does not make use of the time-of-flight technique to attempt to distinguish between π and K mesons. Instead, what is plotted is the "invariant" mass of the two decay particles under the *assumptions* that:

(a) The two particles are $\pi^+\pi^-$, which results in a "bump" at about 1.74 GeV.
(b) The two particles are π^+K^- or π^-K^+, producing a "bump" at about 1.87 GeV.
(c) The two particles are K^+K^-, which results in a "bump" at about 1.98 GeV.

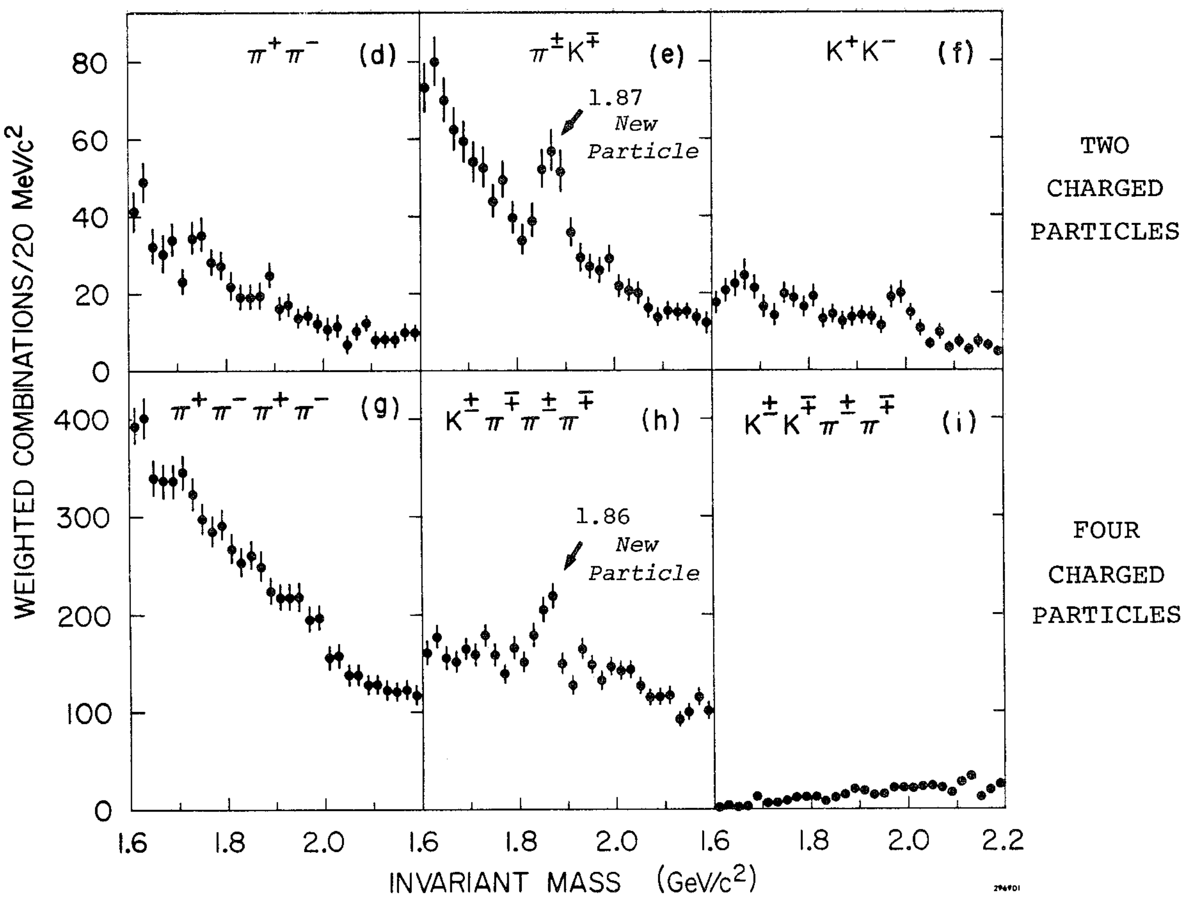
Only one of these assumptions can be correct, but from the data shown here it is not possible to pick out the correct assumption with any degree of certainty. The fact that the "bumps" appear at different values of mass in the three figures is not an actual physical difference but is rather a consequence (called "kinematic reflection") of the different assumptions. If the actual decay is π^+K^- or π^-K^+ (which it is), then calling it $\pi^+\pi^-$ will underestimate its mass, and calling it K^+K^- will overestimate its mass. The figure on the next page describes how the correct alternative assumption was selected.

counters in the Mark I detector. Because the typical difference in flight time between a π and a K meson in the region of interest is only about 0.5 nanosecond (.0000000005 second), a rather stringent set of criteria is applied in assigning particle-identification probabilities to tracks appearing in the detector. Tracks with a net π plus K probability less than 1% are rejected, tentative probabilities are assigned, and then these assigned probabilities are renormalized so that the total "weight" assigned to all $\pi\pi$, πK and KK combinations is made equal to the total number of observed two-body combinations (to avoid double-counting).

The result of all this messing around is shown in the figures on this page. Figures (d)-(f) show the two-charged-particle mass spectum with TOF-weighted combinations. The πK hypothesis in figure (e) now jumps out of the page as the clearly correct choice.

2. *Four-Body Decay Mode*

Similarly, the four-charged-particle mass spectrum with TOF-weighted combinations is shown in figures (g)-(i) below, with the K$\pi\pi\pi$ hypothesis of (h) plainly preferred over the alternate



Two-body. Figures (d)-(f) show the two-charged-particle mass spectrum *after* the time-of-flight information has been used to arrive at "weighted" combinations in which the π and K mesons are assigned a certain probability of correct identification. The weighting technique is described in the text. With the added TOF information, it has become evident that figure (e), the π^+K^- or π^-K^+ hypothesis, is strongly preferred over (d) or (f). In fact, the remaining small bumps in (d) and (f) are consistent with misidentified πK events that have "leaked" through. The large peak in (e) contains about 110 πK events; in physics jargon this peak is "greater than 5 standard deviations." What that means is that the odds against the peak being a purely accidental effect are more than a million to one.

Four-body. Figures (g)-(i) show the four-charged-particle mass spectrum with the same kind of TOF information as above used to arrive at weighted combinations. This analysis again makes it easy to pick out figure (h), the $K^+\pi^-\pi^+\pi^-$ or $K^-\pi^+\pi^-\pi^+$ hypothesis, as the correct choice. The large peak in (h) contains about 125 K3π events, which is also a "5-standard-deviation," or one-in-a-million-accidental-coincidence, effect.

The difference in measured mass between the 1.87 GeV πK mode and the 1.86 GeV K3π mode is discussed in the text but is not important.

4π and $2K2\pi$ possibilities. The four-body decays were selected from the same sample of about 24,000 hadronic events at energies from 3.9 to 4.6 GeV as was used for the two-body decays.

The number of events that appear in the peaks of figures (e) and (h) are, respectively, about 110 πK events and 125 $K3\pi$ events. Both peaks represent "5-standard-deviation" effects--that is, they are unlikely to be accidental effects with odds like a million to one.

3. *Mass And Width*

The paper submitted to *Physical Review Letters* by the LBL-SLAC experimental group (see page *C-3*) takes a running leap at this subject with the following Boomer:

> To determine the masses and widths of the peaks in the $K\pi$ and $K3\pi$ mass spectra, we have fitted the data represented by [the previous figures] with a Gaussian for the peak and linear and quadratic background terms under various conditions of bin size, event selection criteria, and kinematic cuts. . .

With these straightforward stipulations, then, the mass of the $K\pi$ combination comes out at 1870 MeV/c^2, while that for the $K3\pi$ combination measures 1860 MeV/c^2. This apparent mass difference is not real, since it is the same original particle that is decaying in either of these two modes. There is a certain amount of unavoidable error associated with measurements of this kind anyhow, so for now the mass of the new particle is being quoted as 1865 ± 15 Mev/c^2.

In connection with the width of the new resonance, let's first recall that only long-lived particles have a very precisely defined mass. The mass of the stable proton, for example, is 938.2796 MeV to within a gnat's whisker. But short-lived particles have a broad, fuzzy mass, and the shorter the lifetime, the broader is the resonance. *(See Ref. 2, page 8).* In the case of the new particle, its width is narrower than can presently be resolved with the existing experimental apparatus, and for this reason only an upper limit of about 40 MeV/c^2 for the decay width has so far been established.

4. *Cross Section × Branching Ratio*

A "cross section" expresses the probability that a certain particle interaction will occur in a collision. A "branching ratio" expresses that fraction of the time that one specific decay process will occur out of all possible decay processes. For general ease of discussion, let's make the assumption that the new particle just discovered at SPEAR is a $\mathcal{D}^o$ meson. What the experimenters actually detect in their apparatus, however, is either a K and a π meson, or a K and 3 π mesons. We can use this sequence of events to illustrate the meaning of "cross section" and "branching ratio," as follows:

The cross section (CS) for

$$e^+ + e^- \rightarrow \mathcal{D}^o + \bar{\mathcal{D}}^o \qquad (1)$$

expresses the probability that an electron-positron annihilation will create a pair of $\mathcal{D}^o\bar{\mathcal{D}}^o$ mesons. The branching ratio (BR) of the decay process

$$\mathcal{D}^o \rightarrow \pi^+K^- \text{ or } \pi^-K^+ \qquad (2)$$

expresses the probability that the $\mathcal{D}^o$ meson will decay into a charged π and K meson Thus the *overall* probability for the process

$$e^+ + e^- \rightarrow \mathcal{D}^o + \bar{\mathcal{D}}^o, \quad \mathcal{D}^o \hookrightarrow \pi^+K^- \text{ or } \pi^-K^+ \qquad (3)$$

is the product of

cross section × branching ratio

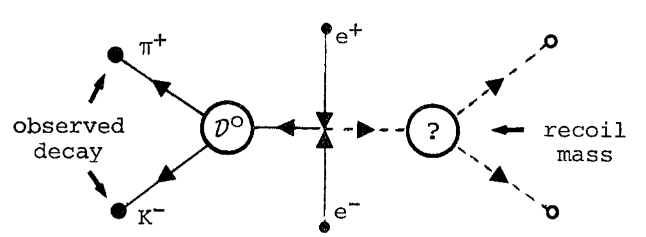
In the case of the new particle we do not know the cross section for process (1), nor do we know the branching ratio for process (2), but we *can* make an estimate of the CS×BR process (3). This estimate is averaged over the energy interval from 3.9 to 4.6 GeV covered by the data. For the $K\pi$ mode the CS×BR is about 0.2 nanobarns, and for the $K3\pi$ mode it is about 0.7 nanobarns.

The new particle properties we've talked about in this section are summarized in the following short table:

Mass	1865 ± 15 MeV/c^2
Width	less than 40 MeV/c^2
Decay Modes	
$K^+\pi^-$, $K^-\pi^+$	CS×BR ≃ 0.2 nb
$K^+\pi^-\pi^+\pi^-$, $K^-\pi^+\pi^-\pi^+$	CS×BR ≃ 0.7 nb

C. RECOIL MASS

In this section we turn our attention away from the new 1.86 GeV particle itself and on to a study of the *other* particles that are produced in the same e^+e^- annihilation interactions that create the new particles. The general idea is shown in the sketch below, which indicates that the mass recoiling against the new particle is a system of one or more additional particles. What we want to determine is the mass of the *whole* recoil system, and to do this we use the same method we used earlier in working out the



"invariant mass" of the new particles in the two- and four-particle decay modes. To repeat briefly, momentum information obtained by tracking charged particles through the magnetic field of the Mark I detector is combined with velocity information from the time-of-flight scintillation-counter system to determine the recoil masses. The masses recoiling against both the Kπ and K3π decay modes of the new particle are arrived at in this way.

The results of these recoil-mass measurements are shown in the two-part figure on this page. Some details about the calculated values of "background" (which is the "noise" from unrelated events) are given in the caption. We will deal with the information contained in the figure in two different ways: first, by giving a simple summary of the conclusions that can be drawn; and second, by giving a more thorough discussion of this rather important aspect of experimental analysis (one or the other can be skipped without losing much of the story).

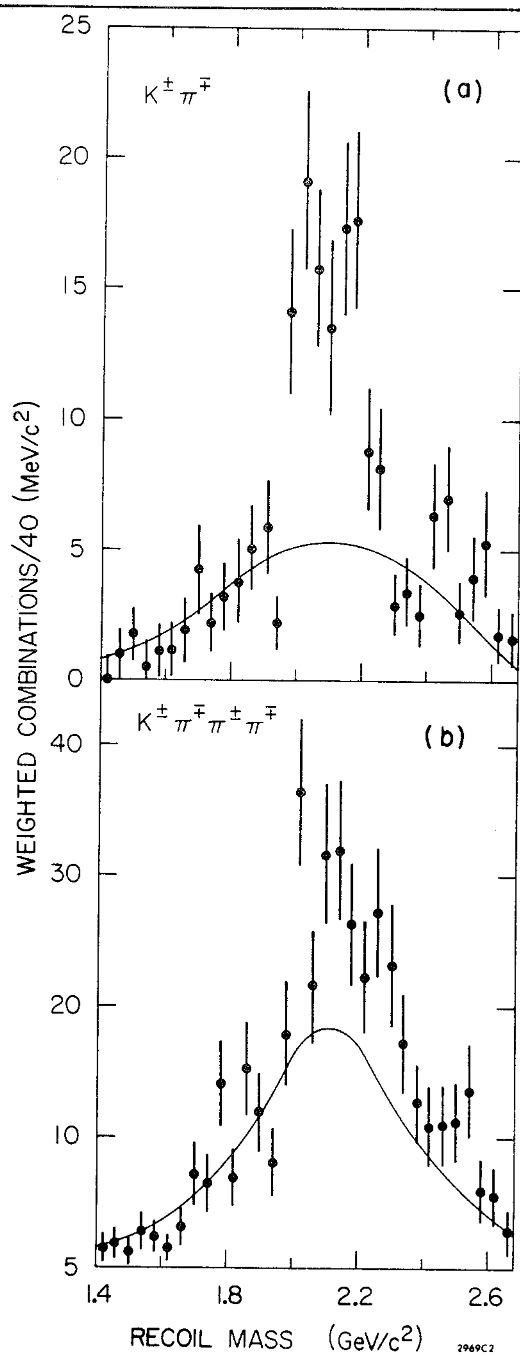
SUMMARY

The significant data points in these figures are those which rise above the smooth background curves. The main conclusions from this recoil-mass data are the following:

1. *Few low- or equal-mass recoils*. There is little evidence in the figures for the formation of recoil systems which have masses that are less than or equal to the 1.86 GeV mass of the new particle. Thus our earlier speculation that production of $D^o\bar{D}^o$ pairs would likely be a very common event is shot all to hell.

2. *But a lot of heavier stuff*. The data points in the figures jump up strongly above the background in the mass region from about 1.95 to 2.20 GeV, with some additional rolling foothills reaching up to about 2.5 GeV. Charm theory predicts that there should be several charmed-particle states in this general mass region, but the data shown in the figures is still too diffuse and mushy to pick them out if they are actually there. The consensus, however, is that the higher-mass charmed states such as the D^* and F mesons (which we'll come to shortly) probably *are* hiding in those bullrushes, and with the continuing analysis will start to emerge as distinct spikes at specific masses.

3. *Threshold effect*. The most common production mechanism thus appears to be creation of the new 1.86 GeV particle in association with a recoil-mass state of, say, 2.00 GeV. (The process is perhaps $e^+e^- \rightarrow D^o\bar{D}^{*o}$.) This means that there is a "threshold" or minimum colliding-beam energy of about 3.86 GeV that must be reached for production to occur. As a check on this conclusion, the LBL-SLAC group looked back over the extensive data they have collected at the ψ "resonance" energies (150,000 events at 3.1 GeV and 350,000 events at 3.7 GeV) to look for any



The recoil-mass spectrum for time-of-flight weighted combinations in the Kπ and K3π peaks. The smooth curves are estimates of the background (unrelated events) that were obtained from combinations whose invariant masses lie in the 1.72 to 1.82 GeV and 1.91 to 2.01 GeV regions on the low and high sides of the 1.84 to 1.89 GeV peak mass region. These spectra point to the surprising (at least to us) conclusion that there is little evidence for the production of recoil systems at masses that are either less than or equal to the 1.87 GeV mass of the new particle. Instead, there is a strong showing of recoil masses in the range from about 1.96 to 2.20 GeV, with some additional hints up to about 2.5 GeV.

sign of the $K\pi$ or $K3\pi$ systems showing up at a mass of about 1.86 GeV, but no such evidence was found.

DETAILED DISCUSSION

We consider here both more generally and in more detail the significance of *recoil mass, missing mass, invariant mass*--all of which are closely related, and all of which form a central part of experimental analysis. It will be helpful to begin by forgetting all about charmed particles and charmed mesons, and to remind ourselves of that we change the symbol we've been using for the new particle from $\mathcal{D}^o$ to D^o for a while.

When a new particle is created in e^+e^- annihilation, the mass recoiling against this new particle can be any of three possibilities:

1. Nothing.
2. Many different combinations of particles.
3. One or two specific particles.

We consider each of these possibilities in turn:

1. Nothing. If the e^+e^- annihilation process could create a single D^o particle and nothing else, then it should only require a total beam energy of 1.86 GeV (0.93 GeV each beam) for the production of D^o's to occur. But in fact D^o's are not created at that energy for the following reason. The only kinds of particles that can be created *singly* in e^+e^- annihilation are the members of the small class of particles called *vector mesons*. There is a clue to why this is so in the quark substructure of these particles, which we show here:

rho = $u\bar{u}$, omega = $d\bar{d}$, phi = $s\bar{s}$, psi = $c\bar{c}$

The vector mesons, then, are those that consist of quarks that are paired with their own antiquarks, with the result that many of their properties (charge, strangeness, charm) cancel each other out.

More fundamentally, let's recall here that the e^+e^- annihilation process actually proceeds in two steps, the first being the creation of a very short lived intermediate state of pure electromagnetic energy called a *virtual photon* or a *virtual gamma ray* (γ):

$$e^+ + e^- \rightarrow \gamma \rightarrow \text{created particles}$$

Since the net values of the various particle properties have to balance out (be conserved) in this particle-creation process, the only states that can be produced singly are those that have the same properties (quantum numbers) as the photon--which is the definition of a vector meson. (The photon/vector meson relationship is sometimes expressed by saying that the photon spends a small fraction of its time *being* each of the vector mesons; or, even more peculiarly, that the photon is a *mixture* of all the vector mesons and therefore contains all quark-antiquark pairs.)

Conclusion: Since the D^o particle is not produced singly, it is not a vector meson.

2. Many different combinations. The sketch showed an example in which the D^o meson decayed into π^+ and K^- mesons, and in such a case there must be some other particles produced in the recoil mass in the annihilation process. But if there were nothing special about the D^o (for example, if it were simply a K^{*o} "excited state"), then there are many different combinations of particles that could be produced to balance the quantum-number books: π^-K^+, $\pi^+\pi^-K^o$, $K^+K^-K^+$, $\bar{\Sigma}^+\pi^+$, etc. Because of this, a graph of the masses recoiling against the D^o particle would show two characteristic features: (i) many *different* recoil-mass values, so that the individual data points would tend to be jumbled up together; and (ii) a large fraction of the recoils at *low* mass values--say less than 1 GeV--because of the preponderence of such simple recoil states as π^-K^+ and $\pi^-\pi^+K^o$.

Conclusion: Many different recoil masses and recoiling systems of low mass would point toward an unspecial particle. But these are not observed with the D^o, which is likely therefore to be quite special.

3. One or two specific particles. If the mass recoiling from the D^o shows sharp peaks at one or two specific values, the probable interpretation is that the D^o is commonly created in association with one or two other specific particles, rather than with many different combinations. In particular, if the recoiling system has the same or a somewhat greater mass than the D^o, this is a signal for a pair-production process in which the pairs carry opposite values of some fundamental particle properties--that is, of *particle-antiparticle* pair production. As common examples, gamma rays (real or virtual) create electron-positron pairs (+ and - charge), K^+K^- or $K^o\bar{K}^o$ pairs (+ and - strangeness), and $p\bar{p}$ pairs (+ and - "baryon number"). So the recoil systems in the mass range from about 1.95 to 2.20 GeV that are produced in association the D^o particle are likely to be its excited-state antiparticle relatives such as $\bar{D}^{*o}$ (+ and - charm).

Conclusion: The 1.86 GeV + ≃ 2.00 GeV ≃ 3.86 GeV threshold for, say, $D^o\bar{D}^{*o}$ production at SPEAR looks very much like the production of of a charmed particle-antiparticle pair.

> The collision and annihilation of electrons and positrons is one of the hottest forms of experiment in physics today, and promises to be one of the longest running. . . . Week by week and month by month, as the energy of the electron and positron beams is gradually raised, a seemingly endless succession of discoveries is reported. . . .
>
> --*Science News*
> May 4, 1976

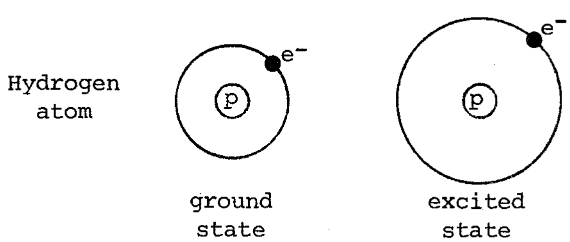
IV. SOME THEORY AND SOME LATE RESULTS

In this final section we plan to proceed in the following way. (a) We first describe some of the properties of and relationships within the meson family, emphasizing *charmed mesons*, in order to gain a better idea of what we are looking for. (b) Then we report briefly on a very recent new experimental result that became known shortly before we go to press: the discovery of the *charged state* of the new particle as observed through its decay into $K^+\pi^-\pi^-$ and $K^-\pi^+\pi^+$. (c) Then finally we try to pull together the various threads of the story in order to summarize *the argument for charm.*

A. CHARMED MESONS

The boxed column on this page describes the six ways in which a charmed quark/antiquark can combine with an uncharmed antiquark/quark to form charmed mesons, and also how these six charmed mesons fit into the basic family of all the mesons. After the discovery of the psi particles in November 1974 had revived the older theoretical idea of charm, a large number of theoretical papers began to appear with predictions about the properties that charmed particles were likely to have. For reasons that will become more obvious a bit later, the consensus was that the family of charmed $\mathcal{D}$ and $\mathcal{F}$ mesons would have masses that lay in the range from about 1.8 to 2.0 GeV. The "excited" states of these mesons, $\mathcal{D}^*$ and $\mathcal{F}^*$ (spoken as "$\mathcal{D}$-star" and "$\mathcal{F}$-star"), were expected to be somewhat more massive--say up to 2.1 GeV--and to decay into their "ground states" by emitting a pi meson or a photon, e.g., $\mathcal{D}^* \to \mathcal{D} + \pi$ or $\mathcal{D}^* \to \mathcal{D} + \gamma$.

To avoid possible confusion, it may be worth noting that the excited states of a particle still consist of the same basic quark combination as the ground state, the only difference being that the excited states represent different patterns of relative motion of the constituent quarks. In this regard, the analogy with the hydrogen atom is again useful:



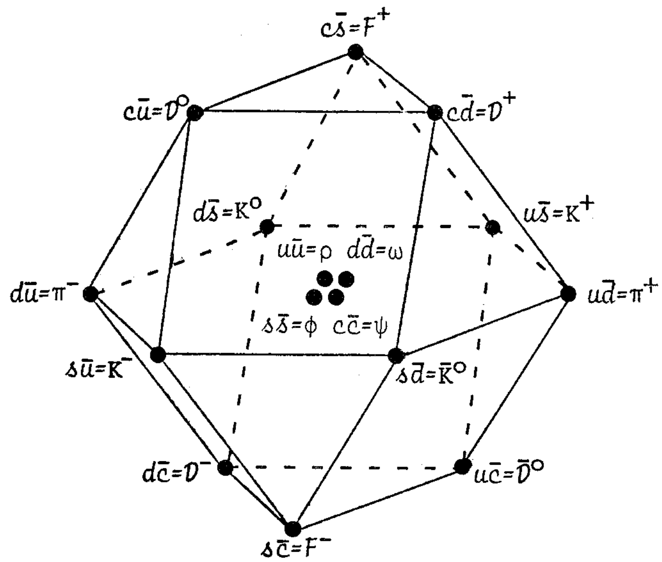
As we saw earlier, the new particle was observed at SPEAR through its decay into either of two *neutral* combinations of well-known mesons: (1) $K^+\pi^-/K^-\pi^+$ or (2) $K^+\pi^-\pi^+\pi^-/K^-\pi^+\pi^-\pi^+$. Since the *net* electric charge of any of these combinations is zero, the parent particle from which they decayed must also be electrically neutral. This is why we chose the tentative designations $\mathcal{D}^0$ and $\bar{\mathcal{D}}^0$ from the suggested family names for the predicted charmed mesons. But having discovered

CHARMED MESONS

Any meson consists of a quark-antiquark pair. The various quark-antiquark combinations that can be made using either the charmed quark c or the charmed antiquark $\bar{c}$ are shown in the following list:

Tentative Family Name	*Quark Content*	*Name Of Particle/Antiparticle*	
$\mathcal{D}$ mesons	$c\bar{u}$	$\mathcal{D}^0$	
	$u\bar{c}$		$\bar{\mathcal{D}}^0$
	$c\bar{d}$	$\mathcal{D}^+$	
	$d\bar{c}$		$\mathcal{D}^-$
$\mathcal{F}$ mesons	$c\bar{s}$	$\mathcal{F}^+$	
	$s\bar{c}$		$\mathcal{F}^-$

Although it not essential for our purposes, it may be interesting to see how the postulated $\mathcal{D}$ and $\mathcal{F}$ charmed mesons relate to the already known π and K mesons to form a complete grouping of all the quark-antiquark possibilities. This grouping or pattern is shown in the following sketch:



(The central cluster of 4 is from a slightly different--but less confusing--family than the others.) The 3 particles in the upper triangle have a net charm value of +1; the 3 in the lower triangle have charm -1.

It is characteristic of the theory that describes hadrons as being built up from quark sub-constituents that the possible quark combinations for each main family of particles can be displayed in geometric figures of the kind shown above. The particular figure shown is known as a "cuboctahedron." One of the most persuasive arguments in favor of the quark picture of the hadrons is the fact that all of the known hadrons can be fitted into these geometric patterns.

the neutral state, an obvious next step is to search for the new particle in its electrically charged forms, and this is the topic we now turn to.

B. CHARGED STATES OF THE NEW PARTICLE

A PEP Users Conference was held at SLAC on June 23-25. Near the end of the Conference, Ida Peruzzi of SLAC Experimental Group C (on leave from the Frascati Laboratory in Rome) presented an up-to-date summary of the experimental data that had been obtained on the new particle. The last part of her talk dealt with evidence for the discovery of a new state with approximately the same mass as that already observed, 1.87 GeV, but which decayed into three charged particles rather than the two or four we've already talked about. The method of searching for this new state was very similar to that described earlier on pages *C-5* through *C-7*. The time-of-flight information was used to arrive at "weighted" combinations in which the K and π mesons are assigned a certain probability of correct identification, and the data were plotted using the several different possible assumptions about three-charged-particle decay modes: $\pi\pi\pi$, $K\pi\pi$, $KK\pi$, etc.

Sticking with our practice of calling the new particles $\mathcal{D}$ mesons, this three-body analysis resulted in a clear resonance peak for the decay modes

$$\mathcal{D}^- \to K^+\pi^-\pi^- \quad \text{and} \quad \mathcal{D}^+ \to K^-\pi^+\pi^+$$

but no such bumps in any of the other combinations. (An interesting sidelight here is that the new charged states do *not* appear in the decay modes

$$\mathcal{D}^- \not\twoheadrightarrow K^-\pi^+\pi^- \quad \text{or} \quad \mathcal{D}^+ \not\twoheadrightarrow K^+\pi^-\pi^+$$

although on the face of it these would seem to be possible. We are told that there is a subtle reason for this, and we believe it because we couldn't understand the first three explanations we got.)

Recoil masses. The recoil-mass spectra that have been worked out so far for the new three-body decays are similar to the earlier data shown on page *C-9* for the two- and four-body decays in the sense that the prominent recoiling systems occur at masses greater than 1.87 GeV. We mentioned earlier that the data shown in the figure on *C-9* was still too diffuse to be able to pick out any specific well-defined recoil states. However, this situation has now started to improve--both for the original $\mathcal{D}^0\bar{\mathcal{D}}^0$ discovery and the newer $\mathcal{D}^+\mathcal{D}^-$ particles. We have seen very recently some new recoil-mass figures that show sharper structure, with apparent peaks at mass values of about 2.00 and 2.15 GeV. But our attempt to purloin one of these figures for this article (via the usual midnight requisition route) succeeded only in touching off a burglar alarm and a couple of sirens in Group C.

C. THE ARGUMENT FOR CHARM

The SLAC-LBL authors listed on page *C-3* conclude their paper on the new particle with the following remarks (presumably spoken as with a single voice by all 41 of them):

> In summary, we have observed significant peaks in the invariant mass spectra of $K^{\pm}\pi^{\mp}$ and $K^{\pm}\pi^{\mp}\pi^{\pm}\pi^{\mp}$ that we associate with the decay of a state of mass 1865 ± 15 MeV/c^2 and width less than 40 MeV/c^2. The recoil mass spectra indicate that this state is produced in association with systems of comparable or larger mass.
>
> We find it significant that the threshold energy for producing this state lies in the small interval between the very narrow ψ' and the broader structures present in e^+e^- annihilation near 4 GeV. In addition, the narrow width of this state, its production in association with systems of even higher mass, and the fact that the decays we observe involve kaons [K mesons] form a pattern of observation that would be expected for a state possessing the new quantum number charm.

The word "charm" appears in this paper only once--as the 1507th and last word. This is certainly a modest way to sneak in a plug for charm, and it will be our purpose here to try to see whether such becoming modesty is appropriate to the circumstances. We do this by looking more closely at the several reasons given in the quotation above for favoring the charm interpretation: (1) narrow width, (2) threshold energy, (3) association with systems of even greater mass, and (4) decays involving K mesons.

1. *Narrow Width*

The width of the new 1.86 GeV particle is less than (probably considerably less than) 40 MeV. This relatively narrow width corresponds, as noted earlier, to a relatively long life, which in the charm interpretation would be explained in the following way. Let's make the not quite correct assumption (see part *3* below) that the following two-step process occurs commonly at SPEAR:

Production

$e^+ + e^- \to \mathcal{D}^0 + \bar{\mathcal{D}}^0$ *Decay*

$\bar{\mathcal{D}}^0 \to K^- + \pi^+$ } *Observed*

$\mathcal{D}^0 \to K^+ + \pi^-$ } *Particles*

In terms of the quark content of the particles involved, the same process looks like this:

Production

$e^+ + e^- \to c\bar{u} + u\bar{c}$ *Decay*

$u\bar{c} \to s\bar{u} + u\bar{d}$ } *Observed*

$c\bar{u} \to u\bar{s} + d\bar{u}$ } *Particles*

The key point here is that the decay of the $\mathcal{D}^0$ and $\bar{\mathcal{D}}^0$ mesons involves the *disappearance* of the property of charm, which can only occur in *weak-interaction* processes. (Like the analagous property of strangeness, charm is assumed to be *conserved* or unchanged in strong interactions, but not conserved in weak interactions.) The characteristic time scale for a weak decay of the kind shown above is roughly 10^{-13} second, as compared to the 10^{-23} second that is typical of strong decays. So the narrow width of the new particle is thus consistent with charmed quarks in the new particles slowly decaying into the uncharmed quarks that make up the common particles that are actually observed.

The decay process just described is exactly analagous to what happens in the case of strange particle decays, for example:

$$\bar{K}^0 \to \pi^+ + \pi^-, \text{ or, in quarks, } s\bar{d} \to u\bar{d} + d\bar{u}$$

Although all of the particles involved are members of the strongly interacting hadron class, the decay process itself involves the disappearance of one unit of strangeness carried by the s quark and is therefore a weak (and thus slow) interaction.

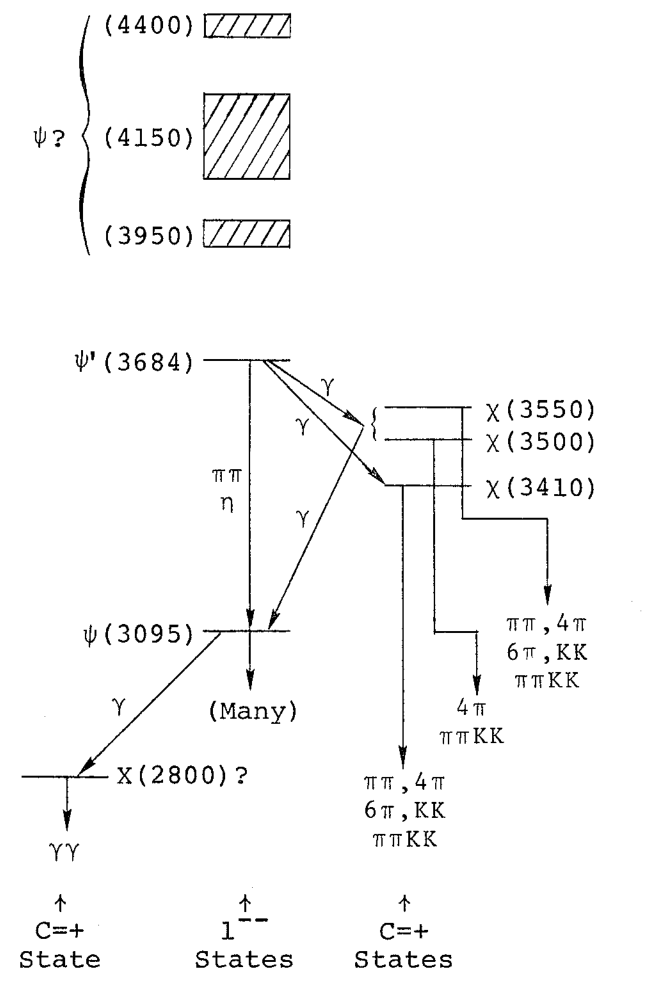
2. *Threshold Energy*

The brief explanation here is the following: The $\psi'(3684)$ is a very narrow state that does not decay into charmed mesons, while higher mass ψ states are much broader and probably do decay into charmed mesons. Thus charmed mesons must start to appear at a threshold or minimum energy that is greater than 3684 MeV but less than the 3950 MeV of the next higher tentatively identified ψ state.

We can see this part of the argument more clearly by consulting the boxed figure on this page, which shows the psion family of particles as it is presently known. For our present purposes we are interested only in the sequence of ψ particles identified in the figure as "1^{--} States." The original two psi particles, $\psi(3095)$ and $\psi'(3684)$, are remarkable for the fact that they are very long-lived or "narrow" states, which means that they are somehow inhibited from decaying in what would be expected to be the "normal" manner for such massive particles. In contrast, the three tentatively identified ψ states of greater mass are much shorter lived or "broader" states which do decay in a "normal" (very fast) manner. If we recall that the ψ particles are assumed to consist of a combination of the charmed quark c with the charmed antiquark $\bar{c}$, we can then take the further step of noting that one of the most common "normal" decay modes of the ψ's should be the following:

$$\begin{array}{ccccc} c\bar{c} & \to & c\bar{u} & + & u\bar{c} \\ \psi & \to & \mathcal{D}^0 & + & \bar{\mathcal{D}}^0 \\ \uparrow & & \uparrow & & \uparrow \\ \text{(psi's)} & \to & \text{(charmed} & & \text{mesons)} \end{array}$$

But we know that this decay mode does not in fact occur in the cases of the $\psi(3095)$ and $\psi'(3684)$, because these are "strong" (very fast) decay processes that would make these two particles have a much shorter lifetime than what is observed. As a consequence, the starting point or threshold for production of charmed mesons must be at an energy greater than 3684 MeV, but smaller than that of the next higher energy ψ state at about 3950 MeV.



The psion family of particles as presently known. The column identified as "1^{--} States" contains particles that are produced directly in e^+e^- annihilation at SPEAR and that are given the name ψ. The other states result from the decays of the ψ particles through radiative transitions (diagonal arrows marked "γ") from these states. The two original psi particles, $\psi(3095)$ and $\psi'(3684)$, are very long lived or "narrow" states. The other 3 possible psi states are shown hatched to indicate that they are much shorter lived and thus "broader" states. The threshold for the production of pairs of charmed particles occurs at an energy greater than the 3684 MeV of the ψ' but smaller than that of the next higher ψ state (about 3950 MeV).

The second significant aspect of threshold energy has to do with the earlier discussion we had on page *C-10* of "recoil mass." We will not repeat that long-winded argument here except in the following summary form:

1. Since the new particles are not produced singly at SPEAR, but rather in pairs, the new particle is not a vector meson.

2. The spectrum of masses recoiling against the new particle shows no evidence for low-mass systems or for many different values of mass. This circumstance favors a particle-antiparticle pair-production mechanism.

3. An energy threshold of 1.86 + about 2.00 GeV ≃ 3.86 GeV fits the predicted energy region for production of a charmed particle/charmed antiparticle pair such as $D^0\bar{D}^{*0}$ or D^+D^{*-}.

3. *Association With Larger Mass Systems*

We learned back on page *C-9* that the masses recoiling against the new 1.86 GeV particle during its production tended to be predominantly in the range from about 1.96 to 2.20 GeV, with some of even higher mass, and very few or none of 1.86 GeV or lower mass. This meant that our initial hypothesis of the production of lowest mass charmed-meson pairs such as $D^0\bar{D}^0$ was definitely not the most common production process. As it turns out, certain versions of the charm theory make the prediction that this simplest $D^0\bar{D}^0$ will not be produced as commonly as the "excited-state" systems $D^0\bar{D}^{*0}$, $D^{*0}\bar{D}^0$ and $D^{*0}\bar{D}^{*0}$. From the recoil-mass information given in the figure on page *C-9* it is not possible to pick out any specific peaks or bumps in the region from 1.96 to 2.20 GeV that may represent the higher mass D^{*0} and $\bar{D}^{*0}$ states, but eventually it will be necessary to identify these D^* (as well as F and F^*) states if the charm hypothesis is to be fully confirmed.

For the time being, however, we can say that the recoil-mass data is consistent with the assumption that the new 1.86 GeV particle is a D^0 or $\bar{D}^0$ meson, and that in one common production process it is probably created in association with D^{*0} or $\bar{D}^{*0}$; for example,

$$e^+ + e^- \to D^{*0} + \bar{D}^0 \to K^- + \pi^+$$
$$\hookrightarrow \pi^0 + D^0 \to K^+ + \pi^-$$

The same kind of situation seems to obtain for the more recently discovered charged states of the new particle, where a likely guess for a common mode of production would be the following similar process:

$$e^+ + e^- \to D^{*+} + D^- \to K^+ + \pi^- + \pi^-$$
$$\hookrightarrow \pi^0 + D^+ \to K^- + \pi^+ + \pi^+$$

4. *Decays Involving K Mesons*

In the limited space remaining we cannot go into any great detail about this point *(but see Ref. 3, page S-15 for a discussion)*. The main idea, stated baldly, is that the charmed mesons are expected to display a strong preference for those decay processes in which strange mesons are produced. This means that the most common of the strange particles, the K mesons, should appear more frequently in charmed-meson decays than they do in common decays. This expectation is well verified in the case of the new 1.86 GeV particle, since K mesons appear in each of the three decay modes so far observed: Kπ, Kπππ and Kππ.

As a way to think about this preference, it may be useful to imagine that the charmed quark can follow the two-step decay path

$$c \xrightarrow[\text{lost}]{\text{charm}} s \xrightarrow[\text{lost}]{\text{strangeness}} u \text{ or } d$$

more easily than it can make the big jump)

$$c \longrightarrow u \text{ or } d$$

Finish. Our time is up. We have been less modest than the physicists about touting charm, but to our lay eye the package seems very persuasive. Charmed, we're sure.

--Bill Kirk

PUSHING THE LIMITS

Quarks:
the smallest specks
we yet suspect.
"The atom."
said the Greeks,
"is indivisible."
But where is the speck
that can't be cut
into further spaces?

Quasars:
the furthest "stars"
with the presence
of a hundred galaxies.
What lies beyond
the blizzard of lights
we call the Milky Way;
beyond the dogma
of our sluggish imagination?

Push the limits
and space will yawn to receive us
once more.

--Peter Nowell
The Christian Science Monitor
May 4, 1976

ACKNOWLEDGMENT: THE PEOPLE BEHIND THE SPEAR MARK I & MARK II MAGNETIC DETECTORS

For the past two years the important physics results from the SPEAR storage ring at SLAC have been reported in a number of different *Beam Line* articles. During most of this time, the implications of the new psion family of particles, and especially the "charm" theory that has been proposed to explain these new particles, have been the most extensively discussed topic in the professional physics literature--the "talk of the town." Although history will be the final judge of the true significance of the SPEAR experimental results, it is already clear that the work has been exceptionally important. What is also clear is the fact that the Mark I magnetic detector at SPEAR has been, ever since its baptism in early 1973, a superb instument for carrying out these experiments.

To the casual observer it might appear that the whole SPEAR program was a rather makeshift, spur-of-the moment enterprise--with a storage ring thrown together out of odds and ends and stuck at the end of the accelerator, and with some cobbled-up experimental apparatus slapped into it just before the ON switch was activated. Not so! The idea of a SPEAR-like storage ring at SLAC goes all the way back to about 1963, with a formal proposal for such a facility completed in 1965. And even this early work had its beginnings in the electron-electron storage rings that had been built at the Stanford High Energy Physics Laboratory, starting in the late 1950's.

Throughout this long period, the design of the storage ring that was to become SPEAR and of the major detection device that was to become the Mark I evolved as a result of a continuing classic dialogue among experimental and theoretical physicists and a number of different engineers. And when the time came to reduce the detector ideas to the actual hardware of the Mark I, the efforts of many more engineers, designers and technicians were vitally needed and willingly provided.

Now that an advanced successor to the Mark I is in sight--the new Mark II detector that was described in last month's *Beam Line*--it seems fitting to recognize the dedicated and creative work of some of the engineers, designers and technicians who brought the Mark I detector into being, and many of whom are now hard at work designing and building the new Mark II. Our acknowledgment of this work, in the following paragraphs, cannot hope to be complete, and we apologize in advance for any important omissions we have inadvertantly made. But to all those at SLAC who have made and are making the Mark I and Mark II detectors a reality, we offer high praise and admiration for a job superbly done.

Criteria developed by the SPEAR physicists were given to Project Engineer Bill Davies-White, who has been ably assisted by George Lee and by Dan Danielson in the designs of the solenoidal magnet coils, the steel flux-return sections, the drift-chamber assemblies, and various other detector components too numerous to list here. In the case of the Mark II, Knut Skarpaas has been responsible for the engineering and design of the special "End Cap" liquid argon shower counters.

The Precision Alignment team under Wade Milner's supervision succeeded in aligning the Mark I detector to the required few thousandths of an inch. The day-to-day running of the Mark I and its occasional modifications have been handled efficiently and expediently by Al Gallagher with the help of a number of people from the Experimental Facilities Department--in particular, Frank Stella, Harris Morales and Bill Black. These individuals will also play a key role during the period from July to November in 1977 when the Mark I is removed from SPEAR and the new Mark II is installed in its place.

Magnetic measurements of the Mark I were carried out by SLAC's Magnet Measuring group under Joe Cobb's direction, and they will repeat this effort for the Mark II.

Some idea of the magnitude of these tasks can be gained from noting that the Mark II magnet will weigh in at about 600 tons, that it will be powered by a 700-volt supply that delivers 5000 amperes, and that it will use about 400 gallons/minute of low-conductivity water for cooling purposes (the Mark I magnet is in the same general ballpark). The problems implied by these numbers are solved by the collective efforts of Plant Engineering personnel and of EFD's Power Supply group--especially Martin Berndt.

The coil for the Mark II magnet will contain 336 turns of aluminum conductor. The enormous task of winding this coil (about 2½ miles of it) was performed by the Magnet Assembly group technicians under the supervision of Larry Didier--who also did the coil-winding for the Mark I.

Herm Zaiss's Mechanical Fabrication shops have naturally played a central role in many aspects of the construction of both detectors. As an example, the wire-chamber system used in the Mark I consisted of 16 concentric rings containing a total of about 115,000 individual wires which had a spatial accuracy of approximately ± .040 inch. The Mark II will use a different design which involves concentric layers of drift chambers containing about 12,800 wires and a spatial resolution of ± .002 inch. Both of these tracking-chamber systems were put together in the Precision Assembly Shop under Don Fuller's supervision.

The Heavy Machine Shop under Stan Butler has succeeded in converting massive slabs of steel into precisely fitting segments of an intricate jigsaw puzzle. On the other hand, these projects also require incredibly small and accurate parts, and these were fabricated with the same care and attention by personnel from the Light Machine Shop under Marion Adams' supervision. Welding and sheet-metal work has been handled by the metal shop in an expert manner under the guidance of George Cruikshank and Vic Carty.

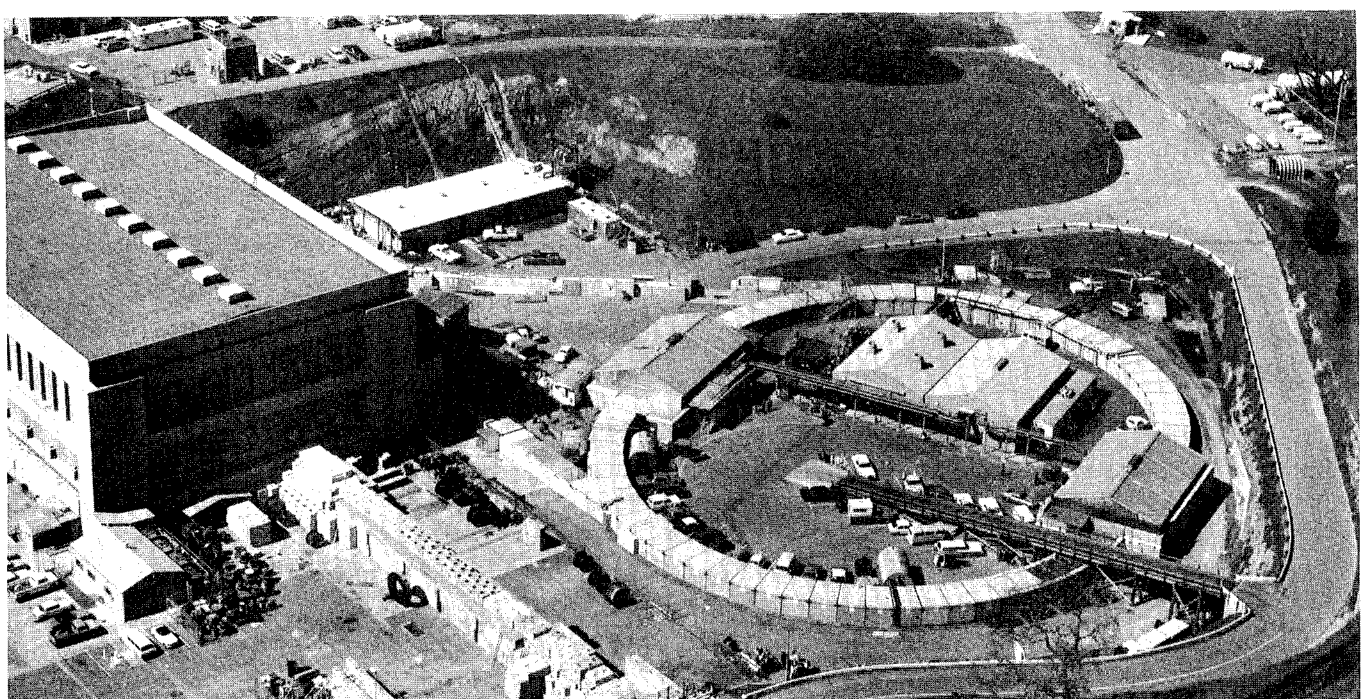
As is the case with all research-oriented equipment, a great deal of trial-and-error work on prototypes is necessary, and this is where the Group C technicians have worked closely with Ray Pickup's Central Lab Machine Shop personnel to carry out many extremely valuable projects.

The Electronics Instrumentation group under Ray Larsen's direction have been responsible for the design and development of the fast and sensitive electronics circuits. Frank Generali's Electronics Fabrication shop has been very busy in building prototypes and in some cases batch runs of much of this circuitry.

EFD's Electrical Installation group has the responsibility for the cable trays and wiring for the detectors, and the Rigging Crew is constantly being called upon to move 30- and 40-ton pieces of steel into impossibly small places. Also, the SLAC Crafts Shops are a very frequent supplier of needed services in plumbing, carpentry and other essential crafts work.

For both the Mark I and II, the Purchasing and Receiving groups have had to cope with the large procurement load that goes with the construction of such major facilities. It is not much of an exaggeration to end this acknowledgment by saying that hundreds of people at SLAC were involved in one way or another in the Mark I detector project and will continue to be involved in the Mark II. We can only hope that the Mark I's great success can be deservedly shared with all those who contributed, and that the new Mark II will achieve an equal distinction throughout the long career that awaits it.

--Rudy Larsen



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