reason, Geoffrey Burbridge, Martin Rees, and others refer to BL Lacs as the best available chance to see the "bare machine."

Building on a model they proposed several years ago, Rees and Roger Blandford, from Caltech, quickly developed an explanation for the relative strengths of the continuum and line radiation by postulating that BL Lacs and quasars are identical objects oriented in different ways to the line of sight from the earth. Their explanation is that the continuum radiation produced by the central object propagates out into space in a fairly tight beam, while the emission line radiation from the gas surrounding the central object propagates in all directions. If the beam is directed toward our galaxy, the continuum radiation dominates and the object is called a BL Lac. If the beam is directed away, we see mostly line emissions and call the object a quasar. This idea is new and was embraced with steadfast neutrality by the Pittsburgh attendees. Problems could arise with the model if there proved to be nearly as many BL Lacs as quasars, however. An analysis of the population question by B. Setti, of the University of Bologna, indicated that, even though observational biases make it difficult to determine the statistical prevalence of BL Lacs, the two types of objects may be equally abundant. Setti concluded, with certain limitations, that there appeared to be 100 quasars per cubic megaparsec of the universe and more than 30 BL Lacs.

Other models were also discussed, including the suggestion by Stirling Colgate that the core of a BL Lac consists of a high-density region of stars that energize the surrounding medium by frequent supernova explosions. A new finding about the polarization features of BL Lacs, however, would put severe constraints on this and every other model. J. E. Ledden, of the Virginia Polytechnic Institute, reported that during the great outburst of AO 0235 +164 the plane of radio polarization had slowly rotated through 130° in the course of several months. This argues strongly that a single, coherent source of radiation was at work, not a disconnected group of stars. The synchrotron process will produce the required coherence if all the synchrotron radiation comes from a single object. (The question of optical coherence is still open, but it is nevertheless mind-boggling to think that for some months AO may have been a 10^{41} watt laser!)

No doubt more models for BL Lacs will be proposed, more observations of their special properties will be made, and radio and optical astronomers working together will try to advance the data base for these objects to the level of completeness that characterizes quasars. At the same time, the present categorizations may change. Martin Rees suggested at Pittsburgh the "need, rather than carrying around all this classical baggage, for a more sensible and logical classification scheme for active galaxies."

The story of BL Lacs is not only the story of a small group of astronomical oddities that have found their way into the mainstream of astrophysical inquiry. It is also an outstanding example of the progression of thought that appears to be occurring throughout astronomy, as many different high-powered objects that have been discovered by different observational techniques—radio, optical, and infrared—are being seen more and more as manifestations of the same phenomenon, powered on different scales by the same machine.—WILLIAM D. METZ

Particle Physics: New Evidence from Germany for Fifth Quark

A long-shot experiment has paid off for two groups of German physicists at the Deutsches Elektronen Synchrotron (DESY) laboratory in Hamburg. On the same day last month, researchers working independently with two different particle detectors on DESY's electron-positron colliding beam accelerator found new evidence for the existence of a fifth quark to go with the four now supposed by physicists to exist. Quarks are believed to be the entities making up the bulk of the "elementary" particles, such as the proton, the neutron, and the pi meson.

The new evidence comes from the DORIS electron-positron storage ring where another kind of meson called the upsilon particle was found. The finding confirms and adds to the results of an altogether different type of experiment with the proton synchrotron at the Fermi National Accelerator Laboratory (Fermilab), where the first evidence for the upsilon was reported last year. Physicists believe that the upsilon can best be interpreted as consisting of the fifth quark and its antiquark bound together by the strong nuclear force, somewhat as the proton and the electron in the hydrogen atom are bound by the electromagnetic force. Because of certain new information not obtainable from the Fermilab experiment, researchers will accept the DESY results as a stronger (but not certain) piece of evidence in favor of the fifth quark, to be called, according to one's taste, either the bottom or the beauty quark.

Quarks come imbued with a variety of properties, such as mass, charge, and spin angular momentum, but they are usually labeled by abstract quantities called, for no apparent reason, flavors. Originally there were three flavors: up, down, and strange. With the discovery of the J/psi meson in 1974, evidence began to accumulate for a fourth flavor now known as charm. Peter Waloschek, a member of one of the groups and now in charge of public relations at DESY, says that after charm must come beauty, but U.S. physicists have tended to stick with bottom as the name for the fifth flavor.

As exciting as the particle discovery itself are the machinations of the DESY accelerator engineers to squeeze the highest possible energy out of DORIS, thus making it, for now, the world's highest energy electron-positron colliding beam storage ring. In the ring, electrons and positrons circulate in opposite directions. At certain designated points along the way, they collide and annihilate each other. The energy released in the annihilation is used to create the particles that are detected. The heaviest particle that can be created has a mass equivalent to the sum of the energies of the circulating electrons and positrons. DORIS started out in 1974 with a maximum energy of 3.5 GeV in each beam, thus the heaviest particle observable would have a mass equivalent to about 7 GeV. Various improvements in succeeding years raised the beam energy to nearly 4 GeV, quite a bit less than needed to observe the upsilon, whose mass was established at about 9.4 GeV by Leon Lederman of Columbia University and his collaborators at Fermilab last summer.

To reach the energy of the upsilon particle, the DESY accelerator engineers had to resort to numerous tricks and are, according to Waloschek, the real heroes of the experiment because, he says, any physicist with a particle detector would

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have found the upsilon once DORIS was running at the requisite energy.

The main engineering improvement was the replacement of eight of the original radio-frequency cavities that transmit power to the circulating electrons and positrons by new cavities designed for the new PETRA storage ring. PETRA is a higher-energy machine, which is now under construction at DESY and scheduled for commissioning this September. Enough cavities were available that some could be spared for DORIS. To make full use of the eight cavities, another modification was introduced to permit both electrons and positrons to circulate in the same ring, whereas separate rings had been used at DESY previously. The details are complicated, but, at high beam energies, a greater number of useful collisions is obtained with the use of only one ring. With these changes and with the magnets (which confine the electrons and positrons to their circular paths) at the maximum possible field, researchers have been able to tweak 9.8 GeV out of DORIS for short periods; but for the days-at-a-time running needed for data accumulation, 9.5 GeV was about the maximum achievable.

The decision to upgrade DORIS was made soon after Fermilab announced its upsilon discovery. After months of effort, it was just at the end of April that the total energy of the two beams reached 9.4 GeV, according to Waloschek, at which time a detailed search for the upsilon began. There was one false start when some researchers in both groups thought they found something suspicious at 9.38 GeV. Then, armed with a precise estimate of the upsilon mass that was furnished by the Fermilab group, it took the German physicists about a week of continuous experimentation to collect enough data points to constitute a publishable finding. (The two detectors used, which are called PLUTO and DASP, sit on opposite sides of DORIS and thus can collect data simultaneously.) The PLUTO group, for example, collected some 2000 events, of which about 1000 were in the peak signaling the upsilon. New particles are signaled when electron-positron collisions are unusually proficient at creating particles of all kinds at a particular energy (resonance). The profusion of particles actually detected is not the new particle itself but the more stable particles produced when it decays. In the upsilon resonance, collisions were about three times as effective in creating particles as at other energies (background).

The upsilon mass is fixed by the energy of the resonance and was put at 9.46 ± 0.01 GeV. The stability (lifetime) of a particle is obtained from the inverse of the width in energy of the resonance by way of the Heisenberg uncertainty principle. Since the actual width was less than the energy resolution of the colliding beams, the upsilon is assumed to be very stable. The finding of a particle with a long lifetime is a strong indication of a new quark. The charge of the putative fifth quark was placed at $-1/3$, thus distinguishing it from an alternative possibility, a quark with a charge of $+2/3$. The Fermilab experiment did not permit a firm conclusion as to what the charge (and hence what the flavor) of the quark involved in the upsilon was.

The story of the upsilon is somewhat a repeat of the earlier J/psi particle discovery, which also involved two experiments, one at a proton synchrotron and one at an electron-positron colliding beam storage ring. The two findings were announced nearly simultaneously in the J/psi case, however, rather than several months apart.

Quarks and the New Physics

More importantly, the discovery of the J/psi, which came after numerous experiments suggestive of quarks preceding it, is regarded as opening the era of the new physics. Before the J/psi, in the old physics, the quark concept was seen as a convenient construct (elementary particles behave as if they were composed of quarks) as much as a concrete reality. The J/psi and the whole family of particles subsequently found to be related to it seemed to require the existence of the charm quark, and the physical existence of quarks somehow became more believable. In particular, the J/psi was explained as being composed of the charm quark and its antiquark bound together. In the analogy with the hydrogen atom, other more massive particles in the family would correspond to excited states of the hydrogen atom. The most conclusive evidence found for the charm quark's existence was a meson that contained a single charm quark and a second uncharmed quark. Because the charm property was not canceled by the presence of the anticharm quark, the meson was said to exhibit "naked charm."

All of this led naturally to speculation concerning how many quarks there really were, what kind of pattern did they fall into, and whether quarks were the real elementary particles. The upsilon discovery at Fermilab seemed to fit naturally into an emerging pattern, and physicists immediately described it as a much more massive analog of the J/psi—that is, a meson composed of a quark heavier than the charm quark and its antiquark. However, detailed studies of the type that unraveled the J/psi story require electron-positron storage rings rather than proton synchrotrons for their execution, but none existing at the time was energetic enough. Thus, the DESY experiments mark the first step in unraveling the nature of the upsilon.

For this reason, the 9.5 GeV energy limit of DORIS is a bit of a shame. The earlier Fermilab experiment also found evidence for a second particle in the upsilon family, with a mass of about 10 GeV. Waloschek guesses that it is unlikely that DORIS can be coaxed to yield 10 GeV, but, he adds, only a few weeks ago 9.5 GeV seemed out of reach as well. Needless to say, DESY researchers will try. Such future studies will, however, be made by the DASP group and by a new DESY–University of Heidelberg collaboration, which has its own detector. As luck would have it, the upsilon find was made just 1 week before PLUTO was to be moved to PETRA. In any case, continuous experimentation is possible only for a few more months because, beginning next January, DORIS will be used part-time as an injector of electrons and positrons into PETRA.

Thus, further studies, including the search for naked bottom or naked beauty, may have to await the completion of PETRA and two other high-energy storage rings at the Stanford Linear Accelerator Center and at Cornell University, both of which will begin operation about a year after PETRA. As it turns out, Cornell may be best suited for study of the upsilon family because its designed energy range (8 GeV maximum energy in each beam) matches the predicted masses of these particles. PETRA and the Stanford storage ring (PEP) are designed to operate efficiently in the range from about 9 to 19 GeV per beam; at lower energies, the number of collisions leading to detectable events drops off rapidly. The two bigger machines therefore may be better used in the search for the even higher-energy analog of the J/psi that contains the hypothetical sixth quark (top or truth with charge $+2/3$ referred to earlier).

One apparent pattern is that each new analog is about three times as massive as the previous. Thus the phi particle (strange and antistrange quark bound together) has a mass of 1.02 GeV; the J/psi particle has a mass of 3.09 GeV; and the upsilon has a mass of 9.46 GeV. The next new analog, if it exists, may thus reside near 30 GeV, which is fair game for PEP and PETRA.—ARTHUR L. ROBINSON