CERN Resets Particle Hunt to October

The 6-month delay due to an accident will give physicists a chance to fine-tune their detectors, but the whole affair is quite embarrassing

One of the drawbacks of being way out in front of the pack is that everyone can see if the leader stumbles. At the European Organization for Nuclear Research (CERN) just outside Geneva, Switzerland, sit an accelerator and two giant elementary particle detectors that will have at least 3 years of competition-free running in the search for the currently most coveted prizes in high energy physics—the particles called W and Z. The particles would be the most massive ever created in an accelerator, but their importance would be in confirming that theorists are really on the right track.

Successfully out of the starting blocks with a preliminary run last fall, CERN recently tripped in one of the most embarrassing ways possible. In preparing for a second run in late April, one of the detectors, a \$20-million, 2000-ton behemoth was put out of commission by a common compressed-air line that, unfiltered, shot dirt all over the most sensitive, inner portion of the instrument. Although the mess should be cleaned up by mid-June, the complexities of scheduling experiments at CERN caused the laboratory management to wait until early October before trying again.

Because CERN's nearest rival, the Fermi National Accelerator Labortory west of Chicago, will not have a comparable facility in operation before 1985 (depending on the budgetary process), the slip in the timetable is far from disastrous. But the discovery of the W, which was first postulated about 50 years ago, and its companion of a much more recent vintage, the Z, are so important in current thinking that a Nobel Prize for the finders is widely regarded as likely.

CERN, which has never had a Nobel Prize–winning experiment done on its premises, wants very much to show that the quality of its science matches the size of its budget. A more dignified start for such an august venture could easily have been imagined. Carlo Rubbia, known to his colleagues as a man seldom at a loss for words, sheepishly shrugged off the accident at his group's detector at the Washington, D.C., meeting of the American Physical Society last month as "one of those facts of life for an experimentalist."

The secret of CERN's big lead in the race to find the W and Z, particles that as transmitters of the weak force between elementary particles are ultimately responsible for such processes as nuclear beta decay and all interactions involving neutrinos, is a daring 1978 decision to convert the laboratory's Super Proton Synchrotron (SPS) into a storage ring where counterrotating beams of protons and antiprotons could collide head on (*Science*, 10 July 1981, p. 191). The conversion, completed last spring, increased the effective (center of mass) energy available for creating new particles by almost a factor of 20. For the first time, a machine energetic enough to produce the W and Z, thought by theorists to be 80 to 90 times as massive as the proton, was at hand.

CERN physicists saw the first collisions between protons and antiprotons in the revamped SPS last July with two particle detectors in place, Rubbia's UA-1 experiment and a smaller instrument, UA-5, built by a group headed by John Rushbrooke of the University of Cambridge. The first extended period of running the SPS as a proton-antiproton collider came last fall and ended just before Christmas. During this time, the SPS operators were still learning how to make their machine work efficiently in its new mode, and consequently the event rate was quite low. Nonetheless, the UA-1 group recorded about one-tenth of the 5 million collisions that took place, and a second large detector, UA-2, built by an international collaboration led by CERN's Pierre Darriulat, which replaced UA-5 in November, recorded somewhat fewer. However, only one in 10^7 collisions should contain a W or a Z, so it is no surprise that none has been seen as yet.

So much significance is attached to these particles because they are the keys to more than just the weak force. Of the three forces that elementary particles experience, one (electromagnetic) is well described by a quantum field theory and one (strong nuclear force) is increasingly well described by a mathematically similar but more complex field theory. The weak force, however, can only be adequately accounted for if it is combined with the electromagnetic in a "unified" field theory. In the process, the carriers of the weak force, which normally would be massless—just as the photon and the gluons that transmit the electromagnetic and strong nuclear forces—acquire very large masses. But what at first sight appears to the outsider as an unaesthetic lack of symmetry turns out to be an elegant path toward unifying all the forces (and perhaps eventually gravity, too) within a single mathematical framework. The whole picture hangs together only if the W and the Z have the properties predicted by the unified theory.

Thanks largely to Rubbia's energetic promotion of the project, CERN turned the SPS into a proton-antiproton collider mainly to find the W and Z and to measure as many of their properties as possible, starting with their masses. These particles materialize whenever enough energy is liberated in elementary particle collisions. In the case of CERN's collider, the protons and antiprotons each have 270 billion electron volts (GeV) of energy, in principle releasing up to 540 GeV during a collision, which can be converted into particles by way of Einstein's $E = mc^2$. But, it will be recalled, protons are composite entities consisting of three quarks and the gluons that bind them together, and the energy must be shared between all these. To create a W or a Z, a quark in a proton and an antiquark in an antiproton with a total energy of 80 to 90 GeV must collide and annihilate. In most proton-antiproton "collisions," the quarks and antiquarks do not pass close enough together to annihilate, which is partly why most events do not contain W's or Z's.

In those rare instances in which quarks and antiquarks do annihilate, whether a W or a Z comes out depends on the types of quarks in the collision. A proton consists of two "up" quarks with electrical charge +2/3 and one "down" quark with electrical charge −1/3. An up-antiup or down-antidown collision can (but does not have to) produce a neutral Z or Z^0. An up-antidown collision can create a positively charged W or W^+, and a down-antiup collision can lead to a negatively charged W or W^-. These particles must be detected by their

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decay products as they are highly unstable. The Z^0 could be seen by an abnormally energetic (90 GeV) electron-positron or muon-antimuon pair, the W^+ by a similarly energetic (80 GeV) positron-neutrino or antimuon-neutrino pair, and the W^- by an electron-neutrino or muon-neutrino pair, of the same energy. Moreover, the particles would tend to move in a direction normal to that of the proton-antiproton beam, which is a characteristic of quark-antiquark annihilations.

A problem for high energy physicists is that particles do not come flying out of collisions with labels attached that specify identity and energy. Real particle detectors are composites of several types of instruments that individually provide partial information and together give enough to allow reconstructing the event. The UA-1 detector that was the victim of the unfortunate accident is the most sophisticated in a series of large, general-purpose assemblies that have become increasingly popular as the trend toward colliding beam storage rings has solidified at the expense of fixed-target electron and proton accelerators.

The central part of the UA-1 detector consists of a cylinder 6 meters long and 1.22 meters radius that is divided into six "image chambers" filled with a mixture of argon and ethane gases. Charged particles passing through the gas ionize its molecules as they go. The resulting electrons drift in an electric field to the nearest sense wire in an array consisting of planes of wires spaced 3 millimeters apart. Midway between the planes, which are 40 centimeters apart, are planes of high voltage wires that provide the drift field. From the shape of the voltage pulse induced on the sense wires and the time that passes between the collision and the arrival of the pulse, it is possible to reconstruct the position (in three dimensions) of the particle that caused the ionization. With the addition of a magnetic field, charged particles follow curved trajectories, and from these physicists can deduce the momentum of the particles. Rubbia likes to speak of an "electronic bubble chamber." Only the Time Projection Chamber, recently installed at the PEP electron-positron storage ring at the Stanford Linear Accelerator Center, has a comparable capability of three-dimensional imaging to an accuracy of 300 micrometers.

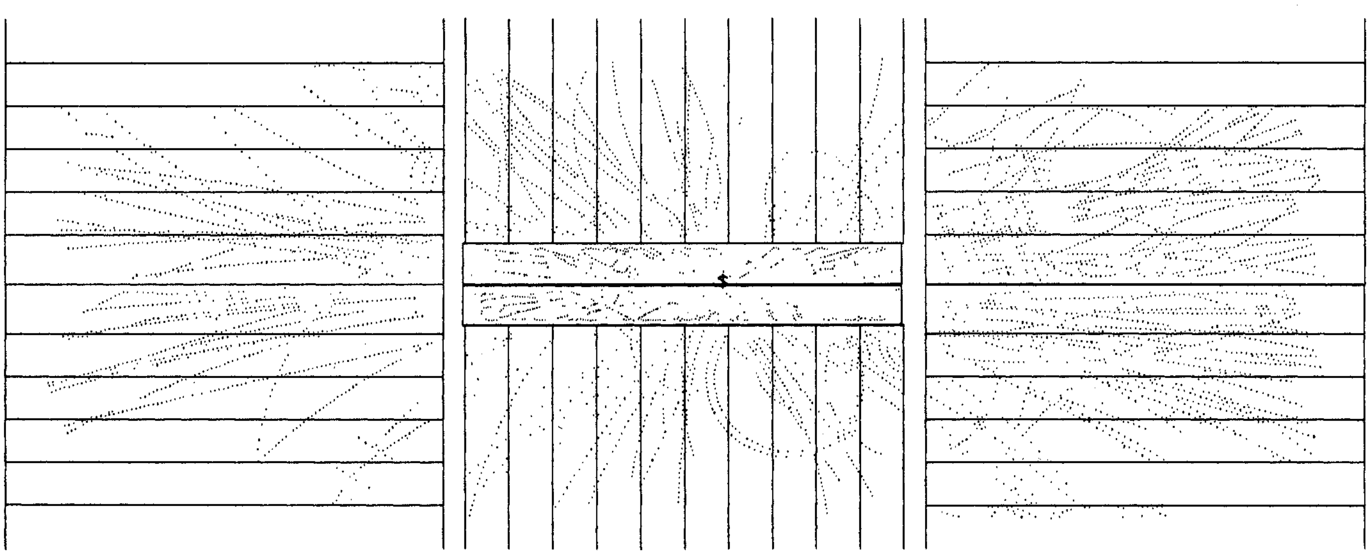
Rubbia's UA-1 experiment is an international collaboration with physicists from 11 institutions in 6 countries, including the United States. In the group's first publication there were 118 authors. CERN with more than one-quarter of the members dominates, however, and was responsible for the central detector. Outside the central detector are two layers of calorimeters, devices that measure the energy of the particles by collecting the light emitted as the particles are slowed down by collisions with the rather large amount of heavy metal (lead and iron) in the calorimeters. With the momentum from the central detector and the energy from the calorimeters, the masses of the particles and hence their identities can be determined. Calorimeters also trap photons, neutrons, and neutral mesons (mainly poins and kaons) that the central detector cannot see at all. Finally, since neutrinos are never trapped and muons hardly ever, any asymmetry in the angular distribution of transverse energy deposited in the calorimeters can be ascribed to these particles.

The final layer consists of drift chambers that operate somewhat in the spirit of the central detector. As charged particles, muons leave a track, whereas neutrinos do not. The whole affair is designed to cover as much of the 4π solid angle around the point where protons and antiprotons collide as possible.

The UA-2 detector is smaller and less expensive than UA-1 and emphasizes calorimetry. It does not have a large central tracking chamber, for example. UA-5, which is smaller still, consists of streamer chambers, which give visible tracks that can be photographed, but does not have a calorimetry capability.

It was UA-1's central detector that was savaged by the dirty compressed-air line. In the fall run, the SPS engineers protected (successfully) the central detector against overheating during a high-temperature bakeout procedure needed to remove contaminants from the vacuum pipe that runs through the center of the cylindrical image chambers. The cooling was achieved by blowing air through two perforated pipes running alongside the vacuum pipe. The procedure during the March preparations for the April run was the same, except for a decision to connect the SPS compressed-air system to an older one elsewhere on the CERN site. Bo Angerth of the SPS staff told *Science* that he believes that the act of connecting the two systems caused a pressure surge that dislodged years of accumulated dirt. The dirt covered the outer surfaces of the central detector and the surfaces between the chambers.

The cleanup procedure is tedious but is proceeding on schedule and should be completed by mid-June. Rubbia early on convinced the CERN directors that the scheduled proton-antiproton run could not proceed without his experiment, but the problem of when to have it took quite awhile to resolve. Rubbia had suggested June. The SPS, however, splits its time



More complex event than usual shows the ability of the UA-1 detector to image particle tracks

between acting as a fixed-target proton-synchrotron and a collider. A fixed-target run was set for June, and the physicists on these experiments, who were not enthusiastic about changing their plans, demanded delaying the collider run to the fall. Darriulat then wrote a memo to the CERN directors saying that "We shall make fools of ourselves if we further delay the next antiproton run . . ." but to no avail. The next day the decision was announced: the collider run begins 4 October.

In the meantime, analysis of the data gathered in last fall's run has been under way, and some results have already been presented, most recently at the Washington physical society meeting. Although the data gathered by UA-1 are mainly being used to tune up the instrument for the W and Z search, there have been some mildly interesting findings, Rubbia reported. One of these is the observation of an anomalously high probability of events with very large numbers of tracks (also seen by UA-5). This result was obtained with the central detector alone. When data from the calorimeters were thrown in, the physicists discovered that those events in which a large fraction of the total energy was due to particle motion perpendicular to the beam direction (transverse energy) were also characterized by a large number of particles, each carrying a small part of the total transverse energy. This result is in contradiction to the naïve expectation that large transverse energy events should be traceable to quark-antiquark interactions that produce a small number of highly energetic particles. The latter phenomenon is termed jets and is one of the ways physicists had hoped to study the strong nuclear force at high collision energies. Now it appears jets will be embedded within these showers of low transverse energy particles and hence more difficult to isolate.

With several months to iron out the numerous little flaws that still remain in the detectors, the UA-1 and UA-2 groups should be primed for the W and Z search this coming fall. One of the big questions is how well the SPS will work as a proton-antiproton collider. The figure of merit for colliding beam machines is the luminosity, which roughly corresponds to the brightness of a light beam. If the luminosity is low, as it was last fall, CERN would have a much more serious situation on its hands than simply a dirty detector.

In a recent meeting of SPS users, Giorgio Brianti, one of the CERN directors, recalled that the highest luminosity achieved last year was 200 times lower than the design figure of 10^{30} cm^{-2} sec^{-1} and the average was ten times lower still. Brianti's projection for 1982, taking into account several improvements in the antiproton production and accumulation machinery, was for an average luminosity of 10^{28} *if* the SPS works reliably. Since it requires 1 day to generate the antiproton beam, it does not take many lost beams to depress the average luminosity even if the peak value is high. Rubbia told the physicists at the Washington meeting that about 10 W's and 1 Z would be produced per day at a luminosity of 10^{29}. On other occasions, Rubbia has argued that no fundamental changes need be introduced into the SPS or the antiproton production and accumulation machinery to reach a peak luminosity of 10^{29}, about three times higher than Brianti's more conservative estimate.

All in all, these seems to be a good chance of seeing candidate W events by the end of the year, but whether there will be enough to provide persuasive statistical evidence remains in considerable doubt.—ARTHUR L. ROBINSON

A Hole in the Milky Way

Beyond the star clouds of Sagittarius there is an energy source like nothing else in the galaxy

For the record, astronomers like to call the thing they have found at the center of our galaxy a "compact source." But, in fact, many of them now believe it is a black hole with as much as one million times the mass of the sun.

There is no absolute proof—the galactic center is 30,000 light-years away and hidden from us by thick lanes of interstellar dust and gas; there may never be absolute proof—but data gathered over the last 5 years at radio, infrared, and gamma-ray wavelengths have made the case for a black hole compelling. At a recent symposium on the galactic center, held at the American Physical Society meeting in Washington, D.C., Richard Lingenfelter of the University of California, San Diego, captured the general tone when he asserted, "Something truly extraordinary is happening there." Marvin Leventhal of Bell Laboratories asked rhetorically, "Does the evidence call for a unique object at the galactic center?" and drew no objection from his colleagues when he concluded, "Yes."

The galactic center, lying in the constellation of Sagittarius, is among the brightest radio sources in the sky. (In fact it was the first extraterrestrial radio source ever detected, in 1932.) But for years it remained a mystery. The resolution of radio telescopes was too coarse to say much about it. Optical telescopes might have done better, but their view of the center is blocked by clouds of gas and dust in the galactic plane. And Earth's atmosphere is opaque to every other wavelength.

During the 1970's, however, new clues began to emerge from the theory of quasars. It seemed increasingly certain that these objects are both very far away and exceedingly bright. Some of them are probably 100 trillion times as luminous as the sun—a thousand times as luminous as the entire Milky Way galaxy. Barring some unknown principle of physics, this prodigious energy output is best explained by postulating a massive black hole embedded in an otherwise normal galaxy.

Gas and dust spiraling into such a hole from the galaxy's central regions would be compressed and heated, converting much of its mass to radiant energy before finally falling in. Detailed calculations showed that this is an exceedingly efficient way for mass to convert into energy—far better than fusion or fission. Given a sufficiently large hole, perhaps a billion times the mass of the sun, the energy output could indeed approach quasar levels.

The model also explains the long jets of matter that shoot out from many quasars. As matter falls toward the hole its angular momentum tends to sweep it into a disk. As it spirals inward the temperature and pressure mount; eventually, some of the material squirts out the axis of the disk as relativistic jets. A spinning

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