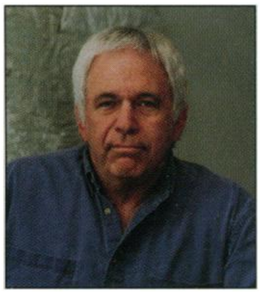
Rare Sightings Beguile Physicists

Over the past year, particle physics experiments have yielded a crop of events that seem to conflict with standard theory. They might be glimpses of new physics—or just meaningless experimental glitches

The sighting came on 28 April 1995, at 10:41 in the evening. Whatever it was, it made one solitary appearance in CDF, a house-sized experiment at Fermilab's Tevatron accelerator. The accelerator had collided a proton and an antiproton at an energy of 1 trillion electron volts, as it had done hundreds of billions of times over the years. The aftermath of this collision, however, was like nothing the physicists had ever seen. Instead of the usual isolated electrons and bundles of common particles like pions, the debris included a pair of very energetic electrons, a pair of equally energetic photons, and—judging by a shortfall in energy in the observed particles—another particle or two that escaped detection entirely. The orthodox theoretical framework that explains the basic particles and forces of nature, known as the Standard Model, didn't seem to explain this pattern, which prompted one of the CDF physicists to offer a $500 prize to anyone who could come up with a plausible explanation.



Seeking supersymmetry. Gordon Kane sees hints of new physics.

Theorists haven't hesitated to venture explanations, although their eyes are on a much bigger prize. In the past few months, two groups have suggested in papers accepted by *Physical Review Letters* that this single event may represent the first, long-sought evidence for physics beyond the Standard Model, in particular a highly touted theory known as supersymmetry. Indeed, the CDF event "fits the criteria for supersymmetry beautifully," says University of Michigan theorist Gordon Kane, one of the authors. The event, both groups argue, implies that the first product of the collision, before the electrons and photons, was a pair of supersymmetric particles, entities never detected before.

CDF's remarkable event is just one of a handful of so-far-inexplicable results that have cropped up in the past year at the world's most powerful accelerators. Only one of these anomalies has been published so far; the others have been disseminated only at conferences or via pervasive rumor. All consist of just a few events of limited statistical power, and none has been replicated by another accelerator experiment. But this barrage of anomalous phenomena has made the last year one of the most fascinating in a decade in physics. "You hear disparaging words about high-energy physics from some quarters," says Henry Frisch, a CDF physicist from the University of Chicago, "that somehow this is the Götterdämmerung, we're in the waning days. Quite the opposite. This is the most exciting time I've ever seen in this field."

It has also confronted physicists with an uncomfortable dilemma. All of these phenomena may be signs of new physics—in particular, of the long-sought Higgs boson or of a host of predicted supersymmetric particles—or they may not. They may all be the product of experimental artifacts, statistical fluctuations, or extremely rare phenomena that could still fit within the Standard Model. And that leaves physicists puzzling over how seriously to take them, and how widely to publicize them. "To what extent is it good for science and the public for us to be a little more open in talking about these things, and how much does it just add noise to the system and degrade the quality of a clear discourse?" asks Frisch. On the one hand, he says, "we have a natural reluctance to talk about these new things." On the other, "what we're unsure of is exactly what's so interesting to us and what can be so productive for us to talk about."

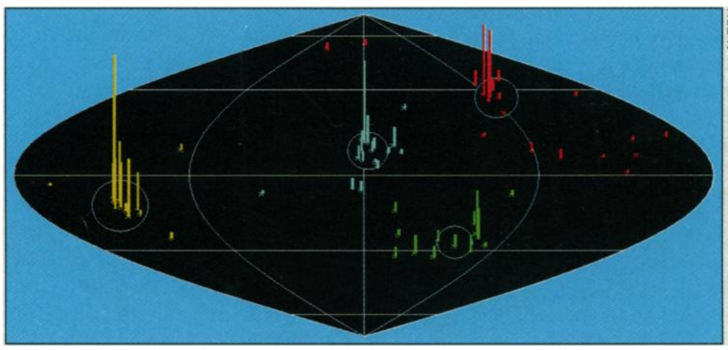
If history is any indication, researchers would be wise to exercise caution, says Nobel Prize–winning physicist Sam Ting of the Massachusetts Institute of Technology and the European particle physics laboratory, CERN. The problem is that anomalies are bound to proliferate at times like these, when accelerators have finished up their data-collecting runs. That's the case at both the Tevatron proton-antiproton collider and CERN's Large Electron-Positron Collider (LEP), which are both awaiting upgrades. Meanwhile, the physicists have sifted through billions of collisions from the completed runs, analyzing those phenomena for which they have copious data. What's left, says Ting, are the proverbial loose ends. "Some people wait, analyze these carefully, and they disappear," says Ting, "and other people publish and say it may be a new phenomenon."

Indeed, physicists got burned a decade ago when they hailed such end-of-a-run anomalies as potential new physics. In the mid-1980s, as two experiments at CERN and a third at the Stanford Linear Accelerator Center ended their runs, anomalies proliferated, and experimentalists openly speculated about their significance. Theorists responded with scores of papers interpreting the results as signs of new physics—including, even then, the first signs of supersymmetry—and newspapers brimmed with reports of new discoveries. Finally, when more powerful machines came along, all of the anomalies turned out to be artifacts or statistical fluctuations. The end result may have been captured best by Harvard University Nobel Prize–winner Sheldon Glashow, a theorist, who finally announced: "I do not feel I have the right to write another wrong paper based upon these experiments, which I no longer believe."

A theory's charms

Yet there's a powerful incentive to take anomalies like the CDF event seriously. If real, they would go a long way to relieving the field's current frustration, which is a frustration born of success: the remarkable agreement between the Standard Model and all the experimental data ever gathered. It has been 20 years, for instance, since a particle physics experiment has turned up anything that was both surprising and real. "It's a bit sad," says Ting, "that everything agrees with the Standard Model."

That situation won't last for-



ALEPH

Four-way puzzle. Mapped by angle and energy, a CERN event reveals four debris jets, perhaps from the decay of two unknown particles.

ever, theorists believe, because the Standard Model is an unwieldy construction. It is composed of two similar but distinct quantum theories—the electroweak theory that describes the electromagnetic force and the weak force that governs some radioactive decays, and quantum chromodynamics, which describes the strong force that binds the atomic nucleus. Theorists would prefer one theory to do both jobs. The Standard Model also fails to offer a natural explanation for the masses of the elementary particles. It has to invoke, ad hoc, what is known as the Higgs mechanism, embodied by an as-yet-undiscovered particle or particles that would bestow mass on the elementary particles.

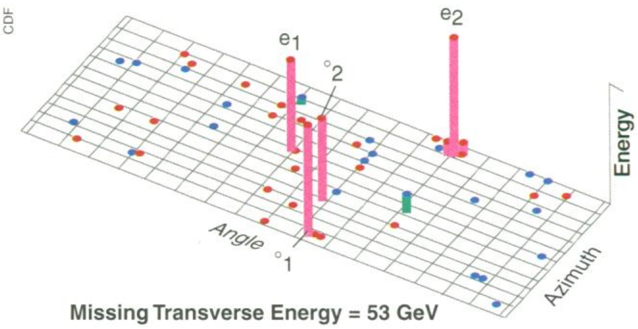
For the past 15 years or so, the best bet to extend the Standard Model and unify the quantum forces in one theory has been supersymmetry. Supersymmetry postulates an unseen symmetry in the universe between the particles that constitute matter—known as the fermions—and the bosons, which are the photonlike particles that mediate forces. For every fermion, supersymmetry predicts a new boson partner, and for every boson, a new fermion.

Supersymmetry has compelling charms, says Kane. It naturally incorporates the Higgs mechanism, for instance, and the symmetry it posits permits the unification of the quantum forces at some extraordinarily large scale of energy. Adding to supersymmetry's theoretical appeal, says University of California, Santa Cruz, physicist Michael Dine, are its connections to superstring theory, which is the current best bet for a theory of everything, one that encompasses gravity as well as the quantum forces (*Science*, 15 September 1995, p. 1511). "Superstrings are a context in which supersymmetry arises quite naturally," says Dine.

Regrettably, none of the known particles are superpartners of any of the other known particles. To skeptics, this is a sign that supersymmetry is probably not the next great theory. But to the optimists, it means there is a world of particles left to be discovered, just over the next horizon of mass and energy. The result is an extraordinary readiness on the part of both theorists and experimentalists to see signs of supersymmetric particles or the Higgs particle, which supersymmetry suggests must have a mass low enough to be found at the upper limits of current accelerators or in the very next generation. As Fermilab physicist Rick Vidal puts it, "People are getting a little desperate to see new physics. They've been looking so long. The theoretical weight is so heavy that even the smallest experimental data will be claimed as justifying all this theoretical work."

Words of caution. Sam Ting cites historical lessons.

The past 4 months have illustrated that phenomenon over and over again. CDF provided the first public example this past winter, when it reported an unexpectedly large number of debris jets spraying at sharp angles from high-energy collisions between protons and antiprotons (*Science*, 9 February, p. 758). While most theorists argued that the effect, described in a paper submitted to *Physical Review Letters*, could be explained without substantial changes to the Standard Model, some suggested that the excess might reflect the existence of a heavier brother of the Z0, a known particle that carries the electroweak force. That would be dramatic enough, as the existence of this heavier Z, known as the Z′, would represent surprising new physics. But physicists also raised an even more remarkable possibility: that the excess jets might indicate that quarks—thought to be fundamental particles—actually have even smaller constituents inside them. The evidence, however, was at best ambiguous, and it has become more ambiguous since then: Investigators at the other Tevatron detector, known as D0, have recently been reporting in conferences that they have seen no sign of the anomaly.



Signature event. Two electrons, two gamma rays, and 53 billion electron volts of missing energy might be the signature of decaying supersymmetric particles.

But even as the first published anomaly is vanishing, plenty more are taking its place. Since 1989 CERN's LEP has been smashing together electrons and positrons, spawning Z particles by the millions in the debris. LEP physicists have been measuring how often these Z particles decay into different families of quarks. These branching ratios, as they're called, are predicted by the Standard Model. But lately the branching ratios haven't matched expectations, says Alain Blondel, a physicist with the French National Center for Scientific Research and a member of the Aleph experiment at LEP. The Z's seem to decay too frequently into bottom quarks, which are the second heaviest of the quarks, and not quite frequently enough into charm quarks, the third heaviest.

While the statistical power of the anomaly has grown over the years, no single LEP experiment has enough of these events to make the claim on its own; the data from all four have to be combined for the anomaly to have statistical power. To Ting, who heads the L3 experiment at LEP, this alone is enough to suggest it is not real. Theorists, however, have been hard at work linking the anomaly to new physics. One supersymmetric possibility is that the Z can go through what's known as a virtual loop during its decay. For an infinitesimal moment, it can turn into a pair of supersymmetric particles—partners of the top quark, known as the stop, and of a charged Higgs boson, known as a chargino—and then emerge as a pair of bottom quarks. That decay pathway would increase the production of bottom quarks and explain a good part of the anomaly—but not all of it, says University of Pennsylvania theorist Paul Langacker.

The other possibility theorists suggest is again the Z′, the existence of which would affect the properties of the Z0 in such a way that it would increase the expected share of decays into bottom quarks. But that proposal raises problems of its own: This particular Z′ should have already shown up in many experiments, says Langacker, unless it has a very specific set of properties. As a result, theorists have suggested that this Z′ preferentially interacts with hadrons—i.e., quarks—rather than particles known as leptons, which include electrons. These so-called leptophobic or hadrophilic models have not won the admiration of all, however. Even Guido Altarelli, a theorist at CERN and the University of Rome who proposed the leptophobic Z′, calls them "a little bit weird."

A glimpse of selectrons?

The single event from Fermilab, however, requires no such theoretical contortions, which is why it hovers near the top of the excitement list. Because it is just one event and no more, the CDF researchers have not published it. They have cleared it to be shown at conferences, however, which has led to the two forthcoming theoretical papers, one by Kane and his collaborators and the other by Dine and collaborators.

While physicists could imagine Standard Model physics producing an event with electron and photon pairs and the huge missing energy, the chance of such an event occurring in the Tevatron's proton-antiproton collisions is "negligibly small," says CDF co-spokesperson William Carithers. On the other hand, that configuration happens to be just what theorists expect to see if supersymmetry is real. In that case, as both of the papers suggest, the original collision could have created a pair of "selectrons"—the supersymmetric partners of electrons—which then decayed. Kane says his scenario also provides a supersymmetric explanation for the Z decay anomaly at LEP, along with predictions of several more possible supersymmetry signatures, which might already be hiding in the data at Fermilab or CERN.

Those interpretations rest on a foundation that could easily crumble, say CDF experimentalists. With only one event, it's effectively impossible to rule out the possibility of an extraordinarily rare glitch in their experiment, or some freak event from the Standard Model. Quite simply, says Carithers, one event is not enough to do an analysis, or at least not a meaningful one.

As for the last two anomalies, they include one that has no possible theoretical explanation, so that not even theorists believe it, and another that is still, and maybe forever, no more than a rumor. The first of these was made public by the Aleph collaboration at a recent conference in France and will be published in *Zeitschrift fuer Physik C*. The anomaly comes from data taken last fall when LEP ran for 3 weeks at energies up to 140 GeV (billion electron volts)—45 GeV higher than before—and the Aleph detector recorded nine to 12 events (depending on the method of analysis) marked by four jets of debris. While the Standard Model predicts that Z decays will occasionally generate four jets, it also predicts that Aleph should have seen at most one such event. The excess suggests, says Blondel, "that what is seen is either a very rare statistical fluctuation or pair production of new particles," which then decayed to produce the jets.

Aleph, however, was the only one of the four LEP experiments that saw the excess. The other three looked for it and came up empty. "If it's true, it calls for rather drastic consequences," says Altarelli. "But the general attitude at this moment is that the observation is so weak and so marginal that we [theorists] should not waste our imagination power on it."

The last anomaly is one that CDF physicists have tried hard to keep under wraps while they assess its potential reality, refusing even to discuss it at conferences. Despite their efforts, the rumors have spread far and wide. ("Sure I've heard of it," says Altarelli, for instance, "but they haven't announced it yet, so we'd better shut up. It's really bad taste to speak of rumors.") Physicists refer to it as "the Higgs bump" or the "rumored Higgs bump," even though it can't be the Higgs, because CDF has no sensitivity to the signature of a Standard-Model Higgs. This potentially nonexistent anomaly already has theorists speculating about top quarks decaying into the supersymmetric particles called stops, and, once again, the existence of a very heavy Z.

In the end, the data will win out, as they always do. In June, LEP will take another step up in energy, to 161 GeV, which should enable CERN experimentalists to confirm or eliminate the anomalies they have—and almost assuredly spark some new ones. At Fermilab, the Tevatron is being refitted to generate a 20-fold increase in the rate of collisions in its next run, scheduled for 1999, and CDF and D0 are upgrading their detectors accordingly. And the theorists will just speculate and hope.

"Out of many of these anomalies, we hope at least one will survive, and that's enough," says Altarelli. "I would like at least one of these things to be true. But maybe it's all nothing again."

–**Gary Taubes**

SCIENTIFIC MISCONDUCT

Panels Look for Common Ground

Although scientific misconduct may have dropped off the radar screen of the media and Congress, efforts to set federal policy on the subject are heating up. Last week a committee of government research officials began what they hope will be a 3-month effort to draft a definition of research misconduct and guidelines for all government agencies. As this effort was getting under way, another is winding up: Within a month, a working group at the Department of Health and Human Services (HHS) is expected to recommend misconduct policies for the department. And the National Academy of Sciences (NAS) has stepped into the fray with a letter harshly critical of some of the proposals being discussed.

The latest round of activity on a subject that has bedeviled the scientific community for more than a decade was kicked off last November by a report from the HHS Commission on Research Integrity (*Science*, 1 December 1995, p. 1431). The 12-member panel, created at Congress's behest and headed by Kenneth Ryan, a reproductive biologist at Brigham and Women's Hospital in Boston, recommended replacing the widely used standard of "falsification, fabrication, and plagiarism" with the terms "misappropriation, interference, and misrepresentation." Any definition, it added, should uphold "the fundamental principle that scientists be truthful and fair in the conduct of research and the dissemination of its results."

Last month the NAS Council sent a letter to HHS science adviser William Raub, who is leading the HHS working group, arguing that such a definition could generate investigations into "every accusation of untruthfulness and unfairness." The council urged the government to revisit suggestions an NAS panel made in 1992 which, it said, preserve the "creative process" in the laboratory. "We don't need all of this [additional language]," says NAS Council member Donald Brown of the Carnegie Institution of Washington.

"If they don't like the report ... I would challenge them to do better."

—Kenneth Ryan

Ryan defends the commission's 18-month effort and notes that even the NAS Council calls its recommendations "a well-intentioned attempt to address a problem." And he adds, "If [NAS Council members] don't like the commission's report ... I would challenge them to do something better."

Much of the same criticism has been leveled by officials of the Federation of American Societies for Experimental Biology, which is sponsoring a meeting next week in Washington featuring Raub and Ryan. But not everyone has been so quick to reject the Ryan panel's arguments. The Association of American Medical Colleges' Committee on Research Integrity, for example, concurs with much of the report, including the idea that institutions have primary responsibility for investigations, but would like to revise the panel's definition of misconduct.

Raub's working group is expected to send its recommendations to HHS Secretary Donna Shalala sometime next month. Meanwhile, last week a committee of the president's National Science and Technology Council (NSTC) held its first meeting to craft a governmentwide definition of research misconduct. The group considers the Ryan report to be "one of several inputs," says a senior White House official. The interagency group, headed by NASA science adviser France Cordova, hopes to submit its report to NSTC's Committee on Fundamental Science by 1 July. Given the contentiousness of the issue, however, such an accelerated pace may be optimistic.

–**Jocelyn Kaiser**