PARTICLE PHYSICS

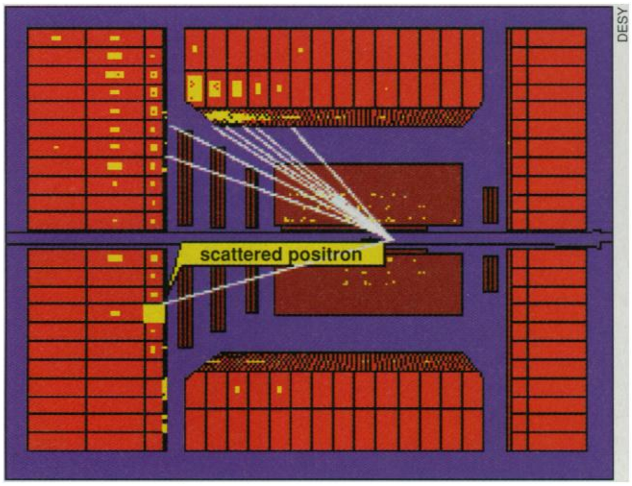
Deep Within the Proton, a Flicker of New Physics?

For weeks, tantalizing rumors have been leaking out of the Deutsches Elektronen-Synchrotron in Hamburg, Germany. Now, DESY researchers have raised the curtain on what they have been seeing, and the speculation has shifted to a new plane. Last week, at a DESY seminar, researchers from the two particle detectors on DESY's HERA accelerator reported that 3 years of smashing positrons—the antimatter counterpart of electrons—and protons together at high energy have produced a handful of collisions too "hard," or violent, to be easily explained within the current theory of the fundamental structure of matter, called the Standard Model. And now theorists, who have long speculated about particles and forces beyond the Standard Model, are discussing some tempting possibilities.

In the most dramatic one, the excess could be the first hint of a particle called a leptoquark—long a topic of speculation—that might combine the properties of quarks, the building blocks of protons, and leptons, the particle family that includes positrons and electrons. Or it might be the track of another beast called a stop, the hypothetical counterpart of the top quark in a family of theories called supersymmetry. Then again, it could be a sign that quarks, the presumably pointlike building blocks of protons and neutrons, are actually made up of smaller pieces. And there are a host of more mundane possibilities as well—including a 1% to 7% chance that the signal is due to statistical fluctuations, says Bruce Straub of Columbia University and coordinator of the "exotics" experimental group on HERA's ZEUS particle detector.

The excess of hard collisions, in which the positron rebounds nearly straight back from the collision, is far too small to let physicists distinguish among the many possible explanations. As Herbi Dreiner of the Rutherford-Appleton Laboratory in the United Kingdom puts it, "I'm excited, but the data don't tell you at all what it is." The results "are not a clear indication that the Standard Model has been overturned," agrees Harry Weerts of Michigan State University and a spokesperson for the D0 particle detector at the Fermi National Accelerator Laboratory in Illinois. "On the other hand," says Weerts admiringly, "that's a pretty nice 'fluctuation' they've got there."

In HERA's 6.3-kilometer ring, buried beneath the outskirts of Hamburg, bunches of protons and positrons whirl in opposite directions and collide with nearly a trillion electron volts of energy. Two detectors, ZEUS and H1, each staffed by a multinational collaboration of hundreds of physicists, detect and analyze the collisions. Most are glancing, says Lothar Bauerdick, an experimentalist in the ZEUS group, but sometimes the positron "is really violently scattered back." Those deeply penetrating, hard collisions function like a fantastically powerful microscope, he says, probing the proton's structure down to a thousandth of its overall size and laying bare the interactions between positrons and quarks during their closest encounters.



Taken aback. In HERA's ZEUS detector, a positron rebounds from an unexpectedly "hard" collision with a proton.

Because interactions between quarks and leptons are supposed to be relatively feeble in the Standard Model—involving only the weak nuclear force and electrostatic repulsion—such hard collisions should be rare. Indeed, the ZEUS group would have expected just one such event over twice as much running time as HERA has accumulated, says Bauerdick. "You must already be very lucky to get two" by statistical chance, says Bauerdick, "and we see five events." And there is no mistaking the signature of these collisions in the ZEUS detector, he says: "They really look spectacular. The [positron] gets an enormous momentum from the quark."

The second detector, H1, sees a similar anomaly: seven events rather than the one the Standard Model predicts, says Yves Sirois of the École Polytechnique in Paris and the H1 collaboration. When the two independent data sets were merged for the first time last week, he says, "the combination seemed to give a signal which is at least comparable to or better than a single experiment"—a relief for both groups. Still, the events seemed to be showing up in slightly different energy ranges in the two detectors, a discrepancy that Straub calls "somewhat confusing."

As to the reason for the excesses, says Sirois, "theorists will speculate, and this will be interesting." The initial blue-skying centers on previously unseen particles like stops and leptoquarks. By wedding the two families of matter represented by the colliding proton and positron, such particles might explain the extra apparent collisions. If a leptoquark were spawned by a colliding positron and proton and then quickly decayed into the same particles, for example, the positron might be flung almost straight backward, as if the original particles had violently crashed together. Stop formation could also provide a temporary resting point for the energy of the quarks and positrons, making hard collisions look more frequent.

Detecting these particles "would be a revolution that would change everybody's way of thinking," says Michael Barnett, a particle theorist at Lawrence Berkeley National Laboratory. By melding two disparate forms of matter, for example, leptoquarks "would give tremendous insight into what's missing in the Standard Model" and point to a "unified" theory that would transcend it, he says. But Barnett adds that, based on the few recorded events, the case for such an upheaval is "not statistically compelling."

Other theorists note that the hard events might not be caused by a particle at all: They could conceivably point to unexpected structure—hard "pits," for example—within quarks, which are taken to be pointlike in the Standard Model (*Science*, 9 February 1996, p. 758). Or they might call for a radically new picture of how many short-lived "virtual" quarks are rattling around inside a proton at a given instant. Most of the explanations being kicked around "would be a big surprise," says Frank Wilczek of the Institute for Advanced Study in Princeton, New Jersey. "It's not what anybody predicted."

There is only one way to resolve these mysteries, says John Dainton, of the University of Liverpool in the United Kingdom and the H1 team at DESY: "We just need very, very much more data." These data should continue to pour in from HERA, and later from Fermilab, whose Tevatron accelerator is scheduled to stoke up again in 1999 after a major upgrade. Until the evidence one way or another becomes overwhelming, the speculation will continue to swirl.

–James Glanz