E158

The E158 experiment at Stanford Linear Accelerator Center explored the weak force over multiple energy scales.

asymmetric insight

by Heather Rock Woods

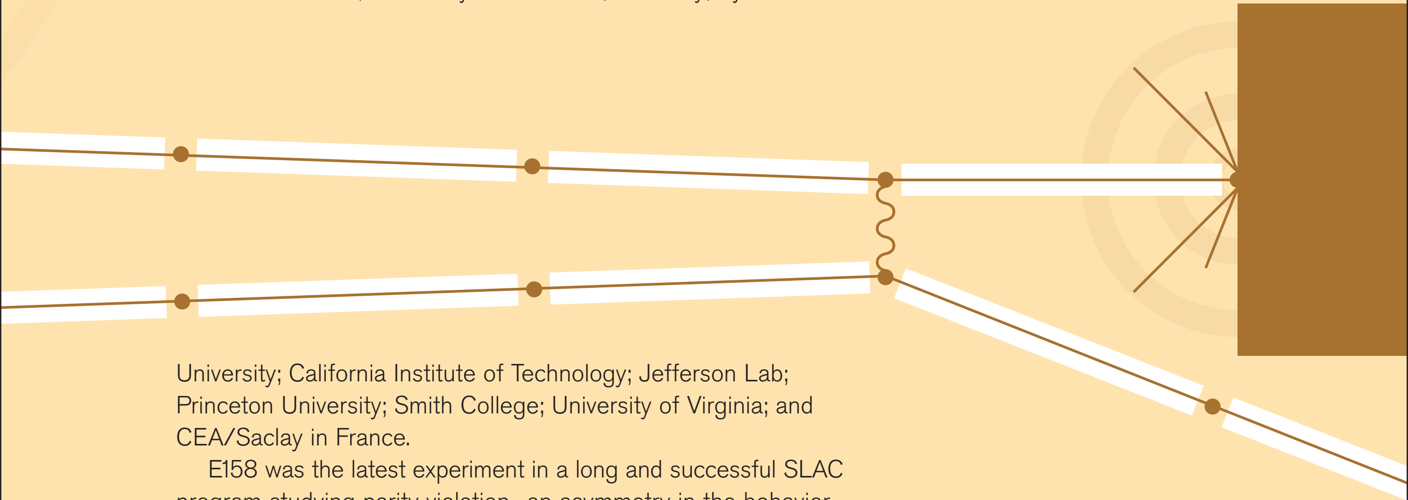
Like climbers assessing a new route before making the ascent, physicists have been looking for footholds on a vertiginous new terrain. These footholds contain important information for trekking to TeV heights (the lofty trillion electron volts energy scales of future colliders).

One example of an exploratory experiment is E158, a low-energy experiment at the Stanford Linear Accelerator Center (SLAC) that has recently tested the terrain—indirectly—by making extraordinarily precise measurements of the weak force, one of nature's four fundamental forces. The results prove key, and expected, characteristics of the weak force, as well as give hints about potential new particles at the TeV scale. The successful experiment also demonstrated that its technically challenging set up could be used for experiments at the proposed International Linear Collider.

"E158 has been a real tour de force by a talented group of experimentalists," says Bill Marciano, a theoretical physicist at Brookhaven National Laboratory. Although not on the experiment, he has worked extensively on precision weak interaction calculations.

E158 co-spokesman Krishna Kumar, professor of physics at the University of Massachusetts-Amherst, says, "The technical challenge required remarkable collaboration between accelerator physicists who delivered the electron beam and the physicists who manned the experimental detectors."

The collaboration involved 60 physicists from SLAC; University of Massachusetts; University of California, Berkeley; Syracuse University; California Institute of Technology; Jefferson Lab; Princeton University; Smith College; University of Virginia; and CEA/Saclay in France.



E158 was the latest experiment in a long and successful SLAC program studying parity violation—an asymmetry in the behavior of the weak force. *Z* particles, which carry the weak force, are slightly more likely to act on left-spinning (or left-handed) particles than on right-spinning ones. In contrast, the electromagnetic force acts equally on both, and *W* bosons, responsible for weak nuclear decays, act only on left-spinning particles.

E158 made the first observation of this left-right asymmetry in electron-electron interactions in 2003. The asymmetry is so tiny—131 parts per billion—that if you did the experiment with clocks, a left-handed clock would be only one hour faster after 1000 years. This is just as expected in the Standard Model, which describes the actions of the weak force, electromagnetism, and the strong force.

Smashing an electron beam into a fixed target, experimenters looked for scattering (or deflection) between beam electrons and target electrons. In scattering, the electrons don't collide; they bend away from each other the way two cars merging into the same spot veer away from each other to avoid a crash. The deflection is powered by the electromagnetic force (by exchanging a photon) or by the weak force (by exchanging a *Z*).

Higher-energy experiments at SLAC and the European particle physics laboratory CERN had directly produced *Z* particles in head-on collisions, enabling a close-up measure of the strength of the electron's weak charge (which determines the strength of the weak force between two electrons). E158 instead measured the charge in scattering interactions, where the electrons are farther apart from each other.

By comparing conditions at low and high energies, E158 researchers made the landmark observation that the weak charge is effectively lessened at longer distances. The phenomenon of the charge varying with distance is called "running."

One normally thinks of forces acting with less strength as physical distance increases (or decreases, in the case of the strong force). The Sun's gravitational pull on the outer planets is weaker than on the inner planets. But the inherent strength of gravity has not changed: the Sun maintains the same mass, the same gravitational constant.

What E158 showed is that the "inherent" strength of the weak force weakens with distance, in addition to the effects of physical distance. This happens because of quantum fluctuations. The vacuum surrounding every particle randomly spits out and reabsorbs virtual particles, making an ephemeral cloud that effectively forms a screen between distant interacting electrons. At "long" distances—approximately 10 times the width of a proton—this virtual shielding shrinks the charge experienced between two electrons to just half the short-distance charge explored by earlier high-energy experiments.

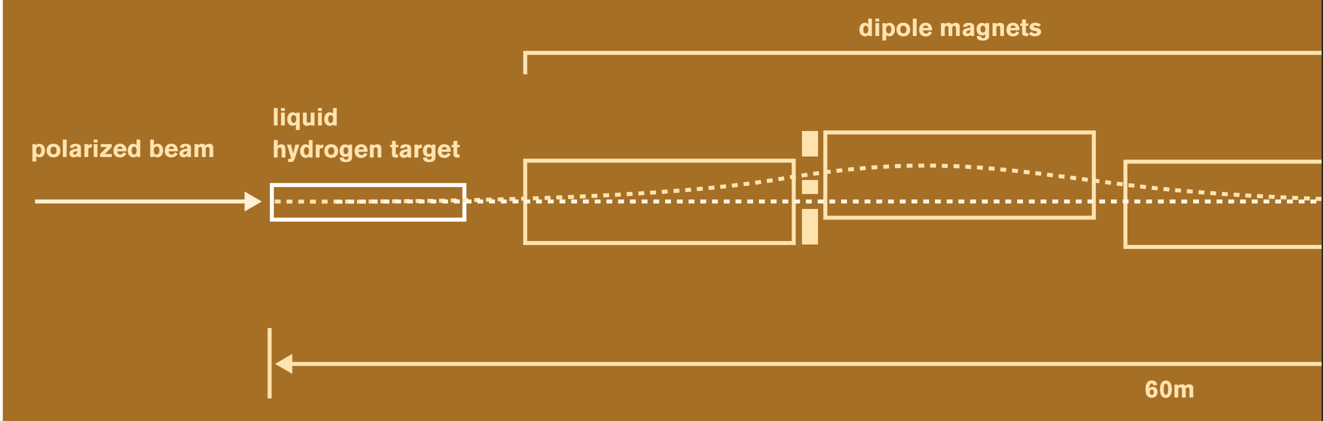
"E158 is sensitive to this rich structure that exists in the microscopic world, the structure of nothing, of the vacuum," says Yury Kolomensky, leader of the analysis and assistant professor of physics at the University of California, Berkeley.

Running had already been established for the strong and electromagnetic forces. E158's findings, published in August 2005, confirm for the first time an important aspect of Standard Model theory. Theories that attempt to unify these three fundamental forces require their running strengths to become the same at extreme energies (10^{16} GeV).

The experiment has also made its mark at the terascale. Like using a telescope to peer farther than the unaided eye can see, E158 used the power of precision measurements to search for indirect signals from new particles that might exist at TeV energies.

Many theories of extra dimensions and unified forces mathematically require one or more new forces. The hypothetical particles that would mediate these forces are generically called *Z'* (*Z*-prime) particles.

The precision measurements required enormous numbers of electrons. SLAC's linear accelerator sent 500 billion electrons in a single bunch



to a target, and repeated this 700 million times. The electrons were polarized to spin right-handed in half of the bunches, and left-handed in the other half. The researchers needed to sort out the one in a million scattering events that was mediated by the weak force in a sea of electromagnetic interactions. The experiment was so sensitive it could also detect if *Z'* particles were at work. Imagine standing on shore and looking—amidst the wakes of cruise ships (photons) and rowboats (*Z*s)—for the wake of a sea otter.

To do this, the experiment looked for interference effects from *Z'* on the asymmetric rate of left-handed versus right-handed scattering, a technique akin to inferring the existence of Neptune by observing Uranus' wayward orbit. The disappointed researchers did not detect any interference, suggesting that if the *Z'* exists, it must be at least 10 times the mass of the *Z*.

"We're getting into an interesting region; we haven't gone past it yet," says SLAC theorist Michael Peskin, referring to the search for new mediating particles in the range of the mass of the *Z* particle up to 50 times its mass.

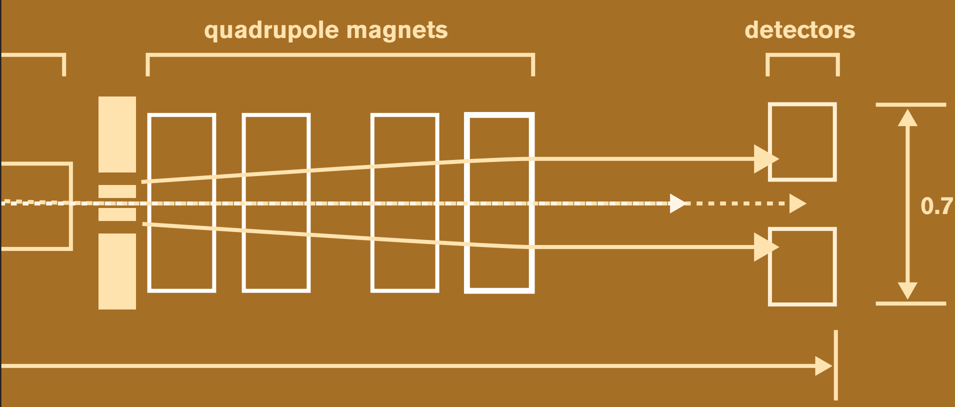
Results such as these give hints and constraints on the higher-energy terrain ahead and show future experiments where they don't need to look, or how to decipher what they might find. The TeV energy colliders are the Large Hadron Collider, being built now to come online in 2007 at CERN, and the proposed International Linear Collider.

"When you see new physics at new colliders, experiments like E158 become very important to understand what you saw," says Kumar. "If the LHC sees new physics, they initially won't have enough events to interpret their results—is it a Higgs or a *Z'*? You can figure out: if it's this mass, then it can't be *Z'* or E158 would have seen it."

Kumar adds: "The fact that we were able to reach the multi-TeV scale is an important legacy of E158."

Marciano agrees that the experiment contributes to the coming frontier-energy physics. "Perhaps just as important as its final result, E158 provides a clear demonstration that this technique can be employed at the proposed ILC by scattering its high-energy polarized electron beam off a fixed target of electrons. With the higher energy and much larger effective luminosity provided by that facility, unprecedented precision studies of polarized electron-electron scattering will be possible. These studies will probe deeply for virtual particles that pop in and out of existence and other signs of new physics."

In revealing the character of the symmetry-defying weak force, E158 has provided tools and exposed dead ends for the coming climb to higher peaks.



Source: E158 collaboration, SLAC

The SLAC linac collided left- and right-polarized electrons into a liquid hydrogen target, where a beam electron would occasionally scatter with a target electron via the weak force. A series of magnets and collimators filtered out the irrelevant particles, allowing the deflected electrons to reach the detectors.