

Limiting the genealogy of particles

Scientists working in the field of high energy physics, the branch of science that catalogues the basic components of our universe and makes sense of their complex and counter-intuitive interactions, believe they have discovered a limit to the number of fundamental particles.

by Scott Hagan

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Results hailing from the Stanford Linear Collider (SLC) in California and the Large Electron-Positron (LEP) ring at Cern near Geneva, Switzerland suggest that there are only three 'generations' of elementary particles.

Each generation consists of a quartet: two quarks and two leptons. For instance, the first generation unites the 'up' and 'down' quarks, most familiar to us as the components of the proton and neutron, with the electron and the neutrino. Of the 12 particles in the three known generations, all but the 'top' quark (or 'truth' as aesthetes prefer) have been experimentally detected.

Curiously, virtually all ordinary matter is accounted for by the first family alone (For those of you saw the movie Roxanne Darryl Hannah goofed on this point). Scientists are baffled as to why nature might choose to replicate itself in such a redundant fashion.

In the beginning

The mystery began in 1938 when the 'muon' was discovered. The muon acts just like the electron except that it is substantially heavier. The fact that it seemed to perform no unique function in the scheme of things led to considerable confusion. In the following decades, the situation was only compounded by the discovery of the remaining second generation particles, the 'strange' and 'charm' quarks and the muon neutrino. Subsequently a third generation turned up. This meant that until recently there was no compelling reason to believe that there should be a limit to the number of generations. But the findings at LEP and SLC have dramatically altered this perspective.

To determine a limit on the number of possible families, scientists at both facilities have focused their attention on the Z particle. This giant in the world of elemen-

tary particles is difficult to produce, even in the most powerful accelerators. For this reason, its discovery in 1983 came years after theorists first conjectured its existence as one of the authors of the 'weak' force. To understand what this means, it is important to understand light.

Light

Particles of matter exchange packets of light called 'photons' as if they were telegrams telling one another how to interact — codes of conduct as it were. This line of thought led to the most successful physical theory to date, quantum electrodynamics (QED), and led scientists to conjecture that particles might communicate the other basic forces of nature. Light is, of course, massless. But imagine if light was heavy — as heavy as the Z particle. If eyes could still exist in such a world, they would be able to see only to a horizon of 10^{-15} centimetres. 'Heavy light' from further away would be too lazy to make the trip. This is how the Z operates, shuttling only between particles very close together, telling them to interact in a certain defined way.

On the other hand, photons have an unlimited range. Scientists coined the name of the force 'carried' by the Z based on its inability to extend beyond a tiny sphere of influence. Surprisingly, events on the minuscule scale of the weak force play an important role in the functioning of our sun and other stars.

For our purposes it is important only that the Z is, by elementary particle standards, massive and remarkably short-lived. After only about 10^{-24} seconds, it decays into a particle and an antiparticle. In an accelerator, the Z particle can be detected because the signatures produced by the decay products of the particle are written in monolithic detectors straddling the accelerator at a target point. The de-

tor allows detailed information to be extracted from the sub-atomic world. In this case, decay product information presents itself as the ideal test of the number of generations already known. Each result, taken separately, leaves little room for error and the corroboration of the five makes for a formidable finding indeed. There still remains the eventuality that none of the members of a fourth generation have masses less than half that of the Z. This would make it impossible to produce these particles as by-products of the Z alone. Scientists in the field, however, find this an unlikely scenario. The known neutrinos are all massless or at least very light; a fourth generation neutrino would not be expected to radically depart from this tradition.

Measurements made at the Mark II detector at SLC and four similar detectors at LEP (specifically ALEPH, DELPHI L3 and OPAL) indicate that the Z decays only into particles of the three generations already known. Each result, taken separately, leaves little room for error and the corroboration of the five makes for a formidable finding indeed. There still remains the eventuality that none of the members of a fourth generation have masses less than half that of the Z. This would make it impossible to produce these particles as by-products of the Z alone. Scientists in the field, however, find this an unlikely scenario. The known neutrinos are all massless or at least very light; a fourth generation neutrino would not be expected to radically depart from this tradition.

Some cosmologists had hoped that a fourth neutrino might solve the 'missing mass' problem. Detectable matter makes up only one tenth of the mass known to be present in the cosmos. While another neutrino might have simultaneously accounted for the bulk of the mass of the universe and escaped detection by probing physicists, the new result from LEP and SLC will force scientists to search elsewhere for candidate solutions.

The accelerators

Plagued with difficulties from the outset, the Californian collaboration saw their first Z in the spring of last year, already well behind schedule. Originally the SLC facility had been constructed for much lower energies than were necessary to produce a profusion of Z's. The task of modifying a 20-year-old design proved to be fraught with difficulties never encountered by accelerator physicists.

Beams of electrons and their anti-particles, positrons, had to be made to collide within a target only a few micrometers across, a formidable feat to perform with particles that are invisible to even the best

microscopes. To make matters worse, the entire structure sits astride the San Andreas fault. While North American sports fans were waiting for the World Series to resume after the San Francisco earthquake, scientists at SLC had their hands full with a raft of new problems. By comparison, LEP had been making Z's for six years, since a team of scientists there first discovered it. Despite everything, SLC published the first result. But the people at LEP were fast on their heels; a matter of mere days made the difference. Statistically speaking, the European-based teams made a stronger statement, and better bounds on the error continue to come out, with the Fermilab National Accelerator Laboratory (FNAL) near Chicago recently joining the fray.

By no means does all this suggest that our understanding of nature's basic building blocks is complete. While we need no longer look beyond the third generation, nothing presently forbids the extension of each generation to include more than four particles each, or the discovery of new forms of matter that don't fit into the family picture.

High energy physics is beset with a plethora of theories proposing a wide variety of yet unfamiliar and exotic forms that matter might take — like squarks, sleptons and technicolour particles — that could be beyond the scope of present accelerators to detect. Even within the currently accepted framework known as the Standard Model, which unites all the known particles in a consistent fashion, the 'top' quark remains to be found. While most physicists do not dispute its existence, the discovery will settle some lingering questions about details of the model.

More urgent is the quest for the elusive 'Higgs boson' without which the entire structure might collapse. Originally it was hypothesized in order to explain how particles in the early universe gained mass. It is now incorporated into the fundamental precepts of the Model so that everything is in doubt while it evades detection — so much so that Higgs himself has renounced his own theory. All these possibilities await more powerful accelerators than the ones now in operation to confirm or contradict them.

Modifications to the Cern laboratory are currently underway, 'upping the ante' for the coming round of particle investigations. Higher energies and greater numbers of particles will broaden the vistas accessible to the high energy physicist and entrench Cern as a world leader in the field for much of the 1990s. Work on a brand-new facility in Texas, the controversial Superconducting Super Collider (SSC) on which the American government will lavish billions of dollars over the next several years, has only just begun. Slated for completion near the turn of the century, it is expected to outstrip all competitors. But first some major technological hurdles will have to be overcome. The explosion of data produced by the accelerator will be beyond the capacity of modern computers to handle. It is hoped that considerable advances will be made in both hardware and the software used to analyze the complicated 'events', before the SSC comes 'on-line'.

