Breaking the symmetry between fundamental forces

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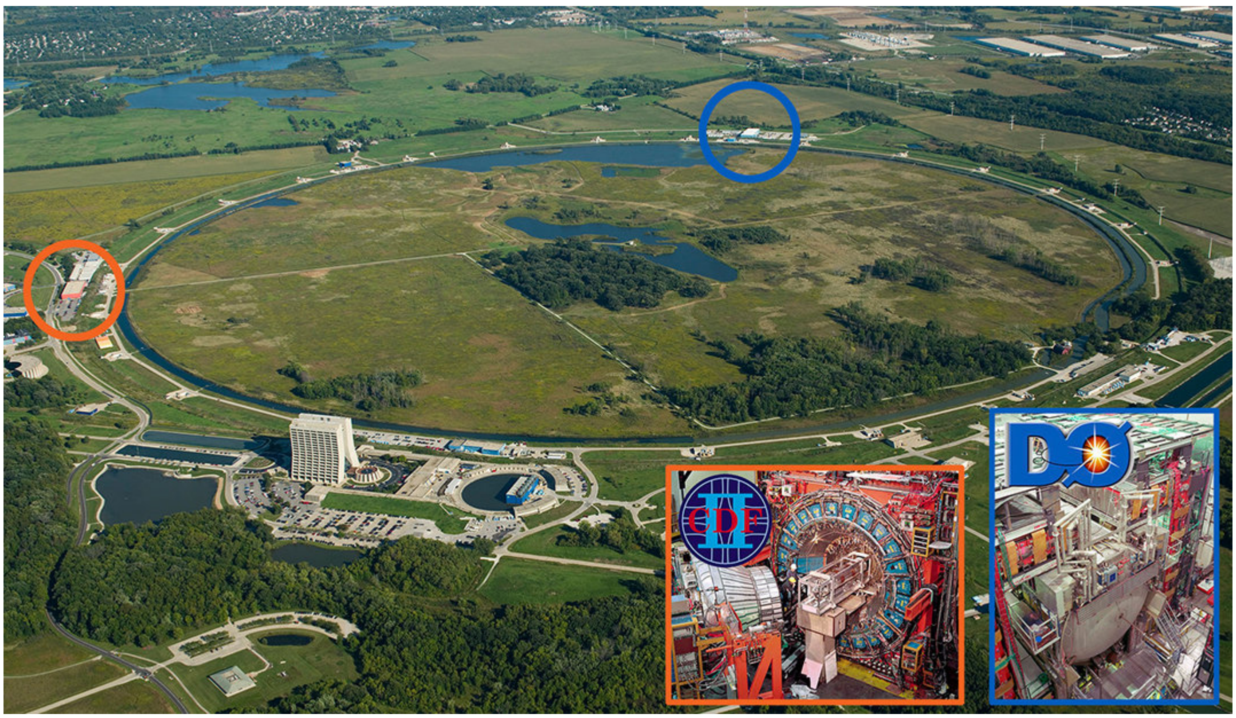

Aerial view of the CDF and DZero experiments at the Fermilab Tevatron Collider, the highest energy particle collider in the world for over the two decades until 2009. Credit: US Department of Energy

A fraction of a second after the Big Bang, a single unified force may have shattered. Scientists from the CDF and DZero Collaborations used data from the Fermilab Tevatron Collider to re-create the early universe conditions. They measured the weak mixing angle that controls the breaking of the unified force. Measuring this angle, a key parameter of the standard model, improves our understanding of the universe. The details of this symmetry breaking affect the nature of stars, atoms, and quarks. The new measurement of the weak mixing angle helps cement our understanding of the past, the character of what we observe today, and what we believe is in store for our future.

Previous determinations of the weak mixing angle from around the world disagreed. This allowed for the possibility that maybe there are new fundamental particles to be discovered. Or maybe there was a misunderstanding in how we think about the fundamental forces. This new combined result helps to resolve the discrepancy and reinforces our standard theory of the fundamental forces.

At present, scientists think that at the highest energies and earliest moments in time, all the fundamental forces may have existed as a single unified force. As the universe cooled just one microsecond after the Big Bang, it underwent a "phase transition" that transformed or "broke" the unified electromagnetic and weak forces into the distinct forces observed today.

The phase transition is similar to the transformation of water into ice. In this familiar case, we call the transition a change in a state of matter. In the early universe case, we call the transition "electroweak symmetry breaking."

In the same way that we characterize the water-to-ice phase transition as occurring when the temperature drops below 32 degrees, we characterize the amount of electroweak symmetry breaking with a parameter called the weak mixing angle, whose value has been measured by multiple experiments over the years.

By re-creating the early universe conditions in accelerator experiments, we have observed this transition and can measure the weak mixing angle that controls it. Our best understanding of the electroweak symmetry breaking involves the Higgs mechanism, and the Nobel Prize-winning Higgs boson discovery in 2012 was a milestone in our understanding.

For two decades, the most precise measurements of the weak mixing angle came from experiments that collided electrons and positrons at the European laboratory CERN and SLAC National Accelerator Laboratory in California, each of which gave different answers. Their results have been puzzling because the probability that the two measurements agree was less than one part in a thousand, suggesting the possibility of new phenomena—physics beyond the standard model. More input was needed.

Although the environment in Fermilab's proton-antiproton Tevatron Collider was much harsher than either CERN's or SLAC's collider, with many more background particles, the large and well-understood data sets of the Tevatron's CDF and DZero experiments allowed a new combined measurement that gives almost the same precision as that from electron-positron collisions. The new result lies about midway between the CERN and SLAC measurements and thus is in good agreement with both of them, as well as with the average of all previous direct and indirect measurements of weak mixing angle. Thus, Occam's razor suggests that those new particles and forces are not yet necessary to explain our observations and that our present particle physics and cosmology models remain good descriptors of the observed universe.

More information: T. Aaltonen et al. Tevatron Run II combination of the effective leptonic electroweak mixing angle, *Physical Review D* (2018). DOI: 10.1103/PhysRevD.97.112007

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