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PHYSICS

Alone at the Top

CLOSER TO GOD: FERMILAB MAKES SOLO TOP QUARKS BY ALEXANDER HELLEMANS

The world's biggest accelerator, the Large Hadron Collider (LHC) at CERN, the European laboratory for particle physics near Geneva, will come on line in a few months. Even so, for the next few years it may have a hard time upstaging the Tevatron collider at Fermi National Accelerator Laboratory (Fermilab) in Batavia, Ill., which appears to have generated "single" top quarks. The finding, reported last December, helps to narrow the search for the long sought after Higgs particle and raises the possibility that Fermilab will find it before the LHC does.

In 1995 Fermilab first produced top quarks, the heaviest and most elusive of the six quark types, in collisions between protons and antiprotons that generated both the top quark and its antimatter twin. These top-antitop pairs form via the so-called strong force, which binds quarks together. Very rarely, according to the Standard Model of particle physics, top quarks may emerge in collisions via the weak force, which causes radioactive decay and can convert one flavor of quark to another. Such weakly made tops, however, would come without their antitop companions (instead a different antiquark, an antibottom quark, forms with the top quark).

Not only is single top production extremely rare, but its signature is not all that distinctive. "The backgrounds of events that look just like the single top quark events are very high," says Ann Heinson, a physicist at the University of California, Riverside, and co-leader of a group in DZero, one of the two research collaborations using the Tevatron.

From the trillions of collisions recorded since 2002, DZero has now identified 62 events indicative of single top quarks. That is not a lot of evidence, but still the data have strongly encouraged Tevatron researchers' hopes of beating CERN's LHC

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ON TOP: Fermilab's main injector ring (*foreground*) feeds accelerated particles to the Tevatron ring (*background*), which is two kilometers wide and sits 10 meters below ground. Particle collisions have yielded top quarks without their antimatter twins.

in hunting down the Higgs. This "God particle," predicted by the Standard Model, would explain why protons, neutrons and other types of matter have mass.

The detection of single top quarks serves as a kind of Tevatron dress rehearsal for finding the Higgs. "If the Higgs is of relatively low mass, it will have the same decay signature as that of the single top quark: a *W* particle, a bottom quark and an antibottom quark," says Gregorio Bernardi of the University of Paris, who is co-leader of DZero's Higgs physics group. This similarity would enable the group to utilize the advanced analysis techniques developed for the search of the single top. "We have improved our understanding and modeling of the background of the single top, and both improvements can also be transferred directly to the Higgs search," Heinson adds. What sets the Tevatron ahead of the LHC is background "noise." The Tevatron smashes protons with antiprotons so that their constituent quarks and antiquarks collide directly. The LHC, however, smashes protons with protons. Quarks end up colliding with antiquarks within a virtual "sea" of quark-antiquark pairs that continuously appear and disappear inside antiprotons. That complicates data analysis.

And for the Tevatron, things now look good. In January the Collider Detector at Fermilab (CDF) collaboration announced a mass determination of the *W* boson to within 0.06 percent—the best ever obtained. The new weighing of the *W* mass pushes the upper limit for the Higgs mass down from 166 billion electron volts (GeV) to 153 GeV, improving the odds that the Higgs mass is near its lower limit of about 114 GeV.

CDF member Tommaso Dorigo of the University of Padua argues that if the Higgs particle mass is around 114 GeV, the LHC will have a harder time finding a light Higgs particle than the Tevatron will. The LHC will have to detect the creation of two gamma-ray photons by a decaying Higgs particle, which are, in the strong background noise, much harder to sense than the bottom and antibottom quarks that would be produced by a disintegrating Higgs in the Tevatron.

A heavier Higgs, above 130 GeV, may escape Fermilab, because the Tevatron delivers just one seventh the wallop of the LHC. In fact, the LHC could find such a heavy Higgs rather quickly, explains David Plane, an experimental physicist at CERN. In the meantime, Plane remarks, "the Tevatron has the field pretty well to itself, until 2010 or maybe beyond."

Alexander Hellemans, based in Paris, profiled Alain Connes and noncommutative geometry, an alternative to string theory, in the August 2006 issue.

NEED TO KNOW: MAKING SURE

Out of trillions of collisions since 2002, the DZero collaboration at Fermilab's Tevatron has found 62 events that signal the presence of "single" top quarks. "Data have to be at least doubled, even tripled, before you have a really clear scientific picture," says Thomas Müller of Karlsruhe University in Germany, who is a member of the CDF collaboration, which is also looking for single top quarks at the Tevatron. DZero member Ann Heinson expects that within a year DZero will have analyzed a sufficient amount of data to claim an unequivocal identification of the particle.

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