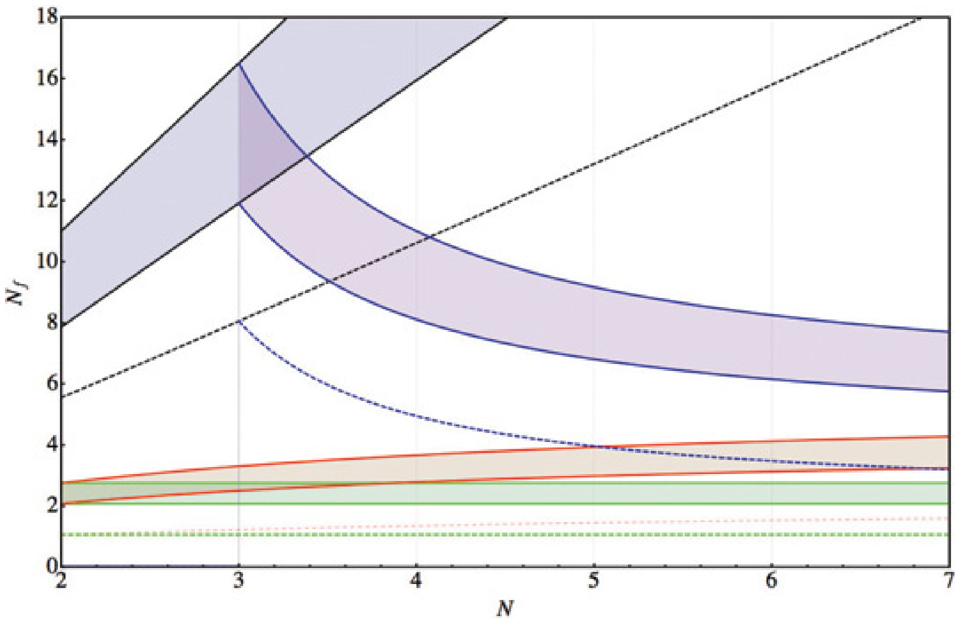
Testing Technicolor Physics

Researchers use Ranger to explore what might lie beyond the Standard Model of particle physics



Above is a map of the technicolor particles theories that DeGrand studies. The axes represent (horizontal) the number of colors and (vertical) the number of flavors of quarks. The different colors describe different kinds of color structure for the quarks. The shaded bands are where these theorists (D. Dietrich and F. Sannino) predict that there are "unparticle" theories.

As the Large Hadron Collider ramps up the rate and impact of its collisions, physicists hope to witness the emergence of the Higgs boson, an anticipated, but as-yet-unseen fundamental particle that scientists believe gives mass to matter.

The Higgs boson is a central component of the Standard Model, which defines the relationships between the forces of the universe. But another possibility exists, one that divides the theoretical community.

What if the Higgs boson is not a fundamental particle, but rather a bound state of new particles that themselves have not yet been seen?

"From the beginning of the Standard Model, there have been people who have been unhappy with the idea that the Higgs boson is a fundamental particle," said Thomas DeGrand, professor of physics at the University of Colorado. "There are a variety of reasons why they don't like it, associated with how the Standard Model could be embedded in a theory which includes even higher energy scales. But I think the main reason is one of aesthetics."

Theorists who advocate such new physics are motivated by the theory of superconductivity, in which the superconducting state, so different from ordinary matter, is not characterized by truly new particles, but by Cooper pairs — bound states of electrons.

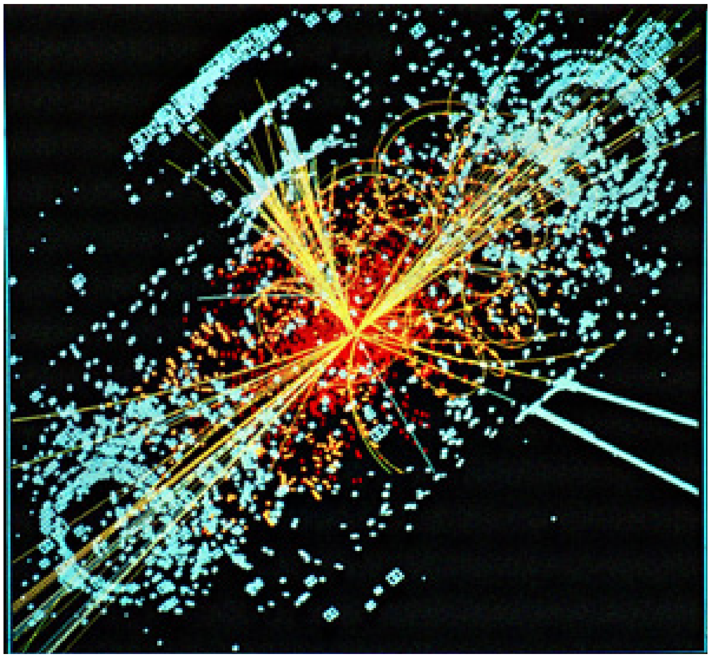
The Large Hadron Collider is designed to probe the highest energies ever explored. Physicists expect to see some kind of new physics, either the Higgs particle or something else. This new physics would only be "seen" obliquely in a flash of smashed atoms that lasts less than a trillionth of a second. Perhaps what the experiments will reveal is not the Higgs Boson, but something else yet to appear.

No one knows if there is any deep reason why the particle content of the Standard Model — six flavors and three colors of quarks (up, down, strange, charm, bottom, top), plus the eight gluons, the electron and its partners and the neutrinos, and the photon, W and Z particles — is what it is. A logical possibility exists that there could be more kinds of quarks and gluons, with different numbers of colors, strongly interacting with each other.

Collectively, these possibilities are known as Technicolor theories. The name is a play on the word ``color'' which describes the forces that bind quarks and gluons into strongly interacting particles like the proton. In the last thirty years, the theory behind the interactions of quarks and gluons, called quantum chromodynamics (QCD), has gone from a theoretically robust, but largely unknown field, to a highly precise and experimentally proven science.

DeGrand spent many years studying QCD before he turned his attention to Technicolor theories. In fact, he was a co-author of one of the standard books on the field. However, QCD does not describe all of the Standard Model, especially the fundamental or non-fundamental nature of any "final" undiscovered particles. It was the construction of the LHC, and the sense that new knowledge could be waiting around the corner, that drew DeGrand to explorations of alternative particle theories.

"I had gotten a little tired of lattice QCD," DeGrand said. "It's successful and really big science now, with big groups of people working on it, and I'm not a big group of people kind of person. The Technicolor theories held more interesting questions and you could fool around."



An example of simulated data modelled for the CMS particle detector on the Large Hadron Collider (LHC) at CERN. Here, following a collision of two protons, a Higgs boson is produced which decays into two jets of hadrons and two electrons. DeGrand's theories represent an alternative to the Standard Model.

Phenomenologists had been thinking about Technicolor models for the last 30 years, but it was only five or six years ago that scientists realized that many of the techniques that had been invented to do lattice gauge simulations for QCD could be applied to these new theories as well. DeGrand was invited by two colleagues from Tel Aviv University, Yigal Shamir and Benjamin Svetitsky, to join their research team.

Using the same methodology DeGrand helped perfect for QCD, the team has been methodically simulating Technicolor candidate theories and drawing conclusions from the odd outcomes of these simulated worlds.

To do so, DeGrand and his collaborators calculate the interactions of new kinds of quarks and gluons in various configurations on lattices of giant grids within a supercomputer. These grids are housed (virtually) in boxes of various sizes, and the reaction of the particles to the box size provides the researchers with information about the energy characteristics of the system.

"This is not something an experimentalist can do," DeGrand said. "But we, as theorists, can invent these fake worlds where the system sits in a specific sized box. Then we measure the coupling constant," the strength of the quark-gluon interactions, "in large boxes, medium boxes and small boxes to see how it changes. Changing the energy or momentum scale, in quantum mechanics, is related to changing the physical size of the system."

Because the process involves solving the Schrodinger quantum equations for a large number of particles, these calculations require powerful supercomputers and lots of processing time. Over the last two years, computing on the Ranger supercomputer at the Texas Advanced Computing Center, DeGrand and his colleagues have used nearly 3 million processing hours to perform studies that simulated new particles made up of new quarks with two colors and three colors, respectively. The simulations help characterize the potential systems and determine whether they may be viable candidates for beyond-the-Standard-Model physics.

"Nobody knows whether any of these theories are phenomenologically viable, so we're beginning to make a map of them," DeGrand said. "We're starting with the things that are simplest to simulate and hoping to get intuition from these theories."

The simulations revealed that the simplest Technicolor models, with two colors, have properties which are very different from a conventional particle system. Prof. H. Georgi of Harvard had coined the name, "unparticle theory," to describe such systems, which behave much like a liquid-gas mixture at its critical point.

The three-color system was even more mysterious. The researchers could not tell if it was a particle theory or an unparticle theory. However, the simulations clearly revealed that it did not represent a viable real-world scenario. For any Technicolor theory to be a feasible candidate for new physics, it must exhibit rather unusual behavior to avoid conflict with present day, "old physics" experimental constraints. The three-color system did not satisfy these criteria. They are now beginning work simulating four-color quark systems.

Thomas DeGrand, professor of physics at the University of Colorado.

“Many physicists are looking for more elegant explanations for the Higgs mechanism. The alternative idea that it could be caused by the strong interactions of still-to-be-discovered elementary particles has been with us for some time, but until recently, it has been difficult to test this idea for lack of adequate computing resources,” said Carlton DeTar, a longtime collaborator not involved in the current research. “DeGrand and collaborators are among the foremost groups in the world using powerful numerical simulations to investigate this exciting alternative. The results could have profound implications for the search for the Higgs particle at the Large Hadron Collider in Europe.”

Even the unreal systems tell DeGrand something about the nature of particle physics. Just as Salvador Dali’s surreal paintings reveal taken-for-granted aspects of our material world, the alternative theories explored by DeGrand and others have intellectual value. They teach us about particle theories by placing them in larger context, and tell us what is special about QCD.

“I myself think the Technicolor theory is rather dubious,” DeGrand said. “But I also think it’s fun, like the good old days of QCD, 25 or 30 years ago, when people really didn’t know what they were doing.”

For DeGrand, the exploration, the stretching of the mind, is what matters most. That and the adventure of discovering something truly novel.

“It’s high risk, high reward research,” he said. But if he and his colleagues find a viable alternative to the Standard Model, it might drive the next theory of everything.

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