Seeking the Nature of Nature

Ricardo Eusebi, Teruki Kamon, Alexei Safonov, David Toback and other physicists at Texas A&M University are part of a worldwide effort, using some of the most powerful high-energy physics equipment ever built, to help understand the fundamental construction of the physical world.

They are on the trail of almost unimaginably small fundamental particles of matter and energy—the existence of which has as yet only been theorized. Determining whether those particles are real may depend on two machines that are massive, half a world apart, and both being utilized in a search for the ultimate definition of the fabric of reality.

The particles under investigation bear exotic names: Higgs boson, supersymmetry, and heavy Z-prime boson. Proof or disproof of their existence will determine the future of the entire discipline of high-energy physics—confirming or denying a whole way of thinking about the nature of nature itself.

The startup of the Large Hadron Collider (LHC) particle accelerator at the European Organization for Nuclear Research (CERN) near Geneva, Switzerland—already dubbed the largest scientific tool ever built by humankind—in late 2009 caught the imagination of millions of people around the world, and the LHC has been at the center of media attention ever since.

In 2005, the experimental collider high energy group at Texas A&M brought its decades of combined collider expertise to the Collider Muon Solenoid (CMS) collaboration, one of the two flagship LHC experiments that uses a large detector. This large detector is the size of a five-story building and surrounds the point where protons are collided. Since then, the group, now 25 members strong, has become a key component of the science exploration team at CMS, bringing new ideas, expertise, and leadership.

The first LHC results were presented at the 2010 International Conference for High Energy Physics, the world’s largest particle physics conference. Based on a small set of data, the LHC physicists were able to “re-discover” the W and Z bosons—particles transmitting interactions between other particles—showing excellent performance of the LHC experiments. Another example of such bosons is the photon, which carries electromagnetism. (When two magnets are placed near each other and they attract, photons fly back and forth between the particles inside each of the magnets and “create” the visible attractive force. Pieces of matter do not fall apart because particles are constantly interacting with each other.)

W and Z bosons are similar to photons, but they are carriers of the “weak” force, which is responsible for many radioactive decays. Most discoveries of the second half of the 20th century were directly related to the weak force, W and Z bosons, etc. W and Z bosons were first predicted and then
observed at CERN in two collider experiments, similar to what physicists are doing now, but on a much smaller scale. Physicists are now focusing on particles at the next level of “smallness,” and thus the LHC now collides protons at much higher energies suitable for finding new phenomena.

Both preceding and complementing current efforts at the LHC, Texas A&M physicists have acquired considerable expertise in physics analysis from the group's work on the Collider-Detector at Fermilab (CDF) experiment at the Tevatron, the world's second largest circular particle accelerator after the LHC, at the Fermi National Accelerator Laboratory in Batavia, Illinois. The Tevatron has been the setting for exploring the frontier of high-energy research for years prior to the LHC’s ramp-up to full operation, and it continues to be an important tool for physicists investigating fundamental questions. Texas A&M professors Robert Webb and Peter McIntyre, in fact, were founding members of the CDF experiment at the Tevatron in 1980. Part of the Texas A&M group is still actively involved in searches for the Higgs boson and supersymmetry at the Tevatron, using data from the CDF experiment. Toback says that the team there hopes to continue providing important contributions from the Tevatron over the next few years, while the LHC is brought up to even greater levels of power for further long-term investigations.

What is the significance of the Higgs boson? It's “a missing piece of the puzzle,” as Safonov puts it, in the Standard Model that encompasses current knowledge of particle physics. It “has to be there,” according to the Standard Model—but it has yet to be physically discovered. Sometimes dubbed the “God” particle, the Higgs boson is responsible for giving masses to all other particles that physicists know, via interaction with these other particles.

Supersymmetry is a theoretical model that would explain dark matter observed astronomically (there is a lot of it—as much as six times more than ordinary matter that consists of atoms and molecules) but for which there is so far no explanation whatsoever. “Supersymmetry has other promising theoretical features as well, and has the exciting potential to tie together cosmology and particle physics at the earliest moments after the Big Bang,” says Kamon; but so far, it is just a theory. The LHC and CDF experiments are expected to either find evidence of it, or largely disprove the theory behind it. Either result will mean a revolution in particle physics.

By the end of 2010, the LHC will log 60 times more data than it did before the 2010 conference, as it
starts breaking new ground in particle physics exploration. Within the next year, the dataset will increase again by a factor of about 50, which could already be sufficient to bring some of the anticipated new discoveries. Physicists plan to use proton-proton collisions in the LHC and Tevatron in hopes of explaining the origin of mass and dark matter.

The Texas A&M group is working not only on physics data analysis, but also on the design and development of new detectors and techniques for current and future experiments. The group's contributions are well recognized by the CMS collaboration. Just recently, for example, Jim Pivarski, a Texas A&M postdoctoral researcher, was selected for the 2009 Achievement Award for his important contributions to commissioning the CMS detector. As more data becomes available, members of the Texas A&M group analyze collision events looking for evidence of the Higgs boson, supersymmetry (a theory in physics that precisely relates all elementary particles of one kind, bosons, with another kind, fermions), and some other new particles predicted in well-motivated theoretical models, such as the heavy Z-prime boson. This year, with the support of American Recovery and Reinvestment Act (ARRA) funding, awarded by the U.S. Department of Energy, the group will complete the setup of a high-speed digital electronics shop to design and build state-of-the-art electronics for future detectors. With the support of ARRA and the Norman Hackerman Advanced Research Program, the group is preparing to install and commission a new Tier-3 computing center on the Texas A&M campus. This project is a joint venture with Texas A&M’s Academy for Advanced Telecommunications and Learning Technologies. The Texas A&M Tier-3 center will join the GRID network of computing centers around the world later this year. It will be used to process and analyze petabytes (a unit of information equal to one quadrillion bytes or 1000 terabytes) of data per month from the Large Hadron Collider by Texas A&M researchers.

With the new expertise brought by Professor Ricardo Eusebi, who joined the Texas A&M faculty in 2009, the A&M team is now expanding its capabilities to join the work on building a new high-performance silicon pixel detector that allows precision tracking of charged particles produced in the LHC collisions.

View of the CMS Detector before closure. Photo by Joseph Gobin. ©CERN

Physicists already know that even if they find the Higgs boson, the Standard Model is already incorrect—some aspects of the mass of particles called neutrinos do not quite fit the model—in addition to being incomplete, as the model provides no clues as to what dark matter or dark energy are. In addition to giving answers on how to correct the Standard Model, discoveries at the LHC and the Tevatron will mean big changes in physicists’ understanding of how particles interact with each
other, where they came from, and where they get their mass. Even confirmation of the absence—non-existence—of the Higgs boson will be extremely significant, because it will mean that physicists will need to rethink a lot of theories and assumptions.

In the meantime, the Texas A&M physics group at the LHC and the Tevatron remain enthusiastic and committed participants in the quest to understand the fundamental nature of nature itself.