Bringing the Big Bang into View

In a large underground tunnel that straddles the French–Swiss border, the Large Hadron Collider smashes particles together at almost the speed of light and at unheard-of energies to examine their basic properties. (Courtesy of CERN, the European Organization for Nuclear Research.)

DURING the first milliseconds after the big bang, quarks, the most elementary of all known particles, roamed free in the universe. But their lifetimes were vanishingly brief. As the universe began to cool, quarks and the gluons that hold them together coalesced into protons and neutrons, two basic constituents of atoms. Efforts to re-create the high-energy and high-density conditions of the big bang—and thereby examine the fundamental physics of matter as it existed then—have been exceedingly difficult.

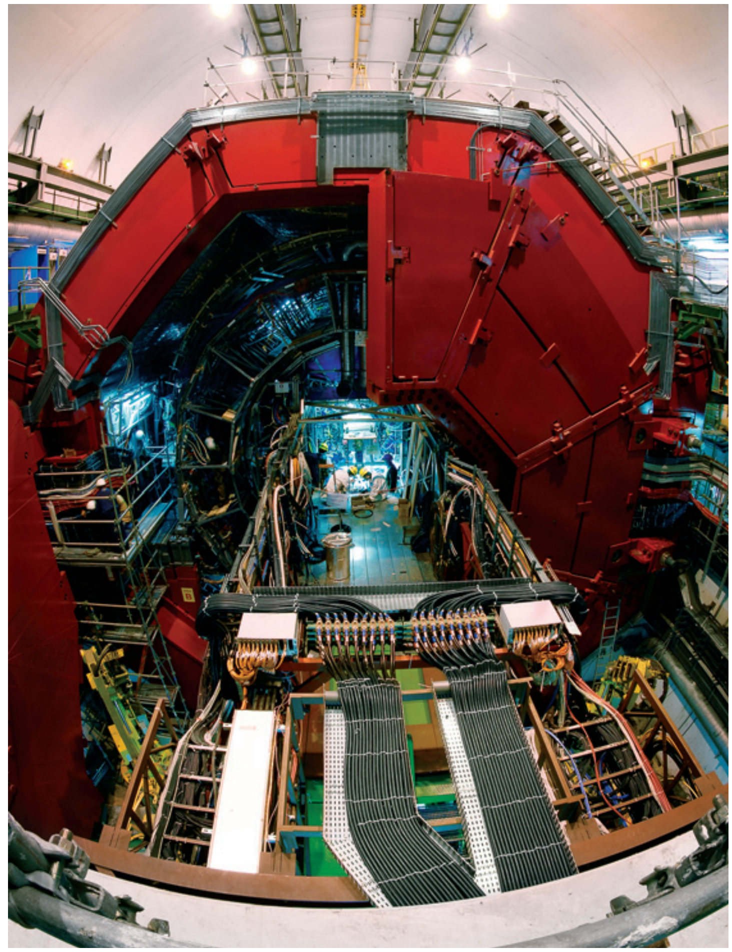
It takes an enormous and extraordinarily expensive particle collider to create the environment in which quarks and gluons might again be free of their confinement as constituents of larger particles. Because such colliders are few and far between, hundreds of partner institutions collaborate on the experiments. For the past decade, a team of Livermore researchers, led by particle physicist Ron Soltz in the Physical and Life Sciences Directorate, has worked at one such facility—the Relativistic Heavy Ion Collider (RHIC) operated by Brookhaven National Laboratory. Inside this particle accelerator, two beams of gold ions travel in opposite directions around the 3.8-kilometer ring at nearly the speed of light. When the two beams smash into each other, they briefly produce a quark–gluon plasma similar to the one generated in the big bang. (See *S&TR,* January/February 2003, pp. 4–9.)

While Soltz and his many collaborators continue to make substantial discoveries at RHIC, they also have a new, far more powerful collider at their disposal. The Large Hadron Collider (LHC) is a ring 27 kilometers in circumference in a tunnel under the French–Swiss border near Geneva, Switzerland. Approximately 10,000 scientists, engineers, and technicians collaborate at LHC, which was built and is operated by the European Organization for Nuclear Research, known by its French acronym, CERN.

LHC came on line briefly in 2008 before equipment problems forced CERN to shut it down for several months. In 2009, LHC began powering up and will eventually generate energies approximately 28 times higher than those at RHIC. Current LHC operational energies are about half that amount, or 2.7 trillion electronvolts per nucleon, still many times higher than the 200 billion electronvolts per nucleon typically produced by RHIC.

"About 80 percent of experimental time at LHC is used to study proton collisions," says Soltz. "One of the many goals for LHC researchers is to pin down the existence of a particle known as the Higgs boson, which is thought to give mass to matter. In fact, Livermore scientists Doug Wright, David Lange, and Jeff Gronberg are working toward that goal as part of another LHC effort called the Compact Muon Solenoid experiment."

CERN also allocates about a month of collider time each year for experiments designed to free quarks inside protons and neutrons. Soltz and his partners are studying results produced by both types of LHC experiments to discern how collision by-products behave.



A Large Ion Collider Experiment (ALICE) is a giant cylindrical device used by Livermore researchers and their partners to measure the collisions of lead ions and examine the conditions existing in the universe a few seconds after the big bang. (Courtesy of CERN.)

Down the Rabbit Hole with ALICE

LHC experiments smash lead nuclei together, rather than gold. With this heavier element and LHC's longer circumference, nuclear collisions are 40 times more energetic than those generated at RHIC, resulting in plasmas with unprecedented temperatures and energy densities. Livermore researchers and their partners are conducting research on LHC's A Large Ion Collider Experiment, or ALICE. This experiment is designed to measure the properties of lead ions as they collide in the cylindrical belly of ALICE and create the "quark soup" of the big bang. A calorimeter provided by U.S. collaborators measures and records the very high energies dissipated by the particle collisions within the plasma.

The primary focus for the U.S. scientists working on ALICE is to further examine a surprising finding from their RHIC research. In those experiments, the collision of highly charged heavy ions generated high-energy, asymmetric "jets" in the surrounding plasma. Each jet—a spray of by-products from the reaction—interacts with the plasma, where it deposits some or all of its energy. "In a vacuum, colliding particles such as protons routinely create jets," says Soltz, "but those jets are symmetric. A central question in this area of physics is to understand why jets behave so differently in plasma. Through further experiments and modeling, we can begin to measure the phenomenon and what, if any, effect it might have had on the big bang's quark–gluon plasma."

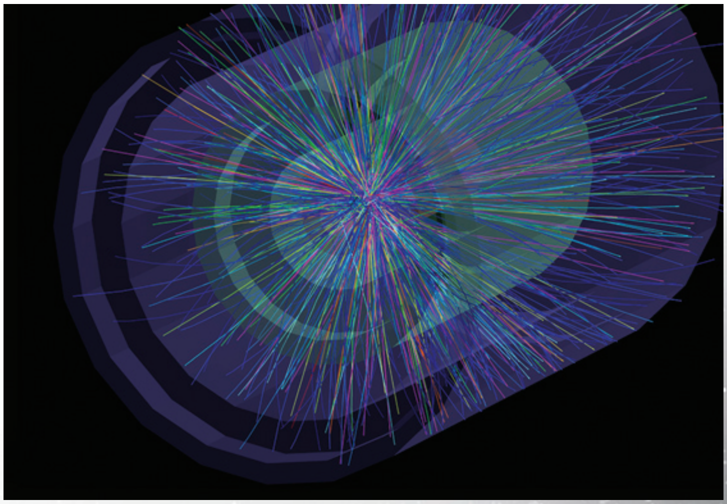
Sorting Out the Data

LHC experiments such as ALICE generate about 10 trillion bytes (terabytes) of data per day. Storing and processing so much information in one place is impossible. To get around this problem, CERN funnels data to a grid of computing centers located around the world.

Lawrence Livermore and Lawrence Berkeley national laboratories have jointly developed one such receiving point at Berkeley's National Energy Research Scientific Computing Center. Together, the two laboratories, with funding from the Nuclear Physics Program in the Department of Energy's Office of Science, are providing the primary computing and storage resources for ALICE collaborators in North and South America. The 1,000-plus collaborators worldwide can access those data using the ALICE Grid. Ten percent of all data from ALICE is transmitted from Switzerland to Berkeley and Livermore over ESnet, the Department of Energy's Energy Science Network.

"Making sense of experimental results at ALICE is difficult," notes Soltz, who serves as the computing coordinator for the Office of Science. "Experiments produce giant sprays of particles. Sorting them all out and determining what they mean requires a lot of high-performance computing power."

Livermore scientists (from left) Teresa Kamakea, Jeff Cunningham, and Ron Soltz view a map showing the member sites of the international ALICE collaboration that link to the Laboratory's Green Linux Compute Cluster.



Lead ion collisions recorded by ALICE reveal a spray of particles. Data produced in these experiments are processed on a giant international grid of high-performance computers, including Livermore's Green Linux Compute Cluster. (Courtesy of CERN.)

Livermore's ALICE cluster is called the Green Linux Compute Cluster. Installed in September 2010, it is the third largest ALICE cluster as measured by jobs completed per 24-hour period, and the associated 650-terabyte storage element for processed data is among the most heavily used. The cluster, which processed a series of simulations in preparation for the first heavy-ion experiments last November, is Livermore's first grid computing project involving an international collaboration.

Postdoctoral researchers Irakli Garishvili and Betty Abelev are working with Soltz on a Laboratory Directed Research and Development project to interpret ALICE data. In particular, they are searching for telltale signs of jets and the dissipated energy absorbed by the surrounding plasma. Soltz admits that at this point, researchers are unsure what the collider study of jet–plasma interactions will teach them about the big bang plasma. Jets may not have been present in this same form in the early universe, but says Soltz, "At a minimum, they serve as indispensable probes for examining the plasmas in our experiments."

He notes that the physics of big bang and LHC plasmas are identical, but they began in different ways. "The big bang plasma was born extremely hot and highly uniform except for the tiny clumps that eventually coalesced into galaxies, solar systems, planets, and us," says Soltz. "At LHC, nuclear collisions rapidly heat up to produce the plasma. In studying these events, we hope to learn what role jets play in the process."

—Katie Walter

Key Words: A Large Ion Collider Experiment (ALICE), big bang, European Organization for Nuclear Research (CERN), Green Linux Compute Cluster, Large Hadron Collider (LHC), quark–gluon plasma, Relativistic Heavy Ion Collider (RHIC).

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