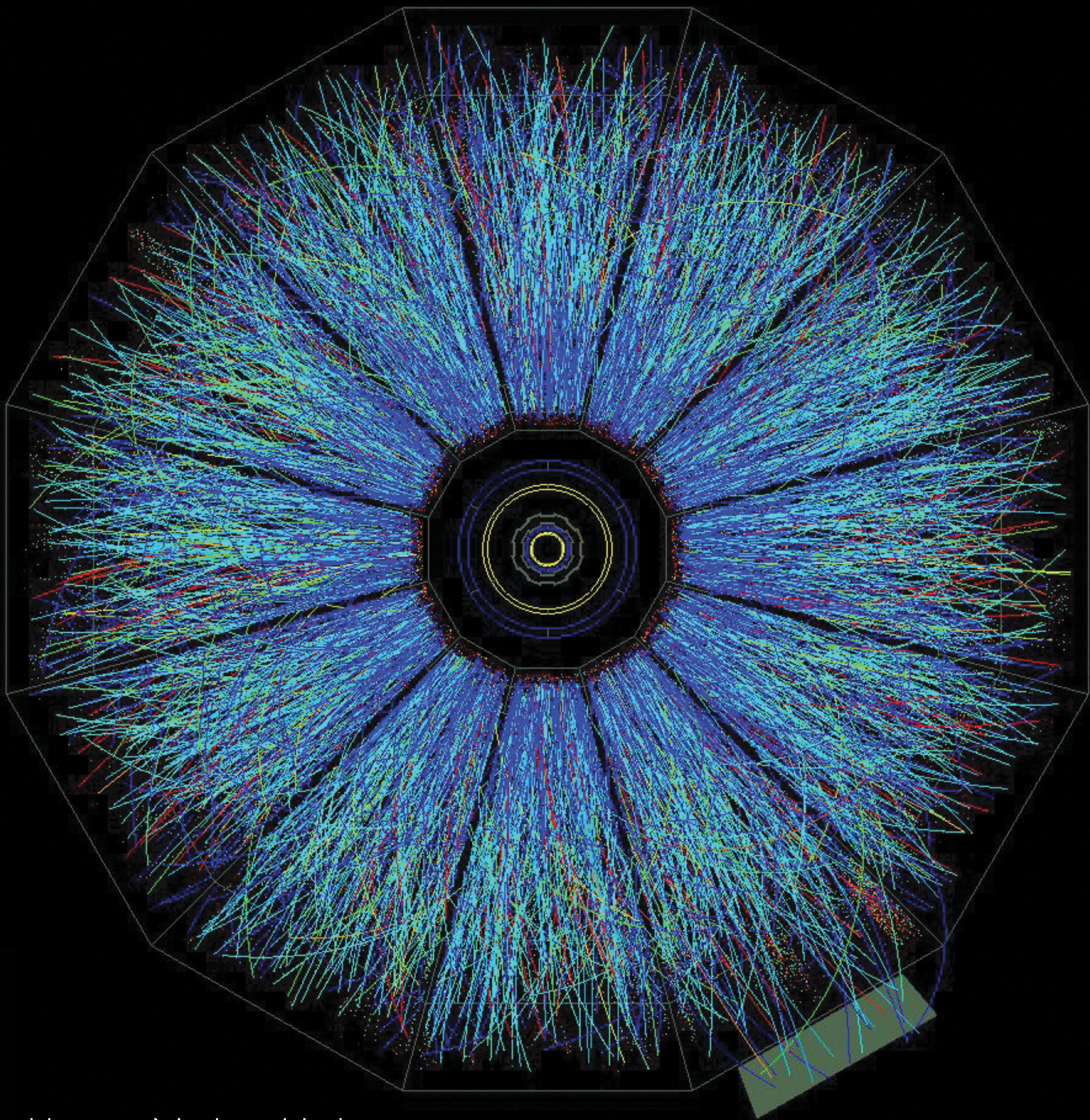

Brookhaven National Laboratory

The Relativistic Heavy Ion Collider (RHIC)

An Exciting Beginning and a Compelling Future

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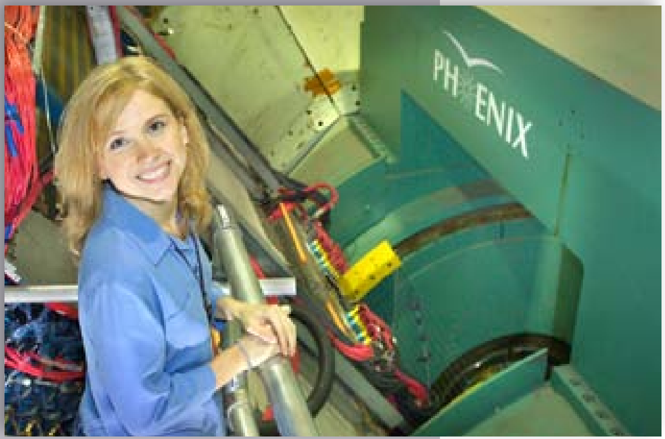
At the Relativistic Heavy Ion Collider (RHIC), a world-class particle accelerator at Brookhaven National Laboratory, physicists are exploring the most fundamental forces and properties of matter and the early universe, with important implications for our understanding of the world around us.

Complex detectors capture RHIC collisions for physicists to analyze.

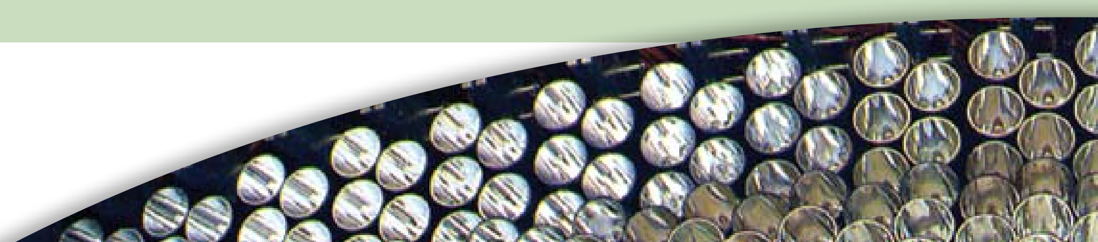


Operated with funding from the U.S. Department of Energy's Office of Science, the Relativistic Heavy Ion Collider (RHIC), was designed to recreate a state of matter thought to have existed immediately after the Big Bang some 13 billion years ago, and to investigate how the proton gets its spin and intrinsic magnetism from its quark and gluon constituents. Large detectors located around the 2.4-mile-circumference accelerator take "snapshots" of collisions between beams of particles — from protons to the nuclei of heavy atoms such as gold — to get a glimpse of the basic constituents of matter. Understanding matter at such a fundamental level will teach us about the forces that hold the universe and everything in it together.

While no one can predict what, if any, practical applications that knowledge will yield, other, earlier physics studies on the basic structure and properties of matter have yielded countless, unforeseen advances and technologies we now take for granted — things like personal computers, medical instruments, and tiny hand-held cellular phones. The idea behind RHIC is simply to delve deeper into the mysteries of matter. In so doing, RHIC has become one of the world's premiere training grounds for young physicists.

Supercomputing at RHIC

Since 2000, RHIC's detectors have taken digitized "snapshots" of billions of particle collisions – data-dense "pictures" that reveal details about the early universe and the fundamental properties of matter. Keeping up with the data and the theoretical calculations of quantum chromodynamics (QCD), the theory that describes nuclear particles' interactions, requires large-scale supercomputing. Designing the systems to meet these computing needs continues to push the evolution of technology in ways that may benefit us all – as did the development of the World Wide Web, first designed as a way for physicists to share data.



A perfect surprise

A series of stunning discoveries at RHIC have captured worldwide attention and shone a spotlight on U.S. leadership in science.

First, RHIC scientists had expected collisions between two beams of gold nuclei to mimic conditions of the early universe and produce a gaseous plasma of the smallest components of matter — the quarks and gluons that make up ordinary protons and neutrons. But instead of behaving like a gas, the early-universe matter created in RHIC's energetic gold-gold collisions appears to be more like a liquid. And it's not just any liquid, but one with coordinated collective motion, or "flow," among the constituent particles.

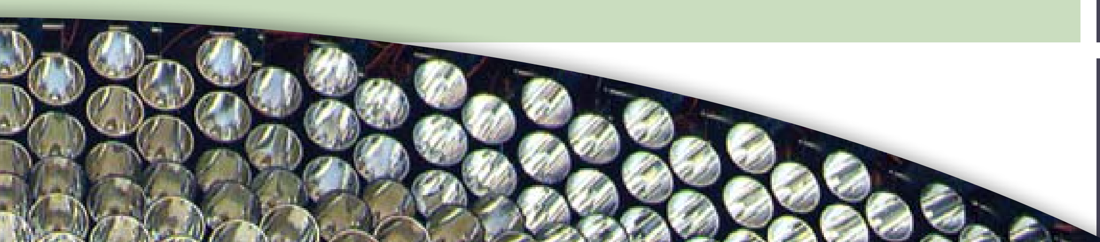
The scientists describe this fluid motion as nearly "perfect" because it can be explained by the equations of hydrodynamics for a fluid with virtually no viscosity, or frictional resistance to flow. In fact, the high degree of collective interaction and rapid distribution of thermal energy among the particles, as well as the extremely low viscosity in the matter being formed at RHIC, make it the most nearly perfect liquid ever observed.

It also turns out to be the hottest matter ever created in a laboratory, measuring some four trillion degrees Celsius, or 250,000 times hotter than the center of the Sun. That's far above the temperature at which protons and neutrons melt to free their constituent quarks and gluons, showing definitively that RHIC's perfect liquid is hot enough to be the long-sought quark-gluon plasma.

RHIC's quark-gluon plasma exhibits other unusual properties that have intrigued scientists. Tiny "bubbles" formed within this hot soup may internally disobey fundamental symmetries that normally characterize the interactions of quarks and gluons. These first hints of symmetry violations at RHIC suggest that scientists may now have a unique opportunity to test in the laboratory some crucial features of symmetry-altering bubbles speculated to have played important roles in the evolution of the infant universe.

RHIC's "perfect" liquid

For data storage and analysis, RHIC physicists rely on a "farm" of 3,300 Linux processors and a super-fast robotic tape storage system, at times augmented by computing resources from collaborating sites around the world. At the same time, three supercomputers at BNL are contributing another important element to RHIC physics. Two are QCDOC machines — for "QCD on a chip" — which are capable of performing 10 trillion arithmetic calculations per second, a speed necessary for the complex calculations of QCD. The third, New York Blue, is a 100-terraflop machine — the fastest supercomputer in the world for general users — that will help interpret current RHIC data and model future runs at the collider.



RHIC has long been a training ground for young physicists who go on to careers in many fields.

Moving forward

RHIC's research to date has enriched physicists' understanding of quantum chromodynamics (QCD), the theory that describes the interactions of the smallest known components of the atomic nucleus. But it also raises compelling new questions about QCD.

To address these questions, key improvements are planned for RHIC to further the study of QCD both experimentally and theoretically. As part of a symbiotic research program using Brookhaven's 100-teraflop Blue Gene supercomputer, New York Blue, and two 10-teraflop QCDOC (for QCD On a Chip) supercomputers, these upgrades will create a QCD laboratory at RHIC unlike any research center in the world.

Already, RHIC's accelerator physicists are working to increase the machine's luminosity, or collision rate, approximately tenfold and improve the sensitivity of the detectors to record extremely rare processes — some of which occur in fewer than one in a billion collisions.

A longer-term upgrade would add a high-energy electron beam to collide with either polarized protons or heavy ions at RHIC, creating an Electron Ion Collider, a major new research facility. With this powerful added dimension, physicists expect to probe yet more deeply into the way quarks and gluons interact to form the atomic nuclei that make up the visible matter in our universe. In particular, this new collider capability will explore the fundamental role of gluons in the substructure of the world around us.

Spinning in another direction

In addition to investigating the primordial properties of the universe, some RHIC scientists are looking into another fundamental question of particle physics: What is responsible for proton "spin"? Spin is a magnetic property of particles as basic as their mass and their electrical charge. While we routinely manipulate proton spins to look inside the body with magnetic resonance imaging (MRI), we do not understand the origin of the proton's spin.

Using specialized magnets known as Siberian snakes to keep the spins of protons mostly aligned in the same direction, physicists at RHIC can collide beams of these "polarized protons" to examine the structure underlying the proton's spin. This research will offer further insight into the structure and interactions of subatomic particles.

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