EXPLORING THE HEART OF MATTER

By Kandice Carter

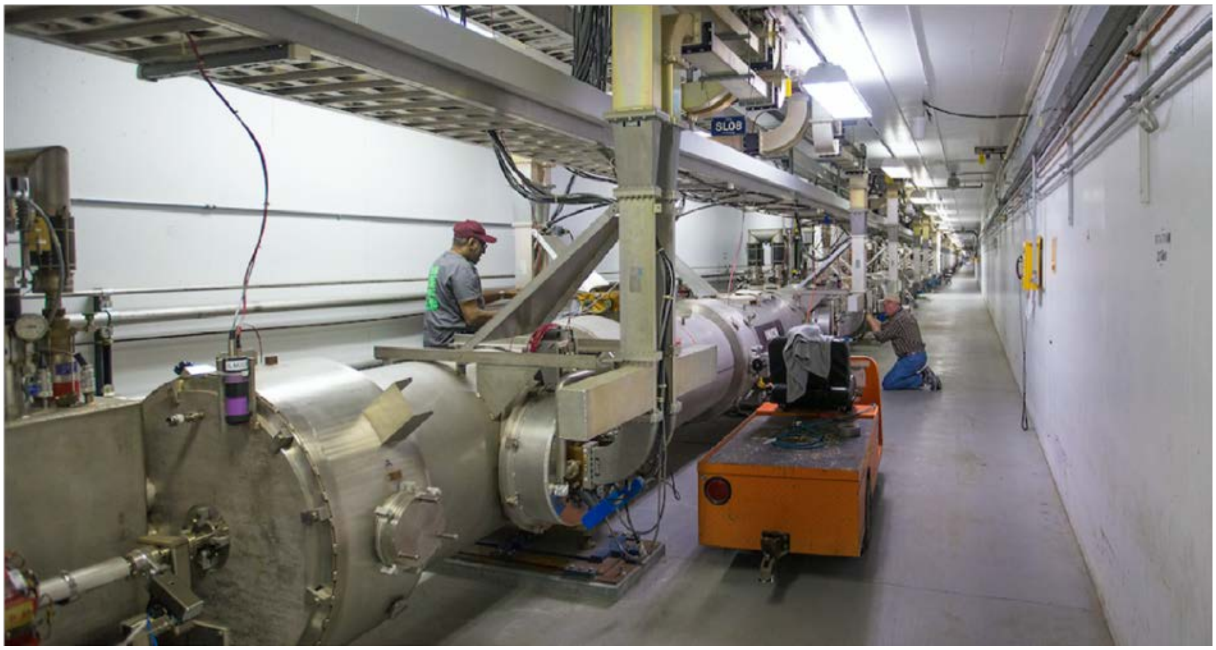
To explore the nucleus inside an atom, scientists use giant particle accelerators that act like microscopes. Detectors like this one collect the information for scientists to analyze.

Our visible universe is almost entirely underpinned by the tiny particles and forces that reside in the nucleus of the atom, the very heart of matter. To gain a better understanding of our universe, nuclear physicists must plumb the depths of the atomic nucleus, which is 10,000 times smaller than the already minuscule atom. So how do they do it?

To explore the tiniest bits of matter, scientists require a big machine, such as the Continuous Electron Beam Accelerator Facility. CEBAF is a large particle accelerator located at the Thomas Jefferson National Accelerator Facility—known as Jefferson Lab—in Newport News, Virginia.

A MICROSCOPE FOR THE NUCLEUS

CEBAF acts like a giant microscope. It stuffs electrons with extra energy by accelerating them to nearly the speed of light. This extra energy allows the electron to travel inside the atom's nucleus to probe its protons and neutrons.



The CEBAF accelerator is located in a racetrack-shaped, narrow tunnel that is 25 feet underground and nearly 7/8 of a mile long.

From earlier particle accelerators, we know that protons and neutrons are made up of quarks and gluons. CEBAF's electrons can be so energetic and can be controlled with such precision that they can also probe deep inside protons and neutrons to touch the quarks and gluons for study.

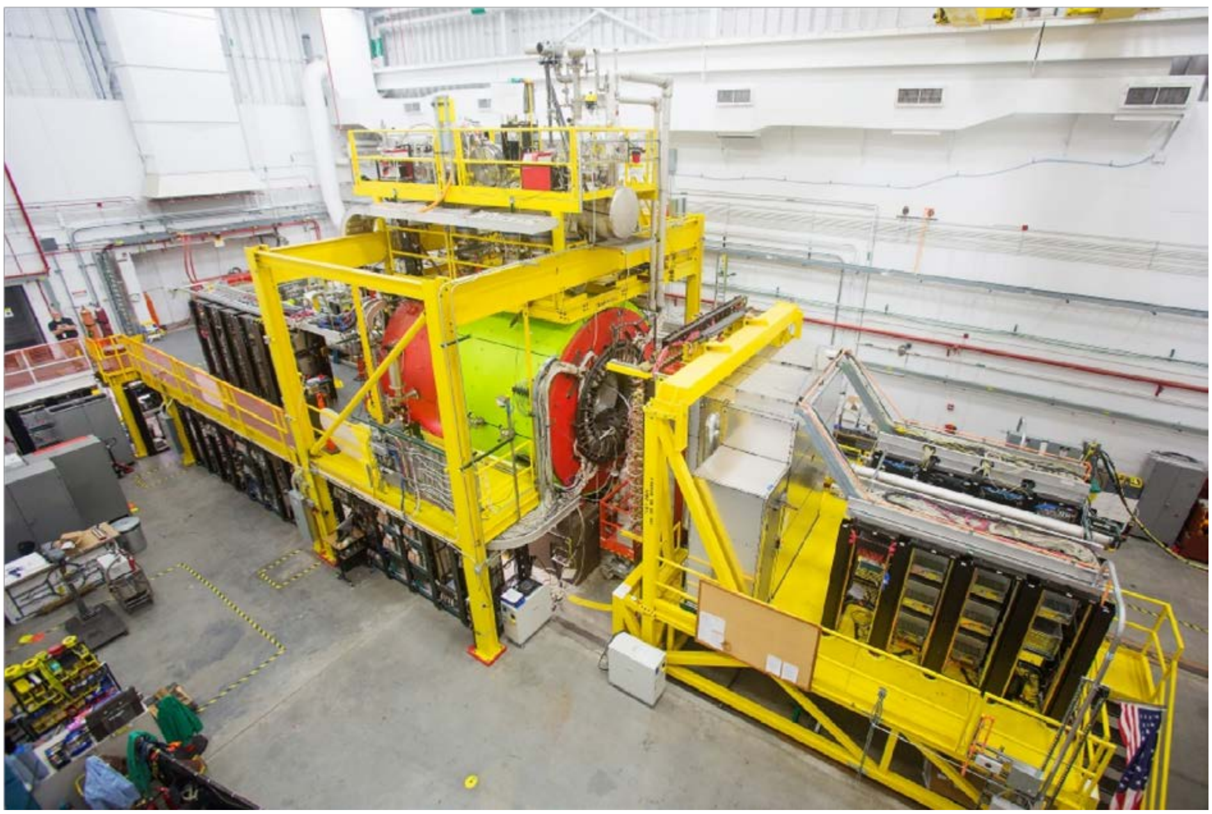
When probing the particles inside a nucleus, many of the electrons pass right through with no effect, but others crash into these subatomic particles, sending them careening out of the nucleus along with the electrons. Smashed and crashed particles are collected in large devices called detectors that measure characteristics such as mass, charge, or speed, which scientists can use to reconstruct the collisions to learn about the particles, their structure, and their behavior inside the nucleus.

ENERGETIC ELECTRONS

The CEBAF accelerator was originally designed to provide electrons with 4 billion electron-volts (GeV) of energy -- to enhance their ability to probe the nucleus. But soon after the machine achieved 4 GeV in 1995, operators realized they could surpass that. By incrementally pushing CEBAF's limits, the original machine eventually achieved 150 percent of its original design energy, providing 6 GeV electrons for experiments in August 2000.

For more than a decade, scientists exploited CEBAF's 6 GeV atom-smashing capabilities to study the characteristics of protons, neutrons, and other particles. Such experiments have yielded a better understanding of the structure of protons and neutrons and how they behave inside an atomic nucleus, as well as refinements to the theory that describes the subatomic realm. Even so, scientists have gotten just a taste of what this microscope has to offer.

Construction began on an upgrade of the machine in 2008. The goal is to further increase the energy of the electrons, thereby increasing the resolution of the CEBAF microscope for probing ever more deeply into the nucleus of the atom and even accessing the force that binds those particles together.



CEBAF's newest detectors are looking to find what binds quarks together into protons, neutrons and other particles.

TRIPLE THE POWER

The 12 GeV Upgrade, once complete, is designed to provide electrons with triple the energy as the original machine and double the energy of electrons provided by the original machine at its maximum energy.
The upgrade entails adding 10 new particle acceleration modules and support equipment to CEBAF, as well as construction of a new facility to house detectors, called an experimental hall (upping the total number of experimental halls from three to four), as well as upgrades to equipment in the existing halls and other components.

SUCCESS!

While the upgrade project is ongoing, some tasks have been completed. The accelerator is complete, and commissioning activities for it and two of the four experimental halls are underway. In spring 2014, the accelerator recorded several important milestones as operators carefully checked its systems and began cranking it up toward full energy.

Then, in late December 2015, the machine reached its full design energy for the first time, delivering its first 12 GeV electrons.

MORE ON THE WAY

Work continues on the 12 GeV Upgrade project, which has a completion date of September 2017. More than 1,500 nuclear physicists are busy working to make sure they are ready to use the upgraded CEBAF to full advantage, vying for the chance to run their experiments. These experiments are aimed at furthering our knowledge of the particles and forces at play in the heart of matter.

The 12 GeV CEBAF microscope offers nuclear physicists a very rare opportunity to continue exploring with a precision that other microscopes can't match. Everything they discover is giving us all a window into the inner workings of the particles that build our universe.

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http://energy.gov/articles/exploring-heart-matter

Photos courtesy of Jefferson Lab.