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The Electron-Ion Collider - A machine that will unlock the secrets of the strongest force in nature!

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Electron-Ion Collider
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DISCLAIMER

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A machine that will unlock the secrets of the strongest force in nature!

The computers and smartphones we use every day depend on what we learned about the atom in the last century. All information technology – and much of our economy today – relies on understanding the electromagnetic force between the atomic nucleus and the electrons that orbit it. The science of that force is well understood, but we still know little about the microcosm within the protons and neutrons that make up the atomic nucleus. That's where Brookhaven National Laboratory (BNL) comes in.

Brookhaven National Laboratory (located in Suffolk County, NY, about 60 miles east of midtown Manhattan) was recently chosen as the building site for an Electron-Ion Collider (EIC), a one-of-a-kind nuclear physics research facility. The EIC will be a discovery machine for unlocking the secrets of the "glue" that binds the building blocks of visible matter in the universe. The machine design will take advantage of the existing and highly optimized Relativistic Heavy Ion Collider (RHIC) that's been operating at Brookhaven Lab since 2000.

Beyond sparking scientific discoveries in a new frontier of fundamental physics, the Electron-Ion Collider will trigger technological breakthroughs that have broad-ranging impact on human health and national challenges.

Our existing collider, RHIC, is the first machine in the world capable of colliding heavy ions, which are atoms which have had their outer cloud of electrons removed. RHIC primarily uses ions of gold—one of the heaviest common elements—because its nucleus is densely packed with particles. RHIC collides two beams of gold ions head-on when they're traveling at nearly the speed of light (what physicists call relativistic speeds). The beams travel in opposite directions around RHIC's 2.4-mile, two-lane "racetrack" and collide inside the house-sized STAR and sPHENIX detectors. When ions collide at such high speeds, fascinating things happen. If conditions are right, the collision "melts" the protons and neutrons and, for a brief instant, liberates their constituent quarks and gluons. Just after the collision, thousands more particles form as the primordial matter cools off. Each of these particles provides a clue as to what occurred inside the collision zone. Physicists sift through those clues to help determine the properties of matter milliseconds after the birth of our universe.

RHIC will shut down in 2025 and the construction of the world's first polarized Electron-Ion Collider will begin. BNL's EIC Directorate, in partnership with Thomas Jefferson National Accelerator Facility, is working closely with other domestic and international partners to deliver the $1.7—$2.8 billion construction project and then begin EIC operations in the early 2030s. BNL's EIC engineering staff initially worked with physicists on conceptual designs and now are in the detailed design stage of the project.

But how does a particle accelerator work, what role do power supplies play, and what do BNL electrical engineers who work on these discovery machines do?

In a particle accelerator, magnets that keep particles travelling in the vacuum chambers without hitting the walls require precision DC, both ramped and pulsed power supplies. Many different power supply topologies will be used in the EIC, including SCR, linear, switch mode, interleaved H-Bridge, and multi-level converters.

More than 1000 power supplies are currently in use for RHIC. By the time the EIC is completed, over 2000 power supplies will be in operation. Working in the power supply system means getting involved with power electronics (Silicon Controlled Rectifiers - SCRs, transistors, Insulated Gate Bipolar Transistors - IGBTs, diode rectifiers), power distribution and high-power components (circuit breakers, fused disconnect switches, bus work, transformers, chokes, filter banks, pulse forming networks), high-voltage power supplies (20kV to 600kV), high-current power supplies (up to 20,000A) analog electronics (regulation boards, various analog control boards, op amps), digital electronics (commands and status), Field Programmable Gate Arrays (FPGA) (controlling the power supply), firing circuits for the SCRs, and IGBTs, and Programmable Logic Controllers (PLCs) to control the power supply. The use of circuit simulation programs like PSpice, PSIM or Micro-Cap are essential tools that we use in power supply design and to stabilize power supply regulators.

In addition to powering the warm EIC magnets, we must protect superconducting EIC magnets like we currently protect the existing superconducting magnets in RHIC. These are cooled to 4.5K with liquid helium so they have zero resistance. There are conditions that could make the magnets lose their superconducting properties – what we call a "quench." These quenches must be detected, and the energy in the magnets must be safely removed when they happen.

Quench detection can be done in several different ways. All require precision analog circuits to measure the magnet voltages, as well as a Digital Signal Processor (DSP) or an FPGA to analyze and perform calculations on these voltages to determine if a magnet is quenching. If it is determined that the magnet is quenching, the FPGA or DSP sends a signal to the quench protection system to shut down the power supply, extract the energy from the magnet, and dump the particle beams from the ring before they can cause damage.

The energy in a quenching magnet must be extracted quickly so the magnet is not damaged by the high temperatures that the energy can generate. Power Supply crowbars, IGBT energy extraction switches and energy extraction resistors must be designed and sized properly to protect the magnet.

There are many different projects and technologies an Electrical Engineer can get involved in when working on power supplies at the EIC. AC Power Distribution, DC, Ramped and Pulsed Power Supplies, RF, Vacuum, and Beam Instrumentation are just a few examples. The projects are complex, and the learning is continuous. The fun is in working in an R&D environment with a collaborative team of diverse professionals. If you're interested in learning more about the EIC project, visit bnl.gov/eic. And if you're interested in career opportunities at Brookhaven, visit jobs.bnl.gov – We're hiring!

About Brookhaven National Laboratory

Brookhaven National Laboratory (www.bnl.gov) delivers discovery science and transformative technology to power and secure the nation's future. Brookhaven Lab is a multidisciplinary laboratory with seven Nobel Prize-winning discoveries, 37 R&D 100 Awards, and 75 years of pioneering research. The Lab is primarily supported by the U.S. Department of Energy's (DOE) Office of Science. Brookhaven Science Associates (BSA) operates and manages the Laboratory for DOE. BSA is a partnership between Battelle and The Research Foundation for the State University of New York on behalf of Stony Brook University.