The Electron-Ion Collider

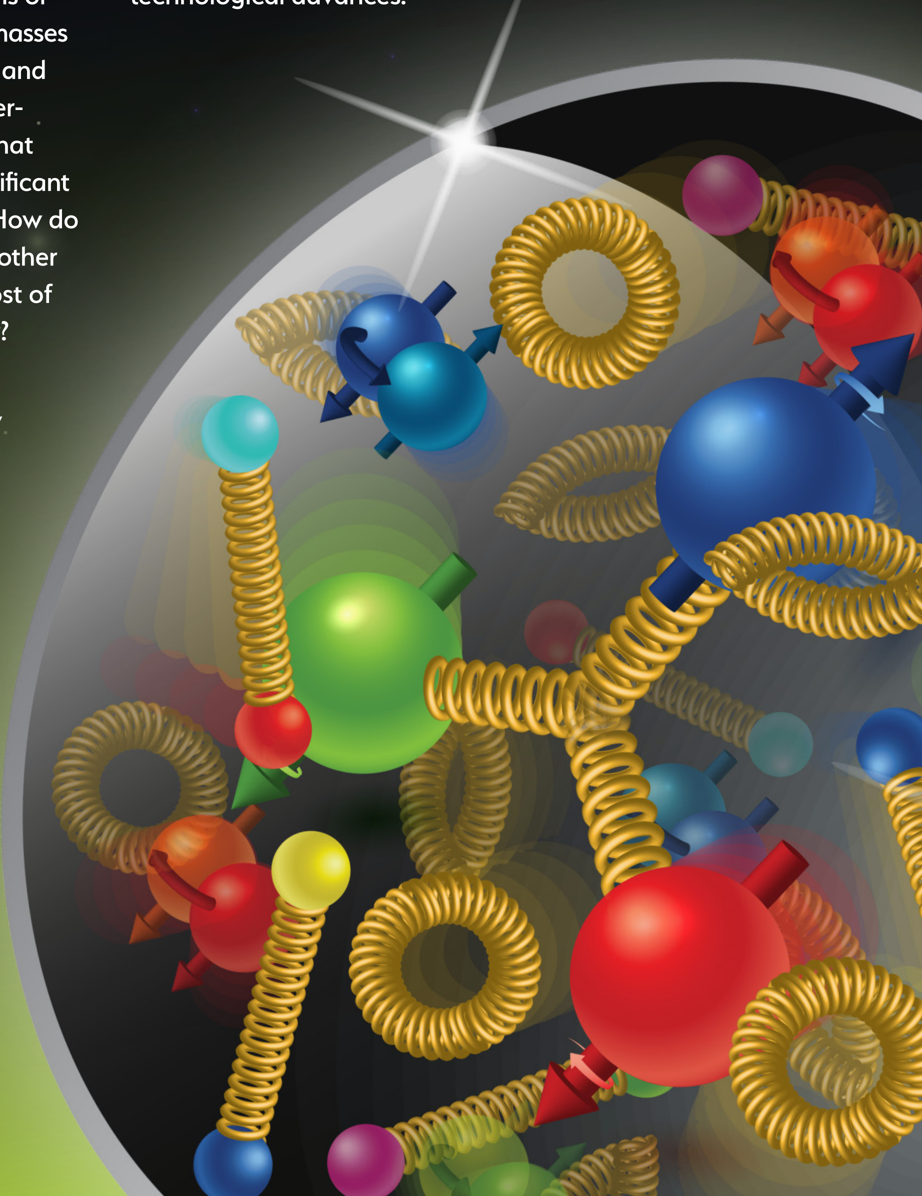
A machine for delving deeper than ever before into the building blocks of matter

Protons and neutrons constitute about 99.9 percent of the mass of the matter we see in the universe, everything from people to planets to stars. Through experiments using particle accelerators, we have learned much about these particles in the century since their discoveries. Yet we still know little about how their internal constituents—quarks and gluons—combine to produce their well-known properties, particularly mass and spin. The role of quarks, antiquarks, and gluons in determining mass and spin remains one of the greatest unsolved mysteries in physics. To solve that mystery, scientists need a new type of particle collider—the world's first polarized Electron-Ion Collider.

Quarks themselves have mass and spin but not nearly enough to account for the levels observed in protons or neutrons. Previous experiments suggest that quark masses account for a tiny fraction of the mass of a proton, and quark spin contributes only about a third of the overall particle's spin. These experiments also suggest that gluons, which have no mass themselves, make significant contributions to these properties. This is stunning. How do particles of zero mass, when interacting with each other and with the quarks inside a proton, give rise to most of the mass of the visible matter in the universe today?

The proposed Electron-Ion Collider (EIC) will allow scientists to explore these questions using precisely defined and controlled collisions of very-high-energy ion and electron beams. The collisions will produce three-dimensional pictures of the quarks, antiquarks, and gluons inside individual protons and atomic nuclei, allowing scientists to learn about their contributions and interactions. The EIC will also be able to explore a new frontier of ultra-densely packed gluons inside these particles, with the potential to discover a new form of matter. The proposed EIC would be distinguished from all past, current, and contemplated facilities around the world by enabling high interaction rates with a versatile range of kinematics (particle motion), beam polarizations (alignment of particle spin), and beam species (types of particles collided).

Building an EIC and its research program in the U.S. would strengthen and expand U.S. leadership in physics and stimulate economic benefits well into the future. Just as studies of fundamental particles and forces have driven scientific, technological, and economic advances for the past century—from the discovery of the electrons that power computing and communications devices to the understanding of the structure of the cosmos—the new EIC research will spark innovation and enable widespread technological advances.



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Overall, the Electron-Ion Collider will:

- Drive development of innovative accelerator, particle detector, and computational technologies, advancing both known and yet-to-be-invented technologies
- Leverage investments in infrastructure and core expertise at Brookhaven National Laboratory (BNL), Thomas Jefferson National Accelerator Facility (Jefferson Lab), and other DOE National Laboratories, building on decades of pioneering particle accelerator experience
- Inspire the next generation of scientific explorers, engineers, and tech-savvy workers needed to address some of our nation's greatest challenges.

In 2015, the Nuclear Science Advisory Committee, advising the Department of Energy and the National Science Foundation, recommended an EIC as the highest priority for new facility construction. In 2018, after reviewing the science case for a future U.S.-based EIC, a National Academy of Sciences (NAS) committee concluded that an EIC is timely and that the science it will achieve is unique and world leading and will ensure global U.S. leadership in nuclear science, accelerator science, and the technology of colliders. The NAS report emphasized that the science questions regarding the building blocks of matter are fundamental and compelling; that an EIC is essential to answering these questions; that the answers will have implications for particle physics and astrophysics and possibly other fields; and that innovations required to construct an EIC will benefit all accelerator-based sciences.

The community of EIC scientists—already more than 800 strong, from more than 175 institutions in 30 countries on 6 continents—is working on the scientific and technical challenges to meet the EIC's objectives. And scientists at BNL and Jefferson Lab are collaborating on strategies and designs for a new facility while optimizing the use of existing infrastructure.

Benefits Beyond Physics

Nuclear physics has produced significant applications that directly benefit society:

- Accelerators that deliver particle beams with cell-killing energy directly to tumors
- Radioisotopes for diagnosing heart disease and tracking and treating cancer
- Detector technologies that screen for dangerous substances at borders and ports and for cancers deep inside the human body
- Accelerator technology for manufacturing and studying new materials, including computer chips, electronics, batteries, and pharmaceuticals
- New methods for inspecting and protecting our food supply
- Computational tools for managing "big data" with widespread application
- Facilities for exploring the effects of space radiation to protect future astronauts and spacecraft

Building an EIC will push this field to the next frontier, expanding opportunities for scientific discovery and technological advances.