Richard Milner discusses new U.S. particle accelerator project

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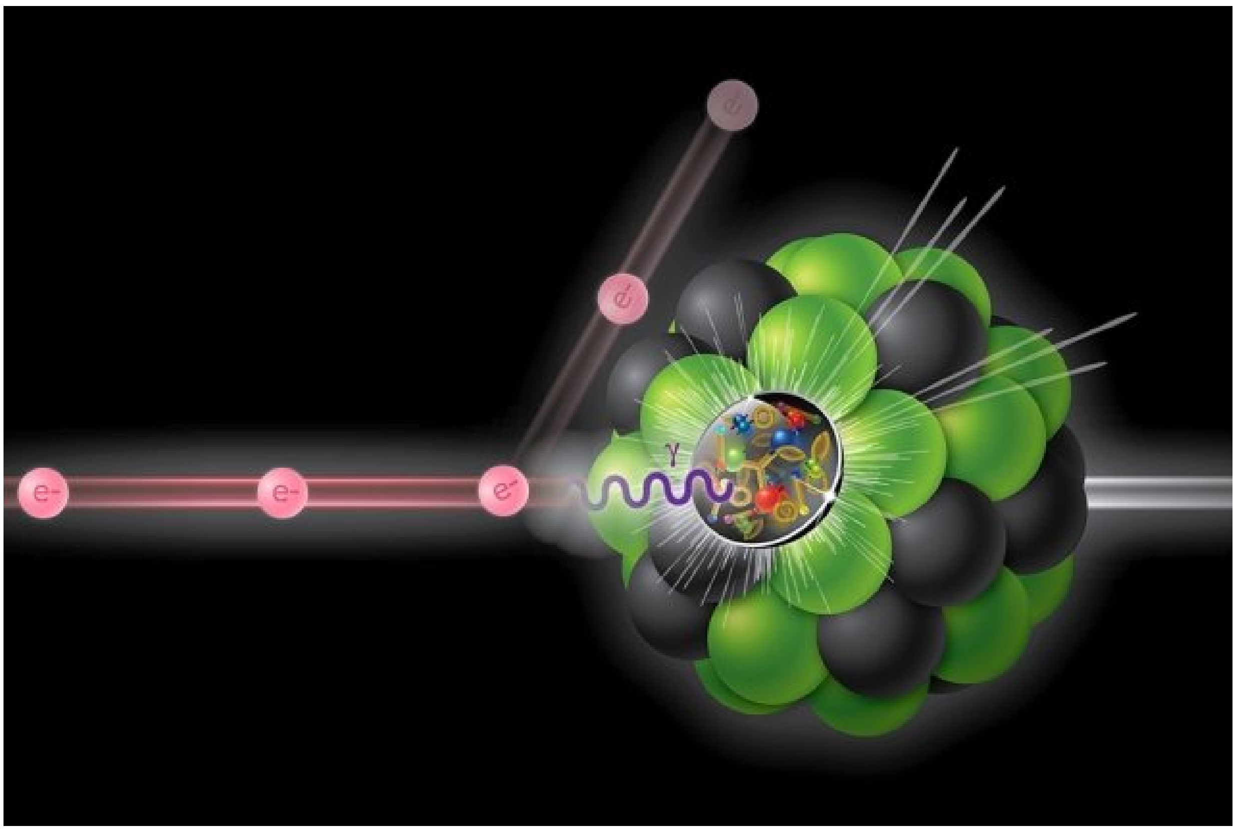

In an Electron-Ion Collider, a beam of electrons (e-) would scatter off a beam of protons or atomic nuclei, generating virtual photons (λ) — particles of light that penetrate the proton or nucleus to tease out the structure of the quarks and gluons within. Credit: Brookhaven National Laboratory

The case for an ambitious new particle accelerator to be built in the

United States has just gotten a major boost.

Today, the National Academies of Sciences, Engineering, and Medicine have endorsed the development of the Electron Ion Collider, or EIC. The proposed facility, consisting of two intersecting accelerators, would smash together beams of protons and electrons traveling at nearly the speed of light. In the aftermath of each collision, scientists should see "snapshots" of the particles' inner structures, much like a CT scan for atoms. From these images, scientists hope to piece together a multidimensional picture, with unprecedented depth and clarity, of the quarks and gluons that bind together protons and all the visible matter in the universe.

The EIC, if built, would significantly advance the field of quantum chromodynamics, which seeks to answer fundamental questions in physics, such as how quarks and gluons produce the strong force—the "glue" that holds all matter together. If constructed, the EIC would be the largest accelerator facility in the U.S. and, worldwide, second only to the Large Hadron Collider at CERN. MIT physicists, including Richard Milner, professor of physics at MIT, have been involved from the beginning in making the case for the EIC.

MIT News checked in with Milner, a member of MIT's Center for Theoretical Physics and the Laboratory for Nuclear Science, about the need for a new particle collider and its prospects going forward.

Q: Tell us a bit about the history of this design. What has it taken to make the case for this new particle accelerator?

A: The development of both the scientific and technical case for the EIC has been in progress for about two decades. With the development of quantum chromodynamics (QCD) in the 1970s by MIT physics Professor Frank Wilczek and others, nuclear physicists have long sought to bridge the gap between QCD and the successful theory of nuclei based on experimentally observable particles, where the fundamental constituents are the undetectable quarks and gluons.

A high-energy collider with the ability to collide electrons with the full range of nuclei at high rates and to have the electrons and nucleons polarized was identified as the essential tool to construct this bridge. High-energy electron scattering from the proton was how quarks were experimentally discovered at SLAC in the late 1960s (by MIT physics faculty Henry Kendall and Jerome Friedman and colleagues), and it is the accepted technique to directly probe the fundamental quark and gluon structure of matter.

Significant initial impetus for the EIC came from nuclear physicists at the university user-facilities at the University of Indiana and MIT as well as from physicists seeking to understand the origin of the proton's spin, at laboratories and universities in the U.S. and Europe. Over the last three long-range planning exercises by U.S. nuclear physicists in 2002, 2007, and 2015, the case for the EIC has matured and strengthened. After the 2007 exercise, the two U.S. flagship nuclear facilities, namely the Relativistic Heavy Ion Collider at Brookhaven National Laboratory and the Continuous Electron Beam Accelerator Facility at Jefferson Laboratory, took a leadership role in coordinating EIC activities across the broad U.S. QCD community. This led to the production in 2012 of a succinct summary of the science case, "Electron-Ion Collider: The Next QCD Frontier (Understanding the glue that binds us all)."

The 2015 planning exercise established the EIC as the highest priority for new facility construction in U.S. nuclear physics after present commitments are fulfilled. This led to the formation of a committee by the U.S. National Academy of Sciences (NAS) to assess the EIC science case. The NAS committee deliberated for about a year and the report has been publicly released this month.

Q: Give us an idea of how powerful this new collider will be and what kind of new interactions it will produce. What kinds of phenomena will it help to explain?

A: The EIC will be a powerful and unique new accelerator that will offer an unprecedented window into the fundamental structure of matter. The electron-ion collision rate at the EIC will be high, more than two orders of magnitude greater than was possible at the only previous electron-proton collider, namely HERA, which operated at the DESY laboratory in Hamburg, Germany, from 1992 to 2007. With the EIC, physicists will be able to image the virtual quarks and gluons that make up protons, neutrons, and nuclei, with unprecedented spatial resolution and shutter speed. A goal is to provide images of the fundamental structure of the microcosm that can be appreciated broadly by humanity: to answer questions such as, what does a proton look like? And what does a nucleus look like?

There are three central scientific issues that can be addressed by an electron-ion collider. The first goal is to understand in detail the mechanisms within QCD by which the mass of protons and neutrons, and thus the mass of all the visible matter in the universe, is generated. The problem is that while gluons have no mass, and quarks are nearly massless, the protons and neutrons that contain them are heavy, making up most of the visible mass of the universe. The total mass of a nucleon is some 100 times greater than the mass of the various quarks it contains.

The second issue is to understand the origin of the intrinsic angular momentum, or spin, of nucleons, a fundamental property that underlies many practical applications, including magnetic resonance imaging (MRI). How the angular momentum, both intrinsic as well as orbital, of the internal quarks and gluons gives rise to the known nucleon spin is not understood. And thirdly, the nature of gluons in matter—that is, their arrangements or states—and the details of how they hold matter together, is not well-known. Gluons in matter are a little like dark matter in the universe: unseen but playing a crucial role. An electron-ion collider would potentially reveal new states resulting from the close packing of many gluons within nucleons and nuclei. These issues are fundamental to our understanding of the matter in the universe.

Q: What role will MIT have in this project going forward?

A: At present, more than a dozen MIT physics department faculty lead research groups in the Laboratory for Nuclear Science that work directly on understanding the fundamental structure of matter as described by QCD. It is the largest university-based group in the U.S. working on QCD. Theoretical research is focused at the Center for Theoretical Physics, and experimentalists rely heavily on the Bates Research and Engineering Center for technical support.

MIT theorists are carrying out important calculations using the world's most powerful computers to understand fundamental aspects of QCD. MIT experimental physicists are conducting experiments at existing facilities, such as BNL, CERN, and Jefferson Laboratory, to reach new insight and to develop new techniques that will be used at the EIC. Further, R&D into new polarized sources, detectors, and innovative data-acquisition schemes by MIT scientists and engineers is in progress. It is anticipated that these efforts will ramp up as the realization of the EIC approaches.

It is anticipated that the U.S. Department of Energy Office of Science will initiate in the near future the official process for EIC by which the U.S. government approves, funds, and constructs new, large scientific facilities. Critical issues are the selection of the site for EIC and the participation of international users. An EIC user group has formed with the participation of more than 700 Ph.D. scientists from over 160 laboratories and universities around the world. If the realization of EIC follows a schedule comparable to that of past large facilities, it should be doing science by about 2030. MIT has a long history of providing leadership in U.S. nuclear physics and will continue to play a significant role as we proceed along the path to EIC.

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