

An electron-proton collider could bridge the gap between the LHC and its successor

Whether the CERN facility goes ahead will depend on community support for it in the next European strategy for particle physics.

Last year the CERN council gave the green light to increasing by an order of magnitude the luminosity of the Large Hadron Collider. The beefed-up LHC is expected to start up around 2025 and run for about a decade. Beyond that, the jury is out on what future machines CERN—and the global particle-physics community—should pursue.

Max Klein of the University of Liverpool thinks he has the perfect “Goldilocks” experiment that could bridge the discovery gap between the LHC and its successor: an electron-proton collider. Dubbed the LHeC, the new machine

would require the construction of an electron accelerator that would shoot electrons at protons and ions produced by the LHC. And whereas next-generation colliders are projected to cost tens of billions of dollars, the LHeC would have a price tag of a half a billion to a billion dollars.

The funds could be scraped together from CERN’s regular budget. It’s not peanuts, but it’s not a multibillion dollar machine. “It’s in between,” says Klein. “It’s too big to just smuggle in. It’s a serious decision.”

No one can say the physics case for the LHeC is not good, says Achille Stocchi, director of the Linear Accelerator Laboratory in Orsay, France. “But people can have different priorities.” He notes that among potential partners, momentum is growing for his lab to build an experiment that would be a test bed for LHeC technology and a user facility for

particle, nuclear, and applied physics; a decision is likely by the end of this year.

Deep inelastic scattering

Scattering electrons off protons probes hadronic substructure (see the story on page 14 of this issue). For example, HERA, the only previous electron-proton collider, which ran from 1992 to 2007 at DESY, the German Electron Synchrotron in Hamburg, opened a window into the distribution of gluons inside protons. Without the HERA data, “we wouldn’t have been able to quantitatively interpret the Higgs boson,” says Klein. “The LHeC will measure the gluon distribution in protons much more precisely. Quantum chromodynamics can be improved dramatically.” The LHeC would smash electrons and protons together at four times the center-of-mass energy and 1000 times the luminosity of HERA.



LAL ORSAY

ISSUES & EVENTS

In electron-proton collisions, explains Klein, the W and Z bosons emit Higgs bosons. And with the high-luminosity LHC, there will be enough collisions for scientists to measure the subsequent decay of the Higgs into charm and bottom quarks with great precision. That capability is crucial, he says, for exploring the Higgs "as a portal to new physics, such as dark matter, exotic scalar bosons, and anomalous Higgs-top quark couplings."

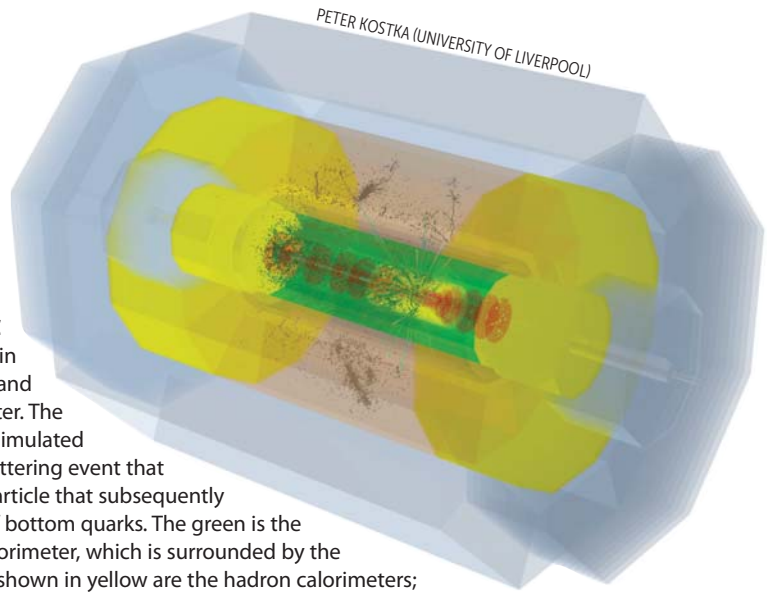
The LHeC could make significant contributions in several other areas too. The observation of a predicted nonlinear interaction would change our understanding of the evolution of gluons and quarks and of proton structure, says Klein. The LHeC may find instantons, topological solutions of the Lagrangian in quantum chromodynamics. And electron-proton collisions could determine if sterile neutrinos exist (see PHYSICS TODAY, October 2016, page 15). Another "huge terra incognita," he says, is electron-ion physics.

Exploiting the LHC

Although the LHeC concept has been around for some years, so far it "is not so popular," says Herwig Schopper, former CERN director general, chair of the lab's international advisory committee on the LHeC, and a fan of the proposal. "Many would say electron-proton [physics] is not interesting. They are fixated on weak interactions in the standard model." He notes that "high-energy physics is in a strange situation." Theory does not indicate which way to go, he says. Studying electron-proton collisions would be "special. It doesn't exist anywhere else,"

IN ITS CURRENT DESIGN, THE LHEC DETECTOR

is 12 m in the beam direction and about 9 m in diameter. The schematic shows a simulated electron-proton scattering event that produces a Higgs particle that subsequently decays into a pair of bottom quarks. The green is the electromagnetic calorimeter, which is surrounded by the solenoidal magnet; shown in yellow are the hadron calorimeters; the red circles are the wheels on which silicon detectors that track particle signals are mounted; and the gray on the outside is the muon detector.



and it would "exploit the LHC as much as possible—the big investments in terms of money and human effort."

Whatever its science reach, the LHeC would be far cheaper than the bigger colliders being contemplated by the international particle-physics community—namely, the International Linear Collider (ILC) electron-positron machine in Japan; a large circular collider in China, with electron-positron, proton-proton, and electron-proton options; and, under study at CERN, the compact linear collider (CLIC) for electrons and positrons or the Future Circular Collider (FCC), which incorporates all three collision scenarios (see PHYSICS TODAY, July 2014, page 23, and March 2013, page 23). A next-generation machine may happen, but it will take a long time, says Schop-

per. Oliver Brüning, deputy project leader for the LHC high-luminosity upgrade and co-leader with Klein of the LHeC project, says, "Management likes the [LHeC] idea as a possibility, but they are shy to say, 'Do it.'"

As envisioned in a 2012 conceptual design study, the LHeC would have a racetrack-shaped electron accelerator housed in its own 9 km tunnel and would kiss the LHC tunnel at one spot, where the detector would be located. The accelerator's straight sides would each include 1-km-long linacs. The electrons would circulate three times, gaining 10 GeV in each linac pass, for a total of 60 GeV when they are released at the collision site. After the beam passes through the interaction site, its energy would be recovered by introducing a



ELECTRO-OPTICAL PRODUCTS CORP.

TEL: (718) 456-6000 • FAX: (718) 456-6050 • www.EOPC.com

**Breakthrough, practical,
energy-saving solutions for
OEM customers worldwide!**

Low Cost Optical Shutters

- Laser Safety (Interlock) Shutters
- X-Ray Shutter
- Shutters/Choppers

Choppers & Modulators

- Tuning Fork Choppers
- Low Frequency Choppers
- Chopping Systems
- Modulating Systems
- Choppers/Shutters

Scanners & Deflectors

- Resonant Scanners
- Beam Deflectors
- Scanning Systems
- X,Y Raster Scanners



**Resonant Scanners
Beam Deflectors
Scanning Systems**



**Tuning Fork Choppers
Choppers/Shutters
Chopping Systems**



**Low Cost Shutters
X-Ray Shutters
Laser Safety (Interlock) Shutters
Shutters with Position Indicators
Ultra-Low Vibration Shutters**



**Motorized
Filter
Selectors**

Used in vacuum, high temperature and cryogenic environment.
Meets military specifications.

For industrial, medical, aerospace and scientific applications worldwide.

**Products are suitable for long life dedicated applications, OEM,
built into instruments or portable systems.**

Products You Trust... Performance You Deserve... Prices You Expect

phase change and decelerating the beam and would be stored for use in the next acceleration cycle.

The approach is called energy recovery, and the idea is to use minimal power and reduce energy losses. For the LHeC, using an energy recovery linear (ERL) accelerator makes it possible to reach higher luminosity than limits on how much power CERN can draw from the grid would otherwise permit.

The ERL approach has been realized with a single pass. But for the LHeC the technology needs to be tested at higher currents and with the beam making multiple passes. That's the goal of a proposed test bed at Orsay—PERLE (Powerful ERL for Experiments). Klein notes that the LHeC would work as an add-on to the LHC, a higher-energy LHC, or the FCC. And the ERL approach would be "a long-term investment for CERN's hadron collider program."

According to Stocchi, who is spearheading the PERLE proposal, the facility could accelerate electrons up to 500 MeV by having them zip around the loop at least three times. Simulations show that the energy could be scaled up to the LHeC, he says. The PERLE facility would be an international collaboration; partners so far include CERN, the Thomas Jefferson National Accelerator Facility in the US, the Budker Institute of Nuclear Physics in Russia, and Daresbury Laboratory and Liverpool University in the UK. The PERLE project has not been completely costed, but building it from scratch would come to around €20 million (\$21.5 million), Stocchi says. If partners provide magnets, cryomodels, and other components, that would bring down the tab and provide R&D for future facilities; some in-kind commitments have been made already. If PERLE gets approval and funding, it could be ready by about 2021.

For Stocchi, a key selling point for PERLE is that it would serve not only as a prototype for the LHeC, but also as a user facility with a high flux of electrons and photons; the photons are to be produced by backscattering laser light off the electron beam. The electrons would be used for experiments in nuclear and particle physics, and the photons would be used for medical sciences, nanoscience, nuclear physics, materials science, and more. Successful technology demonstration at PERLE is not a guarantee that the LHeC will go ahead, Stocchi

says. But PERLE is worthwhile on its own, he argues, and "if you don't do PERLE, you won't do the LHeC."

If the LHeC does happen, the most suitable site for the electron-proton collisions is where the ALICE heavy-ion experiment's detector is located, Klein notes. The other potential LHC interaction regions are ruled out because they are reserved for ongoing experiments or because of civil engineering constraints. The ALICE experiment is planned to run at the LHC through 2029. That timing works for the LHeC; it would give the multiturn ERL technology, a precision electron-hadron detector, civil engineering, and other preparations time to get ready. The detector would be installed during LHC down time. "We would not interrupt the LHC," says Klein, who stresses that LHeC's electron-proton collisions could run simultaneously with the LHC's proton-proton collisions.

Collision decisions

Another experiment under study at CERN that could be done on a shorter time scale and lower budget than CLIC or the FCC is an energy upgrade to the LHC. Switching out the superconducting niobium-titanium electromagnets for stronger bending electromagnets made of niobium-tin would nearly double the collision energy. Beyond the potential for discovery that higher collision energies might bring, the switch would be a technology demonstrator for a future FCC.

So far, experiments have been made with roughly 1% of the LHC's integrated luminosity. The accepted approach among particle physicists is to take more data before making any major decisions on future machines. And if Japan decides to go ahead with the ILC, or if CERN goes for CLIC, the "LHeC would be wiped out," Brüning says, since CERN's investments in those other projects would leave little wiggle room for funding.

"I do think [the LHeC] could be a good project between the luminosity [upgrade] and the next project, but 2029 sounds too early—more like 2035 or 2040," says Frédérick Bordry, CERN's director for accelerators and technology. The project needs more support from the particle-physics community, he notes. "The next European strategy for particle physics will be very important for the LHeC." The strategy recommendations are slated to come out in 2020, and decisions may be delayed beyond that.

Toni Feder

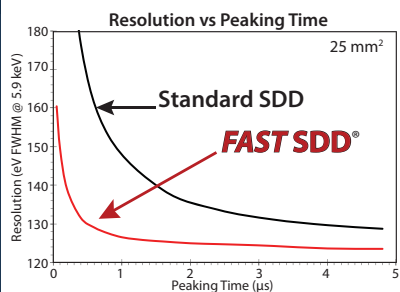
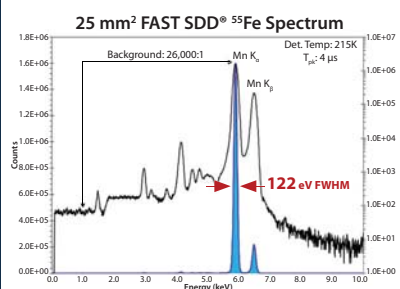
Ultra High Performance Silicon Drift Detectors

FAST SDD®

Count Rate = >1,000,000 CPS

The True State-of-the-Art

- New in-house manufacturing
- Lower noise
- Lower leakage current
- Better charge collection

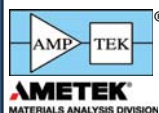


Options:

- 25 mm² collimated to 17 mm²
- 70 mm² collimated to 50 mm²
- Windows: Be (0.5 mil) 12.5 μm, or C Series
- TO-8 package fits all Amptek configurations



Please see our web site for complete specifications and vacuum applications



AMPTek Inc.
sales@amptek.com
www.amptek.com

AMETEK
MATERIALS ANALYSIS DIVISION