

Japan tests the waters for hosting International Linear Collider

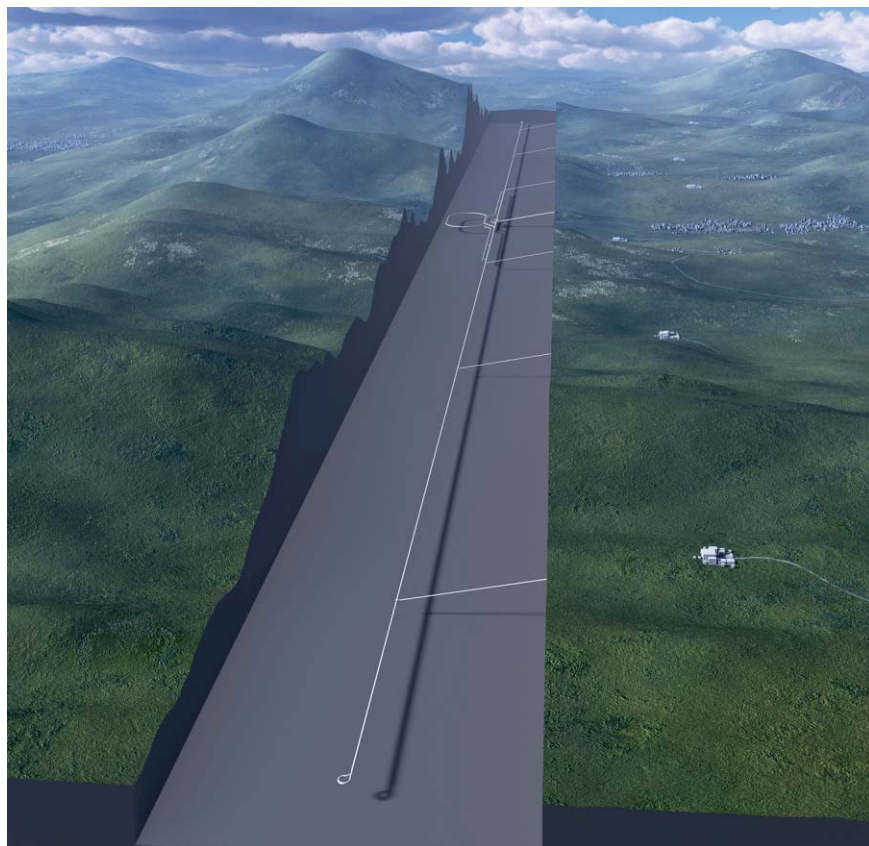
Bid now or bust: The high-energy physics community is gearing up to plan its future facilities.

Momentum is growing to revive the International Linear Collider (ILC) as a contender for the next big particle-physics machine. In the works for about two decades, the electron-positron collider is emerging from limbo thanks to a confluence of scientific, political, and financial developments. Proponents have worked out a phased approach to the ILC. The idea now is that it would start as a Higgs factory at 250 GeV (instead of 500 GeV). Because the lower energy can be achieved with a shorter accelerator, the estimated price tag has dropped by as much as 40%, to roughly \$5 billion (not including labor).

The scaled-down ILC got the stamp of approval from the Japan Association of High Energy Physicists last summer. That was followed in November by an endorsement from the International Committee for Future Accelerators (ICFA), which includes the directors of the world's major particle-physics laboratories. Now, a clear signal from Japan—the only potential host country—that it wants to go ahead with the machine would put it back in the running. But that signal has to come this year, or European particle physicists will chart their future without the ILC.

Higgs factory

The Higgs boson was discovered in 2012 at the Large Hadron Collider (see *PHYSICS TODAY*, September 2012, page 12). By 2016 the LHC had failed to turn up new particles beyond the standard model. “We either needed much more data, or new physics was hiding behind the Higgs,” says Tatsuya Nakada, a particle physicist at the Swiss Federal Institute of Technology in Lausanne and chair of ICFA’s Linear Collider Board. “That realization reemphasized the importance of precision physics of the



REV. HORI/KEK

THE TUNNEL FOR THE INTERNATIONAL LINEAR COLLIDER is rendered here as a cutout. It would be dug into a single granite formation in the Tohoku region of Japan.

Higgs properties and justified the science case for a linear collider at a lower energy as a first step.”

Given the Higgs mass of 125 GeV, an electron-positron machine that produces 250 GeV collisions would yield plenty of Higgs bosons. And because the colliding particles are elementary, the Higgs could be studied in detail, in ways not possible with the messier proton collisions at the LHC. A top priority would be measuring the coupling of the Higgs to vector bosons, quarks, and leptons. A mismatch between measurements and theoretically expected values could reveal physics beyond the standard model.

The Higgs is a unique particle, says Fermilab director Nigel Lockyer. “It’s the only fundamental spin-zero particle we have observed. Mixing with a new particle could show up by making precise measurements of Higgs properties, and

deviations could be related to dark matter, cosmic inflation, or extra dimensions. You would be nuts not to study the heck out of the Higgs.”

Proponents of building a 250 GeV ILC don’t want to stop there. To produce the 172 GeV top quark, 350 GeV collisions would be needed. And to study how the Higgs boson couples to itself requires 500 GeV. That self-coupling “is very interesting to understand the structure of the vacuum, among other things,” says Joachim Mnich, director for particle physics and astroparticle physics at the German Electron Synchrotron in Hamburg.

Ready technology

There are other options for follow-on machines to the LHC. In the Compact Linear Collider (CLIC) under development at CERN, colliding electron and



FERMILAB'S ANNA GRASSELLINO (right) and Mayling Wong-Squires study how nitrogen doping and infusion increase the performance of superconducting RF cavities such as those the International Linear Collider would use. They are readying a cavity for baking in the high-temperature oven behind them.

positron beams are each powered by a parallel drive beam. It is generally considered suitable for TeV energies. And competing with the linear collider route is the idea of going to higher energies

with a 100 km ring—nearly quadruple the LHC circumference. Two such projects are being researched: the Future Circular Collider (FCC) at CERN and the Circular Electron Positron Collider

(CEPC) in China. In both cases, the intention would be to start as a Higgs factory with electron–positron collisions. The FCC would build up to 350 GeV; the CEPC to 240 GeV. Eventually the machines would be converted to proton–proton colliders in the original tunnels.

Another proposed future experiment is an add-on to the LHC that would smash together protons and electrons. The LHeC, as it is called, is generally not seen as a competitor to the ILC, but as doing complementary physics at a much lower price point. (See *PHYSICS TODAY*, May 2017, page 29.)

But the technology for the ILC is the most advanced. Superconducting RF cavities similar to the ones proposed for the ILC are already in use at labs in the US and Germany. “The ILC concept relies on technology that has been proven,” says Mnich. “It has been tested in a large-scale facility, and industry knows how to make it.”

A technical design report for a 500 GeV ILC was completed in 2013. In halving the energy to 250 GeV, cost savings would come mainly from using fewer superconducting RF cavities. The length of the accelerator complex would be shortened from 30 km to 20 km. Reducing the cross section of the tunnel could also save money.

Once a tunnel is in place, the machine can be upgraded either by lengthening it or by developing better technologies, says Hitoshi Murayama of the University of California, Berkeley, and the Kavli Institute for the Physics and Mathematics of the Universe in Tokyo. “It’s premature to talk about the way to ramp up.”

Some better technologies are already in the works. At Fermilab, researchers discovered that the acceleration gradient increases when the outermost skin of the niobium superconducting RF cavities is infused with nitrogen. “We don’t yet know why,” says Anna Grassellino, deputy head of Fermilab’s technical division, “but we get the maximum acceleration when the impurities penetrate a few nanometers.” By increasing the gradient, she says, “for the same money you can upgrade to higher energy, which means more physics, or you make the accelerator shorter, which saves money.” The approach is already being implemented, with deeper doping, at the Linac Coherent Light Source-II at SLAC. The new RF developments contribute about

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Among the arguments against the ILC is that 250 GeV is too low—to access the top quark and widen the scientific scope, the next machine should be at least 350 GeV. But the lower energy is a good start, says SLAC physicist Michael Peskin. “High-energy physics machines cost billions, so you have to be patient.”

Some particle physicists prefer a circular machine, which could more easily achieve high luminosities. Absent a clear case for much higher energies, a linac no longer makes sense, they say. Some also worry that the ILC has been pushed politically to “a point of no return,” so that the community feels it has no choice but to get behind it, according to a particle physicist who requested anonymity.

Others wonder if the manpower will be available to build the ILC in Japan—and if people from other countries will want to spend a decade there working on it. “No doubt infrastructure is lacking for foreigners living in Japan,” says Murayama. For example, he notes that no international K–12 schools are near the proposed ILC site.

“But the infrastructure would be built up if the project goes ahead,” says Murayama. And with high-energy projects so costly and rare, any global facility that gets realized will attract physicists and accelerator scientists. “Build and people will come,” says Lockyer.

“Keep pushing”

Japan is showing numerous signs of renewed ILC-related activity. Working groups are looking into the scoped-down version of the ILC for the Ministry of Education, Culture, Sports, Science and Technology (MEXT). Academics from many fields are weighing the cost, design, and scientific value against other possible investments. “The staged approach should reduce the sticker-price shock from the point of view of the Japanese government,” says Murayama, who serves on an advisory committee on ILC issues for KEK, Japan’s high-energy lab. He notes that about a quarter of the Diet, Japan’s parliament, supports going forward with the ILC.

A site in Tohoku, in the Kitakami mountains in northeastern Japan, was selected for the ILC in 2013, but it remains unofficial until the government gets formally behind the project. Because



PARTICIPANTS AT A 2016 CONFERENCE IN JAPAN discuss the International Linear Collider.

the site is within a single formation of granite, it should be safe in the event of an earthquake. The local city and prefecture governments support the project in the hope that it will provide an economic

boost and help revitalize the area, which was devastated in 2011 by the earthquake, tsunami, and nuclear accident. (See *PHYSICS TODAY*, November 2011, page 20.)

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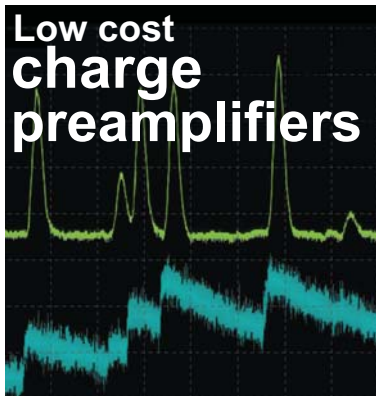
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A delegation from Japan met high-level officials in France and Germany early this year to discuss the ILC, and Japanese officials have talked about the project with the US Department of Energy and members of the US Congress. Further meetings are planned with those and other countries. "We have to start with an unofficial framework," says University of Tokyo particle physicist Satoru Yamashita, who participated in the recent talks in Europe. The 20-strong delegation included representatives from Japanese science, industry, and government.

Yamashita says that a key to raising hopes for the ILC is ICFA's explicit statement that the country should not just host but also lead the project. Previously, he explains, the envisioned organizational model for the ILC was more like that of ITER, the international fusion demonstrator under construction in France. In that project, partners jointly hashed out details from the start. In contrast, an organization with one country at the helm is simpler and may have an easier time avoiding the delays and budget overruns that have made ITER a cautionary tale. (See PHYSICS TODAY, January 2016, page 30.) "The important thing is to keep pushing at all levels," Yamashita says.

Window of opportunity

Time pressure comes from the European Strategy for Particle Physics, a community effort to prioritize future projects. The process is currently in the information-gathering stage, and the strategy is slated for completion in early 2020.

Halina Abramowicz of Tel Aviv University leads the European strategy process. If Japan doesn't clearly indicate a desire to host the ILC by the end of 2018, she says, it "would be irrelevant in the discussion of the future. And that has tremendous implications." For example, greenlighting the ILC could shift the focus of research at the high-luminosity LHC—an approved upgrade—to the high-energy end of proton-proton interactions, which is a "whole different ballgame" from studying the Higgs boson with the LHC.

Recommendations in the US would come a bit later than in Europe. The counterpart process, known as the Particle Physics Project Prioritization Panel,

gave high marks to a 500 GeV ILC (see PHYSICS TODAY, July 2014, page 18). If a scaled-down version gets serious, the US community would need to take a closer look. "There are a stack of decisions," says Jim Siegrist, DOE's associate director of science for high-energy physics: "First, is the science at 250 GeV good enough? Does Japan want to host? And then, how do we execute the project?" High-level discussions between MEXT and DOE are under way, he notes.

Proponents believe the timing for the ILC could be propitious. In the US, the Deep Underground Neutrino Experiment should be up and running by 2026, says Lockyer, "so the big money in the US high-energy program starts to free up." And CERN will have finished the LHC high-luminosity upgrade but not yet started with magnets for an energy upgrade. "There is a global window of opportunity," he says. The best-case scenario for the ILC would see it completed in the early 2030s.

The ILC would be the first international scientific facility led by and built in Japan. That is a source of both fear and pride. Yamashita says MEXT's lack of experience in leading a project of this size is the biggest challenge. Another challenge is funding. "I don't see it happening if the MEXT budget remains flat," says Murayama. Although the division of costs and in-kind contributions can't happen until the project proceeds and the partners are on board, Japan would be expected to foot more than half the bill. If the project does go ahead, China, India, Russia, and others may also join.

Making the ILC collaboration official presents a chicken-and-egg problem, says Nakada. "The Japanese government doesn't want to stick out its neck unless there is a positive outcome, and Europe and the US need to see a clear intent to lead before they will commit."

"What's needed is a move from neutrality," says CERN's Lyn Evans, director of the Linear Collider Collaboration, which coordinates global research on the ILC and CLIC. "Things are slow and opaque in Japan. It's a diode. We give information in, but get nothing out." The same thing happened with discussion of a contribution from Japan to the LHC, he recalls. "Suddenly, out of the blue, one came."

Toni Feder