Muon collider gains momentum

Fermilab pins hopes on untested technology in race to stay at the cutting edge of physics.

As beams of protons again begin zipping around the underground ring of the Large Hadron Collider (LHC), teams of physicists are already competing to design a successor. Last week, US scientists staked their claim in a daring new venture: the world's first muon collider.

The collider could overtake two more-mature concepts, each of which plan to smash together electrons and positrons that have been accelerated through long, straight tunnels. But some physicists at the Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois, are concerned about the expense and feasibility of the linear colliders, and question whether they would push the boundaries of physics beyond what the LHC is expected to achieve. They are now trying to rally enthusiasm for a collider that smashes muons, a particle that is about 200 times more massive than the electron.

"The question is, 'can we build it?'," said Fermilab director Pier Oddone at a muon-collider workshop held at Fermilab on 10–12 November. The meeting is seen as an important step in reviving an approach that has been in hibernation since it was first proposed in the mid-1990s. It also puts the muon collider in direct competition with the 31-kilometre-long International Linear Collider (ILC), a global design effort split between the United States, Europe and Asia, and the 48-kilometre-long Compact Linear Collider (CLIC) project based at CERN, the European particle-physics centre near Geneva, Switzerland, which already hosts the LHC.

Although it poses daunting research and development challenges, a muon collider would have many advantages over an electron smasher. The heavy particles offer a wider target and make for cleaner collisions, for example. Their ability to generate Higgs bosons, the as-yet unobserved particles believed to be part of the mechanism that gives particles mass, is expected to be so prodigious that muon colliders are sometimes dubbed 'Higgs factories'. But they have to accelerate the muons to near-light speeds quickly, so that the time-dilation effects of general relativity increase the lifetime of the particles beyond the typical 2.2 microseconds.

Muons can be boosted to these speeds in a relatively small — and therefore less expensive — accelerator ring because they don't lose much energy when muscled magnetically around curves. Circulating electrons emit much more energy, in the form of illuminating X-rays called synchrotron radiation, which is often used for crystallography.

Electron accelerators that need to reach energies of greater than a few hundred gigaelectronvolts (10^9 electronvolts) can limit their energy loss through synchrotron radiation by keeping the electrons moving in a straight line. But this makes for bigger, more expensive colliders (see graphic). A ring collider also has the advantage of higher collision rates, as the circulating particles get multiple chances to hit their target. Electrons in a linear collider get just one chance to hit the oncoming positrons, making precise beam alignment much more critical.

On the campaign trail

Just a few years ago, Oddone was lobbying to host the ILC (see *Nature* **435,** 728-729; 2005). Now, he favours the muon collider, partly because it would be small enough to fit comfortably on Fermilab's campus. The facility already hosts the world' highest-energy particle accelerator, the Tevatron — at least until the LHC reaches its target energy of 14 teraelectronvolts (10^{12} electronvolts). Moreover, Fermilab will soon have a way to make its own muons. After the Tevatron shuts down in a year or two, the lab intends to pursue Project X, an intense proton beam that will be used initially to study neutrinos, but could also be fashioned to make muons. A step-wise programme to a muon collider, says Oddone, makes more sense then biting off the "whole enchilada" at once.

Fermilab has submitted a proposal to the US Department of Energy to form a national muon-accelerator project and to increase funding for muon-collider research from $9 million to $15 million per year. At a high-energy physics advisory meeting in Washington DC on 22 October, William Brinkman, director of the department's Office of Science, said that the high cost of the ILC has put it on the "back burner". Instead, he wants Fermilab to pursue the idea of a muon collider. "It would be nice to head in a direction that has some real innovation," he said.

Muon-collider advocates acknowledge that they have much catching up to do before they can compete with the ILC and CLIC, and Oddone wants to have a more detailed design concept in place by 2012. By that time, the LHC should have produced results revealing how much energy these colliders would need to reveal new physics.

The leader of the ILC effort, Barry Barish,

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Fermilab (above) hopes to build a muon particle collider to keep it at the forefront of physics.

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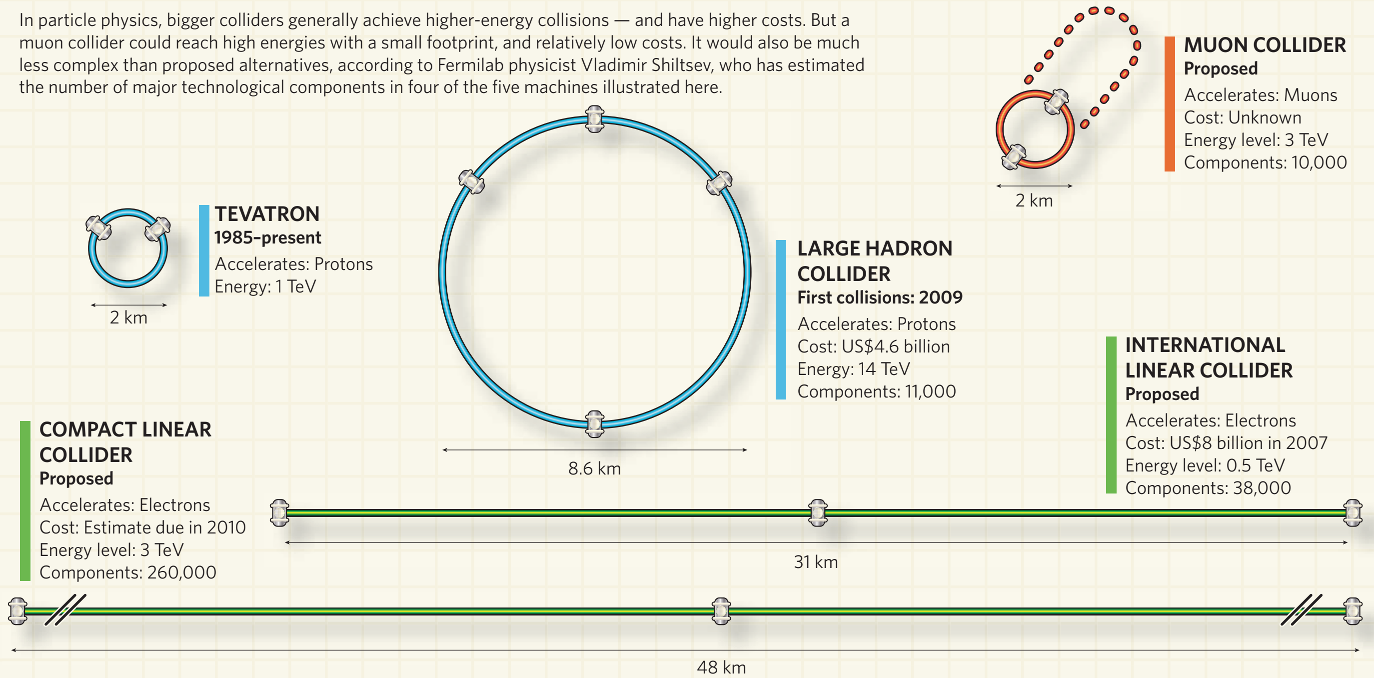
SIZE ISN'T EVERYTHING

In particle physics, bigger colliders generally achieve higher-energy collisions — and have higher costs. But a muon collider could reach high energies with a small footprint, and relatively low costs. It would also be much less complex than proposed alternatives, according to Fermilab physicist Vladimir Shiltsev, who has estimated the number of major technological components in four of the five machines illustrated here.



says that muon-collider advocates now need to demonstrate that the technology can actually work. "The director of Fermilab has been campaigning for it," says Barish, who is also an emeritus professor at the California Institute of Technology in Pasadena. "That doesn't mean that anyone outside the United States takes it seriously."

Eye-watering costs

It's been a tough two years for the ILC, which was once the clear front runner among next-generation collider designs. It boasts a superconducting acceleration technology that has matured rapidly, and had an aggressive timetable set out. But at the end of 2007, budget cuts all but ended research efforts on the collider in the United States and Britain (see *Nature* **451,** 112–113; 2008).

The biggest problem with the ILC is its $20-billion price tag, says Robert Cahn, a physicist at Lawrence Berkeley National Laboratory in California who works at the LHC. He is blunt about the ILC's chances of being built. "The ILC is dead," he says.

Barish says that the project is still the most mature proposal, and that the true cost is closer to an $8 billion estimate made in 2007 than the energy department's projected figure of $20 billion, which reflects the price decades from now. He adds that the team is considering design changes that could cut the cost by 15%.

Barish acknowledges, however, that it would be a challenge to scale up the ILC beyond its target energy of 500 gigaelectronvolts if the LHC results suggest that its successor would need to explore even higher energy regimes. Building a bigger ILC to access those energies would require more superconducting cavities and more tunnel digging, a huge additional expense.

CLIC avoids the ILC's peak energy limitations with a nifty trick. Instead of relying on superconducting cavities, it uses conventional magnetic components, but in two beam tunnels. A beam in one tunnel would be accelerated until engineers slam on the brakes, siphoning off the energy and transferring it to an electron beam in the second tunnel. CLIC study leader Jean-Pierre Delahaye, based at CERN, declined to estimate costs for the project until a design study is finished next year. But it aims to achieve energies of 3 teraelectronvolts — six times the peak energy of the ILC — and has tunnels nearly 20 kilometres longer, making it a much more expensive prospect. CLIC will also require 440 megawatts of power, equivalent to the output of a small nuclear power station and much more than CERN has available.

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The fate of the three concepts depends partly on the energy levels needed for the LHC to make its discoveries. Many theorists expect new high-energy particles to arise from supersymmetry, a theory that would double the number of known particles in the quantum bestiary. If the LHC doesn't find any, then the relatively low energies of the ILC might not be enough to uncover much of interest, further boosting the case for Fermilab to build a muon collider.

There are already indirect hints from experiments that rule out lower-energy supersymmetrical particles, says Fermilab's Steve Geer, who heads the muon-collider research and development effort. "It is all pointing to the energy scale for the new physics being higher."

However, even a 3-teraelectronvolt muon collider could reveal physics that is inaccessible to the LHC. The LHC smashes protons at much higher energies, but because those protons are made up of smaller particles, called quarks, collisions are much messier, cutting their effective energy by about a factor of ten compared with electron or muon colliders.

Despite their optimism, physicists such as Fermilab's Alan Bross, spokesperson for an experiment called MuCool (Muon Ionization Cooling Research and Development), must first solve the thorniest problem of a muon collider. MuCool is trying to work out how to get a hot cloud of muons to line up and march along in the cool, narrow beam needed for acceleration before all the muons decay.

Delahaye is glad that the muon research is being done, but he reminds his competitors that it can take a long time to win the case for a collider: he began working on CLIC in 1986. "To go immediately to the conclusion that [a muon collider] is simpler and less expensive, that's going too far," he says. ■

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