ISSUES AND EVENTS

Convocation at Snowmass Looks into the Future of US High-Energy Physics

More than a thousand physicists gathered for three weeks in July at Snowmass Village, in the Colorado Rockies near Aspen, to talk about the future of particle physics in the US—and the rest of the world. "Snowmass 2001" was convened by Chris Quigg (Fermilab), chair of the American Physical Society's division of particles and fields, and Ron Davidson (Princeton), chair of the APS physics of beams division. Exploiting the mountain metaphor, Quigg has described the convocation as an opportunity "to look beyond the horizon . . . to take stock of the new possibilities at the highest energies [and at other] experiments that look at the universe through new eyes."

The unceremonious termination of the Superconducting Super Collider by Congress in 1993 has left the particle-physics community particularly sensitive to the political realities of the very expensive facilities it needs nowadays to wrest secrets from nature. The community's first priority, many believe, is to arrive at a consensus as to which of the proposed big-ticket accelerators ought to be built first—with what technology and at what site. Snowmass 2001, with its several dozen specialized working groups on experimental and theoretical physics and accelerator and detector technology, was meant to move toward such a consensus.

Quigg calls Snowmass 2001 "a collective exercise at self education." Its deliberations are to provide an essential input to the upcoming report of the HEPAP subpanel on long-range planning for US high-energy physics. HEPAP is the High Energy Physics Advisory Panel to NSF and the Department of Energy. Subpanel cochairs Jonathan Bagger (Johns Hopkins) and Barry Barish (Caltech) expect to submit their report to HEPAP in October.

What to build next

The organizers did not intend that Snowmass 2001 should end with a formal consensus. But, as the meeting progressed, it became increasingly obvious that something of an informal consensus was emerging: Building a high-luminosity linear electron–positron collider with a collision energy of 500 GeV—upgradable to 800 or 1000 GeV—was, for most participants, the obvious next big undertaking of the world particle-physics community.

> A 500-GeV electron–positron linear collider, most particle physicists believe, should be the next big accelerator.

"The physics such a machine would discover is indispensable, and present-day accelerator technology is up to the task." That, with variations, was the bottom line heard again and again in the plenary talks of the working groups that had grappled with a great range of theoretical, experimental, and accelerator issues. Even the groups that had been concentrating on longer-term accelerator schemes or nonaccelerator experiments, though they stressed the need for a broad-based physics program, generally appeared to concede the e^-e^+ linac's priority. The same priority was recently endorsed by ECFA, the European Committee for Future Accelerators.

This emerging consensus does not, however, extend to two central questions: How and where should this 500-GeV linear collider be built? With a price tag on the order of $5 billion, it is obvious that the world community would not build more than one such machine. There are two competing high-luminosity radio-frequency linac design concepts: the 1.3-GHz superconducting TESLA design developed by an international collaboration based at Germany's DESY laboratory in Hamburg, and the 11.4-GHz "warm" copper linac design developed primarily at SLAC in California and KEK in Japan (see PHYSICS TODAY, May 2001, page 27).

The shorter RF wavelength subjects the copper machine to stricter alignment tolerances than TESLA. On the other hand, the superconducting RF cavities impose an absolute limit on TESLA's accelerating gradient. Either machine would be about 30 km long. At that length, TESLA's collision energy would be limited to 800 GeV. Whether the copper machine could get up to 1000 GeV depends on solving the problem of cavity surface damage at the highest accelerating fields.

Where to put it

Aside from the relative strengths and limitations of the two schemes, there is the delicate political question of where the international community proposes to site the machine. There was talk, for example, of putting the TESLA linac at Fermilab, a prairie location that might accommodate an eventual lengthening upgrade to 1.5 GeV more easily than the proposed DESY site. Building the linear collider at Fermilab would also address a widely expressed concern: The Large Hadron Collider (LHC), a 14-TeV circular proton–proton machine now under construction at CERN, will start doing physics in about five years. Many in the US and abroad worry about the future health of particle physics in this country if the e^-e^+ linac is also built in Europe. There is even some concern that building TESLA in Germany might erode CERN's traditional role as the linchpin of European particle physics.

But one cannot see the Pacific Ocean from the Illinois prairie. This geographic truth was pointed out rather bluntly at Snowmass by KEK director Hirotaka Sugawara. He reminded his audience that the joint work on the copper linac design in the US and Japan was undertaken with the understanding that the machine would be sited somewhere on the Pacific Rim, presumably in Japan or California. Sotoru Yamashita of Tokyo University was more specific: Europe already has the LHC. Given the impressive recent successes at the Super Kamiokande neutrino detector and the KEKB asymmetric B factory (see page 19 of this issue), he argued, it was now Japan's turn to build an energy-frontier machine. The Japanese linear collider, he asserted, could be ready to do physics by 2009.

Who will pay?

Wherever the linac is eventually sited, the worldwide community is expected to contribute substantially to its cost. But the host country, it is assumed, would have to bear about half the expense. That brings up the question of government purse strings. At an evening session devoted to this touchy issue, the community was addressed by Michael Holland of the White House Office of Management and Budget. In what many perceived as a "reality check" on the wish lists floating around Snowmass, Holland posed some unpleasant questions: How much importance do scientists *outside* your immediate community attach to your fervent quest for the Higgs boson? How else would you expect us to evaluate your priorities? What would you do if the government refused to fund any big accelerator?

AT SNOWMASS 2001, DESY director Albrecht Wagner (right) chats with (right to left) Renée Dorfan, Nigel Lockyer (University of Pennsylvania), and SLAC director Jonathan Dorfan. Behind Dorfan are Mark Strovink (Berkeley), conference organizer Chris Quigg (Fermilab), and Nicholas Hadley (University of Maryland).

"I find the spirit of your words unfriendly to science," responded CERN Director General Luciano Maiani after Holland's talk. But Quigg, in his closing remarks a few days later, suggested that the community put these seemingly harsh questions to good use. Instead of taking umbrage, he urged, particle physicists should offer good answers—for example, explaining why energy-frontier accelerators are indispensable.

Hadron and lepton machines

Why does one call a 500-GeV e^-e^+ collider an "energy frontier" machine when the 2-TeV proton–antiproton Tevatron collider at Fermilab has been around for more than a decade? The answer is that electrons, like muons and quarks, are point particles, whereas hadrons like the proton are extended quark–gluon composites. Because one is interested primarily in the energy with which a pair of point particles or constituents collides, an e^-e^+ or $\mu^-\mu^+$ lepton collider of a given beam energy is, in a sense, the equivalent of a hadron collider whose beam energy is larger by an order of magnitude. Furthermore, a lepton machine is spared the enormous hadronic debris that complicates pp and $p\bar{p}$ collisions. And the quantum numbers of the initial collision state are much more cleanly defined.

That, in essence, is the case for building the 500-GeV e^-e^+ collider as soon as possible. The only ingredient of the standard model of particle theory that has not yet been seen is the Higgs boson, which is presumed to be the particle manifestation of the mechanism that breaks electroweak symmetry and gives the fundamental bosons and fermions their masses. The Higgs is thought to have a mass of not much more than 200 GeV. It might even be as light as 115 GeV. If the Tevatron collider doesn't see it first, particle physicists are confident that the Higgs—or some nonstandard mechanism that takes its place—will be found promptly when the LHC turns on.

But simply finding the Higgs is not nearly enough. One must measure, with precision, its decay branching ratios, self-coupling strength, and other detailed properties that will discriminate between a "minimal" standard-model neutral Higgs and various elaborations suggested by theoretical expansions of the model—particularly supersymmetry, the widely favored candidate for breaking out of the confines of the standard model.

The Snowmass working groups looking into the theoretical and experimental aspects of electroweak symmetry breaking concluded that a high-luminosity 500-GeV e^-e^+ collider, upgradable to 800 or 1000 GeV, is precisely what's needed for carrying out these indispensable precision follow-ups. There's an obvious echo here of the 1980s and 1990s. The heavy vector bosons ($W^\pm$ and Z^0) that mediate the weak interactions were discovered at the CERN SPS $p\bar{p}$ collider. But detailed comparison of their properties with the predictions of the standard model required the precision capabilities of the LEP e^-e^+ collider, which has now been dismantled to make way for the LHC.

In the longer run

There was also much discussion at Snowmass about what accelerators should be built after the e^-e^+ linac. A TeV $\mu^-\mu^+$ collider could be much more compact than an e^-e^+ machine, and it would be a more profuse source of Higgs bosons (see PHYSICS TODAY, March 1998, page 48). Though such a novel machine would take accelerator builders into uncharted territory, the scheme has the virtue of being modular. It could be developed in comparatively easy learning stages, each of which would have important uses for neutrino physics.

One would first build a high-intensity "proton driver" that bombards a target to generate muons whose decay would provide neutrino beams of unprecedentedly high flux. The next stage would be to master the cooling, acceleration, and storage of the muons in a ring so that their decays would yield an even more intense, well-collimated, and tunable neutrino beam—a full-fledged "neutrino factory." In the ultimate stage, countercirculating μ^- and μ^+ beams in the ring would be made to collide.

The Very Large Hadron Collider (VLHC), a proposed 200-TeV pp collider, would involve more straightforward accelerator issues. But its immense scale would make cost-cutting tricks imperative. At CERN, work continues on a novel two-beam electron acceleration scheme, called CLIC, that might eventually be used for a 3- to 5-TeV e^-e^+ linear collider. Chan Joshi (UCLA) reported at Snowmass on an "afterburner" plasma acceleration idea, now under study at SLAC, that might eventually be fitted to the last few meters of an RF e^-e^+ collider to double its collision energy.

Particle physics is, of course, much more than just big accelerators. The Snowmass 2001 participants heard many proposals for new underground facilities and orbiting satellites that would investigate crucial phenomena like proton decay, neutrino oscillation, nonbaryonic dark matter, and the accelerating expansion of the cosmos. Though the community cannot do without new accelerators at the energy frontier, it is determined not to neglect the other kinds of experiments that have, especially in recent years, revealed so many surprises.

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