

high-speed silicon tracking devices.

It will certainly be more difficult to do experiments at $2 \times 10^{34} \text{ sec}^{-1} \text{cm}^{-2}$ than at the lower design luminosity of the SSC. At $10^{33} \text{ sec}^{-1} \text{cm}^{-2}$ each bunch crossing produces only one or two background events instead of dozens. But for some purposes the lower energy of the LHC makes the higher luminosity indispensable if one is to have usable event rates. Cross sections for the production of heavy objects grow steeply with increasing energy near threshold. For Higgs production, the relevant issue is the energy of a pair of colliding gluons in their own center-of-mass frame. The typical energy of a gluon-gluon collision at the LHC would be only 2 TeV. Above that, gluon-gluon collisions become increasingly rare as they appropriate a larger share of the total 15-TeV collision energy.

"We don't always have to run at full luminosity," Rubbia told us, "but I've asked the detector groups to come up with instruments that can handle the luminosity the collider is capable of delivering. None of them has told me I'm crazy, so they must think they can do it." The groups have been pursuing novel technologies on many fronts. The goal is to have the detectors ready to go by the time the collider is commissioned.

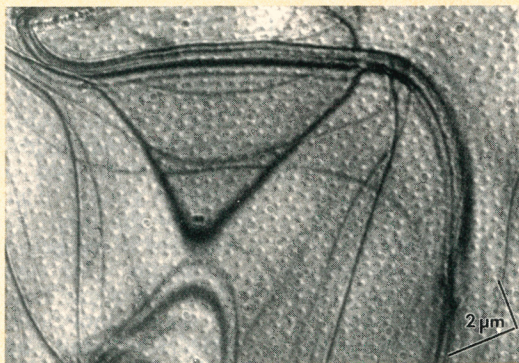
Electron and heavy-ion beams

Whether or not the LHC will ever run as an electron-proton collider depends on what kinds of interesting results are discovered at HERA. LEP 200 will begin doing e^+e^- physics at 200 GeV toward the end of next year, when all the superconducting rf cavities necessary for doubling LEP's beam energies have been installed. It is scheduled to run for at least three years, until the beginning of the yearlong shutdown required for the completion of the LHC. Does LEP have any future after the LHC is built? That depends on what the 200-GeV e^+e^- collisions unearth by then.

By contrast, the LHC's heavy-ion program is not a contingent question. "The LHC *will* be a heavy-ion collider from the start," says Christopher Llewellyn Smith, who takes over from Rubbia as CERN director general next January. The SPS has already served as a heavy-ion accelerator for fixed-target experiments. An injector capable of inserting beams of ions as heavy as Pb is in place. The LHC design calls for heavy-ion beam energies of 3 TeV per nucleon. That's 30 times the energy experimenters will get at RHIC, the heavy-ion collider now under construction at Brookhaven.

—BERTRAM SCHWARZSCHILD

Video Tracks Motion of Magnetic Flux Vortices



The photo shown above is just one frame of a video that tracks the motion of magnetic flux vortices in a type-II superconductor as the temperature or magnetic field is varied. The video has received thumbs-up reviews from condensed matter viewers, many of whom have studied the behavior of such vortices, especially in the high-temperature superconductors.

The video was made by Akira Tonomura of Hitachi Advanced Research Laboratory in Saitama, Japan, and his colleagues from Hitachi and the University of Lecce, Italy, who produced the images in an electron microscope.¹ They sent an electron beam vertically downward through a film of niobium 700 Å thick that was tilted at a 45° angle and placed in a horizontal magnetic field.

The researchers obtained images of the flux lines by extending the technique of Lorentz microscopy to the realm of quantum interference. Electrons passing on opposite sides of the magnetic flux lines experience different phase shifts as a result of the Aharonov-Bohm effect, and these phase shifts bend the beams in different directions. The effect of these phase shifts is seen only when the microscope is defocused: The differently directed beams then either separate or overlap, decreasing or increasing the intensity. Thus, a given vortex line appears in the photographs as a small bump that is dark on one side and light on the other. (The dark lines running through the photograph above are contours along which atomic planes have been bent to a favorable angle for imaging.)

The phase shifts produced by magnetic vortices are formidably small—on the order of 10^{-6} rad. To detect such small shifts, Tonomura's group developed a 300-keV field emission tip that produces a coherent electron beam with a divergence angle much less than 10^{-6} rad.

The instrument records the vortex motion at the rate of 30 frames per second as the magnetic field is slowly increased. The video shows that, vortex lines suddenly appear when the field reaches the lower critical field H_{c1} , at which the magnetic field can begin to penetrate a type-II superconductor. The vortices increase in number as the field grows stronger, forming the predicted hexagonal lattice. Occasionally one sees a vortex hop to or from a weak pinning site.

The films are not only an impressive technical feat but also a powerful observational tool. One can study how fast vortices move and by what mechanisms, what defects pin them and what collective motions they have. It would be particularly interesting to image high-temperature superconductors, where there is evidence of phase transitions in the vortex configurations (see *PHYSICS TODAY*, October, page 17). So far the Hitachi-Lecce team has not applied its technique to such materials. The challenge will be to produce a high- T_c film no more than 1000 Å thick. Tonomura hopes to extend the technique to fields as high as 1 tesla.

The dynamic displays will complement static images produced by older methods. These include the Bitter technique of decorating the surface with magnetic particles to reveal the spatial arrangement of the vortices; scanning tunneling microscopy, which probes the electron densities of state; Hall probes mounted in place of the tip of an STM to sense the magnetic field directly; and a magneto-optical technique that has good time resolution but limited spatial resolution.

—BARBARA GOSS LEVI

Reference

1. K. Harada, T. Matsuda, J. Bonevich, M. Igarashi, S. Kondo, G. Pozzi, U. Kawabe, A. Tonomura, *Nature* **360**, 51 (1992).