

temperature was lowered below about 7 K. (An earlier experiment had hinted at the zero-field splitting.³)

The splitting of the conductance peak indicates time-reversal symmetry breaking: It reveals an energy splitting between states that are time-reversed pairs of one another. A magnetic field, which breaks time-reversal symmetry, can cause such a splitting, so whatever is causing the splitting at $B = 0$ may itself be violating time-reversal symmetry. One such mechanism, suggested by Mikael Fogelström, Dierk Rainer and Jim Sauls of Northwestern,⁴ is the appearance near the surface of what they call a subdominant pairing interaction—that is, one that normally cannot compete with the d-wave pairing (corresponding to an electron-pair wavefunction resembling a four-leaf clover) that prevails in the

bulk. To explain the zero-bias splitting, the component of the electron wavefunction associated with the subdominant interaction must have a different symmetry from the d-wave—most likely s wave. In the Northwestern theory, the relative phase between the s wave and d wave leads to an energy splitting between the time-reversed surface states, which is seen directly as a splitting of the zero bias conductance peak. The data produced by the Illinois–Northwestern group are in reasonable agreement with the calculations of Sauls and his colleagues.

Zero-bias conductance peaks can also be caused by magnetic impurities in the tunnel junction. However, Greene argues that such an explanation is inconsistent with the data. Instead, she and her colleagues assert that the zero-bias peak stems from Andreev scattering—

that is, the interaction of an electron-like quasiparticle with a superconducting pair, which breaks the pair and causes the quasiparticle to be reflected as a hole.

Greene is eager for other experiments to confirm her group's results. And she's watching to see whether their results are related to those of several other experiments, which also indicate the possible appearance of a second order parameter.

BARBARA GOSS LEVI

References

1. M. Covington, M. Aprili, E. Paraoanu, L. H. Greene, F. Xu, J. Zhu, C. A. Mirkin, *Phys. Rev. Lett.* **79**, 277 (1997).
2. J. Lesueur, L. H. Greene, W. L. Feldman, A. Inam, *Physica C* **191**, 325 (1992).
3. J. Geerk, X. X. Xi, G. Linker, *Z. Phys. B* **73**, 329 (1988).
4. M. Fogelström, D. Rainer, J. A. Sauls, *Phys. Rev. Lett.* **79**, 281 (1997).

Stanford Wants to Build a TeV Linear Collider with Japan

Four years ago, accelerator physicists at the Stanford Linear Accelerator Center (SLAC) began construction of the Next Linear Collider Test Accelerator (NLCTA), a 42-meter-long experimental prototype segment of what they call the "Next Linear Collider." The NLC they hope to build early in the next century would be a face-to-face pair of 10-km linacs firing electrons and positrons at each other with collision energies up to a TeV (10^{12} electron volts).

The highest e^+e^- collision energy now available to experimenters is the 200 GeV provided by LEP, the 27-km-circumference storage-ring collider at CERN. But the theorists tell us that crucial new physics is bound to manifest itself when point-particle (electron, positron, muon, quark or gluon) collision energies approach a TeV. Because protons, by contrast, are composite particles, a proton collider will have to get up to significantly higher energies to explore this promised land. For particles as light as the electron, a TeV e^+e^- storage ring is excluded by synchrotron radiation loss, which increases as the inverse fourth power of the mass.

Now the NLCTA is nearing completion. (See the photo on page 22.) But even in its various incomplete stages, the test accelerator has already provided significant results¹ with regard to the accelerator technologies the NLC designers hope to exploit: non-superconducting, klystron-powered, multi-bunch radio-frequency acceleration at an "X band" frequency of 11.4 GHz.

This is, of course, not the only interesting option for a TeV lepton collider in the next decade: The DESY

As the small test accelerator for the proposed 20-km electron-positron collider nears completion, SLAC and KEK have drafted a memorandum of understanding.

laboratory in Hamburg, for example, has opted for a superconducting RF linac operating at 1.3 GHz. CERN, for a time, actively pursued the notion of a "two-beam" linac, with a low-energy, high-current auxiliary electron beam replacing the klystrons as the source of microwave power. Even more exotic is the idea, put forward by Robert Palmer (Brookhaven) and collaborators, that one could build a circular 4-TeV $\mu^+\mu^-$ collider only a few km in diameter. Each of these choices has its own particular strengths and difficulties. But one can argue that the NLC option, or a similar design under study in Japan, involves the smallest extrapolation from accelerator technology already in the field.

Memorandum of understanding

Four months ago, SLAC director Burton Richter and Hirotaka Sugawara, director of KEK, the Japanese high-energy laboratory near Tokyo, drafted a memorandum of understanding stating that the two labs want to work together toward the design of a TeV linear collider, for which a site would eventually be chosen by the participating governments, somewhere in the US, Japan or some other country in the Pacific region. "Originally," Richter told us, "Sugawara, [DESY director] Bjorn Wiik and I had intended to study

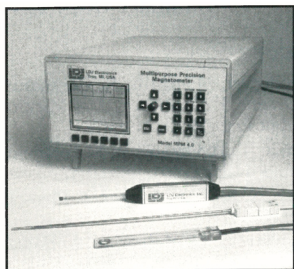
various technical options and then proceed to a truly worldwide collaboration. But now Wiik intends to complete a superconducting RF linac design for a site adjoining DESY, and submit it to the German government for funding. Sugawara and I think the room-temperature X-band option is at least as good, and certainly more ready. So now we have to proceed without DESY."

Because Sugawara, unlike Richter, is a government official, formal signing of the memorandum of understanding must await the approval of the Japanese science ministry, sometime in the next month or so. The non-governmental Japanese High Energy Physics Committee has already given the proposed joint R&D program its blessing. SLAC can continue its own R&D effort toward the collider without special new DOE approval at this juncture. Nor would the signed memorandum commit either government to the NLC.

DOE approval would, however, be required for the Conceptual Design Report (CDR) phase, which Richter hopes would begin early in 1999. In the meantime, the pace of the SLAC effort will depend somewhat on the priority assigned to a TeV e^+e^- collider by the DOE High Energy Physics Advisory Panel's subpanel on planning for the future of US high-energy physics. The subpanel, chaired by Fred Gilman (Carnegie-Mellon University), will report its recommendations to HEPAP early next year.

In the CDR phase, the collaboration, having arrived at something like an optimal parameter set, would produce a detailed engineering design. The site

ANNOUNCING
A NEW STANDARD
IN MAGNETIC
MEASUREMENT
VERSATILITY...



MULTIPURPOSE
PRECISION
MAGNETOMETER 4.0

- Operates as a Gaussmeter, Fluxmeter, Thermometer, and Magnetic Field Controller
- Graphical Data Display, Customizable to Specific Application
- Displays and Measures up to Eight Channels Simultaneously



LDJ Electronics, Inc.

1280 E. Big Beaver Rd.

Troy, MI 48083

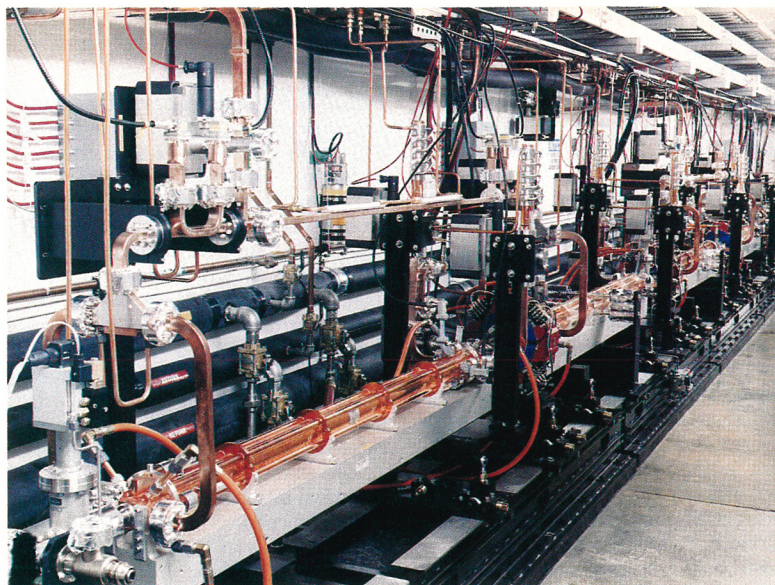
(248) 528-2202

FAX (248) 689-2525

E-Mail: info@LDJ-Electronics.com

Web: www.LDJ-Electronics.com

Gaussmeters • Fluxmeters
Magnetizers • Electromagnets
Magnetic Measurement Services
Magneto-Optical and
Magneto-Resistive
Measurement Systems



THE NEXT LINEAR COLLIDER TEST ACCELERATOR (NLCTA) is now completely installed at Stanford. This 42-meter-long prototype test segment of the NLC, a proposed 20-km-long TeV electron-positron collider, has five 1.8-m-long RF accelerating structures, fed by three 50-megawatt X-band klystrons. Each structure is a horizontal stack of about 200 copper cavities, each about 9 mm thick and 4 cm across. They are to provide an accelerating gradient of 50 MV/m, and eventually 85 MV/m.

would have to be about 30 km long. Richter hopes that "we can deliver the CDR late in calendar 2000 and ask for the first construction funding for fiscal 2003." At this point the plan is to design a machine that would operate first at 500 GeV (250 GeV in each linac) and would then be readily upgraded, with minimal interruption and no added length, to full TeV operation. A later upgrade to 1.5 TeV would be more demanding.

"A TeV accelerator clearly requires an international collaboration," says Richter. "We've learned from the SSC." KEK and SLAC have, in fact, been working together for many years on various parts of the collider R&D.

The test accelerator

The NLCTA and the Final Focus Test Facility at SLAC, together with a prototype injector and damping ring at KEK, are key elements of the R&D program. A 100-GeV first-generation linear e^+e^- collider has, in fact, been doing physics at SLAC since 1989. (Hence the appellation *Next* Linear Collider, which will probably be replaced by a more ecumenical name.) The Stanford Linear Collider (SLC), fed with 50-GeV electrons and positrons by the venerable two-mile-long SLAC linac, uses two semicircular arms to bring the electron and positron beams from the one linac into collision. At TeV energies, however, such an economical single-linac configuration is ruled out by synchrotron radiation in the curved arms, even in a single-pass collider (as distinguished from a storage ring).

The SLC and the proposed NLC have much in common. But it is the important differences required by the move to much higher energy that the test facilities at SLAC must principally address. The NLC's 11.4-GHz frequency is four times the frequency of the two-mile linac. That implies a four times smaller wavelength—only 2.6 cm—which allows for an RF structure of much higher accelerating gradient and greatly reduced cross-sectional area. That's good for costs, but it's quite demanding on the beam dynamics. The beam, running through very small apertures in the compact accelerating structure, induces intensely disruptive electromagnetic wake fields in the copper RF cavities. The wake-field problem is exacerbated by the fact that the NLC will have to run at a thousand times the luminosity of the SLC to produce useful event rates at TeV energies.

Bunch trains

Therefore it will be necessary to divide the requisite 10^{12} electrons and positrons of each machine pulse out among a train of a hundred or so smaller bunches. The two-mile linac, by contrast, accelerates only single bunches of electrons and positrons per SLC pulse.

This multibunch operation does alleviate the problems caused by excessive charge concentration, and it makes for more efficient use of the RF power. But it poses new problems: Later bunches feel the wake fields of their predecessors and they also experience a weaker accelerating gradient.

To suppress the wake-field modes, the stacks of RF cavities in the NLCTA accelerating structure have off-center damping channels cut through them. (The cavities were fabricated at KEK.) A detuning trick is also being tested: To avoid resonant disruption of the pulse train, successive cavities have slightly different iris and wall dimensions. It's something like a marching column breaking cadence when it crosses a bridge.

The test accelerator, like the NLC in its first 500-GeV phase, is designed to begin life with an accelerating gradient of 50 megavolts per meter. But this nominal gradient applies only at zero beam current. The more current one pushes through, the lower the effective gradient. In multibunch operation, this "beam loading" affects the trailing bunches more than the leaders. Therefore, to preserve the narrow beam-energy distribution the physics will require, the NLCTA group is experimenting with RF pulse reshaping to make all bunches think they see the same beam loading.

A 50 MV/m gradient—three times that of the SLC linac—implies enormous electric fields that can generate deleterious "dark current" at any imperfections on the copper surfaces of the RF cavities. It also requires the development of special klystrons and pulse-compression devices capable of delivering 200 megawatts of X-band power for 0.25 microseconds.

As of this writing, new klystrons developed at SLAC are exceeding these requirements. Of the NLCTA's 9 meters of RF accelerating structure, the first 5.4 m have already achieved the desired 50 MV/m gradient, and the last 3.6 m are still going through the high-power RF "conditioning" required to burn off surface imperfections on the cavities and waveguides. The entire structure has already accelerated an electron beam and demonstrated that pulse reshaping can reduce the beam-loading energy "droop" from 15% to 0.3%.

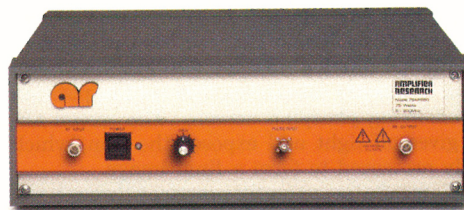
DESY hopes to achieve an accelerating gradient of at least 25 MV/m for "TESLA," its proposed superconducting RF collider. The lab has already exceeded 20 MV/m with experimental cavities. A superconducting machine would not lose gradient by beam loading. Nor would its roomy 1.3-GHz accelerating structure suffer beam-dynamics tolerances as stringent as those of the more compact NLC. But a major problem for TESLA's designers will be to bring down its cost per GeV.

BERTRAM SCHWARZSCHILD

Reference

1. R. D. Ruth *et al.*, SLAC preprint 7532 (1997). ■

Silence Is Golden.



High-speed blanking circuitry in AR Quiet Amps keeps RF waveforms square, and reduces noise to near thermal. You detect even the smallest transients from your sample—no small matter in the world of NMR/MRI, where received signals are notoriously prone to decay.

Application and recovery stay fast and noise-free.

Other features in Quiet Amps keep the effects of applied RF true to form—gated, rapid pulse rise and fall time, no-droop with long pulse width due to Class A operation, wide bandwidth. The 75AP250 and 250AP250 headline this group, which includes instruments with a variety of features to meet a variety of NMR/MRI applications.

*Don't keep questions to yourself. Drop us a call.
Or visit our refurbished website at www.ar-amps.com.*

ar **AMPLIFIER
RESEARCH**

The Force Behind The Field.

160 School House Road, Souderton, PA 18964-9990 USA • TEL 215-723-8181 • FAX 215-723-5688
In Europe, call EMV: Munich: 89-614-1710 • London: 01908-566556 • Paris: 1-64-61-63

www.ar-amps.com

Copyright © 1997, Amplifier Research. The orange stripe on AR products is Reg. U.S. Pat. & Tm. Off.

Circle number 16 on Reader Service Card