San Francisco Accelerator Conference

'Where are today's challenges in accelerator physics?' was the theme of the open session at the San Francisco meeting, the largest-ever gathering of accelerator physicists and engineers. There were over 1500 participants at this, the 14th Conference in the IEEE series, held in the USA every alternate year, confronting this time well over a thousand invited and contributed papers (an increase of 50% compared to the previous Conference). This was an impressive sign of the health of the field, spearheaded by the demands of particle physics but fleshed out by the bulk of activity in other areas of science and in practical applications.

The superconducting proton ring (top) at the HERA electron-proton collider now being commissioned at the DESY Laboratory in Hamburg could give the world's highest energy proton beams.

Linear colliders

The most difficult challenge is to continue the steady climb in peak energies for physics with lepton (electron) beams; as with hadrons (protons), this has climbed by a factor of ten about every twelve years. The tradition with colliding proton beams is being sustained by the US Superconducting Supercollider (SSC) and CERN's Large Hadron Collider (LHC) projects, but, since both size and cost of lepton rings increase as the square of the energy, CERN's existing LEP machine, with its coming 90 GeV per beam for colliding electrons and positrons, looks like the last of its kind.

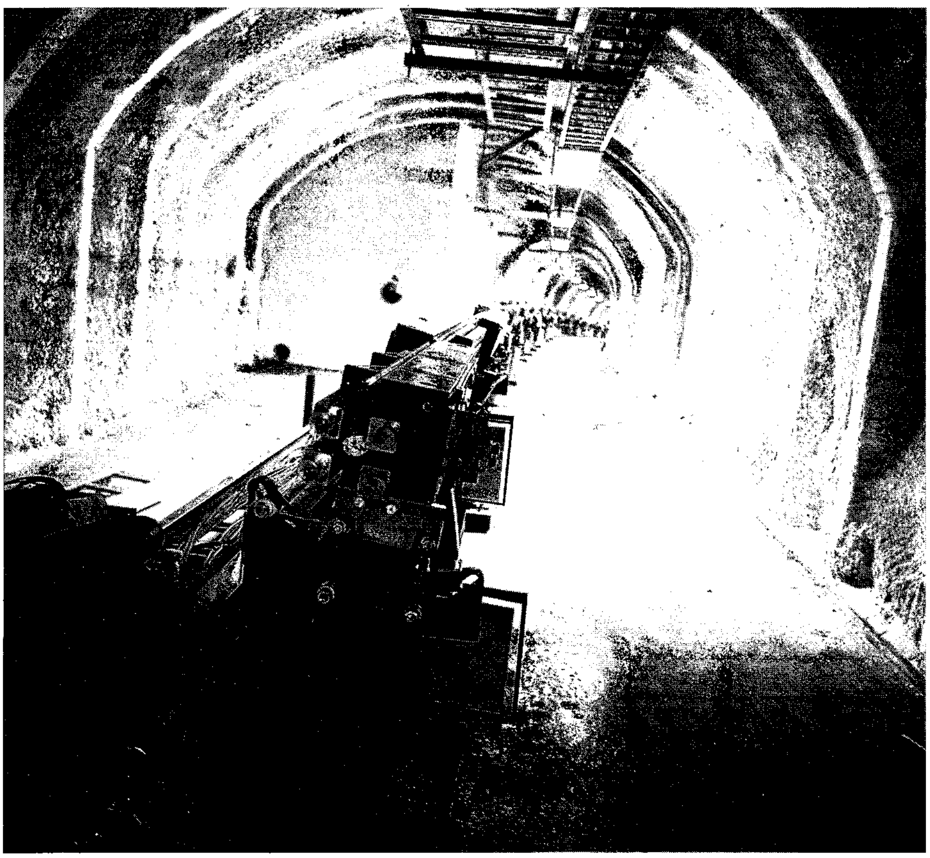
Physics needs 1 TeV lepton beams with luminosities of 10^{33} per sq cm per s and the route must be linear colliders where costs are proportional to the energy. The problems are to provide efficient high frequency sources of radiofrequency accelerating power, to cope with the wakefields caused by the interaction of the intense beams with accelerator structures, and to handle micron-size beams involving extreme precision in structure alignment and compensation for random ground motion.

A guiding light in thinking about such machines has been the experience at the hybrid Stanford Linear Collider. Though the SLC physics programme may have been drowned by the flood of data from LEP, it has been brilliantly successful in revealing and mastering some of the accelerator physics problems for linear colliders. Much has been learned about beam dynamics in such machines and about handling micron-size beams with huge peak currents.

Stanford Linear Accelerator Center (SLAC) Director Burt Richter reviewed present approaches to linear colliders involving close collaboration between many Laboratories. At SLAC the project is called NLC (Next Linear Collider) proposing mode-damped structures operating at around 12 GHz with up to 100 MV per m accelerating gradients. Prototype work (together with DESY in Germany, KEK in Japan, Novosibirsk in the USSR and Orsay in France) includes a Final Focus Test Beam on the 50 GeV SLAC linac to study beam spot sizes down to 1 x 0.06 microns (November 1990, page 11).

The most advanced work in terms of hardware is the construction of the Accelerator Test Facility at KEK with completion scheduled for 1993 in preparation for the JLC, Japan Linear Collider. The ATF has a source, linac, damping ring (for studies of low emittances down to 3×10^{-8} m.rad), a mode-damped 1 GeV X-band linac with 100 MV gradients, and a final focus configuration focusing down to 0.03 microns in the vertical plane. Beam monitors are being developed to cope with nanometre beam sizes. An example of the meticulous engineering involved is a prototype quadrupole for the final focus with pole profiles accurate to better than 2 microns.

At Cornell the emphasis is on the use of superconducting r.f. structures. This could be an expensive route, requiring a much longer machine, but would relax many of the fierce challenges of other schemes, since it would require lower peak power, field gradient, *Stanford's SLC Linear Collider – physics output so far eclipsed by CERN's LEP, but brilliantly successful in exploring and mastering linear accelerator problems.*



and operating frequency. It would also tolerate greater beam sizes and less stringent structure alignment. The scheme is known as TESLA for TeV Energy Superconducting Linear Accelerator (November 1990, page 20). Sets of parameters for progressively increasing energies (a superconducting machine should be easily adaptable), from 0.1 to 1.5 TeV in the centre of mass, have been drawn up with the expectation of field gradients of 15 MV in the near future and maybe as high as 40 MV in ten years (single cell cavities now regularly reach 25 MV).

This work rides on the back of the successful operation of superconducting cavities in accelerator conditions. Y. Kojima listed major contributions, particularly from KEK where 32 five-cell niobium cavities have operated for many thousands of hours in TRISTAN with no deterioration in performance. Other large-scale use is at DESY, CEBAF (series production started last October at the rate of twelve cavities per month) and CERN (where the technique of niobium sputtering on copper has brought a significant reduction in cost – very important for the LEP upgrade which will ultimately have three times CEBAF in superconducting r.f. power).

A more conventional technique for linear colliders is proposed at DESY (April, page 15). At the other end of the spectrum, the most technologically difficult is the CLIC, CERN LInear Collider, proposal using intense drive beams in a superconducting linac alongside the main linac. It would be a 25 km machine providing 1 TeV beams. A test facility is scheduled for completion at the end of 1992. Very tight structure and alignment tolerances are involved, down to 1 micron for the quadrupoles, which could be exceeded by normal ground motion. A dynamic alignment system, using signals taken from the beam to drive micro-movers sustaining components in position, is giving encouraging results.

Gyroklystrons have moved to the fore among possible power sources for linear colliders particularly following work at the University of Maryland. They have operated a two-cavity X-band gyroklystron at 9.85 GHz and achieved output power in excess of 8 MW. There are plans for a new tube to operate near 20 GHz with similar output.

None of these far-reaching plans for linear colliders will come to fruition before well into the next century but they are provoking still more refined mastery of charged particle beams which has been the way ahead for decades, leaving a multitude of other applications in their wake.

In the meantime, LEP carries the lepton energy flag forward. Jean-Pierre Koutchouk, reporting LEP performance and plans, announced a new interpretation of its acronym to describe the work ahead – Luminosity, Energy and Polarization. The luminosity upgrade involves a pretzel scheme with an increase in the number of orbiting bunches (see page 5). The energy upgrade will be complete in 1994 taking the machine beyond the threshold for the production of W pairs. Polarization studies are underway; significant values will not be trivial to achieve but they could improve the accuracy of the present Z mass measurement by a factor of ten compared to its present value of

± 20 MeV. Operation with polarized beams is anticipated in 1996.

Factory fever

Stepping back from the high energy frontier, many Laboratories are proposing machines for specific tasks. As M. Zisman brought out in his review of Beauty Factories, these machines attack the luminosity frontier because they want to accumulate massive statistics of particular interactions, much beyond what can be achieved at existing facilities.

A long-standing contender is the KAON Factory project at TRIUMF in Vancouver, Canada. After encouraging initial support from the provincial British Columbia administration (December 1990, page 29), recent developments had been less encouraging. However news of fresh political support came through during the Conference.

Beauty Factories are comparatively new on the scene, prompted by the prospect of fresh information on the two-decade-old problem of charge-parity violation, which could be seen with B mesons as with kaons. Though the B pairs are produced at comparatively low energies, production rates and the need for high statistics requires machines of very high luminosity – about 3 x 10^{33} per sq cm per s, thirty times higher than currently achieved at Cornell's CESR in this energy range. Extracting the physics is also helped by having a moving centre-of-mass and the Factories involve either dual storage rings or storage ring and linac of asymmetric energy. Since beam-beam interactions would limit luminosities, many bunches and small beam sizes are necessary. (The word 'micron', hardly ever heard at accelerator conferences as recently as a few years ago, cropped up repeatedly in San Francisco.)

Beauty Factory schemes are being developed at Cornell (see page 8), Stanford/Berkeley (June, page 8), KEK (January/February, page 21), DESY (adding a ring to PETRA) and Novosibirsk (6.5 on 4.3 GeV). There has even been thought of using the vacated ISR tunnel at CERN (June 1990, page 10).

First money for construction of a Phi Factory at Frascati was liberated a year ago for a five-year construction project (September/October 1990, page 43) to give a luminosity of 10^{33} with intense electron and positron beams at 1 GeV centre-of-mass. Other phi factory schemes are under study at UCLA (superconducting single-ring with 1 A beams) and at KEK (double-ring with 9 A total current). A Tau-Charm Factory is proposed for Seville (see page 13).

The Superconducting Proton Rings

The big machine talk which excited most interest came from Bjorn Wiik reporting progress on commissioning the HERA collider at DESY. To bring this pioneering high energy electron-proton machine into action within budget and on schedule is a very impressive achievement.

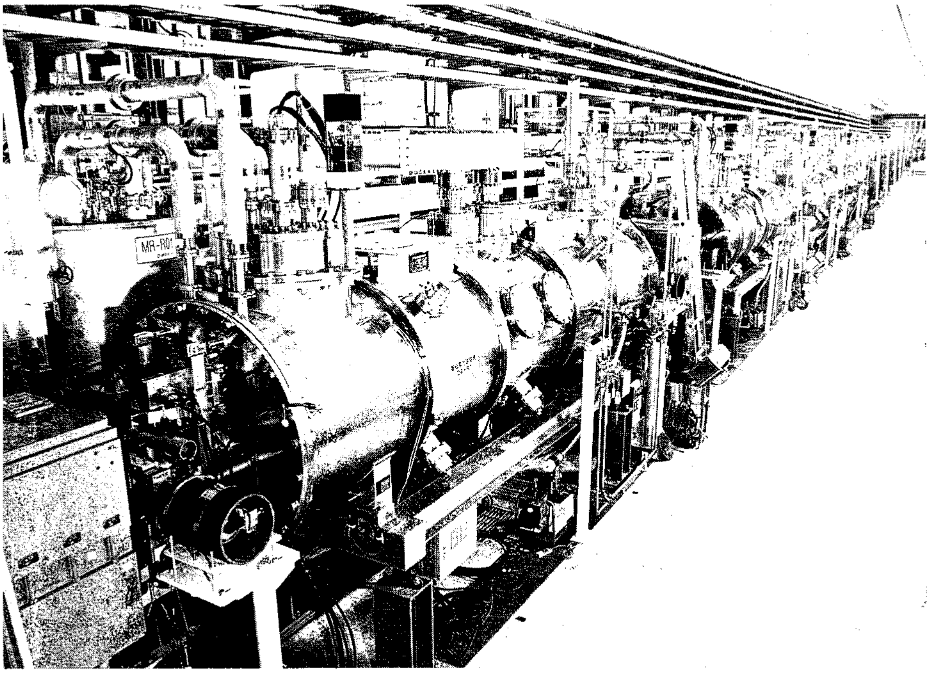
The industrial production of the 1820 superconducting magnets for the proton ring has gone very well – none quenched below the design field of 4.7 T and 98% of them required only two quenches to reach their stable fields. The achievable current gives over 30% safety margin compared to the design value (corresponding to 820 GeV operation) with good field quality and will make it possible for the ring to exceed the energy of Fermilab's Tevatron, currently the world's highest energy proton machine.

The worry about persistent currents affecting injection conditions in an unpredictable way is receding as the fields are reproducible and can therefore be compensated. The cryogenic system seems well up to its job – when a single magnet goes normal, it can be brought back into action in a few minutes.

Steve Holmes described the improvement programme at the Fermilab Tevatron, pioneer of superconducting rings. As Leon Lederman pointed out in one of his usual elegant talks, the machine has an important piece of physics within its grasp since the top quark is predicted to have a mass between 80 and 220 GeV, and upgraded performance should make the top easier to find. Present machine luminosity reaches to 2 x 10^{30} (twice the design figure) and the intention is to push this to over 5 x 10^{31} in a phased improvement programme. This is starting with installation of electrostatic separators, a linac upgrade to double the injection energy into the Booster to 400 GeV, improvements to the antiproton source and finally the construction of a new ring (the Main Injector – June, page 13) to replace the existing Main Ring, where beam transmission is the present major limitation on Tevatron performance. The whole programme should be complete early in 1996 and give several years of extended physics potential in the USA pre-SSC.

The success story of the development of high current niobium-titanium superconductor, which lies behind the achievements at the Tevatron and HERA and the plans for the SSC and LHC projects, was reviewed by David Larbalestier. Critical currents now exceed 3200 A per sq mm in superconductor avail-

Superconducting radiofrequency cavities at the TRISTAN electron-positron collider at the Japanese KEK Laboratory have operated reliably for thousands of hours.



able from industry and 3700 A per sq mm when produced in laboratory conditions. An example is the current density achieved in the latest focusing quadrupoles for the collision regions of the Tevatron; they reach 3100 A per sq mm, almost twice that in the original ring dipoles. As the control of extrinsic effects, like sausaging of the conductor strands, and intrinsic effects, improving flux pinning, are taken still further, it could be possible to push these figures even higher – a 50% improvement may be a realistic figure.

The Superconducting Super Collider requires 8000 superconducting dipole magnets in its two 20 TeV proton rings. The Laboratory is now tackling the magnet design change to accommodate the dipole aperture increase from 4 to 5 cm, which prudence dictated following massive simulations of particle loss over millions of turns. Bob Palmer described the work analysing quench behaviour which points to individual strand movement as being the major culprit. Conductor reconfiguration, with a larger copper to superconductor ratio to take more heat away prior to a quench, has given better performance in the short 5 cm aperture magnets tested so far; they all exceeded design field prior to the first quench and had good field quality with the exception of one multipole.

Roy Schwitters and Don Edwards also reported SSC progress. The parameters of the injectors are being finalized so that civil engineering for the machine can start; all the necessary land acquisitions will be completed in autumn and it is intended to place the first tunnelling contracts by the end of the year. Staff are moving into a huge building on the Laboratory campus near Waxahachie. The Magnet Test Facility is almost complete and a major milestone will be the operation of a half-cell of five dipoles and a quadrupole next summer. First full energy collisions are scheduled for autumn 1999.

The most challenging work on superconducting magnets is being confronted in preparation for the Large Hadron Collider project at CERN. This was covered by Carlo Rubbia in his talk on the broad research programme at CERN which caters for half of the world particle physics community. Given the requirement that the LHC will sit above the LEP ring, there is need for the highest possible magnetic fields to give 8 TeV proton beams. Also space restrictions in the LEP tunnel, plus potential cost savings, point to the use of magnets with two apertures for the counter-rotating beams in a single cryostat. Thus CERN has to aim for the higher fields than yet achieved, plus 'two-in-one' magnets operating at 1.8 K rather than the usual 4.2 K. This ambitious programme has a milestone of testing a string of magnets in June 1992. Authorization of the project is anticipated at that time, with first collisions anticipated in March 1998.

Viktor Yarba reported on UNK construction progress at Serpukhov. Tunnelling is essentially complete, about half the components for the 400 GeV conventional ring are ready and serial production of the 5 T HERA-style superconducting magnets for the 3 TeV ring has started. The initial intention is to operate this ring for fixed-target physics at beam intensities of 5 x 10^{12} protons per second with commissioning in 1995.

To complete the superconducting ring stories, 374 low field (3.45 T) dipoles are needed for the RHIC ion storage ring at Brookhaven. After development at the Laboratory, magnet fabrication is being placed in industry. Completion is scheduled for 1996. KEK have also been looking at the design of an ion machine with two superconducting rings, able to collide gold ions at energies up to 7 GeV per nucleon, using the existing 12 GeV machine as injector.

Applications

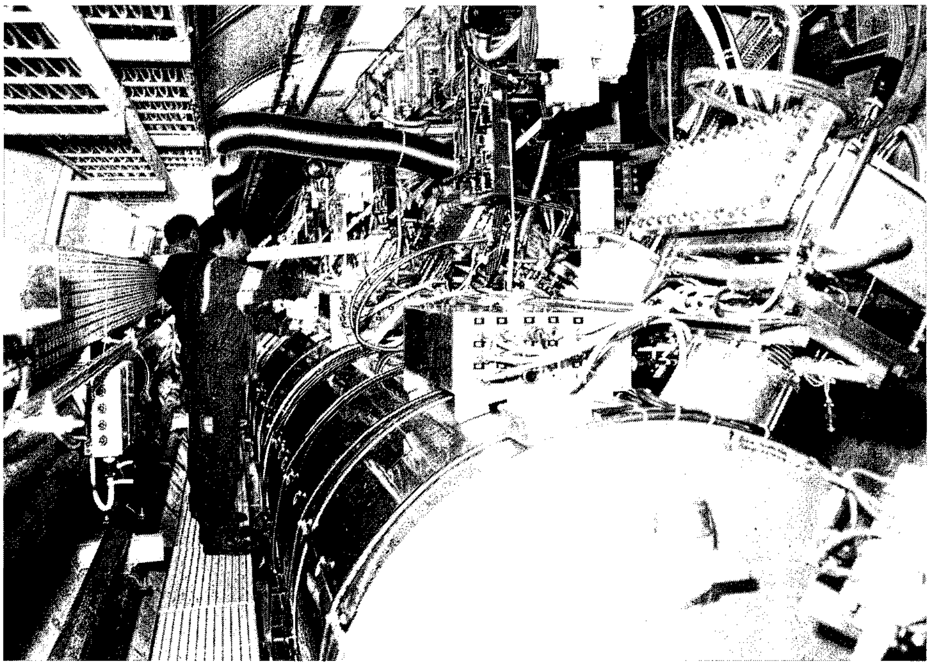
The use of accelerators and storage rings in synchrotron radiation sources and free electron lasers is now so widespread that the field calls its own large conferences, and every year sees new facilities under construction. It is a pleasing feature of this field that the construction and operation of these radiation sources, for basic and applied research, is also within the reach of countries who do not yet have much experience in accelerator technology. Examples reported at the Conference were synchrotron radiation sources in Korea and Taiwan.

Stan Krinsky reviewed the challenges of still brighter sources. Here again the monitoring of micron-size beams is becoming standard and is essential to maintain the necessary orbit stability. These sources bring the problem of high power densities impinging on optical components. Solutions range from water-jet cooling at Brookhaven to cryogenic cooling or liquid gallium cooling planned at the European ESRF machine in Grenoble and Argonne's APS respectively. Free Electron Lasers, packing great power into a small wavelength band, still have much unrealized potential for taking photon fluxes higher. National FELs are under discussion using linacs or storage rings.

Commercial use of compact synchrotron radiation sources for X-ray lithography in the production of microchips is imminent. Their ability to etch patterns on silicon chips with a resolution already down to near a tenth of a micron could make it possible to pack a megabyte of memory onto a full-stop within the next ten years. IBM has calculated that a single machine could produce six times the computer memory capacity used worldwide last year.

A superconducting compact synchrotron from Oxford Instruments is coming into action at IBM's East Fishkill research centre and will be the first to start commercial chip production. Sumitomo in Japan has a superconducting ring commissioning since August of last year.

At the US National Synchrotron Light Source, Brookhaven has a two-phase programme, SXLS – Superconducting X-ray Lithography Source, involving Grumman Corporation and General Dynamics. They are beginning with a conventional ring using low field (1.1 T) magnets, now being commissioned at 200 MeV with average currents of 720 mA well above design value, and will build a superconducting version (3.87T) for 700 MeV operation by 1993. The Texas Accelerator Center are also developing a design based on superferric 3 T magnets. This could prove one of the most important practical applications of accelerator technology.



CERN's LEP electron-positron collider now spells Luminosity, Energy and Polarization. Superconducting radiofrequency will boost the machine's beams from about 50 to 90 GeV.

(Photo CERN 359.1.90)

The use of accelerators and storage rings in fusion reactors was reviewed by Stan Humphries. They range from neutral particle injectors into Tokomaks (the next goal is the ITER - International Thermonuclear Experimental Reactor – involving Europe, Japan, USSR and USA) to high power ion beams focused onto deuterium pellets in inertial fusion systems. Sandia and Karlsruhe lead the light ion beam work, while Berkeley, Livermore and Darmstadt concentrate on the use of heavy ion beams. The construction of a heavy ion test facility at Berkeley has been recommended by the USA Fusion Policy Advisory Committee.

New medical applications of accelerators are illustrated by the cancer therapy facility now in use at the Loma Linda hospital in California. Jim Slater reported that treatments began on the 250 MeV proton synchrotron (designed and built at Fermilab) in October of last year. Beams can be guided eventually into four treatment rooms at variable energies. Eye, head and neck tumours are presently treated at the rate of ten per day. Whole-body radiations will start soon and the aim is to be able to treat a hundred patients a day. Ion Beam Applications in Belgium have funding for design work on a cyclotron for proton therapy. A deuterium machine for neutron radiography is being built at Argonne.

Among topics covered in other papers were the use of accelerators for the transformation of radioactive waste, for energy production bombarding thorium or uranium, for tritium production, for angiography using superconducting wigglers to achieve adequate radiation intensities, and for geophysical prospecting in boreholes producing gamma rays to measure the Compton density of rock strata.

The Conference was held in the refurbished Palace Sheraton Hotel, one of the first stately hotels to be built in America. One or two refurbishment bugs were still to be ironed out and the proceedings were occasionally interrupted by a loudspeaker message: 'We have a minor alarm situation. There is no reason for concern. Everything is normal.' The fact that everything stayed normal throughout the meeting was a credit to organizer Matt Allen and his colleagues. Hopefully his successor in two years' time will confront yet another 50% rise in activity in this thriving field.

By Brian Southworth

Accelerator awards

During the San Francisco Particle Accelerator Conference, several awards were presented in recognition of contributions to accelerator physics and technology:

- *The 1991 IEEE Particle Accelerator Conference Technology Award to Zoltan Farkas and Perry Wilson, SLAC, 'for their invention and implementation of the SLED scheme for doubling SLAC energy' and to David Larbalestier, University of Wisconsin, and Ron Scanlon, Lawrence Berkeley Laboratory (LBL), 'for the development of niobium-titanium material for high current density application in high field superconducting magnets'.*
- *The US Particle Accelerator School Prize to Wolfgang Schnell, CERN, 'for the development of accelerating systems and diagnostic systems for high energy accelerators' and Glen Lambertson, LBL, 'for the development of injection/extraction technology, accelerator instrumentation and microwave devices'.*
- *The US Particle Accelerator School Special Recognition to Rolf Wideroe 'for the invention of radiofrequency acceleration'.*
- *The Robert R. Wilson Prize to Reg Richardson 'for his original contributions to the invention of cyclotrons, including the first demonstration of phase stability, the first synchrotron and the first sector-focused cyclotron. This work is the basis of numerous cyclotrons that have major impact on nuclear physics, solid state physics, chemistry and medicine'.*
- *1991 Award for outstanding doctoral thesis to Jeffrey Calame, University of Maryland, 'for research which led to operation of a 10 GHz gyroklystron with 20 MW peak output power in a pulse of one microsecond, a factor of 400 increase compared with previous experiments, establishing the gyroklystron as a candidate for driving future electron-positron colliders'.*