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**Berkeley Conference**

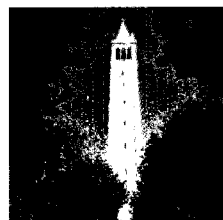
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Cover photograph:

The campanile tower of the University of California's Berkeley campus,  
scene of this year's International Conference on High Energy Physics  
(Photo Douglas McWilliams).

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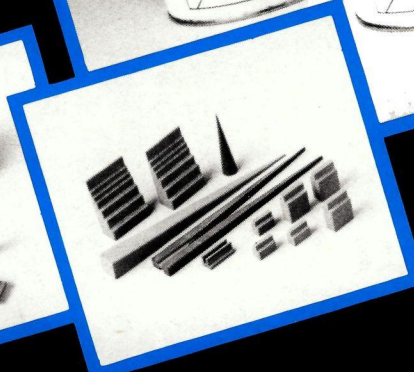
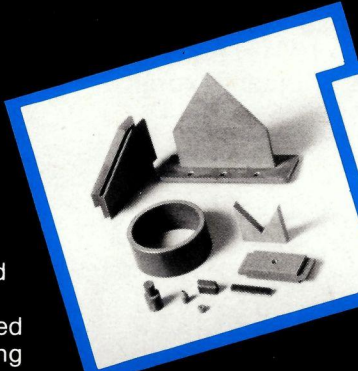
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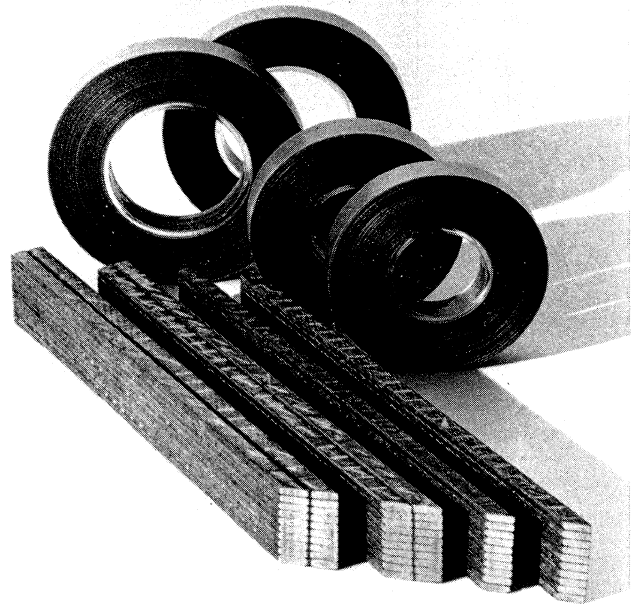
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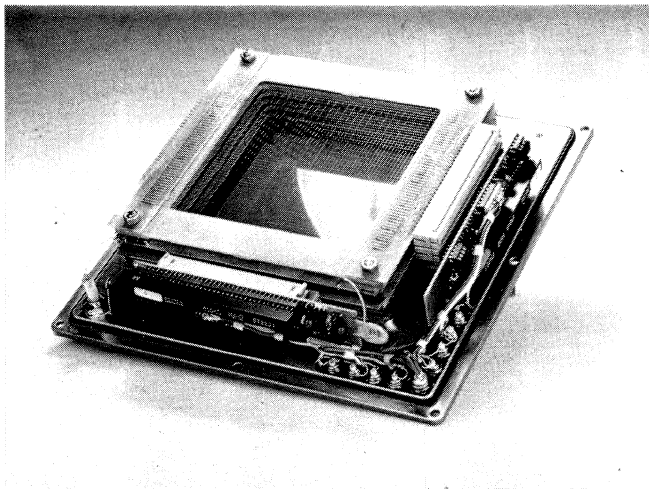
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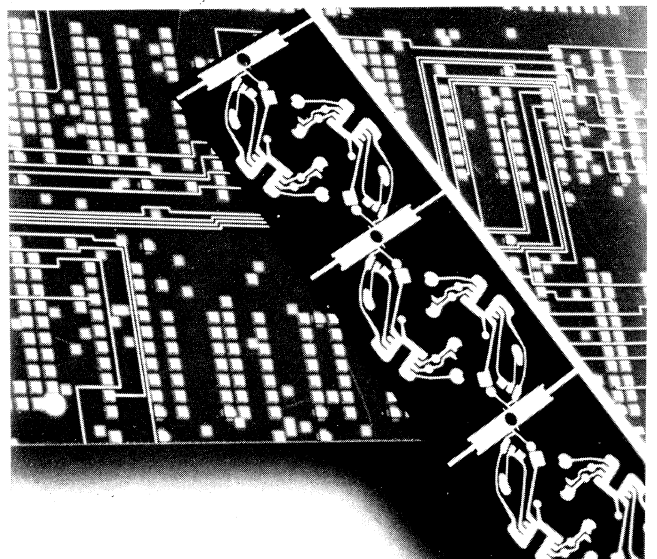
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# Berkeley Conference

*The Zellerbach auditorium on the Berkeley campus, scene of the plenary sessions at the meeting.*

*(Berkeley photos by Douglas McWilliams)*

To a regular observer at annual international meetings, progress in particle physics from one year to the next sometimes might seem ponderously slow. But shift the timescale and the result is startling.

Opening his summary of the 1986 International Conference on High Energy Physics, held in Berkeley, California, from 16-23 July, Steve Weinberg first recalled the 1966 Conference, also held in Berkeley. Then the preoccupations were current algebra, hadron resonances and the interpretation of scattering in terms of Regge poles, and the theory of weak interactions. Physics certainly has moved.

In those days the luxury of today's Standard Model was 'inconceivable'. This picture (the electroweak unification plus the quark/gluon field theory of nuclear forces) is now 'not seriously questioned', said Weinberg, 'however it is full of holes and loose ends'. The absence of the sixth ('top') quark 'was not a worry'. 'More troublesome' was the absence of clues to the Higgs mechanism (the source of mass in the electroweak sector), but 'something must show up by 1 TeV (1000 GeV)', he maintained.

Weinberg compared quantum chromodynamics (QCD, the field theory of quarks and gluons) to hydrodynamics. Both are complicated theories with difficult equations. 'One doesn't study turbulence to test the Navier-Stokes equations (of hydrodynamics)', he declared. Quark/gluon interactions under simpler conditions, as in the production of 'jets' of hadrons, were in his view a better test of the theory.

Earlier on the final day of the Conference Bill Scott of the UA1 team at CERN covered the status



of QCD. Good measurements of the quark/gluon distributions inside nucleons are required as input and this data is steadily accumulating and improving.

'Impressive' according to Scott was the agreement between theory and experiment for the production of W and Z particles and of jets (indicative of violent interactions between quarks — or gluons — inside the colliding particles) in proton-antiproton annihilations. Since the first jet data from the CERN proton-antiproton Collider were presented at Paris in 1982, the experiments have gone on to cover an enormous kinematical range. Additional insights come

from last year's results over the range of energies obtained by 'ramping' the CERN Collider. It is interesting that the level of lower energy jets increases at higher collision energies.

'Fragmentation' — the description of how invisible quarks and gluons produce visible particles — has benefited from data covering a wide range of conditions. Different methods exist for comparing the behaviour of quarks and gluons, but appear to give similar results. In past years there had been two main contending explanations — the so-called 'string' and 'independent fragmentation' models, but the latter is now

*Stewart Loken of Berkeley, chairman of the Local Organizing Committee at the Conference. With some 1600 participants, it was one of the biggest physics meetings ever.*

'dead', affirmed Scott.

Among Weinberg's 'loose ends' were the outstanding questions of why certain symmetry patterns work and why there are a limited number of quarks and leptons grouped into generations. He spoke of the 'frustration' of the alternative theoretical attempts to answer these questions, none of which had anything to show. However Weinberg was confident that the energy frontiers being opened up by new machines would help.

Like several other speakers during the Conference, Weinberg mentioned a few events picked up by the UA1 detector at the CERN Collider producing a pair of jets together with some 'missing energy' indicative of an invisible escaping particle and which could fall outside the net of conventional physics.

The implications of unified theories which attempt to remove unsatisfactory loose ends were covered by Roberto Peccei of DESY. After briefly describing the new suggestion of a fifth force (see April issue, page 9), and the unexplained effects seen in heavy ion studies at Darmstadt (see April issue, page 22), Peccei turned to the 'superstring' idea, the main contender for a 'Theory of Everything' (see page 12). Whatever else they imply, superstrings have to invoke supersymmetry, which means that the number of particles has to be doubled. Thus the search is on for the LSP — Lightest Supersymmetric Particle. Peccei did not think that the couple of UA1 dijet events were a candidate LSP signal since UA1 sees mostly single 'monojets' accompanying missing energy.

In charting the vast energy ranges covered by these ambitious theories, Peccei underlined the inaccessibility of most of the ter-



rain through laboratory experiments, indicating that we would probably have to rely on non-accelerator experiments to peek into this obscure world.

As for the theorists trying to explain it all, Peccei classified them either as 'desert trekkers' who started from global first principles and worked from the top down, or as 'moose herders' who basically worked from the bottom up while trying to keep their feet firmly on the ground.

It was John Schwarz of Caltech who led the plenary audience to worship at the shrine of superstrings. This theory was also stoutly defended by Weinberg, who maintained that in the absence of other ideas superstrings provided 'the only avenue for understanding'.

Although describing the theory as 'compellingly beautiful' and comparing it to Einstein's general relativity, Weinberg warned that it required a 'high entrance fee' in terms of mathematical education,

hindering communication between theorists and experimentalists.

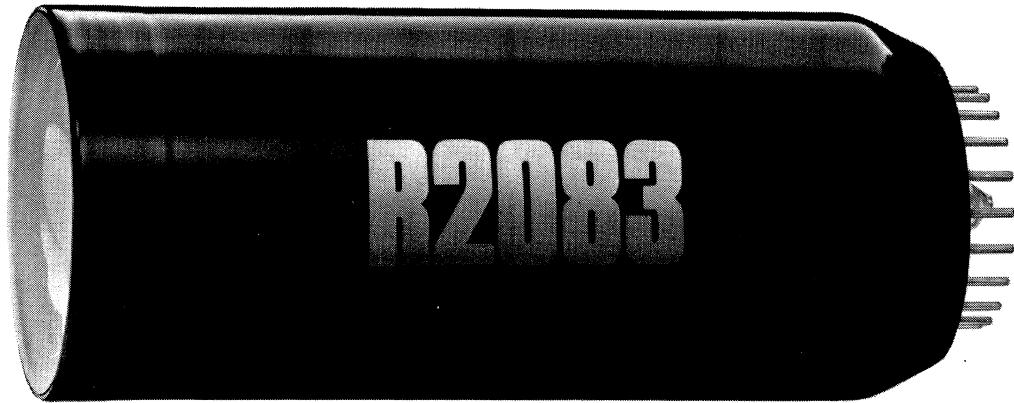
The non-accelerator experiments which are increasingly being relied upon to probe otherwise inaccessible energy domains were described by Maurice Goldhaber of Brookhaven. The motivation for these studies had come from initial efforts to construct Grand Unified Theories, which predicted an unstable proton. The limits on proton stability are steadily being pushed out. Goldhaber pointed out that if the proton lifetime needs to be as long as  $10^{47}$  years, it implies a few counts per hour for the whole of the planet. 'The detector is ready but not the readout', he remarked.

Isolated examples of candidate decays have been found, but Goldhaber maintained that 'a single event does not show that the proton decays'.

Turning to other effects, Goldhaber underlined the 'versatility' of detectors constructed to look for proton decay. 'They could detect



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a number of things but they haven't', he commented wryly.

Michel Davier of Orsay had the task of summarizing searches for new particles, and admitted at the outset that despite having 'hundreds of transparencies' at his disposal, he had only negative results to report. The sixth (top) quark which had been hinted at by UA1 in recent years had no new supporting evidence. An embarrassment was the continuing inability to pin down the Higgs mechanism — 'more elusive than we thought', remarked Davier.

The electroweak sector that according to Weinberg had been 'inconceivable' back in 1966 was covered by Guido Altarelli of Rome, who described the impressive precision now being attained in determinations of the electroweak parameters. Pointing to the couple of possibly unexplained UA1 dijet events, Altarelli classified them as 'interesting but not statistically significant' and preferred to wait and see.

The initial evidence for B particle mixing from the UA1 experiment (see page 17) gives additional insights into the Standard Model, said Altarelli. As for the missing Higgs, he pointed to theoretical implications which had yet to be tested.

More support for the Standard Model came from Murdock Gilchriese of Cornell, speaking on weak interactions. The lifetimes and decay modes of the tau lepton and of charm and beauty quarks were steadily being sorted out, although here and there some more work was needed. Overall, the Standard Model was 'not seriously questioned' claimed Gilchriese, and moreover there was not even any 'smoking gun' pointing at potential

► page 5

*Berkeley Conference summarizer Steve Weinberg displays a model of coupled neutrino oscillations which demonstrated how the behaviour of a neutrino beam could change on passing through matter. This 'MSW' effect (the W does not stand for Weinberg) could throw new light on the long standing puzzle of solar neutrinos.*



## Still controversial

*It is some sixty years since the existence of the neutrino was controversially postulated by the controversial Wolfgang Pauli. Today, the neutrino remains controversial. At the Berkeley Conference, summarizer Steve Weinberg kept the spotlight on these enigmatic particles during a considerable portion of his talk.*

*The neutrino sector was specifically covered earlier in the plenaries by Guido Altarelli of Rome, speaking on the standard electroweak model. Neutrino results from passive experiments away from accelerators were dealt with in a plenary talk by Maurice Goldhaber of Brookhaven. These summary talks reflected in turn the in-depth treatment of an earlier parallel session on neutrino masses and oscillations.*

*The so-called 'solar neutrino problem' has puzzled physicists*

*for years. So far the measured level of neutrinos arriving from the sun is consistently less than what is expected from conventional calculations based on models of the sun's interior. To check and extend these measurements, a new generation of solar neutrino experiments is being prepared.*

*Last year an interesting new explanation for the solar neutrino problem was put forward. Now called the MSW Effect (Mikhaev / Smirnov / Wolfenstein), it proposes that different types of neutrinos can mix through a subtle resonance effect which depends on the density of the surrounding matter. Weinberg brought to Berkeley a toy model of coupled oscillations to illustrate it.*

*The neutrino session began with a masterly description by Lincoln Wolfenstein of Carnegie-Mellon of standard neutrino dogma, indicat-*

ing current 'theoretical prejudices'. Despite the difficulties of estimating the expected level of solar neutrinos on earth, the classical prediction can now be made with considerable confidence. However, if the new oscillation idea is correct, then new measurements of solar neutrinos could show more effects. Solar studies should be a useful probe of small neutrino masses, said Wolfenstein.

With the interest turning to neutrino masses, John Wilkerson described a new measurement at Los Alamos of the electron-neutrino mass using helium 3 beams, indicating a mass below 27.2 eV. This is inconsistent with the value most favoured by the long-standing study at Moscow's Institute for Theoretical and Experimental Physics, but not entirely inconsistent with the ITEP mass range of 17 to 40 eV.

Orrin Fackler of Livermore gave a review of neutrino mass measurements using helium 3. About a dozen studies are underway throughout the world. The Moscow ITEP group's range has to be reconciled with new measurements at SIN (Switzerland — see June issue, page 15). A Japanese experiment is giving an upper limit of 33 eV, and a similar limit is being reported by a Chinese experiment.

Neutrino masses lead on to neutrino oscillations — transformations between 'different' types of neutrinos. The group working at the Bugey reactor (France) has a small kinematical corner where neutrino oscillations are not ruled out, but which is disallowed by other experiments. The Bugey data were described by Roy Aleksan of Saclay, who said that in an effort to clarify the situation new data had been taken at a further Bugey experi-

ment. Results would soon be available, perhaps towards the end of this year.

After several talks on the implications of oscillations for solar neutrinos, E. Bellotti of Milan gave a status report on the Gallex solar neutrino experiment now being prepared for the Gran Sasso underground Laboratory in Italy by a Heidelberg / Karlsruhe / Milan / Munich (TU) / Nice / Rome / Saclay / Weizmann collaboration.

After presentations from individual experiments, François Vannucci of Paris gave a review of neutrino oscillation searches at accelerator experiments. He had only limits from negative results to report, except for a clue from an Athens / CERN / Paris study at CERN which set out to look for decays of heavy neutrinos but found instead an excess of electromagnetic showers, hinting at an unexplained excess of electron neutrinos.

With CERN's low energy neutrino beam no longer available, this study had switched to Brookhaven, amassing fifteen times the data taken at CERN. An analysis of the first third of this new data shows that the anomalous signal is still there.

In his summary talk, Altarelli suggested however that there is 'little hope' of seeing (vacuum) neutrino oscillations at reactors and accelerators, but oscillations were of importance for solar neutrinos.

In his concluding talk, Weinberg suggested that hints of a synthesis of Nature's forces beyond the electroweak sector might not come from proton decay searches, as had once been the hope. Instead it could be that solar neutrinos provide us with a new window into physics in some otherwise unattainable energy range.

◀ defects in the theory.

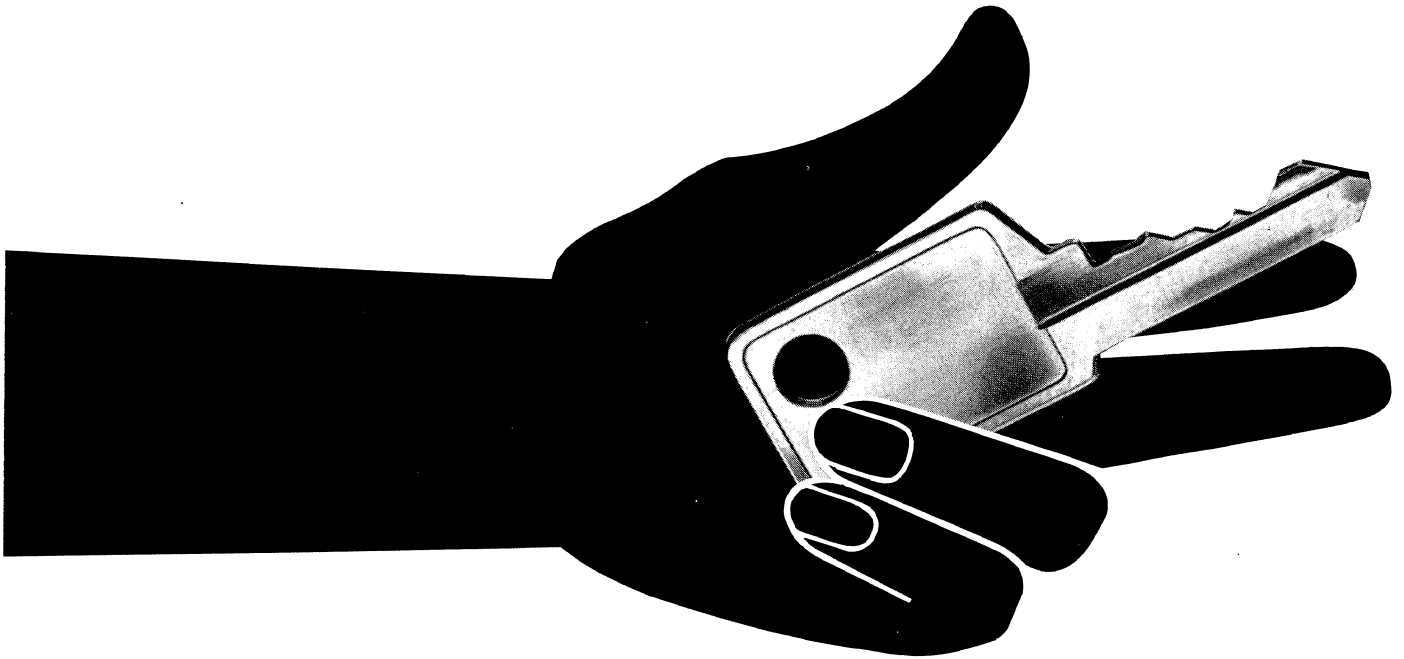
Quark spectroscopy was handled by Susan Cooper of Stanford who tried to unravel the tangle of possible 'glueball' candidates — particles composed of gluons instead of or in addition to quarks. In some areas there were a lot of states being found, not all of which looked like a quark bound to an antiquark. This might be hard to sort out, she suspected. Both Cooper and Gilchriese did a valiant job in coping with the new meson nomenclature (see November 1985 issue, page 390).

Introducing the plenary sessions, local organizing committee chairman Stewart Loken said it had been a 'disappointment' that two distinguished Soviet speakers had not been able to attend the Conference. At short notice, Orlando Alvarez of Berkeley covered the general properties of field theory, stepping in for A. Polyakov of Moscow, and Larry McLerran of Fermilab dealt with high energy nuclear interactions in place of E. Shuryak of Novosibirsk.

Several years ago, experiments with muon and electron beams found that the quark structure of nucleons depended very much on the surrounding nuclei. Dubbed the EMC (European Muon Collaboration) Effect, it provoked much theoretical speculation. 'The EMC Effect is alive and well but smaller than before', observed McLerran. New data from the EMC experiment at CERN now show a less marked variation in one kinematical region.

Echoing what was said in the parallel session, McLerran suspected that less radical mechanisms might be required to explain this gentler effect, and perhaps conventional nuclear physics ideas

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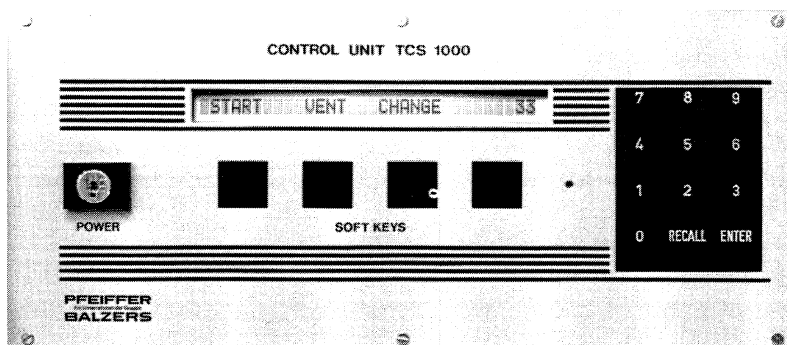
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would be enough. However, additional information on nucleon structure in nuclei is required, which might soon be available.

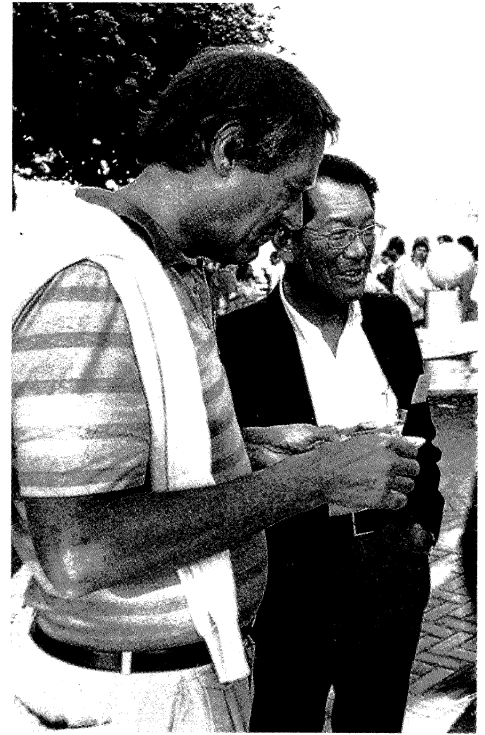
The developments in experimental techniques which exploit the new machines and provide new physics data occupied one parallel session, summarized by Fabio Sauli, who underlined the need for simple and reliable construction techniques in building today's (and tomorrow's) detectors. He concluded with an enormous transparency depicting the development of tracking detectors.

Chris Llewellyn-Smith of Oxford looked into the future, predicting what might be found at new high energy colliders. It was 'a scandal', he remarked, to say that electroweak unification was a success when we do not understand why the photon (the carrier of electromagnetism) is so much lighter than the carriers of the weak force. Depending on what it turned out to be, even the discovery of the

Higgs mechanism might not clear up this question.

Introducing Weinberg's concluding talk, Italo Mannelli, chairman of the Particles and Fields Commission of the International Union of Pure and Applied Physics, thanked the local organizers for their tireless efforts. With 1600 participants from 45 countries, the Berkeley Conference was one of the biggest physics meetings ever. The next meeting in this series is scheduled for Munich in 1988, by which time big new machines should be providing samples of the physics harvest of the next decade.

*Berkeley reports by Gordon Fraser*



*Time out at Berkeley. Wolfgang Kummer of Vienna and President of CERN Council with Satoshi Ozaki, head of the TRISTAN project at the Japanese KEK Laboratory.*

## After the intermission

*The Berkeley conference seemed to mark a brief intermission in high energy particle physics. A first survey with big non-accelerator experiments built to search for proton decay has given largely negative results and showed that new physics horizons are further away than expected. At the Laboratories, big machines which once made physics headlines are no longer in the front line, while even the big experiments at the CERN proton-antiproton Collider making physics history only a few years*

*ago are undergoing major surgery to prolong their active lives.*

*Meanwhile a new generation of big machines and detectors is being prepared in the wings. The Tevatron Collider at Fermilab, TRISTAN in Japan, Stanford's new Linear Collider, LEP at CERN, HERA in Germany... These projects will be the focus of attention at future international physics meetings. Encapsulated in the Berkeley High Energy Physics meeting was a stimulating parallel session on accelerator technology, highlighting the*

*progress being made towards these big new machines of tomorrow.*

*Satoshi Ozaki of the Japanese KEK Laboratory commenced proceedings with an update of progress in Japan. A committee set up to look into future particle physics requirements has come up with a number of recommendations: on the home front, an electron-positron collider in the TeV (1000 GeV) range is advocated, while Japanese participation in experiments at the proposed US*



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Lineup of Laboratory/project notables for the Accelerator Technology parallel session at the Berkeley Conference: Standing, left to right, Burt Richter (Stanford), Maury Tigner (US Superconducting Supercollider), Andy Sessler (Berkeley), Derek Lowenstein (Brookhaven); seated Satoshi Ozaki (TRISTAN, KEK, Japan), Leon Lederman (Fermilab), Herwig Schopper (CERN).



Superconducting Supercollider is encouraged. In addition, the main ring energy of KEK's TRISTAN electron-positron Collider (now being completed) could be increased, the 12 GeV Proton Synchrotron at KEK could be upgraded, an additional investment could be made in non-accelerator physics, and a hadron machine could be built to cater for the growing nuclear physics community.

Turning to the TRISTAN Collider, Ozaki described how first electron-positron collisions had been observed in the Accumulation Ring at 10 GeV. However this is only a springboard to the main objective of commissioning the TRISTAN Main Ring, scheduled for later this year. With conventional radiofrequency equipment, beam energies of 22-25 GeV are foreseen, and experiments would begin recording collisions next year. In 1988, the Main Ring would be fitted with superconducting radiofrequency equipment to boost the beam energy beyond 30 GeV.

Fermilab Director Leon Lederman took over to describe progress at the Tevatron — 'the highest energy collider on this planet'. The end of last year had seen a 'desperate' attempt to see 1.6 TeV proton-antiproton collisions — the highest collision energy ever achieved in a laboratory, but at the expense of 'the world's lowest recorded luminosity'. However the payoff of a further year's toil should be seen at 09.00 hrs on 1 December or thereabouts, when the Tevatron Collider begins its first real period of operations.

'Experience at UA1 and UA2 (the experiments at CERN's proton-antiproton Collider) has shown that integrated luminosity (a measure of the number of available collisions) must double each year', said Lederman, going on to outline a plan for an upgraded Tevatron with a doubled collision energy and significantly boosted collision rate by about 1992.

CERN Director General Herwig Schopper gave a high speed review of the impressive sweep of

activities going on at CERN, pointing out the continual improvements being made in antiproton supply. Construction of the ACOL Antiproton Collector, now underway, will push the antiproton levels still higher. He outlined the current status of LEP operations, with tunnelling, concreting and installation all going ahead in parallel, and reported good progress in developing the superconducting cavities to push LEP's energy up from the initial level of some 50 GeV per beam.

Derek Lowenstein of Brookhaven pointed to his Laboratory's achievements with polarized protons, attaining 2000 times the design intensity (see page 15). With a new booster in the pipeline to extend the capabilities of the venerable AGS Alternating Gradient Synchrotron, and with the RHIC Relativistic Heavy Ion Collider on the cards to at last make use of the big empty tunnel on Long Island, Brookhaven has a lot to look forward to.

At Stanford, the SLC Linear Collider now nearing completion should be operational for initial physics next Spring, said Director Burt Richter, albeit at a small fraction of its design luminosity. Improved performance would follow after mastery of the delicate new SLC techniques.

The width of the thin pencils of SLC's colliding beams would be measured in microns, but a conjectured 'Large Linear Collider' to attain 10 TeV and good collision rates would require beam radii measured in angstroms! Some of the new accelerator schemes involving laser and plasma techniques now being looked into might not be reliable enough to produce a cheap, stable and efficient running, said Richter, pointing



At the ICFA Meeting in Berkeley, Yoshio Yamaguchi was unanimously elected Chairman of ICFA for three years from the beginning of 1987 and Owen Lock was re-appointed Secretary. In the photograph, from left to right, Yamaguchi is seen with the ICFA representatives from China, Fang Shou-Xian, and from the 'Fourth Region', P. K. Malhotra.

(Photo LBL)

## ICFA meets at Berkeley

The International Committee for Future Accelerators, ICFA, held its fourteenth meeting during the Berkeley Conference and had detailed reports from three of the four Panels which were set up in 1984 (see October 1984 issue, page 319).

The Panel on Superconducting Magnets and Cryogenics, chaired by Giorgio Brianti, organized a recent Workshop at Brookhaven (see September

issue, page 3). They are also setting up two subpanels — one to establish standards in specifications and measurements of superconducting wires and cables, the other to work on computational methods.

The Instrumentation Panel, chaired by Tord Ekelof, will hold a School on 'Instrumentation in Particle Physics' at the International Centre for Theoretical Physics, Trieste, next June.

They have launched a regular 'Instrumentation Bulletin' and are preparing a 'Catalogue of Instrumentation Issues'. The Panel on Novel Accelerator Schemes, chaired by Andy Sessler, is compiling a list of the topics and the names of the research workers in this field. It has already been circulated in draft form and ICFA was able to add its own suggestions.

There was a report from Jean Sacton, Chairman of the European Committee, ECFA, and a brief discussion about the possibility of collaboration with UNESCO for the organization and support of future meetings.

The next ICFA meeting is scheduled for next April, probably in Budapest, and at the same time there will be a preparatory meeting for the second 'Seminar on Future Perspectives in High Energy Physics' to be held at Brookhaven in October 1987. Participation will be by invitation with up to some twenty people from each region.

towards the 'conventional' two-beam approach as the optimal basis for such a machine. However, such a multi-TeV project might be too big a step from the present SLC, and perhaps there was a call for a 1 TeV machine in about five years. One problem would be to decide in which continent it would be built.

Maury Tigner, Director of the Design Group of the proposed 40 TeV US Superconducting Supercollider, chose to rush through the status of this project and concentrate instead on a hypothetical 200 TeV machine 'one step beyond the SSC'. Even taking for

granted some unforeseen technological breakthrough to increase magnetic fields fivefold, the power consumption of such a machine would attain gargantuan proportions. The discounted technological breakthrough for magnetic fields would not be enough, said Tigner.

Andy Sessler of Berkeley looked at some of the new techniques now being investigated and tentatively signposted as routes to future accelerators. The need to invest in detector research and development work has been evident for some time and periodic meetings and workshops have accurately reflected the trends of current

thinking (see, for example, July/August issue, page 8).

Missing from the lineup of big new projects in the Berkeley parallel session were the HERA electron-proton Collider being built at the German DESY Laboratory in Hamburg and the UNK project at Serpukhov, but these were filled in by Don Edwards of Fermilab in the subsequent plenary talk.

With Fermilab's Tevatron Collider, Stanford's Linear Collider and KEK's TRISTAN scheduled to supply their first beams soon, any brief physics intermission is nearly over.



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# Superstring superstars

by André Neveu

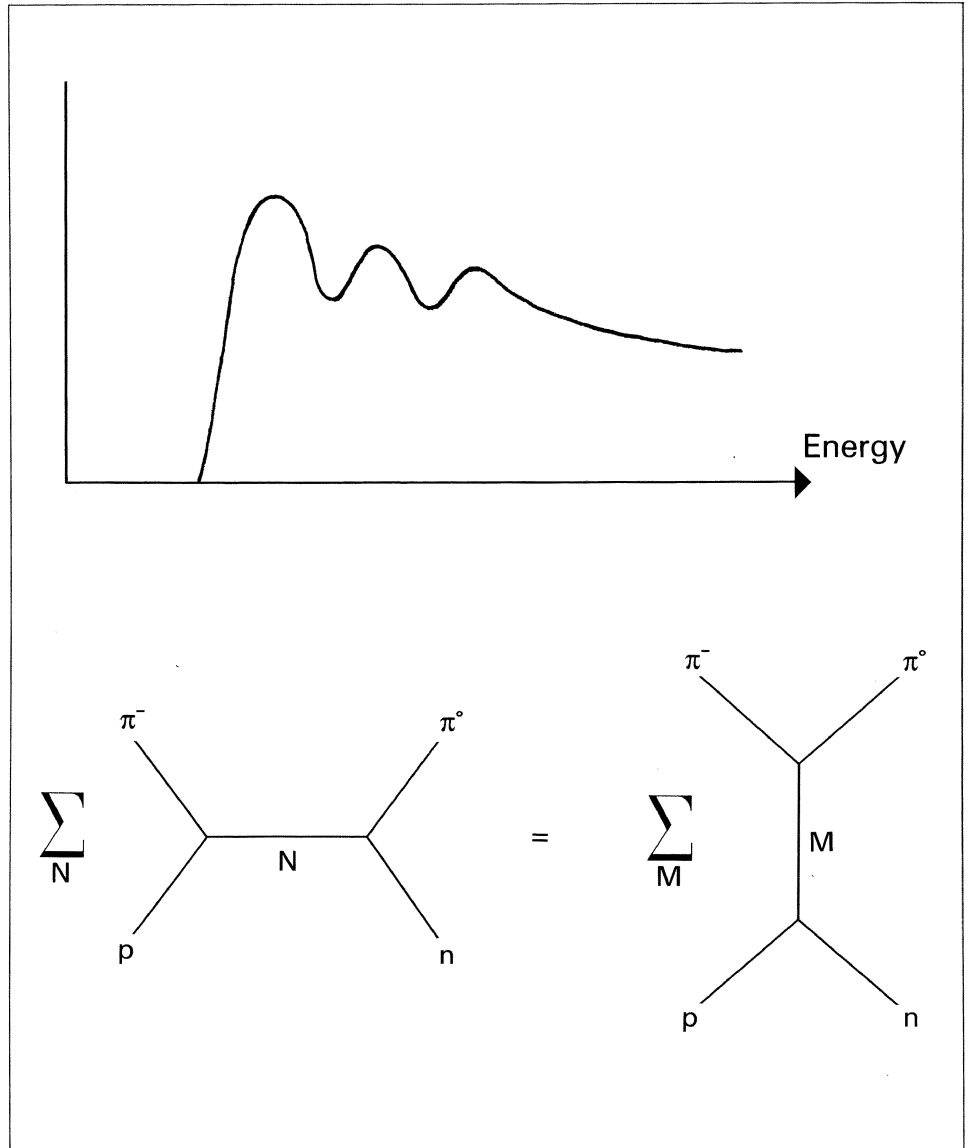
*Schematic behaviour of negative pion-proton scattering with energy, showing first a series of distinct resonances followed by a smooth fall-off at higher energies. The observed behaviour can be looked at either as a series of baryon (proton-like) resonances (N) or as a series of meson transfers ('exchanges', M). The two 'dual' descriptions are fully interchangeable.*

*Superstrings are seemingly irresistible for physicists in search of the 'Theory of Everything', unifying all known forces and particles. However, as often happens in physics, superstrings were developed in a very different context, and the discovery of their remarkable properties came only slowly.*

A string is a generalization of the concept of a point particle and is the simplest extended object compatible with special relativity. Superstrings (short for supersymmetric strings) are the first candidates for a quantum theory unifying gravitation with strong, weak and electromagnetic interactions and in addition having some chance of describing the real world.

However, strings were not invented for such an ambitious purpose, and appeared in a rather roundabout way at the end of the sixties. In scattering negative pions off protons, for example, a series of low energy peaks is seen corresponding to the formation of baryon (proton-like) resonances. At higher energies, the behaviour becomes smoother, described instead by the transfer ('exchange') of the mesons responsible for the forces between the pion and the proton. It is remarkable that as the energy is increased, the denser and denser baryon resonances conspire to reproduce precisely the meson exchange mechanism. Similarly, when the energy is decreased, the mesons reconstruct the peaks due to baryon resonances.

This phenomenon is called 'duality', and the first theory was pro-



posed 18 years ago in a simplified model, the Veneziano formula, containing only mesons, which was the historic starting point for string theories.

The theory was quickly generalized, and it was discovered that the set of particles required corresponded to the quantized motion of a relativistic string. The shortest distance between two points is a straight line, but finding the 'shortest distance' between two strings

involves looking at the relativistic analogue of the soap-bubble problem. The solution, expressed in a suitable form, is precisely the equation describing the vibrations of a piano or violin string.

The simplest motion of an open free string is the rotation of a line around its centre with constant angular velocity so that its ends move with the speed of light. Expressing this motion in quantum form gives a 'Regge trajectory' —

a set of particles whose intrinsic angular momentum (spin) increases as the square of their mass.

Interactions between strings are described in a geometrical way — two open strings can join by their ends to form a single one, which can subsequently break in two, a process which can repeat itself. Twelve years ago, it was shown that adding up all possible intermediate string configurations corresponds exactly to the summation over baryon resonances in hadron scattering. Such a geometrical theory is both beautiful and conceptually simple. It is also rigid, as modifications generally bring intractable complications.

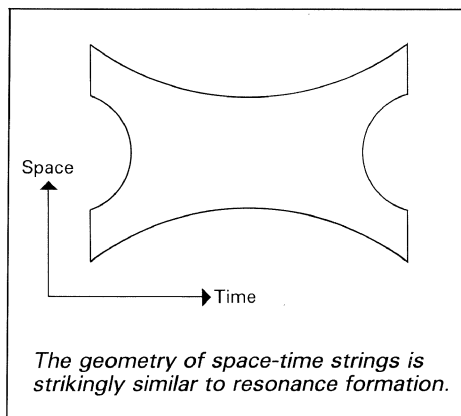
The simplest string is called bosonic, because all the particles of its spectrum have integer spin. It also has the misfortune of giving rise to 'tachyons' — particles which travel faster than light. The necessary addition of half integer spin (fermionic string), together with the removal of the tachyons, is solved by the so-called Neveu-Schwarz-Ramond model.

The bosonic string has only orbital degrees of freedom, corresponding to its position in space. A fermionic string also has spin degrees of freedom, which can be interpreted as a distribution of half integer spins along the string. Depending on the external (boundary) conditions, one may have an odd number of these spins, giving a fermion, or an even number, giving a boson.

To preserve the geometrical simplicity of the theory and its compatibility with relativity, the orbital and spin degrees of freedom have to be connected through a special symmetry, called supersymmetry, using numbers which anticommute (so that  $x$  times  $y$  equals minus  $y$  times  $x$ ). Supersym-

metry appeared for the first time in this way, but went on to have important applications in other branches of physics and in mathematics.

Strings have remarkable properties not shared by theories of ordinary point particles. The most spectacular is probably that quantization prefers space-times of definite and rather mysterious dimensions — 26 for the bosonic string and 10 for fermionic strings, for which there exists no simple explanation. They also give rise to massless particles, which quickly made it clear that as such they could not form the basis for a fundamental theory of strong interactions, which have no massless particles.



Joel Scherk and John Schwarz capitalized on these drawbacks, turning them into crucial assets for theories with quite different and much more ambitious aims. They suggested reinterpreting them as candidate unified theories of all interactions, including gravitation, with a hitherto unwanted massless spin-two particle in the role of the graviton — the carrier of the gravitational force. This parallels the history of the so-called non-Abelian gauge theories, developed by Yang and Mills initially for

use with strong interactions, but which became more fruitful when applied instead to the unification of the weak and electromagnetic interactions.

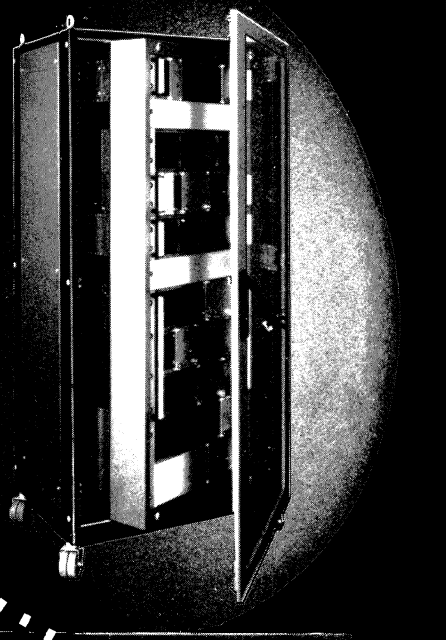
The mass scale of the superstring theory then changes from the GeV scale characteristic of strong nuclear interactions to the so-called Planck scale,  $10^{19}$  GeV, when the gravitational interaction of two electrons becomes comparable to their electromagnetic interaction. Scherk and Schwarz also proposed that the extra dimensions of the theory are 'compactified' — curling up on themselves like tiny circles or spheres invisible at presently accessible energies.

The only observable particles are the massless ones. A given string model predicts a unique spectrum of massless particles and their interactions, and among them there is always gravitation and the graviton. This is useful not only because gravity is unified with other interactions (which supergravity theories also achieve), but because it tames the troublesome infinities which crop up when gravity, and even supergravity, are quantized. Some superstring theories even manage to avoid infinities completely.

Although all these nice properties were known or suspected for some time, they did not trigger off the present boom. It was the discovery in 1984 by Michael Green and John Schwarz that superstrings in ten dimensions which naturally distinguish left from right (like weak interactions) do not necessarily present the inconsistencies generally plaguing such (chiral) theories.

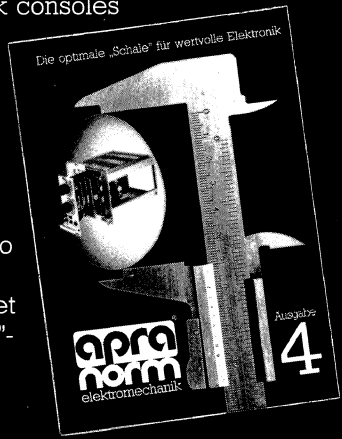
These inconsistencies (chiral anomalies) are absent in superstrings if and only if their internal symmetry is either  $SO(32)$  (rota-

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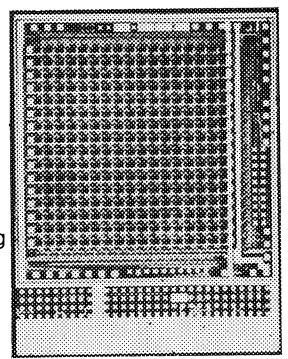
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tional symmetry in 32 Euclidean dimensions) or the direct product of two special symmetry groups ( $E_8 \times E_8$ ). The latter case contains most symmetries already proposed for the unification of strong, weak and electromagnetic forces.

Another promising development concerns the so-called compactification procedure, and is due in its general form to two mathematicians, Igor Frenkel and Victor Kac, although the first example was discovered by a physicist, M. B. Halpern. The initial suggestion of Scherk and Schwarz may seem arbitrary — what governs the size and shape of the compactified dimensions? This process would also break the rotational symmetry in the compactified dimensions to (at best) some much smaller discrete crystallographic symmetry. Frenkel and Kac showed that this need not be so, and that continuous internal symmetries can actually be generated by cleverly compactifying the unwanted dimensions.

This generation of internal symmetries through compactification is a unique feature of string theories, and is a crucial ingredient in

the construction of candidate models.

Current investigations are proceeding in different directions. On the more formal side, string theories remain poorly understood, lacking the powerful formalism of conventional quantum theories. More phenomenologically, it must be understood how the number of dimensions falls from ten to four at low energies. This reduction in dimensions determines the spectrum of observable particles and governs the predictive power of the theory.

The gap between the ten dimensions of superstrings and the four of the real world is currently bridged through a series of steps. First a low energy limit looks only at the interactions of massless particles, giving a ten dimensional supergravity theory in much the same way that the old picture of the weak interaction (the Cabibbo theory) was the low energy limit of today's electroweak theory. Then six unwanted dimensions are compactified. The Frenkel-Kac procedure, which requires a tachyon, does not work for superstrings. Instead physicists resort

to special six-dimensional curved spaces, called Calabi-Yau manifolds, in which superstrings can move while retaining their nice properties.

Thus compactification generally gives a well defined four-dimensional supergravity theory. Supersymmetry is then broken dynamically to give particles with mass (as in the electroweak theory, where the photon carrier of the electromagnetic force is massless but the W and Z carriers of the weak force are very heavy).

The mechanisms for this symmetry breaking and generation of mass in superstrings remain obscure, but most schemes predict one or more additional phenomena not contained in the Standard Model but which should show up at a few hundred GeV energy — additional (electrically) neutral currents of the weak interaction, supersymmetric partners of observed particles, and additional quarks.

A lot of theoretical work is required to improve the predictive power of superstring theories, but the discovery in the meantime of one or another of these new effects would be a great boost!

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## Around the Laboratories

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### BROOKHAVEN More spin surprises

The Brookhaven Alternating Gradient Synchrotron supplies the world's highest energy beams of polarized (spin aligned) protons and is continuing the tradition of supplying puzzling new results when new regions of spin physics

are explored.

The Argonne ZGS machine supplied a crop of spin results in the 70s which are still controversial today. When this machine was closed a big effort was mounted to produce polarized beams at the Brookhaven AGS. The first beams were produced in 1984 (see October 1984 issue, page 328), at an energy of 16.5 GeV, surpassing the old ZGS record of 12.75 GeV.

In February, after several weeks of intense operations, the AGS polarized beam was turned off after several weeks of intense physics during which the beam energy reached as high as 22 GeV (see May issue, page 17).

First results from this work are emerging from a study by a Brookhaven / Maryland / Michigan / MIT / Notre Dame / Texas A and M / ETH Zurich group which uses

Another spin surprise. The unexplained strong spin dependence found at 10-12 GeV at the old Argonne ZGS suddenly dives towards zero using 18.5 GeV polarized (spin oriented) protons from the Brookhaven Alternating Gradient Synchrotron.

a polarized target in addition to the polarized beam. While the ZGS experiment found an unexpectedly large spin dependence, the new result shows that this effect suddenly falls to zero at the higher energies available at the AGS.

Alan Krisch of Michigan, a dedicated spin physicist, says 'spin experiments may be trying to tell us something, but we do not yet understand the message'.

The result was discussed at the recent Lake Louise conference on particle and nuclear physics (see September issue, page 1) and was also presented in a parallel session at the Berkeley high energy conference in July (see page 1) by Donald Crabb of Michigan:

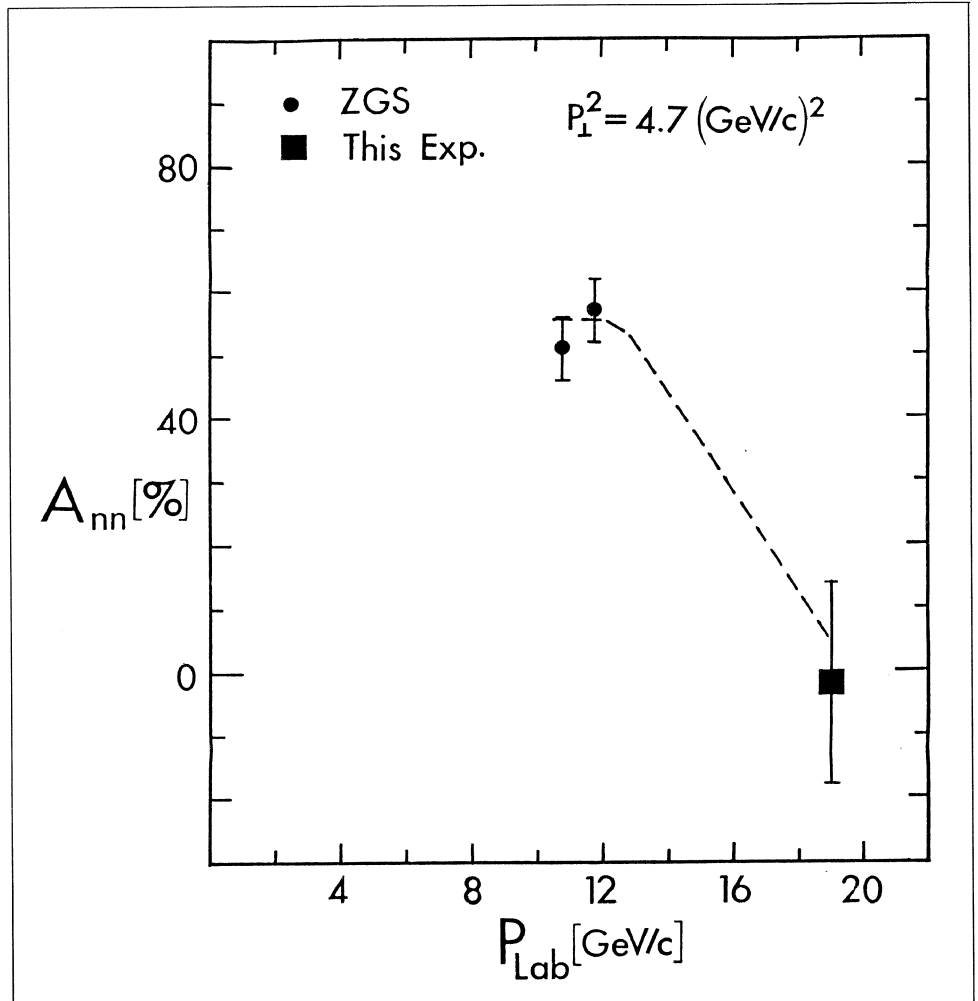
## DESY HERA progress

After setting out from the South Hall last summer, the tunnelling machine for the new HERA electron-proton Collider at the German DESY Laboratory in Hamburg has reached the North Hall, thus having completed half of its 6.3 km underground journey.

Meanwhile the first quadrant of the tunnel is being prepared for installation of equipment. The two proposed experiments for HERA — H1 (see September issue, page 11) and ZEUS (July / August issue, page 16) — have been recommended for approval.

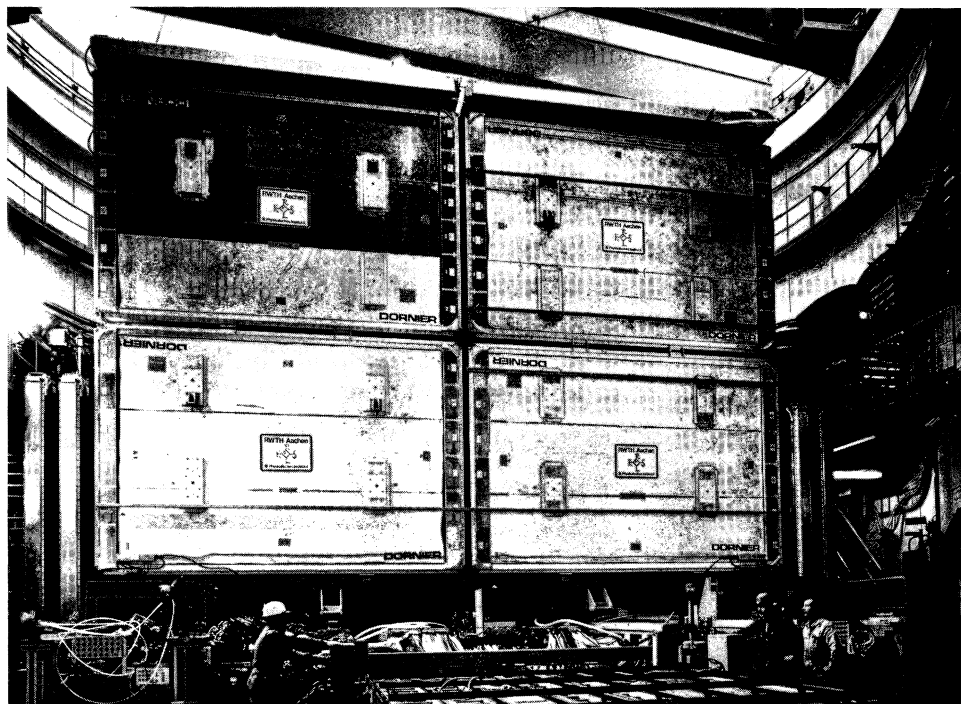
Concrete segments piled up ready to line the tunnel being bored for the new HERA electron-proton Collider at the German DESY Laboratory in Hamburg. Half of the 6.3 km tunnel has been excavated.

(Photo DESY)



The outer muon chambers of the UA1 experiment at CERN's proton-antiproton Collider. These played a vital role in the sighting of initial evidence for heavy meson 'mixing'.

(Photo CERN 46.1.82)



## CERN Oscillating flavours

New results from the big UA1 experiment at CERN's proton-antiproton Collider reveal a subtle and intriguing physics effect. Heavy mesons carrying both the 'beauty' and the 'strangeness' quantum numbers show a delicate quantum mechanics mixing previously unseen outside the restricted world of the neutral kaons.

Like all other particles, the well-known neutral kaon has its antiparticle, carrying equal and opposite quantum numbers. The neutral kaon particle and antiparticle are distinguished only by their strong interaction label (strangeness). However, strangeness is not conserved in weak interactions, so that the neutral kaon particle and antiparticle can mix. This neutral kaon system provides a rich scenario for the weak force. In particular, it provides the only known

example of the breakdown of the combined particle-antiparticle / left-right, or CP, symmetry.

The 'Standard Model' of modern physics has six quark flavours grouped into three 'generations' of two (up and down, strange and charm, beauty and top), and all the flavour changes resulting from the weak force can be described by the so-called Kobayashi-Maskawa matrix. There is not yet a theory which predicts all its parameters, but input from recent experiments gives the physicists some predictive power, in particular for subtle flavour mixing effects.

The particle-antiparticle mixing seen in the neutral kaon system should repeat itself with other heavy mesons carrying suitable quantum numbers. However, the experimental constraints now suggest that the main contender is the electrically neutral beauty meson  $B_s$ , containing beauty and strange quarks, and its antiparticle.

The muons (or electrons) emitted

in the 'beta' decays of heavy quarks provide a useful window on heavy quark production. With the historic W and Z discoveries in the bag, the UA1 experiment was improved with extra screening and with added streamer tubes surrounding the detector to filter out and pick up the muons which traverse the rest of the apparatus.

Analysis of experimental data from a variety of sources suggested that production of muon pairs at high transverse momentum in the CERN Collider would be dominated by beauty quark-anti-quark pairs.

Three years' accumulated UA1 data were carefully sifted for their muon pair content, and the contributions from resonances and background processes removed. The results demonstrate clearly that the beauty (b) quarks dominate the relevant production mechanisms, as expected. In fact the CERN Collider is a prolific source of B mesons.

The special kinematics of these reactions make theorists more confident about calculations using the quantum chromodynamics — QCD — picture of quark interactions. There is close agreement between the calculated levels of particle production through beauty quarks and those observed by UA1.

However, the QCD theory (which covers only the strong interactions of quarks) cannot take into account the mixing of the b quarks due to the weak interaction. This mixing would affect the observed relative levels of muon pairs with two equal electric charges (++) or (--) to those carrying opposite charges (+-). UA1 sees a ratio of the order of 50 per cent, while only about 25 per cent would be expected without b quark mixing.

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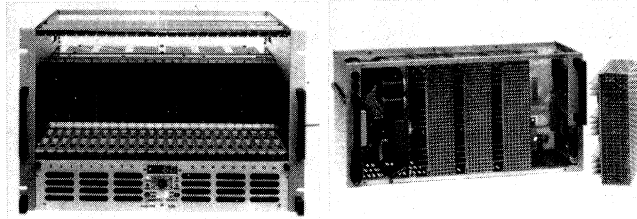
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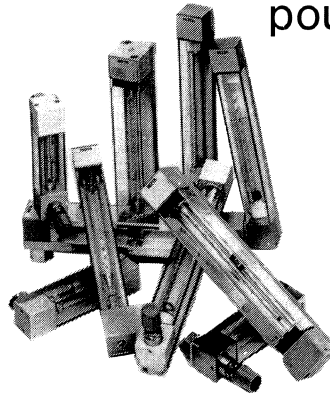
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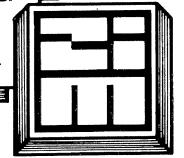
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On 22 August one of the machines tunnelling for CERN's LEP electron-positron Collider made another major breakthrough. About 24 of the 27 kilometres of the tunnel have been excavated, with the remainder being taken care of partly by tunneller and partly by explosive. Excavations are expected to be complete early in the New Year.

(Photo 198.8.86)

An apparent excess of like sign muon pairs was seen by UA1 some time ago, but the number of events was insufficient for physicists to call it a definite physics effect. However, the excess survived the test of more data, and can now be confidently attributed to the mixing of the neutral B mesons carrying beauty and strange quarks — a measurable physics effect due to a particle which has yet to be seen directly!

The appearance of this effect where it was expected adds to physicists' confidence in the underlying theory. The hope is that like its neutral kaon predecessor, the  $B_s$  system will provide another window on the still unexplained mechanism of CP violation. However this would require a much larger data sample.

(From Ahmed Ali, Karsten Eggert, Cecilia Jarlskog.)

## Single photons

As well as interacting through exchange of gluons, quarks are electrically charged and should give off electromagnetic radiation when disturbed. The emission of such single photons from strongly interacting particles is a particularly clean process to calculate, providing a useful check on the underlying theory.

At CERN, pioneer single photon studies were carried out at the Intersecting Storage Rings. With the effect clearly identified, dedicated experiments (NA24 — Bari / Freiburg / Moscow / Munich MPI and WA70 — Geneva / Glasgow / Liverpool / Munich / Neuchâtel) looked at single photon production using high energy beams at the



CERN SPS proton synchrotron.

Picking up these single photons is a difficult job because of the high background due to copiously produced neutral pions which decay into photons and mask the true single photon effect.

The observed single photon signals agree with theoretical calculations. In particular, the production rates using negative pions are higher than those using positive pions because collisions of negative pions with protons have more quark-antiquark annihilation possibilities.

The challenge of detecting these rare single photons was also taken up by the UA2 experiment at CERN's proton-antiproton Collider.

At these energies, the single photon production rate is expected to be nearly four orders of magnitude down on that of hadron 'jets'. After painstaking analysis to eliminate background, the UA2 single photon signal is isolated and found to agree nicely with theory. In particular, the production level increases by a factor of 1.14 when the collision energy is pushed from 546 GeV to 630 GeV.

Pioneer studies of the single photons emerging from the collisions of strongly interacting nuclear particles were made by what went on to become the Axial Field Spectrometer (AFS) group, working at the CERN Intersecting Storage Rings.

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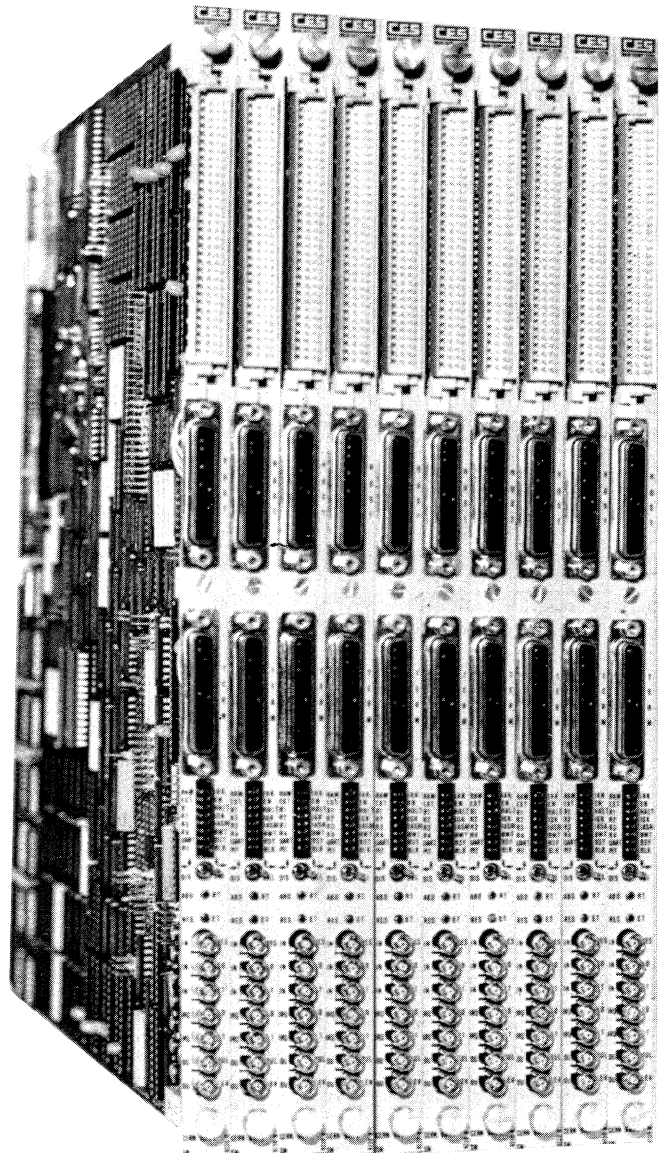
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To learn more about photons, the group went on to look at the low energy electron-positron pairs produced at low transverse momentum (detected through their positron component). These pairs are understood as coming from the otherwise elusive low energy ('soft') photons produced deep inside the collisions. Several other experiments had previously reported an unexplained excess of low energy electron (or muon) pairs at low momentum transfer.

Interesting behaviour is seen when the level of electron-positron pairs observed by AFS is compared with the number of charged particles produced. Instead of a steady proportionality between electron pairs and charged particles, the number of pairs grows as the square of the number of charged particles.

Such unusual behaviour has been predicted by theoretical models which describe the electron pairs as coming from soft photons in the annihilation of quarks and anti-quarks formed early in the collision. The more violent the collision, the greater the number of quarks, and the greater the number of charged particles produced.

This interpretation in terms of a volume effect is of interest to people looking for signs of the long-awaited quark-gluon plasma phase of nuclear matter, when nucleons fuse together. This would also be expected to show a similar effect, but so could a number of other mechanisms. Whatever the explanation for the behaviour seen by AFS, it shows that there is still a lot more to learn about soft hadron interactions.

*Murdock Gilchriese, Chairman of the Task Force on Detector Research and Development for the proposed US Superconducting Supercollider.*

## SUPERCOLLIDER Superdetector

Its design report complete, the proposed 85 km US Superconducting Supercollider, the SSC, waits for its go-ahead from the US Administration. In parallel with the compilation of the design report (see July / August issue, page 12), additional effort has helped prepare for this enormous project.

Last year the SSC Central Design Group set up a Task Force on Detector Research and Development, chaired by Murdock Gilchriese of Cornell. To help it in its task, working groups were set up to cover specialist areas — tracking devices (chaired by Dave Nygren of Berkeley); calorimetry (Brad Cox of Fermilab); electronics, triggering, data acquisition and computing (Don Hartill of Cornell); particle identification (Gilchriese); superconducting magnets (Shigeki Mori of Tsukuba, Japan); simulation (Frank Paige of Brookhaven).

The Task Force summarizes its report by recommending 'that a vigorous programme of basic, generic research and development for SSC detector needs should begin within the next year. This should have as its highest priority



the investigation of those areas which will involve major detector subsystems at the SSC, and those areas which require solutions of problems unique to the SSC environment. Such areas include radiation damage studies of all relevant devices, increases in speed of tracking and calorimetric detectors and of associated electronics, new methods of particle tracking and calorimetry in high particle fluxes, and cost reduction of electronics.

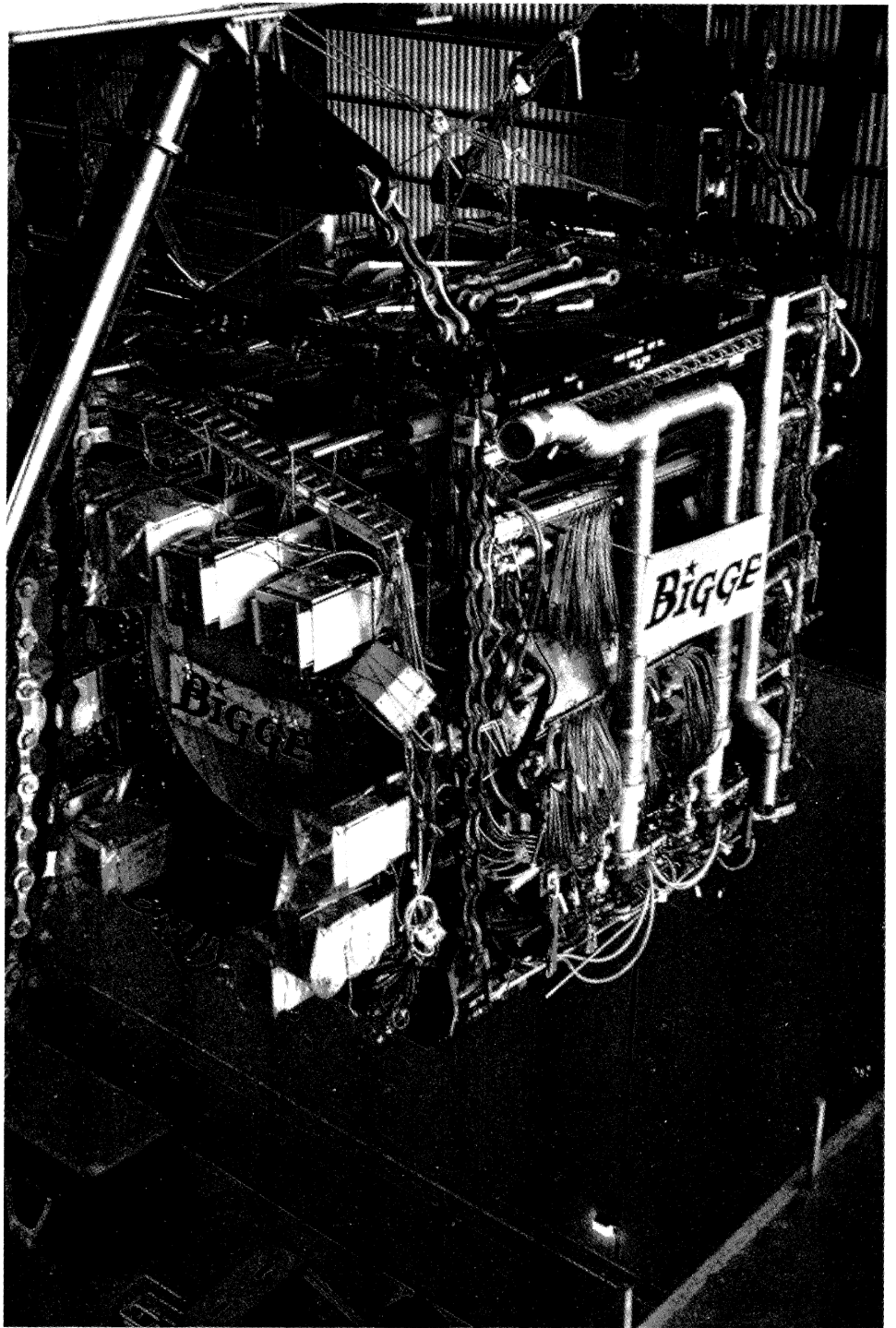
Although traditionally detector R & D has, in general, accompanied proposals for specific experiments, we believe that a generic R & D programme not related to specific detector proposals is required for the SSC era. First, there are many common problems associated with constructing detectors for the SSC, for example radiation damage and electronics development. Second, the timescale for the construction of major detector subsystems, tracking and calorimetry, is likely to be long, given the expected complexity of large detectors at the SSC. Decisions regarding the type of such subsystems must be made early, and basic research on new techniques must be completed before these decisions are made. Third, the extrapolation required from present detector technology to the needs of the SSC is greater than that required for the machines which will have preceded it. Substantially more basic R & D is needed to provide effective solutions. Finally, the SSC will represent an increased opportunity and need for international collaboration in the construction of detectors and operation of experiments. The concomitant organizational scale suggests that an early start to detector R & D will greatly improve the probability of having effective detectors available early.

The Task Force also recommends that the Central Design Group at Berkeley should play a leading role in encouraging detector R & D. At present the CDG is uniquely qualified to act as an advocate for a strong programme of SSC detector R & D at the international level. However, we do not recommend that the CDG act as sole coordinator at this time. It is our hope that there will be sufficient interest in the international high energy physics community for continuing existing R & D relevant to the SSC and for initiating new programmes where necessary.

However, we do wish to emphasize that a programme of basic detector R & D is crucial to the success of experiments at the SSC and that future circumstances may require more direct involvement of the CDG or another coordinating agency in facilitating it. We therefore recommend that the status of detector R & D related to the SSC be reviewed within the next year. While our report attempts to outline R & D needs in a general context, a review within the next year should develop, if necessary, a specific programme and timetable.'

▲ The Mark II detector dangles perilously over the 56 ft pit around the final focus of the Stanford Linear Collider, now nearing completion. After having seen service at both the SPEAR and PEP electron-positron rings at Stanford, Mark II hopes to catch the first SLC collisions early next year.

(Photo Gerhard Fischer)



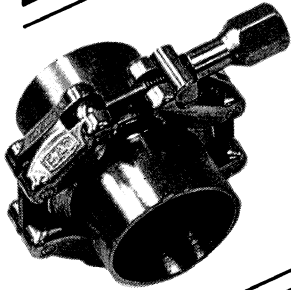
► Installation work is nearing completion for the arcs and final focus to bring the electrons and positrons from the new Stanford Linear Collider into collision. Seen here is the end of the South arc (to handle positrons) immediately before the final focus section.

(Photo Joe Faust)



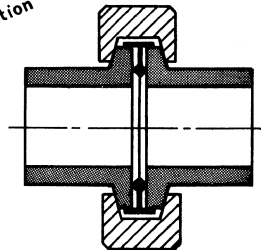
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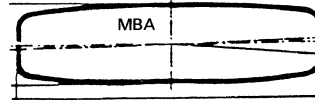
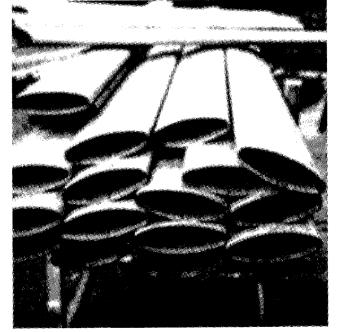
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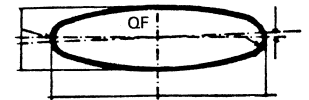


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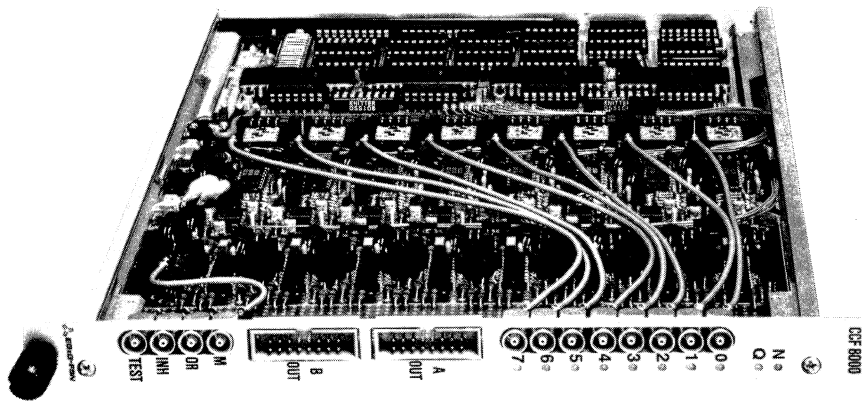


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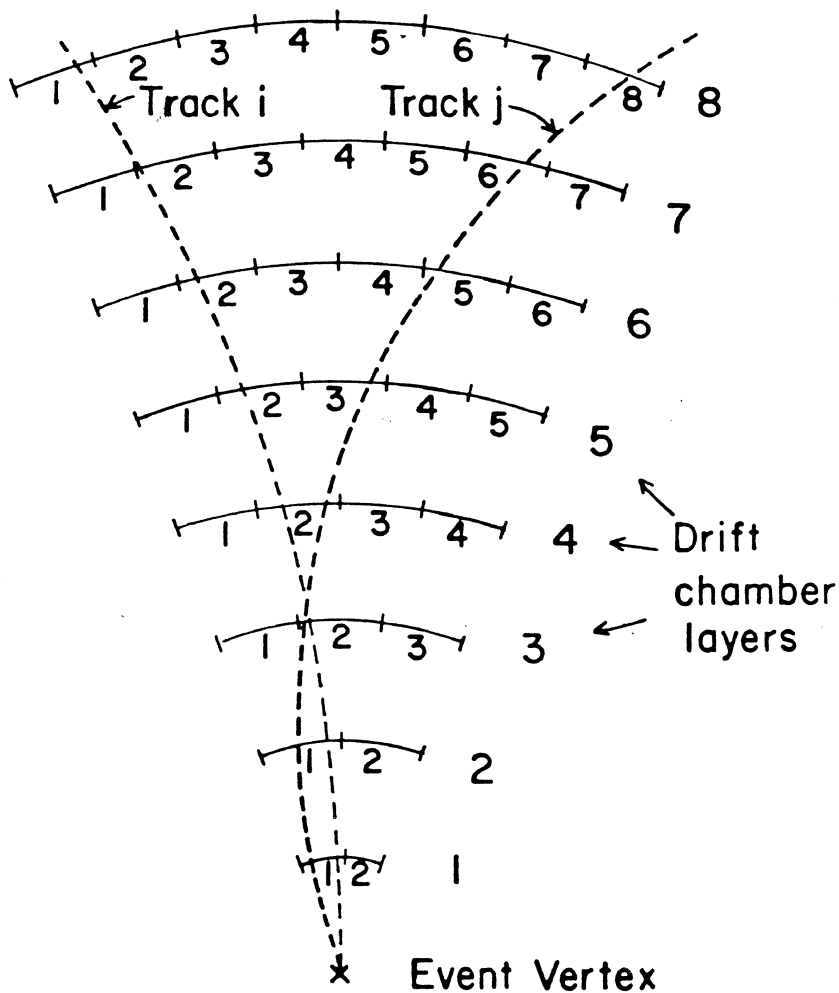
## Making tracks

At the heart of the big detectors used at high energy colliders, tracking chambers pick up signals from the secondary particles produced in the collisions. These trackers frequently use strings of 'sense wires', and a vital job is to process the information from the 'hits' made by particles on the wires and reconstruct what the collision looked like.

In many modern tracking chambers, the sense wires, rather than being lined up uniformly, are grouped into clusters to facilitate the pattern recognition process. However, with higher energy machines providing collisions richer in secondary particles, event reconstruction becomes more complicated.

A Caltech / Illinois / SLAC / Washington group developed an ingenious track finding and fitting approach for the Mark III detector used at the SPEAR electron-positron ring at SLAC (Stanford). This capitalizes on the detector's triggering, which uses programmable logic circuits operating in parallel, each 'knowing' the cell patterns for all tracks passing through a specific portion of the tracker (drift chamber).

To process the input, the Mark III group use a dictionary which contains all 12,832 cell hit patterns corresponding to real tracks. For each event, the pattern of hits is compared with this dictionary. This approach



Track i = (1, 1, 2, 2, 2, 2, 2, 1)

Track j = (1, 1, 2, 2, 3, 5, 6, 8)

is fast as it avoids the need for numerical computation.

Combined with improved track fitting, this pattern recognition method triples the speed of the operation, while giving more reliable tracking.

A recent article (June issue,

'Dictionary' definition of a particle track, illustrating the technique developed for the Mark III detector at the SPEAR electron-positron collider at Stanford.

page 27), described how track reconstruction has been implemented on a 'super' vector computer.

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## STANFORD Mark III

Although no longer in the centre of the high energy physics stage, the team using the Mark III detector to study electron-positron collisions at Stanford's SPEAR ring has steadily accumulated many valuable new results. Mark III's physics may lack glamour, but it doesn't lack dedication. With the decays of many heavy particles still in a turmoil, this commendable effort will continue for several more years.

One early milestone Mark III result was to determine the nature of the eta-c particle, a charmed quark and antiquark bound together with their spins antiparallel. The eta-c seems to like decaying into states with strange quarks.

Also in 1983 came the sighting of a mysterious state at 2.2 GeV in the decays of J/psi particles producing a photon and a pair of charged kaons not seen in other electron-positron collider experiments, but consistently seen in the large Mark III data samples.

In the radiative decays of J/psi (producing photons) unusual states are found which are candidates for 'glueballs' — states containing gluons rather than quarks. They appear to decay predominantly into particles containing strange quarks. However, the glueball candidate pattern in other types of experiments looks different and the situation is confused.

New studies of J/psi decays producing hadrons throw light on the quark content of new meson states; however here again there are many puzzling features, and

conclusions are difficult to draw.

Other results have provided new insights into the behaviour of charmed mesons. Direct measurements of the decays of charged and neutral D mesons have implications for other experiments which rely on these results to extract charm production levels.

Due to construction work for the new Stanford Linear Collider, the next Mark III run is not scheduled until next February. In the meantime a new high resolution vertex detector is being built to surround the beryllium beam pipe.

Although physics has marched on, the decays of charmed particles have yet to be completely sorted out. In this and other areas the collaboration sees at least another three years of careful work ahead.

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# Physics monitor

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## Channeling efforts

Channeling is the process where charged particles are steered by the rows or planes of atoms in a perfect crystal. During the last decade there has been an increasing realization that channeling at GeV energies might be interesting. Beautiful pioneering work by an Aarhus-CERN group laid the foundation for such investigations. At Fermilab, Tsyganov conceived the idea of using channeling in crystals to deflect particle beams and went on to demonstrate the technique at Dubna (USSR). During the same

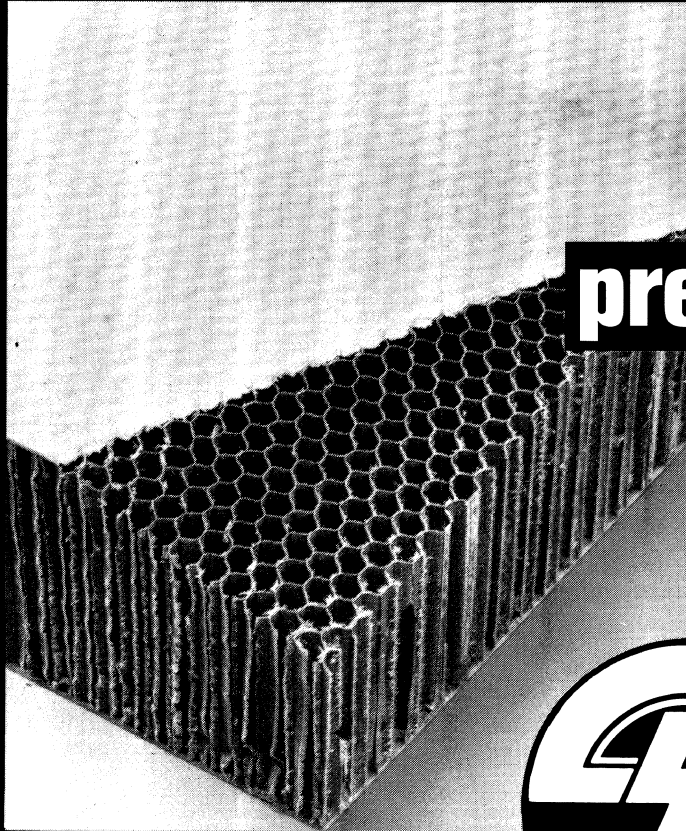
period, Kumakhov pointed out that electrons and positrons moving in channeling trajectories should radiate. By now GeV-scale channeling and channeling radiation experiments have been carried out at laboratories all over the world. Recently a NATO Advanced Scientific Workshop was held at Villa Del Mare in Maratea, Italy, to review the field and appraise the future possibilities for channeling activity. The workshop was co-sponsored by the Danish Committee for Accelerator Physics. The workshop directors were Dick Carrigan of Fermilab and Jim Ellison of the University of New Mexico.

By now many features of channeling are well understood. Theo-

retical models of dechanneling in the low MeV region conform well to experiments and seem to extrapolate in agreement with experiment up to 800 GeV.

Channeling radiation has now been studied from below 1 MeV to more than 100 GeV. These studies have looked at both electrons and positrons and a wide variety of materials. Channeling radiation, even though distinctively different for electrons and positrons, is closely related to coherent bremsstrahlung and there are regimes where the two processes can mix.

At GeV energies a classical picture is appropriate for channeling radiation while MeV channeling



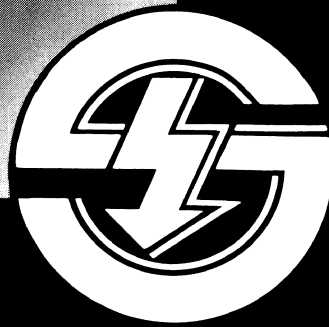
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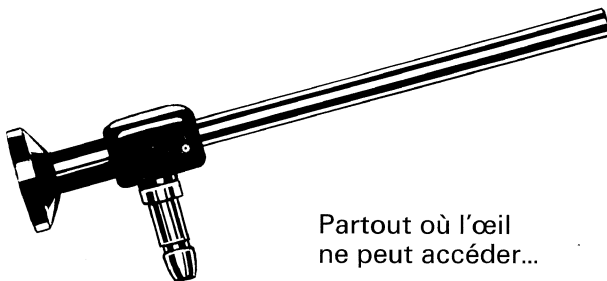
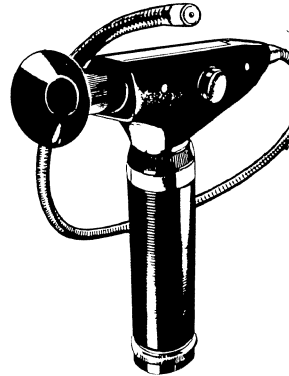
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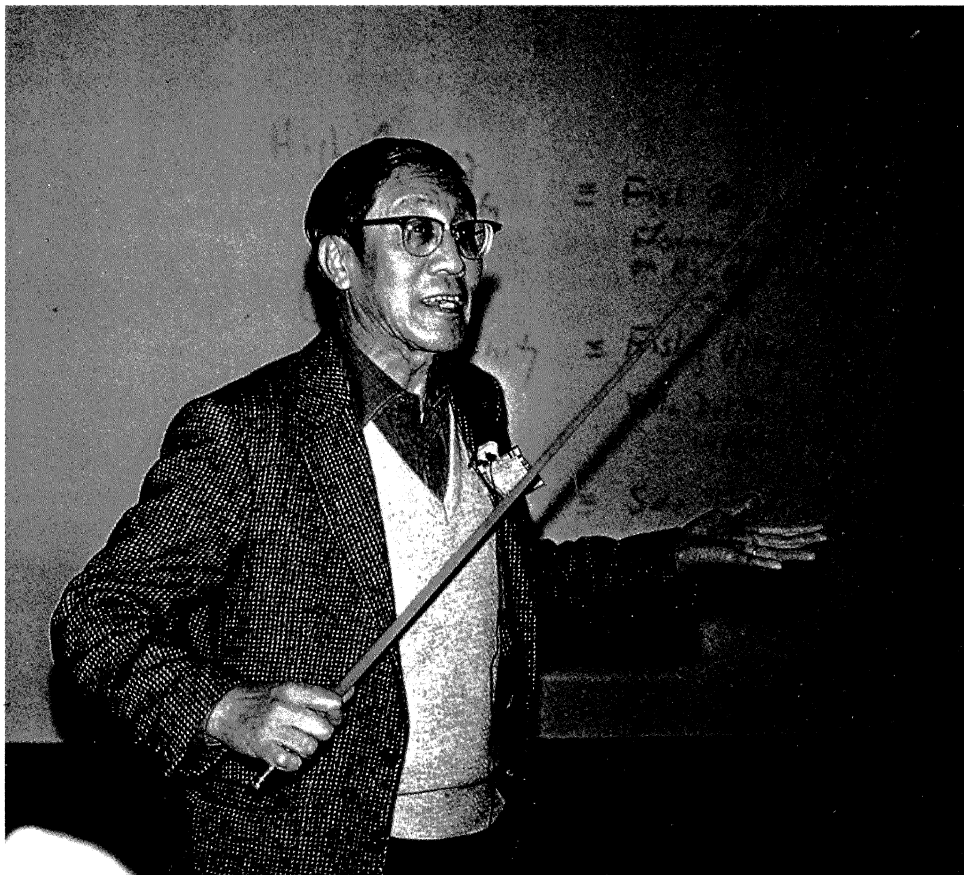
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*C. R. Sun of the State University of New York, Albany, at the recent workshop on relativistic channeling held at Villa Del Mare in Maratea, Italy.*



radiation requires a quantum treatment. Both for low energy electrons and GeV particles, the experiments are in good agreement with theory. However, in the region from 10 to 100 MeV there appears to be some real disagreement.

In the last few years Cue and Kimball at the State University of New York, Albany, have looked at strong field effects for pair production and other processes in aligned crystals. These are not due to channeling but are more general alignment effects and in some ways resemble coherent bremsstrahlung. For crystal fields of  $5.0 \times 10^{10}$  volts per centimetre (characteristic of a string of nuclear centres in silicon) strong field effects appear at photon energies somewhere between 100 and

1 000 GeV giving rise to a pseudo-threshold. Recently a nice experiment has been carried out at CERN within the NA33 collaboration by a group from Lyon, Annecy, and Albany. This group has seen the pseudo-threshold and also examined the angular dependence of the effect. Calculations and theory now agree in some detail for the process.

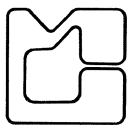
A number of possibilities exist for channeling applications. For example, since the photon yield for aligned crystals is so much higher it may be useful to incorporate crystals in existing electron beams that are used to produce photons.

Channeling in bent crystals has now been used for several realistic beam bending applications. At

Fermilab a crystal was used to attenuate an 800 GeV beam by a factor of 1000. Such beam throttle applications occur quite frequently when primary beams are being used to study short-lived particle cross-sections. A crystal has also been used to extract beam from the Dubna Synchro-Phasotron with an extraction efficiency of one part in ten thousand. Sun and others have also looked at the possibility of crystals for extraction from the proposed US Superconducting Supercollider. The alternative to a crystal is an electrostatic septum hundreds of metres long using thin wires. An interesting practical sidelight on the possibility of bent crystals for an extraction septum is the work on permanently bent crystals by a Chalk River group working at Fermilab. Chalk River along with Bell Northern has bent germanium crystals through many milliradians using micron-thick layers of sputtered zinc oxide to form the one convex face of a crystal.

Another particle physics application that has been suggested is the use of bent crystals to provide an unbiased trigger for short-lived particles. In essence a sample of short and long-lived particles is snatched away from the forward production direction and transported around the crystal bend. Long-lived particles survive the bend while short-lived particles decay as they traverse the bend.

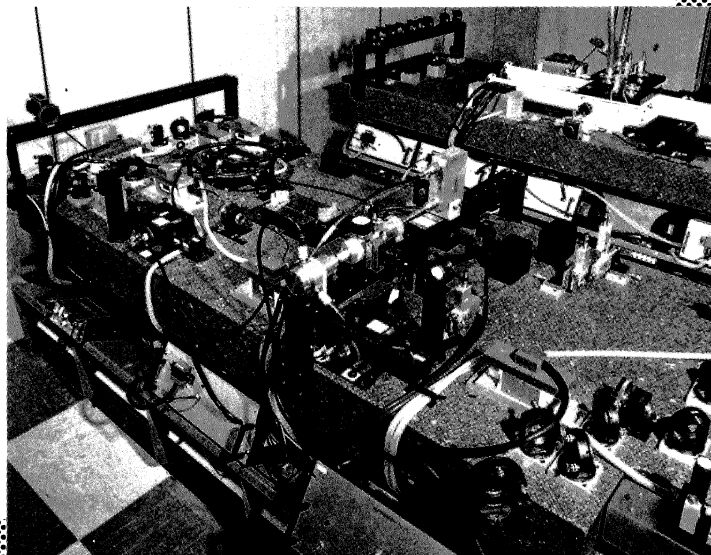
If a short-lived particle can be captured in a bent crystal, then its magnetic moment would precess under the influence of the crystal electric field which acts like a magnetic field in the particle rest system. Thus it could become possible to make magnetic moment measurements on short-lived particles.



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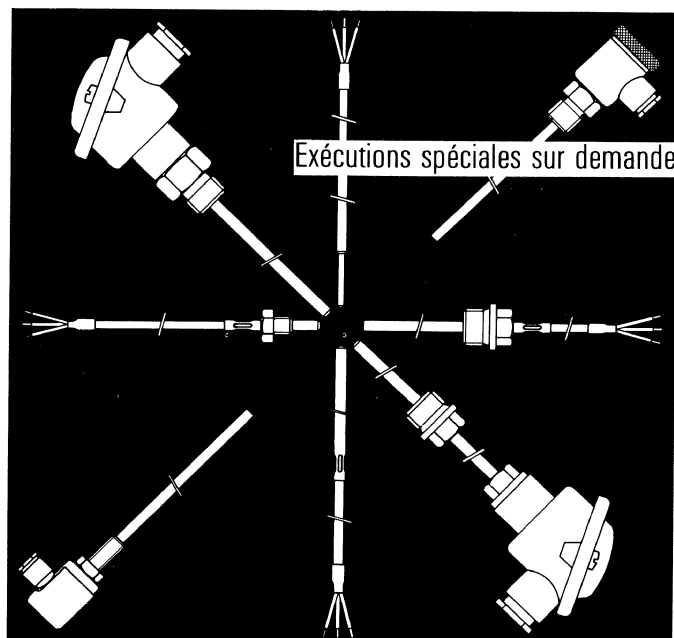
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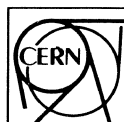
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A number of applications have also been discussed for channeling radiation. The radiation from axially channeled particles can be very intense with a broad spectrum, while planar channeled positrons produce sharp photon peaks. Uggerhoj has pointed out that a 1-10 GeV positron beam from an accelerator such as DESY could be used to produce a tunable monoenergetic MeV photon source for photo-nuclear work. For a crystal thickness around 1 mm, the yield would be about 1 photon/positron. It may also be possible to produce a laser using channeling radiation. The concept is to pump the crystal with an optical laser and then use the electron beam to drive the high energy lasing action. There is also surprising interest by electron microscopists in the features of channeling radiation. The radiation has potential use in crystal alignment and the very small beam size makes it possible to use micron-size crystals so that a much wider variety of crystals could be investigated.

Interest is also building in the use of relativistic channeling and channeling radiation for various material science applications. Already channeling radiation has been used to measure crystal potentials, thermal vibration amplitudes, and defect densities. Also the effects of diamond platelets and superlattice structure on the channeling radiation spectrum have been investigated.

A channeling technique that has been used for material studies is to implant ions such as mesons and look at the blocking patterns that develop in the crystal when they decay. Blocking is essentially the inverse of ordinary channeling. Some of the ions that have been implanted include radioactive in-

dium, positive pions, and muons. Blocking of the charged decay products can be used to investigate ion location within the lattice including the effects of annealing. The technique is complementary to Mössbauer and angular correlation studies. Pion and muon implantations have been carried out at both SIN and LAMPF. The experiments are not easy; one needs very large crystals, high particle fluxes, and quite a bit of space around the apparatus to achieve the necessary resolution for blocking studies. Kaons may also be interesting, and future kaon factory plans may want to allow for this technique.

Another technique that is just coming into its own is high energy heavy ion channeling. Work is now under way at GANIL, France.

A persistent theme is radiation damage. In practice there is little damage to the lattice for fluences less than  $10^{18}/\text{cm}^2$ , but channeling techniques can shed more light on the entire process of damage in many other processes.

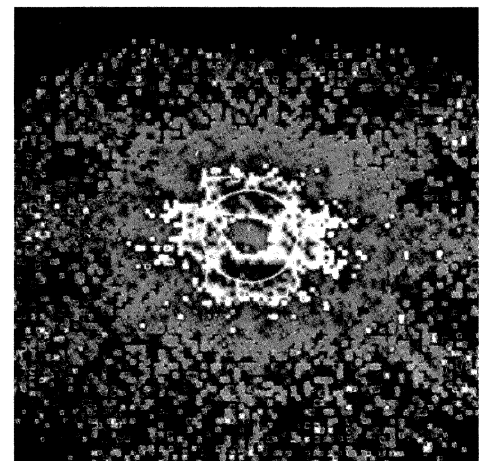
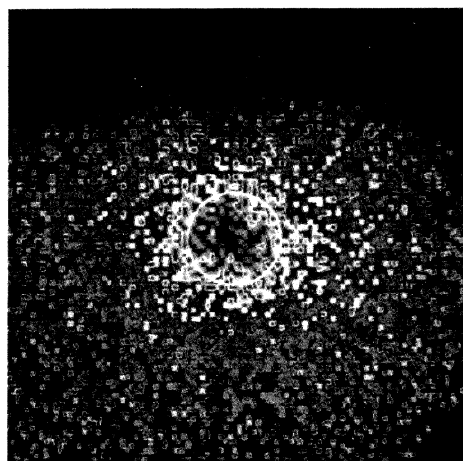
While channeling may constitute a useful tool for material scientists, applications of channeling call for extra effort on their part. In particular, many channeling applications

require large, almost perfect crystals. Fortunately a billion dollar research effort by the semiconductor industry has produced satisfactory silicon and germanium crystals. On the other hand, some metallic crystals are essentially impossible to work with. Even picking up a copper single crystal can render it useless.

In summary, the basic relativistic channeling and channeling radiation processes are understood well enough so that they can be applied with some confidence. It is remarkable that the theoretical description of the channeling phenomena has been shown to cover an energy range from below an MeV to hundreds of GeV. Many applications of relativistic channeling and channeling radiation are now in use and a number of other possibilities appear interesting.

*By Dick Carrigan and Jim Ellison.*

*Electrons and positrons moving near an axis of a silicon crystal in a recent Aarhus/CERN channeling experiment show markedly different behaviour. Electrons (left) are bound tightly to the crystal "strings" and radiate along the axis, while positrons (right) are repelled by the strings. Positrons can also be bound between atomic planes, giving rise to the double bands radiating outwards.*



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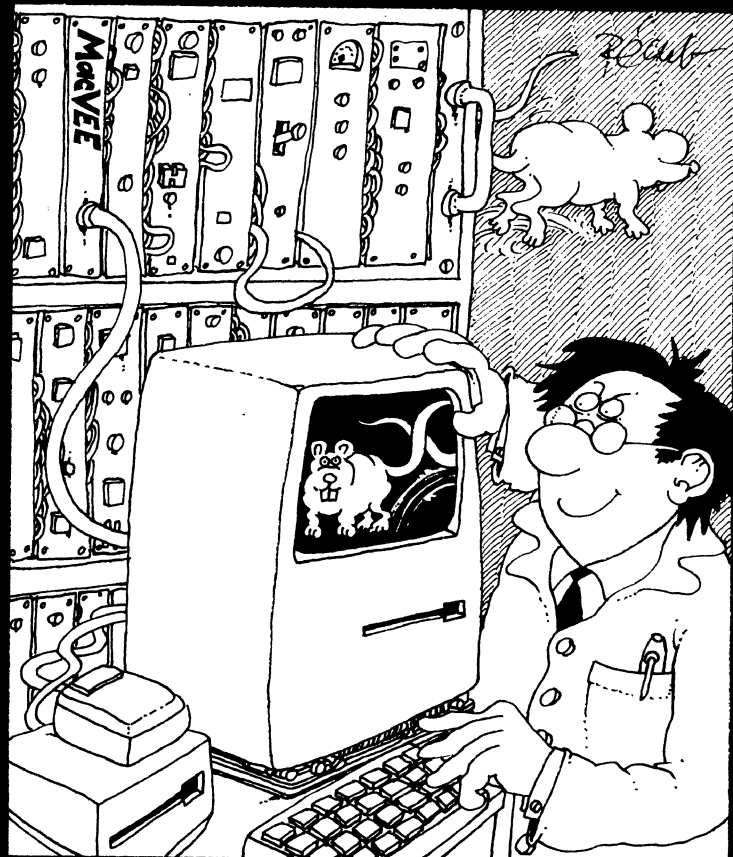
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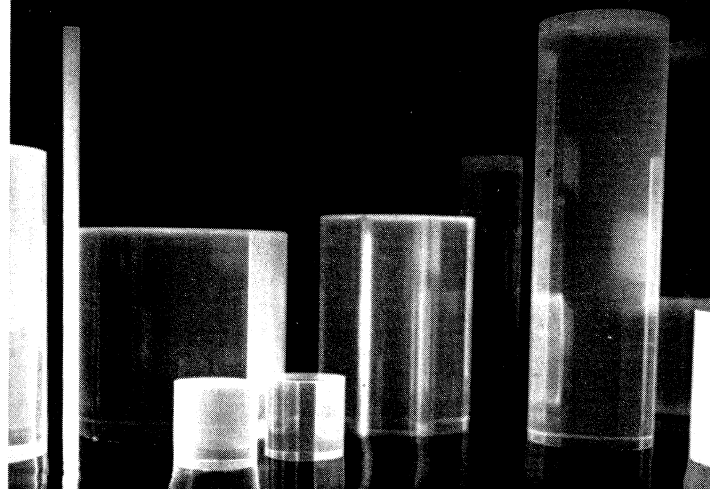
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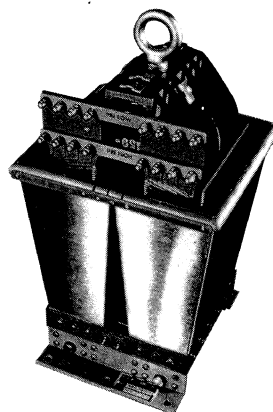
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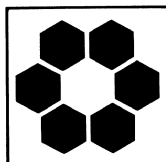
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# People and things

*Helen Edwards of Fermilab —  
E. O. Lawrence Memorial Award.*

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## On people

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*Sir Rudolf Peierls, Emeritus Professor of Theoretical Physics at the University of Oxford, has been awarded the Copley Medal of the UK Royal Society in recognition of his fundamental contributions over a wide range of topics and his pioneering work towards nuclear chain reactions.*

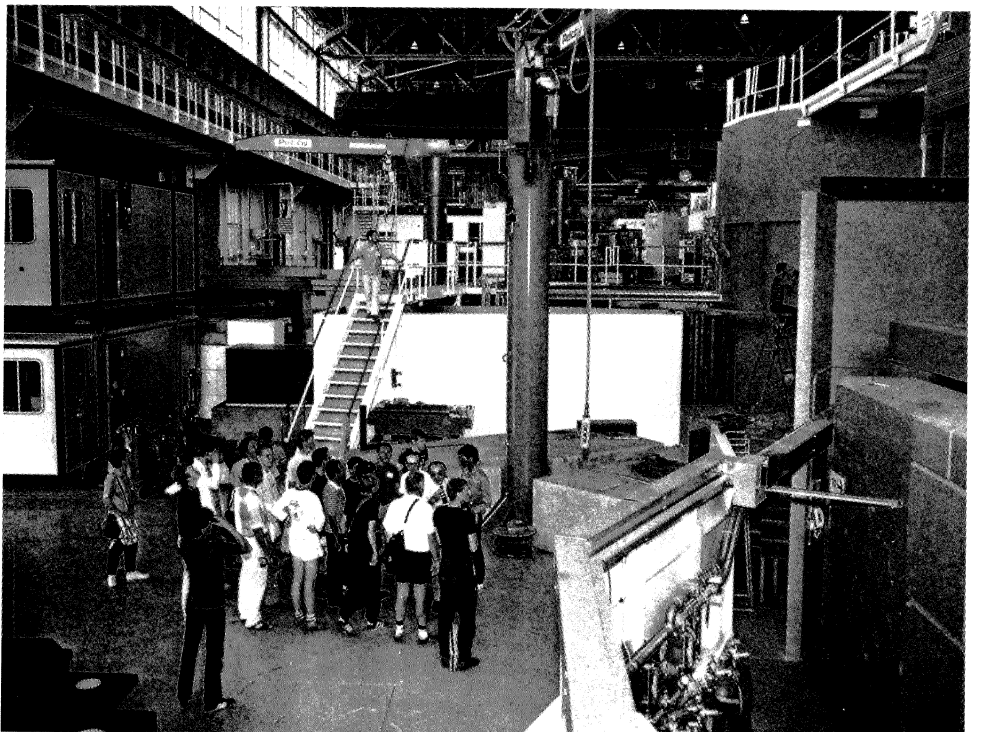
*Helen Edwards from Fermilab was amongst the six recipients of the 1986 Lawrence Memorial Awards for her key role in bringing the world's first large superconducting accelerator, the Tevatron, into operation.*

*Among those who received US National Medals of Science from President Reagan at the White House earlier this year were H. Richard Crane of Michigan, Herman Feshbach of MIT, Robert Hofstadter of Stanford and Chen Ning Yang of the State University of New York, Stony Brook.*

*Spanish theorist Luis E. Ibanez has been awarded the King Carlos 1st prize for outstanding junior investigators. Alberto Galindo and Pere Pascual shared the prestigious Ramon y Cajal award for their lifetime labours in furthering modern theoretical particle physics in Spain.*

*In July, some competitors in the XVII International Physics Olympiad in London visited the Rutherford Appleton Laboratory, and are seen here at the ISIS pulsed neutron source. The Olympiad is a competition for pre-university students and involves both theoretical and practical examinations.*

*(Photo Rutherford Appleton)*



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We are seeking scientists to fill a number of full-time positions in the research division. Significant areas of research and studies will include spectrometer design and development, instrumentation for experimental equipment and halls, and development of the general physics program. Our philosophy is to find individuals who will both contribute to our long-range research effort and to the development of state-of-the-art tools for a new generation of nuclear physics experiments.

Interested applicants should submit a curriculum vitae, list of publications and three professional references to:

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The Nuclear Physics section (K) of NIKHEF, the Netherlands' National Institute for Nuclear Physics and High-Energy Physics, has two openings for a position resident at Geneva (CERN) for an

## **Experimental Postdoctoral Physicist (m/f)**

to participate in the New Muon collaboration (NMC) which has an approved research programme on the EMC-effect and related QCD-aspects of nuclei at the 300 GeV muon beam at CERN. They will act as local contact person and supervisor of PhD students of the recently initiated Dutch participation in this programme. Experience in High-Energy and/or Nuclear Physics Instrumentation is required.

The appointment will be for two years with the Foundation for Fundamental Research on Matter (FOM). Information can be obtained from Dr. R. van Dantzig, tel. (20) 5920120 or 430315.

Candidates are invited to apply within a month after appearance of this advertisement, while enclosing a curriculum vitae and names of referees, to

**Prof. Dr. G. van Middelkoop,  
Scientific Director  
of NIKHEF section K,  
P.O. Box 4395,  
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## **RESEARCH SCIENTISTS EXPERIMENTAL HIGH ENERGY PHYSICS**

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Two prominent CERN physicists, experimentalist Charles Peyrou and theorist Jacques Prentki, both now retired, receive 1986 Grand Prix of the Académie française.

Eric Forsyth has been appointed Chairman of Brookhaven's new Accelerator Development Department which is responsible for the Laboratory's role in the proposed US Superconducting Supercollider, the construction of the new Booster for the Alternating Gradient Synchrotron, and the technical development for the proposed Relativistic Heavy Ion Collider.

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#### Dirac Medals

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The 1986 Dirac Medals of the International Centre for Theoretical Physics, Trieste, Italy, have been awarded to Yoichiro Nambu and Alexander Polyakov for their important contributions to mathematical physics.

Nambu, of the Enrico Fermi Institute, Chicago, receives the award for his work in spontaneous symmetry breaking, for his formulations of quark models and for his geometrical interpretations of dual resonance models.

Polyakov, from the Landau Institute, Moscow, is cited for his work in applications of scale invariance and topology in quantum field theory, and for the discovery of new field theory solutions (monopoles, instantons).

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#### Lev Lapidus

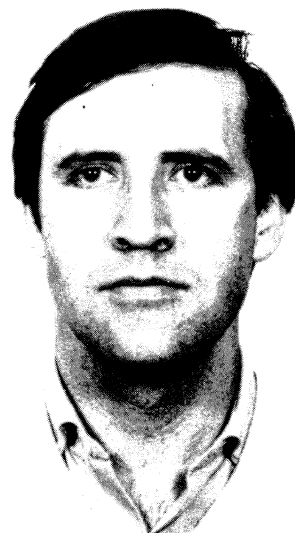
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Lev I. Lapidus, a leading physicist at the Joint Institute for Nuclear Research, Dubna, USSR, died on

15 May. For more than 20 years he had been the Vice Director of JINR's Laboratory of Nuclear Problems, and was widely recognized for his theoretical work on a range of particle physics questions.

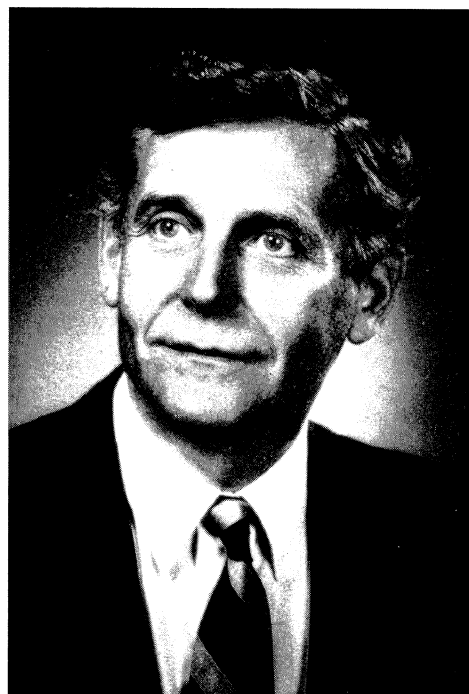
## Physics marathon

The Sunday separating the parallel and plenary sessions at the Berkeley meeting (see page 1) coincided with the San Francisco marathon, and five conference participants passed up such attractions as a champagne brunch cruise round San Francisco Bay to run the gruelling 26 mile (42 km) circuit. Dennis Nordstrom, Editor of the Particle and Fields issue of Physical Review, crossed the line in 3 hours 23 minutes, among the first 1000 of the 7000 or so finishers. Daniele Dominici of Florence and Geneva took 3 hours 51 minutes, with CERN Courier Editor Gordon Fraser in pursuit 25 minutes behind. Berkeley host Harry Bingham came in later, gallantly paced by Tony Hey from Southampton, UK. Other physicists in the race included Stan Wojcicki of the Superconducting Supercollider Design Group (3 hours 45 minutes) and two students working on the Mark II detector at Stanford — Paul Webber (3 hours 27 minutes) and Eric Soderstrom (3 hours 56 minutes).



▲ Luis E. Ibanez — King Carlos 1st prize (see page 33)

▼ Eric Forsyth is Chairman of Brookhaven's new Accelerator Development Department.



# EXPERIMENTAL HIGH ENERGY PHYSICS UNIVERSITY OF HOUSTON INVITES APPLICATIONS FOR

## Post Doctoral Research Associate

An opening exists at the University of Houston for a Post Doctoral Research Associate. Recent Ph.D's (0-5 years) in Experimental High Energy Physics with strong hardware background are encouraged to apply. This person will initially live in Houston, Texas, to work on the construction of streamer tubes for the LVD experiment at the Gran Sasso Tunnel, Italy. Later assignments will depend upon the course of development of the experiment and may involve residence in Europe for one more years.

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The State University of New York at Stony Brook has several positions available to work in development and testing of modules for the uranium absorber – liquid argon calorimetry for the  $D\bar{0}$  Detector, which will study 2 TeV  $\bar{p}p$  collisions at Fermilab. The calorimetry will be calibrated in a beam test program at Fermilab.  $D\bar{0}$  is expected to have an initial run in 1988. Salary and level of appointment commensurate with experience. Applications, including vitae and 3 letters of reference, should be addressed to:

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The successful applicant will have an advanced degree in physical science or engineering with a broad technical background encompassing electrical engineering and physics. Work experience should include five or more years of experience with the analysis and design of control and instrumentation systems for particle accelerators and storage rings as documented by engineering practice and publications. Formal education or practical experience in accelerator and storage ring physics is highly desirable.

Qualified candidates are encouraged to submit a resume and cover letter highlighting their qualifications to: Carl Cork, #26577, High Energy Physics Laboratory, Hansen Laboratories, Stanford University, Stanford, CA 94305, U.S.A.

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## Continuous Electron Beam Accelerator Facility

# ACCELERATOR SCIENTISTS

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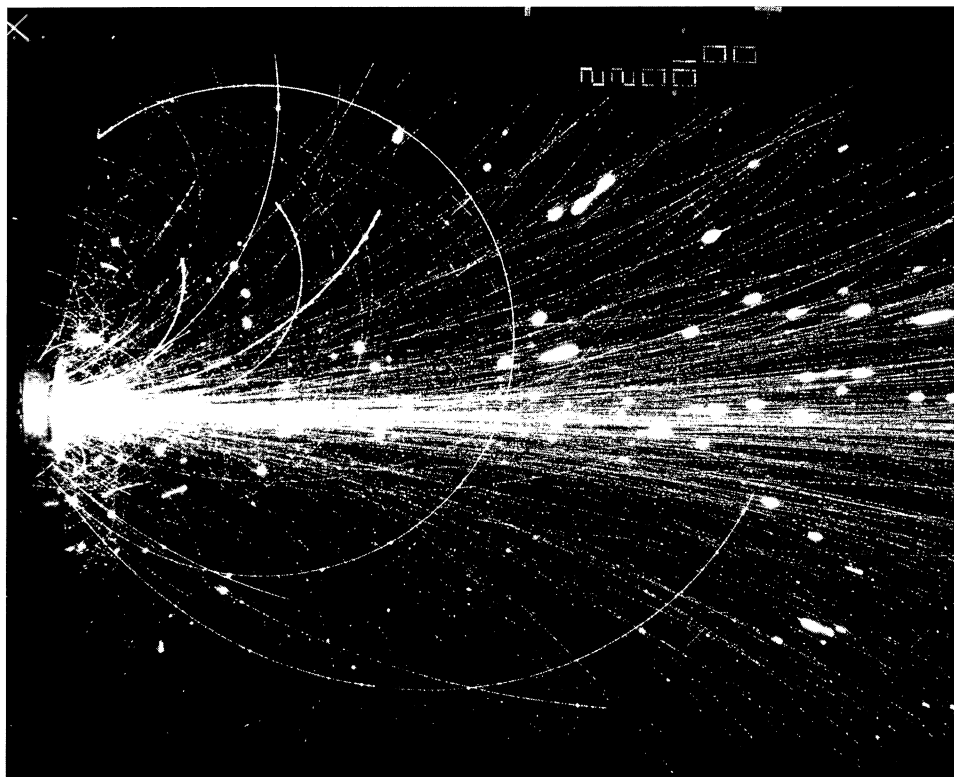
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- RF and feedback
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A streamer chamber picture showing what happens when 3200 GeV (3.2 TeV!) oxygen ions from the CERN machines hit a target.



## CERN's big machines surpass themselves

Already acknowledged as the world's most versatile system of particle accelerators, CERN's complex of big machines put on a spectacular performance after the short summer shutdown.

On 3 September, the new LEP Injection Linac (LIL) was put through its paces and the ejection line tested in readiness for the next step. The next evening the 'Proton' Synchrotron held onto a 500 MeV beam of electrons. In the initial tests, the electrons were not accelerated, but later they were taken up to the 3.5 GeV energy foreseen for injection into the next machine, the SPS, before passing to the new LEP. Thus the PS adds electrons to its already impressive

repertoire of protons, antiprotons, deuterons, alpha particles, and most recently oxygen ions, and the preparations for LEP beams pass another important milestone.

The electrons held only one slot in the complicated 14.4 second PS 'supercycle' supplying also beams of deuterons and oxygen ions ready for injection into the SPS. Thus the PS was hard at work, but supplying no protons at all!

After using the higher intensity deuterons for setting up, on 7 September the big machine had its first taste of oxygen. Suspense as the particles were accelerated to 200 GeV per nucleon — 3200 GeV or 3.2 TeV per ion, the highest

energy beam ever produced! — and fed to waiting experiments. These oxygen beams give currents thousand of times down on those of standard proton beams, and special beam monitoring techniques had to be developed.

At the end of the beamlines, experiments will eagerly search for signs of the long-awaited 'quark-gluon plasma', a new state of nuclear matter. The first physics run is scheduled for November.

### Stan Livingston

*Stanley Livingston, one of the great accelerator pioneers, died in Santa Fe on 26 August. From collaboration with Ernest Lawrence on the construction of the first cyclotron through to participation as Associate Director in the formation of Fermilab, Stan Livingston was a leading figure in the field.*

*Probably his most famous era was his time at Brookhaven when he led construction of the first big proton machine, the Cosmotron, in the early fifties. It was during this time that, together with Ernest Courant and Hartland Snyder, he invented strong focusing — one of the crucial steps in the development of accelerators.*

*He will also be remembered as Director of the Cambridge Electron Accelerator and for his definitive book 'Particle Accelerators' written in collaboration with John Blewett.*

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0-309-03548-1; 1986, 336 pages, paperbound, £30.40/\$38.00

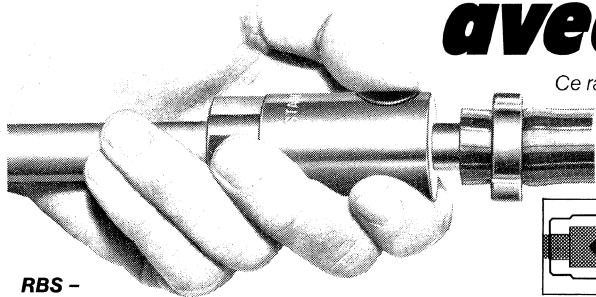
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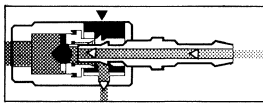
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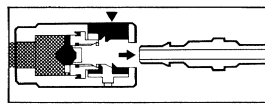
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This year's prizes for Achievement in Accelerator Physics and Technology awarded by the US Particle Accelerator School go to (left to right) Tom Weiland, Helmut Piel and Maury Tigner.

### Accelerator Prizes

This year's prizes for Achievement in Accelerator Physics and Technology awarded by the US Particle Accelerator School go to Tom Weiland of DESY for his work in

the development of novel methods for calculating electromagnetic fields in complex structures, and to Helmut Piel of Wuppertal and Maury Tigner, Director of the Central Design Group of the proposed US Superconducting Supercollider, for 'their contributions to making radiofrequency superconductivity a practical reality'.

The results of Weiland's work are used world-wide in the design of accelerators to minimize para-

sitic wake field effects and to optimize the design of radiofrequency cavities. The push to develop superconducting r.f. techniques has paid dividends and has led to its adoption for large new accelerator projects in Europe, the US and Japan.

The prizes will be awarded at the Joint US/CERN Topical School on Particle Accelerators, South Padre Island, Texas, from 23-29 October.

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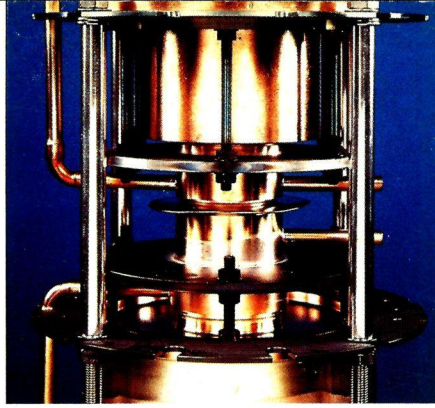
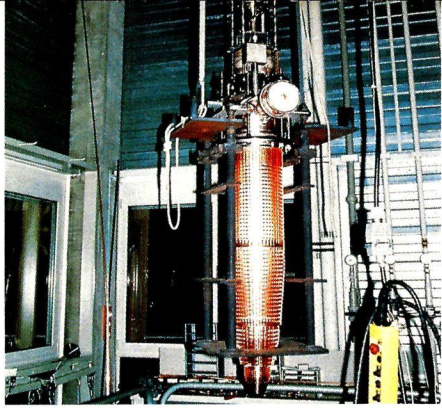
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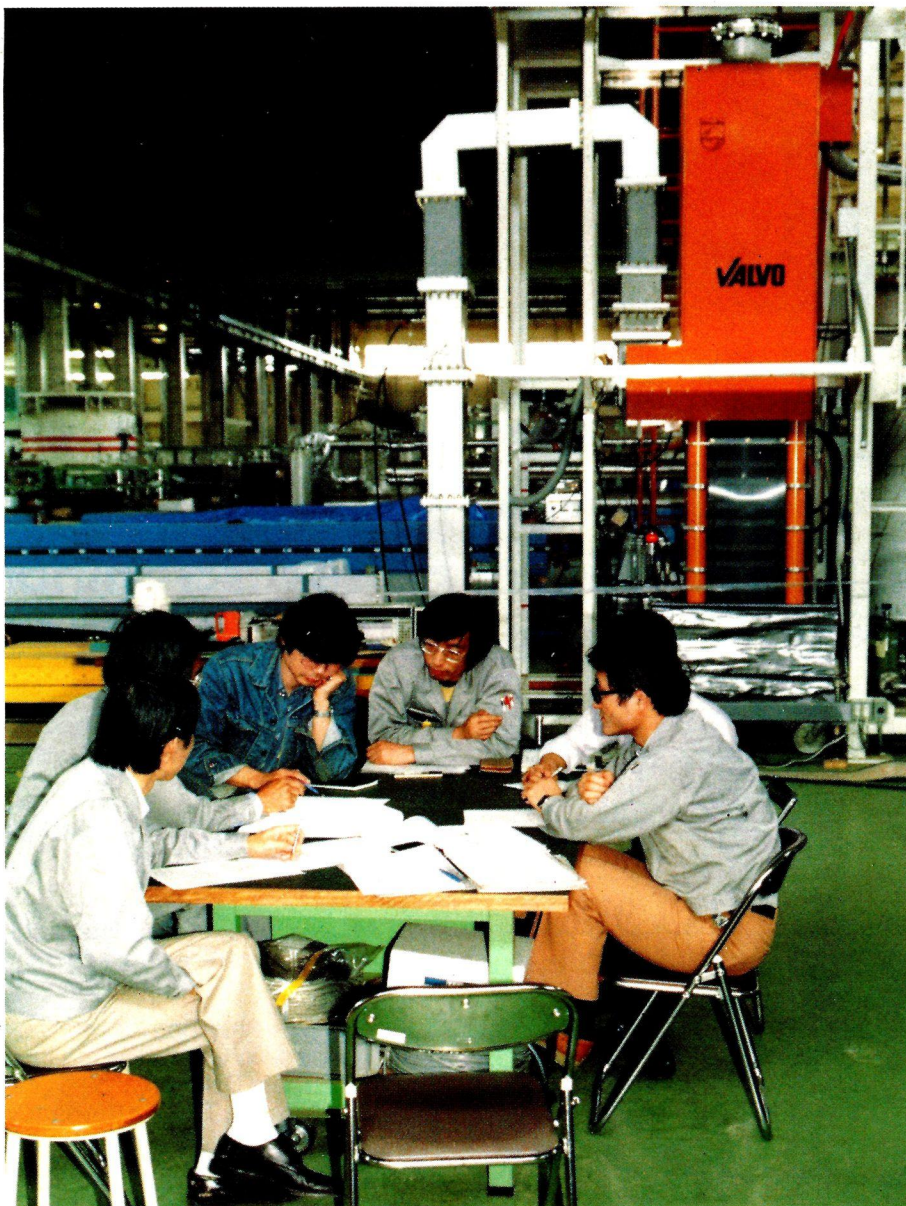
# PHILIPS



## Good luck.

In November, TRISTAN, the largest ring accelerator built to date, will go into action at the Tsukuba Science City in Japan. It will enhance the research facilities of KEK, the National Laboratory for High Energy Physics.

# Power for TRISTAN. We provide it.



PHILIPS wish all those involved at KEK a successful start for the TRISTAN facility, and a future full of rewarding scientific achievements.

The r. f. energy at 508 MHz, needed for particle acceleration is generated by klystrons of 800 kW and 1000 kW output power. Of the installed power of 14 MW, Valvo klystrons provide 9.2 MW. This includes equipment of the 1000 kW stages with 6 YK1303 klystrons.

KEK recently chose Valvo in Germany, the centre of competence for Philips' advanced klystron technology, because of Philips' long experience with large klystrons for major accelerator operations such as DESY and CERN.

In addition to meeting an extremely tight schedule, the specifications demanded by KEK required innovations, such as vapour cooling, which had never been used before with klystrons of this power. The YK1302 and YK1303 are the first vapour-cooled 800 kW and 1000 kW klystrons. The YK1303 is also the first klystron of 1000 kW continuous-wave power at 508 MHz.

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