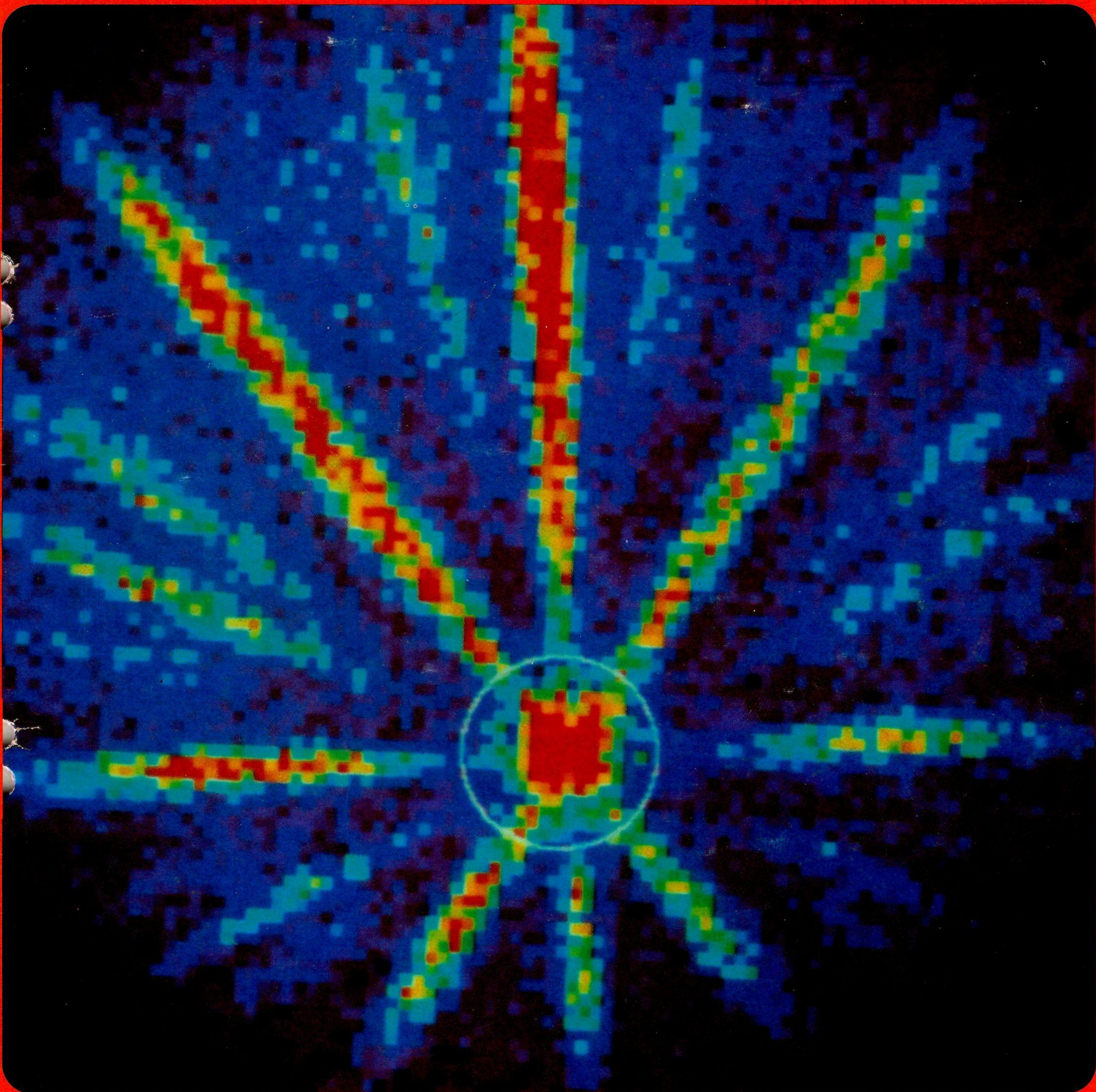
CERN COURIER

International Journal of High Energy Physics



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CERN COURIER

International Journal of the High Energy Physics Community

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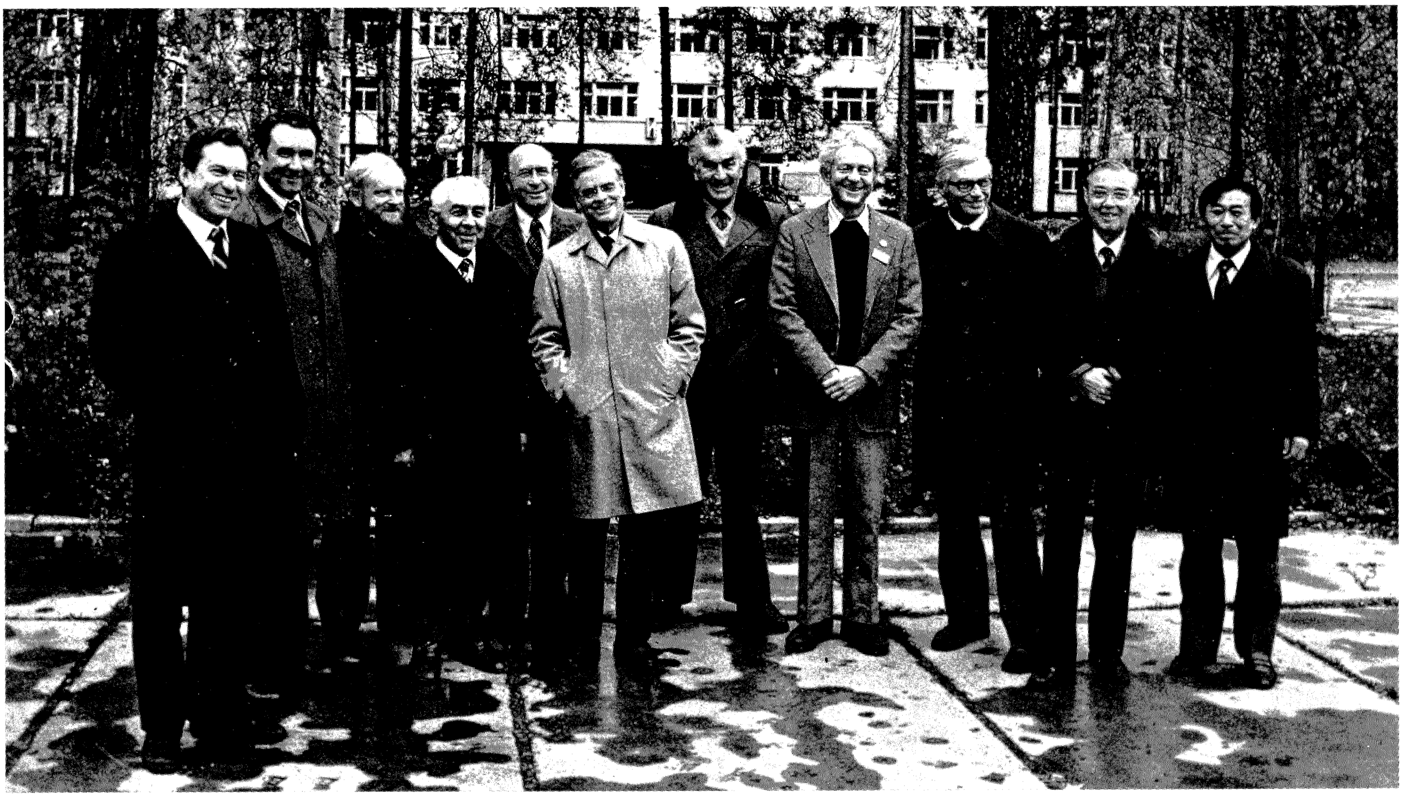
Cover photograph: Intensity distribution of a particle beam passing through a thin crystal, showing the steering effect (channelling) produced by the atomic axes and planes in the crystal in an experiment by an Aarhus/CERN/Strasbourg group (see also page 337).

Future Accelerators Seminar in Japan

Album shot from the 1981 meeting of the International Committee for Future Accelerators at Protvino in the USSR. Left to right: K. Myznikov, V. Yarba, J.H. Mulvey, V.P. Dzelephov, V. Telegdi, R. Wilson, J.B. Adams, L. Lederman, K. Lanius, W.O. Lock and Y. Yamaguchi.

(Photo A.M. Stepanets)



ICFA, the International Committee for Future Accelerators, was set up by the Particles and Fields Commission of the International Union of Pure and Applied Physics (IUPAP) in 1976. Its mandate was 'To organize workshops for the study of problems related to an international super-high energy accelerator complex (VBA) and to elaborate the framework of its construction and of its use. To organize meetings for the exchange of information on future plans of regional facilities and for the formulation of advice on joint studies and uses.'

In the seven years of its existence (it first met in August 1977), ICFA has organized three workshops on the first topic — two on 'Possibilities and Limitations of Accelerators and Detectors' (Fermilab, 1978 and Les Diablerets, 1979) and one on 'Possibilities and Limitations for Superconducting Accelerator Magnets' (Protvino, 1981). At an ICFA meeting at Fermilab in August 1983, it was realized that the second topic had been somewhat neglected. It was therefore decided to postpone a fourth workshop scheduled at the Japanese National Laboratory for High Energy Physics (KEK) and to organize instead a Seminar on 'Future Perspectives in High Energy Physics' similar to that held in New Orleans in 1975, which had in fact led to the creation of ICFA.

The Seminar (jointly hosted by the Institute of Nuclear Study of Tokyo University and KEK, with support from the Ministry of Education, Science and Culture, the Yamada Science Foundation and the Nishina Memorial Foundation) took place from 14-20 May. There were about a hundred participants, mostly senior scientists from Western and Eastern Europe, USA, USSR and Japan (including the Directors of almost all the major high energy physics Laboratories) and representatives from Australia, Canada, China, India, Mexico, South Korea and Vietnam. The seminar was opened by KEK Director General T. Nishikawa, who paid tribute to the late Sir John Adams, ICFA Chairman from 1978 to 1982. This was followed by a videoed 'keynote talk' from V. Weisskopf (see page 322).

The first Session was devoted to the seven accelerator facilities now under construction in different parts of the world. The theoretical scene was set by V.I. Zacharov (ITEP, Moscow) and J. Ellis (CERN), who stressed the importance of electron-positron machines which are equivalent to proton colliders of considerably higher energy, the exact factor depending on the physical process under study, but varying between two and ten. In addition the events are expected to be cleaner and to give more direct information than hadron collisions. These talks were followed by a panel discussion chaired by T. Ekelöf (Uppsala) on Detector and Related Machine and Instrumentation Issues.

Attention focused on calorimetric measurements, muon measurements and minivertex detection with the conclusion that further development of these techniques would be an important task for universities and national Laboratories during the years to come. Because of the large number and scale of many of the devices considered, more collaboration with industry seems desirable.

In the discussion of machine performance it was suggested that hadron colliders should have the highest possible luminosity (even above 10^{33} per cm^2 per s) though most probably the experiments would not be running all the time at the highest rate. It was recommended that ICFA set up a more permanent working panel on Future Instrumentation Innovation and Development to stimulate interregional cooperation on these topics.

Future options for hadron machines now under active discussion were described by M. Tigner (Cornell) and G. Brianti (CERN). Tigner presented the USA reference studies for a 40 TeV collider — 20 TeV per beam. This is the Superconducting Super Collider, SSC, with circumferences varying from 90 to 164 km depending on the magnetic field strength. It is estimated that three years' research and development are required before a final design can be established and Government approval requested. Construction is estimated to take about six years so that the SSC could be operational in 1993-1994. Brianti presented options using the LEP tunnel as covered in the June issue of CERN COURIER, page 185. In one scenario a 10-12 TeV collider could be constructed relatively quickly and cheaply with the possibility of later going to electron-proton collisions of 80 GeV electrons with 6 TeV protons. An alternative, more expensive and time-consuming, requiring the development of the technology for the series production of 10 Tesla superconducting magnets, would be a high luminosity 18 TeV collider.

Accelerator facilities now under construction

Name	Location	Particles	Energy	First operation for physics (estimated)
BEPC	Beijing, China	electrons and positrons	2.8 + 2.8 GeV	1988
TRISTAN	KEK, Japan	electrons and positrons	30 + 30 GeV	1986
SLC	Stanford, USA	electrons and positrons	50 + 50 GeV	1987
LEP	CERN, Geneva	electrons and positrons	Initially 50 + 50 GeV then 100 + 100 GeV	end 1988-early 1989
TEVATRON I	Fermilab, USA	protons and antiprotons	1 + 1 TeV	end 1986-early 1987
HERA	DESY, Germany	electrons and protons	30 + 820 GeVp	1990
UNK	Serpukhov, USSR	protons protons	600 GeV 3 TeV	1990 1992-93

More long-term ideas for high energy electron-positron colliding linacs were put forward by B. Richter (SLAC) and A. N. Skrinsky (Novosibirsk). Richter considered linacs of some 25 km length to achieve 1 TeV in the centre of mass with a luminosity of 10^{33} per cm^2 per s, which would require a power consumption of some 350 MW. If accelerating voltages of 125 MV per m could be achieved, each linac need be 'only' 8 km long. He estimated that three to four more years of detailed study would be required, as well as experience with the linear collider now being built at Stanford, before a design could be envisaged. Accepting this, such accelerators would probably lag some years behind comparable proton machines.

Skrinsky described the VLEPP project (see December 1982 issue, page 417) which would yield 150 GeV colliding beams with linacs of 1.5 km, and power consumption of 15 MW. At a later stage this could be upgraded to 500 GeV, with linacs 5 km long, and 40 MW power consumption. In both cases the luminosity would be 10^{32}. The key issue for such colliding linear accelerators is to achieve the pulsed radiofrequency power and the goal is energy gains of at least 100 MeV per metre. In this respect Skrinsky was more optimistic than Richter, maintaining that after two years' further study a design could be presented and that Stage I of VLEPP could be built within five years of project approval.

After having set the scene for future accelerator possibilities, four speakers gave examples of cooperation in various aspects of research and development. H. Hirabayashi (KEK) spoke on superconducting magnets, Skrinsky on beam dynamics in linear colliders, C. Pellegrini (Brookhaven) on new methods of acceleration and C. W. Fabjan (CERN) on detectors.

The seminar continued with a series of discussion panels. The first, chaired by A. M. Sessler (Berkeley), was on 'Future R and D Cooperation'. Sessler put forward a specific proposal for the creation of a number of ICFA-sponsored groups to coordinate efforts, share personnel and equipment and motivate research in a number of clearly defined fields, such as superconducting magnets, radiofrequency, beam dynamics, novel accelerator schemes, etc. There was a consensus that ICFA could play a valuable role in improving inter-regional collaboration and communication.

The next panel discussion, chaired by W. K. H. Panofsky (SLAC) was on the more delicate topic of cooperation in accelerator construction. Panofsky posed the question 'What would be the best world-wide configuration of colliders from the point of view of science?' L. Lederman (Fermilab) argued the case for the SSC, stressing that physics requires new energy domains in the 1990s. He mentioned that the SSC could perhaps be built on an international basis following the HERA scheme; however, he realized that it will take several years to solve the problem of the balance of facilities among the different regions. Skrinsky underlined the complementary nature of lepton and hadron machines and the need to be prepared for completely new phenomena. In his view a wide range of colliding particles should be available, including nuclear colliders.

H. Schopper (CERN) said that the aim should be to have complementary facilities in the regions, open to all. He gave two examples of a possible distribution of new machines which could be built in the three major regions, with differing timescales depending on their size and complexity. However he said that it was necessary to continue research and development work both on accelerators and detectors, and to see how the Stanford Linear Collider and the upgraded hadron facilities operate, before considering specific scenarios for the 1990s, with the goal of reaching energies five to ten times greater than the machines under construction.

Some speakers felt that the SSC was too expensive compared to various possibilities of hadron colliders in the LEP tunnel; others felt that the main effort in the USA should be on high energy colliding electron-positron linacs. Most participants recognized that the US community needs a new facility in the 1990s and that a hadron collider in the LEP tunnel clearly cannot serve all of the world's high energy physicists. C. Rubbia (CERN) advocated a 'quick' hadron collider in the LEP tunnel open to all as a first step followed by the SSC. Also, if the SLC worked well one could then envisage designing a dedicated high energy linear collider.

Present membership of the International Committee for Future Accelerators (ICFA):
Chairman: V.L. Telegdi.
Secretary: W.O. Lock.
CERN Member States: J. Sacton, H. Schopper.
JINR Member States other than USSR: Nguyen Van Hieu.
USA: B. McDaniel, L. Pondrom, N. Samios.
USSR: E. Myae, A.N. Skrinsky, V.A. Yarba.
Japan: Y. Yamaguchi.
Fourth Region: P.K. Malhotra.
Chairman of IUPAP Particles and Fields Commission (ex officio): L.D. Soloviev.

The final panel discussion, chaired by V. L. Telegdi (ETH, Zurich), addressed the problem of how to achieve what the Panofsky panel had discussed. On the role of ICFA, Richter stressed the importance of its workshops for the development of new ideas which had laid the basis for both the SLC and the SSC, and of its guidelines on the 'open door' policy which is now accepted by all the major high energy Laboratories. However it had not tackled the VBA question, for which the need was not obvious for the next decade at least. He felt that it is not ICFA's role to approve plans for new accelerators, but that it is the responsibility of the regions based on the consensus reached in each region. This viewpoint was generally agreed and it was suggested that ICFA's mandate could be revised to remove the VBA concept, which sometimes gives rise to misleading impressions of what ICFA is trying to do. However, Y. Yamaguchi (Tokyo) expressed the hope that one day a world Laboratory would be created in which the developing countries would also be involved. Other speakers stressed that the needs of the small countries should not be forgotten, and that for many of them the only way to participate in particle physics is via international organizations such as CERN and Dubna.

It was generally accepted that each main region needs a vigorous research programme in high energy physics with complementary facilities open to all. J. H. Mulvey (Oxford) expressed this by saying that in a sense a world Laboratory already exists but on several sites. ICFA's main role would be to sustain this pattern and to encourage collaboration in construction projects. In conclusion, Telegdi stressed the importance for ICFA to carry out its new tasks with enthusiasm and vigour, now that the objectives had been simplified and clarified.

ICFA then had the difficult task of

drawing conclusions from all the ideas expressed. First, ICFA sees its major role as facilitating construction of high energy accelerators and not as arbitrating among regional options. It will promote international collaboration in their construction and use. Second, ICFA agreed to sponsor international panels on Superconducting magnets and cryogenics, Beam dynamics, New accelerator schemes and Future instrumentation, innovation and development. It is hoped to set up these panels at the next ICFA meeting in October 1984. Third, ICFA agreed to convene seminars at regular intervals to review the status of high energy physics and to anticipate future activities.

The arrangements for the Seminar by the Japanese authorities and especially by S. Ozaki, Chairman of the Local Organizing Committee, and his colleagues were excellent. Generous financial assistance meant that a number of participants were able to overcome problems of foreign currency restrictions; in this way the international nature of the Seminar was assured. The Proceedings of the Seminar will be published by KEK.

(We are grateful to Owen Lock for this information.)

Weisskopf's view

The recent ICFA Seminar in Japan was prefaced by a video keynote address sent by Viktor Weisskopf, who expressed ideas about world cooperation in high energy physics.

'The last 30 years have also witnessed a thorough internationalization. Up to the 1950's, the USA had a kind of monopoly on the highest energy machines. That did not prevent a number of important discoveries to be made elsewhere with cosmic rays. But from the mid-fifties on, Laboratories with accelerators at the energy frontier appeared in Western Europe, in the Soviet Union, and in Japan, so that high energy physics became indeed a truly international enterprise. A special significance must be attributed to CERN since it was the first great Laboratory in this field that is internationally owned, run and paid for, albeit only by Western European nations. As such it represents an innovation in the sociology of science of which the Western Europeans are justifiably proud. Together with an analogous international effort at Dubna, it spawned other inter-European activities in astronomy, space science and molecular biology.

The international world character of our field is seen more clearly in the exploitation of the national or regional accelerators. All major accelerators around the world are used and exploited by groups of nationals of other countries or regions than the one which 'owns' the machine. This international exploitation has become more important in the past decades because of the growth in size and cost of modern accelerators and of experimentation. It is no longer possible for one nation or region to have all types of machines necessary for the progress of the field. It is a financial necessity to have the different types of very high energy accelerators distributed over the regions of the globe. Duplications of facilities may be very useful for physics and convenient for the physicists, but we can afford them only for smaller scale machines. Work in other countries is necessary if research is supposed to cover the whole frontier as it should. It is therefore of utmost importance that international exploitation is maintained and facilitated as much as possible.

The world high energy physics community must get together and solve the problem of what should be done where, with the financial, intellectual and technical resources that we expect to be available. It must be the responsibility of the community to find the solution that is best for the progress of our field, best to maintain the enthusiasm of all participants, and best to attract many young people in the field. There is time enough to find a reasonable solution in the coming few years.

Looking at the situation from my own distant point of view, which is further away from the daily, monthly, and yearly struggles in which you all are immersed, I find our field full of strength from past successes and future promises. The problems and the clashes of interest stem from an overflow of ideas, projects and possibilities, from an 'embarras de richesses' rather than from internal weakness. We have reasons to be proud of our world community in the past. Let us keep our standards of cooperation and mutual understanding. Only then will we be able to continue our great search of the innermost structure of nature.'

CERN under the microscope

Two researchers, John Irvine and Ben Martin, from the Science Policy Research Unit at the University of Sussex, Brighton, UK, have just published the results of a study 'CERN: past performance and future prospects' which they have carried out over the past few years. The study is reported in three papers — 'CERN's position in world high energy physics', 'The scientific performance of CERN accelerators', and 'CERN and the future of world high energy physics'.

The authors attempt to evaluate the scientific performance of CERN in detail over the ten years 1969 to 1978, and in broader terms over the years 1961 to 1982, as manifest in the experimental results coming from the accelerators and storage rings. They leave aside contributions to theory or other aspects such as the impact on university education, technological contributions, stimulation of industry, and CERN's role in promoting international collaboration.

A particular method based on 'converging partial indicators' is used in the evaluation. Several indicators of scientific performance, each in themselves recognized as imperfect, are employed, and if they point in the same direction, they are assumed to have a greater validity than approaches based on a single indicator. The indicators are — number of papers arising from experimental research and published in international journals (a measure of productivity), total citations to the research results (a measure of impact), numbers of highly cited papers (a measure of major discoveries), and peer evaluation (a measure of the perceived significance of the research within the scientific community).

In a short article it is impossible to cover the mass of detail and all the qualifying comment in the three papers (each about 30 printed pages long), but some selected information from the study is still of interest. (To judge the authors' contentions more systematically, consult the papers in *Research Policy,* Volume 13 (1984), issues 4, 5 and 6.)

To set some of the scales for the comparisons made in the study, the authors collected data on world funding for high energy physics and on the number of experimentalists who are served by this funding at the research centres in Western Europe and the USA. These are shown for the years 1969-78 in Table 1. When the exchange rates are adjusted to reflect real purchasing power (using factors agreed in Europe and the USA), the cost per high energy physicist per year is fairly similar either side of the Atlantic; for example in 1978 the calculations give 0.53 million Swiss francs in Western Europe and 0.68 MSF in the USA. (Particular years can show fluctuations because the money going into machine construction projects is not constant.)

The number of publications per Laboratory, expressed as a percentage of the world total of experimental high energy physics papers, again for the years 1969-78, is shown in Table 2, the sum total of publications over these years being just over 5400 papers. Table 2 also shows the percentage share of the world citation total for each Laboratory (from a total number of 28 000 citations) with additional information on those papers which were particularly frequently cited. While some papers achieve a significant impact, they are not necessarily always 'correct' papers (for example, A2 splitting at CERN or the 'high-y anomaly' at Fermilab). Although CERN's share of the world total of highly cited papers remained at over 25 per cent for papers cited 15 or more times in a year, it declined significantly when the threshold was set instead at 50 or 100 per year since, in the decade under study, CERN's contributions to the list of really great discoveries was limited to that of neutral currents in 1973, while J/psis, taus and upsilons were cropping up in the USA. Thus although CERN led the world in terms of number of papers and number of citations, it was behind Fermilab, SLAC at Stanford and DESY in Germany in terms of average number of citations per paper.

'Peer evaluation' involved interviewing 182 theorists and experimentalists from the US, Western

Table 1 Funding at main Western high energy physics centres, 1969-78

	Users (percentage of world total)	Total funding (percentage of world total)
CERN	25-32	25-32
DESY	4	4-5
Brookhaven	5-6	6-7
Fermilab	11-12	12-13
SLAC	5-6	6

Europe and Eastern Europe. One of the questions was to rank the accelerators according to their contributions to high energy physics as perceived by those being interviewed. For the period under review, SLAC was voted top, with CERN second, followed by Fermilab.

After this general assessment in the first paper, the authors focus in the second on the individual performances of the three CERN machines — PS, ISR and SPS — and compare them with the Brookhaven AGS, Serpukhov and Fermilab. This more detailed analysis covered the years 1961-1983, the period being broken down into four-year intervals. The indicators clearly show that in the early 1960s CERN was learning how to operate as an international high energy physics Laboratory and European physicists were learning how to carry out experiments on the scale required at the PS. Americans, with their experience of the Cosmotron and Bevatron coupled with their traditional experimental flair, 'scooped' the field with the muon-neutrino, the omega minus and charge-parity violation.

The section on the period 1965 to 1968 is entitled 'The CERN PS comes of age', and that on the period 1969-1972 'CERN achieves world pre-eminence'. The indicators during these eight years show the PS moving alongside or ahead of the Brookhaven AGS while that great machine of an earlier era, the Berkeley Bevatron, slipped back behind the newer and higher energy accelerators. In the latter period, SLAC came to prominence with new results which probed the deep interior of nucleons, while Serpukhov had the total cross-section (reaction rate) measurements, while shortly after the first results emerged from the CERN Intersecting Storage Rings and from Fermilab.

Table 2 Scientific productivity of major accelerators and impact of results, 1969-78

	Percentage of world high energy physics resources (users and funding)	Percentage of world total of experimental publications	Percentage of world total of citations to recent papers	Number of times papers earned over 15 citations in a year (percentage of world total)
CERN	25-32	26.5	26.5	27.5
DESY	4-5	3	4	4.5
Brookhaven	5-7	11.5	10.5	8.5
Fermilab	11-13	8.5 13.5 for 1973-8	19 23.5 for 1973-8	23.5
SLAC	5-6	15.5	14	19

The period 1973-1976, which is titled 'The American revolution', began with the neutral current discovery at the CERN PS, prompting the authors to comment that 'CERN witnessed in 1973 what was probably the most successful year in its history (at least until 1983)'. However, after that, it was the American Laboratories, with excellent support later from DESY, which swept us into the charmed era of the 'new physics'. From 1977 to 1980 the CERN SPS joined Fermilab in the 400 GeV range, and while Fermilab was initially in the lead (particularly with the upsilon discovery), it was gradually overhauled by the SPS.

The post-1980 period is entitled 'The European renaissance'. Though the shining glory of the renaissance is the CERN proton-antiproton Collider, recent years have also seen the world share of papers from the CERN accelerators climb from 24.5 per cent in 1980 to 33 per cent in 1982 (the last year for which data have been collected), with a similar swing occurring in terms of the number of citations. Papers with the highest average number of citations, however, came from CESR at Cornell and PETRA at DESY, at least until the first results from the CERN Collider appeared.

The 'peer evaluation' results of the detailed comparisons of similar machines over the relevant period show the Brookhaven AGS clearly ahead of the CERN PS in terms of 'crucial experiments and discoveries', but suggest that the PS had the better record for 'precise measurements'. It is interesting that the three factors most often quoted in explaining these ratings are: 'more bold, speculative ethos of the US physicists — Europeans more conservative, less risky approach' (quoted by 51 per cent of the interviewees); 'problems of CERN being multinational — slow committees, over-conservative choice of experiments' (51 per cent); and 'greater experience of US physicists — Europeans had to learn to use a large accelerator' (36 per cent). These remarks of course cover the AGS-PS comparison, but it would be interesting to have this analysis up-dated to cover the CERN accelerators as perceived in 1984.

The peer evaluation of the ISR and SPS compared to Fermilab and the Serpukhov 76 GeV proton synchrotron put Fermilab ahead for discoveries and the SPS for precise measurements with the ISR not far behind. The ISR is recognized by the authors as a 'tremendous success' from a technical point of view. Peer evaluation comments on factors limiting scientific performance were — 'poor choice of detectors initially' (quoted by 72 per cent of the interviewees), and 'had to learn from scratch how to use the machine — proton-proton collisions inherently very complex' (42 per cent). For the SPS/Fermilab comparison, the main comments were 'Fermilab had four-year lead' (58 per cent), and 'more resources and technical support for CERN experiments' (50 per cent).

The third of John Irvine and Ben Martin's papers, 'CERN and the future of world high energy physics', moves out of statistics into what we might call 'informed speculation', attempting to show how systematic comparisons of past scientific performance, together with analyses of the factors structuring recent performance, might contribute to decisions on future projects. They draw up a list of criteria for assessing the future prospects for new accelerators, and use the LEP project as a guinea-pig. The criteria (financial, technical and scientific) are drawn from the retrospective study of CERN's scientific performance in which, in the authors' view, various factors determining the success (or lack of success) of different accelerators could be discerned. The authors argue that this approach to assessing the prospects for future research projects could be of considerable help to those charged with deciding national science policy.

Such assessments from past research performance may contribute useful pointers but they are a long way from being a sure guide to the future. To stay with the research field which the authors have studied with such thoroughness — on the basis of past performance, few would have predicted that the brilliant Brookhaven team would have had those sad problems in preparing for ISABELLE (although, as Irvine and Martin point out, the problems with upgrading the AGS in the early 1970s should have served as a warning of the Laboratory's declining technological capabilities). Similarly, nobody could have predicted the success of PETRA at DESY compared with PEP at Stanford, given the previous superiority of Stanford's SPEAR ring over DESY's DORIS. Lastly, given CERN's previous reputation for 'conservativeness', the courageous decision to proceed with proton-antiproton project was unpredictable. In such a fast moving field as high energy physics, the future clearly cannot be derived simply from extrapolations from the past.

The authors conclude that a turning point has been reached in the balance of power between Europe and the US, a conclusion reinforced by the dramatic discoveries in the past 2 years of the W and Z particles and the new indication of the top quark.

Stanford's big new detector

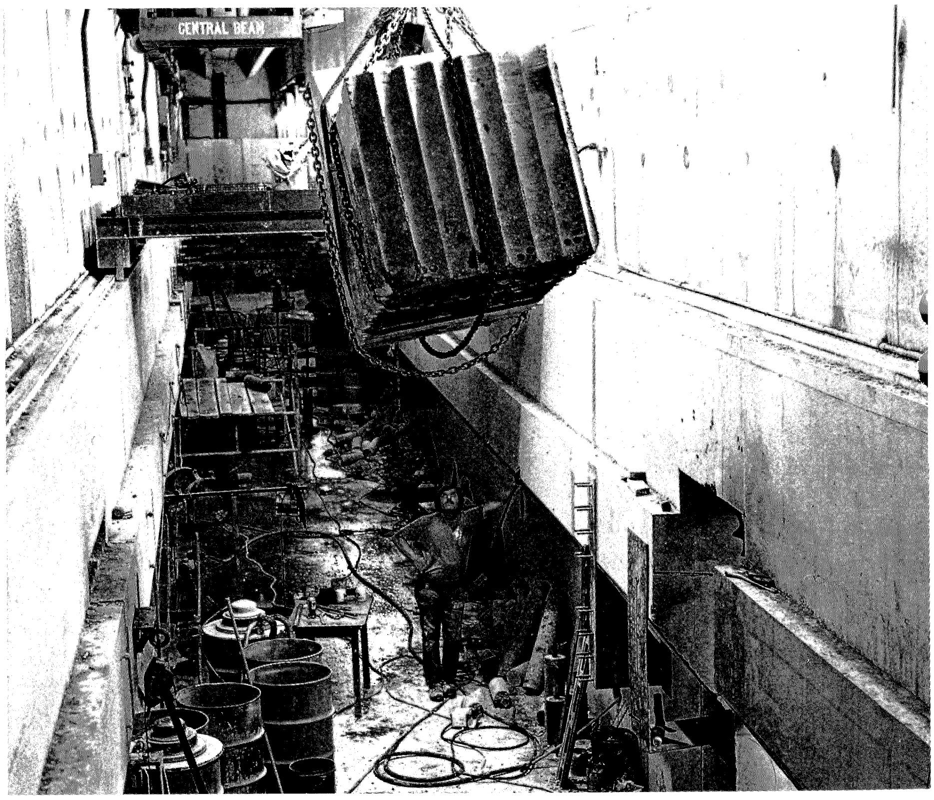
At the Stanford Linear Accelerator Center (SLAC) in the US, work forges ahead for the Stanford Linear Collider (SLC), a new approach to electron-positron collisions.

In conventional electron-positron rings, the stored particles, rotating in opposite directions, circulate continuously. To handle higher energy circulating beams, the overall diameter of the storage ring has to be increased. For example the LEP ring now under construction at CERN has a diameter of nearly nine kilometres.

In an effort to sidestep this explosion in storage ring dimensions (and costs), the linear collider concept was put forward in Stanford and in Novosibirsk (USSR). Instead of storing particles, the idea at Stanford is to accelerate electrons and positrons down the big two-mile linac, separate them into two opposing arcs, and bring them round to collide, once only. (At Novosibirsk, the VLEPP machine will have two separate linacs firing particles towards each other — see December 1982 issue, page 417.)

At Stanford, the aim is to try for first SLC electron-positron collisions at the end of 1986, two years before the LEP machine at CERN is turned on. The trusty Mark II detector, with a long history of fine physics

Up and away. Removing the portion of concrete wall which was all that separated the Stanford linac tunnel from the newly bored section which will house one of the arcs of the new collider.



LEP detectors

This month we interrupt our series of articles on the detectors being built for the LEP electron-positron ring under construction at CERN and feature instead the SLD detector for the electron-positron collider being built at Stanford, USA. Next month we return to LEP to highlight the OPAL detector.

achievements at both the SPEAR and PEP electron-positron rings at Stanford, will be there to intercept the first SLC colliding beams. Mark II has already been taken out of the PEP ring for a facelift, and the improved version will be moved back into PEP for tests early next year.

To follow up the initial SLC investigations and to really exploit the full capabilities of the new machine, a big detector is being developed by a 100-strong collaboration, headed by Charles Baltay of Columbia and Marty Breidenbach of SLAC, involving some 20 research centres, mainly from the US but with collaboration also from Canada, Italy, and the UK.

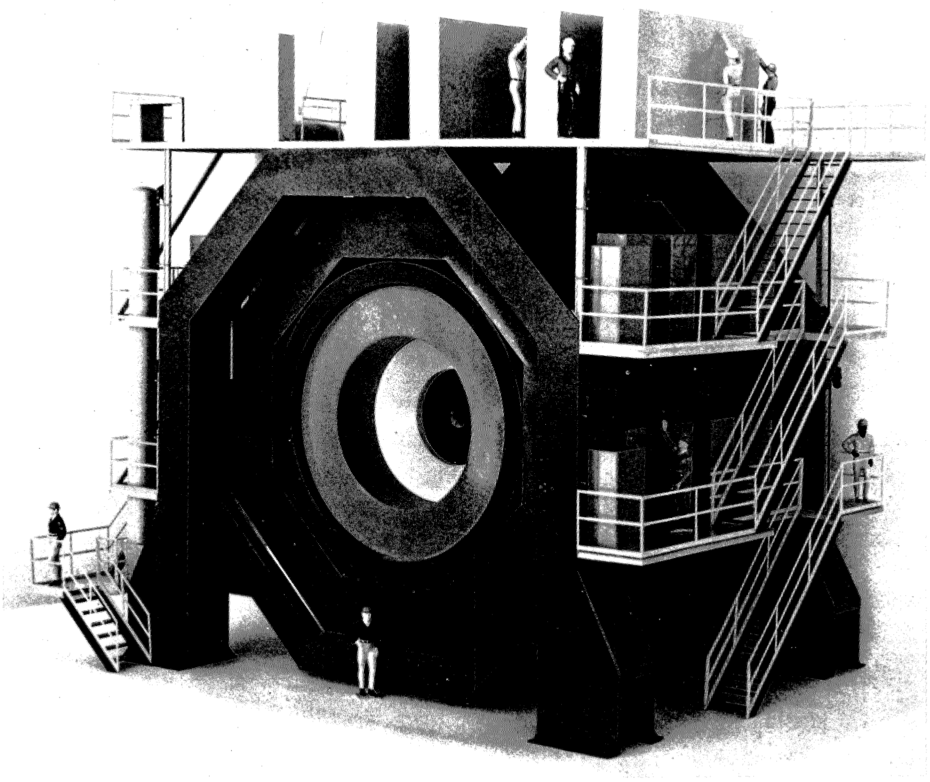
Called plain SLD, this new instrument is designed to study a wide range of physics — properties of the Z^o, heavy quarks, hunting the Higgs, etc., as well as hoping for the unexpected.

Like the detectors being built for LEP, SLD will include good electromagnetic and hadronic calorimetry (measurement of energy deposition) with instrumentation surrounding the full solid angle around the collision point, and good particle identification. It is the introduction of a high level of hadron calorimetry which re-

More progress at Stanford for the new Linear Collider. The vault to house the positron damping ring takes shape.

A scale model of the SLD detector for the new SLAC Linear Collider. This detector should be ready end-1988, but the trusty Mark II detector will be there to catch the first SLC electron-positron collisions, scheduled for end-1986.

(Photos SLAC)



ally distinguishes this new generation of electron-positron detectors from their predecessors.

Calorimetry involves catching high energy particles (including the electrically neutral ones which leave no track elsewhere) in a heavy radiator such as uranium or lead, and measuring the amount of energy released. The power of good hadron calorimetry was demonstrated in the spectacular results achieved in a relatively short time at the CERN proton-antiproton Collider.

In the SLC, beams will be focused down to small spots only a few microns in diameter, so that the beam pipe can be extremely slender. Thus the inner dimensions of the 'vertex detector' immediately surrounding the beam pipe can be of a few centimetres. (Inside the LEP experiments, the beam pipe will be 16 cm across.) This innermost portion of the SLD detector will use an array of semiconducting chips (charge-coupled devices — CCD) to provide precision (5 micron) information on the location of the tracks leaving the collision point. Using pixels 22 microns square, 17 tracks per square mm have been resolved.

The main SLD tracking device will be the central drift chamber, with 80 layers of sense wires monitoring the bending of particle tracks in the 1 tesla magnetic field of the surrounding superconducting solenoid. A full-length (2 metre) prototype has been undergoing tests.

Also inside the superconducting solenoid will be the Cherenkov Ring Imaging Detector (CRID) for particle identification, and a liquid argon calorimeter (LAC).

The CRID modules will use both liquid freon and isobutane as Cherenkov light generators. The produced photons will be converted into electrons in TMAE (see March 1982 issue, page 49), and the photoelectrons will drift towards a set of proportional wires for readout. Current results from beam tests show clear Cherenkov rings with some 20 photoelectrons per track.

The LAC includes both uranium and iron as radiators, with projective towers grouped in both inner (electromagnetic) and outer (hadronic) sections. Having such substantial calorimetry inside means that the thickness of the surrounding solenoid is not critical. (With external calorimetry, the solenoid has to be thin to minimize particle losses.) Additional hadron calorimetry outside the coil will be supplied by iron interspersed with streamer tubes, thus also providing tracking of the highly penetrating muons which traverse the rest of the apparatus.

The design of the SLD endcaps reflects that of the main barrel of the detector, thus providing uniform technology throughout.

The design of the superconducting coil has yet to be finalized, but studies of the available options are pushing ahead so that a decision on this key component of the detector can be made. One possibility being explored is a new internally cooled system proposed by the US National Magnet Laboratory at MIT in which liquid helium flows through the spaces in an enclosed superconductor (a 'rope in a pipe').

Electronics (Fastbus and VSLI) are in the capable hands of SLAC specialists and a team from the University of Illinois.

Including a substantial contingency, the detector will cost just under $50 million, with contributions from the Italian INFN (Frascati and Pisa sections are involved in the outside iron calorimeter), and from Canada (TRIUMF Laboratory and the Universities of British Columbia and Victoria). The Rutherford Appleton Labo-

Around the Laboratories

ratory in the UK is working on the inner vertex detector.

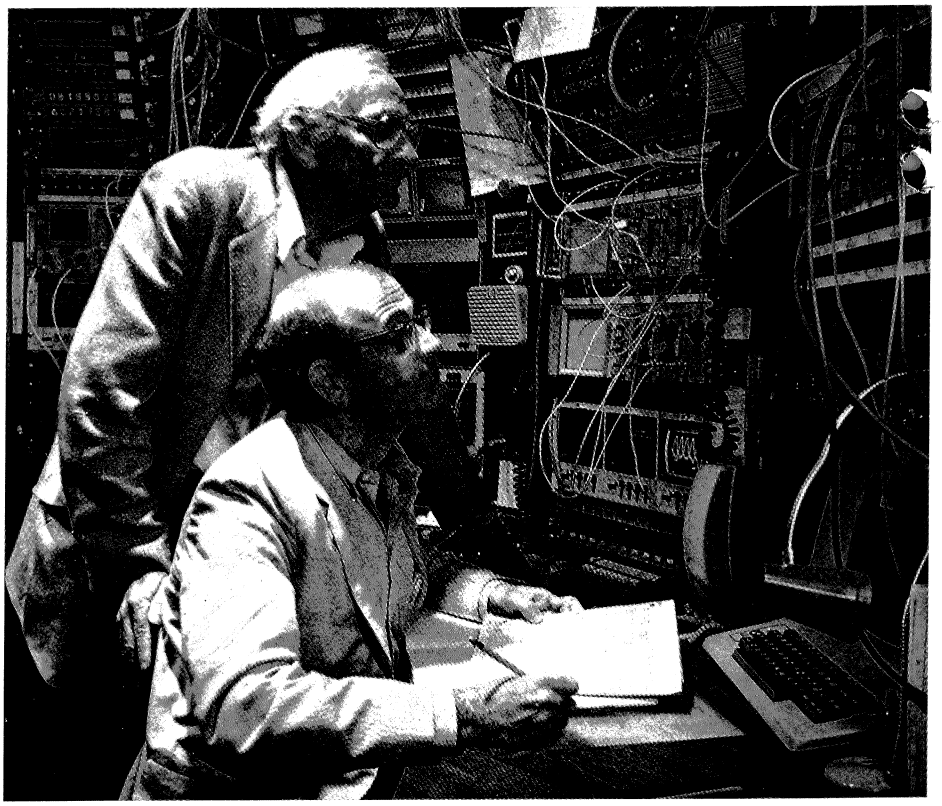
If all goes well at SLAC, the Mark II detector could cream off some interesting physics during the two-year head start that the Stanford Collider will have over CERN's LEP machine. But it will not be until late 1988 or early 1989, with the arrival of the new SLD detector, that the full physics capabilities of the Stanford machine will be exploited. By that time, LEP should be operational, with higher design luminosity and its complement of four large specially built detectors, together with the prospect of a substantial energy upgrade (with the introduction of superconducting r.f. accelerating cavities).

BROOKHAVEN
Polarized protons at the AGS

The auspicious day of Friday July 13 1984 was the official start of physics experiments with the polarized proton beam at the Alternating Gradient Synchrotron, operating at 16.5 GeV with a polarization of about 40 per cent and an intensity of about 10^{10} protons per pulse. This is the highest energy polarized proton beam ever achieved, surpassing the old ZGS (Argonne) record of 12.75 GeV. Polarizations of 70 per cent and 63 per cent had been achieved earlier at 12 and 14 GeV, close to the injected polarization of 70 to 75 per cent.

About 100 technicians, scientists and engineers from Argonne, Brookhaven, Michigan, Rice and Yale had worked intensively on the project for more than four years. Their pleasure at the project's success was quite evident at the 'Polarized Beam Celebration' held on the previous day in the AGS courtyard. There was also perhaps a bit of amazement as people reflected on the complex and sophisticated techniques that were required to produce polarized protons and then maintain the polarization through the entire AGS acceleration cycle.

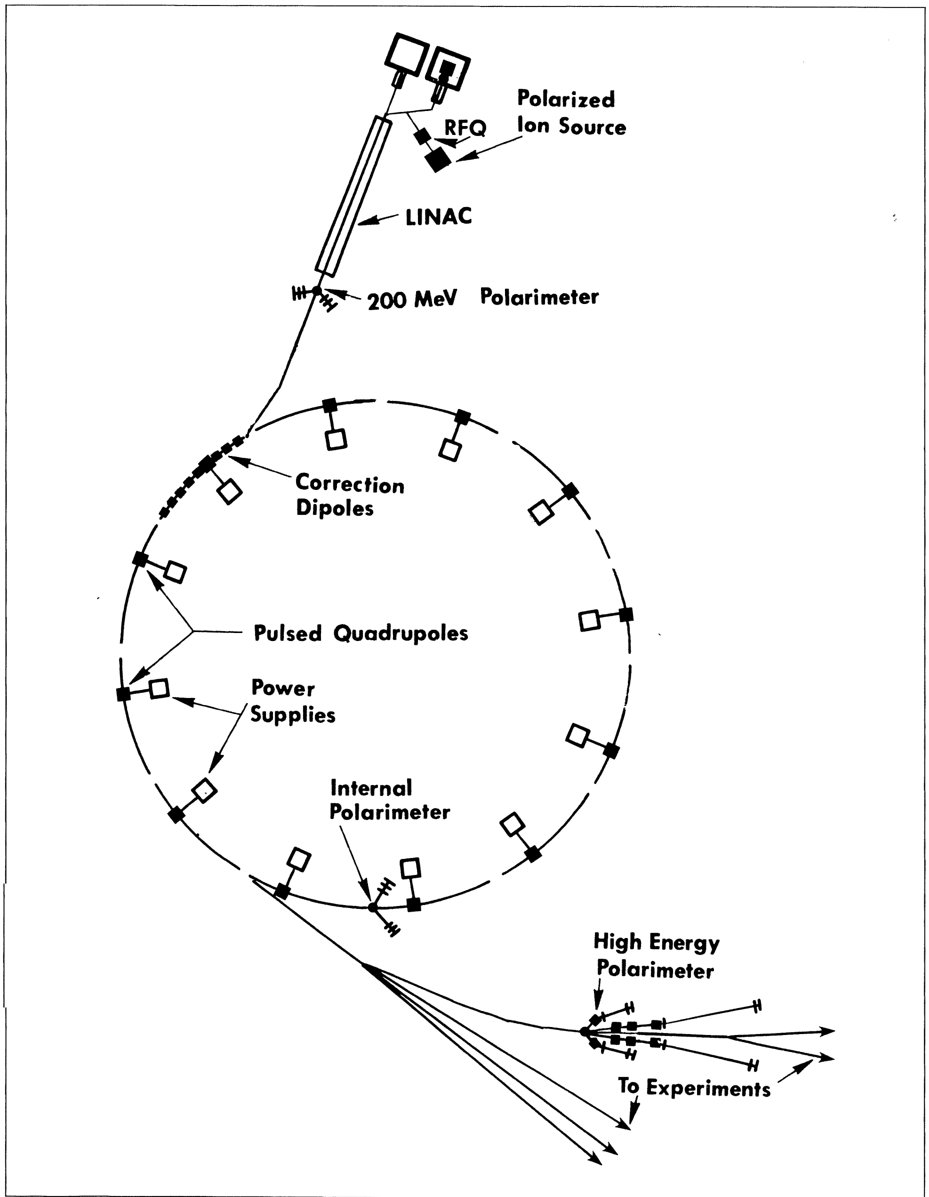
Setting the stage to navigate the many depolarizing resonances required new state of the art hardware in almost every part of the AGS. A world record 25 microamp polarized negative hydrogen ion source of the caesium charge exchange type was developed. The world's first on-line radiofrequency quadrupole (RFQ) was built to accelerate the polarized ions to 760 keV (see April issue, page 100). A new transport line with low-level diagnostic instrumentation



The AGS resonance navigating crew: Alan Krisch of Michigan (seated) and Larry Ratner of Brookhaven.

(Photo Brookhaven)

The stage setting for polarized beam physics at the Brookhaven AGS. Navigating the various depolarizing resonances lying in wait for the unwary required new state of the art hardware in almost every part of the machine.



was built to transport the beam from the source to the Linac and a 200 MeV polarimeter was installed after the Linac to measure the polarization.

The most difficult problem lay ahead within the AGS main ring; there were many depolarizing resonances to negotiate during the acceleration cycle. Because the AGS is a strong focusing accelerator, these resonances were believed to be about ten times stronger than at the weak focusing ZGS. The three strong 'intrinsic' depolarizing resonances were indeed that much stronger, just as originally calculated. The 'resonance navigating crew', led by Alan Krisch of Michigan and Larry Ratner of Brookhaven, were able to jump all three resonances using the new fast pulsed quadrupole magnets. The twelve pulsed quadrupoles, with 1.6 microsec risetimes, were built of ferrite by Michigan, and the eight massive 1500 amp, 15 000 volt power supplies for them were built at Brookhaven.

There were also some 30 'imperfection' depolarizing resonances between injection and 16.5 GeV. These were also estimated to be about ten times stronger than at the ZGS and it was planned to correct them using 96 tiny correction dipole magnets distributed around the AGS ring. These 96 magnets acting together can produce a sine wave with the correct number of oscillations to match each resonance as it is passed. These imperfection resonances all occurred at the predicted energies, but were even much stronger than expected, by about a factor of ten. It had been hoped that only about five of them would have to be corrected and the rest could be ignored. However each of the 30 resonances caused significant depolarization and each had to be corrected individually with the 96 dipole magnets. Fortunately it was possible to do an 'on-line' upgrade of the dipoles and all imperfection resonances up to 16.5 GeV were corrected.

But there was another surprise waiting for the navigators: a third type of depolarizing resonance! These are imperfection resonances driven instead by the 'intrinsic' betatron oscillations of the accelerator. Kent Terwilliger (Michigan) and Ernest Courant (Brookhaven) had thought that such resonances might exist and some contingency preparations were made for dealing with them. Nevertheless at the 27th imperfection resonance, the polarization was lost and extensive efforts to correct the 27th harmonic (27 sine wave oscillations around the ring) did not restore polarization. However when the 9th harmonic was finally

Handling spin

The appearance of very large spin effects in wide angle proton-proton scattering at Brookhaven (see September issue, page 274) is something to think about. In the conventional theory of quarks and gluons (quantum chromodynamics), calculations are difficult to handle under these conditions, but this does not deter alternative descriptions of quark dynamics.

Large spin effects can be accommodated, for example, in the 'Quark Geometrodynamics' picture, in which quarks are allowed to propagate only in allowed 'orbits' corresponding to observable hadrons, and the probability for transition between allowed orbits is determined by their geometry.

turned on, the polarization was easily restored. To understand this one must note that the 27th imperfection resonance is very close to the strong 36-ν intrinsic resonance since the tune value, ν, the number of vertical betatron oscillations in one turn around the AGS, is equal to 8.75, very close to 9.

At the 27th resonance, the 9th harmonic correction can fully restore the polarization to +40 per cent, while with no correction the polarization is about −30 per cent. If the wrong correction is made, then the spin is totally flipped and the polarization is about −40 per cent. The change in the dipole correction field, which takes the polarization from full correction to full spin flip, is only a few gauss. Tricky!

The polarization at high energy was measured using two polarimeters, both built by Michigan. The internal polarimeter used a moving strand of nylon fishline and gave a very fast measurement of the polarization at any energy in the acceleration cycle. Unfortunately there is little fundamental knowledge about spin effects in proton-fishline scattering and this polarimeter had to be calibrated against the much slower external polarimeter which used a liquid hydrogen target to obtain a clean measurement of the left-right asymmetry in proton-proton elastic scattering events.

Polarized beam improvements will continue through the coming year to increase the energy and polarization up to the design goals of 26 GeV and 60 per cent. The intensity goal of 5×10^9 has already been achieved, but efforts will be made to reach even higher intensity. The AGS crew is optimistic that there will be significant progress in energy, polarization, and intensity prior to next year's polarized beam run.

DESY HERA progress

The HERA electron-proton collider being built at the German DESY Laboratory in Hamburg is making rapid progress. The most complicated and technologically advanced components of this project, the 5 tesla magnets for the 820 GeV proton ring, are in a good shape. Planners of future projects may keep an eye on these developments, in which the 6 tesla limit seems to be already surpassed on a nearly industrial production scale.

Aerial view of the construction work for the South Experimental Hall for the HERA electron-proton collider being built at the German DESY Laboratory in Hamburg.

In August, a 6 metre-long superconducting magnet of the 'cold-iron' type, built by Brown Boveri and Co of Mannheim (see March issue, page 52) was successfully tested at DESY. The magnet reached a current of 7860 ampere at 4.69 kelvin, which corresponds to a field of about 5.75 tesla, computed taking into account saturation effects in the iron. Only 4.53 tesla are required for 820 GeV protons in HERA. This magnet type offers the advantages of simpler quench protection using passive components and better mechanical suspension with smaller heat losses.

In order to add the benefits of this cold-iron magnet with those of the warm-iron type already produced and tested at DESY, a hybrid model is now being produced for HERA. Two one metre-long test magnets will be built at DESY and four 9 metre-long prototypes (see June issue, page 184) will be built under contract by BBC Mannheim. DESY will wind and 'collar' the coils (aluminium collars are now used instead of stainless steel to support the coils) and BBC will assemble the magnet yokes and the cryostats.

A six metre-long coil with the new collars and with a vacuum pipe already provided with the correction coils required for HERA (which have been built by NIKHEF Amsterdam and the Dutch HOLEC company) is being tested in a vertical bath cryostat at DESY.

Meanwhile, the excavations for HERA's South experimental hall, which began on 15 May, have been completed and the concrete floor 23 metres below ground level has been poured. Work on the West experimental hall, located on the DESY site, is underway.

An important modification has been made to the HERA parameters. The beams should now cross at zero degrees in the four interaction regions, instead of the earlier proposed 20 mrad. This decision is based on new results of tracking calculations for crossing beam geometries which indicate a blow-up of the proton beam by the space charge forces of the electron beam. This effect already happens at very low electron currents. The mechanism of this blow-up is the excitation of satellite resonances, an effect which was first observed at the DORIS storage ring (in the days when it had two rings). The computer simulations show that this effect is more serious at HERA due to the absence of synchrotron damping for the protons.

Work on many other components of HERA is progressing according to plan. A source for negative hydrogen ions has been purchased from Fermilab and a model radiofrequency quadrupole to accelerate them to 750 keV is under construction at the University of Frankfurt.

The HERA refrigeration plant will be subdivided into three units, all located at the West Hall on the DESY site. Liquid helium will be piped around the ring and gaseous helium will be returned to the central units. Each of these units will provide 6500 Watt at 4.3 K, 20.5 g/s liquid helium and 20 kW between 40 and 80 K. Two of the three plants are required for steady-state operation.

As well as HERA, there is research work going on at the PETRA and DORIS electron-positron storage rings. At DORIS, a new run at the upsilon energy began in August to carry out further studies on the recently reported zeta particle (see September issue, page 266) with twice the present statistics. About 200 000 upsilons should be collected and analysed within a few months. Over 200 new events are expected in the 1.07 GeV peak observed in the energy spectrum of single photons emitted in upsilon decays.

WORKSHOP Radiofrequency superconductivity

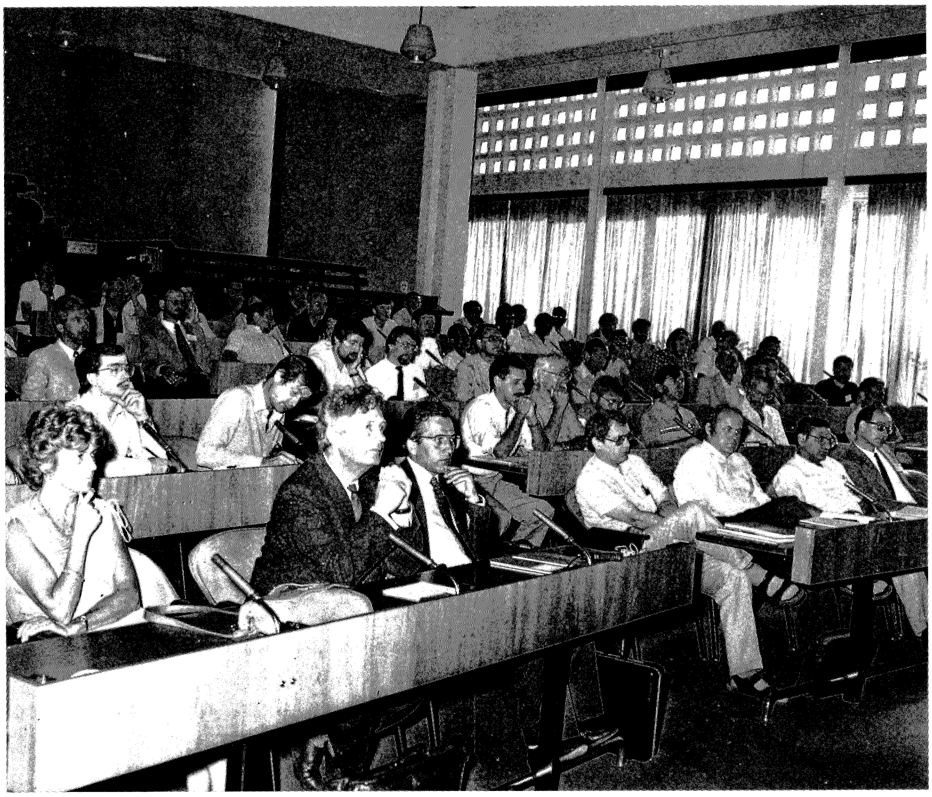
The Second Workshop on Radiofrequency Superconductivity was held at CERN from 23-27 July, four years after the first, organized at Karlsruhe. 35 invited talks were presented to the about 80 participants from Australia, Brazil, Europe, Japan and the United States. For the first time, ten Laboratories operating or planning superconducting accelerators for heavy ions participated and shared their experience with the community proposing the use of superconducting accelerating sections for electron accelerators.

The meeting opened with status reports from the Laboratories. The Argonne Superconducting Heavy Ion Post Accelerator has so far collected successfully 16 000 h of beam time for experiments and further development of this accelerator using niobium split-ring resonators is under way. At Saclay a heavy ion accelerator is under construction based on the Karlsruhe experience with helix resonators. At Stony Brook a different technology is pursued by the use of superconducting lead-plated copper resonators in their ion post accelerator. The running experience of this machine demonstrates the applicability of this technique to low frequency (100 MHz) resonators. In the field of heavy ion accelerators the use of superconducting cavities appears to be generally accepted today.

Very good results were reported by the CERN group. Accelerating fields of 5 MV/m were obtained in a

The second Workshop on Radiofrequency Superconductivity was held at CERN from 23-27 July, four years after the first meeting in Karlsruhe.

(Photo CERN 311.7.84)



500 MHz five-cell cavity used previously for a test in PETRA and an encouraging 13 MV/m could be reached in a single cell cavity made from high thermal conductivity niobium. Efforts are now concentrated on single and multicell cavities at 352 MHz, a frequency which is presently favoured also for the superconducting cavities for LEP at CERN. At Cornell a storage ring experiment is being prepared with two five-cell cavities with rotational symmetry at 1.5 GHz fabricated from purified niobium. 15.3 MV/m were obtained in one of these cavities fully equipped with the r.f. couplers necessary for accelerator use.

At DESY, work is concentrating on two nine-cell cavities (1 GHz) to be installed and operated in PETRA this fall. New and easy-to-apply surface treatments were developed together with a silver plating technique to lead the way to a more economical cryostat design. At DESY, cavity fabrication is carried out with significant industry participation. The same is true for the work done at KEK (Japan) where a first test of a 500 MHz three-cell cavity has been performed in the TRISTAN accumulation ring. An accelerating field of 5.2 MV/m was reached and a beam of 10 mA was stored at 2.5 GeV with the superconducting cavity alone. At Wuppertal efforts are focused on a 130 MeV superconducting 'recyclotron' for electrons which is constructed at the Technische Hochschule Darmstadt. Their frequency is 3 GHz and research is concentrated on field limitations, niobium-tin covered cavities and resonators in the very high frequency regime (20 to 90 GHz). At Orsay work is in progress to study surface cleaning techniques by gas discharge methods and Stanford University is planning to apply r.f. superconductivity to a free electron laser. Next door at SLAC, very high peak surface fields (up to 70 MV/m) are obtained by exciting superconducting single-cell cavities (2.85 GHz) with microsecond r.f. pulses.

After this grand tour, attention turned to special topics. The use of niobium of higher purity and thereby increased thermal conductivity was considered as one of the main improvements of the past year. The new material increases the thermal stability of cavities and reduces their sensitivity against lossy defects which so far were the prime reasons for field limitations. The progress in diagnostic methods since the last workshop, especially the temperature mapping technique which today allows the guided removal of field limiting defects, was reviewed. Refinements in surface treatment and clean work in dust-free environments were discussed. The importance of all these manufacturing techniques was recognized and is considered responsible for the higher degree of reliability with which superconducting resonators can be fabricated today.

Electron loading in superconducting cavities was another important topic. The plague of resonant electron loading (multipactor) appeared to be quantitatively defeated by the introduction of spherical or elliptical shaped cavities, a shape now unanimously accepted.

In recent experiments at CERN a very special kind of two-point electron multiplication was discovered which asks for a revival of attempts to lower the secondary emission yield on technical niobium surfaces.

Aside from this singular effect, field emission is certainly the next hard barrier to be overcome if much higher fields have to be reached, for example in superconducting cavities for future linear colliders. New fabri-

LEP Project Director Emilio Picasso has been a driving force in the push for superconducting cavities for the future of the LEP electron-positron ring now being built at CERN.

(Photo CERN 307.7.84)

cation techniques like sputter deposition of niobium onto copper, copper or silver-plated niobium cavities or niobium cavities with a niobium-tin surface were reviewed and are considered to be very worthwile directions for future research aiming particularly to reduce cryogenic losses even further and to simplify cryostat designs. For the time being however, shaping half cells from niobium sheet and subsequent electron beam welding is the generally accepted fabrication technique.

One morning of the workshop was given over to detailed discussions on specific questions of superconducting heavy ion accelerators. A new design, the quarter-wave resonator, was introduced, new acceleration ideas, like the Munich separated cyclotron ring with a superconducting acceleration cavity, and special questions regarding vibration disturbances in resonators of complex shape were discussed.

The last day was devoted to the application of superconducting cavities to large electron-positron storage rings. Up to now four accelerator tests have been performed — by the groups at Cornell and KEK in their storage rings and by groups from Karlsruhe and CERN (at the PETRA ring at DESY). Two more are under preparation at Cornell and DESY. All these tests were 'premières' for the respective groups and all of them were successful, revealing no major or unexpected problems. A number of non-fundamental failures of equipment were observed but no test was seriously interrupted. It was felt nevertheless that more tests have to follow to apply the initial lessons learned. In particular, attention should be paid to the long term behaviour and to the routine operation of superconducting cavity arrays in the environment of a large storage ring.

During the final session, the CERN effort to introduce superconducting accelerating sections into LEP was covered. The LEP project and its special requirements for r.f. energy was introduced to the workshop participants and the challenge of using r.f. superconductivity for LEP was outlined. Based upon the experience from the first test of an experimental prototype module in PETRA, a new cavity design and improved coupling schemes for the fundamental and higher order mode r.f. power have been introduced.

A discussion on cryogenic engineering applied to cavity cryostats and refrigeration systems revealed that a great deal of work has to be devoted to this essential matter.

Comparing the results reported at this workshop with those of four years ago, no significant advance in the maximum fields or cavity quality factors is apparent. The main and most important development is demonstrated by the fact that the design performance of extended cavity arrays can be reached today with a much higher degree of reliability than in the past. This has to be attributed to the improved understanding of field and quality factor limiting phenomena and is of decisive importance for future large scale projects.

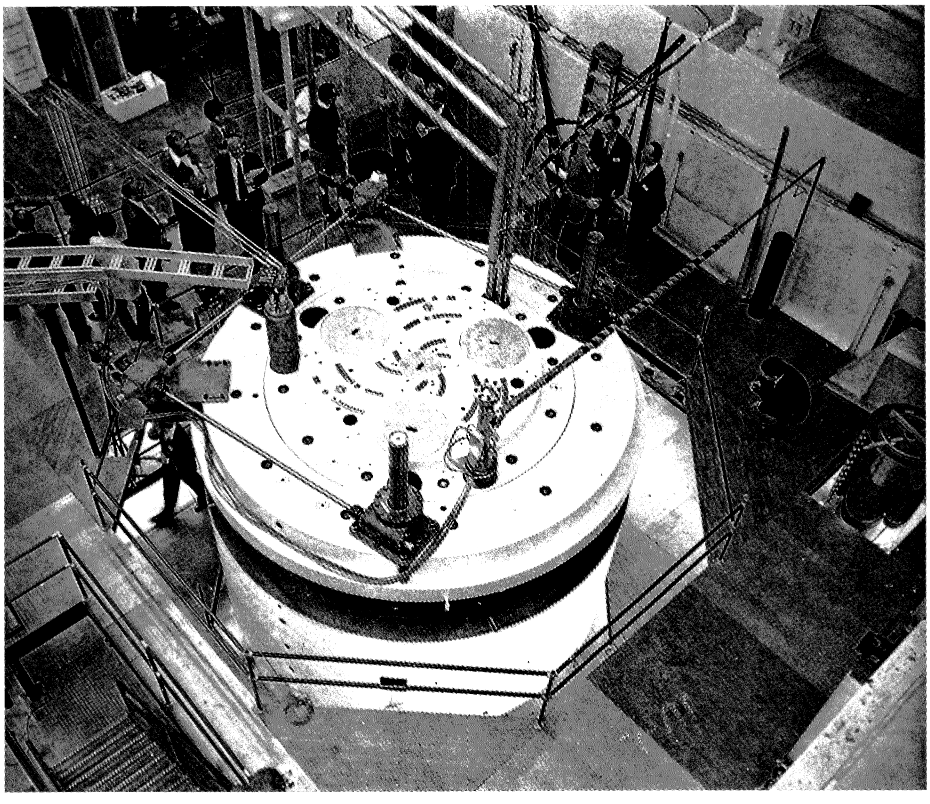
(From H. Lengeler and H. Piel)

MICHIGAN Cyclotron conference

A sense of excitement was in the air as cyclotron physicists and engineers from 17 countries convened on 30 April for the opening of the Tenth International Conference on Cyclotrons and Their Applications. Some 50 years after its invention, the redoubtable cyclotron remains a topic of compelling current interest. Cyclotron experts gathered at Michigan State University's Kellogg Center to hear of latest developments, of progress and successes on new machines which had come into operation, of new projects which were underway, and of dreams which lay ahead.

Both the first speaker, John A. Martin of Oak Ridge, and the last, J. R. Richardson of TRIUMF, reminded the audience of historical perspectives. The conference was occurring just 25 years after the first conference at Sea Island, Georgia and Martin reviewed highlights of intervening meetings at Los Angeles, Geneva, Gatlinburg, Oxford, Vancouver, Zurich, Bloomington, and Caen. Richardson began his talk by noting that the conference was being held almost precisely 50 years after the date on which he began working with E. O. Lawrence as a graduate

J.-P. Blaser (left) of SIN, Switzerland, talks with Henry Blosser of the US National Superconducting Cyclotron Laboratory, Michigan, during this year's International Conference on Cyclotrons and their applications.



The magnet of the K800 superconducting cyclotron at Michigan on display for the International Cyclotron Conference. Full design field was achieved one week after the Conference.

student at Berkeley—his talk traced the development of the cyclotron through his own observations of the early work at Berkeley into the years of the isochronous machines, meson factories, and possibly kaon factories next.

Invited papers at the first conference session described the start up of the frontier heavy ion facility at GANIL (Caen, France), the first of the superconducting cyclotrons at MSU, and the booster ring at Grenoble. All of these facilities are now regularly providing beams to a large community of experimental users — from all this work quantitative new information about heavy ion reactions is flowing into the scientific literature, revealing interesting and in some cases unexpected new aspects of nuclear behaviour.

Progress reports on projects under construction — the superconducting cyclotrons at Chalk River and Milan, the new injector at SIN, Switzerland, and many smaller projects were interspersed with sessions on evolving new construction techniques, such as superconducting magnets, new r.f. structures, and new types of ion sources, particularly the Electron Cyclotron Resonance sources for producing intense beams of highly charged heavy ions. In the realm of future dreams, U. Trinks of Munich described a structure in which the Separated Orbit Cyclotron concepts of M. Russell might be combined with superconducting magnets to obtain some very attractive performance features.

A conference session devoted to competing technologies featured speakers reporting on developments in large electrostatic accelerators, in superconducting linacs, and in high intensity, high duty factor synchrotrons. The session on applications of cyclotrons particularly featured applications in the field of medicine and the competition between cyclotron-based systems and the rapidly evolving NMR systems as techniques for improved medical diagnosis.

An exciting series of talks featuring Pollock of Indiana, Katayama of Tokyo and Hagedoorn of Eindhoven and Julich described design studies and progress on construction of a series of devices aimed at utilizing beam cooling techniques to achieve extraordinary precision and resolution in nuclear physics experiments. Progress on these exciting projects will clearly be a highlight of forthcoming conferences.

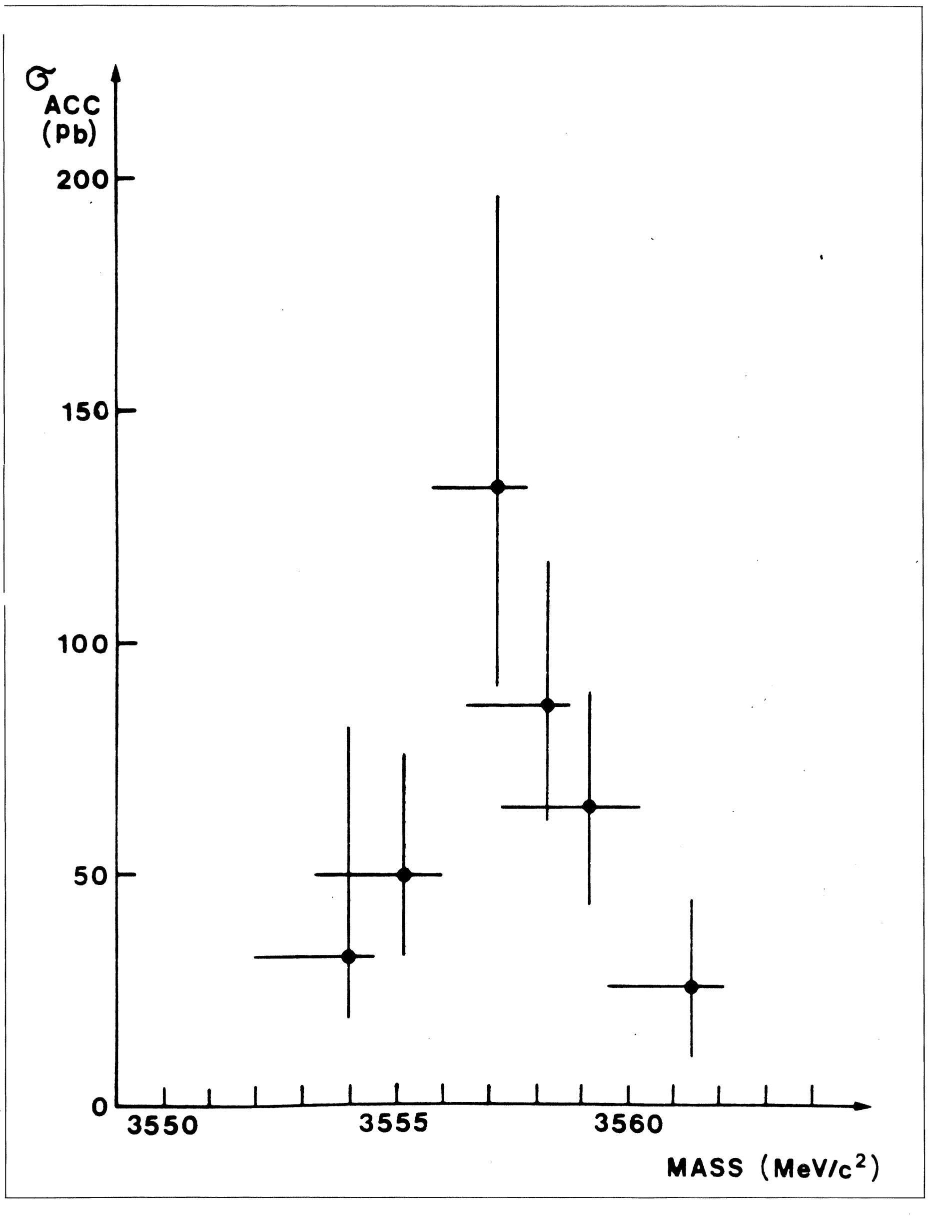
A surprise at the final Conference session was the announcement by M. L. Mallory of the local group of the successful first testing of the magnet for the K800, the second of the pair of MSU superconducting cyclotrons. (In these tests full design field was achieved in the week following the Conference — the maximum energy orbit in this magnet has a magnetic rigidity of 5 tesla metres, the highest bending power yet achieved in an isochronous cyclotron, and exceeding that of all synchrocyclotrons too except for the 1 GeV machine at Leningrad.)

The International Organizing Committee confirmed their decision to hold the Eleventh Conference in Tokyo in the fall of 1986, thus introducing a new third component into the traditional North American-European alternation of Conference sites. A tentative decision was also taken to hold the Twelfth Conference in Berlin.

CERN
Final ISR experiment

First results are now emerging from the last experiment to use the CERN Intersecting Storage Rings (ISR), now being dismantled. This was the gas jet target by an Annecy / CERN / Genoa / Lyon / Oslo / Rome / Strasbourg / Turin team (see December 1983 issue, page 417).

For this experiment, the ISR was operated in a novel mode, with a carefully tuned beam of antiprotons in one ring hitting a fine jet of protons (hydrogen gas). In such proton-antiproton annihilations, the selection rules are less restrictive than in the electron-positron case. Thus certain charmonium (charmed quark bound to a charmed antiquark) states could be studied directly which could only



The chi 2 charmonium state as seen by the recent gas jet target experiment in the CERN Intersecting Storage Rings. As the antiproton beam energy is swept across the energy range, a sharp resonance is picked up.

be accessed indirectly at electron-positron machines.

First results to emerge from the experiment (announced at this summer's conferences) concern the so-called chi states, where the charmonium quarks, as well as having angular momentum due to their aligned spins, also have mutual orbital angular momentum. This gives a triplet of possible levels (chi 0, 1 and 2).

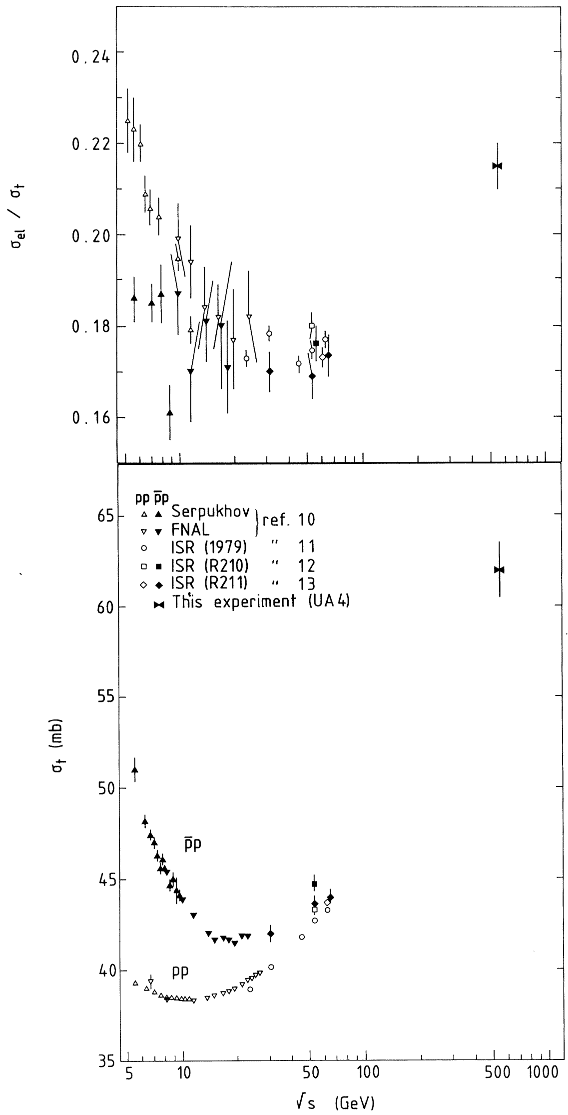
The chi 1's mass is found to be 3511 MeV, with a partial width for the proton-antiproton channel of just 62 eV, while the chi 2 is found at 3557 MeV, with a proton-antiproton width of 200 eV. The intrinsic accuracy of this experiment is reflected in its small errors, the possible variation of the mass values being estimated as below 1 MeV. More data from these and other charmonium states is being analysed.

Bigger and more absorbent

Elastic scattering, when particles 'bounce' off each other without changing their form, gives important insights into particle behaviour. With the world's highest available collision energies, measurements of proton-antiproton elastic scattering are high on the list of priorities at the CERN Collider.

Initial results from both the big UA1 experiment (which measures just about everything) and the special UA4 study (Amsterdam / CERN / Genoa / Naples / Pisa — see September 1982 issue, page 271) gave hints of a number of interesting effects (see June 1983 issue, page 183). To pin these down, the UA4 experiment took more data last year in a dedicated 'high beta' run of the Collider. (For hunting rare particles, the Collider is normally run in the low beta mode, with magnetic fields squeezing the colliding beams to boost the collision rate.)

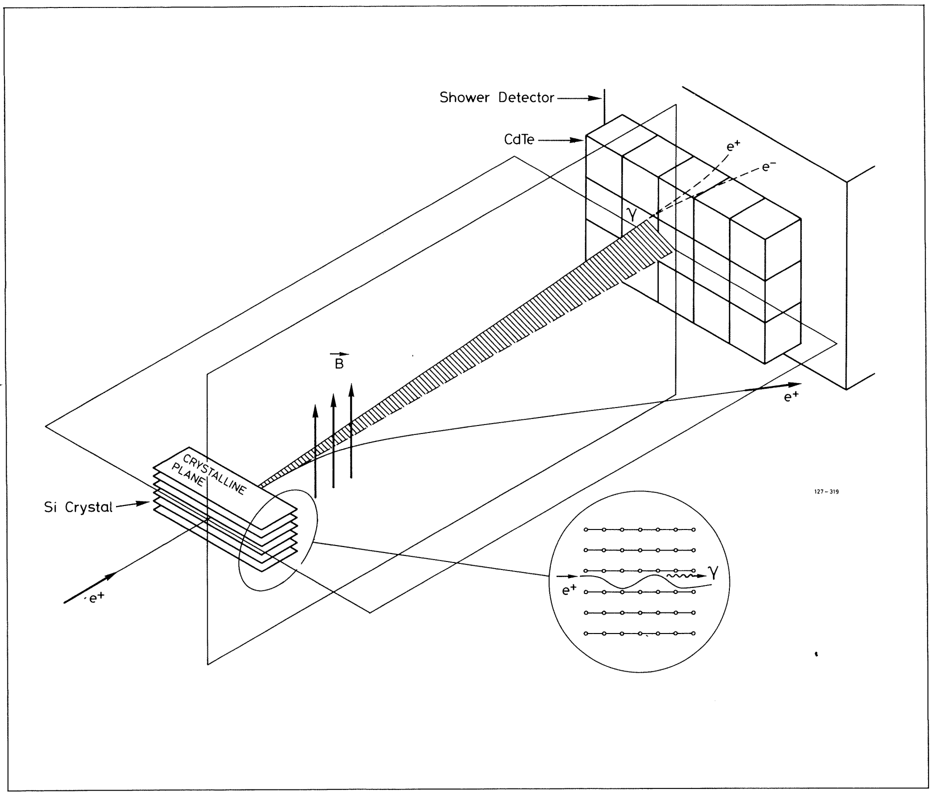
Bottom, comparison of proton-proton and proton-antiproton total cross-sections (a measure of the effective 'size' of the colliding particles) with increasing energy. The point on the right comes from the UA4 experiment at the CERN Collider.
Top, comparison of elastic to total cross-sections. Together these results show that at Collider energies the particles become both larger and more absorbent.

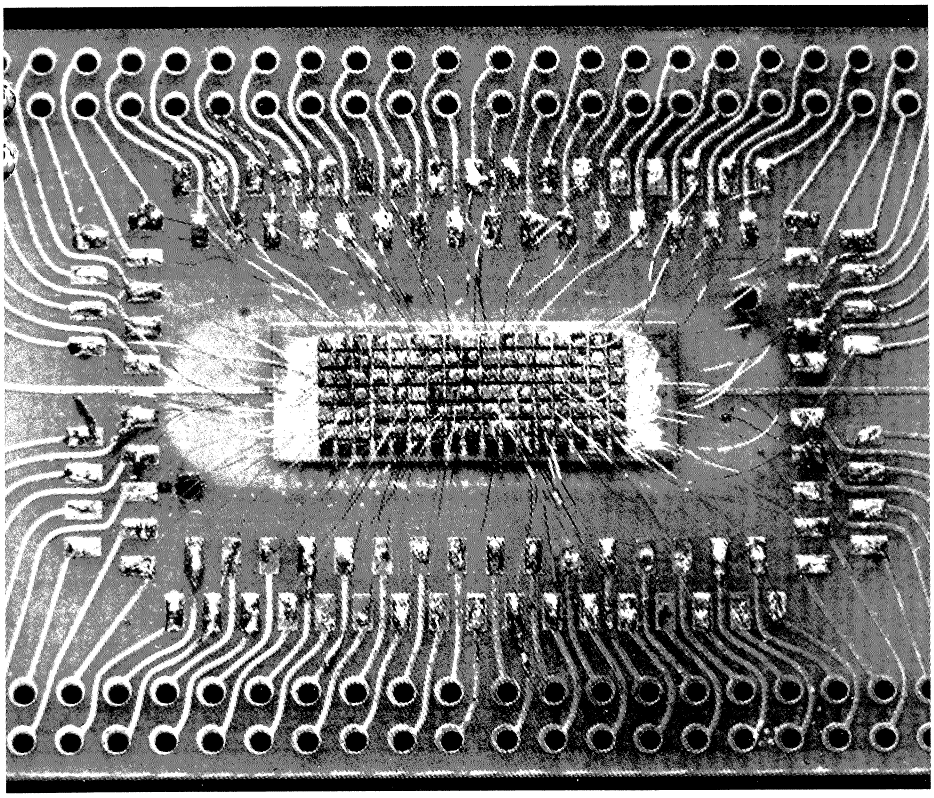


At the Collider, the elastic scattering spectrum falls off exponentially with momentum transfer, with this exponential 'slope' changing at about 0.14 GeV^2. For smaller momentum transfers, the exponential slope is about 15, flattening to 13 at higher values. This 'break' is qualitatively similar to the behaviour seen at lower collision energies at the CERN Intersecting Storage Rings, but the Collider values for the exponential slopes are about 2.5 units higher — the elastic scattering spectrum shrinks.

The total proton-antiproton cross-section (a measure of the effective 'size' of the colliding particles) attains 62 mb at the Collider energy of 540 GeV. Compared with the behaviour seen at lower energies, this

Schematic diagram of the apparatus used by an Aarhus/CERN/Strasbourg experiment studying the angular distribution of channelling radiation.





shows that the proton size increases almost as fast as allowed by general principles (the Froissart bound).

Especially intriguing is the result that the ratio of elastic to total cross-sections increases from around 0.175 at ISR energies to 0.215 at the Collider. Not only does the proton become larger, it also becomes more absorbent.

DETECTORS New semiconductors . . .

In the relentless search for the Best Detector, new materials, as well as new techniques, are being continually exploited.

Semiconductors, such as silicon, are sensitive to charged particles, releasing many times more electrons per particle than a gas. Silicon and germanium strip detectors were developed some twenty years ago and extensively used by nuclear spectroscopists, but only recently has the technique become widely adopted for particle physics. Now large position-sensitive silicon strip detectors are being developed for many new experiments.

Although industry has a big investment in silicon and germanium, they are not the only semiconductors available, and research groups around the world are looking at other semiconductors in the continual search for better detecting materials.

The list of materials being worked on is both long and exotic. A promising material is cadmium telluride, which has been investigated for several years at the French Centre de Recherches Nucléaires, Strasbourg,

The channelling radiation was monitored by an array of cadmium telluride semiconducting detectors.

initially for use in X-ray and gamma-ray spectroscopy. It offers some interesting bonuses compared with other semiconductors, in particular its big nuclei and good energy resolution making it eminently suitable for detecting photons. It can also be handled in small pieces, allowing position-sensitive modules to be built.

A prototype device was developed for an experiment by an Aarhus / CERN / Strasbourg group studying the angular distribution of the channelling radiation emitted when beams of electrons (or positrons) oscillate as they are steered between the planes of a single crystal (see December 1982 issue, page 414).

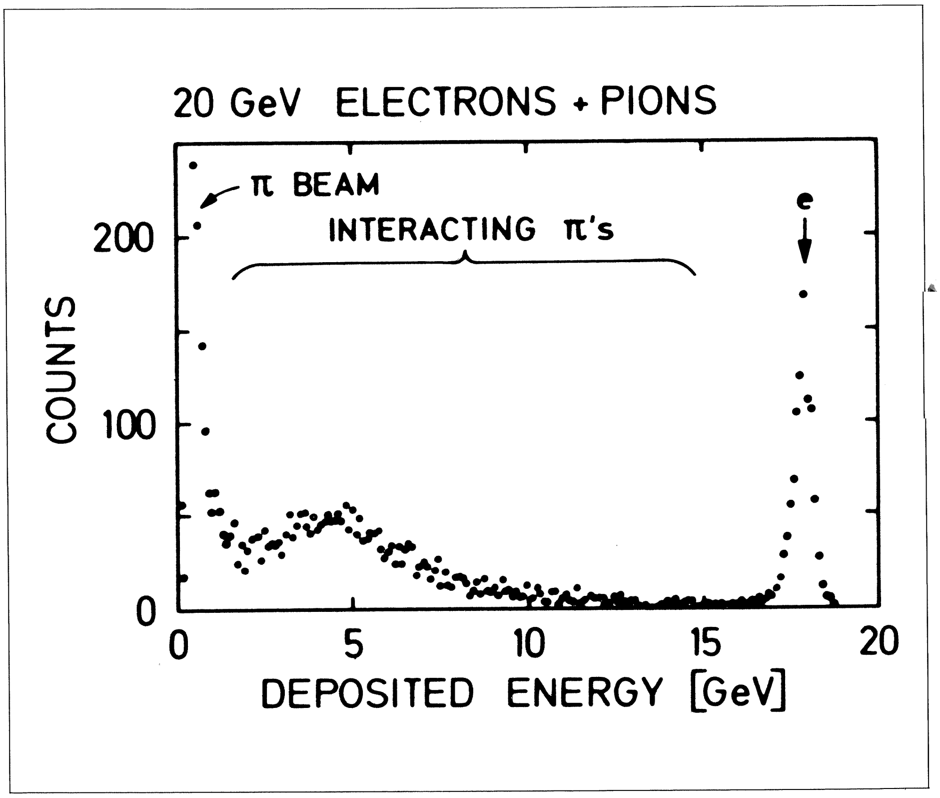
A broad spectrum of photon energies is emitted, but narrow energy bands can be selected by careful angular collimation, thus providing a tunable, almost monoenergetic, photon beam of up to 100 MeV energy. Such a beam, with one photon produced per incident electron (positron), could be extremely useful in nuclear physics experiments.

In the experiment at CERN, a six-by-sixteen array of cadmium telluride detectors (each 0.8 × 0.8 × 1 mm) was used to pick up the direction of the channelling photons and in their energy measurement. A new array, with semiconductors 3 mm thick, has been built to increase efficiency. These cadmium telluride modules are interesting as they are relatively inexpensive and much less prone to radiation damage than delicate doped silicon surfaces.

. . . and new scintillators

New materials are also being investigated as possible new scintillators for detecting photons. The traditional sodium iodide is very difficult to handle (requiring canning) and other substances, like the bismuth germanate (BGO) now making its appearance, are very expensive.

Pulse height spectrum for a 20 GeV beam of mixed electrons and pions, as measured in a caesium iodide test device by an Erlangen/MPI Munich group at CERN, showing good electron/hadron separation. Caesium iodide looks to be a very promising material for high resolution electromagnetic calorimetry.



Barium fluoride has been receiving attention (see May issue, page 141), and recently a small test has been carried out by an Erlangen / MPI Munich group to evaluate thallium-activated caesium iodide for use in high resolution calorimetry. It has a radiation length 1.86 cm, compared to 2.56 cm for sodium iodide and 1.12 cm for BGO. The scintillation light yield is very high, with more than 4 × 10^7 photons/GeV having been measured. The crystals are very rugged, can be machined easily and can be given a simple (but sufficient) water polish.

For the test no sufficiently long crystals were available, and four raw crystal blanks, 10 cm long and 10 cm diameter, were machined and polished to make a small 40 cm-long calorimeter. This was installed in a test beam from the CERN SPS. The photodiode readout elements were originally developed by the MPI Munich group for the readout of BGO calorimeters in magnetic fields. The high light yield and the good spectral matching make photodiode readout for caesium iodide very appealing, allowing calibration and monitoring using radioative sources. (Using a cobalt 60 source and a small crystal — 10 x 10 x 25 mm — the observed resolution above 1 MeV is superior to that of sodium iodide with photomultiplier readout.)

The calorimeter was exposed to an electron beam of between 1 and 20 GeV momentum. Between 4 and 20 GeV a constant resolution of about one per cent was measured. The resolution at 1 and 2 GeV was 4 and 2.5 per cent respectively, however the beam was very poor at these energies and these numbers are only upper limits. With a mixed electron/hadron beam of 20 GeV momentum, the electron/hadron separation in this simple test was very good.

This short test (completed in 4 night shifts) showed that caesium iodide is a very promising material for high resolution electromagnetic calorimetry. Limitations are given by the rather long signal decay time of some 900 nsec. The radiation resistance is about the same as NaI(Tl), but detailed studies are needed. Its resistance is in any case inferior to BGO as it is not self-healing. Although cheaper than BGO it is no replacement for it in the case of very compact detector requirements, like the L3 detector for LEP at CERN. Its longer radiation length would significantly increase the overall cost. Meanwhile tests continue to evaluate other materials for high resolution calorimetry.

(From E. Lorenz)

The continuing challenge of solar neutrinos

Following the colloquium 'Astrophysics and Fundamental Interactions' at Cargese last July, a study and planning group on nuclear physics, particle physics and astrophysics was set up. The main topics relating to areas in the forefront of these three fields for which there was a common interest in France and which deserve encouragement and support were set out in a document submitted to the Centre National de la Recherche Scientifique. One of the major topics was solar neutrino detection.

According to the standard model of the sun, a continuous flow of neutrinos arrives on the earth at the rate of some hundred thousand million per square centimetre per second. To date, little work has been done on the measurement of the flow and energy spectrum of solar neutrinos. The experiment led by R. Davis, using radiochemical methods, has detected neutrinos with an energy higher than the 1 MeV from boron decay, but sees only a third of the expected level of neutrinos. It is therefore essential to study the whole of the energy spectrum. Astrophysicists and elementary particle physicists alike are extremely interested in these measurements since they would increase our understanding of all the physical processes of the sun's deep interior.

However, this is a difficult task as the neutrinos are extremely reluctant to interact with matter and their very low energy (several hundreds of keV) makes the choice of target critical (the threshold problem) and the background noise associated with natural radioactivity a serious hindrance.

Earlier this year, an international meeting was held at the Laboratoire de Physique Corpusculaire at the Collège de France in Paris to discuss these questions. The main discussion focused on the capture of solar neutrinos by indium. The nuclear reaction induced in indium by the solar neutrinos releases electrons, and the low threshold (128 keV) in principle makes it possible to examine the neutrino spectrum thoroughly and to measure the energy of the incident solar neutrino directly.

The idea of using indium as a target for solar neutrinos was first suggested in 1976 by R. S. Raghavan (Bell Laboratories). He and M. Deutsch (MIT) took part in the Paris meeting where they presented recent work on indium detectors.

The feasibility of such an experiment has yet to be demonstrated. Several techniques are being investigated: conventional techniques using liquid scintillators and indium cathode wire chambers are under study at the Département de Physique des Particules Elémentaires at Saclay. More recent techniques using chemical compounds of indium which permit ionization drift are being examined at the Ecole Polytechnique and at Saclay. Finally, techniques using the superconducting properties of indium are currently being studied: Norman Booth (Oxford) and Bell Labs are looking at the use of the phonon-assisted tunnel effect in an indium monocrystal, while feasibility studies of a detector with superconducting, metastable indium grains are being conducted at the University of Paris VII and in three French research centres: LAPP at Annecy, Collège de France and the Centre de Recherches Nucléaires at Strasbourg. To this list should also be added projects to detect the neutral currents induced by solar neutrinos in a granule detector (Max Planck Institute, Munich).

The detection of solar neutrinos remains an experimental challenge for astrophysicists and elementary particle physicists. But the Paris meeting showed that there are many researchers eager to take it up.

People and things

Kaye Lathrop, who comes to the Stanford Linear Accelerator Center (SLAC) from Los Alamos to become Associate Director, Technical Division.

On people

Sir Alec Merrison, currently President of CERN Council, becomes also President of the UK Institute of Physics.

At the Stanford Linear Accelerator Center (SLAC), Kaye Lathrop becomes Associate Director, Technical Division. He comes to SLAC from Los Alamos, where he was Associate Director for Engineering Sciences.

A Boston organization called 'Friends of Switzerland' have awarded its 1984 Stratton Prize to Viktor Weisskopf. The prize has a nice touch associated with it in that the recipient is asked to pass on its monetary value to a younger person. Professor Weisskopf chose Rafel Carreras who has for many years been a popular communicator of science at CERN. Among the activities of Rafel Carreras are a series of lunchtime talks on science topics, a science press cuttings collection called 'Picked up for you' and science programmes on Swiss TV.

75th birthday of N. N. Bogolyubov

On 21 August, leading Soviet mathematician and theoretical physicist Nikolai Nikolaevich Bogolyubov, Director of the Joint Institute for Nuclear Research, celebrated his 75th birthday. His name is linked with milestone discoveries in the field of mathematical physics, quantum statistical physics, quantum field theory and the symmetry of elementary particle interactions, covering non-linear oscillation theory, time ordering in statistical physics, his chain method in classical statistical physics, the Bogolyubov transformation in quantum statistical physics, axiomatic quantum field theory and particle symmetries.

N. N. Bogolyubov's many fundamental scientific achievements, the diversity of his interests, the depth of his physics ideas, the richness of his methods in theoretical physics, his skill as a teacher, his scientific generosity and, of course, his personal charm provided fertile ground for the creation of a number of successful schools of mathematical and theoretical physics in Moscow, Kiev, Dubna and other cities. He has been honoured for his work as an outstanding scientist and organizer of science by many awards and scientific prizes, both in the Soviet Union and abroad.

The distinctive full colour shot of the Brookhaven radiofrequency quadrupole that adorned the cover of our April edition has gone on to win a number of awards for Brookhaven photographer Mort Rosen, including category winner in this year's national convention of the Professional Photographers of America.

Meetings

The second Jerusalem Winter School of Theoretical Physics, sponsored by Israel's Ministry of Science and the Institute for Advanced Studies of the Hebrew University of Jerusalem will take place form 27 December 1984 to 4 January 1985, with the title 'Physics in Higher Dimensions'. Lecturers will be Raoul Bott (Harvard), Michael Duff (Imperial College and CERN), John H. Schwarz (CalTech), Steven Weinberg (Texas), and a fifth lecturer to be announced.

In the last few years there has been a revival of interest in the old idea that space-time may have more than four dimensions, all but four having been curled up into a small circumference. In this view the various particles and interactions we see at ordinary energies arise from a simple, perhaps purely geometrical, theory in higher dimensions. This idea has profound implications for elementary particle physics and cosmology, and raises challenging problems of mathematics.

Applications should be sent to Tsvi Piran, Jerusalem Winter School of Physics, Institute for Advanced Studies, Hebrew University of Jerusalem, Jerusalem 91904, Israel.

The essentially non-linear nature of many accelerator-related processes is being increasingly realized. In parallel with this, recent years have seen great progress in the wider field of non-linear dynamics. Thus the first Topical Course organized by the Joint US-CERN School on Particle Accelerators is on Non-Linear Dynamics, to be held in Santa Margherita di Pula, Sardinia, from 31 January to 5 February 1985, is on Non-Linear Dynamics. Further information from J. M. Jowett, LEP Division, CERN, 1211 Geneva 23, Switzerland. Closing date for applications is 22 October, and attendance is limited to 100.

The US/CERN School on Particle Accelerators is a joint effort by the CERN Accelerator School and the US Summer School on High Energy Particle Accelerators.

The International Conference on Hypernuclear and Kaon Physics will be held next year from 9-13 September at Brookhaven National Laboratory. Further information from R. E. Chrien, Bldg. 510, Brookhaven National Laboratory, Upton, New York 11973, USA.

ICEPP Tokyo

Formed this year in the University of Tokyo is ICEPP — International Centre for Elementary Particle Physics — under Masatoshi Koshiba. The primary activity is collaboration in the big OPAL experiment at the LEP electron-positron collider being built at CERN, but ICEPP members also work on the JADE experiment at the German DESY Laboratory in Hamburg, and in the Japanese Kamioka nucleon decay search.

Bubble chamber soccer

With sports commentators exhausted after the long grind of the British football season, the 10th UK National Bubble Chamber Five-a-Side Soccer Tournament held in London earlier this year did not attract the media coverage it deserved.

This annual competition has developed from humble beginnings in 1975 to become a highlight of the sporting calendar, attracting no less than 15 entries from high energy groups large enough to field a team — Birmingham, Oxford, Rutherford Appleton Laboratory, and London's Imperial College and University College.

The competition includes ladies' teams too, who make their own mark on the initial gruelling league competition.

The two top teams from each of the two leagues go through to the hotly contested semi-finals, while the top two ladies' teams play off for their own championship. This year, two teams from Rutherford together with Oxford and Imperial College went through to the semi-finals, the first time in living memory that Birmingham has never made the last four.

The long-awaited final brought together the holders, Rutherford A, and Imperial College Wanderers. The result hung in the balance and it needed a lone goal by the London team well into extra time to force a decision. Oxford Ladies had no such problems in disposing easily of Rutherford.

Artist's impression of this year's UK National Bubble Chamber Five-a-Side Soccer Tournament, held in London's Hyde Park.

Heavy ions at Brookhaven

In mid-1986, a new high energy heavy ion research programme will begin at the Brookhaven Tandem — Alternating Gradient Synchrotron complex. Ions of carbon 12, oxygen 16, and sulphur 32 at 15 GeV/nucleon will be available with intensities in excess of 10^9 particles per pulse. First proposals for heavy ion experiments will be considered shortly.

A user organization, the Heavy Ion Users Group (HUG), is being formed, along parallel lines to the existing Brookhaven High Energy Discussion Group (HEDG) the forum for AGS particle physics. An executive committee has been appointed with Peter Braun-Munzinger of the State University of New York, Stony Brook, as chairman.

Young scientists

Fermilab, along with Argonne National Laboratory, AT and T Bell Labs and ten other scientific and technological research centres in the Chicago area, recently organized 'Intech 84' — a science competition which attracted 46 student entrants from 23 neighbourhood high schools. Participants had to choose a project in one of a number of areas of science and prepare papers and a public exhibit. Entrants benefitted from contacts with professional advisers, and the contest was widely acclaimed by entrants and organizers alike.

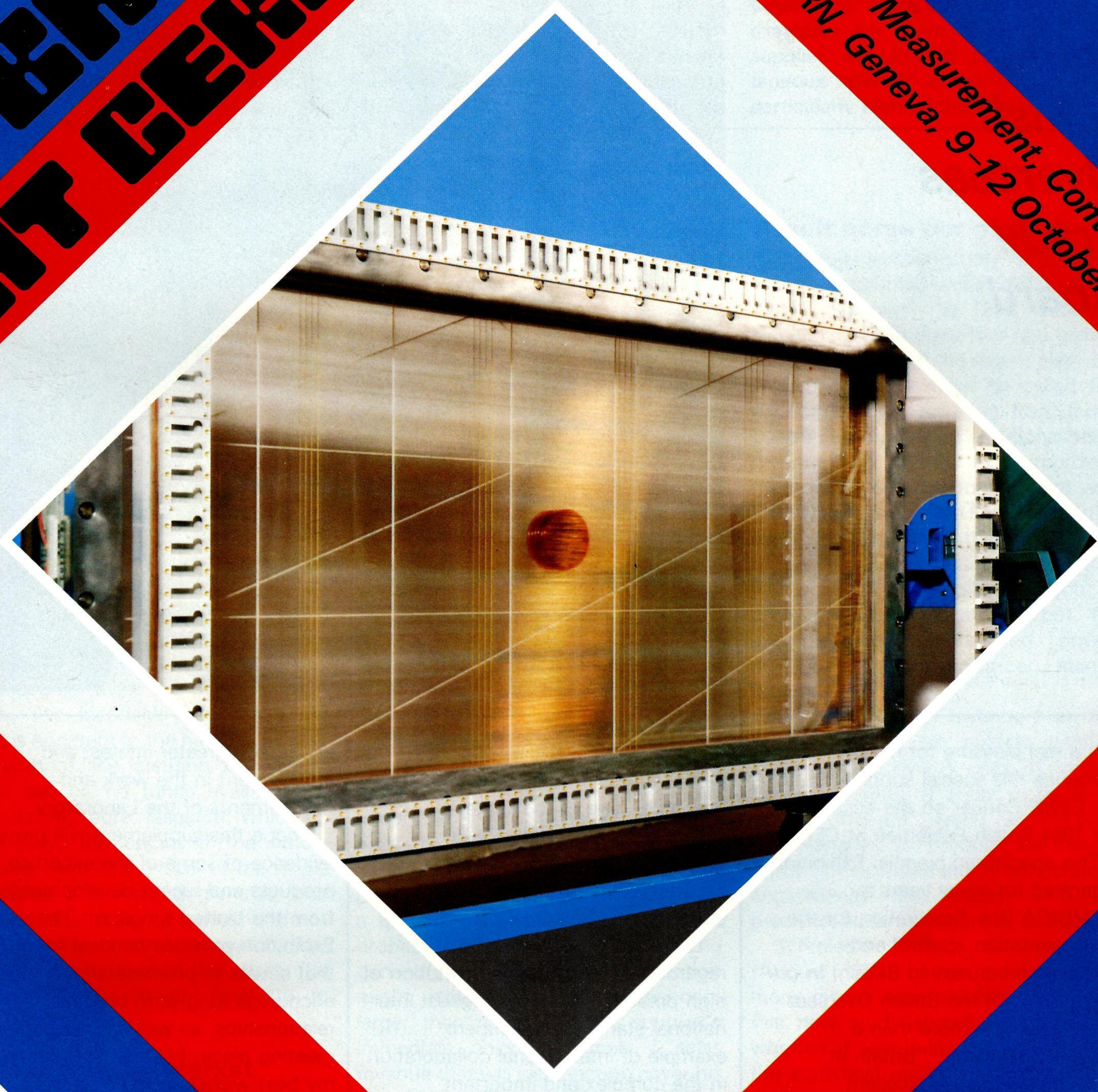
First prize of $ 1000 and a year's free tuition at Northern Illinois University went to a sixteen year old lad who devised a method for finding roots of rational numbers.

CERN at 30

During September, a series of events was organized at CERN to mark the Laboratory's 30th anniversary, culminating in an official ceremony on 21 September with many distinguished visitors and guests from Member States, including King Juan Carlos of Spain. A full report will feature in our next issue.

BRITAIN AT CERN 1984

British Exhibition of Measurement, Control and Automation at CERN, Geneva, 9–12 October 1984



British Overseas Trade Board

GAMBICA

Message from The Rt Hon Earl Jellicoe DSO MC *Chairman of the British Overseas Trade Board*

It is a real pleasure for me to introduce this special supplement to the CERN Courier on the occasion of the 1984 British Exhibition at CERN.

This specialised biennial Exhibition, organised for many years by GAMBICA (the Association for the instrumentation, control and automation industry in Britain) in co-operation with the British Overseas Trade Board, is more than a conventional event. "Britain at CERN" provides an excellent opportunity for British companies, already active in this technical and challenging market, to exchange views with their CERN contacts, and renew and develop relations both with the experimental scientists and those concerned with the selection and purchase of equipment. I am particularly glad to see that, for the first time, nine of the some 40 companies taking part will be presenting a technical lecture programme covering a wide range of scientific and industrial subjects.

CERN is rightly and widely regarded as a pioneering institution of high prestige and of the highest international standing — a superb example of international collaboration in the complex and important discipline of research into particle physics. We attach particular importance to this market. Indeed the BOTB's European Trade Committee has set up a special group to bring the opportunities at CERN to a larger audience of British industry to encourage greater interest and involvement in the work and requirements of the Laboratory.

I hope this supplement will provide evidence of some of the expertise, products and recent developments from the United Kingdom. The Exhibition provides an ideal forum that serves to promote and encourage long-term business relationships, as well as a valuable meeting place. I should like to send my best wishes to the organisers and to the British firms for a successful and productive exhibition.

JELLICOE

Particle-physics research, spin-off and British industry

Particle-physics research can, quite often, give rise to applicable and useful technology, although usually after some considerable period of time. A more direct link with the industrial world arises from the need that the research itself has for advanced products and methods. This provides a healthy stimulus for industrial development, and in this article instances are given of products and techniques that were initiated in this way. British industry has made significant contributions to these developments, and examples are given of some British supplies to LEP. A further advantageous spin-off is the human one, particularly highly trained manpower.

by J. D. Walsh
Nuclear Physics Division, UK Science and Engineering Research Council

The conventional model, such as is found in textbooks on management, of the bringing to market of an industrial product, is linear. Starting at one end, research is followed by development, by engineering, manufacture and, finally, marketing. Factors of 10 (cost) and 10 per cent. (likelihood of success) are often quoted as a transfer function between successive stages.

At the national level, the same model translates into the familiar rationale for supporting scientific research: scientists do research; other scientists and engineers apply some of that research; and manufacturing engineers and industrialists use some of that result to create wealth.

Of course, these are oversimplifications. The feedback loop that must exist is apparent in the national model, for without the creation of wealth, there can be no funds available for speculative, 'pure' research, which is, ostensibly, the origin of the whole process. And at the level of the single enterprise it is increasingly true, and obvious, that it is the market and not the randomly creative innovator, that provides the motivation that drives the process. So the straight lines are, in fact, closed paths.

Research is the market

In particle physics, as perhaps in some other areas of scientific research, there exists an interesting variation of the model. The traditional concept also applies; at least a few of today's discoveries in the most exotic branches of science will be the foundation of whole industries in decades to come. But there is a much more immediate connection between particle-physics research and economic realities; this arises because *the research is itself the market.*

The level of technical sophistication required in particle-physics research is exceeded, if at all, only in space research. It represents an incessant demand for constantly improved products. Computers have to be quicker, electronics more reliable, materials more certain in behaviour. Mundane components like valves, metal extrusions and cables have to perform to specifications that are rarely to be found in off-the-shelf items. We do not, after all, have to wait 20 or 30 years for spin-off. It is a present fact, created by market pull rather than research push.

The situation faced by the supplier to the particle-physics-research market is, at first sight, different only slightly from that which he faces anywhere else. The client — in this case an international collaboration of research physicists, or someone acting for such a group — wants a product that is probably more advanced than anything generally available. Its production might require an R&D component larger than usual, but the supplier's immediate object is simply a sales revenue that will well-enough cover his input cost. But now suppose that, having concluded his business with the physicists satisfactorily, he finds that the product development that he has necessarily undertaken has given him an edge in a more general market.

That is, in fact what happens. The closed loop produces a tangent: spin-off.

Result borne out of study

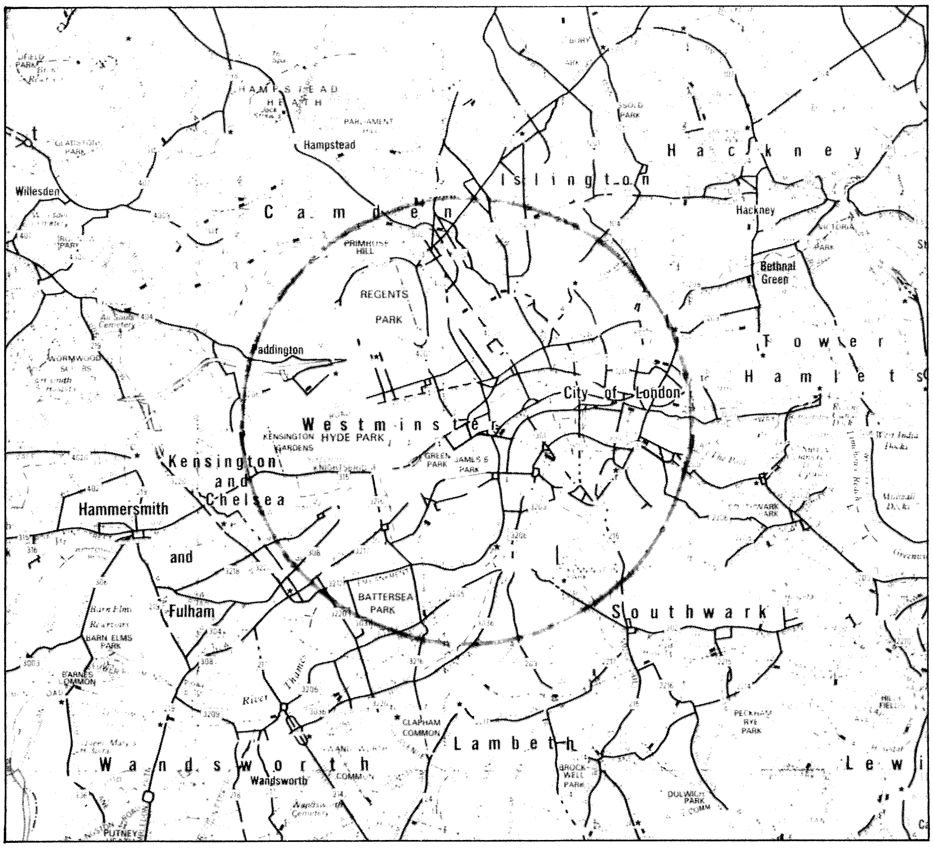
This result has been amply ventilated in a study conducted under CERN's aegis by H. Schmied[1] in 1975. Schmied investigated 130 firms that had gained CERN contracts in the recent past. He tried to measure what he called the economic utility resulting from those contracts, comprising additional sales revenue and savings from improved methods. The former component was found to be by far the largest, and the surprising finding was that 80 per cent. of the total utility resulted from sales to markets outside physics research: it came not from laboratories, but, for example, from shipbuilding, power distribution and motor-car manufacture.

For every unit of revenue from the CERN contract, the average supplier later received over 5 units of further sales. The ratio of utility to value of CERN contract varied enormously depending on the product; the lowest figure 1.7, occurred in low-temperature engineering; the largest, 31.6, in precision electromechanical devices.

Schmied's findings are currently (August 1984) being updated using more recent case studies. Whatever this new study shows, we may ask whether it seems likely, leaving aside the statistical results of surveys, that particle-physics research is indeed a market force. Is there any evidence that techniques and devices developed for, or invented in, this esoteric area of research, have found significant application elsewhere? To put it succinctly, where are the particle physicists' nonstick frying pans?

Well, the industrial kitchen is full of

The size of the particle-physics research market is a function of the size of the accelerators used — and they get bigger as time goes on. The tunnel of the LEP project, currently under construction at CERN, is here shown as if it had its centre on Piccadilly Circus in London.



them! The following list is a selection based on the author's ability to understand the subject matter of the items; it probably therefore omits many of the most significant.

1. The *flat-cabling technique,* invented at the Rutherford Laboratory for superconducting cable, is now used worldwide for superconducting as well as warm transformer coils.

2. *Hydrostatic extrusion of multicore superconducting wire* was started because of a physics research requirement.

3. *Liquid-cooled d.c. cable* was developed following a requirement for an experiment at the Intersecting Storage Rings (ISR) at CERN; the JET project is currently reaping this particular harvest.

4. The ISR also gave a boost to *ultra-high vacuum systems,* stimulating the development of techniques for constructing and out-gassing very large, high-vacuum systems and the necessary new pumping devices.

5. *Particle detectors,* which, as their name implies, had no conceivable use other than in particle-physics research, are now widely used in diagnostic medicine and in a variety of fluid-dynamic studies in industry.

6. *Particle accelerators,* similarly, were developed to do just what their name implies. But the synchrotron radiation emanating from electron accelerators is now one of the basic tools of research in the study of metals and materials. And extracted particle beams are used routinely in hospitals for radiation therapy.

7. *Large superconducting magnets* were first developed for particle-physics research. Without them, medical NMR scanners would not exist.

8. In particle-physics research, the requirements for *data handling and transmission* have regularly set the standard for later commercial performance. This fact was recognised by the European Community when it sponsored the STELLA project which linked CERN via satellite to several research centres in Europe. The rate of data transmission had to be unprecedented, and its accuracy had to be virtually absolute if it was to be at all useful to its recipients. If they are to stay in business, the suppliers of the 1990s will have to emulate what particle-physics researchers expect today.

An essentially human activity

The above list is selective, and certainly CERN-centred. It is notable, however, that this belief in particle-physics research as a market force is not solely cis-Atlantic. L. M. Lederman, in his paper[2] to the National Science Foundation Workshop of 1982, makes the point that the scientific under-pinnings of all the modern science and technology rest on the achievements of very basic research up to and through the 1940s. He defines very basic research as an essentially human activity, led by curiosity — something that governments are prepared to provide a budget for as a measure of their cultural commitment. He goes on to suggest, using a list of spin-offs much longer than that above, that this open-handed investment in fact pays for itself rather handsomely. He quotes another writer, on the transistor: "... a breakthrough came from work dedicated to the understanding of fundamental phenomena, rather than the cut-and-try method of producing a useful device".

Lederman's paper deserves reading by anyone with an interest in physics research, whether as a *modus vivendi* or as a living. He covers more fully than the present author the difference between spin-off and long-term hopefulness. It is noteworthy that he feels one of the most useful products of this business to be the trained, able people that it produces. The human product is, of all the results of doing research in particle physics, the least measurable. Of the industrial hardware product, the sceptic can say with more or less conviction that, if the particle physicists hadn't done it, someone else would have. This rings hollow on serious inspection. But human beings are not so easily completely investigated. The randomness that afflicts — or enhances — our individual career paths is perhaps best not looked at too closely. Statistics cannot quite cope with the diversity of will that separates man from the rest of the animal kingdom.

Experience well illustrates this point. In the United Kingdom, we know that shown in Figure 1 for VPTs and photomultipliers (with no magnetic field). These distributions, which are equivalent to those expected from 400 MeV electrons in the OPAL detector, are indistinguishable. The RAL group is confident that a VPT device will satisfy its needs and that the unit cost, including a hybrid preamplifier, will not be too different from that of a photomultiplier.

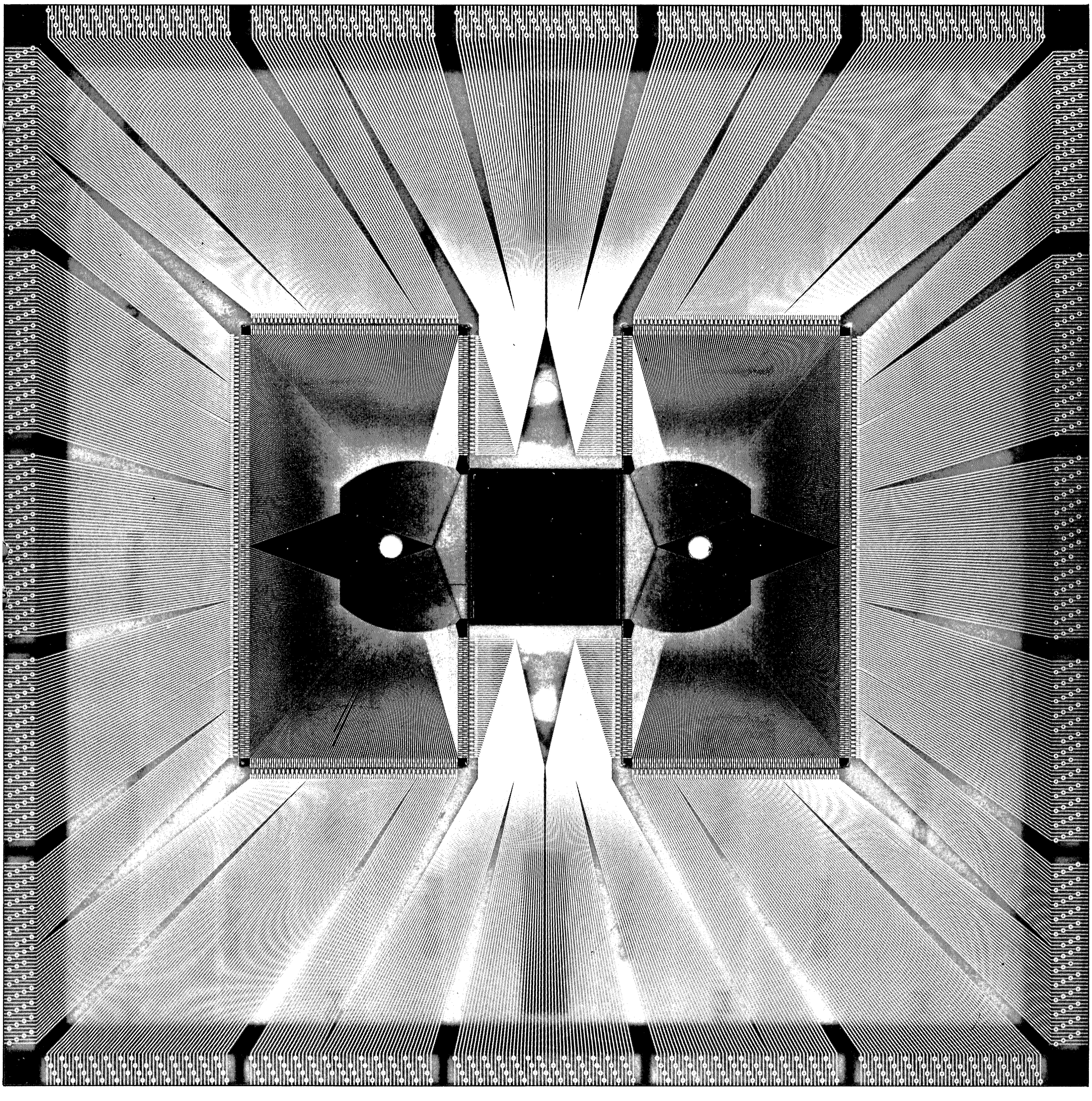
2. Silicon microstrip devices

Techniques used by the electronics industry in the manufacture of high-density integrated circuits are now being applied to the production of high-spatial-precision particle detectors.

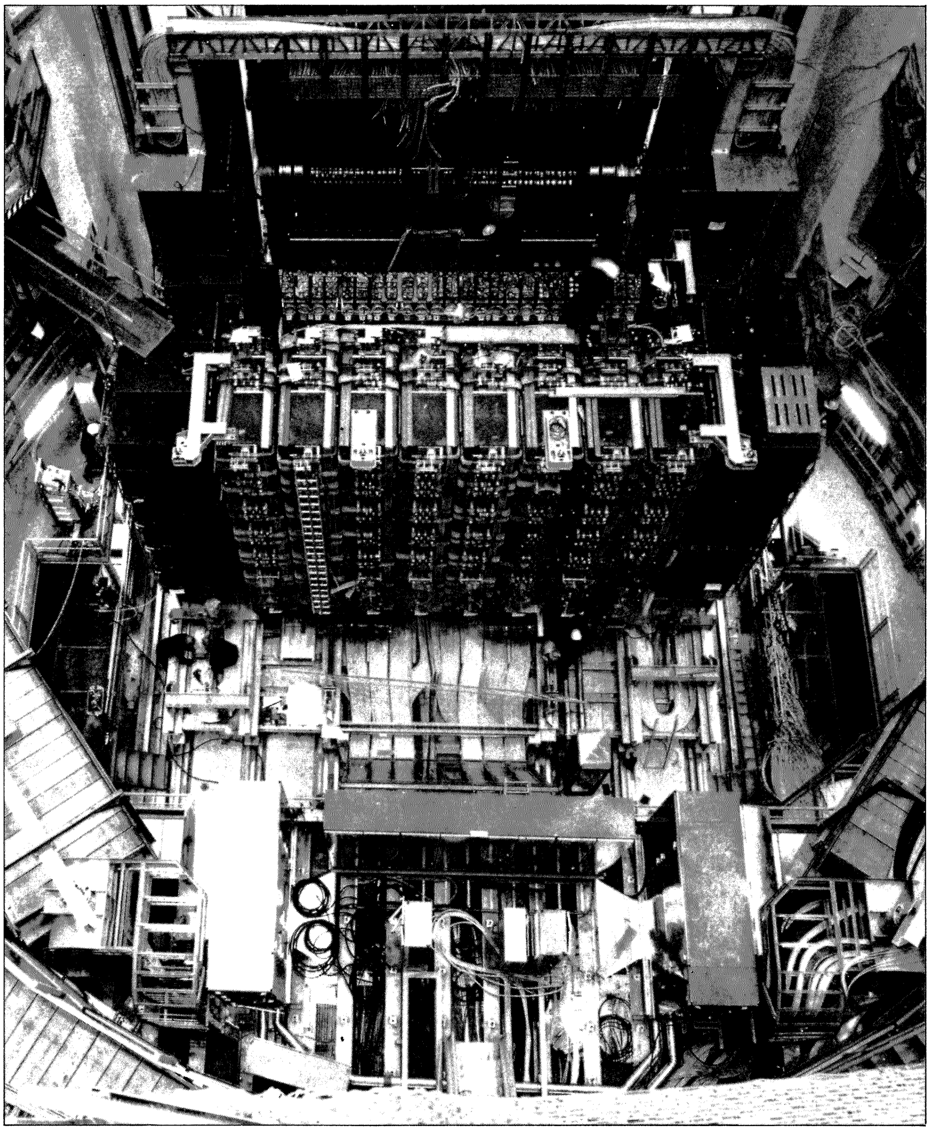
The NA-14 experiment at CERN will use high-energy photons to study the production and decay of particles containing charmed quarks. These particles have short lifetimes and travel only a fraction of a millimetre before they decay. Their observation requires detectors capable of measuring and resolving track coordinates with a precision of the order of 20μm. Such dimensions are coarse by integrated-circuit standards, and an Imperial College, London, group, together with a new British company, Micron Semiconductor, have together undertaken the construction of a square 50 x 50 mm particle detector using reverse-biased diodes implanted in strips on silicon wafers with a pitch corresponding to the required precision.

The basic requirements of a silicon detector for high-energy particles are simple. The charge signal available from the ionisation energy loss in a

Fig. 2. Detector plane — one of a stack of eight produced by Micron for use in the NA-14 experiment



The complexity of the requirements is exemplified by CERN's UA1 detector, a major contributor to the recent discoveries of the W and Z bosons and, very recently, of the 'top' quark.



about one-third of our new PhDs in particle physics find their first jobs in industry. We don't know if they stay there. More importantly, we don't know what the other two-thirds do after their possibly abortive attempts to stay with the vocation they have chosen. All that we do know, in qualitative terms, is that a research student who works on a CERN experiment has to learn a lot about delivering on time, price and specification, and that this often involves him or her in getting dirty fingernails along the way. And all this in at least two languages.

British business with CERN

Returning to the more immediate world of CERN and the business a British firm can do there, how well *do* United Kingdom firms do? It has been shown elsewhere[3] that we do fairly well, but that we could do better. Why this potential improvement is a source of concern has been foreshadowed above; if firms can't supply CERN now they are unlikely to be supplying the rest of the world in the future.

The informed taxpayer in Britain may be very happy that his Government chooses to be a member of CERN. He may for example know that British industry receives CERN contracts whose annual value is about one-fifth of our contribution to the CERN budget. Using Schmied's average factor of 5, he can calculate that the whole of this contribution returns as economic utility: a local and very specific result that seems to bear out Lederman's belief, researched on quite different data, that the research is far from being an economic drain.

The same informed layman, if of a speculative frame of mind, may reason that since CERN has learned how to create and store antimatter, it now has at its disposal an energy source that is, in principle, infinite, and infinitely exploitable: we can forget our windmills and tidal storage schemes.

But this article addresses the more practical world of the here-and-now. CERN is indeed a difficult customer, unlikely to be satisfied with stock items. Those firms in Britain — or anywhere else — which are willing to accept the challenge and act accordingly, can benefit in the longer term. It may be difficult to match the exacting standards set by CERN, but the standard setter becomes the shop-window.

From 1989, when LEP will be working, how much will this remarkable international venture owe to British industry? It is too early to write the catalogue yet, with so much of the LEP infrastructure and of the machine itself not yet ordered; but we know already that the sextupole magnets, the RF storage cavities, some of the waveguide and quadrupole magnets and the electron gun that lies at the heart of the whole machine, will be of British manufacture. We hope to add to this list in the coming two years as the final third of the LEP capital cost is translated into the form of contracts.

An international harmony

Finally, my many friends in British industry would share my view that it would be churlish to finish this article on a note of self-interest within just a few weeks of the 30th anniversary of CERN. Thirty years is a long time and the world was very different in 1954. The technical director of a British firm that is a regular supplier to CERN has made the point that, in 1954, the member states who came together to form CERN had been only nine years previously devoting their best efforts to killing each other; the international harmony created by particle-physics research is perhaps its most valuable spin-off.

References

1. **H. Schmied,** A study of economic utility resulting from CERN contracts, *CERN report 75-5, 1975*
2. **L. M. Lederman,** Viewpoint from fundamental science, *NSF workshop paper, 1982*
3. **D. C. Imrie and J. D. Walsh,** The other side of CERN, *New Scientist, 7 June 1984*

Safety, research and CERN — A British view

All places of work in the United Kingdom are effectively covered by the Health and Safety at Work Act, 1974. Its general duties and powers for making regulations provide protection for all people at work and for the general public. These statutory duties, coupled with the interpretations given over the years in judgments in civil cases related to safety in employment, provide a very sound basis for establishing safe places of work with safe access and egress and the adoption of safe systems of work.

Employees in manufacturing industries and in offices and shops were previously protected under specific legislation, but those in research laboratories (among others) had no statutory provision while at work. Major research laboratories produced their own codes of practice, sometimes based on the legislation for manufacturing industries, in order to guide and control the researchers and their work such that safe conditions were achieved.

The regulations made under the Health and Safety at Work etc. Act apply to all places of work and, in conjunction with the previous knowledge and experience, have enabled British research laboratories to achieve a very high level of safety.

by Eric Hartley
Head of Health and Safety Group
Rutherford Appleton Laboratory

Safety in particle-physics research

Safety considerations are given a high degree of priority in all major research laboratories. Within them safety organisations are established by the management, and representatives of the workforce are members of working safety committees. Professional engineers and scientists are employed in advisory roles.

Safety, like the study of particle physics which it supports, crosses all boundaries and all barriers; it is a common subject which requires a common-sense approach and, regardless of language, discipline, attitude or skill, it has a common aim and a common purpose — that of safeguarding life and limb and, in addition, safeguarding complex and vastly expensive equipment thus permitting more and more sophisticated and detailed research to be carried out. Without the benefit of the safety analysis and safety considerations, none of today's very advanced experiments could be, or indeed dare be, attempted.

If safety in large-scale research is so important, how is this analysis and consideration to be carried out? The most crucial influence is that of the designer: adequate consideration at this stage cannot be bettered later. Thereafter the manufacturer, the supplier, the importer, the installer and the eventual user each in turn plays his part in ensuring a continued safe provision.

To aid each of these links there must be adequate information to guide, instruct and inform, but in order to prepare the required information there must be adequate research. The wheel turns full circle: in order to carry out research there must be research!

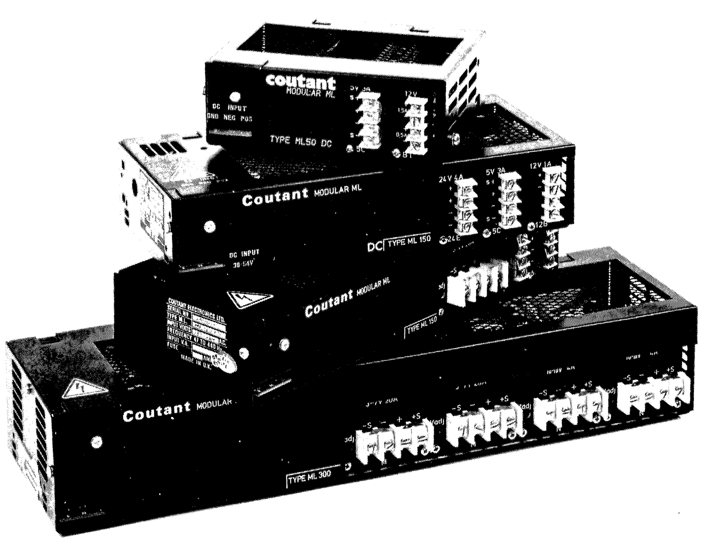
Satisfactory information systems must be established, prepared and edited and the information disseminated. These tasks fall sensibly into the role of the safety professional who must be prepared to give advice at all levels and to establish and monitor these systems to ensure that they are used and are satisfactory for use. The safety professional must monitor, analyse and liaise within and without his own establishment to attempt to assist in preventing the occurrence or recurrence of hazardous incidents, injurious accidents or dangerous occurrences.

The hazards of research

Many hazards exist within these areas of research:
Electrical — high voltage, heavy current, high magnetic fields, radiations at high power, at microwave and radio frequencies, and lasers;
Mechanical — machinery, heavy loads, pressure and vacuum systems;
Explosion and fire risks — flammable liquids, gases and hazardous materials;
Chemicals — toxic and corrosive;
Ionising radiations — accelerators, sources and induced activity;
General — noise, confined spaces, working at a height;
and, the most significant hazard of all,
People — thousands of employees, visitors, users and contractors!

All these hazards are analysed, and great care is taken and considerable resources are expended to ensure

All of these switch-mode power supplies, ranging from 1 W to 1500 W, are manufactured in England to BS and VDE specifications by Coutant Electronics Ltd. They feature the latest technology and offer a high degree of flexibility towards customer requirements as well as a high level of safety in operation.



healthy and safe conditions; nonetheless, accidents do still occur. The accidents which occur are not specifically related to the nature of these hazards or the specialised work carried out in these research establishments. The types of accidents are those which occur in all workplaces: falling while handling goods; and stepping on or striking against objects — often placed in the way by the injured person.

The special case of CERN

CERN is an international laboratory with an international population and a well deserved international reputation. This internationalism brings with it many problems. How can CERN overcome these difficulties and carry out its research — not only to the satisfaction of the scientific community but also safely? How can it overcome the absence of specific legislation which requires the provision of safe plant and equipment with established safe procedures, safe systems of work and a safe place of work with safe access to it and safe egress from it?

CERN must first of all rely on its own safety organisation, the Technical Inspection and Safety Commission. This is a highly competent professional group which has expertise and can give advice in all the relevant problem areas. This organisation produces all the safety codes and safety information required.

Very effective liaison exists between those in CERN safety and those in the safety departments of similar British users. A common approach has been taken with regard to the exchange and production of safety information; all the associated major research laboratories in Europe collaborate in safety discussions and practise a free exchange of ideas and information. Standards, certification, authorisation and records prepared and issued by one laboratory will, where applicable, generally be acceptable to and be agreed by the host establishment. The general rule is that where two standards appear to apply, the stricter one should be followed.

As the European Community develops its directives, they will become common to all laboratories, and this will enable CERN to accept readily that its standards do not and need not differ.

CERN must also rely on its contributors, not only on the researchers but also on their suppliers of equipment and of articles and substances to be used in the research, and on the manufacturers and designers of the specified systems which are to be employed.

If the decision is taken to purchase equipment from the United Kingdom, the intending purchaser at CERN and the safety organisation must be able to expect that the necessary safety considerations have been made and that adequate safe provision is already incorporated.

What Britain has to offer

British law in its common (civil) and criminal (statute) applications places great emphasis on safety. Not only does it place duties on each employer and employee, but it singles out particularly the designer and the manufacturer in order to emphasise clearly the role that they must play in the provision of safe equipment, or in the supply of articles and substances which have been sufficiently researched such that any hazard associated with them and their use has been assessed.

To assist this safe design and safe manufacture, a whole range of guidance documentation exists. Specific British Standards and selected standards and codes of practice are referred to by the Health & Safety Executive (the inspecting and enforcement arm of the law in Britain with regard to health and safety at work) when providing advice.

There are 13 sets of regulations in which British Standards are quoted and four Standards have been approved recently; in addition, there are over 150 references to British Standards in the HSE's own published guidance. These Standards define, broadly, what is expected of employers and of suppliers and their competitors. They cover product standards such as buildings, steel, electrical equipment, lifting equipment, pressurised equipment and access equipment. User standards cover such areas as the design of buildings, maintenance, selection of electrical equipment, detection and alarm systems, test standards and miscellaneous procedures of general use and guidance.

Within British laboratories safety codes and safety information are also produced which relate to the hazards associated with their particular branches of research. In particle physics, particular codes have been produced such as: The use of hydrogen and deuterium; Flammable gases and liquids; Electrical safety rules; Portable electrical equipment; Safety in the use and handling of cryogenic liquids; Pressurised equipment and gas systems; Lifting equipment; and Dangerous atmospheres and confined spaces. These codes and the associated information are used as rules of procedure to be followed by all concerned; many are mandatory and must be complied with. If variations to these procedures are considered, or required, there must always be full consultation with the safety organisation.

There is a continuing dialogue between similar British research laboratories and with their University users to ensure common, agreed standards which permit the research to be carried out safely and effectively. This exchange and collaboration permits easy acceptance of standards, records and indeed of personnel, from one establishment to another. Certificates of test issued by one laboratory are accepted by others and there are then consequent savings in time, expense and manpower, and the avoidance of unnecessary delay prevents frustration and ill-feeling.

Safety standards met by British equipment

Thus, the CERN safety requirements should already be met as a result of the attention to safety detail being given throughout the preparation of experimental equipment in Britain. The CERN TIS Commission though will still need to advise, to monitor, to question and to continue its liaison and collaboration with others. However, it should be able to rely on the knowledge that behind all the wealth of safety information available in Britain lies the fact that its production, its dissemination and its use are required by law.

British industry's role in developing detectors for high-energy physics

The interaction between research organisations and British industry has always been fruitful, the needs of the former stimulating the ingenuity and resourcefulness of the latter, as well as arousing its entrepreneurial instincts. In the field of detectors for high-energy physics there are many examples, three of which are treated in some detail here.

by David M. Websdale
Physics Department, Imperial College, London

The role played by industry in the construction of particle accelerators is evident and has long been acknowledged as an essential one. Joint technical developments between the machine engineers and physicists on the one hand and industry on the other have been necessary and fruitful in such fields as vacuum technology, superconducting magnets, high-power radio-frequency devices etc. But industry also has a role in the development of detectors for particle-physics experiments. Given the size of detectors now operating and proposed for colliding-beam machines, each of which may cost as much as 10 per cent. of the machine, the interest of industry is likely to be commercial as well as scientific.

This article features just three examples of joint development programmes in which British industry is currently involved with high-energy-physics groups. In each case the requirements of the physicist can not be met by available products, but the necessary manufacturing and processing techniques have been developed by the company concerned.

1. Vacuum phototriodes

OPAL is one of the four large detectors under construction that are to be used at LEP. The Rutherford Appleton Laboratory (RAL) has undertaken the task of equipping the end caps of its big solenoid magnet with a Pb-glass electromagnetic calorimeter. The energy measurement of electromagnetic showers requires a precise measurement of the amount of Cerenkov light emitted. A standard, multistage, high-gain photomultiplier tube would normally be adequate for this purpose. In this case the Pb-glass is situated in a magnetic field which can be as high as 1 Tesla and in which standard photomultipliers will no longer work. A silicon photodiode will function in the magnetic field but it provides no gain, and the noise produced by the solid-state amplifiers required would yield an unacceptably poor energy resolution.

The requirement is thus for a photosensitive device incorporating an intrinsic gain of at least 10–20 which operates reliably in a high magnetic field. Since more than 2500 such devices are required for this application alone, the unit cost is a major consideration. EMI has proposed a vacuum phototriode (VPT) to meet these requirements and, during the past eighteen months, has undertaken, together with the RAL group, the development of the device. The VPT is a photomultiplier with a single stage of amplification. To allow an acceptable operation in magnetic fields, EMI has adopted a conical geometry for the dynode and anode of the VPT. The aim is to achieve uniformity of response over the photocathode surface, and gain variations with magnetic field which are small and consistent from one device to another.

The development programme has involved a close collaboration with feedback from the physicist testing the devices at CERN to the company. It was necessary to determine the optimum geometry and mechanical mounting of the electrodes, the voltages to be used and the method of photocathode preparation. Tests of the EMI prototype yield a gain of 10 in magnetic fields in the range 0.4–1 Tesla. The pulse-height distributions from high-energy muons traversing a Pb-glass block are

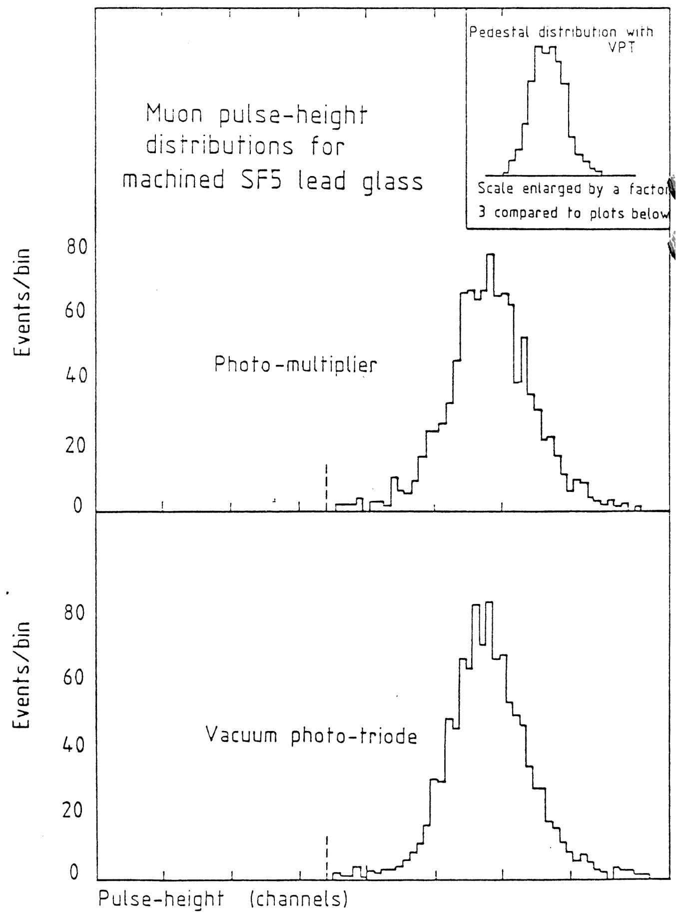


Fig. 1.
Muon pulse-height distributions for machined SF5 Pb-glass

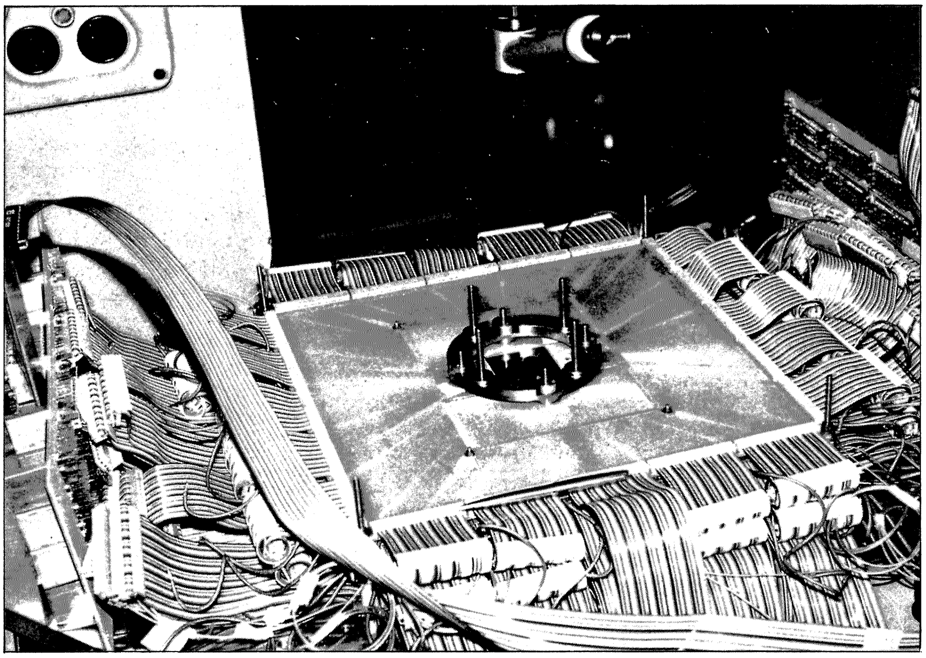


Fig. 3. Detector planes being assembled at Imperial College, London, to form a stack aligned to within a few micrometres

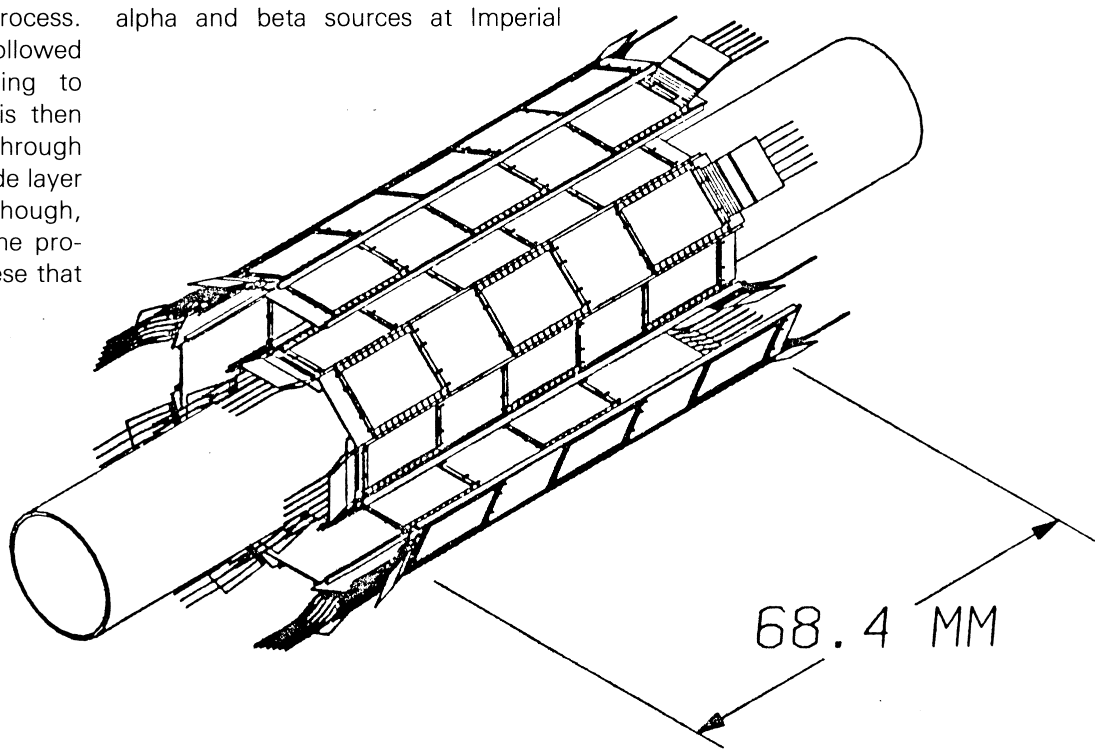
300μm silicon wafer is about 4 fC. For this charge to be detectable, a low-noise preamplifier is required, and leakage currents in the detector must be minimised by ensuring that it is fully depleted of mobile charges. This last requirement dictates the need for a silicon diode of high resistivity material — 5000–10 000 Ω cm; much higher than that used in the manufacture of integrated circuits. This fact apart, the processing techniques used in making the silicon microstrips follow the general method used for integrated circuits — that of the so-called planar process. This uses oxide passivation followed by photolithographic processing to etch the oxide. The junction is then produced by ion implantation through the windows opened in the oxide layer following the etch. There are, though, many variable parameters in the process, and it is the choice of these that provides the art and closely guarded secrets of the manufacturer. Several prototype detectors were produced by Micron. The energy of ions used in the implantation, the temperature of annealing and the degree of activation, the metal used for the ohmic contacts — all are examples of parameters requiring study before the production of quality microstrip detectors with a high yield was possible. The verification of prototypes involved simple current–voltage measurements by Micron at the factory and tests using alpha and beta sources at Imperial College and particle beams at CERN.

The detector plane shown in Figure 2 is one of a stack of eight produced by Micron and which will be used in the NA-14 experiment. It contains 1000 strips at a pitch of 50μm. The strips were bonded ultrasonically to the printed-circuit board which fans out the conductors to standard ribbon cable connectors. The photograph in Figure 3 shows the planes during assembly at Imperial College to form a stack which was aligned with a precision of a few micrometres.

This joint project has now progressed to the production phase, and the company has since produced prototype detectors for several other particle-physics experiments at CERN and at Fermilab. These involve the use of non-rectangular geometrics. and of an assembly which incorporates the preamplifiers on the circuit board which supports the silicon detectors.

The microstrip detector as described has one obvious disadvantage, that of instrumenting all strips with preamplifiers and associated signal-processing electronics. There are several options available to avoid this.

Fig. 4. Arrangement of ladders to make up the barrel detectors for the SLAC linear collider



One of the most interesting, due to Gatti and Rehak, is to drift the signal charge along the detector and obtain the spatial precision from a drift-time measurement. The development of such a silicon drift chamber requires the implanting of microstrips on silicon wafers to provide the required electric-field configuration. Micron has started work on a prototype device that was designed by G. Hall at Imperial College. If successful, such a device could find applications other than as a particle detector. Owing to its low capacity it could provide a photodiode with spatial precision at low light levels and thereby find a use in circumstances where photomultipliers or charge coupled devices are not appropriate.

3. Charge coupled devices

The charge coupled device (CCD) is used in the scientific community by astronomers. It provides a high-spatial-precision photon detector with good sensitivity. The idea that such a device could be used as a particle detector that provides 2-dimensional readout and excellent two-track resolution has been followed by C. Damerell and colleagues at the Rutherford Appleton Laboratory.

The RAL group has already verified that commercial CCDs with 2500 pixels per square millimetre provide a spatial precision of about 5 μm for detection of charged-particle tracks with high efficiency. The specific application foreseen is at the SLAC linear collider where a CCD detector would be used to identify short-lived decays of heavy leptons and particles containing charmed or bottom quarks. The characteristics of the colliding beam allow detectors to be situated as close as 10 mm to the interaction point, and an array of CCDs in a barrel structure is proposed to provide wide angular coverage. A schematic of the array is shown in Figure 4.

An important role in this development has been played by the British company GEC by which the CCDs are manufactured. The success of the project depends on the continuation of this close relationship. The manufacture of the final detector will require the assembly of a number of CCDs on a low-mass substrate and the means to supply drive pulses to read out the CCDs in parallel. The detectors will be subject to background radiation, and the lifetime of the CCD in this environment is important. Weaknesses in the design and fabrication must be identified and eliminated to provide reliable radiation-resistant devices. At present, scientific-grade CCDs, that is of low noise and high efficiency, are supplied only in ones and twos to astronomers. The requirements of the SLAC collider experiment are for several hundred devices, and it is expected that the joint R&D programme between GEC and RAL physicists will continue until 1987. Its progress will be followed with interest by the astronomers who are themselves proposing to use large arrays of CCDs for X-ray space telescopes.

Britain at CERN 1984 — **CONFERENCE PROGRAMME** — TH Conference Room, Building 4

Date	Time	Title of lecture	Lecturer
Tuesday 9 October	0900–0945	New applications for mineral-insulated cables	H. Baker, BICC Pyrotenax
Tuesday 9 October	1000–1035	The application of optical time-domain reflectometry to fault finding in optical fibres	M. Mansfield, Cossor Electronics
Tuesday 9 October	1045–1120	Single-photon detection with avalanche diodes	S.J. Barber, Cossor Electronics
Tuesday 9 October	1130–1200	Very-high-power critical switching parameters/ Optimisation of parameter tradeoffs	Dr R.J. Bassett, Marconi Electronic Devices
Wednesday 10 October	0900–0945	Applied superconducting and cryogenics at Oxford Instruments	Dr M. Wilson, Oxford Instruments
Wednesday 10 October	1000–1100	The application of real-time digital-filter techniques to multichannel waveform-acquisition systems	D.F. Bond, Data Laboratories
Wednesday 10 October	1115–1200	Modern photon-counting imaging systems	A. Lyons, Instrument Technology
Thursday 11 October	0900–0945	The Lindapter — a unique concept in mechanical fixing	D.B. Thompson, Lindapter
Thursday 11 October	1000–1030	Silicon detectors for high-energy physics	C.D. Wilburn, Micron Semiconductor
Thursday 11 October	1040–1110	Scintillation-detector materials for high-energy physics	T. Peel, Nuclear Enterprises
Thursday 11 October	1120–1150	A NIM 4000 channel analyser based on G64	T. Peel, Nuclear Enterprises

BRITAIN AT CERN 1984
Guide to exhibiting firms

AVICA EQUIPMENT (Bestobell (UK) Ltd)

Mark Road, Hemel Hempstead, Herts.,
England HP2 7DQ

Stand 30

Avica specialises in the manufacture of custom-engineered thin- and thick-walled vacuum vessels, bellows, bellows expansion units, thin-wall tubing and flexible metallic hose, for high- and low-energy nuclear-physics research and nuclear-fusion projects.

Vacuum vessels and associated fabrications can be manufactured from 0.1 mm (0.004 in) -thick sheet, up to 50 mm (2 in)-thick plate material.

All these products can be manufactured from Type 304, 316 and 321 stainless steels, Inconel, Incolloy, Monel and Nimonic alloys, aluminium, titanium and other metals.

All components supplied for high-vacuum and ultrahigh-vacuum applications are produced under clean-area conditions and are cleaned, vacuum-leak tested and packed to meet applicable conditions.

Avica also produces V-flange coupling assemblies for remote-handling conditions, together with a range of all-metalic seals.

Exhibits will be: thin- and thick-walled stainless fabricated vessels; bellows; tubing; and flexible metallic tubing for the vacuum and cryogenic industries.

BDH CHEMICALS LTD

Broom Road, Poole, Dorset, England
BH12 4NN

Stand 28

BDH will be exhibiting a range of crystalline scintillator materials, including barium fluoride which has advantages over other scintillators because of its speed, density and environmental stability.

Also exhibited will be thallium-doped caesium-iodide crystals 30 cm long. This material is required in increasing quantities because of its good matching to silicon photodiodes.

BDH offers components either as blanks or polished, and materials in both forms, in various shapes, will be exhibited.

BICC PLC

PO Box 5, 21 Bloomsbury Street, London
WC1B 3QN

Stands 16–21

The BICC Group will be represented by a number of its manufacturing companies and will be exhibiting a wide range of products for the electrical and electronics industries.

Products on show will include: XLPE-insulated cables for voltages 11 kV to 132 kV; LSF cables for conduit wiring, power, control and telecommunications; Flambic (flame-resistant) cables; coaxial cables, control cables, X-ray cables; pressure-sensitive cables; LHS cables; equipment wires; cables for electronics applications; mineral-insulated general-wiring cables which, in addition to the normal properties expected from an MI cable, have excellent radiation resistance, a high level of EMP performance, are fireproof and have high-temperature performance; and optical cables for network applications, associated accessories and a new, single-mode fibre-fusion splicing unit that is believed to be unique.

Total support capability will be demonstrated by a range of concrete inserts, steel framing systems, cable ladders, cable cleats and cable ties, including the new Strap X fastening system. Also on show will be the busbar and waveguide capability of Balfour Beatty Power Construction Ltd (Busbar Unit).

A number of the products on display have been designed specifically to meet the requirements of CERN.

BRITISH OVERSEAS TRADE BOARD — Exports to Europe Branch

1 Victoria Street, London SW1H 0ET

Stand 12

The British Overseas Trade Board (BOTB) is responsible for advising the British Government on its strategy for overseas trade. It directs and develops the Government's export-promotion services on behalf of the British Department of Trade and Industry.

The Exports to Europe Branch is one of eight territorial branches of the BOTB which are responsible for the provision of export services to British exporters. It can help CERN personnel by

- identifying sources of supply for all requirements in the UK
- arranging introductions directly with companies in the UK
- planning a programme for visitors to companies in the UK.

Further information is available from:
BOTB Exports to Europe Branch (CERN Desk)
Department of Trade and Industry
1 Victoria Street London SW1H 0ET
or
British Consulate-General 6th Floor
rue de Vermont 37–39 1211 Geneva 20

C & K SWITCHES LTD

Cunliffe Drive, Northfield Avenue, Kettering, Northants., England NN16 8LF

Stand 34

C & K Switches is a manufacturer of miniature and subminiature electrical switches. The company's manufacturing facility at Kettering supplies industry throughout Western Europe — 70 per cent. of sales being outside the UK.

The product range covers miniature and subminiature toggle, rocker, lever, pushbutton, slide and rotary switches. Designs are based on modular construction and standardised parts, permitting hundreds of thousands of discrete models to be made, thereby providing great versatility in application. Recent additions to the range (Series E, ET and EP) provide fully sealed construction to withstand wave soldering and full-immersion cleaning and are compatible with the PCB-mounting versions of 7000 and 'Tiny' Series unsealed types.

Particular emphasis is placed on performance, reliability and quality which, coupled with BS and UL listing of many models, ensures their suitability for use in professional applications.

CENTRONIC LTD

Centronic House, King Henry's Drive, New Addington, Croydon, Surrey, England
CR9 0BG

Stand 6

Centronic Ltd claims to be the foremost manufacturer of all forms of neutron and radiation detectors in the United Kingdom, and has been active in this field since 1946. Since then, it has built up an impressive record of supplying detectors worldwide, for the majority of reactor applications, including research reactors.

Centronic's products fall into two principal categories.

1. Neutron detectors for in- and near-core monitoring of neutron flux in reactors and used for reactor control and safety systems. These are principally: *a.* a wide range of compensated and uncompensated boron ion chambers used in reactor types such as MAGNOX, CANDU etc.; *b.* pulse and d.c. fission chambers as used in the AGR, THTR, FBR; and *c.* boron trifluoride counters as used in various PWR systems.
2. In the gamma- and X-ray detection areas, Centronic manufactures a wide range of gas-filled devices. These detectors range from large gamma monitor chambers, through various forms of proportional counters, to miniature metal Geiger–Müller tubes.

COSSOR ELECTRONICS LTD

The Pinnacles, Harlow, Essex, England
CM19 5BB

Stand 11

Cossor Electronics has a wide experience of producing speciality signal-processing equipment. Among the range of equipment is a family of optical-fibre instruments for fault location, attenuation measurements and fibre-optic modems.

The long-range Optical Fault Locator (OFL) widely used by international PTTs, has a distance-measuring capability of over 30 km. For short range and high accuracy, the OFL 108/L offers the test engineer a compact, lightweight portable instrument.

An Optical Attenuation Measuring Set will also be demonstrated measuring the performance of various optical-fibre cables.

Development work currently taking place with photon-counting techniques has led the company to explore new applications using avalanche photodiodes as very-low-level light detectors.

For many years, the company's activity has been centred on the development and manufacture of radar and communications equipment. Today, this work embraces a range of skills in data acquisition, data communications to 1553 standard, fast signal processing and VME bus systems.

COUTANT ELECTRONICS LTD

Kingsley Avenue, Ilfracombe, Devon, England EX34 8ES

Stand 27

Coutant Electronics Ltd sees itself in the forefront of the modern art of power, having been manufacturing power supplies for 25 years.

Today, the firm stands stronger than ever as the result of its innovative and flexible designs. It can offer, as the sole European source, 1000 W and 1500 W power supplies, which have been sold successfully for the past two years.

Coutant's range of power supplies offers:
ML Series — 50–400 W switch mode; 110, 220, 240 V a.c. 48 and 24 V d.c.; 1–6 outputs;
ML Series in Europabox and DIN connector — 110, 220 and 240 V a.c.; 150 W and 300 W; 5 V 20 A, or 5 V 20 A ±12 V 3 A: available now.
SL Series — 600 W, 1000 W, 1500 W switch mode; 110, 220 and 240 V a.c. Single and multiple ouputs, plus custom versions available.
A Series — High specification linear power-supply units.
GPE Series — enclosed linear power-supply units.

DATA LABORATORIES LTD

28 Wates Way, Mitcham, Surrey, England CR4 4HR

Stand 13

Datalab is a British company that specialises in the design, manufacture and supply of waveform digitisers and computer-based waveform-acquisition and -processing systems.

The main emphasis of the company's products lies in the area of multichannel waveform-recording systems operating under computer control and in high-speed waveform recorders operating in the MHz region.

New products that will be on show at CERN this year include:
System 1298 — a complete waveform-capture and -processing workstation centred on a Datalab DL1200 multichannel waveform recorder combined, by means of a comprehensive software package, with a 16 bit microcomputer;
Multitrap — a modular waveform recorder with a range of plug-ins which include digitisation capabilities up to 100 MHz;
DLF 100 — a state-of-the-art programmable digital filter for perfect phase-response signal conditioning.

Both Multitrap and the DLF 100 are making world debuts at CERN.

EDWARDS HIGH VACUUM

Manor Royal, Crawley, West Sussex, England RH10 2LW

Stand 15

Edwards High Vacuum has introduced new instruments for high-vacuum measurement and control, analysis and leak detection. A feature is the use of microprocessor techniques which greatly extend the operational facilities available.

The Series 2000 Controller is a freely programmable unit for measurement and control over the range 1000 to 10^{-11} mbar. The controller has been selected for the JET nuclear-fusion project.

The Series 1000 instruments are new Pirani and Penning vacuum gauges, while the Anavac gas analyser features a new double-filament analyser head.

The new Spectron 3000 is a microprocessor-based helium mass-spectrometer leak detector with many advanced features.

EEV

Waterhouse Lane, Chelmsford, Essex, England CM1 2QU

Stand 38

EEV, a member of the GEC Group of companies, is a leading designer and manufacturer of professional electronic tubes for industrial, communications and broadcasting applications.

On the firm's stand at the CERN exhibition will be ignitrons for high-current switching of field-coil supplies in toroidal experiments and for capacitor discharge.

Spark gaps will also be featured. These are used for voltage-surge protection, high-energy pulsed switching and pulse generation. The GXG is a recent development for laser switching and is fast becoming the most favoured method of pulsing CO_2 lasers in confined mobile and portable applications.

EEV is renowned in the field of broadcast and CCTV camera tubes. Now the range of electro-optic devices has been extended to include solid-state imaging. Charge-coupled devices give monochrome observation of fast-moving objects or of rapid events and are compatible directly with standard monitors and video recorders. The P4 320 CCD camera, which will be on display, is an example of the highly practical rugged construction of all the cameras in the range.

GAMBICA

Leicester House, 8 Leicester Street, London WC2H 7BN

GAMBICA is the association for the instrumentation, control and automation industry in the United Kingdom and, as such, represents the industry to governments and to international, technical and commercial bodies.

GAMBICA combines the interests and resources of three major trade associations, namely: the British Industrial Measuring and Control Apparatus Manufacturers' Association (BIMCAM), the Control and Automation Manufacturers' Association (CAMA) and the Scientific Instrument Manufacturers' Association (SIMA).

Since 1977, the three associations have worked together as an informal group, but the successes achieved collectively led to the decision to constitute GAMBICA formally as an association in its own right in January 1981. The companies in membership of GAMBICA number some 250.

The British instrumentation, control and automation industry is a leader in technology innovation, and the wide range of products and services coming within the scope of the association reflects this leadership in areas ranging from sophisticated automation systems, through to instruments and components. The association members continuously keep abreast of technology evolution.

GEC LARGE MACHINES LTD — Steel Products Division

Mill Road, Rugby, Warks., England CV21 1BD

Stand 39

Steel Products incorporates GEC's well established Fabrication Shops, Press Shops and Tool Room facilities. For many years these have been producing the sophisticated components required for the manufacture of electrical machines. These have ranged from small assemblies up to, and including, the 827 t hydro-generators recently commissioned by the UK's Central Electricity Generating Board at its Dinorwic generating station in the Welsh mountains. Other recent contracts include the recently commissioned 940 t generators for the Joint European Torus at the UKAEA Culham Laboratory and the S.N.S. Magnet for the Rutherford Appleton Laboratory.

The Division operates as an autonomous unit, producing components for the GEC group and as a subcontract supplier to other electrical-machine manufacturers within the UK and overseas. Steel Products Division is quality rated to the UK's MOD 05-21 and CEGB BS 5750 Part 1; also Lloyds and ASME codes, together with BNFL and UKAEA requirements.

GOULD BRYANS INSTRUMENTS LTD — Gould Recording Systems Division

14–16 Wates Way, Mitcham, Surrey, England CR4 4HR

Stand 41

Gould Recording Systems Division, formerly Gould Bryans, is part of the worldwide Gould Electronics Group and specialises in high-quality graphics recorders and plotters for both analogue and digital applications.

A new Business Graphics Group has been formed within Gould RSD specifically to support the fast-growing market for business-graphics users, an area in which Gould is becoming a major force.

In the computer-graphics market, Gould's Colorwriter graphics plotter is already highly successful and is the beginning of a growing product line to which Gould is very much committed.

Other products from Gould RSD include a full range of flat-bed analogue plotters and wave-form recorders and includes one of the fastest pen movers in the world.

GTE UNISTRUT LTD

Unistrut Export, Pump Lane, Hayes, Middlesex, England UB3 3NX

Stand 40

GTE Unistrut Ltd, part of GTE Products Corporation, has been manufacturing a comprehensive range of mechanical and electrical support systems in Europe for 30 years. The Unistrut metal framing systems, currently manufactured in seven locations, and distributed from 130 service centres worldwide, is a concept that permits rigid metal construction without welding or drilling. Its engineered system of standard components can be used to create a virtually unlimited variety of support and structural elements. Unistrut products are available in galvanised structural-grade mild steel or in marine-grade stainless steel where the ultimate in corrosion protection is required.

With the accent on quality and technical back-up, Unistrut has been specified and used for major projects worldwide. Recent projects where Unistrut has been used in Europe include the nuclear power stations at Heysham and Torness in the UK, at Tihange and Doel in Belgium and at Leibstadt in Switzerland.

HILGER ANALYTICAL LTD — Crystal Materials Group

Westwood, Margate, Kent, England CT9 4JL

Stand 5

The name Hilger has been involved with scientific instruments for over 110 years, with an involvement in radiation detectors over the last 35 years.

Today, Hilger Analytical produces a comprehensive range of scintillation detectors in a variety of materials, including alkali halides and metal oxides. The standard range of detectors, available as mounted crystals with or without photomultiplier tubes, is illustrated in full in Hilger's current brochure. The new range of ruggedised high-temperature detectors to cover applications in hostile environments is also illustrated in the brochure.

Crystals from the oxides of bismuth and tungsten are also available, and are of particular interest for applications in which their high density and short decay characteristics are necessary.

INSTRUMENT TECHNOLOGY LTD

29 Castleham Road, St Leonards-on-Sea, East Sussex, England TN38 9NS

Stand 33

I T L was formed in 1968, in response to a demand by the scientific community for a company which could accommodate relatively small production runs and limited development projects effectively. Since that time it has continued to satisfy the needs of high-technology researchers for a specialist service that includes the supply of ultrahigh-speed detectors.

The company has worked closely with major research centres in the UK and Europe, including universities and government establishments, and has developed a range of fast detectors, including vacuum photodiodes, microchannel-plate photomultipliers, image intensifiers, streak camera tubes and two-dimensional imaging systems with digital output, designed to be interfaced with computers.

In addition to its electro-optic devices, I T L routinely manufactures an extensive range of ultrahigh-vacuum components, including ionisation gauges and controllers and viewports in glass, quartz, sapphire and magnesium fluoride.

ISOPAD LTD

Stirling Way, Borehamwood, Herts., England WD6 2AF

Stand 14

Isopad manufactures a complete range of electric surface-heating equipment, including heating tapes, panels, jackets, mantles and drum heaters. Equipment suitable for installation in hazardous and inhospitable environments is a speciality.

The Isopad exhibits at CERN will include the following items.

Soft jackets constructed of glass-insulated elements on a glass-cloth heating surface with ceramic-fibre insulation. The outer covering of these consists of a special aluminium-coated glass carrier to ensure that the completed heating jackets are extremely flexible. The soft jackets supplied to CERN are used to heat acceleration and storage rings to temperatures up to 300°C, thus heating and expanding the air contained in these rings to allow it to be drawn out more efficiently to create a vacuum.

Photographs of *heating jackets* constructed with a metal cladding as supplied to VAT for bake-out applications in particle-fusion research on the JET project.

In addition, *electric heating tapes* of various kinds will be displayed.

Photographs of *drum-heating equipment* and laboratory *heating mantles* will also be displayed.

LINDAPTER

Lindsay House, Saltaire Road, Shipley, W. Yorks., England BD18 3HJ

Stand 1

The Lindapter company is the manufacturer of a mechanical fixing that is claimed to be unique.

Using the Lindapter bolt adapters with standard bolts, the system offers an alternative method of fastening to steel without the need for on-site drilling or welding.

The extensive range of Lindapter bolt adapters can be used in various combinations to secure monorail systems, trunking, sprinkler pipework, pipework and cables etc., and has been used throughout the world in all types of industry for over 40 years.

A selection of the Lindapter range will be exhibited at CERN, showing a variety of applications.

Also on exhibition will be the latest product in the range, the Lindapter Floorfast, a totally new concept in floorplate fixing that enables one man, working from above, to secure steel floorplates to supporting steelwork without the need for welding, drilling or underneath-access equipment. The system also reduces drawing office time dramatically.

MARCONI ELECTRONIC DEVICES LTD

Doddington Road, Lincoln, England LN6 3LF

Stands 36–37

Marconi Electronic Devices (MEDL), the high-technology power base of the Marconi Group of Companies, provides the enabling technology that is vital to the group's continued leadership in state-of-the-art electronic systems.

Under the Power Division's banner there are the first European high-power gate turn-off thyristors (GTOs). Typical of these devices are the EG220 and EG300, rated for 1200 V/300 A and 1200 V/2500 A, respectively, forming part of a family that is capable of handling 4500 V/2500 A. The GTOs will be displayed alongside the light-activated thyristor (LASCR) – a 100 mm silicon device with 4500 V switching potential. Bipolar *n-p-n* power transistors are also featured strongly.

On display from the Microwave Division will be new ferrite materials, dielectric, ceramic and polystyrene matrix materials, low/medium and high-power waveguide and coaxial devices. Particularly featured will be a wide selection of coaxial and microwave rotating joints available for all power levels, from the low-power miniature models designed for airborne use to 5 mW L- and S-band types. Water-cooled rotating joints are available for up to 25 kW operation. Ferrite cores for kicker magnets are also featured, and of particular interest will be microwave power measurement techniques.

WILLIAM McGEOCH & CO. (BIRMINGHAM) LTD

124 Electric Avenue, Witton, Birmingham, England B6 7DZ

Stand 31

Established for more than 150 years, William McGeoch & Co. Ltd provides a total service in concept understanding, design ability and high-quality production to meet the demands of modern industry worldwide.

The company currently holds MOD Def St. 05-21, which is the highest-attainable design and quality-assurance standard available to defence contractors in the United Kingdom.

Products for the following areas are available from the company.

Ultrasonic measurement — highly accurate, intrinsically safe single- and multichannel liquid-level measurement systems.

Energy transfer — switched-mode power supplies for fighter aircraft and other military applications.

Slip rings and connectors — products used in sophisticated missile systems, and weatherproof and flameproof components for industry.

Lighting equipment — weatherproof and watertight lighting for indication or for special purposes.

Machinable glass ceramic — high-performance zero-porosity material combining the advantages of ceramics with the machinability of metal.

MICRON SEMICONDUCTOR LTD

1 Royal Buildings, Churchill Industrial Estate, Lancing, Sussex, England BN15 8UN

Stand 35

Micron Semiconductor is a specialist UK manufacturer of silicon detectors for nuclear-physics particle detection, fabricated in planar technology with ion-implantation methods. High-density microstrip detectors are a speciality, including the complex printed-circuit-board fan-out CAD designs and assembly with detectors from both 76 mm (3 in) and 102 mm (4 in)-diameter silicon of pitch from 20 μm and total depletion depths from 200 to 500 μm. These detectors are supplied with 100 per cent. readout, capacitance division or resistive division, and can incorporate preamplifiers within the printed circuit. New developments include microstrips on ceramic substrates with Kapton leaf fanouts and double-sided structures for two-dimensional readout.

Other detector types include large-area silicon calorimeter detectors in single-area quadrant or segmented designs from 1 cm^2 to 50 cm^2 in both low-cost undepleted form and in the totally depleted format. Silicon photodiodes are also assembled in ceramic substrates with transparent resin coatings for interfacing scintillators and fibre optics. These photodiodes feature responsivity 0.25 A/W 550 nm, dark current 3 nA/cm^2, capacitance 70 pF/cm^2 and rise- and falltimes from 1 ns. Custom photodiode arrays in standard and hybrid form are also becoming a speciality of the company.

NUCLEAR ENTERPRISES LTD

Bath Road, Beenham, Reading, England RG7 5PR

Stand 25

Nuclear Enterprises is a subsidiary of Thorn EMI Electronics.

A total of 300 people are employed, 60 of whom are dedicated to research and development of nucleonic measuring instruments for life sciences, research sciences, radiological protection and environmental monitoring.

Nuclear Enterprises manufactures a wide range of radiation detectors including large-area large-volume plastic scintillators, without which many high-energy-physics experiments of the last ten years would not have been possible.

Approximately 60 per cent. of the company's output is exported, the majority of it going to Western Europe.

The most recent developments in detectors and instruments are being shown on Nuclear Enterprises' stand at CERN.

OXFORD INSTRUMENTS LTD

Osney Mead, Oxford, England OX2 0DX

Stand 2

Oxford Instruments has established a worldwide reputation as a supplier of high-quality cryogenic equipment and of both superconducting and resistive magnet systems.

In the field of nuclear-particle research, Oxford Instruments is active in the following areas:

i. High-field magnets up to 15 Tesla.
ii. Routine production of very large magnets of approximately 2.5 m diameter. Oxford has participated in projects for 5.5 m-diameter solenoids, including the Rutherford Appleton Laboratory DELPHI project, and has carried out design studies on a small superconducting electron synchrotron and a 3 m-diameter x 3 m-long solenoid magnet for the Cornell CLEO project.
iii. Cryostats for all applications in spectroscopic-analysis techniques.
iv. Dilution-refrigerator systems which operate routinely within 4 mK above absolute zero.
v. Electronic equipment for measurement and liquefied-gas parameters.
vi. A worldwide spare-parts service for cryogenic engineering.

PANTAK LTD

Vale Road, Windsor, Berks., England SL4 5JP

Stands 7–8

Pantak is a specialist in high-voltage engineering and industrial X-ray equipment. Its high-voltage and high-power d.c. supplies and constant-potential X-ray units are in daily use at CERN and elsewhere around the world.

During the 1970s, Pantak achieved a technological breakthrough with the development of its novel high-frequency solid-state electronic high-voltage d.c. generator, which was designed specially to meet the stringent requirements of the revolutionary computerised axial tomographic scanner.

Pantak's HF power supplies feature outstandingly high performance, particularly with regard to stability, smooth, ripple-free, accurate output, precision controls and reliability. They are used in many and varied industrial and scientific applications.

HF power supplies are incorporated into Pantak's comprehensive range of high-quality X-ray units that are intended for industrial radiography and real-time imaging systems. In addition, there are machines that have been designed specially for high-precision applications, such as the calibration of radiation-measuring instruments.

PENNY & GILES DATA RECORDERS LTD

Mudeford, Christchurch, Dorset, England BH23 4AT

Stand 29

Penny & Giles will be exhibiting the new chart recorder TELETREND, which eliminates pens, inks and chart paper by using a combined full-colour c.r.t. display and tape cartridge drive. Signal input, range, scales and chart speeds are fully programmable from a plug-in keypad. Long-term storage is achieved using an integral tape cartridge drive.

Also featured on the P&G stand will be neon-plasma and LCD bargraph indicators, available in various case sizes, with alarm and multichannel format.

Penny & Giles potentiometers and displacement transducers will be on display for measurement and control applications. High reliability and accuracy of these instruments are ensured, even in adverse environments. Most types can be produced in materials resistant to ionising radiation. A wide range of instruments is available from stock, and specials can be designed for specific applications not covered by standard types.

RACAL RECORDERS LTD

Hardley Industrial Estate, Hythe, Southampton, Hampshire, England SO4 6ZH

Stand 32

Racal Recorders is an acknowledged expert in the design and manufacture of instrumentation recording systems and offers what is claimed to be the finest range of analogue magnetic-tape recorders in Europe and the USA. These instrumentation recorders are ideal for laboratory and mobile applications and are in use in widely diverse fields for the recording of vital data. These fields include scientific research, medical physics, aerospace instrumentation, oil-rig structures, rail- and road-vehicle testing, heavy industrial plant, agricultural machinery, ice-floe behaviour, submersible research and development.

Instrumentation recorders are also becoming increasingly popular for use in communications for data modem line checking and surveillance of the many forms of electronic intelligence.

Racal Recorders are designed to give laboratory-quality data capture in a 'go anywhere' package.

SIFAM LTD

Woodland Road, Torquay, Devon, England TQ2 7AY

Stand 9

Sifam's new 'Presentor' Range of three-in-one panel meters offers a choice of presentation in four distinct styles from one basic design and a standard of accuracy and performance comparable with existing types.

The new meters have a distinctive style of their own, but combine the presentation characteristics of Sifam's established types in one meter, adapted for back-of-panel presentation or front-of-panel with mask or bezels. There are four sizes, with scale lengths of 34 mm, 60 mm, 78 mm and 100 mm.

Accuracy of the Presentor is in accordance with IEC 51, typically ±1.5 per cent., where the scale length is 50 mm or more, and ±2.5 per cent. where scale length is less than 50 mm.

Sifam claims its 'Harmony' as the world's first dual analogue/digital LCD panel meter. It is programmable to read in any engineering unit — even nonlinear quantities.

Also available are ranges of collet knobs and push-on knobs in sizes 10, 11, 15, 21 and 38 mm, with nut covers, figure dials and caps in eight different colours.

SOLARTRON INSTRUMENTS/ SCHLUMBERGER AG

24 Victoria Road, Farnborough, Hants., England GU14 7PW

Stands 3–4

STERLING GREENGATE CABLE CO. LTD

Bath Road, Aldermaston, Berks., England
RG7 5QD

Stand 10

Sterling Greengate manufactures a wide range of signal, communications, control, data and power-transmission cables. Also produced are the associated joints, glands and terminations, and a range of flexible Lamincon busbars.

A family of LSOH (low smoke and zero halogen) elastomeric and thermoplastic insulation and jacketing compounds is among the latest materials to be developed by Sterling Greengate. Sold under the Non Hal® trade name, these compounds meet the most stringent emission and safety requirements.

Specialist miniature cables now complement the Sterling Greengate range, utilising high-performance compounds to give the cable increased operating and ambient-temperature characteristics.

Sterling Greengate has the plant, equipment and manufacturing expertise to meet the requirements of the most complex and demanding cabling projects.

Production and quality-control standards conform to, and comply with, a wide selection of specifications and approvals for both general and specific applications.

THORN EMI AUTOMATION LTD — Rectifier Product Group

PO Box 4, Rugeley, Staffs., England
WS15 1DR

Stand 23

The Rectifier Product Group of Thorn EMI Automation provides a variety of standard and custom-built silicon diode, thyristor and transistor power-conversion equipment for rectifier, inverter and chopper applications.

In general, these applications comprise battery charging, electrolytic and general uses.

Each application and environment receives careful consideration to utilise available technology and components. Each equipment arrangement reflects a progressive attitude towards reliability, maintenance, space and cost.

The rectifier equipments are supplied with the power outputs required, i.e., various voltages and currents up to, say, 1900 A. Similarly, cooling techniques, e.g. natural air, forced air or water are chosen to provide the optimum arrangements.

THORN EMI INSTRUMENTS LTD

Archcliffe Road, Dover, Kent, England
CT17 9EN

Stand 22

Thorn EMI Instruments Ltd develops and manufactures electrical and electronic test and measuring instruments, marketed under the brand names of Avo, Megger, Sullivan and Foster. The product range covers analogue and digital multimeters, insulations, continuity, ground, low-resistance, line-ground loop and circuit-breaker testers, oil test sets and cable-fault-location equipment.

Some 50 per cent. of the company's business is export, with representation in 33 countries.

Exhibits of Megger products will include the BMD1 battery-operated handheld digital insulation multitester and the PAT2 portable appliance tester which conforms to IEC 414. The PAT2 checks the electrical safety of portable appliances by performing simple tests for ground bonding, insulation, flashtesting, normal operation and low-voltage load test. Versions of the PAT2 are available to suit the mains supply and appliance plug types used in many parts of the world.

New in the Avo product range is the B183, a handheld battery-operated digital LCR meter. This small, lightweight component tester is ideal for service and quality-assurance engineers who wish to measure component values quickly. It is equally well suited to laboratory use.

Also on show will be the company's developments for monitoring electrical parameters and the servicing and development of microprocessor systems.

THORN EMI ELECTRONICS

120 Blyth Road, Hayes, Middlesex, England
UB3 1DL

Stand 24

Thorn EMI Electronics is a major business centre within Thorn EMI PLC — an international company operating in 33 countries and employing nearly 100 000 people worldwide — and has manufacturing centres and sales offices in the United Kingdom and ten countries overseas. In terms of sales, the company currently provides around 10 per cent. of the £3 billion turnover of the Thorn EMI group as a whole.

A key factor in the company's success is its proven ability to produce innovative engineering solutions in areas of the greatest technological challenge.

THORN EMI ELECTRON TUBES LTD

Bury Street, Ruislip, Middlesex, England
HA4 7TA

Stand 26

Thorn EMI Electron Tubes Ltd will be showing its comprehensive range of photomultipliers and accessories, vidicon camera tubes, image-intensifier systems, vacuum photodiodes and phototriodes and silicon photodiodes.

Particular emphasis will be placed on devices used in high-energy-physics applications. These include the 9903 series 38 mm linear-focused photomultiplier.

The 9870 series, with its hemispherical photocathode, adds a new dimension to photon counting for extended or diffuse light sources.

Vacuum photodiodes and phototriodes are designed for use in high magnetic fields.

Photomultiplier bases and dynode chains are available to special design.

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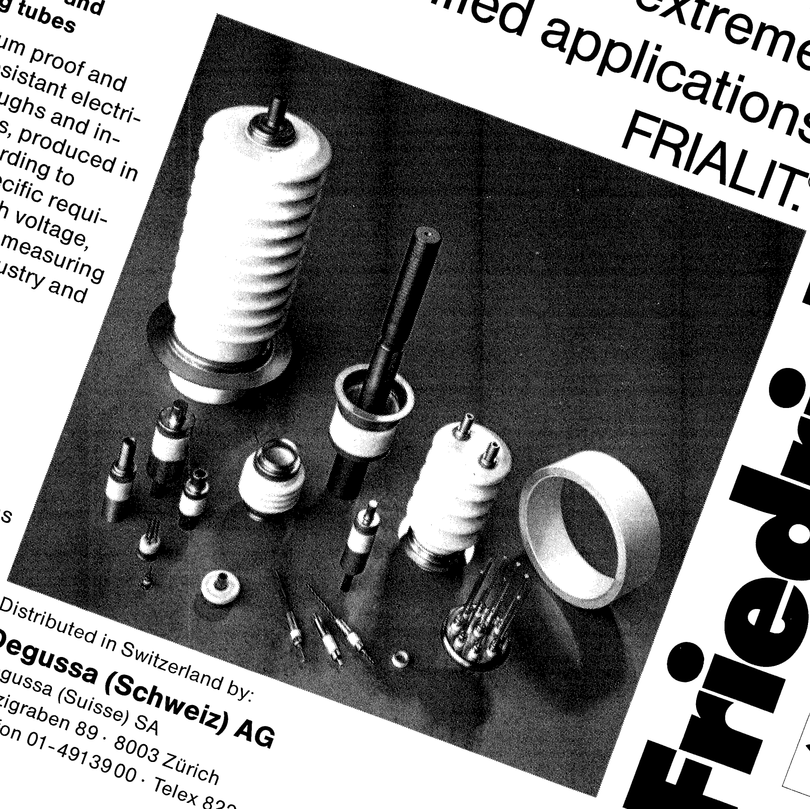

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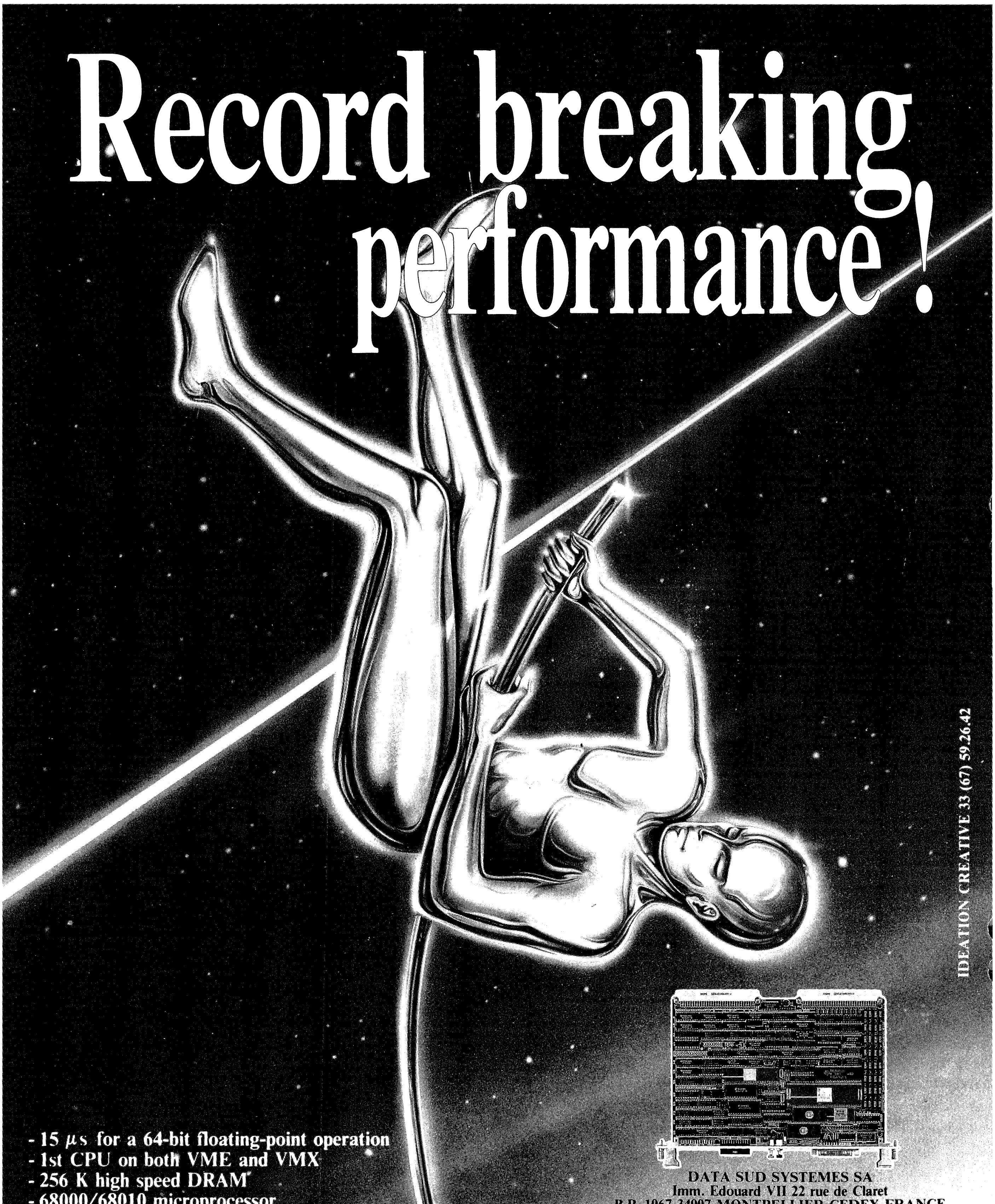
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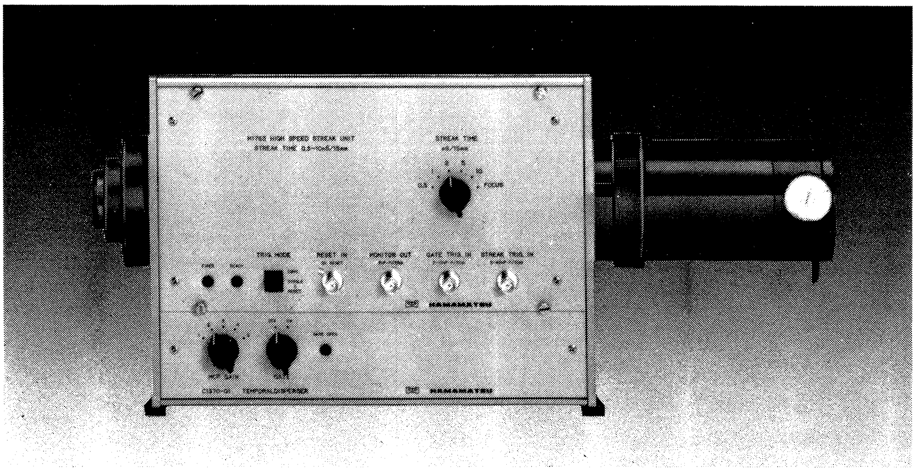

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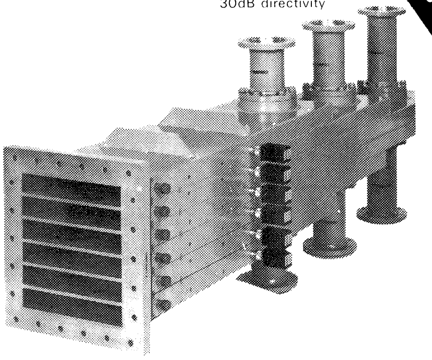

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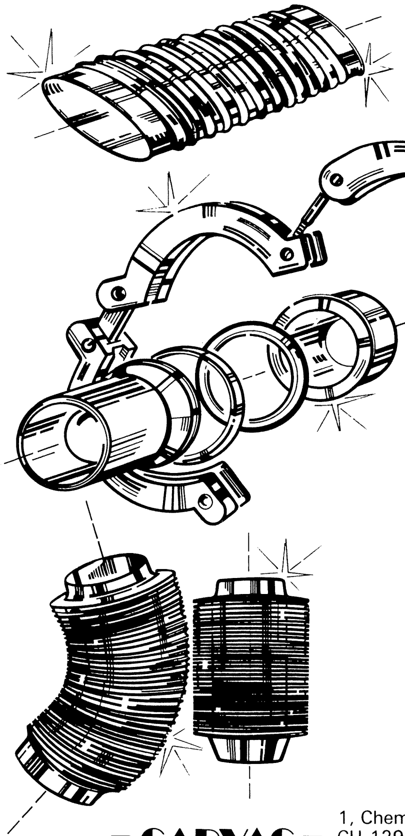

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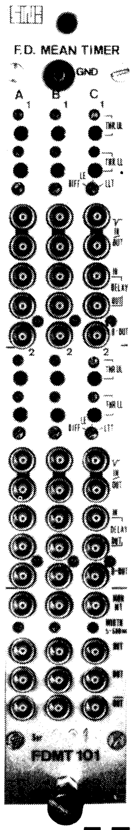

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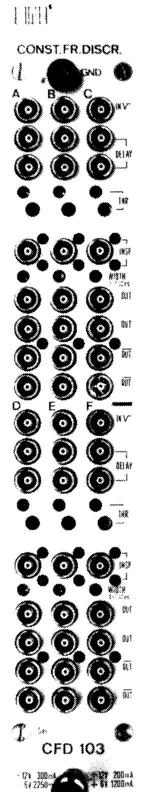

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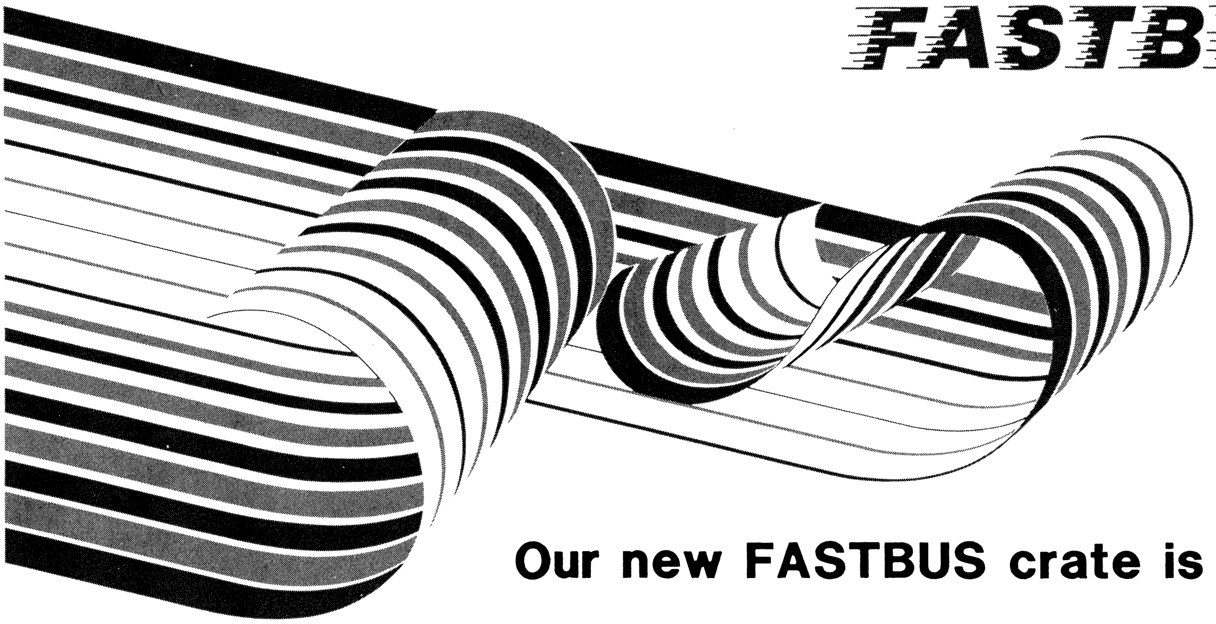

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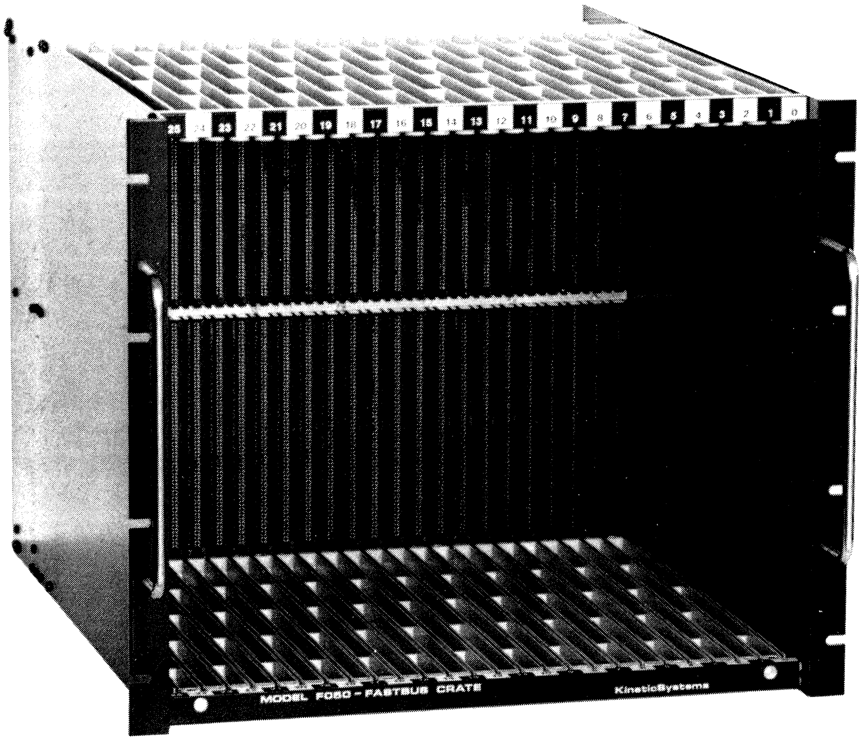

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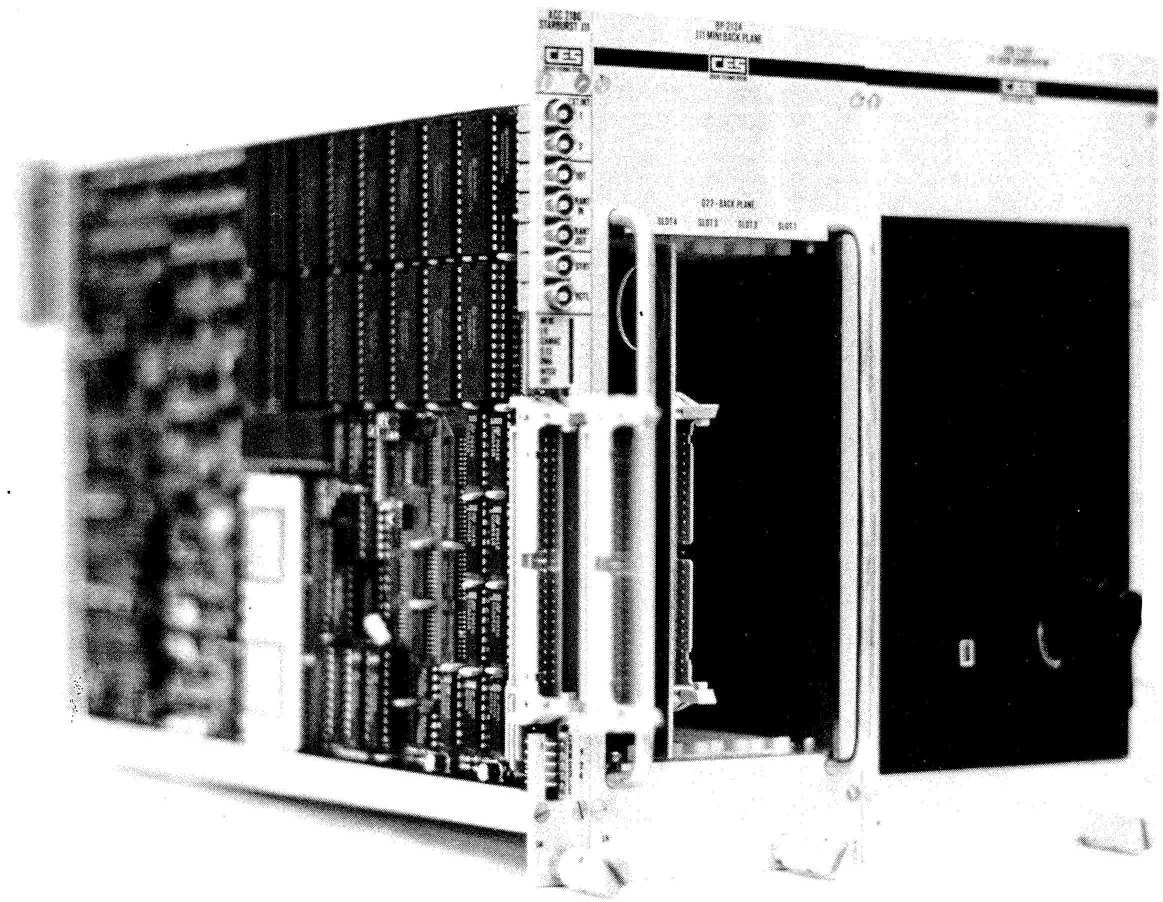

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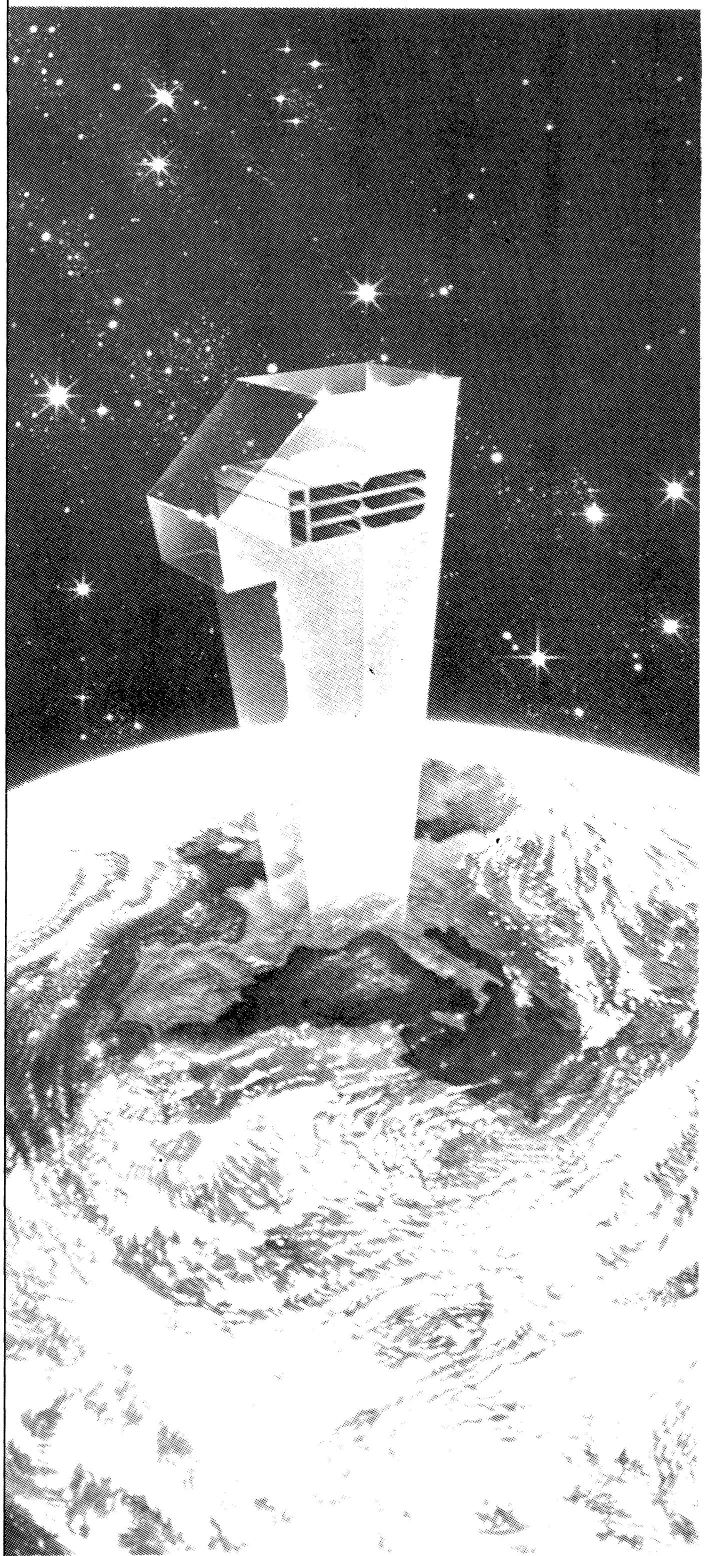
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