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Cover photograph: As seen from lunar module hovering just above the location of Interaction Region 6 of the PEP electron-positron storage ring at the Stanford Linear Accelerator Center. Construction work on the project is now obviously under way in earnest. (Photo Joe Faust)

October Conferences

From 20-22 October, Fermilab was host to the 'Ben Lee Memorial International Conference on Parity Non-conservation, Weak Neutral Currents and Gauge Theories'. The purpose of this Conference was to pull together the latest experimental data and theoretical work in the fields of particle physics, nuclear physics, atomic physics and astrophysics.

From 10-15 October, Rutherford Laboratory was host to the 'ECFA Study Week on Electron-Proton Colliding Beams'. This meeting was sponsored by the European Committee for Future Accelerators to investigate the physics interest and the experimental possibilities in the field of electron-proton colliding beams.

From 17-21 October, Brookhaven was host to the 'Workshop on Heavy Ion Fusion'. This meeting was called by DOE (or ERDA as it then was) to pursue the feasibility of using heavy ion beams in a fusion reactor.

1. Ben Lee Memorial Conference

The Fermilab meeting marked the 20th anniversary of the discovery of parity violation, theoretically predicted by T.D. Lee and C.N. Yang in 1956 and experimentally found by C.S. Wu in 1957. It also honoured B.W. Lee who was killed in a traffic accident in June of this year. As head of the Fermilab Theory Department, Ben Lee had helped organize the Conference prior to his death.

The Conference, which was under the Chairmanship of David Cline, attracted about 600 physicists and was unusual in grouping several pure physics disciplines so that the ways in which they contribute one to another could be seen. John Wheeler spoke of 'the cosmic connection' between the phenomena observed while studying sub-nuclear particles and the phenomena observed in the Universe at large on the vast scale of stars and galaxies.

It is a surprising fact that information unearthed about particle behaviour has been vital to the understanding of cosmological events and the two fields overlap considerably when speculating on the properties of black holes, the life stories of stars, the birth of the Universe and so on. Many of the technicalities of these overlap areas were discussed in the course of the Conference.

There was nothing new in the particle physics information because the Conference was held hot on the heels of those at Budapest and Hamburg which were spilling over with news. Nevertheless the impact of the Upsilon discovery, with its threat of more types of heavy quark, coupled with the tau discovery, with its threat of more heavy leptons, had obviously seeped further into the theoretical consciousness.

Participants emerging from the auditorium during the Fermilab Conference. Over the main door can be seen an enlarged photograph of Ben Lee to whose memory the Conference was dedicated.

In the course of the Conference at Fermilab, C.N. Yang, a former colleague of Ben Lee at Stony Brook, gave the Memorial address. Yang was also prominent at the Conference as co-predictor of parity violation twenty years ago.

(Photos Fermilab)

2. e-p Study Week

The ECFA / Rutherford meeting on electron-proton beams, excellently organized by John Thresher and Peter Norton, made it obvious that by achieving high energy e-p collisions, a new area of physics will be opened up. No-one has yet staked a claim to this area.

Options to have both electron and proton storage rings have been talked about in connection with the LSR project at CERN, the PEP electron-positron project at Stanford, the ISABELLE proton-proton project at Brookhaven, the Energy Doubler project at Fermilab, the SPS at CERN and the PETRA electron-positron project at DESY. It seems clear that whichever of these Laboratories takes the decision to go for e-p will be into this virgin physics territory first.

What is so attractive about the physics which would come from high energy electron-proton colliding beams is that it crosses the boundary where, assuming that our present knowledge can be extrapolated, the weak force, which is growing in strength as the energy increases, becomes equal in strength to the electromagnetic force. We seem bound to uncover something new when this happens.

Other attractions are the possibility of penetrating deeper into the proton structure with a probe (the electron) which is well understood. The collision energies which are talked about would make it possible to look at distances an order of magnitude smaller than on present machines and under 'cleaner' conditions than with proton-proton collisions. Intermediate boson (W and Z) production, the study of heavy leptons, photon physics and hadron physics are also on the menu.

Up to now, more work on electron-proton colliding beams has been done in Europe than in the USA and there are two attractive possibilities.

One is the addition of an electron storage ring at the CERN SPS, a project known as CHEEP which was described in the June issue page 184. Its major parameters are 25 GeV peak electron energy against 270 GeV protons (or 400 GeV protons if the SPS ring is pulsed rather than run d.c.), a peak luminosity of 0.5×10^{32} per cm^2 per s, and one or two interaction regions.

The second is the addition of a proton storage ring at PETRA. This was first proposed in 1973 but a revised scheme was presented to the Study Week and tentatively gained the name of PROPER (Proton Ring On PETRA Electron Ring). PROPER has a 280 GeV proton ring, using superconducting (4.5 T) magnets, fed by the DESY synchrotron (which has already accelerated protons) at 5 GeV. The peak luminosity is estimated at a few 10^{32} per cm^2 per s and there would be six interaction regions.

The important characteristics for comparison of the two schemes are — CHEEP covers a higher centre of mass energy range (90-200 GeV compared to 50-140 GeV). PROPER has slightly higher luminosity. The installation of an electron ring in CHEEP would probably be easier and less expensive than that of a superconducting proton ring in PROPER. CHEEP would also make an electron ring available as injector for any future high energy electron-positron rings such as are recommended by ECFA (see June issue, page 186). PROPER has the great advantage of six interaction regions and could probably also give a high proportion of its time to electron-proton physics, whereas CHEEP would almost certainly have only limited running time within the broad SPS physics programme.

Which scheme (if any) is taken up will depend on the overall development of high energy physics facilities in Europe. The Rutherford meeting underlined the interest of e-p physics and showed that two realistic projects are feasible.

3. Heavy Ion Fusion Workshop

The DOE / Brookhaven Workshop, headed by Al Maschke, covered the latest thinking on how to achieve inertial fusion of deuterium-tritium pellets by bombardment with heavy ion beams. (This topic was reviewed in the September issue 1976.) A scheme to test the principle is beginning to crystallize out of the many ideas which have been put forward and DOE hopes to finance a project, called HIDE for Heavy Ion Demonstration Experiment, in the early 1980s.

To begin at the end — several aspects of pellet design were spelled out more clearly than before at the Brookhaven meeting and have important implications in setting the necessary accelerator parameters. Much of the work on fusion pellets is classified and, therefore, the reasons for the conditions which are conveyed to the accelerator community are not known.

The first point is that it is desirable to deposit energy in the pellet at a density greater than about 20 MJ/g. This means that beam energies, for exam ple for uranium ions, should be held down to below 25 GeV. The second point is that it does not seem necessary to have higher symmetry in bombardment of the pellet than the one obtained by having two opposing beams. The pellet people are now stating with much more confidence that they can deliver pellets able to take 1 MJ in 10 ns and give a gain of up to a thousand.

To study the accelerator schemes, three groups were formed to look at r.f. linacs, synchrotrons and induction linacs, while other people looked at problems such as the final beam transport system. We limit ourselves here to features which seemed to gain rather wide acceptance at the Brookhaven meeting.

Consideration of the type of ion which should be used is now concentrated on ions of atomic number in excess of 200 and carrying only a few charges (1 to 4, though singly-charged will probably come out favourite). Ion sources at the tens of mA output level are now in operation, e.g. 25 mA of singly-charged xenon ions at Berkeley, and probably 50 mA is a reasonable figure to feed into the accelerator design at this stage.

To build up intensity at the low energy end, a hierarchy of linacs looks very promising. They would be of the Wideroe (π - 3π structure) type, used for example at GSI Darmstadt, beginning with say eight in parallel operating (necessarily) at 15 MHz, feeding four at 30 MHz (with bunches from twice the number of linacs slotting into twice the number of buckets in the next set of linacs), feeding two at 60 MHz, feeding one at 120 MHz.

The use of r.f. linacs will probably have to halt at this stage. To go further may require many kilometres of Alvarez type linac followed by a system of accumulator rings, each sending out many beams, in order to convey the necessary energy to the pellet.

The synchrotron approach replaces the long linac by a ring or rings. A fast cycling synchrotron feeding an accumulator may be needed to build up the intensity and even then the times involved, around 1 s, look dodgy from the point of view of ion lifetimes because of the charge exchange cross sections.

The induction linac for the final stage begins to look rather attractive. It would probably be preceded by an accumulator ring taking the output of the r.f. linacs (something over 100 mA at 1 GeV), rapidly bunching the ions and using a special beam transfer procedure to feed the induction linac. A final compressor stage would be needed at the end of the long induction linac.

A HIDE project may well confront the common problems of all the schemes by building the low energy r.f. linacs and an accumulator. Some sections of induction linac and of compressor could be added. In the meantime there remains a lot of research and development on such topics as ion sources, charge exchange cross sections both within the beam and beam-gas (though detailed information may only emerge from an accumulator), beam neutralization possibilities and bunching.

The difficulties of achieving a fusion reactor using heavy ion beams should not be underestimated but there are many people who think that this route to fusion looks 'less hopeless' than the other techniques. Certainly if governments remain willing to put large sums into the development of fusion technology, some of it should go to testing the heavy ion possibilities. European governments have not yet come around seriously to considering heavy ion fusion as part of their energy research programme. Maybe now that the JET Tokamak fusion reactor project is off the ground, heavy ions can be considered without seeming to jeopardize the study of other approaches.

Around the Laboratories

BONN
A neutron storage ring

A neutron storage ring, designed and manufactured at the University of Bonn, was brought into operation at the end of September on the 'ultracold' neutron beam from the research reactor of the Institut Laue-Langevin, Grenoble.

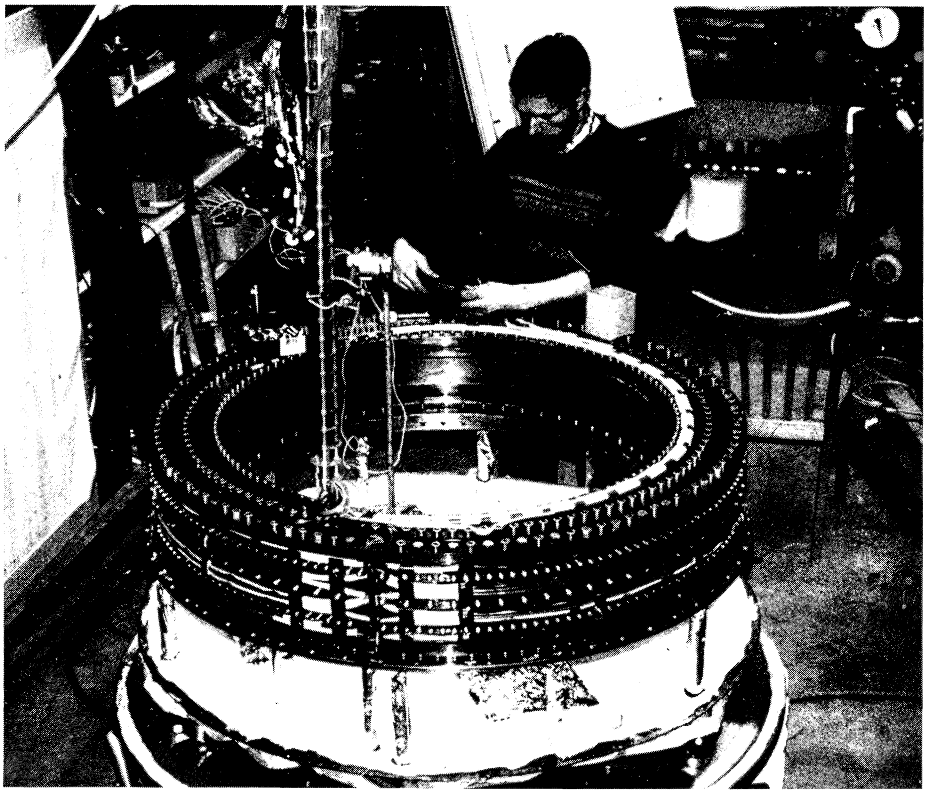
At first sight, such a feat is impossible. Storage rings operate by using magnetic and electric fields to get hold of the electric charges carried by particles such as the proton or electron. The neutron has no electric charge. However, it has a magnetic moment, which is a much smaller handle than an electric charge, but it is just possible to get hold of it. The principle of the Bonn ring is analogous to that of a storage ring for charged particles except that the bending and focusing of the neutrons is done by the interaction of their magnetic moment with magnetic fields.

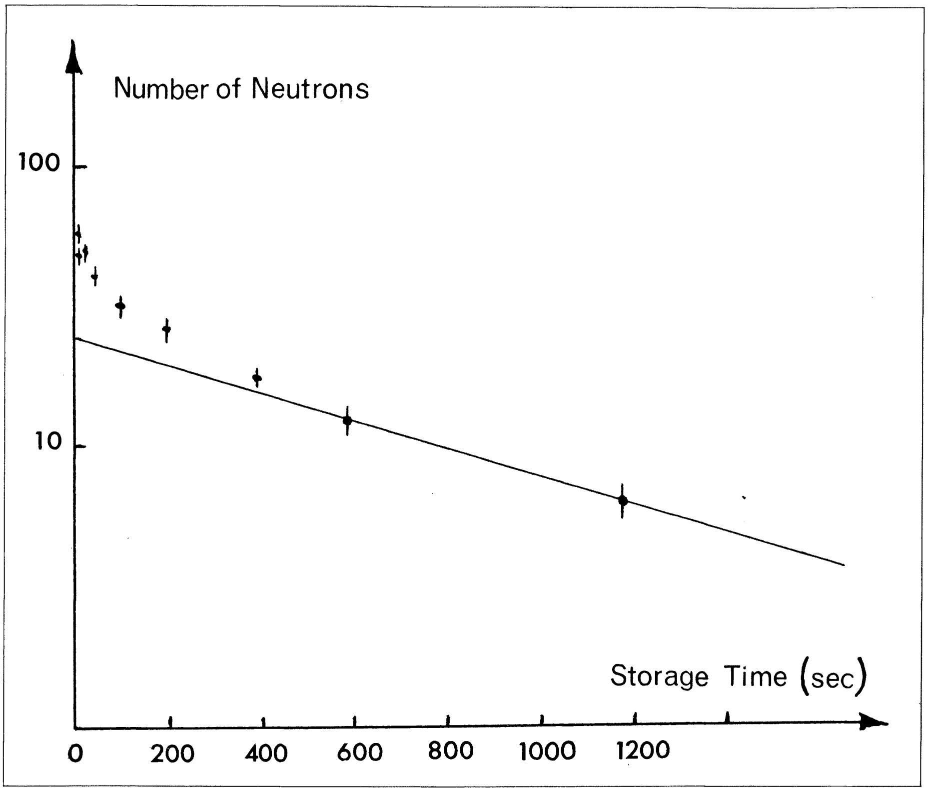
It requires very low energy neutrons and high magnetic fields. Even using a field gradient of 1.2 Tesla per cm, the neutron velocities are limited to 20 m per s, corresponding to the modest energy of 2×10^{-6} eV! In addition, multipole fields one order higher than in the case of charged particles are needed. The bending and focusing functions of dipoles and quadrupoles respectively are therefore replaced by quadrupoles and sextupoles. The ring is 1.2 m diameter using superconducting magnets with a maximum sextupole field of 3.5 T.

The number of betatron oscillations is of the order of 3 to 6 per turn depending on the velocity of the neutrons. In a charged particle ring, problems due to field imperfections can be minimised by choosing particles with only a very small momentum spread ($\Delta p/p$ of about 10^{-3}) so as to have a well-defined machine working point. For the neutron ring, however, The neutron storage ring under construction at the University of Bonn. Its 1.2 m diameter superconducting magnet gives a peak field of 3.5 T and enables neutrons to be stored for some 20 minutes at an energy of 2×10^{-6} eV. The ring is now in operation at the Institut Laue-Langevin research reactor, Grenoble.

(Photo Bonn)

Preliminary results from the Bonn neutron storage ring. After some losses in the first few minutes, the level of neutrons begins to decrease simply as a result of beta decay, with a half life of some 15 minutes. This will enable the lifetime of the neutron to be measured accurately.





taking its particles from the low energy region of the Maxwellian distribution of neutrons emerging from the reactor, a precise velocity selection would reduce the number of neutrons to an unacceptable level. The Bonn storage ring therefore has to work with a wide momentum spread (Δ p/p of about 3), with the result that many 'stopbands' and resonance effects have to be confronted.

To stabilise the neutron orbits and minimise losses due to these effects, the periodic sextupole field is supplemented by a non-linear decapole contribution, which makes the betatron frequency amplitude-dependent. Particle oscillations, which occur with increasing amplitudes in these resonance regions, can be controlled.

Only one spin component of the neutrons, with the spin parallel to the magnetic field, can be confined, and care has to be taken in the design of the field to avoid spin flips so as to maintain the number of stored neutrons.

Neutrons from the reactor are guided and injected into the ring by a system of bent nickel-coated glass mirrors. Neutrons passing through matter have an effective refractive index and, under the right conditions, total reflection may occur, as with electromagnetic radiation. The injection system can be moved out of the storage zone by a pneumatic mechanism which operates fast enough to allow injection of a single turn. The stored neutrons are detected by moving helium-3 counters into the ring.

The whole apparatus, including the superconducting magnet, was constructed at Bonn and then moved to ILL. Within three weeks neutrons were successfully stored at the first attempt. After some losses in the first few minutes of each storage, the remaining neutron intensity decreases simply as a result of beta decay, which has a half-life of about fifteen minutes. Neutrons are still detectable after twenty minutes.

Christof Schmelzer (left), Director of GSI Darmstadt, presents the heavy ion linac, UNILAC, to Hans Krollmann (centre), Hessen Minister of Education, and Hans Matthöfer, German Minister of Research and Technology, on the occasion of the inauguration on 24 October.

After this initial success, a careful study of the properties of this prototype neutron 'bottle' is being made and the first experiments will include measurements of the neutron lifetime and electric dipole moment. The neutron lifetime is currently one of the less well-known of particle parameters, while the existence of a non-zero electric dipole moment for the neutron would have interesting consequences.

Such a dipole moment would immediately indicate parity violation and would also show that time reversal invariance does not hold. If observed, this would be the first indication of the violation of time symmetry apart from the behaviour of the neutral kaons.

DARMSTADT UNILAC inauguration

On 24 October the heavy ion linear accelerator, UNILAC, was officially inaugurated at the Gesellschaft für Schwerionenforschung (GSI) at Darmstadt. Among the distinguished guests was Hans Matthöfer, Minister for Research and Technology in the Federal Republic of Germany and Hans Krollmann, the Hessen Minister of Education.

UNILAC has been in operation since January 1976 and is providing ions up to uranium with energies up to 10 MeV per nucleon. The Laboratory has a staff of about 450 people including 100 scientists about half of whom are involved in the experimental programme together with some 100 external users, mainly from the German Universities.

The accelerator is fed by two injectors and has three sections — Wideroe structure up to 1.4 MeV/nucleon (from where beams can be conveyed to a low energy experimental area), Alvarez structure up to 5.9 MeV/nucleon (after stripping and change state selection) and, finally, twenty single gap cavities allowing a variety of output energies up to 10 MeV/nucleon. A peak energy of 10.26 MeV/nucleon was achieved with argon ions in August of this year. Accelerated ions have included argon, titanium, nickel, copper, krypton, xenon, lead and uranium. The output beams can be split into three channels and guided to many experiments.

The machine and experimental areas have an impressive, well-engineered look about them and this is born out in the machine performance which is sustaining a vigorous experimental programme. Foreseen improvements are the duplication of Penning sources in the two injectors, dropping a less reliable duoplasmatron system. (Work on sources to provide different types of ion is to be curtailed so as to concentrate on increasing source intensities.) R.f. amplifiers in the single gap stage occasionally cause trouble and will receive further attention. Changes will be introduced into the timing system to enable the output energy to be varied from pulse to pulse.

About a fifth of the experimental programme goes to the search for and study of new nuclides — both the predicted super-heavy elements and the nuclei far from stability (as at the CERN ISOLDE).

Several experiments have searched for superheavies using a variety of elements, including uranium on uranium, without any being seen. The methods have set upper limits for the production cross sections of about 10^{-36} cm^2 looking at possible fission decay with half lives between an hour and several hundred days. Far from stability nuclei are studied with a mass separator on-line, a velocity separator and a helium jet. New isotopes of tellurium, iodine, xenon, iridium, osmium, rhenium, *The high energy experimental area at UNILAC. In the foreground can be seen the three channels into which the accelerated beam can be split to divide the heavy ions between the various experiments.*

(Photos GSI)

tungsten, thallium, actinium, palladium and uranium have been produced and examined.

Close on half the experimental programme is devoted to the study of reaction mechanisms including deep inelastic collisions, fusion reactions, correlated transfer of several nucleons and Coulomb fission. The deep inelastic work has been carried out with sophisticated experimental techniques so as to extend the work already done elsewhere.

Other major topics include the study of nuclei in high spin states in several experiments (again with sophisticated detection techniques) and the investigation of atomic phenomena. In addition, UNILAC can contribute to the information which is necessary in order to pursue the possibility of achieving inertial fusion using heavy ion beams. GSI has experience in several areas of the necessary machine technology.

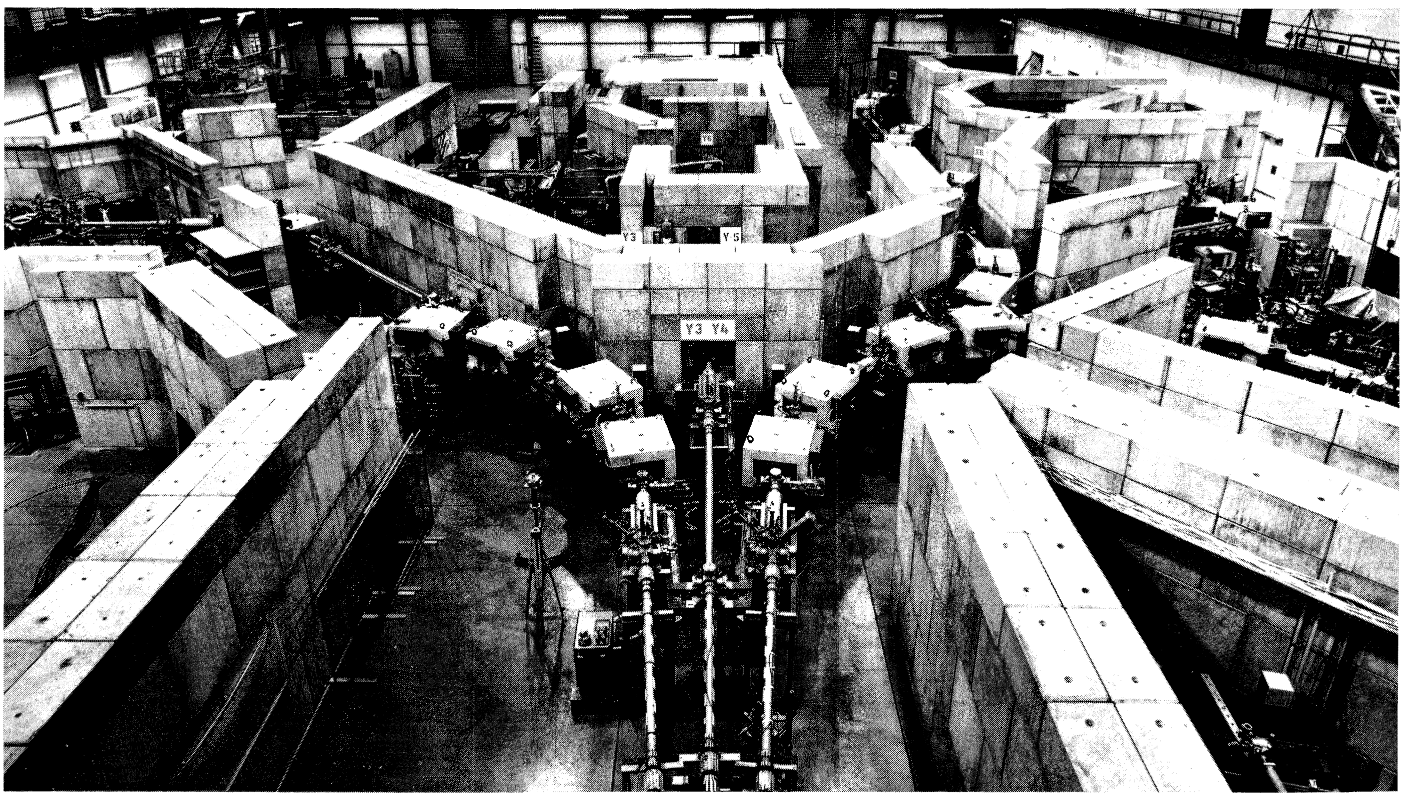
With the machine operating well and formally inaugurated, eyes are being lifted to the future. A possible extension of the facilities at GSI to higher ion energies has already been listed as one of the potential developments in the pure research programme of the Federal Republic of Germany.

The option favoured at GSI is the construction of a heavy ion synchrotron, to be fed by UNILAC, taking ion energies as high as 800 MeV per nucleon. It is known as SIS for SchwerIonenSynchrotron. An initial study of the synchrotron design has been carried out. It would be located alongside the existing high energy experimental hall. The diameter is about 50 m with bending magnets providing 1.8 T fields.

Special problems exist in the areas of r.f. (very large frequency swing of 200 to 1800 MHz), high vacuum and power supply (though the average power would be only about 2 MW the peak rate would be about 50 MW). In general, techniques to achieve high intensity need attention. These topics are being studied further and a Conference will be held in March of next year to discuss the energy extension and possible applications in the fields of medicine and energy sources.

Similar high energy heavy ion ideas are being pursued elsewhere. In Dubna there is a project, called 'Nuklotron', to convert the synchro-phasotron to heavy ion acceleration constructing a new linac and booster. In Japan, at the Tokyo Institute for Nuclear Study, a project has evolved under the name of 'Numatron' (NUclear MAtter TRON). It has a synchrotron and storage ring (as the route to adequate intensity) fed by a linac similar in design to UNILAC.

Both the Soviet and the Japanese projects are hoping to receive authorization during 1979. The situation with regard to the GSI project is likely to be much clearer after the March meeting.



Construction work for the PEP electron-positron colliding beam project at Stanford is now well under way and the scars of the excavations can be clearly seen in this aerial view. The linear accelerator, which will provide the PEP beams, is seen upper left leading into its beam switchyard and research area. Top right of this triangular-shaped research area the existing SPEAR electron-positron storage ring can just be seen, dwarfed in comparison with the new project some 700 m in diameter encircling most of the ground seen in the photograph.

(Photo Joe Faust)

CERN
Workshops on ISR and intermediate energy physics

End-September was Workshop time at CERN and this article pulls out some of the major themes which emerged. A week was given to the second session of a 'Workshop on future ISR physics' and another week to a 'Workshop on the role of CERN in European intermediate energy physics'. The general aim is to stir the melting pot of ideas on the physics, the detector capabilities and the machine potential for the coming years so as to arrive at some consensus of opinion as to the best course to follow. Any ultimate decisions will, of course, have to take into account not only the consensus emerging from a part of the community but also some overall consensus on priorities and an appreciation of the available resources.

At the Meeting on the Intersecting Storage Rings it was obvious that there is a rich crop of physics to occupy the machine through to the early 1980s. In addition, there were two factors to add to the thinking which had emerged at the first session in October of last year (see November 1976 issue, page 394). The first is the possibility of storing antiprotons of adequate intensities. The second is the crystallizing of thought about future options for development of the storage rings themselves onto a superconducting conversion to achieve peak beam energies of 120 GeV with very high luminosities.

P. Strolin presented an enthusiastic review of the physics which would open up if intense antiproton beams are available. In effect it is the proton-proton ISR physics of the past five years covered anew (using the whole set of sophisticated detectors which are now installed) with colliding proton-antiproton beams which are believed to have different quark content. In particular it will be important to check the expected growth in the total cross section of the proton-antiproton interaction at higher energies. Such a growth is seen in all other hadron-hadron interactions but, up to the highest energies achieved so far in the Fermilab investigation, the proton-antiproton cross section has levelled out but not started to increase. In addition, the present understanding of proton structure could be checked including the study of large transverse momentum phenomena and lepton pair production.

The antiproton possibility comes as a consequence of the beam-cooling work for which the main aim is proton-antiproton collisions at up to 270 GeV in the SPS. (The present peak ISR collision energy, 31 GeV, does not quite cover the energy range where it is predicted that the W and Z particles, the carriers of the weak force, will be found.) Studies of beam cooling techniques under Simon Van der Meer to achieve high intensity antiproton beams are scheduled to begin in ICE, Initial Cooling Experiment, this December (see June issue page 183).

In the ISR itself the success of stochastic cooling has been such that the ISR team are confident that they can store and improve an antiproton beam. A cooling rate of 1.7% per minute has been achieved and further improvement is possible. Coupled with this, there is greater theoretical understanding of the technique following the work of Frank Sacherer. So content are the CERN machine physicists with the progress in stochastic cooling that they will probably use this technique exclusively in producing antiproton beams and not add the electron cooling technique.

At the first ISR Workshop three options were considered for any future development of the machine itself. One involved rather complex additions of bypasses to the ISR and SPS to bring beams into collision at higher energies. Another, known as MISR for Moved ISR, involved taking the ISR magnets to the SPS and stringing the two rings together to achieve 60 GeV proton beams for collision with the SPS beams. The third, known as SCISR for Superconducting Conversion of the ISR, involved replacing the existing conventional magnets by superconducting magnets in the same tunnel.

In his review of these options, Franco Bonaudi showed that SCISR has emerged the clear favourite. Work on the SCISR design has yielded a very attractive set of parameters, including luminosities as high as 4×10^{33} per cm^2 per s. SCISR would have four intersection regions, an energy span from 25 to 120 GeV and currents from 25 to 15 A. The construction time is estimated at 3½ to 4 years and the cost at 160 million Swiss francs.

Behind the emphasis on SCISR is a considerable confidence that superconducting magnets of the high quality necessary for storage rings can be built. This has come from the satisfactory experience in building the prototype superconducting quadrupole for a low beta insertion in one of the present rings (see December issue 1976, page 441). The work on mechanical structure, coil winding procedure and insulation requirements in building the series of coils for the prototype enabled a very detailed specification to be passed to industry where four such magnets are now to be built (by Alsthom S.A.).

At its meeting on 20 October the CERN Research Board, taking account of the Workshop discussions which led to an ISR Committee recommendation, approved the building of superconducting magnets for the second ring to complete the low beta, high luminosity insertion in the ISR so that it can be used for physics experiments. It will be very important for the study of lepton pair production and also for proton-antiproton work.

The 'Workshop on the role of CERN in European intermediate energy physics' brought together a different community of physicists. At the moment, the CERN machines (particularly the 600 MeV synchro-cyclotron but also the 28 GeV proton synchrotron where there are beam-lines devoted to research in the sub-GeV energy region) are serving some 200 European scientists for such research. The aim of the Workshop was to try to indicate priorities in intermediate energy physics for the coming years so that CERN will be aware of the requirements of the community when deciding where to allocate resources.

Among the major areas of research at intermediate energies, the results from the investigation of 'exotic' atoms, where negatively charged particles other than electrons are captured orbiting the atomic nucleus, have been among the finest in the world. A similar status belongs to the work on nuclei far from stability on the ISOLDE on-line isotope separator.

The ISOLDE programme had a prominent place at the Workshop. They have an imminent development, which will extend the range of nuclei open to investigation, because the acceleration of helium ions in the SC is scheduled for early 1978. It became clear that higher intensity is not ISOLDE's priority — the range of elements already available in adequate intensities is such that a waiting list of targets exists. What seems more interesting to the ISOLDE programme is the possibility of using beams of other ions onto the targets.

Ions up to carbon (carrying four charges) may be possible from the SC, with energies up to about 1 GeV, without major modification of the internal machine electrodes. The technique involves the addition of a loop in the r.f. feeder line. Also, the machine vacuum has been found to be better than previously believed (3×10^{-7} torr rather than 10^{-6} torr) which may already be adequate for the acceleration of the heavier ions.

Another requirement to emerge from the Workshop was for a high quality stopped polarized positive muon beam (often referred to as an 'Arizona beam' after its pioneers from Arizona who developed such a beam at Berkeley). The muons have particular applications in two areas of research which are extensions of the intermediate energy physics covered at present. They are molecular biology and the study of metal hydrides.

In general, there was little interest in improved low energy pion beams. The work which is possible on such beams can be better done in the high fluxes from the meson factories at Los Alamos, SIN and TRIUMF. However, better kaon beams at the PS and high intensity antiproton beams, in the wake of the beam-cooling projects, will give research facilities which are not available elsewhere. The possibility of drawing intense beams from the 800 MeV booster on the PS was also raised.

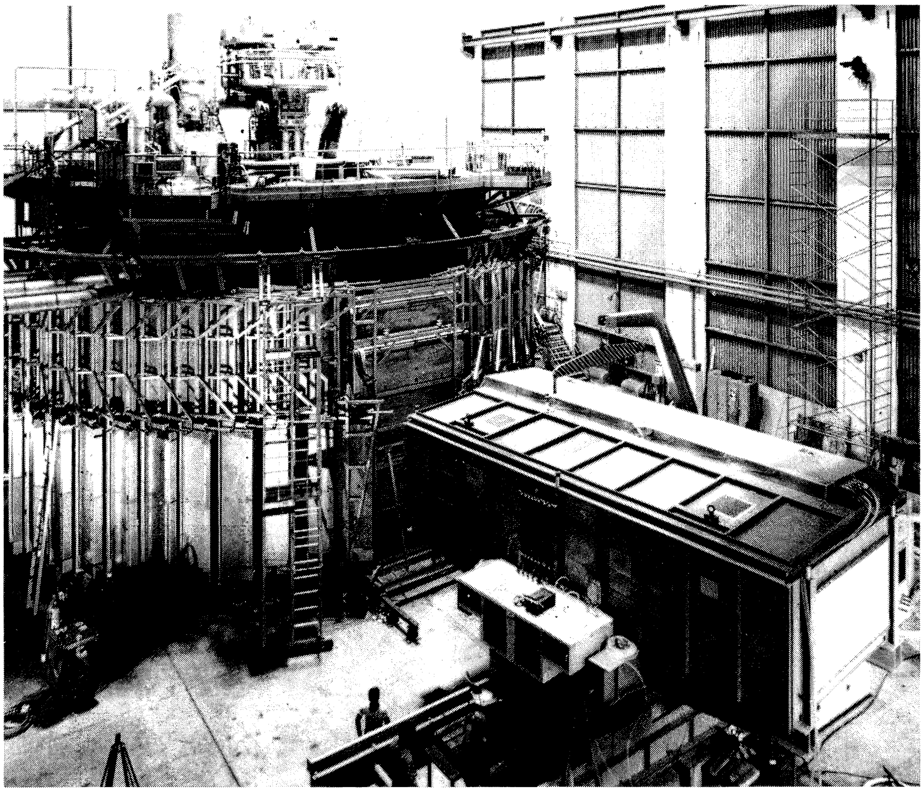
Identifying particles at bubble chambers

The big bubble chambers at the SPS, the 3.7 m European bubble chamber (BEBC) and the heavy liquid bubble chamber (Gargamelle), are now aided in their task of identifying the particles emerging from the high energy collisions by external electronic detection systems.

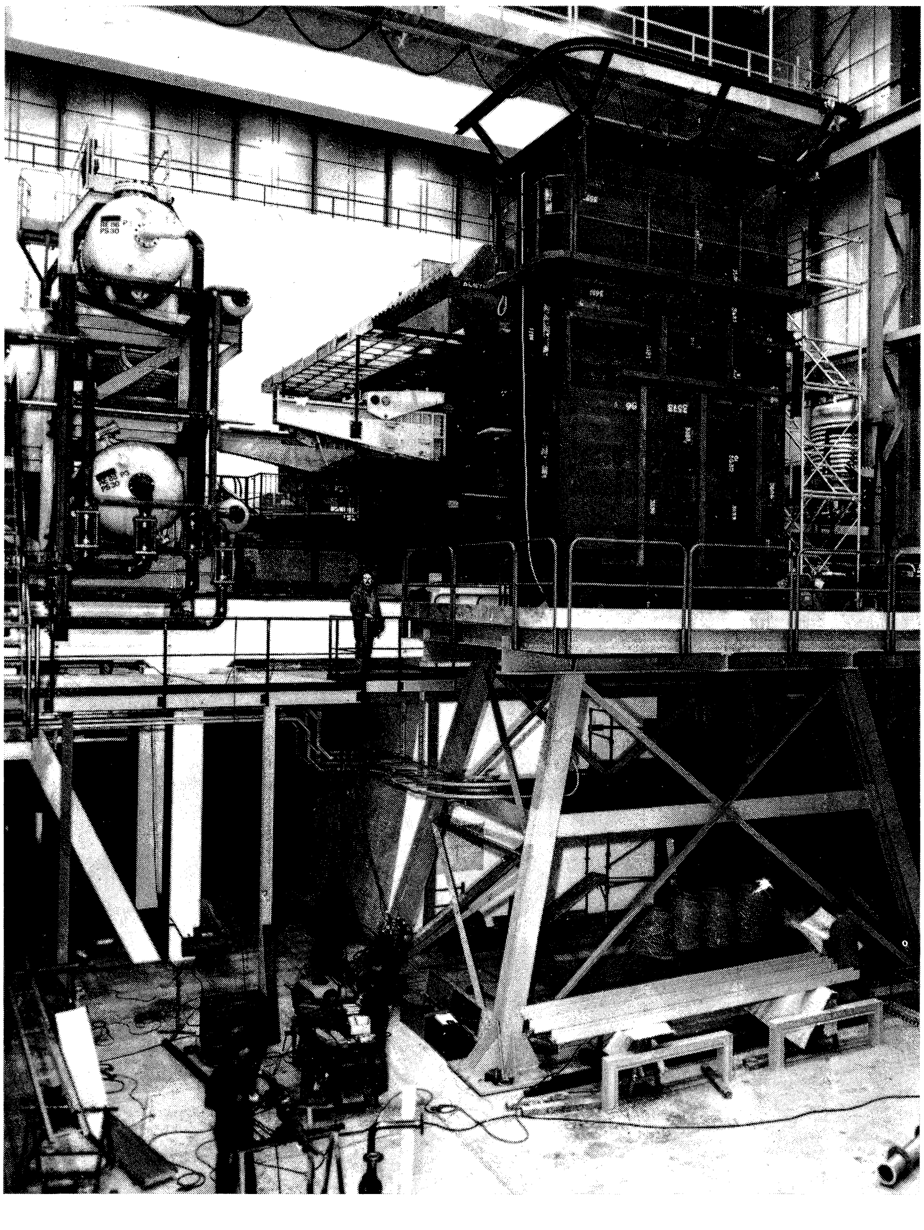
Preparing for its first physics run is the 52 ton External Particle Identifier (EPI) at BEBC. Containing 4096 proportional counters in 128 layers of 32 stacked in a pressurised box, the EPI is 8.5 m long with an effective detecting surface approximately 1 m by 2 m. The EPI, developed at CERN, is the first operational large-scale multilayer proportional counter system using the technique of relativistic rise of ionisation. It will enable hadronic experiments using the very pure radiofrequency separated beams at the SPS to distinguish between fast outgoing pions, kaons and protons over a wide energy range.

At lower energies, this identification is normally made with the help of Cherenkov counters, which enable the velocity of a particle to be measured. If its momentum is already known from measurements of its curvature in the bubble chamber magnetic field, then its mass can be calculated and the particle identified. At higher energies, such as those at the SPS, the problem is that the higher particle velocities demand bigger Cherenkov counters. Such counters soon become unmanageable and some other method

The 52-ton External Particle Identifier in position downstream of the 3.7 m BEBC bubble chamber in the West Area of the CERN SPS. Around the bubble chamber can be seen the modules of the External Muon Identifier, used to assist in measurements on neutrino interactions.
(Photo CERN 113.10.77)



Gargamelle being made ready in its new position in the West Area. Now equipped with its External Muon Identifier, it has already taken over 15000 pictures in the neutrino beams available from the SPS.
(Photo CERN 153.11.76)



of particle identification is needed.

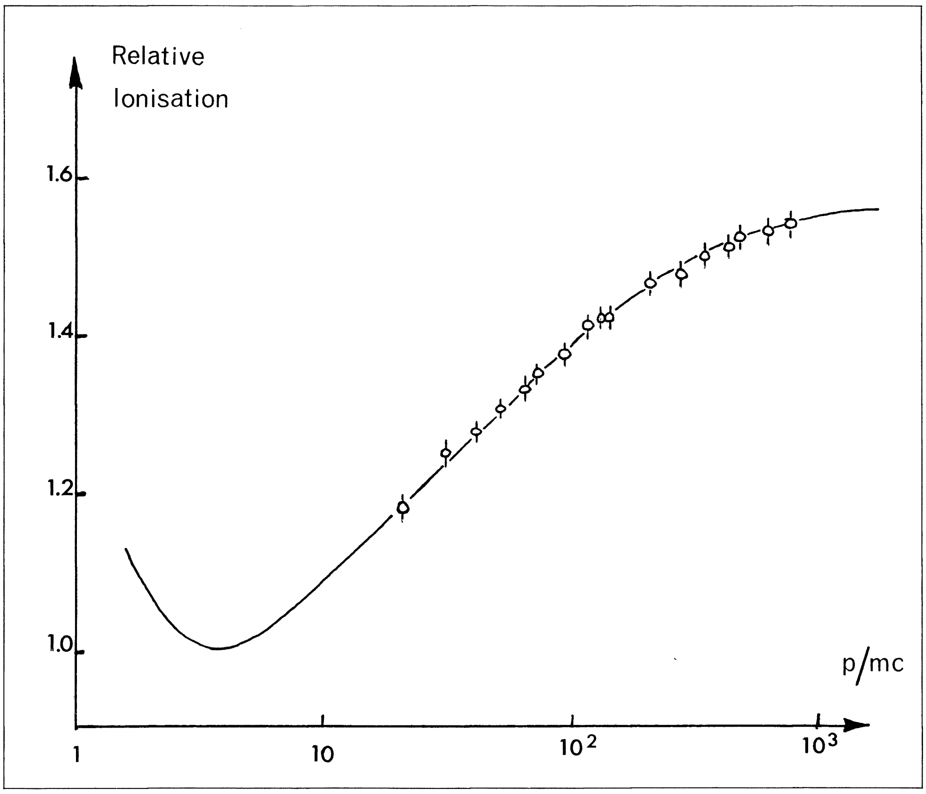
The principle of the EPI is quite simple. The ionisation energy deposited in the cells hit by a traversing particle is digitized by the electronics mounted directly on the detector, then transferred after each SPS cycle via a data link to the on-line Nord - 10 minicomputer and written onto magnetic tape. The ionisation is thus sampled along each particle track in up to 128 independent measurements which permits a final resolution to within three per cent. This is the best experimental precision achieved so far with a detector of this type.

The relativistic rise of ionisation in gas depends upon the ratio of the particle energy to its mass (Lorentz factor, γ). The ionisation increases from a minimum at low energies until a saturation level (Fermi plateau) about 60% higher is reached (which for pions occurs near 100 GeV/c). The difference between the ionisation due to a pion and a kaon of the same momentum is only about 12 % so obviously a very high resolution is necessary to enable identification to be made, and this in turn requires many layers of counters.

Another difficulty arises from the highly asymmetric form of the ionisation loss distribution in a single detector which would otherwise make identification difficult. The influence of the tail in such a distribution is compensated by selecting only the lower, more confined half of the ionisation values for data processing.

The calibration of the EPI was successfully carried out this summer and the relativistic rise of ionisation precisely measured in the momentum range 20-110 GeV/c. The performance of the EPI and experience gained in the long term stability and reproducibility of the results could help in the design and construction of other ionisation sampling devices envisaged in different laboratories, such as ISIS for the European Hybrid Spectrometer

The relativistic increase of ionisation in gas as measured with the External Particle Identifier at the BEBC bubble chamber. From a minimum value at low energy, the ionisation level increases by about 60 per cent until a plateau is reached at higher energy. The x-axis (particle momentum divided by mass times c, the velocity of light), enables the graph to be used for any type of ionising particle. This graph effectively calibrates the particle identifier.



at CERN and the Time Projection Chamber for PEP (see September issue, page 277 and October issue, page 328).

To assist in neutrino experiments, Gargamelle, like BEBC, has been fitted with an external muon identifier (EMI). Apart from the geometrical arrangement of the apparatus, the multiwire proportional chambers used for muon identification in Gargamelle and BEBC are the same (see April 1976 issue, page 137).

In addition, two special purpose multiwire proportional chambers are used: a 'picket fence' behind the bubble chamber to give the time of events occurring inside Gargamelle, and a 'veto counter' in front to give the time of background events. A downstream calorimeter is used to assist in the measurement of very high energy hadron showers.

Muons are readily identified by their ability to pass through a lot of absorbing material, but the incident neutrinos interact in the surrounding material as well as in the bubble chamber target, so that events in the EMI do not necessarily correspond to neutrino events in the bubble chamber. The EMI has to record everything that comes its way during each beam spill, so that when a neutrino interaction is spotted in the bubble chamber, it can be tied in with the position of the corresponding EMI signals. However, this means that the EMI also picks up lots of background.

The EMI electronics has temporary data stores, or 'buffers' designed to record all signals received during a beam spill, and this information is processed and transferred to magnetic tape after the spill. Without this arrangement, all the incoming signals could not be recorded and valuable information would be lost.

The correspondence between the bubble chamber pictures and the muon signals in the EMI is established off-line, after the experimental run is complete. Only in this way can EMI signals be correlated with what is happening in the bubble chamber, but hundreds of events have to be examined to extract one 'good' signal coming from a neutrino interaction in the bubble chamber.

The use of bubble chambers and external electronic counters in conjunction is an example of detector 'hybridisation'. The ability of the EMI to identify and assist in the measurement of neutrino events can be used to preselect bubble chamber pictures of particularly rare but interesting events.

It is also proposed to use the EMI electronics to actually trigger the bubble chamber cameras. This triggering could be feasible under certain conditions and for some classes of events. As well as saving film, it would also reduce the scanning and measuring workload.

Equipped with its External Muon Identifier and with the enhanced neutrino beams available from the SPS, Gargamelle is ready to add further chapters to its already illustrious history. Already it has taken over 15000 pictures at the SPS.

Computer expansion

One of the most striking features of the experimental scene in high energy physics is the continuing increase in the demand for computing power. With an IBM 370/168 added only last year to a CDC 7600 for the central computing service at CERN (see January issue, page 13), new estimates of the future computing requirements, including increased demands from the West Experimental Area of the SPS as well as the imminent start-up of operations in the North Area, indicate that a 50 per cent increase in capacity will be necessary by 1980, even though most of the CERN high energy physics data is now analysed outside CERN.

First plans were to increase the capacity of the existing IBM 370 / 168 machine by means of an 'attached processor' to supplement the already considerable computer power provided by the 7600 machine, 'front-ended' by CDC 6500 and 6400 computers.

Recently, IBM disclosed plans for a powerful new processor, the 3032, which, if installed alongside the existing 370/168, would increase CERN's IBM computing capacity by about 90 per cent. This processor is now on order and should be available by the end of 1978.

As well as processing power, the expansion in high energy physics data requires both storage space and some means of getting the stored data to the computer. Some 120000 reels of data on magnetic tape have already been accumulated at CERN and this number is increasing at the rate of about 20000 reels each year.

The management of all this data creates problems because disc space is necessarily limited and the mounting and dismounting of tape reels requires a lot of manpower. IBM now has available so-called 'mass storage systems' in which small reels of wide magnetic tape are moved into position automatically, like a sort of giant jukebox, eliminating much of the manpower requirement.

At the same time, the ability to quickly shift data back and forth between these special tapes and disc gives the user the impression that he has much more disc space at his disposal. The 3850 Model A1 mass storage unit envisaged for CERN would effectively increase the total available disc space by a factor of 20, while enabling input / output traffic to be speeded up with little or no additional manpower effort. It could be delivered to the central computing service at CERN by the Summer of 1978.

Bubble chamber physicists (left to right) Sam Barish, Edith Smagalski, Virgil Barnes and Malcolm Derrick grouped at Argonne around a projection of the millionth picture taken in the Fermilab 15 foot chamber. The event, not decipherable in the picture, was a candidate for a neutral current interaction produced by an antineutrino in hydrogen during an Argonne / Carnegie Mellon / Purdue experiment.

(Photo Argonne)

DESY Moving to higher energies

At the end of October the electron-positron storage ring, DORIS, came back into action after a shutdown during which two higher power PETRA-type r.f. cavities were introduced so as to increase the peak energy of DORIS to 4.3 GeV. As described in the October issue (page 320), the magnet ring is good for 5 GeV peak energy and if all goes well with the 4.3 GeV tests an attempt will be made (with four more high power cavities) to reach the region of the 10 GeV Upsilon particles.

For the higher energy operation the magnet system in DORIS has been altered so as to have the two beams circulating in a single ring rather than the two rings which have been used up to now at lower energies. This is because there is a considerable gain in luminosity with one ring at the higher energies.

Meanwhile construction of the PETRA storage ring to achieve electron-positron colliding beams at up to 18 GeV energy continues at the same rapid pace that it has assumed since its start some eighteen months ago. On 23 October, PETRA received electrons for the first time and they were taken through one of the completed octants. (Positrons had already performed this preliminary exercise in May.) The beam monitoring system was in action and all is looking well.

The next milestone is scheduled for 25 November when the electrons will be taken through the straight section following a completed octant and eight r.f. cavities will be installed there. By the end of the year, the trajectory will be extended through a second octant and the beam tests will then be halted until the complete ring is ready. Commissioning is scheduled for autumn of next year and everything is on programme to achieve this date.

With PETRA rushing towards completion, the collaborations carrying out the five experiments already approved (see November 1976 issue, page 388) have their work cut out to keep pace with the hectic schedule. However, they are all confident that they will be there in time to use early PETRA particles and equipment testing is well under way.

But the experimental programme for PETRA is by no means already a closed shop. New groups would find it difficult to be there to see the first electron and positron collisions but the PETRA Research Committee welcomes more proposals.

The five currently approved experiments use only four of the intersection regions (PLUTO and CELLO will share the same intersection and use the same cryogenic facilities), there are two intersections vacant (deliberately left empty initially so as to be able to respond quickly to any new physics or new developments in detection techniques) which could be used for physics soon after the machine starts up. As well as using these extra experimental areas, new experiments could also be installed alongside those already approved.

The PLUTO collaboration is particularly busy. The PETRA schedule requires that this detector should move to its new site in May next year but it still has a heavy programme at DORIS hoping to capitalise on the higher energies before moving to pastures new at PETRA. DASP, the other main detector at DORIS, is now run by a new collaboration, the old team having disbanded to prepare experiments for PETRA (although a major proportion of the team is intact in the collaboration developing the TASSO detector).

There is still a lot of useful DASP data to be analysed and it is hoped to extend the documentation of the decay modes of the heavy lepton discovered at Stanford. In particular the decay into its neutrino and a pion needs to be studied. This reaction can be calculated theoretically but present limits on the branching ratio are below the predicted value while the corresponding decay into a neutrino and a rho looks fine. This is a small cloud on an otherwise clear horizon.

DASP is now manned by an enthusiastic new collaboration which is seeking further members to bring it up to strength. While PLUTO is constrained by the tight PETRA schedule, DASP will be able to fully exploit the higher energies and luminosities available from the uprated DORIS, and hopes to be able to explore the Upsilon mass region in detail before anyone else. DASP will also continue to measure the decays of the new heavy lepton, where improved statistics will be available with the higher DORIS luminosities. Charmed baryons, yet to be studied in detail at storage rings, are also high on the agenda.

PLUTO's place at DORIS will be taken by BONANZA, a detector built by a Bonn / DESY / Mainz collaboration which has already had a run at DORIS and accumulated some data on a rare decay of the eta prime into two gamma rays, a reaction which could provide insight into the exact nature of the quantum numbers of quarks. Statistics are still insufficient to get a positive result but, after the departure of PLUTO, BONANZA will be able to collect further data and, hopefully, continue the impressive record of achievement at DORIS.

This achievement has not only been in the field of high energy physics. A vigorous programme of research with the synchrotron radiation from the orbiting beams has also been under way — one area receiving the light from the electron beam and another (run by the European Molecular Biology Laboratory) receiving the light from the positron beam. On 19 October a symposium on synchrotron radiation research was held at DESY and future plans for such research were discussed.

A Committee headed by M. Cardona has examined the needs in the Federal Republic of Germany and has concluded that two machines are desirable — one to cover the lower energy ultraviolet radiation region and one to cover the higher energy X-radiation region. The Government has decided to locate the ultraviolet facility, a 750 MeV electron ring, in Berlin, probably in a new Institute. It will be used by research centres, by the National Bureau of Standards and by German industry, which is interested in pursuing the technique of X-ray lithography for replicating very fine structures. Prior to the completion of the Berlin machine (probably in 1983), industry will have a light beam from DORIS to pursue this research.

The X-ray requirements will be met on DORIS by considerably extending the existing facilities. It is intended to wrap a two storey building around a full quadrant of the ring and to draw light from ports after each of six magnets. These beams will be split to give ten X-ray beams and ten or more vacuum ultraviolet beams. The user community has already forwarded fifty proposals for experiments with the extended facility. The facility could be ready by 1979 depending upon when DESY resources, now heavily taxed by the PETRA project, can be brought to bear.

A high proportion of the DORIS operating time should then be available for synchrotron radiation work since the role of the storage ring in the injection system of PETRA will be taken over by the new ring PIA (see October issue). Also the high energy physics interest in that energy range is likely to have waned.

DORIS, plus Berlin, LURE at Orsay, SRS at Daresbury and probably ADONE at Frascati, should see Europe happily through the next five years

The two big detection systems on the DORIS electron-positron storage rings at DESY.

1. The PLUTO spectrometer with the two halves of its superconducting magnet pulled back. PLUTO will have a brief run at the new higher energies and luminosities on DORIS before moving to PETRA in May of next year.

2. The DASP spectrometer manned by a new collaboration, which could usefully absorb further members, will remain on DORIS and hopes to be the first detection system to cover the Upsilon mass range in detail.

(Photos DESY)

and more of synchrotron radiation research. The European Science Foundation has set up a Committee to look at needs beyond the existing or imminent facilities and its report is expected soon.

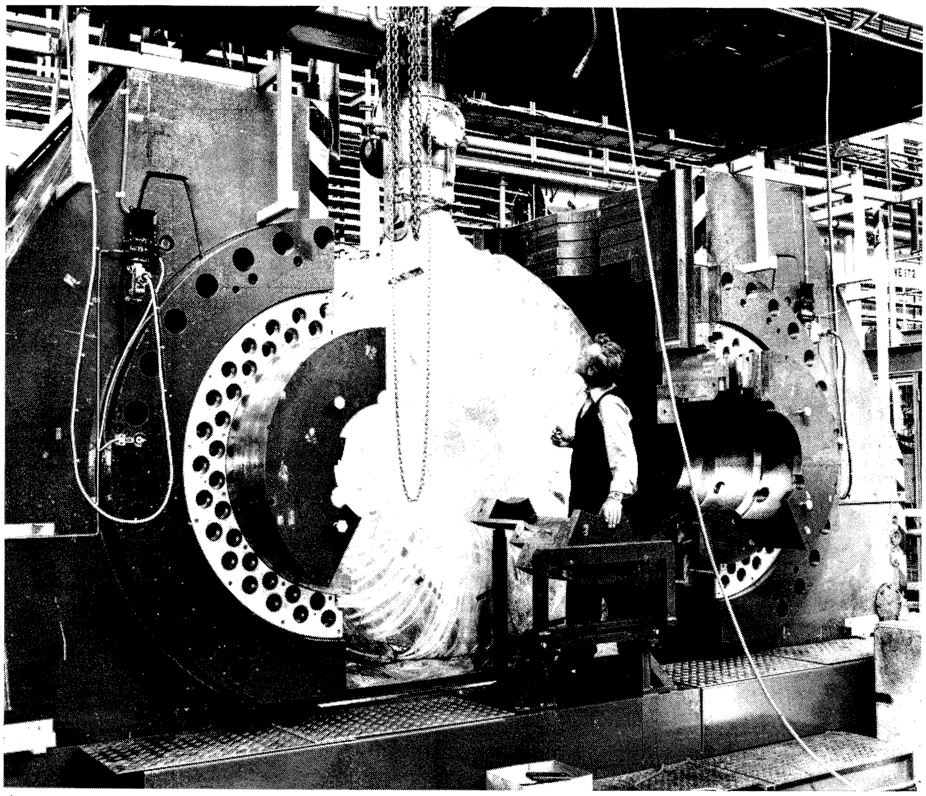
KEK
Polarized proton filter for neutrons

A polarized proton filter for thermal and epithermal neutrons has been constructed and successfully operated by the KEK Polarized Target Group at the KEK Laboratory in collaboration with the Japanese Atomic Energy Research Institute and Tohoku University. The filter will be used to polarize the neutron beam at the KEK booster.

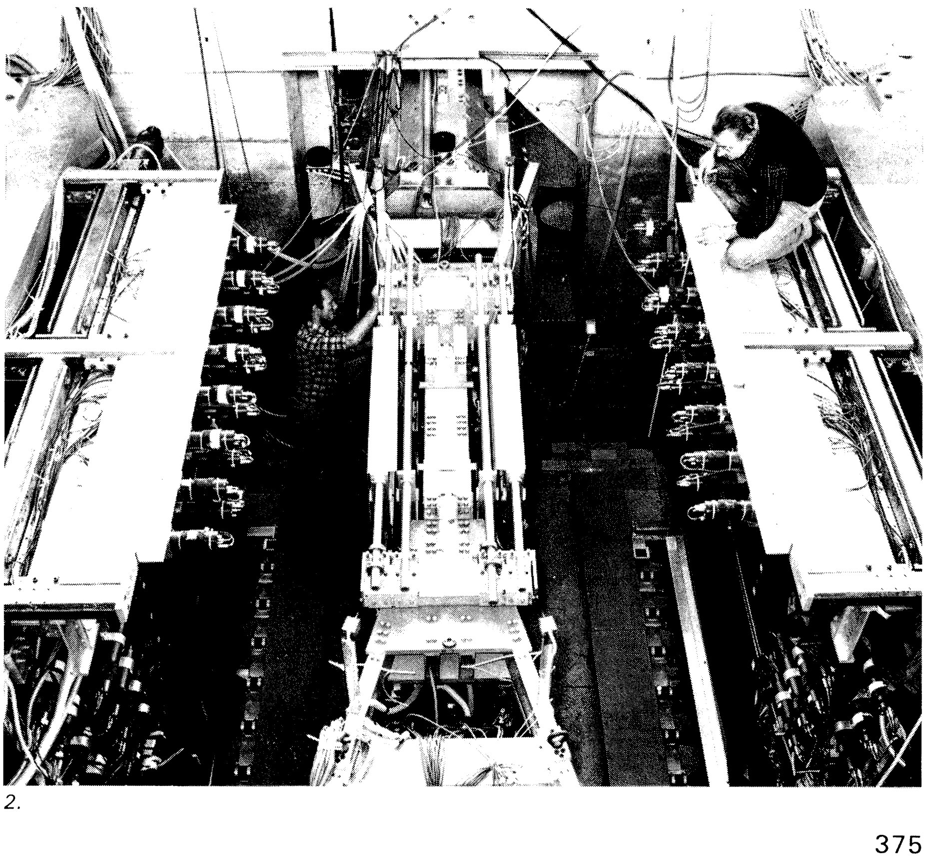
This is one of the useful applications of a technique developed in the field of high energy physics to another field of physics. The idea came from the fact that the cross section for neutron-proton scattering is much larger when the proton and neutron spins are antiparallel than when they are parallel.

The possibility of polarizing a neutron beam by passing it through a polarized proton filter was demonstrated by F. Shapiro and his colleagues at Dubna more than ten years ago. Applications for a thermal and epithermal neutron beam were proposed by A. Masaike in the polarized target group of KEK and a similar idea for polarization analysis of cold neutrons came from the Institute Laue-Langevin after the discovery of the high polarization of protons by a dynamic method at helium-3 temperatures.

Ethylene-glycol containing a few per cent of Cr^{V} ions was used as filter material at KEK. The filter size was about 3.5 mm in diameter and 9.6 mm in length and the filter material was surrounded by liquid helium-3 for cooling (except in the beam path so as to

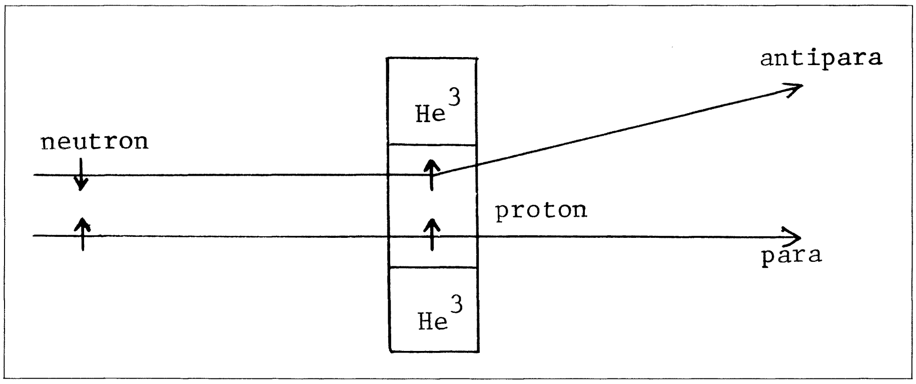


1.



2.

Polarizing a neutron beam by passing it through a polarized proton target. This schematic representation indicates how the different scattering cross sections in the target (which is surrounded by helium-3) results in the transmitted beam being predominantly of neutrons which have their spins parallel to those of the protons in the target.



avoid the absorption of neutrons by helium nuclei). The technique of dynamic polarization of protons in ethylene-glycol is almost the same as in the polarized proton targets for high energy physics. The ethylene-glycol is irradiated by microwaves of 70 GHz in a magnetic field of 2.5 T giving a proton polarization of about 72%.

This target was exposed to the 0.08 eV neutron beam from a reactor of the Atomic Energy Research Institute. The ratio of the numbers of transmitted neutrons, parallel to anti-parallel with respect to the direction of the proton polarization, was larger than ten. The result indicates that a thermal and epithermal neutron beam polarization higher than 90% can be obtained by this method.

It has several advantages over the Bragg scattering on iron-cobalt or a polarization filter of samarium-149. It can take polarized neutron beam intensities almost of an order of magnitude higher and it imposes no restrictions on the angular divergence of the incoming beam. In addition, it covers the energy range between 10^{-3} eV and 10^{4} eV which is much wider than covered by other methods.

FERMILAB Muon Workshop

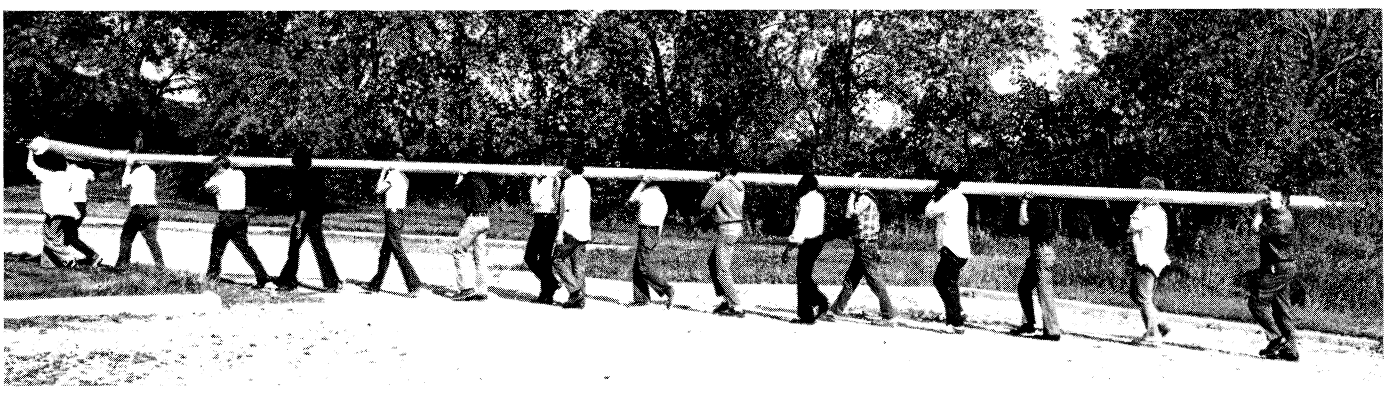
A Muon Workshop was organized to discuss the next generation of muon experiments at Fermilab. The first generation, carried out by groups from Chicago / Harvard / Illinois / Oxford and Cornell / Michigan State, discovered a violation of Bjorken scaling in deep inelastic lepton-nucleon scattering and conclusively demonstrated that no simple redefinition of the scaling variable (a method tried with some success on earlier, lower energy electron scattering data at SLAC) was adequate to eliminate the observed effects. The Workshop was challenged to find equally exciting new goals for the next experiments and, with the advent of the impressive new muon beam and experimental facilities at the CERN SPS, this challenge was considerable.

In the Workshop, organized by T. Kirk (Associate Head of the Neutrino Department), new theoretical and experimental questions were explored. Central to the discussions was the expectation that a new muon beam would be developed in the context of the 1000 GeV Tevatron programme, so that intense beams of good optical quality could be produced with energies up to 800 GeV and intensities up to 10^{8} per pulse. This would give a factor of 2.5 in energy relative to the beam now being developed at CERN and a factor of 50 in intensity relative to the existing Fermilab beam.

J.D. Bjorken (SLAC) and J.S. Sullivan (Illinois) covered the physics which can be investigated with such a beam. The most obvious extension of present work is to push the scale violations further in an attempt to determine their precise behaviour which is important for theoretical understanding of the scale breaking mechanism. There is also much to be gained in studying the recoil hadrons in muon-proton and muon-deuterium collisions, particularly in the large momentum transfer region where the existing

Looking like a bizarre scene from an Ingmar Bergman film, this photograph records the move of an 18 m length of helium transfer line for the Fermilab Energy Doubler project. It will be used with three superconducting dipole magnets.

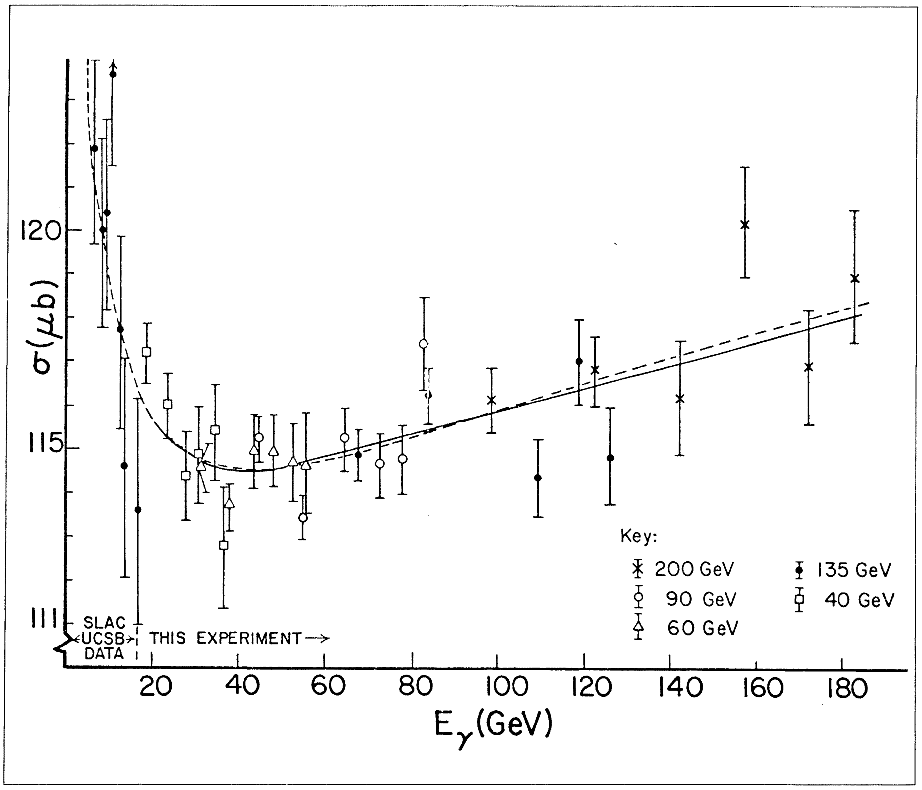
(Photo Fermilab)



Fermilab data is sparse. The increase from 300 to 800 GeV muons will be particularly welcome as it adds a unit of rapidity to the accessible kinematical regime.

In addition to these obvious extensions of present work, both Bjorken and Sullivan emphasized that muon scattering in heavy nuclei will enable an important class of experiments on quark propagation in nuclear matter to be studied. Such experiments explore very fundamental particle properties and are not, as many physicists seem to believe, merely messy nuclear physics. Rather well developed theoretical tools are now available for analysing the scattering in heavy nuclei.

J.-J. Aubert (Annecy) gave a stimulating review of the work planned at CERN by the European Muon Collaboration. He was followed by a number of experimenters discussing ideas for interesting physics which could become accessible with the new beam. They also outlined ways in which the experiments could be done. Among the ideas were experiments on high luminosity inclusive muon scattering, multi-muon production, electromagnetic / weak interference experiments, charged current weak interactions, and various final state hadron detection and measurement schemes.

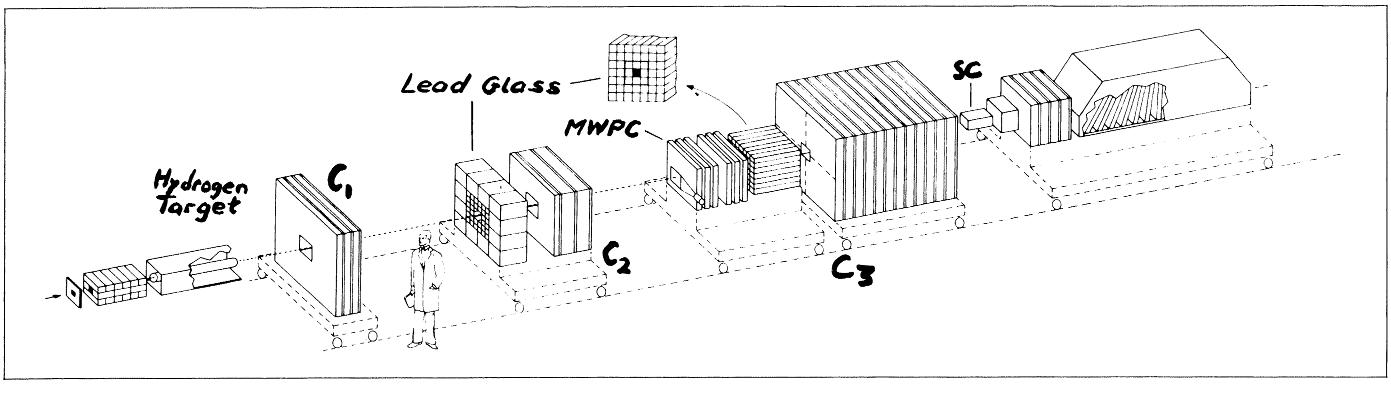


The photon total cross section recorded with the tagged photon beam at Fermilab. They have pushed the measurement to new high energies, confirming the rise with energy as seen for other hadrons, and achieved sufficient accuracy to observe the small effect due to the existence of charm.

Photon total cross sections

A Fermilab / Santa Barbara / Toronto group recently completed measurements on the hadronic photoproduction total cross section on hydrogen. The experiment used a tagged photon beam in the Proton Area in conjunction with a sophisticated hadronic spectrometer of interlaced calorimeters and wire chambers.

Measurement of the photon total cross section provides very fundamental information. For example, because of the hadronic nature of the photon, one expects a rising cross section at high energies such as is observed in typical hadron scattering. Earlier theoretical ideas suggested that the cross section would follow an appropriate sum of vector meson-proton cross sections whose energy dependence can be estimated from the quark



Drawing of the detection system in the photon experiment as positioned for photons from a 90 GeV electron beam. C_1, C_2 and C_3 are scintillator calorimeters. Electromagnetic events are recorded in a central lead lucite shower counter (SC). Wire chambers (MWPC) identify wide angle electromagnetic events.

model and measurements of pion-proton and kaon-proton total cross sections.

Adding charm to this picture produces noticeable effects as charm channels cut in. Some plausible arguments indicate that the onset of charm could lead to an increase of the order of 2% for the total cross section. A precise experiment, with statistics better than 1%, was required to resolve this question. The recent experiment not only extended the measurements to a new high energy but did so with much greater precision than achieved before.

Most photon interactions in a hydrogen target are not hadronic but involve electromagnetic processes that are highly collimated in the forward direction, which means that a transmission measurement of the total cross section is not satisfactory. Instead, the detector collected all the hadronic products outside of a narrow forward cone (just slightly smaller than the rho opening angle). This region is covered with both charged and neutral hadron detectors. Behind the central hole, an electromagnetic shower counter measured electromagnetic energy and helped to veto pair events. Detectors were arranged so that they could be moved along the beam to scale for different energy ranges.

Photons were produced by bombarding a thin radiator with an electron beam of known energy. The electrons bremsstrahlunged to produce forward going photons with part of the incident energy, while electrons that radiated proceeded with the remaining energy. A magnet just after the radiator deflected the electrons into a series of shower counters which measured their energy so that it was possible to tag the energy of the photon.

This system functioned well both in determining the energy of the photons and in establishing their flux with remarkable precision. To cross check operation of the beam, the experiment ran at several different electron energies up to 200 GeV and it was possible to measure the photon total cross section on hydrogen from 18 to 185 GeV.

The results show a total cross section of about 115 microbarns rising linearly by about 2 microbarns per 100 GeV. The errors are less than 1%. This data seems to connect with much of the lower energy data and the energy dependence is in agreement with earlier models which relate the cross section to vector-meson production. However, the net cross section is several microbarns higher than would be expected if charm is not taken into account.

Data was also taken using heavy nuclei targets to study the energy and A dependence of nuclear shadowing, which is yet another manifestation of the hadronic nature of the photon. Preliminary results on carbon and copper in the 45 to 90 GeV range indicate that the shadowing effect has, if anything, increased over that at lower energies.

Son of CAMAC

One of the big spin-off successes in high energy physics has been in the field of fast electronics with the development of the standard CAMAC interface techniques which enable data collection and control systems to be developed for all types of applications and for use with a wide range of different computer equipment and electronics. Without CAMAC, or similar standards, data acquisition systems would have to cope afresh with the exact hardware and software requirements of each application.

As well as being a worldwide standard for high energy physics and nuclear physics experiments, CAMAC is also used in a wide range of other laboratory environments, and even further afield in industry wherever there is a large scale requirement for data acquisition or telemetry.

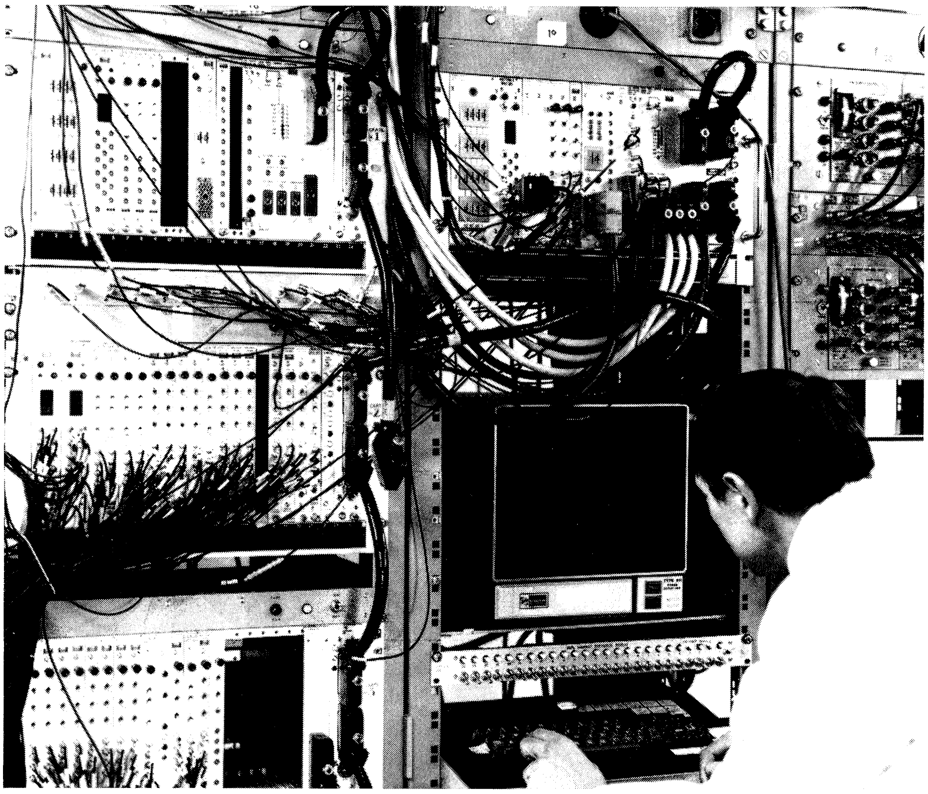
However, the fast rate of development in data processing techniques and electronics has been generally interpreted as limiting the useful life of CAMAC in its present form, and it is realised that sooner or later a replacement or complementary interface method will be required to offer increased speed, scope and flexibility.

In 1975, formal representations were made to the Nuclear Instrumentation (NIM) and CAMAC committees in the USA, suggesting that future experiments designed to take data at very high rates would find themselves hampered by the present CAMAC maximum speed of 1 MHz per 24 bit transfer, and by other limitations, pointing to a need for a long term replacement system.

An investigatory group was set up, which recommended that a formal Advanced Systems Study Group should be established to examine, in detail, the requirements for data collection rates in future experiments, the future trends in minicomputer speeds and design, and the increasing use of 'distributed intelligence' in which processing power is dispersed through

A typical CAMAC set-up. CAMAC has been one of the big spin-off successes in high energy physics and is now used in a wide range of different data acquisition and computer control applications. But the fast development taking place in this field means that a replacement or complementary interface technique will soon be required.

(Photo CERN 130.12.72)



a system rather than being centred in one place. The Study Group was to put forward its conclusions on the requirements for a 'next generation' of interface systems. Its terms of reference said that, while compatibility with existing CAMAC techniques should be a subject for study, it was not necessarily a binding commitment.

In its report, published earlier this year, the Study Group concluded that CAMAC has some general shortcomings which would severely limit its usefulness for future experiments using new data acquisition and processing techniques. While CAMAC might be able to work with these problems for a long time to come, a long term replacement system is clearly needed. These objectives are now being incorporated into preliminary designs for the new system. Final specifications should be complete by the middle of 1979, with production models ready soon after.

At the same time, the ESONE collaboration responsible for the maintenance of CAMAC standards in Europe has acknowledged the need to investigate the long term future of CAMAC and has its own Study Group. Although not directly involved in the new USA design work, CERN is closely monitoring progress and has observers at the regular NIM meetings.

Some of the future needs identified by the USA Study Group included block transfer requirements involving the high speed transfer of blocks of data words (for example, between different buffers); the increasing use of preprocessing and parallel processing techniques (for example, using microprocessors to select data as early as possible, reducing the volume of data to be transmitted), and the handling of 'sparse data' in large arrays of detector elements, only a few of which would contain relevant information.

Control and data acquisition software requirements are taken into account at the outset of the new specification, while provision is being made for parallel processing and multiprocessing, including the required communications protocols. Other general requirements which have been identified include the need to read and write individual registers, to initiate activities (such as interrupts) remotely, and to enable the status of the whole system to be changed by a single signal.

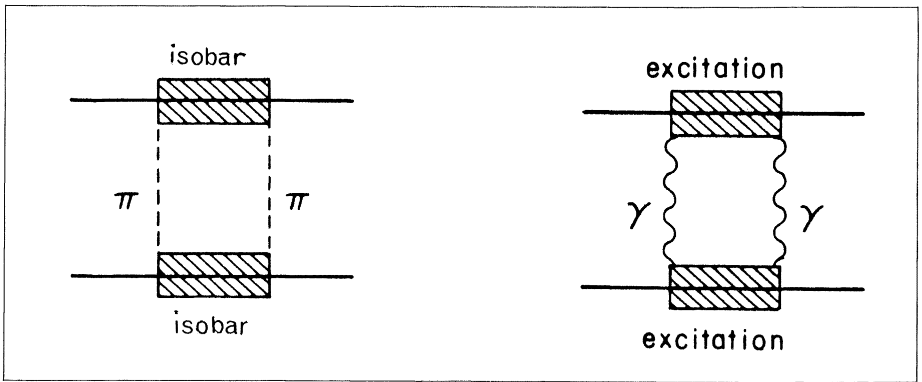
To fulfil these requirements, the new interface standard will need to operate at a speed at least ten times that of CAMAC (that is, more than 10 MHz) and be able to operate in two transfer modes — a 'handshake' mode involving exchange of signals between two devices and another mode where blocks of data could be transmitted without necessarily having to wait for a response. It should be able to handle 'sparse data' as a matter of routine. The Study Group also had reservations about CAMAC's addressibility and its compatibility with distributed processing techniques.

The limitations of CAMAC can also be illustrated by the relatively large number of ad hoc electronic systems which have been developed in recent years for special applications. Each of these systems overcomes one or two of the major CAMAC problems, but none of them can really be regarded as forming a basis for general development.

Whatever the outcome of the new design work, CAMAC will probably still be with us for many years to come. Far from disappearing from the scene when the new systems emerge, CAMAC could well obtain an extra lease of life.

Physics monitor

Contrary to popular belief, nucleons are not held together by exchanges of single pions. Instead, the dominant attraction could come about through the excitation of 'nucleon isobars' with two-pion exchange (as sketched on the left). This is analogous to the dipole-dipole interactions of excited states in the van der Waals forces in molecules (right).



The nucleon-nucleon force

The interaction between pairs of nucleons, the NN force, is one of the main points of contact between nuclear physics and particle physics. A good understanding of this interaction enables nuclear physicists to better understand and describe the behaviour and properties of nuclear matter, while particle physicists gain a deeper insight into the mechanisms which influence individual particles.

The traditional way of looking at the NN force is as a series of Yukawa-like single meson exchanges. The observed properties of the interaction require five mesons (pi, rho, omega, phi and sigma), each with its own characteristic behaviour. A long-standing embarrassment has been the light (450 MeV) sigma meson, which has been introduced into the theory to provide a central attractive potential. But no such meson exists!

Two-pion exchange can simulate the required features of sigma-exchange, so that the need to identify with a physical particle is not necessary. Nevertheless the idea of the exchange of a single particle is a useful form of 'shorthand' to describe the required central attraction between pairs of nucleons. The exchange of two pions creates a force directly analogous to the van der Waals force in molecules and enables a deep and satisfying analogy to be drawn between the binding of nuclear matter and the forces at work in molecules.

The figure shows on the right the interaction between two neutral molecules in terms of photon exchange. The first photon induces an electric dipole in one molecule and this dipole transmits a photon to the second molecule, creating another dipole. These two dipoles interact and give rise to the van der Waals forces. The overall effect of these induced dipole-induced dipole interactions is described by a characteristic structure constant — the electric polarizability.

In the nucleon-nucleon case, pions take the place of photons, while the excitation of nucleon isobars corresponds to the creation of induced dipoles. This mechanism gives rise to a medium-range attraction which dominates effects due to single pion exchange. Thus, contrary to popular belief, nuclei are held together by a pionic equivalent of the van der Waals mechanism and not by single pion exchange.

While the nucleon-nucleon interaction is attractive at medium range (a distance greater than about 0.8 fermi), there is a strong repulsion from about 0.5 fermi inwards, interpreted as the result of omega exchange and it is this repulsion which makes the close study of the proton so difficult. It is inside this repulsive core that quarks could exist, confined by a suitable mechanism (see below).

Thus the nucleon-nucleon interaction is well described at relatively long distances while the investigation of the inner regions is more difficult. The single omega exchange, strongly repulsive for the nucleon-nucleon case, becomes attractive between nucleons and antinucleons and could enable bound states to occur (see August issue, page 243). One immediate task is to identify the quantum numbers of such 'baryonium' states and to formulate the correct selection rules.

This study provides more fuel both for quark model investigations and for nuclear dynamics, so extending the valuable common ground between nuclear and particle physicists.

Quark confinement: 1. Quantum chromodynamics

Despite the impressive list of predictions to its credit, the quark model of hadrons was long overshadowed by the reluctance of the quarks to unashamedly reveal themselves. Now, this reluctance is interpreted as the result of quark 'confinement' — the quarks are there all right, but they find it difficult to leave each other's company.

There are number of ways of trying to explain this permanent confinement of quarks inside hadrons. One, called quantum chromodynamics, is yet another example of the use of gauge theories in particle physics (see September issue, page 271), while a totally different approach sidesteps the problems of field theory and presupposes that the quarks exist only inside a small volume, or 'bag'. Quarks in bags, etc., will be dealt with in a subsequent article.

In the early days of the quark model, the non-appearance of quarks was explained by supposing that free quarks were extremely heavy, but were bound together by tremendously strong forces which swallowed up most of this rest mass to give relatively light hadrons. This in essence was the first model of quark confinement.

In such a picture of heavy quarks cemented together by the major proportion of their rest mass, one would expect additional quark-antiquark pairs to be created relatively easily, and this is not seen. Also such a picture did not tie in with notions of quark 'additivity', where many good predictions can be made simply by adding together the properties of the constituent quarks in a reaction. Quark model calculations could literally be done on the backs of envelopes and, what's more, gave some good results. If the quarks retained their individuality in strong interaction dynamics to such an extent, it would be difficult to imagine them as being crushed together by some still stronger force.

The next clue came from the classic experiments at SLAC which showed that hadrons probed with high energy electron beams behave like boxes of small, extremely light particles, or 'partons'. Subsequent experiments with neutrino beams at CERN using the Gargamelle bubble chamber showed similar behaviour and demonstrated that these parton constituents inside nucleons had quark-like properties.

These and similar experiments show that when the deep inner structure of the nucleon is probed by weakly and electromagnetically interacting particles, spin 1/2 quarks show up. Analysis shows that the masses of these quarks are negligible compared with the accompanying momentum transfers of 1 GeV or so and under these conditions even the quark-quark interactions seem to become negligible.

This discovery forces us to the conclusion that while free quarks are reluctant to come out into the open, they are nevertheless only loosely bound together in hadrons. Quarks stick together permanently but gently!

Asymptotic freedom

In a Yang-Mills field theory, the parameters describing internal particle properties (isospin, etc.) are allowed to depend on space and time so that a formalism can be developed which is broadly analogous to the highly successful techniques of quantum electrodynamics.

Several years ago, it was discovered that using such a Yang-Mills field theory within a small enough region of space-time, quarks would not interact very much, a condition known in the trade as 'asymptotic freedom'. If this space-time volume were enlarged, the level of interaction between the quarks would become stronger. This is in complete contrast with quantum electrodynamics, where the effective charge on the electron becomes bigger and bigger as the space-time volume of interaction is decreased, leading eventually to an infinite charge for a 'bare' electron.

This infinity in quantum electrodynamics is naturally removed from the theory by the process of 'renormalisation' which takes account of the additional interactions surrounding a bare electron to give the small observable electronic charge. In Yang-Mills field theory, the corresponding 'bare' charge for the isolated particle is zero, and becomes bigger as the additional surrounding interactions are included.

Colour

In the same way as electromagnetic interactions are mediated by the exchange of massless spin one photons, so such a field theory of quark-quark interactions says that the interactions are mediated by the exchange of massless spin one particles, called 'gluons'. An analogous quantity to electric charge must exist in the quark theory, and this is where 'colour' comes in. The gluons carry colour between the quarks, which have a colour charge.

The need for additional quark quantum numbers besides 'flavour' (up, down, strange, charm and whatever else) had been suspected for some time. When the decuplet of heavy baryons (the family which includes the Omega-minus) is constructed from three quarks, it has a wave function which is symmetric both in flavour and angular momentum (spin). However, according to the Pauli exclusion principle, the wave functions of all particles with half-integer spin (including baryons) should be antisymmetric.

This is easily remedied by bringing in another quantum number like 'colour' but the ideas of colour soon take on a deeper significance. In the colour picture, quarks have three additional attributes which like charge, isospin, etc., carry over into hadrons. If there were no restrictions, the colour model would produce all sorts of colour variations of the hadrons built from quarks, but such variations are not seen. (It is important to remember that 'colours' refer only to quantum numbers, and cannot be seen as colours, any more than 'flavours' can be tasted !)

To keep down the number of possible hadrons, we can say that all observed particles have to have zero colour (i.e. they are 'white' in a composite colour picture). For baryons made from three quarks, the zero colour combination is found to be antisymmetric, so if the total baryon wave function is built up from three factors, flavour, angular momentum and colour, then it is indeed antisymmetric as required by the exclusion principle.

Quark interactions must therefore be such that all hadrons have zero colour, and the problem of quark confinement is then put in another way: why cannot colours be separated ? The simplest quark configurations which have zero colour are a quark-antiquark pair (a meson) and a triplet of three quarks (a baryon). Other combinations of quarks having net colour and non-integer quantum numbers are not seen.

Problems

In principle, the problem of quark confinement and the general behaviour of the quark-quark interaction can be studied using a Yang-Mills field theory which incorporates these ideas of colour. This theory is quantum chromodynamics, frequently abbreviated to QCD.

However, in field theory, the only calculational framework which is well understood is the perturbation technique in which successive levels of interaction are obtained to get a closer and closer approximation to the 'answer'.

In quantum electrodynamics, the effective charge which describes the size of the interaction between a charged particle and the electric field is a small number. A perturbation series expansion therefore has successive terms which get smaller and smaller and this series is easy to handle.

Using these perturbation techniques in quantum chromodynamics, we can handle the small colour charges which occur when quarks are described in small enough regions of space-time, but the effective colour charge quickly increases outside this small regime of asymptotic freedom to give series expansions which cannot be handled.

Using these limited calculational techniques, quantum chromodynamics cannot describe quark confinement. This is not to say that the theory is wrong: it is just that the right mathematical methods for handling the calculations have yet to be found.

Nevertheless, perturbation theory can still be applied in the small space-time regions around each quark where the effective colour charge is small enough. This is equivalent to treating the hadron as some kind of 'box' of free quarks and, if the idea is applied to neutrino-nucleon interactions, results are obtained which mysteriously agree with experiment!

Thus we arrive at a picture of quark interactions which can only be applied inside small enough regions of space-time. This does not explain confinement but, nevertheless, gives some results which agree with experiment. This state of affairs is not yet understood, but it does mean that further useful calculations using asymptotic freedom might be possible, given the right kinematical conditions.

Until the mathematical tools available for field theory have been developed further to give a more complete framework for calculations, some people are turning away from this incomplete description of quark interactions in favour of one which presupposes confinement. This 'bag' model will be dealt with in a subsequent article.

People and things

On stage

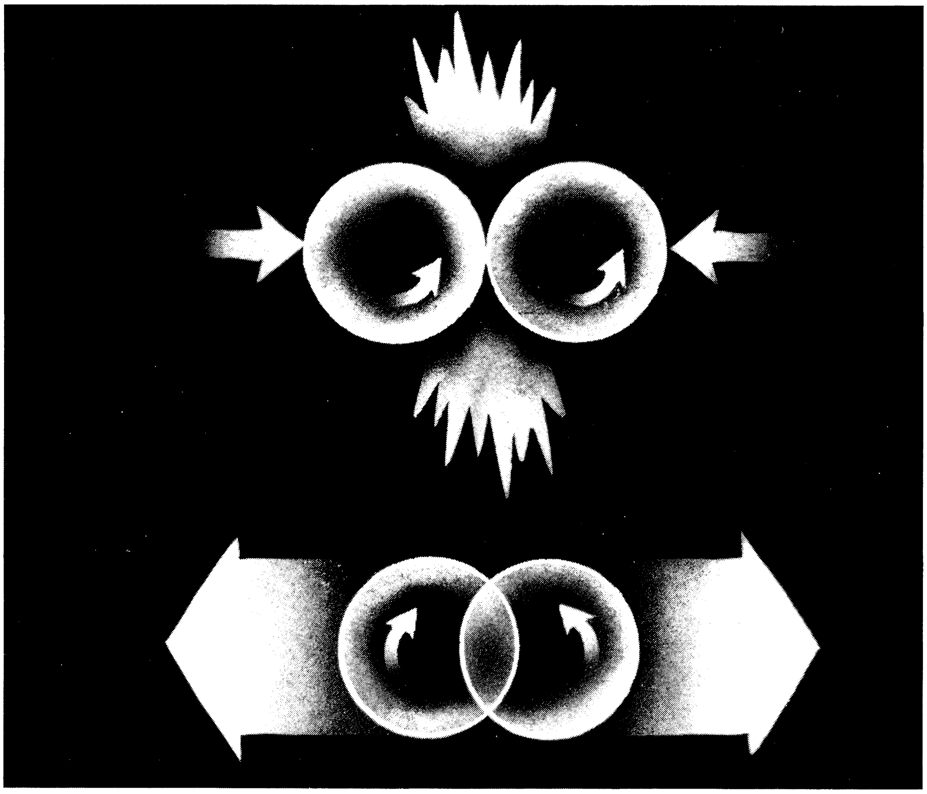
An experimental theatre group called 'The Phantom Captain' has brought particle physics to the London stage with a work entitled 'The (2nd) Changeness Congress'. Using Nigel Calder's 'The Key to the Universe' and Fritjof Capra's 'The Tao of Physics' as sources of inspiration, they put together, in cabaret form, a lively (and accurate) presentation of the present turmoil of our understanding of the nature of matter. Robert Walgate, favourably reviewing the event in the 'New Scientist', maintains that The Phantom Captain have made a breakthrough being 'the first group ever to make particle physics sexy'. We are obviously going to pay dearly for the discovery of charm.

CERN School of Physics

The 1978 CERN School of Physics is being organized in collaboration with the Dutch Physical Society. It will be held from 4-17 June at Austerlitz-Zeist near Utrecht in the Netherlands. The aim of the School is to communicate aspects of current theoretical physics to young experimental physicists mainly from the CERN Member States. Further information may be obtained from Miss D.A. Caton, Scientific Conference Secretariat, CERN, CH-1211 Geneva 23, Switzerland.

USA reorganization

We mentioned in the September issue the creation of the Department of Energy (DOE) in the USA under Secretary of Energy, James Schlesinger. Within the Department there is an Office of Energy Research headed by a Director who reports to the Secretary on the physical research programmes, such as high energy physics, transferred from the former Energy Research and Development Administration (ERDA). The Director of



A neat diagramatic representation of the results of the experiment using a polarized proton target and a polarized proton beam (reported in the August issue, page 237). The upper picture shows that when the two protons are spinning in the same direction, the probability of hard scattering increases. The lower picture shows that, when the two protons are spinning in opposite directions, the particles can pass through one another more readily.

(Photo Argonne)

the OER is John Deutch former Chairman of the Chemistry Department at MIT. The Laboratories under OER include Berkeley, Brookhaven, Fermilab and SLAC.

Muon number conserved

A lot of excitement was generated earlier this year when preliminary data hinted that the muon breaks up occasionally into an electron and a gamma ray. If this proved to be so, the distinctiveness of the muon as opposed to the electron (expressed as muon number conservation) would have broken down. A Montreal / British Columbia / TRIUMF / Melbourne collaboration, working at the TRIUMF cyclotron, has analysed 20% of their data collected using two large sodium iodide detectors to look at muon decays. They see no sign of the electron-gamma decay and have set a new lower limit of less than 3.6×10^{-9} of the decay into an electron and two neutrinos. The muon number is thus conserved down to this level of detection ability. The remaining data is likely to be analysed by the end of this year.

Somebody out there loves us

The Commission of the European Communities carried out a survey of attitudes to science in the nine countries of the EEC. The results, from questioning some 9000 people, were strongly pro-science and pro-government support of science, indicating that the widely voiced belief in public apathy or antagonism towards science is not based on fact. 69% of those interviewed considered science one of the most important factors in the improvement of our daily life. (This should be balanced with a 67% response that very dangerous repercussions can ensue from civilian applications of science.) 80% believed in 'the future of scientific research' and 81% that the State should subsidize such research. 79% were for the research being carried out by a joint effort of the Member States of the EEC. There was also great interest expressed in scientific information put out by the media. Science writers can now sleep in their beds at night.

CERN COURIER moves mountains

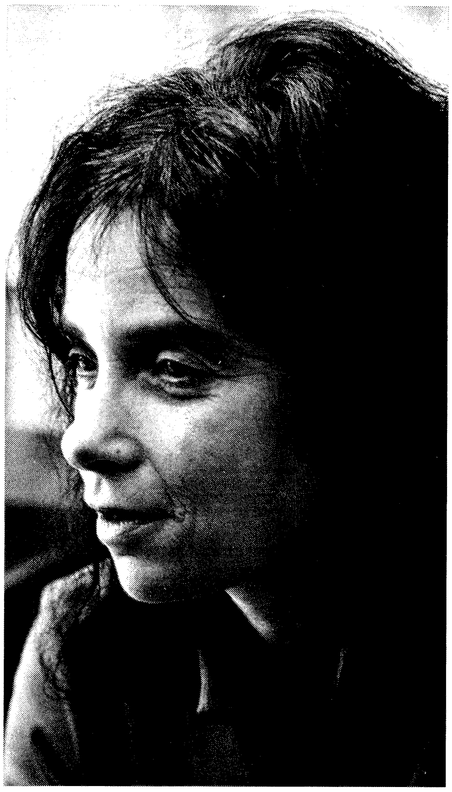
In our September issue, page 289, we made reference to the famous 'Centauro' high energy cosmic ray event seen in nuclear emulsions exposed on Mount Chacaltaya in Brazil. Oscar Rondon-Aramayo from Case Western Reserve University alerted us to possible annexation of part of his native Bolivian Andes where Mount Chacaltaya is actually located. We were misled by the experiment collaboration which is Brazil / Japan. Bolivia's Physics Research Institute operates the Cosmic Ray Laboratory on the mountain. It was on this mountain that C.F. Powell, G.P.S. Occhialini and C.M. Lattes exposed, in the late 1940s, the emulsion that revealed the pion for the first time.

Anniversary at Uppsala

Five hundred years ago, in 1477, the first University in Sweden was founded at Uppsala. To celebrate the anniversary, conferences, symposia, exhibitions and concerts have been organized throughout the year and the festivities culminated during the last week of September with the conferment of the degree of Doctor Honoris Causa on a number of outstanding scientists among whom were Wolfgang Paul, present Chairman of the CERN Scientific Policy Committee, and Glenn Seaborg, Associate Director at the Lawrence Berkeley Laboratory.

As part of the celebrations some of the Departments of the University organized 'Open Days' during which the public was invited to take a closer look at the research activities. One of the Institutions to open its doors was the Gustaf Werner Institute at which research in high energy physics is carried out. The research domains of the Institute are particle physics, nuclear physics and physical biology. The basic equipment of the Institute is a synchrocyclotron and, as a major project in Sweden, this accelerator is now being upgraded to become a sector-focusing machine which will yield 10 μA of protons at variable energy up to 200 MeV. Heavier ions up to oxygen-16 will also be accelerated. The new machine, which will be ready in three years, will find extended use in particle physics (nuclear structure physics and detector development for experiments at CERN), nuclear chemistry, physical biology, clinical tumour treatment and production of isotopes for medical use.

During the Open Day at the Institute



1.

2.

1. Rena Chasman
2. Helwig Schopper

on the 30 October, organized in parallel with that of the Tandem Accelerator Laboratory (basic equipment: 6 MV terminal voltage tandem Van de Graaff accelerator) of the University, instrumentation from both the physical and biological research activities was displayed and their operation was explained to the lay-man on posters. The activities at CERN were shown using photographs, slides, posters and the projection of the film 'Inside CERN'. Physicists were present to explain and discuss with the visitors. The atmosphere was lively throughout the day and the public apparently appreciated this informal way of contact with the scientists. In this respect the event was reminiscent of the 'physique dans la rue' events organized at the Aix-en-Provence Conference in 1973.

On people

Brookhaven has suffered another sad blow to its community of accelerator physicists. Coming soon after the loss of Ken Green, one of his close colleagues Renate Chasman died on 17 October. Rena Chasman moved to Brookhaven in 1963 and became an expert particularly on the theoretical aspects of beam behaviour in accelerators. She worked on the design and construction of the AGS 200 MeV linac, the design of the ISABELLE proton-proton storage ring and the design of the electron storage ring for the National Synchrotron Light Source.

Herwig Schopper, Director of the DESY Laboratory, is on a three week visit to China where he will be discussing the possible participation of Chinese scientists in the experimental programme on the PETRA electron-positron storage ring.

Staff movements at Fermilab: Tom Kirk has assumed responsibility as Associate Department Head of the Neutrino Department. Peter McIntyre has become Group Leader of the Internal Target Area. Richard Lundy has been appointed Business Manager. Alvin Tollestrup has joined the Fermilab staff in the Energy Doubler / Saver Group and will also head a new group in the Research Division responsible for research and development of electron detectors and data-acquisition techniques. Larry Coulson succeeds Peter Gollon as Head of the Radiation Physics Group and the Laboratory Radiation Safety Office.

Arie van Steenbergen is heading the construction of the National Synchrotron Light Source at Brookhaven. The $24 million project was described in the December 1976 issue. It will provide facilities for synchrotron radiation research in the X-ray and ultra-violet regions as from 1981.

Bob Wilson, Director of the Fermilab, has written an extensive article about his Laboratory's 'Tevatron' 1000 GeV project in the October issue of 'Physics Today'.

One that went by while we were looking the other way — In the report of the Serpukhov Accelerator Conference in the August issue we refered to A.A. Logunov as Director of the Serpukhov Institute of High Energy Physics. Academician Logunov has, of course, been succeeded as Director by Professor L. Soloviev.

Hiroo Kumagai of the Institute of Nuclear Physics, University of Tokyo, died on 5 November. He was an accelerator specialist, particularly in the field of vacuum technology.

Staff movements at Brookhaven: Dereck Lowenstein succeeds Horst Foelsche as Head of the Experimental Planning and Support Division and Y.Y. Lee succeeds Lyle Smith as Head of the AGS Division. During Foelsche's term the EP and S Division constructed the High Energy Unseparated Beam (using four superconducting dipoles), constructed a high-intensity, high-energy pion beam, designed a new high-flux low energy separated beam, and constructed the hypernuclear spectrometer. Under Lyle Smith, the integrated proton flux of the AGS doubled (to 5.5×10^{19} per year), the peak intensity passed 10^{13} protons per pulse, and the average internal intensity approached 10^{13}ppp.

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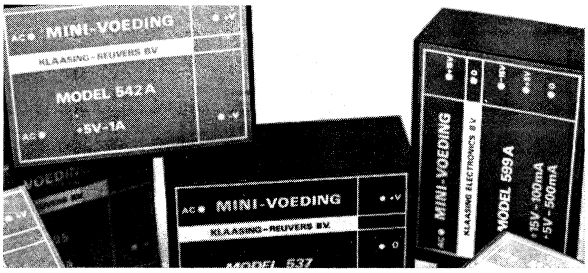

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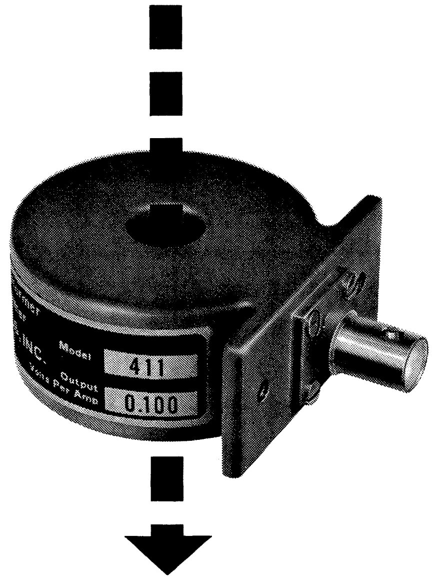

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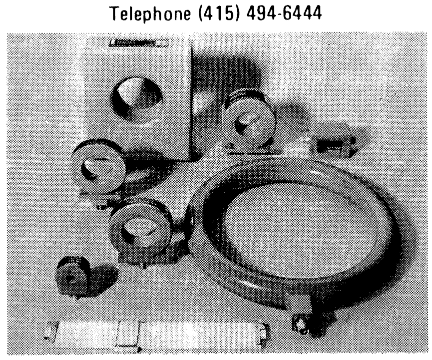

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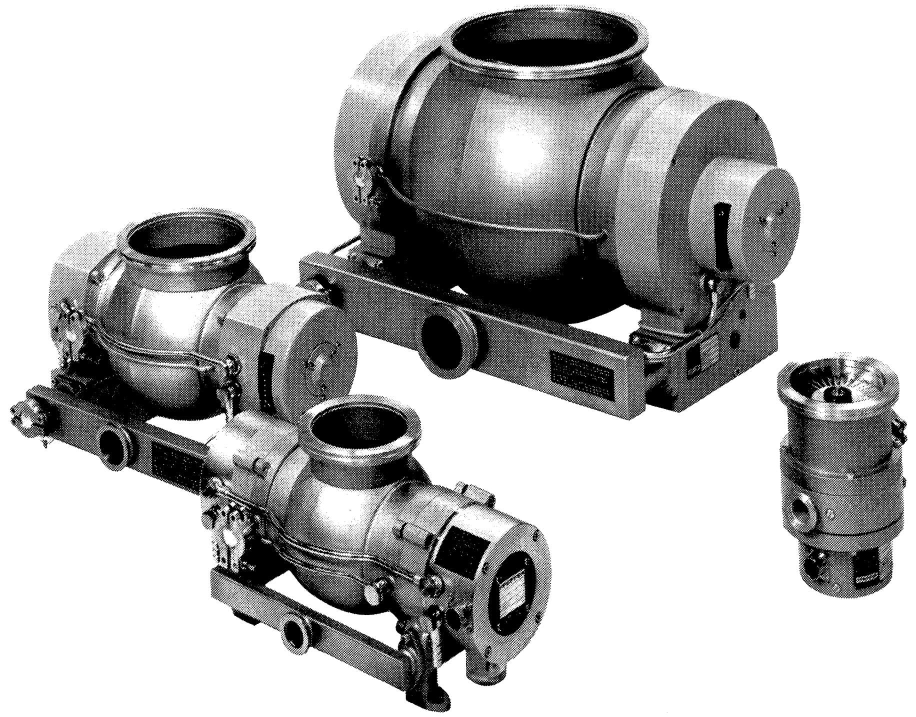

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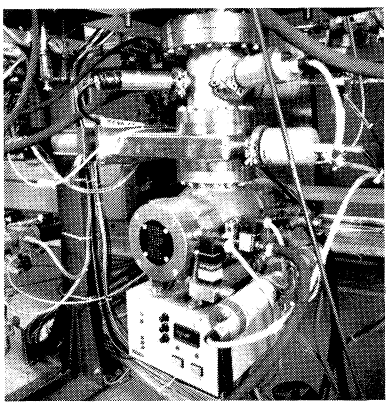

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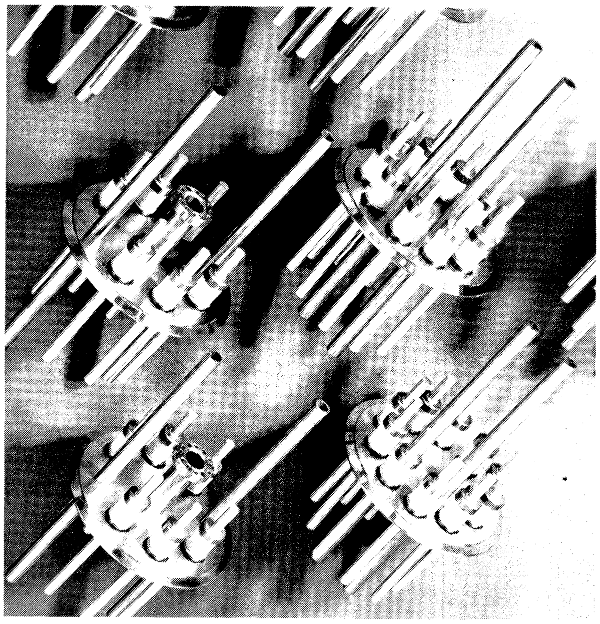

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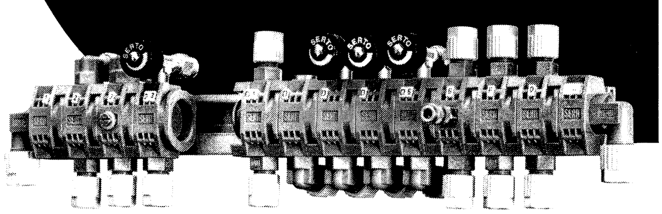

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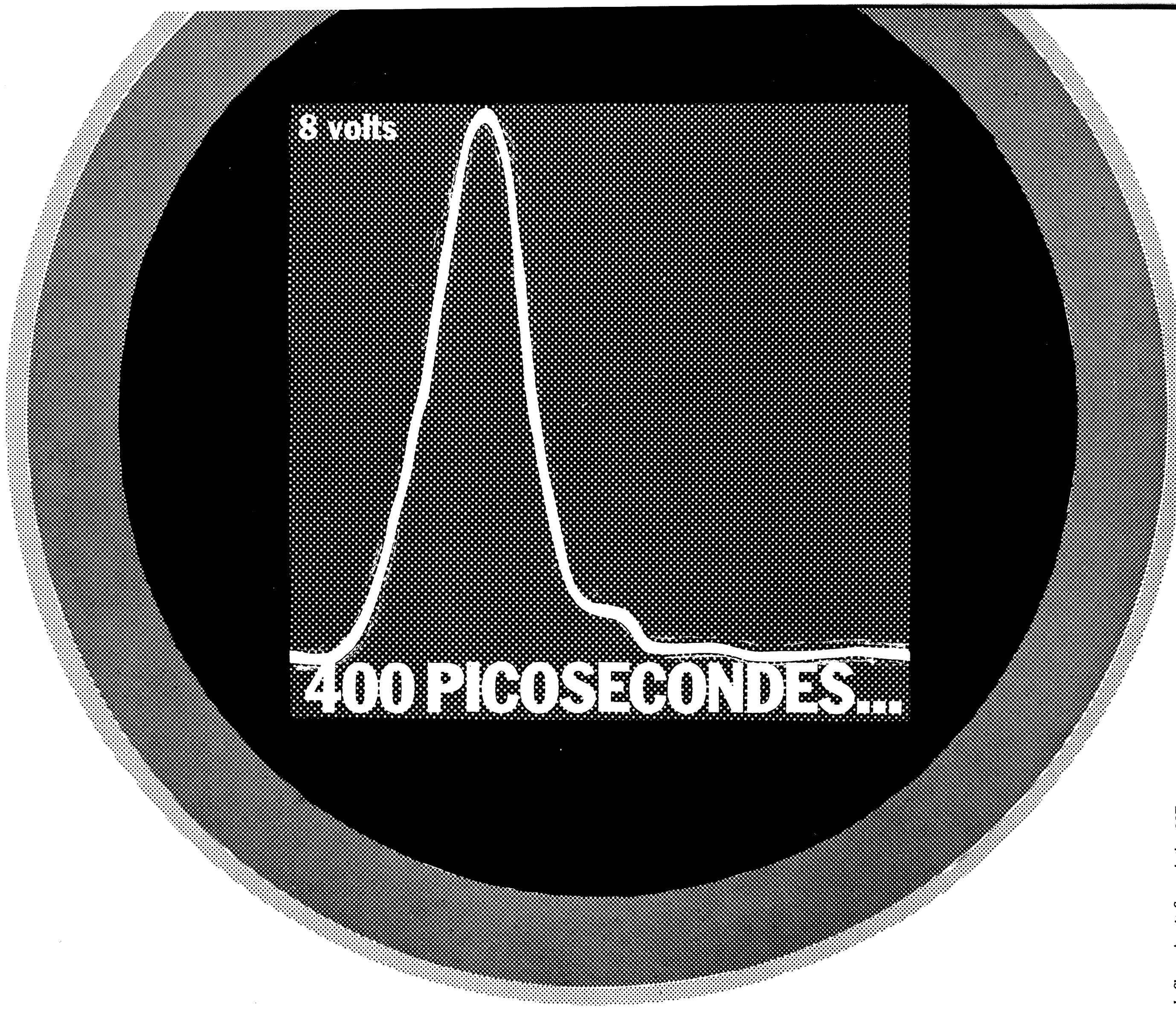

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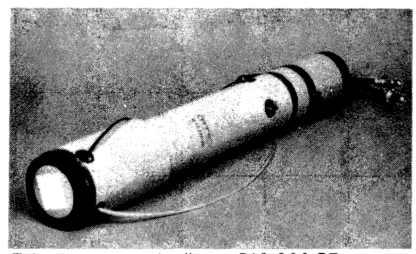

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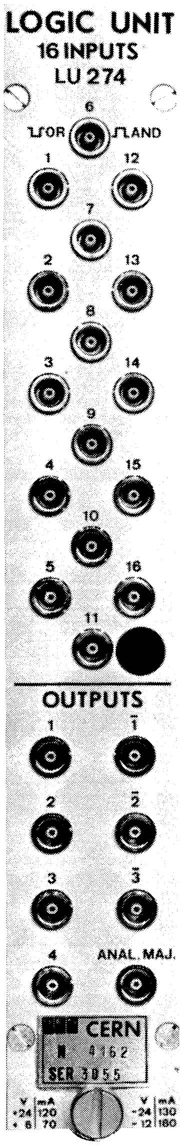
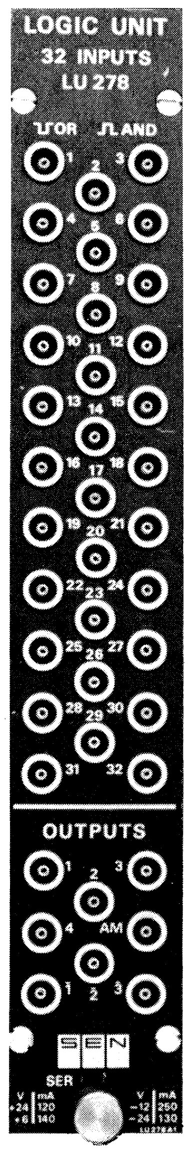


LU 278
32 input logic unit



- 16 – or 32 – OR/AND Logic unit
- more than 1, 2, 3, 4 logic majority outputs
- analog majority output

inputs	:	32 (LU 278) or 16 (LU 274) 50 Ω decoupled NIM level
width	:	minimum 5 ns for 4 majority output, minimum 3.5 ns for 1 majority output
logic outputs	:	4 outputs allowing to discriminate if more than 1, 2, 3 or 4 simultaneous inputs 3 complementary outputs
level	:	16 mA current sources
width	:	input width or overlap minus 2, 3 or 4 ns for outputs 1, 2 and 3
I/O delay	:	⩽ 11ns
analog output	:	1 output allowing to discriminate if 1, 2, 3, 4, 5 or 6 inputs
level	:	current source 2,66 mA/input
width	:	input width or overlap minus 2.5 ns
I/O delay	:	⩽ 6.5 ns

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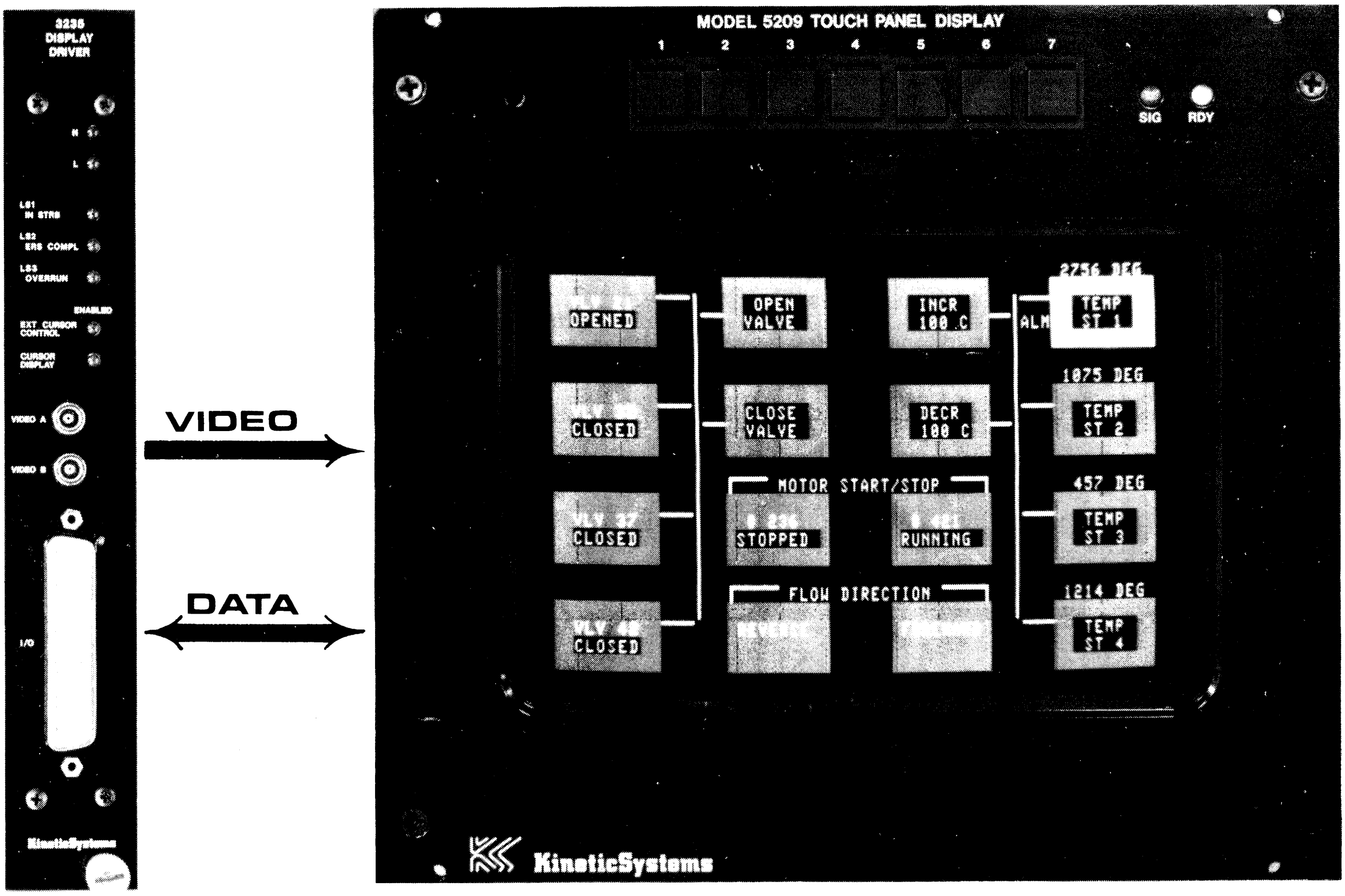

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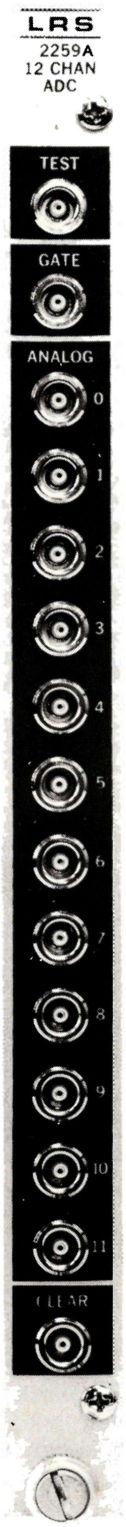

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