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Contents

The cover photograph is an aerial view of the new neutrino facility, the subject of the main article in this issue of CERN COURIER. Top left can be seen the wheel shape of the proton synchrotron and the finger of the new neutrino beam line points from it to the bottom right hand corner. The tunnel, containing the units which focus the 'neutrino parents', is now tidily covered with earth shielding. After that comes the large, 6000 ton, block of steel, to filter the neutrino beam, and finally the building which will house the neutrino detectors – the CERN heavy liquid bubble chamber, and the spark chamber array. The building to house 'Gargamelle', the very large heavy liquid bubble chamber being constructed at Saclay, will eventually be built behind the present detector building.

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The European Organization for Nuclear Research, more commonly known as **CERN** (from the initials of the French title of the original body, 'Le Conseil européen pour la Recherche nucléaire', formed by an Agreement dated 15 February 1952), was created when the Convention establishing the permanent Organization came into force on 29 September 1954.

In this Convention, the aims of the Organization are defined as follows:

> **'The Organization shall provide for collaboration among European States in nuclear research of a pure scientific and fundamental character, and in research essentially related thereto. The Organization shall have no concern with work for military requirements and the results of its experimental and theoretical work shall be published or otherwise made generally available.'**

Conceived as a co-operative enterprise in order to regain for Europe a first-rank position in fundamental nuclear science, CERN is now one of the world's leading laboratories in this field. It acts as a European centre and co-ordinator of research, theoretical and experimental, in the field of **high-energy physics,** often known as **sub-nuclear physics** or the **physics of fundamental particles.**

High-energy physics is that front of science which aims directly at the most fundamental questions of the basic laws governing the structure of matter and the universe. It is not directed towards specific applications – in particular, it plays no part in the development of the practical uses of nuclear energy – though it plays an important role in the education of the new generation of scientists. Only the future can show what use may be made of the knowledge now being gained.

The laboratory comprises an area of about 80 ha (200 acres), straddling an international frontier; 41 ha is on Swiss territory in Meyrin, Canton of Geneva (the seat of the Organization), and 39.5 ha on French territory, in the Communes of Prévessin and St.-Genis-Pouilly, Department of the Ain.

Two large particle accelerators form the basis of the experimental equipment:

- a 600 MeV synchro-cyclotron,
- a 28 GeV proton synchrotron,

the latter being one of the two most powerful in the world.

The CERN staff totals about 2300 people.

In addition to the scientists on the staff, there are over 360 Fellows and Visiting Scientists, who stay at CERN, either individually or as members of visiting teams, for periods ranging from two months to two years. Although these Fellows and Visitors come mainly from universities and research institutes in the CERN Member States, they also include scientists from other countries. Furthermore, much of the experimental data obtained with the accelerators is distributed among participating laboratories for evaluation.

Thirteen Member States contribute to the cost of the basic programme of CERN in proportion to their net national income:

Austria (1.90 %)
Belgium (3.56 %)
Denmark (2.05 %)
Federal Republic
of Germany (23.30 %)
France (19.34 %)
Greece (0.60 %)
Italy (11.24 %)
Netherlands (3.88 %)
Norway (1.41 %)
Spain (3.43 %)
Sweden (4.02 %)
Switzerland (3.11 %)
United Kingdom (22.16 %)

Poland, Turkey and Yugoslavia have the status of Observer.

The 1966 budget for the basic programme amounts to 149 670 000 Swiss francs, calling for contributions from Member States totalling 145 860 000 Swiss francs.

Supplementary programmes, financed by twelve states, cover construction of intersecting storage rings for the 28 GeV accelerator at Meyrin and studies for a proposed 300 GeV accelerator that would be built elsewhere.

The Next Neutrino Experiments

by **C. A. Ramm**

Leader of Nuclear Physics Apparatus Division

Of all the particles so far identified in man's search for an understanding of the nature of matter, the neutrino is the most tantalizing. Even Pauli, who, in 1931, correctly deduced from indirect evidence in beta-decay that neutral, very light and very feebly interacting particles must exist, apologized to his close associates for postulating a particle which he believed could never be observed experimentally. Indeed he wagered a case of champagne against the direct observation of neutrino interactions; some twenty years later, so the story runs, he paid for it to celebrate the famous neutrino experiments of Cowan and Reines.

Including anti-neutrinos, four distinct members of this family of particles are known. The particle Pauli postulated is now called the electron anti-neutrino ($\bar{\nu}_e$). It has neither detectable charge nor mass and is produced together with an electron in the beta-decay of a nucleus; we call the interactions of neutrinos 'weak' as it is evident that the forces involved are quite different from those of the 'strong' and 'electromagnetic' interactions. The beta-decay of the neutron is the simplest process:

$$n \rightarrow p + e^- + \bar{\nu}_e$$

Energy, momentum and spin are conserved in the disintegration, but if the presence of the $\bar{\nu}_e$ were unknown and only the properties of the electron and proton were observed, the process would have to be interpreted as a spectacular violation of hitherto inviolate laws. It was just because of his conviction in the validity of these laws that Pauli concluded that the $\bar{\nu}_e$ must exist to conserve, together with the electron and proton, the energy, momentum and spin of the original neutron.

Sources

The most prolific sources of $\bar{\nu}_e$ are the reactors of the atomic energy establishments and nuclear power stations. Although an appreciable fraction of the energy liberated by a reactor is in the form of $\bar{\nu}_e$, so that each of us is bombarded by thousands per second from all the reactors in the world, the detection of the $\bar{\nu}_e$ is one of the most difficult experiments to perform. The first experimental observation of 'neutrino' interactions was the detection of positrons and neutrons from the absorption in matter of $\bar{\nu}_e$ from the Savannah River reactor. The experiment was the culmination of many years of painstaking development.

For us earth-dwellers, the sun is the most powerful known source of electron neutrinos (ν_e), which are produced in association with a positron in the fusion of hydrogen to produce heavier elements. For example, if two protons combine to give a deuteron a ν_e is released:

$$p + p \rightarrow d + e^+ + \nu_e$$

The sun bathes us with a flux of ν_e of more than 10^{10} per cm^2 per second. They carry away a substantial fraction of the total energy radiated, perhaps a few per cent, for all we know, in a perpetually irretrievable form. The ν_e absorption by the earth is so feeble that the ambient flux is the same in the night, when the earth is between us and the sun, as it is in the day, except in so far as our distance from the sun varies!

What is their role ?

It is easy to sense, then, some of the fundamental and intriguing puzzles of neutrinos. Our environment is immersed in a sea of these all permeating particles, involving indeed a significant fraction of the total energy of the universe. What role does this neutrino sea play in the cosmological evolution ? Will we ever succeed in obtaining some answer to this question ? Until quite recently, because of their very feeble rate of interaction, even the detection of neutrino interactions, let alone their study, was a technical impossibility; neutrinos can cross the whole universe with trivial probability of interaction. Does that part of the energy in the form of neutrinos, which all stars radiate, remain forever in that form; effectively in a gigantic cosmic sink, aloof from interactions with other matter and with electric and magnetic fields, and confined to the boundaries of space only by those aspects which make energy and mass equivalent manifestations of matter ? Does the neutrino sea continue to fill up indefinitely, acquiring relentlessly a share of the energy resources of the universe in a way somewhat analogous to the gradual loss of our worldly resources into the seas and oceans of our planet ?

Perhaps it is not surprising that many scientists devote their inspirations to devising means of observing and analysing neutrino interactions.

Solar and cosmic neutrinos

To study the neutrinos from the sun, very large detectors have been installed deep in the earth to escape confusing background radiations. Almost unbelievably refined techniques have been invented to detect, for example, the transformation of only 100 atoms of Cl^{37} to A^{37} in a mass of 500 tons of perchloroethylene by solar neutrino capture in the process:

$$Cl^{37} + \nu \rightarrow A^{37} + e^-$$

This seemingly impossible sensitivity has already been achieved after a decade of development; the apparatus is now ready to operate. Will, at last, the solar neutrino flux be detected and measured ? If so, it will be possible to understand more precisely the mechanism of the sun's transformation of mass into energy.

A property of neutrinos which is of particular experimental importance is that their cross-section for interaction increases about a million-fold as their energy increases from a few MeV to a few GeV. Thus, it is possible to study much smaller extra-terrestrial neutrino fluxes than that from the sun, if the neutrinos are of a much higher energy. In fact neutrinos from cosmic rays are now being studied with apparatus of a similar experimental grandeur to that being used for the solar neutrino studies, also located deep underground, where the horizontal flux of all known cosmic rays is finally reduced to neutrinos. Already there is clear evidence of muon neutrino (ν_μ) interactions, consistent with the estimated ν_μ flux from the disintegration of pions and kaons produced in the atmosphere by the primary cosmic ray particles, mostly protons. Actually, ν_μ and ν_μ are manifest in disintegrations involving muons, very similar to ν_e and $\bar{\nu}_e$ in disintegrations involving electrons; the commonest parents are pions and kaons:

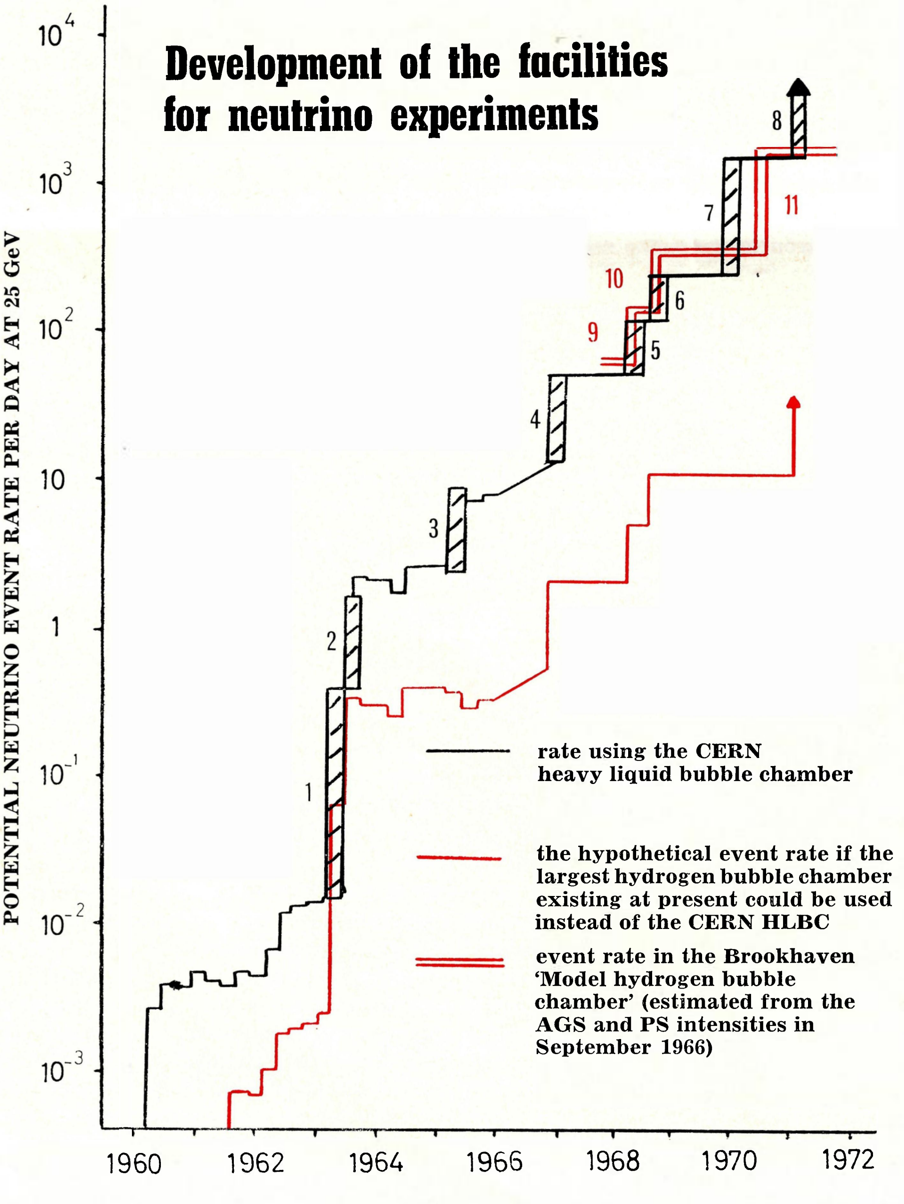
$$\pi^+ \rightarrow \mu^+ + \nu_\mu,\ \pi^- \rightarrow \mu^- + \bar{\nu}_\mu$$
$$\text{and}\quad k^+ \rightarrow \mu^+ + \nu_\mu,\ k^- \rightarrow \mu^- + \bar{\nu}_\mu.$$

'Laboratory' neutrino experiments

The cosmic ray neutrino experiments are sufficiently successful and important to justify enlarging. They will always yield some information at higher energies than otherwise available. However the ν_μ and $\bar{\nu}_\mu$, as we shall discuss later, are also especially suitable for experiments in laboratories with high energy accelerators. For this reason, we now know 'most' about the interactions of ν_μ and $\bar{\nu}_\mu$, but this 'most' is relative to ν_e and $\bar{\nu}_e$; in comparison with the knowledge of other much less abundant particles, our experimental knowledge of ν_μ and $\bar{\nu}_\mu$ is abysmally vague. During the last five years, the neutrino interaction rate in bubble chambers at the large accelerators has increased about ten thousand times; in the next five years an increase by at least another factor of a thousand is assured, so that during a decade experimental neutrino physics will pass from being technically unfeasible to one of the most important experimental fields in high energy physics. CERN is making a substantial contribution to this technical development; for the next neutrino programme, scheluded for March 1967, an entirely new experimental area will be used. First, however, we shall review briefly the results of the previous experiments.

Previous PS neutrino experiments

During the experiments in 1963-64, about 1000 interactions of ν_μ were detected in the CERN heavy liquid bubble chamber (HLBC). Only about half of these

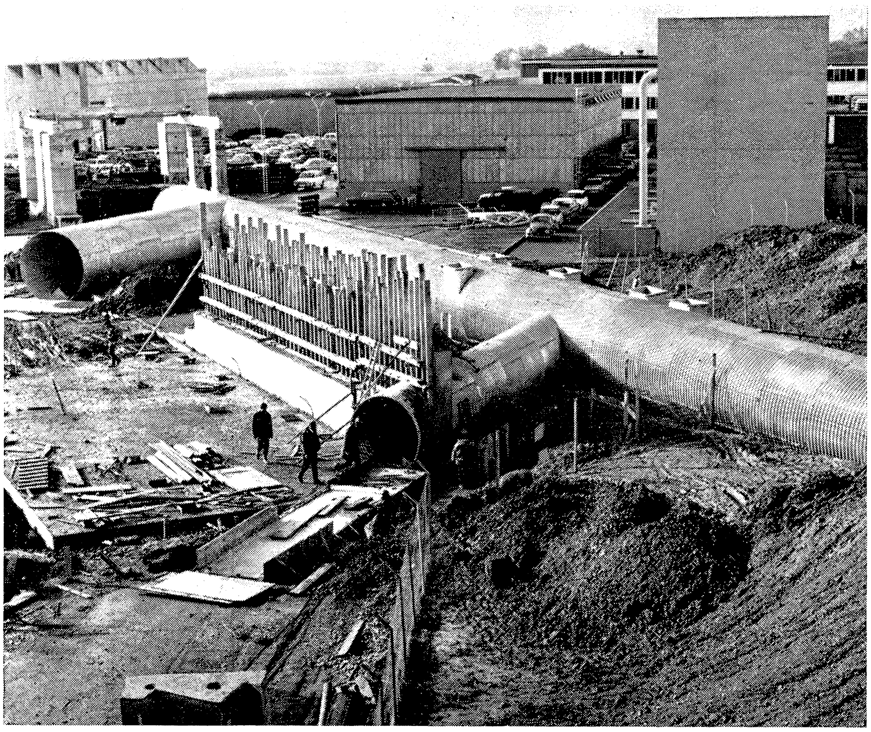


Development of the facilities for neutrino experiments

The major increases in the event rate shown in the graph originate as follows:

1. Fast extraction of the proton beam from the synchrotron
2. Use of the magnetic horn
3. Enlargement of the CERN heavy liquid bubble chamber, using propane. (This is the total number of events, 20 % of which will be on 'free' protons)
4. Completion of the new neutrino facility
5. Increase in synchrotron repetition rate (with new power supply, etc.)
6. ? Use of heavier shielding
7. 'Gargamelle' takes over from the HLBC
8. ? Increase in intensity with a new booster injector.

9. Increase in repetition rate at the Brookhaven synchrotron
10. Use of heavier shielding
11. Increase in AGS intensity with new injector



An early view of the construction of the neutrino tunnel protruding from the earth mound on the PS. The tunnel was constructed from corrogated steel sections for speed of assembly and for economy. The two access points can be seen. In the background are the stacks of steel ingots which are now tightly packed into the large shielding block which filters out the penetrating neutrinos from other particles.

CERN/PI 162.2.6

were retained for analysis, effectively those which were in a region of the chamber sufficiently far from the walls for reliable measurements, but from this comparatively small number of events many deductions were possible. The event rate for 'elastic' interactions was consistent with the estimated spectrum of neutrino energies and the theoretically predicted cross-section. The results of the previous Brookhaven experiment, which demonstrated the existence of the two neutrinos, ν_e and ν_μ, were confirmed and the evidence that ν_μ interacts to produce muons and never electrons, was increased. For the first time, it was shown that the distribution of magnetic moment and charge in a nucleon, deduced from electron experiments, is similar when studied with neutrinos.

Several other aspects of weak interactions were also explored, for example the possibility that the ν_μ from kaon parents are different from those from pion parents. No evidence was found for this idea, nor for a postulate that the type of particle called 'strange' is often produced in $\bar{\nu}_\mu$ interactions.

Perhaps the most widespread interest at that time was the lack of evidence for the existence of the intermediate boson, the W. This particle was postulated by some theorists to be the carrier of the weak force, in analogy to the role of the pion in strong interactions and the photon in electromagnetic interactions. A very large spark chamber array had been prepared to observe what was predicted to be the most likely mode of disintegration of the W, which would be produced together with a μ^- in the interaction of a ν_μ with a nucleon:

$$\nu_\mu + Z \rightarrow \mu^- + W^+ + Z$$

decaying into a positive muon and a neutrino:

$$W^+ \rightarrow \mu^+ + \nu_\mu$$

Since the W was predicted to be very short-lived, its expected 'signature' would be the observation of the muon pair. Among the 10 000 neutrino events in the spark chamber no such pairs were found. Had the boson decayed to produce an e^+ and ν_e, or just pions, as was also considered possible, it could have been seen in the HLBC, but again no such decay was found. Thus, it was deduced that if the W exists at all, its mass must be greater than 2 GeV/c², which is much higher than was first thought. As Professor Weisskopf has so often remarked, the absence of the W both in the neutrino experiments and in other subsequent experiments in strong interactions, has made the study of neutrino interactions even more interesting, more fundamental, and more essential for a deep understanding of the weak forces.

Plans for the next step

We will now retrace the scientific reasoning on which the development of our new facilities for neutrino experiments is based.

The principal quantitative information from the first experiments came from the analysis of the 'elastic' interaction of a neutrino with a neutron to give a muon and a proton:

$$\nu_\mu + n \rightarrow \mu^- + p.$$

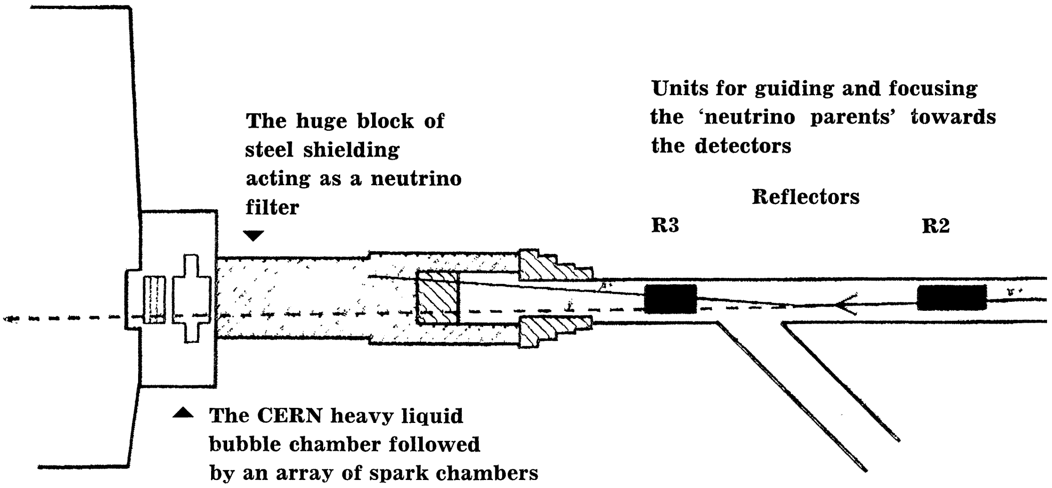
Although the target neutrons were bound in the nuclei of freon CF_3Br, the working fluid in the HLBC, a meaningful analysis was possible because both the muon and the proton had a high probability of escaping from the nucleus without further interactions taking place, so that often they could be observed directly.

Inelastic interactions are much more difficult to investigate. The simplest for experimental study is the interaction of a neutrino with a proton:

$$\nu_\mu + p \rightarrow \mu^- + \pi^+ + p.$$

The muon and proton produced in this interaction in a nucleus have just the same probability as in an elastic event of escaping secondary interaction, but the pion is likely to be absorbed in the nucleus where it is produced, so that the kinematic analysis of the interaction will be less accurate. This problem would not occur for neutrino interactions on targets of 'free' protons, the nuclei of hydrogen atoms, a situation which could be achieved by using a hydrogenous liquid in the HLBC instead of the CF_3Br, where all

The new neutrino beam-line



the protons are bound together with neutrons in the nuclei of carbon, fluorine or bromine. An obvious next step in the study of inelastic neutrino interactions is therefore to set up an experiment in which the target nuclei are free protons, by using a working fluid in the HLBC like propane, C_3H_8, which contains even more hydrogen per unit volume than liquid hydrogen !

Why has a bubble chamber fluid containing free protons not been used already as a detector of neutrino interactions ? Even if the CERN HLBC had been replaced by the world's largest hydrogen bubble chamber during the first experiments, only about 30 neutrino interactions per million pictures would have been obtained. There is no reason to believe that this number of events would have added much information to our knowledge of inelastic processes. Also, since there are no neutrons in liquid hydrogen, the elastic process could not have been studied at all; nor would it have been possible to investigate the lepton conservation laws, or look for the intermediate boson as we could with 1000 events in the HLBC. To use propane in the HLBC with the intensity of the neutrino beam at that time, would have produced many fewer events than by using freon. There would have been less information about lepton laws, about the W and about elastic interactions; for the inelastic phenomena, there would have been scarcely 40 events on free protons — a poor compromise for the loss of the other data. Obviously in an exploratory phase the total neutrino event rate is of major importance. It was decided to postpone an experiment using propane until about as many events on free protons could be obtained as there were elastic neutrino interactions in the first experiments.

What is needed ?

The total mass of the 'free' protons in liquid propane is about 10 % of the mass of the protons bound in nuclei in an equal volume of liquid freon. Thus to obtain the same event rate on free protons in propane as on bound protons in freon, for equal liquid volumes requires, approximately, a ten-fold increase in the neutrino flux — 'approximately' because the event rate on a given mass of protons is somewhat dependent on whether or not the protons are bound in a nucleus, and in which nucleus.

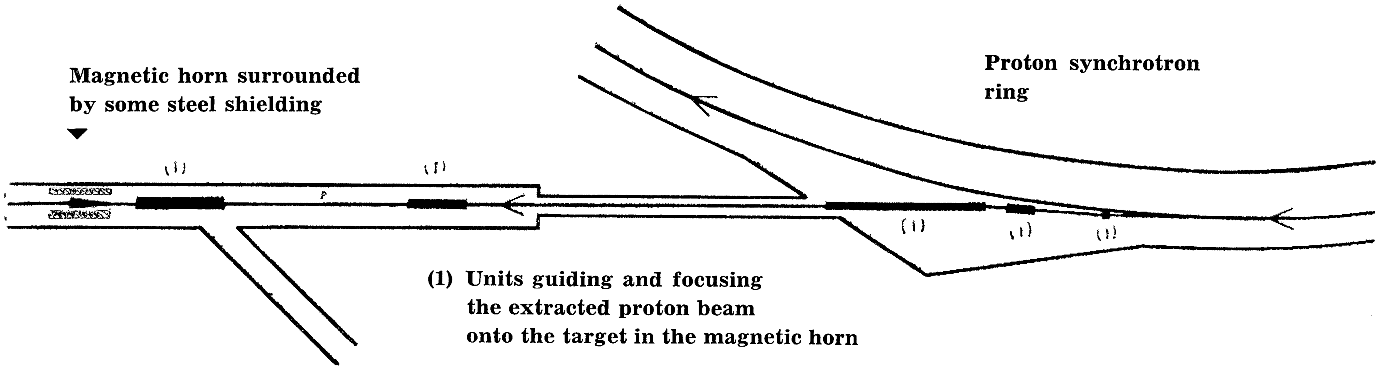
For the first experiments, the neutrino flux at CERN was higher than that available in any other Laboratory and was achieved by using every known and available technique. To obtain an extra factor of ten in event rate seemed, at first sight, impossible. In fact, at the time this problem was formulated, its solution was technically impossible, but as with many technical problems that keep within the bounds of the laws of nature, known or unknown, the fundamental factor in overcoming their difficulties is whether the aim is judged to be worth the effort. Fortunately, there were many enthusiasts who believed that to increase the intensity of the neutrino beam was a worthy technical challenge indeed, whose achievement would make possible experiments of fundamental importance.

Apart from increasing the intensity of the PS beam itself, which obviously is directly reflected in the neutrino flux, there are broadly two fields which enthusiasts may develop to increase the neutrino event rate — the detector, and the production of the neutrino beam from protons incident on a target.

The detector

As a first contribution to the increase in event rate the volume of the heavy liquid bubble chamber was increased from 500 to 1180 litres. For the same definition of the 'useful' volume of the chamber this enlargement gave more than a threefold increase in event rate and, incidentally, made the CERN HLBC again the largest in the world. Two other important experiments (called 'X_2' and 'X_4') have already been possible as a direct consequence of this reconstruction. The contribution to the event rate is proportional to the mass of working fluid in the useful volume.

Perhaps it is interesting to note here that when 'Gargamelle' (the HLBC being built under contract by Saclay for CERN) is available for neutrino experiments, according to the present schedule in August 1969, its effective volume should be some seven times more than the present HLBC — a valuable factor.



(1) Units guiding and focusing the extracted proton beam onto the target in the magnetic horn

The neutrino beam

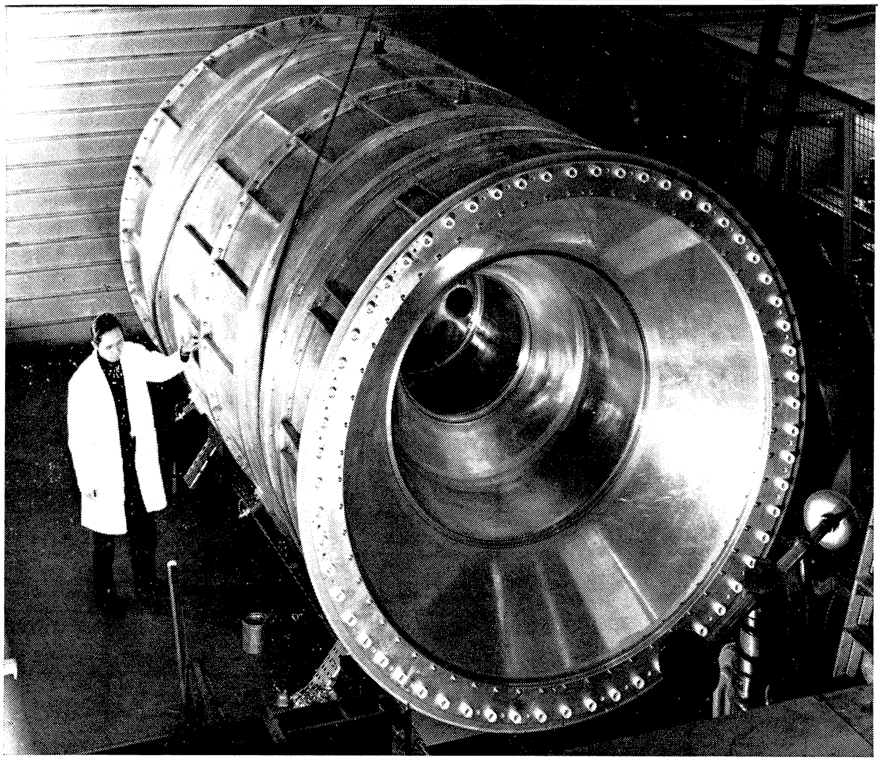
The production of a neutrino beam from the proton synchrotron involves several steps. First the accelerated proton beam is brought out from the synchrotron, by means of the fast extraction system, and directed onto a target where secondary particles are produced in the high energy collisions. Subsequently the two types of 'neutrino parents', the positive pions and kaons which decay after a short time to produce neutrinos, must be guided and focused so that in their disintegration, the neutrinos produced will have the best chance of reaching the detector. In front of the detector is placed sufficient shielding to filter out all other types of particles from the very feebly interacting neutrino beam. Evidently the intensity of the neutrino beam depends on the efficiency of extraction of the PS beam, the secondary particle production, the focusing techniques and the shielding. Whether a neutrino or anti-neutrino beam is obtained, depends on the choice of sign of the focused parent particles. By looking back at the preceding examples of decays it will be seen that neutrinos are obtained by focusing the positive parents, antineutrinos by focusing the negative parents. From a target bombarded by protons the secondary particles have a positive excess, so that there are less antineutrino parents. This, together with the lower cross-section for interaction, makes antineutrino experiments more difficult than neutrino experiments.

The efficiency of the fast extraction system is already high, more than 95 %, so that there is little to be gained in neutrino flux from its improvement. (It is true, however, that some further developments of operational possibilities will be of great importance for the PS experimental programme).

In the first series of experiments, the neutrino parents were focused by a magnetic horn, invented by S. van der Meer at CERN. The horn is a device intended to gather as many as possible of the pions and kaons of one sign into a parallel beam. Intrinsically, any such system confronts the same difficulties as are met in optics in producing an intense and truly parallel beam of light from an extended source. There is much less difficulty in obtaining an intense illumination from a convergent beam of light. Evidently, if the principle of the focusing system could be changed from the simple idea of the horn producing a parallel parent beam, to a system producing a parent beam convergent towards the bubble chamber, the neutrino flux could be significantly improved.

In the new focusing system, the neutrino parents will be partially focused by a new magnetic horn after which two extra magnetic correcting elements (reflectors R 2 and R 3) developed by A. Asner and Ch. Iselin, will converge them towards the detector. The new magnetic horn, which has been designed by D.H. Perkins of the University of Oxford and W. Venus, is about 1.5 times as effective as its predecessor in gathering neutrino parents from a target and directing them towards the reflectors. The effect of the reflectors in the new beam is that a neutrino from the decay of a parent pion or kaon will have a 3 times greater probability of passing through the bubble chamber than in the previous beam.

The shielding has been rebuilt from the steel ingots which were generously lent to us by the Swiss authorities for the previous experiments. For the particular focusing arrangement for the neutrino parents, the neutrino flux at the HLBC is almost inversely proportional to the thickness of this 6000 ton steel 'block'; the density of the 'block' controls the stopping power for filtering out unwanted particles from the neutrino beam. Great care, therefore, has been devoted to packing the ingots tightly to obtain the highest neutrino flux with the least contamination from other particles produced in the tremendous burst of secondary particles generated by the extracted PS beam in the neutrino tunnel. It is easy to understand how valuable the higher density of uranium would be as a shielding material — the neutrino flux could be increased by almost a factor of two with the thinner shielding block which could be tolerated. This advantage is much more likely to be achieved by Laboratories in the USA, which have easier access to scrap, depleted uranium metal, than CERN. Nevertheless, even without uranium, the newly packed steel block, which is slightly shorter than before, the new horn and the new reflectors will produce a total neutrino flux per proton incident on the target about 6 times greater than before.



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The R3 reflector, one of the three major 'neutrino parent' focusing units, seen in almost completely assembled form at the beginning of November. This end-view shows also the conical inner conductor.

This brief description of the features of the new facility does no justice either to the long, painstaking research into the principles of production of neutrino beams, or to the art by which the designers and constructors have created the almost weird new focusing elements. Additional direct gains will come from the recent increase in intensity of the PS beam; also by operating the PS at a slightly lower energy than before, a higher repetition rate can be used to increase the number of neutrinos per second at the HLBC. Adding all these factors together, the final situation will be that, if freon were used in the rebuilt HLBC as previously in the smaller version, the event rate in the new facility would be more than 40 times greater for the same PS running time.

At other Laboratories

Perhaps it is timely here to inquire what is happening with other neutrino facilities. At present, Argonne is the only Laboratory in which neutrino experiments are actually in progress. There, a very large spark chamber array is being used to study interactions produced from a neutrino beam in which the parents are focused by a magnetic horn rather similar to the first CERN experiment. Some hundreds of events have already been obtained and the experiments will be completed this year. At Brookhaven, where the first neutrino experiment was made without any focusing device, and where there was some difficulty with the focusing device used in their second series of experiments, there is a significant advantage for neutrino facilities in that the AGS has a higher energy, faster repetition rate and more intense beam than the PS. In September last, the effect of these various factors would be to give our neutrino beam installation a direct gain of 3.5 times in neutrino flux if installed at the AGS instead of the PS.

In the past this 'machine advantage' has compensated for somewhat less effective parent focusing installations. For the future however, a new focusing system very similar to the new CERN installation is being prepared. An experiment with it, using spark chambers as detectors, is planned for next spring; as the diagram shows, when this new facility is used with the projected 'model' hydrogen bubble chamber of 7 m^3 the neutrino facility at Brookhaven will be outstanding. As for the neutrino plans for the new 70 GeV accelerator at Serpukhov, very little is known, but probably as well as becoming the world's highest energy laboratory it will also have the world's most advanced neutrino facility !

The next experiments

It is impossible to measure cross-sections for neutrino interactions without a precise knowledge of the spectrum of neutrino energies. Although it cannot be measured directly, because of the very low interaction rates, the neutrino spectrum can be inferred from the spectrum of the muons generated simultaneously when the parent particles decay. In the new facility it will be possible to measure the muon fluxes at various depths in the shielding, simultaneously with the neutrino experiment, to conserve PS time.

On the 'other' side of the shielding the HLBC will be installed, to operate with propane for the first time. A few neutrino events on 'free' protons are expected per day, with about five times as many events on carbon nuclei. With the magnetic field of 27 kG it will be possible to select the candidates for neutrino interactions on free protons so that less than 10 % will be neutrino interactions on carbon. If sufficient events are obtained, a quantitative study of the inelastic process will result; neutrino experiments are one of the few in high energy physics in which the major limitation is statistics ! The 'carbon' events, being in propane, can be measured with much greater precision than in the first experiment and will make possible an invaluable re-examination of all the previous conclusions.

Associated with the HLBC will be spark chambers, some of which were used in the first experiments.

This installation originates from a proposal by some of the first spark chamber team to test more precisely a law of 'muon conservation'. It is believed that the ν_μ always transforms to a μ^-, and a $\bar{\nu}_\mu$ to a μ^+. Is this law exact ? The spark chamber array will study muons whose sign will be determined when they pass through the high magnetic field in the HLBC, and it will be able to detect a violation of this law as small as one μ^+ per thousand muons producted by ν_μ.

Occasionally, it is necessary to verify that the operation and synchronisation of the HLBC is perfect during the $2 \mu s$ when the neutrino beam is incident on the chamber, so that the one interaction which occurs every few hundred expansions is correctly registered. Such a verification is impractical with the neutrino beam itself, but it is simple to open a small hole in the shielding by letting mercury out of an iron pipe. Muons, produced at the same time as the neutrinos, will then be able to pierce the shielding and be observed in the HLBC. Incidentally, these test pictures, which will be obtained from a momentum analysed muon beam will not be wasted afterwards; they will be used by a different group of experimenters for a feasibility study of a proposal for a future study of inelastic muon interactions in the HLBC.

From this brief description, in which some other studies which are simultaneous with the neutrino experiment, such as the 'Adler test' and 'shielding studies', have not even been mentioned, it is clear that it would be more correct to describe all the different activities in operation simultaneously as a programme rather than a single experiment. It may be interesting to review later, what has been the outcome of the effort and machine time invested in this programme and to assess what contributions have been made to increase our understanding of the nature of neutrino interactions.

Inside the neutrino tunnel, looking down from the proton synchrotron. The first units, which will guide the extracted proton beam onto the target in the magnetic horn, are being mounted in position. The horn itself will be located where the steel ingots for shielding can be seen further down the tunnel. Further down still, is the end of the reflector R2 whose power cables run along the right-hand side of the tunnel.

CERN/PI 63.10.66

CERN News

CESAR

A further series of experiments have been carried out at the CERN Electron Storage and Accumulation Ring, CESAR. As described in the July issue (p. 135), this small electron storage ring is providing some important information for the large intersecting storage ring project (ISR), and is also making possible some interesting research in basic accelerator physics.

The vacuum pressure in the ring has been maintained at 4×10^{-10} torr for five months (an achievement in itself, since CESAR is the largest vacuum enclosure in the world operating at such a low pressure) and, because of this, the latest investigations have been with electron beams with much longer 'lifetimes' than previously. The predominant factor determining how long electron beams can be stored is the scattering of the electrons by the gas molecules remaining in the vacuum chamber. With a pressure of 4×10^{-10} torr, beams have been achieved with half-lives (the time taken for the beam to fall in intensity to half its value at injection) of 3 to 10 seconds (depending on where the beam is orbiting in the vacuum chamber and on the setting of the magnets).

This ability to observe beams over longer lifetimes has had several effects. It has made possible experiments with the radio-frequency system which can be reliably interpreted. It has given a first look at the possible existence of instabilities which could cause the beam to be lost, but which develop slowly. And finally it has increased confidence in the theoretically predicted lifetimes for the proton beams in the ISR. To simulate the ISR conditions exactly, it would be necessary to watch beams in CESAR for 100 seconds. This would involve achieving a vacuum about ten times better than at present and the indications are that this could not be done without extensive rebuilding of the vacuum system.

The efficiency with which the injected pulses of electrons can be stacked into a beam has been examined. Theoretically, this should depend on the number of pulses one stacks and on the speed with which one accelerated the successively injected pulses to the stacking orbit. Both these theoretical predictions have been checked and, in particular, a detailed curve showing how the stacking efficiency varies with the number of injected pulses for a given setting of the r.f. has been obtained in very good agreement with the theory.

Another investigation using the r.f. system, fed known amounts of 'noise' (random fluctuations) into the r.f. signal which is seen by the beam. In a conventional accelerator, where the acceleration process is over in a second, tiny fluctuations in the r.f. fields are of little importance. But with the ISR, beams will be subjected to r.f. fields for many minutes. Will imperfections in the r.f. then be serious ? Again the results from CESAR are in agreement with theory, and say nothing which will give the ISR builders sleepless nights. They also indicate the degree of imperfection which can be tolerated while still achieving high stacking efficiency.

Most of the work on CESAR is now being concentrated on beam instabilities. Three types have been observed and are being investigated. The first, which may drastically limit the life of the beam, is due to magnet imperfections (octupole and decupole components in the magnetic field). The second is thought to be an instability caused by electrostatic interaction between the electrons, resulting in 'bunching' of the beam (a rearrangement of the beam into a number of short sausages). The third results in coherent oscillations transverse to the direction of motion of the electrons and is probably due to an electromagnetic field in the vacuum chamber, produced by the beam itself and following it like a wake. The last two instabilities occur above a certain intensity and impose an upper limit to the current. This will be relevant to all high intensity machines.

Storage Ring Symposium

An international symposium on electron and positron storage rings was held at Saclay, France from 26 - 30 September. The symposium was devoted mainly to short research contributions, status reports on machine design, theory, and physics with storage rings. Several representatives from CERN covered the progress on the ISR project. (The contribution on work with the storage ring model CESAR is described above).

The Table on page 219, lists the storage rings in operation, under construction or proposed throughout the world. Here, we will consider only two new ideas which were discussed.

The first has been developed at the Cambridge Electron Accelerator. Scientists there hoped to construct storage rings for their electron synchrotron but the proposal was not supported since electron rings at Stanford can potentially achieve much higher intensities. Attention then moved to the possibility of using the existing machine to accelerate a positron beam in the opposite direction to the usual electron beam, thus dispensing with the expensive storage ring. A positron injector has been requested for the Laboratory in the 1967 budget.

A pulse of positrons would be injected into the synchrotron ring and accelerated to an energy of a few GeV. At this energy, the synchrotron radiation from the beam damps the random motions of the positrons. The small beam would then be decelerated to injection energy and another pulse of positrons fed in, this pumping procedure continuing until 100 mA of positrons were stored. An electron beam of equivalent intensity would then be injected and the two beams simultaneously accelerated, in opposite directions.

The intensities would still be low for colliding beam work and the second aspect of the proposal involves the construction of a 'bypass' — a loop alongside the synchrotron ring into which the full energy beams could be deflected. In the bypass, very high vacuum could be maintained (to increase the probability of looking at electron-positron collisions and not collisions with gas molecules) and also, by a special arrangement of magnets, the beams could be focused to very small cross-sections in the intersecting region. This would overcome the intensity limitation of the larger cross-section beams in the synchrotron.

CERN/PI 22.11.66

Starting on the ISR tunnel. This photograph was taken on 2 November when work began at the position of the intersecting rings on the French half of the CERN site. The earth excavated in carving out this tunnel, 15 m wide about 7 m high and with an average diameter of 300 m, will be transported to a dump on the opposite side of the Geneva - St.-Genis road using a tunnel cut under the road. The earth required later as shielding around the storage rings will be stocked on the site.

The idea will probably be incorporated in the Stanford proposal and the possible advantages of using a similar system for the ISR at CERN have been considered. It appears, however, that only small gains would be possible and at considerable increase in the cost and size of the project.

The second new development, from Novosibirsk, concerns the use of 'electron cooling' to increase the density of proton or antiproton beams in storage rings. The size of a beam is determined by the spread in energy of the particles it contains and by the spread in the radial and vertical oscillations of the particles. Any technique which reduces these 'spreads' can result in a more dense beam.

The 'electron cooling' idea is to use a parallel beam of electrons, with uniform velocity equal to that of the ideal average proton, to take the 'heat' out of the proton (or antiproton) beam, where 'heat' is considered as the random motion about the average proton energy. The carefully prepared electron beam would be fed into the proton beam, for example, along the length of a straight section in the storage ring. The 'hot' protons would tend to give up some of their energy to the electrons each time they passed through the electron beam. Over a very large number of turns, the random motion of the protons would be slowly reduced.

The use of electron cooling is a vital part of the 'VEPPONE' project (see Table). It is now being studied at ISR, to see if it could be employed in any future move to proton-antiproton physics.

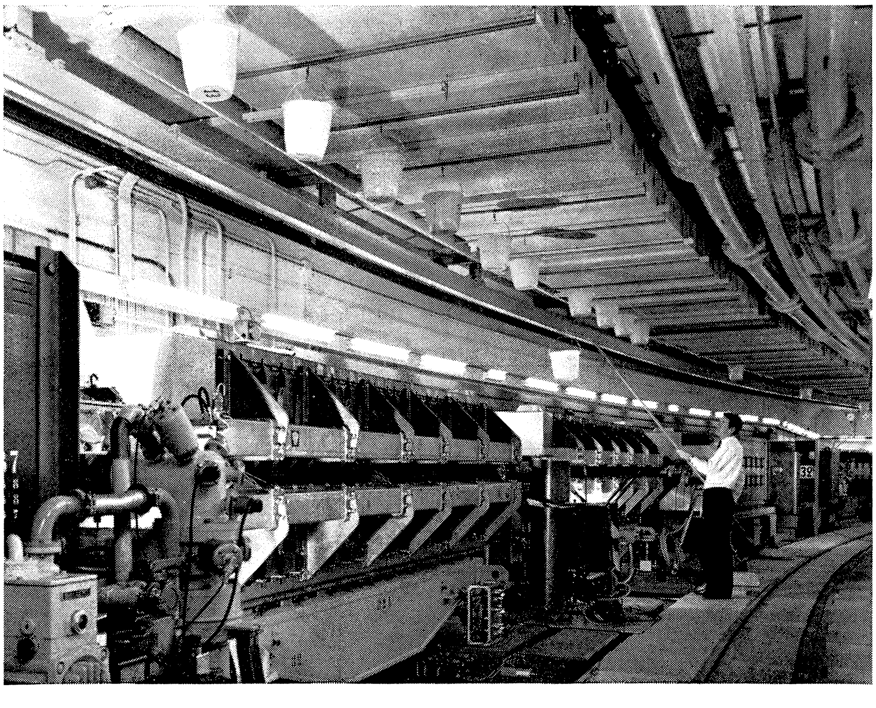
Machine	Laboratory	Colliding beams	Beam energy	Comment
ADA	**Orsay/Frascati**	**electron-positron**	**200 MeV**	**Design study machines**
VEP I	**Novosibirsk**	**electron-electron**	**150 MeV**	
—	**MURA**	**electron-positron**	**200 MeV**	
PRI-STAN	**Princeton/Stanford**	**electron-electron**	**550 MeV**	**First generation**
VEP 2	**Novosibirsk**	**electron-positron**	**700 MeV**	
ACO	**Orsay**	**electron-electron**	**500 MeV**	
—	**Kharkhov**	**electron-electron**	**100 MeV**	
ADONE	**Frascati**	**electron-positron**	**1.5 GeV**	**Under construction**
'VEPPONE'	**Novosibirsk**	**proton-antiproton**	**25 GeV**	
		electron-positron	**5 GeV**	
ISR	**CERN**	**proton-proton**	**28 GeV**	
CEAB	**Cambridge**	**electron-positron**	**3 + GeV**	
—	**Stanford**	**electron-positron**	**3 + GeV**	**Proposals**
—	**DESY**	**electron-positron**	**3 + GeV**	

CERN Colloquia

The CERN Colloquia for 1966/67 began on 20 October and continue through to June 1967. A short exhortation on the subject of the colloquia from Dr. Hagedorn, Chairman of the Organizing Committee, appears on page 220.

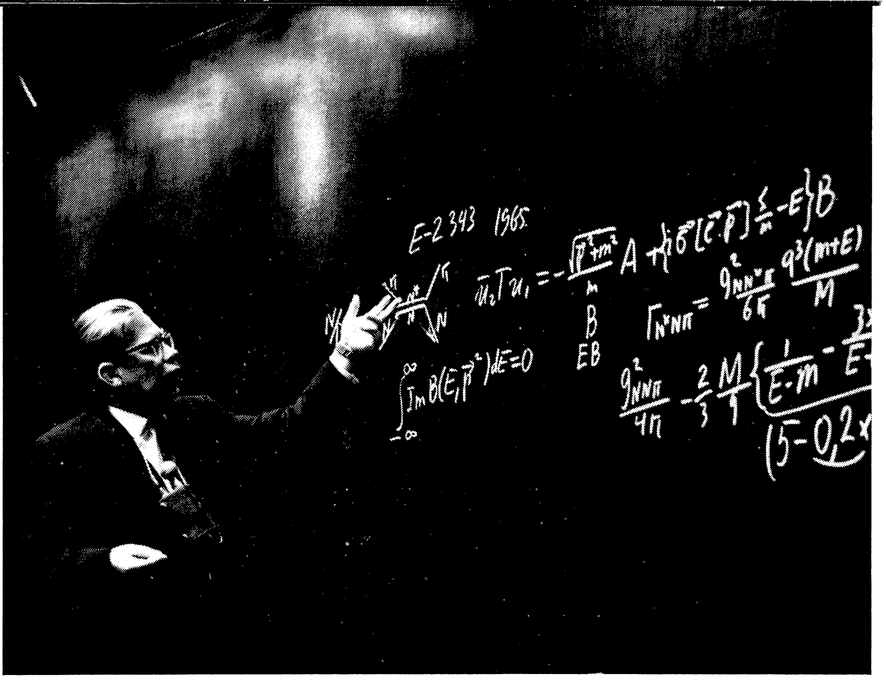
The Committee are trying to ensure as big an attendance as possible at the colloquia — first, to fulfil their basic aim of increasing awareness of work in other branches of science, and also to ensure that the efforts of the speakers in coming to CERN, often from very far away, will be rewarded by the pleasure of speaking to a large audience. To help towards this end, each issue of CERN COURIER will carry some information on the colloquia scheduled for the coming month.

For the month of December, two seminars have been arranged. On 1 December, Professor O. Frisch from the Cavendish Laboratory, Cambridge, U.K. will give a talk with the title 'Take a photon...'. On 15 December, Professor J. D. Jackson from the University of Illinois, USA, will talk on 'Peripheral processes of intermediate energy'. These two colloquia will assume some knowledge of physics.



CERN/PI 212.10.66

This line of buckets hanging over part of the circumference of the proton synchrotron ring is not an indication of inadequate protection against the rain. It is, in fact, those most unorthodox experimenters from the Lawrence Radiation Laboratory, Berkeley, the Rutherford Laboratory, U. K., and CERN, who are carrying out a very detailed study of shielding properties. Not content with digging little holes in the earth mound over the PS tunnel (see CERN COURIER vol. 6 no. 9 (September) p. 176), they have also distributed their detecting samples in this curve of buckets to examine the radiation fluxes inside the tunnel. A second arc of detectors (covering the quadrant centred on the target in straight section 32) is visible above the magnet on the extreme right.



CERN/PI 193.10.66

Professor Bogolyubov, Director of Dubna, lecturing at CERN on 19 October on some problems in the theory of particle physics which are of particular interest to him.

Visitors

Mr. K. Bondevik, the Norwegian Minister of Church and Education, visited CERN on 5 November. He was accompanied by Mr. J. Bargem, Secretary of State, by Mr. Holtan-Hartvig and by the Norwegian ambassador, Mr. S. Chr. Sommerfelt, who is a delegate to the CERN Council. Mr. Bondevik met the Director General, Professor Gregory, and other members of the CERN staff including several Norwegian scientists. About thirty Norwegians are at present working at CERN.

Another welcome visitor was Professor N. N. Bogolyubov, the Director of the Joint Institute for Nuclear Research, Dubna, USSR. He spent several days at CERN for discussions with senior staff and, on 19 October, included a seminar on the work of the Laboratory of Theoretical Physics at Dubna.

On 29 September, a group of 22 physicists attending the General Assembly of IUPAP (International Union for Pure and Applied Physics) at Basle visited CERN. They were accompanied by Prof P. Huber of the University of Basle. IUPAP sponsors the large international conferences in high energy physics, such as that held at Berkeley this year.

In addition to these distinguished visitors, the flow of people coming for a general visit on Saturdays continues. More specialized visits during the week bring people from other Laboratories and Universities to acquaint themselves with CERN and to meet CERN staff. For example, on 7 and 8 October, 24 physicists, engineers, technicians and film-scanners from the High Energy Laboratory of the Belgian 'Institut inter-universitaire des Sciences nucléaires' came to CERN. This group is one of the many teams throughout Europe doing 'physics at a distance', using the photographs produced at the bubble chambers on the CERN 28 GeV accelerator. About 85% of the film from CERN is sent foran analysis to other European Laboratories and it is estimated that some 700 physicists and students are supplied with their research material in this way.

Come to CERN Colloquia

Colloquia have been organized for many years at CERN, following more or less the same pattern as Colloquia which are a long-established feature of University life throughout the world. But there is a great difference between our environment and a University. At University, you have your friends and colleagues from other faculties right next door. Here at CERN, you may find people with interests in many other fields, but expert knowledge is concentrated in the fields of physics, mathematics and engineering and related subjects such as nuclear chemistry and health physics. Science, however, is a whole, and CERN scientists are definitely the poorer for this lack of loose contact with other branches of Science, which is so necessary to set our work in perspective. We must remain aware of the fact that our science is no better than any other and that it forms only part of the general aim of man to know where and what he is.

Much more than in any University, the CERN Colloquia serve to keep alive an awareness of what is happening elsewhere in Science. The Committee organizing the lectures go to considerable trouble to induce outstanding scientists to speak at CERN. They are chosen not only for their distinction in their fields but also because they are known to be good speakers.

It proved difficult to have a selection of suitable speakers concentrating on one overall theme for each academic year (as was initially intended) and as a result the Colloquia cover a variety of topics. The variety is broad enough to provide everyone, including non-scientific staff with something of interest. Therefore, everyone is invited to attend these lectures — all CERN staff and people from outside CERN. The lectures are given in English and their titles are usually designed to indicate whether they are of a rather technical nature, understandable only to those with some basic knowledge of physics or mathematics.

If all this does not suffice to attract you to go to the Colloquia, then please think of another point: if **you** had been invited to a distant Laboratory (perhaps three days of travel there and back) and found yourself lecturing in a huge hall in front of twenty lonely people... not a pleasant thought? But that is what some colloquia speakers have suffered at CERN.

R. Hagedorn

Rencontres de Midi

The 1966/67 series of 'Rencontres de Midi' opened on 31 October with a talk by Mr. P. Gilliand on the subject of 'town and country planning' in the Canton of Geneva.

These lunchtime meetings, organized jointly by the Staff Association and the Welfare Section are designed to enable staff to hear prominent local personalities on subjects of general interests. They continue throughout the winter months with a programme of speakers from the principal political parties in Geneva, each presenting the philosophy and manifesto of their party. The programme is planned as follows :

28 November, 1966 — Socialist Party

30 January, 1967 — Independent Christian-Socialist Party

27 February, 1967 — Radical Party

20 March, 1967 — Liberal Party

20 April, 1967 — Communist Party

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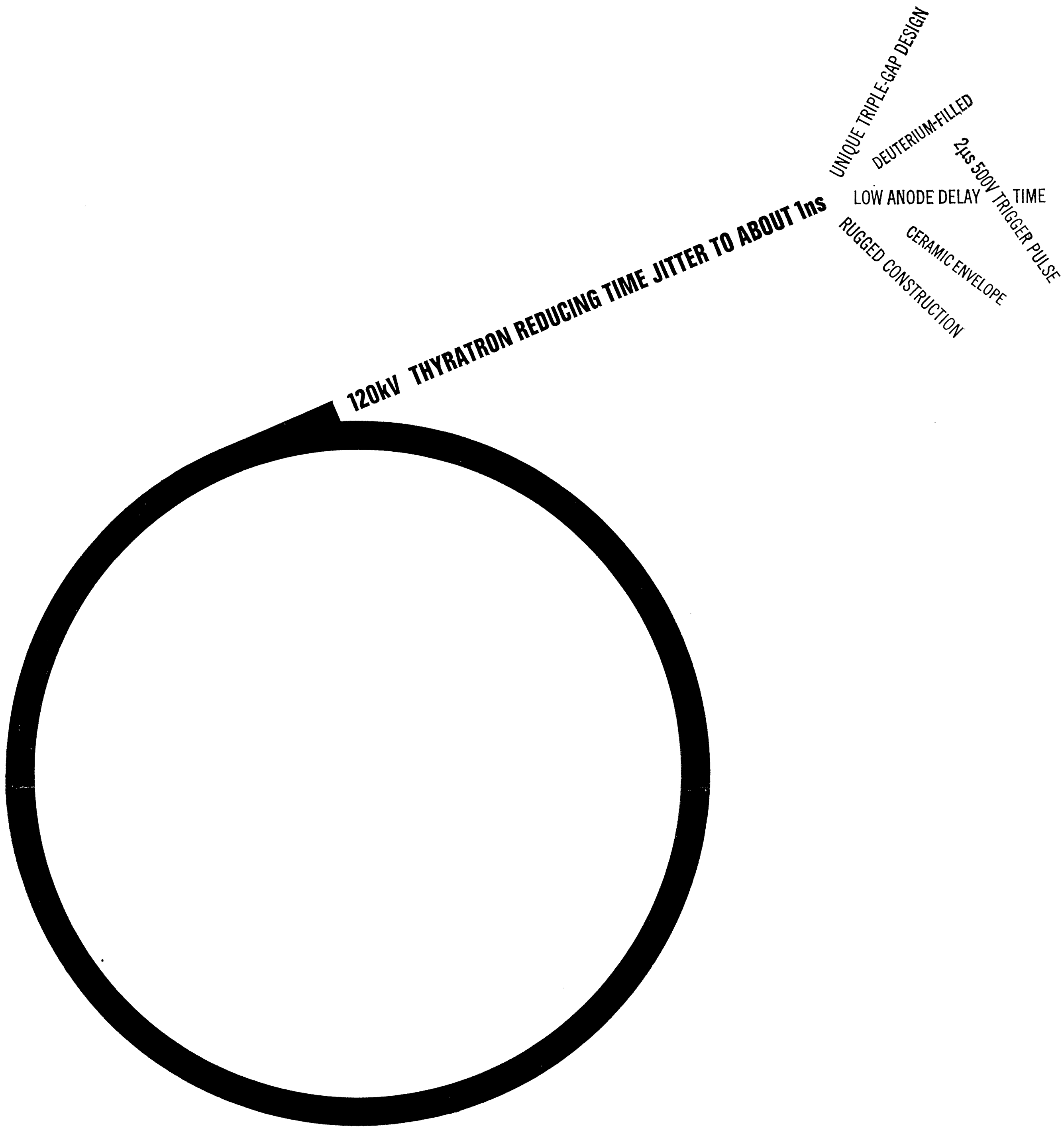
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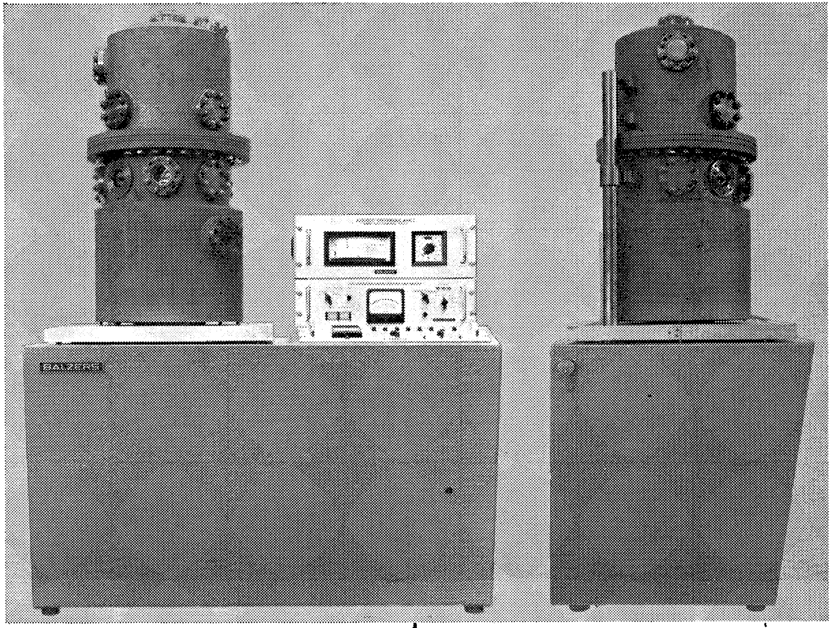

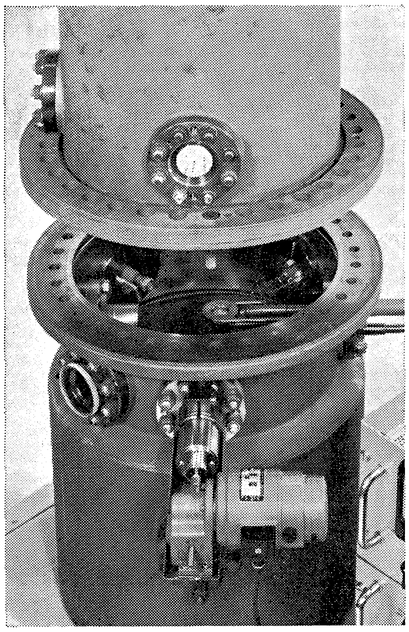

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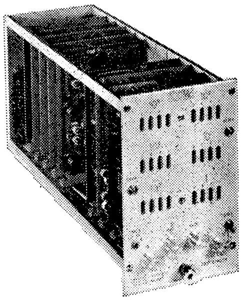

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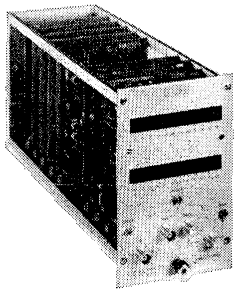

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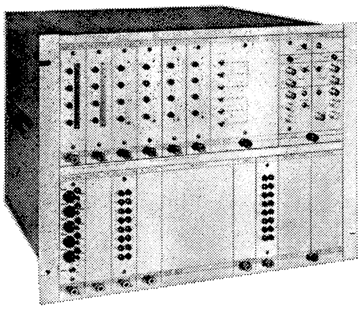

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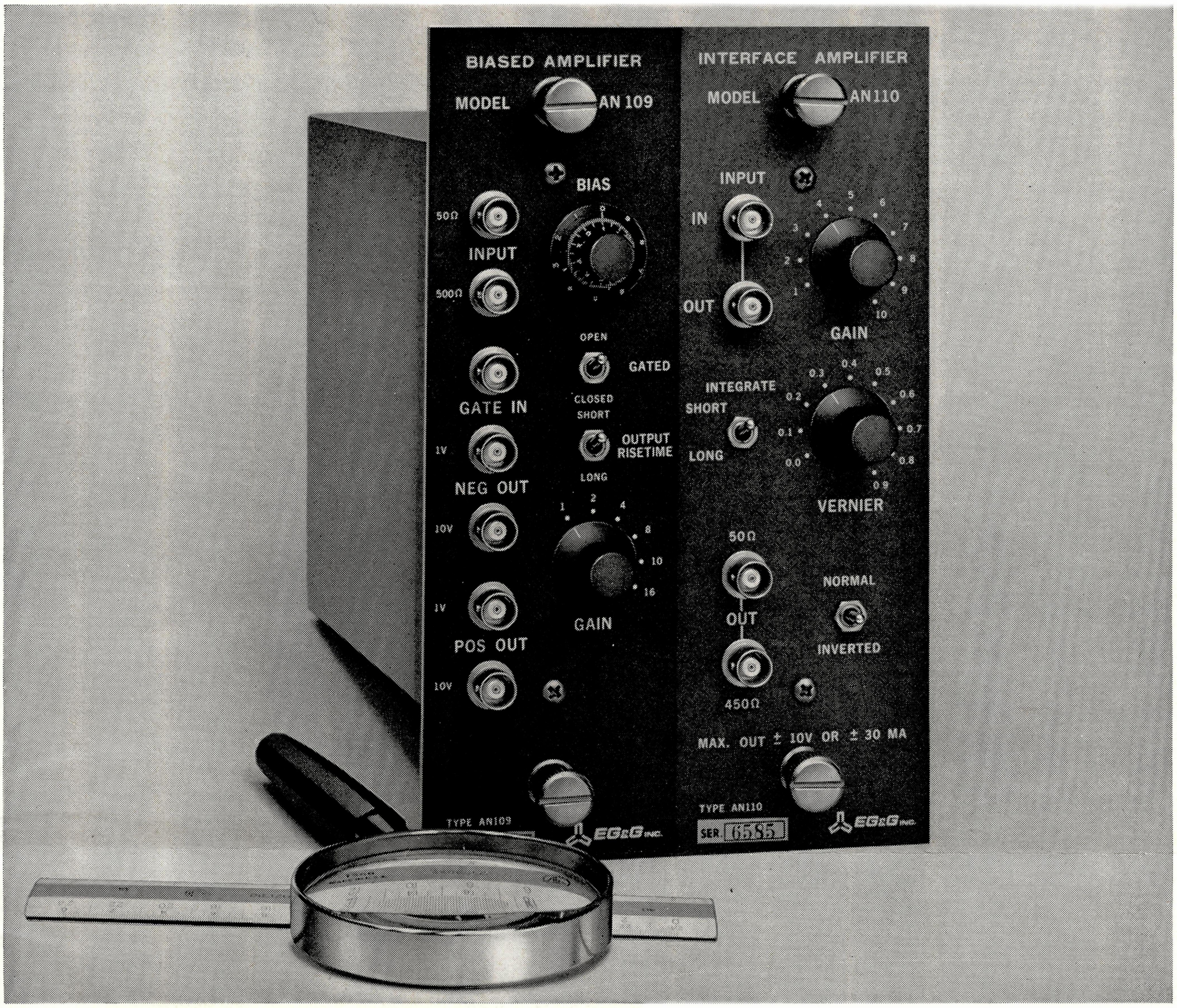

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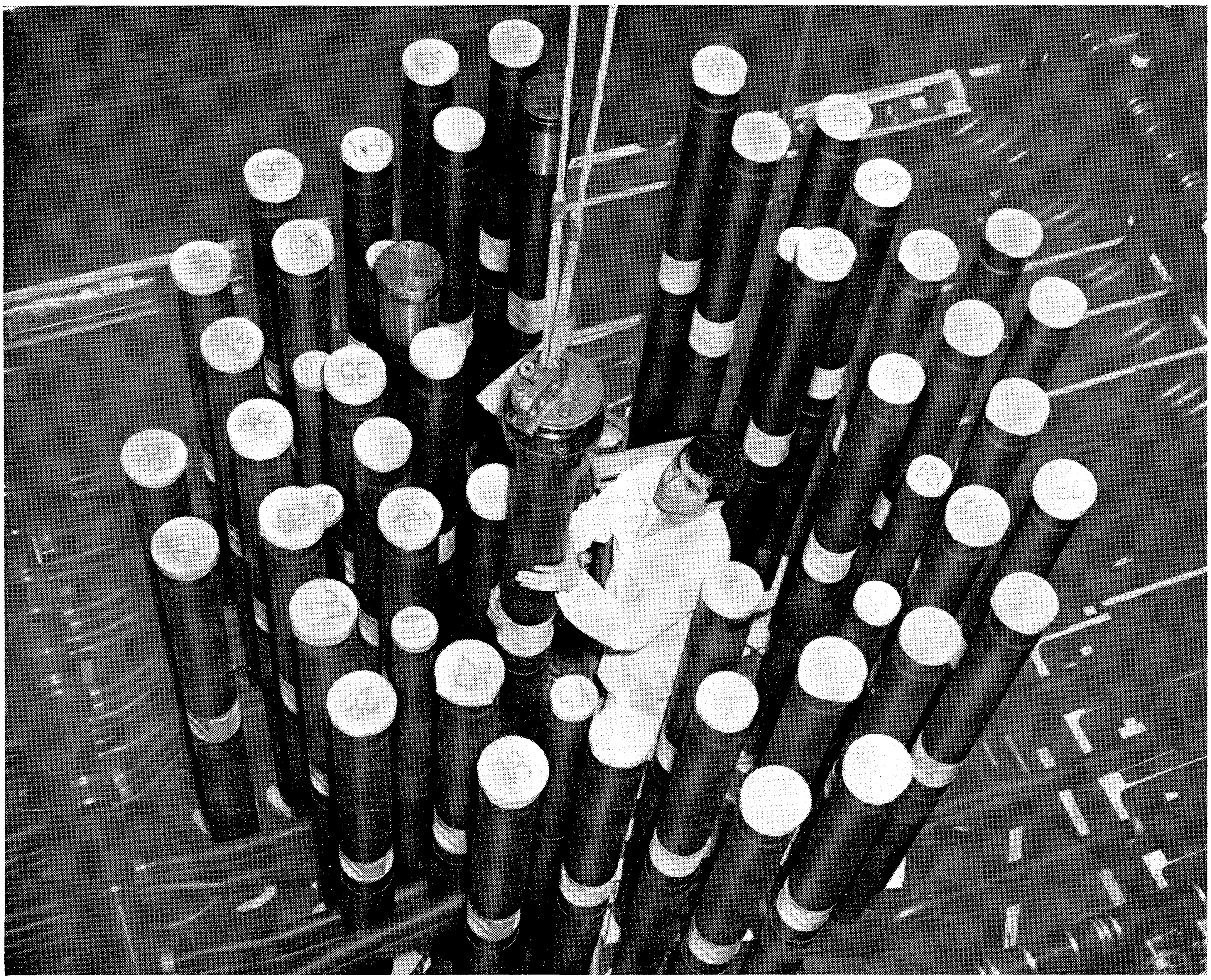

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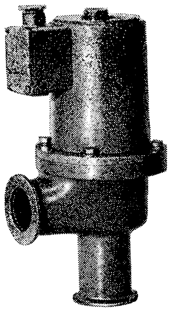

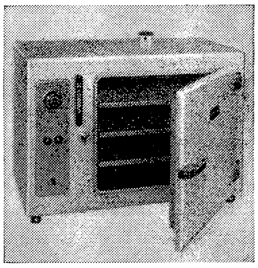

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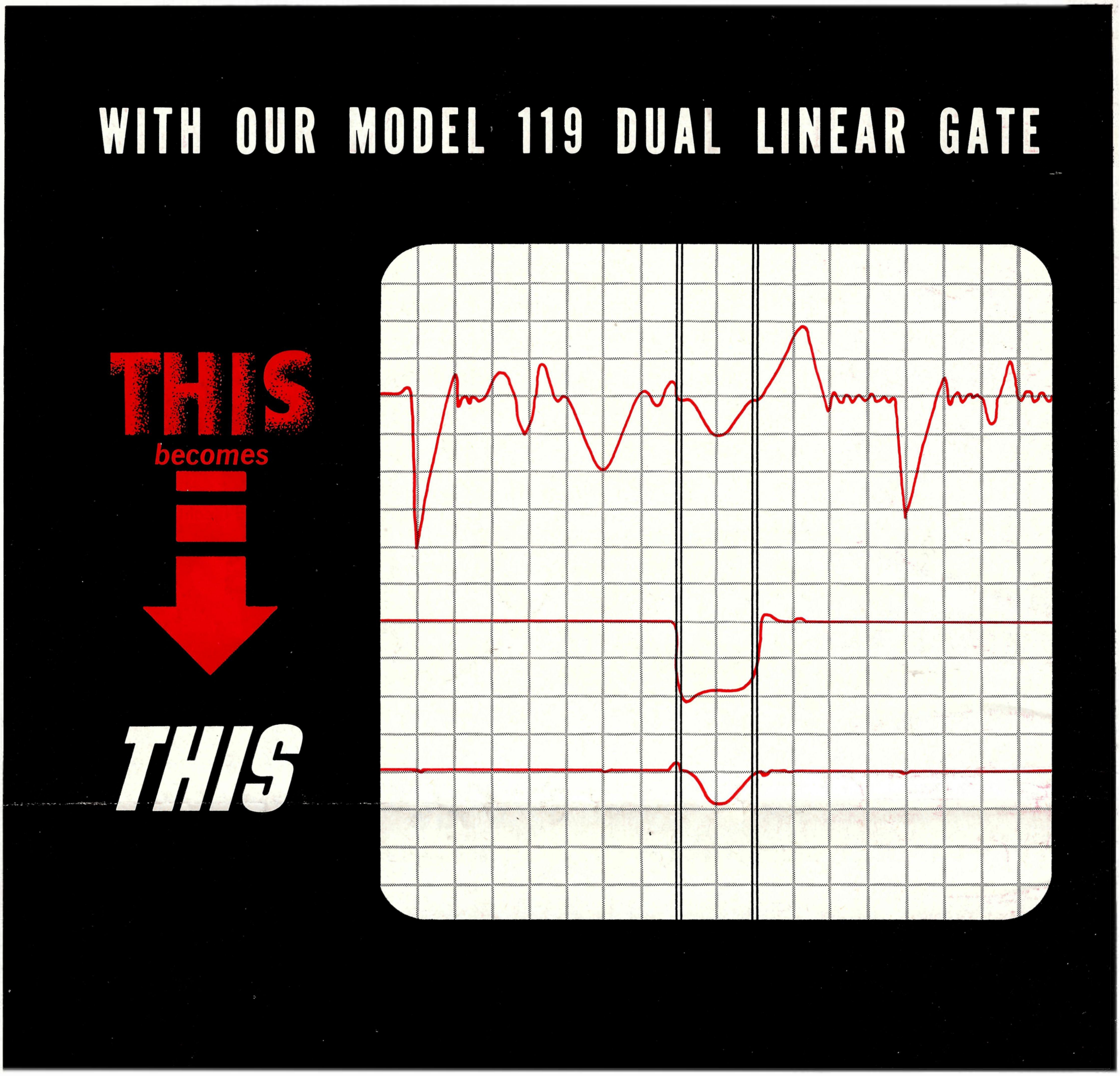

Model 119 is a NANOLOGIC 100 Dual Fast Linear Gate designed for nuclear spectrum analysis. Linearity is ±2%; the pedestal can be adjusted through zero; it is direct-coupled -inputs and outputs. Gate rise and fall time is better than 2 nsec. Maximum gate transient is 15 mV, 2 nsec wide **maximum.** Signal feedthrough is less than 10 mV out for a 1 volt input. Protection is ±100 volts (50 nsec) or 2 watts DC. Reflection is ±10%, gate open **or** closed.

Model 119—two identical fast linear gates with zero interaction between the sections—is priced at $556.50*. A reasonable price for a nearly-ideal electronic switch. Fast . . . stable . . . minimum feedthrough.

Technical literature available upon request. Those whose applications require a fast linear gate and stretcher are invited to request data for Model 116 Fast Linear Gate And Stretcher.

***Prices f.o.b. Mt. Vernon, New York U.S.A.**

CHRONETICS

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Europe: 39 Rue Rothschild, Geneva, Switzerland **(022) 31 81 80 TELEX 22266**