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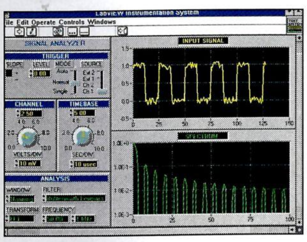
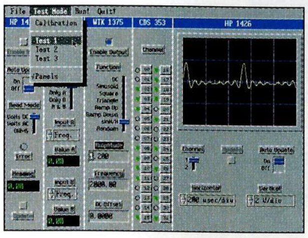

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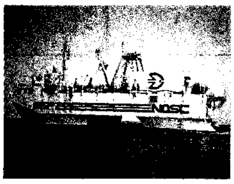

Cover photo: deploying apparatus for the DUMAND underwater neutrino project in the Pacific Ocean off Hawaii (see page 36).

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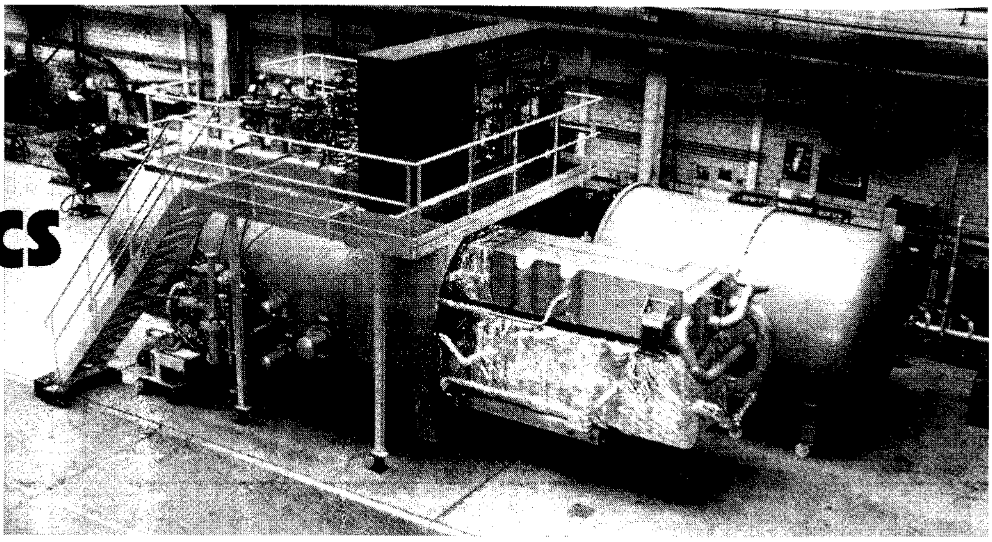
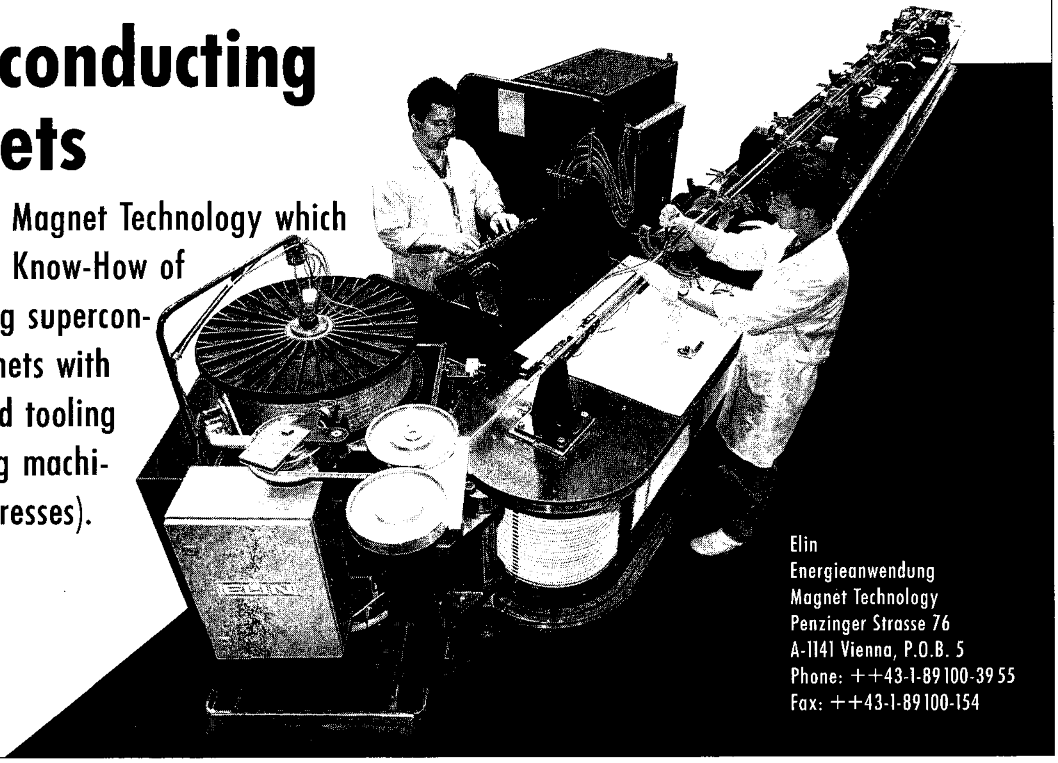




The paradox particle

by Christine Sutton

Neutrino physics

It is at first sight paradoxical that elementary particle physics - the search for and study of the smallest constituents of matter - requires some of the largest installations known to science. With neutrinos, the smallest and most reluctant to interact of all the known particles, the contrast is even more marked. Even measured by the yardstick of Big Science, neutrino detectors are big.

This special issue, with its specially-commissioned introduction from Christine Sutton, sketches the history of this enigmatic particle, from its hesitant introduction by Wolfgang Pauli more than 60 years ago and the prediction that it could never be observed, through its dramatic discovery and eventual transformation into an everyday physics tool, and finally the realization that neutrinos played, and continue to play, a fundamental role in cosmology. Contributions were solicited from major world Laboratories active in this area, where neutrino physics has, and continues to be, a major part of the experimental programme.

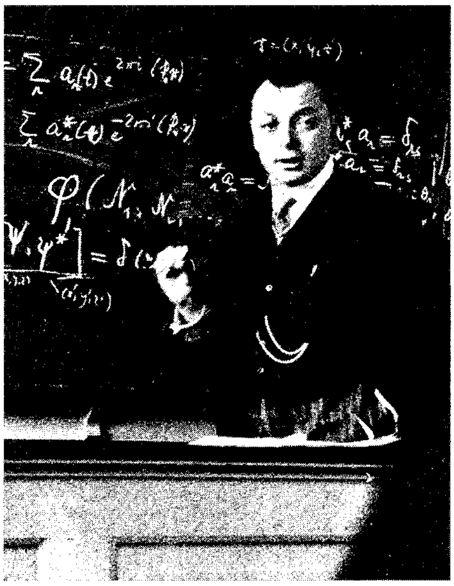
The neutrino has always been controversial. Its prediction was controversial, and some subsequent 'results' have continually ebbed and flowed on the tides of experimental statistics. A good example is the saga of the 17 keV neutrino, first reported in tritium decay experiments in 1985, but not disproved until very recently.

Reluctant to reveal itself, the neutrino is also reluctant to reveal its secrets. Forty years after the neutrino was first seen, many of its properties have yet to be accurately measured.

As well as being a leading physics writer, Christine Sutton of Oxford is also a particle physicist, currently working on the Zeus experiment at DESY's HERA electron-proton collider. Her latest book "Spaceship Neutrino" (Cambridge University Press ISBN 0 521 36404 3 [hardback] or 0 521 36703 4 [paperback]) is a fascinating account of the emergence of the neutrino on the stage of science. In sixty years, the neutrino has been transformed from an apologetic idea its originator dared not publish to one of the main experimental tools of modern high energy research, while cosmologists have realized that this bizarre particle could play a major role in the Universe.

In an ordinary way I might say that I do not believe in neutrinos ... Dare I say that experimental physicists will not have sufficient ingenuity to make neutrinos? Arthur Eddington, 1939

Eddington, fortunately, turned out to be wrong. The neutrino was not only made and eventually detected, but was destined to become a significant tool in studies that extend nowadays beyond the nucleus to include the workings of the Sun and other stars as well as the evolution of the Universe.



Wolfgang Pauli - desperate way out (Photo Goudsmit Collection, AIP Niels Bohr Library)

The physics of neutrinos began with studies of radioactivity and the peculiar energy spectrum of beta-decay. Initially it seemed that the process should be a two-body decay, the original nucleus producing a new nucleus and emitting an electron. Conservation of energy and momentum dictate that in such a two-body decay the products should emerge back-to-back each with a unique energy.

However, by 1927, Charles Ellis and William Wooster in Cambridge had demonstrated unequivocally that the energy spectrum of these electrons is instead continuous. Physicists were puzzled, and no less a person than Niels Bohr proposed forgoing the sacred law of energy conservation: "... we may say that we have no argument, either empirical or theoretical, for upholding the energy principle in the case of beta-ray disintegration".

But Wolfgang Pauli was far from convinced by Bohr's line of argument, and late in 1930 he produced his own "desperate way out" to save the energy law. He proposed that the electron is accompanied by a lightweight, neutral, penetrating particle, the particle now known as the (electron) neutrino. His first words on this subject were in the famous letter to Lise Meitner, Hans Geiger and other experts gathered at a meeting in Tübingen, which began "Dear radioactive ladies and gentlemen" (and which also explained that he could not attend the meeting as a ball

Left to right Enrico Fermi, Werner Heisenberg and Wolfgang Pauli, pictured at Lake Como in 1927. Over the following years their ideas were crucial to the emergence of a neutrino theory.
(Photo F.D. Rasetti, Segrè Collection, AIP Niels Bohr Library)

made his presence in Zürich "indispensable"!).

Pauli commented in the letter that for the time being he dare not publish anything about the idea, and other than archival conference proceedings he never did write a paper proposing the existence of the new particle. He was persuaded to talk about it, however, and in 1934 the hypothesis gained respectability when Enrico Fermi included the neutrino as an essential ingredient in his theory of beta-decay.

Still, the prospect for detecting neutrinos appeared bleak. Soon after Fermi's theory was published, Hans Bethe and Rudolf Peierls calculated that the cross-section for the absorption of a neutrino by a nucleus, in inverse beta-decay, was so small that the neutrino was very likely undetectable.

It turned out that Nature was not so unkind. The discovery of the nuclear chain reaction in 1939 led to the development of nuclear reactors, which emit a vastly greater flux of neutrinos than any radioactive source previously imaginable. Later, in the 1960s, neutrinos with energies thousands of times higher, and correspondingly higher interaction cross-sections, were produced at accelerator laboratories and the neutrino became an investigative tool rather than a curiosity of physics .

The experiment of Clyde Cowan, Fred Reines and colleagues, which finally detected the neutrino, stemmed from a far-fetched idea to observe neutrinos emitted in a nuclear bomb explosion. The original plan was to suspend a detector below ground in a vertical shaft some 40 m from the site of the explosion. When the bomb exploded, the detector would be released to fall freely down the shaft, landing on a bed of feathers and foam rubber.

The detector itself was to consist of a tank of liquid scintillator, and the aim was to observe the process of inverse beta-decay (where a neutrino hits a proton, producing a neutron and emitting a positron) through the detection of the gamma-rays produced by the subsequent annihilation of the positron.

Although this bizarre plan received a green light from Fermi and Hans Bethe, it was never put into practice. In considering how they might improve the signature for inverse beta-decay, Reines and Cowan realized that they could also detect the neutron, through the gamma-rays emitted by its eventual capture.

The "lifetime" of the neutron would be typically a few microseconds, so inverse beta-decay would reveal itself through the "delayed coincidence" between those gamma-rays emitted by the annihilating positron and those emitted later after the capture of the neutron. This signature, Cowan and Reines argued, would enable them to eliminate much of the background and detect neutrinos produced in a more leisurely fashion from the controlled reactions of a nuclear reactor.

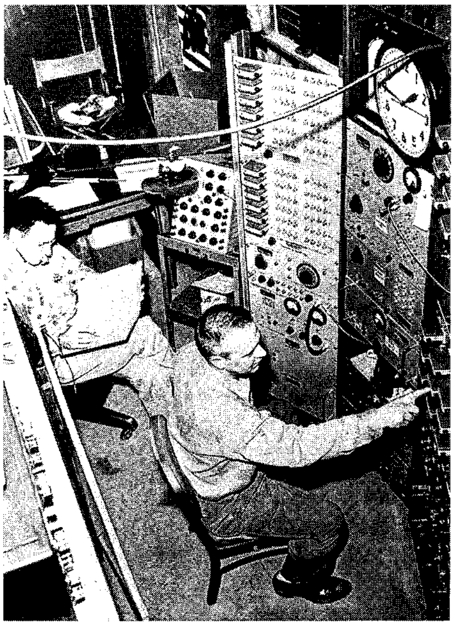
So in 1953 they set up "Project Poltergeist" at the reactor at the Hanford Engineering works in Washington state.

With a 300-litre drum of liquid scintillator surrounded by 90 phototubes, they found evidence for a slight increase in the delayed coincidence counting rate when the reactor was on.

Encouraged by their results, and by John Wheeler, they moved on with an improved detector to the more powerful Savannah River reactor in South Carolina. Now they had 10 tonnes of apparatus, including three tanks each of 1400 litres of scintillator viewed by 110 phototubes. The three tanks were sandwiched around two smaller tanks of cadmium-doped water, which provided the "target" protons to intercept the neutrinos, and cadmium to capture the neutrons.

Clyde Cowan (left) and Fred Reines (right) with their 'Project Poltergeist' team which at a Hanford reactor in 1953 saw the first suggestions of neutrino interactions. (Photo Los Alamos National Lab)

Clyde Cowan and Fred Reines at their neutrino experiment. (Photo Los Alamos National Lab)



With the reactor on, they detected on average three delayed coincidences per hour, over about 100 days of running. Then, having made many cross-checks, on 14 June 1956 Reines and Cowan sent a telegram to Pauli - "We are happy to inform you that we have definitely detected neutrinos ...".

Nuclear beta-decay (which gives rise to the reactor neutrinos) is of course not the only source of neutrinos. The related weak decays of pions and kaons produce neutrinos in the company of muons, and the muon itself decays to not one but two neutrinos (a neutrino together with an antineutrino).

During the 1950s the question arose as to whether the neutrinos produced with muons in pion decay, for example, were the same as those produced with electrons in beta-decay. Cowan and Reines considered an experiment to test the identity of the neutrinos, but they were told by their superiors at Los Alamos that they had "had enough fun" and should "go back to work".

However, there were others to take up the challenge. In July 1959, Bruno Pontecorvo at Dubna submitted a paper to JETP, entitled "Electron and muon neutrinos", in which he proposed detecting neutrinos from the decays of pions produced at an accelerator. His idea was to test whether the neutrinos, born with muons, could produce positrons, as in the reaction that Cowan and Reines had observed, rather than positive muons. The signal for positron production would be a delayed coincidence, to be detected in cadmium-doped scintillator.

With no access to a suitable accelerator, Pontecorvo could proceed no further. However, late in 1959, Melvin Schwartz at Columbia University, inspired by theorist T.D.Lee, began dreaming up a way to use neutrinos to study weak interactions at high energies.

The neutrino's only interaction (other than through gravity) is through the weak force, and so it makes an ideal - if intransigent - tool to probe weak interactions.

Schwartz realized that he could use a beam of pions to make a neutrino beam: a thick absorbing wall placed a sufficient distance downstream would absorb the muons produced by the upstream pion decays, as well as any remaining pions, leaving only neutrinos beyond the wall.

Leon Lederman and Jack Steinberger, both at Columbia at the time, supported Schwartz's scheme, and they pushed hard to set up a neutrino beam and detector at the Alternating Gradient Synchrotron being built at the Brookhaven Laboratory.

The result was the famous "two-neutrino" experiment, for which Lederman, Steinberger and Schwartz were to earn the Nobel Prize in 1988. The detector consisted of a 10-tonne spark chamber - which Lederman has described as the biggest they could think of! - with attendant trigger and veto scintillation counters, surrounded by concrete and steel shielding - armour plate from an old warship.

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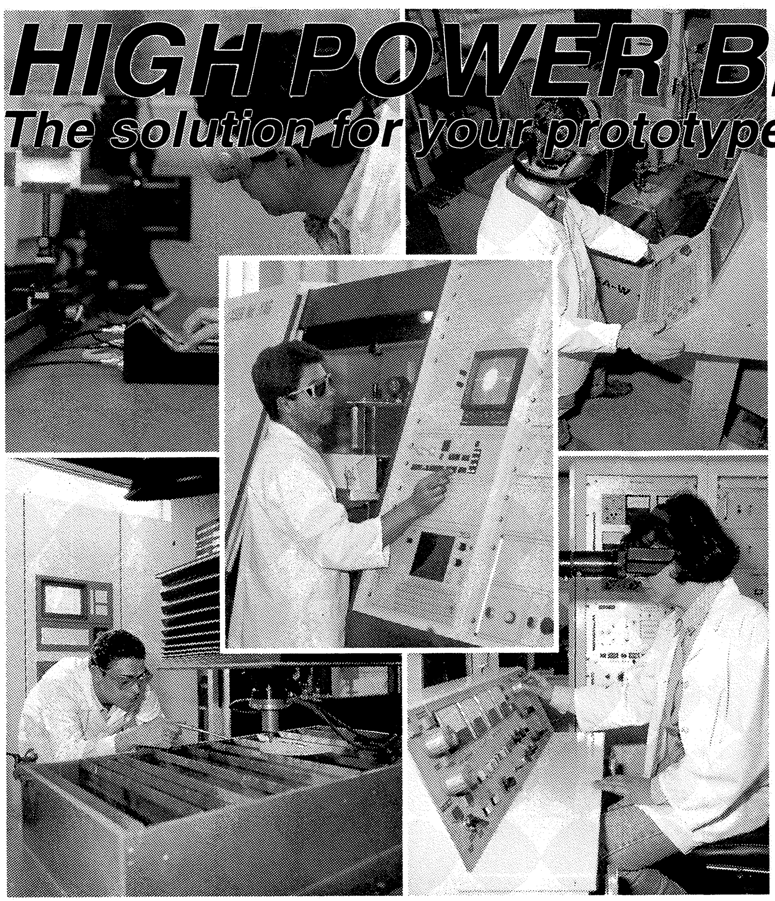

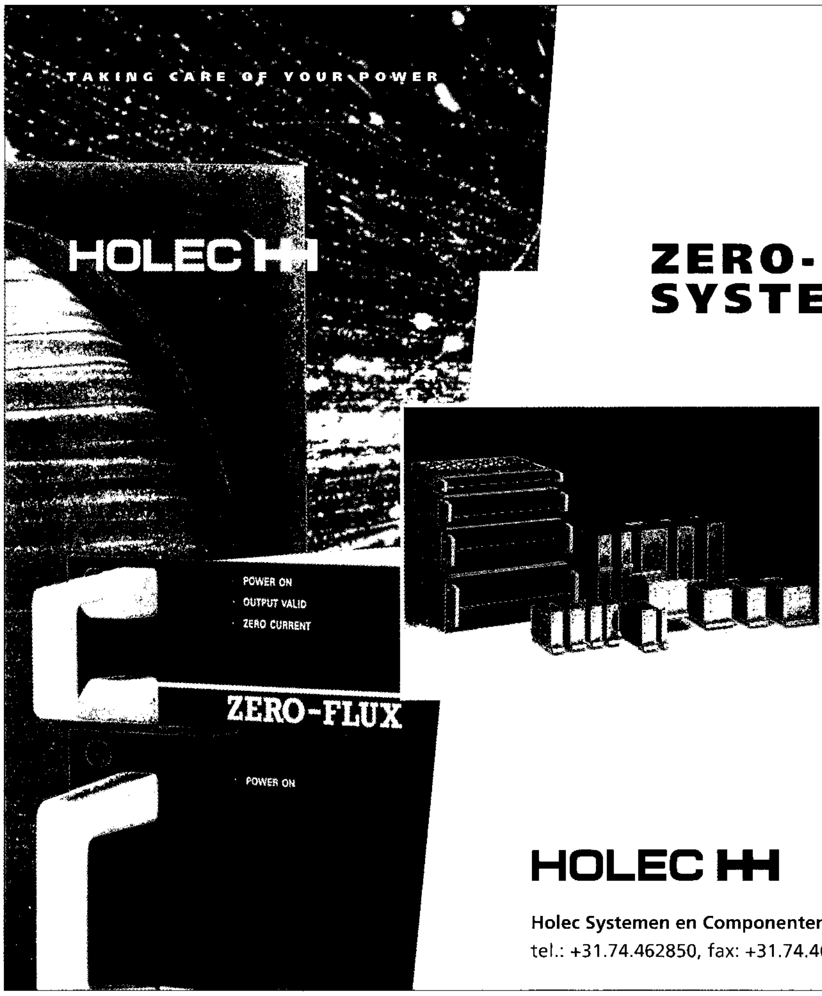
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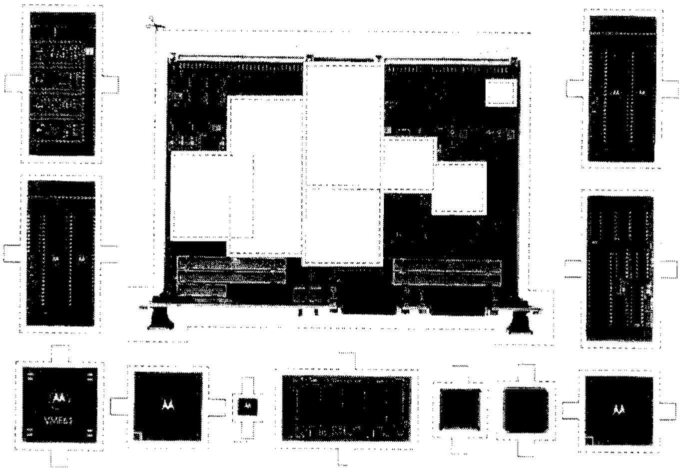
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Neutrinos should have been formed in the Big Bang as readily as other particles, contributing their share to the energy density of the early Universe. The size of this contribution would depend on the number of neutrino types present. It would also have a vital influence on the evolving Universe as the higher the energy density, the faster the rate of expansion; and the faster the rate of expansion, the more neutrons there would be at the start of nucleosynthesis, eventually to become locked in helium-4. (A slower rate of expansion would give the neutrons more time to decay to protons before the Universe became cool enough for nucleosynthesis to begin.) Thus the number of neutrino types present in the early Universe should have left its indelible imprint on the amount of primordial helium-4 observed in the Universe today.

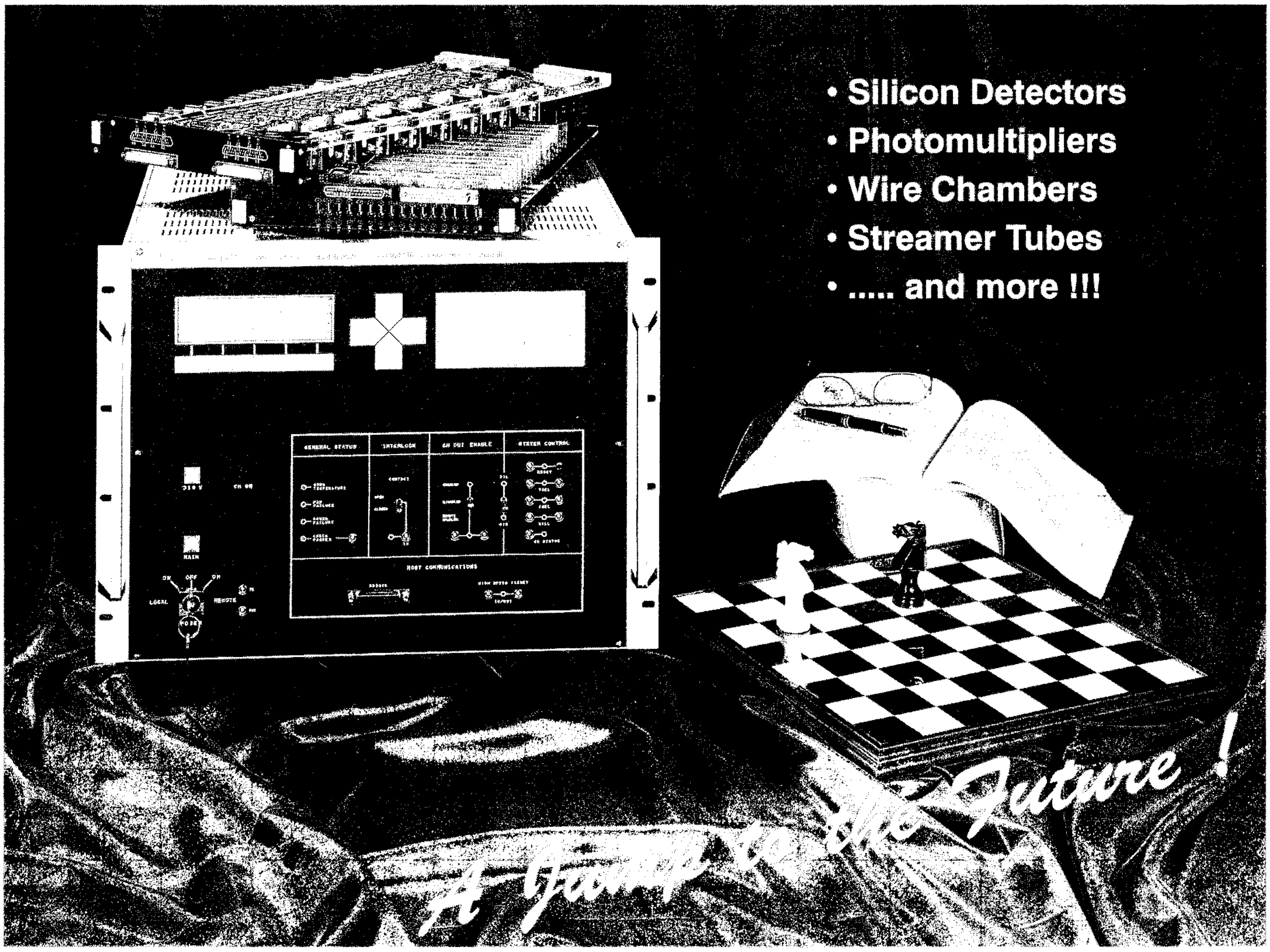
The discovery of the tau lepton in 1976 brought the expected number of neutrino types to three, and inspired Gary Steigman, David Schramm and James Gunn to calculate that there should be at most seven neutrino types, working from the estimated amount of primordial helium-4. Seven years later, in 1984, this calculated upper limit had fallen to four, and in 1989 the measurements of the decay of the Z at two new high energy electron-positron colliders - LEP at CERN and Stanford's SLC - demonstrated that there must be three, and only three, types of neutrino.

When the early Universe had cooled to about 10 billion degrees, the weak interactions between neutrinos slowed below the rate of expansion. At this stage, about one second into the life of the Universe, the neutrinos "decoupled", no longer appearing and disappearing in reactions with other particles.

The neutrinos that existed then should be with us still, dispersed through space as a relic of the Big Bang, the neutrino equivalent of the cosmic microwave background radiation, with a few hundred ancient neutrinos per cubic centimetre of space.

Could these relic neutrinos, if some of them have a small mass, hold the key to the future evolution of the Universe? Could neutrinos with a small mass form part of the non-luminous dark matter that is necessary at the very least to explain the dynamics of galaxies and the clusters they form? These are questions being argued over by a growing band of cosmologists, astrophysicists and particle physicists, all intent on discovering the nature of our Universe - and the important role within it of the ubiquitous, albeit almost undetectable, neutrino.

Richard Taylor (left) and Don Perkins (right) played central roles in pioneer high energy scattering experiments in the 1960s using, respectively, electrons and neutrinos. In the picture, taken in July at a special seminar at Oxford to mark Perkins' formal retirement, George Kalmus appears to be the referee.



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Neutrinos at CERN

As Head of Nuclear Physics Apparatus Division in the early 1960s, Colin Ramm played a major role in launching CERN's programme of neutrino experiments.

CERN's long and distinguished neutrino tradition began in 1958 at the then new 500 MeV synchrocyclotron (SC) with the first observation of the decay of a charged pion into an electron and a neutrino.

At that time, the first ideas on the special (vector/axial vector) structure of the weak interactions had been put forward by Feynman and Gell-Mann and by Marshak and Sudarshan, but the continual non-observation of that charged pion decay was holding up progress.

This decay is only one part in ten thousand, and is masked by the dominant muon-neutrino channel. A special telescope was built to pick up the high energy electrons from the pion decay. In 1962 came another SC neutrino success, with the first measurement of the decay of a charged pion into a neutral one, with emission of an electron and a neutrino.

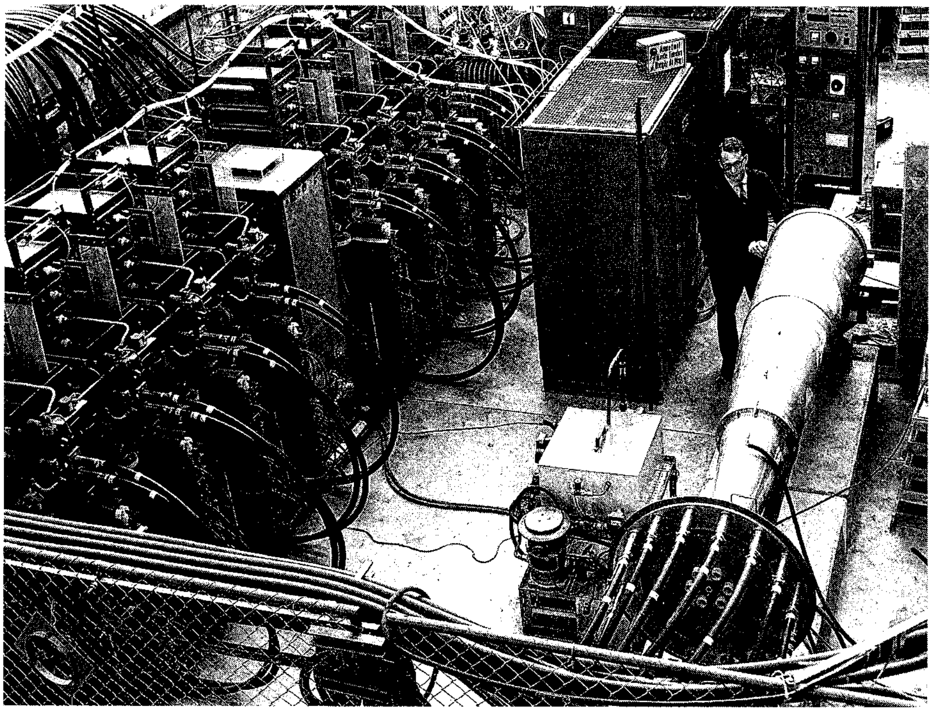
Meanwhile the main thrust of CERN's neutrino effort was taking shape at the PS. By the close of 1960, CERN had decided to attack neutrino physics using several detectors - a 1m heavy liquid bubble chamber from André Lagarrigue's team in Paris, a CERN 1 m heavy liquid bubble chamber, and a hybrid chamber/counter from a group led by Helmut Faissner.

In 1961 work on this experimental programme was abruptly terminated when it was realized that the available neutrino beam would not provide enough particles for the detectors being planned. Brookhaven stole the thunder and discovered muon neutrinos (see page 13).

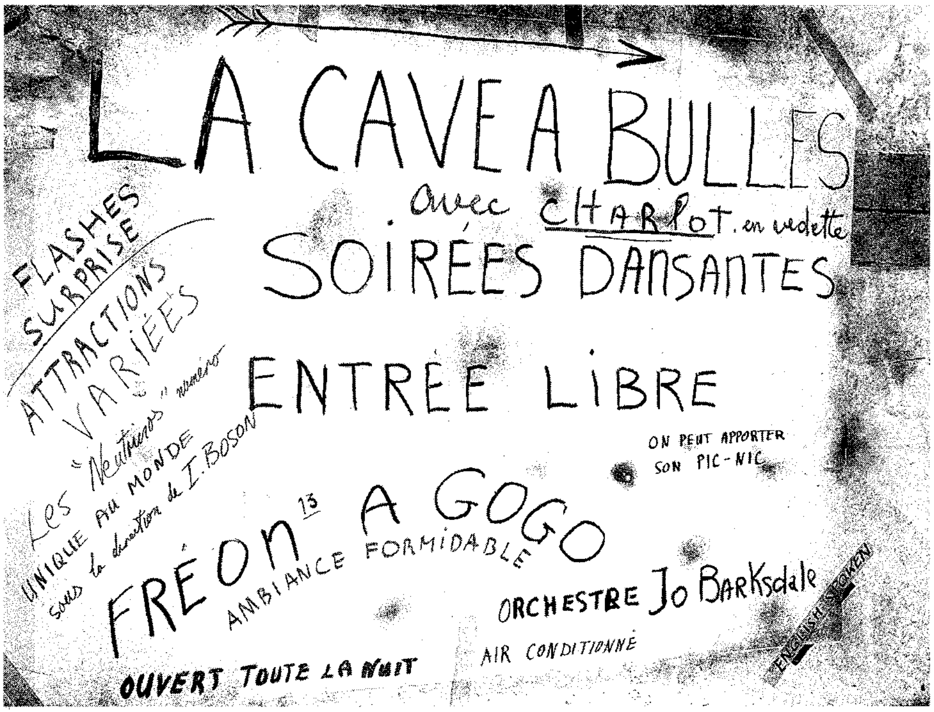
CERN abandoned its initial idea of several smaller detectors and plumped instead for a big spark chamber, mounted in series with Colin Ramm's 1-metre heavy liquid bubble chamber. (Neutrino interactions are so few and far between that a neutrino beam can be fired through a series of targets, lined up one after the other.)

To boost the PS neutrino supply, new focusing techniques - the famous 'magnetic horn' - were developed by Simon van der Meer, with beams of charged pions and kaons being concentrated in the decay region to boost the neutrino supply. Crucial to this idea was the fast ejection system developed in 1959 to rip particles from the PS beams.

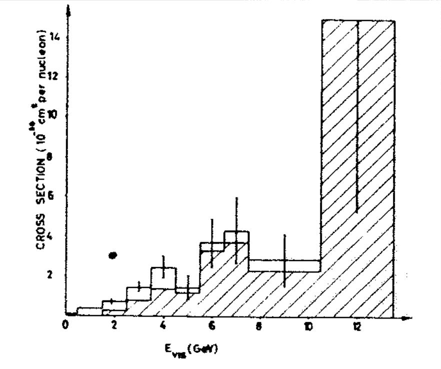
Although CERN had a machine to rival Brookhaven, it was clear that in 1961 CERN detector expertise was lacking. Neutrinos needed massive detectors on a scale never seen before, and such a major programme had not been foreseen. In 1961 CERN's Director General John Adams said 'there is no group with sufficient staff for such a project and



Simon van der Meer's famous magnetic horn increased the intensity of the parent beams and made for more neutrinos.
(Photo CERN 317.1.63)



Graffitti were still rudimentary when CERN's neutrino programme got underway.



More writing on the wall. 1964 - evidence for the increasing reaction rate (cross-section) of neutrinos.

there is no budget for such a major piece of equipment.'

The lesson learned, the necessary investment was made and CERN's neutrino programme pushed ahead with new vigour, beginning in earnest in 1963.

To increase the particle supply after its modest start, CERN authorized a 1 GeV 'Booster' synchrotron, while a major project in France for a huge heavy liquid bubble chamber was expedited, capitalizing on André Lagarrigue's initial experience with a 1-m design. The outcome, the Gargamelle chamber, 4.8 metres long, containing 18 tonnes of freon, and with infrastructure weighing 1000 tonnes, was initially installed at the 28 GeV PS proton synchrotron, coming into operation at the end of 1970.

Before 1973, weak interactions had only been seen to operate through a 'charged current', where electric charges get swapped around.

In contrast, in neutral current interactions, the neutrino sets other particles in motion without changing charges. Such neutral currents had been predicted by the 1967 electroweak unification of electromagnetism and the weak force by Sheldon Glashow, Abdus Salam and Steven Weinberg, but had never been seen. In 1971 Weinberg had taken another look at the neutral current prediction and saw that the effects would anyway be very small. The experiments had not looked hard enough.

In 1973 came the big pay-off for Gargamelle and CERN - the discovery of neutral currents, the first new type of physics interaction to be seen for forty years.

In the face of intense competition from across the Atlantic and with post-war European physicists unused to running at the front, European confidence in the Gargamelle result had occasionally wavered. But thanks to the perseverance of its strong personalities, the bubble chamber team remained totally committed and clinched the vital discovery.

Ten years before, at the modest start of the CERN neutrino programme, bubble chamber work had seen that neutrino interaction rates increased with energy. Some far-sighted people had been intrigued, but at the time there were no explanations on the market.

At the end of the 1960s, experiments at Stanford with high energy electron beams showed that small scattering centres - 'partons' - carrying half a unit of spin were hidden deep inside the proton. What was the electric charge of these partons?

In 1972, just before the neutral current discovery, experimental results from several directions and new theoretical analysis converged. The striking similarity of nucleon structure seen at Stanford using electrons and at CERN using neutrinos and antineutrinos confirmed that the dynamic scattering centres, the partons, could be identified with the static quark building blocks, carrying fractional electric charge, which explained particle spectroscopy.

In particular, the neutrino interaction rate seen in Gargamelle was approximately three times that of antineutrinos. In 1969 theorists David Gross and Christopher Llewellyn Smith showed how this factor of three is explained by neutrino scattering off the three valence quarks of the nucleon, each carrying half a unit of spin.

Gargamelle also showed that there was room inside nucleons for something else other than quarks. It was an early hint that nucleons could also contain gluons, the carriers of the inter-quark force

Higher energies - the SPS era

With neutrino interactions now on a much firmer footing, the next quest was to understand the structure of the new weak interaction.

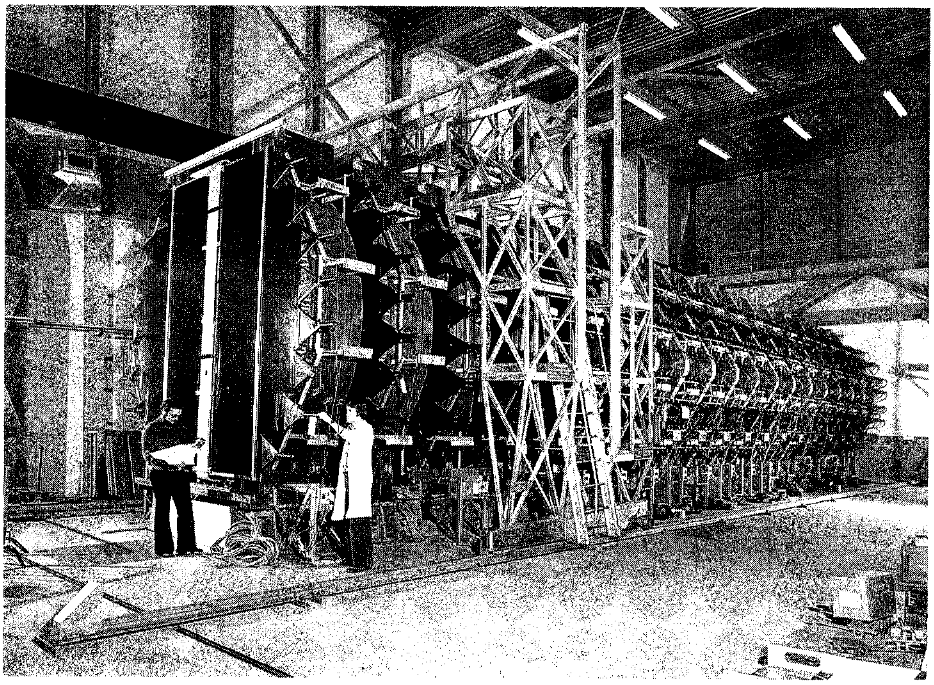
Fermilab in the US had started to explore a new field of higher energy neutrino physics in 1972 (see page 22).

In 1977, CERN's new SPS 450 GeV proton synchrotron came into action, armed with an impressive array of four major neutrino detectors lined up one after another in the beam.

The Gargamelle bubble chamber, hoping to add new jewels to its neutral current crown, had been resited for the new beams, but unfortunately was forced to retire the following year when its tired chamber cracked from metal fatigue.

The 3.7-metre diameter 'Big European Bubble Chamber' (BEBC), commissioned in 1973 with hydrogen filling for hadron work, added to its repertoire a heavier neon-hydrogen filling for SPS neutrino studies. It was also fitted with an outer wire chamber 'fence' for muon detection.

Sandwiched between the two big bubble chambers in the SPS West Area were two major new all-electronic detectors. Jack Steinberger's WA1 CERN/Dortmund/Heidelberg/Saclay group used a 20-metre long, 1500-ton array of neutrino-catching iron-cored toroidal magnets interspersed with drift chambers and scintillation counters. Immediately downstream of WA1 was Klaus Winter's 'CHARM' (CERN/Hamburg/Amsterdam/Rome/Moscow) collaboration, with a substantial and fine-grained target calorimeter preceding a magnetized iron calorimeter. Together, WA1 and CHARM occupied nearly 40 metres of experimental hall. Although they were separate experiments, they occasionally combined forces for joint studies.



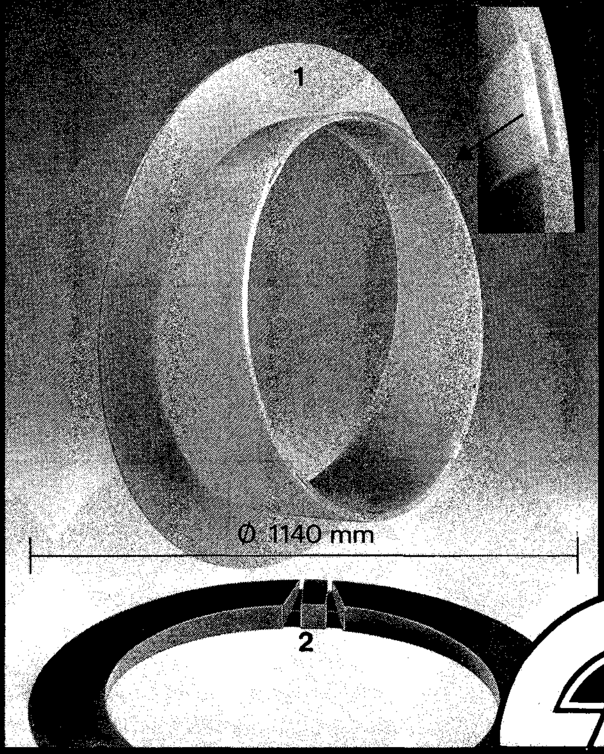
In the mid-70s, CERN's new SPS proton synchrotron featured two major all-electronic neutrino experiments. WA1 (a CERN/Dortmund/Heidelberg/Saclay collaboration) used a 20-metre long, 1500-ton array of neutrino-catching iron-cored toroidal magnets interspersed with drift chambers and scintillation counters...
(Photo CERN 1.10.76)

For eight years, these big detectors made precision studies on the structure of the charged and neutral currents of the weak interaction. In contrast with early neutrino studies which were happy to collect handfuls of events, these big detectors recorded millions. While the charged current is left-handed, the weak current has both right- and left-handed behaviour, and pinning down this 'handedness' was vital to understanding the underlying theory.

A thorough study of multimuon final states gave valuable information on the production of the fourth ('charm') quark, showing how this new quark played a vital role. In addition neutrino interactions deep inside target protons and neutrons probed the underlying quark field theory - 'quantum chromodynamics'.

Having several detectors in series enabled physicists to compare upstream and downstream neutrino signals and gave authoritative new limits on neutrino oscillations.

By 1985, CHARM had given way to CHARM II, a 700-ton array of glass plates interspersed with scintillator and streamer tubes and a downstream muon spectrometer. CHARM II collected several thousand examples of the rare but very clean scattering of neutrinos off electrons, providing precision information on the neutral current mediating these interactions, and showing that the axial-vector part of the electron coupling (the difference between its right- and left-handed behaviour) is -0.5, in agreement with the underlying symmetry picture, where the electron and its neutrino are paired with the 'up' and 'down' quarks.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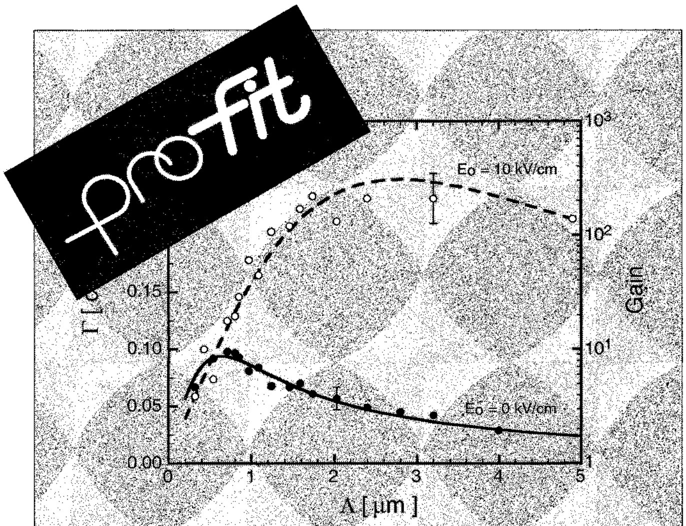
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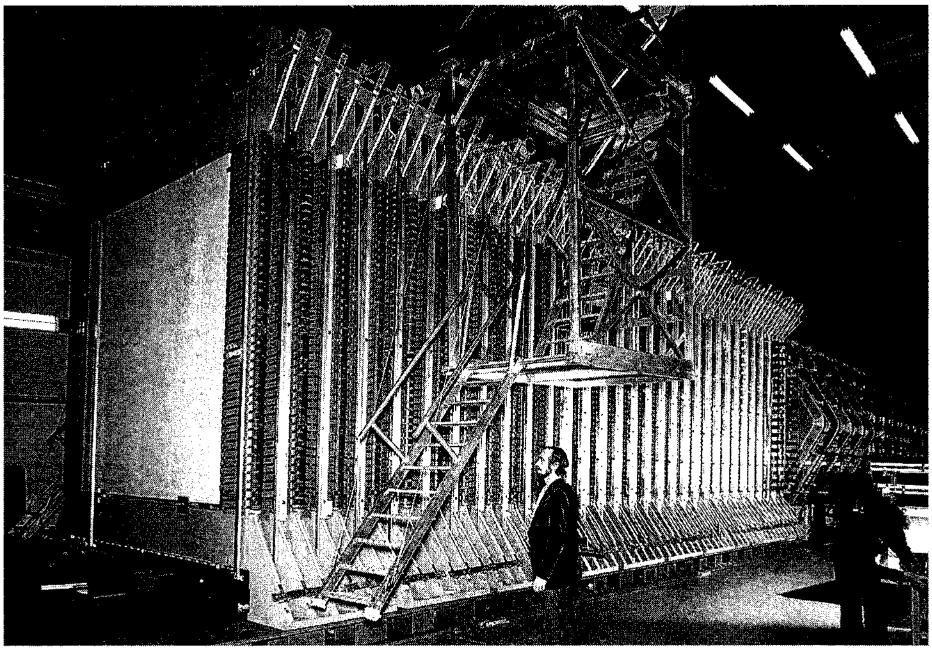
Downstream of WA1 (just visible on the right) was the big 'CHARM' (CERN/Hamburg/Amsterdam/Rome/Moscow) detector, with a substantial and fine-grained target calorimeter preceding a magnetized iron calorimeter. Together, WA1 and CHARM occupied nearly 40 metres of experimental hall.
(Photo CERN 213.12.77)



The high energy information from these collider experiments was also a perfect complement to the lower energy studies using neutrino beams, giving a wide reach on the consistency of the electroweak unification which is still quoted today.

While the big UA1 and UA2 experiments at the proton-antiproton collider did not explicitly catch neutrinos, they pioneered the 'missing energy' technique for showing where neutrinos had been. Even conventional particles can sometimes 'disappear' down cracks between detector components. UA1 and UA2 made sure that all such cracks in the detector screen were firmly covered. Outgoing energies on two opposite sides of the detector were added up, and any mismatch showed where energy had been carried off by particles, such as neutrinos, which had passed right through the detector.

In this way they could see, for example, the tell-tale coincidence between an electron and a neutrino coming from the decay of a W.

In 1989, CERN's LEP electron-positron collider began mass-produc-

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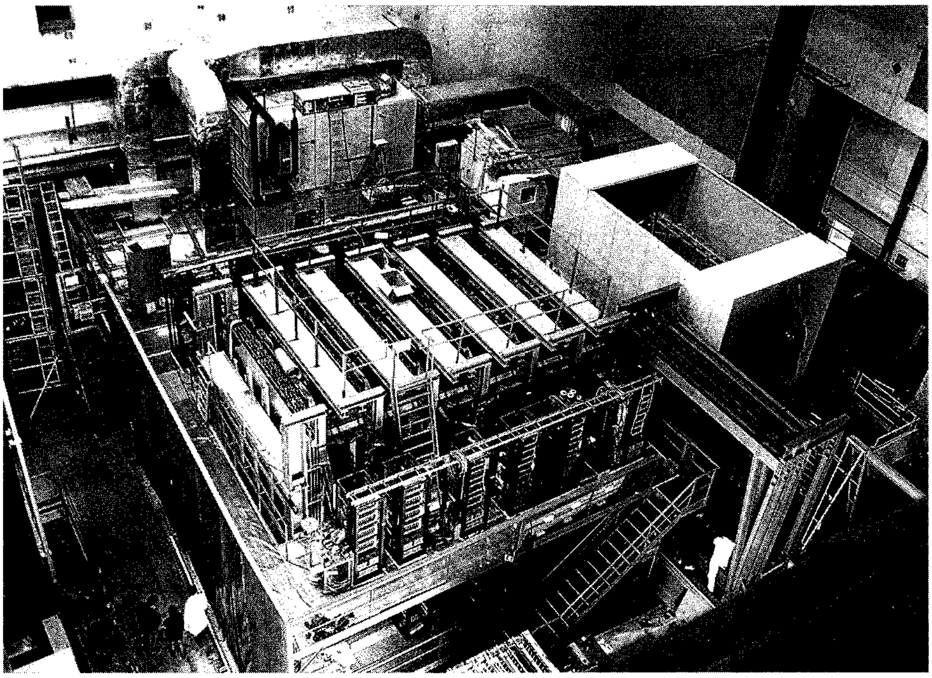
The electroweak picture

The big new high energy neutrino experiments had also made the first precision measurements of the electroweak parameters. For the first time, the hunters of the W and Z bosons, the particles carrying respectively the charged and neutral currents of the weak interactions, knew exactly where to look. In 1983, the big experiments at CERN's proton-antiproton collider discovered the W and Z bosons just where they were expected.

It was a triumph for the W and Z hunters, for the underlying theory, and all the preparatory studies. The electroweak picture was ready for the textbooks.



Next year, CERN's big third generation neutrino experiments -NOMAD and CHORUS - will open a new chapter in this area of science. Seen here is the muon spectrometer of CHORUS, with, to the right, its calorimeter (drawn back) and the box housing among other things the emulsion target.
(Photo CERN EX 44.7.93)

ing Z particles. Within a few months, a survey of Z decays (which can go among things into a neutrino-antineutrino pair) showed that there was room in Nature for only three kinds of light neutrinos, those associated with the electron, the muon and the tau. The lid had been shut on the list of known particles.

Future

After the termination of CHARM II in the summer of 1991, CERN neutrino operations came to a halt for the first time in 28 years. CERN's neutrino facilities have now been substantially upgraded, while preparations forge ahead for the third generation of CERN neutrino studies, with two big new experiments in the WA1/CHARM style, and together involving some 200 physicists. Upstream will be CHORUS, Klaus Winter's major Europe/Russia/Turkey/Japan collaboration using an 800 kilogram emulsion target, while NOMAD (a Europe/Russia/US/Australia collaboration with François Vannucci as spokesman) will use a magnetic spectrometer. The new CERN neutrino beam could also serve more distant detectors, but these plans are still being discussed

The aim of CHORUS and NOMAD is to look for interactions of the third type of neutrino, that associated with the tau lepton, and to search for possible 'oscillations' between neutrino types, where a beam cyclically changes its affinity as it travels along. With the modest neutrino playing a major role in the Universe at large, these results could have a vital bearing on new ideas in astrophysics and cosmology.

Around the Neutrino Laboratories

BROOKHAVEN

Neutrino physics has been an integral part of the Brookhaven research programme for much of the Laboratory's 46-year history. Milestones have been the determination of the helicity of neutrinos (1958), the establishment of the existence of two kinds of neutrinos (1962) for which Leon Lederman, Mel Schwartz and Jack Steinberger were awarded the 1988 Nobel Physics Prize, the discovery of charmed baryons in the 7' Bubble Chamber in 1975, and the ongoing measurements by Ray Davis and collaborators of solar neutrinos, first reported in 1968.

There have also been significant contributions to the understanding of neutral currents in exclusive hadron and electron channels. In addition some of the earliest, and to date best, accelerator limits on electron-muon neutrino oscillations are from Brookhaven experiments. The Laboratory is also the 'B' in the IMB underground experiment, built to search for proton decay and which caught neutrinos from the SN1987a supernova.

At present Brookhaven is heavily involved in the Gallex project in the Gran Sasso and recently a new collaboration has received scientific approval for a long baseline experiment to search for muon neutrino oscillations via muon neutrino disappearance.

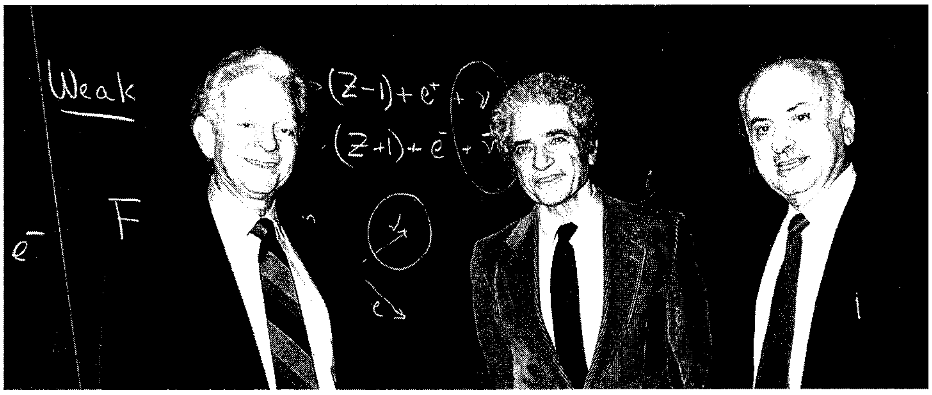
History

In the mid-fifties a major issue was the space-time structure of the weak interaction. While it was clear that the interaction had to be either scalar/tensor or vector/axial-vector, there was conflicting evidence for either hypothesis. In preparing for an invited talk on beta decay, Maurice Goldhaber realized that not only would a measurement of the neutrino helicity (spin direction) clearly differentiate between the two hypotheses but also that there was an isotope of europium which had the required properties for the proposed measurement. This classic experiment, carried out by M. Goldhaber, L. Grodzins and A.W. Sunyar on a laboratory bench in an old army barracks in the fall of 1957, took less than two weeks from conception to completion and showed the validity of the vector/axial-vector picture.

Another issue at the time was whether the neutrinos from beta decay and pion decay were different. The non-observation of the decay of the muon into an electron and a photon led G. Feinberg, then at Brookhaven, and T.D. Lee and C.N. Yang to suggest the existence of two distinct neutrinos.

The experimental verification came from the first neutrino experiment at Brookhaven's Alternating Gradient Synchrotron (AGS) accelerator, commissioned in 1960. The basis for

Cont'd page 21



Leon Lederman (left), Mel Schwartz (right) and Jack Steinberger were awarded the 1988 Nobel Physics Prize for their 1962 experiment at Brookhaven which showed that neutrinos come in more than one kind.

this experiment was when Mel Schwartz saw that, with the weak interaction increasing with energy, then despite the relatively small yield of neutrinos at an accelerator compared to a reactor it should be possible with a large detector to detect neutrino interactions at an accelerator.

The proposal was to create a neutrino beam from the decay of pions and kaons produced from an internal AGS target. The outcome (see page 4) was that the neutrinos of pion decay are intrinsically different to the neutrinos of beta decay.

The advent of neutral currents and charm particles brought the next phase of accelerator-based neutrino activity. All the subsequent Brookhaven experiments used a new fast extracted beamline, commissioned in 1973. The beam was extracted in one turn by a fast kicker and transported to the neutrino target. The 8° bend in the transport was accomplished using the first superconducting magnet installed in an accelerator complex. The particles from the target were focussed by a magnetic horn system developed by Bob Palmer and allowed to decay in a 50 metre tunnel. The resulting wide band beam peaked near 1 GeV and had a long tail with approximately 10% above 4 GeV. Essentially unmodified, this beam was Brookhaven's neutrino source for well over a decade. Intensity and reliability have increased steadily to the point where, once the new Booster is fully operational, it will be possible to produce some 6 x 10^{13} protons on target every 1.5 sec. This high rate with the associated timing structure is at the heart of all present planning for continuing neutrino physics at Brookhaven.

The beam was originally designed for use with the 7' cryogenic bubble chamber, built by Ralph Shutt's group, which first took data in 1974. The first hydrogen exposure of the chamber showed a charged current event with a lambda decay and a number of soft charged tracks.

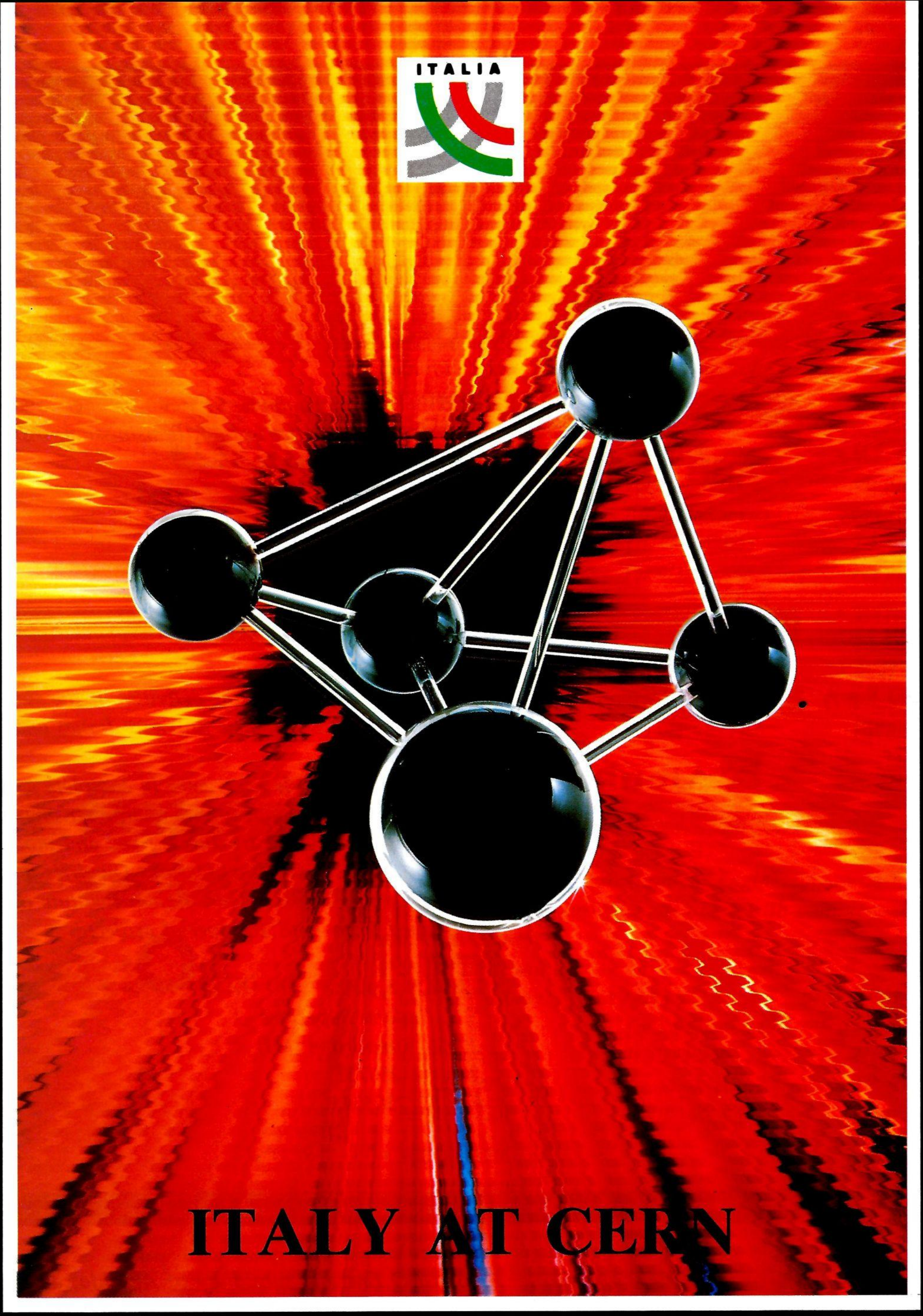
After six months of painstaking work a Brookhaven group led by Nick Samios concluded that there were no missing neutrals and that all the charged tracks, apart from the muon, were pions. This implied that a hitherto classic selection rule had been violated and the event was the production of a charm particle - the first observation of 'open' charm. The c-suffix nomenclature for charmed baryons introduced in these papers went on to become standard.

The Brookhaven Bubble Chamber group headed by Samios and Palmer together with the Columbia group led by Charles Baltay were also working during this period on E53 at Fermilab. This heavy liquid experiment in the Fermilab 15' bubble chamber measured neutrino-electron elastic scattering and produced significant results on the strange particle content of opposite sign dilepton events, helping to establish that charm production was the source.

Not long after the Brookhaven beamline became operational, two electronic experiments began looking at exclusive hadronic neutral current interactions; E605, a Brookhaven/Columbia/Illinois/Rockefeller collaboration led by W. Lee, used an optical spark chamber while E613, a Brookhaven/Harvard/Pennsylvania/Wisconsin collaboration with L. Sulak and H.H. Williams as spokesmen, used a large segmented liquid scintillator detector.

The success of E613 led to a much more ambitious liquid scintillator project - E734 - a major US-Japan collaboration led by R. Lanou, A.K. Mann, Y. Nagashima and D.H. White and eventually involving Brookhaven, Brown, Hiroshima, KEK, Osaka and SUNY Stony Brook. The initial goal was to measure the elastic scattering of neutrinos and antineutrinos on electrons and protons. The 150 ton main detector had segmented planes of liquid scintillator followed by proportional drift tubes. As well as determining the weak mixing angle, this measurement was also sensitive to the strange quark content of the proton.

E734 also provided one of the earliest limits on the mixing angle in muon-electron neutrino oscillations, and since the detector was close to the neutrino source the limit has survived. Recently a dedicated



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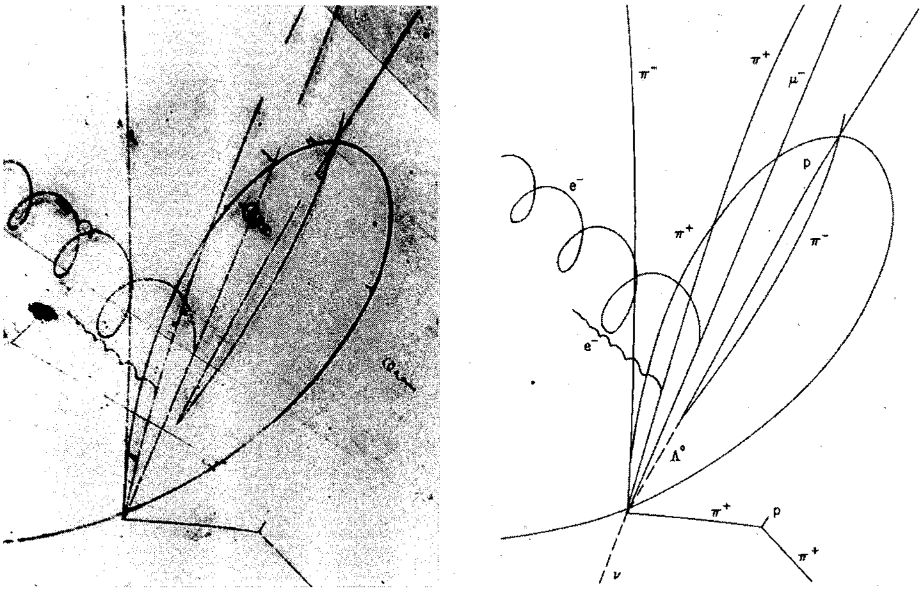
Charm comes out into the open. Photograph from Brookhaven's 7' cryogenic bubble chamber showing a charged current event with a lambda decay and six charged pion tracks.



neutrino oscillation experiment, E776, a Columbia/John's Hopkins/ Illinois collaboration with W. Lee as spokesman, in the same beam but located at 1 km, significantly improved the mass limit for large mixing angles.

The solar neutrino problem is still one of the most intriguing unresolved problems in physics. While it is clear that the sun is a copious source of neutrinos, it was only in the late 1950s with W.A. Fowler's conjecture that the solar cycle could be expected to produce boron-8 with its high energy decay neutrino that it seemed experimentally feasible to detect solar neutrinos.

A number of potential detectors were discussed and some test modules built. The immediate outcome was the Brookhaven Chemistry Department chlorine experiment led by Ray Davis. This large tank of chlorine-rich cleaning fluid has been active in the Homestake gold mine in Lead, South Dakota now for close to 30 years. The original projections were that the total solar neutrino capture rate in 520 metric tons of chlorine would be 2 to 7 per day. Solar neutrino capture produces argon-37 atoms which can be extracted and counted in a small proportional counter with very low noise electronics, developed in Brookhaven's Instrumentation Division.

The original 1968 paper only gave an upper limit on the solar neutrino flux from boron-8 as the observed rate was consistent with the background rate from the counter. However more data, more sophisticated analysis methods, and improvements in electronics led to a definite determination of the flux.

While the accumulated data over the past years has sometimes led to conjectures about solar cycles or other phenomena, the observed rate has been consistently less than solar model predictions.

Brookhaven is a member of the IMB collaboration which in 1979 proposed to search for proton decay in a large water Cherenkov detector. By 1983 they had already established that the proton lifetime was much longer than predicted by the minimal grand unification model.

In the course of refining these limits, the collaboration have extended their mandate, covering also extraterrestrial neutrinos, and making two important measurements. In 1987 they observed 8 neutrino events resulting from the SN1987A supernova explosion and recently have noted an inconsistency between the calculated and observed ratio for atmospheric muon and electron neutrinos.

Brookhaven's solar neutrino tradition is extended with the new Gallex experiment in the Italian Gran Sasso Laboratory which sees neutrinos from the primary solar proton-proton interaction. The IMB group will also participate in the Japanese Superkamiokande project (see page 32).

A new collaboration - Brookhaven, UC Santa Barbara, Linfield College, Los Alamos, New Mexico, Pennsylvania, Southern, Temple, TRIUMF, and Valparaiso - has recently had scientific approval for a major new initiative on neutrino oscillations. The aim is to search for muon neutrino oscillations via muon neutrino disappearance with emphasis on small mass differences. The goal is to cover the region allowed by the anomalies in the atmospheric neutrino rates recently reported by both Kamiokande and IMB with three detectors, the furthest being at least 20 km from the neutrino target.

Brookhaven has had a long and profitable association with the neutrino, with experiments which have contributed greatly to our understanding of the neutrino itself, to the evolution and validation of weak interactions and the Standard Model and which have exploited the neutrino as a probe of rare phenomena. With a major new experiment being prepared, the Laboratory's strong neutrino tradition lives on.

Wide and narrow bands

Getting neutrino beams is all about getting enough parent particles. The pioneer neutrino experiments at Brookhaven in 1962 used no focusing tricks, however the invention of the magnetic horn by Simon van der Meer at CERN enabled a wide range of parent kaon or pion momenta to be concentrated into a cone, boosting the subsequent neutrino yield in a 'wide band beam'. The focusing horn also selects the electric charge of the pions and kaons, thereby determining whether neutrinos or antineutrinos are obtained. However there is little indication of what the energies of these neutrinos (or antineutrinos) are.

Another approach is the 'narrow band beam', where a limited range of parent pion or kaon momenta is selected, giving a forward peak. Here the offset of the neutrinos from the forward direction gives an indication of their energy. However as pions and kaons decay in different ways, the resultant neutrino beam covers two (narrow) momentum bands, and is 'dichromatic'. The first such beams were used at Fermilab in the early 1970s.

FERMILAB

Neutrino experimentation at higher energies was among the justifications for the construction of Fermilab and the earliest studies utilized these new beams produced with 350-400 GeV protons. This pre-Tevatron period used both electronic counters and the new 15-foot cryogenic bubble chamber.

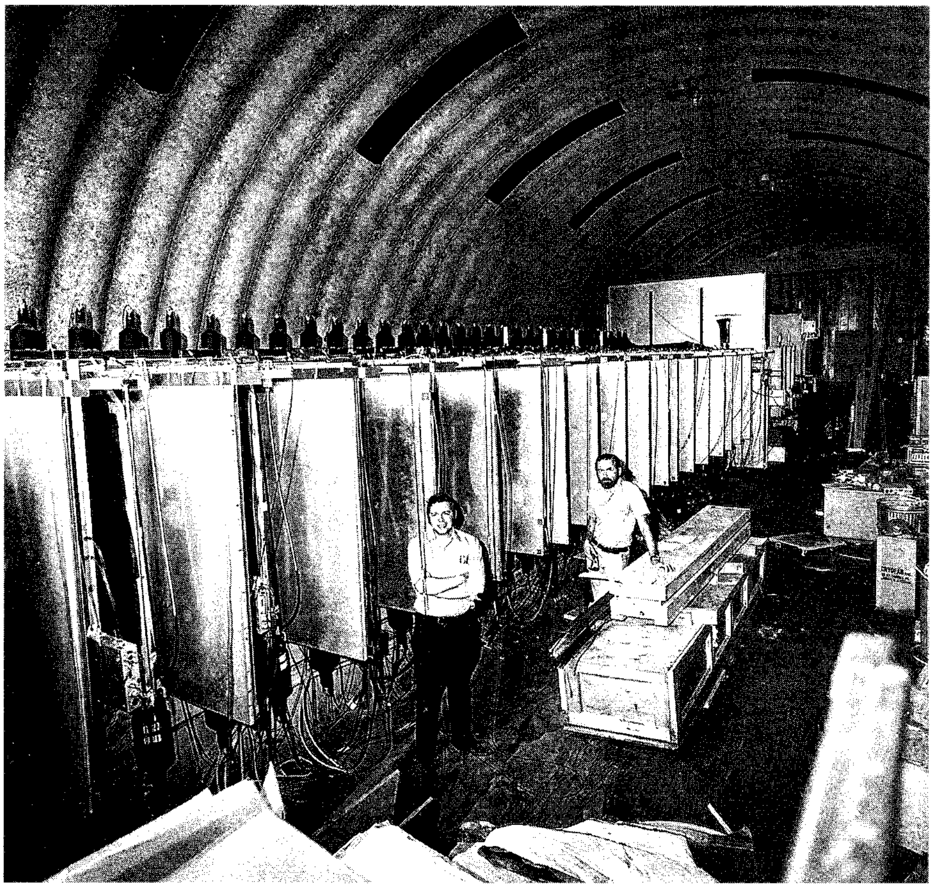
The counter experimental programme was basically divided into two generations. The first covered the discovery of new phenomena and confirmation of the parton model using high rate wide-band and the first dichromatic narrow-band neutrino beams. The second concentrated on precision measurements with dichromatic beams.

One flagship experiment, designated "E1A", was originally a collaboration of Harvard, Pennsylvania and Wisconsin, and was the prototype of large neutrino calorimeters: a target/ calorimeter followed by a large set of iron toroidal magnets. E1A and its successor, E310 (which included Rutgers), ran for a total of 6,650 hours from 1972 through 1978. Contemporary with these experiments was another large counter experiment by CalTech and Fermilab, designated originally as E21A. Along with its successors, E262, E320, and E356 (which collected data over some 4,600h) it took part in the first generation programme, and subsequently spearheaded the second generation with precision measurements of both charged current structure functions and the weak mixing angle. Finally, this latter collaboration extended its participation into the early Tevatron era, and will continue through the 1990s.

The E1A-inspired programme ended with E310 and a dedicated low-mass, highly visible counter neutrino experiment, E594 took its place. E616 plus E594 constituted the second generation of pre-Tevatron Fermilab experiments.

The Fermilab "15-foot" bubble chamber (actually, a 12 foot diameter sphere with a 3 foot upstream nose), began operation in 1973, with a neon-hydrogen mixture exposed to

The Fermilab 'flagship' E1A neutrino experiment pioneered the use of large neutrino calorimeters. In this 1973 photo are, left to right, standing, Alfred Mann, Richard Imley, David Cline, T.Y. Ling, Don Reeder, Jim Pilcher and Bernard Aubert; seated, Carlo Rubbia, Karen Mattison and Fred Messing.



The E21A counter neutrino experiment by CalTech and Fermilab, here tended by Frank Sciulli (left) and Barry Barish.

the wide-band beam in conjunction with E28, a collaboration of CERN, Hawaii, LBL, and Wisconsin. This was followed by a series of 15 other experiments using wide- and narrow-band beams focused for both neutrinos and antineutrinos.

The 15-foot chamber was later modified to include an external muon identifier and an internal "picket fence".

The first generation experiments at Fermilab were responsible for measuring the ratio of neutral to charged current interactions with high statistics, although the priority on the actual discovery of neutral currents was somewhat controversial. The first observation of opposite sign dilepton final states and their determination occurred at Fermilab in E1A (dimuon final states) while precision measurements of the accompanying strange particle content of those events were carried out by the bubble chamber experiments (muon-electron final states).

Observation of trileptons and same-sign dimuons led to a decade of further experimentation and subsequent verification of the Standard Model.

The nucleon structure functions were determined through both charged current and neutral current scattering during this period. By the early 1980s, the total neutrino experimental programme at Fermilab had contributed greatly to our understanding of the parton model and particle production in charged current events.

There were three "other" experiments of note during the pre-Tevatron era which deserve mention. The first was E253, a 1978 experiment designed to observe and measure neutrino-electron scattering, with an early determination of the weak mixing angle.

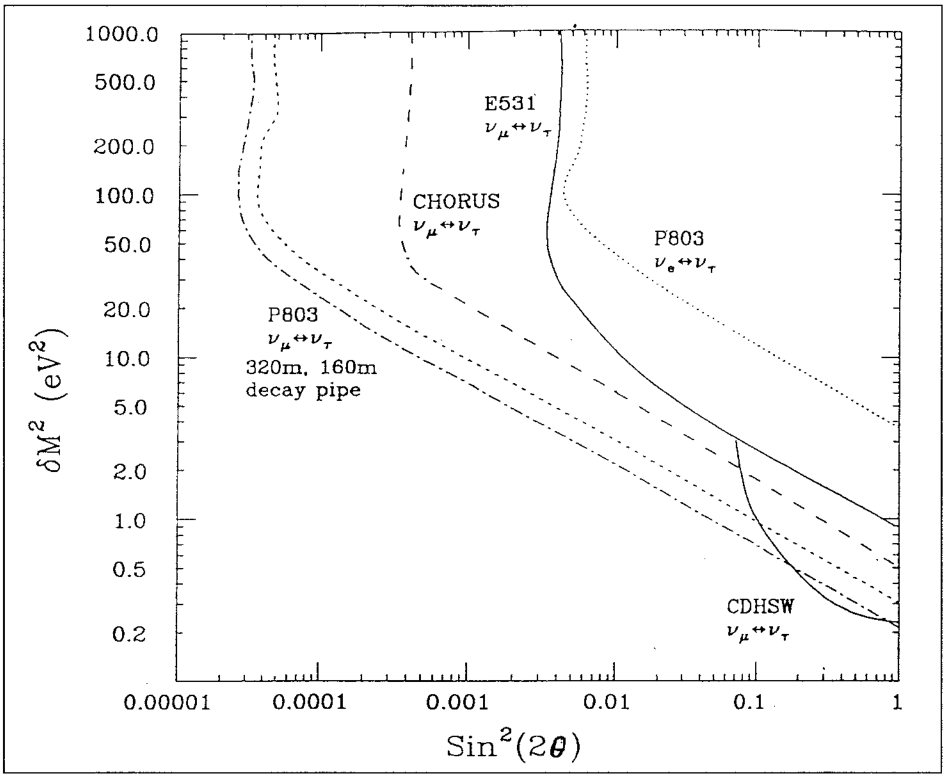
The second was the first major emulsion neutrino experiment, E531. This was highly successful, establishing a detailed understanding of charmed particle production and the properties of charmed particles. Interestingly the limits set on the oscillation of muon to tau neutrinos through a search for the appearance of the latter still stand today. Also of note was E701 (the original E616 apparatus with an upstream detector) - a true 'disappearance' oscillation experiment in the dichromatic beam in 1982.

The advent of the Tevatron with its higher energies boosted Fermilab's programme, with neutrinos produced (indirectly) from 800 GeV protons. This era saw the continuation of the CalTech/Fermilab programme, augmented by Columbia, Chicago, Rochester, Rockefeller, and subsequently Wisconsin (CCFRW), the continuation of the flash-chamber programme (E733), and the introduction of holography in bubble chambers with the 15-foot (E632) and hybrid (E745) chambers. These studies have extended the precision of many Standard Model tests and form the basis for the second generation of Tevatron neutrino experiments scheduled for 1995.

Future neutrino experiments

As Fermilab moves into its third decade of operation, much of the experimental programme, particularly in the fixed target area, emphasizes

Limits on neutrino oscillation parameters expected from several future experiments, compared with the historical results from CDHSW (WA1) at CERN.



precision experiments to probe deep inside the Standard Model and hopefully get a glimpse of what lies beyond it.

Neutrinos are penetrating probes and will make up an important part of this ongoing programme.

After more than a five-year hiatus, the detector used for the CCFRW (Chicago/Columbia/Fermilab/ Rochester/Wisconsin) collaboration's experiments (E770/774) will be reincarnated as E815, an experiment designed to make precision measurements of the basic electroweak parameters.

One of these - the electroweak mixing parameter (Weinberg angle, linking the two neutral carriers of the theory with the physical photon and Z boson) - can be obtained in a number of ways: direct measurement of the W and Z masses, left/right asymmetry in Z decays, neutrino-nucleon scattering, and atomic parity violation. Measuring this parameter in several processes provides insight into small effects due to higher order corrections to the Standard Model as well as possible deviations from it.

The other parameter - Greek rho - dictates the strength of the neutral current interaction, and in the basic Standard Model is equal to 1. Small effects can creep in due to various electroweak corrections, such as those depending on the mass of the long-awaited sixth ('top') quark. Present values of the Standard Model parameters predict rho to be 1.0026 ± 0.0038, along with a top heavier than 113 GeV, and a higgs particle somewhere in the range 60 to 1000 GeV.

Experiment 815 will measure rho to a precision of ± 0.005, and the mixing parameter to ± 0.003. The key feature will be the operation of a new charge selected beam to provide neutrinos or antineutrinos. Separate running in each beam will open up the two vital parameters.

To date such an analysis has not been worthwhile due to the paucity of antineutrino data. E815 anticipates normal operation of 10^{13} protons per cycle, for a total of 2 x 10^{18} integrated protons after an eight-month run. This should yield approximately 1.2 million neutrino charged current, 400,000 neutrino neutral current, 220,000 antineutrino charged current and 84,000 antineutrino neutral current events.

As the end of the decade approaches, Fermilab's new Main Injector (May, page 10) will provide new opportunities for fixed target experiments using either the increased intensity Tevatron beam, or the high intensity 120 GeV beam extracted directly from the Main Injector, and available during collider operation.

One of the most exciting of these opportunities is a search for neutrino oscillations and the concomitant evidence for neutrino mass.

The 120 GeV Fermilab Main Injector beam will deliver more than 4 x 10^{13} protons per two-second cycle, producing an unprecedented flux of high intensity, high energy neutrinos.

A preliminary beam design foresees a muon-neutrino beam with an average energy of 15 GeV.

One proposal wants to use this beam with a hybrid emulsion spectrometer for a short baseline experiment to search for muon/tau-neutrino oscillations. This follows the philosophy of the Fermilab E531 experiment and CERN's CHORUS experiment currently under construction.

A compelling feature of this idea is the possibility to actually detect the interaction of a tau neutrino via the tau-neutrino/tau charged current interaction. With the tau neutrino yet to be directly observed, this group

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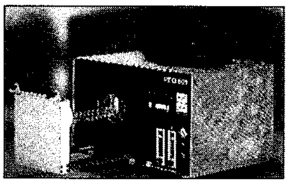

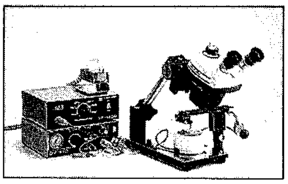

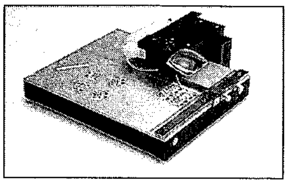

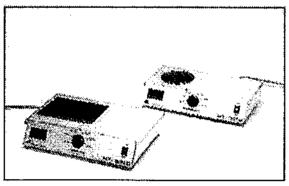

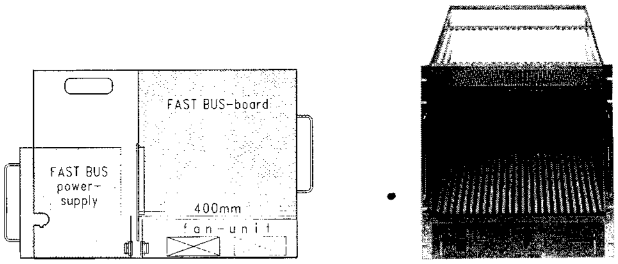
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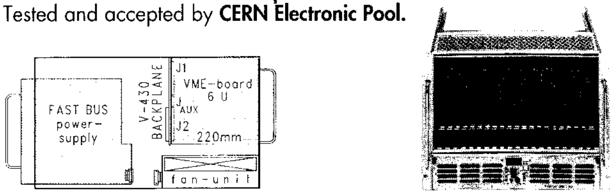
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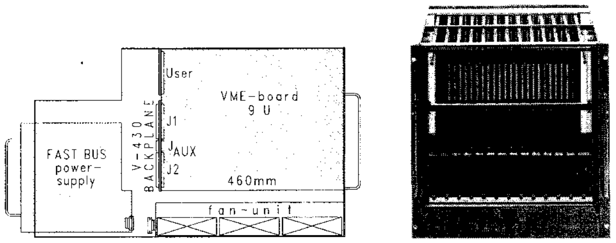
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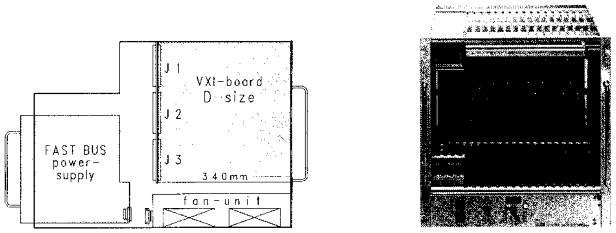
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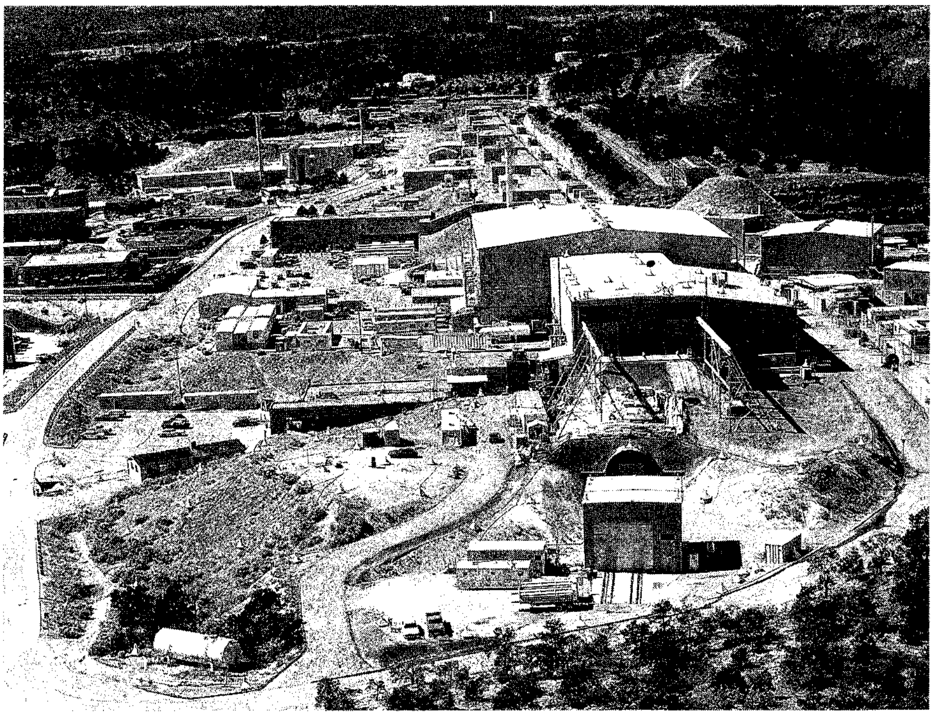
J 2
J 3
FAST BUS power-supply
340mm
fan-unit

proposes a tau-neutrino beam dump which could use the 800 GeV proton beam prior to the completion of the Main Injector. This proposal will soon be submitted for formal consideration.

Also being developed are plans for a long baseline experiment. One idea is to extract the Main Injector beam in a direction so that the neutrinos travel toward Soudan, Minnesota, 800 kilometres to the northwest of Fermilab, home of a major underground laboratory. In such a scheme, the near and distant detectors would use the same beam and some common modules.

Other long baseline options being studied involve using protons extracted from the existing 120 GeV Main Ring, the 8 GeV Booster, or the Antiproton Debuncher Ring, the idea being to produce a high intensity neutrino beam, albeit of low energy. This gives good sensitivity to oscillations over a shorter distance, allowing the "far" detector to be much nearer, even on the Laboratory site.



An aerial photograph of the LAMPF facility with the experimental areas in the foreground. The tunnel housing the LSND neutrino experiment is visible in the lower centre of the photo behind a service building. LSND is about 11 metres downstream of the LAMPF beam stop.

LOS ALAMOS

Following the historic observation of neutrinos in the mid-1950s by two Los Alamos scientists, Fred Reines and Clyde Cowan, Jr, using inverse beta decay, there has been a long and distinguished history of experimental neutrino physics at LAMPF, the Los Alamos Meson Physics Facility. LAMPF is the only meson factory to have had an experimental neutrino programme.

In the late 1970s, the first LAMPF neutrino experiment used a 6-tonne water Cherenkov detector 7 metres from the beam stop. A collaboration of Yale, Los Alamos and several other institutions, this experiment searched for the forbidden decay of a muon into an electron and two neutrinos, and measured the reaction rate of a neutrino interacting with a deuteron to give two protons and an electron - the inverse of the reaction that drives the sun's primary energy source.

The next LAMPF neutrino experiment, a UC Irvine/Maryland/Los Alamos collaboration, ran from 1982 through 1986 and measured the elastic scattering rate of electron-neutrinos and protons, where both neutral and charged weak currents contribute.

With its precision of about 15%, the experiment provided the first demonstration of (destructive) interference between the charged and neutral currents.

More recent neutrino experiments at LAMPF have searched for neutrino oscillations, especially between muon- and electron-neutrinos.

The newest experiment to pursue this physics (as well as oscillations in other channels) is LSND (July/August, page 10 and cover).

In addition to searching for these oscillations, LSND will measure neutrino-proton elastic scattering at low momentum transfer, providing a sensitive measure of the strange-quark contribution to the proton spin. LSND began taking data in August.

Los Alamos physicists have also been busy in neutrino physics experiments elsewhere.

One such experiment looked at the beta decay of free molecular tritium to obtain an essentially model-independent determination of the electron-neutrino mass. The present result gives an upper limit on the electron-neutrino mass of 9.3 eV, showing that electron neutrinos cannot by themselves 'close' the universe.

Pioneer solar neutrino experiments (see page 21) suggested that the observed flux of high-energy neutri-

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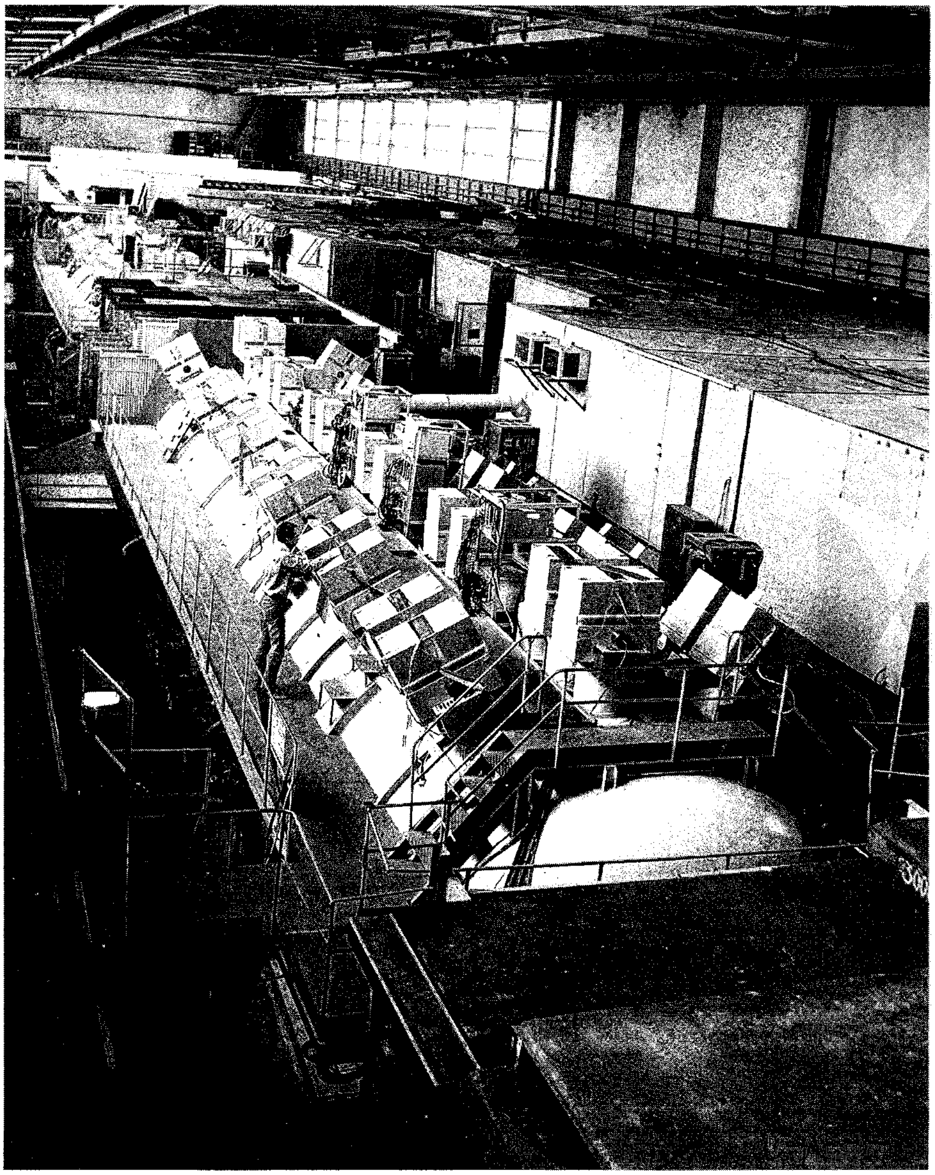
nos from the sun is lower than expected. This could be a manifestation of neutrino oscillations or could be due to a problem with the solar models used to predict the expected neutrino flux. Los Alamos has played a major role in the SAGE experiment in Russia to detect solar neutrinos using gallium. With gallium, the detection energy threshold is low enough that neutrinos from the main energy-producing solar (proton-proton) reactions can be detected; should the flux measured in this experiment also be low, new neutrino properties must be the culprit.

Los Alamos is also participating in the Sudbury Neutrino Observatory (SNO) experiment in Canada using 1000 tonnes of heavy water to observe solar neutrinos both via charged current and neutral current reactions. This is a promising experiment because the rate of neutral current events should be independent of whether or not neutrinos oscillate, while the charged current rate is initiated only by electron neutrinos. SNO is expected to begin data-taking in late 1995.

SERPUKHOV

Neutrino investigations at the Serpukhov accelerator of the Institute for High Energy Physics, Protvino, Russia, date back to 1968. A neutrino channel for wide band beams, consisting of a 70 GeV proton transport system, target, focusing system for secondary hadrons, 140m decay pipe and 12,000 ton iron muon filter, under the leadership of V.Kotov, A.Samoilov and R.Rzaev from the Beam Department, was constructed from 1969 to 1974.



The neutrino detector of Serpukhov's Tagged Neutrino Facility (TNF) with its two Big liquid ARgon Spectrometers (BARSes) interleaved with muon iron toroid spectrometers.

The original focusing system proposed by A. Samoilov still gives neutrino fluxes of about 20 billion particles per square metre per spill over 5 microsec.

The initial 20-ton neutrino detector based on optical spark chambers was a joint IHEP-ITEP(Moscow) effort led by A.Mukhin and V. Kaftanov. First neutrino events were detected in April 1974. The next eight years with this detector covered many aspects of neutrino behaviour - dimuon production, quasielastic and total cross-sections, and 'prompt' neutrinos from beam dump experiments.

Initial experience with emulsion targets for neutrinos showed feasibility of this technique for studying charmed particle production.

The average neutrino energy from the Serpukhov accelerator is around 10 GeV. At these energies, neutrinos do not probe deeply and low multiplicity final states dominate.

This called for a neutrino detector capable of seeing individual particles in the final state. The result was the 7 cubic metre SCAT (from the Russian abbreviation for Serpukhov CAmera Heavy) propane-freon bubble chamber.

Construction of this chamber took almost a decade (1965-1974). Many USSR industrial enterprises took part, supervised by the Efremov Laboratory, Leningrad (V.Titov) and IHEP (E.Kuznetzov). First neutrino event pictures were obtained in May 1975.

This bubble chamber went on to provide the bulk of the neutrino data, with the international Protvino/ Zeuthen (East Germany) team, co-spokesmen V.Ammosov and

EPAC94

FOURTH EUROPEAN PARTICLE ACCELERATOR CONFERENCE

Queen Elizabeth II Conference Centre, London,
27 June to 1 July 1994

After Rome, Nice and Berlin, the fourth conference in the series will be held at the prestigious Queen Elizabeth II Conference Centre, opposite Westminster Abbey and only a short walk from the Houses of Parliament, in the city of Westminster, London.

The conference aims to provide a comprehensive overview of research, technology and special applications in the field of accelerators. In the planning of the programme special emphasis is placed on excellent review papers and particular attention will be paid to high-intensity accelerators. The programme will include invited talks, contributed papers, oral poster presentations and poster sessions. Parallel sessions will be kept to a minimum.

Papers from the whole field of accelerators are solicited, including low- and high-energy machines and accelerators for medical and industrial purposes. The deadline for the receipt of Abstracts at the Scientific Secretariat is 15 December 1993.

An industrial exhibition, as well as an exhibition of CERN's proposed LHC Project, will be held during part of the conference and the conference programme will include a special session whose theme will be the transfer of technology from accelerator laboratories to industry. Information regarding the exhibition and seminar may be obtained from the Exhibition Manager.

Local organization is in the hands of the RAL and Daresbury laboratories. The registration fee is £225 if received before the deadline of 27 April 1994 and is increased to £250 thereafter. Due to the huge demand for accommodation in London in June and July, requests for accommodation should also be made prior to this date. Complete information concerning registration and accommodation may be obtained from the Conference Secretariat.

World-Wide Web (W3) and Internet Gopher will be used as additional means of disseminating information on the conference as it becomes available. Indications as to how to use these systems, as well as complete information on the conference are given in the First Announcement and Call for Papers available from the Conference Secretariats.

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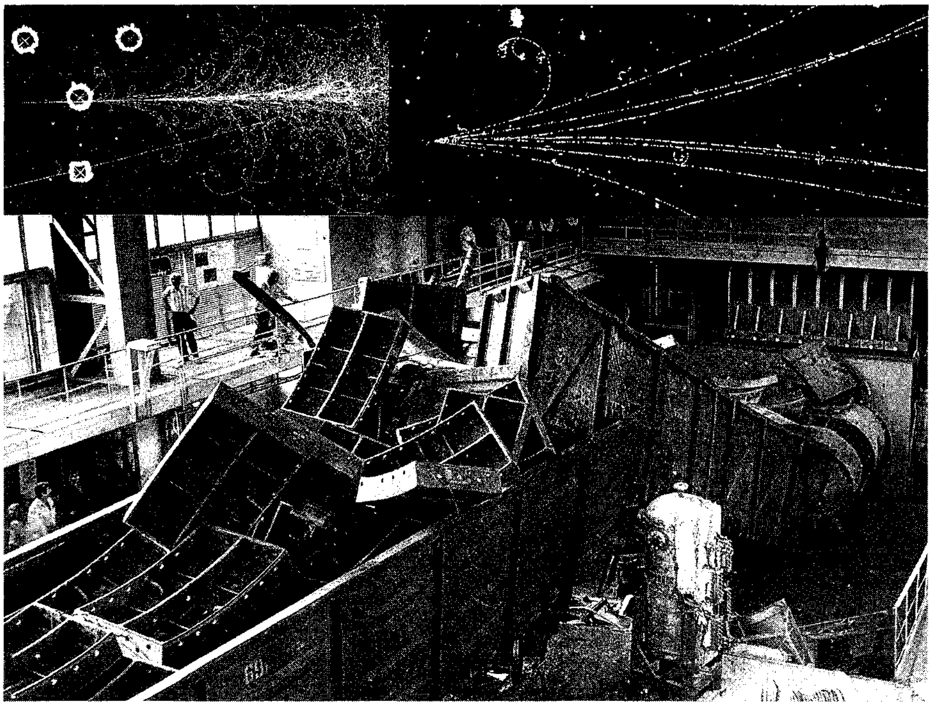
The first 'impact' of perestroika on Russian fundamental science was on 11 June 1989, when three railway wagons loaded with slabs for Serpukhov's new UNK synchrotron and moving at 50 km/h slammed into the SCAT heavy liquid bubble chamber, ready for its autumn neutrino run. With characteristic determination, the Serpukhov physicists recalled the words of a folk song - "Our armour was strong and our hands were still quick." SCAT was fixed in just two months and started to work with new propane-freon mixture (event in right corner) just as successfully as it did before with freon (electron-neutrino event in left corner).



R.Nahnhauer, publishing more than 30 articles.

Among the research highlights were measurements of the electroweak mixing angle from full measurement of single pion coherent production, pioneer measurements of charmed baryon production, and the recent first observation of quasielastic production of the charmed doubly charged sigma* (2450).

The chamber lived for a respectable 18 years and just managed to survive through the 1989 "perestroika" (see photo). It saw a new era in neutrino investigations at IHEP with the availability of the booster. It was only in 1992, after 1.7 million pictures, that the last of the large bubble chamber "Mohicans" finally disappeared from the scene.

The new booster increased the intensity of the proton beam on the neutrino target from 3 billion to 12 billion particles per cycle. The first successful run with the booster was in October 1987. For this SCAT was filled with light propane-freon mixture (90% propane).

A 100-ton conventional fine-grain calorimetric neutrino detector with a downstream muon spectrometer of magnetized steel toroids was built by a collaboration of IHEP, JINR(Dubna) and IHEP (Zeuthen) (cospokesmen A.Vovenko, S. Bunyatov and M. Walter). The target consists of 36 horizontal planes of liquid scintillation counters alternating with aluminium plates inside magnetized iron frames. This detector can detect both muon- and electron-neutrino interactions, and analysis of nucleon quark structure (structure functions) for momentum transfer is in progress.

A new experiment aims to push back the limits in the search for electron-/tau-neutrino oscillations in unfocussed hadron decays in a short 12.5m decay pipe.

Looking to make maximum use of neutrino beams at full booster intensities, Neutrino Department head Sergei Denisov hit on the idea of tagged neutrinos. Recently physicists from Pisa, Dubna, Zeuthen and Protvino, led by Denisov, have completed construction of the Tagged Neutrino Facility (TNF).

The novel idea is to detect simultaneously all other particles in the decays of kaons giving electron- and muon-type neutrinos. It uses a special tagging station (TS) between the decay pipe and muon shielding, consisting of eight 4x4 metre planes of scintillation hodoscopes and a 2000-cell electromagnetic calorimeter. This information allows electron and muon identification, reconstructs their trajectories, and measures energies of emerging electrons and gammas to tell where the kaon decay happened, together with the direction of the neutrino and its energy.

A special narrow-band neutrino beam and a novel neutrino detector were constructed for TNF. The detector consists of two Big liquid ARgon Spectrometers (BARSes), each containing 300 tons of liquid argon. An important BARS feature is its high ratio of active to passive material, giving good energy resolution, especially for electrons.

BARSes are followed by muon spectrometers of 5-m diameter magnetized iron toroids interleaved with drift tubes. The main advantages of the tagged neutrino beam are good energy resolution (3-5%) and low background (2-3 orders of magnitude less than in usual neutrino beams). It is hoped that the TNF will start data collection next year.

Plans for IHEP neutrino experiments were linked to the construction of the new 3 TeV UNK, whose proton beam intensity would have been considerably higher than other synchrotrons. However these hopes began to fade and vanished last year for the present generation of physicists when a decision was taken to complete the construction of the initial 600 GeV UNK machine and to limit work on the superconducting 3 TeV UNK accelerator to R&D. But even at 600 GeV the rate of neutrino interactions is interesting, and sighting the tau-neutrino and searching for oscillations into tau-neutrinos in new kinematic regions are still on the cards.

JAPAN

With the research structure for high energy physics attaining maturity, experimental neutrino physics flourished in Japan in the 1980s. Neutrino studies during this period used three approaches: accelerators, nuclear beta decays, and a deep underground experiment. The latter, using an imaging water Cherenkov detector, was so successful that it is being considerably expanded and will dominate Japanese research in this field in the 90s.

In the 80s, the E10 experiment (KEK/Tokyo/Osaka) was the first to search for a heavy neutrino in stopped-kaon decays at the Japanese KEK Laboratory's 12 GeV Proton Synchrotron, and was soon followed by dedicated experiments, E89 and E104 (Tokyo/KEK). Using a high resolution magnetic spectrometer with an extensive photon-veto system, a good 1982 limit linked mass and mixing probability in the 100 MeV mass range. After ten years, the synchrotron is again to go into action for neutrino-related research (experiment E261a - see below).

At KEK's TRISTAN electron-positron collider, the VENUS Collaboration studied radiative neutrino-pair production, and combining their data with those from other electron-positron colliders, concluded that the number of light neutrino species had to be less than four, even before LEP experiments made their definitive 1989 measurement.

In late 1980, motivated by a claim by a Moscow experiment for the finite mass of the electron antineutrino, a group including physicists from INS (Institute for Nuclear Study, Tokyo) had proposed a precision measurement of the tritium beta-ray spectrum near its end point. Emphasis from the beginning was on reliable calibration.

About four years were spent developing an optimal beta-ray source and on calibration to give high quality measurements. Over the subsequent four years, a series of measurements gave a 13 eV upper mass limit.

Early in 1991, a KEK/INS collaboration, including also some American physicists, embarked on a decisive experiment on the controversial 17 keV neutrino. Knowing the danger of relying on subtle effects in beta spectrum slopes, they searched for a neutrino emission threshold effect in the spectrum with high resolution, low background and unprecedentedly high statistics. The result of a three month measurement clearly excluded such a neutrino.

Towards the end of the 1970s, the very attractive idea of the Grand Unification of forces had fostered a new generation of large underground experiments to search for the predicted decay of the proton. In Japan the large Kamiokande underground experiment (Tokyo/Institute for Cosmic Ray Research/KEK/Niigata collaboration) looked for proton decay in the 3000-ton imaging water Cherenkov detector 1000 m underground. Installation of 1000 specially designed photomultiplier tubes was completed in July 1983 and the first result reported six months later.

Detector response was calibrated using electrons (below 5 MeV) from stopped cosmic-ray muons.

Successful measurement of such low energy electrons showed how the detector could also recognize recoil electrons from low energy neutrino interactions. To improve sensitivity to nucleon decay and to lower the energy threshold for solar neutrino detection, the collaboration was expanded to include a Pennsylvania group. A water Cherenkov veto counter was constructed around the main body, and the water purifier as well as the electronic system considerably improved. The upgraded detector, Kamiokande-II, went live at the end of 1985 and produced its first result the following year from 48.5 days of data.

To further reduce background radioactivity, work continued through 1986 to improve the water purification system.

These painful efforts were dramatically rewarded. On 25 February 1987, a telefax informed the group of an astronomically 'nearby' supernova. Perhaps the detector's routine running could have intercepted neutrinos from this explosion.
Data tapes were immediately rushed to Tokyo for analysis.

On 27 February a whole night was spent scanning the few hundred pages of energy-versus-time plots collected over 2.5 days. An unmistakable burst of activity soon showed up. Recorded on 23 February at 07: 35: 35 UT (±1 minute) and lasting 13 seconds, it contained 11 electron events with each energy ranging from 7.5 to 36 MeV. These neutrinos from the SN1987A supernova marked the beginning of neutrino astronomy.

With continuous operation of the detector under very low backgrounds and with the collaboration extended, a new range of physics opened up when solar neutrinos were detected for the first time in a real-time directional measurement. The recent result of the flux measurement, from a 1554-day data sample, is 0.50 ± 0.04(stat.) ± 0.06 (sys.) of the standard solar model prediction.

This low flux of solar boron-8 neutrinos, to which the Kamiokande detector is sensitive, confirmed the solar neutrino deficit first observed in the classic chlorine-based experiment. In addition, the measured Kamiokande flux has not shown any sign of seasonal variation or day-night variation.

Atmospheric neutrino interactions in the Kamiokande detector had to be carefully studied to establish the background for any proton decays. This background study led to a surprising conclusion - the so-called atmospheric neutrino anomaly - in which the measured ratio of muon-like to electron-like events is some 60% of the expected value. This smaller than expected muon-neutrino flux has been suggested to be the result of new neutrino behaviour.

Study of atmospheric neutrino events requires good knowledge of muon-electron discrimination, detection efficiency for low momentum muons and pions, and nuclear effects in neutrino interactions in water.

In view of the potential importance of the measured anomaly, a thorough check of detector performance was called for and at the KEK Proton Synchrotron, experiment E261a (Kamiokande collaboration) was approved for the purpose. Construction of a 1000-ton water tank began in 1992 outside the North Experimental Hall, and the installation of 408 20-inch photomultipliers has just been completed. The experiment will start early next year with a beam of electrons, pions and muons of momenta from 0.2 to 1 GeV.

The tank is equipped with four beam entrances with beam pipes of different lengths. After this measurement, the collaboration working on the IMB underground experiment in the US will bring in their photomultipliers for a similar experiment.

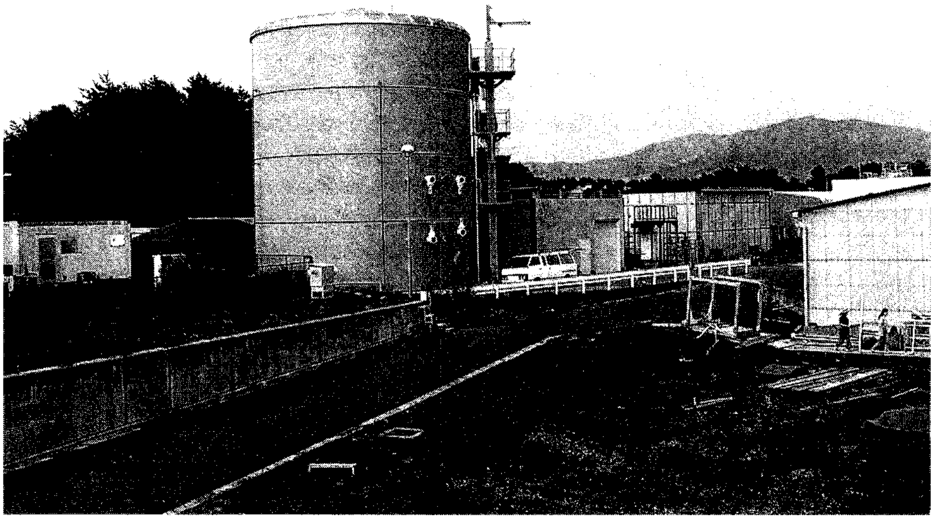
This water Cherenkov detector might also be used to study interactions of neutrinos from the synchrotron, where the beam energy spectrum happens to resemble that of atmospheric neutrinos.

As a next-generation underground experiment, the Super-Kamiokande project (an expanded Kamiokande collaboration, together with a similar number of American physicists) was approved in 1991 (May 1991, page 9).

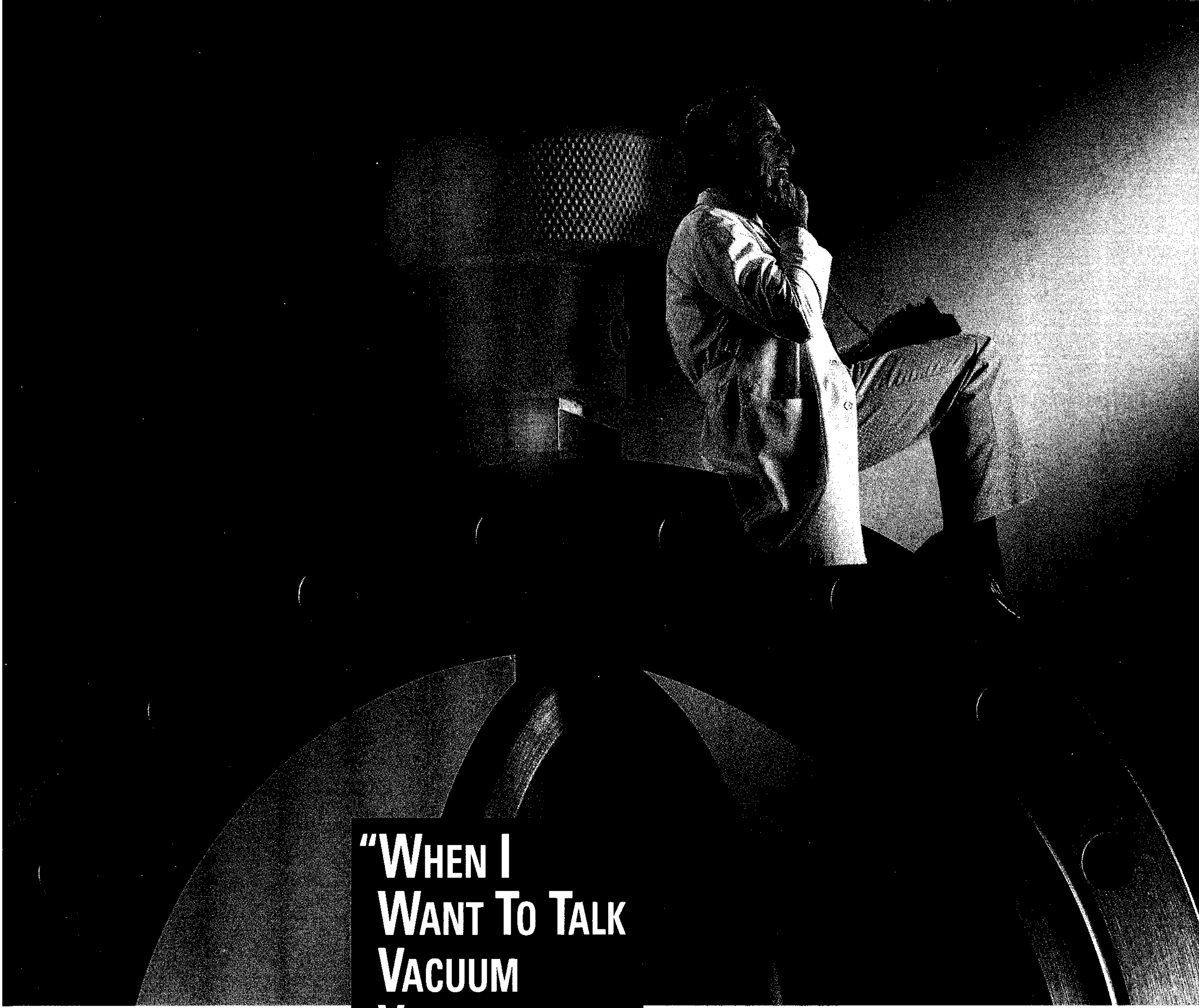
Excavation for a 50,000-ton water tank (40m x 41 m) is well underway about 150 m from the present detector. New 20-inch photomultipliers and front-end electronics have already been developed and are in production. Prototype electronics has already been exploited in the last phase of the present experiment.

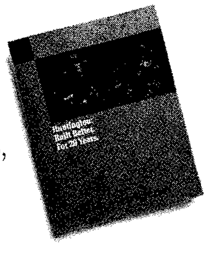
It will be operational from late 1996 and is expected to yield 26,000 solar neutrino events and 8,000 atmospheric neutrino events after three years. It should also serve as an astronomical neutrino observatory. There is also an idea to fire a KEK neutrino beam into this detector to search for neutrino oscillations.

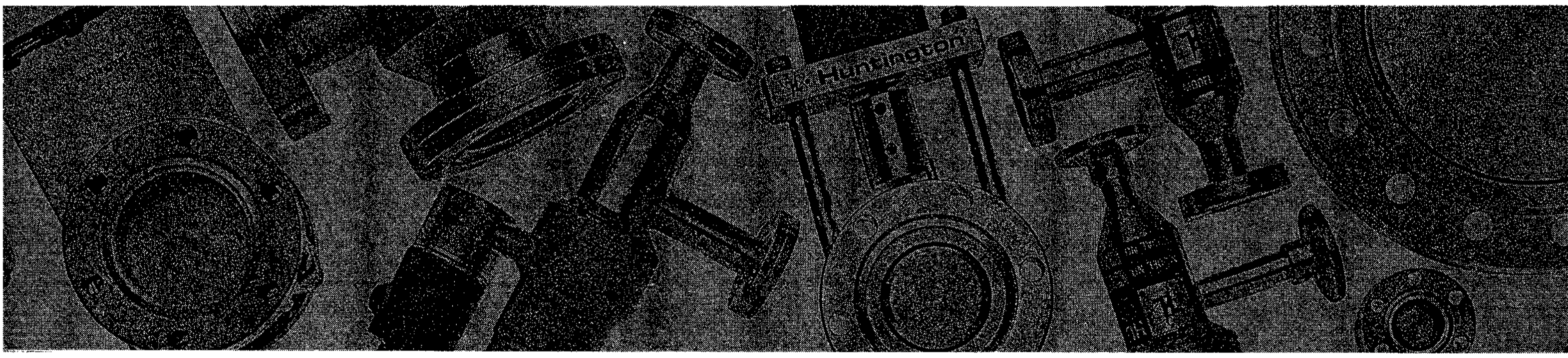
An article on the KARMEN neutrino experiment by a Germany/UK collaboration at the Rutherford Appleton Laboratory will appear in a forthcoming issue.



1000-ton water Cherenkov detector constructed for tests near the experimental hall of the 12 GeV Proton Synchrotron at the Japanese KEK Laboratory. Construction is underway for a new low-momentum secondary beamline.







Physics monitor

Neutrino sunshine

On 10 June 1992, at the Neutrino 92 meeting in Grenada, Spain, Till Kirsten of Heidelberg's Max Planck Institute reported that neutrinos from sunshine had been seen.

Most of the energy pumped out by the Sun comes from the fusion of protons into alpha particles, a process which also liberates neutrinos. While it takes about a million years for radiant energy formed in the deep interior of the Sun to fight its way to the surface, the highly penetrating neutrinos emerge almost immediately.

It was in 1970 that Ray Davis and his team began taking data with a tank containing 615 tons of perchloroethylene (dry cleaning fluid) 1500 metres underground in the Homestake gold mine, South Dakota.

The observed signal is consistently smaller than what is expected. This 'solar neutrino problem' was confirmed by the Kamioka mine experiment in Japan, looking at the Cherenkov light released by neutrino interactions in some 700 tons of water.

However these experiments are only sensitive to a tiny high energy tail of the solar neutrino spectrum, and to understand what is going on needs measurements of the primary neutrinos from proton fusion.

To get at these neutrinos, two large new detectors, using gallium and sensitive to these lower energy particles, have been built and commissioned in the past few years. The detectors are SAGE ('Soviet' American Gallium Experiment) in the Baksan Neutrino Observatory in the Caucasus, and Gallex, a team from France, Germany, Israel, Italy and the US in the Italian Gran Sasso underground Laboratory.

At Grenada, Kirsten reported unmistakeable signs of solar neutrinos of proton origin recorded in Gallex.

SAGE and Gallex do not yet have enough data to unambiguously fix the level of primary solar neutrinos reaching the Earth, and the interpretation of the interim results tends to be subjective.

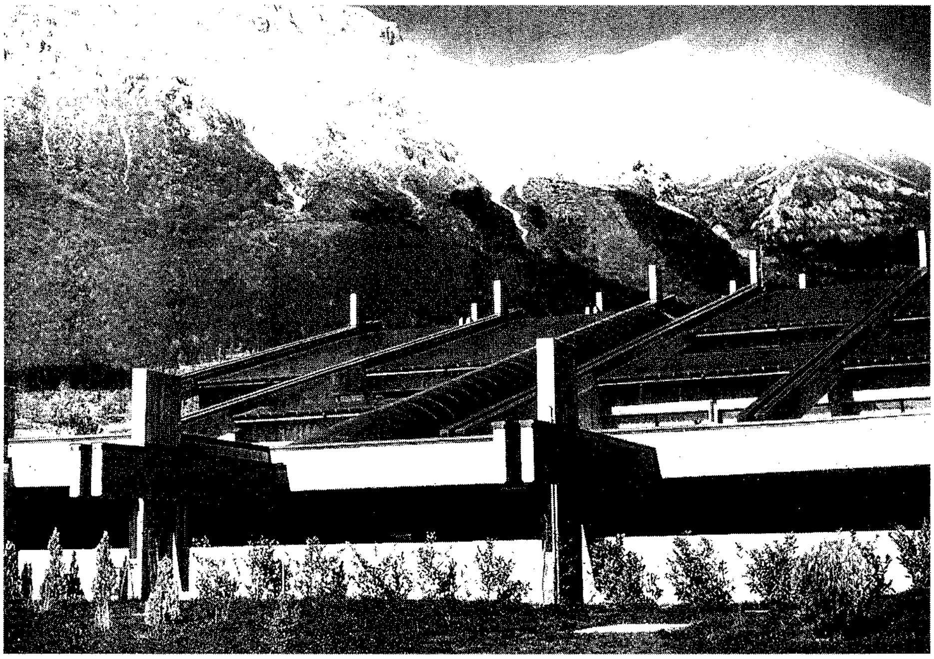
However after 23 years of conditioning through watching the solar neutrinos' high energy tail, the prospect of a neutrino deficit is taken very seriously, and has led to ideas of neutrino oscillations, and oscillation resonances.

If the different neutrino varieties - electron, muon and tau - have a mass, then they can oscillate between themselves. A neutrino beam starting off as pure muon-type, for example, would change its composition as it went along. Setting limits on this behaviour is an important objective in neutrino experiments, with 'long baseline' studies - beams covering a long distance between source and detector, playing a vital role.

Lincoln Wolfenstein, one of the architects of the new neutrino oscillation scenarios, says 'it is still not clear whether neutrinos have masses or not'. Laboratory experiments try to measure these masses, but so far only upper limits have been established. These studies are beginning to reach the limit of their sensitivity and are unlikely to improve drastically. 'But there is indirect evidence,' says Wolfenstein, 'that neutrinos are much lighter.' 'The solar neutrino problem is really to solar neutrino opportunity,' he continues.

Future experiments with gallium and other new neutrino detection techniques, coupled with new high energy neutrino studies, will answer the question.

Exterior of the Italian Gran Sasso underground Laboratory, home of a range of ongoing experiments homing in on extraterrestrial neutrinos.



UNIVERSITY OF OXFORD

Department of Physics

Research Associateship on ZEUS

Research Support 1A - Salary £ 12,828 to £ 20,442

Applications are invited for a Research Associate position to work in the ZEUS group at the University of Oxford. The successful candidate would be expected to work on matters relating to the ZEUS Central Tracking Detector for which Oxford has major responsibilities. It would also be expected that the candidate becomes involved in physics analysis of ZEUS data, the broad range of interests within the group include deep inelastic scattering and exotic physics. The experiment is located at DESYand although the successful applicant would be based at Oxford, he/she should be prepared to spend significant periods of time in Hamburg, The appointment, which is funded by the SERC, will becomes available from 1st October 1993 and would be for 2 years in the first instance.
Applicants should have obtained, or be about to obtain, a PhD in Experimental Particle Physics or a related topic. A knowledge of high-speed readout and data acquisition systems would be an advantage but certainly not essential.
Letters of application supported by a full CV should be addressed to :

Mr. P F Dobbs
Deputy Administrator
Department of Physics
Nuclear Physics Laboratory
Keble Road
Oxford OX1 3RH

Applicatnts should also arrange for 2 references to be sent to the same address by the closing date which is 30 November 1993.

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Postdoc Position

At the National Institute for Nuclear Physics and High Energy Physics (NIKHEF) the Pulse Stretcher/Storage Ring AmPS recently came into operation. This electron ring will operate in the energy range 250-900 MeV. The circumference of AmPS is -200 m. Its injector (MEA) is a 200 m. long electron linac.

AmPS was originally designed to increase the duty factor of the facility (Pulse Stretcher option) from 1% to 80%. The high-duty factor beam is used to perform nuclear physics coincidence scattering experiments.
An internal gas-jet target is installed in the machine as well; this setup will use the stored beam of AmPS (Storage Mode option).

Recently a proposal to investigate the possibility to implement a VUV FEL into the AmPS ring was approved by our funding agency F.O.M. To carry out this feasibility study we invite applicants with experience in the field of storage-ring FELs, optical klystrons and beam dynamics. The successful candidate will be appointed for a maximum period of 18 months.

Candidates with a Ph.D. who fulfil the above-mentioned requirements are invited to send their CV to: Mr. T. van Egdom, head of the Personnel Department, NIKHEF, PO Box 41882, 1009 DB Amsterdam, the Netherlands.
Information on this position can be obtained from dr. R. Maas, phone 31.20.5922087 (or 5922142), e-mail: robm@paramount.nikhefk.nikhef.nl.

NIKHEF

Faculty Opening in Physics
University of California at Berkeley

The Physics Department of the University of California at Berkeley, pending budgetary approval, intends to make one (or more) faculty appointment(s) effective July 1, 1994. Candidates from all fields of physics will be considered, but those in the fields of atomic physics, experimental particle physics and particle theory are especially encouraged to apply. Appointment(s) at the tenure-track assistant professor level are preferred, but tenure level appointments will also be considered.
Please send a curriculum vitæ, bibliography, statement of research interests, and a list of references to **Professor Herbert Steiner, Chairman, Department of Physics, University of California, Berkeley, CA 94720**, before December 10, 1993. Applications submitted after the deadline will not be considered. The University of California is an Equal Opportunity, Affirmative Action Employer.

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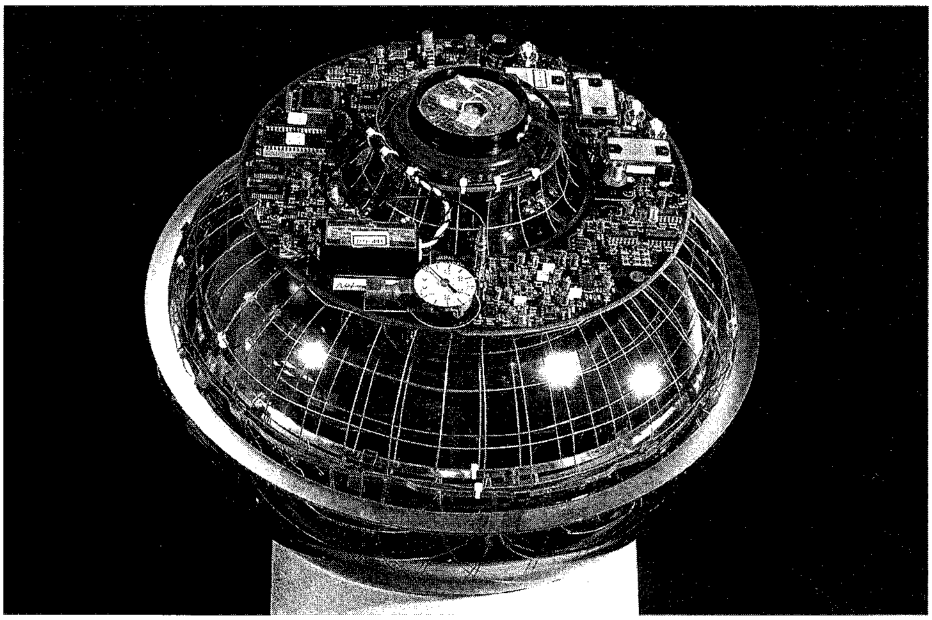
The vacancies exist for computer scientists or physicists with PhD or equivalent, who are younger than 32, and who would like to work on the development, the implementation and operation of

the automation of central computing and networking by making use of OOP and expert systems,
high speed networking, mass storage environment, and data management.

Both topics will require experience with UNIX in addition to the techniques mentioned above. For the first topic experience with operating systems such as MVS and VMS will be needed as well.
The appointments will be for a three year period with a salary according to the principles of the German civil services (IIa MTV Ange stellte). Applications including a curriculum vitæ with special emphasis on computing, bibliography, and the names and addresses of three referees should be sent before November 30, 1993 to :

DESY Personalabteilung
Notkestrasse 85
D - 22603 HAMBURG
Tel. : 0049-40-8998 3628

Optical detector module for the DUMAND underwater scheme with its upper glass pressure vessel removed and showing the coarse wire mesh of the magnetic screen.



UNDERWATER
The tide turns....

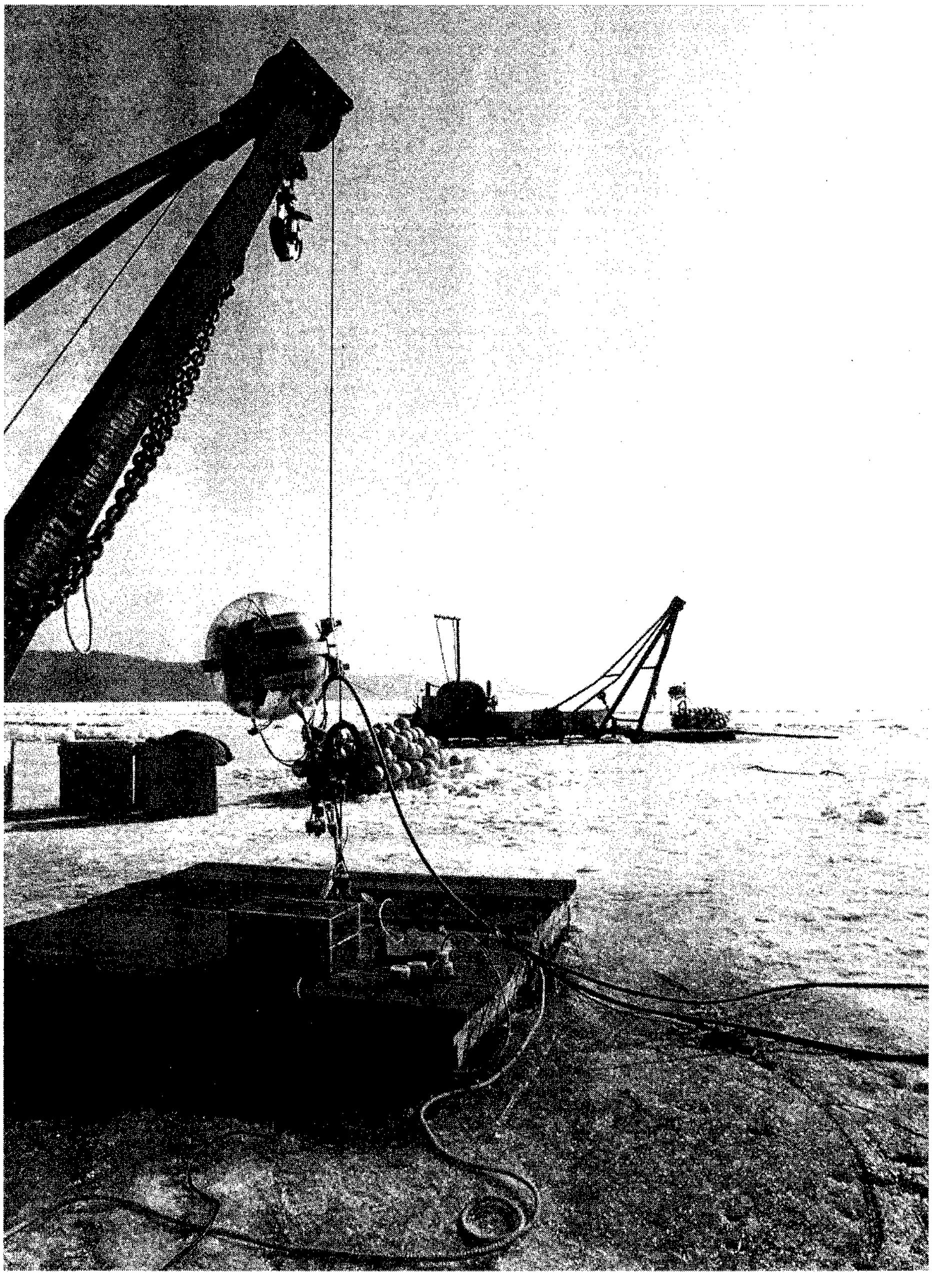
In the late 1970s, attempts to synthesize quark and electroweak forces into one 'grand unified theory' predicted that the proton might occasionally decay. To search for this instability, new experiments were built, notably the Irvine/Michigan/ Brookhaven (IMB) study in the US and the Kamiokande project in Japan.

To search for proton decay, both these experiments used large tanks of water, where passing high energy particles produce characteristic Cherenkov radiation, picked up by arrays of photosensitive detectors.

While no sign of proton decay was seen, it became clear that these huge detectors could also pick up other particles, their big moment of glory coming in 1987 when they recorded hits by neutrinos from outside the solar system - particles released by the 1987 supernova.

However before grand unification had been seriously considered, the potential of water for catching extraterrestrial neutrinos had been realized. The clearest known natural waters are in the deep oceans, and the idea was to suspend strings of photosensitive detectors in the sea.

As well as catching neutrinos, such detectors could also solve one of the big open questions of astrophysics - the origin of very high energy cosmic rays. The cosmic accelerators producing these cosmic rays can be localized only by electrically neutral particles like neutrinos or photons,



Preparing to immerse components of the Baikal neutrino telescope from the thick winter ice layer. The glass spheres contain 37-cm diameter photomultipliers.

since charged particles get tangled up in galactic magnetic fields. Two sources of TeV gamma rays have been recently identified: the Crab pulsar and the active galaxy Markarian 421, giving hope that point sources might also be found with underwater neutrino detectors.

Early to 'get off the ground' was DUMAND off Hawaii, where construction is now underway for nine strings, each about 350 metres long, containing 216 optical modules. The first strings are now being deployed using a submarine, and the full configuration should be in operation next year. The neutrino target will be about 2 Megatons, with some 20,000 square metres of active area to pick up muons released in neutrino hits.

Since April a deep underwater Cherenkov detector has been operating in the clear water of Lake Baikal, Russia. It consists of 36 optical modules in three vertical strings at 1.1 km depth. The detector, christened "NT-36", is the first step towards a neutrino telescope of 192 modules ("NT-200").

NT-36 was deployed despite the many complications due to the economic plight in Russia. Its three strings are held by an umbrella-like frame, positioned in 1992 and which will eventually carry the full array with eight strings, each twice as long as the present ones.

The array consists of 37-cm diameter photomultipliers produced in Novosibirsk. The devices, named QUASAR, have an excellent time resolution of 2 nsec. Time calibration uses two nitrogen lasers positioned several metres above the array. The basic telescope trigger is tailored to record relativistic muons. In addition, a special logic scans the data for patterns typical of slowly moving, 'bright' particles such as magnetic monopoles or strange quark nuggets.

The muon sensitivity of underground and underwater arrays depends on their effective area. For NT-36, this amounts to 270 square metres for 1 TeV muons and to about 1000 square metres for 10 TeV muons. The latter figure is just the effective area of the presently biggest underground neutrino telescope, the MACRO detector in the Gran Sasso Laboratory.

Already 30 million muons have been recorded with this first multistring underwater detector. Their zenith angular distribution is satisfactorily described by the known parametrizations for muons generated in the atmosphere a dozen kilometers above the array. However there remains a small number of events, about a tenthousanth of the total sample, corresponding to upward moving muons. These resemble neutrino events which are in fact a hundred times rarer. Sufficient reconstruction power to identify genuine neutrino events is expected with the 96-photomultiplier array which will be deployed next Spring. However a suppression factor of 10^{-4} is considered encouraging for such a small test array.

As well as allowing Baikal physicists to check the complete electronics system, NT-36 gives the first possibility to check numerous simulations of underwater muon reconstruction and background rejection.

The Baikal collaboration includes

For the NESTOR underwater neutrino project, a Greek/Russian group surveyed the coastal waters off Pylos, Greece, in 1991, deploying a prototype umbrella-like phototube module.

UNIVERSITY OF OXFORD

Department of Physics

Research Officer

Salary £ 12,828 to £ 20,442

There is a rare opportunity for a well qualified and highly motivated Physicist to joint the Particle and Nuclear Physics group in the Department of Physics at Oxford. The department is the largest in the UK, with a wide-ranging and very active research programme. The present research programme includes experiments with the DELPHI detector at LEP (CERN) and the ZEUS detector at HERA (DESY); the SOUDAN 2 experiment on proton decay; measurement of neutrino mass; the Sudbury solar neutrino project, the development of cryogenic detectors. The successful applicant would be expected to participate in the above programmes and contribute to the teaching activities of the department. An appointment will be made as soon as possible and would be for 3 years in the first instance, with the possibility of extension for a further 2 years.

Letters of application supported by a full CV, list of publications and a statement of research interests should be sent to : **Professor R. J. Cashmore Head of Particle and Nuclear Physics,Nuclear Physics Laboratory, Keble Road Oxford OX13RH**

Applicants should also arrange for 3 references to be sent to the above address by the closing date, which is **30 November 1993**.

This is a re-advertisement Previous applicants need not re-apply.

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Universität Heidelberg

Am Physikalischen Institut ist zum frühestmöglichen Termin eine

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Bewerbungen mit den üblichen Unterlagen sind zu richten an den **Dekan der Fakultät für Physik und Astronomie, Albert-Überle-Str. 11, D - 69120 Heidelberg.** - Die Fakultät bemüht sich um eine Erhöhung des Frauenanteils in Forschung und Lehre und bittet qualifizierte Wissenschaftlerinnen besonders um ihre Bewerbung.

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Des offres écrites avec des traductions de textes déjà effectuées sont à présenter au rédacteur du Courrier CERN,

Gordon Fraser
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CH -1211 Genève 23 (Suisse)

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several Russian institutes, notably the Moscow Institute of Nuclear Research and the universities of Moscow, Irkutsk and Tomsk, as well as DESY-IfH in Zeuthen, Germany, and KFKI Budapest.

In neutrino studies, detector size is all important. The newest entry into the underwater field is NESTOR (November 1992, page 16), where a major array will be deployed by an international team (Athens/Moscow/Florence) off historic Pylos, S-W Greece.

They also plan an atmospheric neutrino oscillation experiment, and enjoy the fortunate geographic coincidence that CERN, the Italian Gran Sasso underground Laboratory and Pylos lie in a straight line! NESTOR's location on the other side of the globe to DUMAND will make for complementary sky coverage.

With 1994 seeing deployment of detectors at all three sites, next year might turn out to be the turn of the tide for deep underwater neutrino detectors.

Not strictly underwater is AMANDA, a project to locate detectors in the deep clear ice at the South Pole, where existing infrastructure can handle the drilling, although the diameter of the shafts might limit the size of the photomultipliers used.

Surface arrays provide another route to water-based neutrino detection, where a number of proposals are being groomed.

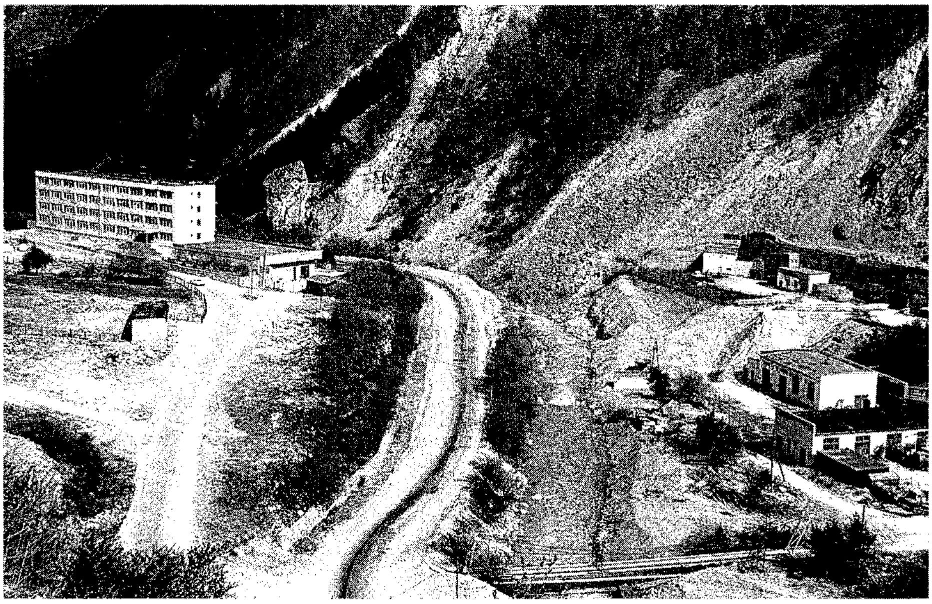
UNDERGROUND

Cossetted deep underground, sheltered from cosmic ray noise, has always been a favourite haunt of neutrino physicists. Already in the 1930s, significant limits were obtained by taking a geiger counter down in Holborn 'tube' station, one of the deepest in London's underground system.

Since then, neutrino physicists have popped up in many unlikely places - gold mines, salt mines, and road tunnels deep under mountain chains. Two such locations - the IMB (Irvine/Michigan/Brookhaven) detector 600 metres below ground in an Ohio salt mine, and the Kamiokande apparatus 1000m underground 300 km west of Tokyo - picked up neutrinos on 23 February 1987 from the famous 1987A supernova.

Purpose-built underground laboratories have made life easier, notably the Italian Gran Sasso Laboratory near Rome, 1.4 kilometres below the surface, and the Russian Baksan Neutrino Observatory under Mount Andyrchi in the Caucasus range. Gran Sasso houses ICARUS (April, page 15), Gallex, Borexino, Macro and the LVD Large Volume Detector, while Baksan is the home of the SAGE gallium-based solar neutrino experiment.

Elsewhere, important ongoing underground neutrino experiments include Soudan II in the US (April, page 16), the Canadian Sudbury Neutrino Observatory with its heavy water target (January 1990, page 23), and Superkamiokande in Japan (May 1991, page 8).



The Baksan Gorge in the Caucasus mountains, Russia. On the right is the entrance to the four-kilometre tunnel leading to the Baksan Neutrino Observatory experimental area, thousands of metres under Mount Andyrchi.

Bruno Pontecorvo 1913-1993.

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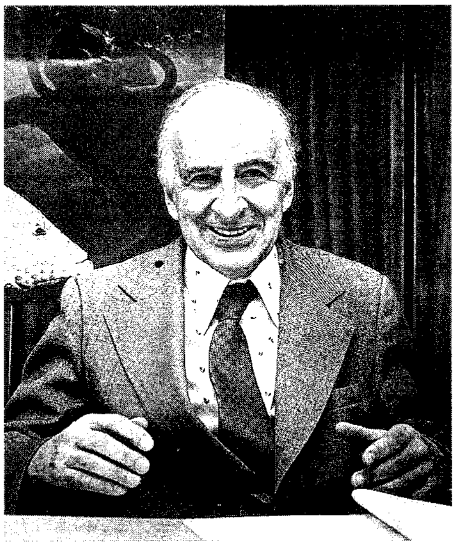
Bruno Pontecorvo 1913-1993

Academician Bruno Pontecorvo, one of the outstanding physicists of our times, died on 24 September 1993 at the age of 80. He was born on 22 August 1913 in Pisa, Italy. As a student he was noticed by Enrico Fermi and admitted to his world-famous group in 1933, where he participated in the classical investigations of slow neutrons which paved the way for practical applications of nuclear power.

In 1936 Pontecorvo joined Joliot-Curie's group in Paris, again participating in research which laid a foundation for modern nuclear physics, and making significant discoveries of his own. From 1940-42 he worked in the USA, where he devised and introduced a neutron logging technique which is still used in oil prospecting. Then he worked in Canada, the UK (Harwell), and in 1950 moved to the Soviet Union, immediately joining the research at the world's then most powerful synchrocyclotron, which had just been put into operation at Dubna.

Pontecorvo had an impressive ability to generate profound ideas and show how they could be applied. From the middle 1940s he concentrated on weak interaction physics, especially neutrinos. In 1946, while still at Chalk River, he proposed the chlorine-argon method for radiochemical detection of neutrinos which went on to become a powerful tool in the discovery and subsequent study of solar particles.



In 1947, following the discovery of the muon, he proposed the idea of a 'universal' weak interaction for electrons and muons. Ten years later, when he was in residence in the Soviet Union, came another outstanding neutrino contribution - his idea to look for muon neutrinos. This involved using high energy accelerators to produce pions, which decay predominantly into muons and neutrinos, and so obtain an artificial beam of high energy neutrinos. This led to the classic experiment at Brookhaven by Leon Lederman, Jack Steinberger and Mel Schwartz which showed that such accelerator-produced neutrinos gave muons rather than electrons. Pontecorvo's suggestions were acknowledged when the trio received their 1988 Nobel physics prize. Later came a third major Pontecorvo neutrino suggestion, the idea of oscillations.

He was also an influential personality and teacher. For some 20 years he headed the elementary particle physics section at Moscow State University. His presence during discussions of new ideas or results created fertile ground for new research challenges. Especially significant was his fruitful contribution to the creative atmosphere and development of research fields at the Joint Institute for Nuclear Research in Dubna, where he worked, and at the

Institute of High Energy Physics in Protvino, with which he had close contact.

His outstanding ability brought international recognition. He was awarded the State Prize and the Lenin Prize, became a Corresponding Member of the USSR Academy of Sciences in 1958 and a Full Member in 1964. He was elected a foreign member of the Italian Academia dei Lincei.

Those who knew him were charmed by his friendliness and consideration, and impressed by his dedication to science and his clear and critical mind, and by his great tact in relations with people, his modesty and his culture.

As well as being a brilliant scientist, he was also exceptionally gifted in other spheres, from sport to writing. He was a man with a high sense of duty who had a difficult but vivid life. Our memory will always be of a great scientist and a remarkable person.

(From a contribution by his Dubna colleagues)

Ruhr-Universität Bochum

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wieder zu besetzen.

Es wird vorausgesetzt, dass sich die Stelleninhaberin oder der Stelleninhaber angemessen an der Physikausbildung von Haupt- und Nebenfachstudenten beteiligt und insbesondere die Kern- und Schwerionen-Physik vertritt. Das Forschungsgebiet soll die Kernphysik im Mittelenergiebereich sein, insbesondere an Beschleunigern wie COSY (Jülich) und ELSA (Bonn). Erfahrungen und Experimenten an Grossgeräten sind erwünscht. An der Universität selbst stehen die Niederenergiebeschleuniger des Dynamitron Tandem Laboratoriums für Forschungszwecke zur Verfügung.
Habilitation oder gleichwertige Qualifikation werden vorausgesetzt. Bewerbungen mit Lebenslauf, Schriftenverzeichnis und Angabe der bisherigen Lehrtätigkeit werden bis zum 30. November 1993 an den Dekan der Fakultät für Physik und Astronomie der Ruhr-Universität Bochum, Postfach 10 21 48, D - 44780 Bochum, erbeten.
Die Rurh-Universität Bochum bemüht sich um die Förderung von Frauen in Forschung und Lehre. Die Bewerbung Schwerbehinderter ist erwünscht.

UNIVERSITY OF OXFORD
Department of Physics

Professorship of experimental physics

The electors intend to proceed to an election to the Professorship of Experimental Physics, with effect from 1 October 1994 or such later date as may be arranged. The stipend of the professorship is currently £34,984; a pensionable allowance (currently £6,090) will be added in respect of the duties as head of the Sub-department of Particle and Nuclear Physics for any periods during which these are assigned to the professor. Professor R.J. Cashmore has been assigned the headship until 30 September 1996.
A non-stipendiary professorial fellowship at St. Catherine's College is attached to the professorship.
Applications (ten copies, or one from overseas candidates), naming three referees, should be received not later than 29 November 1993 by the Registrar, University Offices, Wellington Square, Oxford OX1 2JD, from whom further particulars may be obtained.

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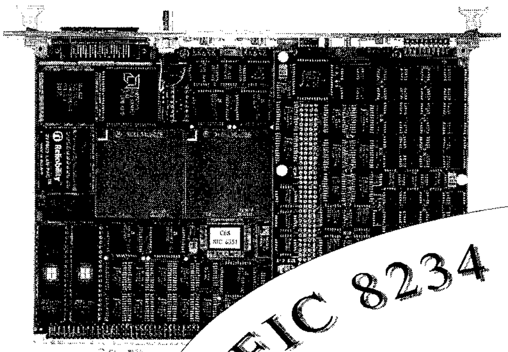

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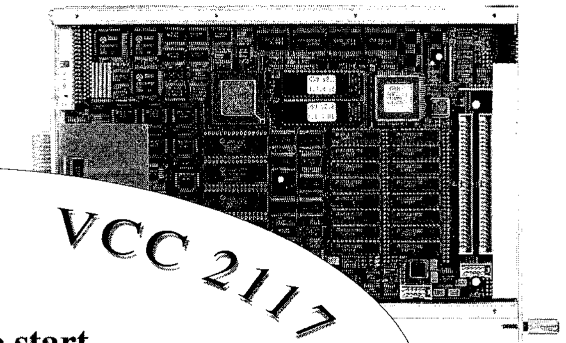

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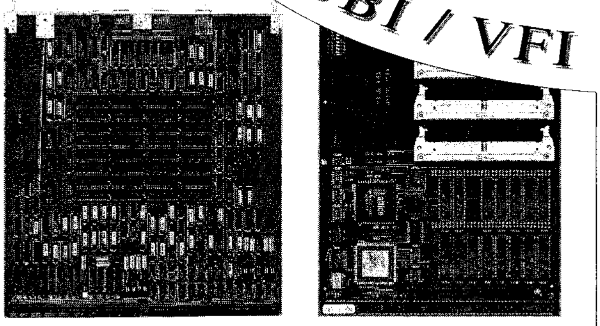

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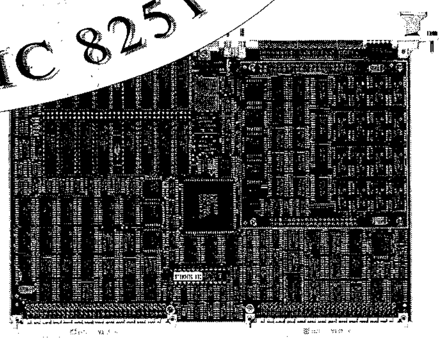

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