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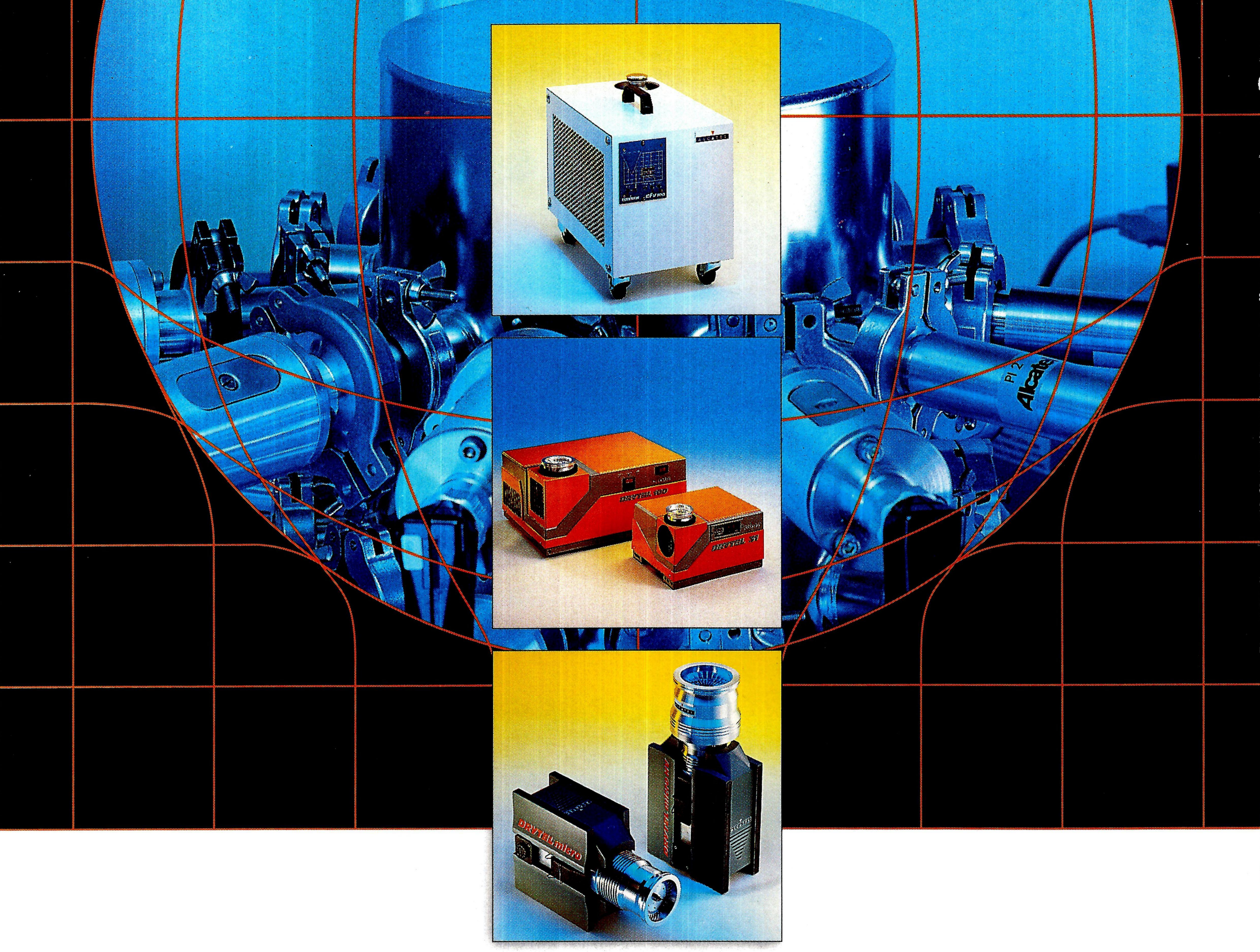

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Cover photograph: A view of the new science exhibition 'Infinitos' illustrating our current understanding of the Universe on all scales, from the innermost structure of matter to the far flung galaxies. A new joint venture by CERN and the European Southern Observatory (ESO), it was formally opened in Lisbon on 22 April in the context of Lisbon's programme as 1994 European City of Culture. The joint CERN/ESO exhibition will go on to visit other European cities, beginning with Berlin and Stockholm.

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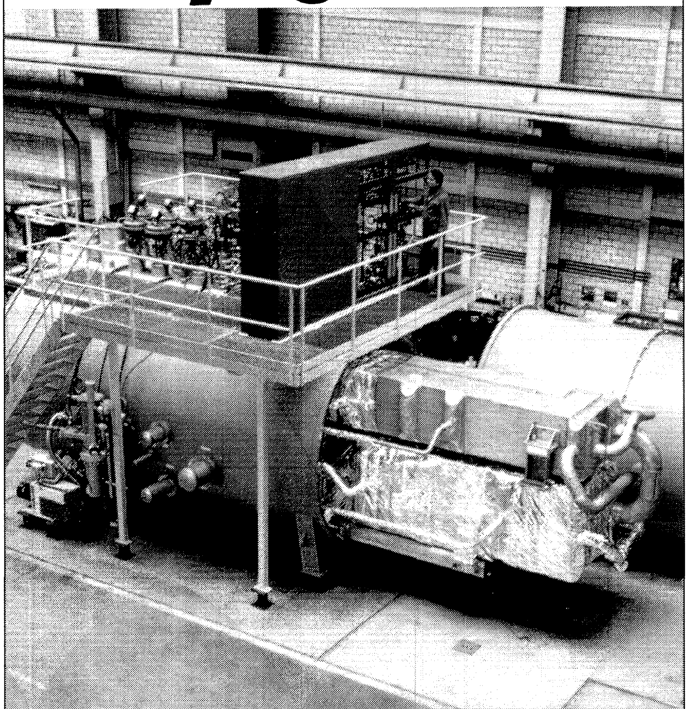

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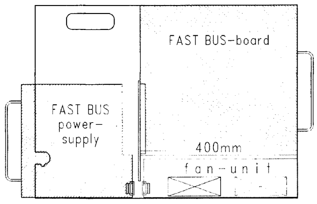

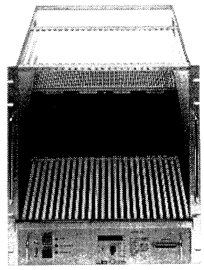

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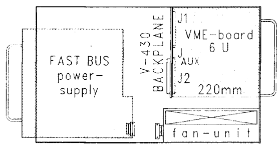

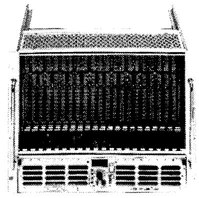

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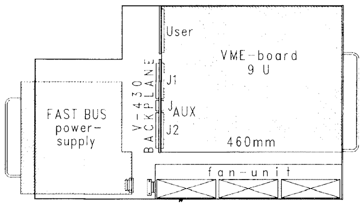

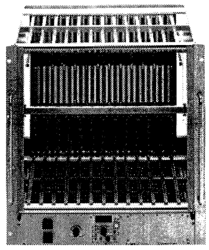

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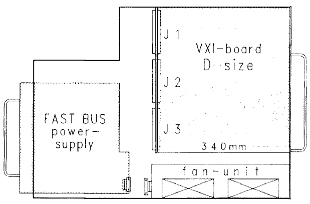

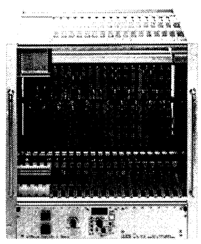

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The top in sight

At a media briefing at Fermilab on 26 April, Melvyn Shochet of the University of Chicago, co-spokesman for the CDF experiment at Fermilab's Tevatron proton-antiproton collider, presents evidence for the sixth - top - quark.

On 22 April, after many months of careful analysis, the CDF collaboration at Fermilab's Tevatron proton-antiproton collider proudly submitted a 150-page paper to The Physical Review reporting evidence for the top quark. At a Fermilab seminar four days later, CDF co-spokesmen Melvyn Shochet of the University of Chicago and William Carithers of Lawrence Berkeley Laboratory described the analysis of a trillion proton-antiproton collisions which had netted a dozen candidate top events.

The top quark, the partner of the bottom quark discovered at Fermilab in 1977, is required if the Standard Model of particle interactions (see page 4) is correct. At the Tevatron, top quarks are produced in pairs. Each top quark promptly decays into a bottom quark and a W boson, the carrier of the weak nuclear force.

CDF used data collected between August 1992 and June 1993 for three top quark searches, differing in the way the W bosons and bottom quarks are observed. In each search, top candidates emerge from the background non-top processes that can mimic top decay. When the three searches are combined, the excess is statistically more significant. Although the total excess could be a rare statistical fluctuation, it is natural to interpret it as evidence of top quark production.

When interpreted this way, the top quark mass is 174 GeV, with an uncertainty of 17 GeV - the top quark is almost as heavy as an entire gold nucleus! It has yet to be explained why the top quark is far heavier than any other elementary particle yet observed.

Another Tevatron Collider run has recently started. If the accelerator can continue to run for the next 15 to 24 months, the sample of data could increase by a factor of five or more, allowing the effect to be confirmed and the mass uncertainty to be more than halved. Measuring the properties of the top quark is now a major physics priority, and for the next decade this work can only be carried out at Fermilab's Tevatron, the world's highest energy accelerator.

The search for the top quark

At Fermilab, top quarks can be created by the energy released in proton-antiproton collisions. When this happens, a top quark and its antimatter partner, the top antiquark, are released together. The top quark decays almost immediately into its quark pair partner - a bottom quark, together with a W boson, the carrier of the weak nuclear force. The W, in turn, also rapidly decays into any of the quark or lepton pairs, for example an electron and an electron-neutrino. Each final quark is seen as a collimated jet of particles in the detector.

The CDF experimenters searched for the top quark in three ways. In the first, events were sought in which the W bosons from both the top quark and the top antiquark decayed into lepton pairs, either electron and electron-neutrino or muon and muon-neutrino. Two such events were observed compared to the expected background of approximately one half of an event.

The other two methods searched for events in which one of the two W bosons decayed into an electron and electron-neutrino or a muon and muon-neutrino, with the other W decaying into a quark pair. The expected rate of such top events is considerably larger than in the first search mode, but there is also more background. To reduce this background, both the second and third searches identify one or more of the produced b quarks.

The second search looked for the

small flight distance a b quark travels before it decays. Six such events were observed, compared to an expected background of approximately two.

The third search looked for an electron or a muon from the decay of a b quark. Seven such events were seen, compared to three expected background events. (Three of the events seen in the third search were also caught by the second method.)

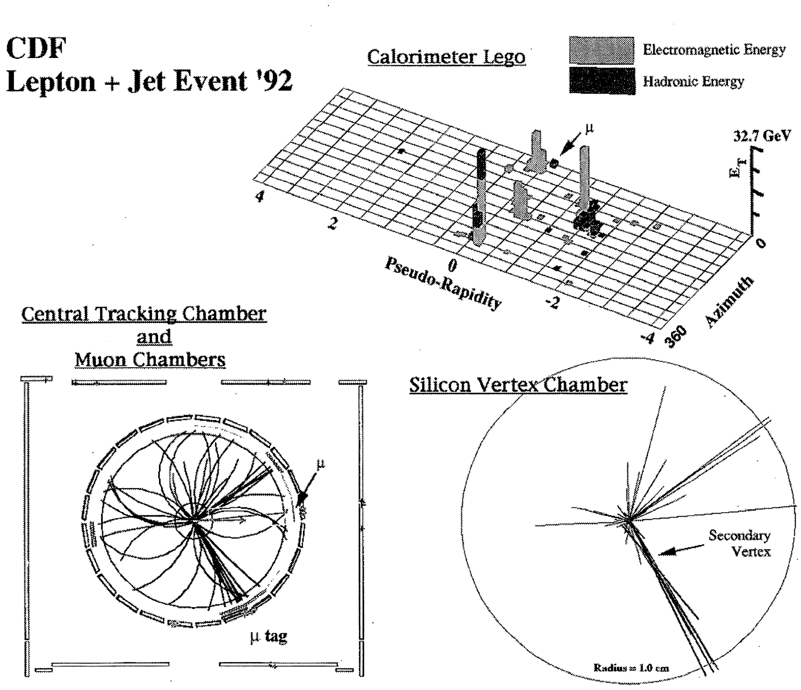
The probability that the background could fluctuate up to at least the number of events observed is one in four hundred. Although this appears very small, scientists generally need to be more confident, and more data is needed to confirm the top quark.

To exploit the different kinematic features expected in top quark and background events, an additional analysis looked for events with the expected features of top quark production. An excess of such events over background included many of the events with an identified b quark.

Seven of the events have enough information to allow the top quark mass to be calculated. Six cluster between 160 and 190 GeV, and together they give a top quark mass of 174 ±17 GeV, close to the centre of the top mass range predicted by the Standard Model using precision data from Z boson decay at CERN and SLAC, W boson decay at the Fermilab Collider, and neutrino interactions at Fermilab and CERN.

The CDF data were in hand over nine months ago and candidate top quark events were soon identified, with the candidate sample becoming stable in August. Then much of the CDF effort on the top quark search became focused on background processes that can mimic a top quark event.

It is the complexity of top quark events that makes this background so difficult to handle. Once elementary particle discoveries could be based on a few particle tracks. The heavier the parent particles, the more offspring they can produce, and the top, the heaviest of them all, is the most prolific. In addition, a proton-antiproton collision produces other particles, as well as a top quark and a top antiquark. Each top quark then quickly decays into a bottom quark and a W boson. However these particles are also unstable and thus decay into electrons, muons, neutrinos, pions, kaons, etc. For a typical top quark event approximately 100 particles enter the CDF detector. This background was the subject of painstaking analysis and continual discussion, and the lessons learned will continue to be useful in the search for other rare particles.



Top quark candidate event display from the CDF detector at Fermilab's Tevatron. The top quark does not live long enough to be visible directly. However one of the top quarks from a quark-antiquark pair decays into a b quark which is seen to decay in the silicon vertex chamber (bottom right) close around the beam pipe, while the muon from this decay is also identified (bottom left). The calorimeter lego plot shows how the detector resolves individual jets from quark processes. Unravelling the kinematics gives a top mass of 169±10 GeV.

The CDF experiment contains approximately 100,000 individual particle detectors around the proton-antiproton collision point. Most of the apparatus was constructed between 1981 and 1987 with funds provided by the US Department of Energy, the Italian Institute for Nuclear Physics (INFN), the Japanese Ministry of Science, and the US National Science Foundation. Improvements were added in 1988, 1992, and this past summer. The collaboration currently consists of over 440 physicists, including 142 graduate students from the United States, Italy, Japan, Canada, and Taiwan.

(The D0 collaboration, CDF's companion experiment at the Tevatron, has seen a few similarly interesting events but these do not emerge significantly from the background.)

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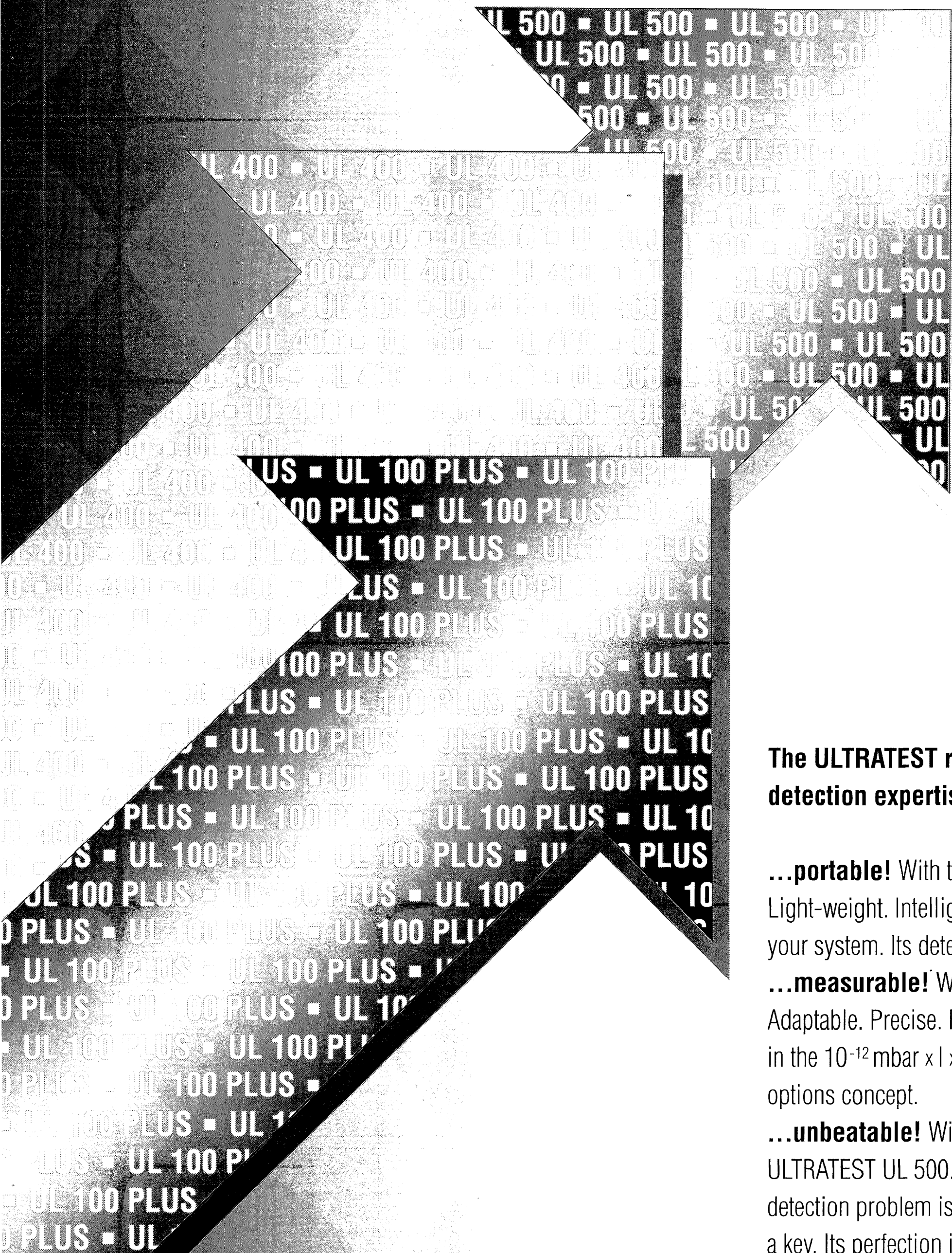

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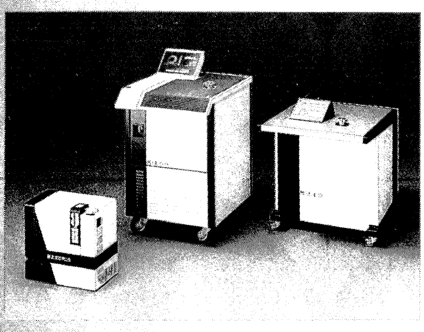

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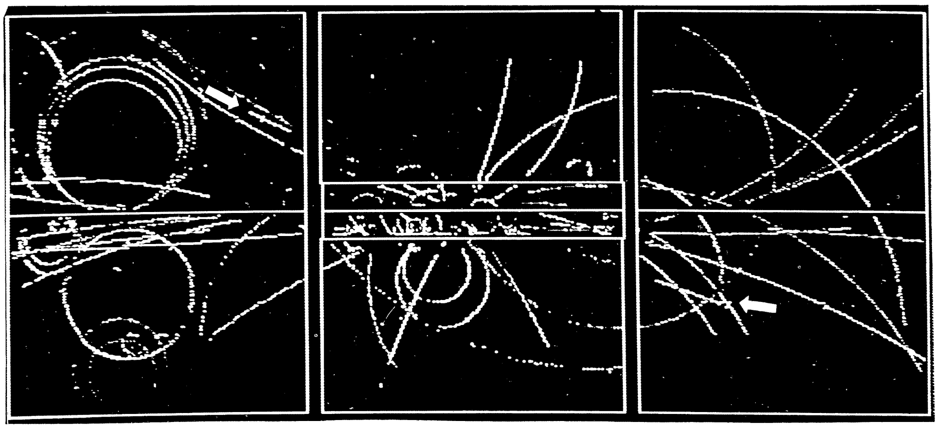
The Standard Model

by Christine Sutton

In May 1983, the central detector of the UA1 experiment at CERN's proton-antiproton collider showed the tell-tale signature of the long-awaited Z particle as it decays into an electron-positron pair (arrowed). As the electrically neutral carrier of the weak force, the Z^0 plays a vital role in the Standard Model.



The initial evidence from Fermilab (see previous article) for the long awaited sixth ('top') quark puts another rivet in the already firm structure of today's Standard Model of physics. Analysis of the Fermilab CDF data gives a top mass of 174 GeV with an error of ten per cent either way. This falls within the mass band predicted by the sum total of world Standard Model data and underlines our understanding of physics in terms of six quarks and six leptons.
In this specially commissioned overview, physics writer Christine Sutton explains the Standard Model.

It is nearly 100 years since the discovery of the first subatomic particle, the electron, which we still recognize as one of the basic building blocks of matter. Since then research has revealed a rich "microworld" of particles, from protons and neutrons to quarks, gluons, and W and Z particles. The field has flourished particularly during the past 40 years, culminating today in what we call the Standard Model of particle physics.

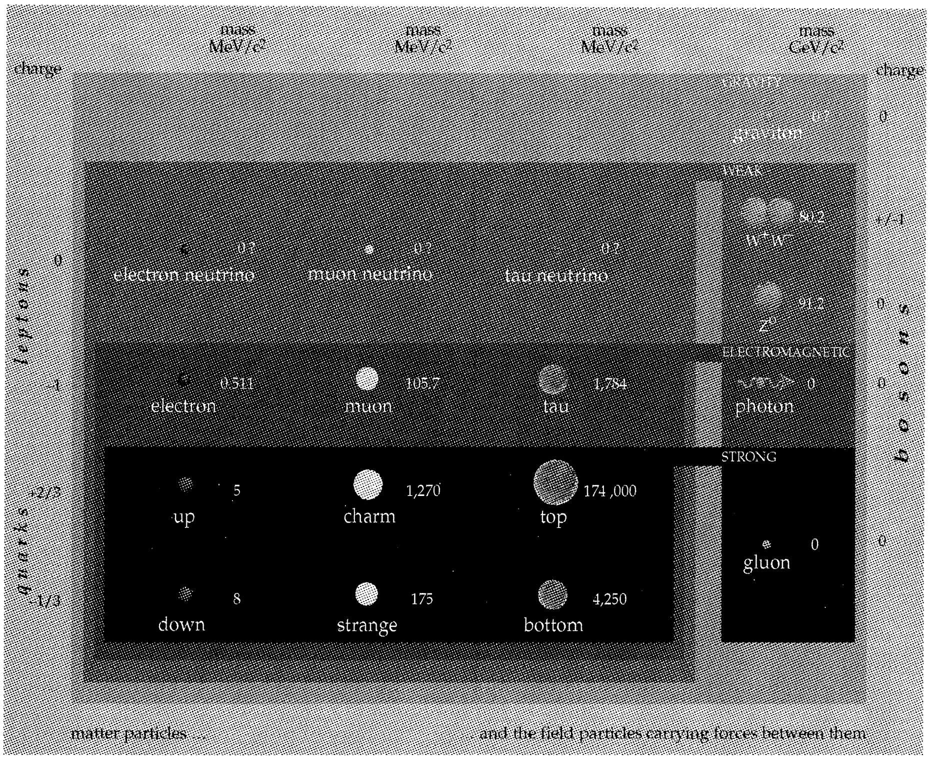
Standard models arise in many different parts of science. They provide a basis for understanding the behaviour of a particular system. The Ancient Greeks, for example, had their own standard model of matter built from four "elements" - earth, fire, air and water - with which they tried to explain various phenomena in the world about them. Nowadays, astrophysicists talk of a "standard solar model", which follows the evolution of the Sun from an initial prescription to its present state.

In particle physics, the Standard Model encompasses all the elementary particles we now know and three of the fundamental forces. The basic building blocks are two sets or "families" or "matter particles" - the quarks and the leptons (see page 5). These particles interact with each other through the exchange of force carriers or "messengers". (These messengers are also particles, but they are distinct from matter particles as we shall see.) The three forces of the Standard Model are the electromagnetic force, which acts only on charged particles; the strong force, which acts only on quarks and is ultimately responsible for binding protons and neutrons within the nucleus; and the weak force which acts upon all quarks and leptons, including those with no electric charge, and which underlies radioactive beta-decay. (A fourth force, gravity, remains outside the Standard Model, but this does not invalidate the model as gravitational effects on particles are far smaller than the effects of the other forces.)

The Standard Model is a synthesis of our present understanding of the quarks and leptons and the forces that act upon them. The key word here is "synthesis", for the model is not an elegantly hewn theory from which the quarks and leptons and their interactions emerge. Instead it is an amalgam of the best theories we have, which we can bolt together because they have enough in common to suggest an underlying unity, although due to our ignorance the joins still clearly show.

The structure as a whole rests on a single theoretical framework known as quantum field theory. This has its roots in attempts to understand the most familiar of the three forces of the Standard Model, the electromagnetic force, which acts upon anything with an electric charge. The charge is the source of an electromagnetic field, and it is our understanding of how this field works at a fundamental level that has led to quantum field theory, and the concept of the messenger particles.

Quantum field theory treats the electromagnetic field as a sea of tiny lumps of energy, or photons, the "particles" of light. In electromagnetic radiation, such as visible light, the photons are "real"; in other words, energy is conserved when they are emitted or absorbed. However photons that do not conserve energy can also exist, albeit only temporarily. Their "borrowed" energy must be repaid according to the dictates of Heisenberg's Uncertainty Principle, which limits the time for the "loan" -



The matter particles - quarks and leptons - of the Standard Model. (On the right are the 'messenger' or field particles which carry the different forces of Nature.)

the time between emission and absorption. In this way, the imbalance is not observable, but is masked by the uncertainty inherent in processes that occur at a quantum level. Such photons living on borrowed energy are known as "virtual" photons, and they are the messenger particles of electromagnetism. It is they that carry the electromagnetic force between electrically charged particles.

Quantum electrodynamics (QED), the quantum field theory of electromagnetism, is arguably the best theory we have, the effects of the electromagnetic force being predictable to better than 1 part in 100 million. One of the theory's most important features is its "gauge symmetry", which means that when independent changes to local field values are made at different points in space the equations of QED are not changed. However, this symmetry is ensured only if the quantum description of a charged particle contains an electromagnetic field with its messenger particle; in other words, gauge symmetry demands the existence of the electromagnetic force and the photon! Moreover, the symmetry is intimately linked to the ability to "renormalize" QED, so that it yields sensible, finite results.

The messenger particle must have an intrinsic angular momentum, or spin, of one unit, just as the photon does. Particles that have whole units of spin are known as "bosons", so the photon, which ensures the gauge symmetry of QED, is referred to as a "gauge boson". This property of spin distinguishes the photon (and other messengers) from the matter particles (quarks and leptons) which have half a unit of spin, and are known as "fermions".

QED appears to be much more

Quarks and leptons

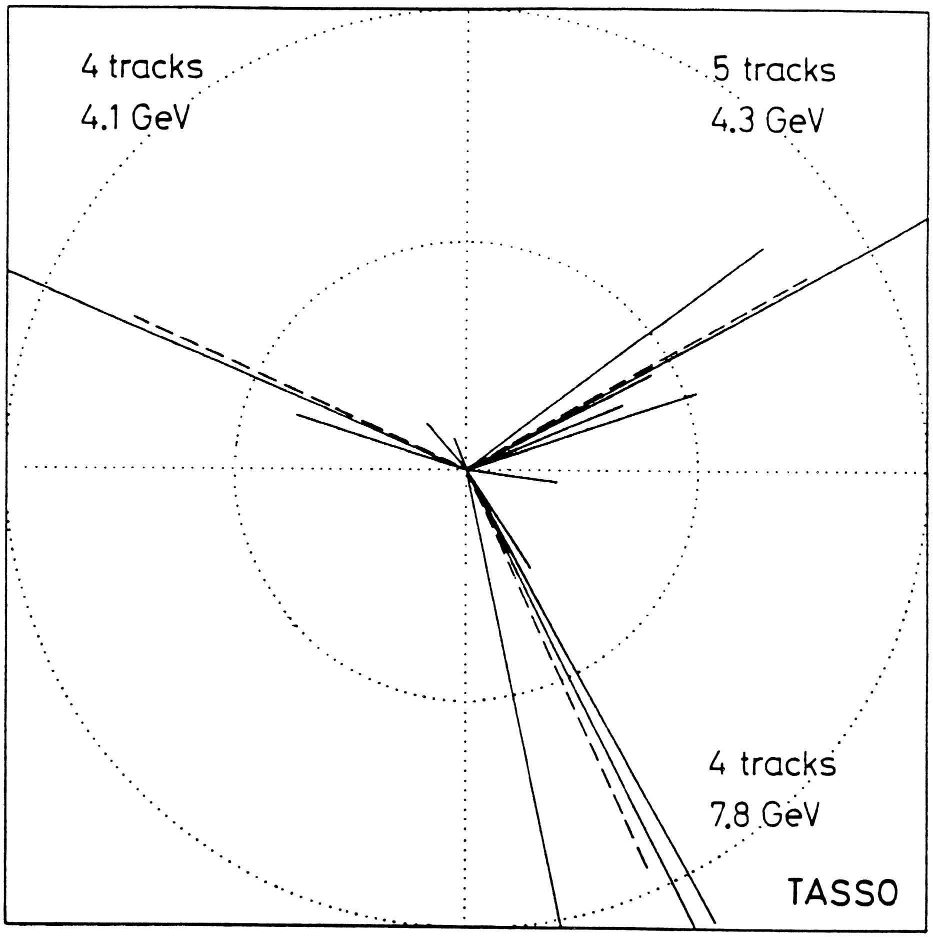
Research in particle physics has revealed a wide variety of subatomic particles, from the long-lived proton and electron to the resonances that live for only 10^{-23} seconds, no longer than it takes for light to cross them. Beneath this rich world, however, lies a deeper simplicity, for we have found that it is built from only two types of building block - the quarks and the leptons.

The quarks are distinguished by the fact that they feel the strong force, and that they carry "fractional" electric charge, either 2/3 or -1/3 the size of the electron's charge. The strong force binds the quarks within the larger clusters we observe as particles. Three quarks form a baryon, such as the familiar proton, while a quark coupled with an antiquark together form a meson, for example the pions and kaons common in cosmic rays and in accelerator experiments.

To make all the known baryons and mesons, five quarks are needed - up, down, charm, strange, and bottom - with the sixth quark - top - completing a pattern of six pairs. Only the lightest quarks of each charge, up (2/3) and down (-1/3), are needed to build the protons and neutrons of everyday matter. Nature however apparently requires the existence of two additional, heavier "generations" of quark pairs - charm and strange, top and bottom.

The lepton family also contains six members, but in this case they can be grouped in pairs with charges -1 and 0. The most familiar lepton is also the lightest charged lepton, the electron. This occurs in stable matter, while its neutral partner, the electron-neutrino, is emitted naturally in beta-decay when radioactive nuclei change to more stable forms. As with the quarks, this pair of leptons is repeated in two more generations, in which the charged member increases in mass. The neutral members - the neutrinos - have little mass by comparison, and may indeed all be massless.

In 1989, some of the first results from the new SLD and LEP electron-positron colliders at Stanford (SLAC) and CERN respectively showed that there are no further types of lightweight neutrino like these to be discovered, and this in turn implies that there are probably no more generations of quarks and leptons like these. Why there are three generations, but no more, is a mystery that remains to be solved.



Evidence for the gluon, the carrier of the strong inter-quark force, emerged in 1979, when the TASSO experiment at the DESY Laboratory, Hamburg, saw three clear sprays, or 'jets', of particles coming from electron-positron collisions in the PETRA collider. Two of these jets come directly from the produced quark and antiquark, while the third is from a gluon radiated by the quark or the antiquark.

than an arbitrarily successful theory. It has therefore rightly served as a blueprint for theories of the other forces that act upon matter particles - the strong force and the weak force. Although QED deals specifically with the interactions of charged particles, its underlying structure provides a guide to the essential nature of a workable theory for any force between particles.

The range of the electromagnetic field is infinite, and so gives rise to large-scale phenomena. The weak and strong forces, on the other hand, appear to have ranges limited to sub-nuclear dimensions. It might seem natural, therefore, to place the weak and strong forces within the same theory, as indeed Hideki Yukawa attempted in his meson theory in the 1930s. However, the big step forward with the weak force proved eventually to come through linking it intimately with the wide-ranging electromagnetic force. Surprisingly, the phenomena of electrostatics and magnetism have a common origin with the weak processes of radioactive beta-decay and proton-proton fusion in the Sun.

The link between the electromagnetic and weak forces seems remarkable when you consider that the short range of the weak force implies that the messenger particle must be heavy, unlike the photon which is massless. The time for which the energy of the massive particle can be borrowed is short so that it cannot move far, even at the speed of light; the massless photon, on the other hand, can take an infinitely small amount of energy and travel an infinite distance.

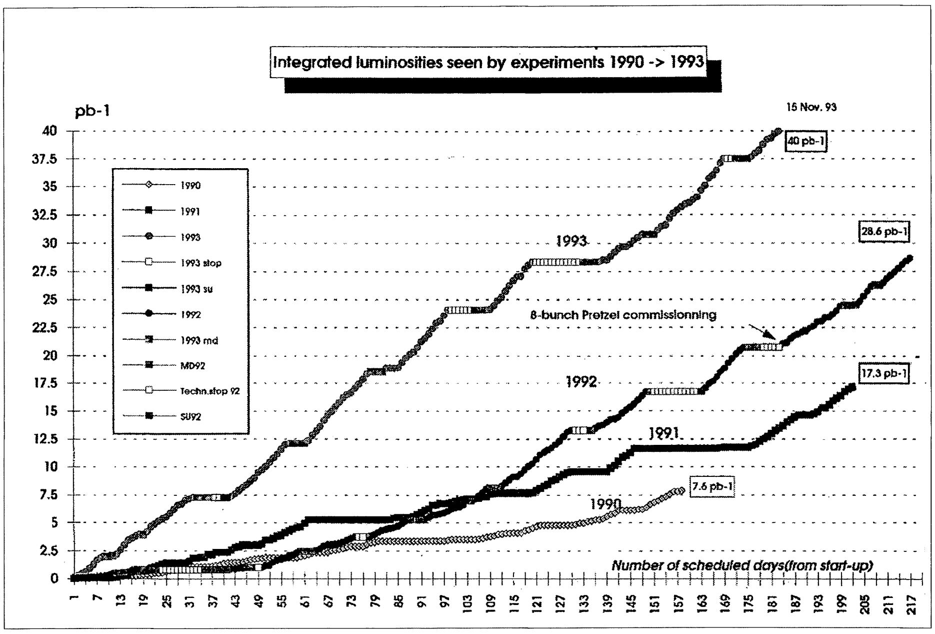
However, during the 1960s, attempts to find a theory of the weak force with gauge symmetry suggested that the correct theory should indeed include both weak and electromagnetic interactions. Such an "electroweak" theory requires four spin-1 massless messenger particles, or gauge bosons - two charged (+,-) and two neutral. The two charged messengers explain weak reactions such as beta-decay where charge changes hands (a neutron decays into a proton, for example). However, the messengers must be heavy to explain the short range of the weak force and introducing masses for these at first seemed to wreck the gauge symmetry! As for the neutral messengers, while one could be the massless photon, what of the other?

The solution to the difficulty with the massive messenger particles came with the introduction of a new field, which we now call the higgs field, with its own messenger particle, the higgs boson. The charged messengers of the electroweak theory - the particles known as W^+ and W^- - appear massive in our experiments as a result of their interactions with the higgs field. The neutral states of the underlying theory behave in a slightly more complicated manner to produce one neutral messenger that remains massless, the photon, and one that has a similar mass to the charged messengers. This massive neutral messenger should give rise to a weak "neutral current" - a weak interaction with no change of charge. The particle is now well known as the Z^o, although by the end of the 1960s there was still no evidence for the weak neutral currents that it should mediate.

The introduction of the higgs field into electroweak theory solves the problem with the gauge symmetry because in the basic theory the messenger particles have no mass, and so the symmetry remains unbroken. It is only at the relatively low energies of our experiments that the underlying symmetry appears broken, because at low energies the higgs field is not zero. At higher energies, the higgs field goes to zero (rather as the field in a magnet disappears above the Curie temperature) and the symmetry is there for all to see!

One question that remained by the end of the 1960s was whether the unified electroweak theory was renormalizable - in other words, would awkward infinities that natu-

Just ten years after the discovery of the Z° at CERN, the LEP electron-positron collider now mass-produces them. In 1993 the four experiments together saw 3 million Zs, making a total of some eight million since LEP began operating in 1989. This hefty slice of precision data has played a vital role in refining the Standard Model parameters.



rally occur in the theory cancel out, so that it could, like QED, make sensible predictions? In 1971, the young Gerard 't Hooft made the breakthrough that proved this was indeed the case. Two years later a last missing piece of experimental evidence fell into place. The Gargamelle team at CERN found the first neutral current events: neutrino interactions that could be explained only by the existence of the predicted massive neutral messenger particle, the Z°.

By 1979 the accumulated mass of evidence for electroweak theory had become unavoidable, and the Nobel committee duly awarded the main protagonists, Sheldon Glashow, Abdus Salam and Steven Weinberg with the Nobel Prize for physics. Then in 1983, CERN's proton-antiproton collider yielded sufficient energy and intensity to shake loose a handful of real (as opposed to virtual) W and Z particles. The Nobel Prize followed swiftly for CERN's Carlo Rubbia and Simon van der Meer, and electroweak theory, one of the mainstays of the Standard Model, was here to stay.

The second important structural element of the Standard Model deals with the third of the forces, the strong force. Like electroweak theory (and QED contained therein), the theory for the strong force is a quantum field theory with gauge symmetry. In this case the theory has again to deal with a force that acts over a short range but this time only on quarks, and in such a way that quarks are unable to exist on their own. Quarks always occur bound within larger particles: clusters of three quarks form baryons, such as the proton and neutron, while quark and antiquark pairs form the various kinds of meson. If you try to knock a quark out of a proton by hitting it with another high-energy proton, say, you succeed only in creating new quarks and antiquarks, that is, new mesons.

However, a clue to understanding the strong force comes from studying it at high energies, which in the quantum world is equivalent to probing small distances. (The higher a particle's energy, the shorter its associated wavelength.) At these small distances, the force between quarks is weaker than it is across the dimensions of a proton. This behaviour contrasts sharply with that of the electromagnetic force, which diminishes as the distance between charges increases.

Surprisingly enough, a theory very similar to QED has been constructed to explain the strong force. Instead of being built on the property of electric charge, the new theory is built on a "strong charge" that occurs on quarks (but not on leptons, which do not feel the strong force). This strong charge differs markedly from electric charge in that it must occur in three forms, with three opposite "anticharges". (By contrast, positive and negative electric charges are just one form of charge and its anticharge.) Because it occurs in three varieties, the strong charge has been given the name of "colour", in analogy with the three primary colours of light. The quarks occur in each of the three colours, but it seems that they can together form only particles that are neutral, or "white", in colour. Baryons, with three quarks, contain a quark of each colour, while mesons contain a quark-antiquark pair with opposite colour and anticolour.

The theory, in which colour charge replaces electric charge, is known as quantum chromodynamics, or QCD, emphasising the structural similarities with QED, although the more complex origin for the strong force leads naturally to a more complex theory. Instead of one messenger particle as in QED, the theory of QCD contains eight messengers - the gluons - which are massless particles, like the photon, with one unit of spin. At first sight, this might seem unlikely, as the strong force is short range, acting only at sub-nuclear distances. However, a crucial difference between the strong force and the electromagnetic force lies with the fact that while the photon itself has no electric charge, the gluons carry colour. This means that gluons can interact among themselves, with fascinating consequences for the strong force.

A virtual photon emitted by an electron can in principle travel off towards infinity, unaffected by other nearby photons. A gluon, however, feels the influence of any other gluons, and their interaction can indeed lead to more gluons. So a virtual gluon emitted by a quark, say, cannot proceed far before it is in effect caught in a net created by its interactions with other gluons. The result is that the strong force has a short range.

In summary, the Standard Model sees the world as built from two sets of particles, the quarks and leptons, whose interactions are described by two similar theories, electroweak theory and QCD. In these theories, forces are transmitted by messenger particles - the gauge bosons - some of which acquire mass through their interactions with an additional field, the higgs field. The model is a curious amalgam, evolved over years of wrong turns and dead ends. So far, it has worked much better than we have any right to expect.

The development of science this century

2 - from 1946 to 1970

by Victor F. Weisskopf

This is the second in a series of three articles which together are a slightly revised version of a talk delivered at the meeting of the American Association for the Advancement of Science, in Boston, on 14 February 1993, and at a CERN Colloquium, on 5 August 1993, entitled 'Science - yesterday, today and tomorrow'. Together they describe the tremendous growth of scientific knowledge and insights acquired since the beginning of this century. In a highly abridged form, some of these ideas were used in an earlier CERN Courier article ('Crisis - the Weisskopf view'; October 1993, page 22). Because of the restrictions of a single issue of the CERN Courier, the text has been repackaged as three articles, each covering an identifiable historical epoch. The first, covering the period from 1900 to World War II, was published in the May issue. The third article will cover the period from 1970 to the end of the century.

The time from 1946 to about 1970 was a most remarkable period for all sciences. The happenings of World War II had a great influence, especially on physics. To the astonishment of government officials, physicists became successful engineers in some large military research and development enterprises, such as the Radiation Laboratory at MIT, the Manhattan Project, and the design of the proximity fuse. Scientists who previously were mainly interested in basic physics, conceived and constructed the nuclear bomb under the leadership of one of the most 'esoteric' personalities, J.R. Oppenheimer. E. Fermi constructed the first nuclear pile, E. Wigner was instrumental in designing the reactors that produced plutonium, and J. Schwinger developed a theory of waveguides, essential for radar. It was more than that: some of these people were excellent organizers of large-scale research and development projects having good relations with industry, such as the aforementioned military projects.

When World War II was over, the public was under the impression that the physicists had won it. Of course, this was a vast exaggeration, but it is a fact that radar saved the United Kingdom and reduced the submarine threat to transatlantic convoys, and that the atomic bomb led to an immediate end of the war with Japan. Physics and science in general earned a high reputation. This led to

Eugene Wigner - instrumental in designing reactors that produced plutonium. (Photo Kathleen Blumenfeld)

While the US almost monopolized natural science in the 1950s, the establishment of CERN was a signpost to the future. The picture shows a 1953 session of the provisional CERN Council in Amsterdam. (Photo CERN 4.10.52)

higher salaries and to generous financial support from government sources such as the Office of Naval Research (ONR), the creation of the National Science Foundation (NSF) with the purpose of supporting basic research, the National Institutes of Health (NIH) supporting biology and medical research, and the Atomic Energy Commission (AEC) supporting basic research in nuclear and particle physics. The rationale for the support of basic science by government sources, irrespective of military and other applications, was twofold. First, the war experience engendered a strong belief that any basic science research will lead to useful applications; second, the desire to keep scientists happy and numerous since they might be needed again. The lavish support, without any regard as to the type of research, lasted for about a decade after the war; later government sources became increasingly interested in more specific research directed at military or commercial applications. Still basic science fared well until the seventies.

The results of this support were truly amazing. The progress of natural science in the three decades after the war was outstanding. Science acquired a new face. It would be impossible in this essay to list all the significant advances. We must restrict ourselves to an account of a few of the most striking ones without mentioning the names of the authors. The choice is arbitrary and influenced by my restricted knowledge. In quantum field theory: the invention of the renormalization method in order to avoid the infinities of field theory that made it possible to extend calculations to any desired degree of accuracy. In particle physics: the recognition of the quark structure of hadrons establishing order in their excited states, the existence of unstable heavy electrons and of several types of neutrinos (two were discovered in Period II, the third in the next period), the discovery of parity violation in weak interactions, and the unification of electromagnetic and weak forces as components of one common force field. In nuclear physics: the nuclear shell model, an extensive and detailed theory of nuclear reactions, and the discovery and analysis of rotational and collective states in nuclei. In atomic physics: the Lamb shift, a tiny displacement of spectral lines which could be explained by the new quantum electrodynamics, the maser and the laser with its vast applications, optical pumping, and non-linear optics. In condensed matter physics: the development of semiconductors and transistors, the explanation of superconductivity, surface properties, and new insights into phase transitions and the study of disordered systems. In astronomy and cosmology: the Big Bang and its consequences for the first three minutes of the Universe, the galaxy clusters and the 3K radiation as the optical reverberation of the Big Bang, and the discovery of quasars and pulsars. In chemistry: the synthesis of complex organic molecules, the determination of the structure of very large molecules with physical methods such as X-ray spectroscopy and nuclear magnetic resonance, and the study of reaction mechanisms using molecular beams and lasers. In biology: the emergence of molecular biology as a fusion of genetics and biochemistry, the identification of DNA as carrier of genetic information followed by the discovery of its double helical structure, the decipherment of the genetic code, the process of protein synthesis, and the detailed structure of a cell with its cellular organelles. In geology: the development and refinement of plate tectonics using newly available precision instruments, and the discovery of ocean floor spreading by means of sonar and other electronic devices.

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	CBD 8210	
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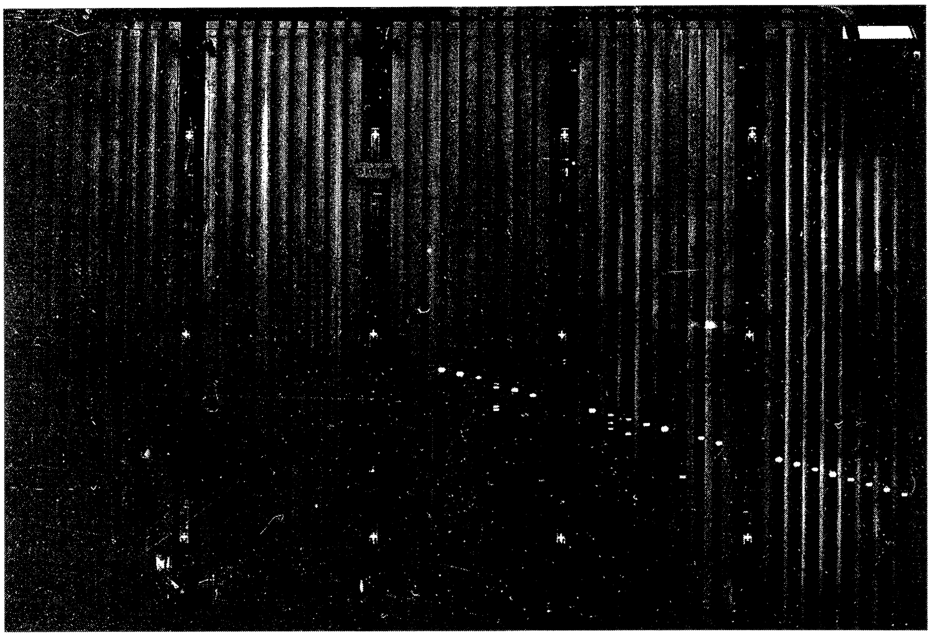
The 1962 discovery at Brookhaven by Leon Lederman, Jack Steinberger and Mel Schwartz that neutrinos came in two kinds was one of the fruits of the support for US basic science in the 1960s. Long tracks in the experiment's spark chambers showed when neutrinos produced muons, rather than electrons.



Many of the new results and discoveries were based upon the instrumental advances in the field of electronics and nuclear physics due to war research. One of the most important new tools decisive for all sciences was the computer. The development and improvements of this tool are perhaps the fastest that ever happened in technology. It brought about new methods of evaluation of experimental data, new ways to model and simulate natural processes. To quote a remark of S. Schweber: 'There are now three types of scientists: experimental, theoretical and computational.'

In spite of the tremendous boost that all sciences owe to computers, there are dangers connected with the use of them. If the computer is used to determine the consequences of a theory, then who has understood it, the computer or the scientist ? The computer sometimes replaces thinking and understanding. The same danger occurs in the overuse of computers in science education.

Character and sociology of science in Period II

Striking in the first two decades of Period II is the preponderance, almost monopoly, of the USA in natural science. Most of the amazing advances in science during the period 1946-1960 were made in the USA. Obviously, the leading cause was the condition of the other countries after the ravages of the war. Europe and East Asia had to be rebuilt. All the more we must admire certain pioneering efforts carried out mainly in England, Italy, and France, such as cosmic-ray research in England under Powell and in France under Leprince-Ringuet, and the important Italian meson absorption experiments by Conversi, Pancini and Piccioni. The situation was the opposite of that in the 1920s. European and East Asian scientists had to spend some time in the USA in order to play a role at home. Europe was 'provincial' and the USA was 'central' in science.

After the 1960s, European and Japanese science became more independent, and could compete with the USA. A number of European international organizations were created, such as CERN in particle physics, the European Molecular Biology Laboratory (EMBL) in biology, and the European Southern Observatory (ESO) in astronomy. A standard of research was developing in Europe and Japan which was equal and even superior to the USA in some fields.

Important changes in the social structure of science took place, especially in particle physics, nuclear physics, and astronomy. The rapid developments in these fields required larger and more complex accelerators, rockets and satellites in space, sophisticated detectors, and more complex computers. The government funding was ample enough to provide the means for such instruments. The size and complexity of the new facilities required large teams of scientists, engineers, and technicians, to exploit them. Teams of up to sixty members were organized, especially in particle physics. (In Period III the sizes of teams reached several hundred.) Other branches of science, such as atomic and condensed matter physics, chemistry and biology, did not need such large groups; these fields could continue their research more or less in the old-fashioned way in small groups at a table top with a few exceptions, for example, in the biomedical field, where larger teams are sometimes necessary.

The large teams brought about a new sociology. A team leader was needed who had the responsibility not only for intellectual leadership, but also for the organization of

The ultra-sensitive and discriminating detectors that had to be developed in high energy physics turned out to be most useful in medicine, biology, and materials science. In 1992 Georges Charpak was awarded the Nobel prize for his detector achievements, particularly his 1968 invention of the multi-wire proportional counter.
(Photo CERN 62.10.92)

subgroups with specific tasks, and for financial support. A new type of personality appeared in the scientific community with character traits quite different from the scientific leaders of the past. The participation in these large teams of many young people, graduate students and postgraduates, creates certain problems. It is hard for them to get recognition for their work, since their contributions get lost in the overall effort of the team. In order to attract young researchers to join big teams, the subgroups must have some independent initiative for well-defined tasks, so that the performers of these tasks can claim credit for their work.

The development of huge research enterprises caused a split in the character of science into 'small' science and 'big' science. Small science consists of all those fields that can be studied with small groups at relatively small cost, whereas big science is found in particle physics, in some parts of nuclear physics and astronomy, in space exploration, and in plasma physics. There is also big science in condensed matter physics and in biology: the use of synchrotron radiation in the former and the human genome project in the latter. Big science needs large financial support, so that the question of justification plays a decisive role.

This has led to another kind of split, related to the applicability of a branch of science in industry, in medical practice, and also in being useful for other sciences by providing tools and insights. Thus, we may distinguish 'applicable' and 'non-applicable' science. Both of these terms must be qualified. We understand 'applicable' science as research for which applications are obvious or easily foreseen; 'non-applicable' is meant to indicate that no or only very few applications are visible today. The philosophical and intellectual significance is not counted as an 'application'. One can never exclude that some present or future discoveries may lead to applications after several years or decades of further developments. This is why we will use the term 'presently non-applicable'.

Applicable science includes parts of nuclear physics dealing with reactors and radioactivity, atomic and molecular physics, certainly condensed matter physics, plasma physics, chemistry, the earth sciences, and, of course, biology with its vast applications in medicine, agriculture and food production.

Particle physics, some parts of nuclear physics, astronomy and cosmology are examples of sciences extremely important intellectually and philosophically but whose applications are not presently tangible. They are characterized by what may be called a 'leap into the cosmos'. Let us call these topics 'cosmic sciences' whereas the obviously applicable fields may be referred to as 'terrestrial sciences'. The processes studied in the cosmic sciences are too far away in time and space to be of immediate interest under terrestrial conditions, such as the Big Bang and its consequences, or the discovery of mesons, quarks, and heavy electrons. Unquestionably, it is a great achievement to be able to study the formation of galaxies in the Universe, or what goes on in the interior of stars and, in particular, to be able to create conditions at the targets of our accelerators that existed fractions of seconds after the Big Bang. Naturally this kind of research is expensive. It is hard to establish cosmic conditions on Earth. But these phenomena are in many ways detached from human environments, and decoupled from other sciences. (The point of view expressed here is different from the one I expressed twenty years ago in an article 'The significance of science', Science 176 , 138 (1972). At that time I was more optimistic as to possible future applications of particle physics and astronomy.)

The division into applicable and presently non-applicable fields is not as sharp as indicated here. Even particle physics has led to applications; it almost did a few decades ago when L. Alvarez suggested that hydrogen molecules made of protons and muons could perhaps initiate fusion processes, but it turned out to be impossible. Most of the applicable items come from what is sometimes called 'spinoff'. Techniques used to satisfy the unusually severe demands of accuracy and reliability do have some use in other fields. In particular, the ultra-sensitive and discriminating detectors that had to be developed in high-energy physics turned out to be most useful in medicine, biology, and material science. G. Charpak was awarded the Nobel prize for this. Furthermore, some of the intricate mathematical developments in quantum field theory have been successfully applied to problems of condensed matter physics. There are good reasons to expect more of such spinoffs in the future.

The present non-applicability of cosmic science is connected with an interesting phenomenon that occurred in the physical sciences, a hierarchy of different subjects that have become to an increasing extent decoupled from each other. We distinguish particle physics on the 'highest' level (no value judgment intended), nuclear physics, atomic and molecular physics, condensed matter, etc., being consecutive lower levels. Each level has its own laws and concepts based upon the interaction of quasi-elementary units that are composed of more elementary units of a higher level, but remain fixed in their ground states under the weaker energy exchanges characteristic of the lower levels. Thus, the internal composition of those units is not important for these levels. There are 'effective' theories describing the conditions at each level that disregard the internal structure of the units. For example, certain parts of nuclear physics deal with protons and neutrons as quasi-elementary particles, whose quark structure is irrelevant; atomic and molecular physics deals with interacting electrons and atoms and nuclei, the inner structure of the nuclei being insignificant. Certainly the quark structure of nucleons is irrelevant for biology, which has its own concepts, laws, and relations. In every step from a higher to a lower level, complexity increases; new laws and regularities appear that are not in contradiction with the more 'basic' laws at higher levels, but they emerge from the complex interactions of the relevant units without being directly derivable from the laws at a high level. When the Universe cooled down and expanded, it seemingly went through stages from the highest levels up to lower ones, creating at each step new diversity and complexity, until it reached life on Earth and perhaps on other planets.

The existence of more or less decoupled levels of physics had an undesirable effect: over-specialization. The scientists working in one level do not know much of what is going on in other levels because they mostly do not need that knowledge for their research. Furthermore, the pressure of competition and the need to follow the ever-increasing literature in their own fields does not give them time to be interested in other levels.

Around the Laboratories

CERN
LHC dipole prototype success

In a crash programme, the first prototype superconducting dipole magnet for CERN's LHC proton-proton collider was successfully powered for the first time at CERN on 14 April, eventually sailing to 9T, above the 8.65T nominal LHC field, before quenching for the third time.

The next stage is to install the delicate measuring system for making comprehensive magnetic field maps in the 10 m long, 50 mm diameter twin-apertures of the magnet. These measurements will check that the required LHC field quality has been achieved at both the nominal and injection fields.

This first valuable prototype will be trained to its maximum field, expected to be close to 10T, only after completion of the magnetic field measurements. Seven prototypes have been ordered from four different industrial consortia. All are expected to be complete before the end of the year. The first prototype was ordered by the Italian INFN and built by Ansaldo.

On 15 April, while the magnet was being put through its paces, a special session of CERN's governing body, the Council, adopted the following resolution on the LHC and CERN's long-term scientific programme pending final approval.

"Council, confirming its belief as stated in the Council's December 1991 resolution that the LHC is the right machine for particle physics and for CERN, and being impressed by the scientific case and by the economical utilization in the LHC project

of investments previously made at CERN;

• notes the overall strategy of CERN proposed for the years 1995-2005 and supports the Management in promoting the LHC as the central element of the long-term programme of CERN;

• wishes to see the LHC implemented as part of the basic programme of the Laboratory, and wishes the project and its financing to be approved by general consensus;

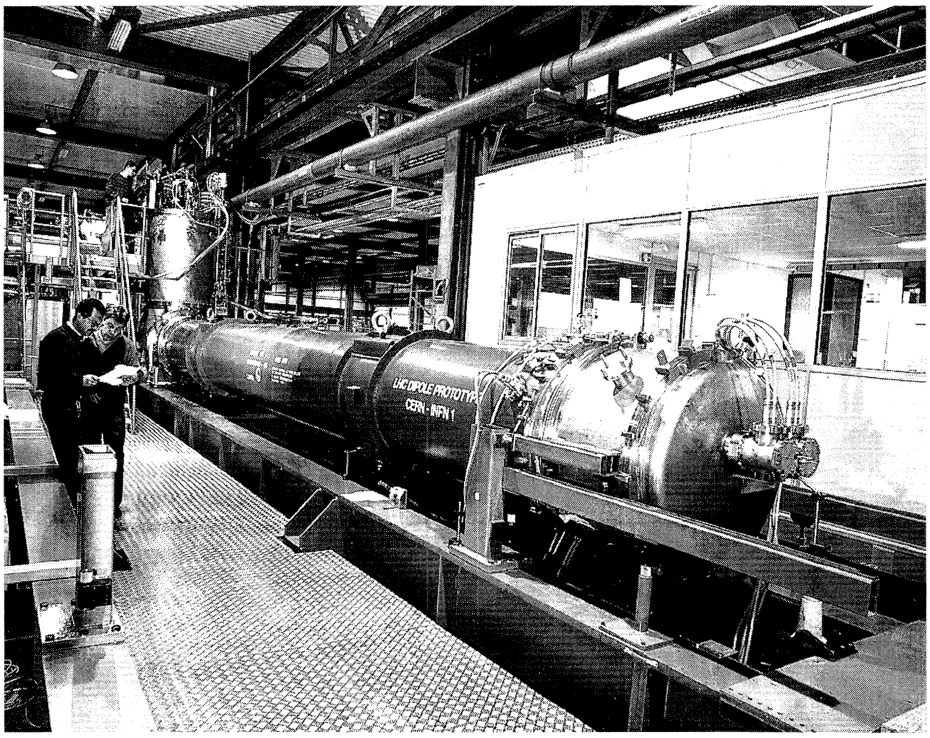
• is conscious of and welcomes the world interest in the project, wishes that involvement of non-Member State physicists should be on the understanding that usage on a significant scale must involve the contribution of resources to the project by the non-Member States concerned, and supports the prospect of creating an appropriate status for the participation of Non-Member States making significant contributions;

• notes that a flexible range of funding options exists, building where appropriate on current expectations concerning supplementary contributions, including options which would allow the LHC to be constructed without such contributions;

• endorses the proposed comprehensive review of the progress of the project, to be carried out at an appropriate moment and in any case before the end of 1997 in order to define more precisely the timetable for the execution of the project in the light of the foreseen funding; and

• expresses its best intention to move to a decision to approve the LHC during the first half of 1994."

In April the first LHC dipole prototype was successfully powered for the first time, sailing to 9T prior to its third quench, above the 8.65T nominal LHC field



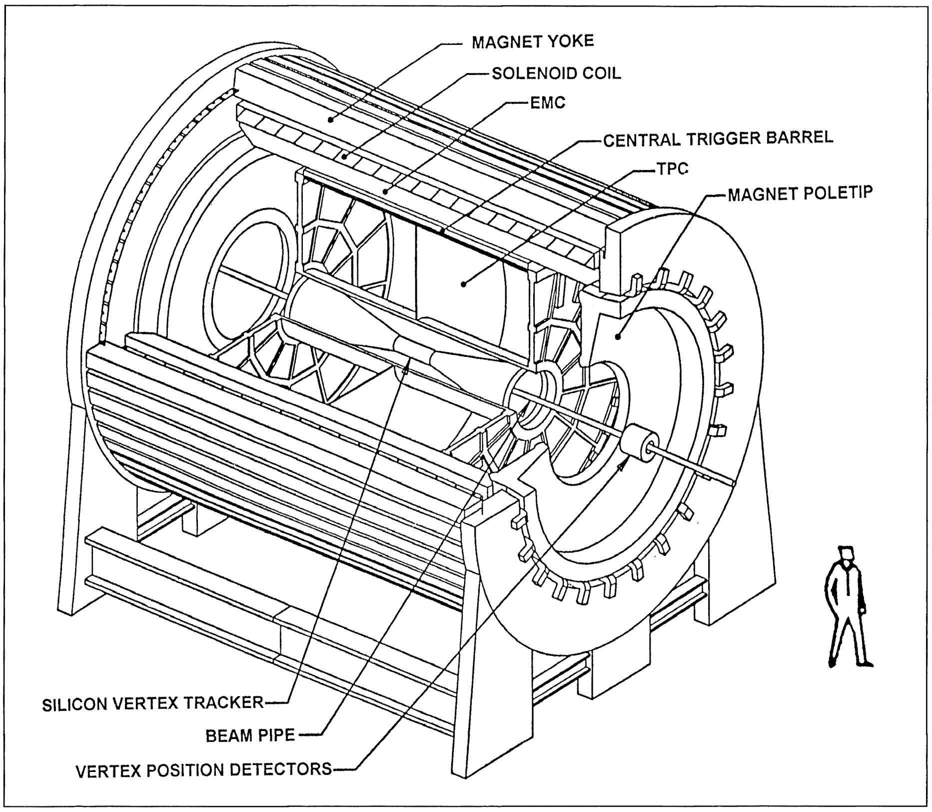
BROOKHAVEN Major detectors for RHIC under construction

On March 9-10, a cost and schedule review at Brookhaven verified construction readiness for the PHENIX detector (May 1993, page 10). PHENIX thus joins STAR (Solenoidal Tracking at RHIC - November 1991, page 17), whose construction plan was ratified in January 1993, as a major detector to take data when the RHIC heavy ion collider is completed in mid-1999.

The goal of both detectors is to search for the transition from ordinary nuclear matter to a new state of matter consisting of (momentarily) unconfined quarks and gluons. This transition to a "quark-gluon plasma" (QGP) is predicted to occur under extreme conditions of temperature and energy density, as is likely to be the case in the collision of heavy ions of sufficient energy. RHIC is expected to produce the highest energy densities ever observed on the nuclear scale.

The focus of the STAR detector is the measurement of hadrons, which comprise 99.99% of the particles produced in heavy ion collisions, with large acceptance and good spatial and momentum resolution. A typical "interesting" collision at RHIC is expected to radiate many thousands of particles. The measurement of "global" observables, such as multiplicity and energy flow, serve to characterize the degree of thermalization and nuclear excitation in such collisions.

The emphasis in STAR will be the measurement of such observables, *Schematic of the STAR detector which will emphasize hadron measurements at Brookhaven's RHIC heavy ion collider. Some of the systems shown represent potential upgrades to the detector.*



and their correlations, on an event-by-event basis as well as making use of hard scattering (by the measurement of jets and mini-jets) to probe the properties of high density nuclear matter. The detector should be sensitive to a wide variety of hadronic "signatures" which have been predicted to be indicative of the plasma state, including event-by-event fluctuations in the global observables, anomalous strange particle production, and "jet quenching."

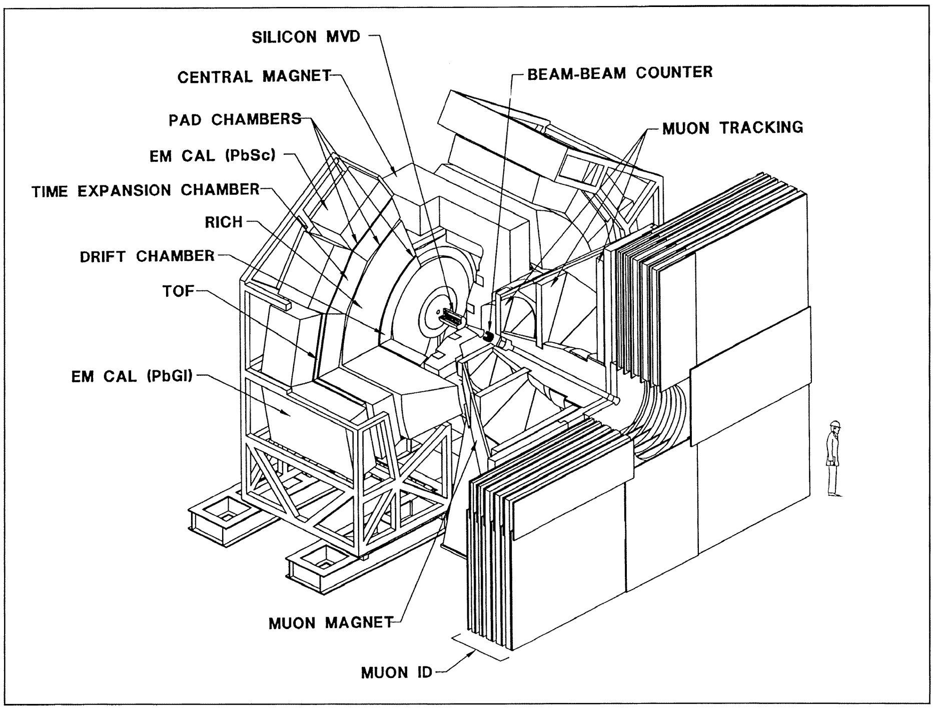
The core of the STAR detector is a large Time Projection Chamber (TPC) immersed in a solenoidal magnetic field. Charged track momentum measurements will be made within a relatively large solid angle with full azimuthal coverage. Particle identification is made by measurement of ionization energy loss within a limited (< 0.7 GeV/c) momentum range and a restricted angular interval.

A number of upgrades are already planned which should significantly increase its physics capabilities. These include a silicon vertex tracker (SVT) and an electromagnetic calorimeter (EMC). The SVT will improve momentum and energy loss resolution, and locate secondary vertices to better than 100 microns. The electromagnetic calorimeter is required for the measurement of jets, direct photons and leading pion production.

Correlation of the information from the EMC and central trigger barrel detector will enable STAR to trigger on events exhibiting unusual pion isospin abundances (such as the Centauro events in cosmic rays) which have been suggested as a signature of exotic nuclear matter in high energy nucleus-nucleus collisions. Additional tracking at smaller angles to the beams, using TPCs outside the magnet (not shown in the figure) is also being considered, as well as a time of flight array to enhance particle identification.

PHENIX, although measuring hadrons within a limited acceptance, and therefore having some overlap with STAR, emphasizes detection of the rare (.01%) leptons and photons. In the conceptual picture of a heavy ion collision, after a formation time of about 1 fm/c (3 x10^{-24} s) a thermalized plasma of quarks and gluons begins to expand and cool. When a critical temperature is reached, hadrons begin to form and the system becomes a gas of interacting hadrons. As expansion continues, a "freeze-out" density is reached after which the hadrons no longer interact with one another. Information from the hot interior of this expanding volume (at an early time) is efficiently carried to the outside by radiation that is not coupled to the strong interaction. Such signals can be carried by photons, which may be "real" (gamma rays), or virtual, appearing as electron-position or muon-antimuon pairs. Thus PHENIX emphasizes detection of particles which are created early in the space-time evolution of the system.

Special emphasis is placed on measuring many potential signatures of the QGP as a function of a well-defined common variable related to the energy density to see if any or all of these signatures show a simultaneous anomaly due to QGP formation. Among such signatures are possible changes in the mass, width, and branching ratios of vector mesons, the energy spectrum of directly produced photons and lepton



Schematic of the RHIC PHENIX detector which will emphasize photon and lepton signals. Instrumenting the muon tracking system shown will require an upgrade of the basic detector.

pairs, and the (much discussed) possible suppression of J/psi and upsilon resonant states .

To accomplish these ambitious goals, PHENIX must of necessity incorporate many sophisticated technologies for particle identification and tracking. The central arms are dominated by a 9.5-metre high, 450 ton magnet, and include many systems for particle identification and tracking. Closest to the interaction point are the inner detectors - 20 two arrays of beam-beam counters which provide a rough vertex location and a precise event time; and a silicon multiplicity detector (MVD) which measures charged particle multiplicity and provides a precise vertex location. These inner detectors are followed by: a drift chamber, for transverse momentum determination; a ring-imaging Cerenkov detector (RICH) for electron identification; pad chambers for tracking; a time-expansion chamber for both tracking and electron identification; time-of-flight (TOF) detectors for hadron identification; and an electromagnetic (EM) calorimeter for photon and electron identification. PHENIX also has a muon arm with magnetic analysis covering a large fraction of one forward hemisphere. The objective of this arm, whose full implementation will require an upgrade of the detector, is the detection of high mass muon pairs to complement the electron pair signal in the central portion of the detector.

The STAR and PHENIX detectors represent nearly 700 collaborators from 68 institutions in 13 countries. Present plans for the initial physics programme at RHIC also include a complement of small detectors. Two experiments, PHOBOS and BRAHMS, have been approved to develop conceptual designs. PHOBOS will employ a large array of silicon strip detectors for measuring charged particle tracks in the central region, while BRAHMS is a two-arm spectrometer to measure single charged particle inclusive spectra over a broad region which includes forward angles.

Thomas W. Ludlam

SERPUKHOV UNK transfer beamline commissioned

At the end of the 1000 hour February-March run of the 70 GeV proton synchrotron at the Institute for High Energy Physics (IHEP), Serpukhov, near Moscow, the new 2.7-kilometre UNK Beam Transfer Line (BTL) was commissioned with proton beam.

BTL will eventually transfer beam from the existing U70 proton accelerator to the first stage of the UNK (UNK-1, now under construction) where it will be accelerated in the 21-kilometre ring up to 600 GeV. BTL was designed for proton energies between 60 and 70 GeV, momentum spread $\pm 2 \times 10^{-3}$ and beam emittance 2 mm.mrad, with systems for fast ejection, beam transfer and injection into UNK-1.

The successful operation of the transfer beamline gives confidence to the main push towards UNK. (At CERN, electrons were precision injected into the first complete portion of the 27-kilometre LEP electron-positron collider tunnel well before the completion of the project in 1989.)

The U70 fast ejection system is used to direct beam to BTL. It includes full aperture kicker and two septum magnets as well as the U70

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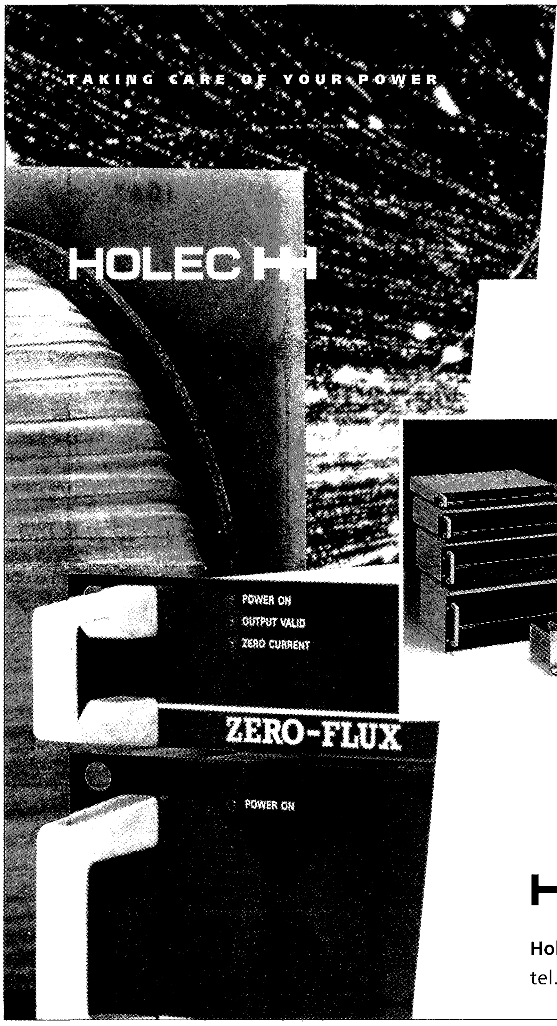

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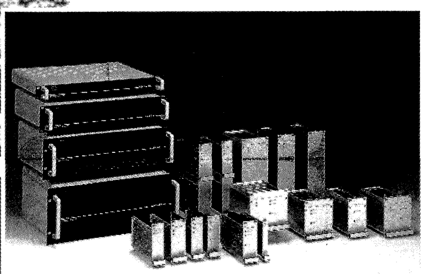

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bump system for closed orbit distortion. The beam transfer part consists of a matching section for adjusting the beam phase spread and dispersion with bend section, a 64-degree bend section and a second matching section to adjust the beam parameters to the UNK lattice.

The considerable distance between the UNK ring and U70 injector is a result of the geological conditions on the IHEP site. The BTL lattice has strong focusing FODO structure with 88 quadrupoles, 52 5.8m dipoles and 56 corrector magnets.

The UNK orbit plane is 6 m below that of U70. Beam diagnostics include beam current monitors, 46 beam position monitors, 26 profile monitors and loss and halo monitors.

The final U70 radiofrequency is 6 MHz, while a 200 MHz accelerating system will be used for UNK-1. A recapturing station is installed in U70 to match the longitudinal phase space.

The first BTL beam test was successfully carried out on 14 March, when U70 beam from was transferred to a beam stop two kilometres from the ejection point. A small fraction of normal U70 beam intensity (5 bunches from 30) was accelerated to 65 GeV and captured by the UNK 200 MHz system with some further acceleration.

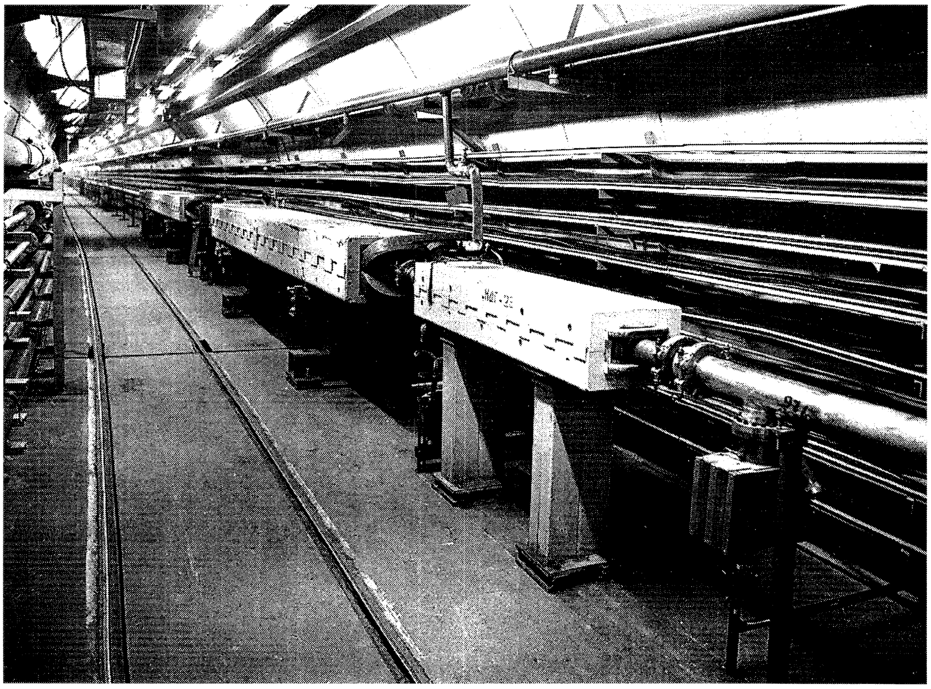
Using corrector magnets and adjusting the bending magnet current the beam was negotiated through the BTL. The emittance of the beam with intensity $3.5x\ 10^{11}$ protons per pulse at the stopper was 1.6 mm.mrad. The beam size was in a good agreement with calculations.

A PC-based control system was implemented for BTL commissioning, with four console computers and equipment controllers connected to the console via serial communication lines and line multiplexes. Magnet power supplies used more then 50 homemade equipment controllers, each one consisting of a separate Multibus-1 crate with LSI-11 type processors, I/O and timing modules. Beam instrumentation electronics was implemented in CAMAC with Intel auxiliary crate controllers inside.

At the same time a prototype UNK control system, developed in collaboration with CERN, was successfully tested. The system consists of an ULTRIX DEC station and a diskless front-end computer linked through MIL-1553 with equipment controllers. Two buildings were connected by a fibre optic computer link with TCPIP communication protocol. All power supplies for the magnet lattice and beam instrumentation (profile and intensity monitors) were controlled through the prototype. A modern graphical interface was developed based on the Motif toolkit. Currents in the magnet elements were set and final beam steering was carried out optimizing the beam profile and intensity.

In parallel a commercial software package was under evaluation, with applications for BTL equipment control. Good operational reliability and perfect flexibility in interface design were demonstrated.

During the run, four U70 experiments (VES - spokesman A. Zaitsev, SVD - spokesman P. Ermolov, CHARM - spokesman V. Kekelidze and Neutrino Detector - spokesmen S. Bunyatov and A. Vovenko) took data for one month.



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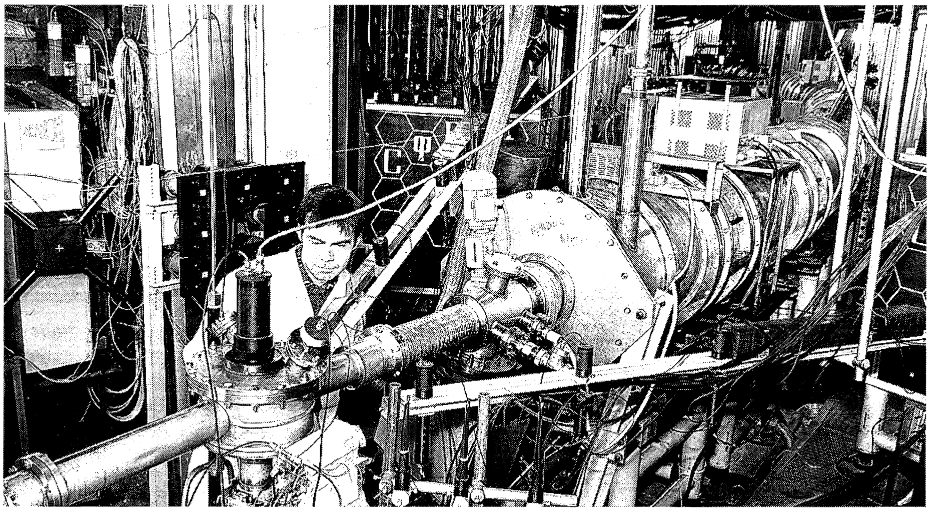
The superconducting Nuclotron at the Joint Institute of Nuclear Research, Dubna, near Moscow, has begun operations for physics. In the foreground is the internal target in a straight section of the machine, with a Nuclotron cryostat in the background.



DUBNA
Relativistic deuterons in the Nuclotron

At the Laboratory of High Energies of the Joint Institute for Nuclear Research - JINR, Dubna - 17-29 March saw the first physics run of the superconducting Nuclotron (July/August 1993, page 9).

The run began just after completion of a synchrophasotron polarized deuteron run. In accordance with the programme, a polarized deuteron beam was injected and accelerated up to 100 MeV nucleon. Subsequently the "Polaris" polarized deuteron source was replaced by the duoplasmatron (providing unpolarized particles) and Nuclotron operation continued for physics.

The magnetic field cycles were 6, 8.5, 10 kGs with a rise of 6 kGs/s. Beam dynamics were stable, with no particle losses observed after 500 ms of acceleration time. The maximum momentum of deuterons of 3.5 GeV/c per nucleon was reached for a beam intensity of 2 $x10^9$ per cycle.

A deuteron beam accelerated to 3.7 GeV/c was provided for the SPHERE spectrometer, the Spectrometer of Recoil Nuclei (SYAO), and the DELTA Experiment of the Institute for Nuclear Research (INR) of the Russian Academy of sciences (Troitsk).

Measurements were performed with the internal target to study the yield of pions, kaons, and nuclear fragments (from protons to helium and lithium isotopes) in deuteron-nucleus collisions. For instance the INR team recorded 10^5 events, enough to identify some 50 rare examples of positive kaon production below the kinematical limit of nucleon-nucleon collisions.

Various technical detector questions were investigated, including the operation of lead glass electromagnetic calorimeters in the background environment of the ring tunnel. UV and X-ray radiation produced by beam particles in film target material was used to study the radiofrequency structure of the accelerated beam.

The next Nuclotron run - with heavy ions - is scheduled for the summer.

FERMILAB
Bob Wilson 80

On March 4, an international symposium and tribute was held at Fermilab in honour of the Laboratory's founding director Robert Rathbun Wilson on the occasion of his 80th birthday.

The symposium - 'Celebrating an Era of Courage and Creativity' - featured talks and reflections by many of Wilson's colleagues and friends including Fermilab Director John Peoples and Director Emeritus Leon Lederman.

The symposium talks also featured Golden Ages, by Chris Quigg of Fermilab's Theoretical Physics Department; Top and B Physics, by Paul Tipton of Rochester; Fixed Target Physics, by Heidi Schellman of Northwestern; Machine Physics, by Gerry Jackson of Fermilab's Accelerator Division; The Resurrection, by Bill Foster of CDF at Fermilab; Wilson's Way, by Lillian Hoddeson, historian at University of Illinois and Fermilab; and Art and Architecture at Fermilab - The Wilson Legacy, by Paul Karchin of Yale.

Ned Goldwasser summarized Wilson's contributions to both Fermilab and the scientific community:

"In achieving his dream for Fermilab, Bob Wilson exercised all of his many talents: a good nose for quality physics and technology, boldness in accelerator design, and a strong sense of aesthetics, anchored by his unwavering conviction that the best science can thrive only in an environment of respect for the right and dignity of all human beings. Those qualities formed the character of the Laboratory from the beginning

and bestowed a heritage that endures today as Fermilab begins what promised to be a great decade of discovery.

For most of his 80 years, Bob Wilson has been an eloquent spokesman for the value and beauty of science. Who can forget his response during a 1969 Congressional hearing, when Senator John Pastore pressed him to explain what the new accelerator the Laboratory proposed to build had to do with defending the United States against its enemies?

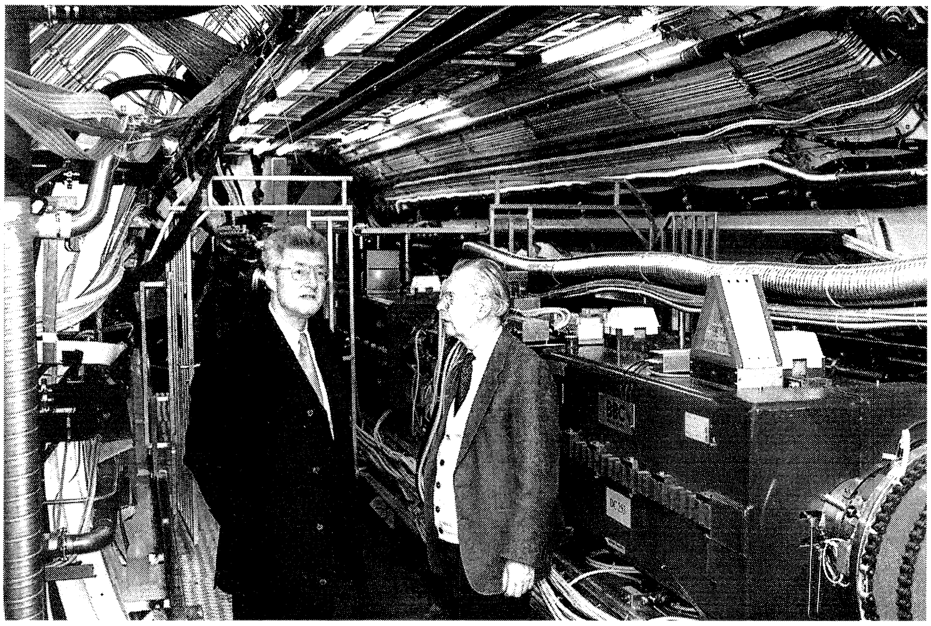
'It has nothing to do directly with defending our country,' Wilson told the senator, 'except to make it worth defending.'

Today, on his 80th birthday, we celebrate Bob Wilson's life and his unique contributions, not simply to particle physics, but to the much broader worlds of science and art and to the bond that joins them. His life's work has shown the transcendence of national boundaries by the exploration of our universe and the search to understand the truth."

Fermilab founding director Robert Rathbun Wilson at an international symposium and tribute held at the Laboratory to mark his 80th birthday.

Physics monitor

H.C. Eschelbacher (left) of the German Ministry for Research and Technology, seen here with former CERN Director General Herwig Schopper, visited CERN on 18 April.



ECFA SURVEY Germany

Few nations can match the scope of German basic physics contributions. Earlier this century, illustrious names (Röntgen, Franck, von Laue, Planck, Sommerfeld, Heisenberg,.....) kept Germany among the front runners. Subsequent history has given German physics a very different profile - the country now participates massively in international projects and is the largest single contributing nation in CERN's research programme. At the same time, an impressive high energy programme at the German national Laboratory at DESY, Hamburg, centred around the 6.3 kilometre HERA ring, the world's only high energy electron-proton collider, attracts scientists from all over the world.

In addition, accelerators at the GSI heavy ion Laboratory at Darmstadt and the Jülich KfA Laboratory, together with installations at individual universities (notably Bonn's ELSA electron stretcher ring and Mainz' MAMI microtron), round out an already full picture. In parallel there are wide ranging activities in theory, phenomenology and accelerator research and development.

Today, the deep scientific commitment in Germany has to be seen against a complicated political and economic backdrop. Already delving deep to finance the unification of East and West Germany, the nation is also supporting projects in several Central and Eastern European countries, all during the deepest economic recession of the post-war period.

With cuts applied across the board, the national science budget has to share the burden. At CERN Council, the German delegation has often alluded to these difficult circumstances, and special temporary concessions have been made for the German contribution to CERN.

German particle physics and its current setting were explained at a recent meeting of the European Committee for Future Accelerators (ECFA) in Dortmund, continuing the ECFA tradition of holding regular meetings in national centres. (A separate meeting will be scheduled for the DESY Laboratory, Hamburg, where as well as the major programme based on the HERA electron-proton collider and neighbouring installations, the integration of the former East Germany has brought the Zeuthen Laboratory in former East Berlin into the DESY fold.)

A recent survey of the German Physical Society showed that there are some 900 active German experimental particle physicists, some 2/3 of whom work at CERN. Of these, the largest contingent (230) works at the LEP electron-positron collider.

The numbers have considerably increased over the past decade. As well as increased interest and higher student numbers, this follows from a reorientation of some research lines. With the increasing awareness of the role of the quark and gluon constituents of nuclear particles in the broader aspects of nuclear physics, heavy ion research, once part of the nuclear physics scene and with a sizeable community in Germany through the Darmstadt GSI Laboratory, has found a new focus. After LEP, the second largest contingent of German physicists at CERN - 140 - is engaged in heavy ion experiments.

At DESY, the 260 German physicists who carry out their research at the HERA collider are among a total of 800 users, showing that the HERA programme has wide appeal. In Germany, international physics collaboration means not only CERN but also DESY.

Funding is split fairly evenly between CERN (195 million Swiss francs per year) and DESY (185 million Swiss francs equivalent - federal funding accounts for 90% of DESY's budget, the remaining 10% coming from regional government). Some 21 MSFr of federal physics spending goes into university-based research, also funded by regional governments. Additional resources come from the Max Planck Gesellschaft.

From 1982-92, the decade of HERA construction, Federal German funding for particle physics grew from 0.2 to 0.28 per mil of GNP. It has subsequently declined to 0.18 per mil.

With the major Zeus and H1 experiments at HERA now completed and in operation, attention is turning towards the major detectors to exploit CERN's proposed LHC proton-proton collider. 21 of the 22 German universities involved in particle physics are now active in LHC work. Detector components for high radiation and counting rates are being developed in Aachen, Bonn, Dortmund, Freiburg, Hamburg, Heidelberg, Karlsruhe and Wuppertal. Tracking work for heavy ion collisions is underway in Darmstadt, Giesen, Frankfurt and Munich, muon chambers are being developed at Aachen, Freiburg, Munich (MPI and University) and Siegen, calorimeters at Aachen, Heidelberg and MPI Munich, triggering and data acquisition at Aachen, Heidelberg, Jena, Mannheim, Munich and Zeuthen, and beam extraction by crystals in Stuttgart.

At HERA, the results now emerging from Zeus and H1 studies provide valuable insights into the quark and gluon content of composite particles in unexplored kinematical territory. New HERA projects still in the pipeline include the Hermes experiment using a polarized gas jet target and a polarized electron beam to look at the spin dependence of quark and gluon structure, while there is also interest in exploiting HERA's proton beam for B physics, continuing the heavy quark physics theme which had been prominent at earlier DESY machines.

Germany's illustrious physics tradition is also reflected in the 200 theorists in 24 universities, with strong involvement in phenomenology.

The high proportion of German students' work carried out in large collaborations makes for valuable experience outside the realm of pure science and is beneficial in subsequent careers in industry and commerce. At the ECFA meeting, Helmut Hufnagel from H1 at DESY gave thoughtful presentation of the current scene as seen from a student's point of view.

While the Dortmund ECFA meeting painted an impressive picture of German science, the preoccupation of this powerhouse nation with major political and economic themes could not be forgotten.

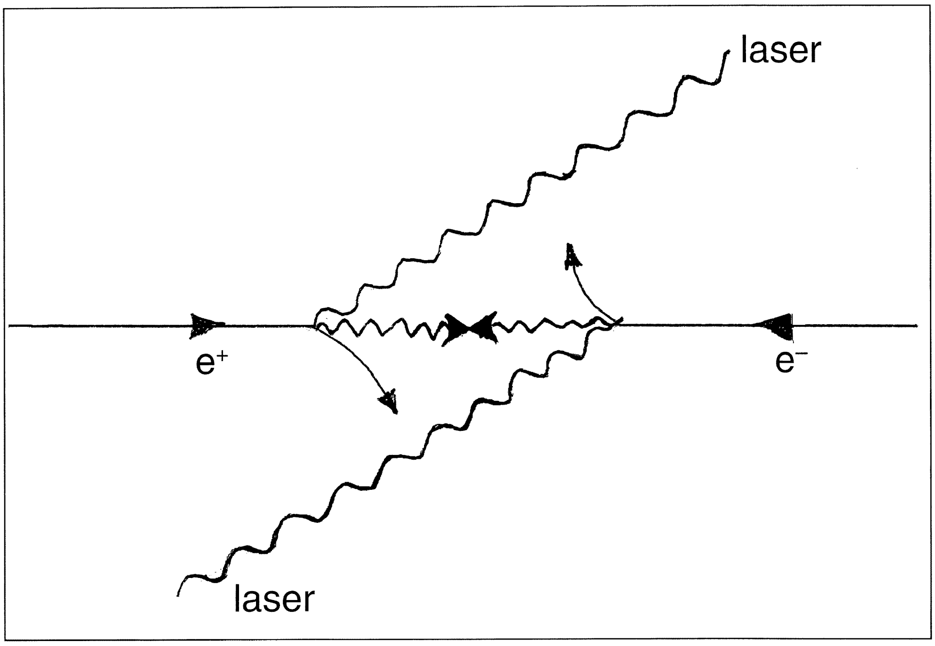
Linear colliders for photon collisions

The enthusiasm of the first international workshop on photon-photon colliders and associated physics, held at the Lawrence Berkeley Laboratory from 28 March - 1 April, could have set a ball rolling.

According to proponents of this physics, the particle physics one can study with a high energy linear collider is special and complements that of a hadron supercollider.

They say that to be most effective, this collider should give from the start electron-positron, electron-photon,

Principle of the photon-photon collider. Laser beams are fired into the path of high energy electrons, producing gamma rays which are pushed forward by the high electron energies. Recoil electrons can be magnetically swept aside. Using one laser rather than two gives an electron-photon collider.



and photon-photon collisions. The physics capabilities and systematics of the different modes are often different and unique. The study of both electron-photon and photon-photon collisions would provide unique access to some areas of fundamental physics, together with some useful overlap with measurements from electron-positron collisions.

Initial studies and working group results have revealed no show-stoppers - these different types of colliders are within technical reach. Therefore even the first conceptual design of a linear collider should include multiple interaction regions, with one dedicated to electron-photon and photon-photon collisions. With electron-positron, electron-photon and photon-photon colliders the same except for the interaction region, the incremental cost of adding photon collisions at one of the interaction regions is relatively small.

While the various forms of linear colliders all require extensive R&D, that required for electron-photon and photon-photon colliders is no more difficult or technologically risky than that for an electron-positron collider, and should be integrated immediately into present programmes.

This R&D has both immediate and long term aspects - detectors and masking, high power lasers including free-electron lasers, special final focus components, bright sources of polarized electrons, and high power, low-loss optical components.

The Stanford SLC could provide a realistic testbed for a higher energy photon-photon collider and, furthermore, would give interesting new physics - many of the problems faced by developing detectors, the final focus geometry, and high power lasers for SLC-II are almost the same as those for a higher energy collider, and the cost-effective upgrade of the SLC to allow for electron-positron, electron-photon and photon-photon collisions will provide an opportunity too good to miss.

The Workshop identified R&D that should be initiated immediately - the development of free electron lasers, experiments in the SLC final focus area, development of a low-rep rate collider at SLC, and implementation of a high-rep rate, high luminosity photon-photon collider at SLC.

Photon-photon physics goals

The quark-gluon structure of the photon is a fundamental and largely unresolved area of investigation. Clearly the electron-photon collision option would provide a powerful tool for these studies. Photon-photon collisions would allow studies of the top quark threshold region that would complement electron-positron collisions. Here unique measurements are possible using polarized photon beams: large circular polarization will allow direct observation of toponium angular momentum states not accessible in electron-positron collisions, while with linear polarization it may also be possible to make very sensitive measurements of the strong coupling constant. Study of W boson pair production in photon-photon collisions provides the most sensitive tests for anomalous interactions of these particles, while the photon-photon option also provides some unique advantages for higgs studies.

Cosmology in miniature

The high energies of particle collisions recreate conditions similar to those a tiny fraction of a second after the Big Bang. Clues from these collisions help reconstruct how the infant Universe was moulded.

One cosmic possibility, suggested in the 1970s by Yakov Zeldovich, I.

Kobzarev and Lev Okun in Russia, and by Tom Kibble of London's Imperial College, is that the initial phase transition in the proto-Universe could have contained defects - tiny regions of space trapped in the 'old' high energy phase. These defects could have gone their own way, developing into separate structures which helped to seed the subsequent evolution of galaxies into clusters and sheet-like 'superclusters'.

When this happened just 10^{-34} second after the Big Bang, the energy densities were out of reach of anything that can ever be recreated directly on Earth, and scientists, for whom ingenuity is an everyday tool, have to be especially resourceful.

In 1985 W.H. Zurek of Los Alamos suggested experiments to look for signs of such defects in model systems, for example the delicate phase transitions of superfluid helium-4 transforming into a normal fluid at about 2K. In this way laboratory studies could be used as models for the infant Universe.

Subsequent experiments saw suggestions for such defects in another delicate system, the rod-like molecules of liquid crystals. Now a British group (Lancaster/Exeter) has seen signs in a liquid helium-4 system. With a sample of highly pure (possibly perfect) helium-4, the team hoped to avoid problems with defects from nucleation around impurities.

One problem with such cryogenic experiments is that any defects are not easy to spot. The trick is to detect them through the attenuation of sound waves across the 4-millimetre space of the experiment. The observed strong attenuation suggests the creation of an excess of vortex-type activity, difficult to explain by hydrodynamics alone.

These defects induced by phase transitions are possible analogues of cosmic seeds.

P.C. Hendry et al, Nature, Vol. 368, p. 315 (24 March 1994)

Bookshelf

Neutrino Interactions with Electrons and Protons - Edited by Alfred K. Mann, published by the American Institute of Physics (ISBN 1-56396-228-4)

Subtitled 'an account of an Experimental Program in Particle Physics in the 1980s', this book is a collection of 13 reprinted papers presenting experimental results from experiment E-734 originally proposed in 1978 to measure the elastic scattering of neutrinos and antineutrinos from electrons and protons using the neutrino beam at the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory.

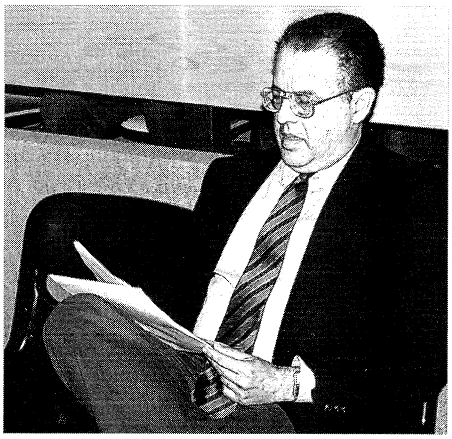
This experiment took data during the 1980s and the apparatus was dismantled in 1990. Its main results cover measurements of the weak mixing angle, and some measurements which were not in the original proposal, such as limits on the electromagnetic properties of the muon neutrino and on the mixing between electron- and muon-neutrinos. The collaboration, with 35 physicists participating, included Osaka and KEK and was the earliest formal collaboration in high energy physics between American and Japanese institutions.

This book gives only a very partial account of neutrino physics in the 1980s. Because of the relatively low neutrino energy of only few GeV, E-734 physics did not include the study of deep inelastic scattering which has greatly contributed to the understanding of the nucleon structure in terms of quarks, antiquarks and gluons. Furthermore, because of the low event rate at the low neutrino energy, most of the E-734 results have been superseded by the more precise results obtained by higher energy neutrino experiments at CERN and Fermilab, however with the exceptions of the limits on neutrino mixing and of the measurement of the neutral current cross-section for neutrino and antineutrino elastic scattering. It is not clear to me why the American Institute of Physics has chosen to publish this book in a series 'Key Papers in Physics'.

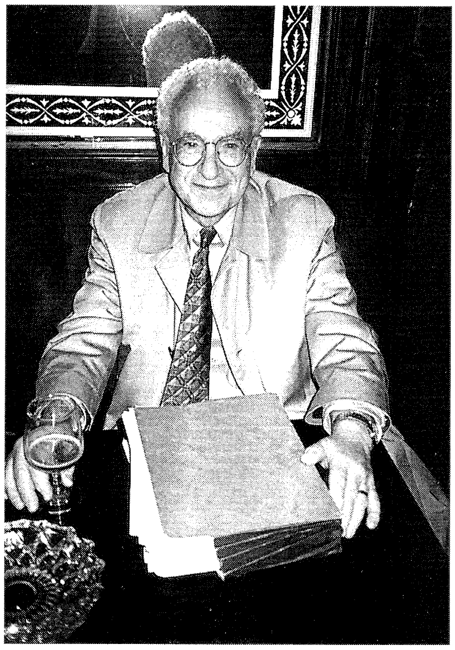
Luigi Di Lella

People and things

On 15 April, Haim Harari of the Weizmann Institute, Israel, was guest speaker at a symposium to mark 20 years of accelerator operation at the Paul Scherrer Institute, Villigen, Switzerland. (Photo Armin Müller)



Maurice Jacob's roving camera caught Murray Gell Mann in a London pub with the manuscript of his book 'The Quark and the Jaguar'.



20 years of PSI

In April, the Swiss Paul Scherrer Institute celebrated 20 years of accelerator operations. Originally built for particle research, these facilities now extend over a wide spectrum of applications, from molecular structure to cancer therapy. Each year over 400 visiting researchers make use of PSI particle beams.

Meetings

An international symposium on strangeness and quark matter will be held from 1-5 September in Crete, covering 1. strangeness and quark-gluon plasma, 2. strangeness condensation, 3. strange astrophysics, 4. strangelets, 5. dedicated instrumentation for strangeness and quark matter. Information from the Secretariat, University of Athens, Physics Dept., Nuclear & Particle Physics Division, Panepistimioupolis, Greece-15771 Athens, tel. (30-1)7247502, 7243362, 7243143, fax (30-1)7235089, email gvassils@atlas.uoa.ariadne-t.gr

French Academy of Sciences

Among the new corresponding members of the French Academy of Sciences (Academie des Sciences de Paris) are Raymond Stora of LAPP, Annecy, well known authority on non-Abelian gauge theories, and Michel Davier, long-time specialist in electron-positron collision physics and former Director of the Orsay Linear Accelerator Laboratory. Other new members are Alain Aspect,

At a special colloquium held at CERN on 20 April to mark Carlo Rubbia's 60th birthday and the tenth anniversary of his Nobel Prize award with Simon van der Meer, left to right - Canadian TRIUMF Laboratory Director and former UA1 co-spokesman Alan Astbury, LHC Project Director Lyn Evans, Carlo Rubbia, Director General Chris Llewellyn Smith, and former UA1 co-spokesman John Dowell. At the colloquium, Evans described Rubbia's major impact on the accelerator field while Dowell covered his considerable contributions to physics. 'Carlo Rubbia's physics achievements put CERN on the world map and got Europe behind the LHC,' said the Director General in his introduction.

Alexei Petrovich Rudik 1921-93

whose elegant experiments verified the Bell inequalities of quantum mechanics; Denis Gratias, one of the discoverers of quasi-crystals; and Bernard Castaing, who among other accomplishments developed a new technique for polarizing helium-3. Three weeks previously, Stora also received the prestigious award of the French Legion of Honour.

Alexei Petrovich Rudik 1921-93

A senior staff member of Moscow's Institute for Theoretical and Experimental Physics and a student of I. Ya. Pomeranchuk, Alexei Petrovich Rudik left a legacy both in particle physics, in work on discrete symmetries, and in the theory of nuclear reactors, where he applied Pontryagin's optimization method. Almost blind and deaf in his later years, he nevertheless continued to be active in research and to write books. He was the author of nine monographs and numerous papers.

Signing the CERN VIP visitors' book on 22 April is Swedish Minister of Labour Börje Hörlund, accompanied by CERN Director of Administration Helmut Weber (left) and Maurice Jacob, CERN Advisor on Relations with Member States.
(CERN HI34.4.94/3)

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Saclay Laboratory, (France)
Elisabeth Locci

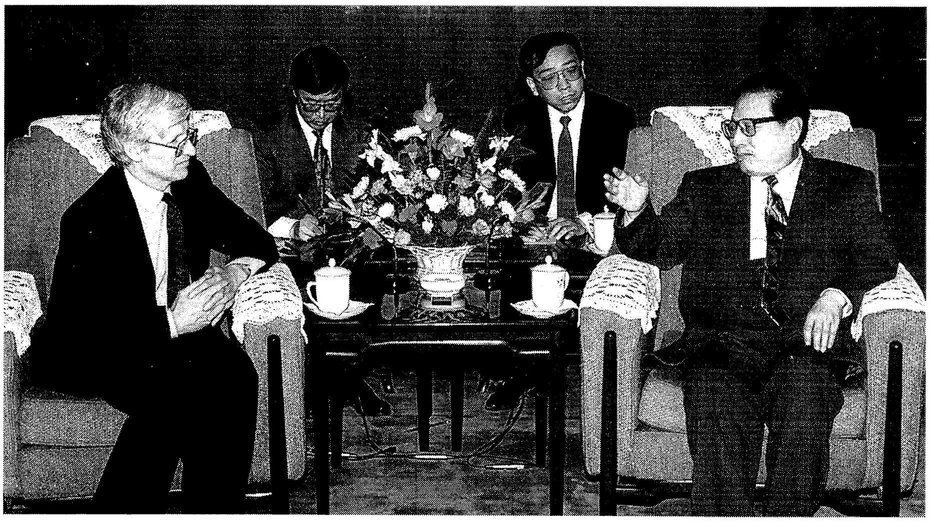
IHEP, Serpukhov, (Russia)
Yu. Ryabov

Stanford Linear Accelerator Center, (USA)
M. Riordan

TRIUMF Laboratory, (Canada)
M. K. Craddock

The first meeting of the Programme Advisory Council (PAC) for Particle Physics at the Joint Institute for Nuclear Research (JINR) Dubna, near Moscow, was held on 12-13 April. Left to right - I. Ivanov (JINR), G. Zinoviev (Ukraine), A. Baldin (JINR), A. Sissakian (JINR), P. Spillantini (Italy, Chairman), N. Tyurin (Russia), R. Voss (CERN). J.E. Augustin (CERN), S. Vokal (Slovakia) and N. Russakovich (JINR).

At the end of March, President of the Peoples' Republic of China Jiang Zemin (right) discussed Chinese participation in the CERN programme with CERN Director General Chris Llewellyn Smith.



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The Editor welcomes contributions. As far as possible, text should be sent via electronic mail.

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