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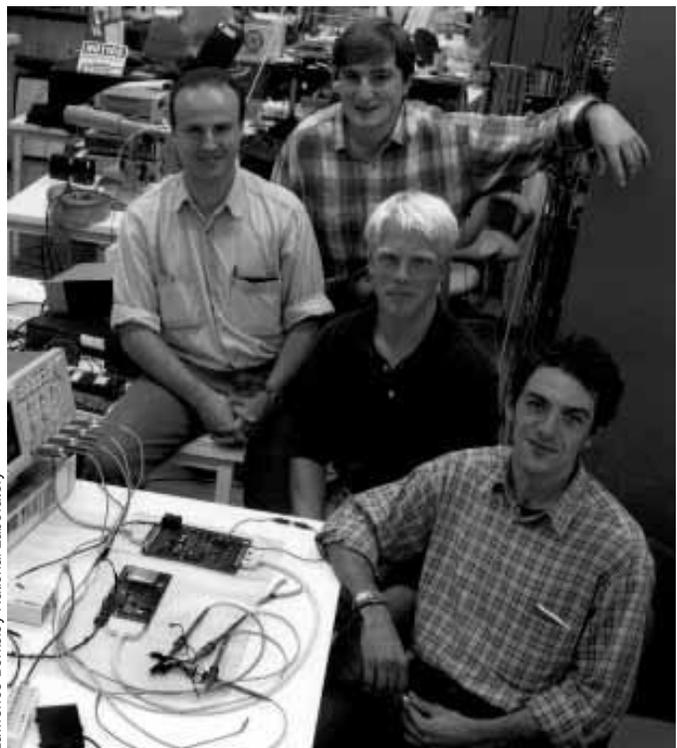
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Reidar Hahn, Fermilab Visual Media Services



Lawrence Berkeley National Laboratory

FOREWORD

IN MANY DIFFERENT FIELDS, ranging from astrophysics to molecular biology, scientists have pushed back the frontiers of their research so far that important advances can now occur only by making huge investments in new equipment. This is certainly true of high energy physics. Having answered the “easy” questions, we now face the really tough ones—such as why quarks and leptons appear in three distinct families and sport the peculiar masses they bear. These are the kinds of issues that the abortive Superconducting Super Collider was designed to address and that CERN’s Large Hadron Collider will take up early in the next century.

If we can learn one thing from the cancellation of the SSC, it should be that—given all the competing interests and demands on the public treasury that governments around the world must satisfy—it is unlikely that any single country will come up with the many billions of dollars, deutschmarks, or yen needed for the most advanced scientific projects, unless there are immediate economic benefits. The rewards of basic research, both the knowledge gained about Nature and its impacts upon future societies and economies, are available to all. Individual governments are still quite interested in supporting scientific research, but they are reluctant to foot a majority of the bill on their own when many others will benefit. Thus scientists have to find effective ways to share their major costs across national boundaries.

Scientific megaprojects that must be located within a single country, such as fusion reactors or particle accelerators, present a particularly thorny problem. As we learned from the SSC episode, support was widespread until a specific site was chosen in one particular state. How much more difficult must it be for governments to dip into their coffers to fund large facilities located in other countries? So far we have dealt with this problem in the high energy physics community mainly by sharing the detector costs while letting the host country or region pay for the accelerator or collider. But to build the multibillion-dollar colliders needed in the future, we must follow the lead of our European colleagues and learn how to share these costs, too.



The author and Hirotaka Sugawara, Director General of the Japanese High Energy Accelerator Research Organization (KEK), at the Next Linear Collider Test Accelerator being built cooperatively by the United States and Japan.

There is another problem to be faced as well—the global distribution of the biggest scientific projects. If it is unreasonable to expect any single country or region to support such a megaproject on its own, it is equally unreasonable to expect any country or region always to pay for projects

built elsewhere. This is especially a problem for high energy physics. International funding and siting of our largest projects are more difficult than for projects such as deep-sea drilling, Antarctic research stations, and the Space Station, which have no specific national home. We have to look across all scientific fields—including, for example, fusion and nuclear physics—when considering the geographical distribution of gigantic facilities. Only in this way will there be enough megaprojects to achieve a global balance. Physicists don't like this “basket” approach, but politicians will find it more acceptable.

This special issue of the *Beam Line* is devoted to the question of international collaboration in high energy physics. It offers perspectives and insights on the programs in Europe, North America, and Asia. And it chronicles some of the international efforts currently under way to design and build the next generation of particle colliders and detectors needed to study physics at the trillion-volt energy scale. I recommend it to all people interested in the future of high energy physics.



INTERNATIONAL COOPERATION

*The Sine Qua Non for the Future
of High Energy Physics*

by S. PETER ROSEN

*The Department of
Energy's new Associate
Director of High Energy
and Nuclear Physics
discusses the promise and
problems of international
scientific collaboration.*

BY ITS VERY NATURE, physics is a science that knows no national boundaries. Particles move according to the same laws of motion no matter whether they be located in Alaska, Africa, or the South Pole. Quantum mechanics is equally valid in a laboratory in China as it is in Europe. Indeed we believe that the laws of physics, those known today and those yet to be discovered, apply throughout the Universe and govern its destiny. Thus it is not surprising that physicists come from all corners of the globe, and that transnational interactions and collaborations are second nature to them.

Initially drawn together by mutual interest, these collaborations have become more and more necessary as the experimental tools of the field have grown in size and cost. After World War II, for example, the nations of Western Europe recognized that in order to play a significant role in the then burgeoning field of nuclear physics, they would have to pool their resources and work together. In 1954, they signed the convention creating the Conseil Européen pour la Recherche Nucléaire (CERN), which has since become one of the great scientific laboratories of the world and a model for peaceful international collaboration.



Individual nations in Europe did not forswear building accelerators entirely. France and the United Kingdom built proton machines (see the essay by Gordon Fraser on page 12), and Germany the DESY electron synchrotron, but they were of much lower energy than the CERN proton synchrotron. The DESY machine was the highest energy electron machine of its time, and the laboratory has been the most successful one in Europe apart from CERN. As is always the case, friendly competition is a spur to excellence.

TODAY WE ARE EMBARKING ON A NEW ERA of international cooperation, the next step beyond the regional cooperation of which CERN is the prime example. Until now, it has been the practice for regions such as Europe, or super-large countries like the United States and Russia, to build the machines that accelerate particles to higher and higher energies on their own, and for international collaborations to build the detectors that are used to study the collisions of energetic particles and analyze their interactions with all kinds of targets. At Fermilab, for example, the Tevatron was built by the United States government, through the agency of the Department of Energy, but the two detectors, CDF and D0, were constructed with significant contributions from Italy, France, Japan, Russia, and other countries. Similarly, Super Kamiokande, a 50,000-ton water detector designed to detect neutrinos from the atmosphere and the sun, and to search for proton decay, was built by Japan with a significant contribution from American physicists. With the Large Hadron Collider (LHC), however, not only the detectors but also the accelerator itself will be built at CERN by a supranational, interregional collaboration.

In this respect the LHC will not only push the energy frontier far beyond the energy of the Tevatron, but it will also test the ability of different regions of the world, in particular Europe, the United

States, Japan, Russia, India, and other countries, to work together in the creation of major new scientific facilities. Europe will still play the major role, since it is providing the site, the infrastructure, and most of the cost. Nevertheless, the United States and Japan will be responsible for the technically challenging magnets of the interaction region, a key element in the successful utilization of the accelerator, and other non-members will contribute important components in additional areas of the machine.

The driving forces behind this move to interregional cooperation are twofold. As high energy physics continues its march towards higher and higher energies in pursuit of the fundamental structure of matter at smaller and smaller distances, it must build larger and larger machines at greater and greater cost over longer and longer periods of time. Obviously cost and time are coupled; the more adequate the money flow, the less time is needed to complete the project. The cost has now become so large that no single country is prepared to build a very large machine by itself on a practical time scale. The sad history of the Superconducting Super Collider (SSC) is sufficient to make the case regarding cost alone. And the speeding up of the LHC completion schedule by three years as a result of non-member contributions speaks to the issue of time. We have reached the point where the entire international community of high energy physicists must work together to achieve its goals on practical time scales.

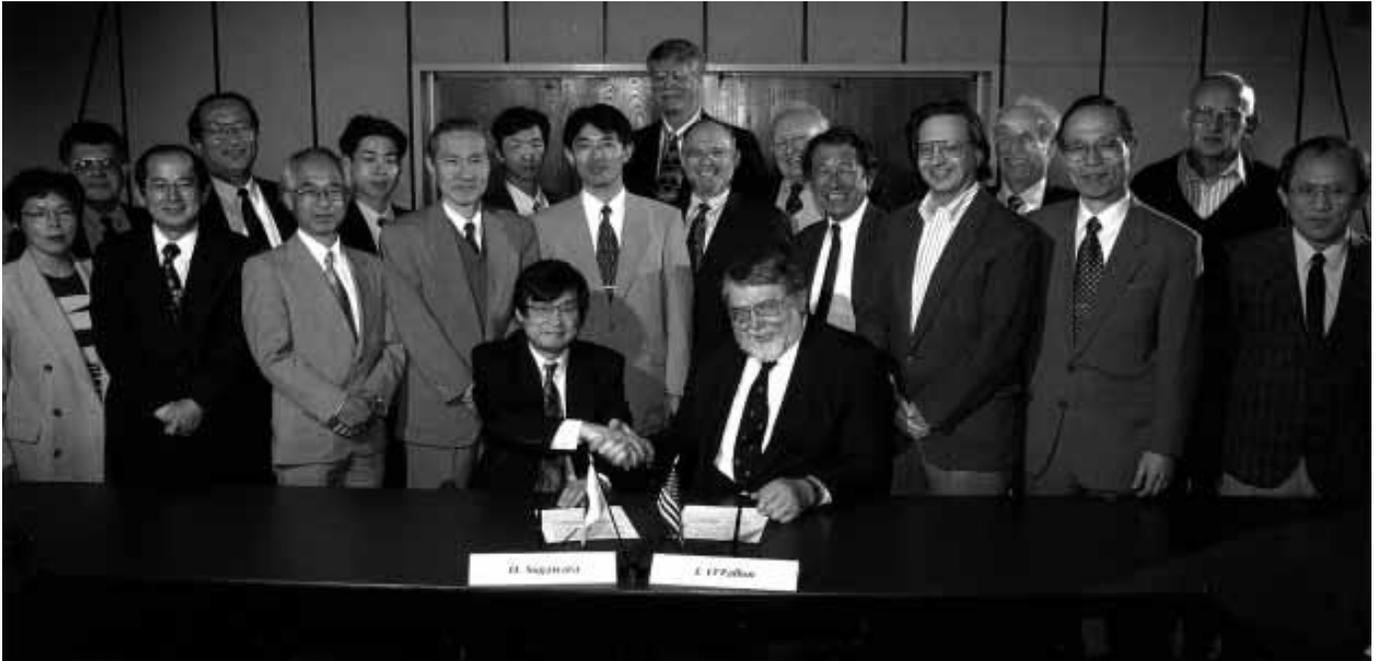
By practical time scale, I mean the length of time a physicist is prepared to invest in the building of an accelerator and the requisite detectors in order to perform significant experiments. If we take the typical career-span to be forty years, including six to seven years in graduate school, and allow about ten years after the PhD to gain tenure, then an incoming graduate student has about sixteen years in which to establish her- or himself as a physicist of tenurable quality. An established physicist, on the other hand, will not be under the same time pressure, but nevertheless will want to make as significant a contribution to the field as he or she can within the allotted span of time. Students entering the field late in the design and construction of the facility will obviously be in the best position to benefit from its use. Given all of these considerations, I would suggest that we should plan to construct and

commission new machines plus detectors within seven to ten years—and no longer—in order to provide a real incentive to physicists to commit themselves to these large projects.

An important issue in the interregional construction of accelerators is going to be the actual location of a major laboratory. As long as the site remains unchosen, all contending partners have a chance of gaining the prize. Once the choice is made, however, does the support for the project by the losing partners begin to soften? Even in large countries like the United States, this becomes a problem, as happened in the case of the SSC. Almost as soon as the Texas site was chosen, political support for the project from other contending states began to disintegrate, and this helped to terminate the project in the end. Could the same behavior occur on the international scene? Certainly, we hope not, and indeed we will need to secure firm commitments ahead of time to ensure that this problem does not arise.

Another important aspect is the nature of the site: do we build upon existing facilities, or do we start with a new “green-field” site? Europe has concentrated most of its resources in one site, namely CERN, and thus has a significant infrastructure upon which to build: the pre-accelerators and injectors, civil facilities, and technical support which are so necessary to the successful functioning of large projects. Clearly this saves a great deal in terms of both cost and time; however, the CERN site is now at its physical limit and is probably at the end of the road unless accelerator technology can be greatly improved. The SSC, on the other hand, was to be located on a green-field site, which obviously required the building of a total laboratory from the bottom up. This adds to the cost of the project and also to the time for completion; but it does provide the opportunity to do everything at the state of the art and to leave room for future extension. In other words an existing site, while it may have the infrastructure, might not meet all the long-term requirements for a new project.

Besides the physical and technical aspects of a green-field site, there are organizational, or, if you like, sociological issues. What body will be responsible for the new laboratory, and how will individual countries relate to it? How will the laboratory be governed and managed? What scientific staff will it have, and how



Hirohisa Sugawara, Director General of the Japanese High Energy Accelerator Research Organization (KEK), and John O'Fallon, DOE's Acting Associate Director of High Energy and Nuclear Physics, shake hands after signing the U.S./Japan Agreement for Cooperation in High Energy Physics in May 1996 at the 18th meeting of the U.S./Japan Committee. (Courtesy Brookhaven National Laboratory)

will they relate to its user community? Under what conditions will users work at the facility: open access based on scientific merit as envisaged in the ICFA guidelines; or “pay to play,” which would require a contribution towards the cost of the facility and possibly consideration of operating costs? What status will employees of the international laboratory have in regard to the host country? What will be the official language of the laboratory? Obviously there are many more questions of this nature that will have to be answered.

At this time CERN itself is one model to follow. It has certainly worked successfully in the physics arena and has much to commend it. Nevertheless, other models should be examined, if only because they might raise important questions that are not readily apparent in the CERN model. Other fields of science—astronomy and space, for example—use models in which use is allocated to individual countries based upon their contribution to the construction of the facility; each country is then free to allocate its allotment to individual scientists on the basis of scientific merit, or other criteria. The Megascience Forum, an activity of OECD to lay groundwork for large international science projects in many fields, is presently engaged in a study of all of these issues as they relate to international cooperation.

IN CONTEMPLATING CONSTRUCTION PERIODS that are long compared to the timescale of electoral politics, it is not unreasonable to ask whether the United States government can be relied on to stay the course once the construction of an international project has begun. One cannot, unfortunately,

make any absolute prediction because so many factors can change markedly over a decade: political moods shift and change, and what may be popular today may become anathema tomorrow; the economy may undergo significant changes for the better, or for the worse; the social climate may bring to the fore issues of great moment that may disrupt the smooth flow of life. Barring such dramatic events and assuming that societal life will make a relatively smooth progression from one epoch to another, I believe that the United States can be relied upon as a partner provided that three basic conditions are met.

The first is that the case for building the facility, both the scientific arguments and the attendant benefits to society, must be made honestly and clearly, without hype. We must not promise the moon, either scientifically or in terms of spinoffs, but we can argue for extending the envelopes of science and technology by undertaking challenges that have never been faced before. We cannot predict the outcome, nor the benefits, but history does show that on some time scales, which may be ten years or fifty years, there are real gains to be made in science and in tools useful to society.

An important part of this argument, I believe, is the benefit to other sciences: high energy physics has borrowed techniques from other sciences, but in return, it has provided them with major new tools. Synchrotron light sources, for example, are of ever growing use in biology, chemistry, and materials science, and they are a direct outgrowth of accelerator science pioneered by high energy and nuclear physics.

I also believe that we must begin the effort to develop support for the project at an early stage, not just within the high energy physics community, but also within the broader community of science and the general public. Outreach must be made to Congressional delegations, local citizens, and industry so as to build a consensus strong enough to withstand any vigorous challenges. The American political system works well when consensus exists for a project, but it does not automatically build one. As Neal Lane, Director of the National Science Foundation, has pointed out, leadership from the science and engineering communities requires a much more public and civic persona.

The second condition is that we must do, and be seen to be doing, a thorough job of establishing the total project cost and funding profile. Once we have set these parameters, we must live within them, even if it means that we must do some limited descoping in order to do so. Time, in the form of upgrades and accelerator improvements, is our ultimate contingency, but we cannot afford to give even the slightest hint, after the project has started that the costs are about to escalate out of control. To do so would undermine credibility and invite the same kind of assault that hit the SSC.

Finally, the project must be technically successful, meeting its milestones as close to the planned schedule as possible. We all know that in any major project there will be hitches, to greater and lesser degrees, but as long as we are open and honest about them, and as long as we can show that we are making serious efforts on the appropriate scale, I do not believe that Congress will lose faith in us. Naturally, an overall record of real progress helps enormously in this regard. Thus, I am reasonably sure that Congress will continue to support a large international project as long as we can be seen to be meeting the expectations that we create.

I T IS MY PERSONAL BELIEF that international collaboration in all aspects of high energy physics is the sine qua non for future progress in the field. Because of the universality of physics, such collaboration comes naturally to physicists themselves, but, unfortunately, it does not come so easily to the governments to whom high energy physicists must turn for the resources they need. Governments tend naturally to think in terms of national interest, and so it becomes necessary to convince them that thinking internationally is as much in the interest of national scientific development as it is for trade and for defense.

It behooves us therefore to create institutions within the international scientific community that are truly representative of that community and will have credibility with governments. Such institutions should have high visibility within the high energy community and derive their authority by interacting with it



Zhou Guangzhao, Special Advisor, Chinese Academy of Sciences, and the author sign the U.S./Chinese collaboration agreement in November 1997.

regularly on all issues of great moment. Their major roles will be to develop a consensus for the next step in high energy physics and can make the case effectively for new international facilities. They can also facilitate the early international planning and joint R&D that are keys to success.

The International Committee for Future Accelerators and the International Union of Pure and Applied Physics can certainly provide a basis for this activity, but they need to be significantly enlarged and become more visible in relation to high energy physics. The Megascience Forum is also a possible vehicle for creating and developing the needed institutions. Other avenues should also be explored.

In conclusion, I would like to say that international cooperation in high energy physics serves a deeper purpose of providing a model for cooperation and reconciliation amongst nations that have, at one time or another, been bitter enemies. This was one of the motivations for the establishment of CERN; the laboratory was able to build upon the natural ties among physicists, and help to bring about reconciliation in Europe. Let us use them for a similar purpose on a global scale. ○

Retrospectives on Interi

IN THE NEXT FEW PAGES we present four different perspectives on international collaboration in high energy physics:

- Gordon Fraser highlights the origins of pan-European cooperation at CERN and DESY.
- Hirotaka Sugawara frankly appraises the Japanese experience and plans for future colliders.
- Alexander Skrinsky reviews the increasing reliance on international exchanges in the Russian program.
- Zhou Guangzhao explains how international collaboration has been the key to China's emergence as a prominent contributor to the field.

Taken together, these articles show how international collaboration has increasingly knit the community together. It has indeed become, in Peter Rosen's apt phrase, "the sine qua non of high energy physics."

All four articles begin on these two pages, 12 and 13. Then they continue as separate columns on pairs of facing pages through page 19 (look for the relevant author's picture at the top of each column).



Gordon Fraser, Editor, CERN Courier, Geneva, Switzerland

AS THE ECHOES of World War II died away, physicists returned to traditional research and teaching interests. In the United States, federal scientific research expenditure had increased tenfold during the war and maintained this growth over the next decade. In war-torn Europe, postwar funding was less generous, but scientists—with Niels Bohr in Copenhagen as a father figure—had immense prestige. Spurred by fresh cosmic-ray discoveries and with strong political and scientific motivation for particle accelerators, France and the United Kingdom pushed ahead with flagship proton machines, culminating with the 3 GeV Saturne synchrotron in 1958 and the 8 GeV Nimrod machine in 1963.

Postwar Europe was in transition. The militant national pride that had

ational Collaboration



Hirotaka Sugawara, Director General, High Energy Accelerator Research Organization, Tsukuba, Japan



Alexander Skrinksky, Director, The Budker Institute of Nuclear Physics, Novosibirsk, Russia



Zhou Guangzhao, Special Advisor, Chinese Academy of Sciences, Beijing, China

I AM WORRIED. I am worried about the future of high energy physics. I am worried about the future of international collaboration in high energy physics. Paradoxically, I am also feeling confident about the future.

The cost of high energy physics is ever increasing and the only way out is to share it among interested countries. However, some physicists accept this idea rather reluctantly and only when it is convenient for their purposes. The failure of ICFA evidently demonstrates the unwillingness of physicists to clearly define mechanisms to promote world-wide collaboration.

High energy physics has a clearly defined set of research tasks to pursue for the next 10 to 15 years. The most important issues in high energy physics in the next few decades will be to establish the Standard Model

WORLD WAR II, the Cold War, and a very real possibility of World War III loomed over the intellectual climate of the mid-1950s, when the first postwar east-west contacts between scientists began. Nuclear and elementary particle physicists played the leading role in this process. At the time it was hardly a trivial matter to discuss interesting and intriguing problems in fields so close to the bomb. But many physicists on both sides of the “Iron Curtain” understood—perhaps better than anybody else—that international collaboration is vitally important both for healthy progress in understanding Nature, and for eliminating the historical, artificial divisions, and confrontations among the nations of the world.

Contacts and collaboration with foreign physicists became part of

CHINA'S HIGH energy physics was developed with the aid of international collaboration. During the 1950s, the country was a member of the Joint Institute for Nuclear Research in Dubna, where Chinese physicists worked with foreign colleagues and obtained many interesting results. Beginning in the late 1970s, following the “Open Door” policy established by Deng Xiaoping, international cooperation in high energy physics entered a new era. In 1979 China and the United States established the PRC/U.S. Joint Committee for Cooperation on High Energy Physics. The Chinese Academy of Sciences has since entered cooperative agreements with high energy physics laboratories all around the world. Hundreds of Chinese physicists, engineers, and students have worked in these labs and



engendered two world wars had given way to a new humility and a desire for international cooperation. In 1946, Churchill spoke of a “United States of Europe.” Under the new United Nations, specialized agencies were also fostering international cooperation. Subnuclear physics, riding the crest of a wave in the United States and with Europeans anxious to make up lost ground, was an obvious focus. At a 1950 general meeting in Florence of UNESCO, the new United Nations’ Educational, Scientific and Cultural Organization, Isidor Rabi was a U.S. delegate. Recently an instigator of the Brookhaven National Laboratory (BNL), run by a consortium of East coast U.S. universities, he saw that it could serve as a role model for Europe.

But the idea of a European laboratory already had two selfless champions—Pierre Auger, French scientist and UNESCO’s Director of Exact and Natural Sciences, and Italy’s Edoardo Amaldi, a former colleague of Enrico Fermi. So thoroughly did they do their work that only a few months later, an ambitious resolution for the nascent European laboratory aimed to build an accelerator more powerful than the Cosmotron and Bevatron then under construction. As astute diplomatic moves made the Conseil Européen pour la Recherche Nucléaire—CERN—a reality, European accelerator experts faced the challenge of building a world-class accelerator in Geneva. In August 1952 a small party went to admire Brookhaven’s progress towards a successor to the Cosmotron.



In August 1952, a visit to Brookhaven National Laboratory by a group from an embryo CERN helped bring about the development of the strong focusing technique which revolutionized the design and construction of synchrotrons. Left to right are George Collins, Chairman of BNL’s Cosmotron department; Odd Dahl, in charge of CERN’s synchrotron project; accelerator pioneer Rolf Wideröe of Brown Boveri, and Frank Goward of CERN.



on a firm ground and then to find evidence for or against supersymmetry. It will also be very important for non-accelerator physics to search for a possible grand unified scale or even the Planck scale.

We will need a linear collider to complement the LHC, a 100 TeV scale pp collider, and perhaps a muon collider to complement the pp collider; we also need several large scale non-accelerator devices. The problem is to allocate these facilities in a reasonable way among the countries or the regions willing to share the cost. Due to current economic conditions, together with technological capabilities, these countries are most likely to be in Europe, North America, or Asia. However, there is no agreed upon mechanism by which physicists can decide the countries or the regions.

My worry is not just about high energy physicists’ reluctance to engage in genuine international collaboration in accelerator management, but also about the attitude of scientists outside high energy physics. Everywhere I hear the cry of anti-big-science mobs. High energy physicists are partly responsible; there has been a lack of effort to communicate well with their neighboring scientists. I find in many cases well established scientists in other fields are envious of us. I believe that good scientists are interested not only in the success of their own field, but also in the advancement of related or even unrelated fields.

Another worry is about our relationship with politicians and government officials. Obviously, in democratic systems we must respect decisions made by our elected representatives; it is also our task to work hard to see that these decisions are made on their scientific merits. The same applies to our interactions with officials in governmental bureaucracies. There are some international organizations that can potentially have a real influence on science policy, such as UNESCO and OECD; however, both have real limitations. First, the U.S. does not belong to UNESCO. Secondly, the OECD was first created to protect the interests of postwar western European nations, so European countries are over-represented and Asian countries are under-represented for discussing big-science matters.

Let me turn to the linear collider issue. In 1986 the Japanese high energy physics community decided that it would participate in a foreign hadron collider project



daily life for Russian high energy physicists and laboratories after the 1963 International Accelerator Conference at Dubna. At this meeting, colliding-beam activities were presented globally for the first time. And friendly collaboration began between the Princeton/Stanford and Novosibirsk groups.



Beginnings of the long-term collaboration between SLAC and the Institute of Nuclear Physics. Gersh Budker, right, and Wolfgang Panofsky at the INP in Novosibirsk, 1975.

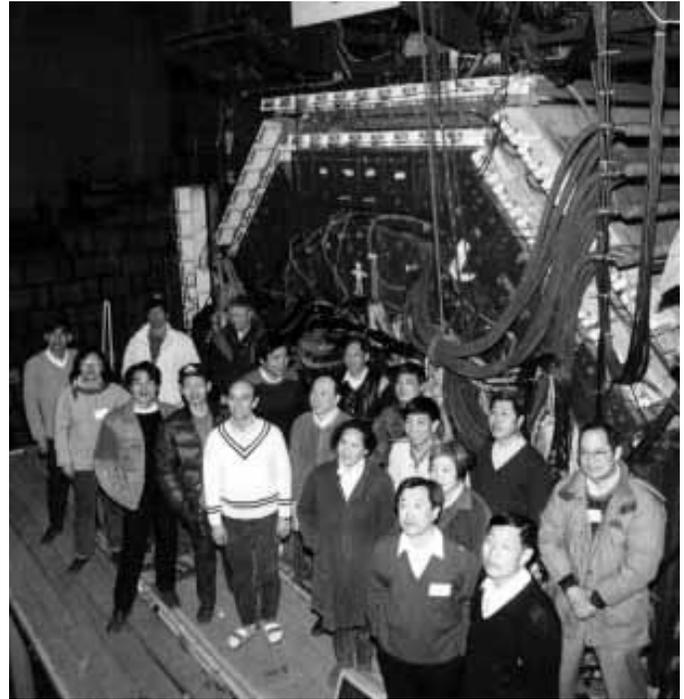
Two years later this rivalry led to the world's first experimental results from electron-electron colliding beams at Stanford and Novosibirsk, followed shortly by the world's first electron-positron experiments at Novosibirsk. This was the real beginning of the now-dominant collider era in particle physics. Wolfgang (Pief) Panofsky and Gersh Budker contributed much effort and enthusiasm to increase the scope of this cooperation. During the 1960s, however, their efforts were not completely successful—mostly because of political reasons. But, unfortunately, even now, when almost all external political obstacles have disintegrated, the Novosibirsk-SLAC collaboration is far smaller in scale than the Budker Institute of Nuclear Physics collaboration with CERN, DESY, and KEK. We could definitely do much more together.

In 1956 the Soviet Union brought scientists together from different socialist countries by organizing the Joint Institute for Nuclear Research at Dubna. Around 1970, CERN and groups from its Member States made important contributions to the Institute of High Energy Physics at Protvino, site of the 70 GeV proton synchrotron—at that time the biggest accelerator in the world. Since



obtained extensive experience, making important contributions to many high energy physics projects.

Without successful cooperation with physicists and laboratories in the United States, Europe, and Japan, the Beijing Electron Positron Collider (BEPC) would not have been built on schedule and within budget. And it would have been impossible to have reached the design luminosity so soon after commissioning it. Physicists from ten American institutions have since been working on the Beijing Spectrometer (BES) at BEPC. This collaboration has been very successful, obtaining many impor-



Chinese physicists with U.S. collaborators working on the Beijing spectrometer.

tant results on tau-charm physics, including a precision measurement of the tau lepton mass and measurements of the D_s and ψ' mesons.

In addition, Chinese high energy physicists have joined international collaborations on experiments all over the world. Our physicists and engineers have made important contributions to the L3, ALEPH, AMS, LVD, and other experiments. They are also making major contributions to the construction of the two B factories and other particle accelerators.



While preparing for their visitors, Brookhaven physicists came up with the idea of strong focusing, and magnanimously shared with their European colleagues the insight that synchrotrons could be made more powerful. CERN gratefully took the baton and ran with it. In a startling demonstration of what European collaboration could achieve, CERN's synchrotron began operations in November 1959, several months before Brookhaven's Alternating Gradient Synchrotron; directed by John Adams, the new CERN machine delivered protons at 28 GeV, then the world's highest energy. It was the start of a U.S.-European tradition of close collaboration tempered by friendly rivalry.

Although the young upstart CERN won that race, exploiting the new synchrotrons was a different matter. Within a few years, the Brookhaven AGS produced major discoveries—the muon neutrino, CP violation, the omega minus. Watching enviously from the wings, CERN had to wait until 1973 before its first important breakthrough, the discovery of neutral current. Meanwhile CERN's next big machine, the Intersecting Storage Rings (ISR), the first proton-proton collider, cruised into action in 1971. Although a triumph of machine building that explored promising new horizons, the initial harvests of physics results were again disappointing.

CERN had learned its lesson for its next project, the proton-antiproton collider. A distinguished tradition of machine building, consummate machine expertise gained from the ISR, and the physics vision of Carlo Rubbia set the stage for the historic discovery of the *W* and *Z* particles in 1983. With Simon van der Meer's development of stochastic cooling, a key accelerator technique again crossed the Atlantic, but this time it went from east to west.

But Europe has more than the CERN string to its bow. In parallel with international efforts, its nations initially continued their individual aspirations. Germany, a CERN founder nation, had no national accelerator. To rebuild a tradition, pioneers such as Wolfgang Paul, Wolfgang Gentner, and Willibald Jentschke pushed for the apparently less glamorous electron synchrotron route.

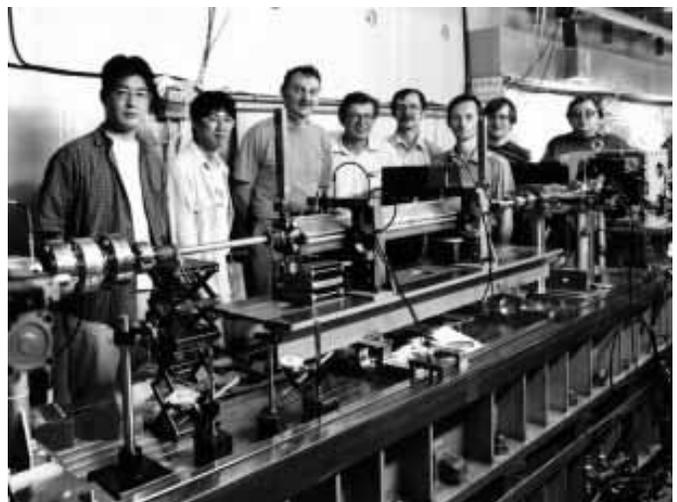
In February 1964 the new Deutsches Elektronen Synchrotron—DESY—began operations in Hamburg at 6 GeV; until the arrival of the 20 GeV Stanford linear accelerator in 1966, it provided the world's highest energy electrons. DESY capitalized on the trend to electron-



and it also would build a domestic linear collider. The High Energy Committee action plan, issued in 1995, states that Japan wants to be the host country for an international linear collider project. The Asian Committee for Future Accelerators (ACFA) supports this action plan. There seems to be a growing consensus among Asian countries that a linear collider project is an appropriate project for Asian-Pacific countries to participate in and that Japan should take the leadership in this project.

The U.S. failed to build the SSC; a high energy physics facility located in the U.S. is certainly needed. It is up to the U.S. high energy physics community to decide which project is the most suitable, given the present circumstances. If a linear collider is selected, a serious consultation between U.S. and Japan becomes necessary.

SLAC and KEK are now working together in the R&D effort for a linear collider within the framework of worldwide collaboration. We are trying to strengthen the effort of the two laboratories by making it more formal. This initial formal agreement will not be to make a common design, but to study together the problems of designing a linear collider, although I believe that we have to proceed with a common design, eventually. The Japanese high energy community decided recently that it wants to have more time to consider the issue before it makes a final decision on whether or not to proceed to the common design stage.



The linac for the accelerator test facility at KEK.



then, Russian groups have taken an increasing role in experiments at CERN, Fermilab, and other western laboratories. A new scale of collaboration began on the LEP collider at CERN, where several Russian labs and groups made major contributions to the big L3 and DELPHI detectors and played important roles in these experiments.

After Perestroika, which brought many good and bad things to Russian life, all Russian science (including high energy physics) suffers from severe economic difficulty. (See Sergei Kapitza's article, "The Future of Science in Russia," in the Fall/Winter 1993 issue of the *Beam Line*, Vol. 23, No. 3.) International collaboration has become essential to the survival of the existing Russian groups and for attracting bright young people to high-energy physics. Russian physicists now collaborate



SLAC



An international team from Japan, India, the Republic of Korea, and Russia participate in a joint test of the prototype of a cesium iodide electromagnetic calorimeter at the tagged photon beam for a future KEK B factory experiment, BELLE. This photo was taken at the Budker INP in Novosibirsk.

actively at practically all the major high energy physics centers in the world, while foreign scientists are involved in experiments at Novosibirsk and Protvino. And use is made throughout the field of well-known Russian inventions and developments such as electron cooling of proton-antiproton and heavy-ion beams, and high-



One of the most important fundamental research fields, high energy physics is also Big Science, requiring large amounts of manpower and resources, which makes international cooperation essential. The world community is pooling every possible effort to overcome the budget challenges and making great endeavors at both the high-energy frontier, with large colliders such as the LHC, and the high-precision frontier, with high-luminosity particle factories. We are confident that international cooperation in high energy physics will be further enhanced during the next century. The Chinese government has given this research strong support, but as a developing country, China can allocate only limited resources to the field, thus making international cooperation crucial. It allows foreign physicists to do research in China, and our own physicists to work at frontier experiments all over the world, following the latest developments.

Chinese physicists are now discussing further development of the BEPC facilities to do high-precision measurements in the tau-charm energy region from 3 to 5 GeV. Such a Tau Charm Factory with a luminosity of $10^{33} \text{ cm}^{-2}\text{sec}^{-1}$ would allow very accurate measurements of light-hadron spectroscopy, especially searches for glueballs and quark-gluon hybrid states, as well as searches for CP violation in tau lepton and *D* meson decays. The proposed Beijing Tau Charm Factory (BTCF) will proceed in three steps—feasibility study, research and development, and official construction project. So far the Chinese government has supported a feasibility study on the BTCF, which was reviewed by an international panel at the end of 1996. Another possibility is for us to upgrade BEPC into BEPC II, having a luminosity of $10^{32} \text{ cm}^{-2}\text{sec}^{-1}$, which would still be sufficient to do most of the research on light-hadron spectroscopy, including the work on glueballs and quark-gluon hybrids. We will do R&D work for both the BTCF and BEPC II, with a final decision to be made around the year 2000. Foreign physicists are welcome to participate in this project; their experience and technology will prove very useful. And foreign contributions to the accelerator and detector would help to get the project approved by the Chinese government.

Another fruitful international collaboration is taking place in Yangbajing, Tibet, where a large air-shower array is being built at 4300 meters above sea level by



positron colliders, first with DORIS, then with PETRA. Europe's initial wave of postwar machines was the culmination of national aspirations. To coordinate these aspirations with science, the European Committee for Future Accelerators (ECFA) was formed during Victor Weisskopf's mandate as CERN Director General from 1961–1965.

For its long-term future, CERN set its sights on a large electron-positron collider. But fertile minds had been exploring a radically different route, electron-proton collisions, to probe the structure of the proton in new depth. Deftly orchestrated by ECFA, CERN got LEP and DESY got HERA. In a curious twist of tradition, CERN, a proton laboratory, had to learn how to handle electrons, while DESY had to take protons on board. Both laboratories took the challenges in stride, adding new depth to Europe's complementarity of particle beams.

CERN had demonstrated the effectiveness of formal international collaboration, with assured funding and guided by vision. In CERN's parliament, or Council, representatives from Member States vote on important issues, such as major new scientific projects, which require prior Council approval before becoming an integral part of the ongoing program. This approved program is then the responsibility of CERN management; CERN's budget, itself governed by a rolling plan periodically updated by Council, finances this program. In this way, approved projects are administered according to their scientific merit and are sheltered from various political pressures in the member States. In building HERA, DESY had taken another approach, inviting international partners to contribute to a shopping list of equipment and resources in return for a research interest in the new facility. There was more than one way of going international.

CERN had written itself a long-lived research ticket by building its LEP tunnel large enough to house a subsequent proton collider, the LHC. LEP is the largest electron synchrotron ever built and may hold that record forever. Crippling losses due to synchrotron radiation mean that higher energy electron machines must be linear colliders. DESY dutifully prepared for the future, pushing accelerator technology on several fronts. Recent achievements using superconducting radiofrequency cavities have shown that this approach may be a prime contender to power a large electron-positron linear collider to complement the LHC in the next century. ○



International collaboration, whether in accelerator R&D, particle research, or laboratory management, is not just a matter of physics. It is a matter of language, beliefs, education, and daily life. In fact, it is a matter of an encounter of all aspects of different cultures. In this respect I envy California which is already very open, multi-cultural, and multi-racial. I love that aspect of Californian style; I want Japan to be more like that and I am glad that there is a persistent and growing tendency in various sectors of Japanese society to make it more open.



Damping ring in the Accelerator Test Facility at KEK.

What a physics laboratory like KEK can contribute to this end is to build a project like a linear collider with genuinely international management and research programs, inviting people from California and the rest of the U.S., from Asia, from Europe, and from all the rest of the world to participate in the project. This has to be done in such a way that our colleagues at SLAC will feel happy about it. Things also should proceed gracefully. I am confident that it can be done. But I am worried. I am very confident, but I am also very worried. ○



precision measurements of particle masses—both originated and first applied at Novosibirsk.

Our participation in the LHC project at CERN now plays an especially important role in the future of Russian high energy physics. It is crucial for our physicists to be full partners in these frontier experiments. But under the current circumstances in Russia, it was almost impossible for our laboratories and institutes to obtain additional funds to contribute to the LHC and participate in designing and building its detectors. Aided by the wisdom and open-mindedness of Carlo Rubbia, Chris Llewellyn-Smith, and our CERN colleagues, we found mutually beneficial and affordable ways to permit this participation, which is now funded equally by CERN and the Russian government.

We in the Russian high-energy physics community truly believe that international collaboration is the best way to conduct our science in the future—not only for Russia but for the world in general. ○

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collaborating with Japanese physicists. Meanwhile, Chinese and Italian physicists are proposing another cosmic-ray experiment known as ARGO in the same place. Indeed, we are even considering the possibility of establishing an international center for cosmic-ray physics experiments at Yangbajing; such a center would provide an ideal site for this kind of research, attracting scientists from all over the world.

Early in the next century, Chinese physicists will continue to make their due contribution in key experiments in other countries. We are participating in the construction of both *B* factories and their experimental collaborations, and have joined both the CMS and ATLAS collaborations at the LHC. Our participation will continue in experiments at the Tevatron and DAΦNE, as well as at other laboratories. Chinese accelerator physicists are interested in collaborative R&D work on the technology for future linear colliders. Other physicists are interested in non-accelerator experiments such as AMS and L3 Cosmics. The Chinese Academy of Sciences strongly supports all these collaborations.

As a developing country, China's contributions to international collaborations will however be rather limited during the next few decades. Therefore our physicists need to concentrate their resources and manpower on key collaborations, make good contributions to these projects, and become more visible. They should identify certain work that can be done in China, such as production of new materials, construction of subdetectors, and developing software. By taking advantage of their particular knowledge, plus the special techniques and know-how of Chinese industries and materials sciences, as well as our cheaper labor, our physicists can make major contributions to these collaborations.

China has taken its place in the world in the realm of science and technology. We are certain that during the next century our country will make even greater contributions to the international community of high energy physics. ○



Fermilab Visual Media Services



Gabriele Otto

A new electron cooling device for the Heavy Ion Synchrotron being delivered to GSI in Darmstadt, Germany. The device was developed and manufactured at the Budker INP. (Courtesy GSI)

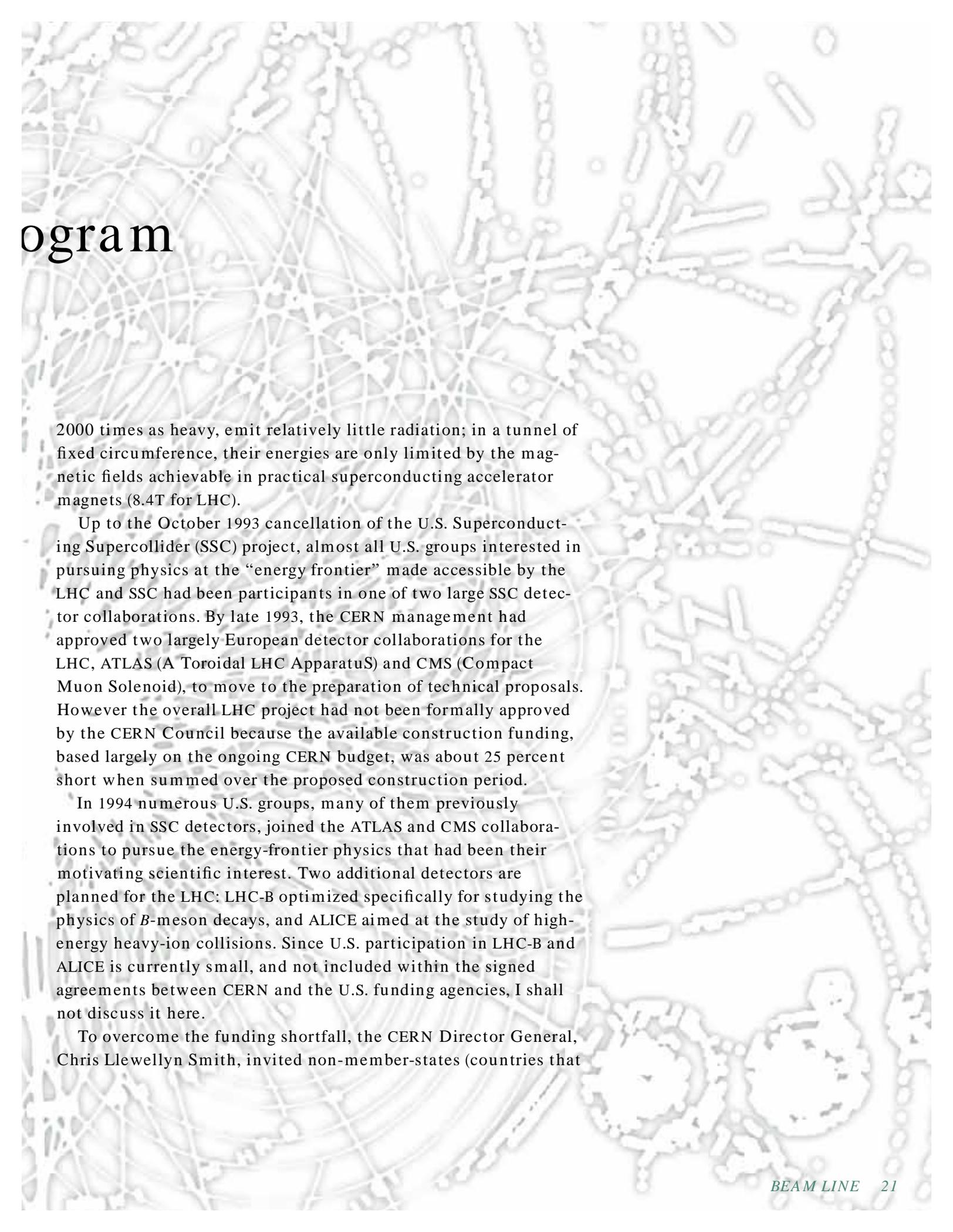
U.S. Collaboration on the LHC

by GEORGE TRILLING

Forty-seven countries and 299 institutions are part of a team to build the CERN Large Hadron Collider and its detectors. This accelerator will bring protons into head-on collision at much higher energies than ever achieved. A member of the U.S. collaboration, who has been involved since its beginnings, discusses its history and participation in this effort.

THE PUSH BY PARTICLE PHYSICISTS toward ever higher particle beam energies is motivated by the fact that much of the complexity observed at lower energies may disappear when the energy becomes sufficiently high. Thus, while beta radioactivity and electromagnetism have been separately known for 100 years, it is only in the last 30 years that new accelerators have provided energies high enough to “unmask” the fundamental relationship between the two phenomena. This is because the basic force carriers involved in radioactivity, the W and Z , are very massive, and can only be produced as identifiable objects with particle beams of very high energy. By moving to yet higher energies, particle physicists hope to unmask many more of Nature’s hidden secrets, including the mechanism by which our basic constituents acquire their masses. Their aspirations are currently focused on future experiments made possible by the Large Hadron Collider (LHC) facility to be built over the next eight years.

The Large Hadron Collider is a proton-proton colliding-beam facility to be housed in the Large Electron Positron Collider (LEP) tunnel at CERN. Its design energy is 7 TeV per beam, a figure seven times as large as the maximum Tevatron beam energy and seventy times as large as the maximum LEP beam energy. The enormous energy difference between the two colliders within the same enclosure arises from the fact that LEP beam energies are limited by the huge amount of electromagnetic radiation emitted by the electrons traveling in circular orbits (a limitation that linear colliders such as the SLAC Linear Collider and the Next Linear Collider are designed to avoid). Circulating protons, by virtue of being



ogram

2000 times as heavy, emit relatively little radiation; in a tunnel of fixed circumference, their energies are only limited by the magnetic fields achievable in practical superconducting accelerator magnets (8.4T for LHC).

Up to the October 1993 cancellation of the U.S. Superconducting Supercollider (SSC) project, almost all U.S. groups interested in pursuing physics at the “energy frontier” made accessible by the LHC and SSC had been participants in one of two large SSC detector collaborations. By late 1993, the CERN management had approved two largely European detector collaborations for the LHC, ATLAS (A Toroidal LHC ApparatuS) and CMS (Compact Muon Solenoid), to move to the preparation of technical proposals. However the overall LHC project had not been formally approved by the CERN Council because the available construction funding, based largely on the ongoing CERN budget, was about 25 percent short when summed over the proposed construction period.

In 1994 numerous U.S. groups, many of them previously involved in SSC detectors, joined the ATLAS and CMS collaborations to pursue the energy-frontier physics that had been their motivating scientific interest. Two additional detectors are planned for the LHC: LHC-B optimized specifically for studying the physics of *B*-meson decays, and ALICE aimed at the study of high-energy heavy-ion collisions. Since U.S. participation in LHC-B and ALICE is currently small, and not included within the signed agreements between CERN and the U.S. funding agencies, I shall not discuss it here.

To overcome the funding shortfall, the CERN Director General, Chris Llewellyn Smith, invited non-member-states (countries that

Countries Participating in the LHC Program

Armenia
Australia
Austria
Azerbaijan Republic
Republic of Belarus
Belgium
Brazil
Bulgaria
Canada
People's Republic of China
Croatia
Cyprus
Czech Republic
Denmark
Estonia
Finland
France
Republic of Georgia
Germany
Greece
Hungary
India
Israel
Italy
Japan
Kazakhstan
Korea
Latvia
Mexico
Morocco
Netherlands
Norway
Pakistan
Poland
Portugal
Romania
Russia
Slovak Republic
Slovenia
Spain
Sweden
Switzerland
Turkey
Ukraine
United Kingdom
United States of America
Uzbekistan

are not CERN member-states), whose physics communities had substantial interest in exploiting the LHC, to participate financially and intellectually in the machine construction. This is a departure from tradition; in contrast to detector facilities, which are built and funded internationally, accelerators are normally funded by the host country or—as in the case of CERN—the host region. The justifications for this departure, expressed from the point of view of U.S. involvement, are the following: (1) The multi-billion-dollar LHC stands at or beyond the limit of what a single region can afford to fund. If such projects are to go forward, they need interregional funding support, and such support is most naturally sought from countries whose scientific communities have strong interest in these projects; (2) The large U.S. community interested in participating in LHC experiments, currently about 600 scientists and engineers, has a strong stake in the timely completion of the accelerator project. U.S. participation in the machine can help ensure this timely completion; (3) Participation in the LHC collider effort would afford new opportunities for the continuing development of U.S. capabilities in the area of accelerators using superconducting magnets.

The proposed U.S. participation in LHC was considered by the 1994 High Energy Physics Advisory Panel (HEPAP) Subpanel on Vision for the Future of High-Energy Physics, under Sidney Drell's chairmanship, which gave a positive recommendation. Further action by U.S. funding agencies awaited CERN Council approval of the LHC project, which came in December 1994. To secure this approval, CERN management presented a staged construction plan, based solely on member-state contributions, that completed the full LHC not earlier than 2008, with the expectation that, with adequate non-member-state support for the machine, the staging might be avoided, and full completion achieved by 2004 or 2005.

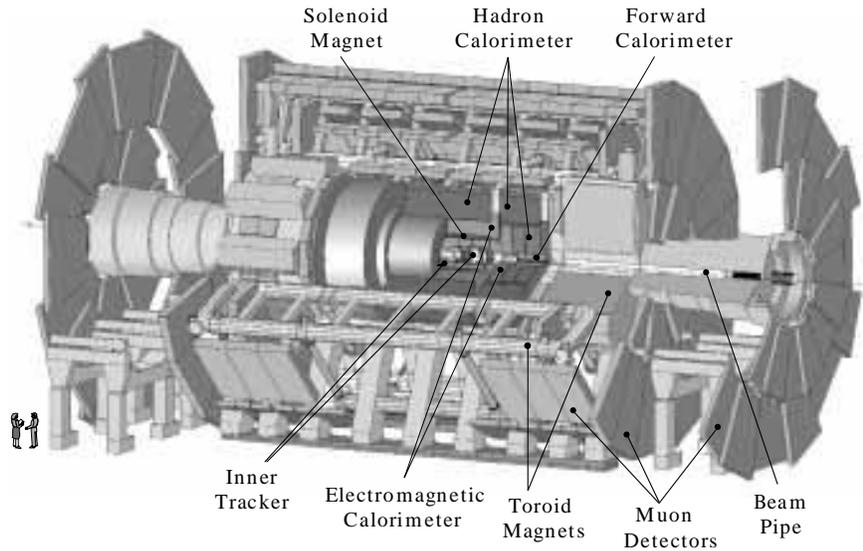
Discussions between the Department of Energy (DOE), the National Science Foundation (NSF), and the CERN leadership, relative to U.S. participation in the LHC program, were initiated in April 1995. They culminated in the signing, on December 8, 1997, by Energy Secretary Frederico Peña, NSF Director Neil Lane, CERN Council President Luciano Maiani, and Director General Llewellyn Smith of a Cooperation Agreement on the LHC

program. More detailed accelerator and experiments protocols were signed later in December. These various agreements set out the “rules” and funding levels under which the U.S. will participate in both LHC accelerator and detectors. The U.S. will commit \$250M from DOE and \$81M from NSF for the ATLAS and CMS detectors, and \$200M from DOE for the LHC accelerator. The totality of NSF plus DOE detector funding is to be split about equally between ATLAS and CMS. The accelerator funding is to be split into \$90M for goods and supplies from U.S. industry, and \$110M for systems and components provided by three national laboratories, namely Brookhaven (BNL), Fermilab, and Lawrence Berkeley. This accelerator collaboration is principally focused on the design, fabrication, and commissioning of elements for the LHC interaction regions.

In light of the proposed U.S. and other non-member-state participation in the machine, the CERN Council, in December 1996, had approved going forward on a non-staged LHC to be completed in 2005. Needless to say, Congressional approval of these funding commitments was essential. In April, House Science Committee Chair Sensenbrenner raised a number of concerns about the proposed U.S.-CERN agreements. To satisfy these, and with the approval of the CERN Council, the agreements were appropriately modified. The full \$35M request for DOE-supported LHC efforts in fiscal year 1998 has been provided.

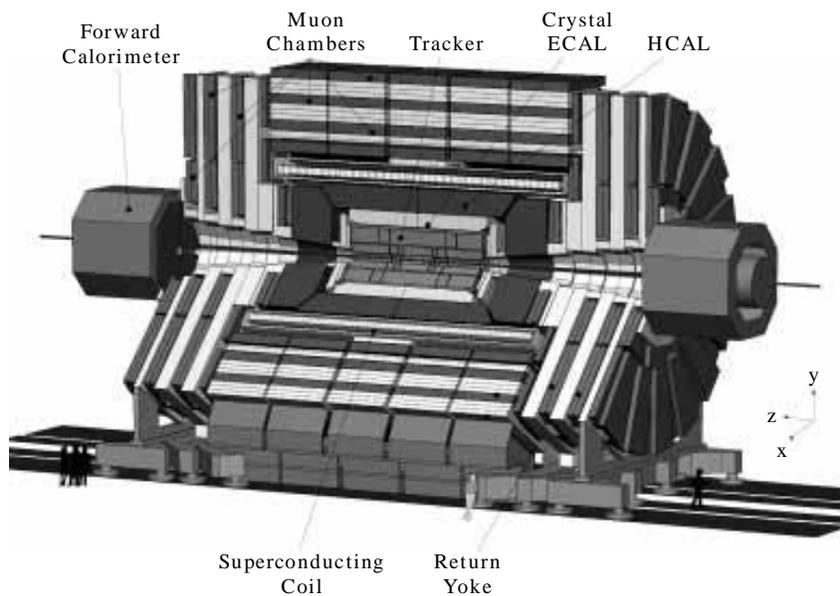
ALTHOUGH THE U.S. HAS PREVIOUSLY participated in detector projects abroad (L3, ZEUS, AMY etc.), such involvement has not yet occurred on the financial scale envisaged for LHC. Strong management is mandatory for the accelerator project and especially for the detectors, which involve collaboration by large numbers of institutions. Each detector project has a U.S. host laboratory (Fermilab for CMS and BNL for ATLAS) with management oversight responsibility given to the host lab director or his appointed representative. Because of the close coupling of DOE and NSF in the detector projects, the two agencies are forming a Joint Oversight Group (JOG) to oversee the detector fabrication efforts. Each detector program will have a U.S. Project Manager reporting to both the JOG and the host lab director.

Cutaway view of the ATLAS detector. The inner detector, calorimeters, and muon detectors measure and identify the various collision products. Magnetic fields to deflect charged particles are produced by a solenoid (for the inner detector) and air-core toroids (for the muon detectors). (Courtesy Lawrence Berkeley National Laboratory)



The physics goals of the ATLAS and CMS detector collaborations are similar to those that motivated the SSC. While the design energy of 7 TeV per beam is one third of that for the SSC (but seven times that of the Tevatron), the design luminosity of $10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$ is ten times higher. These conditions place great demands on the detectors, in terms of performance and survivability in a hostile radiation environment. At full luminosity, each crossing of two proton bunches will produce about 20 interactions, and these crossings will occur every 25 billionth of a second. A whole range of opportunities for physics discovery will open up. These include the Higgs boson or bosons, new spectroscopies such as supersymmetry, new massive gauge bosons, and searches for evidence of compositeness in what have heretofore been point particles. The Higgs sector is connected to the fundamental issue of how all our basic particles (quarks, leptons, and gauge bosons) acquire their masses, and what determines those masses. Recent work has shown that, if supersymmetry is indeed found, the LHC experiments will be capable of numerous measurements to probe its details.

Computer simulations of searches for these phenomena have provided guidance to the design of detector subsystems. Such simulations, done for a sufficiently broad array of processes, give confidence



Cutaway view of the CMS detector. The tracker, calorimeters (including HCAL and ECAL), and muon chambers are the measurement elements for the various outgoing particles. A large solenoid coil produces a very strong magnetic field for charged-particle momentum measurement.

that the ATLAS and CMS detectors can not only uncover what physicists are searching for (if it is there), but also discover unexpected and entirely new phenomena if that is Nature's way.

The main features of both detectors include: (1) high resolution and highly segmented electromagnetic calorimetry to allow detection of the two-photon decay of a light Higgs boson (below 120 GeV); (2) the ability to identify electrons and muons, and measure accurately their charges and momenta over a large angular range; (3) nearly hermetic hadronic calorimetry to measure hadronic energy flow and detect missing momentum transverse to the beam line; (4) capability to identify the presence of a B -hadron decay through detection of a displaced vertex with high position-resolution silicon pixel detectors; (5) operational capability, and survivability at the design luminosity of $10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$.

With such capabilities, these instruments can determine, for each proton-proton collision: the energies and directions of outgoing electrons, muons, photons, and jets; identify those jets originating from bottom quarks; and measure the total transverse momentum associated with neutrinos or other undetectable neutrals. Furthermore they can process enough of this information sufficiently quickly to select, for permanent recording and detailed analysis, just the one

Signing ceremony for the LHC project on December 8, 1997, in Washington, DC. Secretary of Energy Federico Peña, left, congratulates Luciano Maiani, president of the CERN Council. (Courtesy Department of Energy)



K. Shipp

collision in 100 million (still about 10 events/second) that may bear the seeds of an important measurement or new discovery.

Since these detectors are intended to complement each other, their similar design goals are accomplished in substantially different ways. More detailed descriptions of some specific detector subsystems in which U.S. groups have major responsibility are given by Gil Gilchriese (ATLAS) and Dan Green (CMS) in the following articles respectively.

Over the past few months, both detector collaborations have submitted voluminous Technical Design Reports for most of their detector subsystems, and these have undergone painstaking review by the LHC Committee. The U.S. groups hope to have completed their DOE/NSF baselining reviews by early 1998. The scientific and technical challenges are enormous, but powerful international teams including a strong U.S. presence are very effectively working together to meet those challenges. The future looks exciting.



The ATLAS Inner Detector

by M. G. D. GILCHRIESE

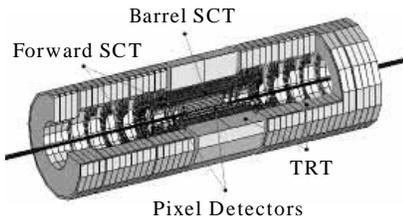
The ATLAS experiment is being constructed by 1700 collaborators in 144 institutes around the world.

It will study proton-proton interactions at the Large Hadron Collider at CERN.

The U.S. leader of one of the major systems describes what it is like working on the inner tracking detector.

A GENERAL DESCRIPTION OF THE ATLAS detector is given in the previous article by George Trilling. Twenty-eight U.S. universities and three national laboratories comprise about 20 percent of the ATLAS (A Toroidal LHC ApparatuS) collaboration, the largest single national group. U.S. physicists are involved in essentially all aspects of the ATLAS experiment, but I will only describe here one area of activity—the inner tracking detector.

Charged-particle tracking at the Large Hadron Collider (LHC) is the most difficult technical challenge faced by the ATLAS and CMS (Compact Muon Solenoid) experiments. There is now considerable confidence that this challenge can be met by the proper mix of technologies at an affordable cost. But a decade ago this was certainly not the general perception. I remember clearly sitting behind a Nobel-prize-winning laboratory director at the 1986 Division of Particles and Fields Snowmass meeting during one of the first presentations of studies of charged-particle tracking for the Superconducting Super Collider (SSC). The then-laboratory director wrote in his notebook: “Won’t work! Impossible!” And this was at a modest luminosity of $10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$ and not the $10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$ we will face at the LHC! This succinct summary



The ATLAS Inner Tracking Detector (approximate length 7 meters).

accurately reflected the uneasiness of many people at that time. So what happened to change this perception and to give us confidence now that even $10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$ may not be the ultimate limit at which charged particle tracking is possible?

The essential change in the last decade has been to realize that it is possible to build tracking detectors with very, very many independent elements (the ATLAS tracking system will have over 10^8 such elements) that can each have a time resolution of a few nanoseconds or better. And that this can be done for an affordable cost (although just barely) and with the ability to survive the hostile radiation environment at the LHC.

Our ability to make these optimistic statements follows from a decade of intense research and development on tracking detectors. A focused program of detector R&D for the SSC began in 1986 and shortly thereafter independently in Europe for the LHC. The results of these R&D programs appear today to be even more successful than the original proponents imagined. The design of the ATLAS inner tracking detector follows directly from these worldwide R&D efforts.

The ATLAS Inner Detector is shown above. It consists of three different tracking technologies. At the outer radii, there are about 400,000 straw tube drift cells that, in addition to their charged-particle tracking function, are used to detect transition radiation X-rays from electrons (therefore named the Transition Radiation Tracker or TRT). At the intermediate radii, there is a large area (60 m^2) silicon strip detector (about 5 million individual channels). For

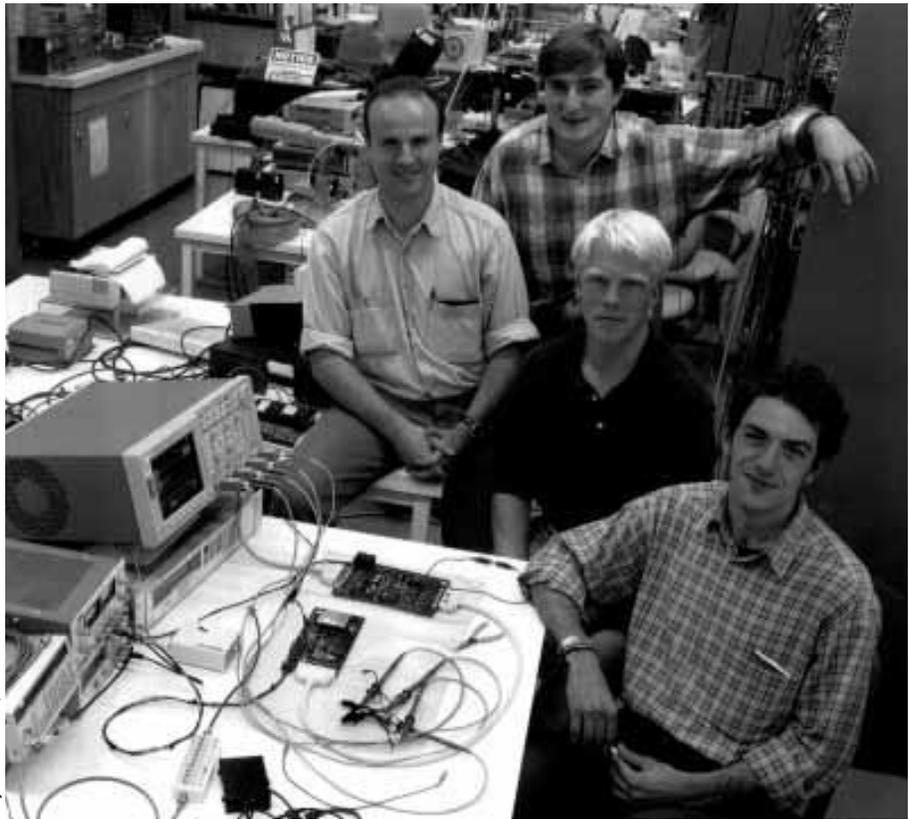
historical reasons this is called the Semiconductor Tracker or SCT. And closest to the interaction point there is about 2 m^2 of silicon pixel detectors with 1.5×10^8 individual elements—pixels.

The innermost radius of each of these types of detectors is determined by either their ability to function at the LHC luminosity of 10^{34} (in the case of the TRT) or by their ability to survive about ten years of operation (in the case of the silicon-based detectors). In fact, the innermost pixel system layer, which is critical to the ability to identify particles containing the b -quark, will last only about one year at $10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$. It will be replaced periodically unless a more radiation-tolerant solution is found. The outermost radius of each type of detector is set in part by performance requirements (for example, momentum resolution) but is even more strongly influenced by the need to keep costs within affordable bounds, not just for the inner tracking detectors but for the entire detector.

The components of the inner tracking detector will be built all over the world and shipped to CERN for final assembly and installation. There are about 60 different institutions involved, which is more institutions than even the largest collaboration for an operating experiment in the United States. This “United Nations” approach to detector design and construction does have its strengths and weaknesses. The primary strength is that the available technical expertise is very substantial and it is therefore possible, in principle, to understand every detail in depth. The principal, and inevitable, weakness is that this

expertise is dispersed all over the planet and, as a result, it becomes difficult to reach decisions and to achieve the concentration of effort that is necessary in a complicated and long technical project. That all of this (usually) works is a reflection of the intense desire of the physicists in each institution and country to “make it work” and ultimately to build the best experiment.

The U.S. collaborators are working on all three parts of the ATLAS inner tracking detector. Duke University, Indiana University, and the University of Pennsylvania did pioneering work in the development of straw tubes for the SDC detector for the SSC. Duke, Indiana, Hampton University, Norfolk State University, and the University of Pennsylvania are now responsible for the barrel part of the Transition Radiator Tracker and a substantial fraction of the TRT electronics. Modules that make up the barrel TRT will be assembled and tested by Duke, Indiana, Hampton, and Norfolk and then shipped to CERN for final assembly. Some of the parts needed for these modules will be made in the United States and others in Europe, including Russia. The University of Pennsylvania, having specialized in the design of integrated circuits and other electronics for the TRT, will fabricate and test these components and then ship them to module assembly sites in both the U.S. and in Europe. This type of exchange of components from the U.S. to Europe, and vice versa, is typical of almost all parts of the ATLAS detector. It is determined by the availability of local expertise both within the high energy physics community and within



Roy Kaltschmidt, LBNL

industries in a specific country and the desire to minimize costs by realizing economies of scale.

Another, even more diverse, example of this type of interchange of components and expertise is in the fabrication of the silicon strip modules for the Semiconductor Tracker. A module consists of silicon detectors, the integrated-circuit-readout electronics that are mounted on these detectors, and the electro-mechanical parts that support and cool the module and connect it to external electronics. About 4100 such modules are needed, which represent more than an order of magnitude increase in scale over existing silicon detectors. In addition, the many institutions involved are located from Australia to Russia, making it possible to accumulate the financial resources required but in so doing creating a substantial organizational challenge.

There will be seven regional centers for assembly of modules, with components coming from even more places. The United States is one regional center, with mod-

From left to right, John Richardson, (LBNL); Julio Bahilo-Lozano (Spain); Leif Ericson (Sweden), and Roberto Marchesini (Italy) are working at Lawrence Berkeley National Laboratory on pixel and semiconductor tracker detector prototypes.

ules and related electronics being designed, assembled, and tested by Lawrence Berkeley National Laboratory (LBNL), the Universities of California at Irvine and Santa Cruz, and the University of Wisconsin. The U.S.-built modules will be assembled and tested at LBNL and UC Santa Cruz, then shipped to England for placement on a supporting structure. UC Irvine and Wisconsin have the primary responsibility for the design and fabrication of electronics that reside outside the detector, in fact outside the ATLAS underground hall, and which are connected by fiber optics to the SCT modules.

The pixel system is located closest to the interaction point. There are two reasons why silicon pixel detectors are needed at the LHC. First, the intense radiation environment of the LHC, especially at small radii, damages silicon detectors. At some point, the damage reduces the signal induced by the passage of a charged particle so much that the fast electronics used, for example by the SCT, cannot sense the charge with good efficiency above the intrinsic noise that is inherent to the system. The trick in the case of a pixel detector is to reduce the noise by reducing the input capacitance seen by the electronics, which means reducing the size of the individual silicon sensing areas from 12 cm × 80 microns in the case of the SCT modules to 300 microns × 50 microns in the case of the pixel detector. As a consequence, the pixel electronics must be mounted directly on top of the silicon sensing elements, and thus the ATLAS pixel detector contains about 2 m² of integrated circuits, a large fraction of

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to survive the hostile
radiation environment
at the LHC.*

the integrated circuits needed for the whole experiment. The LHC interaction rate and radiation environment are such that CCD pixel detectors, such as those so successfully used in the SLAC Large Detector at the Stanford Linear Collider, cannot be considered. The second need for pixel detectors is driven by the high density of tracks in hadronic jets at the LHC and the desire to find particle tracks within these jets for tagging particles containing the *b*-quark as well as for other reasons. The enormous granularity of the pixel detector, located near the interaction point where the track density is highest, greatly improves the track finding capability.

The U.S. institutions working on the ATLAS pixel detector are LBNL, UC Irvine, UC Santa Cruz, University of New Mexico, University of Oklahoma, SUNY Albany, and the University of Wisconsin. Irvine and Wisconsin are responsible for the off-detector electronics, which are similar to those used for the SCT. The other groups are working on all aspects of the pixel detector—integrated circuit electronics, silicon detectors, module construction and mechanics—and will be responsible for delivering the forward/backward disk elements of the pixel system for the experiment.

The construction phase of the subelements of the ATLAS Inner Detector has started. The TRT has entered this phase, to be followed by the SCT next year and then the pixel detector a year later. It has taken more than a decade of R&D involving almost all of the major countries in the high energy physics world to get to this stage. Although the final proof awaits the turn-on of the LHC, it appears now that this long effort has been spectacularly successful. In this sense, the ATLAS inner tracking detector is an example of the best of international collaboration in high energy physics. ○

The CMS Hadron Calorimeter

by DAN GREEN

The CMS experiment will use a large general purpose detector to study proton-proton interactions at CERN's Large Hadron Collider.

A major subsystem, the hadron calorimeter, will measure the energy flow in these interactions.

To be realistic today is to be a visionary—Hubert Humphrey
White House Conference on International Cooperation

THE COMPACT MUON SOLENOID (CMS) collaboration consists of about 1650 high-energy physicists from 150 institutions scattered around the globe whose collective goal is to take the next discovery step at the “energy frontier.” The U.S. part of this collaboration, which formed in response to the 1993 demise of the Superconducting Super Collider, includes about 300 physicists from 40 institutions. Our challenge is to participate successfully in what are arguably the first truly global scientific experiments.

The CMS detector is a general purpose detector. When voyaging into the unknown, it is best to be ready for anything. In the case of CMS, where we do not know exactly what we will find, we must be prepared by building a detector capable of measuring all the known fundamental particles to good accuracy.

The particles of matter are categorized as leptons and quarks. The fundamental force carriers are the photon of electromagnetism; the weak force carriers, W and Z ; and the strong force carriers, the gluons. Quarks interact strongly



W. Wu

Dan Green, left, and Prof. Xuan Zhu of the Chinese Academy of Sciences discuss potential collaboration on CMS between the United States and Chinese groups.

and thus evolve into hadrons—strongly interacting particles such as the pion and proton. The leptons are either charged or neutral. The neutral leptons, called neutrinos, inter-

act so weakly that they escape direct detection. At every moment, for example, billions of solar neutrinos are traversing our bodies without our notice and without causing us harm. We infer the production of neutrinos in a reaction by the energy that they carry off undetected, which shows up in the detector as an imbalance in the momentum. Since particle detection is extremely difficult at small angles to the incoming beams, only the energy imbalance transverse to the beams can be measured.

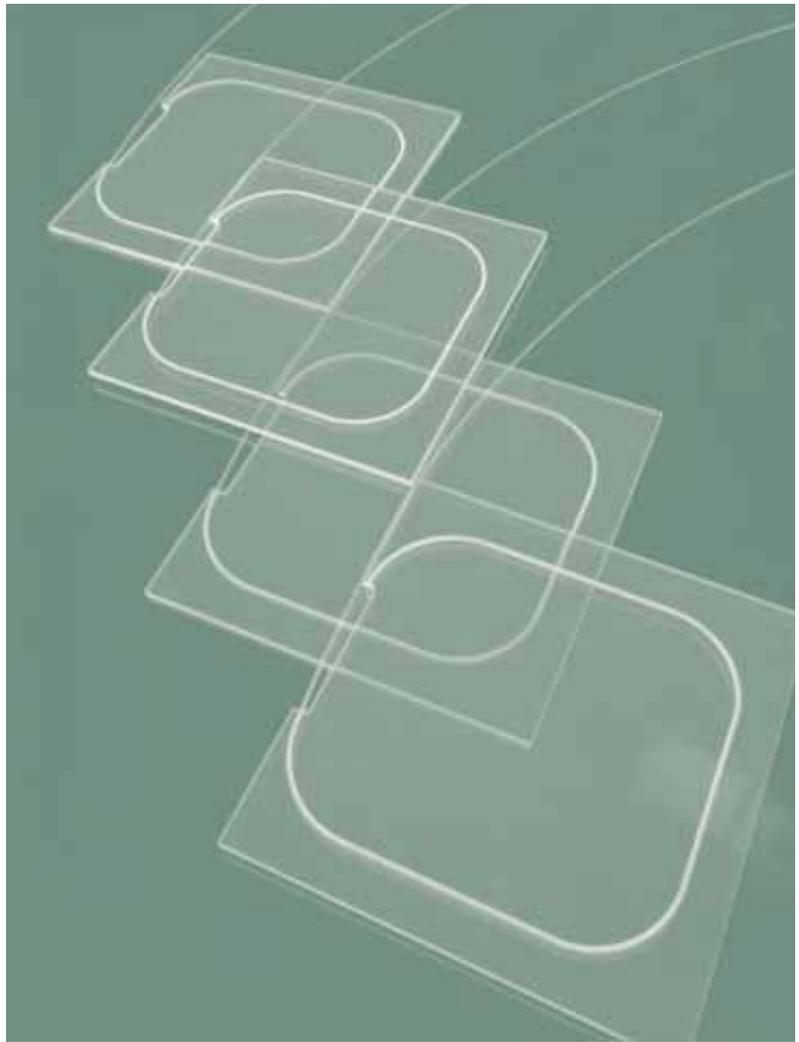
The CMS detector is organized into specialized subdetectors. I will concentrate on the hadron calorimeter—referred to by George Trilling as “nearly hermetic”—in part because U.S. groups have a major role in designing and building it. The purpose of this calorimeter is to measure the energies and directions of all strongly interacting particles—the quarks and gluons—produced in an interaction. The term “hermetic” means that nearly all secondary particles are observed. If this is true, then missing transverse energy in the final state implies the production of a non-interacting particle. Therefore, the detectors must be fully active, without “dead” or inactive regions.

The objects actually observed are not the fundamental particles themselves, which are hidden from our view, but “jets” of ordinary particles. These ensembles of hadrons are emitted as a tightly collimated spray with almost the same direction and energy as the parent quark or gluon. It is these jets which are detected in the calorimeter subsystem. A high-energy jet might attain an energy of 1 trillion electron volts (1 TeV). That energy is 40 billionths of a calorie; therefore, we cannot simply measure the temperature rise in the calorimeter because it is infinitesimal.

The method we use is to convert the energy to mass, à la Einstein, and thus to produce many secondary particles. These particles, in turn, produce tertiary particles. In a fashion analogous to the geometric growth of bacteria, the number of particles in the calorimeter increases rapidly in a cascade of interactions until the “food”—in this case the energy needed to produce new particles—runs out. At that point, multiplication stops. The particles in turn ionize the active detecting medium, and the resultant rapid pulse of deposited energy is measured. Since the number of produced particles is proportional to the incident energy, E , what amounts to counting these particles gives us a measure of the energy.

The statistical fluctuations in the number of particles produced means that the fractional energy error, dE/E , is proportional to $1/\sqrt{E}$. Note that the performance improves with energy, which explains why calorimetry becomes an important tool in high-energy experiments. To be fair, any nonuniformity of manufacturing or performance has the result that the

The tile and wavelength-shifting fiber active elements of the hadron calorimeter detector for CMS. (Courtesy Fermilab Visual Media Services)



mean energy measured in different parts of the detector varies. This effect causes an error, dE/E , that goes as a constant and thus dominates the high-energy behavior of the detector. It is this error that the CMS calorimeter group has worked to reduce to as low a value as possible.

The groups who are working to design and build the CMS hadron calorimeter (HCAL) come from China, Hungary, India, Italy, Russia and Dubna member states, Spain, Turkey, and the United States. Over the past four years we have formed a team with the goal of not only designing and building it, but also installing it in CMS during 2003 and 2004, and using it for physics beginning in 2005. The diversity and geography of the hadron calorimeter groups requires special effort to unify the team. Once the design is complete, it must be tested in beams of particles, and the ones most accessible to all the HCAL groups are at CERN in Geneva, Switzerland. The planning, execution, and analysis of these test beam runs amount to a small international experiment in itself, and it is an enviable accomplishment that the HCAL groups have run every year since 1994.

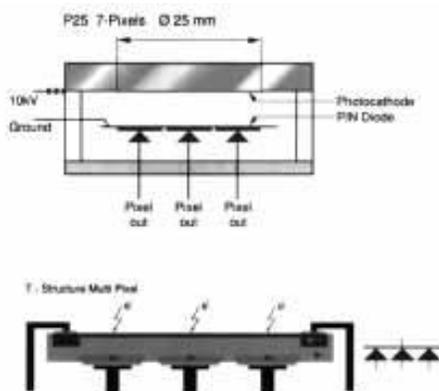
The calorimeter itself is deployed in five distinct pieces: a barrel at wide angles to the incident beams; two endcaps at intermediate angles; and two forward detectors at small angles. These pieces are the responsibility of different subgroups.

The hadron calorimeter is immersed in a 40 kG magnetic field, which is used to deflect charged particles and thus measure their momentum in other CMS subsystems. As a consequence, HCAL must

be built of non-magnetic materials, such as copper. As a result of concerted efforts, the HCAL community has adopted many solutions in common such as the optics and transducers in the barrel and the two endcaps. Because the forward detector system is exposed to high radiation, it requires different solutions; however, we have adopted a common front-end electronics and a common readout system for all of HCAL which will simplify the work of building and commissioning it.

As seen above, we have achieved an almost hermetic design. The active element is a scintillator tile which emits light in the blue. That light is absorbed and shifted to the green by a wavelength shifting (WLS) fiber rather than a conventional light pipe. By using a WLS to “cool” the scintillator light, we can reduce the dead area dramatically, leading to the required performance.

The search for the origin of mass, which is the primary goal of LHC experimentation, requires the study of rare processes. Thus, very high beam fluxes are needed, which means that the hadron calorimeter must endure unprecedented radiation doses. In the barrel and endcaps, scintillator will continue to function; however, the forward detectors will be exposed to up to 1 billion rads, and a different



The CMS prototype hybrid photodetector (top) and a schematic of the pixel readout (bottom). This device functions in the 40 kG field of CMS where a conventional phototube cannot. (Courtesy Fermilab Visual Media Services)

technology is needed. To compare it to everyday life, we all absorb a yearly dose of 0.2 rads from cosmic rays, and a dose of 300 rads is lethal. Because the dose of the forward detectors is high, their optics are made out of pure quartz, which is also used for reactor windows.

In the 40 kG field of CMS, conventional transducers, such as photomultiplier tubes, will not function, so the HCAL community has found and tested other technologies. The device shown on this page is a new hybrid combining a normal photocathode with a silicon diode acting as the anode. The resulting signals must be compactly processed and sent off the HCAL detector to remote counting rooms. In this case, we adopted the solutions of the telecommunications industry and converted the digitized signals back to light for transmission along fiber optic cables. These solutions are again chosen to maintain the hermetic character of HCAL.

The dispersed HCAL community is doing its work more or less in concert using new computing and networking technologies such as electronic mail, teleconferencing, and the World Wide Web. For example, we assembled a 530-page Technical Design Report using everyone's input—which is nothing unusual—but in the process, a “virus” was picked up. After some frantic efforts, it was finally eradicated.

In the future, global efforts will become the norm as we ask deeper questions and thus attack harder problems. As the introductory quote illustrates, this is a practical fact of our scientific life. It is the science that is our pole star, and it guides

us toward a global community. Indeed, the rewards go beyond science. The personal pleasures of meeting and working together with scientists from many cultures make all the challenges stimulating and ultimately even satisfying.



International Collaboration on Linear Collider Research and Development

by GREGORY LOEW & MICHAEL RIORDAN

Physicists around the globe are cooperating on designs for a trillion-volt linear collider.

SINCE THE MID-1980s a growing international collaboration of high energy physics laboratories and other institutions has been doing extensive research and development toward the design and construction of a TeV-scale linear electron-positron collider. The particle physics community has been interested for years in building such a collider, which would fire tiny bunches of electrons and positrons at each other with combined energies between 0.5 and 1.5 trillion electron volts. This interest intensified with the recent decision by the European Laboratory for Particle Physics (CERN) to proceed with the Large Hadron Collider. Indeed, these two machines can make highly complementary contributions to our understanding of elementary particles.

Such a TeV linear collider can serve many functions. It will be a precision tool to study production and decays of the massive top quark. If the Higgs boson (or bosons) and supersymmetric particles exist, it should be instrumental in fostering their discovery and further study. If they do not, such a collider will allow the exploration of other mechanisms being proposed for electroweak symmetry breaking, which is thought to imbue elementary particles with their widely differing masses. These are several of the burning physics questions that need to be elucidated during the coming decade.

In addition, a TeV linear collider will provide exciting physics research opportunities based on high energy electron-electron, electron-photon and photon-photon collisions. Other applications, such as free-electron lasers for the study of matter at atomic dimensions, are also possible.

MOTIVATED BY the late 1980s startup of the SLAC Linear Collider and the possibility of extending this technology to higher energies, a nucleus of institutions began doing collaborative R&D in this field. At first, this effort was fairly informal, resulting in small one-on-one joint investigations. During the 1990s, it gradually evolved into larger projects such as the 300 meter Final Focus Test Beam at the Stanford Linear Accelerator Center. The principal goal of this roughly \$20 million project was to study the design and operation of a state-of-the-art magnet array required to generate the exceedingly narrow, ribbon-like electron and positron beams needed at the interaction point of a TeV linear collider.

Groups from the German Electron Synchrotron (DESY) in Hamburg; the Max Planck Institute in Munich; the

Linear Accelerator Laboratory (LAL) in France; the National Laboratory for High Energy Physics (KEK) in Japan; the Budker Institute of Nuclear Physics (BINP) in Novosibirsk, Russia; the Fermi National Accelerator Laboratory in Batavia, Illinois; and SLAC joined forces to build this facility. The Russians fabricated almost all of the forty precision dipole, quadrupole, and sextupole magnets that serve as “optical” elements in what is essentially the world’s biggest “compound lens.” The last two quadrupoles, which were manufactured by Japanese industry under the direction of KEK physicists, have pole faces machined to micron accuracies. DESY physicists supplied a high-precision alignment system to guarantee that components of this complex magnet array remain in their designated positions. And KEK and LAL built monitors to measure the transverse dimensions of the electron bunches at the focal point—one based on Compton scattering of photons (see photograph at left) and the other on ions scattered from gas jets.

Experiments at SLAC have produced electron beams that are only 120 nanometers high (a typical virus is about 100 nm across), in good agreement with predictions. That’s an extraordinary vertical compression factor of over 300 on the initial 50 GeV beam supplied by the SLAC linear accelerator. This level of demagnification already exceeds what is required for TeV linear colliders. What’s more, the Final Focus Test Beam has demonstrated that such flat, narrow beams can indeed be controlled and monitored, which was not at all obvious when this project began construction.

Tsumoru Shintake and David Burke with the laser beam monitor built by KEK for the Final Focus Test Beam at SLAC.



The diversity of projects

and test facilities we

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is producing a broad body

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all of the projects.

IN EARLY 1987, at a meeting of the International Committee on Future Accelerators (ICFA), SLAC Director Burton Richter had suggested that all groups doing research on linear colliders start working together more cohesively. In 1988 the community began holding two series of regular workshops around the world—one (labeled “LC”) to review and compare the various design alternatives for a large linear collider, and the other to discuss the physics potential of such a machine. During LC93 at Stanford, DESY, KEK, and SLAC exchanged an informal memorandum of understanding to establish an international collaboration whose main purpose was to pursue linear collider R&D cooperatively. The collaboration’s primary objectives, according to David Burke and Richter, was “to enhance the exchange of personnel between participating institutions, to promote coordination in planning and sharing of research facilities, and to provide a mechanism for all interested parties to participate in the evaluation of the alternative technological approaches that are presently being pursued.”

That agreement established a Collaboration Council, whose first formal meeting occurred in July 1994 at the European Particle Accelerator Conference in London. The Council, in turn, set up a Technical Review Committee (TRC) whose specific charge was to examine and compare the various accelerator technologies and designs that might be suitable for a linear collider with an initial center-of-mass energy of 500 GeV and a luminosity in excess of $10^{33}\text{cm}^{-2}\text{sec}^{-1}$, which could be expanded to at

least 1 TeV with roughly five times higher luminosity.

The TRC consisted of more than 50 scientists from 17 institutions around the globe. Meeting and corresponding over the following year and a half, they produced and published a comprehensive R&D report that was distributed to the community in January 1996. This document presents descriptions of all linear-collider designs so far proposed, comparative reviews of major subsystems, descriptions of relevant test facilities and experiments done on them, plus the potential of the various designs for being upgraded to higher energies. The report lists present and possible future areas of collaboration. It concludes that “the diversity of projects and test facilities we have created somewhat spontaneously throughout the world community is a good hedge against mistakes, and . . . it is producing a broad body of knowledge that benefits all of the projects.” The TRC report is available on the World Wide Web at www.slac.stanford.edu/xorg/ilc-trc/ilc-trchome.html; essential

parts of it, including progress reports and tables of major linear-collider design parameters are updated about twice a year.

AFTER NEARLY a decade of international collaboration on linear collider R&D, where does the community stand today? Five major new test facilities have recently begun operation. These include two model test accelerators at DESY, one each at SLAC and CERN, plus an advanced storage-ring facility at KEK whose goal is to study the preparation of narrow, ribbon-like beams to be injected into such linacs. As a result of this and other research, the status of the four principal categories of linear-collider designs (see top table on page 38) is becoming better understood.

Although the parameters and technologies of the main linacs in these design categories differ substantially (see bottom table on page 38), the machines share many common features and problems. To reach the desired luminosity, for example, all approaches (except the Russian VLEPP design) accelerate many electron or positron bunches in each pulse of microwave radiation. But launching such long sequences of closely spaced bunches means that the electromagnetic fields generated in the wake of each bunch—its so-called wakefields—can deflect the following bunches up, down, or sideways. This troublesome effect can make it difficult to maintain the extremely narrow, flat electron and positron beams needed at the interaction point to attain high collision rates. Thus all linear-collider designs (except VLEPP) use techniques to



Linear Collider World Picture

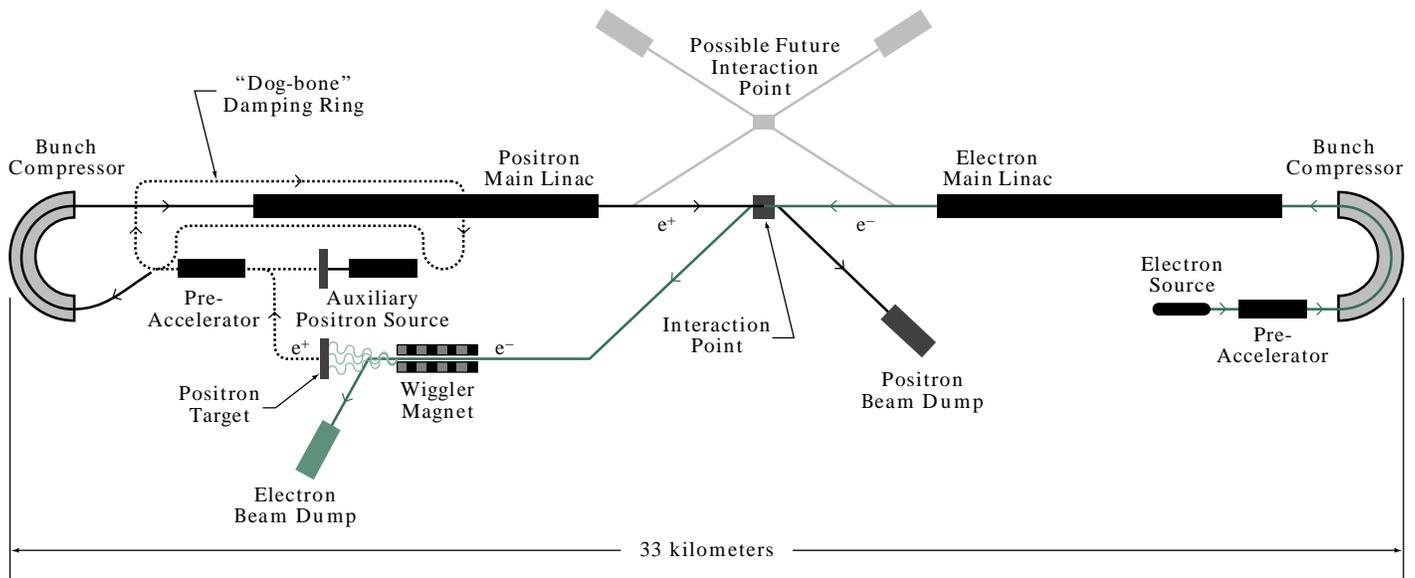
Collider Design	"Hub" Laboratories	Corresponding Test Facilities
TESLA	DESY	TESLA Test Facility
SBLC	DESY	S-Band Test Facility
JLC(C)	KEK	Microwave Systems
JLC(X)	KEK	Accelerator Test Facility
NLC(X)	SLAC	SLC, FFTB, NLC Test Accelerator
VLEPP(J)	LBNL, LLNL	Relativistic Two-Accelerator Test Facility
	BINP	VLEPP Test Facility
CLIC	CERN	CLIC Test Facility



Parameters for a Linear Collider with a Total Energy of 500 GeV

	TESLA	SBLC	JLC(C)	JLC(X)	NLC	VLEPP	CLIC
Main linac frequency (GHz)	1.3	3	5.6	11.4	11.4	14	30
Luminosity ($\text{cm}^{-2}\text{s}^{-1}$) $\times 10^{33}$	6	5.3	7.2	6.1	5.3	9.7	4.9
Beam height at final focus ^a (nm)	38	30	8.6	6.2	12.2	8	10.8
Accelerating Gradient (MV/m)	25	17	33	56	55	78	100
Number of klystrons	616	2517	4184	4400	3030	1400	2 drive linacs
Number of bunches/second	5650	16650	7200	12750	9720	300	30,000

^aThe beam height given here is twice the rms vertical beam dimension σ_y^* generally quoted in technical literature.



suppress these wakefields before they cause serious damage to beam quality.

Other features common to all four design categories include particle injectors; damping rings; alignment systems; ground-vibration suppressors; vacuum systems; feedback, instrumentation and control systems; beam delivery systems; and final-focus systems—as well as much of the civil engineering and electromechanical infrastructure. In all of these areas, valuable cross-fertilization and collaboration occurs among the various groups, which benefit from reviews that take place at the regularly scheduled LC workshops.

H EADQUARTERED AT DESY, the TESLA collaboration involves 22 institutions spanning the globe from Beijing through Warsaw and Paris all the way to Los Angeles. This team has designed the only machine that uses superconducting accelerating cavities for the main linacs (see diagram above). With microwave power at 1.3 GHz accelerating 5650 bunches per second, it has the greatest time lag between bunches (708 nanoseconds), the lowest transverse wakefields and thus the loosest alignment tolerances. Other special features include a long “dog-bone” shaped damping ring and a positron-

production system that uses gamma rays generated by passing the primary electron beam through a wiggler magnet.

The new TESLA Test Facility is being assembled in successive steps through the addition of cryomodules that contain the superconducting cavities. It has already generated a 125 MeV electron beam, and in the next few years it will be extended to incorporate a free-electron laser. Physicists and engineers building this test facility have so far achieved an accelerating gradient of 16 million volts per meter (or 16 MV/m) and are making good progress toward their design goal of 25 MV/m. Their greatest challenge is to develop techniques to turn these encouraging results into a reliable and affordable technology.

The S-band Linear Collider (SBLC) proposed by DESY physicists as a TESLA backup takes advantage of the most widespread and proven microwave technology—the 3 GHz S-band technology used for decades at Stanford and elsewhere. Taken together, its two “conventional” linacs are roughly equivalent to ten SLAC linacs and would stretch about 30 kilometers in all. After TESLA, the SBLC has the next-largest beam height at the final focus. It would operate at 50 microwave pulses per second with 333 bunches per pulse spaced 6 nanoseconds apart. Because

Layout of the proposed TESLA linear collider, which employs superconducting accelerating cavities in both main linacs.



KEK and SLAC physicists who recently performed experiments at KEK's Accelerator Test Facility.

of this multibunch operation, its accelerating structures have been designed to detune and damp most transverse wakefields by using two sets of higher-order mode couplers in each section whose signals can also be used for alignment purposes. Initial tolerances are about 100 microns, and the sections must eventually be aligned to within 30 microns. Prototypes of the 150 megawatt (peak power) klystrons needed by the SBLC have been developed at SLAC as part of a bilateral collaboration with DESY.

In the original TRC report, the C-band Japan Linear Collider, or JLC(C), was not considered in detail because experimental work on it at KEK had not yet begun. Since then an active R&D program has been started on its microwave components, including a 50 megawatt klystron and an ingenious 1.8 m accelerator structure that lets the undesirable transverse wakefields leak out while keeping the longitudinal, accelerating mode “choked” inside the cavity. This choke-mode structure eliminates wakefield problems and has an alignment tolerance of 30 microns. The JLC(C) beam characteristics are similar to those of the X-band designs (see below), except for a longer bunch length.

The X-band Japan Linear Collider, or JLC(X), and the SLAC-designed

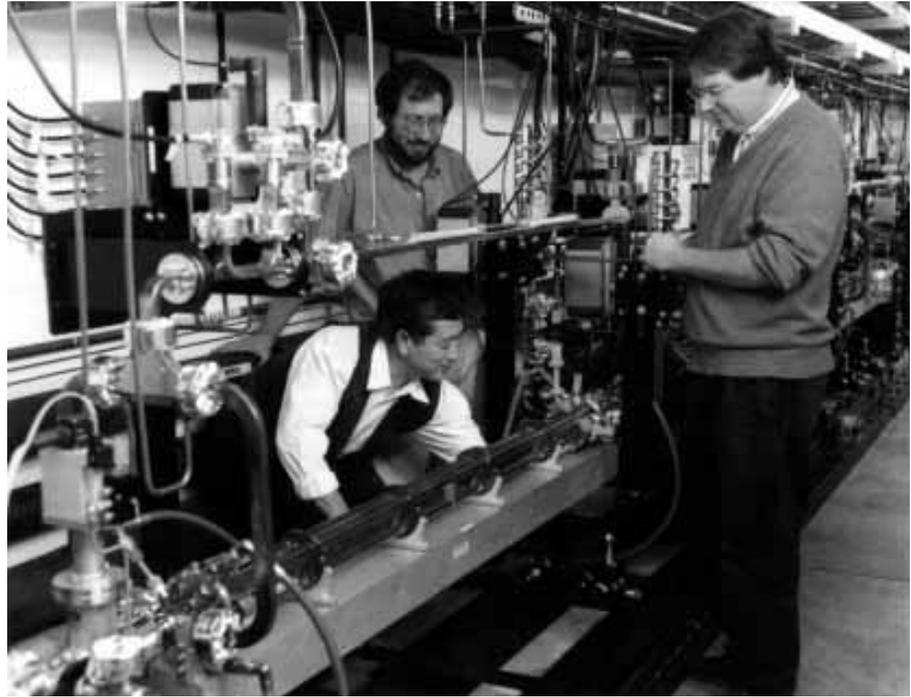
Next Linear Collider, or NLC, both use 11.4 GHz microwave power for their main linacs. They have similar pulse repetition rates, numbers of bunches per pulse, particles per bunch, and peak luminosities. The different beam heights at the interaction point do not arise from any fundamental design differences. As the cooperation between KEK and SLAC matures, this and other remaining differences will likely shrink—a process that has already occurred in the design of the accelerator structures. The NLC currently uses accelerator sections in which transverse wakefields are detuned and damped by coupling these modes to external manifolds and loads. The latest sections of this type have been machined at Lawrence Livermore National Laboratory (LLNL), cleaned at SLAC, diffusion bonded in Japan, and returned to SLAC for final brazing. Tests of these sections have begun on the Next Linear Collider Test Accelerator facility at SLAC (see photograph on the next page).

Microwave power for the NLC will be supplied by 75 megawatt X-band klystrons that use permanent magnets to focus the stream of low-energy electrons traveling through each klystron tube. This energy-saving innovation has recently been successfully tested at SLAC. Similar klystrons will likely be used in the JLC(X) design. To increase the peak power levels, both machines will probably use the delay-line distribution system proposed by KEK physicists to combine the microwave pulses from several klystrons and distribute slices of the resulting pulse to individual accelerator sections. Because much of the cost of these

X-band collider designs comes in the manufacture of their klystrons and the modulators that supply them with electrical power, there are substantial R&D efforts under way to reduce these costs and attain high power-conversion efficiency.

The trains of electron bunches for both machines will be generated by laser beams impinging on photocathodes, and the positron bunches by improved versions of the positron source now used on the SLC. After initial acceleration to about 2 GeV by various L-band and S-band pre-accelerators, these bunches will be compressed by a factor of 100 in height and 10 times in width by circulating them for several milliseconds in damping rings. A full-scale prototype of such a damping ring is now being tested at KEK's Accelerator Test Facility (see photos on pages 16, 18, and opposite) where scientists from Japan, Europe, and the United States are performing joint experiments and making good progress.

Seven Russian institutions have been collaborating on the VLEPP design with physicists from Finland to Japan. This machine would accelerate only a single bunch of electrons or positrons in each microwave pulse, thus eliminating the wakefield problems of the multibunch designs. But VLEPP must achieve its high luminosity by cramming about twenty times more particles into each bunch, which leads to higher backgrounds when the bunches collide at the interaction point. Although the VLEPP project is on hold because of lack of funding, BINP scientists continue to make important contributions by performing

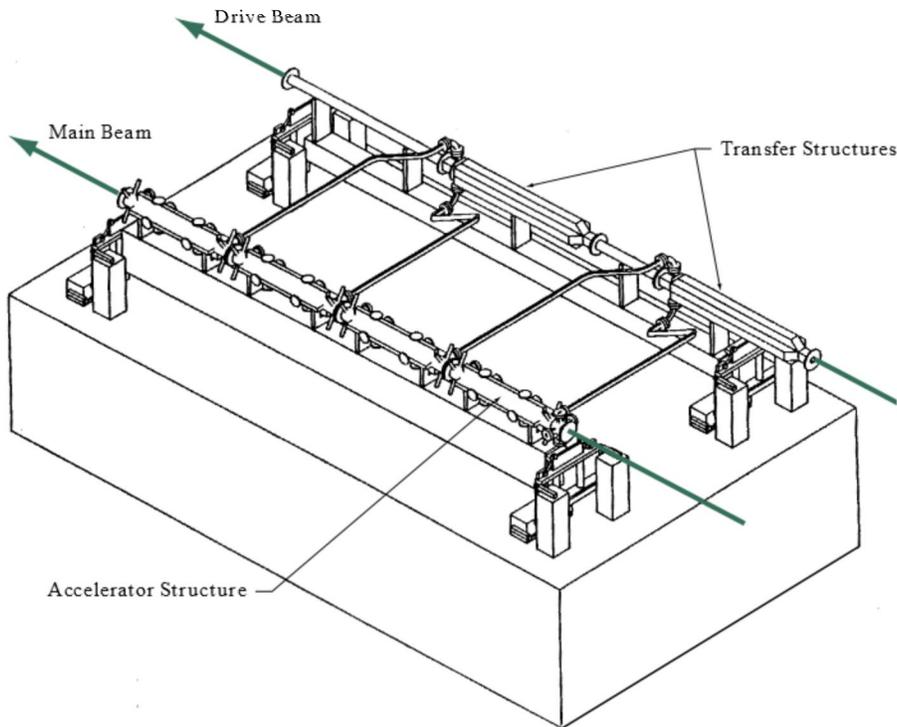


specialized microwave and other studies at home and abroad.

The JLC, NLC, and VLEPP linacs can be upgraded in energy by increasing their active length and/or adding microwave power. Another approach to boosting the NLC energy is being explored by groups at the Lawrence Berkeley and Livermore National Laboratories; this involves the use of a parallel 10 MeV "drive beam" accelerated in an induction linac to generate the microwave power. If successful, such a two-beam technology may replace klystrons in the next decade or two.

The CERN, or Compact, Linear Collider (CLIC) involves a dozen institutions, mainly from Europe but also including the U.S. and Japan, that are combining their R&D efforts on another two-beam accelerating technology that has been pioneered by CERN. This unique machine would operate at the highest microwave frequency, 30 GHz, and have potentially the highest accelerating gradient. But it also has the strongest wakefields, and therefore the tightest fabrication and alignment tolerances, and it requires a number of innovations. Accelerated by LEP-style superconducting cavities, a very intense 3 GeV

Juwen Wang, Ted Lavine, and Chris Adolphsen with the Next Linear Collider Test Accelerator.



A section of the proposed CLIC two-beam accelerator. An intense, low-energy drive beam generates microwave pulses that accelerate electrons or positrons in the main linac.

drive beam induces microwave pulses in transfer structures that transmit these pulses over to the main linac (see illustration above), where they boost bunches of electrons or positrons to their ultimate energies. The challenge of manufacturing thousands of klystrons, modulators and microwave pulse compressors is replaced by the need to develop two high-current beams that can generate high-frequency pulses of the required square-wave shape.

One advantage of the CLIC scheme is that most of the components can be housed in a single tunnel, thus lowering conventional construction costs. But certain features of the drive and main beams remain to be determined—particularly for operation at 60 particle bunches per microwave pulse, which is needed to raise the luminosity to the level of the other designs. These questions will be examined in experiments on the CLIC Test Facility, a 30 m long accelerator that began operation at CERN in 1995 and is now undergoing a major upgrade.

HAVING READ thus far, you may well wonder whether this entire effort is a collaboration, or an intense global competition. Such a reaction would not be totally unwarranted. Although they all share similar problems, TESLA, the “conventional” microwave machines, and CLIC are very different designs. As it seems unlikely, and is probably undesirable, for the world to build more than one TeV linear collider, you may well ask, “How will the present situation unfold?”

In attempting to answer this question, we can only speculate. The linear-collider community has recently bifurcated into two distinct coalitions. KEK, SLAC, and other institutions interested in X-band colliders are gradually joining forces to work toward a single design. DESY and its collaborators are focusing on the superconducting TESLA approach, with SBLC as a backup. These two coalitions intend to prepare conceptual design reports—including complete engineering studies and cost estimates—by the turn of the century. The CLIC program will

continue doing R&D until 1999 and then undergo a broad review to determine how to proceed. Since this two-beam technology offers potential accelerating gradients above 100 MV/m, a design based on it may eventually lead to a third-generation linear collider operating at 1–3 TeV.

From all these efforts, it should be possible to draw some useful and fairly definitive comparisons. Whatever is learned, we hope that countries interested in working on a linear electron-positron collider will eventually join forces and jump on the best bandwagon. In the past, however, a serious obstacle to building an accelerator or collider internationally was the difficulty of agreeing on a single site.

This difficulty is not scientific, nor is it rooted in nationalism—or at least it shouldn't be. Physicists have stood at the forefront of the global movement toward internationalism; they have extensive experience working together on common projects. The difficulty is mainly cultural: where to live, what food to eat, what coffee shop to frequent, what language to speak at the supermarket, where the children go to school. CERN solved this knotty problem many years ago, but in the midst of a relatively homogeneous European culture. The next—and truly international—leap will be substantially greater. Perhaps the resolution lies in the extensive use of jet planes and high-speed computer networks. To some extent, it should be possible for many—but not all—collaborators to remain situated around the globe and still make important contributions to an international linear collider.

THE UNIVERSE AT LARGE

What, and Why, is the International Astronomical Union?

by VIRGINIA TRIMBLE

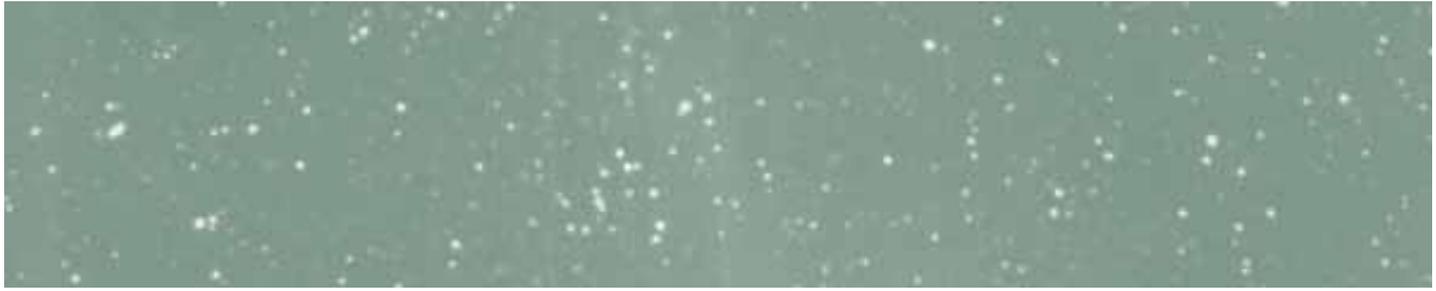
“...it is desirable that the nations at war with the Central Powers withdraw from the existing conventions relating to International Scientific Associations. . .as soon as circumstances permit. . .and that new associations, deemed to be useful to the progress of science and its applications, be established without delay by the nations at war with the Central Powers with the eventual co-operation of neutral nations.”

Resolutions of the Conference of
London, October 1918

ERATOSTHENES (something BC) is supposed to have measured the circumference of the earth by noting that the sun, which cast a seven degree shadow at Alexandria, simultaneously shone straight down a vertical well at Cyrene. We suspect he must have had a long-distance collaborator.* Moving briskly through the Middle Ages and out the other end, we find Kepler in Prague using observations by Tycho Brahe of Denmark to trace out the laws of planetary motion, Galle in Berlin discovering Neptune on the basis of calculations made by Leverrier in France, and so forth.

Indeed, many of the uses and aims of astronomy absolutely demand world-wide cooperation. Unless everybody has the same, accurate, almanacs and clocks that keep the same time, you are likely to find your ship in St. Paul's Cathedral rather than the English Channel or your radio telescope (and this is a real case) apparently in the Black Sea, rather than Crimea. Thus astronomically-based time keeping and navigation have long involved exchanges of observations, results of calculations, and time signals among friendly, and sometimes unfriendly, countries. From a less practical, astronomical point of view, if you want to catalog all the objects of some sort in the sky, you will need cataloguers at several latitudes (owing to the earth being round). Continuous monitoring of the brightness of variable stars means finding collaborators at other longitudes (owing to the sun, unless it is the sun you are monitoring, in which case the other stars get in the way).

**Just how long a distance is not entirely clear, for while the answer they found is generally regarded as having been quite accurate, it was given in Roman stadia, and nobody knows quite how long a stadium was in those days.*



Transits of the sun by Mercury and Venus (historically important in determining the size scale of the solar system), occultations of stars by planets, moons, and asteroids (which calibrate both precise positions and precise sizes), and eclipses of the sun (with their rare opportunities to see the chromosphere and corona and the gravitational deflection of light) also all require being in more than one place at a time or having friends in distant places. All of these activities remain the concern of members of the International Astronomical Union, along with a good many others that would never have occurred to Kepler or Galle, or perhaps even you (but keep tuned). Contrast, by the way, the situation in physics and chemistry where obviously it is often desirable to have the same experiment done by two independent laboratories, exchanging information about their methods and results, but where there is no need for the times of the experiments to be precisely correlated in advance.

THE CARTE DU CIEL AND ITS CONTEMPORARIES

The compiling of catalogues (meaning tables) and atlases (meaning pictures) of stellar positions and brightnesses is one of the most ancient of professional astronomical activities, pioneered by Hipparchus (something else BC) and Ptolemy (moderately AD). Each was able to document about 1000 stars in the part of the sky he could see. Chinese astronomers in the 12th century and the last of the naked eye observers (Tycho again, and Helvelius in 1660) could do no better. The application of small refracting telescopes increased our reach enormously, and the 1689 and 1797 catalogues of Flamsteed and Bradley contained about 10,000 stars each.

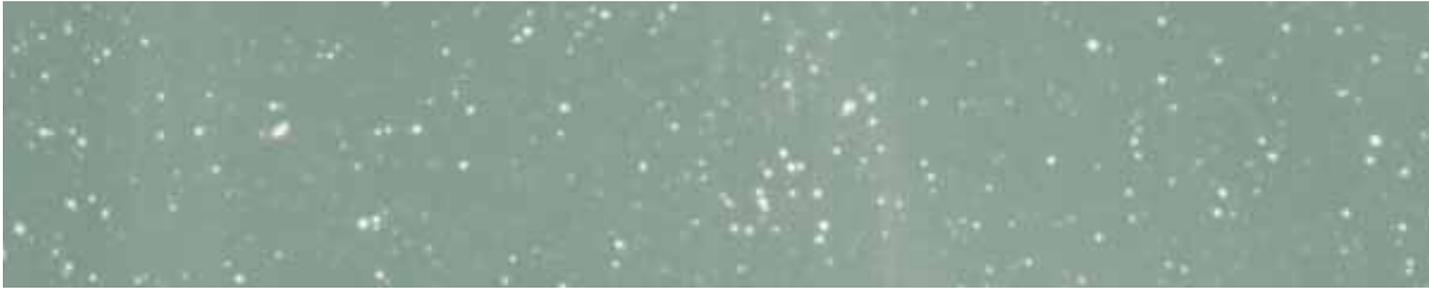
The advent of dry photographic emulsions toward the end of the 19th century presented an opportunity to expand catalogues and atlases by another large factor, as well as to improve accuracy and repeatability. And, in Paris in 1889, a group of astronomers representing more than a dozen countries agreed to divide the sky into zones and produce a “map of the sky” that would have images in its atlas of all stars to 14th magnitude (one ten-thousandth the brightness of faint stars you can see from

cities) and positions in its catalogue of all stars to 12th magnitude. At the urging of David Gill of the U.K. and Admiral Mouchez (director of the Paris Observatory), about 20 observatories agreed to participate. This meant that they would acquire identical telescopes (called astrographs), blanket their parts of the sky with 2 degree \times 2 degree photographic plates, and undertake to publish their portions of the atlas and catalog. Some of the observatories you have probably heard of—Greenwich, Paris, Potsdam, Sydney. . . Others will be less familiar—Hyderabad, Tacubaya, Algiers, San Fernando. . . Potsdam happened to be the only location within the countries that would eventually lose World War I.

No American observatories were involved, and, in retrospect, we were very lucky. Even without overlap between the images, it takes more than 10,000 $2 \times 2^\circ$ plates to cover the sky. Most of them were eventually taken, but, 35 years after the project began, only four of the 20 zones had been completely measured, printed, and distributed (those of Greenwich, Oxford, Perth, and the zone Hyderabad had originally agreed to do, they took on another later). The Carte du Ciel was, in retrospect, a target at which you threw not only money* but also the irreplaceable time of gifted scientists.

Two other turn-of-the-century international projects deserve mention. Astronomers had gradually become more and more interested in how stars are distributed through space in our galaxy (then widely believed to be the entire universe). Thus they had diligently been counting stars as a function of apparent and real brightness, color, motion on the plane of the sky, velocity along the line of sight, and so forth, picking out whichever bits of sky appealed to them. Jacobus Kapteyn of Holland pointed out in 1906 that everybody would get along faster if they all looked at the same bits of sky, rather than getting radial velocities for one field, colors for another, and so forth. He suggested about 200 “selected areas,” distributed so as to probe what then seemed to be the salient features of the galaxy, and naturally, an international

**I think this was originally a description of a golf course: 18 small holes down which you throw money.*



committee was appointed (in 1910) to oversee the coordination. It included Kapteyn (succeeded in due course by van Rhijn, a younger Dutchman), four Anglo-Saxons, and Kustner, director of the Bonn Observatory. Other German astronomers were among the most active in providing data pertinent to the selected areas (which, incidentally, are still used for studies of galactic structure).

Finally we come to the International Union for Cooperation in Solar Research, in which George Ellery Hale (founder of Yerkes, Mt. Wilson, and Palomar Observatories) was the prime mover. They met at least once, at Mt. Wilson in 1910, discussing, among other issues, how to standardize measurements of solar rotation made from different sites, so that real variations across the sun and with time could be identified. That a strong tradition of international solar astronomy had been established is clear from the early structure of the IAU.

THE WAKE OF THE GREAT WAR (MOSTLY POLITICAL)

George Ellery Hale was a man not easily discouraged. With his IUCSR dissolved by the London Conference, he was at the lead in urging the United States to become one of the founders of the International Research Council, whose name bears a curious resemblance to that of the National Research Council, in whose 1916 founding he also had a hand. Representatives of 16 victorious nations met in Brussels in July, 1919, and adopted a set of statutes including the goal of “initiating the formation of international Associations or Unions deemed to be useful to the progress of science.”

The organizational meeting for the International Astronomical Union took place at the same time, and of course Hale was there. An additional 16 nations were declared eligible for IRC membership over the next few years, an important constraint on the IAU, since no country could join it, or even, initially, send people to its meetings, without acquiring IRC membership first. Thus the International Astronomers began as a Union of nine countries at their first official General Assembly in Rome in 1922 and had expanded to 22 by end of the second

GA in Cambridge (U.K.) in 1925. The IRC eventually became ICSU, the International Council of Scientific Unions, and you may very well belong indirectly, because both the U.S. National Academy of Sciences and IUPAP (the International Union of Pure and Applied Physics) are, in different ways, member organizations; I am not prepared to explain exactly what they do.

Additional countries were declared eligible for Union (or having already been so decided to join up) through

FOUNDING MEMBERS INTERNATIONAL RESEARCH COUNCIL

Belgium	Brazil	United States of America
France	Greece	United Kingdom of Great Britain
Italy	Japan	Australia
Poland	Portugal	Canada
Rumania	Serbia	New Zealand
		South Africa

COUNTRIES DECLARED ELIGIBLE THROUGH 1922

China	Siam	Czecho-Slovakia
Chili	Denmark	the Argentine Republic
Spain	Mexico	Monoco
Norway	Holland	Sweden
		Switzerland

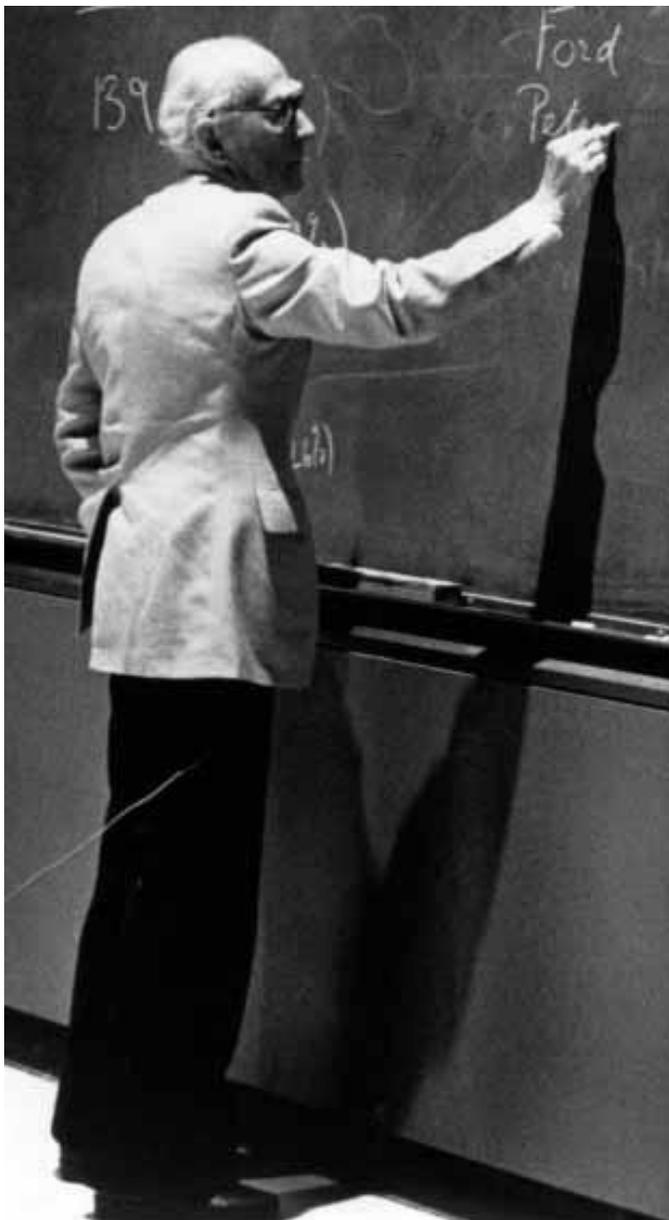
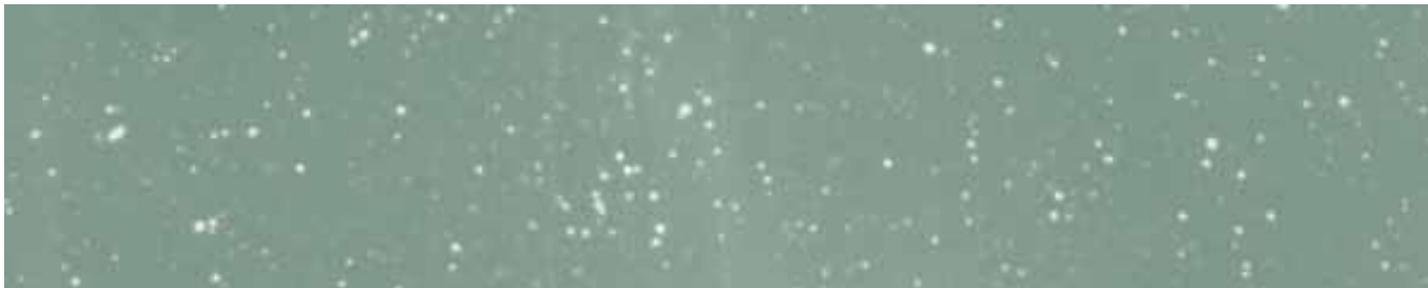
FOUNDING MEMBERS OF THE IAU

Belgium	Canada	Great Britain
France	Greece	Italy
Japan	Mexico	United States

ADDITIONAL IAU MEMBERS TO 1925

Australia	Brazil	Czecho-Slovakia
Denmark	Holland	South Africa
Norway	Poland	Portugal
Roumania	Spain	Sweden
		Switzerland

^aNames of countries are as given in original IAU documents.



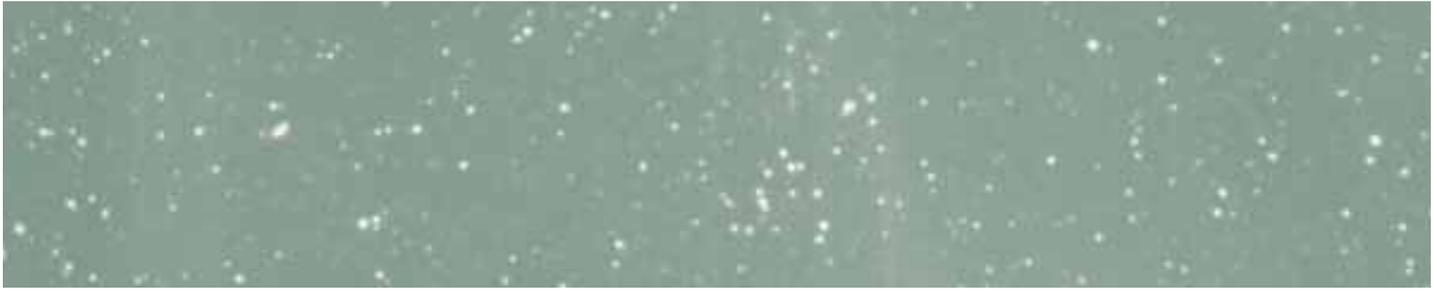
Jan H. Oort, elected to the IAU in 1925, served as both general secretary and president, and was the last person to have been present in Rome in 1922 (though not a registered participant) and to have attended every General Assembly thereafter, through 1982. (Courtesy Astronomical Society of the Pacific)

1939, most notably China and the Soviet Union. Germany, Austria, Hungary, Bulgaria, and Turkey were *patriae non gratae* until after the Second World War. The current list of adhering countries stands at about 60. Recent additions include entities that were formerly part of the Soviet Union, Czechoslovakia, and Yugoslavia (entitled to share their parent countries' memberships as soon as they join ICSU and start paying IAU dues). Expressions of interest from Bolivia, Macedonia, and Central America were considered at the 1997 General Assembly in Kyoto. Departures from the Union, both early and recent, most often reflect non-payment of dues for many years, frequently by small, poor countries. Recent or threatened losses include Cuba, North Korea, Azerbaijan, Morocco, and Uruguay. Rumania apparently holds a record, having been admitted three times. It is currently in good standing.

Traditions established early and still in effect include cycling the triennial meetings among as many different countries as are willing and able to host them and choosing officers and Commission Presidents (of which more shortly) from many and varying countries. Thus we have met of late in Patras (Greece), New Delhi, Baltimore, Buenos Aires, The Hague, and Kyoto, and the last six Union presidents have come from India (Vainu Bappu), Australia (Hanbury Brown), Japan (Yoshihide Kozai), USSR/Russia (Alexander Boyarchuk), Holland (Lodewijk Woltjer), and the U.S. (Robert Kraft). My immediate predecessors and successors as President of Commission 28 (Galaxies)* have been from Holland, Switzerland, Armenia, Italy, and Japan.

This is perhaps as good a place as any to mention that the IAU has never had a woman president, though there have been women members almost from the beginning. The first three were English speaking (Margaret Harwood, M. A. Blagg, and the redoubtable Annie Jump Cannon), though at present the French, Italian, and Latin

**If you are saying, "Oh yes. You were elected to this position for your well-known work on galaxies?" you are not the first. In fact it was a result of starting up a Supernova Working Group (something to which I have contributed a bit) which came under Com m. 28 for arcane historical reasons.*



Colonel F. J. M. Stratton, General Secretary of the IAU before World War II and president for the “long term” of 1938–1948. Stratton, a founding member, was apparently the last person who could say he had attended every general assembly. He was instrumental in keeping some international contacts alive during the war period when General Assemblies were impossible and correspondence difficult. (Courtesy Royal Astronomical Society Library, Presidential Portrait 48)

American delegations have proportionately far more women members than the U.K. or the U.S. There have been two women who served as General Secretary and a number of female Commission Presidents. I believe Comm. 28 is the first to have had three, Margaret Burbidge and Vera Rubin having been among my much more distinguished predecessors.

The IAU differs from virtually all other scientific unions organized under ICSU in having individual members. The numbers have increased from fewer than 200 at foundation to nearly 8000 after the Kyoto General Assembly, where about 700 people, most relatively young (but including Charles H. Townes) were elected, and the necrology included about 100 names.

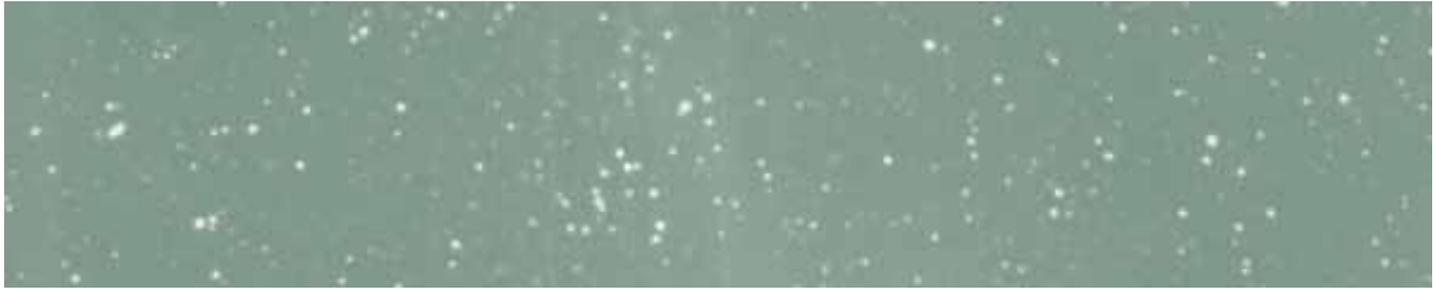
THE WORK OF THE UNION—THEN

The formal structure evolved in Brussels and signed into effect in Rome consisted of Standing Committees “for the study of various branches of astronomy, encouragement of collective investigations, and discussion of questions requiring international agreement or standardization.” The word in the French version of the Statutes (to this day the official text) was “Commissions,” which eventually won out over Standing Committees even in English, perhaps because so many other things were called Committees (nominating, finance, resolutions, . . .). Each was to consist of a President and a number of members, originally no two from the same institution. Most Commissions began with 5–20 members, but, being entitled to co-opt additional members, most grew steadily, meaning that the effective number of individual members of the Union also grew monotonically.

Thirty commissions started out in Rome. A few, connected with drafting the statutes and choosing the first cohort of officers, immediately self-destructed. Solar Radiation (Comm. 10) chose almost immediately to merge with Solar Physics (Comm. 12), leaving the set shown in the table at the time of the 1925 General Assembly, where two more, dealing with the structure of the Milky Way and diffuse matter in space were formed. Much of what the Commissions did in the early days was not just useful but essential in making astronomical research and publications self-consistent and readable throughout the world. That, on the whole, astronomers have done more or less what the IAU told them to do about most of these matters over the intervening 70 plus years is perhaps remarkable. Herewith some examples.

Notations (Comm. 3): The choice of three-letter abbreviations for the names of constellations, the use of *m* and *M* for apparent and absolute magnitude, astronomical units and parsecs as the units of distance in and out of the solar system, and *a* for the semi-major axes of a binary star orbit are decisions that still stand.

Ephemerides (Comm. 4): All issuers of national almanacs were persuaded to have their days start at



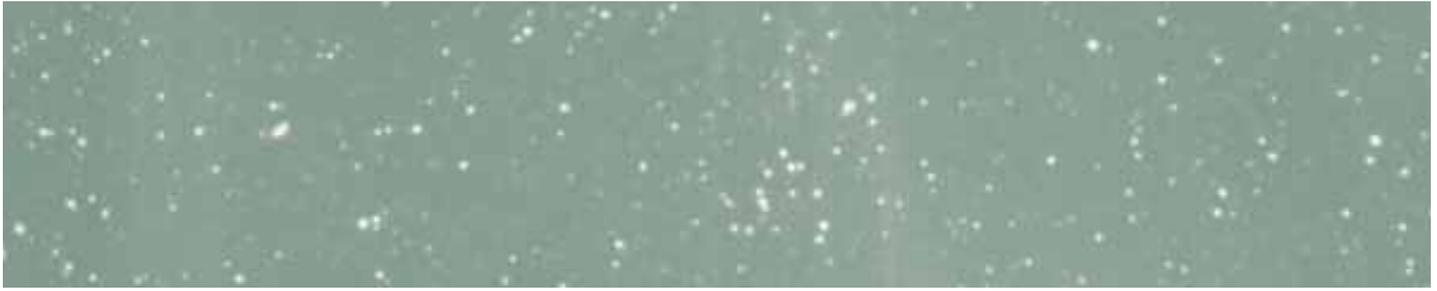
COMMISSIONS THEN AND NOW

1925

- 1 Relativity
- 3 Notation
- 4 Ephemerides
- 5 Bibliography
- 6 Telegrams
- 7 Dynamical Astronomy
- 8 Meridian Astronomy
- 9 Astronomical Instruments
- 10 Solar Photosphere
- 12 Solar Physics
- 14 Standard Wave-lengths
- 15 Solar Rotation
- 16 Planets etc. (Physical)
- 17 Lunar Nomenclature
- 18 Longitude by Wireless
- 19 Variation of Latitude
- 20 Minor Planets etc. (Ephemerides)
- 21 Disbanded before 1925
- 22 Shooting Stars
- 23 Carte du Ciel
- 24 Stellar Parallax
- 25 Stellar Photometry
- 26 Double Stars
- 27 Variable Stars
- 28 Nebulae (& many name changes)
- 29 Spectral Classification
- 30 Radial Velocities
- 31 Time
- 32 (Selected Areas, briefly)
- 33 founded in 1925
- 34 founded in 1925

1990s

- Disbanded
- Disbanded
- Ephemerides
- Documentation and Astronomical Data
- Telegrams
- Celestial Mechanics
- Positional Astronomy
- Instruments & Techniques
- (Merged with 12); reborn as Solar Activity
- Solar Radiation & Structure
- Atomic & Molecular Data
- Physical Study of Comets, Minor Planets, & Meteorites
- Physical Study of Planets and Satellites
- (now done by working group)
- Disbanded
- Rotation of the Earth
- Positions & Motions of Minor planets, Comets, and Satellites
- Light of the Night Sky
- Meteors & Interplanetary Dust
- Merged with 24, 1970
- Photographic Astrometry
- Stellar Photometry & Polarimetry
- Double & Multiple Stars
- Variable Stars
- Galaxies
- Stellar Spectra
- Radial Velocities
- Time
- Structure & Dynamics of the Galactic System
- Interstellar Matter
- 35 Stellar Constitution
- 36 Theory of Stellar Atmospheres
- 37 Star Clusters & Associations
- 38 Exchange of Astronomers
- 40 Radio Astronomy
- 41 History of Astronomy
- 42 Close Binary Stars
- 44 Astronomy from Space (absorbed 48 in 1994)
- 45 Stellar Classification
- 46 Teaching of Astronomy
- 47 Cosmology (founded 1970)
- 48 High Energy Astrophysics (founded 1970)
- 49 The Interplanetary Plasma & Heliosphere
- 50 Protection of Existing & Potential Observatory Sites
- 51 Bioastronomy: Search for Extraterrestrial Life



midnight, like the civil day (though Julian days were to continue to start at noon, a decision endorsed yet again this year) and to adopt a standard set of positions for 1054 bright stars used in navigation.

Astronomical Telegrams (Comm. 6): These announced new astronomical discoveries, observations, and calculations, and astronomers agreed to release things this way first (even before the *New York Times*). The Bureau, originally located in Copenhagen, is now at the Center for Astrophysics in Cambridge, Massachusetts. Early discoveries were most often comets and asteroids and their orbits, with an occasional nova. These days we get supernovae, gamma-ray bursts, gravitational lensing events, and much else. Postcards are still available, but the main distribution is, of course, electronic.

Standard Wavelengths (Comm. 14): This sounds silly. Don't you just go into the laboratory and measure them with as much accuracy as you need for element identification, radial velocity measurements, or whatever? No, for several reasons. First, many strong nebular emission lines are forbidden transitions and cannot be measured in the lab at all. Second, even at high spectral resolution, many stellar absorption features are actually blends of transitions in several elements. Third, even laboratory values may disagree and must be reduced to some standard (a red cadmium line at 6438.4696 Å in those days).

Lunar Nomenclature (Comm. 17, and later commissions and working groups on planetary nomenclature, etc): Every time a better image reveals a new crater, moon, or other namable entity, lots of people want to name it. Someone must adjudicate. Rather impressively, cooperation in this area survived the USA and USSR both photographing the moon up close and wanting to name what they saw for their own assorted heroes.

Meridian Astronomy (Comm. 8), Time (Comm. 31), Variation of Latitude (Comm. 19) and their successors: These dealt with the long-standing problem of establishing the variations in the rotation of the earth and the location of its poles, which feed directly into any accurate system you want to have either for measuring astronomical positions or for finding yourself on the earth's surface, right on down to the GPS.

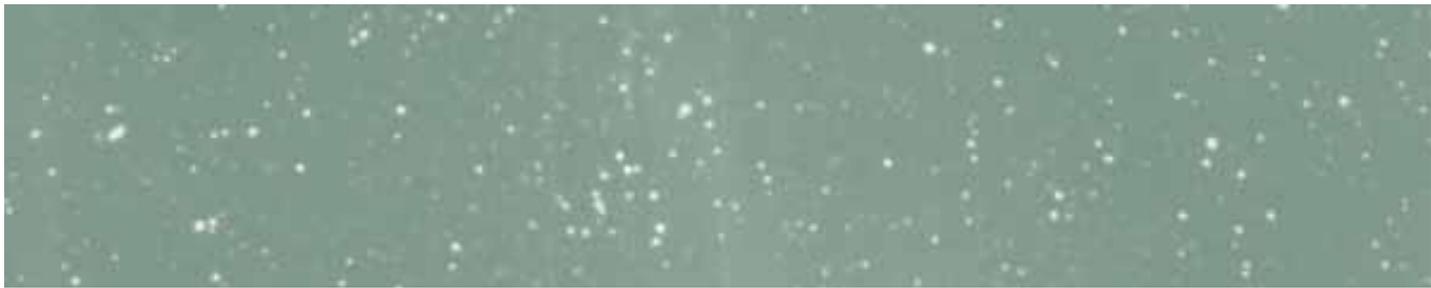
Solar Rotation (Comm. 15): This was, of course, the replacement for part of Hale's solar union.

Carte du Ciel (Comm. 23): Of the three international projects mentioned in the last section, this is the one the IAU embraced mostly closely, in part because only one of the co-operating observatories happened to be located in a Central Powers country, but also partly because the project had built up an enormous constituency within the community. By 1925, the Commission was discussing what else could be done with the plates, especially their use as the first epoch in a very-long-term proper motion survey (this is just now beginning to happen). The Commission finally declared itself out of existence and merged with 24 (by then Parallax and Proper Motion) at the 1970 General Assembly in Brighton, the first one I attended. IAU "adoption" of the Selected Areas program was also discussed from the beginning, but postponed because many of the active participants were German, and they opposed a structure that would exclude them from any decision-making. The problem resolved by the fifth General Assembly in 1935 and Selected Areas became Commission 32 (later merging with 33, Milky Way).

Variable Stars (Comm. 27): The members provided a list of stars that, because of having periods very long, very short, or nearly commensurate with 24 hours, needed international attention to pin down their properties. Some of the ones listed, like R CrB and SS Cyg, are still rather a puzzle (though astrophysically rather than temporally).

THE WORK OF THE IAU—NOW

According to my notes from Kyoto, the IAU now has 39 Commissions and four independent Working Groups. Some of them still deal with issues that go back to the beginning: Planetary System Nomenclature (a working group), Astronomical Telegrams (Comm. 6), Atomic and Molecular Data (Comm. 14, dealing with standardized wavelengths but also transition probabilities and other useful numbers), Rotation of the Earth (Comm. 19), Ephemerides (Comm. 4), and Documentation and Astronomical Data (Comm. 5, which these days includes



non-paper archiving). A few commissions still have only 20–40 members. Others (including Galaxies, Radio Astronomy, and Astronomy from Space) exceed 600. A good many have been renamed, and some numbers have been recycled. But the commissions are still telling us what to do, including, for instance, the need for a more accurate description of the rotation of the earth, a standardized way of correcting times of astronomical observations for effects of general relativity, and the Julian Day (it still starts at noon, but the Modified Julian Date starts at midnight, and PLEASE be sure to tell us which you are using!). Yet another resolution dealt with making the new coordinate system established by the Hipparcos satellite nest properly with ground-based optical and radio coordinates. This last matters even for ordinary science; if you want to know whether the radio and optical knots in the jet of a quasar are correlated or anti-correlated on sub-arcsecond scales, you had better be able to line up the two sets of data to 0.1 arcsec or thereabouts.

The Union and its Commissions have, however, also moved strongly in three directions not envisaged by the founders. The first consists of things about which one can say, with old Ben Franklin, that if we do not hang together, we will all hang separately. The entities called Protection of Existing and Potential Observing Sites (Comm. 50), Future Large Scale Facilities, Encouraging the International Development of Antarctic Astronomy (Working Groups), and the part of Radio Astronomy (Comm. 40) that fights for protected frequencies come under this heading. Second, the IAU has become much more active in promoting astronomy in developing countries. It puts money into three activities along these lines:

1. Exchange of Astronomers (Comm. 38), which administers travel grants for astronomers working under difficult circumstances to pay 3–12 month visits to larger observatories and universities. A few grants also go to people from prosperous places going to less prosperous ones primarily to bring their host organizations into main stream activities. We also send a good many free books.

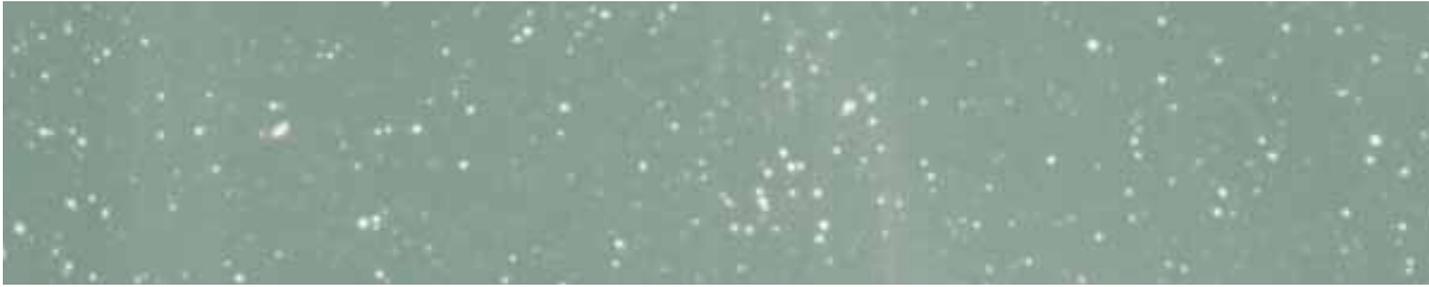
2. An on-going series of both regional meetings (normally in Latin America and in the Asia-Pacific areas) and

international schools for young astronomers from regions centered around the host country—most recently Iran and China.

3. Teaching of Astronomy (Comm. 46) again focuses on developing countries and has coordinated recent workshops for teachers in Vietnam and Central America, with ones in Sri Lanka and Morocco contemplated if funding can be found. This Commission also addresses the problem of teaching astronomy to interested students, uninterested students, and the general public in developed countries.

Third is the great increase in the amount of science presented and discussed at the General Assemblies and at IAU-sponsored symposia and colloquia in non-GA years. Proposals can come from anyone in the astronomical community, but must be endorsed and evaluated by the Commissions most relevant to the topics. The number of proposals typically exceeds the 5–6 symposia and 5–6 colloquia that can be funded each year by a factor of about two. The winners have several things in common. One is scientific merit. But, in addition, the proposals must have broad international representation on their scientific organizing committees and among the invited speakers; organizers must agree to use some of the IAU money for travel grants for young astronomers and those from less developed countries; and the host country must agree to admit participants from every country. The sites are widely scattered. Events scheduled in 1998 will occur in Canada, Spain, Armenia, France, South Africa, Mexico, China, Germany, and probably a couple of other places. And topics include the full range of solar system, stars, galaxies, and the universe.

The most recent General Assembly in August 1997 in Kyoto had a program with six symposia of about four days each (on topics from helioseismology to cosmology), 23 joint discussions of a day or so (ranging from the New International Celestial Reference Frame to The Megamaser-Active Galaxy Connection), brief business meetings of most of the divisions, commissions, and working groups, special sessions on Comet Hale-Bopp, early results from the Infrared Space Observatory (a largely European satellite), and some other entities whose



acronyms I cannot decode, plus a countably infinite number of committee meetings. Maximal packing occurred on Monday, August 25, with 14 simultaneous activities.

About 2000 people participated in these festivities, roughly 700 from the host country and a smaller number from the U.S. (the second largest delegation). That most genuinely participated shows in the number of posters presented (1600 in four three-day shifts of 400 each) and talks (about 900, all the way from hour-long reviews of black holes at galactic centers and convection in stars to 10-minute news flashes on rapid evolution of a particular binary star and X-ray after-glows from gamma ray bursts). The American participants did their fair share, but probably not more: in the three joint discussions I participated in, there were 5 American speakers out of 21 (stellar evolution on short time scales), 3 of 20 (early results from the Hipparcos astrometric satellite), and 9 of 25 (high energy transient sources).

FINANCES

Sums of money from the past always sound ridiculously small. The early IAU accounts were kept in British pounds (though legally assessed in French francs), so the proper comparison is with the £100 a year on which a single woman could live comfortably and “£10,000 a Year,” the title of a book supposed to describe riches beyond the dreams of middle class avarice in about 1920. Thus it was that the Union had an average annual income of £1500 between 1922 and 1925, nearly all of it the contributions from member countries. These, like the dues for the International Research Council, were assessed in proportion to the populations of the nations, with cuts at 5, 10, 15, and 20 million. The U.S. population in 1920 was 108 million, and, in the first few years, we contributed 11 percent of the budget, while making up 24 percent of the membership.

One aspect of this has changed hardly at all. American membership is still pretty close to 25 percent of the total; and our 1997 assessed dues are 86,400 Swiss francs in a total of 716,280, or 12 percent. Expected contributions are now more nearly proportional to



Virginia Trimble

Lodewijk Woltjer, IAU president 1994–1997 bids farewell to participants at the Kyoto General Assembly during the closing ceremonies. His father, Jan Woltjer, was a founding member of Commission 7 (Dynamical Astronomy)

numbers of astronomers in the countries than to total populations, and there is some additional income from publications and other sources. Sporadic special contributions, primarily from the U.S., have added about 200,000 Sfr each triennium, but are earmarked to pay for travel by people from the contributing country.

Where did the money go? In the early days, mostly to subsidize the practical activities of time keeping, monitoring of latitude, and so forth; to support publications;* and to operate the office of the general secretary, who in 1923 took a 10s 8p train ride, had a £26 1s 9p part-time secretary, and bought £8s 9p worth of postage stamps.

Where does the money go? Now, very considerably for science. In the 1994–96 triennium, total outgo was 2,526,601 Swiss francs, somewhere between \$1.6 and \$2.2

*The *Carte du Ciel* was a bottomless fiscal hole for the IAU as well as for the participating observatories, swallowing £100 here and £47 there several times a year to publish bits and pieces of the catalog.



million at any given moment, owing to wildly variable exchange rates. Of this, 45 percent directly supported scientific meetings involving astronomers from all over the world (primarily as travel grants). Another 11 percent was for activities aimed specifically at developing countries—schools, regional meetings, free copies of IAU symposium proceedings, etc. About 12 percent was widely scattered over dues to ICSU and other umbrella organizations, distribution of information to members, archiving, and the traditional support of the telegram bureau, variable star catalogues, and so forth, now down to 1 percent of expenditures. The Carte du Ciel did not get a penny.

Finally (and quite typical for scientific societies), the last third of the budget paid for the secretariat, officers' meetings, bank charges, and such. More than half is salaries, and, of course, the people involved spend nearly all their time coordinating astronomical symposia, publications, activities in developing countries, and all the rest. And, for better or for worse, the share of travel grants going to American astronomers is, on average, slightly larger than the fraction of the income we contribute.



MORE ABOUT THE IAU PAST AND PRESENT

Lankford, John 1997. *American Astronomy: Community, Careers, and Power, 1859–1940*, University of Chicago Press, notes how we benefited from not contributing to the Carte du Ciel.

Blaauw, Adriaan 1994. *History of the IAU* (Dordrecht: Kluwer), is the definitive source, especially on the early days and on how the Union survived the very awkward issues involving the USSR, USA, and two Chinas during the cold war.

IAU Publications: These all appeared under the Reidel (later Kluwer) label for many years, but will be published by the Astronomical Society of the Pacific beginning in 1998. *Symposia* are the usual sorts of conference proceedings. *Highlights* include the science from the General Assemblies. And *Transactions A* are triennial compilations of the highlights of research in the fields of each of the Commissions, assembled by the Commission officers.

Databases and International Collaboration

by PAT KREITZ & MICHAEL BARNETT

STUDENTS AND RESEARCHERS searching the SPIRES-HEP databases or consulting the *Review of Particle Physics* are reaping the benefits of two of the longest standing international collaborations in high energy physics. For decades, each of these collaborations has been working quietly and effectively to provide the field with core reference tools. Together these grass-root efforts produce a comprehensive, up-to-date, and highly accurate suite of resources supporting particle physics that are the envy of researchers and students in other fields. The fact that these tools are available free to the desktops of the worldwide particle physics community is unique and, in fact, only possible through the cost-effective tool of international collaboration.

The SPIRES-HEP collaboration, a joint project between the Stanford Linear Accelerator Center (SLAC) and the German Deutsches Elektronen Synchrotron (DESY) libraries with significant assistance from the Japanese High Energy Accelerator Research Organization (KEK) and the Japanese Yukawa Institute for Theoretical Physics, Kyoto University, produces a number of databases which provide comprehensive access to the literature of high energy physics as well as to conferences, people, institutions, and experiments in the field. The core database, known as SPIRES-HEP, contains over 355,000 records for preprints, articles, reports, and theses from 1974 to the present. The database contains World Wide Web links to the full text of papers when available, with over 100,000 such links currently in the database. These links are provided by cooperative efforts with the Los Alamos Electronic Preprint (E-Print) Archive, other laboratories,

journal publishers, individual physics departments, and experimental groups.

Many other laboratories and physics groups such as CERN in Switzerland, Fermilab in Illinois, and the Institute of High Energy Physics (IHEP) in Serpukhov, Russia, contribute to and download information from the SPIRES-HEP system. The American Physical Society's *Physical Review D* supplies SLAC with advance links to papers accepted for publication and in return downloads SPIRES-HEP citation data and links into their system. The LANL E-print Archive has collaborated with SPIRES-HEP since its inception in 1991. Links in SPIRES-HEP are created nightly to the preprints posted at Los Alamos National Laboratory, and the LANL system downloads SPIRES-HEP cataloging data and citation links. Three sites, Yukawa Institute, DESY, and Durham (U.K.), run full mirror copies of SPIRES-HEP, while IHEP runs a partial mirror

site. Since the beginning, the SPIRES-HEP collaboration and the Particle Data Group have had a productive history of collaborative support and development.

For forty years the Particle Data Group has been an international collaboration that reviews particle physics and related areas of astrophysics and compiles and analyzes data on particle properties. The PDG produces the *Review of Particle Physics* (RPP) and the *Particle Physics Booklet*. These are distributed to 30,000 physicists, teachers, students, and other interested people around the world. The heavily used PDG website provides access to most of the data listings and reviews.

There are several centers of PDG work including Lawrence Berkeley National Laboratory, CERN, KEK, IHEP, SLAC, and INFN, Italy. How-

ever, all of the work is done in collaboration with over a hundred outstanding particle physicists and astrophysicists from throughout the world. In addition the PDG is in frequent contact with 700 leaders of particle physics experiments. The PDG work is the product of efforts by a large fraction of the entire particle physics community. Quality is maintained in part by yearly meetings of an international advisory committee.

Collaborative distribution of effort has enabled the PDG to manage the growing body of literature in the field and to enhance and expand coverage over the past fifteen years, which has seen a tripling of the number of papers added to each edition, and a tripling of the number of reviews. The most recent edition had 1900 new measurements from 700 papers, in addition to the existing 14,000

measurements from 4000 papers. Each new edition is eagerly awaited by the particle physics community, as evidenced by big jumps in the usage of the PDG website.

High-energy physics' strong tradition of international collaboration has been an effective model for efforts such as SPIRES-HEP and the Particle Data Group, enabling them to manage increasing work loads cost effectively, take advantage of distributed, specialized expertise, and continue to create useful and freely accessible research support tools for the particle physics community. Both of these collaborations are made possible not only by the institutional commitments of many organizations but by the personal effort and dedication of individual physicists and support staff who give their time for the good of the entire community. ○

Most Cited Particle Physics Publication

A search in the SPIRES-HEP database to discover how many times the various editions of the Particle Data Group's *RPP* has been cited shows that it is the most heavily cited publication in particle physics. Since 1974 the total for all editions of the *RPP* is an impressive 10,123 citations. The most recent edition (below) is supplemented by web-accessible updates of the reviews, tables, and plots and the 1997 Particle Listings.

Review of Particle Physics by the Particle Data Group, R. M. Barnett, C. D. Carone, D. E. Groom, T. G. Trippe, C. G. Wohl, B. Armstrong, P. S. Gee, G. S. Wagman, Lawrence Berkeley National Laboratory; F. James, M. Mangano, K. Monig, L. Montanet, CERN; J. L. Feng, H. Murayama, LBNL and UC, Berkeley; J. J. Hernandez, Valencia University; A. Manohar, UC, San Diego; M. Aguilar-Benitez, Madrid, CIEMAT, and CERN; C. Caso, Genoa University and INFN, Genoa; R. L. Crawford, Glasgow University; M. Roos, N. A. Tornqvist, Helsinki University; K. G. Hayes, Hillsdale College; K. Hagiwara, K. Nakamura, M. Tanabashi, KEK; K. A. Olive, Minnesota University; K. Honscheid, Ohio State University; P. R. Burchat, Stanford University; R. E. Shrock, SUNY, Stony Brook; S. Eidelman, IYF, Novosibirsk; R. H. Schindler, SLAC; A. Gurtu, Tata Institute; K. Hikasa, Tohoku University; G. Conforto, Urbino University and INFN Florence; R. L. Workman, Virginia Tech; C. Grab, ETH, Zurich; C. Amsler, Zurich University; July 1996, 720 pp.

Formerly titled *Review of Particle Properties*, Published in *Phys. Rev. D*54, 1-720 (1996). *The 1996 Review of Particle Physics* with 1997 updates is available on the web at <http://pdg.lbl.gov/pdg.html>.

Two popular compilations based on the SPIRES-HEP database's citation searching feature, the "Top-Cited HEP Articles, 1998 Edition" and the "All-Time HEP Favorites: 1998 Edition" are being edited by Michael Peskin of SLAC and will soon be available at <http://www-spires.slac.stanford.edu/FIND/spires>.

FROM THE EDITORS' DESK

THIS SPECIAL ISSUE of the *Beam Line* is devoted to international collaboration in the field of particle physics research. It is a part of our continuing effort to describe new developments from around the globe, and to hear from the people who are doing and reporting the work. In this regard, we want to welcome three new contributing editors to our team and masthead: Judy Jackson from Fermilab, DESY's Pedro Waloschek, and Gordon Fraser, the Editor of the *CERN Courier*. In addition to crafting their own articles, they will be on the lookout for contributors in their own domains of the high energy physics community. So if you have an idea for an article and would like some help putting your thoughts on paper, by all means contact one of them (or one of us) for help or advice.



Gordon Fraser



Judy Jackson

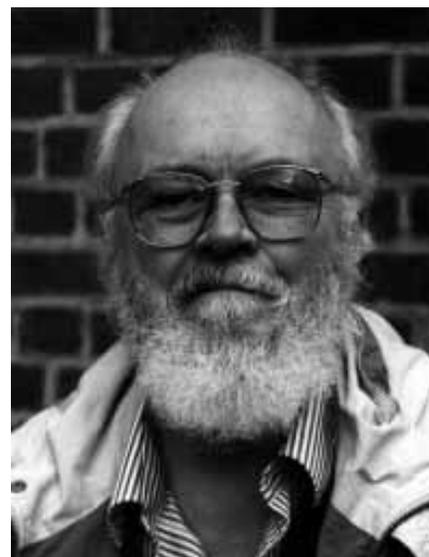
Meanwhile, we've also had a changing of the guard in the *Beam Line* Editorial Advisory Board. James Bjorken, Robert Cahn, and David Hitlin are stepping down after long and productive tenures, to be replaced by Lance Dixon of SLAC, George Trilling of Lawrence Berkeley National Laboratory, and Karl van Bibber from Lawrence Livermore National Laboratory.

It's been a good year for the *Beam Line*. We expect the new and expanded editorial team to help us keep it going.

Rene Donaldson

Bill Kirk

Michael Rindler



Pedro Waloschek

CONTRIBUTORS



S. PETER ROSEN is Associate Director of High Energy and Nuclear Physics for the Department of Energy. He was educated at Oxford University and came to the United States to work with the late Henry Primakoff on double beta decay in 1957 as a research associate at Washington University. After a staff position at the Midwestern Universities Research Association and a NATO Fellowship at Oxford, he joined the faculty of Purdue University. In 1983, he joined Los Alamos National Laboratory as Associate Leader of T-Division for high energy and nuclear physics, and in 1990 he went to the University of Texas at Arlington as Dean of Science. He started his present position in January 1997. His scientific interests include weak interactions, symmetries, and properties of the neutrinos, especially solar neutrinos.



GORDON FRASER studied at London's Imperial College in the mid-1960s, when theoretical physicists were attacking spontaneous symmetry breaking under Tom Kibble and relativistic SU(6) theory under Abdus Salam and Paul Matthews. Fraser also wrote short-story fiction and became side-tracked into journalism. He returned to physics as a science writer, eventually transferring to CERN. He is editor of the monthly *CERN Courier*; co-author, with Egil Lillestol and Inge Sellevag, of *The Search for Infinity* (New York, Facts on File, 1995) which has been published in ten other languages; and author of *The Quark Machines* (Bristol, Institute of Physics Publishing, 1997). He is also editor of *Particle Century*, a collection of contributions to be published by Institute of Physics Publishing later this year.



HIROTAKA SUGAWARA is Director General of the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan. He was educated at the University of Tokyo, and prior to his appointment as a professor there he held research associate positions at Cornell University, the University of California, Berkeley, and the University of Chicago. He has also held visiting professorships at New York University, the University of Hawaii, the University of Chicago, and École Polytechnique in Paris.



ALEXANDER SKRINSKY is director of the Budker Institute of Nuclear Physics Siberian Branch of the Russian Academy of Sciences. Prior to his becoming director in 1978, he served as deputy director. A member of the Russian Academy of Science, he is presently executive secretary for Nuclear and High Energy Physics.

He has served as a past chairman of ICFA, the International Committee on Future Accelerators, and as a member of the CERN Scientific Policy Council. He is presently a member of the Extended Scientific Council for DESY.

Skrinsky was awarded State Prizes in 1967 and 1989. He has written over 300 publications in the field of accelerator physics and technology.



ZHOU GUANGZHAO is a special advisor to the Chinese Academy of Sciences and served as president from 1989–1997. A theoretical nuclear physicist, Zhou has made important contributions to the theory of weak interactions. He studied in Beijing under Peng Huanwu, Max Born's first Chinese student. He also trained at the Joint Institute for Nuclear Research at Dubna in the Soviet Union.

He is vice president for the Chinese People's Association for Peace and Disarmament and chairman of the China Association for Science and Technology.



GEORGE TRILLING is Professor Emeritus in the Physics Department of the University of California, Berkeley, and a member of the staff of the Lawrence Berkeley National Laboratory. He received his BS and PhD from Caltech. Since his move to Berkeley in 1960, he has served as Physics Department Chairman, Director of the LBNL Physics Division, and chaired SLAC's Scientific Policy Committee. He is a member of the National Academy of Sciences and the American Academy of Arts and Sciences.

His research interests have been in high energy experimental physics, and have included hadron resonances, high energy electron-positron annihilation, and colliding-beam experiments at the highest energies. He has recently been involved in the negotiations between CERN and U.S. funding agencies relative to U.S. participation in the Large Hadron Collider project.



M.G.D. ("Gil") GILCHRIESE is a Senior Physicist at Lawrence Berkeley National Laboratory (LBNL). After obtaining a PhD from Stanford University for work at Stanford Linear Accelerator Center in 1977, he worked for one year on neutrino experiments at Fermi National Accelerator Laboratory for the University of Pennsylvania, and then joined the faculty of Cornell University just in time to experience the startup of the CESR facility and the CLEO detector. After eight years in snowy Ithaca, he moved to Berkeley to work with the SSC Central Design Group, and then later to Texas with the SSC Laboratory. He is currently the manager of the Silicon Subsystem for the U.S. ATLAS collaboration at CERN.



DAN GREEN is a research scientist at Fermi National Accelerator Laboratory and actively involved in the CMS hadron calorimeter subsystem for the Large Hadron Collider at CERN. His interest in hadron colliders can be traced back to his Intersecting Storage Ring work at the Pisa-Stony Brook experiment at Brookhaven National Laboratory in the 1970s. More recently he was the leader of the D0 muon subsystem at Fermilab and the calorimeter system leader and deputy spokesperson for the SDC experiment at the Superconducting Super Collider. Following the demise of the SSC, he led the formation of the U.S. CMS collaboration and is presently its spokesperson. In odd moments he has authored a book, *Lectures in Particle Physics*, and is writing another, *The Physics of Particle Detectors*.



GREGORY LOEW is Deputy Director of SLAC's Technical Division and a member of the SLAC Faculty. In 1958 he joined Project M, which was later to become SLAC, to design the constant-gradient accelerator structure for the three-kilometer linac. Since then he has had many diverse assignments at the laboratory, in the international accelerator community, and in various committees of the American Physical Society. Starting in 1994, he led the International Linear Collider Technical Review Committee which produced the report mentioned in the article. In 1996, he chaired the APS Committee on the International Freedom of Scientists. Last October he met many of his colleagues at LC97 in Zvenigorod, Russia, and chaired one of the working groups at this most recent international electron-positron linear collider workshop (group photo at top of page 38).



MICHAEL RIORDAN has spent much of his last twenty years writing and editing general books on science, technology, and their impact on our lives. They include *The Solar Home Book* (1977), *The Day After Midnight* (1981), *The Hunting of the Quark* (Simon & Schuster, 1987), *The Shadows of Creation* (W. H. Freeman, 1991), and *Crystal Fire: The Birth of the Information Age* (W. W. Norton, 1997).

He currently divides his working time between SLAC, where he serves as Assistant to the Director and Contributing Editor of the *Beam Line*, and the Santa Cruz Institute of Particle Physics, where he is researching a scholarly history of the Superconducting Super Collider. For recreation he can often be found paddling his kayak on the waters of Monterey Bay or hiking near his home in the Santa Cruz mountains.



VIRGINIA TRIMBLE, one of the Vice Presidents of the International Astronomical Union, and Past President Alexander Boyarchuk of Moscow may give the impression that the cold war is not quite over, but they were in fact separated only by a table leg, not political or scientific issues, during the closing ceremonies of the Kyoto General Assembly in August 1997.

DATES TO REMEMBER

- Mar 1–7 12th Les Rencontre de Physique de la Vallee d’Aoste: Results and Perspectives in Particle Physics, La Thuile, Aosta Valley, Italy (Giorgio Bellettini, Dipartimento di Fisica, Universita de Pisa, INFN, Sezione di Pisa, Italy, or chiarelli@xpia.pi.infn.it)
- Mar 12–20 Joint Universities Accelerator School (JUAS 1998) on Accelerator Physics and Accelerator Technology, Archamps, France (juas@cern.ch)
- Mar 16–20 1998 American Physical Society Meeting, Los Angeles, California (www.aps.org/meet/index.html)
- Mar 22–27 6th International Symposium on Particles, Strings, and Cosmology (PASCOS 98), Boston, Massachusetts (Donna M. Hawkins, Department of Physics, Northeastern University, Boston, MA 02115, or utpal@albert.physics.neu.edu)
- Mar 30–Apr 7 Spring School and Workshop on String Theory, Gauge Theory, and Quantum Gravity, Trieste, Italy (ICTP, Box 586, I-34100 Trieste, Italy, or smr1090@ictp.trieste.it)
- Apr 1–7 Tropical Workshop on Particle Physics and Cosmology, San Juan, Puerto Rico (Jose F. Nieves, Department of Physics, University of Puerto Rico, Rio Piedras, Puerto Rico 00931-3343, or nieves@ltp.upr.clu.edu)
- Apr 4–8 6th International Workshop on Deep Inelastic Scattering and QCD (DIS 98), Brussels, Belgium (DIS98, IIHE, Pleinlaan 2, 1050 Brussels, Belgium, or dis98@hep.iihe.ac.be)
- Apr 8–11 2nd Latin America Symposium on High-Energy Physics (SILAFAE 98), San Juan, Puerto Rico (Jose F. Nieves, Department of Physics, University of Puerto Rico, Rio Piedras, Puerto Rico 00931-3343, or nieves@ltp.upr.clu.edu)
- Apr 18–21 1998 Joint APS/AAPT Meeting, Columbus, Ohio (www.aps.org/meet/index.html)
- May 4–7 8th Beam Instrumentation Workshop (BIW 98), Stanford, California (Suzanne Barrett, SSRL, SLAC, Box 4349, Stanford, CA 94309-0210, or biw98@slac.stanford.edu)
- May 12–14 1998 Symposium on Radiation Measurements and Applications, Ann Arbor, Michigan (9thSymposium@umich.edu)
- May 18–22 Workshop on Accelerator Operations (WAO 98), Vancouver, Canada (Fred Bach, Secretary, TRIUMF, 4004 Wesbrook Mall, Vancouver, BC, Canada V6T 2A3, or music@triumf.ca)
- Jun 14–21 5th International Wein Symposium: A Conference on Physics Beyond the Standard Model, Santa Fe, New Mexico (WEIN 98, Mail Stop H844, Los Alamos National Laboratory, Los Alamos, NM 87545, or wein98@lanl.gov)
- Jun 22–26 6th European Particle Accelerator Conference, Stockholm, Sweden (C. Petit-Jean-Genaz, CERN-AC, 1211 Geneva 23, Switzerland, or christine.petit-jean@cern.ch)