A report on high-energy physics*

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Physicists who use accelerators call their subject "high-energy particle physics," and their goal is the complete understanding of the physical universe and all of its parts. This includes identifying the fundamental or the simplest objects and the forces that act between them. It also includes an understanding of the origin of the universe and of its subsequent evolution, and there is clearly no small humility here. In fact, if I were to try to characterize the problems of our field, I would say that the primary problem of the field is the arrogance of theoretical physicists and the second problem is the shortage of funds.

The humility question gets a bit worse, because my theoretical colleagues assure me that there is a wide belief that success is very close at hand—that we are rather near a complete theory that contains the most fundamental, the truly elementary, objects and that understands the forces and the buildup of the layers of matter from the primary constituents to the nuclei, to the atoms, to the molecules, the cells, the people, the stars, and the galaxies and, also, the origins from the beginning of time to the infinite future. That is the sweep and the arrogance of our friends.

In 1968, an *Encyclopedia Britannica* article commented that speculations about the underlying structure which composes the observed particles had not led very far in the 1960s. The 1982 comment is that experimental and theoretical work over the past 15 or so years has resulted in a widely held opinion that we are in the midst of a very revolutionary epoch in our effort to understand the structure of matter in terms of fundamental constituents.

A perhaps useful analogy to what we are doing (with acknowledgements to Lucretius) is the analysis of the structure of a library. If you were asked What are the fundamental constituents that make up a library? you might be hasty and say "Books." And then someone will point out that a book is really a very complicated object. Some books are more complicated than others. Continuing to look for a finer ingredient, you quickly dismiss chapters and paragraphs and sentences as not being very useful as fundamental objects. Finally, you get to words, and you are encouraged because, in fact, at the entrance to the library, there is a dictionary which compiles all words. By selecting words in a somewhat orderly manner and putting them together according to certain rules (grammar) with certain aesthetic or other motivations, you organize these into sentences which make the chapters which make the books which make the library. Someone will eventually point out that the dictionary is very thick and that you really only need 26 letters, at least in some countries, and 26 letters is a much handier compendium of things to arrange and put together. In appropriate combinations, subject to certain laws (spelling), these make all the words which make . . . Today, any child will tell you that you do not need 26 letters. All you need is a 0 and a 1 or a dot and a dash. In appropriate combinations, dots and dashes make the 26 letters.

Now, if it makes no sense to take the dot apart, then you have arrived at the truly fundamental, structureless item, and it is

these structureless items and the rules by which you compose with them to make all these things that is the goal of the particle physicist in the search for a world view.

It is a recent practice for theorists to call their world view the "standard model." In 500 B.C., the standard model was much simpler. It had four objects, called air, earth, fire, and water. It also had two forces which Empedocles called love and strife. I do not know whether those were named as whimsically as we name things today. Not to rest, we, at the Fermi Laboratory, tried this model. We succeeded in getting hot, bubbling mud, which was not everything in the world. In 1800, Prout's law looked very promising. It said that everything was made of hydrogen, and so, indeed, the light elements obeyed that rule very nicely until one came to chlorine which did not fit at all.

Later on, the standard picture had the periodic table of elements. This periodic table suggested a cyclic internal structure. Later on, in 1900 when the electron was discovered, we knew that the periodic table, the organization of elements, was a sign or a signal that there was a rich underlying structure which, of course, was the electron shell structure.

By 1920, things looked very simple. We knew about the electron, and we knew about the proton, and we knew that by combining electrons and protons in different ways and subject to certain rules we could understand the structure of the periodic table. There were two forces. We knew about gravity which was not relevant to the structure of elementary particles, but we also knew about electromagnetic forces which bind the electrons into the atom. We had a very elegant picture.

There were a few problems with it. Nitrogen-14 gave troubles especially with the quantum theory. We had to invent different kinds of electrons, some inside the nucleus and some outside. Also, there were a few facts that were not accommodated by that world view.

Radioactivity was not accommodated, and nobody understood why the sun continued to shine. How many people considered these fundamental and how many dismissed them as details I do not know. As you will see, there are modern parallels. Anyway, it was a very elegant standard picture, even if it did not explain everything.

Now, before you give too much credit to the theorists, you should know that the history of particle physics is really a history of inventions, of a series of accelerators of increasing energy and, of course, of instruments for observing and measuring the objects that the accelerated projectiles produce (Table 1).

The first accelerator was Galileo's. It is called a "nearly vertical linear accelerator," and it accelerated particles to about 1/10,000 eV. This was quickly replaced by the Bunsen burner which reached energies of the order of several electron volts. Then followed the x-ray tube and, skipping over many steps, the invention in 1930 by Lawrence of the first cyclotron. There

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Table 1. Summary of development of accelerators

Source	Energy, eV
Galileo, Tower of Pisa	10^{-4}
Bunsen, burner	~ 1
Röntgen, x-ray tube	10^5
E. O. Lawrence, cyclotron	10^6
Postwar synchrotrons (1950)	400×10^6
Cosmotron (1953)	$3,000 \times 10^6$
Bevatron	
AGS	
Stanford Linear Accelerator Center (SLAC)	
Fermilab 1973	400×10^9
Fermilab 1983	$1,000 \times 10^9$

is a very nice exhibit of these in Washington at the National Museum of Natural History.

The first cyclotron was about a meter in diameter. Postwar technology gave us machines that accelerated particles to millions of electron volts—400 million eV in 1951, and then some modestly named things like “cosmotrons” and “bevatrons.” We come now to the present large accelerators. The one at Fermilab is running now at 400×10^9 eV and soon will be upgraded to $1,000 \times 10^9$ eV. There is a relentless logic to this progression. The Bunsen burner at a few electron volts enables one to study the binding of molecules (or the outer electron shells). This is an example of the connection between bombarding energy or excitation by means of accelerators and the size of structure being observed. In the case of the Bunsen “accelerator,” the size of the structure being studied was the outer layers of atoms or the intermolecular system, objects of the order of one-millionth (10^{-6}) of a centimeter.

In the case of the x-ray tube, producing 1,000 to 100,000 eV, the inner shells of electrons at distances of the order of 10^{-9} cm may be studied. Subsequently, the cyclotron providing several tens of million eV allowed one to excite the nucleus, which is at a much smaller scale— 10^{-12} cm or of the order of 1/1,000th of the size of the inner shells of the atom.

The postwar billion-electron volt accelerators gave rise to serious nuclear excitations, and one was able to explore down to about 10^{-14} cm. The constituents of the nuclei—protons and neutrons and the stuff of their binding—were the subjects of these bombardments. We are now at the stage where accelerators have to have scenery around them and are sited relative to nearby mountains. (I wish my accelerator had a mountain nearby, but Illinois is very flat.) These accelerators can probe subcomponent structures and distances of the order of 10^{-17} cm. So, there is a connection between the domain of observation and the size of the accelerator. The deeper one probes into inner space, the larger the accelerator that is required.

What have been the results of all this work? When a proton is bombarded with high-energy particles, new subnuclear things come out. These are created, wrenched out of the strong force field holding the nucleus together. Because these particles were subjected to very strong nuclear forces, they were collectively called “hadrons.”

Once you discover a particle, you name it and then you go claim your reward. The name was usually a Greek letter. One of the great dangers was that we were using up the Greek alphabet in the naming of particles, and there was a momentary crisis. A larger number of particles came out. The quest for simplicity seemed fruitless, and the experts were very discouraged. Something like 100 particles were generated and observed in the early postwar generation of accelerators. These were the cosmotron which was at the Brookhaven Laboratory and accel-

erated protons to 3×10^9 eV and the bevatron at Berkeley which accelerated particles to 6×10^9 eV. The next generation Brookhaven accelerator went to 30×10^9 eV; then the proton synchrotron in Europe went to 25×10^9 and the Stanford Linear Accelerator Center (SLAC) at Stanford accelerated electrons to 20×10^9 eV.

When you do not know what else to do, you try to classify, and in a sort of effort similar to the discovery of the periodic table, Gell-Mann and, independently, Ne'eman found an organization and a symmetry involving these particles. This symmetry, much as the periodic table, constituted a premonition of underlying structure. The organization of these 100 or so particles strongly suggested to Gell-Mann in 1963, and independently to George Zweig, that these hadron particles are made of something simpler, which Gell-Mann called “quarks.” All hadrons that were known in 1963 could be accounted for as being an assembly or a combination of three kinds of quarks. For want of a better description, the attribute that distinguishes among these three quarks was called “flavor.” On the other hand, rather than “strawberry,” “vanilla,” and “chocolate,” they were named “up,” “down,” and “strange.” They had individual properties, and these were so ingeniously contrived that when you put the quarks together in different combinations, presto, out come the proton and the neutron and the π -meson and all the particles designated by these large numbers of Greek letters.

At this point, the quark was proposed as the simplest, irreducible, point-like, structureless (radius equals zero) object, but rich in properties in such a way that they make up all the things that are inside the nucleus. If we combine them with the electrons outside the nucleus and a few other odds and ends of particles that were identified up to that time, we have the key actors, if you like, in the play of how the world works.

Among the other particles were objects known as neutrinos. We now know that each neutrino is closely associated with a charged particle, although this took years to appreciate. The electron neutrino was finally identified and associated with the electron although its existence was strongly suspected in the study of radioactivity. It was identified in 1953. The μ -meson was a charged particle discovered in cosmic rays and in one of the early Brookhaven experiments, the neutrino associated with the μ -meson was discovered. Collectively, these “other” objects were called leptons, as opposed to quarks, because they did not have this very strong force that is characteristic of particles that came out of the nucleus.

So, the world was divided into two classes of particles, the quarks and the leptons. The quarks are put together to make up the hadrons. As an example, look at Table 2 where, at the top, some of the properties of the different quarks are listed; lower down are some examples of how quark composition works to make the most common hadrons.

We have a quantitative theory which, in fact, shows that quarks make the proton in the same way that one electron and one proton make a hydrogen atom, two electrons make a helium atom, and so on.

More history. In 1964, Glashow and Bjorken noticed that there were three quarks and four leptons. They thought that if these particles are indeed the fundamental, irreducibly simple objects it did not seem right that there should be three quarks and four leptons. They said, “Wouldn't it be charming if there were a fourth quark so that there would be symmetry?” Numerology and symmetry, hunch and aesthetics are important in the development of theoretical physics, sometimes even more important than data!

So the charmed quark was proposed and, by the time it was discovered in 1974, it had become not only a charming idea but

Table 2. Quarks and hadrons

Name	Gell-Mann's Chart		Baryon no.
	Mass	Charge	
up (u)	2	+2/3	1/3
down (d)	2	-1/3	1/3
strange (s)	250	-1/3	1/3
Some Composite Hadrons			
			Quark Structure
Proton	1,000	+1	uud
Neutron	1,000	0	udd
Λ	1,150	0	uds
Pion π^+		+1	u $\bar{d}$
π^-	150	-1	$\bar{u}d$
π^0		0	(u $\bar{u}$ + d $\bar{d}$)
Antiproton	1,000	-1	$\bar{u}\bar{u}\bar{d}$

a necessary idea because other data indicated a desperate need in this picture for a fourth quark. In 1974, in what is now known as the November revolution, almost simultaneous discoveries were made at Brookhaven and at Stanford of new objects which could only be explained by the existence of the predicted charmed quark.

Also at Stanford, in 1976 Martin Perl led his group to a conviction that the data indicated the existence of a third charged lepton which was called τ . In 1977, Fermilab was the site of data that suggested very strongly the existence of a fifth quark—it was called "bottom" with the symbol "b."

A theoretical Greek chorus then chanted that if there is a τ lepton which is charged, there must be a neutrino associated with it because the symmetry would otherwise be disturbed. We have an electron and its neutrino. We have a muon and its neutrino; how can we have a τ without its neutrino? So they said that there must be a τ neutrino.

In regard to the fifth quark, since it was called "bottom" it therefore was clear that there had to be a sixth quark called "top," because how can you have a bottom without a top? Other people called the fifth quark "beauty," and then, of course, you had to have a "truth (t)" quark; the solemn notion is that the symmetry demanded quarks to come in pairs.

Detailed studies of the τ lepton strongly suggest the reality of the τ neutrino, although its direct observation has not yet happened. Similarly detailed studies of the b quark suggest that the symmetry is correct and t exists. Hunting for these two objects is one of our main fascinations these days.

Let me talk about the rules by which one engaged these particles and which we call the fundamental forces. The Newtonian concept of a force is an agent that alters the state of motion of a body by changing its speed or direction. The modern concept has additional dimensions. The forces not only can change the energy and momentum, but they can also change the species of particles, either by collisions or by spontaneous interactions. We often use the word "interaction" instead of force. By 1930, we had clearly identified four kinds of forces: (i) gravity, which governs the motion of apples and moons, rockets and galaxies; (ii) electromagnetism, which dominates our environment and the structure of atoms; out of the nucleus came (iii) weak force and (iv) strong force. Progress is characterized by a developing synthesis of these forces, subject to certain underlying constraints. The constraints are the quantum theory, the theory of relativity, and deep ideas about the symmetry of the world.

These forces are apparently very diverse (Table 3). On the relative strengths, the gravity force is extremely weak, so much

Table 3. The forces of nature

Force	Strength	Range	Carrier
Gravity	10^{-39}	Infinite	Graviton
Electromagnetic	10^{-2}	Infinite	Photon
Weak	10^{-13}	10^{-17} cm	W^+ , W^- , Z^0
Strong	0.2	10^{-13} cm	Gluons

so that it plays almost no role in laboratory studies of particle physics.

The other thing that is important about measuring a force is how far out it reaches: The gravitational force reaches out to an infinite extent, as implied by the famous $1/r^2$ law. Its strength diminishes gradually with distance.

Electromagnetism has a strength which is about 0.01 in these units and also has an infinite range. The weak force is very weak compared to the strong force, and its effect is further diminished by its extremely short range.

The strong force is a little more complicated. Its strength, of course, is close to 1 on this scale, and its duration or its range is about 10^{-13} cm.

If one looks at the mathematical structure, all of these forces are field theories. They establish fields of interaction and then, because they are subject to quantum mechanics, you can always talk about the quanta of the field.

There is not yet a successful theory that combines gravity with quantum theory. Nevertheless, the quantum of the field is already named. It is called the "graviton." There is an inverse connection between the mass of this "quantum of a field" and the range of the force. The range of gravity force is infinite, and, hence, the mass of the graviton is supposed to be zero.

The electromagnetic theory began in its modern form in the 1860s and got married to quantum theory and relativity in the 1920s. Its heritage is suggested by its name, quantum electrodynamics or QED. It is a precise and well-tested theory over an enormous range of distances. The quanta of that field are called "photons," and they have zero mass because the range of that force is also infinite.

The weak force was written down first in the 1930s by Enrico Fermi. It has had developing syntheses ever since and has only really become a respectable theory in very recent times. In fact, it was written down by Fermi as an analog to electromagnetism. That analog has become very deep. It has become more than an analog. It has become a synthesis. This synthesis was developed in various details by many theoreticians but most prominently by Abdus Salam and Steven Weinberg in the late 1970s.

Because the weak force has a short range, the particles that carry that force, the quanta of the field, are very massive. There are three of them, the electrically charged W^+ and W^- and the neutral Z^0 . It was indirect evidence for the existence of a force carrier that does not have an electric charge—i.e., the Z^0 —that led to the success of the Weinberg-Salam theory and their Nobel prizes a few years ago. They proposed the unification of the weak and electromagnetic theories and made new predictions on the basis of their synthesis. These predictions were confirmed. We now talk about an electroweak theory.

Finally, we address the strong force which was first postulated by Yukawa in 1935 and which has had a large evolution by a large number of people in the meantime.

It, also, has a heritage, and its modern form is called "quantum chromodynamics," a name inspired by the successful theory of quantum electrodynamics. In electrical forces, we know that charge comes in two forms, and to distinguish them, we use "plus" and "minus." We know that like charges repel, etc. In the case of the strong force, the force between quarks, we find that the analog of the electric charge comes in *three* forms,

so we need something that comes in *threes* to describe this. Primary colors come in threes so we use three colors to distinguish these—say red, blue, and green. (Green is not a primary color but it shows up better.) Thus, the “chromo” in “quantum chromodynamics.”

The quanta of the field, the things that carry the force, are called “gluons,” probably because the word “glue” was suggested. There are eight of these. If you ask a theoretical physicist why are there eight, he will smile and say, “Because eight is nine minus one.” You have asked a foolish question. Quarks come in three colors, we said, because they might have a red color charge or a green color charge or a blue color charge. The gluons have the property of changing the color of a quark, and so the gluons come in two colors. If I look at all those combinations, I get nine. I subtract one because you are supposed to subtract one.

The similarity of the weak, electromagnetic, and strong forces implies the possibility that these forces may, in fact, be further synthesized or unified. We have already mentioned the electroweak theory.

Now, what do we mean by unification? We noticed that the forces are vastly different, but what is very interesting is the variation of the strength of the forces with the energy of the interacting particles (Fig. 1). There is a trend, noticed at laboratory energies, in which these strengths are varying. If one looks at the theory in detail, one can extend these strengths to a scale of energies vastly higher than one can achieve in a laboratory. On this scale, laboratory observations are near the origin of the graph. However, at high energies one finds that all these forces become equal! At this enormous energy, all the forces look alike and there is perfect symmetry.

So, unification is one of the hottest subjects of current particle physics. It was not always that way. There were many skeptics. W. Pauli once said, “What God hath put asunder no man shall ever join.” Another skeptic, when describing the symmetries and the operations that developed the symmetries, said, “That is in which one does something to something and then compares the result with the result obtained by doing the same thing to something else or something else to the same thing.”

Fig. 2 summarizes the whole modern (1982) world view, the standard picture.

There are now six quarks. Each comes in three colors. That makes 18 quarks. But for every quark there is an antiquark—another sacred symmetry—so there are 36 quarks. There are six leptons and six anti-leptons. So there are 12 leptons. There are the particles that carry the forces, the photon, the W^+ , the W^- , the Z^0 , and the eight gluons, and there is something called Higgs which I do not want to talk about. Fig. 2 also has some

FIG. 1. Variation of force with energy of interacting particles. E-M, electromagnetic.

little diagrams that illustrate how the force particles work.

Of these particles, the photon is well known. Rather strong suggestions of the reality of gluons have come out of data recently. The W s and the Z are also the objects of a great hunt now underway in Europe, much to our chagrin.

The good news is that all the data collected in all the laboratories in the world since the Big Bang are consistent with this standard picture. There are no disturbing facts.

The bad news is that the picture does not explain everything. In addition it has an enormous number of parameters, something like 30, that are not defined by the theory. You can measure them, but you do not know why they are there. In particular, we do not explain the number of generations (columns in Fig. 2) or the reason for the difference in masses, say of the W s and the photon, and the enormous energy at which symmetry sets in. Are these unexplained data as significant as the sun's heat was in the 1920s?

Some people believe that the world may be based on something more elegant. That is a subjective opinion. An enormous amount of work is required to refine those parameters and look for clues to some kind of underlying simplicity. The fundamental question that is raised by the complexity of this picture is whether or not the quark and the lepton are the dot and the dash of my library analogy. Or, in fact, are they complicated? Does the quark have a substructure? Are there little people running around inside?

Measurements have been unsuccessful so far in detecting any such structure. The electron is a very familiar particle. We have made extremely precise measurements on the electron and its companion, the muon, and distances of the order of 10^{-16} cm have been probed without revealing evidence of any structure. There is no experimental evidence anywhere of structure to these basic particles.

It may require high-energy accelerators to settle this issue. I show in Fig. 3 the history of the synthesis of the laws of nature. Newton combined astronomy and the ballistics to make gravity in 1620. Maxwell combined electricity and magnetism and found optics and light and created electromagnetism in 1860. Then, out of the nuclear fields came weak and strong forces. Electromagnetic and weak forces were combined or unified by something called the “electroweak theory,” the Weinberg-Salam theory in 1980. Now, theorists are most excited about combining the electroweak and the strong force into something called the “grand unified theory,” or GUTS.

Yes, GUTS is a serious name. The S is added to make it plural because they have not settled on which one they like. There are many varieties of grand unified theories. They make fantastic predictions, and they turn out to be essential in order to project phenomena to much higher energies. Gravity is lurking in the background, and one hopes eventually to combine this into a truly unified, really grand, ultimate theory. There is a lot of optimism on this question.

One of the most difficult things to understand is why it is that these forces we are dealing with, the weak and the strong and the electromagnetic, appear to us (Table 3) so different, and yet one talks about all of them being combined at some super high energy to have a perfectly symmetric and uniform world.

I found the following analogy. If one takes a spherical vessel filled with steam at high temperatures, then the system has perfect symmetry. Everything is equal. The world is homogeneous and satisfactory in that sense. If one cools the system to lower temperatures, the system fragments into water, ice, and steam and the system looks totally asymmetric. So, the theorists tell us that the apparent asymmetry we experience now comes from the fact that, even in the giant accelerator experiments,

FIG. 2. The standard picture in 1982.

we are observing at extremely low temperatures or low energies on the cosmic scale.

Some machines accelerate electrons—one at Stanford, one at Cornell, and one at DESY in Hamburg. Some use protons, like the Brookhaven machine—one in the Soviet Union, Fermilab in Illinois, and one in Geneva, Switzerland. Some bombard fixed solid targets with accelerated particles, and some store particles in circular trajectories and induce collisions between counter-rotating beams because in this way one can reach extremely high effective energies.

Table 4 is an inventory of the world's accelerators at present. This is a large amount of activity. The world leader at this moment is the European CERN (Geneva) accelerator which is colliding anti-protons and protons at an available energy of something like 540 GeV, and it is via this machine that we believe the W s and Z s will be discovered. There is nothing that gets very close until about 1985. The motivation for all this activity has to do with providing the data to demonstrate and guide the development of the syntheses and, also, to address the fundamental question: Do we have the last word on particles?

Let me give you a quick glimpse of the technology being used in accelerators. At Fermilab, approximately 1,000 superconducting magnets are being installed in a 6-km-circumference tunnel cooled by 24 1,000-W refrigerators to get to liquid helium temperatures. Superconductivity is used for two reasons: to get higher energy, and to make it possible to use less electrical

power, which saves money that you then can use for other purposes.

At CERN and, also at Fermilab, another dramatic machine has to do with arranging intense collision between anti-protons and protons. This is a very exotic and sophisticated application of accelerators. You use the machine to make anti-protons and you collect as many as possible; then, you store these anti-protons and collect more. You accumulate them until you have a large number, and then you transfer them back into your accelerator along with protons. They counter-rotate because they have opposite charges, and you accelerate them to the full energy of the accelerator and let them collide.

In order to accumulate anti-protons you have to use exotic systems of "cooling." This presents an interesting technical problem of decreasing the inherent random component of the motion of anti-protons in order to make a large number fit into the storage device. It is machinery of this kind that will permit us to probe deeper into the structure of matter to address the open questions we have discussed.

The quark/lepton picture may not be the last word but clearly it has had an enormous success, and the growing synthesis of the forces again is something which is a contributing factor to the ferment and enthusiasm in the subject. There generally is agreement that we are in a revolutionary period which we have not seen in physics since the heady days of relativity and quantum theory.

FIG. 3. History of the synthesis of the laws of nature.

The work over the past 30 years at accelerator laboratories is also relevant to an understanding of the evolution of the universe from the very first picoseconds after the Big Bang, when everything was made of the simplest components—presumably the quarks and leptons. The most exciting things that are happening in the field are the increasing connections between particle physics and astrophysics.

When you make a collision in a high-energy laboratory, the energy of the collision is equivalent to temperature. For ex-

ample, right now in the universe outside of the laboratory, the average temperature is approximately 3 K. That is equivalent to about 1/3,000th electron volt, and the time is 10^{10} years after the Big Bang.

If we trace the history of the universe backward in time, at 3 min after the Big Bang, the average temperature was 10^9 K or 100 keV. At 1 sec after the Big Bang, it was up to 1 MeV as the universe contracted and became denser and hotter. At about 10^{-12} sec, the energy was 400 GeV, which is the energy of col-

Table 4. Inventory of high-energy accelerators

Machine	What collides*	Date operational	Effective energy, in GeV	Luminosity (related to no. of collisions)
CERN pp	pp	1981	540–600	$\geq 10^{29}$
DORIS upgrade	e^+e^-	1982	10 (upsilon)	$> 10^{31}$
PETRA upgrade	e^+e^-	1982/3	≤ 43	10^{31}
Fermilab TeV II†	pT	1983–85	42 (F.T.)	10^{36}
Fermilab TeV I†	pp	1985	2,000	$> 10^{30}$
SLAC SLC†	e^+e^-	1986	100	10^{30} – 10^{31}
Japan (TRISTAN)	e^+e^-	1987	50	10^{32}
CERN LEP	e^+e^-	1988	100–140	10^{32}
DESY HERA?	e^+p	1988	300	10^{32}
TRISTAN II	e^+p	1989	200	10^{32}
BNL ISABELLE?†	pp	1989	800	$\geq 10^{33}$
USSR UNK	pT	1990	70 (F.T.)	10^{36}
SC† in LEP tunnel?	pp	1990	$\sim 10,000$	10^{30}
USSR UNK Coll.	pp	1993	6,000	10^{30}
VBA (World Lab)	?	2001	20,000	

* T, fixed target.

† In United States.

‡ Superconducting magnets.

lisions made at Fermilab. So, in some sense, our accelerators are like a time machine studying the nature of the universe as it looked 10^{-12} sec after the Big Bang. If we get our new machine working in a few years at 2,000 GeV, we will approach within 10^{-14} sec of creation.

The kind of energies that involve the unification of forces is still a long way off—these are of the order of 10^{13} GeV or about 10^{-35} sec after the Big Bang. Someone made the remark that the early universe is a high-energy laboratory with a totally unconstrained budget. The evolution of the universe provides us with a lot of constraints as to the behavior of matter, and it is those constraints that make the communication between as-

tronomers and accelerator scientists so intense. Astrophysicists are some of the best customers for our data and we, who design experiments and accelerators, look to astrophysics for guidance.

It is always good to have astrophysicists on your side because everyone looks up at the night sky and wonders how it all got there, what is going on, and how will it all end. It is a little more subtle to show the data from inner space rather than that from outer space. The fact that studies, over the last years, of messages from inner space and messages from outer space are beginning to address the same issue should make our field exciting to everybody.