THE GOD PARTICLE

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If the Universe Is the Answer, What Is the Question?

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LEON LEDERMAN
WITH DICK TERESI

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FOR EVAN AND JAYNA

I like relativity and quantum theories
because I don’t understand them
and they make me feel as if space shifted about like a swan that can’t settle,
refusing to sit still and be measured;
and as if the atom were an impulsive thing
always changing its mind.

—D. H. Lawrence

Preface

A FUNNY THING happened to me on the way to Waxahachie . . .

It is awkward writing a preface to a new edition of a 1993 book that was originally based on a false premise. It wasn't the major premise, but a premise nonetheless. And the title of the book, *The God Particle*, problematic to begin with, was based on this misguided assumption.

I had assumed back then that the world of science was on the brink of a series of exciting new discoveries that would bring us closer to understanding how the universe works and the identities of the building blocks that make it possible. We were so close to a major epiphany in 1993 as we looked forward to a brand-new instrument, the Superconducting Super Collider (or SSC), then under construction in Waxahachie, Texas. It was to be the most powerful particle accelerator, or "atom smasher," ever built, designed to answer our most serious questions. But the unexpected intervened.

Before I get into that, however, let me review the main thrust of the book, a thrust that was valid then and remains valid today. *The God Particle* is a history of particle physics that began in about 60 B.C. with the philosopher Thales in the Greek colony of Miletus, as Thales asked himself whether all the varied objects in the universe could be traced back to a single, basic substance, and a simple, overarching principle. The approach of Thales and his followers is still with us today—a belief in ultimate simplicity, still with us in spite of the apparent complexity of our universe revealed in the research of the past 2600 years. Our story paused at Democritus (450 B.C.), who coined the term *atomos* ("too small to see and that which cannot be cut") and proceeded through the centuries and int modern times to explore the accomplishments of Albert Einstein, Enrico Fermi, Richard Feynman, Murray Gell-Mann, Sheldon Glashow, T. D. Lee, Steven Weinberg, C. N. Yang, and many other heroes of particle physics. Although I name only theorists, it was my fellow experimentalists who really did all the heavy lifting.

In 1993 we were justified, I think, in being optimistic about our chances to forge what my colleagu Steven Weinberg calls "a final theory." Late in the nineteenth century only one *atomos* elementary particle, the electron, had been experimentally discovered. The ensuing decades saw us corral the res five more leptons (cousins of the electron), the six quarks, and the essential bosons, the photon, the W and Z, and the gluons, all force-carrying particles. One important particle had eluded us, though: the Higgs boson, a particle that would finally illuminate many of the mysteries of matter. The SSC's primary mission was to find the Higgs.

We were sanguine about the future. The SSC's construction was 20 percent complete. Our pleas fo this machine began under the presidency of Ronald Reagan, construction started in 1990, and we thought we were home free until Congress canceled the project in 1993. Einstein said a physicist's jo was to "read the mind of God." But how do you read the mind of a U.S. congressman? Albert, you ha it so easy! Junking the SSC would free up $11 billion that would fund a cornucopia of other physics experiments, plug up the deficit, eradicate the national debt, banish poverty, cure acne, and bring us peace in our time. (How did that work out, by the way?) But I digress.

Here's the good news. *The God Particle* was ahead of its time. There is now a brand-new machine about to come online. It's called the Large Hadron Collider (LHC). Its first beams are expected in 2007 and 2008, and it is advertised to find the Higgs, to discover supersymmetry (so read the book!), and to explore several new outrageous, if not totally crazy, ideas that have emerged since that black day in 1993. So I was smarter than I thought, just writing in the wrong decade. This new instrument will not be surrounded by the friendly folks of Waxahachie, but will be located in Geneva, Switzerland, which has fewer good rib restaurants but more fondue, and is easier to spell and pronounce. One of the ideas to be explored by the LHC that turns normally phlegmatic theoretical physicists incoherent with excitement is the idea of “extra dimensions.” Hidden dimensions adding t our ~~up-down, left-right, and to-and-fro dimensions (or x-y-z) would reveal a new kind of universe~~ in which we live and play. This is not only important to help underpin exciting “theories of everything,” but, as the experimenter Henry Frisch says, “It will help us find all those missing socks.”

Now, as for the title, *The God Particle,* my coauthor, Dick Teresi, has agreed to accept the blame (paid him off). I mentioned the phrase as a joke once in a speech, and he remembered it and used it as the working title of the book. “Don’t worry,” he said, “no publisher ever uses the working title on the final book.” The rest is history. The title ended up offending two groups: 1) those who believe in Goc and 2) those who do not. We were warmly received by those in the middle.

But we are stuck with it. Some of the physics community has picked up the phrase, and both the *Lo Angeles Times* and the *Christian Science Monitor* have referred to the Higgs boson as “The God Particle.” This may advance our hopes for a movie version. After all, this time we are certainly on th verge of finding the Higgs and exposing a simpler and more elegant universe hitherto hidden from ou sight. It’s all in the book.

Have I ever lied to you?

—Leon Lederman, 200

Dramatis Personae

Atomos or a-tom: Theoretical particle invented by Democritus. The a-tom, invisible and indivisible, is the smallest unit of matter. Not to be confused with the so-called chemical atom, which is merel the smallest unit of each of the elements (hydrogen, carbon, oxygen, and so on).
Electron: The first a-tom discovered, in 1898. Like all modern a-toms, the electron is believed to hav the curious property of "zero radius." It is a member of the lepton family of a-toms.
Quark: One of the a-toms. There are six quarks—five discovered, one still sought after (in 1993). Each of the six quarks comes in three colors. Only two of the six, the up and the down quark, exist naturally in today's universe.
Neutrino: Another a-tom in the lepton family. There are three different kinds. Neutrinos are not usec to build matter, but they are essential to certain reactions. They win the minimalist contest: zero charge, zero radius, and very possibly zero mass.
Muon and tau: These leptons are cousins of the electron, only much heavier.
Photon, graviton, the W^+, W^-, and Z^0 family, and gluons: These are particles, but not matter particles like quarks and leptons. They transmit the electromagnetic, gravitational, weak, and stror forces, respectively. Only the graviton has not yet been detected.
The void: Nothingness. Also invented by Democritus. A place that a-toms can move around in. Today's theorists have littered the void with a potpourri of virtual particles and other debris. Modern terms: the vacuum and, from time to time, the aether (see below).
The aether: Invented by Isaac Newton, reinvented by James Clerk Maxwell. This is the stuff that fill up the empty space of the universe. Discredited and discarded by Einstein, the aether is now makir a Nixonian comeback. It's really the vacuum, but burdened by theoretical, ghostly particles.
Accelerator: A device for increasing the energy of particles. Since $E = mc^2$, an accelerator makes these particles heavier.
Experimenter: A physicist who does experiments.
Theorist: A physicist who doesn't do experiments.

And introducing . . .

The God Particle

(also known as the Higgs particle, a.k.a. the Higgs boson, a.k.a. the Higgs scalar boson)

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The Invisible Soccer Ball

Nothing exists except atoms and empty space; everything else is opinion.
—Democritus of Abdera

IN THE VERY BEGINNING there was a void—a curious form of vacuum—a nothingness containing no space, no time, no matter, no light, no sound. Yet the laws of nature were in place, and this curious vacuum held potential. Like a giant boulder perched at the edge of a towering cliff . . .

Wait a minute.

Before the boulder falls, I should explain that I really don't know what I'm talking about. A story logically begins at the beginning. But this story is about the universe, and unfortunately there are *no data* for the Very Beginning. None, zero. We don't know anything about the universe until it reaches the mature age of a billionth of a trillionth of a second—that is, some very short time after creation i the Big Bang. When you read or hear anything about the birth of the universe, someone is making it up. We are in the realm of philosophy. Only God knows what happened at the Very Beginning (and s far She hasn't let on).

Now, where were we? Oh yes . . .

Like a giant boulder perched at the edge of a towering cliff, the void's balance was so exquisite tha only whim was needed to produce a change, a change that created the universe. And it happened. The nothingness exploded. In this initial incandescence, space and time were created.

Out of this energy, matter emerged—a dense plasma of particles that dissolved into radiation and back to matter. (Now we're working with at least a few facts and some speculative theory in hand.) Particles collided and gave birth to new particles. Space and time boiled and foamed as black holes formed and dissolved. What a scene!

As the universe expanded and cooled and grew less dense, particles coalesced, and forces differentiated. Protons and neutrons formed, then nuclei and atoms and huge clouds of dust, which, still expanding, condensed locally here and there to form stars, galaxies, and planets. On one planet—a most ordinary planet, orbiting a mediocre star, one speck on the spiral arm of a standard galaxy—surging continents and roiling oceans organized themselves, and out of the oceans an ooze of organic molecules reacted and built proteins, and life began. Plants and animals evolved out of simple organisms, and eventually human beings arrived.

The human beings were different primarily because they were the only species intensely curious about their surroundings. In time, mutations occurred, and an odd subset of humans began roaming th land. They were arrogant. They were not content to enjoy the magnificence of the universe. They asked "How?" How was the universe created? How can the "stuff" of the universe be responsible for the incredible variety in our world: stars, planets, sea otters, oceans, coral, sunlight, the human brain? The mutants had posed a question that could be answered—but only with the labor of millennia and with a dedication handed down from master to student for a hundred generations. The question also inspired a great number of wrong and embarrassing answers. Fortunately, these mutants were born without a sense of embarrassment. They were called physicists.

Now, after examining this question for more than two thousand years—a mere flicker on the scale of cosmological time—we are beginning to glimpse the entire story of creation. In our telescopes and microscopes, in our observatories and laboratories—and on our notepads—we begin to perceive the outlines of the pristine beauty and symmetry that governed in the first moments of the universe. We can almost see it. But the picture is not yet clear, and we sense that something is obscuring our vision —a dark force that blurs, hides, obfuscates the intrinsic simplicity of our world.

HOW DOES THE UNIVERSE WORK?

This book is devoted to one problem, a problem that has confounded science since antiquity. What ar the ultimate building blocks of matter? The Greek philosopher Democritus called the smallest unit th *atomos* (literally “not able to be cut”). This a-tom is not the atom you learned about in high school science courses, like hydrogen, helium, lithium, and proceeding all the way to uranium and beyond. Those are big, klunky, complicated entities by today’s standards (or by Democritus’s standards, for that matter). To a physicist, or even a chemist, such atoms are veritable garbage cans of smaller particles—electrons, protons, and neutrons—and the protons and neutrons in turn are buckets full of still smaller guys. We need to know the most primitive objects there are, and we need to understand the forces that control the social behavior of these objects. It is Democritus’s a-tom, not your chemistry teacher’s atom, that is the key to matter.

The matter we see around us today is complex. There are about a hundred chemical atoms. The number of useful combinations of atoms can be calculated, and it is huge: billions and billions. Natur uses these combinations, called molecules, to build planets, suns, viruses, mountains, paychecks, Valium, literary agents, and other useful items. It was not always so. During the earliest moments after the creation of the universe in the Big Bang, there was no complex matter as we know it today. No nuclei, no atoms, nothing that was made of simpler pieces. This is because the searing heat of the early universe did not allow the formation of composite objects; such objects, if formed by transient collisions, would be instantly decomposed into their most primitive constituents. There was perhaps one kind of particle and one force—or even a unified particle/force—and the laws of physics. Within this primordial entity were contained the seeds of the complex world in which humans evolved, perhaps primarily to think about these things. You might find the primordial universe boring, but to a particle physicist, those were the days! Such simplicity, such beauty, however mistily visualized in our speculations.

THE BEGINNING OF SCIENCE

Even before my hero Democritus, there were Greek philosophers who dared to try to explain the worl using rational arguments and rigorously excluding superstition, myth, and the intervention of gods. These had served as valuable assets in accommodating to a world full of fearsome and seemingly arbitrary phenomena. But the Greeks were impressed too by regularities, by the alternation of day an night, the seasons, the action of fire and wind and water. By the year 650 B.C. a formidable technolog had arisen in the Mediterranean basin. The people there knew how to survey land and navigate by the stars; they had a sophisticated metallurgy and a detailed knowledge of the positions of stars and planets for making calendars and assorted predictions. They made elegant tools, fine textiles, and elaborately formed and decorated pottery. And in one of the colonies of the Greek empire, the bustlin town of Miletus on the west coast of what is now modern Turkey, the belief was articulated that the seemingly complex world was intrinsically simple—and that this simplicity could be discovered through logical reasoning. About two hundred years later, Democritus of Abdera proposed a-toms as the key to a simple universe, and the search was on.

~~The genesis of physics was astronomy because the earliest philosophers looked up in awe at~~ the night sky and sought logical models for the patterns of stars, the motions of planets, the rising and setting of the sun. Over time, scientists turned their eyes earthward: phenomena taking place at the surface of the earth—apples falling from trees, the flight of an arrow, the regular motion of a pendulum, winds, and tides—gave rise to a set of "laws of physics." Physics blossomed during the Renaissance, becoming a separate, distinct discipline by about 1500. As the centuries rolled by, and a our powers of observation sharpened with the invention of microscopes, telescopes, vacuum pumps, clocks, and so on, more and more phenomena were uncovered that could be described meticulously b recording numbers in notebooks, by constructing tables and drawing graphs, and then by triumphantl noting conformity to mathematical behavior.

By the early part of the twentieth century atoms had become the frontier of physics; in the 1940s, nuclei became the focus of research. Progressively, more and more domains became subject to observation. With the development of instruments of ever-increasing power, we looked more and more closely at things smaller and smaller. The observations and measurements were followed inevitably by syntheses, compact summaries of our understanding. With each major advance, the fiel divided; some scientists followed the "reductionist" road toward the nuclear and subnuclear domain, while others followed the path to a greater understanding of atoms (atomic physics), molecules (molecular physics and chemistry), nuclear physics, and so on.

THE ENTRAPMENT OF LEON

I started out as a molecules kid. In high school and early college I loved chemistry, but I gradually shifted toward physics, which seemed cleaner—odorless, in fact. I was strongly influenced, too, by th kids in physics, who were funnier and played better basketball. The giant of our group was Isaac Halpern, now a professor of physics at the University of Washington. He claimed that the only reasor he went to see his posted grades was to determine whether the A had a "flat top or a pointy top." Naturally, we all loved him. He could also broad-jump farther than any of us.

I became intrigued with the issues in physics because of their crisp logic and clear experimental consequences. In my senior year in college, my best friend from high school, Martin Klein, the now eminent Einstein scholar at Yale, harangued me on the splendors of physics during a long evening over many beers. That did it. I entered the U.S. Army with a B.S. in chemistry and a determination to be a physicist if I could only survive basic training and World War II.

I was born at last into the world of physics in 1948, when I began my Ph.D. research working with the world's most powerful particle accelerator of its time, the synchrocyclotron at Columbia University. Dwight Eisenhower president of Columbia, cut the ribbon dedicating the machine in June of 1950. Having helped Ike win the war, I was obviously much appreciated by the Columbia authorities, who paid me almost $4,000 for just one year of ninety-hour weeks. These were heady times. In the 1950s, the synchrocyclotron and other powerful new devices created the new discipline of particle physics.

To the outsider, perhaps the most salient characteristic of particle physics is the equipment, the instruments. I joined the quest just as particle accelerators were coming of age. They dominated physics for the next four decades, and still do. The first "atom smasher" was a few inches in diameter Today the world's most powerful accelerator is housed at Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois. Fermilab's machine, called the Tevatron, is four miles around, and smashes protons and antiprotons together with unprecedented energies. By the year 2000 or so, the ~~Tevatron's monopoly of the energy frontier will be broken. The Superconducting Super Collider~~ (SSC), the mother of all accelerators, presently being built in Texas, will be fifty-four miles around.

Sometimes we ask ourselves: have we taken a wrong turn somewhere? Have we become obsessed with the equipment? Is particle physics some sort of arcane "cyber science," with huge groups of researchers and megalithic machines dealing with phenomena so abstract that even She is not sure what happens when particles collide at high energies? We can gain confidence and inspiration by viewing the process as following a chronological Road, one that could plausibly have started in the Greek colony of Miletus in 650 B.C. The Road's destination is a city where all is understood—where the sanitation workers and even the mayor know how the universe works. Many have followed The Road: Democritus, Archimedes, Copernicus, Kepler, Galileo, Newton, Faraday, all the way to Einstein, Fermi, and my contemporaries.

The Road narrows and broadens; it passes long stretches of nothing (like Route 80 through Nebraska) and curvy sections of intense activity. There are tempting side streets labeled "electrical engineering," "chemistry," "radio communications," or "condensed matter." Those who have taken the side streets have changed the way people live on this planet. But those who stay with The Road find that it is clearly marked all the way with the same sign: "How does the universe work?" It is on this Road that we find the accelerators of the 1990s.

I got on The Road at Broadway and 120th Street in New York City. In those days the scientific problems seemed very clear and very important. They had to do with the properties of what's called the strong nuclear force and some theoretically predicted particles called pi mesons, or pions. Columbia's accelerator was designed to produce lots of pions by bombarding innocent targets with protons. The instrumentation was rather simple at the time, simple enough for a graduate student to understand.

Columbia was a hotbed of physics in the 1950s. Charles Townes would soon discover the laser and win the Nobel Prize. James Rainwater would win the Prize for his nuclear model, and Willis Lamb fo measuring the tiny shift in hydrogen's spectral lines. Nobel laureate Isadore Rabi, who inspired all of us, headed up a team that included Norman Ramsey and Polykarp Kusch, both to become Nobel winners in due course. T. D. Lee shared the Nobel for his theory of parity violation. The density of professors who had been anointed with Swedish holy water was both exhilarating and depressing. As young faculty, some of us wore lapel buttons that read "Not Yet."

For me the Big Bang of professional recognition took place in the period 1959–1962 when two of my Columbia colleagues and I carried out the first-ever measurement of high-energy neutrino collisions. Neutrinos are my favorite particles. A neutrino has almost no properties: no mass (or very little), no electric charge, and no radius—and, adding insult to injury, no strong force acts on it. The euphemism used to describe a neutrino is "elusive." It is barely a fact, and it can pass through millio of miles of solid lead with only a tiny chance of being involved in a measurable collision.

Our 1961 experiment provided the cornerstone for what came to be known in the 1970s as the "standard model" of particle physics. In 1988 the experiment was recognized by the Royal Swedish Academy of Science with the Nobel Prize. (Everybody asks, why did they wait twenty-seven years? I don't really know. I used to give my family the facetious excuse that the Academy was dragging its feet because they couldn't decide which of my great achievements to honor.) Winning the Prize was course a great thrill. But that thrill does not really compare with the incredible excitement that grippe us at the moment when we realized our experiment was a success.

Physicists today feel the same emotions that scientists have felt for centuries. The life of a physici is filled with anxiety, pain, hardship, tension, attacks of hopelessness, depression, and discouragement. But these are punctuated by flashes of exhilaration, laughter, joy, and exultation.

These epiphanies come at unpredictable times. Often they are generated simply by the sudden ~~understanding of something new and important, something beautiful, that someone else has revealed.~~ However, if you are mortal, like most of the scientists I know, the far sweeter moments come when you yourself discover some new fact about the universe. It’s astonishing how often this happens at 3 A.M., when you are alone in the lab and you have learned something profound, and you realize that no one of the other five billion people on earth knows what you now know. Or so you hope. You will, of course, hasten to tell them as soon as possible. This is known as “publishing.”

This is a book about a string of infinitely sweet moments that scientists have had over the past 2,500 years. These sweet moments add up to our present knowledge about what the universe is and how it works. The pain and depression are part of the story, too. Often it is the obstinacy, the stubbornness, the pure orneriness of nature that gets in the way of the “Eureka” moment.

The scientist, however, cannot depend on Eureka moments to make his life fulfilling. There must b some joy in day-to-day activities. For me, this joy is in designing and building apparatus that will teach us about this extraordinarily abstract subject. When I was an impressionable graduate student a Columbia, I helped a world-famous professor visiting from Rome build a particle counter. I was the virgin in this and he a past master. Together we turned the brass tube on the lathe (it was after 5 P.M. and the machinists had all gone home). We soldered on the glass-tipped end caps and strung a gold wire through the short, insulated metal straw penetrating the glass. Then we soldered some more. We flushed the special gas through the counter for a few hours while hooking an oscilloscope to the wire protected from a 1,000-volt power supply by a special capacitor. My professor friend—let’s call him Gilberto, because that was his name—kept peering at the green trace of the oscilloscope while lecturing me in faultlessly broken English on the history and evolution of particle counters. Suddenly Gilberto went stark, raving wild. “Mamma mia! Regardo incredibilo! Primo secourso!” (Or somethin like that.) He shouted, pointed, lifted me up in the air—even though I was six inches taller and fifty pounds heavier than he—and danced me around the room.

“What happened?” I stammered.

“Mufiletto!” he replied. “Izza counting. Izza counting!”

He was probably putting some of this on for my benefit, but he was genuinely excited that we had, with our hands, eyes, and brains, fashioned a device that detected the passage of cosmic ray particles registered them by small blips in the sweep of the oscilloscope. Although he must have seen this phenomenon thousands of times, he never got over the thrill. That one of these particles may just possibly have started its voyage to 120th Street and Broadway, tenth floor, light-years ago in a distan galaxy was only part of the excitement. Gilberto’s seemingly never-ending enthusiasm was contagious.

THE LIBRARY OF MATTER

When explaining the physics of fundamental particles, I often borrow (and embellish on) a lovely metaphor from the Roman poet-philosopher Lucretius. Suppose we are given the task of discovering the most basic elements of a library. What would we do? First we might think of books in their various subject categories: history, science, biography. Or perhaps we would organize them by size: thick, thin, tall, short. After considering many such divisions we realize that books are complex objects that can be readily subdivided. So we look inside. Chapters, paragraphs, and sentences are quickly dismissed as inelegant and complex constituents. Words! Here we recall that on a table near the entrance there is a fat catalogue of all the words in the library—the dictionary. By following certain rules of behavior, which we call grammar; we can use the dictionary words to compose all the books ~~in the library. The same words are used over and over again, fitted together in different wa~~ys.

But there are so many words. Further reflection would lead us to letters, since words are “cuttable. Now we have it! Twenty-six letters can make the tens of thousands of words, and they can in turn make the millions (billions?) of books. Now we must introduce an additional set of rules: spelling, to constrain the combinations of letters. Without the intercession of a very young critic we might publis our discovery prematurely. The young critic would say, smugly no doubt, “You don’t need twenty-six letters, Grandpa. All you need is a zero and a one.” Children today grow up playing with digital crib toys and are comfortable with computer algorithms that convert zeroes and ones to the letters of the alphabet. If you are too old for this, perhaps you are old enough to remember Morse code, composed of dots and dashes. In either case we now have the sequence: 0 or 1 (or dot and dash) with appropriate code to make the twenty-six letters; spelling to make all the words in the dictionary; grammar to compose the words into sentences, paragraphs, chapters, and, finally, books. And the books make the library.

Now, if it makes no sense to take apart the 0 or the 1, we have discovered the primordial, a-tomic components of the library. In the metaphor imperfect as it is, the universe is the library, the forces of nature are the grammar spelling, and algorithm, and the 0 and 1 are what we call quarks and leptons, our current candidates for Democritus’s a-toms. All of these objects, of course, are invisible.

QUARKS AND THE POPE

The lady in the audience was stubborn. “Have you ever *seen* an atom?” she insisted. It is an understandable if irritating question to a scientist who has long lived with the objective reality of atoms. I can visualize their internal structure. I can call up mental pictures of cloudlike blurs of electron “presence” surrounding the tiny dot nucleus that draws the misty electron cloud toward it. This mental picture is never precisely the same for two different scientists because both are constructing these images from equations. Such written prescriptions are not user-friendly when it comes to humoring the scientist’s human need for a visual image. Yet we can “see” atoms and proton and, yes, quarks.

My attempts to answer this thorny question always begin with trying to generalize the word “see.” Do you “see” this page if you are wearing glasses? If you are looking at a microfilm version? If you are looking at a photocopy (thereby robbing me of my royalty)? If you are reading the text on a computer screen? Finally, in desperation, I ask, “Have you ever seen the pope?”

“Well, of course,” is the usual response. “I saw him on television.” Oh, really? What she saw was a electron beam striking phosphorus painted on the inside of a glass screen. My evidence for the atom, or the quark, is just as good.

What is that evidence? Tracks of particles in a bubble chamber. In the Fermilab accelerator, the “debris” from a collision between a proton and an antiproton is captured electronically by a three-story-tall, $60 million detector. Here the “evidence,” the “seeing,” is tens of thousands of sensors tha develop an electrical impulse as a particle passes. All of these impulses are fed through hundreds of thousands of wires to electronic data processors. Ultimately a record is made on spools of magnetic tape, encoded by zeroes and ones. This tape records the hot collisions of proton against antiproton, which can generate as many as seventy particles that fly apart into the various sections of the detecto

Science, especially particle physics, gains confidence in its conclusions by duplication—that is, an experiment in California is confirmed by a different style of accelerator operating in Geneva. Also by building into each experiment checks and tests confirming that the apparatus is functioning as designed. It is a long and involved process, the result of decades of experiments.

Still, particle physics remains unfathomable to many people. That stubborn lady in the audience isn’t the only one mystified by a bunch of scientists chasing after tiny invisible objects. So let’s try another metaphor . . .

THE INVISIBLE SOCCER BALL

Imagine an intelligent race of beings from the planet Twilo. They look more or less like us, they talk like us, they do everything like humans —except for one thing. They have a fluke in their visual apparatus. They can’t see objects with sharp juxtapositions of black and white. They can’t see zebras for example. Or shirts on NFL referees. Or soccer balls. This is not such a bizarre fluke, by the way. Earthlings are even stranger. We have two literal blind spots in the center of our field of vision. The reason we don’t see these holes is because our brain extrapolates from the information in the rest of the field to guess what *should* be in these holes, then fills it in for us. Humans routinely drive 100 miles per hour on the autobahn, perform brain surgery, and juggle flaming torches, even though a portion of what they see is merely a good guess.

Let’s say this contingent from the planet Twilo comes to earth on a goodwill mission. To give ther a taste of our culture, we take them to see one of the most popular cultural events on the planet: a World Cup soccer match. We, of course, don’t know that they can’t see the black-and-white soccer ball. So they sit there watching the match with polite but confused looks on their faces. As far as the Twiloans are concerned, a bunch of short-pantsed people are running up and down the field kicking their legs pointlessly in the air, banging into each other, and falling down. At times an official blows whistle, a player runs to the sideline, stands there, and extends both his arms over his head while the other players watch him. Once in a great while the goalie inexplicably falls to the ground, a great cheer goes up, and one point is awarded to the opposite team.

The Twiloans spend about fifteen minutes being totally mystified. Then, to pass the time, they attempt to understand the game. Some use classification techniques. They deduce, partially because o the clothing, that there are two teams in conflict with one another. They chart the movements of the various players, discovering that each player appears to remain more or less within a certain geographical territory on the field. They discover that different players display different physical motions. The Twiloans, as humans would do, clarify their search for meaning in World Cup soccer by giving names to the different positions played by each footballer. The positions are categorized, compared, and contrasted. The qualities and limitations of each position are listed on a giant chart. A major break comes when the Twiloans discover that *symmetry* is at work. For each position on Team A, there is a counterpart position on Team B.

With two minutes remaining in the game, the Twiloans have composed dozens of charts, hundreds of tables and formulas, and scores of complicated rules about soccer matches. And though the rules might all be, in a limited way, correct, none would really capture the essence of the game. Then one young pipsqueak of a Twiloan, silent until now, speaks his mind. “Let’s postulate,” he ventures nervously, “the existence of an invisible ball.”

“Say what?” reply the elder Twiloans.

While his elders were monitoring what appeared to be the core of the game, the comings and going of the various players and the demarcations of the field, the pipsqueak was keeping his eyes peeled fo rare events. And he found one. Immediately before the referee announced a score, and a split second before the crowd cheered wildly, the young Twiloan noticed the momentary appearance of a bulge in the ~~back of the goal net. Soccer is a low-scoring game, so there were few bulges to observe, and~~ each was very short-lived. Even so, there were enough events for the pipsqueak to note that the shape of each bulge was hemispherical. Hence his wild conclusion that the game of soccer is dependent upon the existence of an invisible ball (invisible, at least, to the Twiloans).

The rest of the contingent from Twilo listen to this theory and, weak as the empirical evidence is, after much arguing, they conclude that the youngster has a point. An elder statesman in the group—a physicist, it turns out—observes that a few rare events are sometimes more illuminating than a thousand mundane events. But the real clincher is the simple fact that there *must* be a ball. Posit the existence of a ball, which for some reason the Twiloans cannot see, and suddenly everything works. The game makes sense. Not only that, but all the theories, charts, and diagrams compiled over the pa afternoon remain valid. The ball simply gives meaning to the rules.

This is an extended metaphor for many puzzles in physics, and it is especially relevant to particle physics. We can't understand the rules (the laws of nature) without knowing the objects (the ball) and without a belief in a logical set of laws, we would never deduce the existence of all the particles.

THE PYRAMID OF SCIENCE

We're talking about science and physics here, so before we proceed, let's define some terms. What is a physicist? And where does this job description fit in the grand scheme of science?

A discernible hierarchy exists, though it is not a hierarchy of social value or even of intellectual prowess. Frederick Turner, a University of Texas humanist, put it more eloquently. There exists, he said, a science pyramid. The base of the pyramid is mathematics, not because math is more abstract o more groovy, but because mathematics does not rest upon or need any of the other disciplines, whereas physics, the next layer of the pyramid, relies on mathematics. Above physics sits chemistry, which requires the discipline of physics; in this admittedly simplistic separation, physics is not concerned with the laws of chemistry. For example, chemists are concerned with how atoms combine to form molecules and how molecules behave when in close proximity. The forces between atoms are complex, but ultimately they have to do with the law of attraction and repulsion of electrically charged particles—in other words, physics. Then comes biology, which rests on an understanding of both chemistry and physics. The upper tiers of the pyramid become increasingly blurred and less definable: as we reach physiology, medicine, psychology, the pristine hierarchy becomes confused. A the interfaces are the hyphenated or compound subjects: mathematical physics, physical chemistry, biophysics. I have to squeeze astronomy into physics, of course, and I don't know what to do with geophysics or, for that matter, neurophysiology.

The pyramid may be disrespectfully summed up by an old saying: the physicists defer only to the mathematicians, and the mathematicians defer only to God (though you may be hard pressed to find a mathematician that modest).

EXPERIMENTERS AND THEORISTS: FARMERS, PIGS, AND TRUFFLES

Within the discipline of particle physics there are theorists and experimenters. I am of the latter persuasion. Physics in general progresses because of the interplay of these two divisions. In the etern love-hate relation between theory and experiment, there is a kind of scorekeeping. How many ~~important experimental discoveries were predicted by theory? How many were complete surprises~~? For example, the positive electron (positron) was anticipated by theory, as were the pion, the antiproton, and the neutrino. The muon, tau lepton, and upsilon were surprises. A more thorough stud indicates rough equality in this silly debate. But who’s counting?

Experiment means observing and measuring. It involves the construction of special conditions under which observations and measurements are most fruitful. The ancient Greeks and modern astronomers share a common problem. They did not, and do not, manipulate the objects they are observing. The early Greeks either could not or would not; they were satisfied to merely observe. The astronomers would dearly love to bash two suns together—or better, two galaxies—but they have yet to develop this capability, and must be content with improving the quality of their observations. But España we have 1,003 ways of studying the properties of our particles.

Using accelerators, we can design experiments to search for the existence of new particles. We can organize particles to impinge on atomic nuclei, and read the details of the subsequent deflections the way Mycenaean scholars read Linear B—if we crack the code. We produce particles; then we “watch them to see how long they live.

A new particle is predicted when a synthesis of existing data by a perceptive theorist seems to demand its existence. More often than not, it doesn’t exist, and that particular theory suffers. Whethe it succumbs or not depends on the resilience of the theorist. The point is that both kinds of experiments are carried out: those designed to test a theory and those designed to explore a new domain. Of course, it is often much more fun to *disprove* a theory. As Thomas Huxley wrote, “The great tragedy of science—the slaying of a beautiful hypothesis by an ugly fact.” Good theories explai what is already known and predict the results of new experiments. The interaction of theory and experiment is one of the joys of particle physics.

Of the prominent experimentalists in history, some—including Galileo, Kirchhoff, Faraday, Ampere, Hertz, the Thomsons (both J. J. and G. P.), and Rutherford—were fairly competent theorists as well. The experimenter-theorist is a vanishing breed. In our time Enrico Fermi was an outstanding exception. I. I. Rabi expressed his concern about the widening gap by commenting that European experimentalists could not add a column of figures, and theorists couldn’t tie their own shoelaces. Today we have two groups of physicists both with the common aim of understanding the universe bu with a large difference in cultural outlook, skills, and work habits. Theorists tend to come in late to work, attend grueling symposiums on Greek islands or Swiss mountaintops, take real vacations, and are at home to take out the garbage much more frequently. They tend to worry about insomnia. One theorist, it is said, went to the lab physician with great concern: “Doctor, you have to help me! I sleep well all night, and the mornings aren’t bad, but all afternoon I toss and turn.” This behavior gives rise to the unfair characterization of *The Leisure of the Theory Class* as a takeoff on Thorstein Veblen’s bestseller.

Experimenters don’t come in late—they never went home. During an intense period of lab work, th outside world vanishes and the obsession is total. Sleep is when you can curl up on the accelerator floor for an hour. A theoretical physicist can spend his entire lifetime missing the intellectual challenge of experimental work, experiencing none of the thrills and dangers—the overhead crane with its ten-ton load, the flashing skull and crossbones and DANGER, RADIOACTIVITY signs. A theorist’s only real hazard is stabbing himself with a pencil while attacking a bug that crawls out of his calculations. My attitude toward theorists is a blend of envy and fear but also respect and affection. Theorists write all the popular books on science: Heinz Pagels, Frank Wilczek, Stephen Hawking, Richard Feynman, et al. And why not? They have all that spare time. Theorists tend to be arrogant. During my reign at Fermilab I solemnly cautioned our theory group against arrogance. At least one o them took me seriously. I'll never forget the prayer I overheard emanating from his office: "Dear Lord, ~~forgive me the sin of arrogance, and Lord, by arrogance I mean the following . . ."~~

Theorists, like many other scientists, can be fiercely, sometimes absurdly, competitive. But some theorists are serene, way above the battles that mere mortals engage in. Enrico Fermi is a classic example. At least outwardly, the great Italian physicist never even hinted that competition was a relevant concept. Whereas the common physicist might say, "We did it first!" Fermi only wanted to know the details. However, at a beach near Brookhaven Laboratory on Long Island one summer day, showed him how one can sculpt realistic structures in the moist sand. He immediately insisted that w compete to see who would make the best reclining nude. (I decline to reveal the results of that competition here. It depends on whether you're partial to the Mediterranean or the Pelham Bay schoo of nude sculpting.)

Once, at a conference, I found myself on the lunch line next to Fermi. Awed to be in the presence o the great man, I asked him what his opinion was of the evidence we had just listened to, for a particle named the K-zero-two. He stared at me for a while, then said, "Young man, if I could remember the names of these particles I would have been a botanist." This story has been told by many physicists, but the impressionable young researcher was *me.*

Theorists can be warm, enthusiastic human beings with whom experimentalists (mere plumbers an electricians we) love to converse and learn. It has been my good fortune to enjoy long conversations with some of the outstanding theorists of our times: the late Richard Feynman, his Cal Tech colleagu Murray Gell-Mann, the arch Texan Steven Weinberg, and my rival comic Shelly Glashow. James Bjorken, Martinus Veltman, Mary Gaillard, and T. D. Lee are other great ones who have been fun to be with, to learn from, and to tweak. A significant fraction of my experiments emerged from the papers of, and discussions with, these savants. Some theorists are much less enjoyable, their brillianc marred by a curious insecurity, reminiscent perhaps of Salieri's view of the young Mozart in the movie *Amadeus:* "Why, Lord, did you encapsulate so transcendent a composer in the body of an asshole?"

Theorists tend to peak at an early age; the creative juices tend to gush very early and start drying u past the age of fifteen—or so it seems. They need to know just enough; when they're young they haven't accumulated useless intellectual baggage.

Of course, theorists tend to receive an undue share of the credit for discoveries. The sequence of theorist, experimenter, and discovery has occasionally been compared to the sequence of farmer, pig, truffle. The farmer leads the pig to an area where there might be truffles. The pig searches diligently for the truffles. Finally, he locates one, and just as he is about to devour it, the farmer snatches it away.

GUYS WHO STAYED UP LATE

In the following chapters I approach the history and future of matter as seen through the eyes of discoverers, stressing—not, I hope, out of proportion—the experimenters. Think of Galileo, schlepping up to the top of the Leaning Tower of Pisa and dropping two unequal weights onto a wooden stage so he could listen for two impacts or one. Think of Fermi and his colleagues establishing the first sustained chain reaction beneath the football stadium of the University of Chicago.

When I talk about the pain and hardship of a scientist's life, I'm speaking of more than existential angst. Galileo's work was condemned by the Church; Madame Curie paid with her life, a victim of leukemia wrought by radiation poisoning. Too many of us develop cataracts. None of us gets enough sleep. ~~Most of what we know about the universe we know thanks to a lot of guys (and ladies) who~~ stayed up late at night.

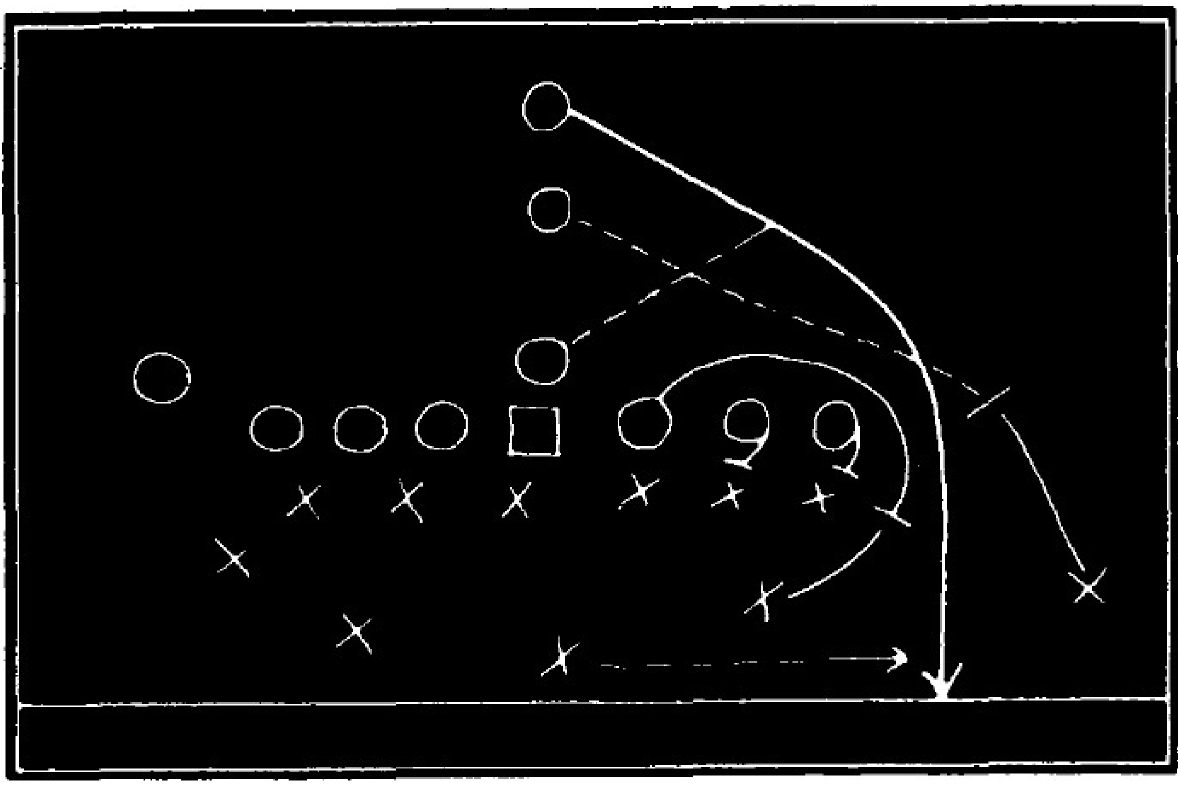
The story of the a-tom, of course, includes theorists. They help us through what Steven Weinberg calls “the dark times between experimental breakthroughs,” leading us, as he says, “almost imperceptibly to changes in previous beliefs.” Weinberg’s book *The First Three Minutes* was one of the best, though now dated, popular accounts of the birth of the universe. (I always thought the book sold so well because people thought it was a sex manual.) My emphasis will be on the crucial measurements we have made in the atom. But you cannot talk about data without touching on theory. What do all these measurements mean?

UH-OH, MATH

We’re going to have to talk a bit about math. Even experimenters cannot make it through life withou some equations and numbers. To avoid mathematics entirely would be like playing the role of an anthropologist who avoids examining the language of the culture that is being studied, or like a Shakespearean scholar who hasn’t learned English. Mathematics is such an intricate part of the weav of science—especially physics—that to dismiss it is to leave out much of the beauty, much of the aptness of expression, much of the ritualistic costuming of the subject. On a practical level, math makes it easier to explain how ideas developed, how devices work, how the whole thing is woven together. You find a number here; you find the same number there—maybe they’re related.

But take heart. I’m not going to do calculations. And there won’t be any math on the final. In a course I taught for nonscience majors at the University of Chicago (called “Quantum Mechanics for Poets”), I straddled the issue by pointing at the mathematics and talking about it without actually *doing it*, God forbid, in front of the whole class. Even so, I find that abstract symbols on the blackboard automatically stimulate the organ that secretes eye-glaze juice. If, for instance, I write $x = vt$ (read: ex equals vee times tee), a gasp arises in the lecture hall. It isn’t that these brilliant children of parents paying $20,000 tuition per year cannot deal with $x = vt$. Give them numbers for x and t and ask them to solve for v, and 48 percent would get it right, 15 percent would refuse to answer on advic of counsel, and 5 percent would vote present. (Yes, I know that doesn’t add up to 100. But I’m an experimenter not a theorist. Besides, dumb mistakes give my class confidence.) What freaks out the students is that they know I’m going to talk about it. Talking about math is new to them and brings about extreme anxiety.

To regain my students’ respect and affection I immediately switch to a more familiar and comfortable subject. Examine the following:



Think of a Martian staring at this diagram, trying to understand it. Tears spray out of his belly button. But your average high-school-dropout football fan yelps, “That’s the Washington Redskins’ goal-line ‘Blast’!” Is this representation of a fullback off-tackle run that much simpler than $x = vt$? Actually, it’s just as abstract, and certainly more arcane. The equation $x = vt$ works anywhere in the universe. The Redskins’ short-yardage play might score a touchdown in Detroit or Buffalo, but never against the Bears.

So think of equations as having a real-world meaning, just as diagrams of football plays—overcomplicated and inelegant as they are—have a real-world meaning on the gridiron. In fact, it’s n all that important to manipulate the equation $x = vt$. It’s more important to be able to read it, to understand it as a statement about the universe in which we live. To understand $x = vt$. is to have power. You will be able to predict the future and to read the past. It is both the Ouija board and the Rosetta Stone. So what does it mean?

The x tells where the thing is. The thing can be Harry cruising along the interstate in his Porsche o an electron zipping out of an accelerator. When $x = 16$ units, for example, we mean that Harry or the electron is located 16 units away from a place we call zero. The v is how fast Harry or the electron is moving—such as Harry tooling along at 80 mph or the electron dawdling at 1 million meters per second. The t represents the time elapsed after someone yells “go.” Now we can predict where the thing will be at any time, whether $t = 3$ seconds or 16 hours or 100,000 years. We can also tell where the thing was, whether $t = -7$ seconds (7 seconds before $t = 0$) or $t = -1$ million years. In other words if Harry starts out from your driveway and drives due east for one hour at a speed of 80 mph, then obviously he will be 80 miles east of your driveway an hour from “go.” In reverse, you can also calculate where Harry was an hour ago (−1 hour), assuming his velocity was always v and that v is known—a critical assumption, because if Harry is a lush, he may have stopped at Joe’s Bar an hour ago.

Richard Feynman presents the subtlety of the equation another way. In his version a cop stops a woman in a station wagon, sidles up to her window, and snarls, “Did you know you were going eighty miles an hour?”

“Don’t be ridiculous,” the woman replies. “I only left the house fifteen minutes ago.” Feynman, thinking he had invented a humorous entrée to differential calculus, was shocked when he was accuse of being a sexist for telling this story, so I won't tell it here.

The point of our little excursion into the land of math is that equations have solutions, and these solutions can be compared to the "real world" of measurement and observation. If the outcome of thi confrontation is succcessful, one's confidence in the original law is increased. We'll see from time to time that the solutions do not always agree with observation and measurement, in which case, after due checking and rechecking, the "law" from which the solution emerged is relegated to the dustbin history. Occasionally the solutions to the equations expressing a law of nature are completely unexpected and bizarre, and therefore bring the theory under suspicion. If subsequent observations show that it was right after all, we rejoice. Whatever the outcome, we know that the overarching trut about the universe as well as the functioning of a resonant electronic circuit or the vibrations of a structural steel beam are all expressed in the language of mathematics.

THE UNIVERSE IS ONLY SECONDS OLD (10^{18} OF THEM)

One more thing about numbers. Our subject often switches from the world of the very tiny to the world of the enormous. Thus we will be dealing with numbers that are often very, very large or very, very small. So, for the most part, I shall write them using scientific notation. For instance, instead of writing one million as 1,000,000, I write it like this: 10^6. That means 10 raised to the sixth power which is a 1 followed by six zeroes, which is the approximate cost, in dollars, of running the U.S. government for about 20 seconds. Big numbers that don't conveniently start with a 1 can also be written in scientific notation. For instance, 5,500,000 is written 5.5×10^6. With tiny numbers, we jus insert a minus sign. One millionth (1/1,000,000) is written like this: 10^{-6}, which means a 1 that is six places to the right of a decimal point, or .000001.

What's important is to grasp the scale of these numbers. One of the disadvantages of scientific notation is that it hides the true immensity of numbers (or their smallness). The span of scientifically relevant times is mind-boggling: 10^{-1} seconds is an eye blink; 10^{-6} seconds is the lifetime of the muon particle, and 10^{-23} seconds is the time it takes a photon, a particle of light, to cross the nucleus Keep in mind that going up by powers of ten escalates the stakes tremendously. Thus 10^7 seconds is equal to a bit more than four months, and 10^9 seconds is thirty years. But 10^{18} seconds is roughly the age of the universe, the amount of time that has transpired since the Big Bang. Physicists measure it seconds—just a lot of them.

Time isn't the only quantity that ranges from the unimaginably infinitesimal to the endless. The smallest distance that is relevant to measurement today is something like 10^{-17} centimeters, which is how far a thing called the Z^0 (zee zero) can travel before it departs our world. Theorists sometimes deal in much smaller space concepts; for instance, when they talk about superstrings, a trendy but ver abstract and very hypothetical theory of particles, they say that the size of a superstring is 10^{-35} centimeters, real small. At the other extreme, the largest distance is the radius of the observable universe, somewhat under 10^{28} centimeters.

A TALE OF TWO PARTICLES AND THE ULTIMATE T-SHIRT

When I was ten years old, I came down with the measles, and to cheer me up my father bought me a book ~~with big print called *The Story of Relativity*, by Albert Einstein and Leopold Infeld. I'll never~~ forget the beginning of Einstein and Infeld's book. It talked about detective stories, about how every detective story has a mystery, clues, and a detective. The detective tries to solve the mystery by using the clues.

There are essentially two mysteries to be solved in the following story. Both manifest themselves a particles. The first is the long-sought a-tom, the invisible, indivisible particle of matter first postulated by Democritus. The a-tom lies at the heart of the basic questions of particle physics.

We've struggled to solve this first mystery for 2,500 years. It has thousands of clues, each uncovered with painstaking labor. In the first few chapters, we'll see how our predecessors have attempted to put the puzzle together. You'll be surprised to see how many "modern" ideas were embraced in the sixteenth and seventeenth centuries, and even centuries before Christ. By the end, we'll be back to the present and chasing a second, perhaps even greater mystery, one represented by the particle that I believe orchestrates the cosmic symphony. And you will see through the course of the book the natural kinship between a sixteenth-century mathematician dropping weights from a tower in Pisa and a present-day particle physicist freezing his fingers off in a hut on the cold, wind-swept prairie of Illinois as he checks the data flowing in from a half-billion-dollar accelerator buried beneath the frozen ground. Both asked the same questions. What is the basic structure of matter? Ho does the universe work?

When I was growing up in the Bronx, I used to watch my older brother playing with chemicals for hours. He was a whiz. I'd do all the chores in the house so he'd let me watch his experiments. Today he's in the novelty business. He sells things like whoopee cushions, booster license plates, and T-shirts with catchy sayings. These allow people to sum up their world view in a statement no wider tha their chest. Science should have no less lofty a goal. My ambition is to live to see all of physics reduced to a formula so elegant and simple that it will fit easily on the front of a T-shirt.

Significant progress has been made through the centuries in the search for the ultimate T-shirt. Newton, for example, came up with gravity, a force that explains an amazing range of disparate phenomena: the tides, the fall of an apple, the orbits of the planets, and the clustering of galaxies. Th Newton T-shirt reads $F = ma$. Later, Michael Faraday and James Clerk Maxwell unraveled the myste of the electromagnetic spectrum. Electricity, magnetism, sunlight, radio waves, and x-rays, they found, are all manifestations of the same force. Any good campus bookstore will sell you a T-shirt with Maxwell's equations on it.

Today, many particles later, we have the standard model, which reduces all of reality to a dozen or so particles and four forces. The standard model represents all the data that have come out of all the accelerators since the Leaning Tower of Pisa. It organizes particles called quarks and leptons—six of each—into an elegant tabular array. One can diagram the entire standard model on a T-shirt, albeit a busy one. It's a hard-won simplicity, generated by an army of physicists who have traveled the same road. However, the standard-model T-shirt cheats. With its twelve particles and four forces, it is remarkably accurate. But it is also incomplete and, in fact, internally inconsistent. To have room on the T-shirt to make succinct excuses for the inconsistencies would require an X-tra large, and we'd still run out of shirt.

What, or who, is standing in our way, obstructing our search for the perfect T-shirt? This brings us back to our second mystery. Before we can complete the task begun by the ancient Greeks, we must consider the possibility that our quarry is laying false clues to confuse us. Sometimes, like a spy in a John le Carré novel, the experimenter must set a trap. He must force the culprit to expose himself.

Particle physicists are currently setting just such a trap. We’re building a tunnel fifty-four miles in circumference that will contain the twin beam tubes of the Superconducting Super Collider, in which we hope to trap our villain.

And what a villain! The biggest of all time! There is, we believe, a wraithlike presence throughout the universe that is keeping us from understanding the true nature of matter. It’s as if something, or someone, wants to prevent us from attaining the ultimate knowledge.

This invisible barrier that keeps us from knowing the truth is called the Higgs field. Its icy tentacle reach into every corner of the universe, and its scientific and philosophical implications raise large goose bumps on the skin of a physicist. The Higgs field works its black magic through—what else?— particle. This particle goes by the name of the Higgs boson. The Higgs boson is a primary reason for building the Super Collider. Only the SSC will have the energy necessary to produce and detect the Higgs boson, or so we believe. This boson is so central to the state of physics today, so crucial to our final understanding of the structure of matter, yet so elusive, that I have given it a nickname: the God Particle. Why God Particle? Two reasons. One, the publisher wouldn’t let us call it the Goddamn Particle, though that might be a more appropriate title, given its villainous nature and the expense it i causing. And two, there is a connection, of sorts, to another book, a *much* older one . . .

THE TOWER AND THE ACCELERATOR

> And the whole earth was of one language, and of one speech.
>
> And it came to pass, as they journeyed from the east, that they found a plain in the land of Shinar; and they dwelt there. And they said one to another, Go to, let us make brick, and burn them thoroughly. And they had brick for stone, and slime had they for mortar. And they said, Go to, let us build us a city and a tower, whose top *may reach* unto heaven; and let us make us a name, lest we be scattered abroad upon the face of the whole earth.
>
> And the Lord came down to see the city and the tower, which the children of men builded. And the Lord said, Behold, the people *is* one, and they have all one language; and this they begin to do: and now nothing will be restrained from them, which they have imagined to do. Go to, let us go down, and there confound their language, that they may not understand one another’s speech.
>
> So the Lord scattered them abroad from thence upon the face of all the earth: and they left off to build the city. Therefore is the name of it called Babel.
>
> —Genesis 11:1–9

At one time, many millennia ago, long before those words were written, nature spoke but one language. Everywhere matter was the same—beautiful in its elegant, incandescent symmetry. But through the eons, it has been transformed, scattered throughout the universe in many forms, confounding those of us who live on this ordinary planet orbiting a mediocre star.

There have been times in mankind’s quest for a rational understanding of the world when progress was rapid, breakthroughs abounded, and scientists were full of optimism. At other times utter confusion reigned. Frequently the most confused periods, times of intellectual crisis and total incomprehension, were themselves harbingers of the illuminating breakthroughs to come.

In the past few decades in particle physics, we have been in a period of such curious intellectual stre~~ss that the parable of the Tower of Babel seems appropriate. Particle physicists have been us~~ing their giant accelerators to dissect the parts and processes of the universe. The quest has, in recent years, been aided by astronomers and astrophysicists, who figuratively peer into giant telescopes to scan the heavens for residue sparks and ashes of a cataclysmic explosion that they are convinced took place 15 billion years ago, which they call the Big Bang.

Both groups have been progressing toward a simple, coherent, all-encompassing model that will explain everything: the structure of matter and energy, the behavior of forces in environments that range from the earliest moments of the infant universe with its exorbitant temperature and density to the relatively cold and empty world we know today. We were proceeding nicely, perhaps too nicely, when we stumbled upon an oddity, a seemingly adversarial force afoot in the universe. Something that seems to pop out of the all-pervading space in which our planets, stars, and galaxies are embedded. Something we cannot yet detect and which, one might say, has been put there to test and confuse us. Were we getting too close? Is there a nervous Grand Wizard of Oz who sloppily modifies the archaeological record?

The issue is whether physicists will be confounded by this puzzle or whether, in contrast to the unhappy Babylonians, we will continue to build the tower and, as Einstein put it, “know the mind of God.”

> And the whole universe was of many languages, and of many speeches.
>
> And it came to pass, as they journeyed from the east, that they found a plain in the land of Waxahachie, and they dwelt there. And they said to one another Go to, let us build a Giant Collider, whose collisions may reach back to the beginning of time. And they had superconducting magnets for bending, and protons had they for smashing.
>
> And the Lord came down to see the accelerator which the children of men builded. And the Lord said, Behold the people are un-confounding my confounding. And the Lord sighed and said, Go to, let us go down, and there give them the God Particle so that they may see how beautiful is the universe I have made.
>
> —The Very New Testament, 11:1