ONE
THE POINT

In which we ask why a group of talented and dedicated people would devote their lives to the pursuit of things too small to be seen.

Particle physics is a curious activity. Thousands of people spend billions of dollars building giant machines miles across, whipping around subatomic particles at close to the speed of light and crashing them together, all to discover and study other subatomic particles that have essentially no impact on the daily lives of anyone who is not a particle physicist.

That's one way of looking at it, anyway. Here's another way: Particle physics is the purest manifestation of human curiosity about the world in which we live. Human beings have always asked questions, and since the ancient Greeks more than two millennia ago, the impulse to explore has grown into a systematic, worldwide effort to discover the basic rules governing how the universe works. Particle physics arises directly from our restless desire to understand our world; it's not the particles that motivate us, it's our human desire to figure out what we don't understand.

The early years of the twenty-first century are a turning point. The last truly surprising experimental result to emerge from a particle accelerator was in the 1970s, more than thirty-five years ago. (The precise date would depend on your definition of "surprising.") It's not because the experimentalists have been asleep at the switch—far from it. The machines have improved by leaps and bounds, reaching into realms that seemed impossibly far away just a short time ago. The problem is that they haven't seen anything we didn't already expect them to see. For scientists, who are always hoping to be surprised, that's extremely annoying.

The problem, in other words, isn't that the experiments have been inadequate—it's that the theory has been too good. In the specialized world of modern science, the roles of "experimentalists" and "theorists" have become quite distinct, especially in particle physics. Gone are the days—as recent as the first half of the twentieth century—when a genius like Italian physicist Enrico Fermi could propose a new theory of the weak interactions, then turn around and guide the construction of the first self-sustained artificial nuclear chain reaction. Today, particle theorists scribble equations on blackboards, which ultimately become specific models, which are tested by experimentalists who gather data from exquisitely precise machines. The best theorists keep close tabs on experiments and vice versa, but no one person is a master of both.

The 1970s saw the finishing touches put on our best theory of particle physics, which goes by the fantastically uninspiring name of the "Standard Model." It's the Standard Model that describes quarks, gluons, neutrinos, and all the other elementary particles you may have heard of. Like Hollywood celebrities or charismatic politicians, scientific theories are put on a pedestal just so we can tear them down. You don't become a famous physicist by showing that someone else's theory is right; you become famous by showing where someone else's theory goes wrong, or by proposing a better theory.

But the Standard Model is stubborn. For decades now, every experiment that we can do here on earth has duly confirmed its predictions. An entire generation of particle physicists has risen up the academic ladder from students to senior professors, all without having a single new phenomenon that they could discover or explain. The anticipation has been close to unbearable.

All this is changing. The Large Hadron Collider represents a new era in physics, smashing together particles with an energy never before achieved by humankind. And it's not just higher energy. It's an energy we've been dreaming about for years, in which we expect to find new theoretically predicted particles and hopefully some surprises—the energy where the force known as the "weak interaction" hides its secrets.

The stakes are high. Peering into the unknown for the first time, anything could happen. There are scads of competing theoretical models hoping to anticipate what the LHC will find. You don't know what you're going to see until you look. At the center of the speculation lies the Higgs boson, an unassuming particle that represents both the last piece of the Standard Model, and the first glimpse into the world beyond.

A big universe made of little pieces

Near the Pacific coast in Southern California, about an hour-and-a-half drive south of where I live in Los Angeles, there is a magical place where dreams come to life: Legoland. At Dino Island, Fun Town, and other attractions, children marvel at an elaborate world constructed from Legos, tiny plastic blocks that can be fitted together in limitless combinations.

Legoland is a lot like the real world. At any moment, your immediate environment typically contains all sorts of substances: wood, plastic, fabric, glass, metal, air, water, living bodies. Very different kinds of things, with very different properties. But when you look more closely, you discover that these substances aren't truly distinct from one another. They are simply different arrangements of a small number of fundamental building blocks. These building blocks are the elementary particles. Like the buildings in Legoland, tables and cars and trees and people represent some of the amazing diversity you can achieve by starting with a small number of simple pieces and fitting them together in a variety of ways. An atom is about one-trillionth the size of a Lego block, but the principles are similar.

We take for granted the idea that matter is made of atoms. It's something we're taught in school, where we do chemistry experiments in classrooms with the periodic table of the elements hanging on the wall. It's easy to lose sight of how amazing that fact is. Some things are hard, some are soft; some things are light, some are heavy; some things are liquid, some are solid, some are gas; some things are transparent, some are opaque; some things are alive, some are not. But beneath the surface, all these things are really the same kind of stuff. There are about one hundred atoms listed in the periodic table, and everything around us is just some combination of those atoms.

The hope that we can understand the world in terms of a few basic ingredients is an old idea. In ancient times, a number of different cultures—Babylonians, Greeks, Hindus, and others—invented a remarkably consistent set of five "elements" out of which everything else was made. The ones we are most familiar with are earth, air, fire, and water, but there was also a heavenly fifth element of aether, or quintessence. (Yes, that's where the movie with Bruce Willis and Milla Jovovich got its name.) Like many ideas, this one was developed into an elaborate system by Aristotle. He suggested that each element sought a particular natural state; for example, earth tends to fall and air tends to rise. By mixing the elements in different combinations, we could account for the different substances we see around us.

Democritus, a Greek philosopher who predated Aristotle, originally suggested that everything we know is made of certain tiny indivisible pieces, which he called "atoms." It's an unfortunate accident of history that this terminology was seized upon by John Dalton, a chemist who worked in the early 1800s, to refer to the pieces that define chemical elements. What we now think of as an atom is not indivisible at all—it consists of a nucleus made of protons and neutrons, around which orbit a collection of electrons. Even the protons and neutrons aren't indivisible; they are made of smaller pieces called "quarks."

The quarks and electrons are the real atoms, in Democritus's sense of indivisible building blocks of matter. Today we call them "elementary particles." Two kinds of quarks—known playfully as "up" and "down"—go into making the protons and neutrons of an atomic nucleus. So, all told, we need only three elementary particles to make up every single piece of matter that we immediately perceive in the environment around us—electrons, up quarks, and down quarks. That's an improvement over the five elements of antiquity, and a big improvement over the periodic table.

Boiling the world down to just three particles is a bit of an exaggeration, however. While electrons and up and down quarks are enough to account for cars and rivers and puppies, they aren't the only particles we've discovered. There are actually twelve different kinds of matter particles: six quarks that interact strongly and get confined inside larger collections like protons and neutrons, and six "leptons" that can travel individually through space. We also have force-carrying particles that hold them together in the different combinations we see. Without force particles, the world would be a boring place indeed—individual particles would just move on straight lines through space, never interacting with one another. It's a fairly small set of ingredients to explain everything we see around us, but frankly, it could be simpler. Modern particle physicists are driven by a desire to do better.