The Ruins of Science

Whatever Happened to the Tevatron?

by

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ABSTRACT

The Tevatron was the world's highest energy particle accelerator for more than two decades. Built at Fermi National Accelerator Laboratory in Batavia, Illinois in the early 1980s, the machine accelerated protons and antiprotons through its 4.26-mile ring of magnets and smashed them together in one of two 5,000 ton detectors that traced and measured the collision debris. Scientists then analyzed the results in search of new fundamental particles or a deeper understanding of existing ones, and in 1995, they discovered the top quark, one of only 17 known fundamental particles in the universe. The discovery made headlines around the world and became the Tevatron's crowning achievement.

When the U.S. Department of Energy decided to shut the Tevatron down in 2011 after a more powerful collider began running in Europe, the old machine entered a kind of limbo. Its life in the world of experimental particle physics was over, but there were no plans for its remains. Using the Tevatron as a case study, this thesis asks the fundamental question: what can and should be done with the ruins that lie in the wake of progress? In doing so, it examines a difficult challenge facing today's science and technology museum curators, namely how to preserve the historical and scientific value of important artifacts amid the acceleration of scientific progress and the growing prevalence of big science.

Thesis Supervisor: Corby Kummer
Title: Senior Editor, *The Atlantic*

THE TEVATRON, LEGENDARY PARTICLE COLLIDER, SHUTS DOWN AT 28
October 1, 2011

The most powerful particle collider in the United States and the second most powerful particle collider in the world shut down yesterday. The Tevatron, located about 40 miles west of Chicago near Geneva, IL, was 28 years old.

A 4.26-mile ring of more than 1,000 long, boxy magnets lined up end-to-end, the subterranean beast's full expanse was only visible from a bird's eye view. And even then, the nearly perfect circle of raised earth only hinted at the scientific marvel lying below the prairie fields of Fermi National Accelerator Laboratory.

Scientists built the Tevatron in the early 1980s to uncover the fundamental components of our universe. It smashed together protons and antiprotons moving at nearly the speed of light, creating tiny microcosms of Big Bang-like conditions. In one second, millions of these collisions would send showers of particle debris flying through one of two three-story, 5000-ton detectors called the Collider Detector at Fermilab (CDF) and DZero.

To control such energetic particles, the Tevatron employed special magnets containing superconducting cables that, when cooled to around negative 450 degrees Fahrenheit, conducted electric current with zero resistance, generating extraordinarily powerful magnetic fields. The demand for so many of these cables gave rise to an entire industry surrounding superconductors, and from that industry sprang MRI technology.

The cryogenic cooling system Fermilab developed to maintain such cold temperatures was named an International Historic Mechanical Engineering Landmark by the American Society of Mechanical Engineers in 1993.

This aerial view of Fermilab reveals the 4.26-mile ring of the Tevatron (Fermilab).

In 1986 the Illinois Society of Professional Engineers named the entire machine one of the top 10 engineering achievements of the previous 100 years.

All in all, the Tevatron left a mark on history comparable to its mark on the Illinois prairie. More than 1,000 physicists earned their PhDs working on the Tevatron, and the technological advances it spurred paved the way for future accelerators.

The Tevatron's most notable discovery came in 1995, when scientists announced that amid collision debris, they found the last of a group of fundamental particles known as quarks. Quarks are tiny building blocks that bind together to form particles called hadrons, which include the protons and neutrons in the nuclei of atoms. In the 1960s, theorists predicted the existence of six types or "flavors" of quarks that, for various reasons, became known as up, down, strange, charm, top and bottom quarks. By 1977, all but the top quark had graduated from theory to reality through direct observation. The top quark, it would turn out, was so heavy that only a machine as powerful as the Tevatron could create it.

In an interview with the *Los Angeles Times* a few days before the shut-down, physicist Giovanni Punzi discussed the importance of that discovery.

"The top quark was crucial because without it, all of our theories of how subatomic particles behave wouldn't work," he said. "Physicists knew there had to be a sixth quark. Everybody was puzzled by the fact that we couldn't find it. The reason we couldn't find it is because its mass was so large that scientists could not produce it until the Tevatron came along. It was a very long search. If we had not found the top quark, understanding all of the rest of physics would have been a problem."

The Tevatron made a whole host of contributions to particle physics, and in its last few years had turned its attention toward the Higgs boson, a particle that physicists have been theorizing about for decades. Unsure how heavy the Higgs will be, Fermilab scientists, like explorers hunting for buried treasure, had been systematically testing different collision energies, hoping to eventually pinpoint the right one that would yield the elusive particle.

Finding the Higgs would have solved the biggest mystery in particle physics today and certainly would have been a fitting sendoff to what was the world's highest-energy collider for more than two decades.

Instead, that search will continue at Europe's Large Hadron Collider (LHC), a 17-mile ring that's more than twice as powerful as the Tevatron. Work began on the LHC in the 1990s, and ever since, the Tevatron's obsolescence has been inevitable. Still, those closest to the Tevatron said that in its last few years, the machine was working better than it ever had before. In fact, Fermilab scientists advocated for keeping the old collider going until 2014 because it was so close to finding the Higgs. But money was tight, and to keep the machine up and running, the lab would have needed an extra $35 million per year.

And so the U.S. government said no, it couldn't afford the three-year extension, and Fermilab scientists would have to leave the Higgs search to the LHC.

Hundreds of people who had worked with the Tevatron over the years flocked to Fermilab from all over this week to say their final goodbyes.

The two detectors were turned off first. Ben Kilminster, one of the scientists who worked on CDF, said a somber goodbye to the 12-meter high behemoth.

"For many of us, CDF is more than a machine," Kilminster said. "It's a living creature that has the superhuman ability to see the microscopic quantum world. So it's going to be with heavy hearts that many of us watch it close its eyes to this world that has captivated us for so long."

After the detectors were turned off, Helen Edwards, who was instrumental in building the machine, had the honor of powering it down. She also had the burden of ending an era in U.S. particle physics.

Over the next week, the Tevatron's magnets will slowly emerge from their deep freeze. When they reach room temperature, Fermilab scientists will remove the cooling liquids and gases.

It's unclear what will happen to the Tevatron's remains. The monstrous corpse is too big to ship off to a museum and would cost too much to dismantle. For curators and historians, this will be a kind of case study in how to deal with the ever increasing size of science experiments.

Some at Fermilab have advocated for the in situ preservation of part of the tunnel as an exhibit, but for now, the Tevatron will just sit in its tunnel 25 feet underground and gather dust. Before long, scavengers will likely start picking at it, taking magnets and detector components for their own experiments.

EXPEDITION TO THE TEVATRON
January 2014

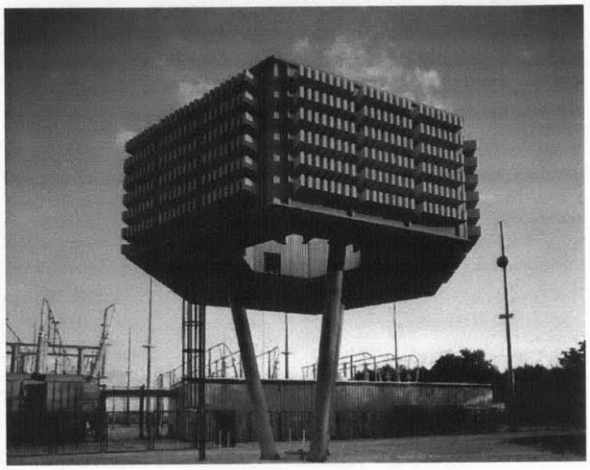
The view through Paul Czarapata's windshield is stark white. The snow-covered road mirrors a blanket of thick clouds, and the surrounding fields are still, bracing themselves for the single-digit cold snap descending upon the Midwest. From the passenger seat, I keep my eyes on the barely-there path ahead while the white-haired electrical engineer laments the dwindling hardware know-how of young scientists who work on computers all day.

Up ahead on the left, I see a squat box of a building with three doors and no sign of life. We pull into the vacant parking lot out front. Czarapata steps out into the cold and stands there for a few seconds in his black pilot's jacket as he decides which door to try. All three are buried in a foot-and-a-half of snow. He walks over to the one on the left and lands his foot directly into the powdery bank, burying the bottom half of his black dungaree pant leg, and reaches forward to unlock the door. I stand waiting a few feet away as he yanks the door toward himself, wedging it into the snow just enough so that we can squeeze through the crack.

I follow Czarapata inside. This is it, I think to myself. I'll finally get to see the Tevatron.

A World of Juxtaposition

Nearly 11 acres of preserved prairie nestled in the Illinois suburbs, Fermilab is a bizarre blend of the natural world and some of humanity's most advanced scientific instruments. Grassy fields, lakes and forest fill the wide gaps between buildings where scientists study the inconceivably small particles that make up everything in the universe, even the seemingly empty voids of space. Along one of the few roads on site, there's a line of towering electric poles in the shape of the Greek letter pi, a monstrous "capacitor tree," and a herd of bison. Old farm houses coexist with architectural wonders like the Proton Pagoda - a black box propped up on four 26-foot-tall legs and connected to the ground by two spiral staircases twisted into a DNA-like double helix.



Ferrmilab's capacitor tree is no longer in use but remains on site as a popular landmark (Reider Hahn, Fermilab).

But among all of the oddities in this small world of juxtaposition, the biggest surprise of all is what lies beneath the grassy fields. Hinted at only by low earth berms that occasionally run tangent to the roads, the Tevatron sits quietly in its tomb 25 feet underground. It's been more than two years since the pride of U.S. particle physics shut down, and while the rest of Fermilab has moved on to new experiments, the Tevatron remains in a kind of limbo - not an exhibit, not on its way to the scrap yard. For now, it lies patiently like a relic from a past civilization waiting to be discovered.

Inside the squat service building set up along the Tevatron ring, Czarapata and I make our way through a forest of electronics and a legion of pipes and dewars built for the Tevatron's liquid helium cooling system. We eventually come to a flight of concrete stairs that leads down to the 10 foot high, 8 foot wide tunnel undercutting more than four miles of prairie. My excitement grows with each step of our descent until finally we enter the evercurving corridor, home of the elusive machine I've read and heard so much about.

The Tevatron's long, boxy magnets lie dormant in the tunnels under Fermilab (Brian Nord, Fermilab).

The lights are low and the air dry. Straight ahead along the tunnel's outer wall, a string of metal boxes about 20 feet long and one foot thick line up end to end, sprouting wires and pipes all along the way. Some red, some blue, these boxes are the Tevatron's magnets. They still look ready and eager to "take beam," which around here is a simple way to say that they're ready for Fermilab's chain of four smaller accelerators to launch streams of speeding particles through their hollow cores. But their days of taking beam are over. They'll just sit around waiting for the occasional visit from old friends like Czarapata or for scavengers to come looking for parts.

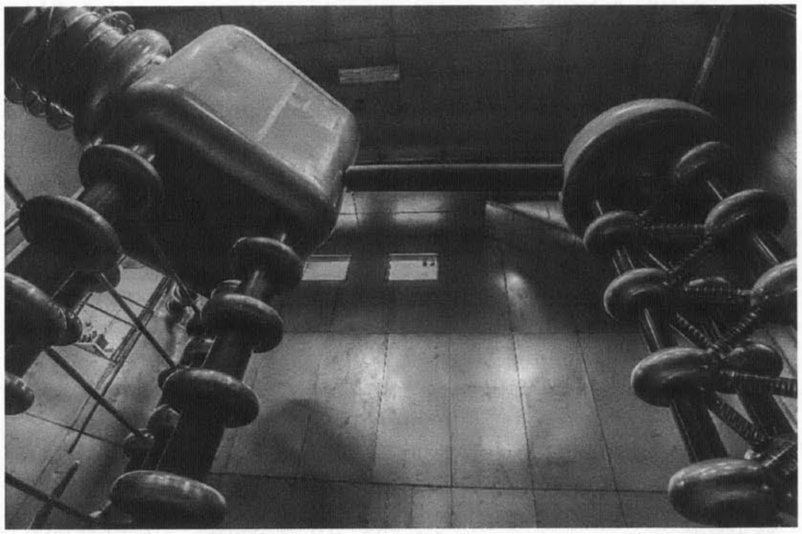
In their heyday, the magnets had the not-so-easy job of controlling billions of protons and antiprotons as they flew past each other in opposite directions 48,000 times per second. Like a set of guiding hands following the particles every step of the way, about one quarter of the 1,014 magnets kept the particles consolidated into tight beams, while the rest led the beams along the curve of the tunnel to keep them from smashing into the outer wall of the surrounding vacuum tube.

Leaning up against the tunnel wall opposite the magnets, Czarapata reminisces. As part of Fermilab's Accelerator Division, he was one of nearly 600 scientists who ran, repaired and maintained the Tevatron over the years. He was at Fermilab 35 years ago when the U.S. Department of Energy authorized the Tevatron's construction, and he was there on September 31, 2011 when the lab shut it down for good. Now, the lab "just doesn't feel the same," he tells me on our way back to the main offices of the Accelerator Division, which shrank in recent years to just over 400 people.

I leave Czarapata in his office and head to the lab's main control room, where scientists and technicians are monitoring a wall of computers that still control Fermilab's four smaller accelerators. I'm here to meet Marty Murphy, an accelerator operator who's been at the lab for 17 years.

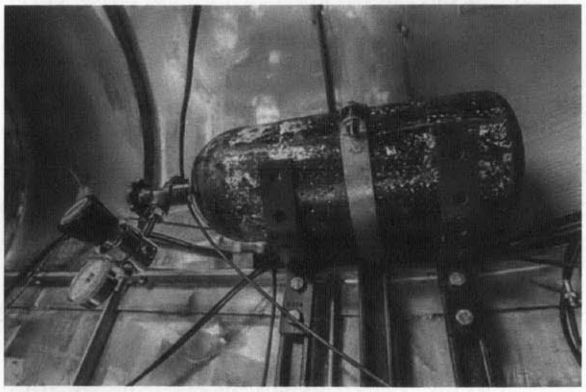
Murphy, a short and stocky guy with a bushy brown beard, takes me to see the old pre-accelerator that used to feed the Tevatron its particles. As we wind through the halls of the Accelerator Division, Murphy tells me the ins and outs of how the Tevatron worked. I'm not sure if it's the t-shirt and cargo pants and occasional "Simpson's" references or just his genuine passion for the Tevatron, but Murphy sounds like a kid talking about his favorite toy.

We come to a door at the end of a hallway, and Murphy turns to me. "All right, so here's an important question. How are you with climbing relatively steep ladders?" He opens the door, and I gaze into an open metal pit. At eye-level across the expanse, a big silvery box stands on four long legs, each with a series of metal rings spaced evenly down to the floor. With its smooth edges and large features, the whole apparatus, known as a Cockroft-Walton, looks like a prop from an old science fiction movie.



From below, the towering Cockroft Walton looks like something out of science fiction. Hydrogen atoms used to shoot out of the Faraday cage on the left, through a tube and into the lab's accelerator chain (Brian Nord, Fermilab).

I let Murphy go first, then follow him down the ladder. From below, the towering Cockroft-Walton looks even more surreal. At its base, we climb onto a shaky platform outfitted with two makeshift PVC pipe handles. The handles don't look very trustworthy, so I take my chances and choose not to hold on. Murphy pushes a button, and the platform jerks to life, slowly bringing us up to the metal box, which is just big enough to fit a few people at a time. We step inside. Looking around, I see some outdated electronics and a yellowing piece of paper full of incomprehensible strings of numbers and letters taped to a wall. Up in one corner, there's a rusty canister the size of a fire extinguisher. That's where it all started, Murphy tells me.



The Hydrogen gas that once filled this canister used to feed the Tevatron its protons (Brian Nord, Fermilab).

The hydrogen gas that used to fill this canister was the Tevatron's proton source. Back in the day, the metal walls of this box, known as a Faraday cage, would build up a charge of negative 750 thousand volts. For reference, typical wall sockets in the United States provide 120 volts of electricity. The charged cage would cause the hydrogen atoms to launch through a tube out of the cage and into the accelerator chain.

Now, like the Tevatron, the canister has nothing to do and nowhere to go. "We kept a lot of the original hardware here cause it's cool looking, and well frankly, there's not a whole lot else we could do with it," Murphy says.

We linger in the Faraday cage for a while as Murphy talks about the old days.

"The collider program was a blast. We were the most powerful machine in the world and doing stuff that no one else could do. It was very complex; it was very challenging, the problems we were dealing with every day. I got to work with everything from cryogens to superconductors to massive power suppliers, working with machines that make antimatter for a living. It was a pretty damn cool gig. It was unique."

Now, he says, the Accelerator Division is much more "factory-like." Fermilab has refocused its efforts on studying particles called neutrinos, so Murphy and his colleagues are in charge of using accelerators to make neutrinos as quickly and plentifully as possible.

After I snap a few pictures in the cage, we ride the platform back down, head up the ladder and return to the control room.

Down the hall, Roger Dixon is settling into a new office. Dixon was two years out of graduate school when he came to Fermilab in 1977 just in time to work on the construction of the Tevatron. By the time it shut down 34 years later, he was head of the Accelerator Division. He stepped down in 2013.

When I stop by to chat, I find Dixon, fit and clean-cut, standing at his desk. The place is spotless and uncluttered. Through a slow Colorado drawl, Dixon offers me a seat at a small round table. Sitting across from me, he looks down at the table and wiggles it, noticing for the first time that it's uneven. We talk for about 45 minutes, and he tells me that he feels lost these days. He's thinking about going into astrophysics, he says, but really doesn't know what to do now that the Tevatron era is over.

"When you've been as close to a machine like that as I was for so many years, it's like losing a person or an entity of some sort rather than just a piece of hardware," he says. "The Tevatron seemed to have a personality."

When I ask him what it was like during his early days at the lab, Dixon's eyes light up.

"I'd be so excited when I'd come to work back then. Sometimes I'd stay for days without going home, and I would think, 'We're really making history here.' There was that feeling that everybody ought to be able to experience in their life - that what you're doing is really something unique, incredible and making history."

THE ROAD TO THE TEVATRON 1897-1985

In 1897, exactly eighty years before Fermilab's first director would testify before Congress for funds to build the Tevatron, British physicist J.J. Thomson made a discovery that launched the field of particle physics.

Thomson was interested in what happened to cathode rays - beams of light that appeared when electric current flowed through empty glass tubes - under the influence of electric and magnetic fields. He did an experiment and found that such fields caused the rays to bend. Knowing that charged atoms and molecules acted similarly in the presence of electric and magnetic fields, Thomson knew the rays were made of charged particles, but because of how far they deflected, he concluded that they were smaller than atoms. He called these new particles "corpuscles." Today, we know them as electrons.

A few years later, Thomson hypothesized that an atom was like plum pudding - a nebulous blob of positive charge (pudding) with negative electrons (plums) dotted throughout. That model was put to the test in 1909 at the University of Manchester, when Thomson's former student Ernest Rutherford, German physicist Hans Geiger, and Rutherford's student James Marsden decided to fire large, positively charged particles called alpha particles at a sheet of gold foil. Knowing that like charges repelled each other, they hypothesized that if atoms really were like plum pudding, then the blobs of widely distributed positive charge in the gold foil would be too weak to do any more than slightly nudge the big, clunky alpha particles as they flew through.

Instead, what they found was that, while many of the alpha particles did fly right through the foil, occasionally, one of them would shoot straight back in the opposite direction. At the time, Rutherford famously said, "It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you." From this experiment it was clear that atoms actually had very concentrated cores of positive charge - nuclei - that were strong enough to stop an alpha particle in its tracks and send it back to where it came from.

About ten years later, Marsden found that if he bombarded hydrogen gas with alpha particles, the hydrogen atoms' nuclei popped out. Rutherford performed the same experiment with nitrogen gas and observed the same phenomenon - the emission of hydrogen nuclei. This convinced Rutherford that nuclei were made of discrete particles and that since hydrogen was the lightest element, its nucleus contained just one of these particles and all heavier elements, like nitrogen, contained multiple of them. He called them protons.

And thus began a long tradition of particle physicists smashing around the tiniest bits of matter to find out what they're made of. But by the 1920s particle physicists themselves hit a wall. To really understand what was in the heart of an atom, they would need to crack one open.

"What we require is an apparatus to give us a potential of the order of 10 million volts, which can be safely accommodated in a reasonably sized room and operated by a few kilowatts of power. We require too an exhausted tube capable of withstanding this voltage...I see no reason why such a requirement cannot be made practical," Rutherford said in 1930 at the opening of a lab in England.

What he wanted was one of the world's first particle accelerators.

Two young scientists - John Cockroft and Ernest Walton - built such a machine under Rutherford's tutelage and in 1932 successfully split open the lithium atom. Their creation - now commonly known as a Cockroft-Walton - worked by passing protons through a series of upwardly zig-zagging tubes. Each tube contained an electric field that, like shots of adrenaline, accelerated the protons until they popped out the other end at extremely high energies.

In particle physics, scientists measure energy in electron-volts (eV). One eV is defined as the amount of energy that one electron gains from a one volt battery. Cockroft and Walton split the atom with protons that reached about 700,000 eV. For comparison, a molecule at room temperature has less than 0.01 eV of energy.

Meanwhile, in the United States, Robert Van de Graaff was working on what is now commonly known as a Van de Graaff generator, and Ernest Lawrence at the University of California, Berkeley, was working on a cyclotron, the first kind of accelerator to send particles around in circles. His cyclotron was made of two half-circle hunks of metal separated by a small gap with their flat sides facing each other. Each half-circle was a magnet that guided particles along its curvature. When the particles got to the gap, an alternating electric field accelerated them as they jumped from one side to the other. The faster the particles went, the wider their circular orbits. In the 1940s, physicists built synchrotrons that, instead of using central magnets of constant strength, used rings of magnets that grew stronger as the particles got faster and therefore kept the beams confined to a fixed circular path.

Over the second half of the 20th century, accelerator energies grew roughly by a factor of ten every six to eight years. Thanks to Einstein's famous equation, $E=mc^2$, scientists knew that energy could turn into mass and vice versa, so when particle collisions reached high enough energies, they not only broke down matter into its constituent parts, they also gave birth to uncommon particles that, unlike electrons, protons and neutrons, weren't readily available in nature.

As accelerator physics progressed, scientists also began experimenting with high-energy particle beams from space known as cosmic rays. These experiments, coupled with new theoretical models of how particles behaved, revealed a world of matter far richer than the atom. Before long, the stable of fundamental particles that just included electrons, protons and neutrons was on its way to becoming a veritable zoo of what is now 17 particles. In the process, a deep culture of competition emerged between Europe and the United States as the two particle physics hubs took turns building bigger and better accelerators.

Settling the Midwest - 1965

When American physicist Robert Wilson first saw the design for a new 200 billion eV accelerator to be built in the U.S., he disapproved. It was 1965 and Wilson, a man known for building things simply and cheaply, thought the proposal was over-designed and far too expensive. A man also known for his love of art, Wilson went to Paris to study drawing just a few days later. The whole time he was there, he couldn't get his mind off what was to be the world's highest-energy accelerator.

During one of his sketching classes, Wilson later recalled to his colleagues, he was supposed to be drawing a nude model but instead spent the whole time sketching accelerator designs and hiding them under other papers. "This was the opposite of the usual schoolboy approach," he said at the time. Remaining in Paris for a few days after the class, Wilson continued to fixate on America's new accelerator.

"I think I spent the whole time going through one machine after another in a fury, making all kinds of designs...It was very funny, because it was such romantic surroundings, and here I was doing this cloddish thing of designing, what even I would have considered was not a very respectable thing to do."

Two years later, in 1967, after a bitter competition between the University of California, Berkeley, and Brookhaven National Laboratory in New York over who would get the new accelerator, the U.S. government decided to build the National Accelerator Laboratory - later named the Fermi National Accelerator Laboratory after Enrico Fermi, one of the preeminent nuclear physicists of the early 20th century - in the Midwest and asked Wilson, then a professor at Cornell University, to be its director.

Robert R. Wilson was the founding director of Fermilab. He resigned in 1978 after the government turned down his request for funds to build the Tevatron (Fermilab).

Like a frontiersman exploring new territory, Wilson took a leave of absence from his professorship and headed west to Illinois farm country.

"We have the opportunity to build a truly magnificent laboratory...with beautiful architecture set in a pleasing environment...a significant laboratory...where we will have the opportunity to push the limits of our knowledge about particles to a point undreamed of 30 years ago," he said at the time.

The lab got right to work on a four-part chain of accelerators, designed with input from various groups around the country. The process would start with an injection of hydrogen atoms from a small fire extinguisher-sized canister into a Cockroft-Walton. There, each atom would pick up an extra electron and shoot into a 500-foot long linear accelerator (Linac). The Linac would kick the atoms up to 400 million eV and then shoot them through a carbon filter that would strip them of their electrons. The hydrogen nuclei - single protons - would emerge on the other side of the filter and take 20,000 laps around a 0.3-mile synchrotron called the Booster and finally head into a 4.26-mile synchrotron called the Main Ring.

Scientists at the lab had high hopes that the machine would be able to answer some of the very esoteric questions that nagged particle physicists: which particles were elementary? What undiscovered particles awaited at higher and higher energies? Was there an overarching law that dictated how all particles behaved? An early design report from the lab ended with, "Nature in the past has always surprised us. It is probable that, as we take the step up to an energy of 200 (billion) eV, more surprises await us."

By 1970 the Cockroft-Walton, Linac and Booster were in place, and the lab was hard at work on the Main Ring. But accelerators can take so long to plan and build that particle physicists often have to start thinking about the next machine when the one they're working on is only just getting started. That's why Wilson was already making plans for something bigger and better. He insisted that while workers installed the Main Ring magnets in the 4.26-mile tunnel, they left enough room for another ring of magnets. One Fermilab scientist later told historians that he remembered treating the space as "sacred territory."

Wilson kept his plans mostly to himself at first, to ensure that the lab stayed focused on completing the Main Ring. But when the Main Ring finally began accelerating particles in 1972, reaching the target 200 billion eV within a few months of operation, it was time for Fermilab to set its sights on the next machine, one that would hold the title of the world's highest-energy accelerator for more than 20 years.

Monster under the Illinois Prairie - 1973

Wilson called it the Energy Doubler.

By 1973 the Main Ring was regularly reaching higher than expected energies, around 400 billion eV, and if all went according to plan, the new machine would reach an unprecedented one trillion eV. It would accelerate the same kind of particles and live in the same tunnel, but instead of using standard electromagnets, the Energy Doubler would use superconducting electromagnets, making it the first large-scale accelerator to do so.

Unlike the horseshoe-shaped hunks of metal or refrigerator decorations most often associated with magnets, electromagnets only generate magnetic fields when electric current runs through them. The more current, the stronger the field. By using superconducting wires, which have no electrical resistance when cooled to extremely low temperatures, the Doubler's magnets would be able handle very high current and therefore generate magnetic fields strong enough to control extremely energetic particles. But no one had used superconducting magnets at this size and scale before, so Fermilab scientists would have to design and build them in-house.

The lab would also needed an extravagant cooling system to deliver liquid helium around the ring to keep the magnets at the requisite negative 450 degrees Fahrenheit. Maintaining such low temperatures would be crucial. If superconductors heat up beyond their critical temperature, they revert to normal conductivity in a violent burst of energy known as a quench, and quenches can completely destroy a magnet.

A cohort of scientists, including a young Roger Dixon, used an above-ground testing facility to do quench testing on strings of connected magnets. In an interview with Fermilab historians, scientist Karl Koepke recalled the early days of quench testing:

"As soon as a quench occurred we'd hear this bang and then...this roar for about 3 or 4 minutes as the helium exhausted through these vents. Anyone standing outside would see this white vapor cloud coming through the cracks in the building and the doors as if the building were on fire...I got so used to walking through that vapor cloud by crawling against the wall to keep my bearings, because you can't see anything."

One day, Dixon was in the above-ground testing facility when a man who helped design the magnets stopped by. The visitor noticed a giant metal shield set up in the facility and asked Dixon what it was for. Dixon explained that quenches could be so violent that the shield was there to deflect flying 500-liter liquid helium containers.

To show the man what a quench looked like, Dixon took him down into the tunnel, where they had already installed a couple of magnets. The young physicist told his guest to stand at one end of a magnet while he stood at the other end about 20 feet away and got on the phone with an engineer above ground.

"Okay, we're ready. Quench the magnets!" Dixon called into the receiver.

Before he knew it, there was an enormous boom and a cloud of vapor roaring toward him at 60 miles per hour. Realizing immediately that he'd made a huge mistake, Dixon screamed into the phone, "Stop the quench!" but knew it was pointless. There was no stopping it.

As soon as the vapor started to clear, Dixon dropped to the floor to look for a sign that the man was okay. Much to his relief, he saw that his visitor had turned and sprinted about 200 feet down the tunnel. The magnet was ruined, and Dixon felt horrible.

Eventually, researchers at the lab came up with a clever scheme for monitoring the resistance in the wires so they could react quickly to slight rises in resistance and avoid serious damage.

By 1977 the lab was ready to fill in the rest of that "sacred" space left in the Main Ring tunnel. That year, Wilson headed to Congress to present a design plan and ask for construction funds. When Congress asked Wilson about how the accelerator would impact national security, he famously responded:

"It only has to do with the respect with which we regard one another, the dignity of men, our love of culture. It has to do with those things. It has to do with, are we good painters, good sculptors, great poets? I mean all the things that we really venerate and honor in our country and are patriotic about. It has nothing to do directly with defending our country except to help make it worth defending."

Wilson assured Congress that the highly efficient machine would save the lab about $5 million per year in electric bills - that's about $20 million in today's dollars - but Congress still wouldn't approve the huge influx of money needed for construction. Wilson threatened to resign in 1978 if the project didn't get funding, and when the money still didn't come, he stepped down as lab director that year.

Fermilab scientist Leon Lederman succeeded Wilson, and one of his first orders of business was deciding whether or not to move forward with the Doubler. He appointed three physicists from around the country to be his "three wise men" and assess the technical feasibility of the machine. He also held a "shoot-out," where supporters and non-supporters of the Doubler stated their cases to a panel of accelerator expert judges. The judges were to "embarrass the advocates as much as possible with penetrating, incisive questions," Lederman wrote in an announcement of the event.

The advocates made a convincing argument, and Fermilab committed to the project. By the end of 1978, the D.O.E. had agreed to fund the project in stages as the construction process reached certain milestones. First, researchers working in the above-ground testing facility would have to do a successful demonstration with a string of 10 full-size magnets. Only then could construction in the actual tunnel begin, but just in one sixth of the tunnel called Section A. If everything went smoothly in Section A, then the D.O.E. would open its wallet for the rest of the ring.

The only other superconducting accelerator in the works at the time was Brookhaven's ISABELLE. That project ultimately lost funding in 1981, after scientists at the lab had trouble with their magnet design. By the time they fixed it and were ready for construction, the plan for their 0.4 trillion eV collider was effectively obsolete.

On July 4th weekend in 1983, the Doubler accelerated its first protons to 512 billion eV, setting a new accelerator record. Staff members flocked to the Fermilab control room and celebrated with champagne. Word of the success quickly spread around the world, and Herwig Schopper, the director-general of the European Organization for Nuclear Research (CERN) at the time, sent a message of congratulations to Lederman:

"Our warmest congratulations for the extraordinary achievement to accelerate protons for the first time in a superconducting ring to energies never obtained before. Fermilab pioneered the construction of superconducting magnets, opening up a new domain of future accelerators. Please convey our admiration to all the staff concerned."

The following February, the Doubler's beam approached a groundbreaking 1 trillion eV, and the machine earned its new name - the Tevatron.

To make the machine even more powerful, Fermilab planned to turn it into a collider. Instead of firing protons into fixed targets, the Tevatron would fire them into a beam of antiprotons flying in the opposite direction. Plenty of accelerators had collided electrons and positrons before, but only CERN had ever done so with protons in a 0.4 mile long non-superconducting Proton Synchrotron. When Fermilab completed its antiproton generator in 1985, the Tevatron began colliding beams and reaching energies closer to 2 trillion eV, cementing its position as the reigning king of particle physics.

SHUTDOWN

The Tevatron only got better with age. By 2001, the lab had incorporated a new accelerator in the chain leading up to the Tevatron. That plus upgrades to the Tevatron itself and its two detectors allowed it to house more collisions at higher energies. As Marty Murphy, the bearded control room operator, and I stand in the Faraday cage of the old Cockroft-Walton, he reminisces about the collider's final years.

"Our data taking, our ability to make collisions had never been better, and we still were working up, it wasn't like we plateaued, we were still on the upswing - we solved a lot of problems that we encountered and we really were doing great stuff."

There was just one problem: CERN had been working on a new 4 trillion eV collider that was scheduled to start working in 2008. When that happened, the Tevatron would have had no choice but to surrender its crown to its European successor and bow out with the 1995 top quark discovery as its crowning achievement. But even with inevitable shutdown looming on the horizon, Fermilab scientists were determined to continue the search for the Higgs boson, or rather, the smaller particles the Higgs would immediately decay into - theory predicted that the actual Higgs would be very large by fundamental particle standards and therefore unstable.

Unfortunately, even if the Tevatron found the Higgs, it wouldn't have been a "discovery." In physics, a result qualifies as a discovery only if it reaches a five on something called the sigma scale. The scale measures the probability that a given result is due to chance. The higher the sigma, the higher the confidence level. A result officially counts as a discovery when it reaches five sigma, or a confidence level of more than 99 percent. Only CERN's more powerful Large Hadron Collider (LHC) would be able to measure traces of the Higgs at a five sigma confidence level. The Tevatron would be able to reach only three or three-and-a-half sigma - around 93 percent confidence. Even so, Fermilab scientists wanted to lead the search.

When the LHC finally started running in 2008, a traumatic quenching incident caused CERN to immediately shut the machine back down for repairs, giving the Tevatron one last shot at finding the Higgs. The D.O.E. seized the opportunity by extending the old machine's run until 2011. Even though plenty of Fermilab physicists were part of the huge international collaboration working on the LHC, the long-standing competitive dynamic between Europe and the U.S. made any further work on domestic soil worth the effort.

When the LHC started back up in 2010, Fermilab asked for an extension beyond its re-scheduled 2011 shutdown, arguing that not only could the Tevatron help find the Higgs, but that it could also provide a clearer picture of the particle's properties. After all, the two colliders were fundamentally different - the LHC smashed protons into protons, and the Tevatron smashed protons into anti-protons.

"Considering the uncharted nature of the Higgs sector, surprises should not be surprising... and the different properties of the two colliders may combine in unexpected ways to shed more light on the nature of the Higgs sector," read the report to the D.O.E..

Although the D.O.E. was tempted by the prospect of the U.S. sharing in the Higgs glory and seriously considered the proposal, it ultimately turned down the three-year extension for lack of funds. In a letter to the chairman of the High Energy Physics Advisory Panel, which advocated for the extension, the director of the D.O.E.'s Office of Science delivered the bad news:

"Unfortunately, the current budgetary climate is very challenging and funding has not been identified. Therefore...operation of the Tevatron will end in FY 2011, as originally scheduled."

This decision didn't just mean the end of a chapter in Fermilab history; it meant the end of a chapter in American particle physics. Before construction even began at the 4 trillion eV LHC, the U.S. was building a 20 trillion eV collider in Texas. But in a devastating turn of events, the government scrapped the project in 1993 because it was getting too expensive. With the death of the Superconducting Super Collider, the Tevatron was the only experiment the U.S. had left in the world of high-energy accelerators.

As the shutdown approached, Dixon insisted that longtime Fermilab physicist Helen Edwards pull the plug. Edwards was the one who hired Dixon back in the 70s. She mentored him through the years and ultimately became one of his idols. Dixon's campaign succeeded, and on September 30, 2011, Edwards shut down the Tevatron. Crowds of people gathered around the lab to watch a live video stream of the event. First, Edwards pushed a red button to shut off the particle beam, and then she pushed a green button to kill the electric current - a kind of lifeblood - running through the ring of magnets.

Marty Murphy was at the lab that day taking pictures. "There was nothing pleasant about it, absolutely nothing pleasant about it at all," he tells me. "It was sort of like taking a race car and working on it and working on it and working on it and making it as perfect as you could ever make it and then saying, 'Awesome, all right, we're gonna scrap it now.'"

The following year, the LHC detected the Higgs. CERN declared an official discovery in 2013.

Dixon tells me that Edwards still comes into the office every now and then. Hers is the door right next to Paul Czarapata's at the end of the hall. Sure enough, I catch her later that week sitting at a desk covered in papers, her white hair the only indication that she's well past retirement age.

We talk for a while about her early days at Fermilab, and like everyone else, she has fond memories of working on the Tevatron. When I ask her if turning off the machine that she had worked on for decades was difficult for her, she responds without skipping a beat. "Oh there's always an emotional connection of course, yeah. But I guess the more important thing is to have a future." Edwards is stoic about moving on to new experiments and doesn't seem to dwell on the past. Still, she's bothered by the way the Tevatron's run came to an end in the middle of the Higgs search.

"There was a real open question of whether that was the right time to shut it down or not shut it down," she tells me. "Personally, I get a little bit antagonistic I guess I would say when people say 'Well, CERN discovered the Higgs Boson you know - like it came from out of the vacuum and suddenly it was there."

Indeed, work at the Tevatron narrowed down the possible energies at which the LHC might have found the Higgs, giving CERN a leg up in the search.

Edwards now splits her time between Fermilab, a lab in Germany and a home in Montana that she shares with her husband. She admits that Fermilab doesn't have the same sense of urgency that it did back in the day. That's why she prefers to work in Germany, she tells me. Perhaps it's because the lab over there has a lot of young people around from a nearby university, she says, but the atmosphere over there just feels more exciting.

An Uncertain Future - 2014

More than two years after the shut-down, I'm surprised to find that there are no plans for the Tevatron's remains and no clear consensus on what should happen to them. Many at the lab, like Edwards, haven't given it much thought. Others don't seem to care or are content to just let it sit there, while some, like Roger Dixon, hope that at least part of the machine gets preserved.

"Up until the time it shut down, it was the most incredible physics machine there ever was," Dixon tells me as we sit at the wobbly table in his office. "So it has a very special place in history I think...Maybe someday someone will come along that has some power there and say, 'Hey, this is an important machine.'"

For now, the Tevatron has time to wait for that person to come along. It would take about 36 million dollars to decommission the whole machine and fill in the tunnels. That would be a lot of money for the D.O.E. to spend just to get rid of something. Michael Procario, the D.O.E.'s associate director for high energy physics, tells me over the phone that decommissioning cost aside, the Tevatron was a big investment, so the government isn't going to just throw it away. Unless Fermilab decides it needs the space for something else, Procario says, the Tevatron will remain in its current "mothballed state" indefinitely.

Everything about the Tevatron's future feels indefinite. No one's in a rush to tear it down; no one's in a rush to preserve it; no one's in a rush to repurpose the tunnels. But everyone is in a rush to get on with new experiments as the Tevatron transitions into an artifact right under their feet. I've always thought of progress as something abstract or perceivable only over long periods of time, but here, for the first time, I see progress happening right before my eyes, and it seems faster than ever.

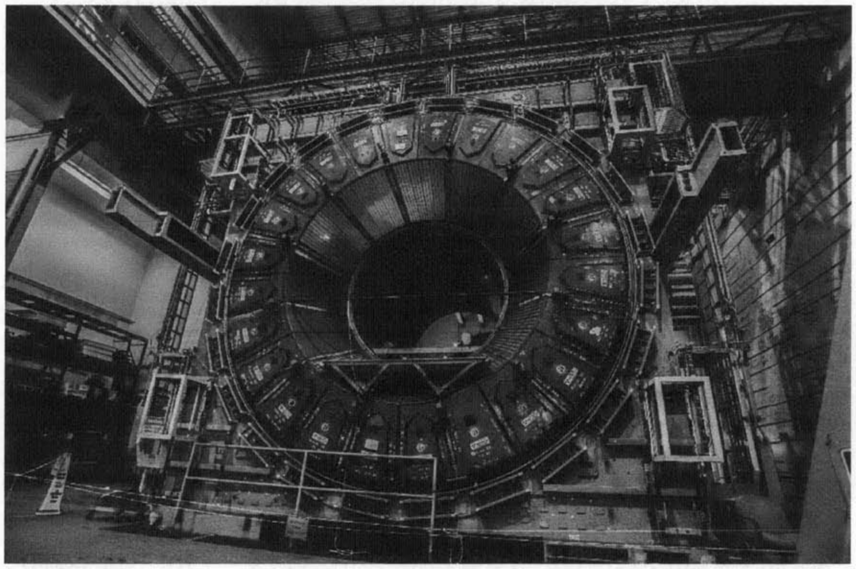
Frankenstein and the Bone-pickers

The Tevatron remains mostly intact, but pieces have begun to go missing - a magnet here or there, vacuum equipment, electronics. Scientists are great scavengers. If there's useful equipment left in the aftermath of an experiment, they'll find it. Equipment is expensive, and government funding is tight, so if there's a way to get something for free, or just for the cost of shipping, why not?

Experiments cobbled together with these found pieces and parts are what some Fermilab scientists call "Frankenstein machines." One long-time scientist at the lab takes me to see one such experiment in the forgotten back corner of a building. As we walk around the clutter of electronics and seemingly endless reams of electric cables, he points to two magnets about twice his height. They're called Rosie and the Jolly Green Giant, he tells me. Why? He doesn't know. He also points out a few devices that are bigger than the scientists would have needed and notes the overall "incoherent aesthetic" of the experiment. It's the quintessential Frankenstein machine. In the midst of explaining what this scrappy - and failed - experiment was meant to do, he stops. I see him sizing up a long metal object, and that's when he tells me that his ulterior motive for taking me here is to check out this field mapper for a new experiment that he's working on.

If the cluttered tomb of Rosie and the Jolly Green Giant has something to offer, then it's no surprise that the Tevatron's meaty corpse too has provided sustenance to these "bone-pickers," as one scientist calls them.

The biggest draw has been the Collider Detector at Fermilab (CDF), one of the two detectors set up in buildings along the ring. A new experiment is in the works that will use both the building and the detector's central magnet. That means the 5,000-ton behemoth has to come apart.



The Collider Detector at Fermilab is one of two 5,000 ton detectors along the Tevatron's ring. In 1995, scientists used this detector to discover the top quark, one of 17 known fundamental particles in the universe. It is now being taken apart (Brian Nord, Fermilab).

Jonathan Lewis is in charge of the detector's dismantling after having worked with it for 22 years. Just outside of the CDF building in a group of trailers, I find the fast-talking, no-nonsense physicist sitting in a cramped, hole-in-the-wall office. He tells me a bit about the proposed new experiment that would use CDF's magnet but is quickly called away for some decommissioning business over in the main building. I tag along for a tour of what's left of the detector. Lewis grabs his hardhat, and we shuffle across the snowy parking lot to where protons and antiprotons used to meet their demise. Not far into the building, we come to a railing overlooking an open expanse reminiscent of an airplane hangar. Down below, I see the round end of a giant, hollow cylinder. The gutted detector, now missing its central component that traced collision debris, lies outside of the beam line that used to bring in the protons and antiprotons. Signatures of scientists who worked on the detector cover a nearby wall.

"You know, in the beginning, it was like you take your baby and you cut up to there, cut up to there," Lewis says of the decommissioning process, motioning to the tip of one of his fingers. "Cut off the end of the finger, and tomorrow I'm gonna cut off the rest of the finger, and then after that I'll go for another finger, and then next week we're going for feet."

Still, Lewis supports the decision to tear it down.

"Either it was going to sit there and do nothing, or it was going to be a display, which was kind of nice...It would've been nice to bring my friends and relatives and show it off, but it's better to do science, he says. "Our legacy is the 600 plus papers that have come out of the CDF experiment."

Later, Lewis sends me an Excel spreadsheet called "TeV Scavengers" that lists who's taken what. It shows pieces of CDF and other parts of the Tevatron going to new experiments at Fermilab, various labs around the U.S. and even all the way to CERN.

For equipment, whether from CDF or other experiments around the lab, that doesn't have a place to go, there's a warehouse on site where reusable bits and pieces come and go. I stop by to take a look at the loot and end up spending an hour and a half wandering the rows upon rows of dusty old devices lining two-story-high shelves. In an open part of the warehouse, I come to a cylinder lying on its side. It's about three meters long and just under three meters in diameter. I've never seen anything like it. The round ends have concentric metal rings dotted with yellow knobs, and the walls are a clear, shimmery orange. The warehouse manager tells me that this was CDF's central tracking chamber, the heart of the detector. From up close, I see that the walls contain thousands of hair-like gold wires stretched from end to end. Back when it was still in use, the chamber was full of argon and ethane gas that became electrically charged as collision debris flew through it. The trails of charge that followed each particle were like unique signatures that the wires could read and relay back to Fermilab scientists for analysis.

This central tracking chamber fit in the center of the Collider Detector at Fermilab. Its job was to trace the debris from particle collisions (Brian Nord, Fermilab).

The manager leaves me to take pictures of the chamber. I stand there in awe. This piece of warehouse detritus found the top quark, I think to myself. Without that discovery, physicists' working theory of fundamental particles wouldn't have made sense. At the chamber's base, random bits of old equipment, dwarfed by the cylinder's grandiosity, look like worshipers bowing before their idol.

THE PLIGHT OF THE CURATORS

In 1965, Intel co-founder Gordon Moore predicted that the processing power of a computer chip would double about every two years, leading to an exponential growth in technology. His prediction, now known as Moore's Law, came true. Today's ubiquitous smart phones, for example, are more powerful than personal computers were in the 1980s. But with great progress comes great waste, so amid such swift advances, the outdated remnants of science are piling up in forgotten closets and warehouses around the world, leaving science museum curators to wade through the rubble in search of historic gems.

John Durant, the director of the MIT Museum, has been thinking a lot about this problem. Back home in Cambridge, Massachusetts, I visit Durant in his office above the museum. "The result of several decades of exponential growth has meant that by late 20th century, you had a scale of activity which was vastly greater than anything anybody had ever witnessed before, so the burden on historians to track it all and museums to collect it all is correspondingly enormous," he tells me.

Much of Durant's concern over the pace of progress stems from a phone call he received nine years ago. It was from a former MIT engineer who had a simple question: "Whatever happened to the Genomatron?" To his dismay, Durant had never heard of a Genomatron and certainly didn't know where it was. He soon found out that it was a state-of-the-art gene sequencing device for a brief period of time during the 90s before more advanced equipment made it obsolete. Genomics technology has advanced even faster than Moore's Law would have predicted, making it easy for something to fall through the cracks. Now, the fate of the Genomatron is still unclear, but one of the curators at the MIT Museum tells me that it looks like the device was simply lent out and never returned.

In the fall of 2013, Durant published a paper titled "'Whatever happened to the Genomatron?' Documenting a 21st century science" in *Studies in History and Philosophy of Science*. In it, Durant argues that his search for the long-forgotten Genomatron is just one example of a much larger problem - the inadequate collection of post-WWII artifacts.

"I know of no serious attempt to quantify the extent of this collective failure globally, but the fact remains that awareness of it weighs on the professional community of museum specialists like some sort of collective guilty conscience," Durant wrote.

Part of the problem is that scientists often don't recognize the historical importance of their equipment; they don't see their devices as artifacts that should be preserved, but rather as tools of their trade. Art museum curators have it easy, Durant laments as he reclines in his office chair. They don't have to go to artists' studios and try to convince them that their paintings or sculptures are worth preserving. Science museum curators, on the other hand, are tasked with sifting through the wake of progress. On the plus side, that means science museums often get their artifacts for free because they're one of few stops between the lab and the landfill.

Debbie Douglas, one of the MIT Museum's curators, tells me that many of the museum's acquisitions are old, dusty instruments that scientists had simply abandoned on their way to newer and better technologies.

"A lot of the stories in our collection are what you might call accidental preservation, meaning things got stuffed in closets and then forgotten about, and then 20 years later somebody is renovating or cleaning out and so things come here and they're like babies left on a doorstep," Douglas says.

Sometimes, artifacts like these abandoned "babies" turn out to be incredibly important to the history of science.

The famous DNA model that James Watson and Francis Crick built in 1953 to test their theory that DNA had a double helical structure was one such artifact. Watson and Crick had dismantled the model without recognizing its importance. It wasn't until the 1970s, when the model was on the brink of being lost forever, when a curious curator from the Science Museum in London decided to track it down. With a team of people from the Science Museum, King's College and Bristol University, the curator recovered the model, which is now prominently displayed in the museum's "Making the Modern World" gallery. Having been visited by millions of people, it's considered one of the world's most famous scientific artifacts.

Of course, as with the general population, all scientists are different. There are hoarders who save everything and others who simply don't care. Douglas has been in the business long enough to notice some trends within disciplines. Engineers, she says, are more likely to be obsessed with their apparatuses and offer her new artifacts, whether or not she wants them. They're the "hedonists" of the science world, she tells me, and on the other end of the spectrum are the "Buddhist monks," or biologists, who tend to care only about what's under the microscope and what it means, not the microscope itself. When it comes to biologists and others in the "monk" category, Douglas says, she tries her best to convince them that there's more to research than just results.

"I realize that the equipment doesn't tell the story, but it tells part of the story, and a great deal of human creativeness and ingenuity went into them, and so maybe it's worth keeping around," she tells me.

Most of the scientists I spoke with at Fermilab did recognize the Tevatron as an important object, and a few of them mentioned that the Smithsonian had expressed interest in taking a piece of the machine, but nothing had come of it. Curious about the holdup, I call Roger Sherman, an associate curator at the Smithsonian's National Museum of Natural History who specializes in physics artifacts. Sherman tells me that he has been thinking about the Tevatron and that if the museum does indeed "collect something," it might be one of the magnets, which he says are important not only for the history of physics, but also for the history of superconducting technology. Or maybe, he says, they'll take that central tracking chamber lying in Fermilab's warehouse.

The problem is, Sherman tells me, even these relatively small components of the machine are still pretty big, and the museum doesn't have that much storage space. When he decides what, if anything, the Smithsonian should take from the Tevatron, he'll send a report to the museum's collections committee with his recommendation, but "the collections committee will say that if there's no space, then we can't collect it no matter how significant it is," he tells me.

The Big Problem of Big Science

Some of the most incredible artifacts of science are also some of the largest - the space station, telescopes the size of buildings, giant particle detectors buried under the South Pole or in old mines. Most of the world gets to ignore these things when they shut down, but someone has to think about whether, what and how to preserve them.

Not far from the MIT Museum at the Harvard Collection of Historical Scientific Instruments, Peter Galison, the director of the collection, has been doing just that. In addition to being a historian of science, Galison is also a particle physicist who worked at the Stanford Linear Accelerator Laboratory, so he has first-hand experience working with large devices in both their prime and their post-mortem.

Between sips of herbal tea, Galison tells me from under his curly gray hair and glasses what drew him to the curatorial profession. "I want to know why things are the way they are today," he says. "One of the things that draws me to the physicality of science is that...it opens a portal to the specificity of the conditions under which this knowledge comes into existence. It's not just science fiction or abstraction."

When it comes to dealing with big science, Galison doesn't have all the answers, but he has some ideas. One way to deal with large artifacts like the Tevatron, he tells me, is to pick an exemplary piece that represents the whole. That's what he had to do with Harvard's 160-ton cyclotron. Originally used for physics experiments in the 1940s and later for proton medical treatment, the old accelerator was decommissioned in 2002. At the time, Galison says, he and the collection staff decided that the cyclotron itself was too big to preserve, so they would just keep the control panel, which had components as old as 1940s steam gauges and as modern as digital technology and early computers. "You could see the material palimpsest of all the different historical layers, so it was dense with information."

When one of the collection's curators and I take a walk through the collection gallery, I spot the control panel along the back wall; it looks like it arrived via time machine. There are notes, stickers, pencils, even a Chinese take-out menu still hanging on the wall of buttons and monitors.

As we stand there looking at the control panel, I wonder what part of the Tevatron could represent the whole. Nothing comes to mind. So much of the Tevatron is its immensity and its surroundings - the tunnels, those massive detector warehouses. The detectors themselves are one-of-a-kind masterpieces of engineering. The magnets certainly have historical importance. But the Tevatron seems to be more than just the sum of its parts, and I sympathize with Roger Sherman at the Smithsonian; he has to actually make this seemingly impossible decision.

There's also the option of in situ preservation, Galison tells me. Harvard has a 20-foot-long 19th-century telescope that's still in its original observatory. It's more evocative in that setting than it would be in a museum, he says. Having seen one of the Tevatron magnets outside of the tunnel, I can say that they too are more evocative in their original setting, and I find myself hoping that Fermilab decides to go this route and keep at least part of the Tevatron as a permanent exhibit. At the same time, I realize, Fermilab is an institute of science, not a museum, and I can't help but wonder what will happen to the Tevatron if the lab comes up with a new way to use the tunnels.

After speaking with Galison and a number of other curators, it's clear that many in the international museum community are grappling with the issue of preserving big science. The Tevatron is just one case study, but as scientists continue to build these large machines and ultimately shut them down, more will arise. Take, for example, the Large Hadron Collider, which is the Tevatron's successor and nearly four times its size.

In The Shadow of a Superstar

"It's been quite interesting to see how incredibly good CERN has been at making the LHC a media story in a way that I don't really think happened with previous generations of accelerators, and I don't quite know what's behind that," says Alison Boyle, a curator at London's Science Museum.

For the past two and a half years, Boyle and a team of museum staff, designers, playwrights, and scientists have worked on an exhibit that tells the story of how the Large Hadron Collider finally discovered the Higgs boson.

The exhibit, which opened last November to rave reviews, takes visitors along the path of a particle beam as it zips through the collider. They start in a mock injection room, complete with one of the hydrogen canisters that fed the LHC. Then they progress through a recreation of the collider's tunnels and come to a room with pieces of detector prototypes. At five stories tall, the actual LHC detectors are too big to recreate, so the museum instead uses a video projection of one that zooms in to give viewers front row seats to a particle collision. After that, visitors walk through a hall of mock offices meant to represent the hours of post-collision analysis. Finally, they end in an empty room with just a table full of scribbles that evoke abstract thoughts on the future of particle physics.

Just outside of the main exhibit, there's a display of historical particle physics artifacts. Visitors can gaze at the cathode ray tube that Thomson used to discover electrons, or they can marvel at part of the original Cockroft-Walton that split the atom. There's even a magnet from the Tevatron. It's there as a modest ode to the LHC's predecessor, but mostly, Boyle tells me over the phone from London, it serves to convey the culture of competition within particle physics and the fact that when the LHC turned on, the Tevatron became obsolete, not that she thinks that should be the Tevatron's legacy.

"There are so many great stories out of Fermilab and out of the Tevatron that I think it would be quite unfortunate if we got to a narrative now which was that it couldn't compete with the LHC, because there's a lot more that can be said other than that," she says.

The London exhibit, called Collider, is temporary - it will be in London until May of 2014 and then go on an international tour until 2016. Inevitably, the next big accelerator will come along, and the LHC, like the Tevatron, will become obsolete. Boyle says that she and others have begun to think about the impending pile of hardware, but there's no plan for what to do with it. In an e-mail message, one of the CERN archivists tells me that the LHC's ultimate fate didn't play a big role in the machine's planning stages "and probably still doesn't, the focus being on immediate scientific challenges."

As for the Tevatron, the future is uncertain. For now, Roger Sherman at the Smithsonian, like Mike Procario at the D.O.E. and the scientists at Fermilab, doesn't seem to be in any rush. "Something big like the Tevatron doesn't necessarily completely disappear. Even if one museum doesn't collect part of it, other parts may get preserved." Case in point, he tells me, the Science Museum in London already has that lone Tevatron magnet in its LHC exhibit.

One magnet, I think to myself. Having just seen the Tevatron in its full glory, there's no question in my mind that one magnet won't do it justice. But I suppose for a machine that already seems forgotten, it's better than nothing.

9007: IN RUINS

In their book *Fermilab: Physics, the Frontier & Megascience*, three historians imagined what it would be like for a future civilization to stumble upon the lab's ancient remains in the year 9007:

"Archaeologists, looking for clues about the people who had inhabited the area, uncovered the remains of suburban dwellings, commercial malls, school, and parking lots. They were perplexed when they discovered a 4.26-mile underground circular tunnel that had been buried under the ice for almost seven thousand years...Historical documents found in the archaeologists' search explained that at the end of that century scientists traveled from around the globe to this ring to use a machine called the Tevatron to understand the nature of matter and energy."

Peter Galison of the Harvard collection says it's difficult to anticipate how our artifacts will impact the far future.

"We sometimes don't know what the future's going to ask...When the mummies were first found, they would throw away all the papyrus that was the ancient paper that was around it and then eventually it was discovered that the papyrus actually had the texts of old books and much of what we know about ancient literature comes from these fragments, and now you just want to kill yourself thinking about what was lost. You know, was there a lost play of Aeschylus? We don't know!"

Today, we look back on the pyramids and marvel at how such an early civilization managed such a technically difficult task. It's impossible to know what will impress or interest people in the coming decades or centuries, but as we blaze ahead, we would do well to cast an occasional glance over our shoulders at the mounds of obsolete objects left in our wake. ■

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