Earliest Top Quark Data from CDF

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THE FOURTH FAMILY OF QUARKS AND LEPTONS[a]

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[a]These papers are the result of a conference entitled Second International Symposium on the Fourth Family of Quarks and Leptons held on February 23–25, 1989 in Santa Monica, California.

Top Search Progress in CDF

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INTRODUCTION

The discovery of the top quark t has been, for more than 10 years, a missing key confirmation of the Standard Model. Together with the proof of its existence, the knowledge of its mass, production, and decay properties will improve our current understanding and have implications for new physics. Lower limits on the t mass, m_t, have been 27 GeV from TRISTAN,[1] and 41 GeV from UA1.[2] There are theoretical arguments that limit the top mass to be less than 180–200 GeV.[3] The observation of the top quark is one of the main physics goals of the Collider Detector at Fermilab (CDF).[4]

The production cross sections for the reactions:

$$p\bar{p} \rightarrow t\bar{t} + X \quad (1)$$

$$p\bar{p} \rightarrow W + X\,;\; W \rightarrow t\bar{b} \quad (2)$$

SUMMARY AND FUTURE PROSPECTS

The Tevatron Collider and CDF are enjoying a very successful run. On the basis of 2 pb^{-1} of data, we expect to see $e\mu$ events from $t\bar{t}$ decays, for top quark mass in the 30 to 60 GeV region. We observe zero candidates. Similarly, in the e + *jets* analysis, we also have not observed any signal from the top quark. We will continue to look at data shortly after they are recorded.

CDF is taking data at the rate of about 0.2 pb^{-1} per week, with a total integrated luminosity of 5 pb^{-1} expected for this run. The e + *jets* and the $e\mu$ analyses, which will be complemented by on-going analyses such as ee and μ + jets that are feasible in CDF, can soon probe the top quark with mass up to 100 GeV.

In the next run, we will have the Silicon Vertex Detector to tag the b quarks in the events, and plan to have a few times more integrated luminosity. For the following run, we hope to have major upgrades for both the accelerator and CDF. With a goal of more than 100 pb^{-1}, we hope to cover the full m_t range allowed by the Standard Model.

SCIENCE
PHYSICS

For Subatomic Searchers, Elusive Particle Is Big Matter

By Faye Flam
Special to The Washington Post

On Halloween, the object of the most expensive and laborious hunt in the history of physics may have been found under the Illinois prairie. Scientists think they might have caught a glimpse of a ghostly particle known as the top quark.

Hundreds of the world's best-trained scientists have invested 14 years hunting this elusive subatomic entity. They've spent millions of dollars on equipment. "We're getting frustrated," said physicist Steve Errede of Fermi National Laboratory. "We have a score to settle with the top quark."

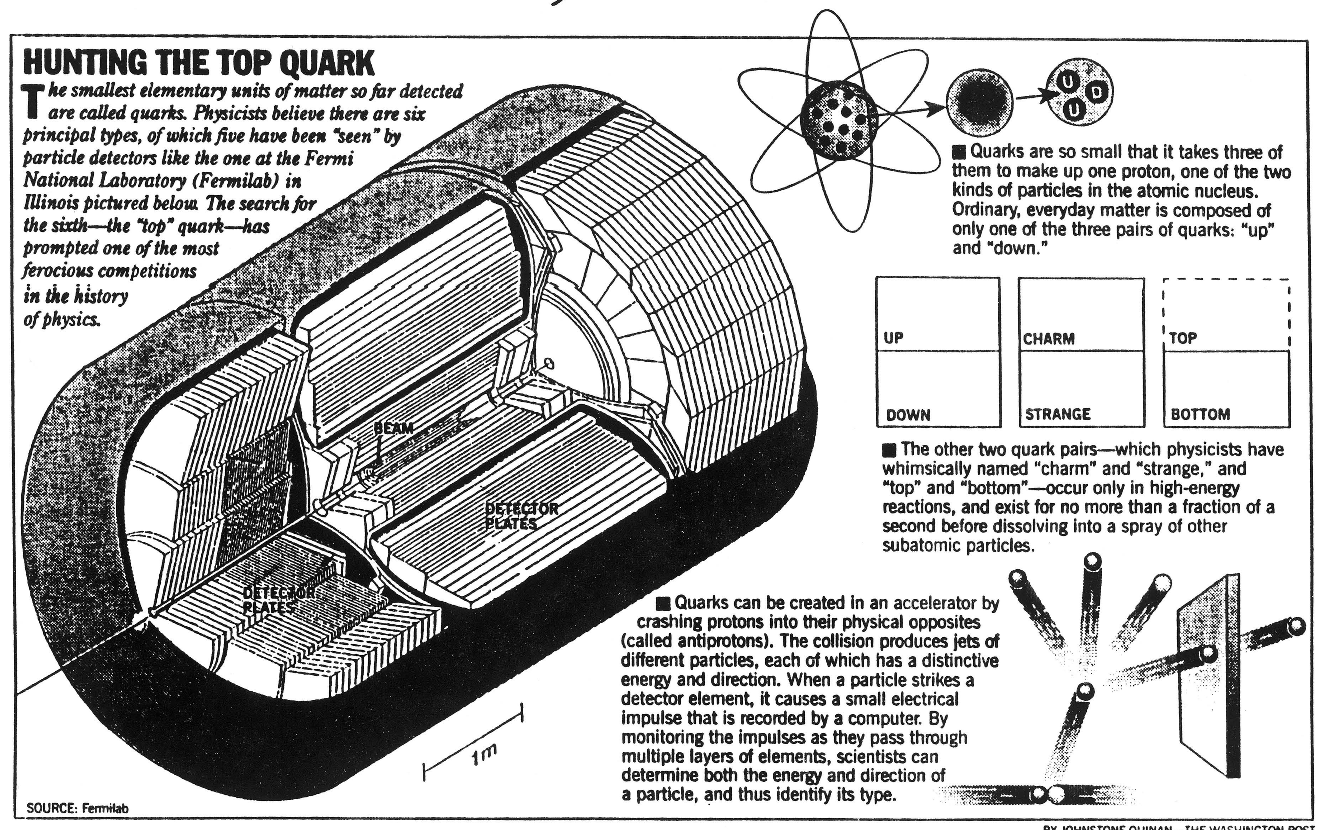
In general, modern science recognizes only 12 fundamentally irreducible components of matter: Six kinds of leptons (a group that includes electrons and their lightweight kin); and six kinds of quarks, the elementary particles that make up heavy nuclear objects such as protons and neutrons. Of this essential dozen, 11 have been experimentally confirmed. Only the top quark remains unsighted, making it the Big Casino for researchers in particle physics.

So excitement was high when a detector at Fermilab in Batavia, Ill., finally recorded what appeared to be the telltale track of the mysterious particle.

"This could very well be the top quark," said Fermilab physicist Gong Ping Yeh. But the physicists cannot be sure—yet. They want another one, and to find it they keep a constant vigil. They trade off restless shifts in their control room, sipping coffee and peering at a console of 40 screens as if they were tracking a NASA mission.

Instead, they are monitoring events in a four-mile-long circular tunnel a few feet below them, where beams of particles traveling at 99 percent of the speed of light crash and destroy each other in a subatomic demolition derby. The debris from those collisions creates lots of new particles, including the wily quarks.

Unfortunately, the vast majority of collisions do not make top quarks. In the hope of getting one, the researchers have to keep smashing particles thousands of times each second. They have achieved a trillion hits since they started in May, said Fermilab physicist John Huth. But to a top quark searcher, "only one in a trillion is interesting."



BY JOHNSTONE QUINAN—THE WASHINGTON POST

Rush of Competition

Nonetheless, the hunters have to hurry. They are racing against another group at Fermilab that is using a detector at the other side of the tunnel. "Of course, we want to win," Yeh said. The physicists at Fermilab already knocked out a European competitor at a facility called CERN near Geneva. But now the Europeans are designing a bigger particle smasher called the Large Hadron Collider that they plan to start up by the end of the decade.

But if the top pops up anywhere in the next few years, it will be at Fermilab, where an accelerator known as the "Tevatron" makes beams of energy denser than anything since the Big Bang. Here, they accelerate protons (former hydrogen atoms with their electrons stripped off) and smash them against their antimatter counterparts, antiprotons. The crash makes a lump of pure energy just a thousandth of a billionth of a meter across.

At that scale, energy can turn into mass, as Einstein's famous equation $E=mc^2$ indicates. The more powerful the accelerator, the higher the collision energy, and the more massive a particle can result when that energy is converted into mass.

That is one reason that the top quark has remained undetected. As such particles go, it's a whopper—perhaps a hundred times heavier than the common "up" and "down" types. Until recently, there was not an accelerator powerful enough to provide that much energy.

"It's like two Volkswagens crashing together to create a Mack truck," said physicist Tony Liss of the University of Illinois. Most of the mass comes from the motion of the speeding Volkswagens.

In theory, the top quark should immediately decay into a predictable number of other kinds of particles, which is what the Fermilab scientists saw.

The event of Oct. 31 happened inside the detector they call CDF (Collider Detector Facility), a 2,000-ton arrangement of sensitive materials: special plastics, gas-filled chambers, silicon. As the whole collision-produced pack of particles—some heavy, some light—spray out, magnets in the detector bend them in different paths depending on their mass and electric charge. Each kind of particle (or its products) has a distinctive trajectory and energy level; and the detector has sufficient sensors to record both, allowing researchers to identify each kind.

On Halloween, an electron left a charged trail in a chamber filled with ethane and argon gas. A heavy cousin of the electron known as a muon plunged through two feet of steel before leaving a trail in another chamber. And two other types of quarks instantly burst into "jets" of assorted particles that send ripples of electric charge through strips of silicon.

Those four trails make up one of the few signatures of the top quark.

In the detector, the electric charges in the trails travel to wires that relay an image of the track to a computer, set to filter out all but the one signal in 10,000 that looks interesting.

Of the thousands of particles raining into the detectors, this array was spotted quickly. "The electronics flagged this one as ultra-interesting," Huth said. "Then it went to one of our scientists, who noticed it was a good candidate." Soon, members of the group started dissecting it. But there were problems.

"The muon signal was suspicious," Yeh said. Such a particle should have registered in two special "muon chambers," but it struck just the outermost one. The physicists say the muon slipped through a "crack" that separates components in the inner chamber. So they cannot be sure it was really a muon.

That ambiguity forces the physicists into a tense dilemma. They can announce a discovery and risk being wrong and ridiculed. Or they can hold out for more events and risk being scooped by competitors on the other detector. "The worst thing you can do for your reputation is to claim there's something new and exciting and then have it go away," said Fermilab physicist Melvin Shochet.

Already One False Alarm

Physicists had one false quark alarm already—back in the early 1980s when CERN researchers headed by Nobel laureate Carlo Rubbia announced that they had "discovered" the top quark. But the Europeans soon realized they were mistaken. One CERN researcher says that around that time he walked by a trash bin full of Scientific American articles announcing Rubbia's discovery, apparently ripped out of the magazine and discarded when CERN researchers realized Rubbia, their leader, was wrong.

Even worse than jumping the gun would be getting beaten. "Having competition can push you to announce your findings faster," Yeh said. The researchers running the CDF detector want to find it before their competitors running the other detector, known as D0. "If D0 finds it first, we would look like fools," Fermilab's Errede said. "We've been running longer. We know our detector better. If we don't get it first, it would be incredibly embarrassing."

Despite the excitement, many researchers in the field of particle physics—where employment opportunities are bleak at best—secretly hope there is no top quark. "The best thing for our field would be if it doesn't show up or it's the wrong mass," said Liss of the University of Illinois.

In theory, the top is an essential piece in the jigsaw puzzle of the subatomic world. "Without it, our theory completely breaks down," Liss said. But that would not be so bad for them. "It would be much more interesting to find there is no top quark," he said. "Our hope really is to open up new and unexpected things."