

The top in sight

On 22 April, after many months of careful analysis, the CDF collaboration at Fermilab's Tevatron proton-antiproton collider proudly submitted a 150-page paper to The Physical Review reporting evidence for the top quark. At a Fermilab seminar four days later, CDF co-spokesmen Melvyn Shochet of the University of Chicago and William Carithers of Lawrence Berkeley Laboratory described the analysis of a trillion proton-antiproton collisions which had netted a dozen candidate top events.

The top quark, the partner of the bottom quark discovered at Fermilab in 1977, is required if the Standard Model of particle interactions (see page 4) is correct. At the Tevatron, top quarks are produced in pairs. Each top quark promptly decays into a bottom quark and a W boson, the carrier of the weak nuclear force.

CDF used data collected between August 1992 and June 1993 for three top quark searches, differing in the way the W bosons and bottom quarks are observed. In each search, top candidates emerge from the background non-top processes that can mimic top decay. When the three searches are combined, the excess is statistically more significant. Although the total excess could be a rare statistical fluctuation, it is natural to interpret it as evidence of top quark production.

When interpreted this way, the top quark mass is 174 GeV, with an uncertainty of 17 GeV - the top quark is almost as heavy as an entire gold nucleus! It has yet to be explained why the top quark is far heavier than any other elementary particle yet observed.

Another Tevatron Collider run has recently started. If the accelerator can continue to run for the next 15 to

24 months, the sample of data could increase by a factor of five or more, allowing the effect to be confirmed and the mass uncertainty to be more than halved. Measuring the properties of the top quark is now a major physics priority, and for the next decade this work can only be carried out at Fermilab's Tevatron, the world's highest energy accelerator.

The search for the top quark

At Fermilab, top quarks can be created by the energy released in proton-antiproton collisions. When this happens, a top quark and its antimatter partner, the top antiquark, are released together. The top quark decays almost immediately into its quark pair partner - a bottom quark, together with a W boson, the carrier of the weak nuclear force. The W, in turn, also rapidly decays into any of the quark or lepton pairs, for example an electron and an electron-neutrino.

At a media briefing at Fermilab on 26 April, Melvyn Shochet of the University of Chicago, co-spokesman for the CDF experiment at Fermilab's Tevatron proton-antiproton collider, presents evidence for the sixth - top - quark.



Each final quark is seen as a collimated jet of particles in the detector.

The CDF experimenters searched for the top quark in three ways. In the first, events were sought in which the W bosons from both the top quark and the top antiquark decayed into lepton pairs, either electron and electron-neutrino or muon and muon-neutrino. Two such events were observed compared to the expected background of approximately one half of an event.

The other two methods searched for events in which one of the two W bosons decayed into an electron and electron-neutrino or a muon and muon-neutrino, with the other W decaying into a quark pair. The expected rate of such top events is considerably larger than in the first search mode, but there is also more background. To reduce this background, both the second and third searches identify one or more of the produced b quarks.

The second search looked for the

small flight distance a b quark travels before it decays. Six such events were observed, compared to an expected background of approximately two.

The third search looked for an electron or a muon from the decay of a b quark. Seven such events were seen, compared to three expected background events. (Three of the events seen in the third search were also caught by the second method.)

The probability that the background could fluctuate up to at least the number of events observed is one in four hundred. Although this appears very small, scientists generally need to be more confident, and more data is needed to confirm the top quark.

To exploit the different kinematic features expected in top quark and background events, an additional analysis looked for events with the expected features of top quark production. An excess of such events over background included many of the events with an identified b quark.

Seven of the events have enough information to allow the top quark mass to be calculated. Six cluster between 160 and 190 GeV, and together they give a top quark mass of 174 ± 17 GeV, close to the centre of the top mass range predicted by the Standard Model using precision data from Z boson decay at CERN and SLAC, W boson decay at the Fermilab Collider, and neutrino interactions at Fermilab and CERN.

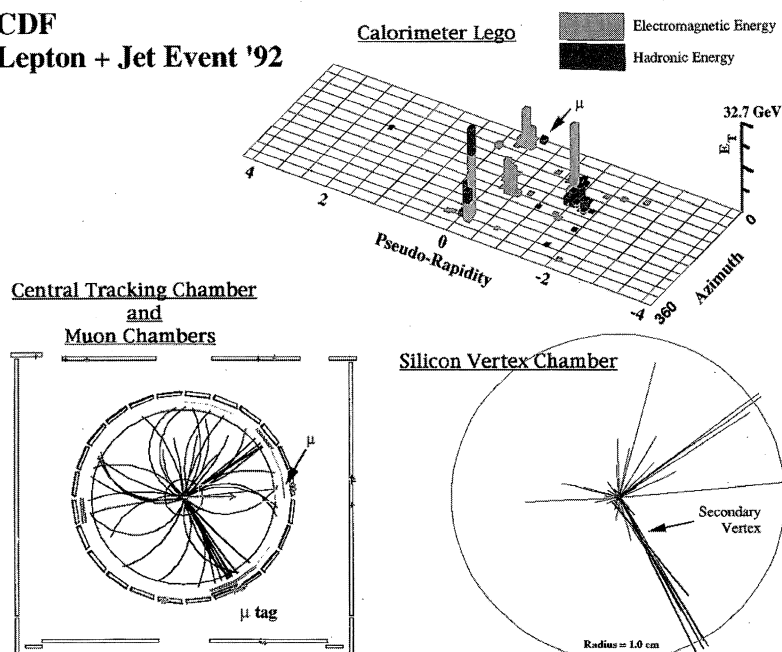
The CDF data were in hand over nine months ago and candidate top quark events were soon identified, with the candidate sample becoming stable in August. Then much of the CDF effort on the top quark search became focused on background processes that can mimic a top quark event.

It is the complexity of top quark

events that makes this background so difficult to handle. Once elementary particle discoveries could be based on a few particle tracks. The heavier the parent particles, the more offspring they can produce, and the top, the heaviest of them all, is the most prolific. In addition, a proton-antiproton collision produces other particles, as well as a top quark and a top antiquark. Each top quark then quickly decays into a bottom quark and a W boson. However these particles are also unstable and thus decay into electrons, muons, neutrinos, pions, kaons, etc. For a typical top quark event approximately 100 particles enter the CDF detector. This background was the subject of painstaking analysis and continual discussion, and the lessons learned will continue to be useful in the search for other rare particles.

Top quark candidate event display from the CDF detector at Fermilab's Tevatron. The top quark does not live long enough to be visible directly. However one of the top quarks from a quark-antiquark pair decays into a b quark which is seen to decay in the silicon vertex chamber (bottom right) close around the beam pipe, while the muon from this decay is also identified (bottom left). The calorimeter lego plot shows how the detector resolves individual jets from quark processes. Unravelling the kinematics gives a top mass of 169 ± 10 GeV.

CDF Lepton + Jet Event '92



The CDF experiment contains approximately 100,000 individual particle detectors around the proton-antiproton collision point. Most of the apparatus was constructed between 1981 and 1987 with funds provided by the US Department of Energy, the Italian Institute for Nuclear Physics (INFN), the Japanese Ministry of Science, and the US National Science Foundation. Improvements were added in 1988, 1992, and this past summer. The collaboration currently consists of over 440 physicists, including 142 graduate students from the United States, Italy, Japan, Canada, and Taiwan.

(The D0 collaboration, CDF's companion experiment at the Tevatron, has seen a few similarly interesting events but these do not emerge significantly from the background.)

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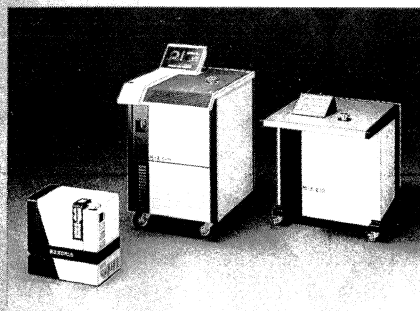
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