UA1 at CERN says it has candidates for sixth quark, top

Early in July the UA1 detector group working at the CERN proton–antiproton collider announced that they have found six candidate events suggesting the top quark. According to the standard model, quark flavors come in pairs—up and down, strange and charmed, bottom and top. The fifth quark, the bottom b, whose mass is about 5.2 GeV, was needed to explain the upsilon meson, found in 1977. But the missing sixth quark could not be found. If the mass of the top t had been less than 22 GeV, experiments at PETRA (at the DESY laboratory in Hamburg) with 22-GeV electrons colliding with 22-GeV positrons would have produced t and $\bar{t}$ from the 44-GeV center-of-mass energy available.

The UA1 candidate events indicate the top quark mass is somewhere in the range 30–50 GeV (and is essentially the same for the free top quark, not observable, or the top meson, presumably observable in a suitable experiment). The UA1 group had culled the top candidates from data collected during the $p\bar{p}$ collider run that ended 13 months ago.

The CERN proton–antiproton collider has been extremely fruitful. Last year both detector groups at the CERN collider, UA1 and UA2, reported the discovery of the charged intermediate vector boson (PHYSICS TODAY, April 1983, page 17). This spring, anomalies in the data from the run ending July 1983 were reported by both UA1 and UA2. Carlo Rubbia (CERN and Harvard), spokesman for the UA1 group, declared at the Washington meeting of The American Physical Society, that although Grand Unified Theories predict a desert, in the new energy regime being explored with the CERN collider, "the desert is blooming already."

The report on the top quark has long been awaited. The Standard Model offered very little guidance on the t mass, although over a year ago Rubbia's door at CERN had a sign posted on it, quoting a mass value for t in the vicinity of 40 GeV.

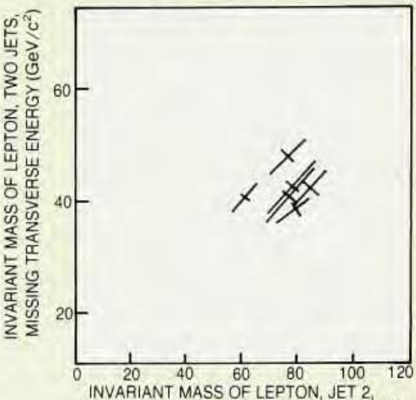
The UA1 group had seen some events over the past year or so, indicating that the W^+ was decaying into $t\bar{b}$ and that the t then decayed semileptonically into a positively charged lepton, a neutrino and a b quark. Similarly, there were some indications that a W^- was decaying into $\bar{t}b$ and then that $\bar{t}$ decayed into a negatively charged lepton, a neutrino and a $\bar{b}$ quark. The heart of the problem was to establish the identity of the lepton above background processes. When the electron channel was examined, five candidate events were found; then the muon channel was analyzed. UA1 reported on their top evidence at two June meetings, first a conference in Lund, then the Neutrinos '84 conference in Dortmund, each time making a somewhat stronger claim.

At a CERN seminar on 3 July, Michel Della Negra (CERN and Annecy) of the UA1 group presented six candidate events indicating the top quark. Although other possible top candidate events have been found, these six are the cleanest sample, and consist of three events with an electron and three with a muon. The group looked for

$$W^+ \to t + \bar{b}$$
$$\bar{b} \to \text{jet}$$
$$t \to l^+ + \nu + b$$
$$b \to \text{jet}$$

so that the signature is an electron (or muon), two (and only two) jets, and missing momentum.

UA1 showed a scatter plot in which one axis is the invariant mass computed from jet 1, jet 2, and the missing transverse energy (from the neutrino). The distribution of the six events consists of one at 60–70 GeV, four at 70–80 GeV and one at 80–90 GeV. From this distribution the group infers that these were W (mass of about 81 GeV) decays. The other axis of the scatter plot contains the invariant mass computed from the lepton, jet 2 (the lower-energy jet), and missing transverse energy (from the neutrino). The distribution on this axis contains one event at 35–40 GeV, four at 40–45 GeV, and one at 45–50 GeV. To obtain these events, energy cuts on the jets and leptons required



Evidence for top quark from UA1 group assumes the W decays into $t\bar{b}$, that the $\bar{b}$ produces jet 1, and that t decays into a lepton, a neutrino and a b, which decays into jet 2. The peak at 70–80 GeV suggests W decay and the peak at 40–45 GeV suggests top decay. From the six events shown, UA1 obtains a top mass range 30–50 GeV.

that the transverse energy in the jet be greater than 7 GeV, and that the lepton rse momentum be greater than 12 GeV/c; additional cuts were made to reduce background.

For the three muon events, the expected background is 0.25 events, and for the three electron events, 0.1 events. The major background for electron events, according to UA1 Wisconsin group member David Cline, is that a charged particle and a neutral might mimic an electron. For the muon events, although a muon can be identified quite readily, there is a small probability it might have started life as a charged pion or kaon.

The keystone to the top report, according to Cline, is the strong peak at 70–80 GeV (suggesting W decay), and the strong peak at 40–45 GeV (suggesting top decay), both peaks standing out above background. For the first time, as far as Cline knows, jets are being used in invariant-mass calculations to observe a new particle. UA1 measures the total energy of a jet through calorimetry, and then treats the jet as if it were just a single particle, a single four-vector, in the mass calculation. This

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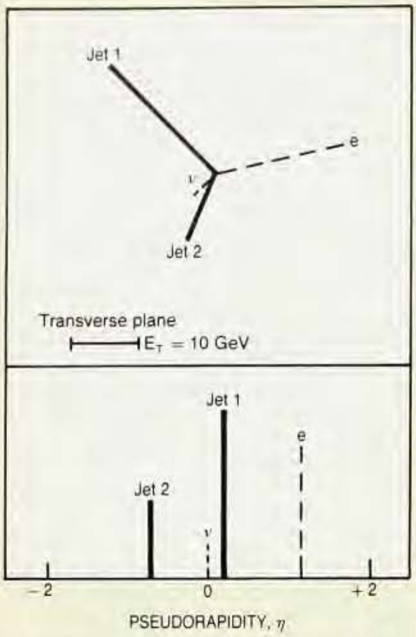

One of the six top candidate events. Top sketch gives transverse momentum of electron, neutrino, jets 1 and 2 in a plane perpendicular to the beam direction. Plot below gives pseudorapidity (a measure of the angle with respect to the $\bar{p}$ beam) of electron, neutrino, jets 1 and 2. Total invariant mass of electron, neutrino, jets 1 and 2 is 76 ± 7 GeV/c^2 and total invariant mass of electron, neutrino and jet 2 is 48 ± 7 GeV/c^2.

simplification appears to pay off, he said, but it's a "novel technique that people aren't comfortable with." For the next generation of hadron colliders, such as the Superconducting Super Collider, with 20 TeV/beam instead of the 270 GeV/beam available last year with the CERN collider, Cline feels such jet analysis will be needed to discover new particles.

Assuming the top quark mass is indeed between 30 and 50 GeV, one can estimate the number of events expected; this number, three, is to be compared to the 6 ± 2.4 events the UA1 group has reported.

Anomalous events. Last fall both the UA1 and UA2 groups reported that among the Z^0 events, there were some in which the Z^0 decays into a single photon and a lepton pair, a decay considered highly unlikely. The new anomalous events reported this spring and summer by the UA1 and UA2 groups don't all appear to be the same phenomenon. At the Washington APS meeting, Jean Marc Gaillard (Orsay) described[1] the UA2 anomalies. The group found three or possibly four events that looked like a W decaying into an electron, a neutrino and extremely energetic jets. Gaillard said there are also preliminary indications of excess events in the mass distributions around 150 GeV.

At the same APS meeting, Rubbia quoted Valentine Telegdi (ETHZ): "Yesterday's sensation is today's calibration and tomorrow's background." He said that UA1 found five events in which a missing transverse energy larger than 40 GeV is associated with a narrow jet. Thus the anomalous events reported[2] by UA1, known as "monojets," could be characterized, Rubbia said, "as a very energetic photon or jet on one side, and essentially nothing on the other side—50, 70 or 80 GeV just disappears."

Rubbia described another anomaly at the APS meeting: when $Z^0 \to e^+e^-$ or $\mu^+\mu^-$, the UA1 group finds that an unexpectedly large number of such decays are associated with two or more jets. "The Standard Model doesn't permit that," he said.

Rubbia feels the anomalies are analogous to the discovery of strange particles, "We're talking about new physical processes! No one mass value shows up. It's too new. Now we'll try to pinpoint it."

Next month, after its 14-month shutdown, the CERN $p\bar{p}$ collider starts operating again and will run for several months. CERN hopes to raise the energy from 270 to 320 GeV/beam and increase the luminosity. Both UA1 and UA2 will be operating with improved detectors, hoping to gain further information on the top quark and the anomalies, and to search for the Higgs boson. —GBL

References

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IRAS exposes a remarkable infrared galaxy

The visible image of Arp220 was just interesting enough to warrant its inclusion in Halton Arp's 1966 *Atlas of Peculiar Galaxies*. But only now are we beginning to see how very peculiar this galaxy really is. While it ranks behind about 10 000 other known galaxies in visible brightness, the recent Infrared Astronomy Satellite (IRAS) survey has shown Arp220 to be one of the ten brightest extragalactic infrared sources in the sky. Almost 99% of its total energy output is in the infrared. From the red shift of its visible line spectrum one deduces a distance of about 100Mpc (300 million light years). At this distance its observed infrared brightness implies a total luminosity of 2×10^{12} times that of the Sun. This astonishing luminosity, a hundred times that of normal galaxies like our own, is exceeded only by the most luminous quasars. Quasars, however, emit strongly at visible and shorter wavelengths.

The 57-cm IRAS infrared telescope was launched into orbit in January 1983 (see PHYSICS TODAY, May, page 17). If the uniqueness of Arp220 had been appreciated before IRAS ran out of its superfluid-helium coolant 10 months later, one might telemetrically have ordered a special detailed scan of this unprepossessing 14th (visible) magnitude galaxy near Arcturus in the summer night sky. But in fact Arp220 did not come to special attention until last January, after IRAS had ceased to function, when Thomas Soifer (Caltech) of the IRAS team was taking a closer look at the data base of the 500 brightest far-infrared point sources found in the IRAS extragalactic survey. He was astonished to discover that one of the very brightest of these corresponded to the very faint optically identified galaxy Arp220.

Soifer and his colleagues now believe that ARP220 is not really unique among the infrared sources discovered by IRAS. They have come to regard it as the closest, and therefore the prototypical example, of a new class of extremely luminous galaxies characterized by the puzzling fact that they radiate overwhelmingly in the infrared. The other observed galaxies of this class, they believe, are so much further away that they are not clearly discernible in the definitive Palomar optical sky survey.

These more distant cousins of Arp220 may well be found among the nine "blank-field sources" identified[1] last September by James Houck (Cornell), Soifer and their IRAS colleagues. Among the bright, presumably extragalactic, infrared sources discovered in the IRAS all-sky survey, Houck and company found nine for which the Palomar Observatory Sky Survey catalog showed no corresponding visible galaxy—just a blank field or a very faint image in the patch of sky delineated by the error bars of the IRAS-measured position of the infrared source. The Palomar catalog, the deepest and most comprehensive optical survey of the northern sky, is reliable for sources brighter than magnitude 18.5.

At the June meeting of the American Astronomical Society in Baltimore, Soifer[2] pointed out that if Arp220 were