Getting up to Standard Jargon

THE Standard Model comes equipped with a Standard Jargon. Despite appearances, this jargon was not expressly designed to bewilder and intimidate the uninitiated. A crash mini-course in remedial jargon follows.

The Standard Model has two components. One is a theory of the strong interaction, called quantum chromodynamics or QCD. The strong interaction is traditionally said to be the interaction responsible for nuclear forces. That is true, but a more modern point of view is that QCD is a theory of interactions among quarks and gluons (out of which atomic nuclei are made). The other component is a theory that gives a unified description of weak and electromagnetic interactions — mercifully this has no special name, and is called simply electroweak theory.

The physical concepts used in the Standard Model are generalizations of concepts familiar in electrodynamics. The quarks and gluons are said to be 'coloured' in various combinations of red, white and blue. What this means is that they carry three distinct types of charge designated by those chromatic names. In electrodynamics, the ordinary photon responds to electric charge. In quantum chromodynamics, the various gluons (there are eight of them) respond to colour charges. An interesting and very important new feature of QCD, as compared with electrodynamics, is that the gluons themselves carry colour charges, unlike the photon which is electrically neutral. Although the equations of quantum chromodynamics are very similar to those of quantum electrodynamics, because of this new feature they are much more difficult to solve and lead to very different physical behaviours.

While gluons are analogues of photons, quarks are analogues of electrons. They carry not only colour charges but also ordinary electric charge. A crude but not entirely wrong model of a proton is that it consists of three quarks held together by constant exchange of gluons.

In the accompanying article you will also come upon the phrase "vector bosons similar to the Z boson, but heavier". The Z boson is a particle mathematically very similar to the photon, but differing in two crucial respects. First, it is massive (the photon has no mass), weighing close to a hundred times as much as a proton. This drastically affects its physical properties, making the Z boson unstable and rendering the forces it mediates very short-range. Second, it responds to an abstract charge that is not the same as electric charge or any colour charge. First observed directly in the early 1980s, the Z boson is an important ingredient in the electroweak sector of the Standard Model. F. W.

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consider this option only under extreme duress. Much more palatable is the possibility of leaving the core of QCD intact, while adding some extra interactions to account for phenomena that don't fit.

One possibility is that the quarks have some sort of super-strong interaction in addition to the strong interaction described by QCD. If all the particles mediating this interaction were heavy, then their influence, although ultimately dominant, would only become visible at high energy — a pattern broadly consistent with the CDF observations. Unfortunately there are no good reasons to welcome such an interaction, and considerable reasons to fear it, for it would tend to render coincidental the marvellous unification of forces[3] that occurs in simple extensions of the Standard Model.

Another widely anticipated possibility is the existence of new vector bosons similar to the Z boson, but heavier. If such Z′ bosons were actually being produced in the CDF experiment, they should decay into pairs of jets whose total effective mass would be the Z′ mass. The observations, however, do not indicate the existence of such a favoured effective mass for jet pairs. This is not the end of the story, though, because the exchange of virtual Z′ bosons could affect the probability of producing high energy jets, even at energies insufficient to produce the bosons themselves.

An extra incentive to consider such possibilities comes from the existence of another small but long-standing discrepancy between the Standard Model and experiment. The rate of Z decay into bottom–antibottom quark pairs appears to be a few per cent higher, and into charm–anticharm pairs a few per cent lower, than the electroweak component of the Standard Model predicts[4]. A Z′ boson, if it existed, could mix with the conventional Z boson and alter its properties. It is possible to find combinations of parameters[5,6] such that both of these electroweak anomalies are accommodated, together with the QCD anomaly found by CDF. There is, however, a weighty theoretical objection to this line of thought. In order to generate an effect as large as that claimed by CDF, the interaction strengths of the Z′ must be quite large. When extrapolated to only slightly higher energies, they actually go to infinity, presumably indicating that the theory is not self-consistent.

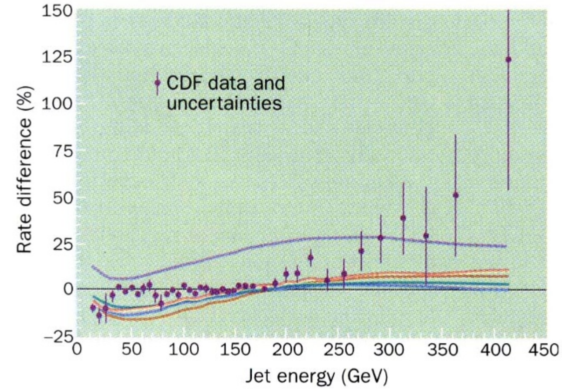

FIG. 2 The relative discrepancy between QCD theory and experiment reported by the CDF group. The experimental values are compared with a number of different calculations of QCD (each using different assumptions about how quarks and gluons behave inside protons) and normalized to one particular calculation. (Adapted from ref. 1.)

Another widely anticipated and extremely attractive possibility is the existence of a whole new world of particles, superpartners of the known particles, a realization of the idea of supersymmetry (ref. 7 and references therein). Again, if CDF were actually producing the superpartners, one would expect to see effects that are not seen — in this case, a gross enhancement in the number of jets and momentum imbalances due to the escape of unobserved neutral particles. So one must appeal, as for the Z′ boson, to interference effects from virtual particles. Unfortunately, despite the abundance of new particles, explicit calculation shows that the effect of supersymmetry below production threshold is too small to explain the CDF observations[8].

So no ready explanation appears compelling. If the CDF phenomenon really does represent fundamentally new physics, it probably takes a form not yet widely contemplated. ☐

Frank Wilczek is in the School of Natural Sciences, Institute for Advanced Study, Olden Lane, Princeton, New Jersey 08540, USA.

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