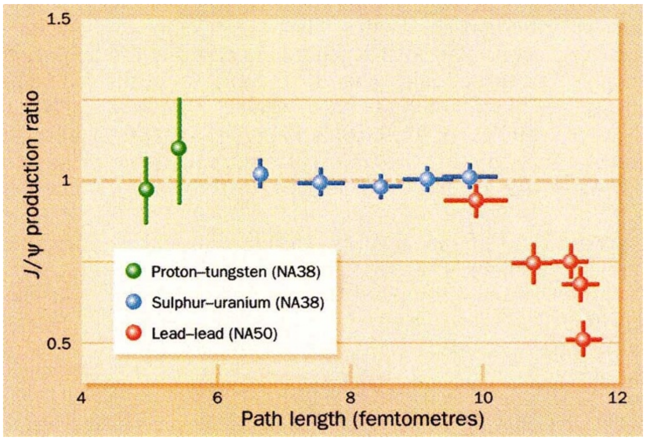
PARTICLE PHYSICS

Beauty stays as charm wilts

David J. Miller

SOME said, before last month's Warsaw meeting*, that 1996 would be the year we began to believe in the theory of supersymmetry. Instead, results from around the world have given even more comprehensive support to the Standard Model, with its three families of quarks and leptons interacting via the electroweak and quantum-chromodynamic forces. As a description of the available laboratory facts (see D. J. Miller *Nature* **349,** 379–387; 1991) the Standard Model is almost all we need, although many of its features remain arbitrary and it ignores gravity completely.



Ratio of observed J/ψ production rate to the rate calculated assuming no quark–gluon plasma formation. The NA50 experiment claims to have reached a high enough energy density to form a quark–gluon plasma which 'dissolves' the J/ψ particles: as the path length through nuclear material increases, fewer particles emerge.

Last spring there were signs from CERN and Stanford that Z^0 bosons were decaying into pairs of beauty (equivalently, bottom) quarks at a significantly higher rate than the Standard Model predicted. But a number of the experimenters have now re-analysed their data, and Alain Blondel (Ecole Polytechnique, Paris) reported a new world average in good agreement with the predictions. An updated fit to the parameters of electroweak theory now needs only one free parameter, the mass of the Higgs boson. The top quark mass is measured at Fermilab to be 175 ± 6 GeV c^{-2}, very close to the prediction from a similar fit made just before top was discovered, which then had two free parameters, the top and Higgs masses. The fit now requires the Higgs mass to be less than 680 GeV c^{-2} with 95% confidence. This is well within the reach of CERN's next approved machine, the Large Hadron Collider.

This is all very reassuring for the Standard Model, but the properties of neutrinos undermine any illusion that we know the whole story. There are now three distinct sets of evidence that neutrinos of any one species — electron, muon or tau — might transform and oscillate back and forth into one or both of the other two species in flight. The first set comes from the LSND collaboration (H. White, Los Alamos). Their neutrino beam has more muon neutrinos than electron neutrinos, but they see more electron-like events in their detector than they expect.

The second comes from experiments that look for solar neutrinos with energies of a few electron volts: they see too few electron neutrino interactions. Yoshioki Suzuki (Univ. Tokyo) reported the first data from the Superkamiokande detector in Japan, which contains 50,000 tonnes of ultra-pure water viewed by an array of photomultiplier tubes. One month with the new detector has produced as many events as the preceding few years with the old Kamiokande experiment, and confirms that they see only 42% of the event rate predicted by the 'Standard Solar Model' (J. N. Bahcall, *Neutrino Astrophysics,* Cambridge Univ. Press; 1989). If the shortfall in the Kamiokande events is compared with the shortfalls observed using a chlorine target (in the Homestake mine) and gallium targets (the SAGE and GALLEX collaborations), there is no consistent explanation that does not involve neutrino oscillations.

The third set of evidence comes from neutrinos of about 1 GeV, which come from cosmic ray interactions in the atmosphere. Too many electron-like events are seen, compared with muon-like events.

Vladimir Smirnov (Moscow State Univ.) described a range of ingenious models that can accommodate any or all of these three sets of results by invoking at least two possible new effects, each of which goes far beyond the Standard Model. One of them, a sterile neutrino (which does not even interact by the electroweak force, only by gravity), gives an extra degree of freedom to the oscillation between species. The other involves rapid resonant oscillations between the species when they pass through matter of the right density and/or magnetization, which would be very important in supernovae and in other high-energy astrophysical systems, as well as in the Sun.

The first clear evidence for a spectacular new QCD effect came from an experiment at CERN called NA50, in which a high-energy beam of lead nuclei hit a lead target — so more than 400 nucleons (protons and neutrons) are involved in each collision (P. Petiau, Ecole Polytechnique). QCD is the hardest part of the Standard Model to check, because the forces carried by gluons between the quarks are so much stronger than either electromagnetism or the weak interaction. As the interaction energy increases, the QCD force gets weaker. In high-energy collisions between nuclei, the energy density (effectively the local temperature) in the central region rises above 250 MeV per cubic femtometre, and a phase-change is predicted in which hadronic matter, with the quarks confined, changes into a quark–gluon plasma where the quarks move freely throughout the high-temperature zone.

The signature of the formation of plasma in NA50 is a sharp reduction in the observed number of decays of J/ψ particles for events where the collision between the nuclei is most violent. The J/ψ is a compact bound state of a charmed quark and a charmed antiquark, both of them heavy and hard to produce. If they come from the same point in a single proton–proton interaction there is a good chance they will stick together to make a J/ψ, but if they then have to travel through femtometres of quark–gluon plasma they are expected to drift apart. The J/ψ will effectively 'dissolve' in the plasma, as the new experiment claims to see.

QCD is hard to test whenever its coupling is strong, but because it gets weaker at high energies, simple, perturbative calculations can be made to predict the properties of hadron jets produced in all kinds of collider at tens or hundreds of GeV. An impressive range of data all fit the theory with a single value for the strength of the quark–gluon interaction (M. Schmelling, Univ. Heidelberg).

But there are still loose ends, especially when the structure of the proton (or of the photon) is probed very deeply. Experiments at HERA show that low-energy gluons inside the proton are much more numerous than had been expected by most theorists (H. Abramowicz, Univ. Tel Aviv), and extra gluons may also be needed at the highest energies, to explain the number of very high-energy jets seen in the CDF experiment at Fermilab (R. Brock, Univ. Michigan). □

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