MEETING BRIEFS

Physicists Polish One Model While Looking to the Next

BRUSSELS, BELGIUM—High-energy physicists' current explanation for the behavior of subatomic particles and forces, known as the Standard Model, is doing just fine. That was the take-home message for the 800 delegates who gathered here from 27 July to 2 August for the International Europhysics Conference on High-Energy Physics. "Mainly this was a conference of consolidation, steady progress, many very beautiful and detailed results," Christopher Llewellyn Smith, director general of CERN, the European particle physics laboratory, told *Science*. But while a multitude of presentations described ever more accurate tests and confirmations of the model, physicists also discussed hints that a whole new range of phenomena beyond the Standard Model is lurking just above the energies of current accelerators—and within range of the next generation of experiments.

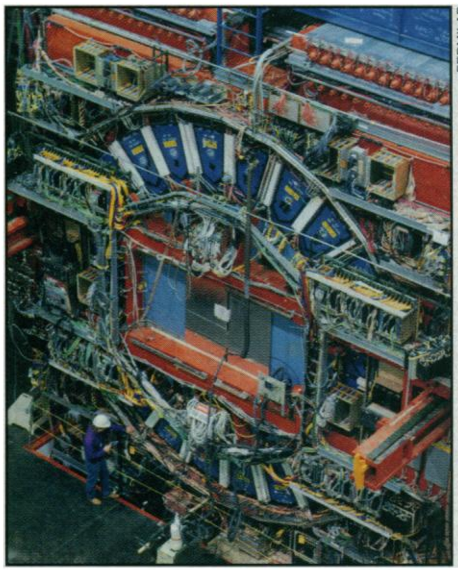
Tuning Up the Standard Model

The last major missing piece of the Standard Model, the reigning theory of particles and forces, fell into place earlier this year, with the confirmation of the discovery of the top quark. The top quark, a massive cousin to the quark varieties that make up the protons and neutrons of ordinary matter, is now at the center of an effort to burnish the model, says Christopher Llewellyn Smith, director general of CERN. The meeting, he says, "saw very high-precision measurements from our laboratory and others, many different ways of indirectly getting the top-quark mass—and all agreeing. This is a fantastic success for the model."

These indirect methods of finding the top-quark mass, which usually involve precision measurements of the masses of other related particles, also agree with direct measurements of the top quark's mass made by the CDF and D0 detector collaborations at the Fermi National Accelerator Laboratory near Chicago, which confirmed the quark's existence in March (*Science*, 10 March, p. 1423). "The data on the top are solidifying," says David Wark of Oxford University. The goal of most of these experimenters, however, is not so much to perfect the Standard Model as to expose any cracks in it. "In a few years," says Wark, "the top mass will be an input to the calculations, rather than a free parameter you have to adjust with respect to, and that will raise our ability to strongly test the Standard Model."

Those tests, and the cracks they reveal, could open the way to more complete and coherent theories of particles and forces. Llewellyn Smith expects that such anomalies will appear in the next generation of accelerators, such as CERN's Large Hadron Collider (LHC), which will attain energies of more than a teraelectron volt (1 TeV) when it is completed in about 2004. "There are very good reasons to think that ... something is going to happen. We can calculate that around 1 TeV the Standard Model starts to give nonsensical answers: probabilities greater than 1, things like that."

One test in which the top-quark mass will play a role, says Bernard de Wit of Utrecht University in the Netherlands, is the search for the Higgs boson, the only particle predicted by the Standard Model that has yet to be observed. By taking the mass of the top quark into account, he says, "we can put more constraints on the values of the parameters of the standard model. This narrows down the area where we will be able to find the Higgs mass."



FERMILAB

Polishing equipment. The discovery of the top quark by groups working at two detectors at Fermilab, D0 and CDF *(shown)*, filled a gap in the standard picture of particles and forces.

The Higgs boson is thought to explain why other particles have mass, and its own mass is predicted by the Standard Model to be between 130 gigaelectron volts (GeV) and 600 GeV. "If it is in this window, then it verifies completely the Standard Model," says de Wit. "If we do not find it in this window, but at a lower energy, then it is even more interesting. We then get a first glimpse of the structure beyond the Standard Model: supersymmetry."

Many believe that the theory of supersymmetry will ultimately supply a better framework than the Standard Model for understanding the physics of particles. One of its main predictions is that each fundamental particle described by the current framework has a very massive supersymmetric partner, collectively known as "sparticles." If the Higgs boson turns out to be less massive than predicted, supersymmetry becomes a more viable proposition, and researchers may then actively start looking for sparticles. De Wit believes that it will be possible to spot a light Higgs boson or even sparticles before the LHC is completed, when CERN's LEP accelerator is upgraded later this year, increasing its collision energy from 93 GeV to about 190 GeV. "We got the feeling in this conference that the discovery of such particles is not so far off anymore," says de Wit.

The Standard Model might also falter at the so-called B-factories currently being planned or under construction at laboratories such as the Stanford Linear Accelerator Center (SLAC), DESY in Hamburg, and CERN, Llewellyn Smith noted. These machines are designed to study a phenomenon that may expose holes in the Standard Model: CP violation. In collisions, the Standard Model dictates that certain attributes of the particles involved must be conserved. But in events that exhibit CP violation, two of those attributes (charge conjugation and parity) are not conserved. The Standard Model allows small amounts of CP violation, but by studying the decay of B-mesons (quark-antiquark pairs containing bottom quarks), the B-factories will search for CP violation in amounts not predicted by the model. "CP violation may be the Achilles' heel of the Standard Model," says Llewellyn Smith.

Tools of the Trade

The flip side of the esoteric quest to push the limits of the Standard Model is the very down-to-earth problem of how to detect and record events in future particle accelerators, which will collide far more particles, with greater violence, than ever before. CERN's Large Hadron Collider (LHC), for example, which is due to come on line in about a decade, "is the most difficult environment for experiments that we have ever had to confront," says SLAC Director Burton Richter. At the Brussels meeting, he and his colleagues described how detector designers are trying to adapt to that harsh environment.

One challenge they face comes from the

high luminosity of the LHC beam, which will be packed with particles to increase the chances of a collision. In the process, it will create a very high radiation level around the collision area. It will be "a challenge to the experimenters," says Richter, to produce equipment that can survive in these conditions. One idea for building radiation-hard detectors is to use diamond instead of silicon, but no one has yet synthesized chunks of diamond big enough for the job. All of the electronics near the collision area will also have to be radiation-proof.

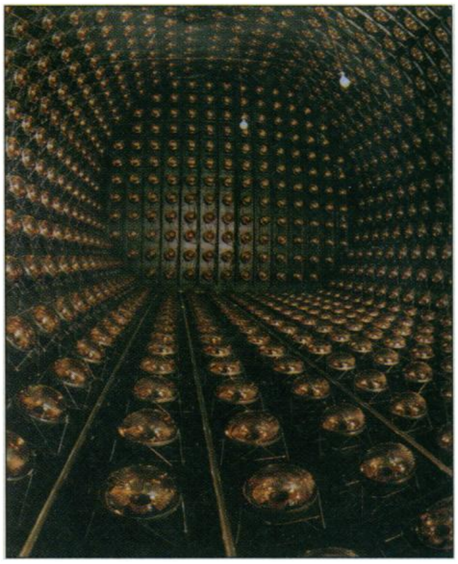
An even bigger challenge for LHC engineers will be sorting rare discoveries from the torrent of events at the collision point. "We are talking at LHC about an event rate of a gigahertz: 10^9 physics events per second," says CERN's Llewellyn Smith. Meanwhile, one possible signature of the long-sought Higgs boson would appear only once every 10^{14} events. "Identifying one event in 10^{14} and being sure that it is not a glitch, something wrong in the detector or background, is very very difficult stuff," says Llewellyn Smith. For the computer power that will be needed, CERN is trusting in the computer industry to keep pushing the limits. "The computing will have to align itself with the historical growth of the field, and I assume that will happen," adds Llewellyn Smith.

When it comes to electronics, the problem is more cost than technology. "The electronics is there, but expensive," says Llewellyn Smith. A large detector for the LHC will have hundreds of thousands of output channels, built from state-of-the-art components. To lower costs, says Richter, "I believe that we are going to have to adopt the mass-production techniques of the chip industry for the electronics." The same goes for mechanical components, he adds. Designers will have to imitate "the mass production techniques of the auto industry for components like tubes, chambers, and so forth," says Richter. "We have to get into advanced manufacturing as well as advanced electronics."

Neutrinos: No Easy Answers

The shiest species in the particle zoo, the neutrino, has been the subject of some major experimental results over the past year. But as physicists reported at the conference, those results have only underscored the nearly 30-year-old mystery that surrounds these phantomlike particles: Why don't nuclear reactions in the sun seem to produce as many neutrinos as theorists predict?

The problem might have been dispelled, or at least reduced, if a test of neutrino detectors completed this year had shown that they are miscounting these particles. But the detectors seem to be working as advertised. January brought the prospect of a different solution, when a group of researchers at Los Alamos National Laboratory reported hints that neutrinos can change their identity on their way to Earth, making them undetectable (*Science*, 10 February, p. 789). But with a few months' hindsight, physicists at the Brussels conference said they remain unconvinced by the Los Alamos evidence.



FRED RICK/LANL

Putting flesh on a phantom. This Los Alamos detector yielded hints that neutrinos may have mass, contrary to Standard Model predictions.

And that leaves neutrino researchers still confronting the problem first reported in 1967, when Raymond Davis, then at Brookhaven National Laboratory in New York, started counting neutrinos with a detector set deep underground, away from background radiation, in the Homestake Gold Mine in South Dakota. Davis reported detecting only about a third as many neutrinos as theories of the nuclear processes in the sun predict—a result that has since been confirmed by other detectors.

Solar physicists have looked hard at their models of the sun for any way around the problem, but the deficit is so great that they have been unable to explain it away by tweaking their theories. Another possible explanation is that there is a systematic error in the detectors. At the end of last year, the GALLEX neutrino detector in the Gran Sasso Tunnel in the Italian Apennines completed a unique test to see if it was detecting all the neutrinos it should. Researchers placed an artificial neutrino source of known intensity, a lump of chromium-51, in the detector. The experiment showed that it operated with a maximum error of 10% (*Science*, 10 February, p. 788), much less than the neutrino deficit—a finding confirmed in a reanalysis of the test data presented at the Brussels conference by Daniel Vignaud of France's atomic energy agency, the CEA, and his colleagues.

If the problem does not lie in the sun or in the detectors, something must be happening to the neutrinos en route between the two. The explanation currently favored by particle physicists is that the neutrinos change type on their journey from the sun, a process called "neutrino oscillation." Physicists believe there are three types, or "flavors," of neutrinos: electron-type, muon-type, and tau-type. The sun produces electron-type neutrinos, which during their travel to Earth might change into muon or tau neutrinos—types that cannot be detected by the solar neutrino detectors currently in use. For neutrinos to oscillate, however, theorists insist that they must have mass, and neutrino mass is forbidden by the Standard Model. That gives physicists a double motivation to look for evidence of neutrino oscillation, as it could not only solve the solar neutrino problem but also give a glimpse of physics beyond the Standard Model.

The Los Alamos group tantalized the neutrino community earlier this year when it announced hints that neutrinos can change their identity in a 30-meter journey from a source to a detector. However, particle physicists at the Brussels meeting expressed some doubt about the Los Alamos results because of the small number of events and the limitations of the detector. "When it was first presented, we only heard the high points. ... You get a different picture of an experiment than when you see the whole thing," says Oxford's Wark. "The results are interesting, but one could not consider it as demonstrating neutrino oscillations at this point."

Group member David Caldwell of the University of California, Santa Barbara, agrees that the evidence is far from conclusive. "The events are of the type neutrino oscillations would produce, but we are not yet claiming that oscillations exist." The Los Alamos group has just submitted a new analysis of the data to *Physical Review Letters*, and on 1 August it began a new experimental run, which will go on until November. KARMEN, a similar experiment at Britain's Rutherford Appleton Laboratory, is now taking more data, which may help resolve the question, Wark says.

Meanwhile, other researchers are still looking to the sun for an answer by building ever more sensitive detectors, two of which should be up and running next year. The Superkamiokande detector in Japan will have a 30-fold increase in sensitivity over its predecessor, called Kamiokande, while the Sudbury Neutrino Observatory in Canada will be able to detect muon and tau neutrinos, thereby testing the neutrino oscillation hypothesis. "It is a very pregnant field," says CERN's Llewellyn Smith. "Two or three years from now we will have some answers to these questions about neutrinos."

–Alexander Hellemans

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