MEETING APS DIVISION OF NUCLEAR PHYSICS

Elusive Particles Yield Long-Held Secrets

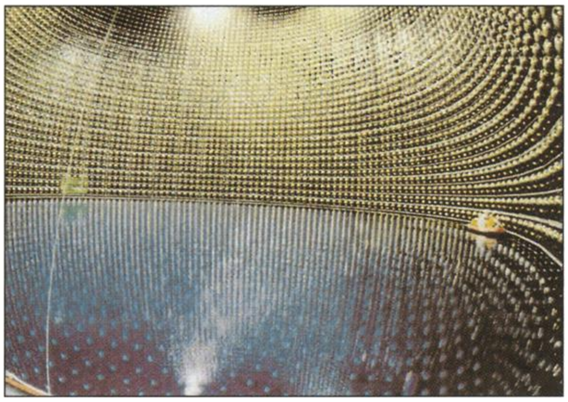
WAILEA, HAWAII—At a lush resort on the west coast of the island of Maui, Japanese and American physicists discussed the latest news in nuclear physics. At the first joint meeting of the nuclear physics divisions of the Japanese Physical Society and the American Physical Society,* surf and waves took a back seat to neutrinos and nuclei, for a few days at least.

Neutrinos Show Their Stuff

Physicists from three groups announced at the meeting that their latest data about neutrinos—also known as ν's (rhymes with "news")—all but confirm earlier indications that the elusive particles have mass. The data, from different neutrino-hunting groups, mark the beginning of a new phase in neutrino physics: Now that the big question is settled, scientists are finally beginning to understand the finer properties of the most mysterious members of the particle zoo. "It's a whole new frontier now," says Kevin Lesko, a neutrino physicist at Lawrence Berkeley National Laboratory in Berkeley, California.

The frontier has remained untamed mainly because neutrinos seldom interact with matter. Most would pass through Earth unhindered, barely noticing the tons of rock and iron in their path. But once in a while, a neutrino does interact and signal its presence. For instance, if a type of neutrino known as an electron neutrino happens to strike a deuterium atom in the 1000-ton sphere of heavy water in a mine in Sudbury, Ontario, it can split the atom, yielding two protons and an electron. By measuring the signature of that electron, scientists at the Sudbury Neutrino Observatory (SNO) can figure out the incoming neutrino's path and energy (*Science*, 22 June, p. 2227).

Over years and months, physicists at SNO and at Super-Kamiokande in Kamioka, Japan, have provided strong evidence that neutrinos oscillate among three "flavors," changing from electron neutrinos to mu neutrinos to tau neutrinos and back again. That can happen only if the neutrinos have mass, a question that the standard model of particle physics leaves open. The latest evidence, presented here last week, supports the earlier results. In an experiment called K2K, physicists at the KEK neutrino laboratory in Tsukuba, Japan, have been shooting a beam of muon neutrinos at the Super-K detector 250 km away since June 1999 (*Science*, 12 February 1999, p. 928). According to Kenzo Nakamura of KEK, scientists have seen 44 of those neutrinos in the Super-K detector thus far. If neutrinos didn't oscillate, scientists should have seen 64. "The probability of no oscillations is less than 3%," says Nakamura.



Particle trap. Photodetectors at Super-K search for traces of the elusive neutrino.

Now, with the big question all but settled, scientists are eager for more specific information. They still don't know how much mass the neutrinos have, nor do they know an important quantity called the "mixing angle," which determines just how the neutrinos oscillate. But a new phase in neutrino research is finally yielding some answers.

According to theory, each of the three flavors of neutrinos, electron, tau, and muon, is a mixture of three "basis" elements, ν_1, ν_2, and ν_3. The "mixing angle" gives a measure of how deeply blended these basis elements are. For example, with a low mixing angle, an electron neutrino might be composed almost entirely of ν_1; with a high mixing angle, an electron neutrino might be, say, roughly equal parts of ν_1 and ν_2, with a little ν_3 thrown in for good measure. The mixing angle has profound effects on neutrinos' behavior; for example, neutrinos with a low mixing angle are affected by their passage through matter much more than those with a large mixing angle. Most theorists preferred small mixing angles, largely because quarks have them. "[Small mixing angles] were everybody's favorite," says Lesko. But no one knew for sure.

To find out, scientists at Super-K checked whether neutrinos coming from the sun behaved differently by day and at night, when they have to pass through Earth on their way to the detector. If the mixing angle were small, the physicists expected to see a fairly distinct day-night variation. They didn't. "There is no indication of a strong day-night flux difference," says Yoichiro Suzuki of the Kamioka Observatory. Combined with data from other neutrino experiments, such as SNO, the Super-K results imply with 95% confidence that the mixing angle is in fact large, says Suzuki. Although it's not an open-and-shut case, small mixing angles are clearly in trouble.

Furthermore, Super-K, K2K, SNO, and other efforts are eliminating some of the more complicated neutrino theories. One idea, that neutrinos oscillate into a fourth, noninteracting, "sterile" neutrino, has been ruled out at the 99% level. Other experiments are hoping to spot a rare nuclear decay that could prove that neutrinos are the same thing as antineutrinos—an assumption contrary to plain-vanilla neutrino theory.

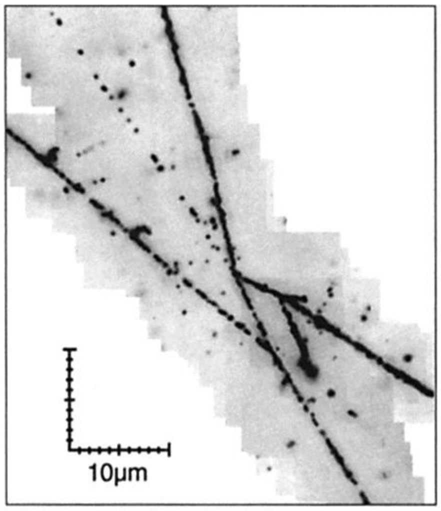
The upshot, Lesko says, is that neutrino physics has moved beyond the basics—proving that neutrinos oscillate—to finding out the details about neutrinos. "That's what's left to us now," he says. "We're getting a theoretical understanding of what must be, and we will have to expand the standard model to account for neutrinos." For the next few years, it is clear that ν's will yield some of the hottest news in physics.

Doubly Strange Particle

Nuclear physics is twice as strange as ever before. For the first time, scientists are confident that they have created doubly strange nuclei: atoms that contain two particles bearing "strange" quarks. This feat has enabled them to make the first rough estimate of the attractive force between these strange particles, filling a gap in scientists' understanding of the basic properties of subatomic particles.

The key to the discovery is an exotic particle known as lambda (Λ). Whereas ordinary neutrons and protons are combinations of so-called up and down quarks—familiar varieties of quark the forces of which physicists understand—a Λ particle is made up of an up quark, a down quark, and a more mysterious particle called a strange quark. Nuclear physicists don't have a complete grasp of the properties of strange matter, such as how strongly parti-

* 17–20 October.



Xi no more. Emulsion at KEK captured demise of a Ξ^- particle and creation of ${}_{\Lambda\Lambda}^{6}\mathrm{He}$.

cles with strange quarks attract each other. For this reason, they have been scrambling to get two Λ particles together to measure how tightly they are bound. "It's the number that everyone's after," says Robert Chrien, of Brookhaven National Laboratory in Upton, New York.

Unfortunately, scientists can't produce beams of Λ particles needed to measure the attraction directly. "The only way to get the lambdas to interact is to put them in the same nucleus," says Chrien. "You can't do the measurement any other way." Though scientists have inserted a single Λ particle into nuclei such as beryllium-7 (*Science*, 9 March, p. 1877), creating "hypernuclei," they have failed to get two Λ particles into the same nucleus—until now.

Last week, Ken'ichi Imai of Kyoto University in Japan presented a picture of an emulsion that provides good evidence of the creation and destruction of ${}_{\Lambda\Lambda}^{6}\mathrm{He}$ (helium-6-lambda-lambda): an ensemble of two protons, two neutrons, and two Λ particles. At the KEK high-energy accelerator in Tsukuba, Japan, Imai and his colleagues smashed kaons—two-quark particles with a strange component—into a diamond target, creating xi-minus (Ξ^-) particles, which each contain two strange quarks. An emulsion, an expensive version of a photographic plate, captured an event that looks for all the world like a Ξ^- particle being absorbed by a carbon atom, creating a ${}_{\Lambda\Lambda}^{6}\mathrm{He}$ along with less interesting byproducts. From this first glimpse of the ${}_{\Lambda\Lambda}^{6}\mathrm{He}$, "the lambda-lambda interaction energy was determined for the first time," says Imai. "It's pretty clean," says Chrien, whose team at Brookhaven has come up with slightly weaker evidence of a different doubly strange hypernucleus, ${}_{\Lambda\Lambda}^{4}\mathrm{H}$ (hydrogen-4-lambda-lambda).

According to these experiments, the lambda-lambda attractive energy seems to be fairly weak—about 1 million electron volts (MeV), much less than the estimate of 4 or 5 MeV reported in an earlier, dubious claim of a doubly strange hypernucleus. The new number is more in line with expectations. "One MeV will make a lot of theorists happy," says Chrien.

Both groups stress that these events are still early results; scientists will need to produce more doubly strange hypernuclei to be certain about the binding energy. But Ed Hüngerford of the University of Houston says the recent advances in strange physics are extremely encouraging. "It's an extra degree of freedom for illuminating nuclear structure," he says. So for once, physicists can be forgiven their extra dose of strangeness.

—CHARLES SEIFE

ARCHAEOLOGY

Spreading the Word, Scattering the Seeds

Did civilization follow the plow? An alluring model of the dispersal of language and agriculture meets resistance

CAMBRIDGE, U.K.—In 1987 Colin Renfrew's story sounded compelling, like a logical extension of Napoleon's observation that an army marches on its stomach. As the Cambridge University archaeologist first framed it then, throngs of farmers, grown strong on newly domesticated crops—wheat and barley in the west, rice in the east—swept across the land beginning 100 centuries ago. Armed with seeds, genes, and language, they pushed aside indigenous hunter-gatherers like a plow through virgin soil. Renfrew's "farming-language dispersal hypothesis" became a leading explanation for the present distributions of language and culture in Europe, Africa, and Polynesia.

But not everyone was eager to jump on the oxcart. Many scholars were suspicious of the grand aspirations of the farming-language hypothesis and of its archaeologist proponents, who they say tend to ignore unfavorable linguistic data. "The phenomenon of major expansion is very real," says linguist Roger Blench of the Overseas Development Institute in London, but "it's inconceivable that there is just one explanation."

Renfrew and Peter Bellwood of Australian National University in Canberra—the pioneer of the hypothesis in the Pacific islands—recently held a conference* here to confront the challenges and foster more genuine collaborations. But new studies presented from India and Southeast Asia further threaten the hypothesis, weakening the case for cereal crops as engines of linguistic dispersal. Along with ongoing controversy over Europe, this adds a heavy burden of complexity to the Renfrew-Bellwood model. "The initial hope of easy answers is being replaced by the realization that there's more to do," Renfrew says.

His original hypothesis—framed in the 1987 book *Archaeology and Language*—pictured culture, biology, and language marching in triumphal lockstep. Testing and elaborating the theory required interdisciplinary input. Archaeologists map the movement of cultures by following a trail of pots, tools, and seeds. Geneticists map the movement of populations by comparing genetic markers of people in one region with those of people in their hypothesized homelands. And linguists map the movement of languages by reconstructing ancient tongues from the shared vocabularies of modern ones. When a family of languages has similar agricultural terms—"wheat," say, or "harvest"—the linguists infer that before the languages branched apart, the ancestral speakers were farmers.

If Renfrew's hypothesis is right, then when these disparate scientists put their maps together, the arrows should point in the same direction, indicating a concerted agricultural dis-

Fantastic voyage. On canoes like this one, the Austronesians traveled from Taiwan to islands in Southeast Asia starting 4500 years ago.

CREDIT: CAMBRIDGE UNIVERSITY MUSEUM OF ARCHAEOLOGY AND ANTHROPOLOGY

* Examining the Farming/Language Dispersal Hypothesis, 24–27 August.