1000 beads were made throughout southern California, after that time manufacture was concentrated on Santa Cruz and Santa Rosa islands. Arnold thinks this centralization was driven by the owners of the tomols, the expensive 2-ton-capacity canoes that were the islanders' chief link to the mainland. They could trade beads for food, which may have been vital during tough times. "They had the most efficient means of distribution to the mainland, so it made sense for bead producers to funnel their product through the canoe owners. In return, the owners traded with the mainland to bring back food to keep their people well fed."

Both researchers acknowledge that material evidence for these ideas is thinner than they'd like; Raab, for instance, wants to find more signs that mainlanders were losing food sources. And Robert Bettinger of UC Davis says Raab may be overemphasizing the effects of the environment. Bettinger notes that people can adapt to water shortages—as they do in the desert—and long-term social processes could also have produced the status changes Raab has traced. Still, he and others note that the period of climate change, about A.D. 1300, was an unsettled time in a variety of American populations. There's evidence of trade disruption on the central California coast, and the collapse of Pueblo society in the Southwest. "I don't question the overall conclusion. Something did go on here," Bettinger says. The challenge for archaeologists is to figure out exactly what it was.

–Joshua Fischman

PHYSICS

Added Weight for Neutrino Mass Claim

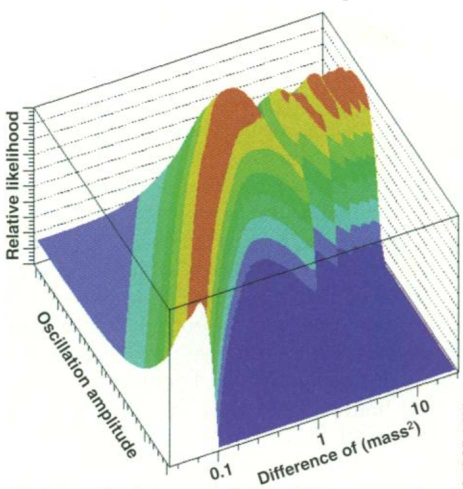
INDIANAPOLIS—Just outside the ballroom where Fred Federspiel described his group's latest results on the mass of the wispy particles called neutrinos, artisans did a brisk business in brightly colored dashikis and kente cloth scarves. The American Physical Society, as it happened, was sharing a conference center with a gospel convention. There wasn't much overlap between the two gatherings—except that Federspiel, a physicist at Los Alamos National Laboratory, had a message for the doubting Thomases in his own field. A large amount of new data from the Liquid Scintillator Neutrino Detector (LSND) experiment, he reported on 2 May, adds up to "very strong evidence for neutrino oscillations"—a tendency to switch identity, which would indicate that neutrinos have mass.

The experiment, located at Los Alamos and involving researchers at 12 different institutions, now has evidence for 22 events in which a neutrino of one "flavor" apparently oscillated, or transmuted, into another flavor. Conventional physics could have produced only four or five events mimicking these oscillations, the group calculated. Described in two papers just submitted to *Physical Review*, the evidence is twice what the LSND group had last fall when it first claimed to have detected neutrino oscillations—a claim that met with some skepticism (*Science*, 22 September 1995, p. 1671). Add to that "a much nicer job" of data analysis, says Frank Sciulli of Columbia University, and "one has to take it seriously. It's an anomaly."

The most tempting interpretation of the anomaly is that neutrinos have mass, for theorists predict that neutrinos can only switch identities if the three known flavors—electron, muon, and tau—have different masses. Although standard particle physics implies that the neutrino is massless, many physicists would be delighted to learn otherwise. Neutrino oscillations could point the way to new physics, and they could explain apparent shortfalls in the number of neutrinos reaching Earth from the sun and from cosmic ray collisions in the atmosphere. And because the universe is swarming with neutrinos, neutrinos with mass could provide some of the invisible dark matter needed to explain how matter coalesced into the large-scale structures seen today.

The LSND group looks for neutrino mass by slamming 800-million-electron-volt protons from an accelerator into a water target. The ensuing reactions send a stream of muon antineutrinos (the antimatter counterparts of neutrinos) into the LSND, a tank filled with 167 metric tons of mineral oil and 1220 light detectors. The muon antineutrinos should almost always pass through the tank without a trace—unless they oscillate into electron antineutrinos along the way. In that case, a fraction of the electron antineutrinos would react with protons in the oil, producing characteristic trails of light.

Aside from doubling the previous data set during 4 months of running time in 1995, the group has become more sophisticated about ferreting out conventional processes that can also produce these light signatures, says D. Hywel White, co-spokesperson for the experiment. On rare occasions, for example, a muon antineutrino can combine with a proton in the tank to produce a neutron and a muon, which in turn can mimic the electron antineutrino signal. But Federspiel developed a method for searching the data leading up to an apparent detection for clues that the event was due to a muon, not a massive neutrino. Because of such improvements, the chance that the new results are a statistical fluke is less than 1 in 10 million, says White: "When the number is that tiny, either there is new physics or we have made a mistake."



Weight of evidence. LSND's likely range of mass differences between the electron and muon antineutrinos.

Sciulli notes that the positive result persists, although at a much lower confidence level, even when the group discards data from a large part of the tank that a former collaborator had argued is especially vulnerable to spurious events from background radiation and cosmic rays. All in all, says George Fuller of the University of California, San Diego (UCSD), who, like Sciulli, is not a member of the LSND group, "it is very significant that the signal has not gone away with further running. There was some speculation that it would."

The most likely mass the LSND results suggest when combined with limits from other experiments—half an electron volt or a little more—would add about the right amount of heft to the universe for cosmologists' tastes. But it is larger than physicists trying to explain the solar and atmospheric deficits had hoped for. More recent calculations by Fuller and Christian Cardall at UCSD show that the solar and atmospheric mysteries, too, could in principle be explained by LSND's mass range. Still, "the game is not over," says White.

White says the only way to be sure that the particles triggering the LSND are neutrinos that have oscillated and not something entirely different is to redo the experiment with several different detectors or at higher energies, where neutrinos interact with matter more often. A larger number of events would allow the experimenters to look for a predicted sinusoidal variation in oscillation frequency with changes in either neutrino energy or travel distance, says White. The group will soon propose an experiment, to be set up at the Fermi National Accelerator Laboratory's 8-billion-electron-volt booster ring, that could search for this telltale variation, he says. A positive result, everyone agrees, could finally turn neutrino mass into physics gospel.

–James Glanz