UPDATES

Precision tabletop neutrino science starts with rare isotopes

To learn about the aloof particles' quantum states, researchers are watching radioactive beryllium, not water.

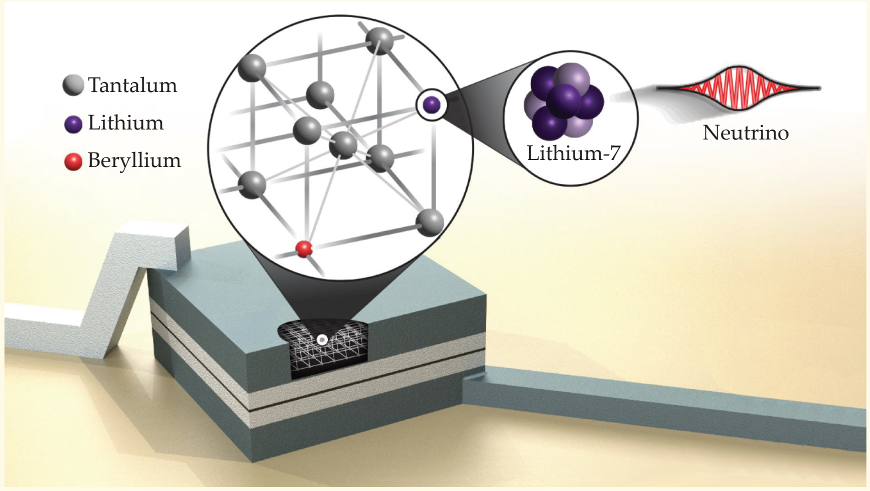

FIGURE 1. BERYLLIUM-7 decays into lithium-7 via electron capture, a process whose only byproduct is an electron neutrino. By embedding ^{7}Be atoms in the tantalum film of a superconducting-tunnel-junction sensor, researchers can precisely measure the recoil energy imparted to the ^{7}Li by the decay. (Image adapted from J. Smolsky et al., *Nature* **638**, 640, 2025.)

Pitching neutrinos can be easier than catching them. Because the lightweight particles stream mostly unencumbered through any matter they encounter, neutrino detectors must monitor gargantuan volumes of water or other material, ever vigilant for the signs of a rare neutrino interaction, wherever it may occur. On the other hand, the processes that create neutrinos, including certain nuclear decays and particle reactions, can be readily localized and precisely studied even in a tabletop experiment.

That's the idea behind the BeEST (Beryllium Electron capture in Superconducting Tunnel junctions), an experiment headed by Kyle Leach of Colorado School of Mines in Golden and Stephan Friedrich at Lawrence Livermore National Laboratory. As illustrated in figure 1, a thin film of tantalum is sprinkled with beryllium-7, a radioactive isotope that decays via electron capture into lithium-7. The decay's only products are the ^{7}Li nucleus and an 862 keV electron neutrino. So from the ^{7}Li recoil energy, which is converted into a measurable current by a superconducting tunnel junction, the researchers can learn about previously unknown properties of the neutrino. To start, they've probed the spatial extent of the neutrino's quantum state.

The experiment wouldn't have been possible more than a handful of years ago, because ^{7}Be occurs in only trace amounts in nature, and there was no way of making it in bulk with the required purity. The situation changed with the advent of rare isotope factories, including the Advanced Rare Isotope Laboratory (ARIEL) at the TRIUMF accelerator center in Canada and the Facility for Rare Isotope Beams (FRIB) at Michigan State University in the US (see Physics Today, June 2023, page 21). Leach and colleagues got their ^{7}Be from TRIUMF; the isotope's half-life of 53 days provides ample time for shipment to the experiment site in Livermore, California.

Figure 2 shows the BeEST's measurement of the recoil energy spectrum: The most common decay channel, shown by the large blue peak, has a standard deviation in energy of 2.9 eV, which corresponds to a ^{7}Li momentum uncertainty of 16 keV/c. Because the nucleus and neutrino have equal and opposite momenta, their momentum uncertainties must be equal. So by the Heisenberg uncertainty principle, the neutrino's position uncertainty—the size of its wavepacket at the moment of its creation—is at least 6.2 pm. That's a conservative lower bound, because not all of the energy spread is due to quantum fluctuations.

Why does it matter how big a neutrino's wavepacket is? Although the implications aren't fully clear, the researchers note that 6.2 pm is several thousand times the size of the ^{7}Be nucleus. Theorists have debated how quantum mechanics treats nuclear decays: Are the interactions localized on the scale of the nucleus or the whole atom? An electron-capture decay, which necessarily involves an electron from outside the nucleus, is perhaps not the best platform for answering that question. Repeating the experiment with a beta decay, whose starting state is an isolated nucleus, is on Leach and colleagues' to-do list. (J. Smolsky et al., *Nature* **638**, 640, 2025.)

Johanna Miller PT

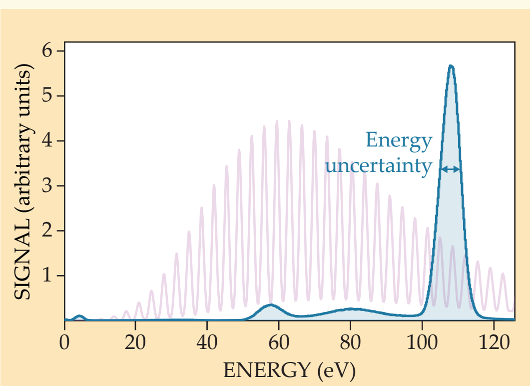

FIGURE 2. IN THE RECOIL ENERGY SPECTRUM of lithium-7, shown in blue, the largest peak has an energy uncertainty of 2.9 eV. From conservation of momentum and the Heisenberg uncertainty principle, it follows that the neutrino produced in the nuclear decay has a position uncertainty of at least 6.2 pm. The frequency comb in faint purple is the spectrum of the calibration laser that researchers used to convert the currents they measured into energy. (Figure adapted from J. Smolsky et al., *Nature* **638**, 640, 2025.)