Scientists demonstrate a new experiment in the search for theorized 'neutrinoless' proc

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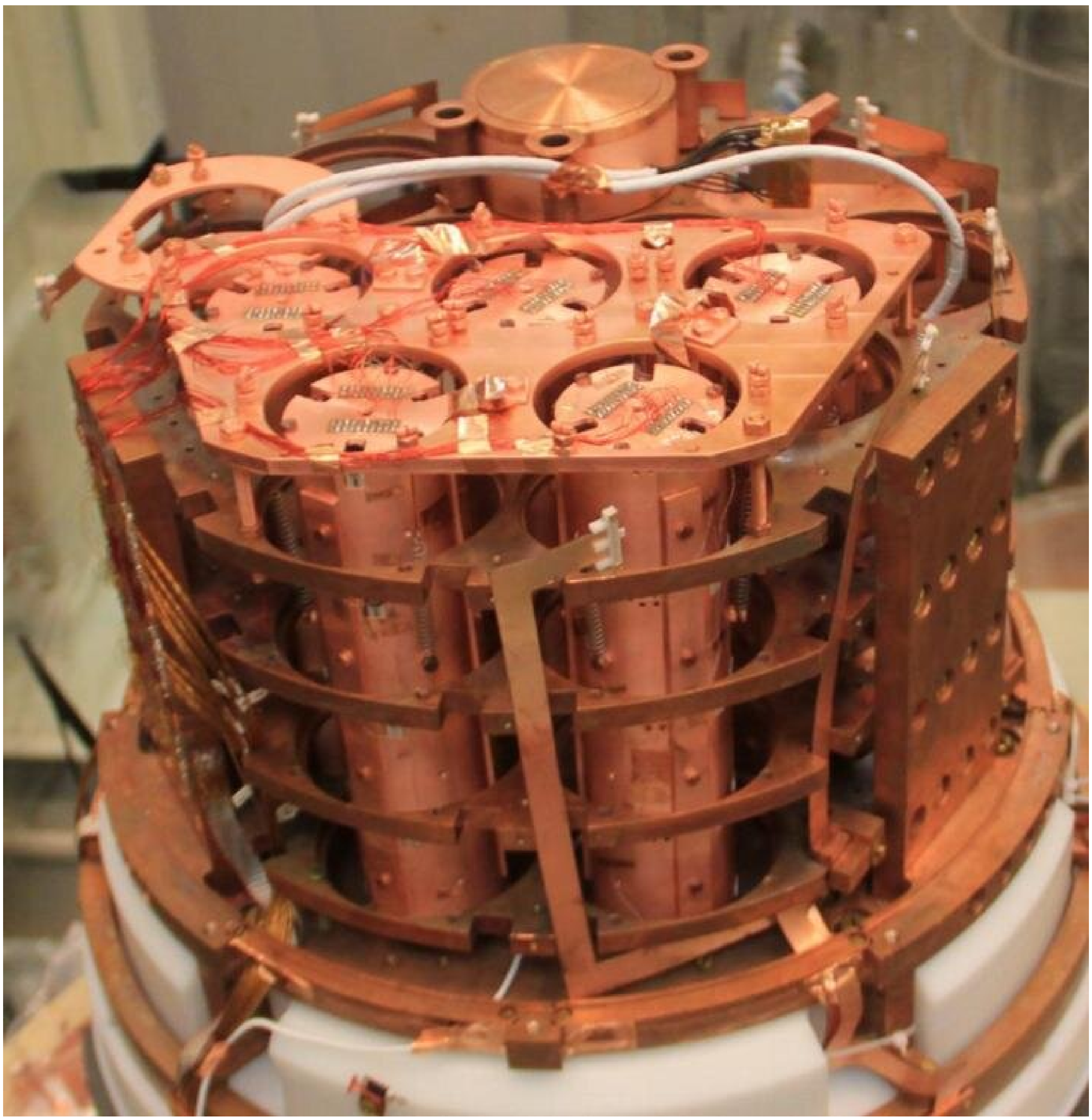


The CUPID-Mo detector is installed in the EDELWEISS cryostat at Modane Underground Laboratory (LSM) in France. Credit: CUPID-Mo collaboration

Nuclear physicists affiliated with the U.S. Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) played a leading role in analyzing data for a demonstration experiment that has achieved record precision for a specialized detector material.

The CUPID-Mo experiment is among a field of experiments that are using a variety of approaches to detect a theorized particle process, called neutrinoless double-beta decay, that could revise our understanding of ghostly particles called neutrinos, and of their role in the formation of the universe.

The preliminary results from the CUPID-Mo experiment, based on the Berkeley Lab-led analysis of data collected from March 2019 to April 2020, set a new world-leading limit for the neutrinoless double-beta decay process in an isotope of molybdenum known as Mo-100. Isotopes are forms of an element that carry a different number of uncharged particles called neutrons in their atomic nuclei.

The new result sets the limit on the neutrinoless double-beta decay half-life in Mo-100 at 1.4 times a trillion-trillion years (that's 14 followed by 23 zeros), which is a 30% improvement in sensitivity over the Neutrino Ettore Majorana Observatory 3 (NEMO 3), a previous experiment that operated at the same site from 2003-2011 and also used Mo-100. A half-life is the time it takes for a radioactive isotope to shed half of its radioactivity.

The neutrinoless double-beta decay process is theorized to be very slow and rare, and not a single event was detected in CUPID-Mo after one year of data-taking.

While both experiments used Mo-100 in their detector arrays, NEMO 3 used a foil form of the isotope while CUPID-Mo used a crystal form that produces flashes of light in certain particle interactions.

Larger experiments that use different detector materials and that operate for longer periods of time have achieved greater sensitivity, though the reported early success of CUPID-Mo sets the stage for a planned successor experiment called CUPID with a detector array that will be 100 times larger.

Berkeley Lab's contributions to CUPID-Mo

No experiment has yet confirmed whether the neutrinoless process exists. Existence of this process would confirm that neutrinos serve as their own antiparticles, and such proof would also help explain why matter won out over antimatter in our universe.

All of the data from the CUPID-Mo experiment—the CUPID acronym stands for CUORE Upgrade with Particle IDentification, and "Mo" is for the molybdenum contained in the detector crystal—is transmitted from Modane Underground Laboratory (Laboratoire souterrain de Modane) in France to the Cori supercomputer at Berkeley Lab's National Energy Research Scientific Computing Center.

CUPID-Mo's 20 cylindrical crystals are pictured in their copper casing. Credit: CUPID-Mo collaboration

Benjamin Schmidt, a postdoctoral researcher in Berkeley Lab's Nuclear Science Division, led the overall data analysis effort for the CUPID-Mo result, and was supported by a team of Berkeley Lab-affiliated researchers and other members of the international collaboration.

Berkeley Lab also contributed 40 sensors that enabled readout of signals picked up by CUPID-Mo's 20-crystal detector array. The array was supercooled to about 0.02 kelvin, or minus 460 degrees Fahrenheit, to maintain its sensitivity. Its cylindrical crystals contain lithium, oxygen, and the isotope Mo-100, and produce tiny flashes of light in particle interactions.

The international effort to produce the CUPID-Mo result is remarkable, Schmidt said, given the context of the global pandemic that had cast uncertainty over the continuing operation of the experiment.

"For a while it looked like we would have to shut down the CUPID-Mo experiment prematurely due to the outbreak of COVID-19 in Europe at the beginning of March and the associated difficulties in supplying the experiment with required cryogenic liquids," he said.

He added, "Despite this uncertainty and the changes associated with the closure of office spaces and schools, as well as restricted access to the underground laboratory, our collaborators made every effort to keep the experiment running through the pandemic."

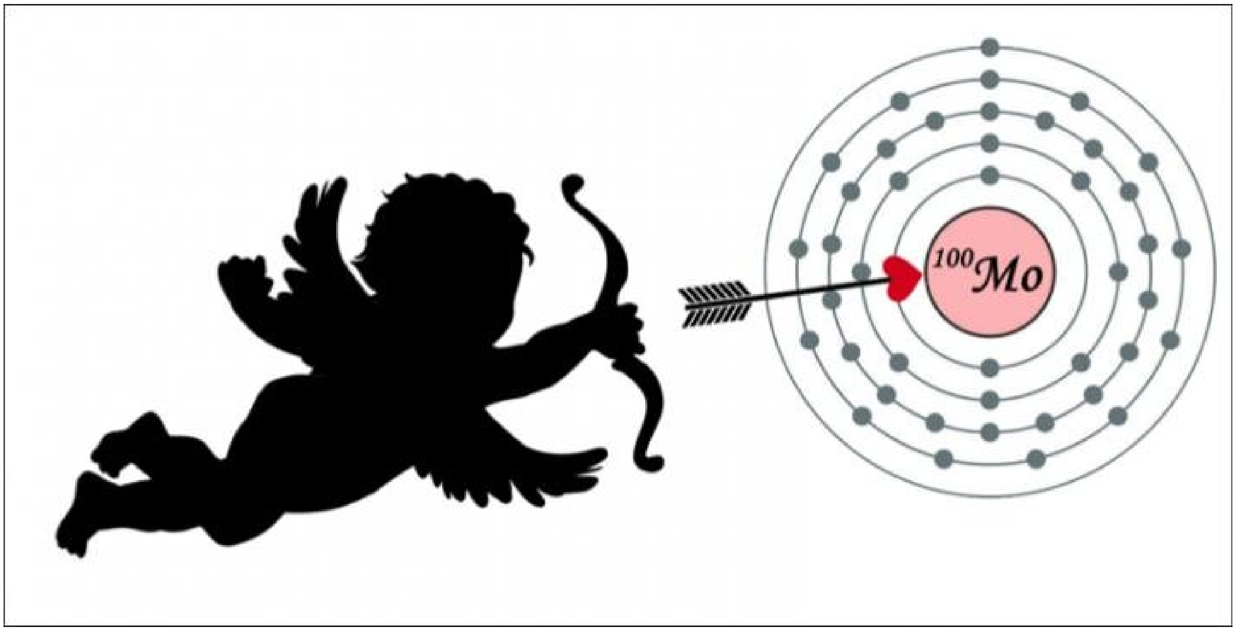
Schmidt credited the efforts of the data-analysis group that he led for finding a way to work from home and produce the results from the experiment in time to present them at Neutrino 2020, a virtual International Conference on Neutrino Physics and Astrophysics hosted by Fermi National Accelerator Laboratory. Members of the CUPID-Mo collaboration are planning to submit the results for publication in a peer-reviewed science journal.

Tuning up ultrasensitive detectors

A particular challenge in the data analysis, Schmidt said, was in ensuring that the detectors were properly calibrated to record the "extremely elusive set of events" that are predicted to be associated with a signal of neutrinoless double-beta decay.

The neutrinoless decay process is expected to generate a very-high-energy signal in the CUPID-Mo detector and a flash of light. The signal, because it is at such a high energy, is expected to be free from interference by natural sources of radioactivity.

To test CUPID-Mo's response to high-energy signals, researchers had placed other sources of high-energy signals, including Tl-208, a radioactive isotope of thallium, near the detector array. The signals generated by the decay of this isotope are at a high energy, but not as high as the energy predicted to be associated with the neutrinoless decay process in Mo-100, if it exists.



CUPID-Mo logo Credit: CUPID-Mo collaboration

"Hence, a big challenge was to convince ourselves that we can calibrate our detectors with common sources, in particular Tl-208," Schmidt said, "and then extrapolate the detector response to our signal region and properly account for the uncertainties in this extrapolation."

To further improve the calibration with high-energy signals, nuclear physicists used Berkeley Lab's 88-Inch Cyclotron to produce a wire containing Co-56, an isotope of cobalt that that has a low level of radioactivity, as soon as the cyclotron reopened last month following a temporary shutdown in response to the COVID-19 pandemic. The wire has been shipped to France for testing with the CUPID-Mo detector array.

Preparing for next-gen experiment in Italy

While CUPID-Mo may now lag behind the sensitivity in measurements achieved by some other experiments—which use different detector techniques and materials—because it is smaller and hasn't yet gathered as much data, "With the full CUPID experiment, which will use about 100 times more Mo-100, and with 10 years of operation, we have excellent prospects for the search and potential discovery of neutrinoless double-beta decay," Schmidt said.

CUPID-Mo was installed at the site of the Edelweiss III dark matter search experiment in a tunnel more than a mile deep in France, near the Italian border, and uses some Edelweiss III components. CUPID, meanwhile, is proposed to replace the CUORE neutrinoless double-beta decay search experiment at Gran Sasso National Laboratory (Laboratori Nazionali del Gran Sasso) in Italy. While CUPID-Mo contains just 20 detector crystals, CUPID would contain more than 1,500.

"After CUORE finishes data-taking in two or three years, the CUPID detector could take four or five years to build," said Yury Kolomensky, U.S. spokesperson for the CUORE collaboration and senior faculty scientist at Berkeley Lab, which is leading CUORE's U.S. collaboration. "CUPID would be a relatively modest upgrade in terms of cost and technical challenges, but it will be a significant improvement in terms of sensitivity."

Physics data-taking for CUPID-Mo wrapped up June 22, and new data that weren't considered in the latest result represent about a 20% to 30% growth in overall data. CUPID-Mo is supported by a group of French laboratories, and by laboratories in the U.S., Ukraine, Russia, Italy, China, and Germany.

NERSC is a DOE Office of Science user facility.

The CUPID-Mo collaboration brings together researchers from 27 institutions, including the French laboratories Irfu/CEA and IJCLab in Orsay; IP2I in Lyon; and Institut Néel and SIMaP in Grenoble, as well as institutions in the U.S., Ukraine, Russia, Italy, China, and Germany.

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