Detector technology yields unprecedented 3D images, heralding far larger application to study neutrinos

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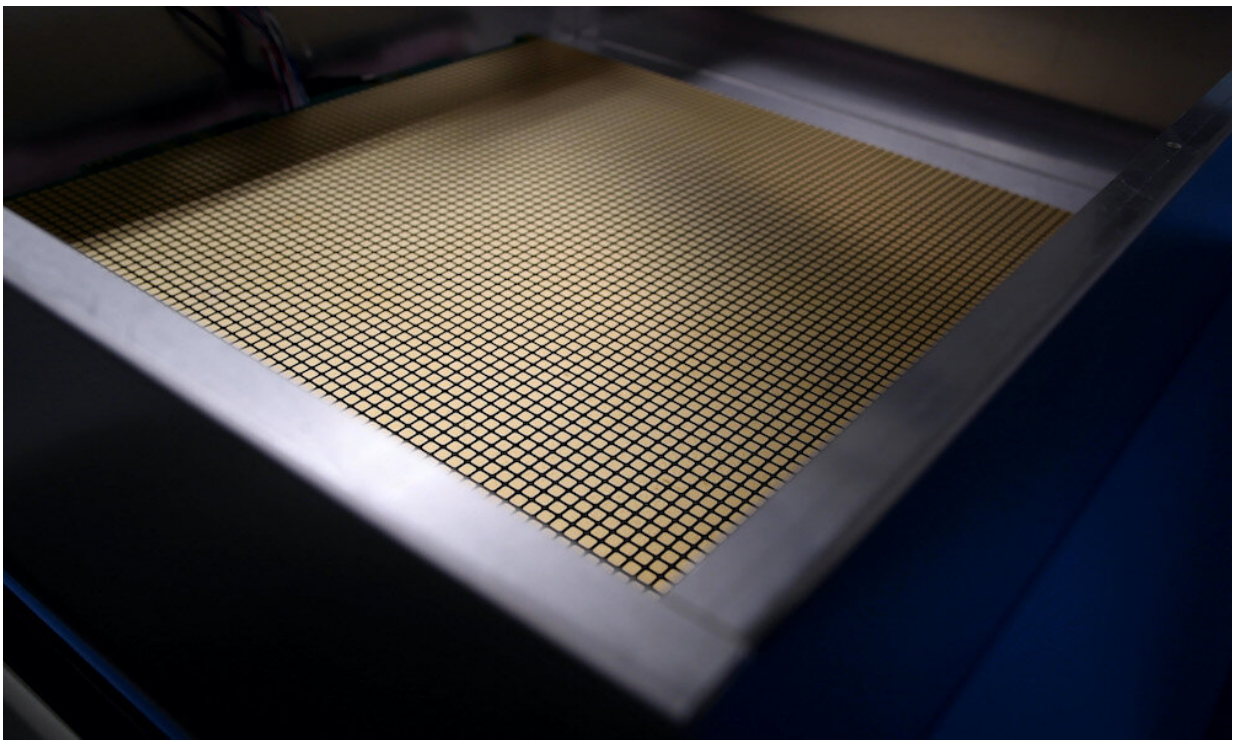

A LArPix sensor with 4900 pixels under testing at Berkeley Lab before shipment to the University of Bern for installation. Credit: Thor Swift, Berkeley Lab

An experiment to capture unprecedented 3D images of the trajectories of charged particles has been demonstrated using cosmic rays as they

strike and travel through a cryostat filled with a ton of liquid argon. The results confirm the capabilities of a novel detector technology for particle physics developed by researchers at Lawrence Berkeley National Laboratory (Berkeley Lab) in collaboration with several university and industrial partners.

Groundbreaking in scale for this new technology, the experiment at University of Bern, Switzerland—directed remotely because of the COVID-19 pandemic—demonstrates readiness for a far larger and more ambitious project: the Deep Underground Neutrino Experiment (DUNE), said Berkeley Lab scientist and team leader Dan Dwyer.

In just a few short years, the Berkeley Lab team has turned an ambitious concept called LArPix (liquid argon pixels) into a reality, Dwyer said. "We have overcome challenges in noise, power consumption, cryogenic compatibility, and most recently scalability/reliability by transferring many aspects of this technology to industrial fabrication."

DUNE is a major new science facility being built by the U.S. Department of Energy (DOE) to study the properties of subatomic neutrinos that will be fired off underground from an accelerator at DOE's Fermi National Accelerator Laboratory (Fermilab) near Chicago, Dwyer explained. Neutrinos are extremely light particles that interact weakly with matter—something researchers would like to understand better in their quest to answer fundamental questions about the universe.

Neutrinos produced by the Fermilab accelerator will pass through a near detector, instrumented with LArPix, on the Fermilab site before moving on to complete their 700-mile journey at a deep underground mine in South Dakota.

LArPix is a leap forward in how to detect and record signals in liquid argon time projection chambers (LArTPCs), a technology of choice for

future neutrino and dark matter experiments, Dwyer explained.

In a LArTPC, energetic subatomic particles enter the chamber and liberate or ionize electrons in the liquid argon. A strong, externally applied electric field drifts the electrons toward an anode side of the detector chamber where typically a plane of wires acts as sensitive antennae to read these signals and create stereoscopic 2D images of the event. But this technology is not enough to cope with the intensity and complexity of the neutrino events to be read for the DUNE Near Detector, Dwyer said.

"So, that's where we at Berkeley Lab come in with this true 3D pixel readout provided by LArPix," Dwyer said. "It will allow us to image DUNE neutrinos with high fidelity in a very busy environment."

Using LArPix, he explained, the planes of wires are replaced with arrays of metallic pixels fabricated on standard electronic circuit boards, which can be readily manufactured. The low-power electronics, he said, are compatible with the demands of the cryogenic state of the liquid argon medium.

This latest achievement would not have been possible without the strong partnership with the ArgonCube Collaboration, a team of scientists focused on advancing LArTPC technology, centered at the University of Bern. For the Bern experiments, the researchers used a detector chamber with 80,000 pixels submerged in a ton of liquid argon at -330 degrees Fahrenheit. The system, he said, provided high fidelity, true 3D-imaging of cosmic ray showers as they traveled through the detector.

"This is a major milestone in the development of LArTPCs and the DUNE Near Detector," said Michele Weber, Director of the Laboratory for High Energy Physics at the University of Bern who also serves as leader of the DUNE International Consortium responsible for building

this detector.

"It's vastly more complicated than anything that's ever been built for LArTPCs," said Brooke Russell, a postdoctoral fellow at Berkeley Lab and member of the LArPix team. With 80,000 channels, she said, the LArPix run at Bern far surpassed the previous state-of-the-art 15,000 channel LArTPC. "The level of complexity going from wires to pixels grew exponentially," she said.

Partners from UC Berkeley, Caltech, Colorado State University, Rutgers, UC Davis, UC Irvine, UC Santa Barbara, UPenn, and the University of Texas at Arlington helped the researchers develop and test this much larger system.

For DUNE, Dwyer said, the system must scale to more than 10 million pixels that will sit in some 300 tons of liquid argon. He said this is doable both because of the modular nature of the detector chambers as well as the ability to tile LArPix boards made up of thousands of individual pixel detectors.

"This technology will enable the DUNE Near Detector to overcome signal pileup resulting from the high-intensity of the neutrino beam at the site," Dwyer said. "It may also find use in the DUNE Far Detectors, other physics experiments, as well as non-physics applications," he said.

At the DUNE Far Detectors, scientists will measure how the quantum flavor of the neutrinos changes in transit from the near detector.

By studying neutrinos, "we think we can learn something about the deeper mysteries of the universe—particularly such questions as why there's more matter than antimatter in the universe," Dwyer explained.

For DUNE to succeed, particle physicists "needed a level of thinking

outside the box when it comes to detector technology," Russell said. "For any breakthroughs in experimental particle physics of course you need novel ideas," she added. "But if your hardware can't deliver then you simply can't make the measurement."

Provided by Lawrence Berkeley National Laboratory

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