Blast from the past—First measurement of mono-energetic neutrinos

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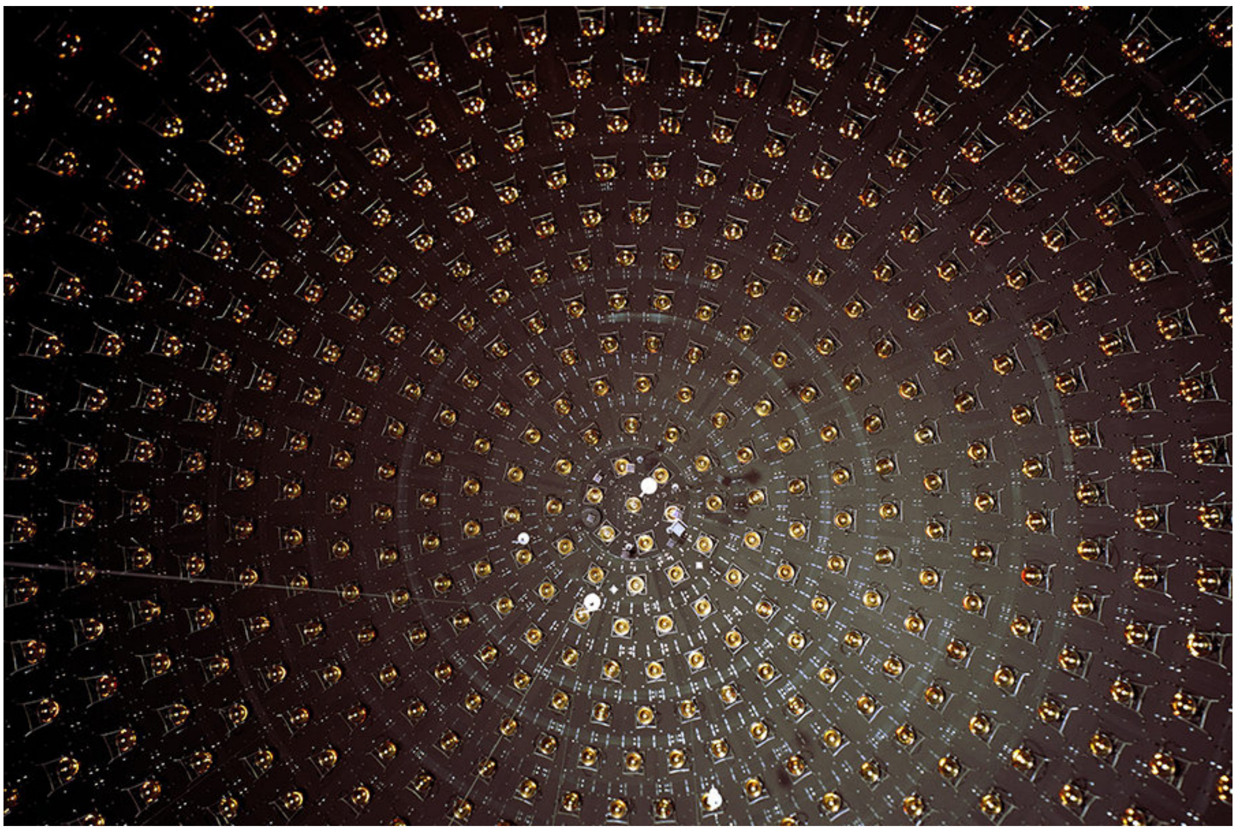

This interior view of the MiniBooNE detector tank shows the array of photodetectors used to pick up the light particles that are created when a neutrino interacts with a nucleus inside the tank. Credit: Fermilab / Reidar Hahn

By analyzing data collected over eight years ago, scientists at the U.S.

Department of Energy's (DOE) Argonne National Laboratory and Fermi National Accelerator Laboratory have made a potentially groundbreaking discovery.

In 2002, scientists began the Booster Neutrino Experiment, known as MiniBooNE, at Fermilab to learn more about how neutrinos—very light, neutral fundamental particles—interact with matter. Scientists recently reexamined data from the experiment taken between 2009 and 2011, and they found the first direct evidence of mono-energetic neutrinos, or neutrinos with definite energy, that are energetic enough to produce a muon.

Neutrinos are extremely light and are only influenced by the weak subatomic force, so they rarely interact with matter. In fact, they could travel through light-years of lead before interacting with it. The particles are very difficult to detect, but not difficult to create. Because of the neutrino's elusiveness, scientists have to work with beams composed of large numbers of the particles. They shoot the beams at nuclei in a detector, hoping for neutrinos to collide with the target material.

"One complication of using these large beams is that the energies of the neutrinos are widely varied and somewhat unpredictable," said Argonne physicist Joe Grange, one of the scientists that helped discover mono-energetic neutrinos. "This makes it difficult to fully interpret the data."

The new discovery could help experimentalists solve this problem. The scientists realized that mono-energetic neutrinos were being released from a nearby neutrino beamline at Fermilab, and they decided to look at the MiniBooNE data to see if any of these neutrinos were detected during that experiment.

Sure enough, analysis of the MiniBooNE data showed evidence of thousands of neutrino-nucleus collisions where the neutrinos all started out with the same energy, 236 mega-electron-volts (MeV). During the MiniBooNE experiment, particles called kaons created in a proton absorber of another experiment decayed into particles called muons and muon neutrinos. The muon neutrinos then traveled to the MiniBooNE detector. Because the kaons were at rest when they decayed, and because they decayed into only two particles, the neutrinos all had the same amount of starting energy before colliding with the nuclei in the MiniBooNE detector.

The decay of a kaon is a well-known reaction. "With this discovery, we can improve our understanding of how neutrinos interact with matter and also plan for future experiments that could leverage this interaction for the search for new physics processes," said Grange. Channeling this decay as a source of neutrinos for experiments would eliminate the uncertainty of the neutrino energies, making analyses simpler and potentially more illuminating.

In addition to inspiring future experimental setups, the data are also helping scientists to learn about the behavior of nuclei when bombarded with neutrinos and can help them refine models of the interactions. When a muon neutrino collides with a nucleus in a detector, a muon having one of a range of different energies can pop out. It is this spectrum of possible energies of the new muons that the scientists observed directly in this study, and it speaks to the way the neutrino transfers energy to the nucleus upon contact.

"A lot of work has been done shooting electrons at nuclei and seeing how they behave electromagnetically," said Grange. "But less work has been done to see how neutrinos interact weakly because of how difficult neutrinos are to work with."

The experimental aspect of this discovery could also help scientists search for the theorized sterile neutrino, a neutrino that only interacts through the gravitational force and not the weak force. A mid-1990s experiment at DOE's Los Alamos National Laboratory yielded neutrino data that were incompatible with data from a separate experiment at the European laboratory CERN, and that discrepancy might be explained by the existence of this "ghost" particle.

The original goal of the MiniBooNE experiment was to confirm or refute the existence of sterile neutrinos. Although the experiment may end up inconclusive, the new discovery from the depths of its data could help future experimentalists to detect their existence. Scientists are already working towards experiments that will use neutrinos from this specific kaon decay to search for sterile neutrinos.

"It's a nice story about how it was almost five years before we realized there was something important in the data," said Grange. "The moral of the story is to keep all the data and continue thinking about what other information is in there that you haven't yet extracted."

The results of the study were published in a paper titled "First Measurement of Monoenergetic Muon Neutrino Charged Current Interactions" in *Physical Review Letters*.

More information: A. A. Aguilar-Arevalo et al, First Measurement of Monoenergetic Muon Neutrino Charged Current Interactions, *Physical Review Letters* (2018). DOI: 10.1103/PhysRevLett.120.141802

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