On the Detection of "Ghost Particles" – Nobel Prize in Physics 2026

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Abstract – Neutrinos are elusive particles produced throughout the universe. They carry valuable information that can help us unravel the mysteries of the most extreme environments in the cosmos. Detecting them, however, has proven to be a formidable challenge, requiring ingenious and unconventional ideas in experimental physics, as well as exceptional scientific leadership. For these reasons, the 2026 Nobel Prize in Physics was awarded to Belgian physicist Francis Halzen "for decisive contributions to the IceCube Neutrino Observatory and the discovery of high-energy neutrinos of astrophysical origin" (Royal Swedish Academy of Sciences, 2026).

Keywords: ***neutrinos, IceCube, Cherenkov radiation, neutrino astronomy.***

Introduction

Ghosts and science are not words one might commonly find together in the same sentence without raising a few eyebrows. However, this year's Nobel Prize in Physics draws atten-tion to a particularly spooky particle that can be described as phantasmagorical without sacrificing academic rigor. This is, of course, the neutrino.

Neutrinos are practically everywhere, but they are rather shy. They are electrically neutral and interact only through two of the fundamental forces of nature, the weak nu-clear force and gravity. In other words, they barely interact with matter, earning them the nickname "ghost particles." They pass through our bodies and planet without us noticing. Because of these elusive properties, their detection is rather challenging. How-ever, this hasn't prevented scientists from finding ways to study these particles.

The neutrino was proposed by Wolfgang Pauli in 1930 to explain the continuous en-ergy spectrum observed in beta decay and was first detected in 1956 by Clyde Cowan and Frederick Reines. Since its theoretical con-ception, this particle has been the protagonist of several Nobel Prizes in Physics, including those awarded in 1988 for the discovery of the muon neutrino, 1995 for the first detection of neutrinos, 2002 for the detection of cosmic neutrinos, and 2015 for the discovery of neu-trino oscillations, which demonstrated that neutrinos have mass (Nobel Prize Outreach, 1988, 1995, 2002, 2015).

The scientific community's fascination with this particle is well deserved. The properties of neutrinos make them exceptional mes-sengers for astrophysical investigations, as they can travel across vast cosmic distances virtually undisturbed. Very high-energy neu-trinos can be produced in extreme environ-ments alongside other particles of the Stan-

dard Model. However, given that they can cross the cosmos without significant alteration, they can provide information that could not be obtained by studying other particles that are affected by various astrophysical phenomena.

Given this, it is clear that finding ways to experimentally study neutrinos is of vital importance to making full use of the information they provide.



Figure 1. *Francis Halzen, recipient of the 2026 Nobel Prize in Physics for his contributions to the IceCube Neutrino Observatory and the discovery of high-energy astrophysical neutrinos.*
Image credit: Photo: Althea Dotzour / University of Wisconsin–Madison. Source: (IceCube Collaboration, 2026).

Halzen's Brilliant Idea

This is where Francis Halzen enters the picture. In 1988, he proposed a way to detect these elusive particles at the South Pole (Halzen and Learned, 1988). The idea is as follows: when a neutrino collides with an atomic nucleus, it can produce charged particles that emit light through a phenomenon known as Cherenkov radiation. This light can then be detected by sensors embedded in glacial ice.

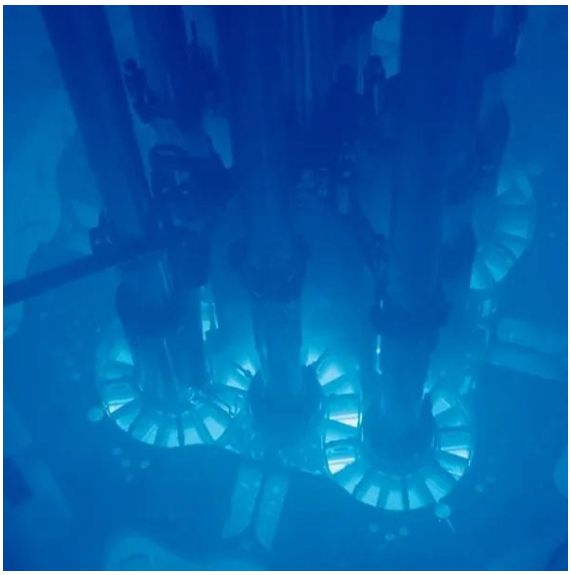


Figure 2. *The characteristic blue glow of Cherenkov radiation observed in the Reed Research Reactor. This phenomenon occurs when charged particles travel faster than the phase velocity of light in a transparent medium.*
Image credit: Credit: U.S. Nuclear Regulatory Commission. Public domain. Source: (U.S. Nuclear Regulatory Commission, n.d.).

It is easy to see why this idea attracted the scientific community's interest.

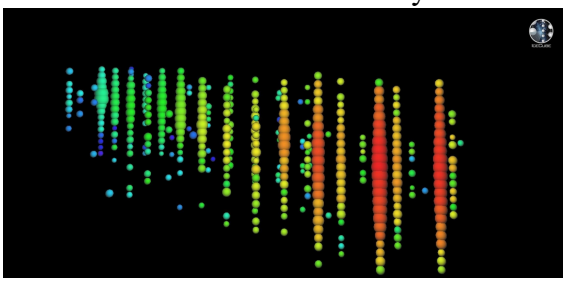


Figure 3. *The IceCube Neutrino Observatory consists of 5,160 optical sensors distributed along 86 vertical strings, covering approximately one cubic kilometer of Antarctic ice.*
Image credit: Credit: IceCube Collaboration. Source: (IceCube Collaboration, n.d.-c).

From AMANDA to IceCube

During the 1990s, the first experimental tests of optical sensors embedded in ice were



conducted. This led to the construction of AMANDA (Antarctic Muon and Neutrino Detector Array), IceCube's predecessor. AMANDA showed that, in fact, Antarctic ice was sufficiently transparent to detect Cherenkov radiation. This exciting confirmation allowed a proposal for a cubic-kilometer neutrino detector to be sent to the U.S. National Science Foundation. As such, IceCube was constructed over seven Antarctic summer seasons and was completed on December 18, 2010, becoming fully operational in May 2011. IceCube consists of 5,160 optical sensors distributed along 86 vertical strings, extending from approximately 1,450 to 2,450 meters below the surface (IceCube Collaboration, n.d.-a,n).

As mentioned, IceCube does not observe neutrinos directly. Instead, it detects the Cherenkov radiation emitted by secondary particles produced when neutrinos interact with matter. This radiation is generated when a charged particle travels faster than the phase velocity of light in a given medium. Optical sensors equipped with photomultiplier tubes can then register the resulting flashes of light. Information about the intensity, timing, and spatial distribution of the detected radiation can be used to reconstruct the energy and incoming direction of the neutrinos (IceCube Collaboration, n.d.-c).

Neutrino interactions produce two important event signatures: tracks and cascades. The former are long trajectories primarily associated with muons produced by muon-neutrino interactions, whereas the latter are localized showers of secondary particles that produce approximately spherical patterns of light. A major experimental challenge is distinguishing astrophysical neutrinos from atmospheric neutrinos and muons produced by cosmic-ray interactions.

IceCube vs. Background Noise

As a matter of fact, IceCube observations must be distinguished from a background of signals produced by cosmic rays entering Earth's atmosphere. Some of the secondary particles generated by these interactions, particularly muons, can penetrate deep into the ice and trigger the detectors. Approximately 250 million such events are registered every day by the observatory (IceCube Collaboration, n.d.-d).

Therefore, to identify the desired cosmic neutrinos, researchers must carefully examine the detected events and use their properties to distinguish those originating from astrophysical sources from those produced by atmospheric neutrinos and muons. In 2013, the research team reported the first compelling evidence supporting the detection of astrophysical neutrinos. By analyzing data collected over two years, they identified 28 high-energy events whose energies and other characteristics could not be adequately explained by the expected atmospheric background. In fact, the observations revealed a statistically significant excess of events, reaching a significance of approximately 4 . Subsequent analyses using additional data provided further confirmation of their discovery (Aartsen et al., 2013).

But this was only the beginning. In 2017, IceCube managed to detect a high-energy

neutrino whose direction was consistent with that of a distant blazar named TXS 0506+056, which is associated with a supermassive black hole (IceCube Collaboration et al., 2018). Further discoveries followed, such as evidence of neutrino emission from the active galaxy NGC 1068 back in 2022 and the observation of high-energy neutrinos originating in our own galaxy in 2023 (Abbasi et al., 2022, 2023). These discoveries helped establish the reputation of neutrino astronomy as a new way of investigating highly energetic phenomena in the cosmos.

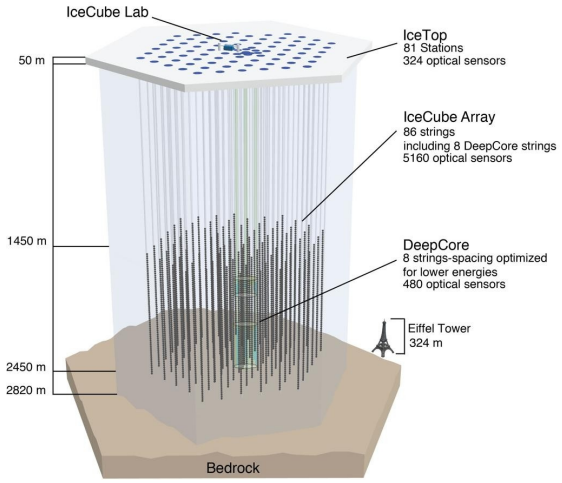


Figure 4. *The IceCube Neutrino Observatory uses optical sensors embedded in Antarctic ice to detect Cherenkov radiation produced by secondary charged particles following neutrino interactions.*

Image credit: Credit: IceCube Collaboration.
Source: (IceCube Collaboration, n.d.-c).

Conclusion

Science is fertile ground for unconventional ideas. Francis Halzen's vision is a clear example of this, as his out of the box thinking evolved from an interesting possibility into one of the major ways modern astronomers explore the universe. Through his ideas, Halzen gave humanity new tools to unravel astrophysical mysteries. He gave astronomy the ability to "see ghosts" and uncover the secrets they carry from the most violent regions of the cosmos.

This year's Nobel Prize should serve as an invitation for scientists to take risks and believe in the potential of their own ideas. To bet against convention and remember that sometimes breakthroughs come in the form of a weird but rather brilliant idea. Who knows? Surely there are other "ghosts" out there waiting to be interviewed by a detector.

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