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# Ice, light and the hadronic sky: Francis Halzen and the 2026 Nobel Prize in Physics

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On 6 October 2026 the Royal Swedish Academy of Sciences awarded the Nobel Prize in Physics to Francis Halzen of the University of Wisconsin–Madison "for decisive contributions to the IceCube Neutrino Observatory and the discovery of high-energy neutrinos of astrophysical origin".[1] Halzen is the sole laureate. The award follows the 2002 recognition of Raymond Davis Jr. and Masatoshi Koshiba for detecting MeV neutrinos from the Sun and SN 1987A, and takes neutrino astronomy some nine orders of magnitude higher in energy, into the regime where cosmic rays are accelerated.

Halzen was born in Tienen, Belgium, in 1944 and received his PhD from KU Leuven in 1969. He has led IceCube as principal investigator since its inception, and the collaboration now comprises about 450 people from 58 institutions in 14 countries.[2] Mark Pearce, chair of the Nobel Committee for Physics, said that Halzen's "tenacity and scientific vision has paved the way for a new kind of astronomy".[1]

## WHY NEUTRINOS

Cosmic rays have been known since 1912, yet their accelerators remain difficult to identify, because Galactic and intergalactic magnetic fields scramble the arrival directions of charged particles. Neutrinos are produced wherever accelerated hadrons interact with ambient matter or radiation, and both routes proceed through pion production. In hadronuclear collisions, which include proton–proton and nucleus–nucleus interactions, the target is gas. In photohadronic reactions, the target is a radiation field. Neutral pions decay into gamma rays, which can be absorbed inside a dense source or, at the highest energies, on background photons in transit. Charged pions decay into neutrinos, which are neither deflected nor appreciably absorbed, so both direction and energy survive. Gamma rays can also be produced by electrons through synchrotron and inverse Compton emission, so a gamma-ray detection alone does not establish a hadronic origin. Neutrinos remove this ambiguity, because they arise only where hadrons interact. A neutrino carries a few per cent of the energy of its parent nucleon. IceCube events from about 10 TeV to a few PeV therefore correspond to parent nucleons from a few hundred TeV to of order 100 PeV. The diffuse flux is close to isotropic on the sky, which points to a predominantly extragalactic origin.

## A CUBIC KILOMETRE OF ANTARCTIC ICE

Astrophysical neutrinos arrive at a low rate and interact so weakly that detecting them requires instrumented volumes of order a cubic kilometre, against backgrounds that exceed the signal by many orders of magnitude. IceCube records roughly 100 astrophysical neutrinos per year, set against about 100,000 atmospheric neutrinos above 0.1 TeV and an atmospheric-muon trigger rate of about 3 kHz, equivalent to $10^{11}$ events per year. In June 1988, Francis Halzen and John G. Learned proposed to instrument the deep polar ice as the detection medium. The predecessor array AMANDA, built between 1993 and 2000, showed that air bubbles at depths of 800–1,000 m scatter Cherenkov light over less than 50 cm, which led subsequent strings to greater depths.[2] IceCube, funded by the US National Science Foundation in 2002, deployed 86 strings carrying 5,160 optical sensors at depths of 1,450–2,450 m between 2005 and 2010, and has operated in its full configuration since 2011 with an uptime above 99%. Below about 2,100 m the ice is optically clear, with absorption and scattering lengths of roughly 200 m and 50 m. Atmospheric muons cannot traverse the Earth, so up-going muon tracks from the Northern sky form a clean sample with sub-degree angular resolution. Cascade events contained within the instrumented volume extend the sensitivity to the Southern sky, including the inner Galaxy.

## FROM DIFFUSE FLUX TO THREE INDIVIDUAL SOURCES

In 2013 IceCube reported 28 events with deposited energies from 30 TeV to 1.14 PeV, and one further year of data rejected a purely atmospheric origin at 5.7σ.[2] The signal has since been established in all three neutrino flavors. Seven astrophysical tau-neutrino candidates exclude the absence of a tau-neutrino flux at 5σ, and the muon-neutrino sample now contains an event of about 11.4 PeV.[2] A single power law from 5 TeV to 10 PeV is rejected at more than 4σ, with a harder spectrum below about 30 TeV.[2]

The flux has since been tied to individual sources. On 22 September 2017 the alert IceCube-170922A, a muon neutrino of about 290 TeV, coincided in direction with the blazar TXS 0506+056 during a gamma-ray flare, which set off a worldwide follow-up campaign.[3] A companion analysis of archival data found a neutrino excess from the same direction between September 2014 and March 2015, at 3.5σ, with no accompanying gamma-ray flare.[2] The 2017 coincidence is consistent with a subdominant photohadronic component in the jet, while the gamma rays themselves are readily accounted for by leptonic emission. The 2014–2015 excess points to a production region opaque to the co-produced pionic gamma rays. Opacity identifies a dense target but does not select the interaction channel, and both photopion production on an external photon field and hadronuclear collisions remain viable.

A search of 110 gamma-ray source positions in IceCube data from 2011 to 2020 revealed an excess of 79 (+22/−20) neutrino events at the Seyfert galaxy NGC 1068, with a global significance of 4.2σ.[4] The excess lies mainly at 1.5–15 TeV and coincides with the strongest neutrino clustering in the Northern sky. The inferred flux exceeds the TeV gamma-ray upper limit by more than an order of magnitude.[4] This ratio points to the dense corona around the central supermassive black hole, where the accompanying gamma rays are absorbed before they escape. Coronal gas makes proton–proton collisions efficient, and the coronal and disk radiation fields sustain photopion reactions, so both channels operate in the same compact region.

The third is the Milky Way, the only source whose parent cosmic rays are also measured directly at Earth. Galactic plane emission, first reported at 4.5σ in 2023, now reaches 5.7σ in twelve years of data.[5] It is the first astrophysical source of high-energy neutrinos established beyond the 5σ discovery threshold. The disk supplies a gas target in which Galactic cosmic rays collide with interstellar protons and nuclei, and the neutrinos are the hadronic counterpart of the diffuse pion-decay gamma-ray emission. Because the gamma rays also carry leptonic contributions, the neutrinos offer the cleanest tracer of the hadronic component. LHAASO has recorded photons up to 1.4 PeV from Galactic accelerators and placed the all-particle knee at 3.67 PeV, and DAMPE has resolved a softening of the proton spectrum near 14 TeV.[2] These measurements bound the Galactic cosmic-ray spectrum at Earth and locate candidate accelerators. The Galactic neutrino signal extends this constraint into the gas-rich disk. The isotropic flux is predominantly extragalactic, and the Galactic plane, detected over 5σ, contributes a measured subdominant share.

## A NETWORK FOR THE SAME SKY

Resolving the isotropic flux into individual objects calls for a network of telescopes. The Nobel Prize Committee points to instrumented volumes beyond a cubic kilometre: IceCube-Gen2 at the South Pole, KM3NeT in the Mediterranean, Baikal-GVD in Lake Baikal, P-ONE off Vancouver Island and TRIDENT (also known as *Hai-Ling* project) in the South China Sea.[2] HUNT, with candidate sites in the South China Sea and Lake Baikal, is designed



**Figure 1. IceCube work area at the South Pole Science Lab.** Credit: Zhonghua Xu, University of Texas at Arlington.

around the Galactic PeVatrons. A low-latitude array in the South China Sea views the inner Galaxy through the Earth, in the sky where the Galactic signal is now established, and complements the northern up-going sample that is IceCube's cleanest channel.

Thirty-eight years after the 1988 proposal, IceCube has opened the TeV–PeV neutrino sky to astronomy. It has delivered a diffuse extragalactic flux, the Milky Way as a discovered source, and active galaxies in which pion production proceeds behind a gamma-ray screen. The 2026 prize honors both the instrument and the scientist who carried it from a proposal to an observatory. The telescopes now under construction in ice, lakes and seas will turn the diffuse flux into a catalogue of individual objects and locate the accelerators that feed them.

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## DECLARATION OF INTERESTS

The author declares no competing interests.